Recent Studies on Multiple-Quark States at BESIII

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(On behalf of the BESIII Collaboration)

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Outline

- Introduction
- $e^+e^- \to K^+K^-\psi(2S)$
- $e^+e^- \to D_s^+D_{s1}(2536)^- + c.c.$ & $D_s^+D_{s2}^*(2573)^- + c.c.$
- $e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0 + c.c.$
- Summary

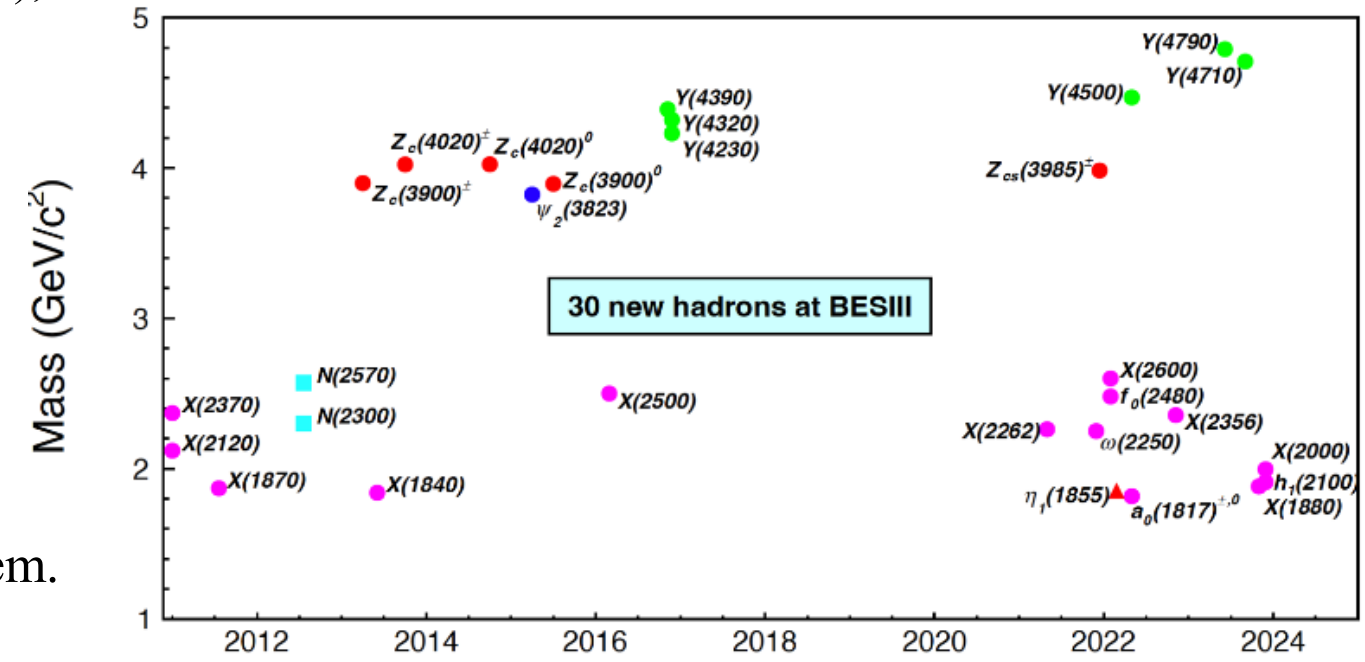
Introduction

- In last twenty years, a series of vector charmonium-like states, such as $Y(4230)$, $Y(4390)$, and $Y(4660)$, etc., have been discovered.

- These states exceeds the predictions of the quark potential model, are viewed as good exotic candidates with complex internal structure (tetra-quarks, molecule, hybrid ...).

