Light Hadron Spectroscopy and Decay at BESIII

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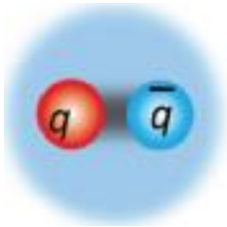
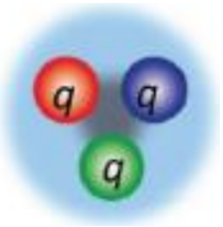
Hadron spectrum

- Conventional hadrons consist of 2 or 3 quarks.

Naïve Quark Model:



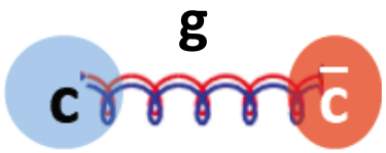
meson



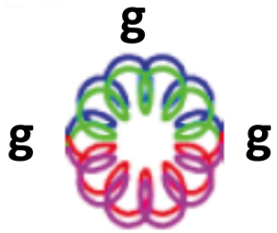
baryon

- QCD predicts the new forms of hadrons:
  - ✓ Multi-quark states: Number of quarks ≥ 4

  - ✓ Hybrids: $q\bar{q}g$, $qqqg$ ….



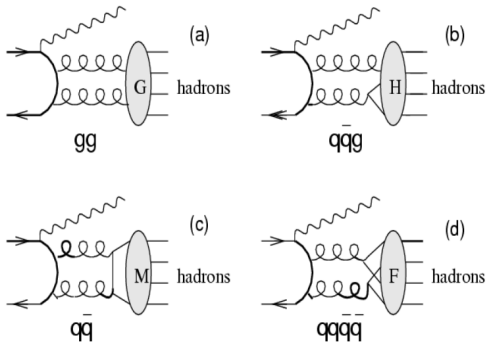
  - ✓ Glueballs: gg, ggg ….



None of the new forms of hadrons is settled !

Hunting the new form of hadrons

- Charmonium decays provide ideal ground for light glueballs and hybrids



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

- Glueballs can mix with ordinary $q\bar{q}$ states

  Predicted large branching fractions for glueballs in J/ψ radiative decays

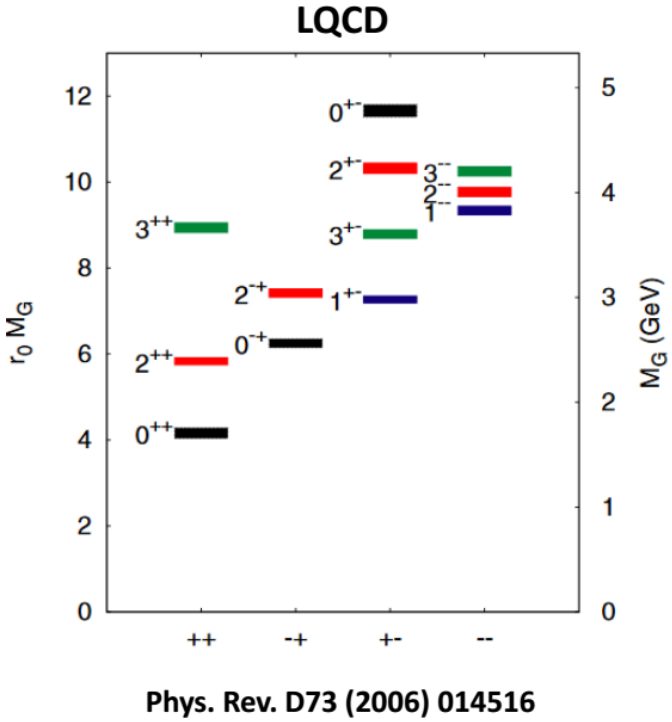
$$\Gamma(J/\psi \to \gamma G_{0^{++}}) = \frac{4}{27}\alpha\frac{|\vec{p}_\gamma|}{M^2_{J/\psi}}|E_1(0)|^2$$

$$\Gamma(J/\psi \to \gamma G_{0^{++}}) = 0.35(8)\ \text{keV}$$

$$\Gamma_{\text{tot}} = 92.9(2.8)\ \text{keV}$$

$$\Gamma(J/\psi \to \gamma G_{0^{++}})/\Gamma_{\text{tot}} = 3.8(9)\times 10^{-3}$$

[Phys. Rev. Lett. **110**, 021601 (2013)]



Phys. Rev. D73 (2006) 014516

$$\Gamma(J/\psi \to \gamma G_{2^{++}}) = 1.01(22)(10)\ \text{keV}$$

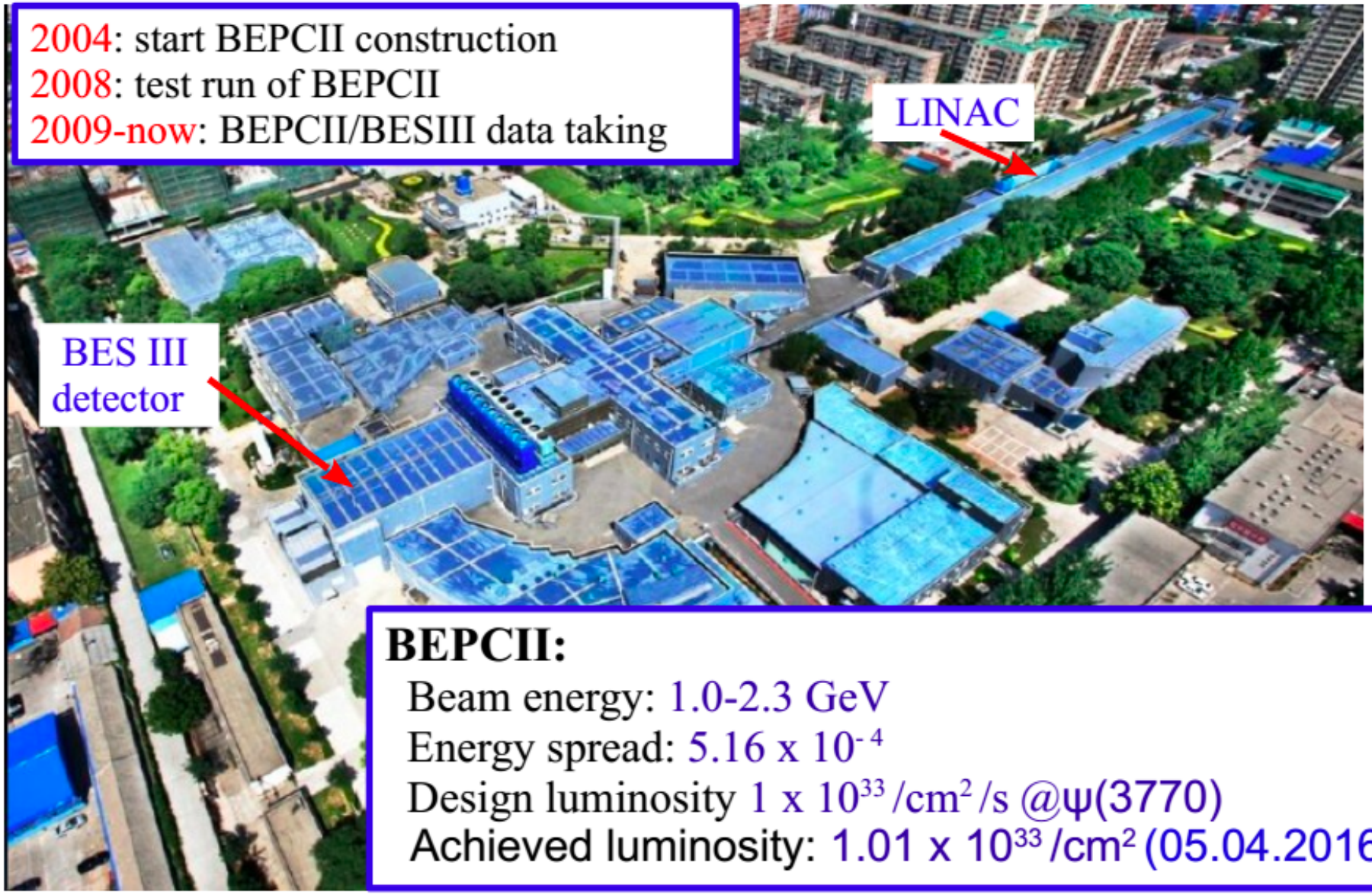
$$\Gamma(J/\psi \to \gamma G_{2^{++}})/\Gamma_{\text{tot}} = 1.1(2)(1)\times 10^{-2}$$

