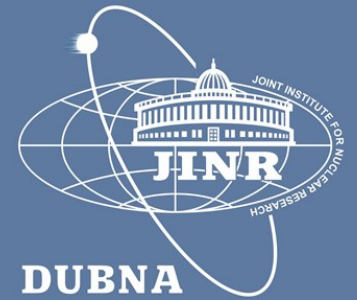


BESIII



Study of charmonia production in e^+e^- annihilation at center-of-mass energies above 3.81 GeV

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The XIXth Workshop on High Energy Spin Physics
Dubna, Russia, September 4-8, 2023

The BESIII experiment

e^+e^- collisions in the τ -charm energy region, $L_{\text{peak}} = 1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Data taking from 2009: the largest data sets at the J/ψ , $\psi(3686)$, and $\psi(3770)$ peaks; scan data at $\sqrt{s} = 2.00 - 4.95 \text{ GeV}$

Superconducting Solenoidal Magnet: 0.9/1.0 T

MDC

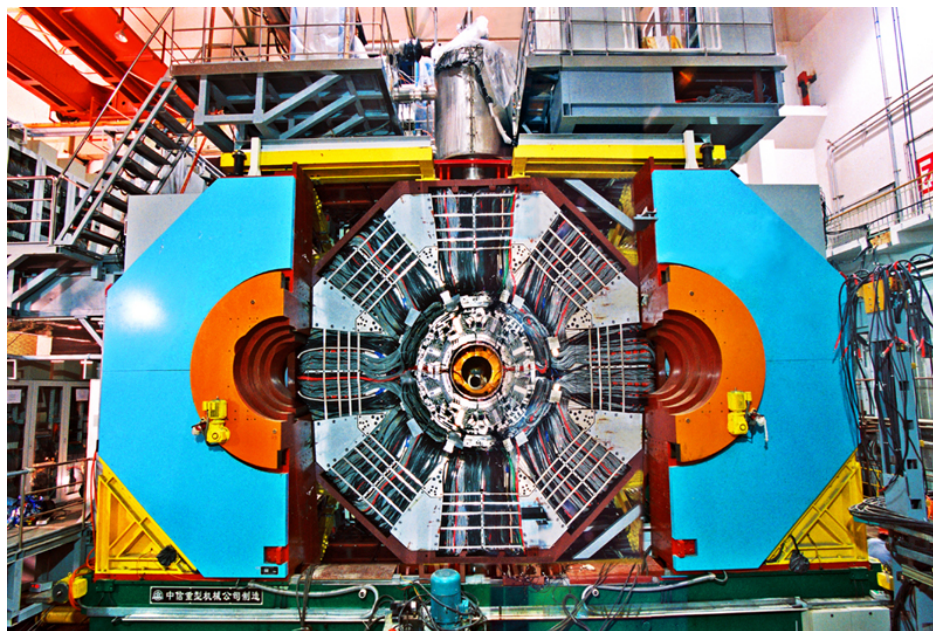
dE/dx : 6%

σ_p/p : 0.5% at 1 GeV/c

TOF

σ_T : 68 ps

110 ps (60 ps)



