

Light Hadron Spectroscopy at BESIII

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(for BESIII Collaboration)

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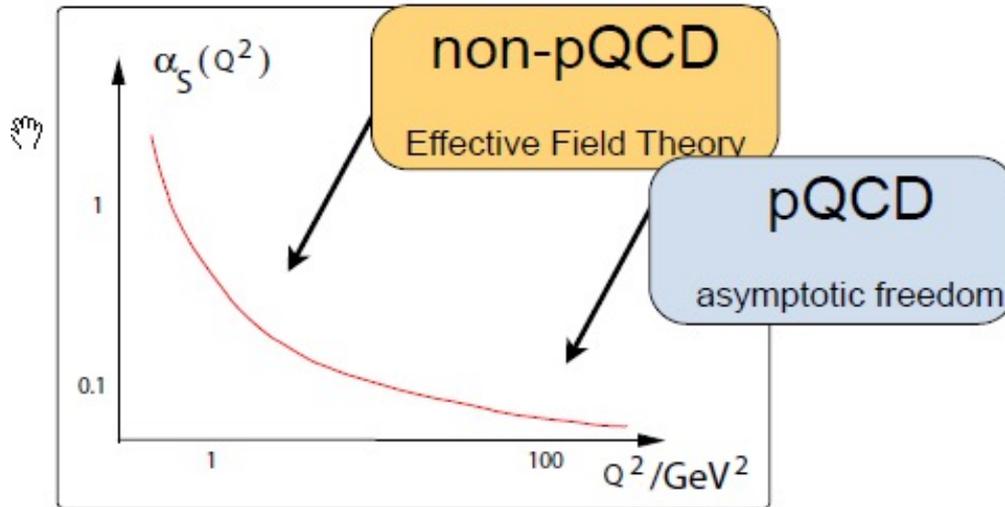
Charm2020, May 31—June 4, 2021

UNAM, Mexico

OUTLINE

- Why light hadron physics
- Progresses at BESIII
 - Light meson spectroscopy
 - Light baryon spectroscopy
- Summary

Why light hadron physics ?



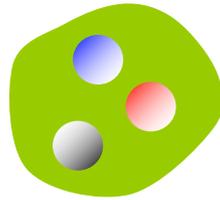
"That [intermediate distance] scale is the richest phenomenologically, and is certainly the crux region to understand...what QCD is really about. And at the heart of the subject is the hadron spectrum, in particular the spectrum built from light quarks. (...) **Without question, there is a great need... for a new round of experiments,...**"

James D. Bjorken (2000)

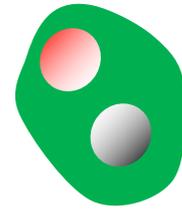
- ✓ QCD degrees of freedom at low energy
- ✓ Understanding of the quark and gluon confinement
 - ✓ Particles beyond the QM

Light hadron spectroscopy

- Quark Model

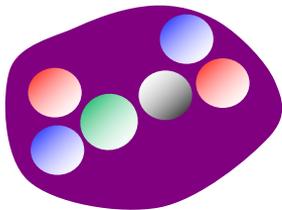


baryon

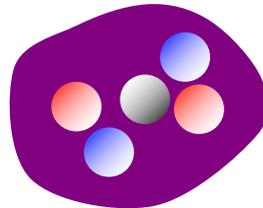


meson

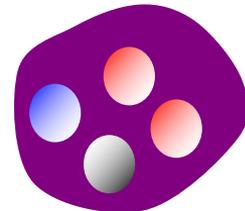
- QCD allows for hadrons beyond Quark Model