[Phys. Rev. Lett. **111**, 091601 (2013)]

BESIII is an ideal laboratory to study the properties of these exotic states!

BEPCII/BESIII at IHEP (Beijing)

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

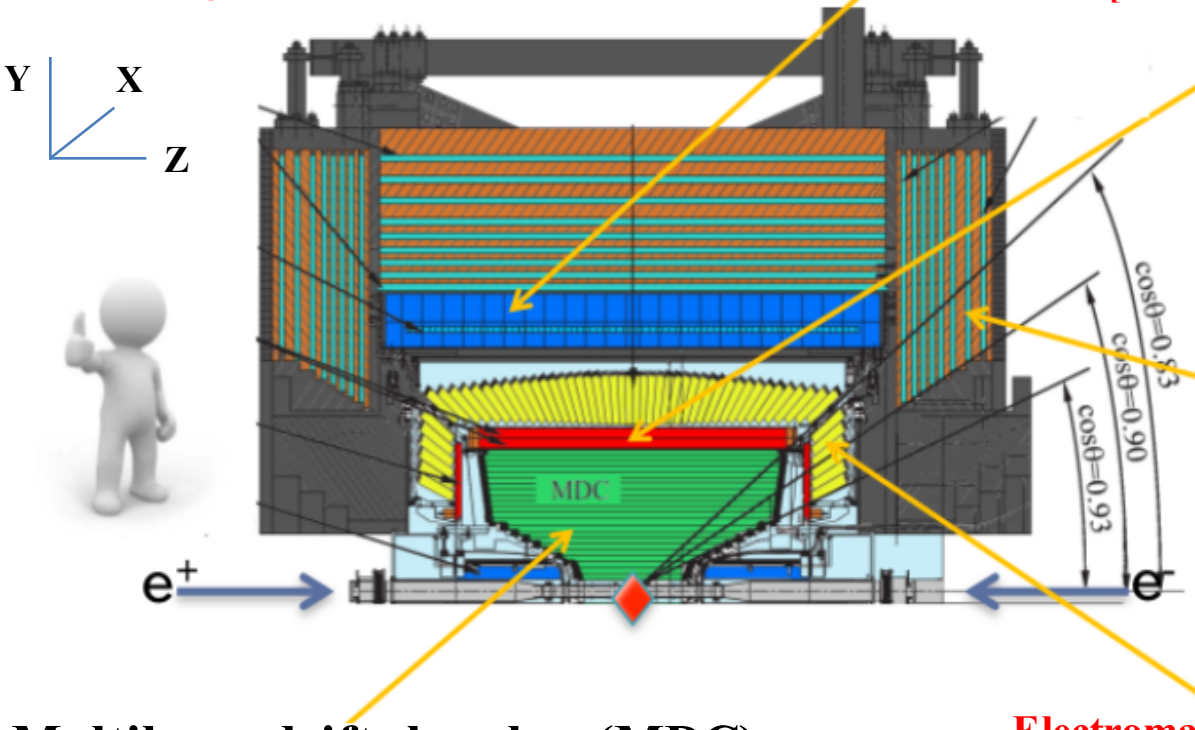


BEPCII:

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

BESIII Experiment

BESIII experiment is a symmetric electron positron collider experiment running as tau-charm region.



Super conducting magnet

✓ 1 Tesla

[Nucl. Instrum. Meth. A614, 345-399 (2010)]

Time of Flight (TOF)

- 2 layer plastic scintillators
- σ_T = 90 ps (barrel)
- σ_T = 90 ps (endcap)
- Particle id

Muon system

- 9 layers of RPC
- P > 400 MeV/c
- $\delta R\phi$= 1.4 – 1.7 cm

Multilayer drift chamber (MDC)

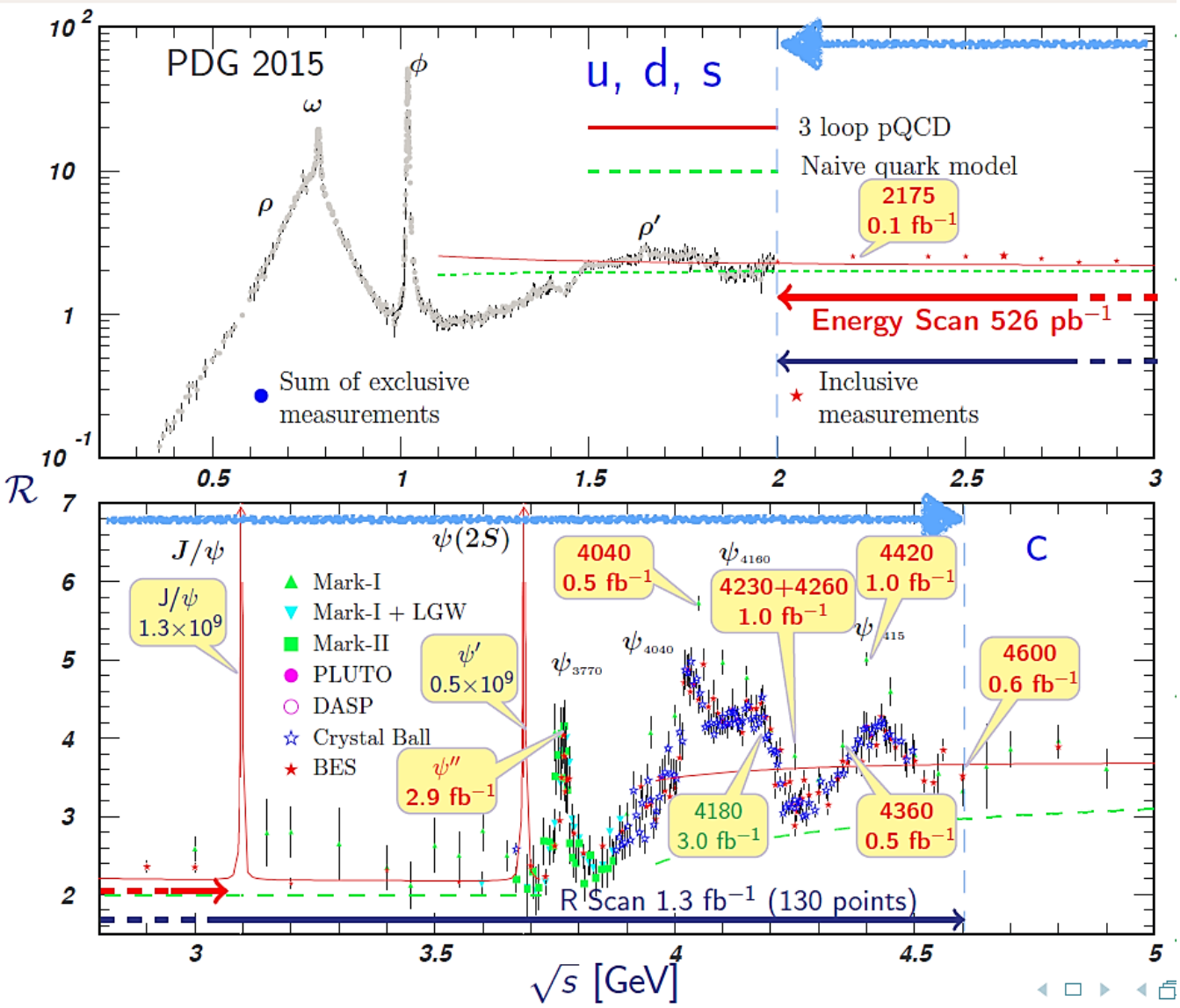
- He/C_3H_8 (60/40)
- 43 layers
- Momentum resolution σ_p/p = 0.5% @ 1 GeV
- Spatial resolution σ_{xy} = 130 µm.

