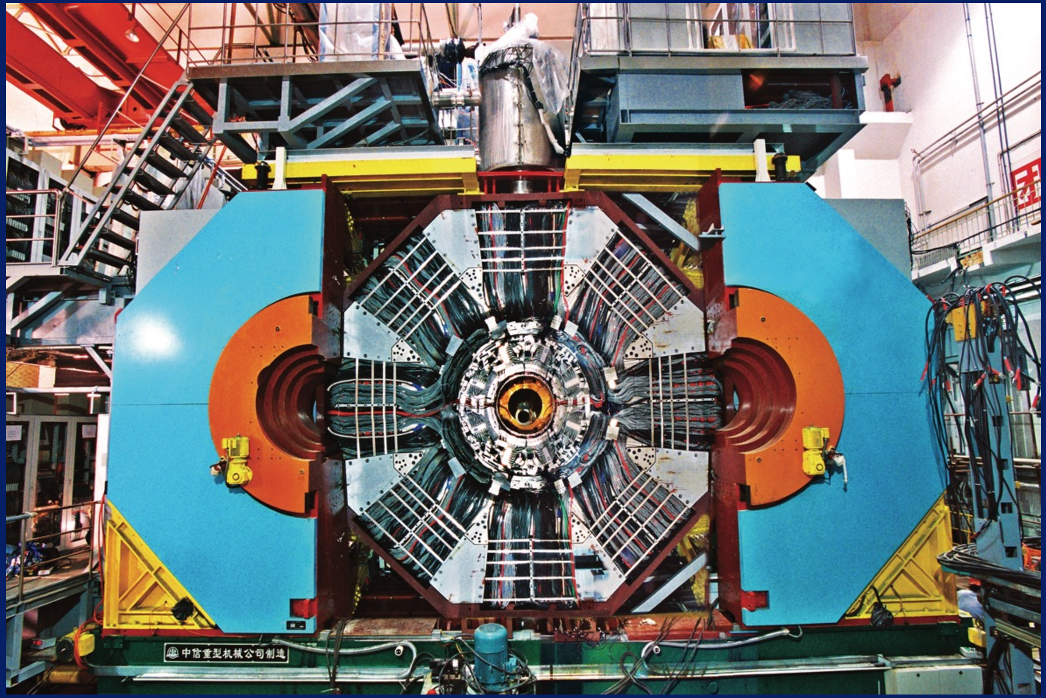
Research Highlights
— The BESIII Experiment —



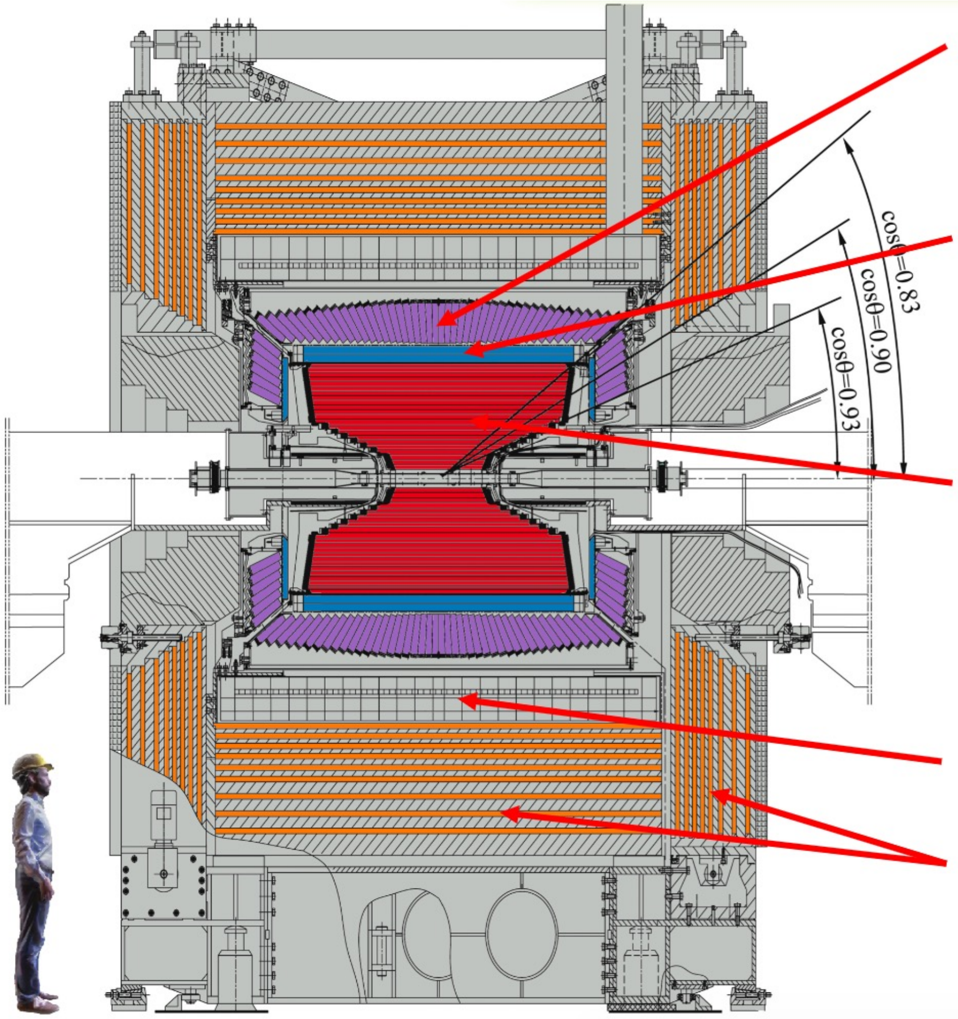
Hai-Bo Li

EPD, Institute of High Energy Physics

Sep. 20, 2023

BESIII detector at BEPCII

The detector is designed for neutral and charged particle with excellent resolution, PID, and large coverage.



EMC: CsI crystals

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

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

TOF:

σ_T = 80 ps Barrel

σ_T = 110 (60) ps Endcap

MDC: small cell & He gas

σ_{xy}= 130 μm

σ_p/p = 0.5% @1GeV

dE/dx = 6%

Magnet: 1T Super conducting

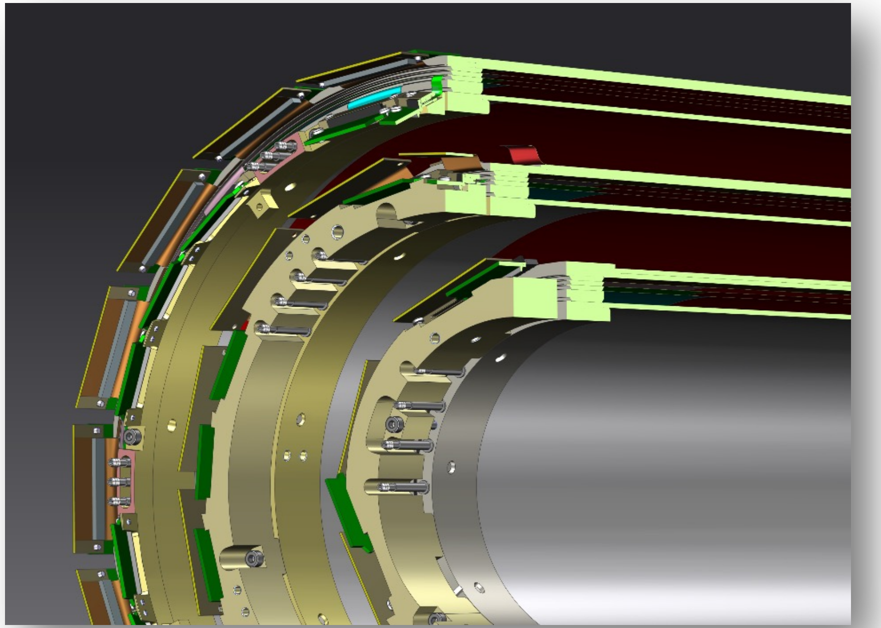
Muon ID: 9 layer RPC

Trigger: Tracks & Showers

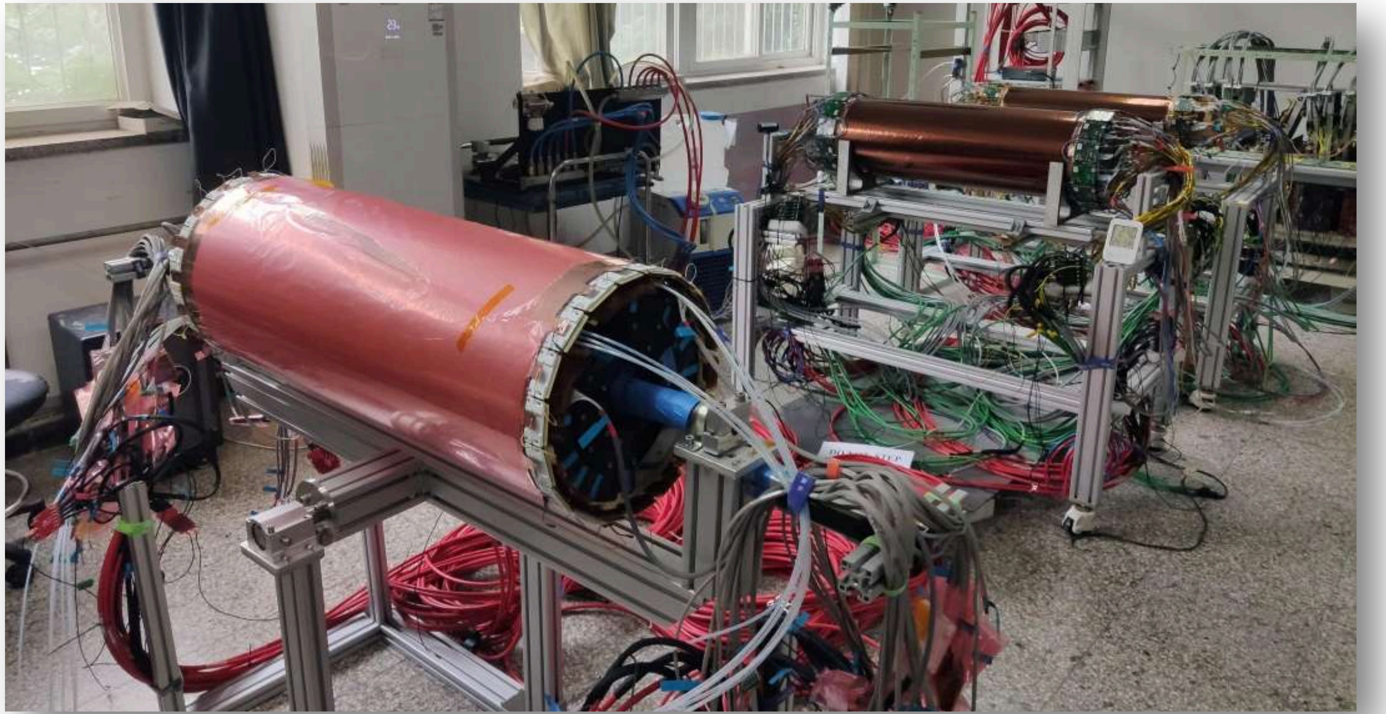
Total weight 730 ton,
~40,000 readout channels,
Data rate: 5kHz, 50Mb/s

Has been in full operation since 2008, all subdetectors are in very good status!

Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT)



- **Three layers of cylindrical triple GEM to replace the inner MDC**
- **Charge and time readout for excellent tracking performance**
  - Improvement in the secondary vertex reconstruction

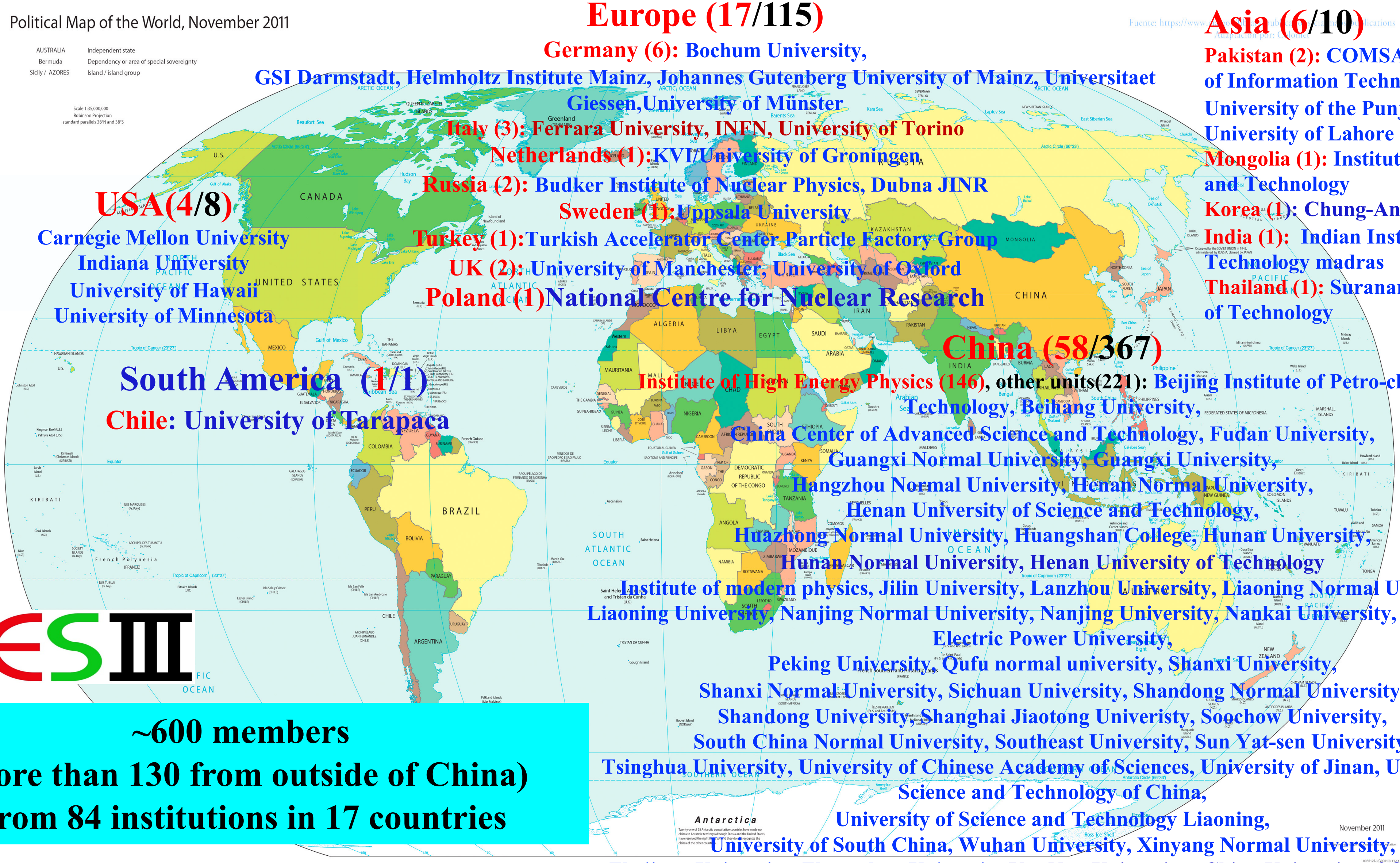


Great efforts from Italian colleagues and supports from INFN

Status and timeline

- System commissioning with cosmics
- Software review → December 2023
- Performance review → March 2024
- Installation during the 2024 shutdown

BESIII Collaboration



Europe (17/115)

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 Torino

Netherlands (1): KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

Poland (1) National Centre for Nuclear Research

Asia (6/10)

Pakistan (2): COMSATS Institute of Information Technology, University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Chung-Ang University

India (1): Indian Institute of Technology madras

Thailand (1): Suranaree University of Technology

USA (4/8)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

South America (1/1)

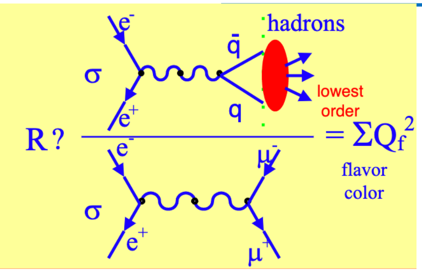
Chile: University of Tarapaca

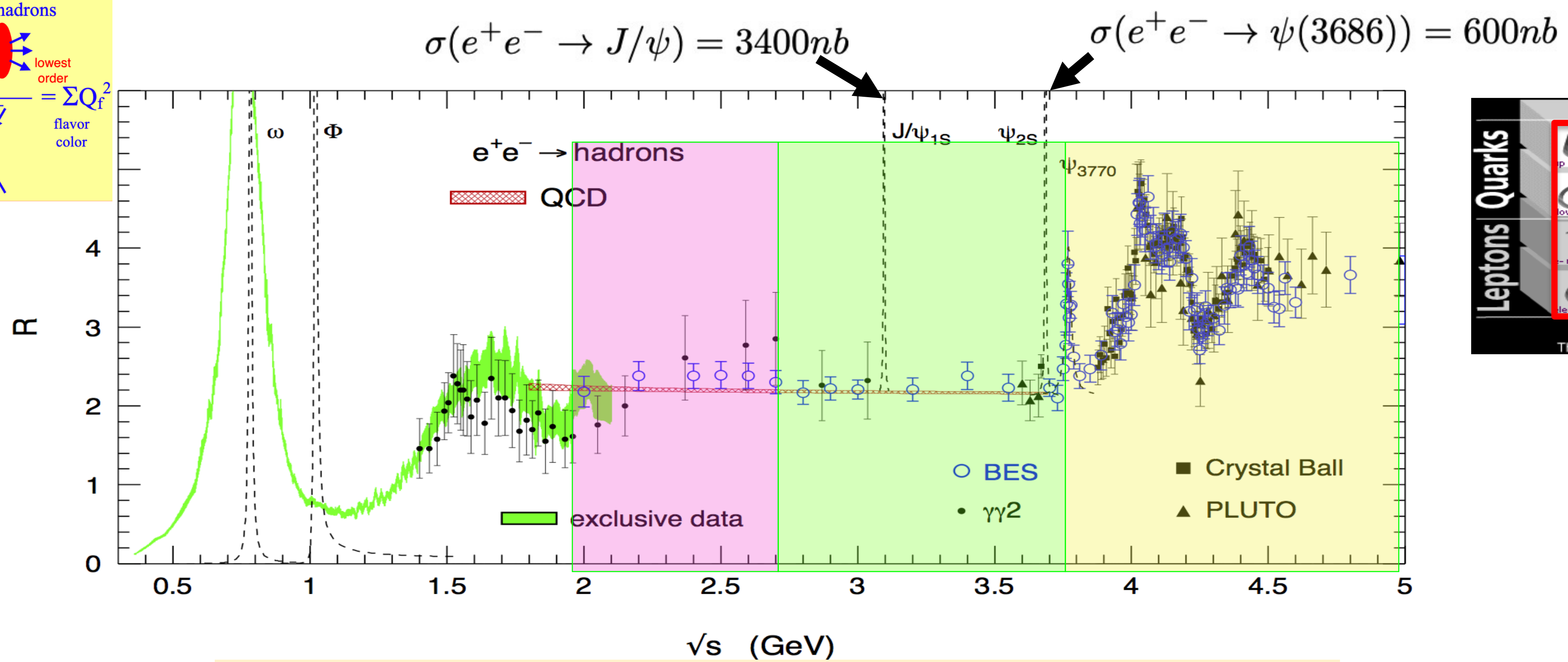
China (58/367)

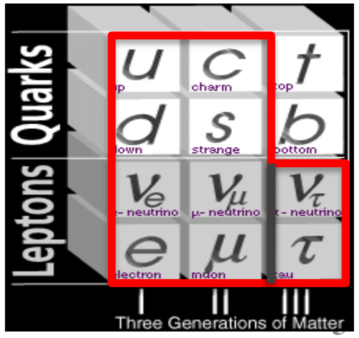
Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Henan University of Technology, Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, 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, Xinyang Normal University, Zhejiang University, Zhengzhou University, YunNan University, China University of Geosciences

~600 members
(more than 130 from outside of China)
From 84 institutions in 17 countries

Physics at Charm Energy Region







Hadron structure & dynamics in the non-perturbative QCD regime

- Hadron form factors
- R values and QCD

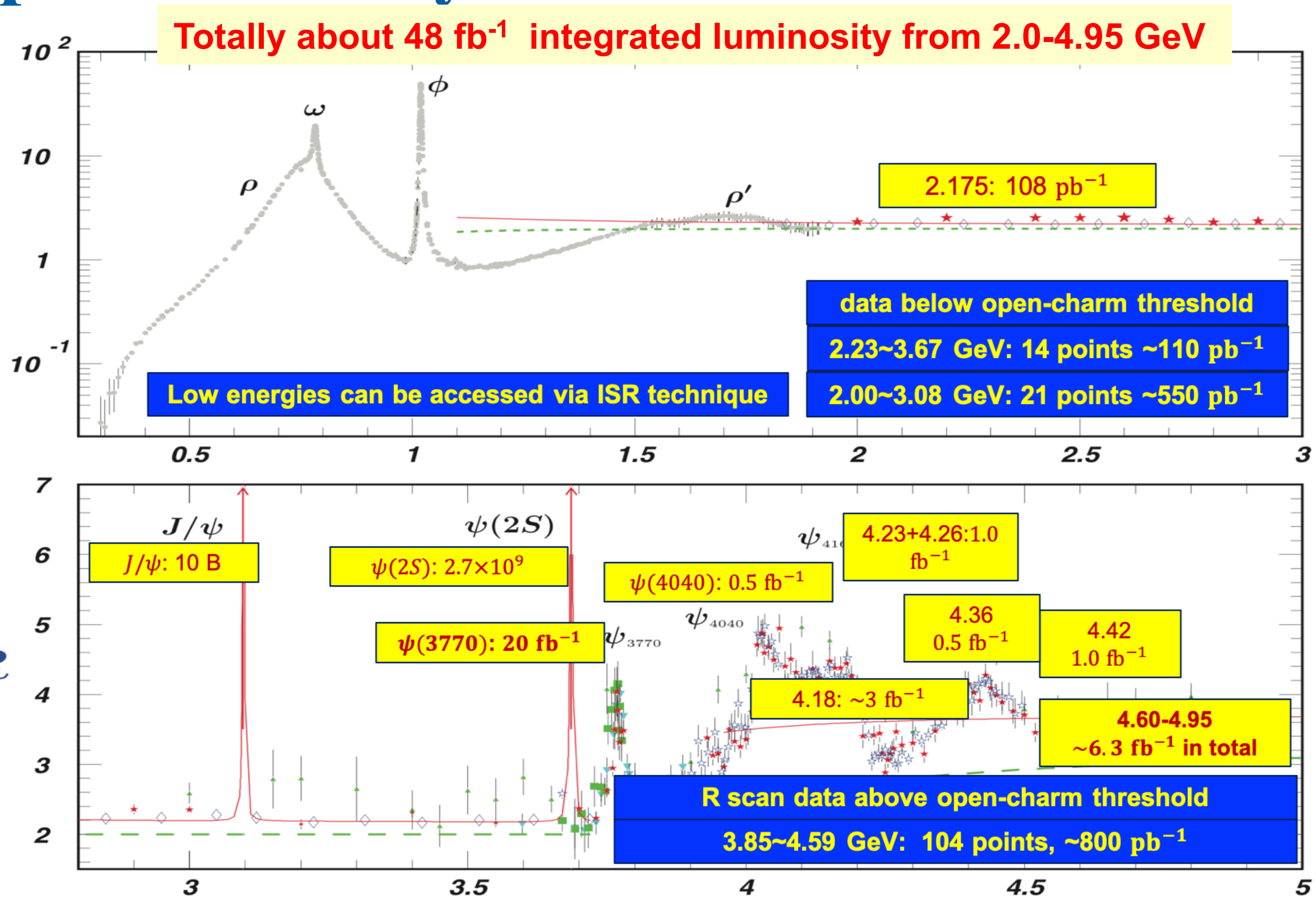
- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with t lepton

