Light Hadron Physics at BESIII

房双世

（For BESIII Collaboration）

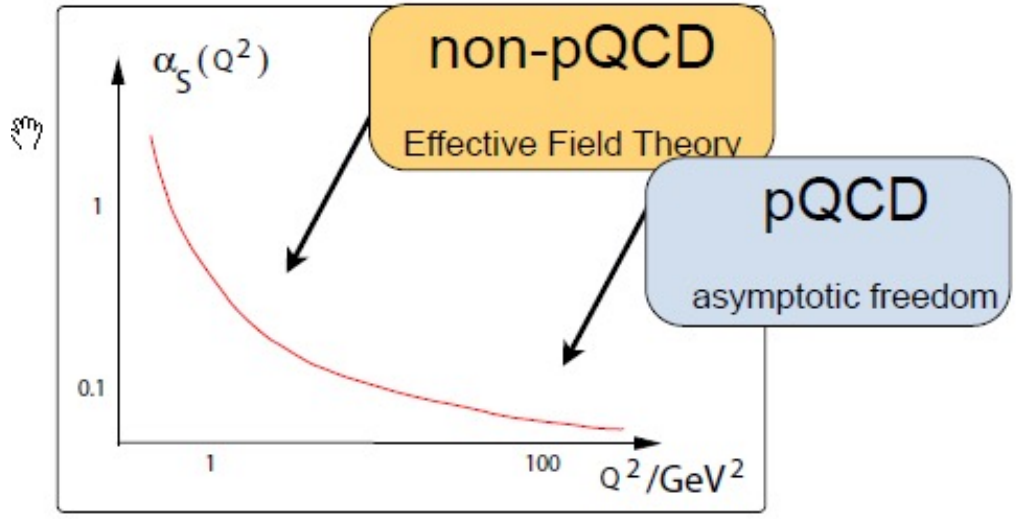
高能物理研究所

第二届强子与重味物理理论与实验联合研讨会
2021年3月27日

OUTLINE

- Why light hadron physics
- Progresses at BESIII
  - Light hadron spectroscopy
  - Light hadron decays
- Summary

Why light hadron physics ?



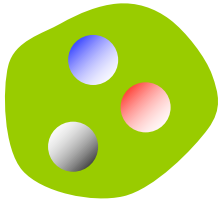
"That [intermediate distance] scale is the richest phenomenologically, and is certainly the crux region to understand...what QCD is really about. And at the heart of the subject is the hadron spectrum, in particular the spectrum built from light quarks. (...) **Without question, there is a great need...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

James D. Bjorken (2000)

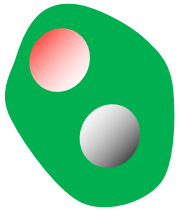
✓ QCD degrees of freedom at low energy
✓ Understanding of the quark and gluon confinement
✓ Particles beyond the QM

Light hadron spectroscopy

- Quark Model

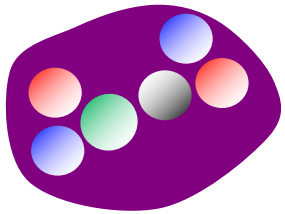


baryon

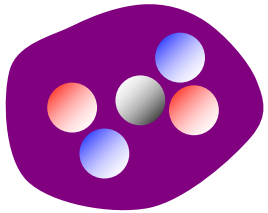


meson

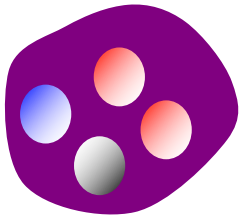
- QCD allows for hadrons beyond Quark Model



