

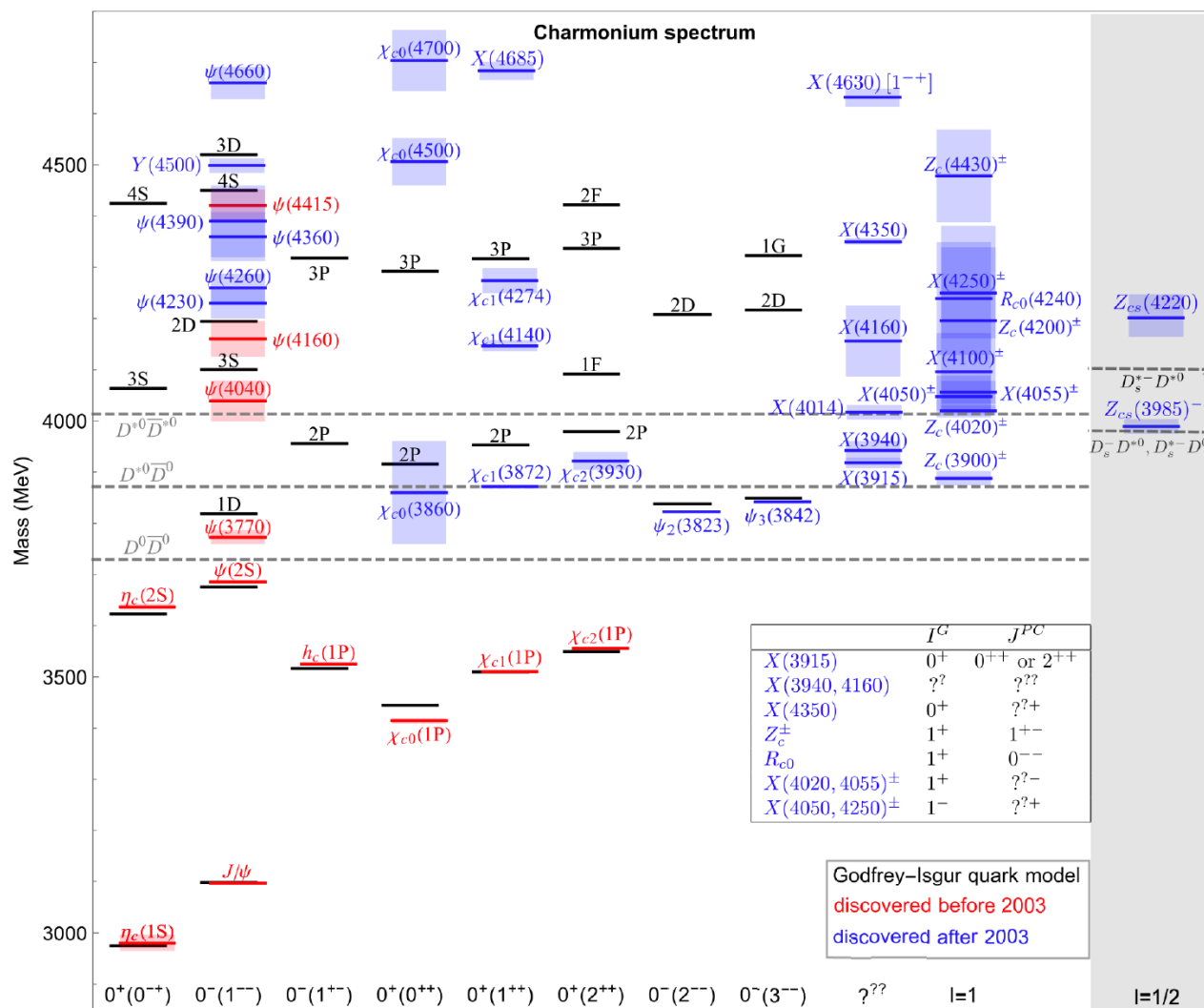


Study of Vector Charmonium(-like) States at BESIII

Wenyu Sun

Shandong University of Technology, China

Charmonium(-like) States Mass Spectrum



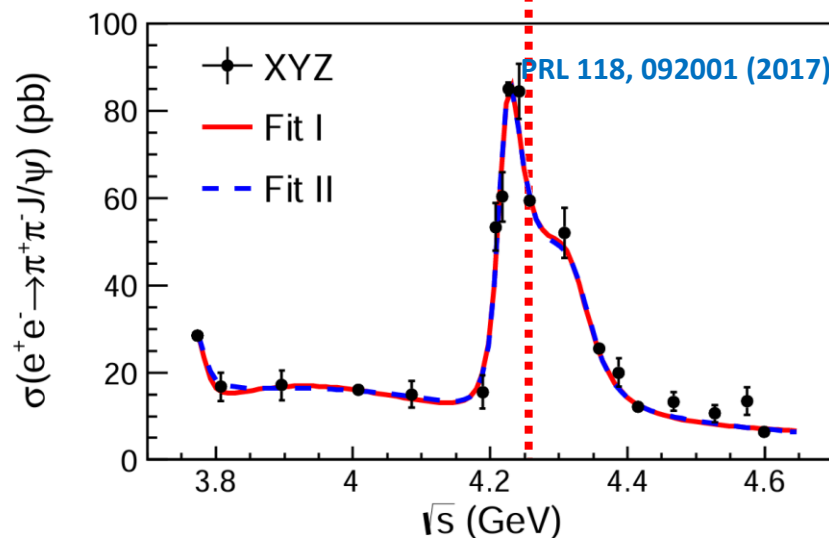
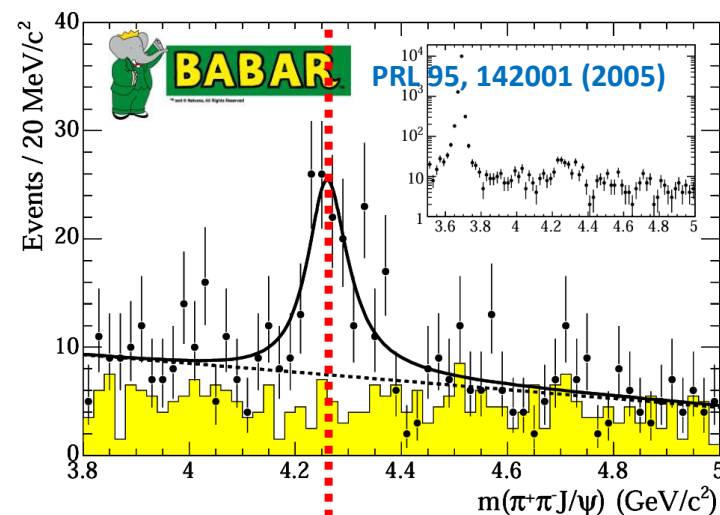
from F. K. Guo

