Studies of charmonium decays at BESIII

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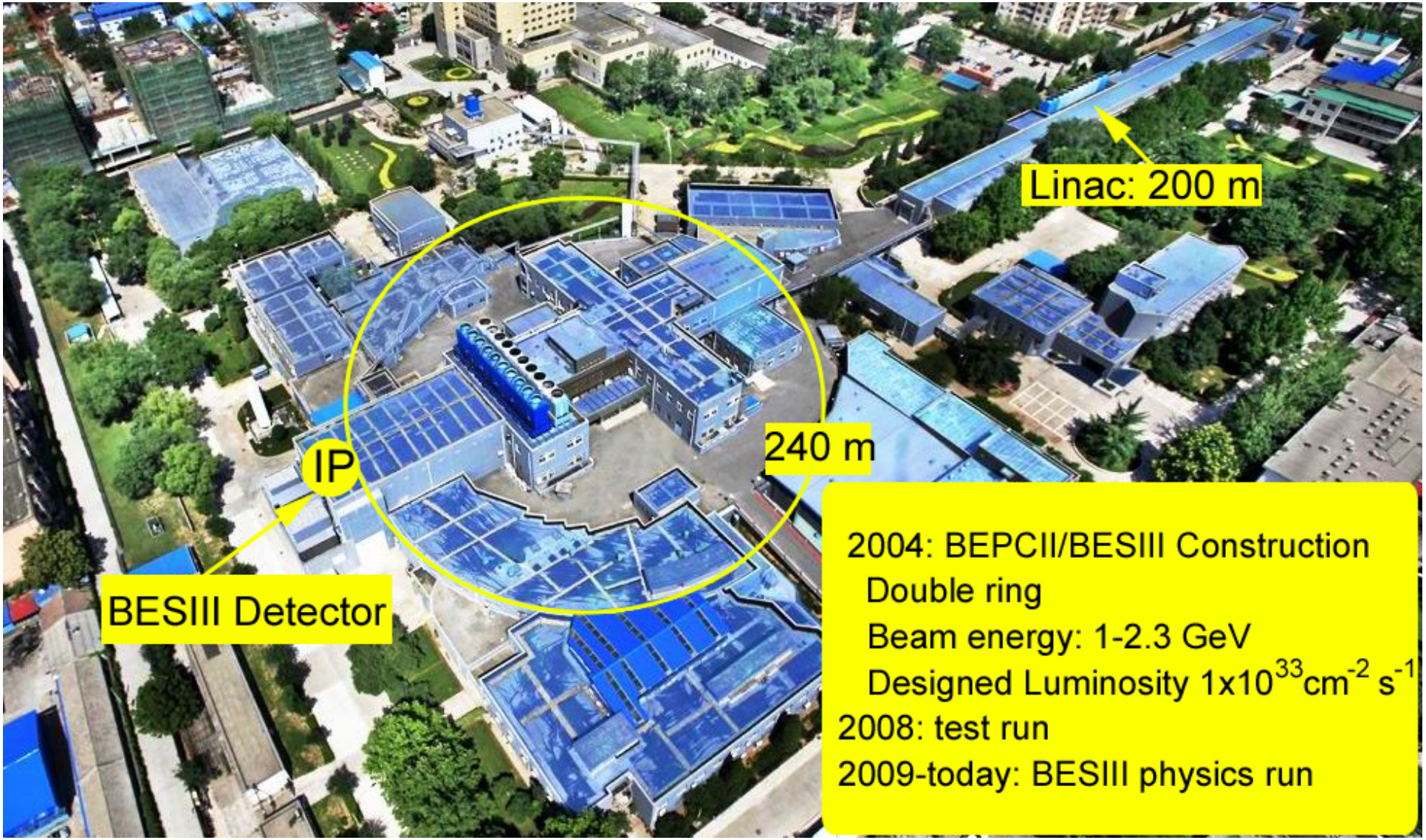
On behalf of the BESIII Collaboration

VIII International Workshop on Charm Physics
September 5 - 9, 2016 Bologna, Italy

Outline

- The BESIII experiment and detector
- The BESIII physics program
- Measurement of the leptonic decay width of J/ψ using initial state radiation
  PLB 761, 98-103 (2016)
- Observation of h_c radiative decay $h_c' \to h_c\gamma$ and evidence for $h_c \to \gamma\eta$
  PRL 116, 251802 (2016)
- Study of χ_{cJ} decaying into $\phi K^*(892)\bar{K}$
  PRD 91, 112008 (2015)
- Conclusions

Beijing Electron Positron Collider II



2004: BEPCII/BESIII Construction
- Double ring
- Beam energy: 1-2.3 GeV
- Designed Luminosity $1 \times 10^{33} cm^{-2} s^{-1}$

