Overview of BESIII

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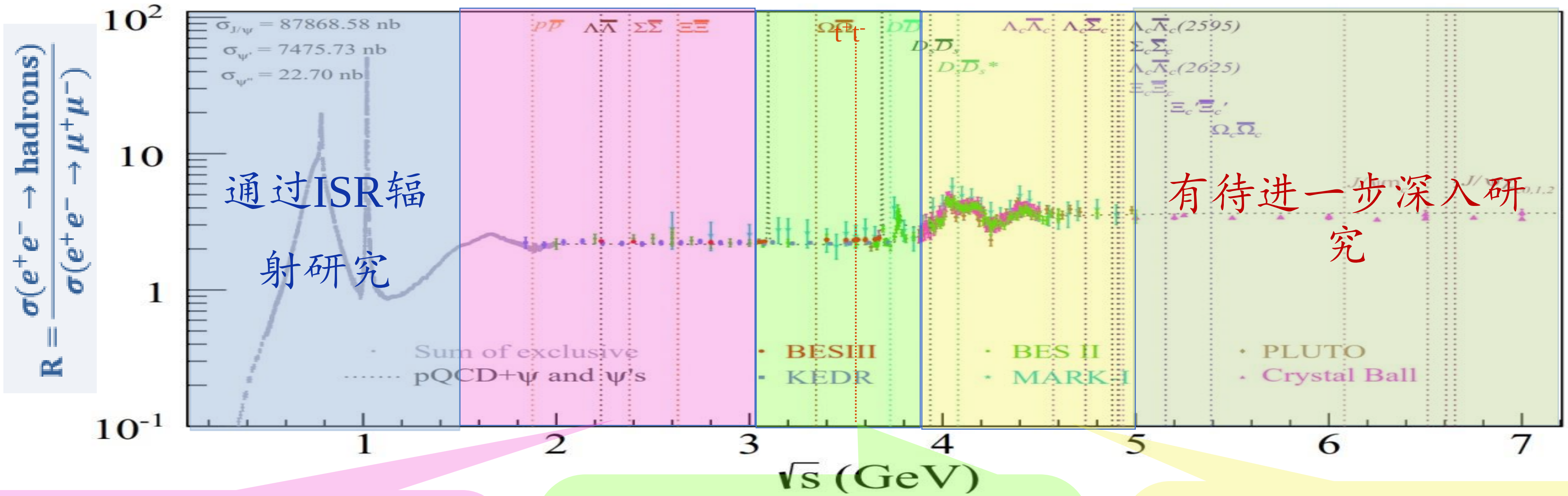
中国科学技术大学

第二十届全国中高能核物理大会
暨第十四届全国中高能核物理专题研讨会
2025.4.24-28, 上海

陶粲能区的独特性和丰富的物理

- 微扰与非微扰QCD的过渡能区
- 丰富的**共振结构**、巨大的**粲偶素**产生截面、阈值产生**强子对**和**τ轻子对**
- 大量**奇特**量子数强子、胶子态、多夸克态、夸克胶子混合态

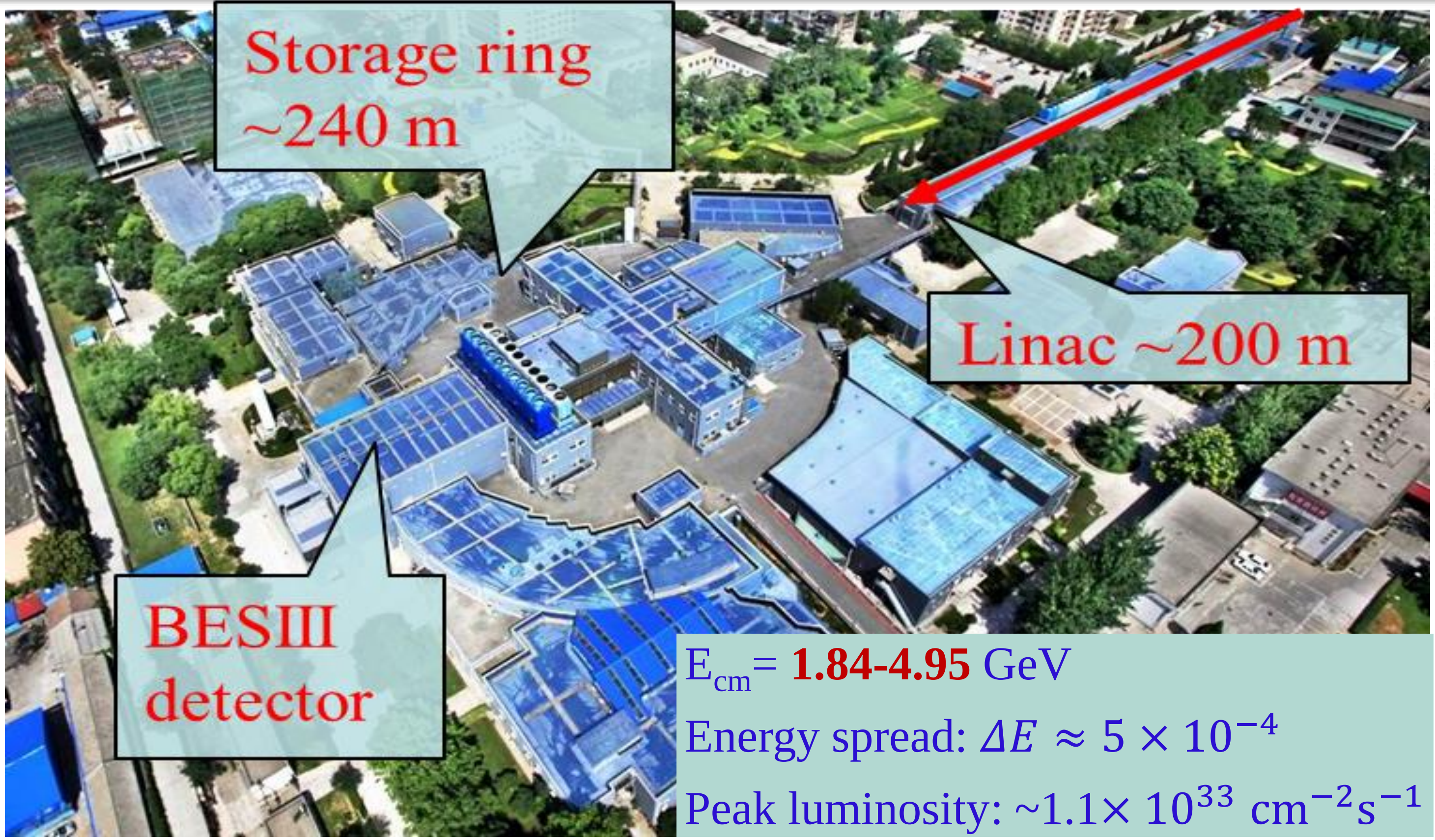


- -R value
- -Fragmentation functions
- -Nucleon/Hadron form factors
- -Y(2175) resonance
- - EM/strong interference

- -LH spectroscopy
- -Gluonic and exotic
- -Hyperon decays
- -Rare and forbidden decays
- -Physics with τ lepton

- -XYZ particles
- -Physics with D mesons
- -f_D and f_{Ds}
- -D_0-D_0 mixing
- -Charm baryons

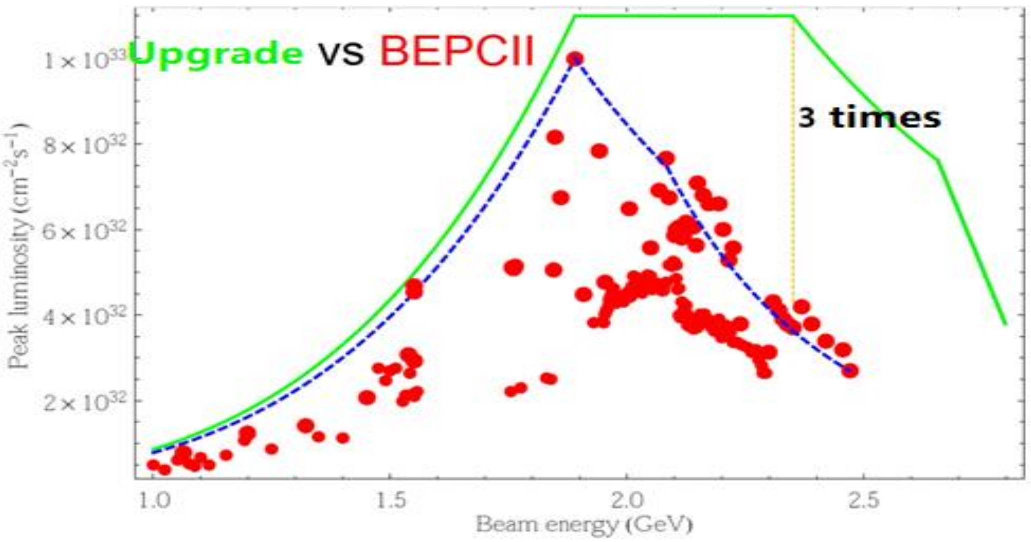
Beijing Electron Positron Collider II



E_{cm}= **1.84-4.95** GeV

Energy spread: $\Delta E \approx 5 \times 10^{-4}$

Peak luminosity: ~1.1×10^{33} $cm^{-2}s^{-1}$



BEPCII upgrade aims at:

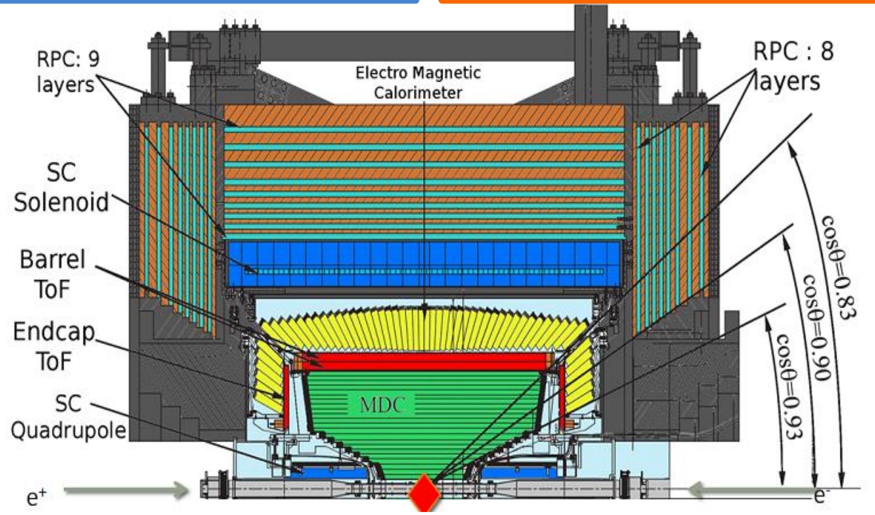
Increase luminosity by a factor of 3

& Increase beam energy to 2.8GeV

Beijing Spectrometer (BESIII)

Electromag. Calorimeter
CsI(Tl): L=28 cm
Barrel σ_E=2.5%
Endcap σ_E=5.0%

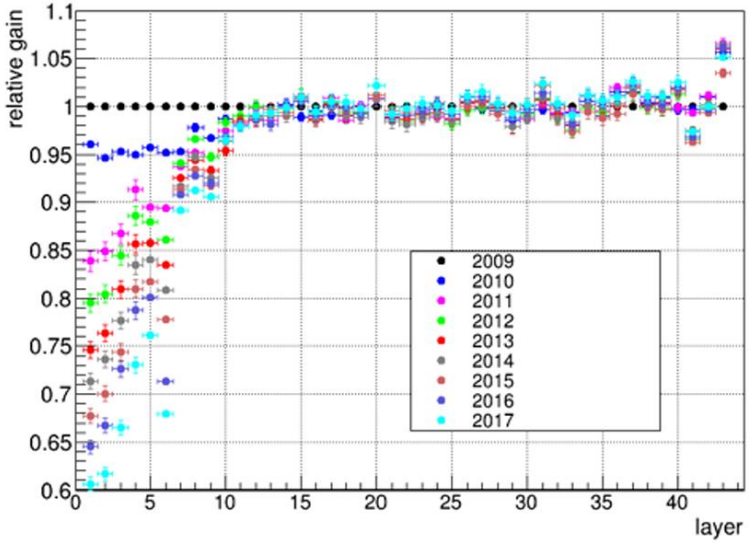
Muon Counter (RPC)
Barrel: 9 layers
Endcap: 8 layers
$\sigma_{spatial}$: 1.48 cm



Main Drift Chamber
Small cell, 43 layer
σ_{xy}=130 μm
dE/dx~6%
σ_p/p= 0.5% at 1 GeV

Time Of Flight
Plastic scintillator
σ_T(barrel): 80 ps
σ_T(endcap): 110 ps (upgrade to 65 ps with MRPC)

Ageing problems of inner MDC



Upgrade inner drift chamber with CGEM

A Wishlist of BESIII since 2019

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

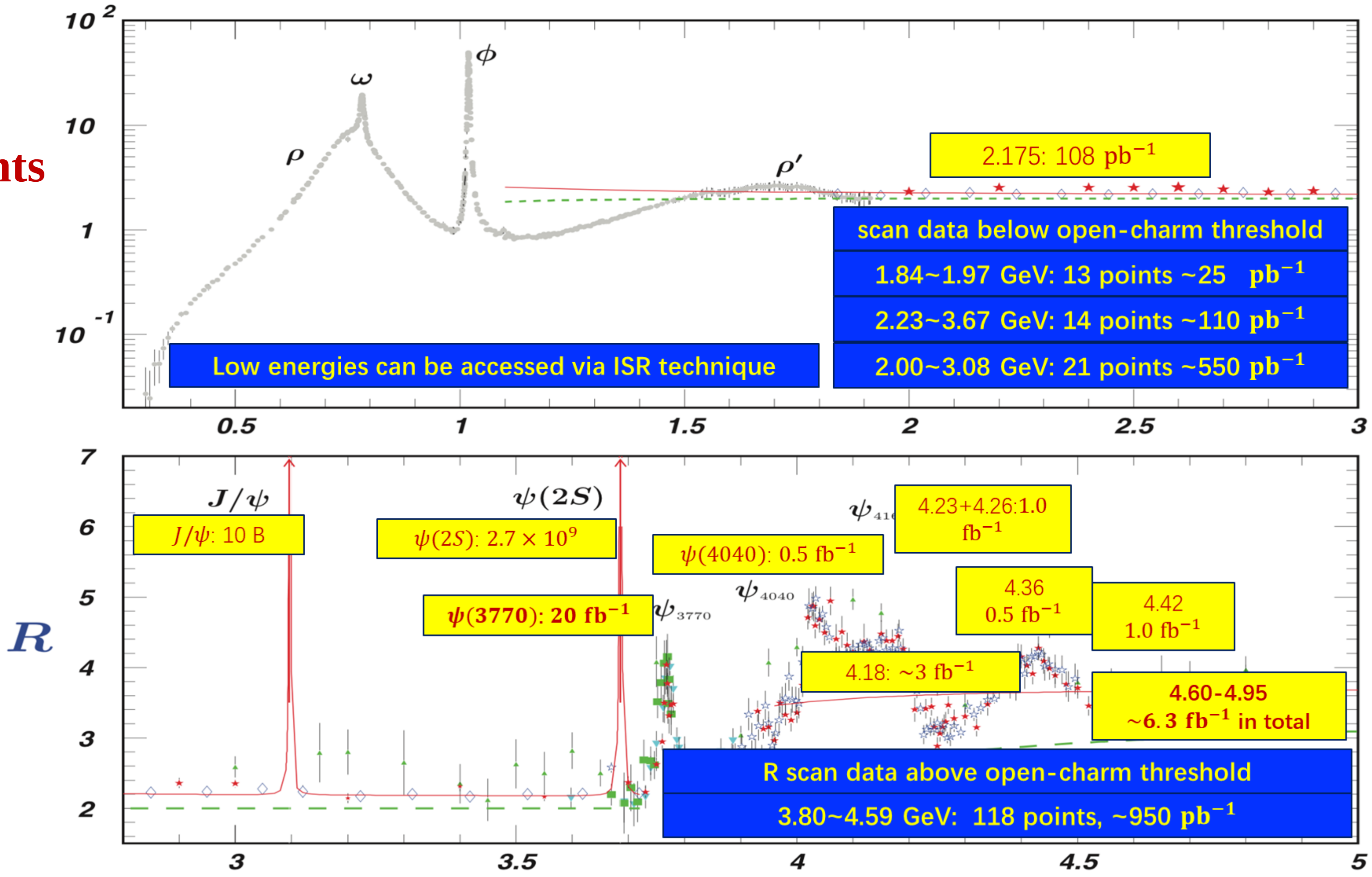
BESIII White Paper
CPC44, 040001 (2020)

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	$\Sigma_c\Sigma_c$ 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

See G.S.Huang's talk

BESIII Data Samples

- $>40\ pb^{-1}$ data collected
- **Large Charmonium(-like) events**
  - 1×10^{10} J/ψ events
  - 2.7×10^{9} ψ' events
  - 20 fb^{-1} at 3.773 GeV ($D\bar{D}$ pair)
- **Unique scan data:**
  - Baryon pair threshold
  - τ lepton threshold
  - Chic1 threshold
  - Λ_c pair threshold
  - R scan
  - XYZ scan



Threshold/pair production, quantum entanglement, clean env. etc.

BESIII Physics Highlights

- Inclusive production and **fragmentation functions**
- Probe **EM structure** of baryons
- **Hyperon physics** from J/ψ and $\psi(3686)$ decays
- EM and strong interference between vector meson
- Light **hadron** & searches of **exotics**
- Charmonium and **XYZ** spectroscopy
- **Charm physics**: $D^{0/\pm}, D_s^+, \Lambda_c^+$
- …

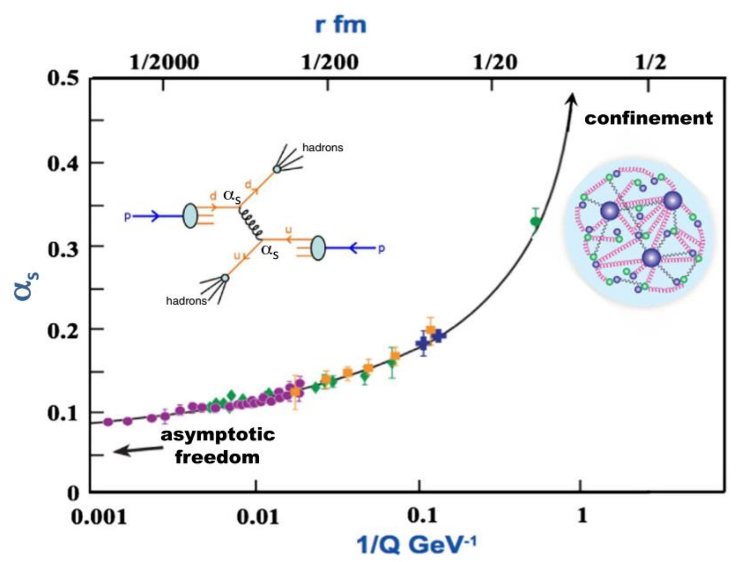
Submitted: 690, **Published: 653**

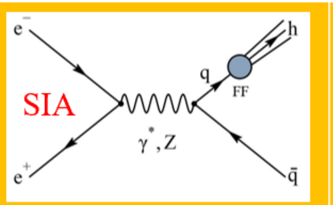
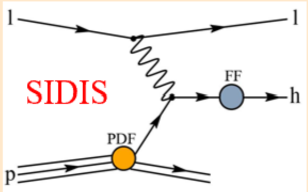
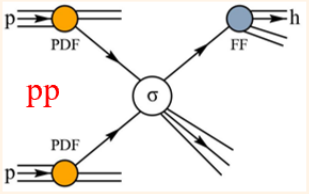
PRL&Nature (physics, communication): 127 published

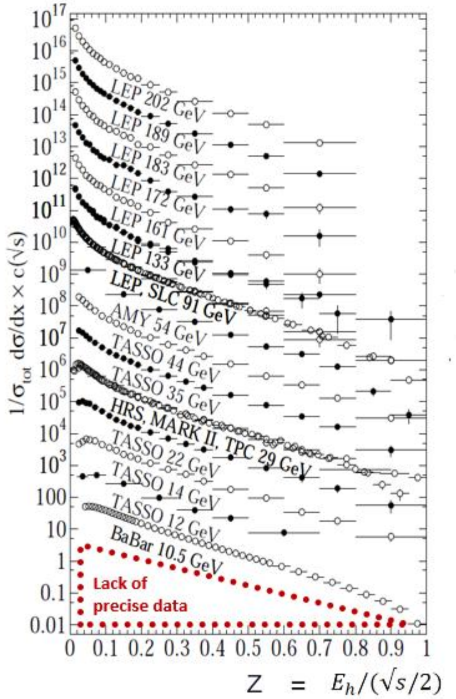
Overview of BES III @ 第十九届中高能核物理大会

http://cicpi.ustc.edu.cn/indico/contributionDisplay.py?contribId=275&sessionId=8&confId=3658

Fragmentation Functions (FFs)

