Recent results on spectroscopy from BESIII

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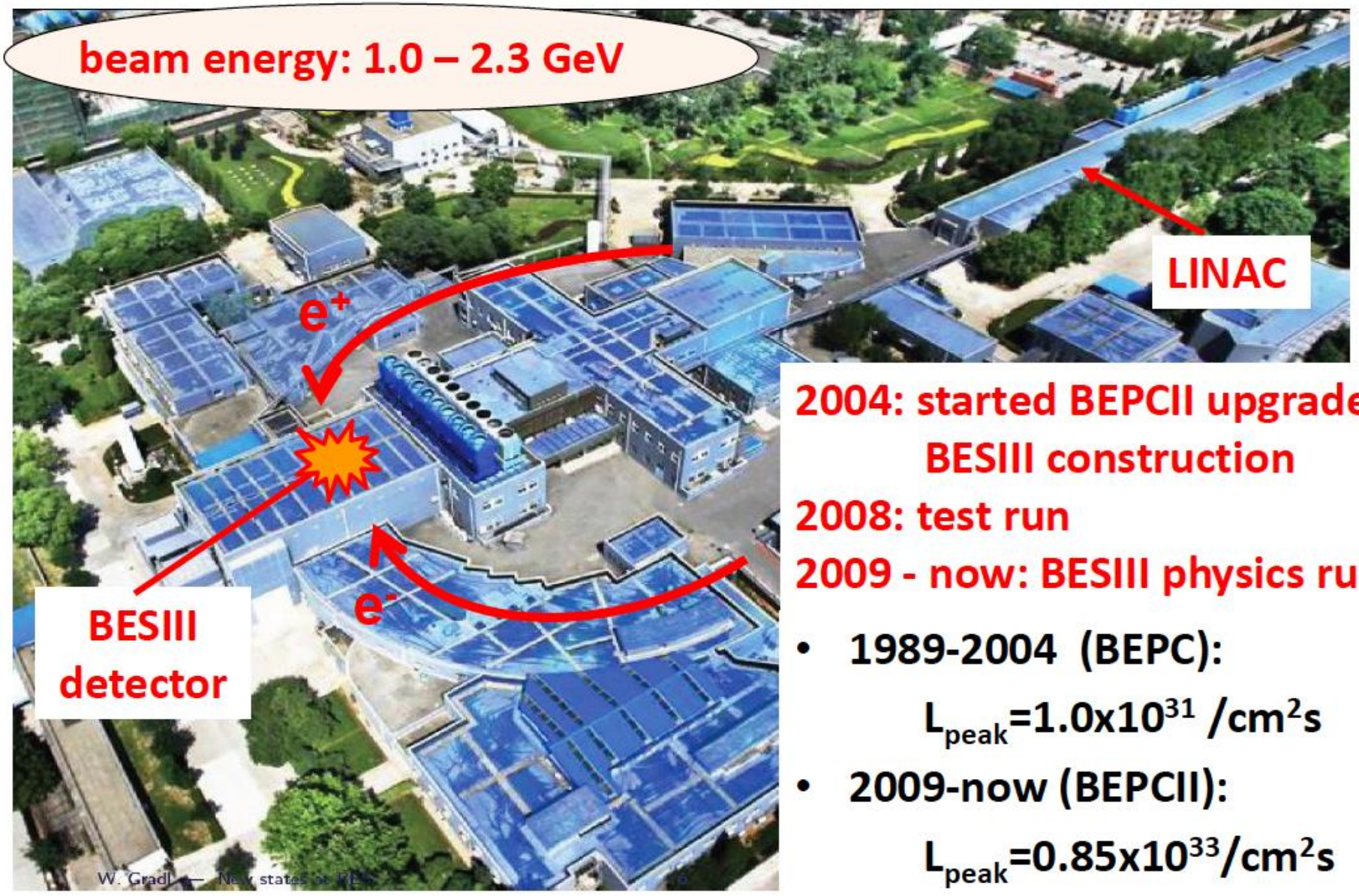
(for BESIII collaboration)

XVI International Conference on Hadron Spectroscopy,
Sept. 13-18, 2015, Newport News, US

Outline

- Introduction
- Selected results from BESIII
  - Light meson spectroscopy
  - Light baryon spectroscopy
  - Charmonium spectroscopy
- Summary

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

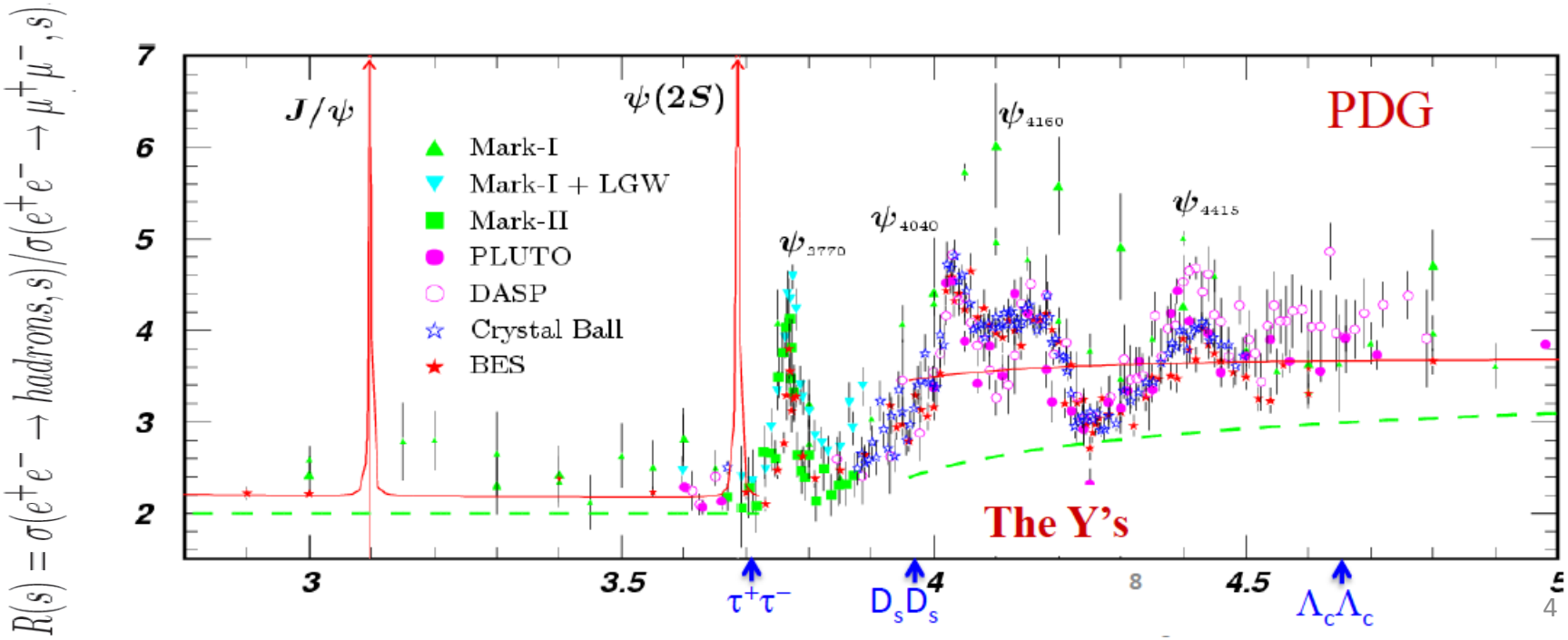
  $L_{peak}=1.0\times10^{31}\ /cm^2s$

- 2009-now (BEPCII):

  $L_{peak}=0.85\times10^{33}/cm^2s$

Features of the BEPC Energy Region

- Rich of **resonances:** charmonia and charmed mesons
- **Threshold** characteristics (pairs of τ, D, D_s, …)
- **Transition between** smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the **gluonic excitations and multi-quark states**



Physics at BESIII

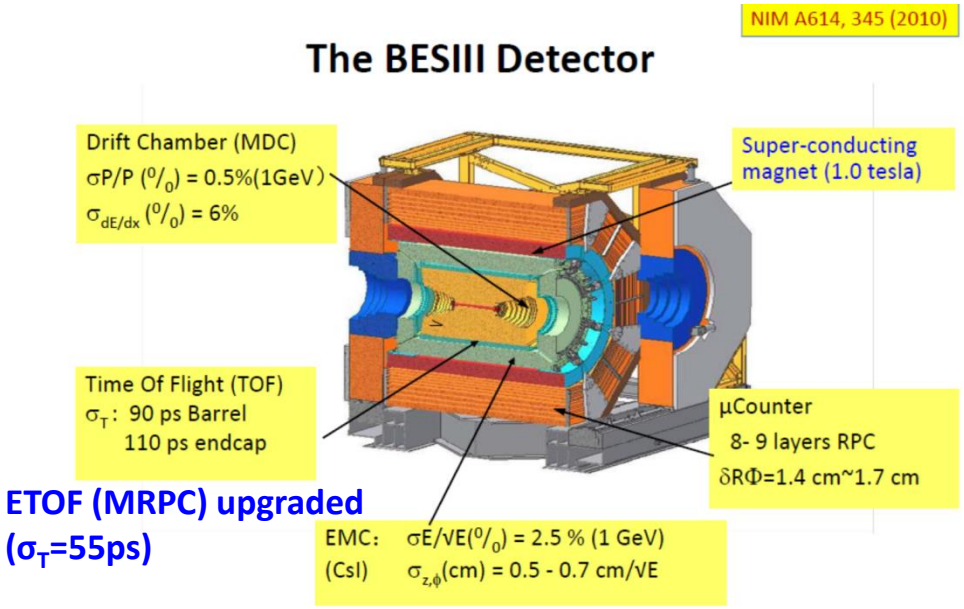
Charmonium physics:
- spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball, hybrid, multiquark
- two-photon physics
- e.m. form factors of nucleon

Open Charm physics:
- (semi) leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- tau decays near threshold
- tau mass scan