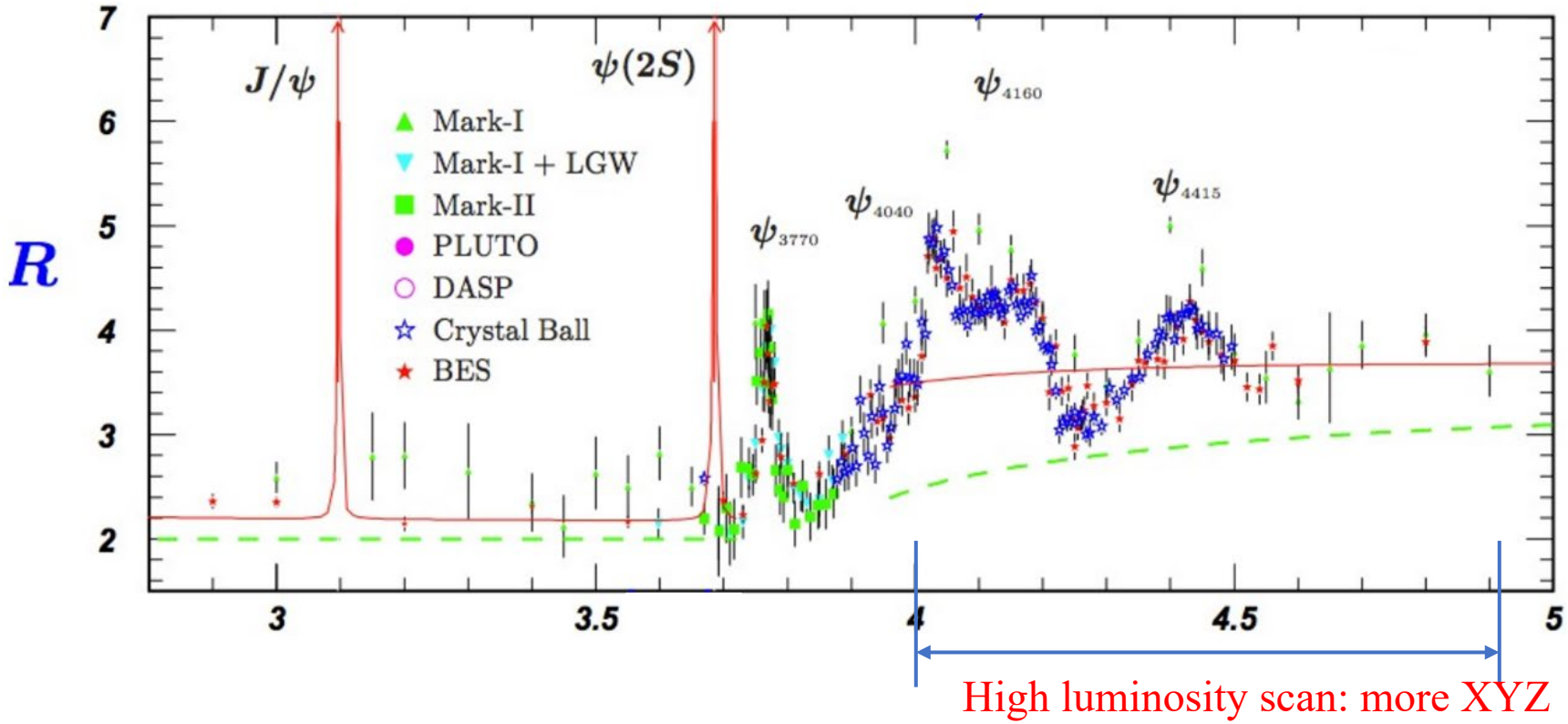
- Further investigations on the line shapes of the cross sections will shed light on the nature of them. This talk will report three relevant studies about hidden-charm, open-charm, and baryon-involved.

New hadrons discovered at BESIII



Introduction

BESIII Data



$e^+e^- \to K^+K^-\psi(2S)$

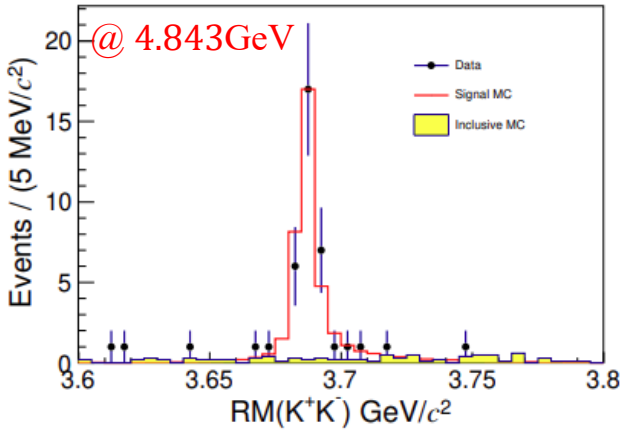
- Cross section of $e^+e^- \to K^+K^-\psi(2S)$ is first measured with 2.5fb^{-1} data collected at $\sqrt{s} = 4.66$ to 4.95 GeV.

  ➡
  - ➢ Vector charmonium-like states
  - ➢ Hidden-charm open-strange tetraquark candidates

- The measurements are carried out using several partial reconstruction techniques.