Electromagnetic calorimeter (EMC) (CsI(Tl))

→ 6240 crystals overall

- $\sigma(E)/E$ = 2.5%
- $\sigma_{Z,\phi}(E)$ = 0.5 – 0.7 cm

BESIII Dataset



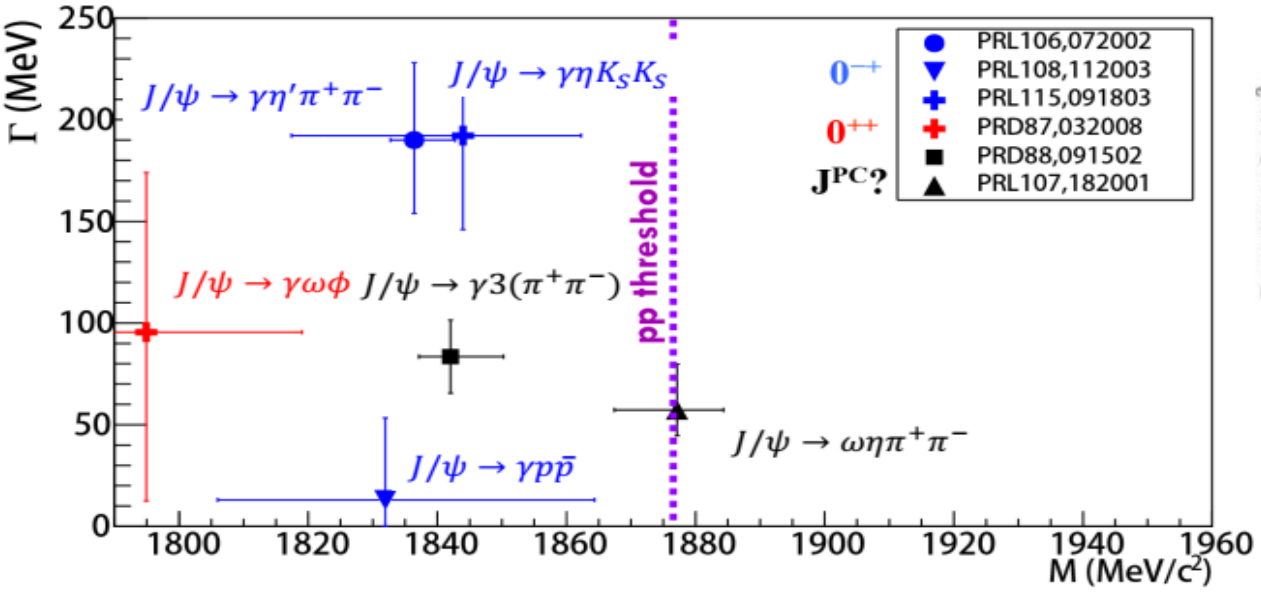
World largest data for

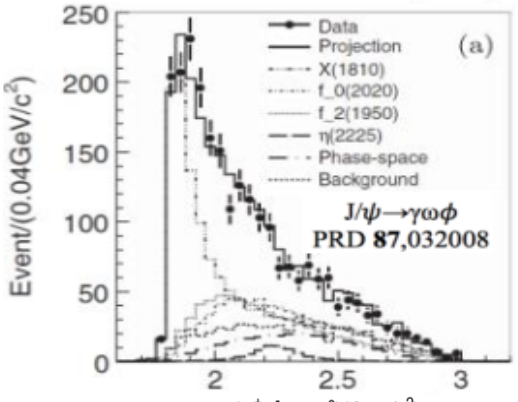
- ✓ Charmonium spectroscopy
- ✓ Charm physics
- ✓ Light hadrons
- ✓ New physics search

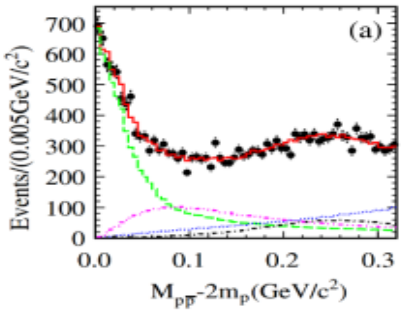
IDEAL ENVIRONMENT TO STUDY LIGHT HADRON SPECTROSCOPY!!

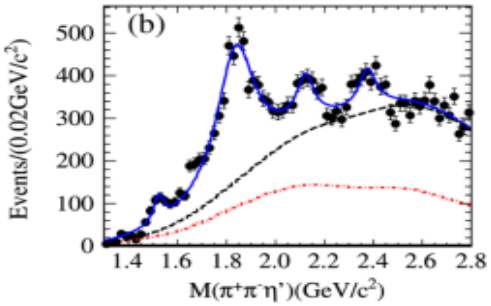
Some important BESIII results presented in previous FPCP conferences

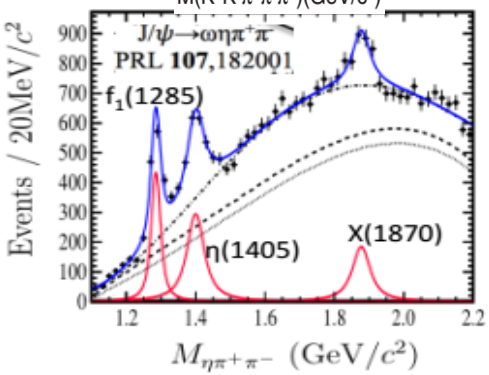
Fang Liu FPCP 2016
Tianjue Min FPCP 2017

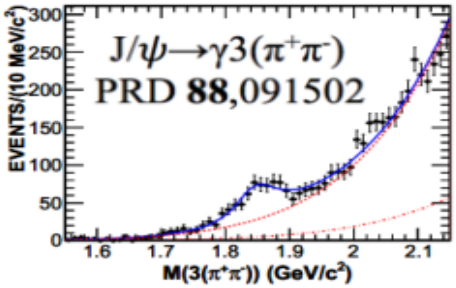












- **Any relations?**
- **What is the role of the ppbar threshold (and other thresholds)?**
- **Patterns in the production and decay modes**

