BESIII 物理结果

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中国科学院研究生院

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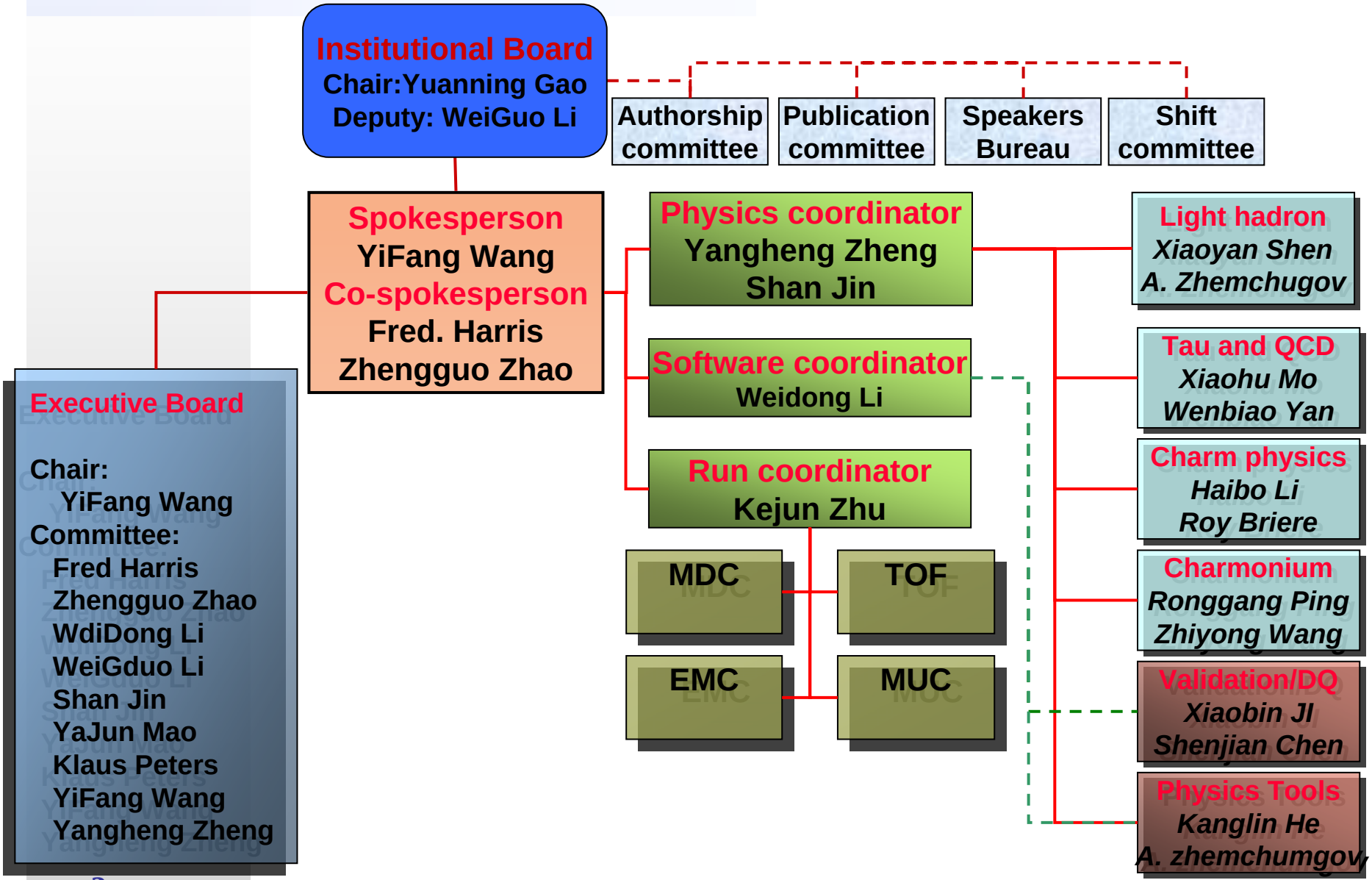
中国物理学会高能物理分会第八届学术年会

报告提纲

- BESIII物理研究的潜力、现状
  - Charmonium physics
  - Light hadron spectroscopy
  - Charm physics
  - Tau & QCD & rare decays
- 总结与展望

物理结果的报告排序不分先后

BESIII组织结构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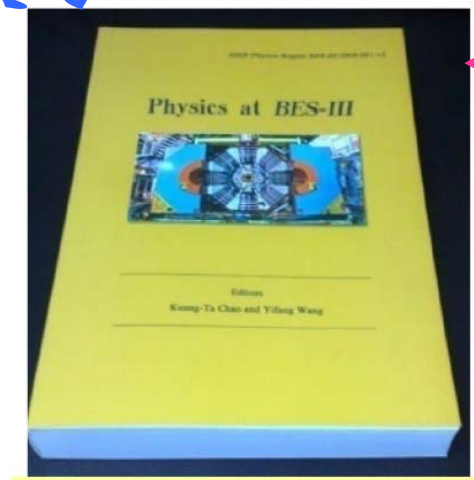
BESIII物理研究

- 理论物理研究
  - 物理图像
    - 建立理论模型
    - 实验现象的理论解释
    - 理论与数学技巧
- 实验物理研究
  - 物理图像
    - 搭建实验装置检验理论模型
    - 实验数据分析与实验结果的统计诠释
    - 实验技巧



hep-ex/0809.1869
IJMP A V24,No 1(2009) supp

BESIII物理实验研究

- 实验装置
  - BEPCII：τ-charm能区下的e^+e^-对撞机
  - BESIII：~4π立体角的通用探测器
- 实验手段：寻找、发现与精确测量
- 精确测量
  - 减小统计误差：提高加速器亮度，改善探测效率
  - 减小系统误差：提高探测器的性能，充分理解实验上使用的探测方法与测量技巧

物理成果的发表步骤

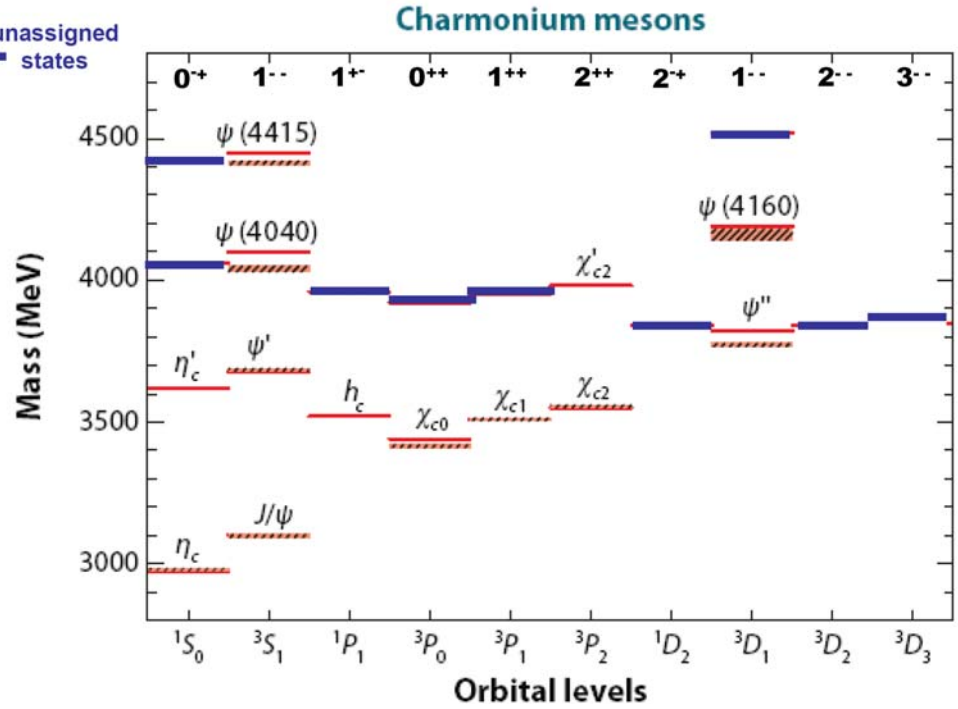
- 实验数据采集
- 数据分析与处理
- 在BESIII所属物理组报告
- 在BESIII全合作组报告
- 准备物理分析Memo
- 指定Referee committee并对物理分析结果详细检查，直至最后确认（通常与Memo作者几个月的互动）
- 物理分析结果在全合作组公开，接受BESIII全部成员质询
- 实验发言人确认同意后提交到Journal
- 与Journal的Referee(s)互动直至发表

Data samples

- CLEOc
  - ~27 million $\psi(2S)$ 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 $\psi(2S)$ decays
  - 58 million J/ψ decays
- BESIII
  - 106 million $\psi(2S)$ decays
  - 220 million J/ψ decays
  - ~3 million DDbar events (~450 pb^{-1})