Reaction chain :

Decays
$e^+e^- \to K^+K^-\psi(2S)$
$e^+e^- \to K^\pm Z_{cs}^\mp, Z_{cs}^\mp \to K^\mp\psi(2S)$
$\psi(2S) \to J/\psi\pi^+\pi^-, J/\psi\pi^0\pi^0$
$\psi(2S) \to J/\psi\eta$
$\psi(2S) \to e^+e^-, \mu^+\mu^-$
$J/\psi \to e^+e^-, \mu^+\mu^-$



A distinct $\psi(2S)$ signal peak is evident.

	N_{obs}	N_{sdb}	N_{sig}	ϵ	σ^B
4700	29	3	27.5	0.286	1.49 ± 0.29
4740	17	1	16.5	0.292	3.08 ± 0.77
4750	22	1	21.5	0.291	1.79 ± 0.39
4780	50	5	47.5	0.294	2.69 ± 0.40
4843	23	6	20	0.287	1.03 ± 0.25
4918	6	1	5.5	0.288	0.67 ± 0.30
4950	8	1	7.5	0.286	1.18 ± 0.44

The signal yield is obtained by counting method.

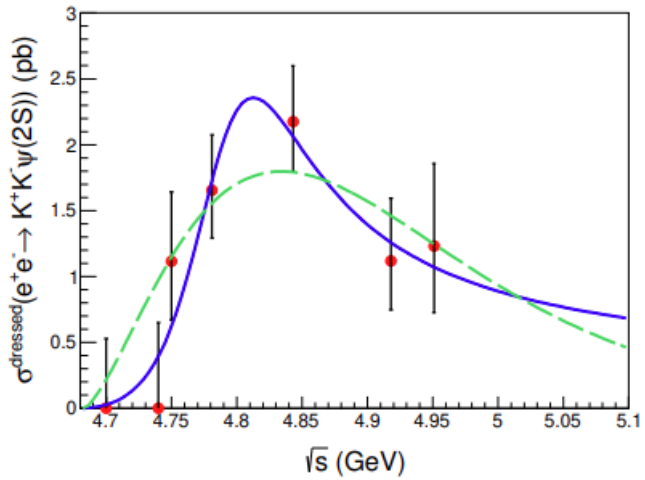
arXiv: 2407.20009, submitted to PRL

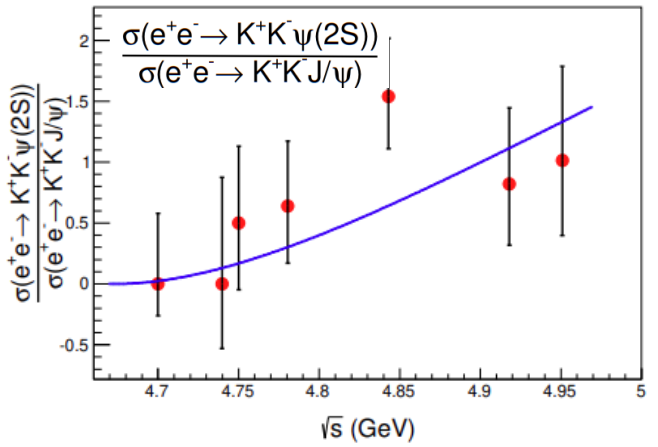
$e^+e^- \to K^+K^-\psi(2S)$

- A study of the cross section line shape has been performed.
  - Assuming the observed signals are from a vector resonance Y decay.
  - A phase space modified Breit-Wigner function is applied to describe the energy-dependent dressed cross section.

$$BW(s) = \frac{M}{\sqrt{s}} \cdot \frac{\sqrt{12\pi\Gamma_{tot}\Gamma_{ee}\mathcal{B}_{Y\to K^+K^-\psi(2S)}}}{s - M^2 + iM\Gamma_{tot}} \cdot \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M)}}$$