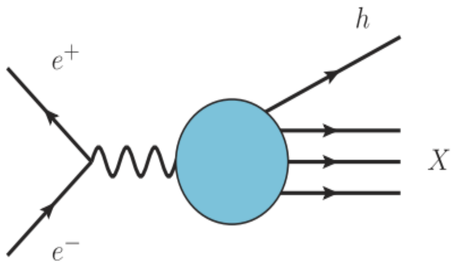


	e^+e^-: $\sigma = \sum_q \sigma(e^+e^- \to q\bar{q}) \otimes FF$ • No PDFs necessary • Calculations know at NNLO • Flavor structure not directly accessible
	SIDIS: $\sigma = \sum_q PDF \otimes \sigma(eq \to e'q') \otimes FF$ • Depend on unpolarized PDFs • Flavor structure directly accessible • FFs and PDFs
	pp: $\sigma = \sum_q PDF \otimes PDF \otimes \sigma(q_1 q_1 \to q_1' q_2') \otimes FF$ • Depend on unpolarized PDFs • Leading access to gluon FF • Parton momenta not directly known



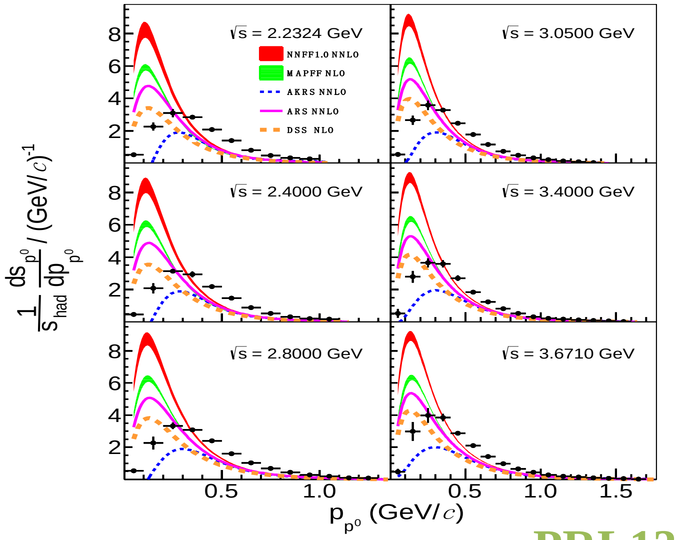
- Fragmentation functions (FFs) encode the long-distance dynamics of **quark/gluons hadronization** in a hard-scattering process, where e^+e^- collider provide the **cleanest input** for FFs fitting
- To accurately extract **Parton Distribution Functions**, precise FFs are required
- There lacks FFs data **at low energy region** from e^+e^- collider

Unpolarized FFs at BESIII

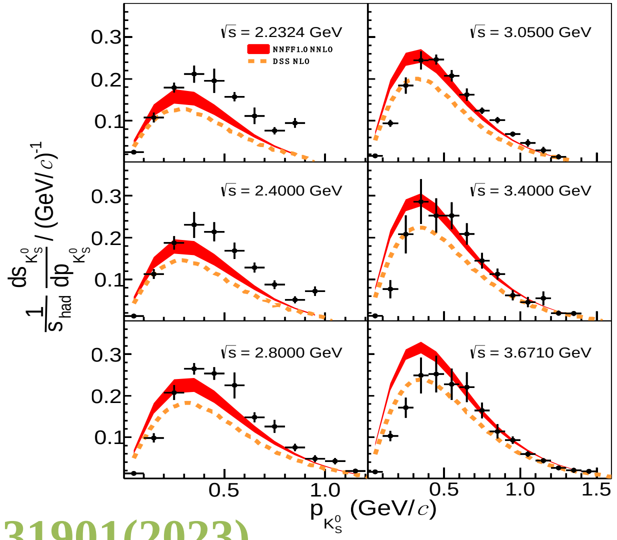


- **Semi-inclusive hadron production:** $E_p \frac{d\sigma_{e^+e^-\to hX}}{d^3p}(s,p) = \sum_f \int \frac{dz}{z^2} D_{h/f}(z,\mu^2) \times E_k \frac{d\hat{\sigma}_{e^+e^-\to \hat{k}X}}{d^3\hat{k}}(s,\hat{k},\mu^2) + \mathcal{O}\left[\frac{\Lambda^2_{\mathrm{QCD}}}{Q^2}\right]$
- **Experimental observable** $\frac{1}{\sigma_{tot}(e^+e^- \to hadrons)} \frac{d\sigma(e^+e^- \to h + X)}{d P_h} \sim \sum_q e_q^2 D_1^{h/q}(z)$ at leading order
- $D_q^h(z)$: FFs of a quark into a hadron, with hadron carries $z = 2E_h/\sqrt{s}$ of parton's momentum

$\pi^0 + X$

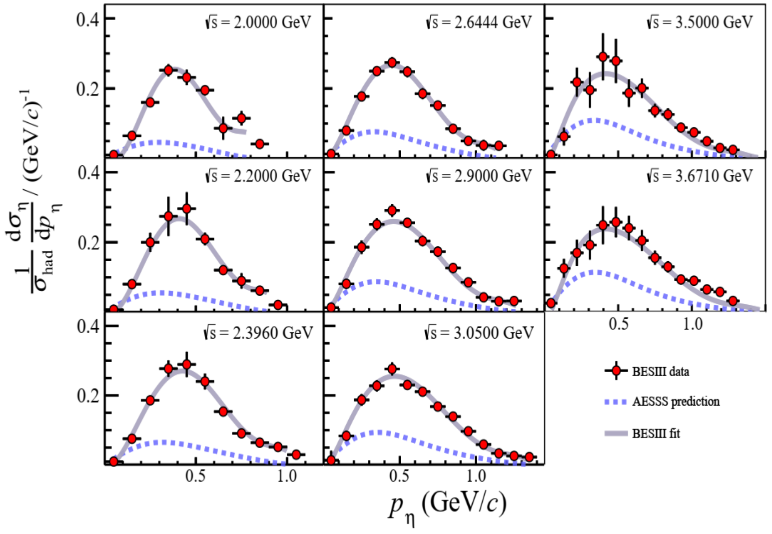


$K_s + X$



PRL130, 231901(2023)

$\eta + X$



PRL133, 021901 (2024)

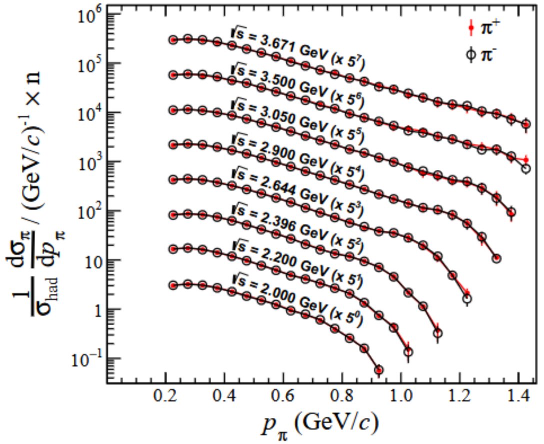
- To well describe data, **NNLO accuracy**, **hadron mass correction**, **higher twist contributions** etc. are needed

Unpolarized FFs at BESIII

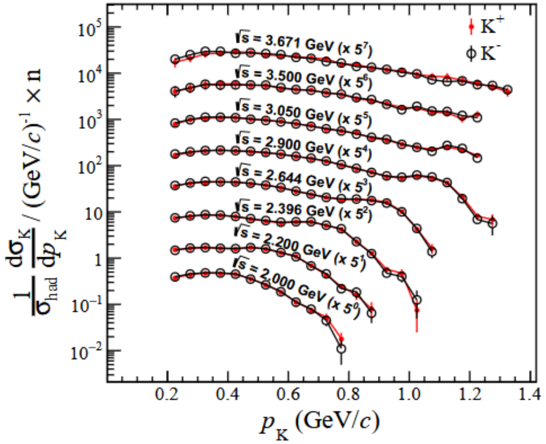
- $\boldsymbol{\pi^{+/-} + X}$ consistent with $\boldsymbol{\pi^{0} + X}$
- $\boldsymbol{K^{+/-} + X}$ systematically higher than $\boldsymbol{K_{s} + X}$ by a factor of ~ 1.4.
- **Global data fit** at NNLO under Nonperturbative Physics Collaboration
- Results support the validity of **isospin symmetry** in parton fragmentation processes.

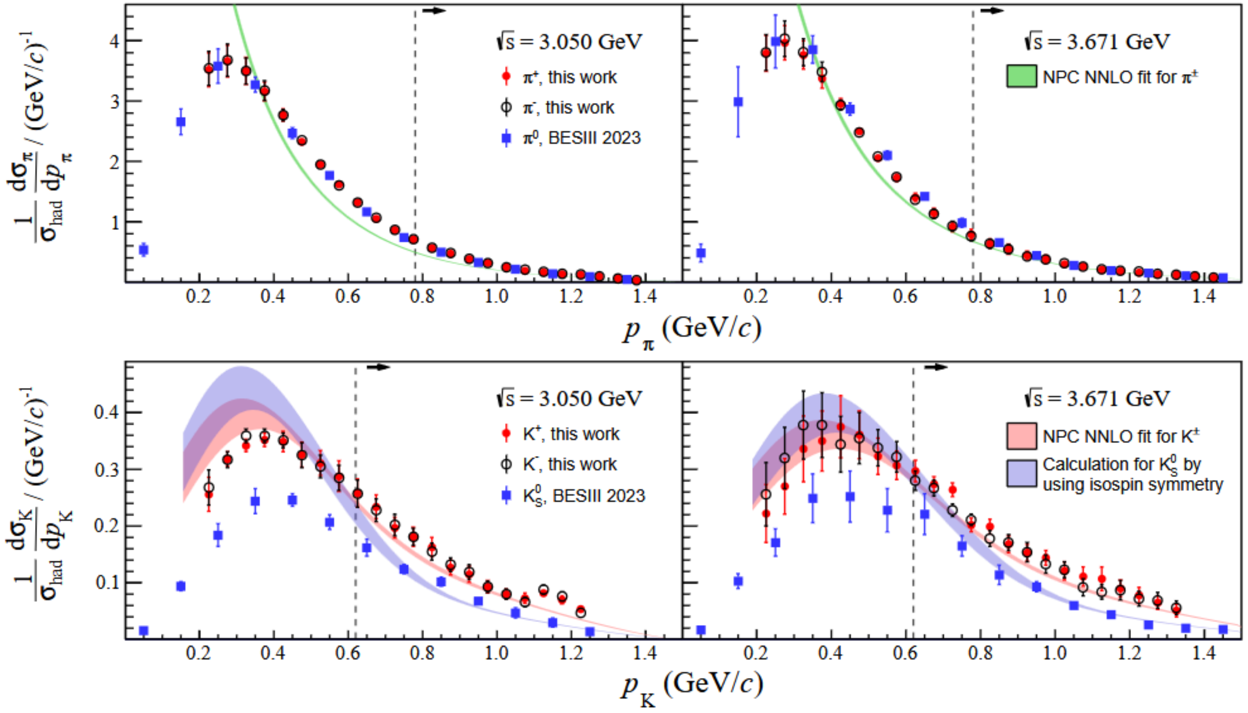
arXiv:2502.16084

$\boldsymbol{\pi^{+/-} + X}$



$\boldsymbol{K^{+/-} + X}$





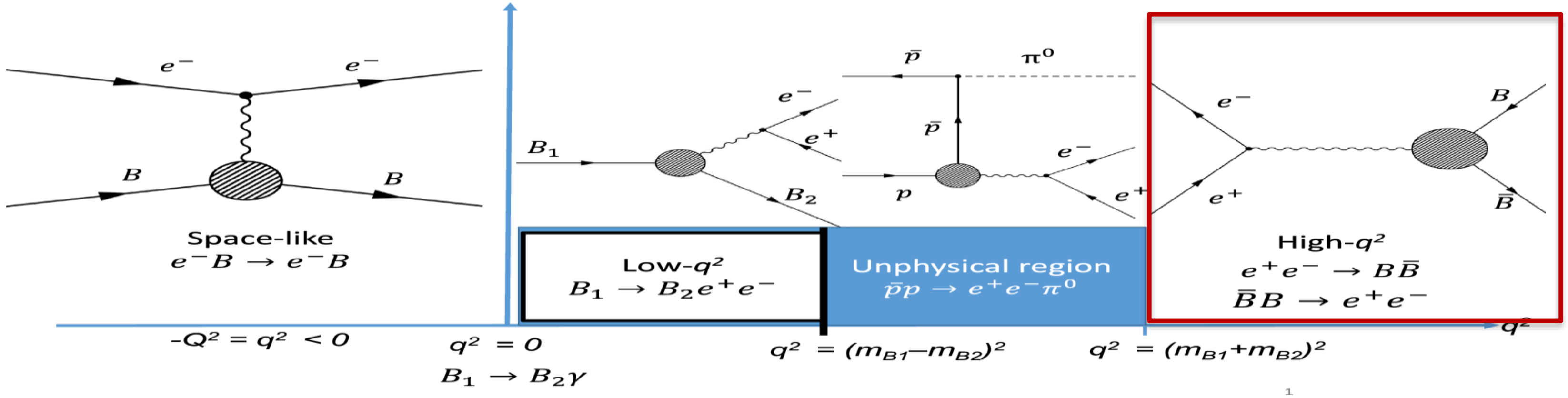
Electromagnetic Form Factors of Baryons

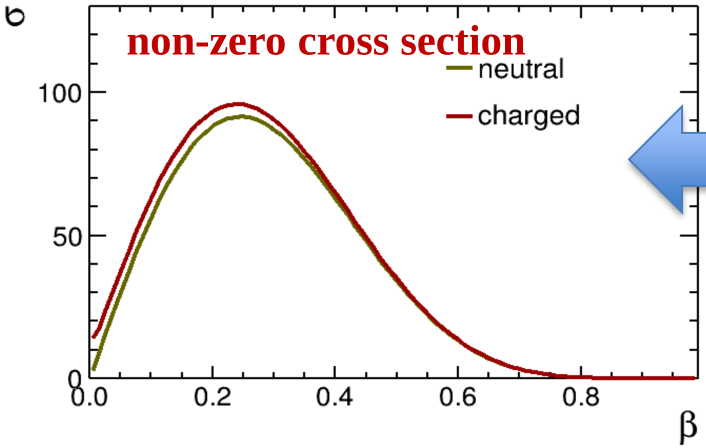
- EMFFs are **fundamental properties of the baryon**
  - Connected to charge, magnetization distribution
  - Crucial testing ground for models of the nucleon internal structure

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

Sachs FFs: $\boldsymbol{G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)}$

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

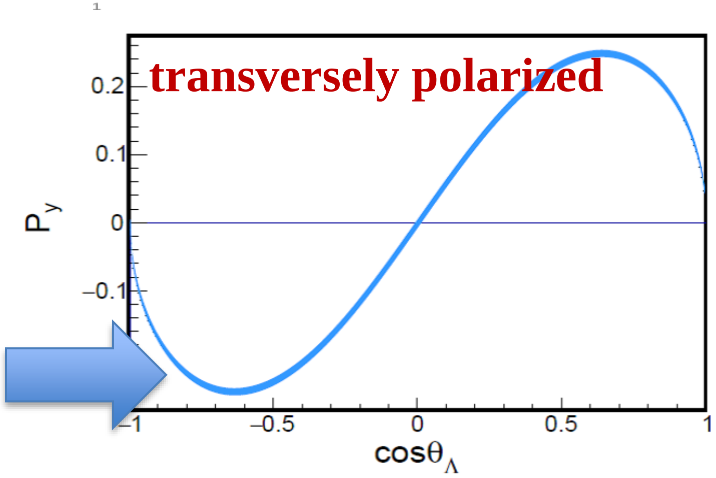




Features in time-like region:

$$\sigma_{B\bar{B}} = \frac{4\pi\alpha^2 \boldsymbol{C}\beta}{3q^2}\left[\left|G_M\right|^2 + \frac{1}{2\tau}\left|G_E\right|^2\right]$$

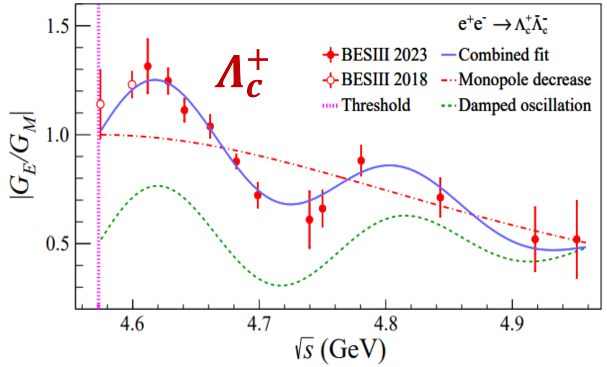
$$P_y = -\frac{\sin 2\theta\, \mathbf{Im}[\boldsymbol{G_E G_M^*}]/\sqrt{\tau}}{\frac{|G_E|^2\sin^2\theta}{\tau} + |G_M|^2(1+\cos^2\theta)}$$

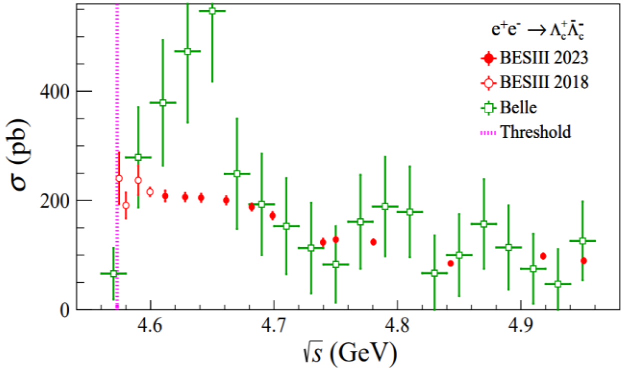


EMFFs of Λ_c^+ and nucleon

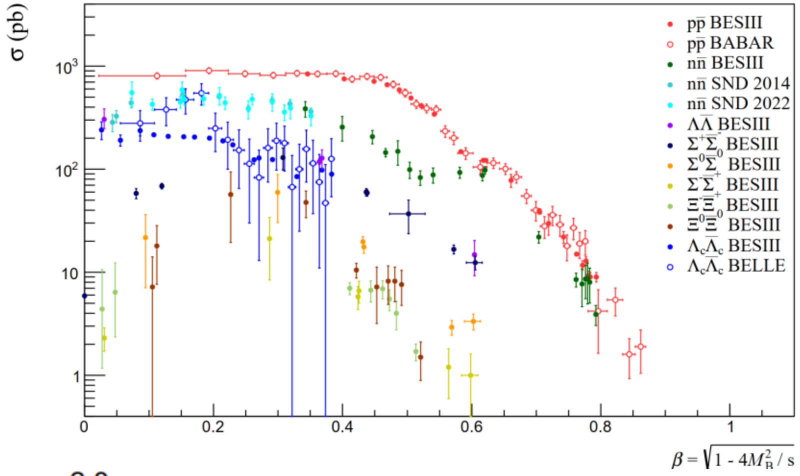
- A step in $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$, followed by a **plateau**. **Threshold effects** observed in various baryons
- Similar **oscillation** in Λ_c^+ **$|G_E/G_M|$** distribution as proton observed
- **Non-zero G_E** of **neutron** indicates inner charge distribution

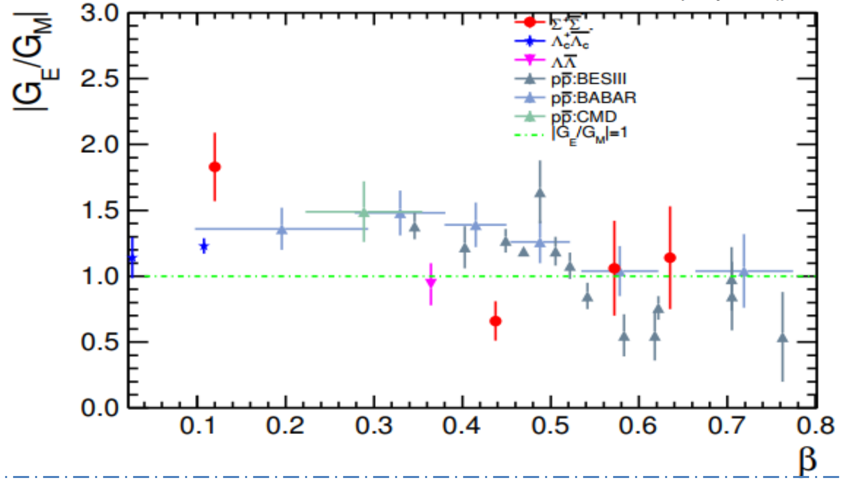
PRL131,191901 (2023)



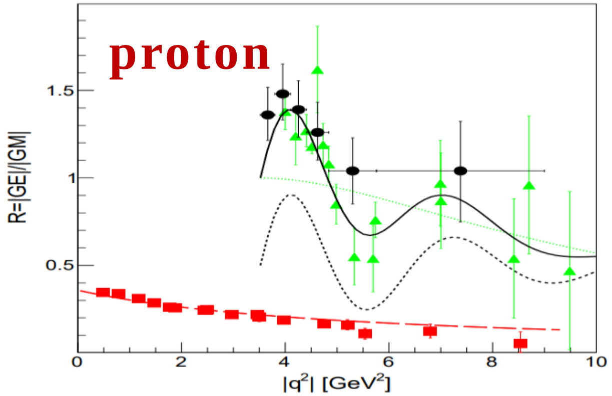


Updated from NSR8, 11, nwab187 (2021)

