# Light Hadron Spectroscopy at BESIII

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On behalf of the BESIII Collaboration

# Outline

- Introduction to BEPCII and BESIII
- Light hadron spectroscopy
- $\eta$ and $\eta$' physics
- Summary

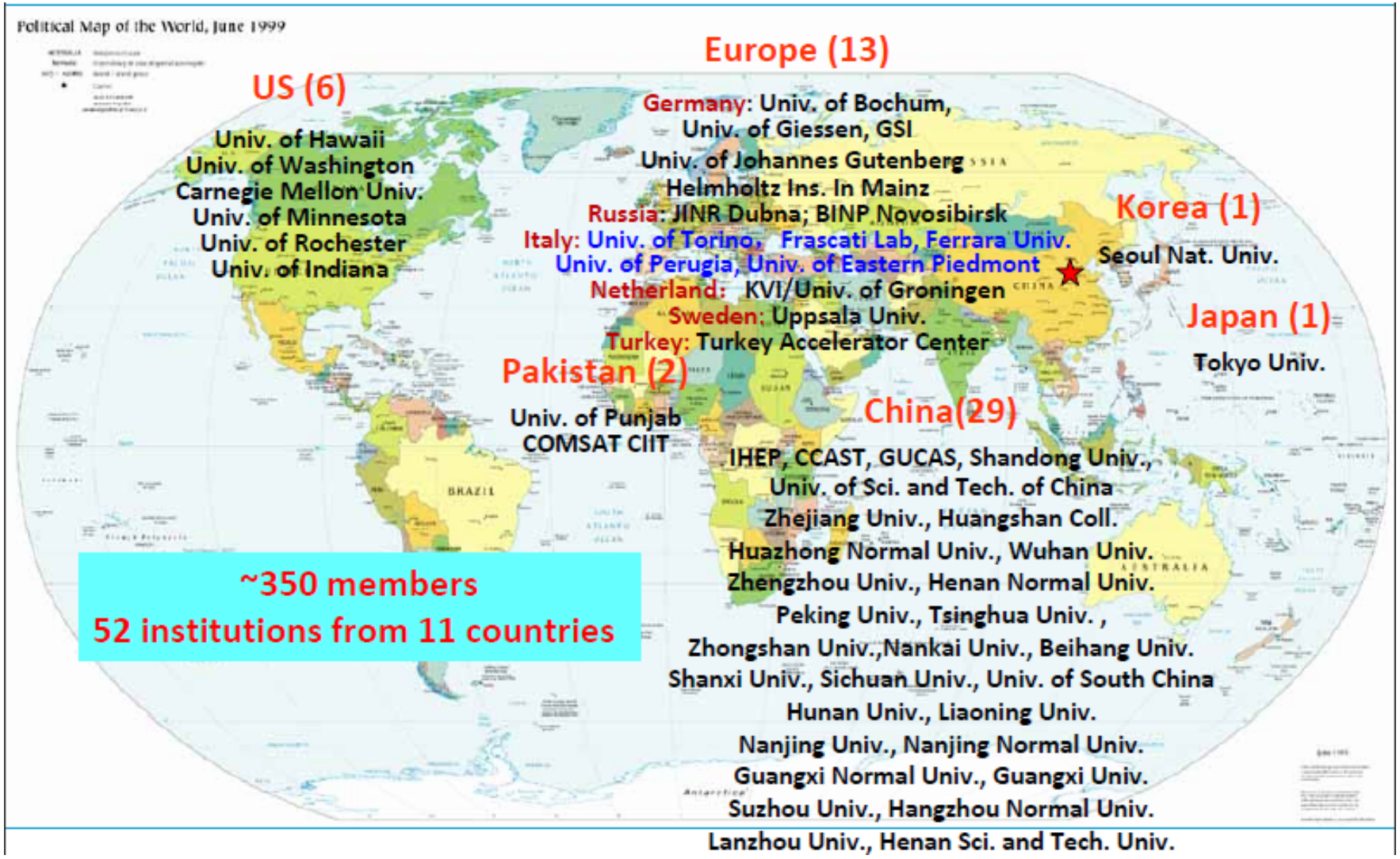
# Beijing Electron Positron Collider II


2004: started BEPCII/BESIII construction

2008: test run

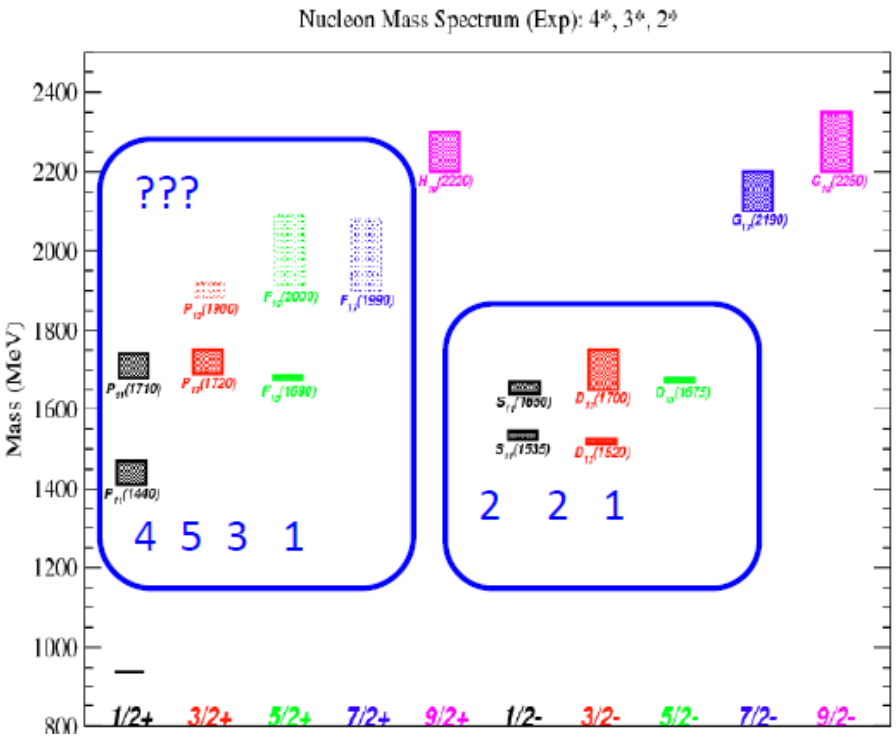
2009 - now: BESIII physics run

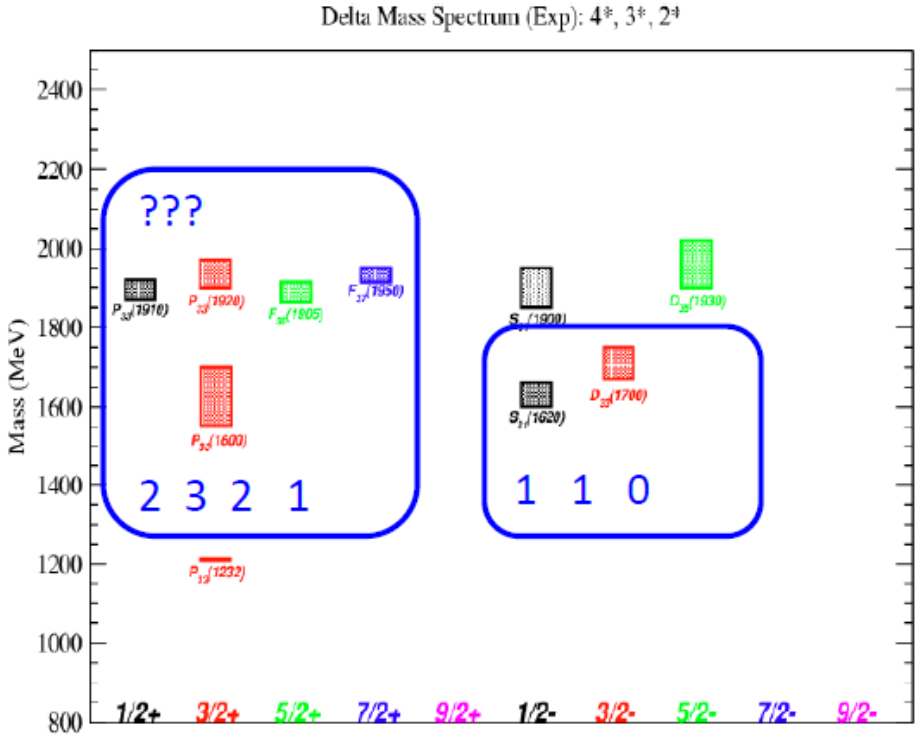
# The BESIII Collaboration



# Spectrum of Nucleon Resonances

*PRD 86, 010001 (2012)*



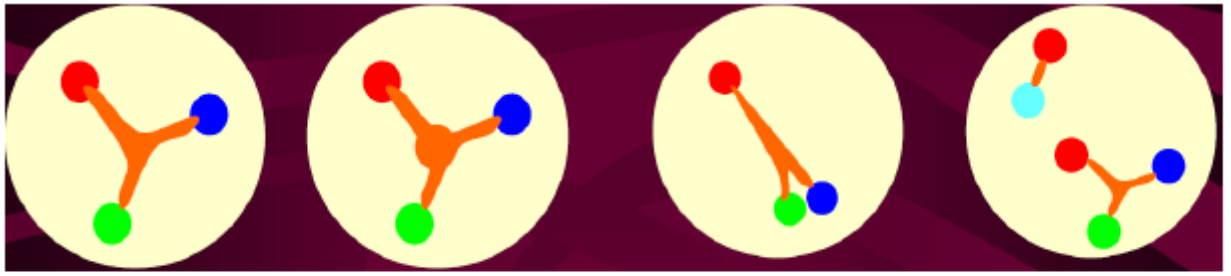

| | **** | *** | ** | * |
|---|---|---|---|---|
| N Spectrum | 10 | 5 | 7 | 3 |