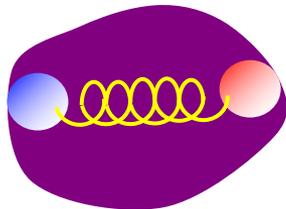
dibaryon



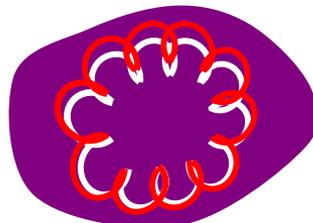
Pentaquark



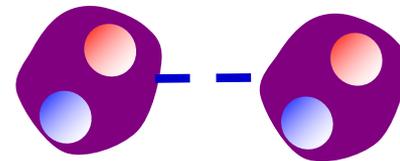
tetraquark



hybrid



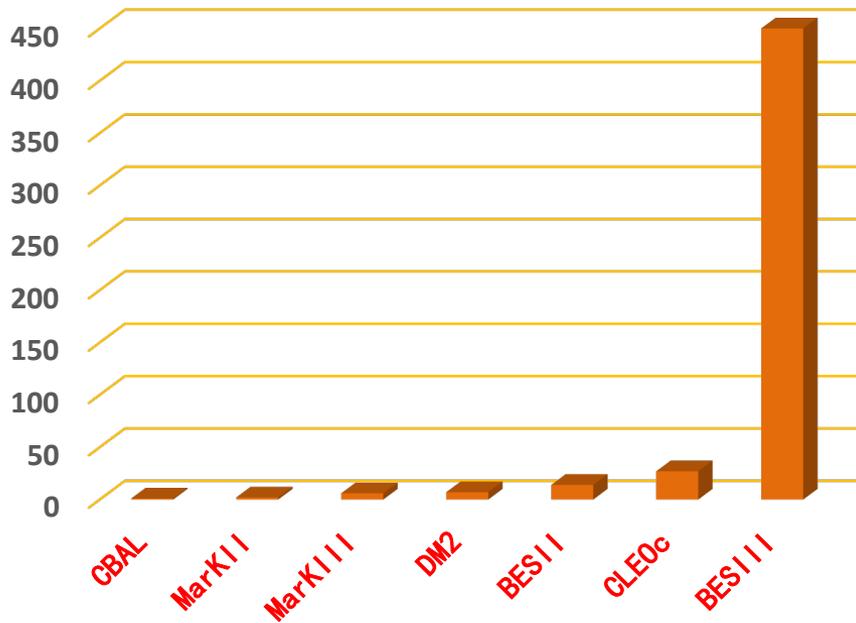
glueball



molecule

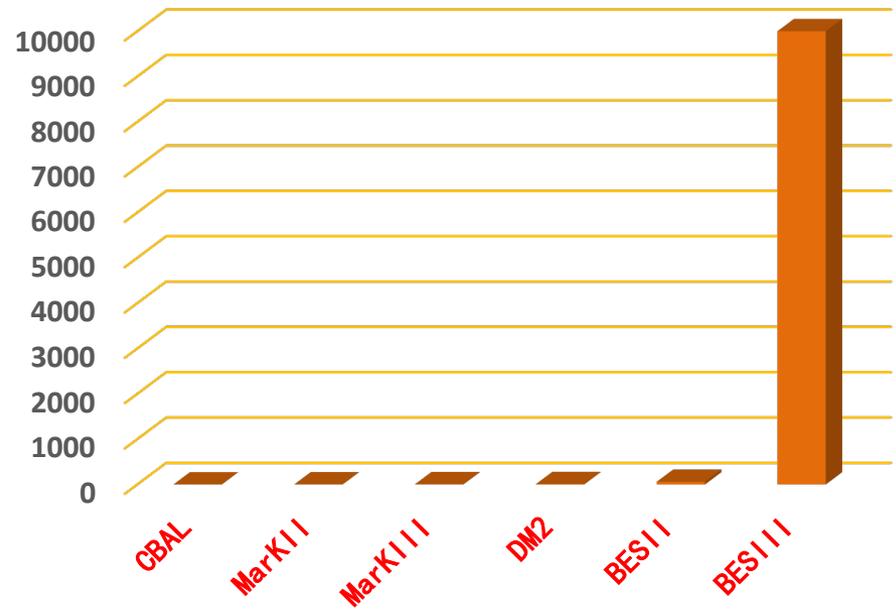
Data samples at BESIII

$\psi(3686)$ events



BESIII: 450 million

J/ψ events

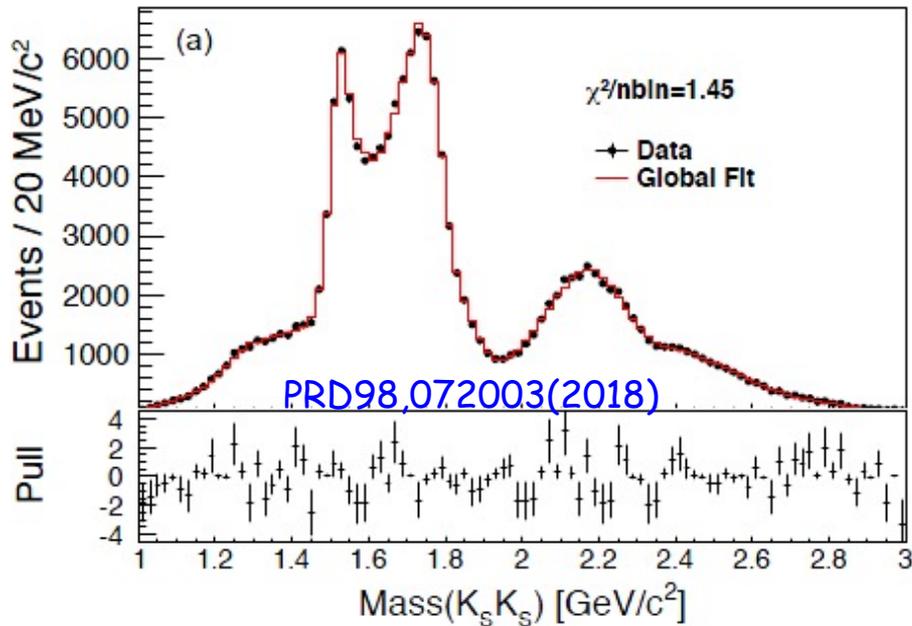


BESIII: 10 billion

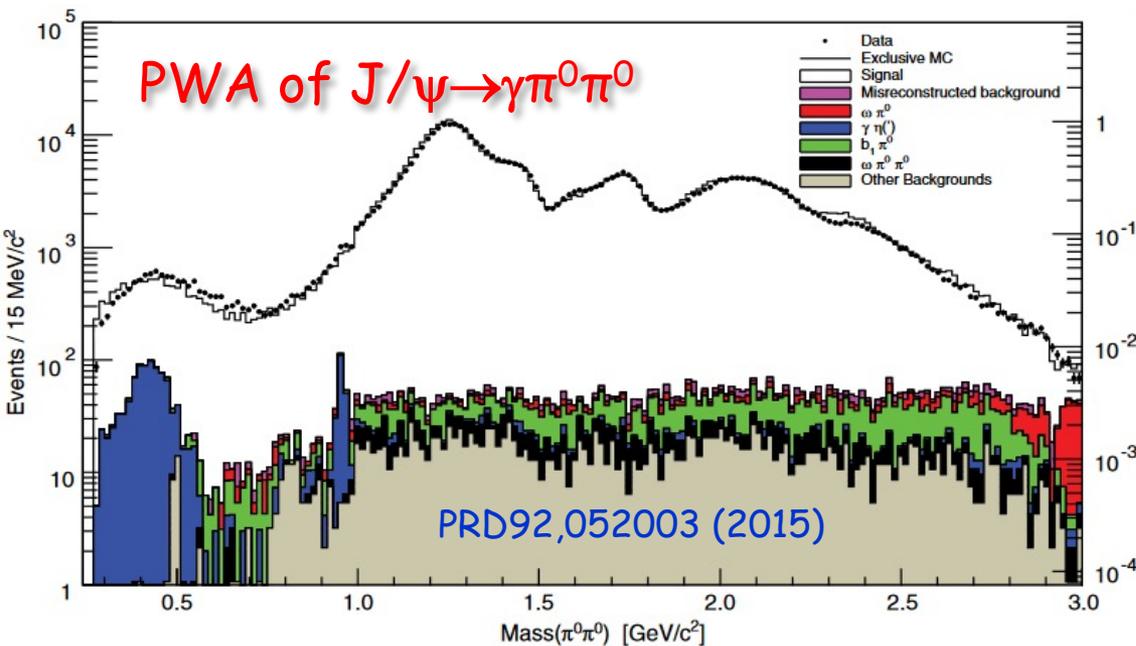
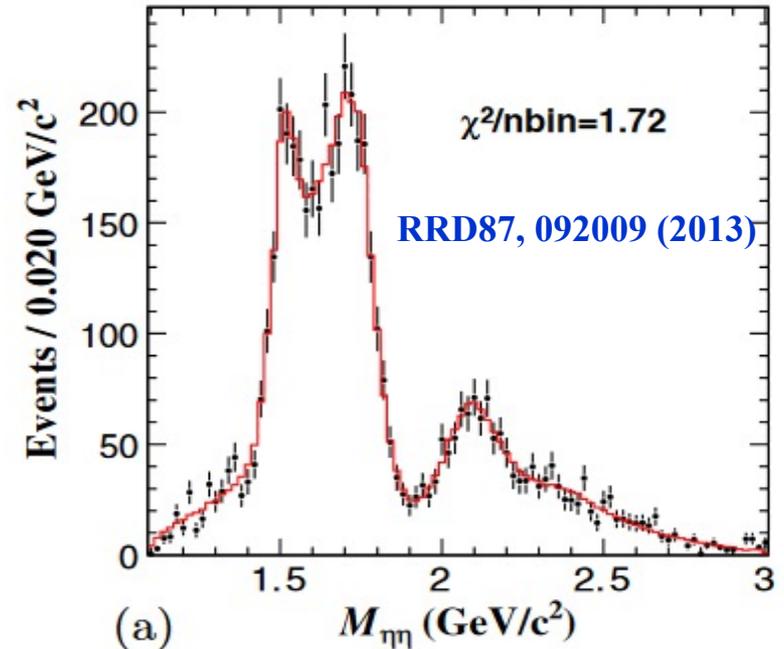
Light meson spectroscopy

- Scalar, tensor and pseudoscalar mesons
- Exotics searches
- Strange mesons and strangeonia states

PWA of $J/\psi \rightarrow \gamma K_S K_S$



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



- $f_0(1710)$ and $f_0(1500)$ are dominant
- $f_2'(1525)$ also seen
- Broad bump above 2 GeV

About $f_0(1500)$ and $f_0(1710)$

- Clearly observed in J/ψ radiative decays
- Production rate of $f_0(1500)$ in J/ψ radiative decays is lower than that of $f_0(1710)$

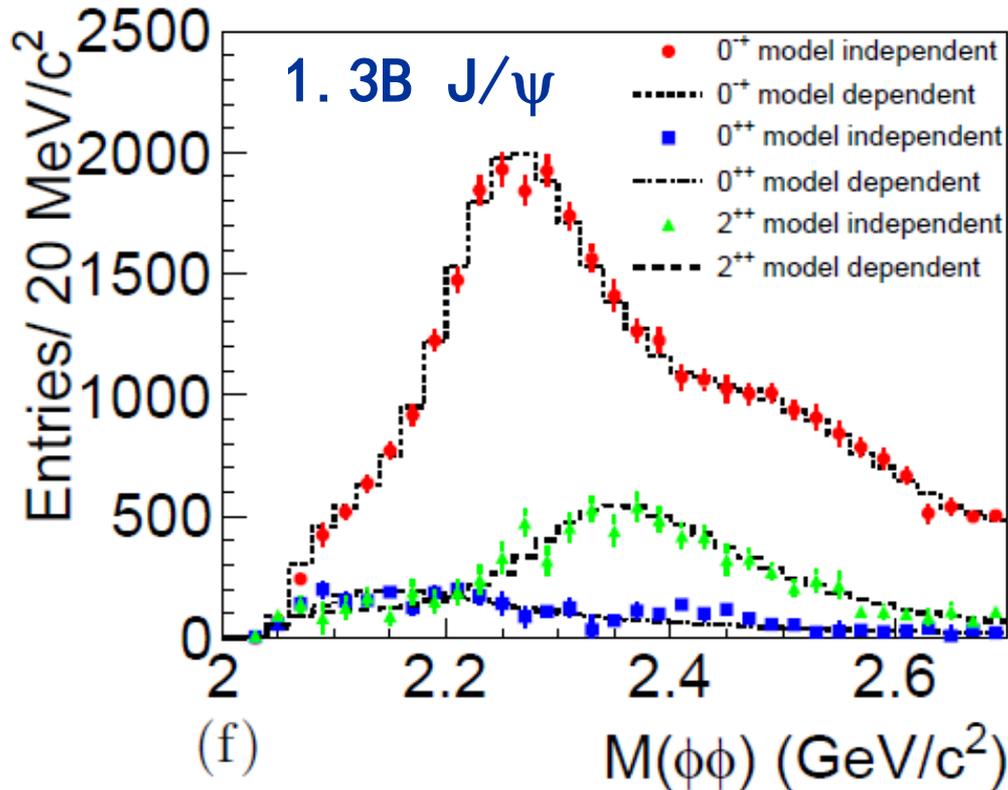
$$B(J/\psi \rightarrow \gamma f_0(1500)) \sim 3 \times 10^{-4}$$

$$B(J/\psi \rightarrow \gamma f_0(1710)) > 1.9 \times 10^{-3}$$

- $f_0(1710)$ has stronger coupling to gluons than $f_0(1500)$ → which one contains more glueball content?

PWA of $J/\psi \rightarrow \gamma \phi \phi$

Phys. Rev. D. 93, 112011 (2016)

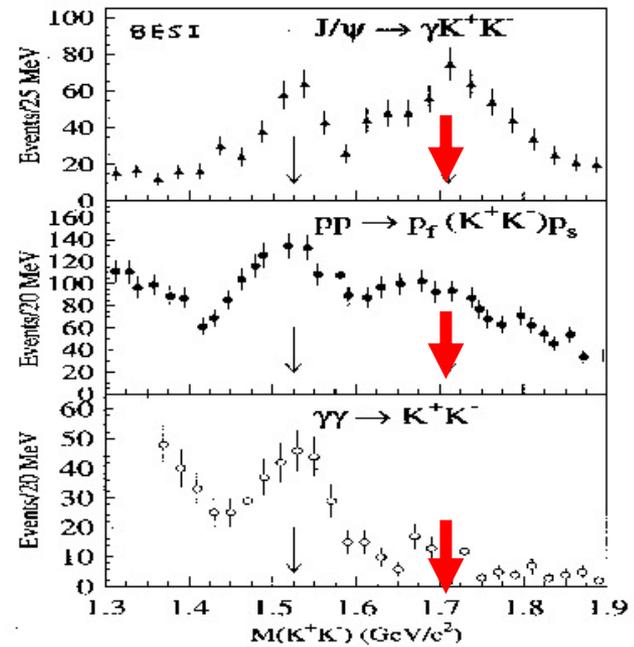


Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$
$\eta(2225)$	2216^{+4+21}_{-5-11}	185^{+12+43}_{-14-17}
$\eta(2100)$	2050^{+30+75}_{-24-26}	$250^{+36+181}_{-30-164}$
$X(2500)$	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}
$f_0(2100)$	2101	224
$f_2(2010)$	2011	202
$f_2(2300)$	2297	149
$f_2(2340)$	2339	319
0^{-+} PHSP		

