BESIII

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

# Hadron Physics at BESIII

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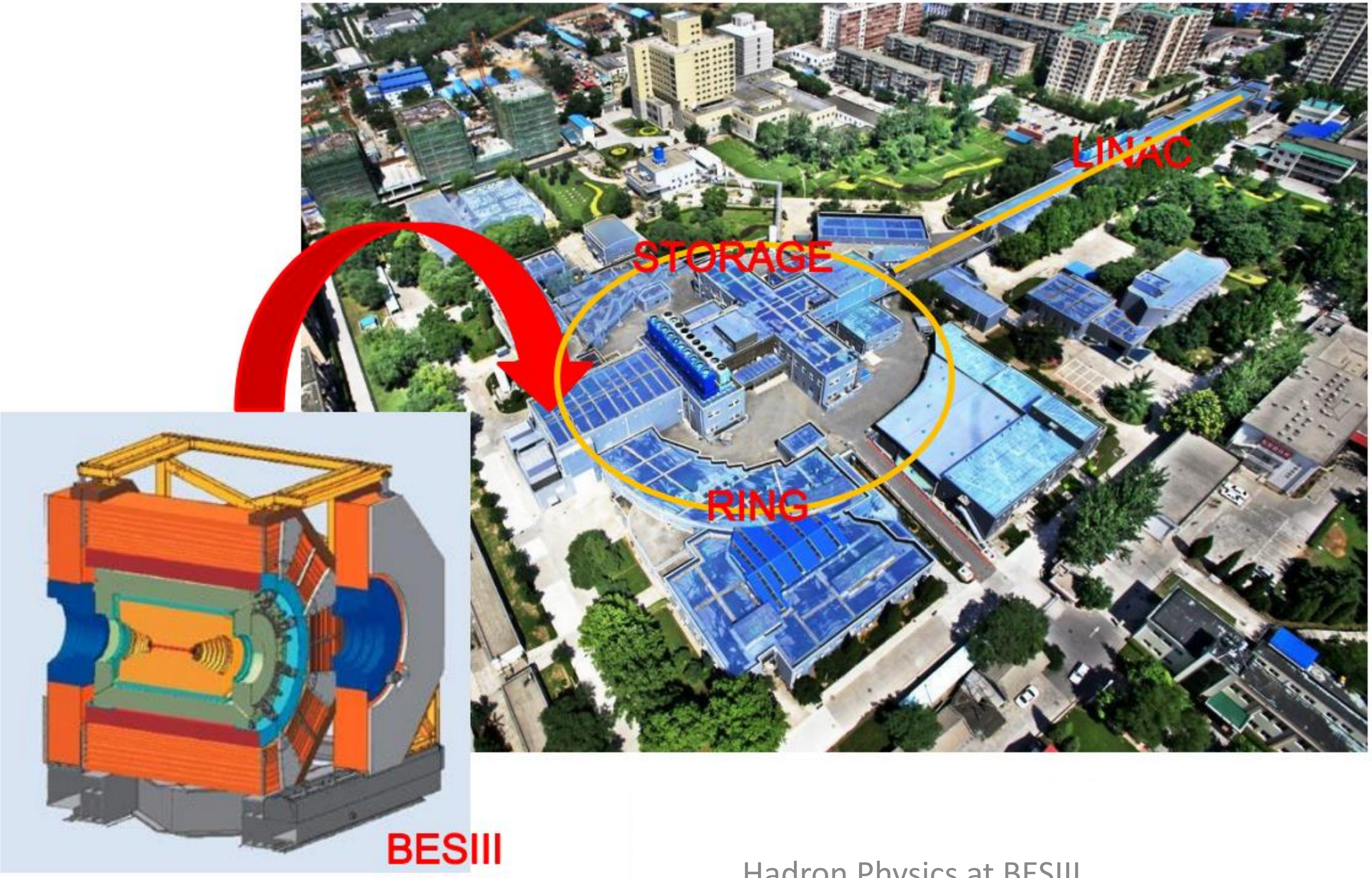
On Behalf of the BESIII Collaboration

**2016 JAEA/ASRC Reimei Workshop: New Exotic Hadron Matter**

**Oct. 25th, Inha University**

# BEPCII and BESIII




Beam energy: 1.0 ~ 2.3 GeV

Luminosity: $1.0\times10^{33}$ $cm^{-2}s^{-1}$
(reached in April 5th, 2016)