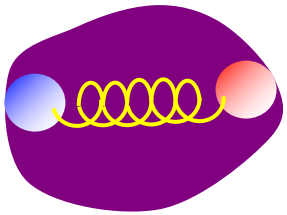
dibaryon



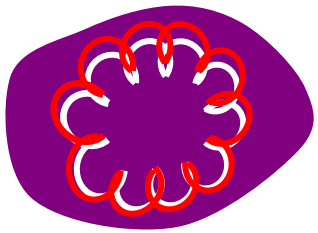
Pentaquark



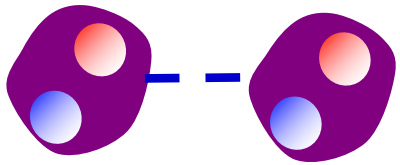
tetraquark



hybrid

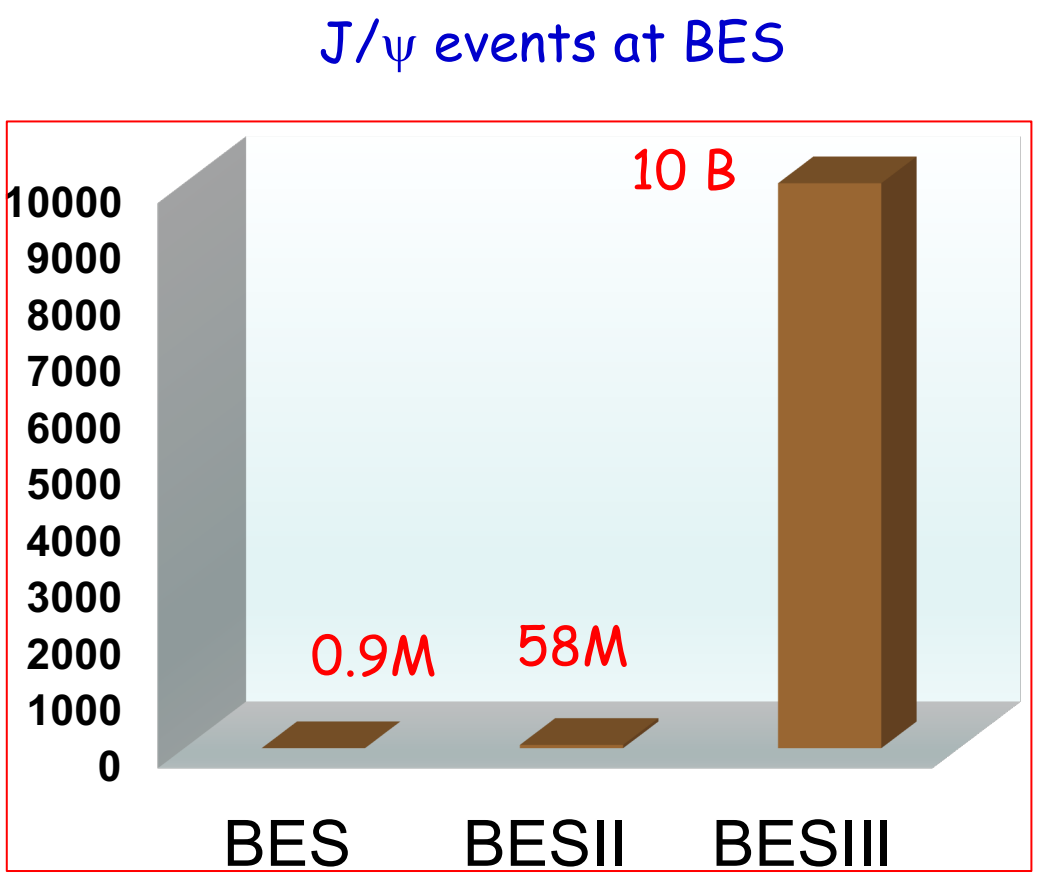


glueball

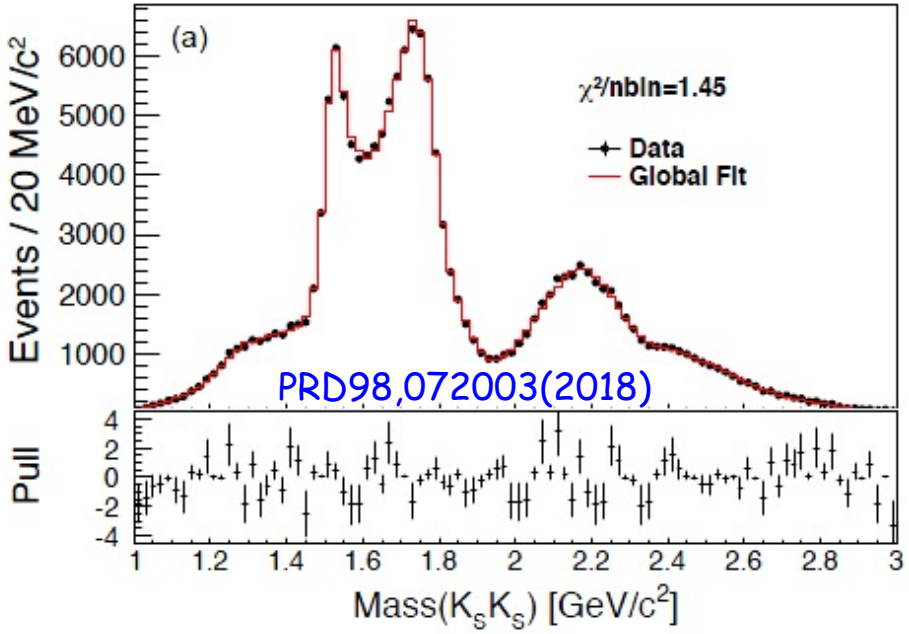


molecule

Mesons in J/ψ radiative decays

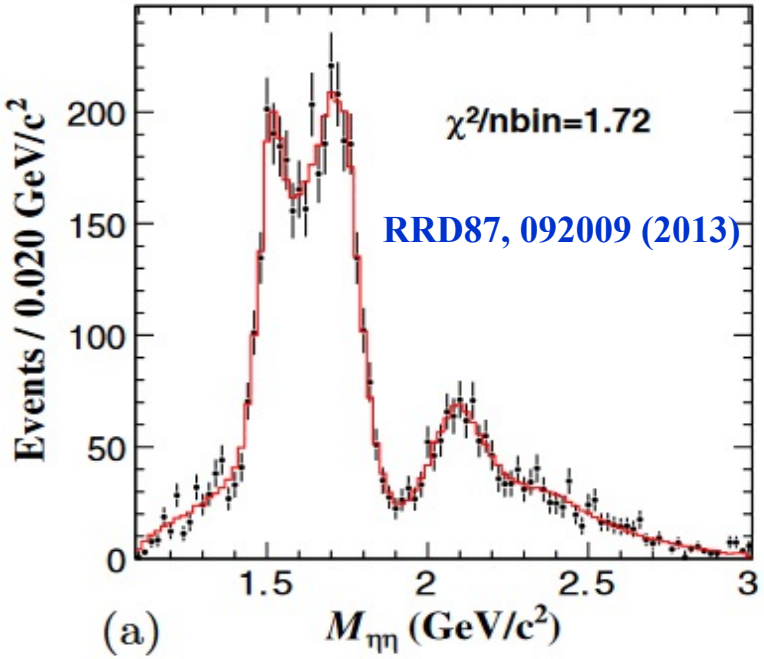


PWA of J/ψ→γKsKs



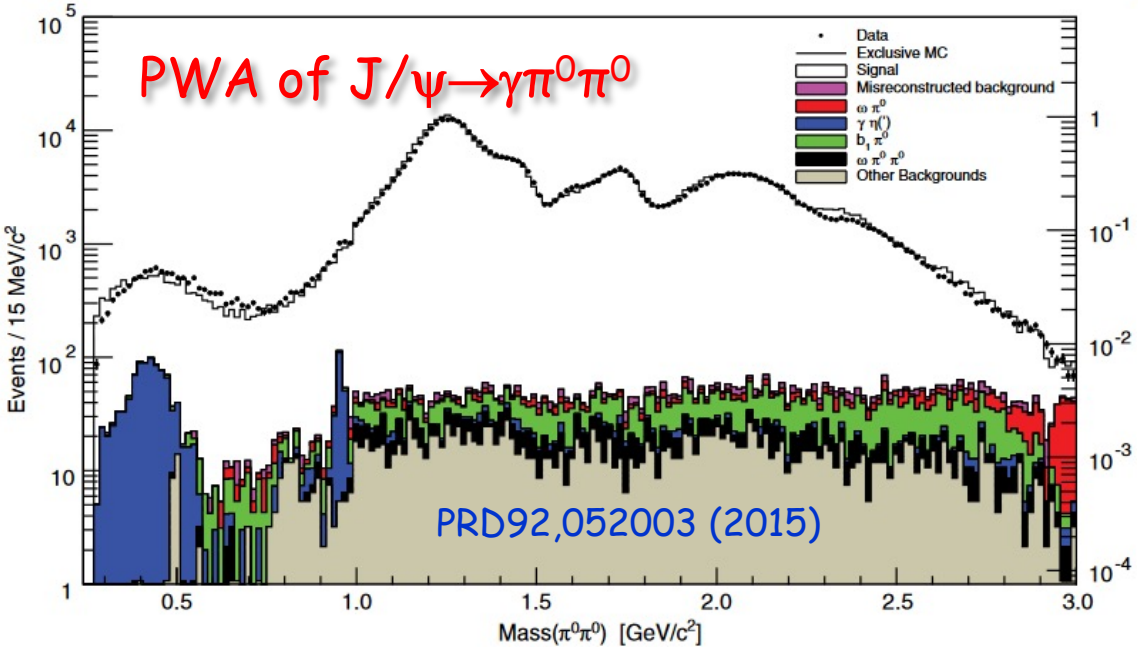
PRD98,072003(2018)

PWA of J/ψ→γηη



RRD87, 092009 (2013)

PWA of J/ψ→γπ⁰π⁰



PRD92,052003 (2015)

- $f_0(1710)$ 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 $f_0(1710)$

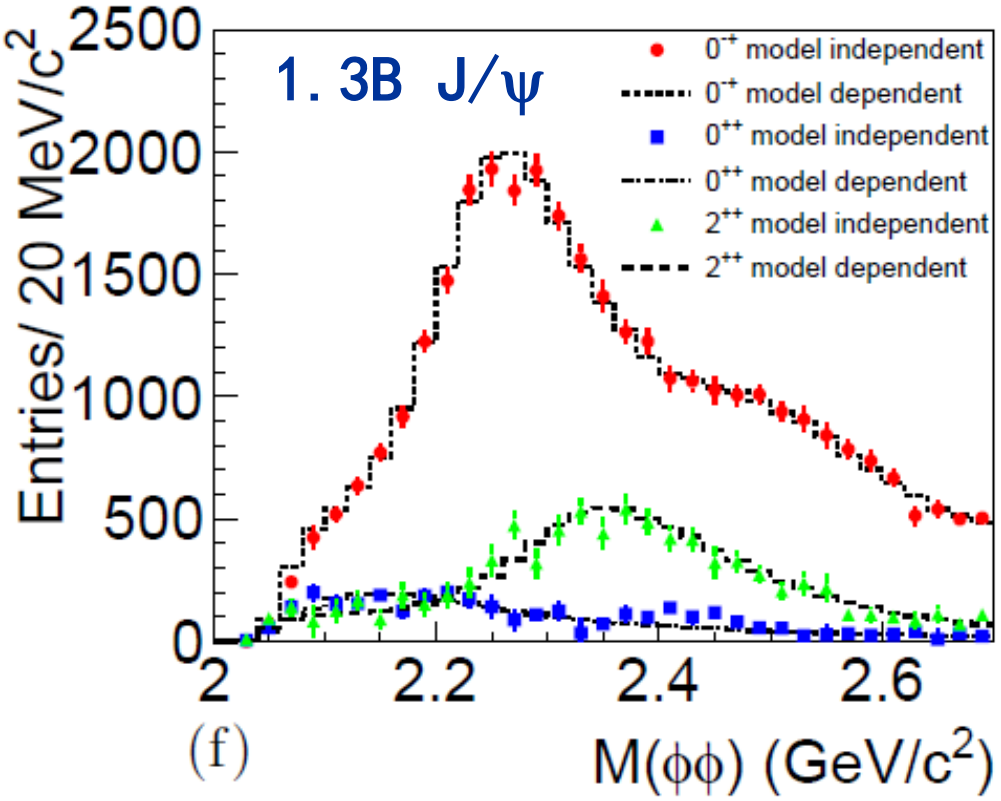
$$B(J/\psi \to \gamma f_0(1500)) \sim 3\times10^{-4}$$

$$B(J/\psi \to \gamma f_0(1710)) > 1.9\times10^{-3}$$

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

PWA of J/ψ→γϕϕ

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



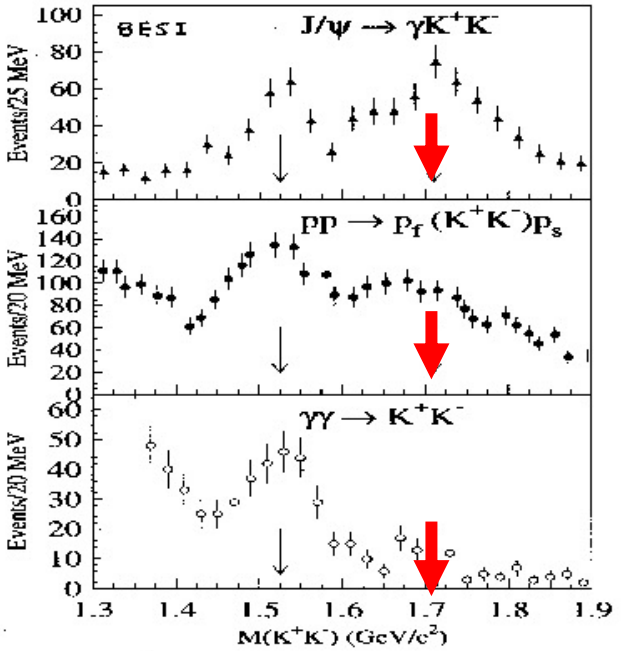
Resonance	M(MeV/c^2)	Γ(MeV/c^2)
$\eta(2225)$	2216^{+4+21}_{-5-11}	185^{+12+43}_{-14-17}
$\eta(2100)$	2050^{+30+75}_{-24-26}	$250^{+36+181}_{-30-164}$
$X(2500)$	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}
$f_0(2100)$	2101	224
$f_2(2010)$	2011	202
$f_2(2300)$	2297	149
$f_2(2340)$	2339	319
0^{-+} PHSP		

- Dominant contribution from pseudoscalars
  - η(2225) is confirmed;
  - η(2100) and X(2500) are observed

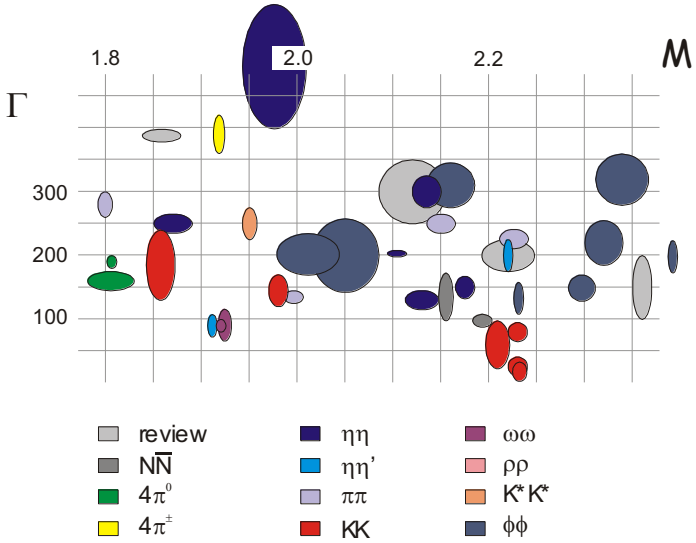
- The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in p^-p reactions are also observed

