Light hadron spectroscopy at BESIII

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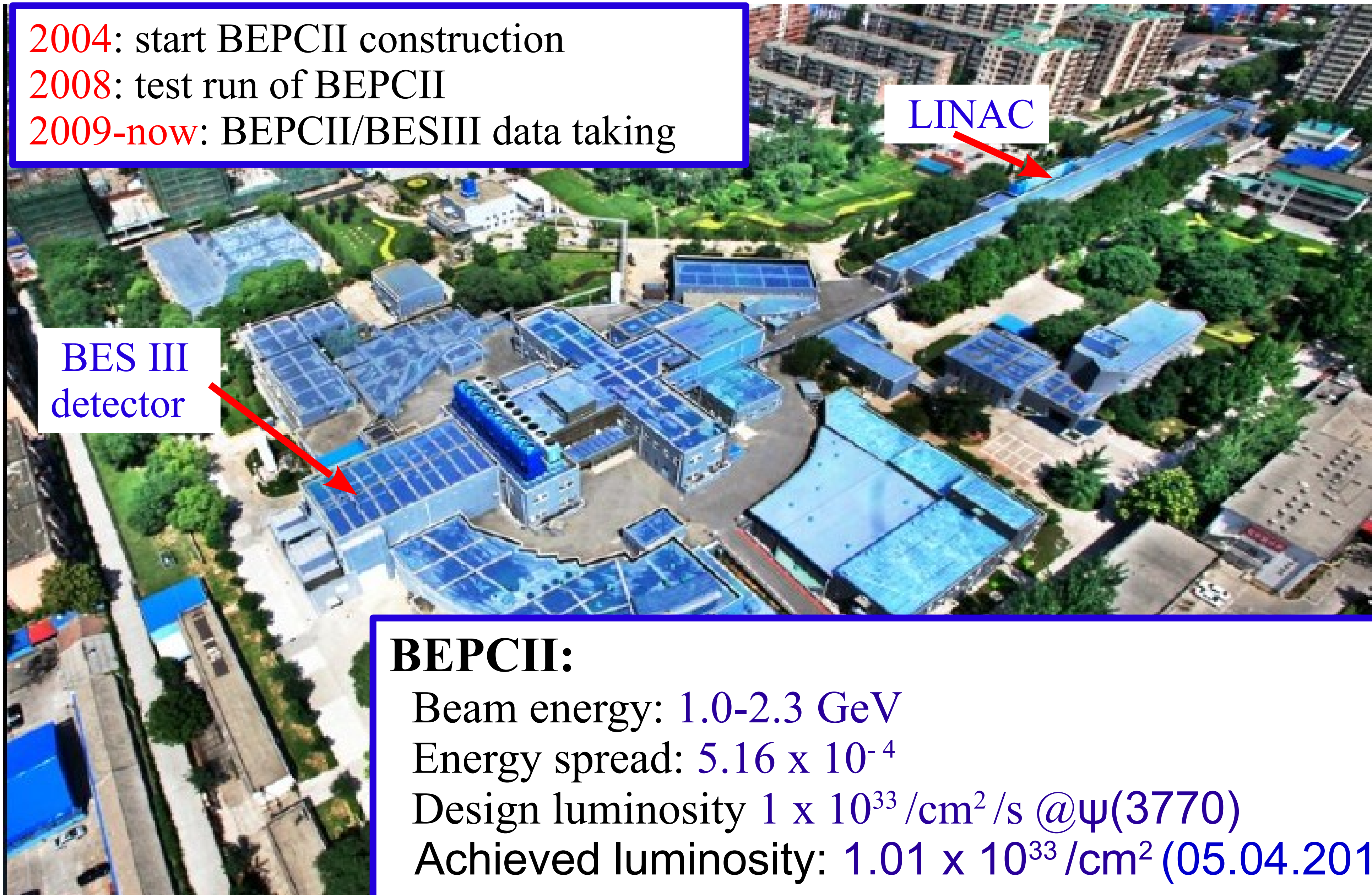
(for the BESIII collaboration)

CHARM'18
21-25 May 2018

BEPCII/BESIII at IHEP (Beijing)

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BEPCII/BESIII data taking



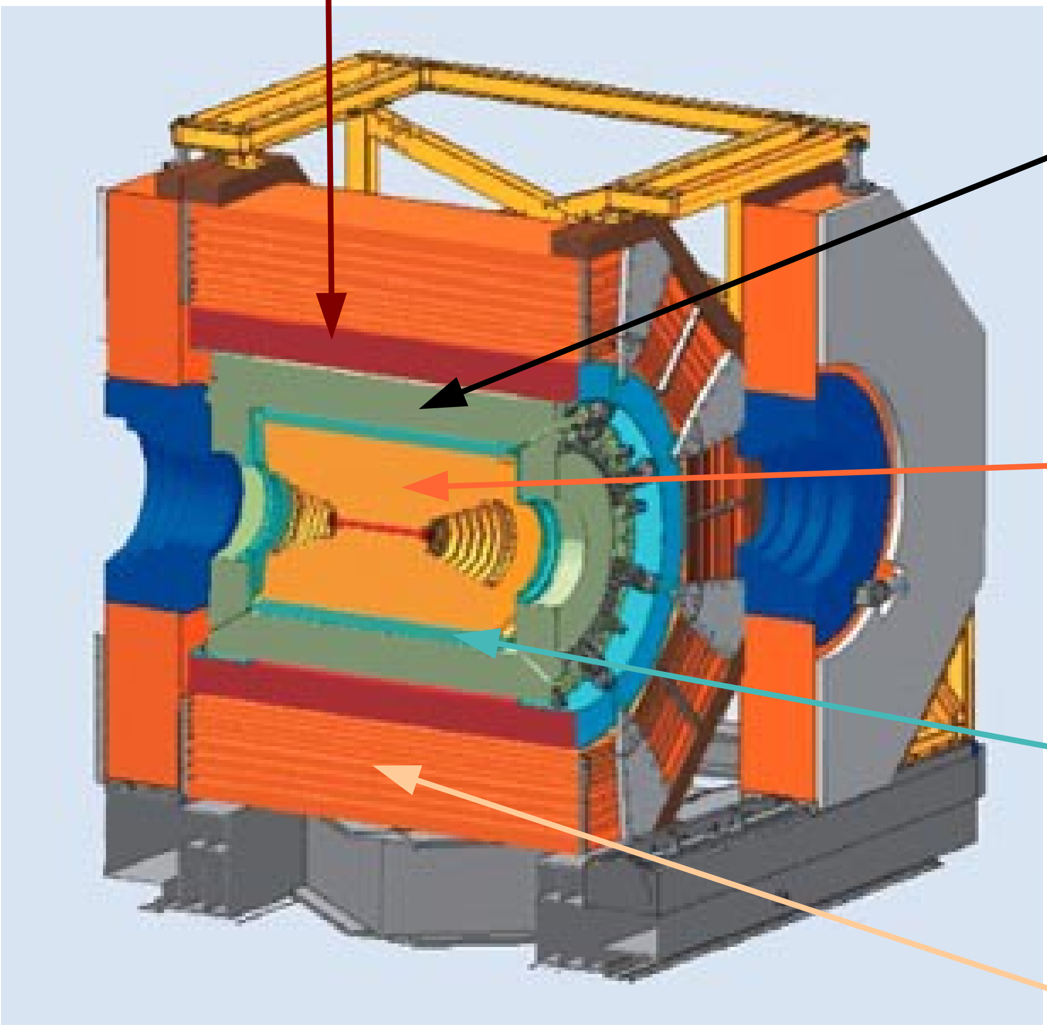
BEPCII:

Beam energy: 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}
Design luminosity 1×10^{33} /cm^2/s @$\psi(3770)$
Achieved luminosity: 1.01×10^{33} /cm^2 (05.04.2016)

The BESIII detector

NIM A614, 345(2010)

