Quarkonium 2017

The 12th International Workshop on Heavy Quarkonium

November 6-10, 2017, Peking University, Beijing, China

BESIII

中国科学院高能物理研究所

Institute of High Energy Physics Chinese Academy of Sciences

Radiative Transitions in e^+e^- collisions above 4 GeV

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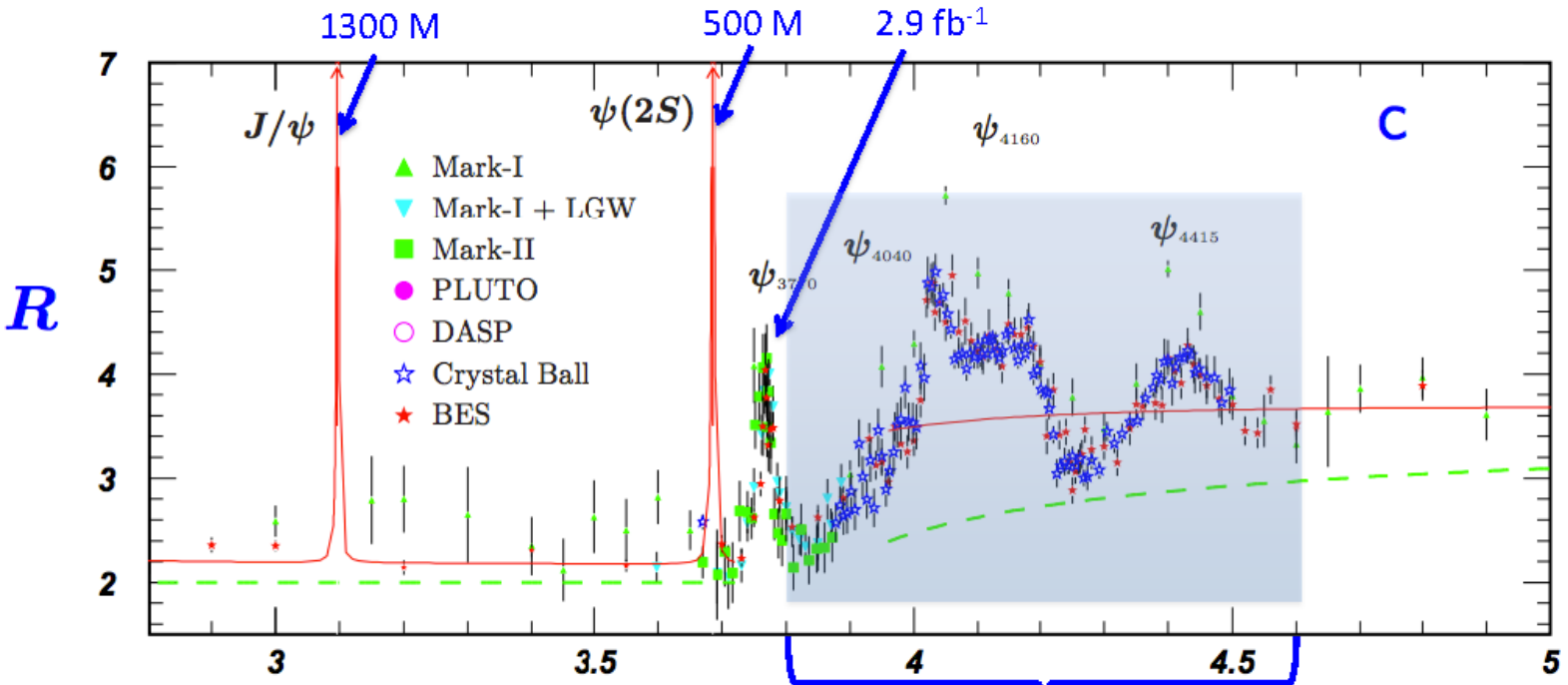
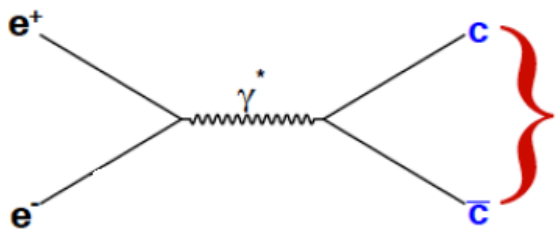
Outline

- BESIII data samples
- Summary of QWG 2016
- Evidence for $e^+e^- \to \gamma\eta_c$
- Summary and Outlook

BESIII data Samples

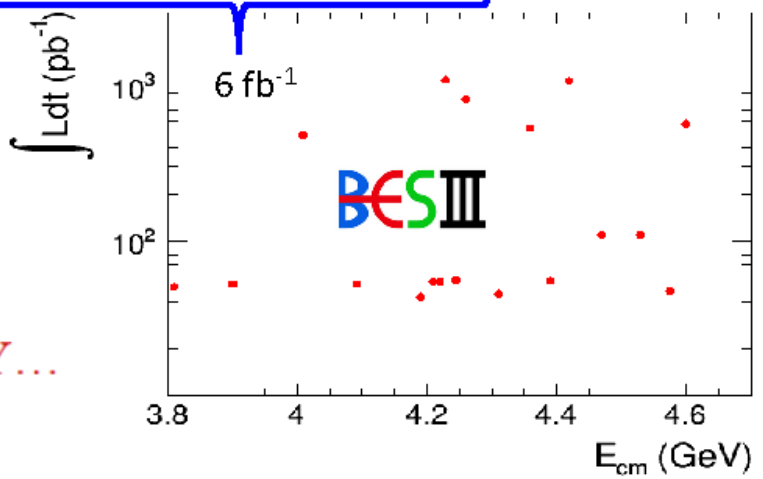


A scan experiment for vector charmonium-(like) states...