- Below $D\bar{D}$ mass threshold
 - ✓ Theoretical predictions match well with experimental observations
- Above $D\bar{D}$ mass threshold
 - ✓ A series of new particles are observed beyond theoretical predictions
→ **Good candidates of exotic states:** hybrid states, hadron molecule, compact tetra-quark, etc.
- Roughly classified to 3 categories
 - ✓ X : Iso-spin $I = 0$ with quantum number other than 1^{--}
 - ✓ Y : Iso-spin $I = 0$, vector states with quantum number equal to 1^{--}
 - ✓ Z : Iso-spin larger than 0



Discovery of Y States

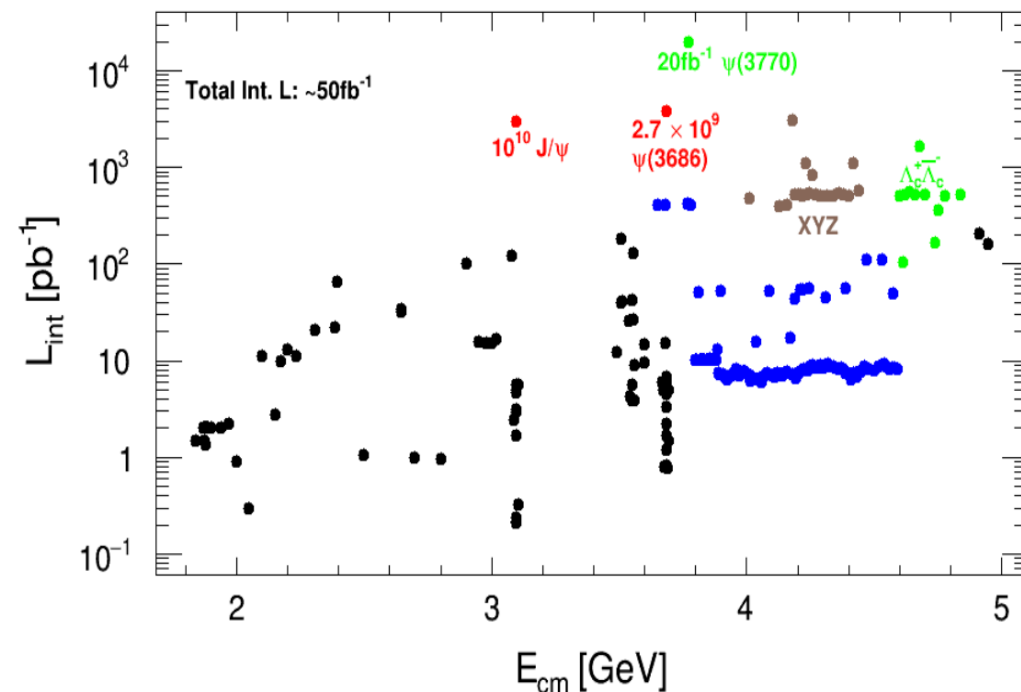
- $Y(4260)$
 - ✓ Discovered with ISR process at *BaBar* in $\pi^+\pi^-J/\psi$ final states
 - ✓ Confirmed by CLEO and Belle latterly
 - ✓ Mass > 4 GeV, above $D\bar{D}$ threshold
 - ✓ Show strong coupling to hidden-charm final states
→ **may not be conventional charmonium states**
- Interpretation
 - ✓ Is $Y(4260)$ hybrid?
 - ✓ According to lattice QCD simulation, both the 1^{--} and 1^{-+} hybrid charmonium lie around 4.26 GeV
 - ✓ Precise measurements in BESIII performed revealed the fine structure of the $Y(4260)$ particle.
- Family Members
 - ✓ Besides $Y(4260)$, multiple new vector charmonium-like states including $Y(4390)$ 、 $Y(4500)$ 、 $Y(4710)$ 、 $Y(4790)$ have been discovered at BESIII.