EMC

$\Delta E/E$: 2.5% (5%) at 1 GeV

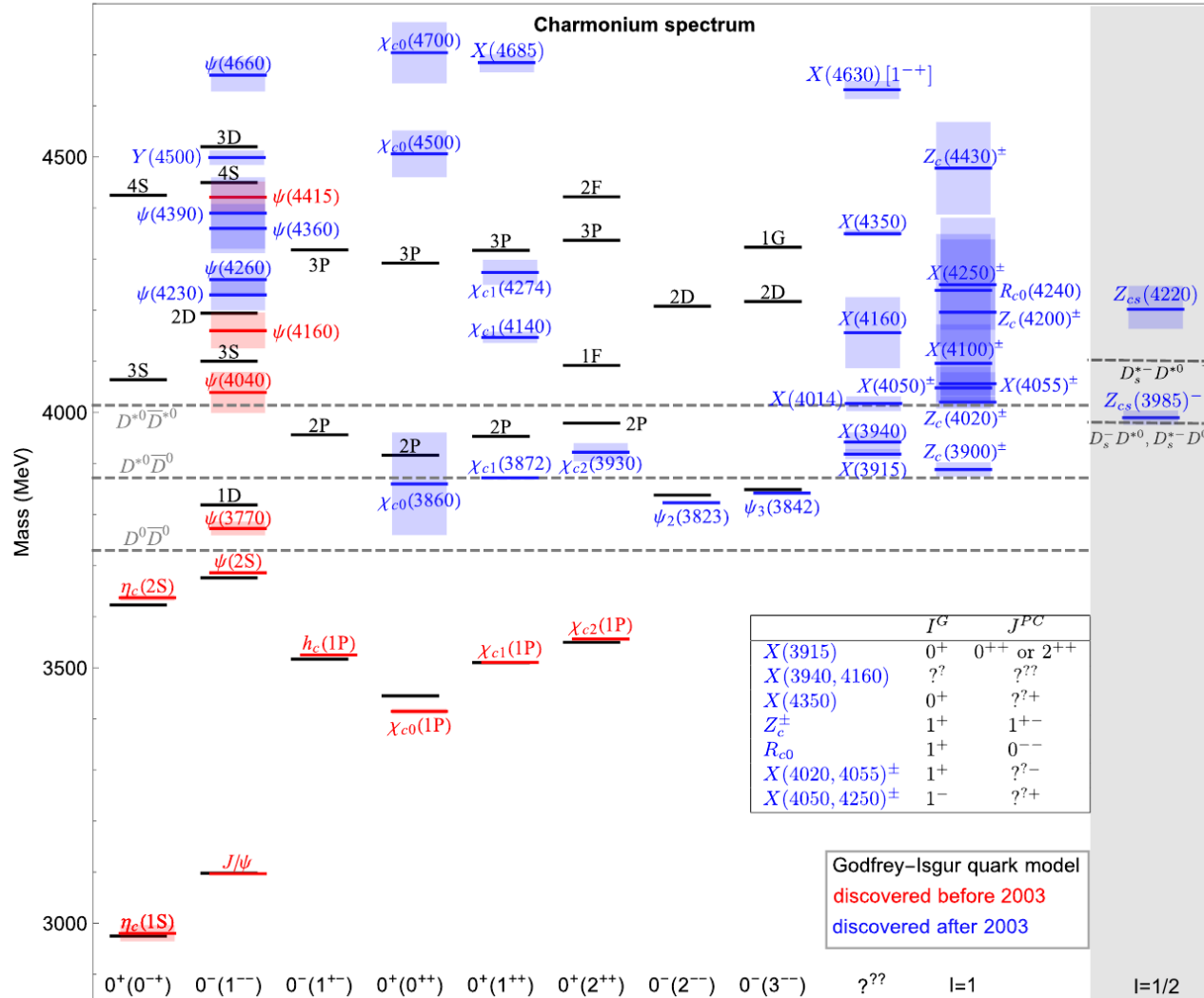
σ_z : 0.6 cm/ \sqrt{E}

MUC

$\sigma_{R\Phi}$: 2 cm

Figure: The BESIII detector at BEPCII.

Charmonium(-like) states



The first observation of three charmonium-like states in $e^+e^- \rightarrow D^{*0}D^{*-}\pi^+$

Data: $\mathcal{L} = 17.9 \text{ fb}^{-1}$, $\sqrt{s} = 4.189 - 4.951 \text{ GeV}$

Phys.Rev.Lett. 130 (2023) 12, 121901

Channel: $e^+e^- \rightarrow D^{*0}D^{*-}\pi^+ + \text{cc.}$, $D^{*0}(D^{*-}) \rightarrow D^0(D^+)\pi^0$, $D^0 \rightarrow K^-\pi^+/K^-\pi^+\pi^0/K^-\pi^+\pi^+\pi^-$, $D^- \rightarrow K^+\pi^-\pi^-$, $\pi^0 \rightarrow \gamma\gamma$