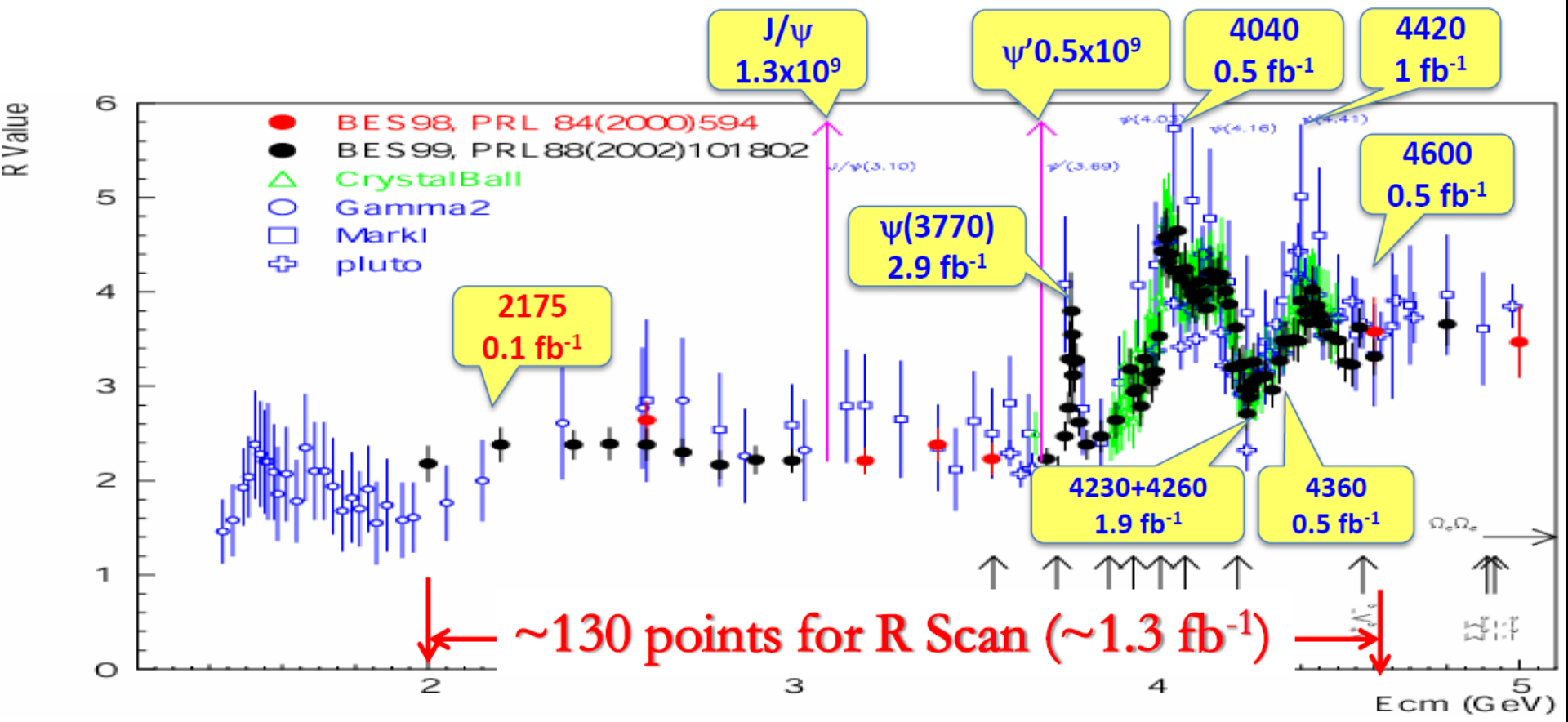
...and many more.



Further presentations at this conference

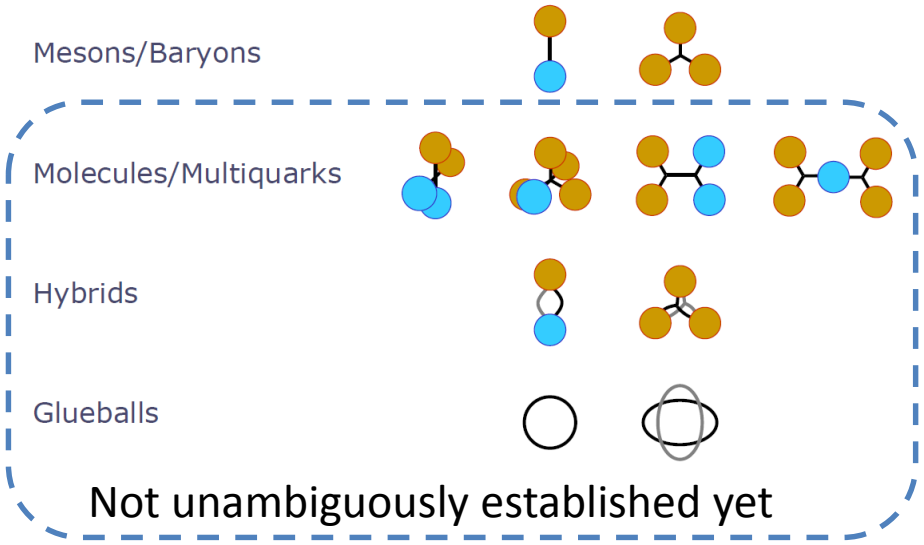
Xiaocong Ai: Studies of Charmonium at BESIII
Dan Bennett: Hadronic Transitions above 4 GeV at BESIII
Qing Gao: Radiative Transitions above 4 GeV at BESIII
Wei Shan: Exotic Zc states at BESIII
Liqing Qin: Light meson decays at BESIII
Yao Qin: Recent results on J/ψ radiative decays at BESIII
Jake Bennett: Progress on the baryon spectroscopy at BESIII
Mihajlo Kornicer: Study of $\chi_{c1} \to \eta\pi^+\pi^-$
Xiaokang Zhou: Charmed baryon Lambda_c decays
Cristina Morales: Form factor measurements at BESIII
Zhu Kai: Collins Asymmetry at BESIII

BESIII data samples



World largest J/ψ, ψ(2S), ψ(3770), Y(4260), …
produced directly from e^+e^- collision

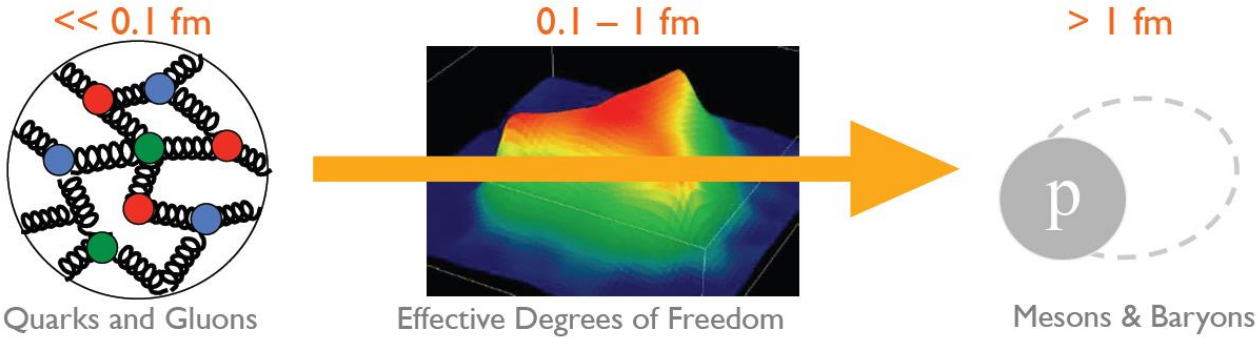
Hadron spectrum



Continuous efforts in experiment and theory

- Hadron spectroscopy is a key tool to investigate QCD

- testing QCD in the confinement regime
- providing insights into the fundamental degrees of freedom



From V. Crede

Light meson spectroscopy

- **Observation of X(1835) in $J/\psi \to \gamma K_s K_s \eta$**
- **PWA of $J/\psi \to \gamma\phi\phi$**
- **Model independent PWA of $J/\psi \to \gamma\pi^0\pi^0$**
- **Amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$**

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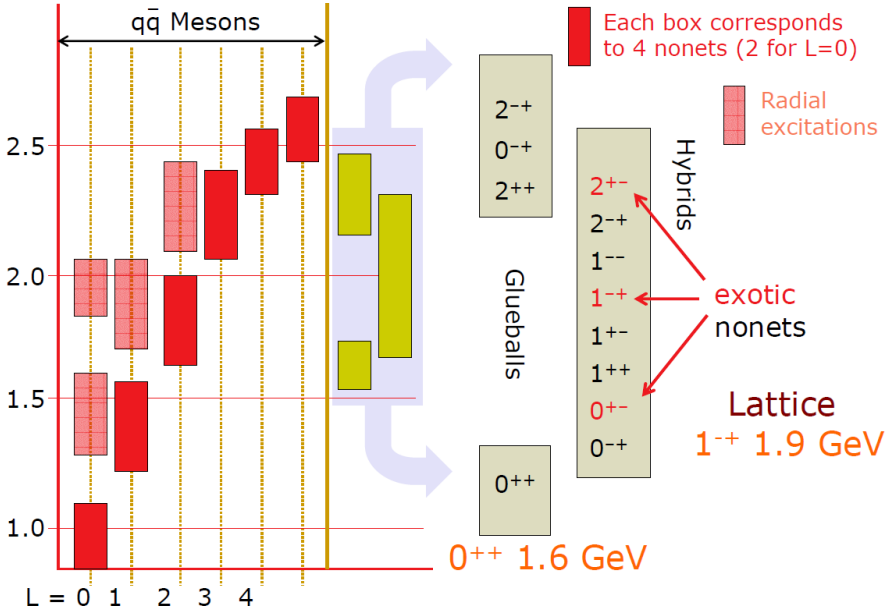
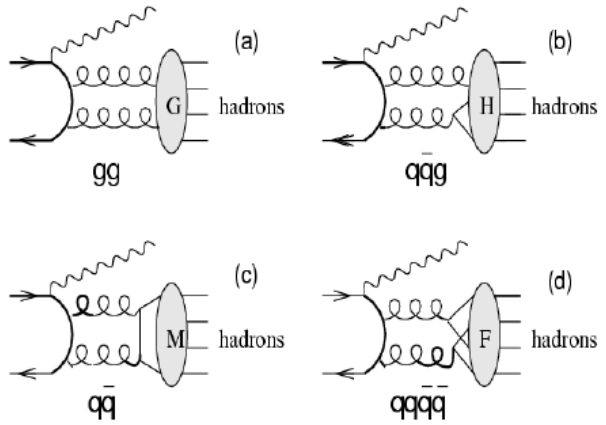
Liqing Qin: Light meson decays at BESIII
Yao Qin: Recent results on J/ψ radiative decays at BESIII
Mihajlo Kornicer: Study of $\chi_{c1} \to \eta\pi^+\pi^-$

Charmonium decays provides an ideal hunting ground for light glueballs and hybrids





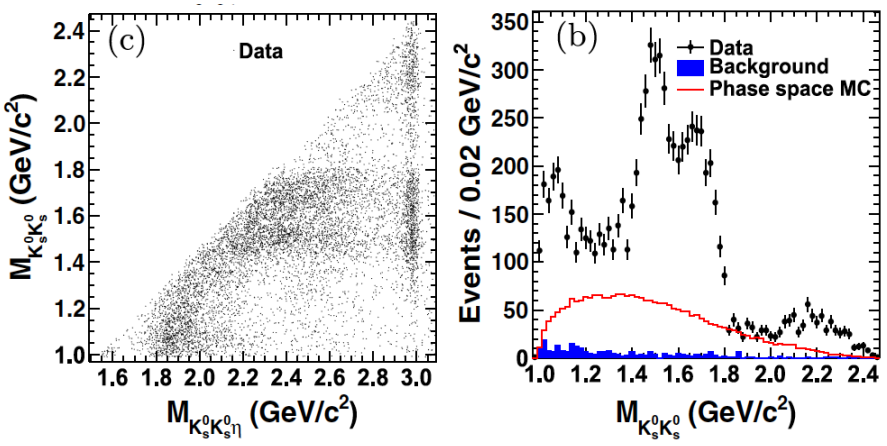
$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$$

$$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$$

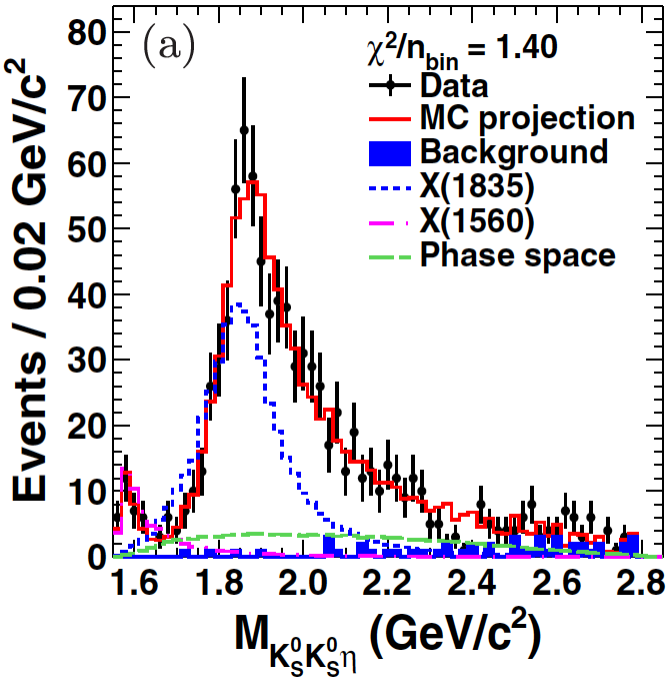
- "Gluon-rich" process
- Clean high statistics data samples from e^+e^- production
- $I(J^{PC})$ filter in strong decays of charmonium