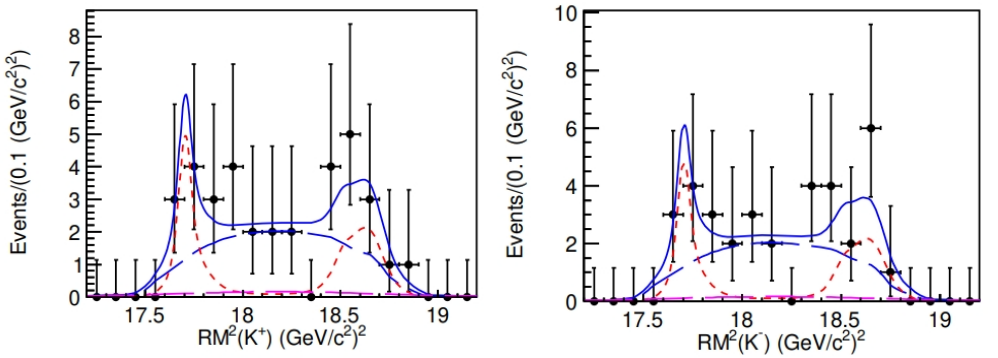
  - It is difficult to indicate the source of the observed $e^+e^- \to K^+K^-\psi(2S)$ signals due to the low statistics.
- The ratio of the phase space of the three-body $K^+K^-\psi(2S)$ to K^+K^-J/ψ reactions also has been studied.
  - The measured ratio at $\sqrt{s} = 4.843$ GeV has about a 2σ statistical deviation from that of phase space, and implied new source of $K^+K^-\psi(2S)$ exist.

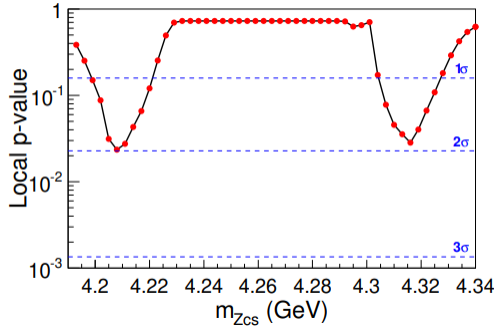


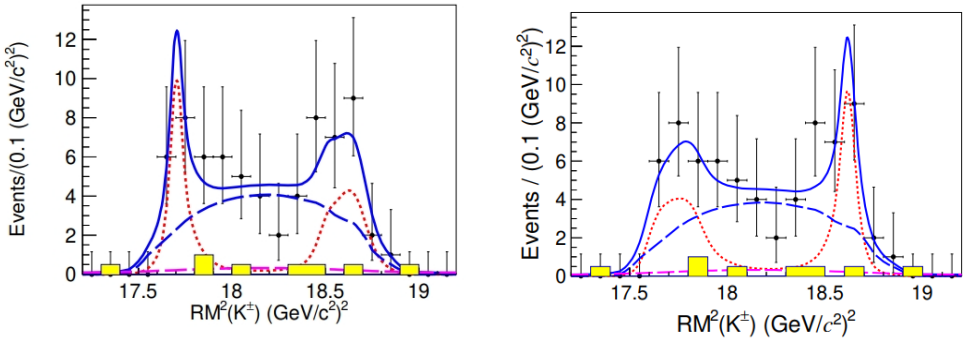


$e^+e^- \to K^+K^-\psi(2S)$

- Study of intermediate states in the $K^+K^-\psi(2S)$ system.
  - A simultaneous fit is perform to extract the $Z_{cs}^{\pm}$ signal yield.
  - The masses around 4.205 GeV and 4.315 GeV give the minimum local p-values, local significances about 2σ.
  - The mass of the Z_{cs} is assumed to be around 4.208 GeV and 4.316 GeV with a reflection at higher mass.







$e^+e^- \to D_s^+ D_{s1}(2536)^-$ & $D_s^+ D_{s2}^*(2573)^-$

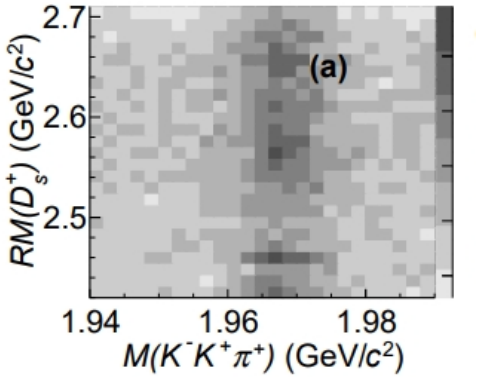
- Measurements of cross section of $e^+e^- \to D_s^+ D_{s1}(2536)^- + c.c.$ and $e^+e^- \to D_s^+ D_{s2}^*(2573)^- + c.c.$ with 6.6fb^{-1} data collected at $\sqrt{s} = 4.53$ to 4.95 GeV.