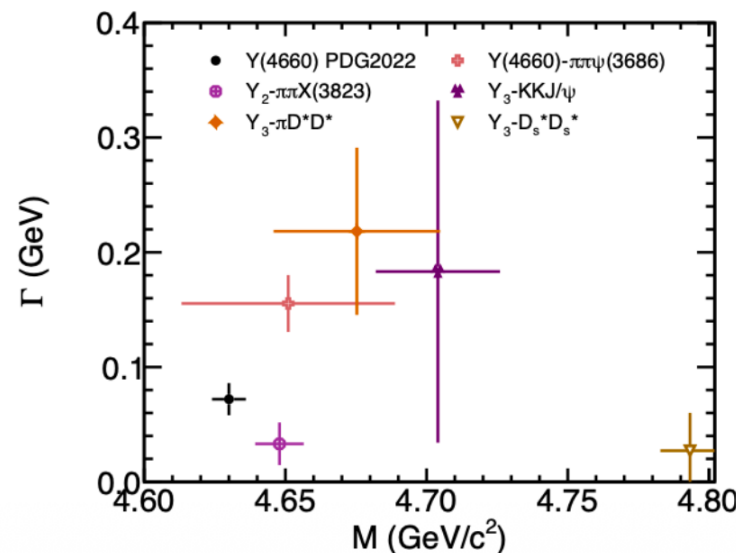
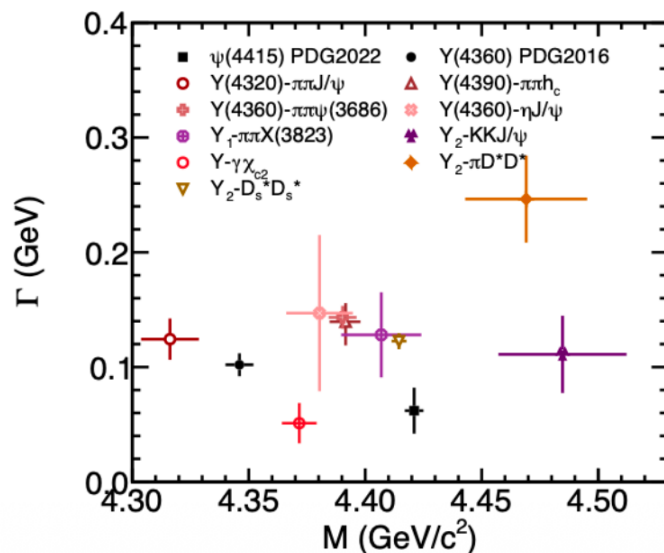
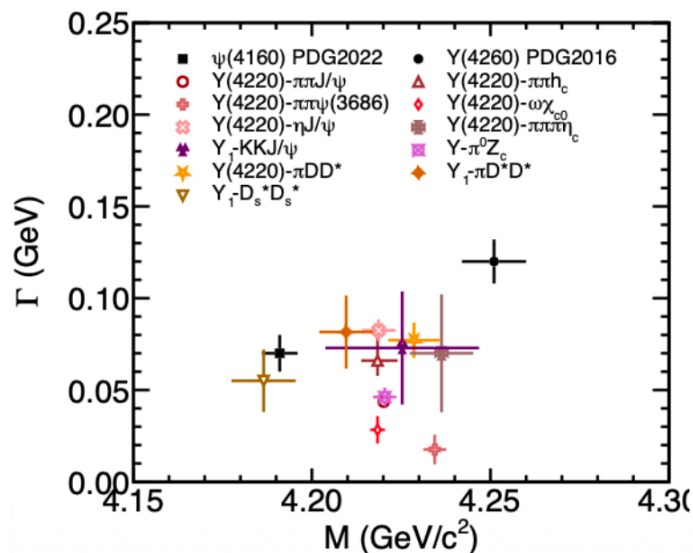
Production and Decays of Y States at BESIII

- BESIII can directly generate Y states by e^+e^- annihilation
- BESIII accumulate $\sim 50 \text{ fb}^{-1}$ collision data events from 3.7~5.0 GeV
- Search for more Y states, study their properties and new decay modes
 - ✓ Hidden-charm final states
 - ✓ Open charm final states
 - ✓ Baryon and light hadron final states

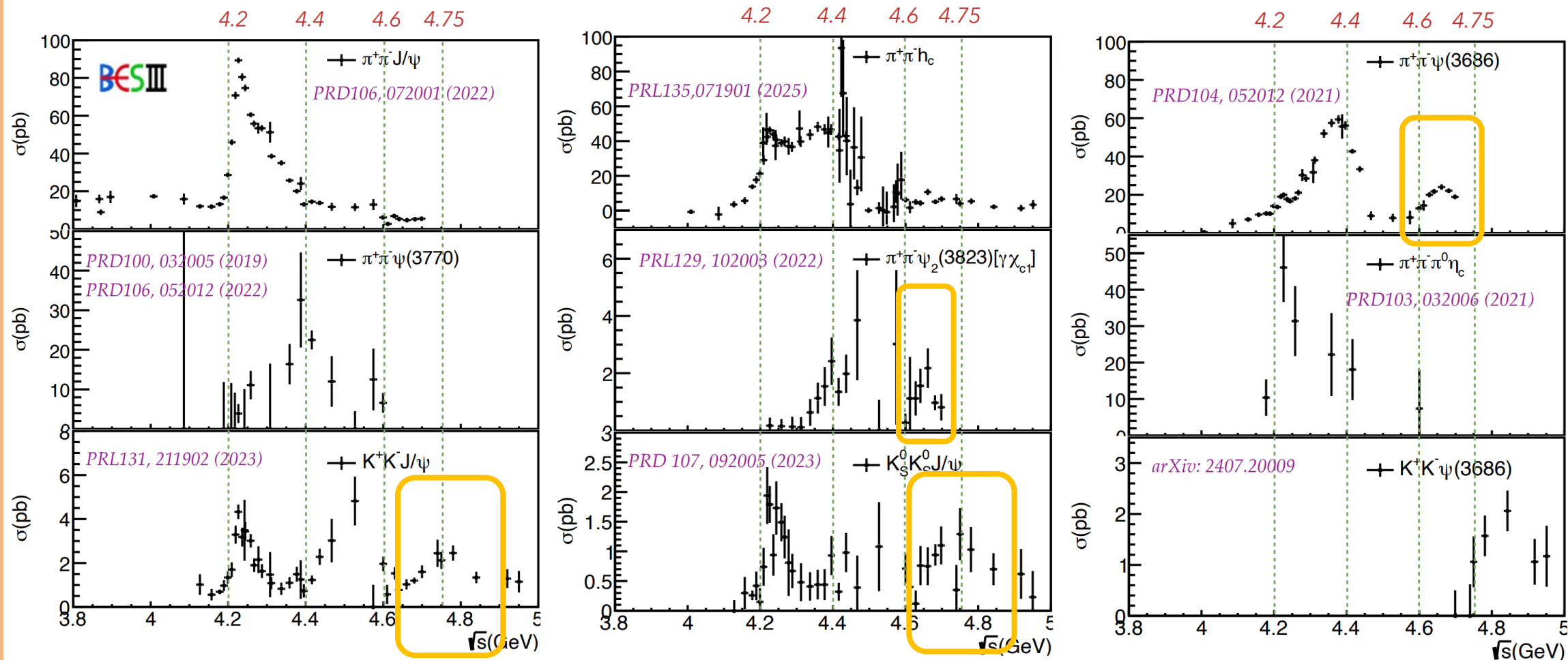


Observation of Y States at BESIII

- Most of the charmonium-like states have been observed in hidden charm and open charm final states.
- Hidden-charm final states: $(\pi\pi/K\bar{K}/\eta/\eta' \dots) + (J/\psi/\psi(2S)/\eta_c/X(3872)/\chi_{cJ} \dots)$
- Open-charm final states: $D_s D_{s1}(2536)$ 、 $D_s D_{s2}^*(2573)$ 、 $D_s^* D_s^*$ 、 $D_s D_s \dots$