| Δ Spectrum | 7 | 3 | 7 | 5 |

**Quark models predict many more baryons than have been observed**

# Where is the "missing baryons"?

(1) Does the quark model completely describe the nature of baryons?

The baryon model links number of baryons. In theory: N4>N2>N1>N3, however, in experiment: Nobserved << N1 .



1, 3 quarks | 2, quarks and flux tubes | 3, quark-diquark | 4, multi quarks | ...

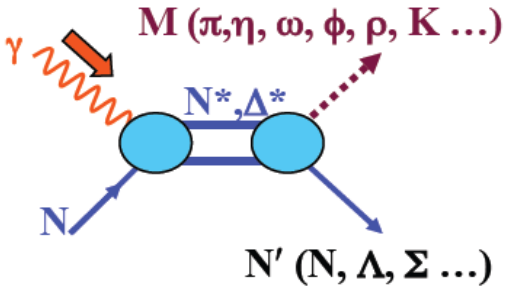
(2) Do the resonances simply escape from detection?

Almost all existing data results come from $\pi$N experiments.

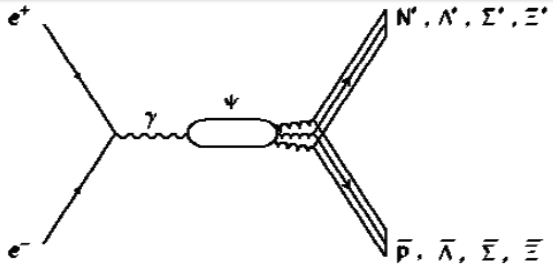
Charmonium decays at the BESIII experiment, give novel insights into baryons and provide complementary information to $\pi$N experiments.

