

Recent highlight physics at BESIII



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Outline

- **BESIII and BEPCII**
- **Highlights of BESIII physics**
 - **Light hadrons**
 - **Charmonium(-like) states**
 - **Baryon/QCD physics**
 - **Charmed hadrons**
- **Future plan**
- **Summary**

Beijing Electron Positron Collider (BEPCII)

beam energy: 0.92-2.4525 GeV

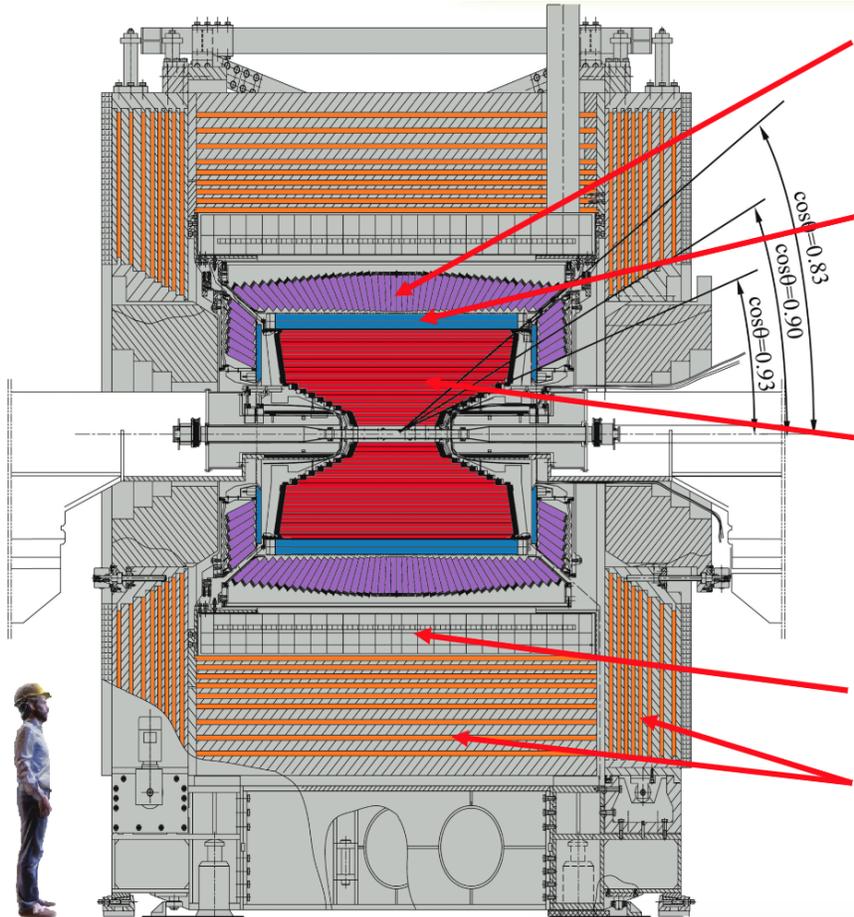


2025: inner chamber → CGEM
20(25): energy upgrade to 0.92-2.4525(2.8) GeV
2004: started BEPCII upgrade, BESIII construction
2008: test run
2009-now: BESIII physics run

- 1989-2004 (BEPC):
 $L_{\text{peak}} = 1.0 \times 10^{31} / \text{cm}^2 \text{s}$
- 2009-now (BEPCII):
 $L_{\text{peak}} = 1.1 \times 10^{33} / \text{cm}^2 \text{s}$ (2022, 2023)

BESIII detector

NIMA614(2010)345



EMC: CsI crystals

$\Delta E/E = 2.5\%$ @ 1 GeV - Barrel

$\Delta E/E = 5.0\%$ @ 1 GeV - Endcaps

TOF:

$\sigma_T = 80$ ps Barrel

$\sigma_T = 110$ (60) ps Endcap

MDC: small cell & He gas

$\sigma_{xy} = 130$ μm

$\sigma_p/p = 0.5\%$ @ 1 GeV

$dE/dx = 6\%$

Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

Excellent resolution, particle identification, and large coverage
for neutral and charged particles

BESIII collaboration

Europe (19)

BESIII

~ 700 members
From 96 institutions
in 16 countries

Germany(6): Bochum University,

GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1): KVI/University of Groningen

Russia(3): Budker Institute of Nuclear Physics, Dubna JINR, **Lebedev Physical Institute**

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(3): University of Manchester, University of Oxford, University of Bristol

Poland(1): National Centre for Nuclear Research

University of Silesia in Katowice

Pakistan(2)

Institute of Business Administration (IBA), Karachi

University of the Punjab

India(1)

Indian Institute of Technology madras

China (63)

Beihang University, Central China Normal University, Central South University, Chengdu University of Technology, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Guangxi University of Science and Technology, Hangzhou Normal University, Hebei University, Henan University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Hengyang Normal University, Huangshan College, Hunan University, Hunan Normal University, Inner Mongolia University, Institute of High Energy Physics, Institute of Modern Physics, Jiangsu Ocean University, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Longyan University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Renmin University of China, Shaanxi Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Management University, Shandong Normal University, Shandong University, Shandong University of Technology, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Southwest University of Science and Technology, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xi'an Jiaotong University, **Xinjiang University**, Xinyang Normal University, Yantai University, Yunnan University, Zhejiang University, Zhengzhou University

Mongolia(1)

Institute of Physics and Technology

Korea(1)

Chung-Ang University

Thailand(1)

Suranaree University of Technology

USA(3)

Carnegie Mellon University

Indiana University

University of Hawaii

College of William and Mary

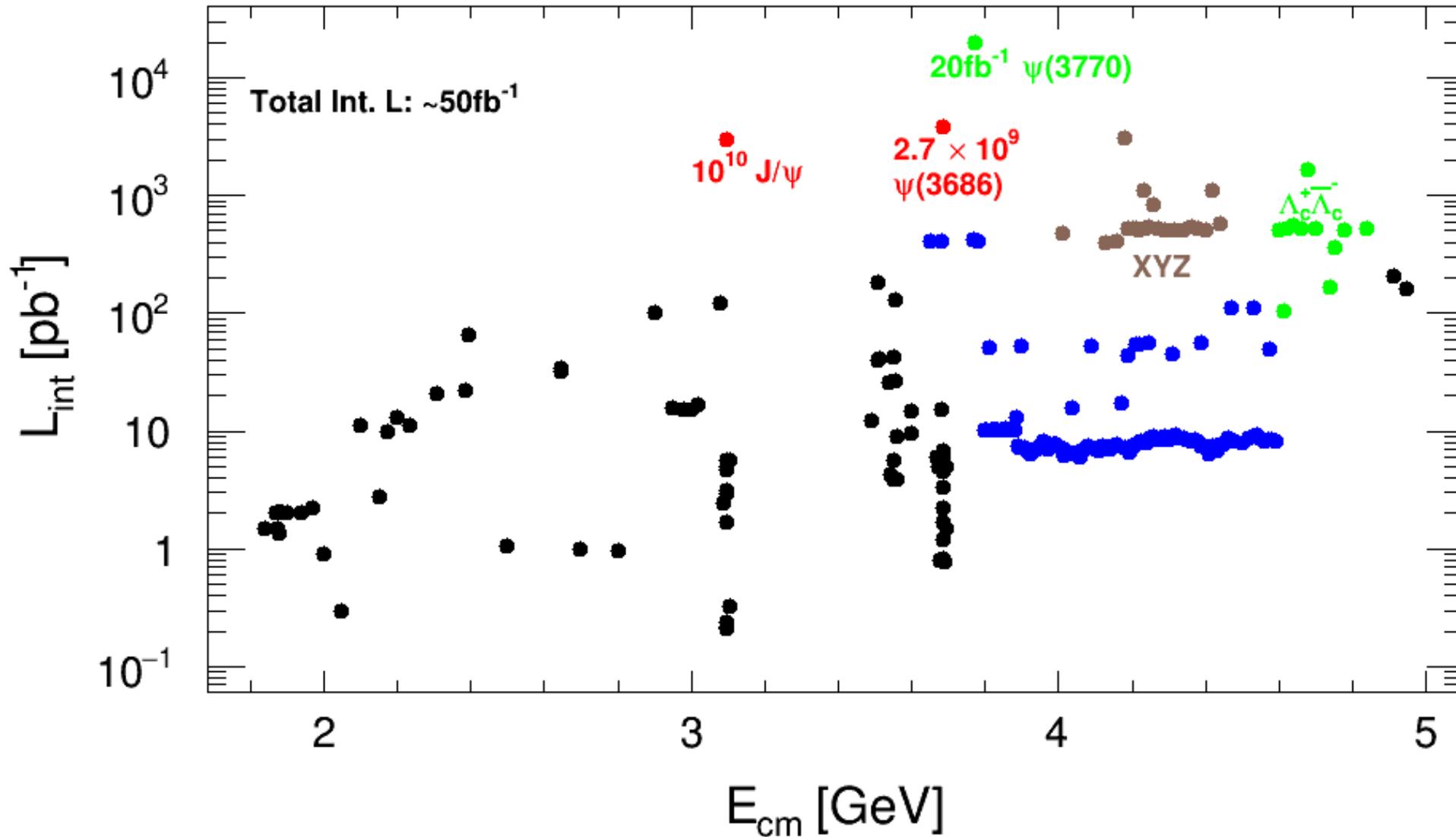
Chile(2)

University of Tarapaca

University of La Serena

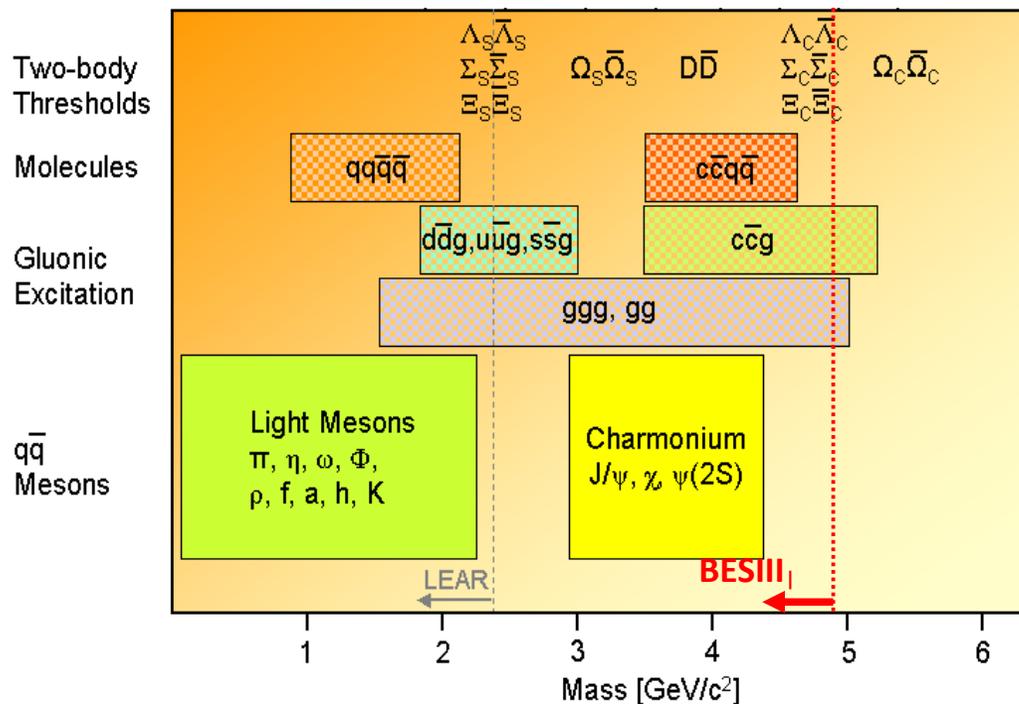


Data samples



$>50 \text{ fb}^{-1}$ at E_{cm} between 1.84 and 4.95 GeV in 15 year running

Unique hadrons at BESIII



Hadron physics opportunities:

- Precision hadron spectroscopy → understand the established hadron states
- Search for the unexpected hadron states and spectroscopy study → explore nature of exotic hadron states

Two golden ways to study hadron spectroscopy:

- Charmonium decays (10B J/ψ and 2.7B $\psi(2S)$): → light hadrons
- Direct production, radiative and hadronic transitions (23 fb⁻¹ data above 3.8 GeV): → heavy hadrons (XYZ)

Charmed hadrons:

- Produced in pair
- Quantum correlated $D^0 \bar{D}^0$

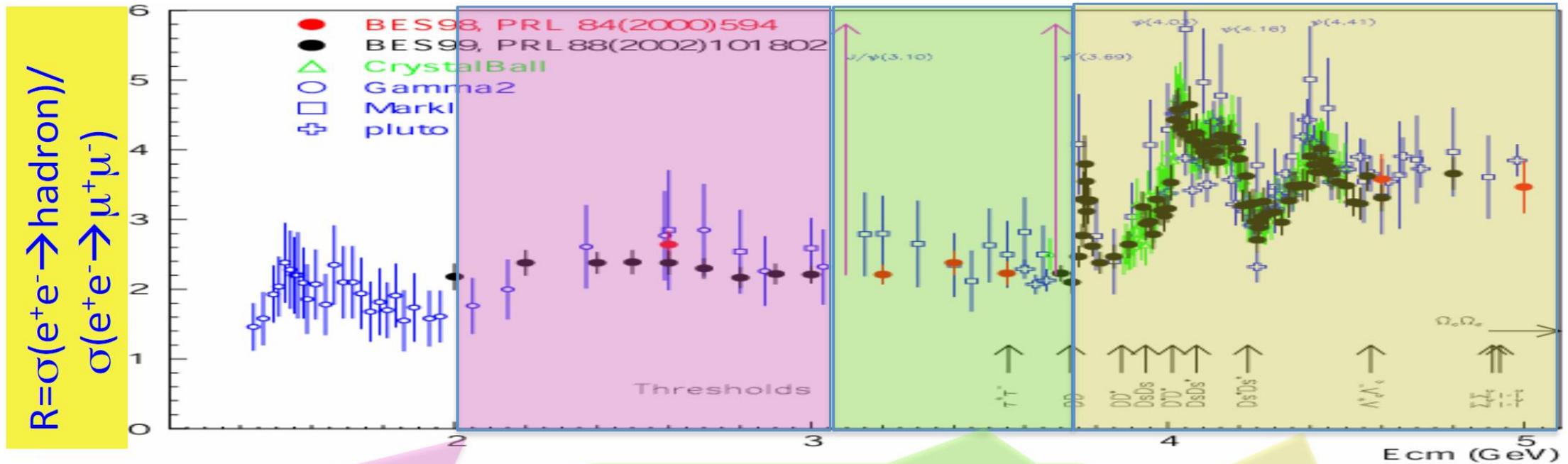
20 fb⁻¹ @ 3.773 GeV → $D^0 \bar{D}^0$ and $D^+ D^-$

0.48 fb⁻¹ @ 4.009 GeV → $D_s^+ D_s^-$

7.33 fb⁻¹ @ 4.13-4.23 GeV → $D_s^* \bar{D}_s$

4.5 fb⁻¹ @ 4.6-4.7 GeV → $\Lambda_c^+ \bar{\Lambda}_c^-$

Physics at BESIII

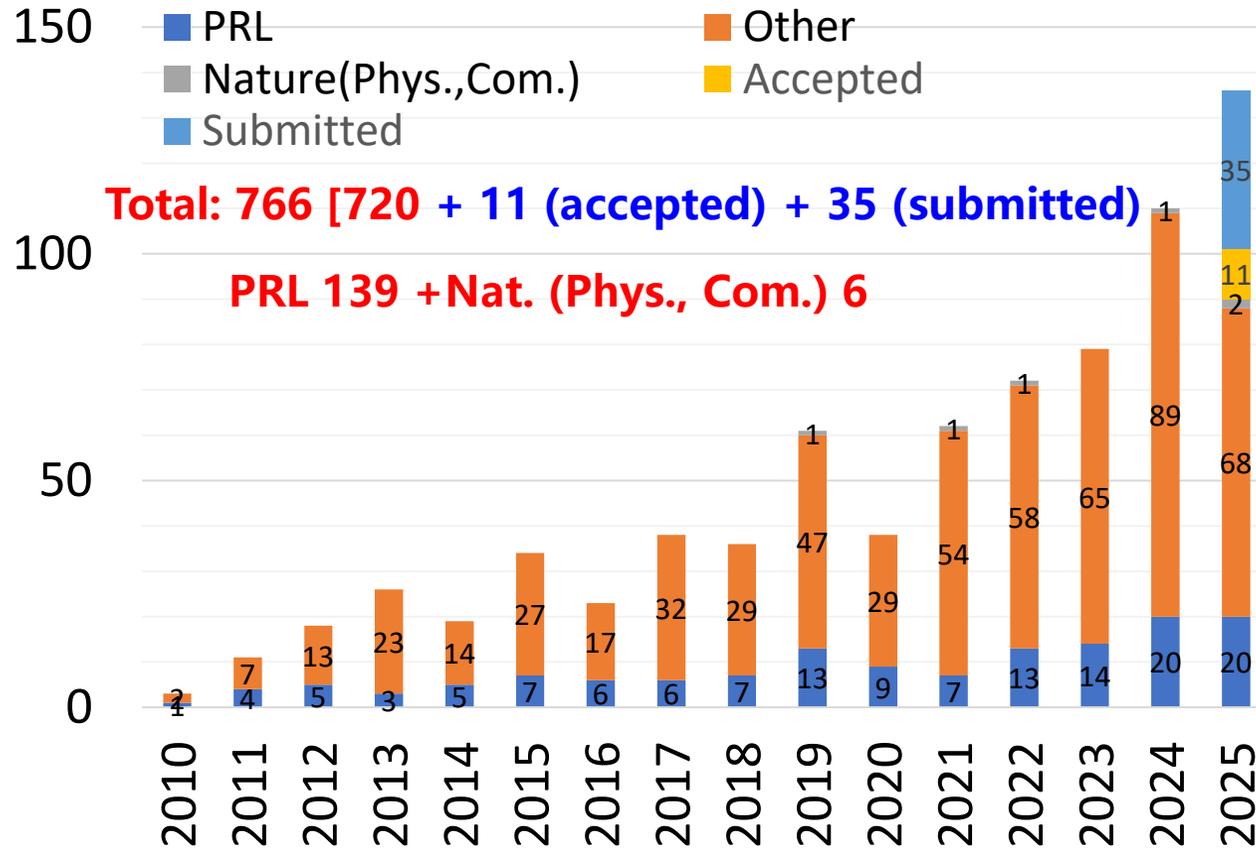


- Hadron form factors
- $Y(2175)$ resonance
- Multiquark states with s quark, Z_s
- MLLA/LPHD and QCD sum rule predictions

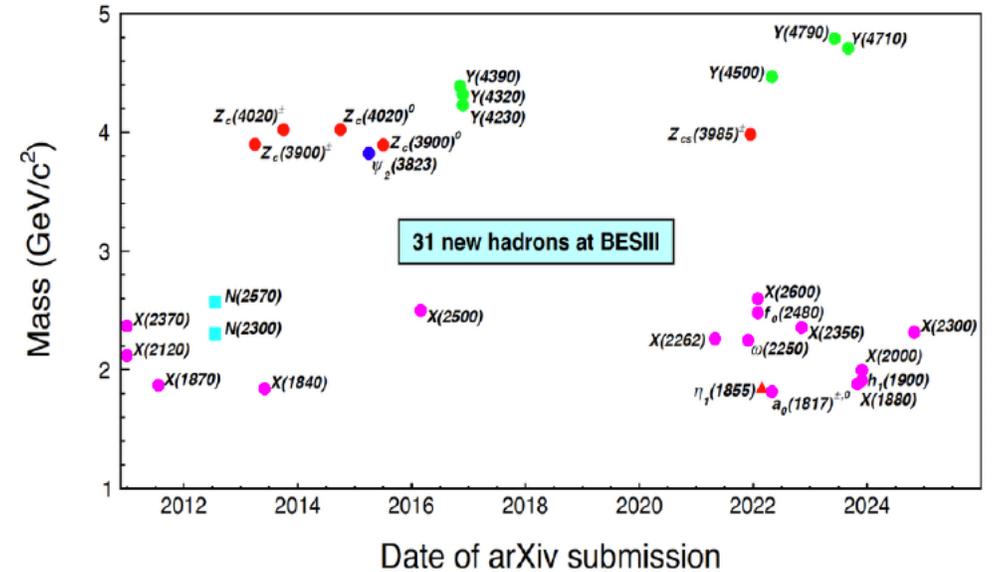
- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{D_s}
- D_0 - \bar{D}_0 mixing
- Charm baryons

Publications of BESIII



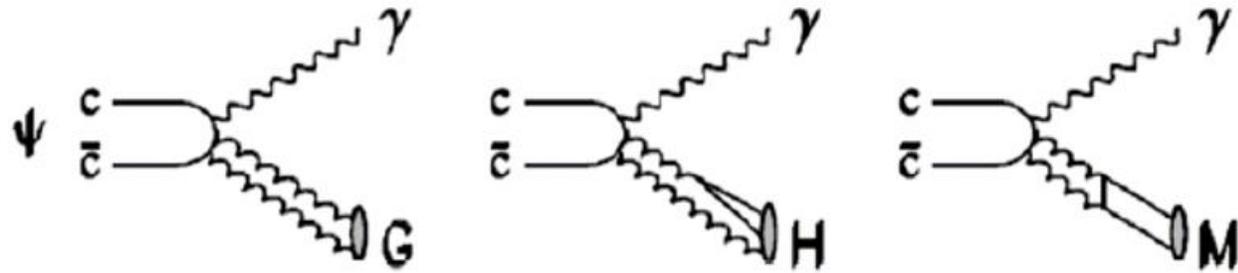
31 New Hadrons Discovered at BESIII



World largest J/ψ , $\psi(2S)$, $\psi(3770)$,... data samples

More than 720 papers and 139 in Phys. Rev. Lett.

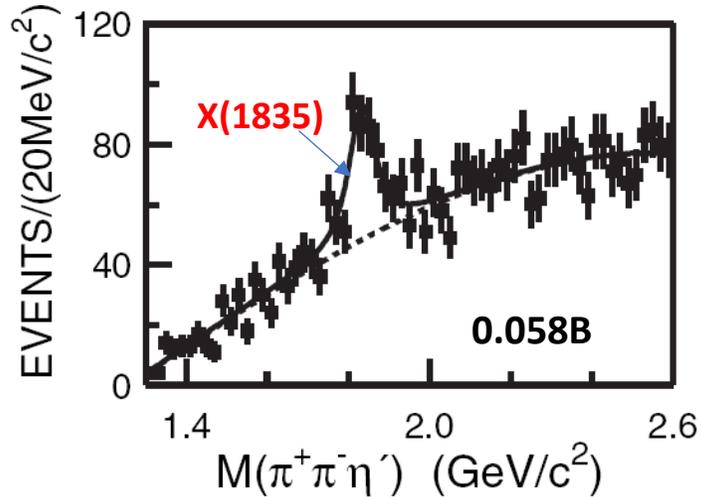
Glueball candidates in radiative J/ψ decays



Striking example: $\chi(1835)$ in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$

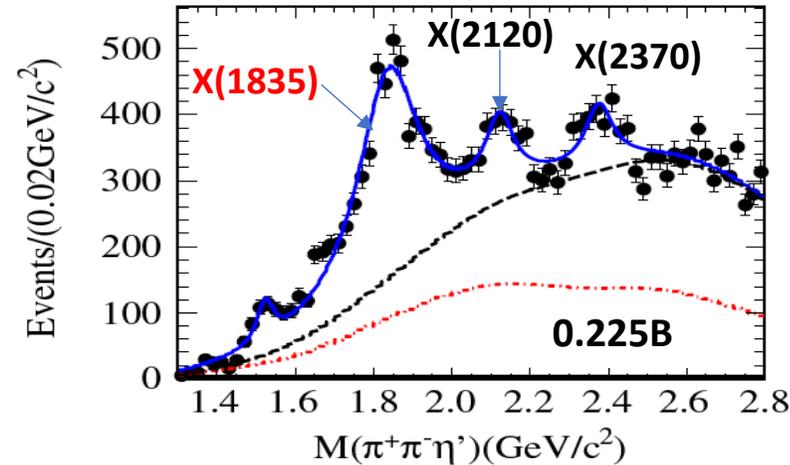
First observed by BESII

PRL95(2005)262001

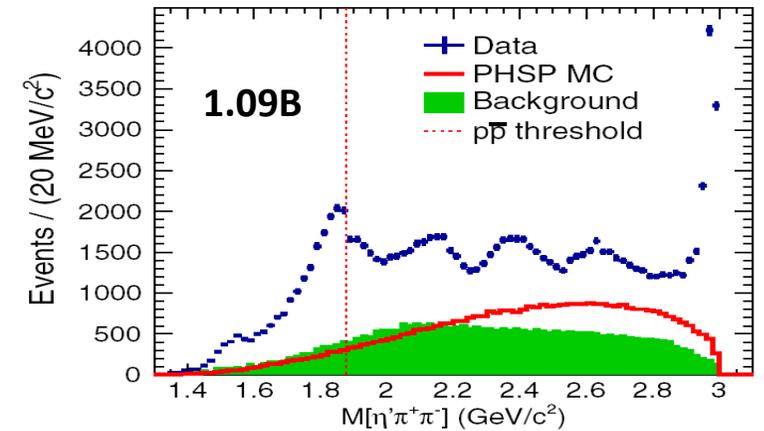


Confirmed by BESIII with much higher significance

PRL106(2011)072002



PRL117(2016)042002

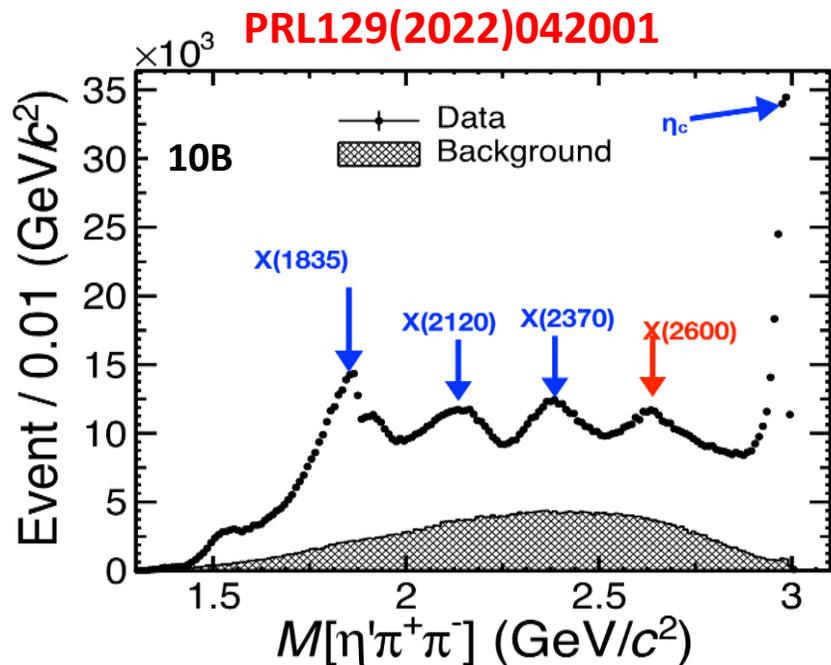


With more and more J/ψ data, more and more features appear:

1. $\chi(1835)$ with a sharp dip at threshold
2. $\chi(2120)$, $\chi(2370)$, $\chi(2600)$, $\eta_c(1S)$

Other examples: X(2370) and X(2600)

Observation of X(2120), X(2370) and X(2600) in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$



J^{PC} : unknown

$$M = 2618.3 \pm 2.0^{+16.3}_{-1.4} \text{ MeV}/c^2$$

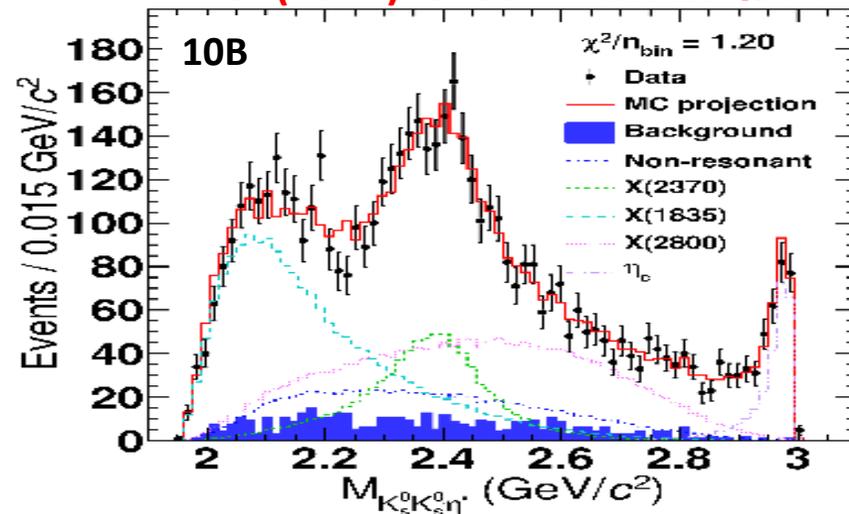
$$\Gamma = 195 \pm 5^{+26}_{-17} \text{ MeV}$$

η radial excitation or exotic hadron?

The J^{PC} of the X(2370) is determined to be 0^+ in $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$

首次确定X(2370)粒子的自旋宇称

PRL132(2024)181901 编辑推荐文章



入选《物理评论快报》2024年度最重要论文合集

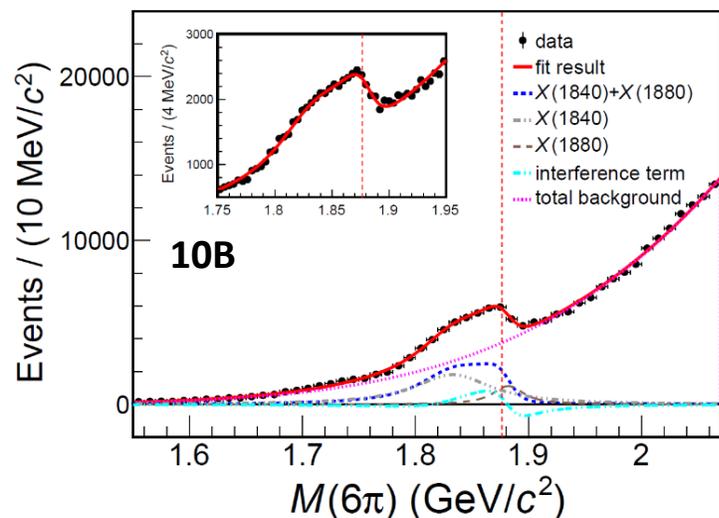
The X(2370) is a strong candidate for a pseudoscalar glueball (based on lattice QCD predictions)!

Other structures around $p\bar{p}$ production threshold

Observation of $X(1880)$ in $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$

揭示存在 $p\bar{p}$ 束缚态。入选为美国物理学会主办杂志《Physics Magazine》，并以“Evidence of a new subatomic particle” 专题报道

PRL132(2024)151901



$$M = 1832.5 \pm 3.1 \pm 2.5 \text{ MeV}/c^2$$

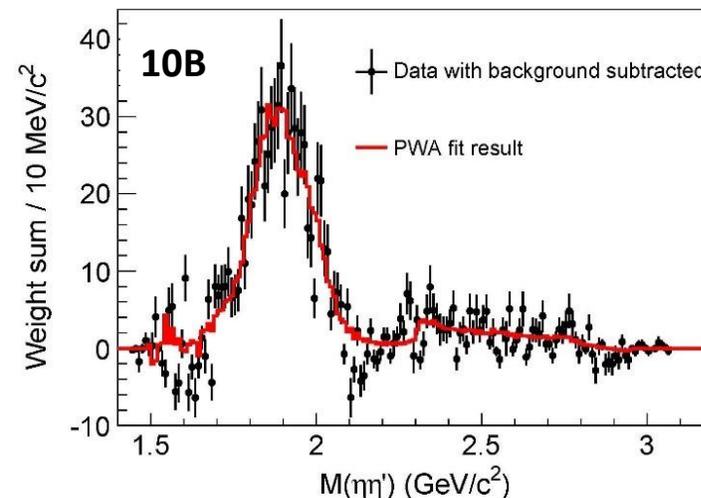
$$\Gamma = 80.7 \pm 5.2 \pm 7.7 \text{ MeV}$$

$$M = 1882.1 \pm 1.7 \pm 0.7 \text{ MeV}/c^2$$

$$\Gamma = 30.7 \pm 5.5 \pm 2.4 \text{ MeV}$$

Observation of $\eta(1855)$ in $J/\psi \rightarrow \gamma \eta \eta'$

PRL129(2022)192002 PRD106(2022)072012



Isoscalar state with exotic quantum numbers $J^{PC}=1^{-+}$

$$M = 1855 \pm 9_{-1}^{+6} \text{ MeV}/c^2$$

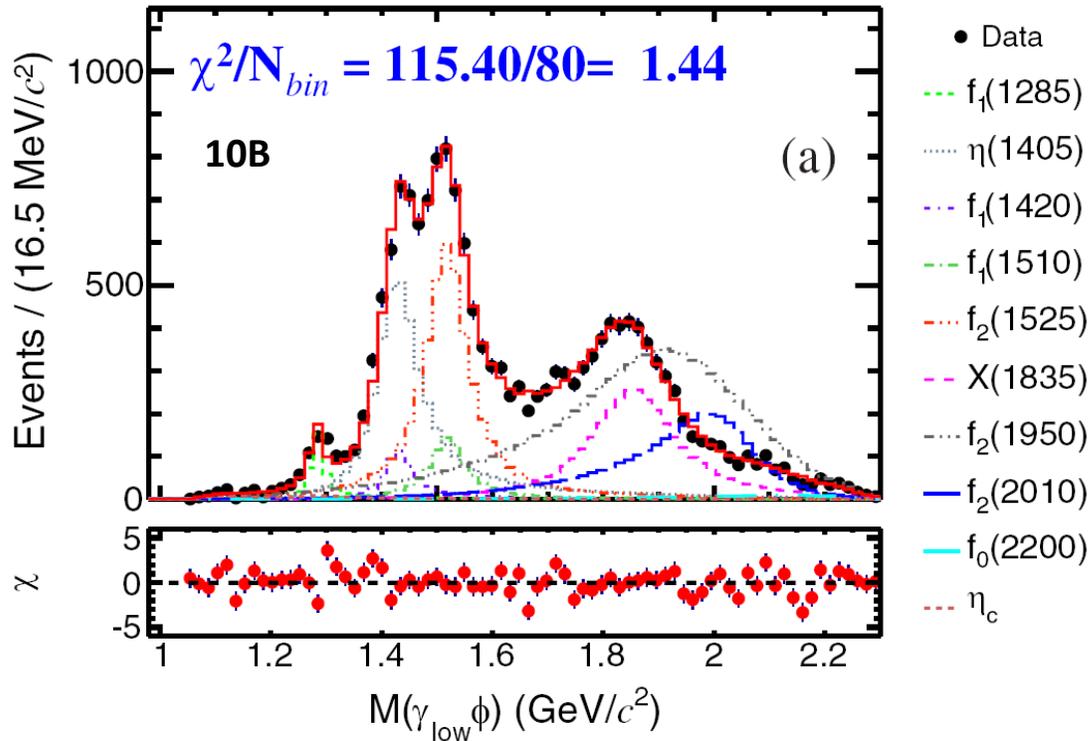
$$\Gamma = 188 \pm 18_{-8}^{+3} \text{ MeV}$$

Critical to establish the 1^{-+} hybrid nonet, Support $f_0(1710)$ overlap with glueball.

Study of $J/\psi \rightarrow \gamma\gamma\phi$

This decay gives an access to the mesons produced in radiative decays of J/ψ

PRD111(2025)052011



Resonance	M (MeV/c ²)	Γ (MeV)	$\mathcal{B}(J/\psi \rightarrow \gamma X) \times \mathcal{B}(X \rightarrow \gamma\phi)$	Significance
$f_1(1285)$	1281.9	22.7	$0.29 \pm 0.03^{+0.11}_{-0.09}$	17.3σ
$f_1(1420)$	1426.3	54.5	$0.55 \pm 0.07^{+0.18}_{-0.17}$	9.0σ
$\eta(1405)$	$1422.0 \pm 2.1^{+5.9}_{-7.8}$	$86.3 \pm 2.7^{+6.6}_{-17.4}$	$3.57 \pm 0.18^{+0.59}_{-0.61}$	18.9σ
$f_1(1510)$	1518.0	73.0	$0.78 \pm 0.09^{+0.34}_{-0.30}$	5.3σ
$f_2(1525)$	1517.4	86.0	$2.76 \pm 0.18^{+0.90}_{-0.61}$	16.4σ
$X(1835)$	$1849.3 \pm 3.0^{+7.6}_{-10.0}$	$179.6 \pm 8.7^{+22.5}_{-27.9}$	$3.37 \pm 0.19^{+0.78}_{-1.10}$	15.3σ
$f_2(1950)$	1936.0	464.0	$9.96 \pm 0.60^{+3.44}_{-2.13}$	13.1σ
$f_2(2010)$	2011.0	202.0	$4.63 \pm 0.43^{+1.42}_{-1.46}$	11.3σ
$f_0(2200)$	2187.0	207.0	$0.20 \pm 0.04^{+0.05}_{-0.07}$	6.3σ
η_c	2983.9	32.0	$0.21 \pm 0.03^{+0.05}_{-0.07}$	12.9σ

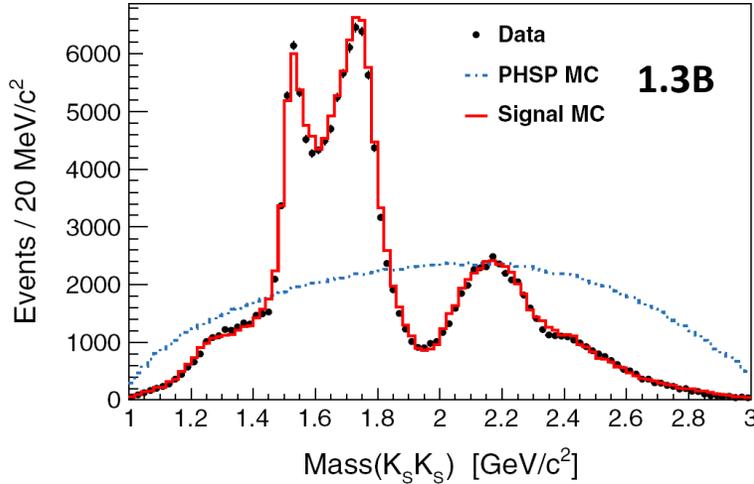
The decay $X \rightarrow \gamma\phi$ should be enhanced for $s\bar{s}$ states.

Note the absence of the $f_0(1710)$ and $X(2370)$ [$\eta(2370)$], for example.

Study of J/ψ and $\psi(3686) \rightarrow \gamma K_S K_S$

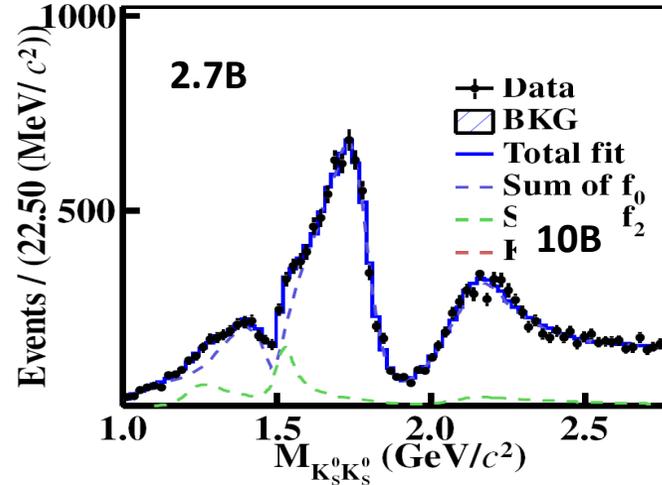
$J/\psi \rightarrow \gamma K_S K_S$

PRD98(2018)072003



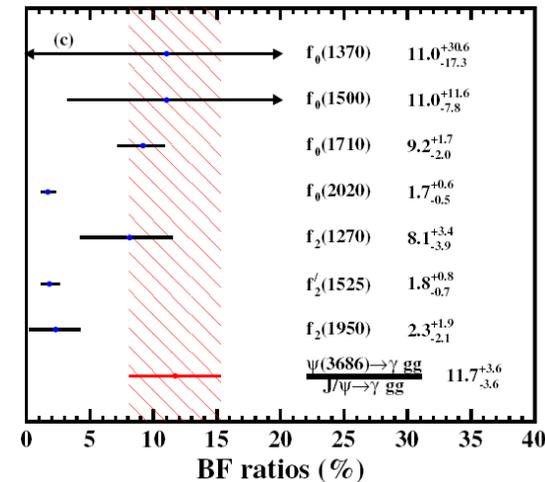
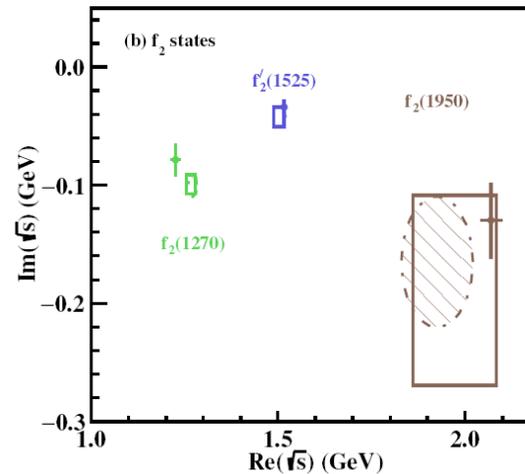
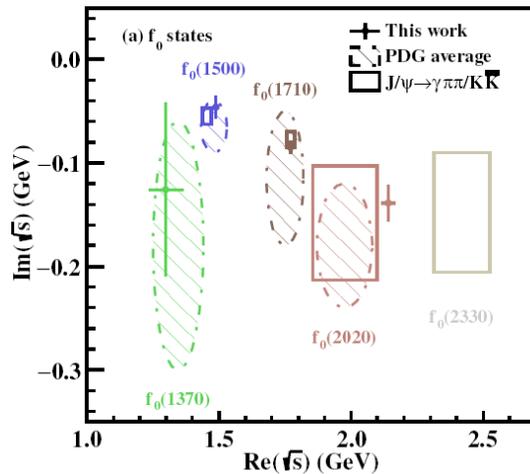
$\Psi(3686) \rightarrow \gamma K_S K_S$

JHEP10(2025)081

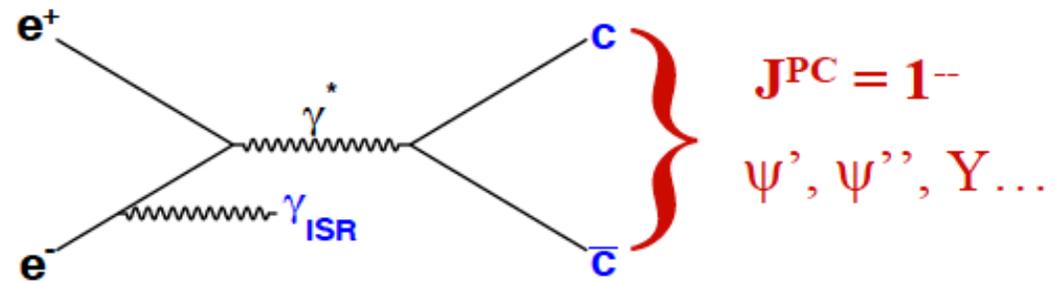


Good check in different ψ decays

The masses and widths of the f_0 [$f_0(1500), f_0(1710), f_0(2020)$] and f_2 [$f_2(1270), f_2'(1525), f_2(1950)$] are consistent between J/ψ and $\psi(2S)$ decays. Production is different.