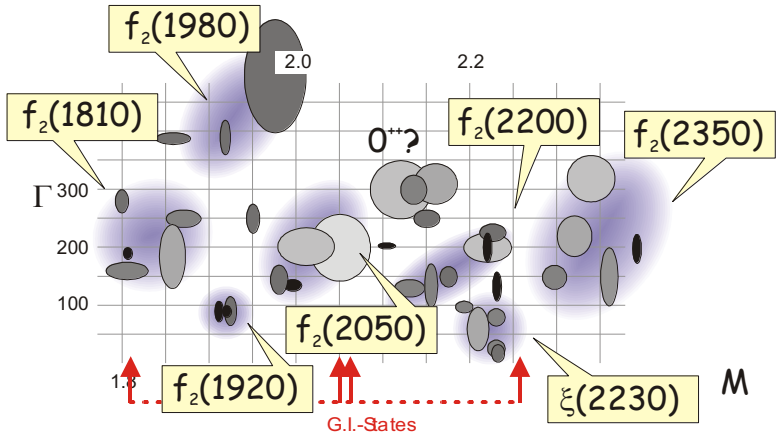
0^+ : experimental results saturated

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



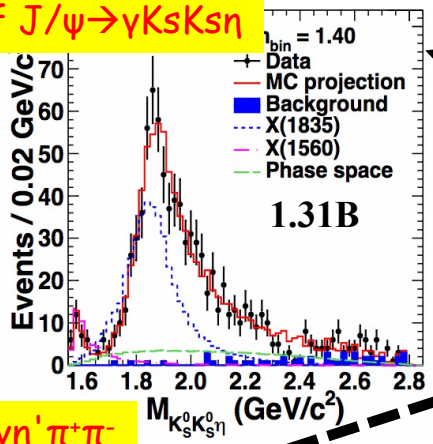
2^+: complicated situation around 2 GeV

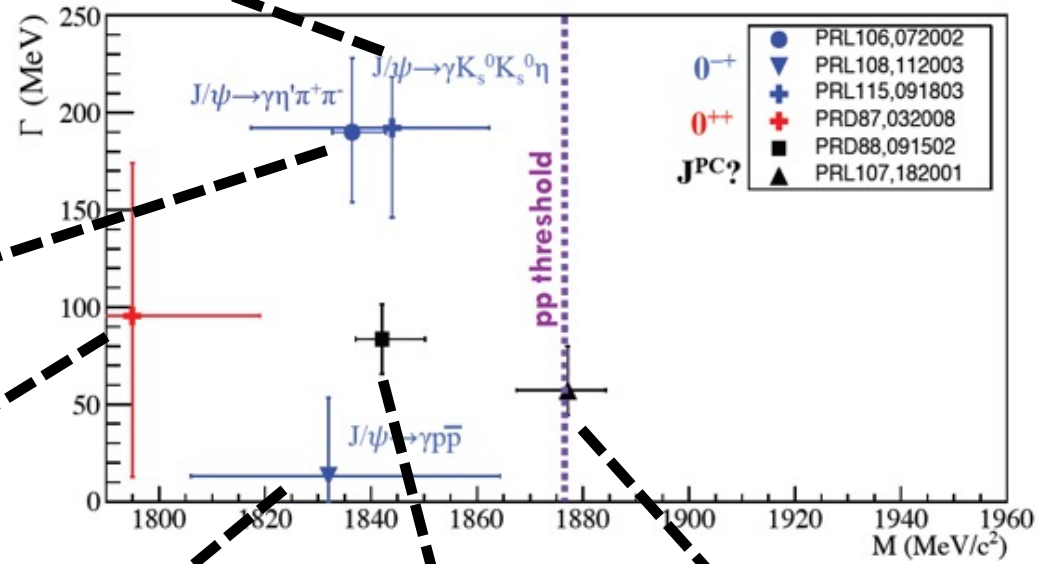




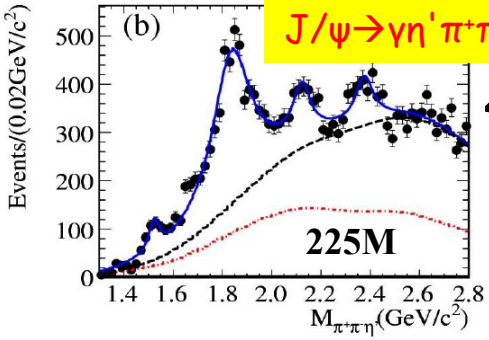
X(18??) between 1.8~1.9 GeV

PWA of J/ψ→γKsKsη

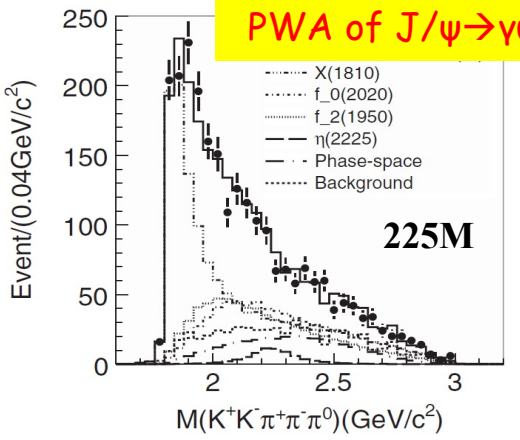




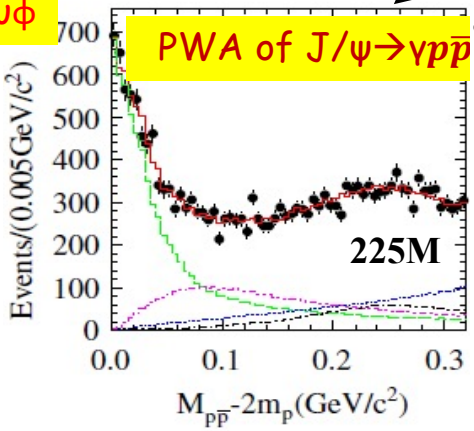
J/ψ→γη'π⁺π⁻



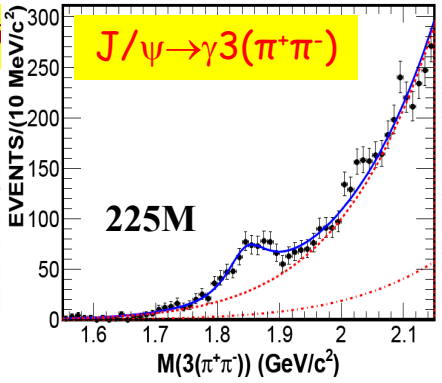
PWA of J/ψ→γωϕ



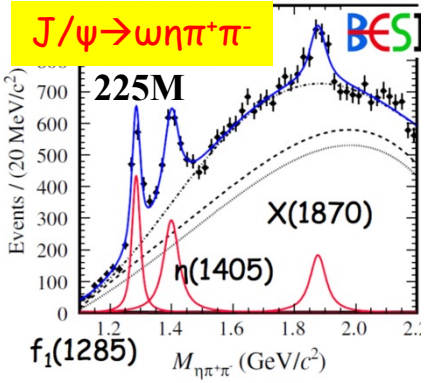
PWA of J/ψ→γpp̄



J/ψ→γ3(π⁺π⁻)



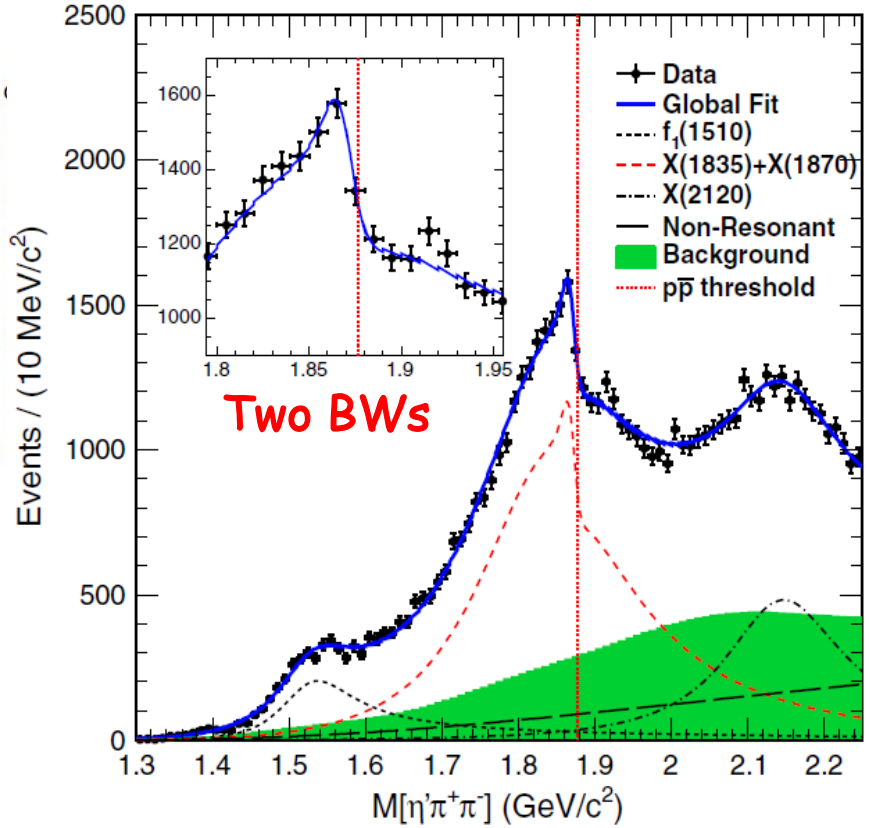
J/ψ→ωηπ⁺π⁻



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

Latest result on X(1835)

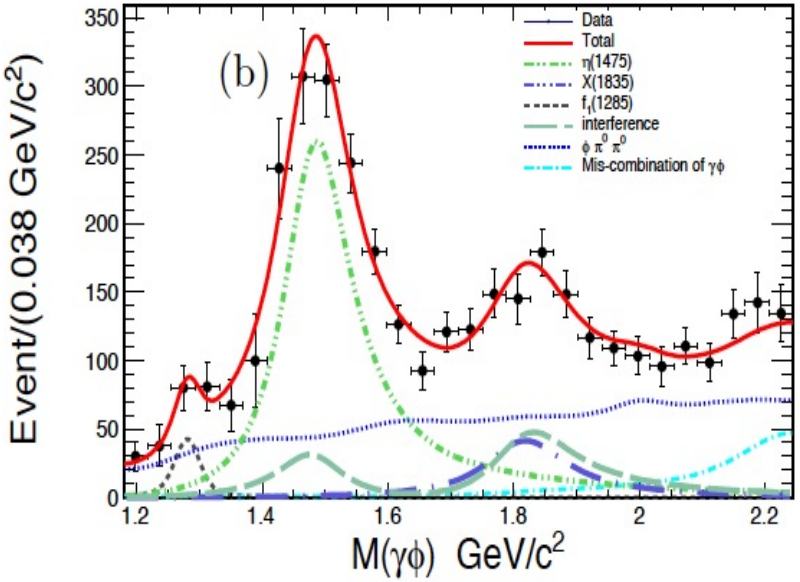
$J/\psi \to \gamma\eta' \pi^+\pi^-$



PRL 117, 042002(2016)

M_2=1870.2±2.2 $^{+2.3}_{-0.7}$ MeV/c^2
Γ_2 = 13.0±6.1 $^{+2.1}_{-3.8}$ MeV

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



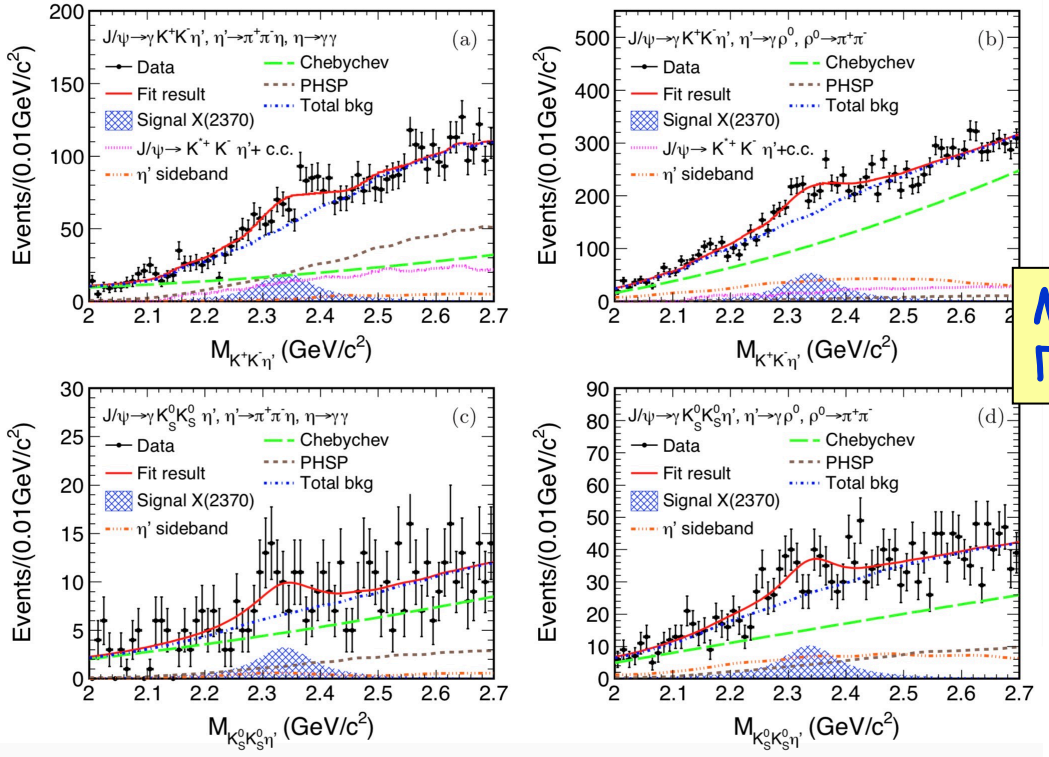
PRD97, 051101 (R) (2018)