Some of the new results produced after FPCP2017 are shown in the next slides

η(1405)/η(1475) puzzle

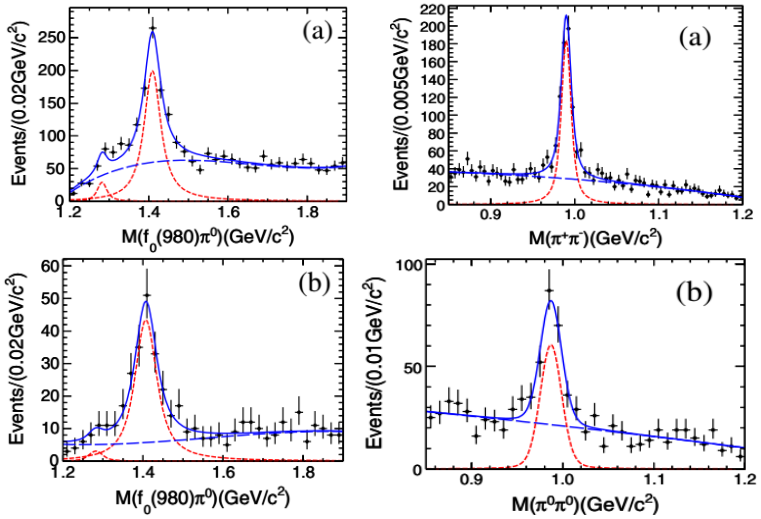
- η(1405)/η(1475) are two different states or one 0^{-+} state in different decay modes?

- MARK III reported two states mixture in the 1400 MeV/c^2 region for the first time in the PWA of $J/\psi \to K_S^0 K^{\pm}\pi^{\mp}$.
  - ✓ Described by $a_0(980)\pi$ and K^*K amplitudes [Phys. Rev. Lett. **65**, 2507 (1990)]

- Confirmed by Crystall Barrel and Obelix [Phys. Lett. B **545**, 261 (2002)]

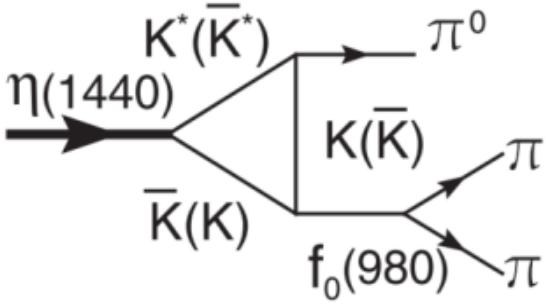
- No observation by L3 on η(1405). Both states not found by CLEO

✓ First observation of $\eta(1405)\to f_0(980)\pi^0$ by BESIII in $J/\psi\to\gamma 3\pi$ decay with a narrow resonance $f_0(980)$ and isospin violation. [PRL **108**, 182001 (2012)]



According to triangle singularity, the shift of the peak positions in different channels occurs via the intermediate $K^*\bar{K} + c.c$ rescattering [PRL **108**, 081803 (2012)]

η(1405) and η(1475) could be one state appeared as different line shape in different channel



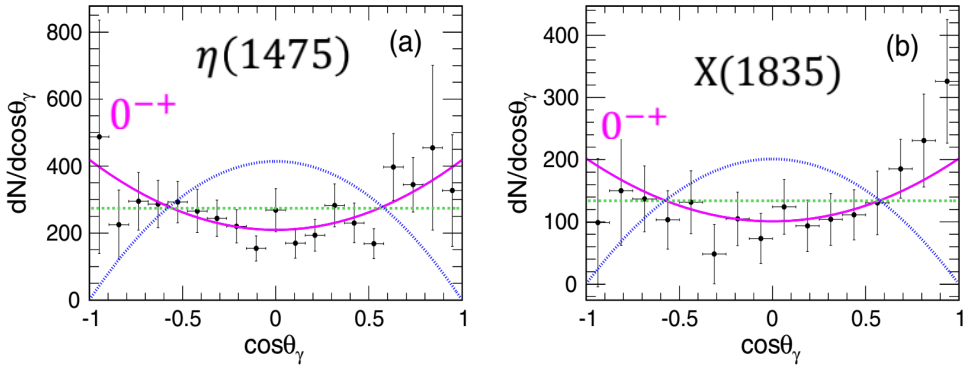
Observation of η(1475) and X(1835) in $J/\psi\to\gamma\gamma\phi$ ($\phi\to K^+K^-$)

Phys. Rev. D 97, 051101(R) (2018)

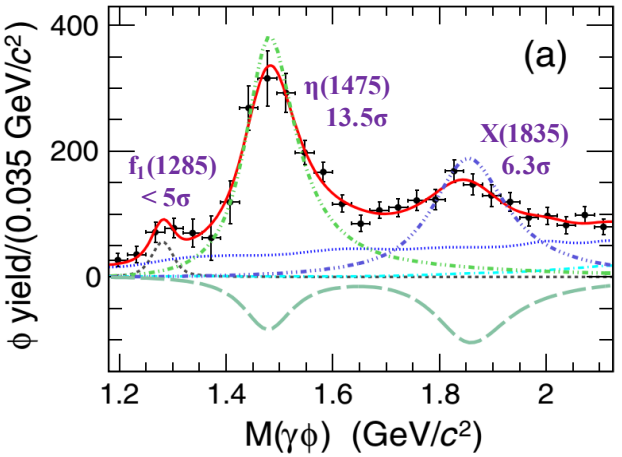
- Two resonance structures corresponding to η(1475) and X(1835) mass positions are observed in the φ yield versus M(γφ) data
  - ✓ Angular distributions are in favor of 0^{-+}
  - ✓ Measured M and Γ are consistent with η(1475) and X(1835)

Solution	Resonance	m_R (MeV/c^2)	Γ (MeV)	B (10^{-6})
I	$\eta(1475)$	$1477 \pm 7 \pm 13$	$118 \pm 22 \pm 17$	$7.03 \pm 0.92 \pm 0.91$
	$X(1835)$	$1839 \pm 26 \pm 26$	$175 \pm 57 \pm 25$	$1.77 \pm 0.35 \pm 0.25$
II	$\eta(1475)$	$1477 \pm 7 \pm 13$	$118 \pm 22 \pm 17$	$10.36 \pm 1.51 \pm 1.54$
	$X(1835)$	$1839 \pm 26 \pm 26$	$175 \pm 57 \pm 25$	$8.09 \pm 1.99 \pm 1.36$

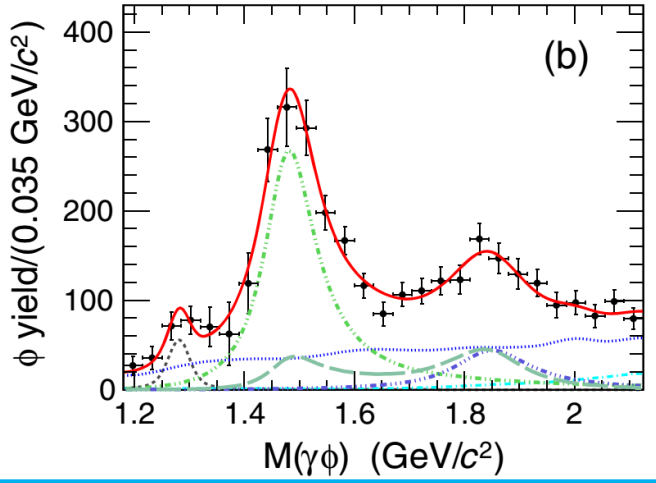
- Γ(η(1405/1475)→γρ):Γ(η(1405/1475)→γφ) is slightly larger than the prediction of 3.8:1 in PRD 87, 014023 (2013) for the case of a single pseudoscalar state.
- Interpretation of η(1475)/X(1835)→γφ
  - ✓ Sizable $s\bar{s}$ component
  - ✓ η(1475) could be a radial excitation of the η′, if η(1405) and η(1475) are different states [PRD 70, 114033 (2013)]