# Why Charmonium?

JLab, ELSA, MAMI, ESRF, Spring-8, ….




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

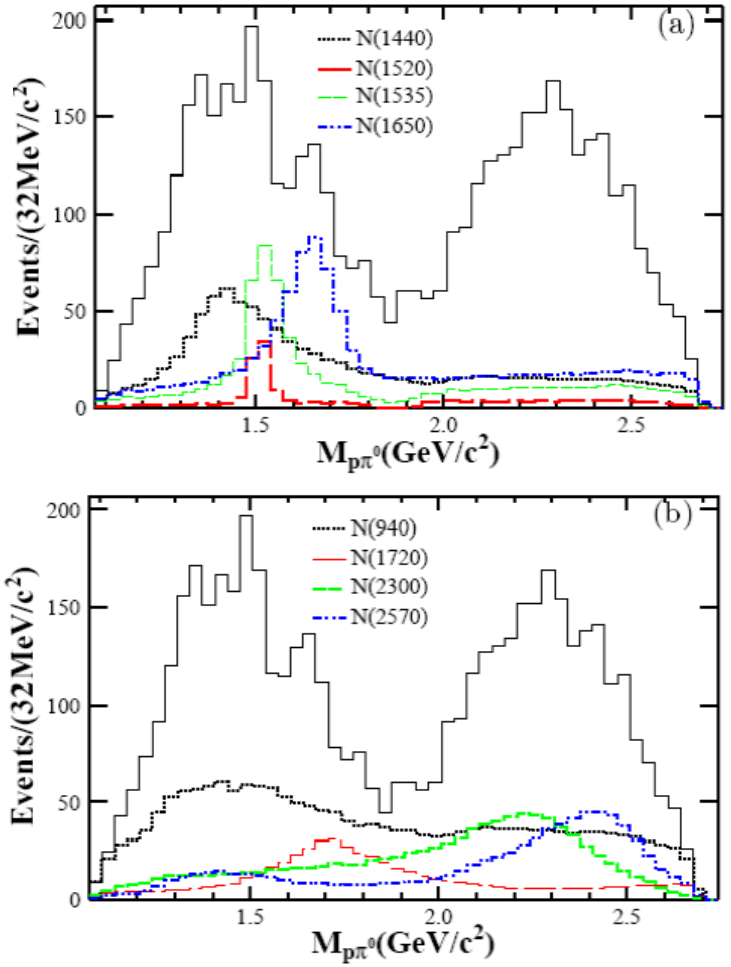



| | Previous Data | BESIII now | Goal |
|---|---|---|---|
| J/ψ | BESII 58 M | 1.2 B (20x BESII) | 10 B |
| ψ (3686) | CLEO: 28M | 0.5 B (20x CLEO) | 3 B |
| ψ (3770) | CLEO: 0.8/fb | 2.9/fb (3.5x CLEO) | 20/fb |
| Above open charm threshold | CLEO: 0.6/fb@4160 | 0.4/fb @4040, 2/fb@4260, 0.5/fb @4360, Data for lineshape | 5-10/fb |
| R scan & τ | BESII | R @2.23,2.4,2.8,3.4, 25/pb tau | |

Interference between N and N*bar could be studied
Not only N*, but also $\Lambda^*$, $\Sigma^*$, $\Xi^*$
High statistics of charmonium@ BESIII

# N* resonances in $\psi(2s) \rightarrow p\bar{p}\pi^0$

*PRL 110, 022001(2013)*




| Resonance | N | $\epsilon(\%)$ | B.F.$(\times 10^{-5})$ |
|---|---|---|---|
| $N(940)$ | $1870^{+90+487}_{-90-327}$ | $27.5 \pm 0.4$ | $6.42^{+0.20+1.78}_{-0.20-1.28}$ |
| $N(1440)$ | $1060^{+90+459}_{-90-227}$ | $27.9 \pm 0.4$ | $3.58^{+0.25+1.59}_{-0.25-0.84}$ |
| $N(1520)$ | $190^{+14+64}_{-14-48}$ | $28.0 \pm 0.4$ | $0.64^{+0.05+0.22}_{-0.05-0.17}$ |
| $N(1535)$ | $673^{+45+263}_{-45-256}$ | $25.8 \pm 0.4$ | $2.47^{+0.28+0.99}_{-0.28-0.97}$ |
| $N(1650)$ | $1080^{+77+382}_{-77-467}$ | $27.2 \pm 0.4$ | $3.76^{+0.28+1.37}_{-0.28-1.66}$ |
| $N(1720)$ | $510^{+27+50}_{-27-197}$ | $26.9 \pm 0.4$ | $1.79^{+0.10+0.24}_{-0.10-0.71}$ |
| $N(2300)$ | $948^{+68+394}_{-68-213}$ | $34.2 \pm 0.4$ | $2.62^{+0.28+1.12}_{-0.28-0.64}$ |
| $N(2570)$ | $795^{+45+127}_{-45-83}$ | $35.3 \pm 0.4$ | $2.13^{+0.08+0.40}_{-0.08-0.30}$ |
| Total | $4515 \pm 93$ | $25.8 \pm 0.4$ | $16.5 \pm 0.3 \pm 1.5$ |

Two new baryonic excited states are observed in PWA analysis. N(2300)$[1/2]^+$, N(2570) $[5/2]^-$ .