Super conducting magnet: 1 T



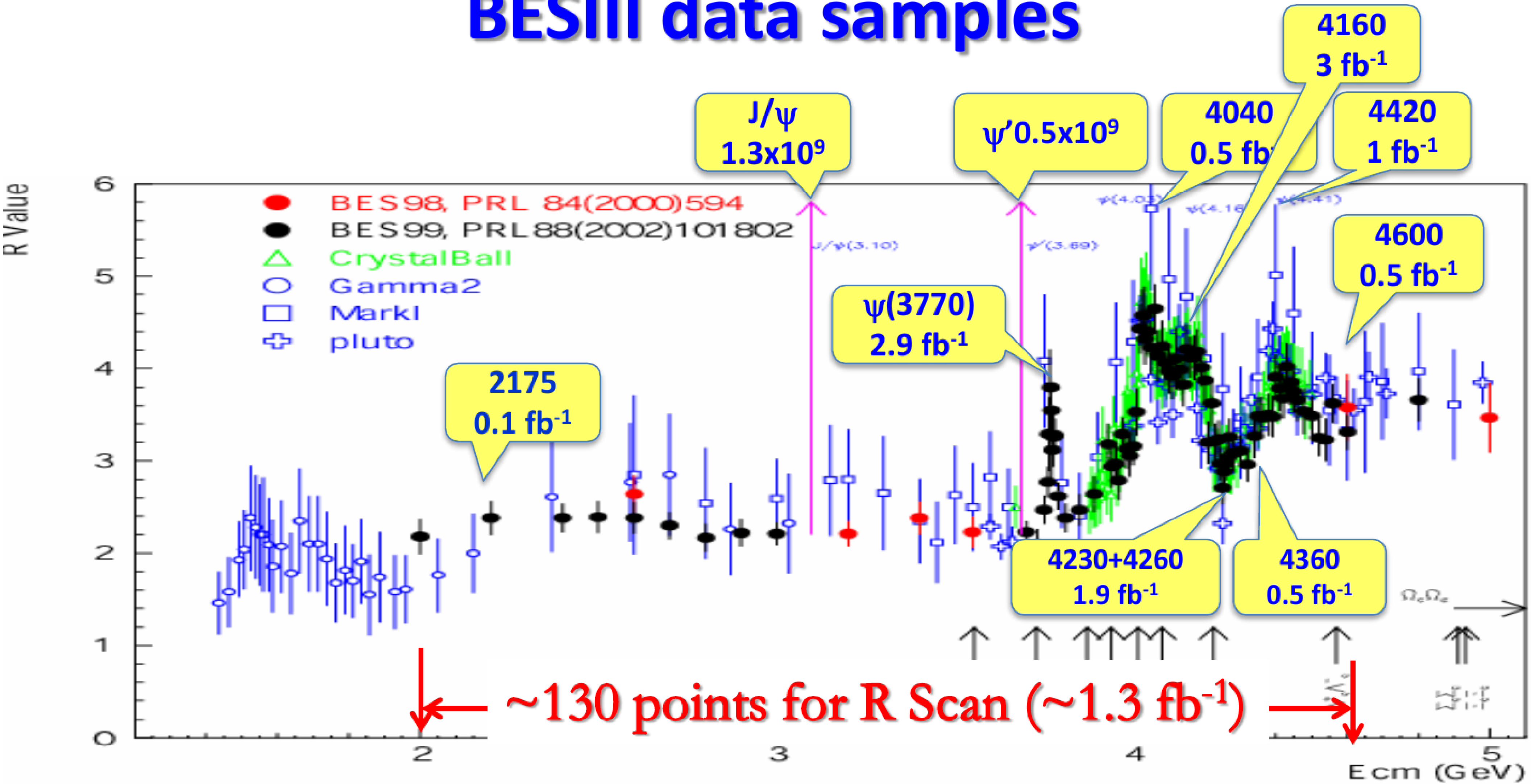
EMC: CsI cristal
- Energy resolution: **2.5% @1GeV**
- Spatial resolution: **6mm**

MDC:
- Spatial resolution: σ_{xy} **= 120μm**
- Momentum resolution:**0.5% @ 1GeV**
- **dE/dx** resolution: 6%

TOF (double layer scintillator):
Time resolution: **80ps** (barrel)
110ps (endcaps)

Muon ID:
9 layers RPC (8 for endcaps) in the flux-return yoke

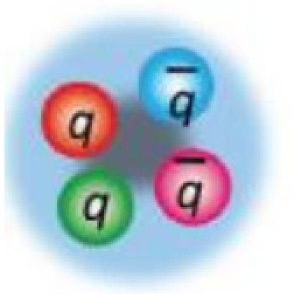
BESIII data samples

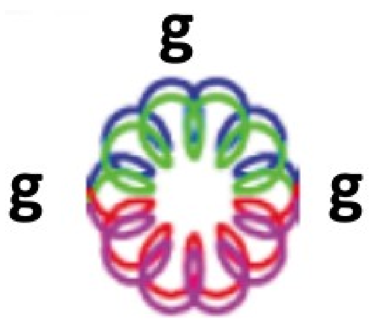


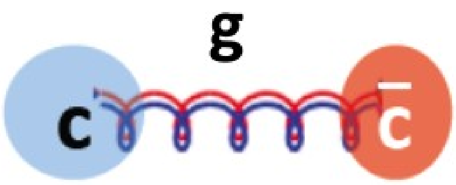
World largest J/ψ, ψ(2S), ψ(3770), ψ(4160), Y(4260), … produced directly from e^+e^- collision

Light hadron spectroscopy

- Hadron spectroscopy is a key tool to investigate QCD in the strong coupling regime.
- One of the most intriguing questions is existence of exotic QCD states, which have been predicted long ago: multiquark states (baryonium, tetraquark states,), glueballs, hybrid states.







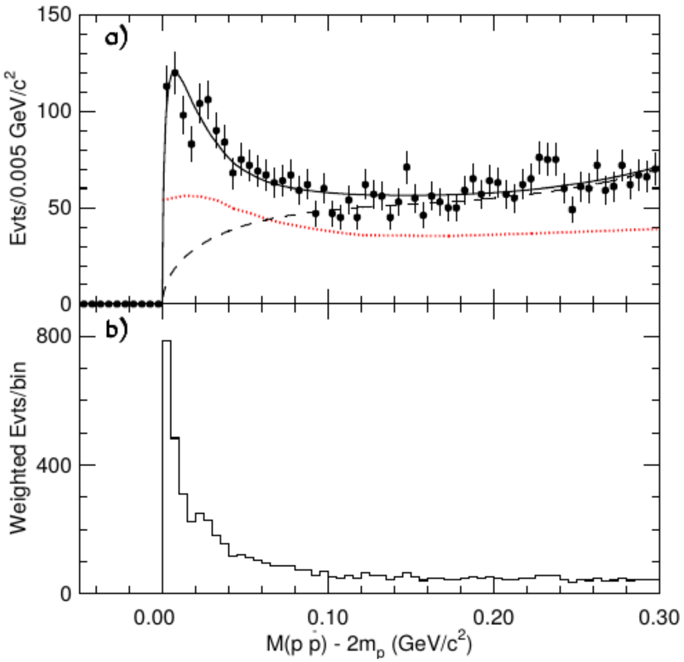
X($p\bar{p}$) and X(1835)

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

BESII

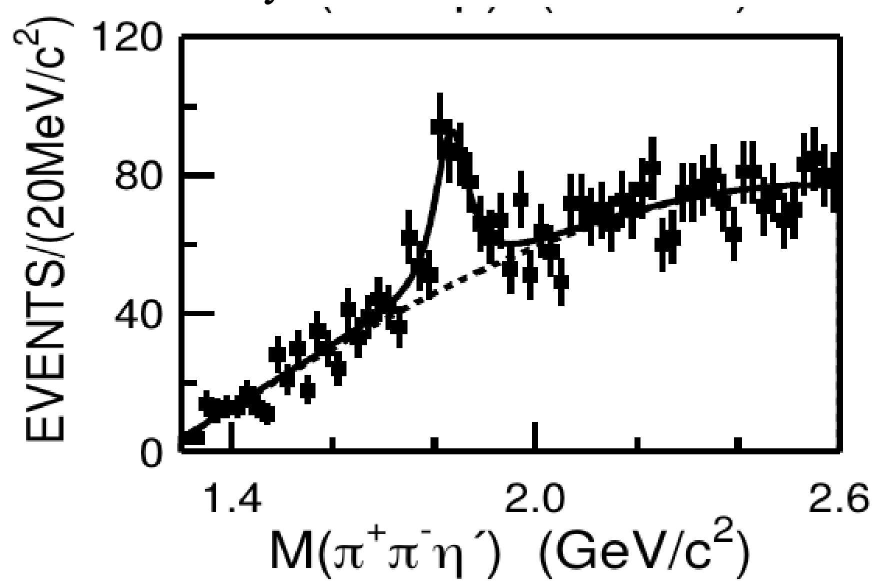
X($p\bar{p}$) in
$J/\psi \to \gamma p\bar{p}$

Phys. Rev. Lett.91.022001



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

Phys. Rev. Lett.95.262001



If caused by resonance:

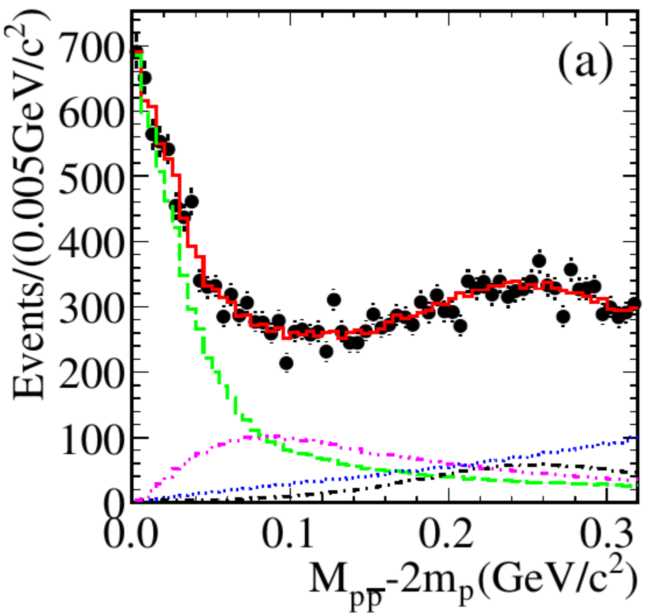
- mass below $p\bar{p}$ threshold
- very strong coupling to $p\bar{p}$
- **baryonium**?

