Recent XYZ results at BESIII

第十一届XYZ研讨会

2026年6月22日至27日，贵州民族大学

朱凯（高能物理研究所）

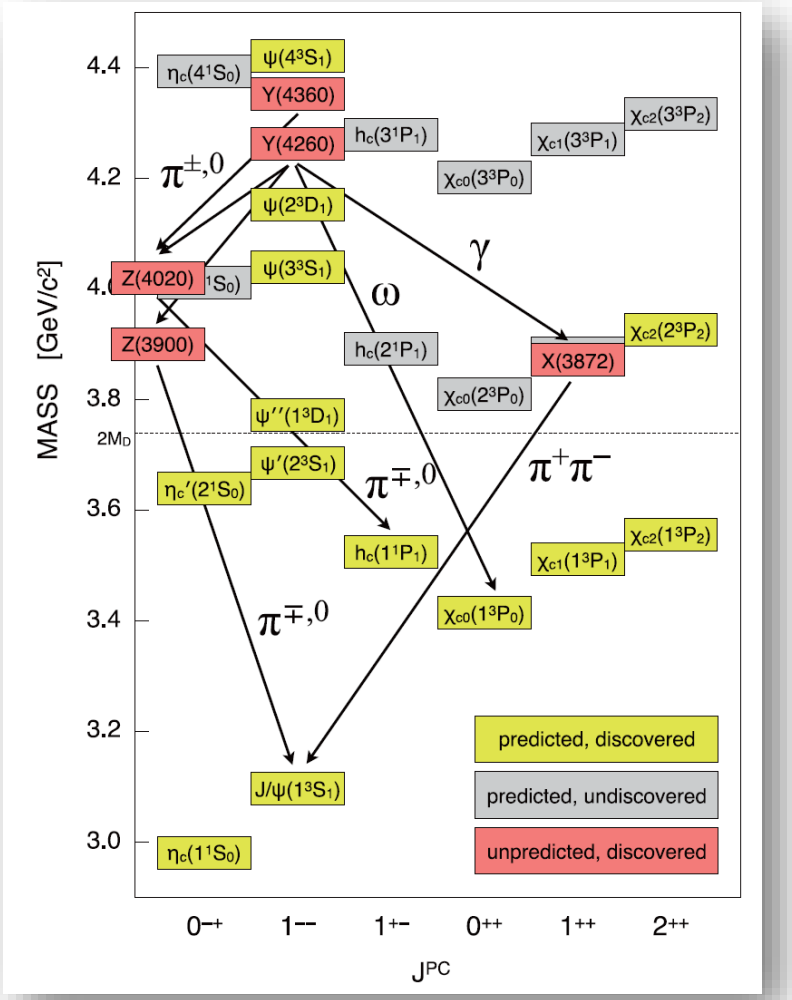
Outline

- Studying XYZ at BESIII: a quick review
- Highlights in the last year
  - PWA of $e^+e^- \to \pi^+\pi^- J/\psi$
  - Multiple channel analysis for $Z_c(4020)$
  - Cross section line shape of $e^+e^- \to \pi\pi h_c$
- More searches and measurements
- Thoughts, analyses, and open questions based on BESIII results
- Prospects and outlook

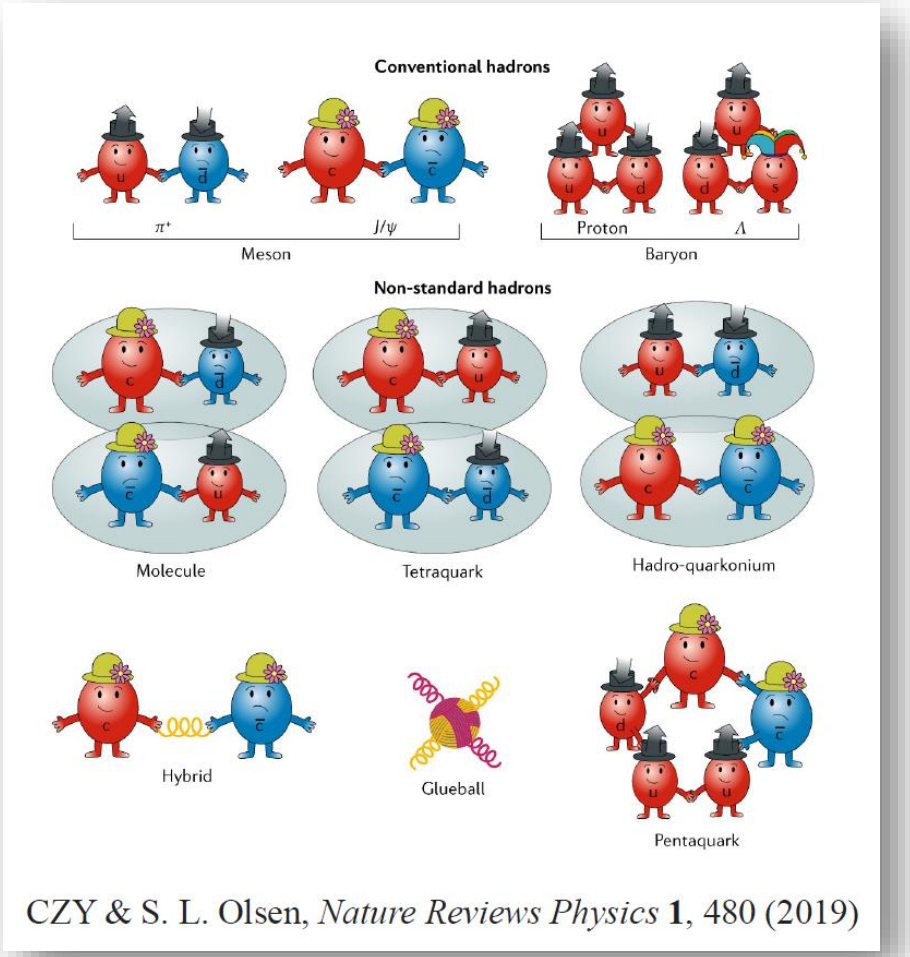
A slide can be skipped in this meeting

What are charmonium-like (XYZ) states

charmonia: $c\bar{c}$



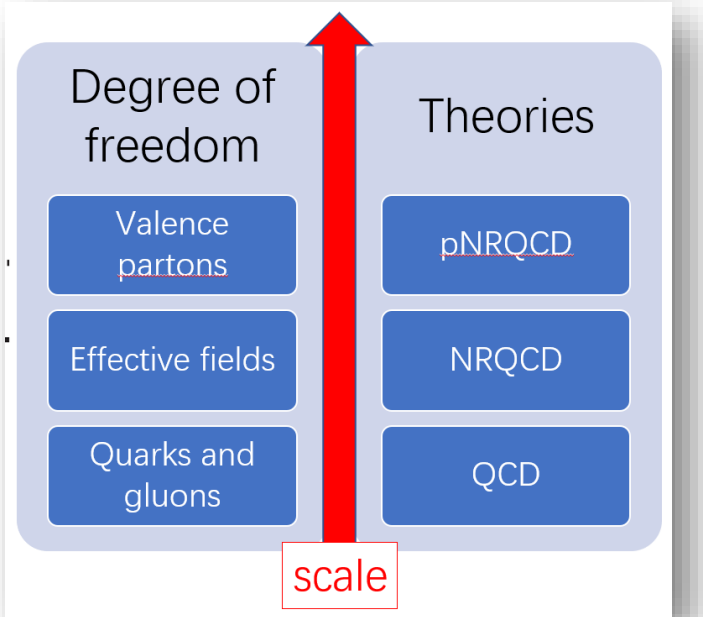
Exotic states with hidden charm



Y: vector states

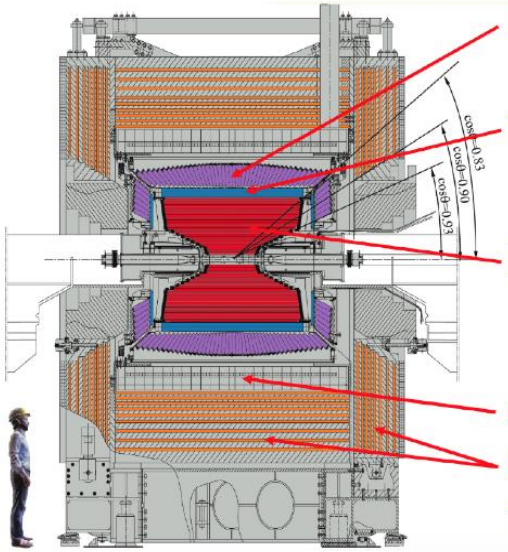
Z: $isospin \neq 0$

X: remained



Beyond convention ccbar states

BESIII at BEPCII



EMC: CsI crystals
ΔE/E = 2.5% @ 1 GeV - Barrel
ΔE/E = 5.0% @ 1 GeV - Endcaps

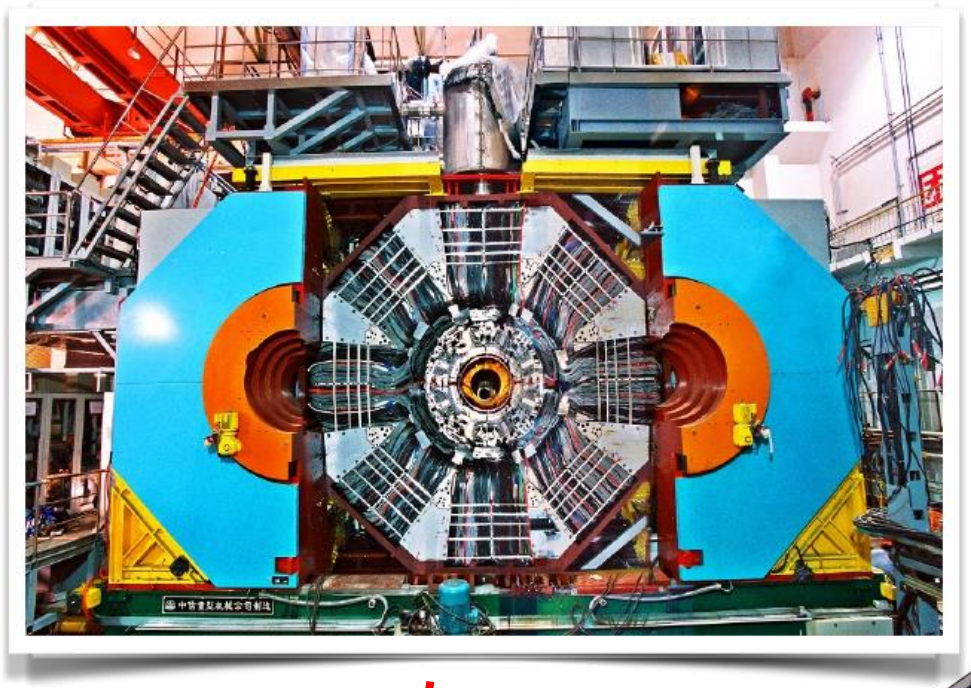
TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