Solution1: constructive interference



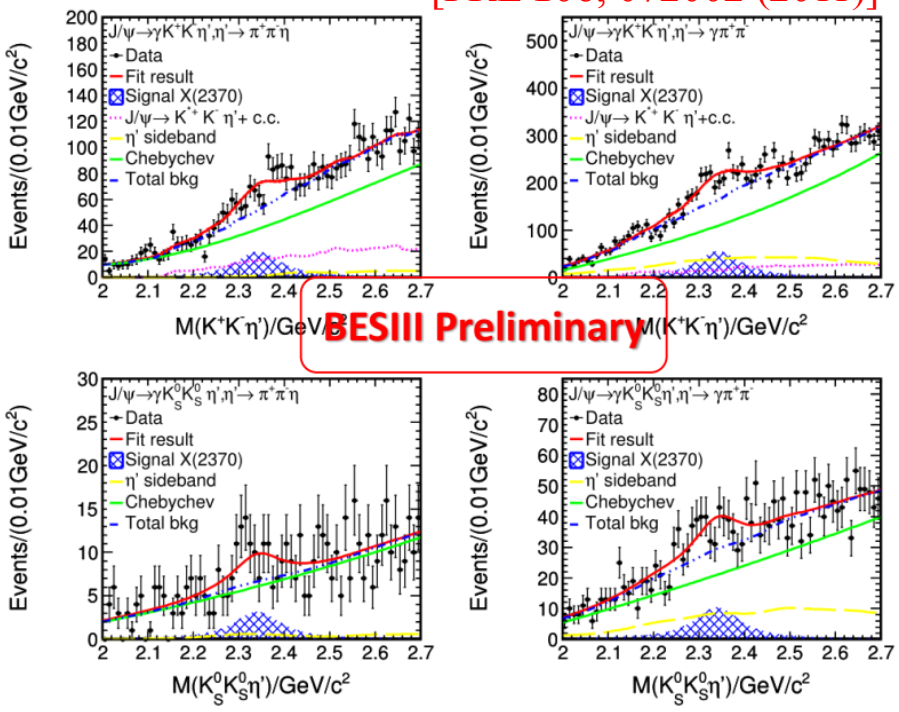
Solution II: destructive interference



Observation of X(2370) in J/ψ→γKKη′

BESIII Preliminary

- The X(2120) and X(2370) states observed in ππη′ invariant mass spectrum through J/ψ→γππη′. [PRL **106**, 072002 (2011)]
  - ✓ Possible pseudoscalar glueball candidates
- **Prediction:** $\frac{\Gamma_{G\to\eta' KK}}{\Gamma_G^{Tot}} = 0.011, \frac{\Gamma_{G\to\eta'\pi\pi}}{\Gamma_G^{Tot}} = 0.090$ **with M(G)=2.37 GeV/c²** [PRD 87, 054036(2013)]
  - ✓ Looking into this channel to support Glueball hypothesis



- Simultaneous fit is performed on all the four decay modes: J/ψ→γK⁺K⁻η′ and $J/\psi \to \gamma K_S^0 K_S^0 \eta'$, each η′ candidate has two modes ηπ⁺π⁻ and γπ⁺π⁻.

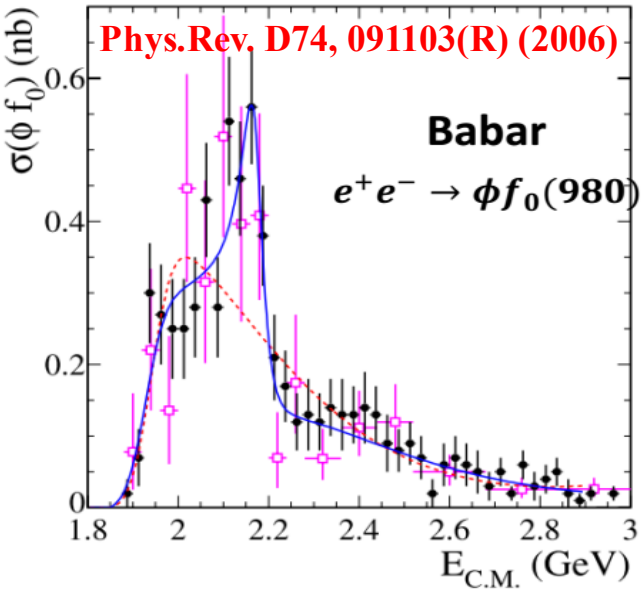
- **M** and **Γ** consistent with the **X(2370)** signal, significance: **7.6σ**.
- No evidence of X(2120) is found and set the upper limit at 90% C.L.

BESIII Preliminary

	combined results
M (MeV/c^2)	$2343.91 \pm 6.88(stat.) \pm 1.23(sys.)$
Γ (MeV)	$117.73 \pm 12.75(stat.) \pm 4.14(sys.)$
$B(J/\psi \to \gamma X(2370) \to \gamma K^+K^-\eta')$	$(1.86 \pm 0.39\ (stat.) \pm 0.29\ (sys.)) \times 10^{-5}$
$B(J/\psi \to \gamma X(2370) \to \gamma K_S^0 K_S^0 \eta')$	$(1.19 \pm 0.37\ (stat.) \pm 0.18\ (sys.)) \times 10^{-5}$
$B(J/\psi \to \gamma X(2120) \to \gamma K^+K^-\eta')$	$< 1.48 \times 10^{-5}$
$B(J/\psi \to \gamma X(2120) \to \gamma K_S^0 K_S^0 \eta')$	$< 4.57 \times 10^{-6}$

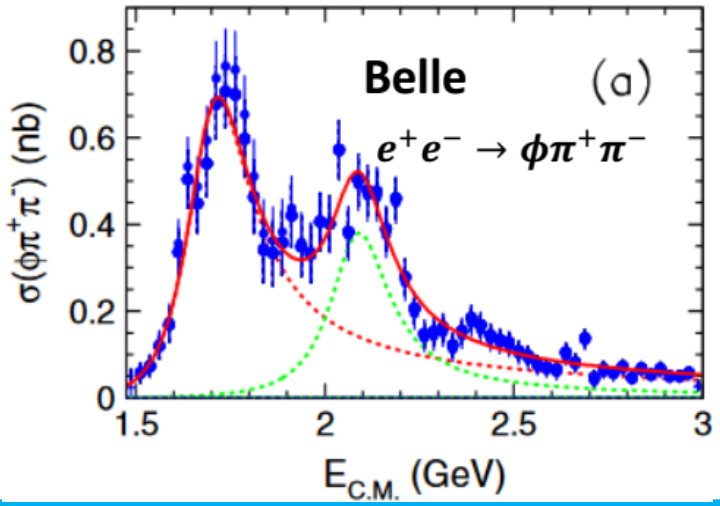
Search for strangeonium-like Z_S

- **Y(2175) was observed by BaBar, and confirmed by Belle, BESII and BESIII**
  - A candidate for a tetraquark state, a strangeonium hybrid state, or a conventional $s\bar{s}$ state