Charmonium(-like) states



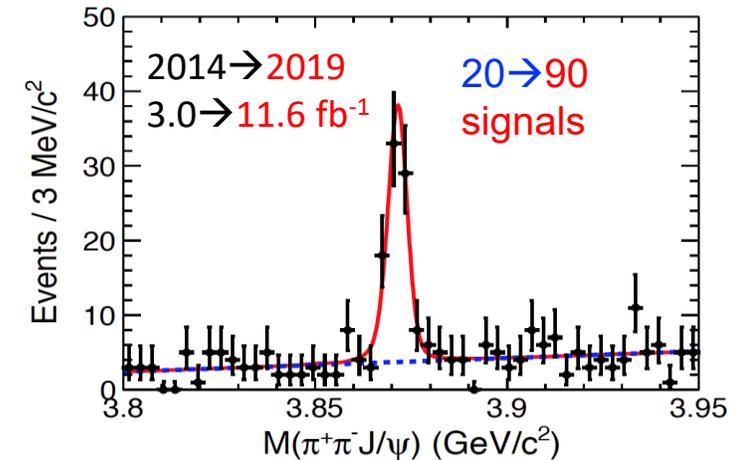
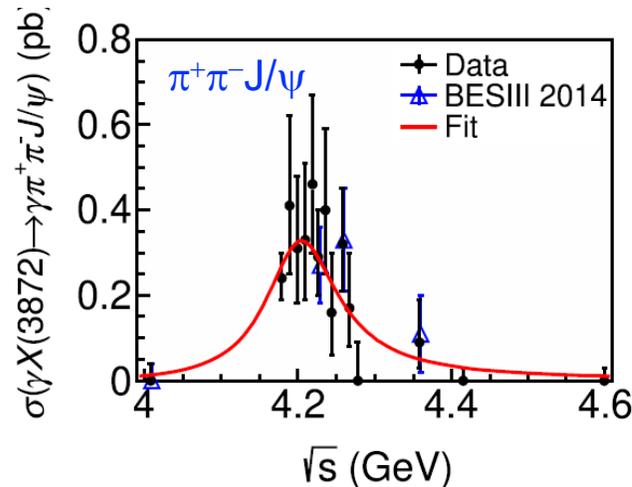
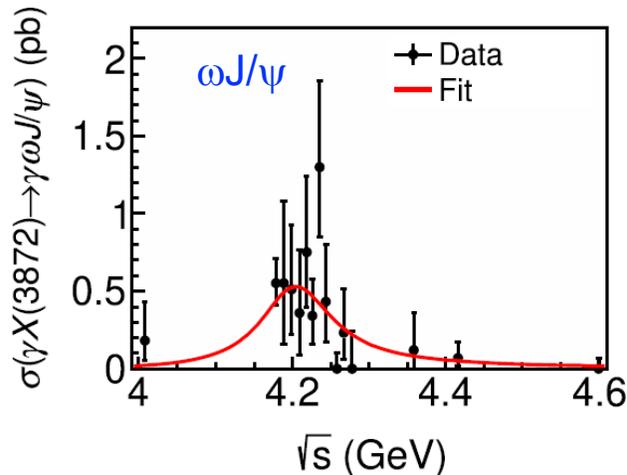
X(3872) (aka $\chi_{c1}(3872)$)

The **X(3872)** was first observed in $B^\pm \rightarrow K^\pm \pi^+ \pi^- J/\psi$ by Belle in PRL91(2003)262001. It was usually studied in B decays, $p\bar{p}$, pp , or e^+e^- collision, by Belle, BaBar, D0, CDF2, LHCb, and BESIII

BESIII

$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi$$

PRL112(2014)092001 \rightarrow PRL122(2019)232002



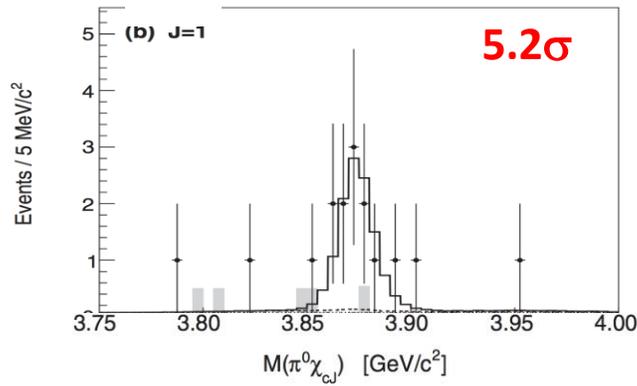
Unique at BESIII: $B[Y(4230) \rightarrow \gamma X(3872)]/B[Y(4230) \rightarrow \pi^+ \pi^- J/\psi] \sim 9\%$

Strongly suggest the $Y(4230) \rightarrow \gamma X(3872)$ transition \rightarrow *Commonality between Y(4230) & X(3872)...*

More decay modes of $X(3872)$

$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \pi^0 \chi_{c1}$$

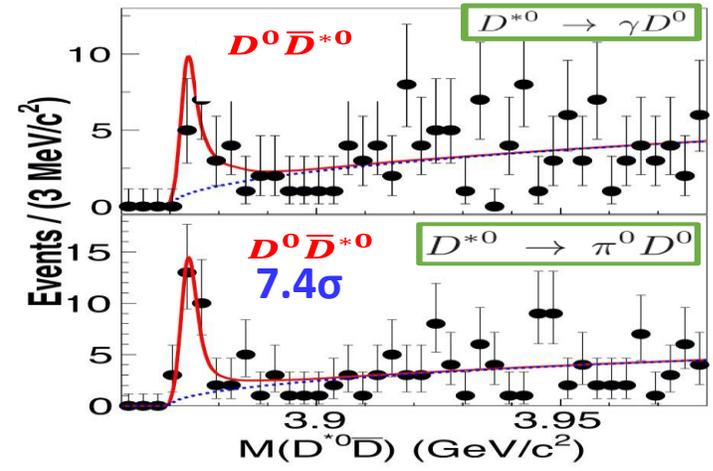
PRL122(2019)202001



$$B[X(3872) \rightarrow \pi^0 \chi_{c1}] / B[X(3872) \rightarrow \rho] / \psi = 0.88^{+0.33}_{-0.27} \pm 0.10$$

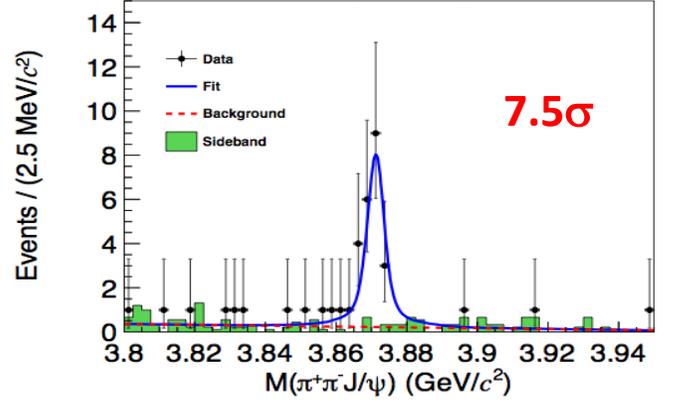
$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma D^0 \bar{D}^{*0}$$

PRL124(2020)242001



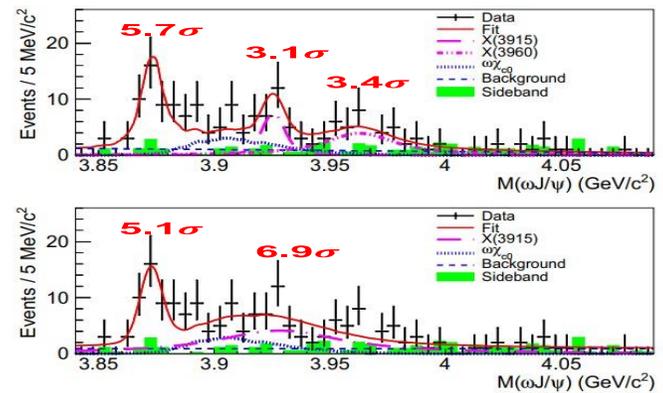
$$e^+e^- \rightarrow \omega X(3872) \rightarrow \omega \pi^+ \pi^- J/\psi$$

PRL130(2020)151904



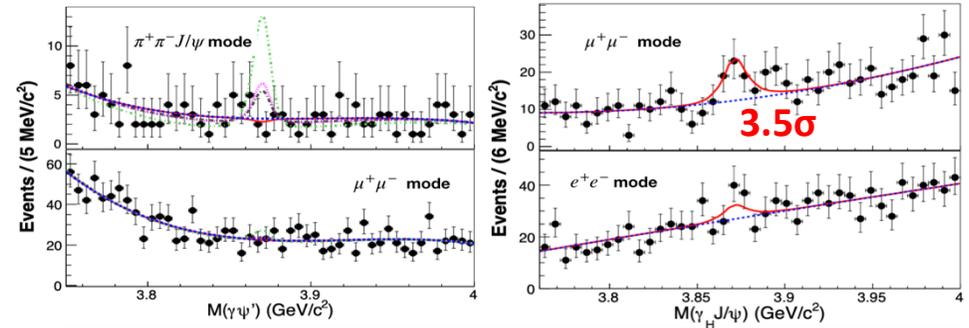
$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \omega J/\psi$$

PRL122(2019)232002



$$B[X(3872) \rightarrow \omega J/\psi] / B[X(3872) \rightarrow \rho] / \psi = 1.6^{+0.4}_{-0.3} \pm 0.2$$

$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma [\gamma \psi(2S), \gamma J/\psi]$$

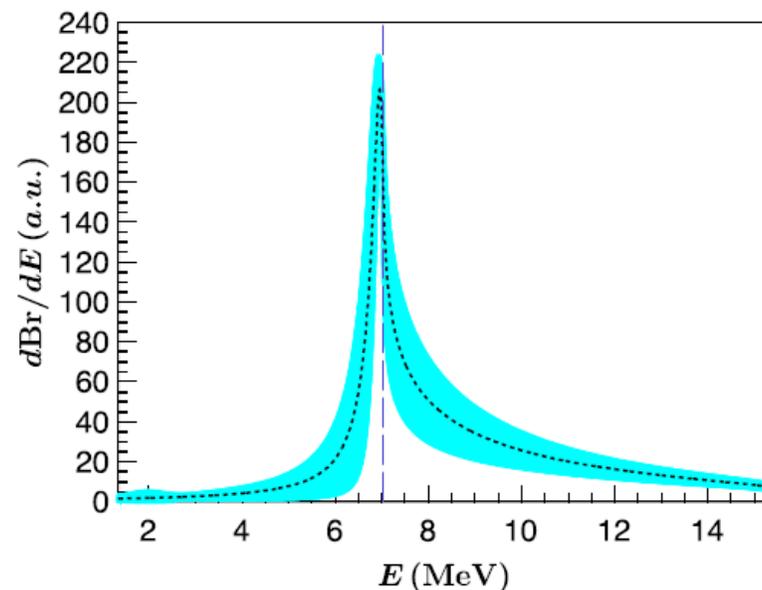
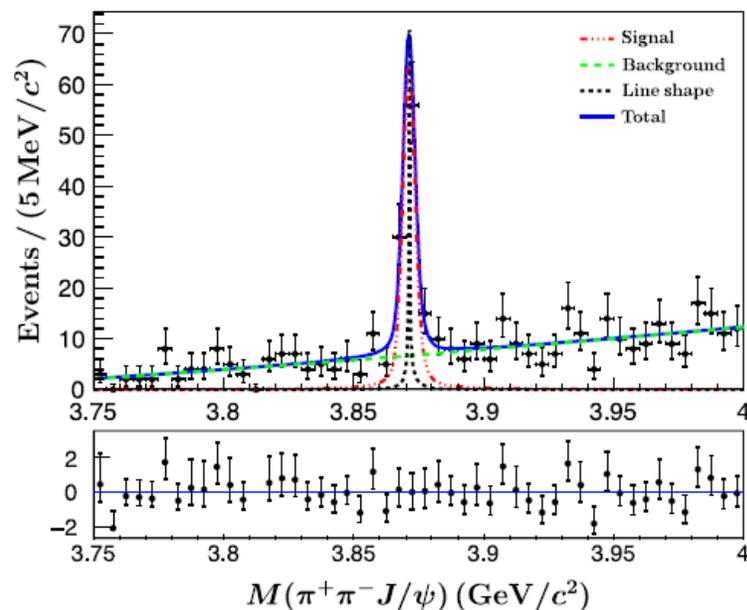
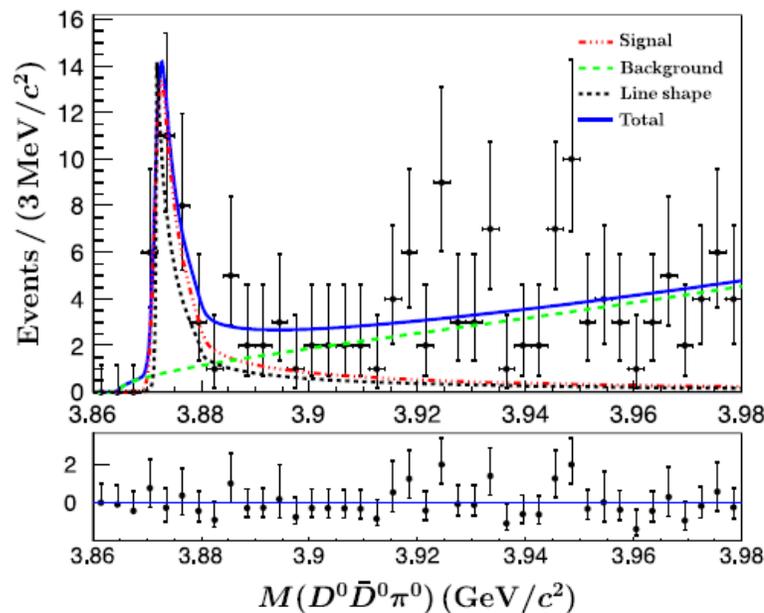


$R = \frac{BF(X(3872) \rightarrow \gamma \psi(2S))}{BF(X(3872) \rightarrow \gamma J/\psi)} < 0.59$ at 90% C.L., agrees with Belle (<2.1), while challenges Babar (3.4 ± 1.1) and LHCb results (2.46 ± 0.70)

Recent update on the X(3872)

Using both $X(3872) \rightarrow \bar{D}^0 D^{*0}$ and $X(3872) \rightarrow \pi^+ \pi^- J/\psi$ to access the T-matrix pole position

PRL132(2024)151903



Using a Flatté parameterization with $\bar{D}D^*$ and $\rho J/\psi$ coupled channels...

T-matrix pole position: $(3871.70 \pm 0.15_{-0.08}^{+0.07}) - i(0.19 \pm 0.08_{-0.19}^{+0.14})$ MeV

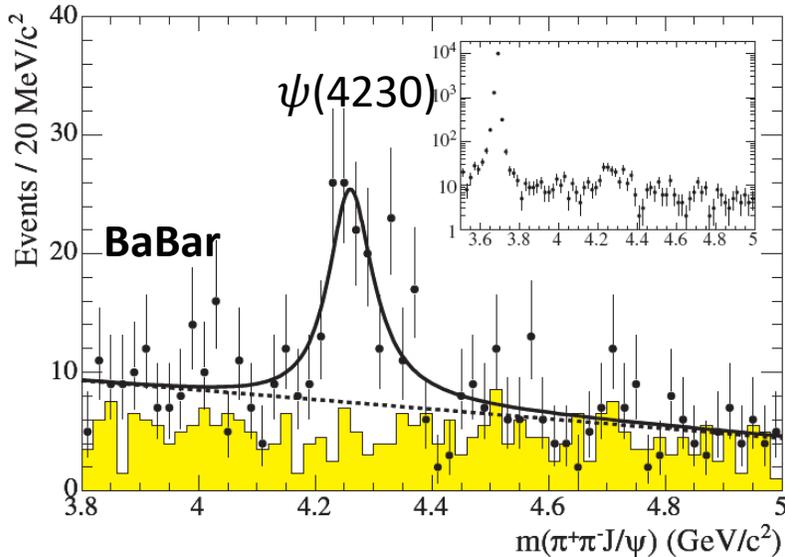
The real part is still consistent with the $\bar{D}^0 D^{*0}$ threshold $(3871.70 \pm 0.11 \text{ MeV}/c^2)$, and the imaginary part leads to a width of 0.38 MeV.

$Y(4260) \rightarrow \psi/\Upsilon(4230)$

Y states: charmonium-like states with $J^{PC}=1^{--}$; observed in initial state radiation (ISR) or direct e^+e^- annihilation

$$e^+e^-(\gamma_{\text{ISR}}) \rightarrow \pi^+\pi^-J/\psi$$

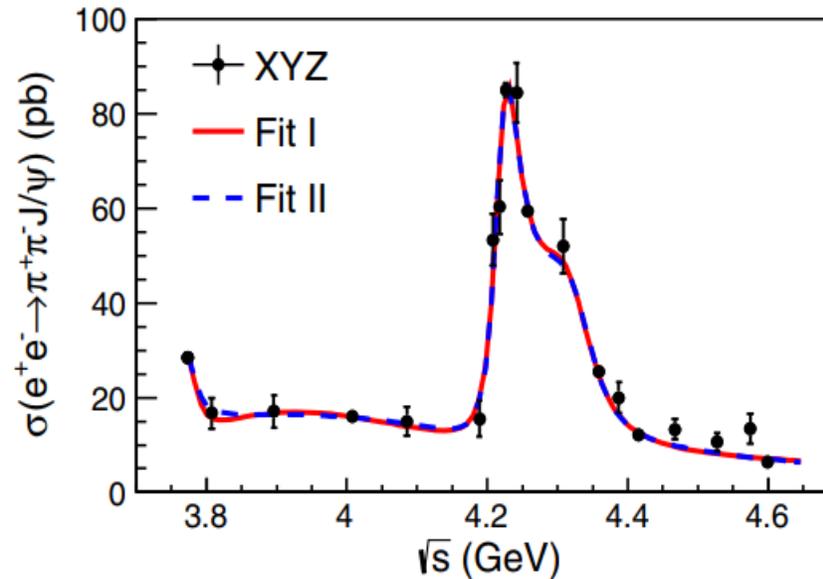
PRL95(2005)142001



BESIII

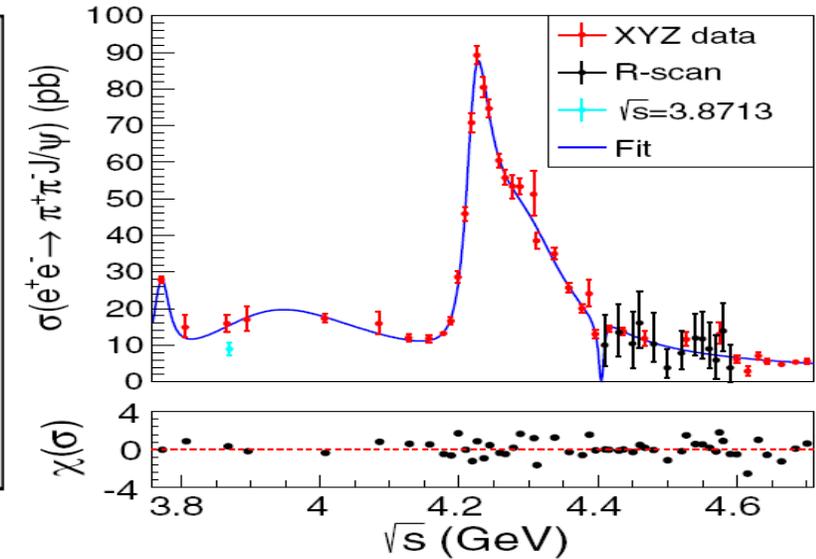
$$e^+e^- \rightarrow \pi^+\pi^-J/\psi$$

PRL118(2017)092001



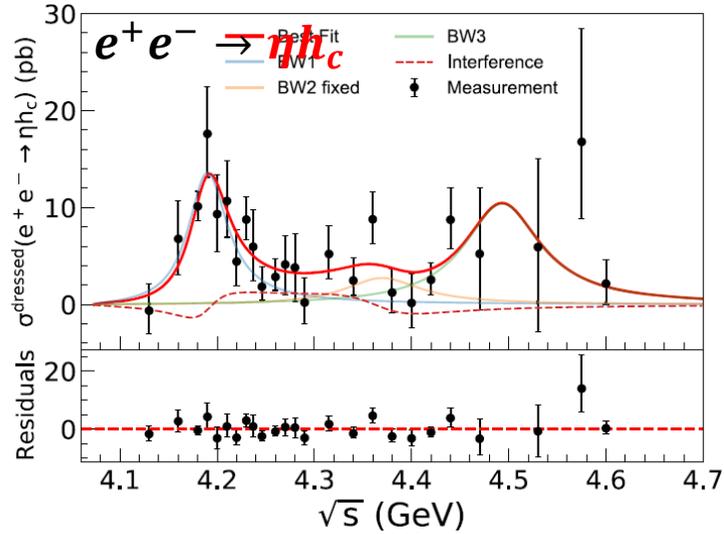
Precision results of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

PRD106(2022)072001

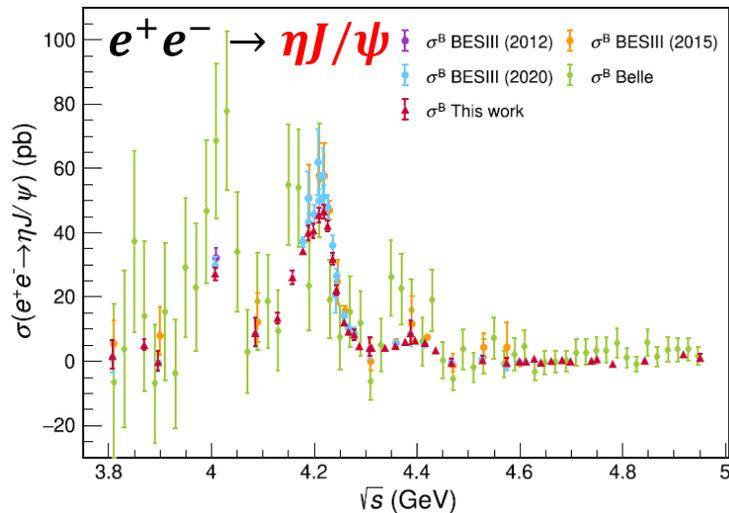


More $\psi(4230)$ information

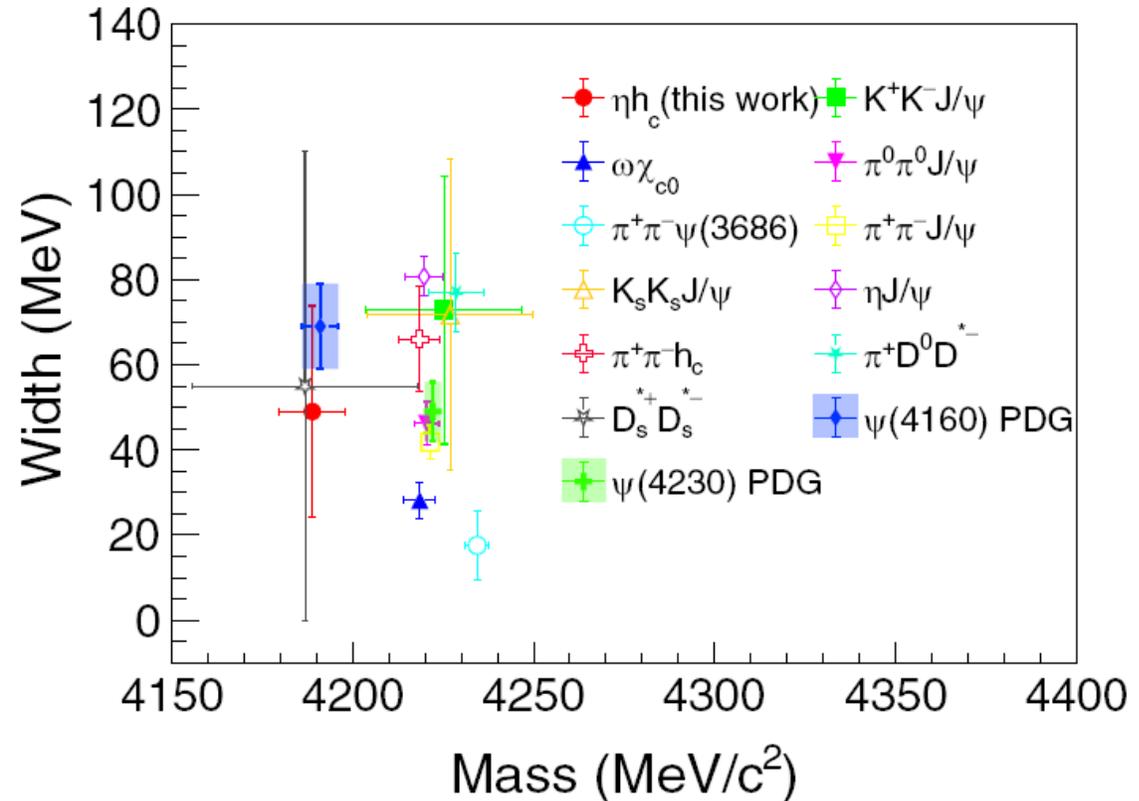
PRD111(2025)L011101



PRD109(2024)092012



Besides $e^+e^- \rightarrow \pi^+\pi^- J/\psi$, other exclusive cross sections also show signs of $Y(4230)$

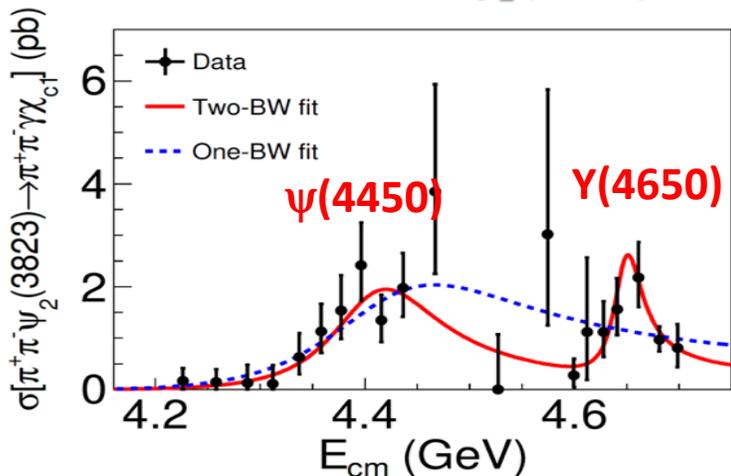


Masses of $Y(4230)$ are consistent among exclusive channels, but widths are not

Examples for Y states with higher mass

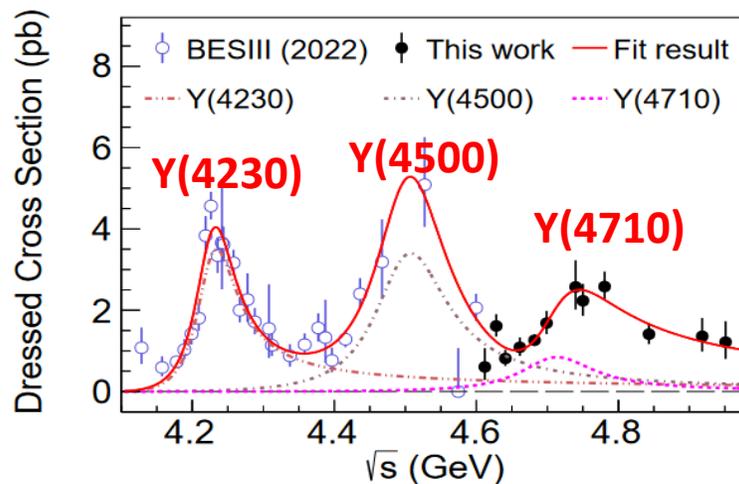
PRL129(2022)102003

$$e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$$



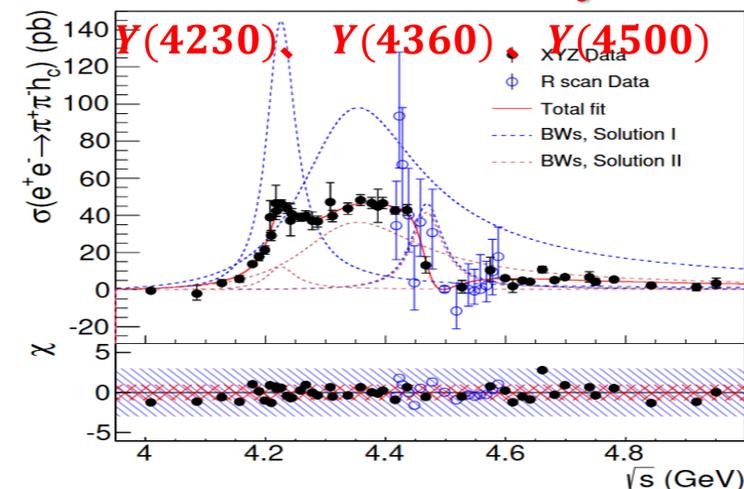
PRL131 (2023) 211902

$$e^+e^- \rightarrow K^+K^-J/\psi$$



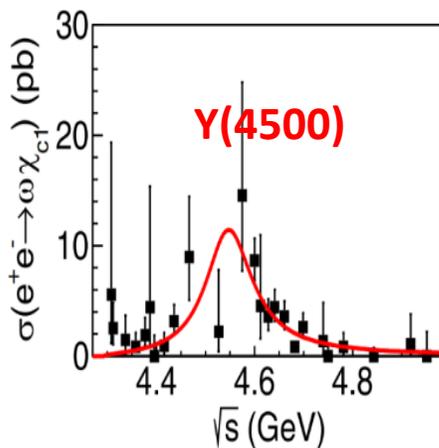
PRL 135 (2025) 071901

$$e^+e^- \rightarrow \pi^+\pi^-h_c$$

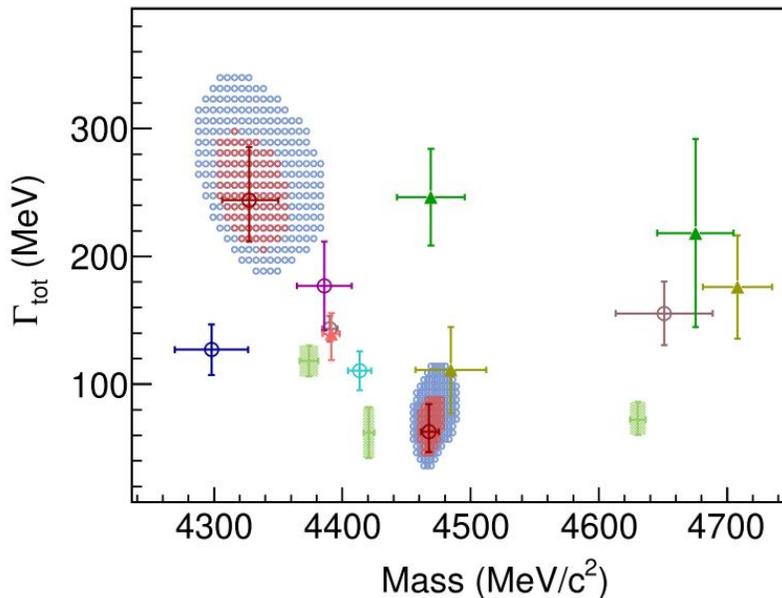
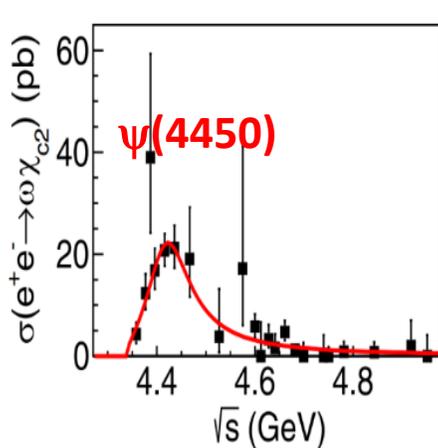


PRL 132 (2024) 161901

$$e^+e^- \rightarrow \omega\chi_{c1}$$



$$e^+e^- \rightarrow \omega\chi_{c2}$$



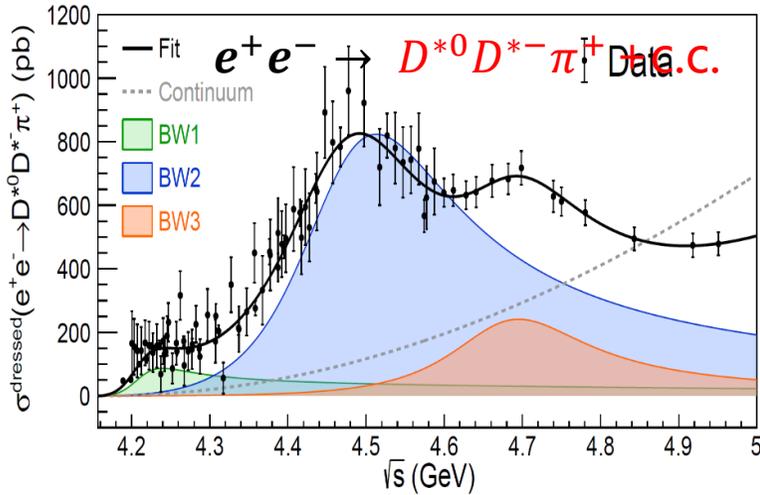
- \circ $\pi^+\pi^-h_c$, this work
- \square 95.5% C.L., this work
- \square 68.3% C.L., this work
- \triangle $\pi^+\pi^-h_c$, Ref. [20]
- \diamond $\pi^+\pi^-J/\psi$
- \star $\pi^0Z_c^0$
- \circ $\pi^+\pi^-\psi(3686)$
- \diamond $\omega\chi_{c0}$
- \diamond $\omega\chi_{c2}$
- \diamond $\pi^+D^0D^*$
- \star $\pi^+D^{*0}D^*$
- \diamond $\eta J/\psi$
- \star K^+K^-J/ψ
- \square PDG

Above the $Y(4230)$, there is little consistency among exclusive channels

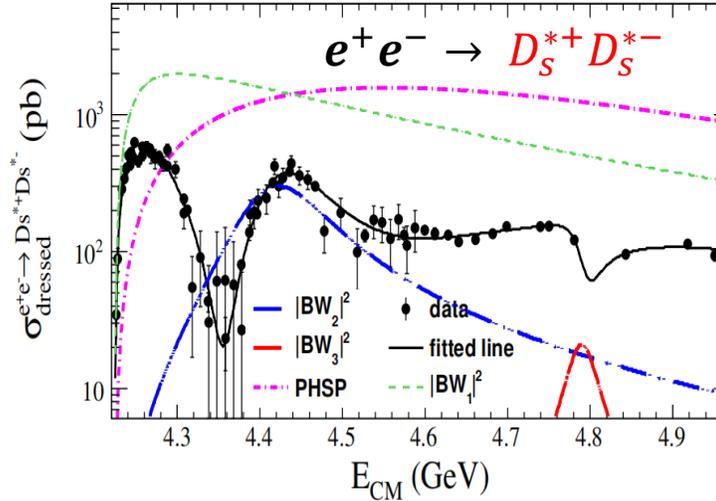
The Y states in open charm channels

Open charm channels have larger cross sections and show more complex structures

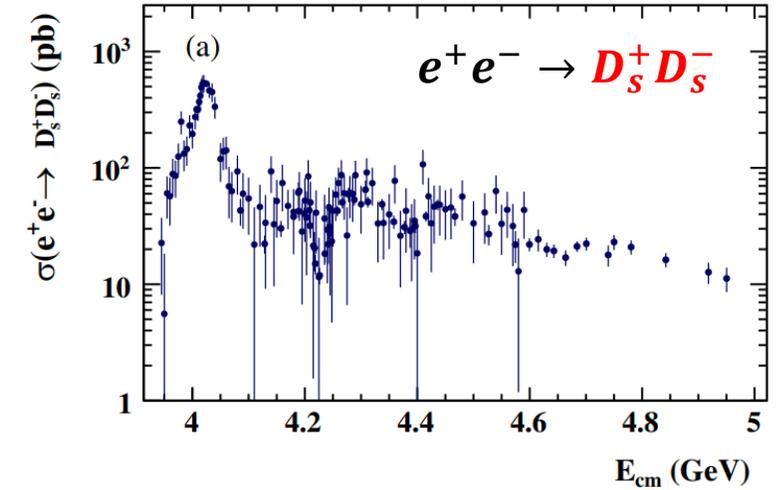
PRL130 (2023) 121901



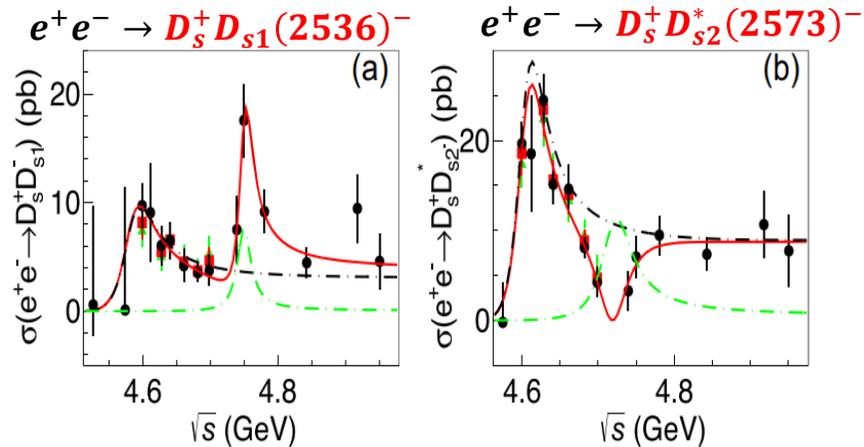
PRL131 (2023) 151903



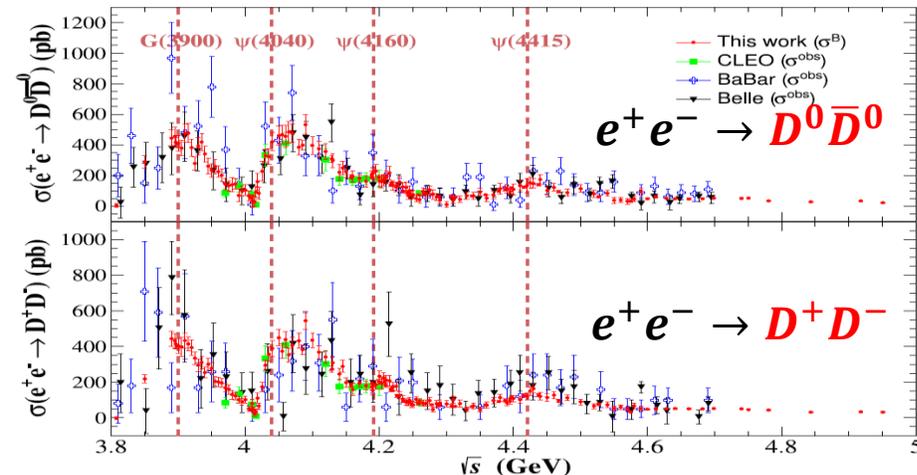
PRL 133 (2024) 261902



PRL133 (2024) 171903



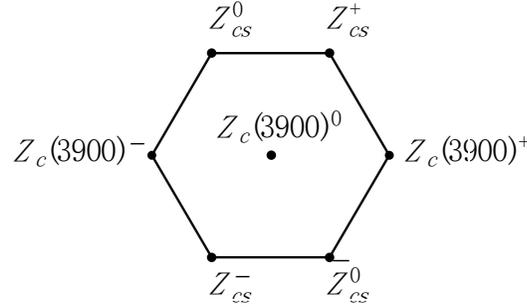
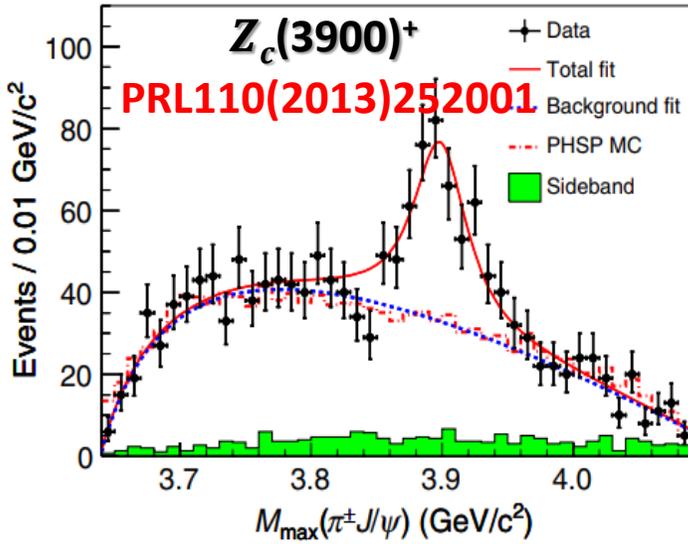
PRL133 (2024) 081901



The $Z_{c(s)}$ states (aka $T_{c\bar{c}}$)

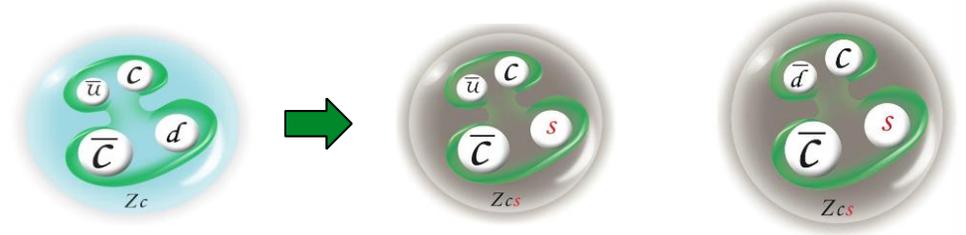
2023年自然科学二等奖

$$e^+e^- \rightarrow \pi^+\pi^-J/\psi$$



Given tetraquark state assumption, there should exist SU(3) partner Z_{cs} state with strangeness

“Tetra”-Octet?