$J^{PC} = 1^{--}$

ψ', ψ'', Υ...

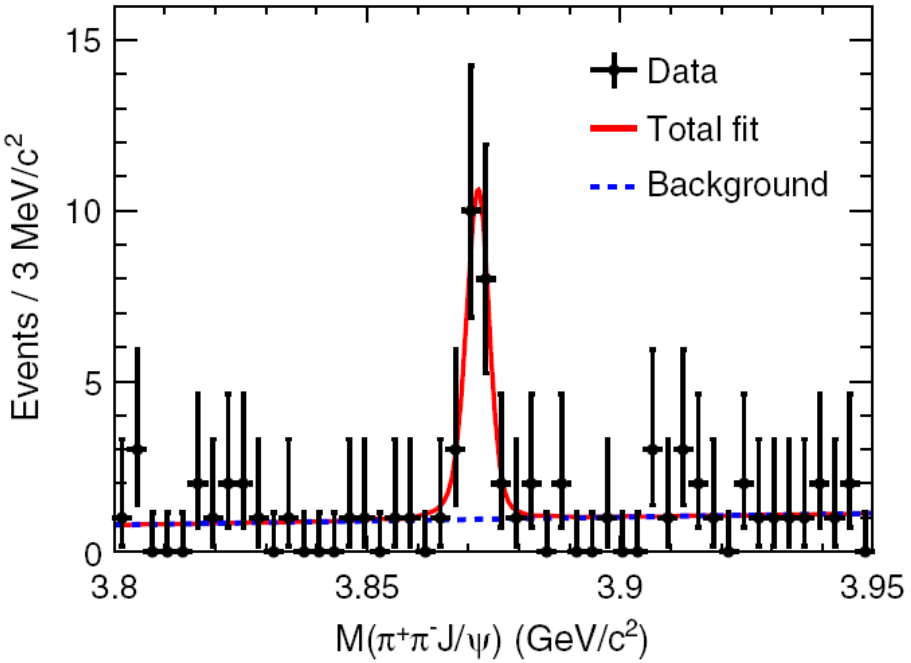


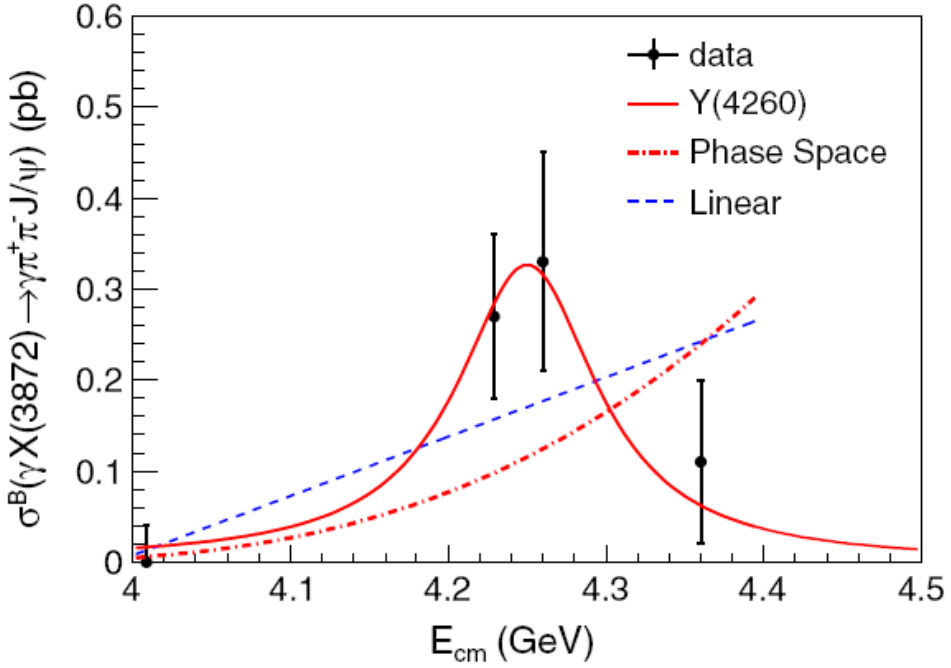
Summary of QWG 2016

- Observation of $X(3872)$ PRL 112, 092001 (2014)
- Search for $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$ PRD 91, 032002 (2015)
- Evidence for $e^+e^- \to \gamma\chi_{cJ}$ CPC 39, 041001 (2015)

PRL 112, 092001 (2014)

Observation of $X(3872)$





- In this Letter, we report the first observation of the process of $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$ at center of mass (c.m.) energy $\sqrt{s}$ = 4009, 4230, 4260, and 4360 MeV.
- The measured mass of the $X(3872)$ is $(3872.9 \pm 0.7_{\text{stat}} \pm 0.2_{\text{syst}})$ MeV/c^2, the width is $0.0^{+1.7}_{-0.9}$ MeV, or < 2.4 MeV @ 90% C.L. The statistical significance of $X(3872)$ is 6.3σ.
- Suggestive of $Y(4260) \to \gamma X(3872)$.

