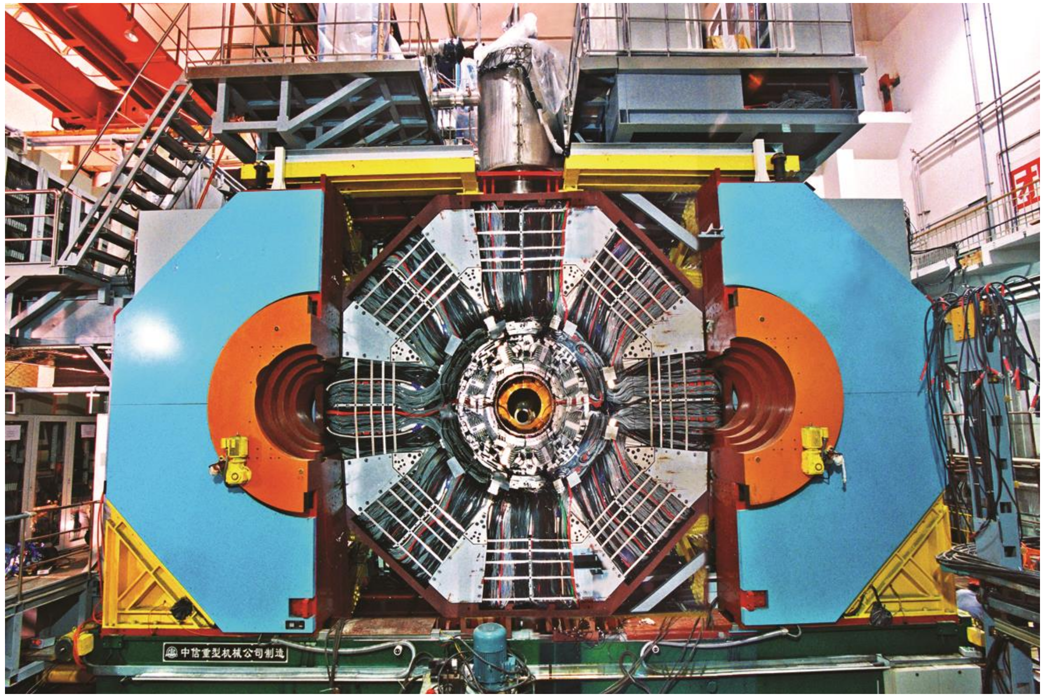
Overview of BESIII Physics



Guangshun Huang

(on behalf of the BESIII Collaboration)

University of Science and Technology of China

22nd Lomonosov Conference on Elementary Particle Physics

Moscow, August 21-27, 2025

BESIII

Outline

- **Introduction**
- **Highlights on recent results**
  - **Hadron production and structure**
  - **Light hadron spectroscopy**
  - **Charmed meson and baryon**
  - **CPV in hyperon decays**
  - **Charmonium(-like) states**
- **Prospects for the future**
- **Summary**

Disclaimer: selected topics only, not possible to cover all.

Beijing Electron-Positron Collider II (BEPCII)

Center of mass energy: 1.84~4.95 GeV

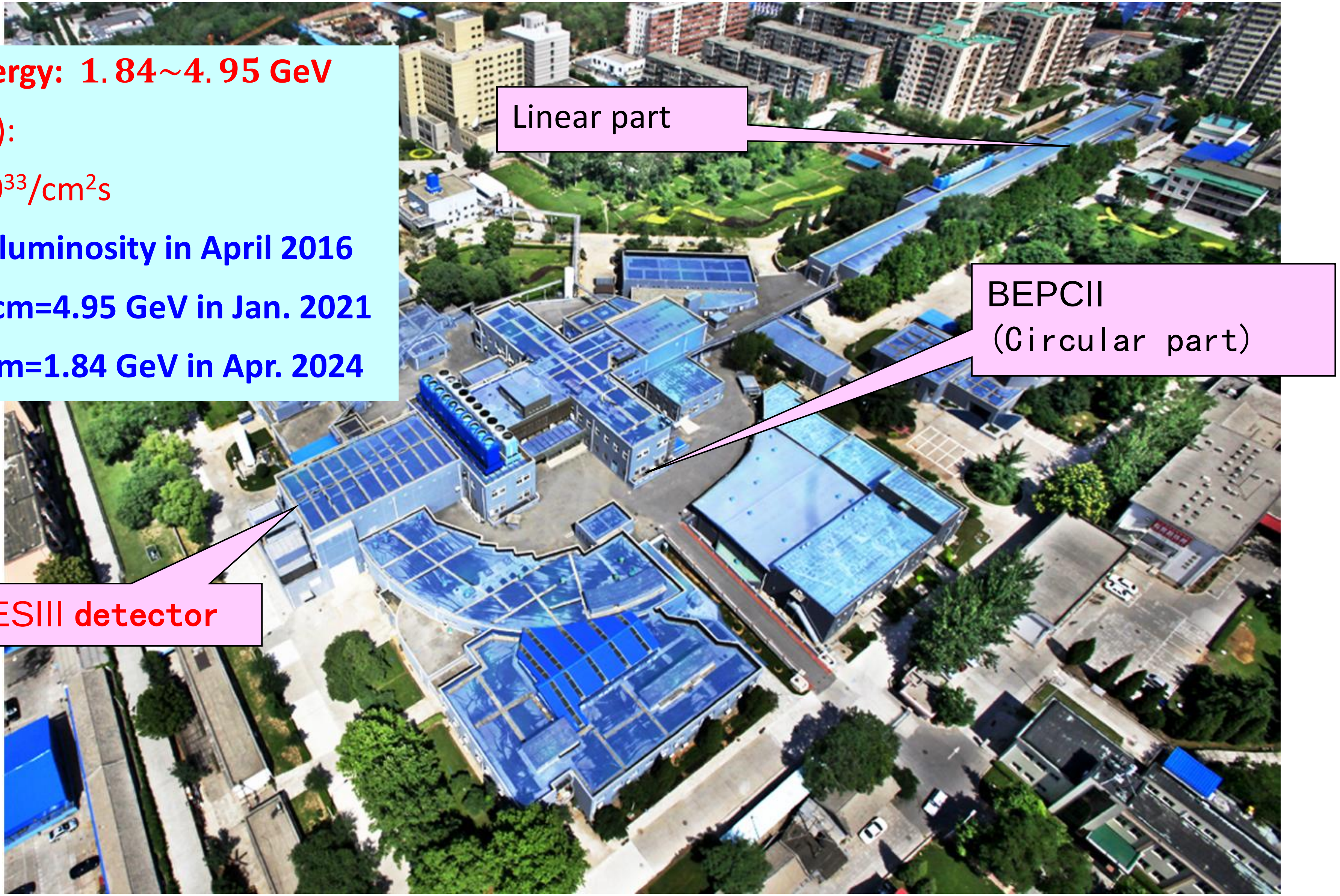
2008- **Now** (BEPCII):

L_{peak} = 1.0 x $10^{33}/cm^2s$

Reached designed luminosity in April 2016

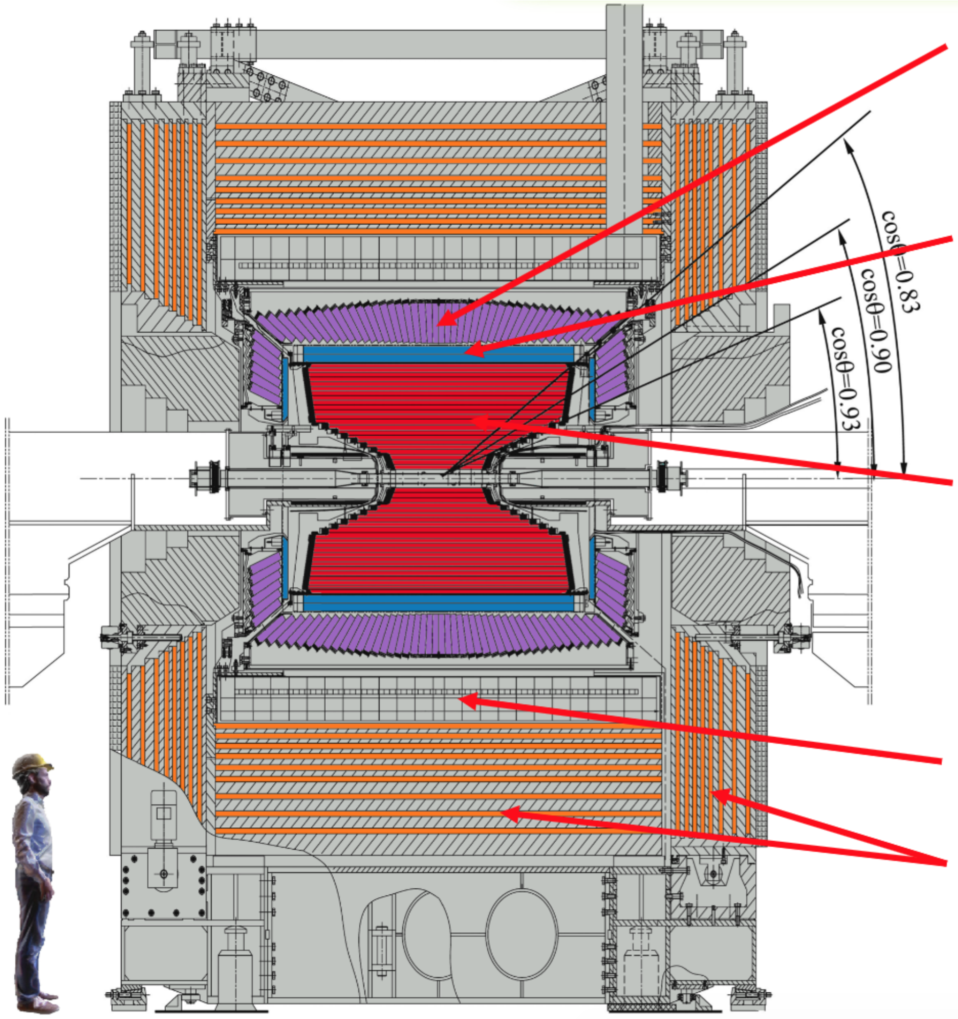
Reached highest Ecm=4.95 GeV in Jan. 2021

Reached lowest Ecm=1.84 GeV in Apr. 2024



BESIII detector

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

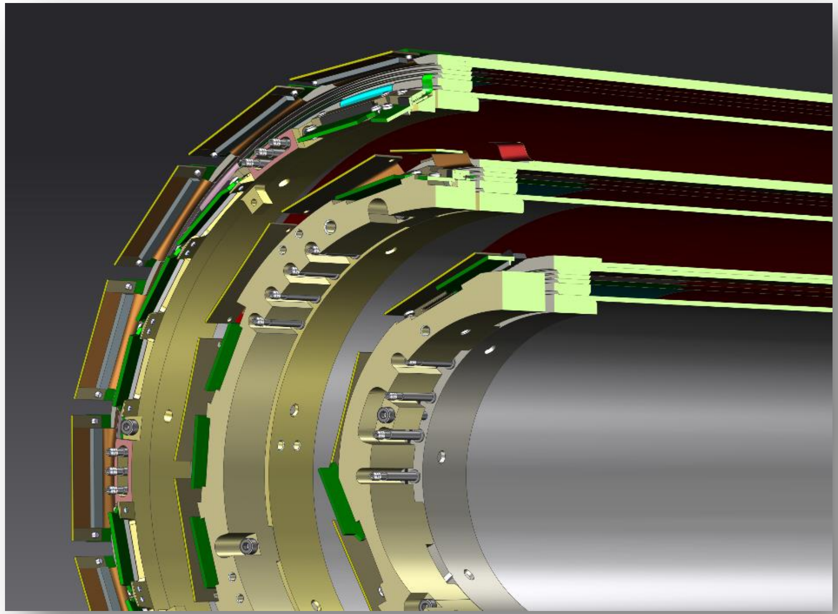
Muon ID: 9 layer RPC

Trigger: Tracks & Showers

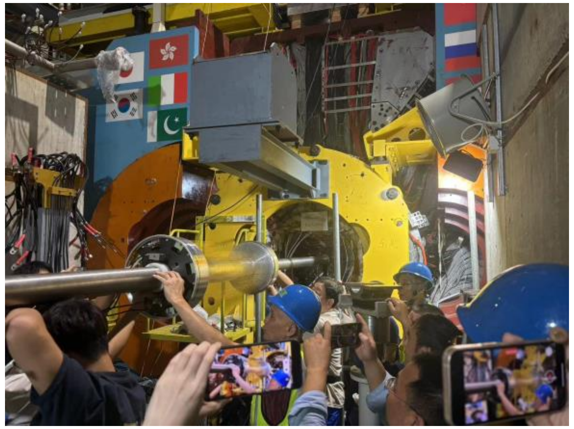
Total weight 730 ton, ~40,000 readout channels, Data rate: 5kHz, 50Mb/s

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

Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT)



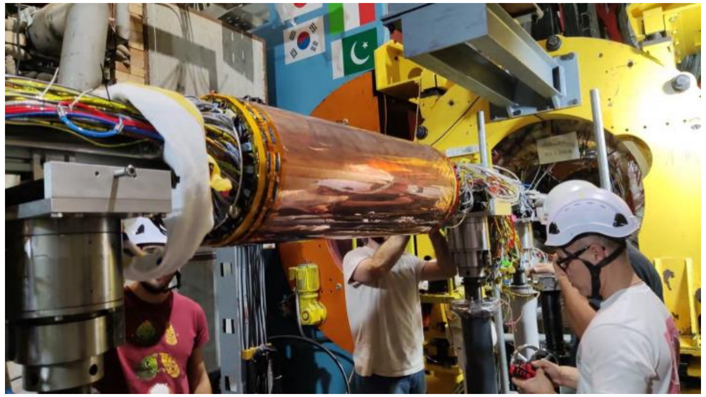
- Three layers of cylindrical triple GEM to replace the inner MDC
- Improve spatial resolution along the beam axis (< 300 μm), rate capability, and radiation hardness



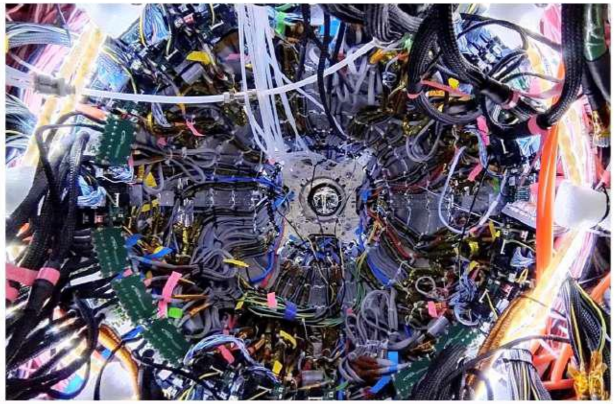
Extraction of inner draft chamber on Sep. 14th

Status and timeline

- Software review on Dec. 1st, 2023
- Performance review on Feb. 20th 2024
- Overall assessments of Installation (March, 2024)
- Installation in October 2024 during the BEPCII-upgrade



Ready for installation on Oct. 2nd



Completed on Oct 18th!

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

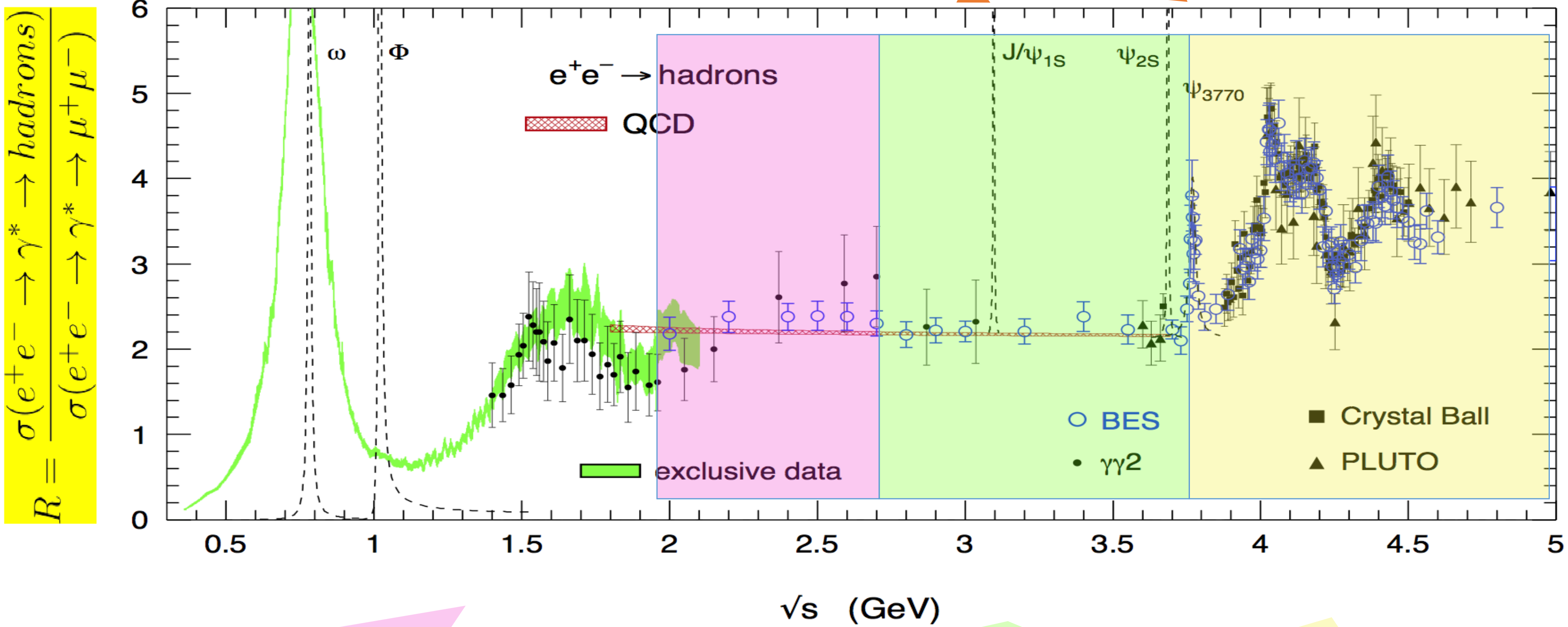
China (58/367)

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 Unive
South China Normal University, Southeast University, Sun Yat-sen Un
Tsinghua University, University of Chinese Academy of Sciences, Univ
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

~700 members
From 86 institutions in 16 countries

Rich Physics at τ-charm Energy Region

$\sigma(e^+e^- \to J/\psi) = 3400nb$ $\sigma(e^+e^- \to \psi(3686)) = 600nb$



- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with τ 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(2*S*) events
- 20 fb^{-1} ψ(3770)
- Scan data between

  1.84-1.97 GeV (13 points, 25 pb^{-1})

  2.0 - 3.08 GeV,

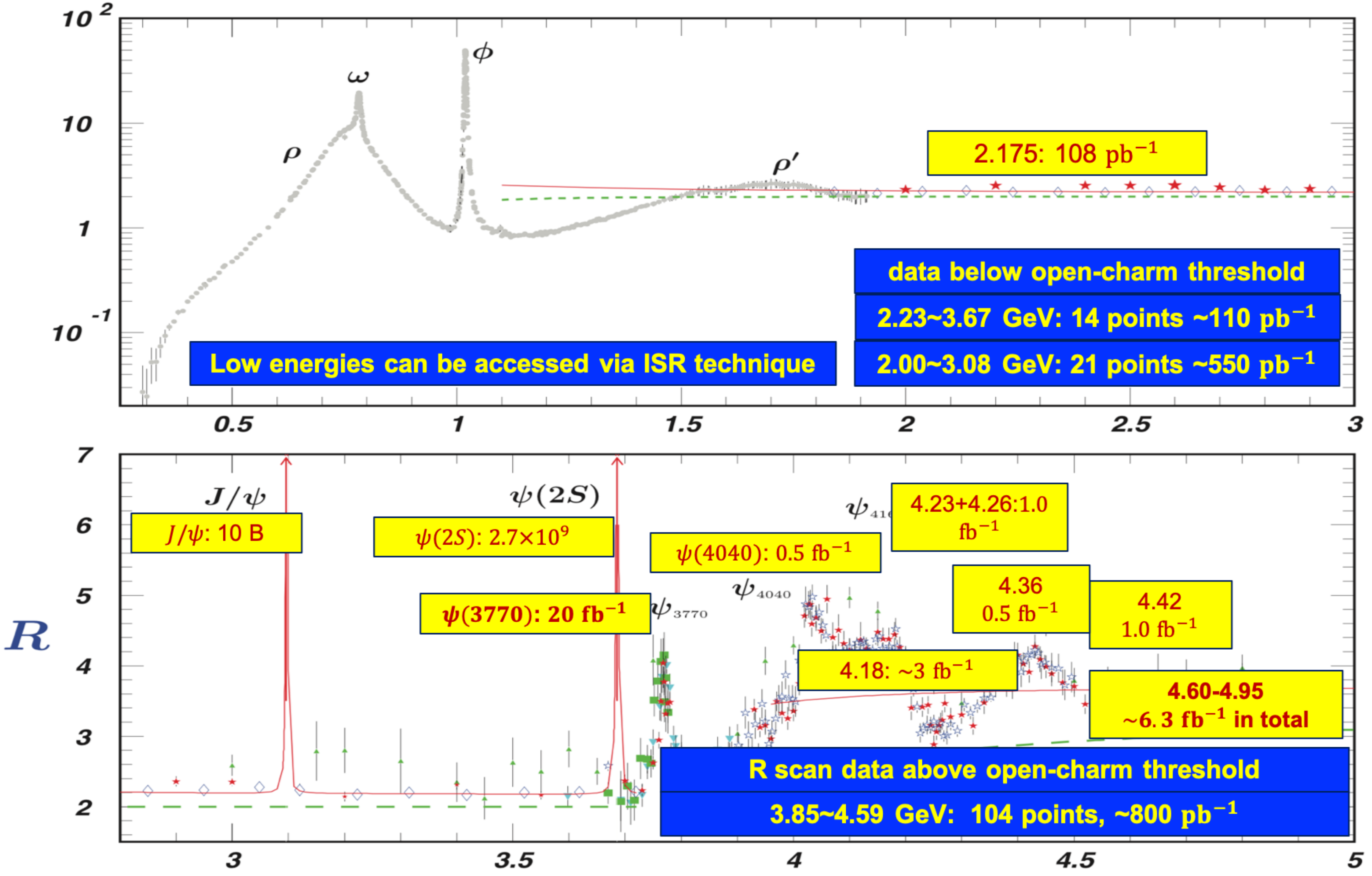
  and above 3.74 GeV
- Large datasets for XYZ studies:

  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.**

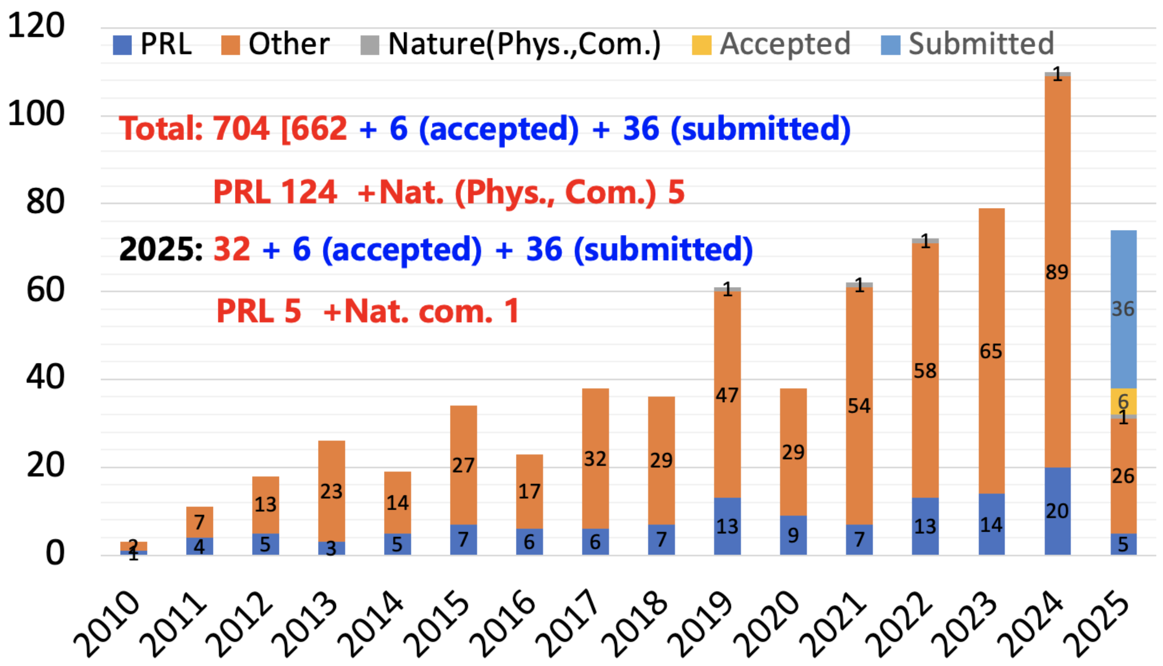
Totally about 50 fb^{-1} integrated luminosity from 1.84-4.95 GeV