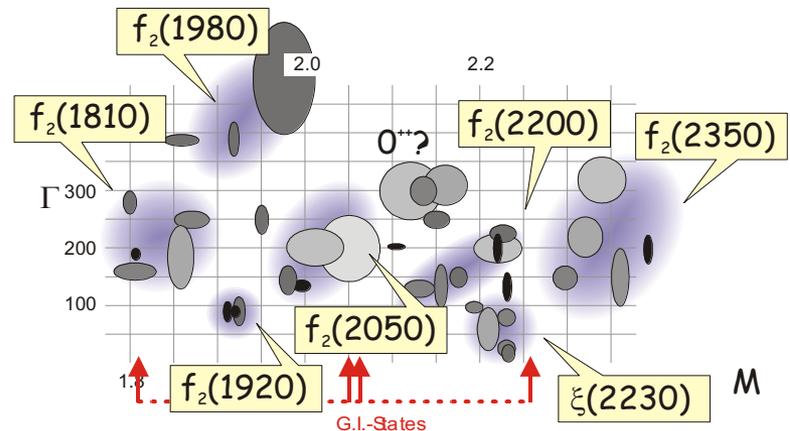
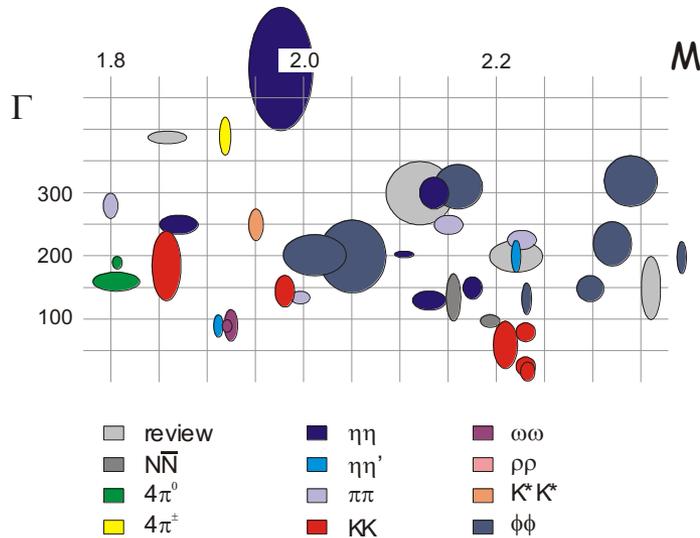
- Dominant contribution from pseudoscalars
 - $\eta(2225)$ is confirmed;
 - $\eta(2100)$ and $X(2500)$ are observed
- The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in p-p reactions are also observed

0^+ : experimental results saturated

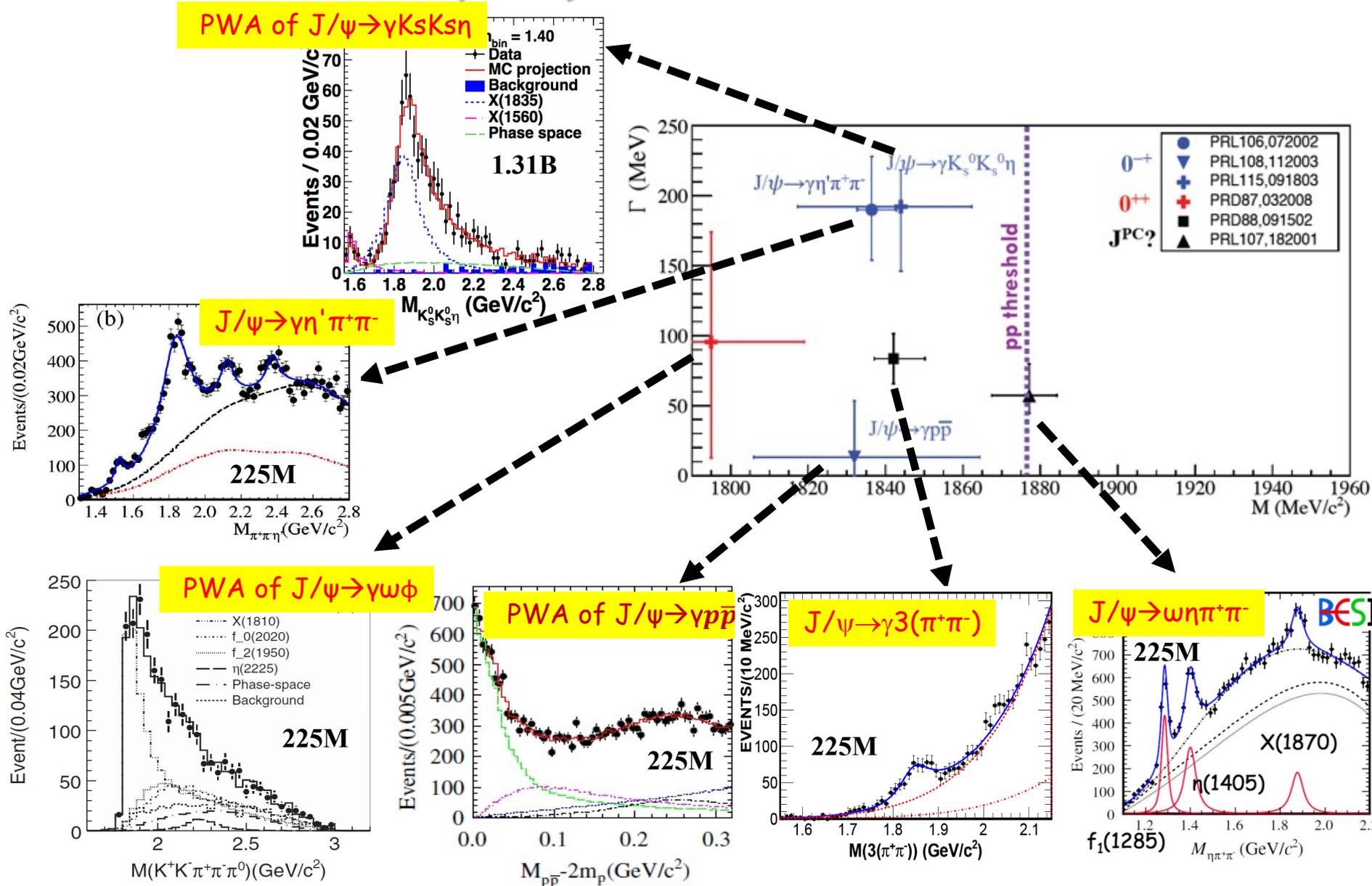
- $f_0(1710) / f_0(1790)$, one or two
- Large production rate of $f_0(2100)$ in gluon rich environment $ppbar$ annihilations and J/ψ radiative decays



2^+ : complicated situation around 2 GeV



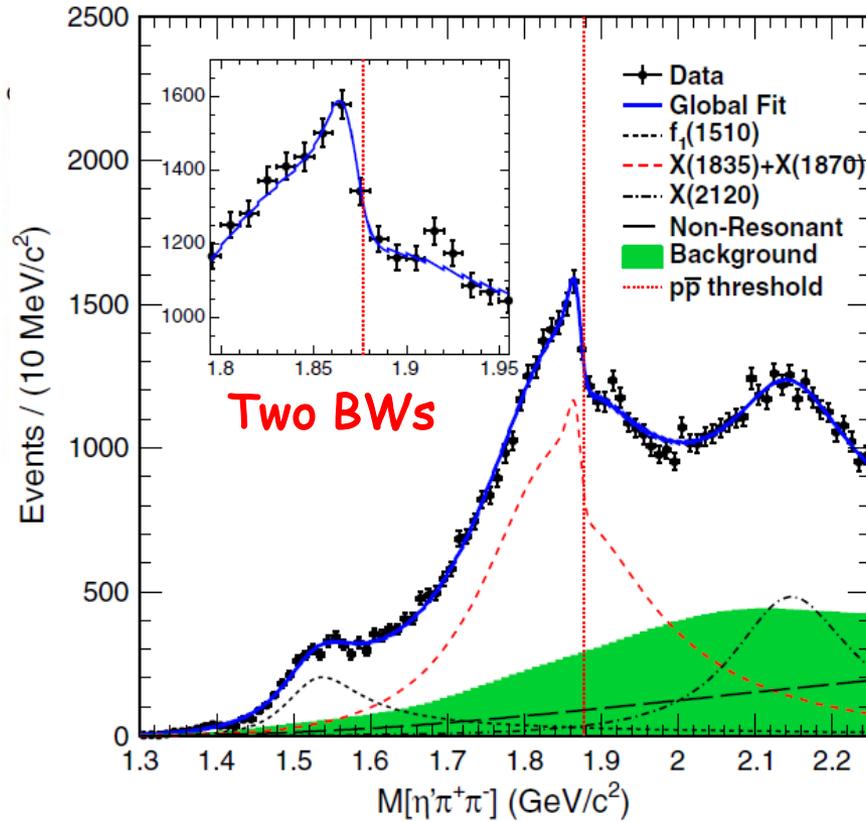
X(18??) between 1.8~1.9 GeV



Are they the same state? It is crucial to understand their connections.

Latest result on X(1835)

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

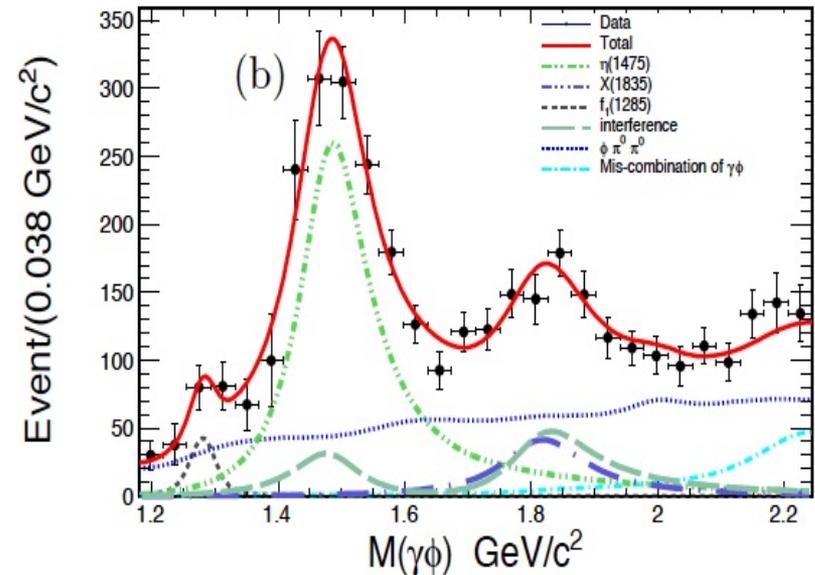


PRL 117, 042002(2016)