Observation and Spin-Parity Determination of the $X(1835)$ in $J/\psi \to \gamma K_S^0 K_S^0 \eta$

Phys.Rev.Lett. 115 091803(2015)



The structure around 1.85 GeV/c² in the $K_SK_S\eta$ mass spectrum is strongly correlated to $f_0(980)$



Partial Wave Analysis for $M(K_SK_S)$<1.1 GeV/c²

- **X(1835)→$K_SK_S\eta$ (the K_SK_S system is dominantly produced through the $f_0(980)$)** $J^{PC}=0^{-+}$, **(> 12.9 σ)**

M=$1844 \pm 9(\text{stat})^{+16}_{-25}(\text{syst})$ MeV/c², Γ=$192^{+20\ +62}_{-17\ -43}$ MeV,

Consistent with X(1835) observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$

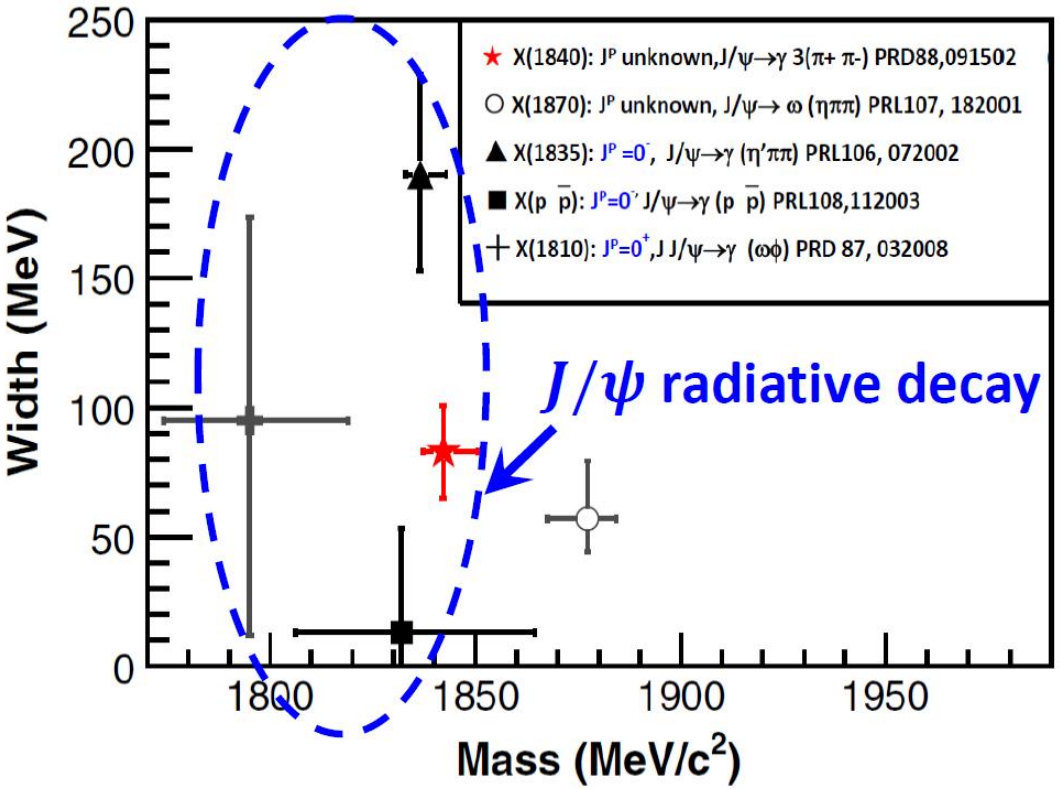
$B(J/\psi \to \gamma X(1835)) \cdot B(X(1835) \to K_sK_s\eta) = (3.31^{+0.33\ +1.96}_{-0.30\ -1.29}) \cdot 10^{-5}$

- **X(1560) → $f_0(980)\eta$:** $J^{PC}=0^{-+}$, **(> 8.9 σ)**

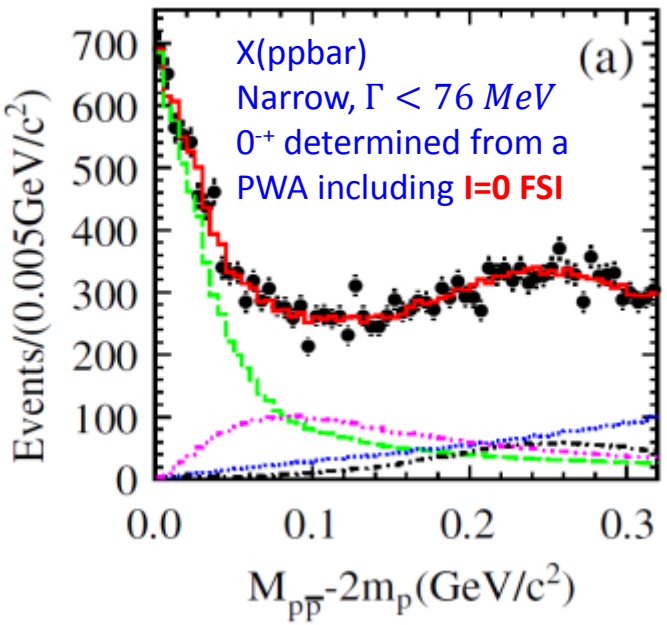
M=$1565 \pm 8^{+0}_{-63}$ MeV/c², Γ=$45^{+14\ +21}_{-13\ -28}$ MeV

consistent with those of $\eta(1405)$ / $\eta(1475)$ within 2.0 σ

Diverse structures near $p\bar{p}$ threshold

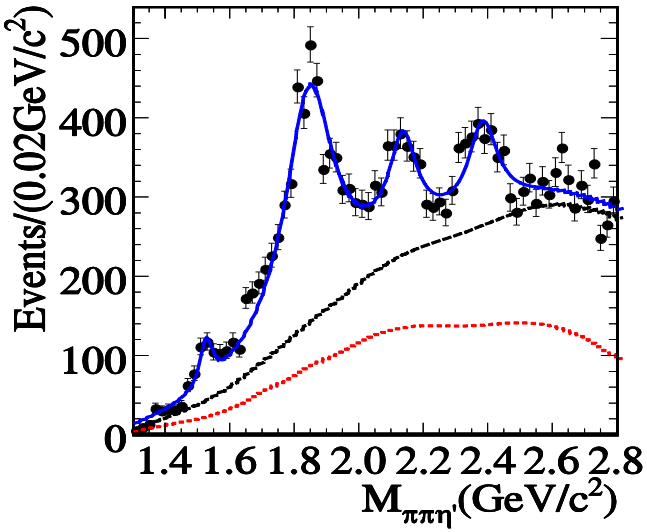


PRL 108,112003(2012)



PRL 106, 072002(2011)

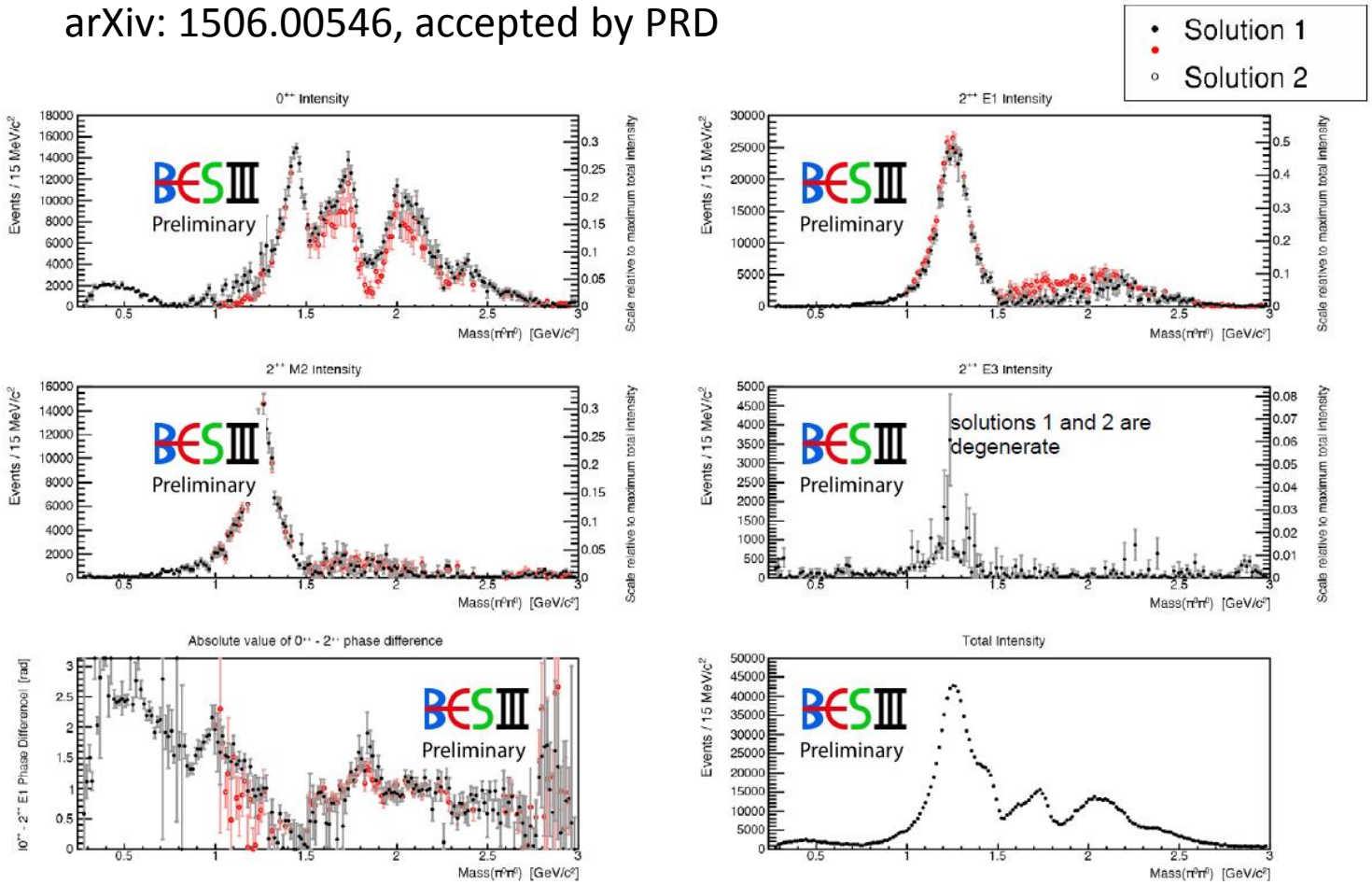
X(1835) consistent with 0–



- Any relations
- What is the role of the ppbar threshold?
  - Non-observation in $J/\psi \to \omega, \eta, \pi^0\ \bar{p}p$