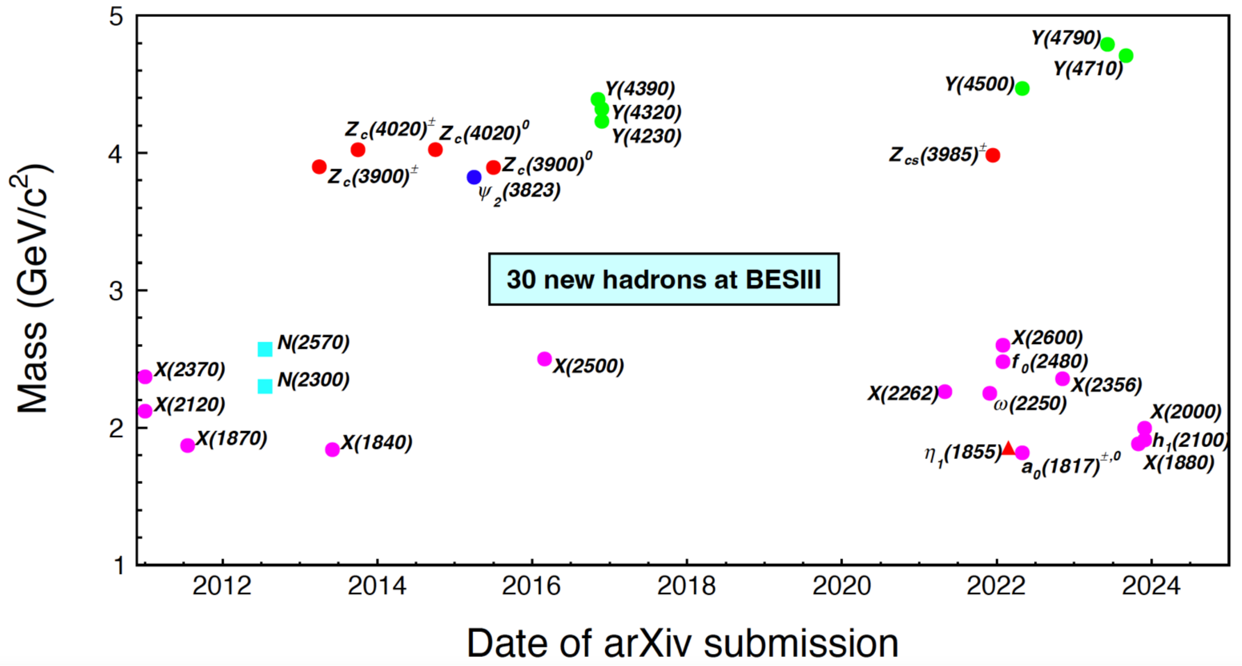


Hadron structure & dynamics in the non-perturbative QCD regime

Publications and achievements

- **110 papers published by BESIII in 2024**
- **68/64 submitted/published as of Aug. 21, 2025**





Advantage: unique data near to the thresholds

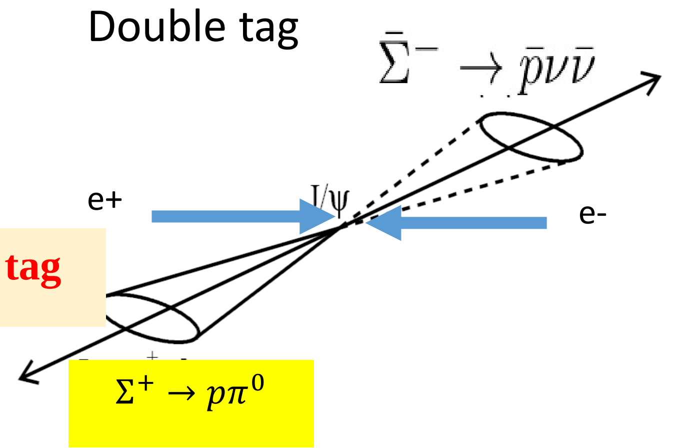
Known initial 4-momentum

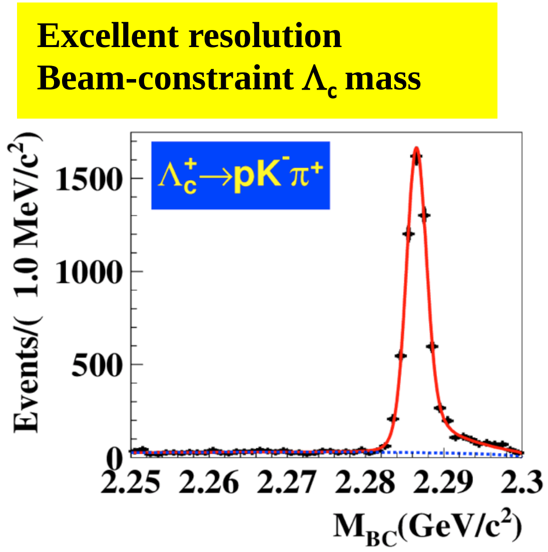
Known beam energy: pair productions

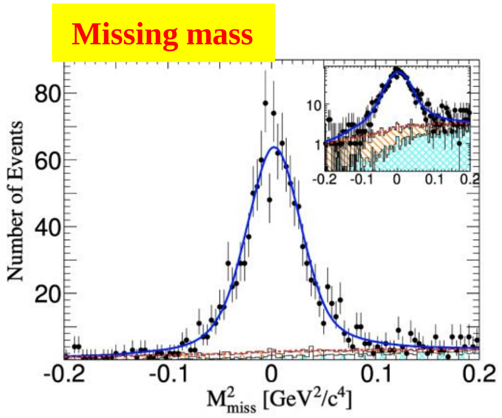
Decay with neutron & π^0

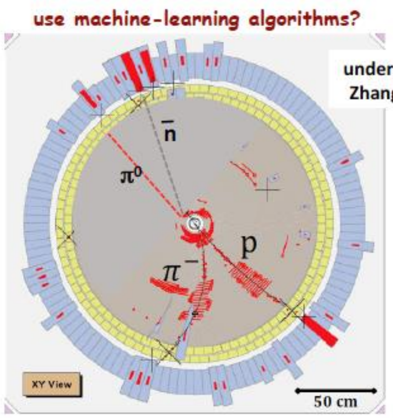
Decay with invisibles: neutrinos

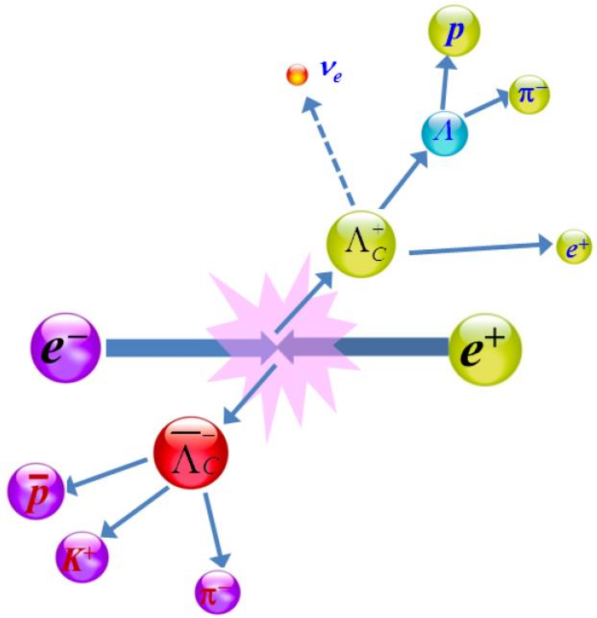
Missing mass or missing energy

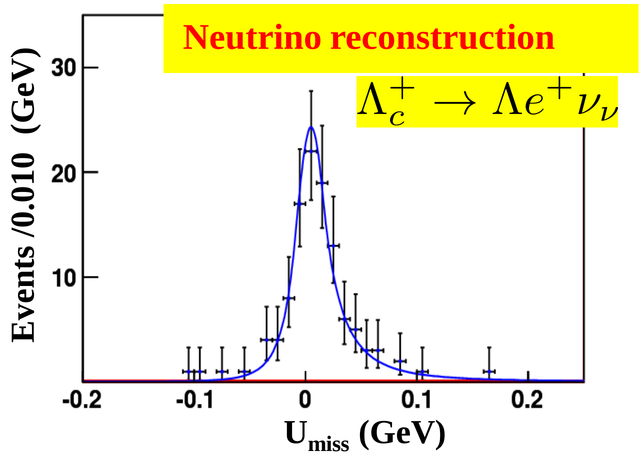






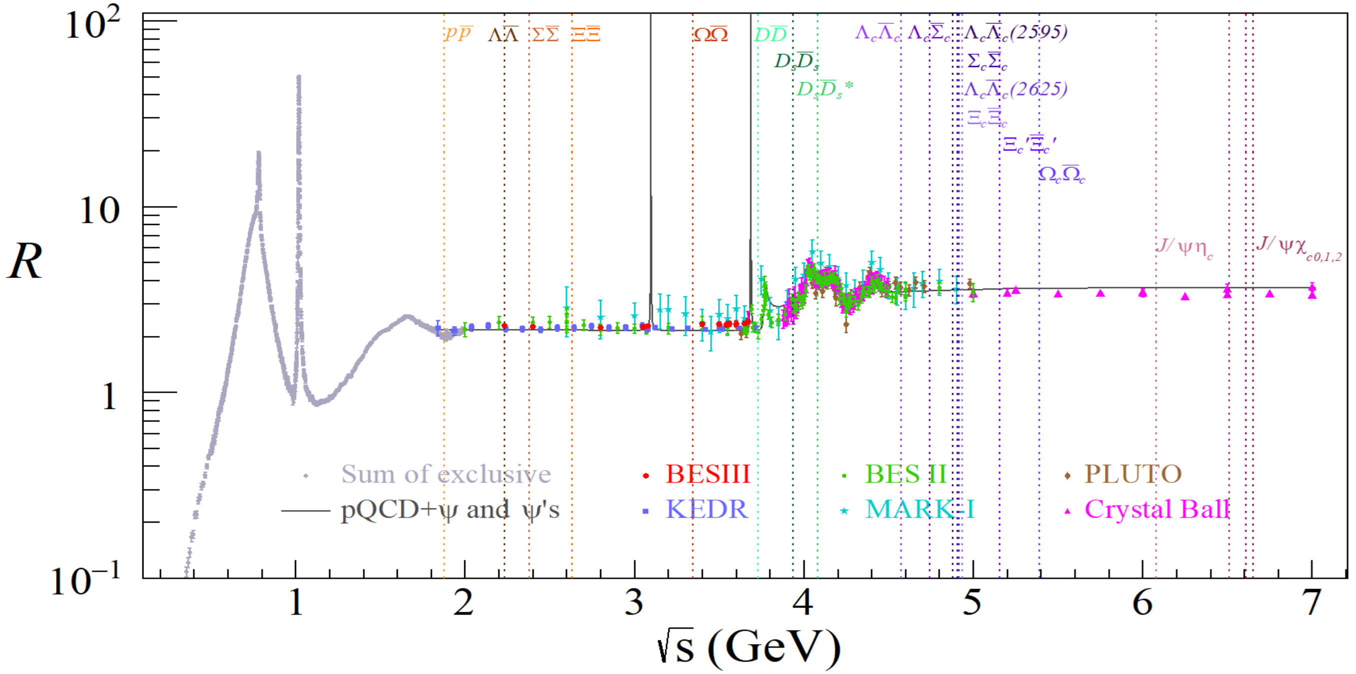


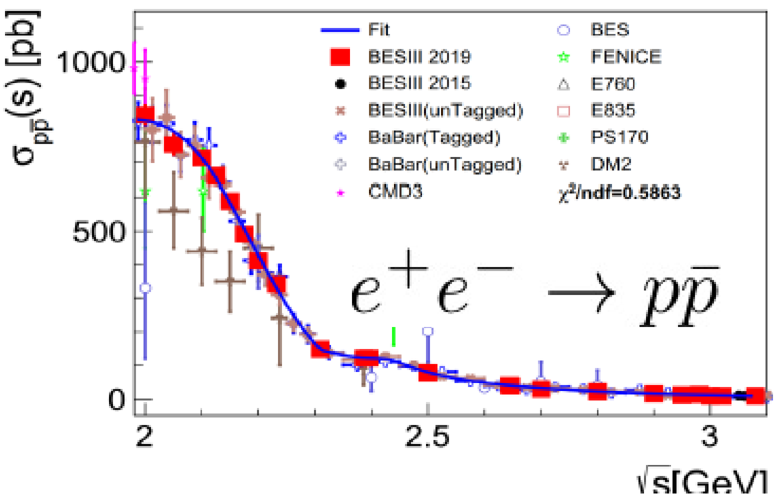




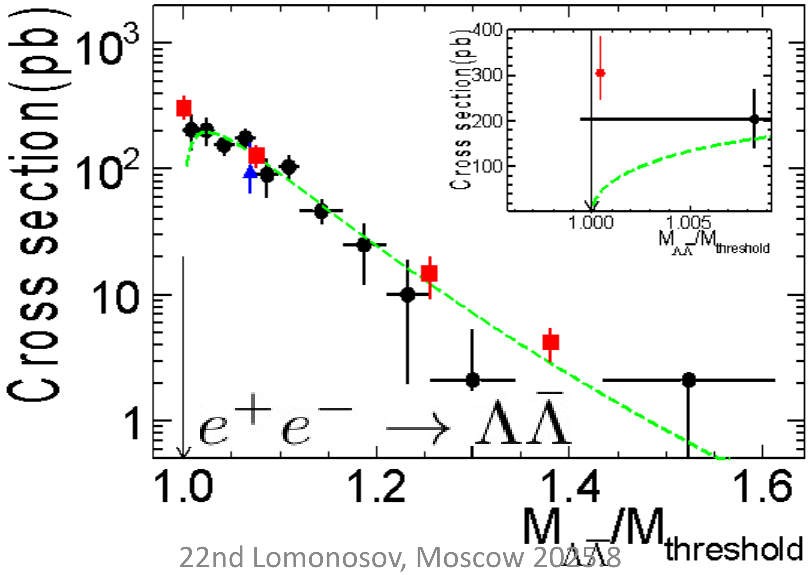
Advantage: data near to the thresholds

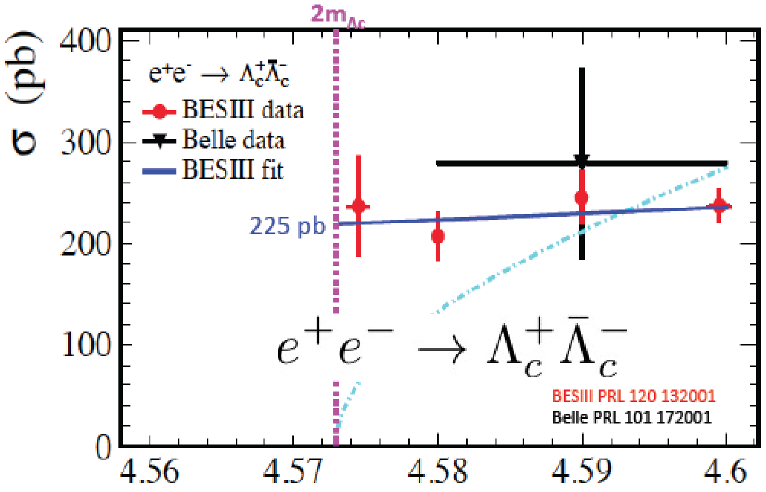
- **Meson and Baryon pairs productions near thresholds: form-factors, relative phase;**
- **Hyperon and charmed baryon entangled Spin polarization;**
- **CP violation with quantum-entangled hadron pairs.**



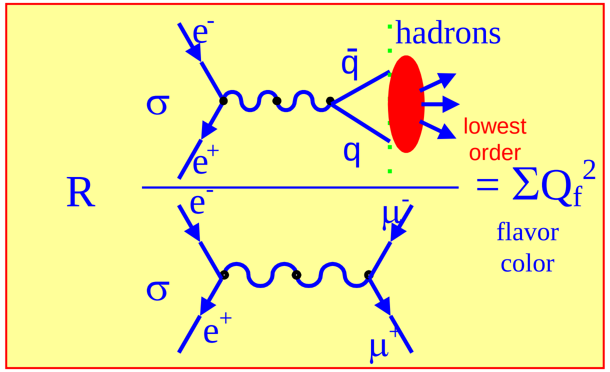


Best precision on σ: 3% (systematic dominant)



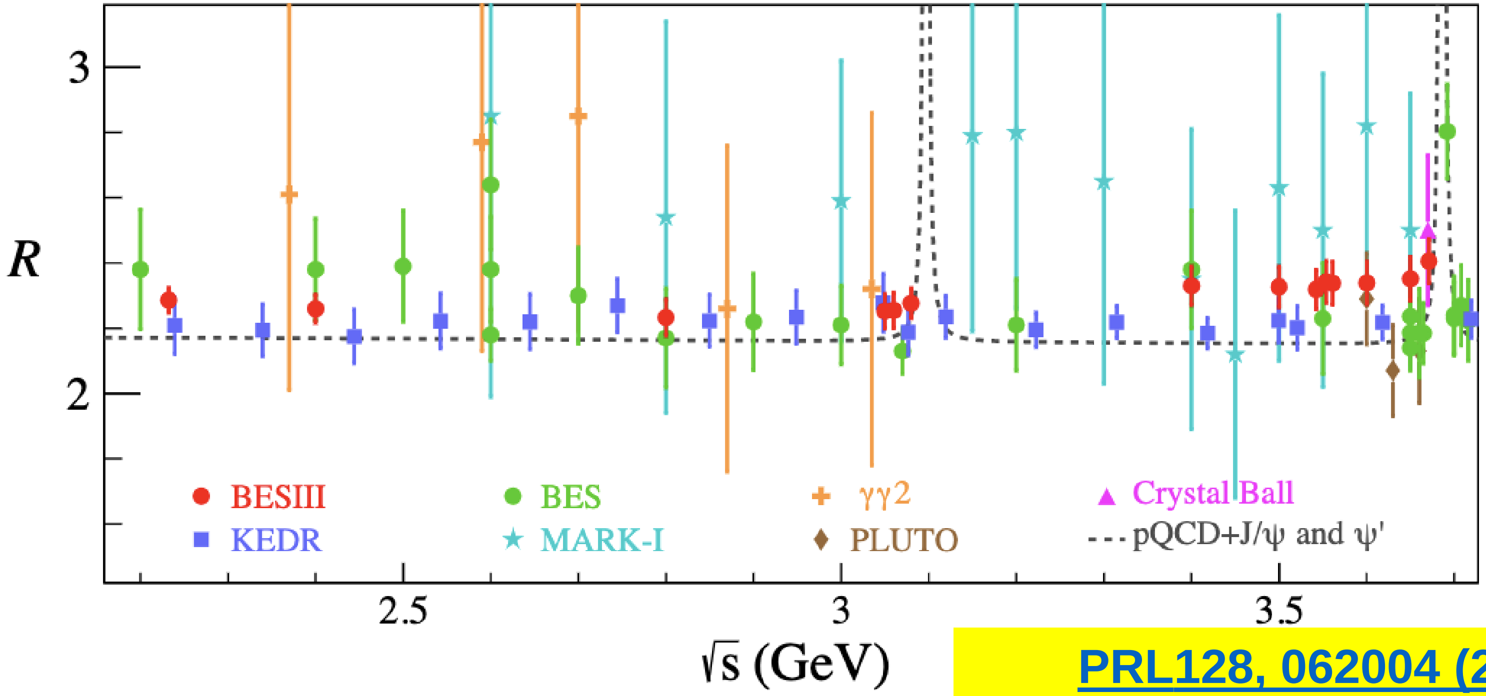


Updated R values at BESIII



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

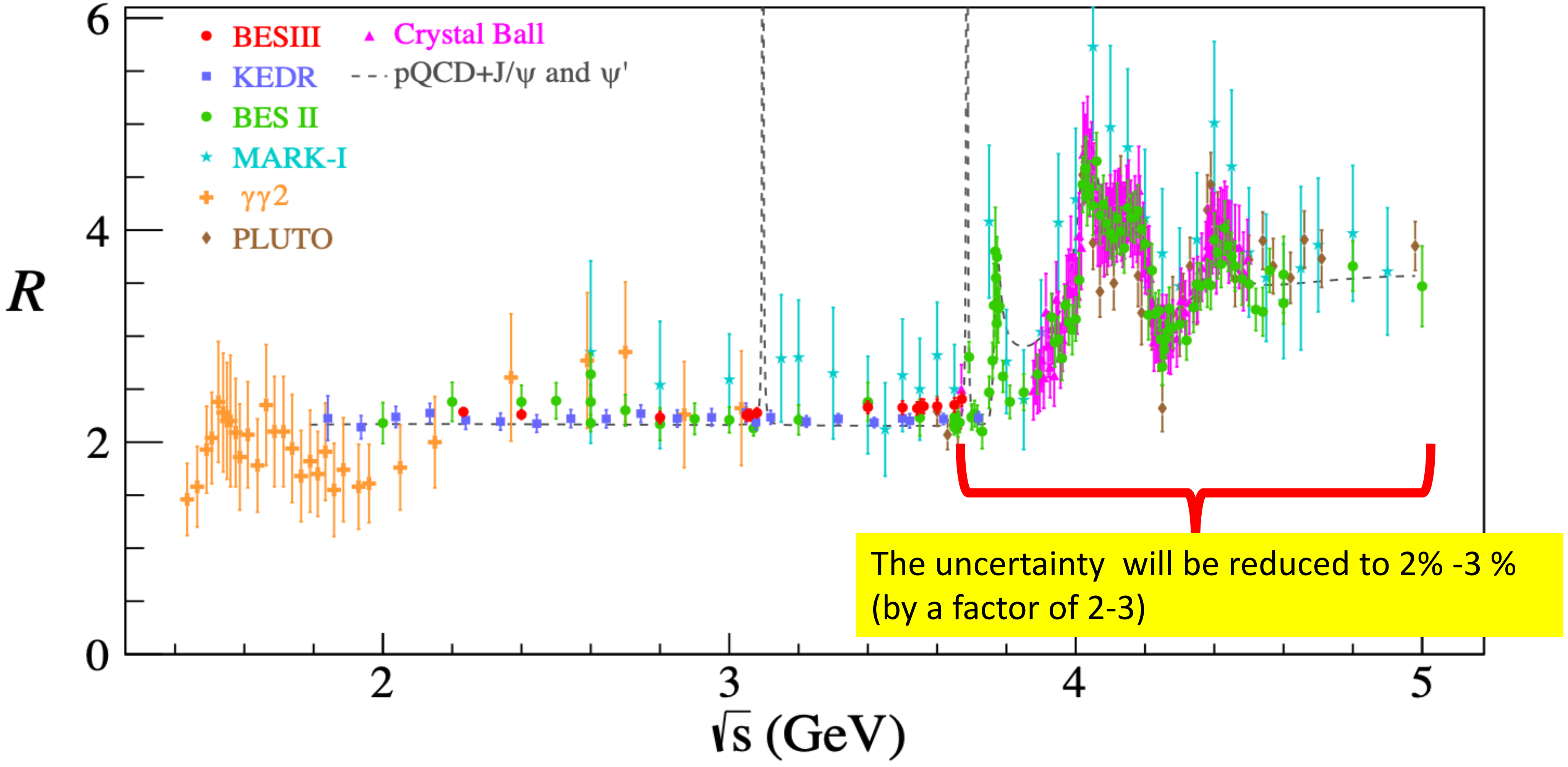
Comparing BESIII R values with previously published results:



PRL128, 062004 (2022)

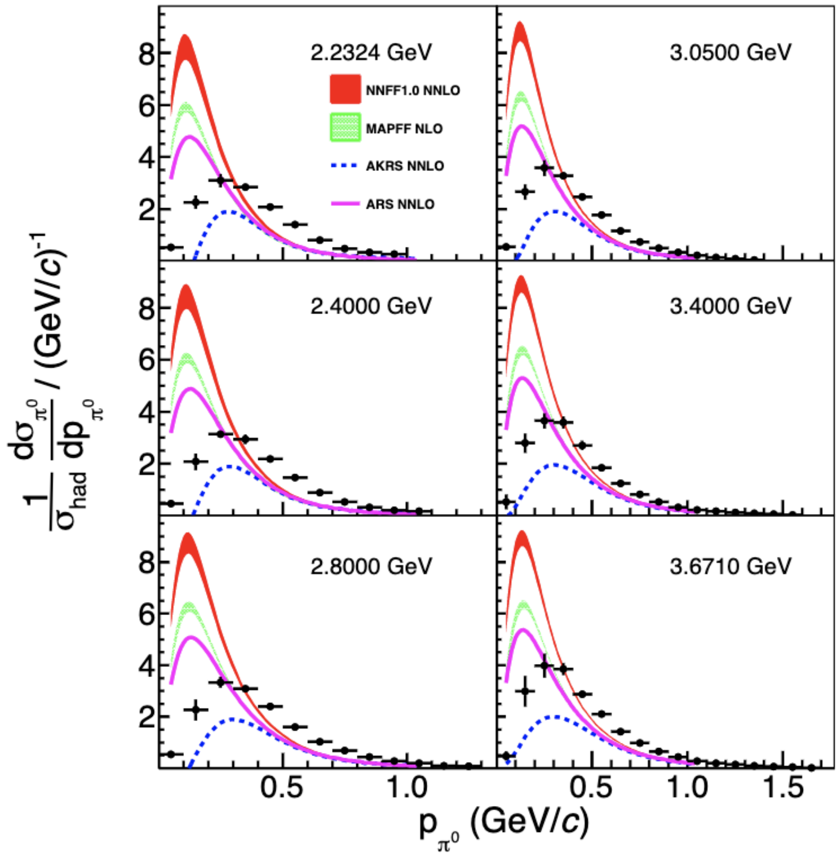
- ► **The accuracy is better than 2.6% below 3.1** GeV **and 3.0% above.**
- ► **Larger than the pQCD prediction by 2.7σ between** 3.4 ~ 3.6 GeV.