2004: BEPCII upgrade

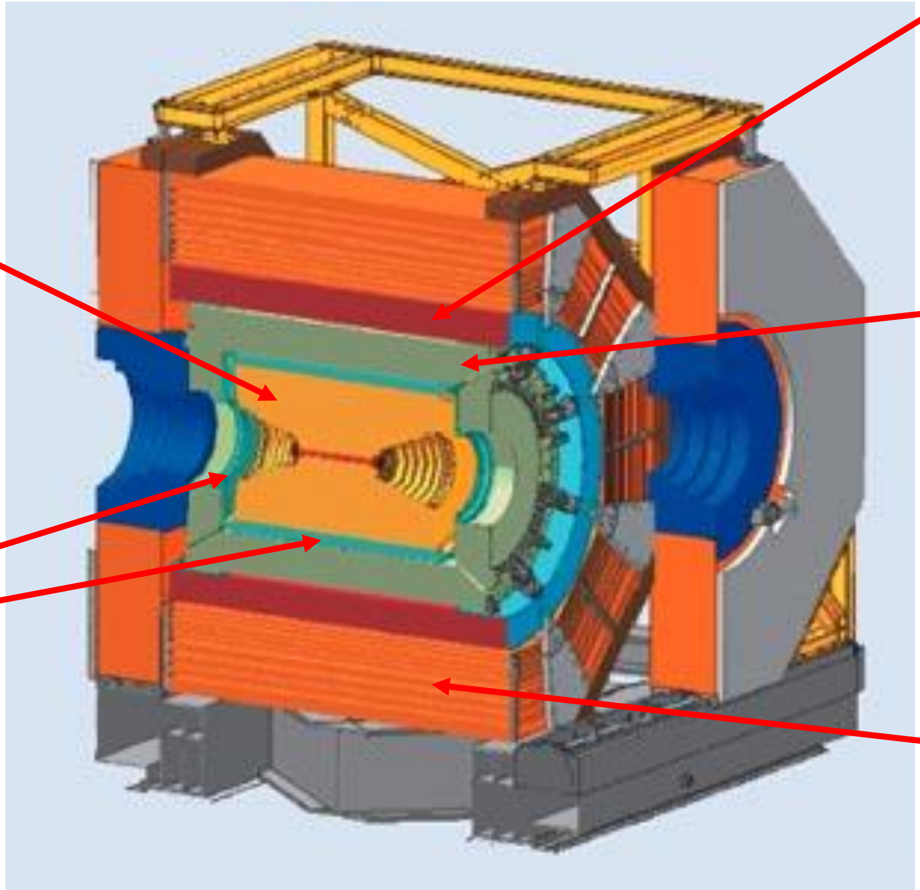
2008: test run

2009 ~ now: physics run

# BEPCII and BESIII

**Main Drift Chamber (MDC)**
$\sigma_P/P$ = 0.5% (1 GeV)
$\sigma_{dE/dx}$ = 6%

**Super-Conducting Magnet**
1.0 T (2009)
0.9 T(2012)

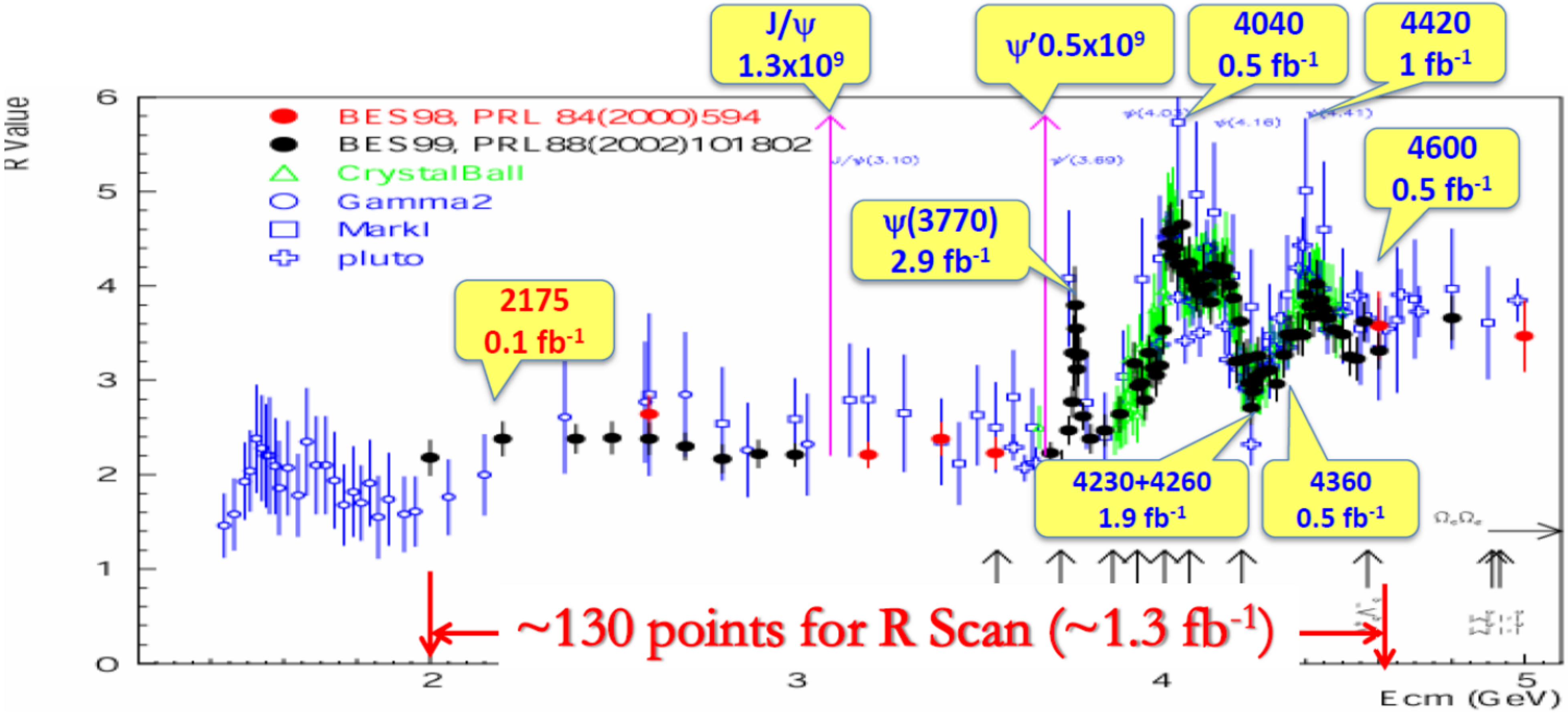


**Electromagnetic Calorimeter (EMC)**
CsI (Tl)
$\sigma_E/\sqrt{E}$= 2.5% (1 GeV)
$\sigma_{z,\phi}$ = 0.5 - 0.7 cm/$\sqrt{E}$

**Time of Flight (TOF)**
$\sigma_T$: 90 ps (barrel)
110 ps (endcap)

**μ Counter (MUC)**
8 - 9 layers RPC
$\delta_{R\Phi}$ = 1.4 cm ~ 1.7 cm

# BEPCII and BESIII




**World largest J/ψ, ψ(3686), ψ(3770), …**

**Produced directly from $e^+e^-$ annihilation: an ideal factory to study hadron spectroscopy**

# Multi-quark state, Glueball, Hybrid

- Conventional hadrons consist of 2 or 3 quarks
  - Meson: $q\bar{q}$
  - Bayron: qqq

**Constituent Quark Model**

- QCD allows hadrons of other forms:
  - Multi-quark state: >= 4 quarks
  - Glueball: gg, ggg, …
  - Hybrid: $q\bar{q}g$, qqqg, …

**Lots of candidates**
**Not established yet**

- Searching for new forms of hadrons provide test of QCD

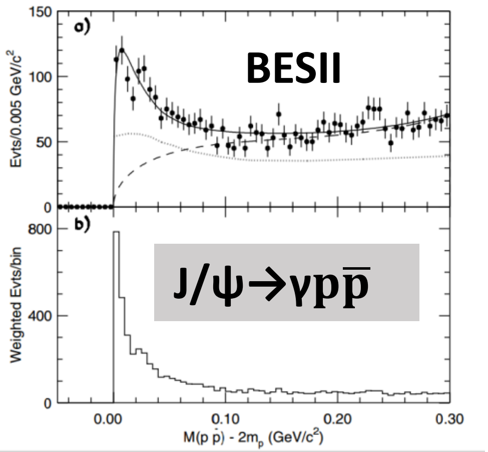
# Recent results on new hadrons from BESIII

- $X(p\bar{p})$ and X(1835)
  - Observation of X(1835) in $J/\psi \to \gamma K_S K_S \eta$ and determination of $J^{PC}$ of X(1835)
  - Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$
- Glueball searches
  - Model independent partial wave analysis of $J/\psi \to \gamma\pi^0\pi^0$
  - Partial wave analysis of $J/\psi \to \gamma\phi\phi$
- $Z_c$ structures

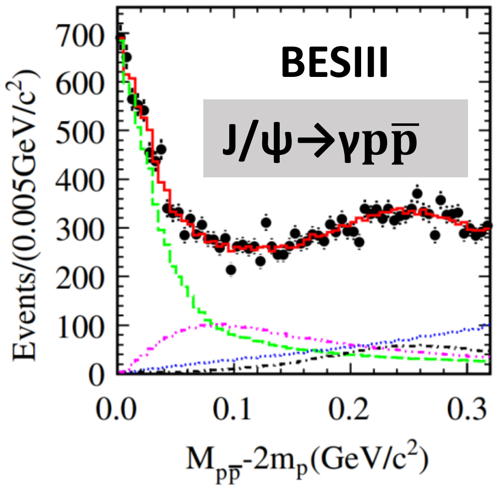
# X($p\bar{p}$) and X(1835)

- Discovered by BESII in $J/\psi \to \gamma p\bar{p}$
- Confirmed by BESIII and CLEO-c in $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$
- Confirmed by BESIII in $J/\psi \to \gamma p\bar{p}$
  - **$0^{-+}$**
  - $M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19\ \mathrm{MeV}/c^2$
  - $\Gamma = 13 \pm 19\ \mathrm{MeV}/c^2$
    ($< 76\ \mathrm{MeV}/c^2$ @ 90% C.L.)