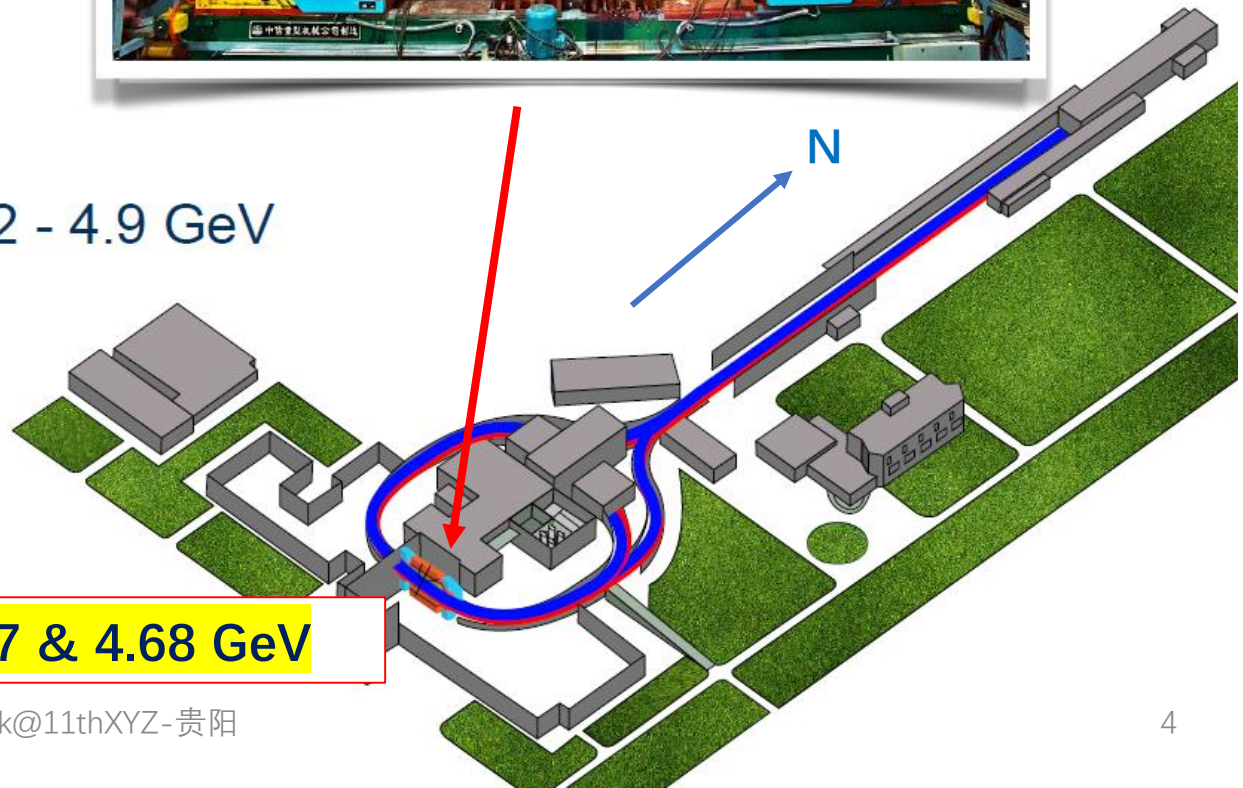
Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers



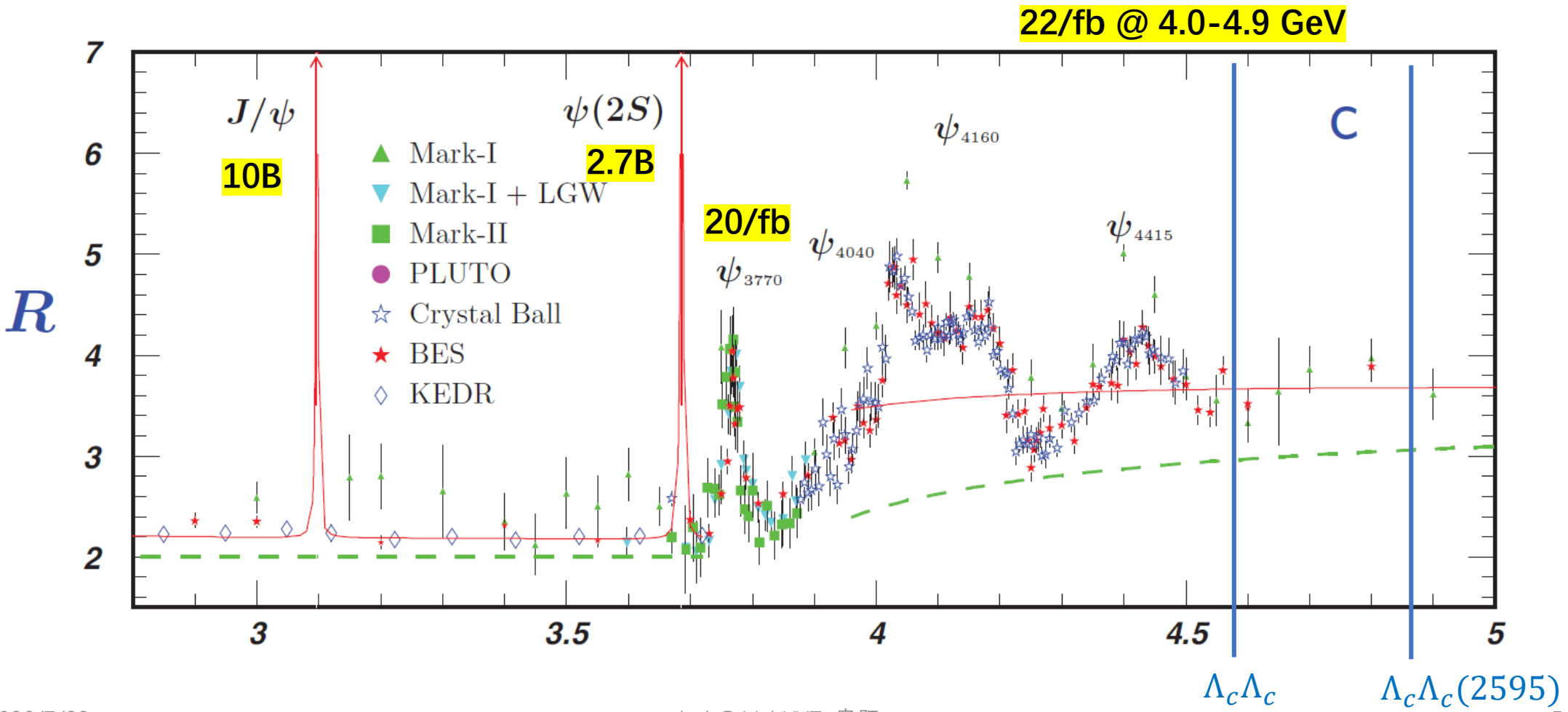
- Center of mass energy range: $\sqrt{s}$ = 2 - 4.9 GeV
- Single beam current: 0.91 A
- Crossing angle: 11 mrad
- Design luminosity: $1 \cdot 10^{33}$ cm^{-2} s^{-1}



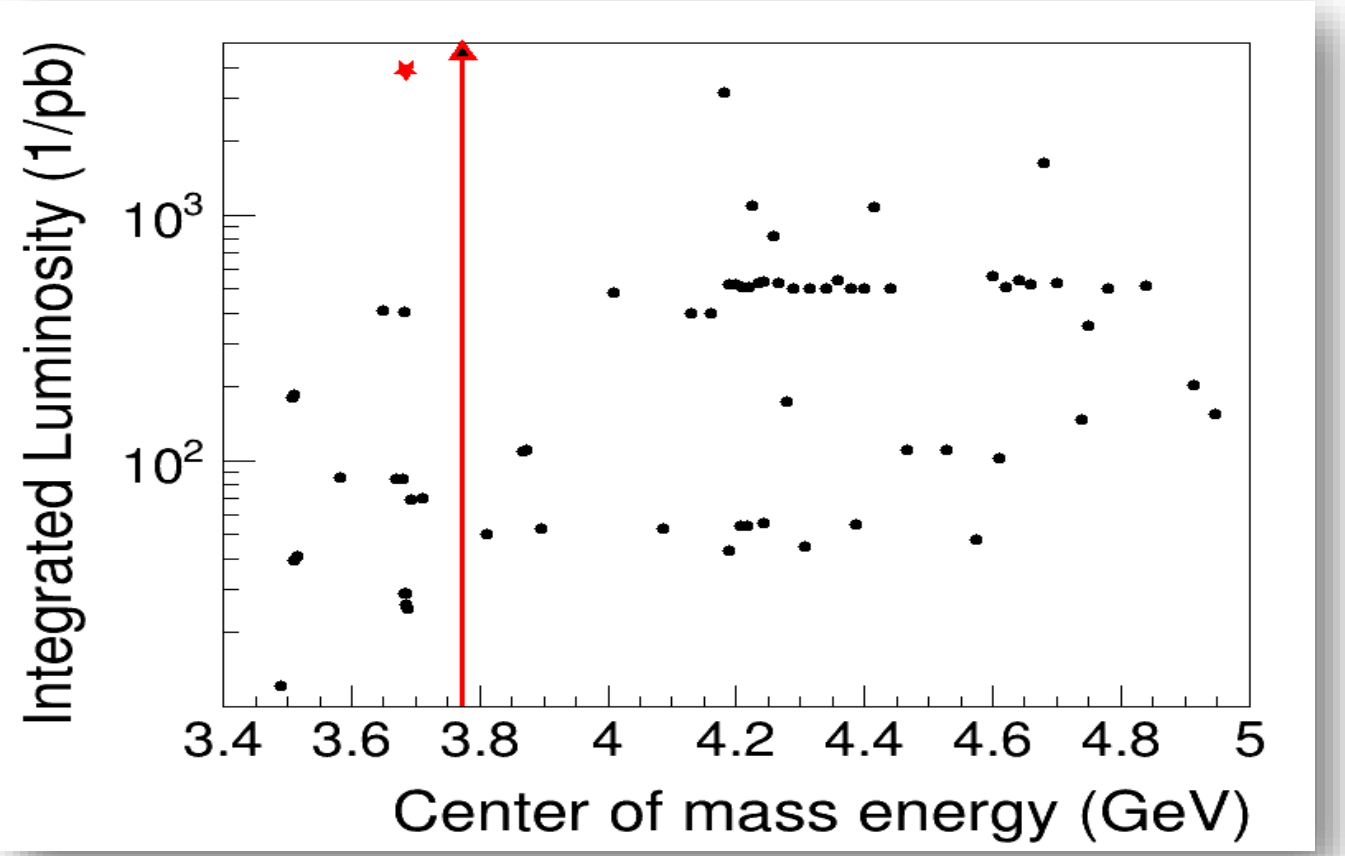
Achieved luminosity: $1.1 \cdot 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ 3.77 & 4.68 GeV

