61st International Winter Meeting on Nuclear Physics

27 - 31 January 2025

Bormio, Italy

RECENT RESULTS FROM THE BESIII EXPERIMENT

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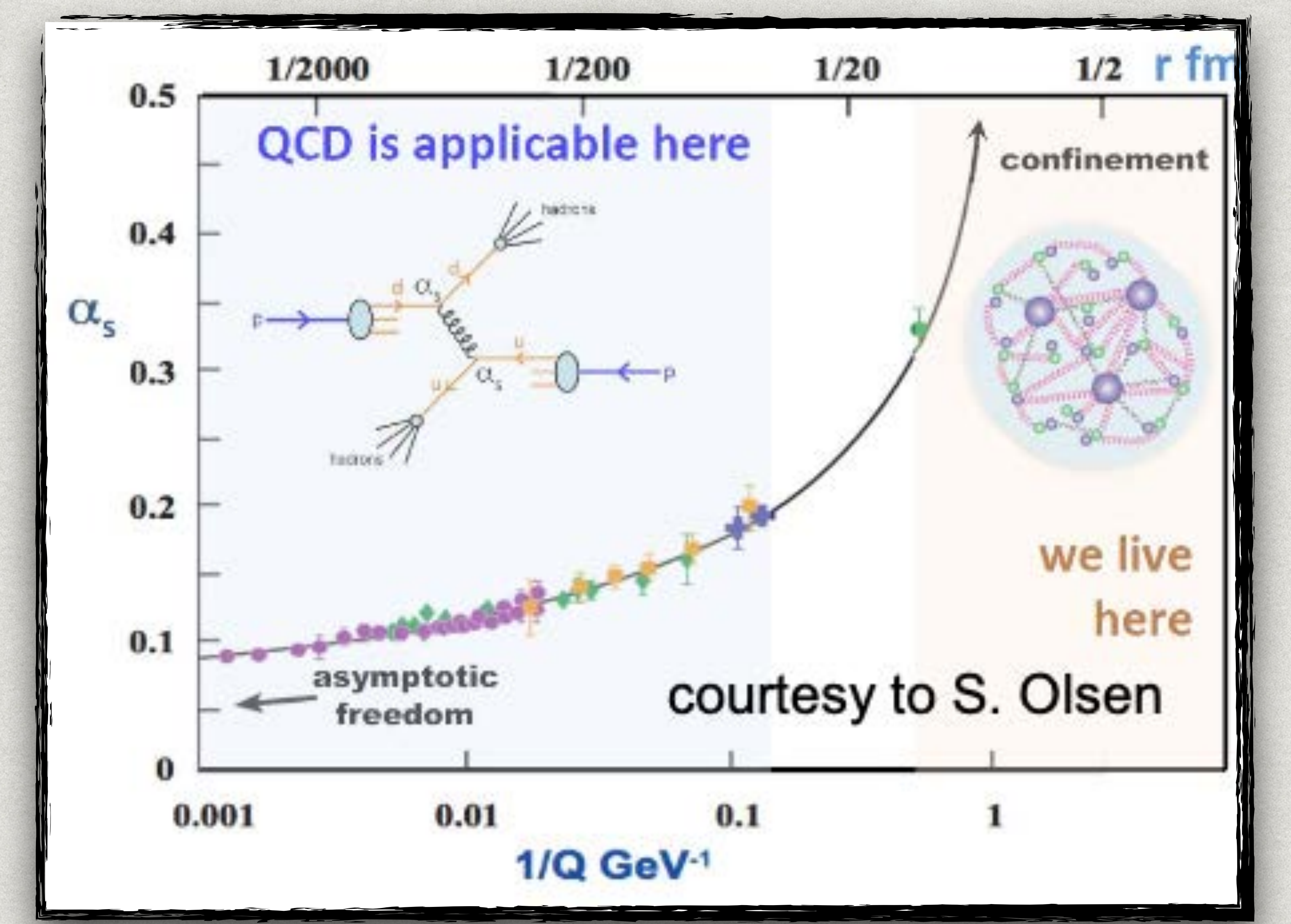
Hadrons

- Dominant part of visible matter in the universe
- To fully understand the strong interaction
    - Understanding the rich and complex features of its bound states, hadrons



- How are hadrons formed from quarks and gluons?
- What is the origin of confinement?
- How is the mass of hadron generated in QCD?
- What is the dynamics of effective DoF in hadrons?

Hadron physics

Structure

Precise tests and rare processes

Interactions

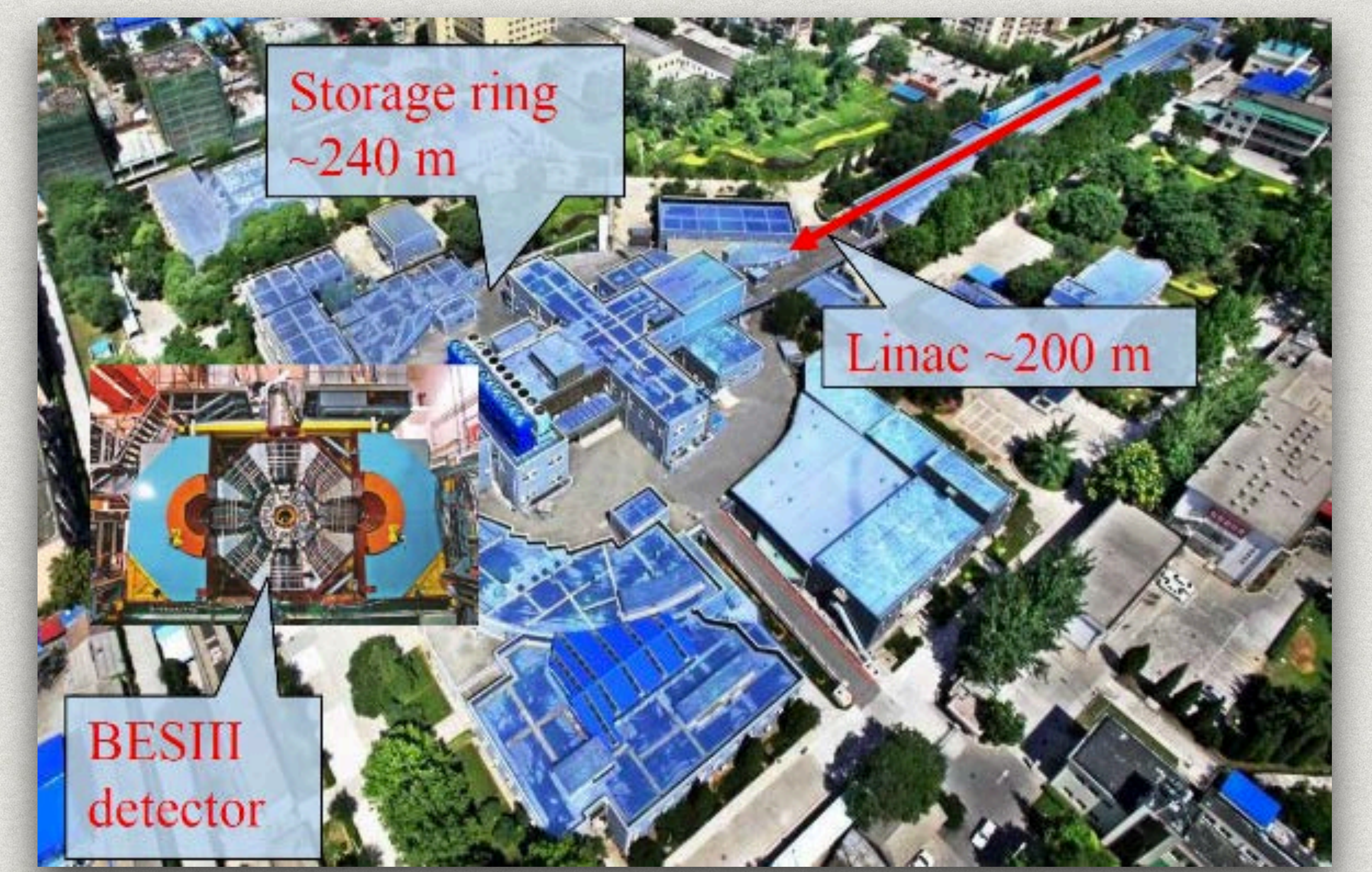
Spectroscopy

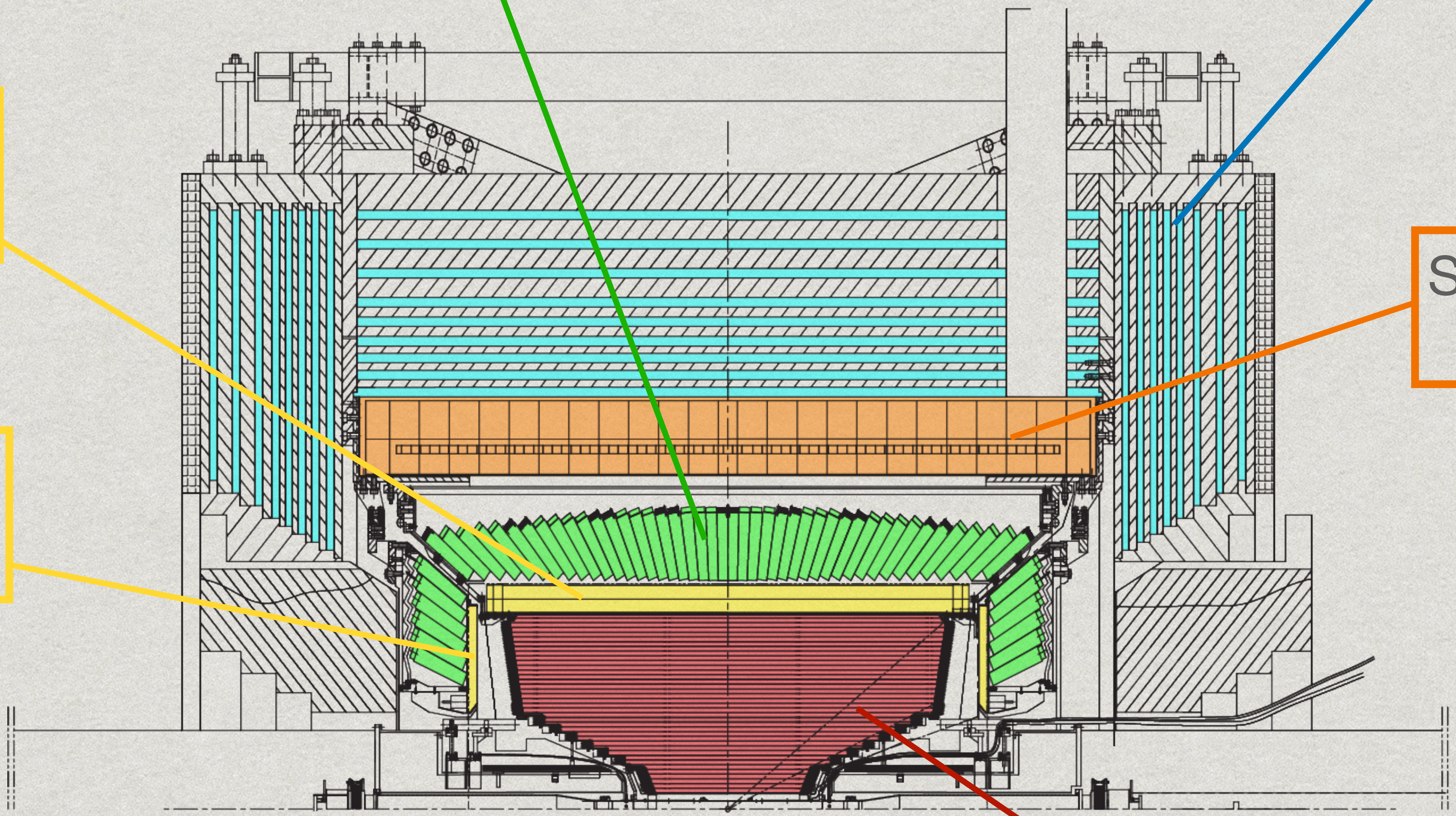
Outline of the talk

- The BESIII experiment
- Hadron structure: Baryon Form Factors
- SM precision tests with semileptonic decays
- Hadron interactions: Study of Antihyperon-Nucleon Scattering
- Spectroscopy
    - Light hadrons
    - Heavy exotics
- The BESIII upgrade program

The BESIII experiment @ BEPCII

- $E_{CM} = 1.84 - 4.95 \ GeV$
- Region below 2 GeV directly accessible (via ISR)
- $\mathscr{L}_{peak} = 1.1 \times 10^{33} \ cm^{-2} s^{-1}$
- Energy spread: $\Delta E \sim 5 \times 10^{-4}$

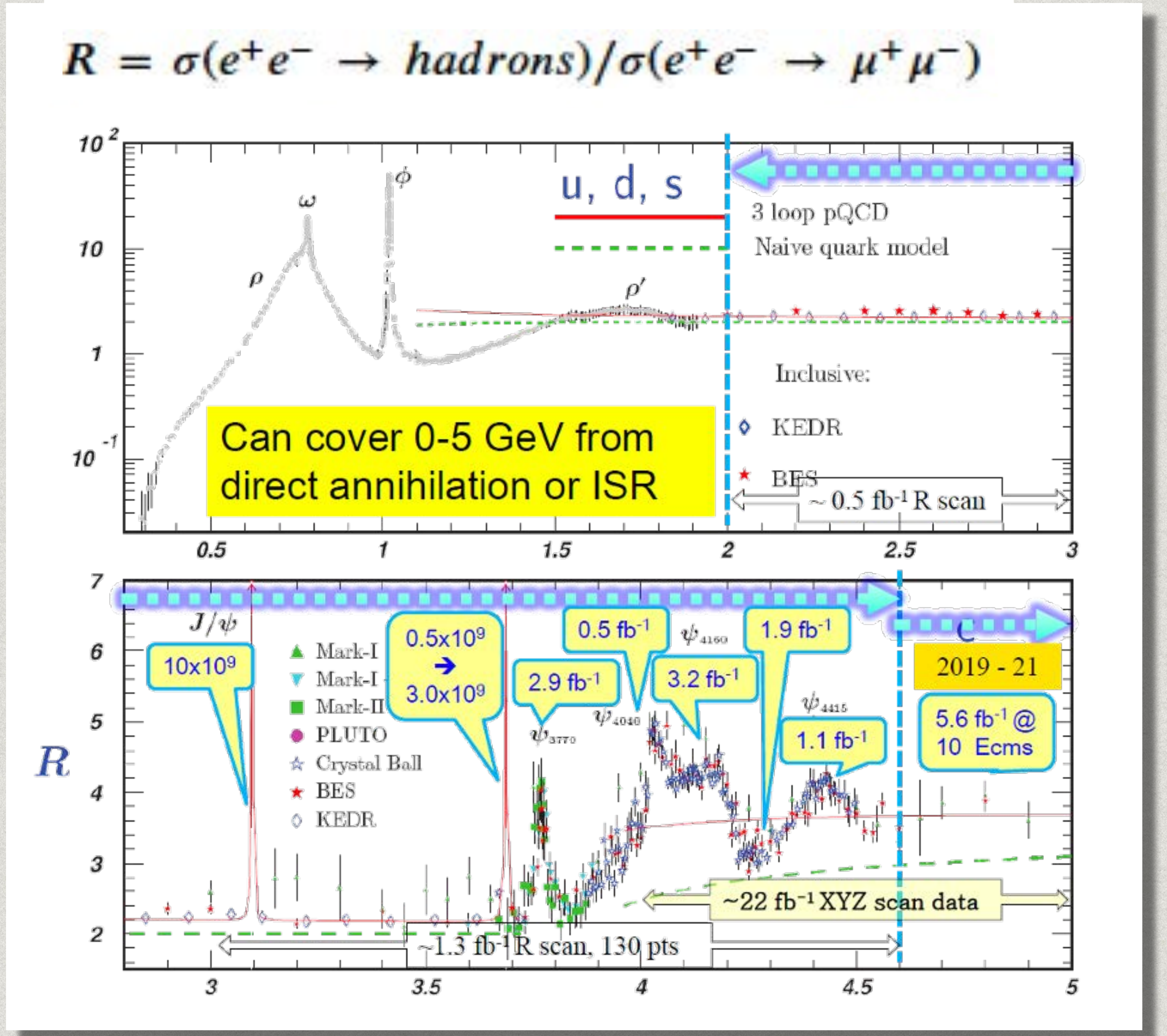




BESIII collaboration: ~600 members from 17 countries, 89 institutions

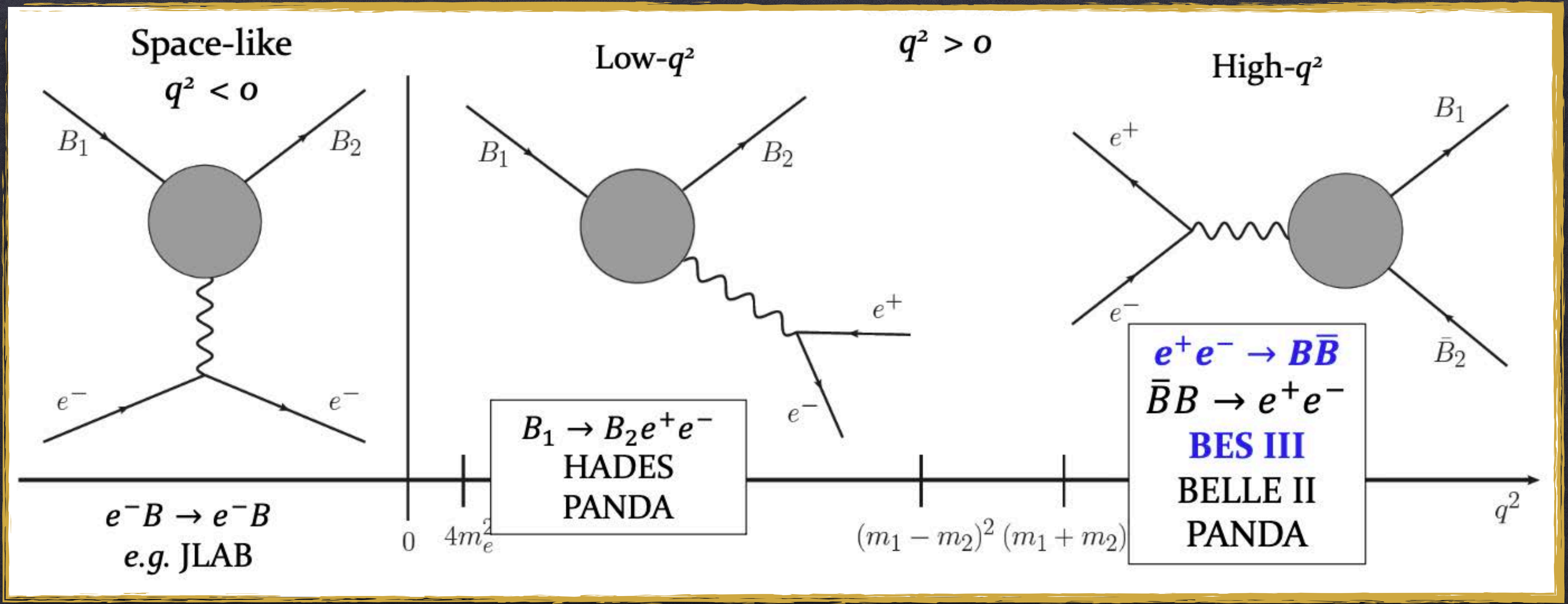
The BESIII experiment @ BEPCII

- $E_{CM} = 1.84 - 4.95\ GeV$
- Region below 2 GeV directly accessible (via ISR)
- $\mathscr{L}_{peak} = 1.1 \times 10^{33}\ cm^{-2}s^{-1}$
- Energy spread: $\Delta E \sim 5 \times 10^{-4}$
- World's largest sample of
  - J/ψ —> 10 billions
  - $\psi(2S)$ —> 3 billions
  - $\psi(3770)$ —> 20 fb^{-1}
- About 22 fb^{-1} of data for Exotic Charmonium Spectroscopy



Spectroscopy & decays of light hadrons and charmonium, charm physics, precision measurements, tests of fundamental symmetry

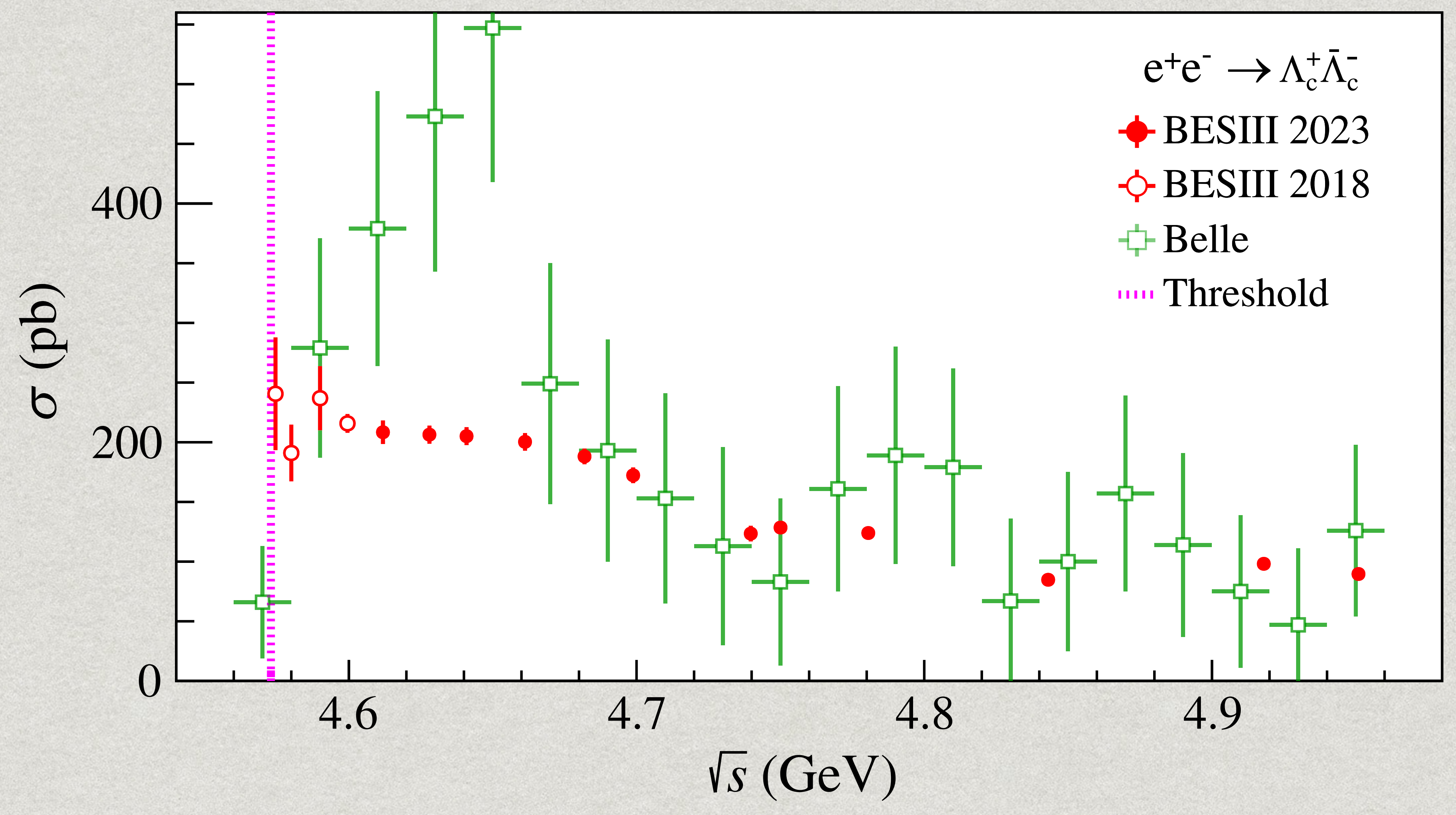
HADRON STRUCTURE

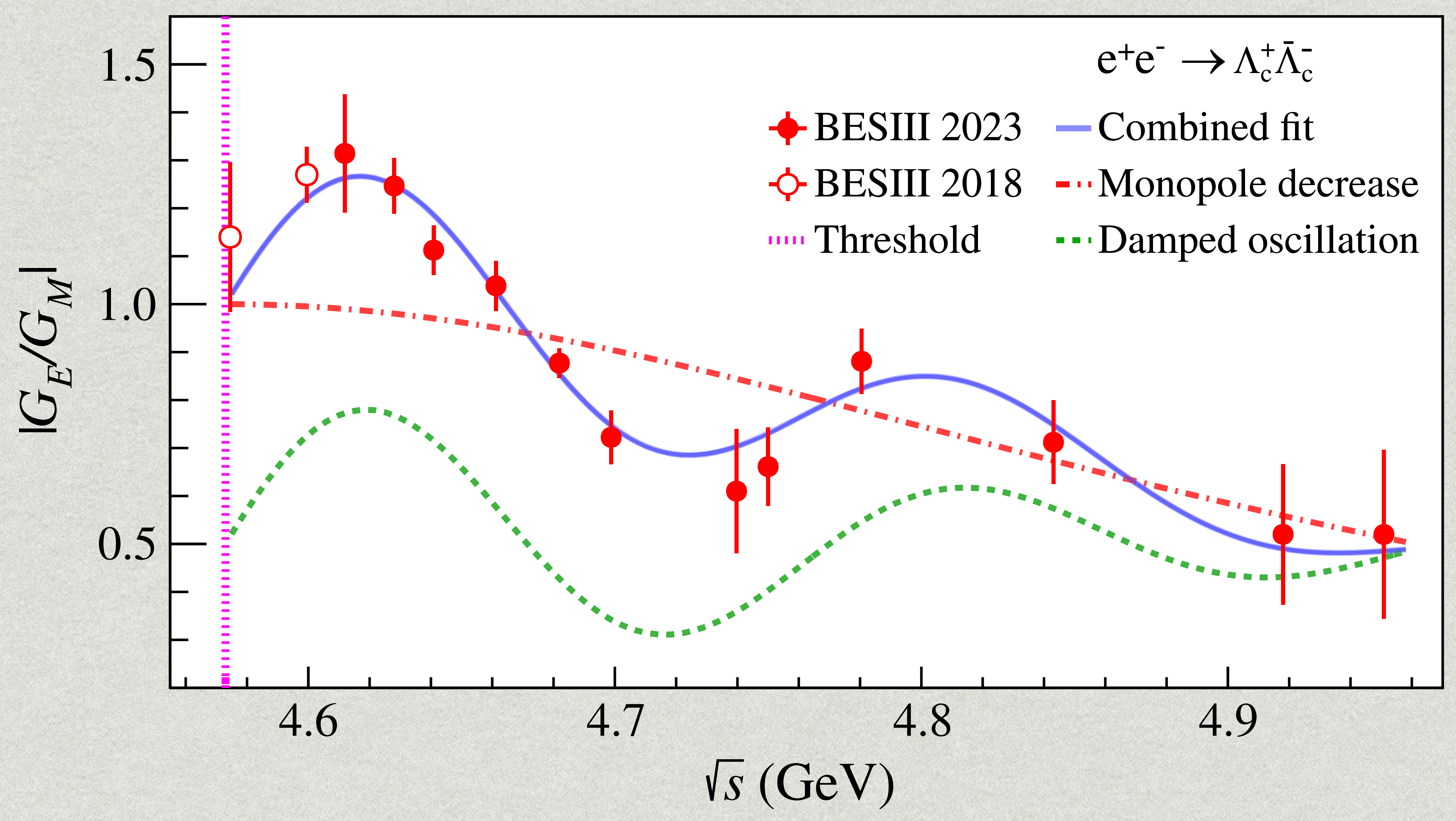


PRL 131, 191901 (2023)

