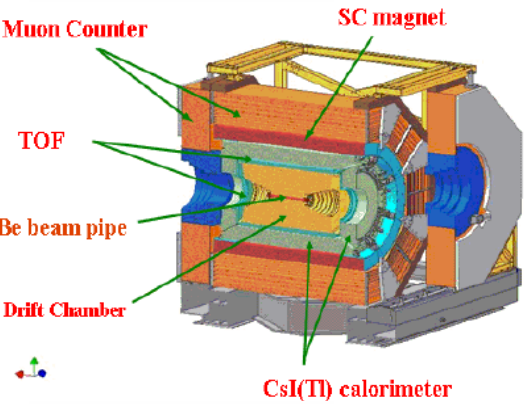
Hadron Physics from τ-Charm factories



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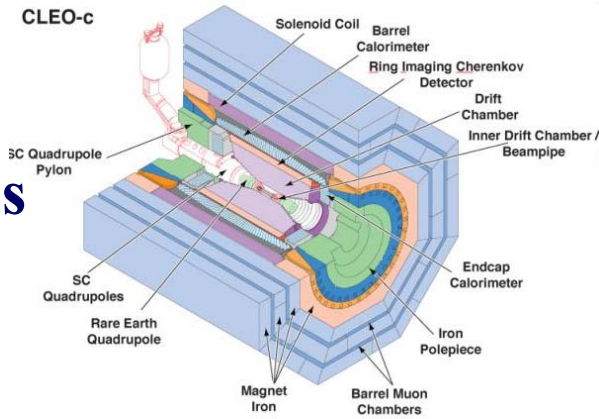
Sep. 21, 2009



Outline

- Recent selected hadron physics results from CLEOc and BESII
  - Charmonium physics
  - Light hadron spectroscopy
- BESIII/BEPCII experiment status and preliminary results
- Summary

Topics are not covered

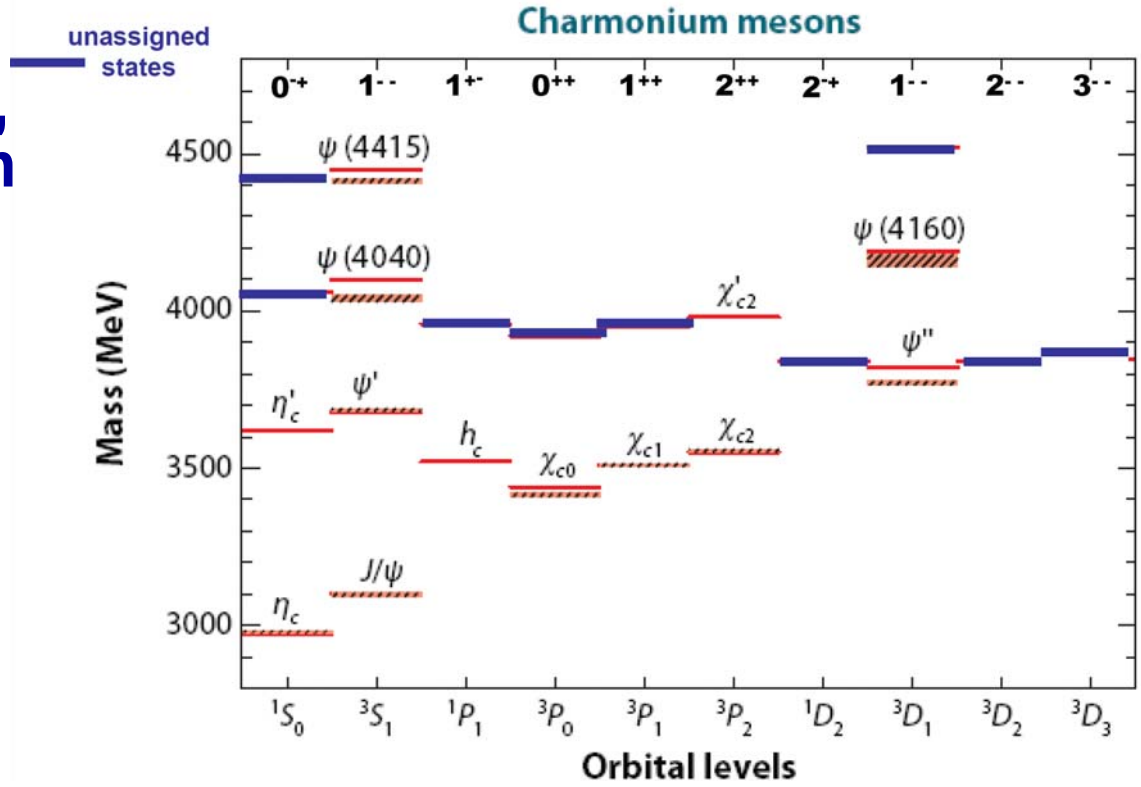
- Open charm physics (D, Ds decays)
- Search for rare and forbidden decays
- Earlier physics results from τ-Charm colliders
- I apologize for not covering many important results

Data samples

- CLEOc
  - ~27 million ψ(2S) decays
  - ~5.4 million DDbar events (818 pb^{-1})
  - ~0.55 million $e^+e^- \rightarrow D_sD_s^*$ events (600 pb^{-1})
- BESII
  - ~14 million ψ(2S) decays
  - ~58 million J/ψ decays
- BESIII
  - ~110 million ψ(2S) decays
  - ~200 million J/ψ decays

Charmonia physics

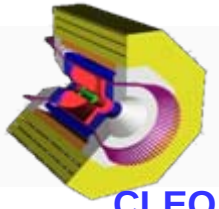
- What to measure?
  - Production, decays, transition, spectrum
- For what ?
  - A lab for pQCD and non-pQCD
  - Calibrate LQCD
  - How quarks form a hadron ?
- Why at tau-charm factories?
  - A clean environment
  - Tagging possible
  - Abundantly produced



Examples of Interesting problems:

- $\rho\pi$ puzzle
- Missing states ?
- Mixing states ?
- New states above open charm (X,Y,Z,…)

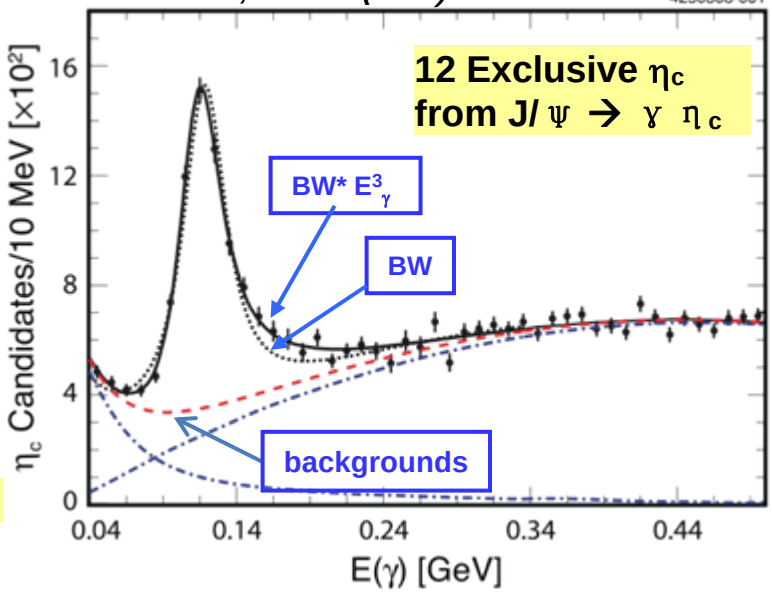
J/ψ, ψ'→ γη$_c$ and the η$_c$ lineshape

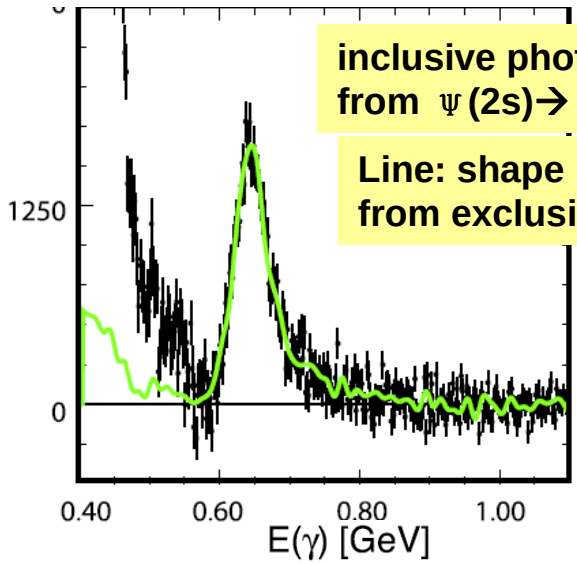


- inconsistent(>3σ) η$_c$ mass measurements
- M1 transition poorly known;
- Data: ψ(2s) → π$^+$π$^-$ J/ψ, ψ(2s), J/ψ → γη$_c$
- Exclusive channels → Distorted lineshapes
- Hard to determine mass and width

PRD 73, 054005 (2006)

PRL 102, 011801 (2009)





B(ψ(2S)→ γ η$_c$)=(4.32±0.16±0.60)×10^{-3} inclusive

B(J/ψ → γ η$_c$)/B(ψ(2S)→ γ η$_c$) =(4.59±0.23±0.64) exclusive

→ B(J/ψ → γ η$_c$)=(1.98±0.09±0.30)%

Lineshapes in exclusive channel at BESIII, and energy dependent ψ(1S,2S)→ γ η$_c$ matrix element → accurate η$_c$ mass & width

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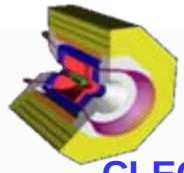
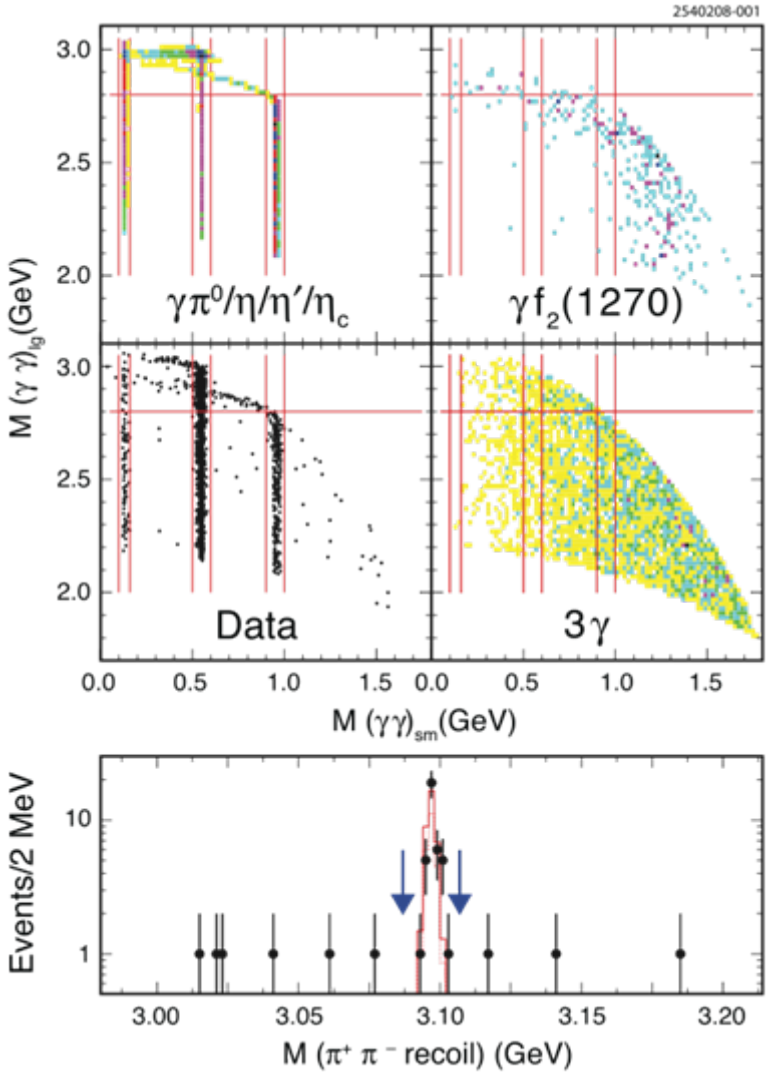
First observation of $J/\psi \to \gamma\gamma\gamma$



- Quarkonium analogue of ortho-positronium.
- Tag J/ψ with $\psi' \to \pi^+\pi^- J/\psi$,
  - 37 events are inconsistent with $\gamma\pi^0/\eta/\eta'/\eta_c$,
  - 24.2 events remain after subtracting backgrounds (dominantly $\gamma\,\pi^0\,\pi^0$).
- $B(J/\psi \to \gamma\gamma\gamma) = (1.2 \pm 0.3 \pm 0.2) \times 10^{-5}$ first 3γ decay mode of any hadron
- Agrees with LO QED, but NLO correction takes rate negative! (Higher order corrections very significant.)
- A search for $J/\psi \to \gamma\,\eta_c$; $\eta_c \to \gamma\gamma$ leads to an upper limit:

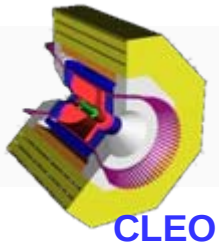
  $B(\eta_c \to \gamma\gamma) < 3\times10^{-4}$ @ 90% C.L.