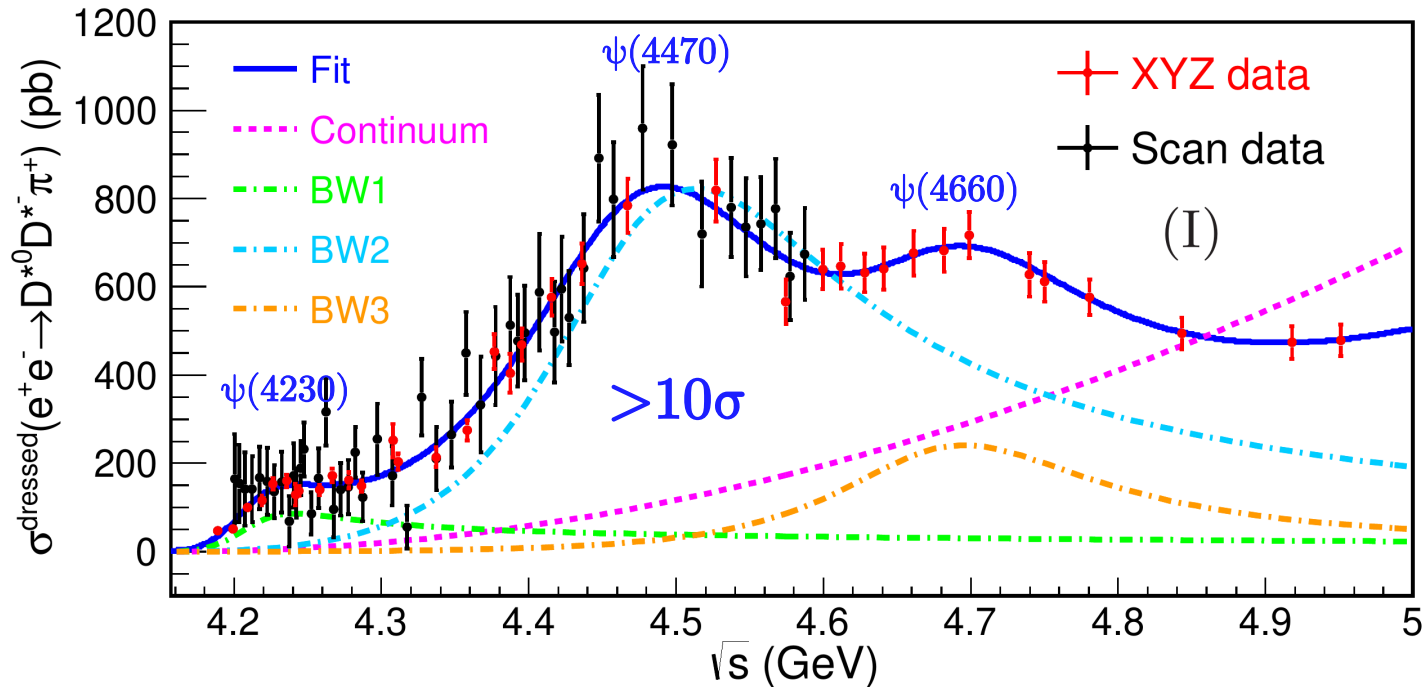


Figure: The fit result to the dressed cross section line shape of $e^+e^- \rightarrow D^{*0}D^{*-}\pi^+$.

The first observation of a new X(3872) production process $e^+e^- \rightarrow \omega X(3872)$

Data: $\mathcal{L} = 4.7 \text{ fb}^{-1}$, $\sqrt{s} = 4.661 - 4.951 \text{ GeV}$

Phys.Rev.Lett. 130 (2023) 15, 151904

Channel: $e^+e^- \rightarrow \omega X(3872)$, $X(3872) \rightarrow \pi^+\pi^-J/\psi$, $J/\psi \rightarrow l^+l^-$ ($l = e, \mu$), $\omega \rightarrow \pi^+\pi^-\pi^0$, $\pi^0 \rightarrow \gamma\gamma$