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) → KKη′

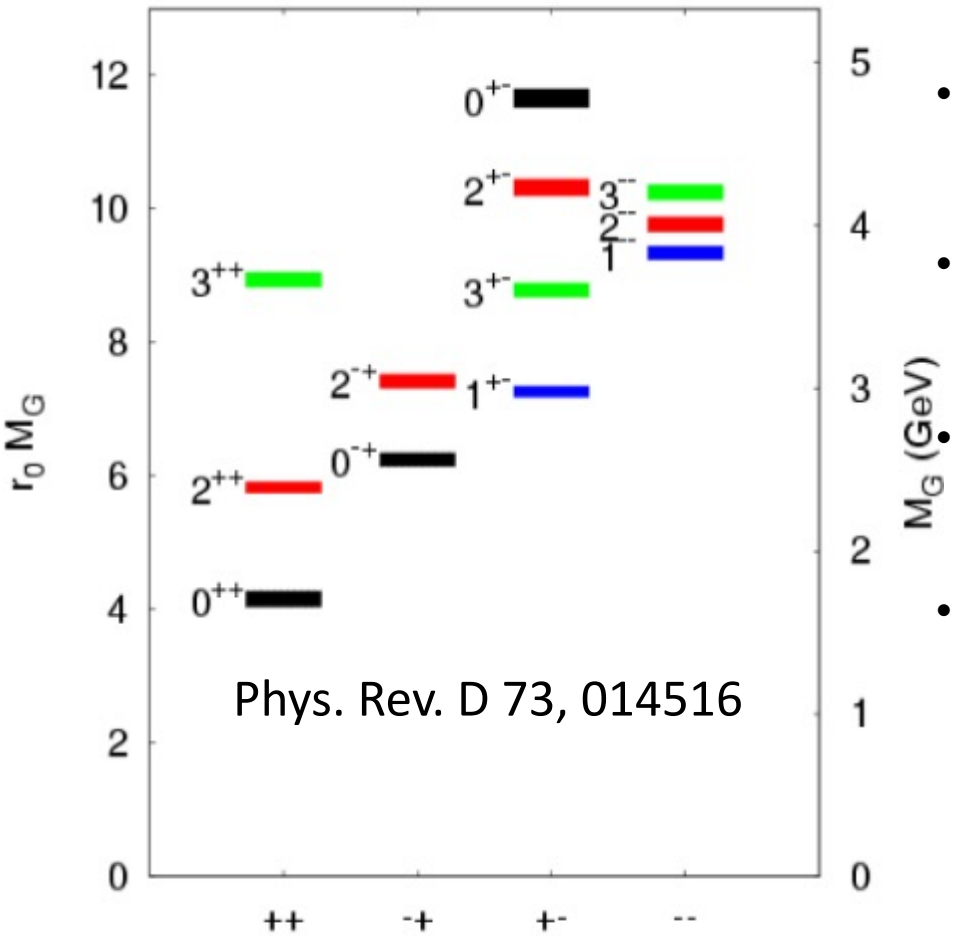
EPJC80,746(2021)



M=2341.6±6.5 ±5.7 MeV/c²
Γ = 117±10±8 MeV

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

Where is the glueball?

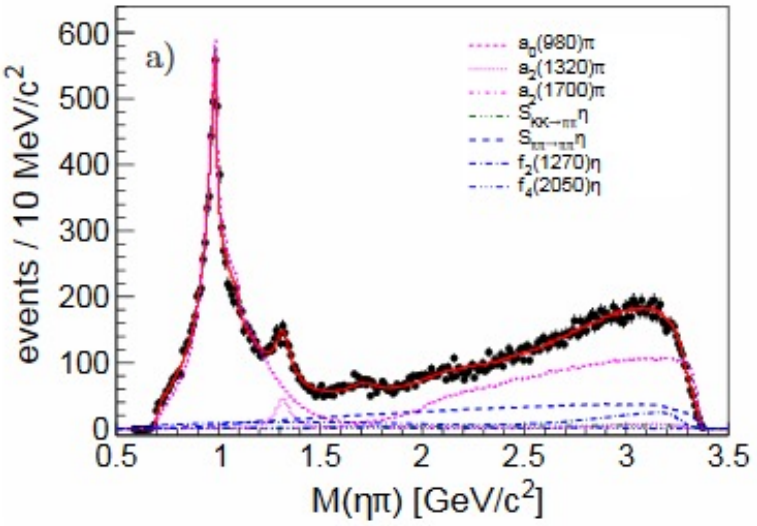


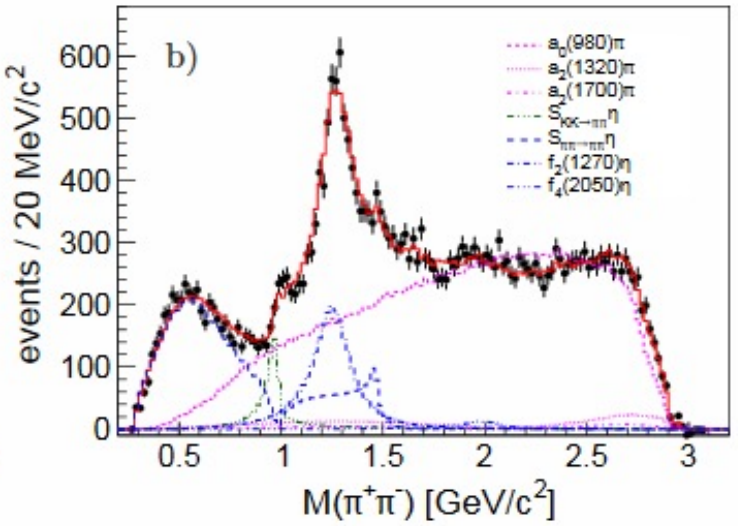
Phys. Rev. D 73, 014516

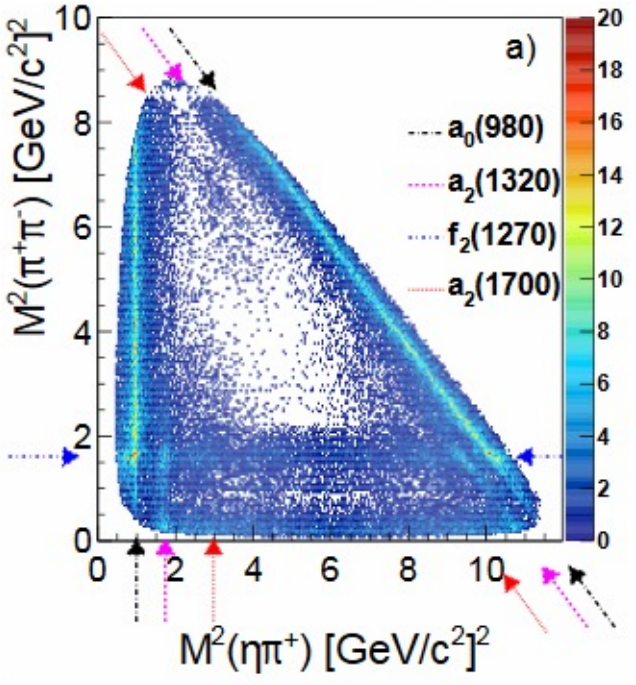
At BESIII

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

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

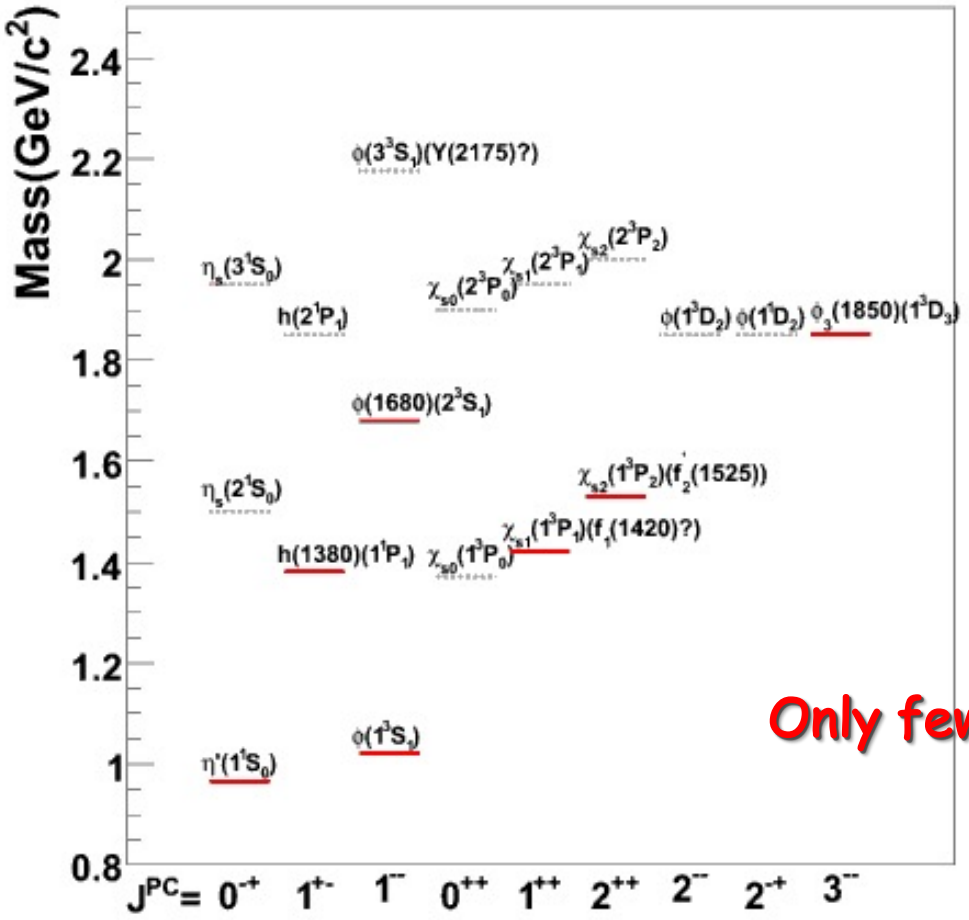






- Clear evidence for $a_2(1700)$ in χ_{c1}decays
- Upper limits for $\pi_1(1^{-+})$ in 1.4 - 2.0 GeV/c^2

Strangeonia spectrum



——— identified

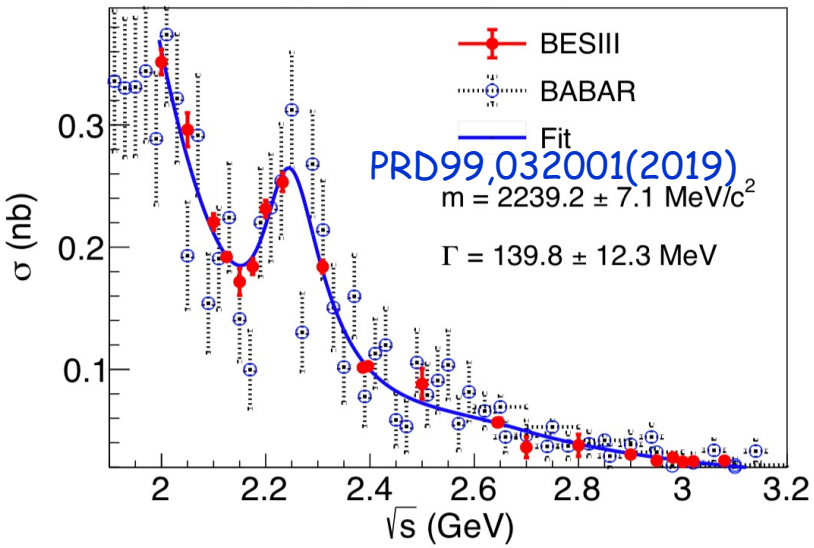
..... not identified

$s\bar{s}$ system – what do we know?