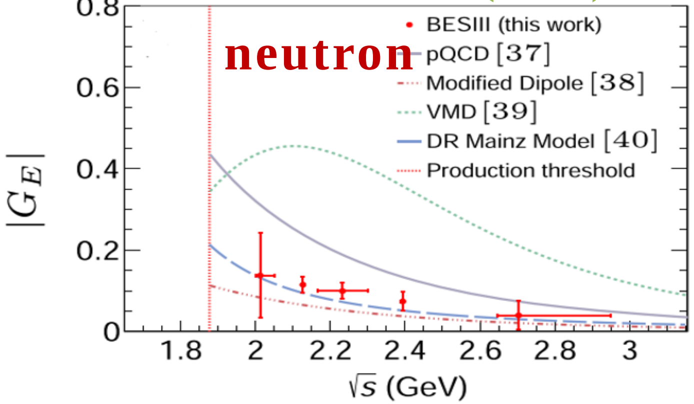




PRL124, 042001 (2020)



PRL130, 151905 (2023)



EMFF phase of hyperons

- The process $e^+e^- \to \Sigma^+(\to p\pi^0)\bar{\Sigma}^+(\to \bar{p}\pi^0)$ is formalized by joint angular distribution:

$$\omega(\xi,\Delta\Phi,\alpha_\psi,\alpha_-,\alpha_\gamma) = 1+\alpha_\psi cos^2\theta_\Lambda$$ Unpolarized part

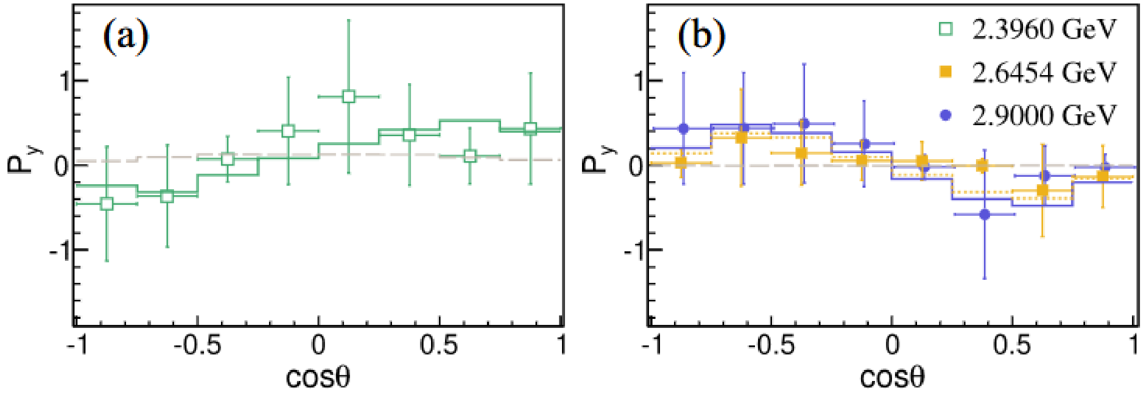
$$+\alpha_-\alpha_\gamma\left[sin^2\theta_\Lambda\left(n_{1,x},n_{2,x}-\alpha_\psi n_{1,y},n_{2,y}\right)+\left(cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z},n_{2,z}\right]$$
$$+\alpha_-\alpha_\gamma\sqrt{1-\alpha_\psi{}^2}\,cos(\Delta\Phi)\,sin\theta_\Lambda cos\theta_\Lambda\left(n_{1,x},n_{2,z}+n_{1,z},n_{2,x}\right)$$ Correlated part

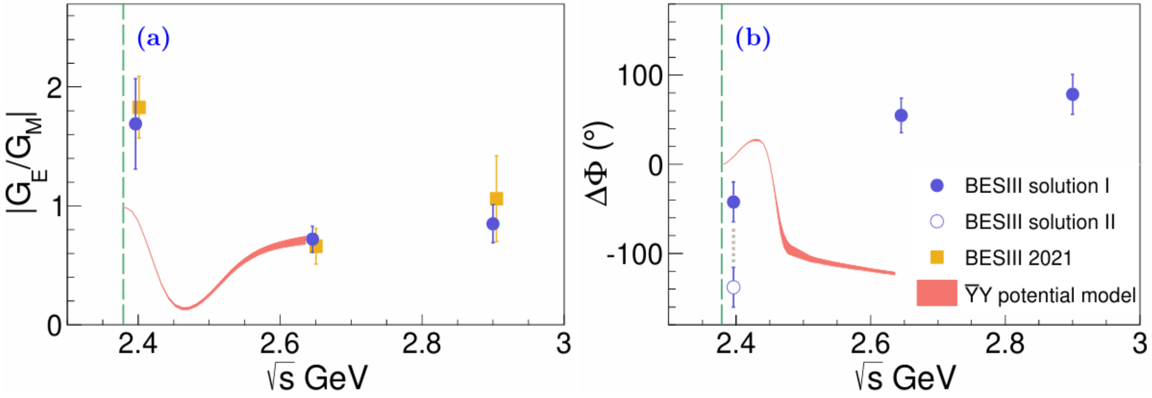
$$+\sqrt{1-\alpha_\psi{}^2}\,sin(\Delta\Phi)\,sin\theta_\Lambda cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_\gamma n_{2,y}\right)$$ Polarized part

- $|G_E/G_M|$ and $\Delta\Phi$ line-shape is compared with **$\bar{Y}Y$ model** (PRD 103, 014028 (2021)), different tendency in $\Delta\Phi$
- The still increasing relative phase indicates the **asymptotic threshold** has not yet been reached

$$P_y = -\frac{\sin 2\theta\ \mathrm{Im}[G_E G_M^*]/\sqrt{\tau}}{|G_E|^2\sin^2\theta/\tau+|G_M|^2(1+\cos^2\theta)}$$

PRL132,081904 (2024)



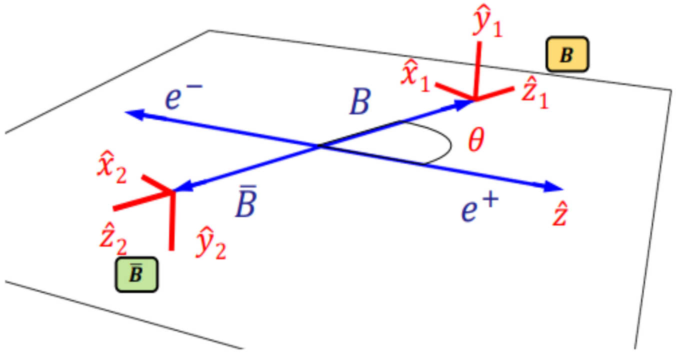


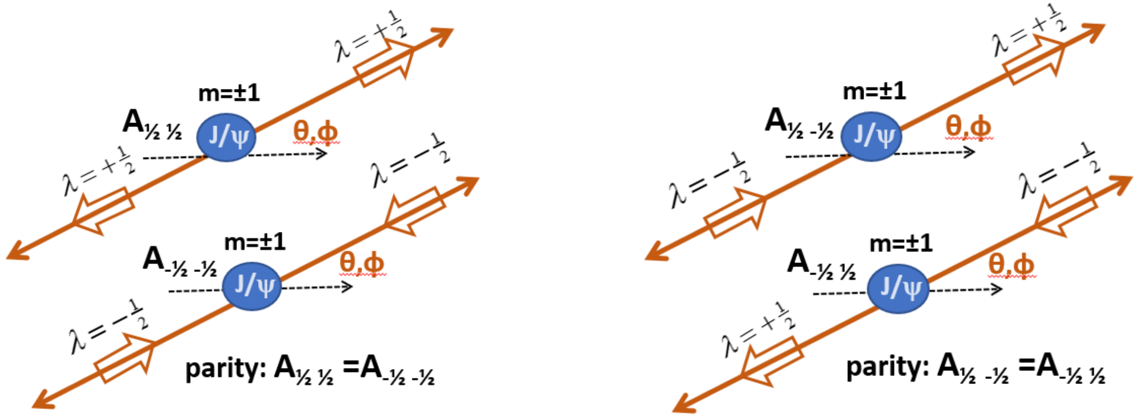
More details on baryon EMFFs see J. F. Hu's talk

Hyperon Physics at BESIII

10 billion J/ψ events collected

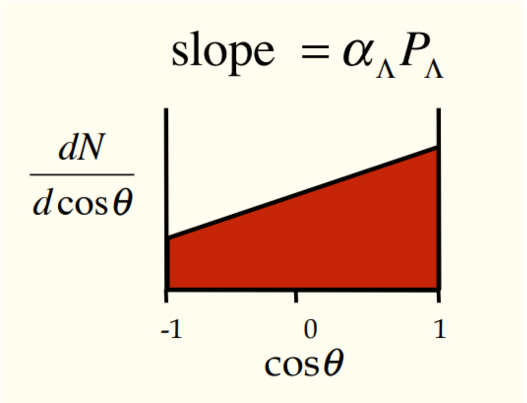
- Large BRs in J/ψ decays ➔ **tens millions hyperons pairs**
- Transversely polarization due to non-zero phase of two helicity amplitudes





Anisotropic baryon decay distribution

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_\Lambda P_\Lambda \cos\theta)$$



$B\bar{B}$ mode	$\mathcal{B}(\times 10^{-3})$	α_ψ	$\Delta\Phi$	P_y^{max} / $\cos\theta^{max}$
$J/\psi \to \Lambda\bar{\Lambda}$	1.89 ± 0.09	0.475 ± 0.003	0.752 ± 0.008	**25%** / 0.64
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.07 ± 0.04	-0.508 ± 0.007	-0.27 ± 0.02	**16%** / 0.82
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.17 ± 0.03	-0.45 ± 0.02	0.09 ± 0.02	5% / 0.80
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.17 ± 0.04	0.66 ± 0.06	1.16 ± 0.02	**27%** / 0.61
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.97 ± 0.08	0.59 ± 0.02	1.21 ± 0.05	**30%** / 0.62

Hyperon Physics: non-leptonic decays

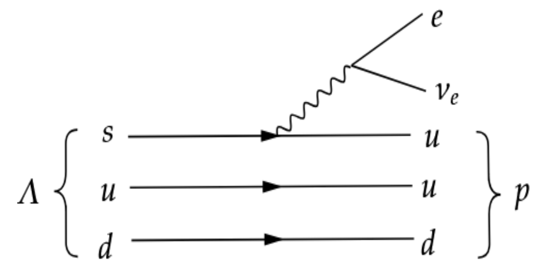
- **Observables:**

$$\boldsymbol{\Gamma} = \frac{e^2 G_F^2}{\pi}\left(|S|^2 + |P|^2\right)$$

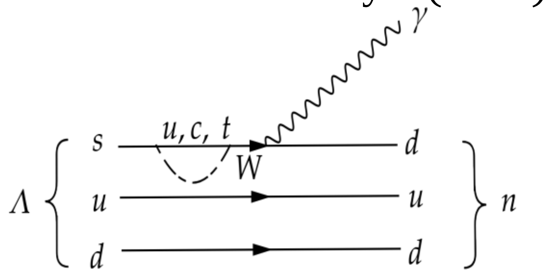
$$\boldsymbol{\alpha_Y} = \frac{2\,\mathrm{Re}\,(S^* P)}{|S|^2 + |P|^2}, \quad \beta_Y = \frac{2\,\mathrm{Im}\,(S^* P)}{|S|^2 + |P|^2}, \quad \gamma_Y = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

$$\beta_Y = \sqrt{1-\alpha_Y^2}\sin \boldsymbol{\phi_Y} \qquad \gamma_Y = \sqrt{1-\alpha_Y^2}\cos\phi_Y$$

Hadronic weak decay $\mathcal{O}(1)$

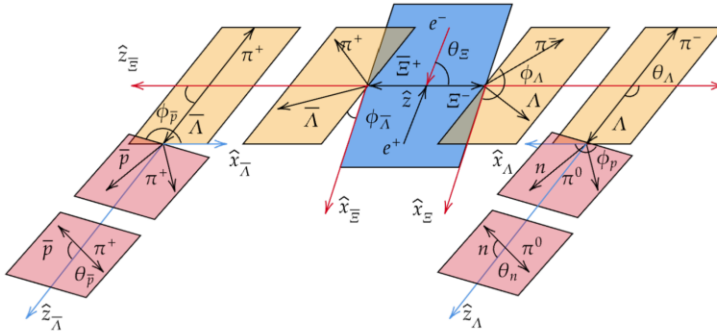


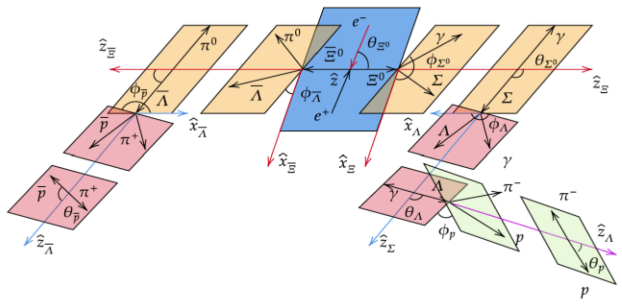
Radiative weak decay $\mathcal{O}(10^{-3})$



- **A joint angular analysis of $J/\psi \to Y^- \bar{Y}^+$**

$$\mathcal{W}(\xi;\omega) = \sum_{\mu,\nu=0}^{3} C_{\mu\nu} \sum_{\mu',\nu'=0}^{3} a^{\Xi}_{\mu\mu'} a^{\Xi}_{\nu\nu'} a^{\Lambda}_{\mu' 0} a^{\bar{\Lambda}}_{\nu' 0}$$





Spin density matrix ($J/\psi \to Y^- \bar{Y}^+$):

$$C_{\mu\bar{\nu}} = 2\times\begin{pmatrix} 1+\alpha_\psi\cos^2\theta & 0 & \beta_\psi \sin\theta\cos\theta & 0 \\ 0 & \sin^2\theta & 0 & \gamma_\psi\sin\theta\cos\theta \\ -\beta_\psi\sin\theta\cos\theta & 0 & \alpha_\psi\sin^2\theta & 0 \\ 0 & -\gamma_\psi\sin\theta\cos\theta & 0 & -(\alpha_\psi+\cos^2\theta) \end{pmatrix}$$

For $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ decay:

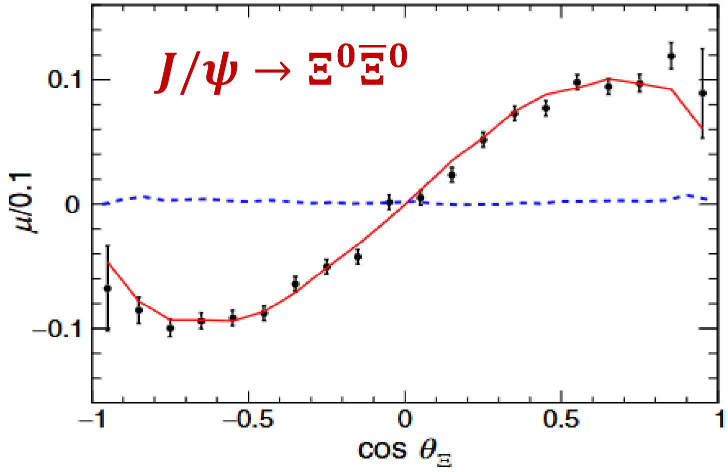
$$a_{\mu\mu'} = \begin{pmatrix} 1 & 0 & 0 & \alpha \\ \alpha\cos\phi\sin\theta & \gamma\cos\phi\cos\theta - \beta\sin\phi & -\beta\cos\phi\cos\theta - \gamma\sin\phi & \cos\phi\sin\theta \\ \alpha\sin\phi\sin\theta & \beta\cos\phi + \gamma\cos\theta\sin\phi & \gamma\cos\phi - \beta\cos\theta\sin\phi & \sin\phi\sin\theta \\ \alpha\cos\theta & -\gamma\sin\theta & \beta\sin\theta & \cos\theta \end{pmatrix}$$

For $\frac{1}{2}^+ \to \frac{1}{2}^+ + 1^-$ decay:

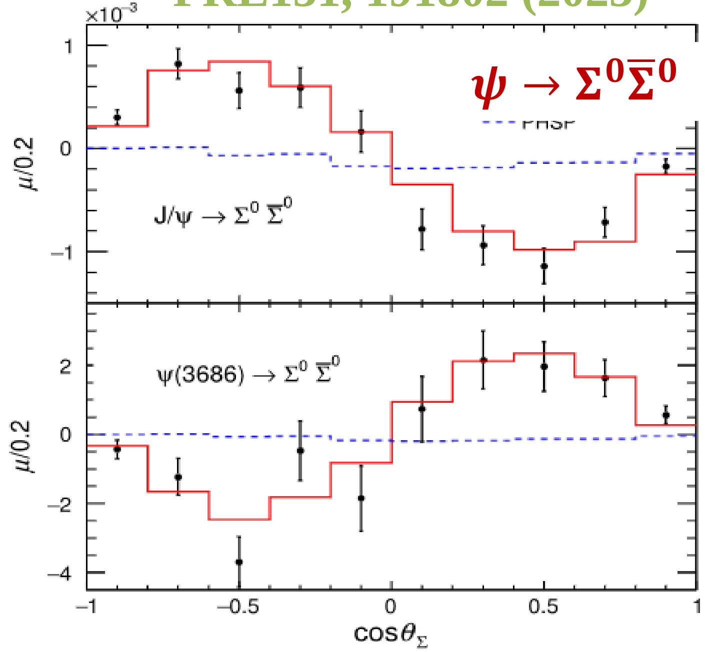
$$b_{\nu\nu'} = \begin{pmatrix} 1 & 0 & 0 & -\alpha \\ \alpha\cos\phi\sin\theta & 0 & 0 & -\cos\phi\sin\theta \\ \alpha\sin\theta\sin\phi & 0 & 0 & -\sin\theta\sin\phi \\ \alpha\cos\theta & 0 & 0 & -\cos\theta \end{pmatrix}$$

Hyperon Physics: non-leptonic decays

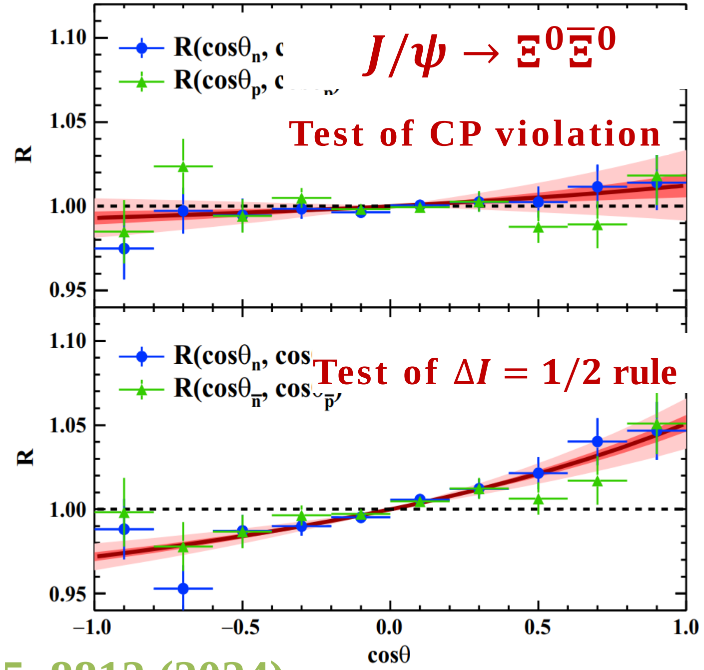
PRD108, L031106 (2023)



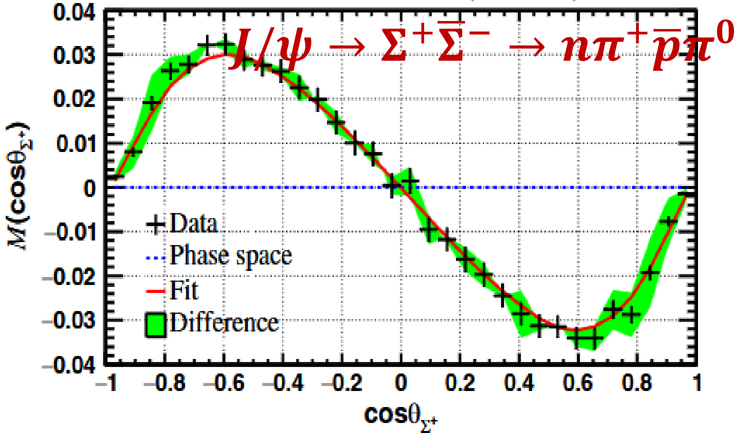
PRL131, 191802 (2023)



