Light meson spectroscopy at e^+e^- machines

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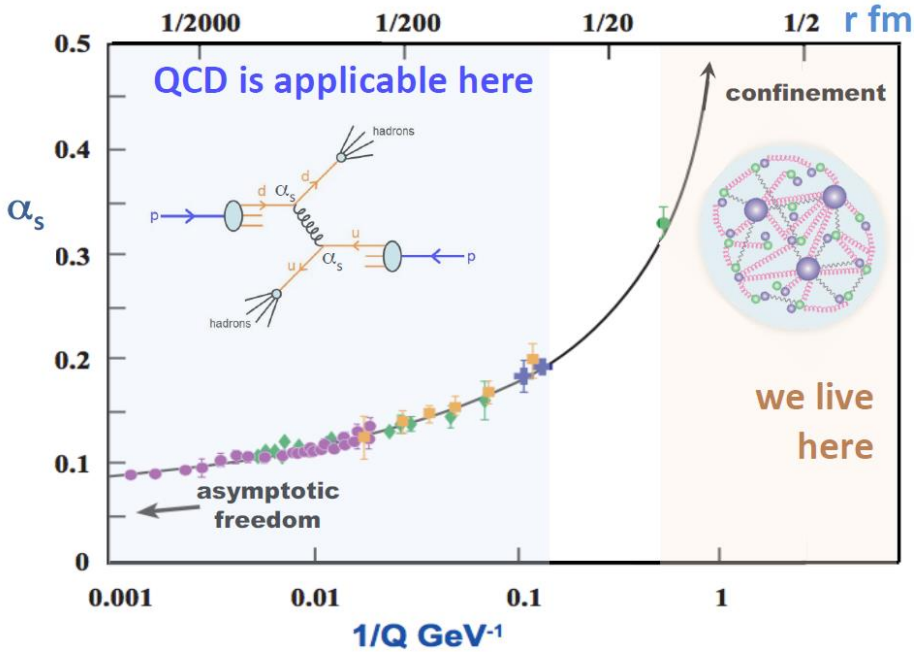
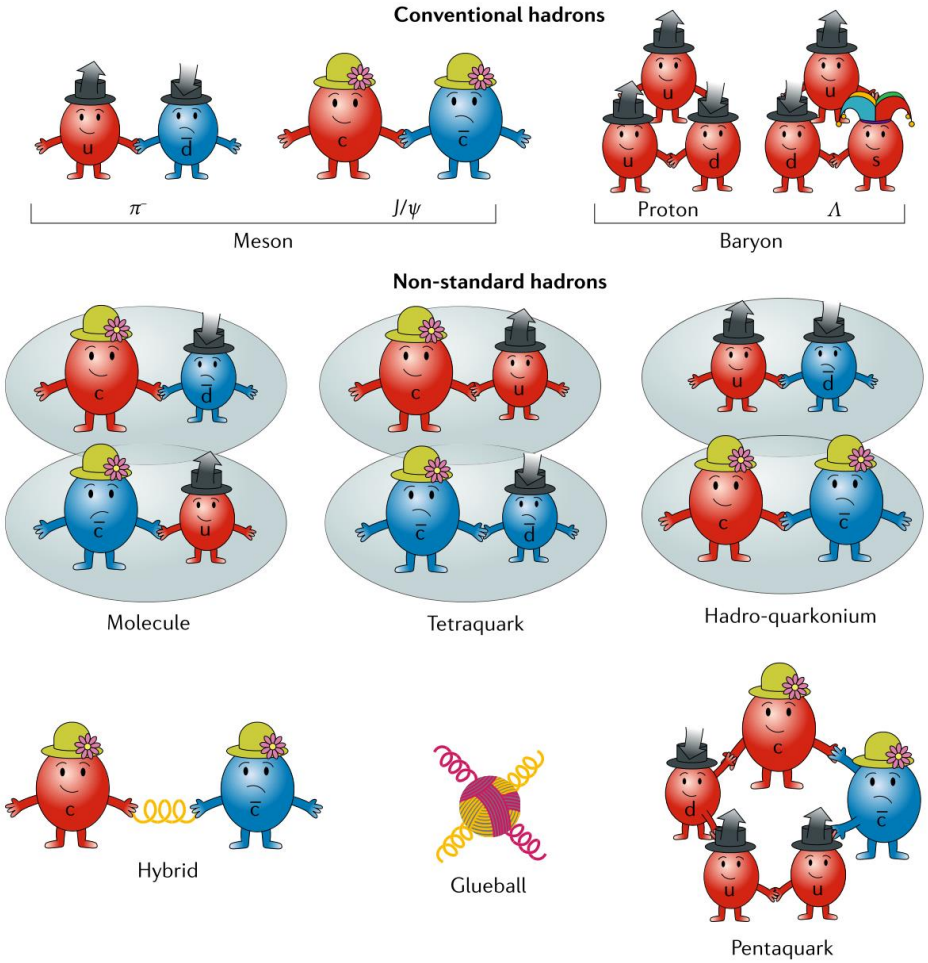
Hadron spectroscopy



- Testing QCD in the confinement regime
- Revealing the fundamental degrees of freedom