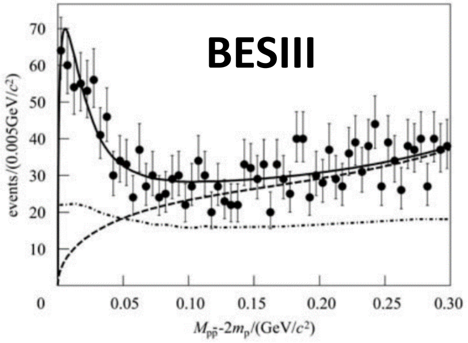
*Phys. Rev. Lett. 91, 022001*



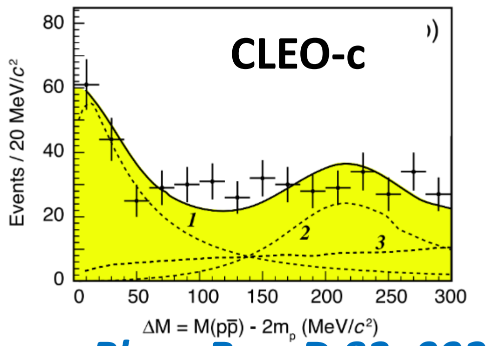

*Phys. Rev. Lett. 106, 072002*




**$\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$**



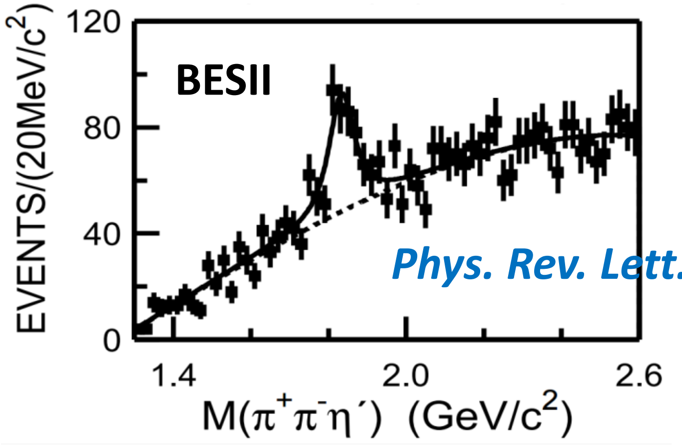

*Chin. Phys. C 34, 421*



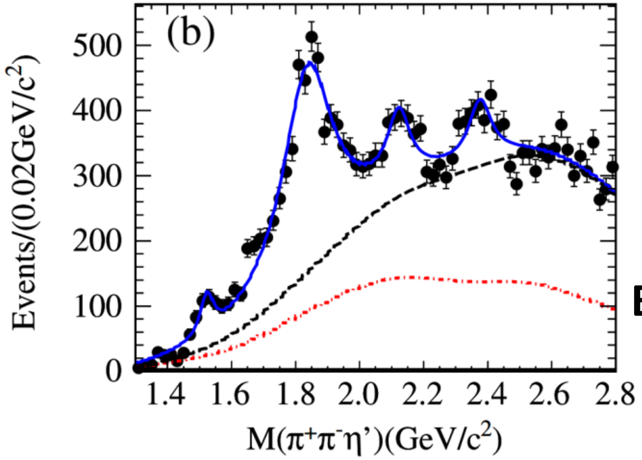

*Phys. Rev. D 82, 092002*

# X($p\bar{p}$) and X(1835)

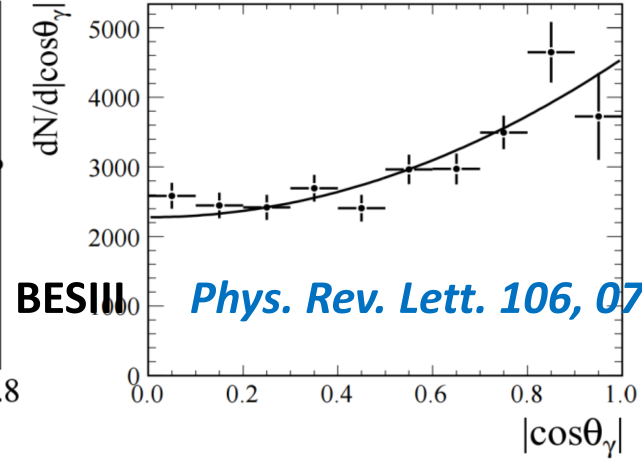
- Discovered by BESII in $J/\psi \to \gamma\eta'\pi^+\pi^-$
- Confirmed by BESIII in $J/\psi \to \gamma\eta'\pi^+\pi^-$
  - ✓ $\mathrm{M} = 1836.5 \pm 3.0^{+5.6}_{-2.1}\ \mathrm{MeV}/c^2$
  - ✓ $\Gamma = 190 \pm 9^{+38}_{-36}\ \mathrm{MeV}/c^2$
  - ✓ **Angular distribution is consistent with $0^-$**




*Phys. Rev. Lett. 95, 262001*




BESIII

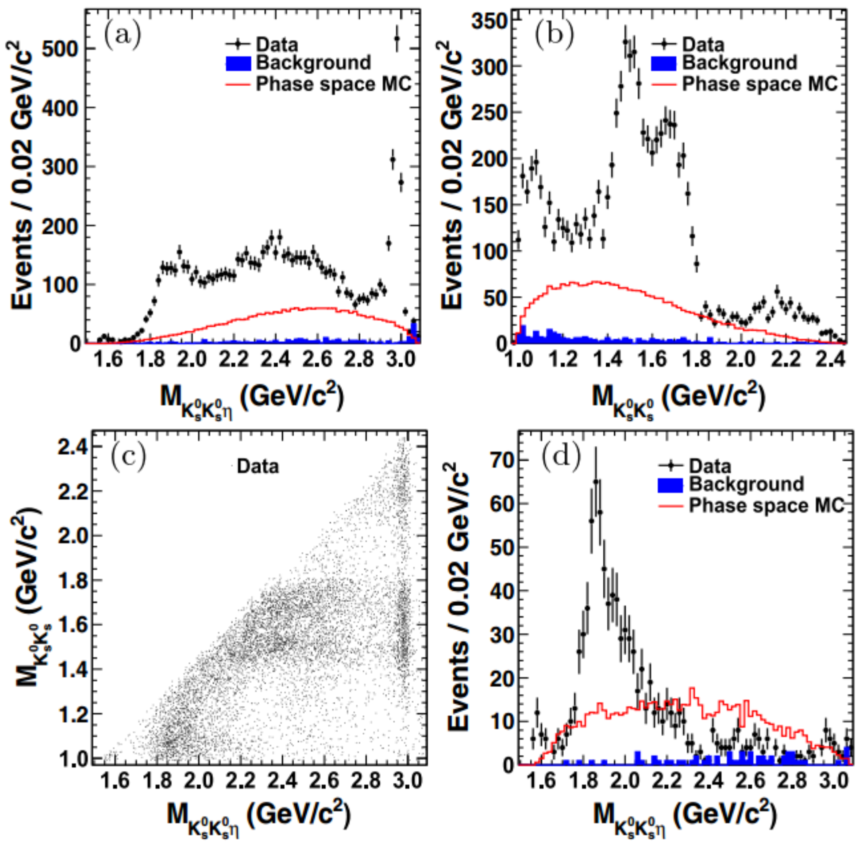



*Phys. Rev. Lett. 106, 072002*

# Observation of X(1835) in J/ψ→γ$K_S K_S$η

- Use 1.3×$10^9$ J/ψ events collected by BESIII in 2009 and 2012
- Clear structure on mass spectrum of $K_S K_S$η around 1.85 $\mathrm{GeV}/c^2$
- Strongly correlated to $f_0(980)$
- PWA for M($K_S K_S$) < 1.1 $\mathrm{GeV}/c^2$

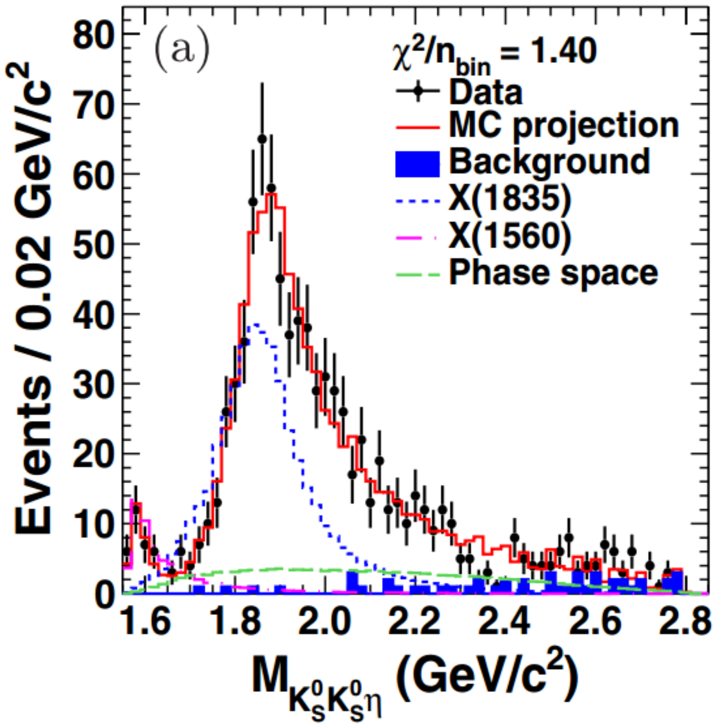
*Phys. Rev. Lett. 115, 091803*



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

- X(1560)
  - $J^{PC}$: $0^{-+}$; $X(1560) \to K_S K_S \eta$ (> 8.9σ)
  - $M = 1565 \pm 8^{+0}_{-63}\ \mathrm{MeV}/c^2$
  - $\Gamma = 45^{+14+21}_{-13-28}\ \mathrm{MeV}/c^2$
  - Consistent with η(1405)/η(1475) within 2.0σ
- X(1835)
  - $J^{PC}$: $0^{-+}$
  - $X(1835) \to K_S K_S \eta$ (> 12.9σ), dominated by $f_0(980)$ production
  - $M = 1844 \pm 9^{+16}_{-25}\ \mathrm{MeV}/c^2$
  - $\Gamma = 192^{+20+62}_{-17-43}\ \mathrm{MeV}/c^2$
  - Consistent with the values obtained from $J/\psi \to \gamma \eta' \pi^+ \pi^-$
  - $\mathfrak{B}(J/\psi \to \gamma X(1835)) \cdot \mathfrak{B}(X(1835) \to K_S K_S \eta) = (3.31^{+0.33+1.96}_{-0.30-1.29}) \times 10^{-5}$