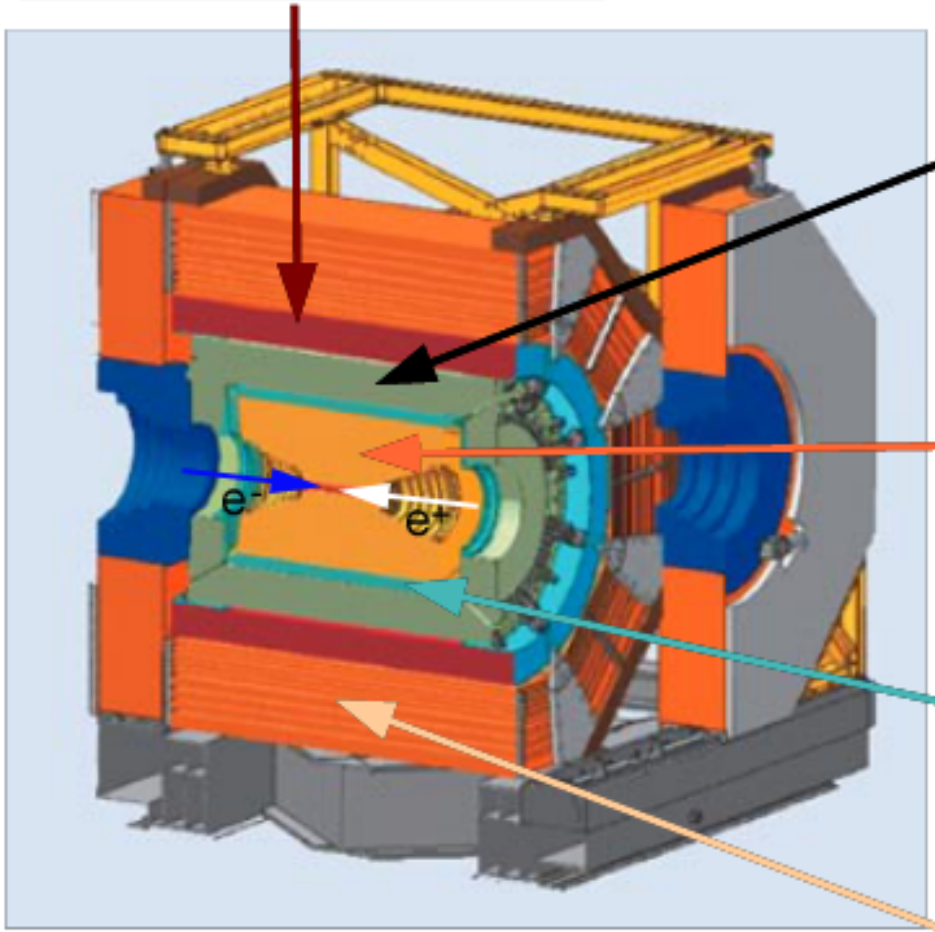
2008: test run

2009-today: BESIII physics run

The BESIII detector

Nucl. Instr. Meth. A614, 345 (2010)

1T superconducting magnet



EMC:
- CsI (Tl) calorimeter
- Energy resolution < 2.5% at 1 GeV (barrel)
- Energy resolution < 5% at 1 GeV (end caps)
- Spatial resolution σ(xy): 6 mm at 1 GeV

MDC: (Drift Chamber)
- Spatial resolution σ(rΦ) = 130 μm (single wire)
- Momentum resolution: 0.5% at 1 GeV

TOF
- σ(t)=90 ps (barrel)
- σ(t)=120 ps (end caps)

Muon ID (RPC)
- 8 layers (end caps) + 9 layers (barrel)
- ΔΩ/4π=93%

BESIII physics program

- Light hadron Physics
  - Meson and baryon spectroscopy
  - Multiquark states
  - Threshold effects
  - Glueballs and hybrids
  - Two-photon physics
  - Form factors
- QCD and τ
  - Precision R measurement
  - τ decay
- Charmonium physics
  - Precision spectroscopy
  - Transitions and decays
- XYZ meson physics
  - Y(4260), Y(4360) properties
  - $Z_c(3900)^+, \ldots$
- Charm physics
  - Semi-leptonic form factors
  - Decay constants f_D and f_{D_s}
  - CKM matrix: $|V_{cd}$ and $|V_{cs}|$
  - D^0-$\bar{D}^0$ mixing, CPV
  - Strong phases
- Precision mass measurements
  - τ mass
  - D, D^* mass

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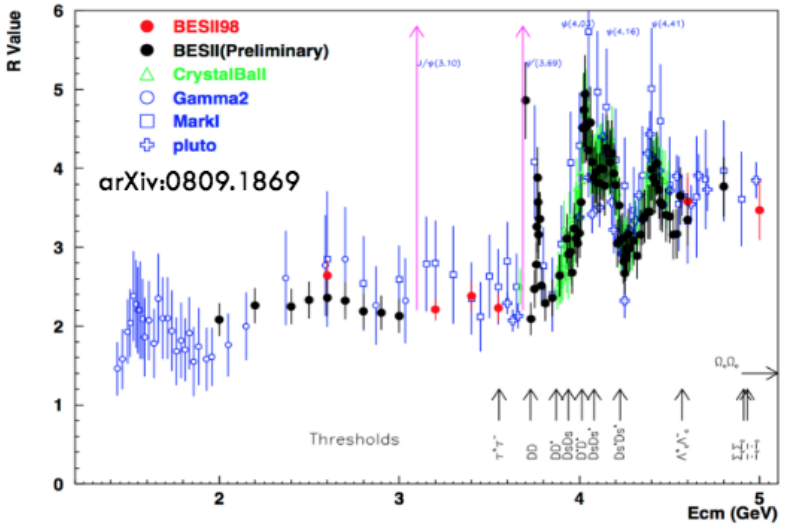
Data samples