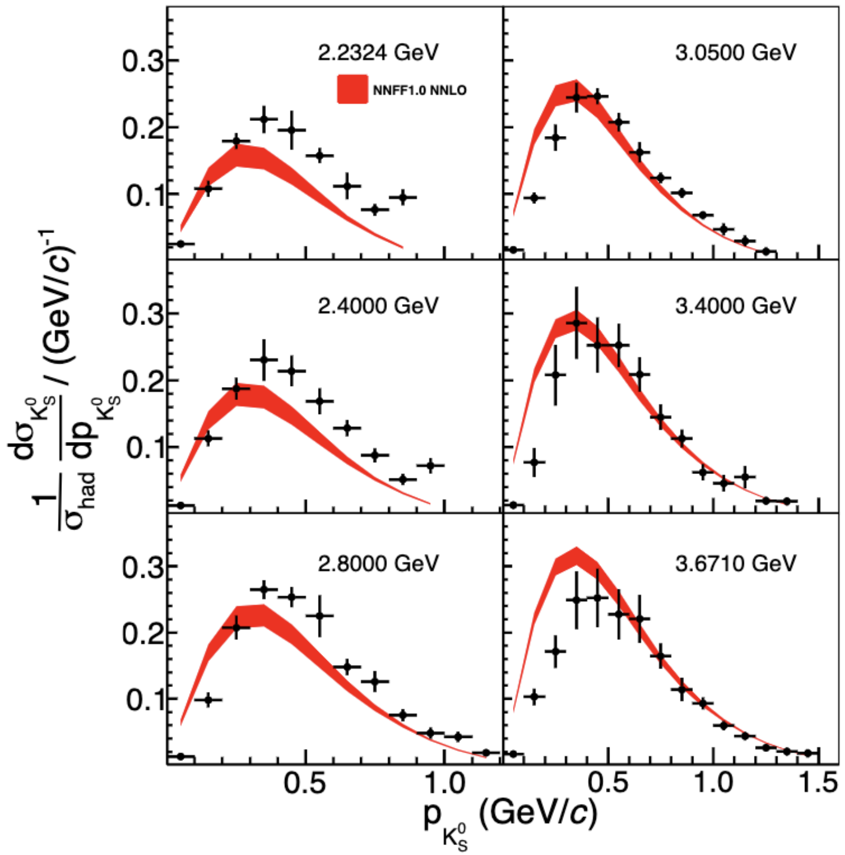
The *R* program at BESIII



- **R values in full range 1.84 - 4.95 GeV to come soon.**

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

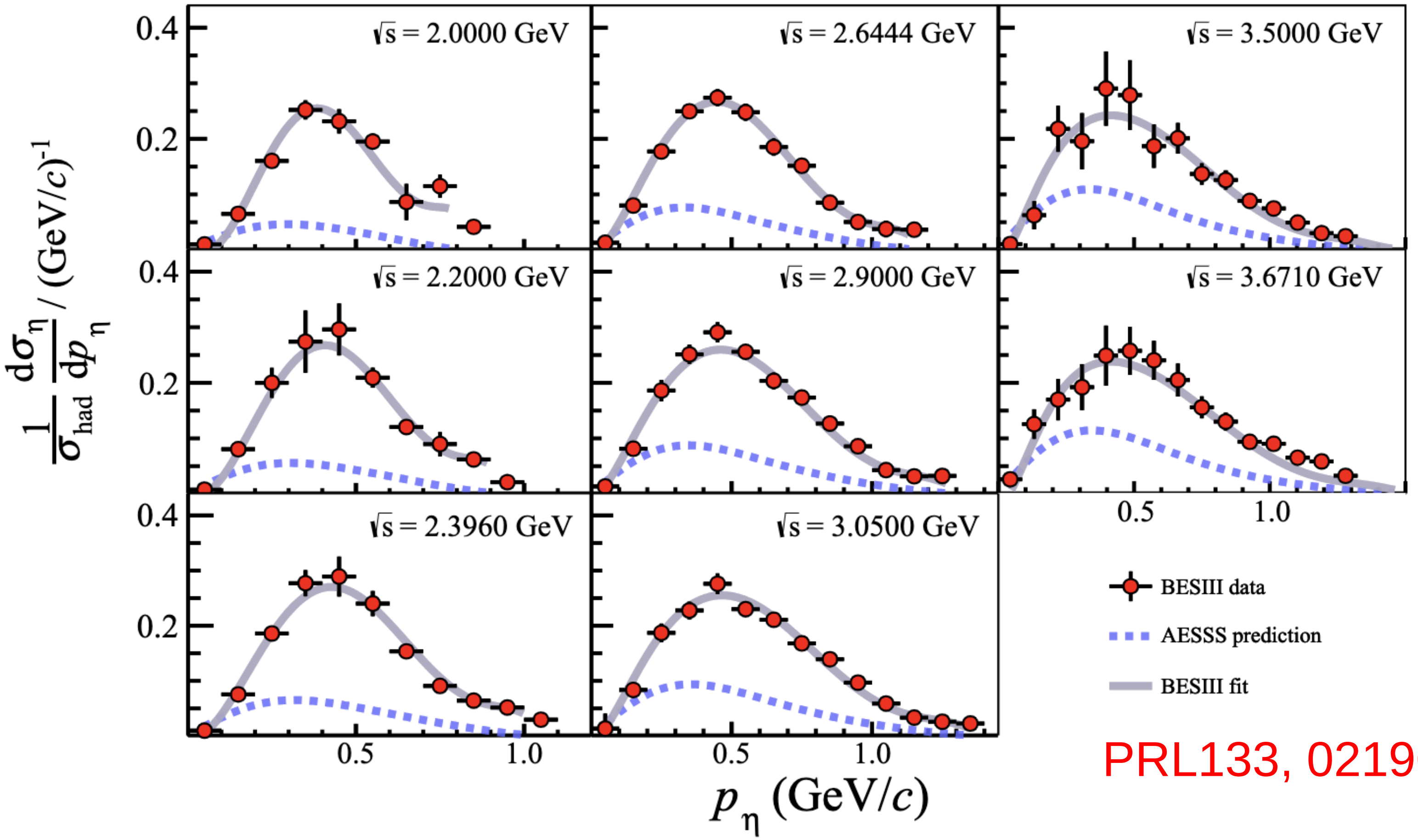




PRL 130, 231901 (2023)

- 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

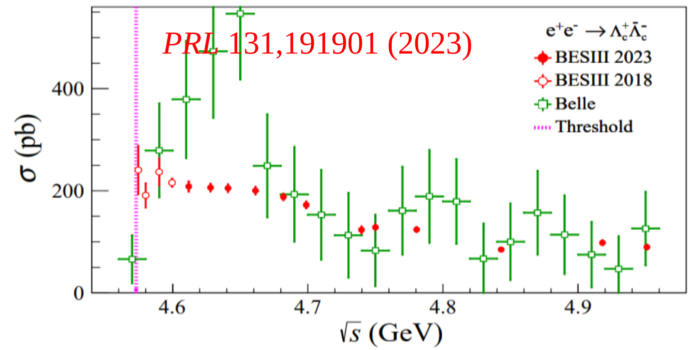
Inclusive η productions in e^+e^- annihilations



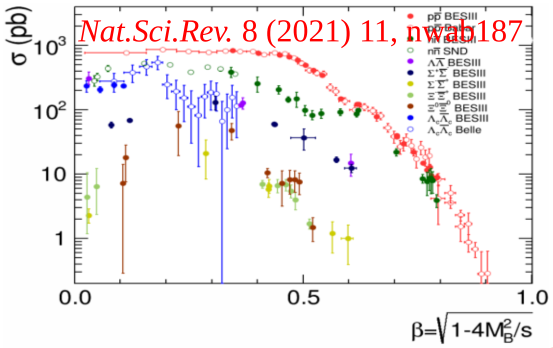
PRL133, 021901 (2024)

- Wide hadron energy fraction coverage $z_h \in (0.1, 0.9)$;
- Disagreement with theory prediction, especially at lower energy.

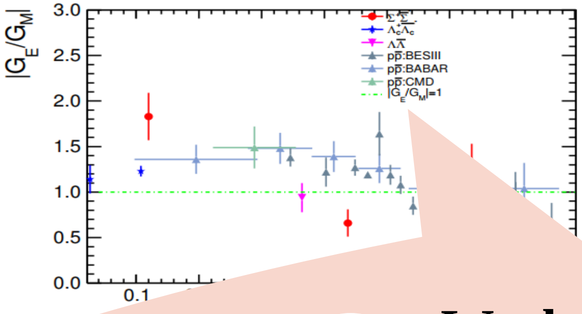
Baryon Electromagnetic form factors (EMFF)

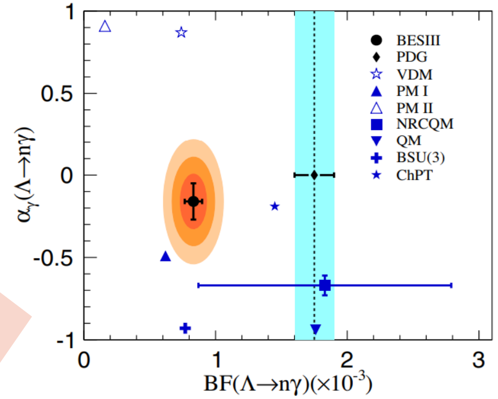


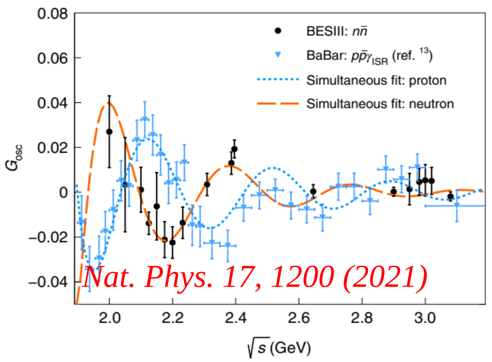
PRL 131,191901 (2023)



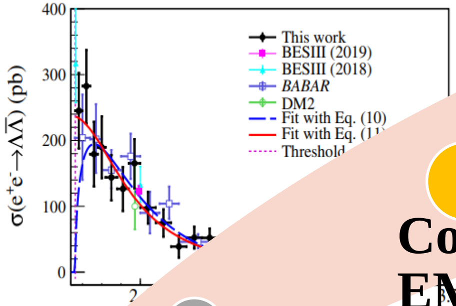
Nat.Sci.Rev. 8 (2021) 11, nwab187

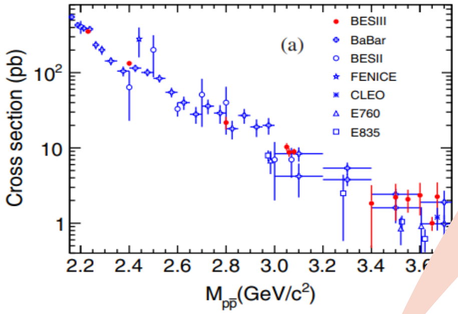






Nat. Phys. 17, 1200 (2021)





PRD 91, 112004 (2015)

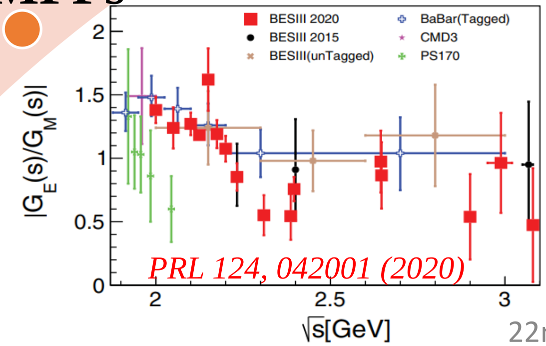
Baryon EMFFs

Threshold effect

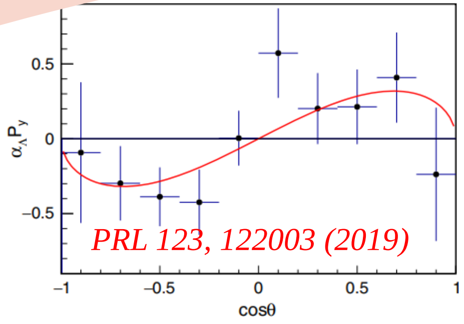
Complete EMFF

CP measurement

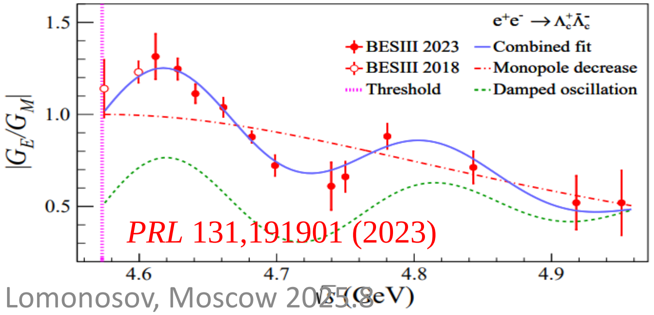
Weak radiative baryon decay



PRL 124, 042001 (2020)



PRL 123, 122003 (2019)

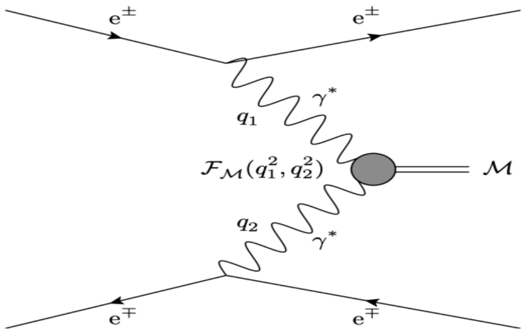


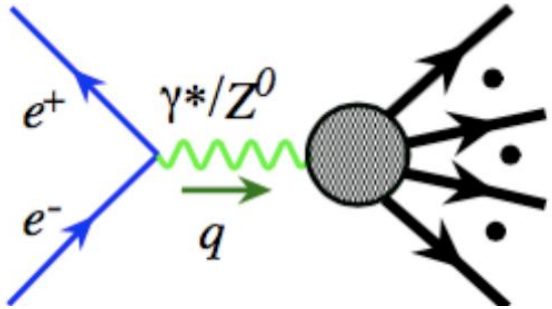
PRL 131,191901 (2023)

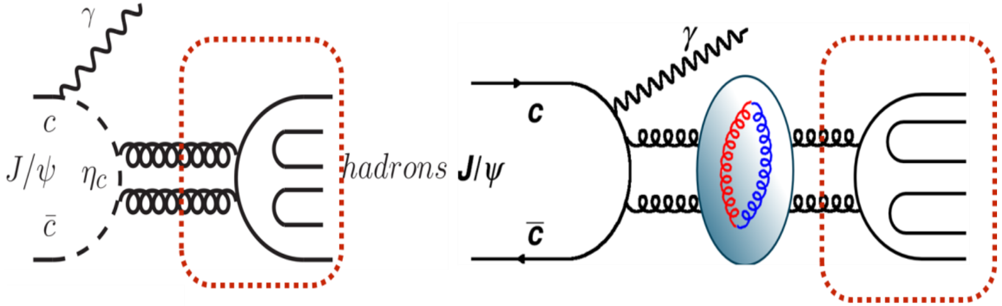
More precise results input to non-pQCD and SM!

Highlight: light spectroscopy

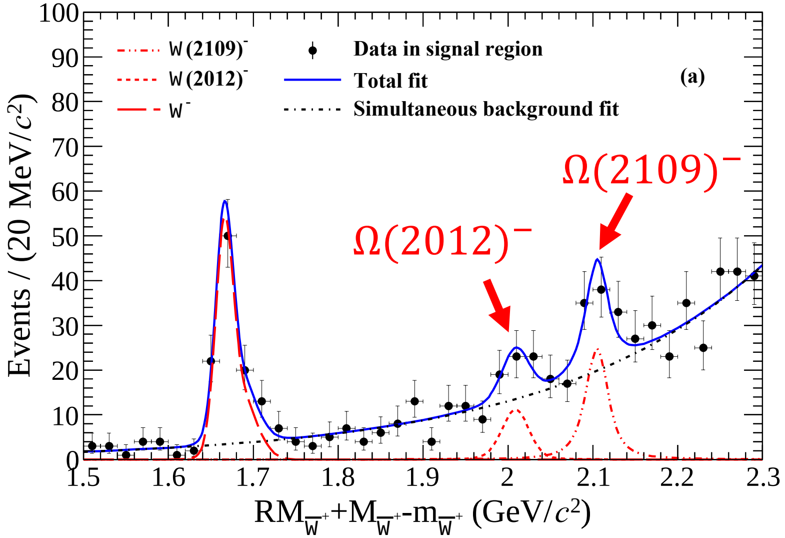
Light hadrons via Electron-positron annihilations, charmonium decays, charmed hadron decays, two-photon processes …
It is crucial to search for light exotic states: glueball, hybrid, multi-quark states …
Rich light scalars, missed excited baryons …



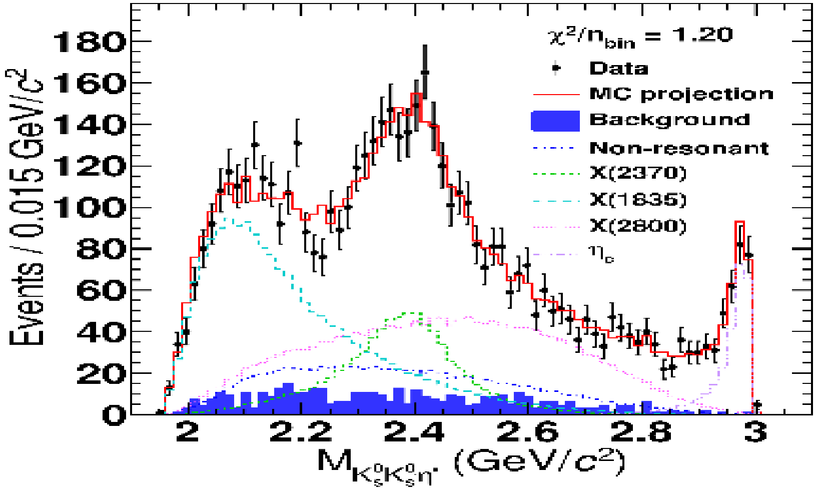




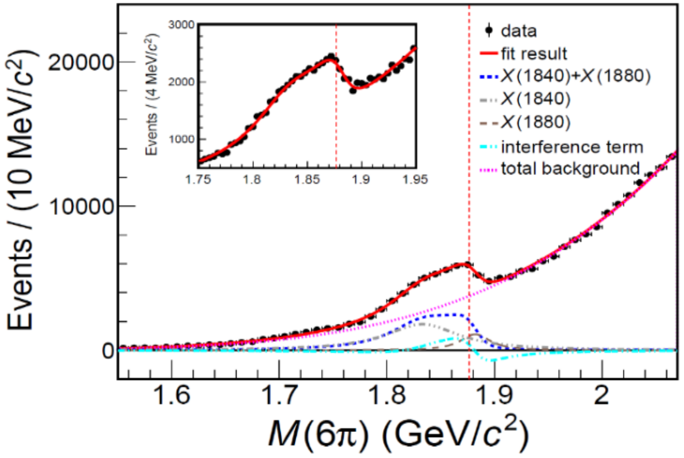
Evidence for Two Excited Ω^- Hyperons
PRL 134, 131903 (2025)



Discovered a Glueball-like Particle – X(2370)
PRL 132, 181901 (2024)



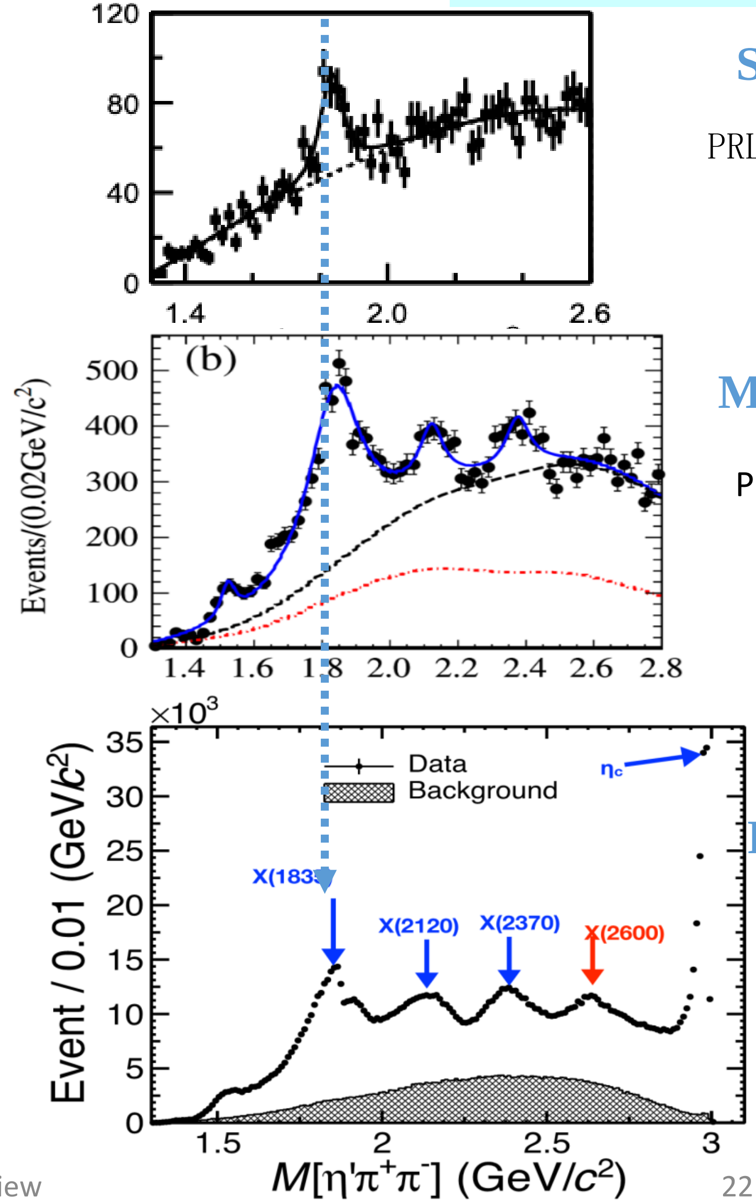
Discovery of fine structure near proton-anti-proton threshold:: X(1840) and X(1880),
PRL132, 151901 (2024)



Hadron spectroscopy: high-statistics data

X(1835) $J/\psi \to \gamma \eta' \pi^+ \pi^-$

58 million



Structure

PRL 95, 262001 (2005)

225 million

More structures

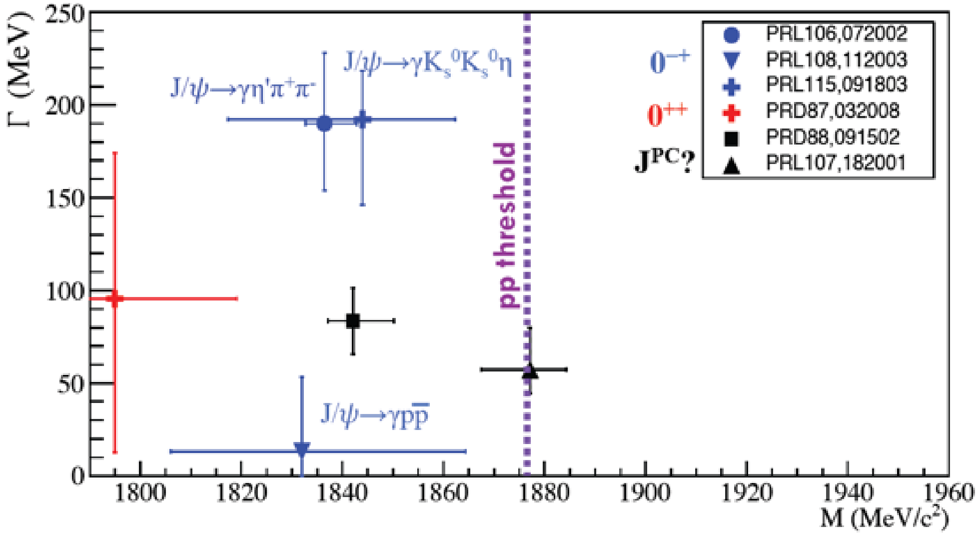
PRL106, 072002 (2011)

10 billion

Fine structures

PRL129, 042001 (2022)

Rich spectra



You never have enough J/ψ events

–The case for a J/ψ factory–

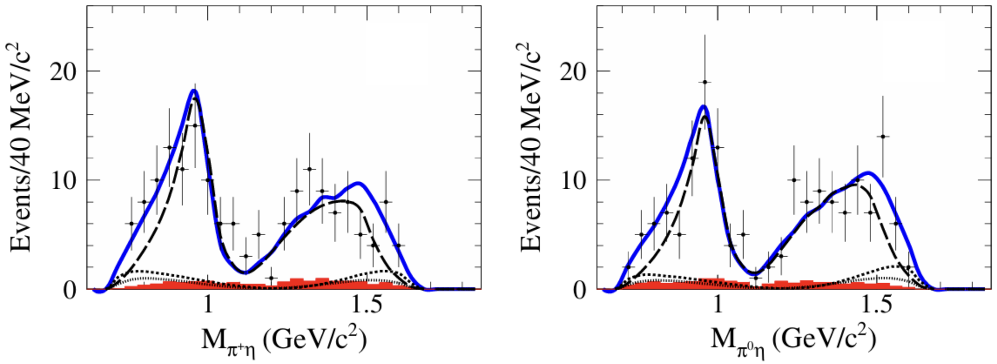
Stephen Lars Olsen

arXiv:2506.20975

Highlight: light hadron from charmed hadron decays

- $a_0(980)$ and $f_0(980)$: two-quark $q\bar{q}$ or tetraquark $q^2\bar{q}^2$?