BESIII data samples

Abundant physical topics: D and Λ_c decays, light hadrons, charmonium and XYZ, τ and R-value, new physics, etc.



How to study charmonium-like states at BESIII

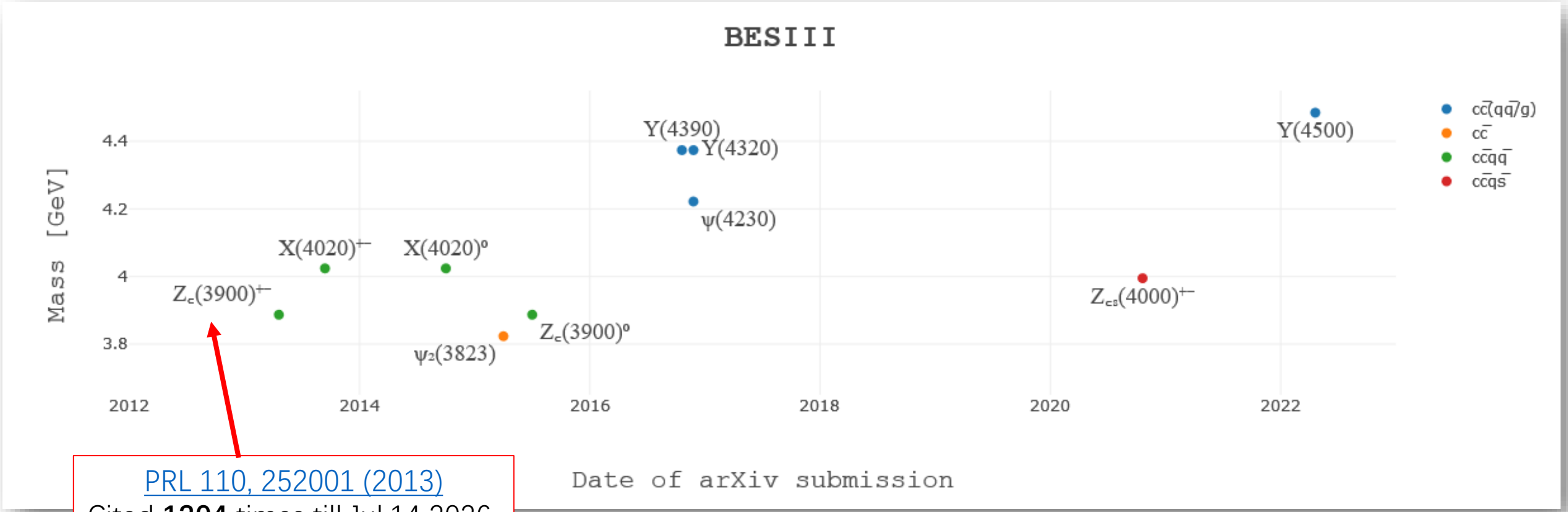


Data samples
accumulated at BESIII
among the years

$22fb^{-1}$ above 4 GeV
$+4.1fb^{-1}$ @ 4.68 GeV (new)

Line shapes of cross-sections for Y, whose (radiative & hadronic) transitions for X and Z

Discoveries of Z and Y states, new modes of X(3872) production and decays, etc.



PRL 110, 252001 (2013)
Cited **1304** times till Jul.14 2026
(counted by Inspire)

From QWG ExoticHub

BESIII has published about 130 XYZ relevant papers till Jul. 2026.

Recent highlights (I): PWA of $e^+e^- \to \pi^+\pi^- J/\psi$

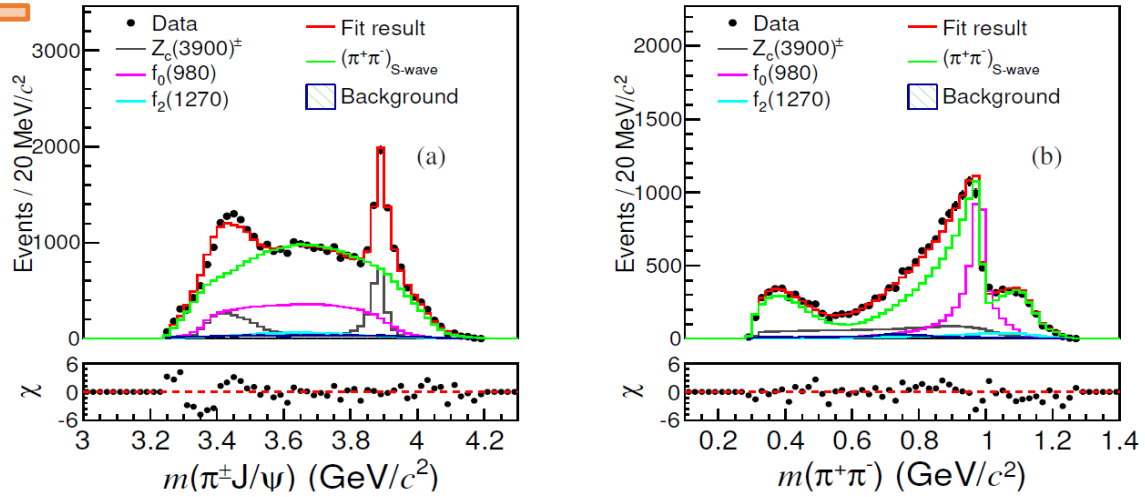
Phys. Rev. D 112, 092013 (2025) | 12.0 fb^{-1}, 4.13 ~ 4.36 GeV

1 $\pi^{\pm}Z_c^{\mp}(3900), f_0(980)J/\psi, (\pi^+\pi^-)_{S-wave}J/\psi$ dominant

$Z_c(4020)$ is not significant

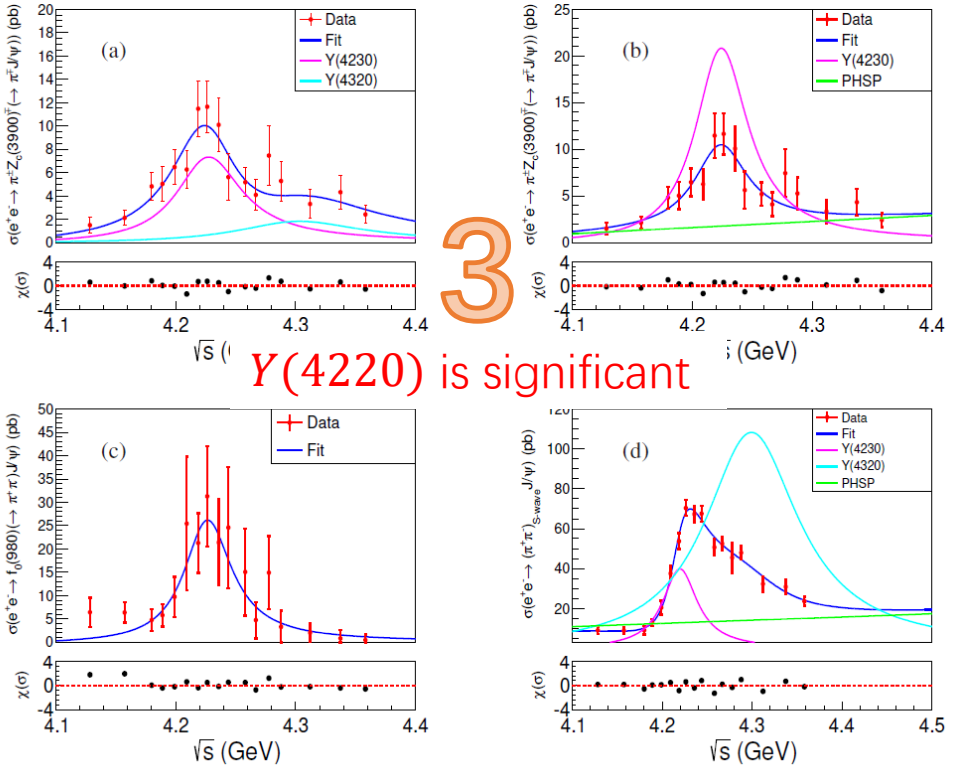
Sample	M (MeV/c^2)	Γ (MeV)
4.1567 – 4.1989	3883.5 ± 1.6	38.6 ± 3.6
4.2091 – 4.2357	3884.0 ± 1.0	37.8 ± 1.6
4.2438 – 4.2776	3884.9 ± 1.8	34.2 ± 3.3
4.2866 – 4.3583	3890.0 ± 2.3	36.1 ± 4.2
Average	$3884.6 \pm 0.7 \pm 3.3$	$37.2 \pm 1.3 \pm 6.6$