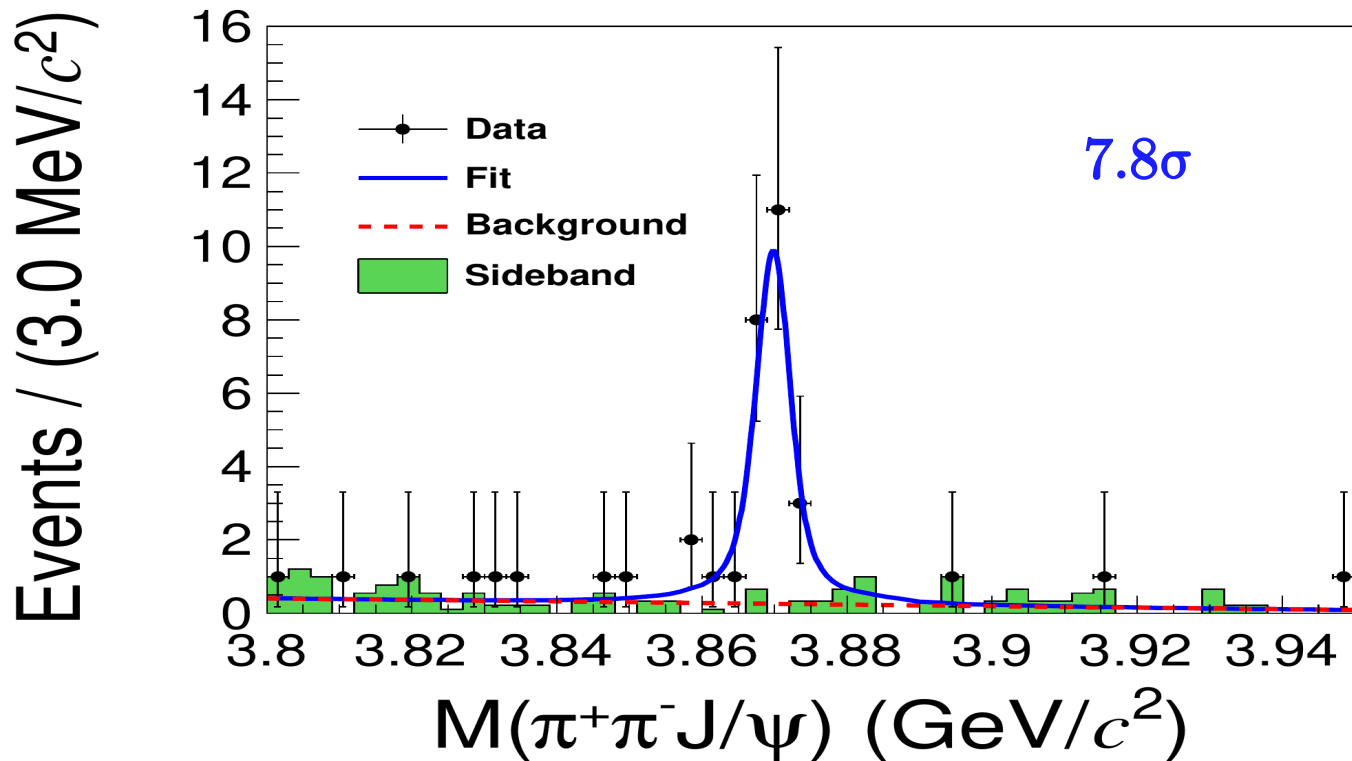


Figure: Fit to the $M(\pi^+\pi^-J/\psi)$ distribution. The filled histogram represents events from the ω and J/ψ two-dimensional sidebands.

Observation of charmonium-like states in the process

$$e^+e^- \rightarrow K_s^0 K_s^0 J/\psi$$

Data: $\mathcal{L} = 21.2 \text{ fb}^{-1}$, $\sqrt{s} = 4.128 - 4.951 \text{ GeV}$

Phys.Rev.D 107 (2023) 9, 092005

Channel: $e^+e^- \rightarrow K_s^0 K_s^0 J/\psi$, $J/\psi \rightarrow l^+ l^-$ ($l = e, \mu$), $K_s^0 \rightarrow \pi^+ \pi^-$, $K_s^0 \rightarrow \pi^+ \pi^-$ or $\pi^0 \pi^0$