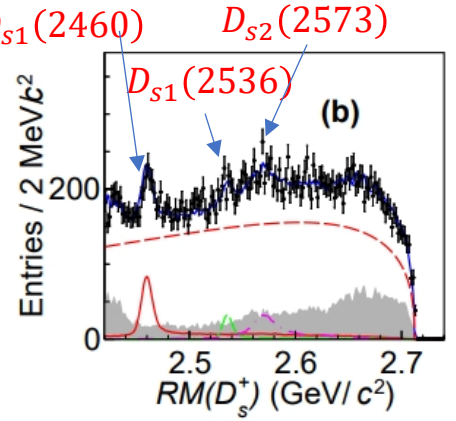
- The absolute branching fractions of $D_{s1}(2536)^- \to \bar{D}^{*0} K^-$ and $D_{s2}^*(2573)^- \to \bar{D}^0 K^-$ are measured for the first time.

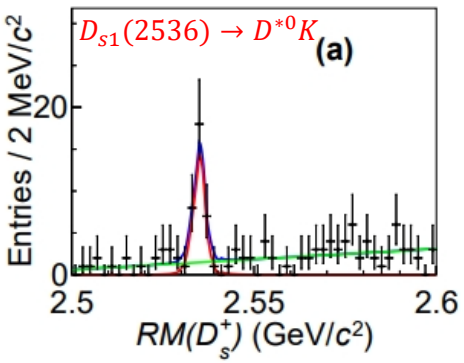
  - Distributions of RM(D_s^+) versus M($K^+K^-\pi^+$) from data at $\sqrt{s}$ = 4.680 GeV.

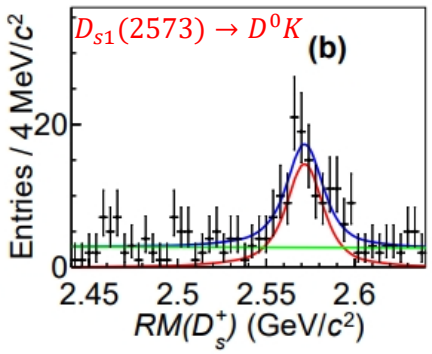
- Measurement method:

  - Inclusive method: recoil $D_s^\pm \to D_{sj}^\mp$
  - Exclusive method: recoil $D_s^\pm K^\mp \to D^{*0}(\bar{D}^{*0})$ or $D^0(\bar{D}^0)$









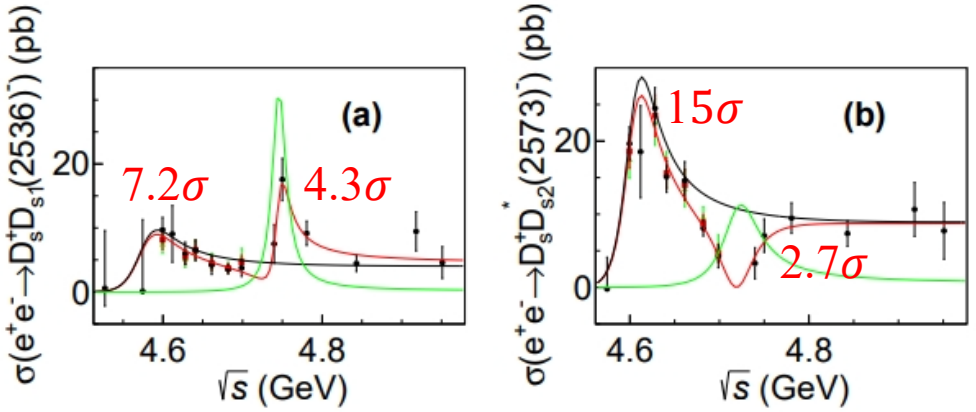
arXiv: 2407.07651, submitted to PRL

$e^+e^- \to D_s^+ D_{s1}(2536)^-$ & $D_s^+ D_{s2}^*(2573)^-$

- A study of the cross section line shape has been performed.

$$\sigma(\sqrt{s}) = |BW_0(\sqrt{s})e^{i\phi_0} + BW_1(\sqrt{s})e^{i\phi_1}|^2$$

  - The 1st structure with mass around 4.60 GeV, consistent with early Belle measurement.
  - The 2nd structure with mass around 4.75 GeV, maybe the same as those in K^+K^-J/ψ & $D_s^* D_s^*$.



