Charmonium study at BESIII

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The BESIII experiment

- **The Beijing Spectrometer III (BESIII)** at the electron-positron collider BEPCII is a highly precise general-purpose detector designed for high luminosity e^+e^- collisions in the τ-charm energy region.

- Since 2009, the BESIII detector has been collecting the largest data sets at the **J/ψ**, **$\psi(3686)$**, and **$\psi(3770)$** peaks, as well as scan data at **$\sqrt{s} = 2.00 - 4.95$ GeV**.

- **BESIII Physics Programme:**
  - ✔ hadron spectroscopy;
  - ✔ tests of various aspects of QCD;
  - ✔ charmed hadron decays;
  - ✔ precision test of the SM;
  - ✔ the probes of new physics beyond the SM.

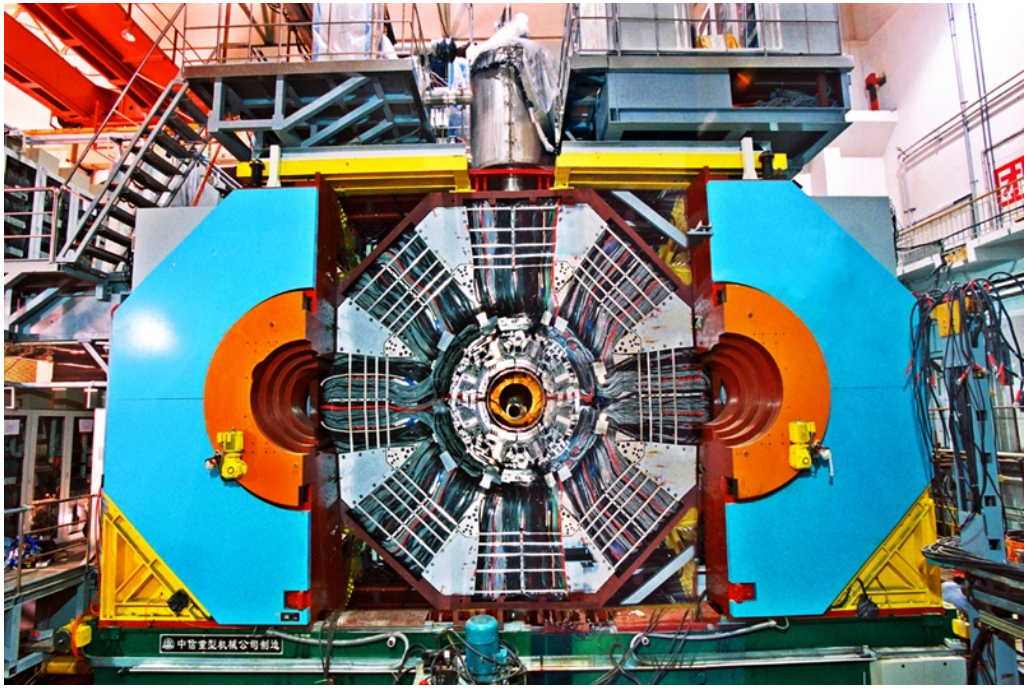


Figure: The BESIII detector.

Prompt inclusive J/ψ production (I)

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)

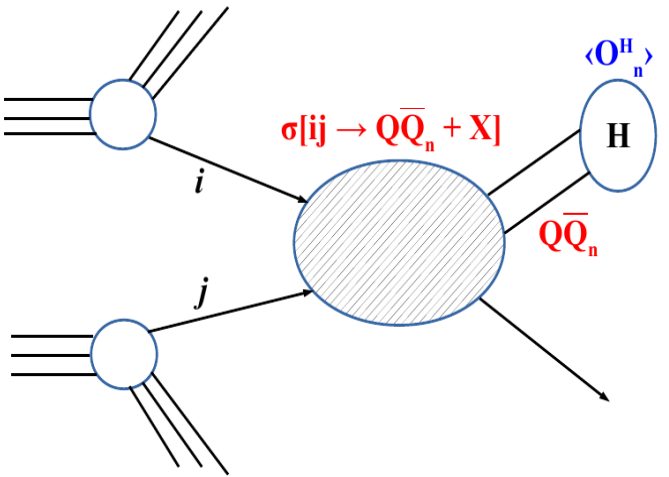


Figure: NRQCD factorization. The LDMEs $\langle O^H_n \rangle$ are determined from experimental data.