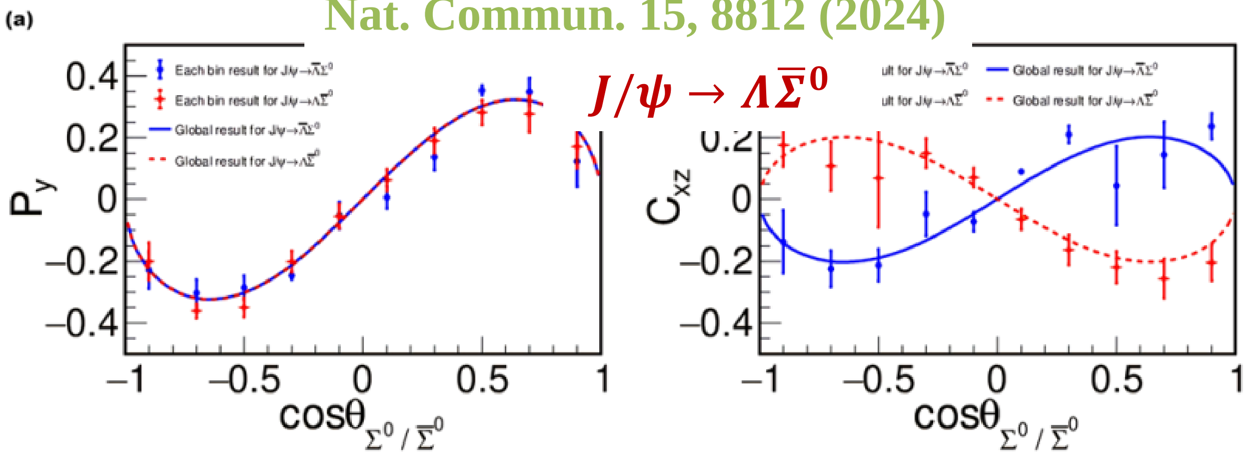
PRL132, 101801(2024)



PRL131, 191802 (2023)

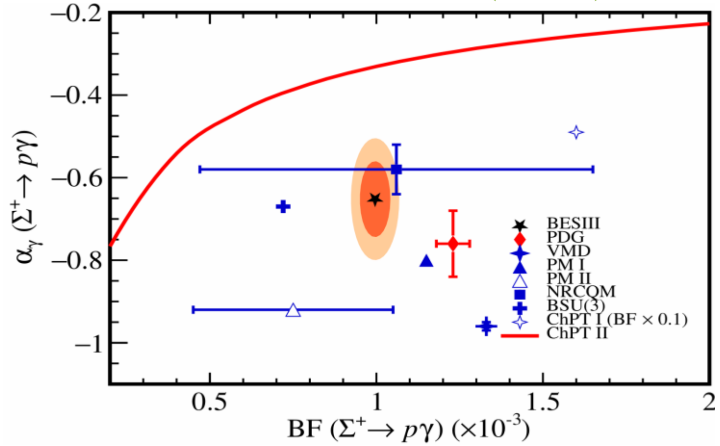


Nat. Commun. 15, 8812 (2024)

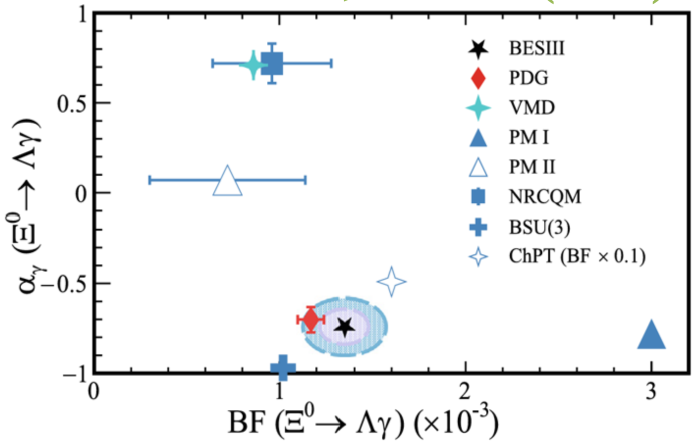


Hyperon Physics: non-leptonic decays

PRL130, 211901 (2023)

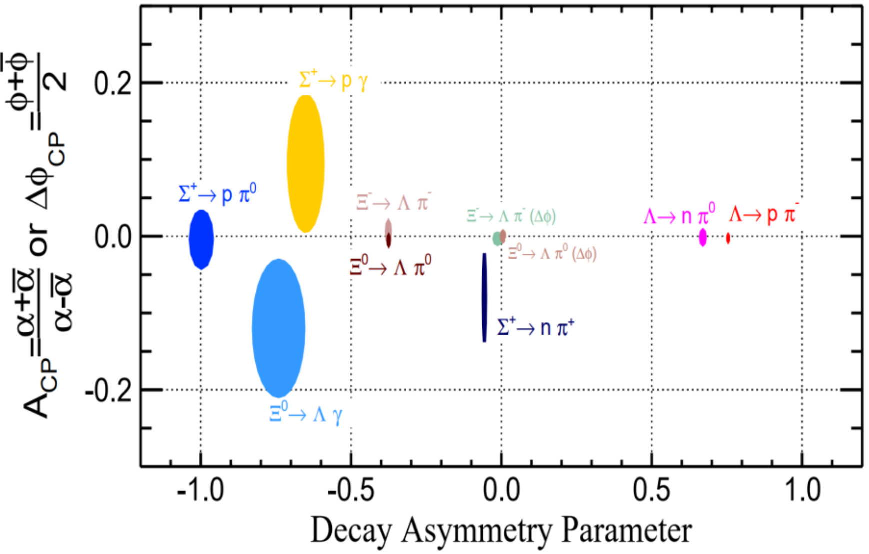


Sci.Bull. 70, 454-459 (2025)



Deacay	$\mathcal{B} \times 10^3$	α_γ
$\Sigma^+ \to p\gamma$	1.04(6)	$-0.76(8)$
$\Sigma^+ \to p\gamma$	0.996(28)	$-0.652(56)$
$\Lambda \to n\gamma$	0.832(66)	$-0.16(11)$
$\Xi^0 \to \Sigma^0\gamma$	3.33(10)	$-0.69(6)$
$\Xi^0 \to \Lambda\gamma$	1.17(7)	$-0.70(7)$
$\Xi^0 \to \Lambda\gamma$	1.347(85)	$-0.741(65)$
$\Xi^- \to \Sigma^-\gamma$	0.13(2)	–

***A recent review on radiative weak decay: CPL 42, 032401 (2025)**



- **Polarization** of hyperon disentangled
- Most precise **decay parameters** obtained
- More CPV observable constructed

$$A = \frac{\alpha+\overline{\alpha}}{\alpha-\overline{\alpha}}, \quad B = \frac{\beta+\overline{\beta}}{\beta-\overline{\beta}}.$$

$A_\Lambda = -0.0025 \pm 0.0046 \pm 0.0011$ (10billion J/ψ)

$A_\Sigma = -0.004 \pm 0.037 \pm 0.010$ (1.3 billion J/ψ)

$A_\Xi = 0.006 \pm 0.013 \pm 0.006$ (1.3 billion J/ψ)

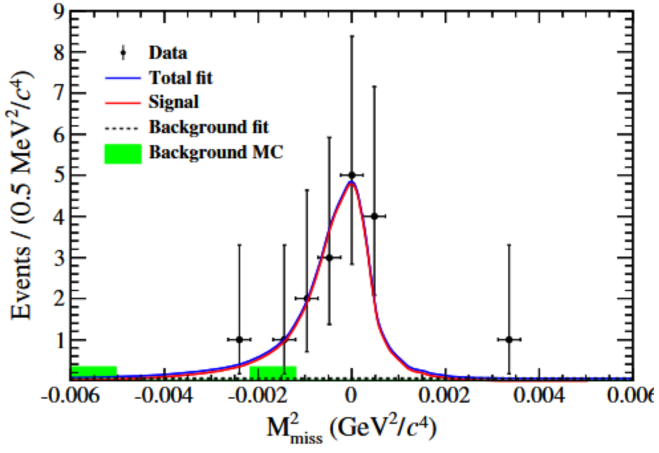
$\Delta\phi_\Xi = -0.005 \pm 0.014 \pm 0.003$ (1.3 billion J/ψ)

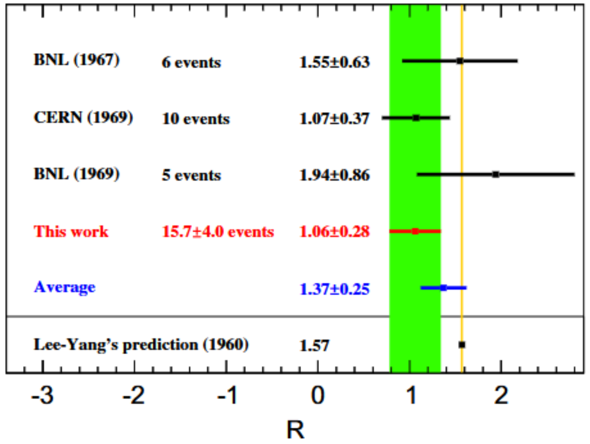
$\xi^P_\Lambda - \xi^S_\Lambda = (-1.1 \pm 2.1)^\circ \in \{-4.5^\circ, +2.1^\circ\}$ (90% C.L.)

Hyperon Physics: Semi-leptonic decay and rare decay

$\Sigma^+ \to \Lambda e^+ \nu_e$

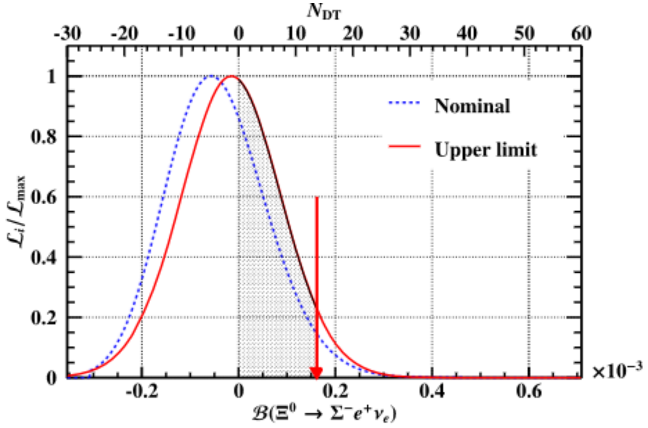
PRD107, 072010 (2023)

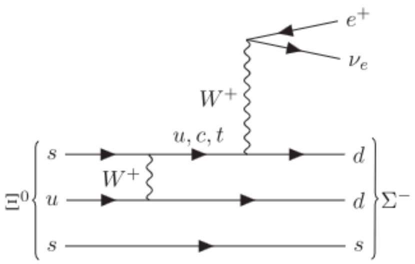




ΔS≠ΔQ: $\Xi^0 \to \Sigma^- e^+ \nu_e$

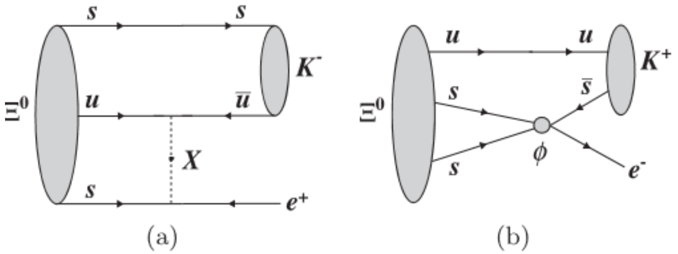
PRD107, 012002 (2023)





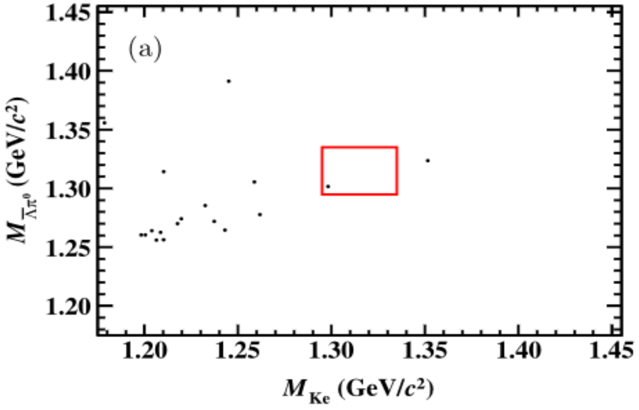
BNL & LNV: $\Xi^0 \to K^\pm e^\mp$

PRD108, 012006 (2023)



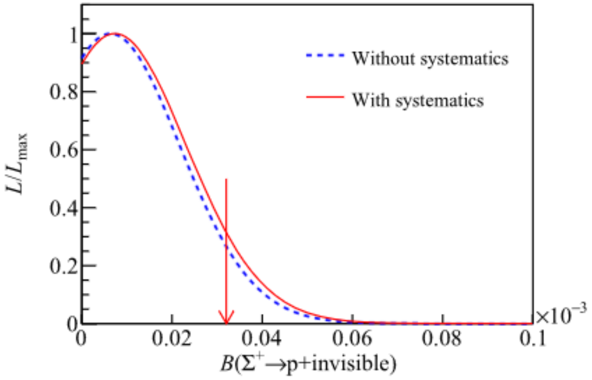
$\mathcal{B}(\Xi^0 \to K^- e^+) < 3.6 \times 10^{-6}$

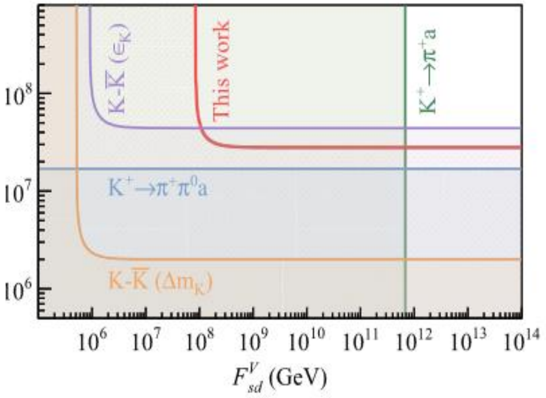
$\mathcal{B}(\Xi^0 \to K^+ e^-) < 1.9 \times 10^{-6}$



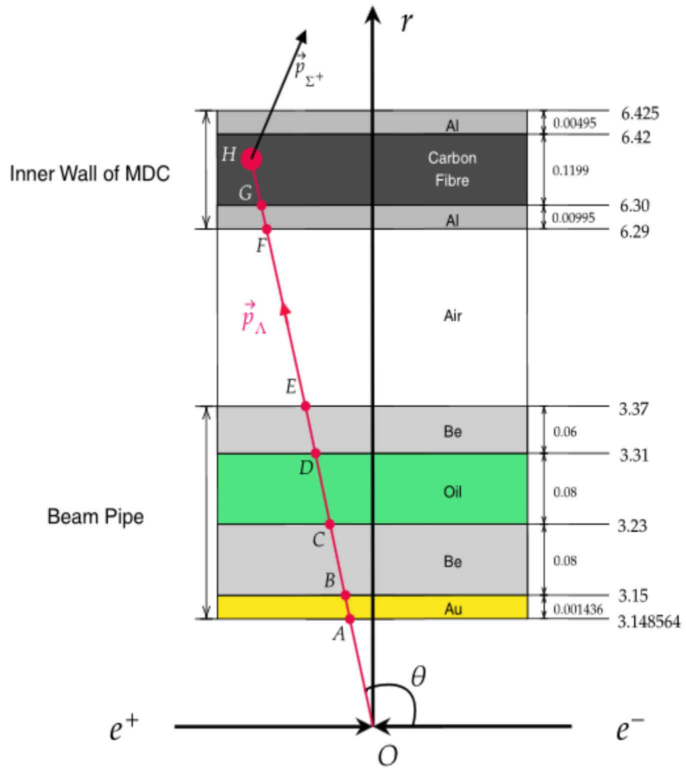
Massless dark photon:
$\Sigma^+ \to p + invisible$

PLB852, 138614 (2024)

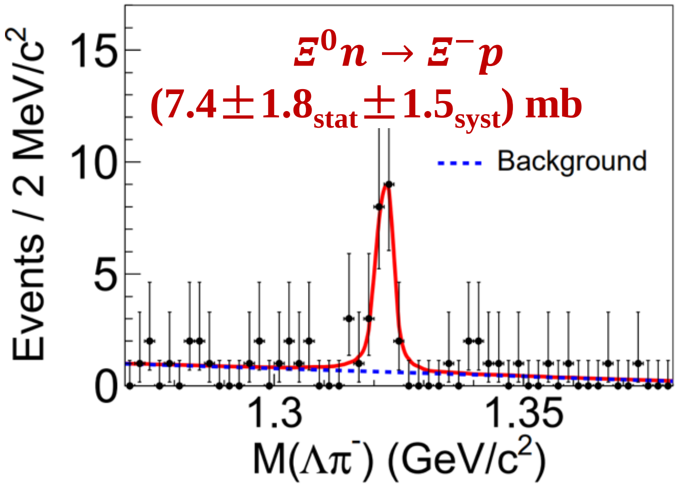




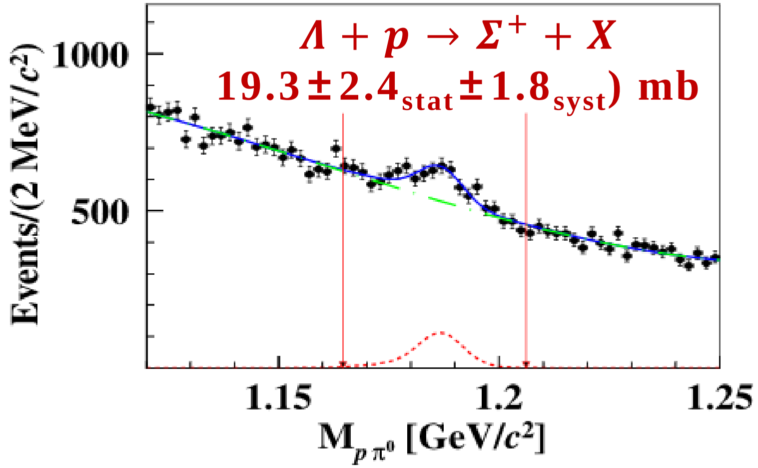
Hyperon-nucleon Interaction



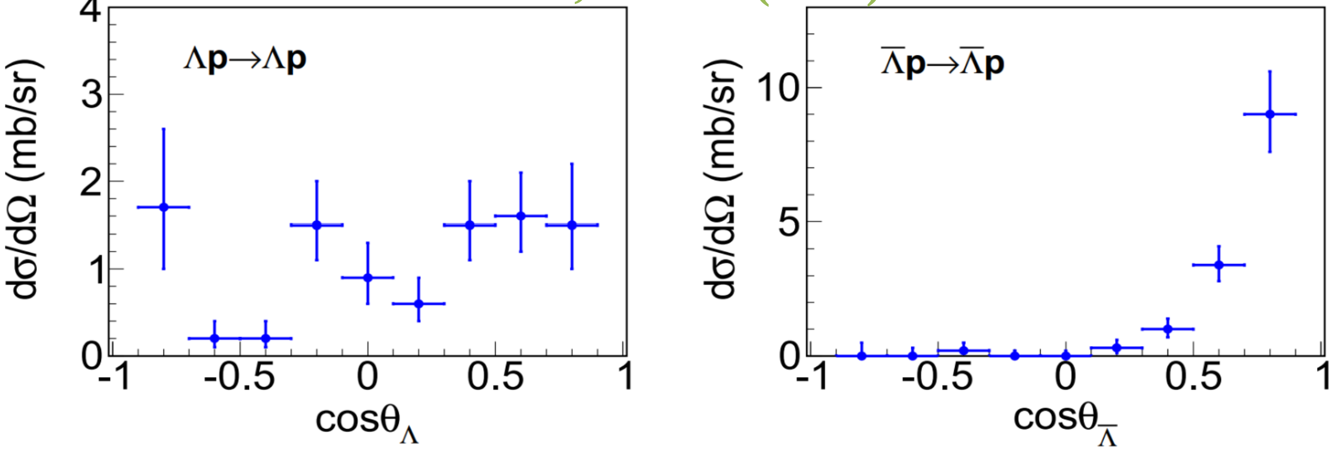
PRL130, 251902 (2023)



PRC109.L052201 (2024)



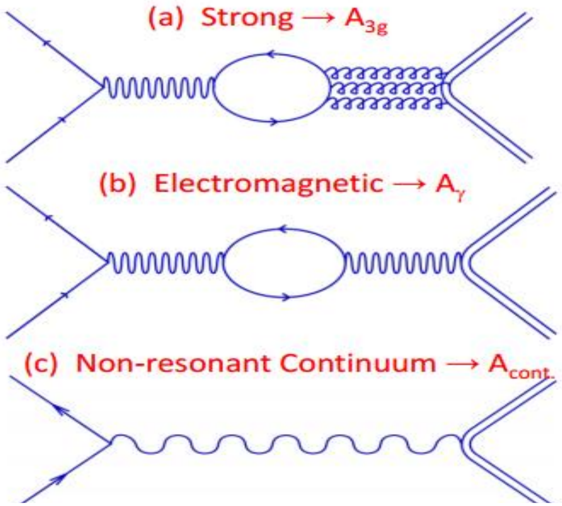
PRL132, 231902 (2024)