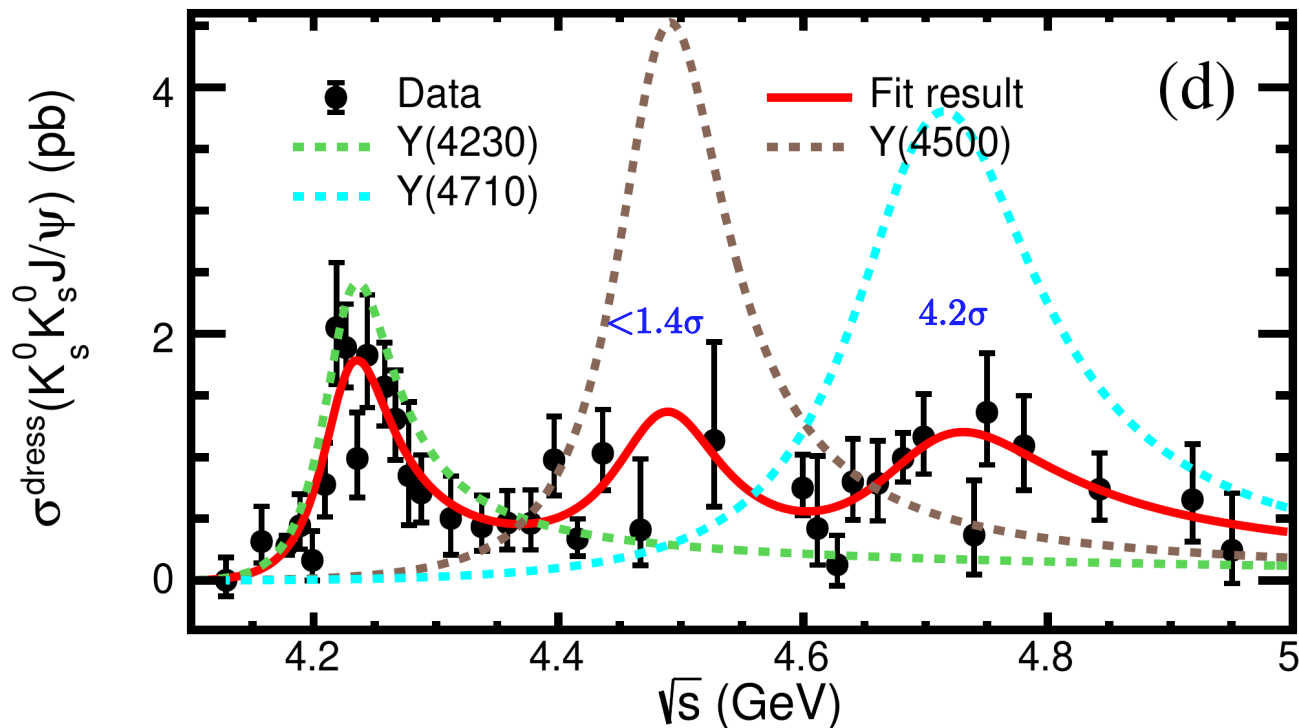


Figure: Maximum likelihood fit to the dressed cross sections of $e^+e^- \rightarrow K_s^0 K_s^0 J/\psi$. The mass and width of the $Y(4500)$ state are fixed.

The first observation of charmonium-like states in the process $e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$

Data: $\mathcal{L} = 11.3 \text{ fb}^{-1}$, $\sqrt{s} = 4.23 - 4.70 \text{ GeV}$

Phys.Rev.Lett. 129 (2022) 10, 102003

Channel: $e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$, $\psi_2(3823) \rightarrow \gamma\chi_{c1}$, $\chi_{c1} \rightarrow \gamma J/\psi$, $J/\psi \rightarrow l^+l^-$ ($l = e, \mu$)