Model independent PWA of $J/\psi \to \gamma\pi^0\pi^0$

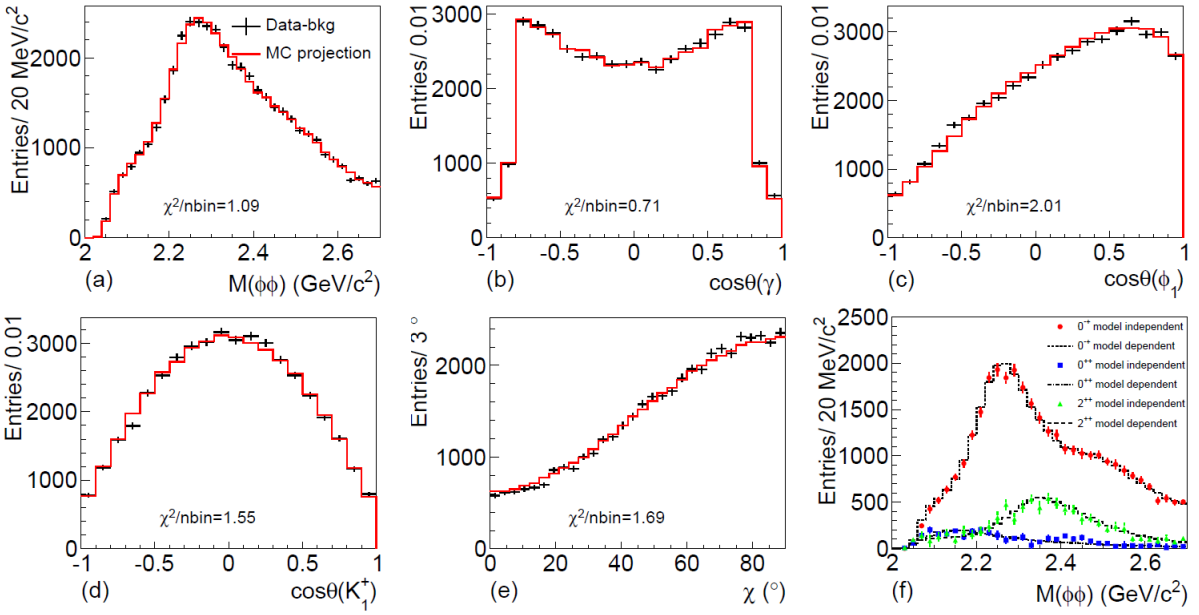
arXiv: 1506.00546, accepted by PRD



A sophisticated mass independent amplitude analysis is performed.
Significant features of the scalar spectrum include structures near 1.5, 1.7, and 2.1 GeV/c² .

Partial Wave Analysis of J/ψ→γϕϕ (preliminary)

Besides η(2225) , very little was known in the sector of pseudoscalar above 2 GeV. The new experimental results are helpful for mapping out the pseudoscalar excitations and searching for 0^{-+} glueball



Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.($\times 10^{-4}$)	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

- **Dominant contribution from pseudoscalars**
  - **η(2225) is confirmed;**
  - **η(2100) and X(2500) are observed with large significance.**
- **The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in π^-p reactions are also observed with a strong production of $f_2(2340)$.**
- **Model-dependent PWA results are well consistent with the results from MIPWA**

Partial Wave Analysis of J/ψ→γϕϕ (preliminary)

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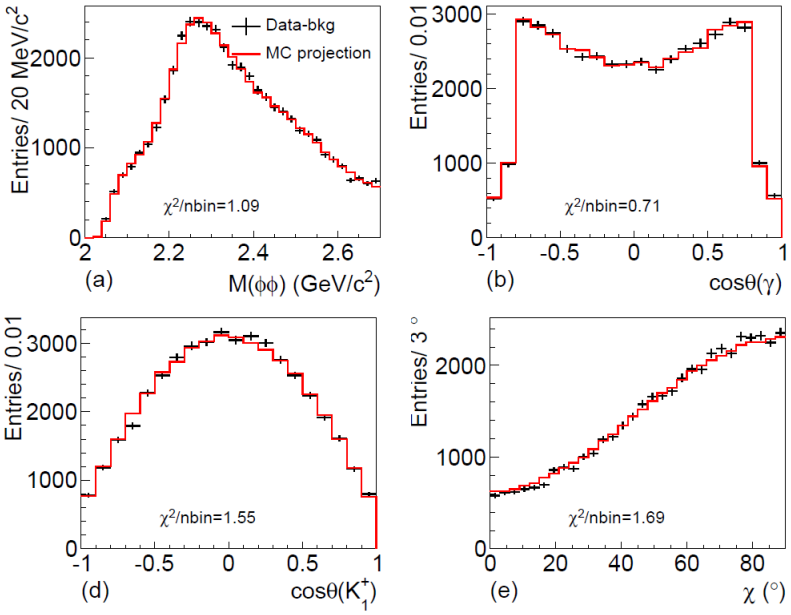

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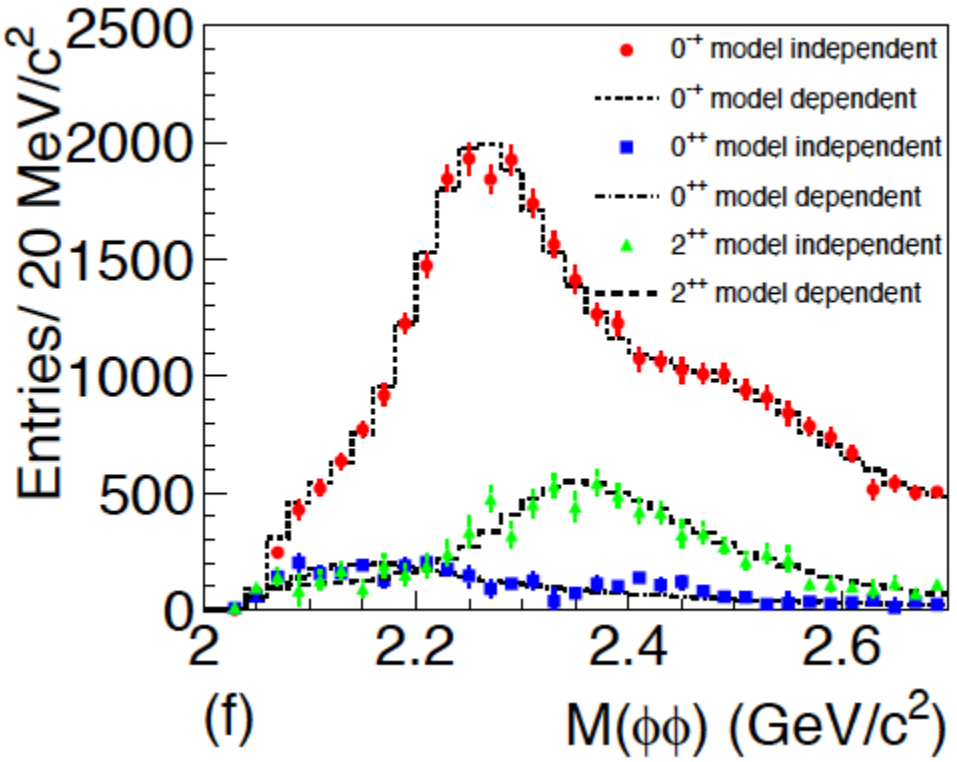
			$.09$ $.15$)	6.4σ
			$.72$ $.69$)	10.7σ
			$.16$ $.48$)	6.8σ



- **Dominant contribution from**
  - **η(2225) is confirmed;**
  - **two additional pseudo**
- **The three tensors $f_2(2010)$, f_2 are also observed with a stro**
- **Model-dependent PWA resul from MIPWA**

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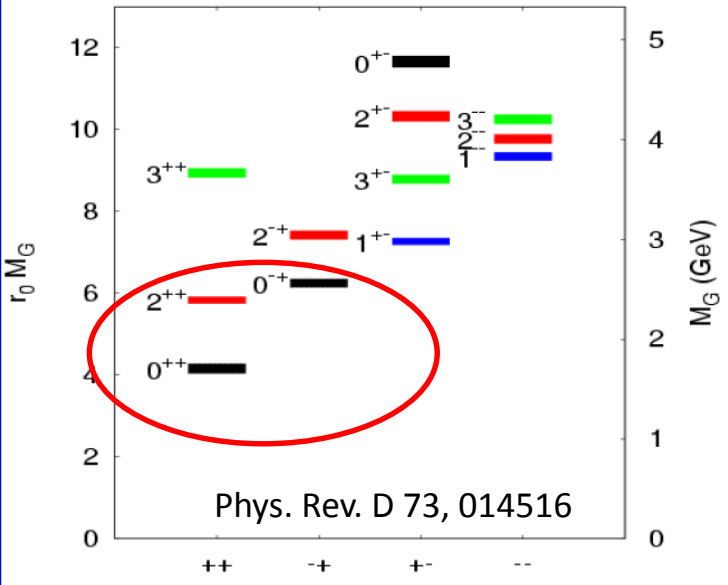
Glueballs from Quenched LQCD



Phys. Rev. D 73, 014516

Phys. Rev. Lett. 110, 021601

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha \frac{|p|}{M^2_{J/\psi}}|E_1(0)|^2 = 0.35(8)keV$$

$$\Gamma/\Gamma\_tot = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

Phys. Rev. Lett. 111, 091601

$$\Gamma(J/\psi \to \gamma G_{2^+}) = 1.01(22)keV$$

$$\Gamma(J/\psi \to \gamma G_{2^+})/\Gamma_{tot} = 1.1(2)\times 10^{-2}$$

Flavor-blindness of glueball decays

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta : \eta\eta' : \eta'\eta') = 3:4:1:0:1$$