Data sample	E_{cm}	Years
1.3×10^9	J/ψ at 3.097 GeV	2009 (0.225×10^9) + 2012
0.5×10^9	$\psi(2S)$ at 3.686 GeV	2009 (0.106×10^9) + 2012
2.92 fb^{-1}	$\psi(3770)$ at 3.773 GeV	2010+2011
0.5 fb^{-1}	$\psi(4040)$ at 4.009 GeV	2011
0.024 fb^{-1}	τ mass scan at around 3.554 GeV	2011
1.9 fb^{-1}	Y(4260) at 4.23 GeV and 4.26 GeV	2013
0.5 fb^{-1}	Y(4360) at 4.36 GeV	2013
0.5 fb^{-1}	Y(4260) and Y(4360) scan	2013
0.8 fb^{-1}	R scan, 104 energy points between 3.85 and 4.59 GeV	2014
1.0 fb^{-1}	at 4.42 GeV	2014
0.1 fb^{-1}	at 4.47 GeV and 4.53 GeV for line shape	2014
0.04 fb^{-1}	at 4.575 GeV (around the threshold of Lambda Charm)	2014
0.5 fb^{-1}	at 4.60 GeV	2014



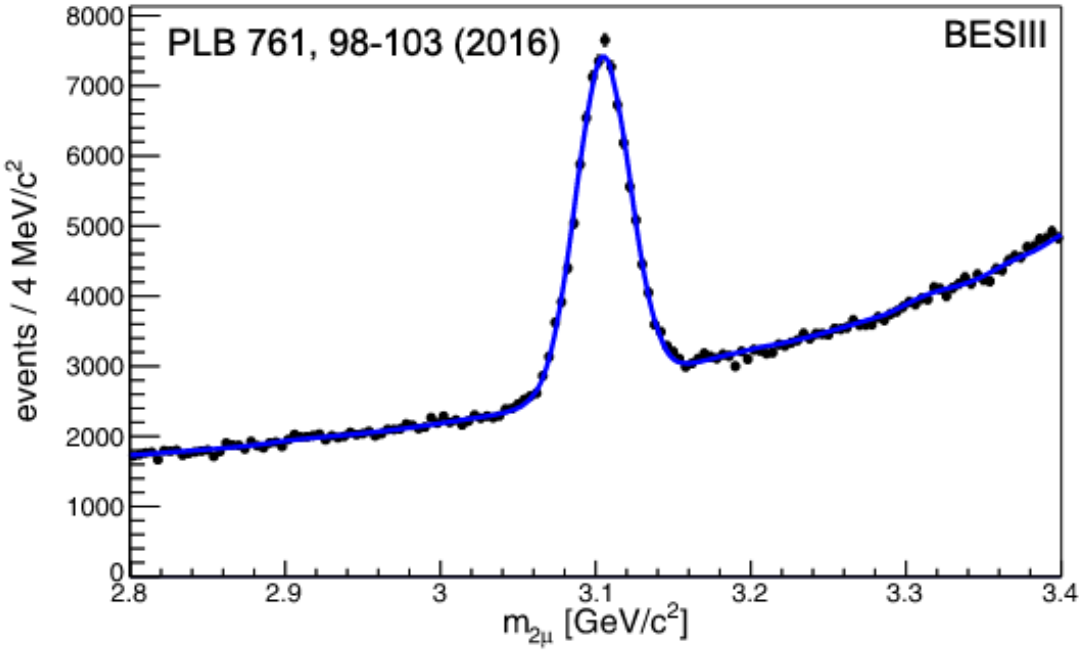
Measurement of the leptonic decay width of J/ψ using initial state radiation

PLB 761, 98-103 (2016)

Introduction

- The electronic width of the J/ψ, $\Gamma_e e$ has been measured by *BABAR* (PRD69,011103R(2004)) and CLEO-c (PRD73,051103R(2006)).
- Also KEDR experiment measured the electronic width with improved precision using a different method (PLB685,134-140(2010))
- BESIII studied the process $e^+e^- \to \mu^+\mu^-\gamma$ using the ISR method, analyzing 2.93 fb^{-1} of data taken at $\sqrt{s}$ =3.773 GeV.
- The cross section $\sigma_{J/\psi\gamma} = \sigma(e^+e^- \to J/\psi\gamma \to \mu^+\mu^-\gamma)$ is proportional to $\Gamma_{ee} \times \mathcal{B}_{\mu\mu}$, where $\mathcal{B}_{\mu\mu} = \mathcal{B}(J/\psi \to \mu^+\mu^-)$.
- With the precise measurement of $B_{\mu\mu}$ from BESIII, we have the opportunity to obtain Γ_{ee} with high precision.

Results



Measurement	$\Gamma_{ee} \cdot \mathcal{B}_{\mu\mu}$ [eV]	Used $\mathcal{B}_{\mu\mu}$ value [%]	Γ_{ee} [keV]
BaBar	$330.1 \pm 7.7_{stat} \pm 7.3_{sys}$	5.88 ± 0.10 [1]	5.61 ± 0.20
CLEO-c	$338.4 \pm 5.8_{stat} \pm 7.1_{sys}$	$5.953 \pm 0.056_{stat} \pm 0.042_{sys}$ [2]	$5.68 \pm 0.11_{stat} \pm 0.13_{sys}$
KEDR	$331.8 \pm 5.2_{stat} \pm 6.3_{sys}$	5.94 ± 0.06 [3]	5.59 ± 0.12
This work	$333.4 \pm 2.5_{stat} \pm 4.4_{sys}$	$5.973 \pm 0.007_{stat} \pm 0.037_{sys}$ [4]	$5.58 \pm 0.05_{stat} \pm 0.08_{sys}$

