Recent results on spectroscopy at BESIII

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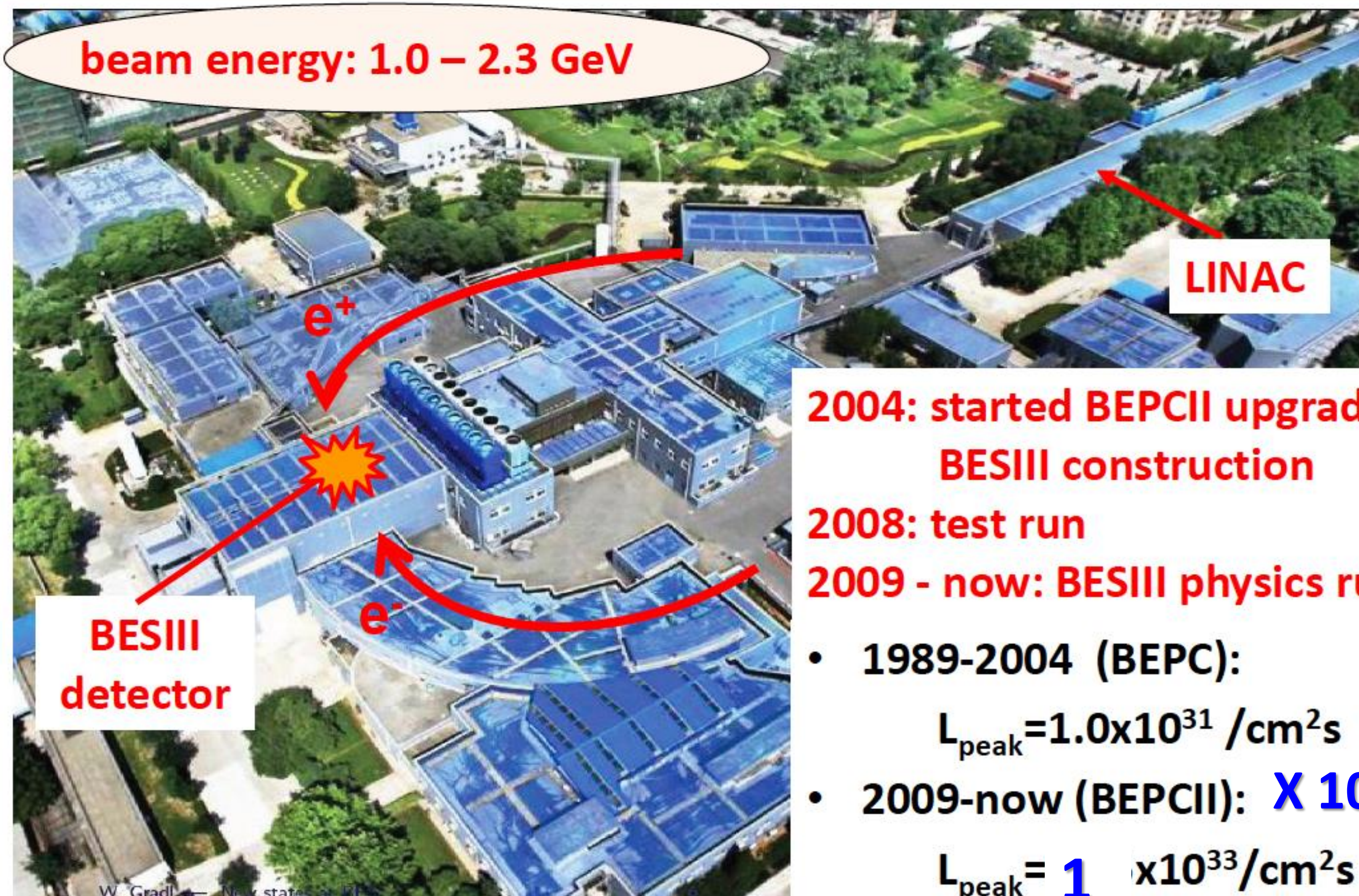
(for BESIII collaboration)

Hadronic Physics with Lepton and Hadron Beams, JLab

Outline

- Introduction
- Selected results from BESIII
  - Light meson 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):**
  $L_{peak}=1.0\text{x}10^{31}$ /cm²s
- **2009-now (BEPCII):** X 100
  $L_{peak}=$ 1 $\text{x}10^{33}$/cm²s

Physics at BESIII

Charmonium physics:
- spectroscopy
- transitions and decays

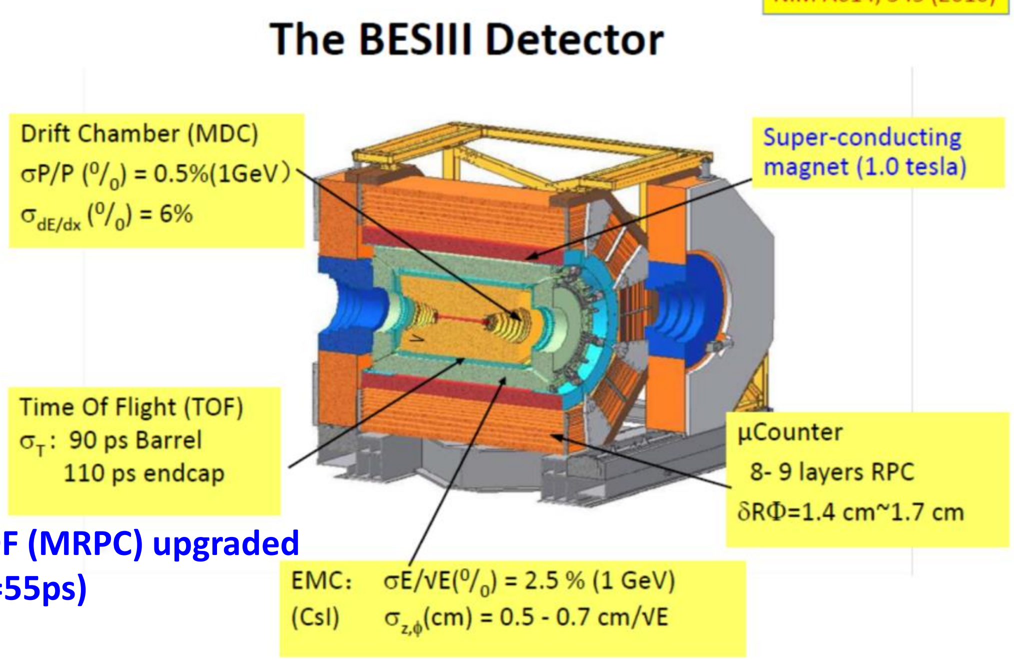
Light hadron physics:
- meson & baryon spectroscopy
- two-photon physics
- e.m. form factors of nucleon

Open Charm physics:
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CPV
- rare/forbidden decays

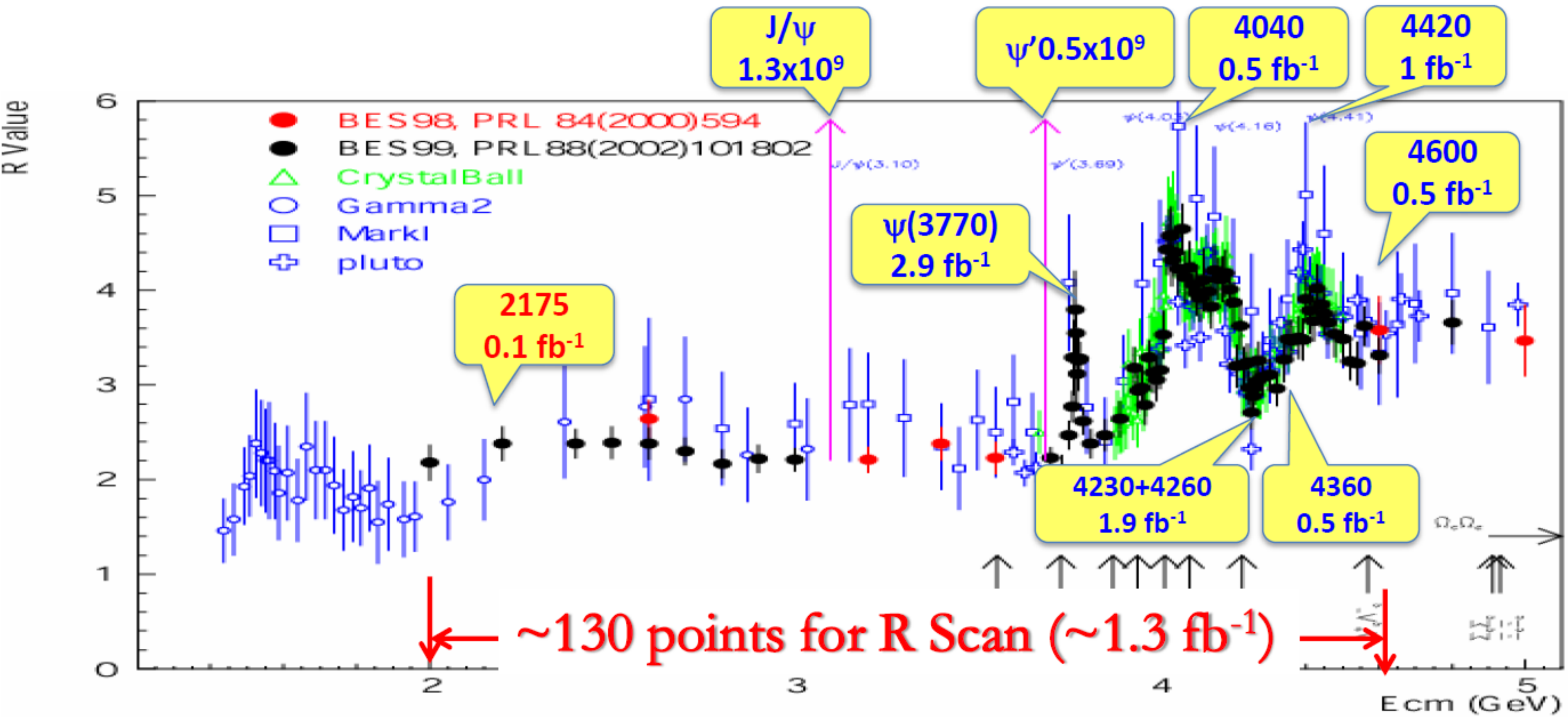
Tau physics:
- tau decays near threshold
- tau mass scan

...and many more.

NIM A614, 345 (2010)

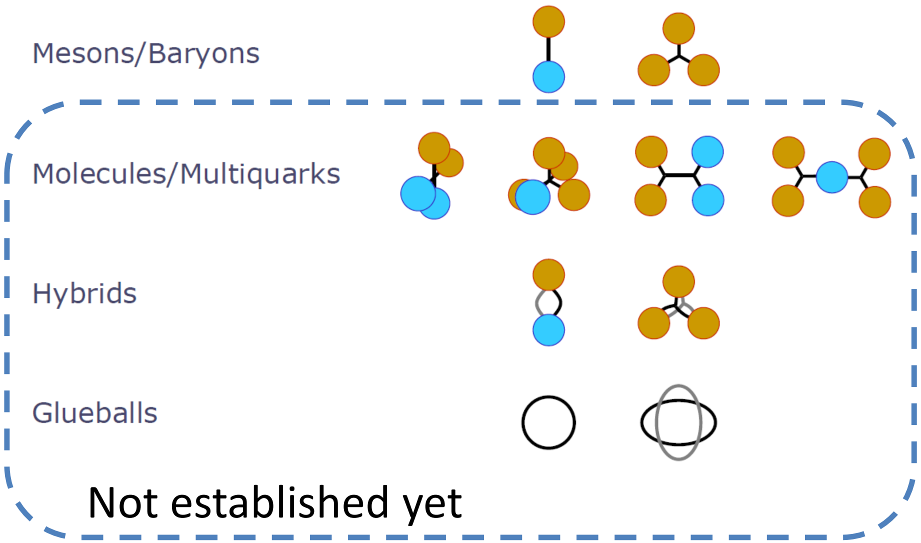


BESIII data samples



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

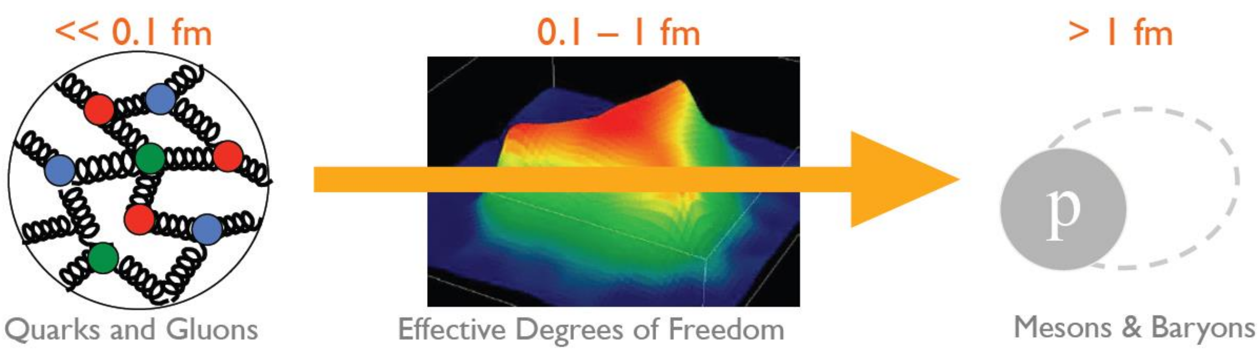
Hadron spectrum



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



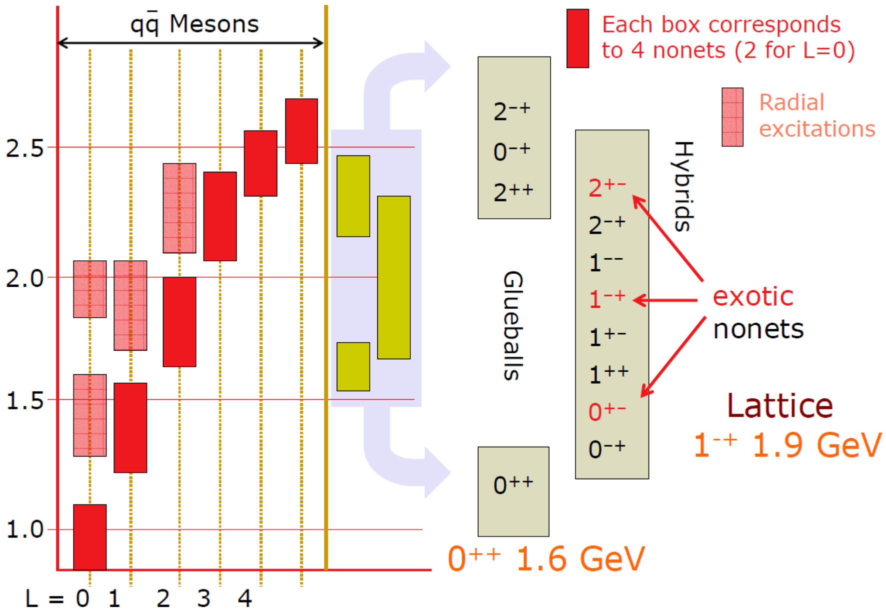
Light meson spectroscopy

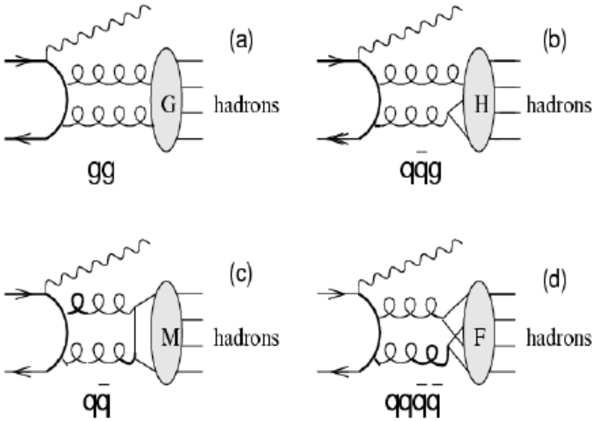
- X(ppbar) and X(1835)

- η (1405)
- PWA of J/ψ→γ φφ
- PWA of J/ψ→γ η η
- PWA of $J/\psi \rightarrow \gamma\pi^0\pi^0$