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

- Energy scans from 4.61 to 4.95 GeV
    - Sharp rise in cross section near threshold
    - Disagreement with Belle data near 4.6 GeV
- No discernible oscillations of the effective form factors G_{eff}
    - Different from the case of proton and neutron
- With the polar-angle distribution of Λ_c^+
    - $|G_E|$ and $|G_M|$ are extracted
    - Energy dependence of $R = |G_E/G_M|$:
        - Damped oscillations with frequency ~3.5 times larger than for the proton





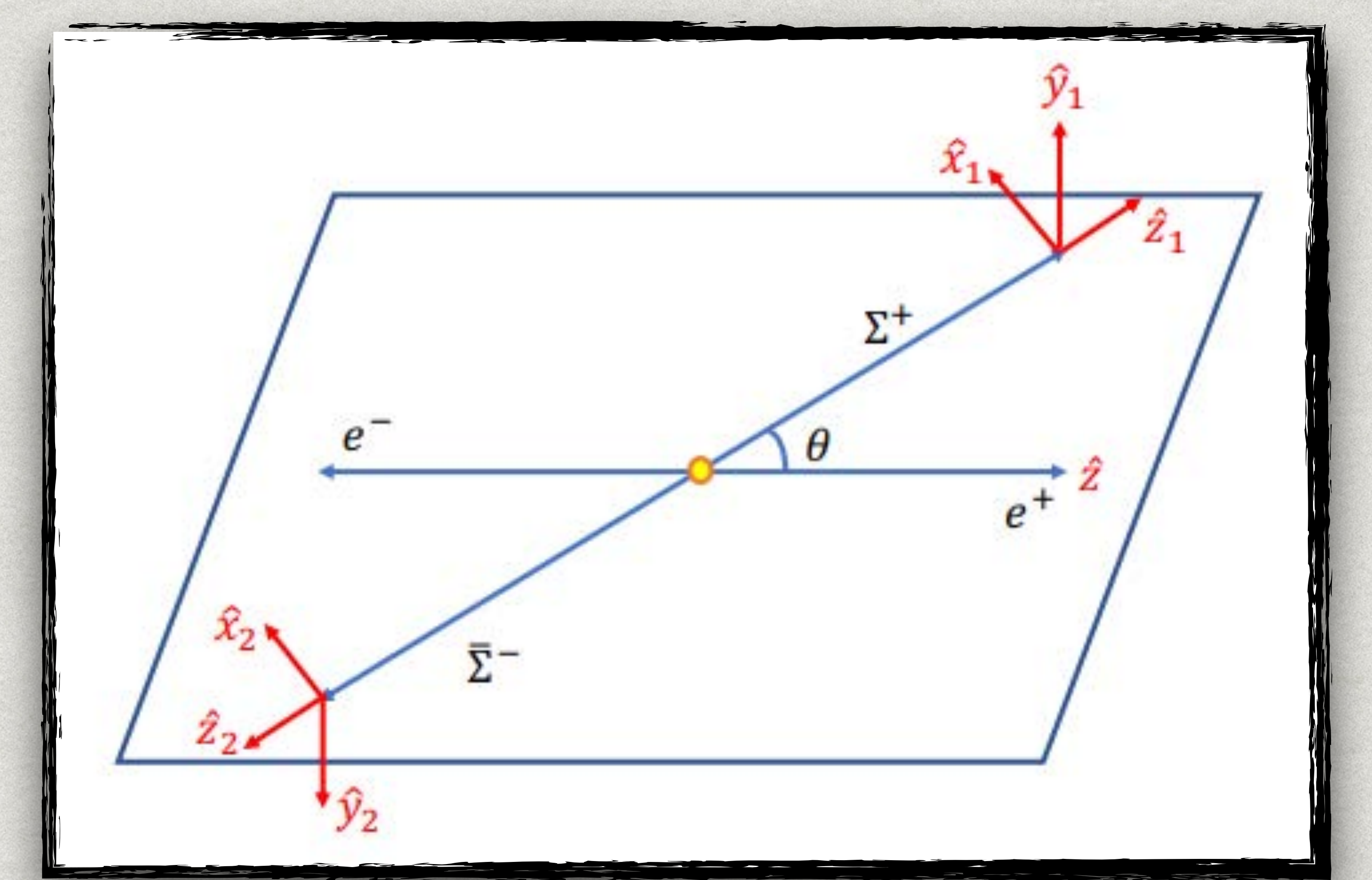
PRL 132, 081904 (2024)

Complete decomposition of Σ^+ EMFFs

Using a fully differential angular description of the final state particles

$$e^+e^- \to \Sigma^+(\to p\pi^0)\bar{\Sigma}^-(\to \bar{p}\pi^0)$$

the relative magnitude and phase of Σ^+ EMFFs can be extracted



$$\begin{aligned} \mathcal{W}(\xi) \propto\ & \mathcal{F}_0(\xi) + \alpha\mathcal{F}_5(\xi) \quad \text{Unpolarized part} \\ & + \alpha_1\alpha_2(\mathcal{F}_1(\xi) + \sqrt{1-\alpha^2}\cos(\Delta\Phi)\mathcal{F}_2(\xi) + \alpha\mathcal{F}_6(\xi)) \quad \text{Correlated part} \\ & + \sqrt{1-\alpha^2}\sin(\Delta\Phi)(-\alpha_1\mathcal{F}_3(\xi) + \alpha_2\mathcal{F}_4(\xi)), \quad \text{Polarized part} \end{aligned}$$

$$\begin{aligned} \mathcal{F}_0(\xi) &= 1 \\ \mathcal{F}_1(\xi) &= \sin^2\theta\sin\theta_1\sin\theta_2\cos\phi_1\cos\phi_2 - \cos^2\theta\cos\theta_1\cos\theta_2 \\ \mathcal{F}_2(\xi) &= \sin\theta\cos\theta(\sin\theta_1\cos\theta_2\cos\phi_1 - \cos\theta_1\sin\theta_2\cos\phi_2) \\ \mathcal{F}_3(\xi) &= \sin\theta\cos\theta\sin\theta_1\sin\phi_1 \\ \mathcal{F}_4(\xi) &= \sin\theta\cos\theta\sin\theta_2\sin\phi_2 \\ \mathcal{F}_5(\xi) &= \cos^2\theta \\ \mathcal{F}_6(\xi) &= \sin^2\theta\sin\theta_1\sin\theta_2\sin\phi_1\sin\phi_2 - \cos\theta_1\cos\theta_2. \end{aligned}$$

A nonzero relative phase leads to polarization P_y of the outgoing baryons

$$P_y = \frac{\sqrt{1-\alpha^2}\sin\theta\cos\theta}{1+\alpha\cos^2\theta}\sin(\Delta\Phi)$$

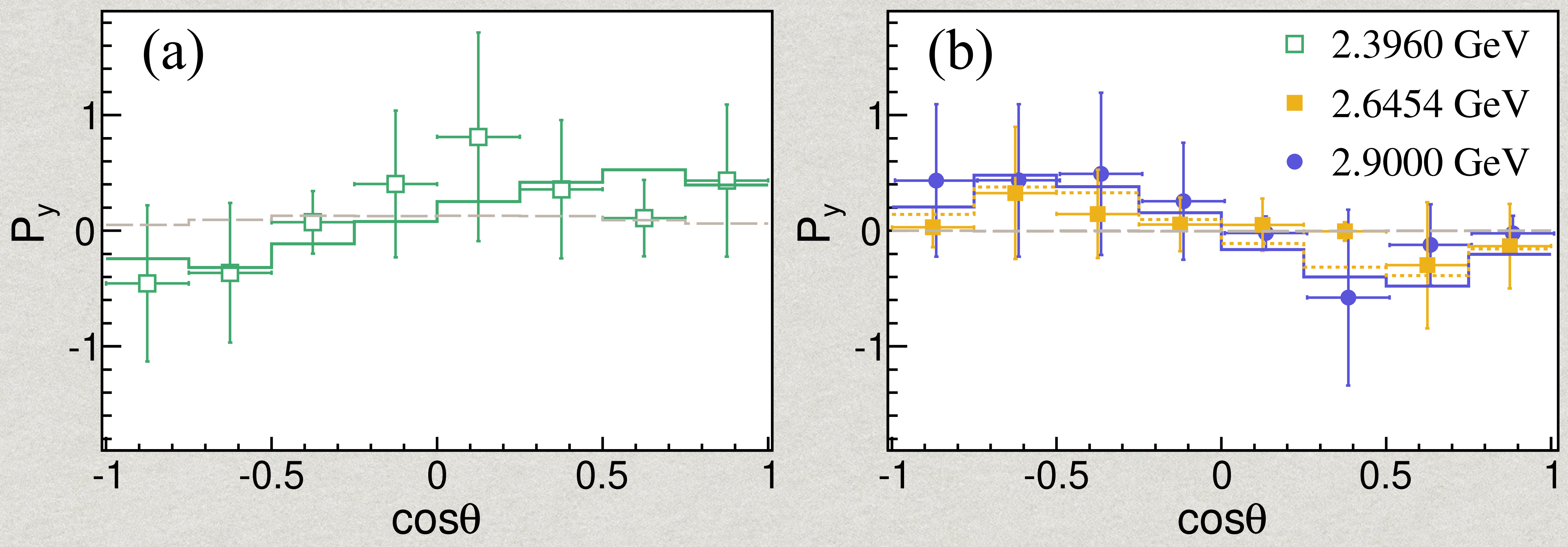
Complete decomposition of Σ^+ EMFFs

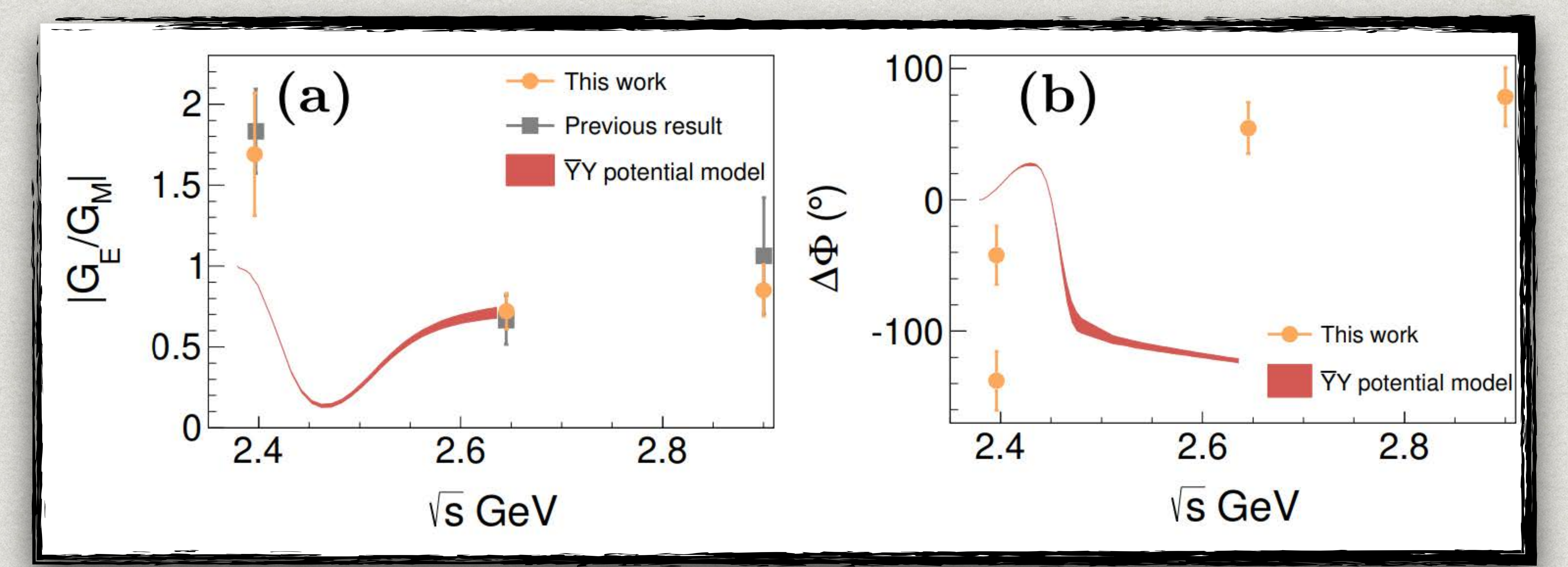
- Polarization is observed at $\sqrt{s}$=2.396, 2.644 and 2.90 GeV with a significance of 2.2σ, 3.6σ and 4.1σ

- Relative phase is determined for the first time in a wide q^2 range

  - $|G_E/G_M|$ and $\Delta\Phi$ line-shape is compared with $\overline{Y}Y$ model [PRD 103,014028 (2021)], different tendency in $\Delta\Phi$

  - $\Delta\Phi$ evolution is an important input for understanding its asymptotic behavior and the dynamics of baryons



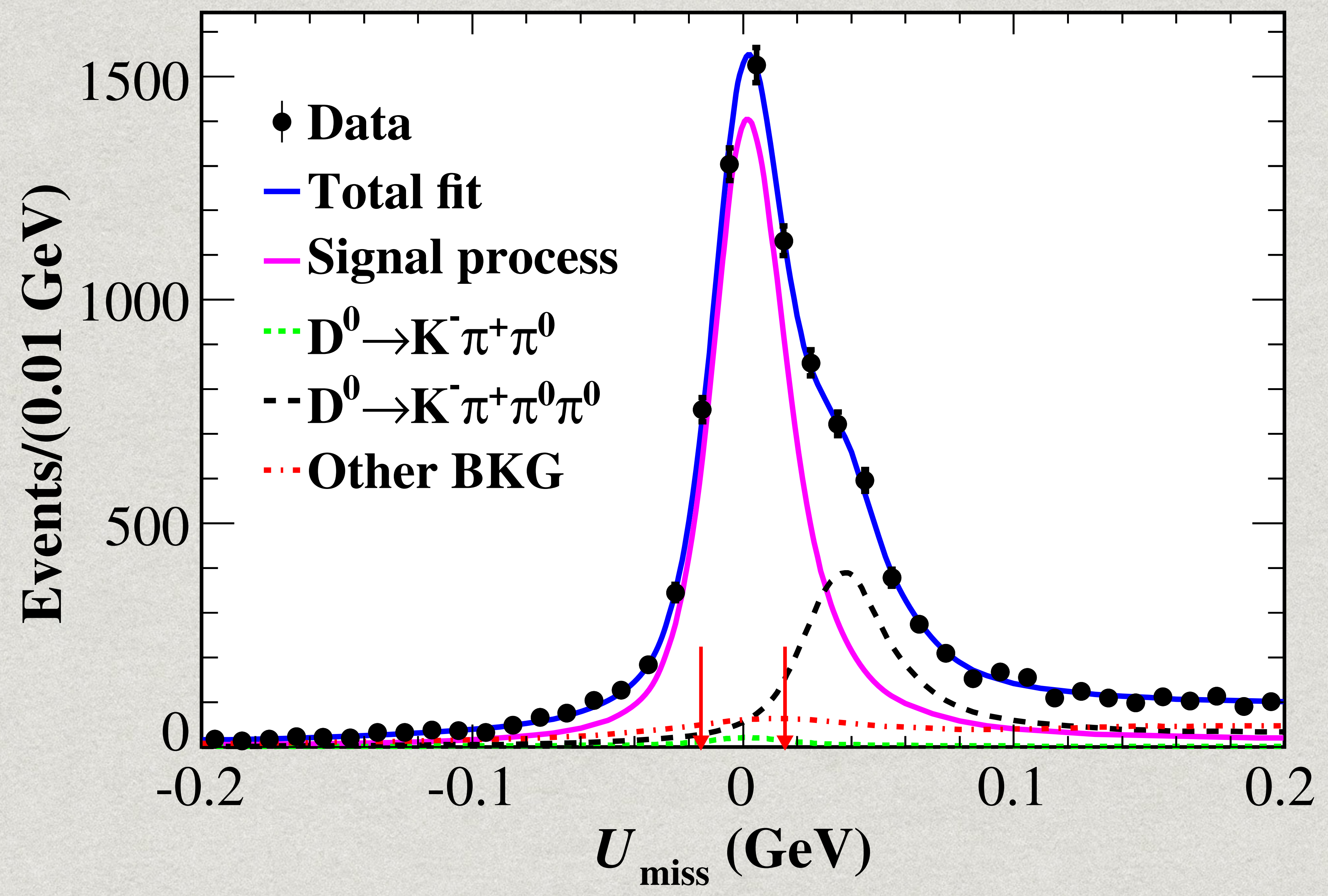


PRECISION TESTS OF THE SM AND RARE PHENOMENA

PRL 134, 011803 (2025)

Test of Lepton Flavor Universality with $D^0 \to K^*(892)^- \mu^+ \nu_\mu$

- $D^0 \to K^- \pi^0 \mu^+ \nu_\mu$ based on 7.93 fb^{-1} data collected at the center-of-mass energy of 3.773 GeV
- Amplitude analysis to extract S and P-wave components
- The dominant P-wave component is observed with a fraction of $f_{K^*(892)^-} = (94.24 \pm 0.35_{stat} \pm 0.29_{sys})\,\%$



$B(D^0 \to K^*(892)^- \mu^+ \nu_\mu) = (2.073 \pm 0.039 \pm 0.032)\,\%$

$$\frac{B(D^0 \to K^*(892)^- \mu^+ \nu_\mu)}{B(D^0 \to K^*(892)^- e^+ \nu_e)} = 1.020 \pm 0.030_{stat} \pm 0.028_{syst}$$

Semileptonic D decays provide a good opportunity to rigorously test the Standard Model through lepton flavor universality

$B(D^0 \to K^*(892)^- e^+ \nu_e)$ from PRD 99, 011103 (2019)

Test of Lepton Flavor Universality with $D^0 \to K^*(892)^- \mu^+ \nu_\mu$

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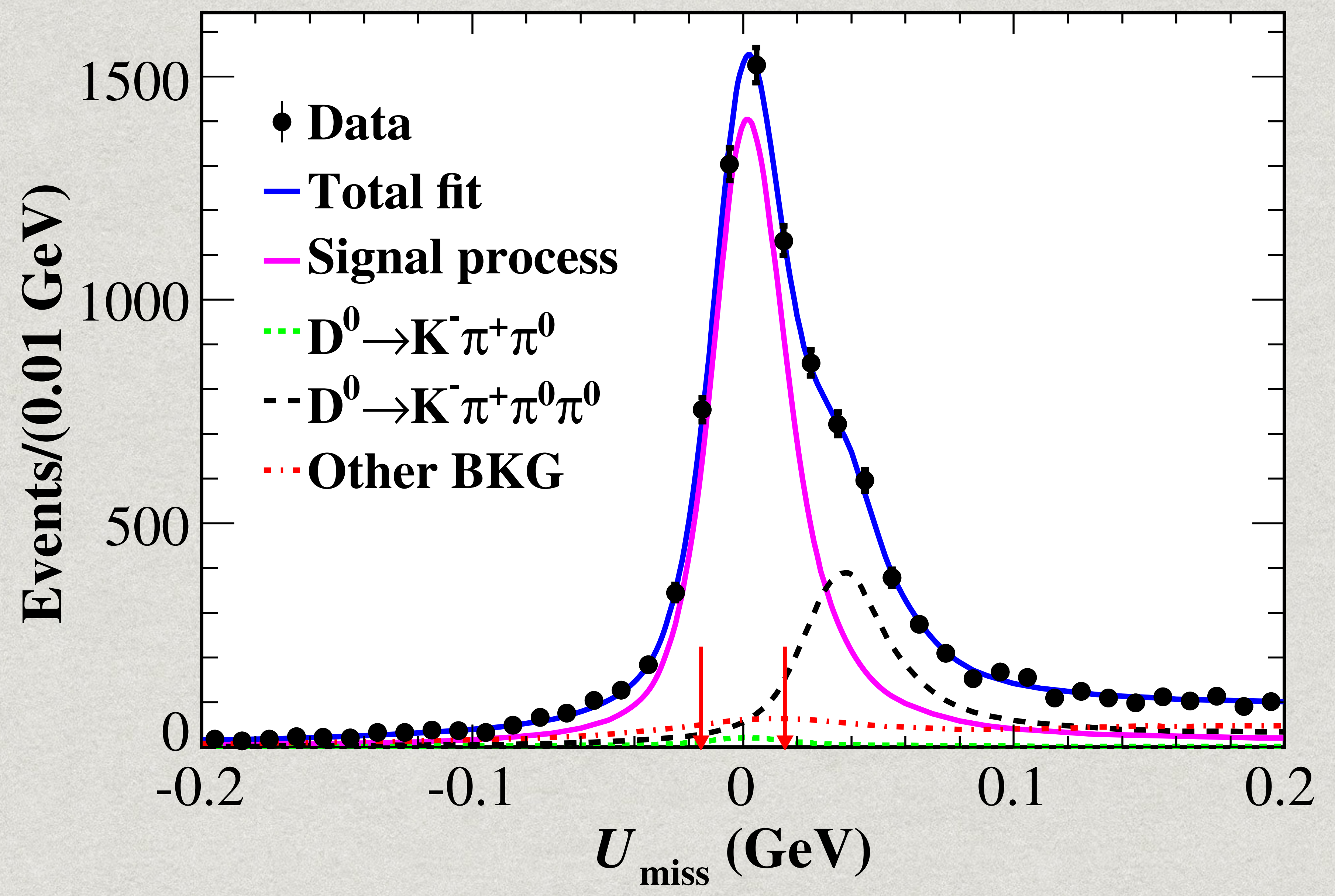
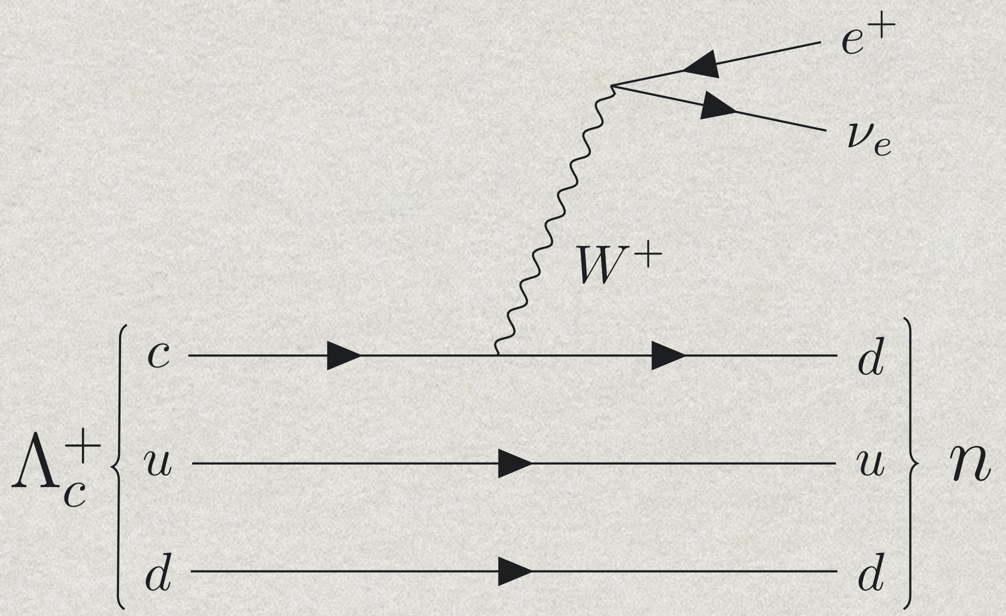