PRD 91, 032002 (2015)

Search for $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$

Three decay modes to reconstructed ϕ:

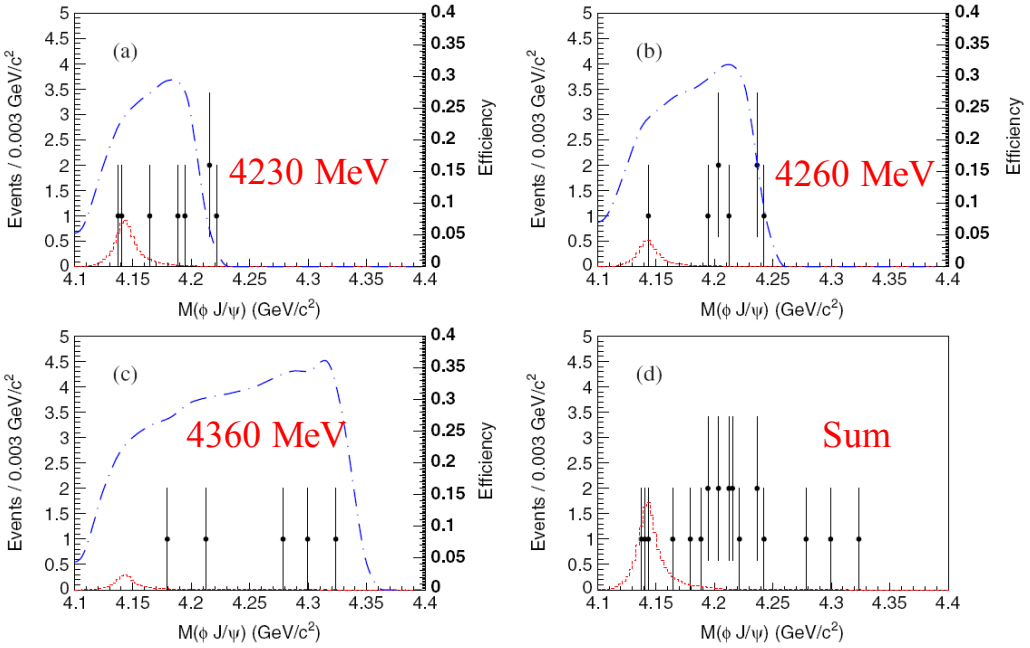
- $\phi \to K^+K^-$
- $\phi \to K_S^0K_L^0, K_S^0 \to \pi^+\pi^-$
- $\phi \to \pi^+\pi^-\pi^0$

Two decay modes to reconstructed J/ψ:

- $J/\psi \to e^+e^-$
- $J/\psi \to \mu^+\mu^-$

Combined 6 modes (3 ϕ modes and 2 J/ψ modes)

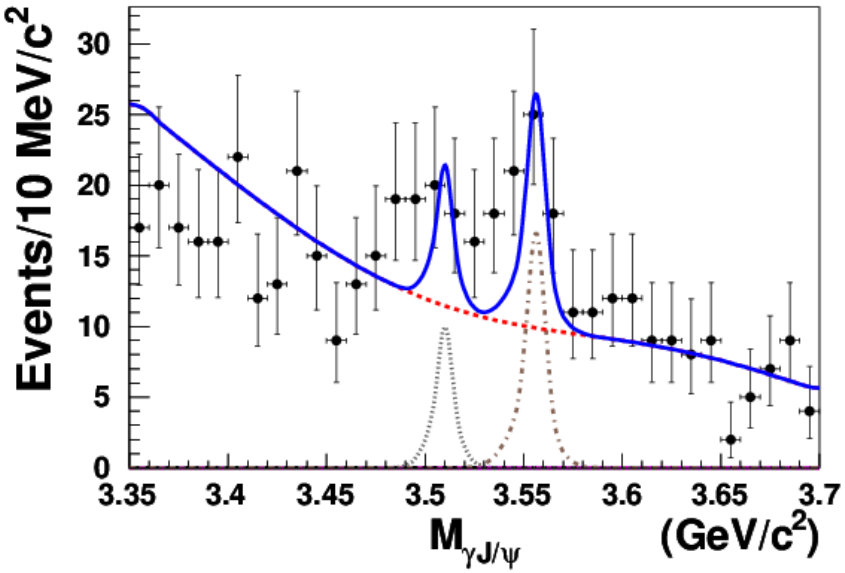
$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})	$(1+\delta)$	n^{prod}	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	<339	<0.35
4.26	827	0.847	<207	<0.28
4.36	545	0.944	<179	<0.33



- No significant $Y(4140)$ signal found at BESIII.
- Set the upper limits on $\sigma^B[e^+e^- \to \gamma Y(4140)] \times \mathcal{B}[Y(4140) \to \phi J/\psi]$ at 90% C.L. The upper limit has the same magnitude of the $X(3872)$ production ($\sigma^B[e^+e^- \to \gamma X(3872)] \times \mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]$).

CPC 39, 041001 (2015)

Evidence for $e^+e^- \to \gamma\chi_{cJ}$



- The statistical significances of χ_{c0}, χ_{c1} and χ_{c2} are 0, 2.4σ and 4.0σ, respectively.
- We find evidence for the processes of $e^+e^- \to \gamma\chi_{c1}$ and $e^+e^- \to \gamma\chi_{c2}$. No evidence of $e^+e^- \to \gamma\chi_{c0}$ is observed.
- The upper limit on the Born cross section are compatible with the theoretical prediction from the NRQCD calculation.

$\sqrt{s}$/GeV		$N^{\rm obs}$	significance (σ)	$N^{\rm UP}$	ϵ (%)	$1+\delta^r$	$1+\delta^v$	$\sigma^{\rm UP}$/pb	$\sigma^{\rm B}$/pb
4.009	χ_{c0}	7.0±6.6	1.6	18	36.4±0.2	0.738	1.04	179	65.0±61.3±4.2
	χ_{c1}	4.4±2.6	2.2	9	23.4±0.1			5.3	2.4±1.4±0.2
	χ_{c2}	1.8±1.7	1.5	6	8.7±0.1			18	4.7±4.4±0.6
4.230	χ_{c0}	0.2±2.3	0.0	7	37.2±0.2	0.840	1.06	26	0.7±8.0±0.1
	χ_{c1}	6.7±4.3	1.9	14	44.4±0.2			1.7	0.7±0.5±0.1
	χ_{c2}	13.3±5.2	2.9	22	42.0±0.2			5.0	2.7±1.1±0.3
4.260	χ_{c0}	0.1±1.9	0.0	5	36.7±0.2	0.842	1.06	25	0.5±8.8±0.1
	χ_{c1}	3.0±3.0	1.1	7	42.7±0.2			1.1	0.4±0.4±0.1
	χ_{c2}	7.5±3.9	2.3	14	41.7±0.2			4.2	2.0±1.1±0.2
4.360	χ_{c0}	0.1±0.7	0.0	3	32.4±0.2	0.943	1.05	23	0.7±5.0±0.1
	χ_{c1}	5.2±4.9	2.4	10	31.7±0.2			2.9	1.4±1.3±0.1
	χ_{c2}	4.4±4.5	2.0	9	30.3±0.2			5.0	2.3±2.3±0.2