See more results about baryons study:

$J/\psi \rightarrow \eta p\bar{p}$ *PRD 88, 032010 (2013)*

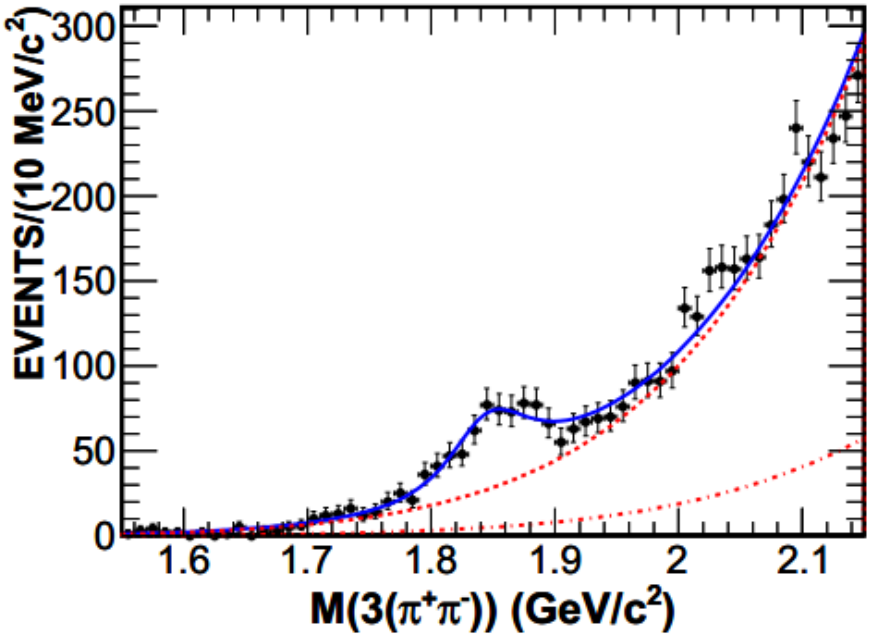
$J/\psi \rightarrow \Lambda\Sigma^0 + c.c$ *PRD 87, 012007 (2013)*

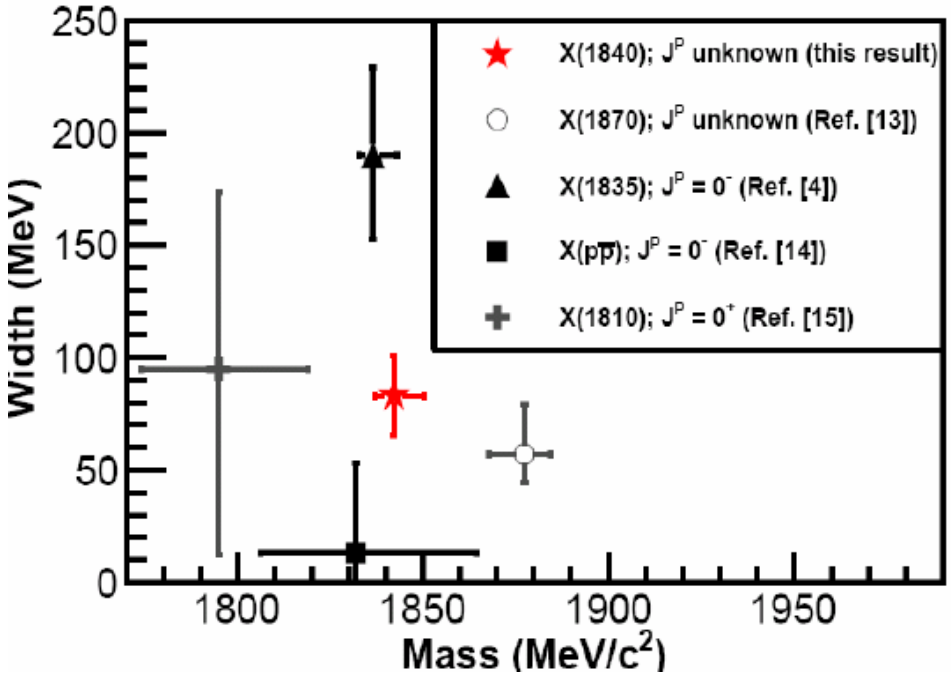
$\psi' \rightarrow \bar{p}K\Sigma^0, \Sigma^0 \rightarrow \gamma\Lambda$ *PRD 86, 032008 (2012)*

$\chi_{c0} \rightarrow p\bar{n}\pi^-(p\bar{n}\pi^-\pi^0)$ *PRD 86, 052011 (2012)*

# X(18??) at BESIII

*PRD 88, 091502(R)(2013)*



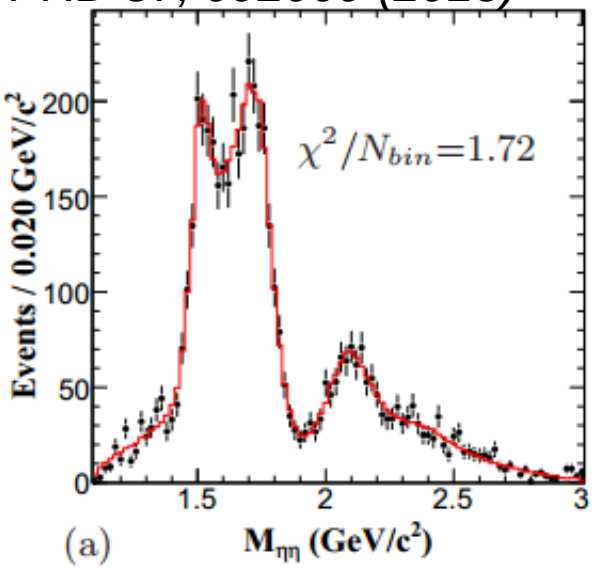

Small mass difference .
Near ppbar threshold production.
Are they the same particle?
What relations between them?
What are their structures?