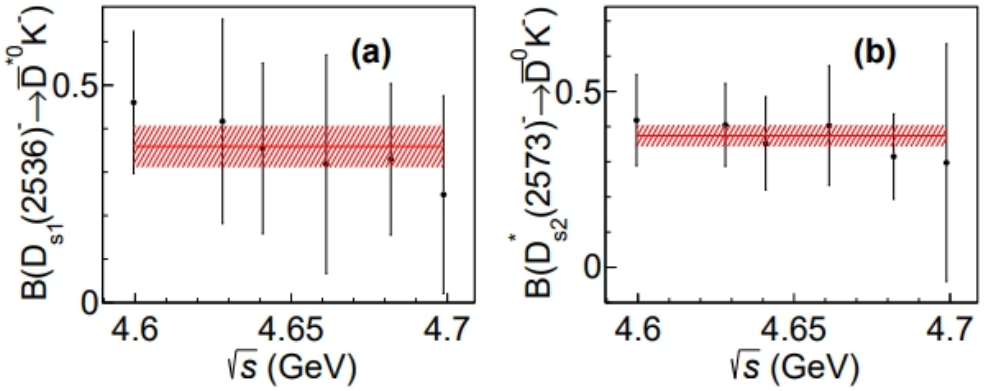
- The absolute branching Fractions .

$$L_i(\sigma_{i,j}^{\rm inc}, \delta_{i,j}^{\rm inc}, \sigma_{i,j}^{\rm exc}, \delta_{i,j}^{\rm exc}; \sigma_{i,j}, \mathcal{B}_i) =$$
$$\prod_{j=1}^{6} L_{i,j}^{\rm inc}(\sigma_{i,j}^{\rm inc}, \delta_{i,j}^{\rm inc}; \sigma_{i,j}) L_{i,j}^{\rm exc}(\sigma_{i,j}^{\rm exc}, \delta_{i,j}^{\rm exc}; \sigma_{i,j}, \mathcal{B}_i),$$

$\mathrm{BF}(D_{s1}(2536)^- \to \bar{D}^{*0}K^-) = (35.9 \pm 4.8 \pm 3.5)\%$

$\mathrm{BF}(D_{s2}^*(2573)^- \to \bar{D}^0 K^-) = (37.4 \pm 3.1 \pm 4.6)\%$

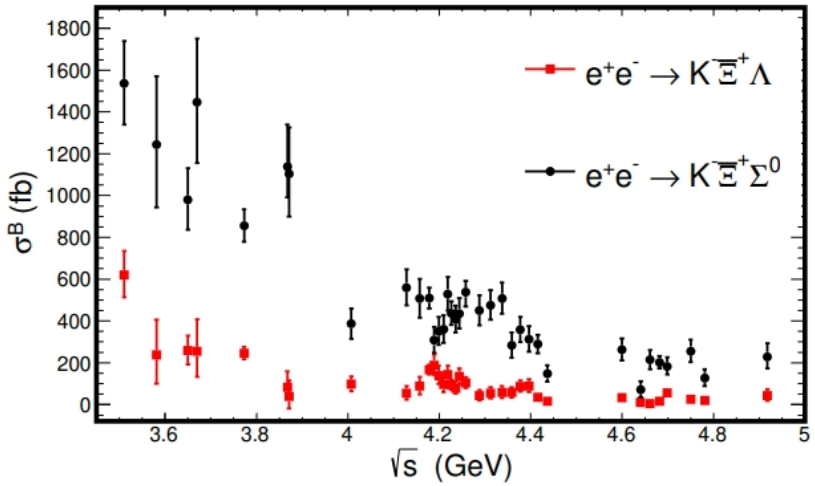
Better understanding the inner structure.