- XYZ particles
- Charm mesons
- Charm baryons

BESIII Data Samples: rich Physics

Data sets collected so far include

- 10×10^9 J/ψ events
- 2.7×10^9 ψ(2S) events
- 16 fb^{-1} ψ(3770)
- Scan data between
  2.0 and 3.08 GeV,
  and above 3.74 GeV
- Large datasets for XYZ studies:
  scan with >500 pb-1 per energy point
  space 10 – 20 MeV apart
- **Entangled hadron pair-productions near thresholds: form-factors, relative phase, polarization and CP violation.**



Hadron structure & dynamics in the non-perturbative QCD regime

About 20 fb^{-1} on the ψ(3770) will be collected by year 2024

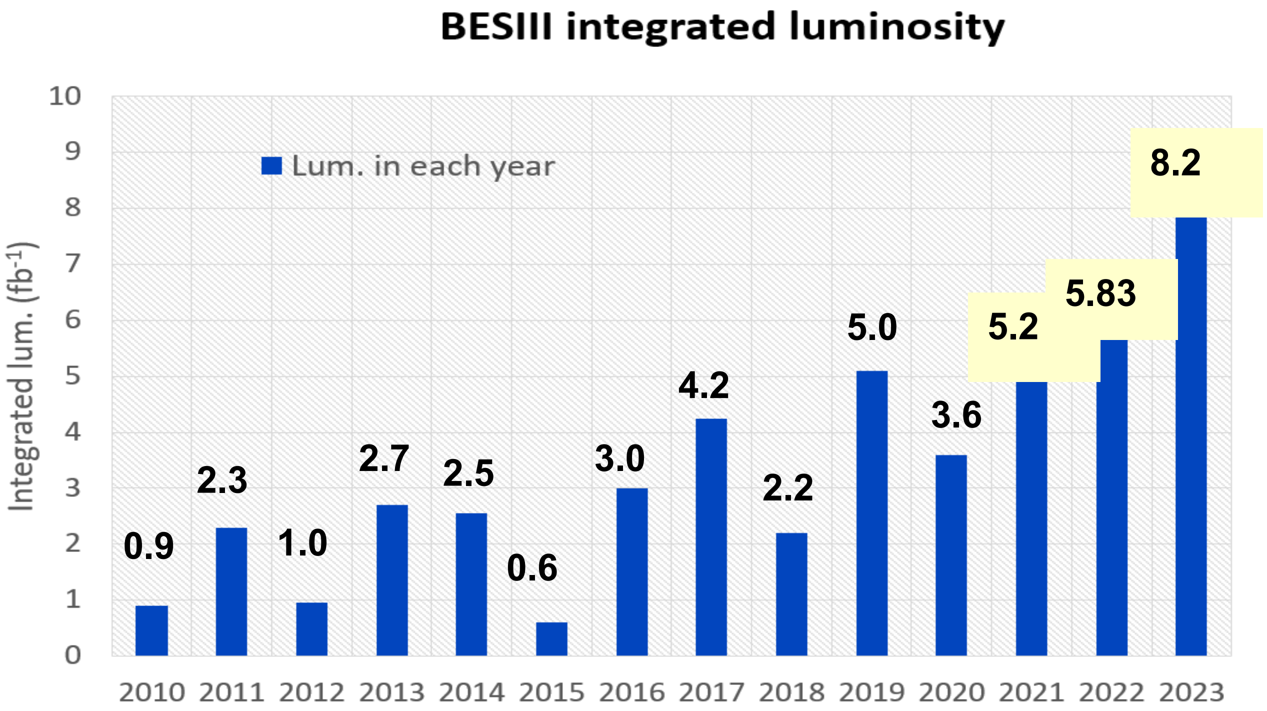
COVID-19: difficulties, but successful data-taking

- BESIII kept data-taking
- Control room shifts

  Chief shift on site: members from Beijing + other region in China

  Remote shifters: members outside of China
- Virtual meetings were working well, but we need face to face meeting!

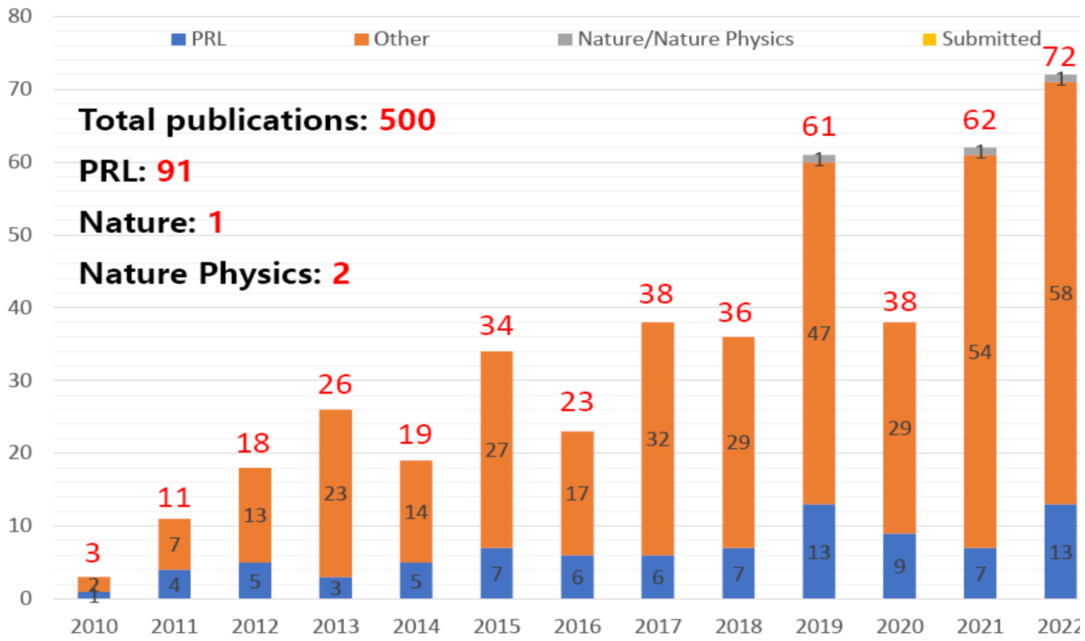
Chief shift on site + a remote shifters



- **In Jan. 2023, BEPCII luminosity reached:$1.1\times 10^{33}\ cm^{-2}\ s^{-1}$, 10% above the designed luminosity**
- **8.2 fb^{-1} integrated luminosity collected in 2023, 40% more than that in 2022.**

BESIII achievements

BESIII publications (May 9, 2023)

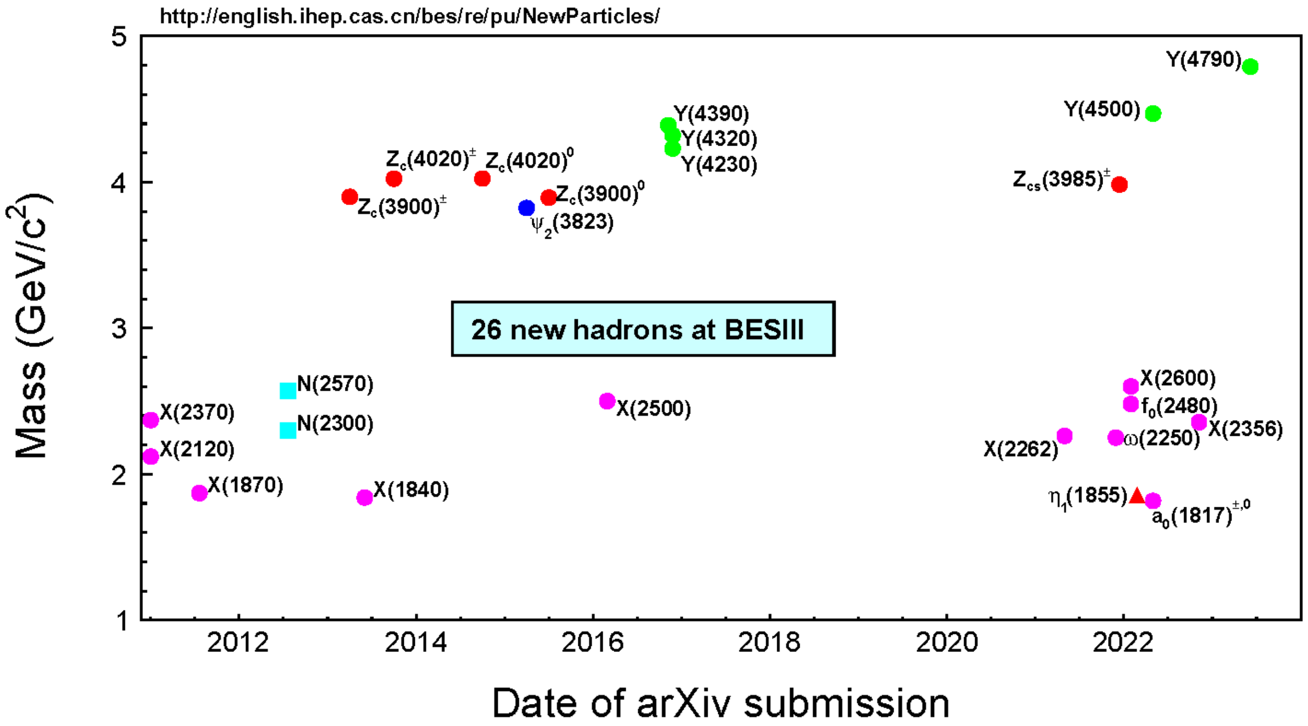


Until Sep. 11th, 536 papers submitted

328 (including 58 PRL) publications since 2018!

26 New Hadrons Discovered

11 new hadrons have been discovered since 2018.

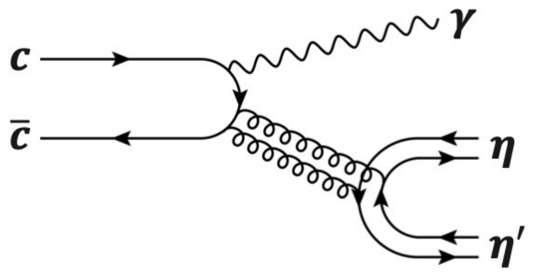


BESIII is playing a leading role on charmed flavor and hadron physics!

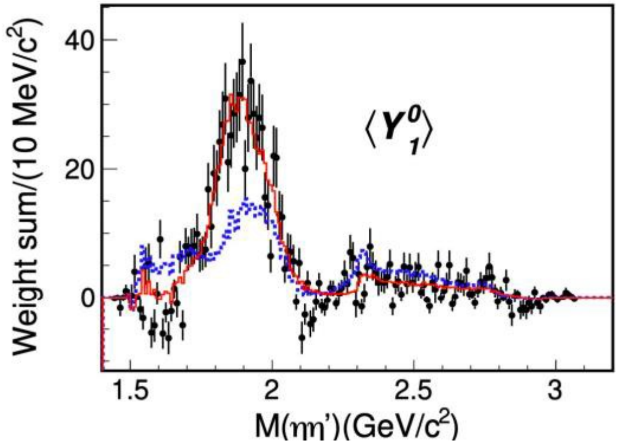
Observation of An Exotic $\mathbf{1^{-+}}$ Isoscalar State $\boldsymbol{\eta_1(1855)}$

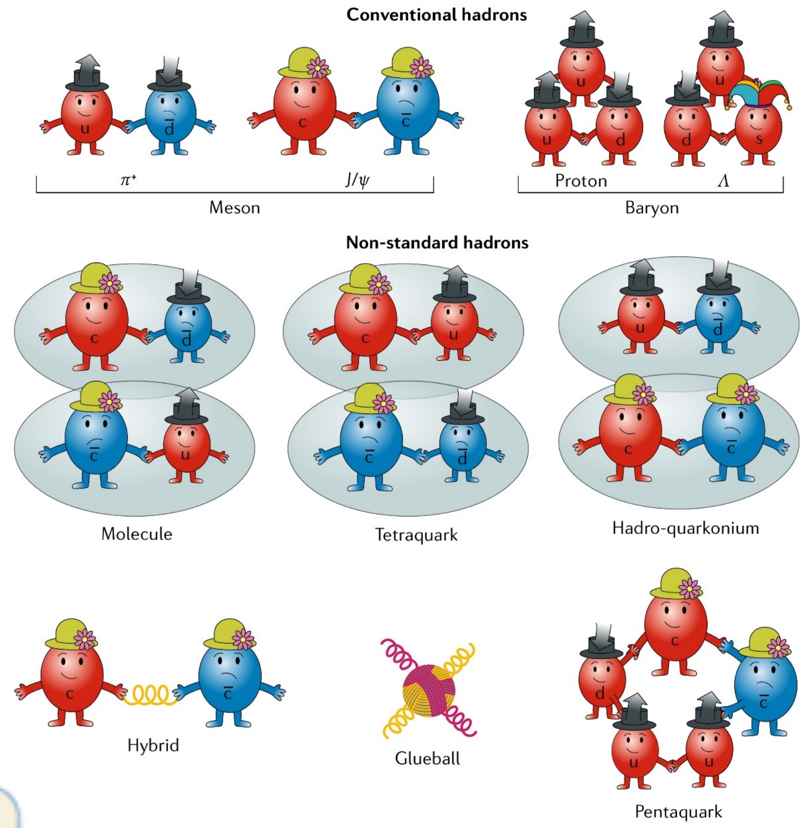
Three 1^{-+} candidates were discovered so far: all are iso-vector states.
the $\pi_1(1400)$, $\pi_1(1600)$, and $\pi_1(2015)$

PWA of $J/\psi\to\gamma\eta\eta'$ using 10 Billion of J/ψ data:



Structure in <Y^0_1>: $\eta_1(1855)$
P-wave component is needed





PRL 129 192002(2022), PRD 106 072012(2022)

An isoscalar $\mathbf{1^{-+}}$, $\boldsymbol{\eta_1(1855)}$, has been observed (>19$\boldsymbol{\sigma}$)

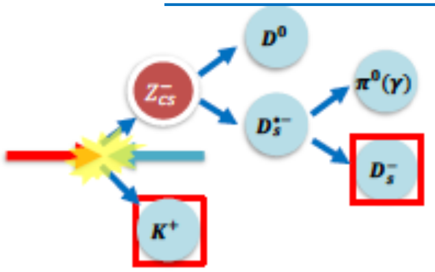
$$M=(1855\pm9^{+6}_{-1})\,\mathrm{MeV}/c^2;\quad \Gamma=(188\pm18^{+3}_{-8})\,\mathrm{MeV}$$

$$\mathcal{B}(J/\psi\to\gamma\eta_1(1855)\to\gamma\eta\eta')=(2.70\pm0.41^{+0.16}_{-0.35})\times10^{-6}$$

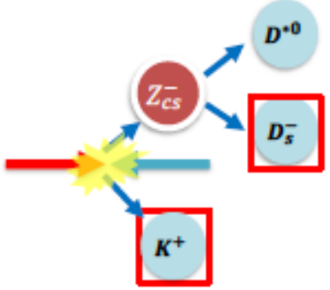
Mass consistent with hybrid on LQCD. Inspired many interpretations: Hybrid/Molecule/Tetraquark?

Opens a new window to completing the picture of spin-exotics

Observation of the $Z_{cs}(3985)^{\pm}$ and Evidence for the neutral $Z_{cs}(3985)^{0}$

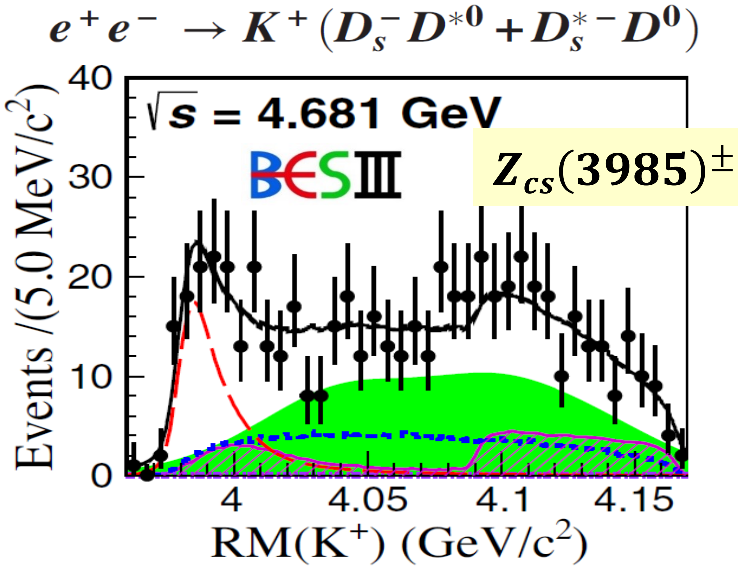


$e^+e^- \to K^+ D_s^{*-} D^0$

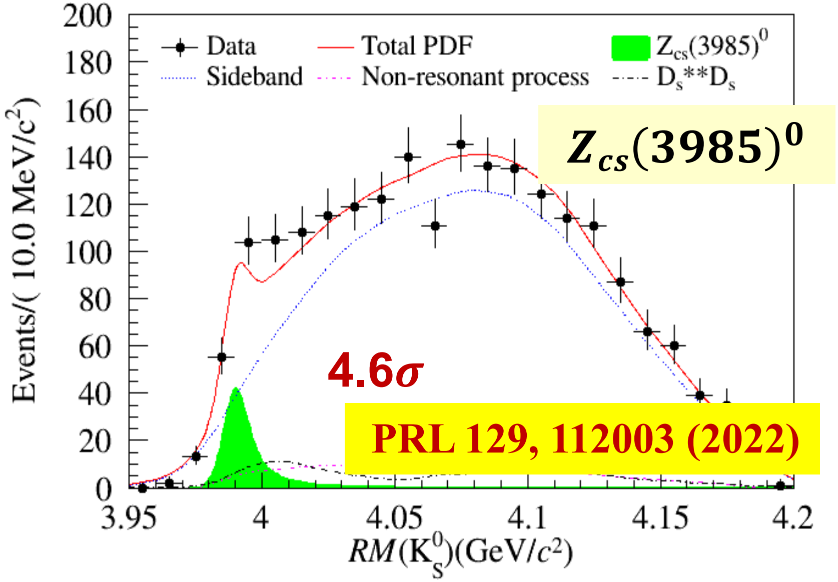


$e^+e^- \to K^+ D_s^- D^{*0}$

Highlighted in Summary talk @ICHEP2022 by Roberto Tenchini



PRL 126, 102001 (2021)



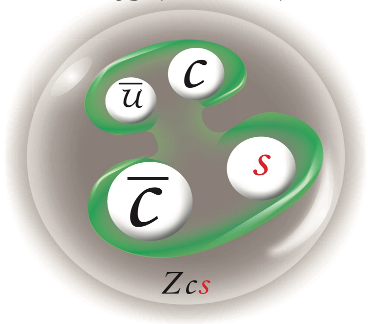
PRL 129, 112003 (2022)

SU(3) counter-part of the Zc(3900): d→ s?