QCD exotics

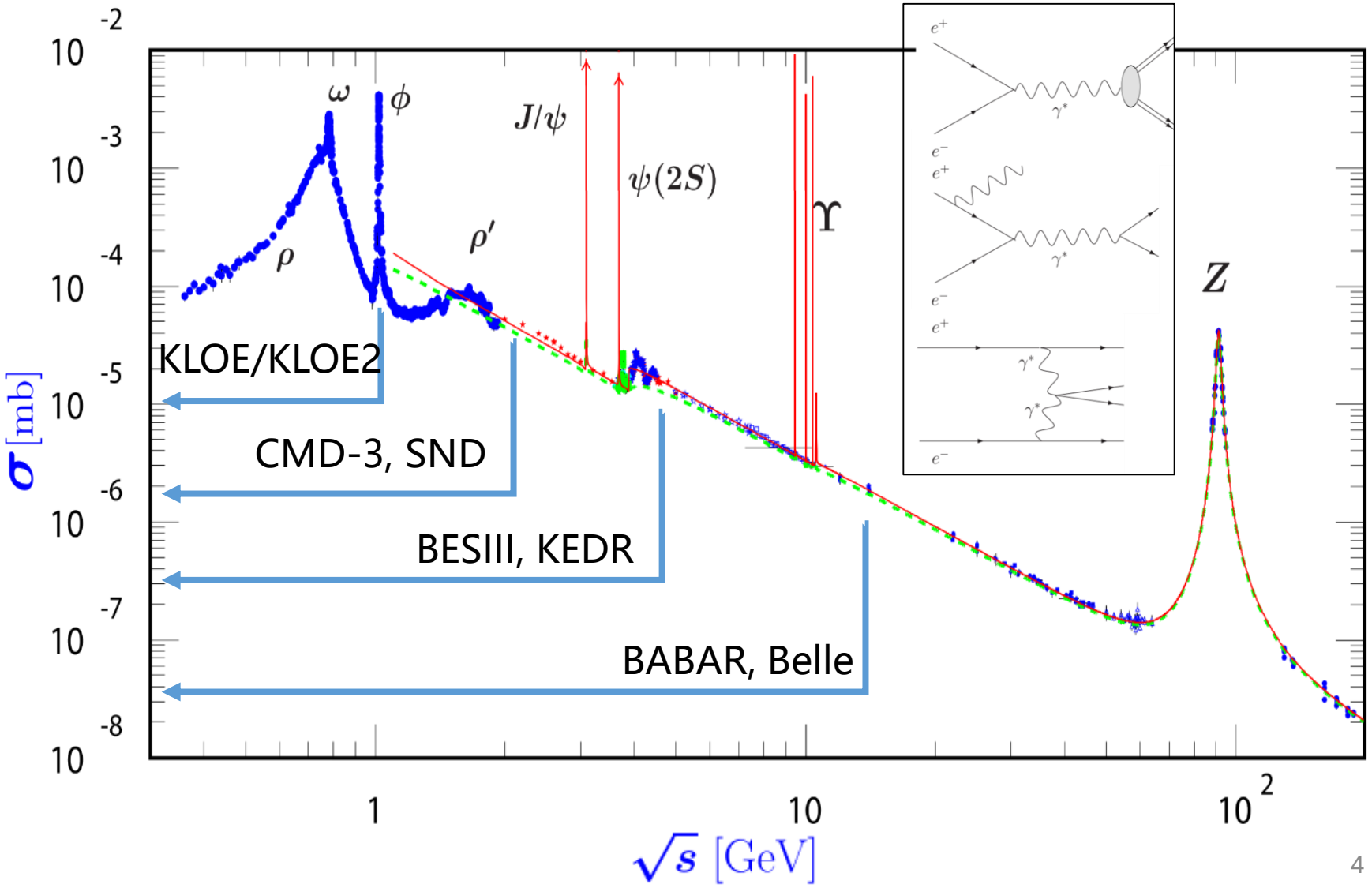
QCD predicts
new forms of hadrons



From Nature Rev.Phys. 1 (2019) no.8, 480

critical for the quantitative understanding of confinement

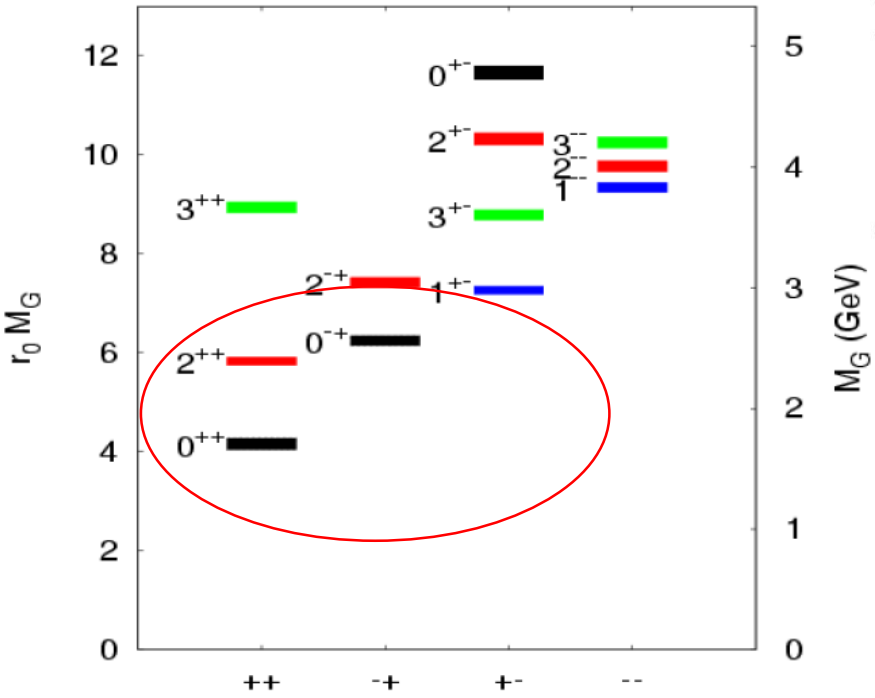
Many sources of data



- Search for glueballs

Glueball

What role do gluonic excitations play in the spectroscopy of light mesons, and can they help explain confinement?



Glueballs from Quenched LQCD

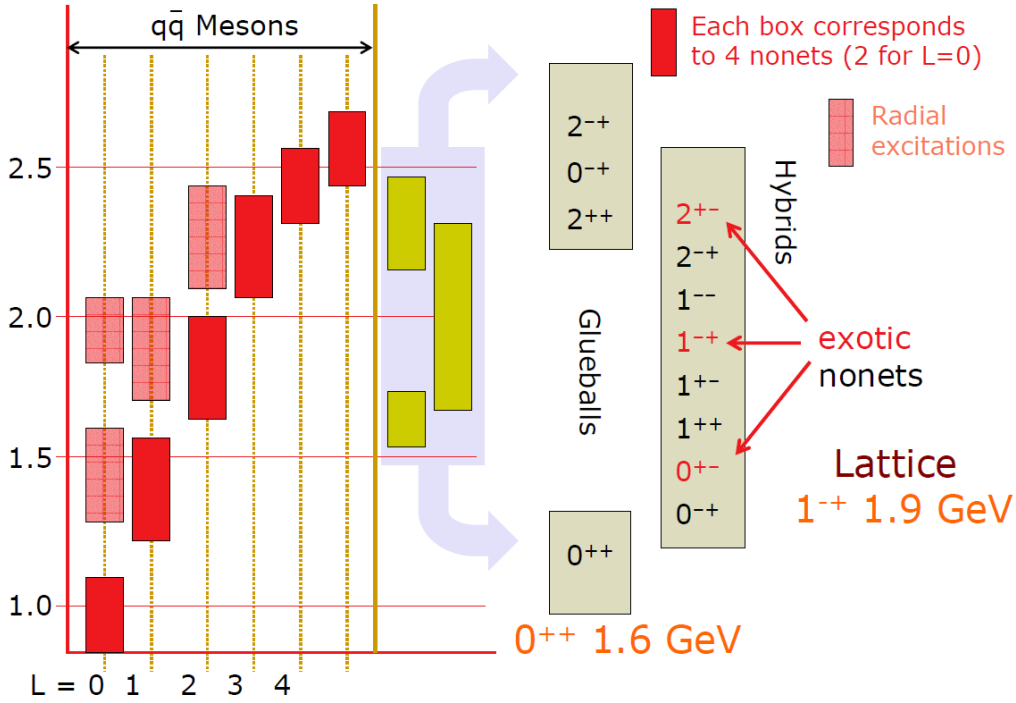
	m_π (MeV)	$m_{0^{++}}$ (MeV)	$m_{2^{++}}$ (MeV)	$m_{0^{-+}}$ (MeV)
$N_f = 2$	938	1417(30)	2363(39)	2573(55)
	650	1498(58)	2384(67)	2585(65)
$N_f = 2+1$ [22]	360	1795(60)	2620(50)	—
quenched [13]	—	1710(50)(80)	2390(30)(120)	2560(35)(120)
quenched [14]	—	1730(50)(80)	2400(25)(120)	2590(40)(130)

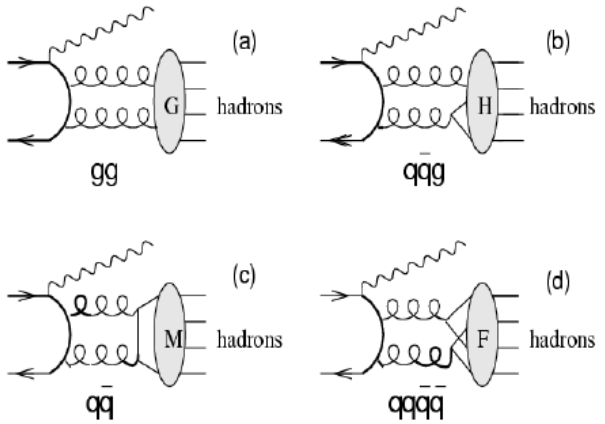
Low lying glueballs with ordinary quantum number →mixing with qqbar mesons

