Charmonium decays into light hadrons at BESIII

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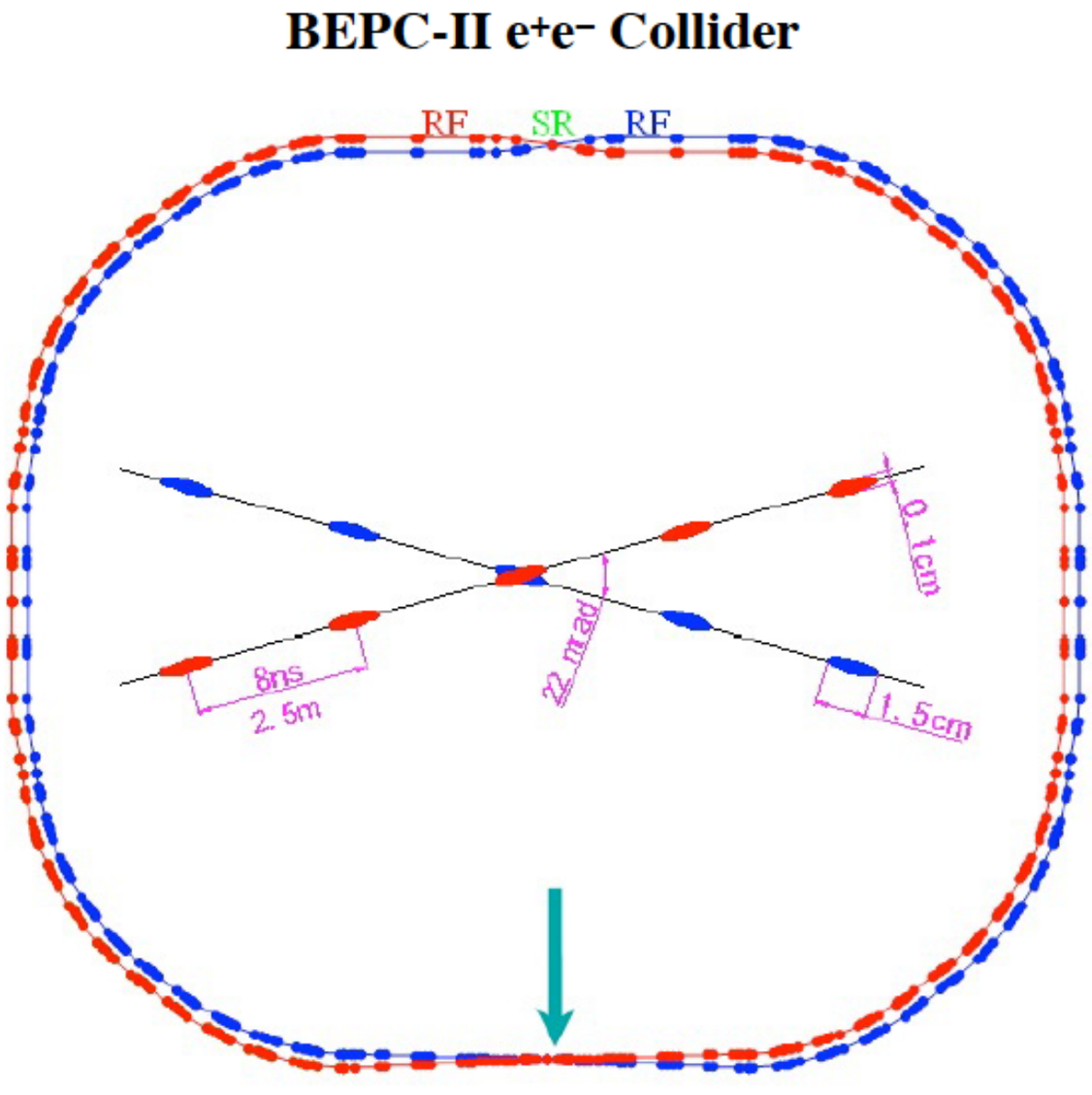
Carnegie Mellon

BESIII

BESIII at BEPCII

- The physics goals of BESIII cover a diverse range:

  Light hadron spectroscopy, charm physics, τ physics, charmonium physics
- e^+e^- collisions in the charmonium region
  - Use the properties and decays of charmonium states to study QCD



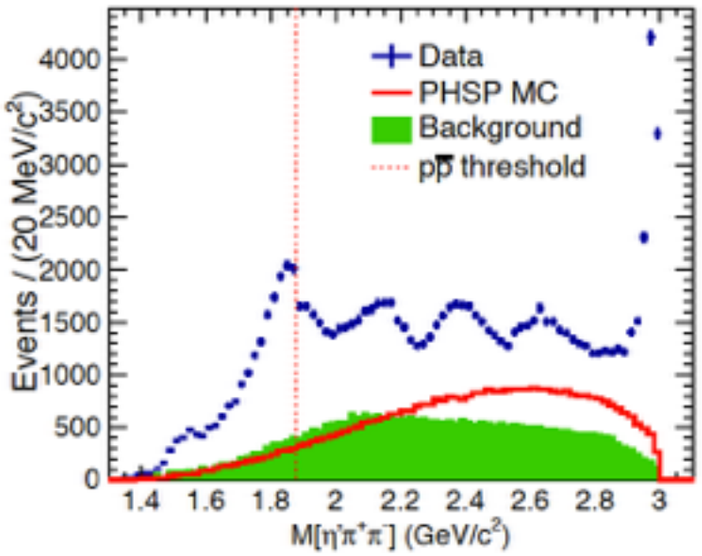
BESIII at BEPCII

See the other BESIII talks this week

- The physics goals of BESIII cover a diverse range:

  Light hadron spectroscopy, charm physics, τ physics, charmonium physics

arχiv:1603.09653 Submitted to PRL



Connection between X(1835) and pp̄ threshold enhancement

Suggestion of the existence of (1) a broad resonance below threshold and (2) a narrow state very close to pp̄ threshold

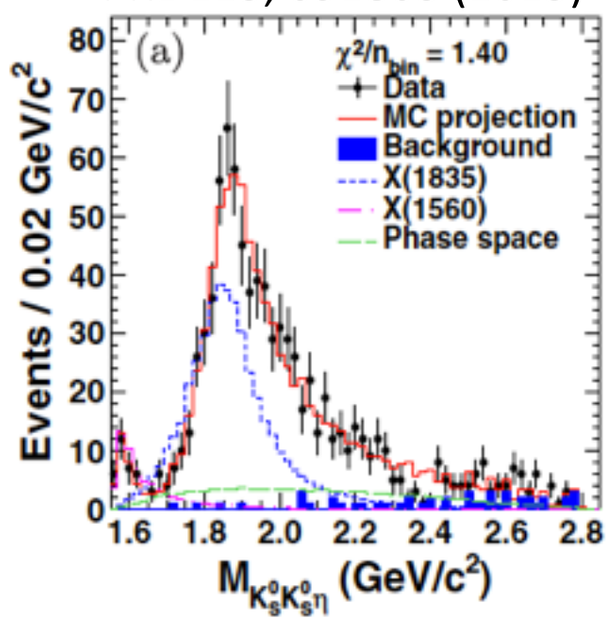
PRL 115, 091803 (2015)

X(1835) in $J/\psi \to \gamma\eta K_S K_S$

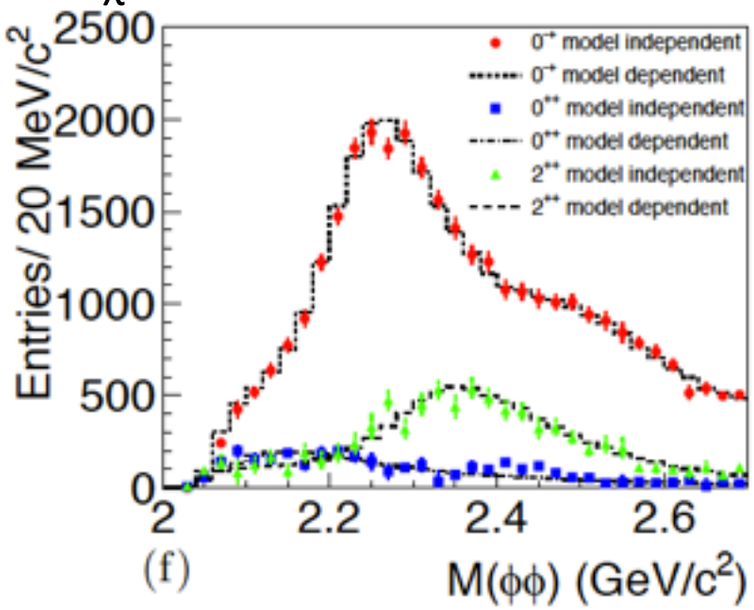
$$M = 1844 \pm 9(\text{stat})^{+16}_{-25}(\text{syst})\ \text{MeV}/c^2$$

$$\Gamma = 192^{+20}_{-17}(\text{stat})^{+62}_{-43}(\text{syst})\ \text{MeV}$$

$$\mathcal{B}_{X(1835)} = [3.31^{+0.33}_{-0.30}(\text{stat})^{+1.96}_{-1.29}(\text{syst})] \times 10^{-5}$$