Charmonia physics

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



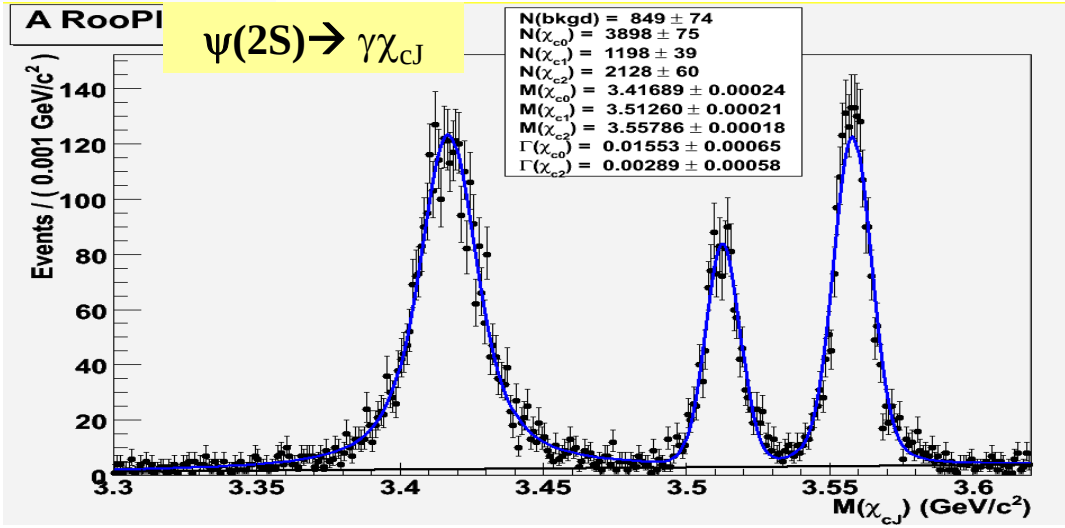
Examples of Interesting problems:

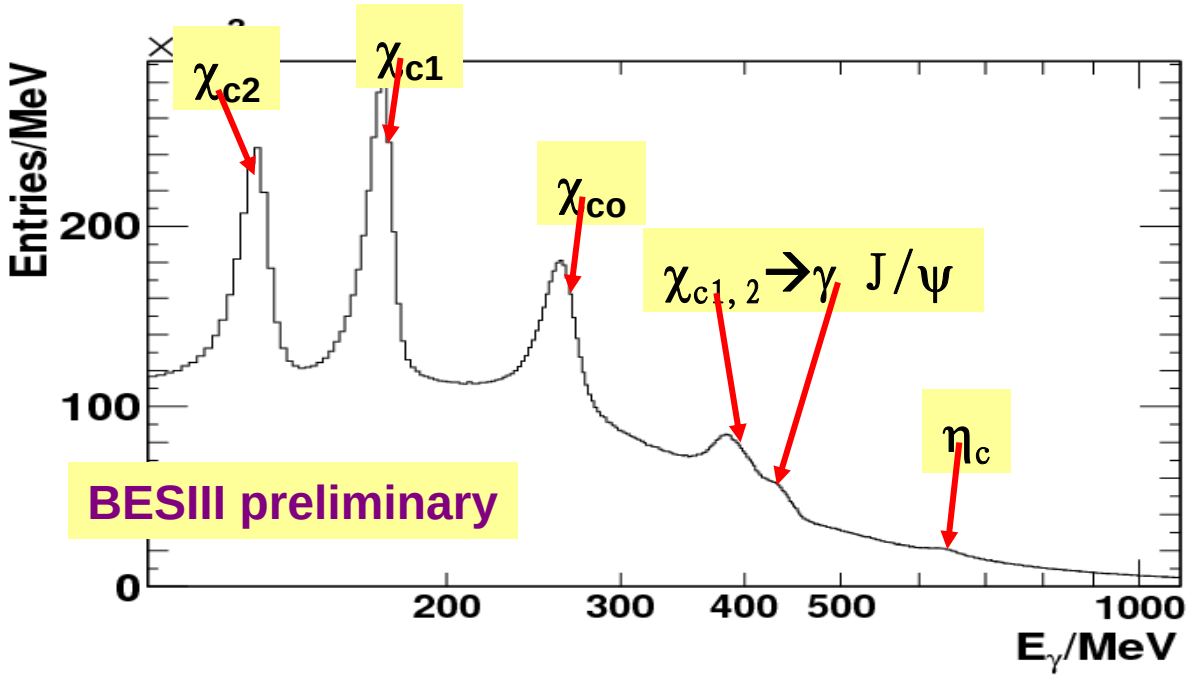
- $\rho\pi$ puzzle
- Missing states ?
- Mixing states ?
- New states above open charm (X,Y,Z,…)

details ⇒ Jingzhi & Jiaming's talk in parallel session

Radiative decay: $\psi(2S) \rightarrow \gamma X$

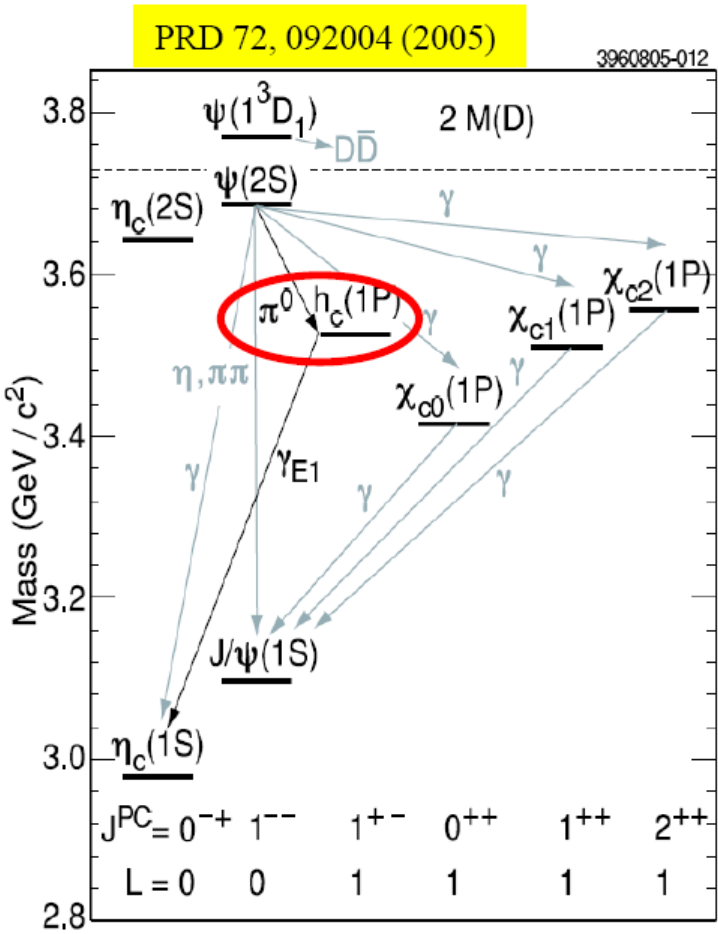
- High statistics
- Inclusive and exclusive
- Excellent detector performance
  - very good photon resolution





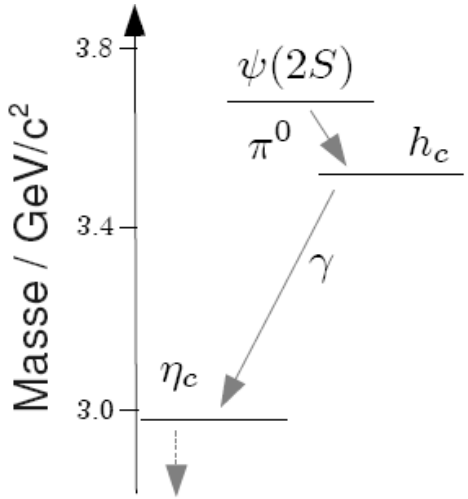
h_c analysis: Motivation

- h_c knowledge is lack till recently
  - experiment E835: evidence in
    $p\bar{p} \rightarrow h_c \rightarrow \gamma \eta_c$
  - CLEOc: observed in
    $e^+e^- \rightarrow \psi' \rightarrow \pi^0 h_c$
- spin-singlet state: h_c (L=1;S=0)
  - spin-triplet state: χ_{cJ} (L=1;S=1)
  - Potential model: 1P Hyperfine mass splitting $\Delta M_{hf} \equiv M<1^1P_1> - M<1^3P_1> = 0 \Rightarrow$ No spin-spin interaction
- Theoretical predictions(see next slides)
- Experimental difficulties: small phase space in $\psi' \rightarrow \pi^0 h_c$