$$M_2 = 1870.2 \pm 2.2 \begin{matrix} +2.3 \\ -0.7 \end{matrix} \text{ MeV}/c^2$$

$$\Gamma_2 = 13.0 \pm 6.1 \begin{matrix} +2.1 \\ -3.8 \end{matrix} \text{ MeV}$$

$J/\psi \rightarrow \gamma \gamma \phi$



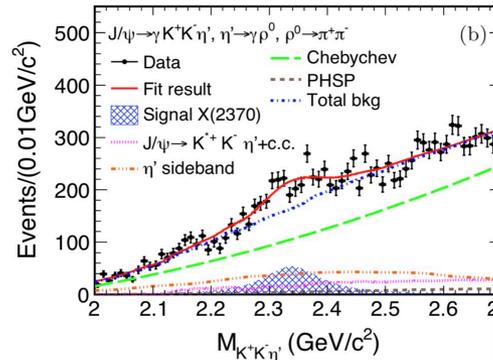
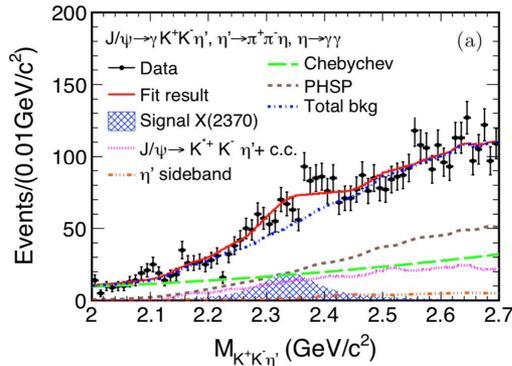
PRD97, 051101 (R) (2018)

Sizeable $s\bar{s}$ components in X(1835): more complicated than a pure $N\bar{N}$ state

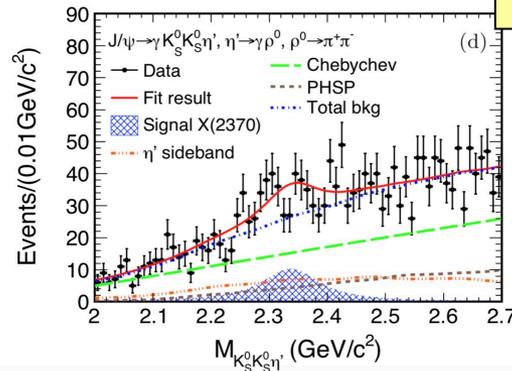
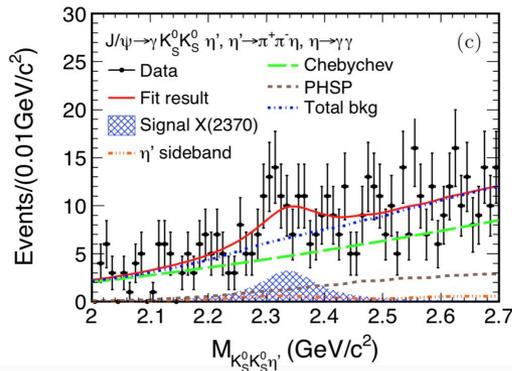
Existence of a structure strongly coupling to $p \bar{p}$?

First observation of $X(2370) \rightarrow KK\eta'$

EPJC80,746(2021)

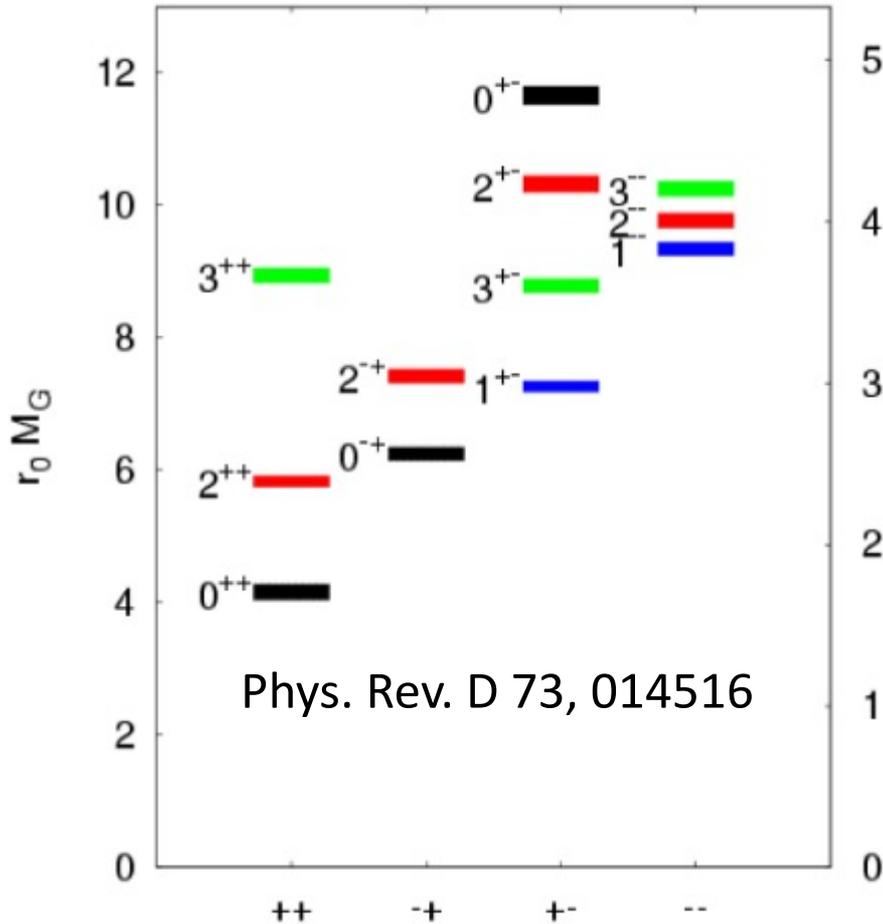


$M = 2341.6 \pm 6.5 \pm 5.7 \text{ MeV}/c^2$
 $\Gamma = 117 \pm 10 \pm 8 \text{ MeV}$



- ❑ Simultaneously fit for two different η' decay modes
- ❑ What is $X(2370)$?

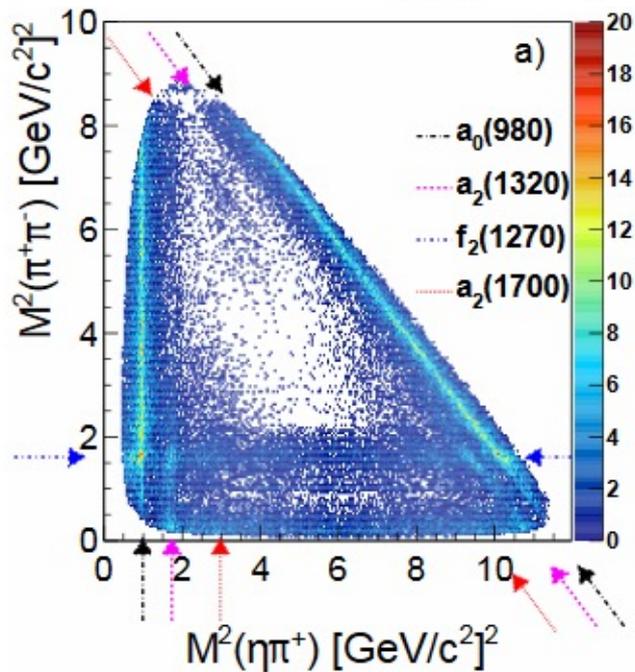
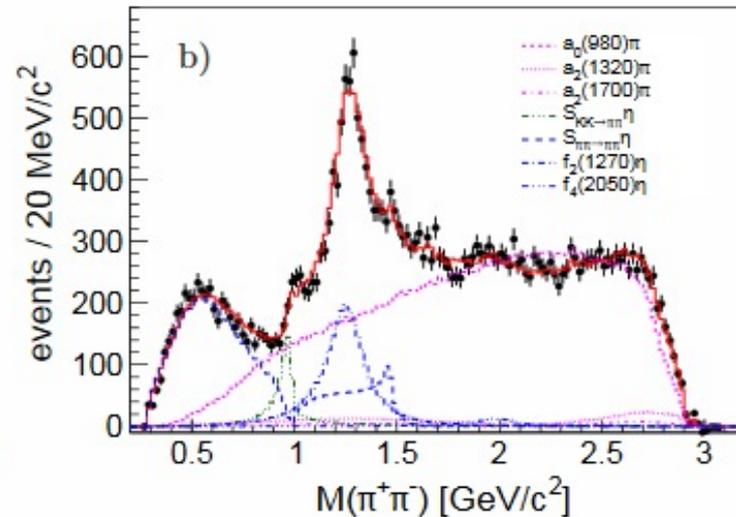
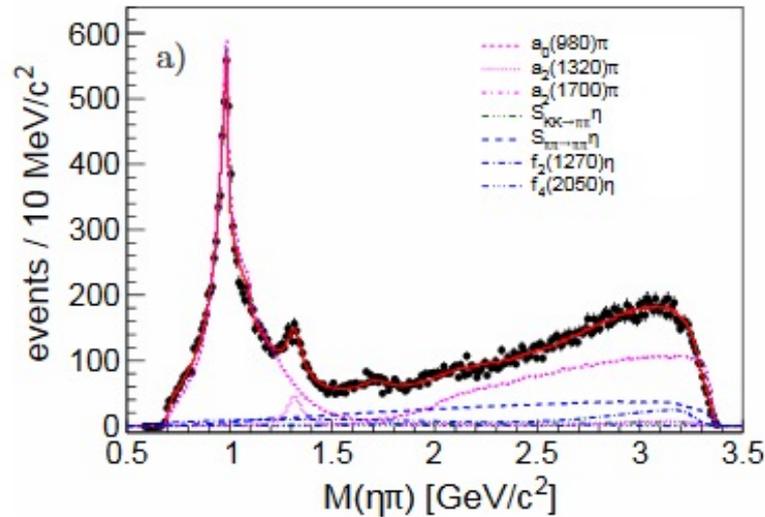
Where is the glueball?