  (PDG: $B(\eta_c \to \gamma\gamma) = (2.7\pm0.9)\times10^{-4}$)



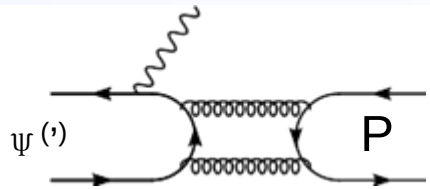
PRL 101, 101801 (2008)

J/ψ, ψ'→γ(π^0, η, η')



- **Measure:**

$$R_n \equiv \frac{\mathcal{B}(\psi(nS) \to \gamma\eta)}{\mathcal{B}(\psi(nS) \to \gamma\eta')}$$



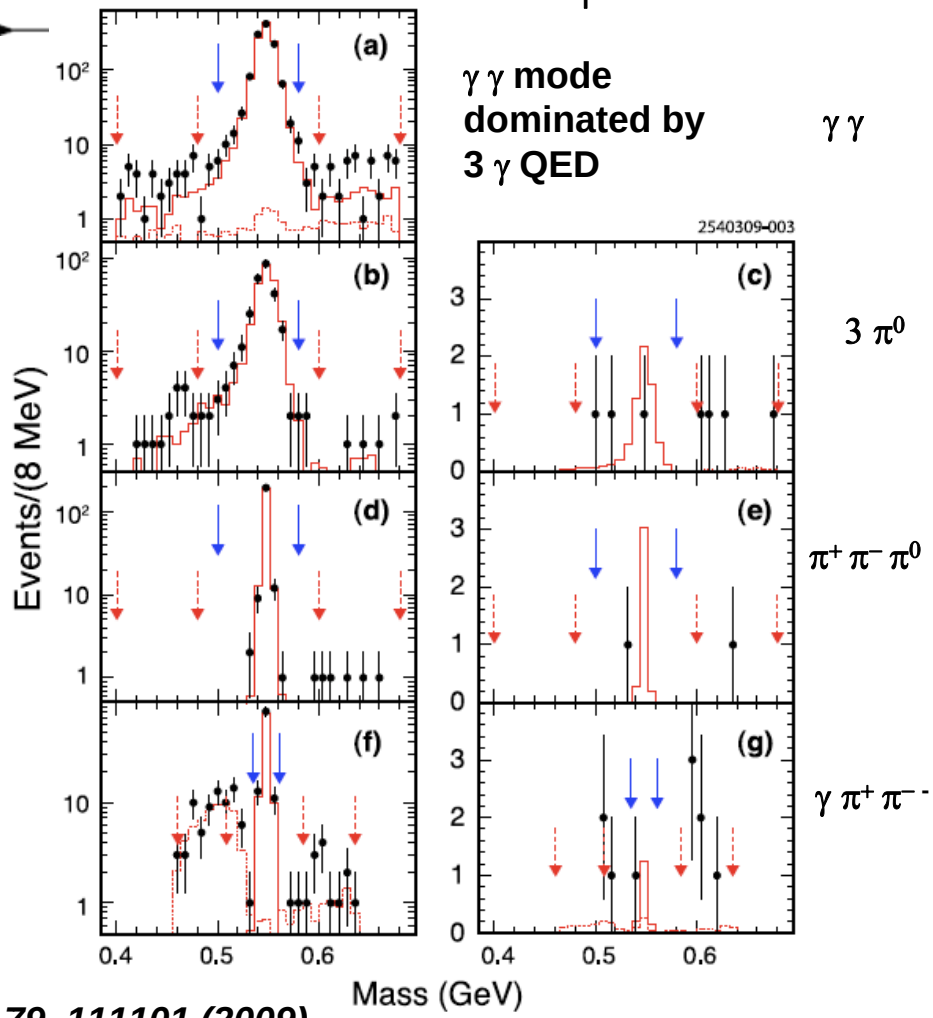
Mode	This result (10^{-4})
$J/\psi \to \gamma\pi^0$	$0.363 \pm 0.036 \pm 0.013$
$\to \gamma\eta$	$11.01 \pm 0.29 \pm 0.22$
$\to \gamma\eta'$	$52.4 \pm 1.2 \pm 1.1$
$\psi(2S) \to \gamma\pi^0$	< 0.07
$\to \gamma\eta$	< 0.02
$\to \gamma\eta'$	$1.19 \pm 0.08 \pm 0.03$

$R_1 = (21.1 \pm 0.9)\%$

$R_2 < 1.8\%$ at 90% C.L.

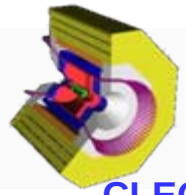
- **R_1 consistent with known η/η' mixing**
- **R_2 expected to be equal to R_1 but it is not!**

γ η Mode



PRD(R) 79, 111101 (2009)

Study of χ_{cJ} decays

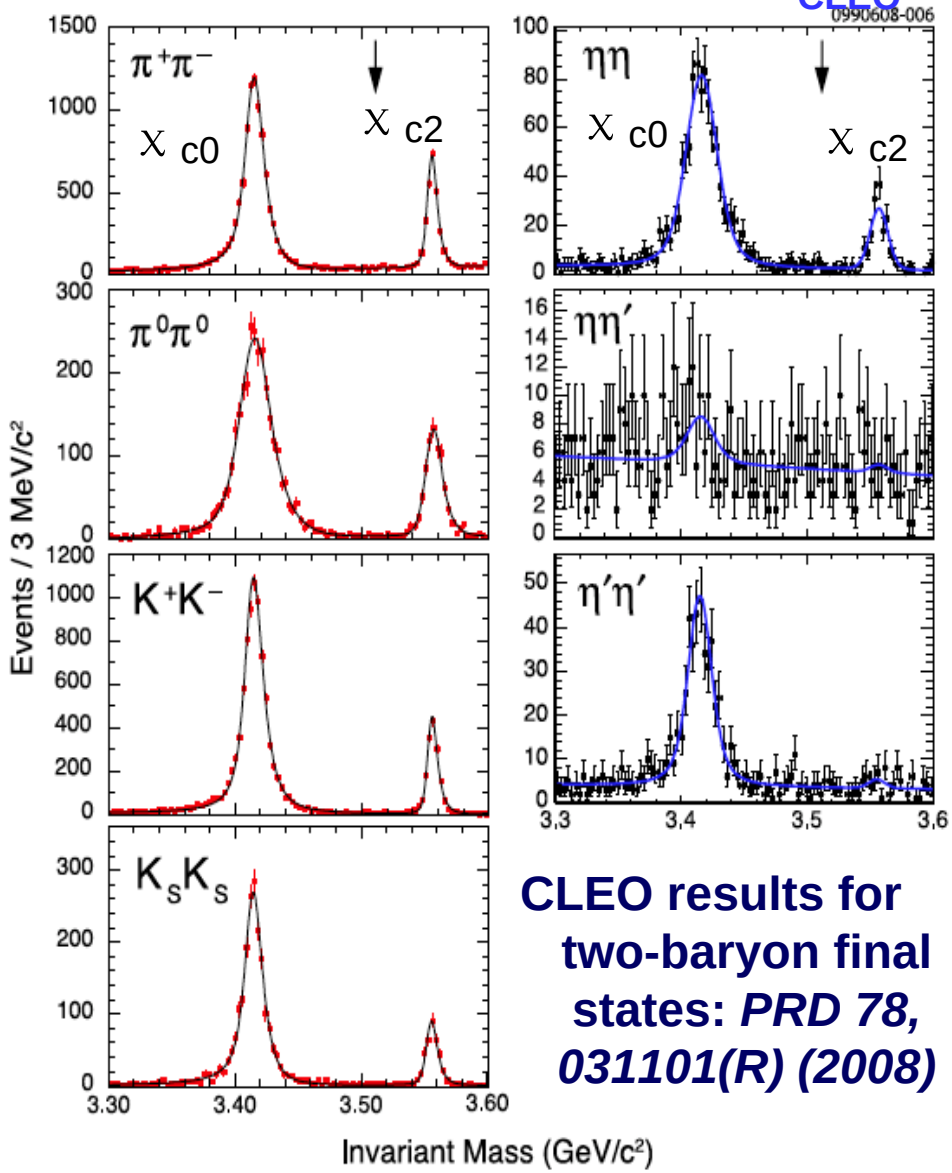


- Clean and multiple J^{PC} states
- Especially two body decays:
  - role of the color octet mechanism
  - probe gluon content in final states
- substantial improvement over current world averages in some channels

Branching Fractions or 90% CL UL [10^{-3}]

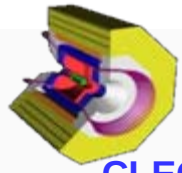
Mode		χ_{c0}	χ_{c2}
$\pi^+\pi^-$	This Work	$6.37 \pm 0.08 \pm 0.29 \pm 0.32$	$1.59 \pm 0.04 \pm 0.07 \pm 0.10$
	PDG [5]	4.87 ± 0.40	1.42 ± 0.16
$\pi^0\pi^0$	This Work	$2.94 \pm 0.07 \pm 0.32 \pm 0.15$	$0.68 \pm 0.03 \pm 0.07 \pm 0.04$
	PDG	$2.43 \pm .20$	0.71 ± 0.08
K^+K^-	This Work	$6.47 \pm 0.08 \pm 0.33 \pm 0.32$	$1.13 \pm 0.03 \pm 0.06 \pm 0.07$
	PDG	5.5 ± 0.6	0.78 ± 0.14
$K^0_S K^0_S$	This Work	$3.49 \pm 0.08 \pm 0.17 \pm 0.17$	$0.53 \pm 0.03 \pm 0.03 \pm 0.03$
	PDG	2.77 ± 0.34	0.68 ± 0.11
$\eta\eta$	This Work	$3.18 \pm 0.13 \pm 0.31 \pm 0.16$	$0.51 \pm 0.05 \pm 0.05 \pm 0.03$
	PDG	2.4 ± 0.4	< 0.5
$\eta\eta'$	This Work	< 0.25	< 0.06
		$(0.16 \pm 0.06 \pm 0.01 \pm 0.01)$	$(0.013 \pm 0.031 \pm 0.001 \pm 0.001)$
	PDG	< 0.5	< 0.26
$\eta'\eta'$	This Work	$2.12 \pm 0.13 \pm 0.18 \pm 0.11$	< 0.10
			$(0.056 \pm 0.032 \pm 0.005 \pm 0.003)$
	PDG	1.7 ± 0.4	< 0.4

PRD 79, 072007 (2009)



CLEO results for two-baryon final states: *PRD 78, 031101(R) (2008)*

Observation of χ_{cJ} (1P) → γ(ρ, ω, ϕ)



Look for:

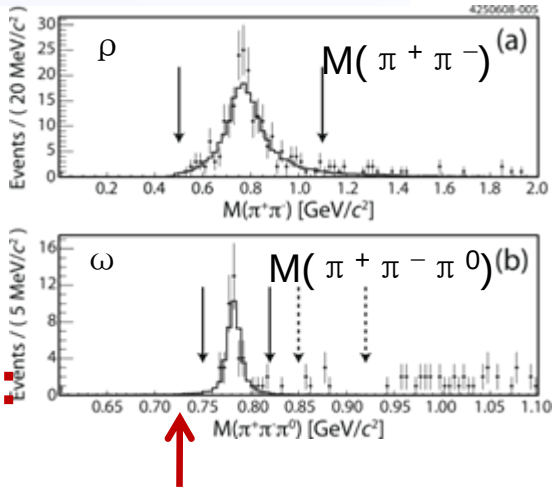
$\psi' \rightarrow \gamma_{(low)}\chi_{cJ}$