- PWA of $\chi_{c1} \rightarrow \eta\pi^+\pi^-$

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





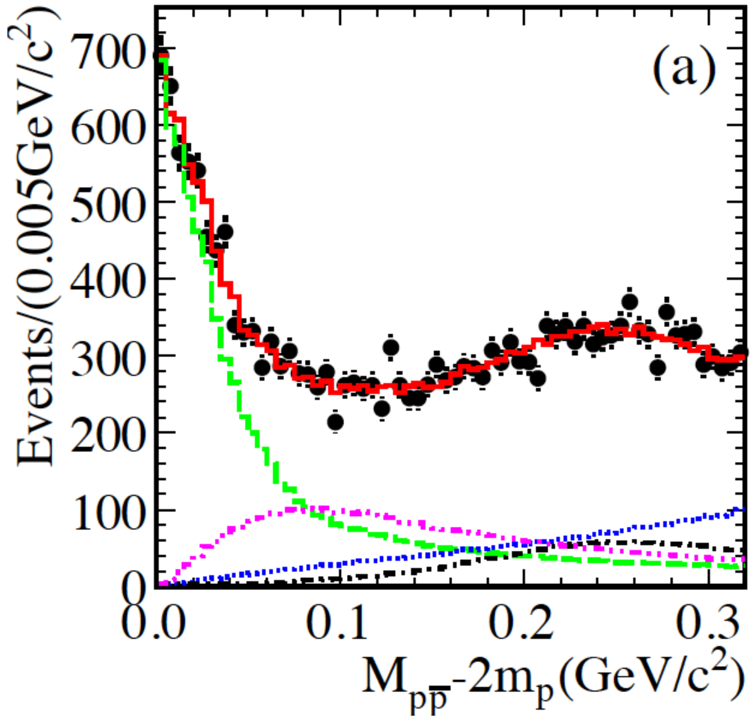
$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$$

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

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

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

Phys. Rev. Lett. 108, 112003 (2012)



- The fit with a BW and S-wave FSI (I=0) factor can well describe $p\bar{p}$ mass threshold structure.
- It is much better than that without FSI effect ($\Delta 2\ln L = 5, 7.1\sigma$)
- Different FSI models → Model dependent uncertainty

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))} = (5.08^{+0.71}_{-0.45}(stat)^{+0.67}_{-3.58}(syst) \pm 0.12(mod))\%$$

Spin parity, mass, width and branching ratio:

$J^{PC} = 0^{-+}, > 6.8\sigma$ *better than other* J^{PC} *assignments*, $M = 1832^{+19}_{-5}(stat)^{+18}_{-17}(sys) \pm 19(model) MeV/c^2$,

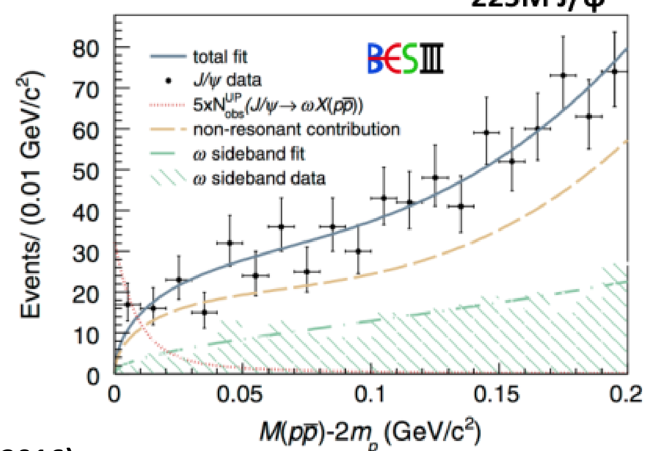
$\Gamma = 13 \pm 39(stat)^{+10}_{-13}(sys) \pm 4(model) MeV/c^2$, $\Gamma < 76\, MeV/c^2\ (90\%\ CL)$,

$$B(J/\psi \to \gamma X) B(X \to p\bar{p}) = \left(9.0^{+0.4}_{-1.1}(stat)^{+1.5}_{-5.0}(sys) \pm 2.3(model)\right) * 10^{-5}$$

In J/ψ hadronic decays

BESIII, Phys. Rev. D87, 112004 (2013)

225M J/ψ



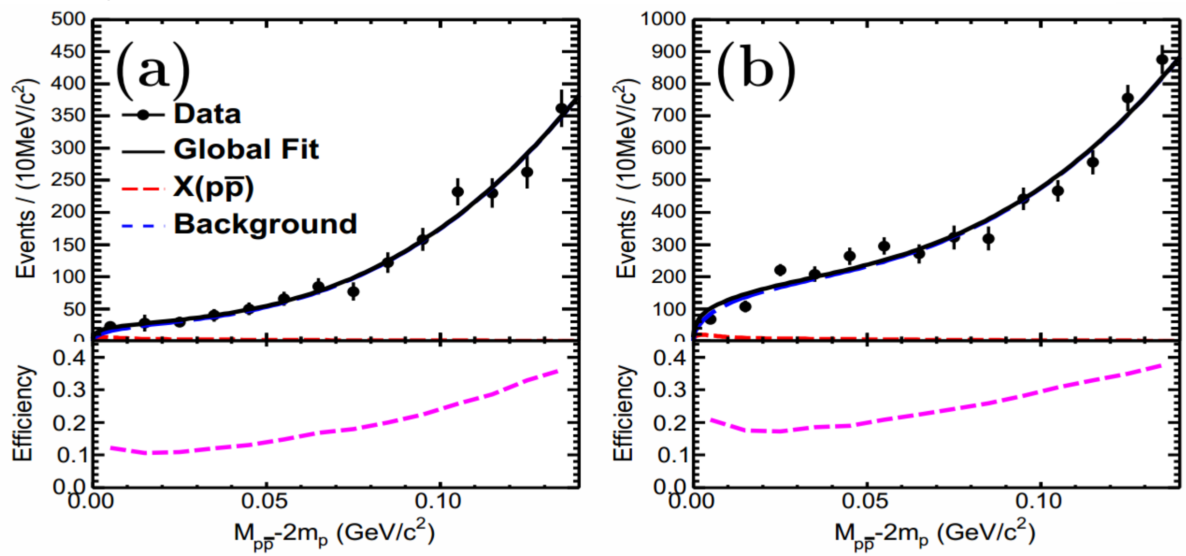
Study of J/ψ→ωpp̄ and J/ψ→Φpp̄ may shed further light on the nature of X(pp̄)

J/ψ→ωpp̄

B(J/ψ → ωX(pp̄) → ωpp̄) $<3.7\times10^{-6}$ (95% CL)

>10x suppressed compared to J/ψ →γX(pp̄)→γpp̄

BESIII Phys. Rev. D 93, 052010 (2016)



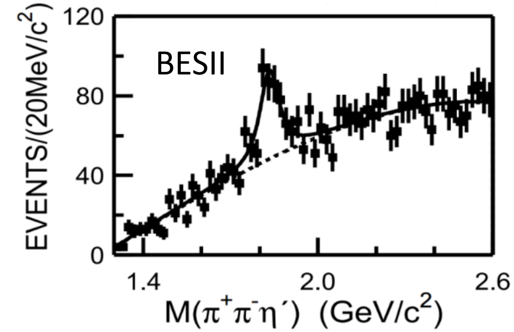
J/ψ→Φpp̄

B(J/ψ→ΦX(pp̄)→Φpp̄) $<2\times10^{-7}$ (90% CL)

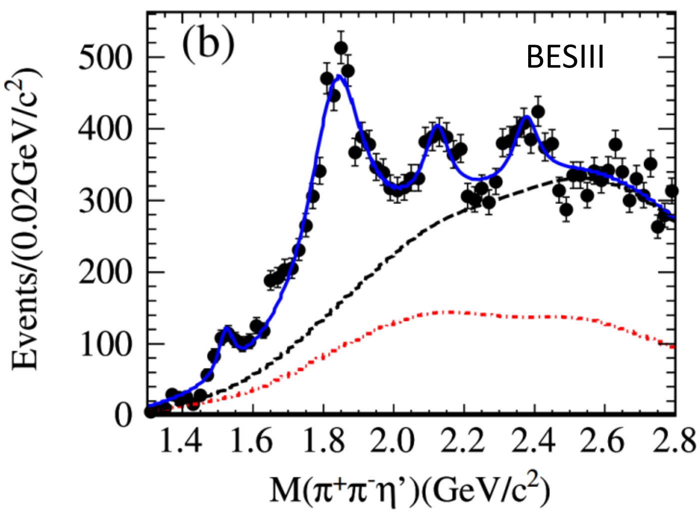
>100x suppressed compared to J/ψ → γX(pp̄)→γpp̄

X(1835)

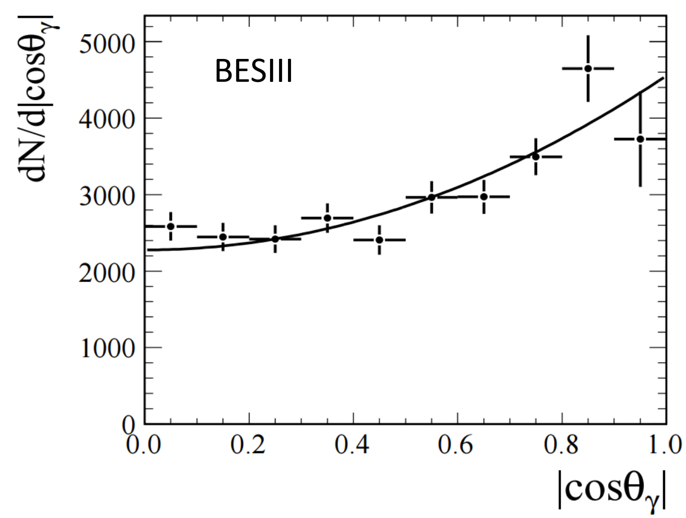
Phys. Rev. Lett. 95, 262001 (2005)



- **Discovered by BESII in $J/\psi \to \gamma\eta'\pi^+\pi^-$**
- **Confirmed by BESIII in $J/\psi \to \gamma\eta'\pi^+\pi^-$**
  - ✓ $\mathrm{M} = 1836.5 \pm 3.0^{+5.6}_{-2.1}\ \mathrm{MeV}/c^2$
  - ✓ $\Gamma = 190 \pm 9^{+38}_{-36}\ \mathrm{MeV}/c^2$
  - ✓ **Angular distribution is consistent with 0^-**

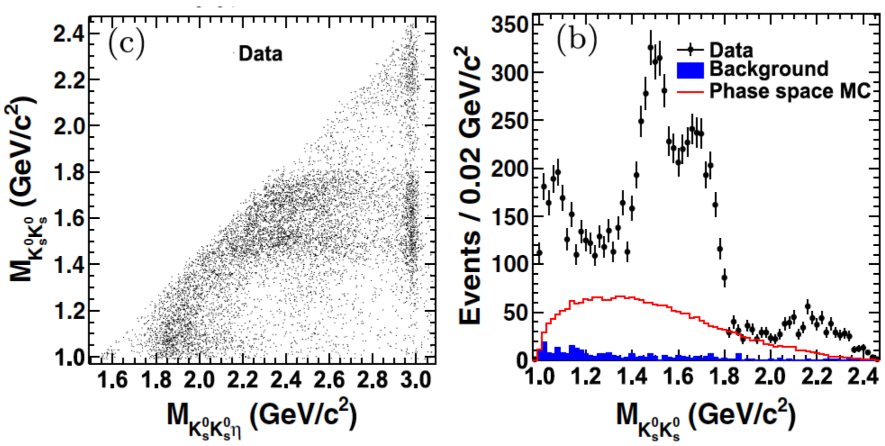


Phys. Rev. Lett. 106, 072002 (2011)

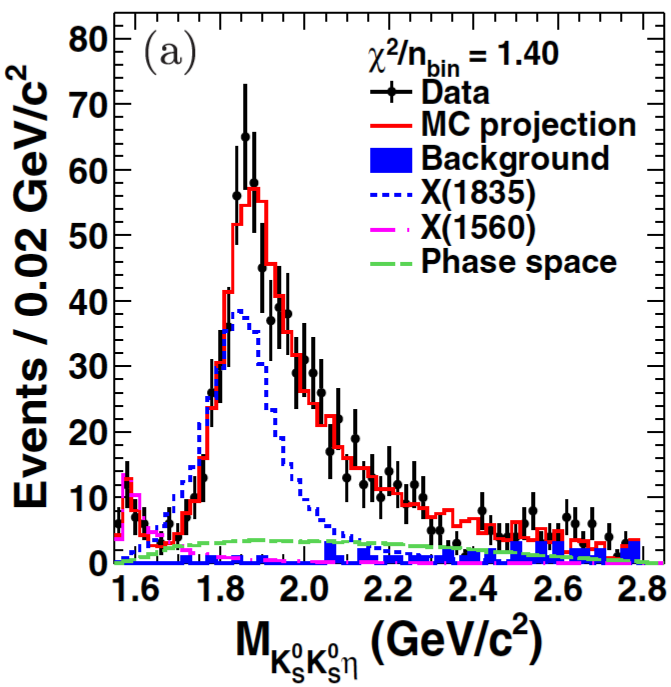


Observation and Spin-Parity Determination of the $X(1835)$ in $J/\psi \to \gamma K_S^0 K_S^0 \eta$

Phys.Rev.Lett. 115 091803(2015)



The structure around 1.85 GeV/c^2 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/c^2

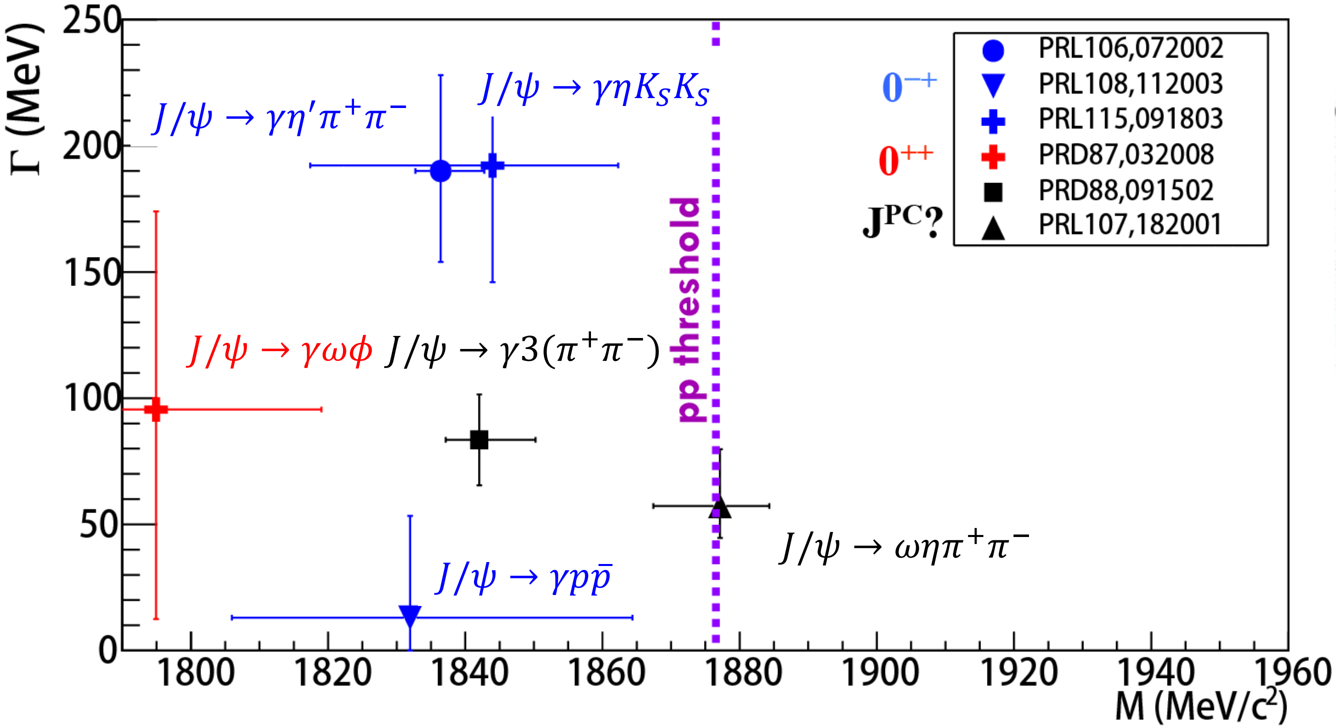
- **X(1835)→$K_SK_S\eta$ (the K_SK_S system is dominantly produced through the $f_0(980)$)**