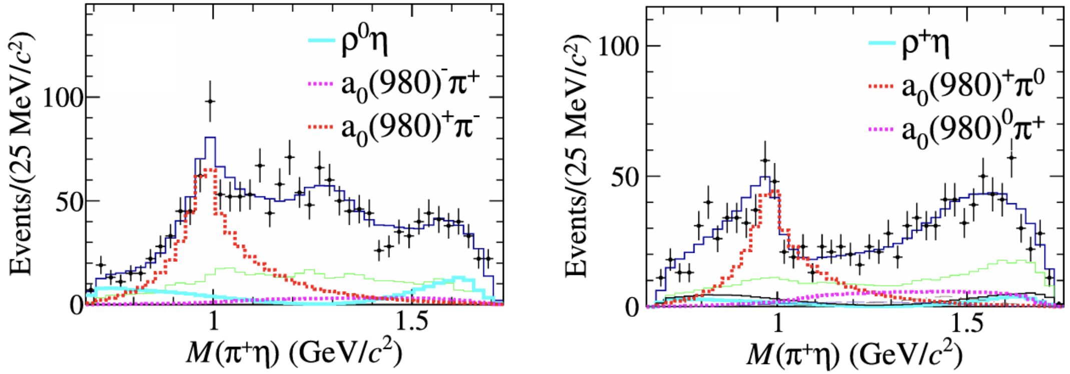
PRL 123, 112001 (2019)



W-Annihilation

$$B(D_s^+ \to a_0\pi, a_0 \to \pi\eta) = (1.46 \pm 0.27)\%$$

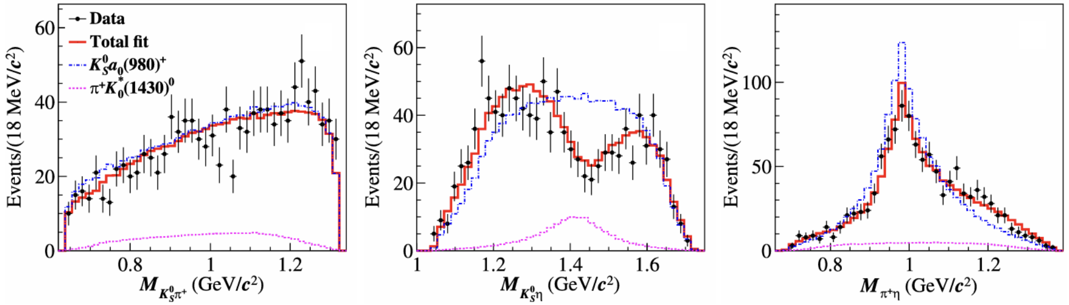
PRD 110, L111102 (2024)



W-Emission & W-Exchange

$$B(D^+ \to a_0^0\pi^+) = (3.7 \pm 1.1); (a_0^+\pi^0) = (9.5 \pm 1.3) \times 10^{-4}$$
$$B(D^0 \to a_0^+\pi^-) = (5.5 \pm 0.9); (a_0^-\pi^+) = (0.7 \pm 0.2) \times 10^{-4}, a_0 \to \pi\eta$$

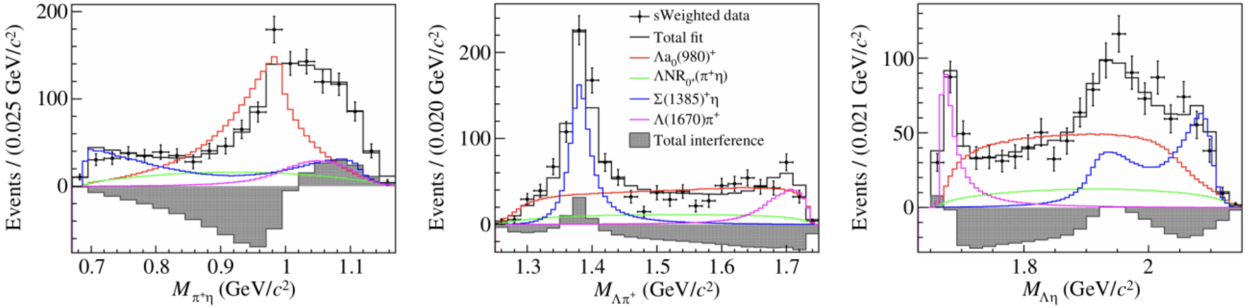
PRL 132, 131903 (2024)



W-Emission

$$B(D^+ \to a_0^+ K_S^0, a_0 \to \pi\eta) = (1.33 \pm 0.06)\%$$

PRL 134, 021901 (2025)



W-Emission & W-Exchange

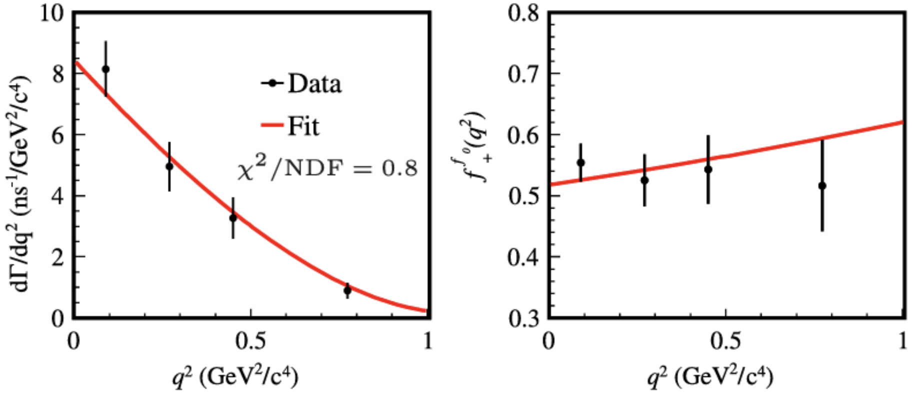
$$B(\Lambda_c^+ \to a_0^+\Lambda, a_0 \to \pi\eta) = (1.05 \pm 0.18)\%$$

All of the measured branching fractions deviate from the predictions made by $q\bar{q}$ model ⇒ $q^2\bar{q}^2$ and Final State Interaction?

Highlight: light hadron from charmed hadron decays

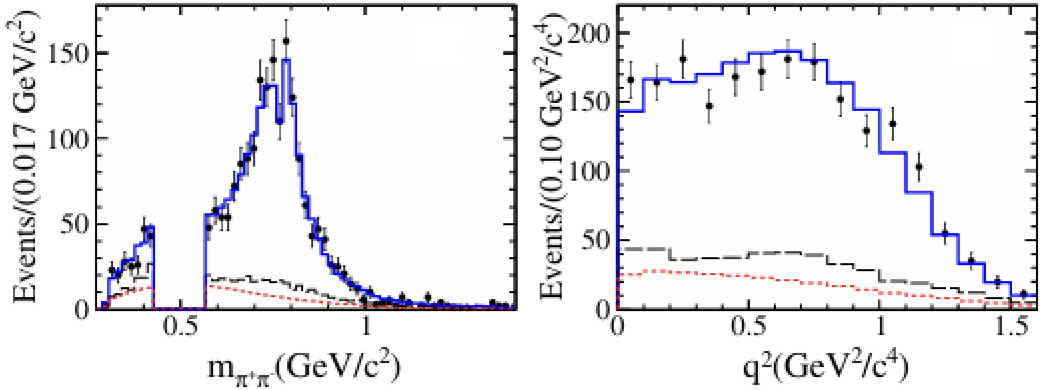
➢ $a_0(980)$ and $f_0(980)$: two-quark $q\bar{q}$ or tetraquark $q^2\bar{q}^2$?

PRL 132, 141901 (2024)



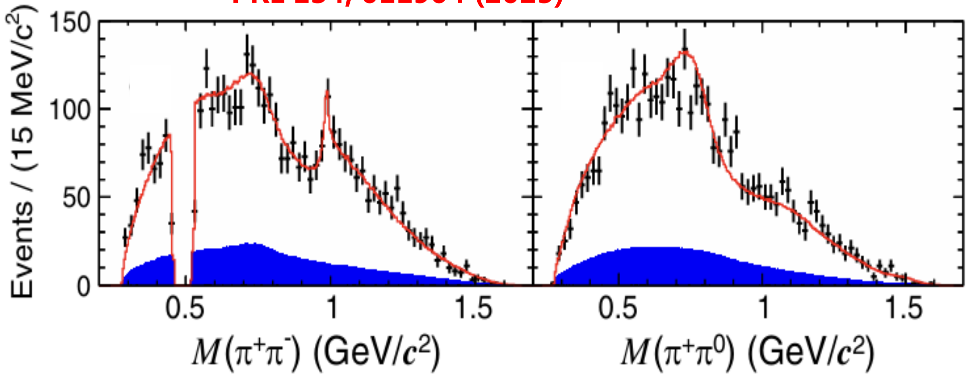
$$B(D_s^+ \to f_0 e^+ \nu_e, f_0 \to \pi^+\pi^-) = (1.72 \pm 0.16) \times 10^{-3}$$
$$f_+^{f_0}(0) = 0.52 \pm 0.04$$

PRL 122, 062001 (2019)



$$B(D^+ \to f_0 e^+ \nu_e, f_0 \to \pi^+\pi^-) < 2.8 \times 10^{-5}$$

PRL 134, 011904 (2025)



$$B(D_s^+ \to f_0(980)\rho^+, f_0 \to \pi^+\pi^-) = (2.57 \pm 0.48) \times 10^{-3}$$

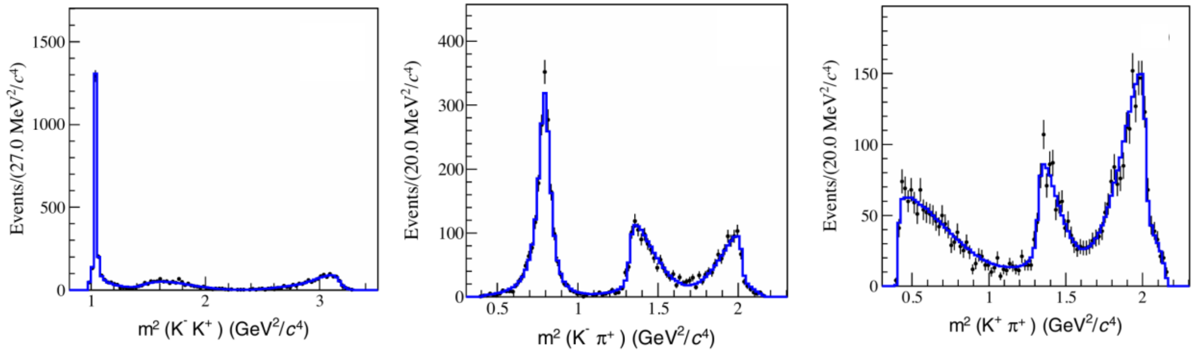
Theoretical predictions by JHEP12(2024)226	$q\bar{q}$	$q^2\bar{q}^2$
$f_+^{f_0}(0)$	0.52 ± 0.02	0.53 ± 0.02
$10^{-3}B(D_s^+ \to f_0 e^+ \nu_e)$	1.69 ± 1.39	1.72 ± 1.48
$10^{-5}B(D^+ \to f_0 e^+ \nu_e)$	1.3 ± 0.1	2.9 ± 0.7

Still being controversial!

Highlight: light hadron from charmed hadron decays

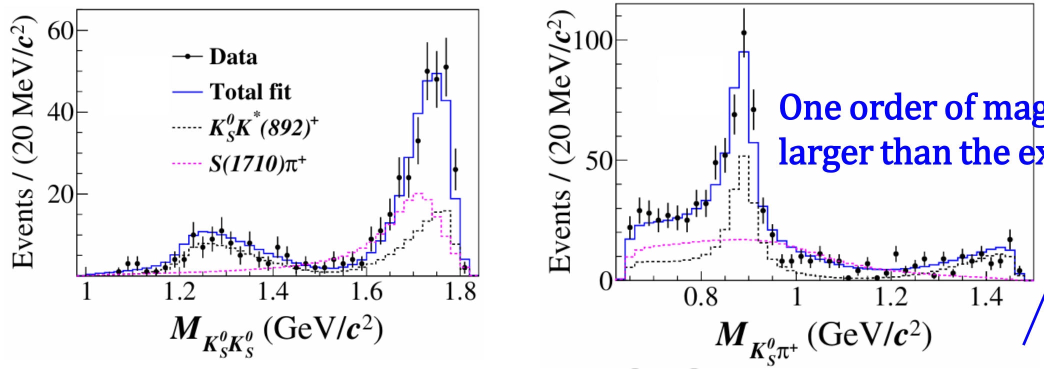
- $a_0(1817)$ and $f_0(1710)$

PRD 104, 012016 (2021)



$$B(D_s^+ \to f_0(1710)\pi^+, f_0 \to K^+K^-) = (0.10 \pm 0.04)\%$$

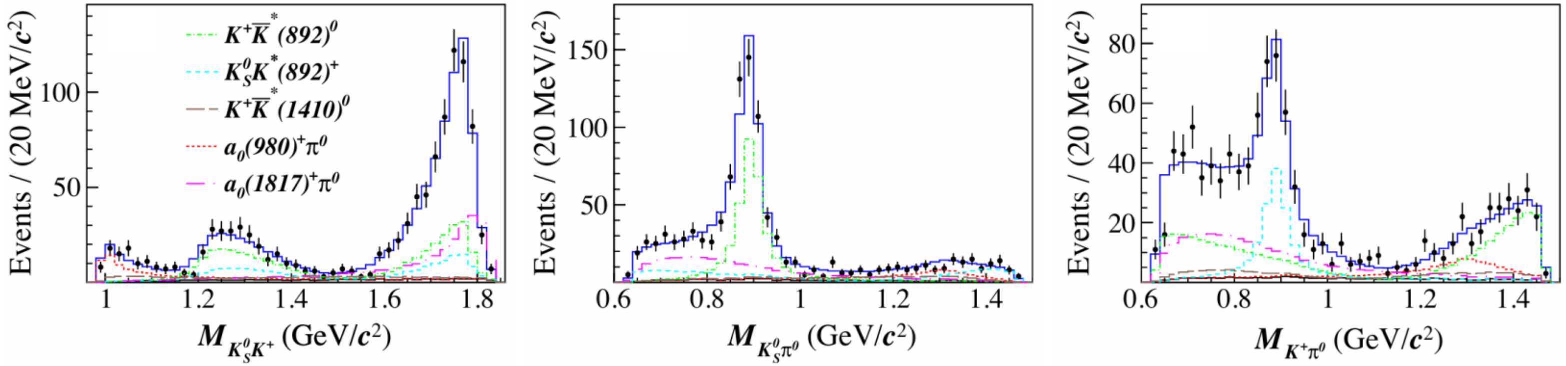
PRD 105, L051103 (2022)



One order of magnitude larger than the expectation!

$$B(D_s^+ \to f_0(1710)\pi^+, f_0 \to K_S^0K_S^0) = (0.31 \pm 0.03)\%$$

PRL 129, 182001 (2022)



Isospin-one partner of $f_0(1710)$ or $X(1812)$?

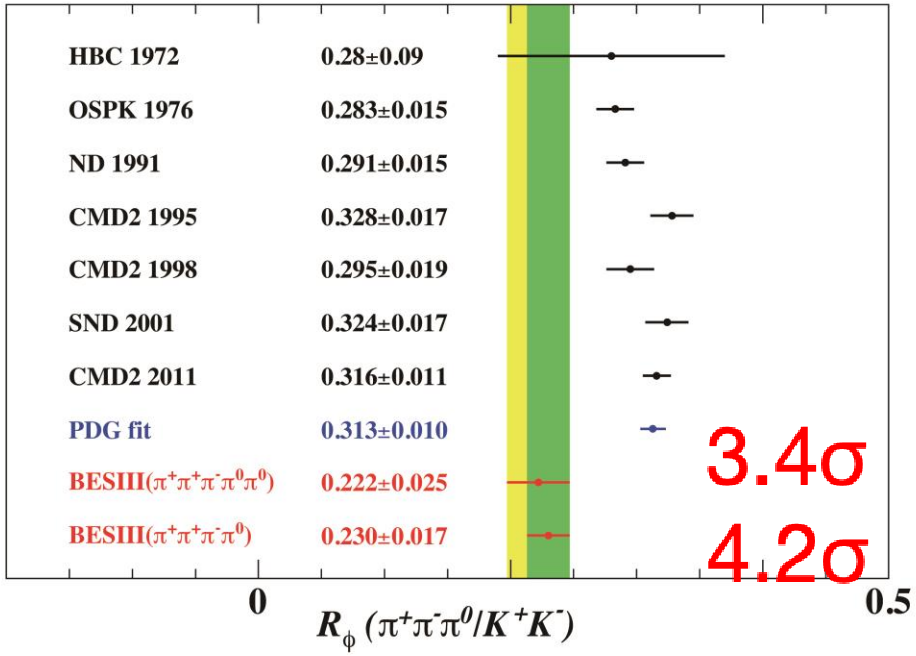
$$B(D_s^+ \to a_0(1817)^+\pi^0, a_0 \to K_S^0K^+) = (3.44 \pm 0.61) \times 10^{-3}$$

Mass: $(1.817 \pm 0.02)\mathrm{GeV}/c^2$ Width: $(0.097 \pm 0.027)\mathrm{GeV}/c^2$

Highlight: Puzzle of ϕ decays in charm

- In $D_s^+ \to \pi^+\pi^+\pi^-\pi^0$, $D_s^+ \to \pi^+\pi^+\pi^-\pi^0\pi^0$ and $K_S^0 K_L^0 \pi^+$ decays, Relative Branching Fraction of ϕ meson deviate from PDG;
- More results are coming. New mechanism?

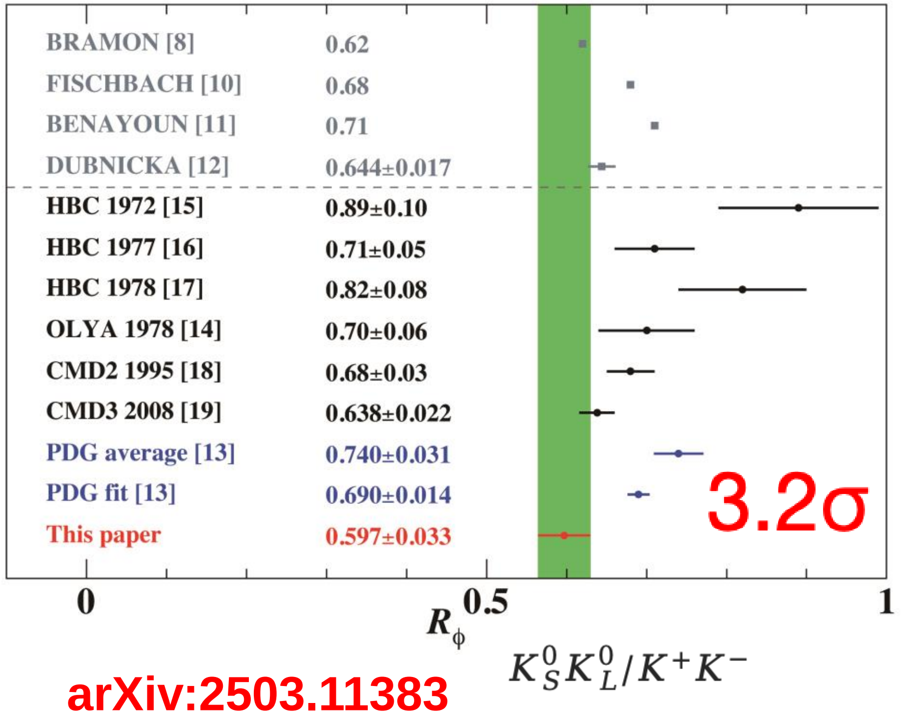
$$R_\phi = \frac{\mathcal{B}(\phi \to \pi^+\pi^-\pi^0)}{\mathcal{B}(\phi \to K^+K^-)}$$



arXiv:2501.04451

PRL 134, 011904 (2025)

$$R_\phi = \frac{\mathcal{B}(\phi \to K_S K_L)}{\mathcal{B}(\phi \to K^+K^-)}$$

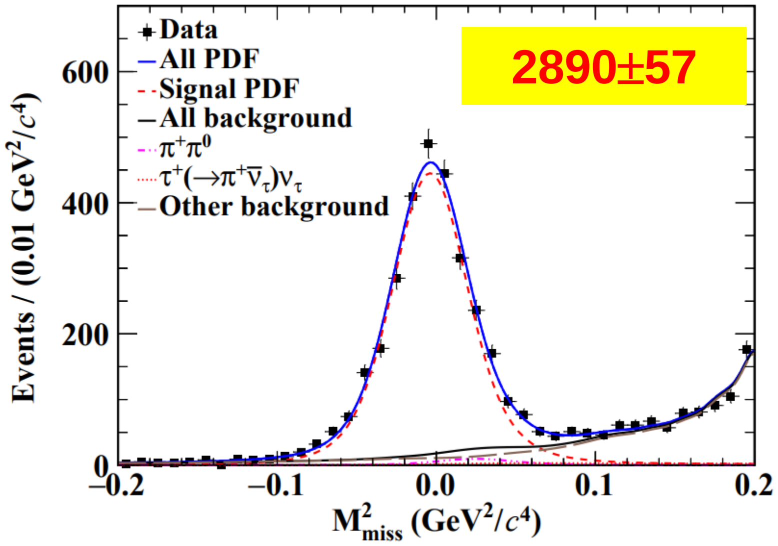


arXiv:2503.11383

Highlights: The most precise measurement of $D^+ \to \mu^+\nu_\mu$

The most precise measurement of $D^+ \to \mu^+\nu_\mu$ with 20.3 fb^{-1}@3.773 GeV

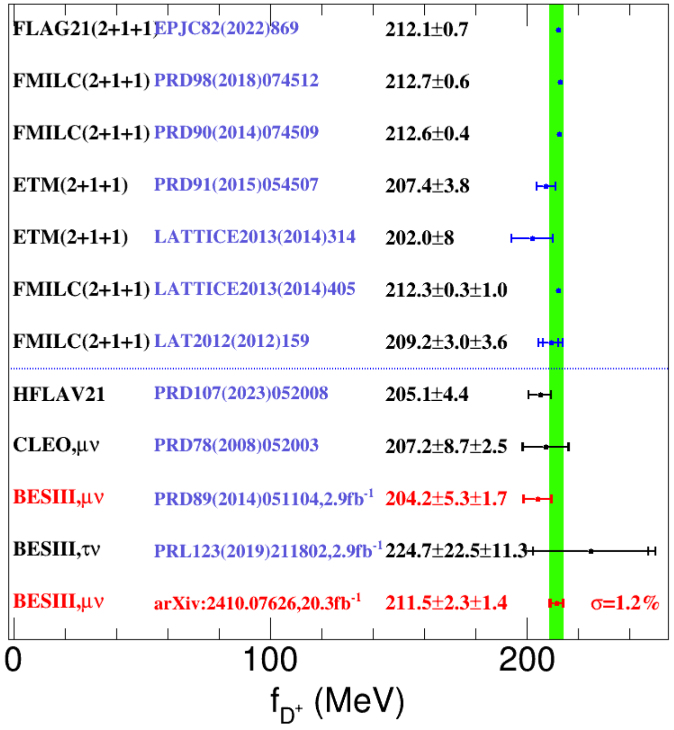
arXiv:2410.07626



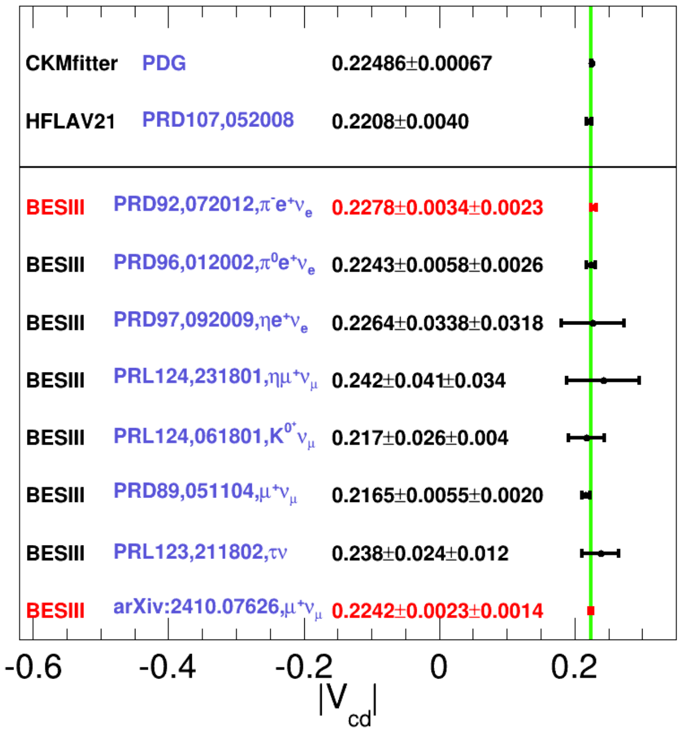
The most precise to date

$$B[D^+ \to \mu^+ \nu] = (3.98 \pm 0.08 \pm 0.04) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = 47.53 \pm 0.48 \pm 0.27\ \mathrm{MeV}$$