2 Z_c Mass and width are consistent in various energies



Process	$Y(4220)$		$Y(4320)$
	M (MeV/c^2)	Γ (MeV)	Significance
$\pi^{\pm}Z_c(3900)^{\mp}$ (model I)	$4225.7 \pm 6.8 \pm 6.8$	$66.5 \pm 16.1 \pm 24.1$	2.1σ
$\pi^{\pm}Z_c(3900)^{\mp}$ (model II)	$4223.1 \pm 6.4 \pm 0.6$	$53.8 \pm 19.1 \pm 0.3$	2.0σ
$f_0(980)J/\psi$ (model III)	$4225.6 \pm 4.5 \pm 0.6$	$48.4 \pm 9.8 \pm 0.2$	0.5σ
$(\pi^+\pi^-)_{\text{S-wave}}J/\psi$ (model IV)	$4218.8 \pm 3.4 \pm 3.7$	$43.5 \pm 5.3 \pm 5.0$	11.7σ
$Y(4220)^{\text{ave}}$	$4225.7 \pm 4.1 \pm 3.4$	$57.5 \pm 9.4 \pm 12.1$	

3



$Y(4220)$ is significant

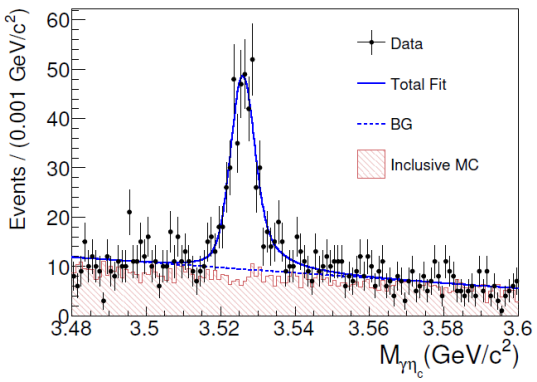
Suffer from local minimum (PWA) and multiple solutions (CroX Fit)

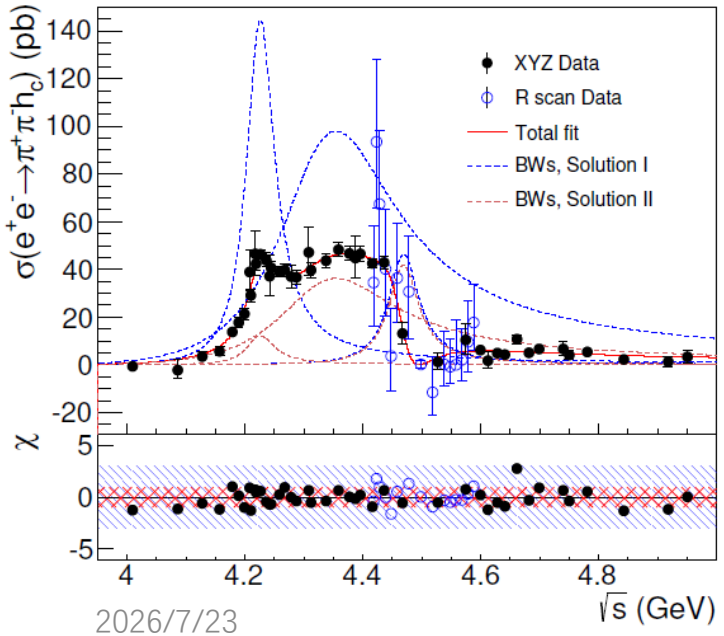
Phys. Rev. Lett. 135, 071901 (2025)

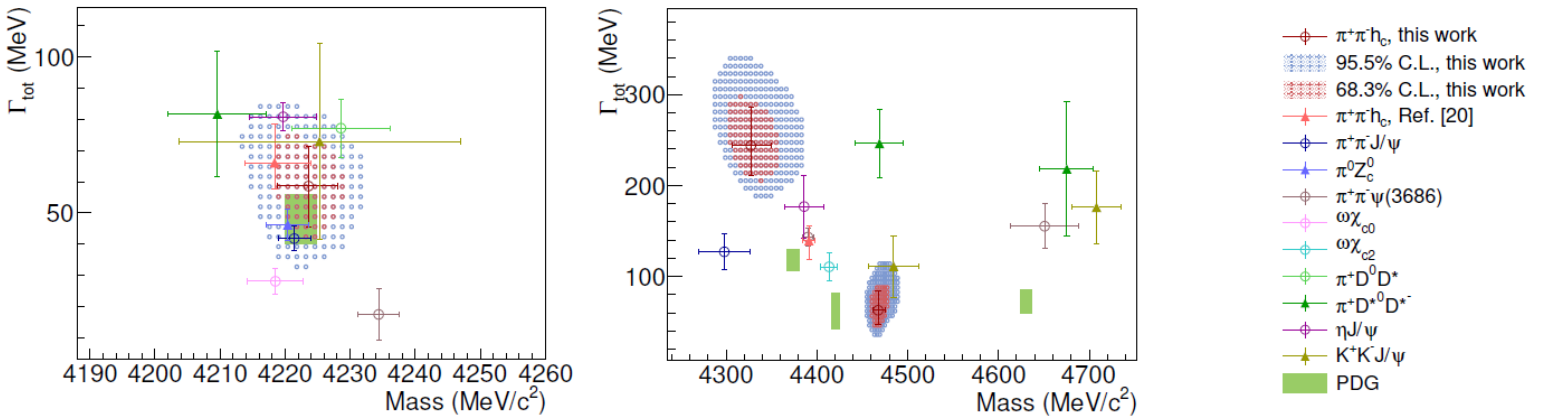
Recent highlights (II): $e^+e^- \to \pi^+\pi^- h_c$

Observation of Three Resonant Structures

4.01 ~ 4.95 GeV, 22fb^{-1}







Parameter	R_1	R_2	R_3
M (MeV/c^2)	$4223.6^{+3.6+2.6}_{-3.7-2.9}$	$4327.4^{+20.1+10.7}_{-18.8-9.3}$	$4467.4^{+7.2+3.2}_{-5.4-2.7}$
Γ (MeV)	$58.5^{+10.8+6.7}_{-11.4-6.5}$	$244.1^{+34.0+24.2}_{-27.1-18.3}$	$62.8^{+19.2+9.9}_{-14.4-7.0}$
$\Gamma_{ee}\cdot\mathcal{B}(R \to \pi^+\pi^- h_c)$ (eV)	$10.2^{+1.2+1.4}_{-1.5-1.4}$ $(0.9^{+0.4+0.3}_{-0.4-0.2})$	$29.1^{+5.7+4.4}_{-3.9-3.4}$ $(10.8^{+2.5+1.9}_{-1.8-1.5})$	$3.9^{+3.5+1.7}_{-1.7-0.5}$ $(3.5^{+3.0+1.5}_{-1.6-0.7})$
ϕ (rad)	...	$3.6^{+0.1+0.1}_{-0.1-0.1}$ $(0.7^{+0.3+0.2}_{-0.3-0.2})$	$0.7^{+0.3+0.1}_{-0.3-0.2}$ $(-2.2^{+0.3+0.2}_{-0.3-0.1})$

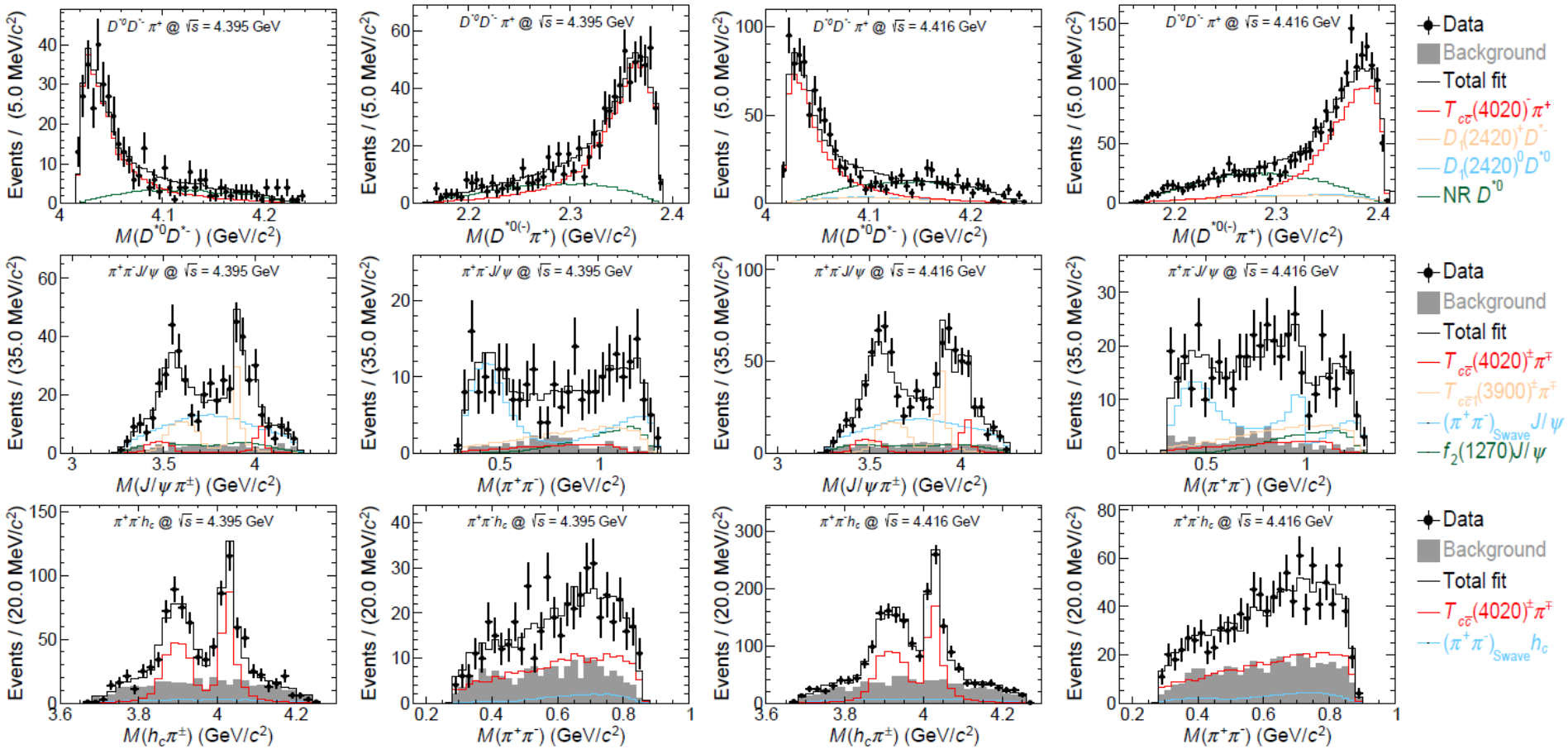
The third resonance is necessary with statistical significance of 5σ

arXiv:2603.05564

Recent highlights (III): multiple channel $Z_c(4020)$

PWA simultaneously on $Z_c(4020) \to \pi h_c, D^{*0}D^{*-}, \pi J/\psi$ to determine: mass/width, quantum number, Brs