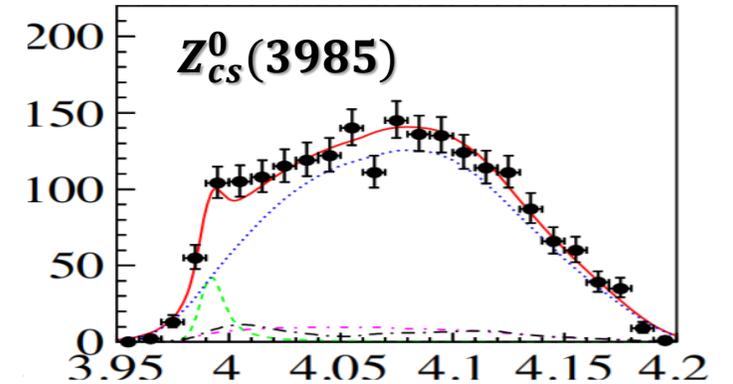
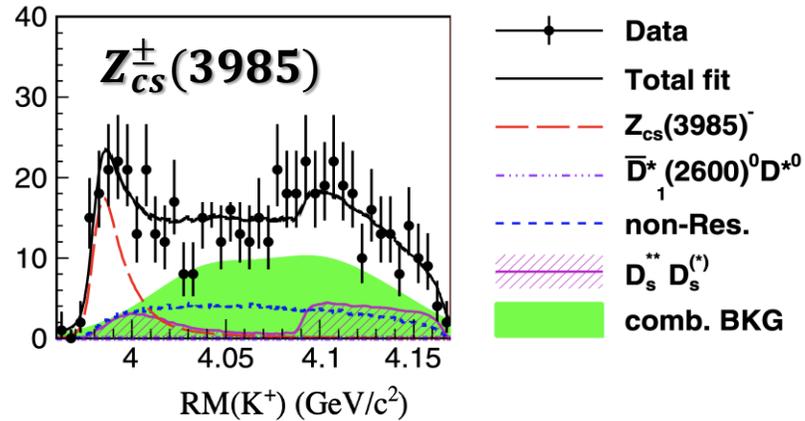
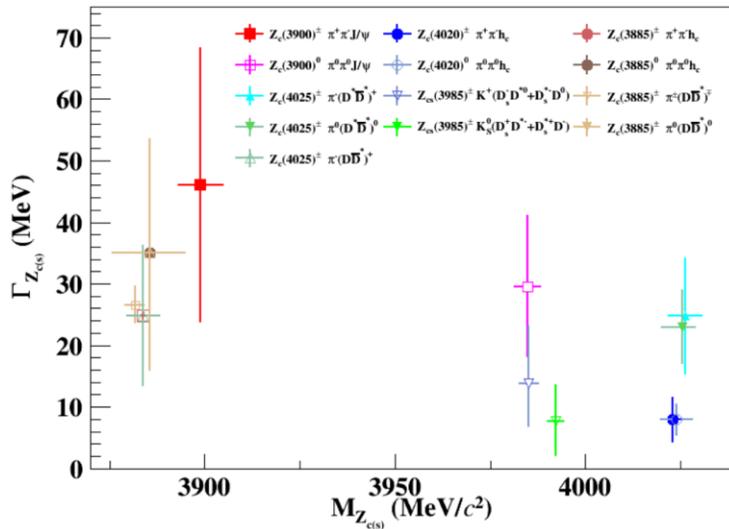


$$e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$$

PRL126(2021)102001

$$e^+e^- \rightarrow K_s^0(D_s^+ D^{*-} + D_s^{*+} D^-)$$

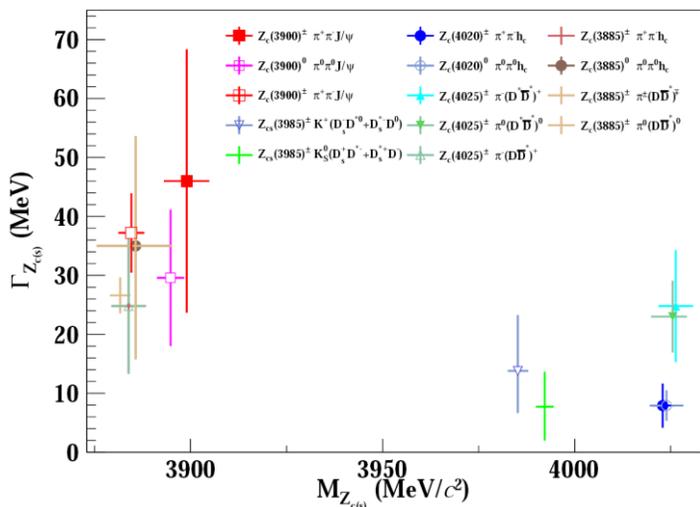
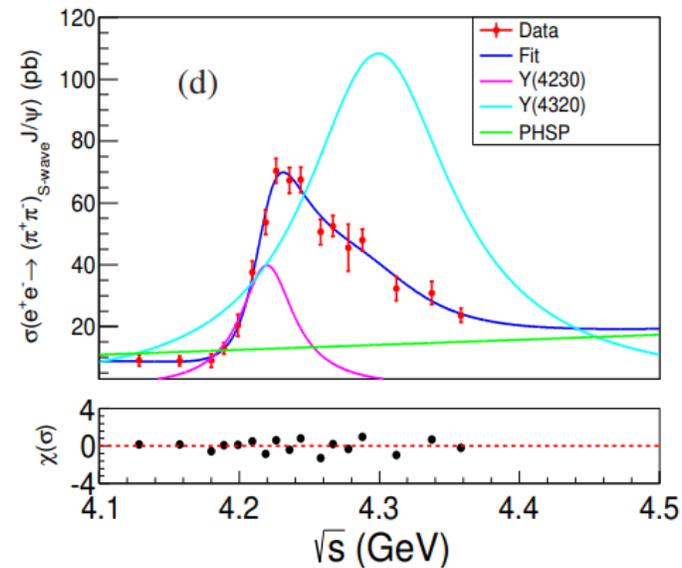
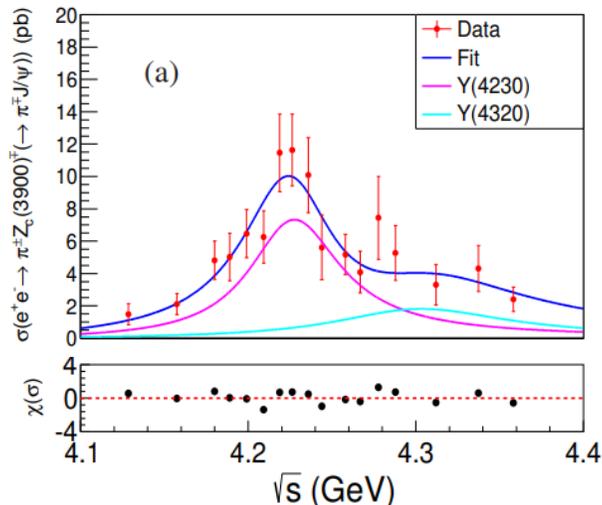
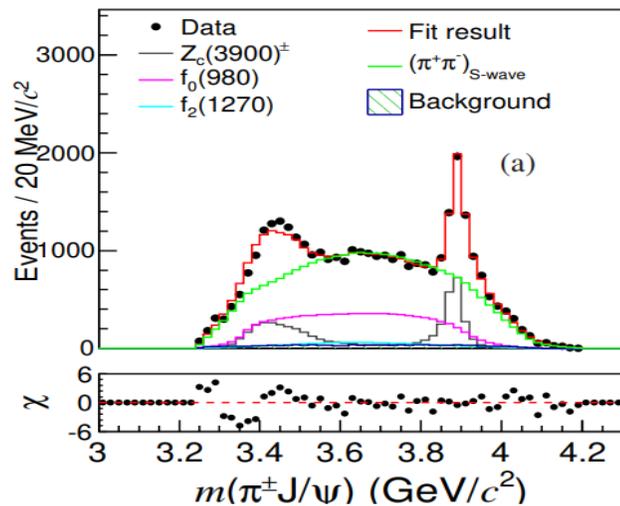
PRL129(2022)112003



Update on the $Z_c(3900)$

The $Z_c(3900)$ is produced through $e^+e^- \rightarrow \pi Z_c$ at E_{cm} around $\psi(4230)$...

PRD112(2025)092013



The latest study uses all data (12 fb^{-1}) between 4.1 and 4.4 GeV. Partial wave analysis is performed on $e^+e^- \rightarrow \pi^+\pi^-J/\psi$. The new data are sensitive to the line shape.

Selected topic of traditional charmonium decays: $\psi(3770) \rightarrow \text{non} - D\bar{D}$

- ★ The decays of $\psi(3770)$ are dominated by $D\bar{D}$ mode:

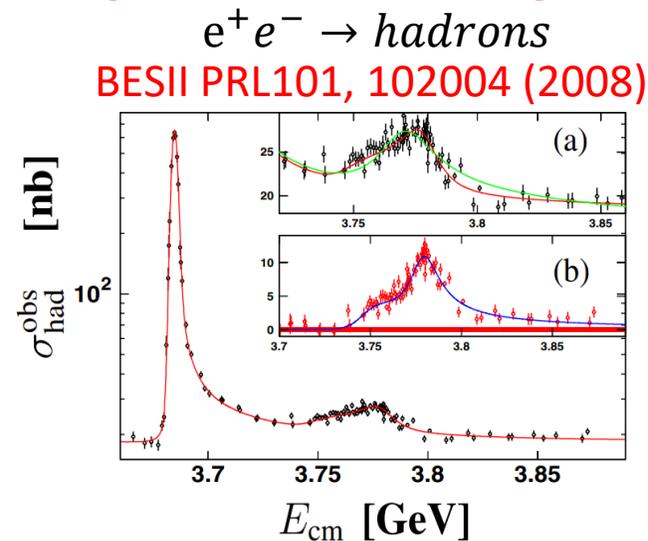
BESII^{PLB641(2006)145}: $B[\psi(3770) \rightarrow \text{non} - D\bar{D}] = (14.7 \pm 3.2)\%$

CLEO^{PRD96(2006)092002}: $B[\psi(3770) \rightarrow \text{non} - D\bar{D}] = (-3.3 \pm 1.4_{-1.8}^{+6.6})\%$

PDG24: $B[\psi(3770) \rightarrow D\bar{D}] = (93_{-9}^{+8})\%$

- ★ **NRQCD calculation**^{PRL101, 112001} gives an upper limit of 5% for light hadron decays, while other phenomenological model, e.g., hadron loops give large fraction^{PRL102, 172001}

Previously, BESII, CLEO and early BESIII searched for ψ charmless by comparing ψ' and 3.65/3.67 GeV data. Will this affect the search for $\psi(3770) \rightarrow \text{non} - D\bar{D}$ decays?



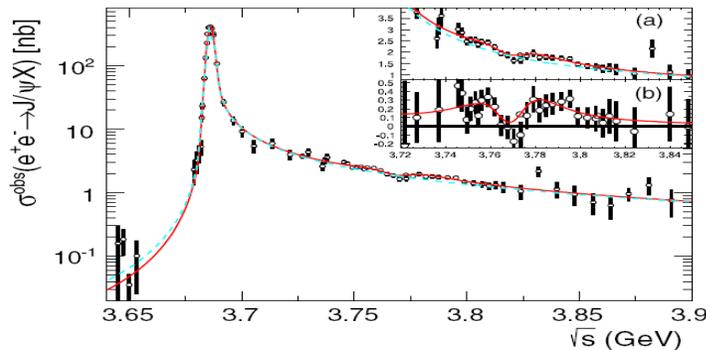
Abnormal structure around $\psi(3770)$ was observed at BESII. Will this anomalous structure affect the BFs of exclusive $\psi(3770) \rightarrow \text{non} - D\bar{D}$ decays?

- ★ Search for ψ decays via fine scan data is helpful and highly desirable

Production and decays around $\psi(3770)$

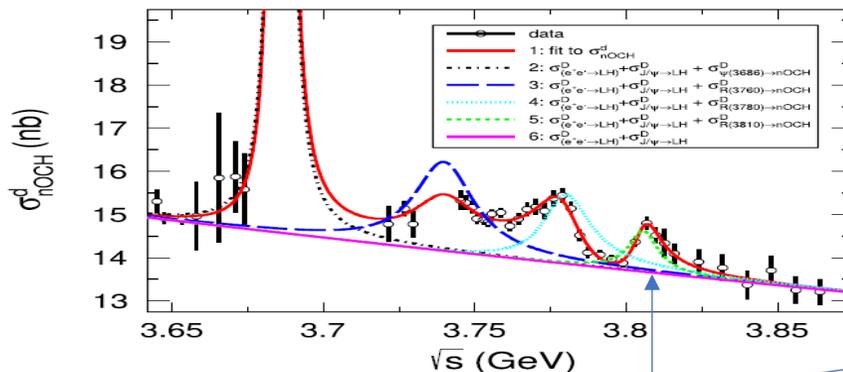
$$e^+e^- \rightarrow J/\psi X$$

PRL127 (2021) 082002



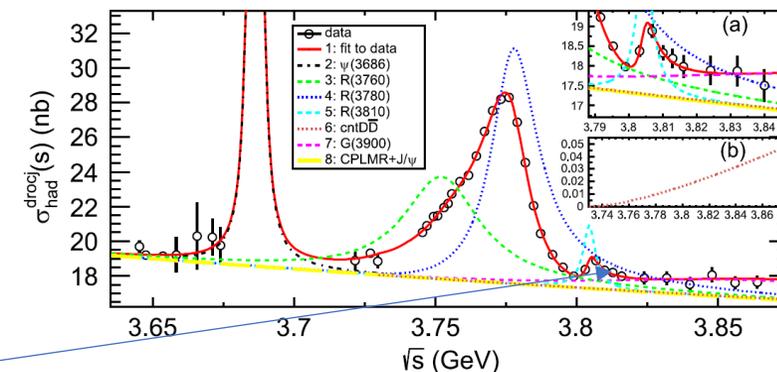
$$e^+e^- \rightarrow \text{hadrons}[non - D\bar{D}]$$

PRL132 (2024) 191902



$$e^+e^- \rightarrow \text{hadrons}$$

PRL133 (2024) 241902



- Strange structures other simple BW of $\psi(3770)$ are found in different processes

- Structure@~3.81 GeV is found in papers 2 and 3
- $B[R \rightarrow non - D\bar{D}]$ are extracted in papers 1 and 2

$$\sigma^{\text{dress}}(s') =$$

$$|A_{\psi(3686)}(s') + e^{i\phi_1} A_{\psi(3770)}(s')^2 + e^{i\phi_2} A_S(s')|^2$$

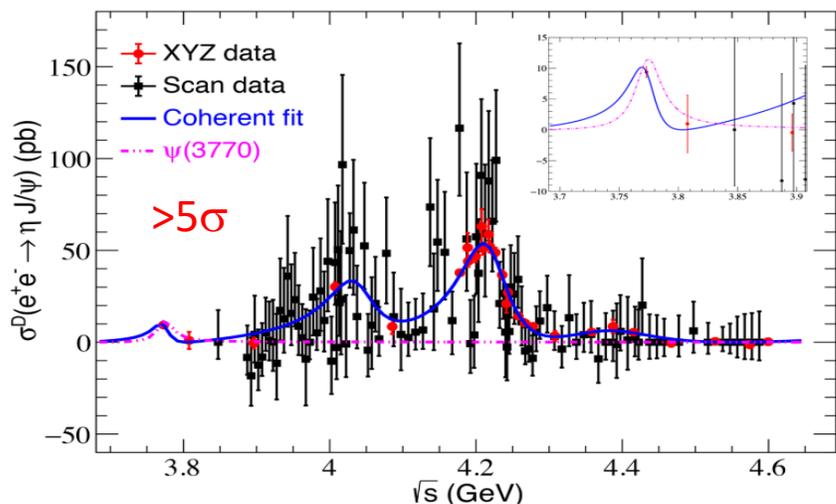
Parameter	Solution I	Solution II
$B(\mathcal{R}_1 \rightarrow f)$	$62.8 \pm 0.6 \pm 1.7$	$62.3 \pm 0.8 \pm 1.6$
$M_{\mathcal{R}_2}$	3773.13	3773.13
$\Gamma_{\mathcal{R}_2}^{\text{tot}}$	27.2	27.2
$B(\mathcal{R}_2 \rightarrow f)$	$55.1 \pm 36.2 \pm 6.3$	$38.1 \pm 41.4 \pm 4.3$
ϕ_1 (degree)	$175 \pm 30 \pm 30$	$60 \pm 37 \pm 10$
$M_{\mathcal{R}_3}$	$3766.2 \pm 3.1 \pm 0.4$	$3766.2 \pm 3.8 \pm 0.4$
$\Gamma_{\mathcal{R}_3}^{\text{tot}}$	$22.1 \pm 5.2 \pm 1.4$	$22.2 \pm 5.9 \pm 1.4$
$\Gamma_{\mathcal{R}_3}^{ee} B(\mathcal{R}_3 \rightarrow f)$	$110.2 \pm 134.4 \pm 16.2$	$79.4 \pm 85.5 \pm 11.7$
ϕ_2	$322 \pm 34 \pm 30$	$213 \pm 48 \pm 20$

Parameters	Result I	Result II
$M_{\mathcal{R}(3760)}$	$3739.9 \pm 4.2 \pm 2.6$	$3739.7 \pm 3.9 \pm 2.6$
$\Gamma_{\mathcal{R}(3760)}^{\text{tot}}$	$23.9 \pm 8.2 \pm 4.8$	$22.5 \pm 8.3 \pm 4.5$
$\Gamma_{\mathcal{R}(3760)}^{ee} B_{\mathcal{R}(3760)}$	$46.8 \pm 29.9 \pm 25.1$	$11.9 \pm 9.0 \pm 6.4$
$\phi_{\mathcal{R}(3760)}$	$228 \pm 52 \pm 58$	$113 \pm 51 \pm 29$
$\Gamma_{\mathcal{R}(3780)}^{ee} B_{\mathcal{R}(3780)}$	$29.9 \pm 16.1 \pm 3.7$	$25.3 \pm 11.6 \pm 3.1$
$\phi_{\mathcal{R}(3780)}$	$82 \pm 126 \pm 17$	$250 \pm 119 \pm 52$
$M_{\mathcal{R}(3810)}$	$3805.7 \pm 1.1 \pm 2.7$	$3805.7 \pm 1.1 \pm 2.7$
$\Gamma_{\mathcal{R}(3810)}^{\text{tot}}$	$11.6 \pm 2.9 \pm 1.9$	$11.5 \pm 2.8 \pm 1.9$
$\Gamma_{\mathcal{R}(3810)}^{ee} B_{\mathcal{R}(3810)}$	$10.9 \pm 3.8 \pm 2.5$	$11.0 \pm 3.4 \pm 2.5$
$\phi_{\mathcal{R}(3810)}$	$52 \pm 149 \pm 25$	$215 \pm 148 \pm 103$
f	$2.28 \pm 0.01 \pm 0.07$	$2.28 \pm 0.01 \pm 0.07$
$B[\mathcal{R}(3760) \rightarrow \text{nOCH}]$	$25.2 \pm 16.1 \pm 30.4$	$6.4 \pm 4.8 \pm 7.7$
$B[\mathcal{R}(3780) \rightarrow \text{nOCH}]$	$12.3 \pm 6.6 \pm 8.3$	$10.4 \pm 4.8 \pm 7.0$
$B[\mathcal{R}(3760) \rightarrow \text{OC}]$	$74.8 \pm 16.1 \pm 30.4$	$93.6 \pm 4.8 \pm 7.7$
$B[\mathcal{R}(3780) \rightarrow \text{OC}]$	$87.7 \pm 6.6 \pm 8.3$	$89.6 \pm 4.8 \pm 7.0$

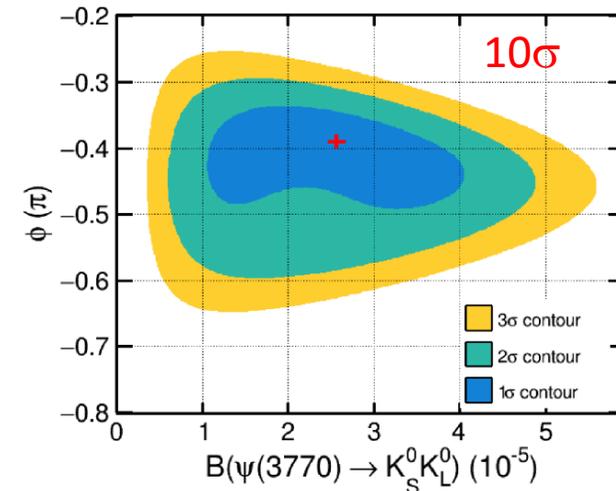
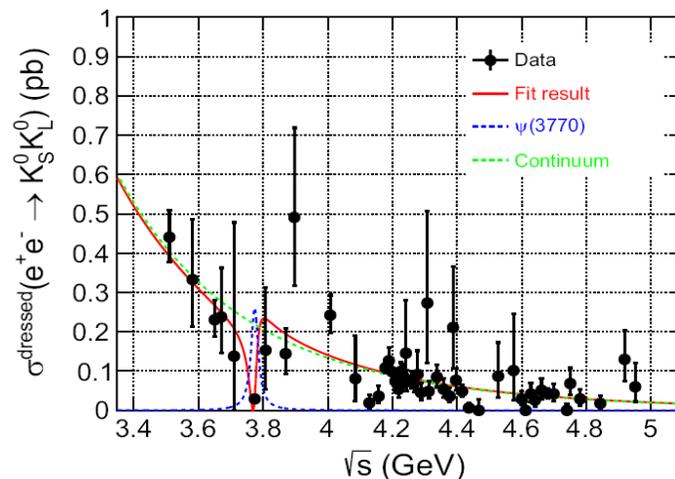
Parameters	Solution I	Solution II
$M_{\mathcal{R}(3760)}$	$3752.6 \pm 4.2 \pm 2.8$	$3751.9 \pm 3.8 \pm 2.8$
$\Gamma_{\mathcal{R}(3760)}^{\text{tot}}$	$31.7 \pm 5.7 \pm 8.4$	$32.8 \pm 5.8 \pm 8.7$
$\Gamma_{\mathcal{R}(3760)}^{ee}$	$206 \pm 83 \pm 96$	$184 \pm 75 \pm 86$
ϕ_1	$-70 \pm 23 \pm 39$	$-49 \pm 29 \pm 27$
$M_{\mathcal{R}(3780)}$	$3778.6 \pm 0.5 \pm 0.3$	$3778.7 \pm 0.5 \pm 0.3$
$\Gamma_{\mathcal{R}(3780)}^{\text{tot}}$	$20.3 \pm 0.8 \pm 1.7$	$20.3 \pm 0.8 \pm 1.7$
$\Gamma_{\mathcal{R}(3780)}^{ee}$	$243 \pm 61 \pm 76$	$265 \pm 69 \pm 83$
ϕ_2	$131 \pm 16 \pm 15$	$151 \pm 23 \pm 17$
$M_{\mathcal{R}(3810)}$	$3804.5 \pm 0.9 \pm 0.9$	$3804.5 \pm 0.9 \pm 0.9$
$\Gamma_{\mathcal{R}(3810)}^{\text{tot}}$	$5.6 \pm 3.6 \pm 3.4$	$5.4 \pm 3.5 \pm 3.2$
$\Gamma_{\mathcal{R}(3810)}^{ee}$	$2.3 \pm 0.8 \pm 1.4$	$19.4 \pm 7.4 \pm 12.1$
ϕ_3	$81 \pm 22 \pm 18$	$-11 \pm 20 \pm 2$
f_c	$2.743 \pm 0.019 \pm 0.081$	$2.741 \pm 0.019 \pm 0.081$

Measured exclusive non- $D\bar{D}$ decays of $\psi(3770)$

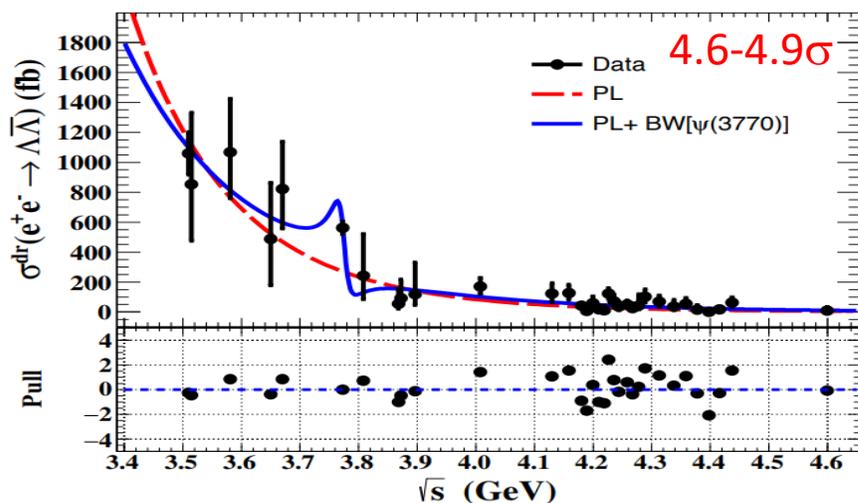
$\psi'' \rightarrow J/\psi \eta$ PRD 107 (2023) L091101



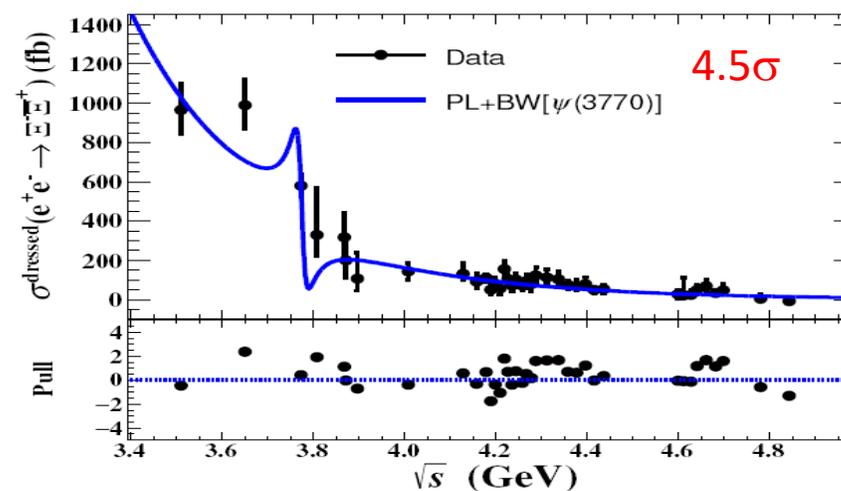
$$\sigma^{\text{dressed}} = \left| BW \cdot e^{i\phi} + \frac{a}{(\sqrt{s})^n} \cdot \sqrt{\Phi(\sqrt{s})} \right|^2 \quad \psi'' \rightarrow K_S^0 K_L^0 \quad \text{PRL 132 (2024) 131901}$$



$\psi'' \rightarrow \Lambda \bar{\Lambda}$ PRD 104 (2021) L091104

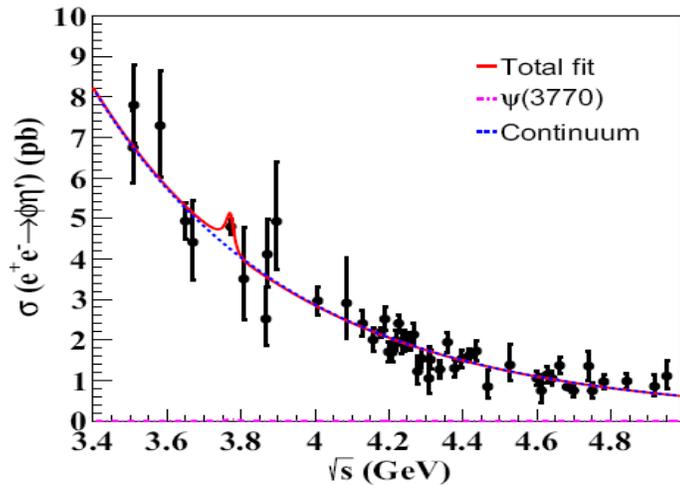


$\psi'' \rightarrow \Xi^- \bar{\Xi}^+$ JHEP11(2023)228

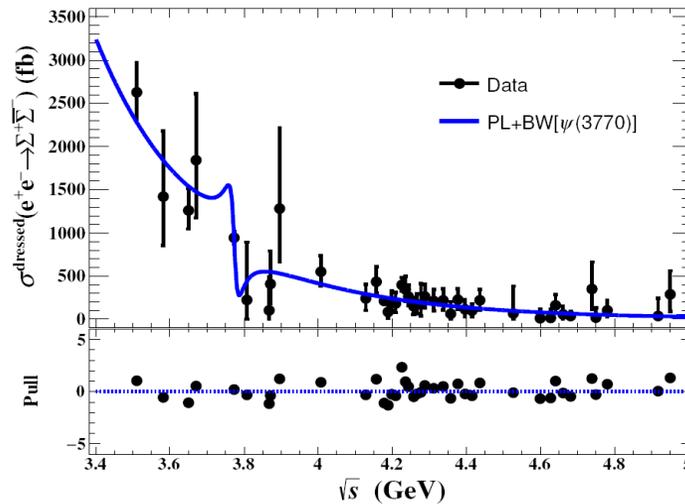


Search for exclusive non- $D\bar{D}$ decays of $\psi(3770)$

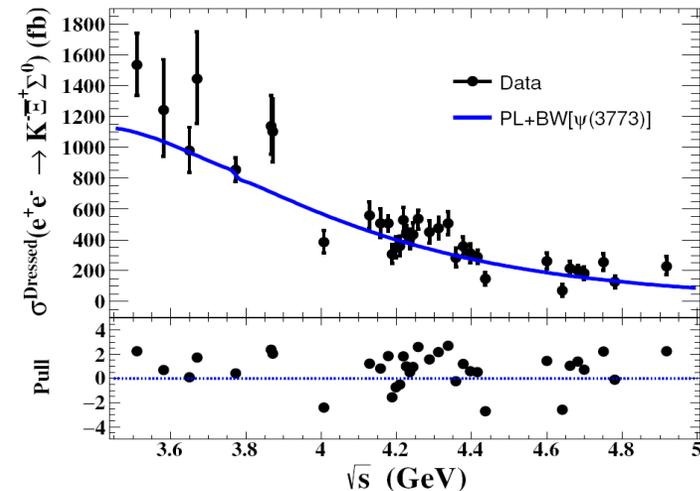
$\psi'' \rightarrow \phi\eta'$ PRD108, 052015 (2023)



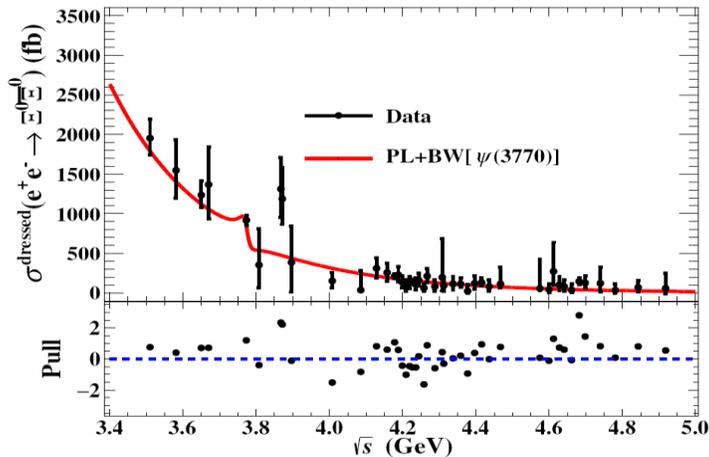
$\psi'' \rightarrow \Sigma^+\bar{\Sigma}^-$ JHEP05(2024)022



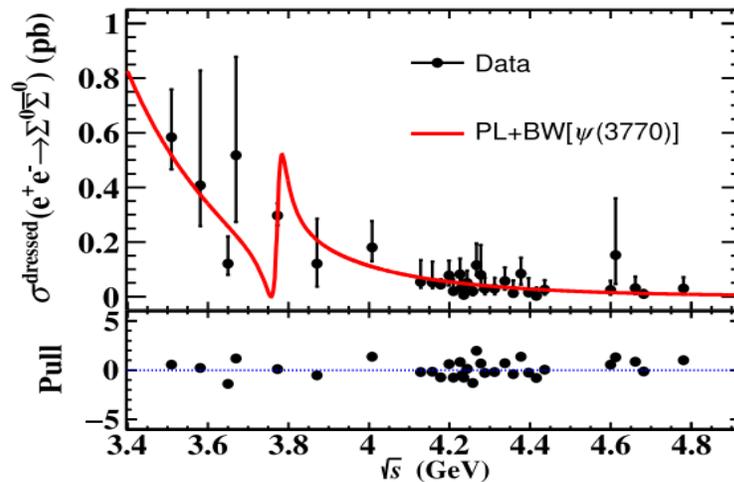
$\psi'' \rightarrow K^-\Lambda\bar{\Xi}^+ + c.c.$ JHEP07(2024)258



$\psi'' \rightarrow \Xi^0\bar{\Xi}^0$ JHEP11(2024)062

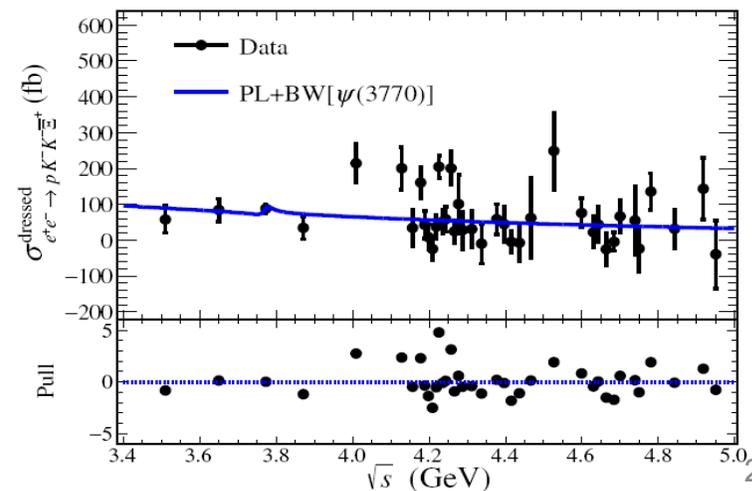


$\psi'' \rightarrow \Sigma^0\bar{\Sigma}^0$ PRD 111 (2025) L051502



$\psi'' \rightarrow pK^-K^-\bar{\Xi}^+ + c.c.$

arXiv:2508.11276



BFs of exclusive non- $D\bar{D}$ decays of $\psi(3770)$

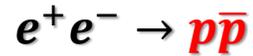
Decay	B	Φ	Reference
$\psi'' \rightarrow J/\psi\eta$ (10^{-4})	$11.3 \pm 5.9 \pm 1.1$	$(3.9 \pm 0.6 \pm 0.1)\pi$	PRD107, L091101
$\psi'' \rightarrow K_S^0 K_L^0$ (10^{-5})	$2.6^{+1.4}_{-1.6}$	$(-0.39^{+0.05}_{-0.10})\pi$	PRL132, 131901
$\psi'' \rightarrow \Lambda\bar{\Lambda}$ (10^{-5})	$2.4^{+15.0}_{-1.9}/14.4^{+2.7}_{-14.0}$	$(183^{+57}_{-40})^\circ/(240^{+17}_{-115})^\circ$	PRD104, L091104
$\psi'' \rightarrow \Xi^-\bar{\Xi}^+$ (10^{-6})	136.0 ± 35.2	$(59 \pm 14)^\circ$	JHEP11(2023)228
$\psi'' \rightarrow \phi\eta'$	$< 2.3 \times 10^{-5}$	$\sim 2.8\pi$	PRD108, 052015
$\psi'' \rightarrow \Xi^0\bar{\Xi}^0$	$< 3.4 \times 10^{-4}$	$(-1.7 \pm 0.2)\pi$	JHEP11(2024)062
$\psi'' \rightarrow \Sigma^+\bar{\Sigma}^-$	$< 3.9 \times 10^{-4}$	$(-2.0 \pm 0.4)\pi$	JHEP05(2024)022
$\psi'' \rightarrow \Sigma^0\bar{\Sigma}^0$	$< 3.7 \times 10^{-5}$	$(-0.8 \pm 0.1)\pi$	PRD111, L051502
$\psi'' \rightarrow K^-\Lambda\bar{\Xi}^+ + c.c.$	$< 3.4 \times 10^{-4}$	$(-1.6 \pm 0.2)\pi$	JHEP07(2024)258
$\psi'' \rightarrow pK^-K^-\bar{\Xi}^+ + c.c.$	$< 3.7 \times 10^{-5}$	$(-1.6 \pm 0.2)\pi$	arXiv:2508.11276

- The BF of $\psi'' \rightarrow K_S^0 K_L^0$ agrees well with the prediction via S- and D-wave charmonia mixing scheme^{PRD78, 077505 (2004)}, proposed to interpret “ $\rho\pi$ puzzle” between J/ψ and $\psi(3686)$ decays
- The BF of $\psi'' \rightarrow \Xi^-\bar{\Xi}^+$ is higher than theoretical calculation by an order of magnitude^{PRD96, 092004 (2017)}
- The measured BFs of $\psi'' \rightarrow$ light hadrons may be up to the same level as their ψ' counterparts

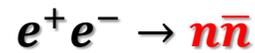
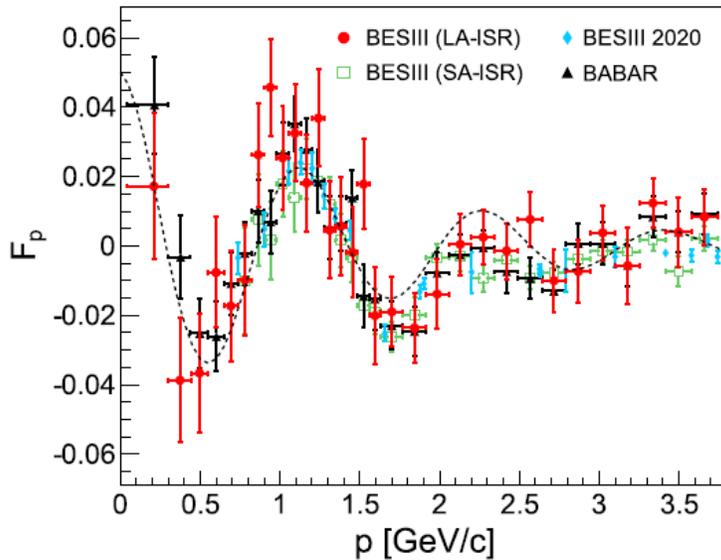
Baryon physics

- **Electromagnetic form factors**
- **Search for CPV**
- **EDM**
- **.....**

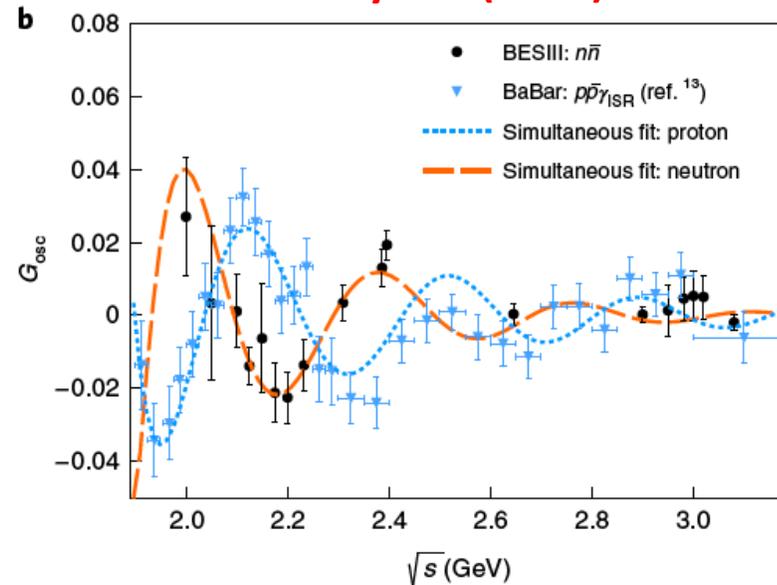
Electromagnetic form factors of baryons



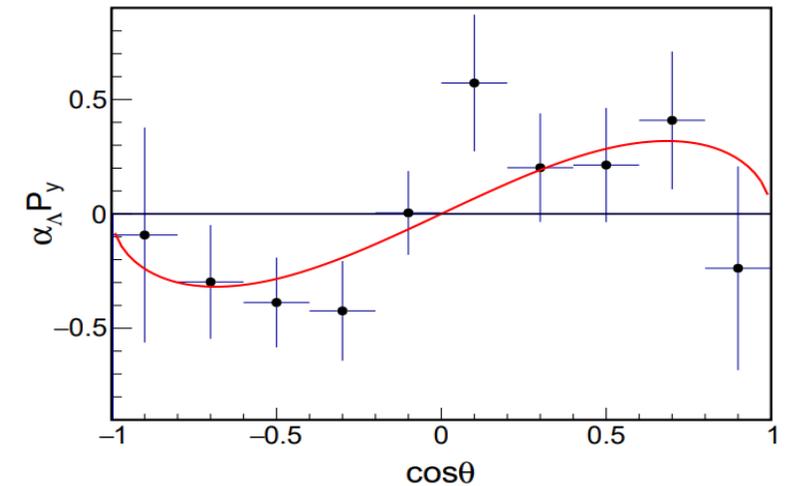
PLB817(2021)136328



Nat. Phys. 17(2021)1200



PRL123(2019)122003



- In the time-like region, the electromagnetic form factors of baryons characterize the internal structure of baryons
- Periodic behavior of $|G_p|$ was first observed at BaBar and **was later confirmed at BESIII**
- **Oscillation of $|G_n|$ is observed at BESIII for the first time**

$$\left| \frac{G_E}{G_M} \right| = 0.96 \pm 0.14(\text{stat.}) \pm 0.02(\text{sys.})$$

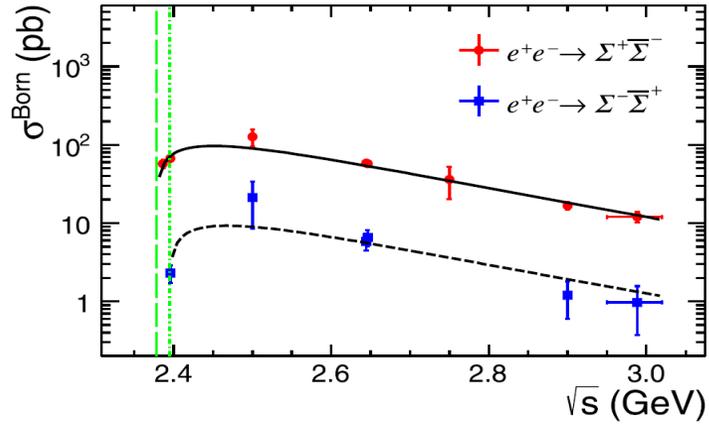
$$\Delta\Phi = 37^\circ \pm 12^\circ(\text{stat.}) \pm 6^\circ(\text{sys.})$$

Confirm the complex form of electromagnetic form factors

Measurements of Σ , Ξ , Ω

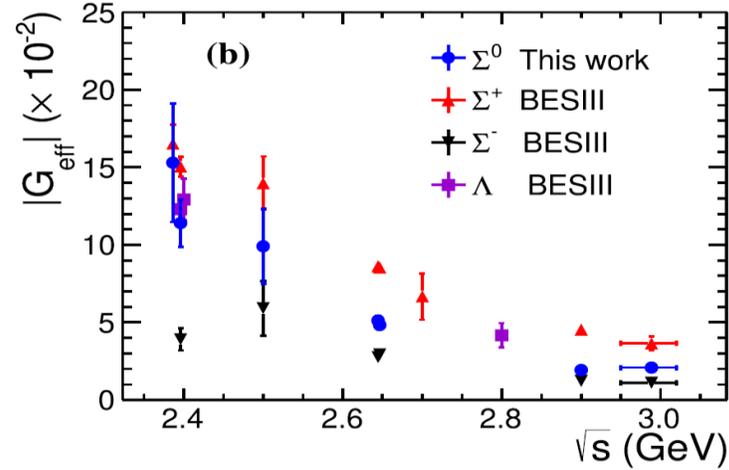
e^+e^- data@2.38-3.02 GeV

PLB 814 (2021) 136110



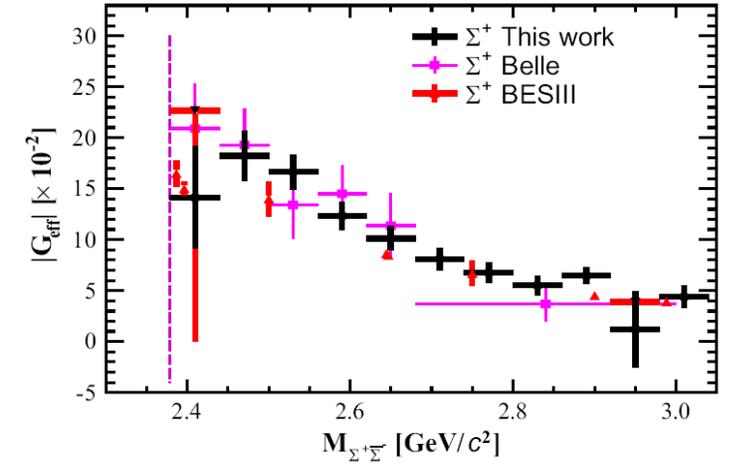
e^+e^- data@2.38-3.02 GeV

PLB 831 (2022) 137187



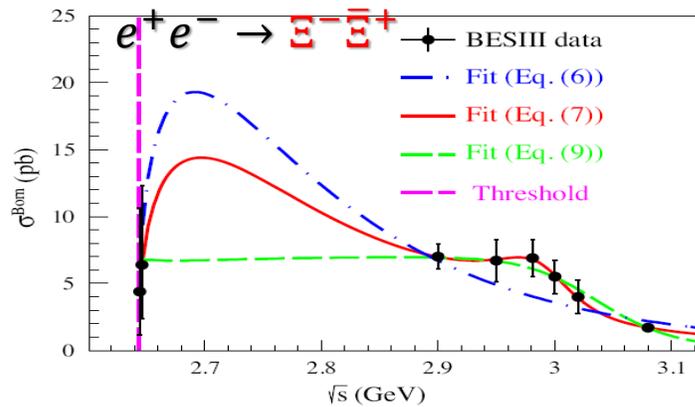
ISR data@3.773 GeV

PRD 109 (2023) 034029



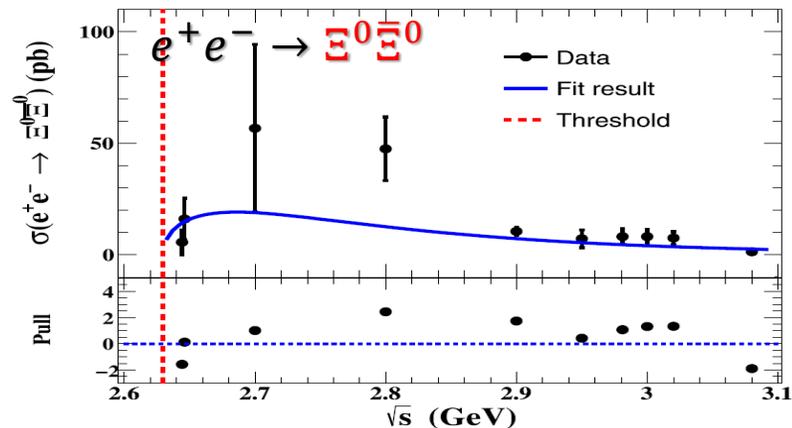
e^+e^- data@2.66-3.08 GeV

PRD103 (2021) 012005



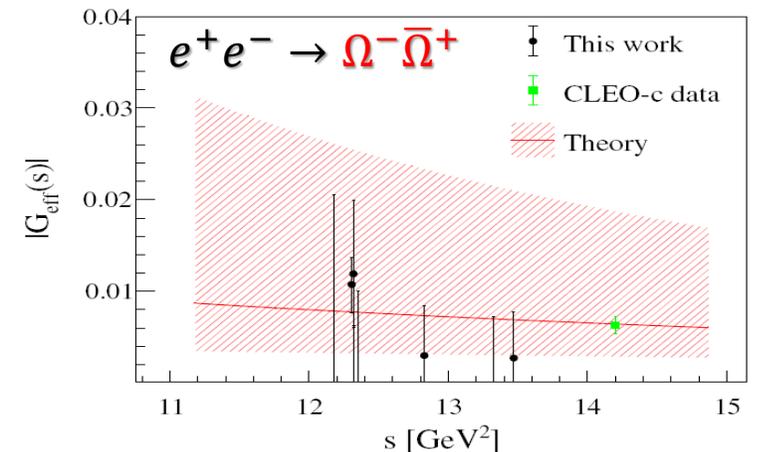
e^+e^- data@2.66-3.08 GeV

PLB820 (2021) 136557



e^+e^- data@3.49-3.67 GeV

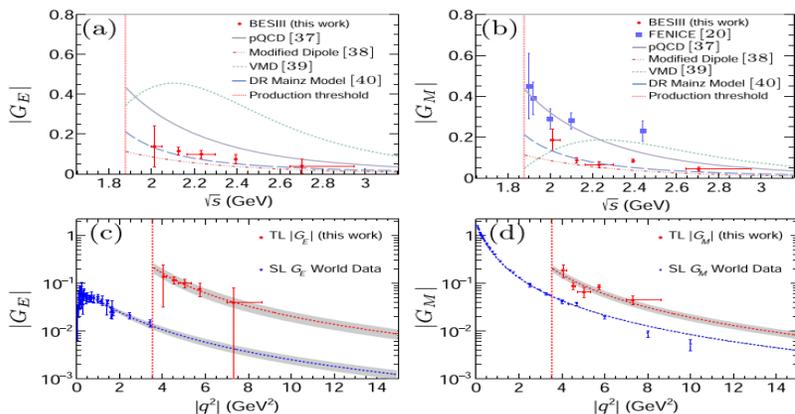
PRD107 (2023) 052003



More electromagnetic form factors of baryons

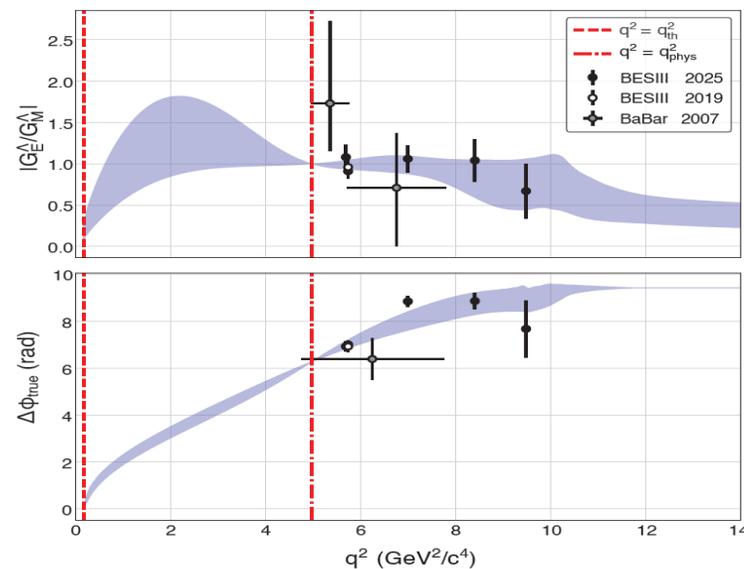
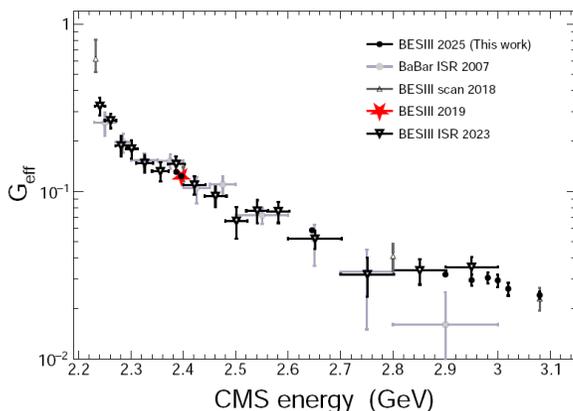
$e^+e^- \rightarrow n\bar{n}$ with data@2.0-2.95 GeV