The decay constant



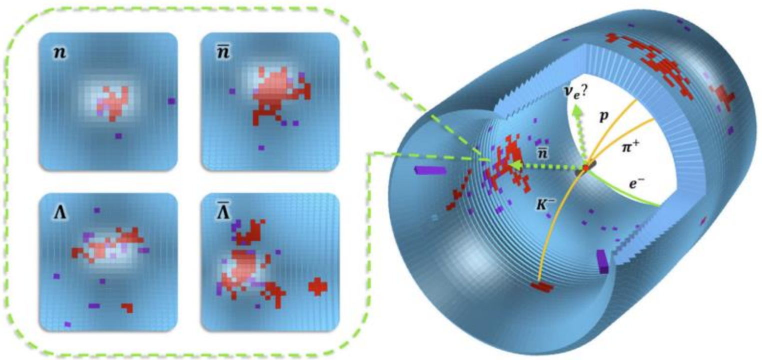
The value of Vcd

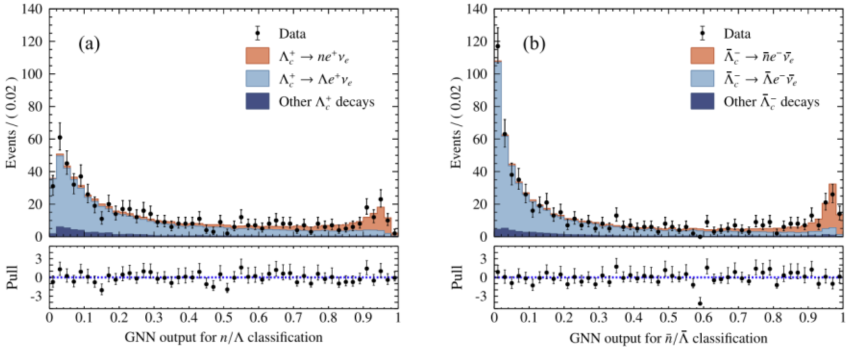
Precision~1.2%

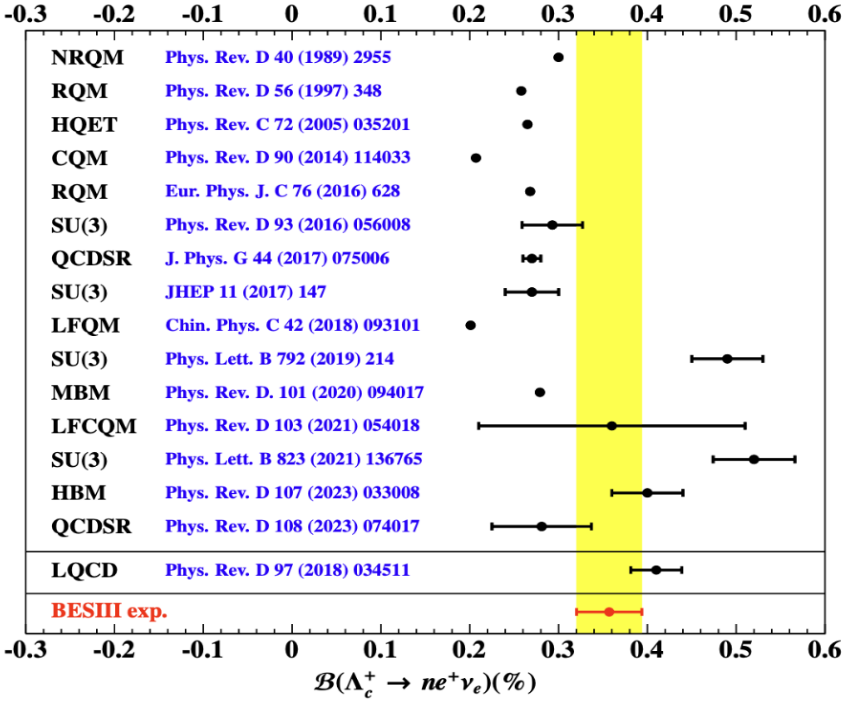
Highlights： observation of $\Lambda_c^+ \to n e^+ \nu_e$

BESIII, Nature Commun. 16, 681 (2025)

- **A novel Deep Learning is utilized to separate signals from dominant background.**
- **First observation of $\Lambda_c^+ \to n e^+ \nu_e$**
  - $\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (0.357 \pm 0.034_{\text{stat}} \pm 0.014_{\text{syst}})\%$ (> 10σ)
  - $|V_{cd}| = 0.208 \pm 0.011_{\text{exp.}} \pm 0.005_{\text{LQCD}} \pm 0.001_{\tau_{\Lambda_c^+}}$
- **This measurement demonstrates a level of precision comparable to the LQCD prediction.**
- **The absence of HCAL restricted us to extract the form factors.**
- **Still, the BF provides significant insights, shedding light on the di-quark structure within the Λ_c^+ core and the $\pi - N$ clouds in the low Q^2**



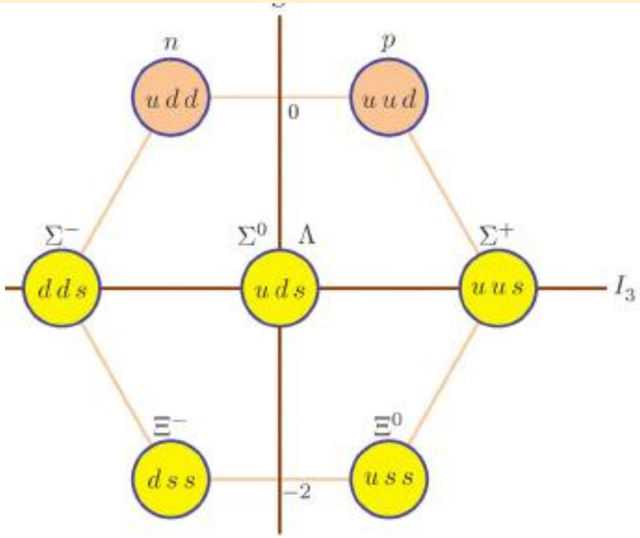




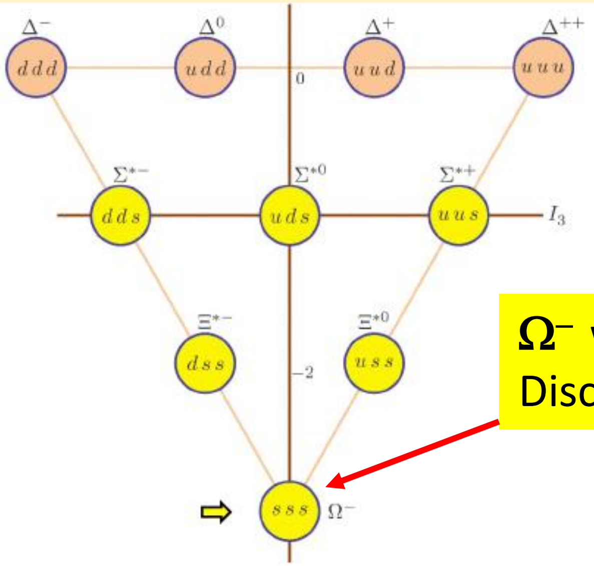
CPV in hyperon decays, #events do we need?

CPV in SM is small :			# events	Experiments
B meson :	O(1)	discovered (2001)	10^3	*B factory*
K meson :	$O(10^{-3})$	discovered (1964)	10^6	*Fix targets*
D meson :	$O(10^{-4})$	discovered(2019)	10^8	*LHCb*
Λ_b baryon:		discovered(2025)		*LHCb*
Hyperon :	$O(10^{-4})$	no evidence (10^{-2})	$O(10^8)$	*Fix targets*

→ BESIII, hyperon factory ?



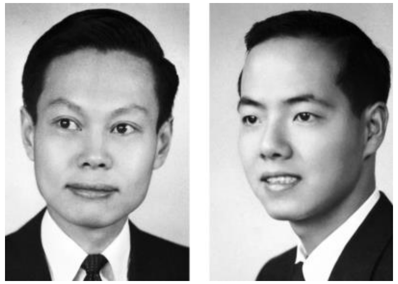
Flavor-SU(3) Octet of spin ½



Ω^- was predicted by quark model
Discovered in 1964 at BNL.

Flavor-SU(3) Decuplet of spin 3/2

CP observables in hyperon decays

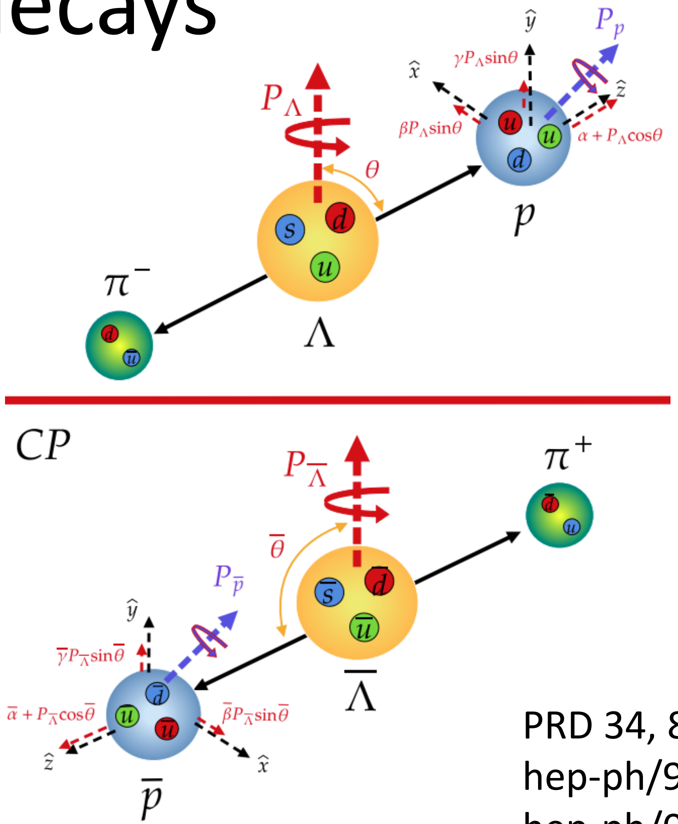


General Partial Wave Analysis of the Decay of a Hyperon of Spin ½

T. D. LEE* AND C. N. YANG
Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

Phys. Rev. 108, 1645 (1957)



PRD 34, 833 (1986)
hep-ph/991023
hep-ph/0002210

The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\mathcal{A} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

The decay parameters are defined as:

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

Two complex amplitudes: **ϕ weak phase, δ strong phase**

$$S = \Sigma^i S_i e^{i(\phi_i^S+\delta_i^S)},\qquad P = \Sigma^i P_i e^{i(\phi_i^P+\delta_i^P)}$$

Under CP transformation:

$$\bar{S} = -\Sigma^i S_i e^{i(-\phi_i^S+\delta_i^S)},\qquad \bar{P} = \Sigma^i P_i e^{i(-\phi_i^P+\delta_i^P)}$$

If CP conserved: $S \xrightarrow{CP} -S$, $P \xrightarrow{CP} P$ ⇒ $\alpha \xrightarrow{CP} \bar{\alpha} = -\alpha$, $\beta \xrightarrow{CP} \bar{\beta} = -\beta$

CPV observables

$$\Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}}$$

$$A = \frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} + \Delta$$

$$B = \frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\beta-\bar{\Gamma}\bar{\beta}} \approx \frac{\beta+\bar{\beta}}{\beta-\bar{\beta}} + \Delta$$

If $\Delta\Phi \neq 0$, Λ and $\bar{\Lambda}$ are transversely polarized

Correlated 5-dim. angular distribution $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

$$\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1+\alpha_\psi\cos^2\theta_\Lambda$$

Unpolarized part

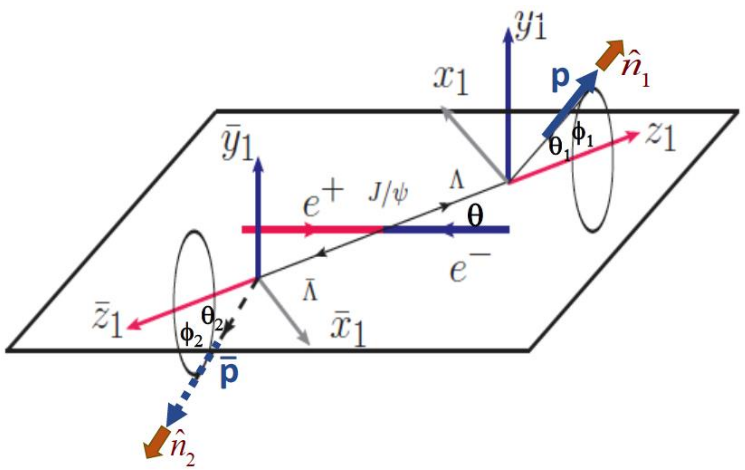
Entangled part

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

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

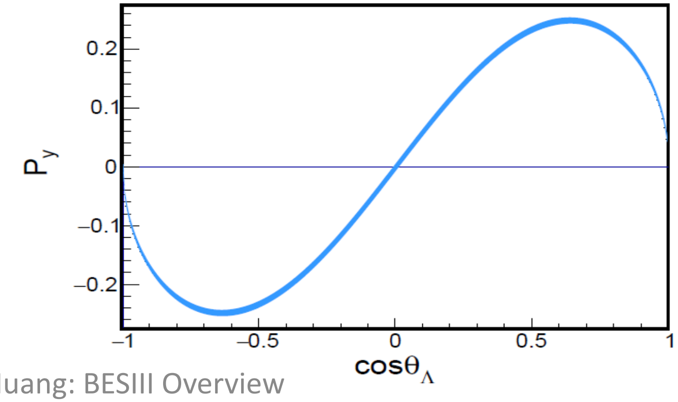
$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right),$$

Polarized part



Polarization-term can be used to determine a_- and a_+ simultaneously

Λ

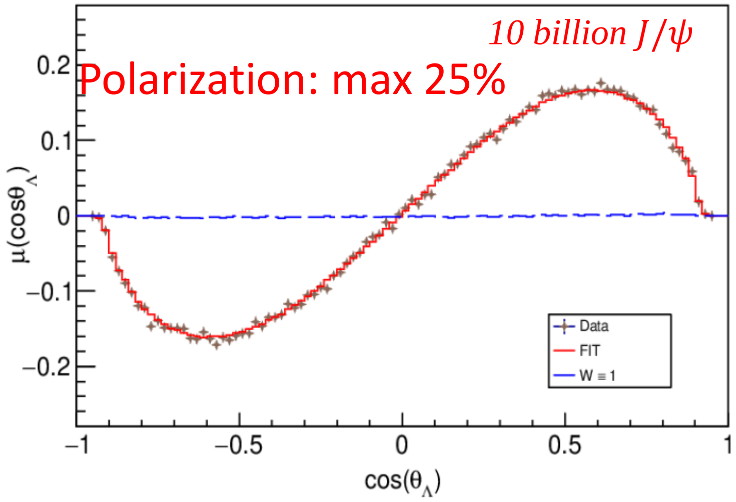


$$P_y(\cos\theta_\Lambda)=\frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

The most precise CP test *in Λ* and $\bar{\Lambda}$ decay

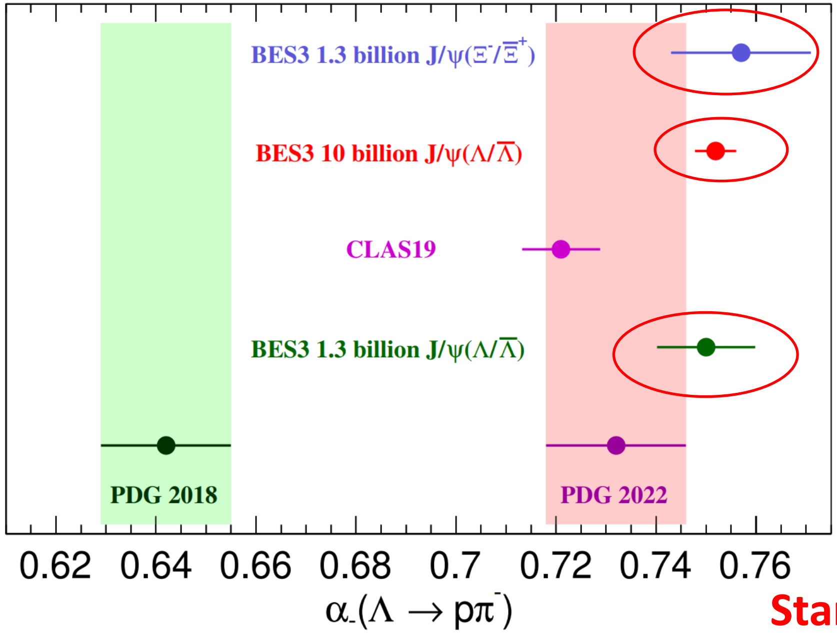
PRL 129, 131801 (2022)

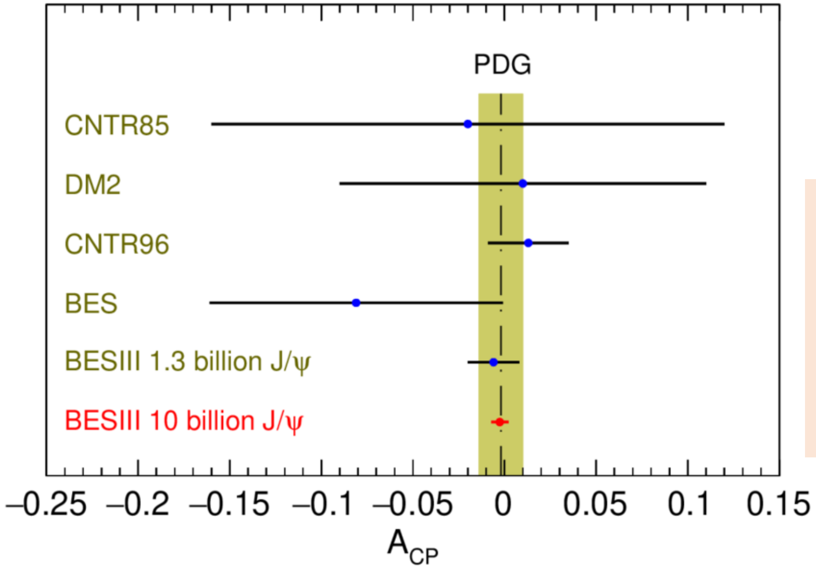
Nat. Phys. 15, 631 (2019)



Paras.	This Work (10 billion J/ψ)	Previous Results (1.3 billion J/ψ)
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$-0.006 \pm 0.012 \pm 0.007$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0020$	----

More than 10 standard deviation shift from all previous measurements





Sensitivity of A_{CP} : below 0.5% unprecedented precision

Standard model prediction : $A_{CP} \sim 10^{-4}$ (PRD 34, 833 (1986))

Search for CPV in Ξ decay

PRD 99, 056008 (2019)
PLB 772, 16 (2017)

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

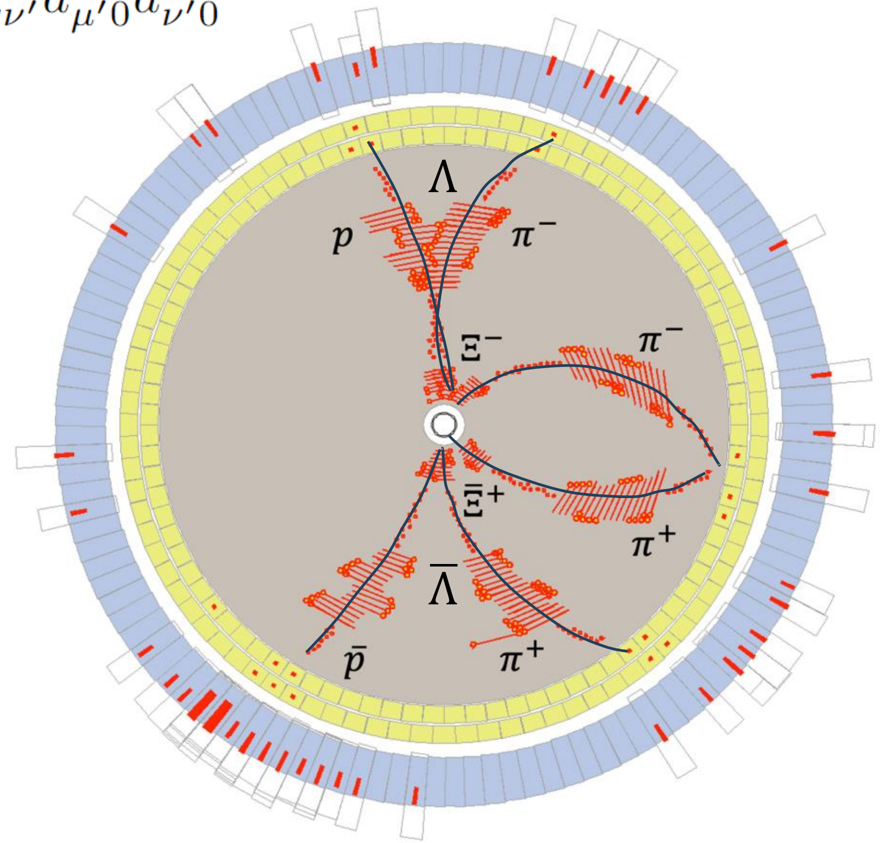
spin-aligned

quantum entangled

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

$\Xi \to \Lambda\pi$, $\Lambda \to p\pi^-$

$\bar{\Xi} \to \bar{\Lambda}\pi$, $\bar{\Lambda} \to \bar{p}\pi^+$



Through the sequential decays of Ξ, the CPV phase can be directly measured!

The *perfect* reaction for hyperon *CPV* searches!

Search for CPV in Ξ decay

Ξ^- 1.3 billion J/ψ

The precision of our analysis (73K $\Xi^-\bar{\Xi}^+$) is comparable with the measurement from HyperCP (144M events), which means that the accuracy of a single event is more than 1000 times higher than HyperCP!

320K $\Xi^0\bar{\Xi}^0$ pairs

10 billion J/ψ Ξ^0

Parameter	Nature **606** (2022) 64-69	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	−0.042 ± 0.011 ± 0.011
$\bar{\alpha}_\Xi$	0.371±0.007±0.002	HyperCP: PRL 93(2004) 011802
$\bar{\phi}_\Xi$	−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	

Parameter	PRD 108, L031106 (2023)
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$
$\xi_P - \xi_S$(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}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$
$\Delta\phi^{\Xi}_{CP}$(rad)	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$
A^{Λ}_{CP}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$
$\langle\phi_\Xi\rangle$(rad)	$0.0052 \pm 0.0069 \pm 0.0016$
$\langle\alpha_\Lambda\rangle$	$0.7499 \pm 0.0029 \pm 0.0013$

First measurements of the weak (CPV) phase difference in Ξ^-/Ξ^0 decays

Three CP tests in Ξ^-/Ξ^0 decays

The results of 10B J/ψ is on the way!