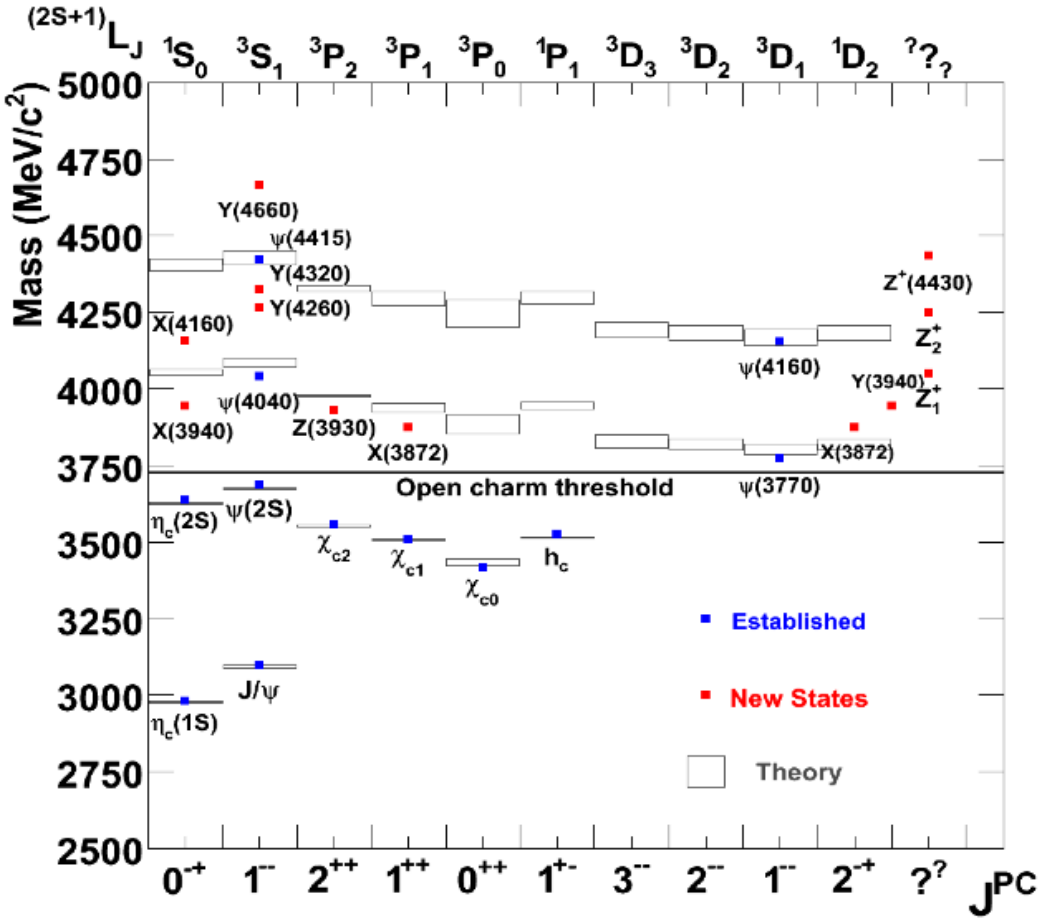
[1]: PRD66,010001(2002);
[2]: PRD71,111103R(2005);
[3]: PLB667(2008);
[4]: PRD88,032007(2013)

Our measurement of $\Gamma_{ee} \times \mathcal{B}_{\mu\mu}$ is consistent with results from *BABAR* , CLEO-c and KEDR.
The measured value for Γ_{ee} is more precise.

Observation of h_c radiative decay $h_c' \to h_c\gamma$ and evidence for $h_c \to \gamma\eta$

PRL 116, 251802 (2016)

Charmonium spectrum



- Many unexpected states have been reported above the $D\bar{D}$ threshold, seemingly too many with $J^{PC} = 1^{--}$. Several exotic hypotheses as to their nature: tetraquarks, hadronic molecules, hybrids, glueballs, hadro-quarkonia.
- Below the $D\bar{D}$ threshold, all expected states have been observed, with properties in good agreement with theory. However, knowledge is still sparse on the P-wave spin-singlet state, $h_c(^1P_1)$.