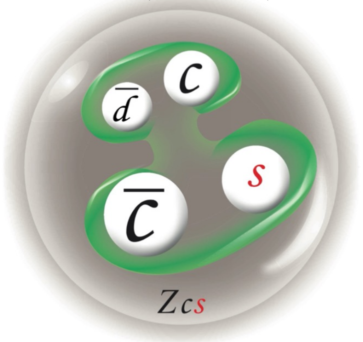
Zcs state with strangeness

PRL129(2022)112003

$Z_{cs}(3985)^{\pm}$



$Z_{cs}(3985)^{0}$



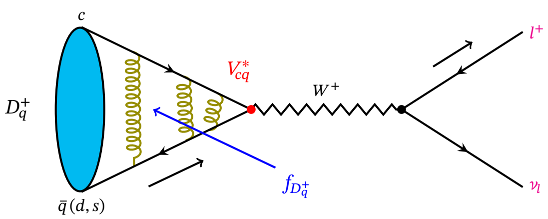
State	Mass (MeV/c^2)	Width (MeV)	Significance
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$	5.3σ
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$	4.6σ

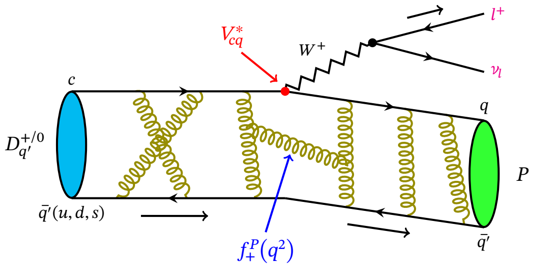
- Minimal quark content $\bar{c}cs\bar{u}/\bar{d}$
- Mass and width consistent with the charged Zcs: $m(\mathrm{Zcs}^+) < m(\mathrm{Zcs}^0)$
- Cross sections are consistent under isospin symmetry

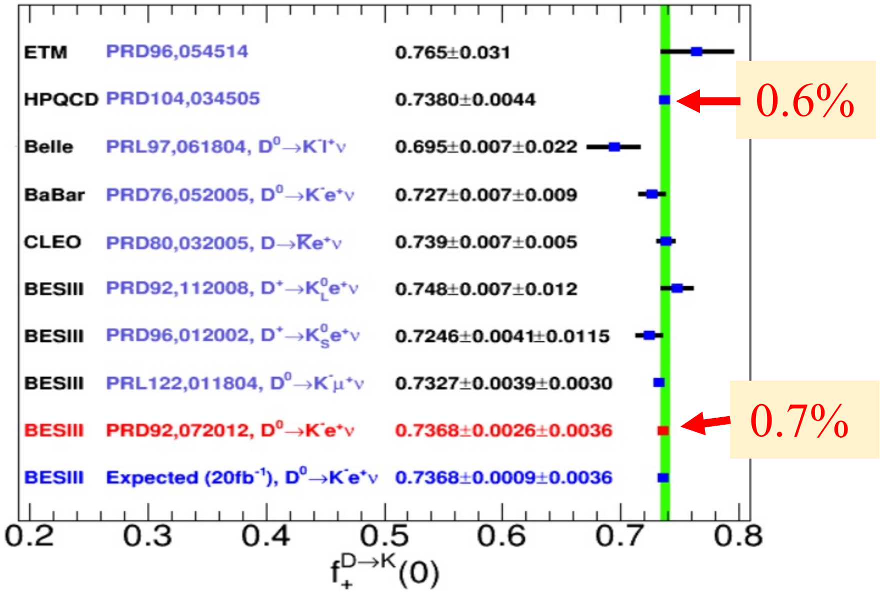
➔ they are isospin partners

Precision charm: (Semi)-leptonic decays of charmed mesons

Bridge between quarks and leptons，probe Standard model:

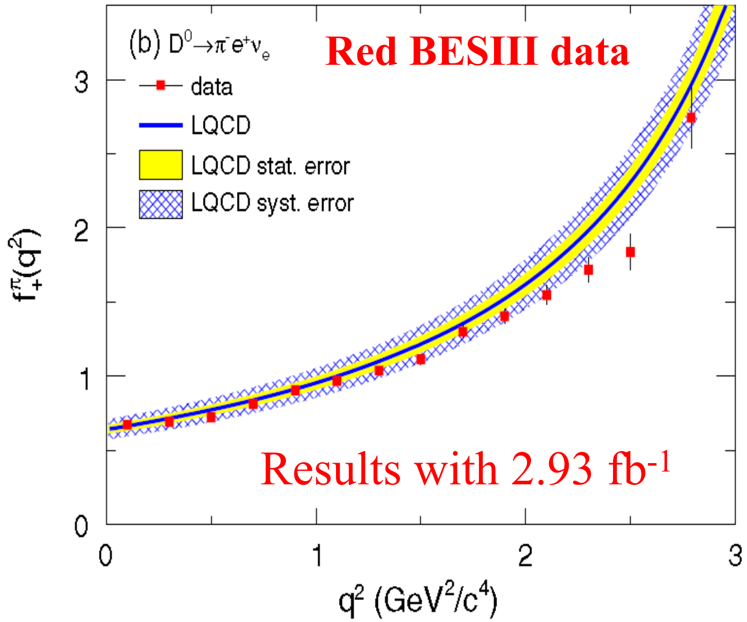


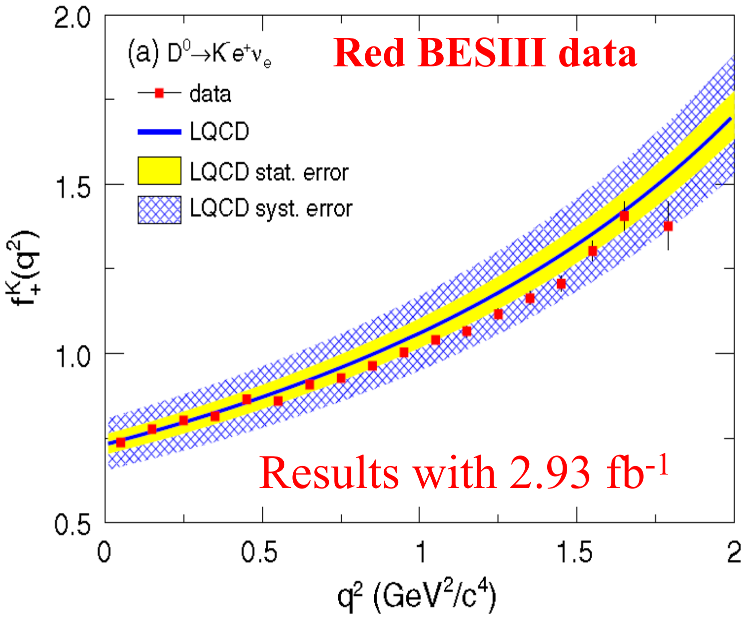


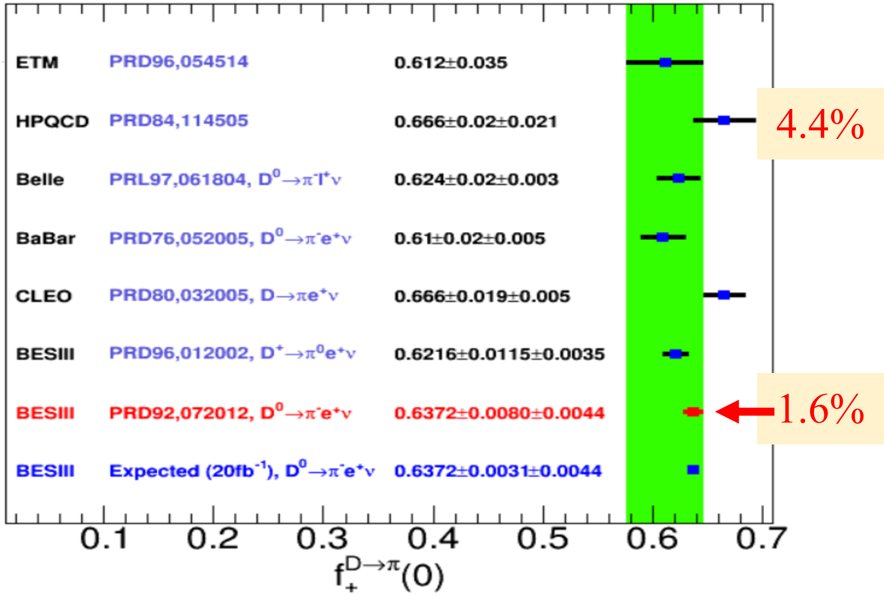


- ✓ $|V_{cs(d)}|$ @ 1% level : test on CKM matrix unitarity
- ✓ $f_{D(s)+}$, $f_+^{K(p)}(0)$ @ 1% level : test LQCD calculations

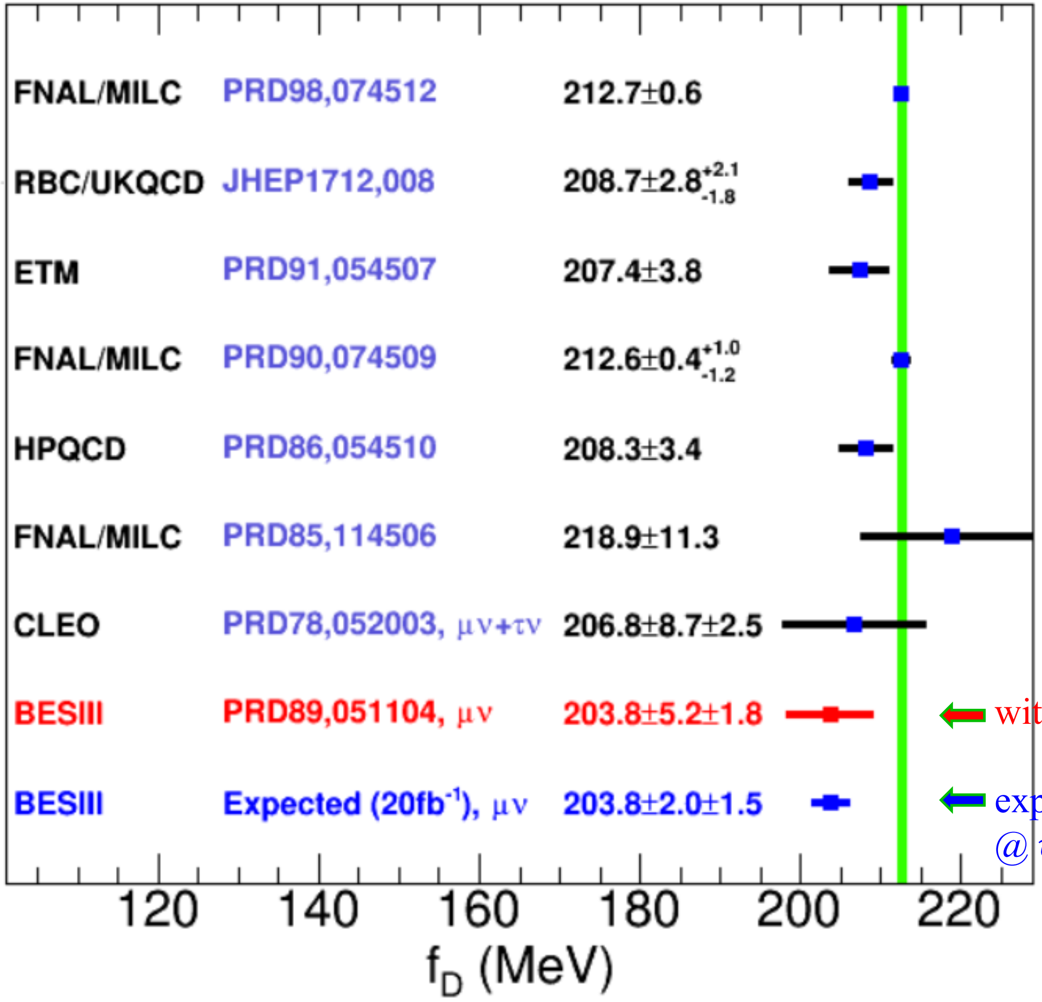
✓ One of the most powerful data to validate LQCD calculations!







Precision decay constants: f_{D^+} and $f_{D_s^+}$

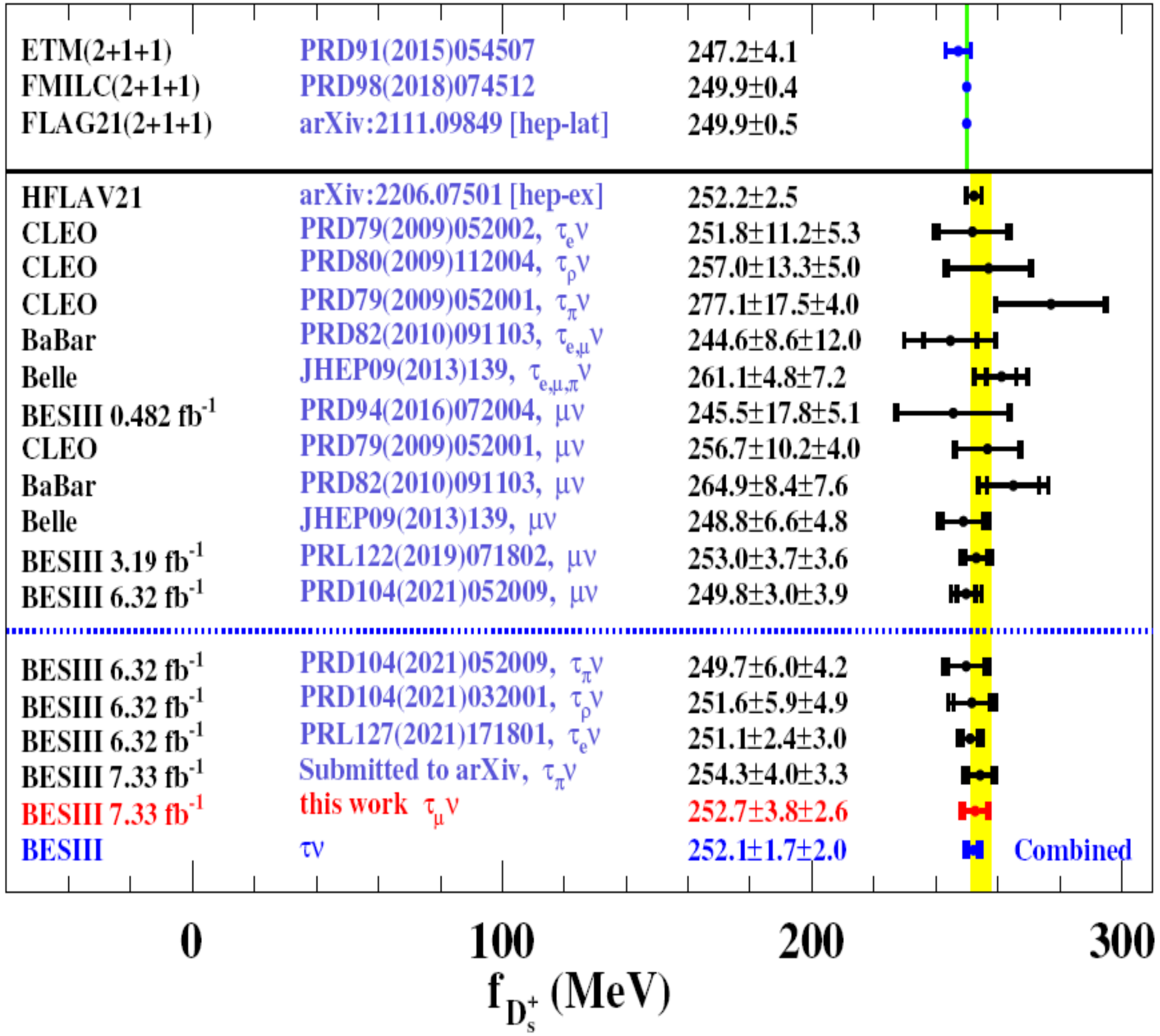


with 2.9 fb^{-1}

expected with 20 fb^{-1} @$\psi(3770)$

Precision: 2.5% with 2.9 fb^{-1}

1.1% with 20 fb^{-1}



Combined precision: 1.0%

Clean data sample for hadronic charm decays

It is good place to study the light nonet [$a_0(980)$, $K^{*0}(700)$, f0(500), f0(980)] and the heavy nonet [$a_0(1450)$, $K^{*0}(1430)$, $f_0(1370)$, $f_0(1500)$].

A list of publications in last 5 years with 2.9 fb^{-1}

$D^+ \to K^0_S\pi^+\eta$	arXiv:2309.05760
$D^0 \to K^0_L\pi^+\pi^-$	arXiv:2212.09048
$D^+ \to K^0_S\pi^+\pi^0\pi^0$	arXiv:2305.15879 accepted by JHEP
$D_s^+ \to K^0_S K^+\pi^0$	Phys. Rev. Lett 129, 182001 (2022)
$D_s^+ \to \pi^+\pi^-\pi^+$	Phys. Rev. D 106, 112006 (2022)
$D_s^+ \to K^0_S K^0_S\pi^+$	Phys. Rev. D 105, L051103 (2022)
$D_s^+ \to K^+\pi^+\pi^-\pi^0$	JHEP 09, 242(2022)
$D_s^+ \to K^+\pi^+\pi^-$	JHEP 08, 196 (2022)
$D_s^+ \to K^+\pi^+\pi^-$	JHEP 08, 196(2022)
$D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$	JHEP 07, 051 (2022)

$D_s^+ \to \pi^+\pi^0\eta'$	JHEP 04, 058 (2022)
$D_s^+ \to \pi^+\pi^0\pi^0$	JHEP 01, 052 (2022)
$D_s^+ \to K^0_S\pi^+\pi^0$	JHEP 06, 181 (2021)
$D_s^+ \to K^+K^-\pi^+\pi^0$	Phys. Rev. D 104, 032011 (2021)
$D_s^+ \to \pi^+\pi^-\pi^+\eta$	Phys. Rev. D 104, L071101 (2021)
$D^+ \to K^0_S K^+\pi^0$	Phys. Rev. D 104, 012006 (2021)
$D_s^+ \to K^0_S K^-\pi^+\pi^+$	Phys. Rev. D 103 , 092006 (2021)
$D_s^+ \to K^+K^-\pi^+$	Phys. Rev. D 104, 112016 (2019)
$D_s^+ \to \pi^+\pi^0\eta$	Phys. Rev. Lett. 123, 112001 (2019)
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	Phys. Rev. D 100, 072008 (2019)
$D^0 \to K^-\pi^+\pi^-\pi^0$	Phys.Rev. D 99, 092008(2019)

Branching fraction or observation

Cabibbo favored

$D_s^+ \to \omega\pi^+\eta$	Phys. Rev. D 107, 052010 (2023)
$D^0 \to K^0_L\phi/\eta/\omega/\eta'$	Phys. Rev. D 105, 092010 (2022)
$D^{(0)+} \to K^0_S\pi^{0(+)}\omega$; $D^{(0)+} \to K^-\pi^+\omega$	Phys. Rev. D 105, 032009 (2022)

Inclusive decay

$D^{(0)+} \to \pi^+\pi^+\pi^-X$	Phys. Rev. D 107, 032002 (2023)
$D_s^+ \to \pi^+\pi^+\pi^-X$	Phys. Rev. D 108, 032001 (2023)
$D \to \eta X$	Phys. Rev. Lett. 124, 241803(2020)

Doubly Cabibbo Suppressed

$D^+ \to K^+\pi^0\pi^0, K^+\pi^0\eta$	JHEP 09, 107(2022)
$D^0 \to K^+\pi^-\pi^0(\pi^0)$	Phys. Rev. D 105, 112001 (2022)
$D^+ \to K^+\pi^+\pi^-\pi^0$	Phys. Rev. Lett. 125, 141802 (2020); Phys. Rev. D 104, 072005 (2021)

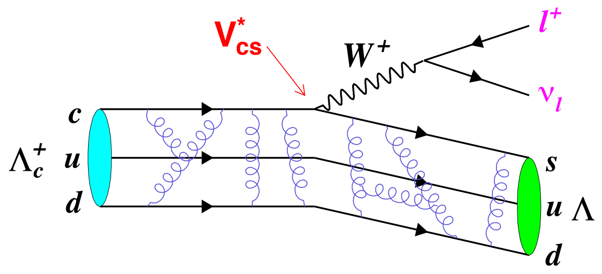
Singly Cabibbo Suppressed

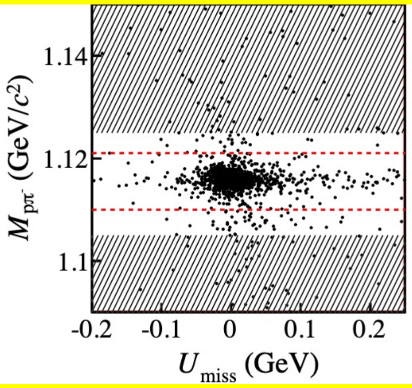
$D^+ \to \eta\eta\pi^+, D^{0(+)} \to \eta\pi^+\pi^{-(0)}$	Phys. Rev. D 101, 052009(2020)
$D \to \omega\pi\pi$	Phy. Rev. D 102 052003 (2020)
$D^+ \to K\bar{K}\pi\pi$	Phys. Rev. D 102, 052006 (2020)
$D^+ \to K^0_{S,L}K^+(\pi^0)$	Phys.Rev. D 99, 032002(2019)

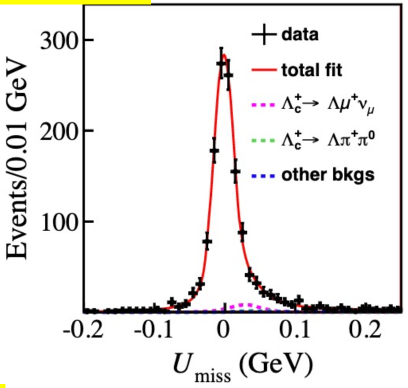
Λ_c^+ semi-leptonic decays with threshold data

Determination of the form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

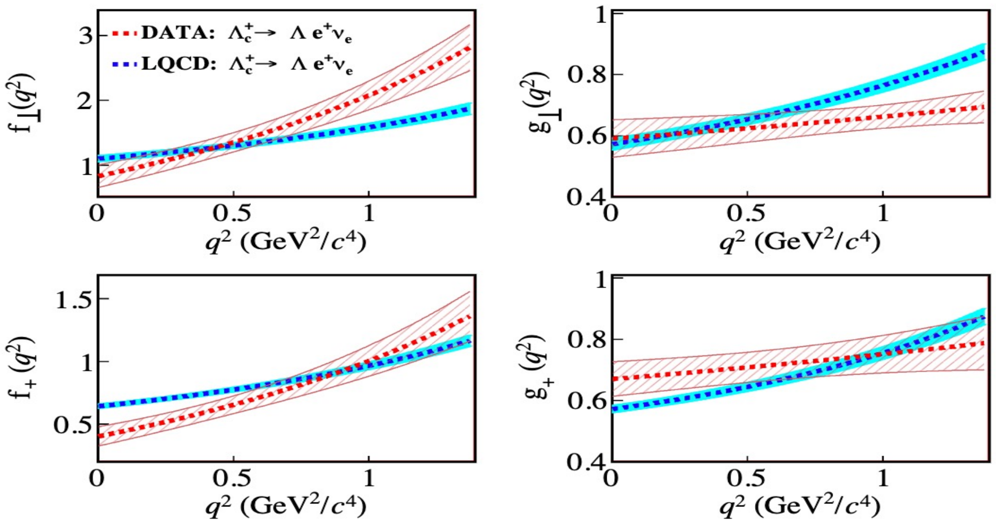
PRL 129 (2022) 231803 arXiv:2207.14149







$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$



First direct comparisons on form factors with LQCD calculations

Semi-leptonic decay

- ✓ Form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ *PRL129, 231803 (2022)*
- ✓ Observation of $\Lambda_c^+ \to pK^- e^+ \nu_e$ *PRD106, 112010 (2022)*
- ✓ *LFU test of $\Lambda_c^+ \to \Lambda l^+ \nu_l$, arXiv:2306.02624*
- ✓ Search for $\Lambda_c^+ \to \Lambda \pi^+ \pi^- e^+ \nu_e$ and $pK_s \pi^- e^+ \nu_e$ *arXiv:2302.07529*

Neutron-involved decay

- ✓ Observation of $\Lambda_c^+ \to n\pi^+$ *PRL 128, 142001 (2022)*

Hadronic CS decays

- ✓ $\Lambda_c^+ \to \Sigma^+ K_s, \Sigma^0 K^+$ *PRD 106, 052003 (2022)*
- ✓ $\Lambda_c^+ \to p\eta'$ *PRD 106, 072002 (2022)*
- ✓ $\Lambda_c^+ \to \Lambda K^+$ *PRD 106, L111101 (2022)*
- ✓ $\Lambda_c^+ \to \Sigma^+ K^+ \pi^-$ *arXiv:2304.09405*

Hadronic CF decays

- ✓ PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ *JHEP12, 033(2022)*
- ✓ W-exchange-only process $\Lambda_c^+ \to \Sigma^+ K^+ K^-, \Sigma^+ \phi$

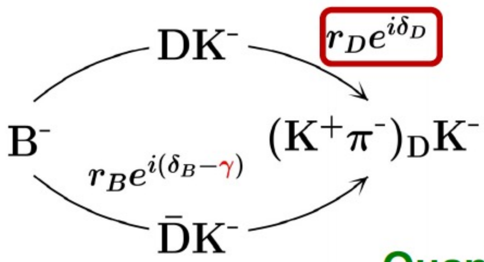
Inclusive decay

- ✓ Improved BF of $\Lambda_c^+ \to e^+ X$ *PRD107, 052005 (2023)*
- ✓ First BF of $\Lambda_c^- \to \bar{n} X$ *arXiv:2210.09561*