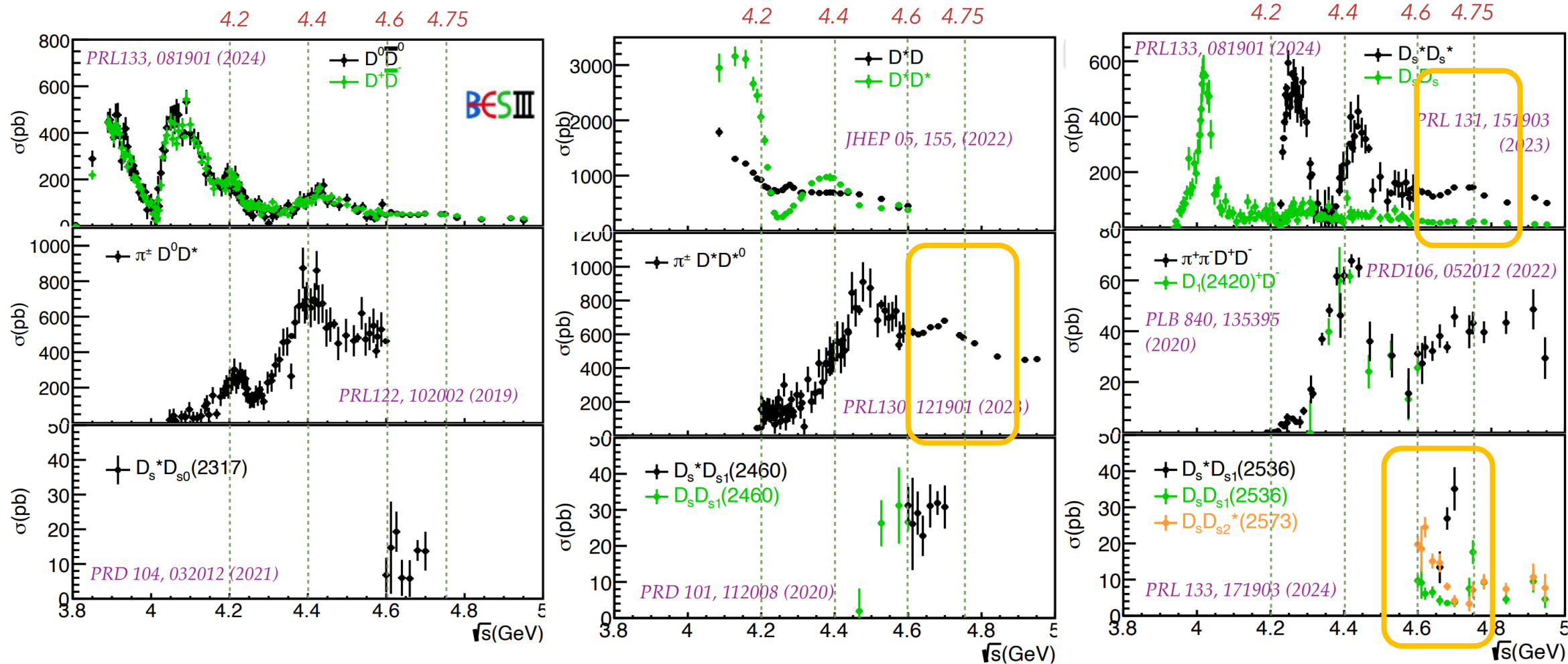
Observation of Y States at BESIII



Pictures from Yuping Guo



Observation of Y States at BESIII



Pictures from Yuping Guo



Observation of New Structures above 4.7 GeV at BESIII

- QCD sum rule calculations suggest the existence of a tetraquark state near 4.75 GeV.
- Are the observed peaks in different processes correspond to the same state?
- Are they conventional charmonium states like $\psi(4D)$ or $\psi(5S)$, or are they tetraquark candidates?

	Mass (MeV/c ²)	Width (MeV)	Significance	
$e^+e^- \rightarrow K^+K^-J/\psi$	$4708^{+17}_{-15} \pm 21$	$126^{+27}_{-23} \pm 30$	5σ	PRL 131, 211902 (2023)
$e^+e^- \rightarrow K_S^0 K_S^0 J/\psi$	$4704.0 \pm 52.3 \pm 69.5$	$183.2 \pm 114.0 \pm 96.1$	4.2σ	PRD 107, 092005 (2023)
$e^+e^- \rightarrow D_S^{*+} D_S^{*-}$	$4793.3 \pm 6.7 \pm 9.3$	$27.1 \pm 6.5 \pm 34$	5.9σ	PRL 131, 151903 (2023)
$e^+e^- \rightarrow D_S^+ D_{s1}(2536)^-$	$4749.9 \pm 8.2 \pm 5.5$	$24.9 \pm 8.0 \pm 1.0$	4.3σ	PRL 133, 171903 (2024)
$e^+e^- \rightarrow D_S^+ D_{s2}^*(2573)^-$	$4720 \pm 13 \pm 2.0$	$50 \pm 12 \pm 1.0$	2.7σ	