Systematic studies needed

PRD60, 034509; PRD73, 014516;
PRD82, 034501; CPC 42 093103

Systematic study of glueball at BESIII





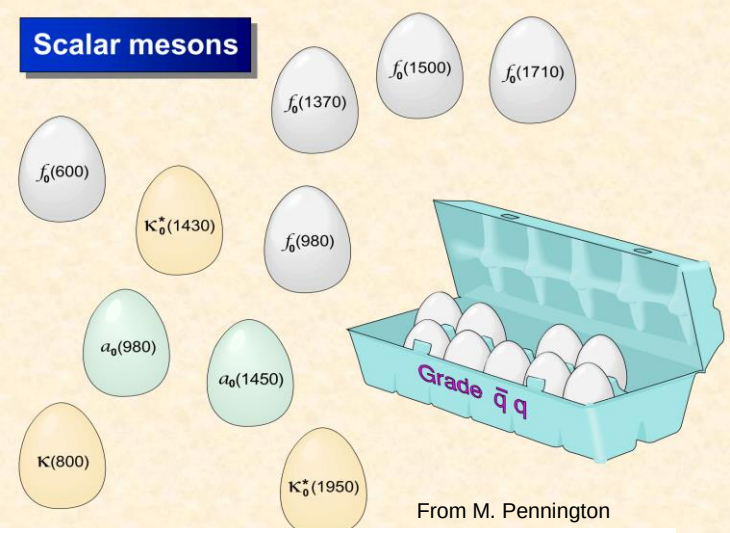
$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$$

$$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$$

Charmonium decays provides an ideal hunting ground for light glueballs

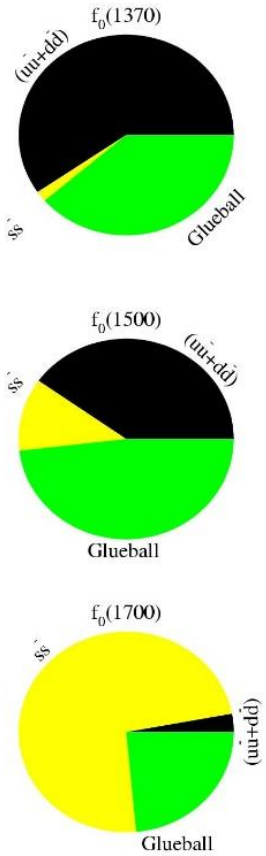
- **"Gluon-rich" process**
- **Clean high statistics data samples from e^+e^- production**
- **$I(J^{PC})$ filter in strong decays of charmonium**

Overpopulated scalar mesons



From M. Pennington

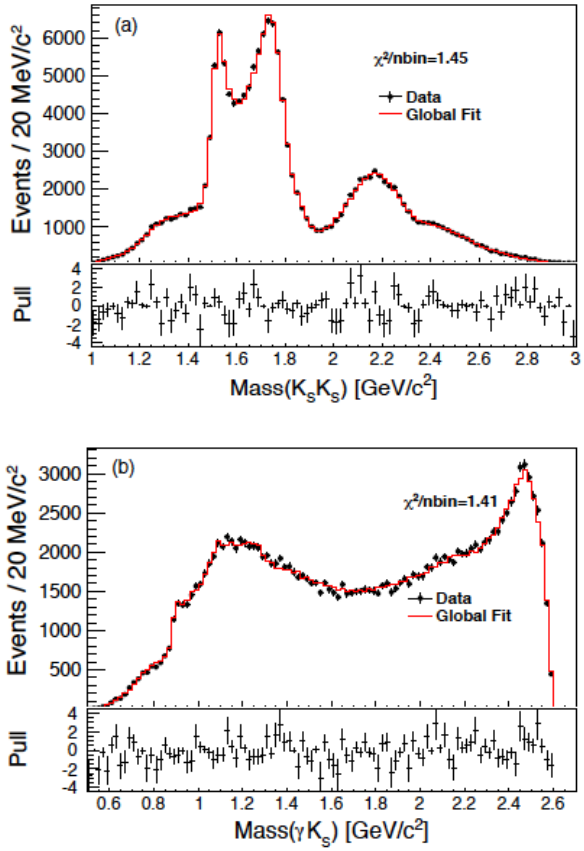
Name	Mass [MeV/c^2]	Width [MeV/c^2]
$f_0(600)$ *	$400-1200$	$600-1000$
$f_0(980)$ *	980 ± 10	$40-100$
$f_0(1370)$ *	$1200-1500$	$200-500$
$f_0(1500)$ *	1507 ± 5	109 ± 7
$f_0(1710)$ *	1718 ± 6	137 ± 8
$f_0(1790)$		
$f_0(2020)$	1992 ± 16	442 ± 60
$f_0(2100)$	2103 ± 7	206 ± 15
$f_0(2200)$	2189 ± 13	238 ± 50



Mixing scheme:
$f_0(1500)$, $f_0(1710)$

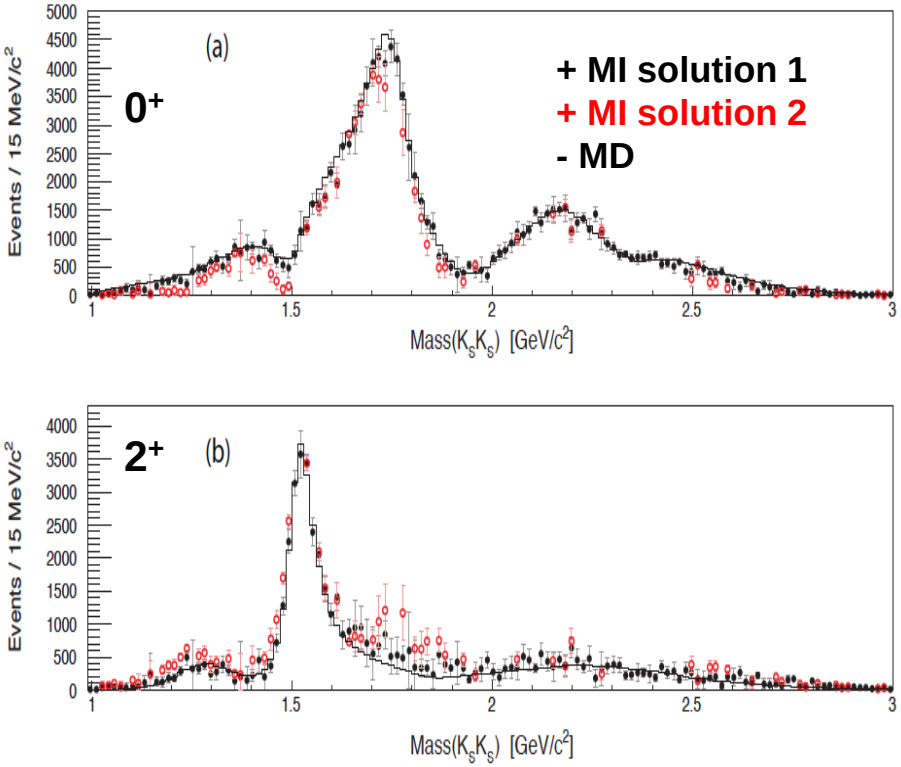
Which one has more gluonic component?

Amplitude analysis of $J/\psi \to \gamma K_S K_S$



BESIII PRD 98 072003 (2018)

MD analysis is well consist with MI analysis

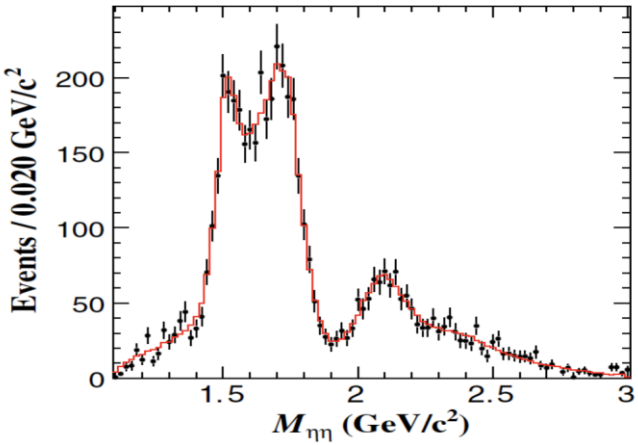


Mass-dependent (MD) analysis using isobar with BW's

Mass-independent(MI) analysis, partial wave decomposition in mass bins

Amplitude analysis of $J/\psi \to \gamma\eta\eta/K_S^0K_S^0$

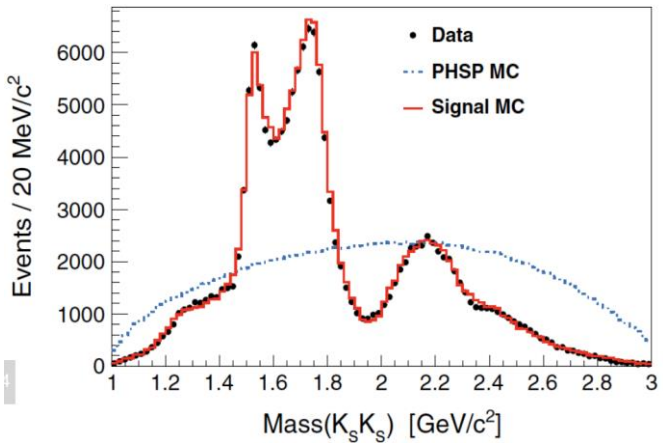
BESIII PRD 87, 092009 (2013)