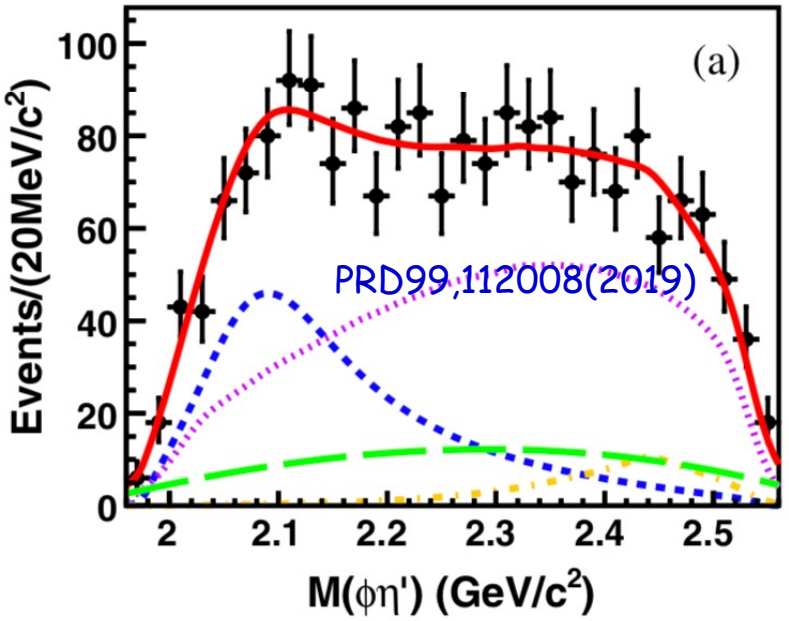
Only few of them have been identified !

$\phi(2170)$ at BESIII

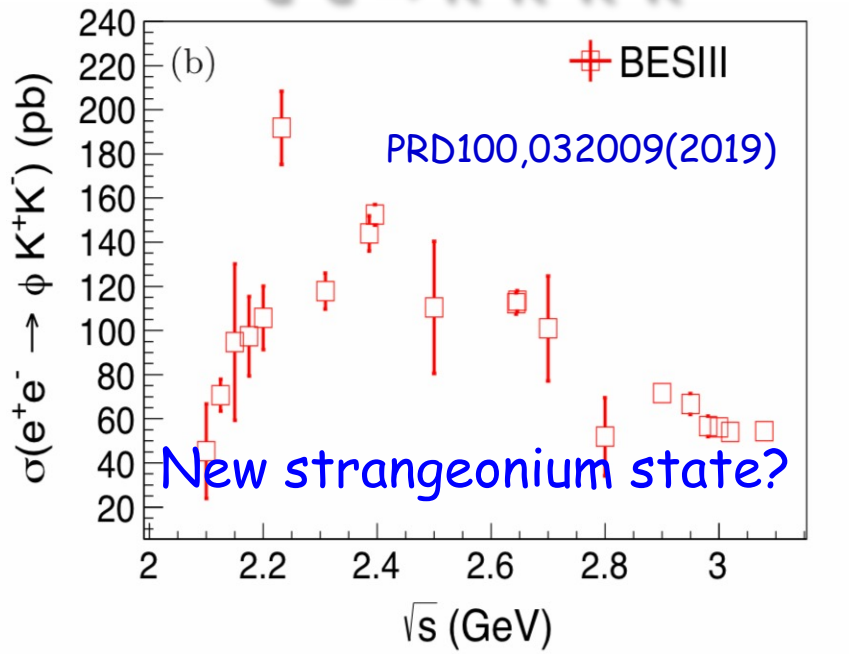
$e^+e^- \to K^+K^-$

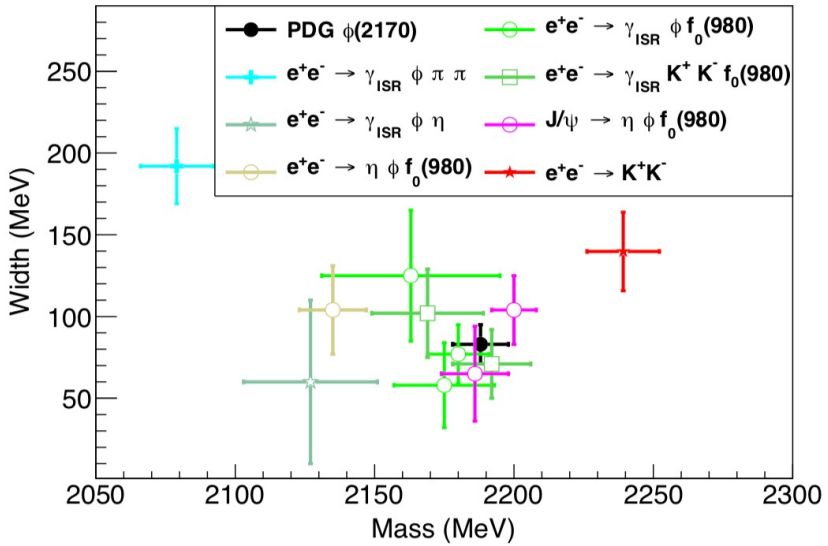


$J/\psi \to \phi\eta\eta'$



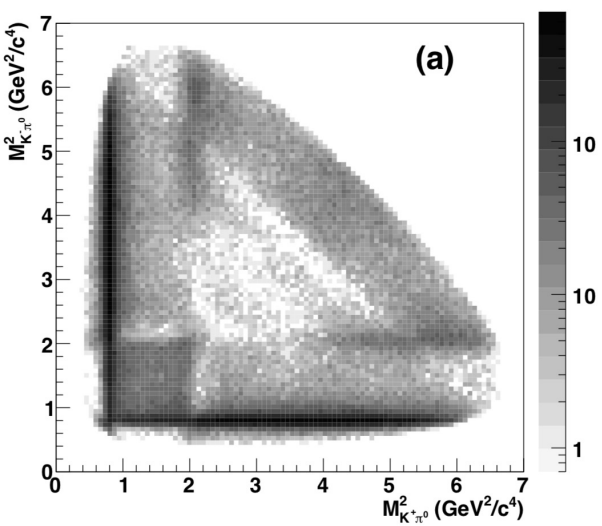
$e^+e^- \to K^+K^-\ K^+K^-$

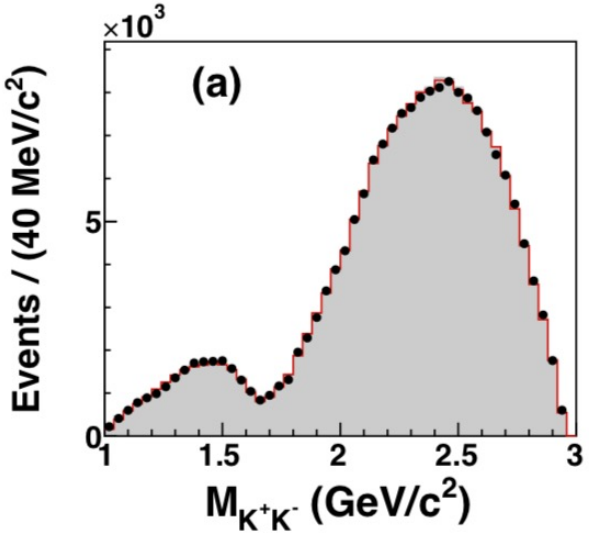


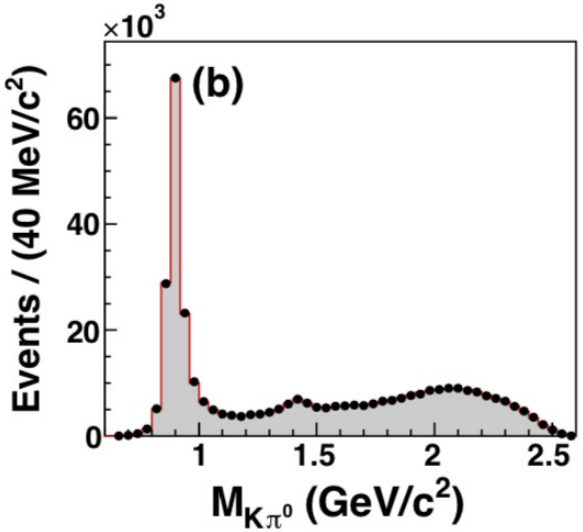


PWA of $J/\psi \rightarrow K^+K^-\pi^0$

Phys. Rev. D100,032004(2019)



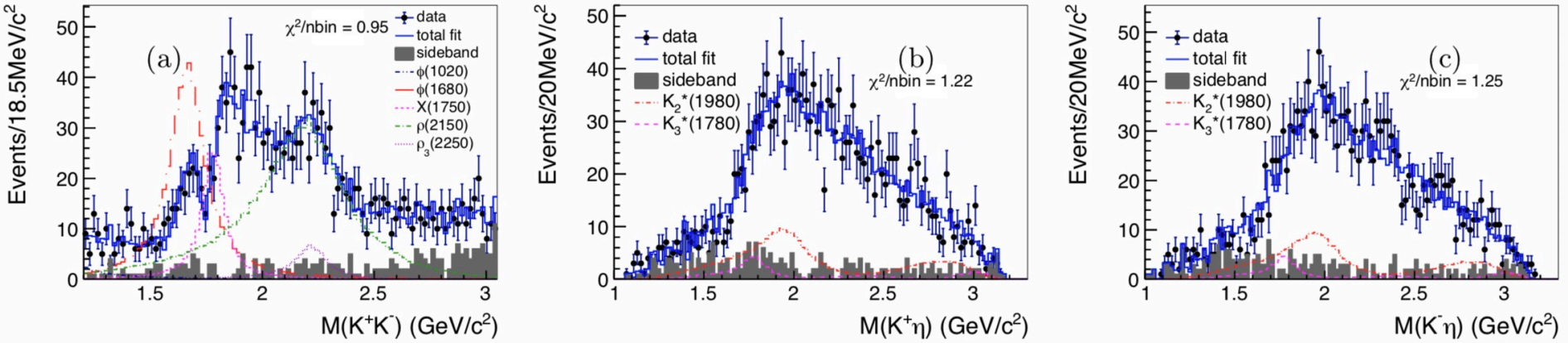




- The dominant contribution is from K*(892)
- First observation of $K^*_2(1980)$ and $K^*_4(2045)$ in J/y decays
- Two broad 1^{--} structures were observed in K^+K^- mass spectrum, Possibly contributed from $\omega(1650)$ and $\rho(2150)$

PWA of ψ(3686) → KKη

Phys. Rev. D101,032008(2020)



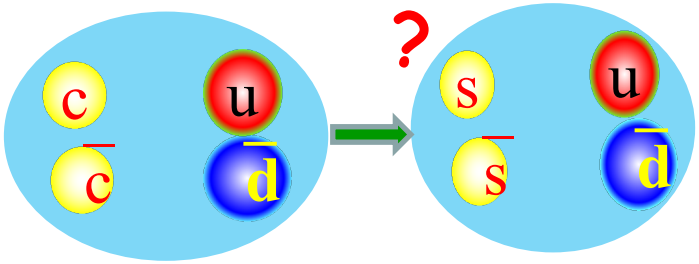
- Observation of both φ(1680) and X(1750) implies X(1750) is a new structure
- A broad structure around 2.2 GeV is observed, either φ(1680) or ρ(2150)?