Prompt inclusive J/ψ production (II)

Data: $\mathcal{L} = 20$ fb^{-1}, $\sqrt{s} = 3.8 - 4.7$ GeV

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

- Prompt J/ψ originates from sources other than known decays or initial-state radiation (ISR).
- Major background sources:
  - inclusive J/ψ decays of ψ(3686) and χ_{cJ}, (J = 1, 2);
  - ISR return to the J/ψ and ψ(3686) resonances.
- The preliminary result for the prompt inclusive J/ψ production in the range 4.5 ~ 4.7 GeV is

$$\sigma = 13.2 \pm 2.1_{\text{stat}} \pm 3.4_{\text{syst}}\ \text{pb}$$

Analysis status: internal review of the BESIII collaboration to obtain permission to publish the results.

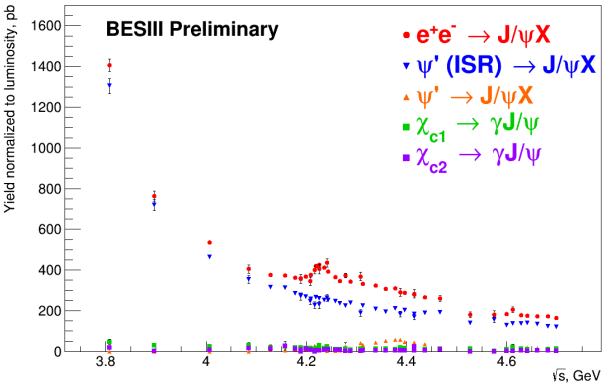


Figure: Yield of J/ψ from different sources normalized to corresponding luminosity.

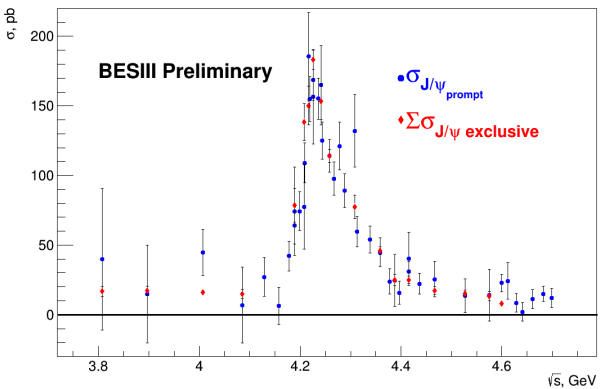
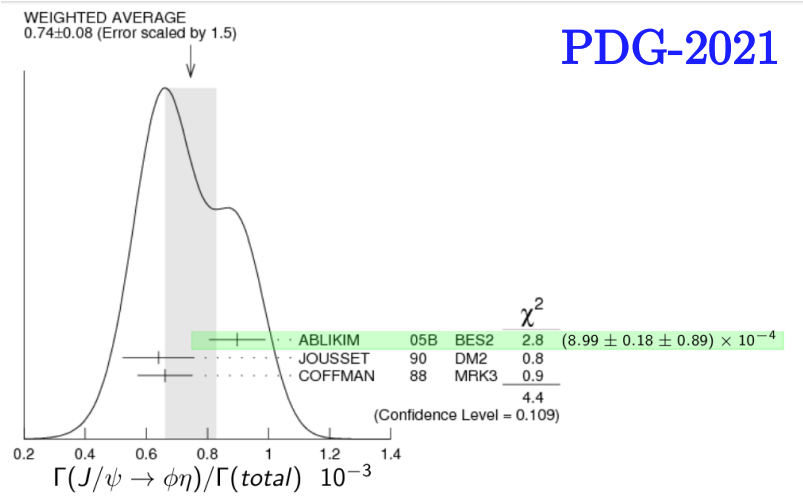


Figure: Prompt and total exclusive J/ψ cross-sections.

The branching fraction of J/ψ decay to ϕη (I)

- **The existing measurements** of $B(J/\psi \to \phi\eta)$ are **ambiguous** (PDG-2021);
- We plan to **use the precise measurements** of the $B(J/\psi \to \phi\eta)$ to **improve the estimation of the mixing angle between the strong and electromagnetic amplitudes** in the analysis of the energy dependence of $e^+e^- \to \phi\eta$ cross-section in the scan data around the J/ψ peak.