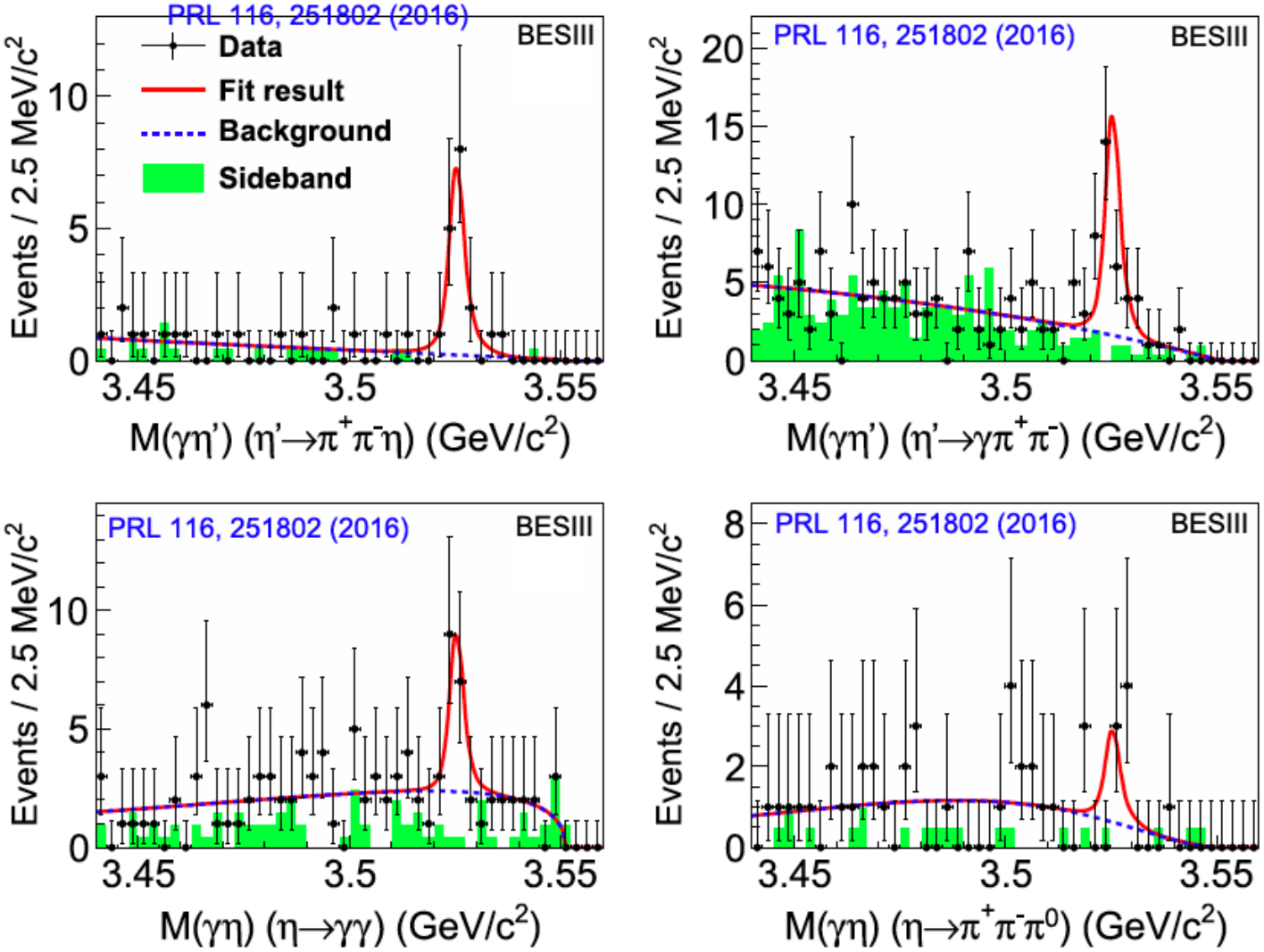
Eur. Phys. J.C71, 1534 (2011)

Introduction

- Only a few decay modes of h_c have been observed, $h_c \to \gamma\eta_c$ (BR$\sim$50%) and $h_c \to 2(\pi^+\pi^-)\pi^0$ (BR$\sim$2%).
- Searches for the new h_c decay modes are useful for providing constraints to theoretical models in the charmonium region.
- The ratio of the branching fraction $\mathcal{B}(h_c \to \gamma\eta)/\mathcal{B}(h_c \to \gamma\eta')$ can also be used to study the $\eta - \eta'$ mixing angle, which is important to test SU(3)-flavor symmetries in QCD.

- We report the observation of the h_c radiative decay $h_c \to \gamma\eta'(\eta)$, where h_c is produced in the decay $\psi' \to \pi^0 h_c$.
- The $h_c \to \gamma\eta'$ is reconstructed by using $\eta' \to \pi^+\pi^-\eta$ and $\eta' \to \gamma\pi^+\pi^-$ with $\eta \to \gamma\gamma$.
- The $h_c \to \gamma\eta$ is reconstructed from decays $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ with $\pi^0 \to \gamma\gamma$.
- The analyses are based on a data sample of 4.48×10^8 ψ' events.

Results



Mode	$N_{h_c\to\gamma\eta'(\eta)}$	$\mathcal{B}[h_c\to\gamma\eta'(\eta)]$	Significance	$[\mathcal{B}(h_c\to\gamma\eta)/\mathcal{B}(h_c\to\gamma\eta')](\%)$
$h_c\to\gamma\eta'$	$44.3\pm7.8(\text{stat})$	$[1.52\pm0.27(\text{stat})\pm0.29(\text{sys})]\times10^{-3}$	8.4σ	$30.7\pm11.3(\text{stat})\pm8.7(\text{sys})$
$h_c\to\gamma\eta$	$18.1\pm5.8(\text{stat})$	$[4.7\pm1.5(\text{stat})\pm1.4(\text{sys.})]\times10^{-4}$	4.0σ	