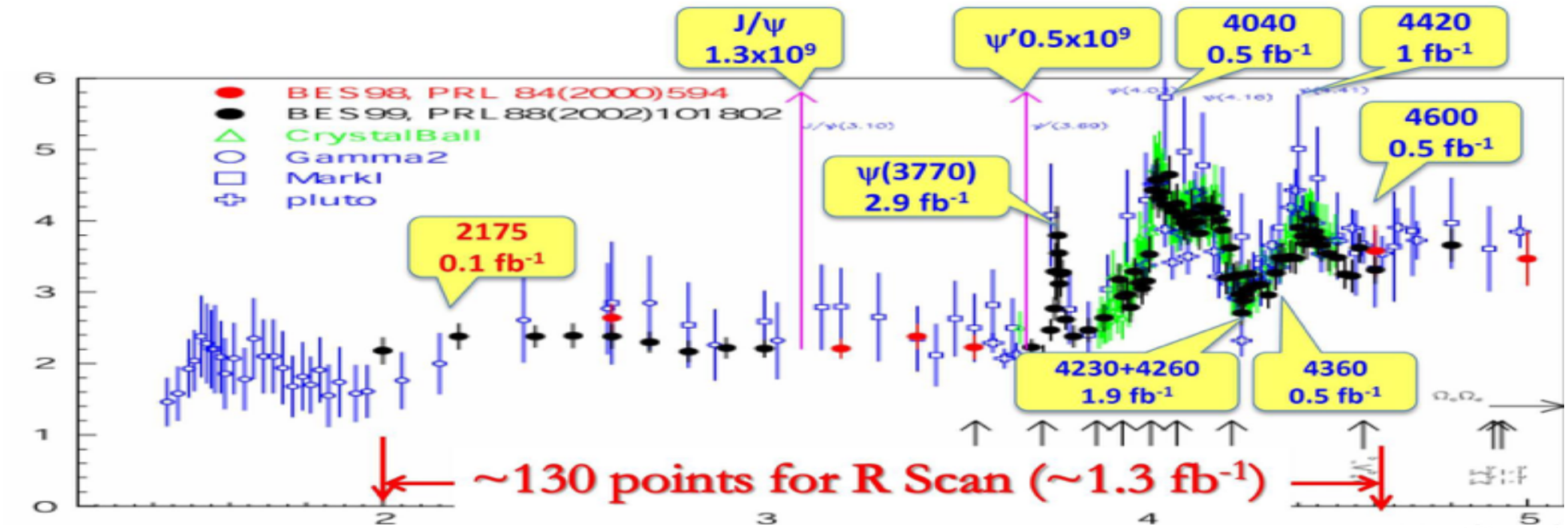
arχiv:1602.01523 Submitted to PRL



Partial Wave Analysis of J/ψ to γφφ

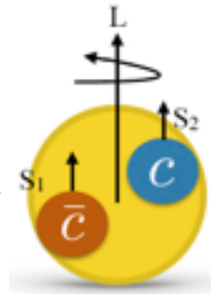
Consistent model-dependent and model-independent results

Charmonium decays to light hadrons

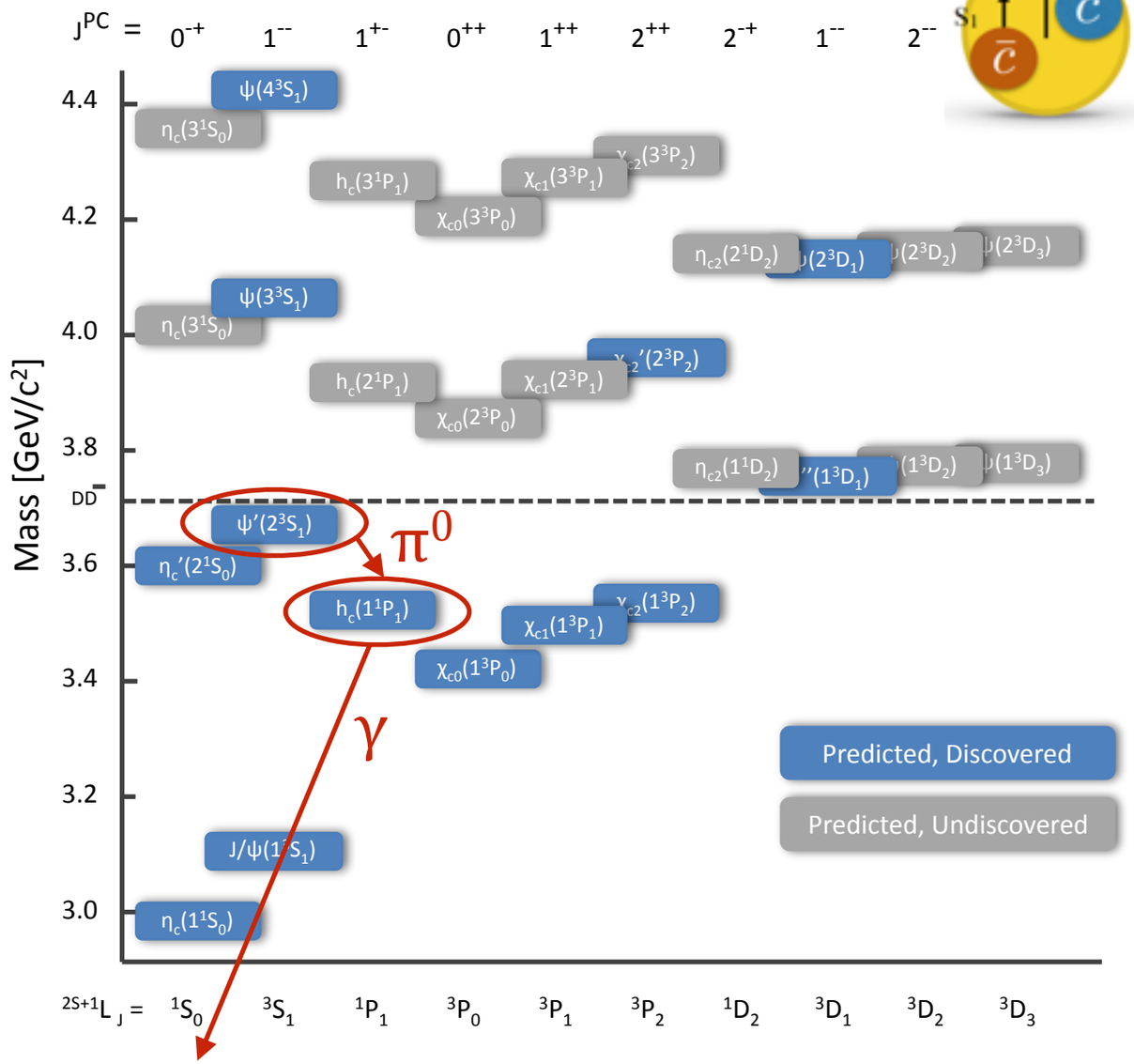


- Charmonium decay dynamics
  - Observation of $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$ — Accepted by PRL
  - $\rho\pi$ puzzle and violation of the 12% rule — PRD 93, 072003 (2016)
  - Helicity selection rule suppression processes — BESIII Preliminary
- XYZ physics in light quark sector
  - Y(2175) as possible s-quark counterpart of Y(4260) — PRD 91, 052017 (2015)
- Opportunities for theory/experiment collaboration
  - Mass independent amplitude analysis of $\pi^0\pi^0$ system — PRD 92, 052003 (2015)

Observation of $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$



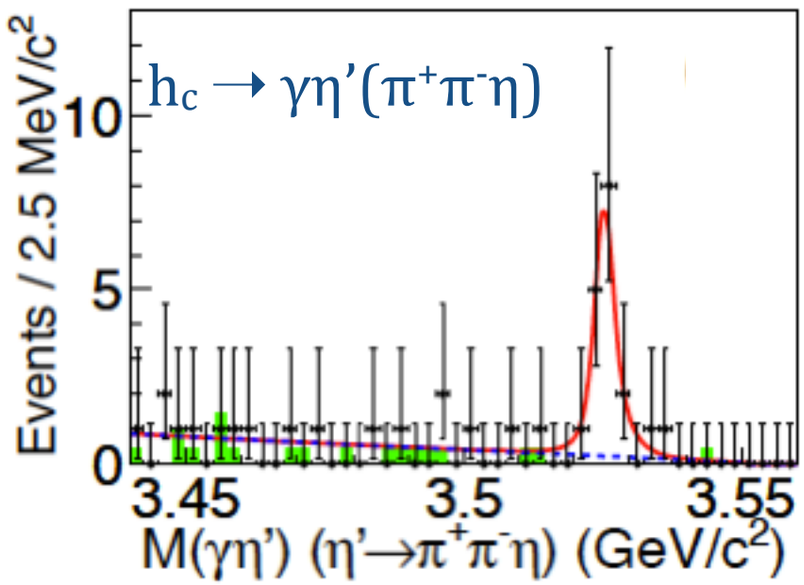
- **Goal**: Obtain a better understanding of charmonium and charmonium-like states
- **Method**: Study pattern of masses, transitions between states, etc.
- Below $D\bar{D}$ threshold, all states have been observed and are well described by $c\bar{c}$ potential models