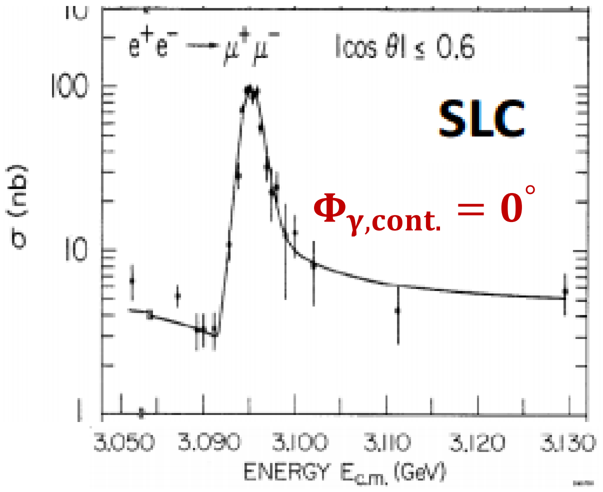
More details on hyperon physics see Tao Luo's talk

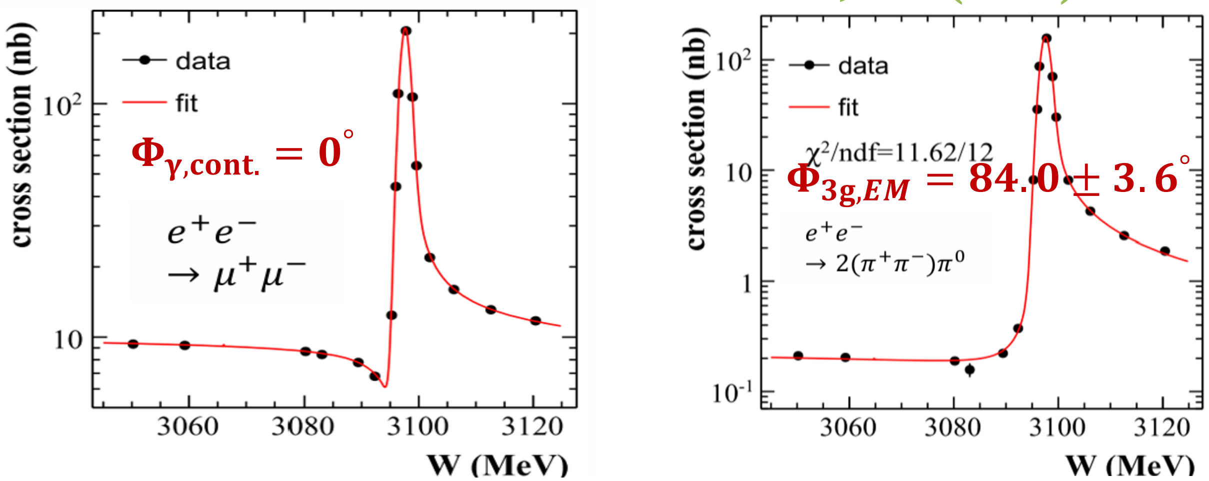
Strong and EM Interference in Vector Meson Decay

- With the **unique scan data** in the vicinity of **charmonium**, the relative phase between different interactions can be obtained.
  - SU(3) predicts phase between A_{3g} and A_{EM} is $\boldsymbol{\Phi_{3g,EM} \sim 90^\circ}$
  - Phase between A_{EM} and A_{cont}: $\boldsymbol{\Phi_{\gamma,cont.} = 0^\circ}$ from $e^+e^- \to J/\psi \to \mu^+\mu^-$
  - Phase between A_{3g} and A_{EM} is $\boldsymbol{\Phi_{3g,EM} \sim 90^\circ}$ from $e^+e^- \to J/\psi \to 2(\pi^+\pi^-)\pi^0$
  - More channels on 1^-0^-, 0^-0^-, 1^-1^-, 1^+0^- , $B\bar{B}$ need to be checked



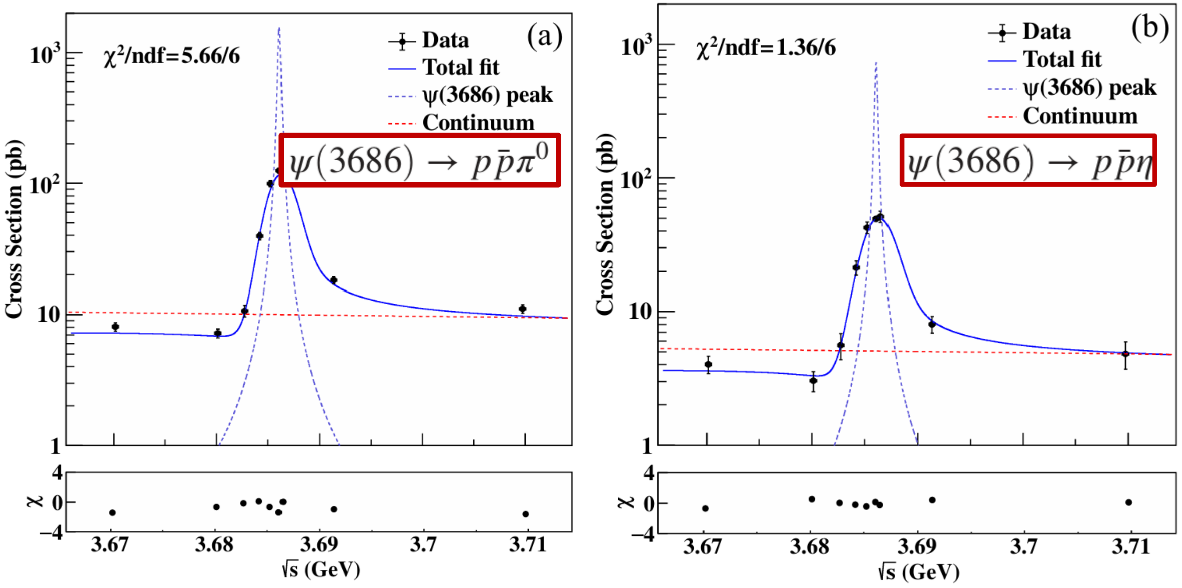
Phys. Lett. B 791, 375 (2019)





Strong and EM Interference in Vector Meson Decay

PRD 111, 032011 (2025)

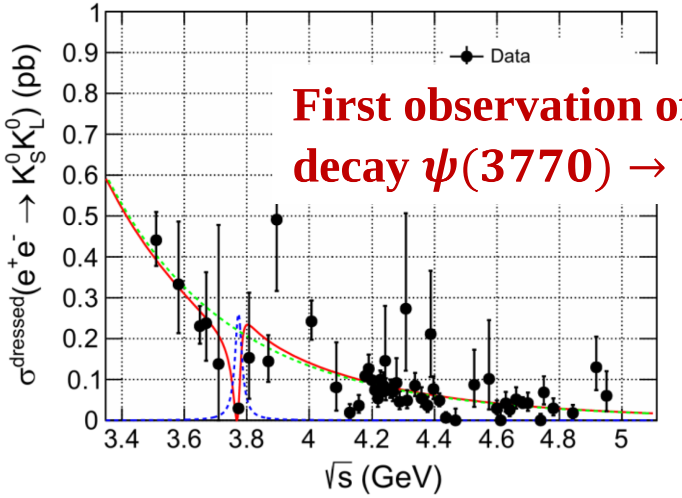


$\psi(3686) \to p\bar{p}\pi^0$	$\mathcal{B}_f\Gamma_{ee}$ (0.1 eV)	ϕ (°)	ΔE (MeV)	$\mathcal{B}_f$ ($\times 10^{-6}$)
Constructive solution	3.12 ± 0.26	65.0 ± 6.7	1.27 ± 0.09	$133.9 \pm 11.2 \pm 2.3$
Destructive solution	4.28 ± 0.32	-68.9 ± 5.7	1.27 ± 0.09	$183.7 \pm 13.7 \pm 3.2$
$\psi(3686) \to p\bar{p}\eta$	$\mathcal{B}_f\Gamma_{ee}$ (0.1 eV)	ϕ (°)	ΔE (MeV)	$\mathcal{B}_f$ ($\times 10^{-6}$)
Constructive solution	1.44 ± 0.15	58.9 ± 14.1	1.39 ± 0.14	$61.5 \pm 6.5 \pm 1.1$
Destructive solution	1.98 ± 0.16	-63.8 ± 12.1	1.39 ± 0.14	$84.4 \pm 6.9 \pm 1.4$

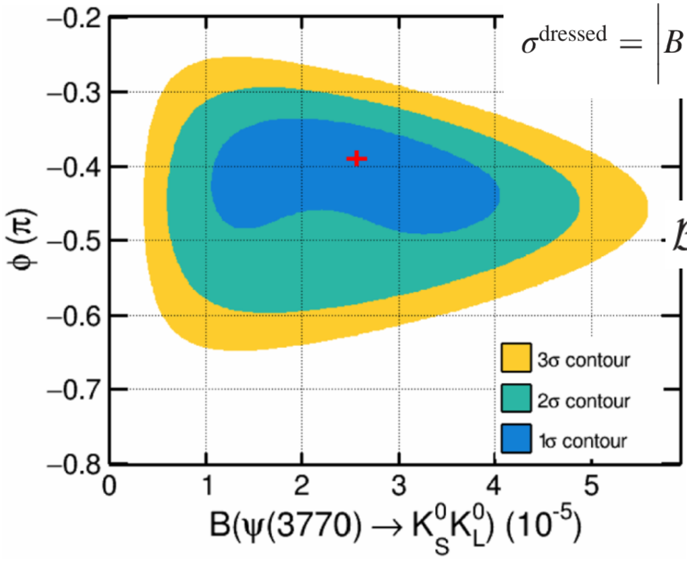
The deviations from PDG results are attributed mainly to the absence of **interference effects** in the previous measurements.

PRL 132, 131901 (2024)

First observation of the charmless decay $\psi(3770) \to K_S^0 K_L^0$



$$\sigma^{\text{dressed}} = \left| BW \cdot e^{i\phi} + \frac{a}{(\sqrt{s})^n} \cdot \sqrt{\Phi(\sqrt{s})} \right|^2$$

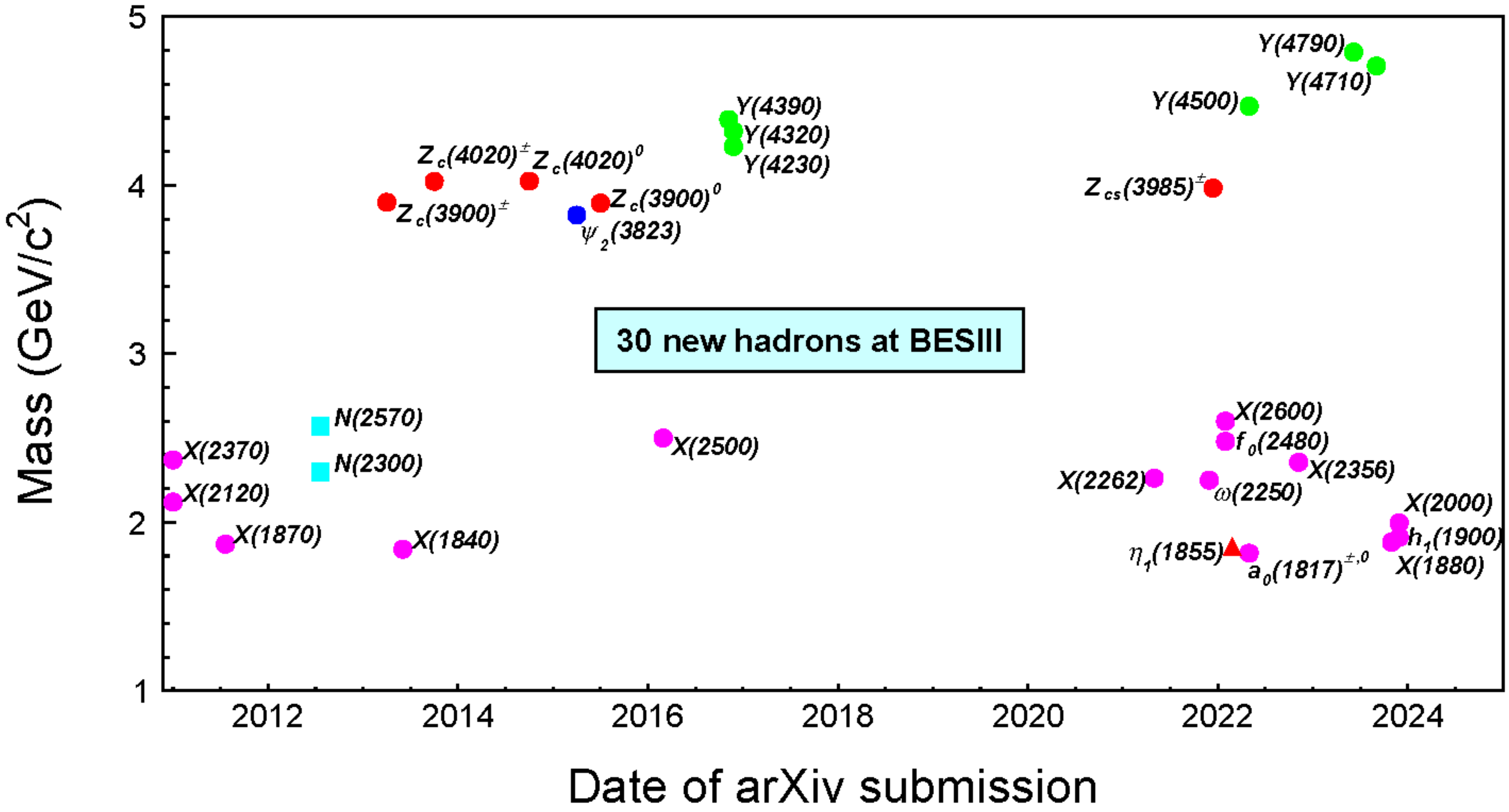


$$\mathcal{B} = (2.63^{+1.40}_{-1.59}) \times 10^{-5}$$

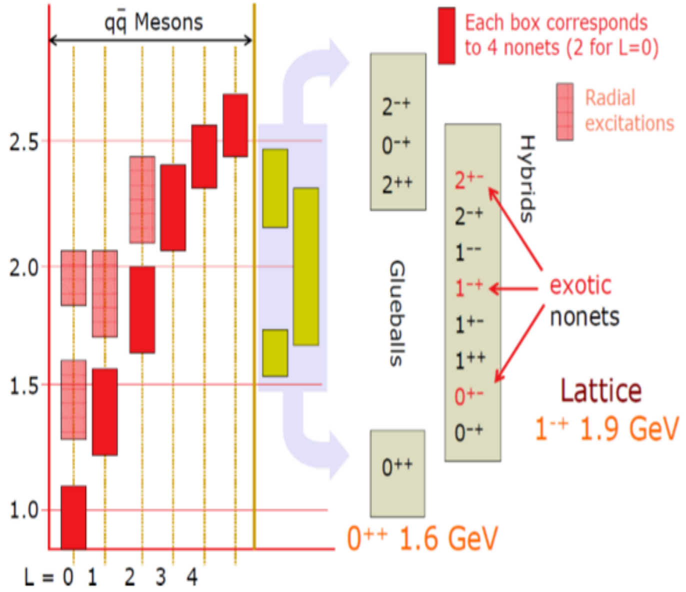
$$\phi = (-0.39^{+0.05}_{-0.10})\pi$$

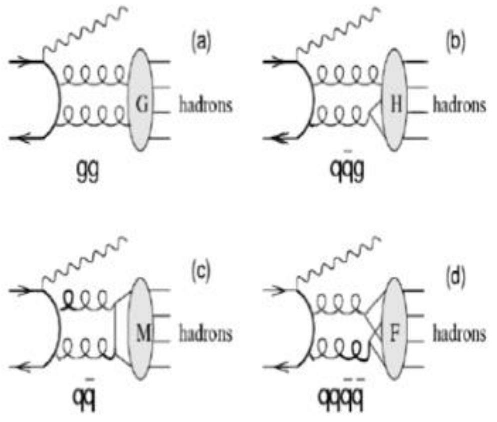
Hadron Spectroscopy

Updated from **Sci. Bull., 68, 2148-2150 (2023)**



Glueballs and Hybrids



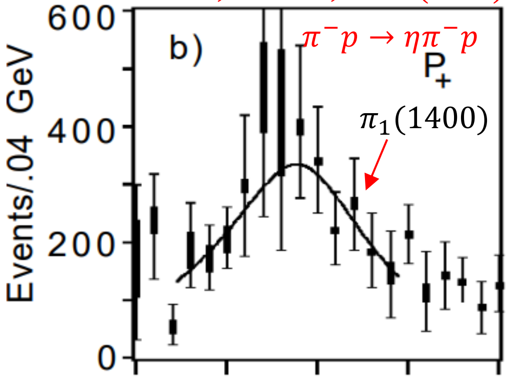


$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

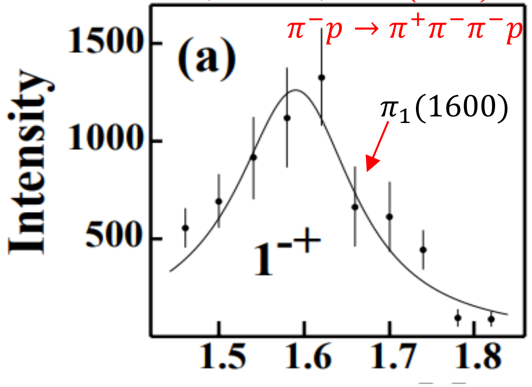
$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

- Experimental evidence for **three isovector** states with $J^{PC} = 1^{-+}$:
  - $\pi_1(1400), \pi_1(1600), \pi_1(2015)$

E852, *PRL* 79, 1630 (1997)

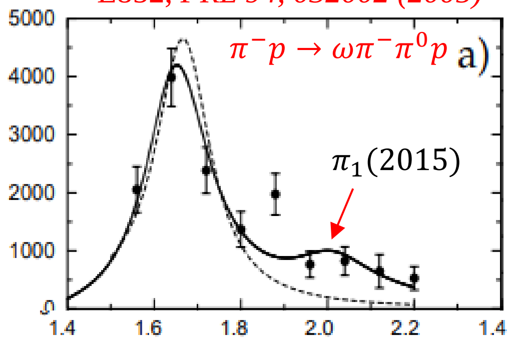


E852, *PRL 81, 5760 (1998)*



- Charmonium decays are **ideal hunting grounds** for light **glueballs** and **exotics**
  - "Glue-rich" environment
  - Clean high statistics data samples from e^+e^- production

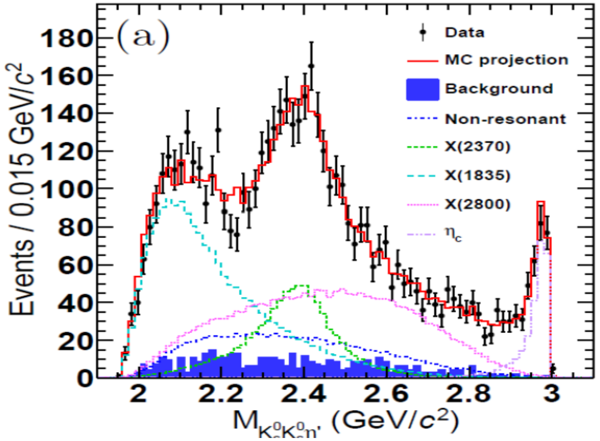
E852, *PRL 94, 032002 (2005)*



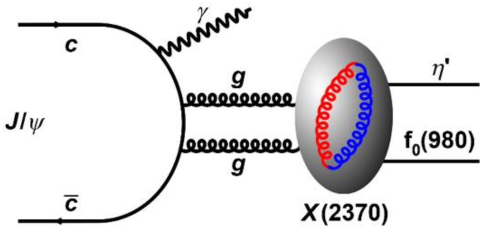
Crucial task: finding an isoscalar 1^{-+} state

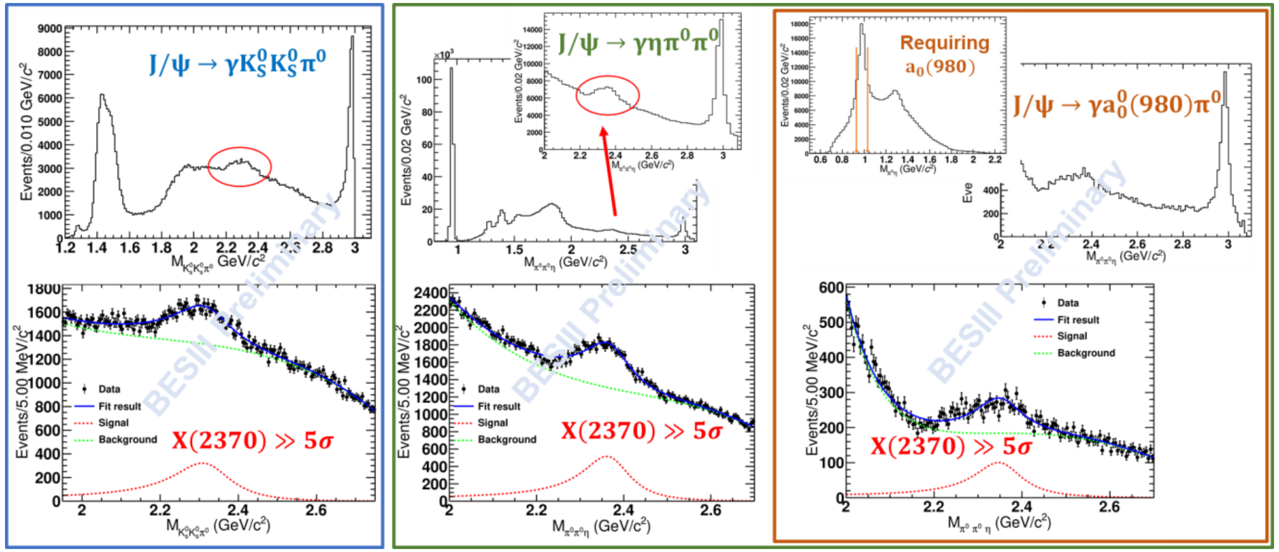
Glueballs and Hybrids at BESIII

PRL132, 181901(2024)