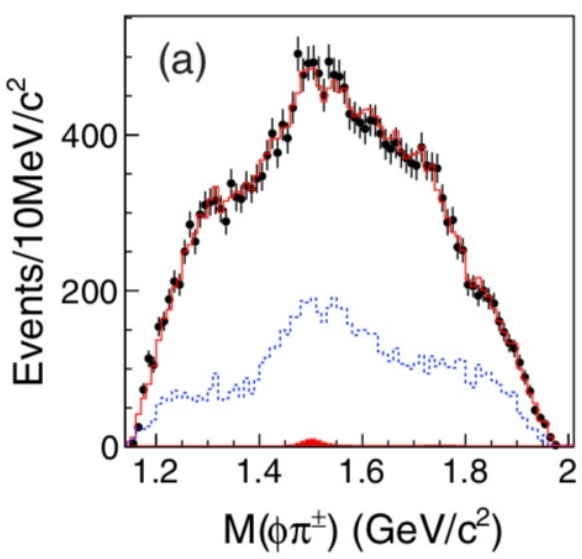
Search for Zs in e+e-⟶ ϕπ π

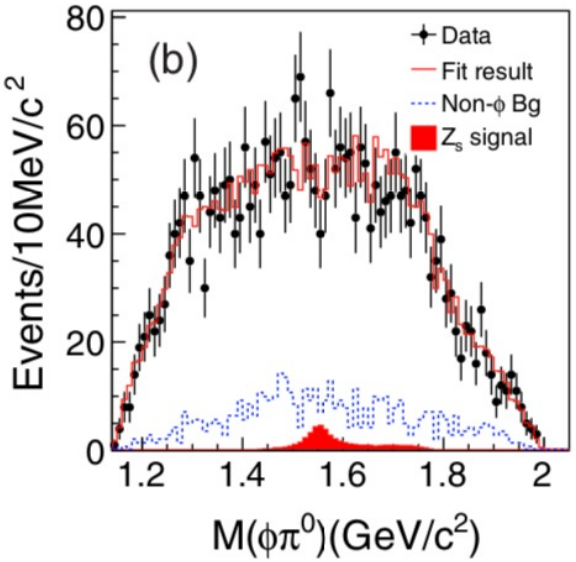
PRD99，011101(2018)

$Y(4260) \to J/\psi\pi^+\pi^-$ charm, ⇒ Z_c

$Y(2175) \to \phi(1020)\pi^+\pi^-$ strange ⇒ Z_s ?



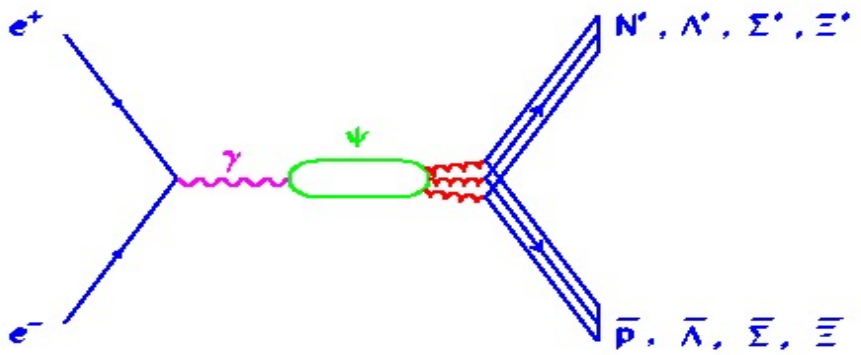




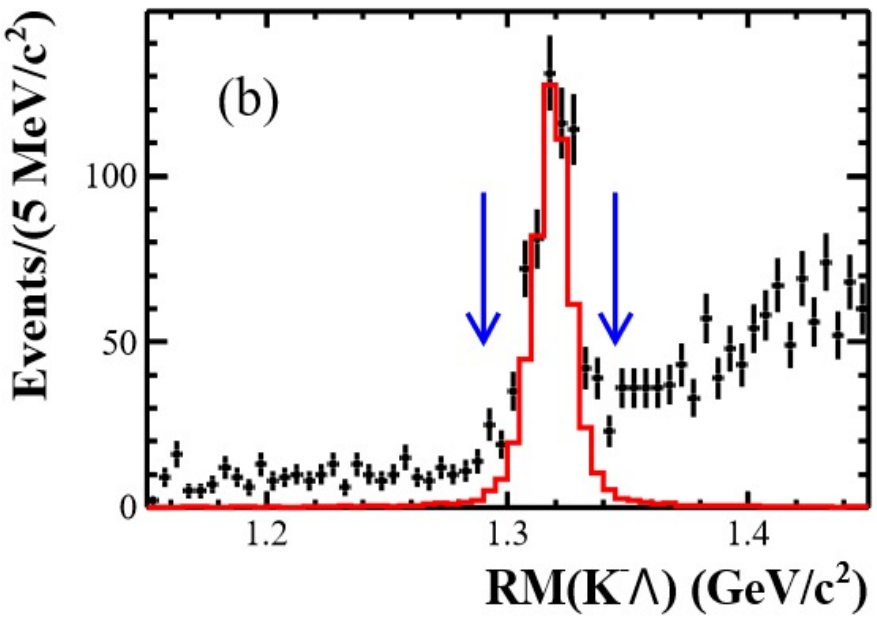
No evident structure observed in ϕπ mass spectra

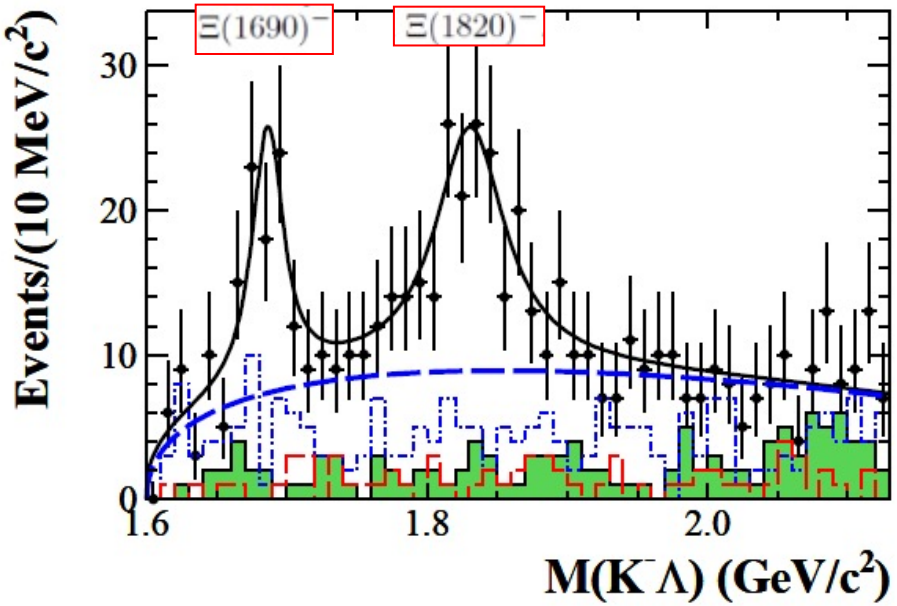
Baryon spectroscopy

Ξ*s in ψ(2S)→KΛΞ



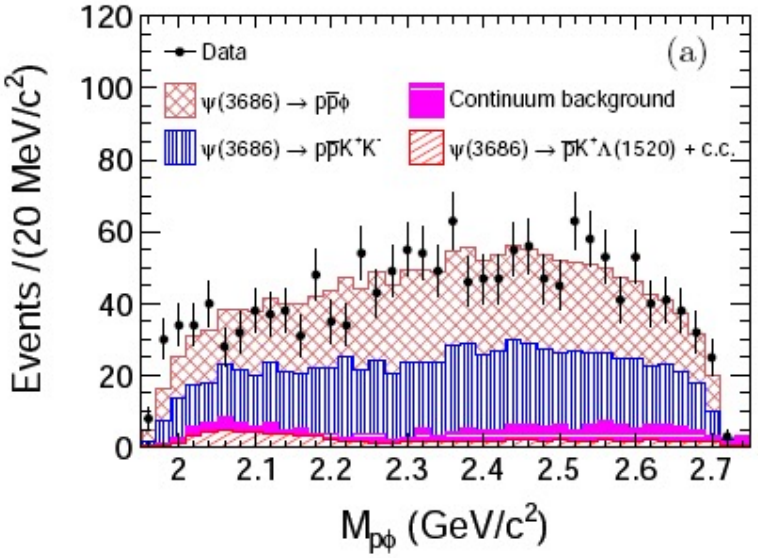
PRD91 (2015) 092006

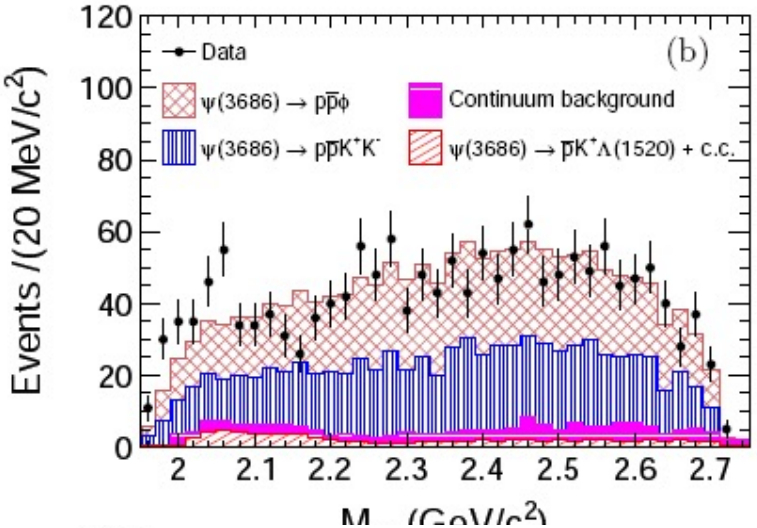


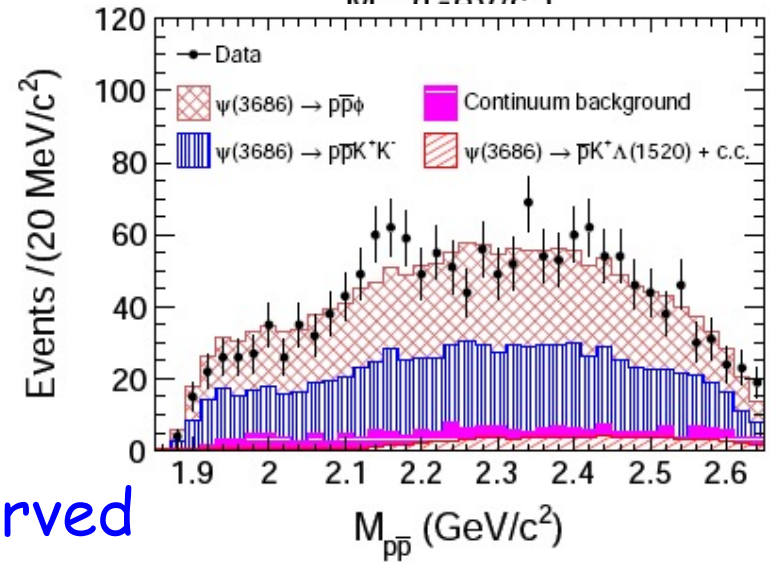


Search for exotics in $\psi(2S)\to\phi p\bar{p}$

PRD99,112010(2019)