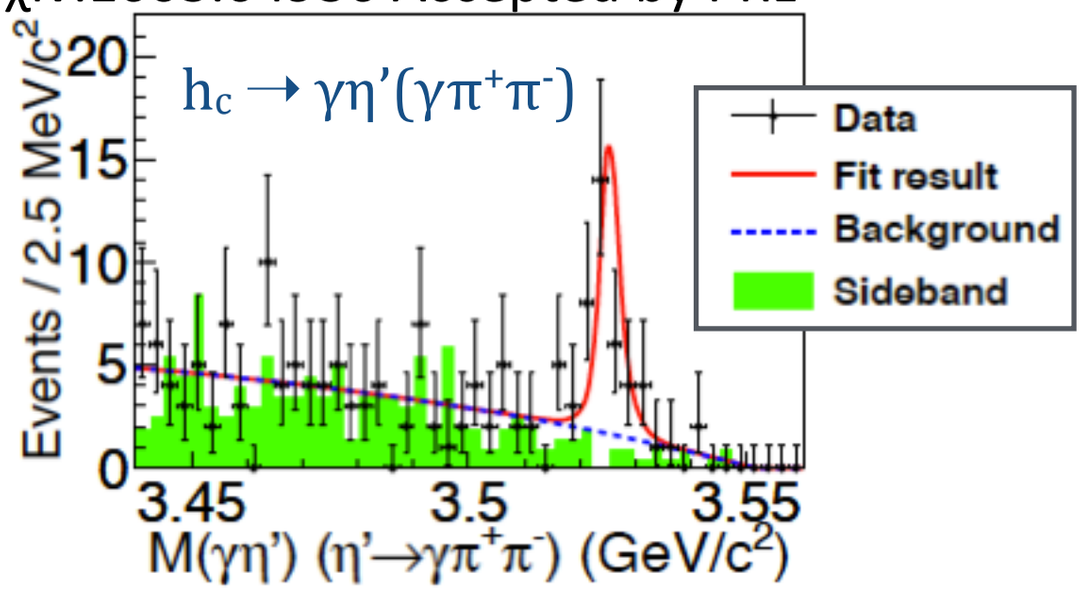


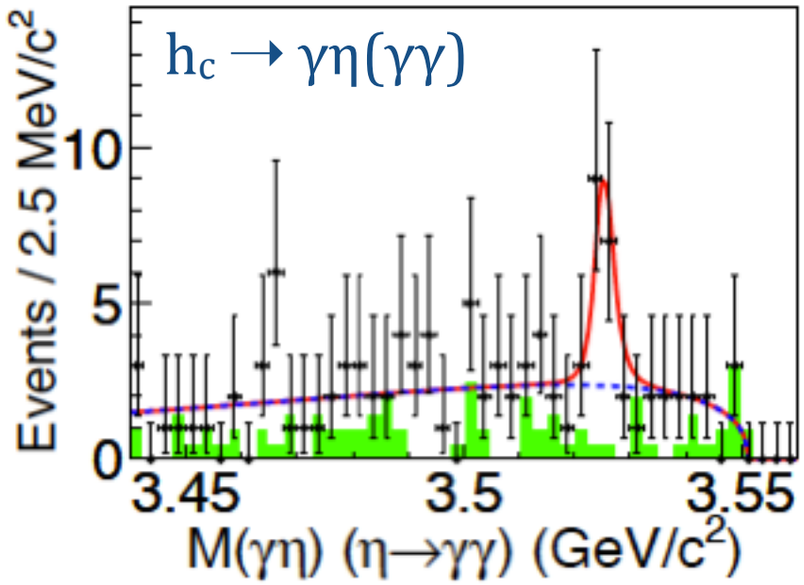
- Knowledge of P-wave spin-singlet h_c rather sparse
  - Not produced in e^+e^- collisions - use hadronic transition $\psi' \to \pi^0 h_c$
  - Search for new decays modes with BESIII sample of 448 x 10^6 ψ' events

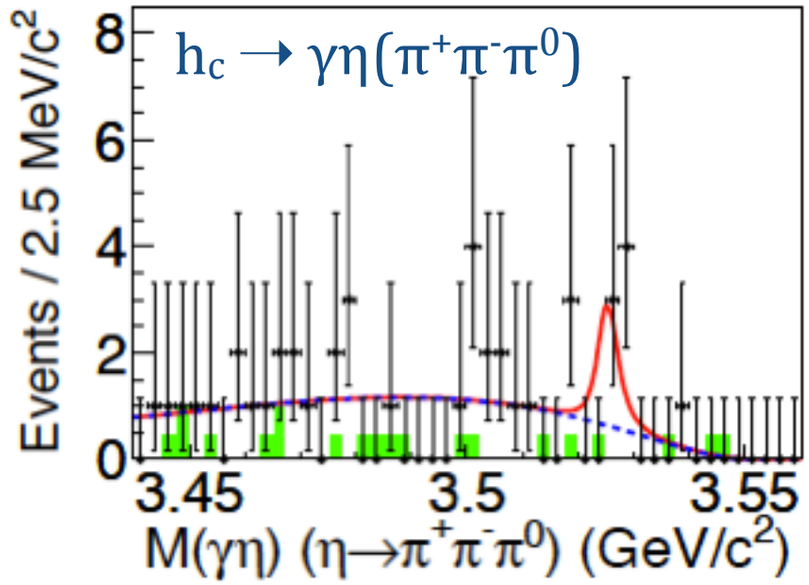
Observation of $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$

arχiv:1603.04936 Accepted by PRL









Mode	$\mathcal{B}(h_c \to \gamma\eta'(\eta))$	Significance	$\frac{\mathcal{B}(h_c\to\gamma\eta)}{\mathcal{B}(h_c\to\gamma\eta')}(\%)$
$h_c \to \gamma\eta'$	$(1.52 \pm 0.27(\text{stat.}) \pm 0.29(\text{sys.}))\times10^{-3}$	8.4σ	$30.7 \pm 11.3(\text{stat.}) \pm 8.7(\text{sys.})$
$h_c \to \gamma\eta$	$(4.7 \pm 1.5(\text{stat.}) \pm 1.4(\text{sys.}))\times10^{-4}$	4.0σ	

Study of ψ decays to $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

- pQCD predicts exclusive decays of J/ψ and ψ' into light hadrons should have widths proportional to the square of the wave function at the origin (the "12% rule")

$$Q_h \equiv \frac{\mathcal{B}(\psi(3686) \to \text{hadrons})}{\mathcal{B}(J/\psi \to \text{hadrons})} \approx \frac{\mathcal{B}(\psi(3686) \to e^+e^-)}{\mathcal{B}(J/\psi \to e^+e^-)} \approx 12\%$$

- Current theoretical explanations of the ρπ puzzle are unsatisfactory, especially for decays to baryon pairs

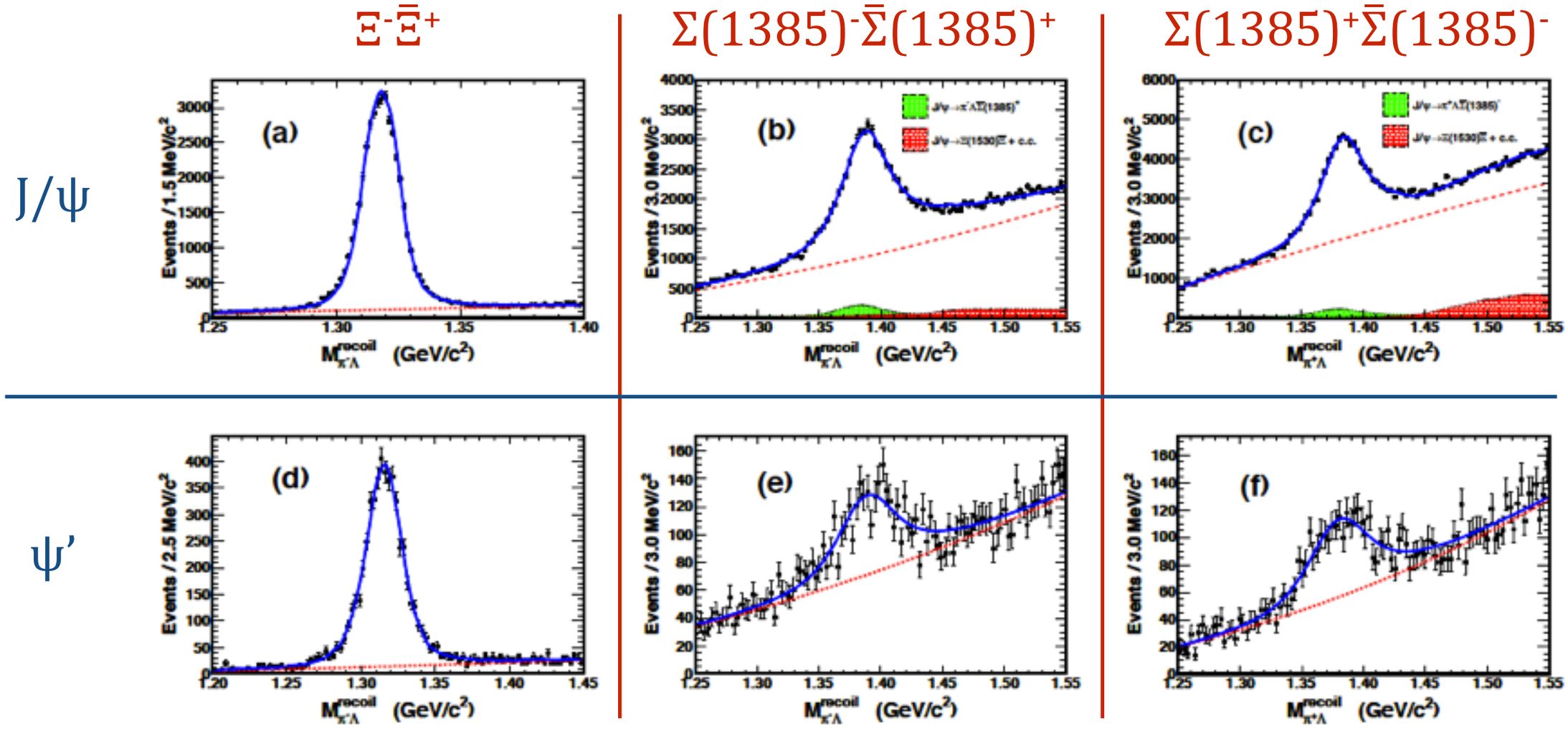
$$Q_{\rho\pi} = \frac{\mathcal{B}(\psi(2S) \to \rho\pi)}{\mathcal{B}(J/\psi \to \rho\pi)} = (0.13 \pm 0.05)\%$$