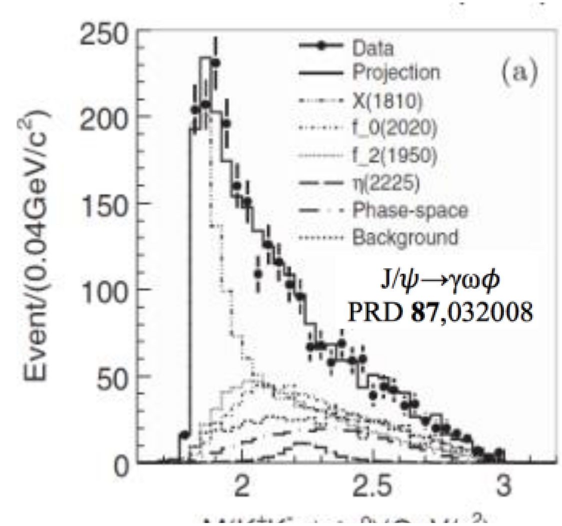
  $J^{PC}=0^{-+}$, (> 12.9 σ)

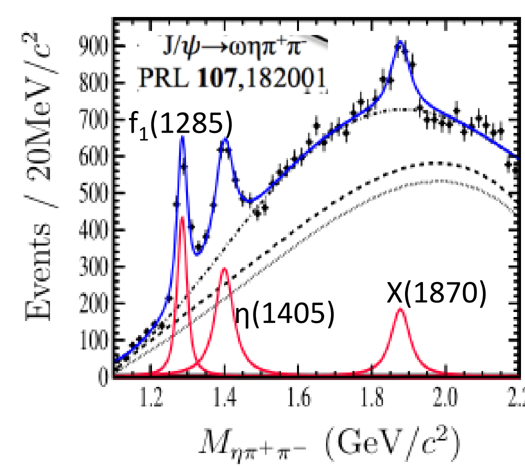
M=1844$\pm$9(stat)$^{+16}_{-25}$(syst) MeV/c^2, $\Gamma=192^{+20}_{-17}{}^{+62}_{-43}$ MeV,
Consistent with X(1835) observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$
$B(J/\psi\to\gamma X(1835))*B(X(1835)\to K_sK_s\eta)=(3.31^{+0.33}_{-0.30}{}^{+1.96}_{-1.29})*10^{-5}$

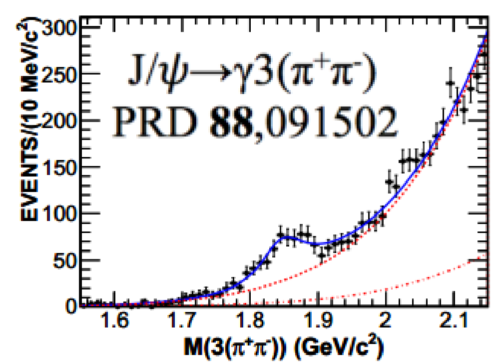
- **X(1560) → $f_0(980)\eta$: $J^{PC}=0^{-+}$, (> 8.9 σ)**

M=1565$\pm$8$^{+0}_{-63}$ MeV/c^2, $\Gamma=45^{+14}_{-13}{}^{+21}_{-28}$ MeV
consistent with those of $\eta(1405)$ / $\eta(1475)$ within 2.0 σ





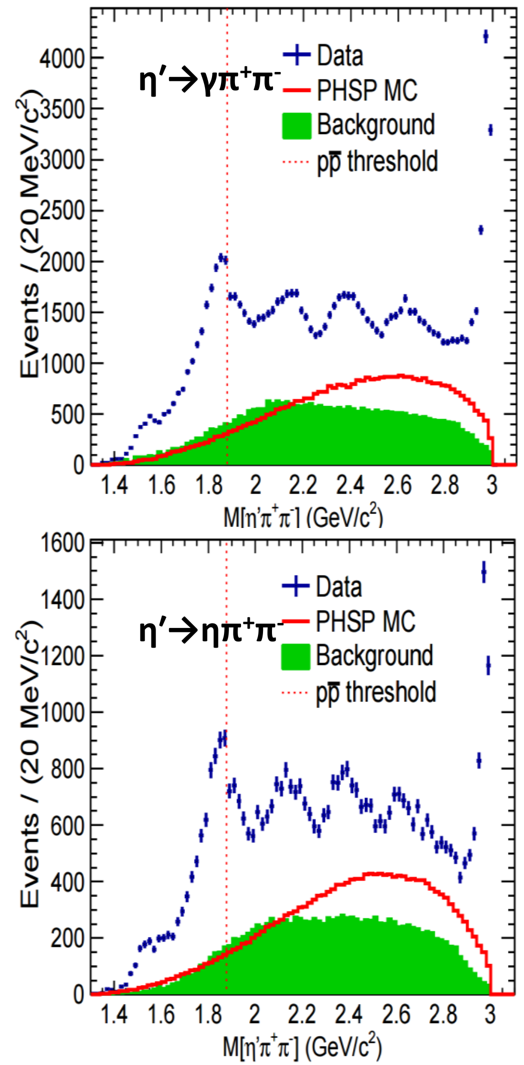




- **Any relations?**
- **What is the role of the ppbar threshold (and other thresholds)?**
- **Patterns in the production and decay modes**

New: connection is emerging

PRL 117, 042002 (2016)

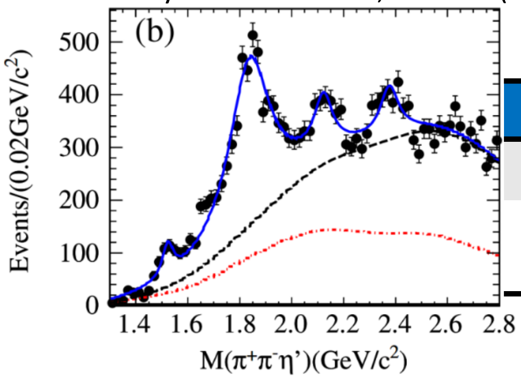


- **Use 1.09×10^{9} J/ψ events collected by BESIII in 2012**
- **Two decay modes of η′**
  - **$\eta'\to\gamma\pi^+\pi^-$**
  - **$\eta'\to\eta\pi^+\pi^-$, $\eta\to\gamma\gamma$**
- **Clear peaks of X(1835), X(2120), X(2370), η_c, and a structure near 2.6 GeV$/c^2$**
- **A significant distortion of the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold**

Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold: connection between X(1835) and X($p\bar{p}$)

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

Phys. Rev. Lett. 106, 072002 (2011)

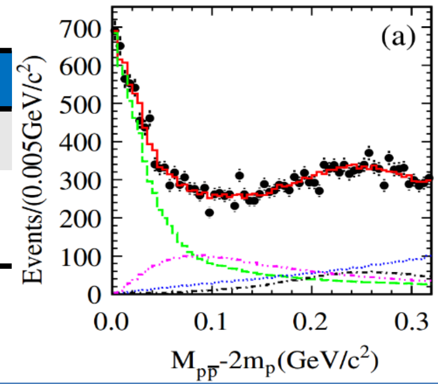


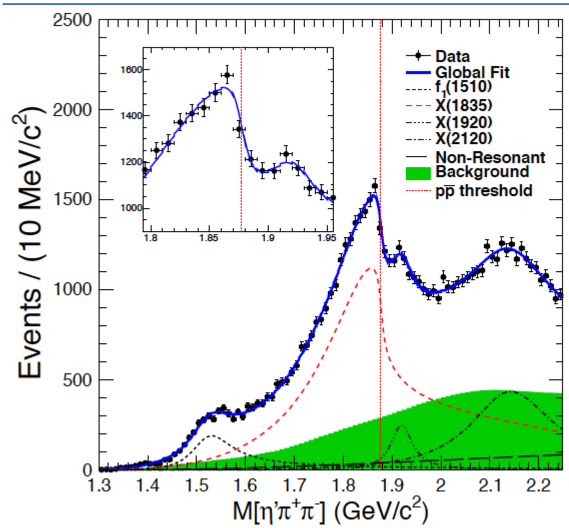
X(1835) $J^{PC}=0^{-+}$
$M = 1844 \pm 9^{+16}_{-25}$ MeV/c^2
$\Gamma = 192^{+20+62}_{-17-43}$ MeV/c^2

X($p\bar{p}$) observed in $J/\psi \to \gamma p\bar{p}$

PRL 108, 112003 (2012)
PRL 115, 091803 (2015)

X($p\bar{p}$) $J^{PC}=0^{-+}$
$M = 1832^{+19+18}_{-5-17} \pm 19$ MeV/c^2
$\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c^2 @ 90% C.L.)



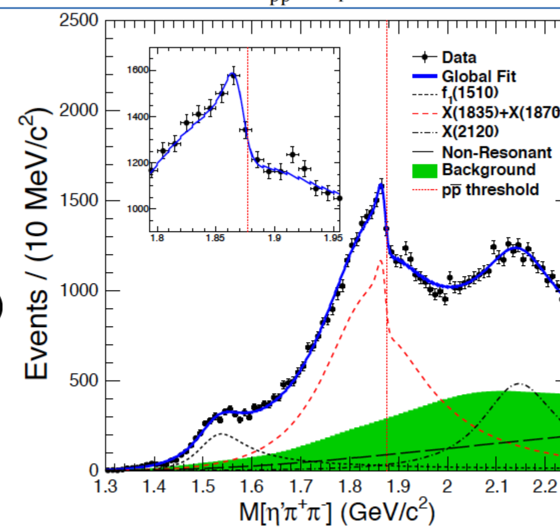


Connection is emerging

PRL 117, 042002 (2016)

Model 1:
Flatte lineshape with strong coupling to $p\bar{p}$ and one additional, narrow Breit-Wigner at ~1920 MeV/c^2

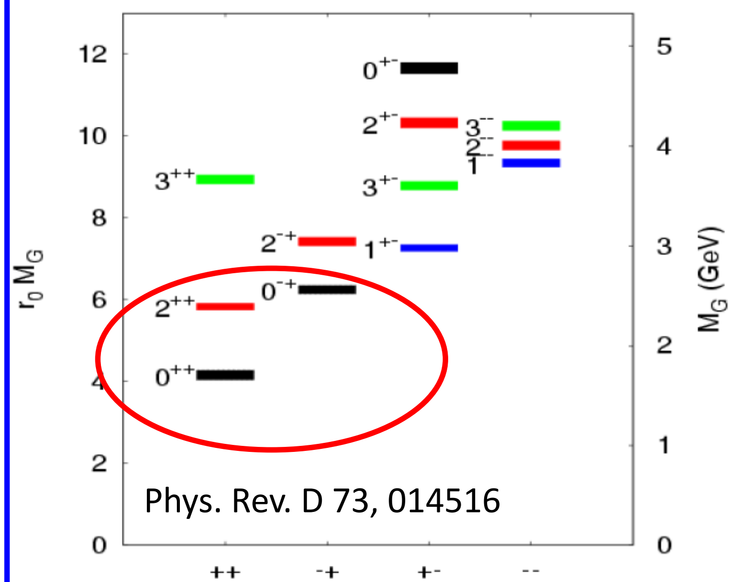
Model 2:
Coherent sum of X(1835) Breit-Wigner and one additional, narrow Breit-Wigner at ~1870 MeV/c^2



The anomalous line shape can be modeled two models with equally good fit quality.

- Suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold
- Support the existence of a $p\bar{p}$ molecule-like state or bound state

Glueballs from Quenched Lattice calculations



Phys. Rev. Lett. 110, 021601

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

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

Phys. Rev. Lett. 111, 091601

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

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

Low lying glueballs have ordinary quantum number
0^{++}(1.5~1.7 GeV), 2^{++}(2.3~2.4 GeV),
0^{-+}(2.3~2.6 GeV)
mixing with qqbar mesons

Large Br in J/ψ radiative decays

Systematic exp. studies are required:

→Over-population
Map out the resonances

→Production patterns
$J/\psi \to \gamma\ /\omega/\phi$ + X
Other experiments: $\gamma\gamma$ processes from Belle2, …

→Decay patterns
"flavor blind", "chiral suppression", …

LQCD and QCD inspired models

Isospin-violating decay of η(1405) → $f_0(980)\pi$

PRL 108, 182001

The long standing E-ι puzzle:

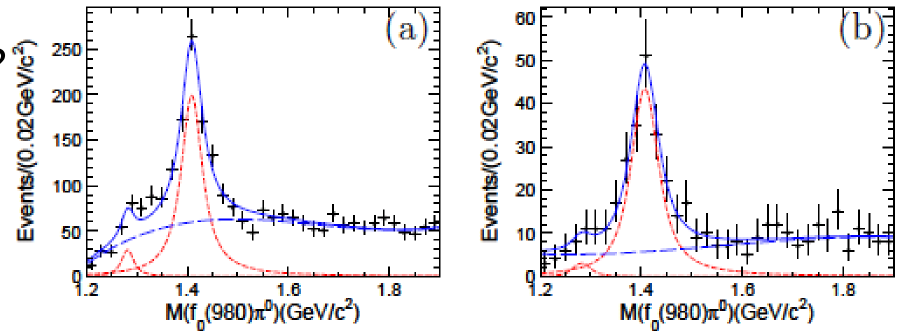
η(1405)→$a_0\pi$, η(1475)→K* $\bar{K}$, overpopulation?

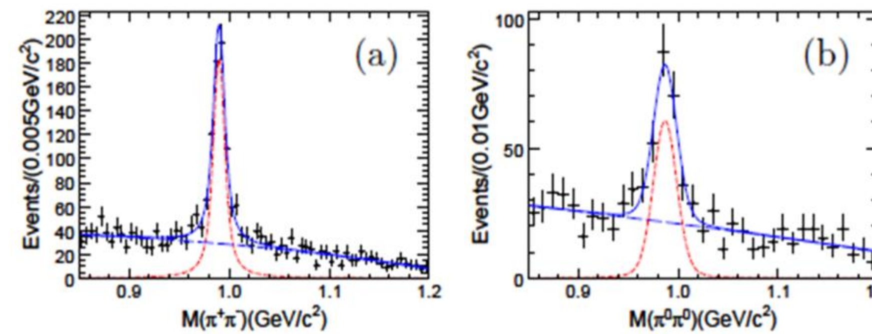
Anomalously large isospin violation:

$$\frac{Br(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\eta(1405) \to a_0^0(980)\pi^0 \to \eta\pi^0\pi^0)} \cong (17.9 \pm 4.2)\%$$

Much larger than a_0-f_0 mixing (PRD 83 032003)

$$\xi_{af} = \frac{Br(\chi_{c1} \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to a_0(980)\pi^0 \to \eta\pi^0\pi^0)} < 1\% (90\%\ C.L.)$$

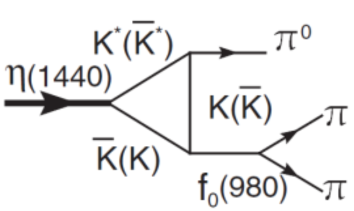




f_0(980) is extremely narrow: Γ ≅ 10 MeV.

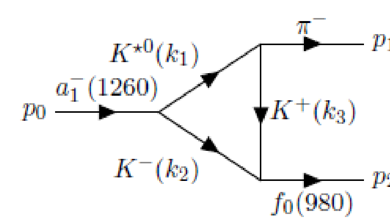
PDG: Γ(f0(980)) ≅ 40~100 MeV.