Rare decay

- ✓ $\Lambda_c^+ \to \gamma \Sigma^+$ *PRD107, 052002 (2023)*

Strong-phase: determination of the CKM angle γ



- **Precision test of the CKM unitarity**
  - Measured with "clean" tree-level $B^{\pm} \to DK^{\pm}$ decays
  - Has negligible theoretical uncertainties [JHEP 01 (2014) 051]
  - Require strong-phase inputs from BESIII

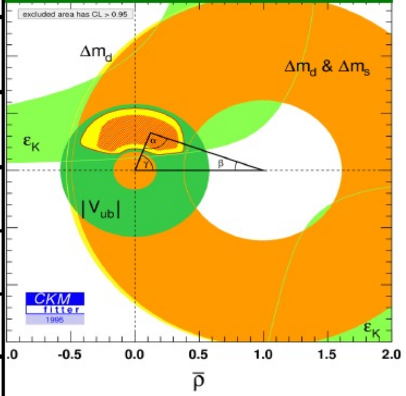
Quantum correlated $D^0\bar{D}^0$ pairs at BESIII is an ideal place to determine the strong-phase parameters and provide best constraints

- γ uncertainty contributed by BESIII inputs is around 1°, lead by $K_S^0\pi^+\pi^-$ decay
- Luminosity of BESIII data will reach 20 fb^{-1} by the year of 2024, and the uncertainty will be less than 0.5°

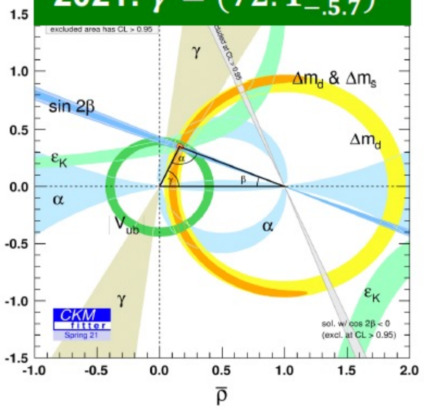
Decay	Strong-phase parameter	Status (based on 2.93 fb^{-1} data)	Reference
$K^0_{S,L}\pi^+\pi^-$	c_i, s_i	Published	PRL 124 (2020) 241802 PRD 101 (2020) 112002
$K^0_{S,L}K^+K^-$	c_i, s_i	Published	PRD 102 (2020) 052008
$K^\pm\pi^\mp\pi^+\pi^-$	δ_D, R_D	Published	JHEP 05 (2021) 164
$\pi^+\pi^-\pi^+\pi^-$	F^+/c_i, s_i	Published/ongoing	PRD 106 (2022) 092004
$K^+K^-\pi^+\pi^-$	F^+/c_i, s_i	Published/ongoing	PRD 107 (2023) 032009
$K^0_S\pi^+\pi^-\pi^0$	F^+/c_i, s_i	Published/ongoing	PRD 108 (2023) 032003
$K^\pm\pi^\mp\pi^0$	δ_D, R_D	Published	JHEP 05 (2021) 164
$K^\pm\pi^\mp$	δ_D	Published	EPJC 82 (2022) 1009
$K^0_S K^\pm\pi^\mp$	δ_D, R_D	Ongoing	
$\pi^+\pi^-\pi^0$	F^+	Ongoing	
$K^+K^-\pi^0$	F^+	Ongoing	

Improvement dominated by more precise strong-phase inputs from BESIII

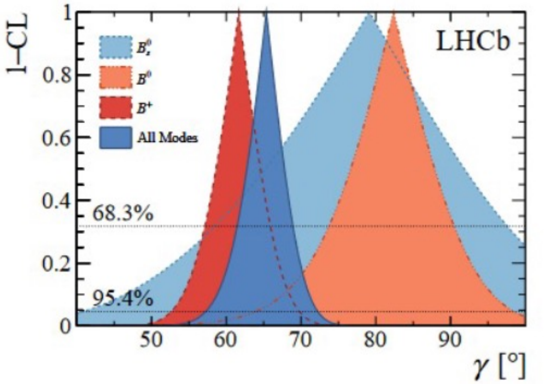
1995: no measurement



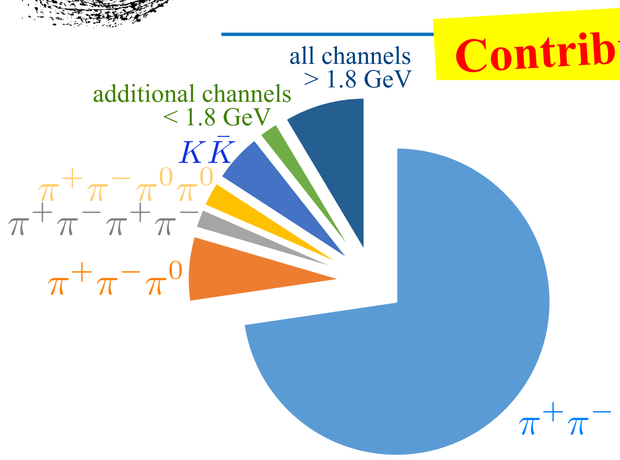
2021: $\gamma = (72.1^{+5.4}_{-5.7})°$

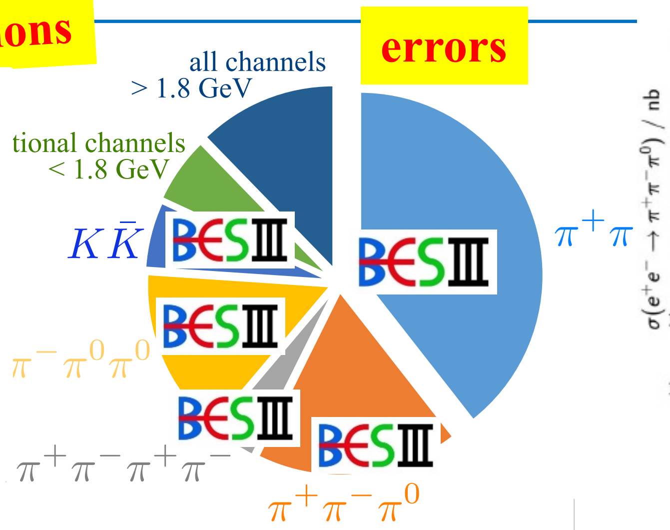


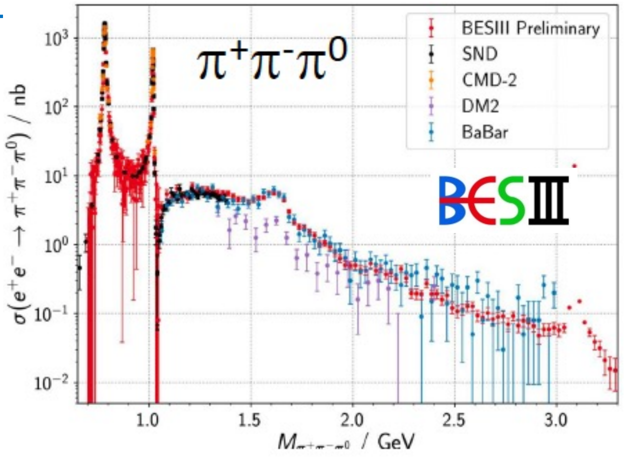
Later 2021 : $\gamma = (65.4^{+3.8}_{-4.2})°$

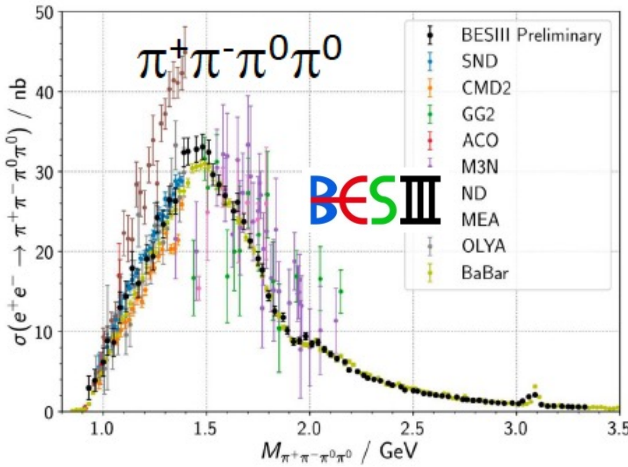


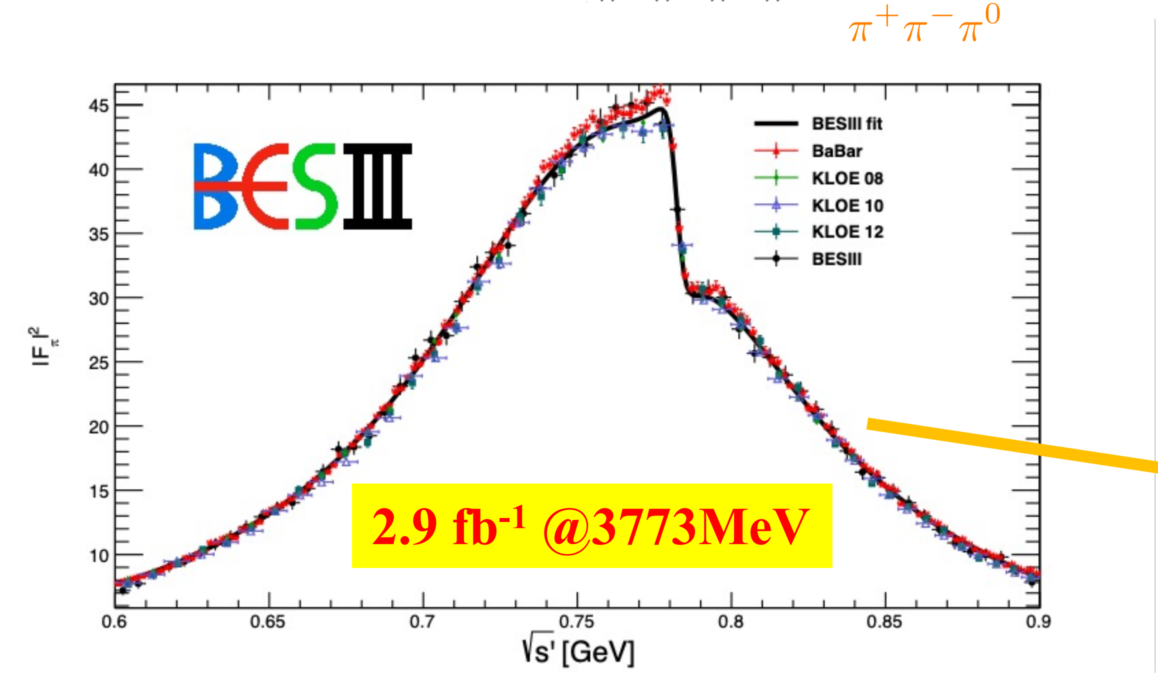
BESIII contributions to hadron vacuum polarization



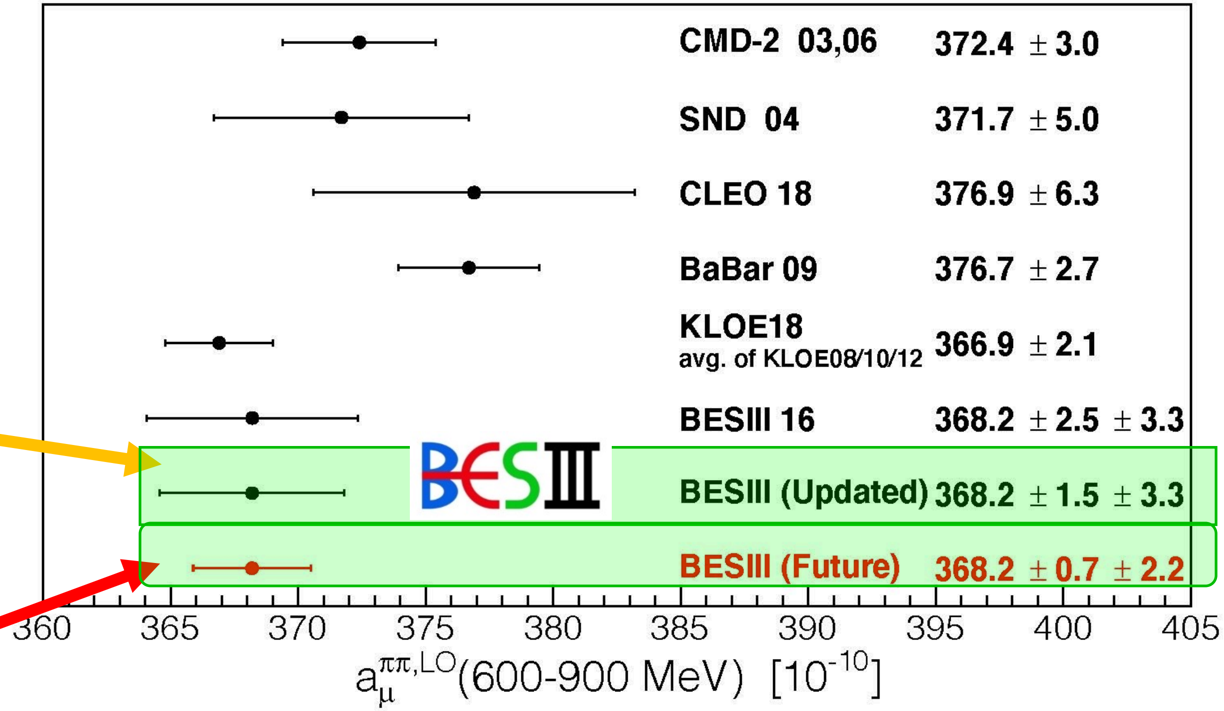






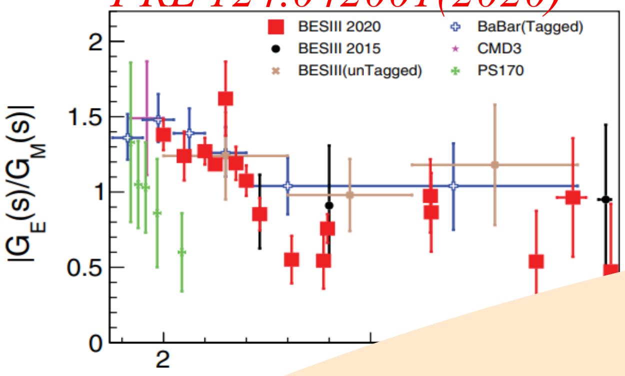


By 2024 : 20 fb^{-1} @3773 MeV

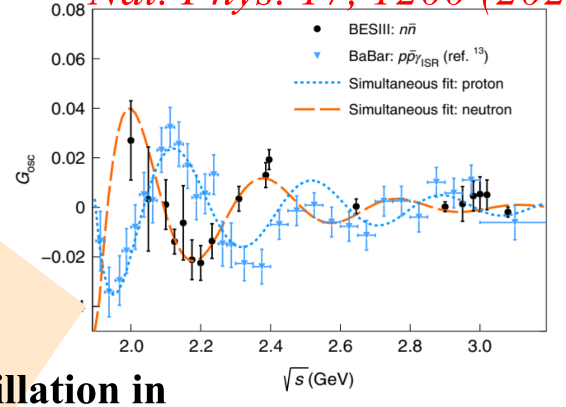


Baryon Electromagnetic form factors (EMFF)

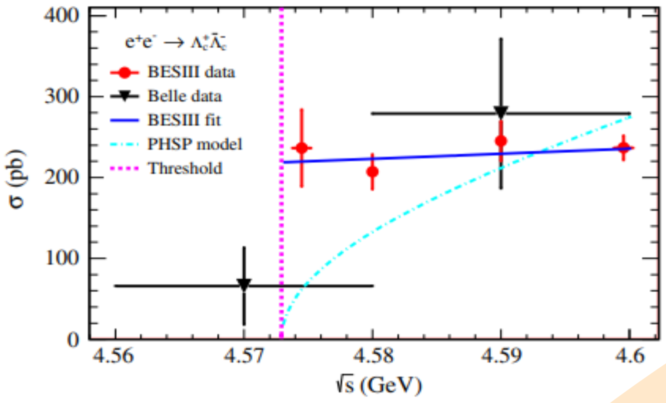
PRL 124.042001(2020)



Nat. Phys. 17, 1200 (2021)



PRL 120, 131001 (2018)



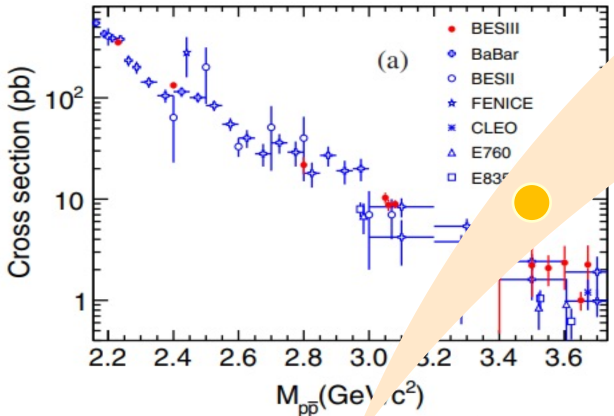
2021,Oscillation in neutron Effective FF

2020, most precise proton EMFF

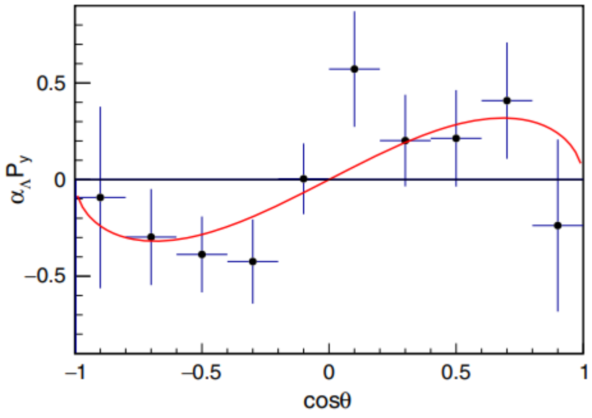
2019, complete Lambda EMFF

2018, threshold effect observed

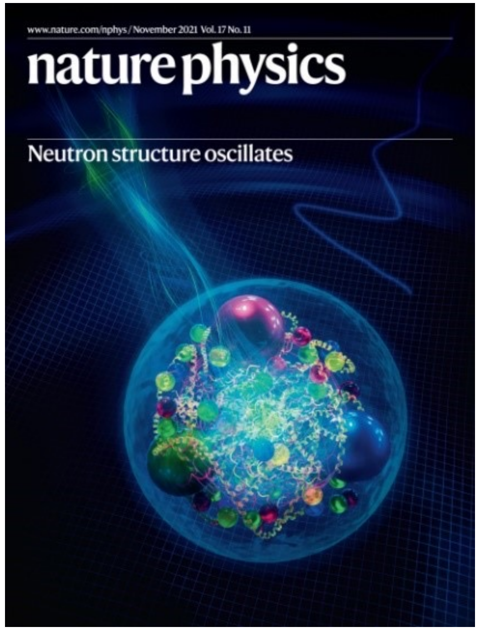
2015, first proton EMFFs



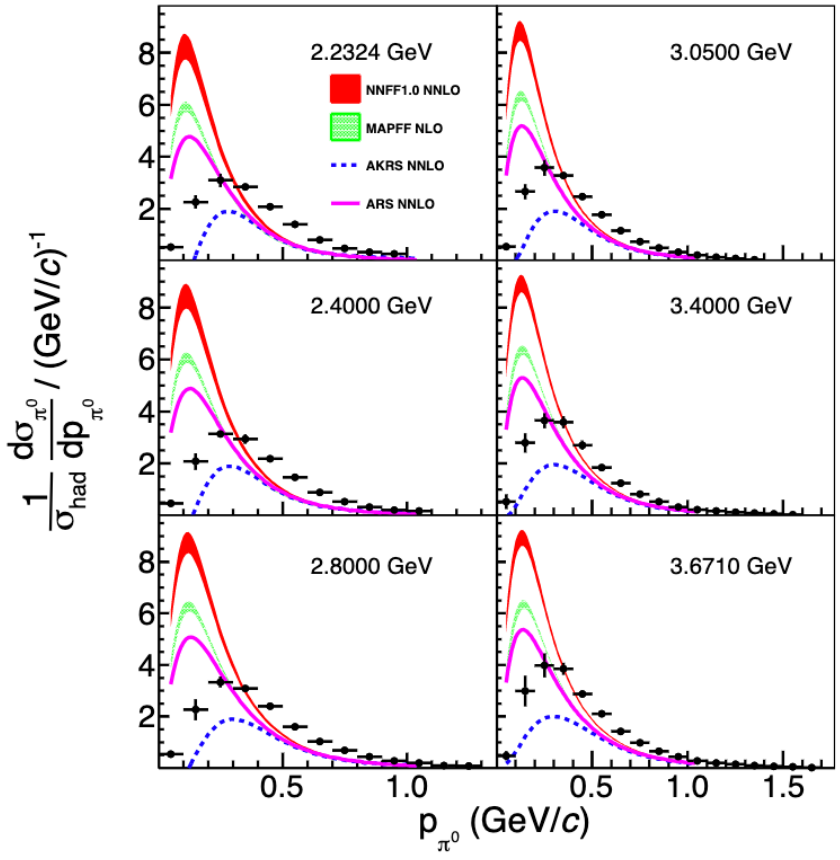
PRD 91, 112004 (2015)

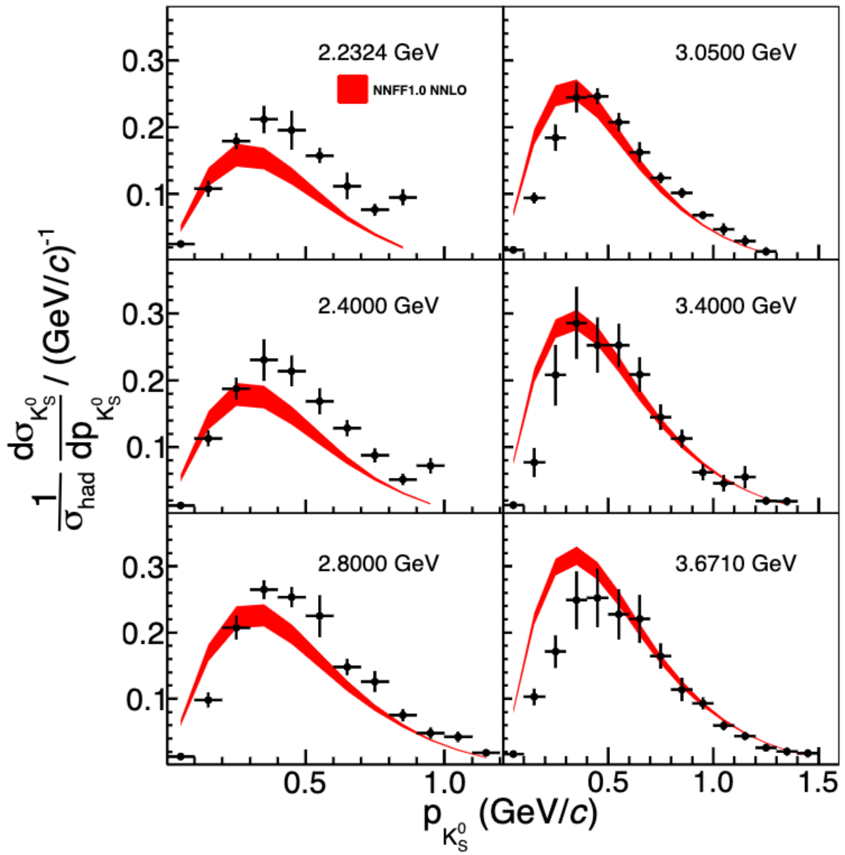


PRL 123, 122003 (2019)



Inclusive π^0 and K_S productions in e^+e^- annihilations





PRL 130 (2023) 231901

- Broad relative hadron energy range z_h from 0.1 to 0.9 with precision of around 3% at $z_h \sim 0.4$.
- Results significantly deviate from several theoretical calculations based on the existing FFs
- Provide brand new inputs in low-energy region to global fits of fragmentation function

BESIII white paper: Future Physics Programme

arXiv:1912.05983 : Chin.Phys. C44 (2020) no.4, 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 right-most column shows the number of required data taking days with the current (T_C) and 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	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ 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

Another 6 years running to collect >60 fb^{-1} data at different energies .