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

BESIII 225M J/ψ

$J/\psi \rightarrow \gamma p\bar{p}$

Phys. Rev. Lett.108.112003



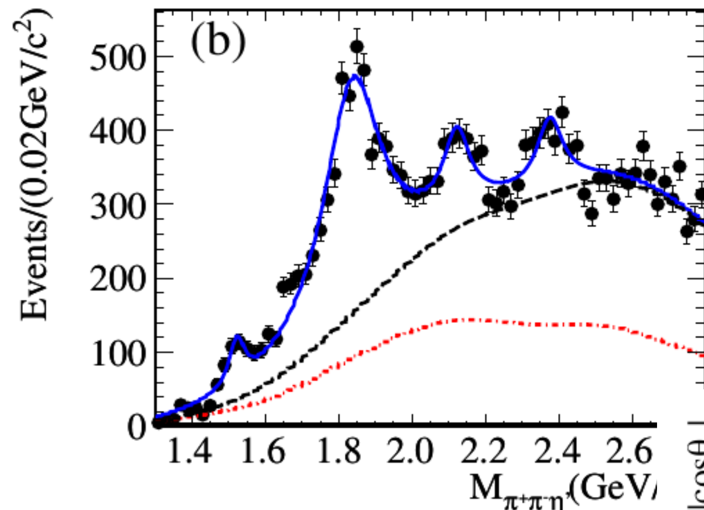
$J^{PC} = 0^{-+}$

$M = 1832^{-5}_{+19}\ {}^{-17}_{+18} \pm 19$ MeV

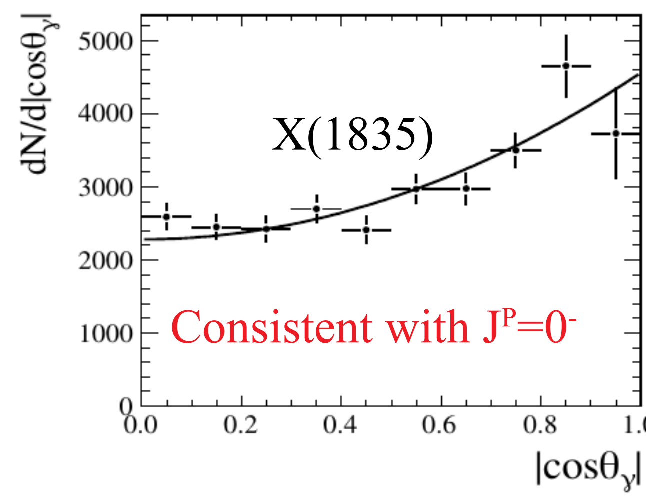
$\Gamma < 76\ MeV \quad @90\%\ C.L.$

FSR corrections notably improve data description.

Phys. Rev. Lett.106,072002



$J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$



$$M = 1836.5 \pm 3.0(\text{stat})^{+5.6}_{-2.1}(\text{syst})\ \text{MeV}/c^2$$

$$\Gamma = 190 \pm 9(\text{stat})^{+38}_{-36}(\text{syst})\ \text{MeV}/c^2$$

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

Phys. Rev. Lett. 115, 091803

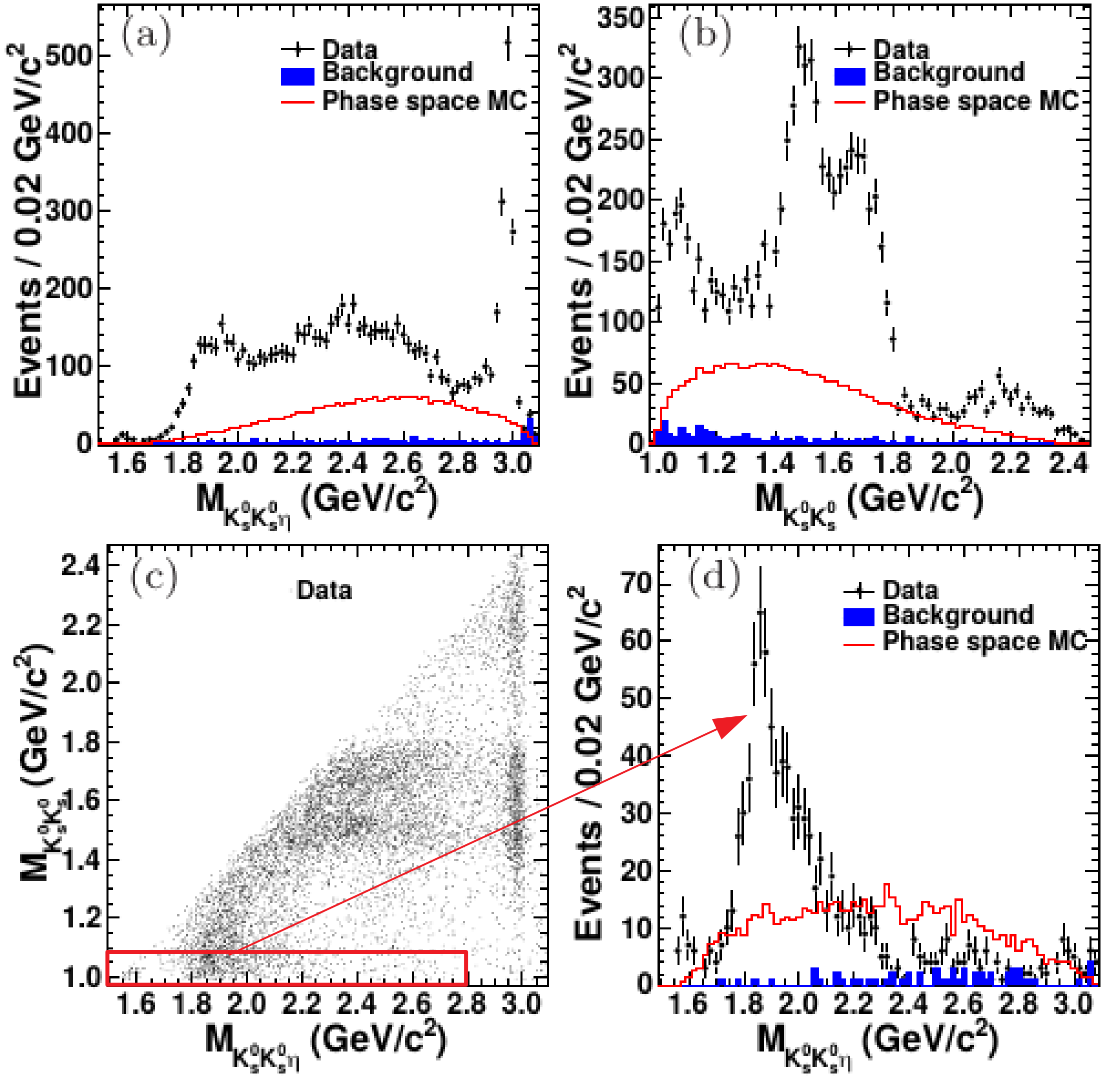
1.3 billion J/ψ events collected in 2009 and 2012 were analyzed.

Absent π^0-related background.

Clear structure in $K_s K_s \eta$ mass spectrum.

The structure strongly correlates with $f_0(980) \to K_s K_s$

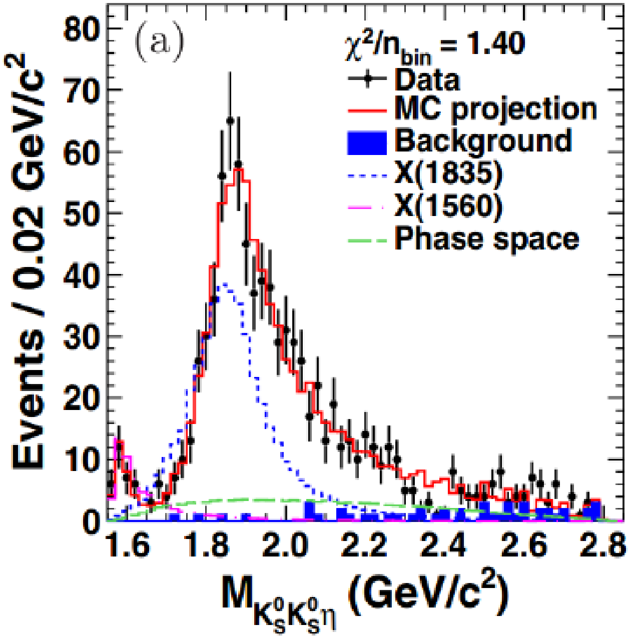
PWA in $M(K_s K_s) < 1.1$ GeV/c^2 region



X(1835) in $J/\psi \rightarrow \gamma K_s K_s \eta$

- X(1560)
  - J^{PC}: 0^{-+}; $X(1560) \rightarrow K_S K_S \eta$ (> 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^{-+}
  - $X(1835) \rightarrow K_S K_S \eta$ (> 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 $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$
  - $\mathfrak{B}(J/\psi \rightarrow \gamma X(1835)) \cdot \mathfrak{B}(X(1835) \rightarrow K_S K_S \eta) = (3.31^{+0.33+1.96}_{-0.30-1.29}) \times 10^{-5}$

Phys. Rev. Lett. 115, 091803



slide from Tianjue Min FPCP 2017

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

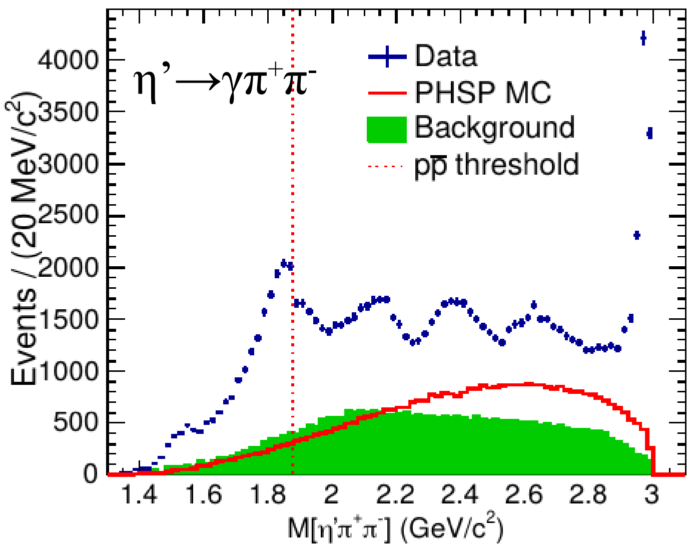
Phys. Rev. Lett. 117, 042002 (2016)

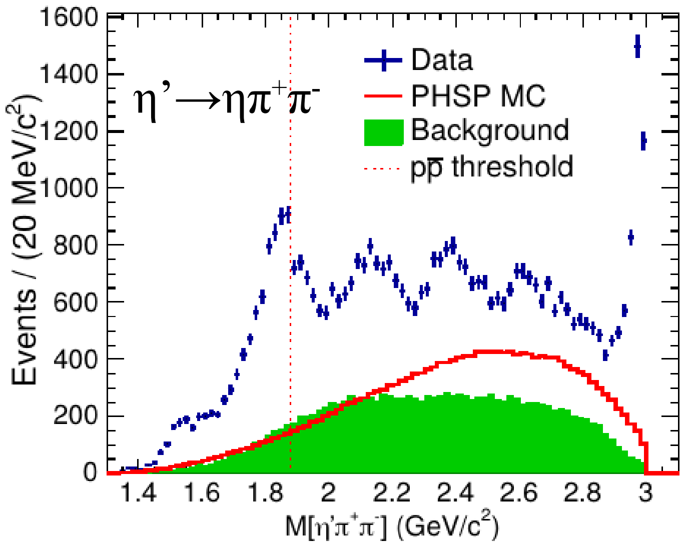
1.09 billion J/ψ events collected in 2012

η' reconstructed from $\gamma\pi^+\pi^-$ and $\eta\pi^+\pi^-$ decay modes

Clear peaks of X(1835), X(2120), X(2370) and η_c.