Observations with 225M J/psi decays

| | | |
|---|---|---|
| ★ | $\gamma\, 3(\pi\ \pi)$ X(1840) | PRD 88, 091502 |
| ○ | $\omega\ \eta\ \pi\ \pi$ X(1870) | PRL107, 182001 |
| ▲ | $\gamma\ \eta'\ \pi\ \pi$ X(1835) | PRL106, 072002 |
| ■ | $\gamma$ ppbar X(ppbar) | PRL108, 112003 |
| + | $\gamma\ \omega\ \phi$ X(1810) | PRD 87, 032008 |

# PWA of $J/\psi \rightarrow \gamma\eta\eta$

*PRL 48, 458 (1982), Crystal Ball.*
*PRD 87, 092009 (2013)*




Searching for glueball candidates.

$$\gamma f\,(1710) \rightarrow \gamma KK \quad (8.5\ ^{+1.2}_{-0.9}) \times 10^{-4}$$
$$\gamma f\,(1710) \rightarrow \gamma\pi\pi \quad (4.0 \pm 1.0) \times 10^{-4}$$
$$\gamma f\,(1710) \rightarrow \gamma\omega\omega \quad (3.1 \pm 1.0) \times 10^{-4}$$
$$\gamma f\,(1710) \rightarrow \gamma\eta\eta \quad (2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$$

*PRL 110(2013) 021601, Long-cheng Gui et al. calculates by LQCD,*

$$Br(J/\psi \rightarrow \gamma G(0^{++})) = 3.8(9) \times 10^{-3}$$

Need more experimental effort.

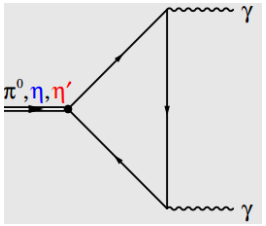
| Resonance | Mass(MeV/$c^2$) | Width(MeV/$c^2$) | $\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$ | Significance |
|---|---|---|---|---|
| $f_0(1500)$ | $1468^{+14+20}_{-15-74}$ | $136^{+41+8}_{-26-100}$ | $(1.61^{+0.29+0.41}_{-0.32-1.28}) \times 10^{-5}$ | 8.2 $\sigma$ |
| $f_0(1710)$ | $1759^{+6+14}_{-6-25}$ | $172^{+10+31}_{-10-15}$ | $(2.35^{+0.07+1.23}_{-0.07-0.72}) \times 10^{-4}$ | 25.0 $\sigma$ |
| $f_0(2100)$ | $2081^{+13+23}_{-13-34}$ | $273^{+27+65}_{-24-18}$ | $(9.99^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$ | 13.9 $\sigma$ |
| $f_2'(1525)$ | $1513^{+5+3}_{-5-10}$ | $75^{+12+15}_{-10-9}$ | $(3.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$ | 11.0 $\sigma$ |
| $f_2(1810)$ | $1822^{+29+61}_{-24-54}$ | $229^{+52+64}_{-42-152}$ | $(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$ | 6.4 $\sigma$ |
| $f_2(2340)$ | $2362^{+31+139}_{-30-59}$ | $334^{+62+164}_{-54-99}$ | $(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$ | 7.6 $\sigma$ |

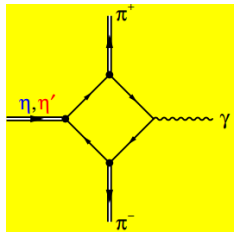
# $\eta$ and $\eta'$ Physics at BESIII

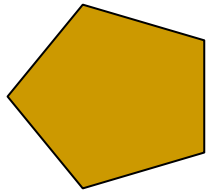
*KLOE, WASA-at-COSY, CB at MAINZ, CLAS, GlueX,* *PRD 19, 2188(1979).*

- Rich physics field:

| | |
|---|---|
| $\eta/\eta' \to 2\gamma$ | **chiral anomaly** |
| $\eta/\eta' \to \pi^+\pi^-\pi^0$ | **quark mass** |
| $\eta' \to \gamma\pi^+\pi^-$ | **box anomaly** |
| $\eta/\eta' \to \pi\pi$ | **CP violation** |
| $\eta/\eta' \to \mu^+\mu^-\pi^0, e^+e^-\pi^0$ | **C violation** |
| $\eta/\eta' \to \mu\, e$ | **LF violation** |



- Huge samples of prompt $\eta/\eta'$ with 1.2 billion J/psi decays.
  - J/psi→$\gamma\eta$ ($\eta'$), J/psi→$\phi\eta$ ($\eta'$)