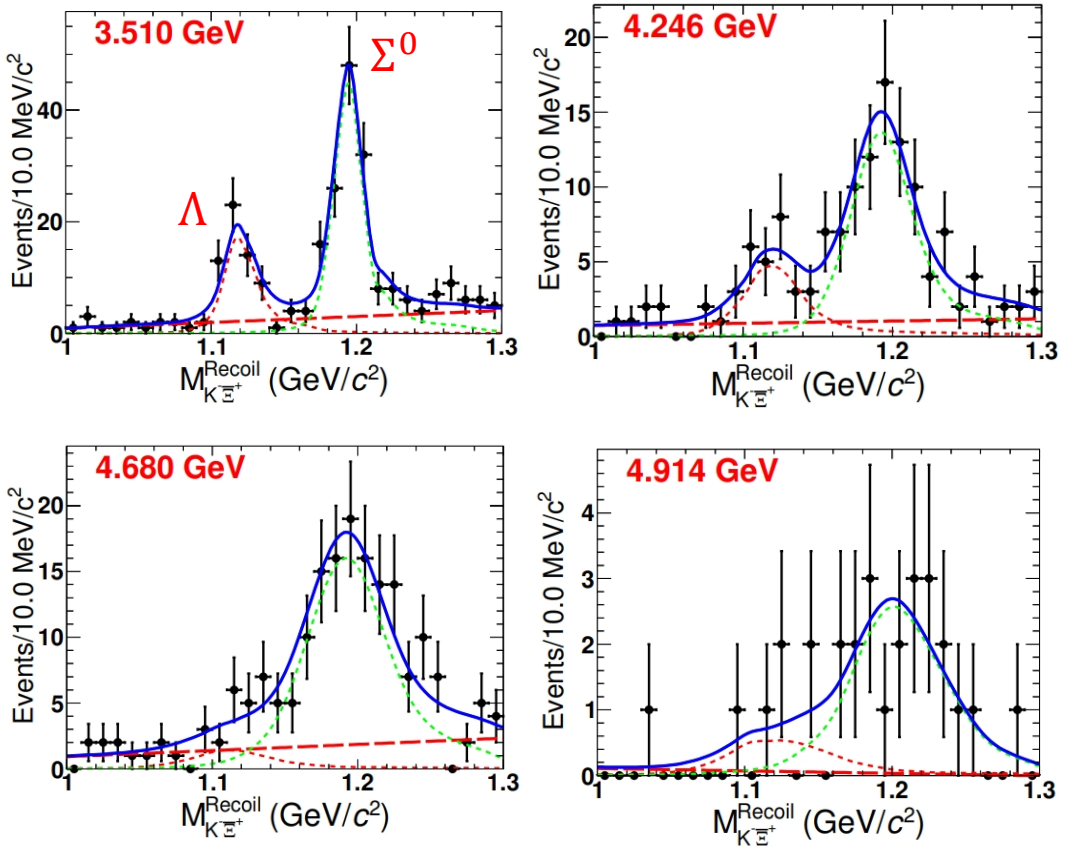


$e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0$

- Cross section of $e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0$ is measured with 25fb^{-1} data collected at $\sqrt{s} = 3.51$ to 4.91 GeV.
  - A partial-reconstruction technique is employed. (recoil $K^-\bar{\Xi}^+$)

$$M^{\text{recoil}}_{K^-\bar{\Xi}^+} = \sqrt{(\sqrt{s} - E_{K^-\bar{\Xi}^+})^2 - |\vec{p}_{K^-\bar{\Xi}^+}|^2}$$





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$e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0$

- A study of the cross section line shape has been performed.

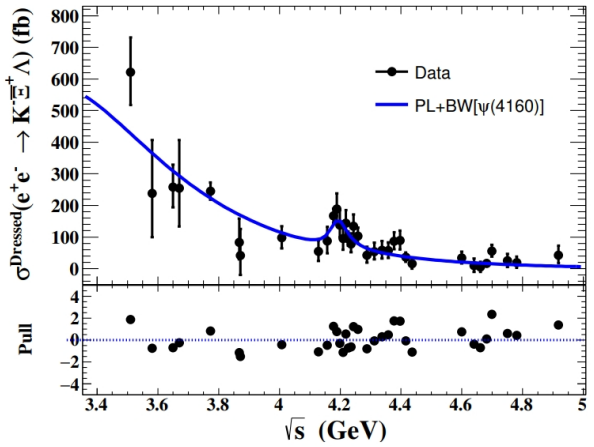
  - Assuming the $e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0$ signals are produced by a resonance decay and the continuum process.

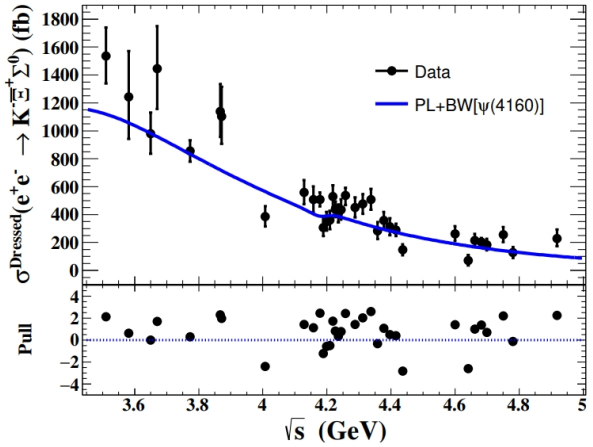
$$\sigma^{\rm dressed}(\sqrt{s}) = \left| c_0 \frac{\sqrt{P(\sqrt{s})}}{\sqrt{s}^n} + e^{i\phi}{\rm BW}(\sqrt{s})\sqrt{\frac{P(\sqrt{s})}{P(M)}} \right|^2,$$

$$ {\rm BW}(\sqrt{s}) = \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}\Gamma}}{s - M^2 + iM\Gamma}.$$