Theory	$\mathcal{B}$ (%)	r_V	r_2
LCSR [7,16]	$2.01^{+0.09}_{-0.08}$	1.39	0.60
χUA [17]	1.98	...	...
CCQM [6]	2.80	1.22 ± 0.24	0.92 ± 0.18
CQM [8,18]	3.09	1.56	0.74
LFQM [9]	...	1.36	0.83
HM$_\chi$T [10]	...	1.60	0.50
Experiments	$\mathcal{B}$ (%)	r_V	r_2
BESIII [39]	...	$1.46 \pm 0.07 \pm 0.02$	$0.67 \pm 0.06 \pm 0.01$
FOCUS [11]	1.89 ± 0.24	$1.71 \pm 0.68 \pm 0.34$	$0.91 \pm 0.37 \pm 0.10$
This Letter	$2.073 \pm 0.039 \pm 0.032$	$1.37 \pm 0.09 \pm 0.03$	$0.76 \pm 0.06 \pm 0.02$

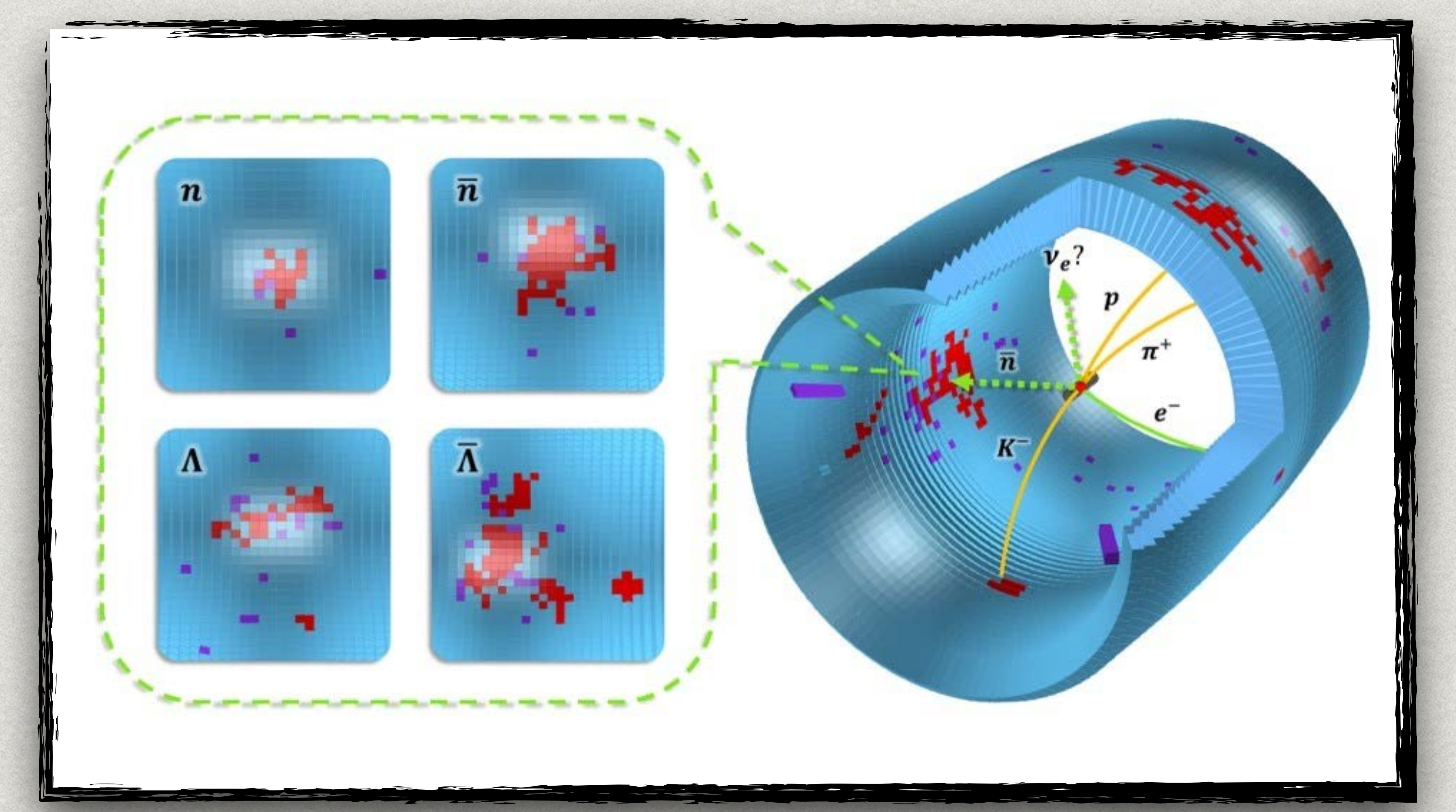
Compatible with light cone sum rules predictions

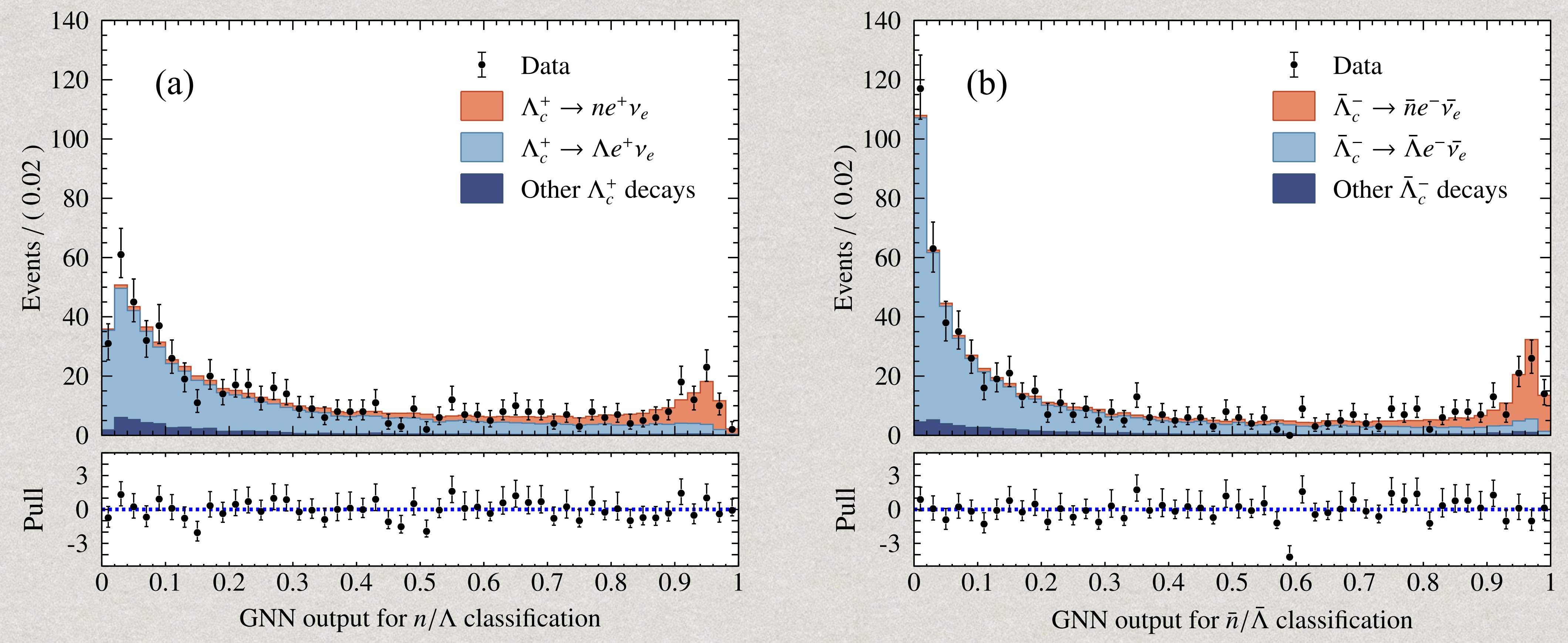
Observation of a rare beta decay of the charmed baryon with a Graph Neural Network

- Provides unique insights into the fundamental mechanism of strong and electro-weak interactions
    - non-perturrbative QCD effects
    - CKM matrix parameters
- The Cabibbo-suppressed decay $\Lambda_c^+ \to n e^+ \nu_e$ presents significant challenges



- Dominant background events from $\Lambda_c^+ \to \Lambda e^+ \nu_e$, $\Lambda \to n\pi^0$





Observation of a rare beta decay of the charmed baryon with a Graph Neural Network

- Based on 4.5 fb^{-1} data collected at center-of-mass energies from 4.6 to 4.7 GeV

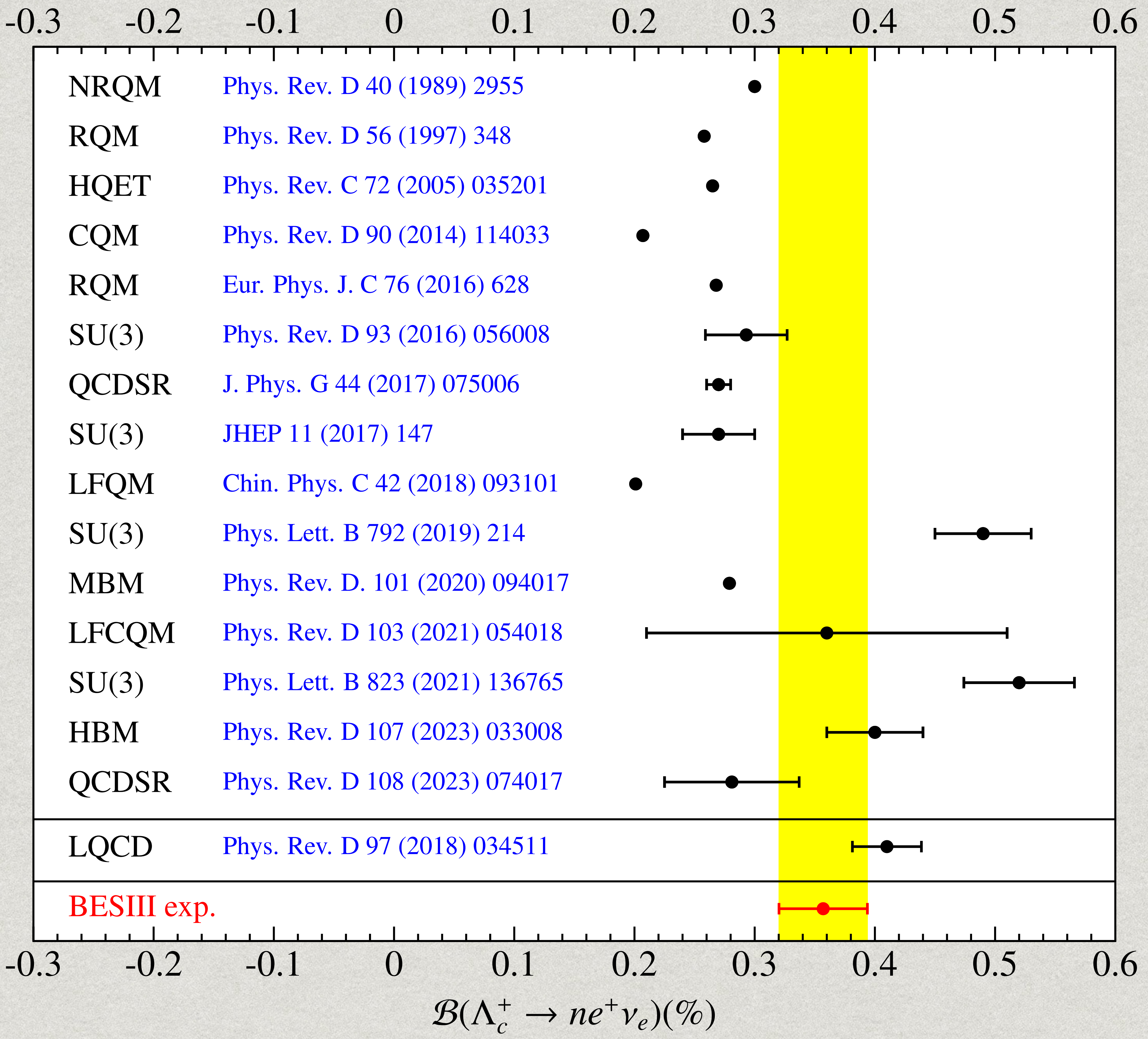
$$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = \left(0.357 \pm 0.034_{\text{stat.}} \pm 0.014_{\text{syst.}}\right)\%$$

consistent with LQCD prediction PRD 97, 034511 (2018)

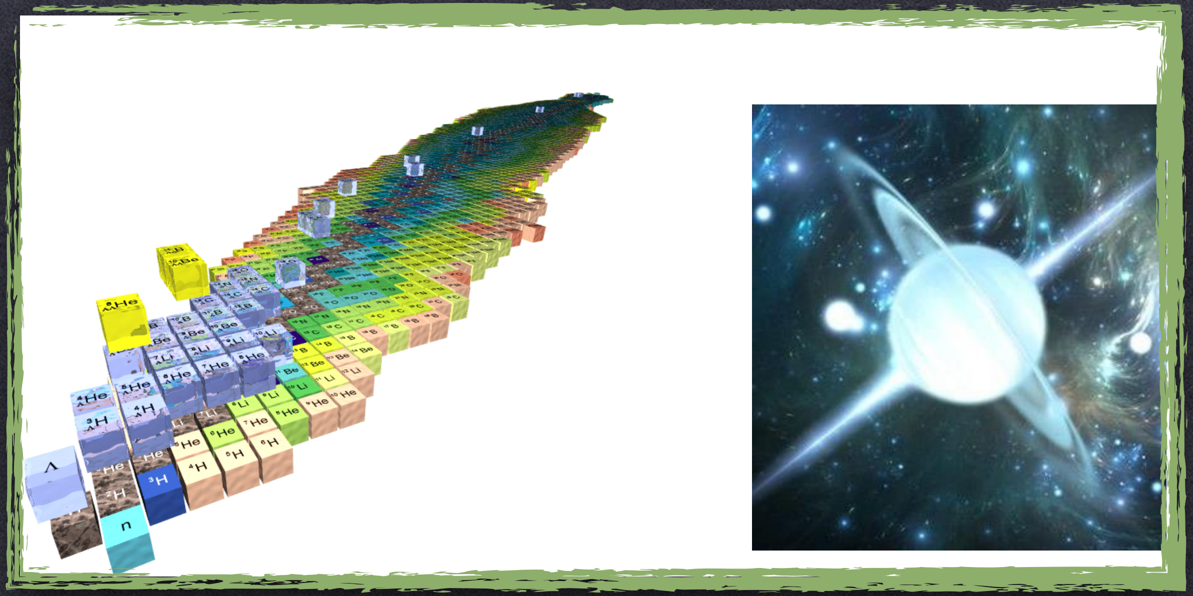
- Impossible to measure the transition FF
- Important reduction of systematic uncertainties thanks to the huge J/ψ data sample
- For the first time, the CKM matrix element $|V_{cb}|$ is extracted via a charmed baryon decay as

$$|V_{cd}| = 0.208 \pm 0.011_{\text{exp.}} \pm 0.007_{\text{LQCD}} \pm 0.001_{\tau_{\Lambda_c^+}}$$

consistent with results from charmed meson (semi-)leptonic decays

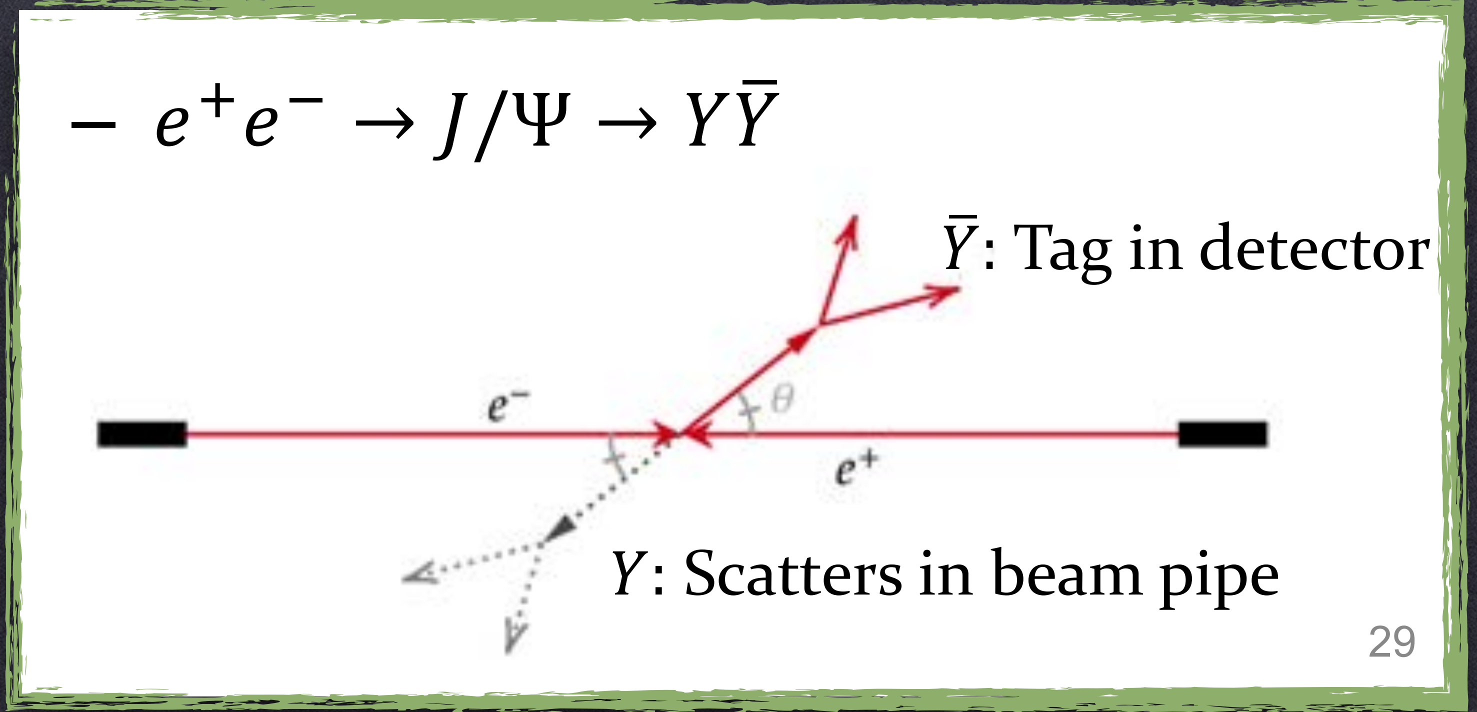


HADRON INTERACTIONS



- Crucial component to predict properties of hypernuclei.
- Needed to understand the hyperon puzzle of neutron stars

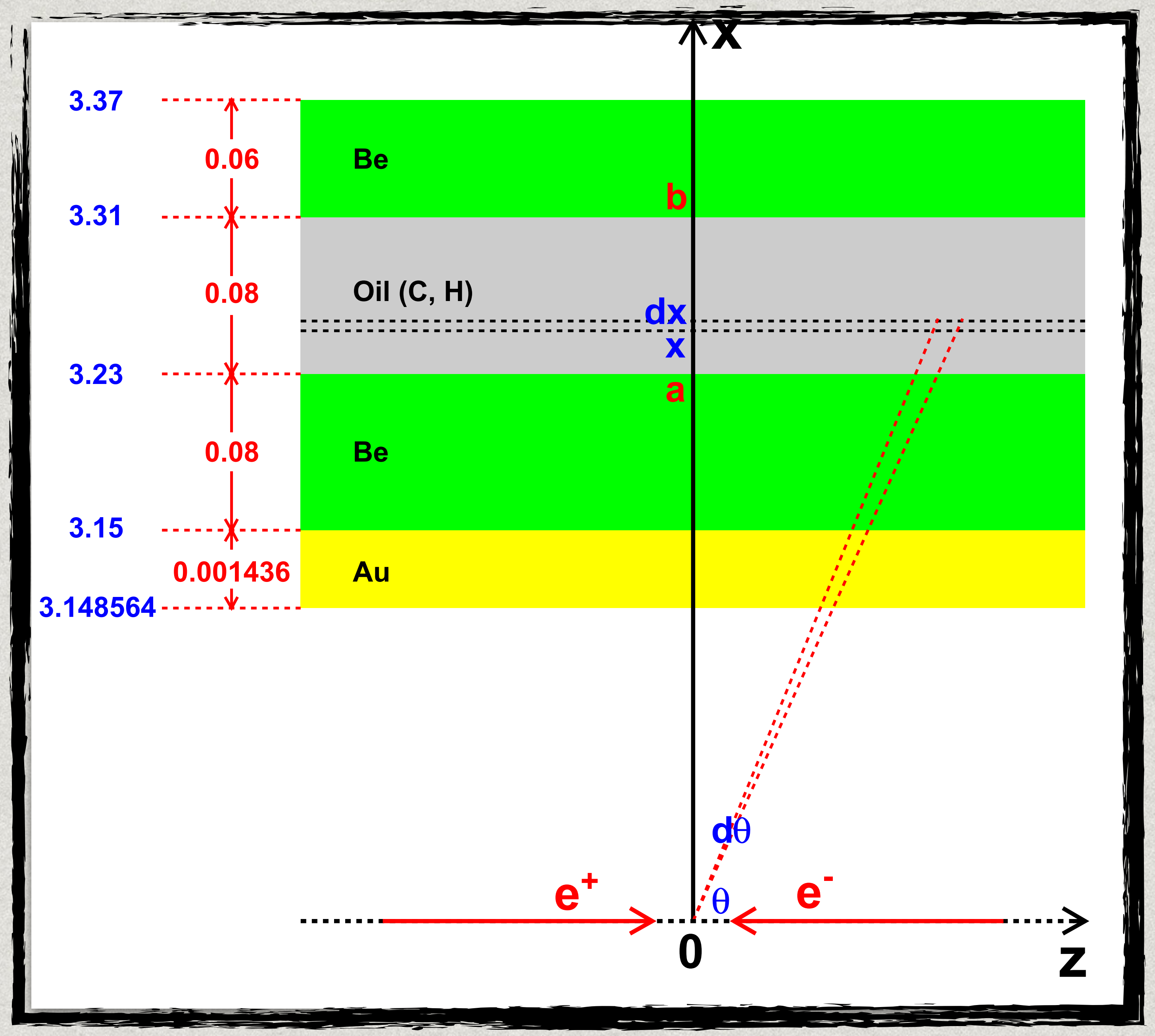
- Hyperon femtoscopy
- Hypernuclear studies
- Secondary YN interactions



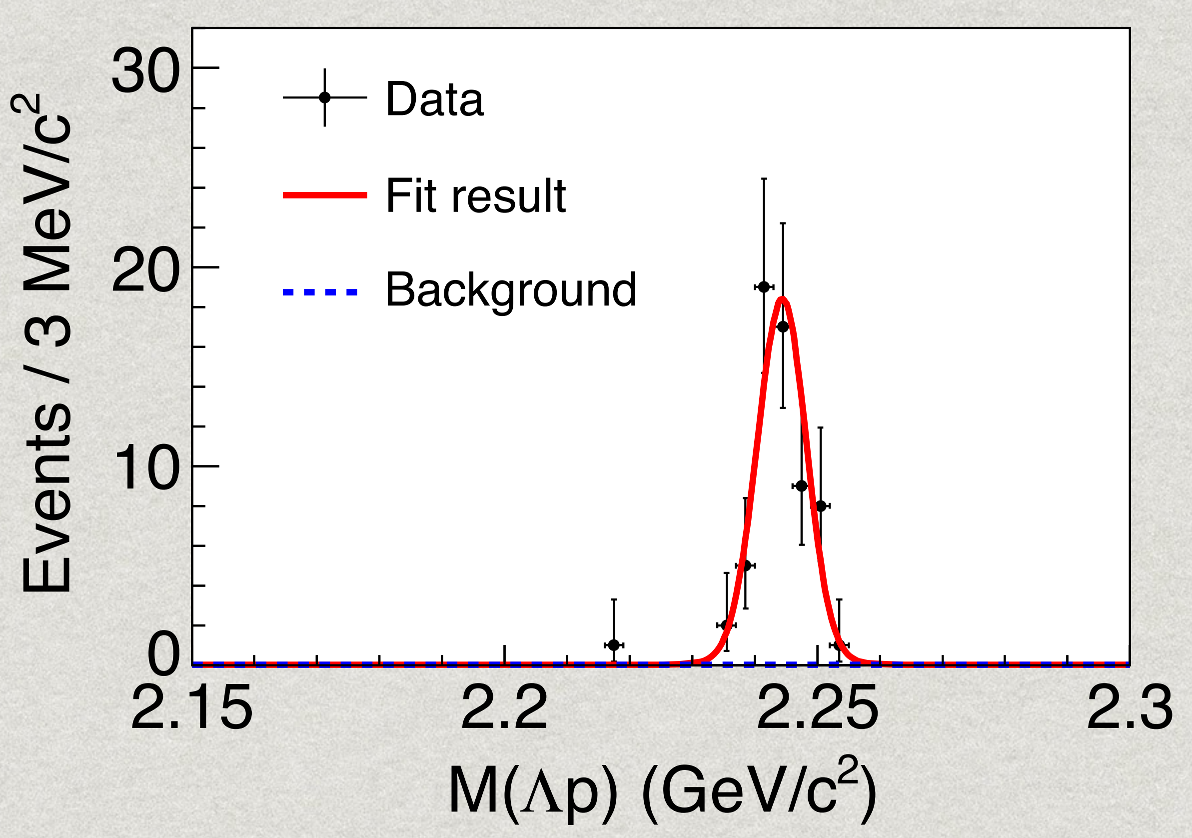
PRL 132, 231902 (2024)