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}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.15^{\cdots}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

Br of $f_0(1710)$ ~10x larger than $f_0(1500)$

BESIII PRD 98, 072003 (2018)



Resonance	M (MeV/c^2)	$M_{\rm PDG}$ (MeV/c^2)	Γ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV/c^2)	Branching fraction	Significance
$K^*(892)$	896	895.81 ± 0.19	48	47.4 ± 0.6	$(6.28^{+0.16+0.59}_{-0.17-0.52}) \times 10^{-6}$	35σ
$K_1(1270)$	1272	1272 ± 7	90	90 ± 20	$(8.54^{+1.07+2.35}_{-1.20-2.13}) \times 10^{-7}$	16σ
$f_0(1370)$	$1350 \pm 9^{+12}_{-2}$	1200 to 1500	$231 \pm 21^{+28}_{-48}$	200 to 500	$(1.07^{+0.08+0.36}_{-0.07-0.34}) \times 10^{-5}$	25σ
$f_0(1500)$	1505	1504 ± 6	109	109 ± 7	$(1.59^{+0.16+0.18}_{-0.16-0.56}) \times 10^{-5}$	23σ
$f_0(1710)$	$1765 \pm 2^{+1}_{-1}$	1723^{+6}_{-5}	$146 \pm 3^{+7}_{-1}$	139 ± 8	$(2.00^{+0.03+0.31}_{-0.02-0.10}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(1790)$	$1870 \pm 7^{+2}_{-3}$	$\cdots$	$146 \pm 14^{+7}_{-15}$	$\cdots$	$(1.11^{\cdots}_{-0.06-0.32}) \times 10^{-5}$	24σ
$f_0(2200)$	$2184 \pm 5^{+4}_{-2}$	2189 ± 13	$364 \pm 9^{+4}_{-7}$	238 ± 50	$(2.72^{+0.08+0.17}_{-0.06-0.47}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(2330)$	$2411 \pm 10 \pm 7$	$\cdots$	$349 \pm 18^{+23}_{-1}$	$\cdots$	$(4.95^{+0.21+0.66}_{-0.21-0.72}) \times 10^{-5}$	35σ
$f_2(1270)$	1275	1275.5 ± 0.8	185	$186.7^{+2.2}_{-2.5}$	$(2.58^{+0.08+0.59}_{-0.09-0.20}) \times 10^{-5}$	33σ
$f_2'(1525)$	1516 ± 1	1525 ± 5	$75 \pm 1 \pm 1$	73^{+6}_{-5}	$(7.99^{+0.03+0.69}_{-0.04-0.50}) \times 10^{-5}$	$\gg 35\sigma$
$f_2(2340)$	$2233 \pm 34^{+9}_{-25}$	2345^{+50}_{-40}	$507 \pm 37^{+18}_{-21}$	322^{+70}_{-60}	$(5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$	26σ
0^{++} PHSP	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$(1.85^{+0.05+0.68}_{-0.05-0.26}) \times 10^{-5}$	26σ
2^{++} PHSP	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$(5.73^{+0.99+4.18}_{-1.00-3.74}) \times 10^{-5}$	13σ

Scalar glueball candidate?

Flavor-blindness of glueball decays

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha\frac{|p|}{M^2_{J/\psi}}|E_1(0)|^2 = 0.35(8)keV$$
$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9) \times 10^{-3}$$

CLQCD, Phys. Rev. Lett. 110, 021601 (2013)

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta : \eta\eta' : \eta'\eta') = 3 : 4 : 1 : 0 : 1$$

*with chiral suppression

PRL 98 149103

$$\Gamma(G \to \pi\pi)/\Gamma(G \to K\bar{K}) \approx \frac{f_\pi^4}{f_K^4} \approx 0.48$$

Experimental results

- $B(J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K}) = (8.5^{+1.2}_{-0.9}) \times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi) = (4.0 \pm 1.0) \times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega) = (3.1 \pm 1.0) \times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta) = (2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$

$$\Rightarrow B(J/\psi \to \gamma f_0(1710)) > 1.7 \times 10^{-3}$$

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta) \approx 1.3 : 3.16 : 1$$

$f_0(1710)$ largely overlapped with scalar glueball?

Other information

Two photon couplings

"Stickness"

PDG2018

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018)

$f_0(1710)$ Γ(i)Γ($\gamma\gamma$)/Γ(total)

Γ($K\overline{K}$) × Γ($\gamma\gamma$)/Γ_{total} **$\Gamma_1\Gamma_4/\Gamma$**

VALUE (eV)	CL%	DOCUMENT ID		TECN	COMMENT
$12^{+3}_{-2}{}^{+227}_{-8}$		UEHARA	13	BELL	$\gamma\gamma \to K^0_S K^0_S$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<480	95	ALBRECHT	90G	ARG	$\gamma\gamma \to K^+K^-$
<110	95	[1] BEHREND	89C	CELL	$\gamma\gamma \to K^0_S K^0_S$
<280	95	[1] ALTHOFF	85B	TASS	$\gamma\gamma \to K\overline{K}\pi$

However, a scalar in $\gamma\gamma \to \pi^0\pi^0$

Belle PRD 78 052004

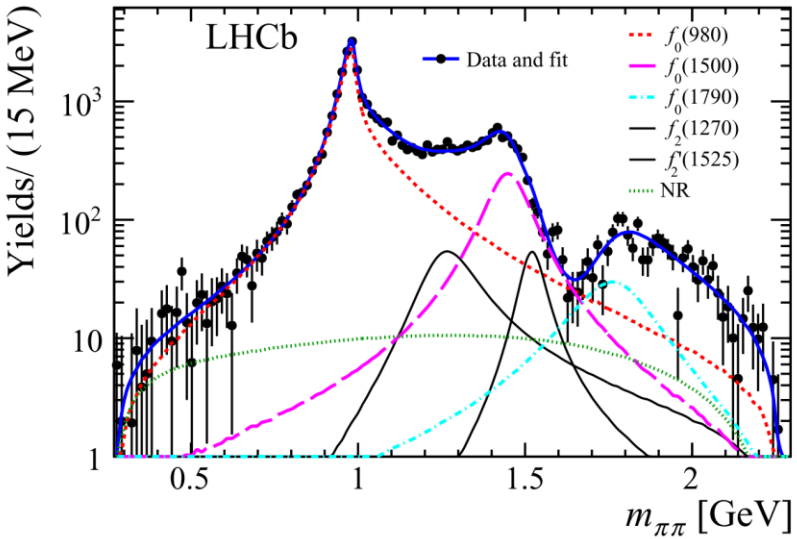
TABLE VI: Fitted parameters of the $f_0(Y)$

Parameter	Belle($\pi^0\pi^0$)	Crystal Ball	$f_0(1370)$(PDG)	$f_0(1500)$(PDG)	Unit
Mass	$1470\ ^{+6}_{-7}\ ^{+72}_{-255}$	1250	1200 - 1500	1507 ± 5	MeV/c^2
Γ_{tot}	$90\ ^{+2}_{-1}\ ^{+50}_{-22}$	268 ± 70	150 - 200	109 ± 7	MeV
$\Gamma_{\gamma\gamma}\mathcal{B}(\pi^0\pi^0)$	$11\ ^{+4}_{-2}\ ^{+603}_{-7}$	430 ± 80	Unknown	Not seen	eV

$f_0(1370)$? $f_0(1500)$?