- More experimental measurements are desirable
- Use large BESIII charmonium samples to make precision measurements of J/ψ and ψ' decays to $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

Study of ψ decays to $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

- Based on (223.7 ± 1.4) x 10^6 J/ψ and (106.4 ± 0.9) x 10^6 ψ' decays
- Avoid full reconstruction of both baryons (low efficiency)
  - Identify $\bar{\Xi}^+$ or $\bar{\Sigma}(1385)^{\pm}$ from recoil mass against $\pi^{\pm}\Lambda$

$$M^{\text{recoil}}_{\pi^{\mp}\Lambda} = \sqrt{(E_{CM} - E_{\pi^{\mp}\Lambda})^2 - \vec{p}^{\,2}_{\pi^{\mp}\Lambda}}$$



PRD 93, 072003 (2016)

Study of ψ decays to $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$

- Based on (223.7 ± 1.4) x 10^6 J/ψ and (106.4 ± 0.9) x 10^6 ψ' decays

Comparison of the branching fractions for $\psi \to \Xi^-\bar{\Xi}^+$, $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$ (in units of 10^{-4})

Source	$J/\psi \to$			$\psi(3686) \to$		
Mode	$\Xi^-\Xi^+$	$\Sigma(1385)^-\Sigma(1385)^+$	$\Sigma(1385)^+\Sigma(1385)^-$	$\Xi^-\Xi^+$	$\Sigma(1385)^-\Sigma(1385)^+$	$\Sigma(1385)^+\Sigma(1385)^-$
This work	$10.40 \pm 0.06 \pm 0.74$	$10.96 \pm 0.12 \pm 0.71$	$12.58 \pm 0.14 \pm 0.78$	$2.78 \pm 0.05 \pm 0.14$	$0.85 \pm 0.06 \pm 0.06$	$0.84 \pm 0.05 \pm 0.05$
MarkI [5]	14.00 ± 5.00	–	–	< 2.0	–	–
MarkII [6]	$11.40 \pm 0.80 \pm 2.00$	$8.60 \pm 1.80 \pm 2.20$	$10.3 \pm 2.4 \pm 2.5$	–	–	–
DM2 [7]	$7.00 \pm 0.60 \pm 1.20$	$10.00 \pm 0.40 \pm 2.10$	$11.9 \pm 0.4 \pm 2.5$	–	–	–
BESII [8, 12]	$9.00 \pm 0.30 \pm 1.80$	$12.30 \pm 0.70 \pm 3.00$	$15.0 \pm 0.8 \pm 3.8$	$3.03 \pm 0.40 \pm 0.32$	–	–
CLEO [9]	–	–	–	$2.40 \pm 0.30 \pm 0.20$	–	–
BESI [26]	–	–	–	$0.94 \pm 0.27 \pm 0.15$	–	–
PDG [3]	8.50 ± 1.60	10.30 ± 1.30	10.30 ± 1.30	1.80 ± 0.60	–	–

PRD 93, 072003 (2016)

$$\frac{\mathcal{B}(\psi(3686)\to\Xi^-\bar{\Xi}^+)}{\mathcal{B}(J/\psi\to\Xi^-\bar{\Xi}^+)} = (26.73 \pm 0.50 \pm 2.30)\%$$

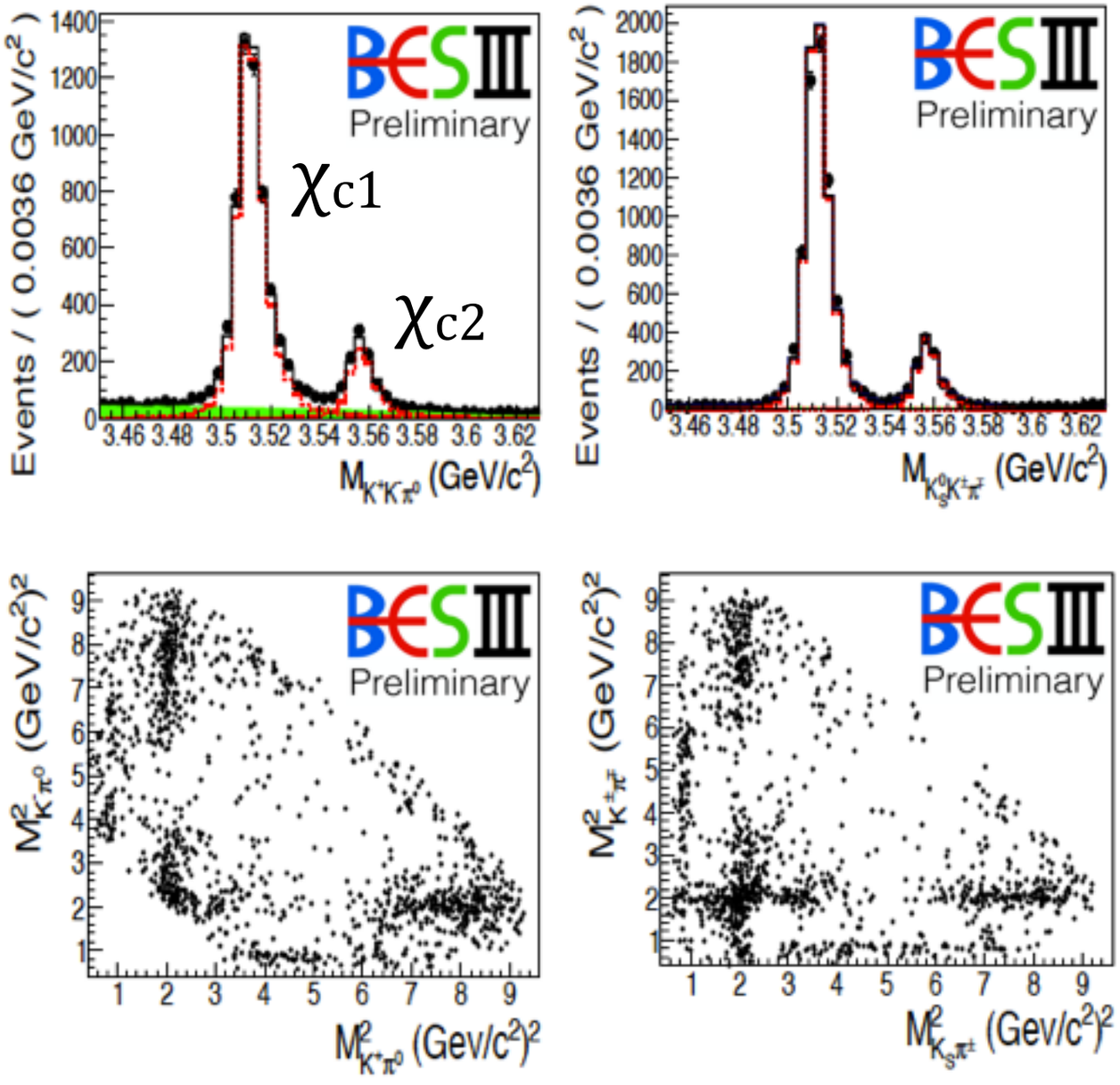
$$\frac{\mathcal{B}(\psi(3686)\to\Sigma(1385)^-\bar{\Sigma}(1385)^+)}{\mathcal{B}(J/\psi\to\Sigma(1385)^-\bar{\Sigma}(1385)^+)} = (7.76 \pm 0.55 \pm 0.68)\%$$

$$\frac{\mathcal{B}(\psi(3686)\to\Sigma(1385)^+\bar{\Sigma}(1385)^-)}{\mathcal{B}(J/\psi\to\Sigma(1385)^+\bar{\Sigma}(1385)^-)} = (6.68 \pm 0.40 \pm 0.50)\%$$

Not in agreement with 12% rule

PWA on χ_{c2} decays to VP

- Precise measurements of Helicity Selection Rule suppressed processes are crucial for a better understanding of the underlying dynamics of the strong interaction
  - Charmonium hadronic decays could be useful to clarify mechanisms that may violate the leading pQCD results
- Use χ_{c2} decays to VP to quantify HSR-violating mechanisms
  - Intermediate meson loops may contribute sizable branching ratios for $\chi_{c2} \rightarrow K^*K + c.c.$
- Based on full ψ' sample $(448.1 \pm 2.9) \times 10^6$ events