PRD(L) Editor's Suggestion

Polarization and CP test in $\Sigma^+\bar{\Sigma}^-$ J/ψ and $\psi(2S) \to \Sigma^+\bar{\Sigma}^-$

$$e^+e^- \to J/\psi, \psi(3686) \to \Sigma^+\bar{\Sigma}^-,\ \Sigma^+ \to p\pi^0,\ \bar{\Lambda} \to \bar{p}\pi^0$$

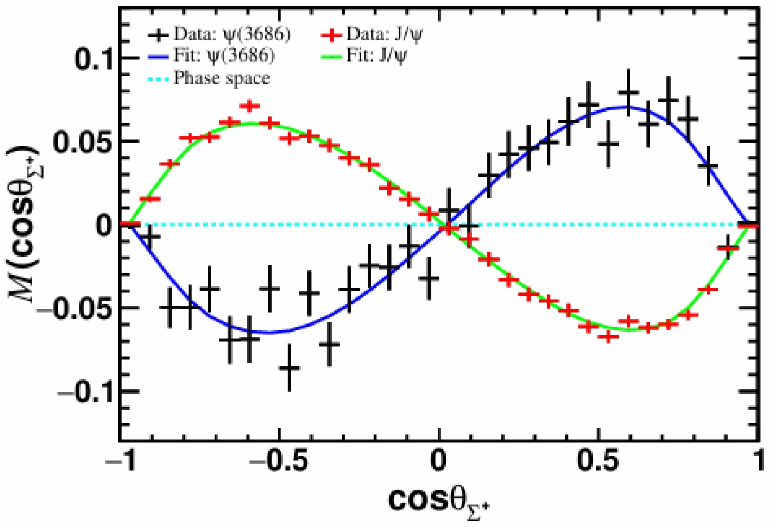
arXiv:2503.17165, submitted to PRL

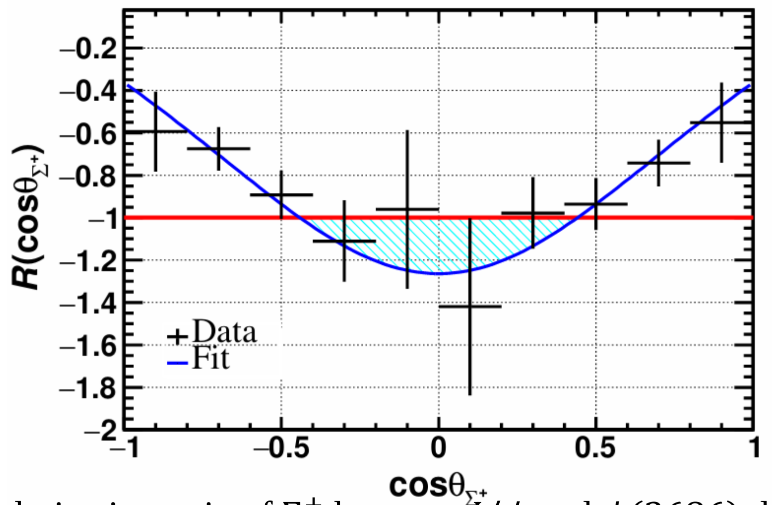
10B J/ψ and 2.7B $\psi(3686)$ 1.12 M $\Sigma^+\bar{\Sigma}^-$ pairs reconstructed

Parameter	This Letter	PRL 131, 191802 (2023)
$\alpha_{J/\psi}$	$-0.5047 \pm 0.0018 \pm 0.0010$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.2744 \pm 0.0033 \pm 0.0010$	$-0.270 \pm 0.012 \pm 0.009$
α_0	$-0.975 \pm 0.011 \pm 0.002$	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.999 \pm 0.011 \pm 0.004$	$0.990 \pm 0.037 \pm 0.011$
$\alpha_{\psi(3686)}$	$0.7133 \pm 0.0094 \pm 0.0065$	$0.682 \pm 0.030 \pm 0.011$
$\Delta\Phi_{\psi(3686)}$	$0.427 \pm 0.022 \pm 0.003$	$0.379 \pm 0.070 \pm 0.014$
$\langle\alpha_0\rangle$	$-0.9869 \pm 0.0011 \pm 0.0016$	$-0.994 \pm 0.004 \pm 0.002$
A_{CP}	$-0.0118 \pm 0.0083 \pm 0.0028$	$0.004 \pm 0.037 \pm 0.010$

- Opposite directions of the Σ^+ polarization in J/ψ and $\psi(3686)$ decays
- Most precise measurements of the Σ^+ decay parameters
- Most precise CP test in the decays of Σ^+

Polarizations of Σ^+





Polarization ratio of Σ^+ between J/ψ and $\psi(3686)$ decays

Search for Strong CPV in $\Sigma^0(\rightarrow \Lambda\gamma)$ decay

PRL 133, 101902 (2024)

The CPV sources in SM:

- Weak interaction, CKM (observed, but too small)
- Strong interaction, θ-term (Not yet observed)

10 B J/ψ and 2.7 B $\psi(3686)$

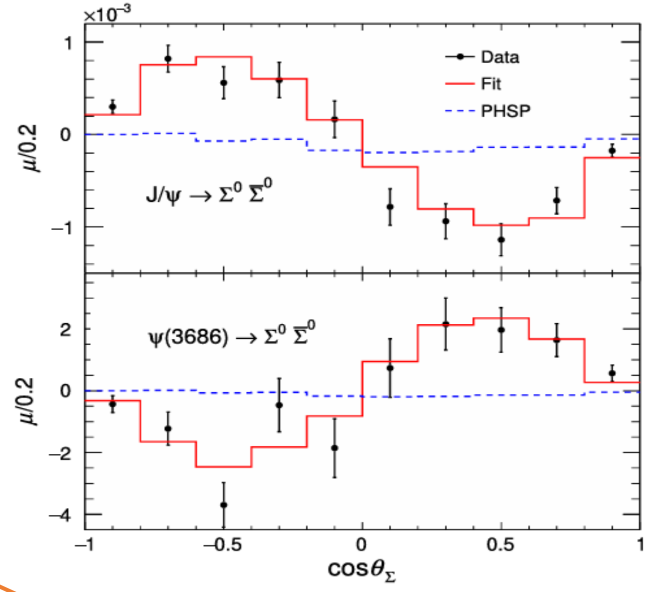
$e^+e^- \rightarrow J/\psi, \psi(3686) \rightarrow \Sigma^0(\rightarrow \Lambda\gamma)\bar{\Sigma}^0(\rightarrow \bar{\Lambda}\gamma), \Lambda \rightarrow p\pi^-, \bar{\Lambda} \rightarrow \bar{p}\pi^+$

Parameter	PRL 133, 101902 (2024)
$\alpha_{J/\psi}$	$-0.4133 \pm 0.0035 \pm 0.0077$
$\Delta\Phi_{J/\psi}$ (rad)	$-0.0828 \pm 0.0068 \pm 0.0033$
$\alpha_{\psi(3686)}$	$0.814 \pm 0.028 \pm 0.028$
$\Delta\Phi_{\psi(3686)}$ (rad)	$0.512 \pm 0.085 \pm 0.034$
α_{Σ^0}	$-0.0017 \pm 0.0021 \pm 0.0018$
$\bar{\alpha}_{\Sigma^0}$	$0.0021 \pm 0.0020 \pm 0.0022$
α_{Λ}	$0.730 \pm 0.051 \pm 0.011$
$\bar{\alpha}_{\Lambda}$	$-0.776 \pm 0.054 \pm 0.010$
A_{CP}^{Σ}	$(0.4 \pm 2.9 \pm 1.3) \times 10^{-3}$
A_{CP}^{Λ}	$(-3.0 \pm 6.9 \pm 1.5) \times 10^{-2}$

PLB **788**, 535 (2019)

The Transition EDM of $\Sigma^0(\rightarrow \Lambda\gamma)$ → SU(3) symmetry → Neutron EDM

$$\frac{d_{\Sigma\Lambda}}{d_n} = \frac{d_{\Sigma\Lambda}^{\rm tree} + d_{\Sigma\Lambda}^{\rm loop}}{d_n^{\rm tree} + d_n^{\rm loop}} \approx -0.88$$



Polarizations of Σ^0

Similar behavior is observed in Σ^+, but not in Λ or Ξ!

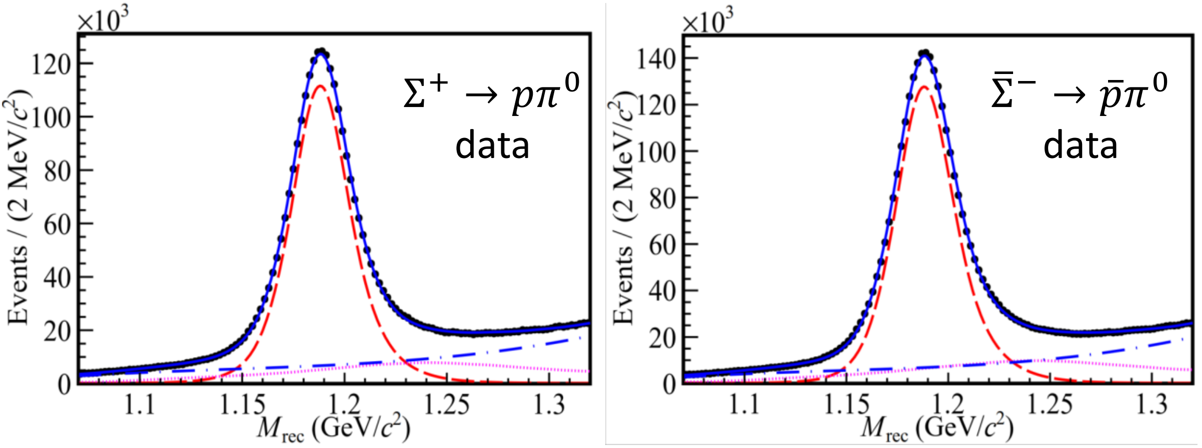
Opposite directions of the Σ^0 polarization

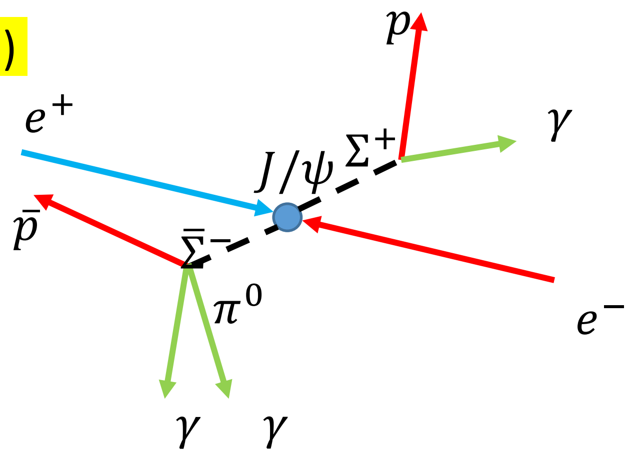
The first attempt to measure the P-violating decay parameter of $\Sigma \rightarrow \Lambda\gamma$.

The first strong-CP test in hyperon decays.

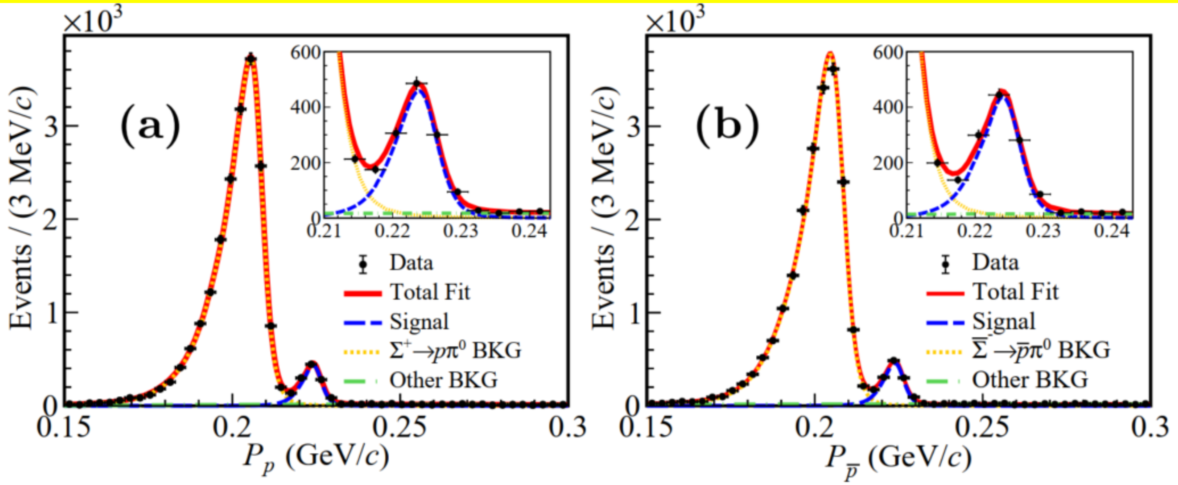
Radiative decay: $\Sigma^+ \to p\gamma$ in $J/\psi \to \Sigma^+\bar{\Sigma}^-$

PRL130, 211901(2023)

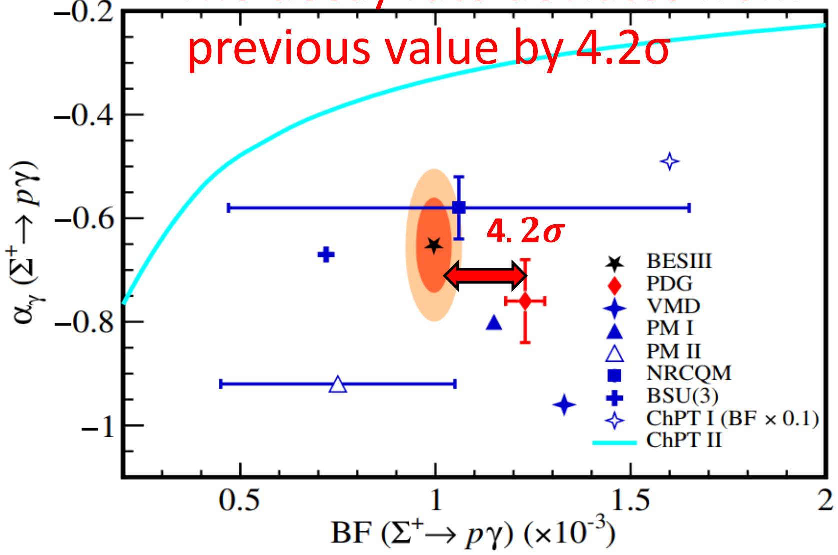




Signal side: momentum distributions of proton in the rest frame of Σ :



The decay rate deviates from previous value by 4.2σ



The CP asymmetry is calculated to be

$$A_{CP} = (\alpha_- + \alpha_+)/(\alpha_- - \alpha_+) = 0.095 \pm 0.087 \pm 0.022$$

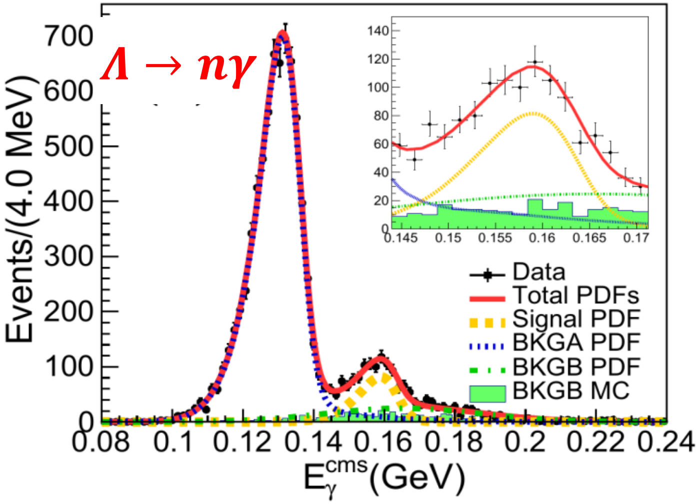
$$\Delta_{CP} = (\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-) = 0.006 \pm 0.011 \pm 0.006$$

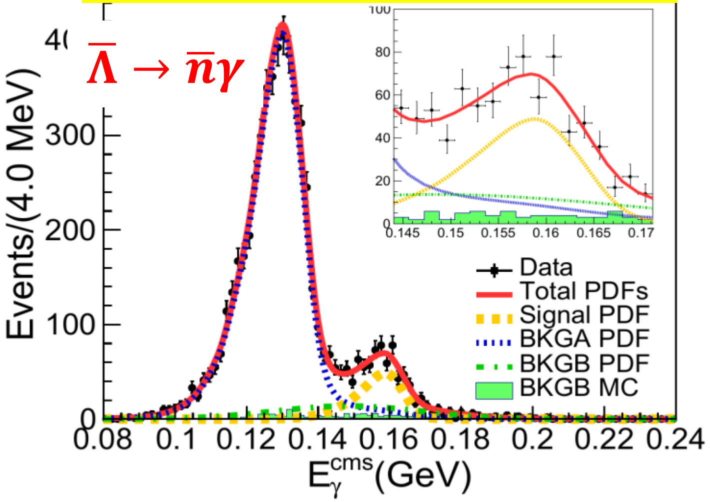
The decay rate $(0.996 \pm 0.022_{stat} \pm 0.017_{syst}) \times 10^{-3}$

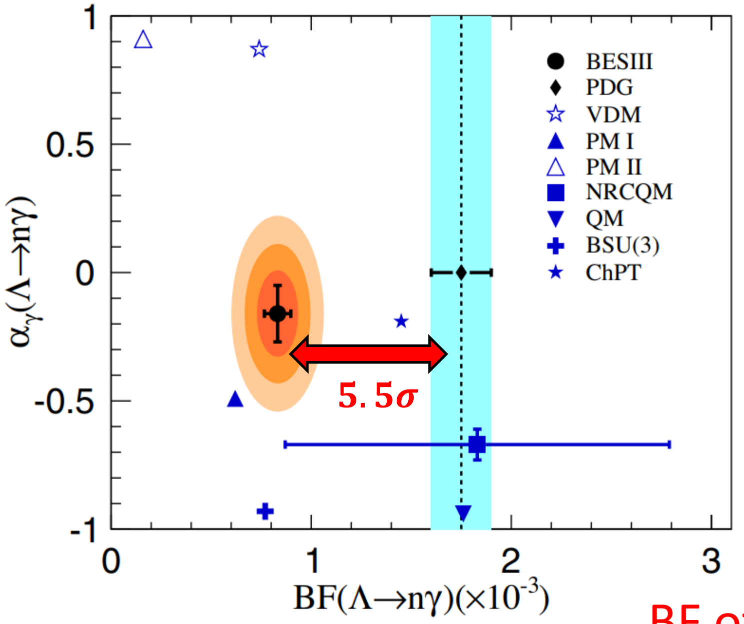
The decay parameter: $-0.651 \pm 0.056_{stat} \pm 0.020_{syst}$

Radiative decay: $\Lambda \to n\gamma$ in $J/\psi \to \Lambda\bar{\Lambda}$

PRL 129, 212002 (2022)





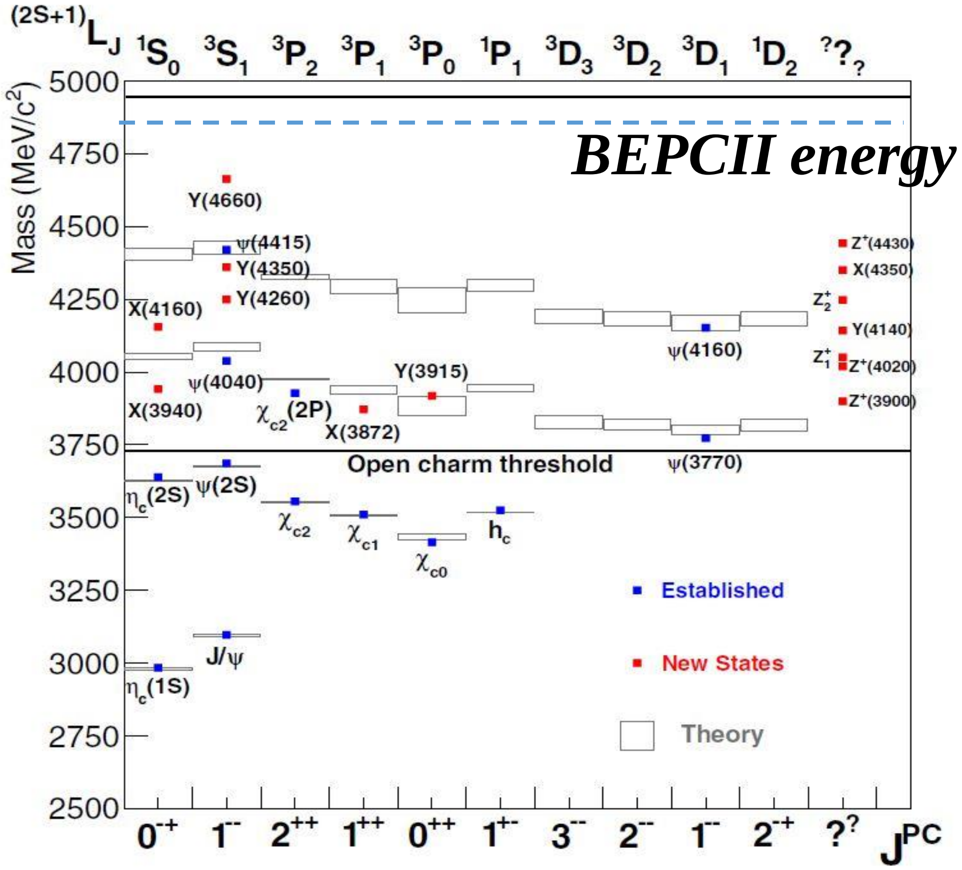


Variables	$\Lambda \to \gamma n$	$\bar{\Lambda} \to \gamma\bar{n}$
BF ($\times 10^3$)	$0.834 \pm 0.046 \pm 0.064$	$0.876 \pm 0.071 \pm 0.082$
α_γ	$-0.13 \pm 0.13 \pm 0.02$	$0.21 \pm 0.15 \pm 0.06$
Δ_{CP}	$-0.025 \pm 0.049 \pm 0.060$	
A_{CP}	$-0.25 \pm 0.61 \pm 0.15$	

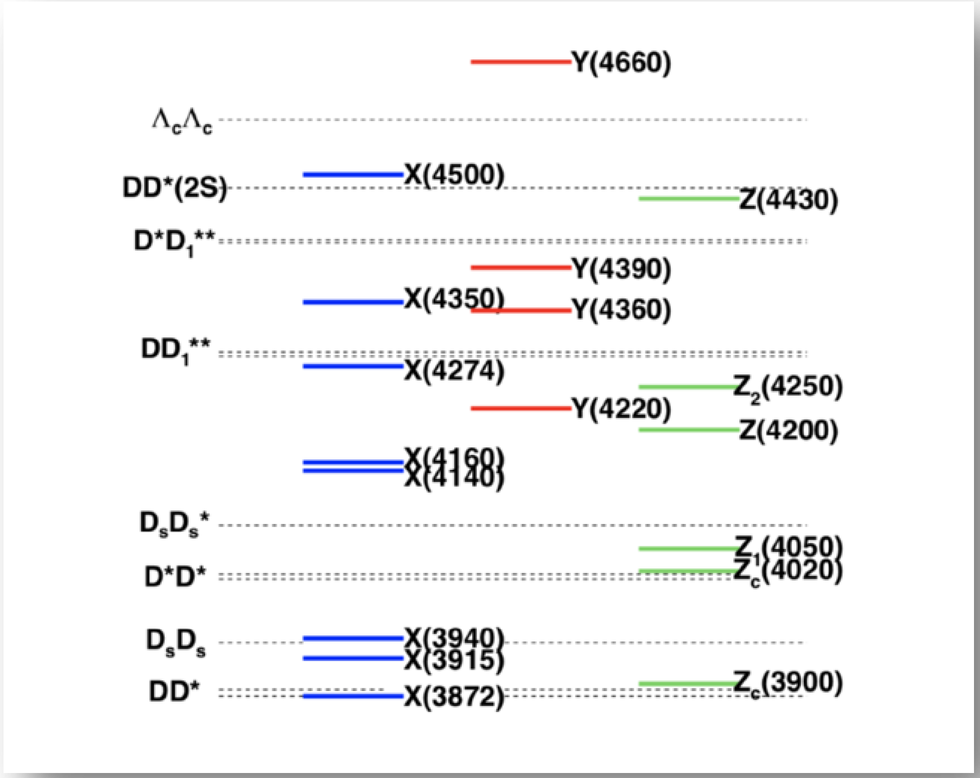
Theoretical attentions: L.S. Geng, Q. Zhao, R.M. Wang et al.