Study of χ_{cJ} decaying into $\phi K^*(892)\bar{K}$

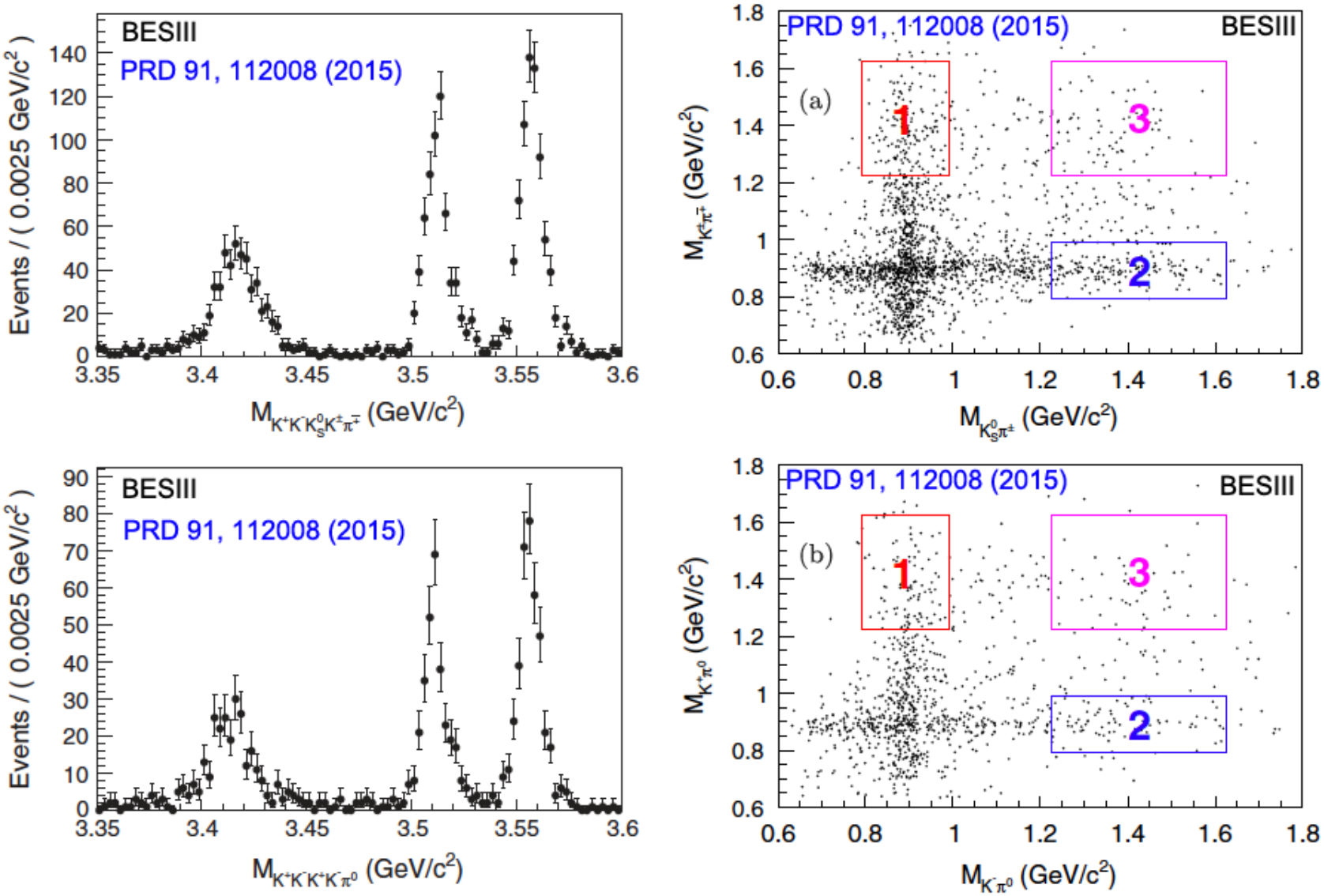
PRD 91, 112008 (2015)

Introduction

- Unlike the J/ψ and the ψ', the P-wave charmonia states χ_{cJ} are not directly produced in e^+e^- collisions and, thus, are less well understood.
- Obtaining more experimental data on exclusive decays of the χ_{cJ} states is important for a better understanding of their nature and mechanisms, as well as for testing QCD-base calculation.
- Since the χ_{cJ} states are produced copious in the E1 radiative transition of ψ', with branching fractions around 9%, the large ψ' data sample taken at BESIII provides a unique opportunity for detailed studies of χ_{cJ} exclusive decays.

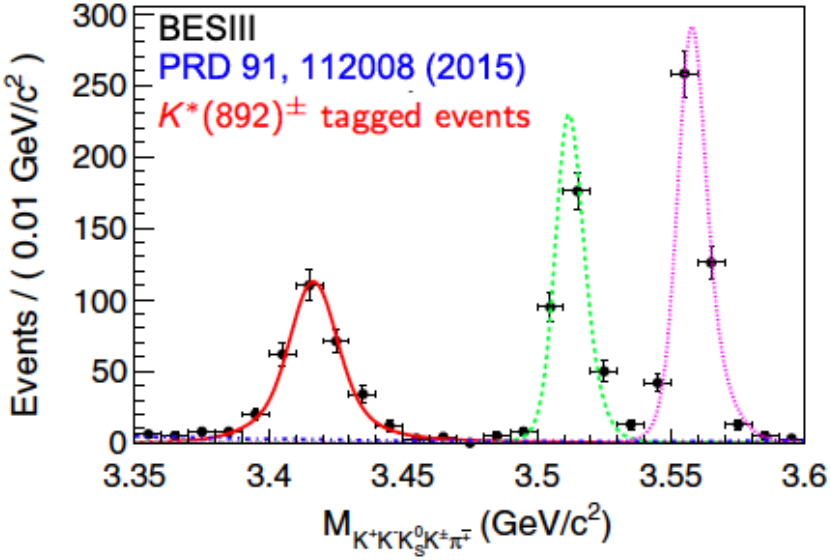
- We report the first measurement of the decay $\chi_{cJ} \to \phi K_S^0 K^\pm \pi^\mp$ and $\chi_{cJ} \to \phi K^+ K^- \pi^0$ in the electric dipole E1 radiative transition $\psi' \to \gamma \chi_{cJ}$, using 1.06×10^8 ψ'. The ϕ is reconstructed via K^+K^-.