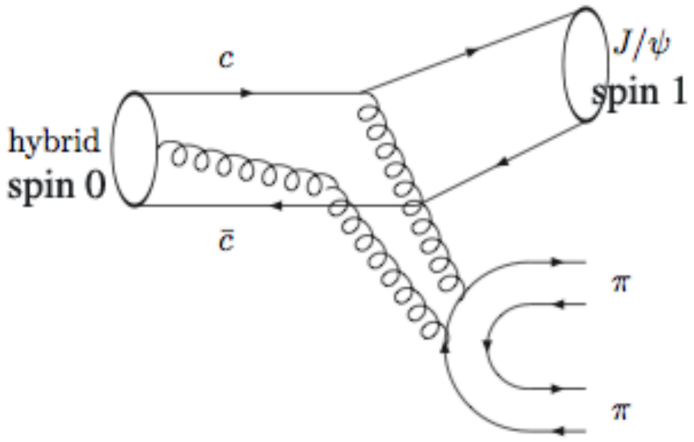
Evidence for $e^+e^- \to \gamma\eta_c$

PRD 96, 051101 (2017) (R)

PRD 96, 051101 (2017) (R)

Motivation

- The $Y(4260)$ was first discovered BABAR in the initial state radiation (ISR) process $e^+e^- \to \gamma_{ISR} Y(4260) \to \gamma_{ISR}\pi^+\pi^- J/\psi$.
- The J^{PC} of $Y(4260)$ is 1^{--}, but it can not be easily explained within the traditional charmonium states.
- One possibility is that the $Y(4260)$ is a hybrid meson. If so, the recent lattice QCD calculations predict that its rate of decay to $\gamma\eta_c$ will be enhanced relative to $\gamma\chi_{c0}$.
- Finding evidence for $Y(4260) \to \gamma\eta_c$ could thus give additional support to the hybrid interpretation.



PRD 96, 051101 (2017) (R)

Analysis technique and data sets

- We report on a search for $e^+e^- \to \gamma\eta_c$, $\eta_c \to X_i$, $X_i = 2(\pi^+\pi^-\pi^0)$, $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^+\pi^-\pi^-\eta$, $K^+K^-\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $\pi^+\pi^-\eta$, $K^\pm K_S\pi^\mp\pi^+\pi^-$, $K^\pm K_S\pi^\mp$, $K^+K^-\pi^0$, $K^+K^-\pi^+\pi^-$, and $K^+K^-\pi^+\pi^-\pi^+\pi^-$ at c.m. energy between 4.01 and 4.6 GeV.

η_c Mode	Branching Fraction (%)
$\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$	17.23
$\pi^+\pi^-\pi^0\pi^0$	4.660
$\eta\pi^+\pi^-\pi^+\pi^-$	4.400
$K^+K^-\pi^+\pi^-\pi^0$	3.500
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	2.020
$\pi^+\pi^-\pi^+\pi^-$	1.720
$\eta\pi^+\pi^-$	1.660
$K^-K_S\pi^+\pi^+\pi^-$	1.375
$K^+K_S\pi^-\pi^+\pi^-$	1.375
$K^-K_S\pi^+$	1.300
$K^+K_S\pi^-$	1.300
$K^+K^-\pi^0$	1.040
$K^+K^-\pi^+\pi^-$	0.9500
$K^+K^-\pi^+\pi^-\pi^+\pi^-$	0.8300

PRD 86, 092009 (2012)

Data sets	
$\sqrt{s}$ (GeV)	$\mathcal{L}_{int}$ (pb^{-1})
4.01	482
4.23	1094
4.26	826
4.36	540
4.42	1074
4.60	567

PRD 96, 051101 (2017) (R)

Event selection -- Four assumptions

$$\sigma = \frac{N_{measured}}{\mathcal{L}(1+\delta^{ISR})(1+\delta^{VP})\,\varepsilon}$$

Four different assumptions about the energy-dependence of the cross section

- σ_{FLAT}: The cross section is constant, consistent with the theoretical calculation.
- σ_{BELLE}: The cross section follows the Belle parameterization of $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$, modeled with a $Y(4008)$ and $Y(4260)$; JHEP 10, 71 (2014)
- $\sigma_{\mathrm{Y(4260)}}$: The cross section follows a nonrelativistic Breit-Wigner distribution for the Y(4260) with mass and width values from the Particle Data Group (PDG);
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Event selection -- Four assumptions