Triangle singularity is proposed (PRL 108 081803)

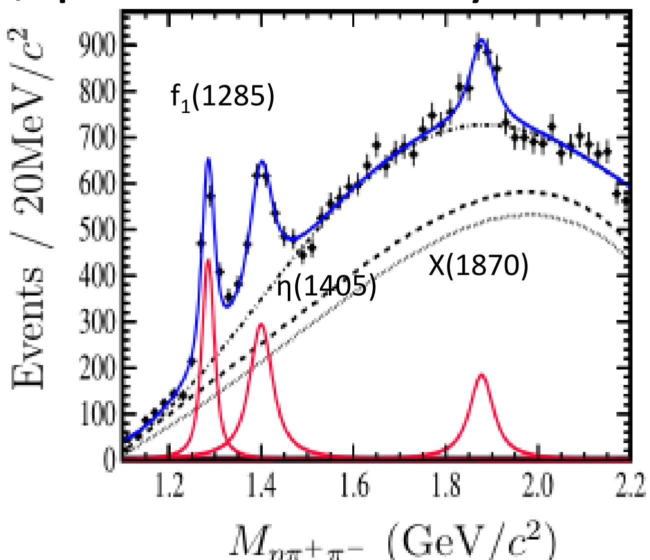


An important dynamical effect of threshold

a_1(1420)
PRD 89 054038



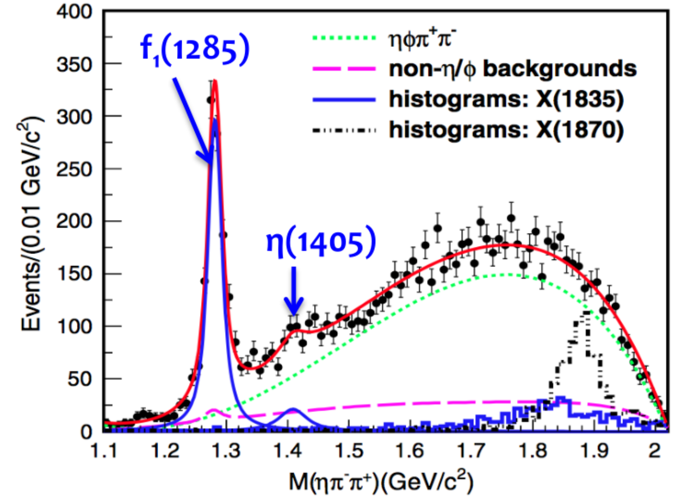
In J/ψ hadronic decays



J/ψ→ωηππ
PRL 107 182001

J/ψ→φηππ

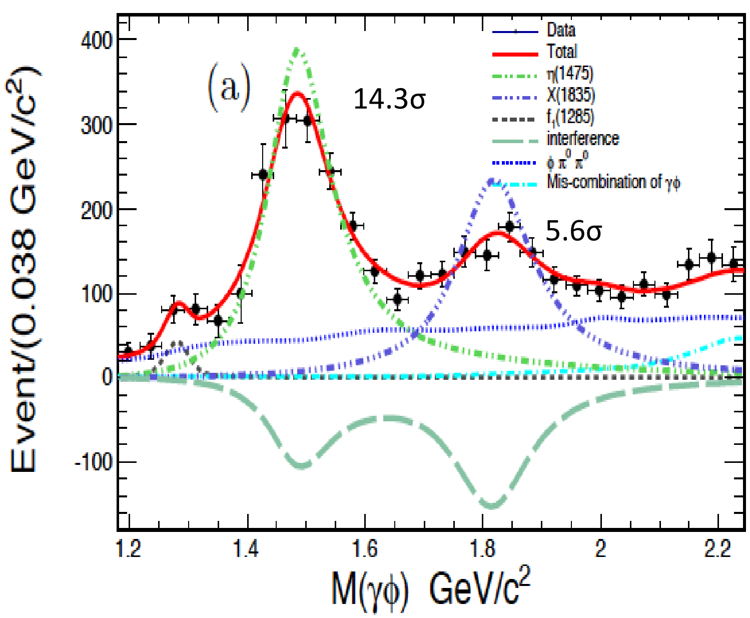
PRD 91,052017 (2015)

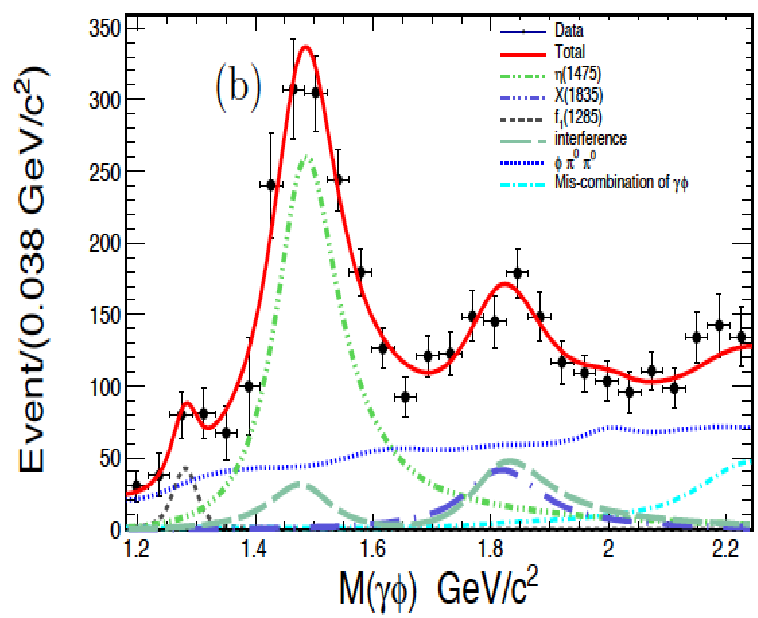


In J/ψ double radiative decays

$J/\psi \to \gamma\gamma\phi$

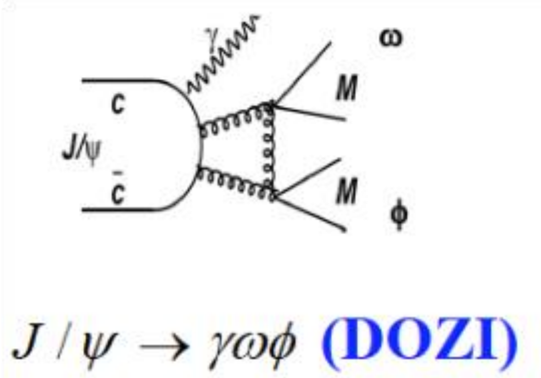
[preliminary]

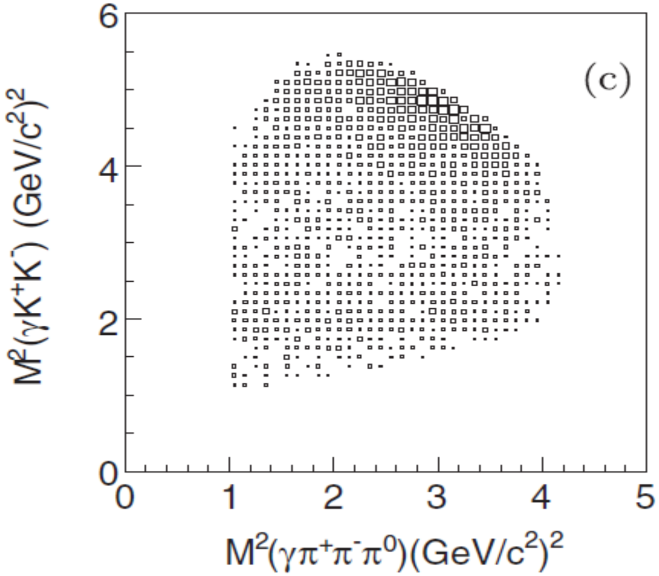


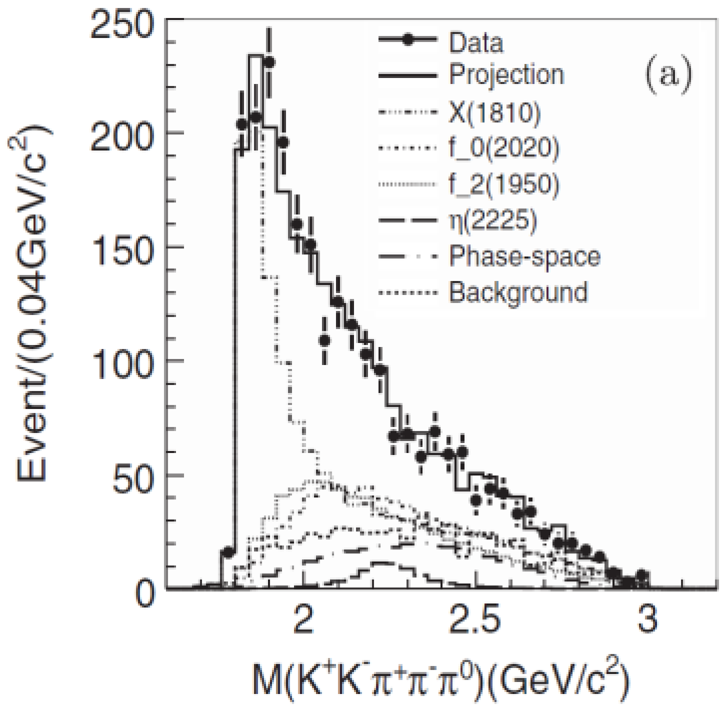


PWA of $J/\psi \to \gamma\omega\phi$

PRD 87, 032008(2013)







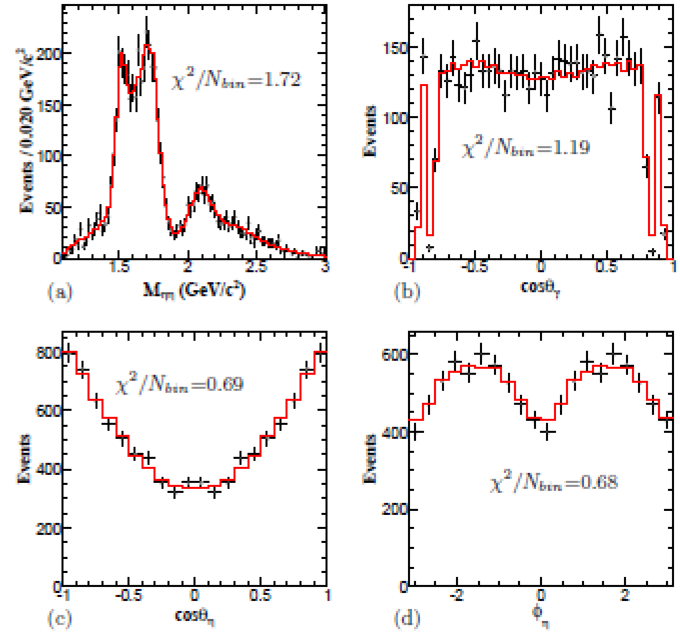
- Confirmed the enhancement observed at BESII

M= $1795\pm7^{+13}_{-5}\pm19$(model) MeV/c², $\Gamma = 95\pm10^{+21}_{-34}\pm75$(model) MeV

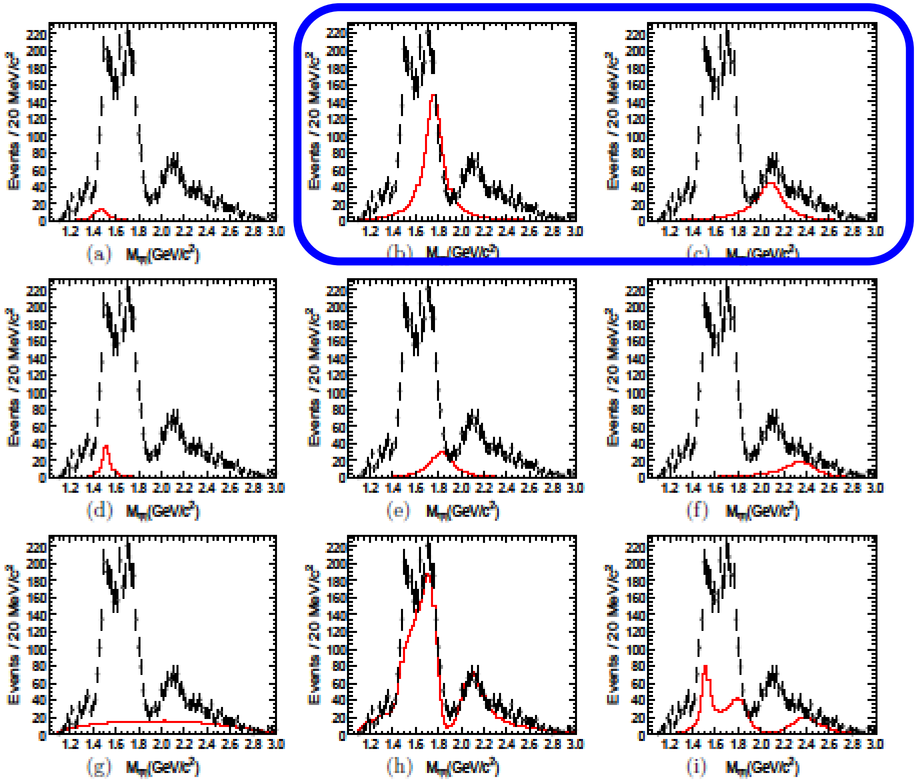
Spin-parity is determined to be 0^+

- the same as $f_0(1710)/f_0(1790)$, or a new state ?

PWA of $J/\psi \rightarrow \gamma\eta\eta$
(Phys. Rev. D87 092009 (2013))



Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

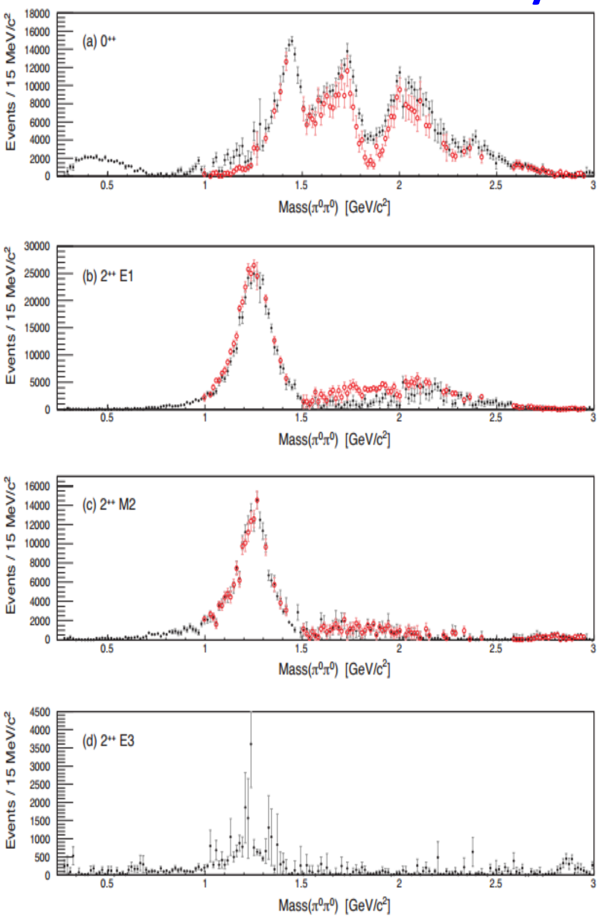


- **Br of $f_0(1710)$ and $f_0(2100)$ are ~10x larger than that of $f_0(1500)$**
  - **Possible large overlap with LQCD predictions of 0+ Glueball: PRL 110 021601 (2013)**

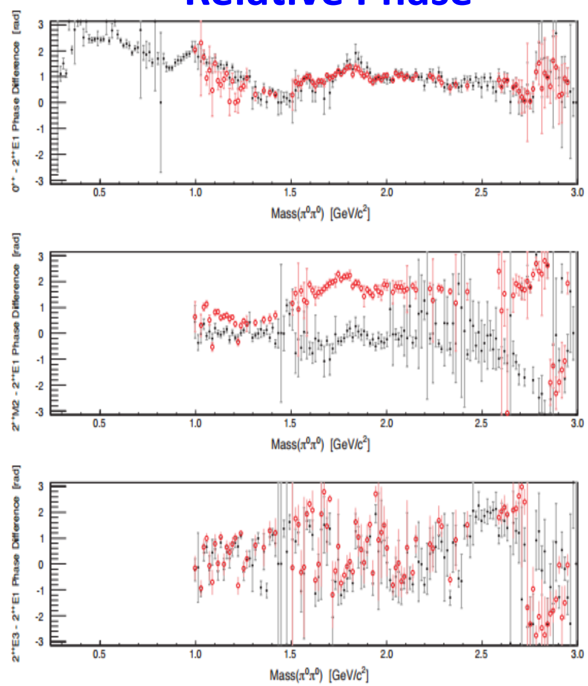
- **Strong production of $f_2(2340)$**

Model Independent PWA of $J/\psi \rightarrow \gamma\pi^0\pi^0$

Extracted Intensity



Relative Phase



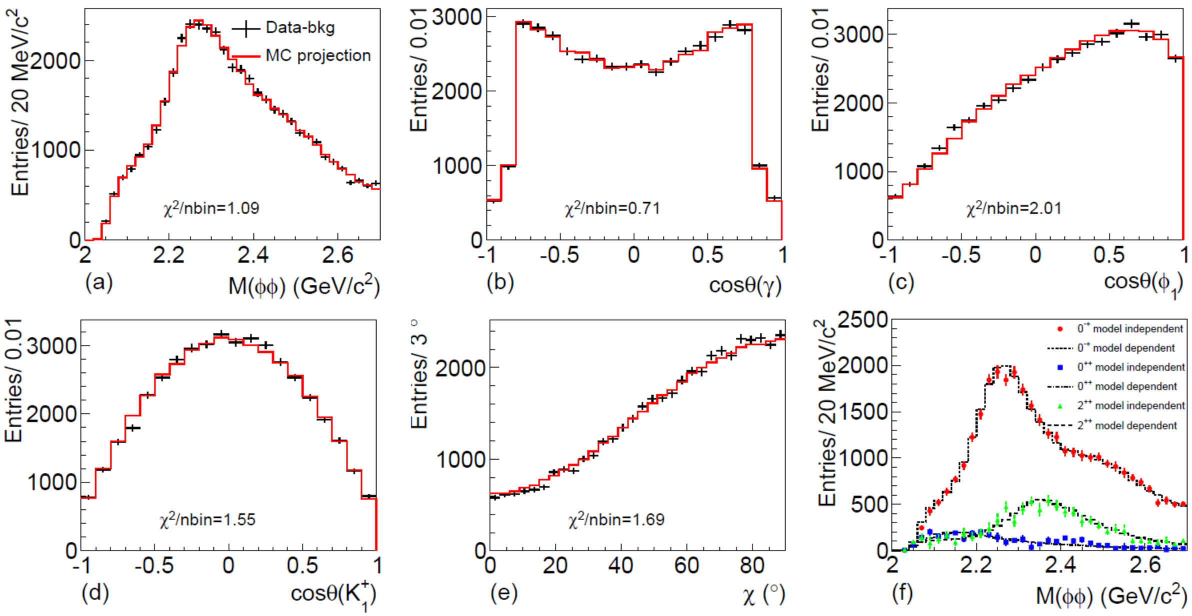
- Solution 1
- Solution 2

Phys. Rev. D 92, 052003 (2015)