- **Low lying glueballs have ordinary quantum number→mixing with qqbar mesons**

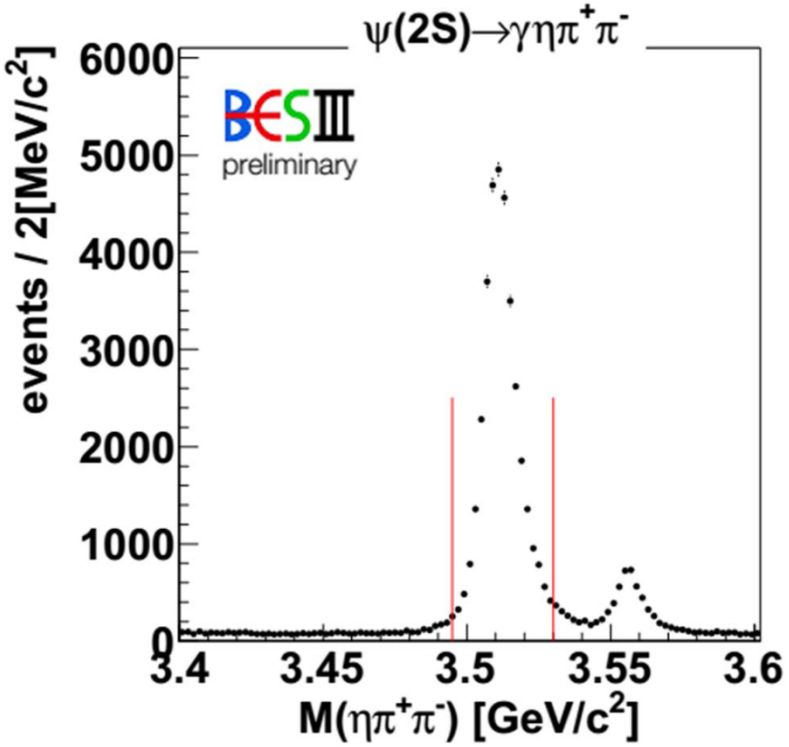
At BESIII

- **$f_0(1710)$ and $f_0(2100)$ are observed with a strong production in $J/\psi \to \gamma\,\eta\eta$ [PRD87, 092009] (as well as MIPWA of $J/\psi \to \gamma\pi^0\pi^0$)**
- **$f_2(2340)$ is observed with a strong production in $J/\psi \to \gamma\eta\eta/\phi\phi$ (as well as MIPWA of $J/\psi \to \gamma\pi^0\pi^0$)**
- **Systematic studies ongoing**
  - $J/\psi \to \gamma\eta\eta'$
  - $J/\psi \to \gamma\eta'\eta'$
  - $J/\psi \to \gamma K_S K_S$
  - $J/\psi \to \phi X, \omega X$
  - …

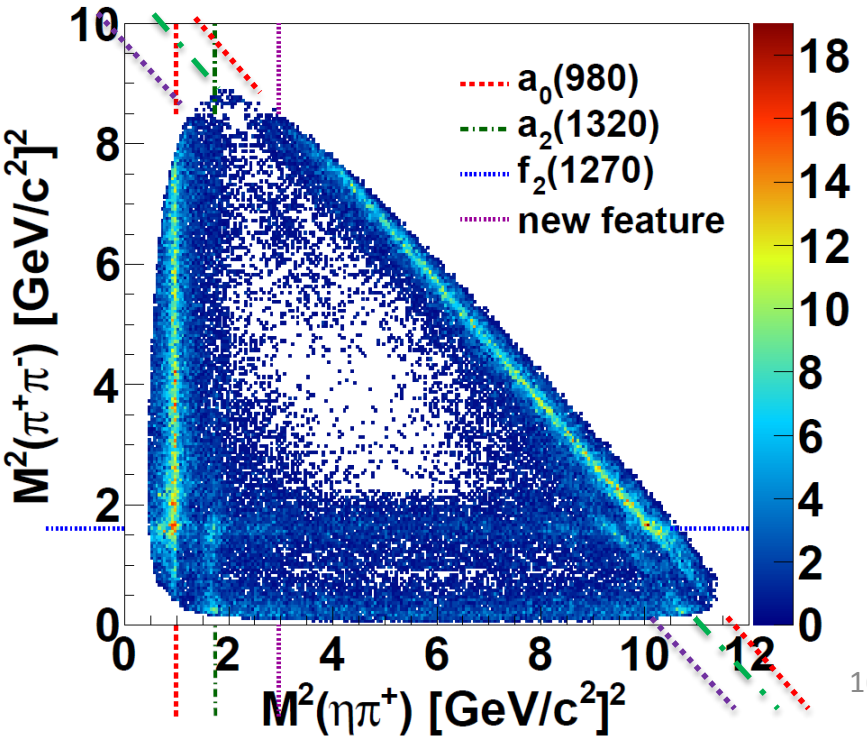
Amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$

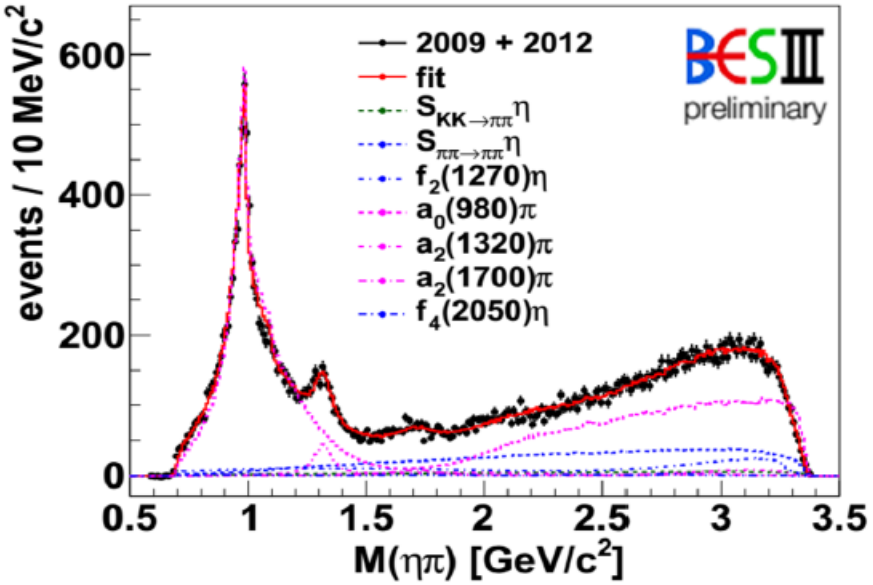
- χ_{c1} **provides another suitable environment to look for 1^{-+}**
  - $\pi_1(1600)$ **studied in χ_{c1} decays by CLEO-c**
  - **only $\pi_1(1400)$ has been reported decays to $\eta\pi$**
- **Properties of a_0 and a_2 still need further studies**

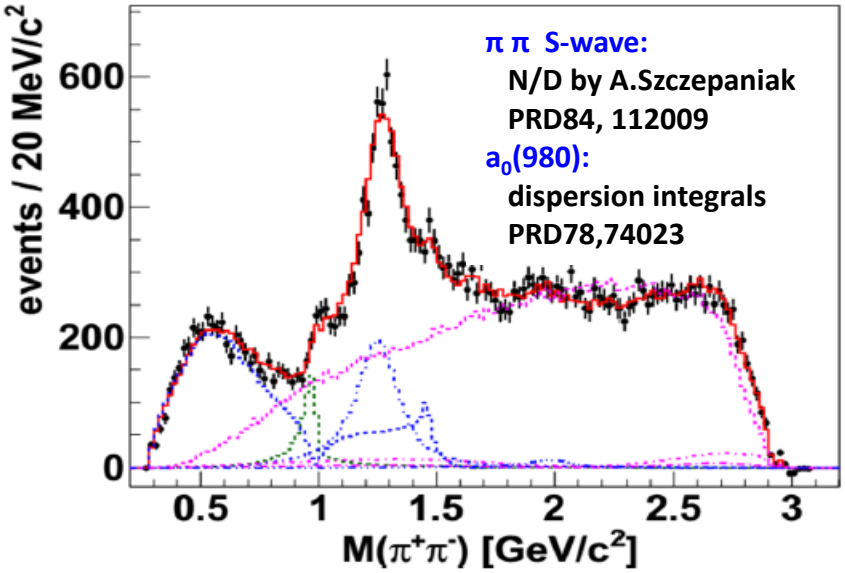
$N(\chi_{c1}) \sim 35000$



compatible with $a_2(1700)$ hypothesis





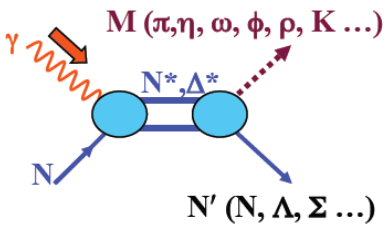


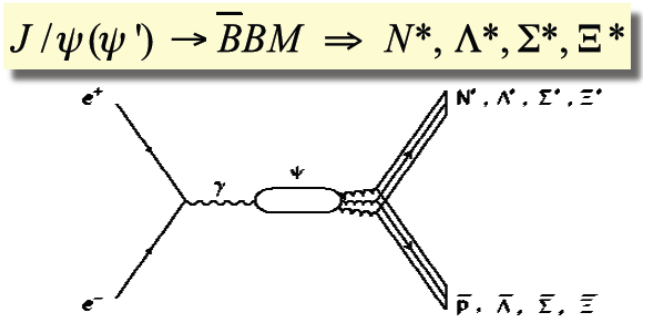
Decay mode	$\mathcal{B}(\chi_{c1} \to \eta\pi^+\pi^-) \times 10^{-3}$
$\eta\pi^+\pi^-$	$4.819 \pm 0.031 \pm 0.088 \pm 0.210$
$a_0(980)^\pm\pi^\mp$	$3.506 \pm 0.034 \pm 0.182 \pm 0.153$
$a_2(1320)^\pm\pi^\mp$	$0.185 \pm 0.009 \pm 0.038 \pm 0.008$
$a_2(1700)^\pm\pi^\mp$	$0.048 \pm 0.005 \pm 0.014 \pm 0.002$
$S_{kk}\eta$	$0.123 \pm 0.007 \pm 0.018 \pm 0.005$
$S_{pp}\eta$	$0.791 \pm 0.019 \pm 0.037 \pm 0.035$
$\pi\pi_S\eta$	$0.859 \pm 0.021 \pm 0.031 \pm 0.037$
$f_2(1270)\eta$	$0.371 \pm 0.012 \pm 0.054 \pm 0.016$
$f_4(2050)\eta$	$0.027 \pm 0.004 \pm 0.009 \pm 0.001$
BESIII Preliminary	U.L. [90% c.l.]
$\pi_1(1400)^\pm\pi^\mp$	0.028 ± 0.010 < 0.048
$\pi_1(1600)^\pm\pi^\mp$	0.005 ± 0.005 < 0.016
$\pi_1(2015)^\pm\pi^\mp$	0.003 ± 0.002 < 0.008

Errors: stat. ± syst. ± extern.