PRL 130 (2023) 151905



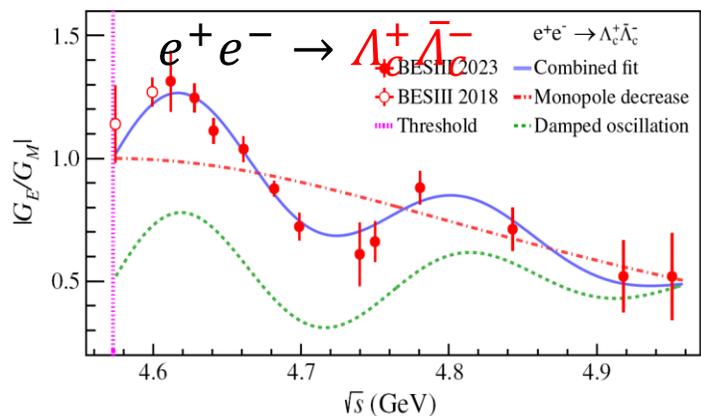
$e^+e^- \rightarrow \Lambda\bar{\Lambda}$ with data@2.386-3.080 GeV

PRL 135 (2025) 191902

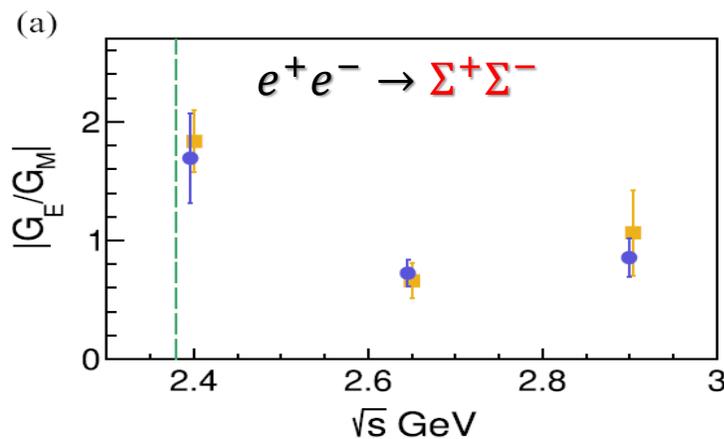


首次精确测量中子类时电和磁形状因子

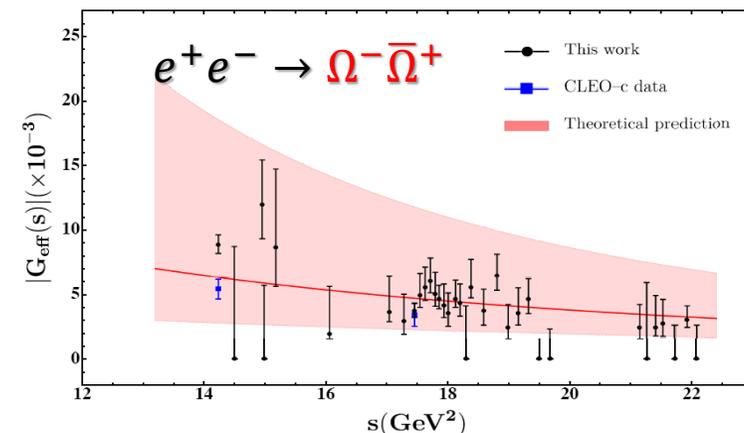
PRL131 (2023) 191901



PRL132 (2024) 081904



arXiv:2508.01359

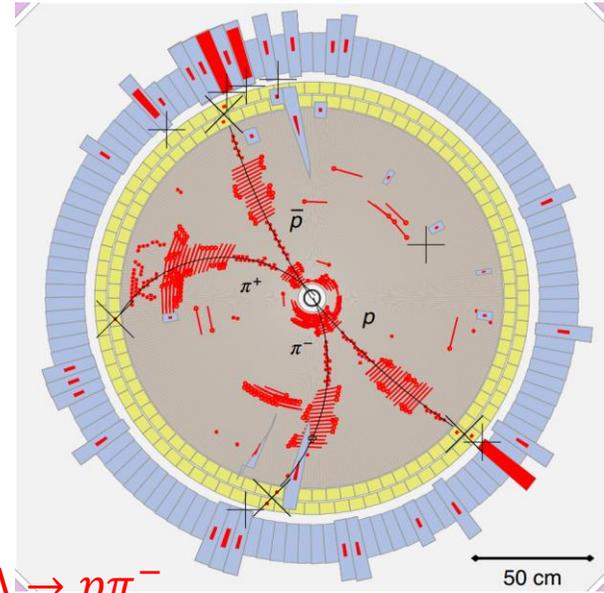


$$e^+ e^- \rightarrow J/\psi \rightarrow \Lambda \bar{\Lambda}, \Lambda \rightarrow p \pi^-, \bar{\Lambda} \rightarrow \bar{p} \pi^+$$

Differential cross-section of this process:

$$\begin{aligned} \mathcal{W}(\xi) &= \mathcal{F}_0(\xi) + \alpha_{J/\psi} \mathcal{F}_5(\xi) + \alpha_- \alpha_+ \quad \text{spin-correlation} \\ &\times \left[\mathcal{F}_1(\xi) + \sqrt{1 - \alpha_{J/\psi}^2} \cos(\Delta\Phi) \mathcal{F}_2(\xi) + \alpha_{J/\psi} \mathcal{F}_6(\xi) \right] \\ &+ \sqrt{1 - \alpha_{J/\psi}^2} \sin(\Delta\Phi) [\alpha_- \mathcal{F}_3(\xi) + \alpha_+ \mathcal{F}_4(\xi)] \end{aligned} \quad (1)$$

polarization

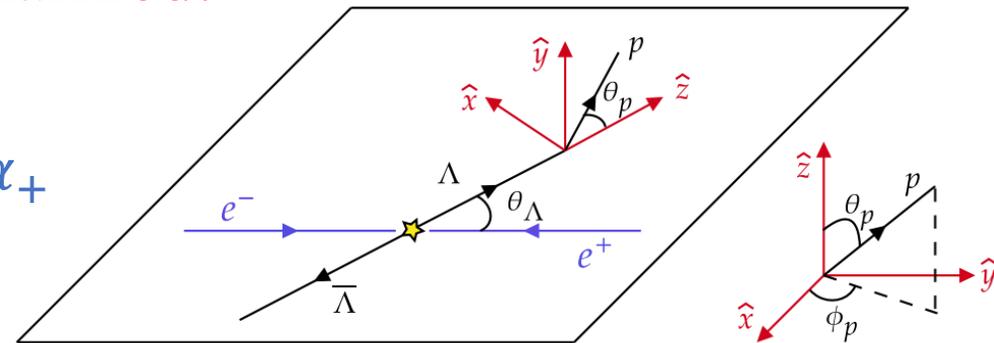


$$\begin{aligned} \alpha_- &: \Lambda \rightarrow p \pi^- \\ \alpha_+ &: \bar{\Lambda} \rightarrow \bar{p} \pi^+ \end{aligned}$$

If $\sin \Delta\Phi \neq 0$, Λ is transverse polarized.

Simultaneous measurement of α_-, α_+

Test CP symmetry



Nuovo Cim. A 109, 241 (1996)
Phys. Rev. D 75, 074026 (2007)
Nucl. Phys. A 190 771, 169 (2006)
Phys. Lett. B 772, 16 (2017)

提出利用量子纠缠，精确测量超子横向极化和CP破坏的新方法，灵敏度提高1000倍

Search for CPV in Λ decay

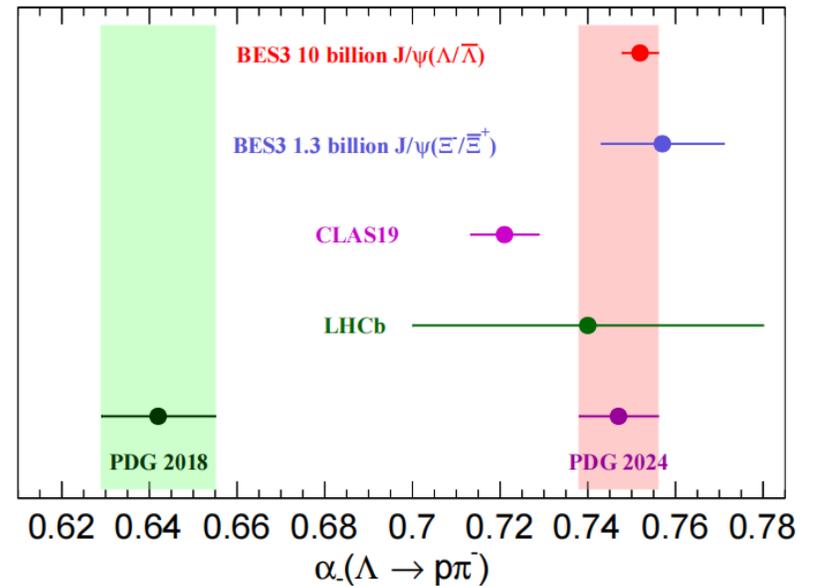
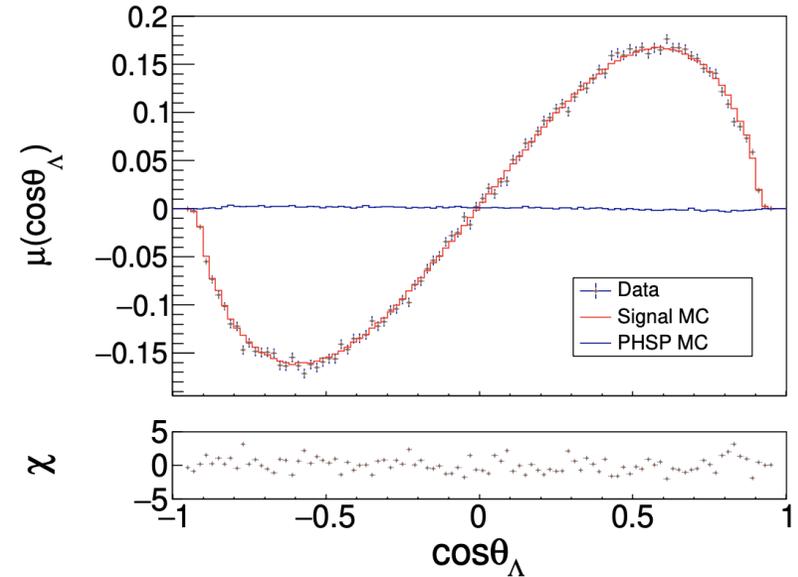
- [1] 1.3 billion: [Nature Phys.15\(2019\)631](#)
- [2] 10 billion: [PRL 129 \(2022\) 131801](#)

Par.	Newest BESIII results
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0031$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0066$
α_-	$0.7519 \pm 0.0036 \pm 0.0024$
α_+	$-0.7559 \pm 0.0036 \pm 0.0030$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0012$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0024$

3.2 M $\Lambda\bar{\Lambda}$ pairs were reconstructed.

- Most precise measurement of Λ decay parameter
- Most precise A_{CP} measurement in hyperon decay:

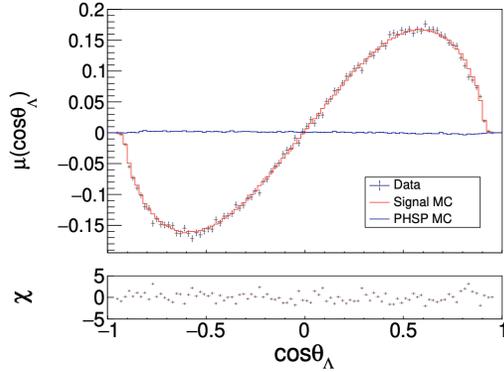
$$A_{CP} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = -0.0025 \pm 0.0046 \pm 0.0011$$



Results of different hyperons

$$J/\psi \rightarrow \Lambda \bar{\Lambda}$$

PRL129(2022)131801

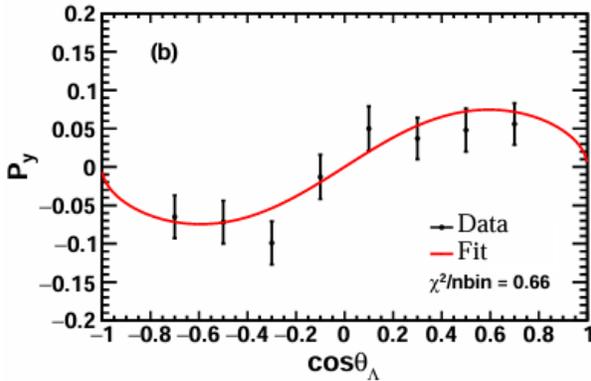


$$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066) \text{ rad}$$

$$A_{CP} = (-0.25 \pm 0.46 \pm 0.12)\%$$

$$\psi(3686) \rightarrow \Lambda \bar{\Lambda}$$

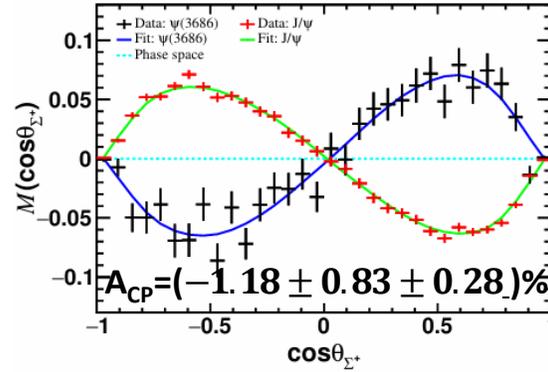
arXiv:2509.15276



$$\Delta\Phi = (0.366 \pm 0.064 \pm 0.013) \text{ rad}$$

$$\psi \rightarrow \Sigma^+ \bar{\Sigma}^-$$

PRL135(2025)141804



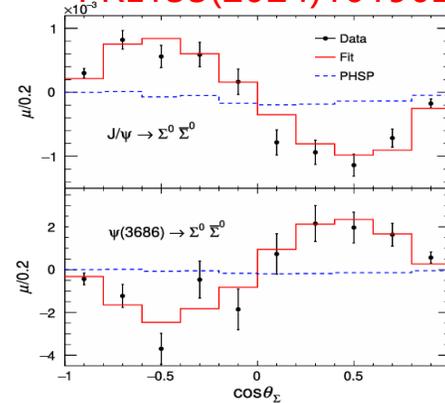
$$\Delta\Phi(J/\psi) = (-0.2744 \pm 0.0033 \pm 0.0010) \text{ rad}$$

$$\Delta\Phi(\psi(2S)) = (0.427 \pm 0.022 \pm 0.003) \text{ rad}$$

$$A_{CP} = (-1.18 \pm 0.83 \pm 0.28)\%$$

$$\psi \rightarrow \Sigma^0 \bar{\Sigma}^0$$

PRL133(2024)101902



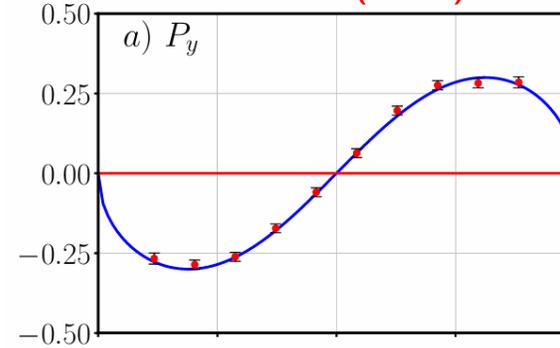
$$\Delta\Phi(J/\psi) = (-0.0828 \pm 0.0068 \pm 0.0033) \text{ rad}$$

$$\Delta\Phi(\psi(2S)) = (0.512 \pm 0.085 \pm 0.034) \text{ rad}$$

$$A_{CP} = (0.4 \pm 2.9 \pm 1.3)\%$$

$$J/\psi \rightarrow \Xi^- \bar{\Xi}^+$$

Nature606(2022)64

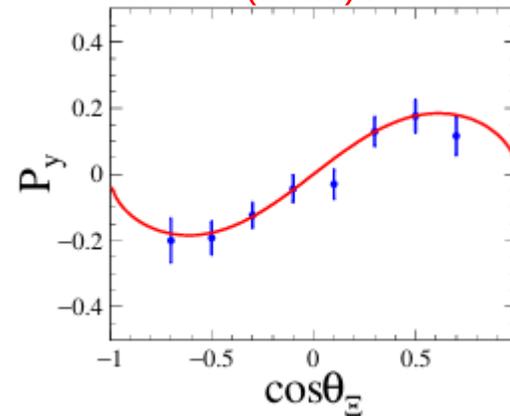


$$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016) \text{ rad}$$

$$A_{CP} = (0.60 \pm 1.34 \pm 0.56)\%$$

$$\psi(3686) \rightarrow \Xi^- \bar{\Xi}^+$$

PRD106(2022)L091101

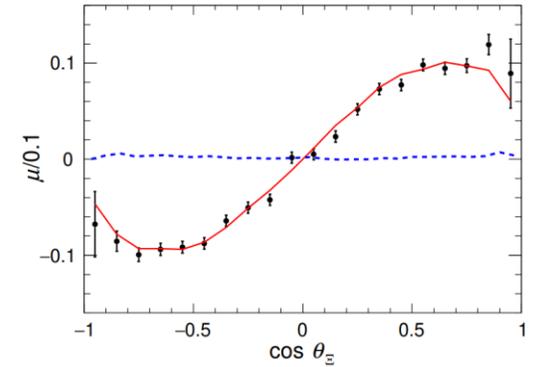


$$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058) \text{ rad}$$

$$A_{CP} = (-1.5 \pm 5.1 \pm 1.0)\%$$

$$J/\psi \rightarrow \Xi^0 \bar{\Xi}^0$$

PRD108(2023)L031106

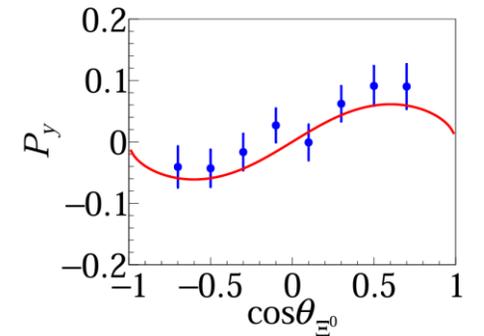


$$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018) \text{ rad}$$

$$A_{CP} = (-0.54 \pm 0.65 \pm 0.31)\%$$

$$\psi(3686) \rightarrow \Xi^0 \bar{\Xi}^0$$

arXiv:2510.19571

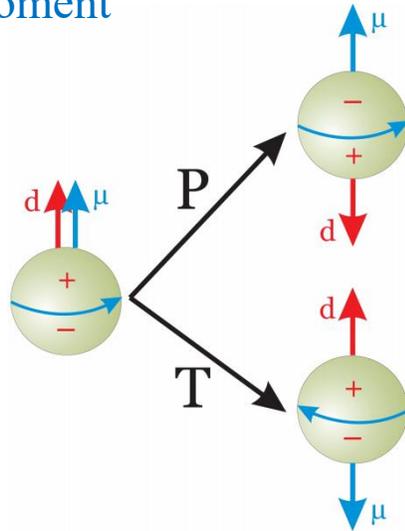


$$\Delta\Phi = (21.0 \pm 3.7 \pm 0.8) \text{ rad}$$

$$A_{CP} = (-1.4 \pm 3.0 \pm 1.0)\%$$

Search for hyperon Electric Dipole Moments (EMD)

μ : magnetic moment
 d : EDM

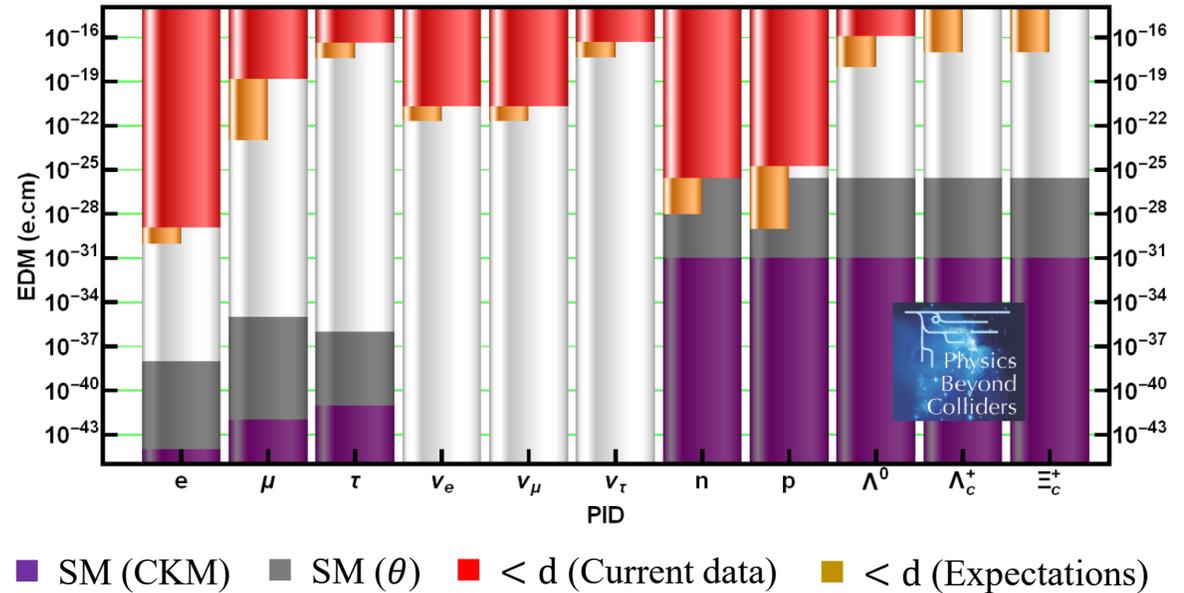


The EDM of the hyperons can be systematically measured at BESIII!

Among the hyperon family, only the EDM of Λ has been measured (with relatively low precision). Utilizing a vast amount of quantum-correlated hyperon-antihyperon pairs, BESIII is expected to improve the precision of the Λ EDM measurement by a factor of 1000 and, for the first time, provide measurements of the EDM for Σ , Ξ , and Ω hyperons.

A non-zero intrinsic EDM would violate both parity (P) and time-reversal (T) symmetries.

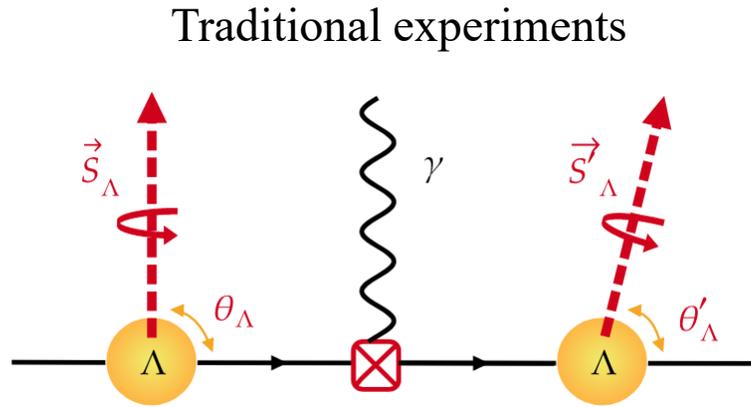
➤ When CPT symmetry is conserved, T violation is equivalent to CP violation.



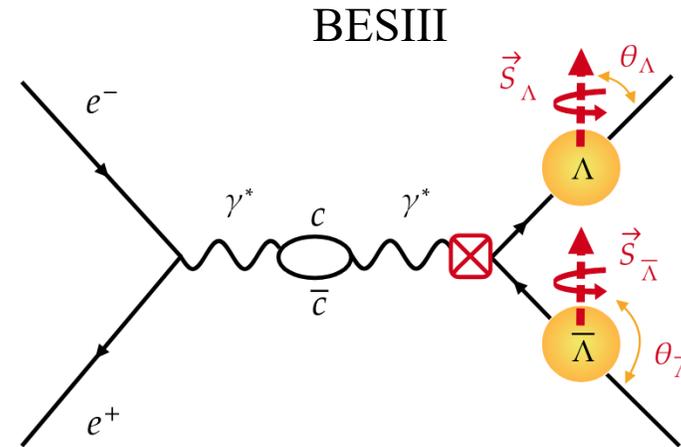
JPG 47 (2020) 010501

World's most precise Λ EDM measurement

PRD 108 (2023) L091301



Spin precession method



Extract EDM through CP-violating FF

Prior direct Λ EDM limit (Fermilab, 1981): $|d_\Lambda| < 1.5 \times 10^{-16} e \cdot \text{cm}$.

- EDM extracted via **full angular analysis** of entangled decays:

$$\text{Re}(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5) \times 10^{-19} e \cdot \text{cm}$$

$$\text{Im}(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6) \times 10^{-19} e \cdot \text{cm}$$

BESIII arXiv:2506.19180

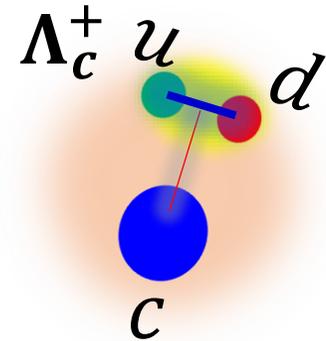
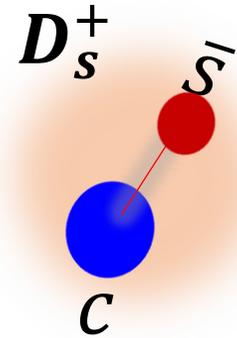
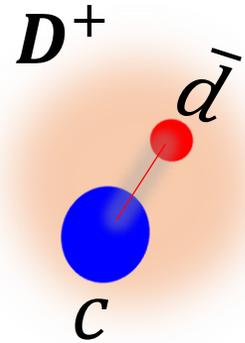
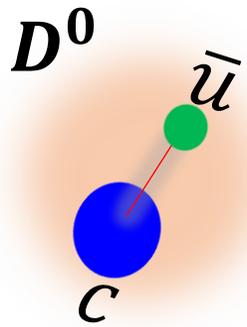
which corresponds to an upper bound of:

$$|d_\Lambda| < 6.5 \times 10^{-19} e \cdot \text{cm} \quad (95\% \text{ CL})$$

- Improves sensitivity by more than **2 orders of magnitude** over the previous best result.

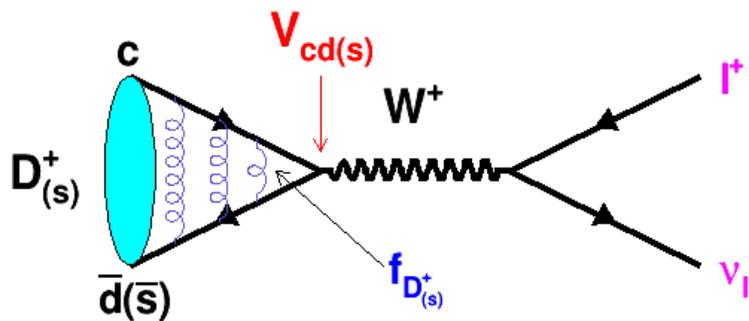
Measurements of the $\Sigma^{+,0}, \Xi^{-,0}$ EDMs are currently underway, with an expected precision comparable to that of the Λ EDM can be achieved.

Charmed hadrons

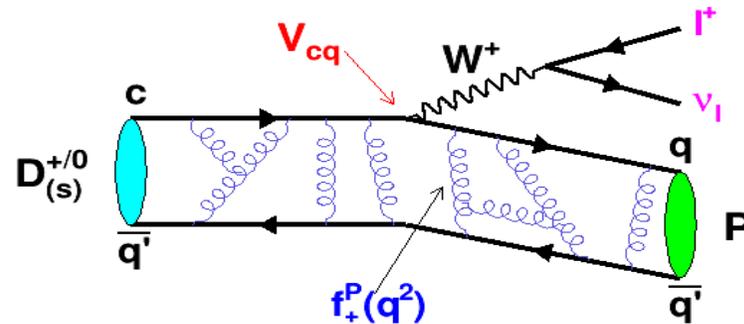


(Semi)leptonic D decays

探讨夸克和轻子相互作用的理想桥梁，检验标准模型的理想探针之一



$$\Gamma(D_{(s)}^+ \rightarrow l^+ \nu_l) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi} |V_{cd(s)}|^2 m_l^2 m_{D_{(s)}^+} \left(1 - \frac{m_l^2}{m_{D_{(s)}^+}^2}\right)^2$$



$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

- 衰变常数、半轻衰变形状因子
- CKM矩阵元 $|V_{cs}|$ 、 $|V_{cd}|$
- 分支比之比 $B_{\mu/e}$ 、 $B_{\tau/\mu}$
- 稀有含轻衰变

- 精密刻度格点QCD等计算
- 在更高精度下检验CKM矩阵的么正性
- 精确检验轻子普适性
- 寻找超出标准模型的新物理效应

$|V_{cs(d)}|$ measurements before BESIII

PDG2014

Direct measurement: (semi)leptonic c D decays

$\Delta V_{ud}/V_{ud} = 0.02\%$

$|V_{ud}| = 0.97425 \pm 0.00022$

$\Delta V_{us}/V_{us} = 0.4\%$

$|V_{us}| = 0.2253 \pm 0.0008$

$\Delta V_{ub}/V_{ub} = 12\%$

$|V_{ub}| = (4.13 \pm 0.49) \times 10^{-3}$

$\Delta V_{cd}/V_{cd} = 3.6\%$

$\nu d \rightarrow c l$

$|V_{cd}| = 0.225 \pm 0.008$

$\Delta V_{cs}/V_{cs} = 1.6\%$

$W \rightarrow c \bar{s}$

$|V_{cs}| = 0.986 \pm 0.016$

$\Delta V_{cb}/V_{cb} = 3.2\%$

$|V_{cb}| = (41.1 \pm 1.3) \times 10^{-3}$

$\Delta V_{td}/V_{td} = 7.1\%$

$|V_{td}| = (8.4 \pm 0.6) \times 10^{-3}$

$\Delta V_{ts}/V_{ts} = 6.8\%$

$|V_{ts}| = (40.0 \pm 2.7) \times 10^{-3}$

$\Delta V_{tb}/V_{tb} = 3.1\%$

1

$|V_{tb}| = 1.021 \pm 0.032$

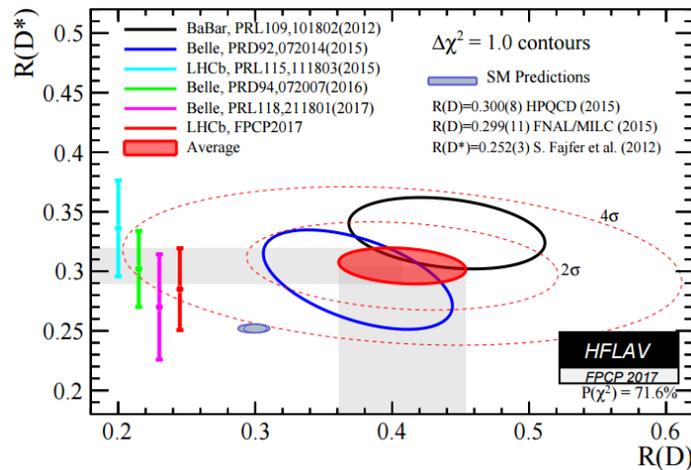
Indirect constraint: Hadronic D decays

V_{ud} , V_{us} and V_{cb} are the best determined due to flavor symmetries: I, SU(3), HQS. Charm (V_{cd} & V_{cs}) and rest of the beauty sector (V_{ub} , V_{td} , V_{ts}) are poorly determined. Theoretical errors on hadronic matrix element dominate.

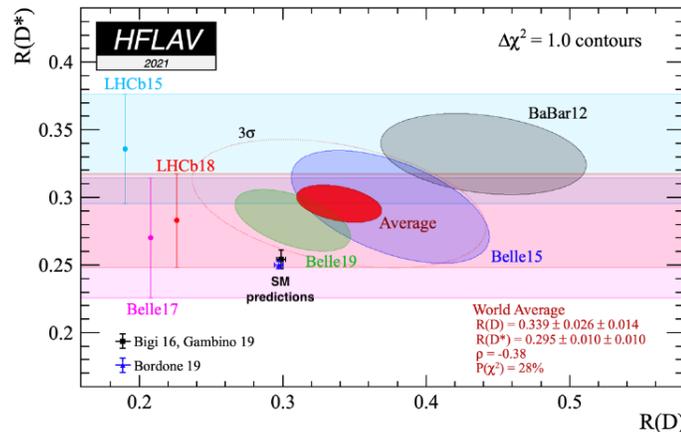
LFU tests in (semi)leptonic D decays before BESIII

Tension in B physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} l \nu_l)}$$



3.9σ



3.3σ

Tension in D physics

$$B^{\text{PDG18}}[D^0 \rightarrow \pi^- \mu^+ \nu] = (0.237 \pm 0.024)\%$$

$$\frac{\Gamma^{\text{PDG18}}[D^0 \rightarrow \pi^- \mu^+ \nu]}{\Gamma^{\text{PDG18}}[D^0 \rightarrow \pi^- e^+ \nu]} = 0.82 \pm 0.08 \quad \text{SM prediction: } 0.985$$

(2.1σ)

The knowledge of semimuonic charm meson decays is very poor

		D^0		D^+	D_s^+	
$c \rightarrow sl^+ \nu$	K^-	4% ^{Belle}	\bar{K}^0	7% ^{FOCUS}	η	NA
	K^{*-}	13% ^{FOCUS}	\bar{K}^{*0}	3% ^{CLEOc}	η'	NA
	K_1^-	NA	\bar{K}_1^0	NA	ϕ	NA
					f_0	NA
$c \rightarrow dl^+ \nu$	π^-	10% ^{Belle}	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17% ^{FOCUS}	K^{*0}	NA
			f_0	NA		
			ω	NA		
			η	NA		
		η'	NA			

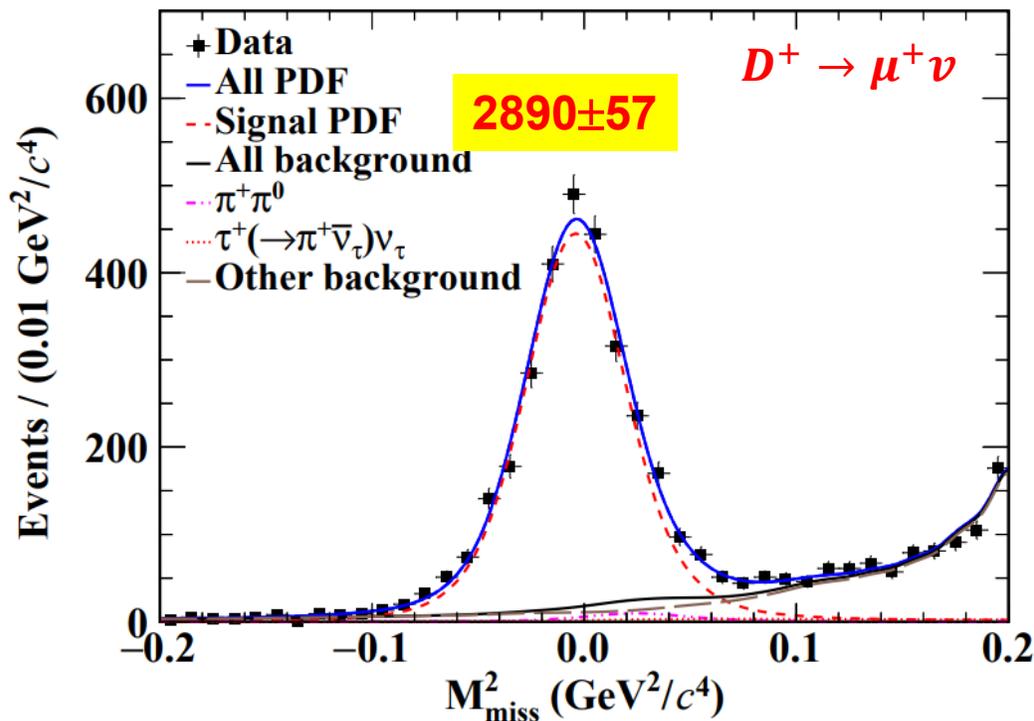
Precision measurements of $D^+ \rightarrow l^+ \nu_l$ and LFU test

PRD89(2014)051104, 2.93 fb⁻¹@3.773 GeV

PRL135(2025)061801, 20.3 fb⁻¹@3.773 GeV

PRL123(2019)211802, 2.93 fb⁻¹@3.773 GeV

JHEP01(2025)089, 7.9 fb⁻¹@3.773 GeV

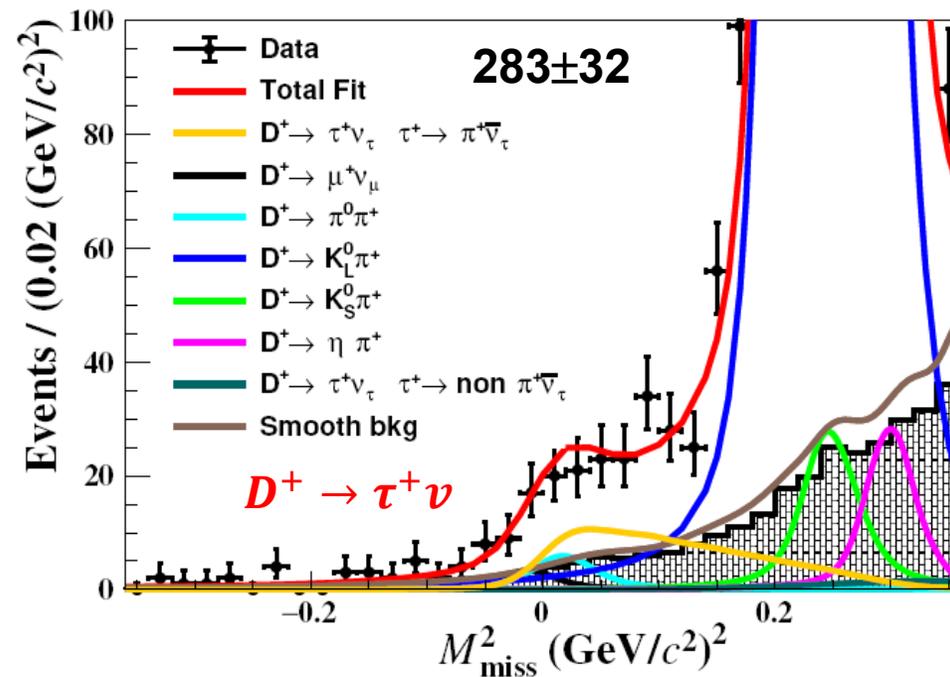


The most precise to date

$$B[D^+ \rightarrow \mu^+ \nu] = (4.03 \pm 0.08 \pm 0.04) \times 10^{-4}$$

$$f_{D^+} |V_{cd}| = 48.52 \pm 0.48 \pm 0.19 \text{ MeV}$$

Precision ~ 1.2%



$$B[D^+ \rightarrow \tau^+ \nu] = (9.1 \pm 1.1 \pm 0.5) \times 10^{-4}$$

$$R_D = \frac{B[D^+ \rightarrow \tau^+ \nu]}{B[D^+ \rightarrow \mu^+ \nu]} = 2.49 \pm 0.31$$

$$f_{D^+} |V_{cd}| = 45.9 \pm 2.5 \pm 1.2 \text{ MeV}$$

Precision ~ 5.5%

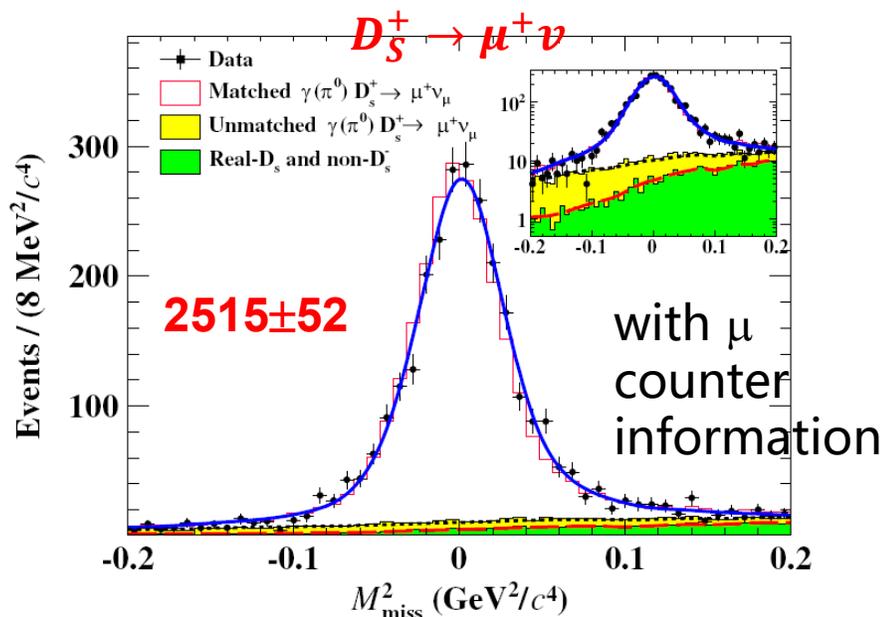
SM prediction: 2.67

Precision measurements of $D_s^+ \rightarrow l^+ \nu_l$ and LFU test

PRL122(2019)071802, 3.19 fb⁻¹@4.18 GeV

PRD104(2021)052009, 6.3 fb⁻¹@4.18-4.23GeV

PRD108(2023)112001, 7.33 fb⁻¹@4.18-4.23GeV



$$B[D_s^+ \rightarrow \mu^+ \nu] = (5.29 \pm 0.11 \pm 0.09) \times 10^{-3}$$

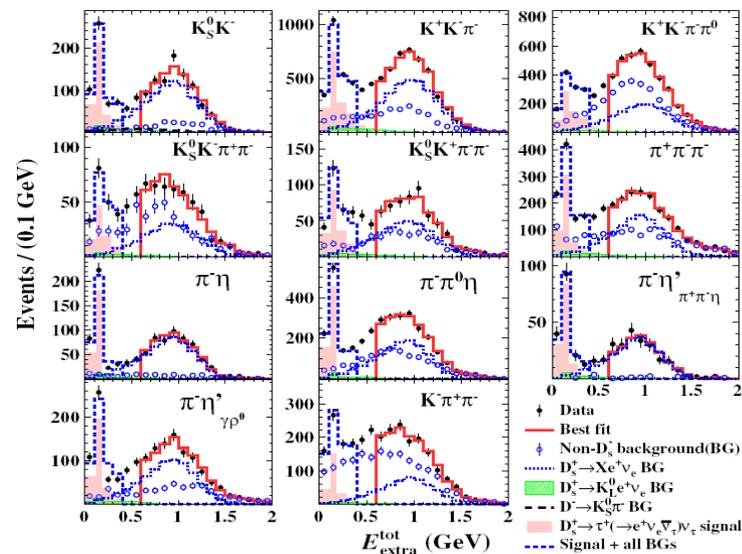
$$f_{D_s^+} |V_{cs}| = (241.8 \pm 2.5 \pm 2.2) \text{ MeV}$$