Recent Progresses at BESIII in 2026

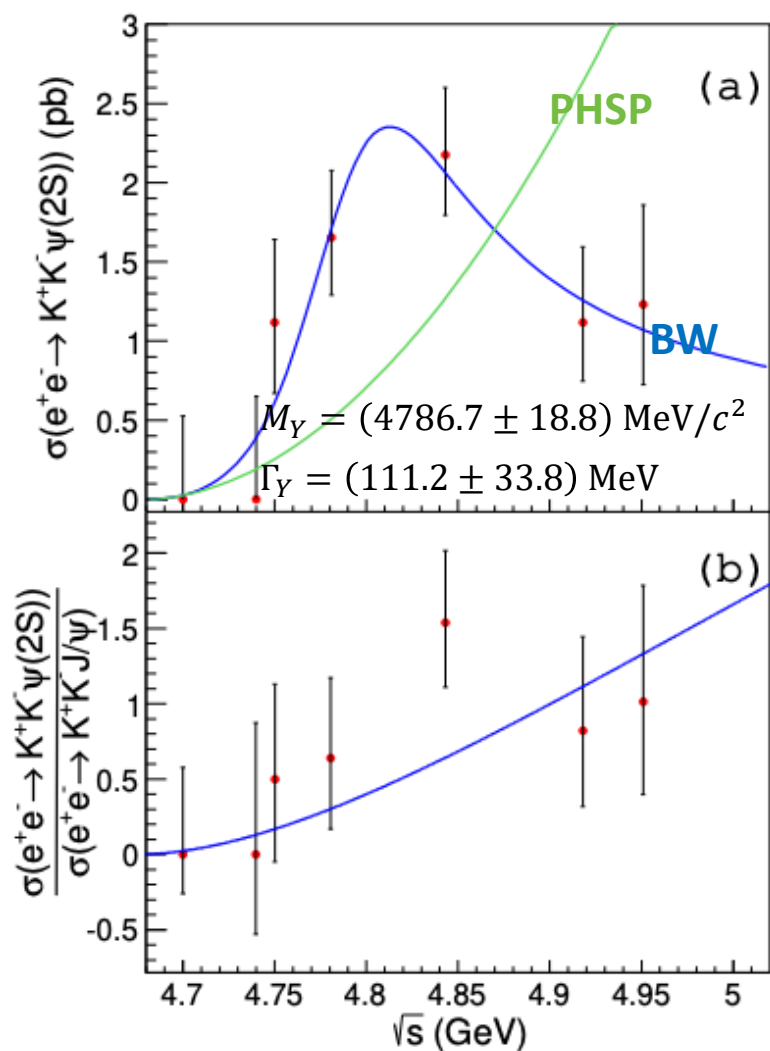
➤ Exploration of the High-Energy Region

- $e^+e^- \rightarrow K^+K^-\psi(2S)$ *arxiv:2407.20009*
- $e^+e^- \rightarrow K^0K^-\pi^+J/\psi + c.c.$ *JHEP 06, 101 (2026)*
- $e^+e^- \rightarrow \eta\eta J/\psi$ *arxiv:2601.15882*
- $e^+e^- \rightarrow \pi^0\pi^0\psi(2S)$ *PRD 113, 112016 (2026)*

➤ Discovery of the Low-Energy Region

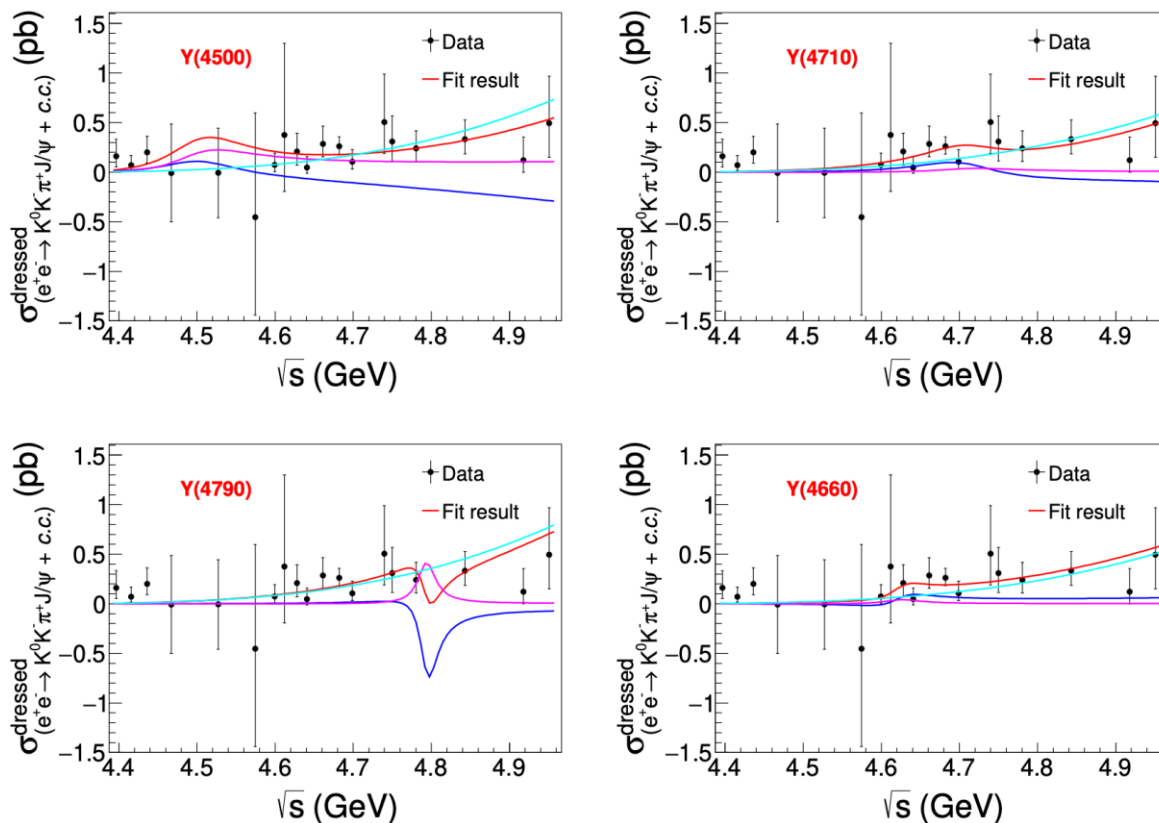
- $e^+e^- \rightarrow K^+\Xi^0\bar{\Sigma}^-$ *arXiv: 2605.19780*
 - $e^+e^- \rightarrow \Sigma^-\bar{\Sigma}^+$ *arXiv: 2602.23835*
- Observation of a charmless $\psi(3770)$ decay to a hyperon pair sheds new light on the long-standing puzzle of the large non- $D\bar{D}$ component of $\psi(3770)$.