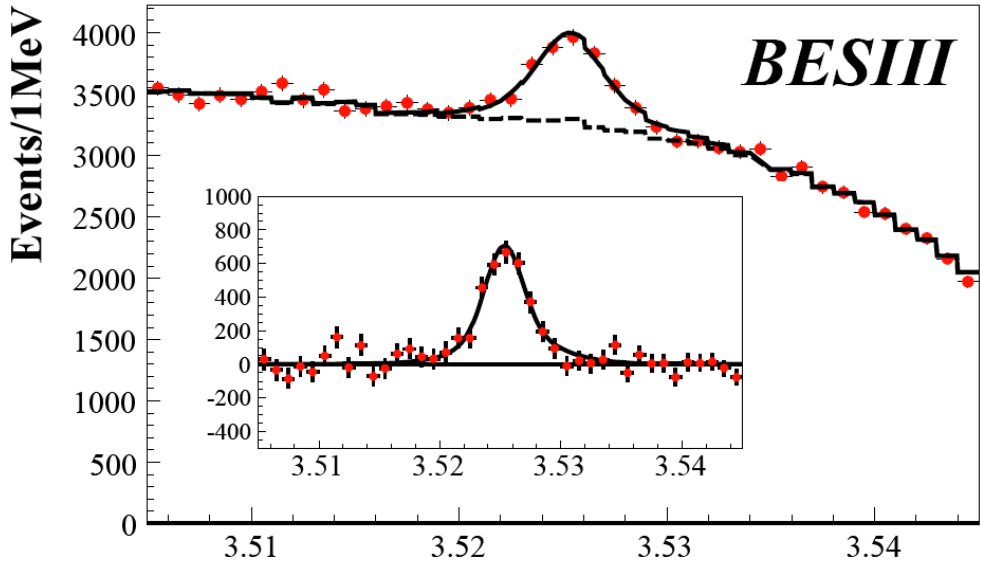
Observation of h_c : Inclusive (tagged)

- Select inclusive π^0 ($\psi' \rightarrow \pi^0 h_c$)
- Select E1-photon γ to tag $h_c \rightarrow \gamma \eta_c$
- Double-Gaussian $\otimes$ BW signal + E1-photon sideband bkg



Results:

- $Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma \eta_c) = (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$
- $M = 3525.40 \pm 0.13 \pm 0.18$ MeV/c^2
- $\Gamma = 0.73 \pm 0.45 \pm 0.28$ MeV (<1.44 MeV 90%C.L.)



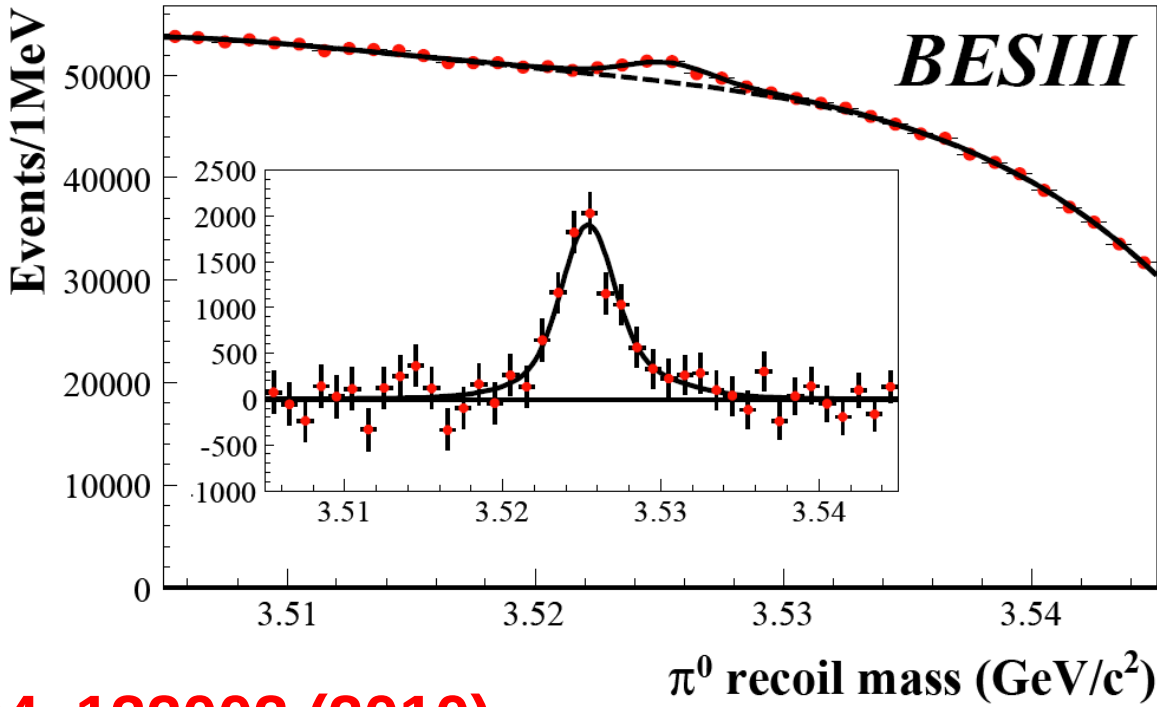
PRL 104, 132002 (2010)

Observation of h_c : Inclusive (untagged)

- Select inclusive π^0 ($\psi' \to \pi^0 h_c$)
- D-Gaussian ⊗ BW signal + 4th Poly. bkg
- Fit: mass and width fixed as tagged measurement

Combined with tagged results, we firstly measured:

- Br($\psi' \to \pi^0 h_c$) $=(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
- Br($h_c \to \gamma \eta_c$) $=(54.3 \pm 6.7 \pm 5.2)\%$



PRL 104, 132002 (2010)

h_c : analysis summary

	BESIII	CLEOc
$Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma\eta_c)$ $[10^{-4}]$	$4.58 \pm 0.40 \pm 0.50$	$4.19 \pm 0.32 \pm 0.40$
M $[MeV/c^2]$	$3525.40 \pm 0.13 \pm 0.18$	$3525.80 \pm 0.19 \pm 0.11$
Γ [MeV]	$0.73 \pm 0.45 \pm 0.28$ <1.44 @ 90%CL	1.1 (NRQCD) Kuang 0.51 (PQCD) Kuang
$\Delta M_{hf}(1P)$ $[MeV/c^2]$	$0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$

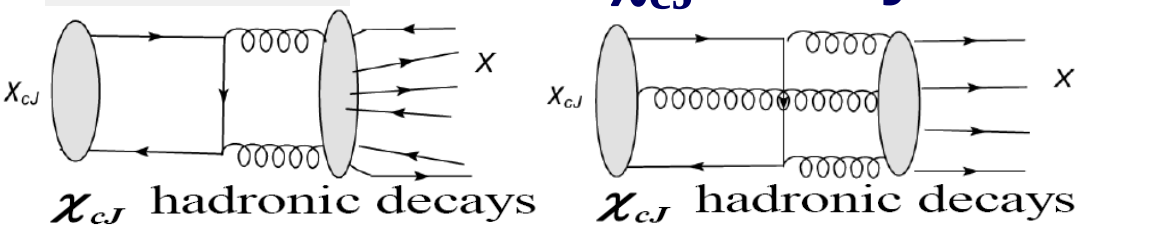
$\Rightarrow$consistent with CLEOc results

	BESIII	theoretical prediction
$Br(\psi' \to \pi^0 h_{c)}$ $[10^{-4}]$	$8.4 \pm 1.3 \pm 1.0$	4 - 13
$Br(h_c \to \gamma\eta_c)$	$54.3 \pm 6.7 \pm 5.2$	41 (NRQCD) Kuang 88 (PQCD) Kuang 38 Godfrey, Rosner

Theoretcial predictions: PRD65, 094024 (2002) & PRD 66, 014012 (2002).

χ_{cJ} decays: motivation

- Most hadronic decay channels of χ_{cJ} not well known
- Test color singlet / color octet mechanism in χ_{cJ} decays



χ_{cJ} hadronic decays at QCD leading order

χ_{cJ} hadronic decays in the color octet theory

- Study of singly and doubly OZI suppressed decays
- Study of light hadrons produced in χ_{cJ} decays

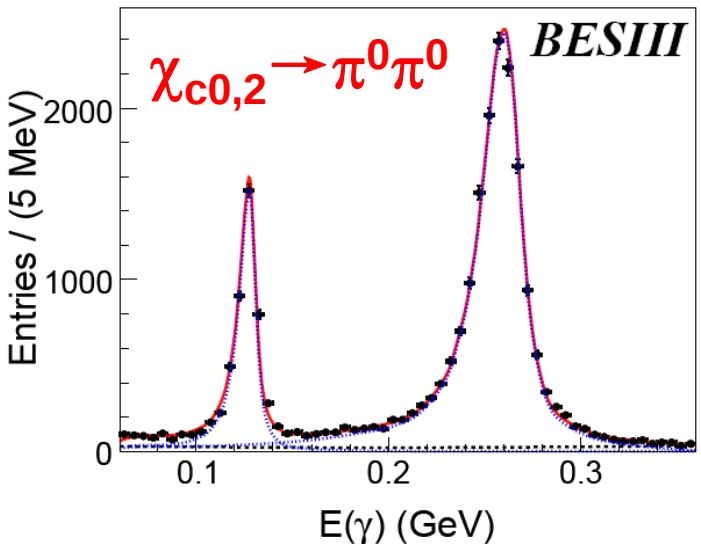
Exclusive decays of χ_{cJ} are a good laboratory to test the color-octet mechanism in P-wave charmonium decays.