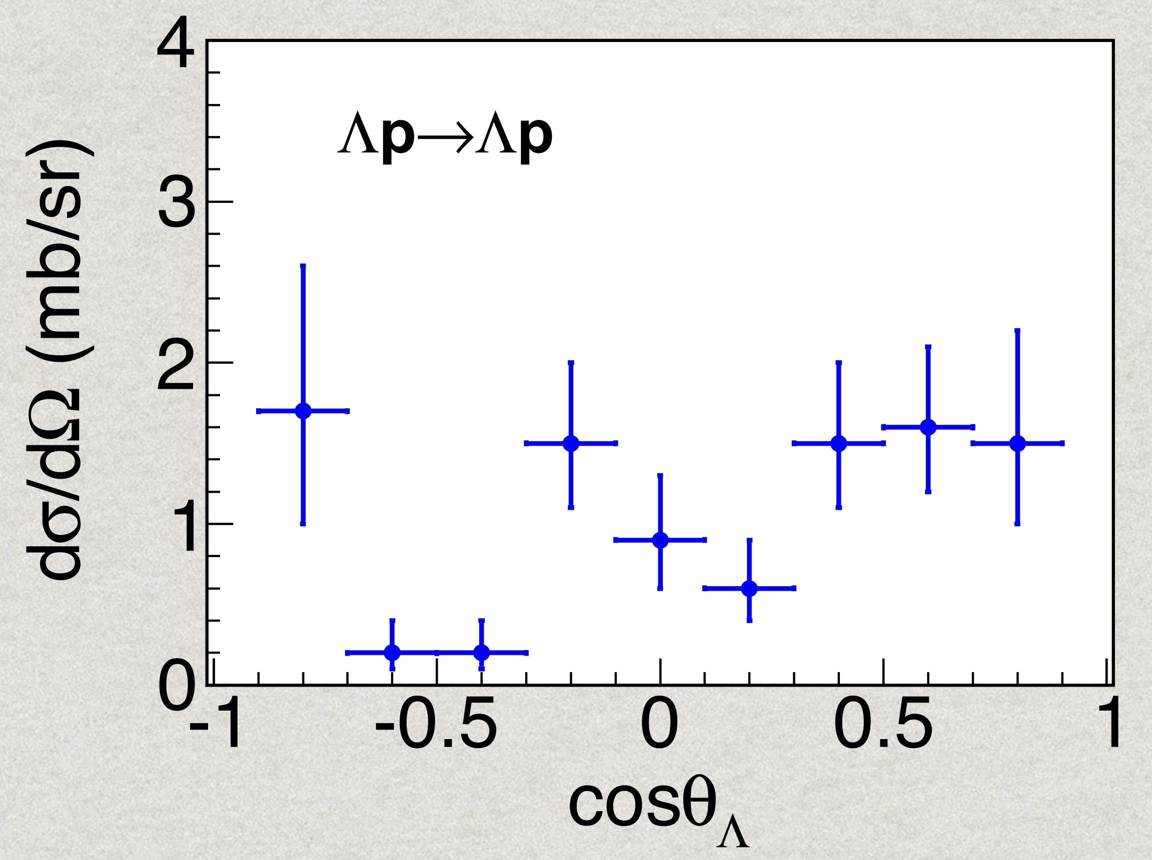
Study of Antihyperon-Nucleon Scattering $\bar{\Lambda}p \rightarrow \bar{\Lambda}p$ and Measurement of $\Lambda p \rightarrow \Lambda p$ Cross Section

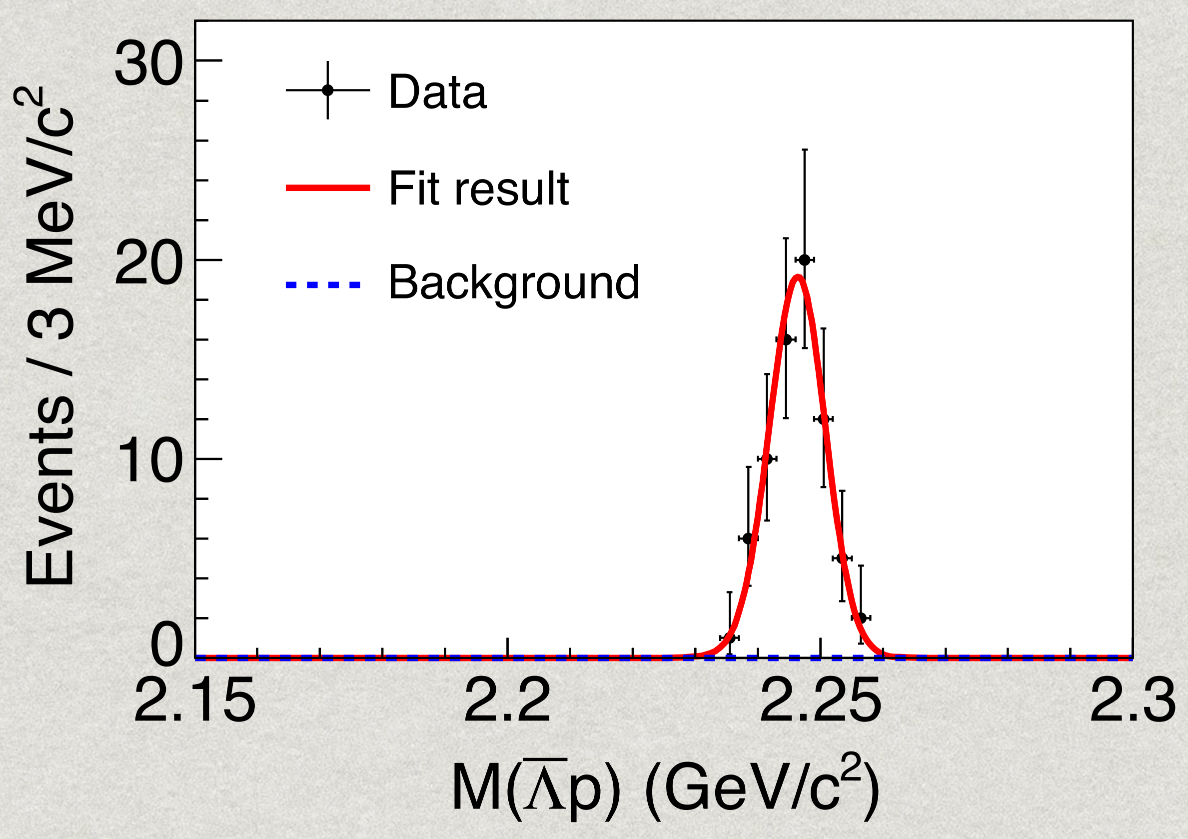
- Almost monoenergetic $\Lambda/\bar{\Lambda}$ beam from 10 billions $J/\psi \rightarrow \Lambda\bar{\Lambda}$
  - $P_{\Lambda} = 1.074 \pm 0.017\ GeV/c$
- Target: proton, the hydrogen nuclei in the cooling oil of the beam pipe
- $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$: look for 5 tracks in the final state
- R_{xy} signal region [3.0-3.5] cm
- Main background from $J/\psi \rightarrow \Lambda\bar{\Lambda}$ where no scattering with proton occurs
- To remove events with scattering against Au, Be and C nuclei $P(p_{oil}) = |P_{\Lambda/\bar{\Lambda}} + P_p - (P_{e^+e^-} - P_{\Lambda/\bar{\Lambda}})| < 0.04\ GeV/c$

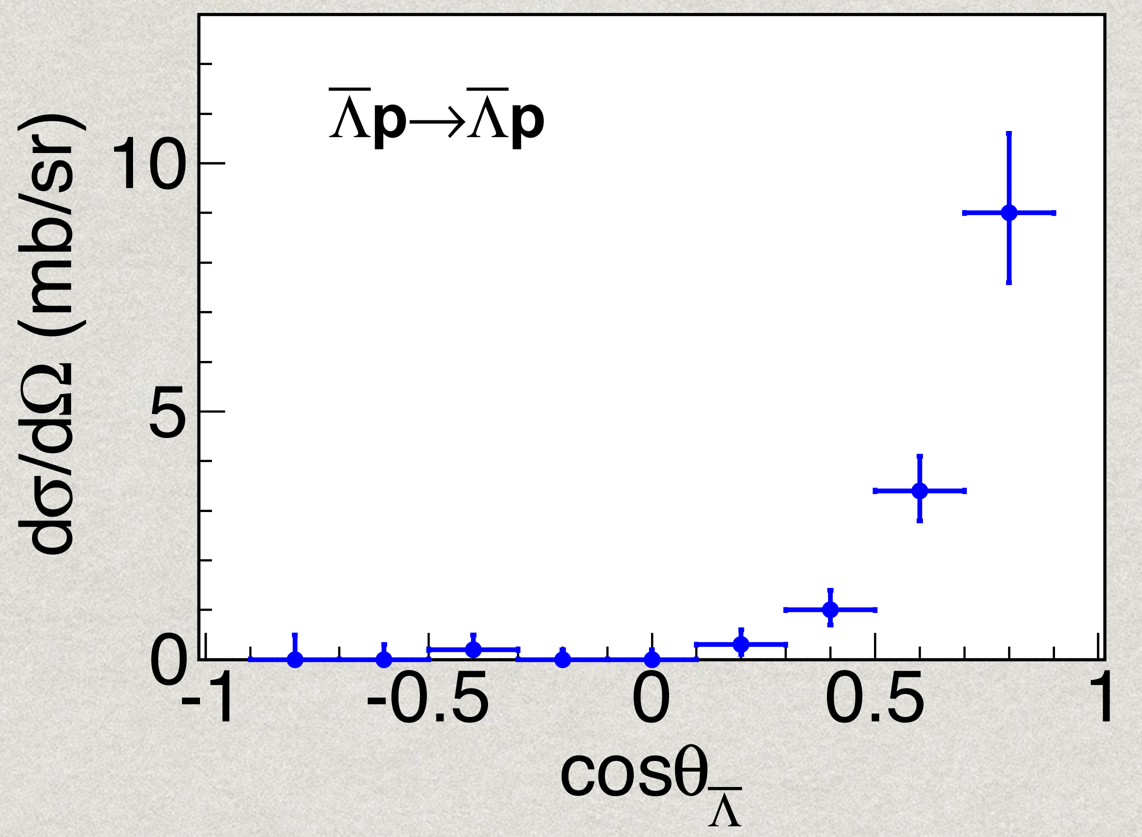


Study of Antihyperon-Nucleon Scattering $\Lambda p \to \Lambda p$ and Measurement of $\Lambda p \to \Lambda p$ Cross Section









Signal CM energy 2.243 GeV/c²

Differential Xsec for
$-0.9 \leq \cos\theta_{\Lambda/\bar{\Lambda}} \leq 0.9$

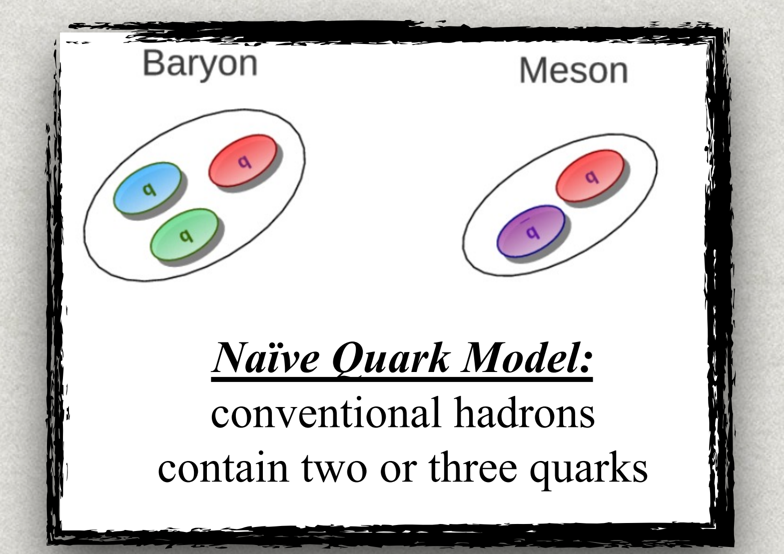
- Slight tendency of forward scattering for $\Lambda p \to \Lambda p$
- Strong forward peak for $\bar{\Lambda} p \to \bar{\Lambda} p$

$$\sigma(\Lambda p \to \Lambda p) = (12.2 \pm 1.6_{\rm stat} \pm 1.1_{\rm syst})\ \text{mb}$$

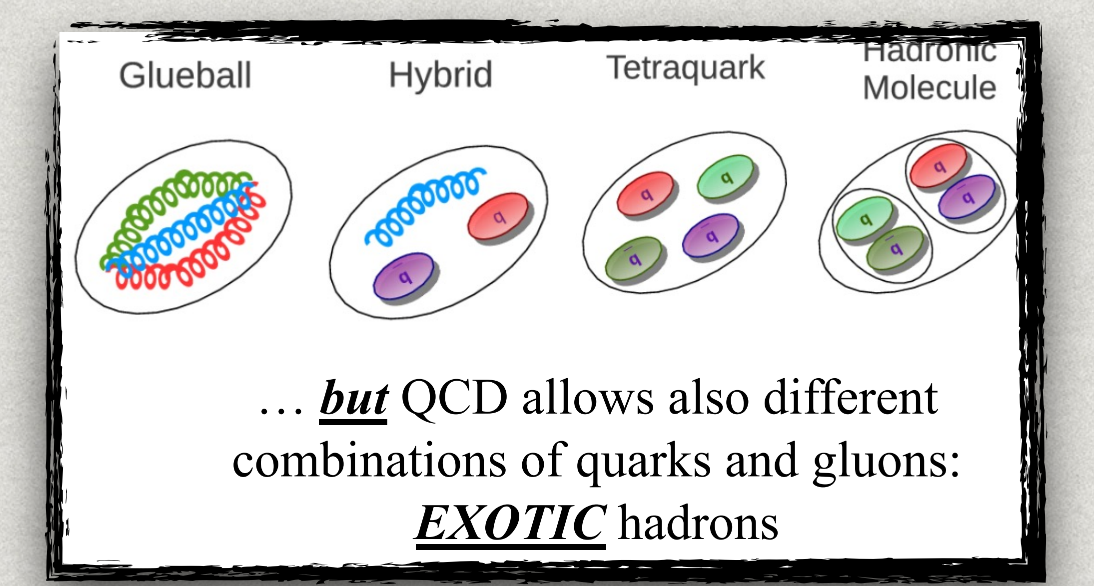
$$\sigma(\bar{\Lambda} p \to \bar{\Lambda} p) = (17.5 \pm 2.1_{\rm stat} \pm 1.6_{\rm syst})\ \text{mb}$$

HADRON SPECTROSCOPY

Intro to hadron spectroscopy

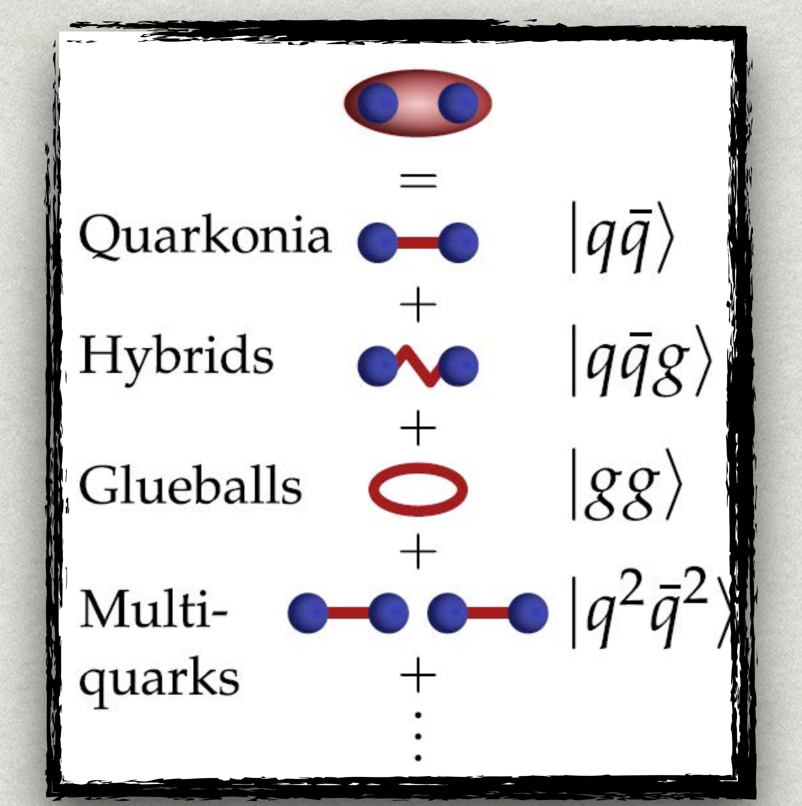


- Hadron spectroscopy: establish the spectrum and study the exotic hadrons properties



- Exotic states observed experimentally, but their nature is still far from being understood!!!

https://qwg.ph.nat.tum.de/exoticshub/



Physical meson: a linear superposition of all allowed color-singlet configurations

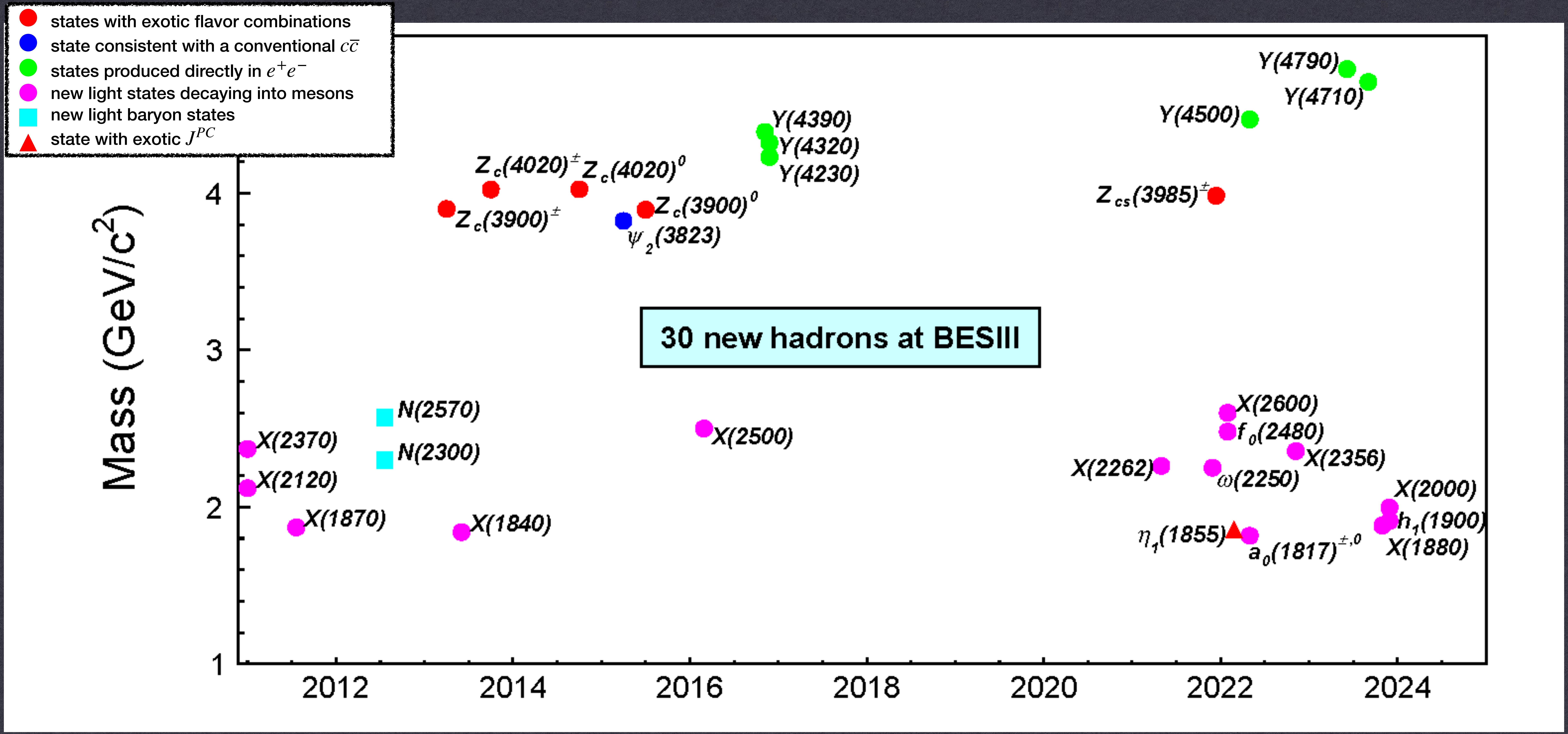
Manifestly exotic

- Quark contents more than qq or qqq
- Quantum number J^{PC} not reachable for ordinary mesons or baryons $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$

Cryptoexotic exotic

- Overpopulation of states
- Mass/width not fitting in spectra
- Production and/or decay patterns incompatible with standard mesons/baryons

Kinematic effects



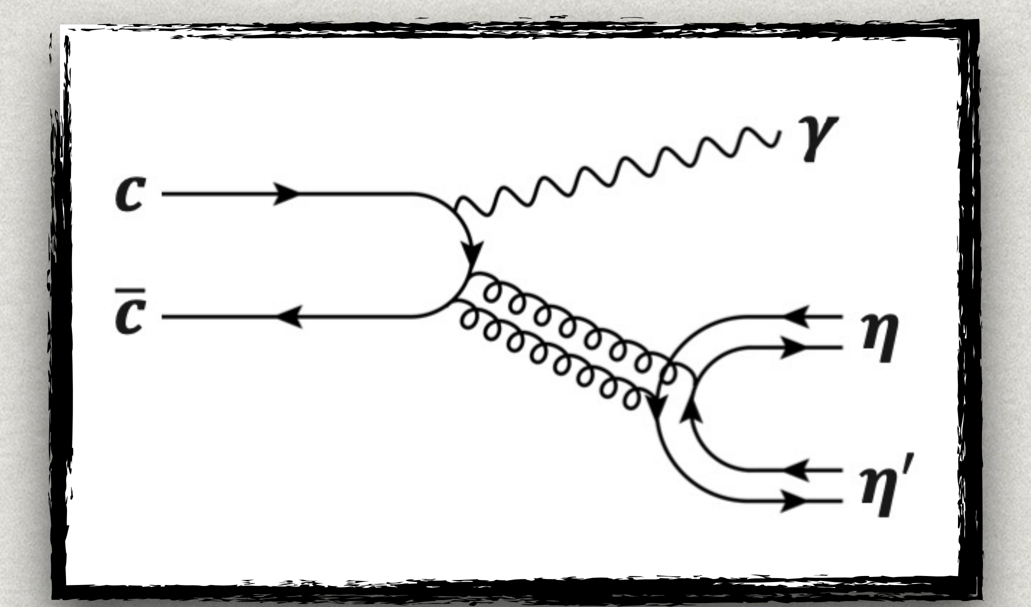
NEW HADRONS DISCOVERED AT BESIII

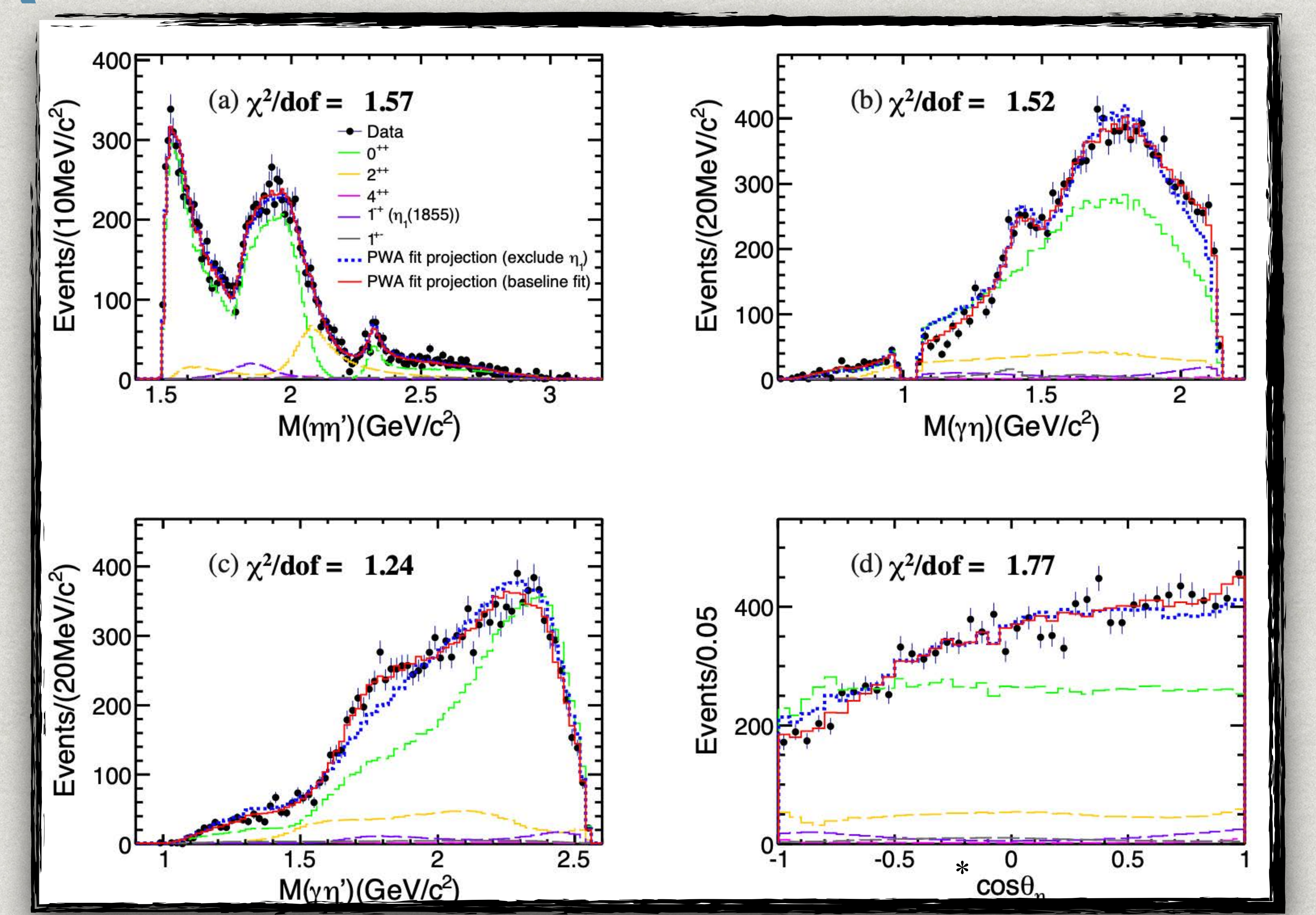
UPDATED JUNE 2024

Observation of Exotic Isoscalar State $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$