$e^+e^- \rightarrow K^+K^-\psi(2S)$ arxiv:2407.20009



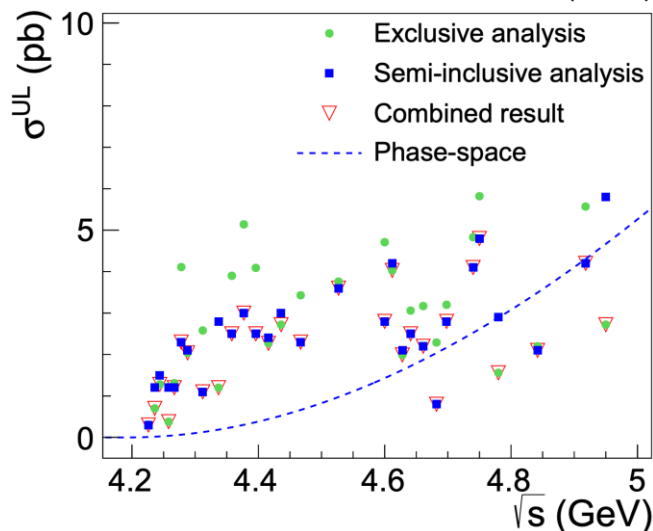
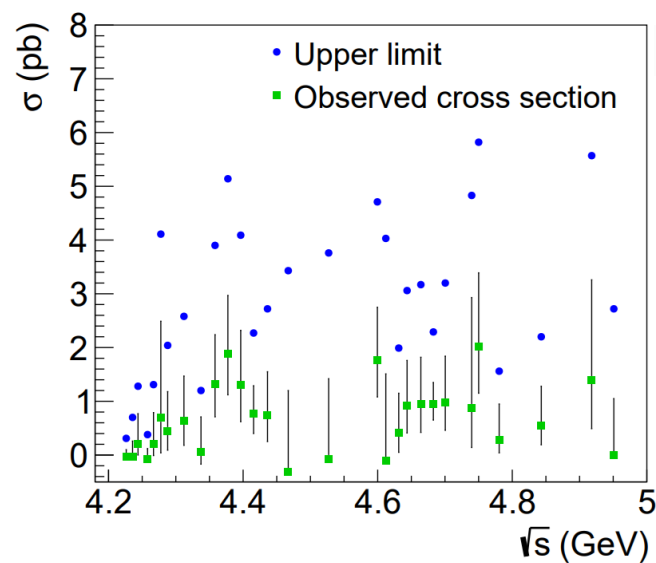
- $\sqrt{s}$: 4.669~4.950 GeV, 2.5 fb⁻¹
- Reconstruction method
 - ✓ K^+ , K^- , and J/ψ , reconstruct $\psi(2S)$ with K^+K^- recoiling mass
 - ✓ K^+ or K^- , $\psi(2S) \rightarrow \pi^+\pi^-J/\psi$, missing the untagged K
 - ✓ K^+ , K^- , and $\psi(2S) \rightarrow e^+e^-/\mu^+\mu^-$
 - ✓ K^+ or K^- , $\psi(2S) \rightarrow e^+e^-/\mu^+\mu^-$, missing the untagged K
- The $\sqrt{s}$ dependent cross section: → **No solid conclusion**
 - ✓ Can be well-described by a BW with free mass and width.
 - ✓ Can also be described with $Y(4710)$ (with mass and width fixed) and continuum process.
- The $\sqrt{s}$ dependent $R = \frac{\sigma(e^+e^- \rightarrow K^+K^-\psi(2S))}{\sigma(e^+e^- \rightarrow K^+K^-J/\psi)}$:
 - ✓ If $e^+e^- \rightarrow K^+K^-\psi(2S)$ and $e^+e^- \rightarrow K^+K^-J/\psi$ proceed with the same mechanism, R should be similar to trend of phase space.
 - ✓ At 4.843 GeV, a deviation of about 2σ with respect to the phase spaces is found → **A distinct production mechanism for $e^+e^- \rightarrow K^+K^-\psi(2S)$?**