$\chi_{cJ} \rightarrow \gamma_{(high)}$ (ρ,ω,ϕ)

Significant signals:

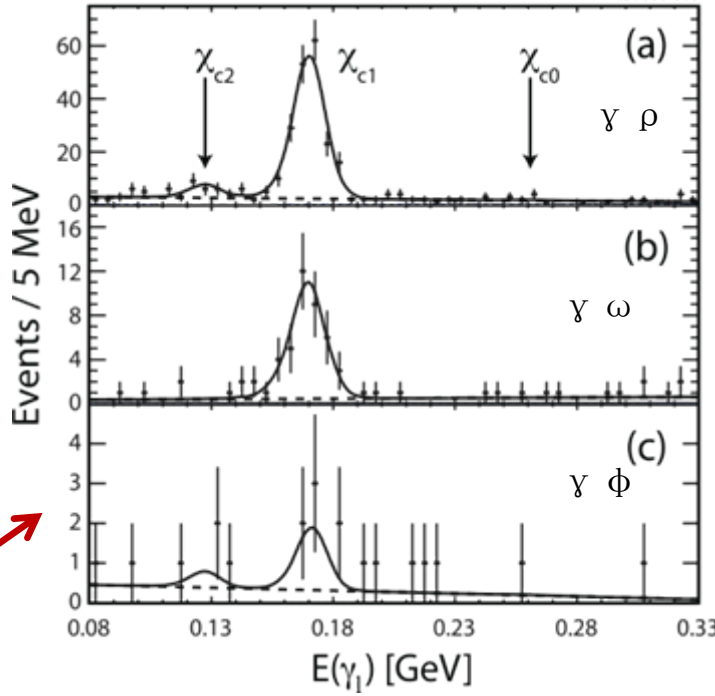
$\chi_{c1} \rightarrow \gamma\,\rho$

$\chi_{c1} \rightarrow \gamma\,\omega$



1. cut on hadronic mass

2. look at E_γ (low)



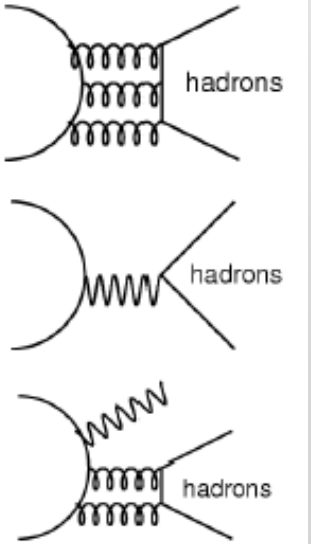
- The process is expected to be analogous to that of glueball production: J/ψ → γ f_J
- pQCD, however, predicts rates an order of magnitude below the observations !
- (Gao,Zhang,Chao, Chin.Phys.Lett. 23, 2376 (2006) [arXiv:hep-ph/0607278])

Mode	$\mathcal{B} \times 10^6$	U.L. $[10^{-6}]$	pQCD $[10^{-6}]$
$\chi_{c0} \rightarrow \gamma\rho^0$		< 9.6	1.2
$\chi_{c1} \rightarrow \gamma\rho^0$	$243 \pm 19 \pm 22$		14
$\chi_{c2} \rightarrow \gamma\rho^0$	$25 \pm 10^{+8}_{-14}$	< 50	4.4
$\chi_{c0} \rightarrow \gamma\omega$		< 8.8	0.13
$\chi_{c1} \rightarrow \gamma\omega$	$83 \pm 15 \pm 12$		1.6
$\chi_{c2} \rightarrow \gamma\omega$		< 7.0	0.50
$\chi_{c0} \rightarrow \gamma\phi$		< 6.4	0.46
$\chi_{c1} \rightarrow \gamma\phi$	$12.8 \pm 7.6 \pm 1.5$	< 26	3.6
$\chi_{c2} \rightarrow \gamma\phi$		< 13	1.1

PRL 101, 151801 (2008)

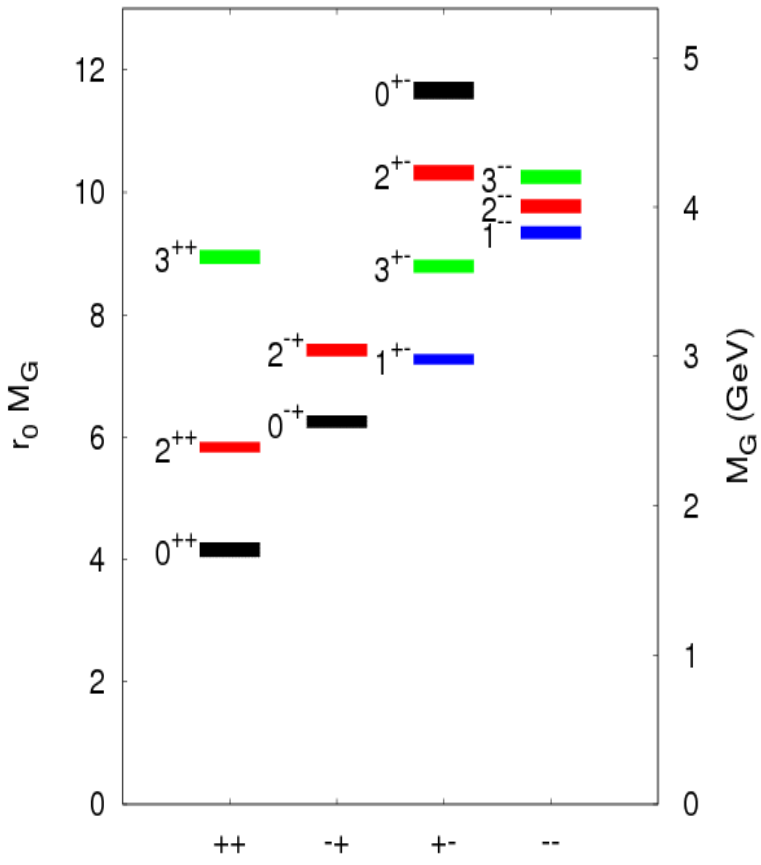
Light hadron spectroscopy

- **Motivation:**
  - Establish spectrum of light hadrons
  - Search for non-conventional hadrons
  - Understand how hadrons are formed
  - Study chiral symmetry in QCD
- **Why at a tau-charm collider ?**
  - Gluon rich
  - Kinematics favorable
  - Clean environment, J^{PC} filter



Many results in BESII:
~ 50 publications
Much more from BESIII:
×100 statistics,
÷10 γ resolution

Glueball spectrum from LQCD



Y. Chen et al., PRD 73 (2006) 014516

Observation of charged κ at BESII

- κ was first found in Kπ scattering data
- However, its phase shift is much less than 180º and it cannot be filled into any nonets of ordinary $q\bar{q}$ mesons. There have been hot debates on the existence of κ.

- In recent years:
- FNAL E791 found evidence of neutral κ in $D^+ \to K^-\pi^+\pi^+$.

$$M = 797 \pm 19 \pm 43\ \mathrm{MeV/c^2}, \Gamma = 410 \pm 43 \pm 87\ \mathrm{MeV/c^2}$$

- CLEO $D^0 \to K^-\pi^+\pi^0$ data find no evidence of κ.
- FOCUS data on $K^+ \to K^-\pi^+\mu^+\nu$ require K^{*0} interfere with either a constant amplitude or a broad 0^+ resonance in Kπ.
- BESII observed neutral κ in $J/\psi \to K^{*0}K\pi \to K\pi K\pi$ in 2006.
  - neutral κ pole:

$$(841 \pm 30^{+81}_{-73}) - i(309 \pm 45^{+48}_{-72})\ \mathrm{MeV/c^2}$$

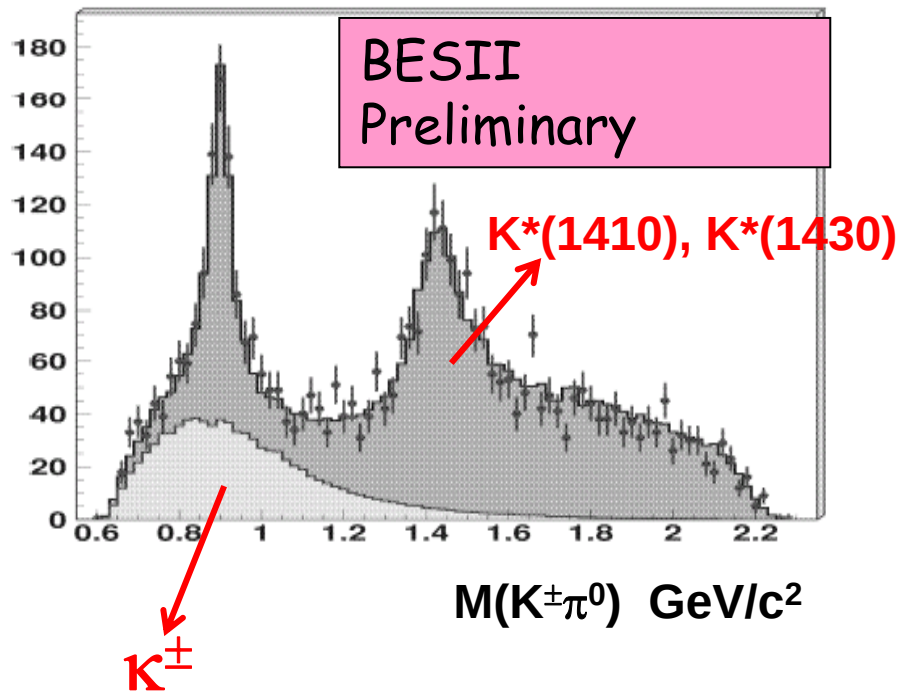
The existence of charged κ is expected !

- CLEO reported the necessity of $\kappa^{\pm} \to K^{\pm}\pi^{0}$ in $D^{0} \to K^{+}K^{-}\pi^{0}$.
- However, no charged κ is needed in BABAR data.
- Charged κ is observed at BESII in $J/\psi \to K^{*\pm}\kappa^{\mp} \to K_{s}\pi^{\pm}K^{\mp}\pi^{0}$

- Different parameterizations of κ are tried in PWA. Consistent results on the pole of charged κ are obtained.

$$(841 \pm 51^{+14}_{-28}) - i(288 \pm 101^{+64}_{-30})\ \mathrm{MeV/c^2}$$

- The pole position for charged κ is consistent with that for neutral κ within the error.



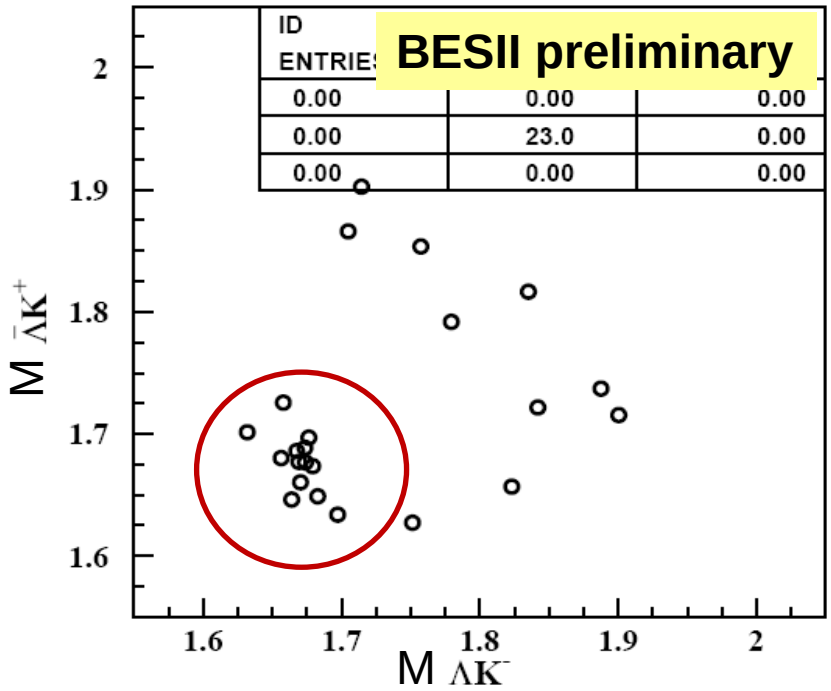
First observation of $\psi(2S)\to\bar{\Omega}^{+}\Omega^{-}$