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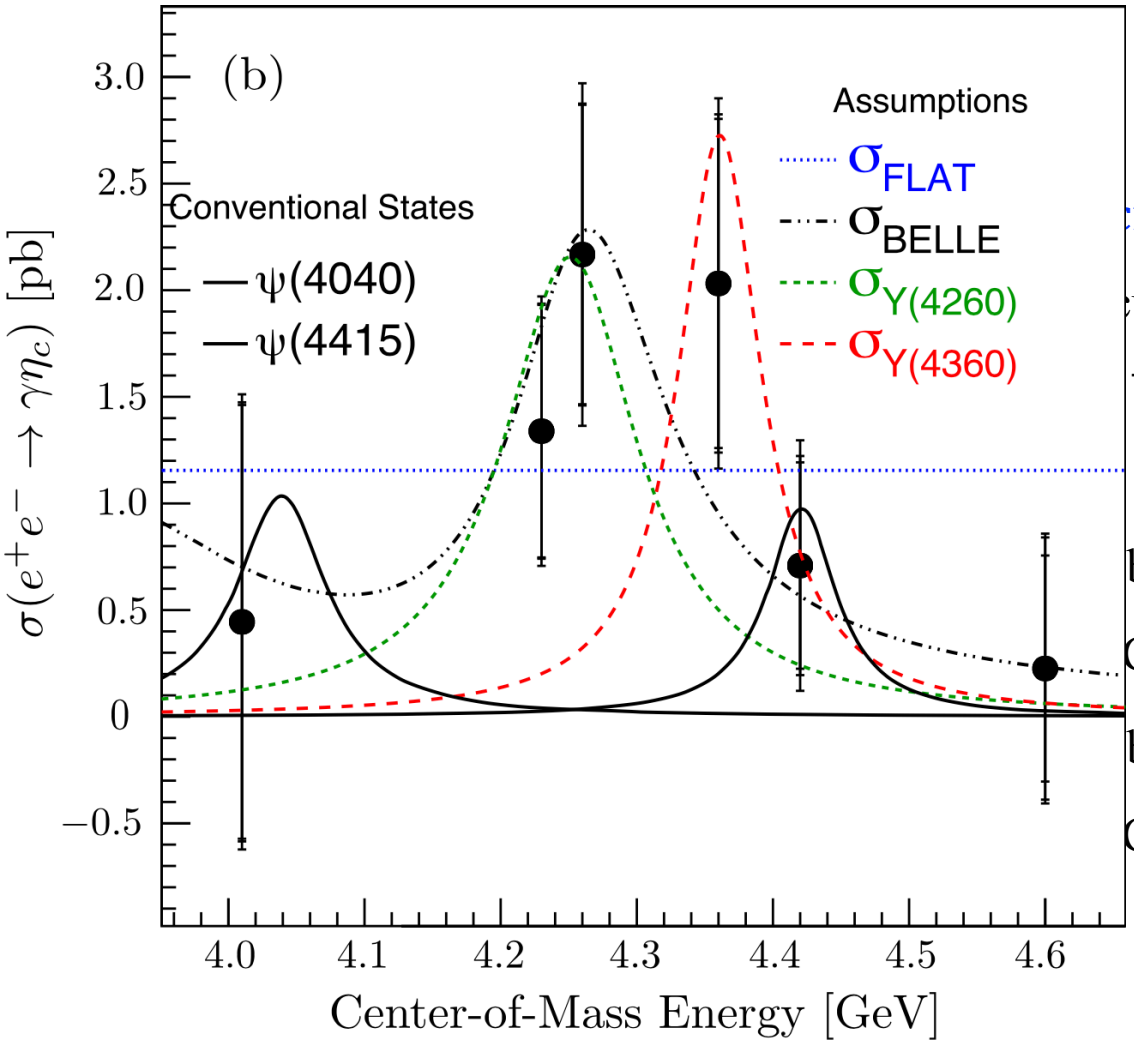

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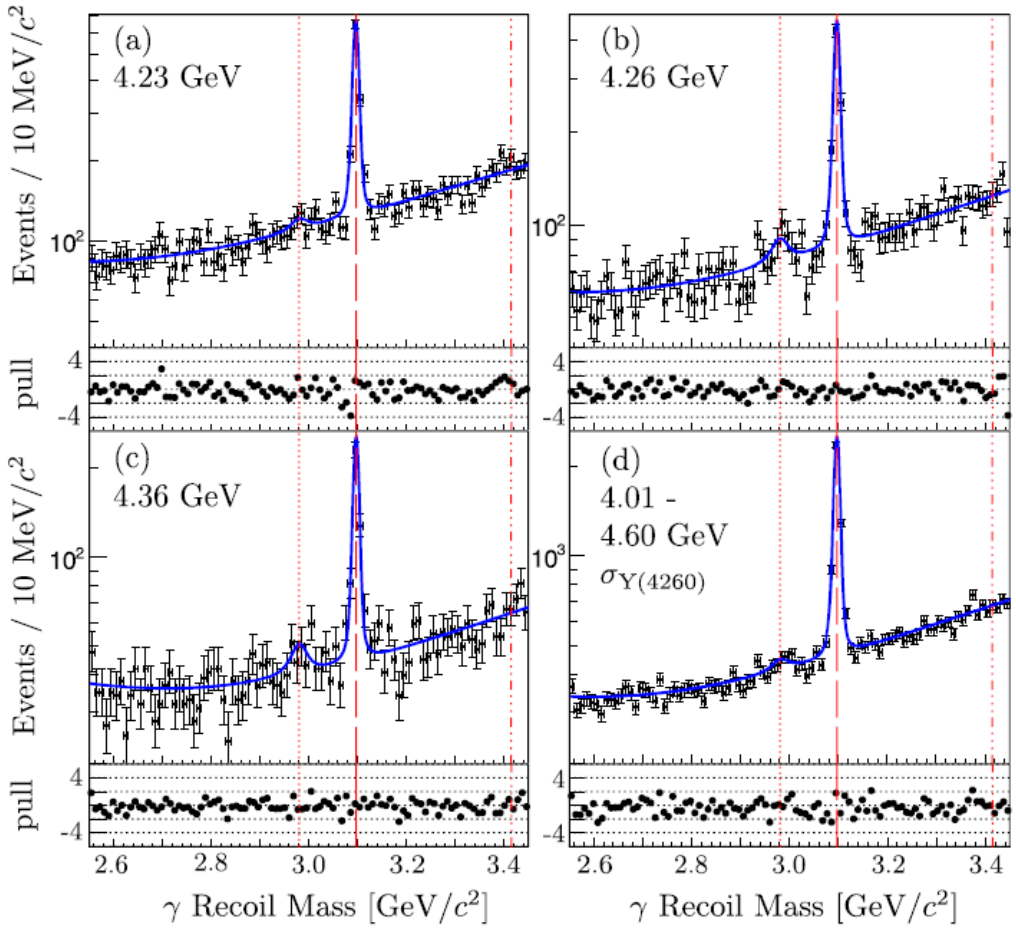
Evidence for $e^+e^- \to \gamma\eta_c$