PRL 129, 192002 (2022)
PRD 106,072012 (2022)
PRD 107,079901 (2023)

- PWA of $J/\psi \to \gamma\eta\eta'$ using 10 Billion of J/ψ data @ BESIII
  - $\eta \to \gamma\gamma$ and $\eta' \to \gamma\pi^+\pi^-$/ $\eta\pi^+\pi^-$





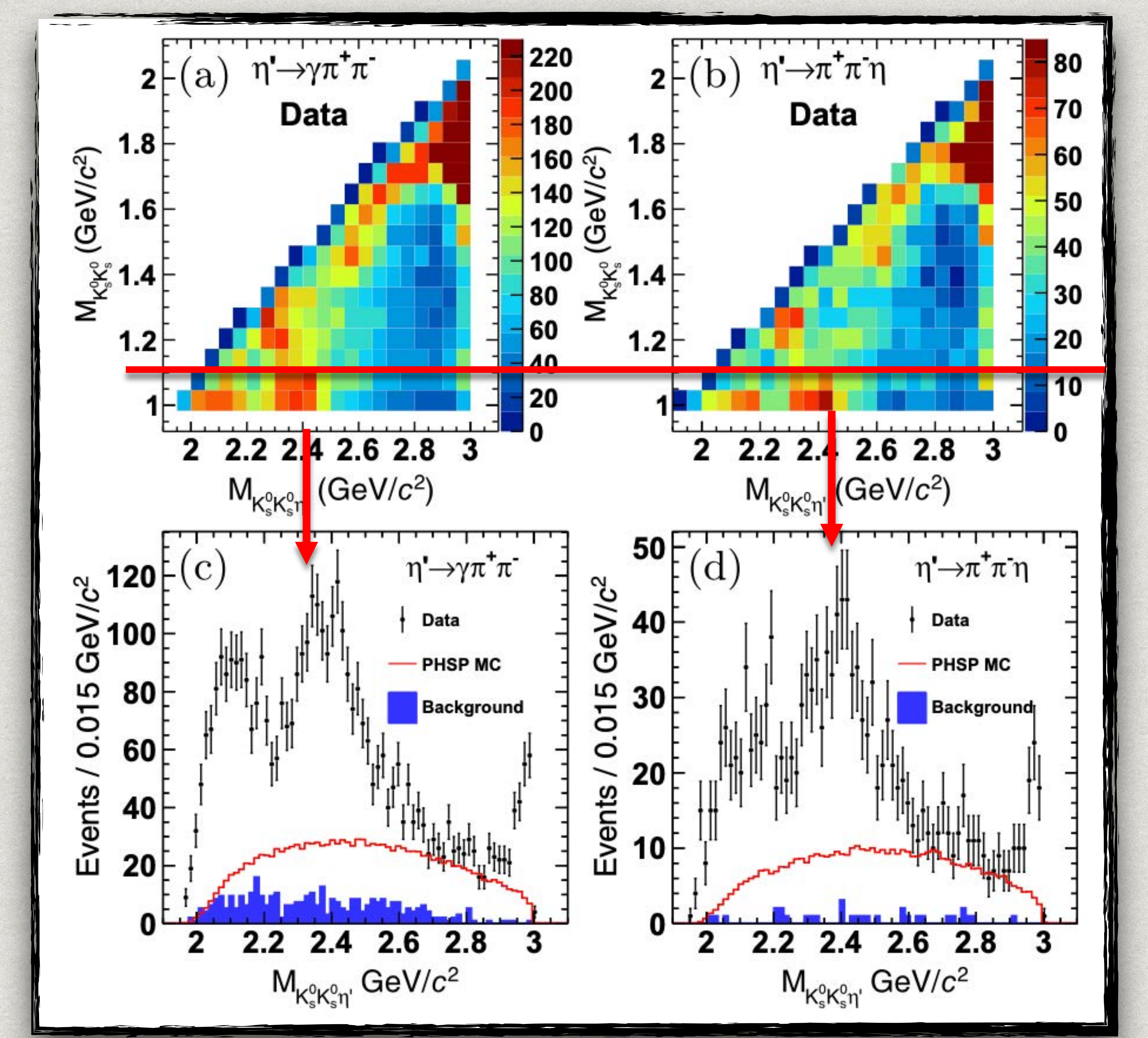
- Only isovector candidate observed: $\pi_1(1400)$, $\pi_1(1600)$, $\pi_1(2015)$
- An isoscalar 1^{-+} state, $\eta_1(1855)$, has been observed with statistical significance larger than 19σ
- Mass is consistent with LQCD calculation for the 1^{-+} hybrid (1.7 – 2.1 GeV/c^2)

$$M = (1855 \pm 9^{+6}_{-1})\,\mathrm{MeV}/c^2; \quad \Gamma = (188 \pm 18^{+3}_{-8})\,\mathrm{MeV}$$

$$\mathcal{B}(J/\psi \to \gamma\eta_1(1855) \to \gamma\eta\eta') = (2.70 \pm 0.41^{+0.16}_{-0.35}) \times 10^{-6}$$

X(2370): Glueball-like particle in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$

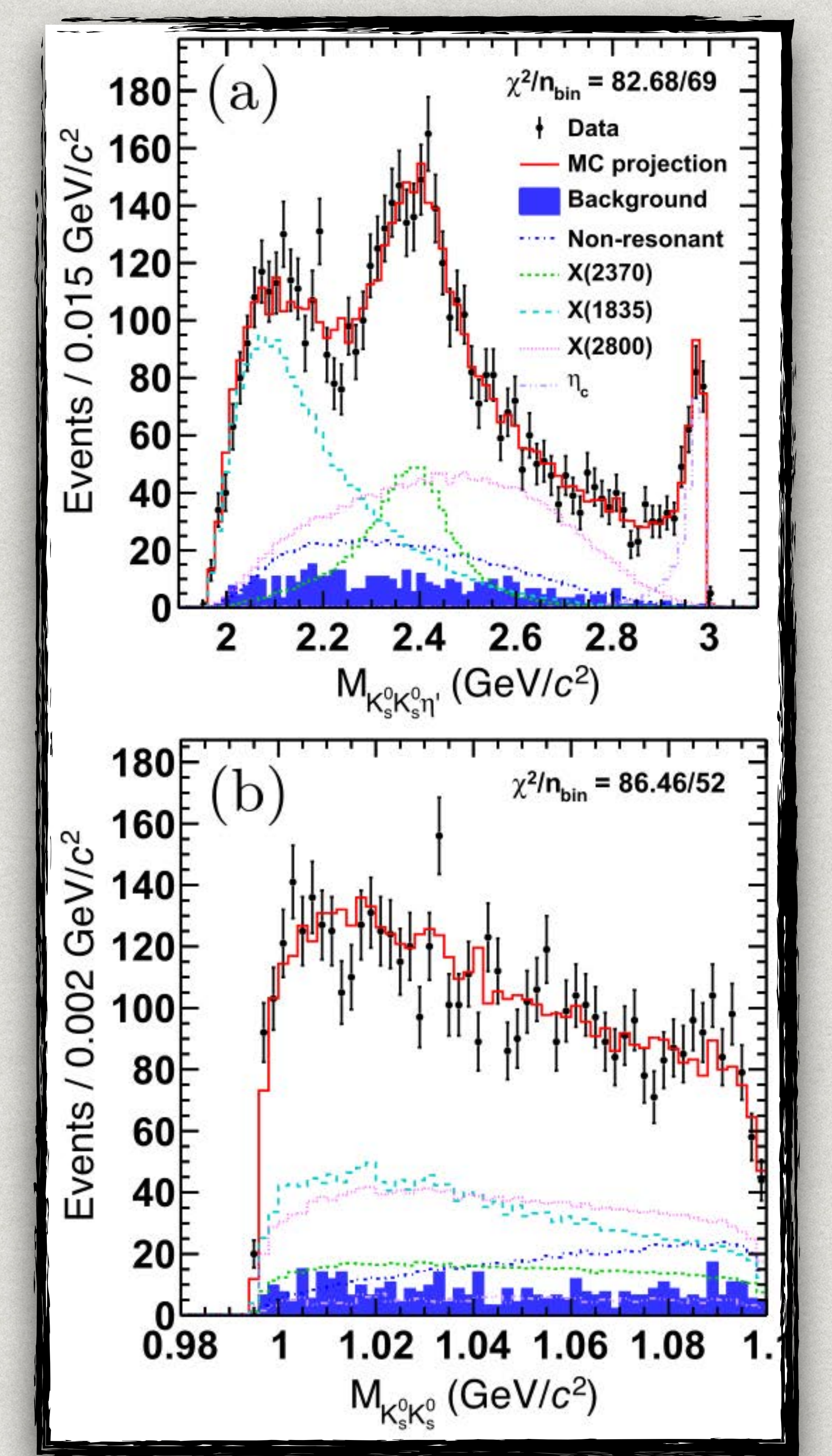
- PWA using 10 Billion of J/ψ data @ BESIII
- Minimal background contribution: $J/\psi \to \pi^0 K_S^0 K_S^0 \eta'$ and $J/\psi \to K_S^0 K_S^0 \eta'$ since they are forbidden by exchange symmetry and CP conservation
- $\eta' \to \gamma\pi^+\pi^- / \eta\pi^+\pi^-;\ K_S^0 \to \pi^+\pi^-$
- Strong enhancement near $K_S^0 K_S^0$ mass threshold from $f_0(980)$
- Clear connection between $f_0(980)$ and the structure around 2.4 GeV
- $M(K_S^0 K_S^0)$ < 1.1GeV to select the $f_0(980)$



PRL 132, 181901 (2024)

X(2370): Glueball-like particle in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$

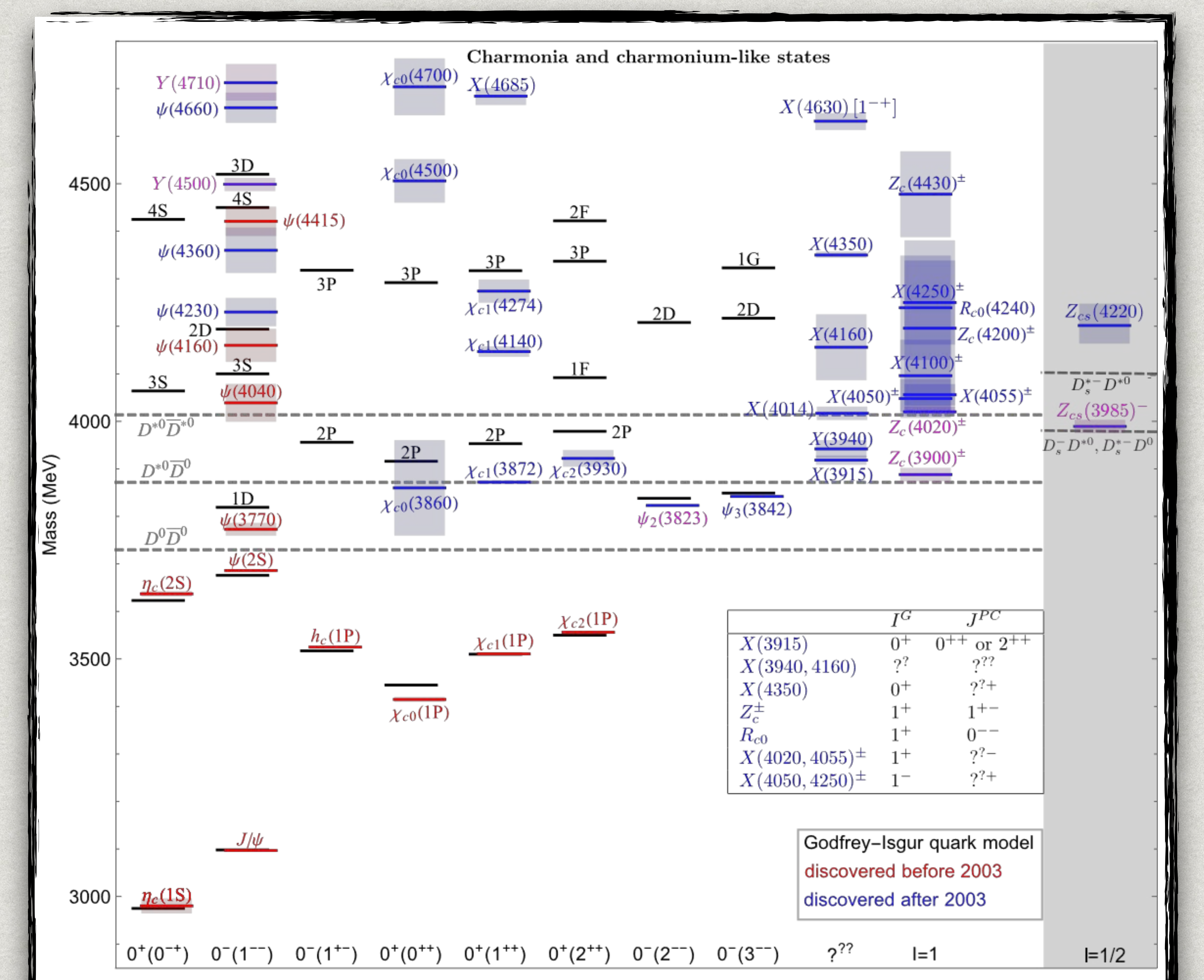
state	J^{PC}	Decay mode	Mass (MeV/c^2)	Width (MeV/c^2)	Significance
X(2370)	0^{-+}	$f_0(980)\eta'$	2395^{+11}_{-11}	188^{+18}_{-17}	14.9σ
X(1835)	0^{-+}	$f_0(980)\eta'$	1844	192	22.0σ
X(2800)	0^{-+}	$f_0(980)\eta'$	2799^{+52}_{-48}	660^{+180}_{-116}	16.4σ
η_c	0^{-+}	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	0^{-+}	$\eta'(K_S^0 K_S^0)_{S-wave}$	$---$	$---$	9.0σ
		$\eta'(K_S^0 K_S^0)_{D-wave}$	$---$	$---$	16.3σ



- Best fit can well describe the data including resonances X(1835), X(2370, X(2800), η_c
- Spin parity of X(2370) is determined to be 0^{-+} with significance greater than 10σ
- X(2800): broad structure to describe the effective contributions from possible high mass resonances (X(2600)) and the tail of the η_c line shape

$$M(X(2370)) = 2395 \pm 11^{+26}_{-94}\ \ \mathrm{MeV/c^2}$$
$$\Gamma(X(2370)) = 118^{+18}_{-17}(\mathrm{stat})^{+124}_{-33}(\mathrm{sist})\ \ \mathrm{MeV}$$

Charmonium-like states

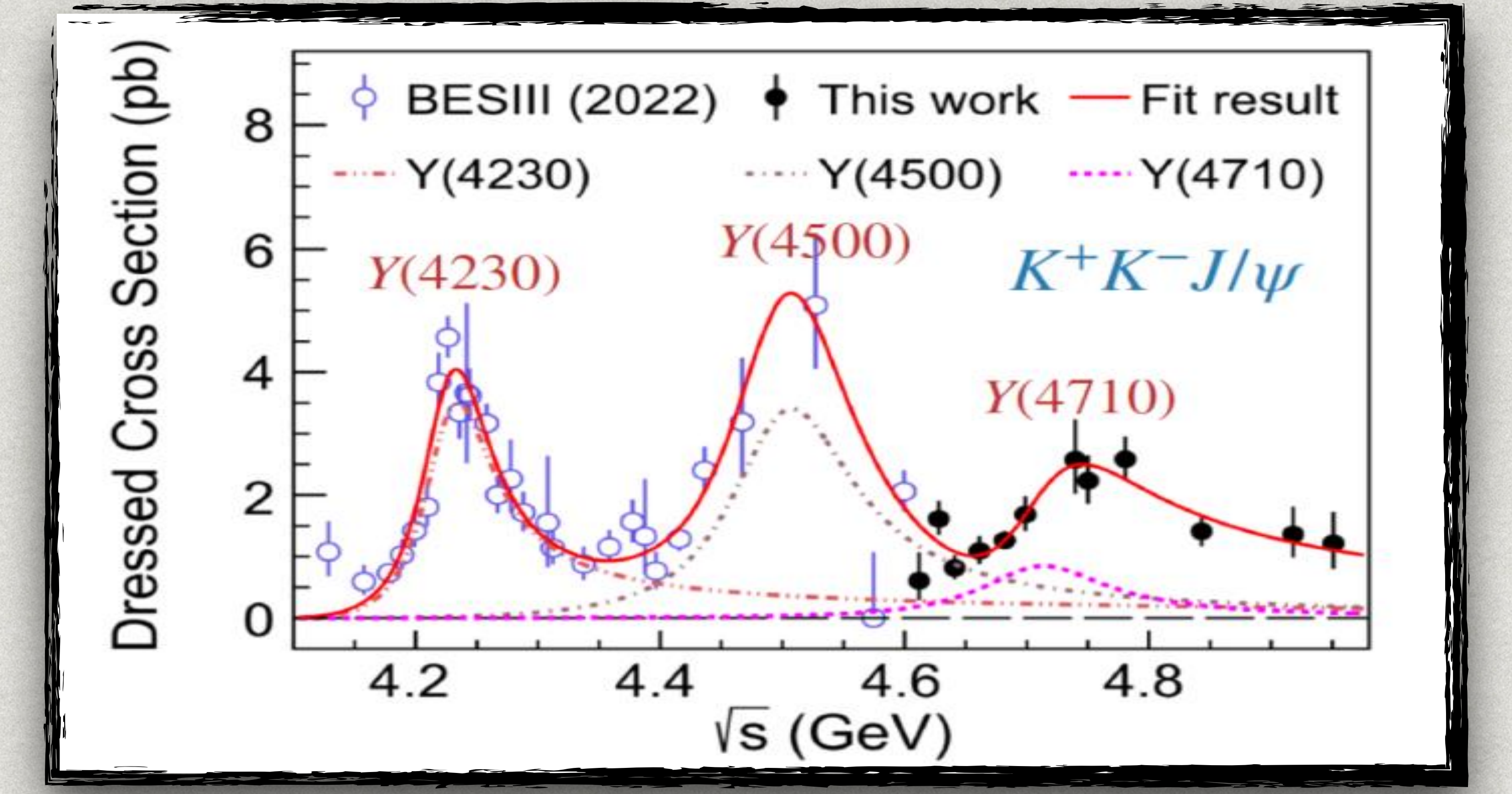


arXiv:2203.08290

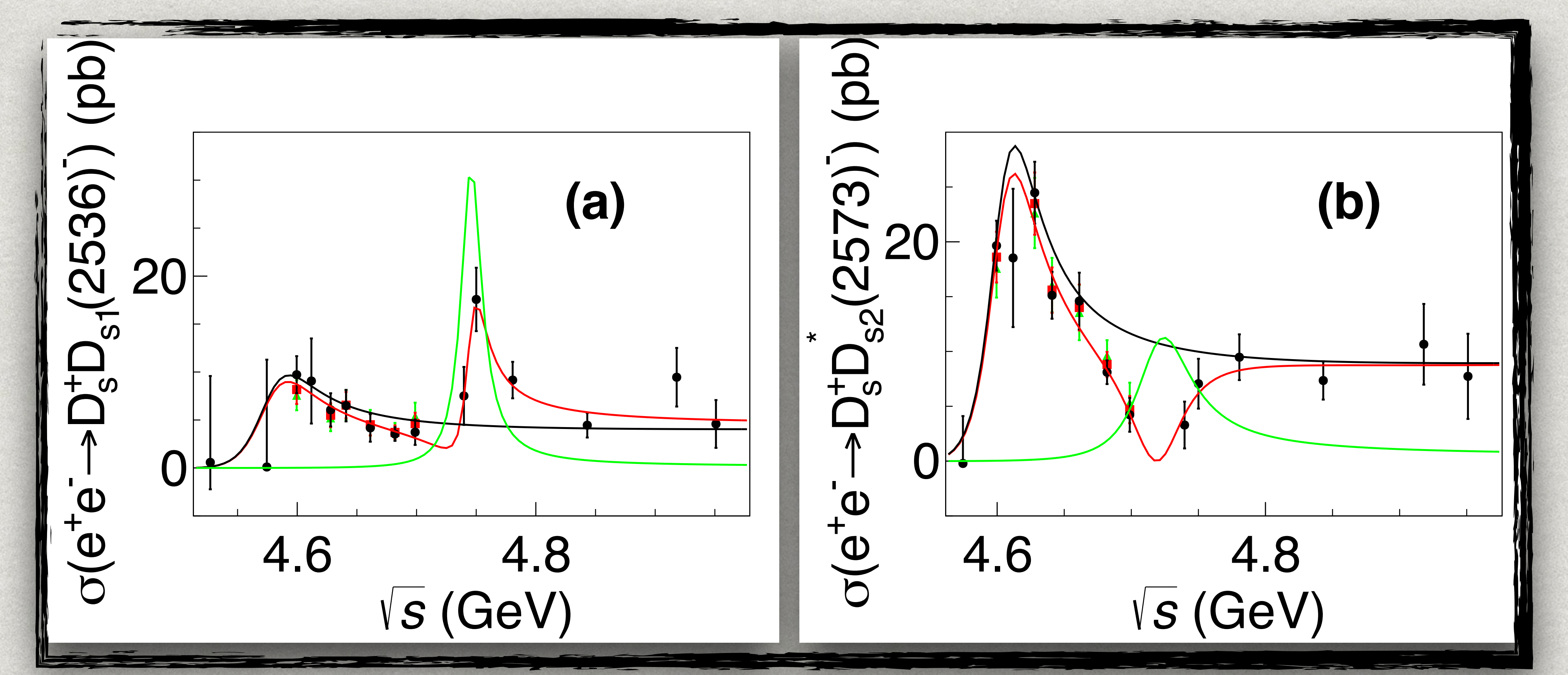
- Conventional $c\bar{c}$ mesons fit well with potential model
- Abundance of new states with various probes
  - b-hadron decays
  - hadron/heavy-ion collisions
  - $\gamma\gamma$ processes
  - e+e- collisions
- BESIII dominant production: vectors and state produced from vector decays

Observations of new vectors structures

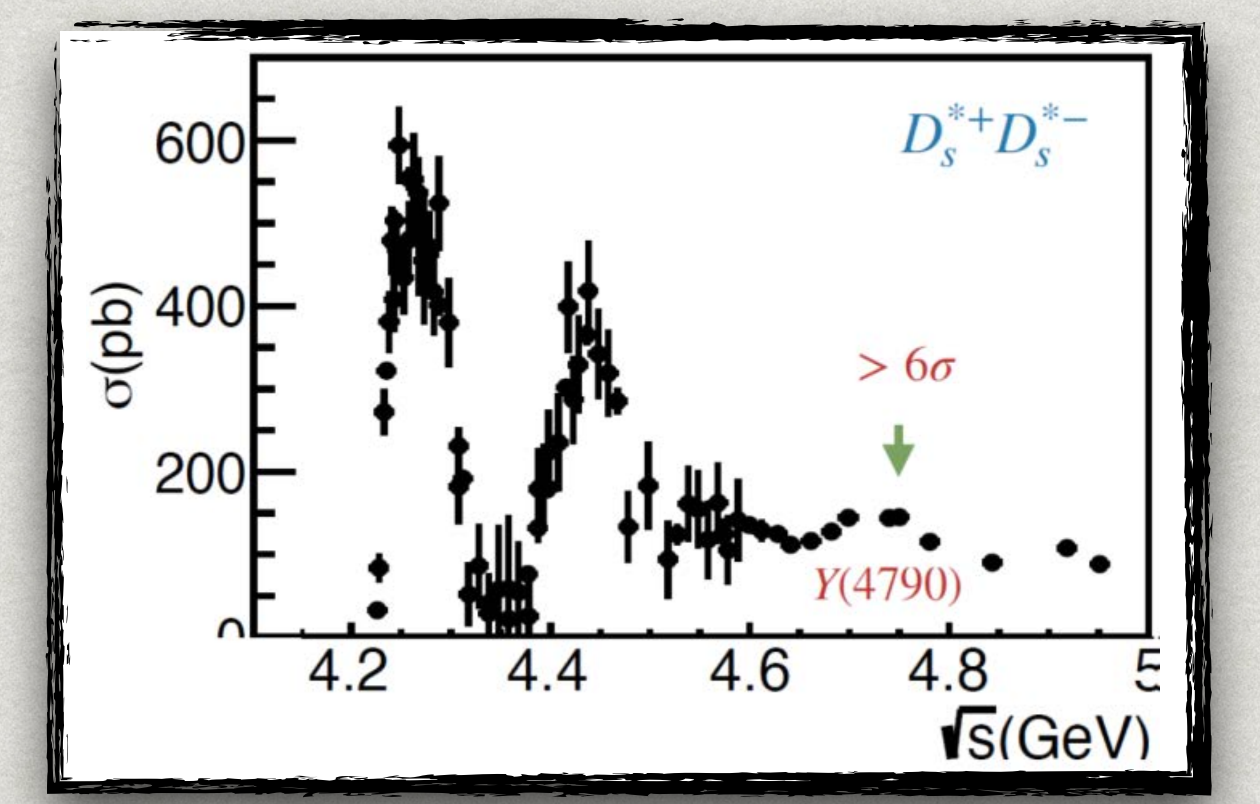
PRL131, 211902 (2023)