$e^+e^- \rightarrow K^0 K^- \pi^+ J/\psi + c. c. \text{ JHEP 06, 101 (2026)}$



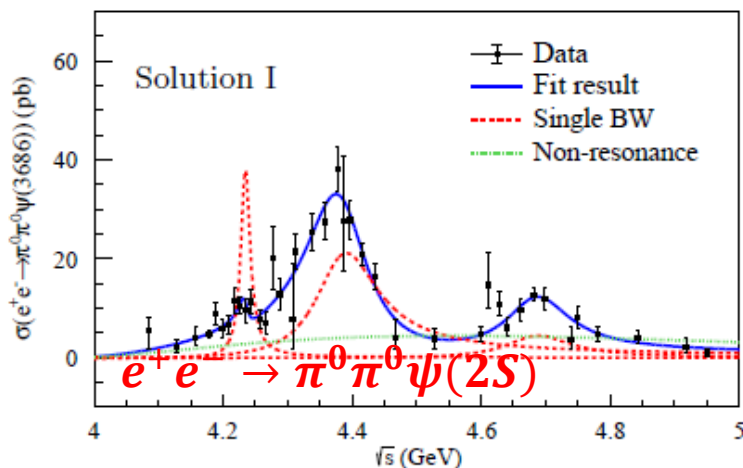
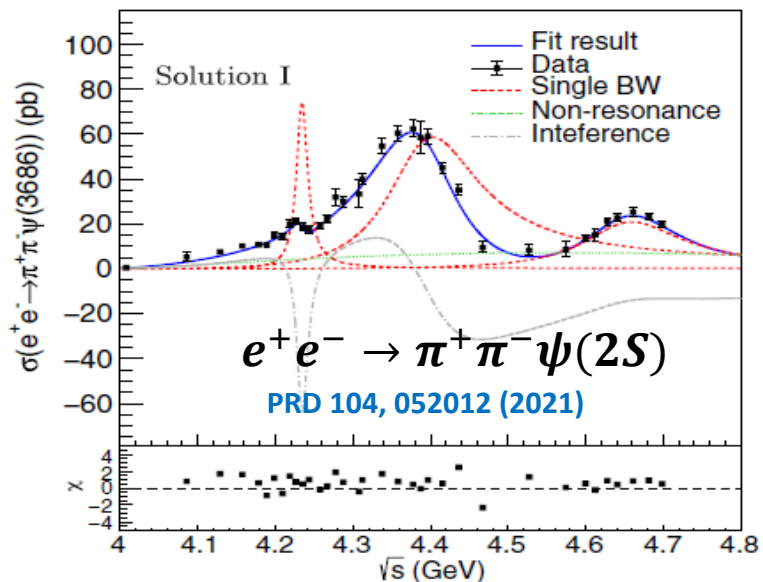
- $\sqrt{s}$: 4.396 ~ 4.950 GeV, 8.86 fb⁻¹
- $e^+e^- \rightarrow K_L^0 K^- \pi^+ J/\psi + c. c.$
 - ✓ Missing a $K_L^0 (K^0/\bar{K}^0)$: $K^- \pi^+ l^+ l^- (l = e, \mu)$
- $e^+e^- \rightarrow K_S^0 K^- \pi^+ J/\psi + c. c.$
 - ✓ Full $K_S^0 (\rightarrow \pi^+ \pi^-) K^- \pi^+ l^+ l^-$
 - ✓ Missing a $K^\pm$ or $\pi^\mp$: $K_S^0 (\rightarrow \pi^+ \pi^-) (K^-/\pi^+) l^+ l^-$
 - ✓ Miss a $K_S^0 (K^0/\bar{K}^0)$: $K^- \pi^+ l^+ l^-$
- The process is observed for the first time:
9.4 σ statistical significance with all data samples summed up.
- The cross section line-shape is tried to be described with a coherent sum of BW and PHSP:
The significance of resonance contribution is less than 2 σ in all fits.

$e^+e^- \rightarrow \eta\eta J/\psi$ arxiv:2601.15882



- $\sqrt{s}$: 4.226 ~ 4.950 GeV, 15.1 fb⁻¹
- Exclusively reconstructing $\eta\eta + J/\psi \rightarrow l^+l^-$: $\eta \rightarrow \gamma\gamma/\pi^+\pi^-\pi^0$
 - ✓ An observation with significance larger than 5 σ : 4.682 GeV (5.7 σ) and 4.750 GeV (8.9 σ)
- Inclusively reconstructing $\eta\eta(\text{missing}) + J/\psi \rightarrow l^+l^-$: $\eta \rightarrow \gamma\gamma$
 - ✓ No observation with significance larger than 5 σ
- Upper limits of cross sections are set with 90% confidence level.
- The combined upper limits show a strong deviation from phase space around 4.4 GeV, however, no clear structures are visible.

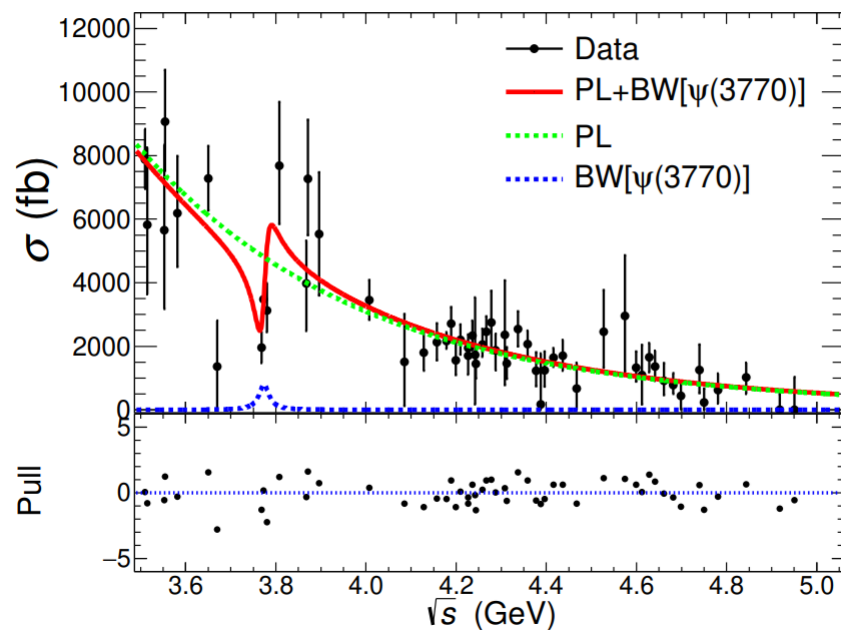
$e^+e^- \rightarrow \pi^0\pi^0\psi(2S)$ Phys.Rev.D 113, 112016 (2026)



- $\sqrt{s}$: 4.008 ~ 4.950 GeV, 22.1 fb⁻¹
- $\pi^0(\rightarrow \gamma\gamma)\pi^0(\rightarrow \gamma\gamma)\psi(2S)(\rightarrow \pi^+\pi^-J/\psi), J/\psi \rightarrow l^+l^-(l = e, \mu)$
- The obtained cross sections are found to be ~one-half of those in charged mode → Consistent with isospin symmetry expectation.
- Fit with a coherent sum of $Y(4230) + Y(4390) + Y(4660) +$ Non – resonant contribution.
- Resonance parameters are consistent between charged and neutral modes.
- The parameters of $Y(4390)$ ($> 5\sigma$) are consistent with previous measurements.
- The parameters of $Y(4660)$ ($> 5\sigma$) are roughly consistent with previous measurements.