- **Clear evidence for $a_2(1700)$ in χ_{c1} decays.**
- **First measurement of $g'_{\eta'\pi} \neq 0$ using $a_0(980) \to \eta\pi$ line shape.**
- **Measured upper limits for $\pi_1(1^{-+})$ in 1.4 - 2.0 GeV/c² region.**

Light Baryon spectroscopy





Charmonium decays can provide novel insights into baryons and complementary information to other experiments

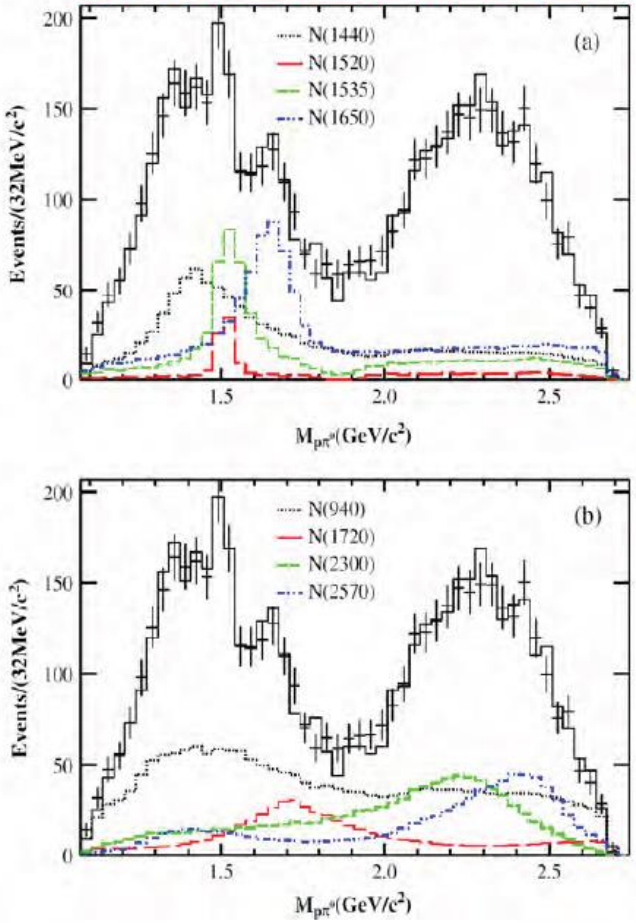
- ✓ Missing N* with small couplings to πN & γN , but large coupling to gggN : $\psi \to N\bar{N}\pi/\eta/\eta'/\omega/\phi, \bar{p}\Sigma\pi, \bar{p}\Lambda K$ …
- ✓ Not only N*, but also Λ^*, Σ^*, Ξ^*
- ✓ Gluon-rich environment: a favorable place for producing hybrid (qqqg) baryons
- ✓ High statistics of charmonium @ BES III

Further presentations at this conference

Jake Bennett: Progress on the baryon spectroscopy at BESIII

PWA of $\psi(2S) \to \pi^0 p\bar{p}$

Phys. Rev. Lett. **110**, 022001 (2013)



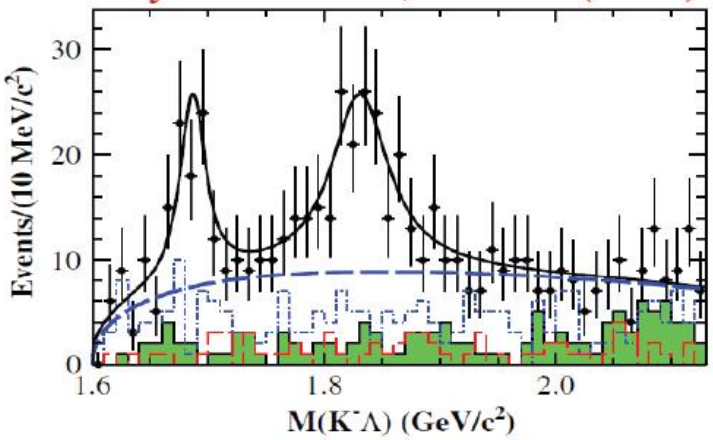
N(2300)	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
N(2570)	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

2 New N* are found (1/2+, 5/2-)

$\psi(2S) \to K^- \Lambda \bar{\Xi}^+$

Observation of $\Xi(1690)^-/\Xi(1820)^-$

Phys. Rev. D **91**, 092006 (2015)



	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\mathrm{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$\mathcal{B}(10^{-6})$	$5.21 \pm 1.48 \pm 0.57$	$12.03 \pm 2.94 \pm 1.22$
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	< 30	24^{+15}_{-10}

Charmonium spectroscopy

X

$e^+e^- \rightarrow \gamma X(3872)$
$e^+e^- \rightarrow \pi^+\pi^- X(3823)$

Y

e^+e^- →hidden charm final states

Z

Observation of Z_c states

- **Intriguing phenomena spring up.**
- **A number of transitions between different exotic states observed, starting to make connections.**
- **Complexities require complementary studies and global efforts: CDF, D0, LHCb, ATLAS, CMS, CLEO, Babar, Belle(2), BES3, …**

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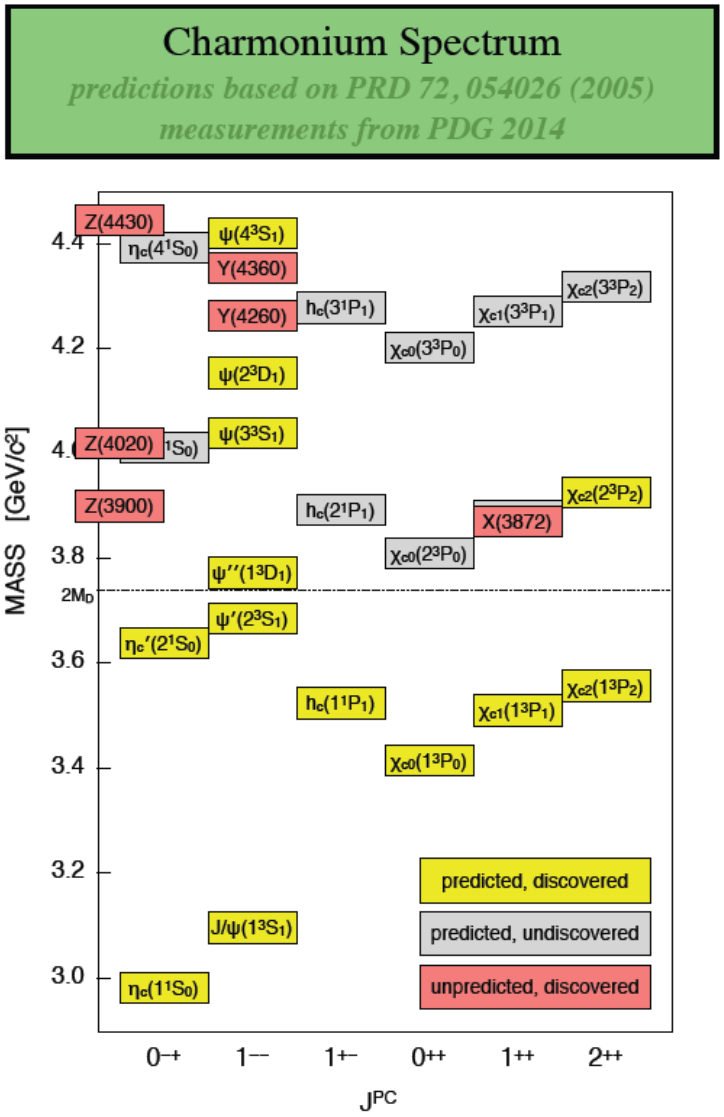
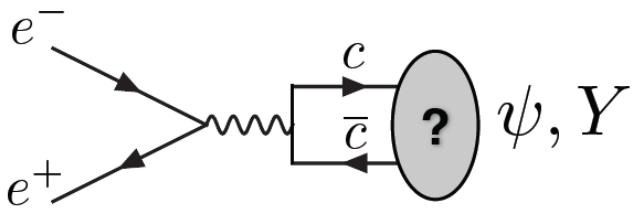
Dan Bennett: Hadronic Transitions above 4 GeV at BESIII
Qing Gao: Radiative Transitions above 4 GeV at BESIII
Wei Shan: Exotic Zc states at BESIII

Charmonium and exotics at BESIII

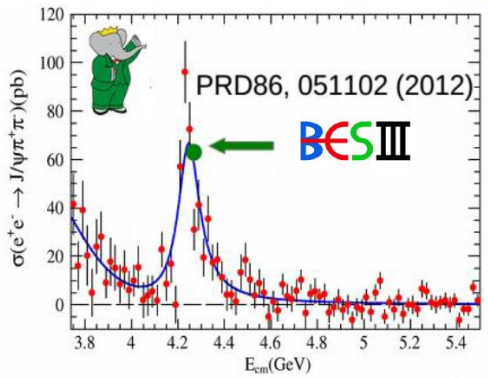


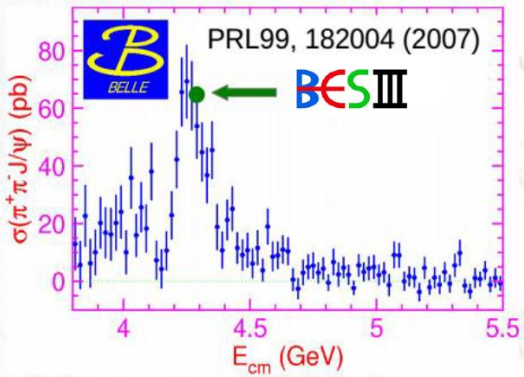


direct production of ψ , Y
radiative and hadronic transitions

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

Compare running at **Belle and BaBar,** with one month at **BESIII !**





BESIII: $\sigma^B = 62.9 \pm 1.9 \pm 3.7$ pb

PRL 110, 252001 (2013)

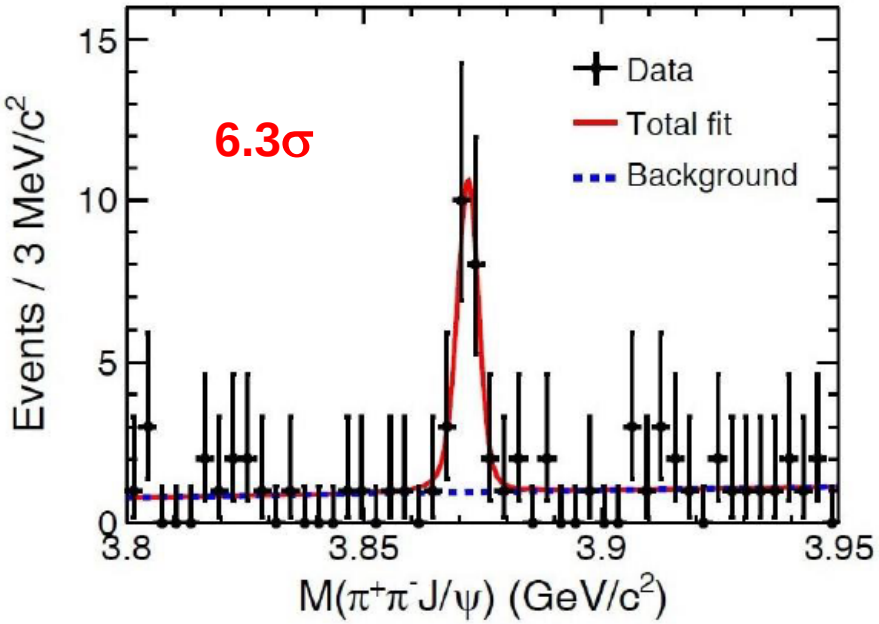
Observation of $e^+e^- \to \gamma X(3872)$