At BESIII

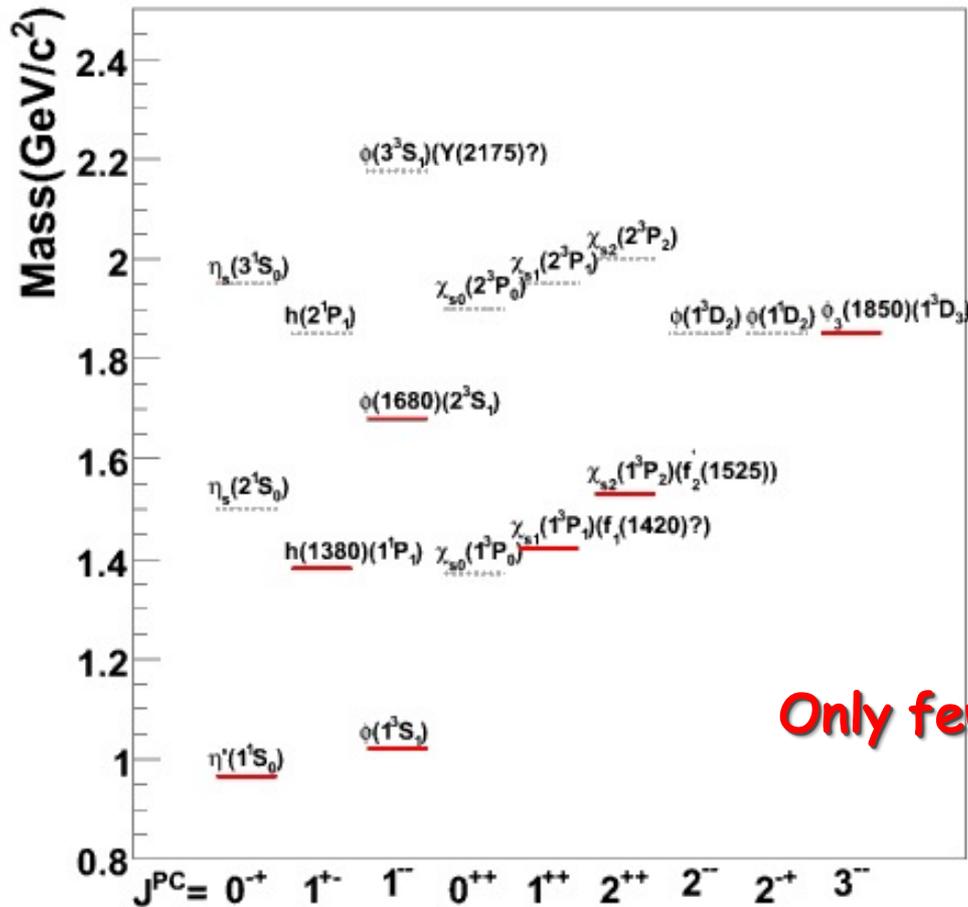
- $f_0(1710)$ and $f_0(2100)$ are observed in $J/\psi \rightarrow \gamma \eta \eta, \gamma \pi^0 \pi^0$
- $f_2(2340)$ is observed in $J/\psi \rightarrow \gamma \eta \eta / \phi \phi / \pi^0 \pi^0$
- $X(2120)$ and $X(2370)$ in of $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$
- **Systematic studies needed**
 - $J/\psi \rightarrow \gamma \eta \eta'$
 - $J/\psi \rightarrow \gamma \eta' \eta'$
 - $J/\psi \rightarrow \phi X, \omega X$

Search exotics in $\chi_{c1} \rightarrow \eta\pi^+\pi^-$



- Clear evidence for $a_2(1700)$ in χ_{c1} decays
- Upper limits for $\pi_1(1^{-+})$ in 1.4 - 2.0 GeV/c^2
- More works in progress in J/ψ and χ_{c1} decays

Strangeonia spectrum



— identified
 not identified

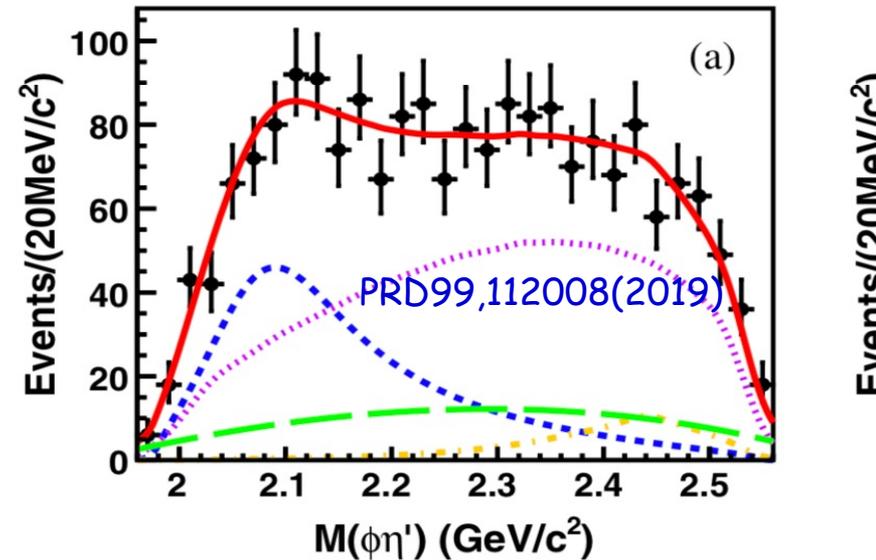
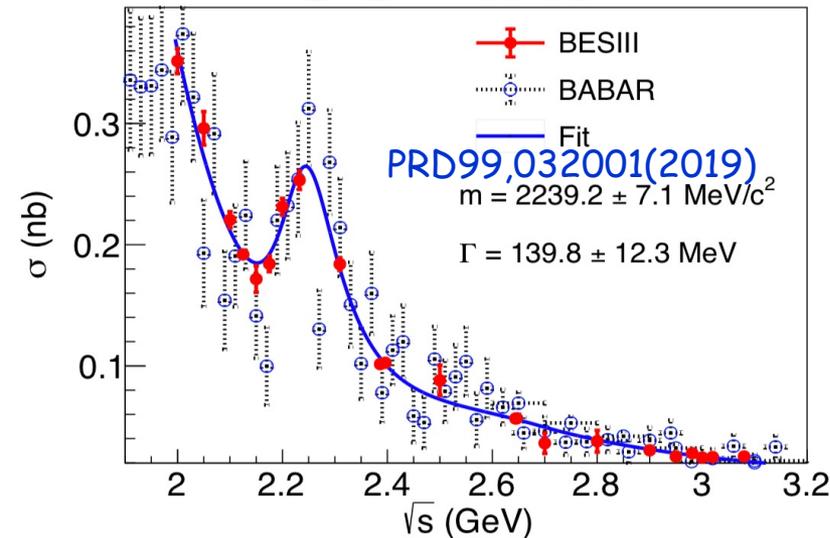
$s \bar{s}$ system – what do we know?

Only few of them have been identified !

$\phi(2170)$ at BESIII

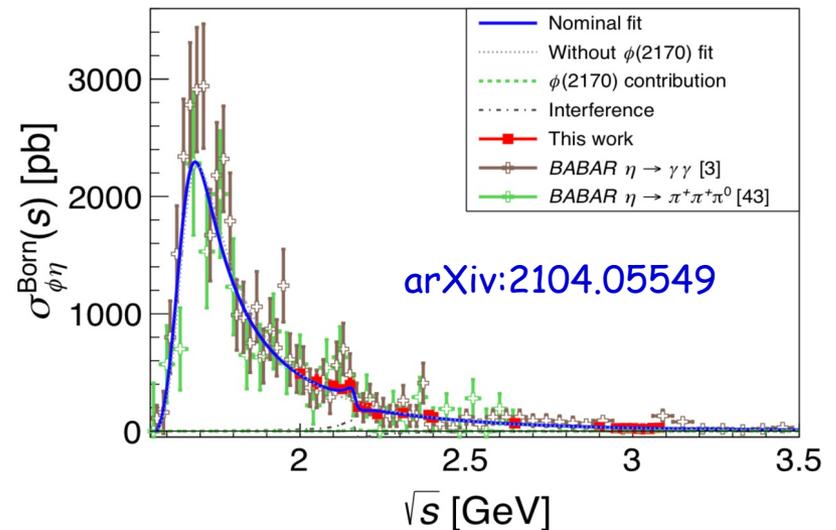
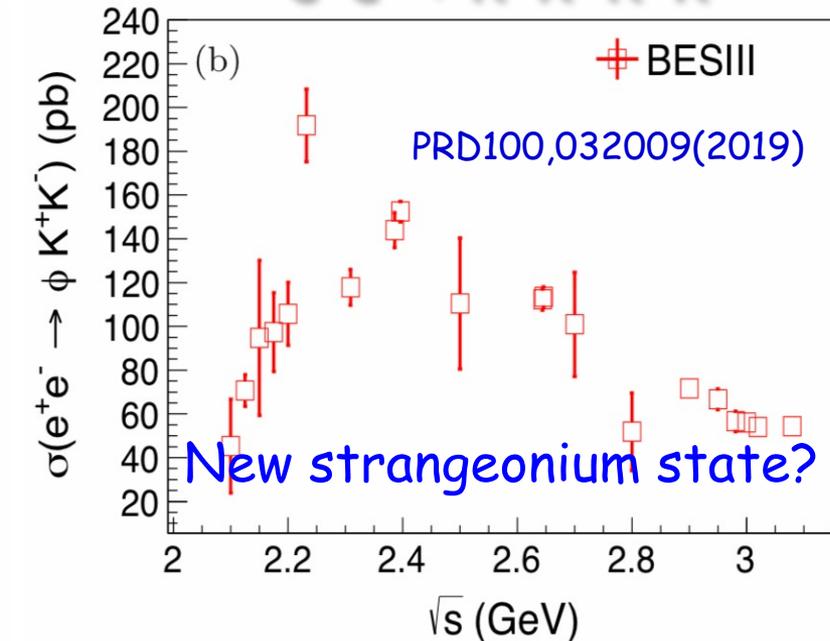
$e^+e^- \rightarrow K^+K^-$