Precision~1.4%

The most precise to date

$$D_s^+ \rightarrow \tau^+ (e^+ \nu \nu) \nu$$

PRL127(2021)171801, 6.3 fb⁻¹@4.18-4.23GeV



4940±97

The most precise to date

$$B[D_s^+ \rightarrow \tau^+ \nu] = (5.27 \pm 0.10 \pm 0.12)\%$$

$$f_{D_s^+} |V_{cs}| = (244.4 \pm 2.3 \pm 2.9) \text{ MeV}$$

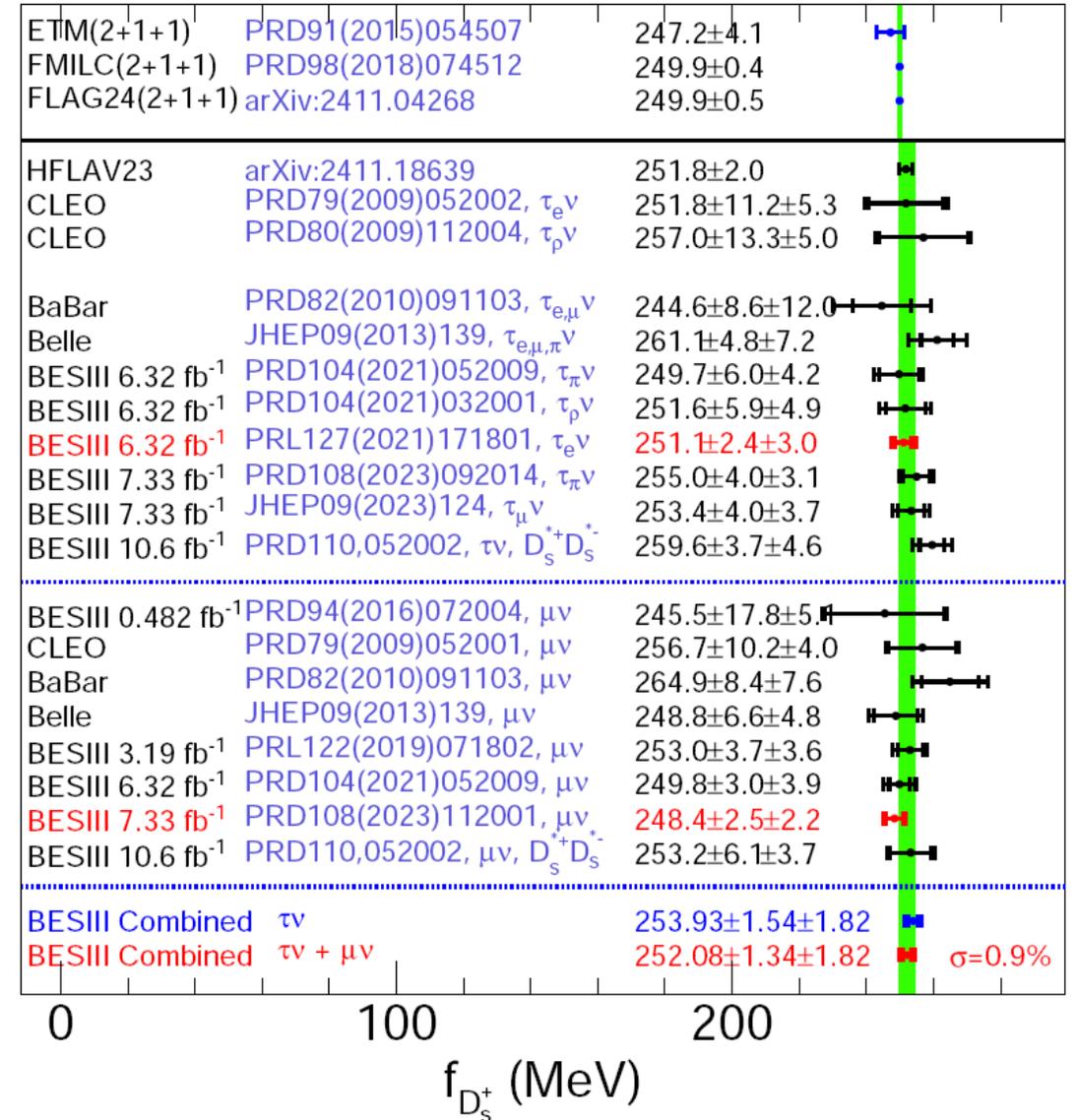
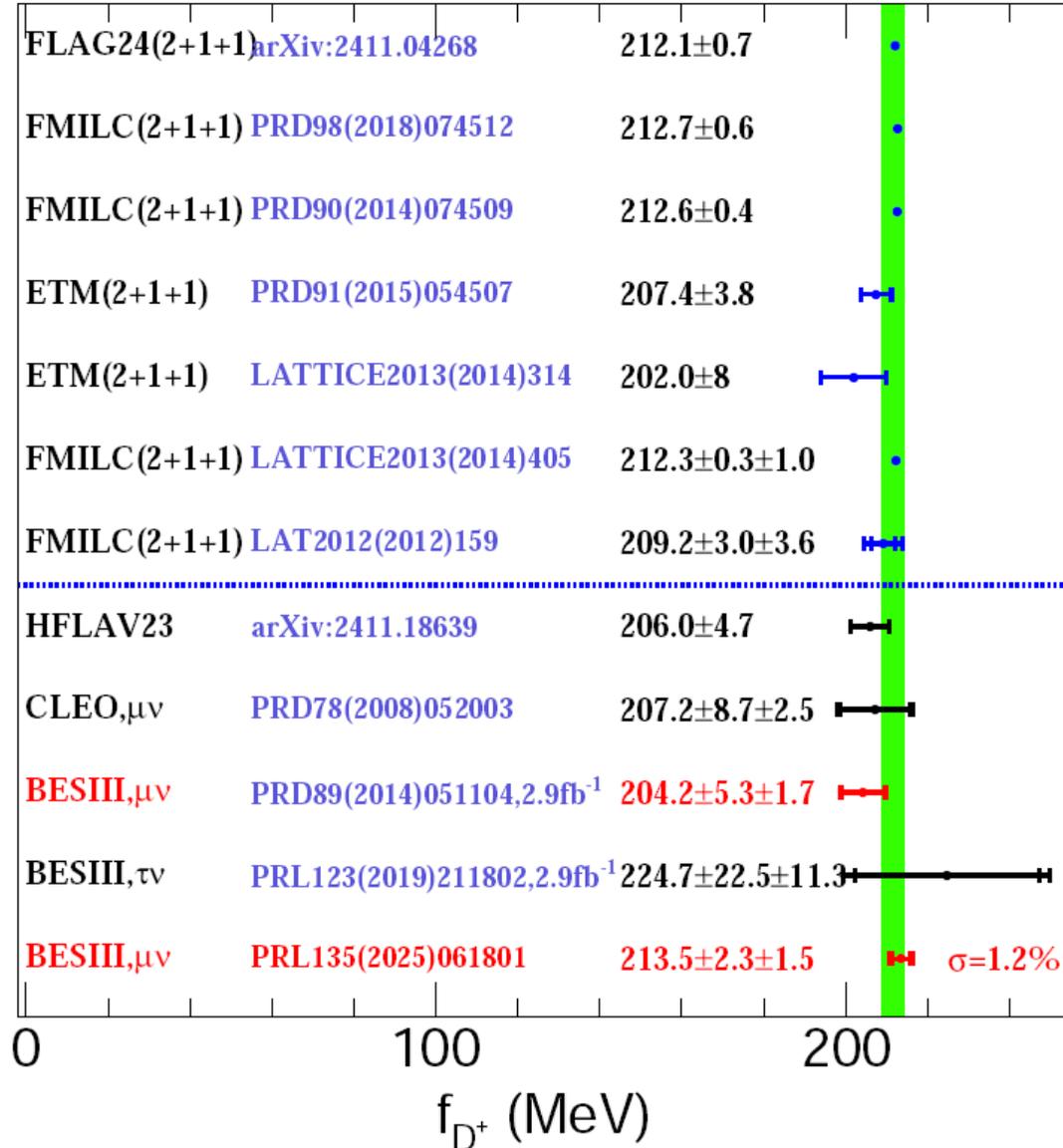
Precision~1.5%

$$B^{\text{BESIII}}[D_s^+ \rightarrow \tau^+ \nu] = (5.32 \pm 0.07 \pm 0.07)\%$$

$$R_{D_s} = \frac{B[D_s^+ \rightarrow \tau^+ \nu]}{B[D_s^+ \rightarrow \mu^+ \nu]} = 10.05 \pm 0.35$$

SM prediction: 9.75

Comparisons of f_{D^+} and $f_{D_s^+}$

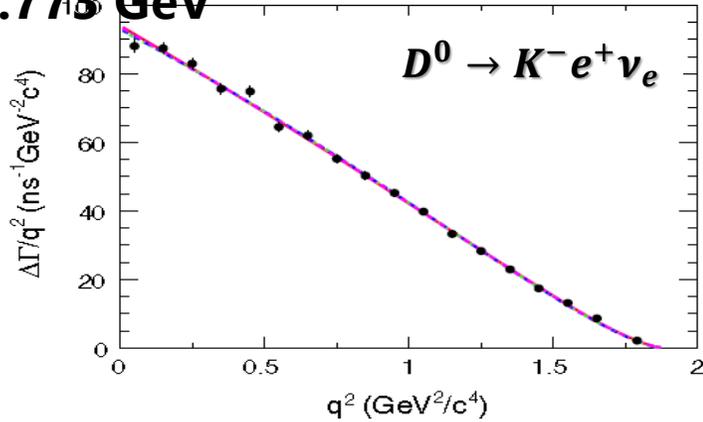


Early results of $D^{0(+)} \rightarrow P\ell^+\nu_\ell$ ($\ell = e$ or μ , $P = K$ or π)

2.93 fb⁻¹

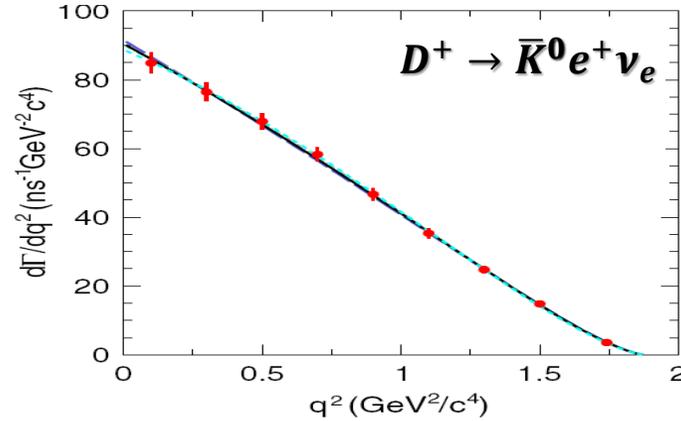
PRD92(2015)072012

@3.773 GeV



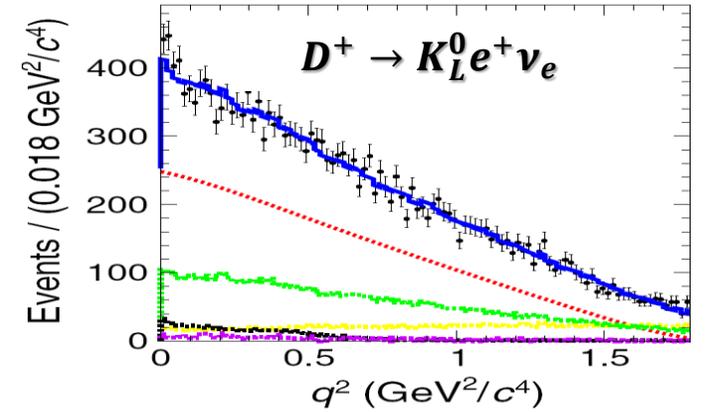
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.717(03)(04)$$

PRD96(2017)012002



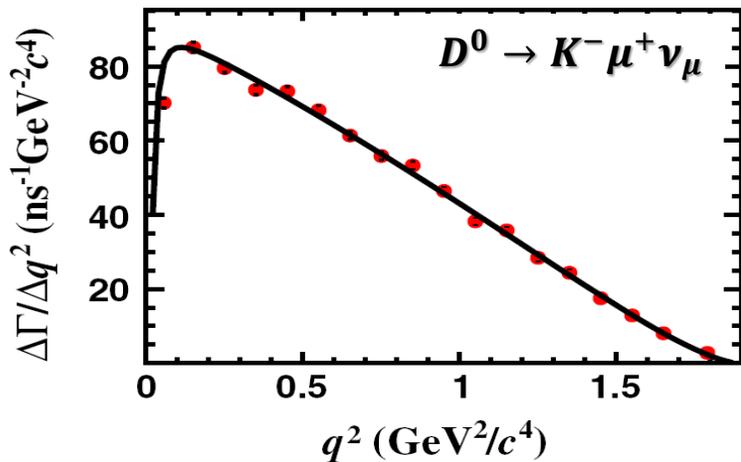
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.705(04)(11)$$

PRD92(2015)112008



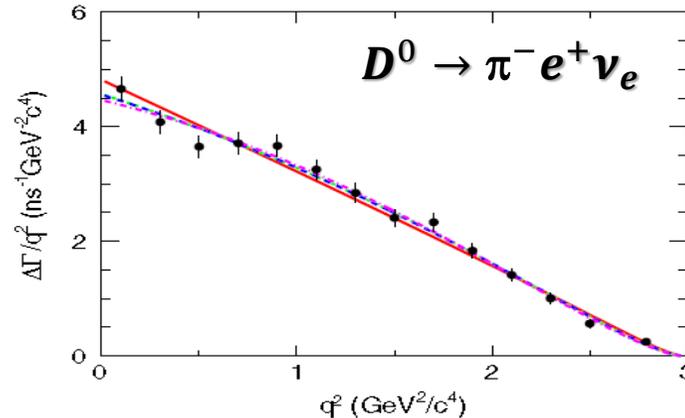
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.728(06)(11)$$

PRL122(2019)011804



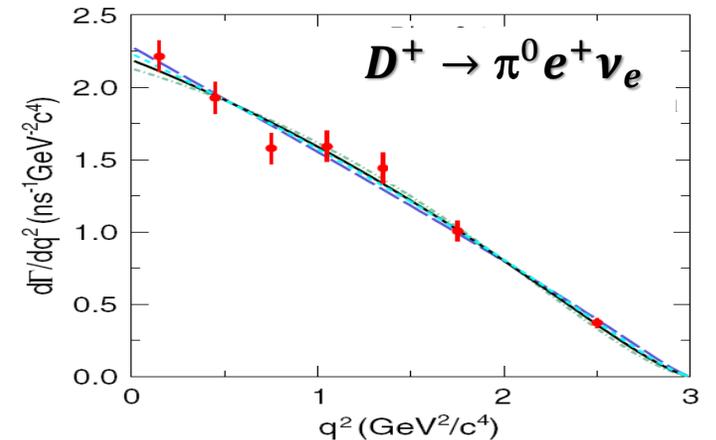
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.7148(38)(29)$$

PRD92(2015)072012



$$f_+^{D \rightarrow \pi}(0)|V_{cd}| = 0.144(02)(01)$$

PRD96(2017)012002

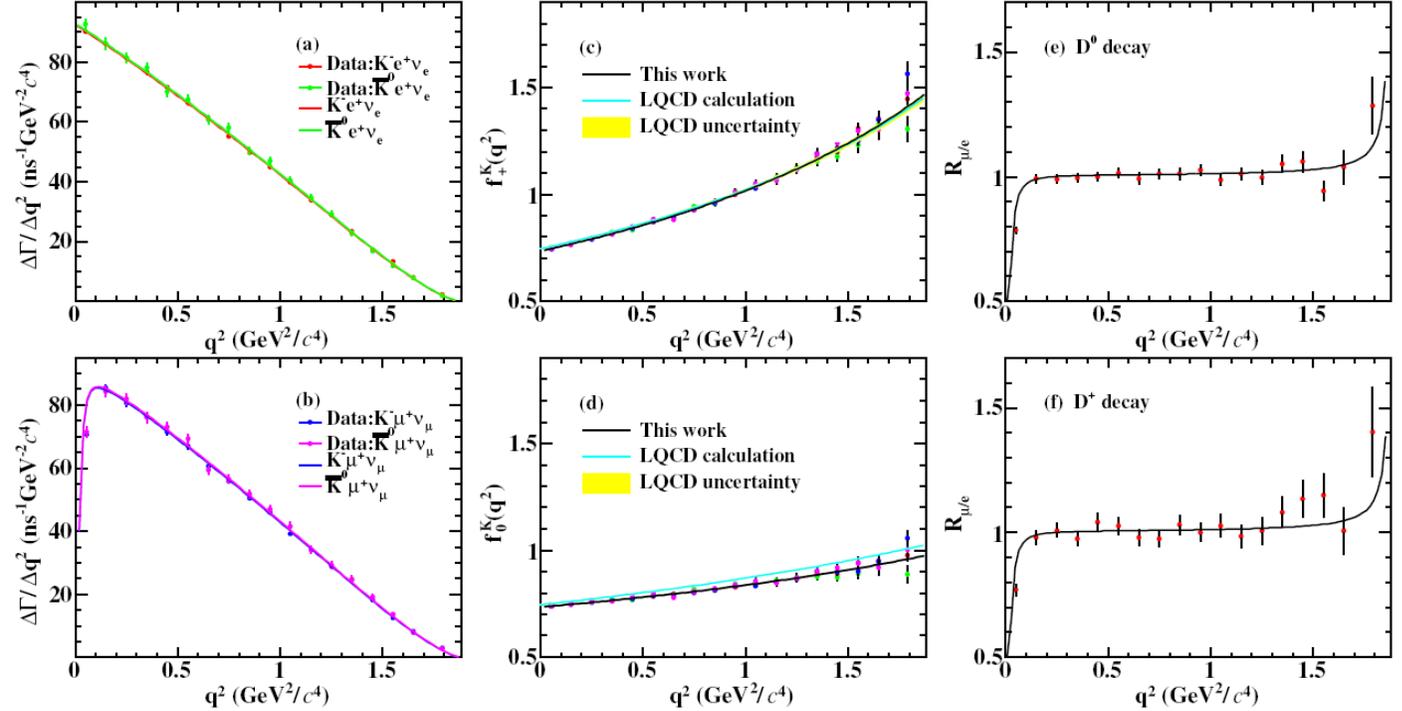
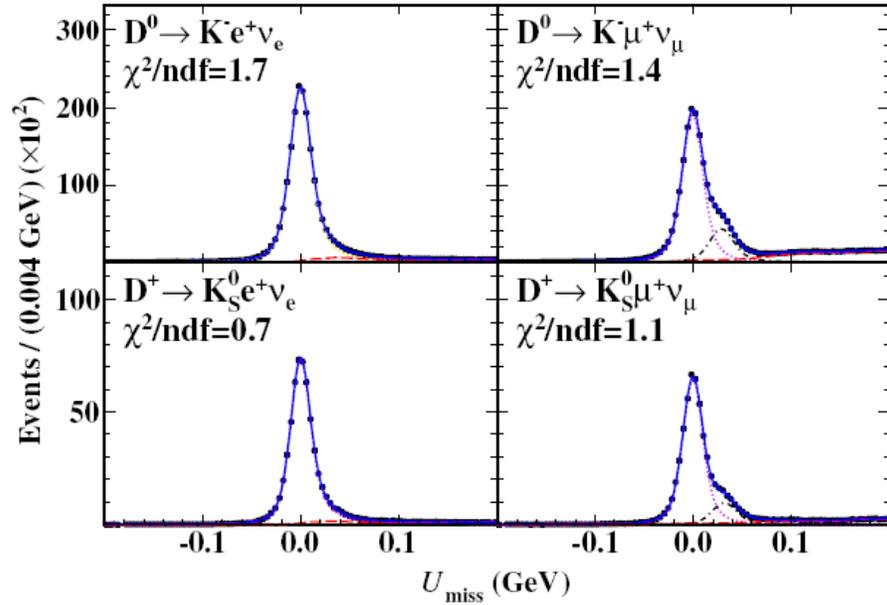


$$f_+^{D \rightarrow \pi}(0)|V_{cd}| = 0.140(03)(01)$$

Precision measurements of $D^{0(+)} \rightarrow \bar{K} \ell^+ \nu_\ell$ ($\ell = e$ or μ)

7.9 fb⁻¹ @3.773 GeV

PRD110(2024)112006



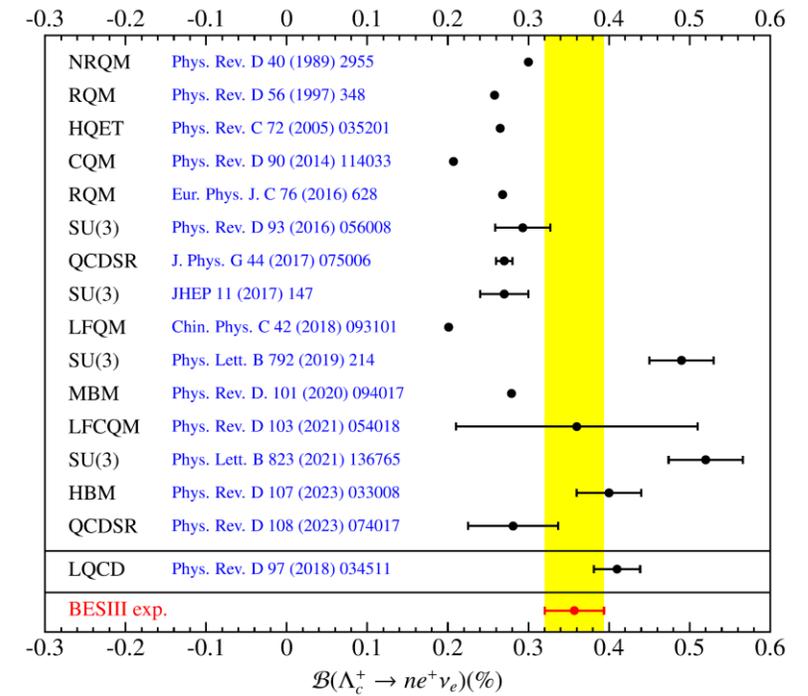
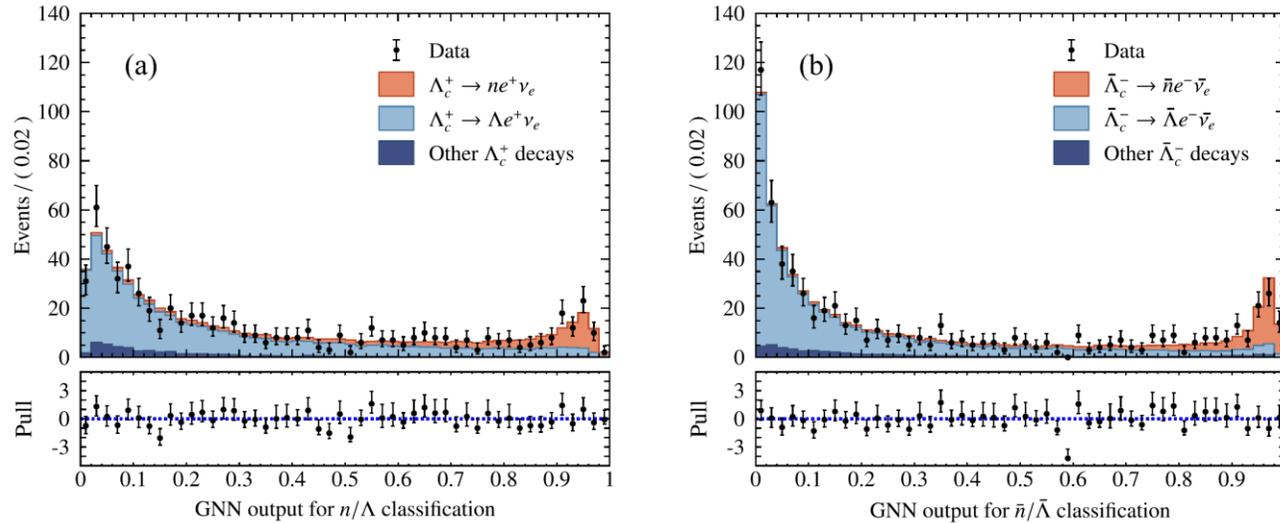
Decay	N_{DT}	$\bar{\varepsilon}_{sig}$ (%)	\mathcal{B}_{sig} (%)
$D^0 \rightarrow K^- e^+ \nu_e$	190605 ± 471	68.79 ± 0.03	$3.509 \pm 0.009 \pm 0.013$
$D^0 \rightarrow K^- \mu^+ \nu_\mu$	147596 ± 488	54.85 ± 0.03	$3.408 \pm 0.011 \pm 0.013$
$D^+ \rightarrow \bar{K}^0 e^+ \nu_e$	57846 ± 256	15.74 ± 0.01	$8.856 \pm 0.039 \pm 0.078$
$D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu$	47229 ± 248	13.14 ± 0.01	$8.661 \pm 0.046 \pm 0.080$

Case	Decay	$f_+^K(0) V_{cs} $	$r_1(t_0)$	ρ_{2par}	χ^2/ndf
Individual fit	$D^0 \rightarrow K^- e^+ \nu_e$	$0.7168 \pm 0.0016 \pm 0.0014$	$-2.30 \pm 0.05 \pm 0.03$	0.53	16.3/16
	$D^0 \rightarrow K^- \mu^+ \nu_\mu$	$0.7150 \pm 0.0022 \pm 0.0016$	$-2.28 \pm 0.08 \pm 0.02$	0.67	17.2/16
	$D^+ \rightarrow \bar{K}^0 e^+ \nu_e$	$0.7204 \pm 0.0027 \pm 0.0033$	$-2.13 \pm 0.10 \pm 0.07$	0.30	13.1/16
	$D^+ \rightarrow \bar{K}^0 \mu^+ \nu_\mu$	$0.7122 \pm 0.0035 \pm 0.0030$	$-2.41 \pm 0.12 \pm 0.08$	0.46	10.4/16
Simultaneous fit	$D \rightarrow \bar{K} \ell^+ \nu_\ell$	$0.7162 \pm 0.0011 \pm 0.0012$	$-2.28 \pm 0.04 \pm 0.02$	0.48	61.2/70

Observation of $\Lambda_c^+ \rightarrow ne^+v_e$

4.5 fb⁻¹@4.6-4.7 GeV

NatComm 16, 681 (2025)



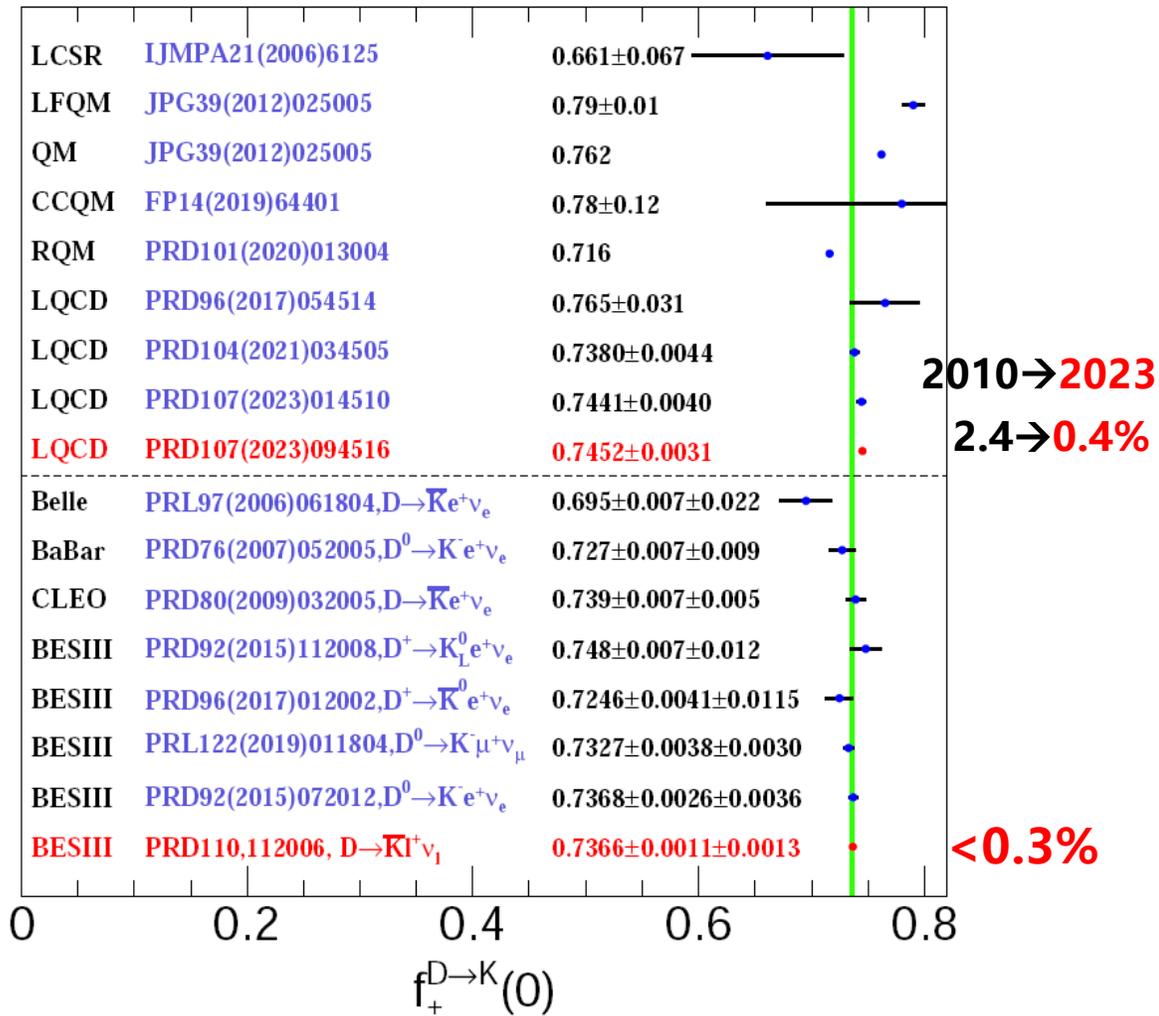
A novel **deep learning method** is developed to separate signal from dominant background

- Use **Graph Neural Network** to classify n/Λ energy deposition patterns on EMC
- Establish a data-driven pipeline for GNN training, calibration, validation and systematic uncertainty quantification.

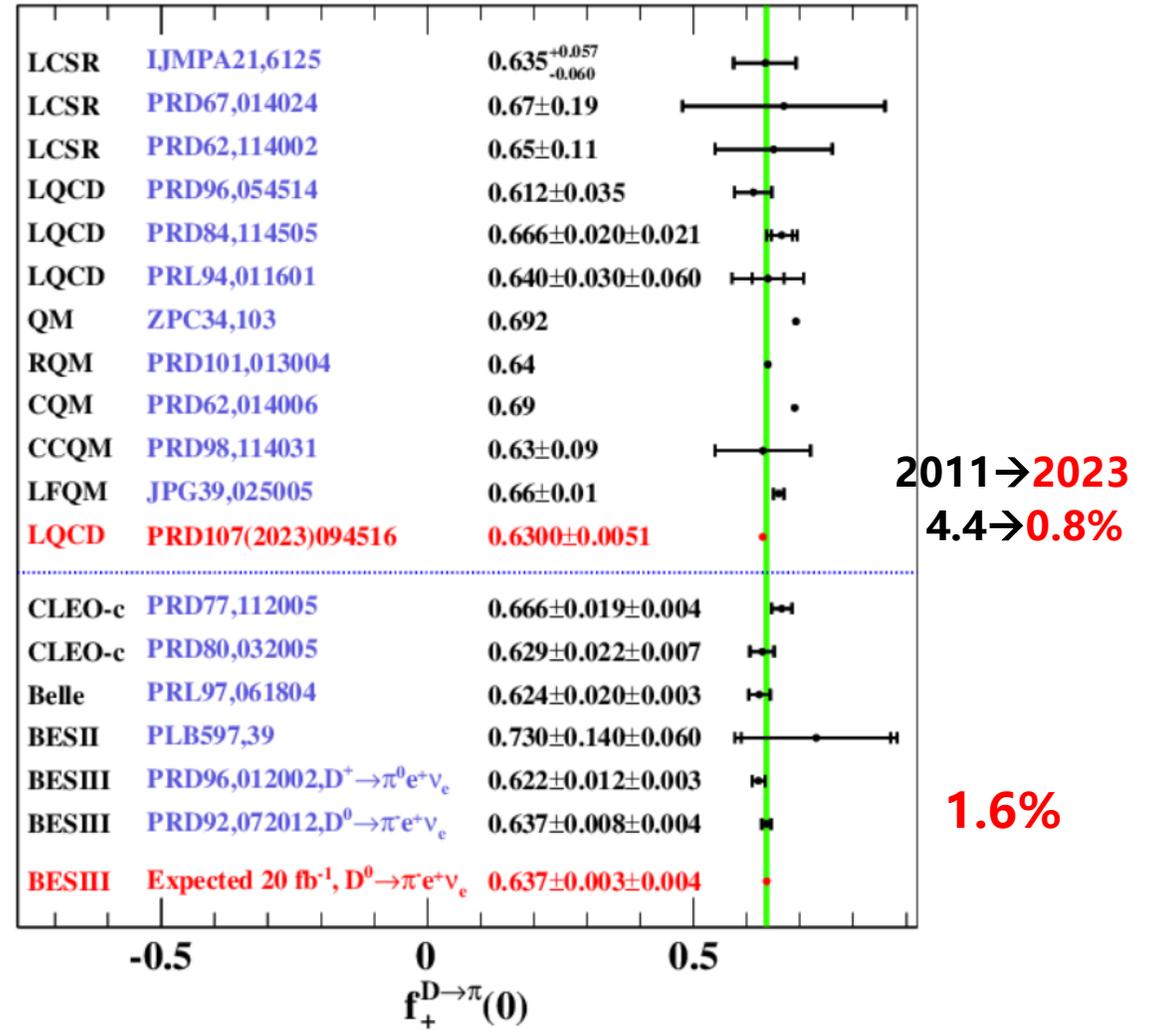
➤ First determination of $|V_{cd}|$ from charmed baryon decays with form factors from LQCD as input

$$|V_{cd}| = 0.208 \pm 0.011_{exp} \pm 0.007_{LQCD} + 0.011\tau_{\Lambda_c^+}$$

Comparisons of $f_+^{D \rightarrow K}(0)$ and $f_+^{D \rightarrow \pi}(0)$

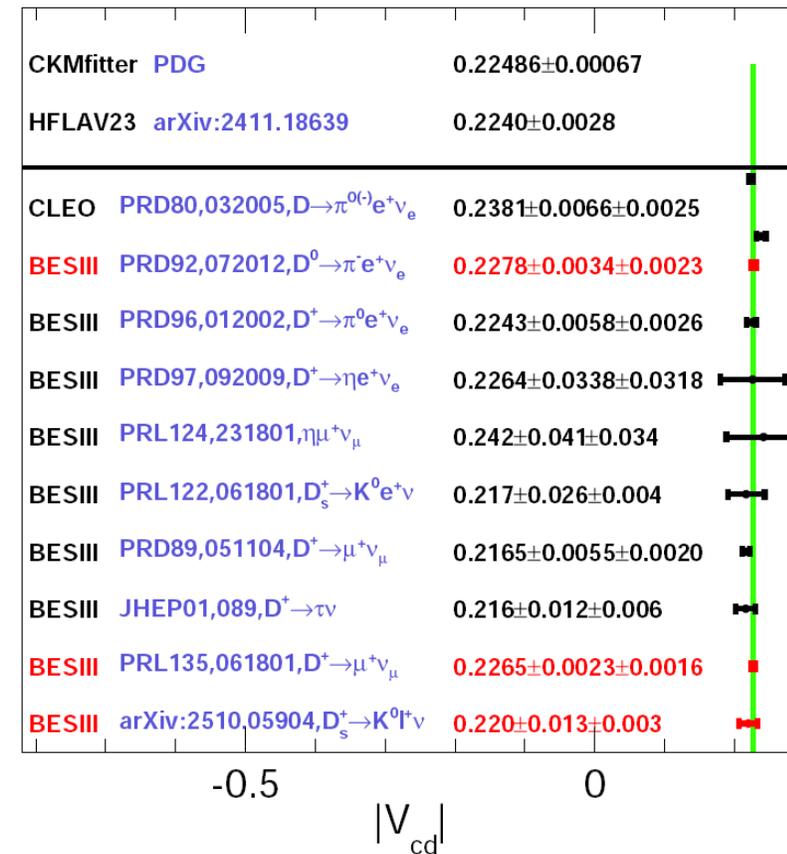
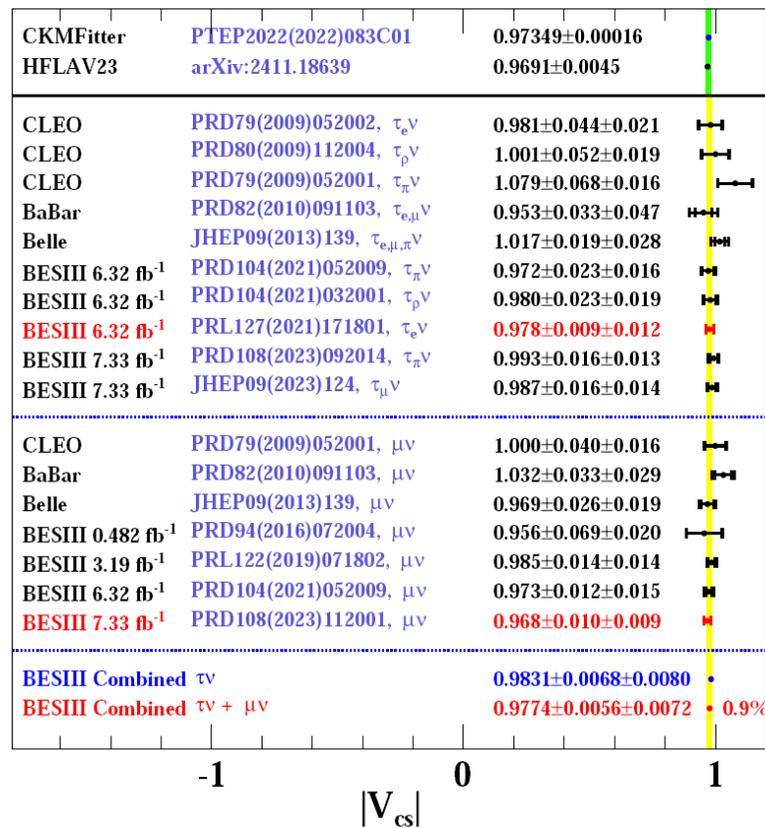
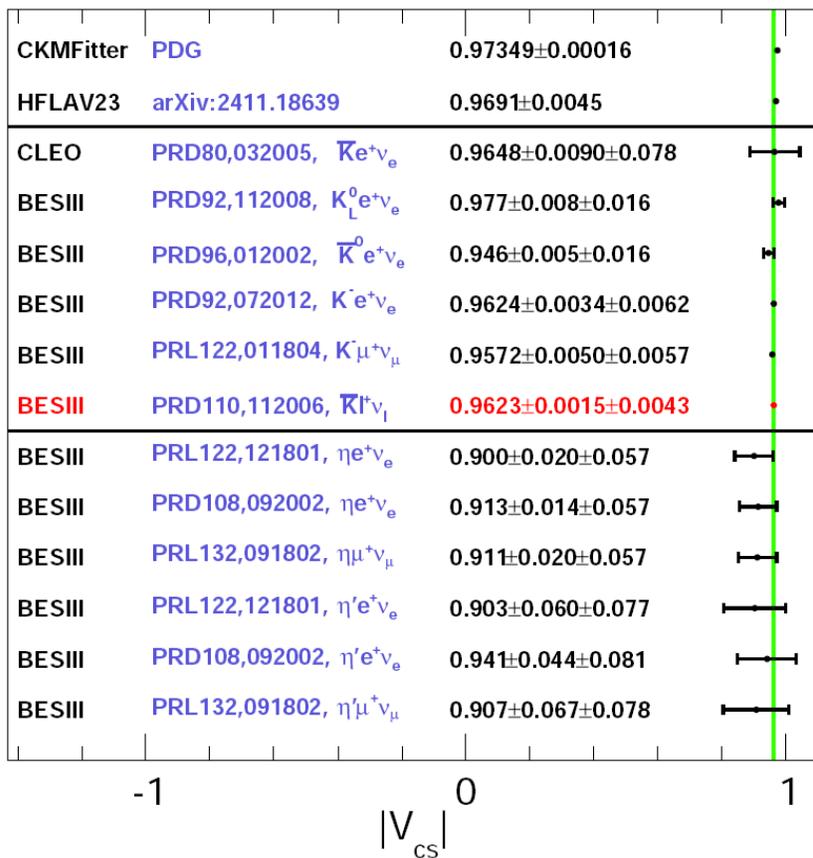


Experimental precision of $f_+^{D \rightarrow K}(0)$ is comparable to the latest LQCD precision



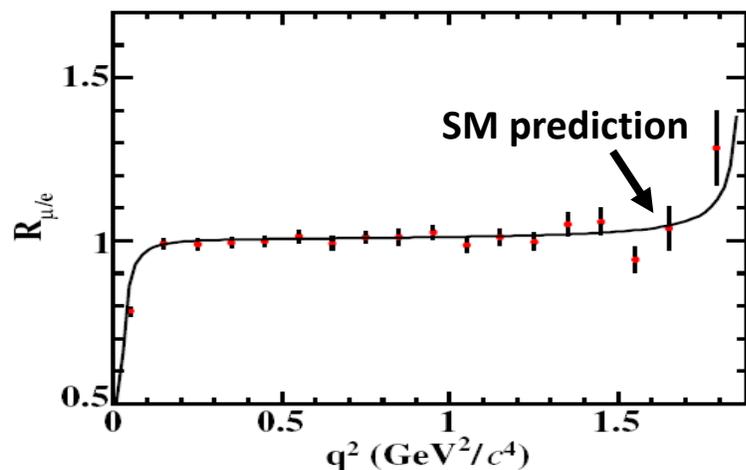
Experimental precision of $f_+^{D \rightarrow \pi}(0)$ is still dominated by statistical uncertainties

Comparisons of $|V_{cs}|$ and $|V_{cd}|$



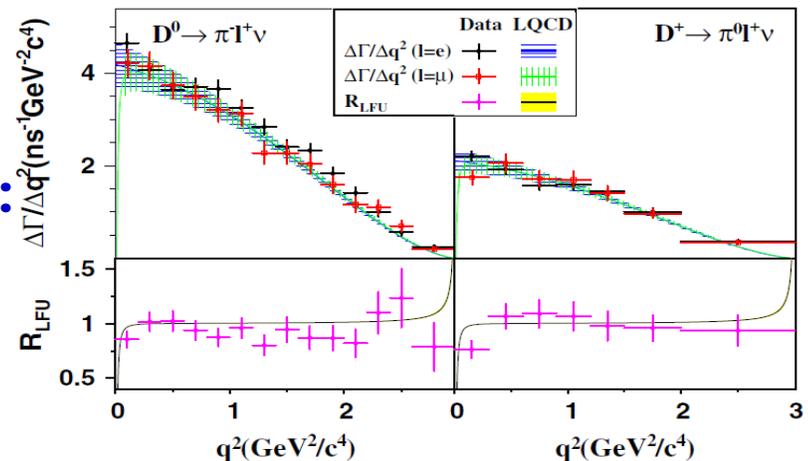
μ -e LFU tests with semileptonic decays in different q^2 bins

$D^0 \rightarrow K^- \mu^+ \nu_\mu$ PRL122(2019)011804 →
PRD110(2024)012006

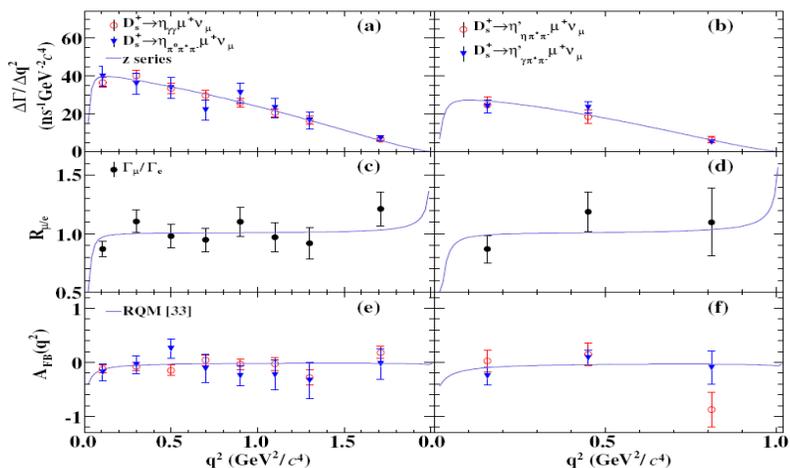


SM predictions:
0.93-0.99

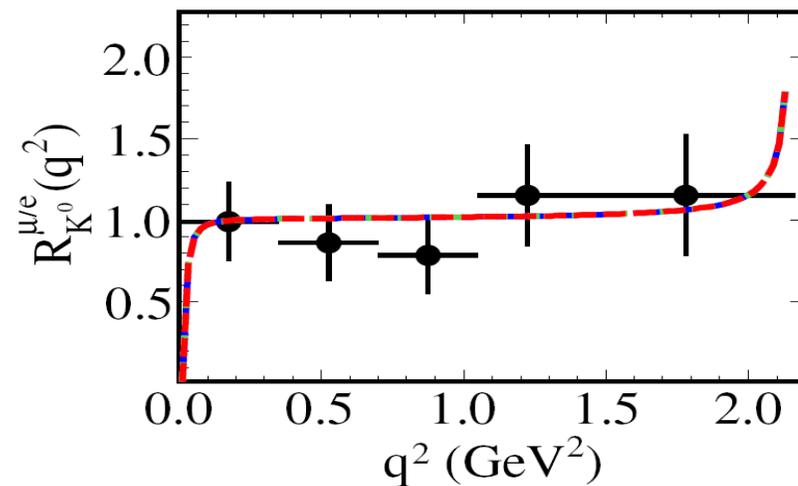
$D^{0,+} \rightarrow \pi^{-,0} \mu^+ \nu_\mu$ PRL121(2018)171803



$D_s^+ \rightarrow \eta^{(\prime)} \mu^+ \nu_\mu$ PRD97(2018)012006 →
PRL132(2024)091802



$D_s^+ \rightarrow K^0 \mu^+ \nu_\mu$ arXiv:2510.05904



Summary of LFU tests

SM predictions for semileptonic decays: **0.90-0.99**

14 new decay modes are observed

No deviation greater than 1.7σ is found!

