Decays studies of charmonium states at BESIII

Gang Yu (yugang@ihep.ac.cn)

(On behalf of BESIII Collaboration)

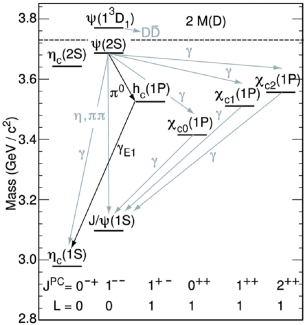
Institute of High Energy Physics (IHEP)

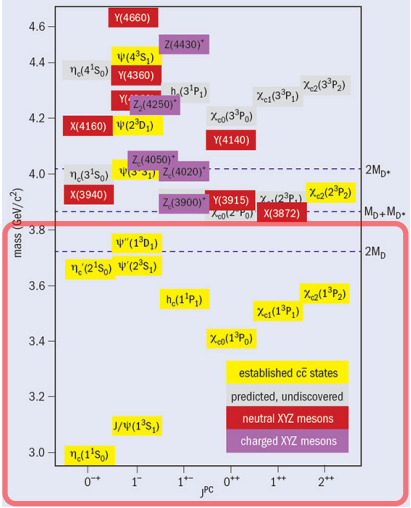
August 18, 2021

The 13th National Conference on Particle Physics

Introduction

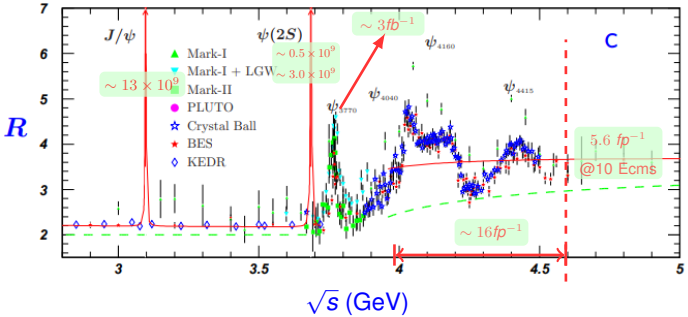
- Charmonuim resonances are located in the transition region of perturbative QCD and non-perturbative QCD, various theoretical models make predictions for charmonium decays.
- Non-vector states still mostly unknown.
- Experimental studies of charmonium decays are essential for understanding the structures and decay mechanisms of charmonium states.
- New results provide more information for theory.





BESIII data sets

- Data sets at BESIII
  - Largest J/ψ, $\psi(3686)$ data sets in the world.
  - More than 20 fb^{-} above 4.0 GeV.



- We can do:
  - Research charmonium physics
  - light hadron spectroscopy
  - new hadronic states
  - D-physics and τ-physics

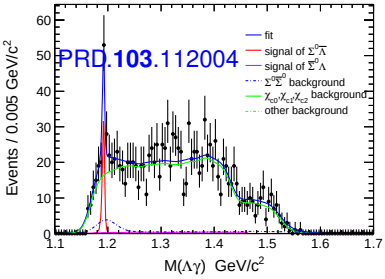
- Recent results on the charmonuim decays:
  - $\psi(3686)$ decays
    - $\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c$
    - $\psi(3686) \to K_s X$
  - χ_{cJ} decays
    - $\chi_{cJ} \to \bar{\Lambda}\Lambda$
    - $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

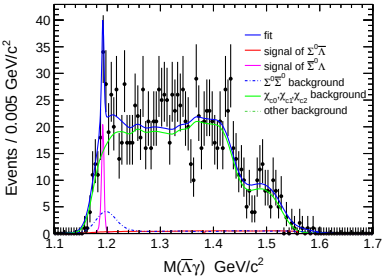
$\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$ and $\chi_{cJ} \to \bar{\Lambda}\Lambda$

- **Data Set :** 09 and 12 (4.48×10^8 $\psi(3686)$ data)
- **Decay Channel:** $\psi(3686) \to \bar{\Sigma}^0\Lambda \to (\gamma\bar{\Lambda})(p\pi^-)$.
- **Measurement Result:**
  - $\mathcal{B}(\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.) \times 10^6$
    $= 1.60 \pm 0.31 \pm 0.13 \pm 0.58$
    $\psi(3686)$-continuum interference

- Smaller than the result using CLEO-c data (12.3 ± 2.4)[a] $\times 10^{-6}$.
- Consisting with[b] theoretical prediction (4.0 ± 2.3)[c] $\times 10^{-6}$.