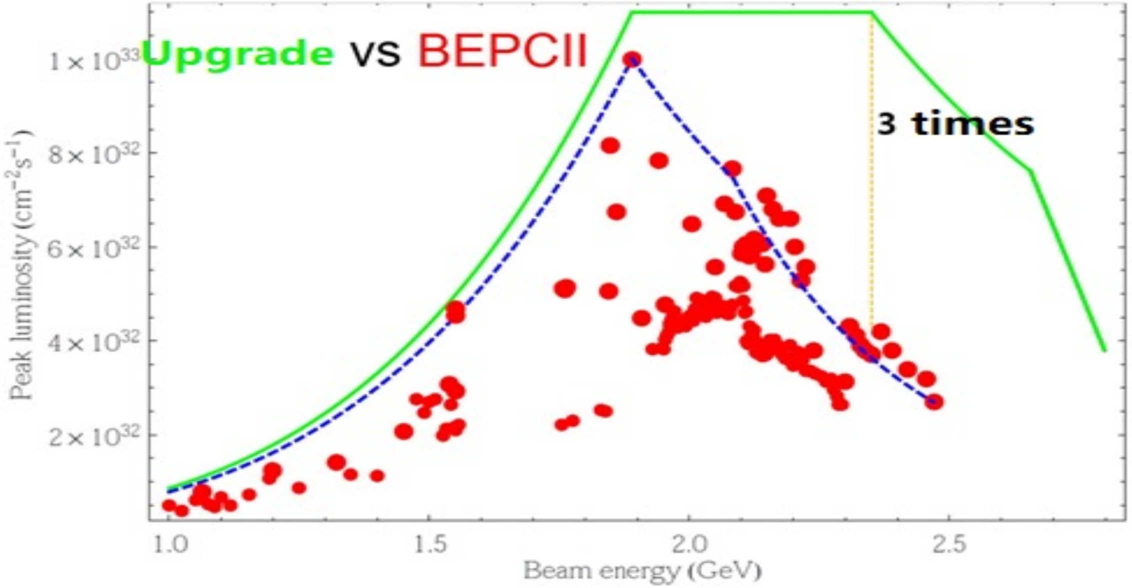
BEPCII upgrades in 2024

BEPCII upgrade (installation: 2024. 6- 2024. 12)

Highest beam energy: : 2.8 GeV

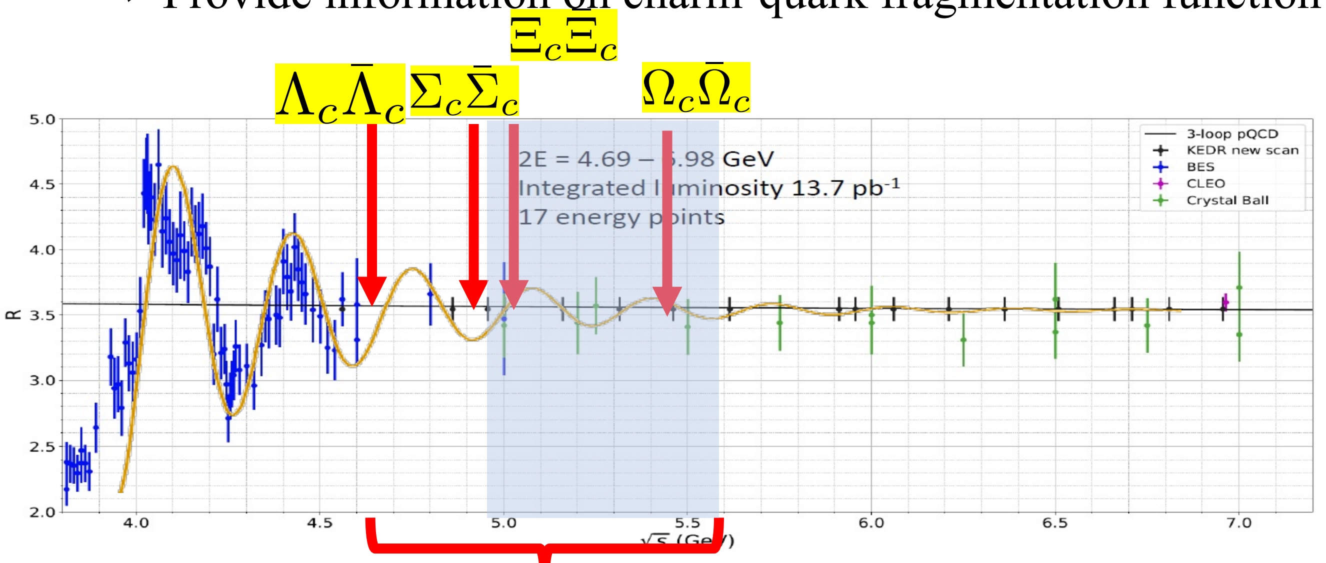
Luminosity: 4.0 ~ 5.0 GeV : 1.2×10^{33} cm^{-2}s^{-1}

5.0 ~ 5.6 GeV: $(0.5\text{-}0.7)\times10^{33}$ cm^{-2}s^{-1}



Potential physics:

- ✓ Cover energy up to 5.6 GeV
- ✓ Deeper studies of the XYZ states
- ✓ Study the ground-state charmed baryons
- ✓ Provide information on charm-quark fragmentation function



Few data and potential physics for XYZ and charmed baryons

HR from IHEP

Staff				Students & Postdocs
Professors	Assoc. Professors & Senior Engineers	Assist. Researchers & Engineers	Total	
19	**23**	**3**	**45**	**60**

Leading scientists

- SHEN Xiaoyan (former Spokesperson from Dec. 2011-Mar. 2018， Deputy IB Chair)
- YUAN Changzheng (former Spokesperson from Mar. 2018-Dec. 2020)
- LI Hai-Bo (Spokesperson, from Dec. 2020-Now)
- LIU Beijiang (Chair of Speaker’s committee, former Physics Coordinator)
- FANG Shuangshi (Light hadron convener, former Physics Coordinator)
- HUANG Yanping (Light hadron)

MA Hailong (Physics Coordinator),DONG Liaoyuan (Charm physics convener), SUN Shengsen(Software coordinator) ……

- **Invited plenary talk @ ICHEP2020 : Xiaoyan Shen**
- **Invited talk @LP2023: Changzheng Yuan**
- **Invited plenary talk @ LP2021: Xiaoyan Shen**
- **More than 100 talks invited talks by international conferences**

IHEP contributions

Operation

MDC & electronics	EMC & electronics	BTOF+ETOF & electronics	MUC	MUC electronics	Trigger & DAQ
IHEP	IHEP	IHEP	IHEP	IHEP+USTC	IHEP

Upgrade

CGEM & electronics	Inner MDC & electronics
INFN+IHEP	IHEP

Software, Data processing

CGEM	MDC	EMC	TOF	MUC	Computing
INFN+IHEP	IHEP	IHEP	IHEP	IHEP	IHEP+……

Publications

Total	IHEP	IHEP + University	Non-IHEP
536	138	189	209

Funding support (million CNY)

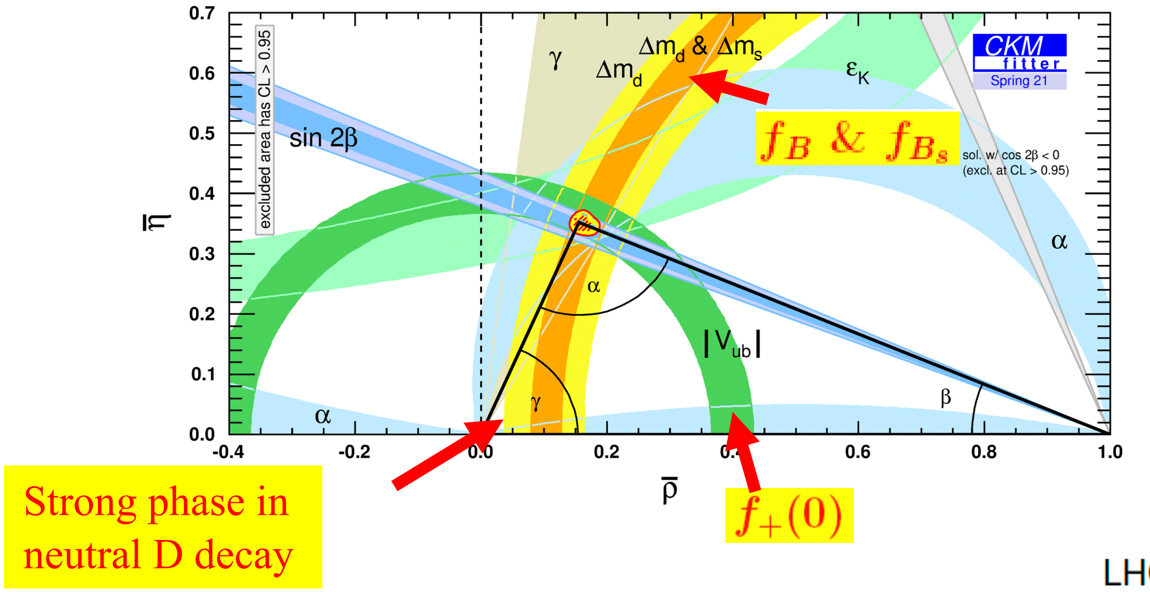
	2018	2019	2020	2021	2022
Detector operation	8.58	8.58	8.58	8.58	8.12
Detector upgrade	7.70	5.30	3.87	3.11	0.00
Research	11.92	19.75	21.38	37.11	40.78
Total	28.20	33.63	33.83	58.80	48.90

We have enough resources to continue running the experiment for another 6 years!

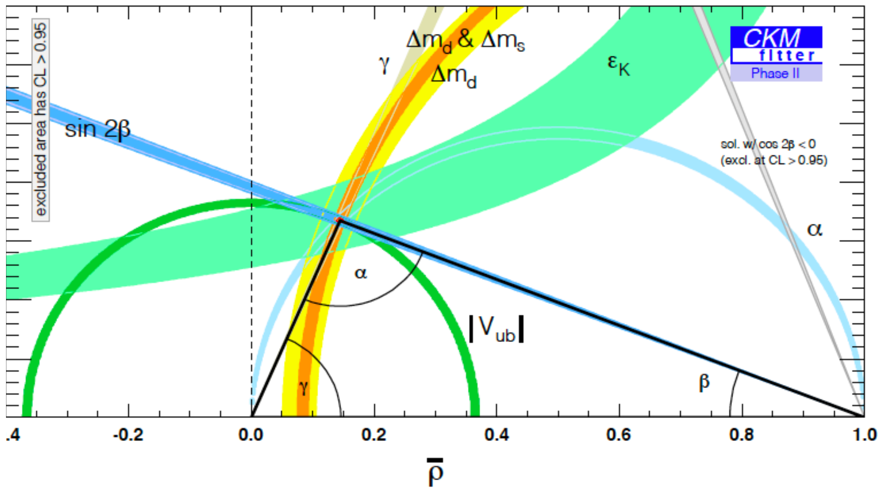
Summary

- BESIII is running smoothly, and very productive now;
- Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT) ready for installation in 2014.
- BEPCII upgrades will be finished by the end of 2024, more data taking above 4.0 GeV, up to 5.6 GeV to study: charmonium-like states (XYZ particles), charmed baryon, charm-quark fragmentation function …
- Advantages at BECPII/BESIII: scan data near thresholds, and quantum-entangled meson and baryon pairs
- BESIII plays leading role in hadron physics, flavor physics(charmed hadron and strange hadron).

2021



2035



Phase 2 ($\simeq$ 2035)

LHCb 300 fb^{-1}, CMS/ATLAS 3000 fb^{-1}, Belle II 50 ab^{-1}

Thank you for your attentions!

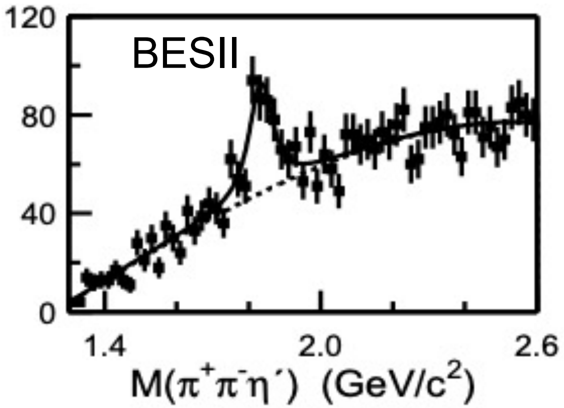
Charm productions at different facilities

Particle	BESIII	Belle II (50 ab^{-1} on $\Upsilon(4S)$)	LHCb (300 fb^{-1})	CEPC (4×Tera-Z)
B^0, $\bar{B}^0$	-	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	-	5.7×10^{10}	3×10^{13}	4.8×10^{11}
B_s^0, $\bar{B}_s^0$	-	6.0×10^8 (5 ab^{-1} on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	-	-	1×10^{11}	7.2×10^8
Λ_b^0, $\bar{\Lambda}_b^0$	-	-	2×10^{13}	1×10^{11}
D^0, $\bar{D}^0$	1.2×10^8	4.8×10^{10}	1.4×10^{15}	5.2×10^{11}
$D^\pm$	1.2×10^8	4.8×10^{10}	6×10^{14}	2.2×10^{11}
$D_s^\pm$	1×10^7	1.6×10^{10}	2×10^{14}	8.8×10^{10}
$\Lambda_c^\pm$	0.3×10^7	1.6×10^{10}	2×10^{14}	5.5×10^{10}
$\tau^\pm$	3.6×10^8	4.5×10^{10}		1.2×10^{11}

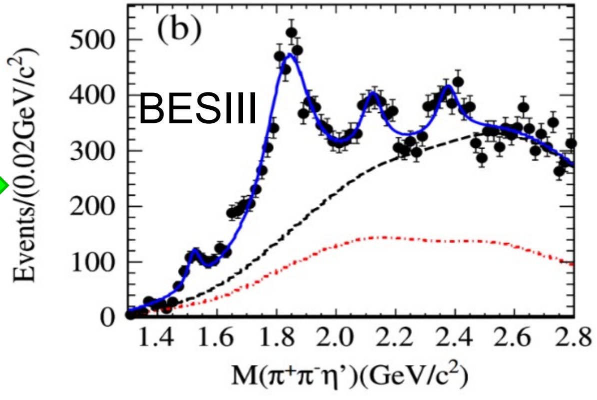
Advantage @BESIII: quantum entangled threshold data sample, and double tag technique.

X(1835), $p\bar{p}$ threshold-enhancement

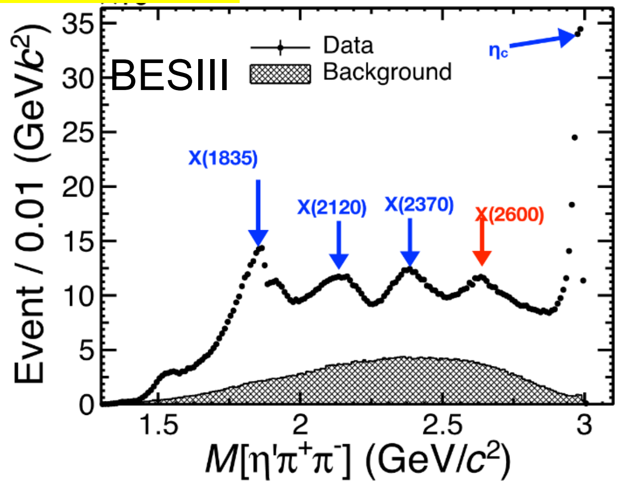
58M J/ψ PRL95(2005)262001



220 Million J/ψ RRL106, 072002 (2011)

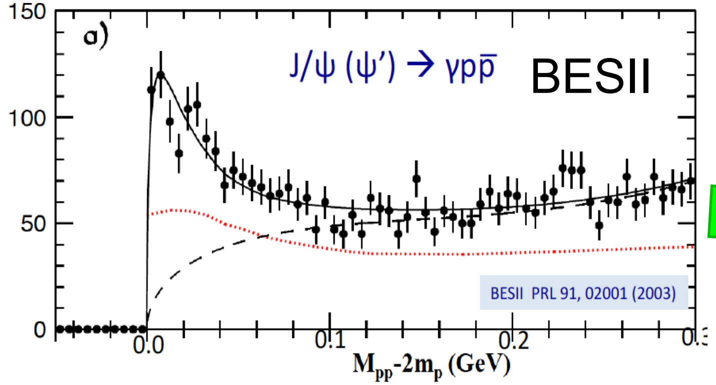


10 billion J/ψ PRL129 (2022) 042001

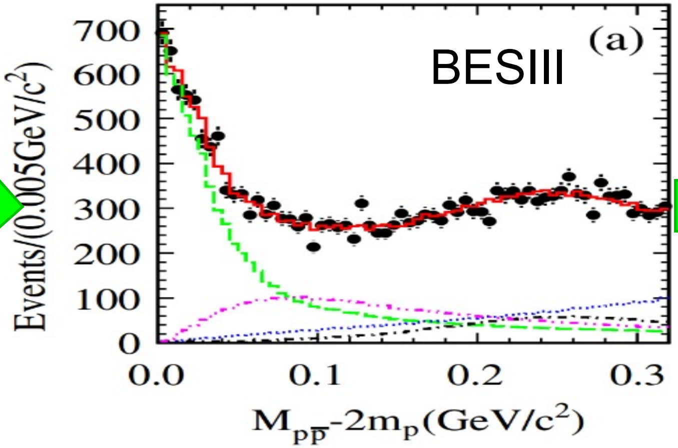


Need more detail study

58M J/ψ PRL 91(2003)022001



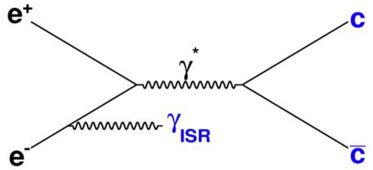
220 Million J/ψ PRL 108, 112003 (2012)



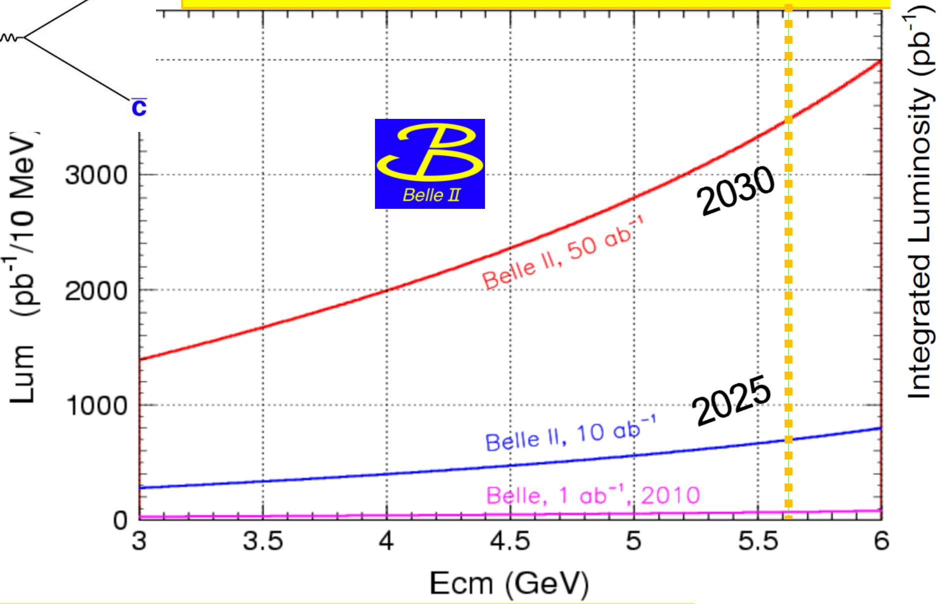
10 billion J/ψ decays ?