*Phys. Rev. Lett. 115, 091803*

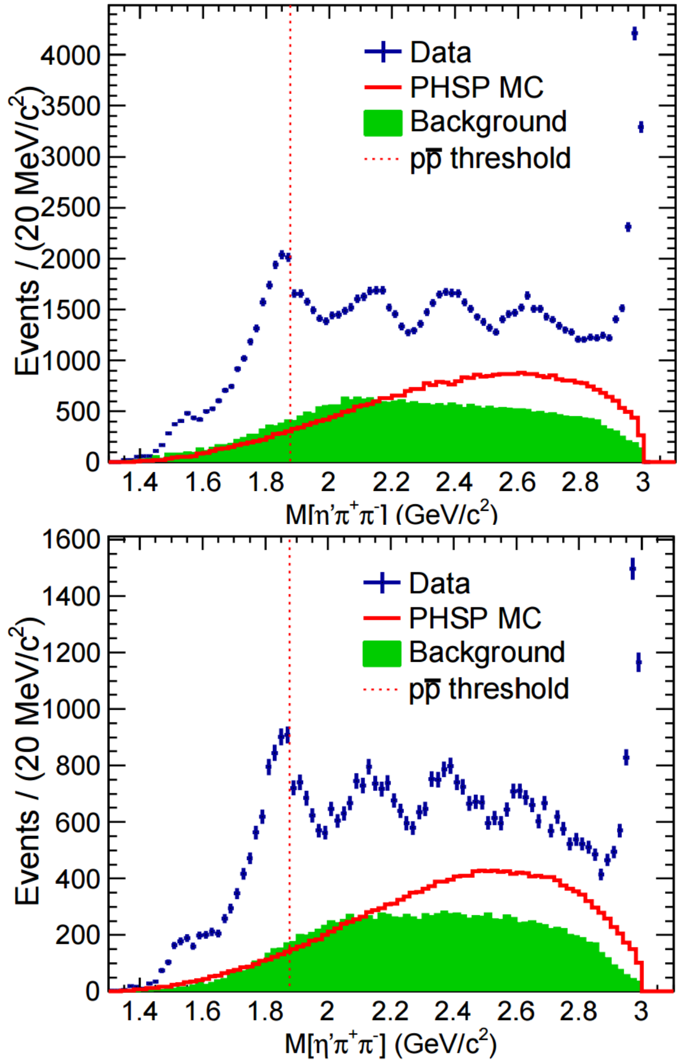


# X($p\bar{p}$) and X(1835)

| X($p\bar{p}$) | X(1835) |
|---|---|
| $0^{-+}$ | $0^{-+}$ |
| $M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/$c^2$ | $M = 1836.5 \pm 3.0^{+5.6}_{-2.1}$ MeV/$c^2$ |
| $\Gamma = 13 \pm 19$ MeV/$c^2$ ($< 76$ MeV/$c^2$ @ 90% C.L.) | $\Gamma = 190 \pm 9^{+38}_{-36}$ MeV/$c^2$ |
| $p\bar{p}$ bound state?<br>… | $p\bar{p}$ bound state?<br>η′ excitation?<br>glueball?<br>… |
| **The SAME state?** | |

# Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

- Use $1.09\times10^9$ $J/\psi$ events collected by BESIII in 2012
- Two decay modes of $\eta'$
  - $\eta' \to \gamma\pi^+\pi^-$
  - $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$
- Clear peaks of X(1835), X(2120), X(2370), $\eta_c$, and a structure near 2.6 $\mathrm{GeV}/c^2$
- **A significant distortion of the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold**

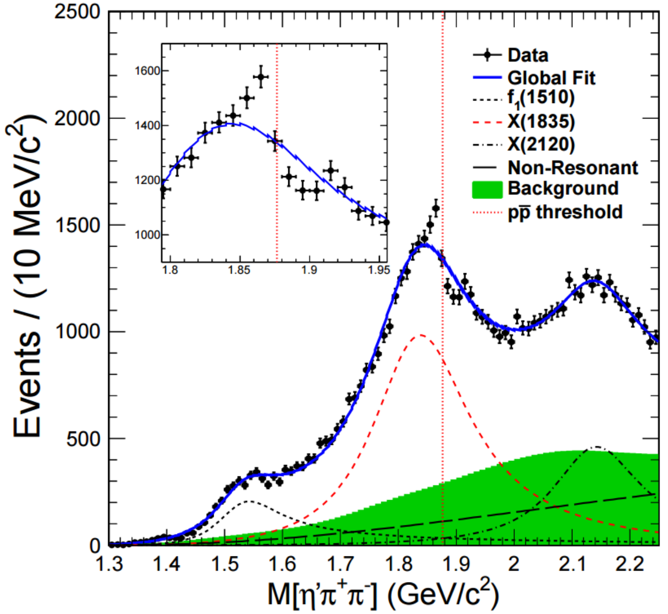



*Phys. Rev. Lett. 117, 042002*

# Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

*Phys. Rev. Lett. 117, 042002*

- Simultaneous fits to two η′ decay modes
- Simple Breit-Wigner function fails in describing the $\eta'\pi^+\pi^-$ line shape near the $p\bar{p}$ mass threshold
- **Two typical circumstances where an abrupt distortion of a resonance's line shape shows up**
  - **Threshold structure caused by the opening of an additional $p\bar{p}$ decay mode**
    - Use the Flatté formula for the line shape
  - **Interference between two resonances**
    - Use coherent sum of two Breit-Wigner amplitudes for the line shape

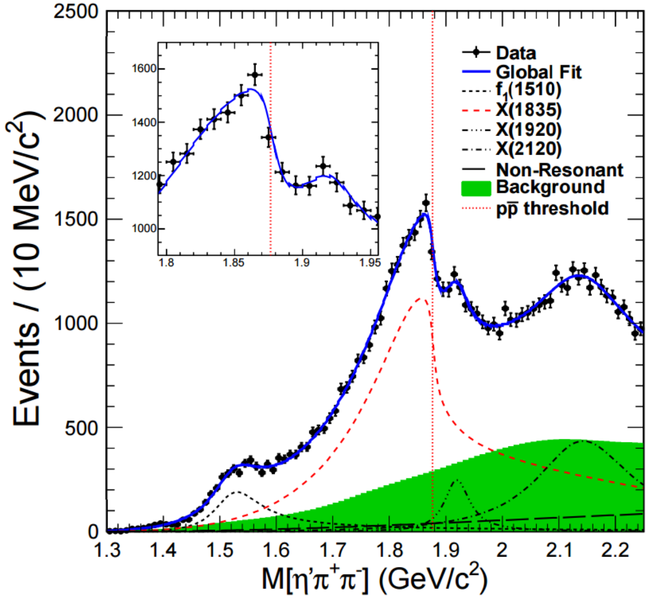



**$\log\mathcal{L}$ = 630503.3**

# Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

*Phys. Rev. Lett. 117, 042002*

- Use the Flatté formula for the line shape
  - $T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}$
    - $\sum_k g_k^2 \rho_k \simeq g_0^2 (\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2} \rho_{p\bar{p}})$
    - $g_{p\bar{p}}^2 / g_0^2$ is the ratio between the coupling strength to the $p\bar{p}$ channel and the sum of all other channels




| The state around 1.85 GeV/$c^2$ | |
|---|---|
| $\mathcal{M}$ (MeV/$c^2$) | $1638.0^{+121.9}_{-121.9}{}^{+127.8}_{-254.3}$ |
| $g_0^2$ ((GeV/$c^2$)$^2$) | $93.7^{+35.4}_{-35.4}{}^{+47.6}_{-43.9}$ |
| $g_{p\bar{p}}^2/g_0^2$ | $2.31^{+0.37}_{-0.37}{}^{+0.83}_{-0.60}$ |
| $M_{pole}$ (MeV/$c^2$) * | $1909.5^{+15.9}_{-15.9}{}^{+9.4}_{-27.5}$ |
| $\Gamma_{pole}$ (MeV/$c^2$) * | $273.5^{+21.4}_{-21.4}{}^{+6.1}_{-64.0}$ |
| Branching Ratio | $(3.93^{+0.38}_{-0.38}{}^{+0.31}_{-0.84}) \times 10^{-4}$ |

* The pole nearest to the $p\bar{p}$ mass threshold

**A $p\bar{p}$ molecule-like state?**

**$\log\mathcal{L}$ = 630549.5**

**Significance of $g_{p\bar{p}}^2/g_0^2$ being non-zero is larger than 7σ**

X(1920) is needed with 5.7σ

# Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

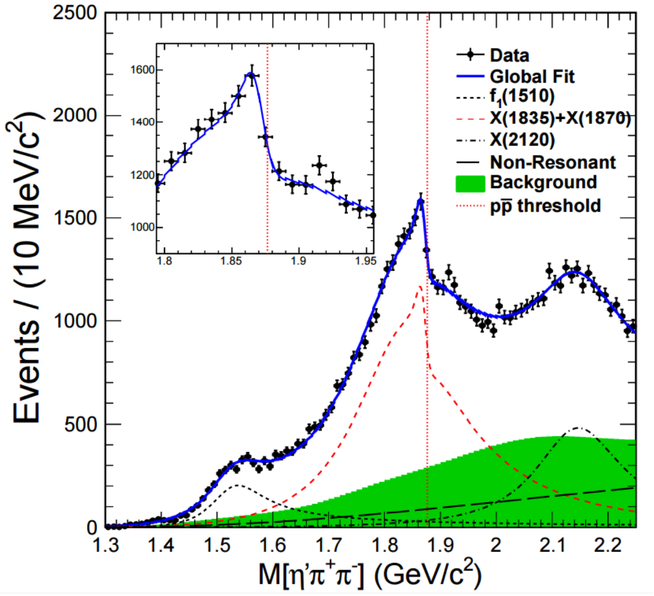
*Phys. Rev. Lett. 117, 042002*

- Use coherent sum of two Breit-Wigner amplitudes
  - $T = \frac{\sqrt{\rho_{out}}}{M_1^2 - s - iM_1\Gamma_1} + \frac{\beta \cdot e^{i\theta} \cdot \sqrt{\rho_{out}}}{M_2^2 - s - iM_2\Gamma_2}$