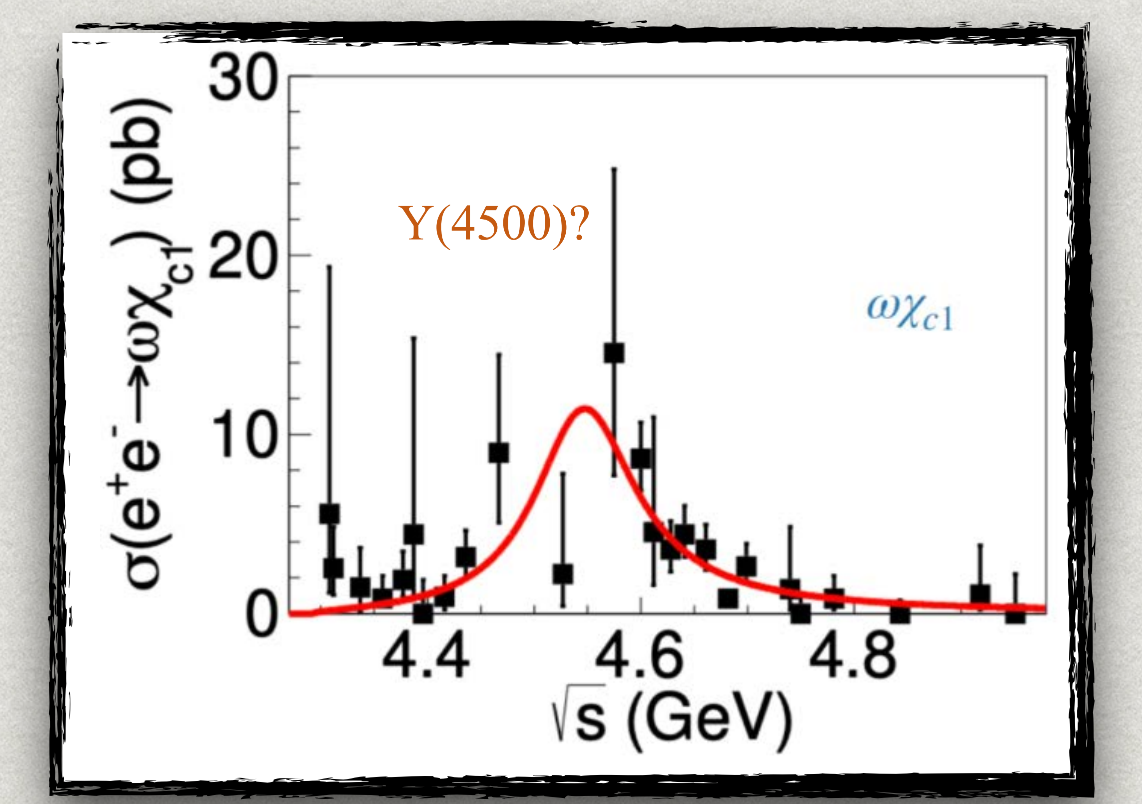
arXiv:2407.07651



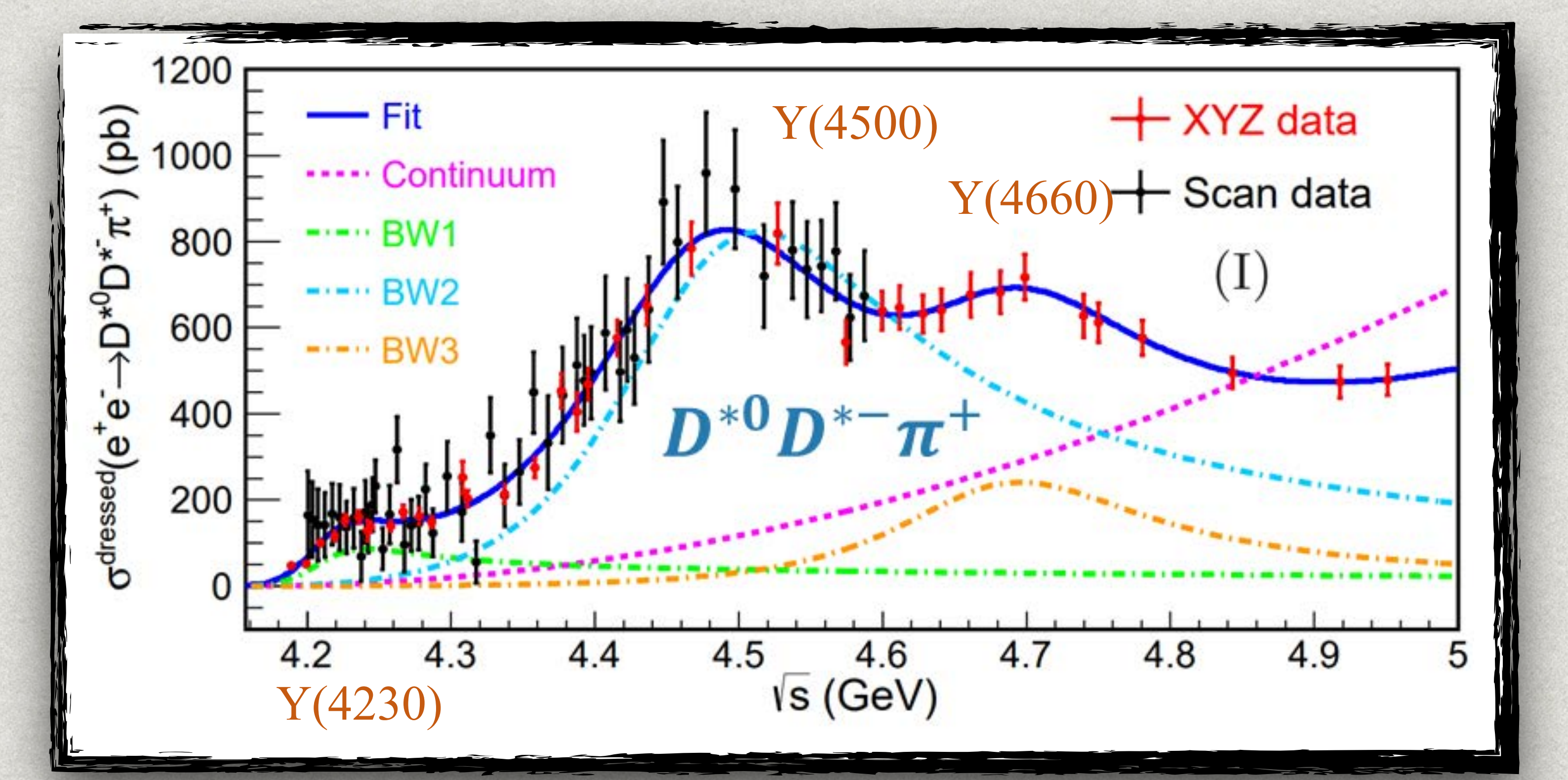
PRL131, 151903 (2023)

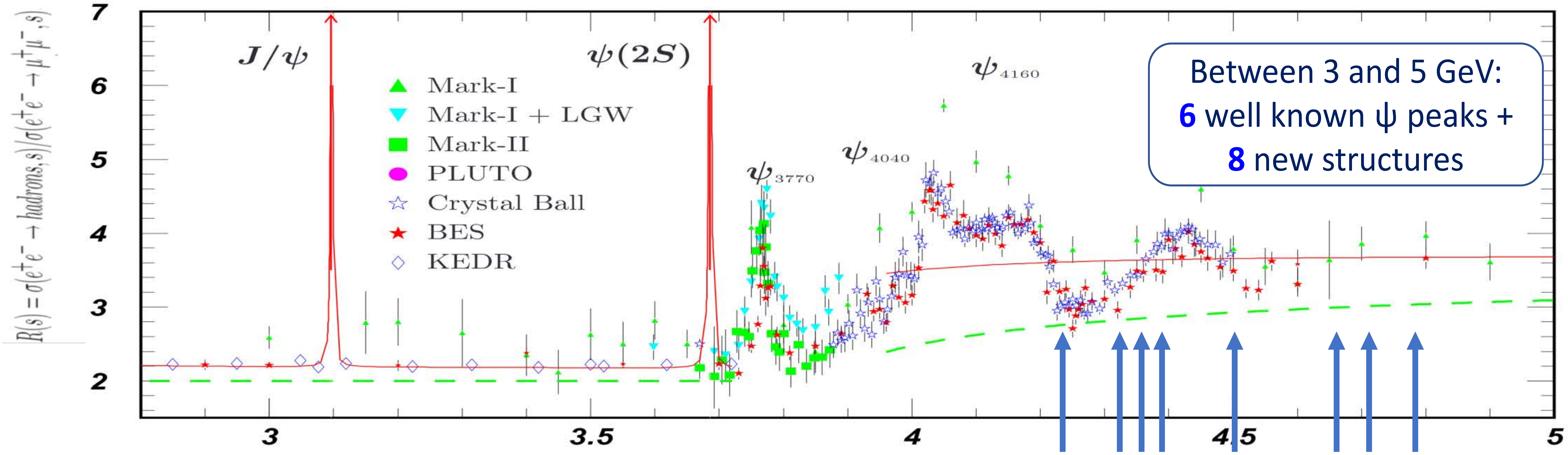


PRL130, 121901 (2023)



PRL130, 121901 (2023)





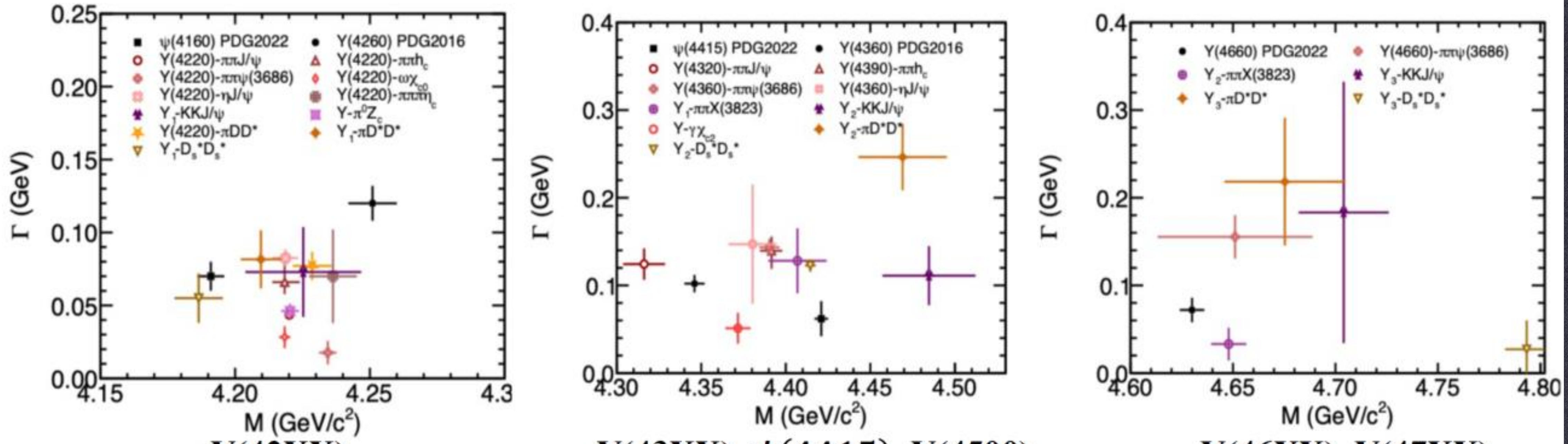
Between 3 and 5 GeV:
6 well known ψ peaks +
8 new structures

Y(4230), Y(4320), Y(4500)
Y(4360), Y(4390)

Y(4660), Y(4710),
Y(4790)

Besides $c\bar{c}$ states, we also expect $gc\bar{c}$ hybrids, and $c\bar{c}q\bar{q}$ tetraquark states. Have they already been observed?

→ **More theoretical/experimental efforts necessary**



Measurements at BESIII

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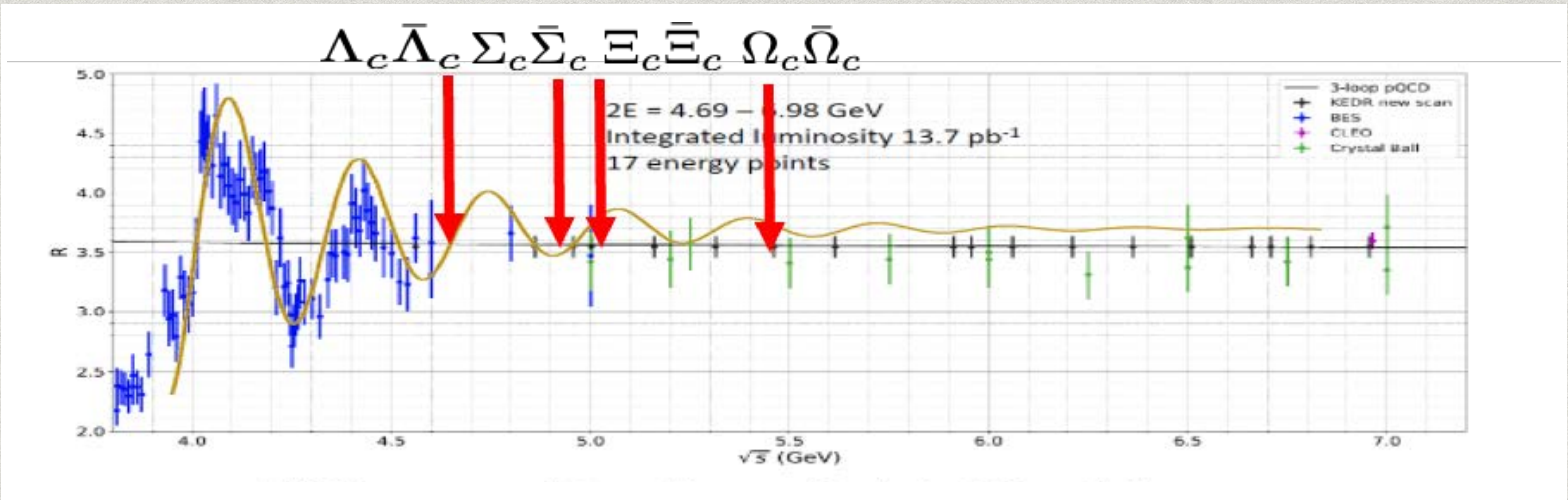
HOW MANY VECTORS IN CHARMONIUM ENERGY REGION?

BESIII UPGRADE

The BESIII upgrade program: physics

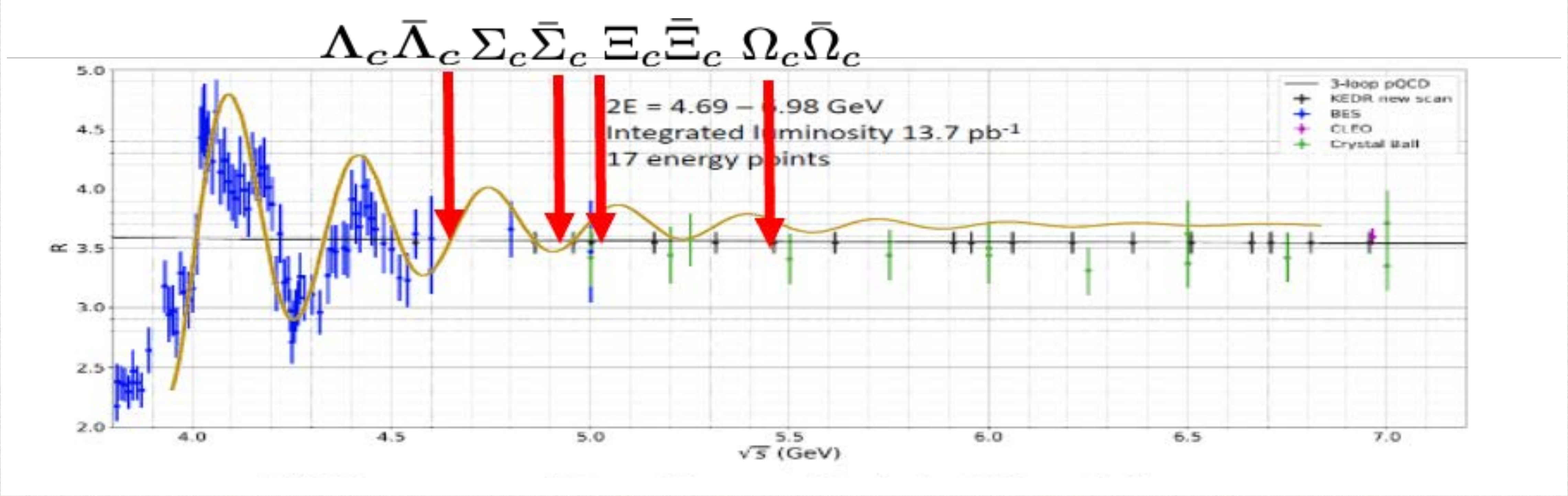


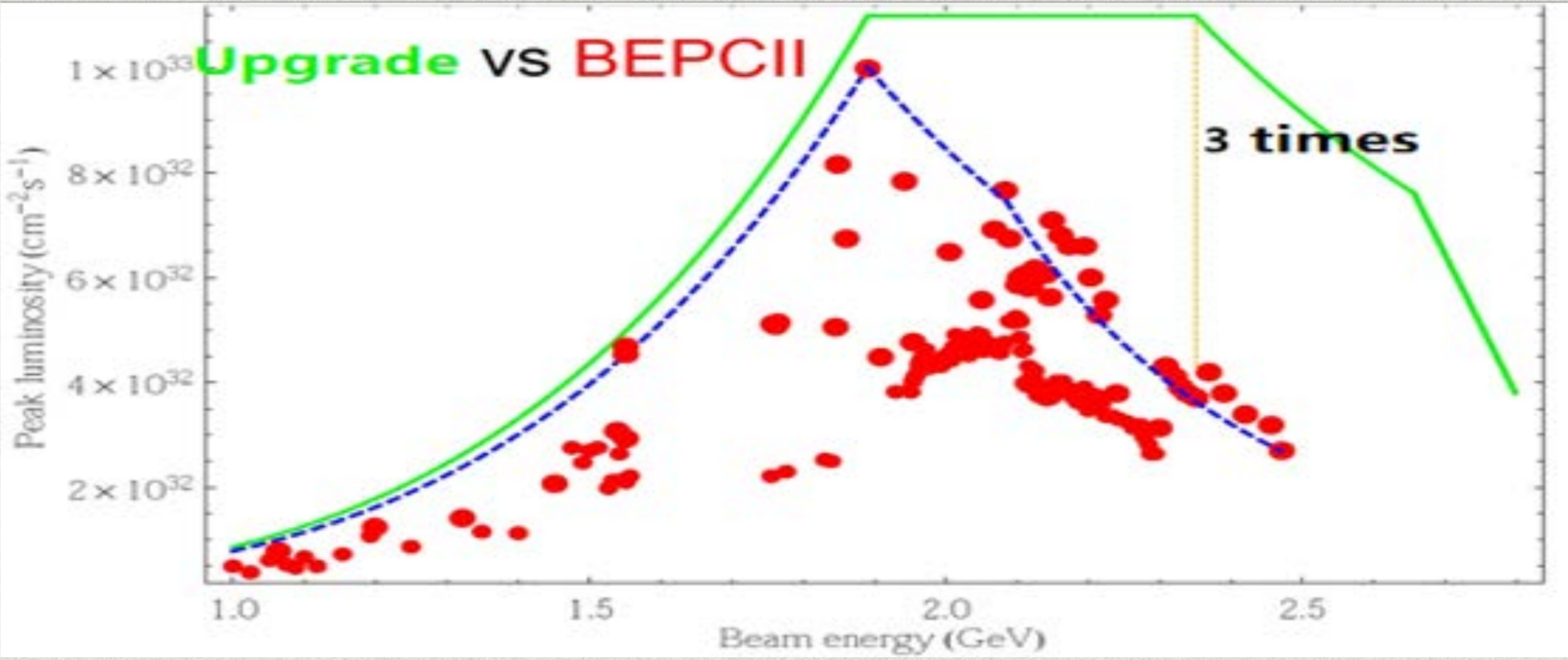
- $e^+e^- \to \Sigma_c\overline{\Lambda}_c^-\pi$
- $e^+e^- \to \Sigma_c\overline{\Sigma}_c$
- $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$ and $e^+e^- \to \Xi_c\overline{\Xi}_c$