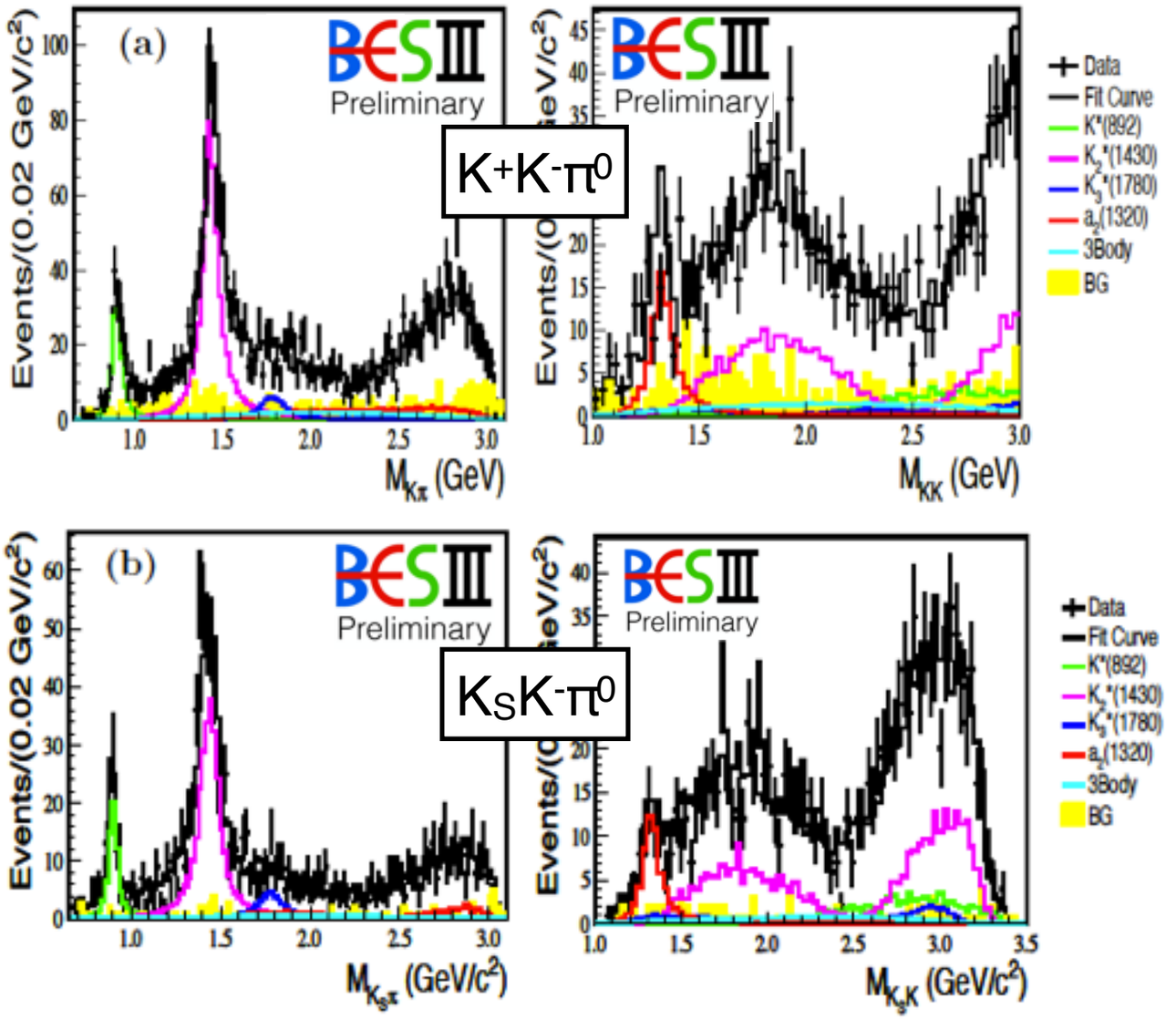
PWA on χ_{c2} decays to VP

- PWA with relativistic Breit-Wigner lineshapes (masses and widths fixed at PDG values)
  - BR rather sizable compared to HSR conserving channel

$$\mathcal{B}(\chi_{c2} \to K^*(892)^0 \bar{K}^*(892)^0)$$
$$(4.67 \pm 0.55 \pm 0.85) \times 10^{-3}$$

  - Isospin conservation suppresses intermediate loop transitions?

$$Br(\chi_{c2} \to \rho^+\pi^- + c.c.)$$
$$[(0.64 \pm 0.28 \pm 0.07) \times 10^{-5}]$$



$Br(\chi_{c2} \to K^*K)Br(K^* \to K\pi)$ and $Br(\chi_{c2} \to a_2\pi)Br(a_2 \to KK)$

Mode	Charged $(\times 10^{-4})$	Neutral $(\times 10^{-4})$
$K^*(892)K$	$1.6 \pm 0.1 \pm 0.2$	$1.3 \pm 0.2 \pm 0.2$
$K_2^*(1430)K$	$8.0 \pm 0.3 \pm 0.6$	$6.5 \pm 0.5 \pm 0.9$
$K_3^*(1780)K$	$1.0 \pm 0.1 \pm 0.2$	$1.1 \pm 0.3 \pm 0.3$
$a_2(1320)\pi$	$0.90 \pm 0.16 \pm 0.23$	$0.66 \pm 0.08 \pm 0.12$

Prediction from intermediate meson loop transitions:

$$[(4.0 \sim 6.7) \times 10^{-5}]$$

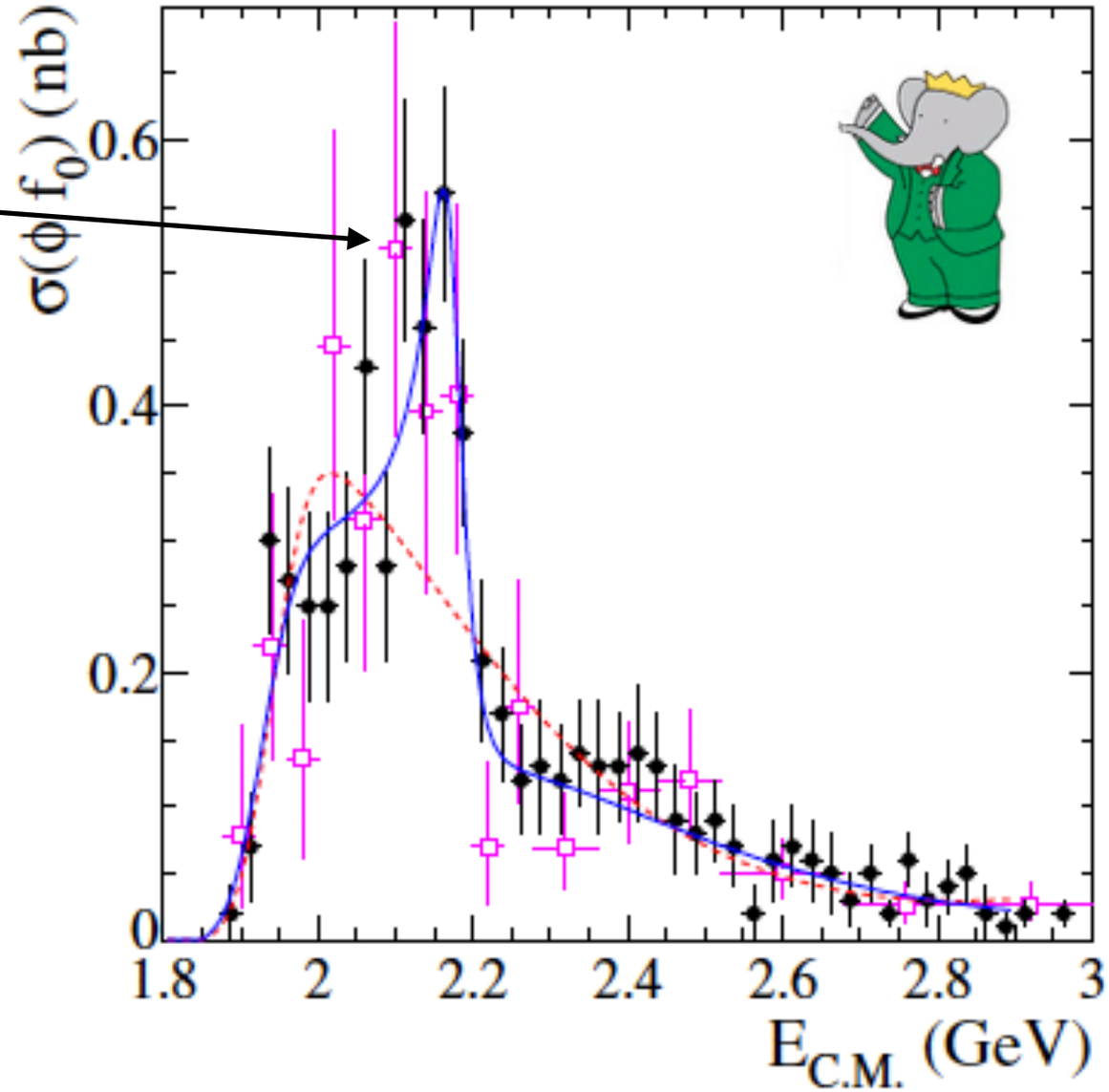
PRD 81 014017 (2010)