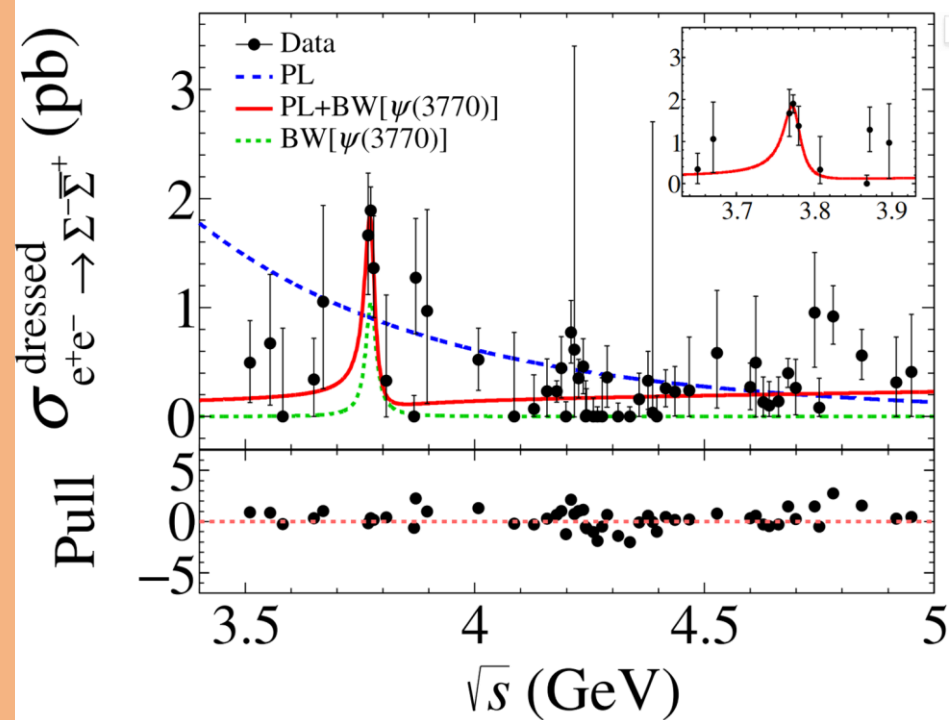


● $e^+e^- \rightarrow K^+ \Xi^0 \bar{\Sigma}^-$ arXiv: 2605.19780



- $\sqrt{s}$: 3.51 ~ 4.95 GeV, 44.55 fb⁻¹
- Partial reconstruction of $K^+ \Xi^0 (\Xi^0 \rightarrow \Lambda \pi^0 (\Lambda \rightarrow p \pi^-, \pi^0 \rightarrow \gamma \gamma)) \bar{\Sigma}^-$ (missing)
- A fit to the dressed cross sections of the $e^+e^- \rightarrow K^+ \Xi^0 \bar{\Sigma}^-$ reaction is performed under the assumption of a charmonium(-like) resonance i.e. $\psi(3770), \psi(4040), \psi(4160), Y(4230), Y(4360), \psi(4415), Y(4500), Y(4660)$ or $Y(4710)$ and a continuum contribution.
- The decay of $\psi(3770) \rightarrow K^+ \Xi^0 \bar{\Sigma}^-$ is observed for the first time with a significance of 6.0σ , including the systematic uncertainty.
- No significant signal for any other charmonium(-like) resonances is found.

● $e^+e^- \rightarrow \Sigma^- \bar{\Sigma}^+$ arXiv: 2602.23835

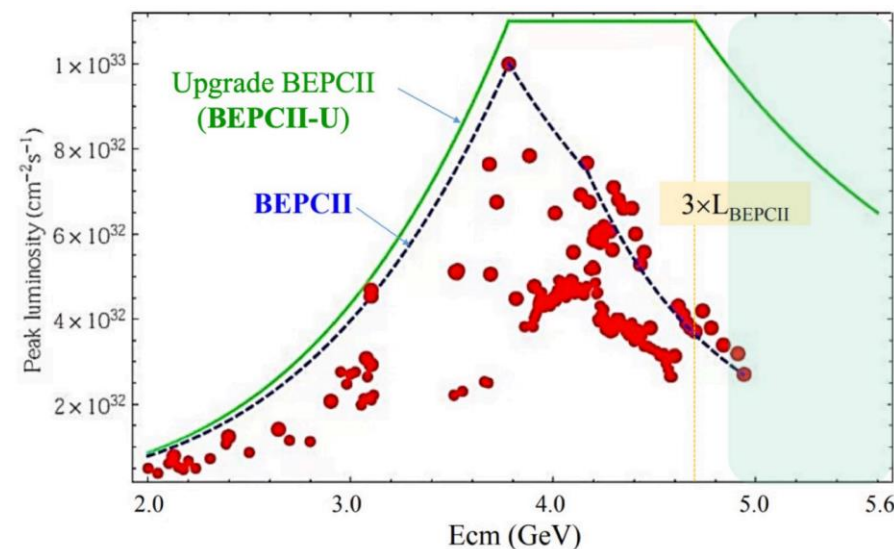


- $\sqrt{s}$: 3.51 ~ 4.95 GeV, 44 fb⁻¹
- Partial reconstruction of $e^+e^- \rightarrow \Sigma^- \bar{\Sigma}^+ (\Sigma^- \rightarrow n(\text{missing})\pi^-, \bar{\Sigma}^+ \rightarrow \bar{n}\pi^+)$
- Fitting the dressed cross sections with a coherent sum of a continuum and individual charmonium(-like) resonances.
- The decay of $\psi(3770) \rightarrow \Sigma^- \bar{\Sigma}^+$ is observed for the first time with a significance of 5.5 σ , including the systematic uncertainty.
- The branching fraction of $\psi(3770) \rightarrow \Sigma^- \bar{\Sigma}^+$ is measured to be $(2.9 \pm 0.3) \times 10^{-4}$ or $(1.1 \pm 0.1) \times 10^{-4}$.
- No significant signal for any other charmonium(-like) resonances is found.



Summary

- BESIII has made new progresses on vector charmonium(-like) states.
- There are still puzzles in vector charmonium(-like) states.
 - Are similar structures observed in different processes the same state?
 - What exactly are the structure and nature of them?
 - Are they theoretically predicted states?
- Higher-mass vector charmonium(-like) states may exist.
- BESIII has a good opportunity to contribute more.
 - ✓ BEPCII upgraded in 2024:
 - Higher luminosity in the XYZ region.
 - $\sqrt{s}$ up to 5.6 GeV.
- More analysis on vector charmonium-like states will come out in the future.





Back Up