| X(1835) | |
|---|---|
| M (MeV/$c^2$) | $1825.3\ ^{+2.4}_{-2.4}\ ^{+17.3}_{-2.4}$ |
| Γ (MeV/$c^2$) | $245.2\ ^{+14.2}_{-12.6}\ ^{+4.6}_{-9.6}$ |
| B.R. (constructive interference) | $(3.01\ ^{+0.17}_{-0.17}\ ^{+0.26}_{-0.28}) \times 10^{-4}$ |
| B.R. (destructive interference) | $(3.72\ ^{+0.21}_{-0.21}\ ^{+0.18}_{-0.35}) \times 10^{-4}$ |

| X(1870) | |
|---|---|
| M (MeV/$c^2$) | $1870.2\ ^{+2.2}_{-2.3}\ ^{+2.3}_{-0.7}$ |
| Γ (MeV/$c^2$) | $13.0\ ^{+7.1}_{-5.5}\ ^{+2.1}_{-3.8}$ |
| B.R. (constructive interference) | $(2.03\ ^{+0.12}_{-0.12}\ ^{+0.43}_{-0.70}) \times 10^{-7}$ |
| B.R. (destructive interference) | $(1.57\ ^{+0.09}_{-0.09}\ ^{+0.49}_{-0.86}) \times 10^{-5}$ |

**A $p\bar{p}$ bound state?**




**log$\mathcal{L}$ = 630540.3**

**Significance of X(1870) is larger than 7σ**

X(1920) is not significant

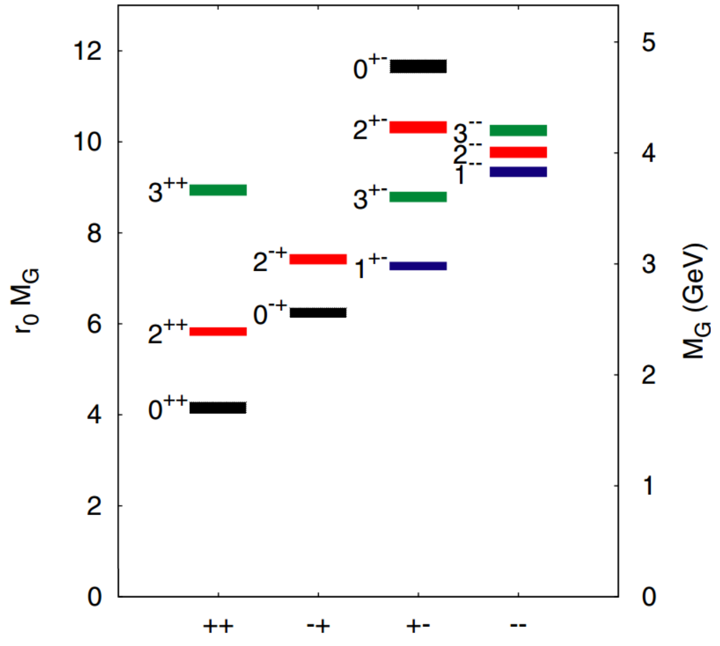
# Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$

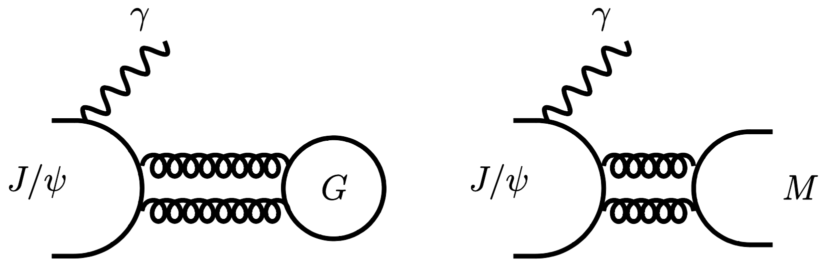
- Both models fit the data well with almost equally good quality
  - Cannot distinguish them with current data
  - **Suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold**
  - **Support the existence of a $p\bar{p}$ molecule-like state or bound state**
- To elucidate further the nature of the state
  - More $J/\psi$ data
  - Study line shapes in other decay modes
    - $J/\psi \rightarrow \gamma p\bar{p}$
    - $J/\psi \rightarrow \gamma K_S K_S \eta$
    - …

# Glueballs

- Formed by gluon-gluon interaction: non-Abel gauge self-interaction
  - Predicted by QCD
  - Not established in experiment
- LQCD prediction
  - $0^{++}$ ground state: $1\sim2\ \mathrm{GeV}/c^2$
  - $2^{++}$ ground state: $2.3\sim2.4\ \mathrm{GeV}/c^2$
  - $0^{-+}$ ground state: $2.3\sim2.6\ \mathrm{GeV}/c^2$
- Radiative J/ψ decays are believed to be an ideal place to search for glueballs

*Phys. Rev. D 73, 014516*

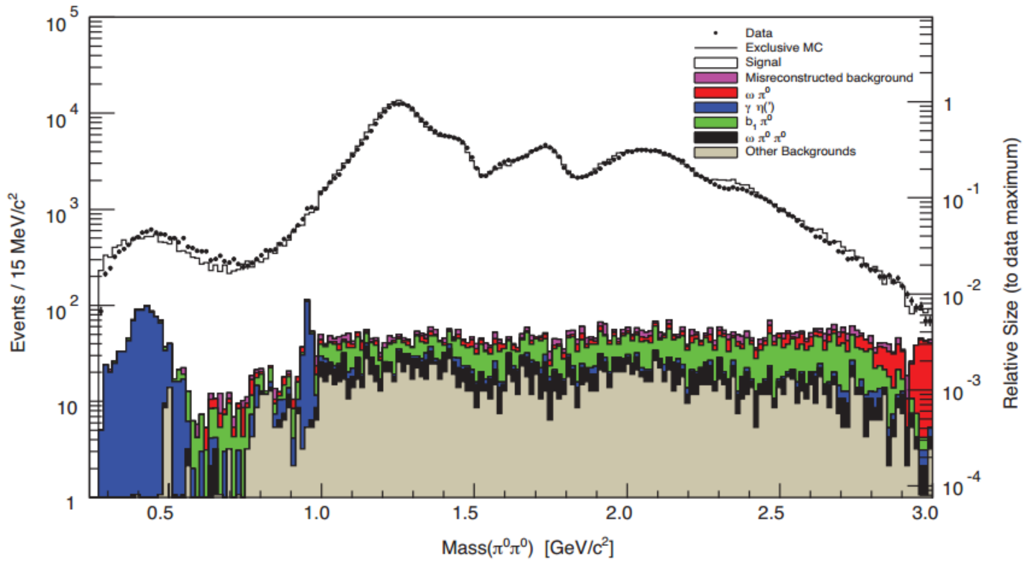


# Model Independent PWA of $J/\psi \rightarrow \gamma\pi^0\pi^0$

- Use $1.3\times10^9$ $J/\psi$ events collected by BESIII in 2009 and 2012
- $\pi^0\pi^0$ system
  - Very clean
  - Large statistics and many open channels
  - Many broad and overlapping resonances (parameterization challenging)
  - Model independent PWA (MIPWA)