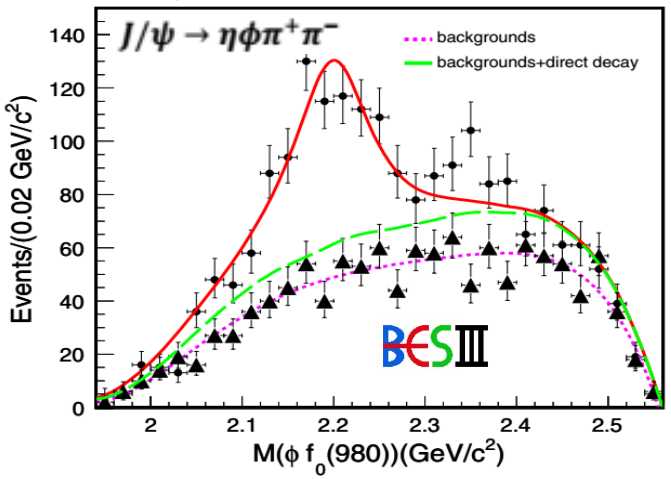


- **Unique place to search for the Z_S:**
  - Y(2175) is regarded as strangeonium-like state analogous to Y(4260)
  - $Z_C \to \pi^{\pm} J/\psi$? $Z_S \to \pi^{\pm}\phi$ $(M_{Z_S} \approx 1.4\ \mathrm{GeV/c^2})$

Phys.Rev. D80, 031101(R) (2009)



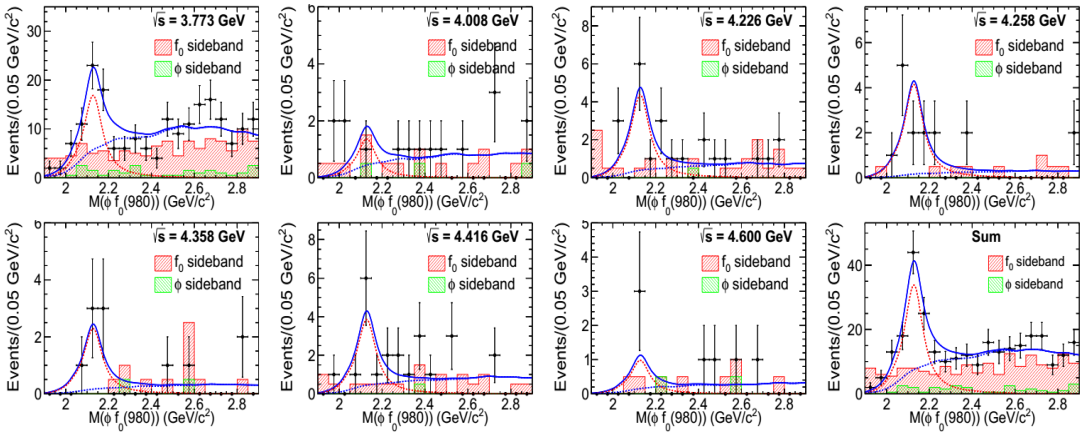
Phys.Rev. D91,052017 (2015)



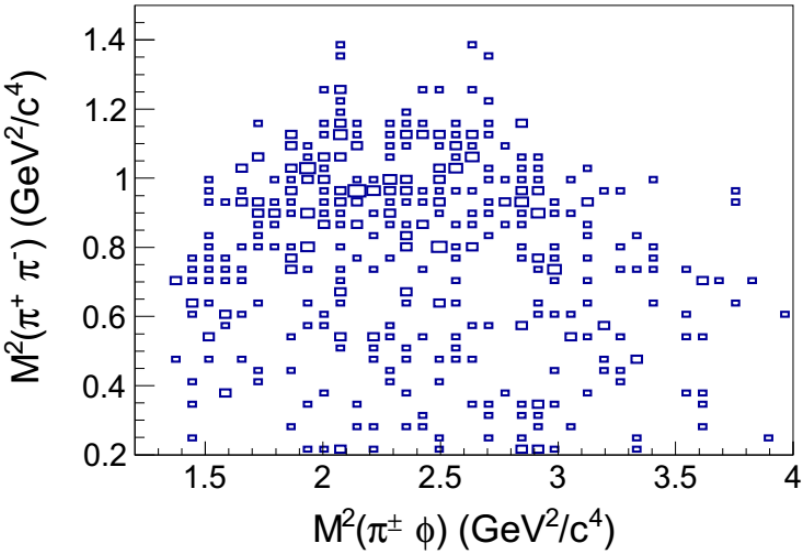
Observation of $e^+e^- \to \eta Y(2175)$ at $\sqrt{s} = 3.7$ GeV

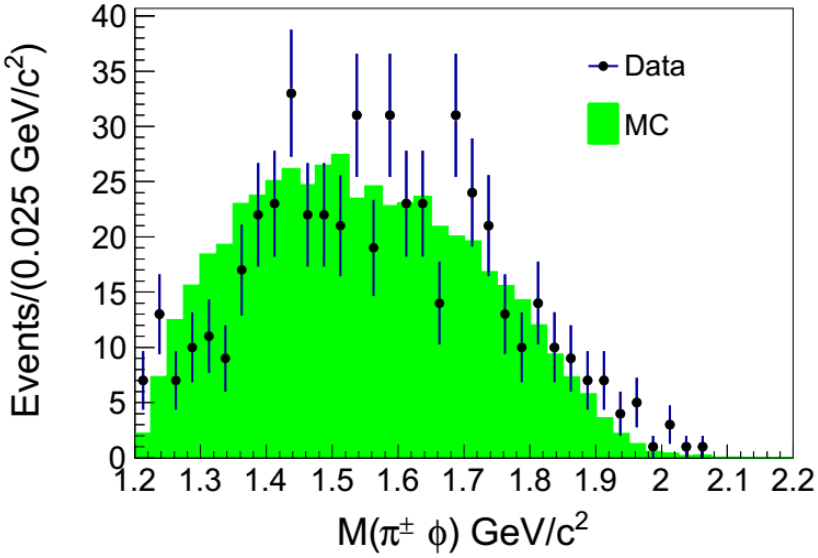
arXiv:1709.04323 (2017) submitted to PRD

- Perform the search for Y(2175) resonance in the process $e^+e^- \to \eta\phi f_0(980)$ using the data collected at the center-of-mass energies between 3.7 and 4.6 GeV.
- Combined significance for Y(2175) signal is observed to be larger than **10σ**.



- No significant Z_S spectrum is found in $\phi\pi^{\pm}$ spectrum.