Study of $J/\psi \to \eta\phi\pi^+\pi^-$

- Y(2175) as possible s-quark counterpart of the Y(4260)
  - Observed by BaBar in $e^+e^- \to \gamma_{ISR}\phi f_0(980)$: $J^{PC} = 1^{--}$
  - Confirmed by BES [$J/\psi \to \eta\phi f_0(980)$], and Belle [$e^+e^- \to \gamma_{ISR}\phi f_0(980)$]
  - Many possible interpretations predict masses consistent with experimental measurements: $s\bar{s}$ hybrid, excited ϕ state, tetraquark, $\Lambda\bar{\Lambda}$ bound state, FSI

- Based on $(225.3 \pm 2.8) \times 10^6$ J/ψ events

BaBar: PRD 74, 091103R (2006)

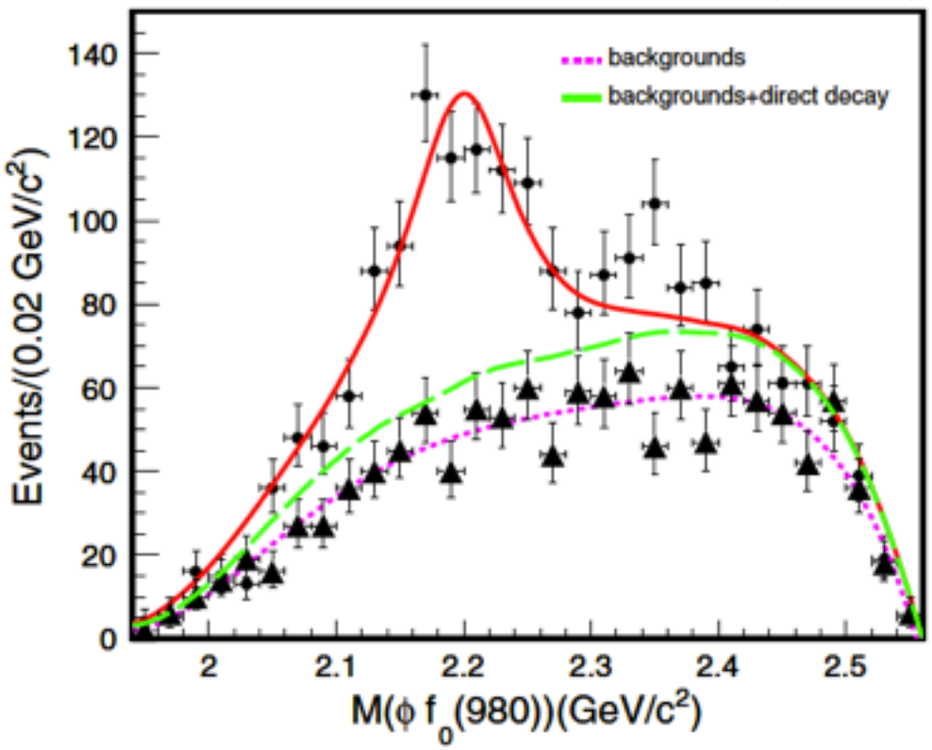


Study of $J/\psi \to \eta\phi\pi^+\pi^-$

- Based on (225.3 ± 2.8) x 10^6 J/ψ events
- Y(2175) observed with significance > 10 σ

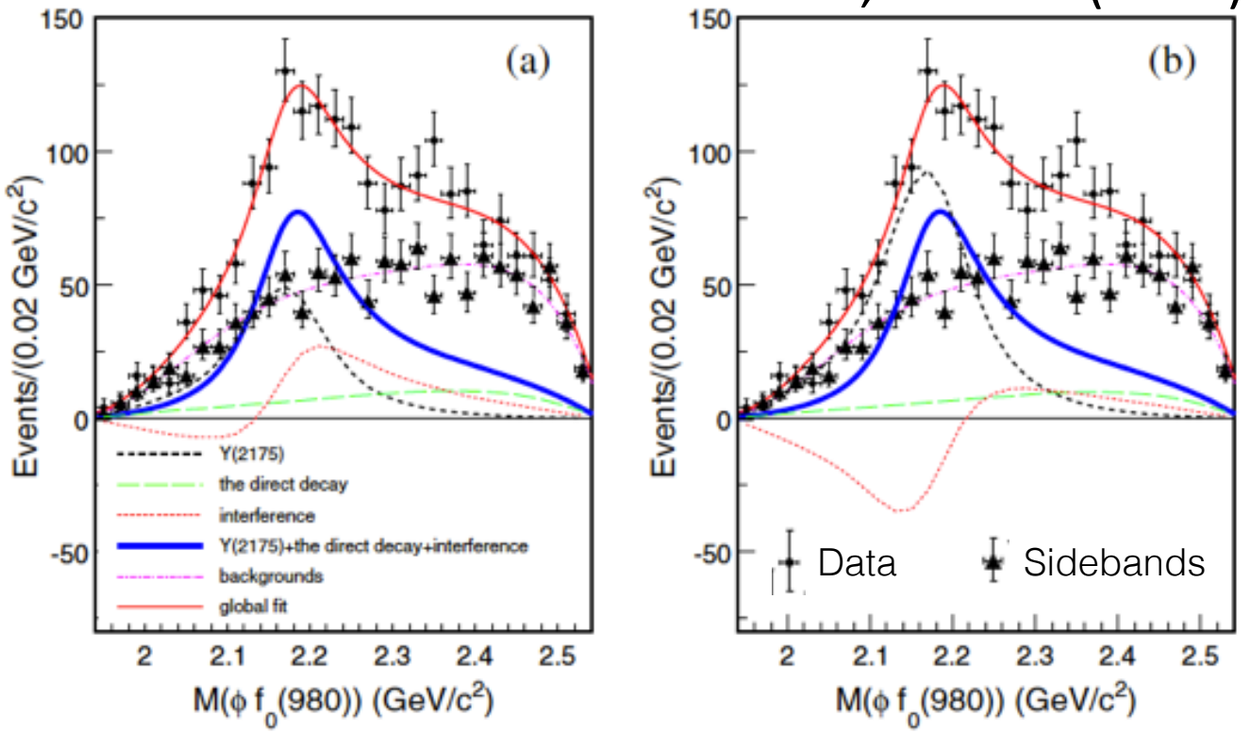
Collaboration	Process	M (MeV/c^2)	Γ (MeV)
BABAR [2]	$e^+e^- \to \phi f_0$ (ISR)	$2175 \pm 10 \pm 15$	$58 \pm 16 \pm 20$
BESII [3]	$J/\psi \to \eta\phi f_0(980)$	$2186 \pm 10 \pm 6$	$65 \pm 23 \pm 17$
BELLE [4]	$e^+e^- \to \phi f_0$ (ISR)	$2079 \pm 13^{+79}_{-28}$	$192 \pm 23^{+25}_{-61}$
BABAR (updated) [5]	$e^+e^- \to \phi f_0$ (ISR)	$2172 \pm 10 \pm 8$	$96 \pm 19 \pm 12$
BESIII	$J/\psi \to \eta\phi f_0(980)$	$2200 \pm 6 \pm 5$	$104 \pm 15 \pm 15$

PRD 91, 052017 (2015)



$$\mathcal{B}(J/\psi \to \eta Y(2175), Y(2175) \to \phi f_0(980), f_0(980) \to \pi^+\pi^-) = (1.20 \pm 0.14(\text{stat}) \pm 0.37(\text{syst})) \times 10^{-4}$$

PRD 91, 052017 (2015)