The spectrum is significantly distorted at $p\bar{p}$ threshold.

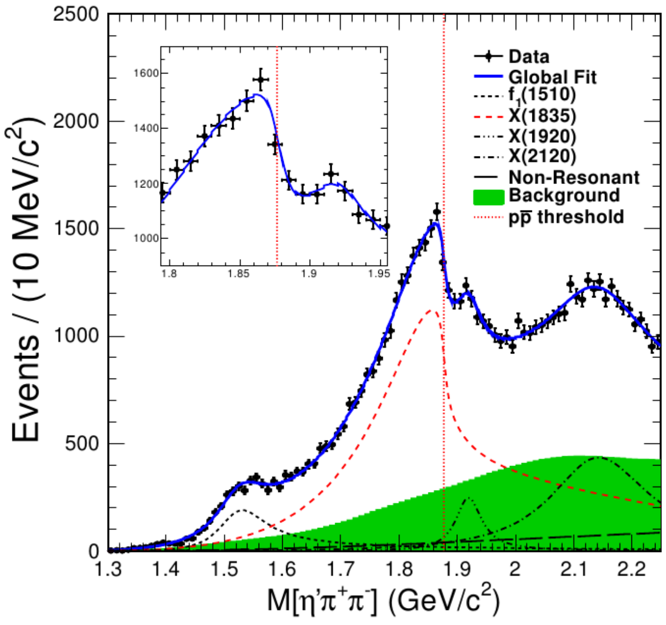


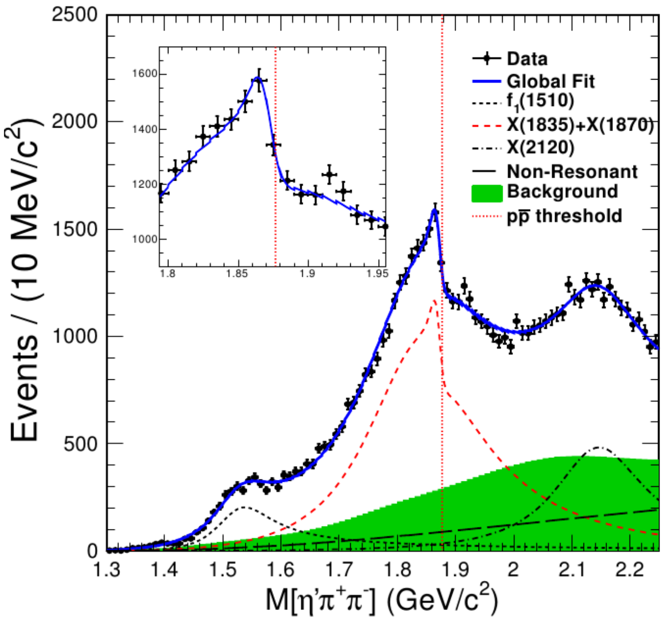


Anomalous line shape of $\pi^+\pi^-\eta'$ mass spectrum near $p\bar{p}$ threshold in $J/\psi \to \gamma\pi^+\pi^-\eta'$

Phys. Rev. Lett. 117, 042002 (2016)

Two solutions with equally good data description.





Model 1:
- Flatte formula with strong coupling to $p\bar{p}$ for X(1835)
- additional narrow resonance at ~1920 MeV/c^2

Model 2:
- Coherent sum of X(1835) and a narrow state with M ~ 1870 MeV/c^2

Solutions support existence of a $p\bar{p}$ molecule-like (broad with strong coupling to $p\bar{p}$) or bound state (narrow below $p\bar{p}$ threshold).

$\eta(1475)$ and X(1835) in $J/\psi \to \gamma(\gamma\varphi)$

Phys. Rev. D97 (2018) no.5, 051101

Use 1.3 billion J/ψ events collected by BESIII in 2009 and 2012.

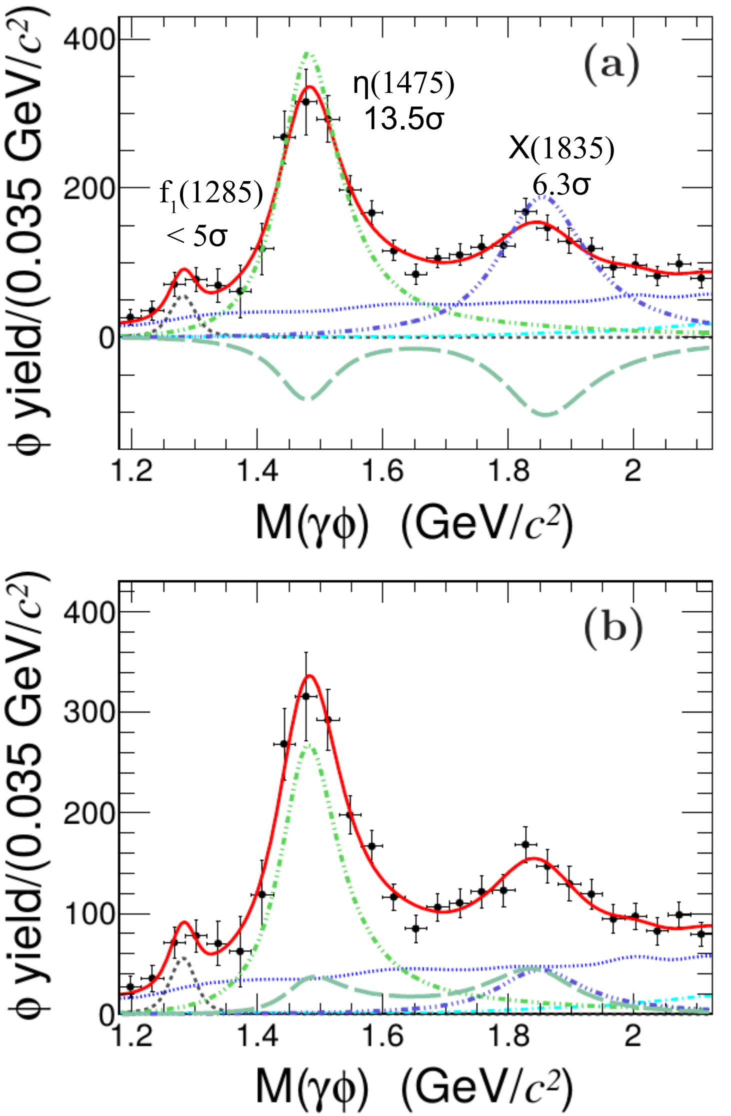
The φ yield is extracted from K^+K^- invariant mass spectrum in $\gamma\varphi$ invariant mass and $\cos\theta$ bins.

In the fit of $M(\gamma\varphi)$ two resonances are observed. Their mass and width are consistent with $\eta(1475)$ (PDG) and X(1835) (previous BESIII measurements).

The photon angular distributions favor JPC=0-+ for both resonances.

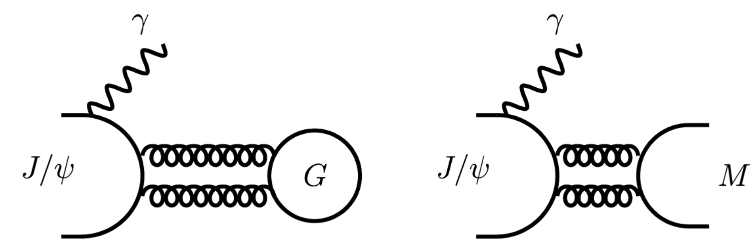
The observation $X(1835) \to \gamma\varphi$ decay indicates presence of sizable $s\bar{s}$ component, disfavoring its interpretation as pure $N\bar{N}$ bound state.

The measurement of $\eta(1475) \to \gamma\varphi$ process provides input for the old $\eta(1405)/\eta(1475)$ puzzle (Phys. Rev. D 87, 014023 (2013)).