$\sqrt{s} = 4.395$ & 4.416 GeV, $L = 1.6\text{fb}^{-1}$



BESIII arXiv:2603.05564

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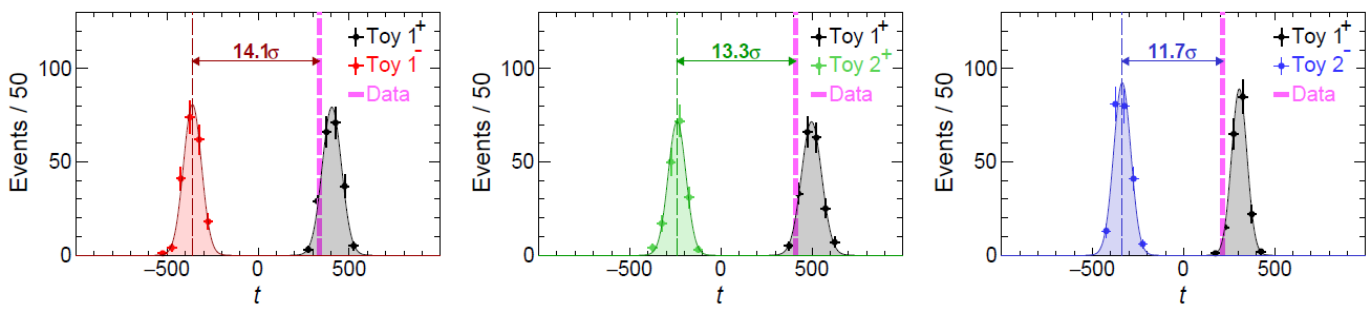
$\sqrt{s} = 4.395$ & 4.416 GeV, $L = 1.6\text{fb}^{-1}$

$$m_{\text{pole1}} = 4022.44 \pm 1.55\,\text{MeV}/c^2,$$
$$\Gamma_{\text{pole1}} = 38.54 \pm 2.94\,\text{MeV},$$

Two candidates of the physical pole position

$$m_{\text{pole2}} = 4023.01 \pm 1.35\,\text{MeV}/c^2,$$
$$\Gamma_{\text{pole2}} = 35.02 \pm 2.20\,\text{MeV}.$$



$J^P = 1^+$ with a significance 11.7σ

Production cross section (in pb)	4.395 GeV	4.416 GeV
$\sigma^B(e^+e^- \to T_{c\bar{c}}(4020)^-\pi^+ + c.c.) \cdot \mathcal{B}[T_{c\bar{c}}(4020)^- \to D^{*0}D^{*-}]$	$335 \pm 21 \pm 35$	$336 \pm 26 \pm 28$
$\sigma^B(e^+e^- \to T_{c\bar{c}}(4020)^-\pi^+ + c.c.) \cdot \mathcal{B}[T_{c\bar{c}}(4020)^- \to \pi^- J/\psi](\times 100)$	$108 \pm 25 \pm 48$	$139 \pm 30 \pm 55$
$\sigma^B(e^+e^- \to T_{c\bar{c}}(4020)^-\pi^+ + c.c.) \cdot \mathcal{B}[T_{c\bar{c}}(4020)^- \to \pi^- h_c]$	$30 \pm 4 \pm 8$	$30 \pm 3 \pm 6$

Other searches and measurements (I)

- Search for 1^{-+} / 0^{--} exotic states via
  - $e^+e^- \to \gamma D_s^+ D_{s1}^-(2536) + c.c.$ Phys. Rev. D 112, 032002 (2025)
  - $e^+e^- \to \gamma\eta^{(\prime)}\eta_c$ Phys. Rev. D 111, 112007 (2025)
  - $e^+e^- \to \eta\eta\psi(2S)$, Phys. Rev. D 113, 092013 (2026)
- Born cross sections with baryon involved ($\sqrt{s} = 3.5 \sim 4.9$ GeV):
  - $e^+e^- \to pK^-K^-\bar{\Xi}^+$, JHEP 11, 111 (2025)
  - $e^+e^- \to \Omega^+\Omega^-$, JHEP 02, 212 (2026)
  - $e^+e^- \to \Xi(1530)^0\bar{\Xi}^0 + c.c.$, Phys. Rev. D 113, 072017 (2026)
  - $e^+e^- \to \Sigma^-\bar{\Sigma}^+$, arXiv:2602.23835
  - $e^+e^- \to K^+\Xi^0\bar{\Sigma}^-$, arXiv:2605.19780
  - $e^+e^- \to p\bar{p}$, arXiv:2606.22762 (evidence of psi(4160/4230))

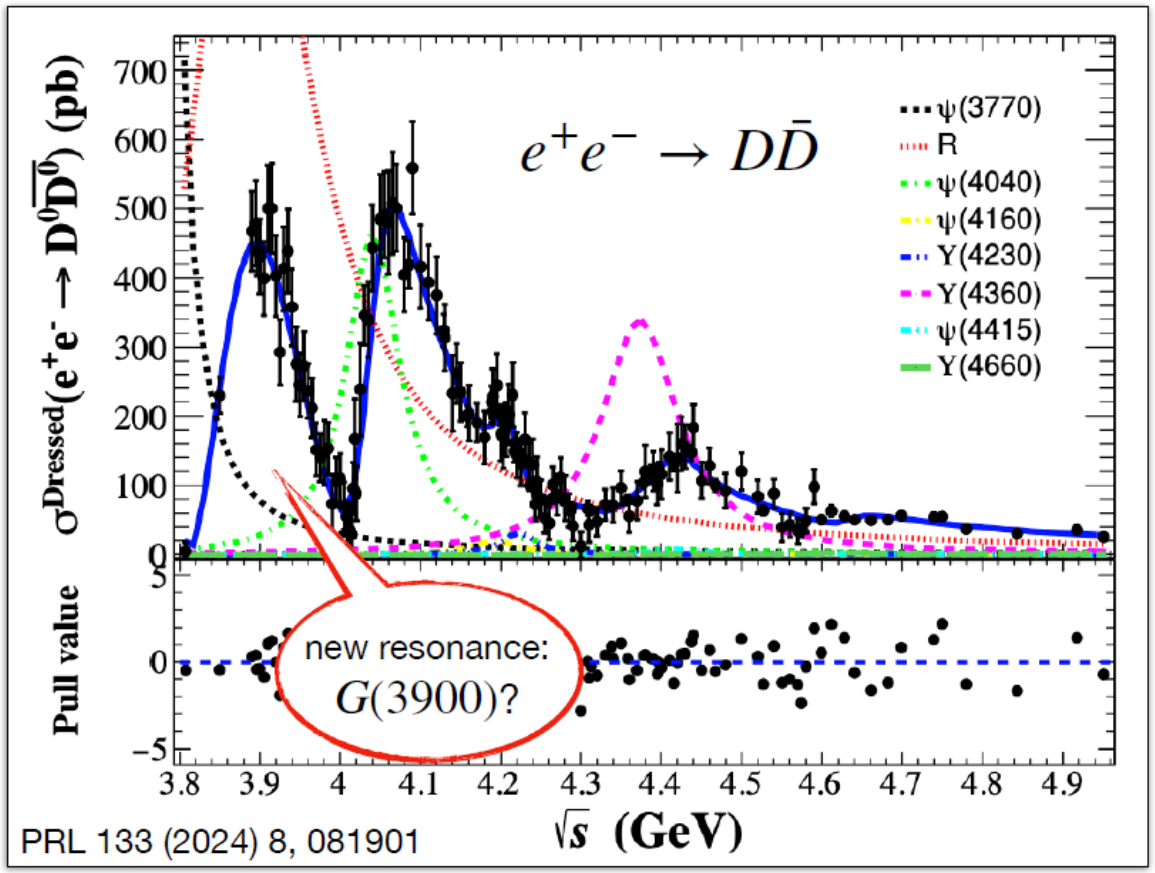
Other searches and measurements (II)

- Cross sections with open charm:
  - Search for a bound state of $\Lambda_c\bar{\Sigma}_c$ near threshold, PRD 112, 114044 (2025)
  - $e^+e^- \to \pi^+\pi^- D_s^+ D_s^-$, arXiv:2606.29141
- Cross sections with hidden charm and (iso-pin partner)$Z_{c(s)}$ states
  - $e^+e^- \to K^+K^-\psi(2S)$, arXiv:2407.20009
  - $e^+e^- \to K^0K^-\pi^+J/\psi$ + c.c., arXiv:2510.13274
  - $e^+e^- \to \eta\eta J/\psi$, arXiv:2601.15882
  - $e^+e^- \to \pi^0\pi^0\psi(2S)$, Phys. Rev. D 113, 112016 (2026) (consistent with charged)
  - $e^+e^- \to \pi^+\pi^-\eta J/\psi$, arXiv:2607.07446
- Search for X(3872) non-charm decay
  - $X(3872) \to K_s^0 K^\pm\pi^\mp$ and $K^*(892)\bar{K}$, Phys. Rev. D 113, L071102 (2026)