- An unbinned maximum likelihood method is used to simultaneously fit the distributions of the recoil-mass distributions of the transition photon associated with the twelve final states γX_i.



- Continuum $q\bar{q}$ processes: second order polynomial function in each decay channel;
- J/ψ ISR process: double Gaussian function whose parameters are fixed using MC studies, the sizes are float in each decay channel;
- η_c Signal: NBW (fixed mass and width) convolved with a histogram derived from MC describing detector resolution and effects due to ISR.

Evidence for $e^+e^- \to \gamma\eta_c$

$E_{\rm CM}$ (GeV)	$\sigma(e^+e^- \to \gamma\eta_c)$ (pb)	sig. (σ)	U.L. (pb)
4.01	$0.44 \pm 1.02 \pm 0.32$	0.4	2.4
4.23	$1.34 \pm 0.59 \pm 0.22$	2.2	2.2
4.26	$2.17 \pm 0.70 \pm 0.39$	3.0	3.2
4.36	$2.03 \pm 0.77 \pm 0.40$	2.7	3.2
4.42	$0.71 \pm 0.48 \pm 0.33$	1.4	1.6
4.60	$0.23 \pm 0.53 \pm 0.35$	0.4	1.4

- The relative difference between four assumptions range from 1% to 6%, which are included in the systematic uncertainties.
- The largest statistical significances (3.0σ) is found at 4.26 GeV.

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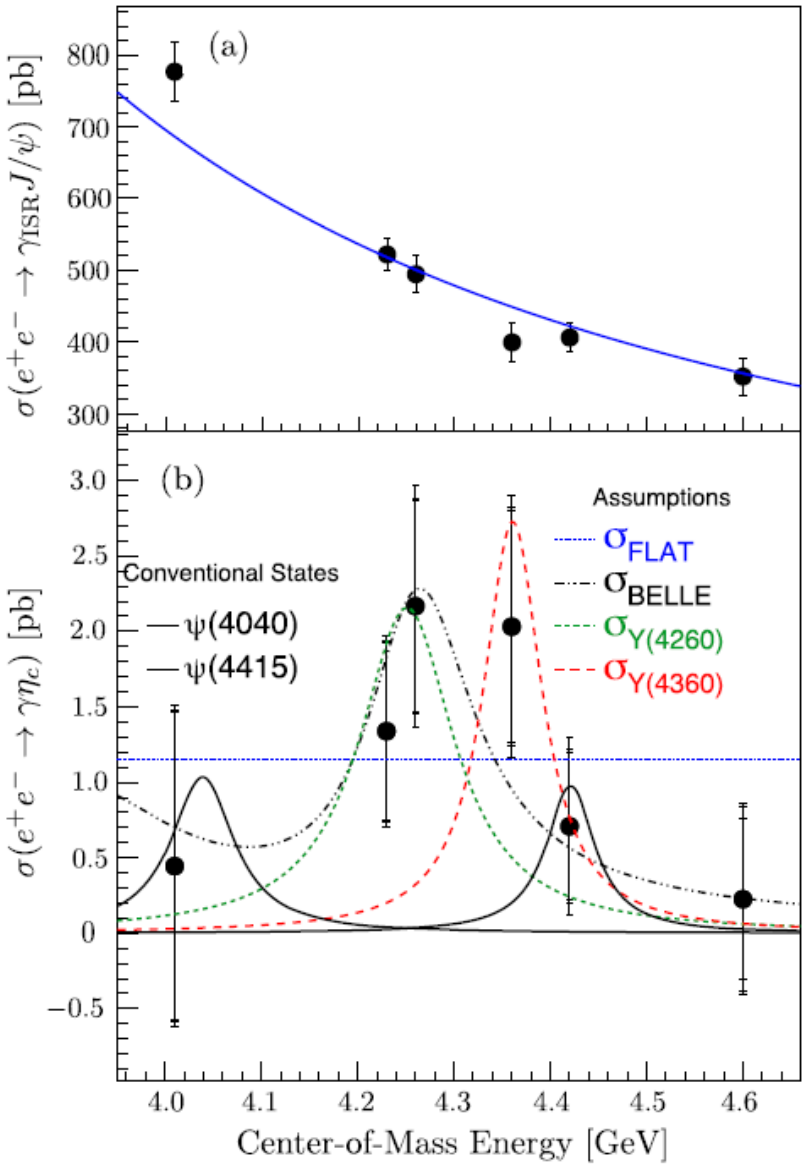
Evidence for $e^+e^- \to \gamma\eta_c$



- The J/ψ ISR cross section, $\sigma(e^+e^- \to \gamma_{ISR}J/\psi)$, serves as an important cross-check to the η_c analysis. The theoretical calculation are shown as the blue line.
- There is a good agreement between the measurements and the theoretical predictions.

- Combining all six energies under various assumptions for the energy-dependence of the cross section.
- The cross sections at different energies are constrained to follow the four assumptions.