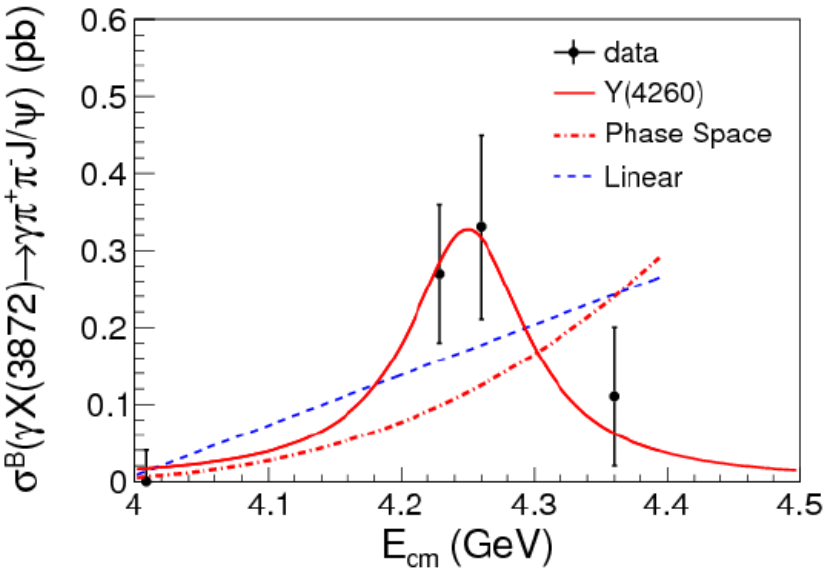
Strong evidence for
$X(3872) \to \pi\pi\, J/\psi$

PRL 112, 092001 (2014)

$M = 3871.9 \pm 0.7 \pm 0.2$ MeV/c^2

Suggestive of
$Y(4260) \to \gamma\, X(3872)$



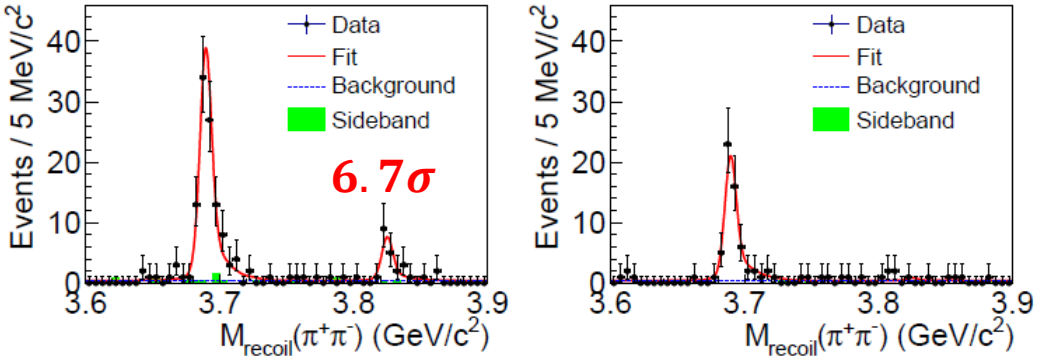


❖ **New mode of production of X(3872) and Y(4260) decay?**

If we take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) \sim 5\%$, (>2.6% in PDG)

$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim$: 10% Large transition ratio !

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^- \gamma\chi_{c1}$



Phys. Rev. Lett. 115, 011803 (2015)

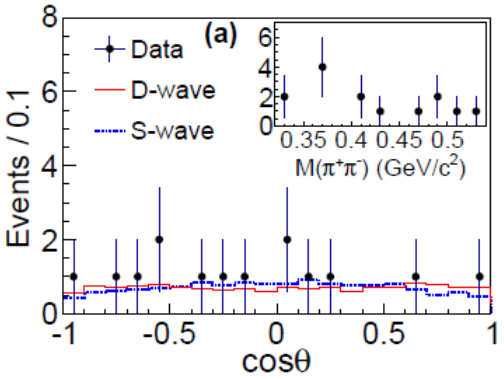
Reconstruct $\chi_c \to \gamma J/\psi \to \gamma l^+ l^-$
look for $\pi^+\pi^-$ recoil

Simultaneous fit of $\gamma\chi_{c1}$ (left) and $\gamma\chi_{c2}$ (right) events

$$M(X(3823)) = (3821.7 \pm 1.3(stat) \pm 0.7(syst))\ \text{MeV}/c^2$$

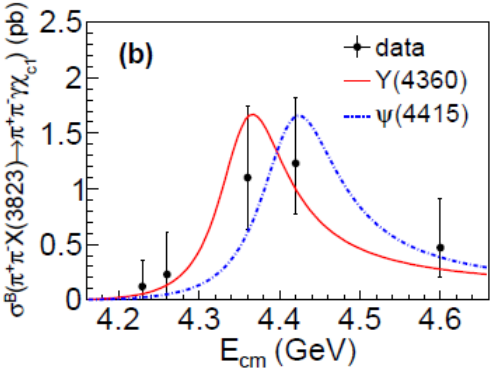
$$\Gamma(X(3823)) < 16\ \text{MeV at 90\% C.L. consist with Belle}$$

$$\frac{\mathcal{B}(X(3823) \to \gamma\chi_{c2})}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})} < 0.42 \quad \text{at 90\% C.L.}$$



X(3823) scattering angle distribution

D-wave is expected.
Limited statistics



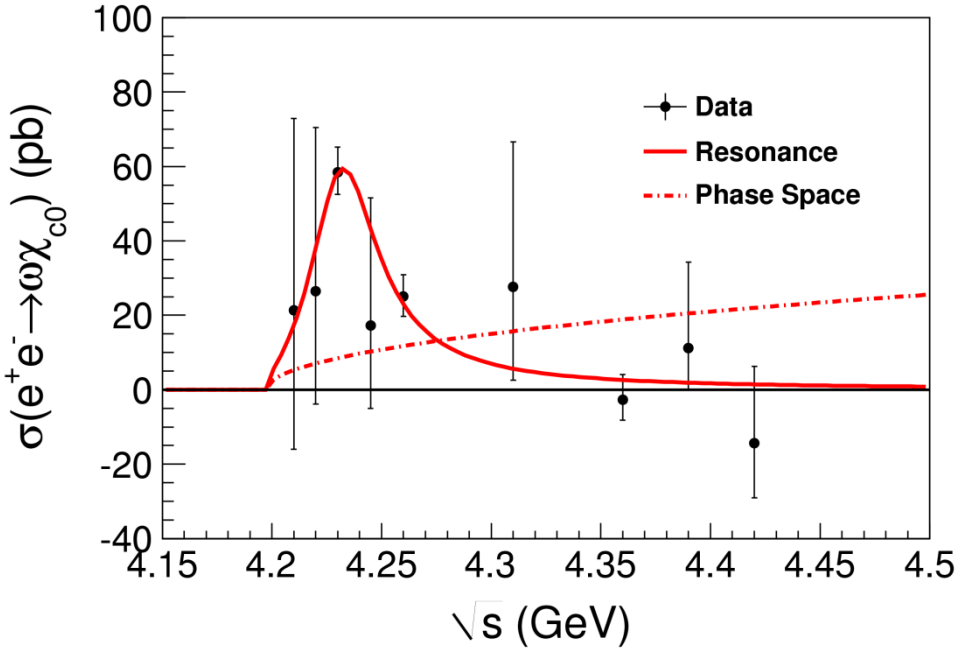
Cross section VS energy

Both Y(4360) and Ψ(4415) line shape give reasonable description

Good candidate of $\Psi(1^3D_2)$.

Observation of $e^+e^- \to \omega\chi_{c0}$

Phys. Rev. Lett. 114, 092003



Fit with a single BW

Mass = $4230 \pm 8 \pm 6$ MeV

Width = $38 \pm 12 \pm 2$ MeV

Significance > 9σ

Inconsist with Y(4260) from $\pi\pi J/\psi$

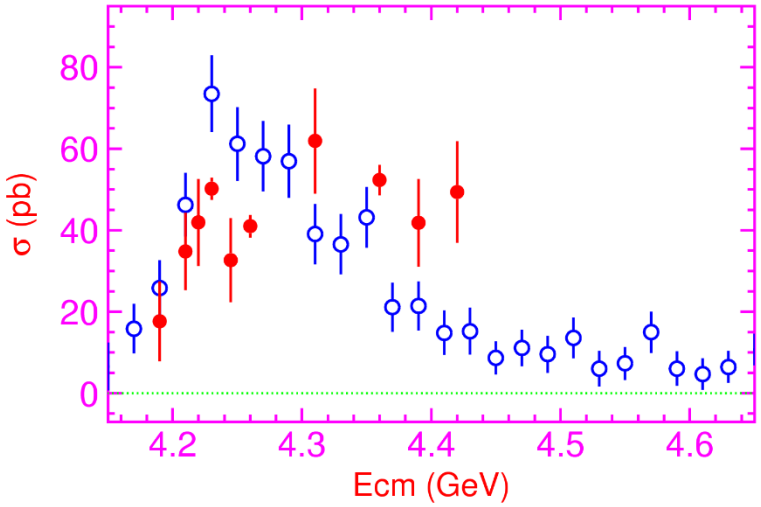
No significant signals for $e^+e^- \to \omega\chi_{c1,2}$

Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$

Phys. Rev. Lett. **111, 242001**

Open circles: Belle $e^+e^- \to \pi^+\pi^- J/\psi$

Solid dots: BESIII $e^+e^- \to \pi^+\pi^- h_c$

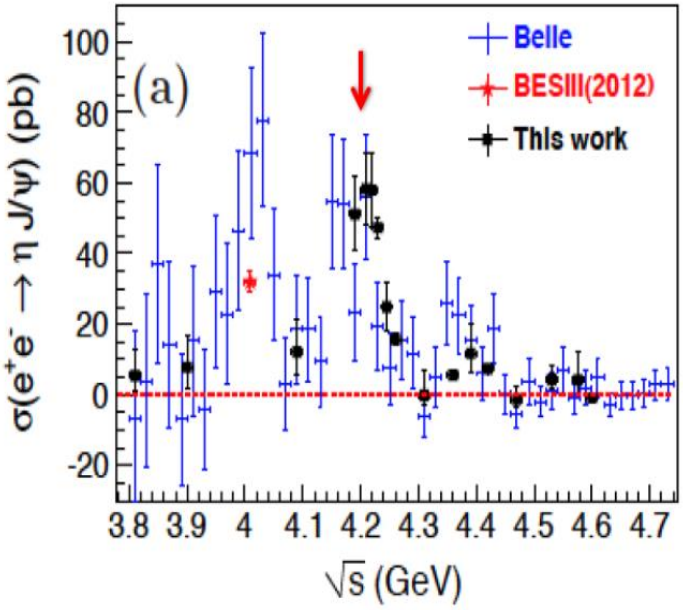


$\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim \sigma(e^+e^- \to \pi^+\pi^- J/\psi)$