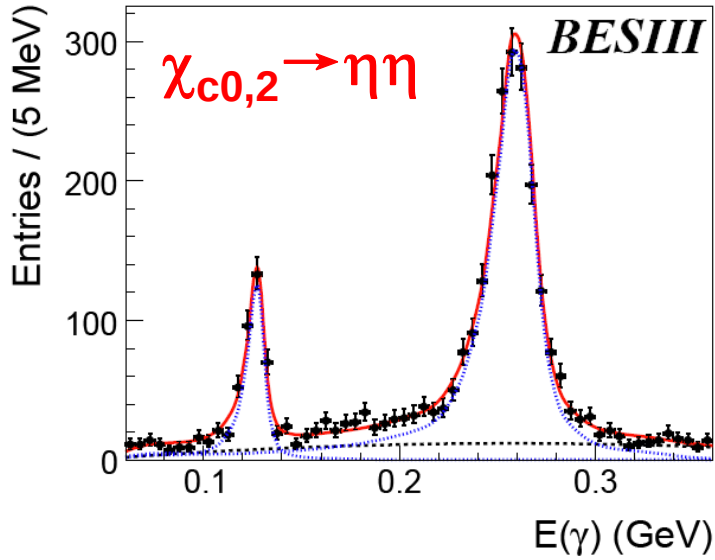
[1] G.T. Bodwin et al., Phys Rev. Lett. D51, 1125 (1995)
[2] H.-W. Huang and K.-T. Chao, Phys. Rev. D54, 6850 (1996)
[3] J.Bolz et al., Eur.Phys.J.C2:705-719 (1998)

decay width	theory[3]	PDG08
$\Gamma[\chi_{c0} \to \pi^0 \pi^0]$ / keV	23.5	25 ± 2
$\Gamma[\chi_{c2} \to \pi^0 \pi^0]$ / keV	1.93	1.4 ± 0.2
$\Gamma[\chi_{c0} \to \eta\eta]$ / keV	32.7	25 ± 4
$\Gamma[\chi_{c2} \to \eta\eta]$ / keV	2.66	

$\psi' \to \gamma\pi^0\pi^0$ or $\gamma\eta\eta$ (π^0 or $\eta \to \gamma\gamma$)

- Interesting channels for glueball searches
- Understand χ_{cJ} decay mechanism: Q.Zhao PRD 72, 074001 (2005).
- Unbinned Maximum Likelihood fit
  - Signal: MC
  - Background: 2nd order Poly.





BR (10^{-3})		χ_{c0}	χ_{c2}
$\pi^0\pi^0$	BESIII	$3.23 \pm 0.03 \pm 0.23 \pm 0.14$	$0.88 \pm 0.02 \pm 0.06 \pm 0.04$
	PDG08	2.43 ± 0.20	0.71 ± 0.08
	CLEOc	$2.94 \pm 0.07 \pm 0.32 \pm 0.15$	$0.68 \pm 0.03 \pm 0.07 \pm 0.04$
$\eta\eta$	BESIII	$3.44 \pm 0.10 \pm 0.24 \pm 0.13$	$0.65 \pm 0.04 \pm 0.05 \pm 0.03$
	PDG08	2.4 ± 0.4	<0.5
	CLEOc	$3.18 \pm 0.13 \pm 0.35$	$0.51 \pm 0.05 \pm 0.05 \pm 0.03$

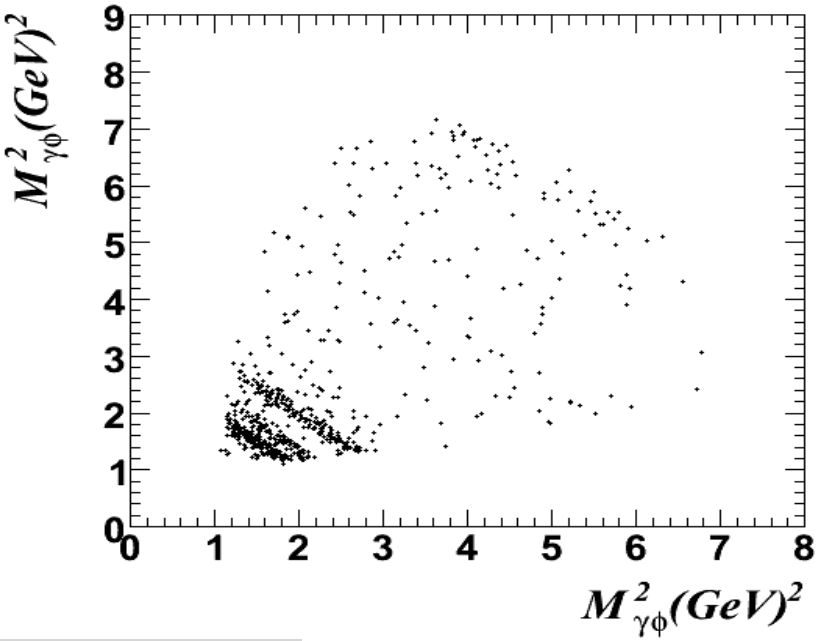
PRD 81, 052005 (2010)

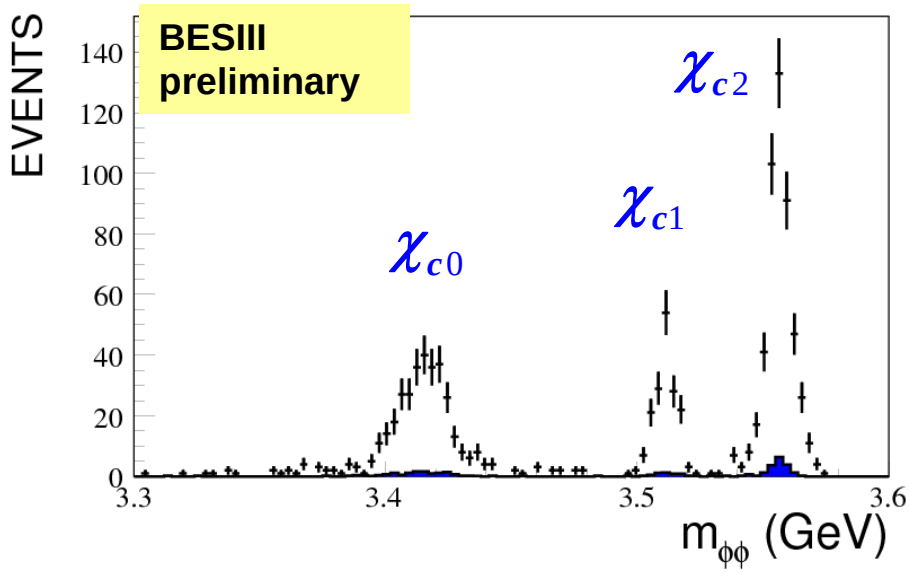
Study of $\chi_{cJ} \rightarrow VV$, V=ω,ϕ

- 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

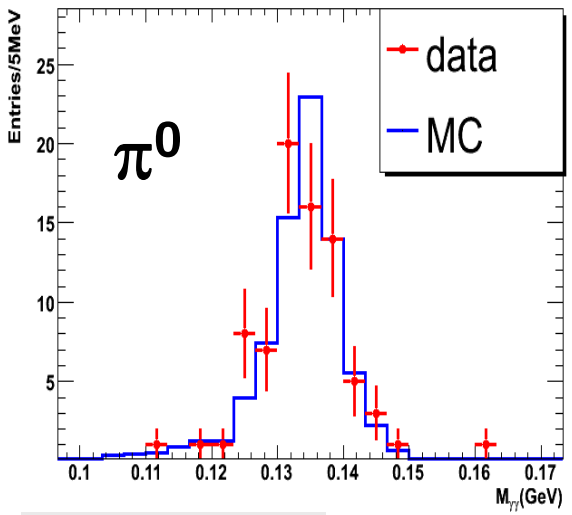
BESII results:		
BR(10^{-3})	χ_{c0}	χ_{c2}
$\phi\phi$	0.93±0.20	1.5±0.3
$\omega\omega$	2.3±0.7	2.0±0.7

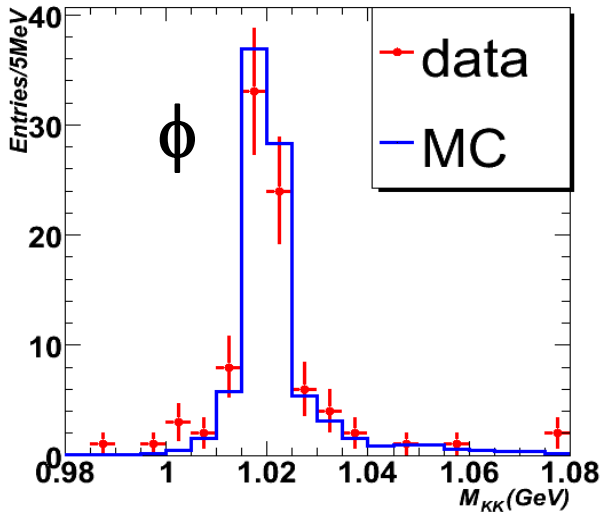
- BK from sideband & 100M MC events
- Clear $\chi_{c1} \rightarrow \phi\phi$ signal