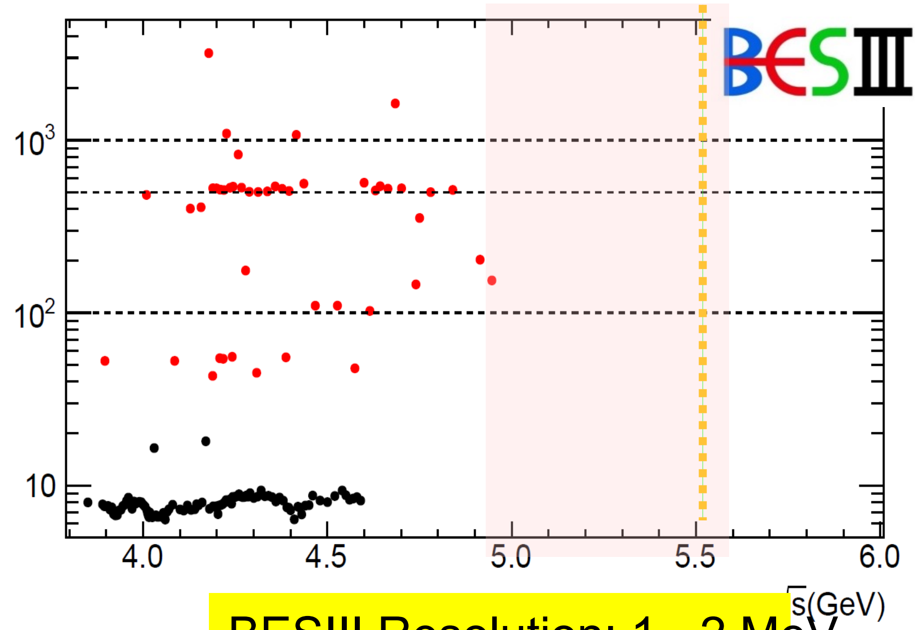
Fine structures were found with more data and better resolution

Scan data at open-charm thresholds: fine structures



ISR effective luminosity @ 10.58 GeV

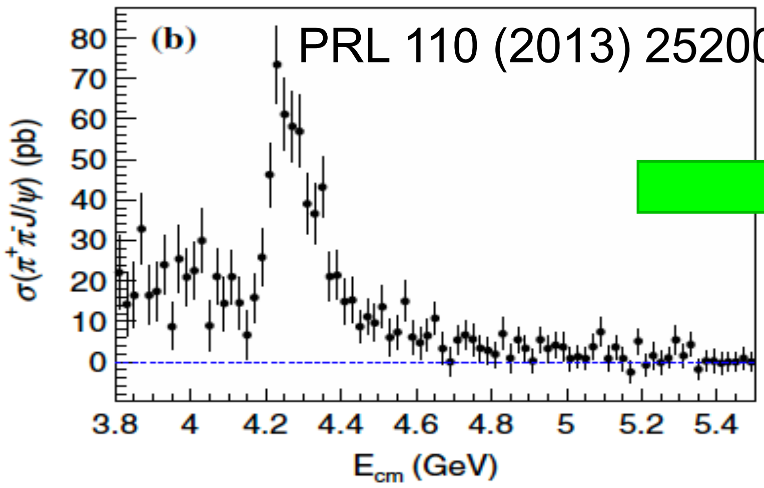


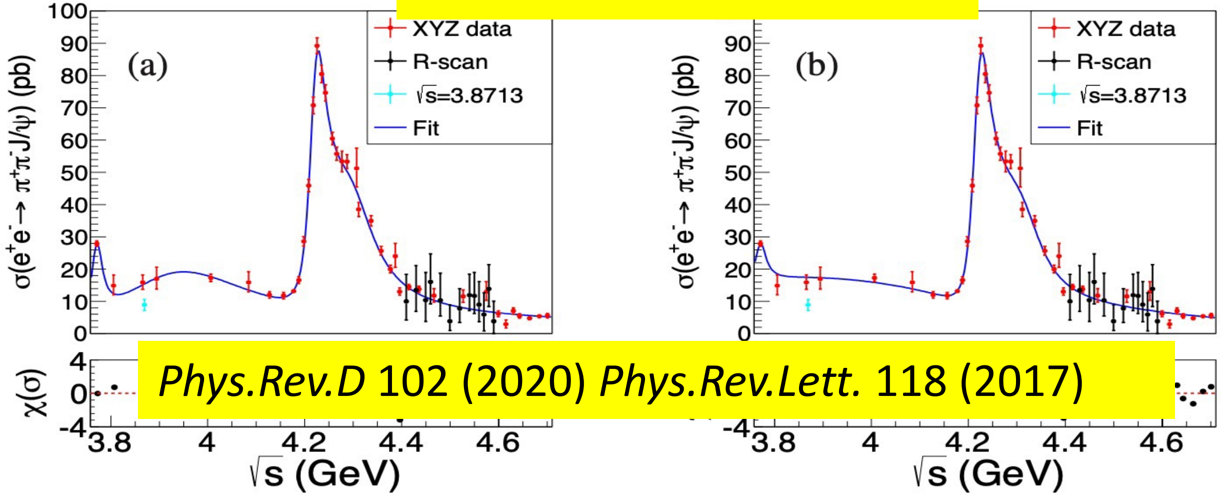


Belle Resolution: about 5-10 MeV

BESIII Resolution: 1 - 2 MeV

PRL 110 (2013) 252002





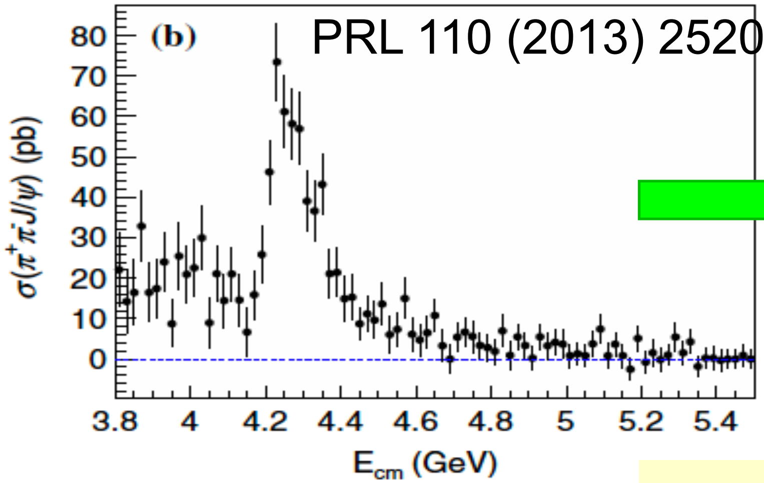
Phys.Rev.D 102 (2020) *Phys.Rev.Lett.* 118 (2017)

Fine structures are seen at BESIII with scan data!

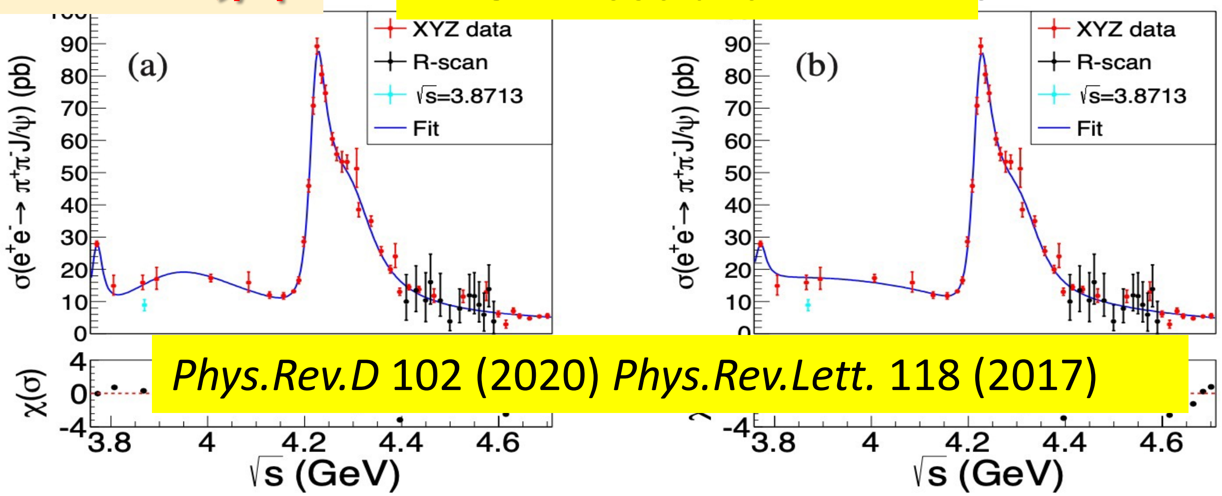
The vector Y states from scan data near open-charm thresholds

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

Belle Resolution: about 5-10 MeV

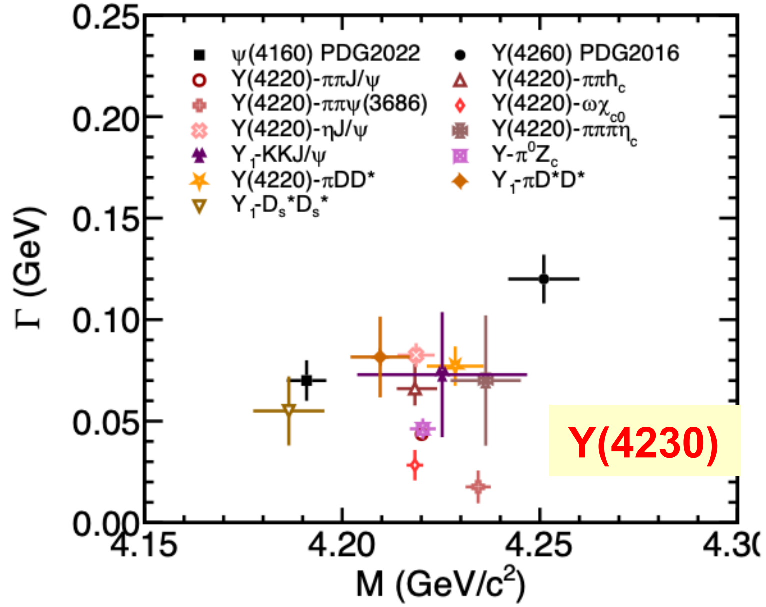


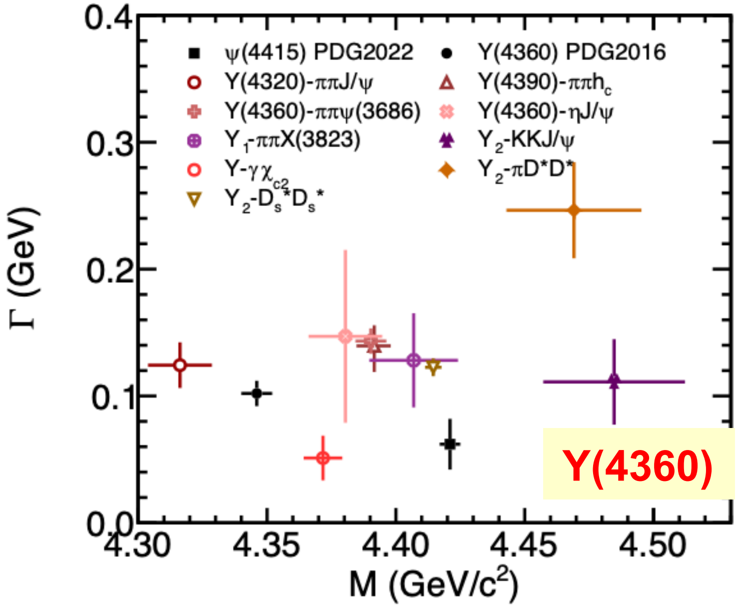
BESIII Resolution: 1 - 2 MeV

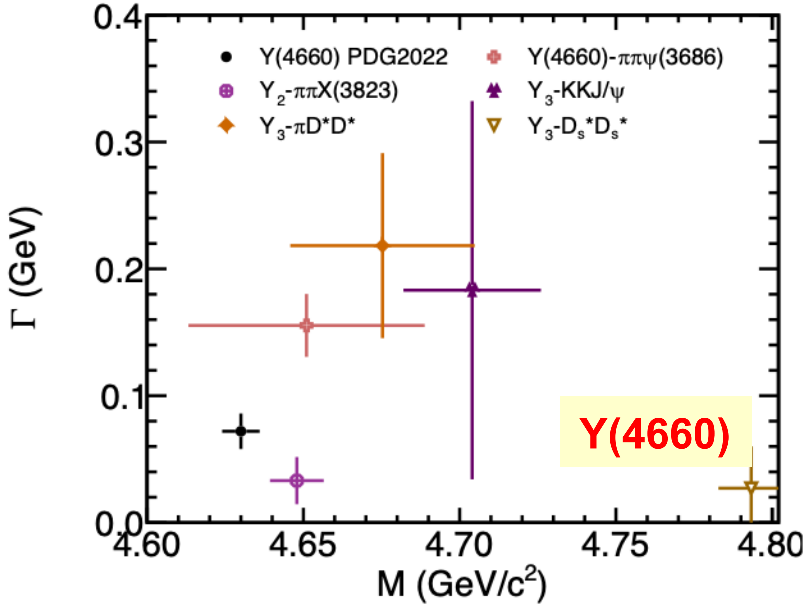


Phys.Rev.D 102 (2020) *Phys.Rev.Lett.* 118 (2017)

Fine structures of Charmonium-like states are seen at BESIII with scan data!



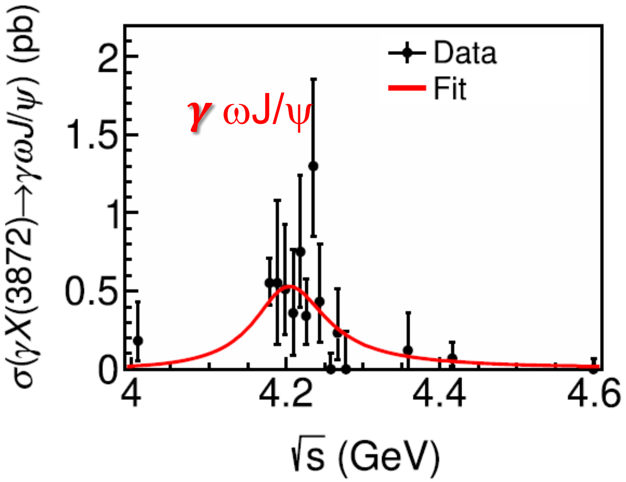


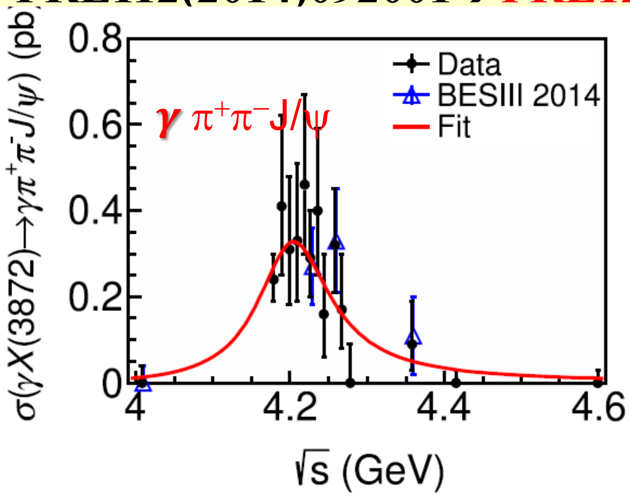


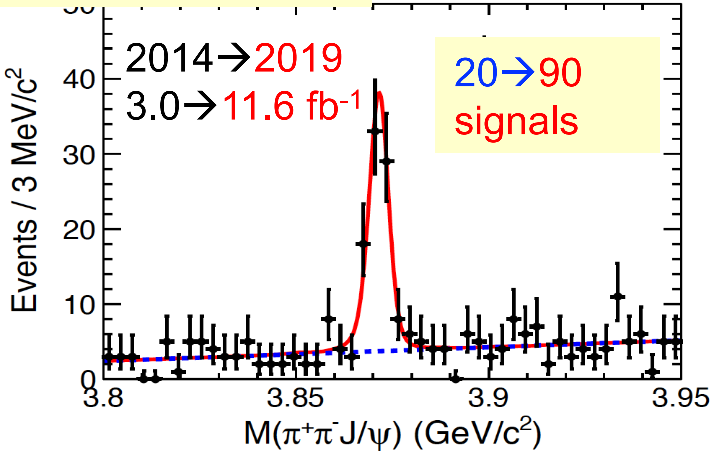
Connection between Y & X: $Y(4260) \to \gamma X(3872)$

$e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$ and $e^+e^- \to \gamma X(3872) \to \gamma D^0\bar{D}^{*0}$

PRL112(2014)092001→PRL122(2019)232002

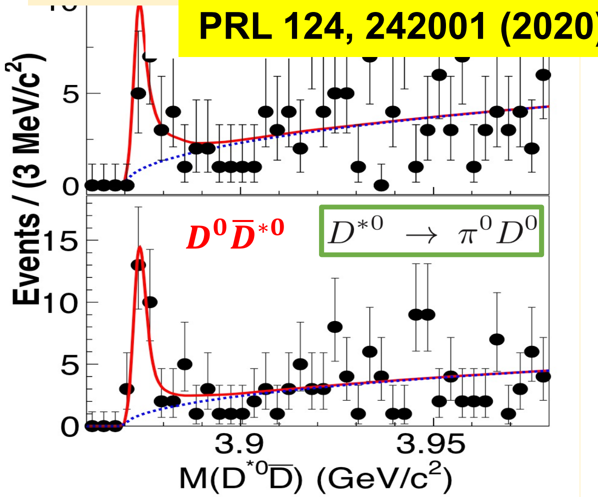






Observation of X(3872) →$D^0\bar{D}^{*0}$

PRL 124, 242001 (2020)



Unique at BESIII:

$B[Y(4260) \to \gamma X(3872)]/B[Y(4260) \to \pi^+\pi^- J/\psi] \sim 9\%$

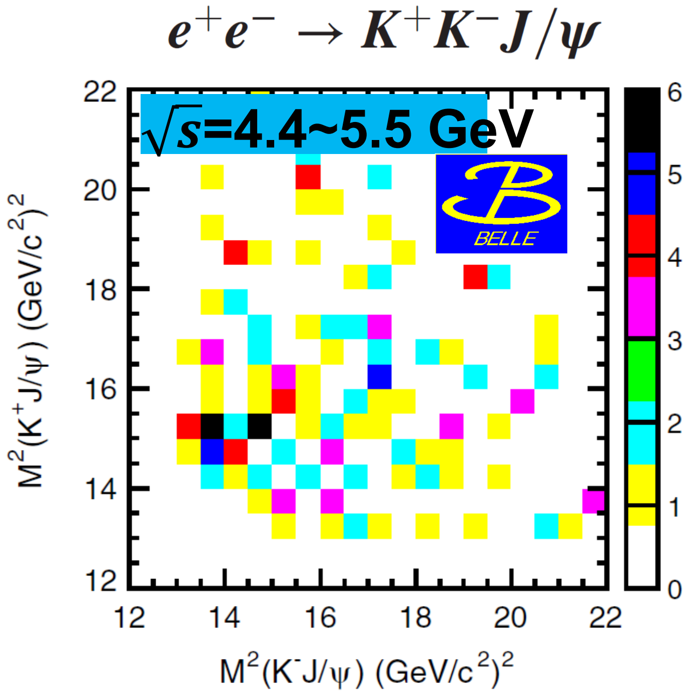
Strongly suggest the Y(4260)→gX(3872) transition：

Commonality between Y(4260) & X(3872)…

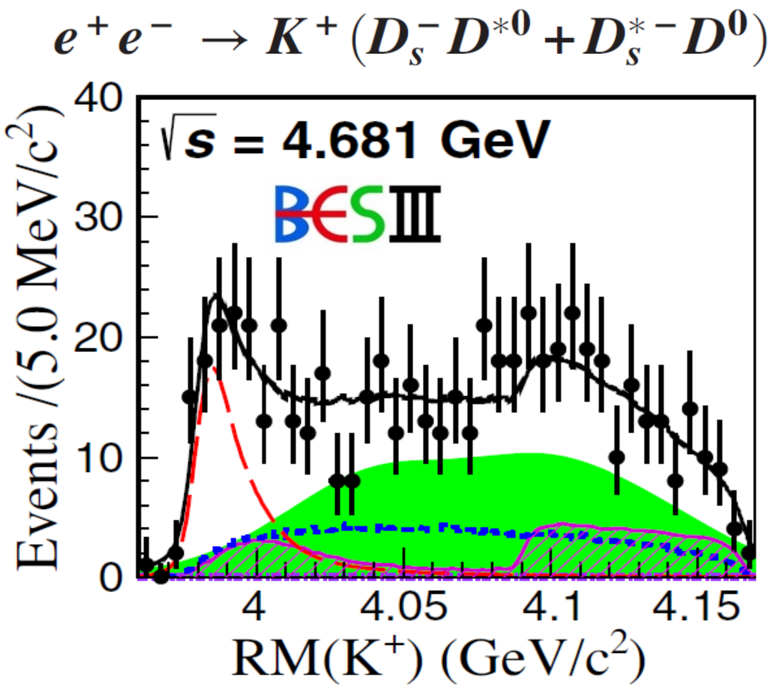
PLB 725, 127 (2013) / RMP 90, 015003 (2018)

$B[X(3872) \to D^0\bar{D}^{*0}]/B[X(3872) \to \pi^+\pi^- J/\psi] \sim (11.8 \pm 3.1)$

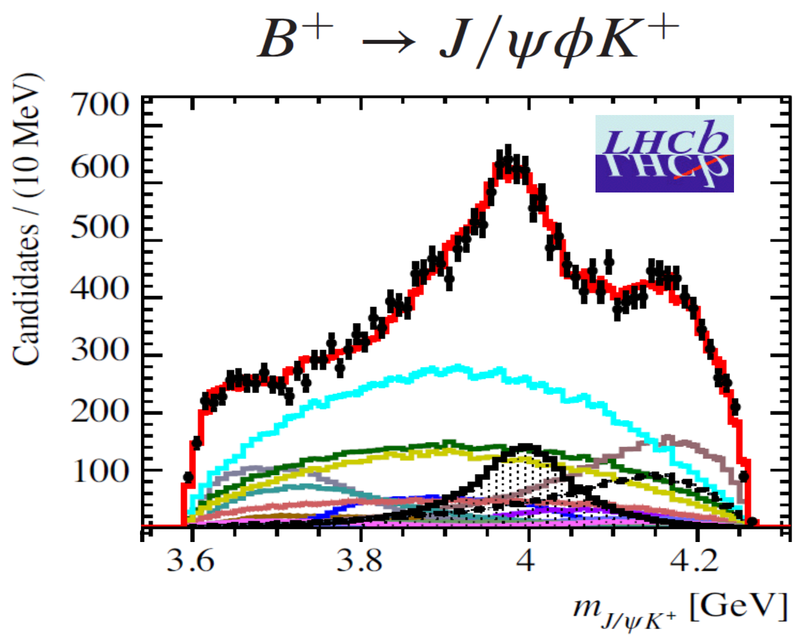
Important milestone to understand the nature of X(3872)!



PRD 89, 072015 (2014)



PRL 126, 102001 (2021)



PRL 127, 082001 (2021)

No significant signal in $K^\pm J/\psi$ decay mode!

(statistics low!)

$Z_{cs}(3985)$ in $\bar{D}^*D_s$ + $\bar{D}D^*_s$ mode!

$Z_{cs}(4000)$ and $Z_{cs}(4220)$ in $K^\pm J/\psi$ decay mode!

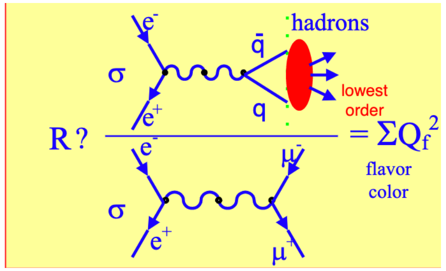
State	Signif.	JP	Mass (MeV)	Width (MeV)
$Z_{cs}(3985)$	5.3σ	??	$3982.5^{+1.8}_{-2.6} \pm 2.1$	$12.8^{+5.3}_{-4.4} \pm 3.0$
$Z_{cs}(4000)$	15σ	1+	$4003 \pm 6^{+4}_{-14}$	131±15±26
$Z_{cs}(4220)$	5.9σ	1+	$4216 \pm 24^{+43}_{-30}$	$233 \pm 52^{+97}_{-73}$

Widths very different, not the same state?