A glueball-like X(2370) spin-parity: 0^{-+}

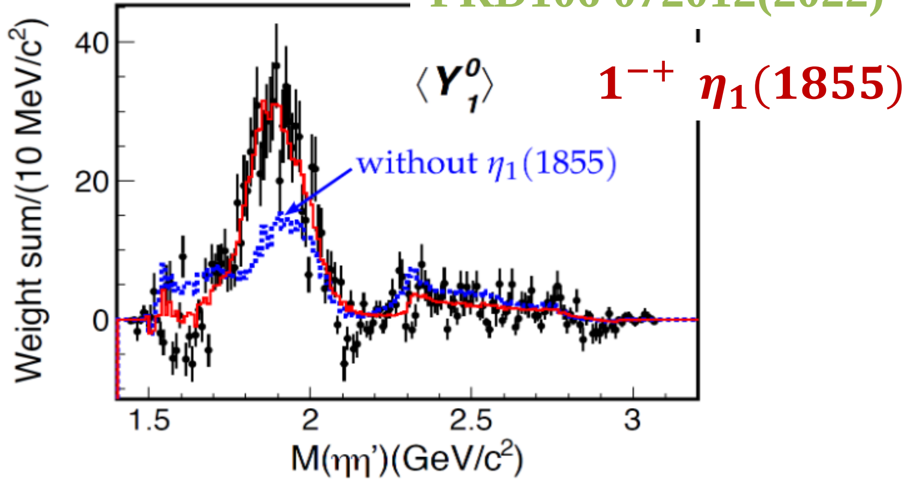


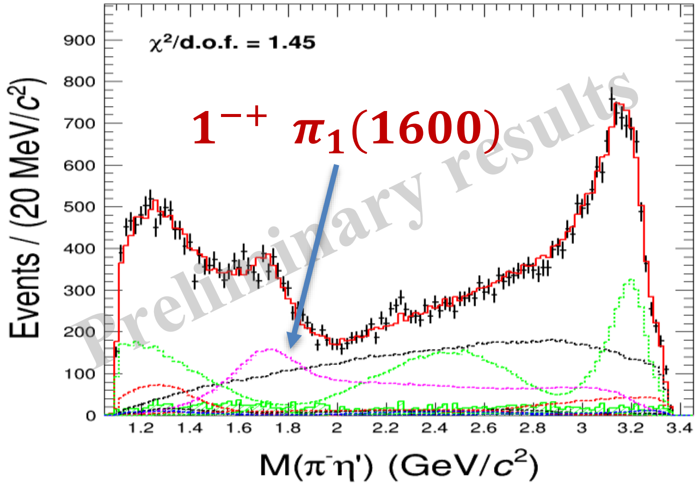


Decode modes $X(2370) \to \eta'\pi\pi, \eta'KK, K^0_S K^0_S \eta, K^0_S K^0_S \pi^0, \eta\pi^0\pi^0, a^0_0(980)\pi^0$ observed, in analog to η_c

Exotic states:

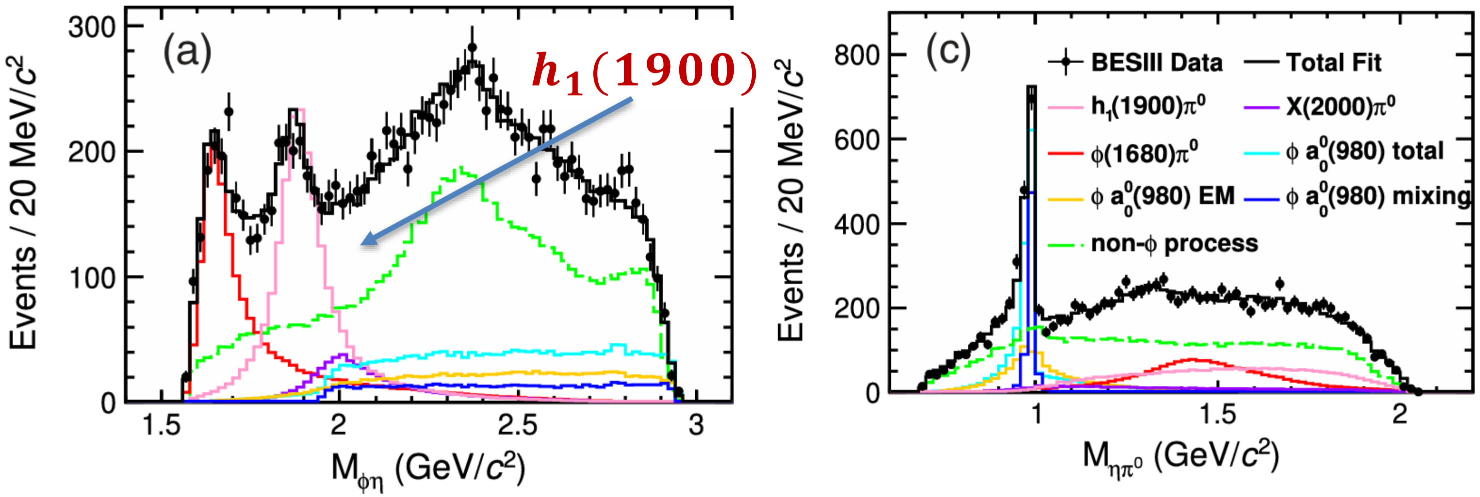
PRL129 192002(2022)
PRD106 072012(2022)



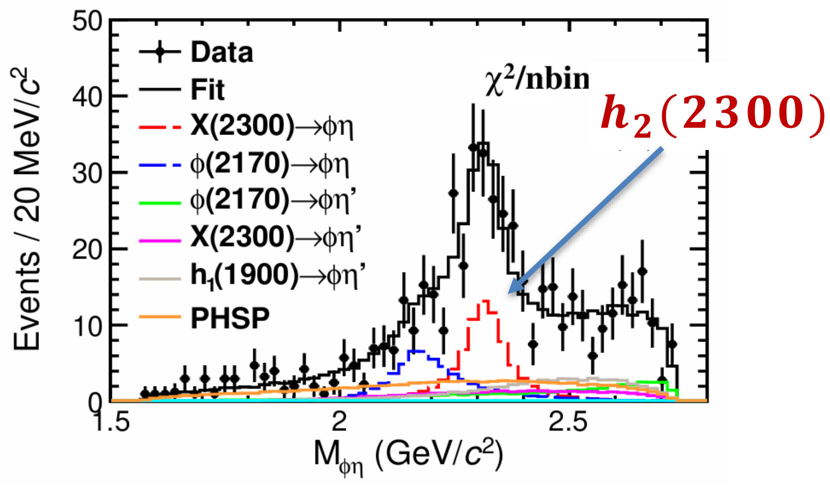


New Light Hadrons

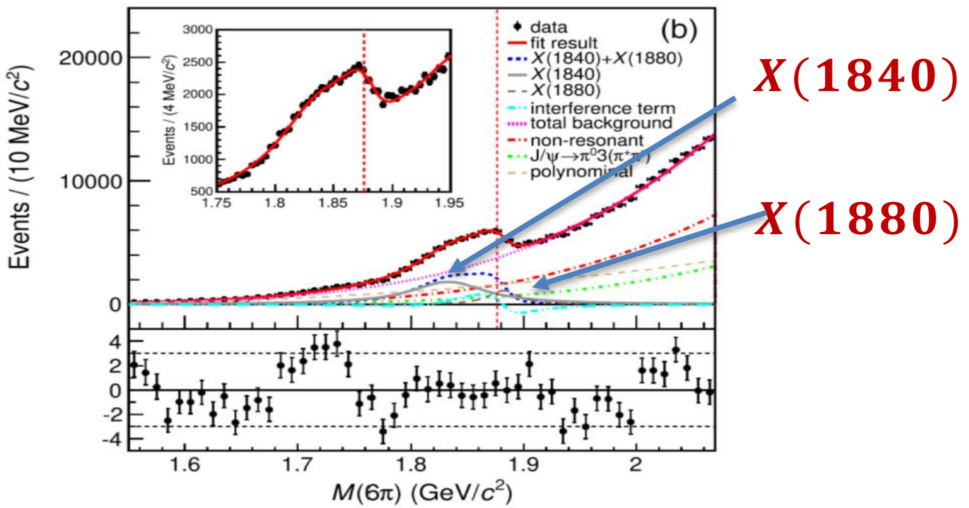
$J/\psi \to \phi\pi^0\eta$ PRD110, 112014 (2024)



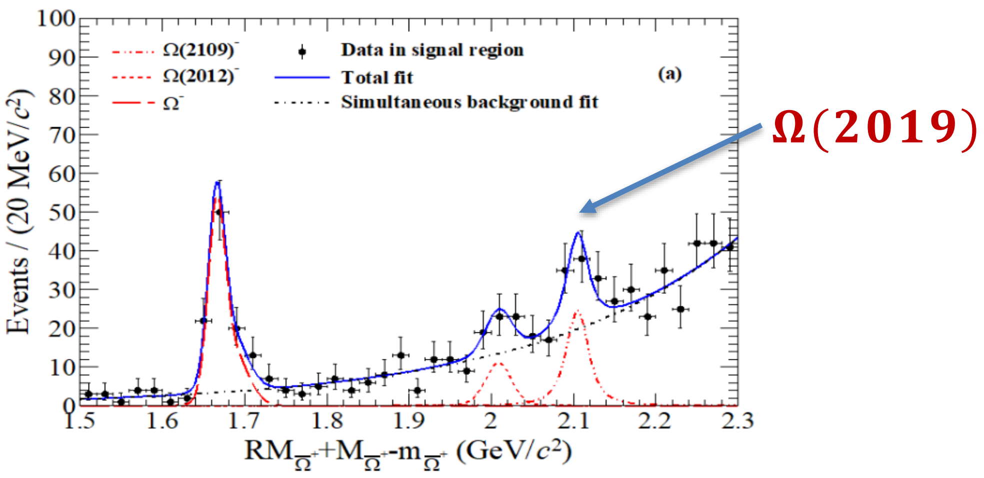
$\psi(3686) \to \phi\eta\eta'$ arXiv: 2410.05736



$J/\psi \to \gamma 3(\pi^+\pi^-)$ PRL 132, 151901 (2024)

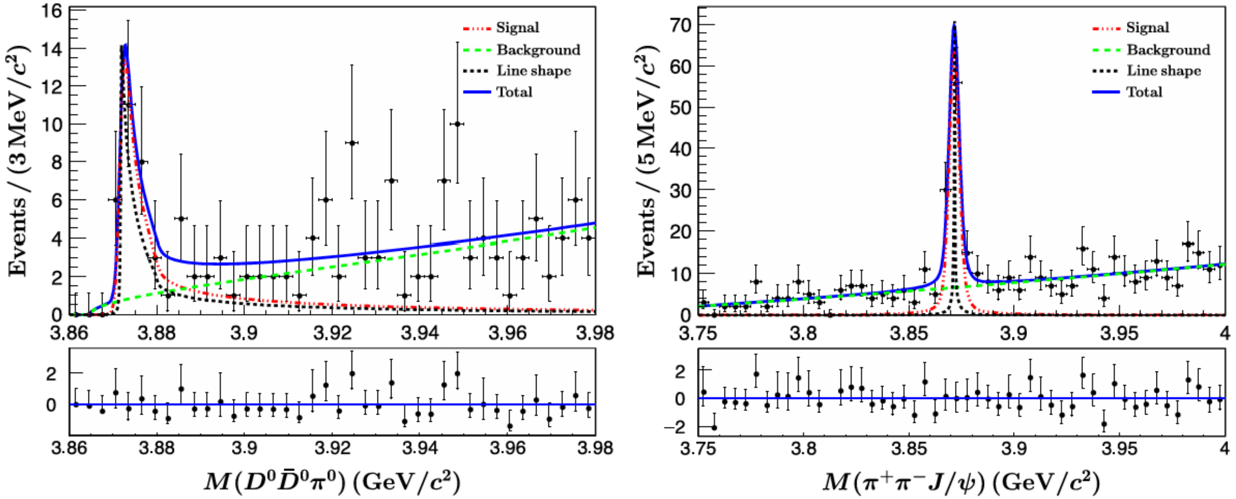


PRL134, 131903 (2025)

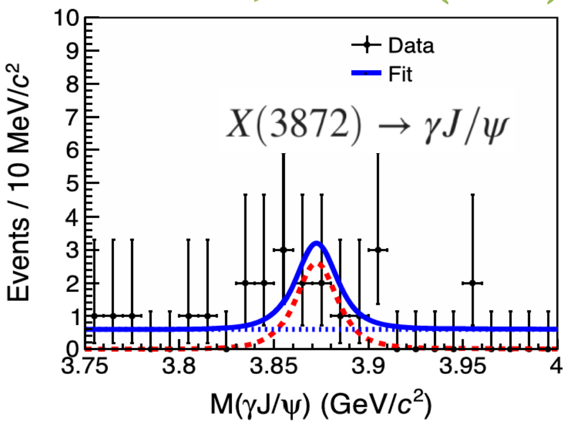


Properties of X(3872)

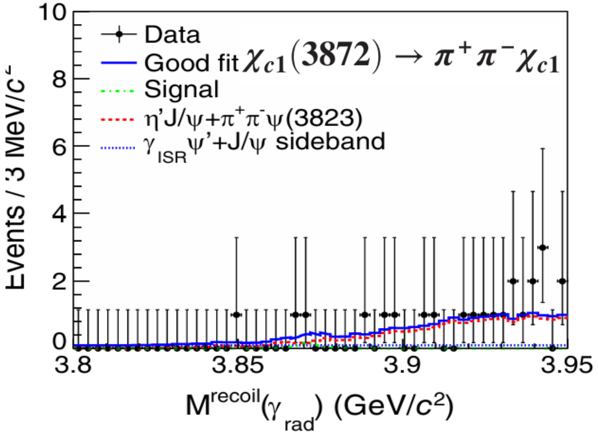
PRL132, 151903 (2024)



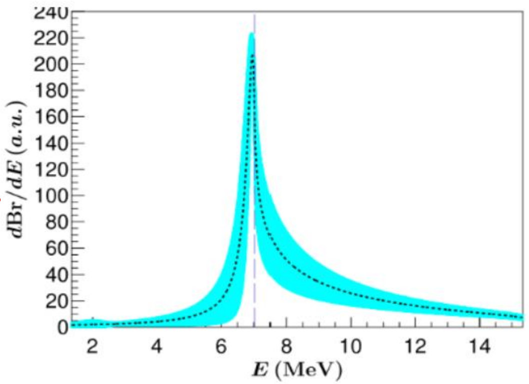
PRD110, 012006 (2024)



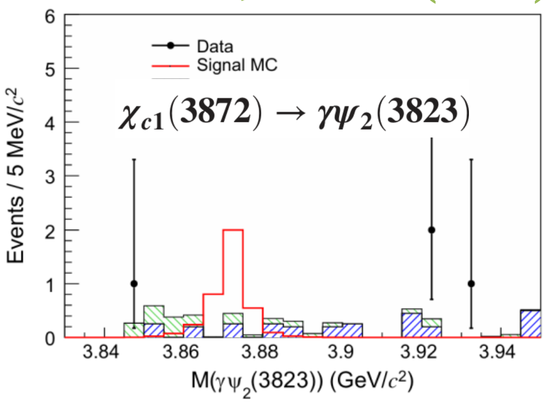
PRD109, L071101 (2024)



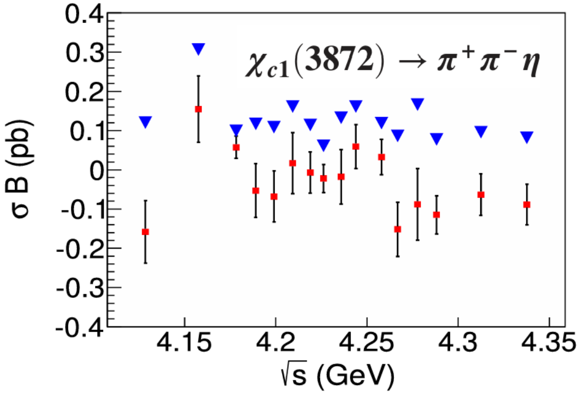
- The effects of the **coupled channels** and the off-shell D^{*0}
- **M=$(3871.63 \pm 0.13^{+0.06}_{-0.05})$ MeV**
- **Line-shape** of X(3872) obtained



PRD110, 012012 (2024)

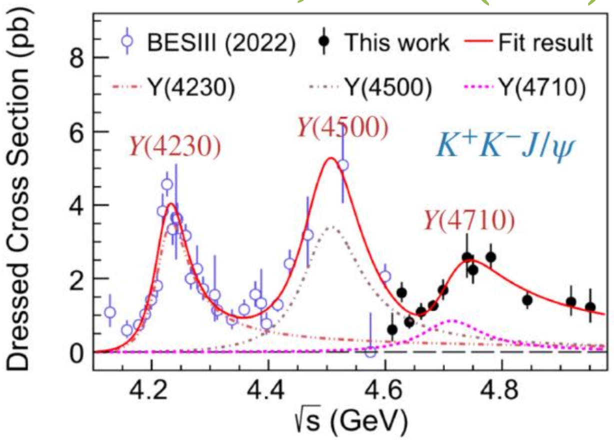


PRD109, L011102 (2024)

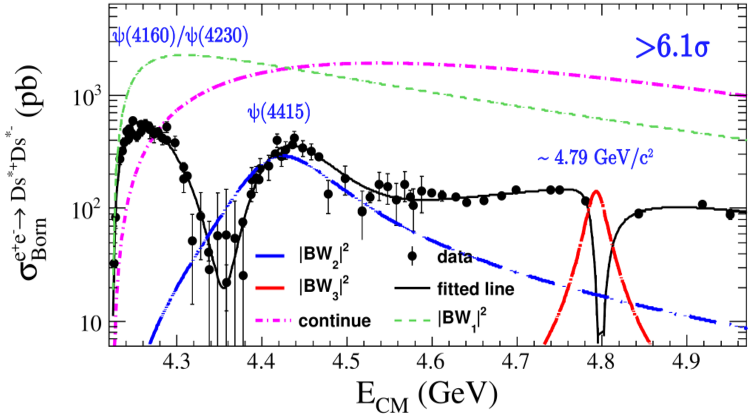


New vectors: Y(4500), Y(4710) and Y(4790) etc.