- This decay mode is thought to be mainly produced from the annihilation of three gluons into $s\bar{s}$ pair.

$$B(\psi(2S)\to\bar{\Omega}^{+}\Omega^{-}) = \frac{N_{obs}^{data}}{N_{\psi(2S)}\cdot B(\Omega\to\Lambda K)^{2}\cdot B(\Lambda\to\pi p)^{2}\cdot\varepsilon}$$

$$= (3.21\pm1.25\pm0.86)\times10^{-5}$$

Statistical significance ~ 5σ

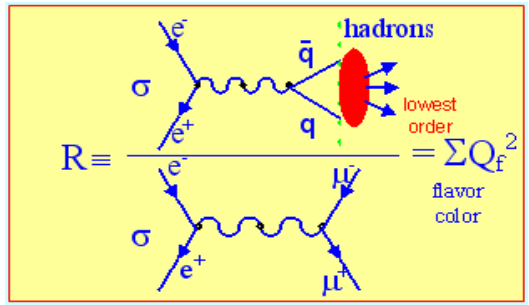


QCD studies at low energies

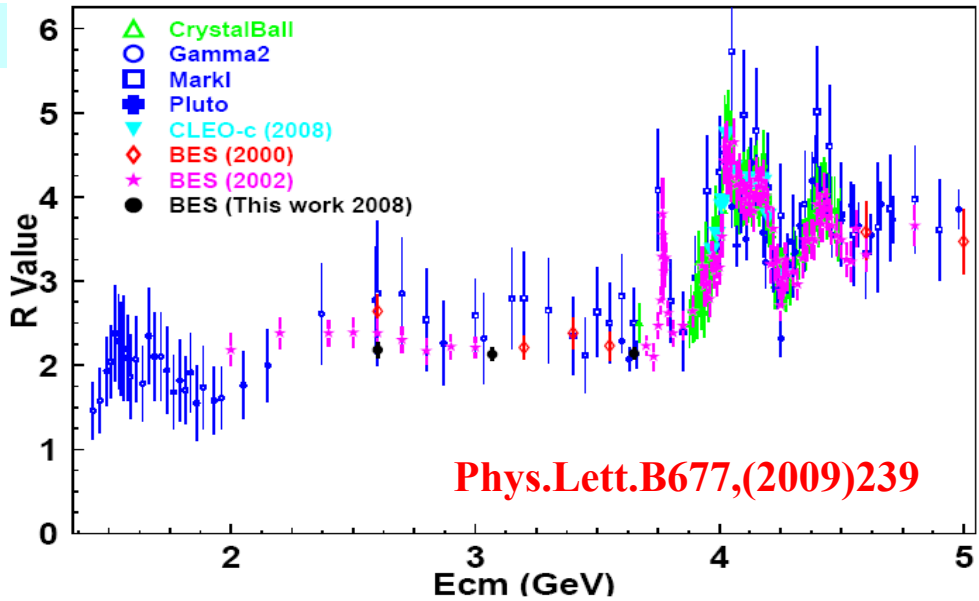
- Understand where exactly pQCD becomes invalid
- Precision measurement of α_s ➔running
- Precision measurement of R
- input to 

- Related to α_{QED} (s), prediction of higgs mass and g-2
- A new measurement at BESII on R
  - Precision at ~ 3.5% **BESIII: < 2%**
  - A new determination of $\alpha_s(s)$:

$$\alpha_s(M^2_Z) = 0.117^{+0.012}_{-0.017}$$



E_{cm}(GeV)	L(pb^{-1})	R	$\alpha_s(s)$
2.60	1.222	2.18±0.02±0.08	$0.266^{+0.030+0.125}_{-0.030-0.116}$
3.07	2.291	2.13±0.02±0.07	$0.192^{+0.029+0.103}_{-0.029-0.101}$
3.65	6.485	2.14±0.01±0.07	$0.207^{+0.015+0.104}_{-0.015-0.104}$



In good agreement with previous results

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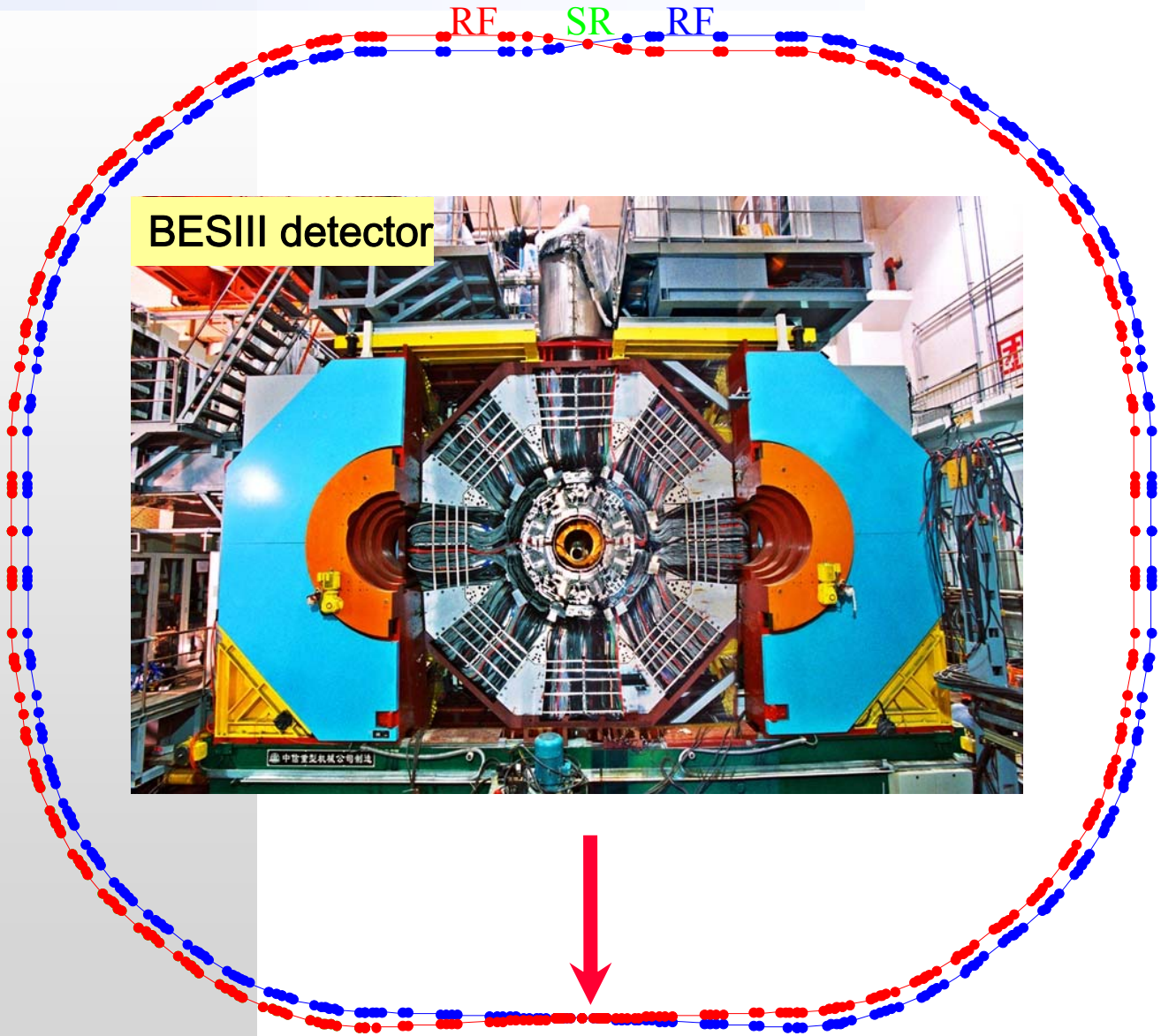
BEPC II Storage ring: Large angle, double-ring

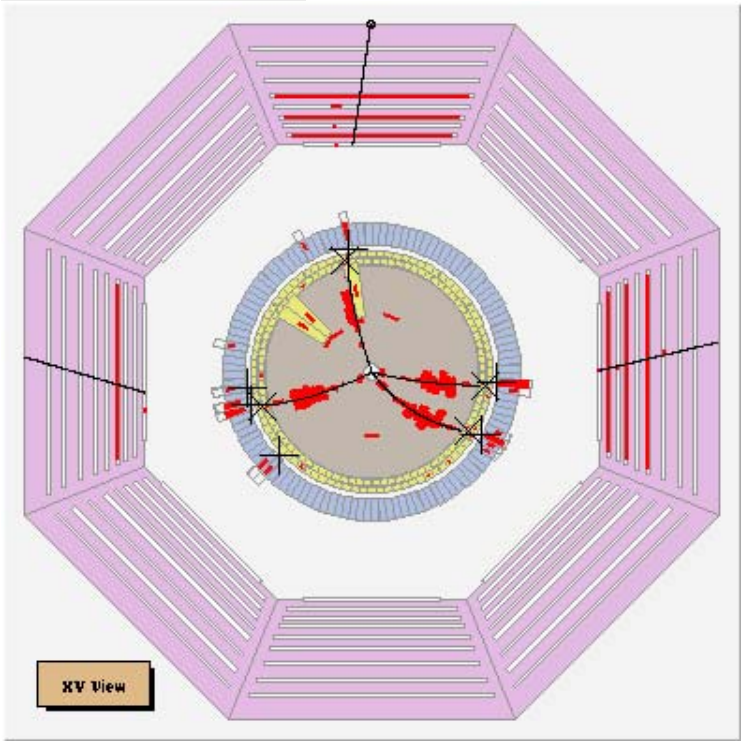


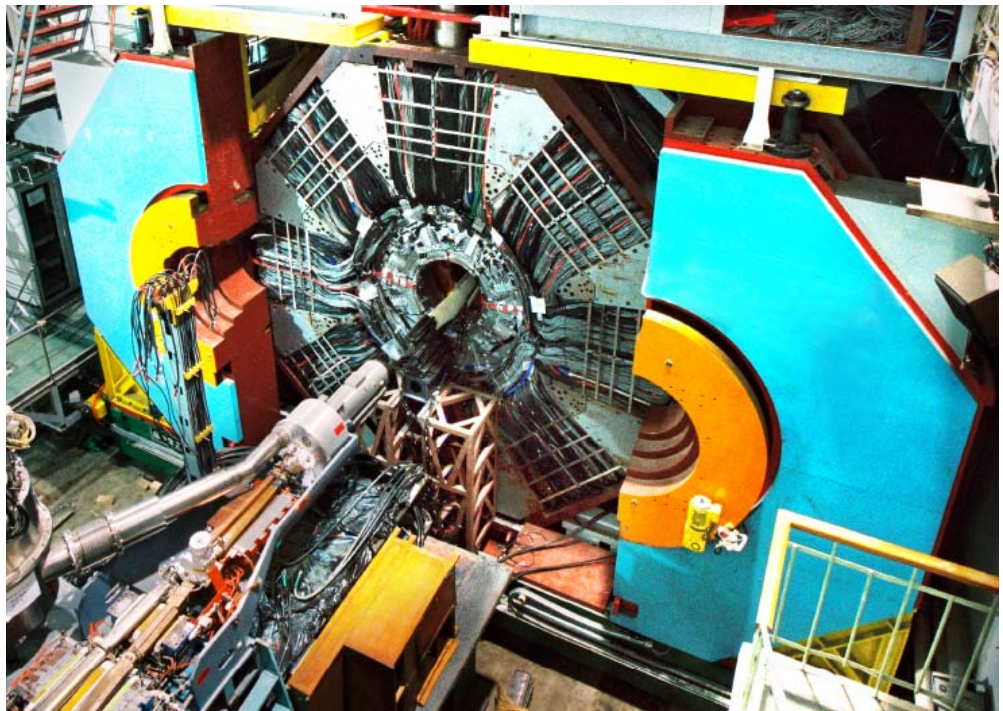
Beam energy:
1.0-2 .3GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A

BESIII Commissioning and data taking milestones

Mar. 2008: first full cosmic-ray event
April 30, 2008: Move the BESIII to IP
July 19, 2008: First e^+e^- collision event in BESIII
Nov. 2008: ~ 14M ψ(2S) events collected
April 14, 2009 ~110M ψ(2S) events collected(×4 CLEOc)
May 30, 2009 42 pb^{-1} at continuum collected
July 28, 2009 ~200M J/ψ events collected(×4 BESII)