- ✓ Extract amplitudes in each $M(\pi^0\pi^0)$ mass bin
- ✓ Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/c^2
- ✓ Multi-solution problem in MIPWA is usually unavoidable.
- ✓ Model Dependent PWA of global PWA fit is still needed to extract resonance parameters

Partial Wave Analysis of $J/\psi \to \gamma\phi\phi$ [PR D93 112011]

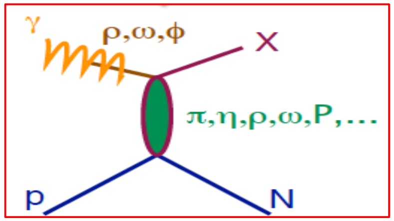
Besides η(2225), very little was known in the sector of pseudoscalar above 2 GeV. The new experimental results are helpful for mapping out the pseudoscalar excitations and searching for 0^{-+} glueball

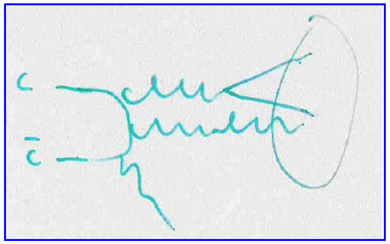


Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.(×10^{-4})	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	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

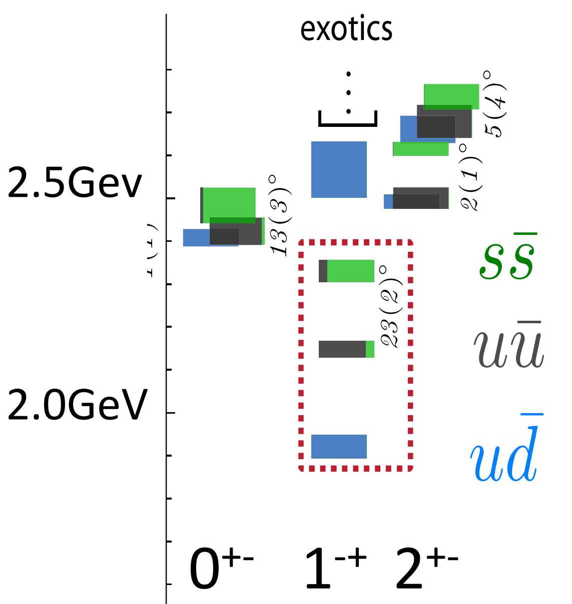
- **Dominant contribution from pseudoscalars**
  - **η(2225) is confirmed;**
  - **η(2100) and X(2500) are observed with large significance.**
- **The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in $\pi^- p$ reactions are also observed with a strong production of $f_2(2340)$.**
- **Model-dependent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

Hybrids

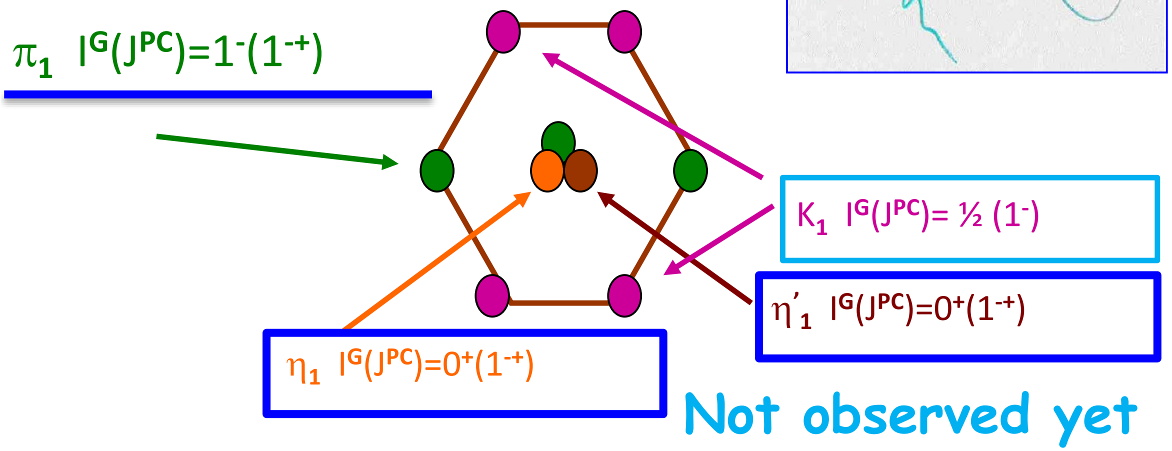




Lattice QCD Predictions:



PRD 83 111502 (2011)

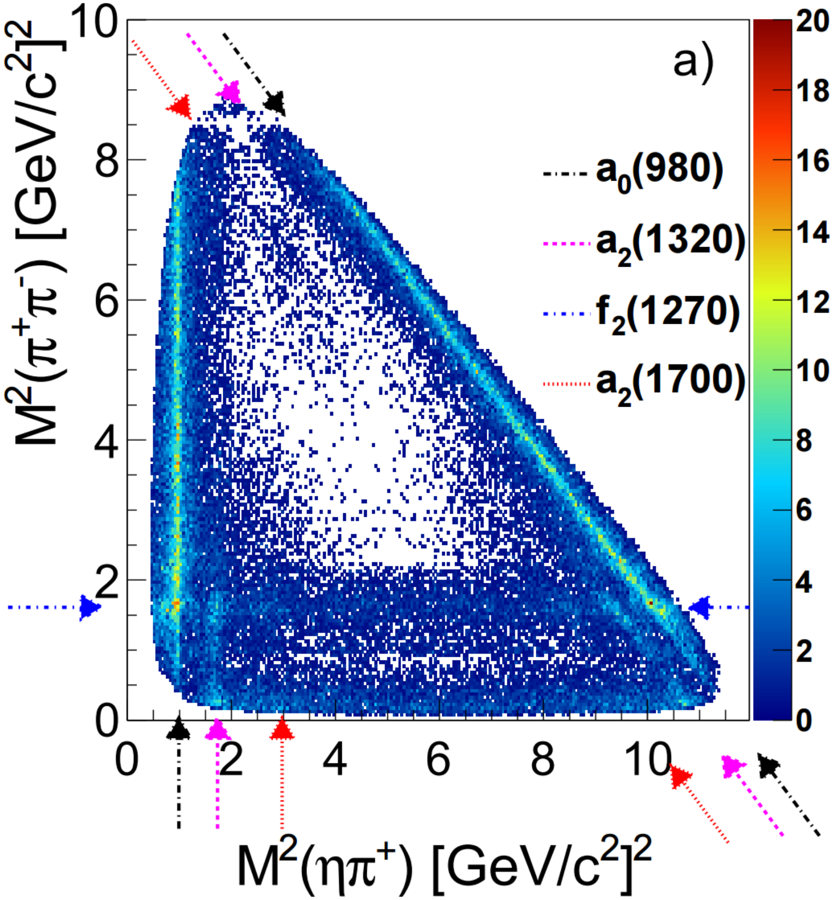


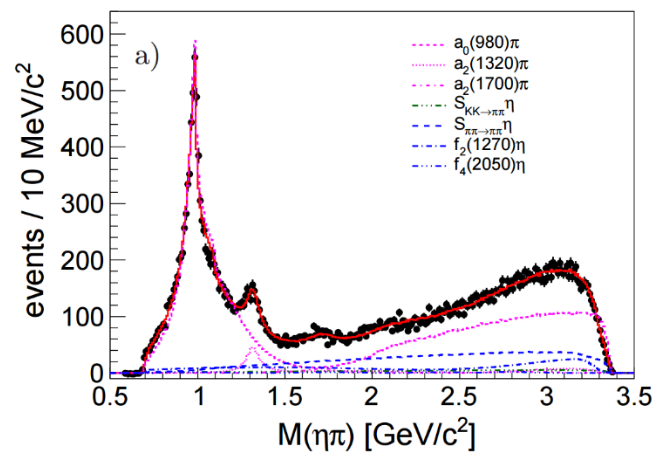
	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	80 – 170	120	$b_1\pi^\dagger$, $\rho\pi^\dagger$, $f_1\pi^\dagger$, $a_1\eta$, $\eta'\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$, 5π, $\eta 3\pi^\dagger$, $\eta'\pi^\dagger$
η_1	2100	1^{-+}	60 – 160	110	$a_1\pi$, $f_1\eta^\dagger$, $\pi(1300)\pi$	4π, $\eta 4\pi$, $\eta\eta\pi\pi^\dagger$
η'_1	2300	1^{-+}	100 – 220	170	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$, $KK\omega^\dagger$
b_0	2400	0^{+-}	250 – 430	670	$\pi(1300)\pi$, $h_1\pi$	4π
h_0	2400	0^{+-}	60 – 260	90	$b_1\pi^\dagger$, $h_1\eta$, $K(1460)K$	$\omega\pi\pi^\dagger$, $\eta 3\pi$, $KK\pi\pi$
h'_0	2500	0^{+-}	260 – 490	430	$K(1460)K$, $K_1(1270)K^\dagger$, $h_1\eta$	$KK\pi\pi^\dagger$, $\eta 3\pi$
b_2	2500	2^{+-}	10	250	$a_2\pi^\dagger$, $a_1\pi$, $h_1\pi$	4π, $\eta\pi\pi^\dagger$
h_2	2500	2^{+-}	10	170	$b_1\pi^\dagger$, $\rho\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$
h'_2	2600	2^{+-}	10 – 20	80	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$

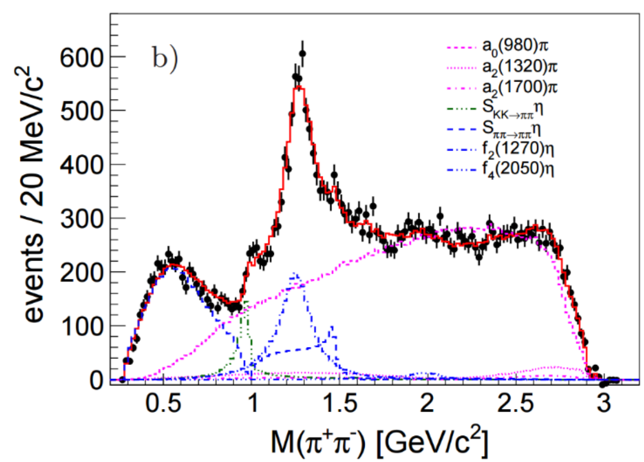
Complementary studies at BESIII

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

Phys. Rev. D 95, 032002 (2017)

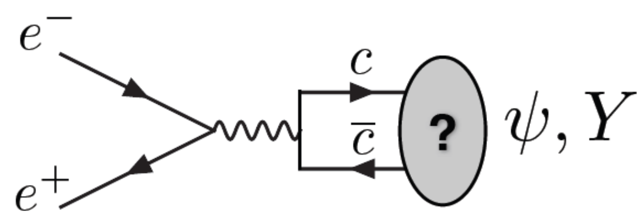






- Clear evidence for $a_2(1700)$ in χ_{c1} decays.
- First measurement of $g'_{\eta'\pi} \neq 0$ using $a_0(980) \to \eta\pi$ line shape.
- Measured upper limits for $\pi_1(1^{-+})$ in 1.4 – 2.0 GeV/c^2 region.

Charmonium spectroscopy

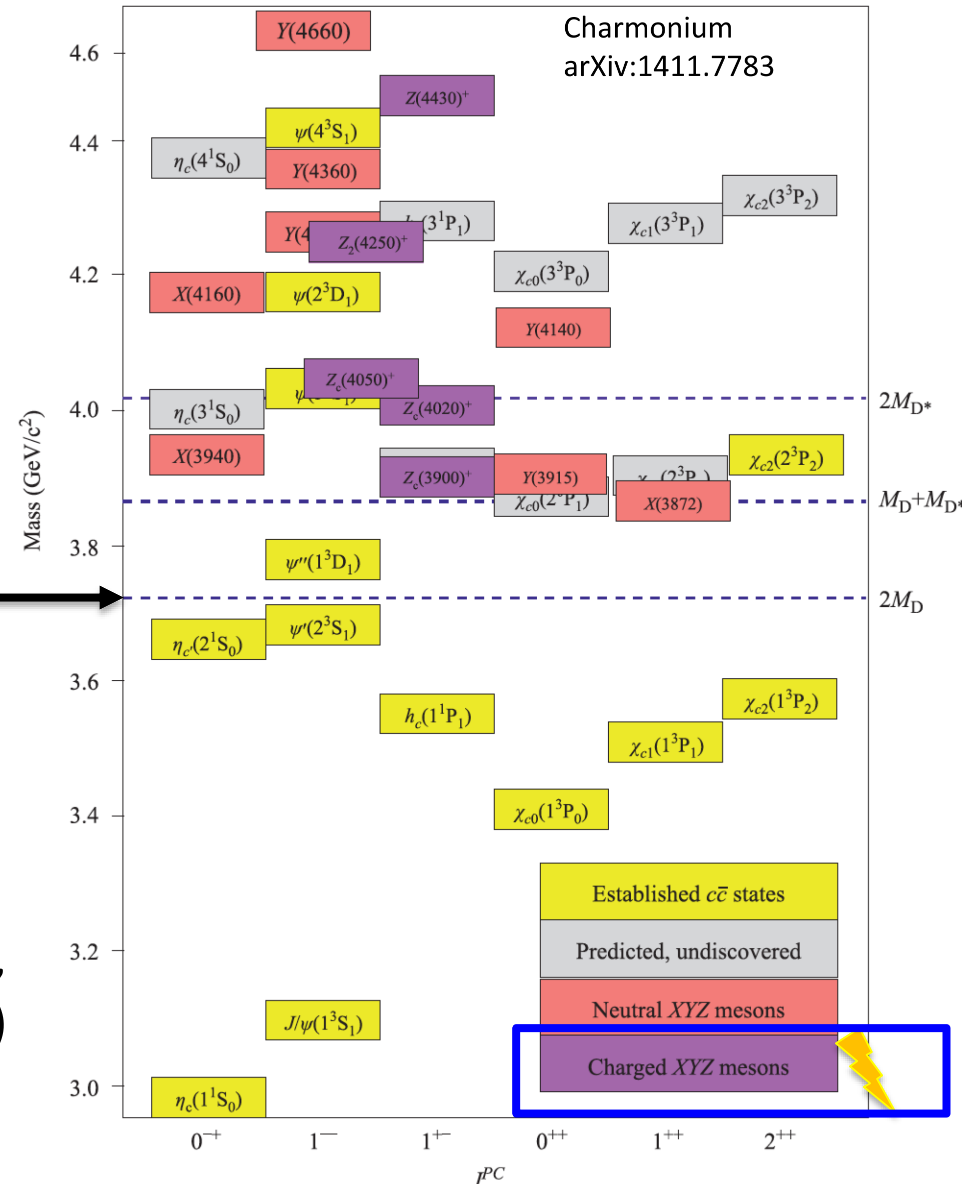


XYZ states:

Cannot fit in the spectrum of conventional heavy quarkonia

Additional degree of freedom from light quarks and gluons?