J/ψ → γPP and J/ψ → γVV

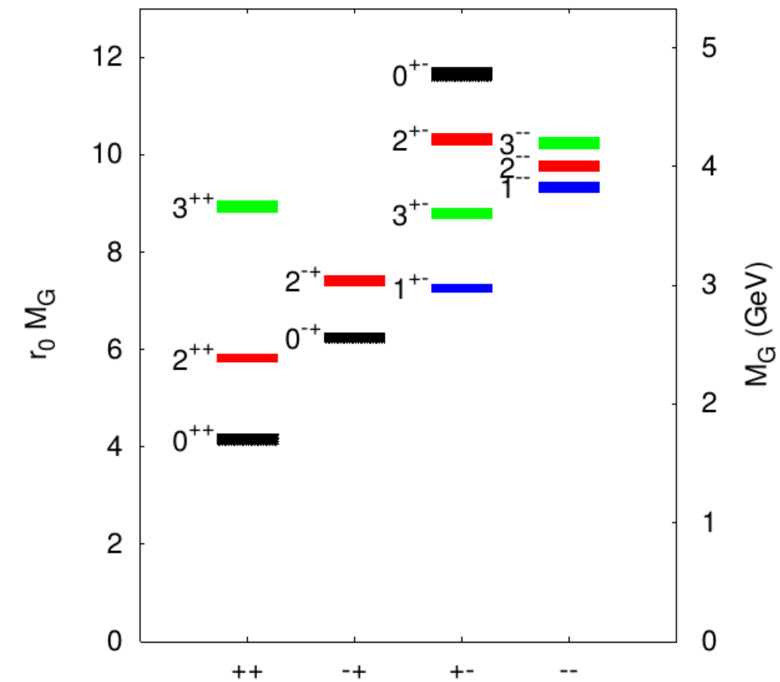
Radiative J/ψ decays have been long suggested as an ideal process to search for glueballs.



Gluon rich environment.

Mostly, one can consider two body dynamics

LQCD predictions for glueball mass:
- scalar: ~1.5-1.7
- tensor: ~2.3-2.4
- pseudoscalar: ~2.3-2.6



Phys. Rev. D 73, 014516

Systematic studies of hadron spectra and resonance production and decay properties are needed due to possible mixing.

Variety of theoretical suggestions

Scalar (0^{++})

- **Eur. Phys. J. C 21, 531–543 (2001), ...**
  - ✓ **f_0(1370):** Large $n\bar{n}$, small $s\bar{s}$ and **significant Glue** content
  - ✓ f_0(1500): $s\bar{s}$ and $n\bar{n}$ out of phase
  - ✓ f_0(1710): Large $s\bar{s}$ content
- **Physics Reports 389 (2004) 61, ...**
  - ✓ f_0(1370) Largely $n\bar{n}$
  - ✓ **f_0(1500)** mainly **Glue**
  - ✓ f_0(1710) mainly $s\bar{s}$
- **PRL 110, 021601 (2013), ...**
  - ✓ **f_0(1710)** dominant **Glueball** components
- **...**

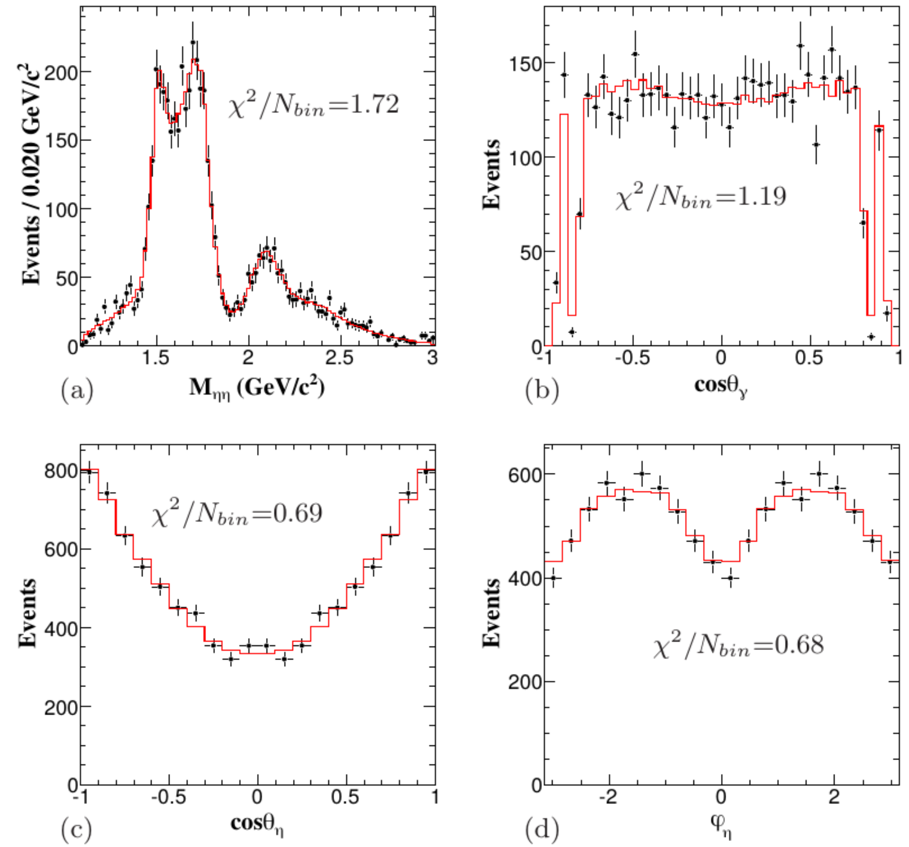
from Guofa Xu at Bergamo Resonance Worksop, 2017

J/ψ → γηη

Phys. Rev. D. 87, 092009 (2013)

- ✔ For J/ψ → γPP the only allowed quantum numbers for PP are 0^{++}, 2^{++}, etc.
- ✔ 225M J/ψ decays
- ✔ Isobar model
- ✔ Dominant contributions from $f_0(1710)$ and $f_0(2100)$.
- ✔ $f_0(1500)$ observed with much small decay fraction
- ✔ Three tensor states observed ($f_2(1525)$, $f_2(1810)$ and $f_2(2340)$)

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	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
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513\pm5^{+4}_{-10}$	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



Amplitude analysis of $\pi^0\pi^0$ system in $J/\psi \rightarrow \gamma\pi^0\pi^0$

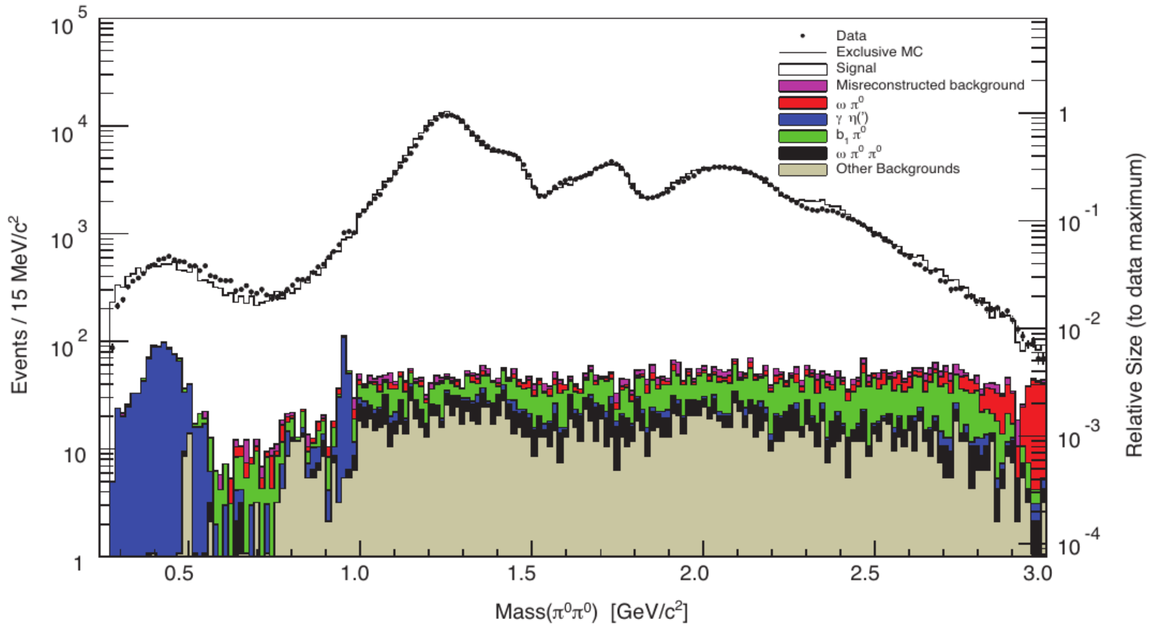
Phys. Rev. D 92, 052003 (2015)

Problem of "simple" isobar approach: **rescattering of pseudoscalars, especially pions, may not be negligible.**

Model-independent PWA is performed to permit development of phenomenological models and to embed these data to multichannel analyses.

1.3B J/ψ events collected in 2009 and 2012 were analyzed.

Clean channel (no irreducible background from $\rho\pi^0$, which is present in $J/\psi \rightarrow \gamma\pi^+\pi^-$).