Formulas of cross section for lineshape fit of $e^+e^- \to \phi\eta$

$$\sigma_{\rm born}(s) = |\mathcal{A}_{cont.} + \mathcal{A}_\gamma + \mathcal{A}_{3g}|^2 = \frac{\sigma_0}{s^2}\left|1 + \frac{3/\alpha\sqrt{s\,\Gamma_e\Gamma_\mu}}{(s-M^2)+i\sqrt{s}\,\Gamma}\cdot(1+Ae^{i\varphi})\right|^2 \times \left[\frac{|P|}{\sqrt{s}}\right]^3$$

$$\text{where}\quad \sigma_0 = \frac{4\pi\alpha^2 s}{3}\cdot\frac{Br(J/\psi\to\phi\eta)}{Br(J/\psi\to\mu\mu)}\cdot\frac{1}{|1+Ae^{i\varphi}|^2}\left[\frac{\sqrt{s}}{|P|}\right]^3$$

The branching fraction of J/ψ decay to ϕη (II)

Data: 448M ψ(3686) 2009 and 2012
Channel: $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \phi\eta$, $\phi \to K^+K^-$, $\eta \to \gamma\gamma$

- We need to use data in which there is no mixing of $J/\psi \to \phi\eta$ and $e^+e^- \to \phi\eta$.
- A good description of the invariant mass of K^+K^- is obtained only under the assumption of interference $J/\psi \to \phi\eta$ with other processes decaying to the same final state.
- The preliminary result for $M(K^+K^-) < 1.08$ GeV/c^2 is

$$B(J/\psi \to \phi\eta) = (8.52 + 0.37/- 0.43_{stat} \pm 0.14_{syst}) \times 10^{-4}$$

Analysis status: internal review of the BESIII collaboration to obtain permission to publish the results.

Comparison with previous measurements

BES2	$(8.99 \pm 0.18 \pm 0.89) \times 10^{-4}$
DM2	$(6.4 \pm 0.4 \pm 1.1) \times 10^{-4}$
MARK-III	$(6.61 \pm 0.45 \pm 0.78) \times 10^{-4}$
PDG2020	$(7.4 \pm 0.8) \times 10^{-4}$

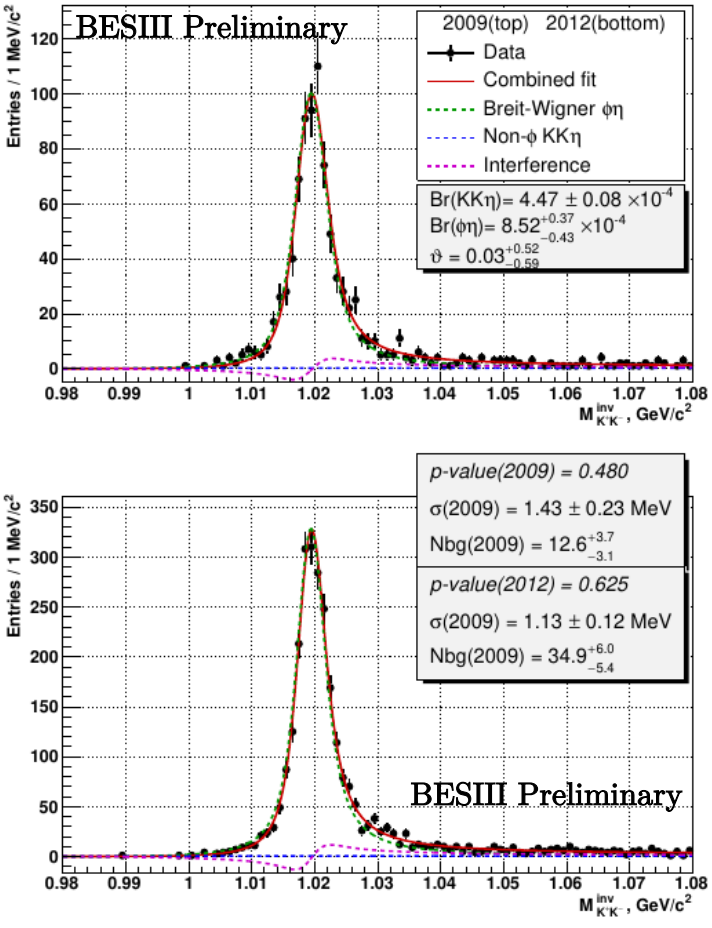


Figure: Combined fit to the $M(K^+K^-)$ to determine the number of ϕ mesons.