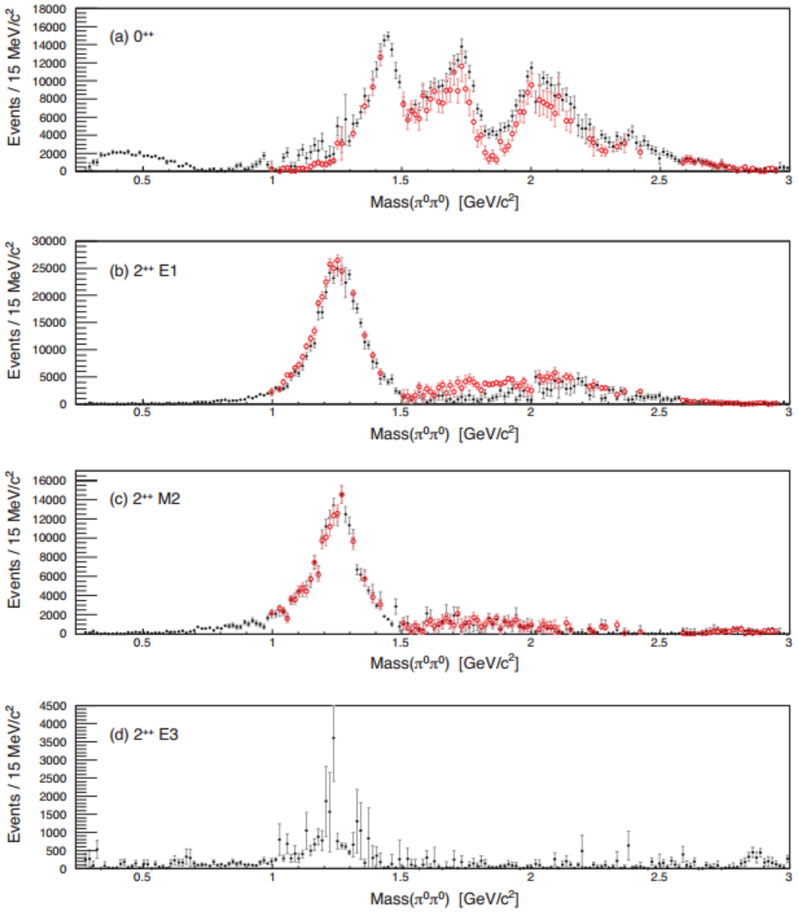
***Phys. Rev. D 92, 052003***



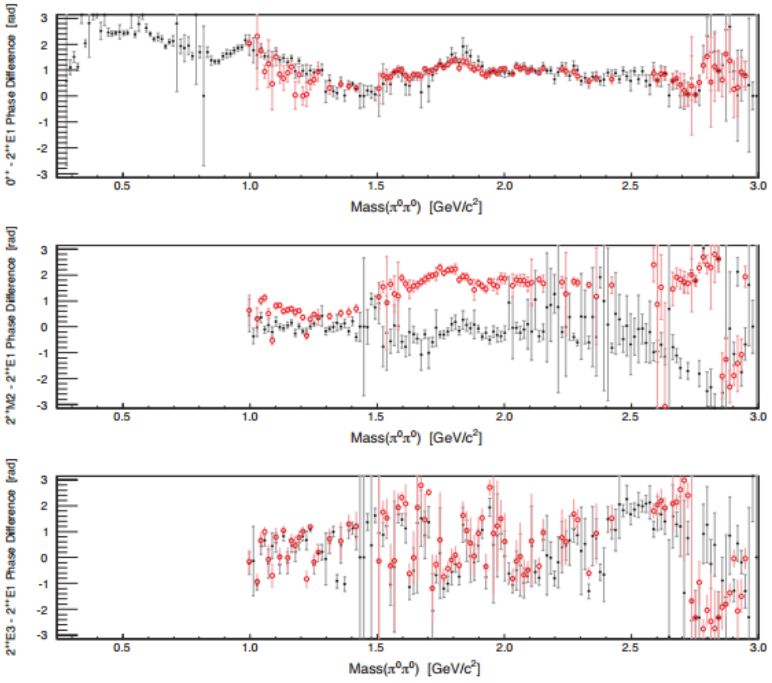

- ✓ More than 440,000 reconstructed events
- ✓ Background level ~ 1.8%

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

## Extracted Intensity




## Relative Phase




- **Solution 1**
- **Solution 2**

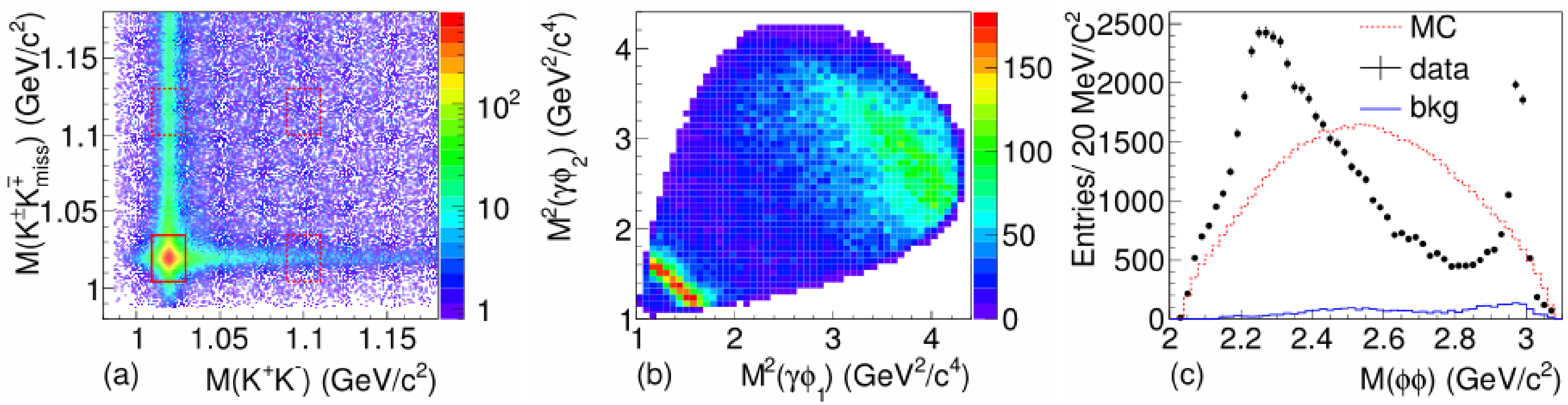
***Phys. Rev. D 92, 052003***

- ✓ 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 $\mathrm{GeV}/c^2$**
- ✓ Multi-solution problem in MIPWA is usually unavoidable.
- ✓ Only Model Dependent PWA of global PWA fit can rigerously extract resonance parameters, but cross-check between MDPWA and MIPWA is helpful.

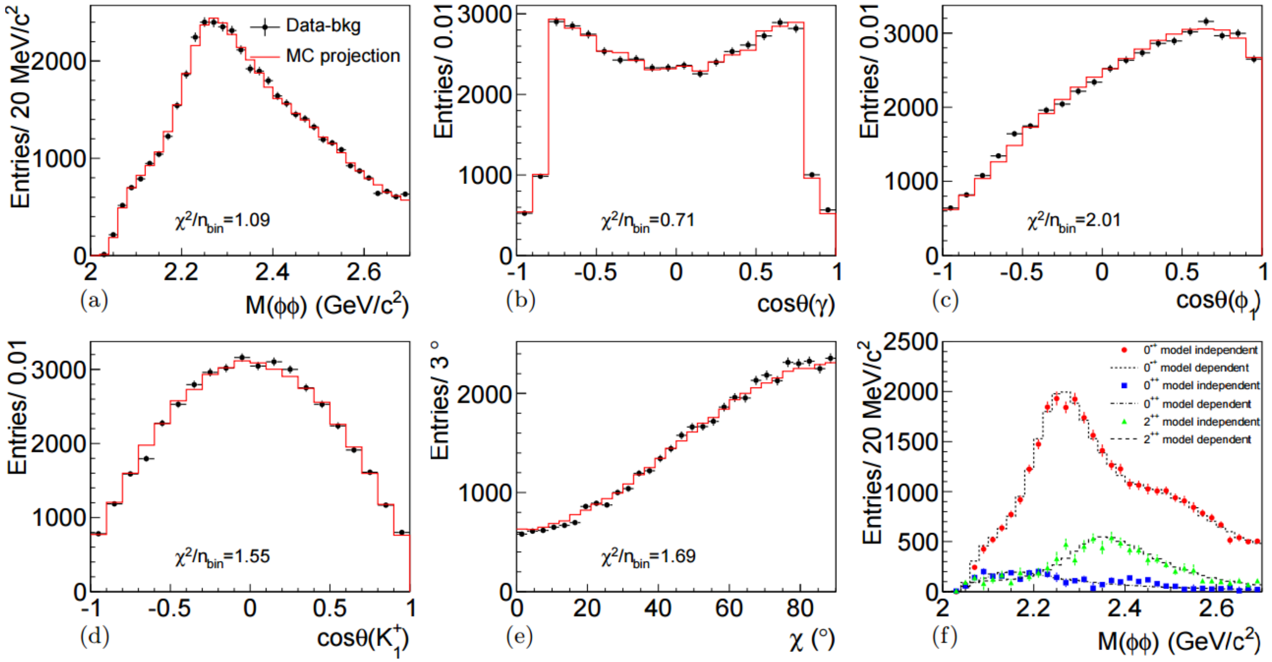
# PWA of J/ψ→γφφ

- Use $1.3\times10^9$ J/ψ events collected by BESIII in 2009 and 2012
- PWA procedure
  - Covariant tensor formalism
  - Data-driven background subtraction
  - Resonances are parameterized by relativistic Breit-Wigner with constant width
  - Resonances with significance > 5 σ are selected as components in solution