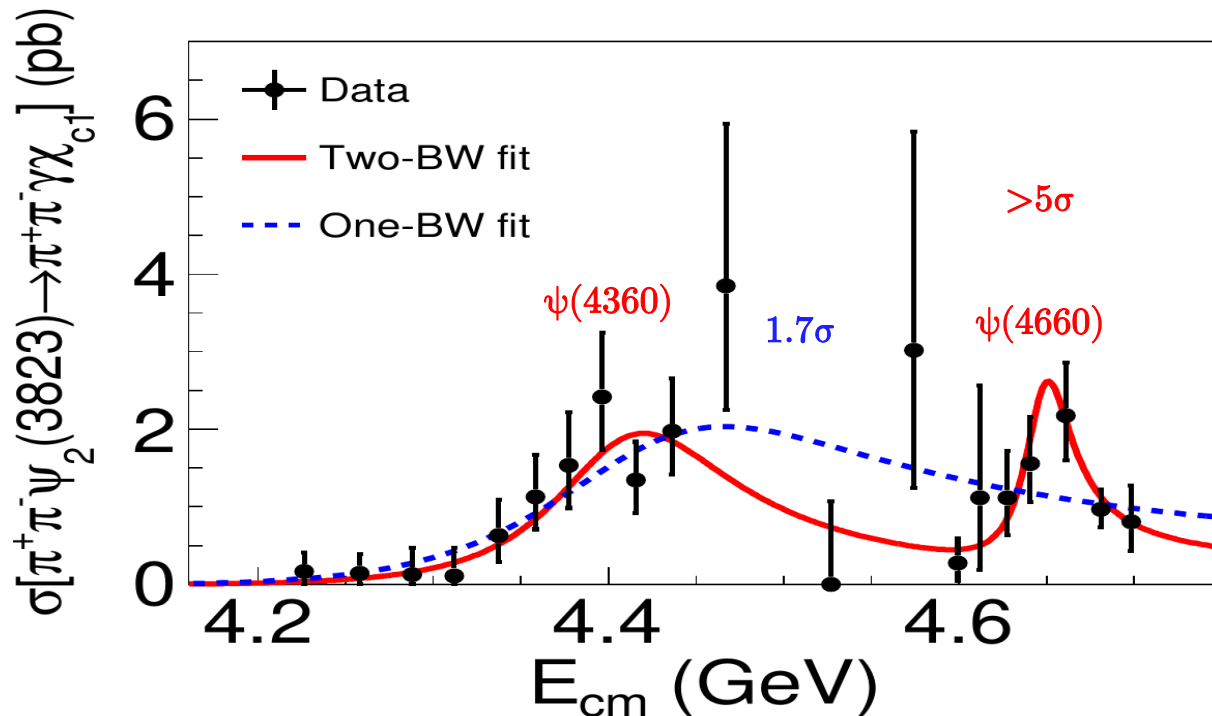
The most precise measurement of the mass:

$M[\psi_2(3823)] = 3823.12 \pm 0.43_{\text{stat}} \pm 0.13_{\text{syst}} \text{ MeV}/c^2$

The most stringent constraint on the width:

$\Gamma[\psi_2(3823)] < 2.9 \text{ MeV}$ at the 90% C.L.

Figure: Result of the fit to the \sqrt{s} -dependent cross section $\sigma[e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)]$ times the branching ratio $B[\psi_2(3823) \rightarrow \gamma\chi_{c1}]$.



Prompt inclusive charmonium production

Goal:

- **Test the NRQCD factorization hypothesis:** the independence of Long Distance Matrix Elements (LDME) that describe the hadronization of the $c\bar{c}$ pair from the process (hadron-hadron collisions, electroproduction, or e^+e^- annihilation);
- **Clarify the contribution of the color octet channel** in the range of \sqrt{s} below the $J/\psi c\bar{c}$ threshold (~ 6 GeV): the color-octet LDMEs are non-zero if $\sigma > 10$ pb at $\sqrt{s} = 4.6 \sim 5.6$ GeV (Eur. Phys. J. C (2017) 77: 597);
- **Test if unknown channels/states exist.**

Data only available at $\sqrt{s} = 10.6$ GeV:

- ✓ 2.5 ± 0.3 pb (BaBar)
- ✓ 1.5 ± 0.2 pb (Belle)
- ✓ 1.9 ± 0.2 pb (CLEO)