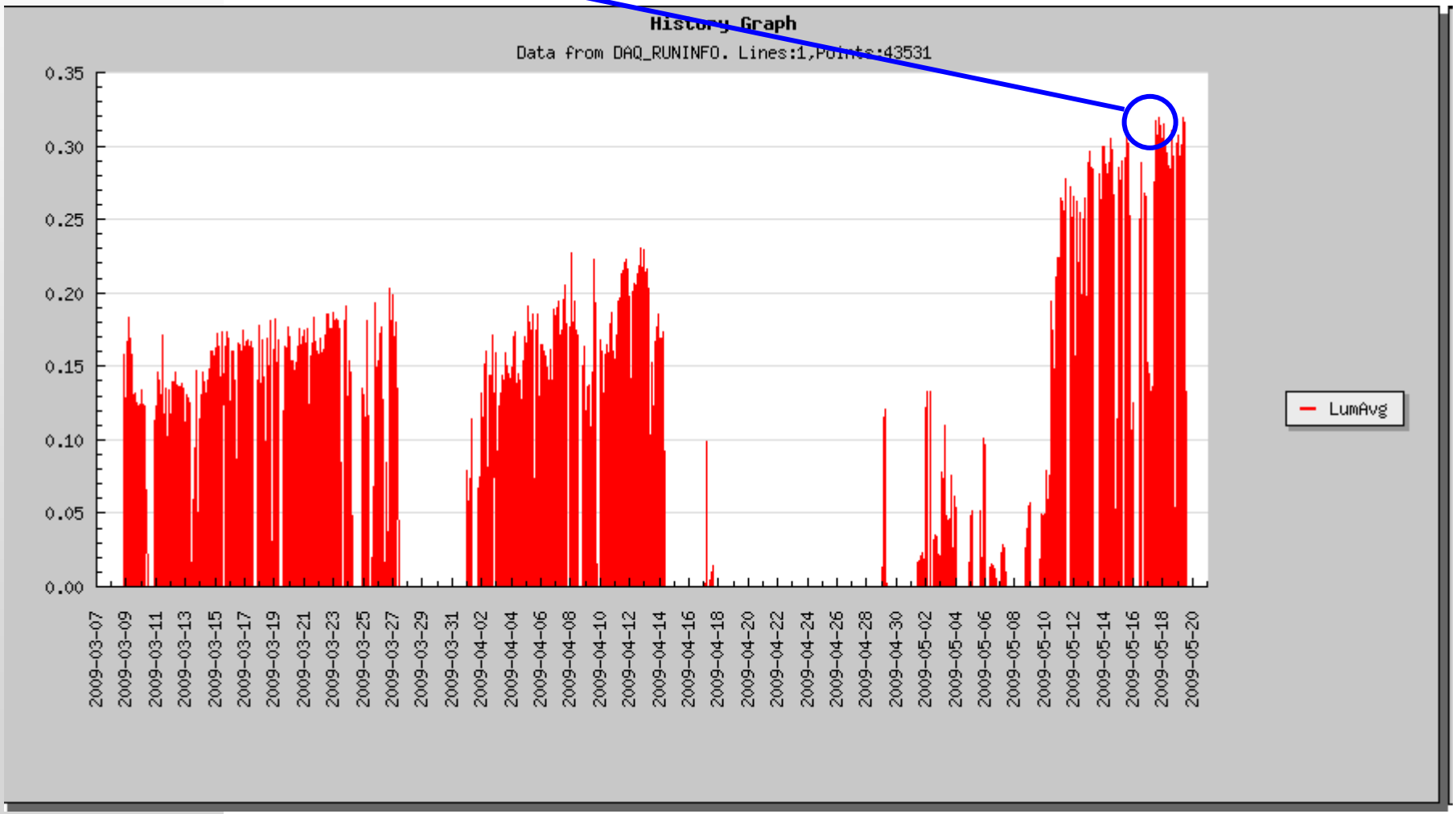
Peak Lumi. @ Nov. 2008:
$1.2 \times 10^{32} cm^{-2} s^{-1}$
Peak Lumi. @ May 2009:
$3.2 \times 10^{32} cm^{-2} s^{-1}$ ➔
×5 CESRc
×30 BEPC