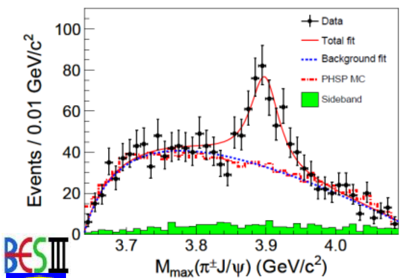
Open charm threshold



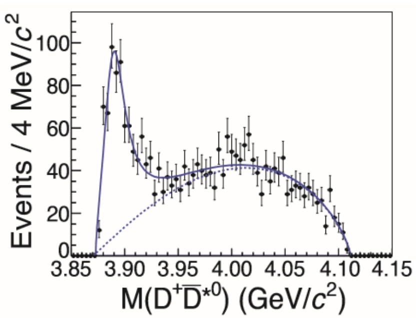
c- and b-quark are heavy
Non-relativistic QM applies

NRQCD approach is a spectacular success, validated by the consistency between $(c\bar{c})$ and $(b\bar{b})$

Observations of Z_c

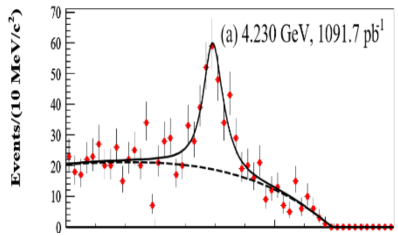


$e^+e^- \to \pi^+ \pi^- J/\psi$

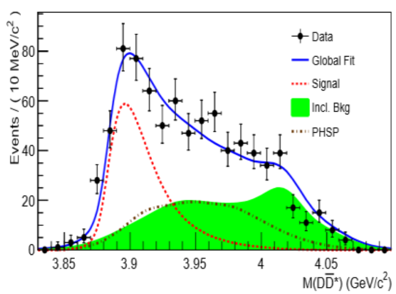


$e^+e^- \to \pi^+ (D\bar{D}^*)^-$

$Z_c(3900)^{\pm}$?

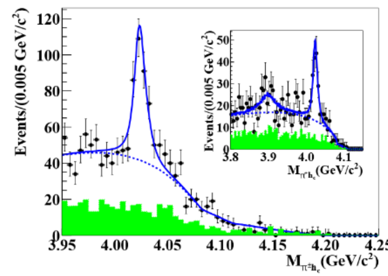


$e^+e^- \to \pi^0 \pi^0 J/\psi$

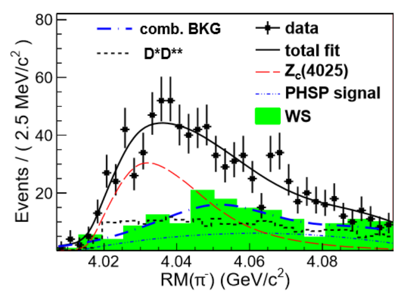


$e^+e^- \to \pi^0 (D\bar{D}^*)^0$

$Z_c(3900)^0$?

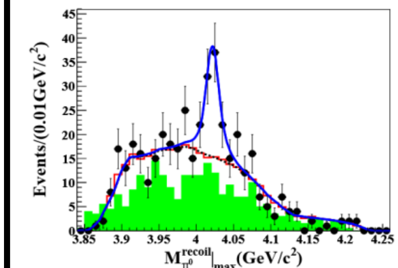


$e^+e^- \to \pi^+ \pi^- h_c$

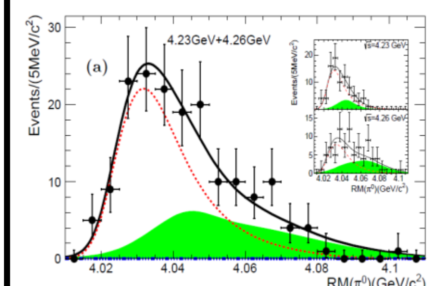


$e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$

$Z_c(4020)^{\pm}$?



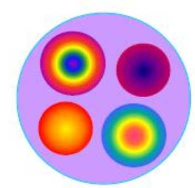
$e^+e^- \to \pi^0 \pi^0 h_c$



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

$Z_c(4020)^0$?

Tetraquark? Hadroquarkonium?
Molecule? Threshold effect?



Summary of the Z_c at BESIII

$Z_c^{\pm}(3900)$	$Z_c^{\pm}(4020)$
$e^+e^- \to \pi^+\pi^- J/\psi$ M=3899.0±3.6±4.9MeV Γ = 46±10±20 MeV	$e^+e^- \to \pi^+\pi^- h_c$ M= 4022.9±0.8±2.7MeV Γ = 7.9±2.7±2.6 MeV
Z_c^0 (3900)	**$Z_c^0(4020)$**
$e^+e^- \to \pi^0\pi^0 J/\psi$ M=3894.8±2.3 MeV Γ =29.6±8.2 MeV	$e^+e^- \to \pi^0\pi^0 h_c$ M=4023.9±2.2±3.8 MeV Γ Fixed at $Z_c^{\pm}(4020)$
$Z_c^{\pm}(3885)$	**$Z_c^{\pm}(4025)$**
$e^+e^- \to \pi(D\bar{D}^*)^{\pm}$ M=3882.2±1.1±1.5 MeV Γ =26.5±1.7±2.1 MeV	$e^+e^- \to \pi(D^*\bar{D}^*)^{\pm}$ M= 4026.3±2.6±3.7 MeV Γ = 24.8±5.6±7.7 MeV
$Z_c^0(3885)$	**$Z_c^0(4025)$**
$e^+e^- \to \pi^0(D\bar{D}^*)^0$ M=3885.7±5.7±8.4 MeV Γ = 35±12±15 MeV	$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$ M= 4025.5±4.7±3.1 MeV Γ = 23.0±6.0 ±1.0MeV

DD* threshold (3875 MeV)

D*D* threshold (4017 MeV)

Two isospin triplets established

Mass/width difference in two modes to be understood

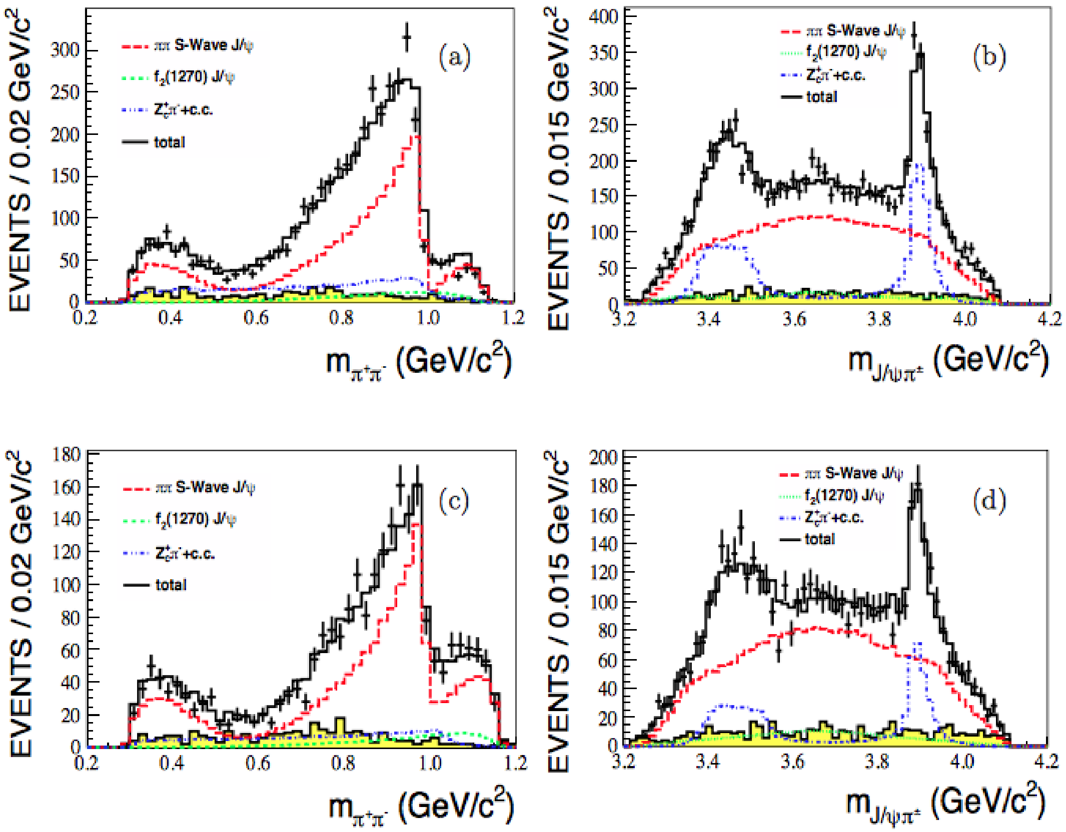
- J^P of $Z_c(3900)=1^+$ determined from PWA
- DD* dominates $Z_c(3900)$ decays and D*D* dominates $Z_c(4025)$ decays
- No significant $Z_c(3900) \to h_c\pi$, $Zc(4020) \to J/\psi\pi$

Determination of J^P of Zc(3900)

Phys.Rev.Lett. 119 (2017) 072001

4.23GeV

4.26GeV



J^P of Zc favor to be 1^+ with statistical significance larger than 7.3σ over other quantum numbers

- ❑Amplitude analysis with helicity formalism formalism taking $\pi^+\pi^- J/\psi$ as final states
- ❑Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- ❑$\pi^+\pi^-$ spectrum is parameterized with σ, f0(980), f2(1270) and f0(1370)

Determination of J^P of Zc(3900)

$Z_c : J^P$	M (MeV)	$g'_1(\text{GeV}^2)$	g'_2/g'_1	$-\ln L$
0^-	3906.3 ± 2.3	0.079 ± 0.007	25.8 ± 2.9	-1528.8
1^-	3903.1 ± 1.9	0.063 ± 0.005	26.5 ± 2.6	-1457.7
1^+	3900.2 ± 1.5	0.075 ± 0.006	21.8 ± 1.7	-1569.8
2^-	3905.2 ± 2.1	0.060 ± 0.004	28.7 ± 2.7	-1516.5
2^+	3894.3 ± 1.9	0.051 ± 0.005	23.4 ± 3.3	-1316.2

- **J^p of Zc favor to be 1^+ with statistical significance larger than 7.3σ over other quentum numbers**

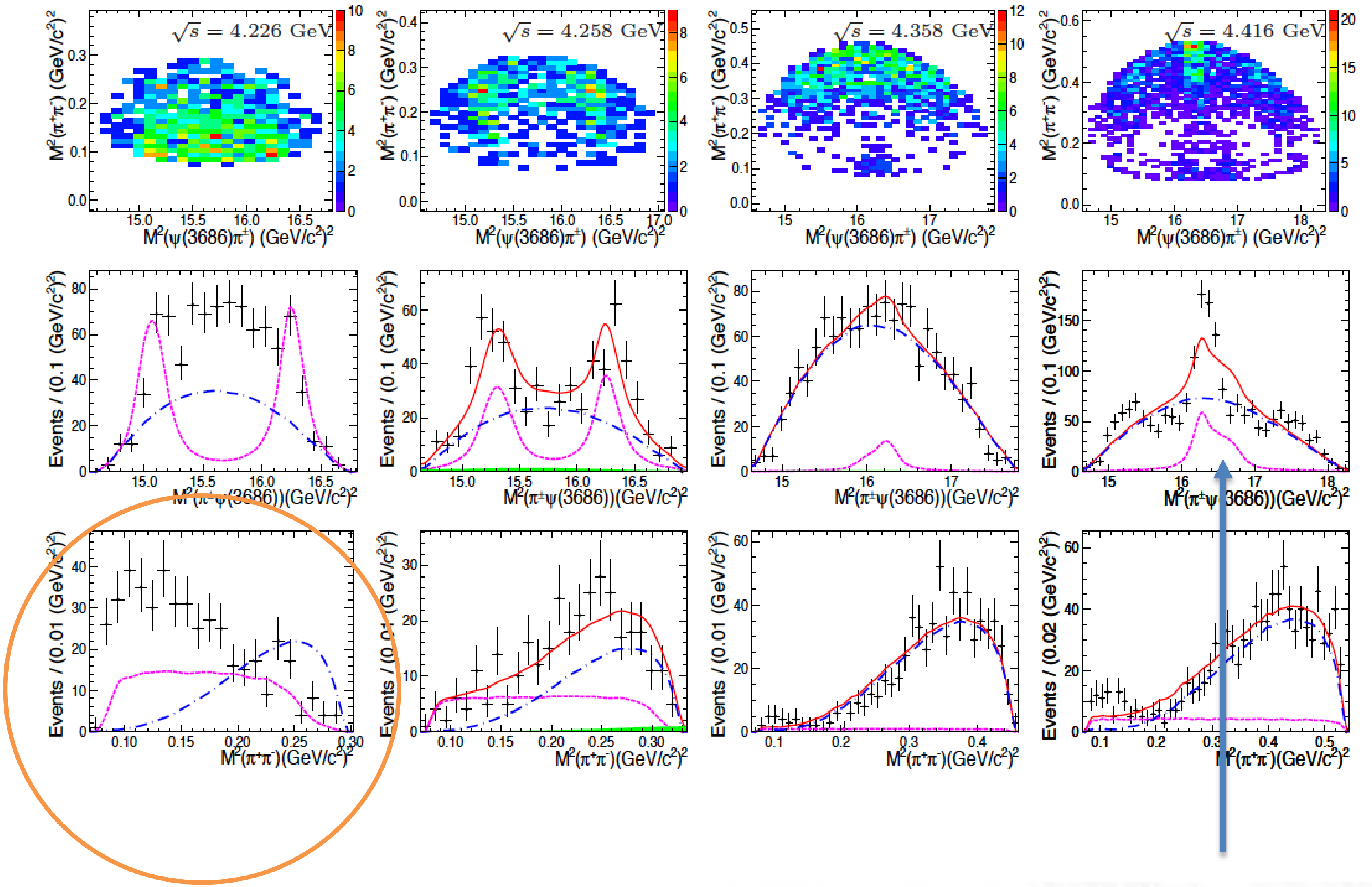
- Significance for $e^+e^- \to Z_c^+(4020)\ \pi^- + c.c \to \pi^+\pi^- J/\psi$ is ~3σ.