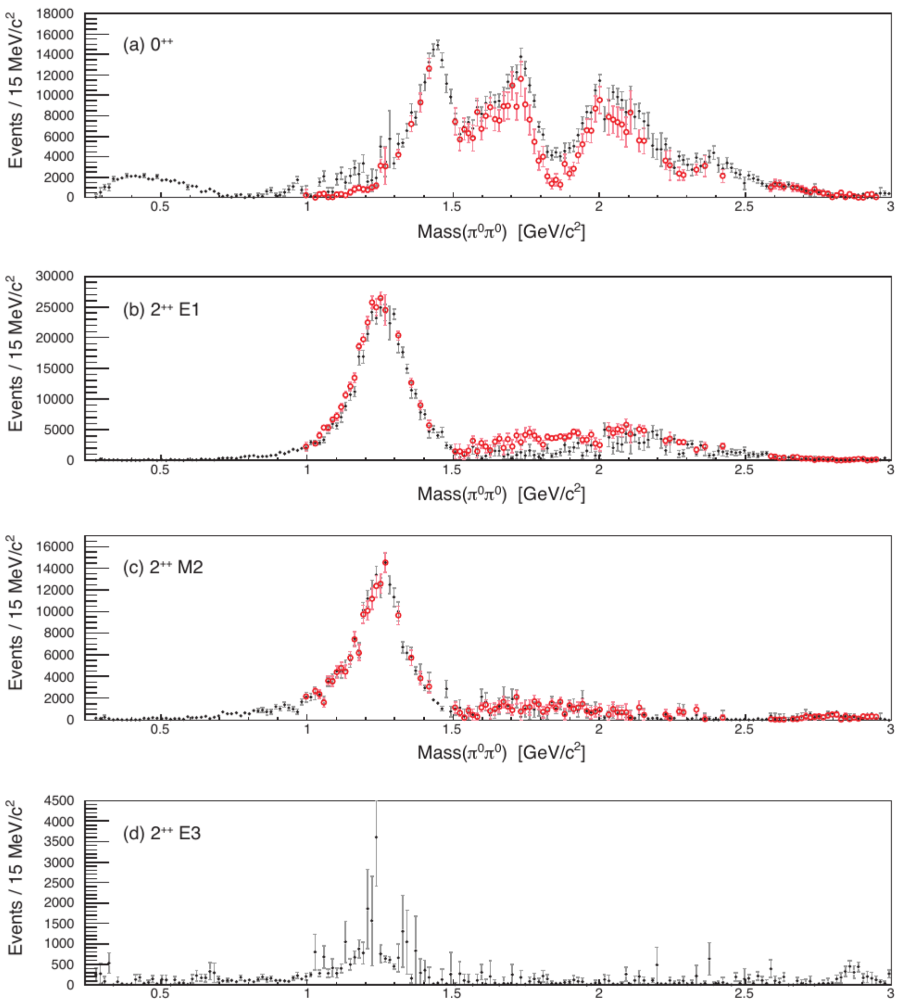


More than 440,000 selected events.
Background level ~1.8%.

Amplitude analysis of $\pi^0\pi^0$ system in $J/\psi \rightarrow \gamma\pi^0\pi^0$

Phys. Rev. D 92, 052003 (2015)

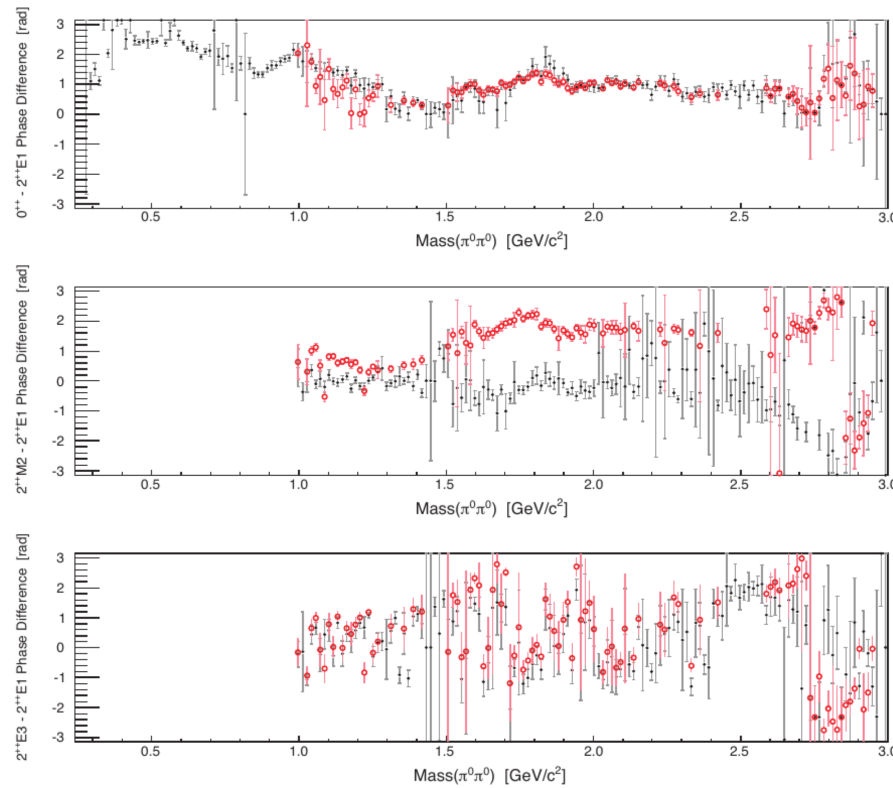
Intensities:



Solution 1

Solution 2

Relative phases:

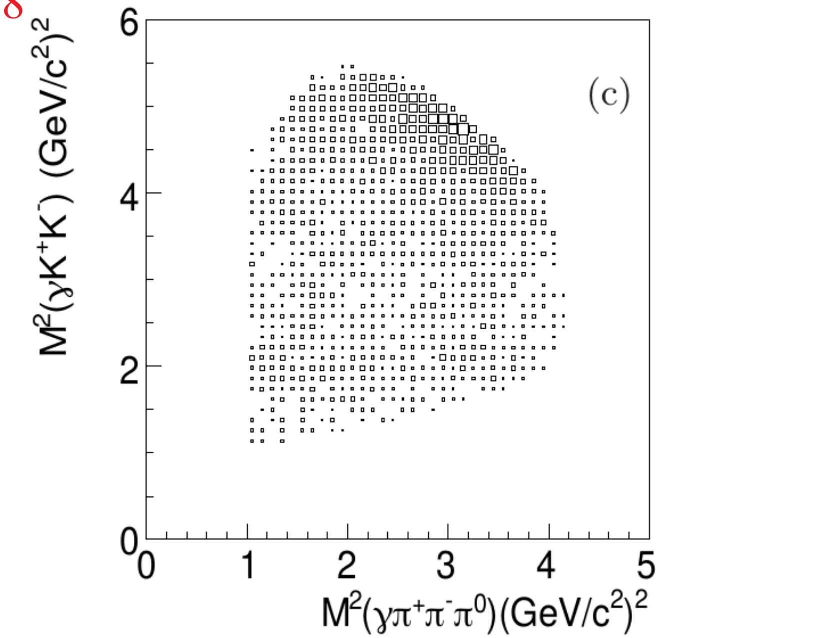


Fit results:

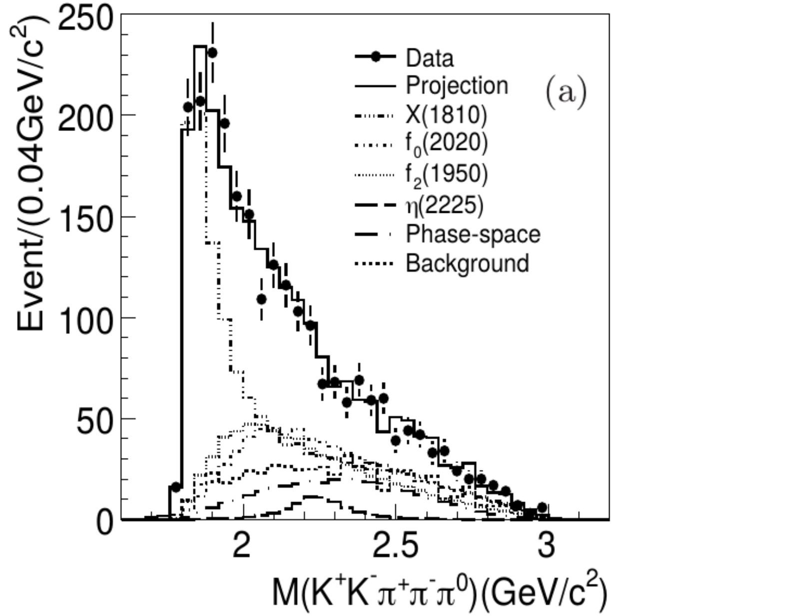
- Only contributions from 0^{++} partial wave and 3 2^{++} partial waves are significant.
- Ambiguous solution.
- Partial wave intensities and relative phases are available as supplementary material.

J/ψ → γωφ

Phys. Rev. D.87.032008



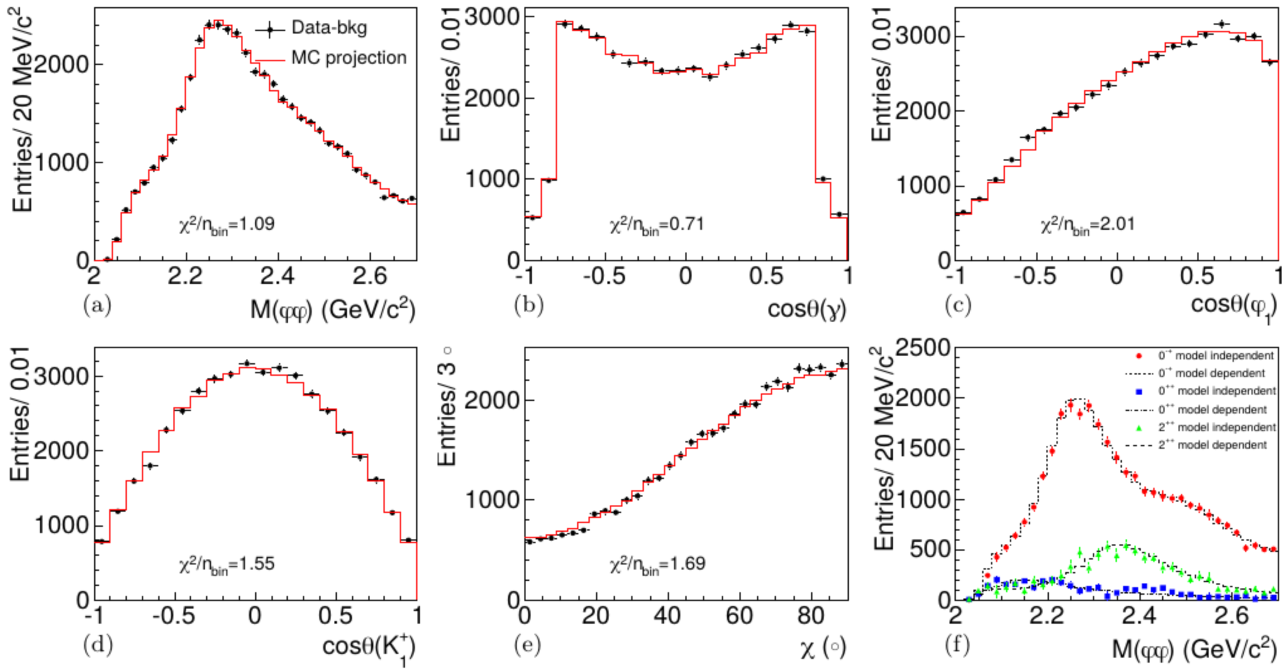
- Double OZI suppressed decay
- Threshold enhancement was firstly observed at BESII (Phys. Rev. Lett. 96, 162002 (2006)). **If it is caused by resonance X(1810), the decay rate is unexpectedly high for DOZI process (~1/2 B(J/ψ → γφφ))**
- Confirmed at BESIII:
  - **JPC = 0++**
  - $M = 1796 \pm 7\ ^{+13}_{-5} \pm 19(\text{model})\ \text{MeV}/c^2$
  - $\Gamma = 95 \pm 10^{+21}_{-34} \pm 75(\text{model})\ \text{MeV}/c^2$
- Is $f_0(1810)$ the same state as $f_0(1710)$?