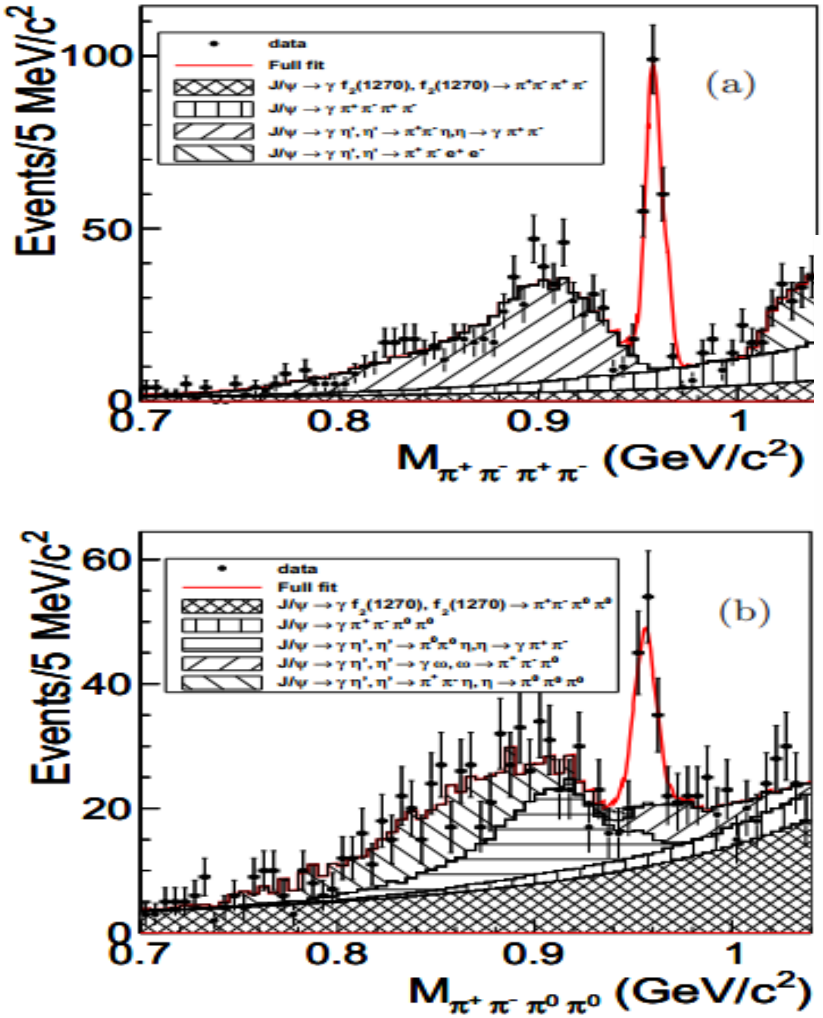
**B(J/ $\psi \to \gamma\eta$)~1.1×10$^{-3}$ → 1.32×10$^6$ $\eta$ events**
**B(J/ $\psi \to \gamma\eta'$)~5.2×10$^{-3}$ → 6.24×10$^6$ $\eta'$ events**
**B(J/ $\psi \to \phi\eta$)~7.5×10$^{-4}$ → 9.0×10$^5$ $\eta$ events**
**B(J/ $\psi \to \phi\eta'$)~4.0×10$^{-4}$ → 4.8×10$^5$ $\eta'$ events**

# Observation of $\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$ ($\pi^+\pi^-\pi^0\pi^0$)

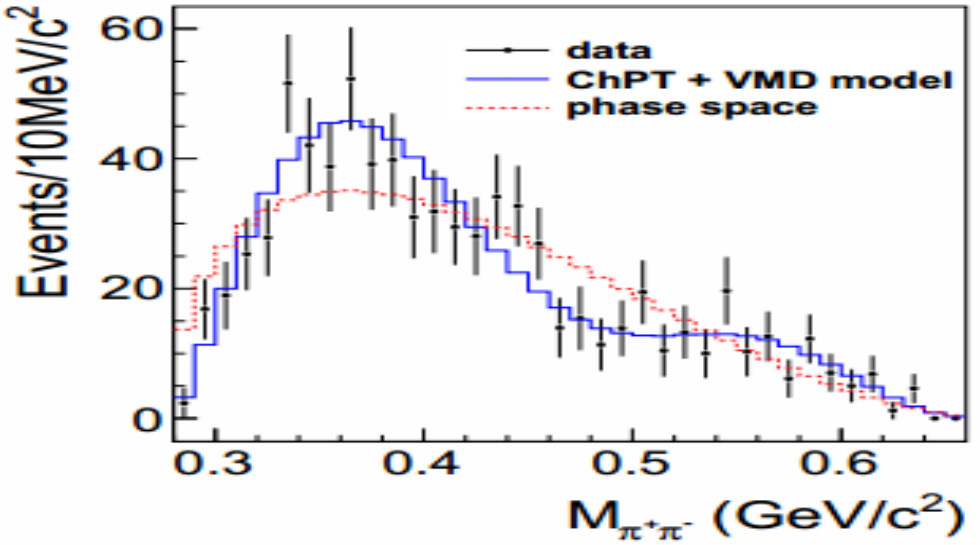
*Submitted to PRL, **arXiv:1404.0096***

CLEO, $\mathrm{br}(\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-) < 2.4\times10^{-4}$

$\mathrm{Br}(\eta' \rightarrow \pi+\pi-\pi+\pi-) < 2.6\times10^{-3}$, 90% C.L.



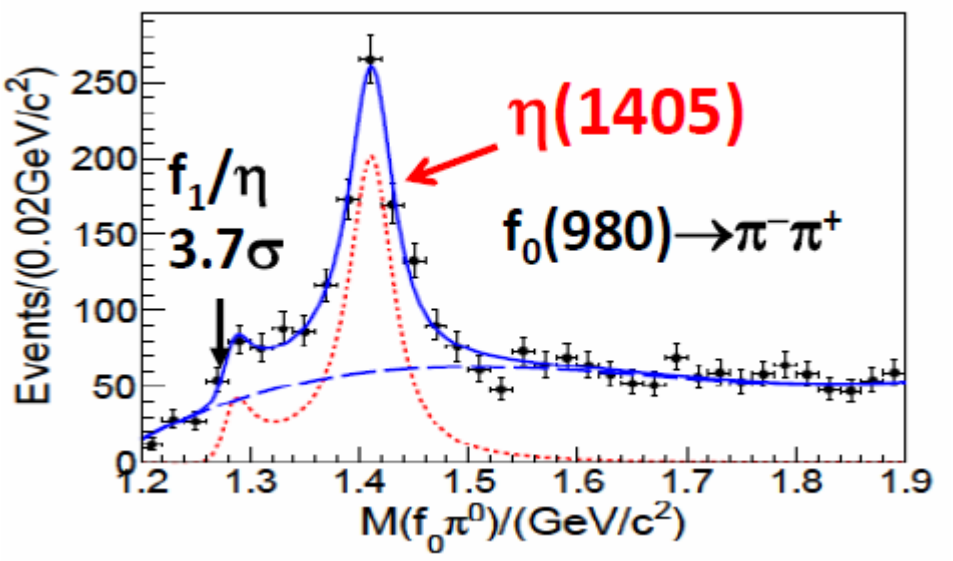

| Mode | Yield | $\varepsilon$ (%) | Branching fraction |
|---|---|---|---|
| $\eta' \to \pi^+\pi^-\pi^+\pi^-$ | $199 \pm 16$ | 34.5 | $(4.40 \pm 0.35 \pm 0.30) \times 10^{-7}$ |
| $\eta' \to \pi^+\pi^-\pi^0\pi^0$ | $84 \pm 16$ | 7.0 | $(9.38 \pm 1.79 \pm 0.89) \times 10^{-7}$ |