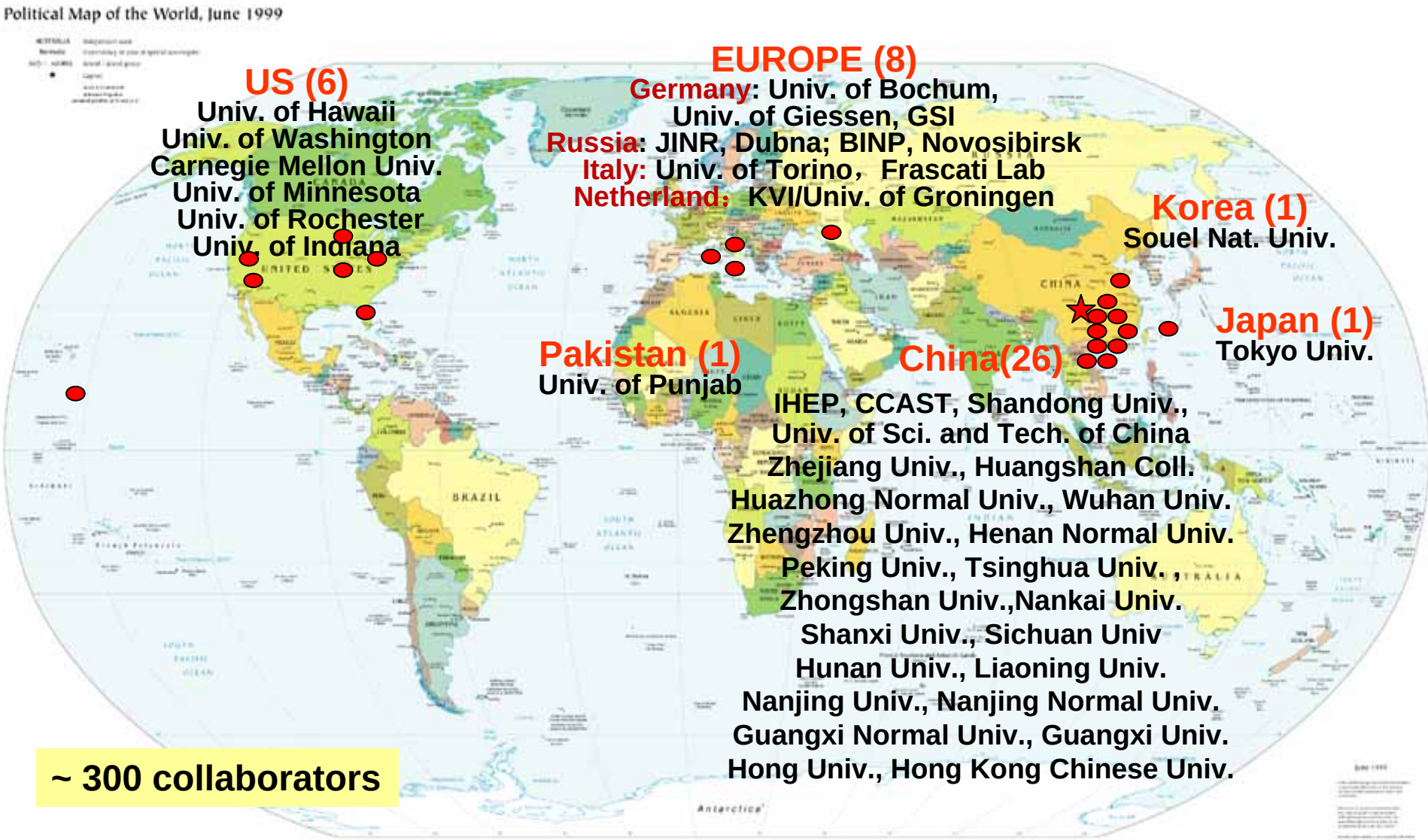


Achieved Luminosity vs Time

Record: 0.32×10^{33} $cm^{-2}s^{-1}$ reached in May 14, 2009

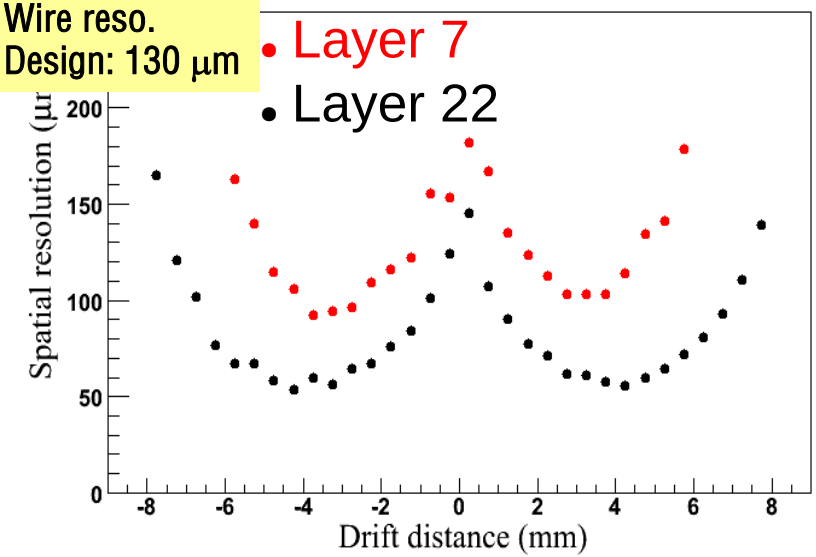


BESIII collaboration

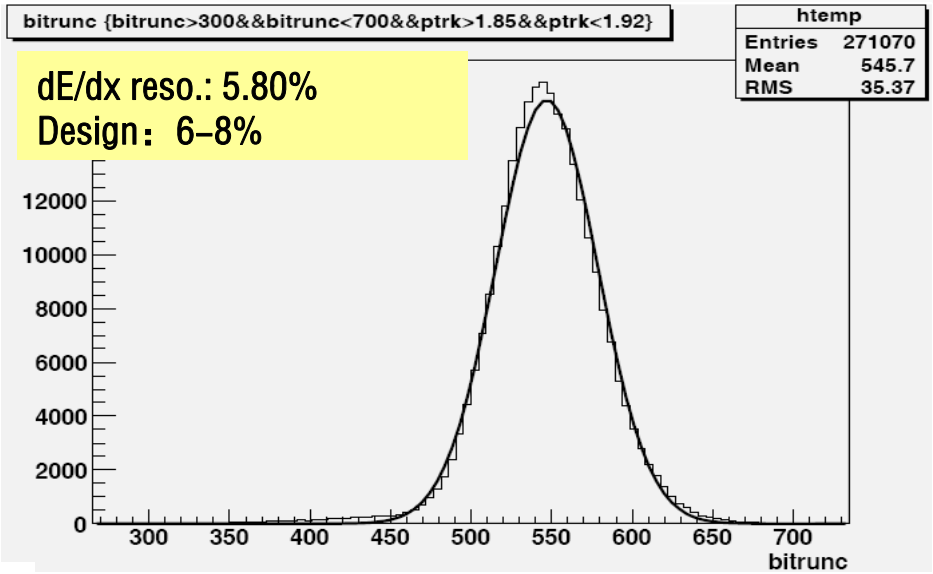


Detector performance and calibration

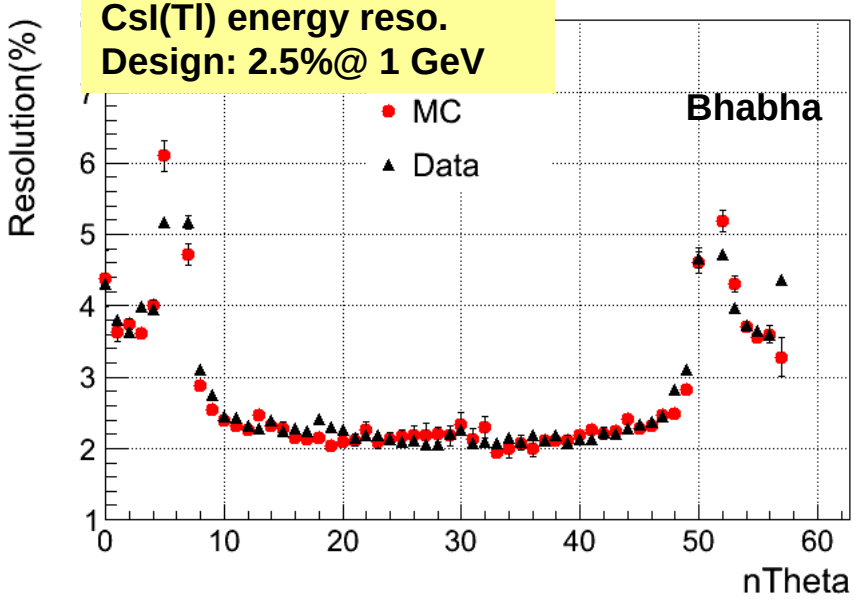
Wire reso.
Design: 130 μm



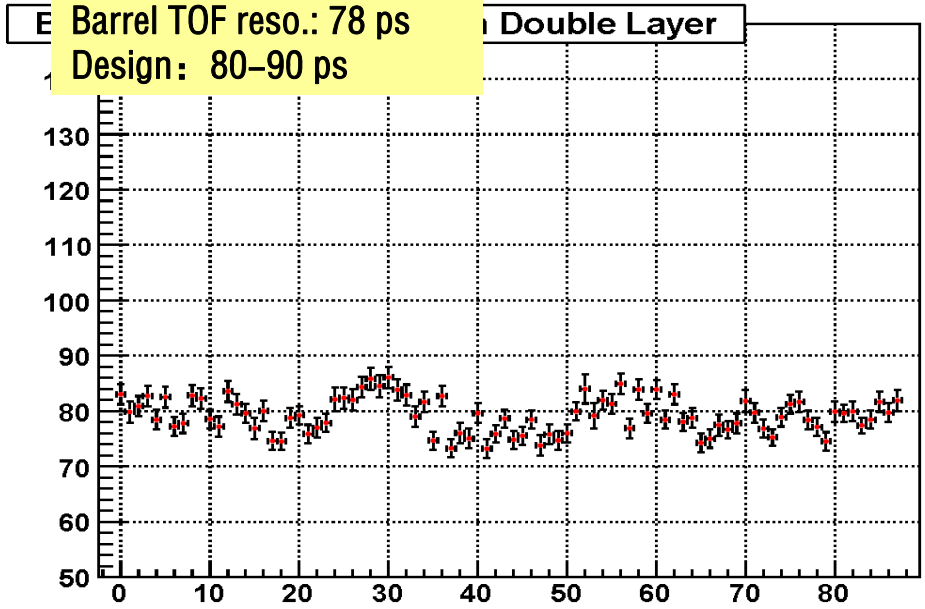
dE/dx reso.: 5.80%
Design：6–8%



CsI(Tl) energy reso.
Design: 2.5%@ 1 GeV



Barrel TOF reso.: 78 ps
Design：80–90 ps



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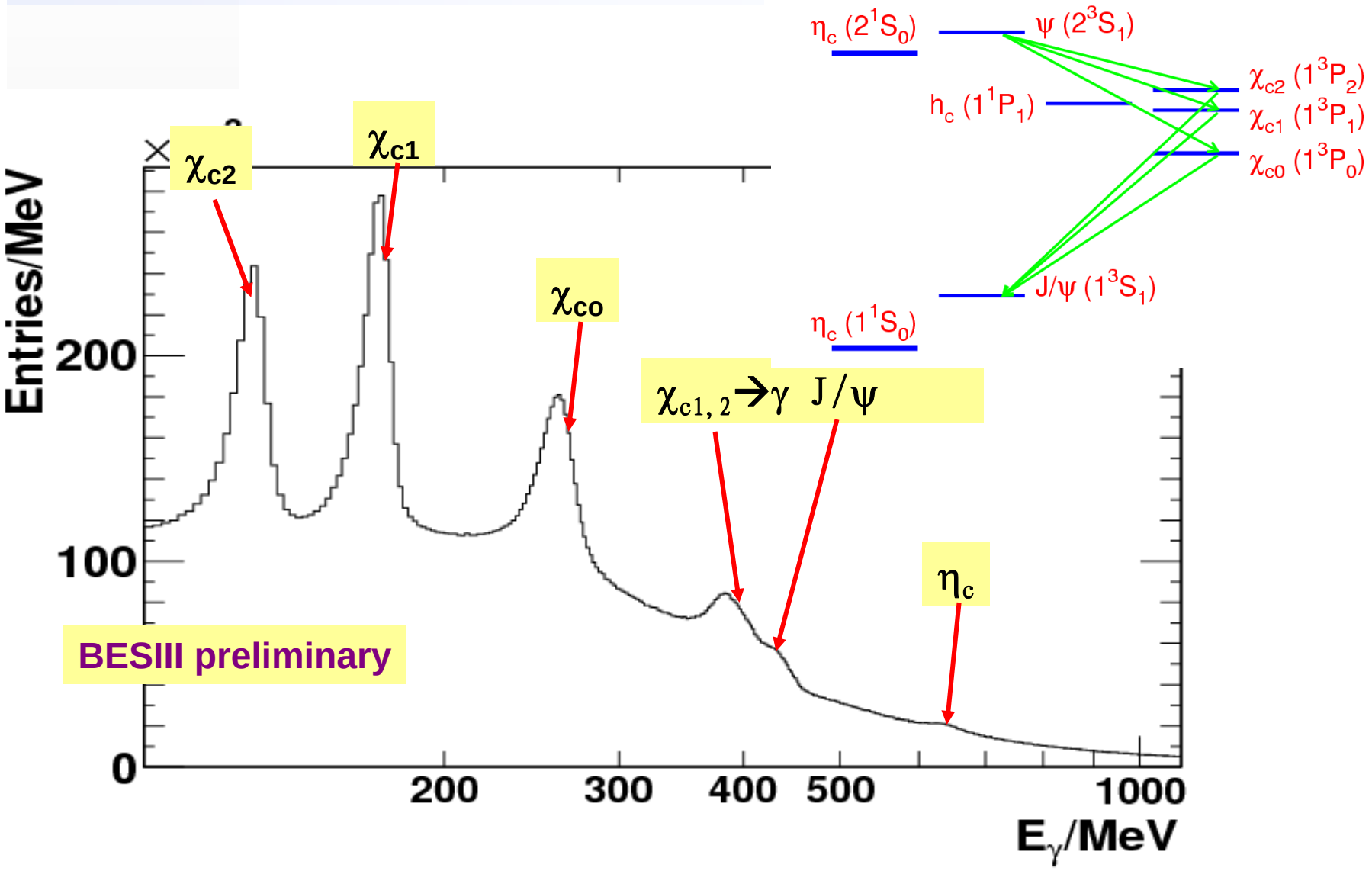
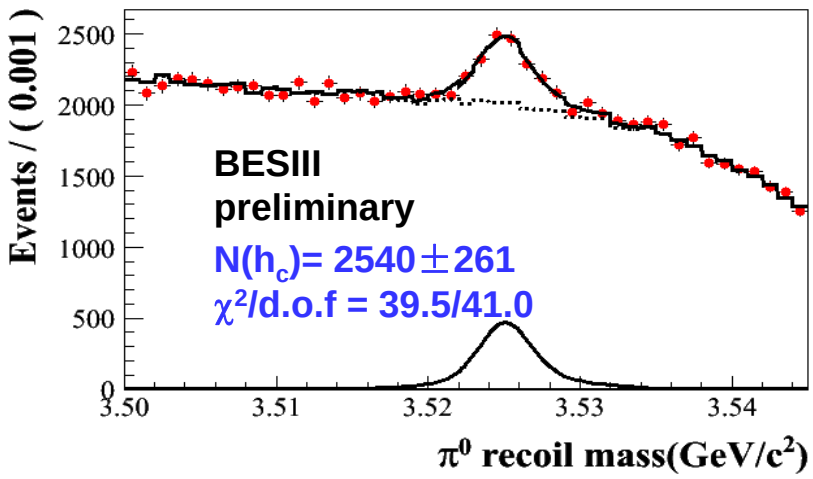
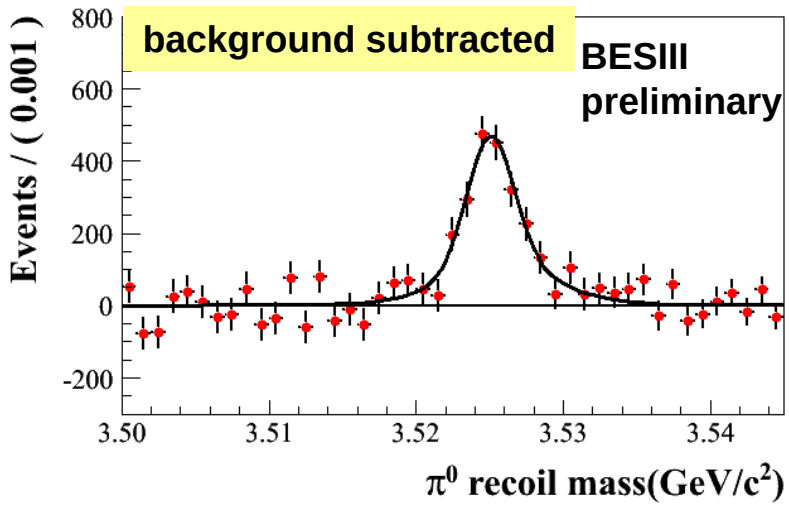
EM transitions: inclusive photon spectrum



Observation of h_c: E1-tagged $\psi(2S)\rightarrow\pi^0 h_c, h_c\rightarrow\gamma\eta_c$





- Select E1-photon to tag h_c
- A fit of Double-Gaussian signal+ sideband bkg. yield:

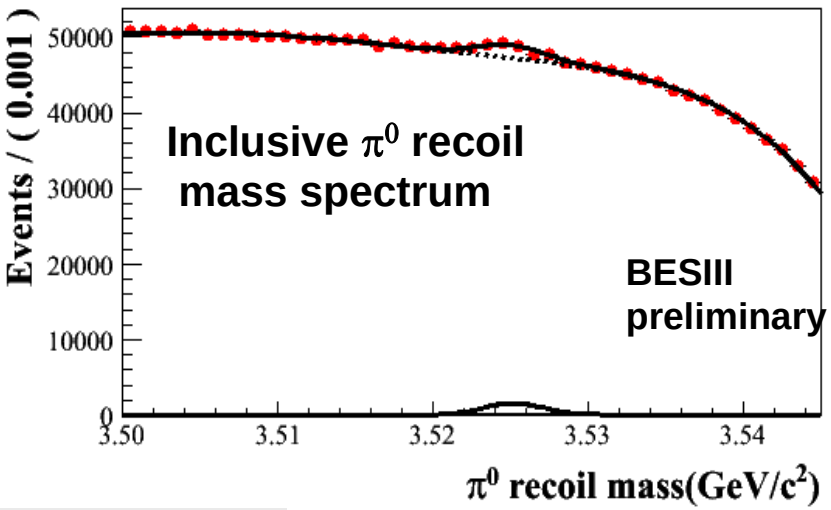
  $M(h_c)^{Inc} = 3525.16 \pm 0.16 \pm 0.10$ MeV

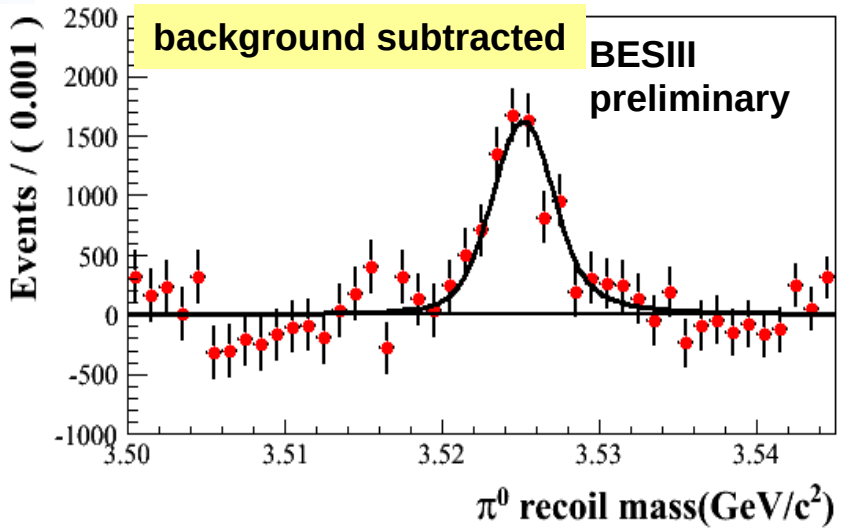
  $\Gamma(h_c)^{Inc} = 0.89 \pm 0.57 \pm 0.23$ MeV (First measurement)