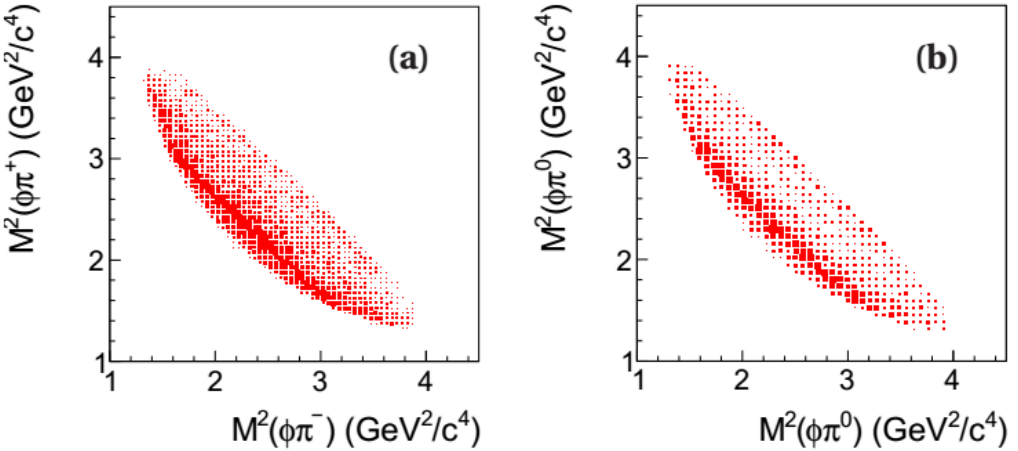
Search for Z_S at 2.125 GeV

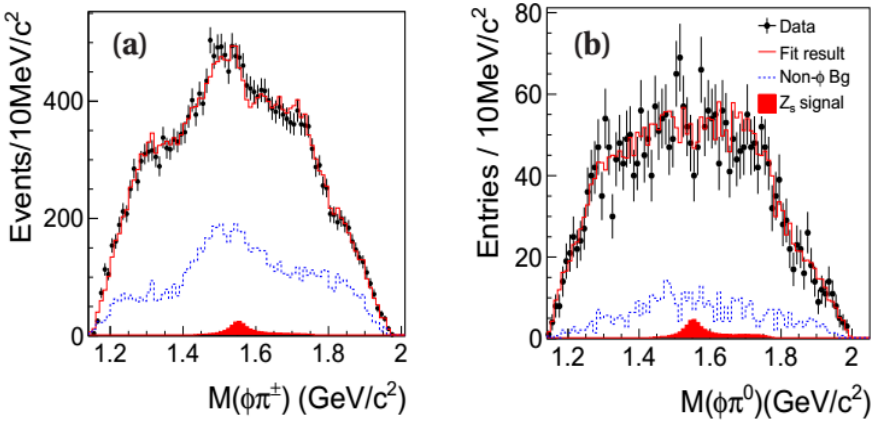
arXiv:1801.1038 (2018) submitted to PRL

- Perform the search for Z_S via $e^+e^- \to \phi\pi^+\pi^-$ ($\phi\pi^0\pi^0$) using 108 pb^{-1} data collected at $\sqrt{s} = 2.125$ GeV.
- PWA is performed

- $\phi\sigma$
- $\phi f_0(980)$
- $\phi f_0(1370)$
- $\phi f_2(1270)$
- $Z_s\pi$

Assumption:
$J^p(Z_s)=1^+$
$M(Z_s) = 1.5\,\mathrm{GeV/c^2}$
$\Gamma(Z_s) = 0.05\,\mathrm{GeV}$





- No clear Z_S signal is observed in the $\phi\pi$ mass spectrums around 1.4 GeV/c^2.

Systematic uncertainty

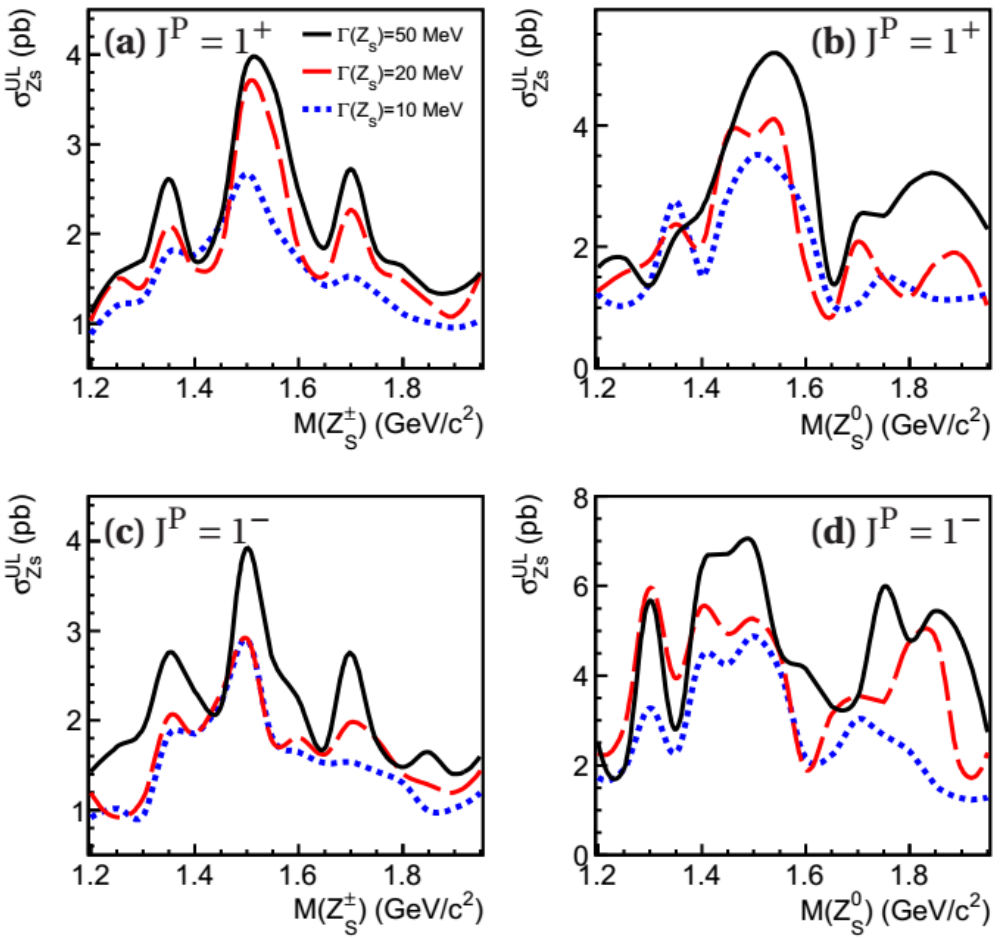
Source	$Z_s^\pm$	$\phi\pi^+\pi^-$	Z_s^0	$\phi\pi^0\pi^0$
MDC tracking	4.5	4.5	1.5	1.5
Photon detection	...	...	4	4
K PID	3	3	3	3
π PID	2	2	...	...
Kinematic fit	2.1	2.1	0.1	0.1
π^0 mass window	...	...	0.1	0.1
K^+K^- mass window	1.5	...	1.5	...
Fitting range	...	0.1	...	1.4
Signal shape	...	1.5	...	2.3
Background shape	...	1.3	...	2.0
Model uncertainty	...	0.8	...	1.3
Branching fractions	1.1	1.1	1.1	1.1
Integrated luminosity	0.7	0.7	0.7	0.7
ISR	3.1	3.1	1.2	1.2
Total	7.2	7.3	5.7	6.5

Search for Z_S at 2.125 GeV

arXiv:1801.1038 (2018) submitted to PRL

- 90% C.L. upper limits on the cross-section for Z_S production are determined.
  - ✓ Different assumptions of mass, width and J^P of Z_S

- In addition, the cross-sections of $e^+e^- \to \phi\pi^+\pi^-$ and $e^+e^- \to \phi\pi^0\pi^0$ at 2.123 GeV/c^2 are measured to be $(343.0 \pm 5.1 \pm 25.1)$ pb and $(208.3 \pm 7.6 \pm 13.5)$ nb, respectively.