BF of $\Lambda \to n\gamma$, with improved precision, smaller than PDG value by 5.5σ

Overpopulated charmonium spectrum



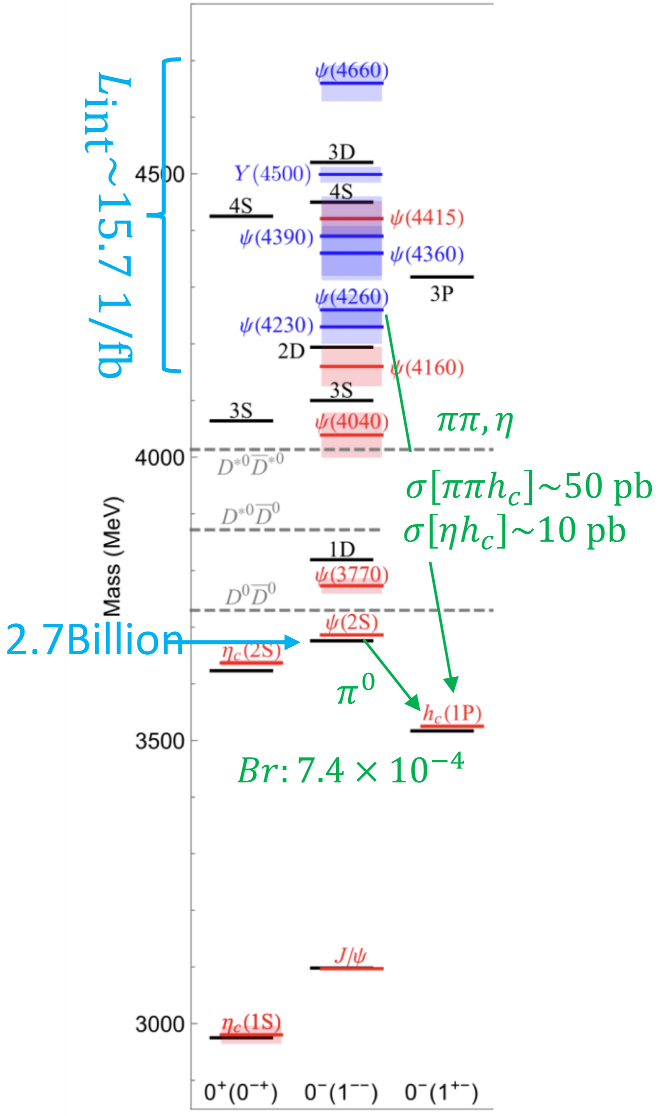
arXiv:1511.01589, arXiv:1812.10947



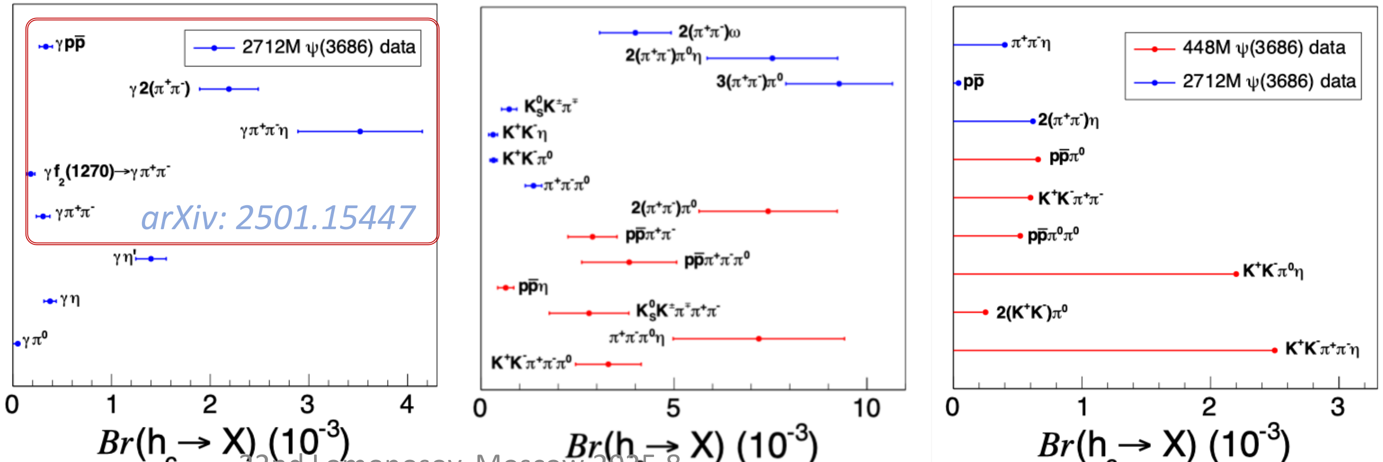
Overpopulated observed charmonium-like states, i.e. "XYZ":

- Most of them are close to the mass thresholds of charmed meson pairs
- Some are not accommodated as conventional meson
  ==> candidate of exotic hadron states
- More efforts are needed to pin down their nature

Highlight: Production and decay properties of h_c



- P-wave singlet charmonium state, first observed by CLEO
- First measurement of $B[\psi' \to \pi^0 h_c]$ by BESIII *PRL95, 102003 (2005)* *PRL104, 132002 (2010)*
- 2M h_c particle in 2.7B ψ' events, possible to explore h_c decay mode with $Br{\sim}10^{-4}$; 0.7M h_c particle from XYZ scan sample
- Decay of h_c:
  - pQCD prediction: $h_c \to \gamma gg{\sim}5.5\%$ *PRD 66, 014012 (2002)*
  - pQCD and NRQCD predictions of $h_c \to$light hadrons: 48% and 8% *PRD 65, 094024 (2002)*

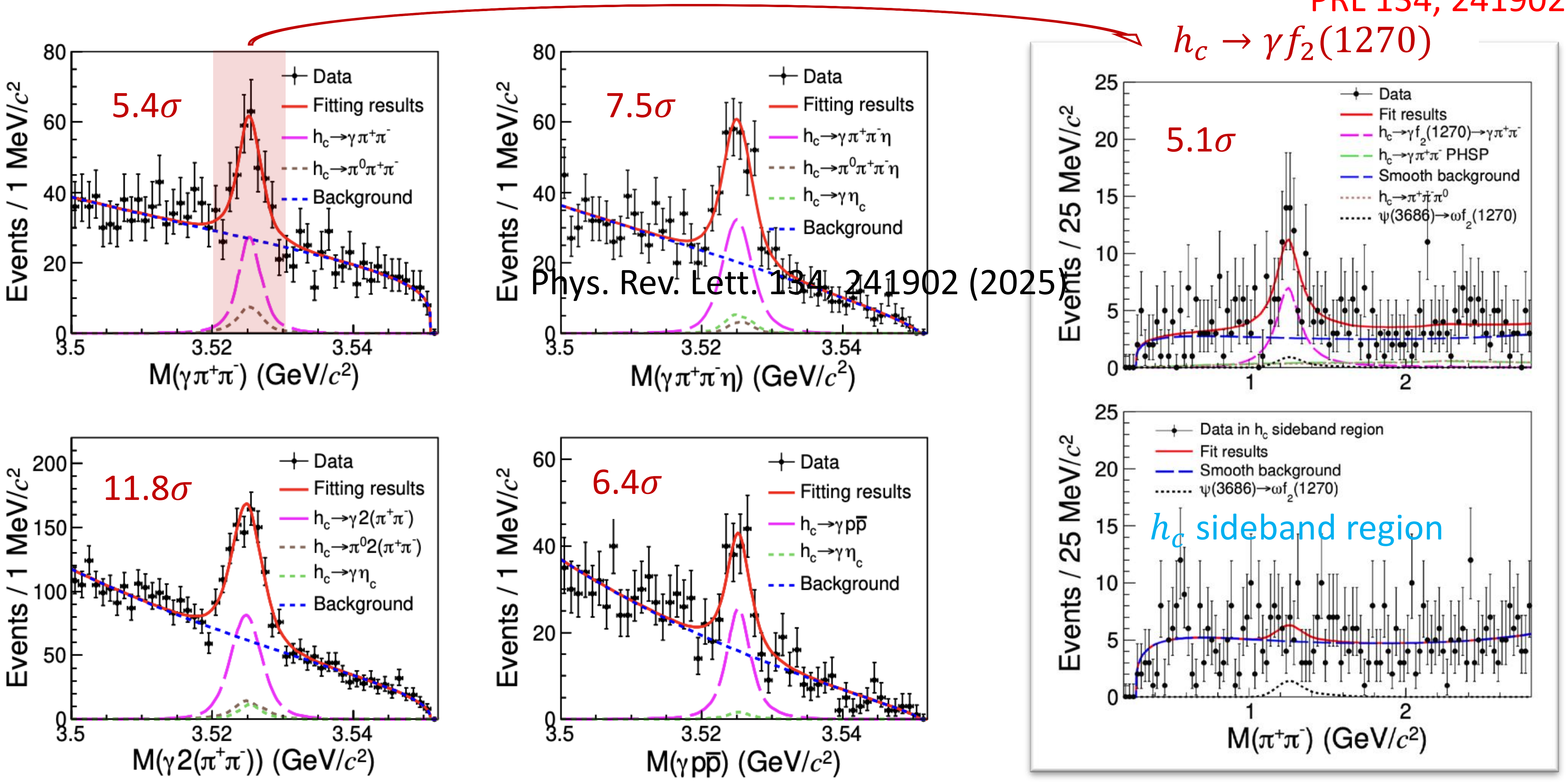


Highlight: Production and decay properties of h_c

Observation of h_c radiative decays and $h_c \to \gamma f_2(1270)$

arXiv:2501.15447

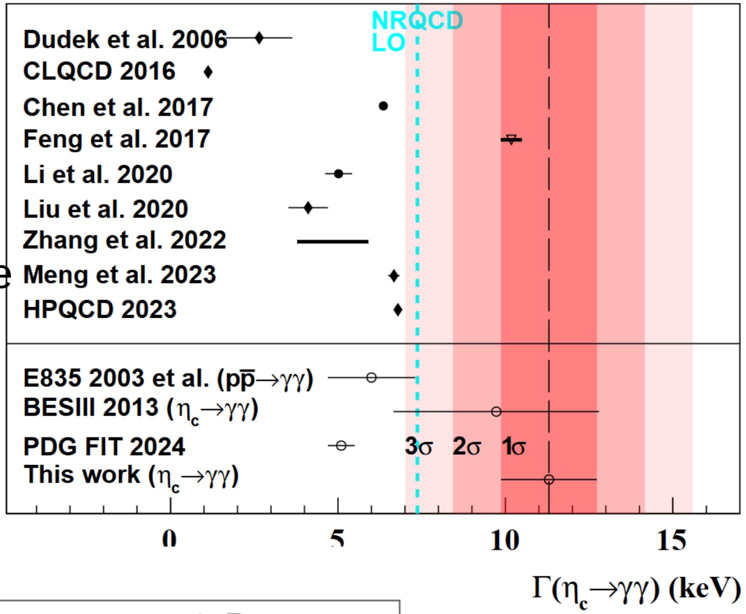
PRL 134, 241902 (2025)



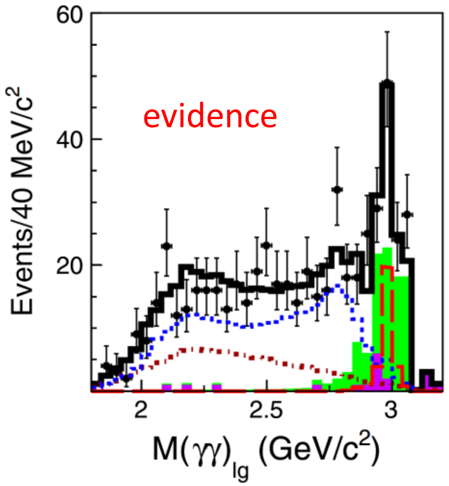
Highlight: measurements of $\eta_c \to \gamma\gamma$

arXiv: 2412.12998
PRL134, 181901 (2025)

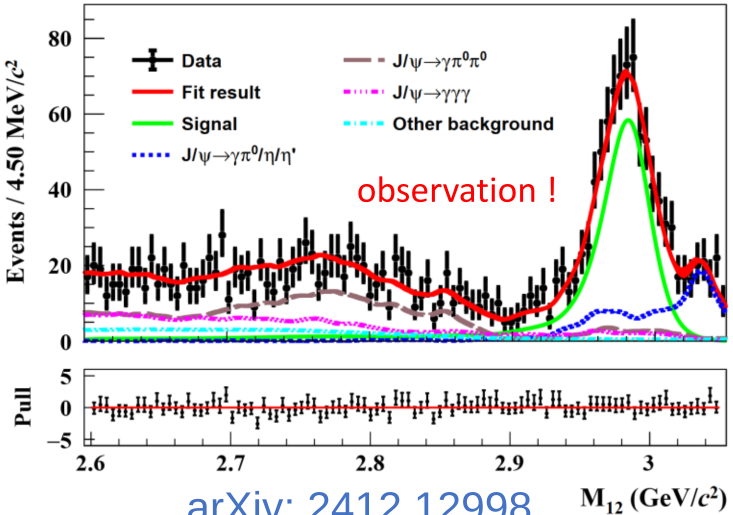
- As the simplest decay of η_c , $\eta_c \to \gamma\gamma$ serves as a benchmark for QCD calculation.
- Most measurements come from the time reversal process $\gamma\gamma^{(*)} \to \eta_c$
- BESIII has the unique opportunity to directly measure $\eta_c \to \gamma\gamma$ via $J/\psi \to \gamma\eta_c$ (first observation) or $h_c \to \gamma\eta_c$ (absolute branching fraction, most precise).
- Measured $B(J/\psi \to \gamma\eta_c) \times B(\eta_c \to \gamma\gamma)$ is consistent with theoretical predictions, while the individual $\Gamma(\eta_c \to \gamma\gamma)$ deviates from the most recent LQCD prediction by more than 3σ.



$$\Gamma(\eta_c \to \gamma\gamma) = (11.30 \pm 0.56_{\text{stat.}} \pm 0.66_{\text{syst.}} \pm 1.14_{\text{ref.}})\ \text{keV}$$

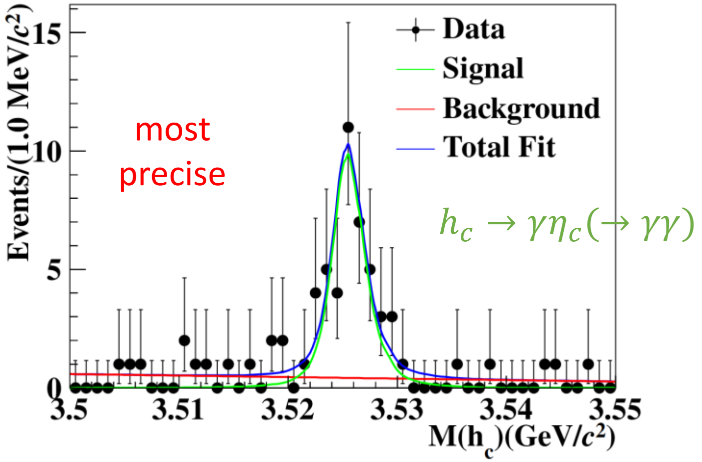


Phys. Rev. D 87 (2013) 3, 032003



arXiv: 2412.12998

$J/\psi \to \gamma\eta_c(\to \gamma\gamma)$



$h_c \to \gamma\eta_c(\to \gamma\gamma)$

The first measurement of absolute branching fraction via $h_c \to \gamma\eta_c$ will provide a brand new reference

in preparation

Precise test of LQCD: hyperfine mass splitting

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

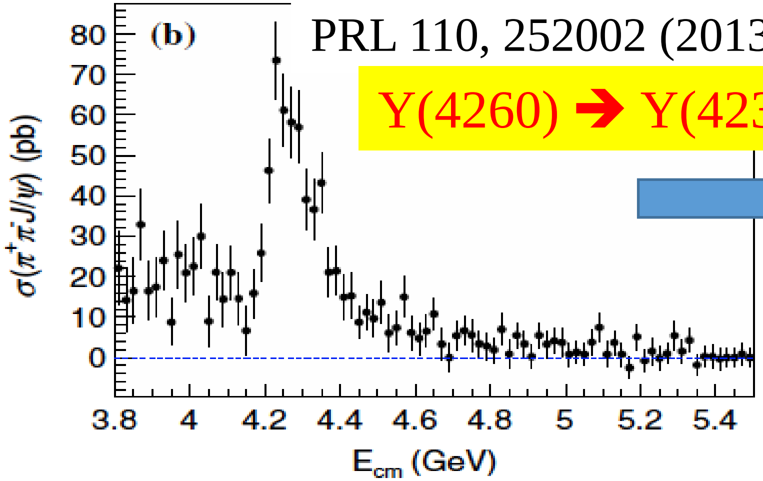
Belle Resolution: about 5-10 MeV

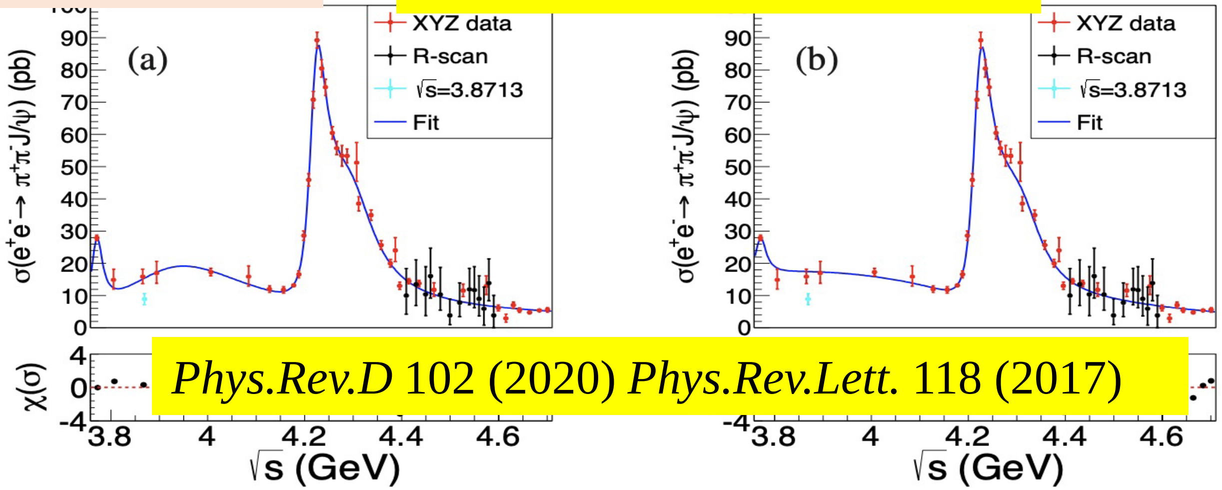
$e^+e^- \to \pi^+\pi^- J/\psi$

BESIII Resolution: 1 - 2 MeV

PRL 110, 252002 (2013)

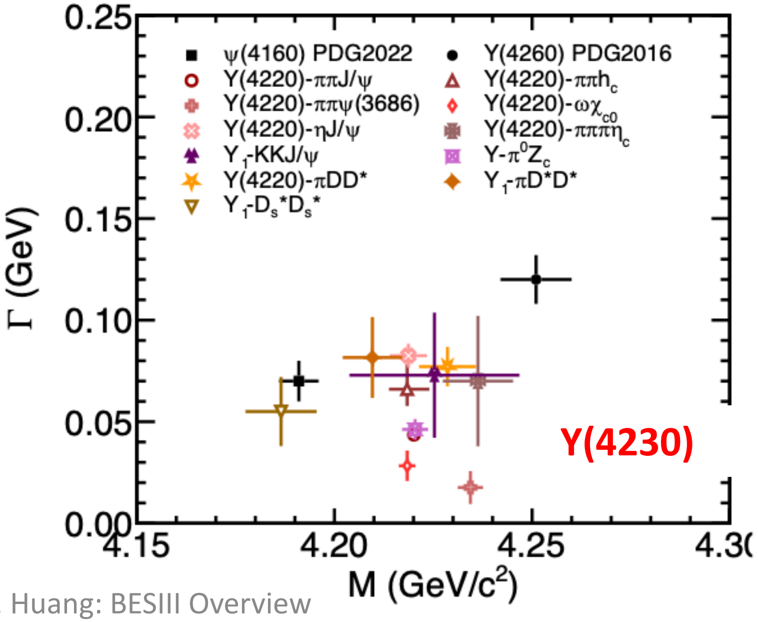
Y(4260) ➔ Y(4230)



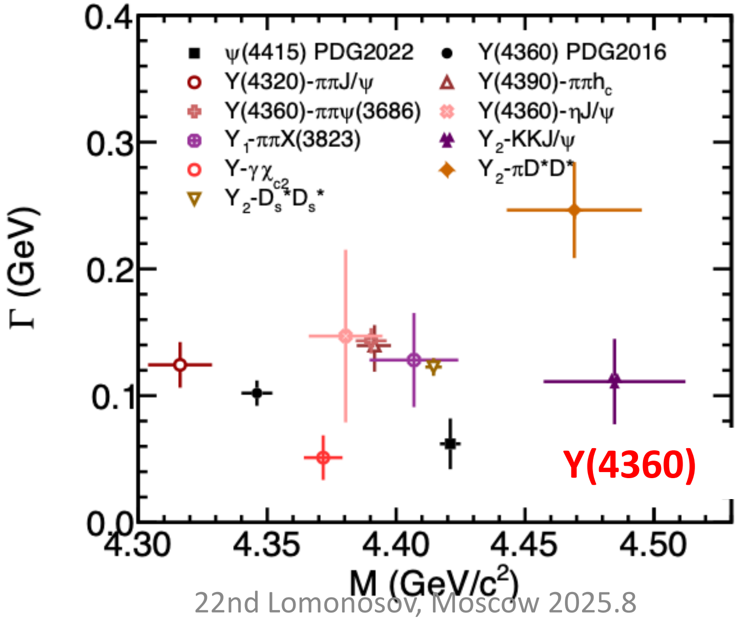


Phys.Rev.D 102 (2020) *Phys.Rev.Lett.* 118 (2017)

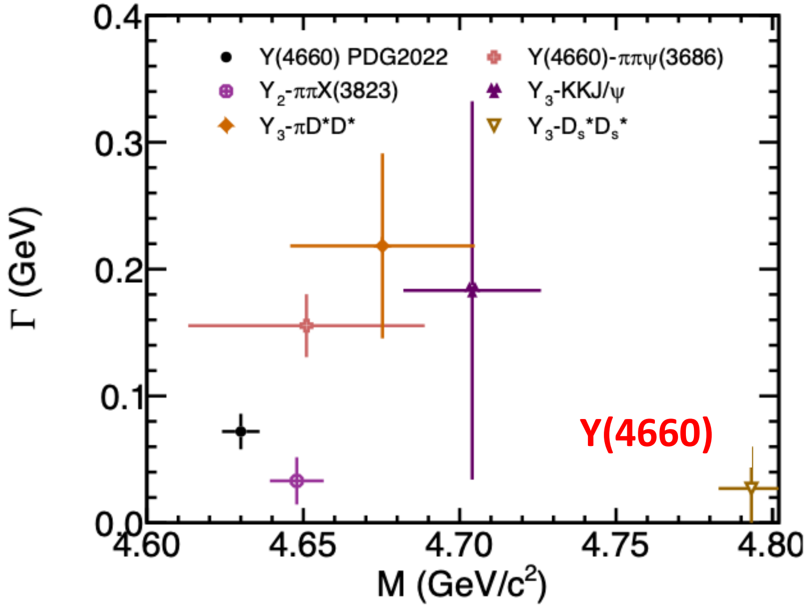
Fine structures of Charmonium-like states are seen at BESIII with scan data!



Y(4230)



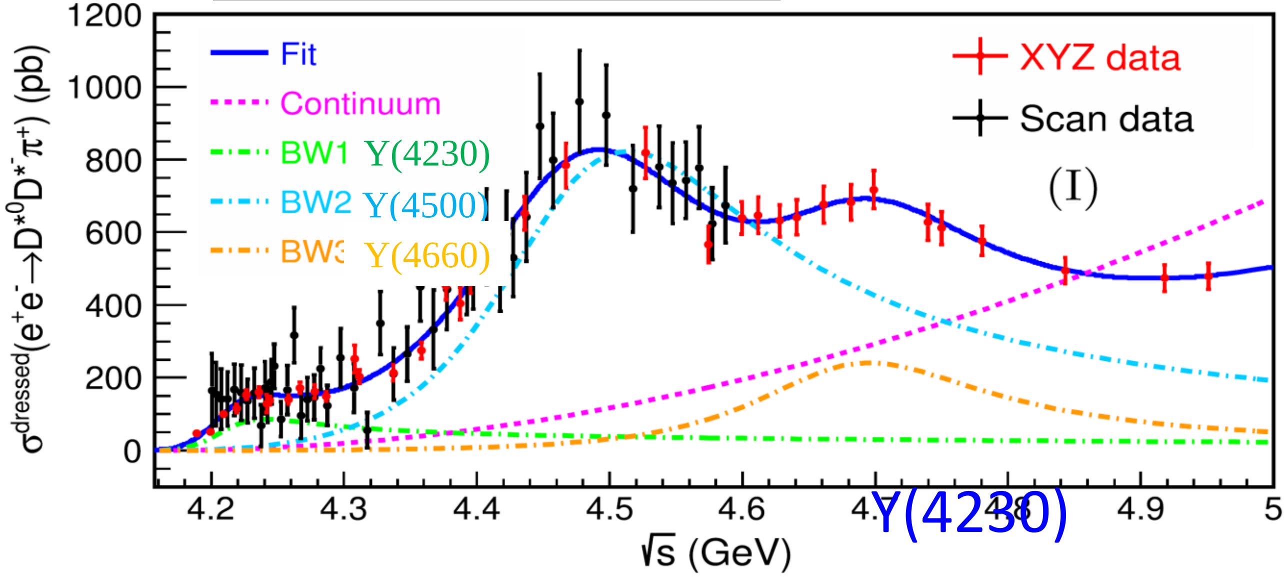
Y(4360)



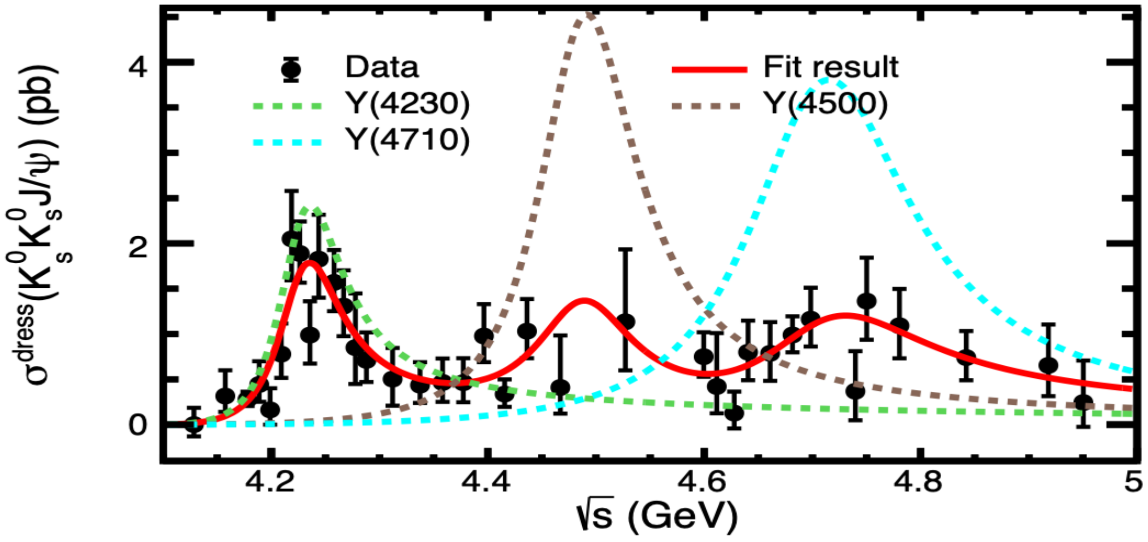
Y(4660)

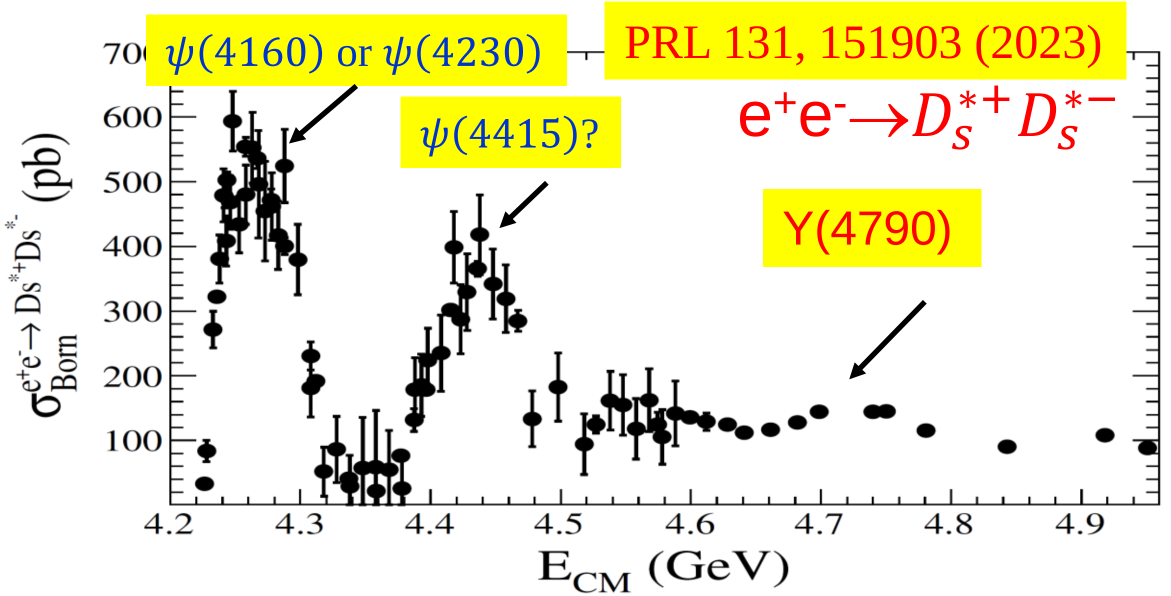
More Y states: Y(4500) ,Y(4710) and Y(4790)