  $Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma\eta_c)^{Inc} = (4.69 \pm 0.48(stat)) \times 10^{-4}$ ($\Gamma(h_c)$ floated)

  $= (4.69 \pm 0.29(stat)) \times 10^{-4}$ ($\Gamma(h_c)$ fixed at $\Gamma(\chi_{c1})$)
- Systematic errors under study
- Details $\Rightarrow$ Dr. LiGang's talk (see parallel talk)

Observation of h_c : Inclusive $\psi(2S) \rightarrow \pi^0 h_c$





- Select inclusive π^0
- A fit of D-Gaussian signal + 4th Poly. bkg yield

  $N(h_c) = 9233 \pm 935$, $\chi^2/d.o.f = 38.8/38.0$
- Combined inclusive and E1-photon-tagged spectrum

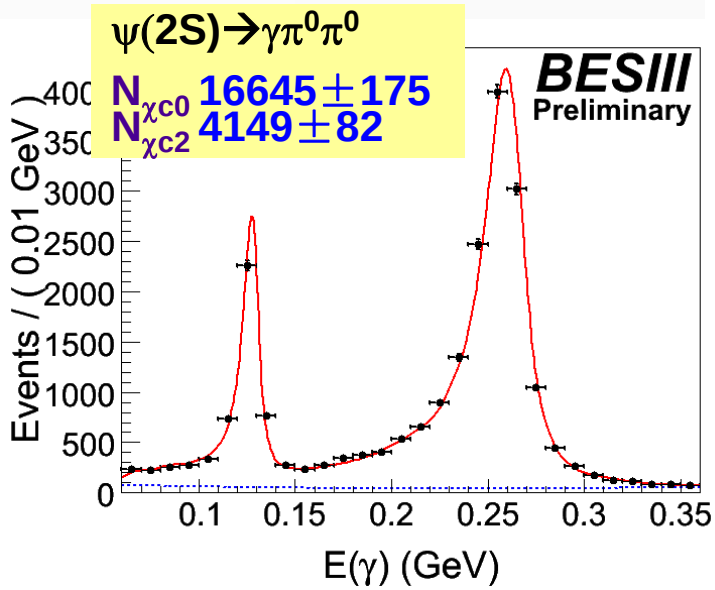
  $Br(\psi' \rightarrow \pi^0 h_c) = (8.42 \pm 1.29(stat)) \times 10^{-4}$ (First measurement)

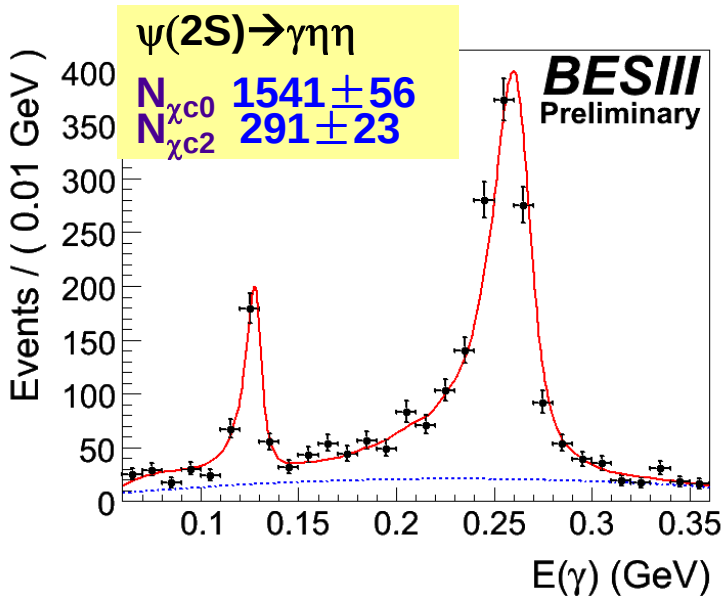
  $Br(h_c \rightarrow \gamma \eta_c) = (55.7 \pm 6.3(stat))\%$ (First measurement)
- Details $\Rightarrow$ Dr. LiGang's talk (see parallel talk)

Systematic errors under study

Study of $\psi(2S) \to \gamma\pi^0\pi^0$, $\gamma\eta\eta$ ($\eta \to \gamma\gamma$, $\pi^0 \to \gamma\gamma$)

- Interesting channels for glueball searches
- Based on 110M $\psi(2S)$
- BK study from 100M inclusive MC sample and 42pb^{-1} continuum sample
- Unbinned Maximum Likelihood fit:
  - Signal: PDF from MC signal
  - Background: 2nd order Poly.





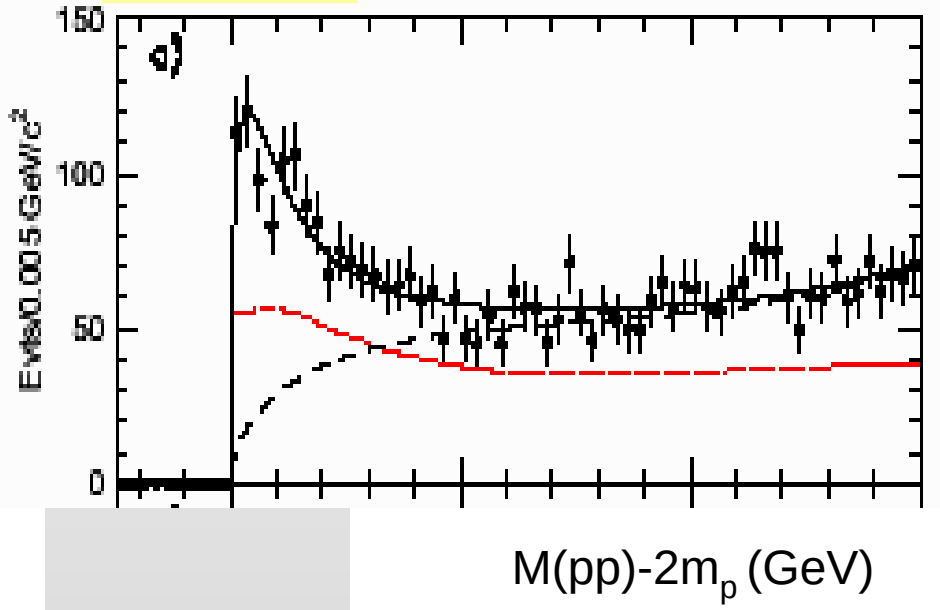
BR (10^{-3})		χ_{c0}	χ_{c2}
$\pi^0\pi^0$	BESIII	3.25±0.03(stat)	0.86±0.02(stat)
	PDG08	2. 43±0.20	0.71±0.08
	CLEO-c	2.94±0.07±0.35	0.68±0.03±0.08
$\eta\eta$	BESIII	3.1±0.1(stat)	0.59±0.05(stat)
	PDG08	2.4±0.4	<0.5
	CLEO-c	3.18±0.13±0.35	0.51±0.05±0.06

CLEO-c
arxiv:0811.0586

Confirmation of the BESII observation: $p\bar{p}$ threshold enhancement in J/ψ decays

BES II

$J/\psi \to \gamma p\bar{p}$

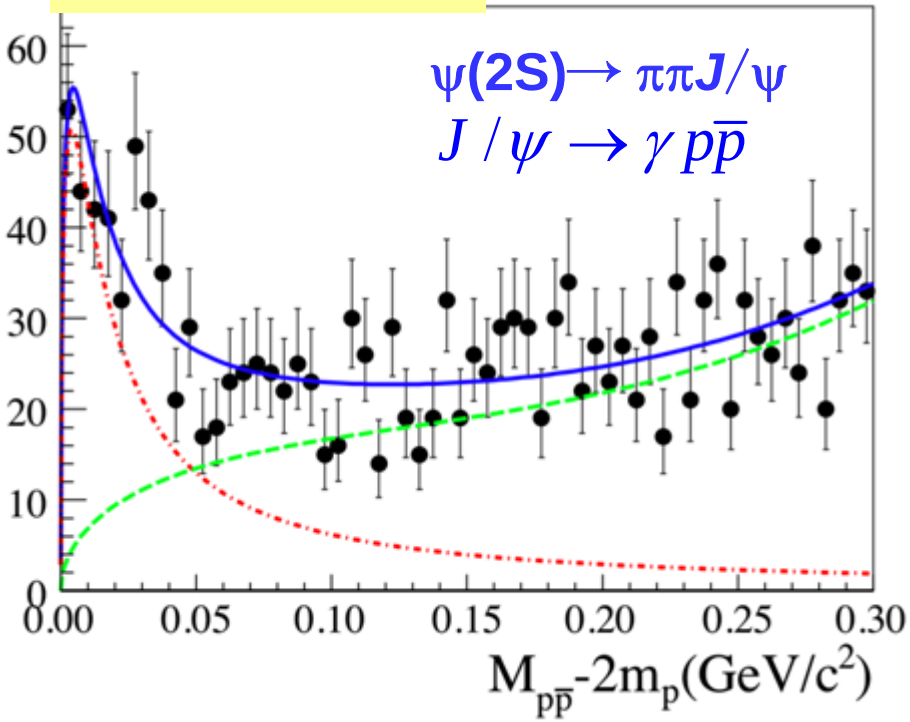


$M = 1859\ ^{+3}_{-10}\ ^{+5}_{-25}$ MeV/c²

$\Gamma < 30$ MeV/c² (90% CL)

PRL 91 (2003) 022001

BES III preliminary



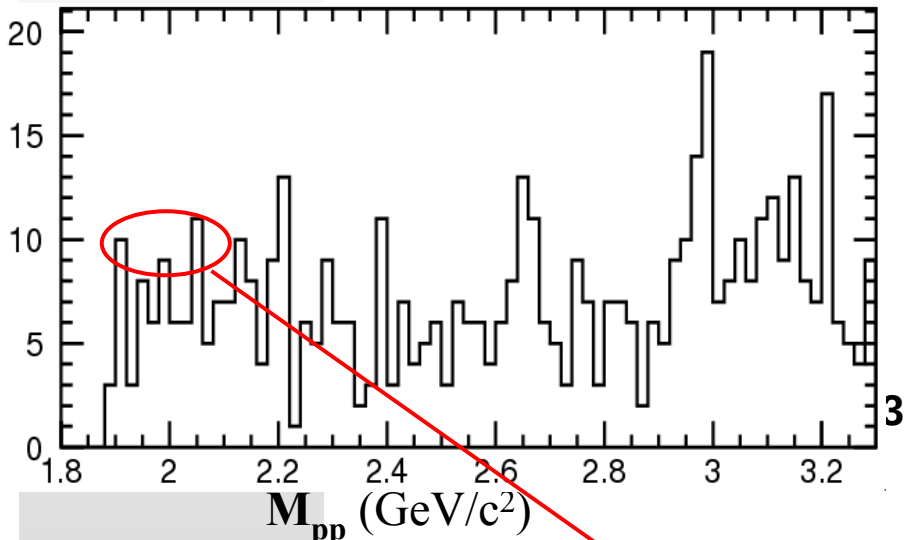
$M = 1865 \pm 5$ MeV/c²

$\Gamma < 33$ MeV/c² (90% CL)

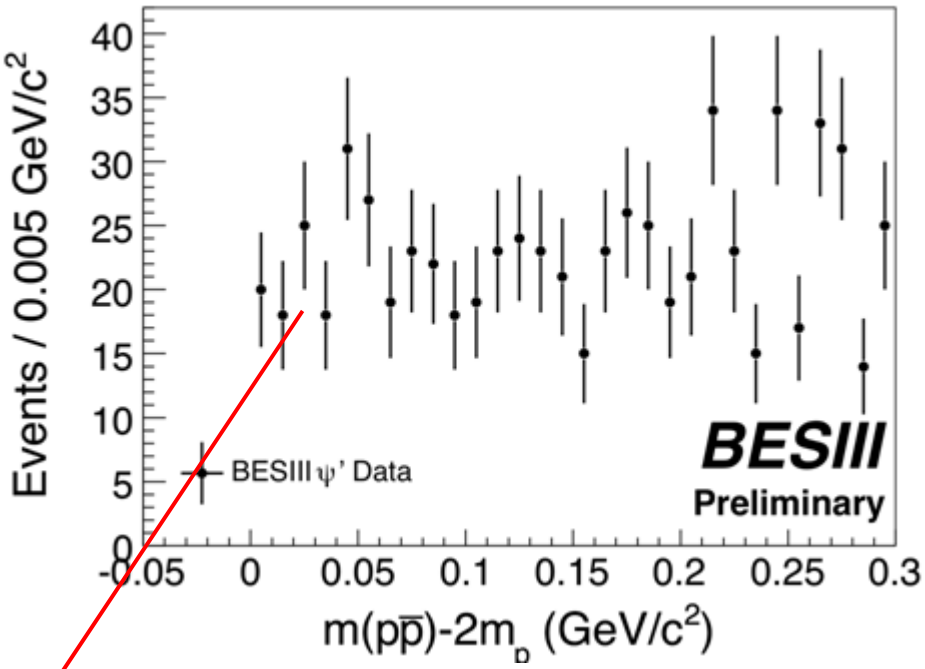
No $p\bar{p}$ threshold enhancement in ψ' decays