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

Apart from η(2225) pseudoscalar spectrum above 2 GeV is poorly known. New experimental results are helpful to mapping out pseudoscalar excitations searching for 0^{-+} glueball.

Phys. Rev. D.93.112011



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	B.F.$(\times 10^{-4})$	Sig.
$\eta(2225)$	2216^{+4+21}_{-5-11}	185^{+12+43}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	$28\ \sigma$
$\eta(2100)$	2050^{+30+75}_{-24-26}	$250^{+36+181}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	$22\ \sigma$
$X(2500)$	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	$8.8\ \sigma$
$f_0(2100)$	2101	224	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	$24\ \sigma$
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	$9.5\ \sigma$
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	$6.4\ \sigma$
$f_2(2340)$	2339	319	$(1.91 \pm 0.14^{+0.72}_{-0.73})$	$11\ \sigma$
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	$6.8\ \sigma$

Analysis results:

- Dominant contribution from pseudoscalars. Two new states (η(2100) and η(2500)) have been observed.
- Three tensor states $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ reported in $\pi^- p$ reactions were observed, with the dominant production of $f_2(2340)$.
- Model-dependent and model-independent results are well-consistent.

Search for Z_s

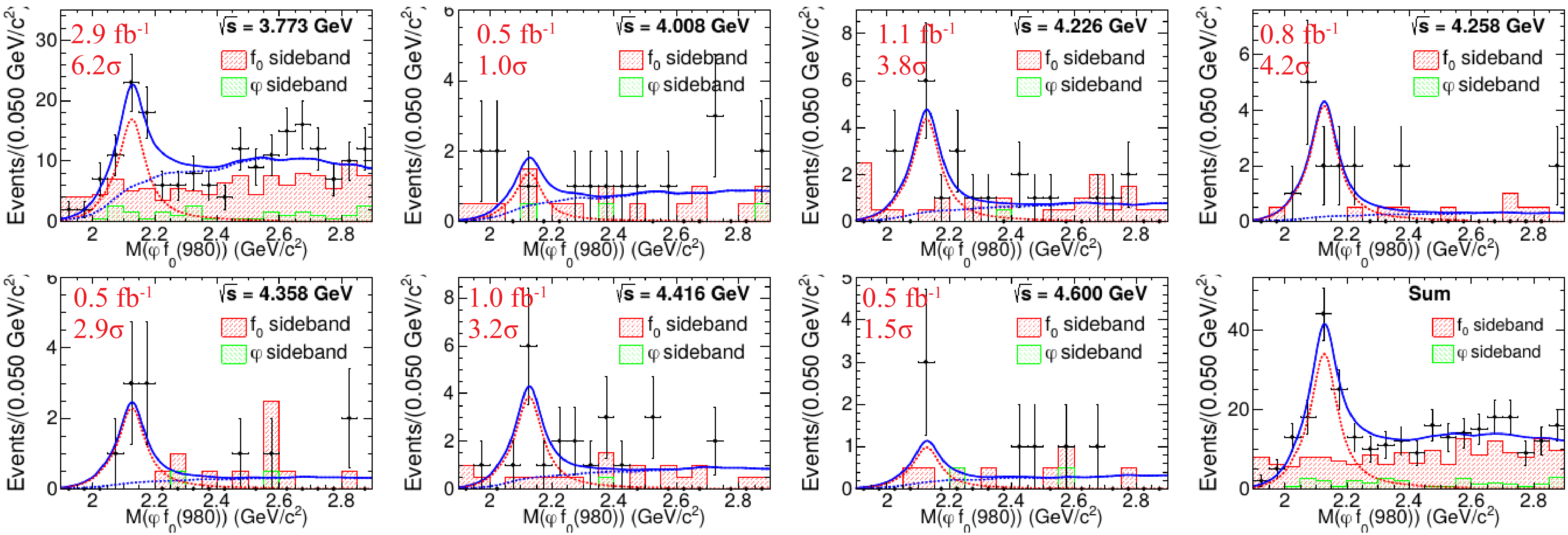
Similarity of Y(2175) and Y(4260) production (ISR) and decay ($f_0\varphi$ and $\pi\pi J/\psi$) properties may indicate **similar nature** of these states (Phys. Lett. B 650, 390 (2007)).

If this conjecture is true, one may expect **narrow** Z_s states in
$Y(2175) \to \pi Z_s \to \pi\pi\varphi$,
with Z_s mass close to $K\bar{K}^*$ and $K^*\bar{K}^*$ thresholds (Eur. Phys. J. C 72, 2008 (2012)).

Observation of $e^+e^- \to \eta Y(2175)$ at $\sqrt{s}$ > 3.7 GeV

Phys. Rev. D.96.012001

The $f_0\varphi$ invariant mass distribution for data samples with √s > 3.7 GeV.



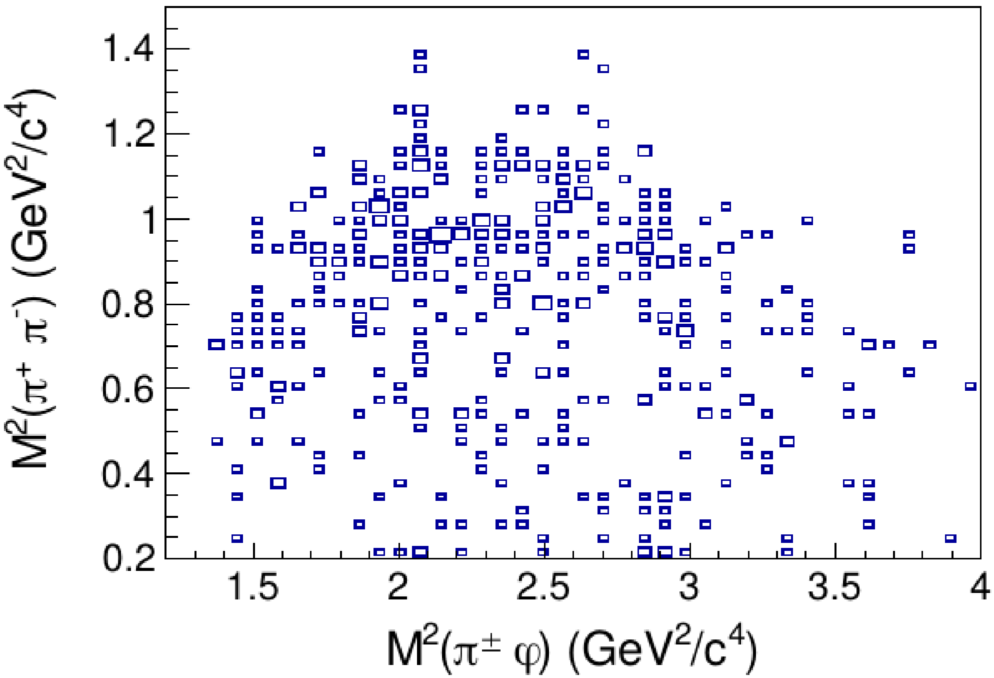
The joint statistical significance > 10σ