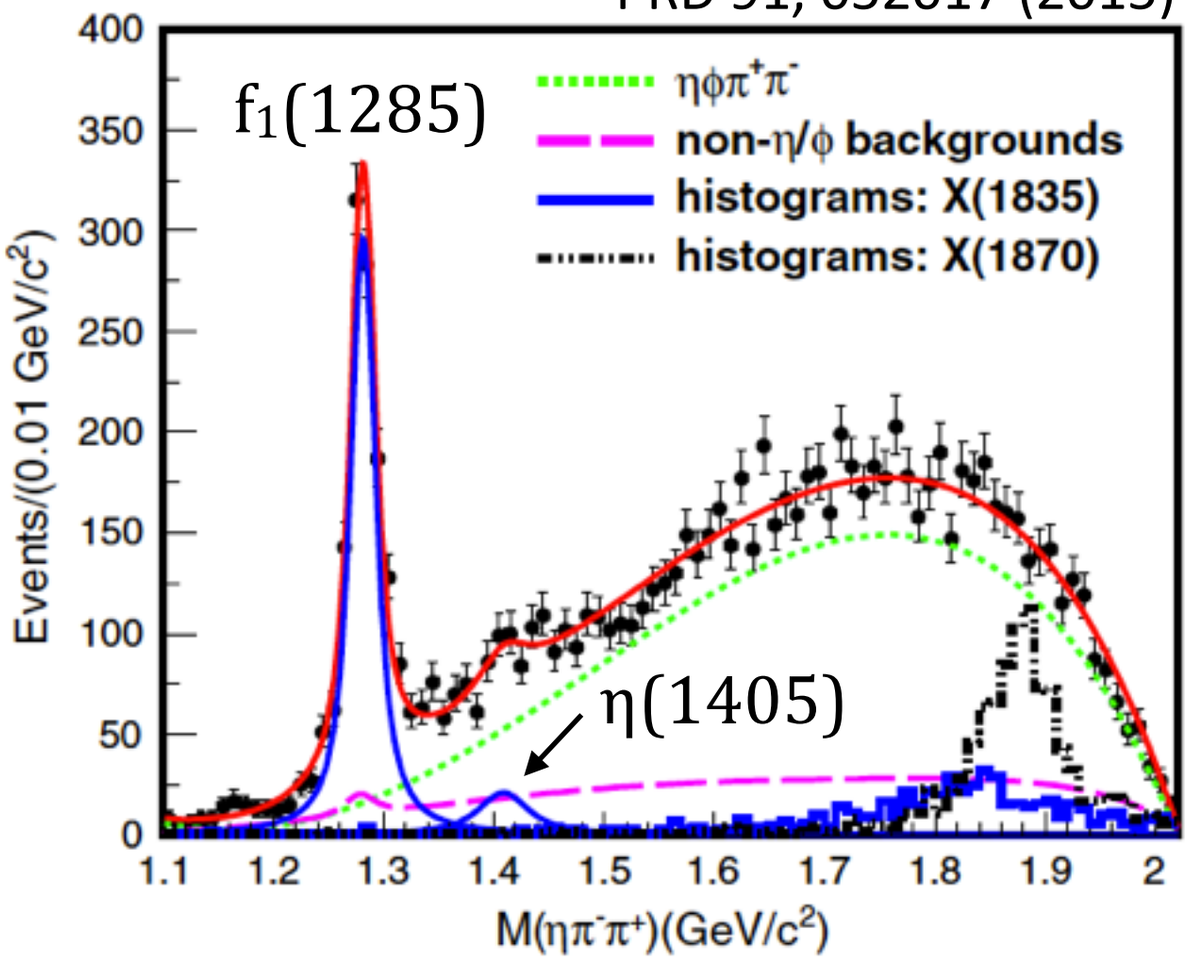
- Also repeat fit including interference between the Y(2175) and the direct decay

Parameters	Constructive	Destructive
M (MeV/c^2)	2171 ± 10	2170 ± 9
Γ (MeV)	128 ± 26	126 ± 25
Signal yields	400 ± 167	744 ± 40
relative angle Φ(rad)	-0.51 ± 0.78	0.60 ± 0.64

Study of $J/\psi \to \eta\phi\pi^+\pi^-$

- Also provides a unique opportunity to investigate properties of other states: $f_1(1285)$, $\eta(1295)$, $\eta(1405)/\eta(1475)$, X(1835), X(1870)

PRD 91, 052017 (2015)



- Fit $\eta\pi\pi$ mass spectrum against the ϕ
- $\eta(1405)$ signal with 3.6σ significance
- No evidence of X(1835) or X(1870)

$B(J/\psi \to \phi f_1 \to \eta\phi\pi^+\pi^-) = (1.20 \pm 0.06 \pm 0.14) \times 10^{-4}$

$B(J/\psi \to \phi\eta(1405) \to \eta\phi\pi^+\pi^-) = (2.01 \pm 0.58 \pm 0.82) \times 10^{-4}$

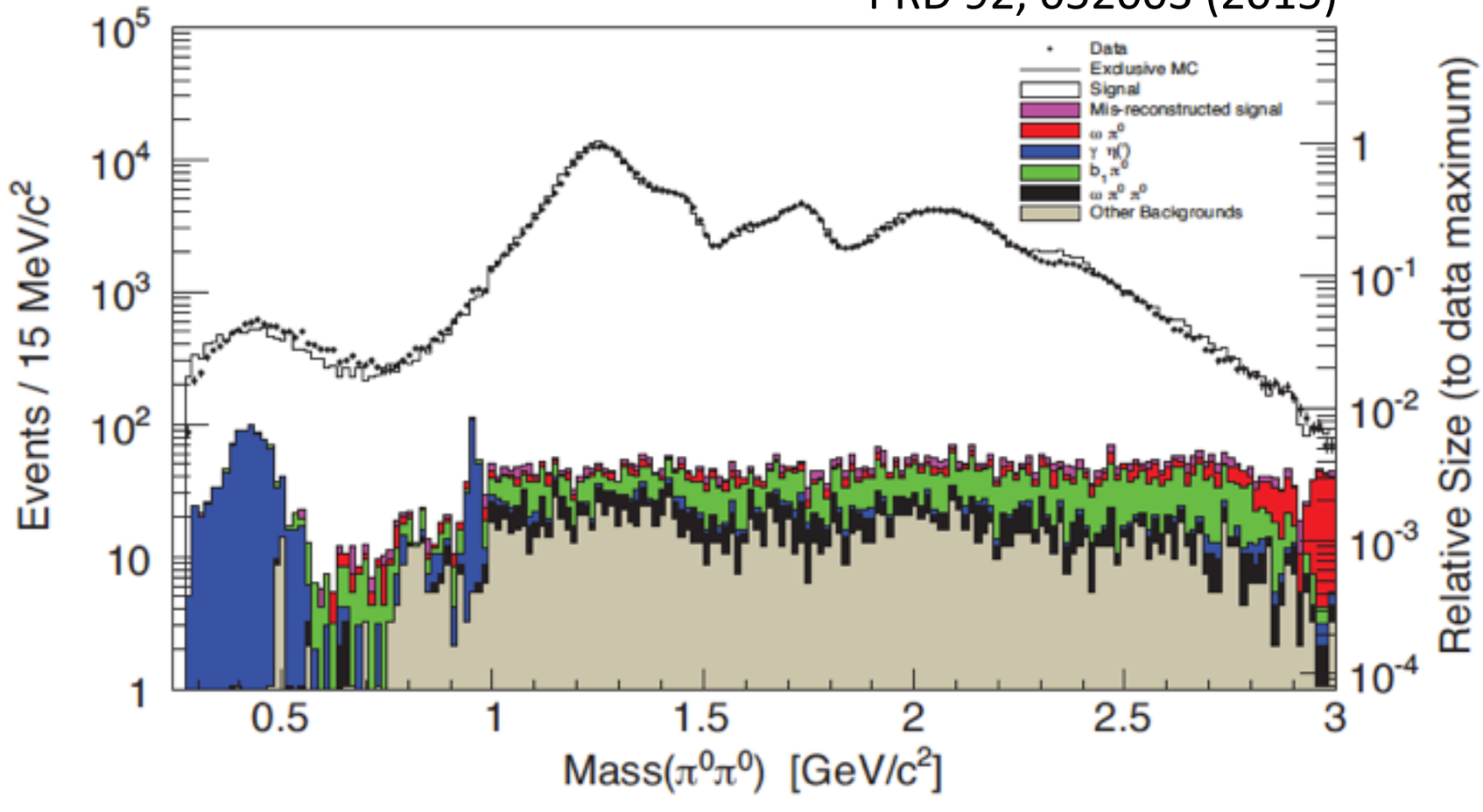
Amplitude analysis of the $\pi^0\pi^0$ system in radiative J/ψ decays

- Study scalar and tensor spectrum in radiative J/ψ decays into two pseudoscalar mesons
  - Only 0^{++} and 2^{++} amplitudes contribute significantly
  - Glueball states predicted in the region around 1.5 and 2 GeV/c^2
  - Presence of broad, overlapping states makes parameterization challenging

Full J/ψ sample
$(1.311 \pm 0.011) \times 10^9$

Very clean spectrum:
~440k events with a background level less than 2%

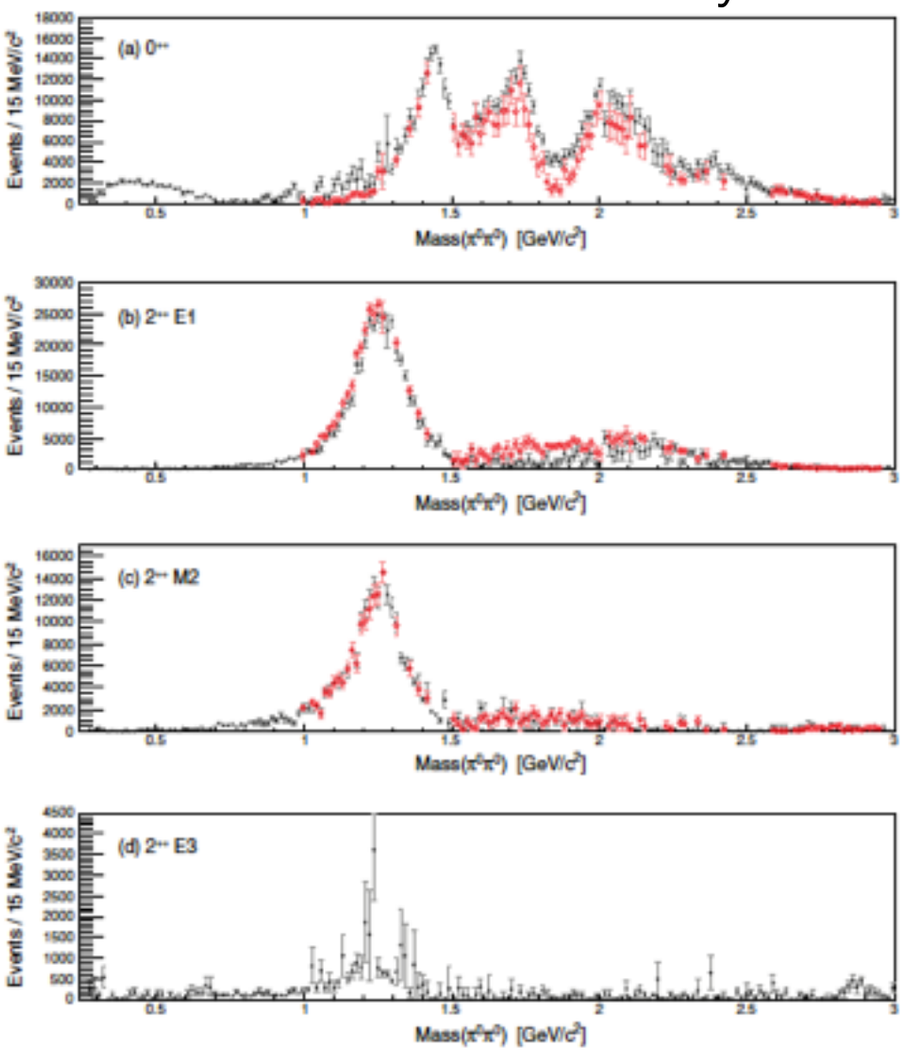
PRD 92, 052003 (2015)