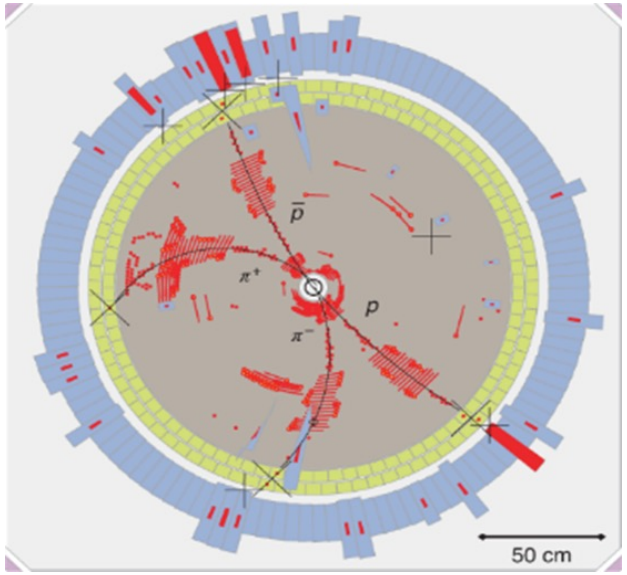
- BES: X(p $\bar{p}$)
- LHCb: Pc states

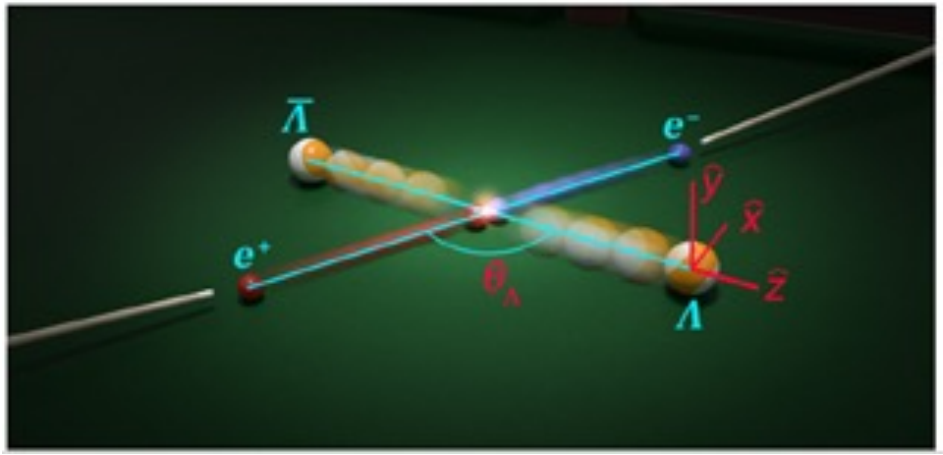
No evident enhancement observed

Light hadron decays

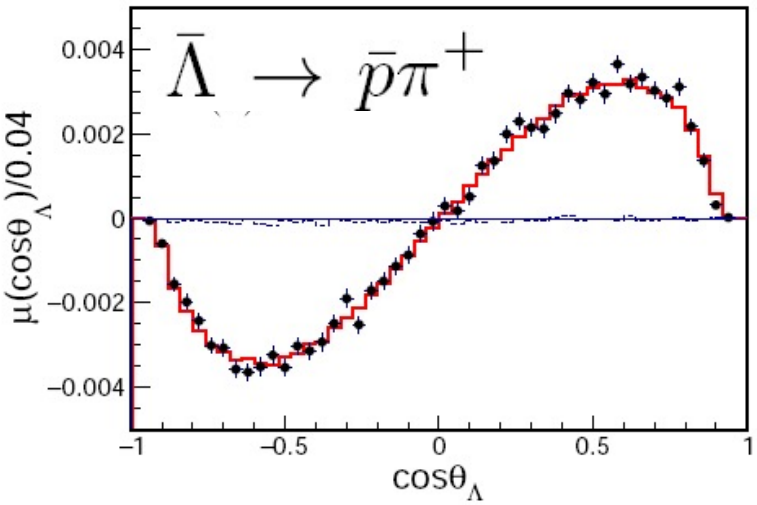
First observation Λ polarization in $J/\psi \to \Lambda\ \bar{\Lambda}$

Nature physics 15,631 (2019)





$$\Delta\Phi = (42.4 \pm 0.6 \pm 0.5)^\circ$$

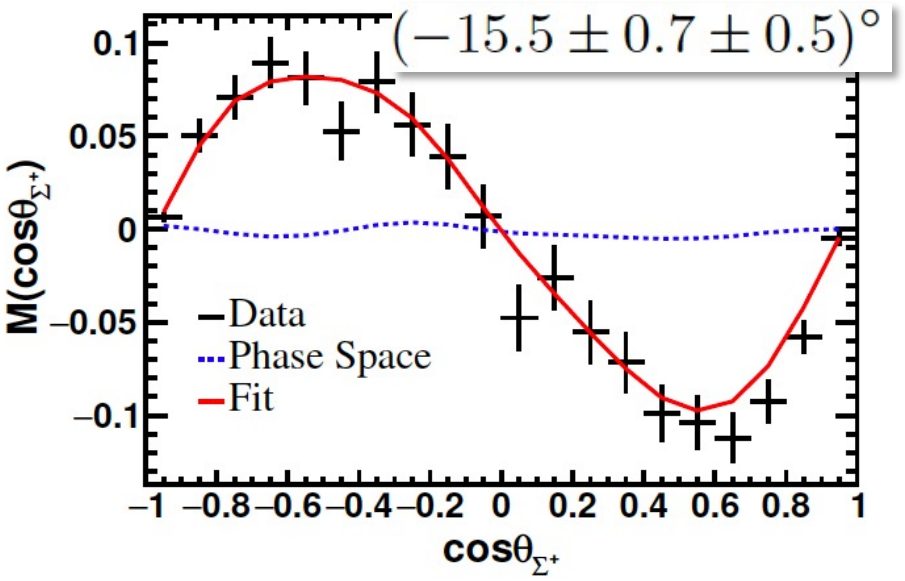


Parameters	This work
α_ψ	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$
α_-	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.758 \pm 0.010 \pm 0.007$
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$

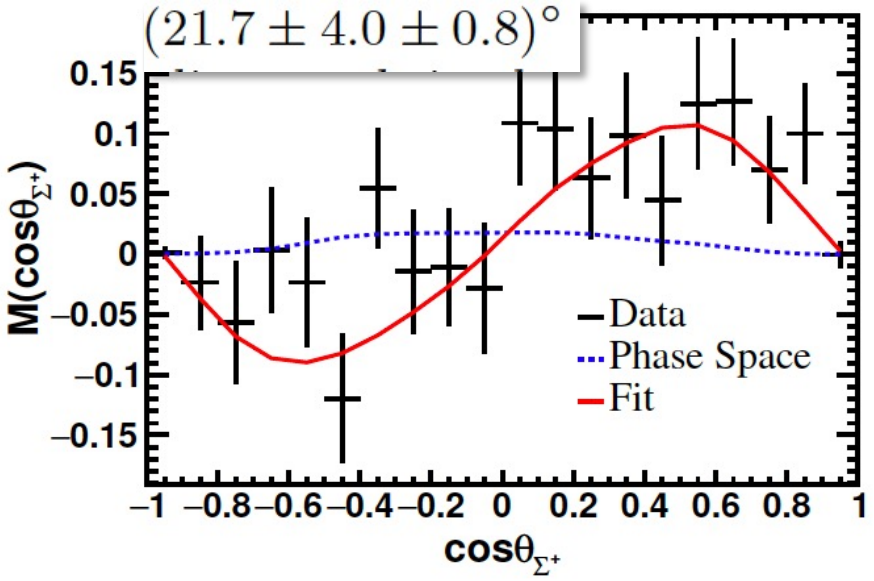
Observation of Σ Polarization

Phys.Rev.Lett. 125, 052004

$J/\psi \to \Sigma\ \bar{\Sigma}$



$\psi(2S) \to \Sigma\ \bar{\Sigma}$

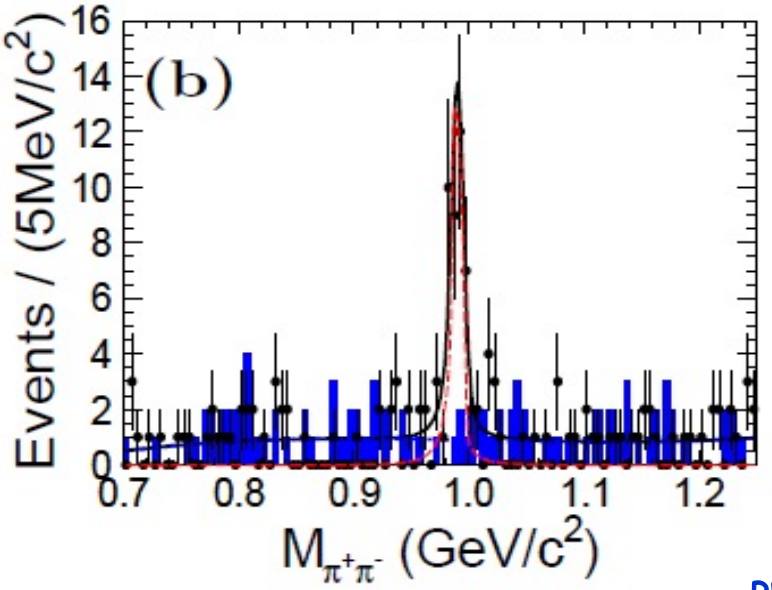


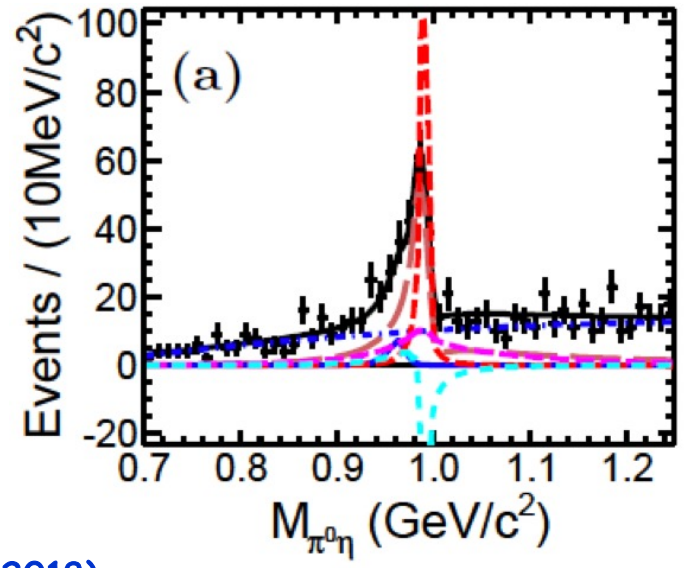
$$\mathcal{W}(\boldsymbol{\xi}) = \mathcal{T}_0(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_5(\boldsymbol{\xi}) + \alpha_0\bar{\alpha}_0\left(\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi\mathcal{T}_6(\boldsymbol{\xi})\right) + \sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\left(\alpha_0\mathcal{T}_3(\boldsymbol{\xi}) + \bar{\alpha}_0\mathcal{T}_4(\boldsymbol{\xi})\right).$$