	Branching fraction ratio		Reference
μ/e	$D^0 \rightarrow K^-$	$0.971 \pm 0.004 \pm 0.005$	PRD110(2024)112006
	$D^0 \rightarrow \pi^-$	$0.922 \pm 0.030 \pm 0.022$	PRL121(2018)171803
	$D^0 \rightarrow \rho^-$	0.90 ± 0.11	PRD104(2021)L091003
	$D^+ \rightarrow \bar{K}^0$	$0.978 \pm 0.007 \pm 0.012$	PRD110(2024)112006
	$D^+ \rightarrow \pi^0$	$0.964 \pm 0.037 \pm 0.026$	PRL121(2018)171803
	$D^+ \rightarrow \eta$	0.91 ± 0.13	PRL124(2020)231801
	$D^+ \rightarrow \eta'$	$1.07 \pm 0.19 \pm 0.03$	PRL134(2025)111801
	$D^0 \rightarrow K^{*-}$	$0.955 \pm 0.022 \pm 0.017$	PRL135(2025)111803
		$1.020 \pm 0.030 \pm 0.028$	PRL134(2025)011803
	$D^+ \rightarrow K_S^0 \pi^0$	$0.94 \pm 0.02 \pm 0.01$	PRL135(2025)171801
$D^0 \rightarrow K_1^-$	$0.74 \pm 0.13 \pm 0.13$	PRD111(2025)L071101	
$D^+ \rightarrow \bar{K}_1^0$	$1.03 \pm 0.14 \pm 0.015$	PRD111(2025)L071101	

	Branching fraction ratio		Reference
μ/e	$D^+ \rightarrow \omega$	1.05 ± 0.14	PRD101(2020)072005
	$D^+ \rightarrow f_0$	1.14 ± 0.28	PRD110(2024)092008
	$D^+ \rightarrow \rho^0$	0.88 ± 0.10	PRD110(2024)092008
	$D_s^+ \rightarrow \eta$	$0.984 \pm 0.028 \pm 0.016$	PRL132(2024)091802
	$D_s^+ \rightarrow \eta'$	$0.989 \pm 0.082 \pm 0.034$	
	$D_s^+ \rightarrow K^0$	$0.97 \pm 0.12 \pm 0.04$	arXiv:2510.05904
	$D_s^+ \rightarrow \phi$	0.94 ± 0.08	JHEP12(2023)072
		$\Lambda_c^+ \rightarrow \Lambda$	$0.98 \pm 0.05 \pm 0.03$
τ/μ	$D^+ \rightarrow \tau^+$	2.49 ± 0.31	JHEP01(2025)089
	$D_s^+ \rightarrow \tau^+$	10.05 ± 0.35	PRL127(2021)171801

Future plan

Plan of BESIII data taking

Future Physics Programme of BESIII:

Chin. Phys. C 44(2020)040001

Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb ⁻¹ (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb ⁻¹ (10 billion)	3.2 fb ⁻¹ (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb ⁻¹ (0.45 billion)	4.5 fb ⁻¹ (3.0 billion)	150/90 days
$\psi(3770)$ peak	D^0/D^\pm decays	2.9 fb ⁻¹	20.0 fb ⁻¹	610/360 days
3.8 - 4.6 GeV	R values XYZ /Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ /Open charm	3.2 fb ⁻¹	6 fb ⁻¹	140/50 days
4.0 - 4.6 GeV	XYZ /Open charm Higher charmonia cross-sections	16.0 fb ⁻¹ at different \sqrt{s}	30 fb ⁻¹ at different \sqrt{s}	770/310 days
4.6 - 4.9 GeV	Charmed baryon/ XYZ cross-sections	0.56 fb ⁻¹ at 4.6 GeV	15 fb ⁻¹ at different \sqrt{s}	1490/600 days
4.74 GeV	$\Sigma_c^+ \Lambda_c^-$ cross-section	N/A	1.0 fb ⁻¹	100/40 days
4.91 GeV	$\Sigma_c \Sigma_c$ cross-section	N/A	1.0 fb ⁻¹	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb ⁻¹	130/50 days

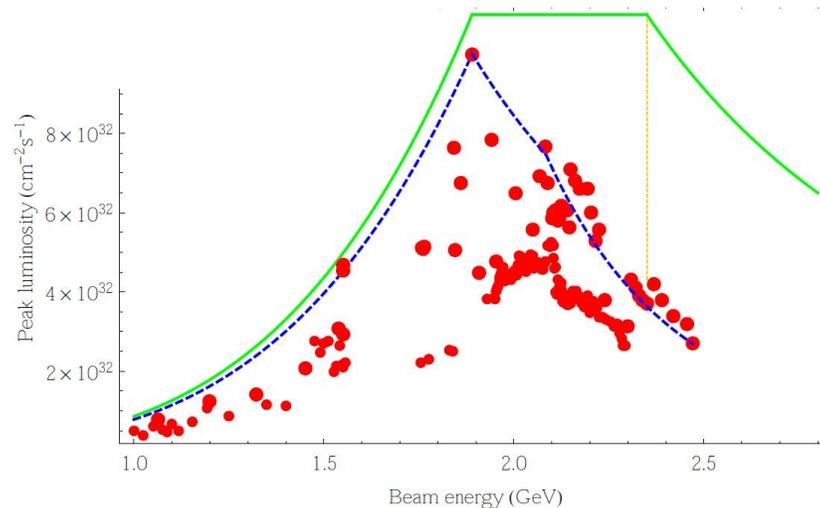
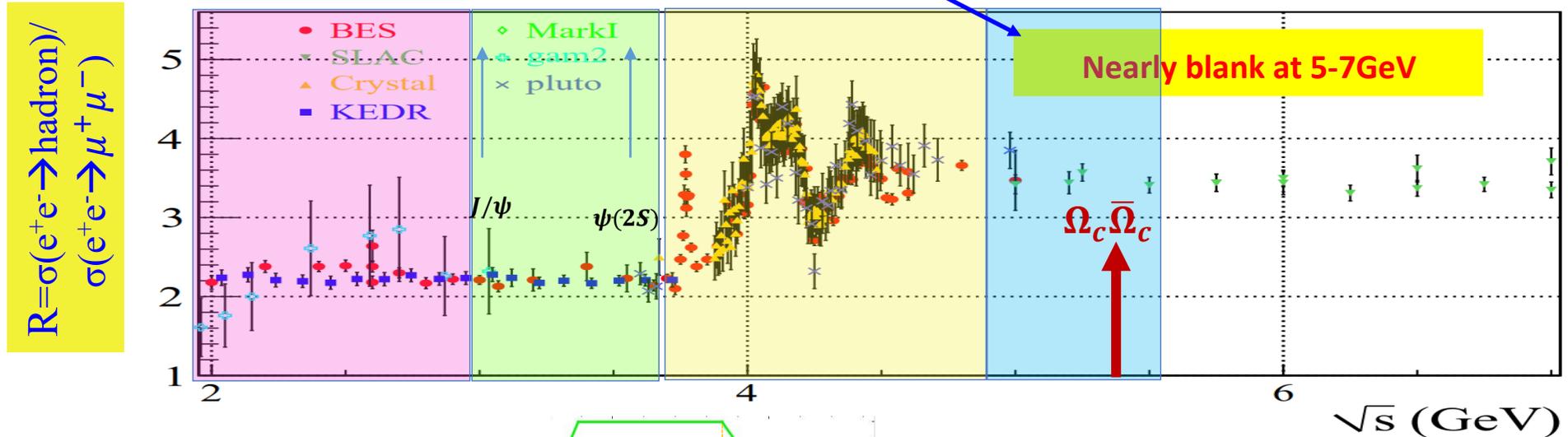
← 10B finished

← 2.7B finished

← 20 fb⁻¹ in hand

Plan of BEPCII upgrade

- Optimize E_{cm} at 4.7 GeV with luminosity 3 times higher than the current BEPCII → more effective data taking
- Extend the maximum E_{cm} up to 5.6 GeV → more physics opportunity



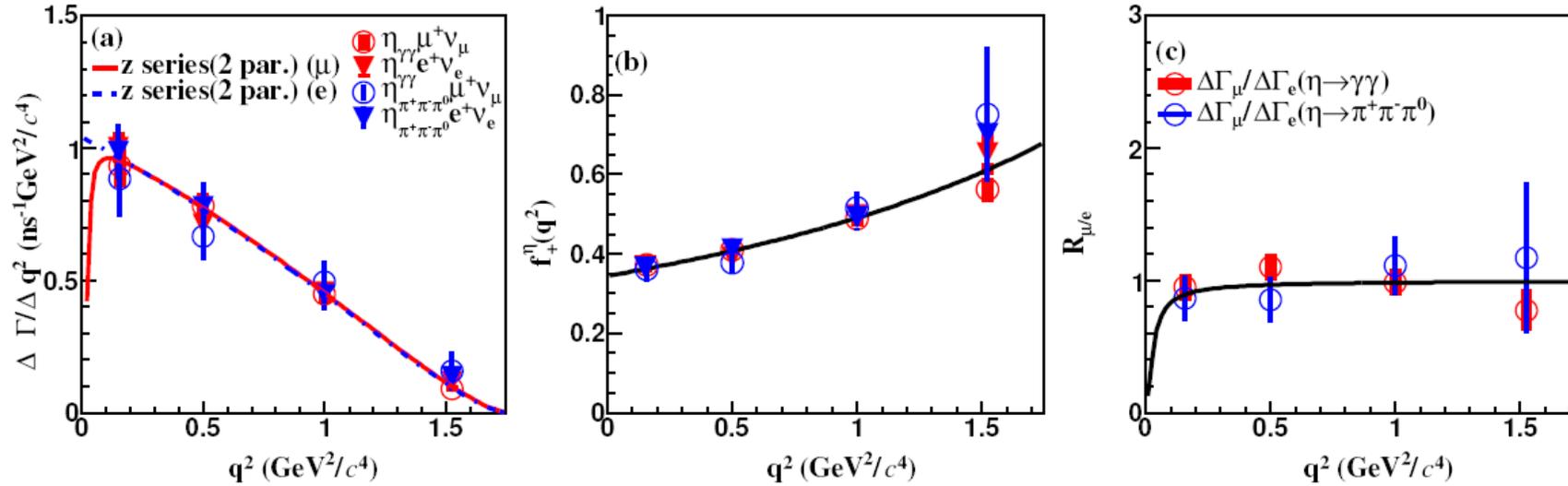
Summary

- Since 2009, BESIII has operated stably and collect $>50 \text{ fb}^{-1}$ data in $E_{\text{cm}} = 1.84\text{-}4.95 \text{ GeV}$
- Many important results have been published, covering many aspects:
 - ✓ Light hadron and glueball search
 - ✓ Charmonium(-like) and strangeness(-like) states
 - ✓ Baryon physics
 - ✓ Charmed hadrons
 - ✓ New physics
- BESIII will continue to run for >5 years. More exciting results are expected in the near future

Thank you!

Recent study of $D^+ \rightarrow \eta \ell^+ \nu_\ell$ ($\ell = e$ or μ)

20.3 fb⁻¹ @3.773 GeV, arXiv:2506.02521

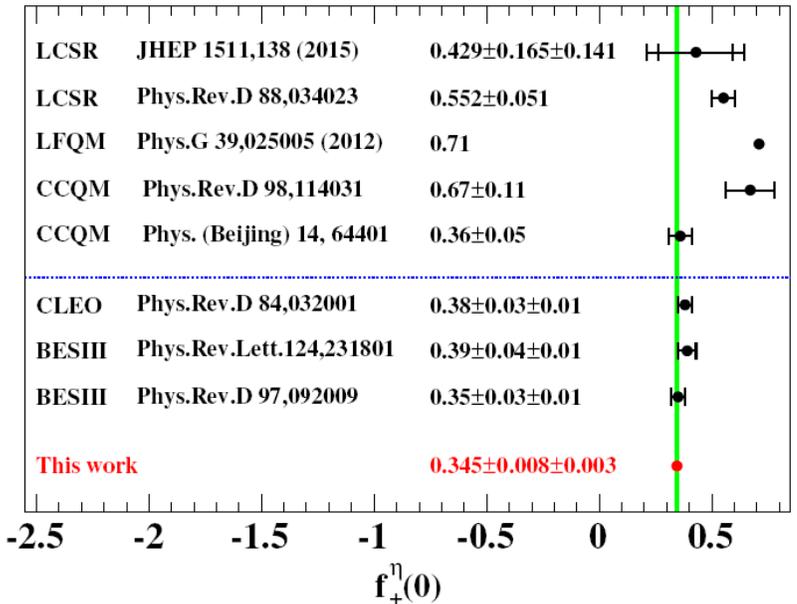


$$\mathcal{B}(D^+ \rightarrow \eta e^+ \nu_e) = (9.75 \pm 0.29 \pm 0.28) \times 10^{-4},$$

$$\mathcal{B}(D^+ \rightarrow \eta \mu^+ \nu_\mu) = (9.08 \pm 0.35 \pm 0.23) \times 10^{-4}$$

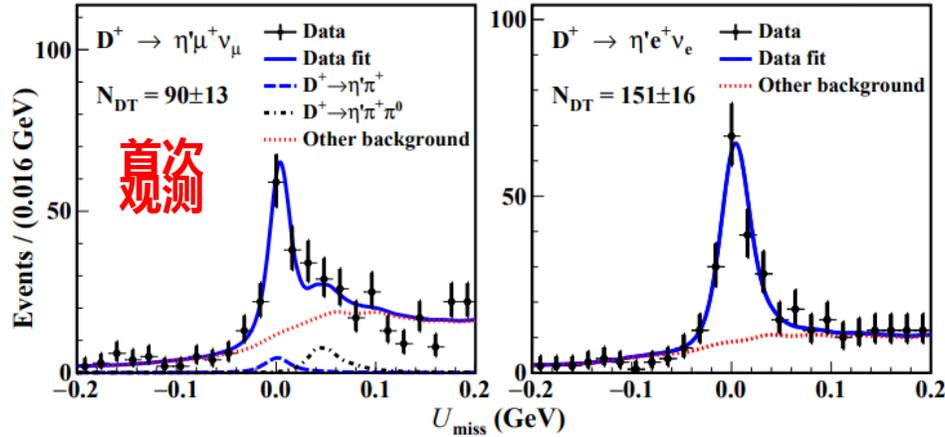
$$f_+^{D \rightarrow \eta}(0) |V_{cd}| = (7.8 \pm 0.2 \pm 0.1)\%$$

分支比精度比此前最好测量改进2倍、
 $D^+ \rightarrow \eta$ 形状因子精度改进3.4倍

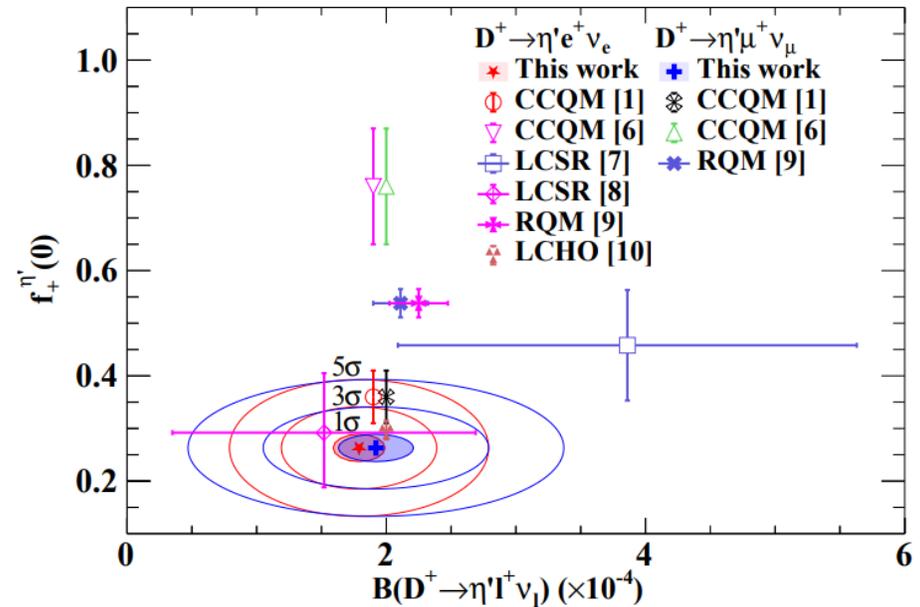
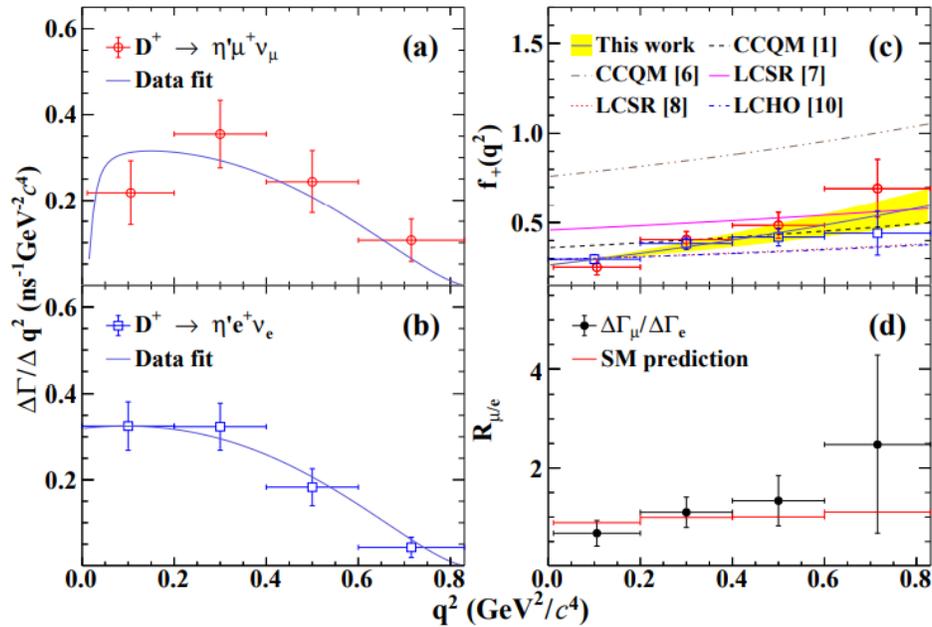


Recent study of $D^+ \rightarrow \eta' \ell^+ \nu_\ell$ ($\ell = e$ or μ)

20.3 fb⁻¹ @3.773 GeV, PRL134(2025)111801



Decay	$\eta' \mu^+ \nu_\mu$		$\eta' e^+ \nu_e$	
	$\eta \pi^+ \pi^-$	$\gamma \pi^+ \pi^-$	$\eta \pi^+ \pi^-$	$\gamma \pi^+ \pi^-$
ϵ_{sig} (%)	1.77 ± 0.01	2.77 ± 0.01	2.70 ± 0.01	5.50 ± 0.01
N_{DT}	90 ± 13		151 ± 16	
Significance	8.6σ		12.9σ	
$\mathcal{B} (\times 10^{-4})$	$1.92 \pm 0.28 \pm 0.08$		$1.79 \pm 0.19 \pm 0.07$	



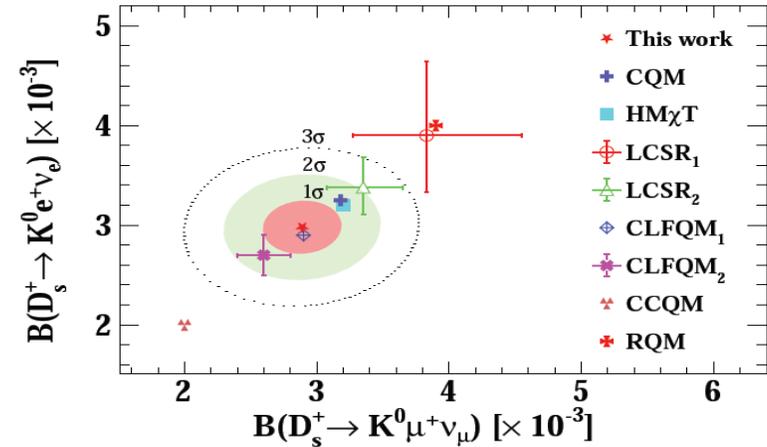
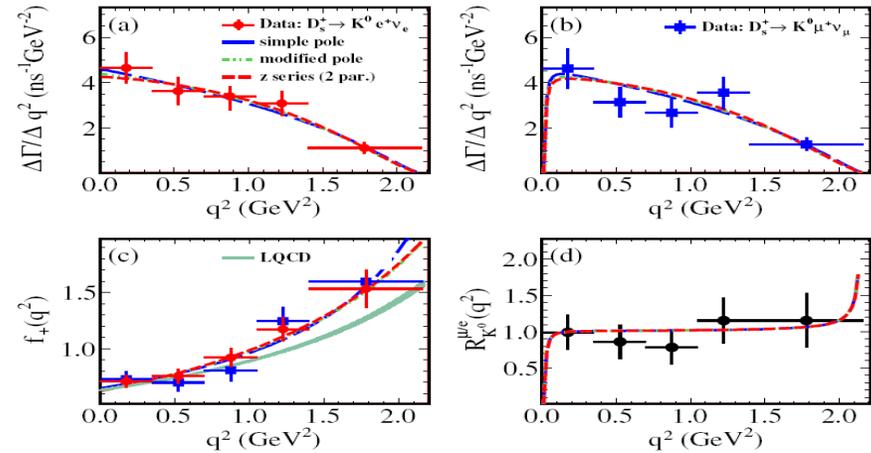
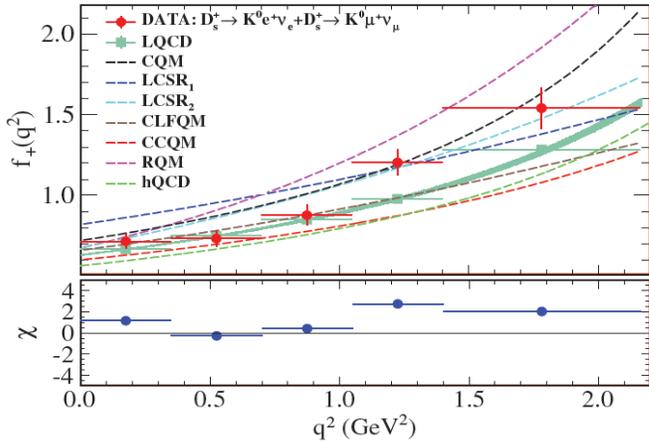
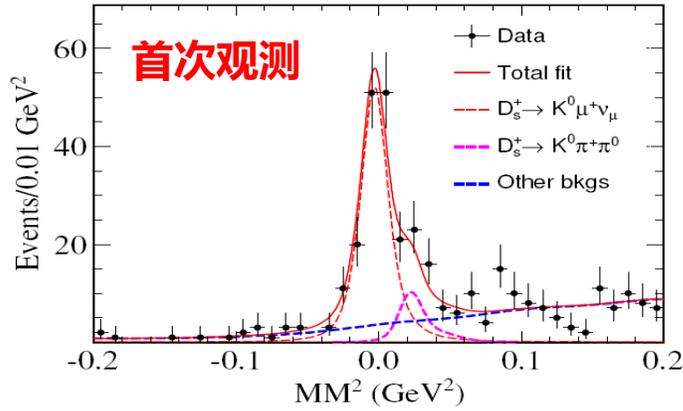
$$f_+^{D \rightarrow \eta'}(0) |V_{cd}| = (5.92 \pm 0.56 \pm 0.13)\%$$

首次抽取 $D^+ \rightarrow \eta'$ 形状因子, 为检验理论计算提供了重要依据

Most recent results of $D_s^+ \rightarrow K^0 \ell^+ \nu_\ell$ ($\ell = e$ or μ)

7.33 fb⁻¹ @4.128-4.226 GeV, arXiv:2510.05904

精确测量 $D_s^+ \rightarrow K^0$ 形状因子

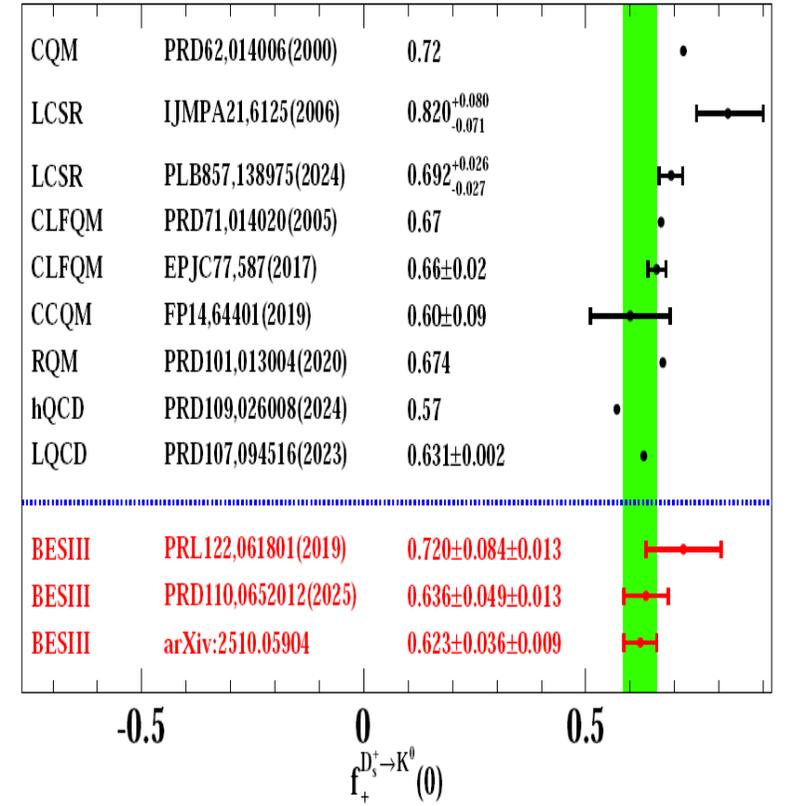
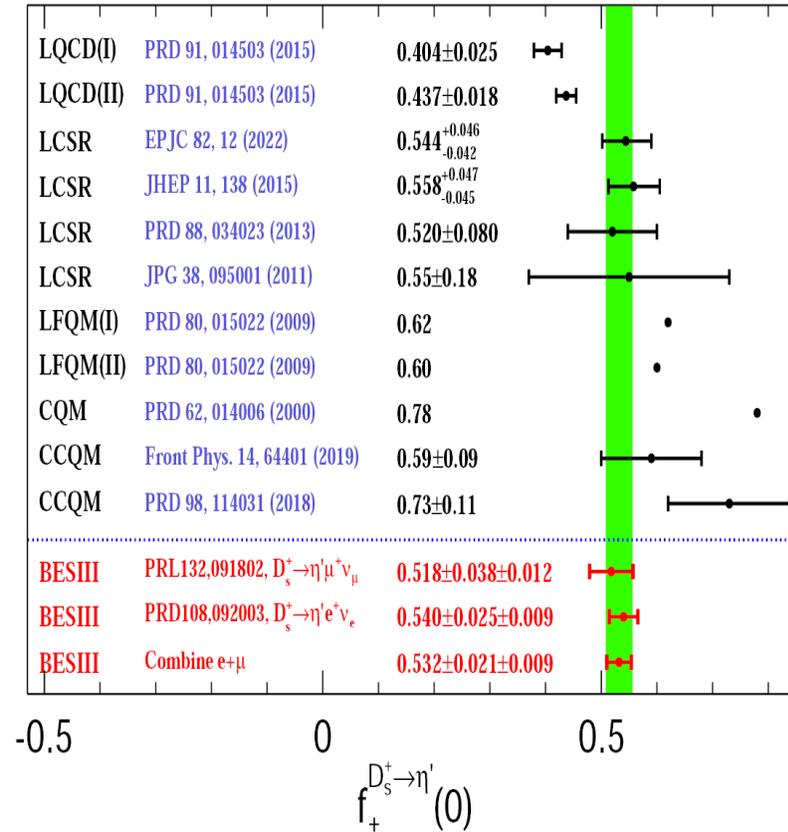
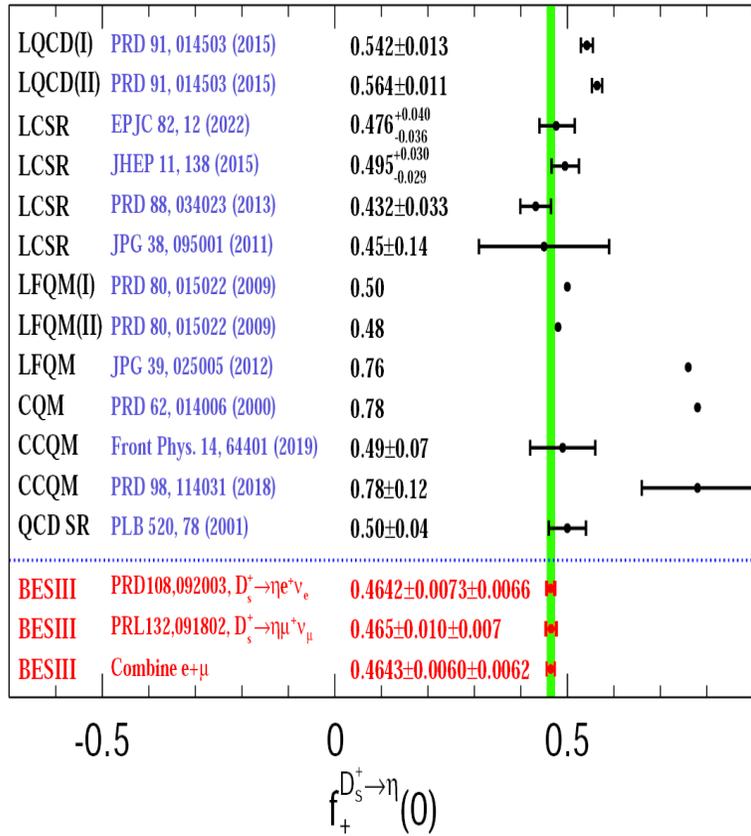


$$B(D_s \rightarrow K^0 e^+ \nu_e) = (2.89 \pm 0.27 \pm 0.12) \times 10^{-3}$$

$$f_+^{D_s \rightarrow K^0}(0) |V_{cd}| = (14.0 \pm 0.8 \pm 0.2)\%$$

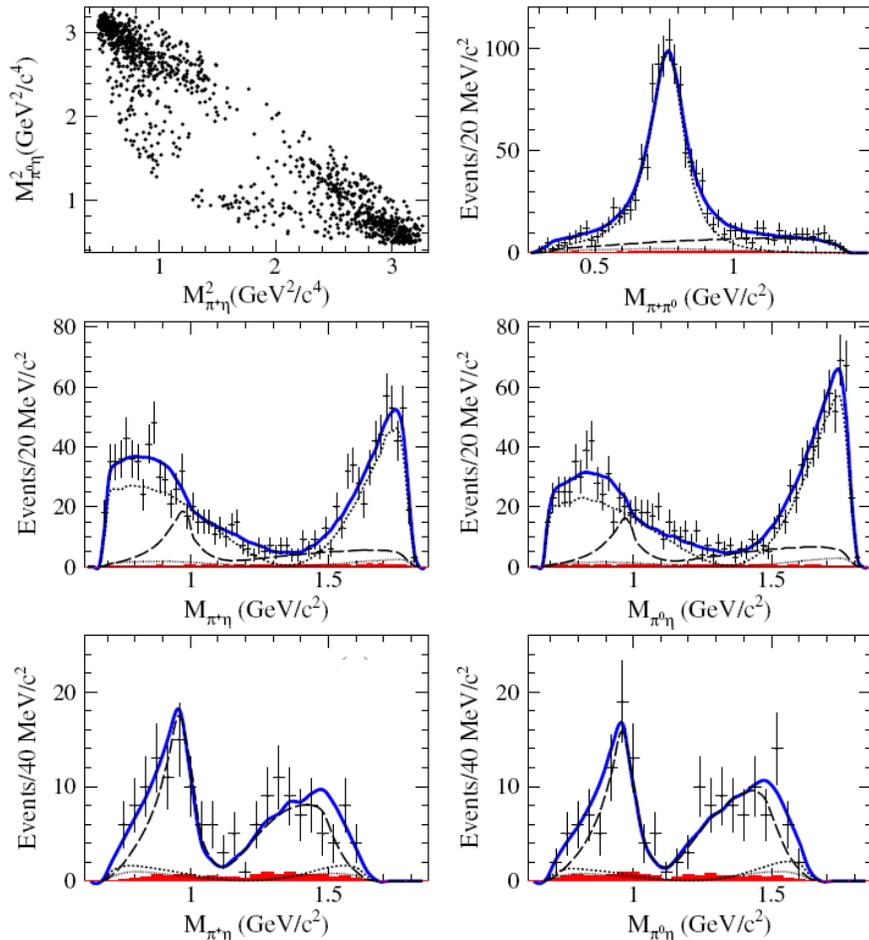
$$R_{D_s^+ K^0} = \frac{\Gamma[D_s^+ \rightarrow K^0 \mu^+ \nu]}{\Gamma[D_s^+ \rightarrow K^0 e^+ \nu]} = 0.97 \pm 0.12 \pm 0.04$$

Comparisons of other $D \rightarrow P$ form factors



Amplitude analysis of $D_s^+ \rightarrow \eta\pi^+\pi^0$

PRL123(2020)112001



Amplitude	ϕ_n (rad)	FF _n
$D_s^+ \rightarrow \rho^+ \eta$	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \rightarrow (\pi^+ \pi^0)_V \eta$	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.025$
$D_s^+ \rightarrow a_0(980) \pi$	$2.794 \pm 0.087 \pm 0.044$	$0.232 \pm 0.023 \pm 0.033$

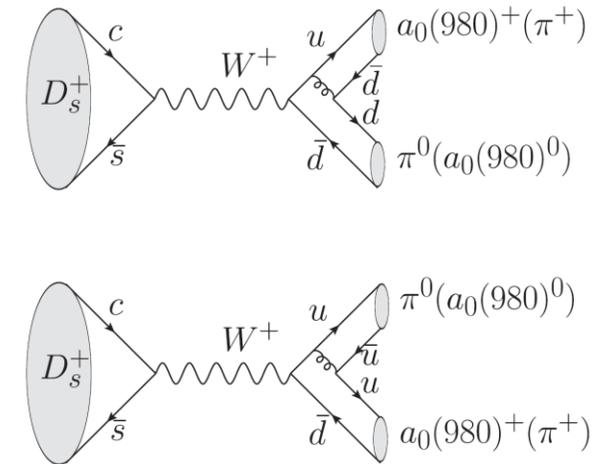
$$B_{D_s^+ \rightarrow \pi^+ \pi^0 \eta} = (9.50 \pm 0.28 \pm 0.41)\%$$

$$B_{D_s^+ \rightarrow \pi^+ \pi^0 \eta}^{\text{PDG18}} = (9.2 \pm 1.2)\%$$

$$B_{D_s^+ \rightarrow \rho^+ \eta} = (7.44 \pm 0.48 \pm 0.44)\%$$

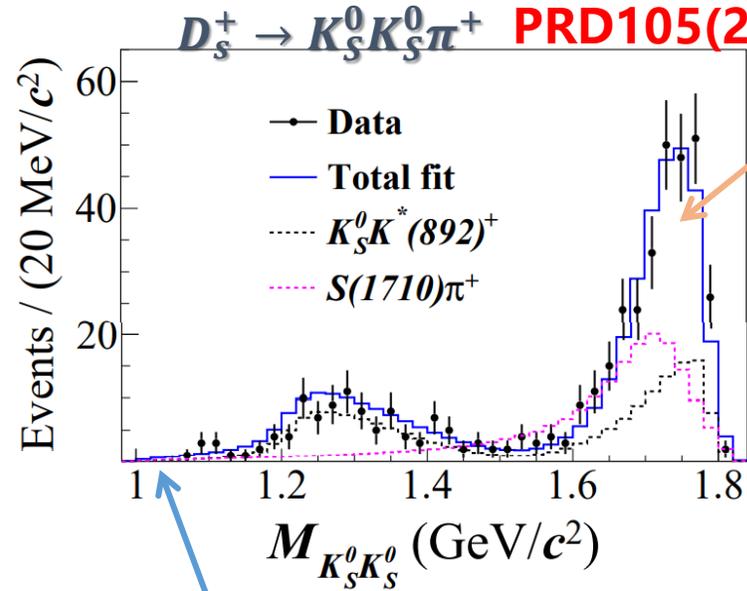
Observation of a W-annihilation process:

$$B_{D_s^+ \rightarrow a_0(980) \pi} = (2.20 \pm 0.22 \pm 0.34)\%$$



which is significantly greater than that of the known D annihilation decay by two orders of magnitude

Amplitude analysis of $D_S^+ \rightarrow KK\pi$

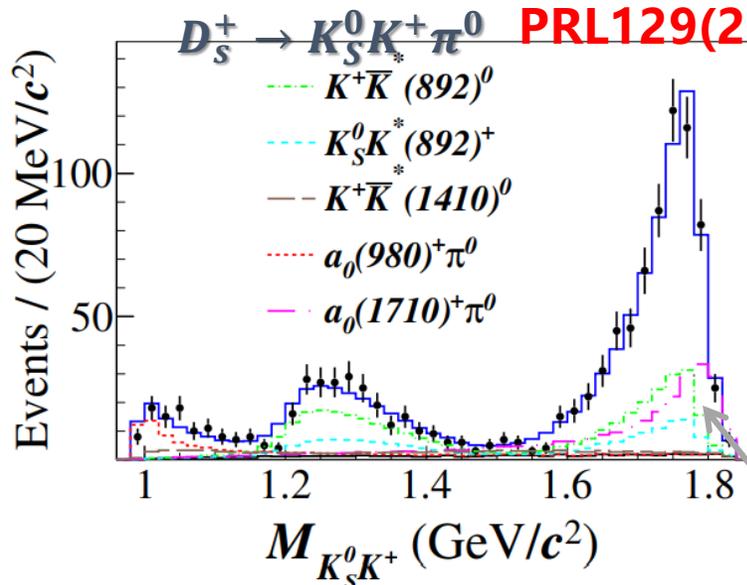


constructive interference: $a_0(1817)$ and $f_0(1710)$

- The isovector partner of $f_0(1710)$ or $X(1812)$?
- Same resonance observed in η_c to $\pi\pi\eta$ by BaBar?