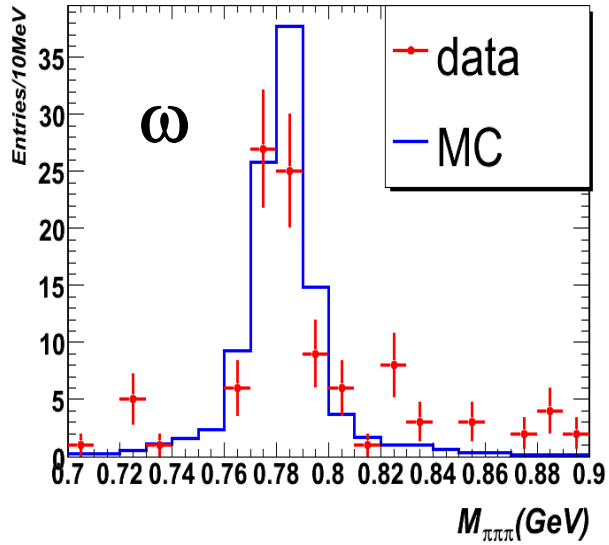




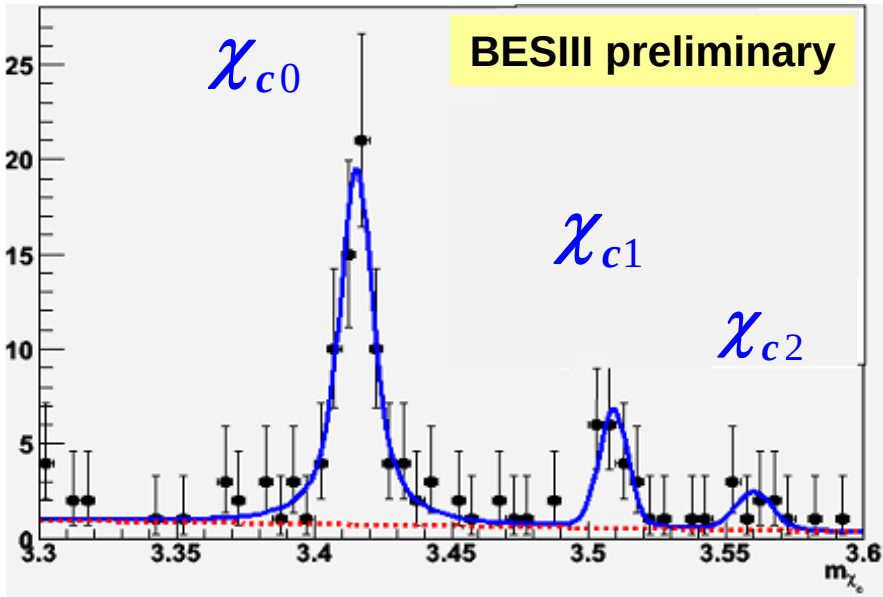
First observation of $\chi_{cJ} \rightarrow \omega\phi$





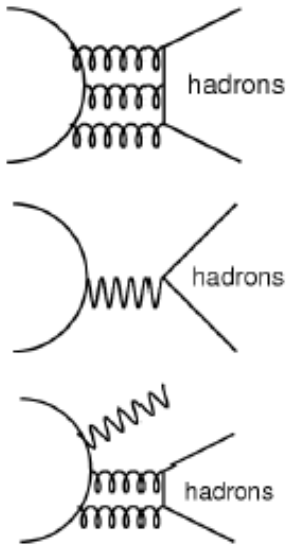


- Background from sideband & 100M MC events
- Clear signal from χ_{c0} /$\chi_{c1} \rightarrow \omega(\pi^+\pi^-\pi^0)\phi(K^+K^-)$



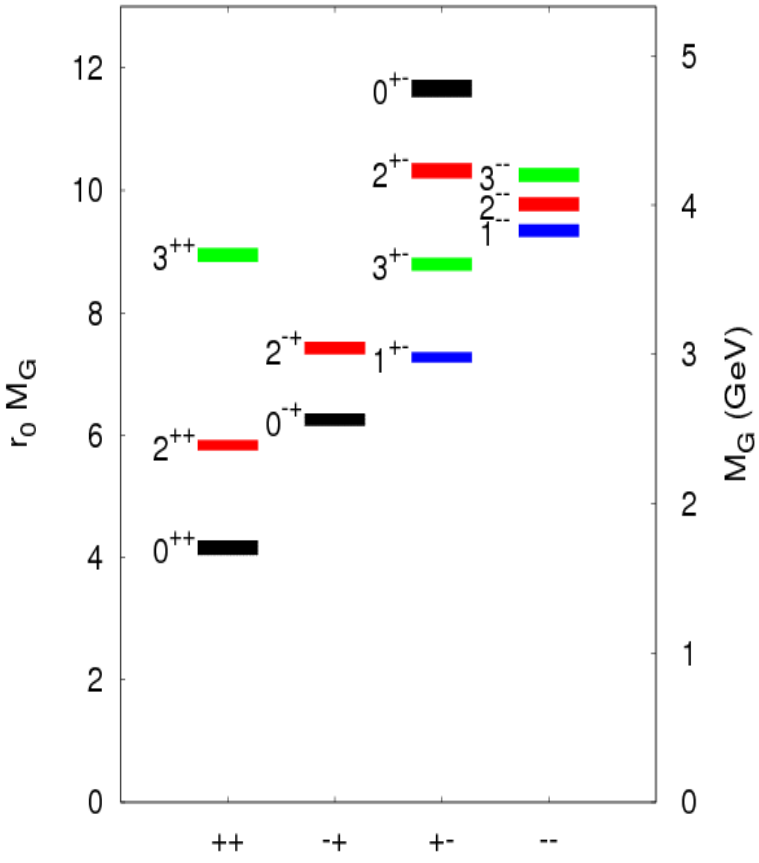
Light hadron spectroscopy

- **Motivation:**
  - Establish spectrum of light hadrons
  - Search for non-conventional hadrons
  - Understand how hadrons are formed
  - Study chiral symmetry in QCD
- **Why at a BESIII ?**
  - 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

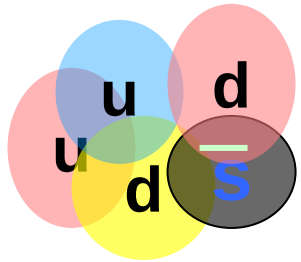
details ⇒ Liaoyuan's talk in parallel session

Probe QCD

non-$q\bar{q}$ or non-qqq hadron spectroscopies:

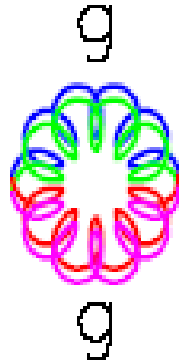
Pentaquarks:

e.g. an S=+1 baryon

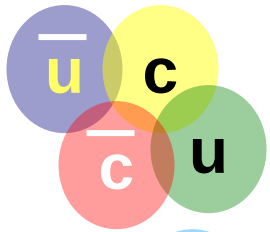


Glueballs:

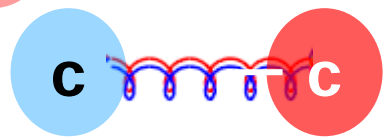
gluon-gluon color singlet states



Multi-quark mesons:

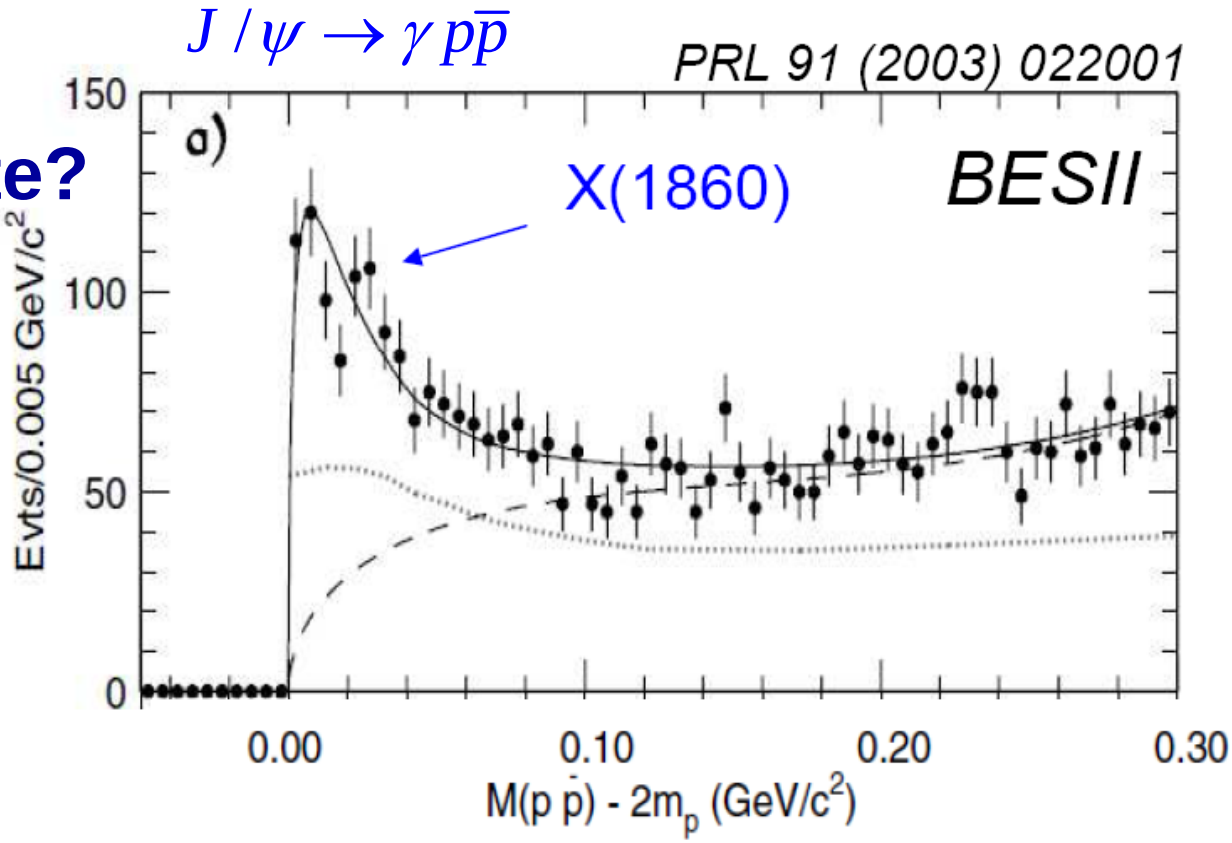


qq-gluon hybrid mesons



pp threshold enhancement @ BESII

- What could it be?
  - pp bound state?
  - FSI effect?
  - or both



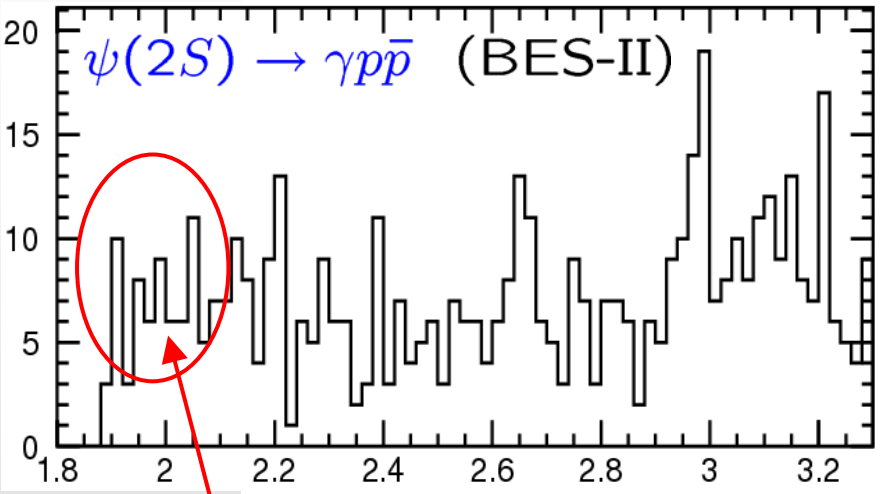
$M = 1859\ ^{+3}_{-10}\ ^{+5}_{-25}\ \mathrm{MeV}/c^2$

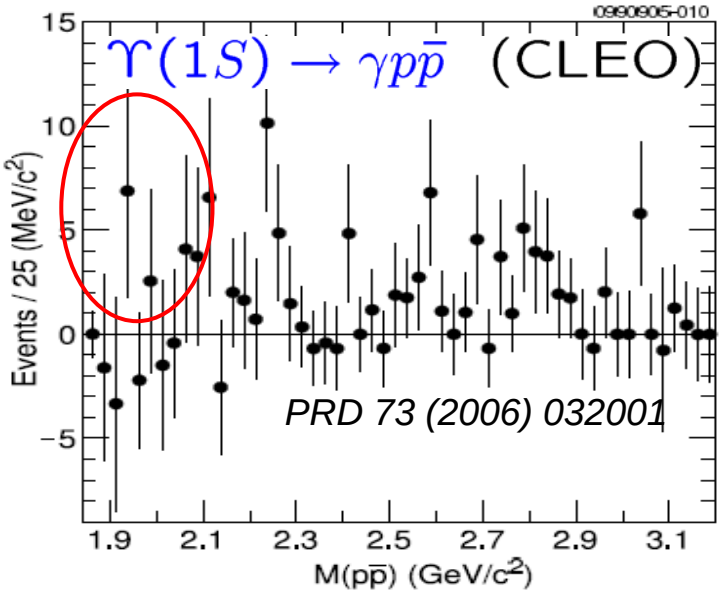
$\Gamma < 30\ \mathrm{MeV}/c^2$ (90% CL)

X(1860) in $p\bar{p}$ close threshold

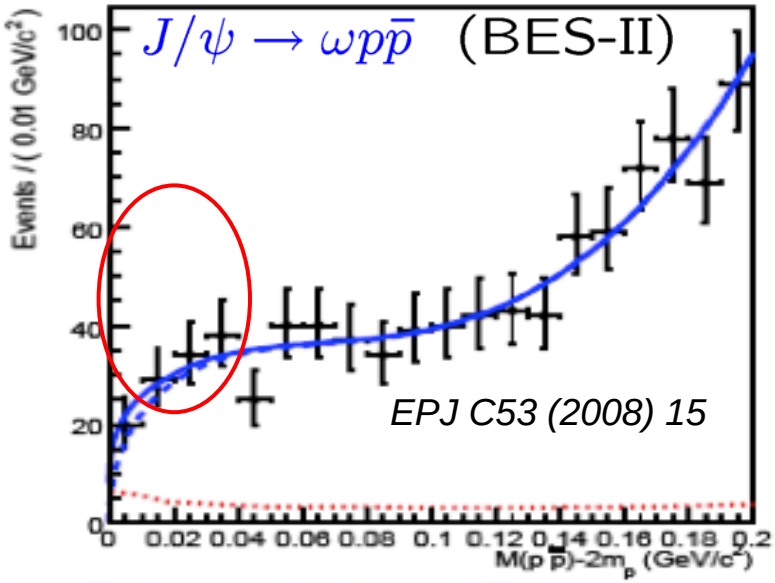
Several ***none*** observations...

PRL 99 (2007) 011802



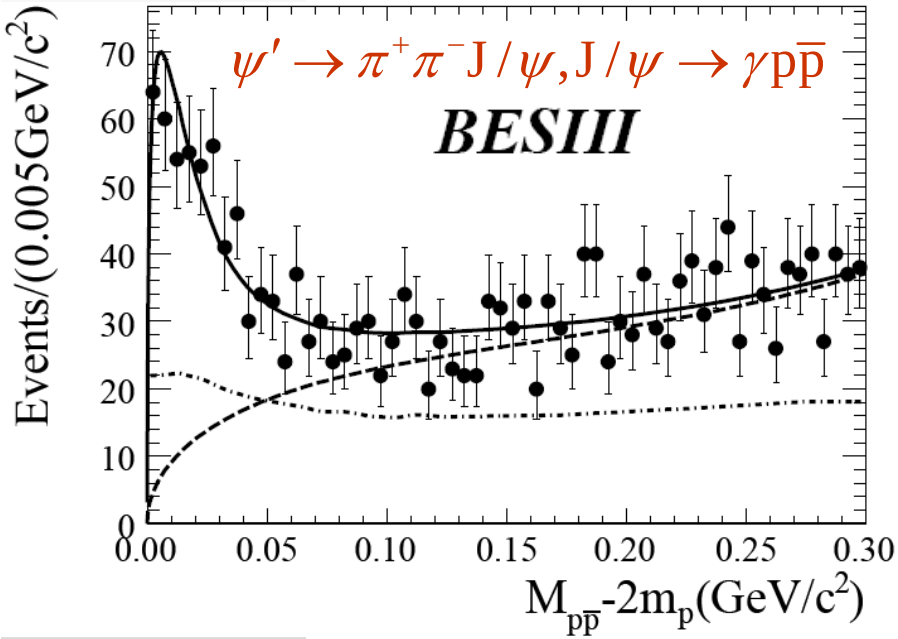


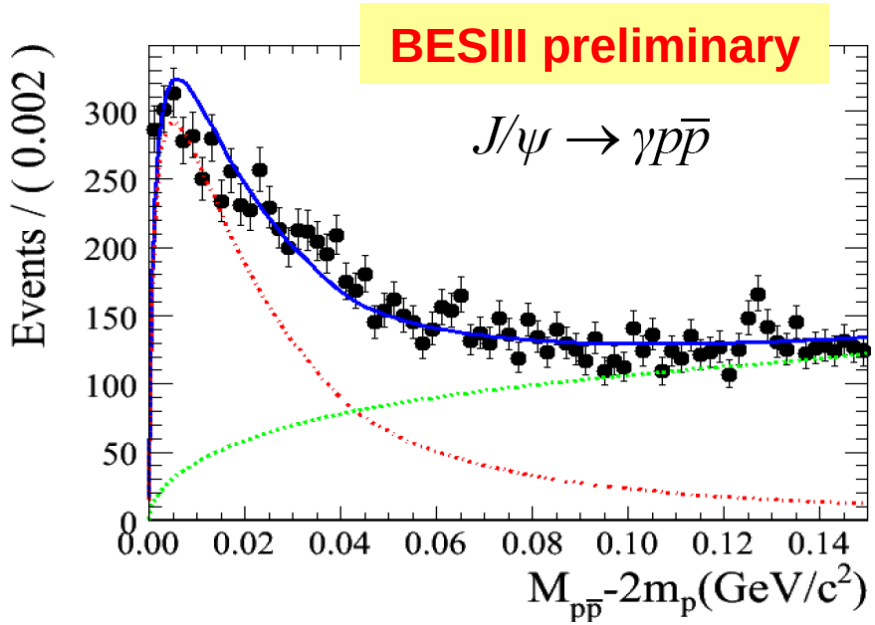
No significant signal of X(1860) found (only 2σ significance)



pp threshold enhancement @ BESIII

Published in
Chinese Physics C 34(2010)421





M=1865 ± 5 MeV/c²

Γ < 33 MeV/c² (90% CL)