$$A_{CP,\Sigma} = -0.004 \pm 0.037 \pm 0.010$$

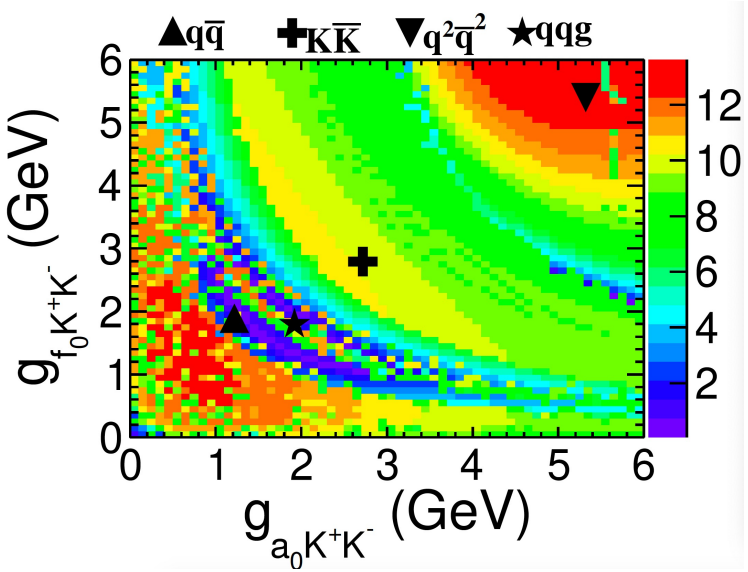
$a_0(980)$ and $f_0(980)$ mixing

$\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-$ $J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0$





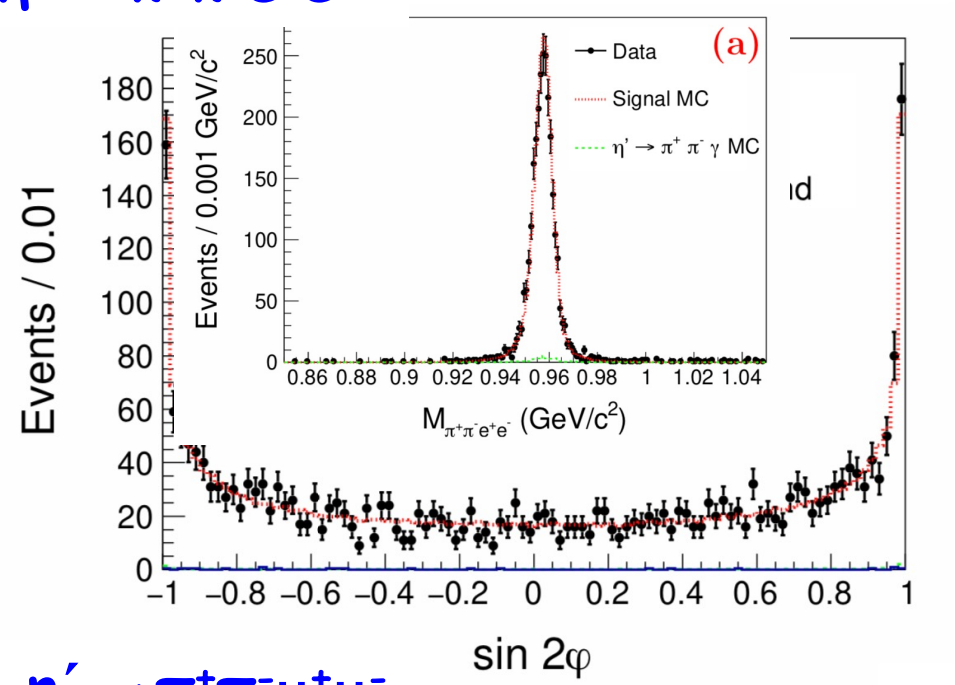
PRL121,022001(2018)

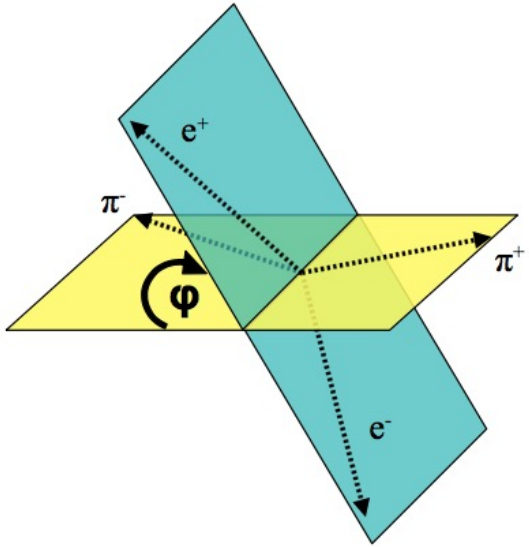


Favors tetraquark states ?

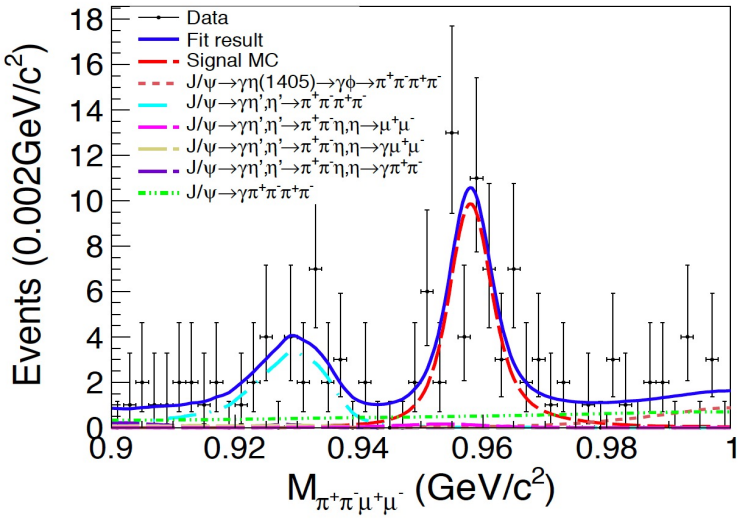
CP violation in $\eta' \to \pi^+\pi^- l^+ l^-$?

$\eta' \to \pi^+\pi^- e^+ e^-$





$\eta' \to \pi^+\pi^- \mu^+ \mu^-$



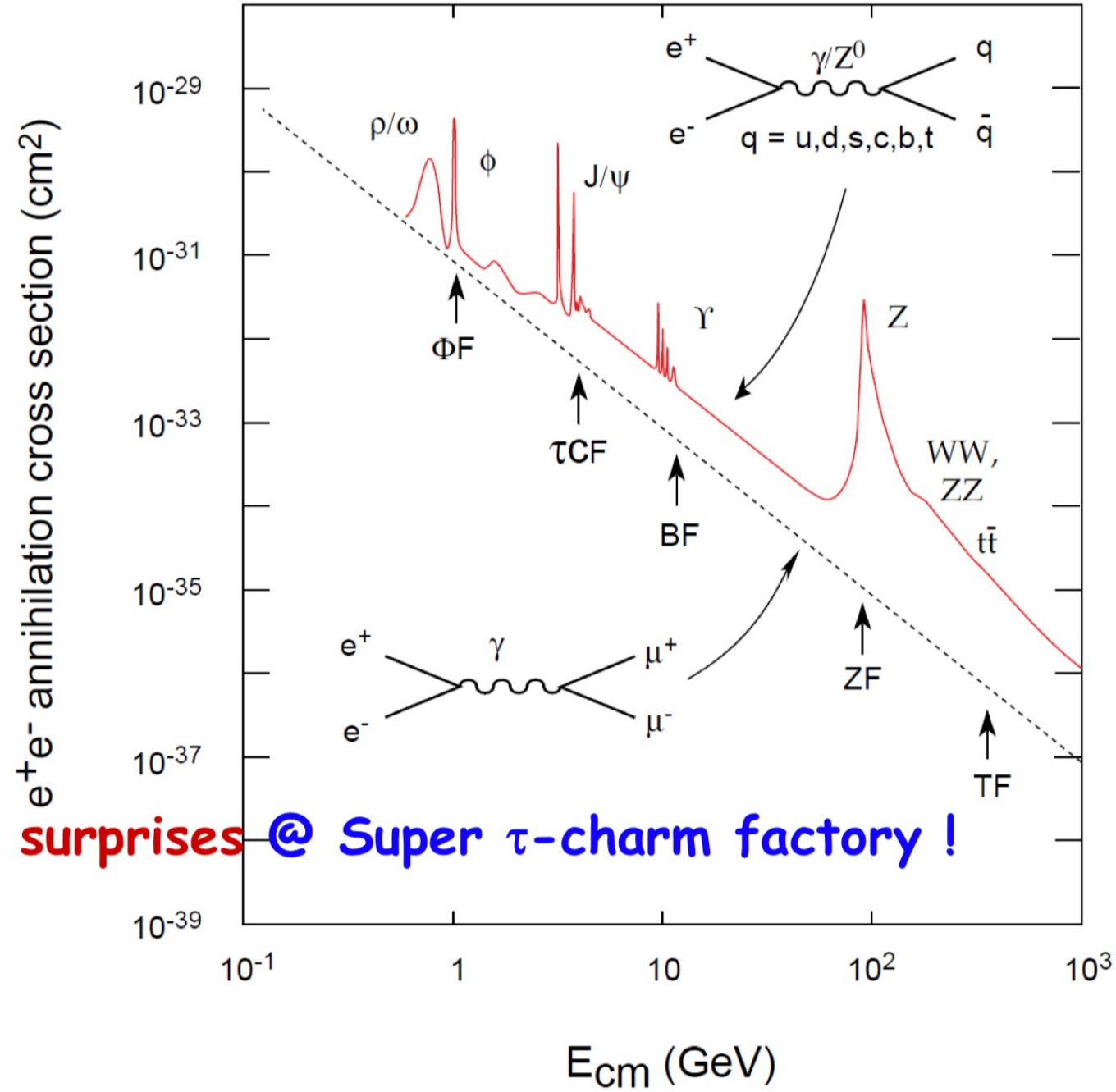
$$\mathcal{A}_\varphi = \frac{N(\sin 2\varphi > 0) - N(\sin 2\varphi < 0)}{N(\sin 2\varphi > 0) + N(\sin 2\varphi < 0)}$$

$$\mathcal{A}_{CP} = (1.6 \pm 2.0_{stat.} \pm 0.6_{syst.})\,\%$$

arXiv:2011.07902, 2012.04257

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 !**



More surprises @ Super τ-charm factory !