PRL 130, 121901 (2023) $e^+e^- \to D^{*0}D^{*-}\pi^+$

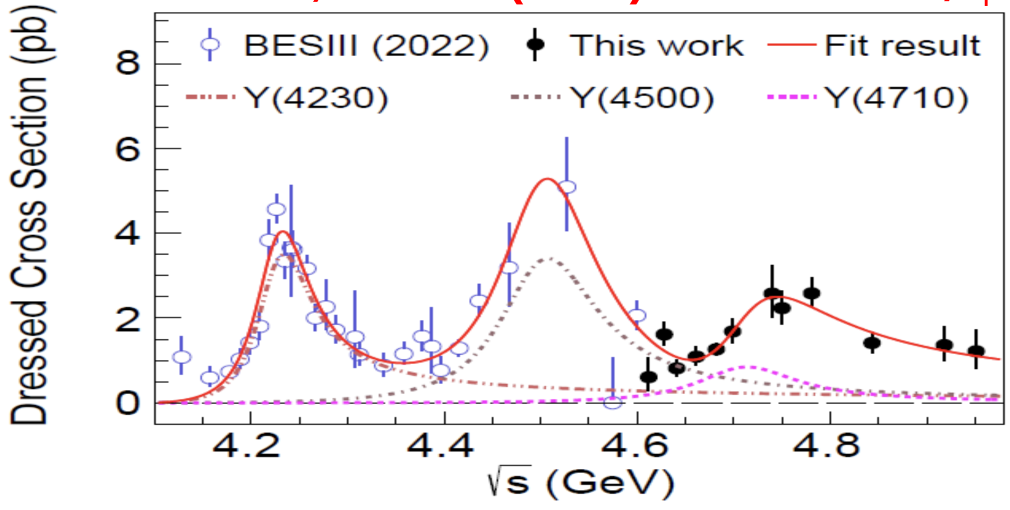


PRD 107, 092005 (2023) $e^+e^- \to K_S K_S J/\psi$



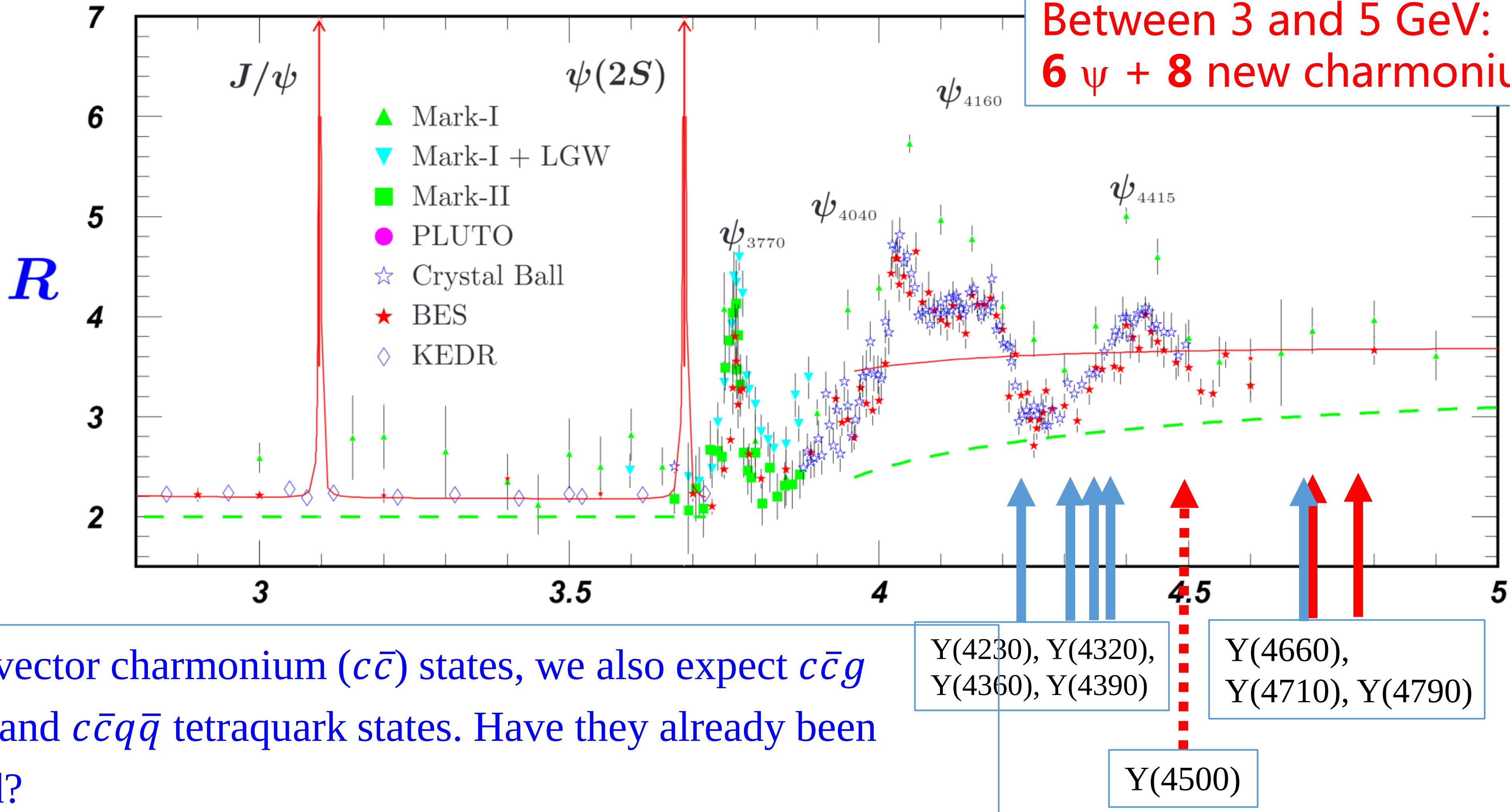


PRL 131, 211902 (2023) $e^+e^- \to K^+K^-J/\psi$



BESIII

How many vectors in charmonium energy region?

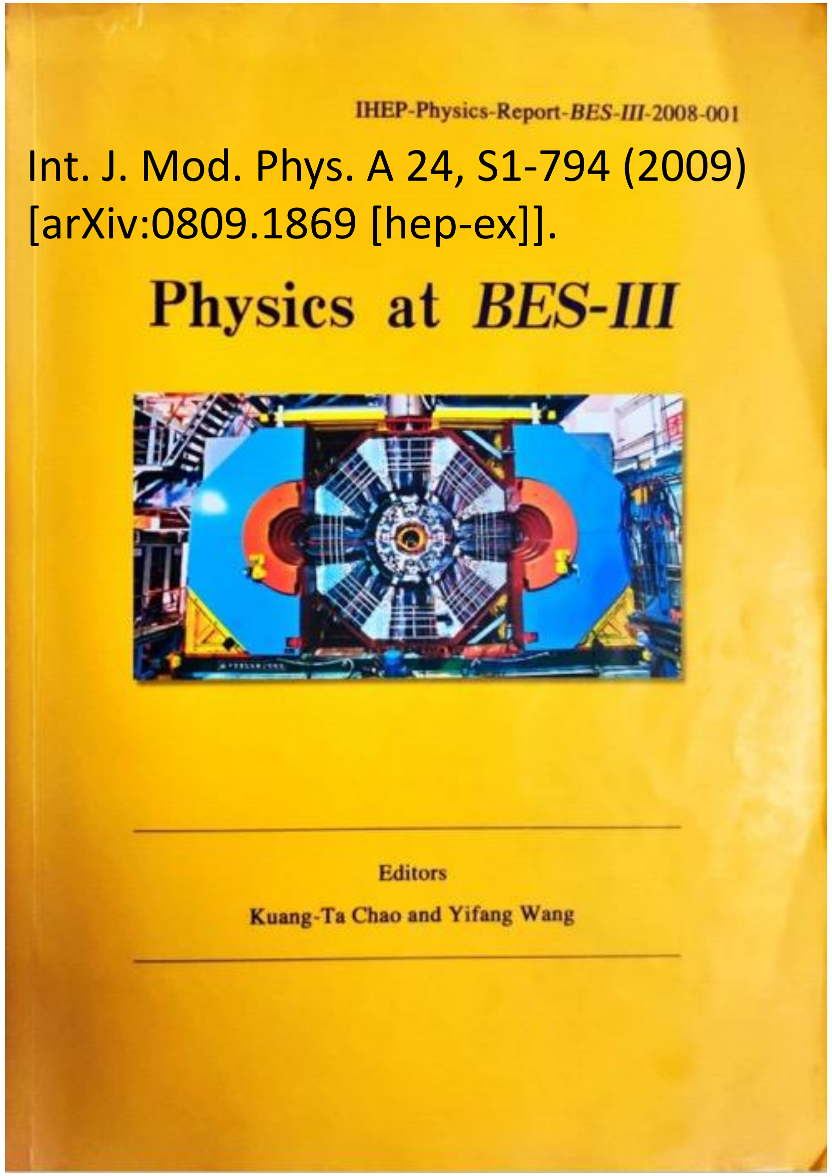


Between 3 and 5 GeV:
6 ψ + **8** new charmonium-like states

Besides vector charmonium ($c\bar{c}$) states, we also expect $c\bar{c}g$ hybrids, and $c\bar{c}q\bar{q}$ tetraquark states. Have they already been observed?

➔ More theoretical/experimental efforts necessary!

BESIII Prospects



Int. J. Mod. Phys. A 24, S1-794 (2009) [arXiv:0809.1869 [hep-ex]].

Yellow book

Chinese Physics C Vol. 44, No. 4 (2020)

Future Physics Programme of BESIII*

Abstract: There has recently been a dramatic renewal of interest in hadron spectroscopy and charm physics. This renaissance has been driven in part by the discovery of a plethora of charmonium-like *XYZ* states at BESIII and *B* factories, and the observation of an intriguing proton-antiproton threshold enhancement and the possibly related *X*(1835) meson state at BESIII, as well as the threshold measurements of charm mesons and charm baryons. We present a detailed survey of the important topics in tau-charm physics and hadron physics that can be further explored at BESIII during the remaining operation period of BEPCII. This survey will help in the optimization of the data-taking plan over the coming years, and provides physics motivation for the possible upgrade of BEPCII to higher luminosity.

DOI: 10.1088/1674-1137/44/4/040001

Received 25 December 2019, Published online 26 March 2020

* Supported in part by National Key Basic Research Program of China (2015CB856700); National Natural Science Foundation of China (NSFC) (11335008, 11425524, 11625523, 11635010, 11735014, 11822506, 11935018); the Chinese Academy of Sciences (CAS) Large-Scale Scientific Facility Program; the CAS Center for Excellence in Particle Physics (CCEPP); Joint Large-Scale Scientific Facility Funds of the NSFC and CAS (U1532257, U1532258, U1732263); CAS Key Research Program of Frontier Science (QYZDJ-SSW-SLH003, QYZDJ-SSW-SLH040); 100 Talents Program of CAS; CAS PIFI; the Thousand Talents Program of China; INPAC and Shanghai Key Laboratory for Particle Physics and Cosmology; German Research Foundation DFG under Contracts Nos. Collaborative Research Center CRC 1044, FOR 2359; Istituto Nazionale di Fisica Nucleare, Italy; Koninklijke Nederlandse Akademie van Wetenschappen (KNAW) (530-4CDP03); Ministry of Development of Turkey (DPT2006K-120470); National Science and Technology fund; The Knut and Alice Wallenberg Foundation (Sweden) (2016.0157); The Swedish Research Council; U. S. Department of Energy (DE-FG02-05ER41374, DESC-0010118, DE-SC-0012069); University of Groningen (RuG) and the Helmholtzzentrum fuer Schwerionenforschung GmbH (GSI), Darmstadt; the Russian Ministry of Science and Higher Education (14.W03.31.0026)

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Article funded by SCOAP3 and published under licence by Chinese Physical Society and the Institute of High Energy Physics of the Chinese Academy of Sciences and the Institute of Modern Physics of the Chinese Academy of Sciences and IOP Publishing Ltd

Chin. Phys. C 44, 040001 (2020) [arXiv:1912.05983 [hep-ex]].

White book

BESIII

White book: planned future data

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

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

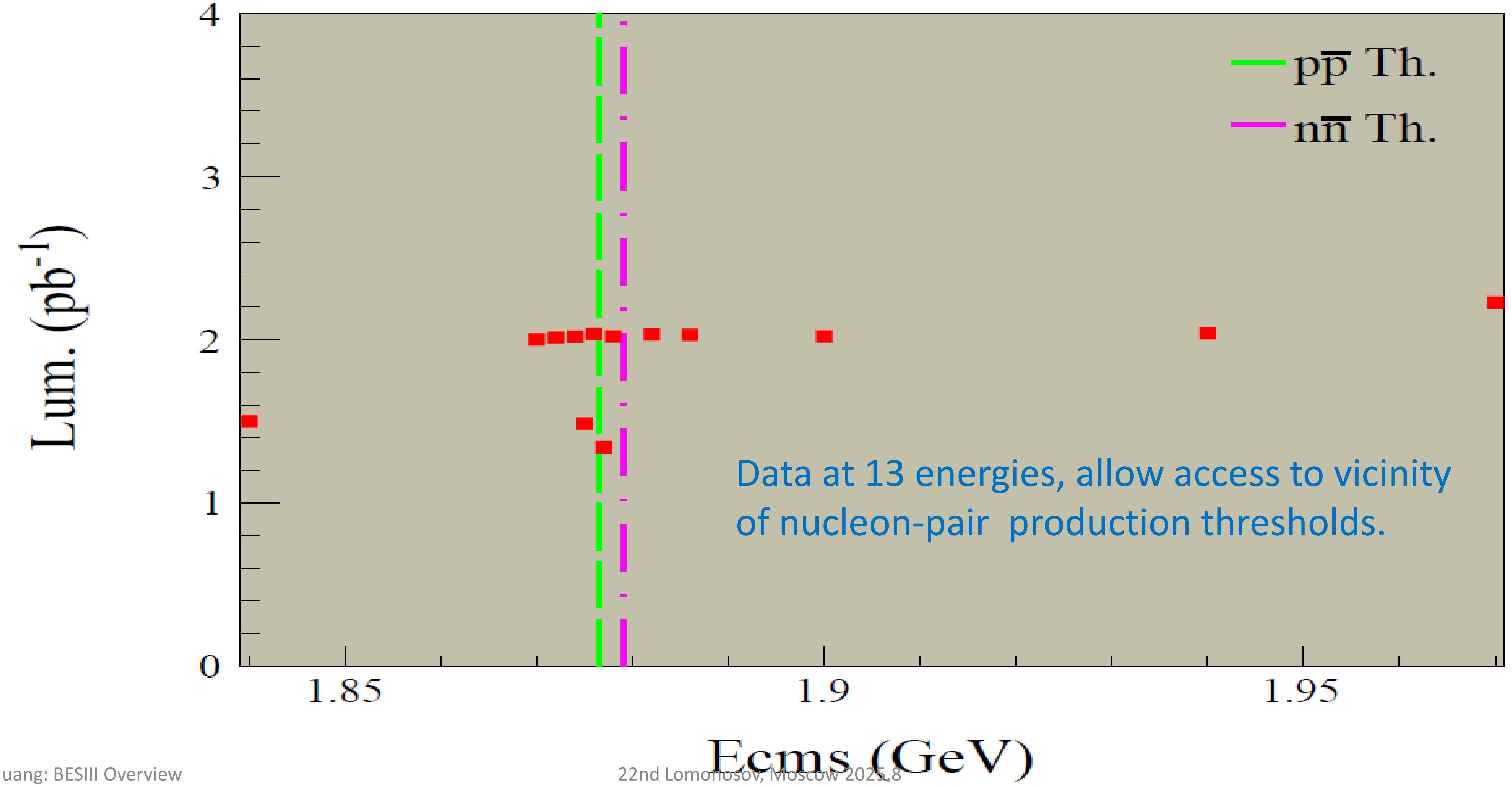
Only part 2024

Completed 2024

BEPCII-U

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

1.84-1.97 GeV: low extremes of BEPCII



Data at 13 energies, allow access to vicinity of nucleon-pair production thresholds.

BEPCII upgrades in 2024

BEPCII upgrade (installation: 2024. 7- 2024. 12)

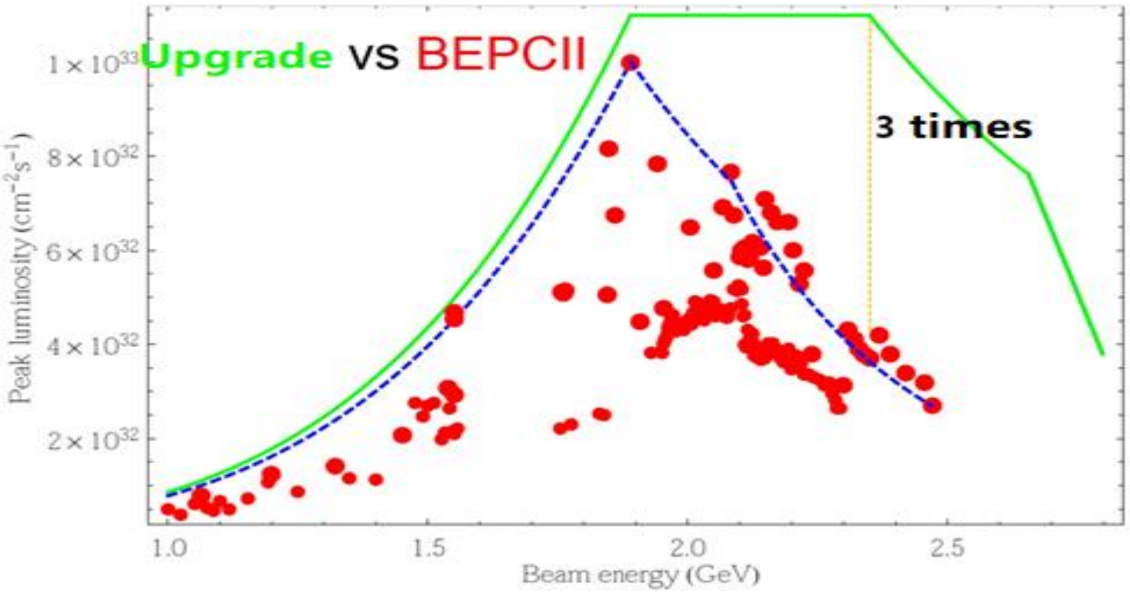
Highest beam energy: 2.8 GeV

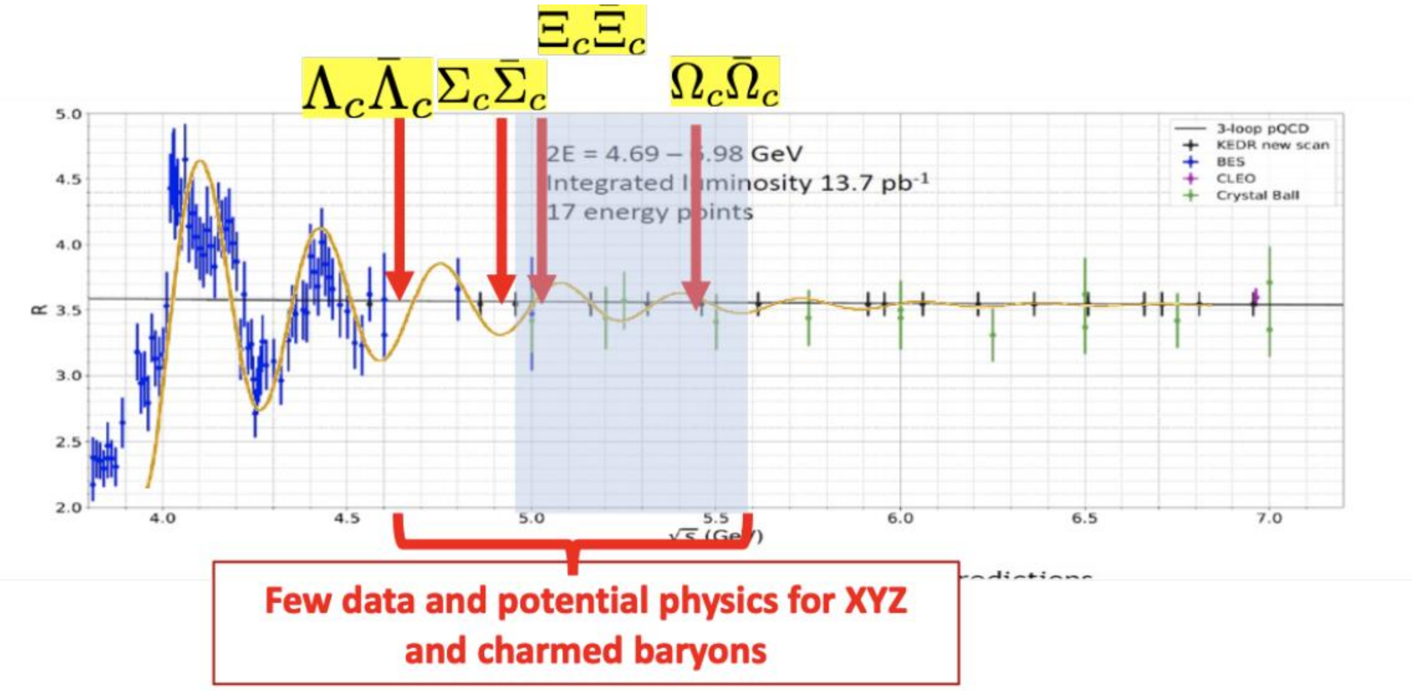
Luminosity: 1.2×10^{33} $cm^{-2}s^{-1}$ （4.0 ~ 5.0 GeV）

$(0.4\text{-}0.7)\times 10^{33}$ $cm^{-2}s^{-1}$ （5.0 ~ 5.6 GeV）

BESIII will collect about **60 fb^{-1}** between 4.0 – 5.6 GeV, and to study 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



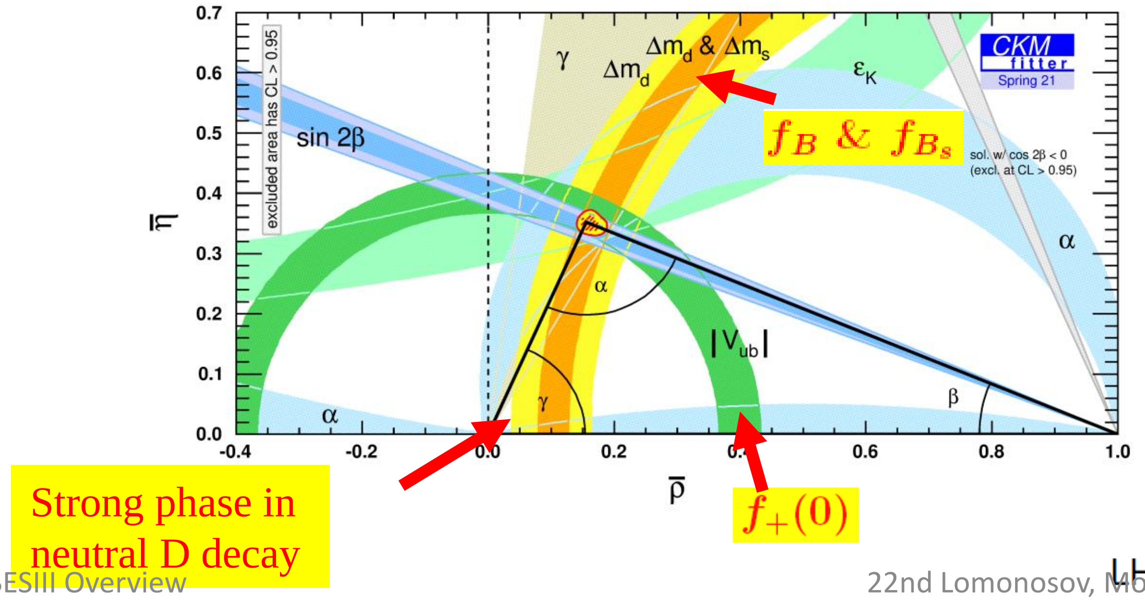


Summary

- BESIII is running smoothly, and very productive now;
- BEPCII upgrades have been finished in 2024, more data taking above 4.0 GeV, up to 5.6 GeV to study: excited charmonium, charmonium-like states, XYZ particles, charmed baryon …
- Advantages at BECPII/BESIII: scan data near thresholds, quantum-entangled meson and baryon pairs
- BESIII plays leading role in hadron physics, flavor physics (charmed hadron and strange hadron).

Charm is still needed for precise test of the SM!

2021



2035