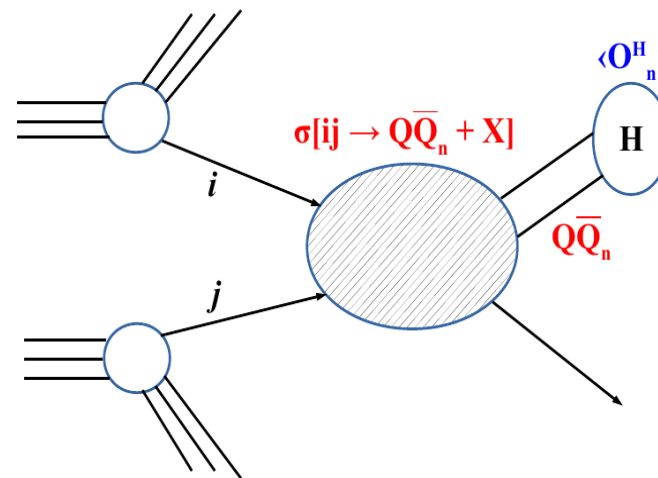


Figure: NRQCD factorization. The LDMEs $\langle O_n^H \rangle$ are determined from experimental data.

Prompt inclusive J/ψ and $\psi(3686)$ production (I)

Data: $\mathcal{L} = 22 \text{ fb}^{-1}$, $\sqrt{s} = 3.81 - 4.95 \text{ GeV}$

Channel: $J/\psi \rightarrow \mu^+\mu^-$, $\psi(3686) \rightarrow J/\psi \pi^+\pi^-$, $\chi_{cJ} \rightarrow \gamma J/\psi$, ($J = 1, 2$)

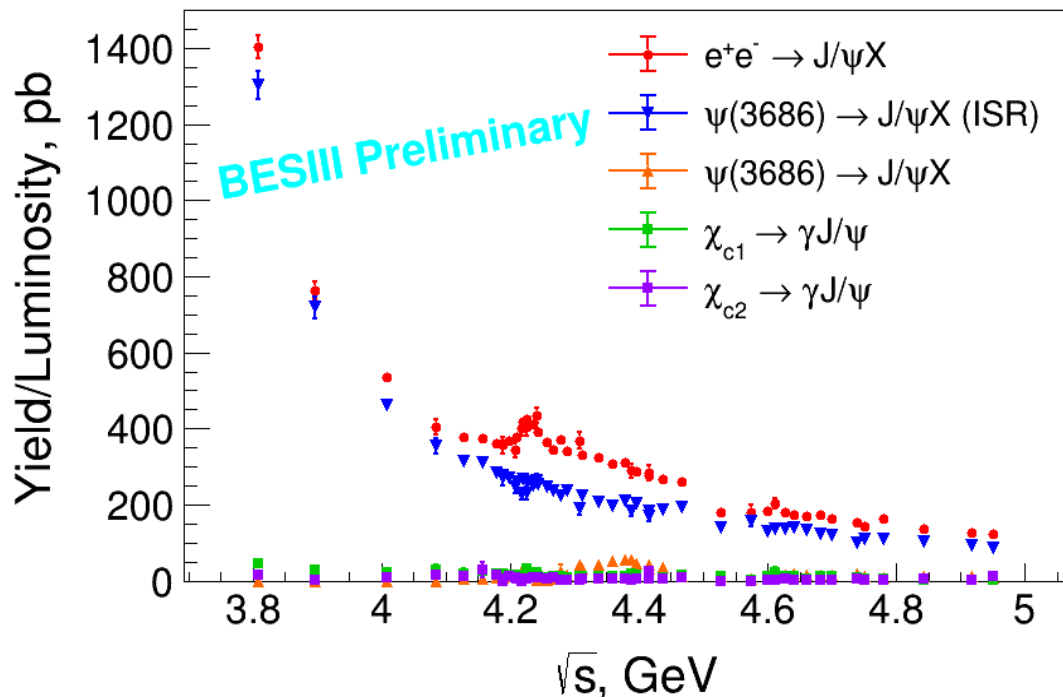


Figure: Yield of J/ψ from different sources normalized to corresponding luminosity.