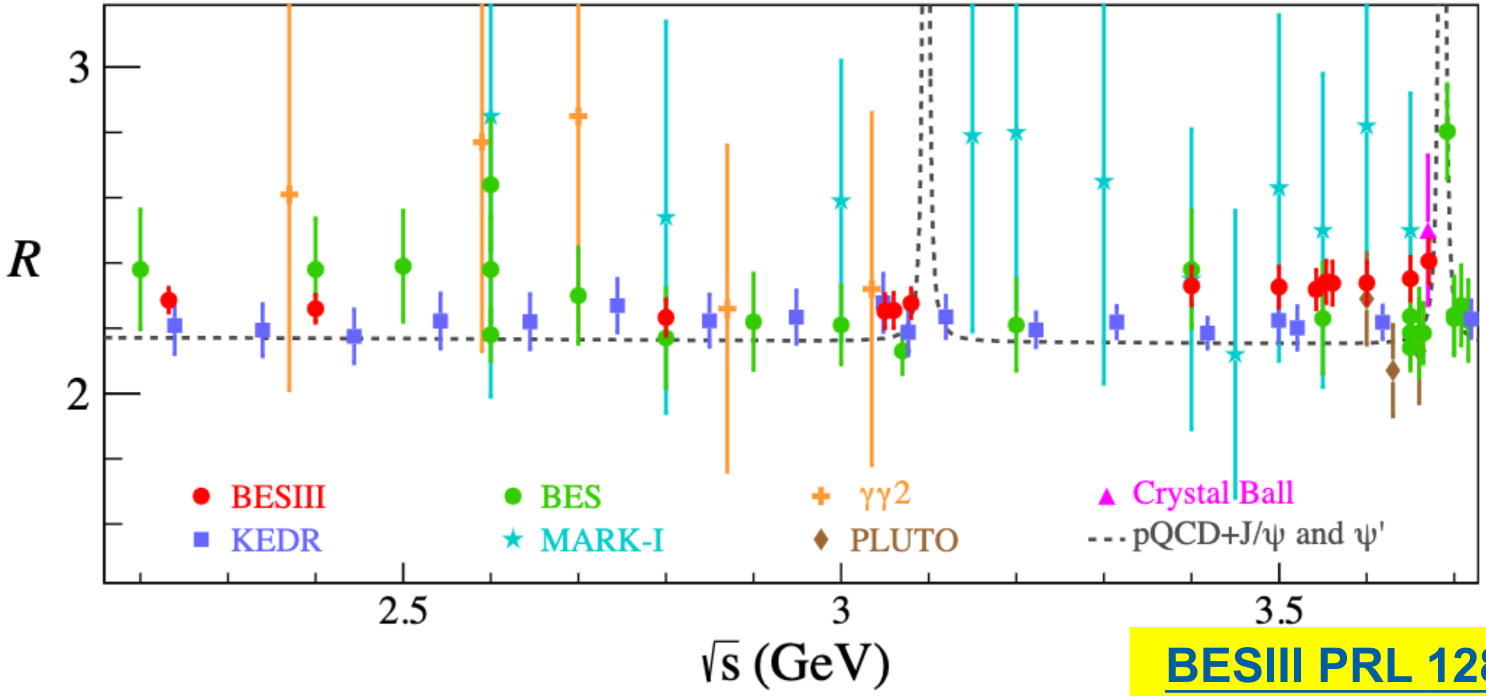
Waiting for BESIII result on $e^+e^- \to K^+K^-J/\psi$ from the same data sample!

Updated *R* values at BESIII

- **14 fine-scan data points from 2.23-3.67 GeV**
- **Important inputs for SM-prediction of g-2**



Comparing BESIII *R* values with previously published results:



BESIII PRL 128, 062004 (2022)

- ▶ **The accuracy is better than 2.6% below 3.1 GeV and 3.0% above.**
- ▶ **Larger than the pQCD prediction by 2.7σ between 3.4 ~ 3.6 GeV.**

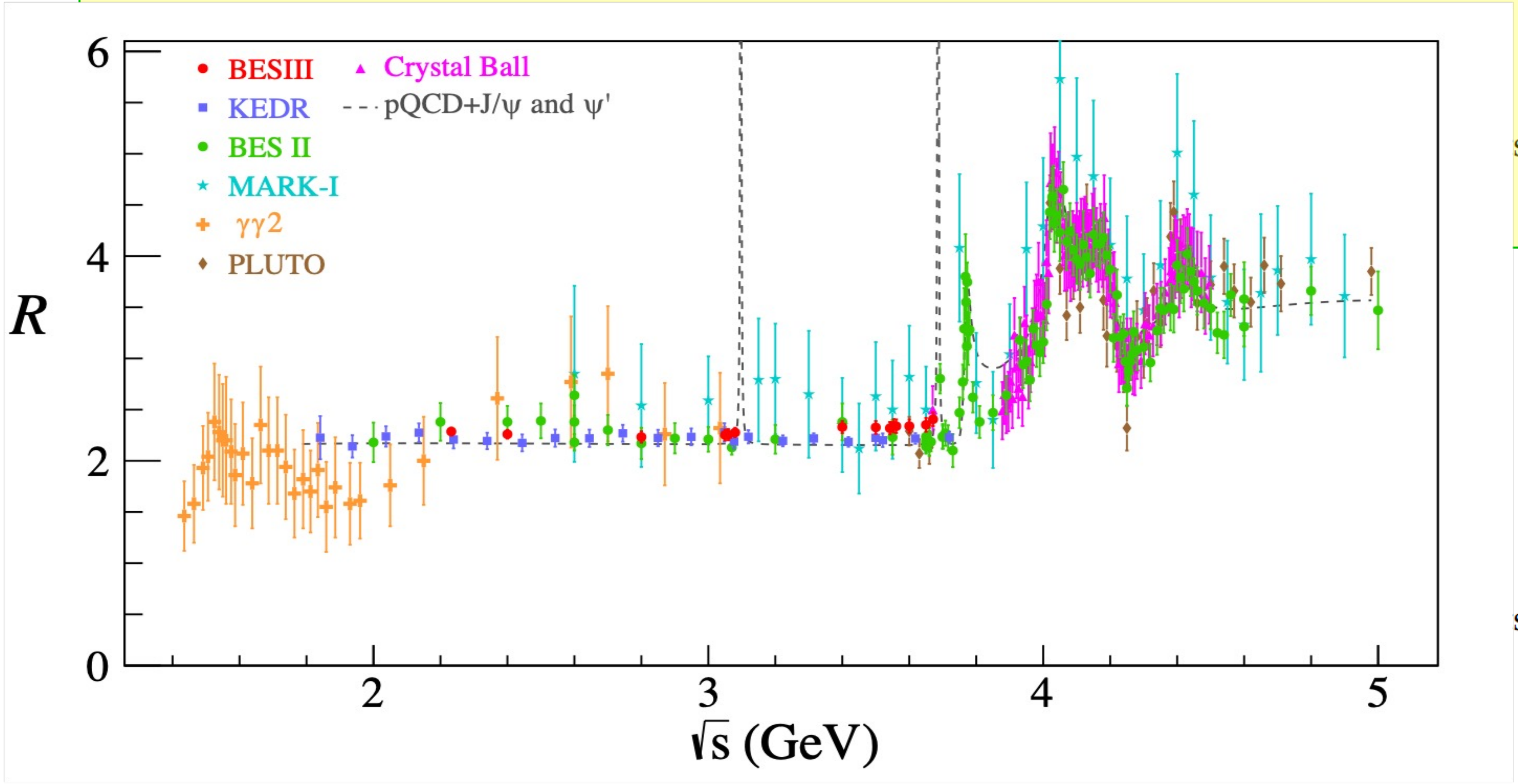
The R program at BESIII

- First bunch of R-scan data was collected in 2012:
  - 4 energy points from 2.2324 to 3.4 GeV for the pilot run.
  - luminosity of $1.7 \sim 3.7\ pb^{-1}$ corresponds to 30k~100k produced hadronic events.
  - 10 data points collected in $2011 \sim 2013$ are added to the program

Done

- Second group of R-scan data was collected in 2013~2014.
  - 104 energy points from 3.85 to 4.60 GeV with covering the open-charm region.
  - luminosity of $8\ pb^{-1}$ corresponds to 150k produced hadronic events.
- Third group of R-scan data was collected in 2015.
  - 21 energy points from 2.00 to 3.08 GeV.
  - luminosity of $1 \sim 100\ pb^{-1}$ corresponds to 20k~2000k produced hadronic events.
  - shared by many exclusive studies and fruitful results are produced.

The *R* program at BESIII

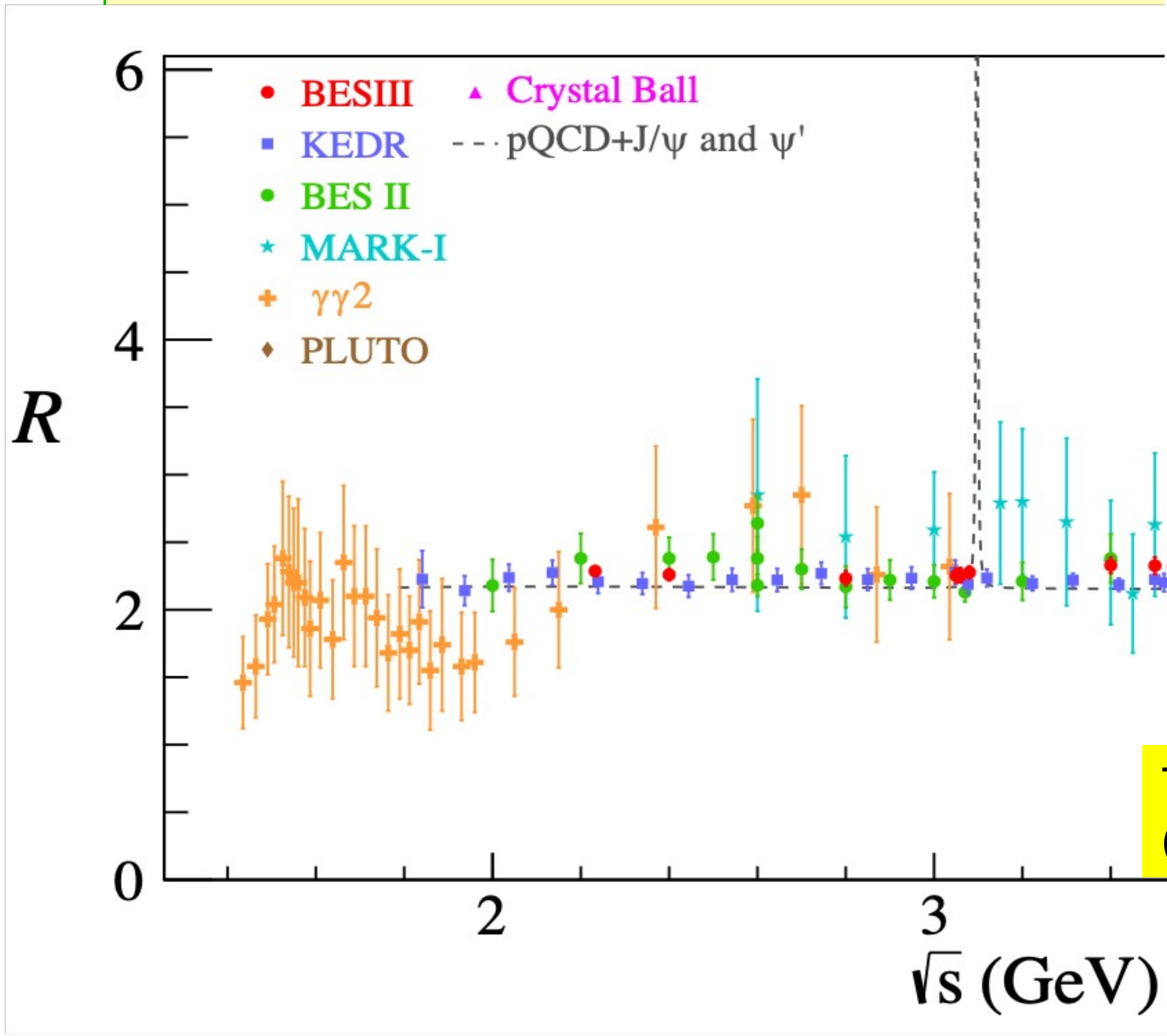


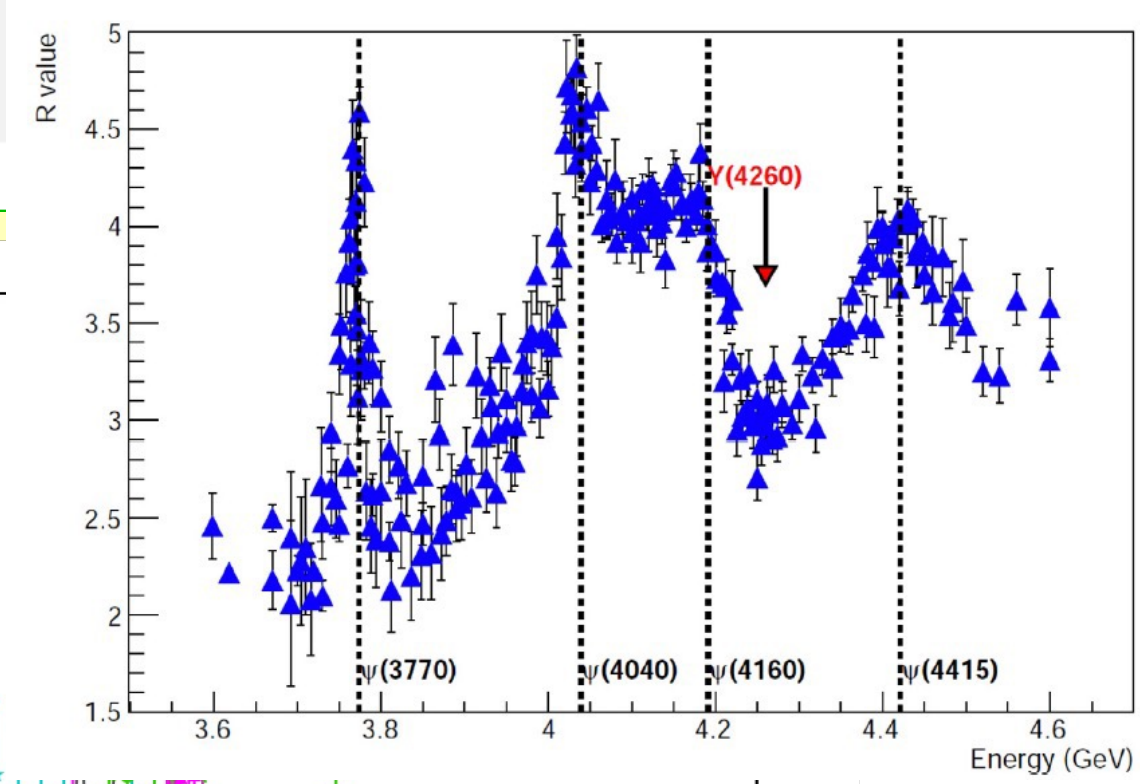
s.

Done

s.

The *R* program at BESIII



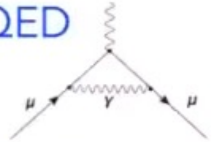


The uncertainty will be reduced to 2% -3%
(by a factor of 2-3)

Muon Anomalous magnetic moment

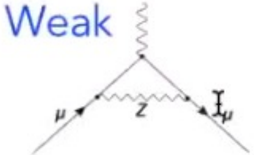
$$a_\mu = a_\mu(\text{QED}) + a_\mu(\text{Weak}) + a_\mu(\text{Hadronic})$$

QED



$+\ldots$ $116\,584\,718.9\,(1) \times 10^{-11}$ 0.001 ppm

Weak

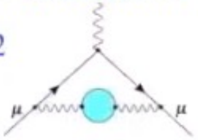


$+\ldots$ $153.6\,(1.0) \times 10^{-11}$ 0.01 ppm

Hadronic…

…Vacuum Polarization (HVP)

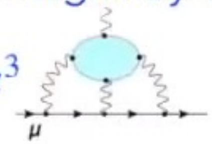
α^2



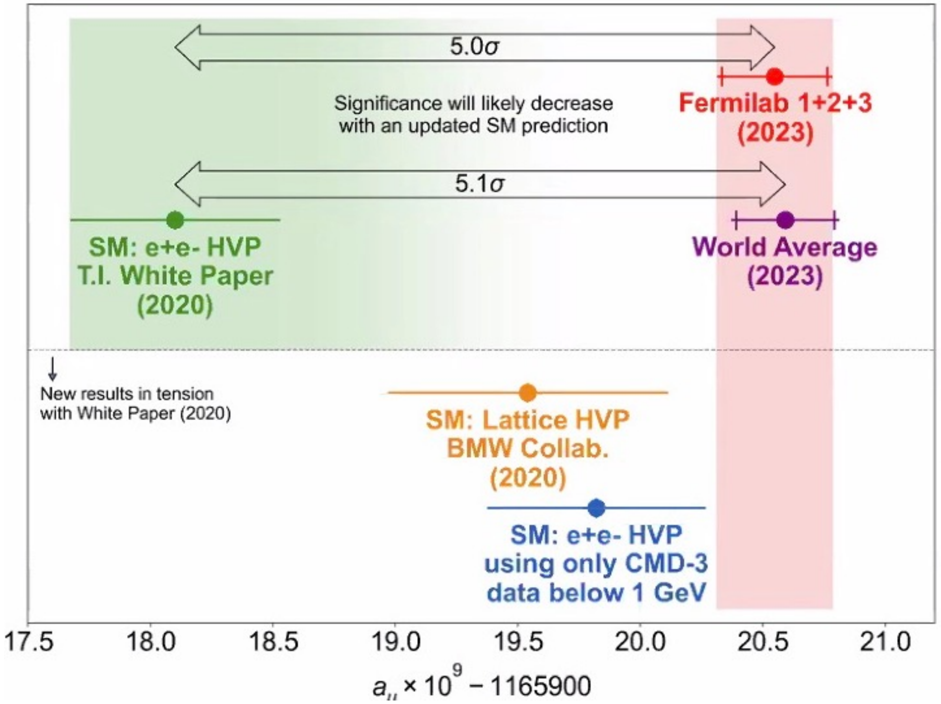
$+\ldots$ $6845\,(40) \times 10^{-11}$ [0.6%] 0.37 ppm

…Light-by-Light (HLbL)

α^3

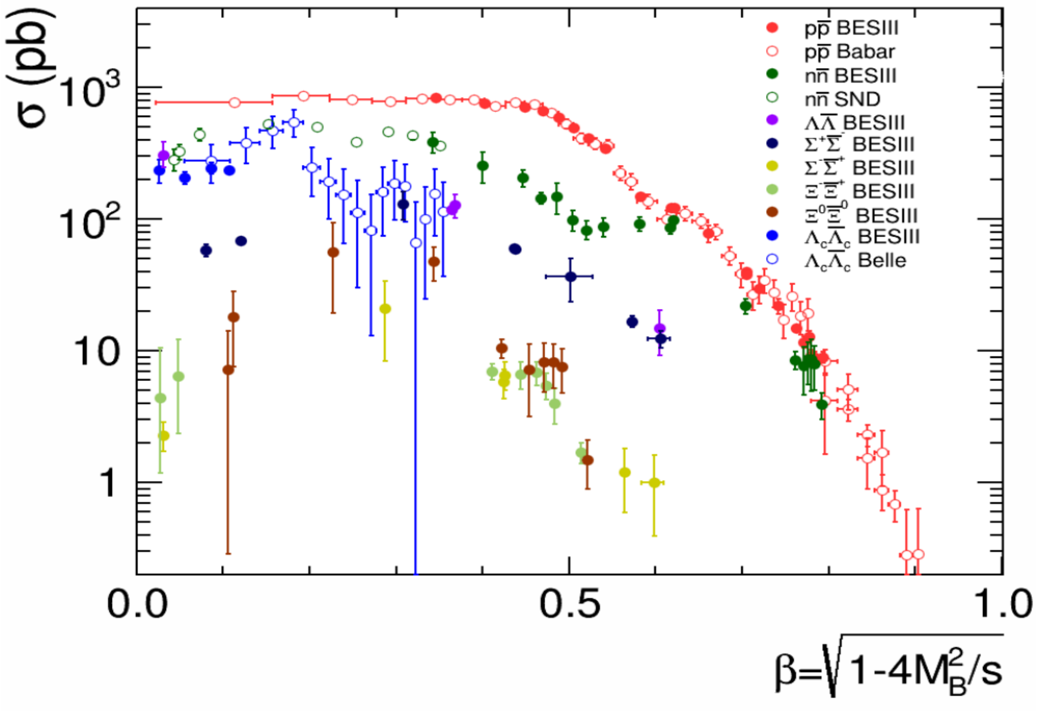


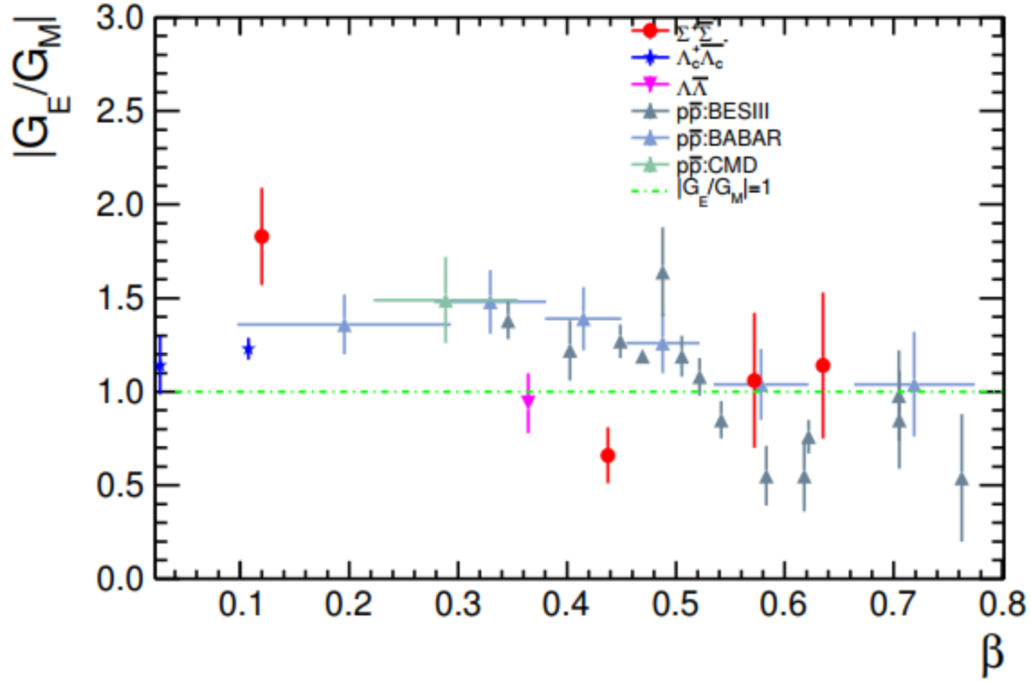
$+\ldots$ $92\,(18) \times 10^{-11}$ [20%] 0.15 ppm



FNAL experiment targets on precision of 0.1 ppm ! HVP with error 0.2-0.3%!