- Upgrade of the C.M. energy to 4.95 GeV, then up to 5.6 GeV
- Measurements of the cross sections near threshold to provide insight of the vacuum productions of $c\overline{c}$ and $s\overline{s}$ pairs
- Study the EM structure of charmed baryons
- Studies of the absolute BFs of Σ_c and Ξ_c

more at arXiv:1912.05983v3

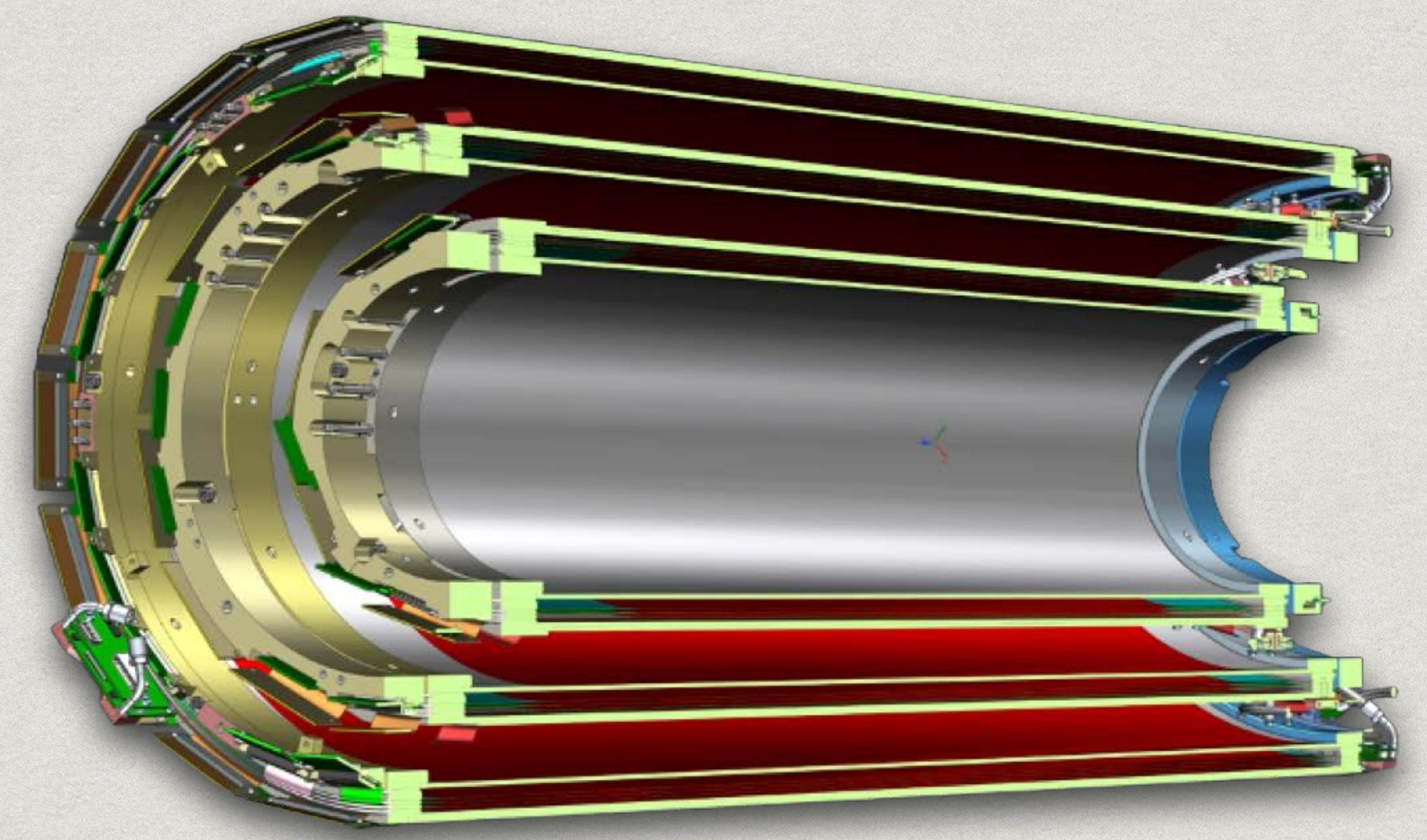
The BESIII upgrade program: machine





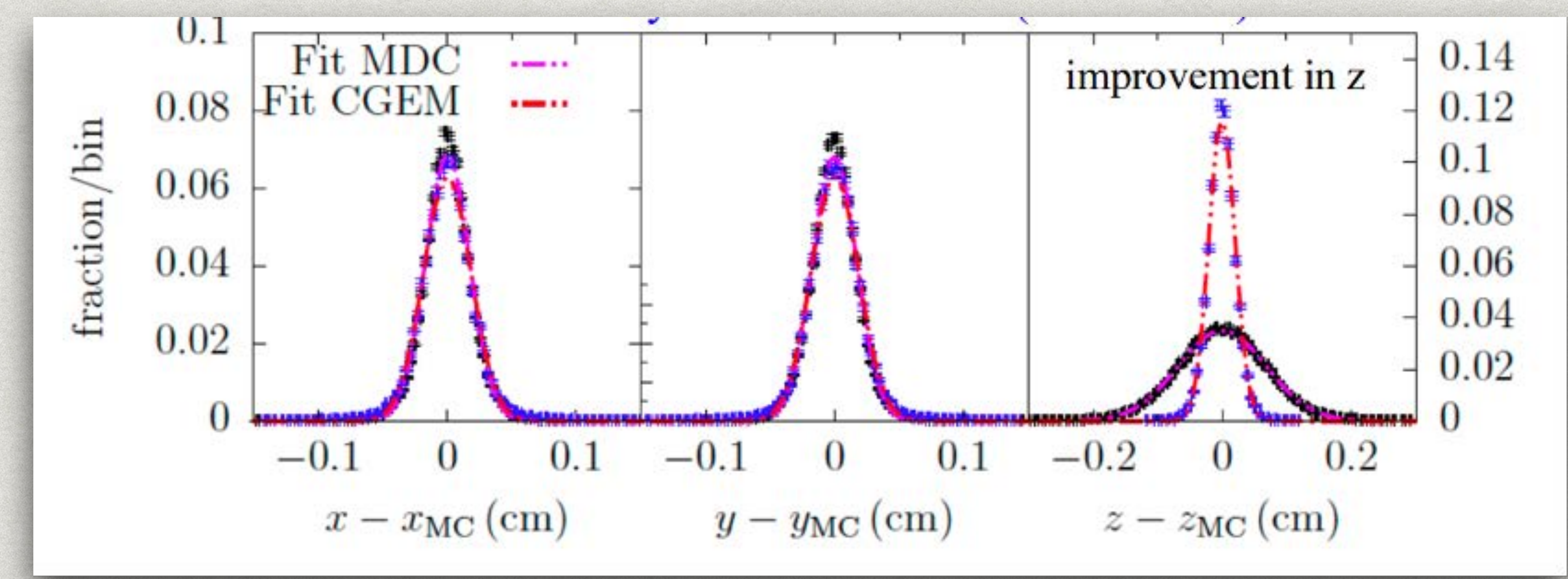
- BEPCII upgrade aims at increasing luminosity by a factor of 3 & increasing beam energy to 2.8 GeV
- Key technologies: double beam power & optics upgrade & new high gradient of magnets

The BESIII upgrade program: CGEM



- 3 layers of cylindrical triple-GEM detectors to replace the inner MDC
- Improve rate capability, aging and secondary vertex reconstruction
- While retaining the current momentum and tracking performance ($\sigma_p/p \sim 0.5\,\%$ @ 1 GeV)
- Main System Requirements
  - Angular coverage: 93%
  - Low material budget (~0.5% of X_0 per layer —> 1.5% of X_0 in total)
  - High azimuthal spatial resolution —> 130-150 μm with charge and time readout
  - Substantial improvements in rad hard and secondary vertex reconstruction (~300 μm in z)

Impact on vertex reconstruction



$\Sigma_c(2455)$ DECAY MODES

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

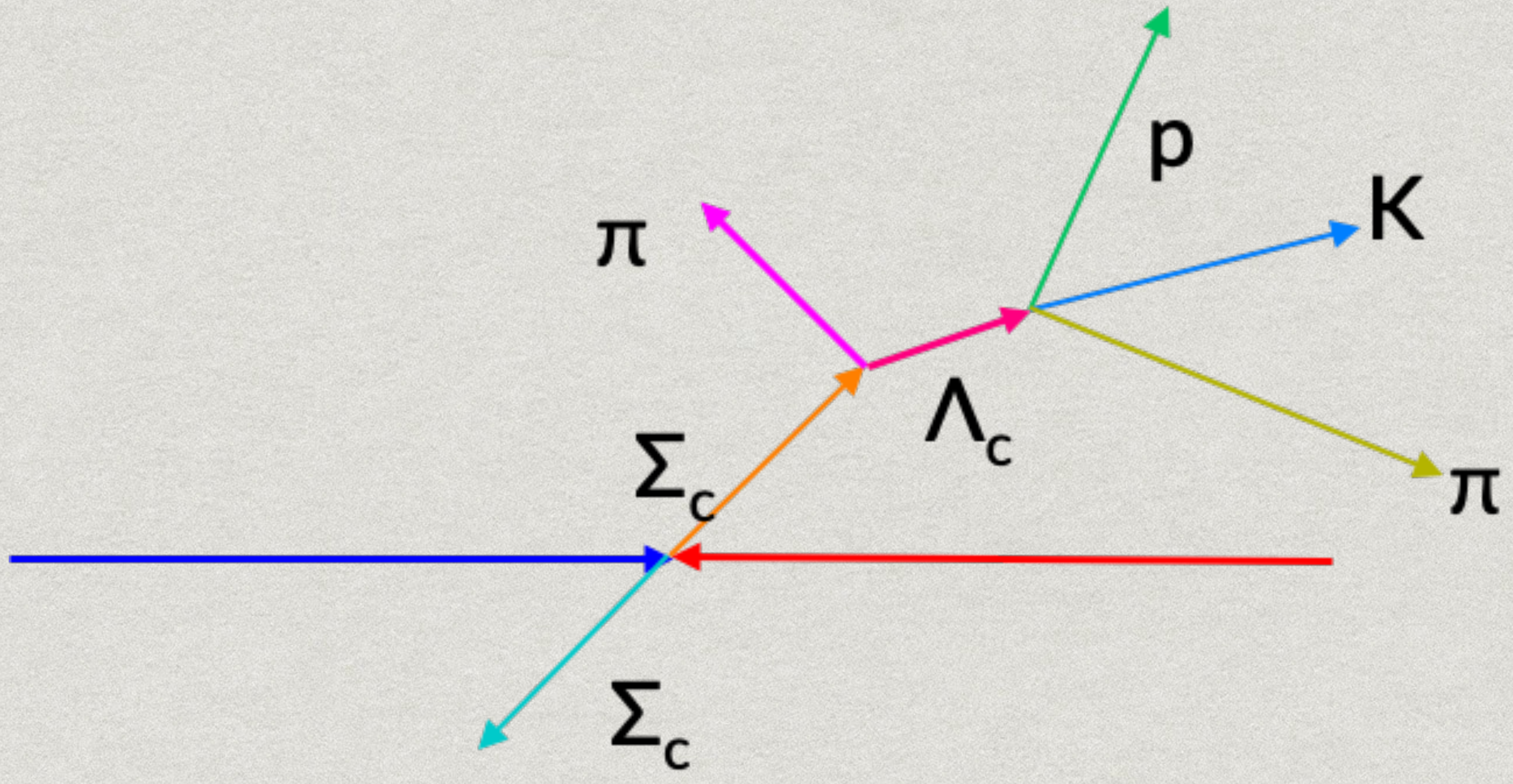
	Mode	Fraction (Γ_i/Γ)
Γ_1	$\Lambda_c^+ \pi$	≈ 100 %

Ω_c^0 DECAY MODES

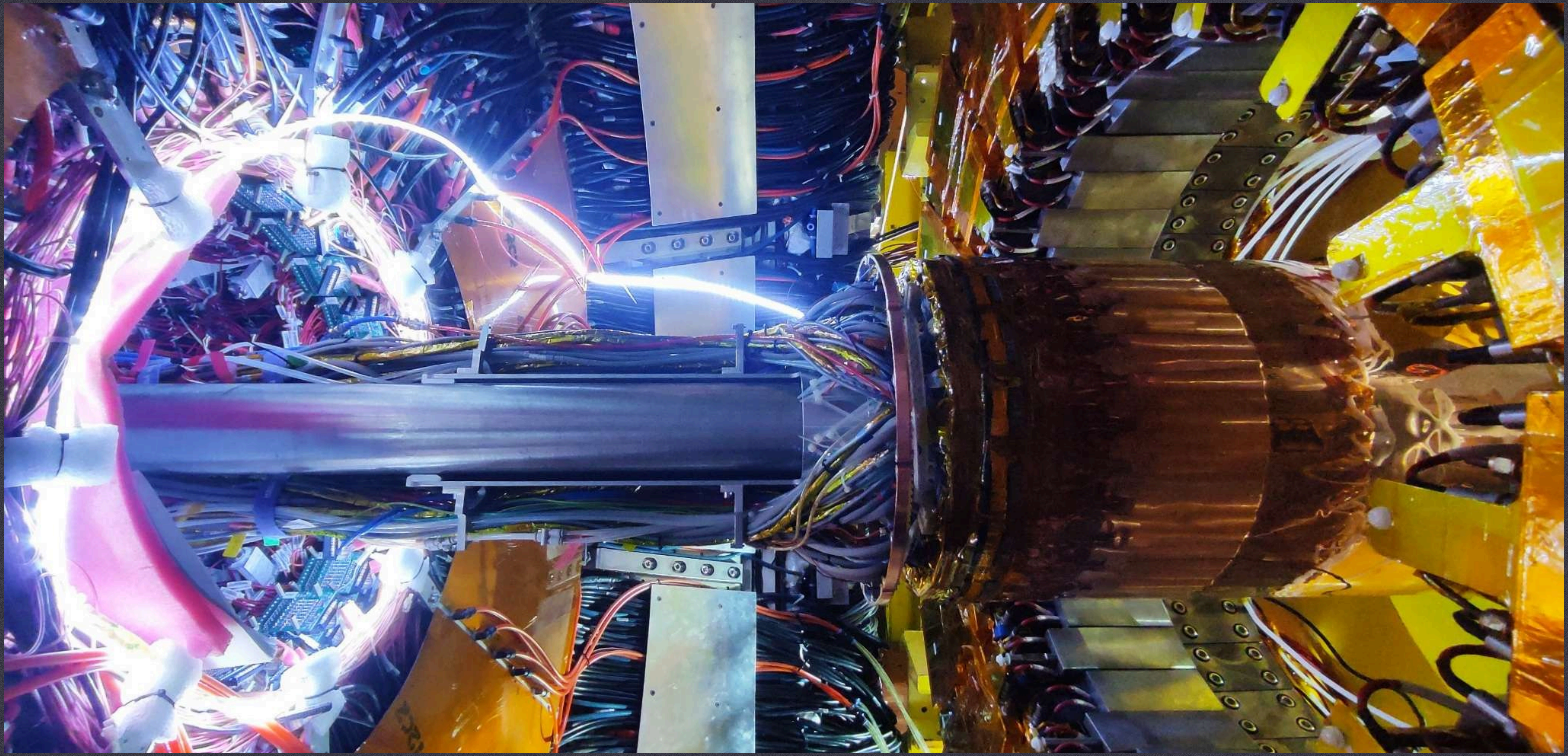
No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Omega^- \pi^+$.

	Mode	Fraction (Γ_i/Γ)	Confidence level
	Cabibbo-favored ($S = -3$) decays — relative to $\Omega^- \pi^+$		
Γ_1	$\Omega^- \pi^+$	**DEFINED AS 1**	

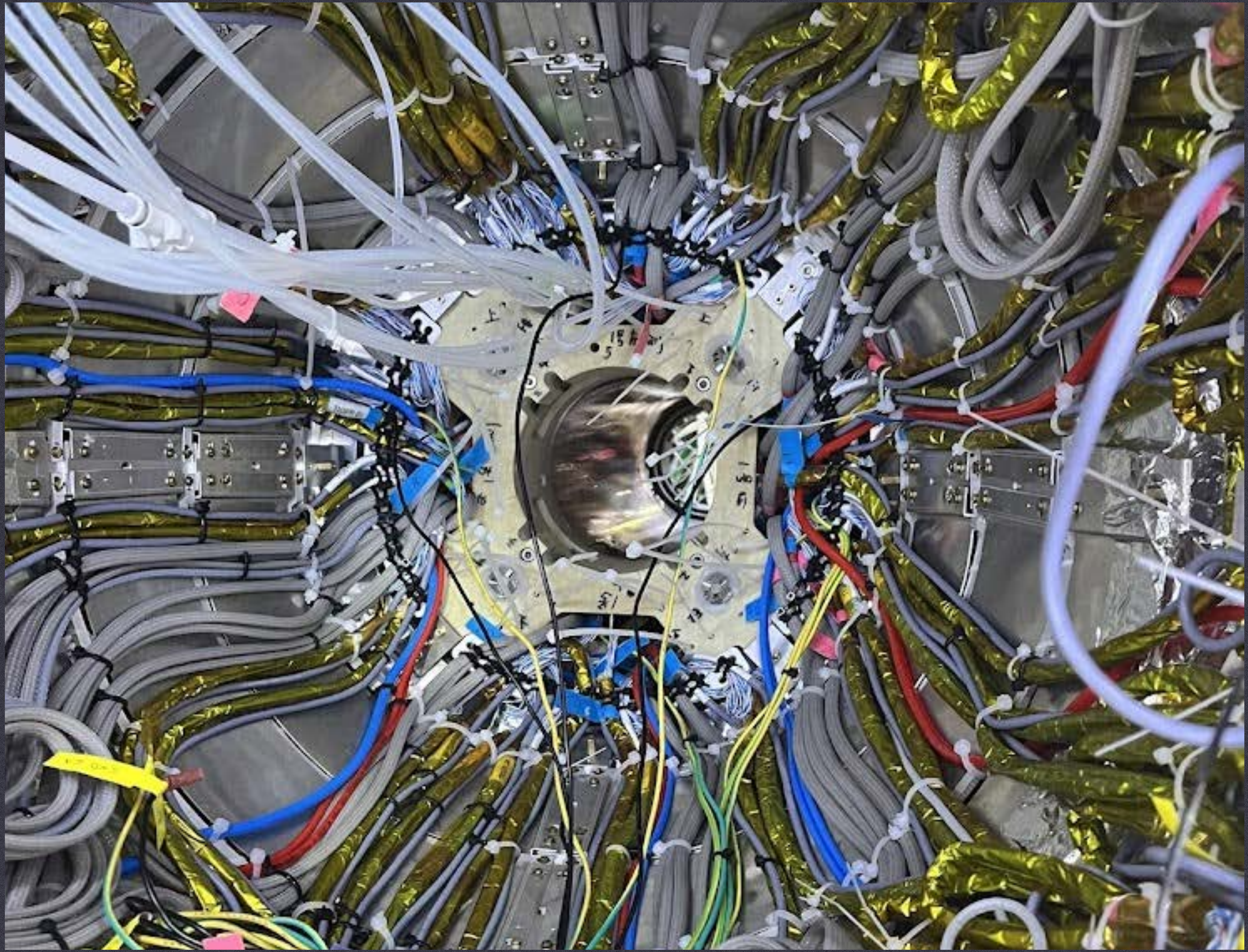
- Expected impact on vertex reconstruction
- Better separation for complex topologies and improvements on secondary vertexes, both crucial for charmed baryon decays



decay topology example



INSTALLATION OF THE CGEM DETECTOR



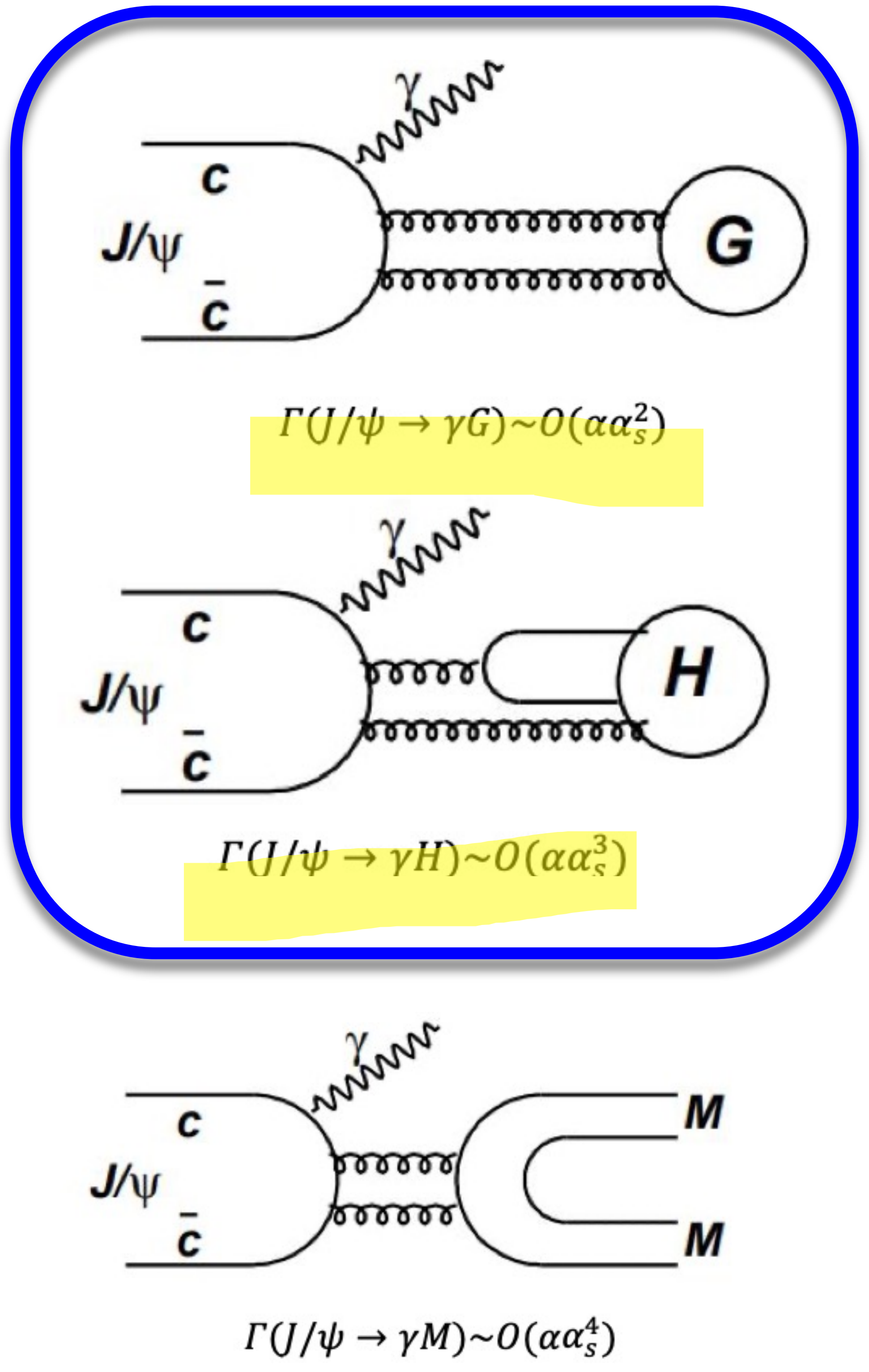
DETECTOR CABLING

Summary and outlook

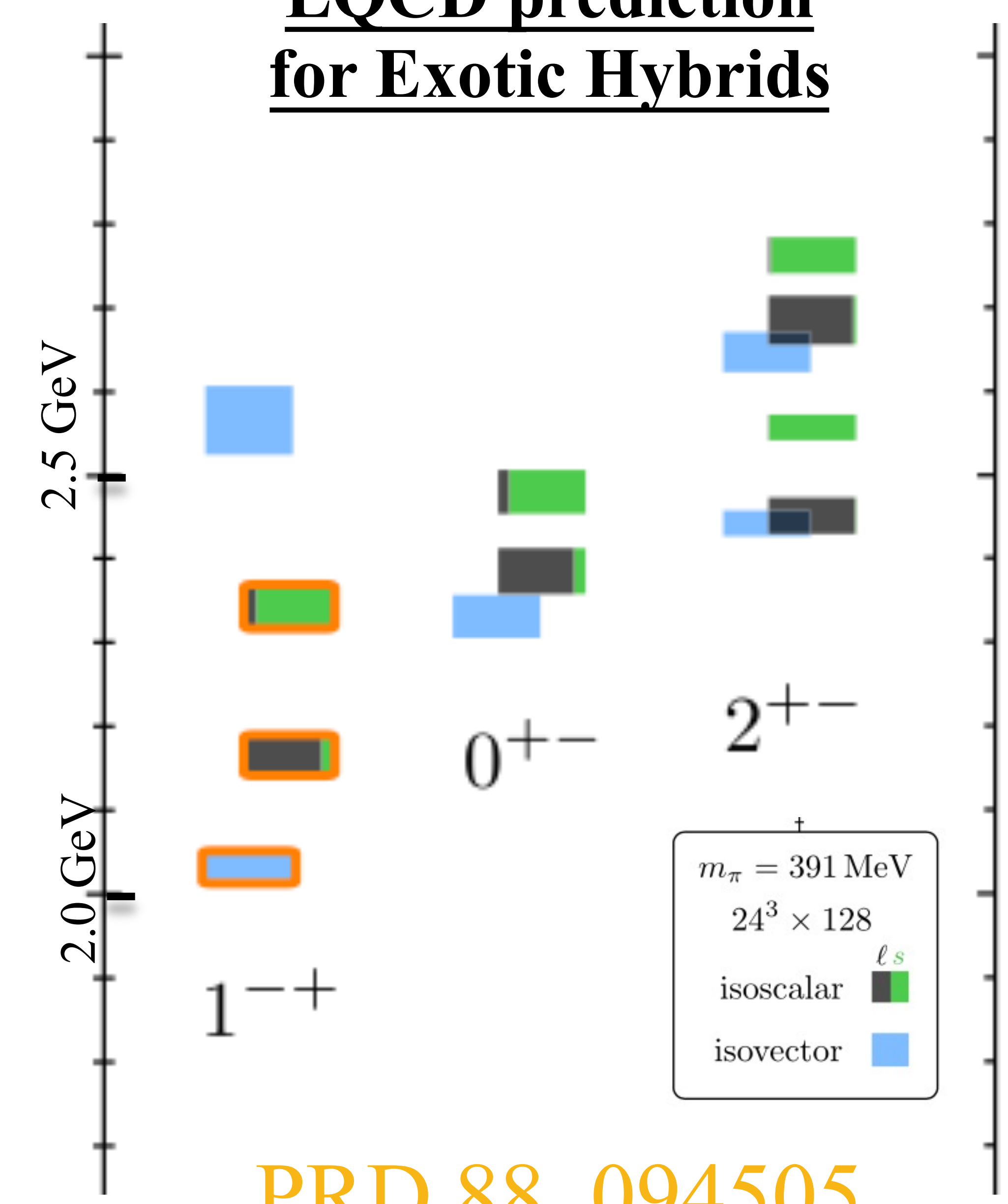
- A selection of recent BESIII results on hadron physics has been presented
  - **Baryon Form Factor** in the timelike region can be studied with great precision
  - First observation of a **rare beta decay of the charmed baryon** with GNN
  - **(Anti)Hyperon-nucleon scattering** campaign has started
  - Primary role in **hadron spectroscopy** continues
- BESIII will continue taking data until the end of the decade
  - An important **upgrade program** is ongoing to provide more and better data

THANKS FOR YOUR ATTENTION

- Charmonium radiative decays is the ideal laboratory for light glueballs and hybrids hadron studies (clean, high statistics and gluon-rich process)