$B_s \to J/\psi f_0$
is selective for $s\bar{s}$

PLB 797 (2019) 134789



observation of $f_0(1500)$,
non-observation of $f_0(1710)$

Assignment requires further study with more sophisticated model

Tensor glueball candidate?

$$\Gamma(J/\psi \to \gamma G_{2^+}) = 1.01(22) keV$$
$$\Gamma(J/\psi \to \gamma G_{2^+})/\Gamma_{tot} = 1.1 \times 10^{-2}$$

CLQCD, Phys. Rev. Lett. 111, 091601 (2013)

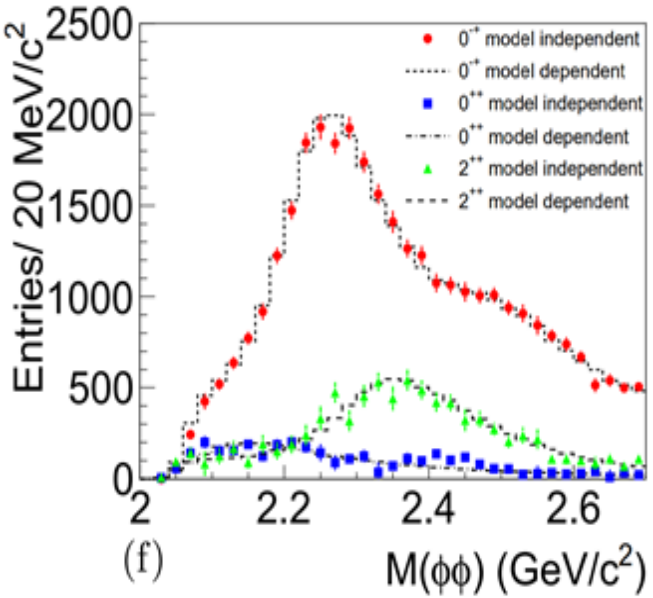
Experimental results

$$Br(J/\psi \to \gamma f_2(2340) \to \gamma\eta\eta) = (3.8^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$$
Phys.Rev. D87, 092009 (2013)

$$Br(J/\psi \to f_2(2340) \to \gamma\phi\phi) = (1.91 \pm 0.14^{+0.72}_{-0.73}) \times 10^{-4}$$
Phys.Rev. D93, 112011 (2016)

$$Br(J/\psi \to \gamma f_2(2340) \to \gamma K_S K_S) = (5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$$
Phys.Rev. D98, 072003 (2018)

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



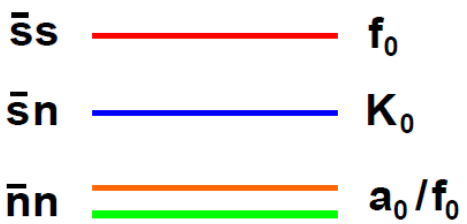
$f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in π^-p reactions are observed with a strong production of $f_2(2340)$

It is desirable to search for more decay modes

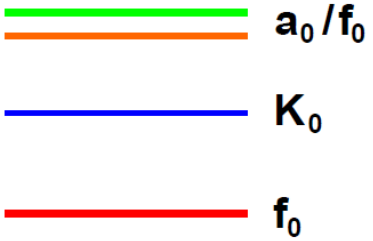
- Search for glueballs
- Scalars near $K\bar{K}$ threshold
  - $a_0(980) - f_0(980)$ mixing

$a_0(980) - f_0(980)$ mixing

- The nature of ground state scalar $\mathrm{a_0(980)}$ and $\mathrm{f_0(980)}$ are controversial



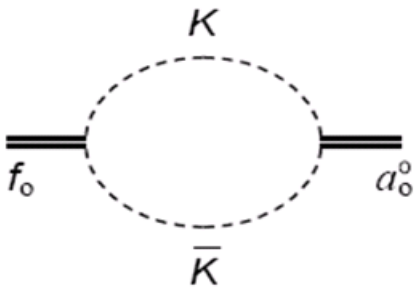
Quark model

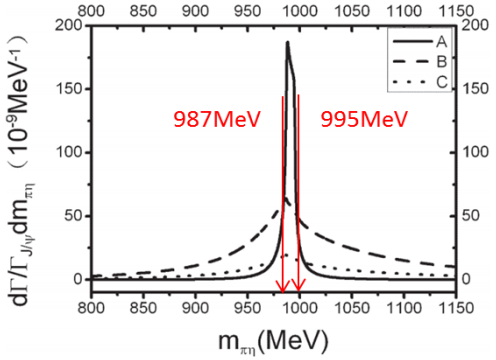


Experimental data

$\mathrm{q\bar{q}}$ mesons, $\mathrm{K\bar{K}}$ molecules, tetraquarks, hybrids,…?

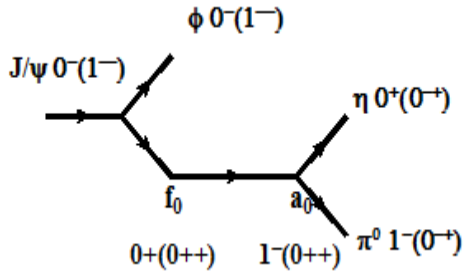
- $a_0(980) - f_0(980)$ mixing (proposed in 1979) is very sensitive to $\mathrm{K\bar{K}}$ coupling, which is an important probe to the internal structure of $\mathrm{a_0(980)}$ and $\mathrm{f_0(980)}$



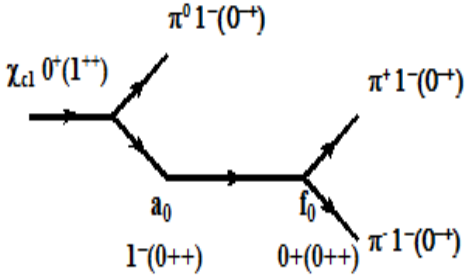


$a_0(980) - f_0(980)$ mixing

- Using isospin violating decays of charmonia



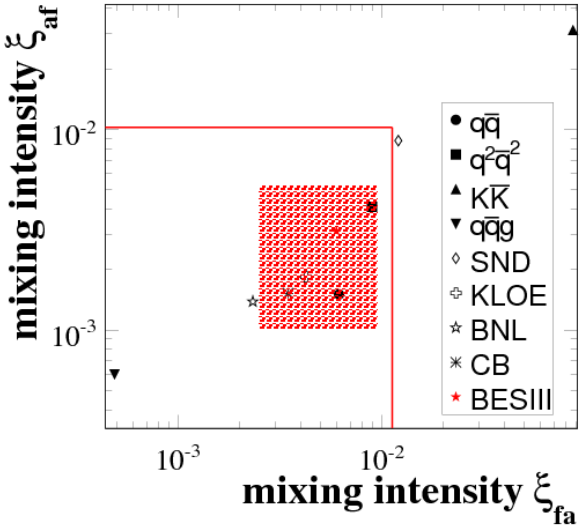
PR D75 114012,
PR D76 074028



PR D78 074017

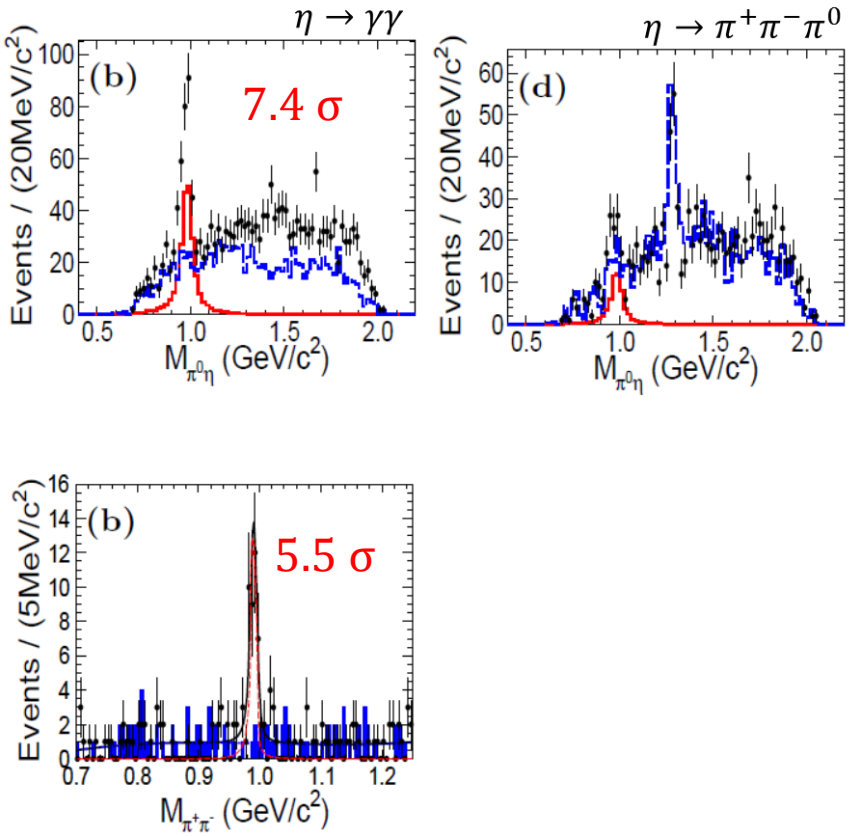
- Upper limit of mixing intensity using 2009 data sets