$J/\psi \rightarrow \phi\eta\eta'$

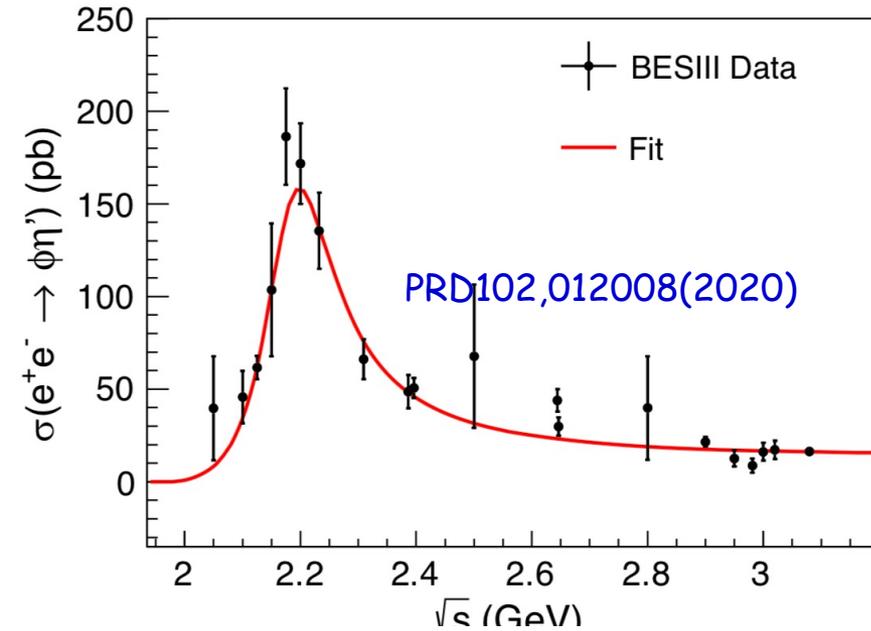


$e^+e^- \rightarrow K^+K^- K^+K^-$

$e^+e^- \rightarrow \phi\eta$



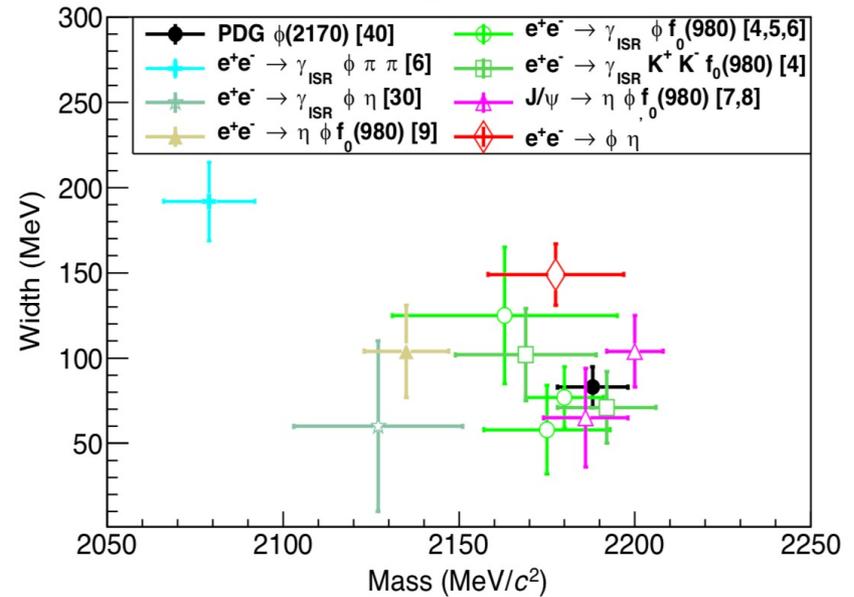
$$e^+e^- \rightarrow \phi\eta'$$



Theorists explain $\phi(2170)$ as

- ✓ $s\bar{s}g$ hybrid
- ✓ 2^3D_1 or $3^3S_1 s\bar{s}$
- ✓ tetraquark
- ✓ molecular state $\Lambda\bar{\Lambda}$
- ✓ $\phi f_0(980)$ resonance with FSI
- ✓ Three body system ϕKK

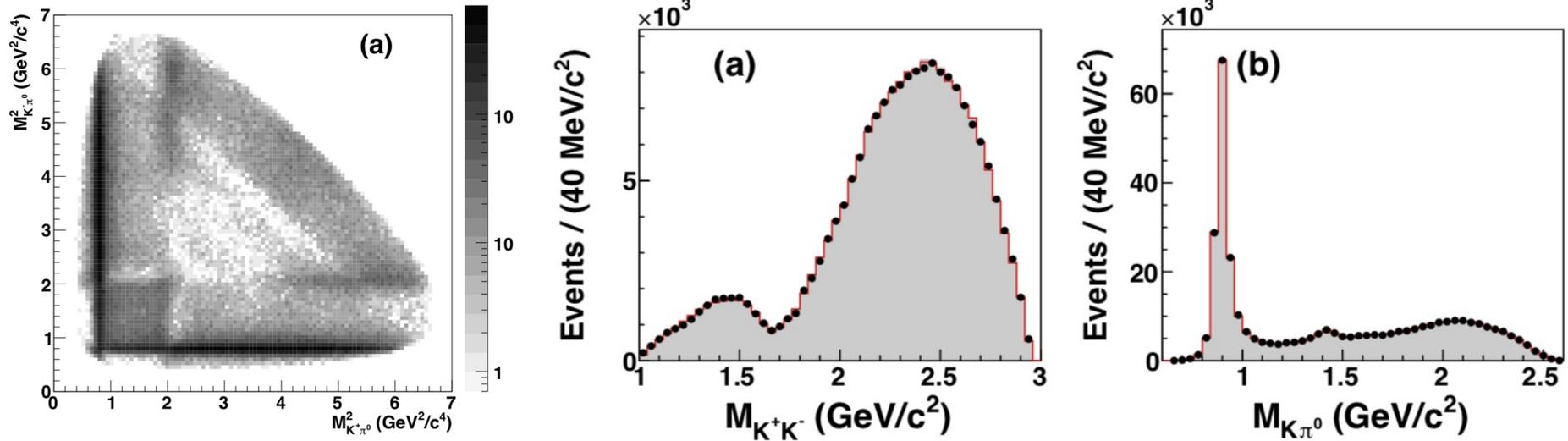
Comparisons



The nature of $\phi(2170)$ still not fully understand !

PWA of $J/\psi \rightarrow K^+K^-\pi^0$

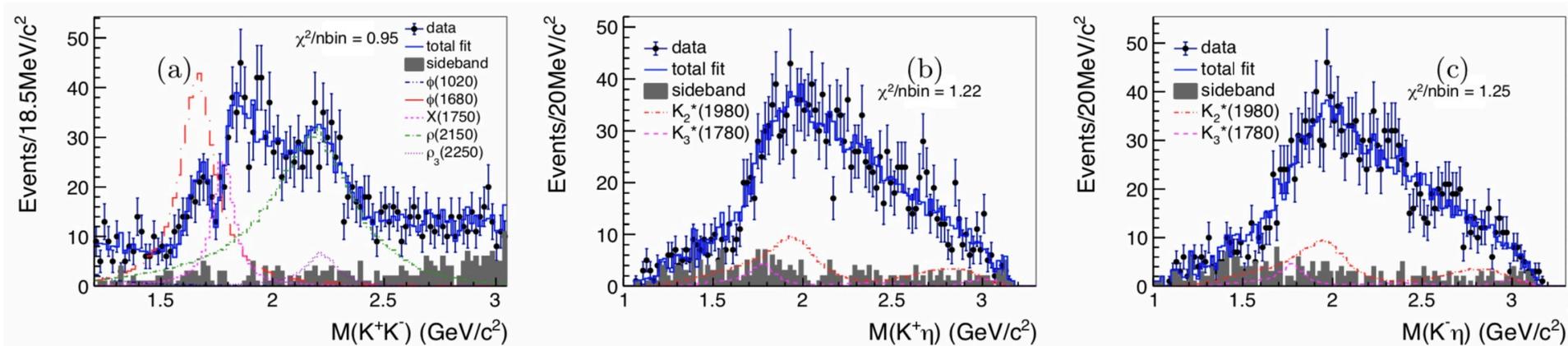
Phys. Rev. D100,032004(2019)



- The dominant contribution is from $K^*(892)$
- First observation of $K^*_2(1980)$ and $K^*_4(2045)$ in J/ψ decays
- Two broad 1^- structures were observed in K^+K^- mass spectrum, Possibly contributed from $\omega(1650)$ and $\rho(2150)$

PWA of $\psi(3686) \rightarrow KK\eta$

Phys. Rev. D101,032008(2020)



- ❑ Observation of both $\phi(1680)$ and $X(1750)$ implies $X(1750)$ is a new structure
- ❑ A broad structure around 2.2 GeV is observed, either $\phi(1680)$ or $\rho(2150)$?