PRD104(2021)072002

destructive interference: $a_0(980)$ and $f_0(980)$

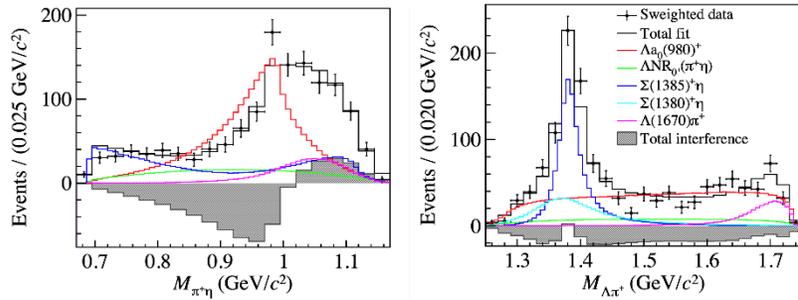


- $M = 1.817 \pm 0.008 \pm 0.020$ GeV/c²
- $\Gamma = 0.097 \pm 0.022 \pm 0.015$ GeV/c²
- $\mathcal{B}(D_S^+ \rightarrow a_0(1817)^+ \pi^0)$
 $= (3.44 \pm 0.52 \pm 0.32) \times 10^{-3}$
- Significance $> 10\sigma$

Observation of $a_0(1817)^+$ in $K_S^0 K^+$ mass spectrum

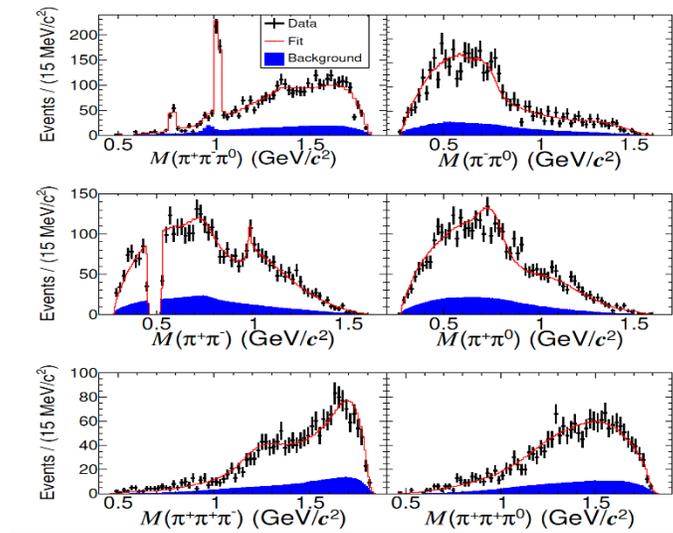
More amplitude analyses of hadronic charm decays

发现 $\Lambda_c^+ \rightarrow \Lambda a_0(980)$ 反常增强,
支持 $a_0(980)$ 是多夸克态物质



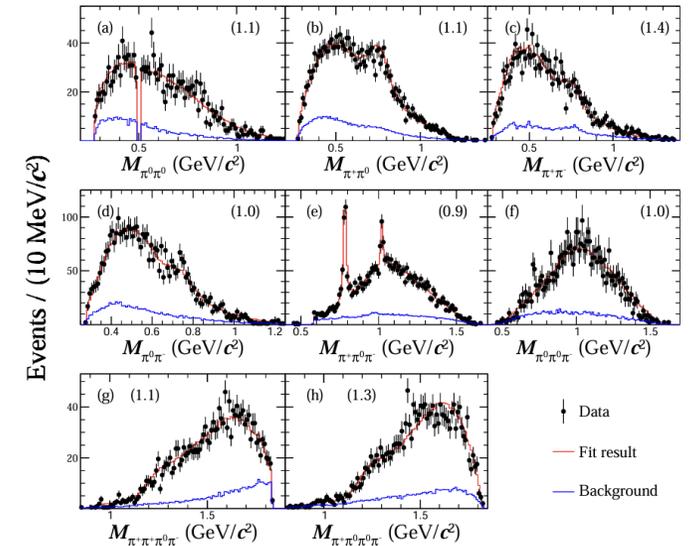
Phys. Rev. Lett. 134 (2025) 021901

发现 $D_s^+ \rightarrow f_0(980)\rho(770)$ 反常增强,
揭示了 $f_0(980)$ 是多夸克态物质



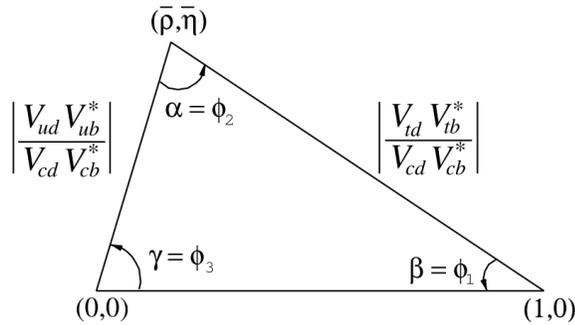
Phys. Rev. Lett. 134 (2025) 011904

首次在 $D_s^+ \rightarrow \omega\rho(770)$ 中
发现反常的矢量介子纵向极化现象,
与理论预期不符



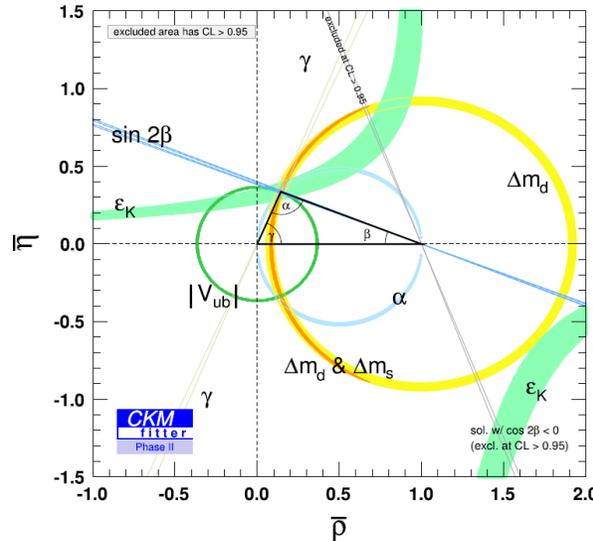
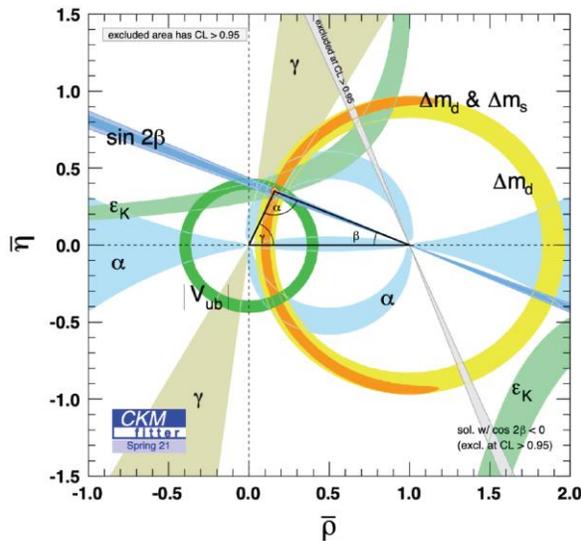
Phys. Rev. Lett. 134 (2025) 201902

Strong phase difference between hadronic D^0 and \bar{D}^0 decays



In B physics, precision measurements of CP violation phase angles α , β and γ offer powerful tests on the EW theories. Among them, the γ precision is the most urgent

Precision measurements of γ at LHCb and Belle II need input the strong phase differences of neutral D decays



Quantum-correlated $e^+ e^- \rightarrow \psi(3770) \rightarrow D^0 \bar{D}^0$ pairs at BESIII offer an ideal opportunity to extract the strong phase differences between D^0 and \bar{D}^0

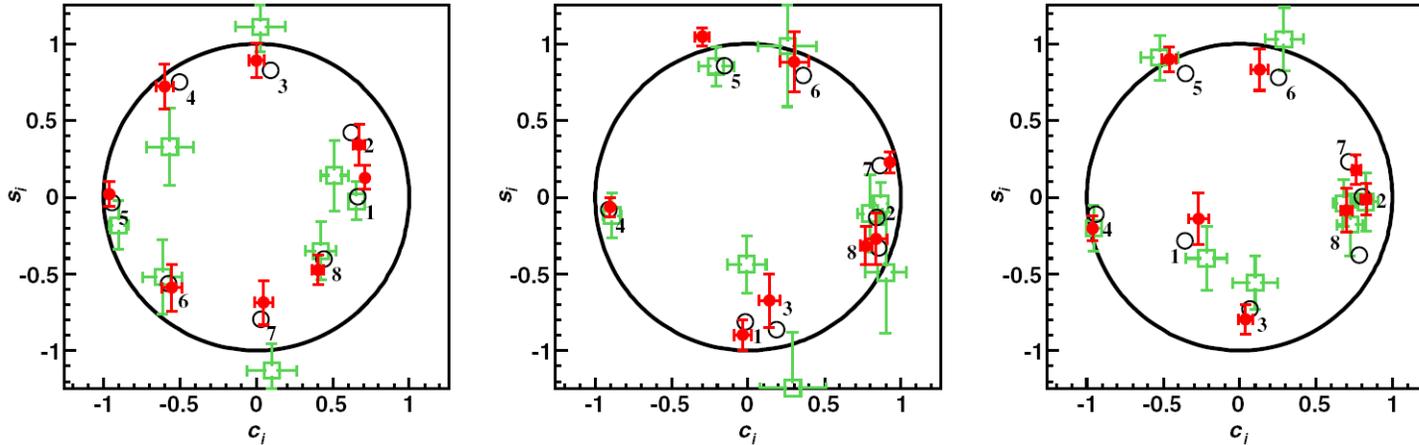
In the future 10-15 years, the statistical uncertainties of the γ measurements will reach at $\sim 1.5^\circ$ and 0.4° at Belle II and LHCb upgrade

The constraint on the γ measurement before BESIII is only 2° . Improved measurements of strong phase differences are highly desirable

Strong phase difference between hadronic D^0 and \bar{D}^0 decays

$D \rightarrow K_{S/L}^0 \pi^+ \pi^-$ PRL124(2020)241802

$e^+e^- \rightarrow \psi(3770) \rightarrow D^0 \bar{D}^0$ at 3.773 GeV



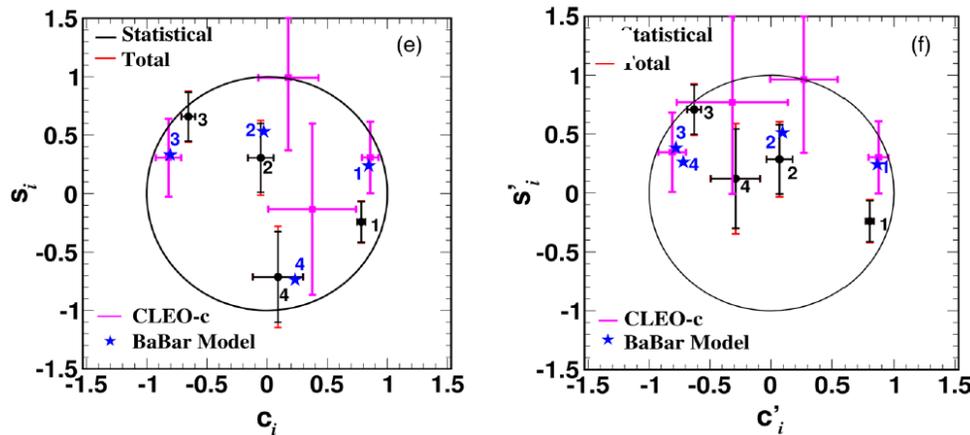
Constraint on γ measurement $\sim 0.9^\circ$

$D \rightarrow K_{S/L}^0 K^+ K^-$

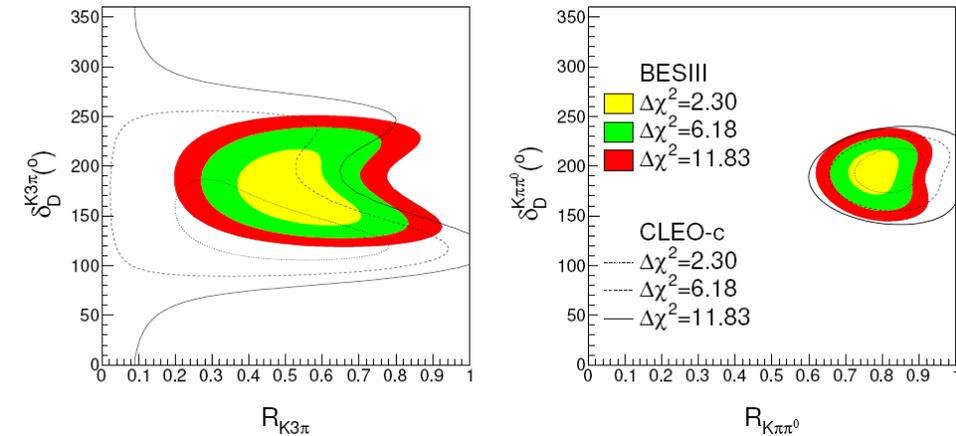
$D \rightarrow K^- \pi^+ \pi^+ \pi^-$ and $K^- \pi^+ \pi^0$

PRD102(2020)052008

JHEP05(2021)164



Constraint on γ measurement $\sim 1.3^\circ$



Constraint on γ measurement $\sim 6^\circ$

Charmed baryon Λ_c^+ decays

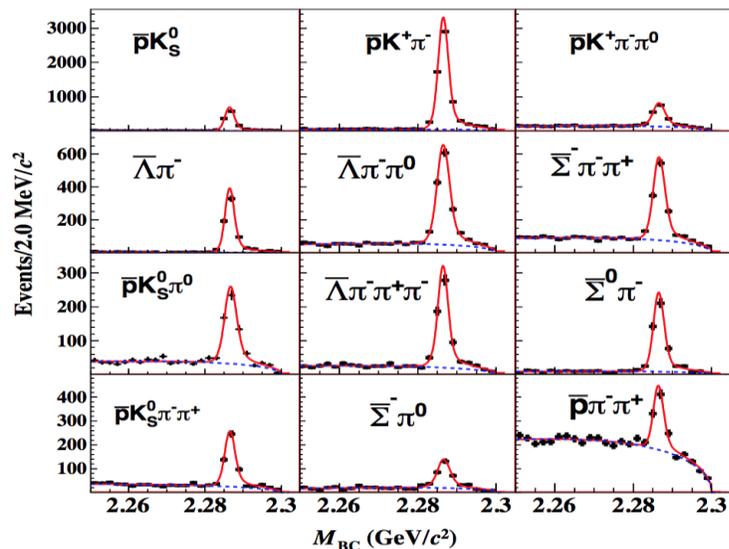
- Knowledge is poor. Taking Λ_c^+ as example
- Λ_c^+ was observed in 1979
- Before 2014, all decays of Λ_c^+ are measured relative to $\Lambda_c^+ \rightarrow pK^-\pi^+$, which suffers large uncertainty of 25%, with data at high energy range. No absolute measurement using data produced at Λ_c^+ pair threshold
- Sum of the BFs of known Λ_c^+ decays is only about 60%
- Similar situation for the other charmed baryons $\Xi_c^-, \Xi_c^0, \Omega_c^0, \Xi_{cc}^{++}$ and Ξ_{cc}^+

Intensive studies of these charmed baryons, search for new decays and absolute BF measurements are important to fully explore charmed baryon decay mechanisms

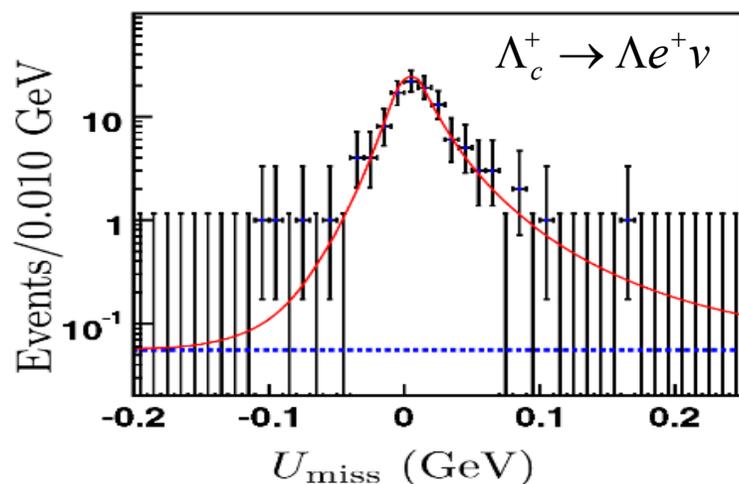
Λ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states			
$p\bar{K}^0$	(2.3 \pm 0.6) %		873
$pK^-\pi^+$	[a] (5.0 \pm 1.3) %		823
$p\bar{K}^*(892)^0$	[b] (1.6 \pm 0.5) %		685
$\Delta(1232)^{++}K^-$	(8.6 \pm 3.0) $\times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b] (1.8 \pm 0.6) %		627
$pK^-\pi^+$ nonresonant	(2.8 \pm 0.8) %		823
$p\bar{K}^0\pi^0$	(3.3 \pm 1.0) %		823
$p\bar{K}^0\eta$	(1.2 \pm 0.4) %		568
Hadronic modes with a hyperon: $S = -1$ final states			
$\Lambda\pi^+$	(1.07 \pm 0.28) %		864
$\Lambda\pi^+\pi^0$	(3.6 \pm 1.3) %		844
$\Lambda\rho^+$	< 5 %	CL=95%	636
$\Lambda\pi^+\pi^+\pi^-$	(2.6 \pm 0.7) %		807
$\Sigma(1385)^+\pi^+\pi^-, \Sigma^{*+} \rightarrow$	(7 \pm 4) $\times 10^{-3}$		688
$\Lambda\pi^+$			
$\Sigma(1385)^-\pi^+\pi^+, \Sigma^{*-} \rightarrow$	(5.5 \pm 1.7) $\times 10^{-3}$		688
$\Lambda\pi^+$			
$\Lambda\pi^+\rho^0$	(1.1 \pm 0.5) %		524
$\Sigma(1385)^+\rho^0, \Sigma^{*+} \rightarrow \Lambda\pi^+$	(3.7 \pm 3.1) $\times 10^{-3}$		363
$\Lambda\pi^+\pi^+\pi^-$ nonresonant	< 8 $\times 10^{-3}$	CL=90%	807
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total	(1.8 \pm 0.8) %		757
$\Lambda\pi^+\eta$	[b] (1.8 \pm 0.6) %		691
$\Sigma(1385)^+\eta$	[b] (8.5 \pm 3.3) $\times 10^{-3}$		570
$\Lambda\pi^+\omega$	[b] (1.2 \pm 0.5) %		517
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω	< 7 $\times 10^{-3}$	CL=90%	757
$\Lambda K^+\bar{K}^0$	(4.7 \pm 1.5) $\times 10^{-3}$	S=1.2	443
$\Xi(1690)^0 K^+, \Xi^{*0} \rightarrow \Lambda\bar{K}^0$	(1.3 \pm 0.5) $\times 10^{-3}$		286
$\Sigma^0\pi^+$	(1.05 \pm 0.28) %		825
$\Sigma^+\pi^0$	(1.00 \pm 0.34) %		827
$\Sigma^+\eta$	(5.5 \pm 2.3) $\times 10^{-3}$		713
$\Sigma^+\pi^+\pi^-$	(3.6 \pm 1.0) %		804
$\Sigma^+\rho^0$	< 1.4 %	CL=95%	575
$\Sigma^-\pi^+\pi^+$	(1.7 \pm 0.5) %		799
$\Sigma^0\pi^+\pi^0$	(1.8 \pm 0.8) %		803
$\Sigma^0\pi^+\pi^+\pi^-$	(8.3 \pm 3.1) $\times 10^{-3}$		763
$\Sigma^+\pi^+\pi^-\pi^0$	—		767
$\Sigma^+\omega$	[b] (2.7 \pm 1.0) %		569
Semileptonic modes			
$\Lambda\ell^+\nu_\ell$	[c] (2.0 \pm 0.6) %		871
$\Lambda e^+\nu_e$	(2.1 \pm 0.6) %		871
$\Lambda\mu^+\nu_\mu$	(2.0 \pm 0.7) %		867
Inclusive modes			
e^+ anything	(4.5 \pm 1.7) %		—
pe^+ anything	(1.8 \pm 0.9) %		—
p anything	(50 \pm 16) %		—

Absolute branching fractions of Λ_c^+ decays

PRL116(2016)052001



PRL115(2015)221805



Based on 0.57 fb^{-1} @ 4.6 GeV:

Very productive for data taken in 35 days!

Hadronic decay

$\Lambda_c^+ \rightarrow pK^- \pi^+ + 11 \text{ CF modes}$

$\Lambda_c^+ \rightarrow pK^+ K^-, p\pi^+ \pi^-$

$\Lambda_c^+ \rightarrow nK_S^0 \pi^+$

$\Lambda_c^+ \rightarrow p\eta, p\pi^0$

$\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+ \pi^0$

$\Lambda_c^+ \rightarrow \Xi^{0(*)} K^+$

$\Lambda_c^+ \rightarrow \Lambda \eta \pi^+$

$\Lambda_c^+ \rightarrow \Sigma^+ \eta, \Sigma^+ \eta'$

$\Lambda_c^+ \rightarrow \text{BP decay asymmetries}$

$\Lambda_c^+ \rightarrow pK_S \eta$

Semi-leptonic decay

$\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

$\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu$

Inclusive decay

$\Lambda_c^+ \rightarrow \Lambda \chi$

$\Lambda_c^+ \rightarrow e^+ \chi$

$\Lambda_c^+ \rightarrow K_S^0 \chi$

Production

$\Lambda_c^+ \Lambda_c^-$ cross section

PRL116(2016)052001

PRL117(2017)232002

PRL118(2017)112001

PRD95(2017)111102(R)

PLB772(2017)388

PLB783(2018)200

PRD99(2019)032010

CPC43(2019)083002

PRD100(2019)07200

PLB817(2021)136327

PRL115(2015)221805

PLB767(2017)42

PRL121(2018)062003

PRL121(2018)251801

EPJC80(2020)935

PRL120(2018)132001

Impact on the world data of Λ_c^+

PDG2014

For example

PDG2021

Λ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states			
$p\bar{K}^0$	(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a] (5.0 ± 1.3) %		823
$p\bar{K}^*(892)^0$	[b] (1.6 ± 0.5) %		685
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$p\bar{K}^0\pi^0$	(3.3 ± 1.0) %		823
$p\bar{K}^0\eta$	(1.2 ± 0.4) %		568

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Λ_c^+ REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1992 edition (Physical Review **D45**, 1 June, Part II) or in earlier editions.

AAIJ	19AG	PR D100 032001	R. Aaij <i>et al.</i>	(LHCb Collab.)
ABLIKIM	19AX	PR D100 072004	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	19X	CP C43 083002	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	19Y	PR D99 032010	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
AAIJ	18N	PR D97 091101	R. Aaij <i>et al.</i>	(LHCb Collab.)
AAIJ	18R	JHEP 1803 182	R. Aaij <i>et al.</i>	(LHCb Collab.)
AAIJ	18V	JHEP 1803 043	R. Aaij <i>et al.</i>	(LHCb Collab.)
ABLIKIM	18AF	PRL 121 251801	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	18E	PRL 121 062003	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	18Y	PL B783 200	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
BERGER	18	PR D98 112006	M. Berger <i>et al.</i>	(BELLE Collab.)
ABLIKIM	17D	PL B767 42	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	17H	PRL 118 112001	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	17Q	PR D95 111102	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	17Y	PL B772 388	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
PAL	17	PR D96 051102	B. Pal <i>et al.</i>	(BELLE Collab.)
ABLIKIM	16	PRL 116 052001	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ABLIKIM	16U	PRL 117 232002	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
YANG	16	PRL 117 011801	S.B. Yang <i>et al.</i>	(BELLE Collab.)
ABLIKIM	15Y	PRL 115 221805	M. Ablikim <i>et al.</i>	(BESIII Collab.)★
ZUPANC	14	PRL 113 042002	A. Zupanc <i>et al.</i>	(BELLE Collab.)
LEES	11G	PR D84 072006	J.P. Lees <i>et al.</i>	(BABAR Collab.)

Hadronic modes with a p or n : $S = -1$ final states

Γ_1	pK_S^0	(1.59 ± 0.08) %	S=1.1
Γ_2	$pK_S^-\pi^+$	(6.28 ± 0.32) %	S=1.4
Γ_3	$p\bar{K}^*(892)^0$	[a] (1.96 ± 0.21) %	
Γ_4	$\Delta(1232)^{++}K^-$	(1.08 ± 0.25) %	
Γ_5	$\Lambda(1520)\pi^+$	[a] (2.2 ± 0.5) %	
Γ_6	$pK_S^-\pi^+$ nonresonant	(3.5 ± 0.4) %	
Γ_7	$pK_S^0\pi^0$	(1.97 ± 0.13) %	S=1.1
Γ_8	$nK_S^0\pi^+$	(1.82 ± 0.25) %	
Γ_9	$p\bar{K}^0\eta$	(1.6 ± 0.4) %	
Γ_{10}	$pK_S^0\pi^+\pi^-$	(1.60 ± 0.12) %	S=1.1
Γ_{11}	$pK_S^-\pi^+\pi^0$	(4.46 ± 0.30) %	S=1.5
Γ_{12}	$pK^*(892)^-\pi^+$	[a] (1.4 ± 0.5) %	
Γ_{13}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$	(4.6 ± 0.8) %	
Γ_{14}	$\Lambda(1520)\pi^+\pi^0$	seen	
Γ_{15}	$pK^-\pi^+\pi^0$	(1.4 ± 0.9) × 10 ⁻³	
Γ_{16}	$pK^-\pi^+2\pi^0$	(1.0 ± 0.5) %	

Significantly improved precision and new decay modes

Stimulate intensive studies of more charmed baryons

Decay Asymmetry of $\Lambda_c^+ \rightarrow \Xi^0 K^+$

➤ Decay asymmetry results

$$\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16 \pm 0.03$$

$$\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90 \pm 0.17 \text{ rad}$$

$$\beta_{\Xi^0 K^+} = -0.64 \pm 0.69 \pm 0.13$$

$$\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58 \pm 0.11$$

➤ Phase difference between S and P -waves

$$\text{Solution 1: } \delta_p - \delta_s = -1.55 \pm 0.25 \pm 0.05$$

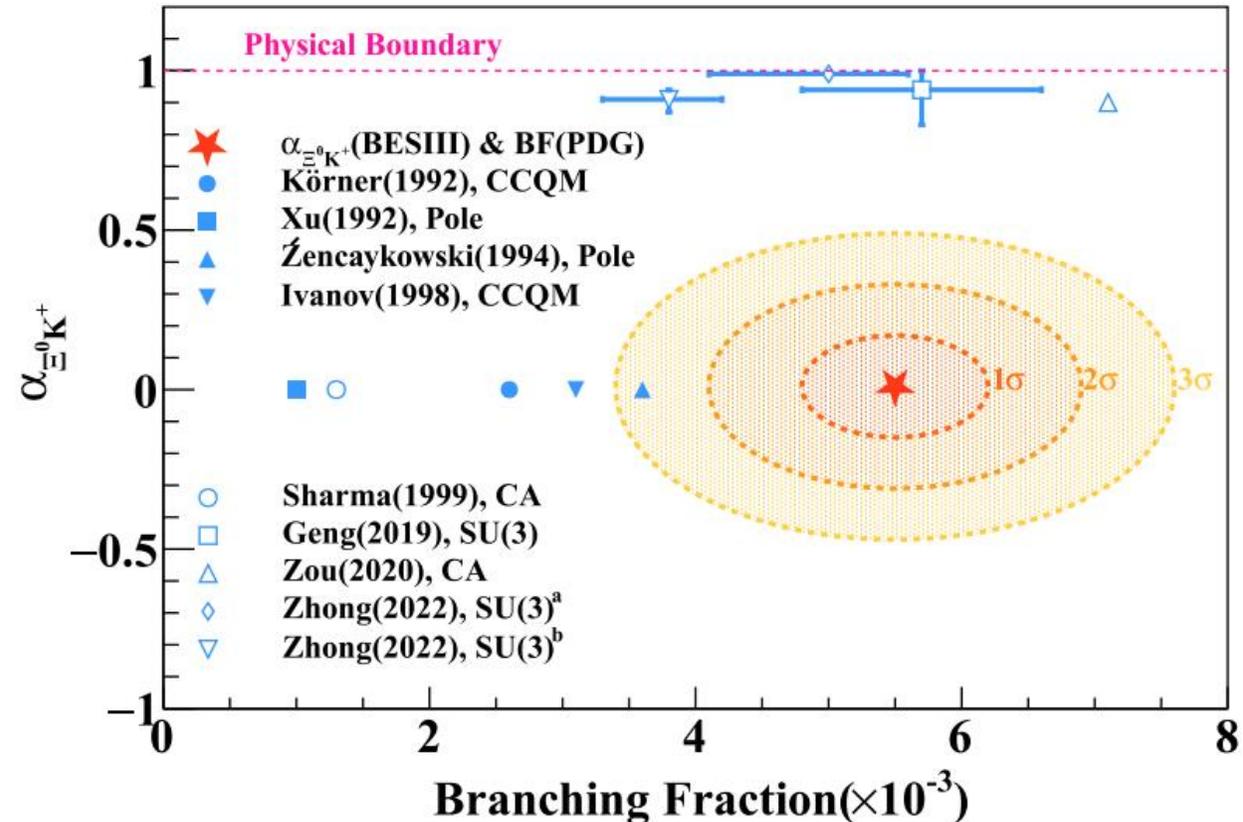
$$\text{Solution 2: } \delta_p - \delta_s = 1.59 \pm 0.25 \pm 0.05$$

➤ $\alpha_{\Xi^0 K^+}$ is in good agreement with zero, providing strong identification for theoretical predictions

➤ $\cos(\delta_p - \delta_s)$ is measured to close to zero, which is not considered in previous literature

➤ Fills the long-standing puzzle on how to model $\alpha_{\Xi^0 K^+}$ and $\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+)$ simultaneously

PRL132, 031801 (2024)

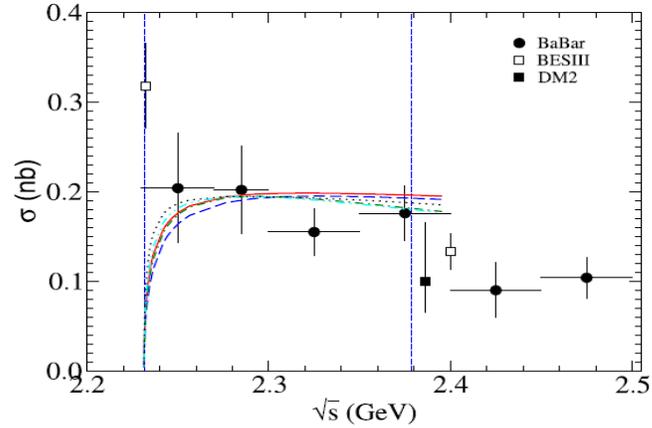


Threshold effect on $e^+e^- \rightarrow B\bar{B}$

A hint of resonance around $\Lambda\bar{\Lambda}$ threshold

$$e^+e^- \rightarrow \Lambda\bar{\Lambda}$$

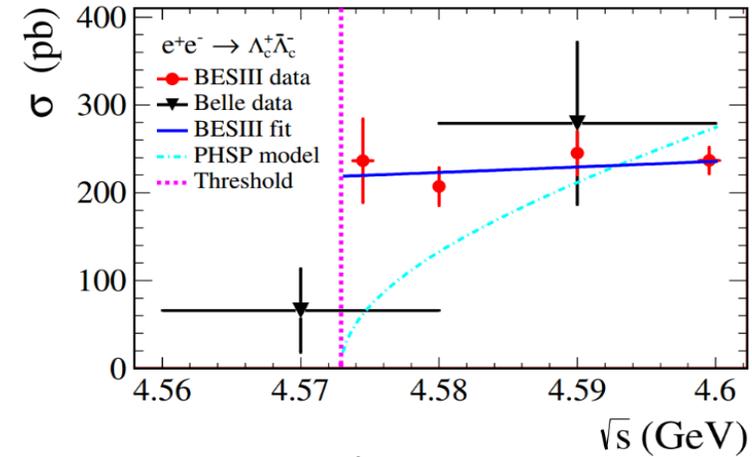
PRD97(2018)032013



More threshold studies:

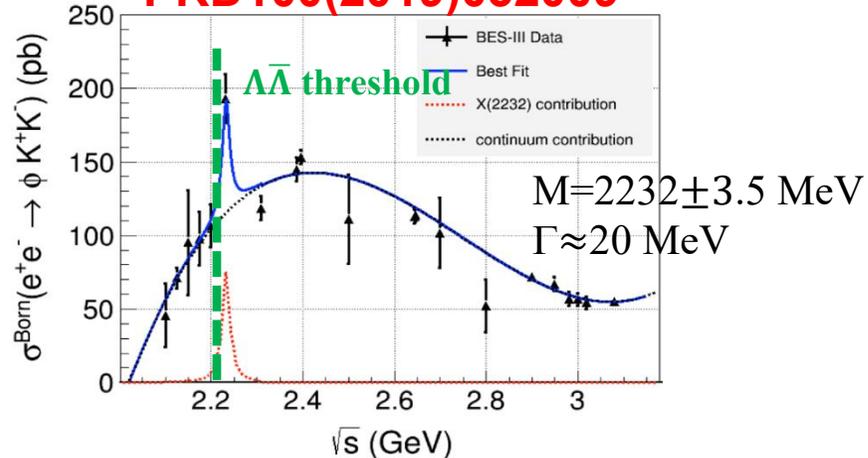
$$e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$$

PRL120(2018)132001



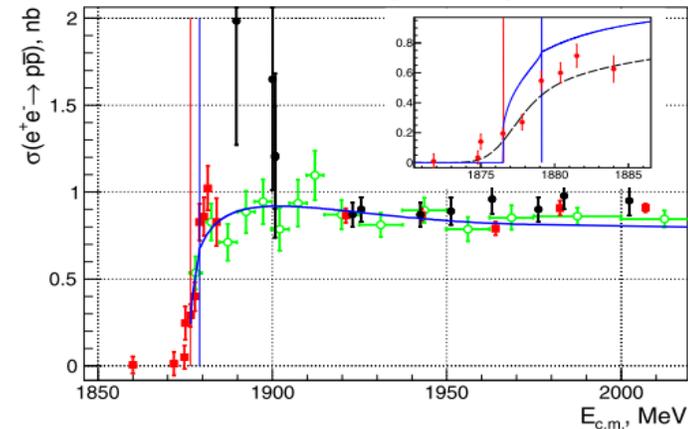
$$e^+e^- \rightarrow KKKK$$

PRD100(2019)032009



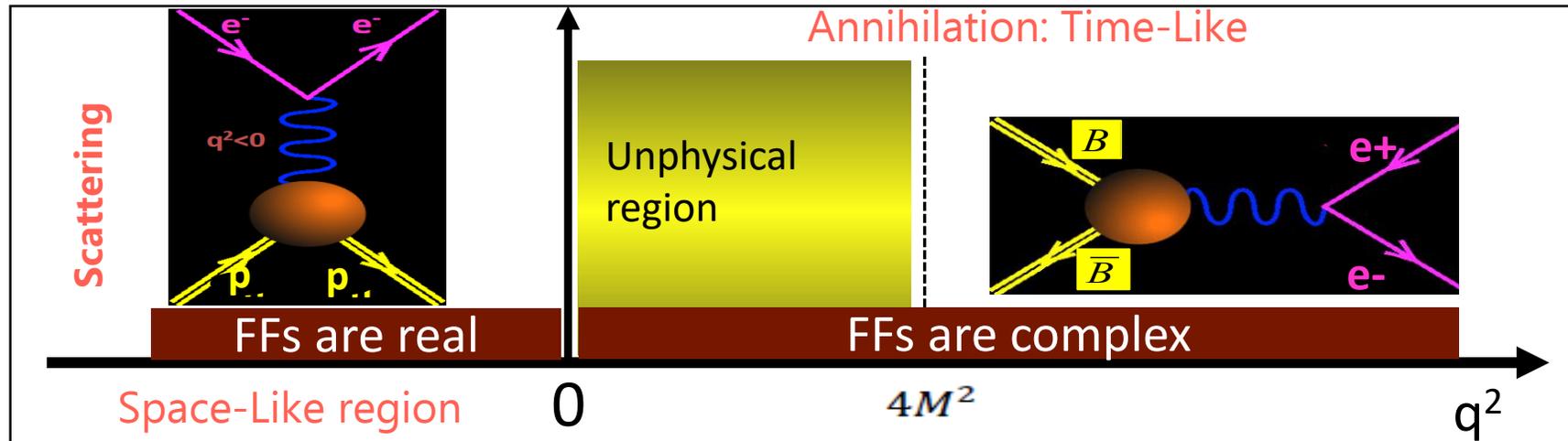
$$e^+e^- \rightarrow p\bar{p}$$

PLB759(2016)634



Electromagnetic form factors of baryons

In the time-like region, the electromagnetic form factors of the baryons characterize the internal structure of the baryons



The nucleon electromagnetic vertex Γ_μ describing the hadron current:

$$\Gamma_\mu(p', p) = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m_p} F_2(q^2)$$

Sachs form factors: $G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$

$$G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$$

Form factors of proton

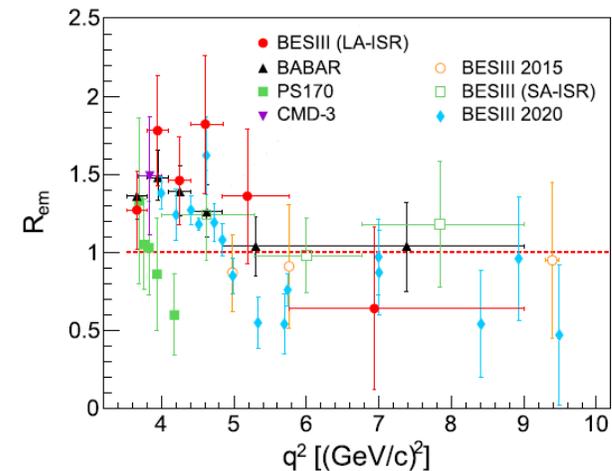
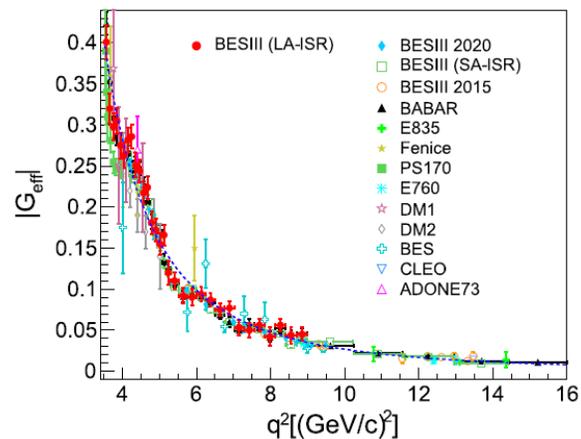
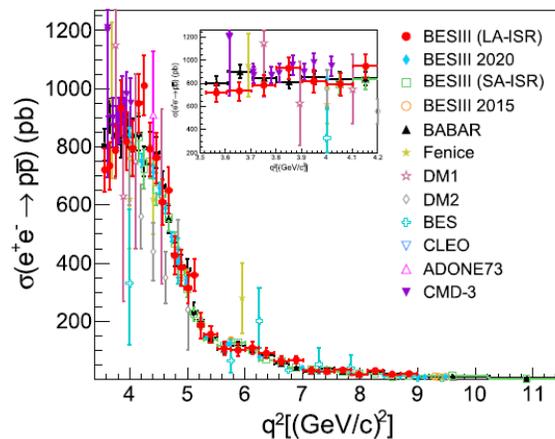
PRD91(2015)112004: $e^+e^- \rightarrow p\bar{p}$ with data from 2.232 to 3.671 GeV

PRL124(2020)042001: $e^+e^- \rightarrow p\bar{p}$ with data from 2.00 to 3.08 GeV

SA-ISR: PRD99(2019)092002: $e^+e^-(\gamma_{\text{ISR}}) \rightarrow p\bar{p}$ with data from 3.773 to 4.6 GeV

LA-ISR: PLB817(2021)136328: $e^+e^-(\gamma_{\text{ISR}}) \rightarrow p\bar{p}$ with data from 3.773 to 4.6 GeV

- Average cross section near threshold is about 840 pb and is close to point-like cross section at threshold
- $|G_E/G_M|$ and $|G_M|$ are determined with **high accuracy** which is comparable to data in space like



Form factors of neutron

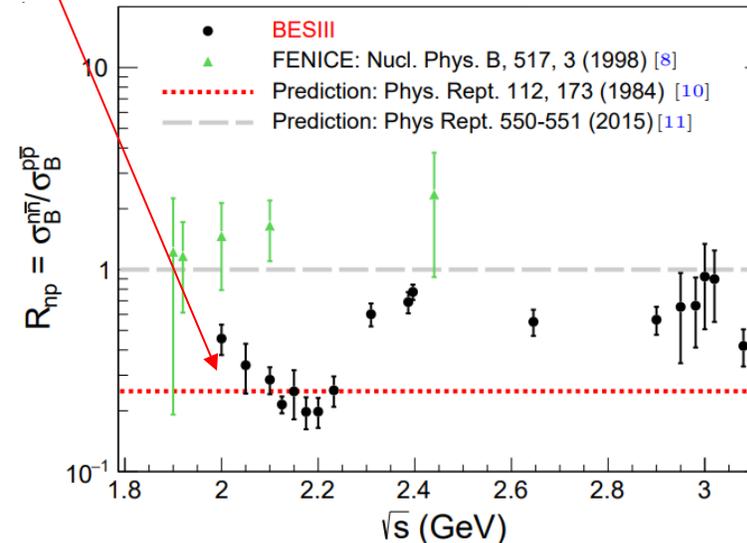
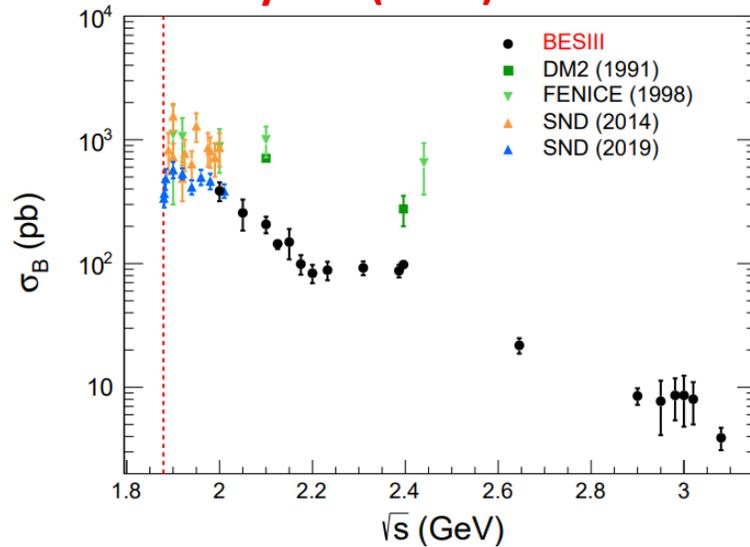
$e^+e^- \rightarrow n\bar{n}$ with data from 2.00 to 3.08 GeV

- Born cross sections are measured with **much improved precision and in larger energy region**
- Agrees with theoretical prediction and thereby clarifies the **“long-standing puzzle”** that the γn coupling is larger than the γp coupling

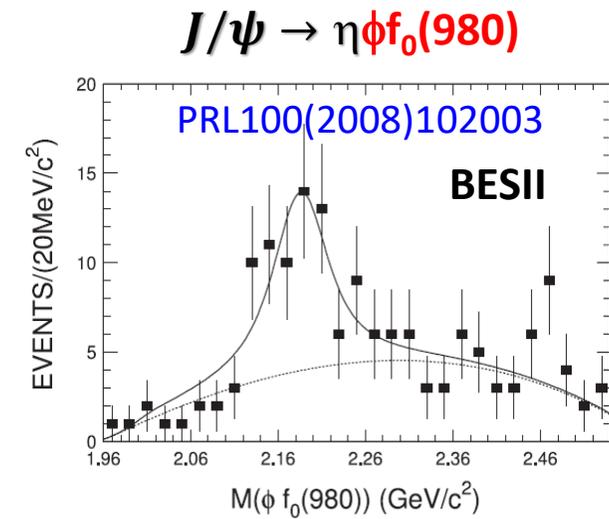
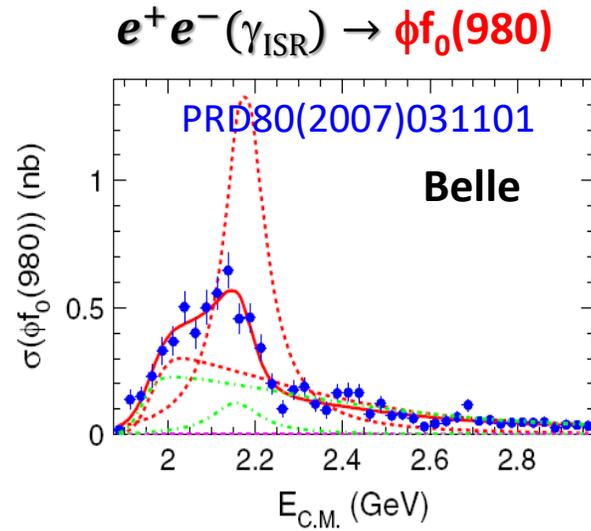
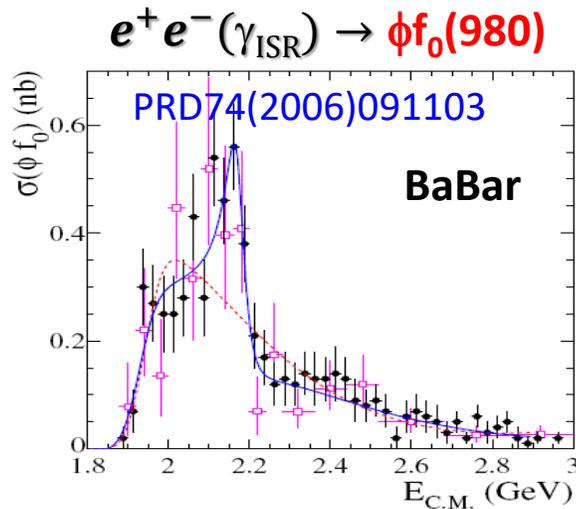
V. L. Chernyak and A. R. Zhitnitsky, Phys. Rept. 112(1984)173

$$\sigma(e^+e^- \rightarrow B\bar{B}) \propto \left| \sum_{q \in B} Q_q a_q^B(s) \right|^2, \quad \frac{\sigma(e^+e^- \rightarrow p\bar{p})}{\sigma(e^+e^- \rightarrow n\bar{n})} \rightarrow \frac{Q_u^2}{Q_d^2} = 4$$