PRL 99, 011802 (2007)

$\psi(2S) \to \gamma p\bar{p}$ @ BESII



$\psi' \to \gamma p\bar{p}$ @BESIII



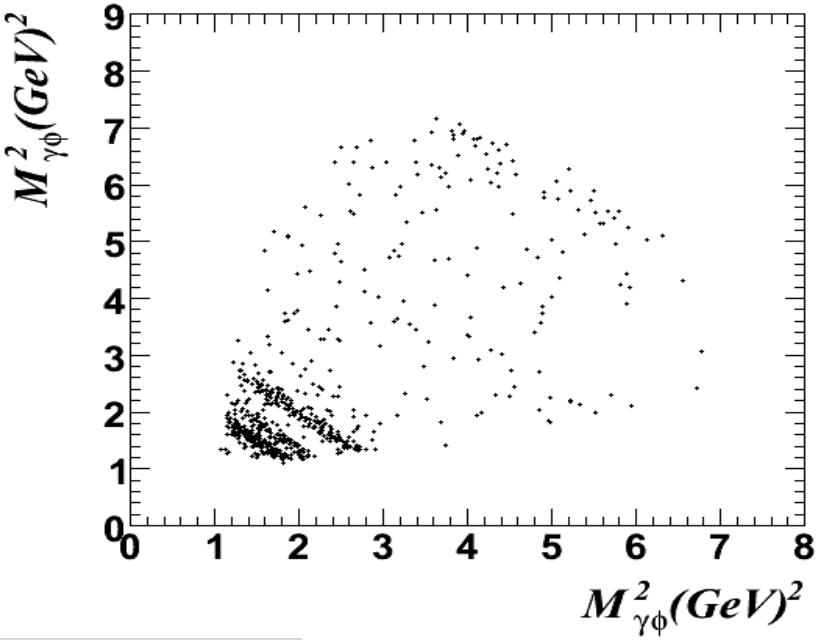
No significant narrow strong enhancement near threshold

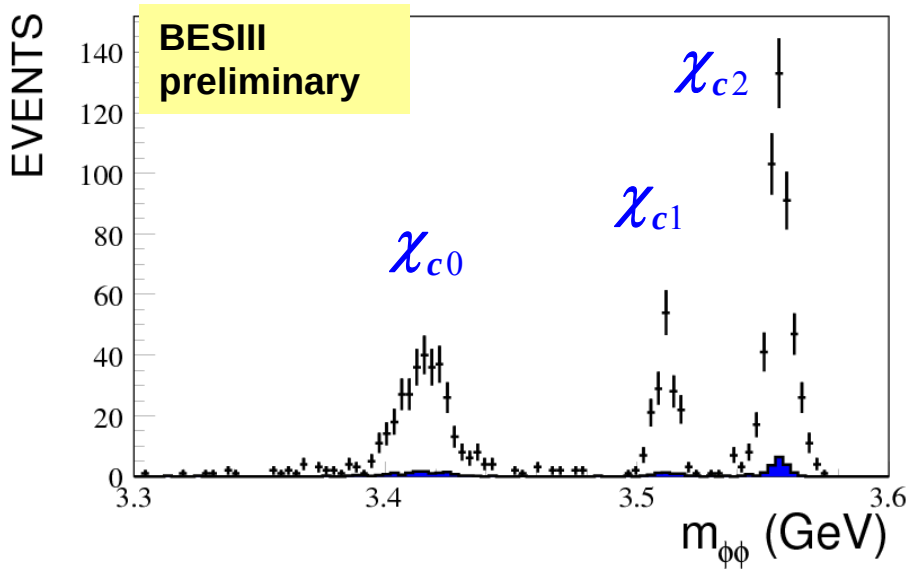
Study of $\chi_{cJ} \rightarrow VV$, V=ω,ϕ

- Test QCD-based theory at χ_{cJ} decays
- Puzzles for $\chi_{c0} \rightarrow$ VV: no helicity suppress
- $\chi_{c1} \rightarrow \phi\phi, \omega\omega$ is only allowed for L=2, suppressed ?
- $\chi_{cJ} \rightarrow \phi\omega$ OZI doubly suppressed

BESII results:		
BR(10^{-3})	χ_{c0}	χ_{c2}
$\phi\phi$	0.93±0.20	1.5±0.3
$\omega\omega$	2.3±0.7	2.0±0.7

- BK from sideband & 100M MC events
- Clear $\chi_{c1} \rightarrow \phi\phi$ signal





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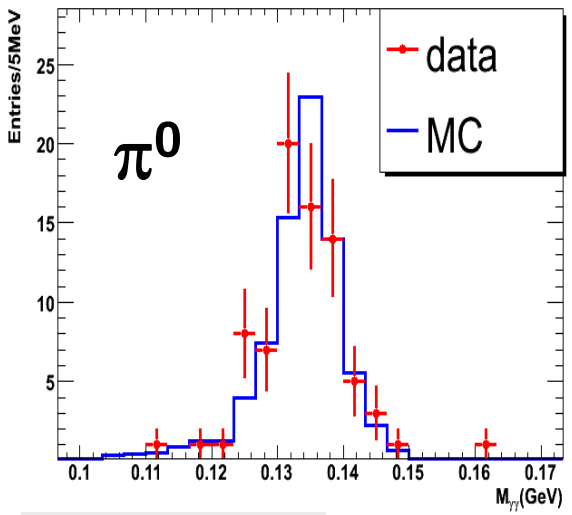
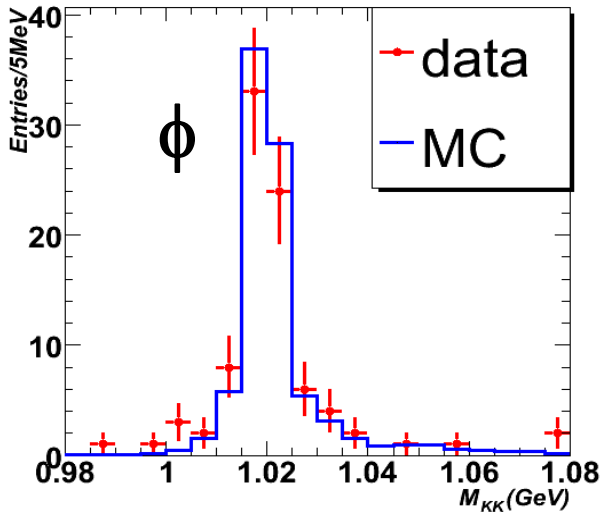
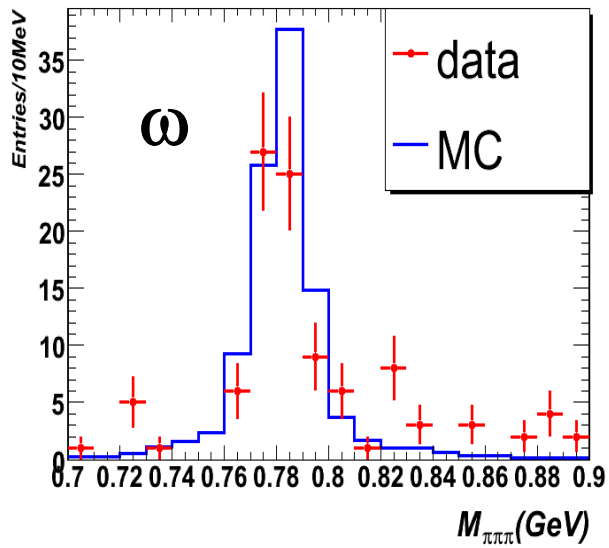
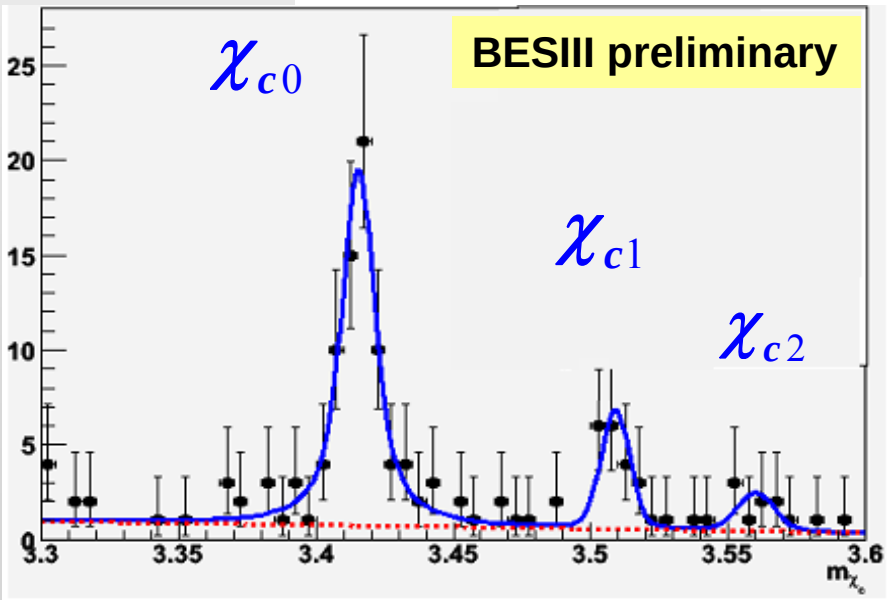
First observation of $\chi_{cJ} \rightarrow \omega\phi$









- **Background from sideband & 100M MC events**
- **Clear signal from**

  χ_{c0} /χ_{c1} → $\omega(\pi^+\pi^-\pi^0)\phi(K^+K^-)$

BESIII Prospects

- BESIII will resume data taking after summer shutdown, ~5 months until next summer.
- Possible data taking plans:
  - 500-1000 M J/ψ events (2-4 months)
  - 500-1000 M ψ(2s) (2-4 months)
  - 2fb^{-1} ψ(3770) (4 months)
  - Lineshape scan of ψ(3770) (2 weeks)

To be decided in Nov.

- Data taking plan in the future:
  - ~10 B J/ψ events (1 year)
  - ~3 B ψ(2s) (1year)
  - ~20 fb^{-1} ψ(3770)+ ψ(4040)+ ψ(4160) (~5 years)
  - R scan/resonance scan: 2.0-4.6 GeV (months)
  - Tau physics (months)
- Possible upgrades:
  - Luminosity: crab waist, bunch spacing, …
  - Beam Energy: E_{max} = 4.6 GeV ➔ 5 GeV
  - e- Polarization
  - Detector: TOF, inner DC, …

Prospects: reach charm programs

- BESIII (2008 – 2018 ?)
- Future charm programs
  - LHCb at CERN（soon）
  - BELLE II at SuperB factory（~ 2014 ）
  - PANDA at GSI（~ 2015）
- New machines under discussion:
  - Frascati(super flavor factory) 2020 ?
  - Novosibirsk(super tau-charm factory)

L ~ $10^{35\text{-}36}$ $cm^{-2}s^{-1}$
Expand the life time of tau-charm colliders to > 50 years !

Summary

- Great progress by CLEOc charmonium physics
- Continuous contributions from BESII
- BESIII is operational since 2008:
  - Detector performance excellent, ready for physics
  - High quality data samples in hand
  - Analysis in progress, papers in a few months
- In the next few years, there will be great leap on physics of light hadron spectroscopy, charmonium, charm, tau and QCD.
- More exciting results is coming

Acknowledgement

- All BESIII collaborators
- Many CLEOc colleagues
- In particular, Yifang Wang, Xiaoyan Shen, Changzheng Yuan, Beijiang Liu, Haibo Li, Gang Li

Thank you