Upper limits at 90% C.L.:

$$\frac{\sigma(e^+e^- \to Z_c^+(4020)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to Z_c^+(3900)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)} < 3.3\% \text{ at } 4.23 \text{ GeV}$$

$<25.1\%$ at 4.26 GeV

A charged structure in πψ'



- M = (4032.1 ± 2.4) MeV/c^2
- Γ = (26.1 ± 5.3) MeV

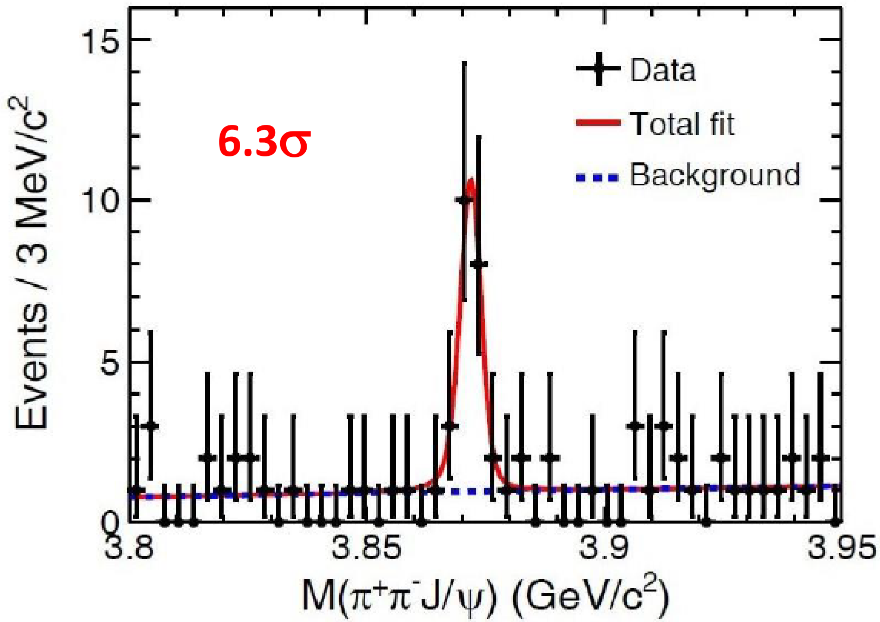
Observation of $e^+e^- \to \gamma X(3872)$

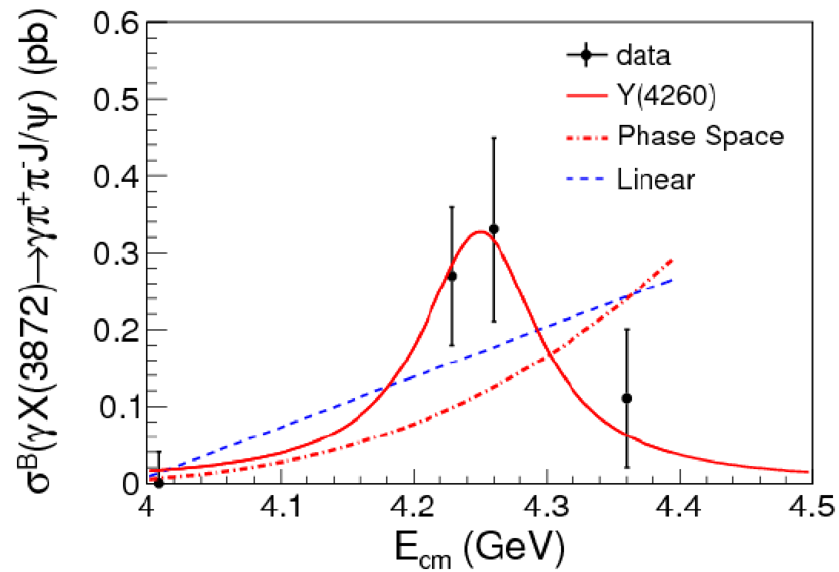
Strong evidence for
$X(3872) \to \pi\pi J/\psi$

PRL 112, 092001 (2014)

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

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





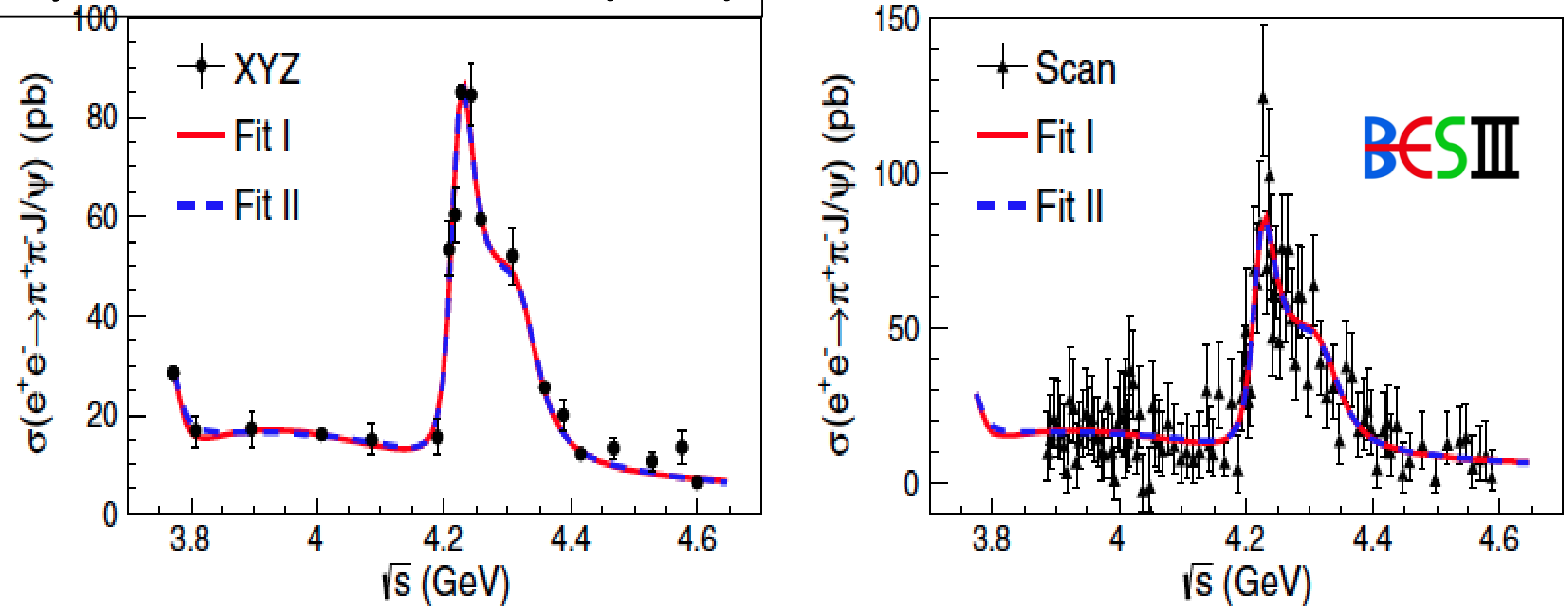
❖ **New mode of production of X(3872) and Y(4260) decay?**

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 !

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

Phys. Rev. Lett. 118, 092001 (2017)



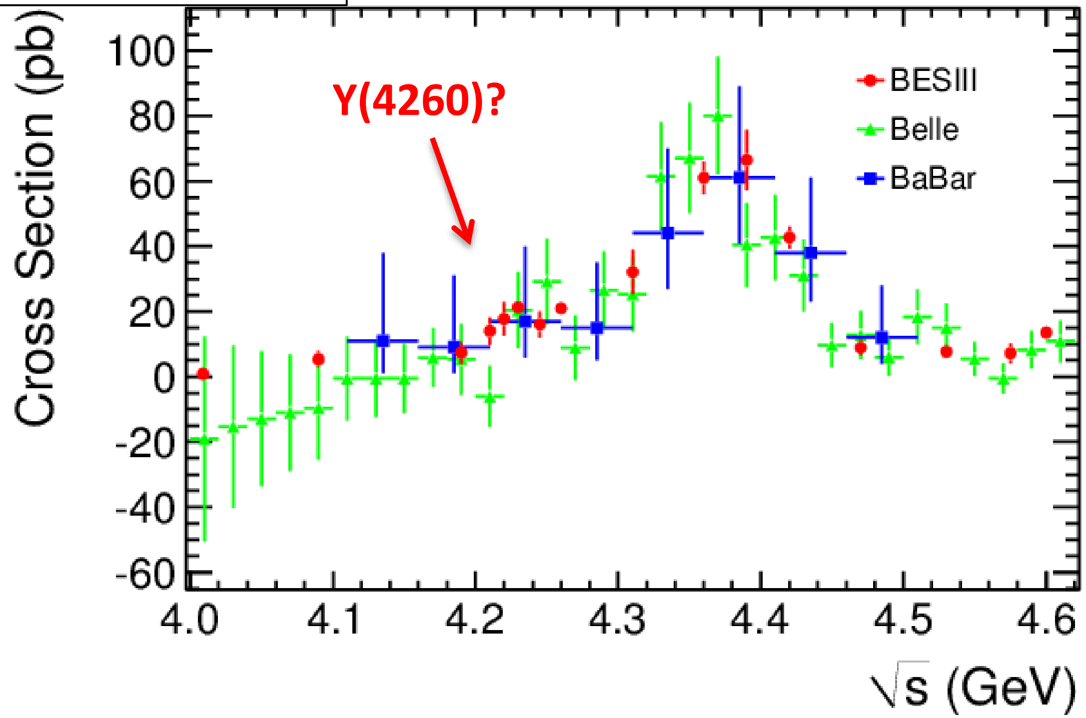
- **Simultaneous fit to XYZ data(left) and R-scan data (right)**
- **Coherent sum of two Breit-Wigner like structure plus one incoherent ψ(3770)**
  - **M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV ,**

    Lower and narrower than previous Y(4260) PDG value
  - **M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV ,**

    a little bit lower than Y(4360) PDG
- **Compare with one Breit-Wigner fit, the significance of the second Breit-wigner is 7.6σ**
- **Is this Y(4260) + Y(4360) ? The first observation of Y(4360)→$\pi^+\pi^- J/\psi$?**
- **Y(4008) is not confirmed**

$e^+e^- \rightarrow \pi^+\pi^-\psi'$

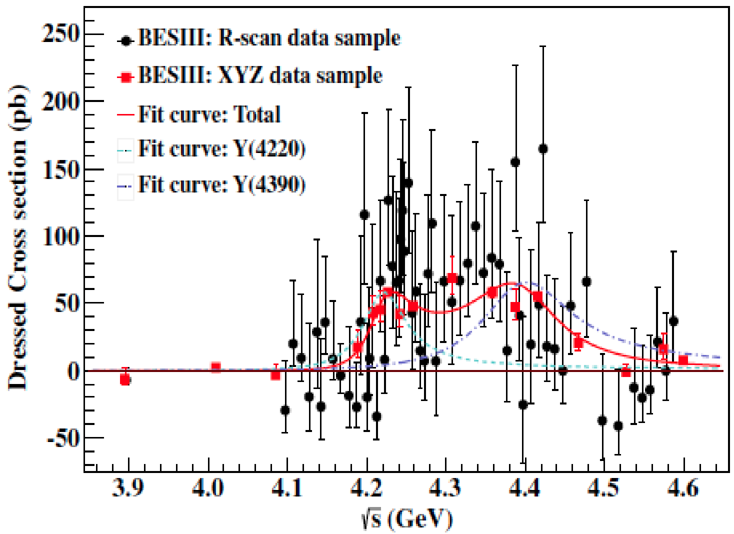
arXiv:1703.08787

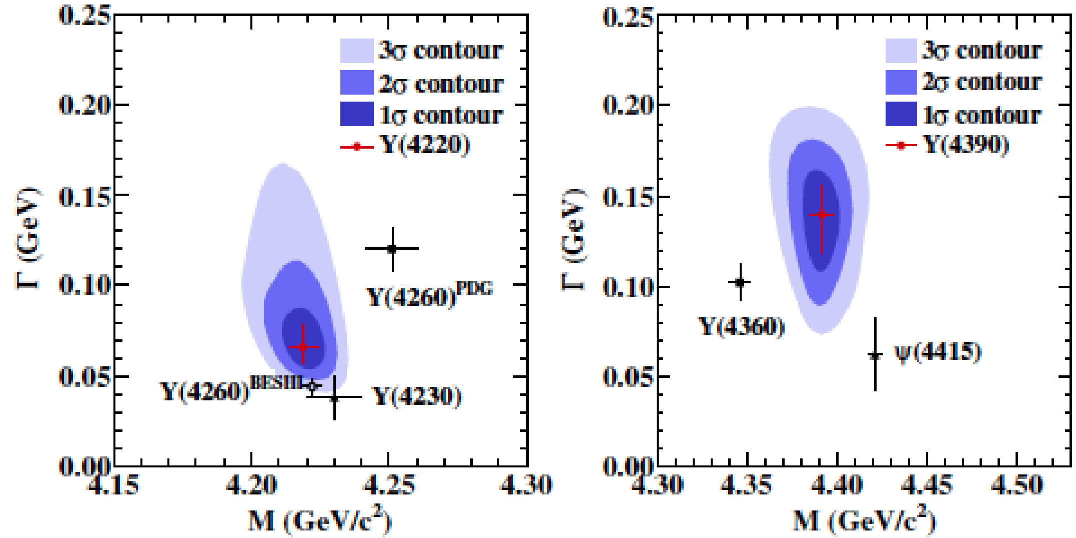


- Cross section of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ has been measured at 16 energy points from 4.008 to 4.600 GeV.
- A clear peak around Y(4360), consistent with Belle&BaBar's results, but with much improved precision
- A fitting on the cross sections is ongoing

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

PRL 118, 092002 (2017)

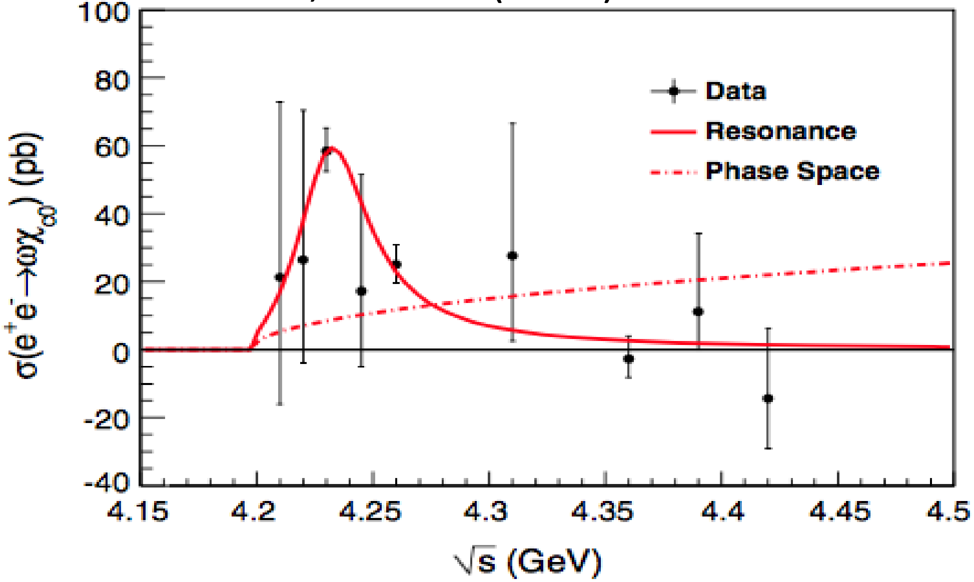


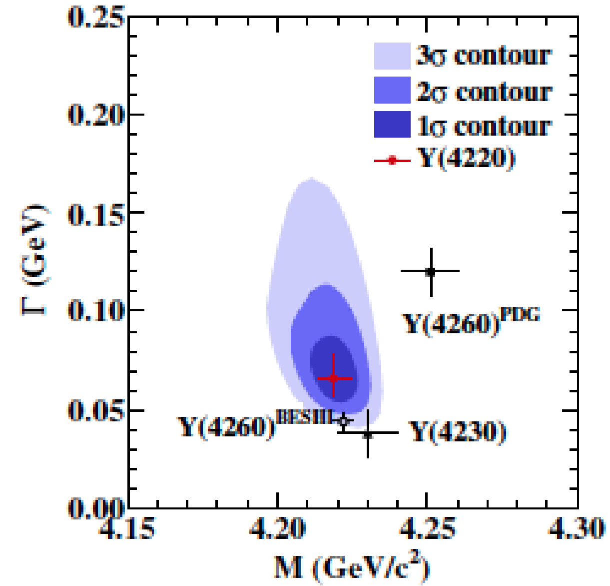


- Fitted with coherent sum of two Breit-Wigner like structue
  - $M_1=4218.4^{+5.5}_{-4.5}\pm0.9$ MeV/c^2, $\Gamma_1=$ $66.0^{+12.3}_{-8.3}\pm0.4$ MeV $\to$ Y(4220)
  - $M_2=4391.5^{+6.3}_{-6.8}\pm1.0$ MeV/c^2, $\Gamma_2=139.5^{+16.2}_{-20.6}\pm0.6$ MeV $\to$ Y(4390)
- The Y(4220) here is consistent with the states observed in $\pi^+\pi^- J/\psi$ around 4222MeV

$e^+e^- \rightarrow \omega\chi_{cJ}$

PRL 114, 092003 (2015)





- **Only $\omega\chi_{c0}$ has significant signal**
- **The cross section is fitted with coherent sum of a Breit-Wigner and a phase space term**