[a] Dobbs, S.; Seth, K. K., et al. Phys. Rev. D **2017**, *96*, 092004.
[b] within 1σ *or* 2σ, depending on the $\psi(3686)$ continuum interference.
[c] Zhu, K.; Mo, X.-H., et al. Int. J. Mod. Phys. A **2015**, *30*, 1550148.





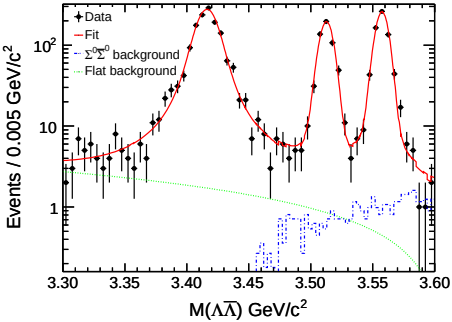
$\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$ and $\chi_{cJ} \to \bar{\Lambda}\Lambda$

- **Data Set :** 09 and 12 (4.48×10^8 $\psi(3686)$ data)
- **Decay Channel:** $\psi(3686) \to \gamma\chi_{cJ} \to \gamma\Lambda\bar{\Lambda}$

$$\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+).$$

- **Measurement Results:**

Mode	$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ})$ $\times\mathcal{B}\chi_{cJ} \to \Lambda\bar{\Lambda})(10^{-5})$	$\mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda})(\times 10^{-4})$ This work	PDG
χ_{c0}	$3.56 \pm 0.10 \pm 0.10$	$3.64 \pm 0.10 \pm 0.10 \pm 0.07$	3.27 ± 0.24
χ_{c1}	$1.28 \pm 0.06 \pm 0.06$	$1.31 \pm 0.06 \pm 0.06 \pm 0.03$	1.14 ± 0.11
χ_{c2}	$1.82 \pm 0.08 \pm 0.17$	$1.91 \pm 0.08 \pm 0.17 \pm 0.04$	1.84 ± 0.15



Consisting with the world average values, but not with the theoretical predictions[1,2,3]

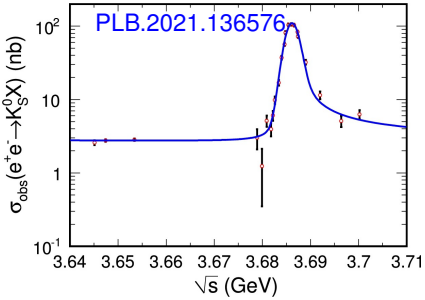
[1] Rong Gang, P.; Bin Song, Z., et al. Eur. Phys. J. A **2005**, *23*, 129–133.

[2] Liu, X.-H.; Zhao, Q. J. Phys. G **2011**, *38*, 035007.

[3] S, W. Eur. Phys. J. C **2000**, 643–671.

$\psi(3686) \to K_S^0 X (X = anything)$

- **Data Sets:** $\psi(3686)$ scan data (5.9 pb^{-1}@ 22 data samples)
- **Decay Channel:** $\psi(3686) \to K_S^0 X \to (\pi^+\pi^-)X$
- **Cross Section:**
  - $\sigma^{obs}_{K_S^0 X} = \sigma^{con}_{K_S^0 X} + \sigma^{\psi(3686)}_{K_S^0 X} + \sigma^{J/\psi}_{K_S^0 X}$
    - continuum cross section:
      Based on QED, assume the formula is satisfied: $\sigma = f/s$.
    - $J/\psi/\psi(3686) \to K_S^0 X$ cross section:
      Using the Breit-Winger function distribute the dress cross section:
      $\sigma = \frac{12\pi\Gamma^{ee}\Gamma^{K_S^0 X}}{(s-M^2)^2+(\Gamma^{tot}M)^2}$.



Parameter	Solution
Energy spread	1.33 ± 0.03 MeV)
f_{con}	28.49 ± 0.80
$M_{J/\psi}$	3096.9 MeV (fixed)
$\Gamma^{tot}_{J/\psi}$	92.9 keV (fixed)
$\Gamma^{ee}_{J/\psi}\mathcal{B}(J/\psi \to K_S^0 X)$	941.28 eV (fixed)
$M_{\psi(3686)}$	3686.03 ± 0.03
$\Gamma^{tot}_{\psi(3686)}$	294 keV (fixed)
$\Gamma^{ee}_{\psi(3686)}\mathcal{B}(\psi(3686) \to K_S^0 X)$	373.8 eV