But line shape is different from Y(4260) in $\pi^+\pi^- J/\psi$

Observation of $e^+e^- \to \eta J/\psi$

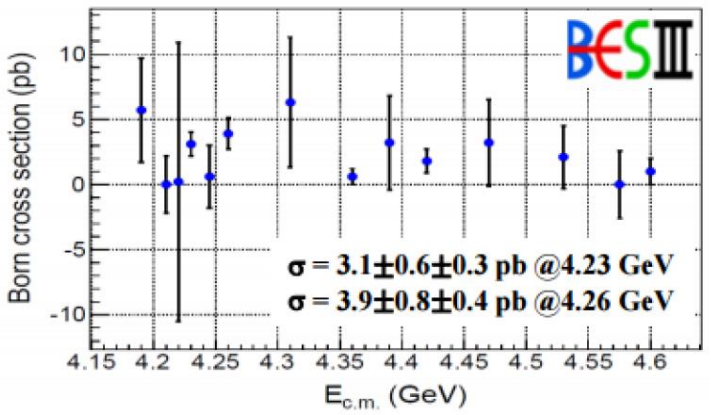
PRD 91,112005 (2015)



- Agree with previous results with improved precision
- non-trivial structure around 4.2 GeV

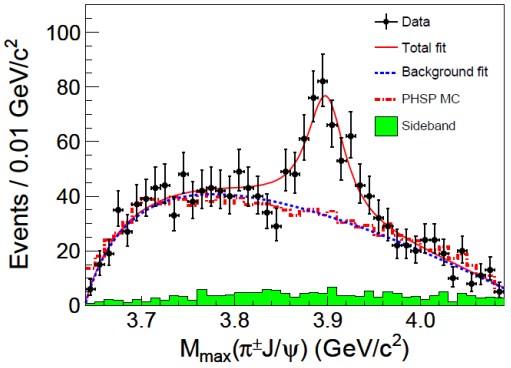
Observation of $e^+e^- \to \eta' J/\psi$

BESIII Preliminary



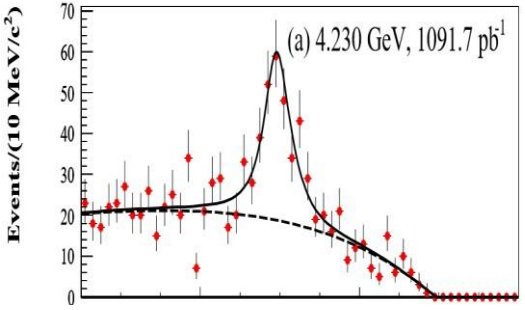
First observation at 4.23GeV and 4.26GeV, couldn't tell the line-shape due to the statistics. $\sigma(\eta' J/\Psi)$ is much lower than $\sigma(\eta J/\Psi)$ which is in contradiction to the NRQCD calculation. PRD 89, 074006 (2014)

PRL 110,252001 (2013)



$e^+e^- \to \pi^+ \pi^- J/\Psi$

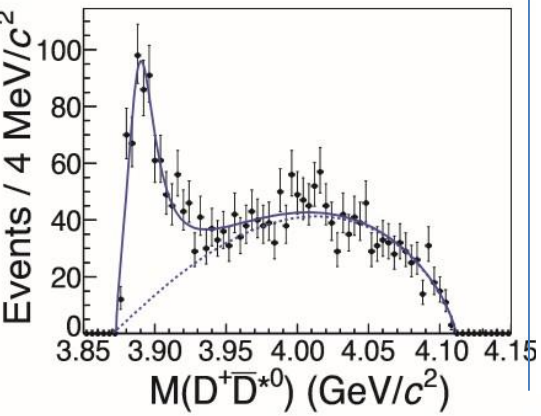
arXiv:1506.06018



$e^+e^- \to \pi^0 \pi^0 J/\Psi$

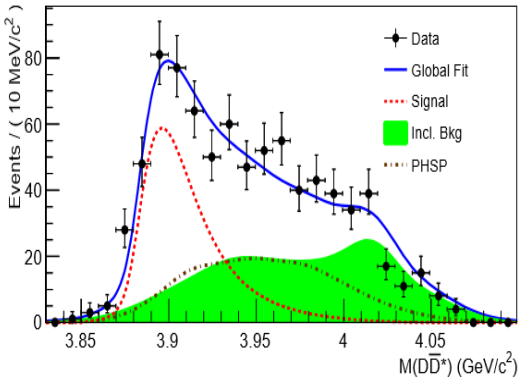
State	Mass(MeV)	Width(MeV)
$Z_c(3900)^\pm$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$
$Z_c(3885)^\pm$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$

PRL 112,022001 (2014)



$e^+e^- \to \pi^- (D\bar{D}^*)^+$

preliminary



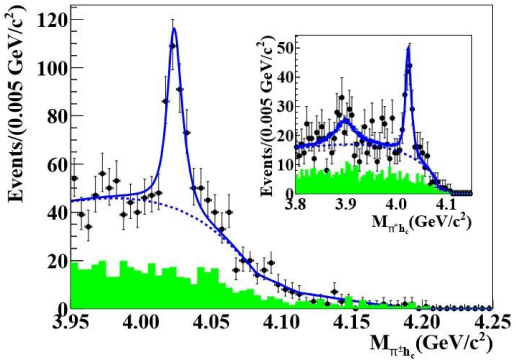
$e^+e^- \to \pi^0 (D\bar{D}^*)^0$

- Near DD* threshold
- Isospin triplet established
- $\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$
- J^P favors 1^+
- Decay mode:
  - Hidden charm,
  - Open charm,
  - **ccbar annihaltion?**

$\Gamma(Z_c^\pm \to \omega\pi^\pm) < 0.2\% \, \Gamma_{total}$

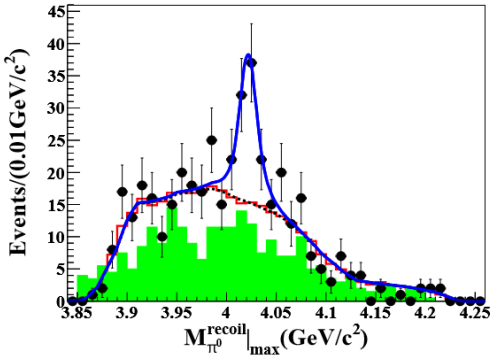
[Phys.Rev. D92 (2015) 032009]

PRL 111,242001 (2013)



$e^+e^- \to \pi^+ \pi^- h_c$

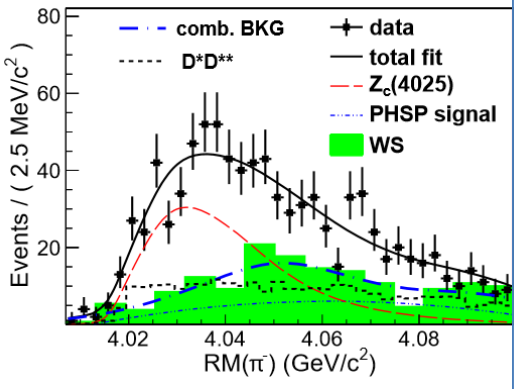
PRL 113,212002 (2014)



$e^+e^- \to \pi^0 \pi^0 h_c$

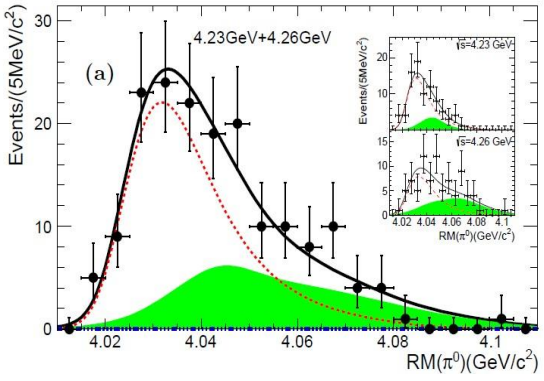
State	Mass(MeV)	Width(MeV)
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$

PRL 112,132001 (2013)



$e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$

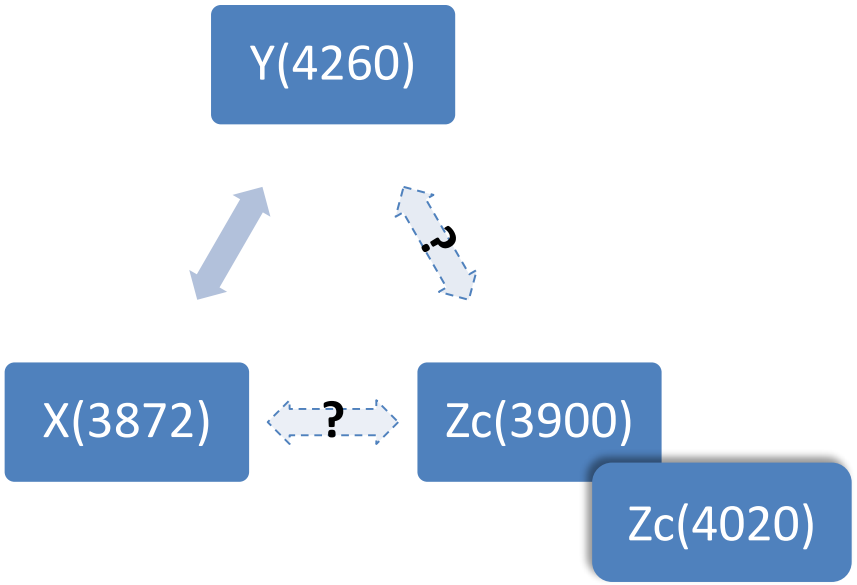
arXiv:1507.02404



$e^+e^- \to \pi^0 (D^*\bar{D}^*)^0$

- **Near D*D* threshold**
- **Iso-spin triplet is established**
- **The $Z_c(4020)$ and $Z_c(4025)$ are consistent within 1.5σ.**
- $$\frac{\Gamma(Z_c(4025) \to D^*\bar{D}^*)}{\Gamma(Z_c(4020) \to \pi h_c)} = 12 \pm 5$$

Emerging connections between XYZ?



Two isospin triplets observed
Building spectrum ?

What is the nature?

Molecule/Tetraquark/
Hybrid/Hadrocharmonium
/Threshold effects/…

Further experimental efforts needed:

Production/Decay mechanism;

Resonance parameters (any kinematic dependency?);

…

Prospects of hadron spectroscopy at BESIII

- **BESIII collected world's largest samples of J/ψ, ψ(2S), ψ(3770), Y(4260), … from e^+e^- production.**
- **It will continue to run 6 – 8 years.**

	BESIII	Goal
J/ψ	$1.3*10^9$ 21x BESII	$10*10^9$
ψ'	$0.6*10^9$ 24x CLEO-c	$3*10^9$
$\psi(3770)$	2.9 fb^{-1} 21x CLEO-c	20 fb^{-1}
Above open charm threshold	0.5 fb^{-1}@ψ(4040), 1.9 fb^{-1} @~4260, 0.5 fb^{-1}@4360, 1.0 fb^{-1} @4420, 0.5 fb^{-1} @4600	5-10 fb^{-1}
R scan and tau	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)	100 pb^{-1} (2015)	
ψ(4170)	3 fb^{-1} (next run)	

Prospects of hadron spectroscopy at BESIII

- **High statistics samples at BESIII provide opportunities for hadron spectroscopy of both light quarks and heavy quarks.**
  - **Systematic investigation of low lying glueballs and hybrids**
  - **Study excited nucleons and hyperons in charmonium decays**
  - **Explore XYZ states and their transitions**

Thank you