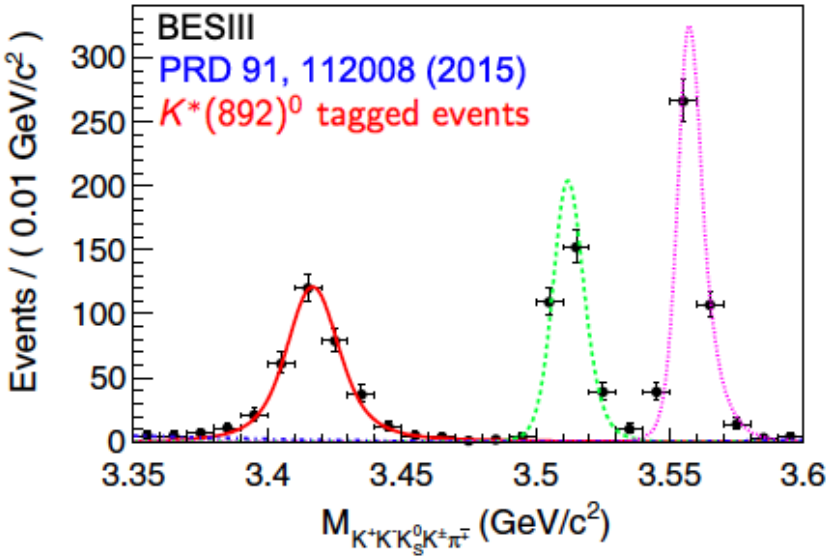
χ_{cJ} invariant mass distribution



- Significant χ_{cJ} signals are observed.
- The dominant processes are the $\chi_{cJ} \to \phi K^*(892)\bar{K}$ three-body decays.

Branching fractions measurement

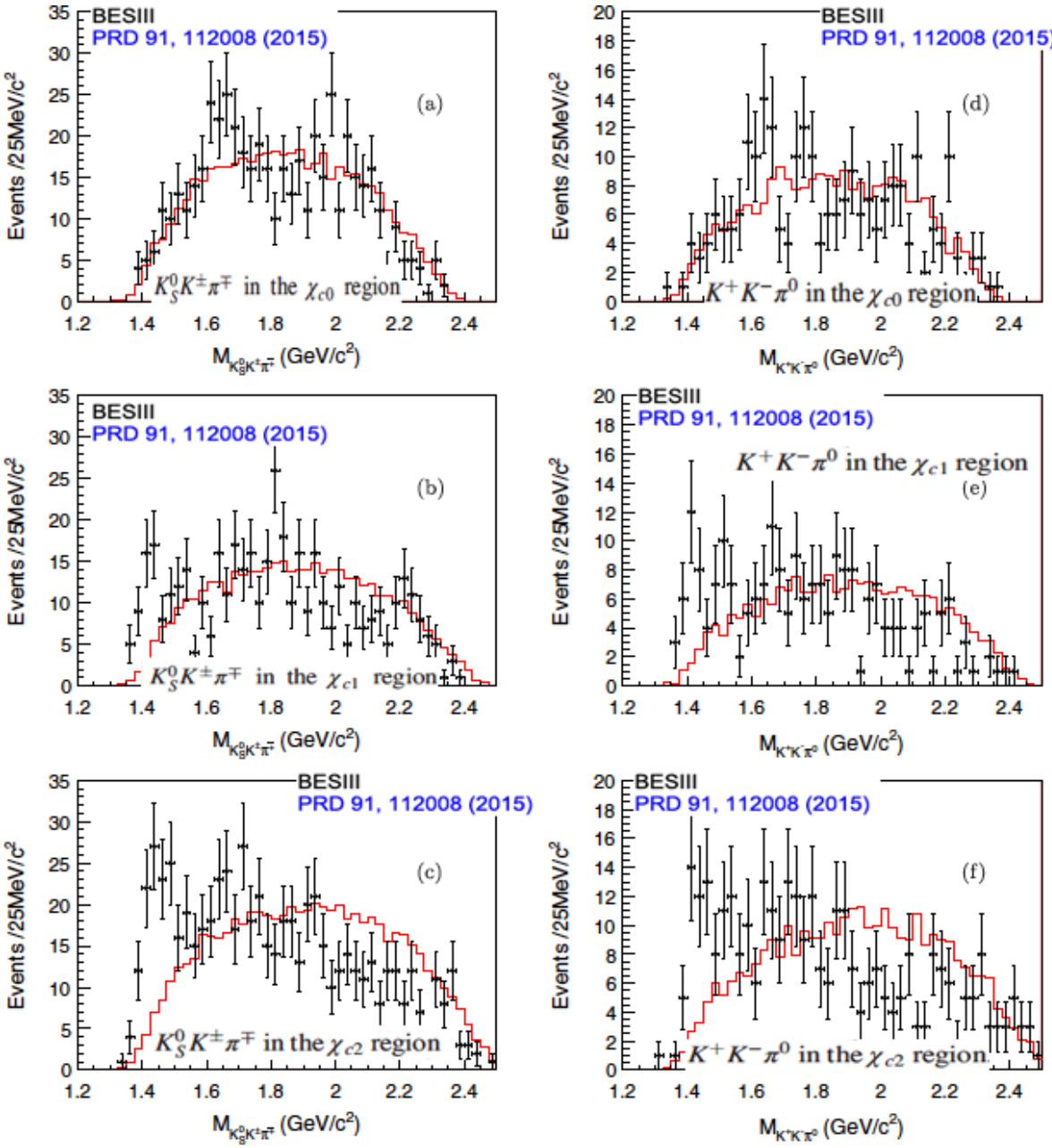




Branching fractions measured in $\phi K\bar{K}\pi$ final states:

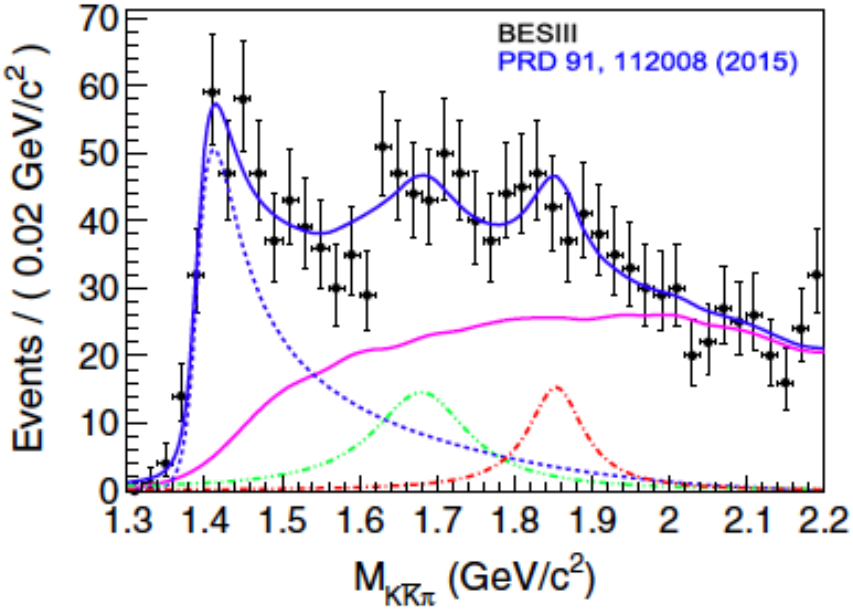
Decay Modes		$\phi K_s K^\pm \pi^\mp$ ($\times 10^{-3}$)	$\phi K^+ K^- \pi^0$ ($\times 10^{-3}$)
χ_{c0}	$\phi K^*(892)^\pm K^\mp$	$1.65 \pm 0.21(\text{stat}) \pm 0.22(\text{sys})$	$1.90 \pm 0.14(\text{stat}) \pm 0.32(\text{sys})$
	$\phi K^*(892)^0 \bar{K}^0 + \text{c.c.}$	$2.03 \pm 0.21(\text{stat}) \pm 0.28(\text{sys})$	$\cdots$
χ_{c1}	$\phi K^*(892)^\pm K^\mp$	$1.76 \pm 0.21(\text{stat}) \pm 0.26(\text{sys})$	$1.62 \pm 0.12(\text{stat}) \pm 0.28(\text{sys})$
	$\phi K^*(892)^0 \bar{K}^0 + \text{c.c}$	$1.51 \pm 0.19(\text{stat}) \pm 0.22(\text{sys})$	$\cdots$
χ_{c2}	$\phi K^*(892)^\pm K^\mp$	$2.56 \pm 0.23(\text{stat}) \pm 0.35(\text{sys})$	$2.74 \pm 0.16(\text{stat}) \pm 0.44(\text{sys})$
	$\phi K^*(892)^0 \bar{K}^0 + \text{c.c.}$	$2.27 \pm 0.22(\text{stat}) \pm 0.32(\text{sys})$	$\cdots$

The $K\bar{K}\pi$ invariant mass and $h_1(1380)$ state



- The $K\bar{K}\pi$ invariant mass distributions are studied in order to identify any intermediate states.
- A threshold enhancement, which can not be described with the phase space, is observed in both χ_{c1} and χ_{c2} signal regions and it has been identify as the $h_1(1380)$.
- In the χ_{c0} decay, a structure, the $\phi(1680)$ is observed. There is also a possible $\phi(1850)$ contribution.

The $K\bar{K}\pi$ invariant mass and $h_1(1380)$ state



- A simultaneous fit is performed to the invariant mass distributions of $K\bar{K}\pi$ for the candidate events in the $\chi_{c1,2}$ signal regions.
- The $h_1(1380)$ is observed with significance of 10σ. This is the first direct observation of this state in its decay to $K^*(892)\bar{K}$
- $m[h_1(1380)]$=1412±4±8 MeV/c^2; $\Gamma[h_1(1830)]$=84±12±40 MeV
- Evidence is also found for the decays $\chi_{cJ} \to \phi\phi(1680)$ and $\chi_{cJ} \to \phi\phi(1850)$ but with significances less than 5σ.
- More data and advanced analysis techniques are needed

Conclusion

- BESIII is successfully operating since 2008, and continues to take data
- It is an excellent laboratory to study charmonium spectroscopy:
  - High statistics
  - Low background
- Many interesting results have been obtained, only few of them are covered in this talk
- Future:
  - More data will be collected
  - More detailed studies will be done

THANKS FOR YOUR ATTENTION!