$\psi(3686) \to K_S^0 X (X = anything)$

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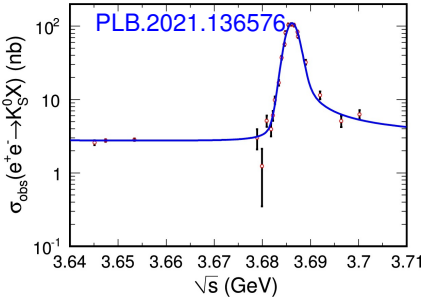

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$\psi(3686) \to K_S^0 X (X = anything)$

Measurement Results:

- The observed cross section for $e^+e^- \to K_S^0 X$ are measured from $\sqrt{s}$ = 3.64 to 3.71 GeV.
- $\Gamma^{ee}_{\psi(3686)}\mathcal{B}(\psi(3686) \to K_S^0 X)$ and $\mathcal{B}(\psi(3686) \to K_S^0 X)$ is first measured to be $(373.8 \pm 6.7 \pm 20.0)$ eV and $(16.04 \pm 0.29 \pm 0.90)\%$, respectively. [4]
- PDG gives the BF of $\psi(3686)$ decays to exclusive K_S^0 is $\sim 5.95\%$[5].
- Many undiscovered exclusive channel for $\psi(3686)$ decays to final states containing K_S^0.

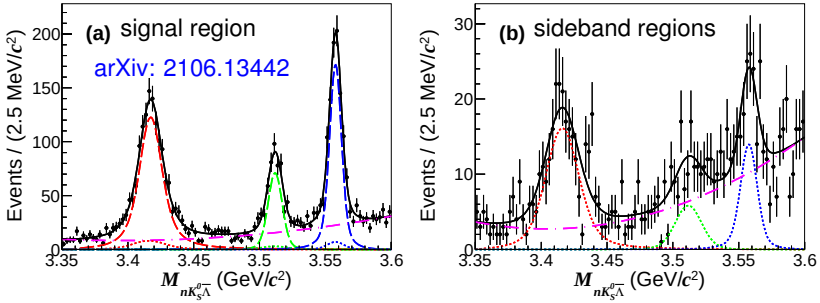
[4] Assuming $\Gamma^{ee}_{\psi(3686)}$ = (2.33 $\pm$ 0.04) keV.

[5] Tanabashi, M.; Hagiwara, K., et al. Phys. Rev. D **2018**, *98*, 030001.

$\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$

- **Data Set :** 09 and 12 (4.48×10^8 $\psi(3686)$ data)
- **Decay Channel:** $\chi_{cJ} \to nK_S^0\bar{\Lambda} \to n(\pi^+\pi^-)(\bar{p}\pi^+)$

Mode	$N_{1,J}$	ϵ_J (%)	BF (10^{-4})	$\frac{BF(\chi_{cJ}\to pK^-\bar{\Lambda}+c.c.)}{BF(\chi_{cJ}\to pK_S^0\bar{\Lambda}+c.c.)}$
χ_{c0}	1288 ± 50	9.95	$6.67 \pm 0.26 \pm 0.41$	$1.98 \pm 0.09 \pm 0.14$
χ_{c1}	410 ± 30	12.44	$1.71 \pm 0.12 \pm 0.12$	$2.64 \pm 0.23 \pm 0.20$
χ_{c2}	900 ± 41	13.03	$3.66 \pm 0.17 \pm 0.23$	$2.29 \pm 0.13 \pm -0.16$



- The decay of $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$ is observed for the first time and the branch fractions are measured.
- Iso-spin symmetry is tested by $\chi_{cJ} \to pK^-\bar{\Lambda} + c.c.$[6], there is no obvious iso-spin violation.

[6] Ablikim, M.; Achasov, M. N., et al. Phys. Rev. D **2013**, *87*, 012007.

Summary

- The largest data sets of $\psi(3686)$ / J/ψ in the world has been collected by BESIII, not only vector decays, but also to study h_c, χ_{cJ} and η_{2s}, et. al, decays of which are mostly unknown.
- The datasets above the $D\bar{D}$ threshold can shed new light on charmonium decays and hint at possible connections between XYZ states and conventional charmonia.
- In this talk, 3 analysis are discussed
  - Measurements of $\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$ and $\chi_{cJ} \to \Lambda\bar{\Lambda}$, **published to PRD**
  - Measurement of inclusive BF for $\psi(3686) \to K_S^0 X$, **accepted to PLB**
  - Observation of $\chi_{cJ} \to nK_S^0\bar{\Lambda} + c.c.$, **submitted to JHEP**
- BESIII collected more $\psi(3686)$ data (about 3.4fp^{-1} @2021), provides a better opportunity for research charmonium.
- More analysis is ongoing with the full $\psi(3686)$ data sets.

Thanks for your attention !!!