***Phys. Rev. D 93, 112011***



# PWA of J/ψ→γφφ




| Resonance | $M(\mathrm{MeV}/c^2)$ | $\Gamma(\mathrm{MeV}/c^2)$ | B.F.$(\times10^{-4})$ | Sig. |
|---|---|---|---|---|
| $\eta(2225)$ | $2216^{+4+18}_{-5-11}$ | $185^{+12+44}_{-14-17}$ | $(2.40\pm0.10^{+2.47}_{-0.18})$ | $28.1\sigma$ |
| $\eta(2100)$ | $2050^{+30+77}_{-24-26}$ | $250^{+36+187}_{-30-164}$ | $(3.30\pm0.09^{+0.18}_{-3.04})$ | $21.5\sigma$ |
| X(2500) | $2470^{+15+63}_{-19-23}$ | $230^{+64+53}_{-35-33}$ | $(0.17\pm0.02^{+0.02}_{-0.08})$ | $8.8\sigma$ |
| $f_0(2100)$ | 2102 | 211 | $(0.43\pm0.04^{+0.24}_{-0.03})$ | $24.2\sigma$ |
| $f_2(2010)$ | 2011 | 202 | $(0.35\pm0.05^{+0.28}_{-0.15})$ | $9.5\sigma$ |
| $f_2(2300)$ | 2297 | 149 | $(0.44\pm0.07^{+0.09}_{-0.15})$ | $6.4\sigma$ |
| $f_2(2340)$ | 2339 | 319 | $(1.91\pm0.07^{+0.72}_{-0.69})$ | $10.7\sigma$ |
| $0^{-+}$ PHSP | | | $(2.74\pm0.15^{+0.16}_{-1.48})$ | $6.8\sigma$ |

*Phys. Rev. D 93, 112011*

**Pesudoscalar:**
η(2225) confirmed
η(2100) and X(2500)

**Dominant**

**Tensor:**
$f_2(2010)$, $f_2(2300)$, $f_2(2340)$

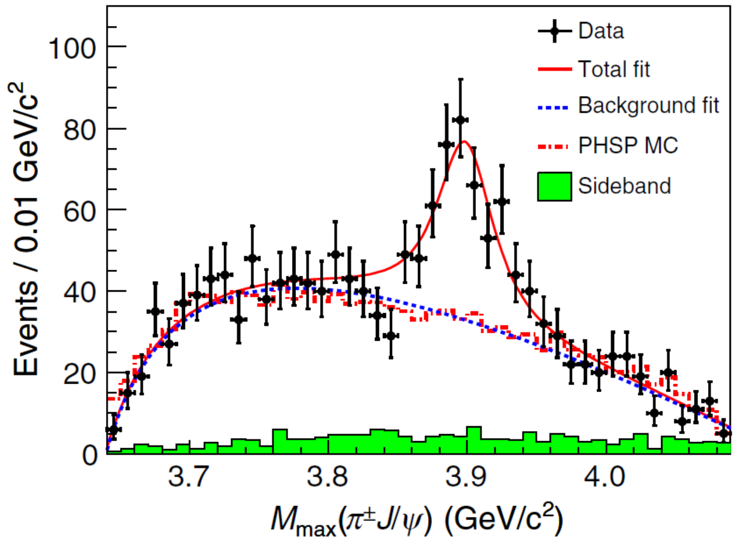
**$f_2(2340)$: tensor glueball?**

✓ **Well consistent with the results from Model-independent PWA**

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

- $e^+e^- \to \pi^+\pi^- J/\psi$
  - 525 $pb^{-1}$ data at $\sqrt{s}$ = 4.26 $GeV/c^2$
  - Born Xsection consistent with the Y(4260) production
- $Z_c(3900)^{\pm}$
  - $M = 3899.0 \pm 3.6 \pm 4.9\ MeV/c^2$
  - $\Gamma = 46 \pm 10 \pm 20\ MeV/c^2$
  - **Charged, decays to J/ψ**
    - **Contains $u\bar{d}(d\bar{u})$ and $c\bar{c}$**
    - ***At least four quarks?***
  - **Close to $D\bar{D}^*$ mass threshold**
    - **Threshold effect?**

***Phys. Rev. Lett. 110, 252001***




✓ $\frac{\sigma(e^+e^- \to \pi^{\pm} Z_c(3900)^{\mp} \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)}$ = (21.5 ± 3.3 ± 7.5)%

✓ **Also confirmed by Belle and CLEO-c**

- *Phys. Rev. Lett. 110, 252002*
- *Phys. Lett. B 727, 366*

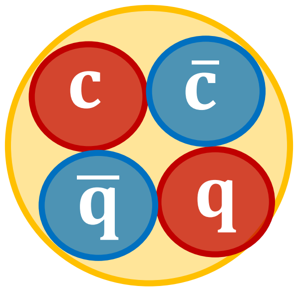
# $Z_c$ structures at BESIII

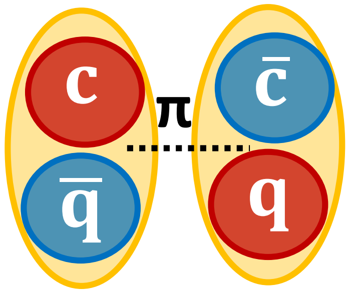
| State | Mass ($\mathrm{MeV}/c^2$) | Width ($\mathrm{MeV}/c^2$) | Decay | Process ($e^+e^- \to$) | Ref. |
|---|---|---|---|---|---|
| $Z_c(3900)^\pm$ | $3899.0 \pm 3.6 \pm 4.9$ | $46 \pm 10 \pm 20$ | $\pi^\pm J/\psi$ | $\pi^+\pi^- J/\psi$ | *PRL 110, 252001* |
| $Z_c(3900)^0$ | $3894.8 \pm 2.3 \pm 3.2$ | $29.6 \pm 8.2 \pm 8.2$ | $\pi^0 J/\psi$ | $\pi^0\pi^0 J/\psi$ | *PRL 115, 252003* |
| $Z_c(3885)^\pm$ | $3883.9 \pm 1.5 \pm 4.2$ Single D tag | $24.8 \pm 3.3 \pm 11.0$ Single D tag | $(D\bar{D}^*)^\pm$ | $(D\bar{D}^*)^\pm \pi^\mp$ | *PRL 112, 022001* |
| | $3881.7 \pm 1.6 \pm 2.1$ Double D tag | $26.6 \pm 2.0 \pm 2.3$ Double D tag | | | *PRD 92, 092006* |
| $Z_c(3885)^0$ | $3885.7^{+4.3}_{-5.7} \pm 8.4$ | $35^{+11}_{-12} \pm 15$ | $(D\bar{D}^*)^0$ | $(D\bar{D}^*)^0 \pi^0$ | *PRL 115, 222002* |
| $Z_c(4020)^\pm$ | $4022.9 \pm 0.8 \pm 2.7$ | $7.9 \pm 2.7 \pm 2.6$ | $\pi^\pm h_c$ | $\pi^+\pi^- h_c$ | *PRL 111, 242001* |
| $Z_c(4020)^0$ | $4023.9 \pm 2.2 \pm 3.8$ | Fixed | $\pi^0 h_c$ | $\pi^0\pi^0 h_c$ | *PRL 113, 212002* |
| $Z_c(4025)^\pm$ | $4026.3 \pm 2.6 \pm 3.7$ | $24.8 \pm 5.6 \pm 7.7$ | $(D^*\bar{D}^*)^\pm$ | $(D^*\bar{D}^*)^\pm \pi^\mp$ | *PRL 112, 132001* |
| $Z_c(4025)^0$ | $4025.5^{+2.0}_{-4.7} \pm 3.1$ | $23.0 \pm 6.0 \pm 1.0$ | $(D^*\bar{D}^*)^0$ | $(D^*\bar{D}^*)\ \pi^0$ | *PRL 115, 182002* |

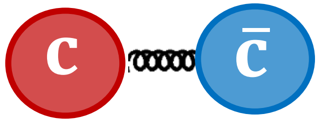
- ✓ **Charged and neutral $Z_c$'s are consistent with isospin triplets expectations.**
- ✓ **Mass and widths of $Z_c(3900)/Z_c(3885)$ and $Z_c(4020)/Z_c(4025)$ are consistent within $2\sigma$ → the same states?**

# Nature of $Z_c$ structures

- Theoretical interepretation
  - Tetraquark states?
  - $\mathrm{D}^{(*)}\overline{\mathrm{D}}^{*}$ molecule states?
  - Charmonium hybrid?
  - Threshold effect?
- Further studies are needed
  - **PWA**
  - **Production**
  - **Decay**
  - **Test theoretical models**
  - **…**