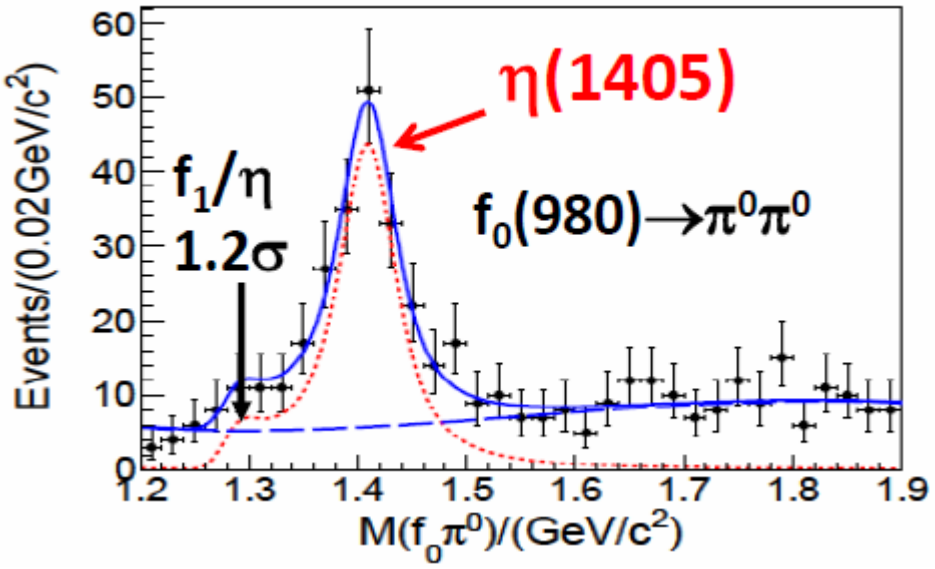



Clearly support the model:
Chiral perturbation + Vector-meson dominance

# $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to \pi^+\pi^-$

*PRL 108, 182001(2012)*



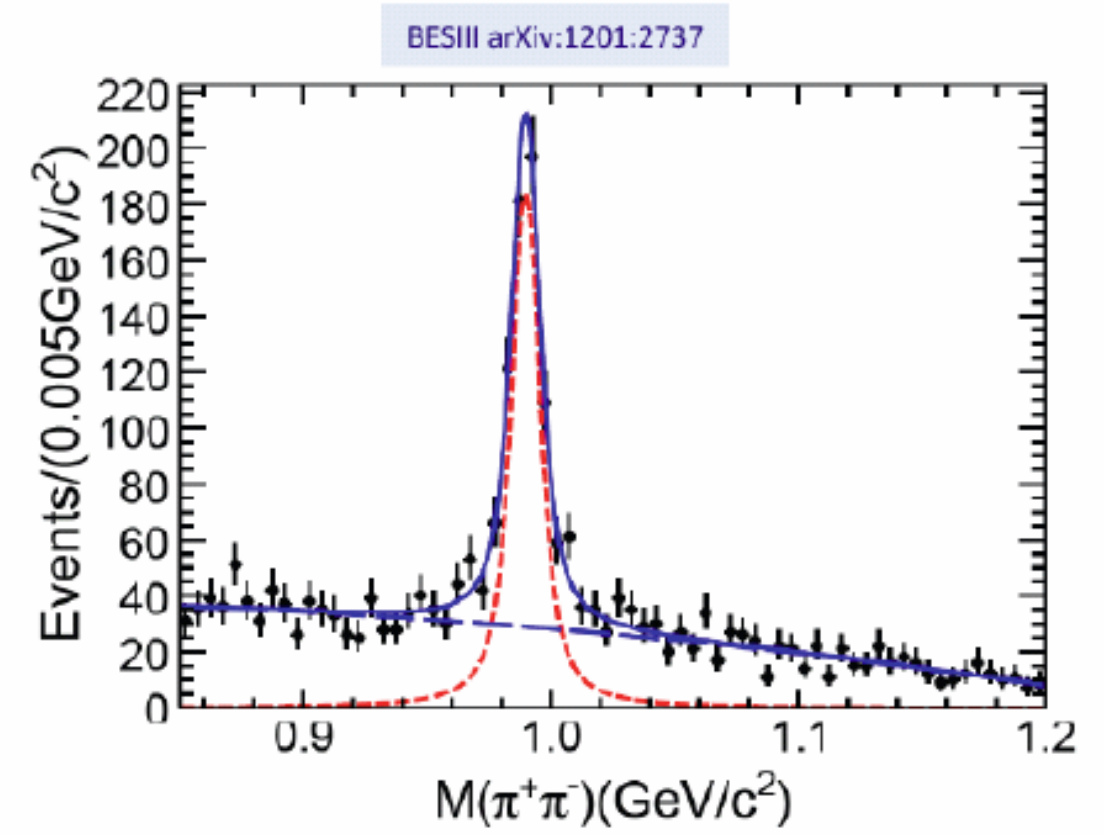

**First observation of $\eta(1405) \to f_0(980)\pi^0$ (isospin violated decays) and $J/\psi \to \gamma f_0(980)\pi^0$**

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}$$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^0\pi^0) = (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}$$

# $f_0(980)$ Line-shape in $\eta(1405) \rightarrow f_0(980)\pi 0$

Anomalous width, much narrower than the PDG value !