Thoughts and analyses based on BESIII results

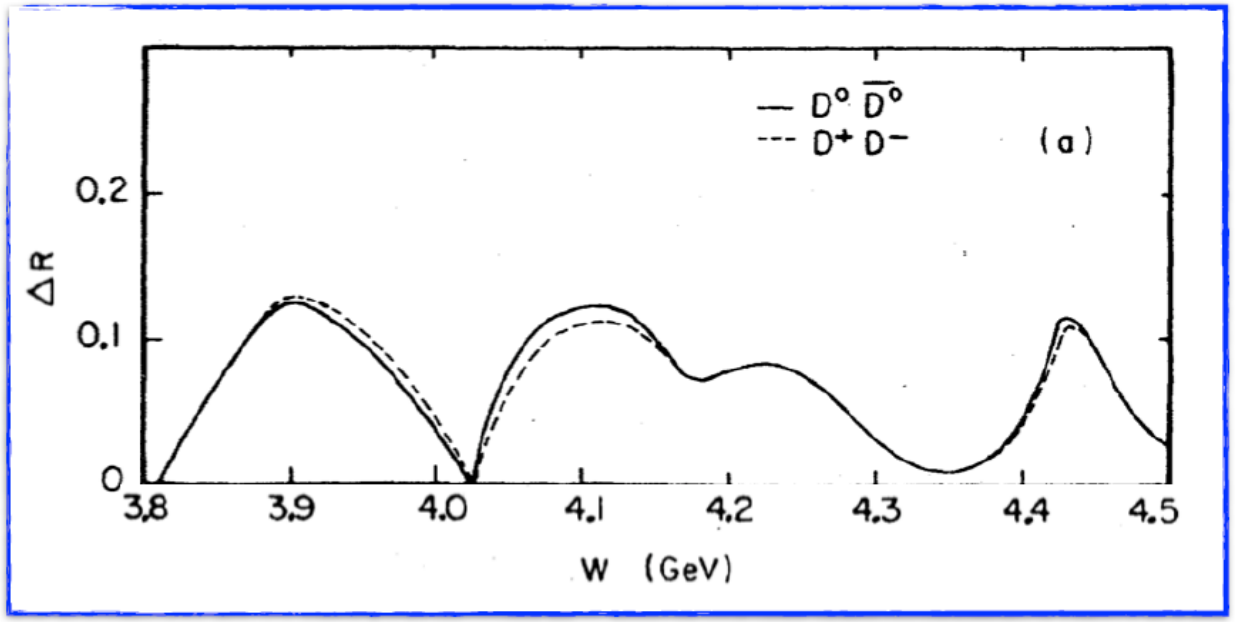
A piece of the puzzle

the $G(3900)$



PRL 133 (2024) 8, 081901

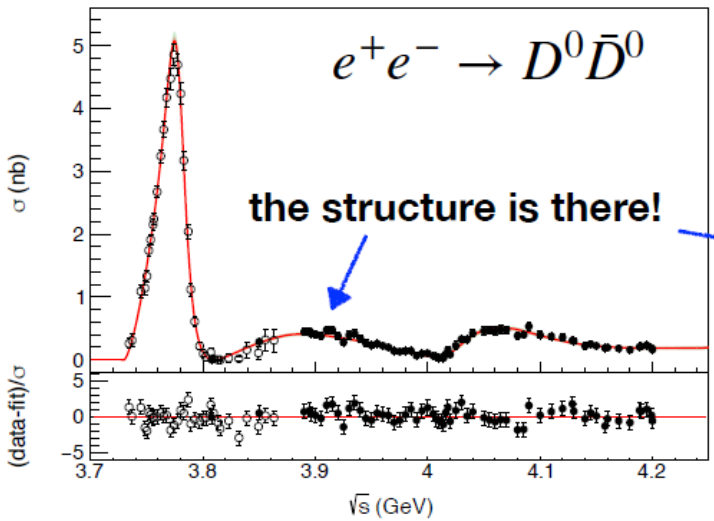
Eichten et al., Phys. Rev. D 21 (1980) 203

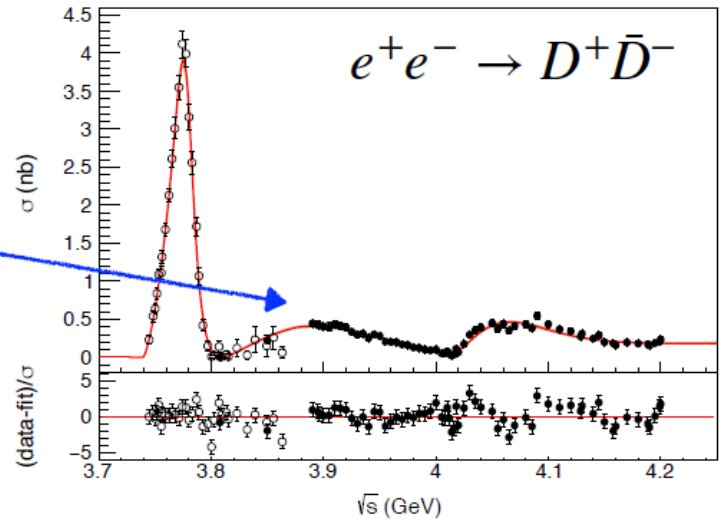


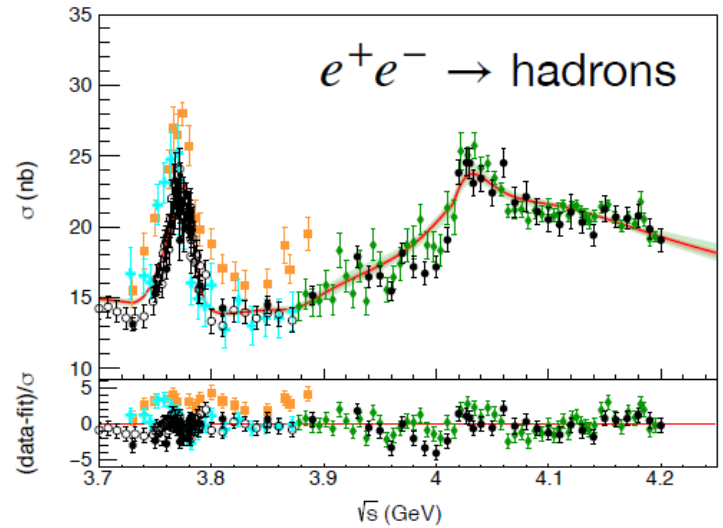
In our calculation there is some weak structure in the 3.9–4.0 GeV region. It does not arise from a $c\bar{c}$ resonance, but from the opening of the $D\bar{D}^* + D^*\bar{D}$ channel and a decrease in the $D\bar{D}$ channel due to a nearby zero in the $3S$ decay amplitude.

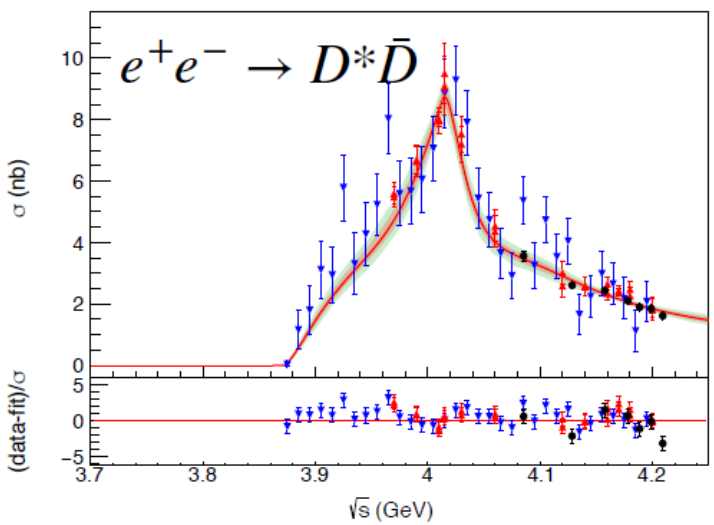
A piece of the puzzle

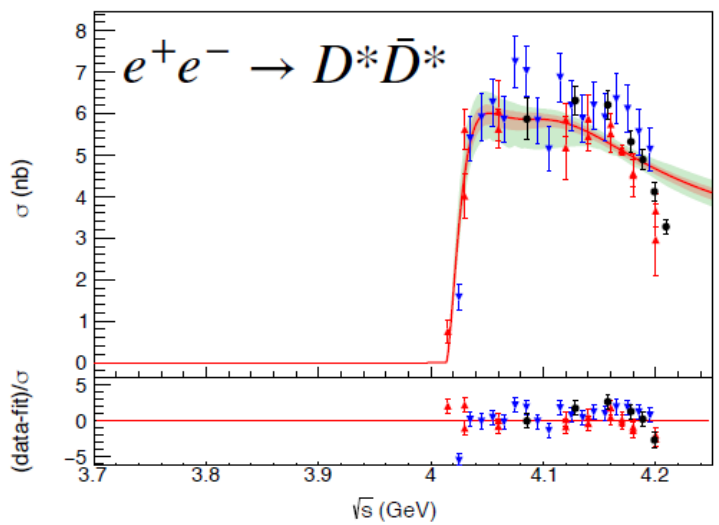
NH, R. Lebed, R. Mitchell, E. Swanson, Y. Wang, C. Yuan
PRD 109 (2024) 11, 114010