Observation of $h_1(1380)$ in $J/\psi \to \eta' K K \pi$

arXiv:1804.05536 (2018) submitted to PRD

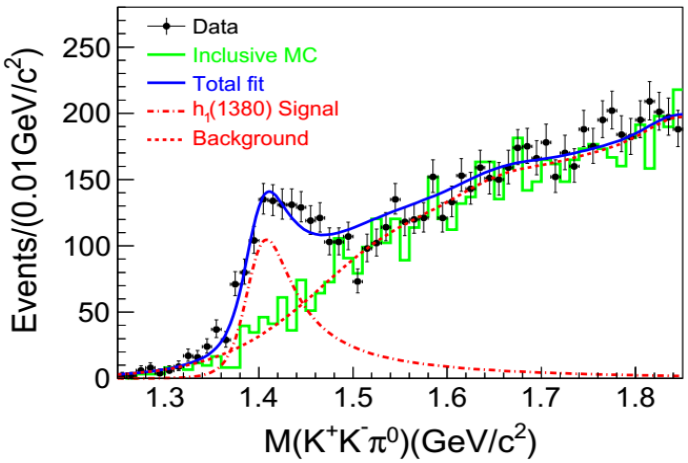
- Experimentally, the state $h_1(1380)$ has been observed by LASS [PLB **201**, 573 (1988)] and Crystal Barrel [PLB **415**, 280 (1997)] collaborations.
- Reconfirmed by BESIII through $\psi(3686) \to \gamma\chi_{cJ}$ (J=1,2), $\chi_{cJ} \to \phi h_1(1380)$, $h_1(1380) \to K^*(892)\bar{K}$.

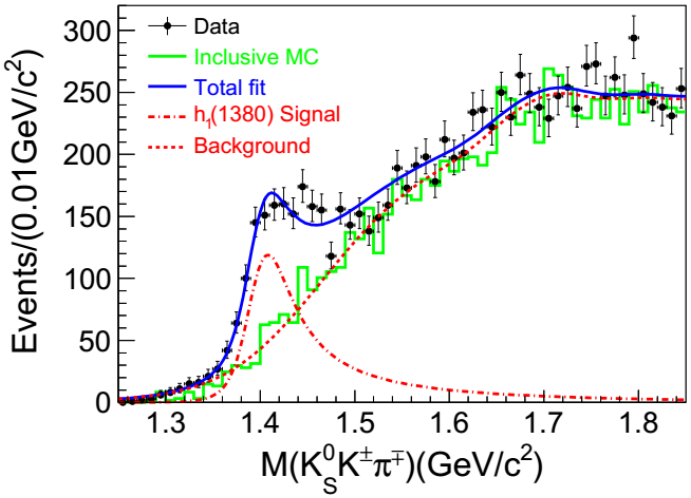
  [PRD **91**, 112008 (2015)]
- Perform the simultaneous fit to the $M(K^*(892)\bar{K})$ in $K^+K^-\pi^0$ and $K_S^0 K^\pm \pi^\mp$ modes.
- Observation of $h_1(1380)$ in $J/\psi \to \eta' h_1(1380)$ **(>10σ)**.
- The quark contents of the $h_1(1380)$ is predominantly $s\bar{s}$:
  - ✓ Mixing angle between $h_1(1170)$ and $h_1(1380)$:$35.9^\circ \pm 2.6^\circ$

    [PLB **707**, 116 (2012)]
- **Branching fractions:**

$M=(1423.2 \pm 2.1 \pm 7.3) MeV/c^2$

$\Gamma=(90.3 \pm 9.8 \pm 17.5) MeV/c^2$





$$\mathcal{B}(J/\psi \to \eta' h_1(1380)) \times \mathcal{B}(h_1(1380) \to K^*(892)^+K^- + c.c.) = (1.51 \pm 0.09 \pm 0.21) \times 10^{-4}$$

$$\mathcal{B}(J/\psi \to \eta' h_1(1380)) \times \mathcal{B}(h_1(1380) \to K^*(892)\bar{K} + c.c.) = (2.16 \pm 0.12 \pm 0.29) \times 10^{-4}$$

BR difference indicates the isospin symmetry violation

Summary and future prospects

- BESIII has been operating successfully since 2008, and will continue to collect data for the next five years (at least).

- Excellent laboratory to study the light Hadron spectroscopy and many other physics processes in the tau-charm region.
  - ✓ High statistics
  - ✓ Low backgrounds

- Many interesting results have been produced by the BESIII recently, and only few of them are reported in this talk.

- BESIII has collected around **4.6 billion additional J/ψ events this year**, and will collect **4.1 billion J/ψ events next year** (total statistics of the data would be **10 billion J/ψ events**).

- More results are expected to come with this new J/ψ data in the near future.

Thank you!

Back up Slide

Observation of X(2370) in $J/\psi \to \gamma KK\eta'$

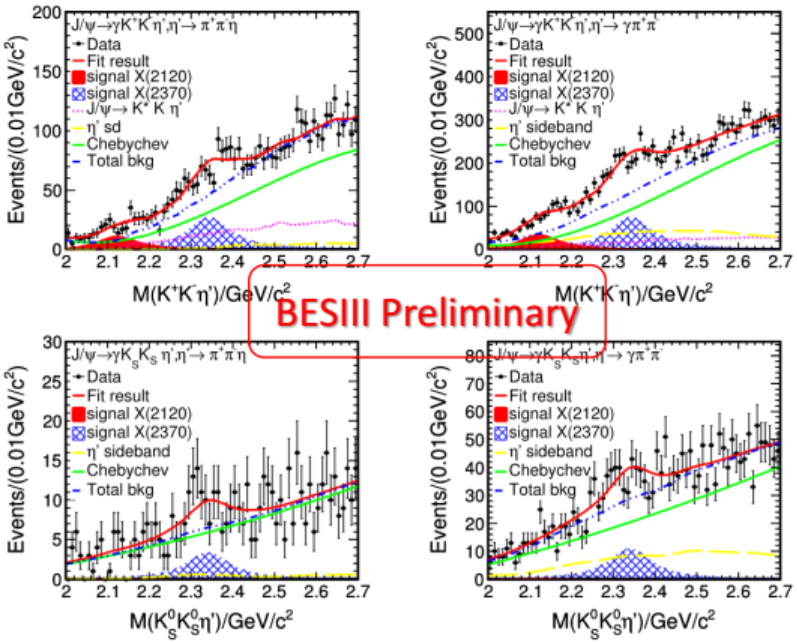
Preliminary

Upper limit(UL) of Branching fraction of $J/\psi \to \gamma X(2120) \to \gamma \eta' K\bar{K}$

- Simultaneous fit is performed.
- Signal and background treatment are similar with the simultaneous fit of the X(2370).
- The mass and width of the X(2120) are fixed on BESIII results
- The mass and width of the X(2370) are fixed on the results obtained in our analysis.
- The statistical significance of the X(2120) is 2.2σ.

	Mass GeV/c^2	Width GeV
X(2120)	2.122	0.083
X(2370)	2.343	0.118

- Fitting results when calculating the UL of $B(J/\psi \to \gamma X(2120) \to \gamma K^+K^-\eta') < 1.48\times10^{-5}$ at 90% C. L.



- Fitting results when calculating the UL of $B(J/\psi \to \gamma X(2120) \to \gamma K_S^0K_S^0\eta') < 4.57\times10^{-6}$ at 90% C. L.