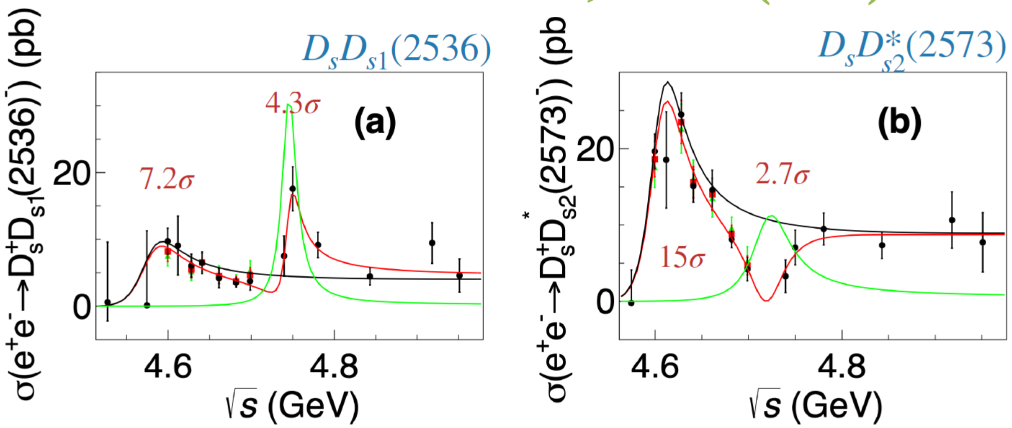
PRL131, 211902 (2023)



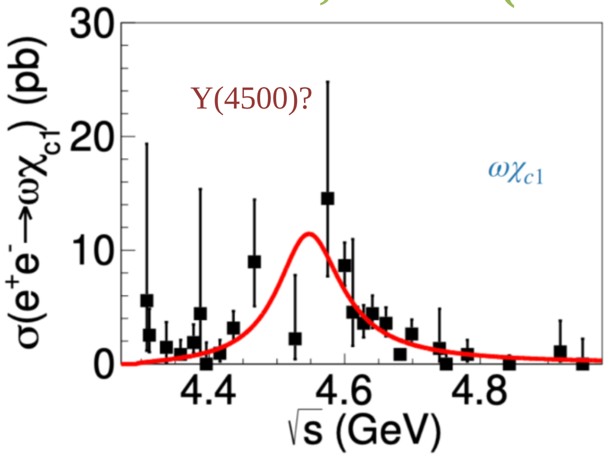
PRL131, 151903 (2023)



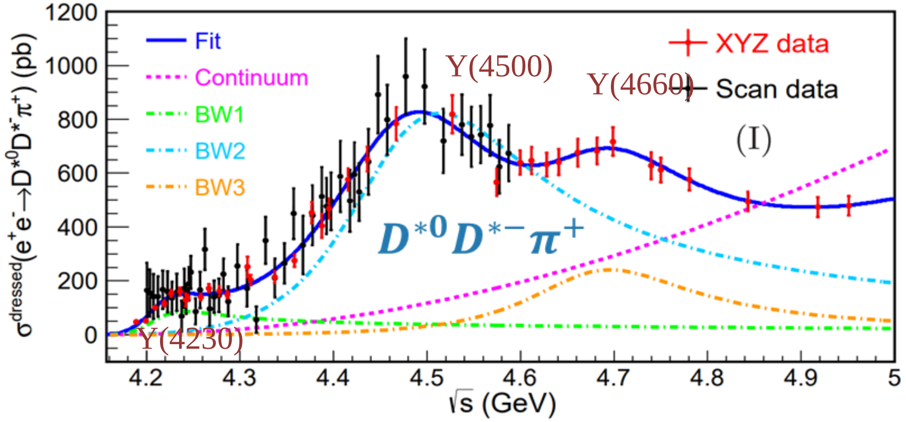
PRL133, 171903(2024)



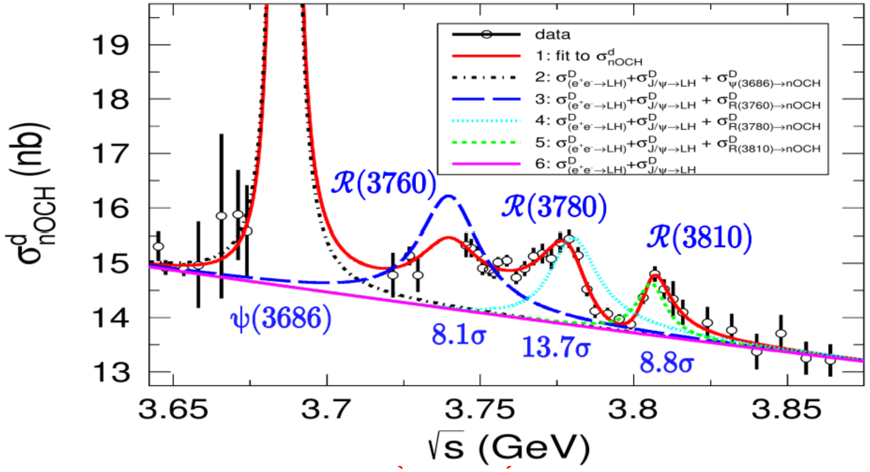
PRL132, 161901 (2024)



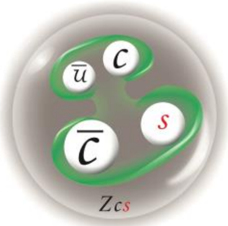
PRL130, 121901 (2023)



PRL132, 191902(2024)



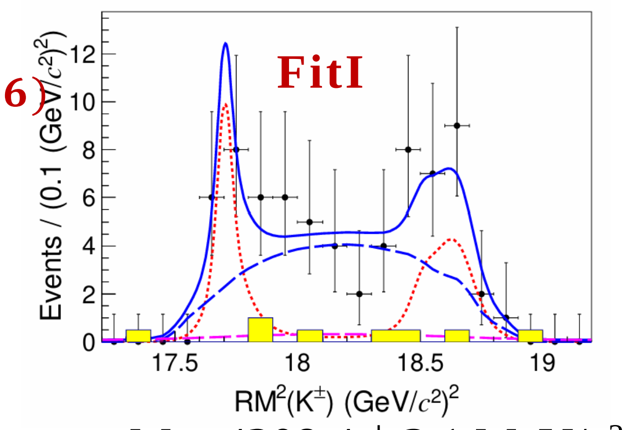
Search for Z_{cs} states

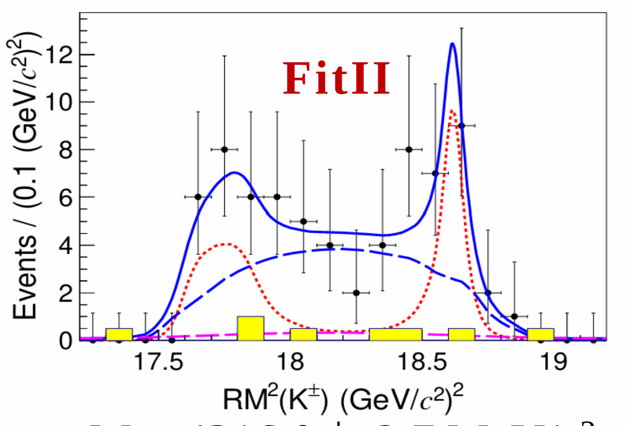


- **Two fit strategies**, where FitI yields a state similar as reported at LHCb, **$Z_{cs}(4220)$**

arXiv:2407.20009

$KK\psi(3686)$



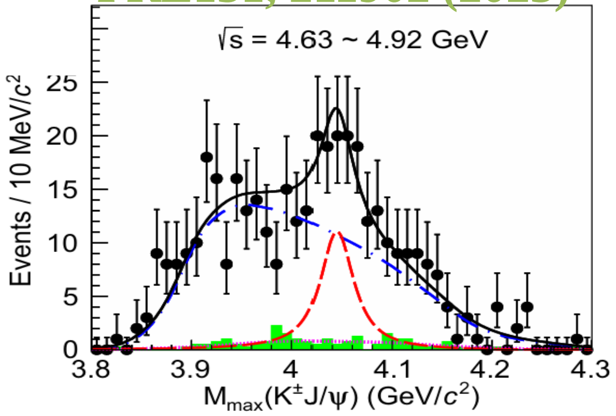


M = 4208.4 ± 3.1 MeV/c²
Γ = 6.1 ± 5.7 MeV

M = 4316.0 ± 2.7 MeV/c²
Γ = 9.0 ± 8.6 MeV

PRL131, 211902 (2023)

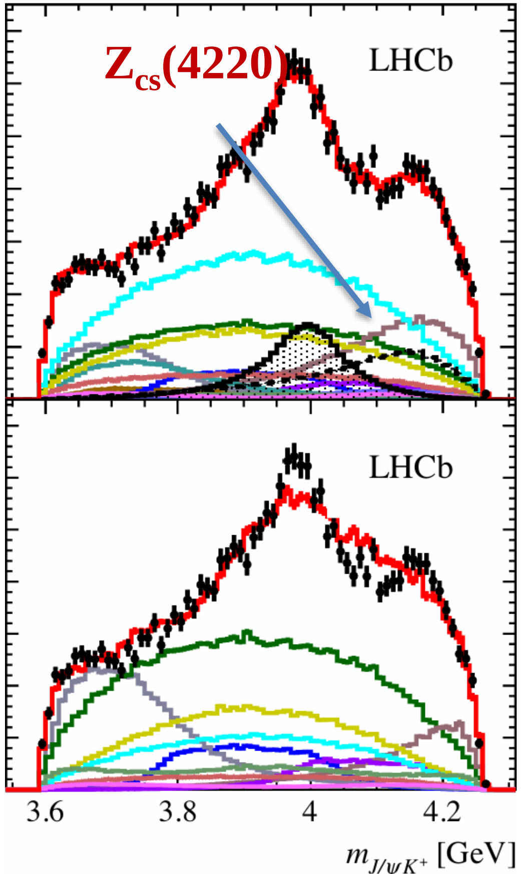
KKJ/ψ



M=4.044±0.006 GeV/c²

Γ =0.036± 0.016 GeV

Statistical significance is 2.3σ.

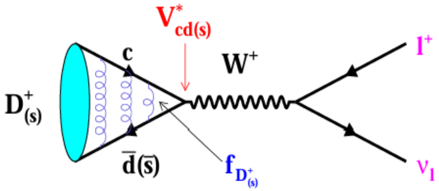


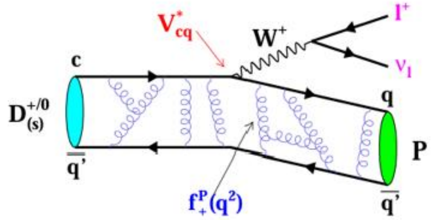
PRL127, 082001 (2021)

Charm Physics

- **CKM matrix** elements are **fundamental SM parameters** that describe the mixing of quark fields due to weak interaction
- **Leptonic** and **semi-leptonic** decays of charmed hadrons ($D^{0/\pm}$, D_s^+, Λ_c^+) provide ideal testbeds to explore **weak** and **strong** interactions

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$





$$\Gamma = \frac{G_F^2}{8\pi}|V_{cq}|^2|f_{D^+_{(s)}}|^2 m_\ell^2 m_{D^+_{(s)}}(1 - m_\ell^2/m_{D^+_{(s)}}^2)^2$$

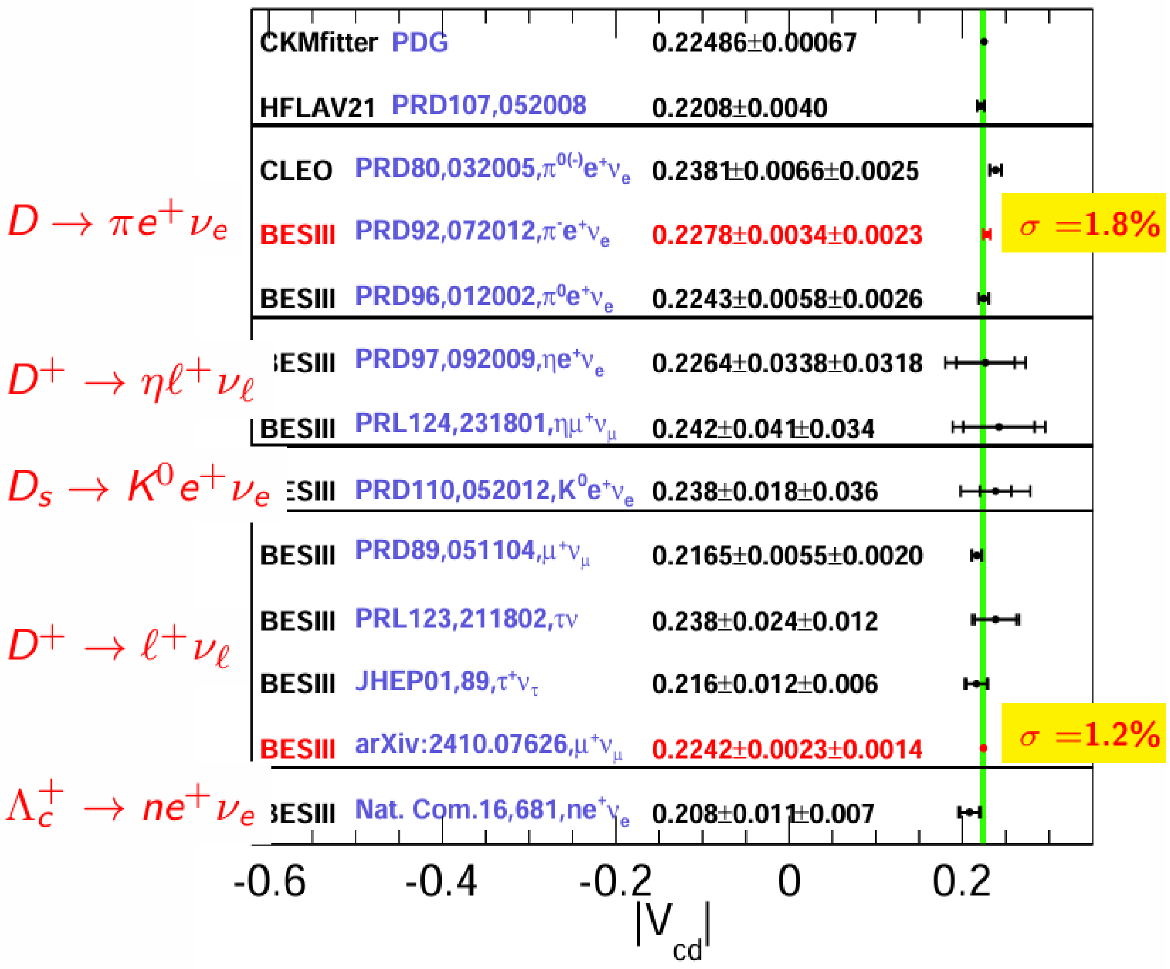
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|\vec{p}_P|^3}{24\pi^3}|V_{cq}|^2|f_+(q^2)|^2$$

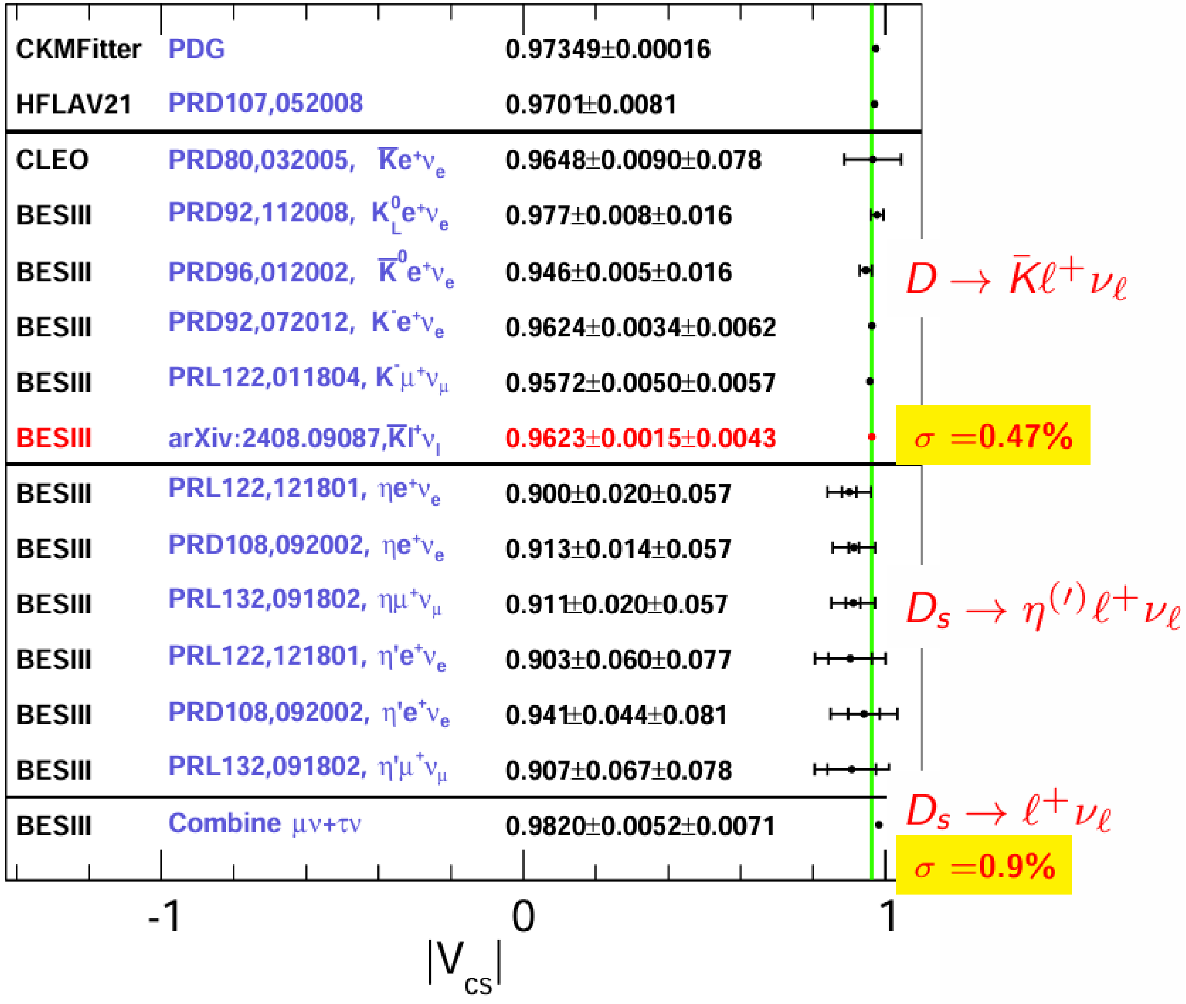
Data sample	E_{cm} (GeV)	Lum. (fb^{-1})	Single-tag yields ($\times 10^6$)
$\psi(3773) \to D\bar{D}$	3.773	20.3	$\bar{D}^0$~16.9; D^-~11.0
$e^+e^- \to D_s^\pm D_s^{*\mp}$	4.128-4.226	7.33	D_s^-~0.8
$e^+e^- \to D_s^{*+}D_s^{*-}$	4.237-4.669	10.64	D_s^-~0.12
$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$	4.6-4.95	6.5	Λ_c~0.15

Low backgrounds and high efficiency; missing technique; Quantum correlations and CP-tagging are unique

Charm Physics: (Semi-)Leptonic Decay

- **$|V_{cs}|$ & $|V_{cd}|$: better test on CKM matrix unitarity**





Charm Physics: (Semi-)Leptonic Decay

Lepton Flavor Universality tests:

$E_{\rm cm}$ (GeV)	Mode	D_s^+ decay	$\mathcal{B}$ (%)	$f_{D_s^+}\lvert V_{cs}\rvert$ (MeV)
4.237-4.699	$D_s^{*\pm}D_s^{*\mp}$	$\tau_e^+\nu_\tau, \tau_\mu^+\nu_\tau, \tau_\pi^+\nu_\tau, \tau_\rho^+\nu_\tau$	$5.60 \pm 0.16 \pm 0.20$	$252.7 \pm 3.6 \pm 4.5 \pm 0.6$
4.178-4.226	$D_s^{\pm}D_s^{*\mp}$	$\tau_\rho^+\nu_\tau$	$5.30 \pm 0.25 \pm 0.20$	$245.8 \pm 5.8 \pm 4.6 \pm 0.5$
4.178-4.226	$D_s^{\pm}D_s^{*\mp}$	$\tau_e^+\nu_\tau$	$5.27 \pm 0.10 \pm 0.13$	$245.1 \pm 2.3 \pm 3.0 \pm 0.5$
4.128-4.226	$D_s^{\pm}D_s^{*\mp}$	$\tau_\pi^+\bar{\nu}_\tau$	$5.44 \pm 0.17 \pm 0.13$	$249.0 \pm 3.9 \pm 3.0 \pm 0.5$
4.128-4.226	$D_s^{\pm}D_s^{*\mp}$	$\tau_\mu^+\bar{\nu}_\tau$	$5.37 \pm 0.17 \pm 0.15$	$247.4 \pm 3.9 \pm 3.5 \pm 0.5$
Average			5.38 ± 0.09	$247.7 \pm 2.1 \pm 0.5$
4.237-4.699	$D_s^{*\pm}D_s^{*\mp}$	$\mu^+\nu_\mu$	$0.547 \pm 0.026 \pm 0.016$	$246.5 \pm 5.9 \pm 3.6 \pm 0.5$
4.128-4.226	$D_s^{\pm}D_s^{*\mp}$	$\mu^+\nu_\mu$	$0.5294 \pm 0.0108 \pm 0.0085$	$242.5 \pm 2.5 \pm 1.9 \pm 0.5$
Average			0.539 ± 0.009	$244.6 \pm 2.0 \pm 0.5$