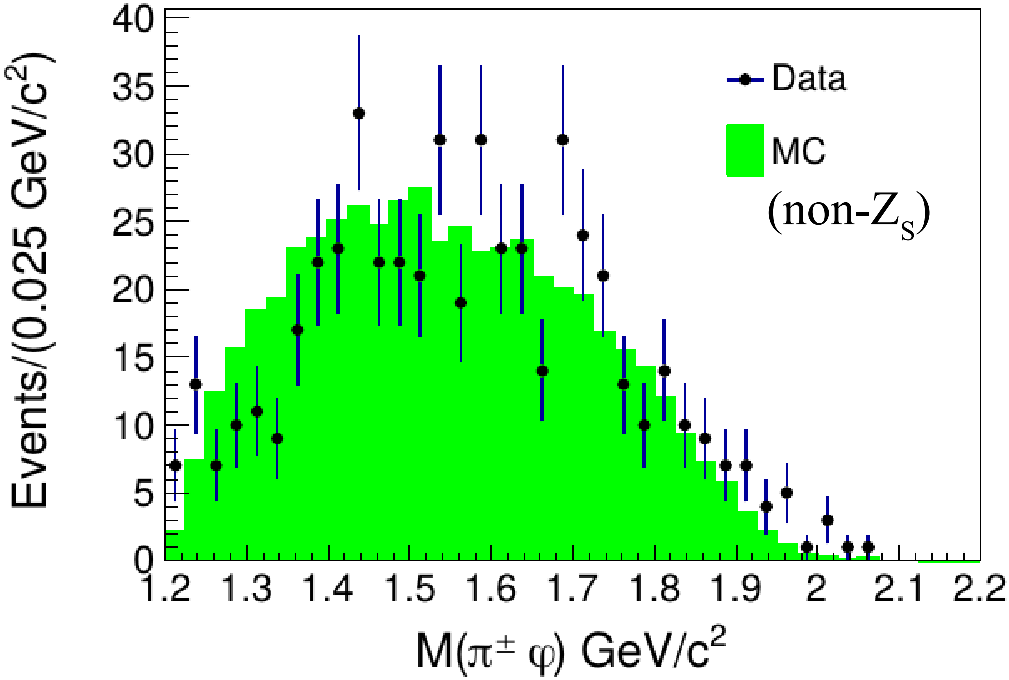
$M = 2135 \pm 8 \pm 9$ MeV/c^2

$\Gamma = 104 \pm 24 \pm 12$ MeV

Observation of $e^+e^- \to \eta Y(2175)$ at $\sqrt{s}$ > 3.7 GeV

Phys. Rev. D.96.012001



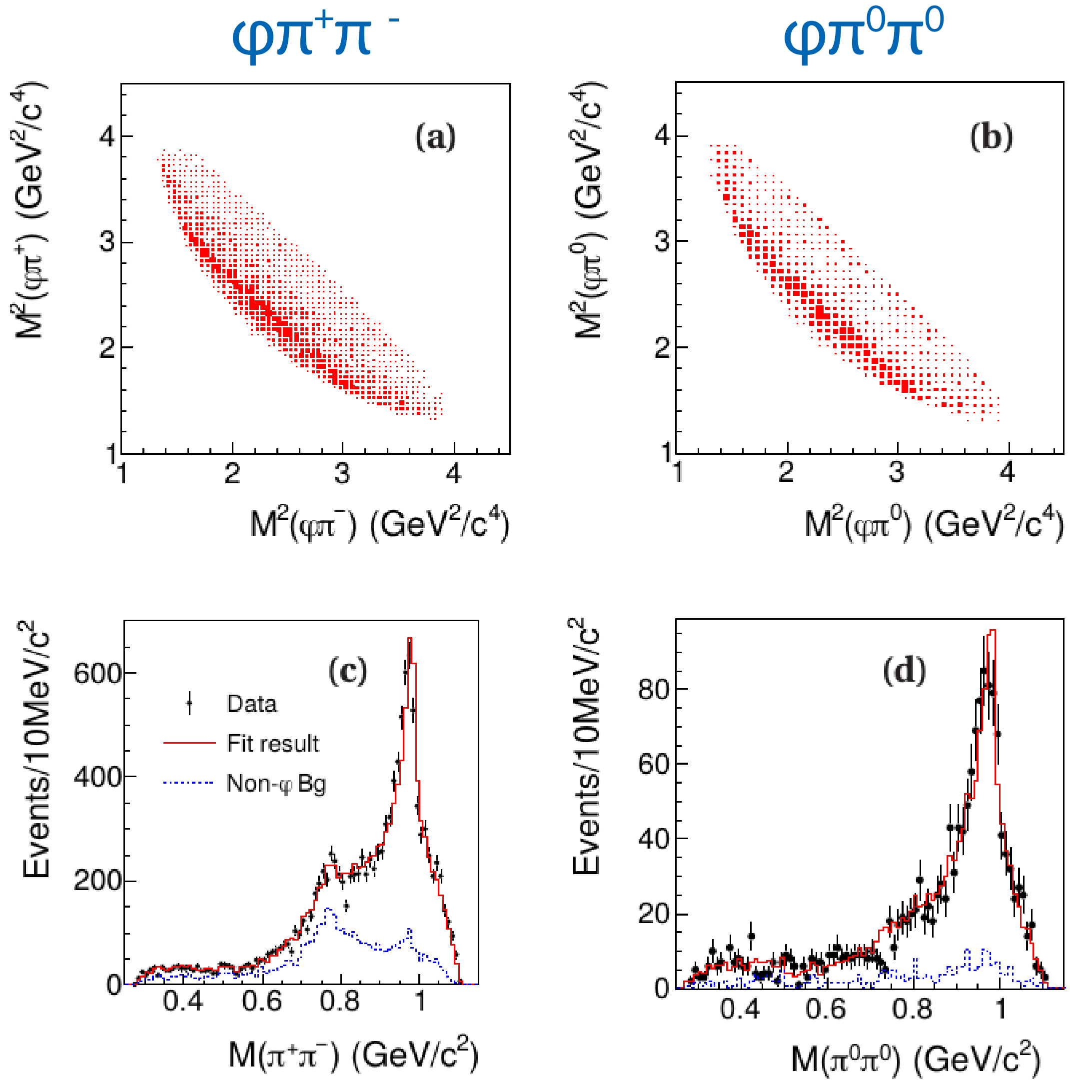


- No clear structures in $\pi^{\pm}\varphi$ invariant mass at $K\bar{K}^*$ and $K^*\bar{K}^*$ thresholds(1.4 GeV and 1.7 GeV)
- Low statistics

Search for Z_s at 2125 MeV

arXiv:1801.10384 , Submitted to PRL

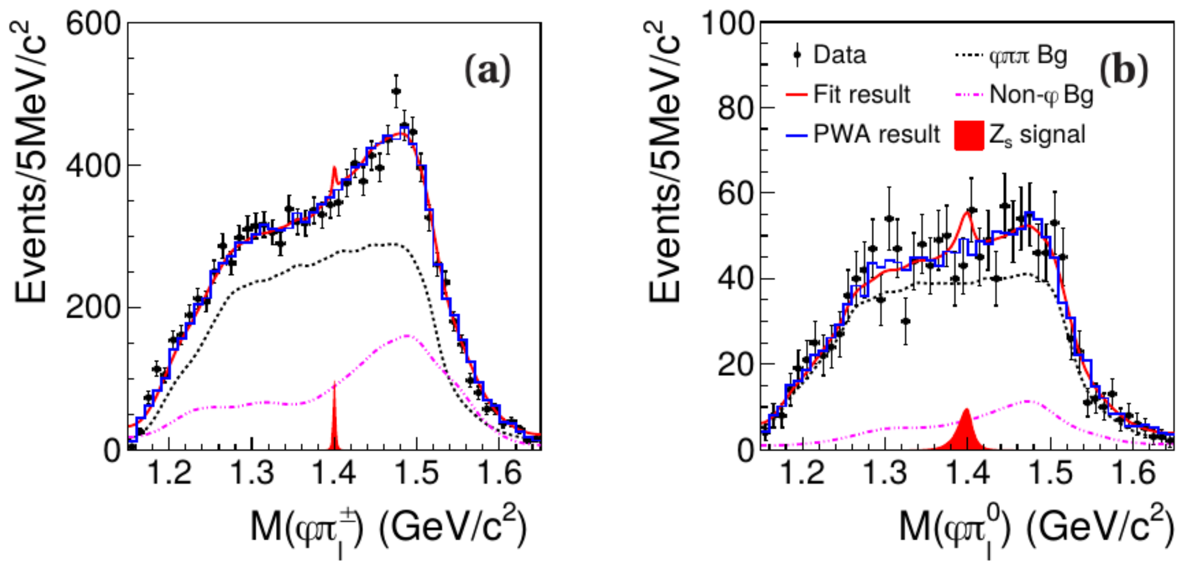
- Data: 108.49 ± 0.75 pb^{-1} collected at collision energy of 2125 MeV
- Two modes: $\varphi\pi^+\pi^-$, $\varphi\pi^0\pi^0$
- No obvious structures in φπ invariant mass
- PWA fit. Nominal PWA solution:
  - $f_0(980)$
  - σ
  - $f_0(1370)$
  - $f_2(1270)$



Search for Z_s at 2125 MeV

arXiv:1801.10384 , Submitted to PRL

Upper limits for $e^+e^- \to Z_s\pi \to \varphi\pi\pi$ cross-section were determined for different assumptions on Z_s mass and width.



Additionally cross-sections for $e^+e^- \to \varphi\pi^+\pi^-$ and $e^+e^- \to \varphi\pi^0\pi^0$ were measured with small stat. uncertainty.

	Γ \ M	1.380			1.400			1.420		
		N^{UL}	ε(%)	$\sigma^{UL}_{Z_s}$	N^{UL}	ε(%)	$\sigma^{UL}_{Z_s}$	N^{UL}	ε(%)	$\sigma^{UL}_{Z_s}$
$Z_s^{\pm}$	0	22.2	47.3	0.90	16.6	46.9	0.68	44.4	46.8	1.82
	5	38.0	47.5	1.54	29.8	46.9	1.22	54.4	47.2	2.21
	10	49.6	47.5	2.01	40.0	47.4	1.62	60.8	47.3	2.47
Z_s^{0}	0	25.6	13.8	3.75	25.2	13.7	3.72	27.2	13.5	4.07
	5	28.0	13.8	4.10	28.6	13.7	4.22	30.2	13.5	4.52
	10	31.2	13.8	4.57	32.4	13.7	4.78	33.6	13.6	4.99

$\sigma(e^+e^- \to Z_s\pi \to \varphi\pi\pi)$ in pb

Summary

- BESIII is a unique laboratory to study hadron spectra and hunt for long suggested exotic QCD states.
- A number of exciting on results, including those relevant to search for baryonium, glueballs, multiquark states, has obtained.
- Expect much more results from BESIII in future!

Thank You!