BESIII PR D83 032003

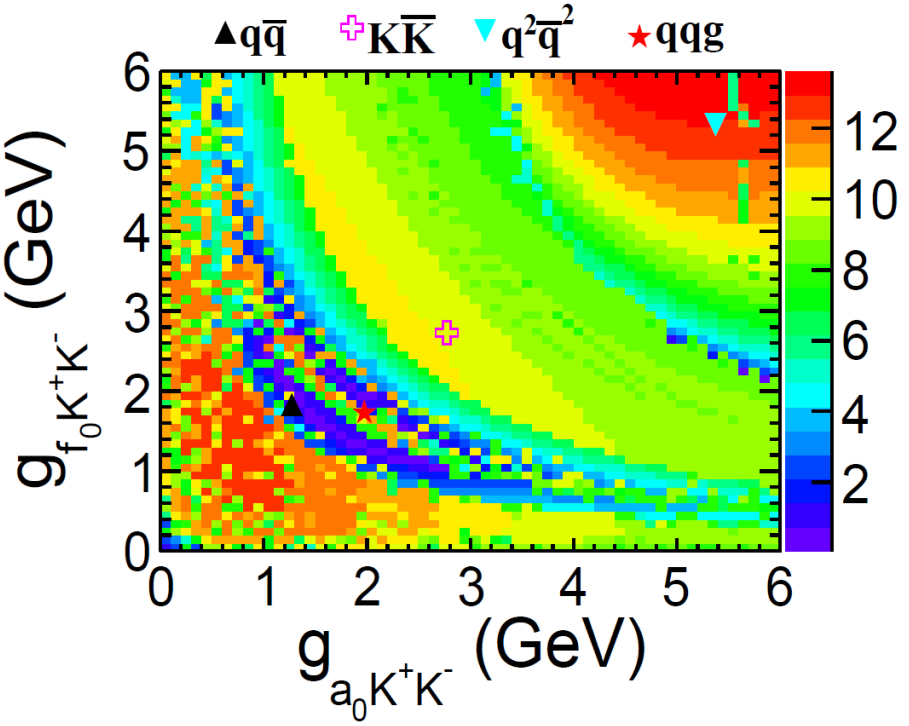


$a_0(980) - f_0(980)$ mixing

- First direct measurement with > 5σ , using high stat. data sets



BESIII PRL 121 022001



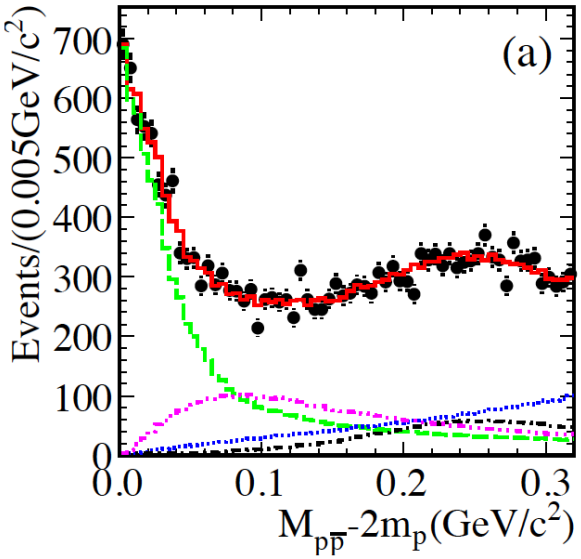
Significance of $a_0 - f_0$ mixing signal VS. coupling of $a_0(f_0) \to K\bar{K}$, compared with model predictions of $q\bar{q}$, $K\bar{K}$ molecules, tetraquarks, hybrids

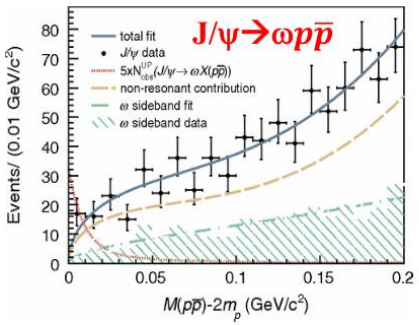
- Search for glueballs
- Scalars near $K\bar{K}$ threshold
  - $a_0(980) - f_0(980)$ mixing
- Structures near $N\bar{N}$ threshold
  - X($p\bar{p}$) and X(1835)

$p\bar{p}$ threshold enhancement X($p\bar{p}$)

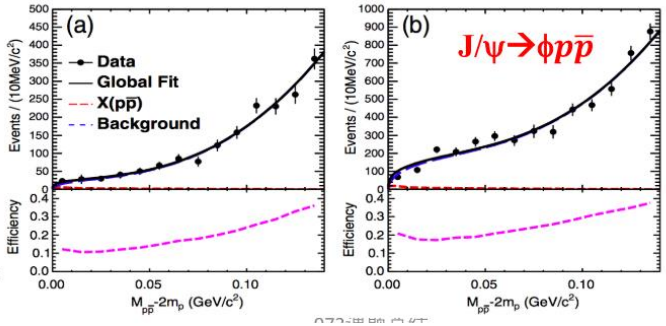
- First observed in $J/\psi \to \gamma p\bar{p}$ at BESII, confirmed by BESIII and CLEO-c
- PWA of $J/\psi \to \gamma p\bar{p}$: $J^{PC} = 0^{-+}$
  - The fit with a BW and S-wave FSI (I=0) factor can well describe $p\bar{p}$ mass threshold structure
- Non-observation in hadronic decays: not from pure FSI

PRL 108 112003

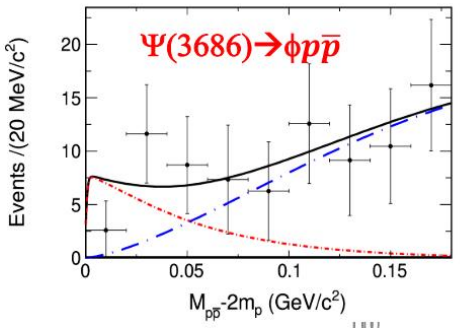




PR D87 112014



PR D93 052010



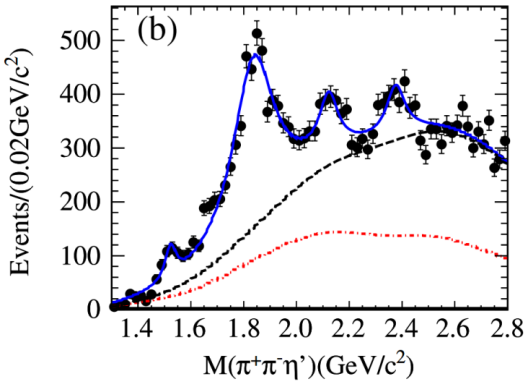
PR D99 112010

X(1835)

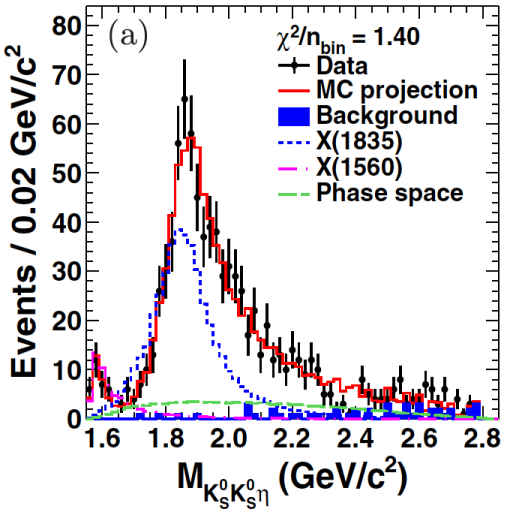
- Observed by BESII in $J/\psi \to \gamma\eta'\pi^+\pi^-$, confirmed at BESIII