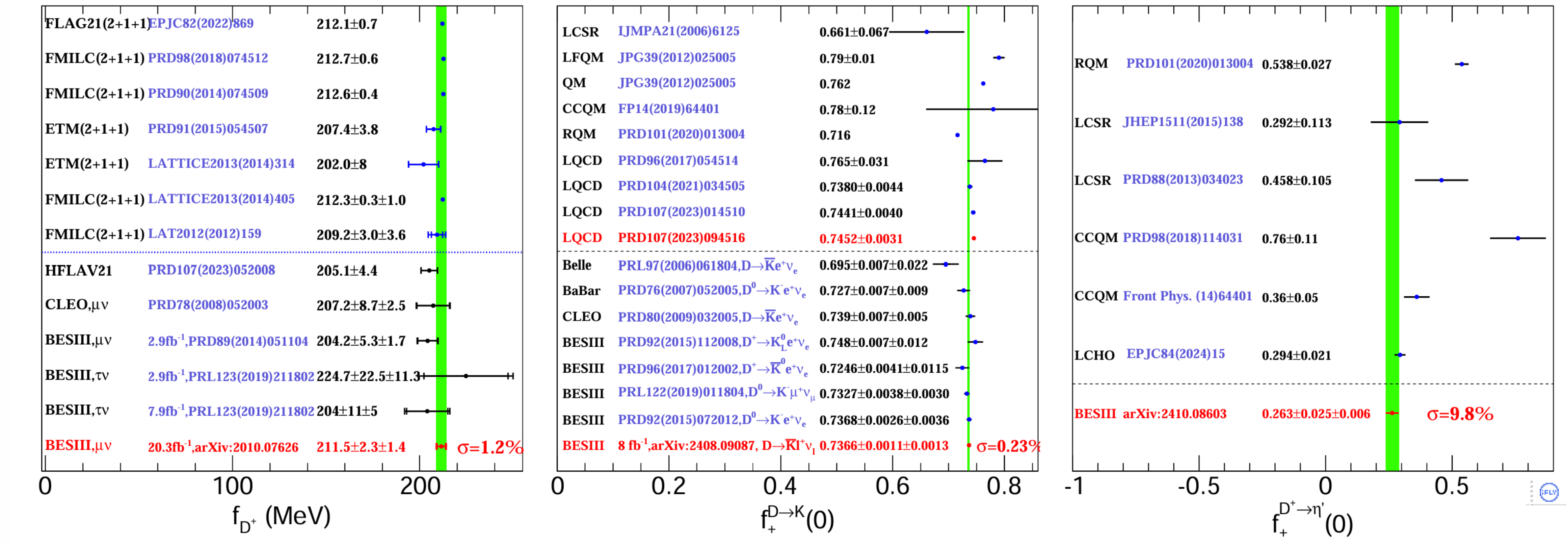
Combined results:

$$R_{D_s} = \frac{\Gamma(D_s^+ \to \tau^+\nu_\tau)}{\Gamma(D_s^+ \to \mu^+\nu_\mu)} = 9.98 \pm 0.24$$

Consistent with SM prediction: 9.75

Charm Physics: (Semi-)Leptonic Decay

Decay constant f_{D^+} and transition form factors $f_+(0)$:

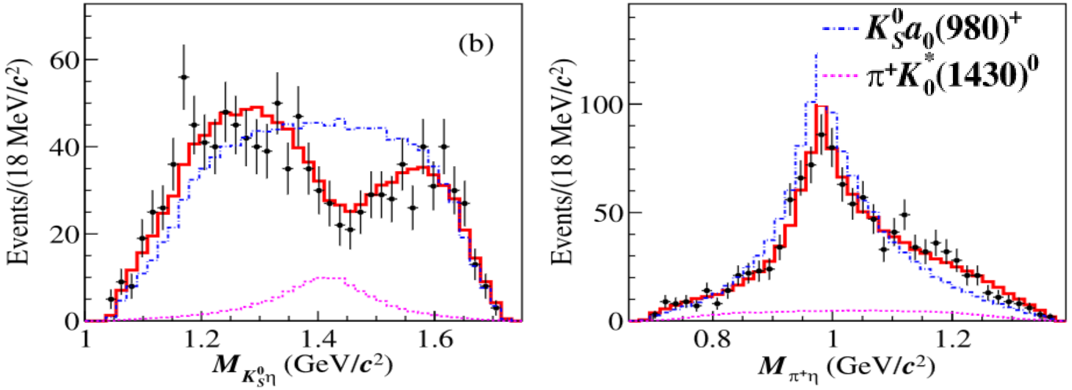


The most precise result $f_+^{D\to\bar{K}}(0)$ is consistent with LQCD calculation with 2.5σ

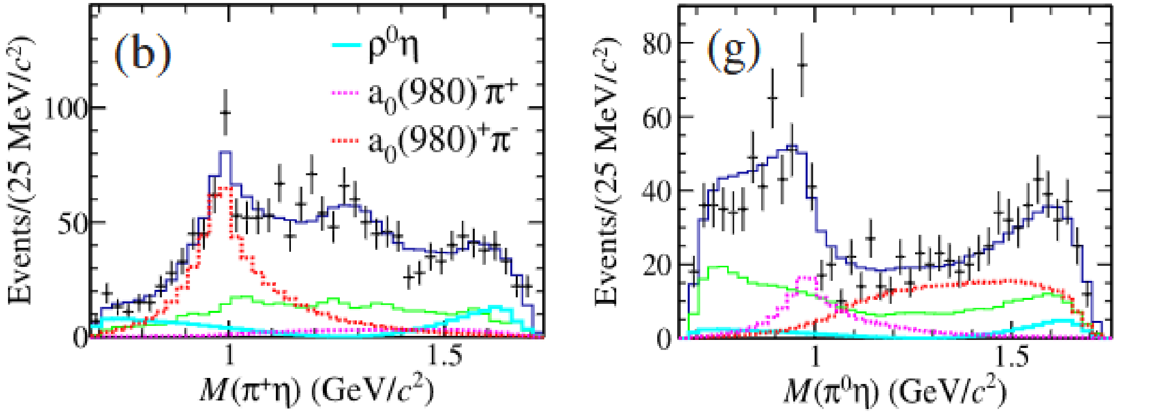
Charm Physics: Hadronic Decay

Amplitude analysis: Observation of $D^+ \to a_0(980)^+ K_S^0, D^0 \to a_0(980)\pi, D^0 \to K^*(892)K_S^0$, $D_s^+ \to f_0(980)\rho^+$, $\Lambda_c \to a_0(980)\Lambda$ etc.

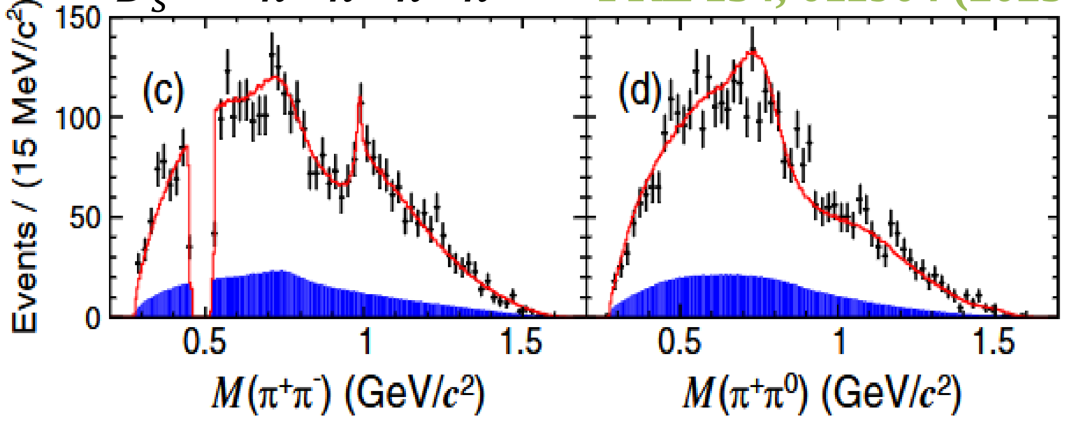
$D^+ \to K_S^0 \pi^+ \eta$ PRL132, 131903 (2024)



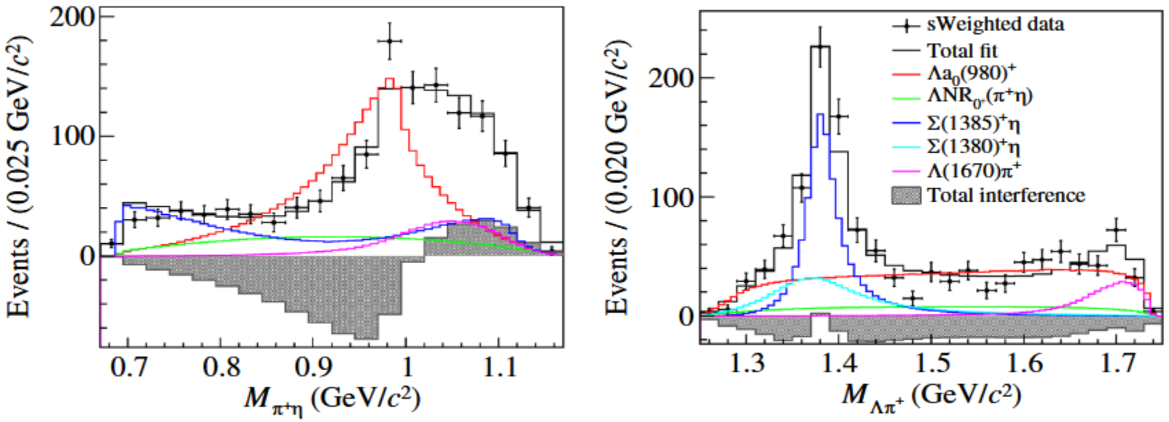
$D^{0/+} \to \pi^+\pi^{-/0}\eta$ PRD110, L111102 (2024)



$D_s^+ \to \pi^+\pi^+\pi^-\pi^0$ PRL 134, 011904 (2025)



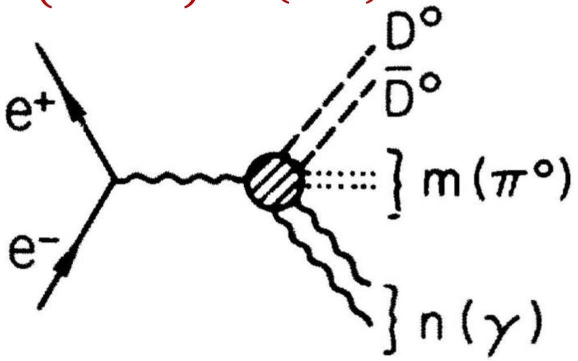
$\Lambda_c \to \Lambda\pi^+\eta$ PRL134, 021901 (2025)



Charm Physics: Hadronic Decay

$$e^+e^- \to D^0\bar{D}^0 + m(\pi^0) + n(\gamma)$$

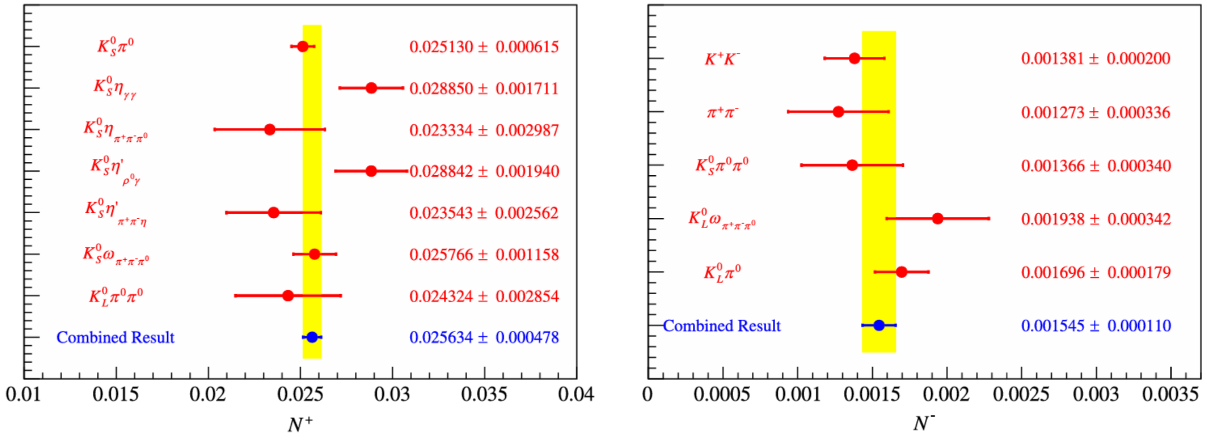
$$C\left(D^0\bar{D}^0\right) = (-1)^{n+1}$$



- Quantum coherent effects:
  - $\Gamma(S|T) \propto A_S^2 A_T^2[(r_D^S)^2 + (r_D^T)^2 - 2R_S R_T r_D^S r_D^T \cos(\delta_D^T - \delta_D^S)]$
  - Tags in analysis:
    - Flavour tags, CP eigenstates, self-conjugated tags

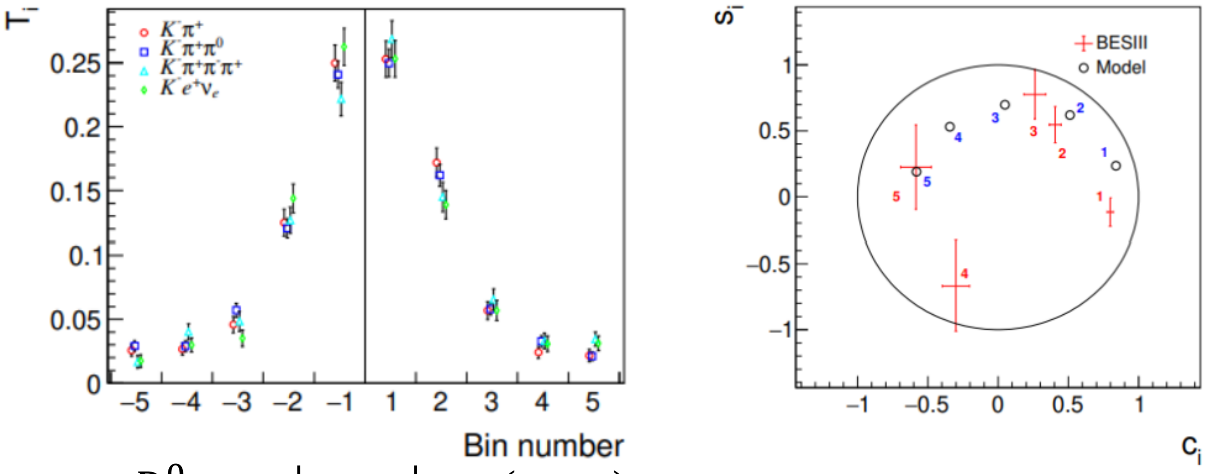
- **Strong phase differences of neutral D decays → contribution on the γ measurement**

PRD111, 012007 (2025)



CP-even fraction in $D^0 \to \pi^+\pi^-\pi^0$

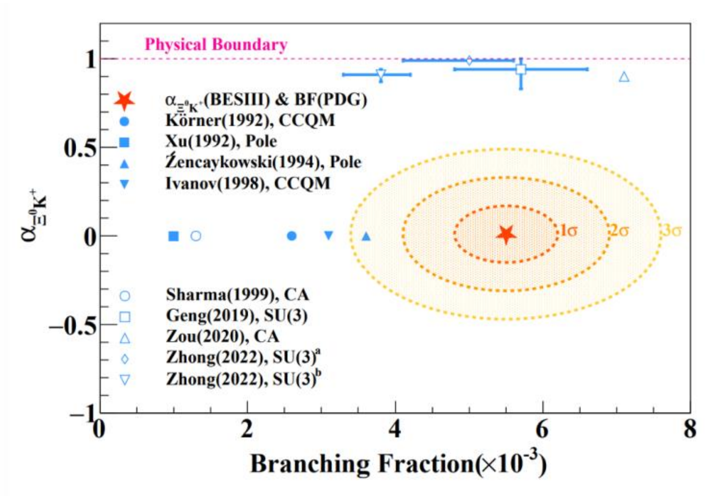
PRD110, 112008 (2024)



$D^0 \to \pi^+\pi^-\pi^+\pi^-$ $(\boldsymbol{c_i}, \boldsymbol{s_i})$ measurements

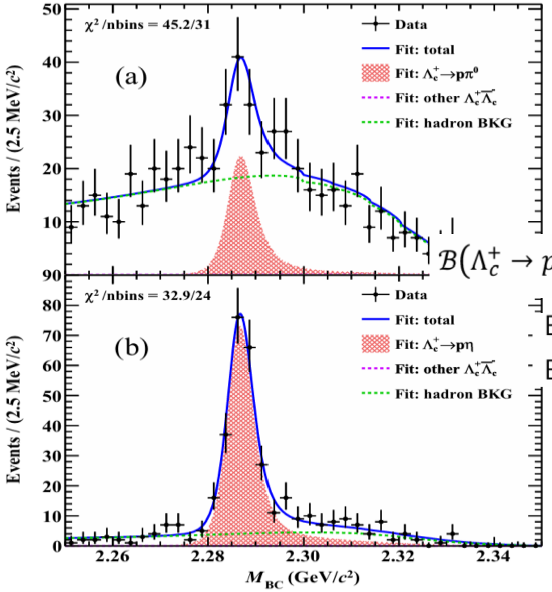
Charm Physics: Hadronic Decay

$\Lambda_c^+ \to \Xi^0 K^+$ PRL132, 031801 (2024)



$$\alpha_{\Xi^0K^+} = 0.01 \pm 0.16 \pm 0.03$$
$$\Delta_{\Xi^0K^+} = 3.84 \pm 0.90 \pm 0.17 \text{ rad}$$
$$\beta_{\Xi^0K^+} = -0.64 \pm 0.69 \pm 0.13$$
$$\gamma_{\Xi^0K^+} = -0.77 \pm 0.58 \pm 0.11$$

$\Lambda_c^+ \to p\pi^0$ PRD111, L051101 (2025)



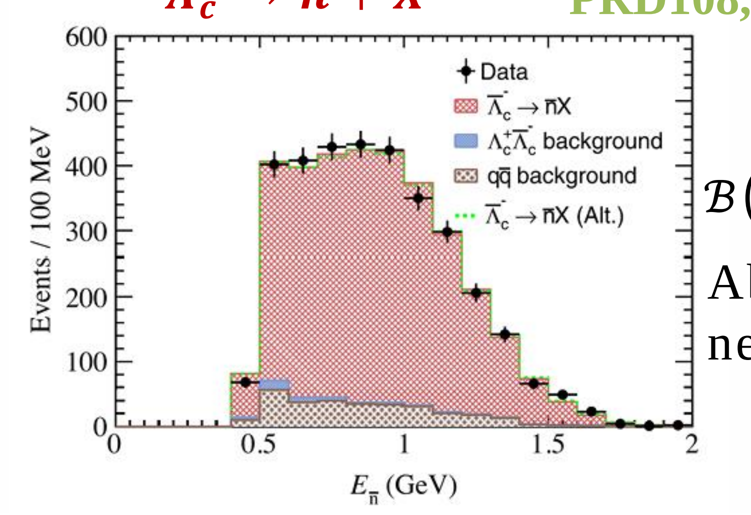
- Deep learning is developed to suppress non- Λ_c^+ hadronic events

$\mathcal{B}(\Lambda_c^+ \to p\pi^0) = (1.79 \pm 0.39_{\text{stat.}} \pm 0.11_{\text{syst.}} \pm 0.08_{\text{ref.}}) \times 10^{-4}$

Belle 2021: $\mathcal{B} < 0.8 \times 10^{-4}$ @ 90% C. L.

BESIII 2023: $\mathcal{B} = (1.56^{+0.72}_{-0.58} \pm 0.20) \times 10^{-4}$ with 3.7

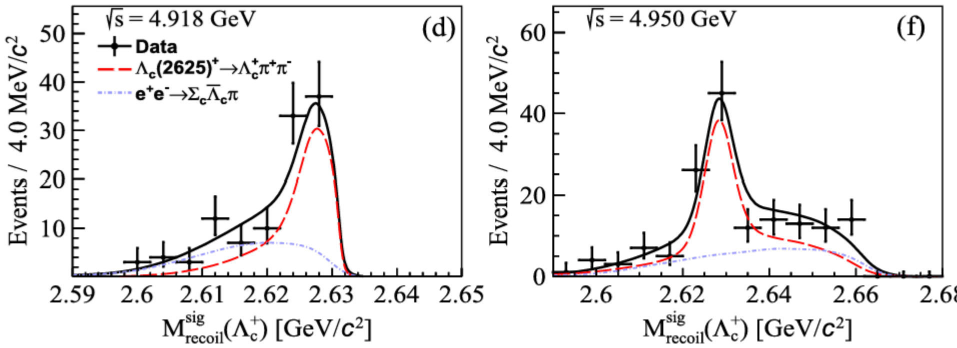
$\bar{\Lambda}_c^- \to \bar{n} + X$ PRD108, L031101 (2023)



$$\mathcal{B}(\bar{\Lambda}_c^- \to \bar{n} + X) = (33.5 \pm 1.4)\%$$

About 20% of Λ_c^+ decays with a neutron are still unobserved

PRD109, 112007 (2024)



$$\mathcal{B}(\Lambda_c(2625)^+ \to \Lambda_c^+\pi^+\pi^-) = (50.7 \pm 5.0 \pm 4.9)\%$$

Summary

- BESIII has **a rich and fruitful program** in hadron spectroscopy and hadron structure, hyperon physics and charm physics etc..
- The installation of **BEPCII upgrade** and **BESIII inner tracker** were finished.
- With **luminosity** tripled and beam energy increased to **2.8 GeV**, BESIII is expected to provide more results in the upcoming operations.

BEPCII-U Operation tentative plan

Jul. 2024 – Dec. 2024 Summer shutdown for installation

Jan. 2025 – Jul. 2025 Commissioning & Data taking @1.843GeV $\psi(3686)$

Aug. 2025 – Sep. 2025 Summer shutdown

Oct. 2025 – Jul. 2026 Data taking around beam energy 2.35GeV (project test)

Aug. 2026 – Sep. 2026 Summer shutdown & LINAC final upgrade

Oct. 2026 – Sep. 2028 Data taking within beam energy 2.1-2.5GeV

Sep. 2028 – Jul. 2030 Data taking within beam energy 2.5-2.8GeV

Thanks!

谢谢！