Search for Z_s in $e^+e^- \rightarrow \phi\pi\pi$

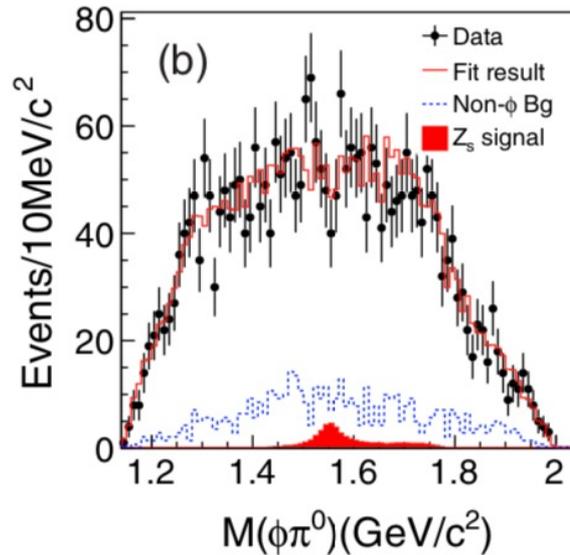
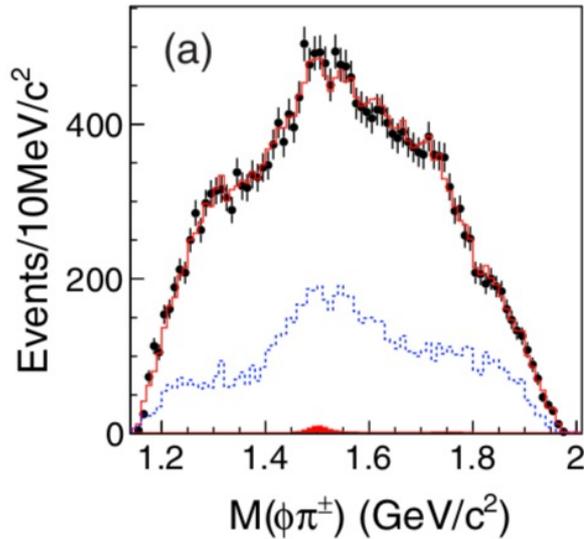
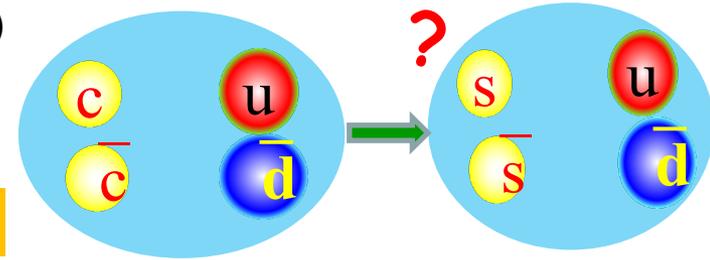
PRD99, 011101(2018)

$$Y(4260) \rightarrow J/\psi\pi^+\pi^-$$

$$Y(2175) \rightarrow \phi(1020)\pi^+\pi^-$$

charm, $\Rightarrow Z_c$

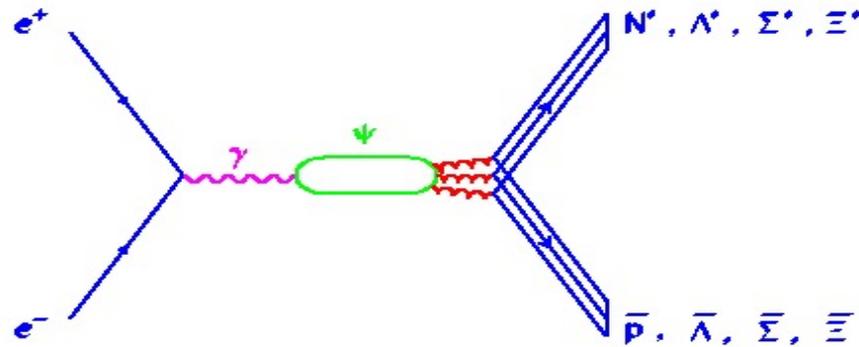
strange¹, $\Rightarrow Z_s ?$



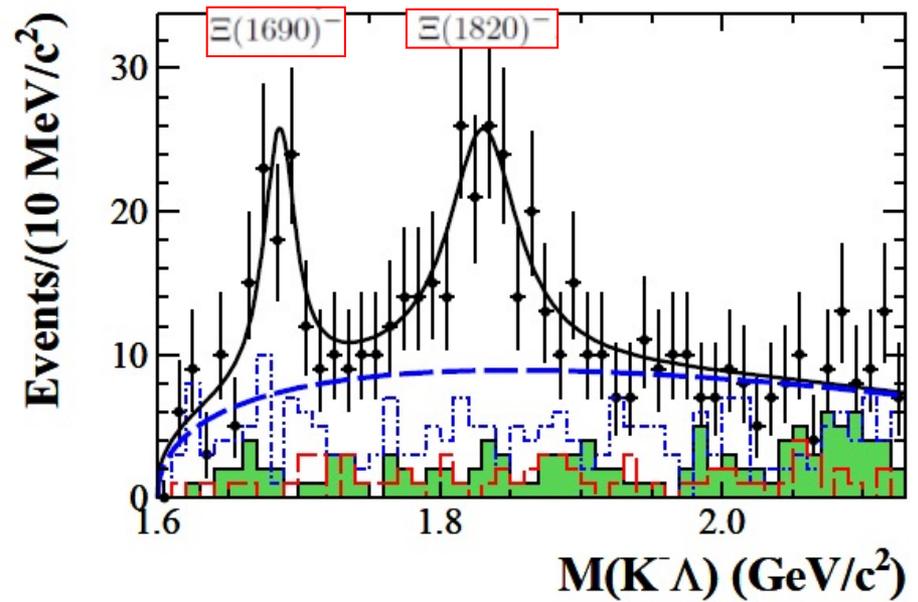
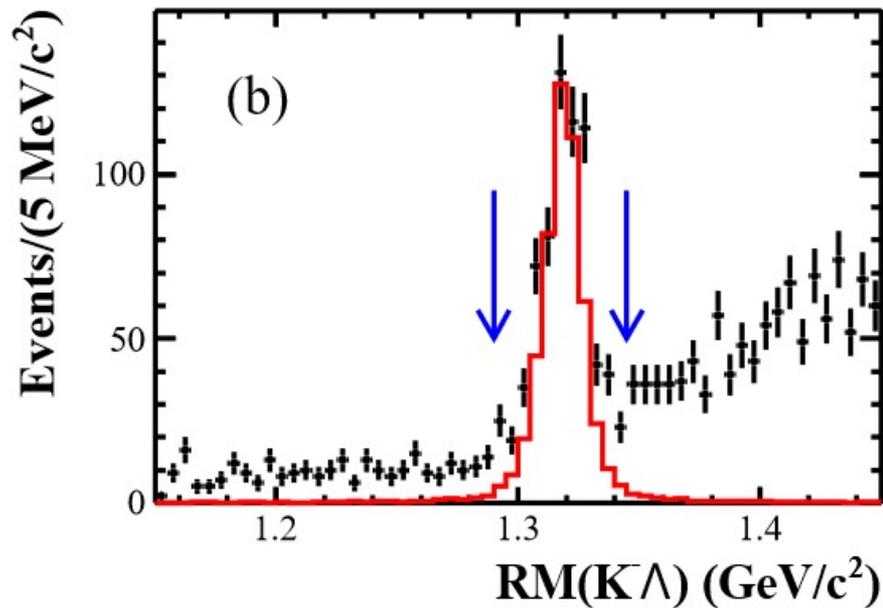
No evident structure observed in $\phi\pi$ mass spectra

Baryon spectroscopy

Ξ^* s in $\psi(2S) \rightarrow K\Lambda\Xi$



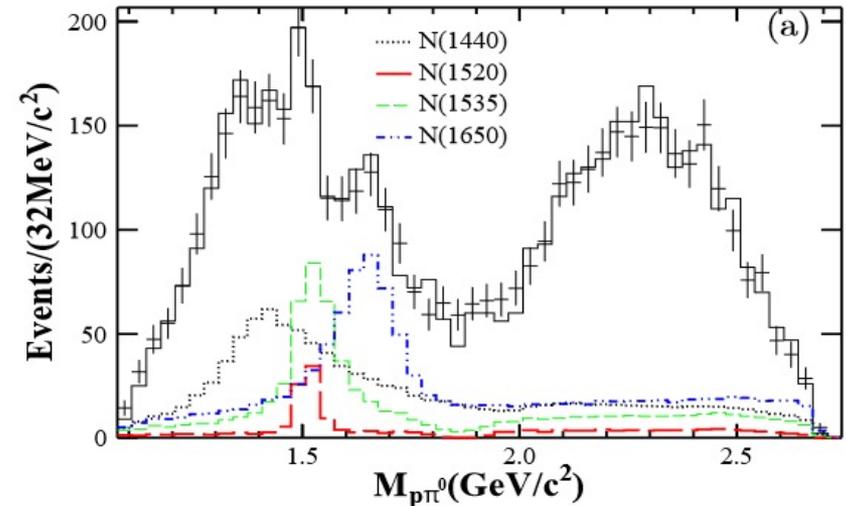
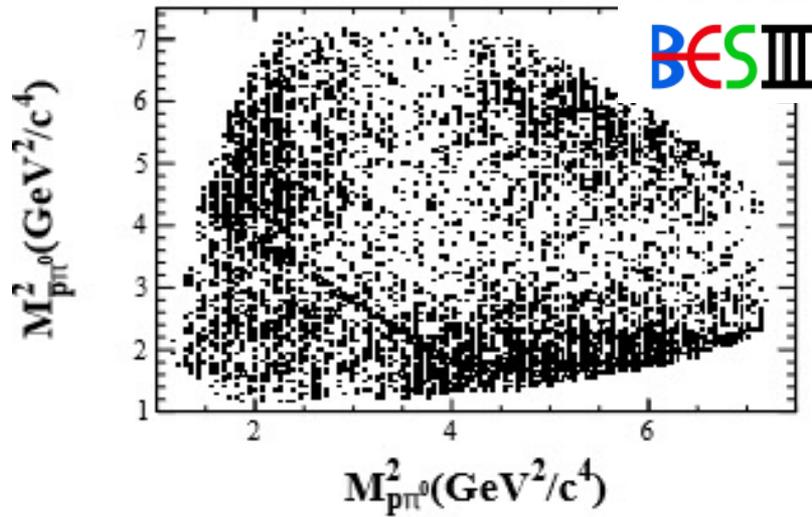
PRD91 (2015) 092006