Baryon EMFFs at BESIII

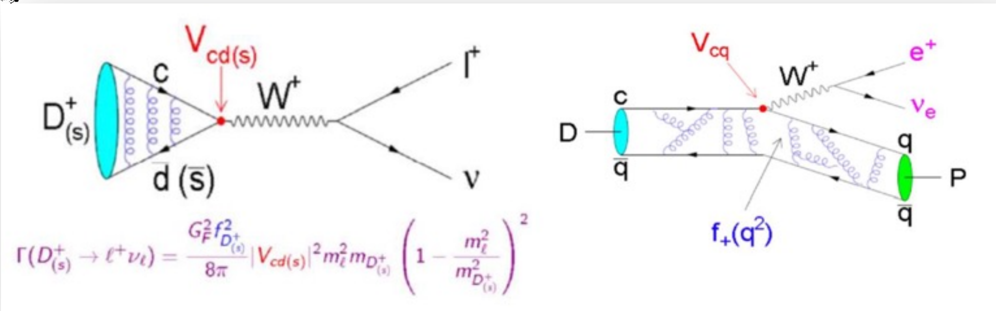




Nat.Sci.Rev. 8 (2021) 11, nwab187

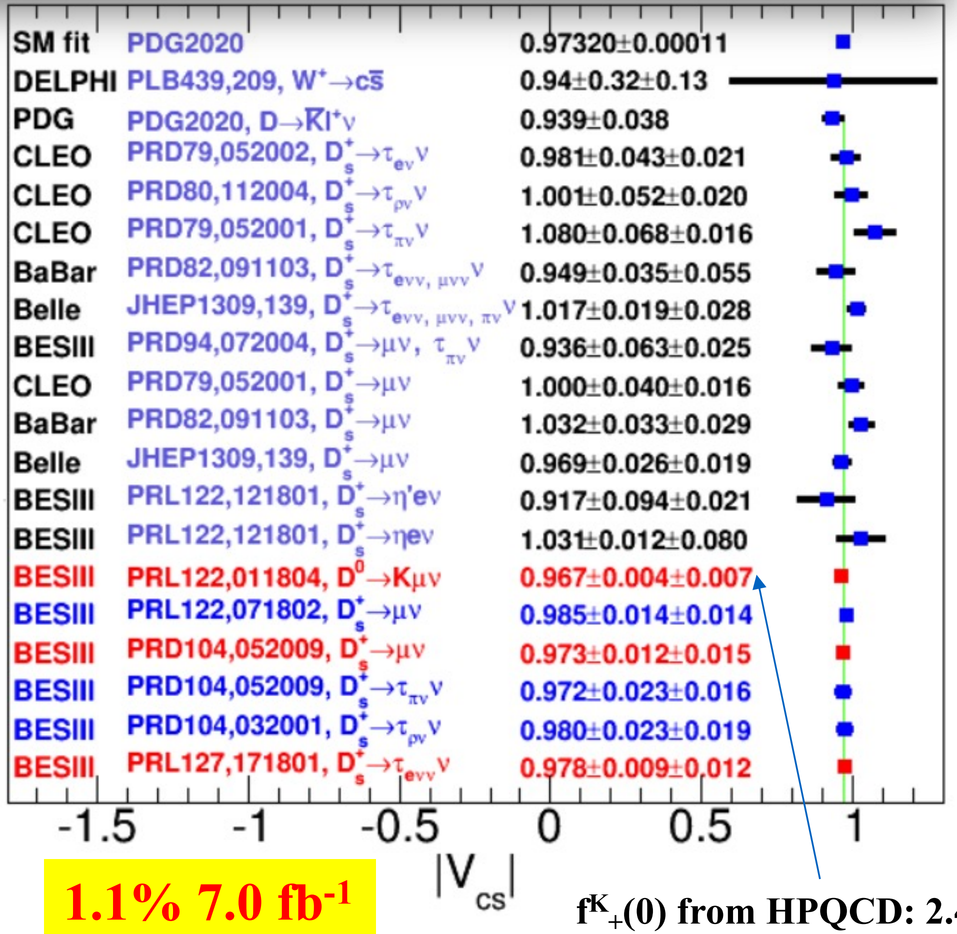
- Abnormal threshold effects observed in various baryon pair production: $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda_c^+\bar{\Lambda}_c^-$ …
- Oscillation structures observed in $p\bar{p}$, $n\bar{n}$
- $|G_E/G_M|$ ratio significantly larger than 1 at low beta for p, Λ_c^+, Σ^+, indicating large D-wave near threshold
- Relative phase angle of form factor $\Delta\phi(\sin\Delta\phi)$ measured for Λ, Λ_c^+

Most precise direct measurement of |Vcs| and |Vcd|



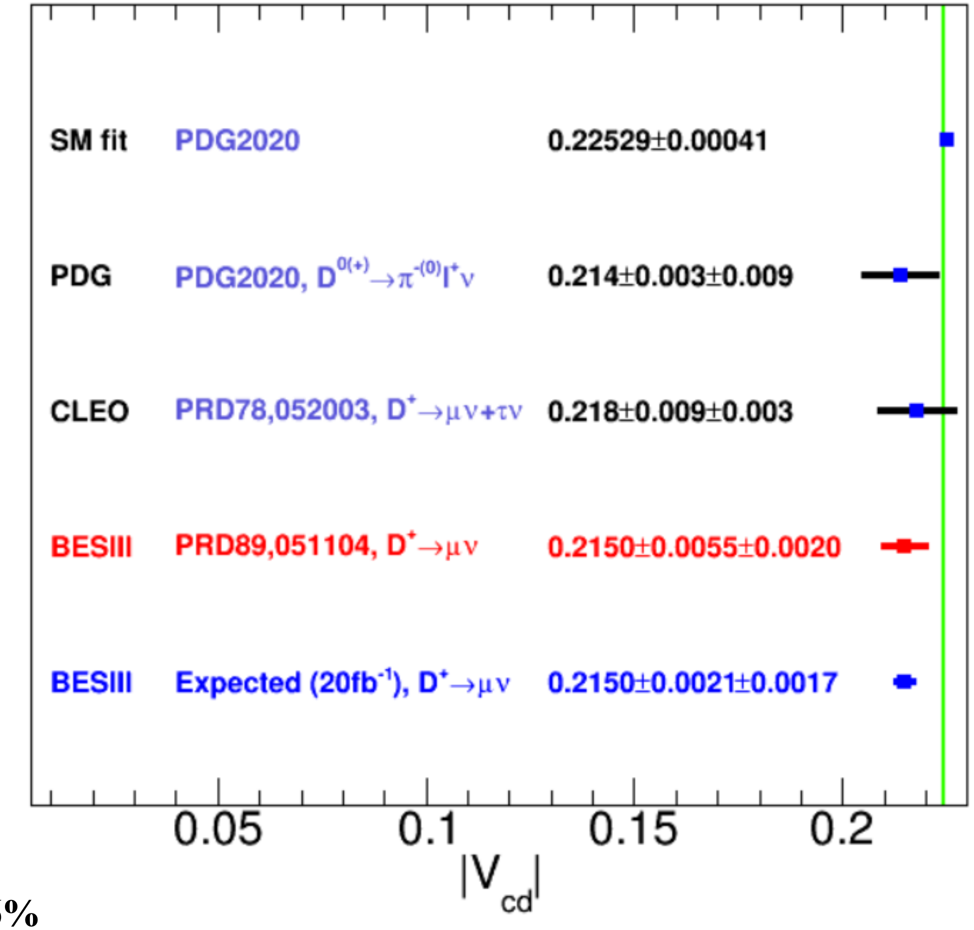
Fermilab Lattice and MILC, arXiv:2212.12648

$$|V_{cd}|^{D\to\pi\ell^+\nu} = 0.2238(11)^{\rm Expt}(15)^{\rm QCD}(04)^{\rm EW}(02)^{\rm SIB}[22]^{\rm QED},$$
$$|V_{cd}|^{D_s\to K e^+\nu} = 0.258(15)^{\rm Expt}(01)^{\rm QCD}[03]^{\rm QED},$$
$$|V_{cs}|^{D\to K\ell^+\nu} = 0.9589(23)^{\rm Expt}(40)^{\rm QCD}(15)^{\rm EW}(05)^{\rm SIB}[95]^{\rm QED},$$



1.1% 7.0 fb^{-1}

$f^K_+(0)$ from HPQCD: 2.4%→0.6%



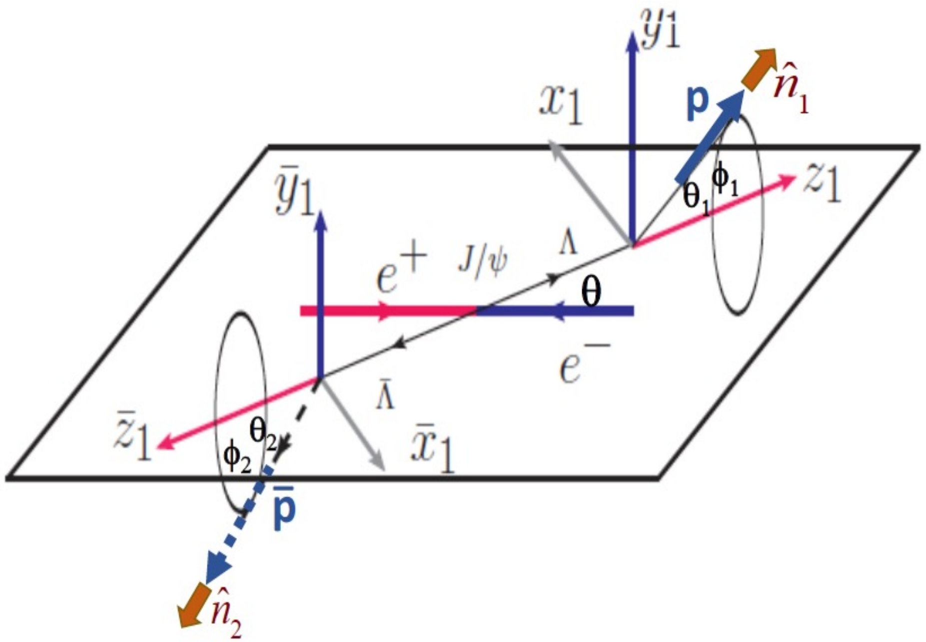
2.6% 2.9 fb^{-1}

1.0% 20fb^{-1}

Observation of hyperon polarization in $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

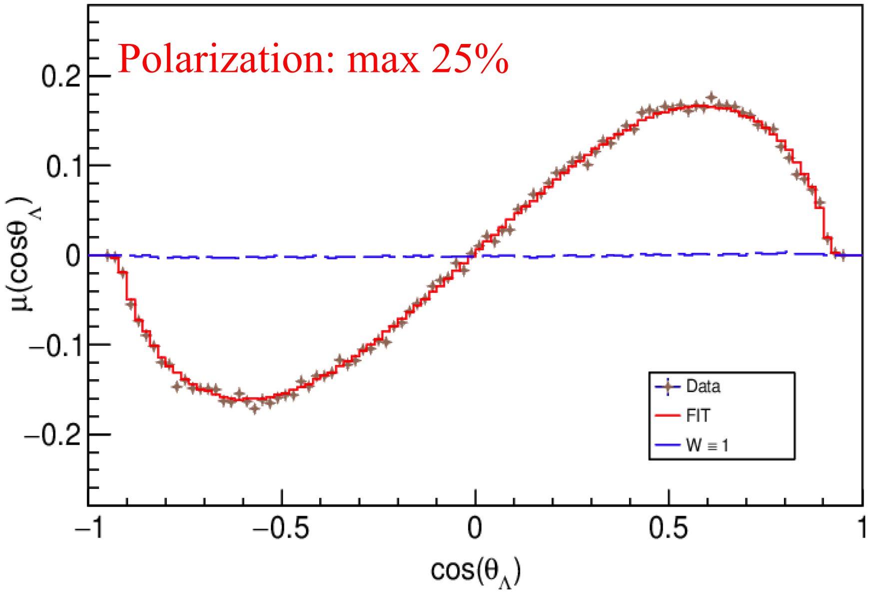
$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$$

Transverse polarization was observed in the entangled hyperon-anti-hyperon production.



1.3 billion ***J/ψ*** Nat. Phys. 15, 631 (2019)

10 billion ***J/ψ*** (Phys. Rev. Lett. 129, 131801 (2022)



Spin directions of both hyperons are perpendicular to the production plane : both of them are up or down.

Polarization of hyperon versus the production angle

The most precise CP test in hyperon decays

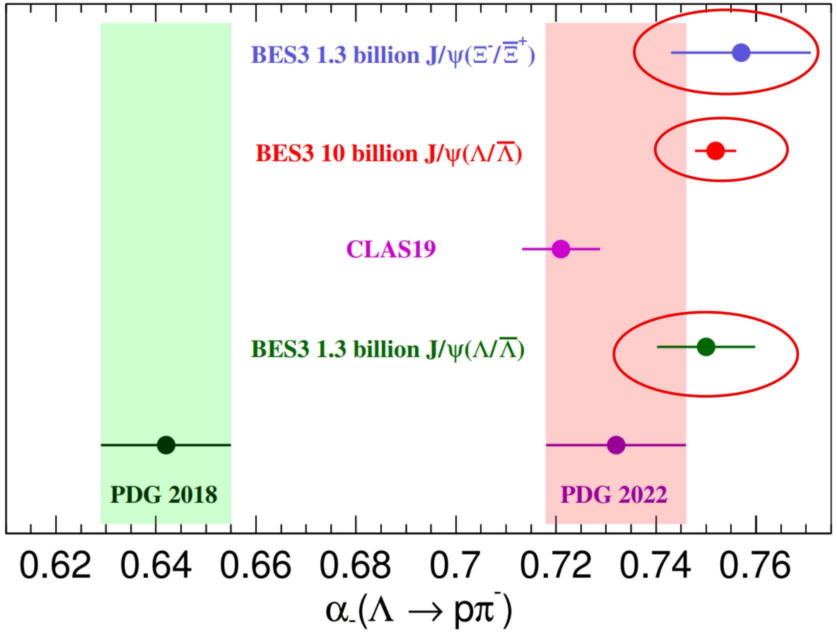
10 billion **J/ψ** (PRL129, 131801 (2022))

Nat. Phys. 15, 631 (2019)

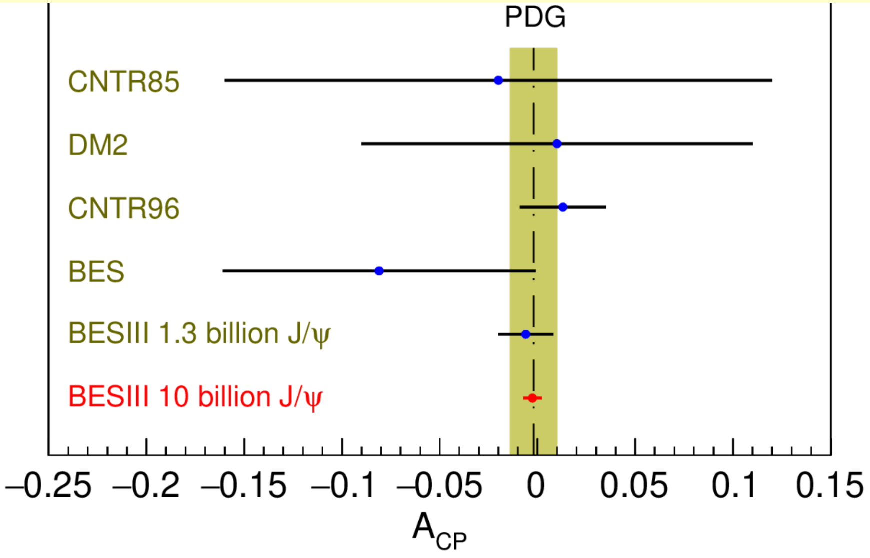
PDG2018

Paras.	BESIII in 2022 (10 billion J/ψ)	BESIII in 2019 (1.3 billion J/ψ)	Previous Results (fix targets)
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027
$\Delta\Phi(\text{rad.})$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$	---
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$-0.006 \pm 0.012 \pm 0.007$	0.06 ± 0.021
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0020$	---	---

More than 10 standard deviation from all previous measurements before 2018



Sensitivity of A_{CP} is improved to the level of below 0.5%



CPV: $e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

Nature 606 (2022) 64-69

13% of total J/ψ decays
~73200 signal events
Negligible background

First direct and simultaneously measurement of the charged Ξ decay parameters

First measurement of weak phase difference in Ξ decay

Three independent *CP* tests

Parameter	This work	Previous result
α_ψ	0.586±0.012±0.010	0.58±0.04±0.08
$\Delta\Phi$	1.213±0.046±0.016 rad	–
α_Ξ	−0.376±0.007±0.003	−0.401±0.010
ϕ_Ξ	0.011±0.019±0.009 rad	−0.037±0.014 rad
$\bar{\alpha}_\Xi$	0.371±0.007±0.002	–
$\bar{\phi}_\Xi$	−0.021±0.019±0.007 rad	–
α_Λ	0.757±0.011±0.008	0.750±0.009±0.004
$\bar{\alpha}_\Lambda$	−0.763±0.011±0.007	−0.758±0.010±0.007
$\xi_P-\xi_S$	$(1.2\pm3.4\pm0.8)\times10^{-2}$ rad	–
$\delta_P-\delta_S$	$(-4.0\pm3.3\pm1.7)\times10^{-2}$ rad	$(10.2\pm3.9)\times10^{-2}$ rad
A^{Ξ}_{CP}	$(6\pm13\pm6)\times10^{-3}$	–
$\Delta\phi^{\Xi}_{CP}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–
A^{Λ}_{CP}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$
$\langle\phi_\Xi\rangle$	0.016±0.014±0.007 rad	

First measurement of the Ξ^- polarization in J/ψ decay

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$
BESIII: $\langle\phi_\Xi\rangle = 0.016 \pm 0.014 \pm 0.007$

We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

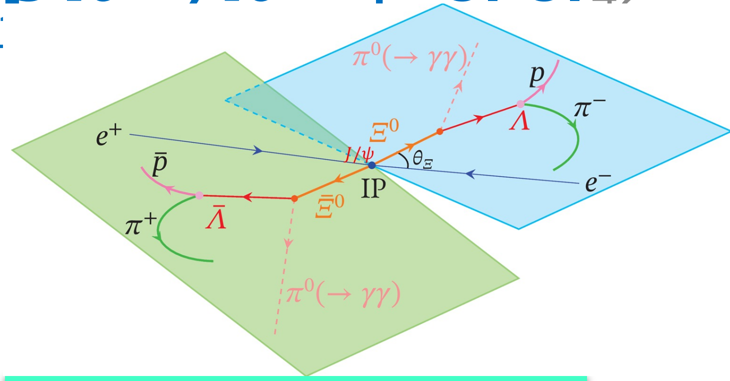
HyperCP: PRL 93(2004) 011802

First measurement of weak phase difference :
weak phase < 3.6 degree
strong phase <6.0 degree

CPV: $e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \Lambda(\to p\pi^-)\pi^0 + c.c.$

Based on 10 B J/ψ events
9-dimensional fit:
~320,000 signal events
Purity: > 98%

arXiv:2305.0921
Accepted by PRD(L) as an Editor's Suggestion



Parameter	This work	Previous result
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$	-
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 0.0047
$\xi_P - \xi_S$(rad)	$(0.0 \pm 1.7 \pm 0.2) \times 10^{-2}$	-
$\delta_P - \delta_S$(rad)	$(-1.3 \pm 1.7 \pm 0.4) \times 10^{-2}$	-
A^Ξ_{CP}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$
$\Delta\phi^\Xi_{CP}$(rad)	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$	$(-7.9 \pm 8.3) \times 10^{-2}$
A^Λ_{CP}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$	-
$\langle\phi_\Xi\rangle$(rad)	$0.0052 \pm 0.0069 \pm 0.0016$	-
$\langle\alpha_\Lambda\rangle$	$0.7499 \pm 0.0029 \pm 0.0013$	0.7542 ± 0.0026

Most precise measurements of the neutral Ξ decay parameters

Three *CP* tests

First measurement of the Ξ^0 polarization in J/ψ decay

First measurement of weak phase difference in neutral Ξ decay, most precise result for any weakly-decaying baryon

Phys. Rev. Lett. 129 (2022) 13, 131801

Comparable with the result obtained from ~3.2 M $\Lambda\bar{\Lambda}$ events.

BESIII achievements on hyperon physics

Parameters	$J/\psi \to \Lambda\bar{\Lambda}$	$J/\psi \to \Sigma^+\bar{\Sigma}^-$	$J/\psi \to \Xi^-\bar{\Xi}^+$	$J/\psi \to \Xi^0\bar{\Xi}^0$
	PRL 129, 131801(2022)	PRL 125,052004(2020)	Nature 606,64(2022)	PRD108,L031106(2023
α_{Ξ^-/Ξ^0}	-	-	$-0.376 \pm 0.007 \pm 0.003$	$-0.3750 \pm 0.0034 \pm 0.0016$
$\alpha_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$0.371 \pm 0.007 \pm 0.002$	$0.3790 \pm 0.0034 \pm 0.0021$
ϕ_{Ξ^-/Ξ^0}	-	-	$0.011 \pm 0.019 \pm 0.009$	$0.0051 \pm 0.0096 \pm 0.0018$
$\phi_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$-0.021 \pm 0.019 \pm 0.007$	$-0.0053 \pm 0.0097 \pm 0.0019$
$A_{CP}(\Xi^-/\Xi^0)$	-	-	$0.006 \pm 0.013 \pm 0.006$	$-0.0054 \pm 0.0065 \pm 0.0031$
$\Delta\phi_{CP}(\Xi^-/\Xi^0)$	-	-	$-0.005 \pm 0.014 \pm 0.003$	$-0.0001 \pm 0.0069 \pm 0.0009$
$\alpha_{\Lambda/\Sigma^+}$	$0.7519 \pm 0.0036 \pm 0.0024$	$-0.998 \pm 0.037 \pm 0.009$	$0.757 \pm 0.011 \pm 0.008$	$0.7551 \pm 0.0052 \pm 0.0023$
$\alpha_{\bar{\Lambda}/\bar{\Sigma}^-}$	$-0.7559 \pm 0.0036 \pm 0.0030$	$0.990 \pm 0.037 \pm 0.011$	$-0.763 \pm 0.011 \pm 0.007$	$-0.7448 \pm 0.0052 \pm 0.0023$
$A_{CP}(\Lambda/\Sigma^+)$	$-0.0025 \pm 0.0046 \pm 0.0012$	$-0.004 \pm 0.037 \pm 0.010$	$-0.004 \pm 0.012 \pm 0.009$	$0.0069 \pm 0.0058 \pm 0.0018$

BESIII best measurements: $A_{CP}^{\Lambda} = -0.0025 \pm 0.0046 \pm 0.0012$

Systematic uncertainties are well controlled!

- Excellent performance of BESIII detectors.
- Data-driven method to study data-MC inconsistency.

BESIII management