- PWA of $J/\psi \to \gamma K_s K_s \eta$
  - X(1835)$\to K_S K_S \eta$ is observed (the $K_S K_S$ system is dominantly produced through the $f_0(980)$)
  - $J^{PC}=0^{-+}$

PRL 106 072002



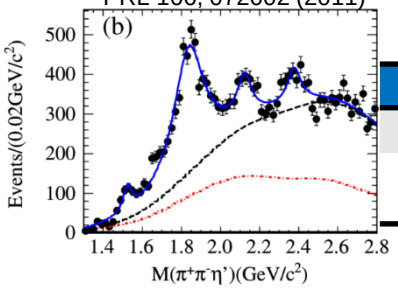
PRL 115 091803



Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold: connection between X(1835) and X($p\bar{p}$)

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

PRL 106, 072002 (2011)



X(1835) $J^{PC}=0^{-+}$

$M = 1844 \pm 9^{+16}_{-25}$ MeV/c^2

$\Gamma = 192^{+20+62}_{-17-43}$ MeV/c^2

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

PRL 108, 112003 (2012)

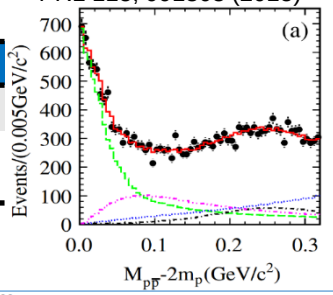
PRL 115, 091803 (2015)

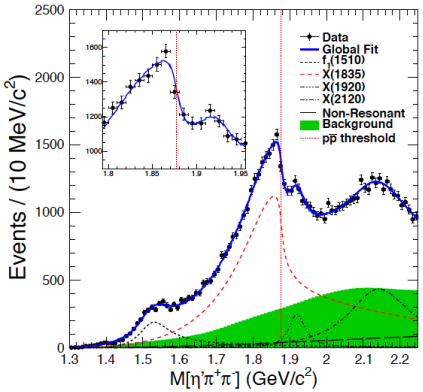
X($p\bar{p}$) $J^{PC}=0^{-+}$

$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/c^2

$\Gamma = 13 \pm 19$ MeV/c^2

(< 76 MeV/c^2 @ 90% C.L.)



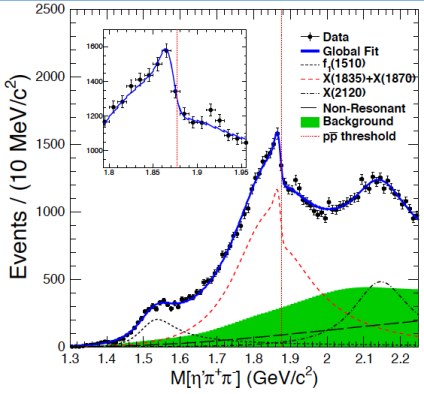


Connection is emerging

PRL 117, 042002 (2016)

Model 1:
Flatte lineshape with strong coupling to $p\bar{p}$ and one additional, narrow Breit-Wigner at ~1920 MeV/c^2

Model 2:
Coherent sum of X(1835) Breit-Wigner and one additional, narrow Breit-Wigner at ~1870 MeV/c^2



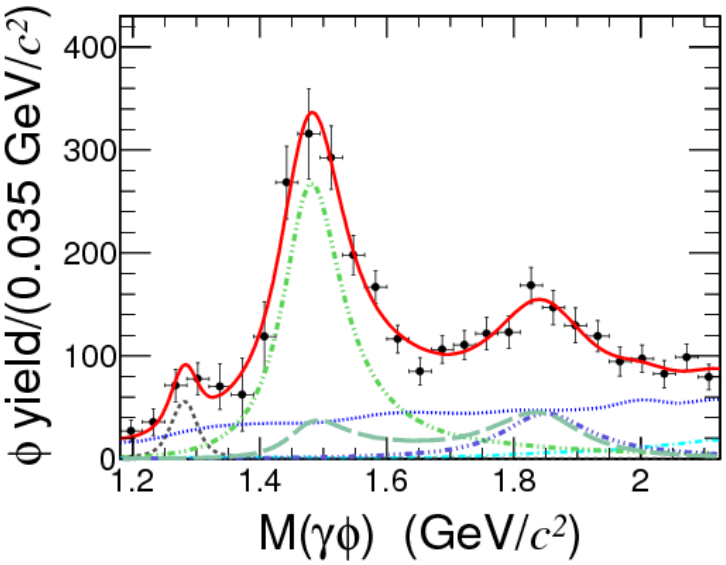
The anomalous line shape can be modeled two models with equally good fit quality

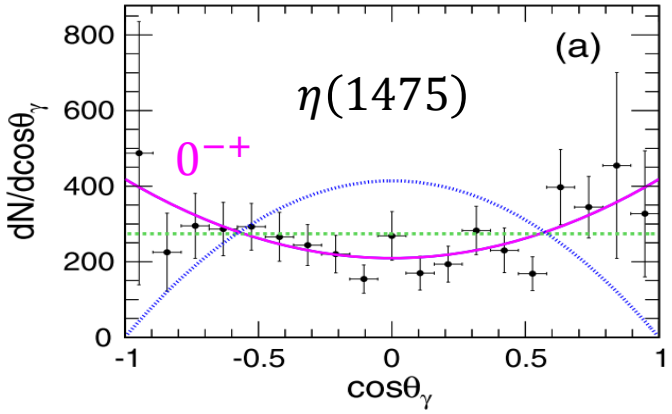
- **Suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold**
- **Support the existence of a $p\bar{p}$ molecule-like state or bound state**

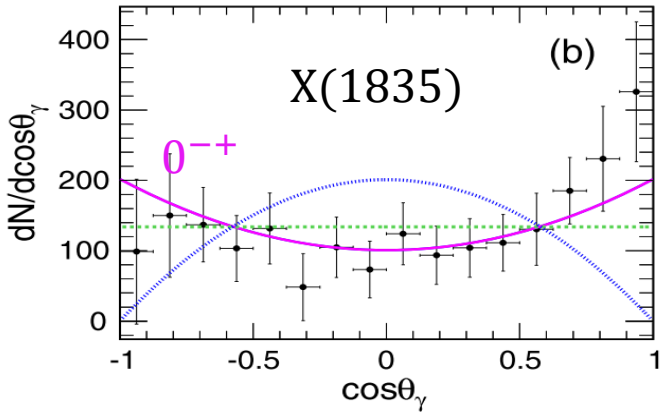
Observation of $\eta(1475)$ and X(1835) in $J/\psi \to \gamma\gamma\phi$

BESIII PRD 97 051101

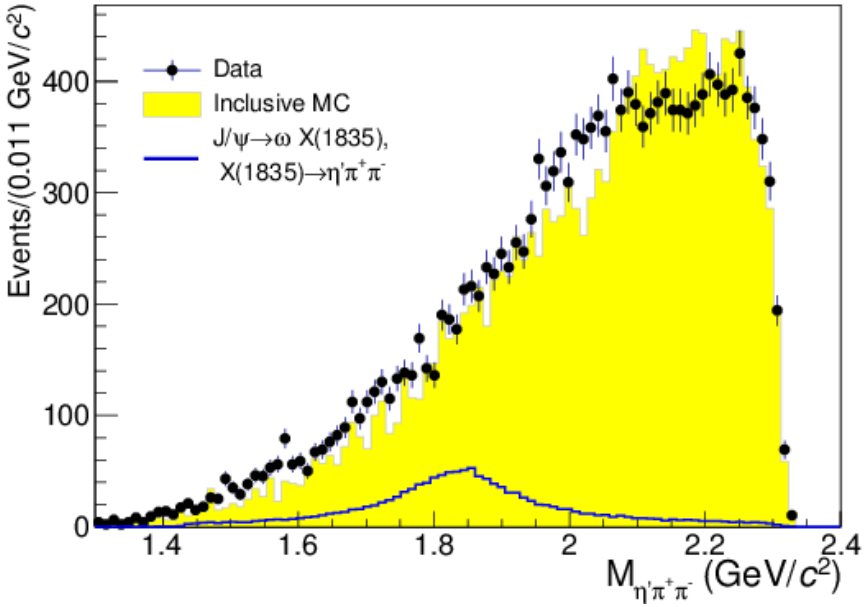
- Flavor filter: sizeable $s\bar{s}$ component