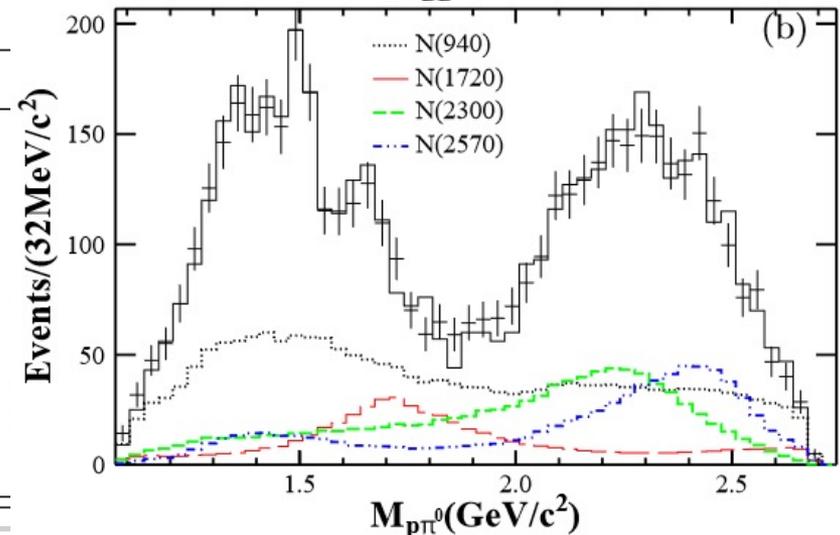
Two new N^* s in $J/\psi \rightarrow p \bar{p} \pi^0$

PRL 110 (2013) 022001

106 M ψ' events



Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}

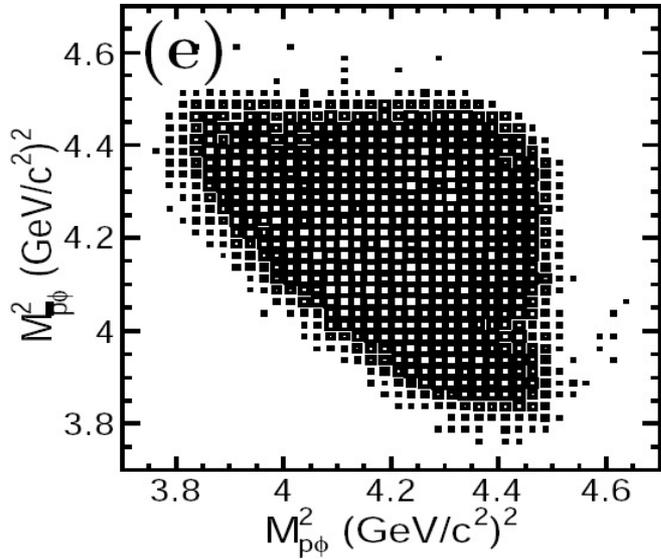


Two new baryonic excited states are observed !

1.3 B J/ψ events

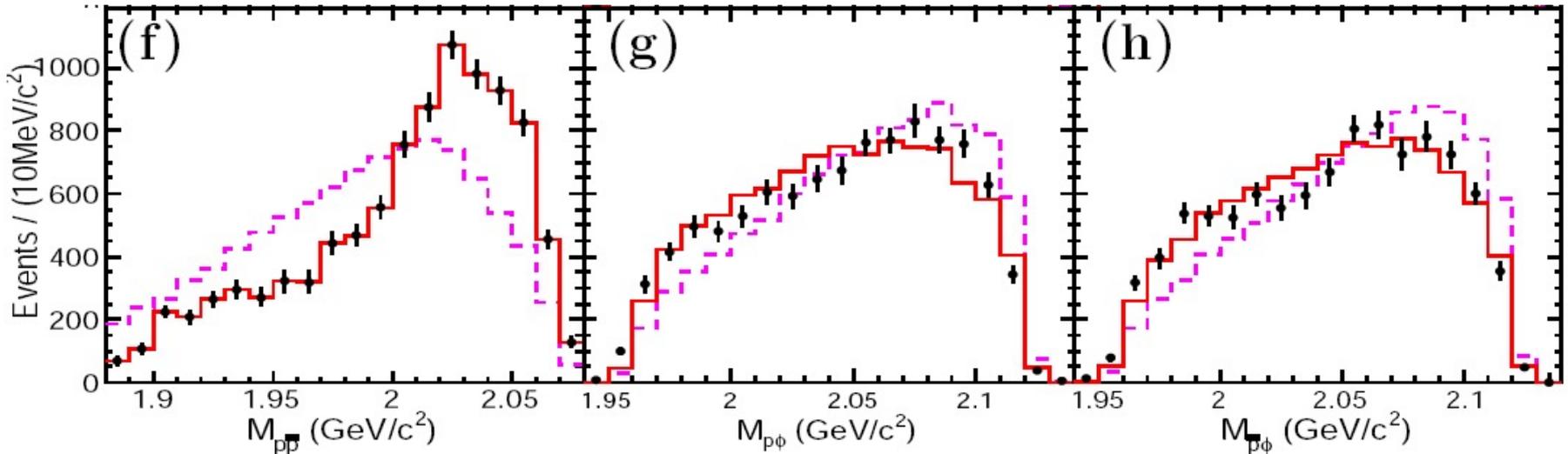
Search for exotics in $J/\psi \rightarrow \phi p \bar{p}$

Phys. Rev. D 93, 052010 (2016)



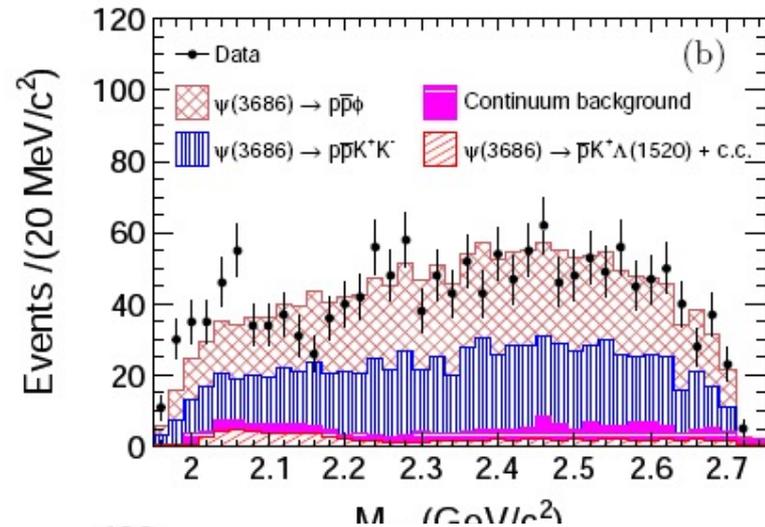
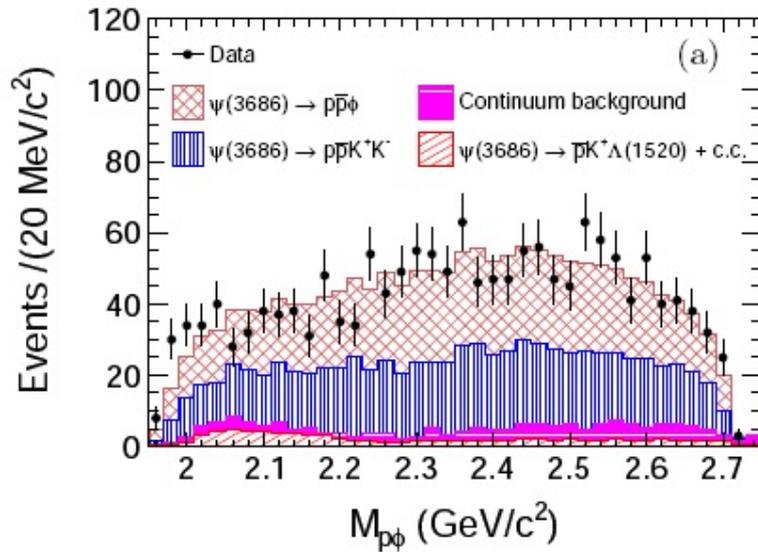
- BESII: $p \bar{p}$ mass threshold enhancement
- LHCb: Pc states

No evident enhancement observed



Search for exotics in $\psi(2S) \rightarrow \phi p \bar{p}$

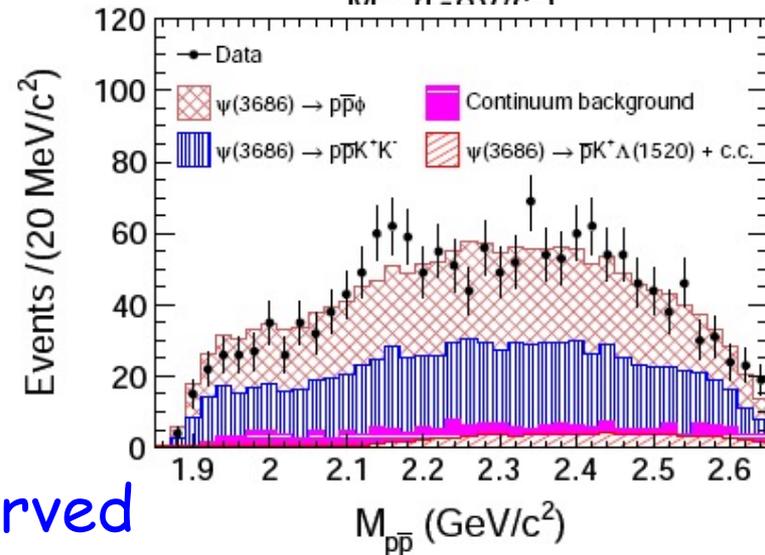
PRD99,112010(2019)



■ BES: $X(p \bar{p})$

■ LHCb: Pc states

No evident enhancement observed



Summary & Prospects

- Rich physics in light hadrons
 - Light hadron spectroscopy → Quark model
 - Light hadron decays → QCD
 -
- 10 billion J/ψ events available at BESIII !
 - A unique opportunity to map the light hadron spectroscopy
- More surprises at BESIII !