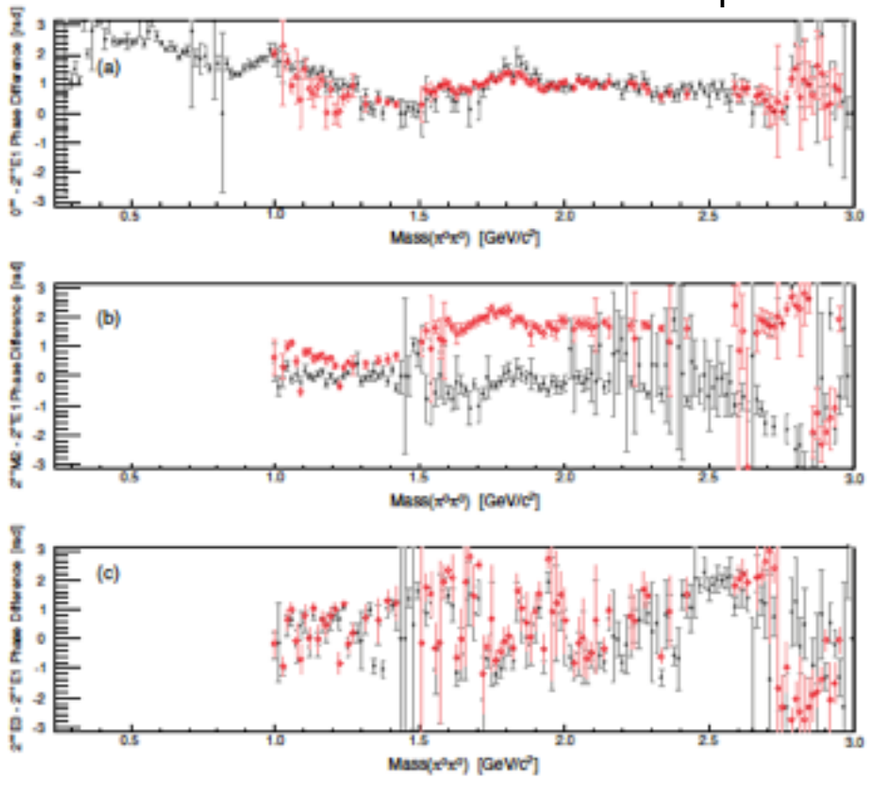
Amplitude analysis of the $\pi^0\pi^0$ system in radiative J/ψ decays

- Perform mass independent amplitude analysis
  - Useful for model development to describe hadronic interactions
  - Great opportunity for collaboration between theory and experiment!
  - Similar approach is under investigation for other systems (e.g. K_SK_S)

Extracted Intensity



Phase difference wrt E1 amplitude



PRD 92, 052003 (2015)

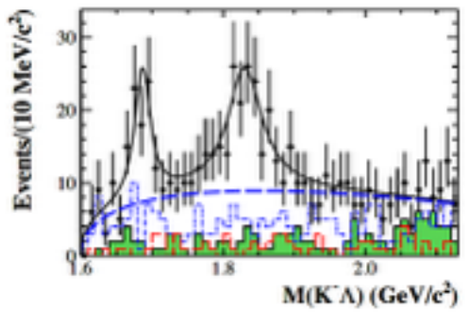
nominal solution
ambigous solution

$$\mathcal{B}(J/\psi \to \gamma\pi^0\pi^0) = (1.15 \pm 0.05) \times 10^{-3}$$

Many more results in light hadron spectroscopy

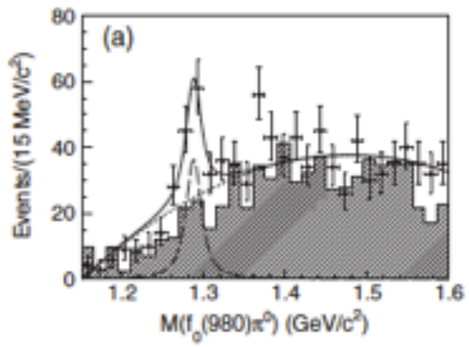
PRD 91, 092006 (2015)

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



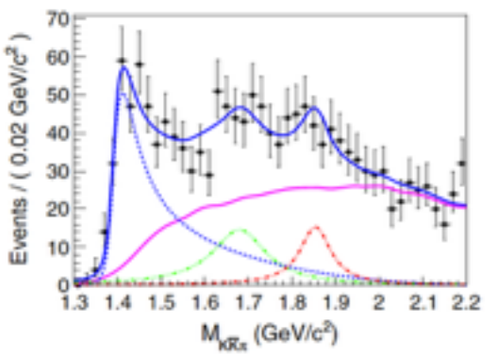
PRD 92, 012007 (2015)

- Observation of the isospin-violating decay $J/\psi \to \phi\pi^0 f_0(980)$



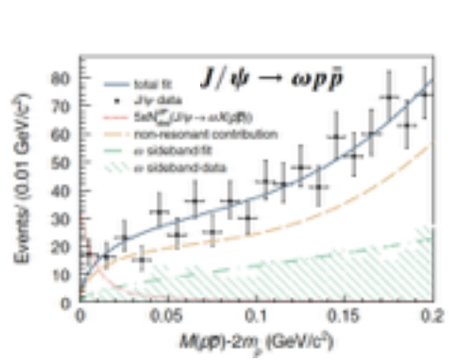
PRD 91, 112008 (2015)

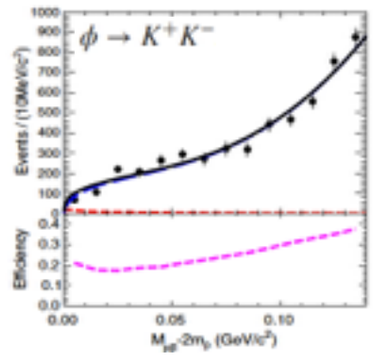
- Study of χ_{cJ} decaying into $\phi K^*\bar{K}$



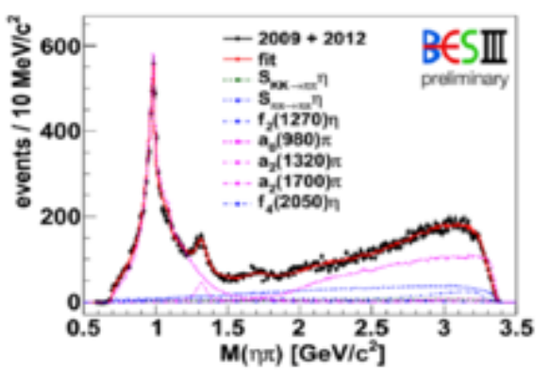
PRD 87, 112004 (2013) PRD 93, 052010 (2016)

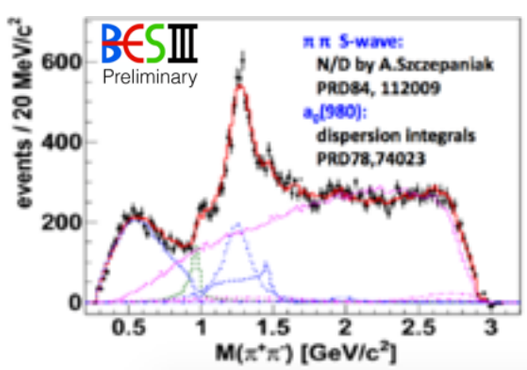
- Studies of the $p\bar{p}$ spectrum in hadronic J/ψ decays





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





Conclusions

- High statistics charmonium data sets are producing many interesting results!
  - Observation of $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$
  - Tests of the 12% rule in ψ decays to $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$
  - Study of helicity selection rule suppressed process $\chi_{c2} \to VP$
  - $\Upsilon(2175)$ observed in J/ψ decays to $\eta\phi\pi^+\pi^-$
  - Mass independent amplitude analysis of $\pi^0\pi^0$ system
  - … many more results in light hadron spectroscopy!

- Still more to come!