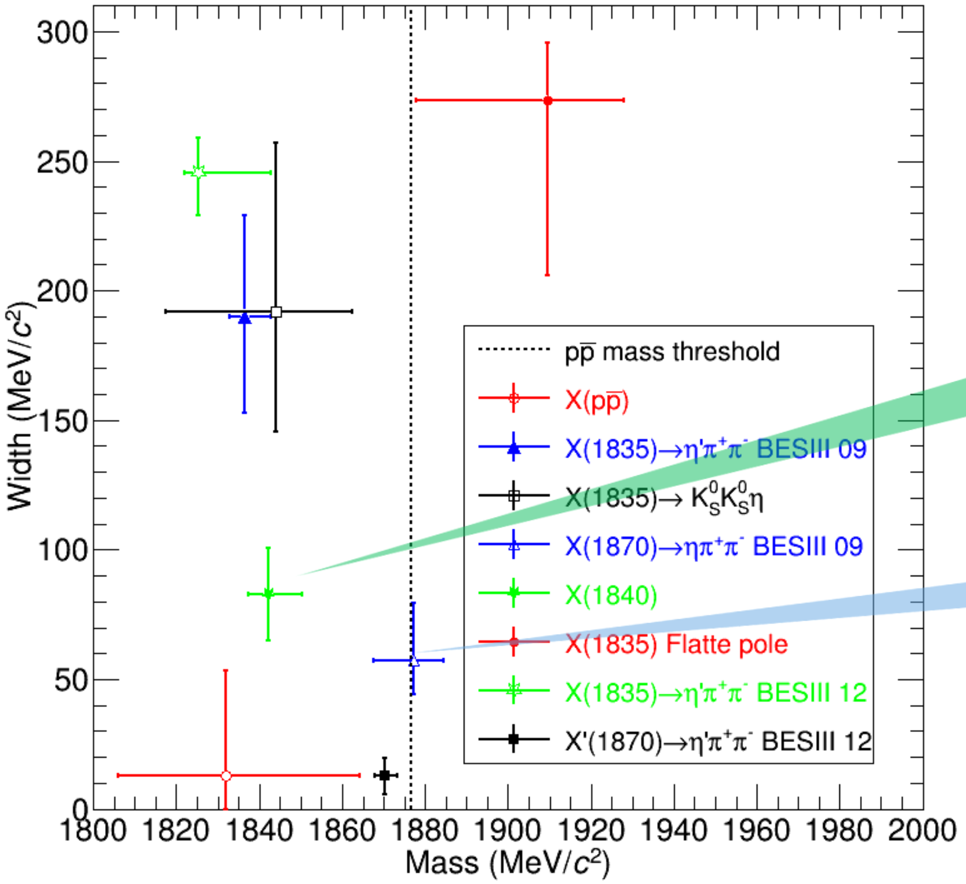



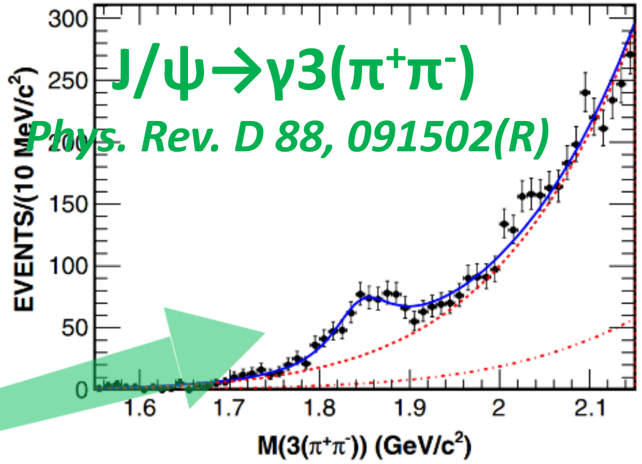
# Summary

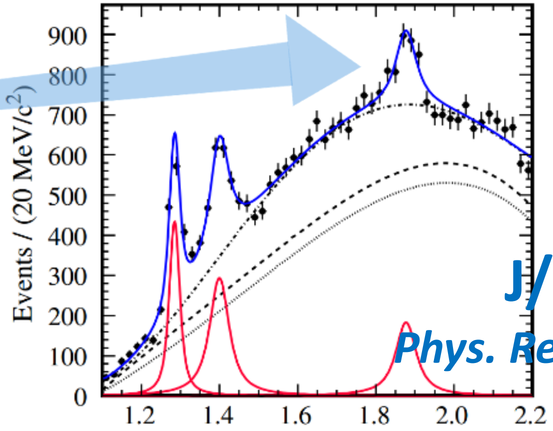
- Highlights of latest results on searching for new forms of hadrons at BESIII
  - Observation of X(1835) in $J/\psi \to \gamma K_S K_S \eta$
    - New decay mode of $X(1835) \to K_S K_S \eta$ and $J^{PC}$ of X(1835) is determined to be $0^{-+}$
  - Observation of anomalous $\eta'\pi^+\pi^-$ line shape near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$
    - Support the existence of a $p\bar{p}$ bound state or molecule-like state
  - Model independent partial wave analysis of $J/\psi \to \gamma\pi^0\pi^0$
    - Useful information of $0^{++}$ and $2^{++}$ components
  - Partial wave analysis of $J/\psi \to \gamma\phi\phi$
    - $0^{-+}$ and $2^{++}$ glueball candidate?
  - Observation of $Z_c(3900)/Z_c(3885)$, $Z_c(4020)/Z_c(4025)$
    - Multi-quark candidates?
- More results are expected in the future!

Thank you!

# Structures around 1.8 $\mathrm{GeV}/c^2$



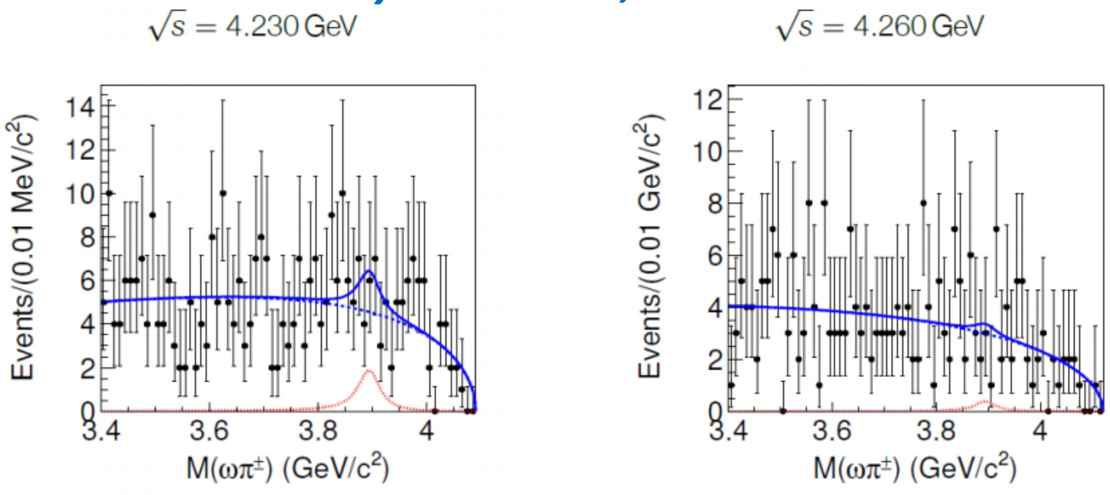



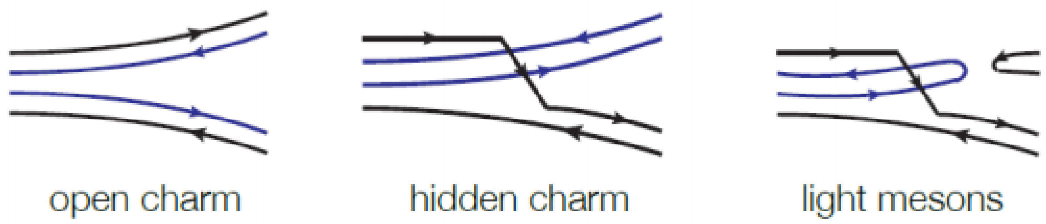




- $J^{PC}$ of X(1840) and X(1870): need PWA
- Search and study those states in more channels

# $e^+e^- \rightarrow \pi^{\pm} Z_c(3900)^{\mp} \rightarrow \pi^+\pi^-\omega$

*Phys. Rev. D 92, 032009*




also happen to threshold effect

NO threshold effect

**No significant $Z_c \rightarrow \omega\pi$ is observed:**

**$\sigma(e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi(\omega\pi)) < 0.26$ pb @ 4.23 GeV**

**$\sigma(e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi(\omega\pi)) < 0.18$ pb @ 4.26 GeV**

$\Gamma(Z_c^+ \rightarrow \pi^+\omega) < 0.2\% \ \Gamma_{tot} \sim 60$ keV

Naive expectations from $\eta_c$ decays, the partial width to an exclusive light hadron mode is typically ~500 keV

**Threshold effect cannot be ruled out**