M=1861.6 ± 0.8 MeV/c²

Γ < 8 MeV/c² (90% CL)

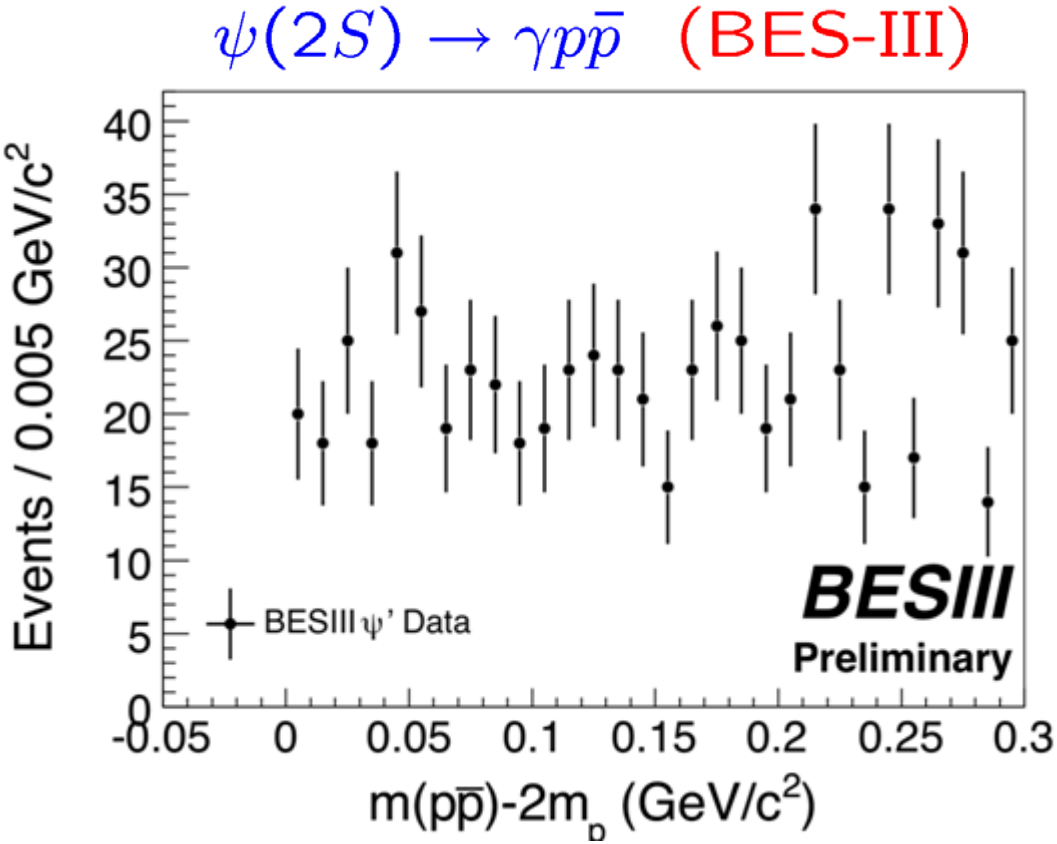
Consistent observation by BESIII !

X(1860) in ψ(2S) decays (prelim.)

- **Checked also for enhancement in ψ' decays (High statistics)**

Confirmation of no observation of enhancement in ψ(2S) channel!!

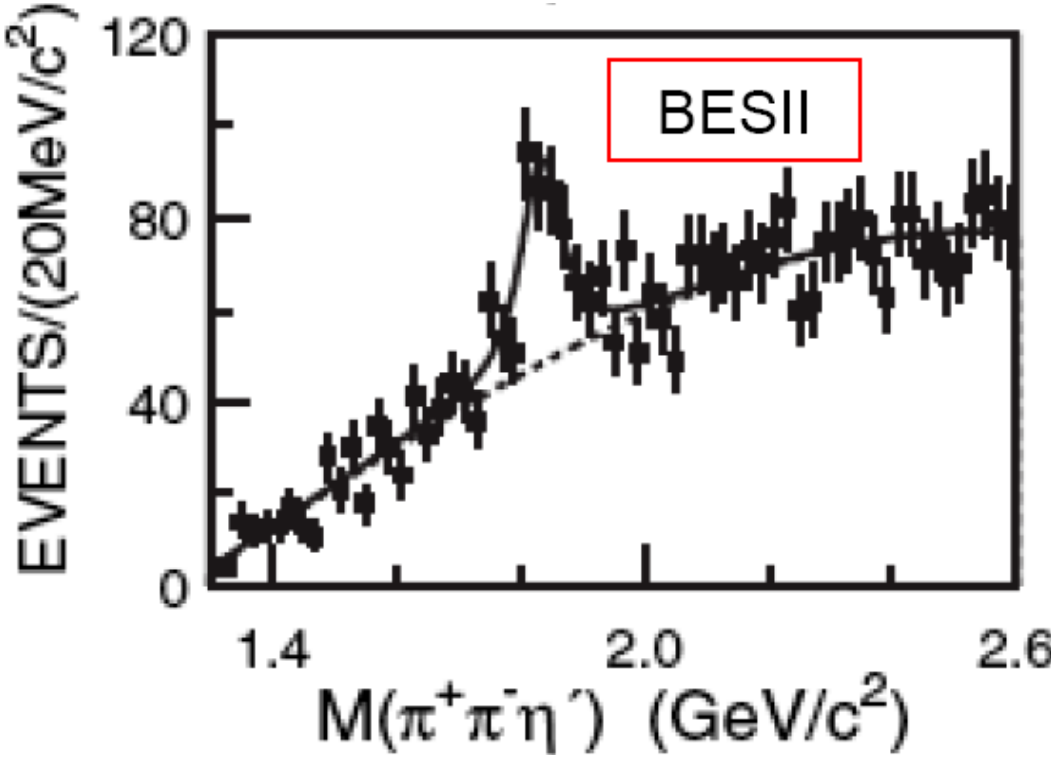
⇒pure FSI effect unlikely



X(1835) at BESII

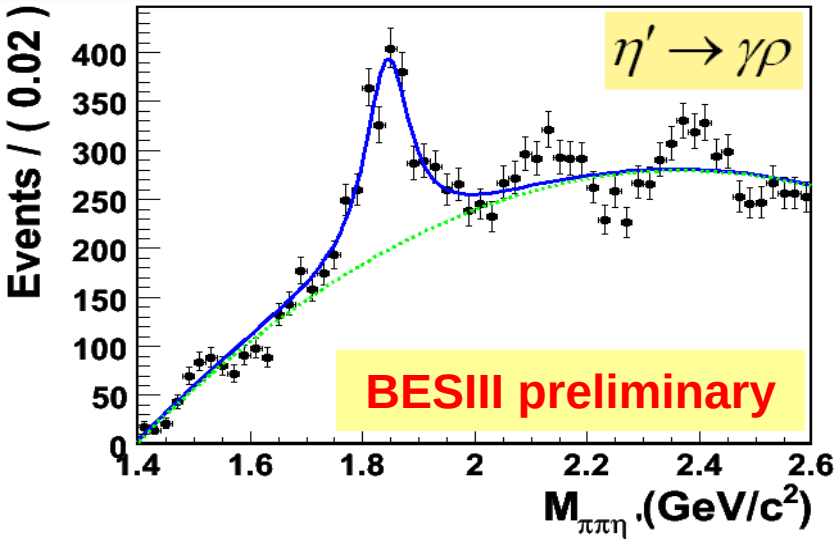
- LQCD predicts the glueball mass of 0^{-+} is ~2.3GeV.
- For 0^{-+} glueball, it may have similar property as η_c (the main decay mode is $\pi\pi\eta'$).
- Confirmation of X(1835) is necessary with BESIII ~220M J/ψ data sample