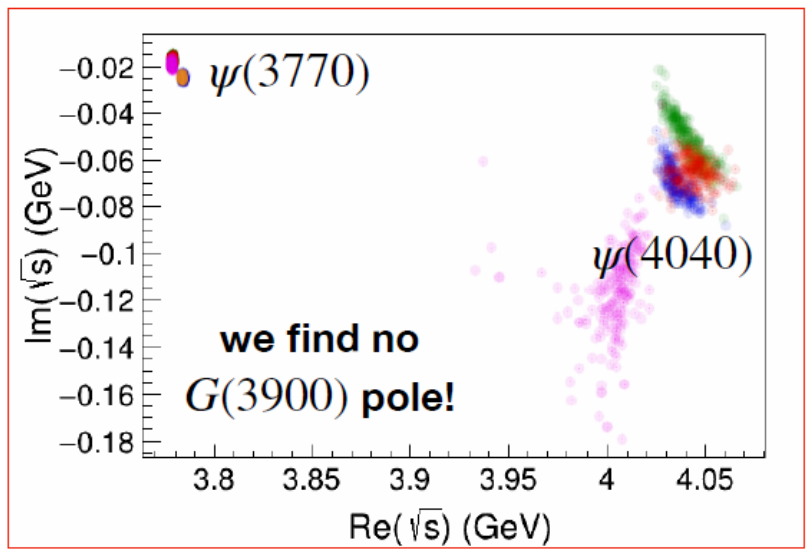












Data dominantly from BESIII

Y.P. Guo and C.Z. Yuan, arXiv:2508.20667

$$\sigma(s) = \left| \frac{c}{s^n} + \sum_k BW_k(s) e^{i\phi_k} \right|^2$$

Multiple solutions with same resonance parameters

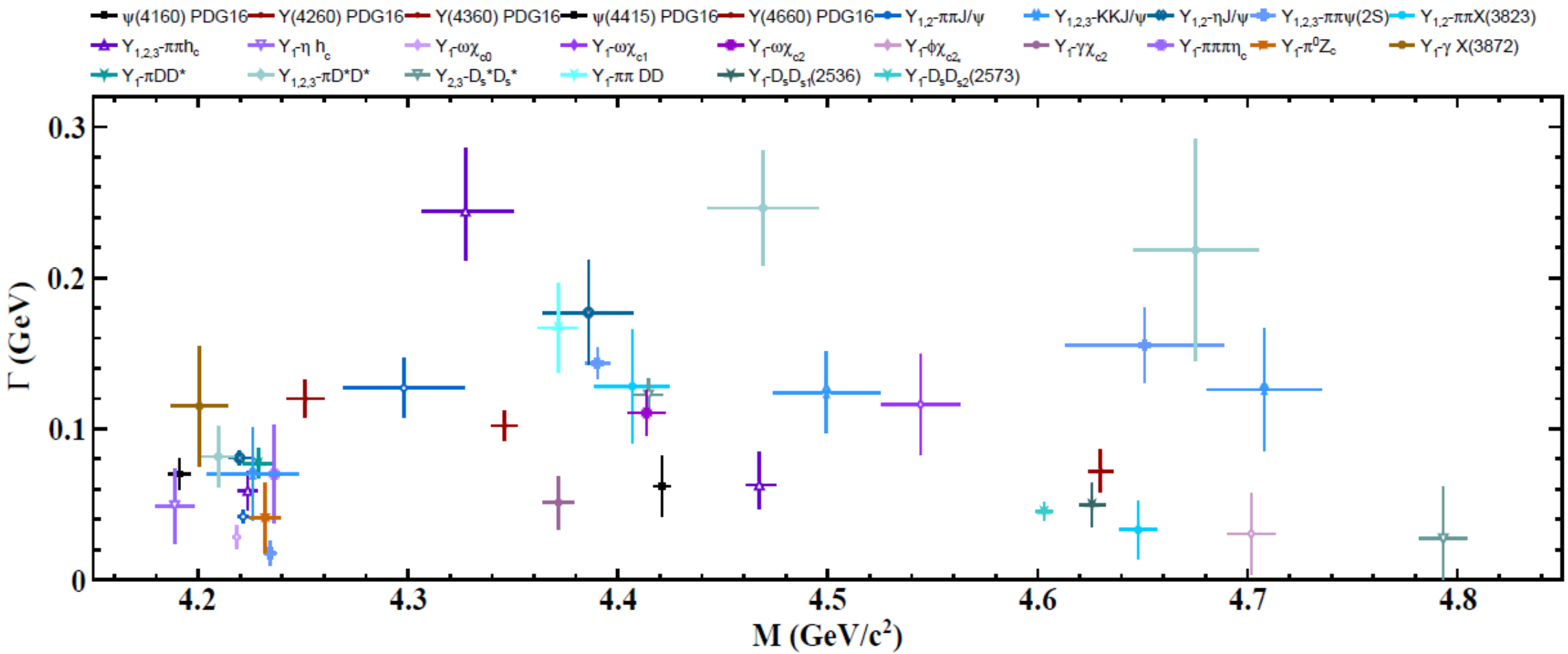
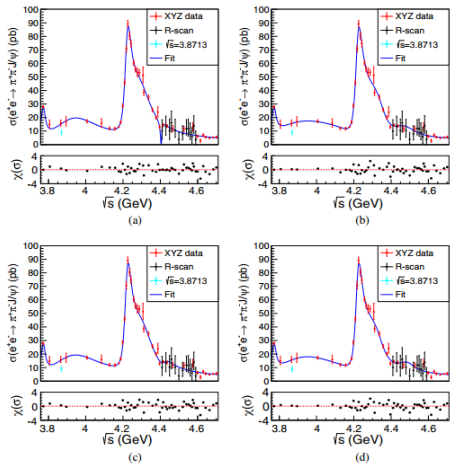


Fig. 7: The parameters of the vector states obtained from single-channel analyses.

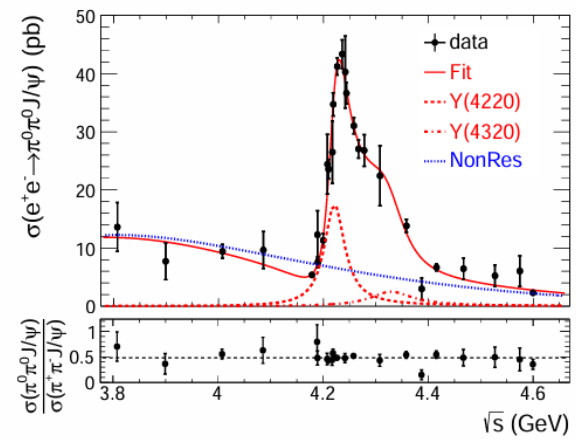
J. Yuan, etc., PRD 112, 116005 (2025)

Multiple solutions in Y(4230) decays

Mode	Solution I	Solution II	Solution III	Solution IV	$\frac{1}{M^2\Gamma_{tot}}$
$\pi^+\pi^- J/\psi$	1.7 ± 0.2	8.2 ± 0.9	3.0 ± 0.5	14.6 ± 1.2	1.3 ± 0.1
$\pi^0\pi^0 J/\psi$	0.99 ± 0.17	4.13 ± 0.28	1.38 ± 0.30	5.72 ± 1.57	1.2 ± 0.1
$K^+K^- J/\psi$	0.42 ± 0.15	0.29 ± 0.10	...	...	0.8 ± 0.3
$K_S K_S J/\psi$	0.13 ± 0.05	0.14 ± 0.06	0.18 ± 0.07	0.20 ± 0.08	0.8 ± 0.4
$\eta J/\psi$	4.0 ± 0.5	5.5 ± 0.7	8.7 ± 1.0	11.9 ± 1.1	0.7 ± 0.1
$\eta' J/\psi$	0.06 ± 0.03	1.38 ± 0.11	...	...	1.0 ± 0.3
$\pi^+\pi^-\psi'$	1.6 ± 1.3	1.8 ± 1.4	...	...	0.7 ± 0.2



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



$\pi^0\pi^0 J/\psi$

Warning:
theoretical analyses usually use $\sigma(e^+e^- \to X)$ @ 4.23 GeV to present $\sigma(e^+e^- \to Y(4230) \to X)$

J. Yuan, etc., PRD 112, 116005 (2025)

Results of physical solutions

The physical solutions of the Y(4230) decays corresponding to the global minimum χ^2

Mode	Solution I	Solution II	Solution III	Solution IV
$\pi^+\pi^- J/\psi$	1.7 ± 0.2	8.2 ± 0.9	3.0 ± 0.5	14.6 ± 1.2
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$K^+K^- J/\psi$	0.42 ± 0.15	0.29 ± 0.10	...	...
$K_S K_S J/\psi$	0.13 ± 0.05	0.14 ± 0.06	0.18 ± 0.07	0.20 ± 0.08
$\eta J/\psi$	4.0 ± 0.5	5.5 ± 0.7	8.7 ± 1.0	11.9 ± 1.1
$\eta' J/\psi$	0.06 ± 0.03	1.38 ± 0.11	...	...
$\pi^+\pi^-\psi'$	1.6 ± 1.3	1.8 ± 1.4	...	...

The solution with small $|s\bar{s}\rangle$ component is the red box.
The solution with large $|s\bar{s}\rangle$ component is the blue circle.