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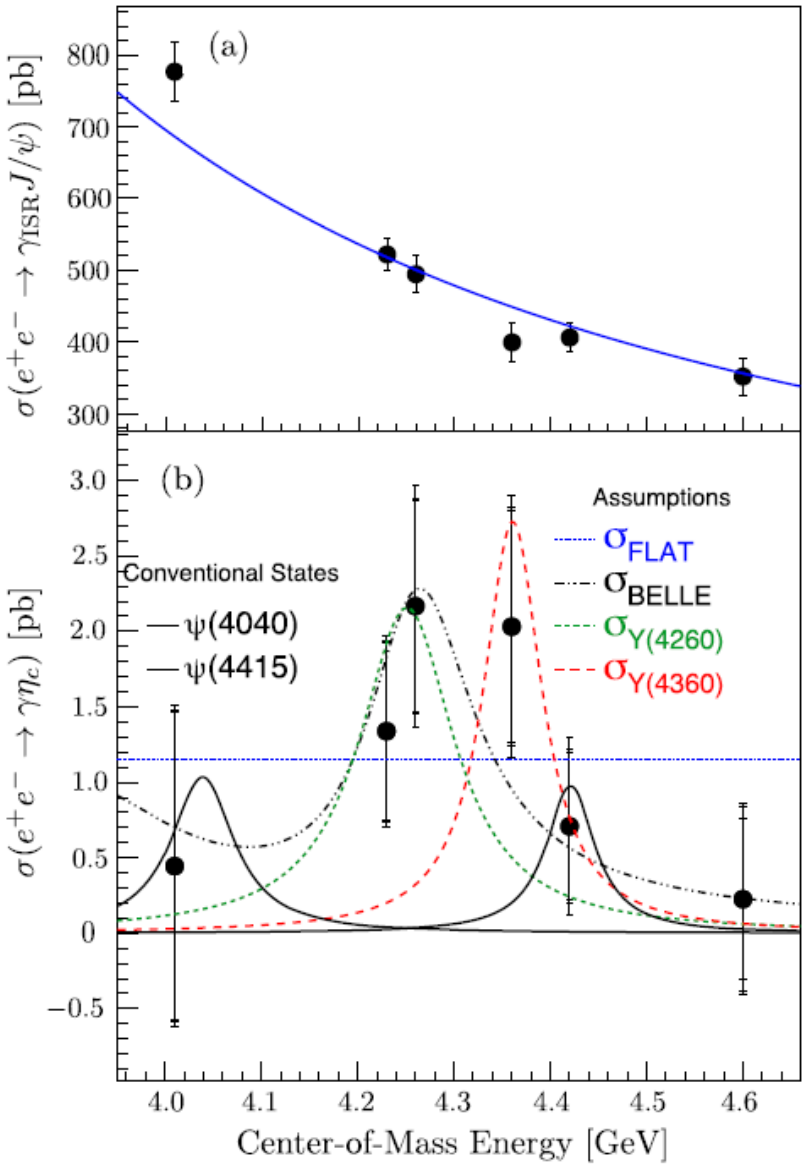
Evidence for $e^+e^- \to \gamma\eta_c$



Assumption	$\sigma_{\text{peak}}(e^+e^- \to \gamma\eta_c)$ (pb)	sig. (σ)	U.L. (pb)
σ_{FLAT}	$1.16 \pm 0.27 \pm 0.20$	4.1	1.6
σ_{BELLE}	$2.27 \pm 0.49 \pm 0.39$	4.5	3.1
$\sigma_{Y(4260)}$	$2.11 \pm 0.49 \pm 0.36$	4.2	2.9
$\sigma_{Y(4360)}$	$2.72 \pm 0.71 \pm 0.46$	3.6	3.9

- Combine all six energies under four assumptions.
- The significances are at least 3.6σ when we combine data sets according to the four assumptions.
- The cross section is better explained by $\sigma_{Y(4260)}$ than by conventional charmonium states, $\psi(4040)$ (1.9σ), $\psi(4160)(3.5\sigma)$ and $\psi(4415)$ (1.9σ).
- $\frac{\sigma_{peak}[e^+e^- \to \gamma\chi_{c0}]}{\sigma_{peak}[e^+e^- \to \gamma\eta_c]} < 2.8$, the enhancement of $e^+e^- \to \gamma\eta_c$ may suggest production via a hybrid charmonium state.