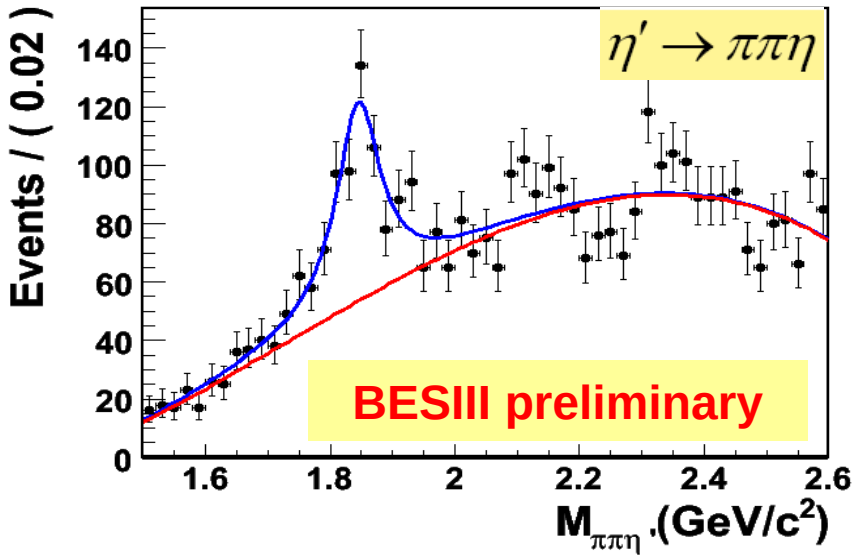
$$J/\psi \to \gamma \pi^+ \pi^- \eta'$$



PRL 95,262001(2005)

X(1835) at BESIII





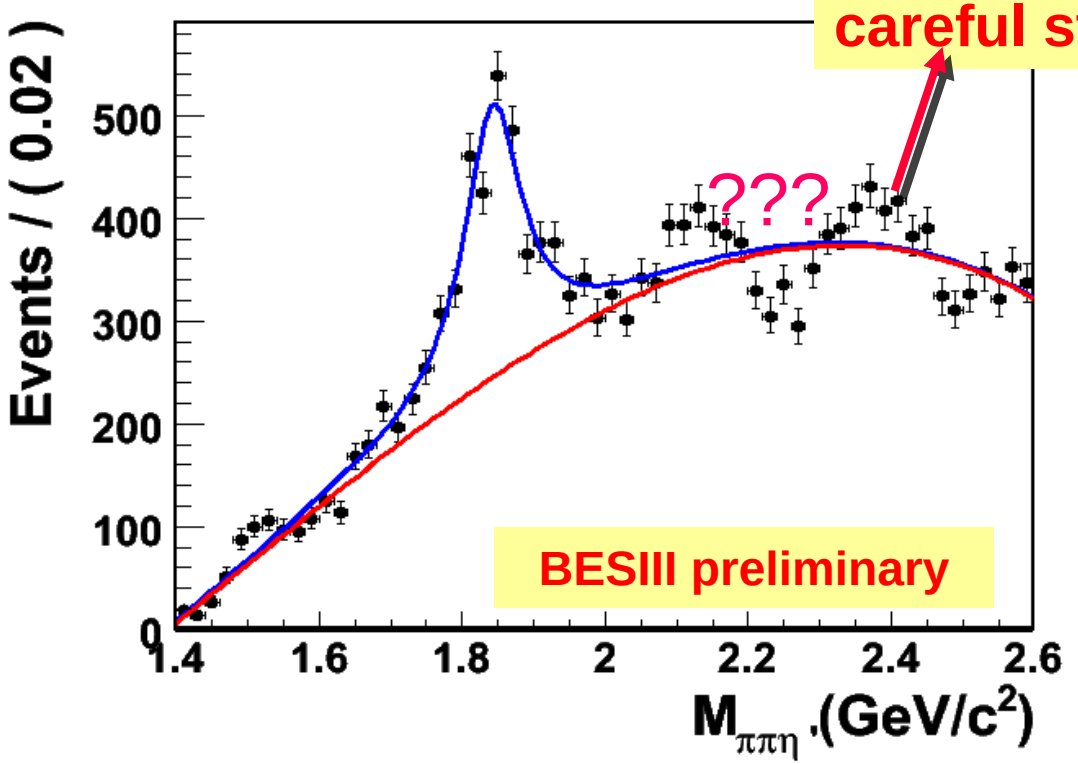
Statistical significance ~18σ

Statistical significance ~9σ

X(1835) confirmed by BESIII

X(1835) at BESIII

Whether there are two new resonances, further careful study is needed.



$$Fit\ result (Statistic\ significant \sim 21\sigma):$$

$$M = 1842.4 \pm 2.8(stat) MeV$$

$$\Gamma = 99.2 \pm 9.2(stat) MeV$$

Charm meson production

- Threshold production at 3.773, 4.03, 4.17 GeV

$$e^+e^- \to D\overline{D}, D_sD_s, D_sD_s^*$$

- If a D meson is produced here it must recoil from a D meson & nothing else: *not enough energy to make any other particles*
- Quantum Coherent of DDbar meson pair
- Double Tag techniques: (partial-) reconstruct both D mesons
- Charm events at threshold are very clean
  - Ratio of signal to background is optimum
  - Lots of systematic uncertainties cancellation while applying double tag method

Charm program

- Absolute branching fractions
- Semileptonic decays
  - $|V_{cs}|$ and $|V_{cd}|$ CKM matrix elements
- Purely leptonic decays
  - f_D and f_{Ds} decay constants
- Neutral D meson oscillations
  - Exploiting quantum correlations @ the ψ(3770)
- CP violation
- …

τ Physics,QCD Testing and Rare decays

- Measurement of τ mass and branching fractions – requires precise beam energy measurement
- Precise R measurements, including spectroscopy above DD threshold
- Hundreds of branching fraction measurements
- Studies of invisible decays
- Rare decays
- …
- Upgrades planned:
  - – precise Beam energy measurement system
  - – Better PID system

BESIII 物理展望

- BESIII正在ψ(3770)共振峰上获取数据，已经采集了～450pb^{-1}的数据
- 8个物理分析已经进入到Referee阶段
- BESIII预期取数计划

Year	Running
2010	ψ(3770) and ψ((3770) scan
2011	J/ ψ (+ ψ (2S)) OR ψ(3770)
2012	ψ(3770) OR J/ ψ (+ ψ(2S))
2013	Ds + R (E > 4 GeV) OR ψ(2S)
2014	psi(2S) OR D_s + R (E > 4 GeV)
2015	R (E < 4 GeV) and τ

总结

- BESIII从2009年初开始正式采集物理数据，探测器表现出了优异的性能
  - 已经获取了高统计量、高质量的物理数据，包括：106M ψ' 事例，220M J/ψ事例，450pb^{-1} ψ(3770)共振峰数据
- 首批物理结果已经公布
  - Confirmation of $p\bar{p}$ threshold enhancement (Chinese Physics C 34(2010)421)
  - h_c from $\psi' \to \pi^0 h_c$: mass width and Br($\psi' \to \pi^0 h_c$) and Br($h_c \to \gamma \eta_c$) (PRL 104, 132002 (2010))
  - $\psi' \to \gamma \pi^0 \pi^0$, $\gamma \eta \eta$ (π^0, $\eta \to \gamma \gamma$) (PRD 81, 052005 (2010))
  - Confirmation of X(1835) (Preliminary)
  - Observation of $\chi_{cJ} \to \phi\phi, \phi\omega, \omega\omega$ (Preliminary)
- 更多的物理结果正在处于合作组内部审核中，将在暑期公布，我们对此非常期待！

致谢

- 大会组织委员会
- BESIII合作组全体成员

谢谢！

backup slides

Systematic errors for h_c

TABLE I. Summary of systematic errors.

Source	$M(h_c)$ (MeV/c^2)	$\Gamma(h_c)$ (MeV)	$\mathcal{B}_1(10^{-4})$	$\mathcal{B}_1 \times \mathcal{B}_2(10^{-4})$	$\mathcal{B}_2(\%)$
Background shape and fit range	0.11	0.23	0.4	0.22	4.4
Energy scale, position reconstruction and 1-C fit	0.13	0.06	0.5	0.10	2.1
Energy resolution	0.00	0.15	0.2	0.03	1.0
Background veto	0.05	0.03	0.0	0.03	0.3
π^0 efficiency	0.00	0.00	0.3	0.14	0.0
$E1$ photon efficiency	0.00	0.00	0.0	0.10	1.2
Number of π^0	0.00	0.00	0.6	0.35	0.6
Number of charged tracks	0.00	0.00	0.1	0.06	0.1
$N(\psi')$	0.00	0.00	0.4	0.19	0.0
$M(\psi')$	0.03	0.02	0.0	0.00	0.0
$M(\eta_c)$ and $\Gamma(\eta_c)$	0.00	0.00	0.0	0.01	0.3
Total systematic error	0.18	0.28	1.0	0.50	5.2

Systematic errors for $\chi_{cJ} \to PP$

TABLE II. Systematic uncertainties expressed in percent.

Mode	$\chi_{c0} \to \pi^0\pi^0$	$\chi_{c2} \to \pi^0\pi^0$	$\chi_{c0} \to \eta\eta$	$\chi_{c2} \to \eta\eta$
Photon detection	5	5	5	5
$\pi^0(\eta)$ reconstruction	2	2	2	2
$p^2_{i\gamma}$	0.9	1.2	0.1	0.3
$\chi_{\eta\eta}$	...	...	0.6	2.6
Signal shape	1.6	1.2	1.4	1.5
Background shape	0.5	0.5	0.2	0.3
Fitting range	0.3	0.3	0.8	1.3
Trigger	0.1	0.1	0.1	0.1
$N_{\psi'}$	4	4	4	4
Total	7.0	6.9	6.9	7.5