**Fitted mass:**

**$M_{"f_0"}$ = 989.9 ± 0.4 MeV**

**$\Gamma_{"f_0"}$ = 9.5 ± 1.1 MeV**

**The peak is midway between $2m_{K^0}$ & $2m_{K^+}$ & width ≈ $2(m_{K^0} - m_{K^+})$**

**PDG2010:**

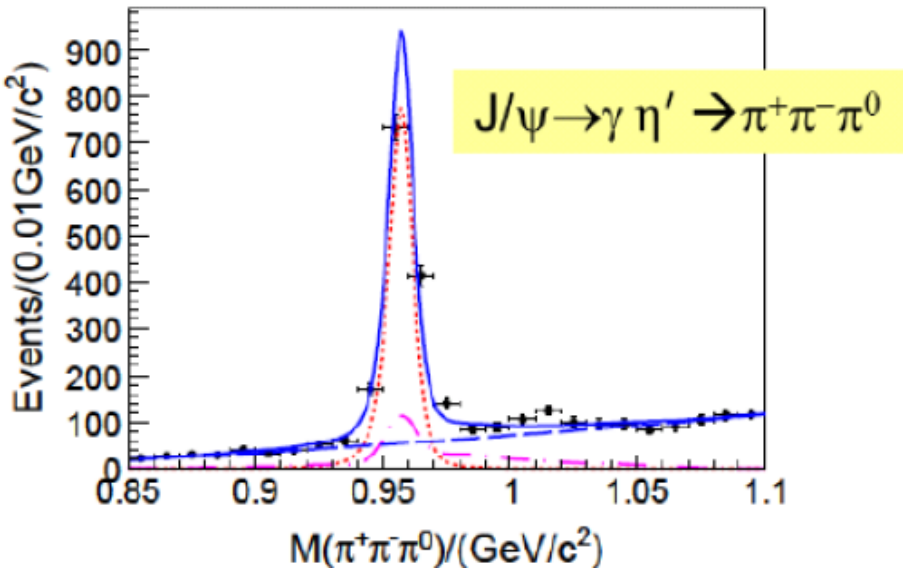
**$M_{f_0}$ = 980 ± 10 MeV**

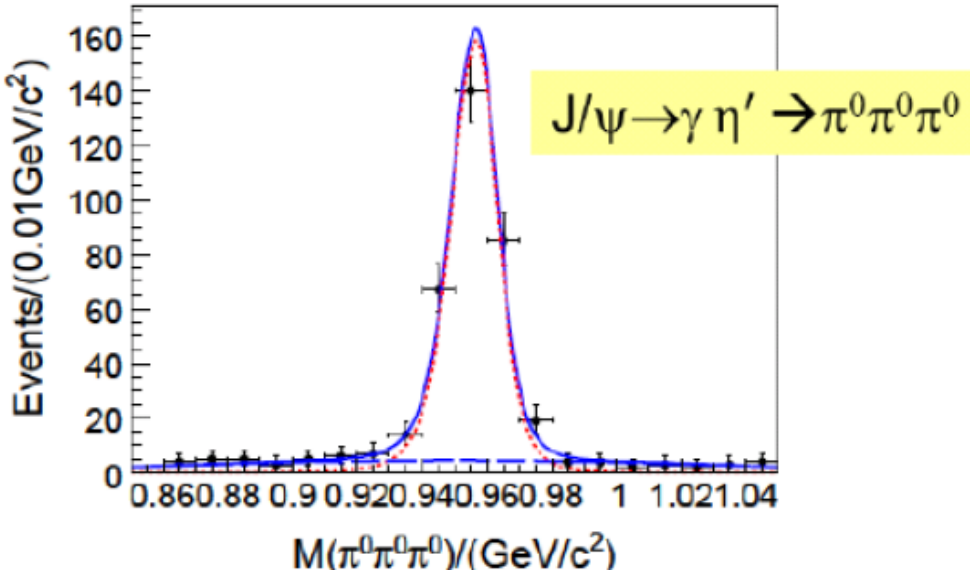
**$\Gamma_{f_0}$=40 ~ 100 MeV**

***Possible explanation: J.J.Wu et al, PRL 108, 081803(2012) effect of Triangle Singularity!***

# $\eta' \to \pi\pi\pi$ in $J/\psi \to \gamma\eta'$

*PRL 108, 182001(2012)*




$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ (PDG2010: $(3.6^{+1.1}_{-0.93}) \times 10^{-3}$) *agreement*

For $\eta' \to 3\pi^0$, the branching ration is two times larger than the world average value.

$Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ $[PDG2010 = (1.68 \pm 0.22) \times 10^{-3}]$

Decay property: Isospin violations in $\eta'$ decays.

$$\frac{Br(\eta' \to 3\pi^0)}{Br(\eta' \to 2\pi^0\eta)} \approx 1.6\%, \frac{Br(\eta' \to \pi^+\pi^-\pi^0)}{Br(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%$$

# Recent $\eta$ and $\eta'$ results from BESIII

1. **BF measurement of $\eta' \to \pi^+\pi^- e^+ e^- (\pi^+\pi^-\mu^+\mu^-)$, PRD 87,092011(2013)**
   - **Good agreement with theoretical prediction.**
2. **Search for $\eta/\eta'$ invisible decays, PRD 87, 012009(2013)**
3. **Search for $\eta/\eta'$ weak decays, PRD 87, 032006(2013)**
   - **Upper limits for new physics.**
4. **Search for CP violation in $\eta/\eta' \to \pi^+\pi^-(\pi^0\pi^0)$, PRD 84, 032006(2011)**
   - **No obvious signal was found.**
5. **Matrix element for $\eta' \to \pi^+\pi^-\eta$, PRD 83, 012003(2011)**
   - **Decay mechanism study.**

# Summary

- Studying low energy QCD from multi-sides.
- New fruitful results were obtained.
- More and more results can be foreseen.


Thanks for your attention