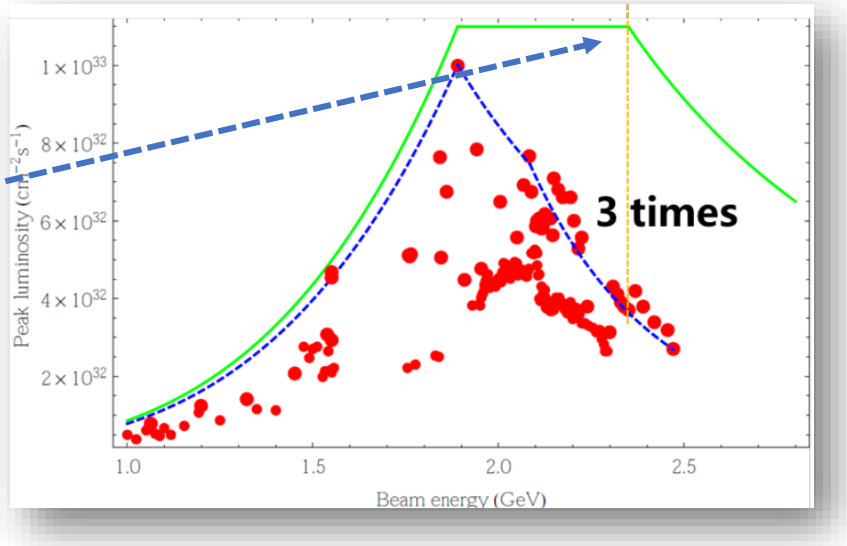
Not sensitive to s-quark except $\eta' J/\psi$

- **Largest $\pi\pi J/\psi$ selected**
- **Predict more precise $\Gamma_{ee}B(Y(4230) \to \pi^+\pi^-\psi(2S)) = (0.3 \pm 0.1)$ eV**

The future of XYZ at BESIII

BEPCII upgrade

- **Luminosity** increase by a factor 3 @ 2.35 GeV (achieved)
- **Maximum energy** increase up to 2.8 GeV (to be tested)



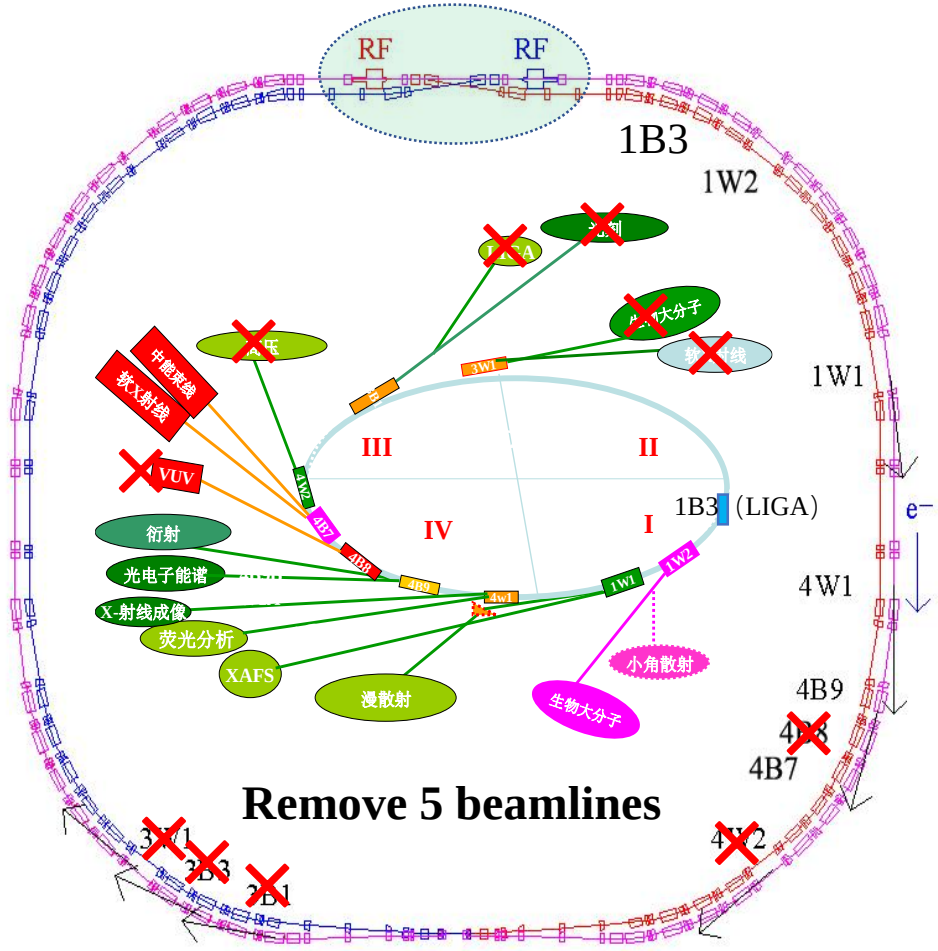
BEPCII Operation plan

- **Jan. 2025 – Jul. 2025** Data taking at beam energy 1.843GeV ψ (3686)
- **Aug. 2025 – Sep. 2025** 2nd SC magnet hor. test & the 4th RF cavity installation
- **Oct. 2025 – Jul. 2026** Data taking around beam energy 2.35GeV (project test)
- **Aug. 2026 – Sep. 2026** 2 SC magnets installation & 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

Accelerator physics

Key Technologies: Double beam power & Optics upgrade & Higher gradient of magnets

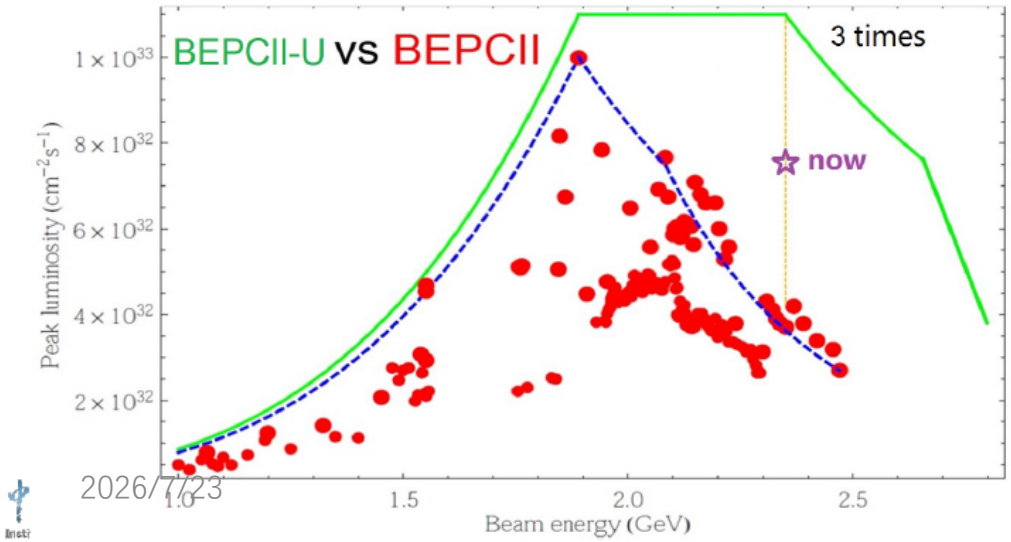
	BEPCII @ 2.35GeV	BEPCII-U @ 2.35GeV	BEPCII-U @ 2.8GeV
L $[10^{32}cm^{-2}s^{-1}]$	**3.5**	**11**	**3.7**
β_y^* [cm]	**1.5**	**1.35**	**3.0**
Beam current [mA]	400	900	450
SR Power [kW]	**110**	**250**	**250**
$\xi_{y,lum}$	0.029	0.033	0.043
Emittance [nmrad]	**147**	**152**	**200**
Couping [%]	**0.53**	**0.35**	**0.5**
Bucket Height	0.0069	0.011	0.009
$\sigma_{z,0}$ [cm]	1.54	1.07	1.4
σ_z [cm]	**1.69**	**1.22**	**1.6**
RF Voltage [MV]	**1.6**	**3.3**	**3.3**

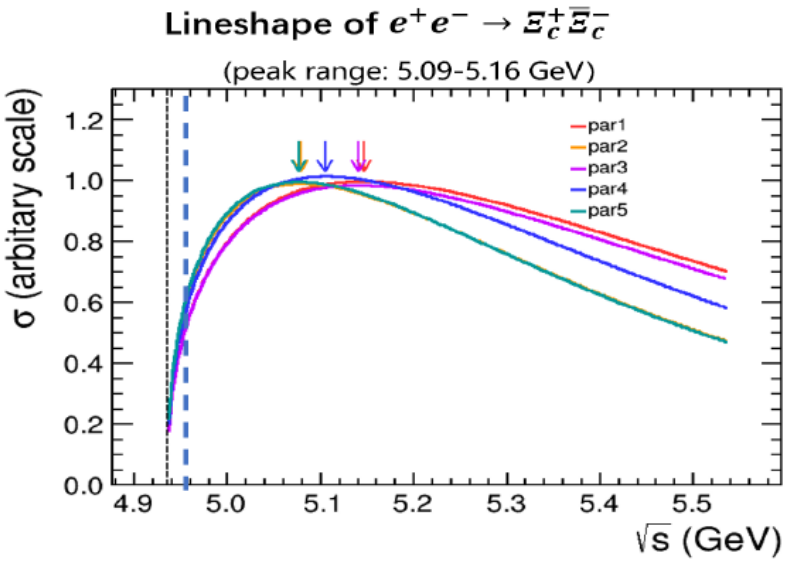


No dedicated SR operation, only parasitic SR experiments, 10 months/year BESIII time.

Data taking: two-year plan

- ✓ Additional 5.0 fb^{-1} @4.68 GeV [4.14 + 5.0 = 9.0 fb^{-1} as planed] : ~5 months
- ✓ 3.870[400 pb^{-1}], 3.8716[400 pb^{-1}], 3.874[400 pb^{-1}] for $X(3872)$: ~1 month
- ✓ 3.554[600 pb^{-1}], 3.5580[200 pb^{-1}], 3.560[300 pb^{-1}] for χ_{c2}: ~1 month
- ✓ Scan above $\Xi_c\bar{\Xi}_c$ threshold (4.95GeV - 5.10 GeV):
  scan data: 2 fb^{-1} @ 20 energy points [optimization of the scan scheme is needed]
  data@ maximal cross-section: 10 fb^{-1}
  Total sample 12 fb^{-1}: 1.5 years





阈值能量：4.9354 GeV
4.951 GeV对应峰值截面的46%-55%

Summary

- Productive XYZ Physics at BESIII: We have published ~130 papers, discovered key XYZ states (Zc, Y), and systematically mapped their production and decay properties.
- In the last year: important discoveries and measurements, including both hidden charm and open charm channels, as well as light hadron final states
- Challenge on from data to knowledge: complex analysis tools such as PWA and coupling analysis are required to extract valuable information, systematic interpretation is desired for the observations and measurements
- Future Frontier with BEPCII-U: The upcoming luminosity upgrade will provide unprecedented data sets, enabling precision measurements of line shapes and searches for new states and decay modes, and exploration of new energy regions (above 4.95 GeV)

Thanks for your attention!