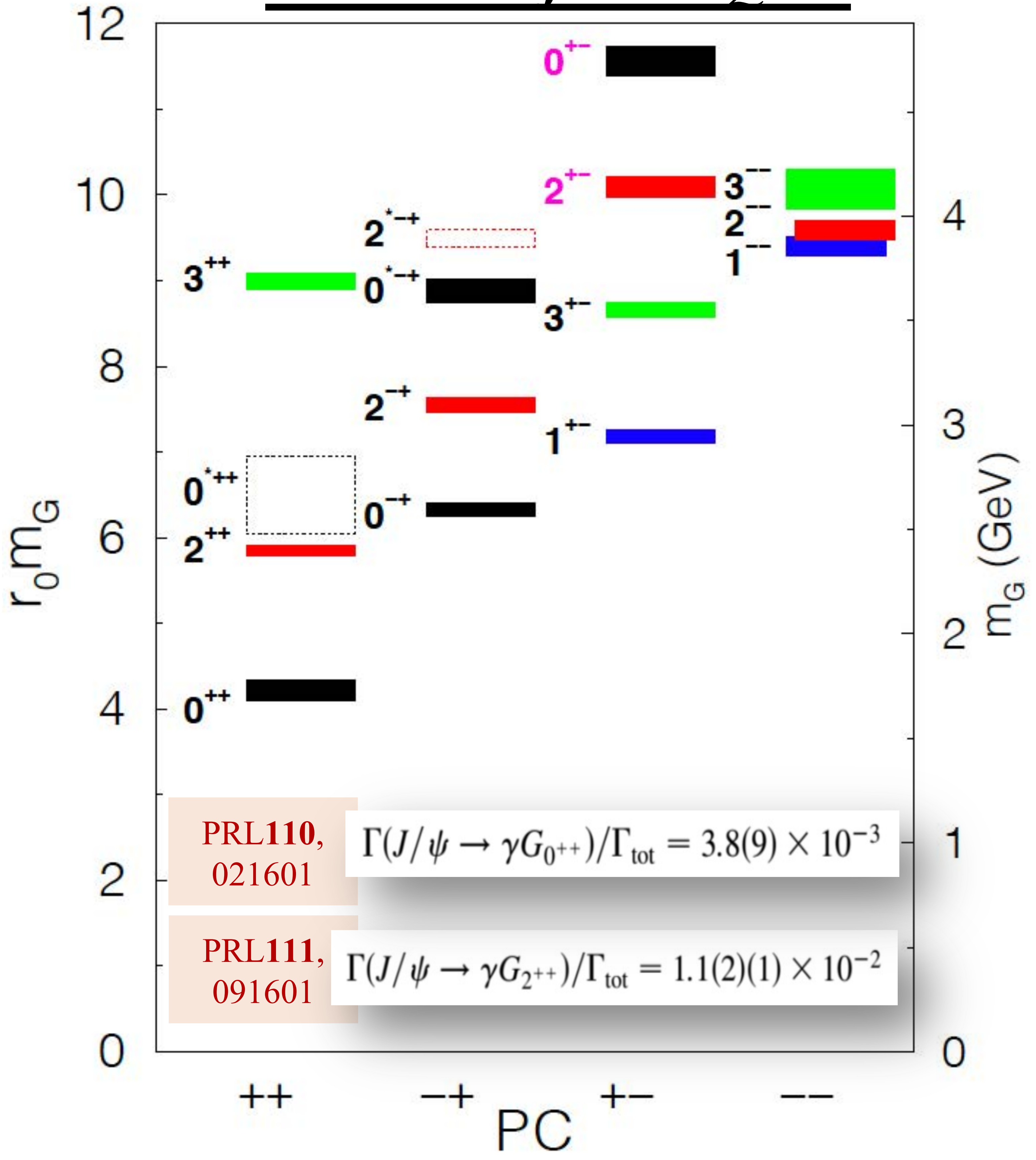


LQCD prediction for Exotic Hybrids



PRD 88, 094505

Prediction from LQCD

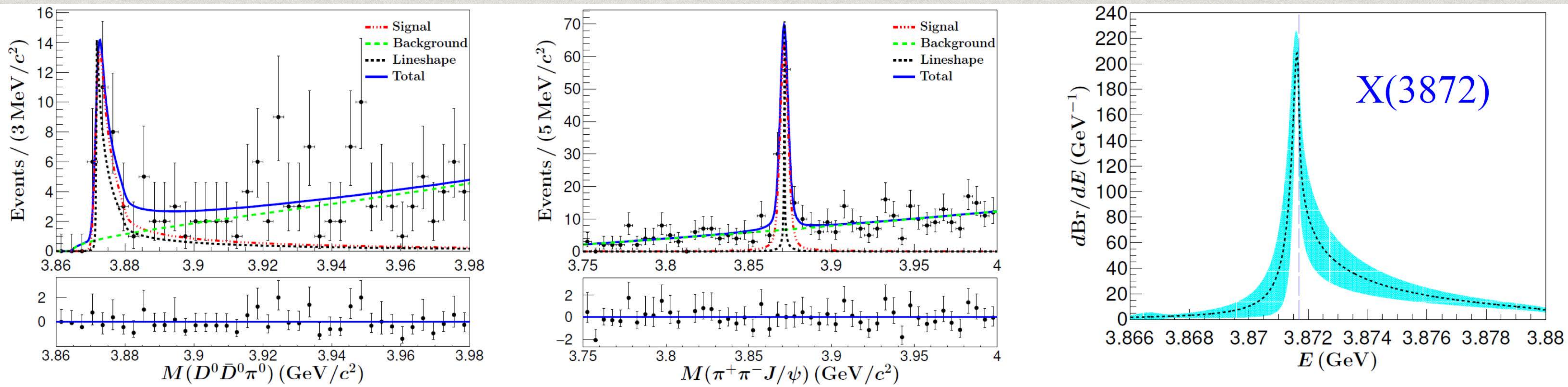


Glueballs and hybrids are expected to have a larger yield compared to mesons

https://doi.org/10.1142/S0218301309012124

GLUON RICH STATES

New insight on X(3872): line shape



Pole positions

Two sheets with respect to $D^{*0}\bar{D}^0$ branch cut

- Sheet I: $E - E_X - g\sqrt{-2\mu(E - E_R + i\Gamma/2)}$
- Sheet II: $E - E_X + g\sqrt{-2\mu(E - E_R + i\Gamma/2)}$

$E_{\mathrm{I}} = (7.04 \pm 0.15^{+0.07}_{-0.08}) + (-0.19 \pm 0.08^{+0.14}_{-0.19})i$ MeV

$E_{\mathrm{II}} = \left(0.26 \pm 5.74^{+5.14}_{-38.32}\right) + (-1.71 \pm 0.90^{+0.60}_{-1.96})i$ MeV

	LHCb	Belle	BESIII
g	$0.108 \pm 0.003^{+0.005}_{-0.006}$	$0.29^{+2.69}_{-0.15}$	$0.16 \pm 0.10^{+1.12}_{-0.11}$
$Re[E_I]$ [MeV]	7.10	7.12	$7.04 \pm 0.15^{+0.07}_{-0.08}$
$Im[E_I]$ [MeV]	-0.13	-0.12	$-0.19 \pm 0.08^{+0.14}_{-0.19}$
$Re[k^+]$ [MeV]	-13.9	-15.3	$-12.6 \pm 5.5^{+6.6}_{-6.2}$
$Im[k^+]$ [MeV]	8.8	7.7	$12.3 \pm 6.8^{+6.0}_{-6.4}$
a (fm)	-27.1	-31.2	$-16.5^{+7.0}_{-27.6}{}^{+5.6}_{-27.7}$
r_e (fm)	-5.3	$-3.0^{+1.3}_{-1.5}$	$-4.1^{+0.9}_{-3.3}{}^{+2.8}_{-4.4}$
$\bar{Z}_A$	0.15 (0.33)	$0.08^{+0.04}_{-0.03}$	$0.18^{+0.06}_{-0.17}{}^{+0.19}_{-0.16}$

Weinberg's compositeness: Z=1: pure elementary state; Z=0: pure bound (composite) state

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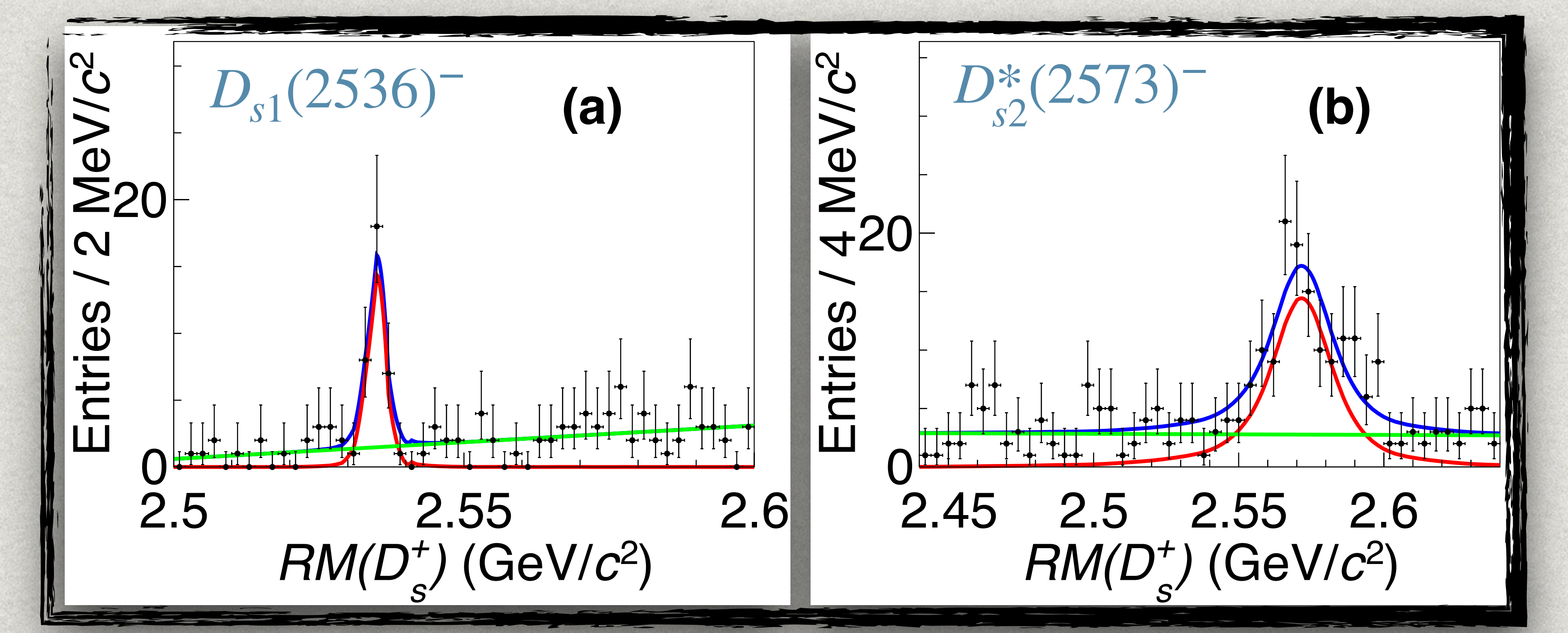
arXiv:2407.07651

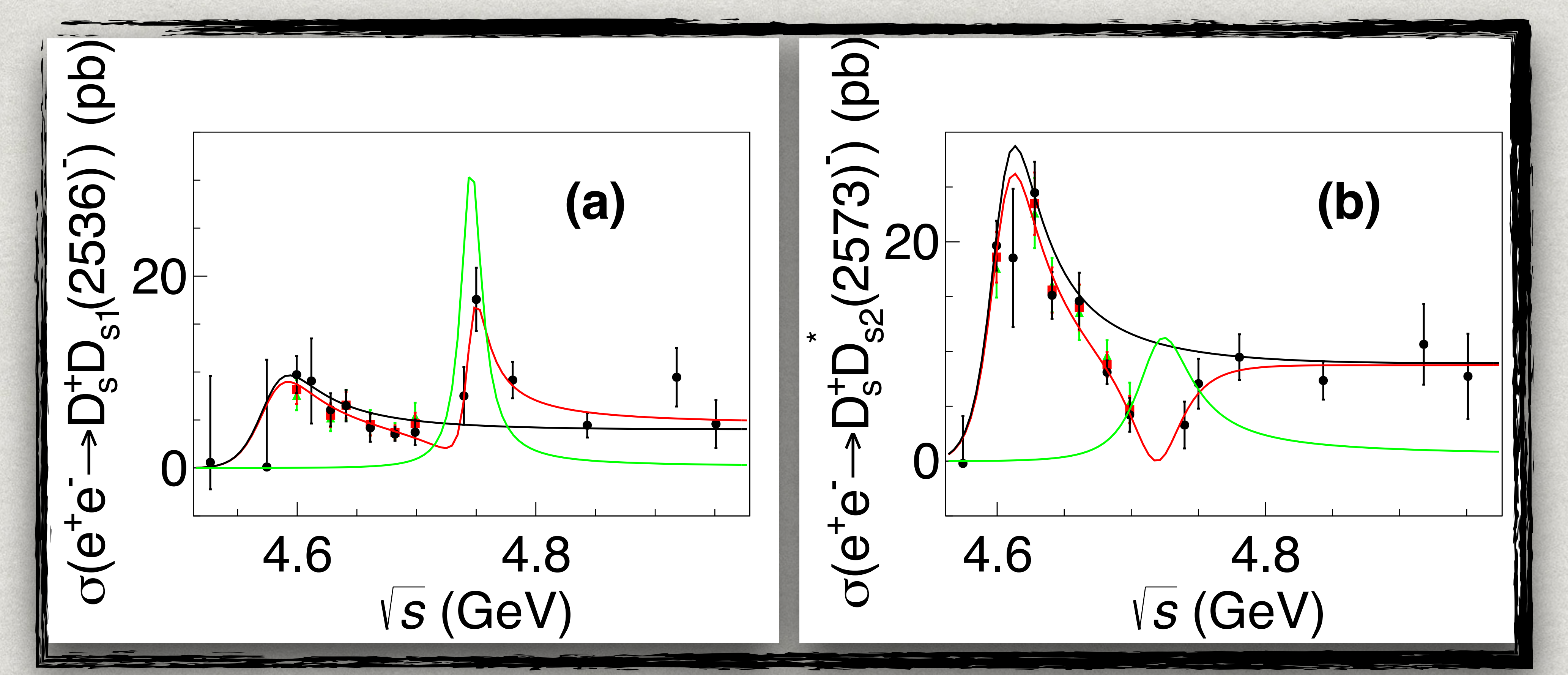
Observations of new vector structures in $D_s^+ D_{s1}(2536)^-$ and $D_s^+ D_{s2}^*(2573)^-$

- To study of the decay and production properties of $D_{s1}(2536)$ and $D^*_{s2}(2573)$



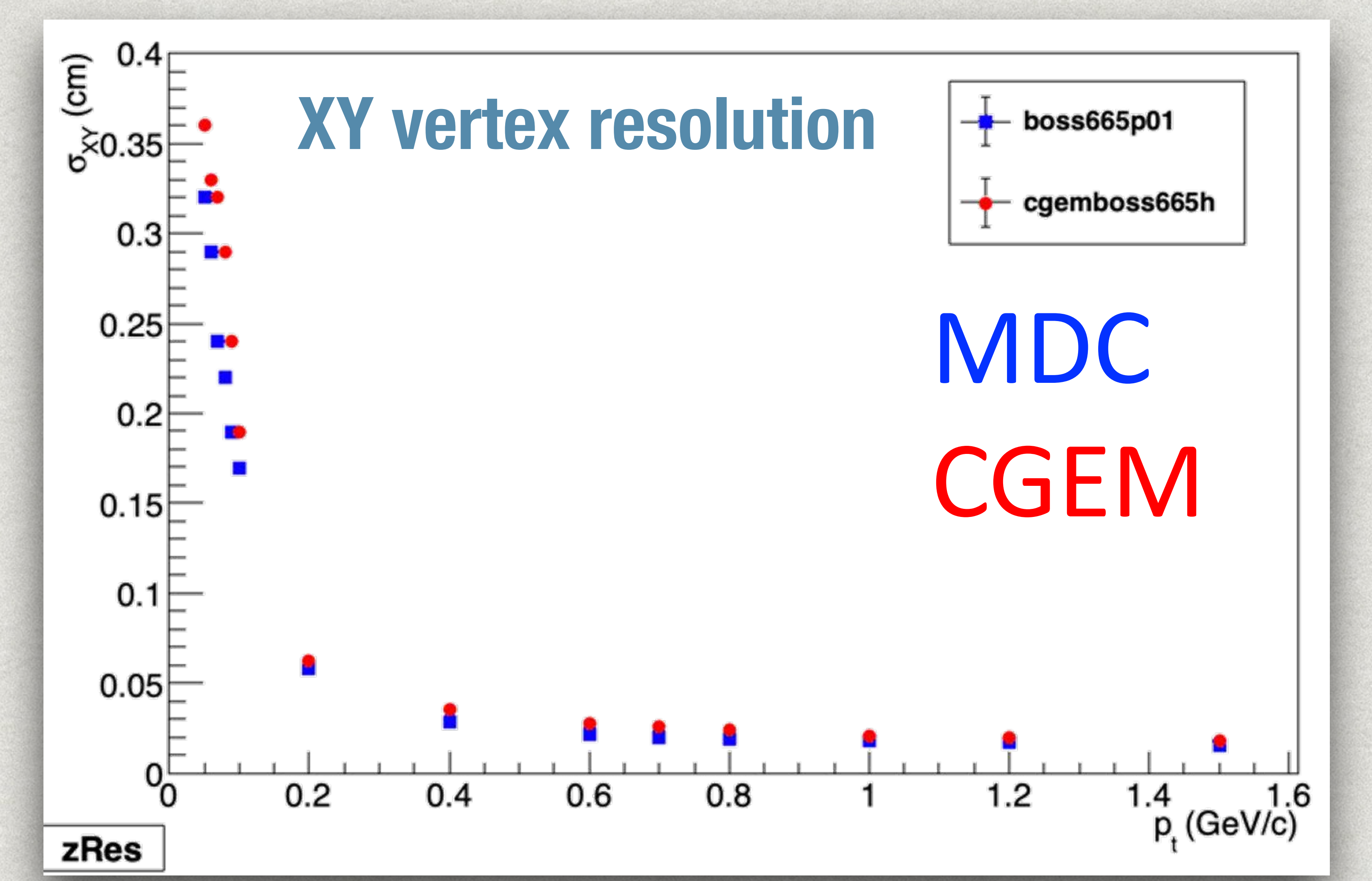
$$\mathcal{B}(D_{s1}(2536)^- \to (\bar{D}^* \bar{K})^-) = (71.8 \pm 9.6 \pm 7.0)\%$$

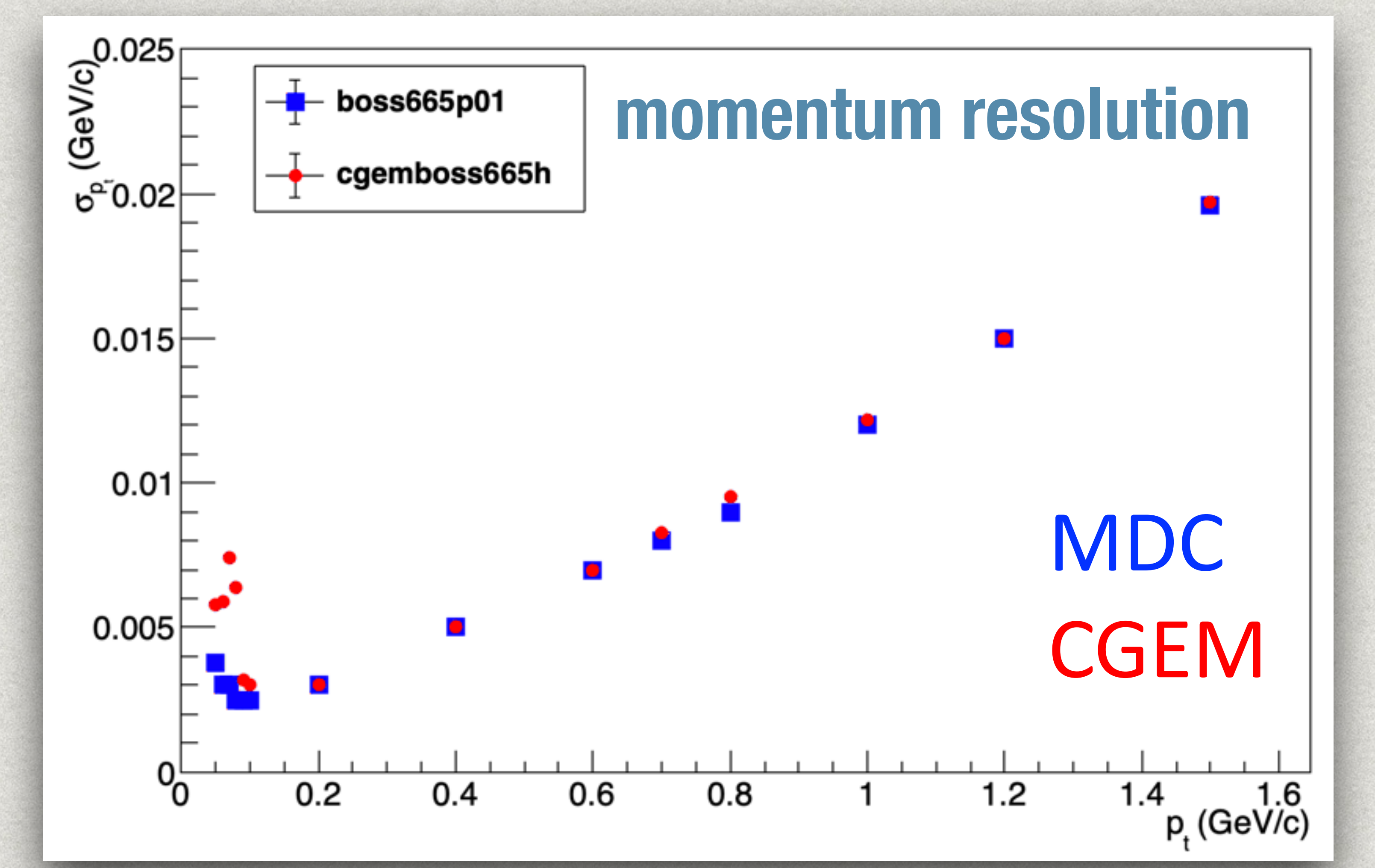
$$\mathcal{B}(D^*_{s2}(2573)^- \to (\bar{D}\bar{K})^-) = (74.8 \pm 6.2 \pm 9.2)\%$$

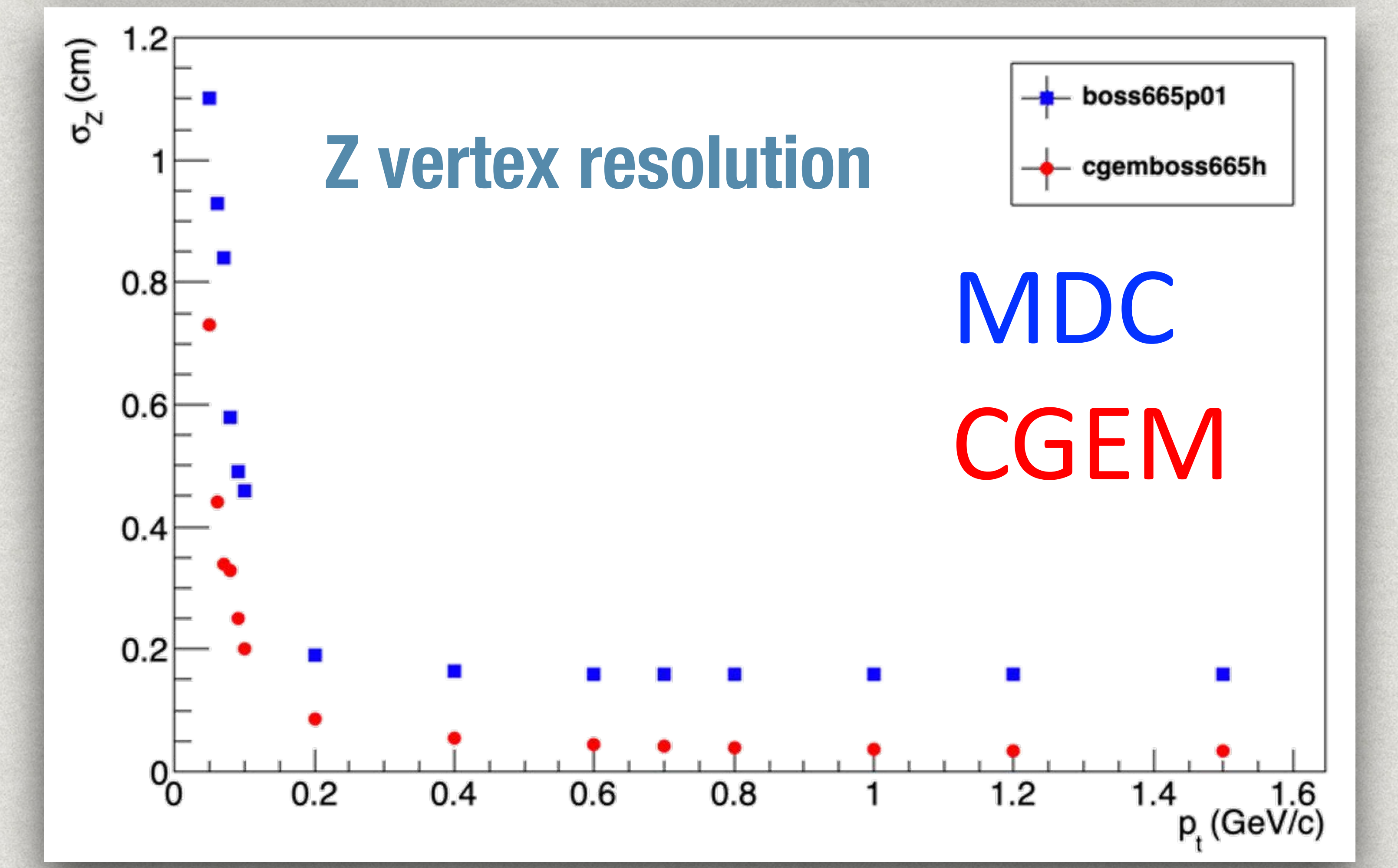


- Tension between BESIII and (ISR) Belle results

Expected performance







- No difference between different multiplicities
- CGEM XY resolutions slightly worse at low pt
- CGEM Z resolution much better
- Momentum resolution worse only at very low pt