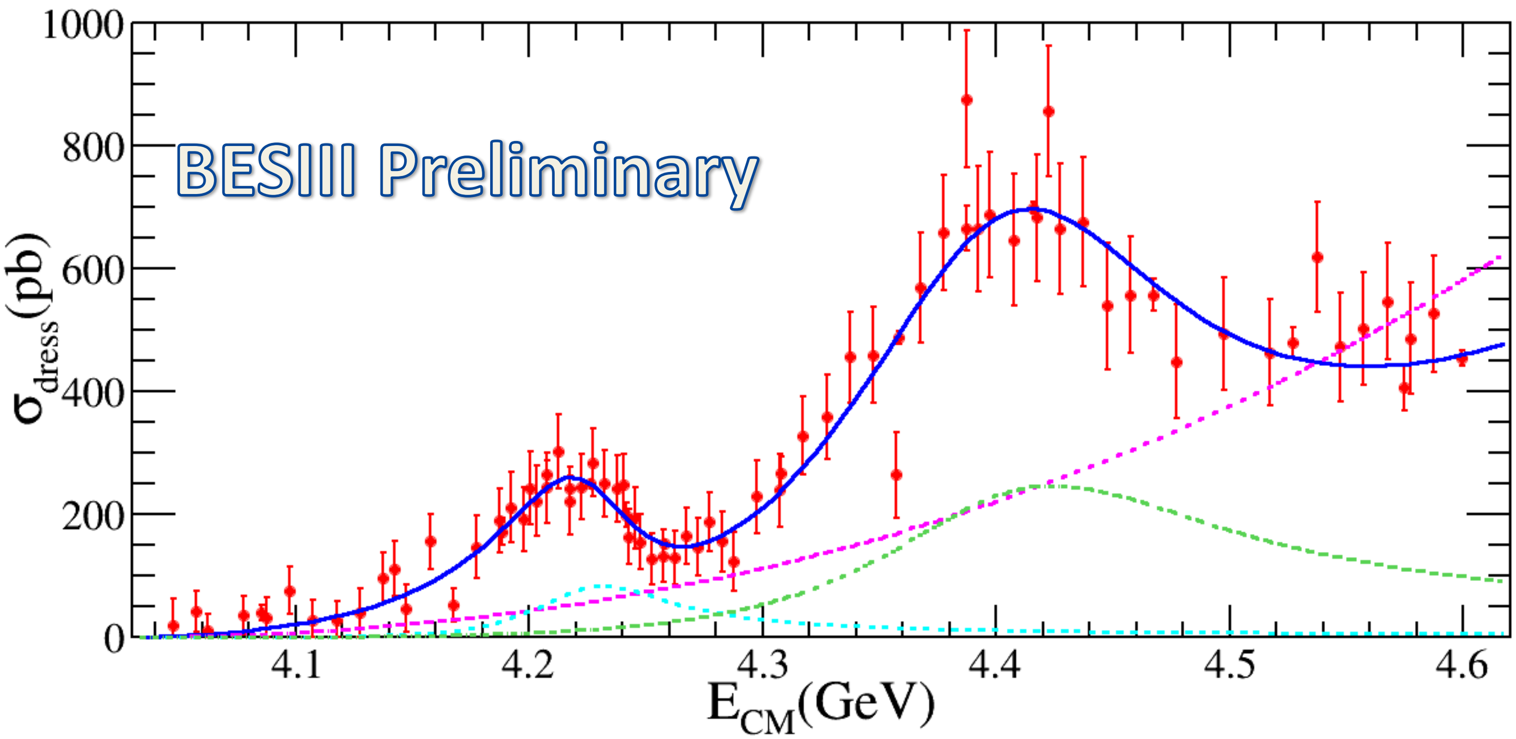
$$M = 4230 \pm 8 \pm 6 \text{ MeV} \;, \Gamma = 38 \pm 12 \pm 2 \text{ MeV}$$

- **The mass and width here is compatible with the Y observed in $\pi^+\pi^- J/\psi$ and $e^+e^- \rightarrow \pi^+\pi^- h_c$**

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

$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)B(D^0 \to K^-\pi^+)\varepsilon}$$

$$\sigma_{\rm dress}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1} B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi_2} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}}|^2$$



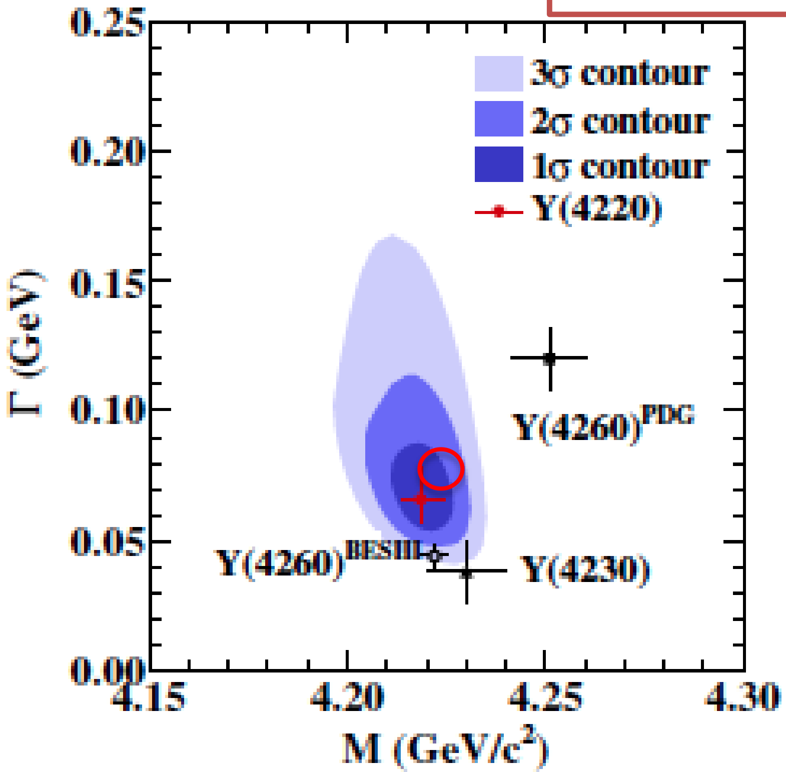
Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

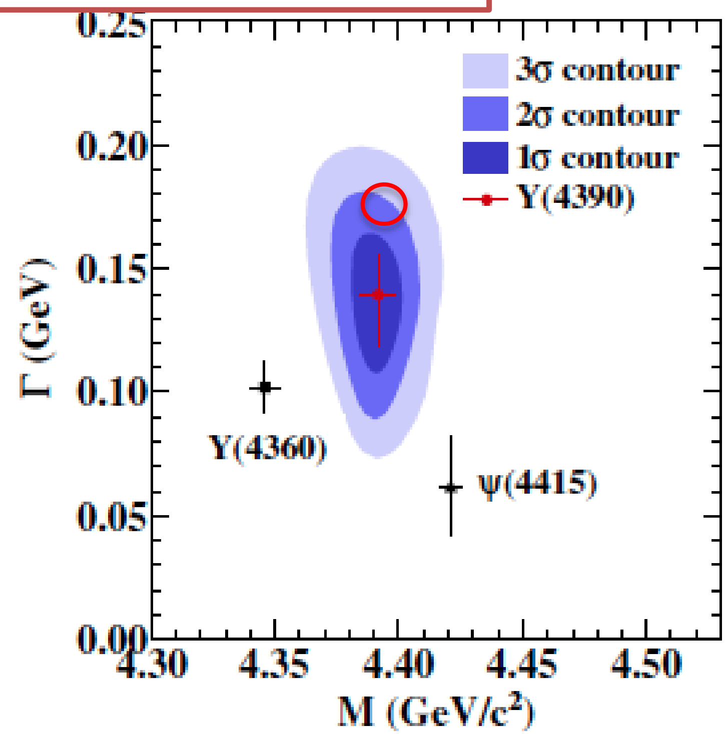
$M(Y(4220)) = (4224.8 \pm 5.6 \pm 4.0)$ MeV/c^2, $\Gamma(Y(4220)) = (72.3 \pm 9.1 \pm 0.9)$ MeV.

$M(Y(4390)) = (4400.1 \pm 9.3 \pm 2.1)$ MeV/c^2, $\Gamma(Y(4220)) = (181.7 \pm 16.9 \pm 7.4)$ MeV.

$e^+e^- \rightarrow \pi^+D^0D^{*-}$

Red circle is the result of $e^+e^- \rightarrow \pi^+D^0D^{*-}$





- The statistical significance of two resonances assumption over one resonance is greater than 10s.
- The resonant parameters of Y(4220) and Y(4390) states are consistent with the structures observed in $e^+e^- \rightarrow \pi^+\pi^-h_c$. The resonant parameters of Y(4220) are also consistent with those of the resonance observed in $e^+e^- \rightarrow \omega\chi_{c0}$ and $e^+e^- \rightarrow \pi^+\pi^-J/\psi$.

Prospects of hadron spectroscopy at BESIII

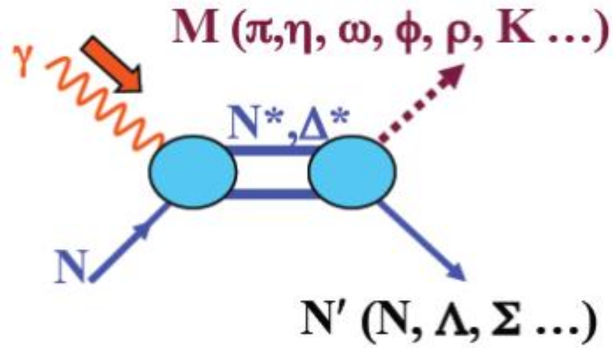
BESIII data taking status & plan (run ~8-10 years)

	Previous data	BESIII present & future	Goal
J/ψ	BESII 58M	1.2 B 20* BESII	10 B
ψ'	CLEO: 28 M	0.5 B 20* CLEOc	3B
ψ"	CLEO: 0.8/fb	2.9/fb 3.5*CLEOc	20 /fb
Above open charm threshold	CLEO: 0.6/fb @ ψ(4160)	0.5/fb @ ψ(4040) 2.3/fb@~4260, 0.5/fb@4360 0.5/fb@4600, 1/fb@4420 Scan from 4.19 – 4.28, 10 MeV step, 500 pb-1/point	5-10 /fb
R scan & Tau	BESII	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)		100 pb^{-1}	
ψ(4170)		3 fb^{-1}	

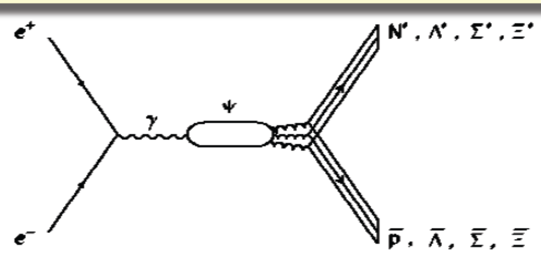
- **The data with unprecedented statistical accuracy and clearly defined initial and final state properties brings BESIII great opportunities to investigate QCD exotics and many other topics**

Thank you

Light Baryon spectroscopy



$J/\psi(\psi') \to \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$

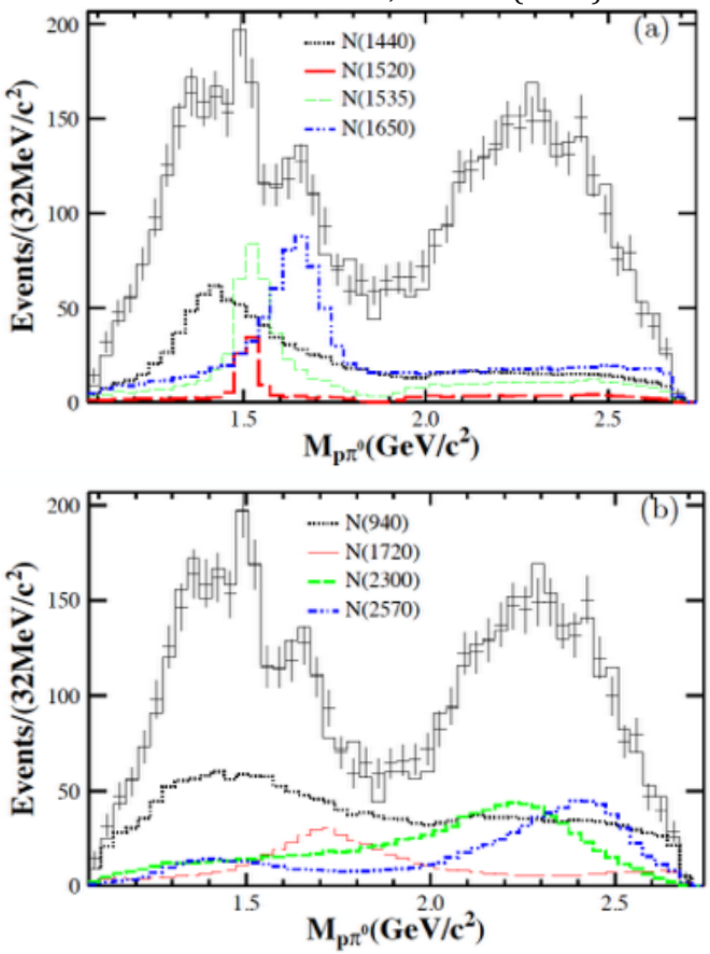


Charmonium decays can provide novel insights into baryons and complementary information to other experiments

- ✓ 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

Observation of two new N* resonances in $\psi(3686) \to p\bar{p}\pi^0$

BESIII: PRL 110, 022001 (2013)



- In photon or meson beam studies, isospin 1/2 and 3/2 resonances are excited, complicating the analysis
- Δ resonances suppressed in charmonium decays to $p\bar{p}\pi^0$, giving a cleaner spectrum
  - Thought to be dominated by two body decays involving N* intermediate states
  - Also consider $p\bar{p}$ resonances ($\psi(3686) \to R\pi^0$)
- Seven N* states observed in partial wave analysis
  - Two new resonances, N(2300) with $J^P = 1/2^+$ and N(2570) with $J^P = 5/2^-$
  - Other five consistent with previous results

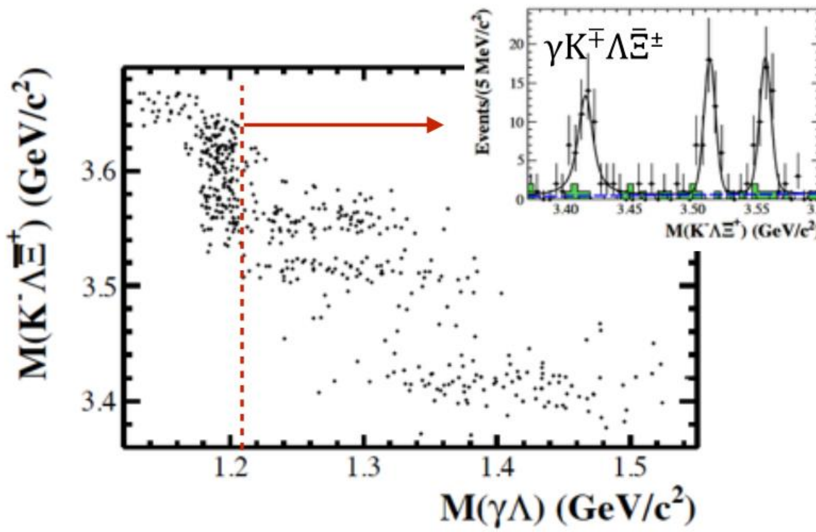
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
N(2300)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$

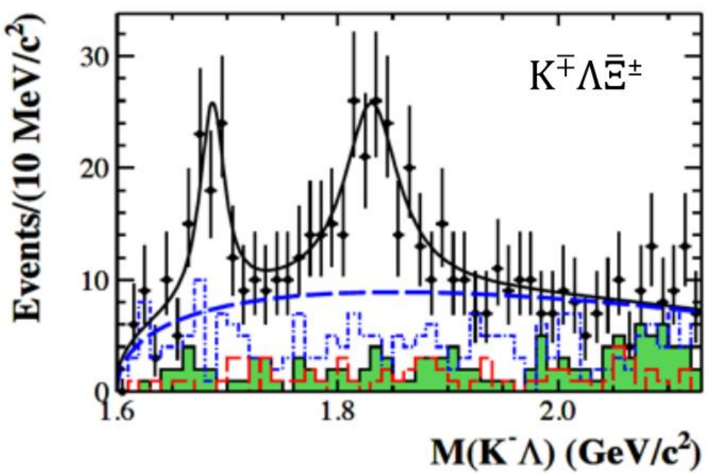
Measurements of $\psi(3686) \to (\gamma)K^{\mp}\Lambda\bar{\Xi}^{\pm}$

BESIII: PRD 91, 092006 (2015)

- $\psi(3686) \to (\gamma)K^{\mp}\Lambda\bar{\Xi}^{\pm}$; $\Lambda \to p\pi$, $\bar{\Xi} \to \Lambda\pi$; $\Lambda \to p\pi$

Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+,\ \Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+,\ \Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0},\ \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1},\ \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2},\ \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$





- Observe two hyperons, Ξ(1690) and Ξ(1820) in M(KΛ)
  - Both are well established states
  - Resonance parameters consistent with the PDG

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	1687.7±3.8±1.0	1826.7±5.5±1.6
$\Gamma(\mathrm{MeV})$	27.1±10.0±2.7	54.4±15.7±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±1.48±0.57	12.03±2.94±1.22
$M_{\mathrm{PDG}}(\mathrm{MeV}/c^2)$	1690±10	1823±5
$\Gamma_{\mathrm{PDG}}(\mathrm{MeV})$	<30	24^{+15}_{-10}