Nat. Phys. 17(2021)1200



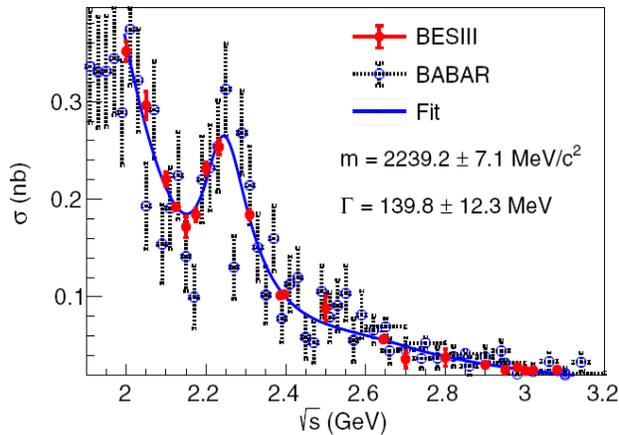
Strangeness-like states: $\Upsilon(2175)/\phi(2170)$



BESIII studies:

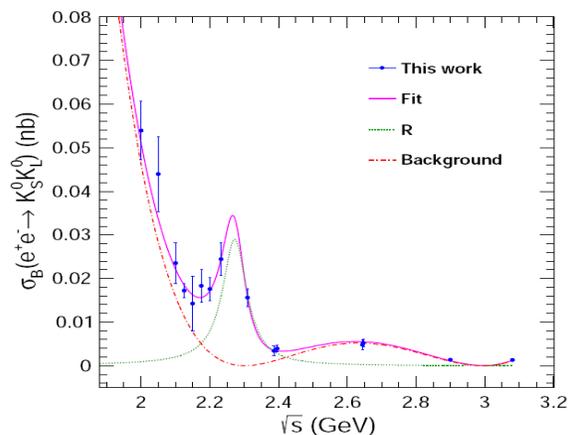
$e^+e^- \rightarrow K^+K^-$

PRD99(2019)032001



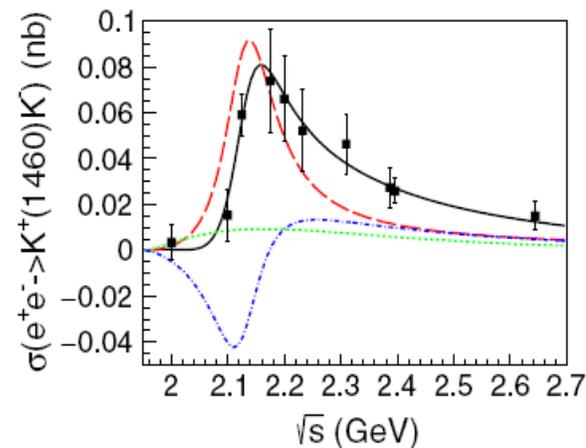
$e^+e^- \rightarrow K_S K_L$

PRD106(2021)092014



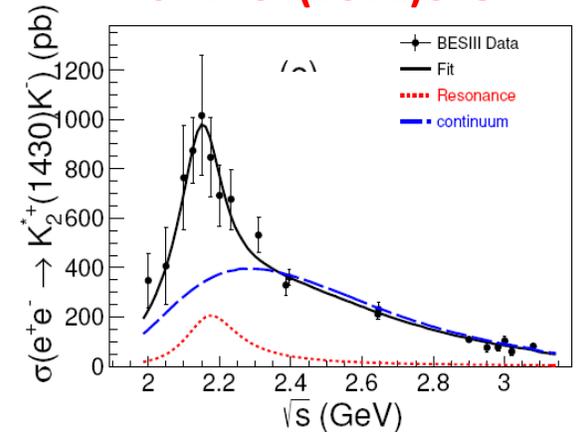
$e^+e^- \rightarrow K^+K^-\pi^0\pi^0$

PRL124(2020)112001



$e^+e^- \rightarrow K^{*+}(1430)K^-$

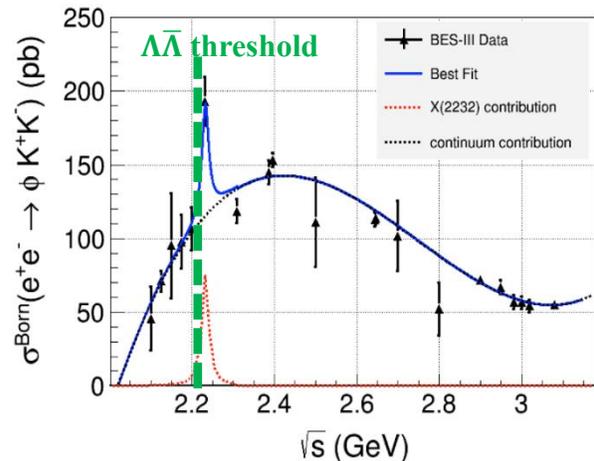
JHEP07(2022)045



More $\Upsilon(2175)$ studies at BESIII

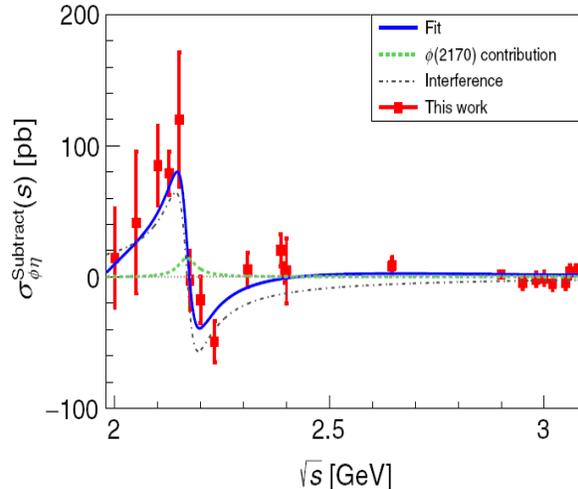
$$e^+e^- \rightarrow \phi K^+K^-$$

PRD100(2019)032009



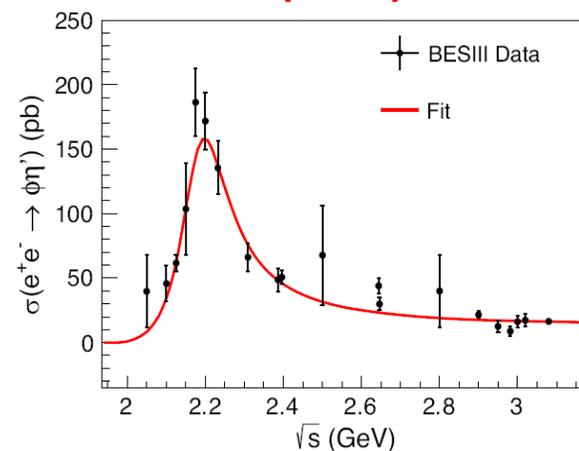
$$e^+e^- \rightarrow \phi\eta$$

PRD104(2021)032007



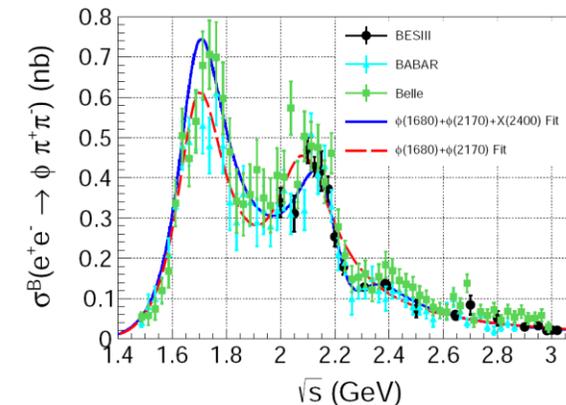
$$e^+e^- \rightarrow \phi\eta'$$

PRD102(2020)012008



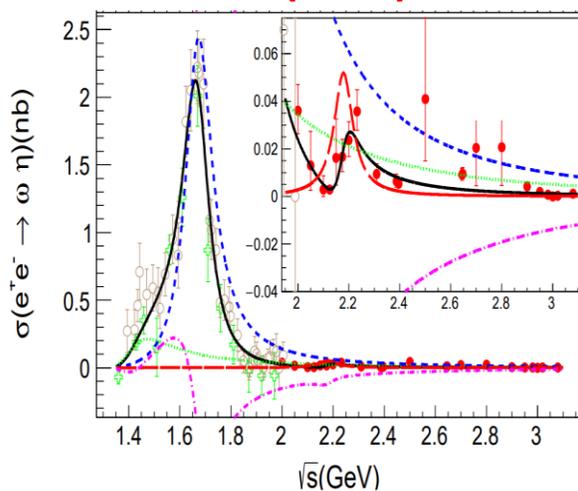
$$e^+e^- \rightarrow \phi\pi^+\pi^-$$

arXiv:2112.23219



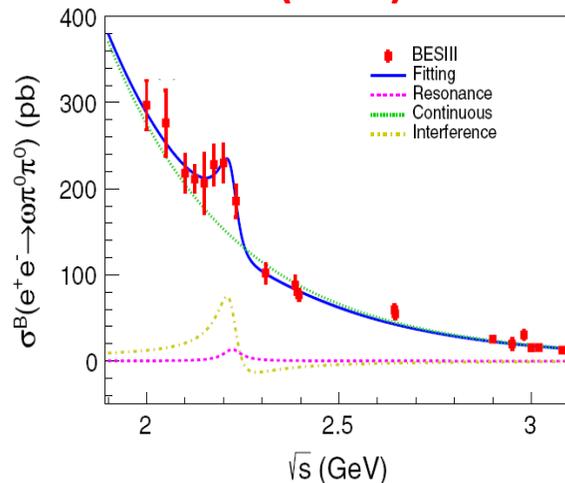
$$e^+e^- \rightarrow \omega\eta$$

PLB813(2021)136059



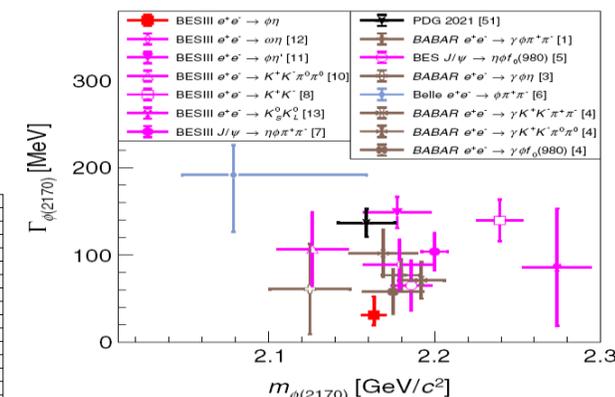
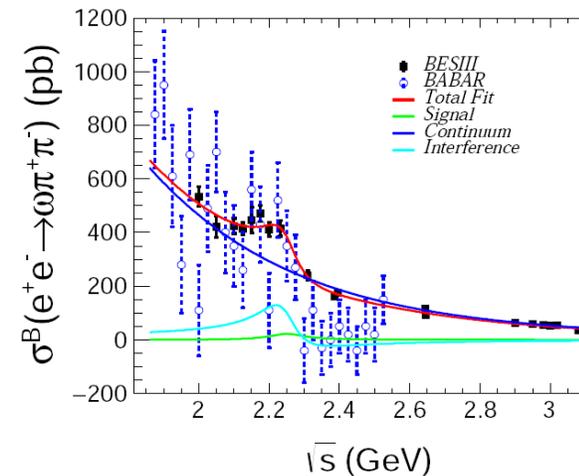
$$e^+e^- \rightarrow \omega\pi^0\pi^0$$

PRD105(2022)032005



$$e^+e^- \rightarrow \omega\pi^+\pi^-$$

arXiv:2208.04507

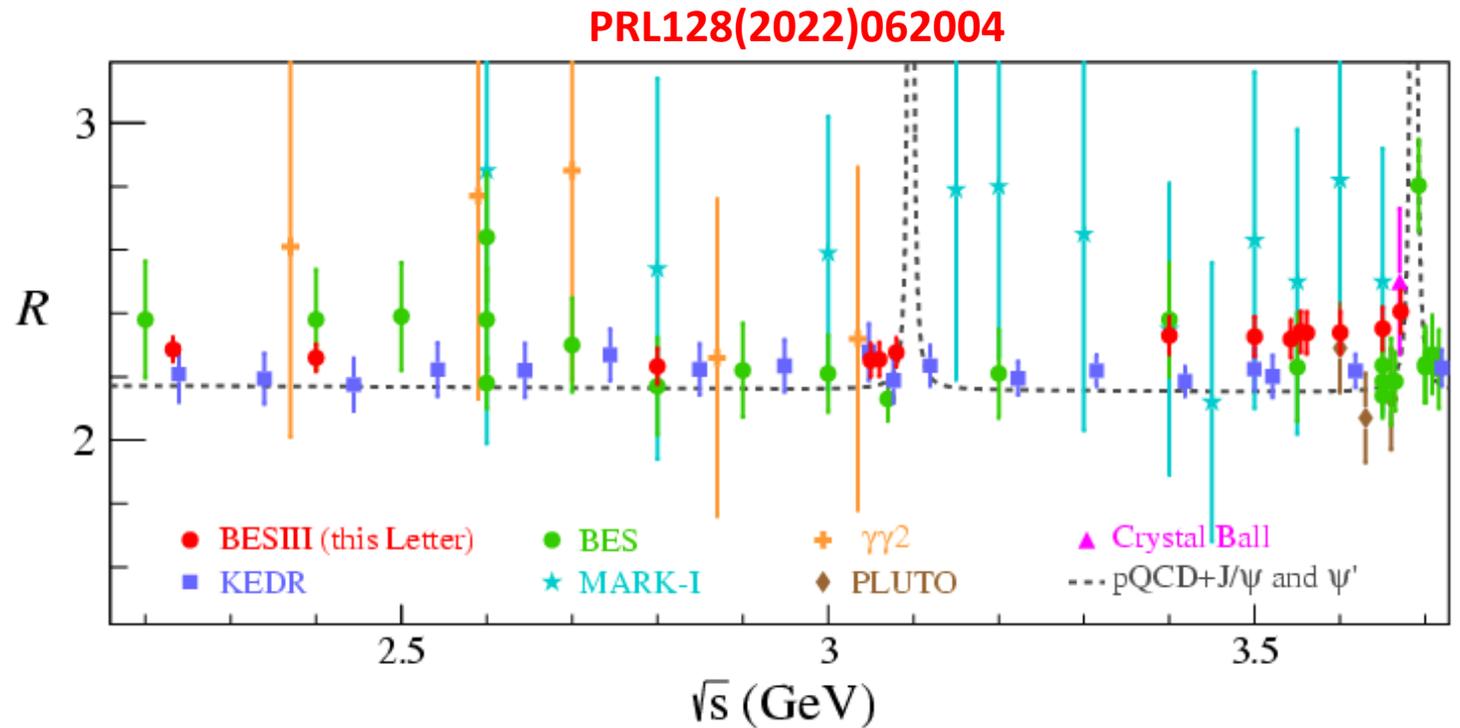
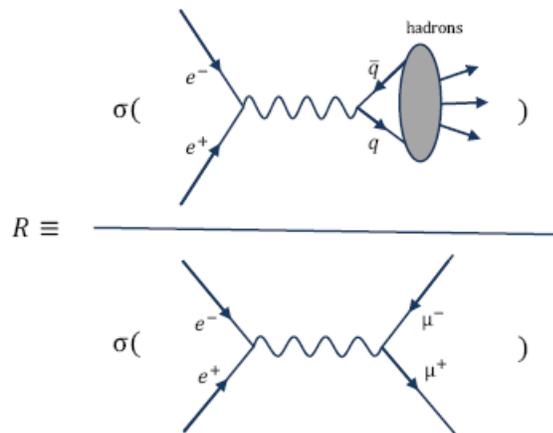


- Different masses and widths
- Limited decay modes
- Nature is mysterious
- More studies are desirable

R values

- Measurement of R values in the energy range of 2.23-3.67 GeV
- Precision is better than 3% and is improved by about twofold compared to the previous best measurement
- Crucial input parameters to calculate the running coupling constant in theory.
- Constrain the muon anomalous magnetic moment, therefore help to clarify the 4σ difference between theoretical calculation and experimental measurement

$$R \equiv \frac{\sigma^0(e^+e^- \rightarrow \text{hadrons})}{\sigma^0(e^+e^- \rightarrow \mu^+\mu^-)} \equiv \frac{\sigma_{\text{had}}^0}{\sigma_{\mu\mu}^0}$$

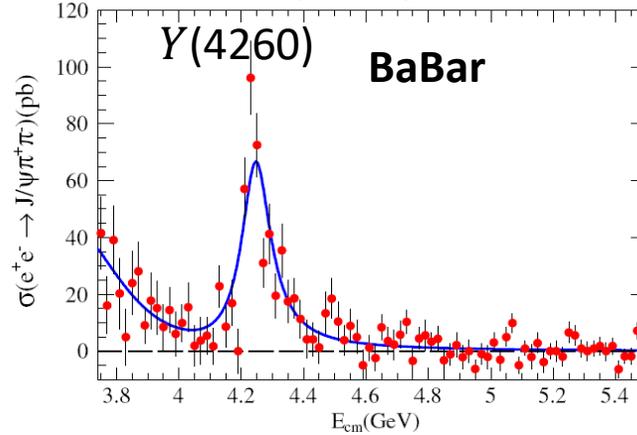


The Y states

Y states: charmonium-like states with $J^{PC}=1^{--}$; observed in initial state radiation (ISR) or direct e^+e^- annihilation

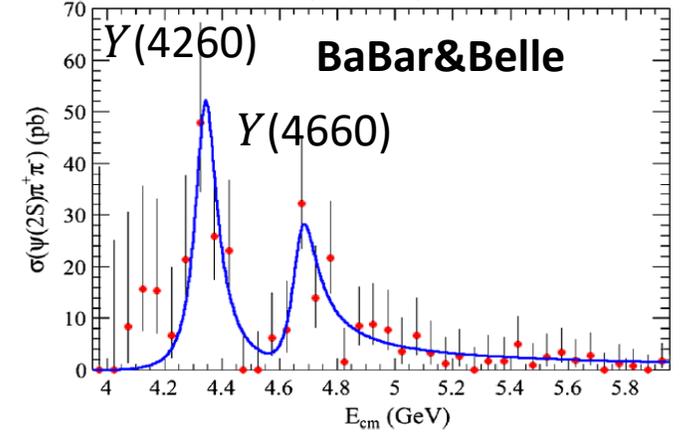
$$e^+e^-(\gamma_{\text{ISR}}) \rightarrow \pi^+\pi^-J/\psi$$

PRD86(2012)051102



$$e^+e^-(\gamma_{\text{ISR}}) \rightarrow \pi^+\pi^-\psi(2S)$$

PRD89(2014)111103

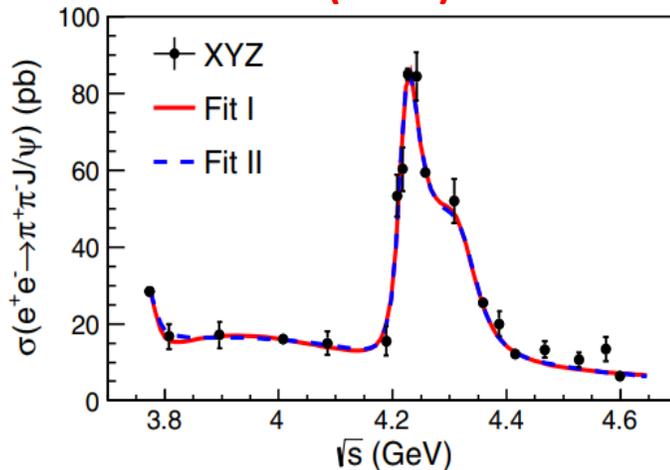


Improved knowledges from BESIII

BESIII

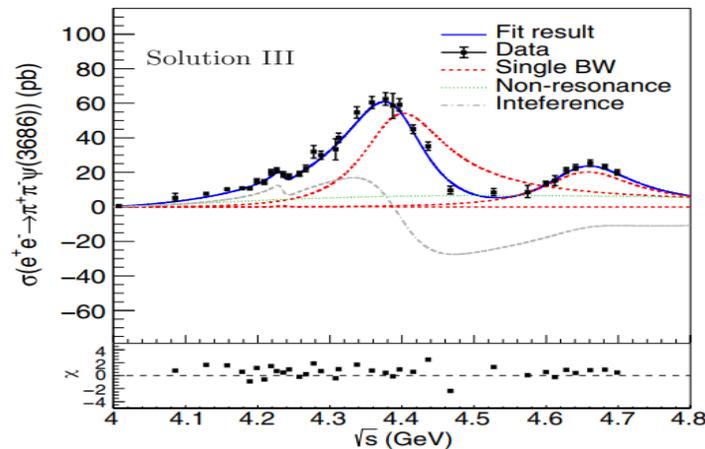
$$e^+e^- \rightarrow \pi^+\pi^-J/\psi$$

PRL118(2017)092001



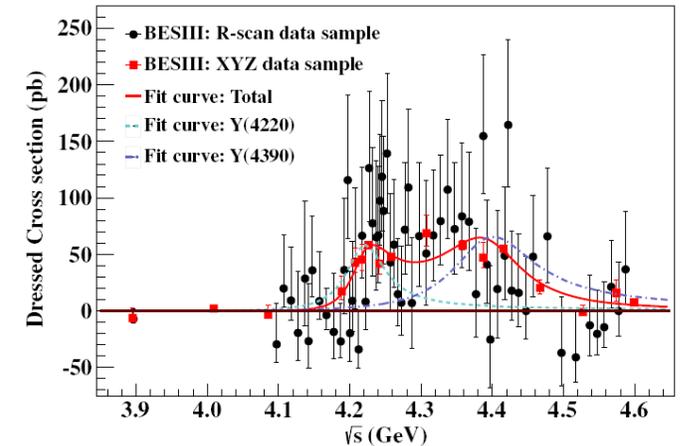
$$e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$$

PRD104(2021)052012



$$e^+e^- \rightarrow \pi^+\pi^-h_c$$

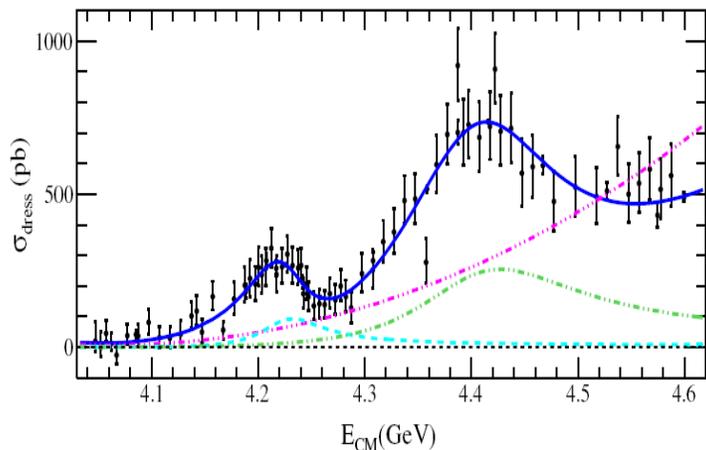
PRL118(2017)092002



$Y(4260) \rightarrow Y(4220)$ and new Y ?

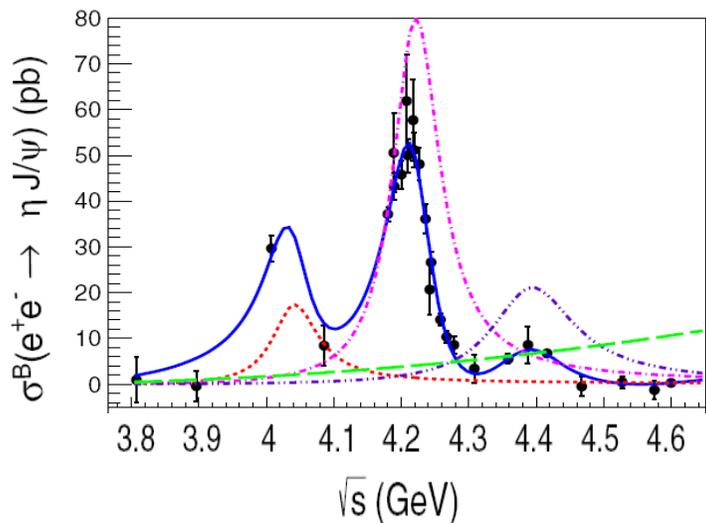
$$e^+e^- \rightarrow \pi^+ D^0 D^{*-} + \text{c.c.}$$

PRL122(2019)102002



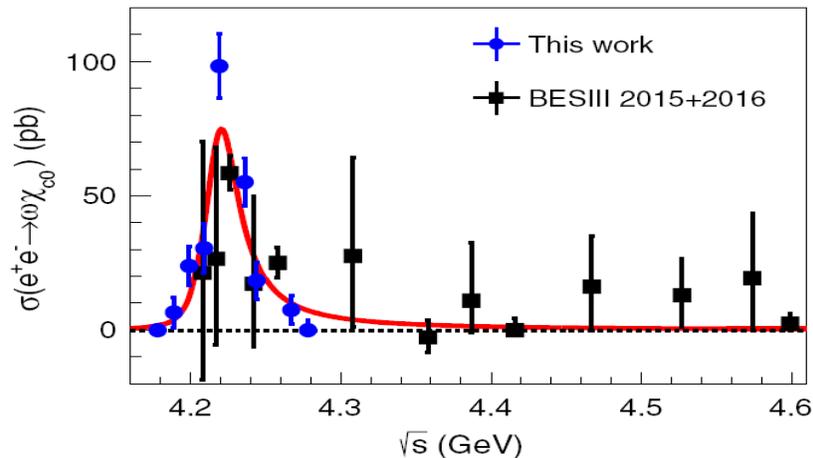
$$e^+e^- \rightarrow \eta J/\psi$$

PRD102(2020)031101(RC)



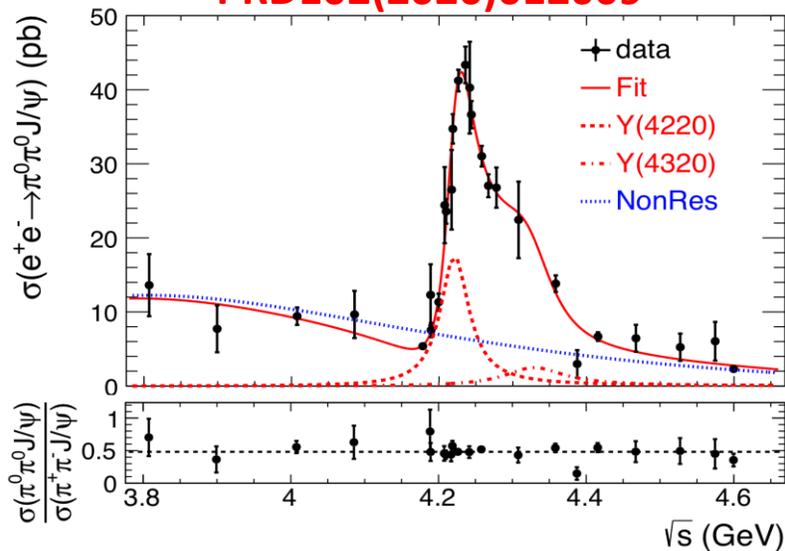
$$e^+e^- \rightarrow \omega \chi_{c0}$$

PRD99(2019)091103(RC)



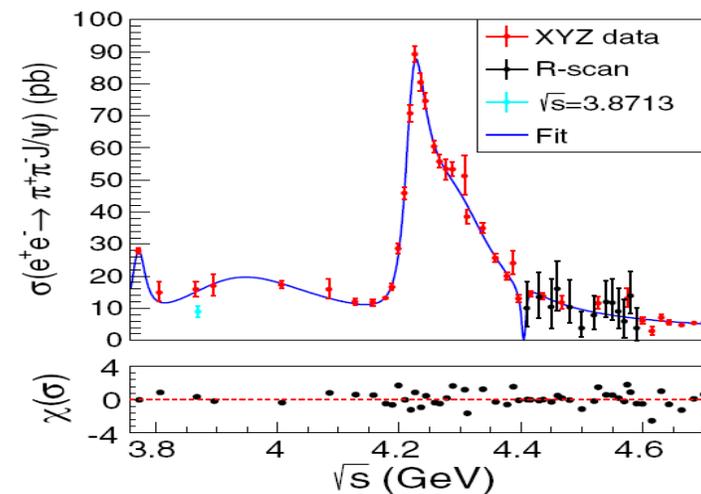
$$e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$$

PRD102(2020)012009

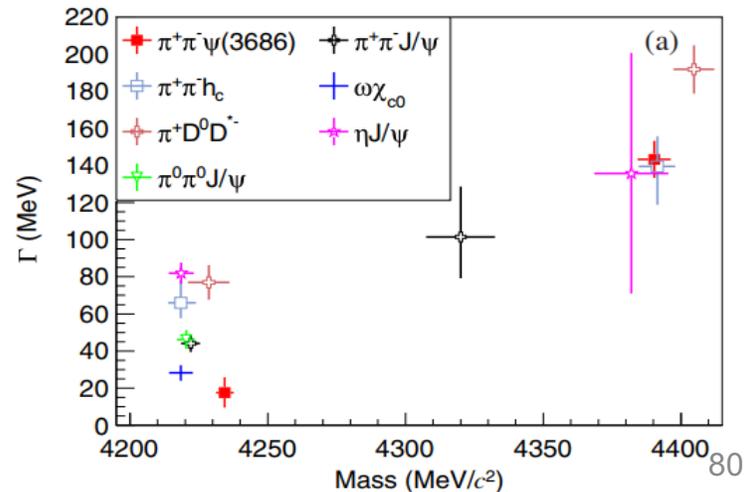


$$\text{Precision results of } e^+e^- \rightarrow \pi^+ \pi^- J/\psi$$

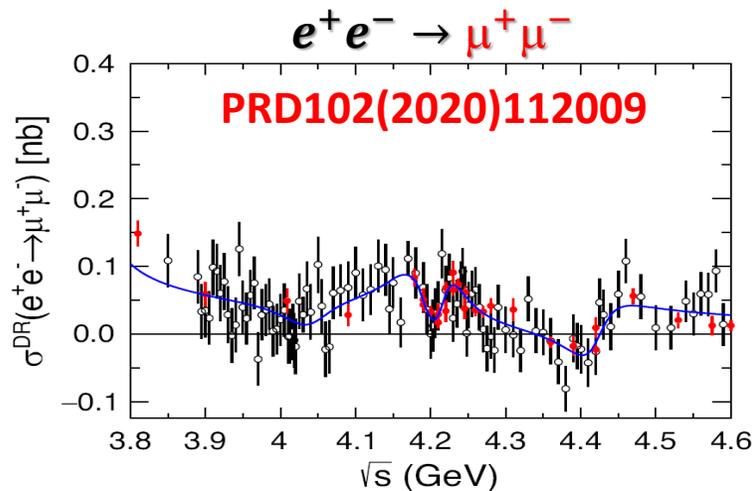
PRD106(2022)072001



Different masses and widths in various processes

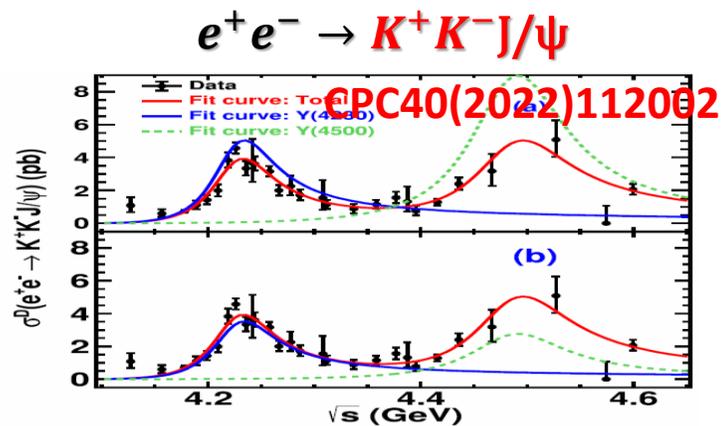


$Y(4260) \rightarrow Y(4220)$ and new Y ?



$$M = 4216.7 \pm 8.9 \pm 4.1 \text{ MeV}/c^2$$

$$\Gamma = 47.2 \pm 22.8 \pm 10.5 \text{ MeV}$$

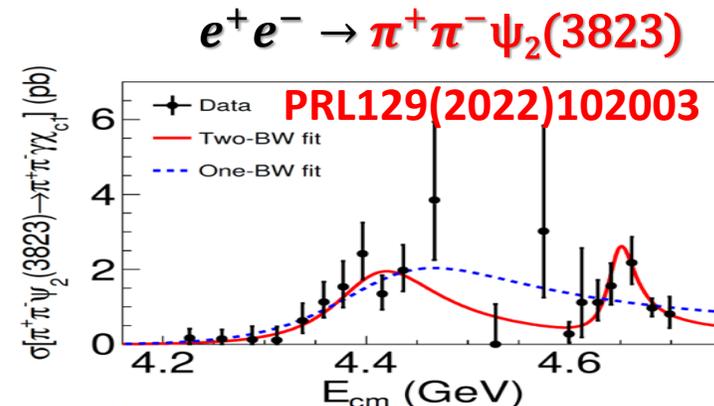


$$M_1 = 4225.3 \pm 2.3 \pm 21.5 \text{ MeV}/c^2$$

$$\Gamma_1 = 72.9 \pm 6.1 \pm 30.8 \text{ MeV}$$

$$M_2 = 4484.7 \pm 13.3 \pm 24.1 \text{ MeV}/c^2$$

$$\Gamma_2 = 111.1 \pm 30.1 \pm 15.2 \text{ MeV}$$

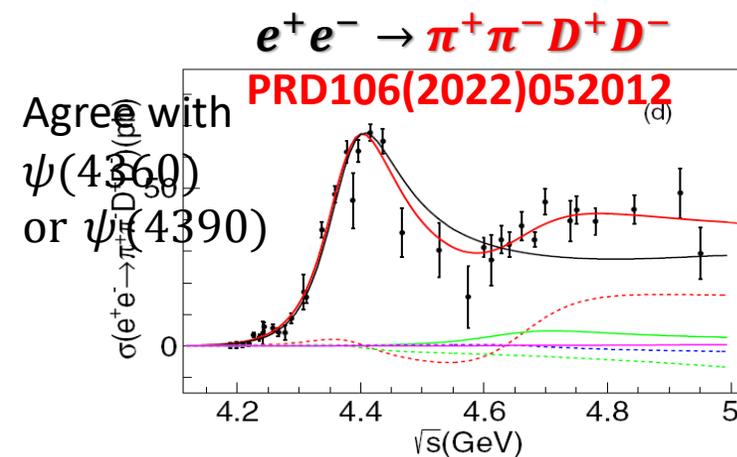
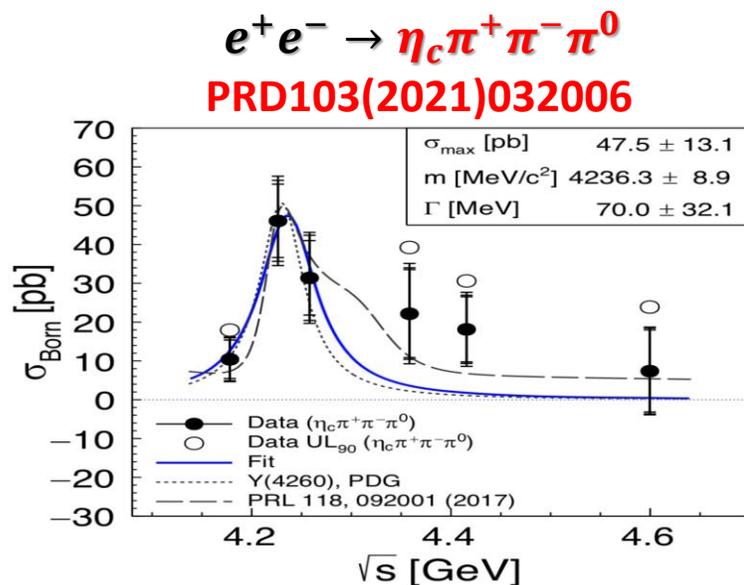
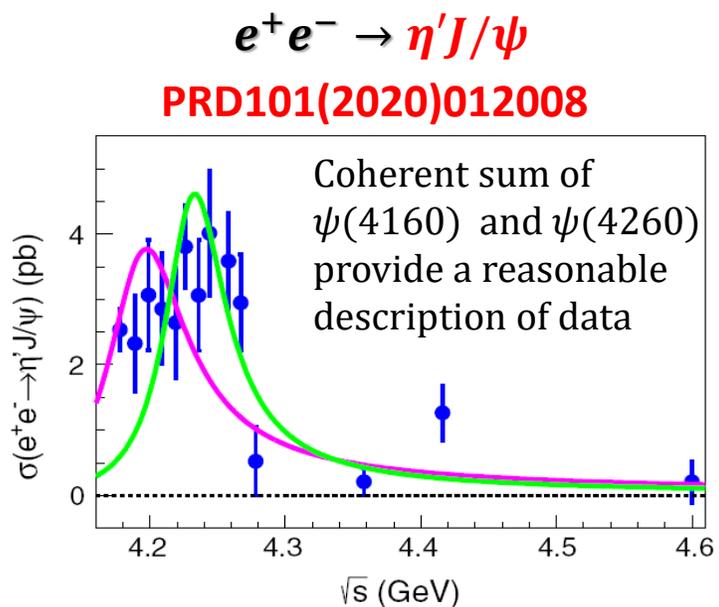


$$M_1 = 4460.9 \pm 17.2 \pm 4.5 \text{ MeV}/c^2$$

$$\Gamma_1 = 128.1 \pm 37.2 \pm 2.3 \text{ MeV}$$

$$M_2 = 4647.9 \pm 8.6 \pm 0.8 \text{ MeV}/c^2$$

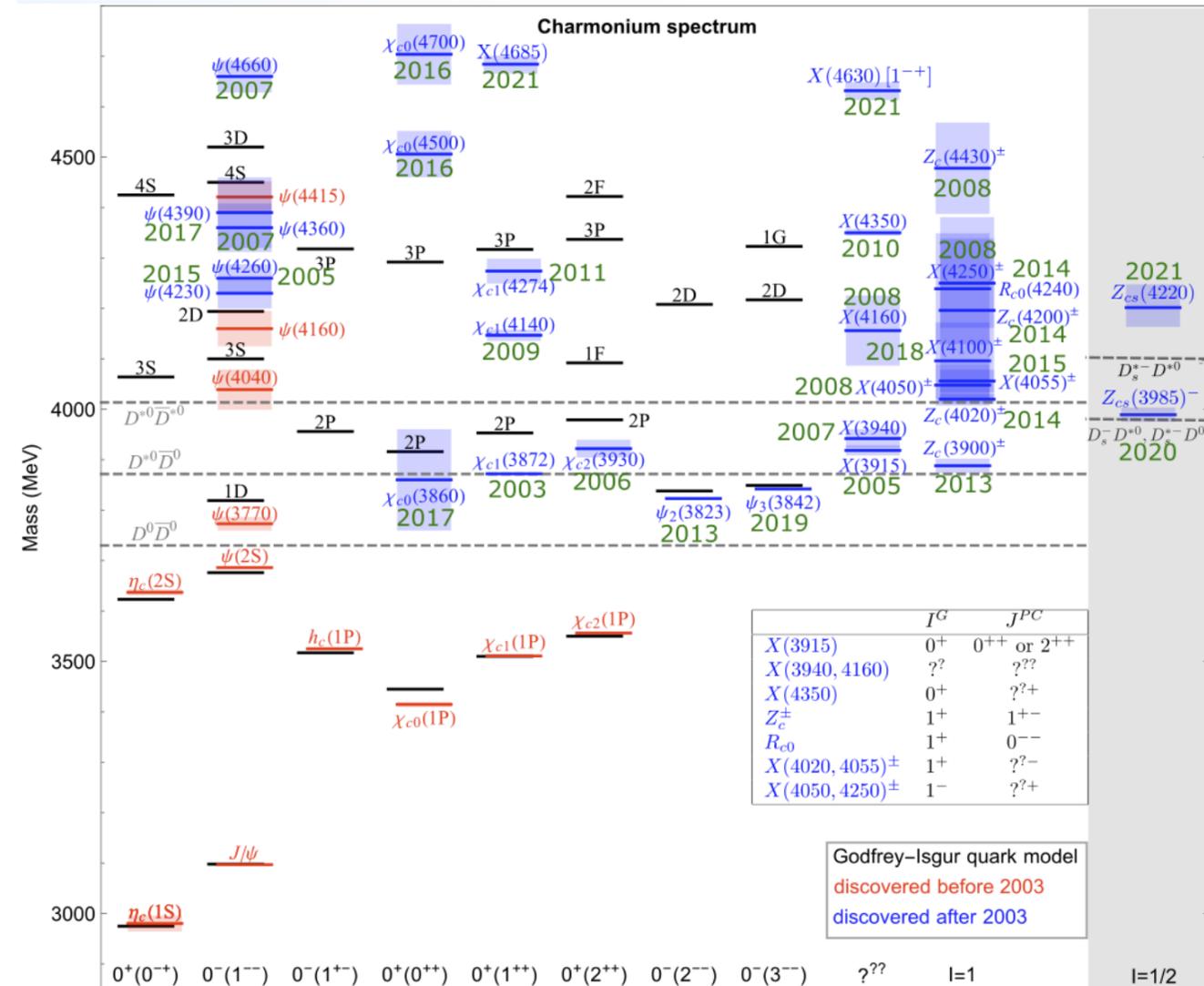
$$\Gamma_2 = 33.1 \pm 18.6 \pm 4.1 \text{ MeV}$$



$$M = 4371.6 \pm 2.5 \pm 9.2 \text{ MeV}/c^2$$

$$\Gamma = 167 \pm 4 \pm 29 \text{ MeV}$$

Charmonium spectroscopy



From F. K. Guo

- Charmonium resonances lie in a transition region perturbative and non-perturbative QCD
- Experimental measurements \rightarrow test theoretical predictions in the low energy regime of QCD

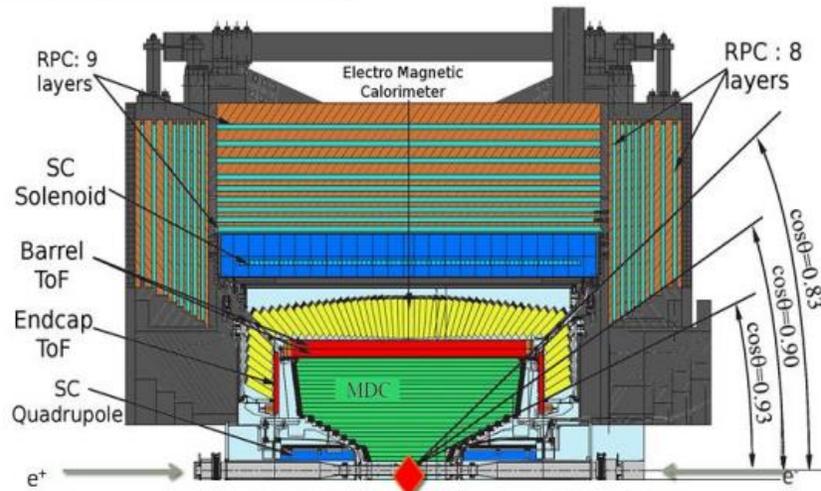
Study hyperons at BESIII

Electromagnetic Calorimeter

CsI(Tl): L=28 cm
 Barrel $\sigma_E=2.5\%$
 Endcap $\sigma_E=5.0\%$

Muon Counter

RPC
 Barrel: 9 layers
 Endcap: 8 layers
 $\sigma_{\text{spatial}}=1.48$ cm



Main Drift Chamber

Small cell, 43 layer
 $\sigma_{xy}=130$ μm
 $dE/dx \sim 6\%$
 $\sigma_p/p = 0.5\%$ at 1 GeV

Time Of Flight

Plastic scintillator
 $\sigma_T(\text{barrel})=80$ ps
 $\sigma_T(\text{endcap})=110$ ps
 (update to 65 ps with MRPC)

With 10 billion J/ψ and 2.7 billion $\psi(3686)$ collected at BESIII, $\sim 10^7$ spin-entangled hyperon pairs can be produced, which enables precise studies of the hyperon physics.

Front. Phys. 12(5), 121301 (2017)

Decay mode	$B(\times 10^{-3})$	$N_B(\times 10^6)$
$J/\psi \rightarrow \Lambda \bar{\Lambda}$	1.89 ± 0.09	~ 18.9
$J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^0$	1.172 ± 0.032	~ 11.7
$J/\psi \rightarrow \Sigma^+ \bar{\Sigma}^-$	1.07 ± 0.04	~ 10.7
$J/\psi \rightarrow \Xi^0 \bar{\Xi}^0$	1.17 ± 0.04	~ 11.7
$J/\psi \rightarrow \Xi^- \bar{\Xi}^+$	0.97 ± 0.08	~ 9.7
$\psi(2S) \rightarrow \Omega^- \bar{\Omega}^+$	0.057 ± 0.003	~ 0.17

More $\psi(3686)$ data will be taken after the upgrade of BEPCII and BESIII inner tracker.

A hyperon factory