$K^-\bar{\Xi}^+\Lambda$						
Resonance	$\Gamma_{ee}\mathcal{B}$ (10^{-3} eV)		ϕ (rad)		$\chi^2/n.d.f$	S (σ)
	I	II	I	II		
$\psi(3770)$	21.0 ± 3.7 (< 25.0)	1.7 ± 0.5	-1.9 ± 0.3	-2.8 ± 0.2	1.8	0.5
$\psi(4040)$	45.0 ± 6.3 (< 62.0)	5.1 ± 2.3	-1.3 ± 0.1	-1.3 ± 0.1	1.4	2.8
$\psi(4160)$	2.1 ± 0.2	1.5 ± 0.4	-1.6 ± 0.1	-1.3 ± 0.2	1.1	4.4
$\psi(4230)$	21.3 ± 1.5 (< 24.9)	0.6 ± 0.3	-1.8 ± 0.1	2.5 ± 0.3	1.5	2.8
$\psi(4360)$	28.9 ± 2.7 (< 35.8)	0.6 ± 0.1	-1.8 ± 0.1	-2.9 ± 0.1	1.6	1.7
$\psi(4415)$	9.3 ± 2.3 (< 14.3)	1.7 ± 1.1	-1.9 ± 0.1	-2.3 ± 0.2	1.6	1.2
$\psi(4660)$	6.8 ± 3.5 (< 13.0)	0.8 ± 1.5	-1.6 ± 0.1	-1.6 ± 0.1	1.7	1.2

  - Evidence is found for the $\psi(4160) \to K^-\bar{\Xi}^+\Lambda$ decay with a significance of 4.4σ.





Summary

- Data samples with energies ranging from 3.51 to 4.95 GeV was used to conduct a series of cross section measurements, including open-charm, hidden-charm, and baryon final states:
  - ✓ $e^+e^- \to K^+K^-\psi(2S)$, is observed for the first time, no significant $Z_{cs}^{\pm}$ signals are observed.
  - ✓ $e^+e^- \to D_s^+D_{s1}(2536)^-$ & $D_s^+D_{s2}^*(2573)^-$, first structure consistent with $Y(4626)/Y(4620)$, second structure could be $Y(4710)/Y(4790)$.
  - ✓ $e^+e^- \to K^-\bar{\Xi}^+\Lambda/\Sigma^0$, evidence for $\psi(4160) \to K^-\bar{\Xi}^+\Lambda$ is found for the first time with a significance of 4.4σ.
- BEPCII will increase the luminosity at $\sqrt{s}$ = 4.70 GeV by a factor of 3, more exciting results on the way!

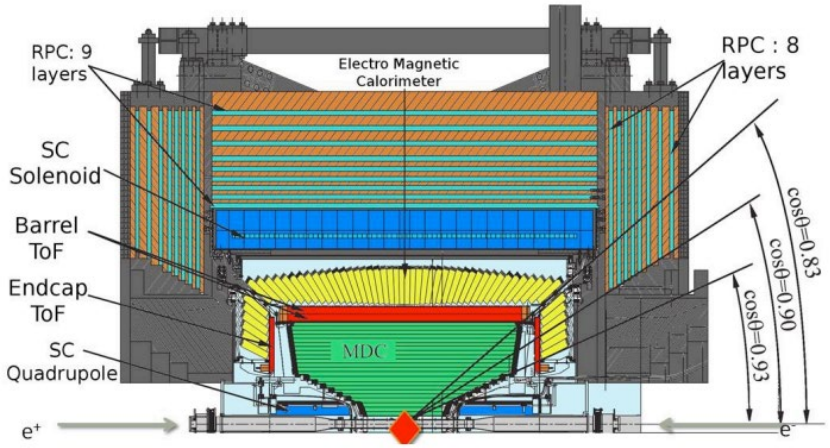
Thanks for your attention !

Back Up

Beijing Electron Positron Collider II (BEPCII)

2004: started BEPCII/BESIII construction
Double rings
Beam energy: 1~2.5 GeV
Designed luminosity: 1×10^{33} $cm^{-2}s^{-1}$
2008:test run
2009~today: BESIII physics run

Beijing Spectrometer (BESIII)



A general purpose spectrometer