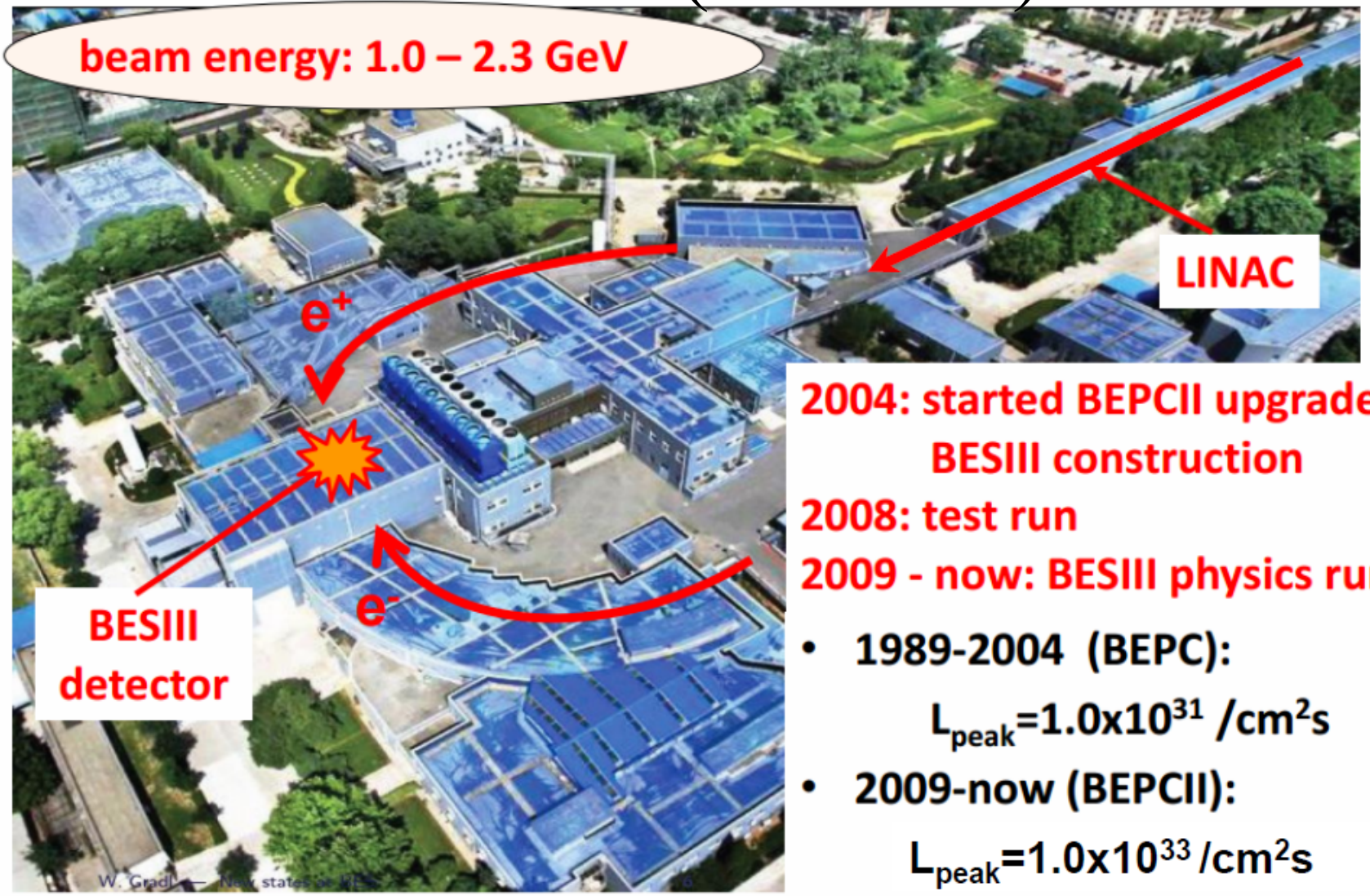
Summary & Outlook

- With the large data sample above 4 GeV and good performance of BEPCII and BESIII, we have searched for some radiative transitions.
- We present first evidence for $e^+e^- \to \gamma\eta_c$ at six c.m. energies between 4.01 and 4.60 GeV.
- We have collected more data samples above 4 GeV, more exciting results will come from BESIII.

Thanks for your attention!

backup

Beijing Electron and Positron Collider(BEPCII)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

  $L_{peak}=1.0\times10^{31}$ /cm^{2}s
- 2009-now (BEPCII):

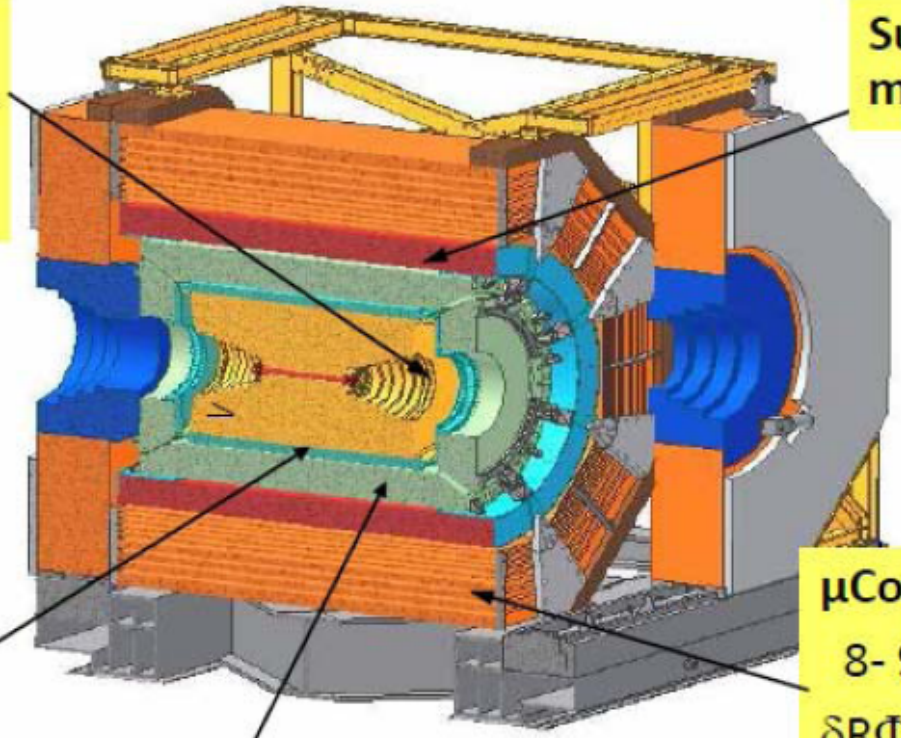
  $L_{peak}=1.0\times10^{33}$ /cm^{2}s

The BESIII detector

Drift Chamber (MDC)

$\sigma P/P\ (^0/_0) = 0.5\%(1GeV)$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$



Super-conducting magnet (1.0 tesla)

Time Of Flight (TOF)

σ_T: 90 ps Barrel

110 ps endcap

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ GeV)$

(CsI) $\sigma_{z,\phi}(cm) = 0.5 - 0.7\ cm/\sqrt{E}$