Prompt inclusive J/ψ and $\psi(3686)$ production (II)

The preliminary result for the prompt inclusive production of

the J/ψ meson in the range
 $4.53 \sim 4.95$ GeV is
 $\sigma = 14.0 \pm 1.7_{\text{stat}}$ pb

the $\psi(3686)$ meson in the range
 $4.84 \sim 4.95$ GeV is
 $\sigma = 16.9 \pm 2.8_{\text{stat}}$ pb

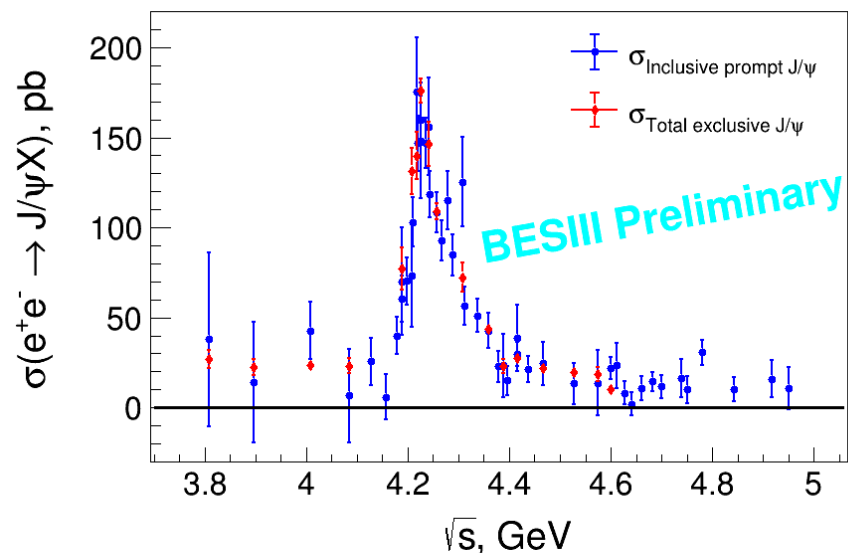


Figure: Prompt inclusive and total exclusive J/ψ cross sections.

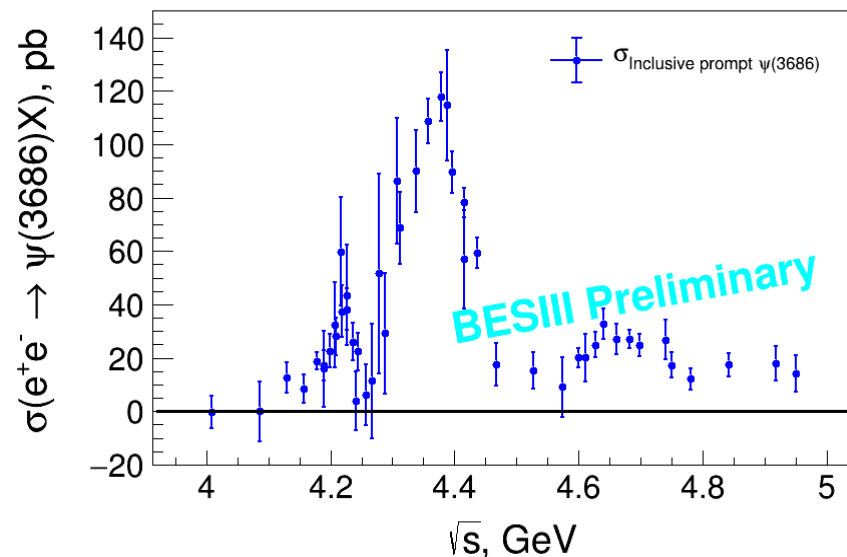


Figure: Prompt inclusive $\psi(3686)$ cross-sections.

Summary

- The charmonia production is a proven tool for verifying the basics of QCD;
- The BESIII experiment successfully applies e^+e^- annihilation data sets to search for new exotic charmonium-like states and study their properties;
- The prompt inclusive production of classical charmonia allows the BESIII experiment to test various theoretical models of the strong interaction at low energies, especially, NRQCD.

Thank you for your attention!