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

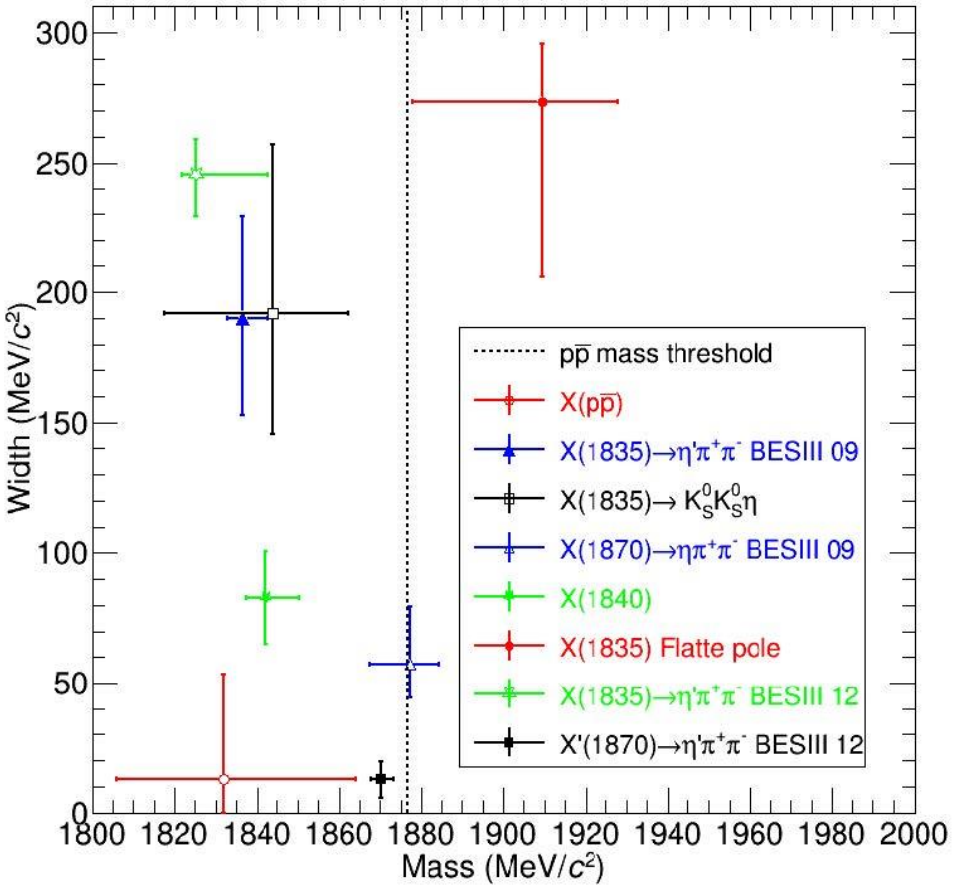


No obvious signal of X(1835) is found.

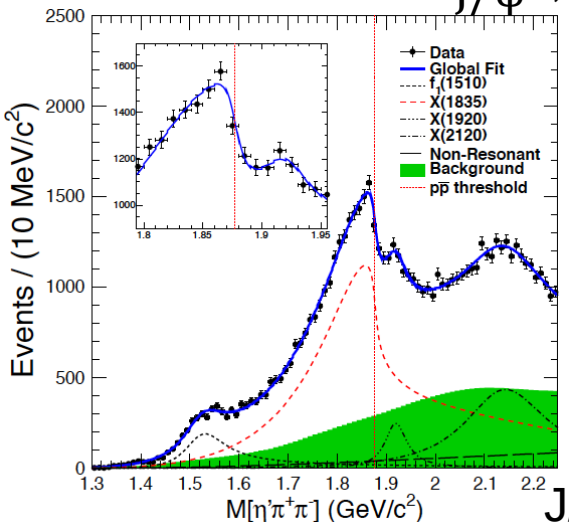
Upper limit on the branching fraction at 90% C. L.,

$B(J/\psi \to \omega X(1835) \to \omega \pi^+ \pi^- \eta') < 6.2 \times 10^{-5}$

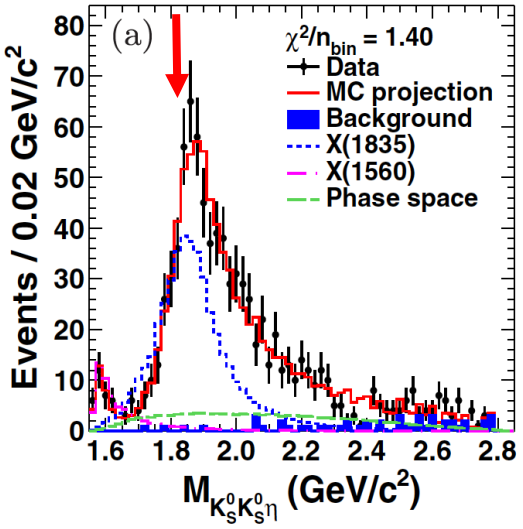
Structures around $p\bar{p}$ threshold



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



$J/\psi \to \gamma K_S K_S \eta$



Threshold effect via $J/\psi \to \gamma N\bar{N} \to \gamma\eta'\pi\pi$?

PRD 98 014005

→

Why not appear in $J/\psi \to \gamma K_S K_S \eta$? Check consistency with $p\bar{p}$ cross sections

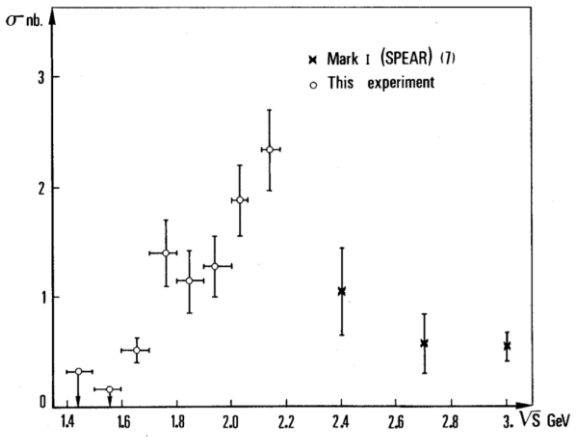
Fine study of lineshape in other channels is needed

- Search for glueballs
- Scalars near $K\bar{K}$ threshold
  - $a_0(980) - f_0(980)$ mixing
- Structures near $N\bar{N}$ threshold
  - X($p\bar{p}$) and X(1835)
  - e^+e^- cross sections

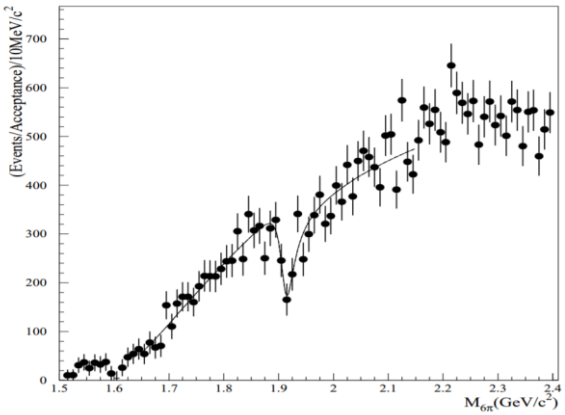
A dip in the six-pion cross sections

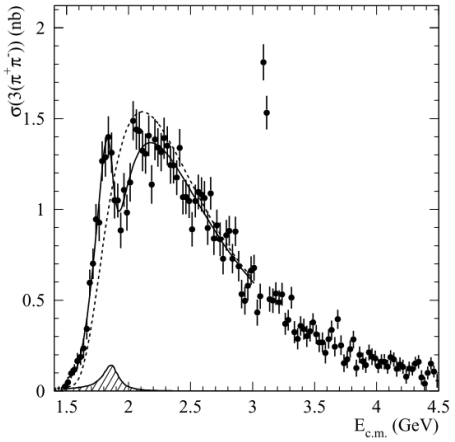
BABAR PRD 73 052003

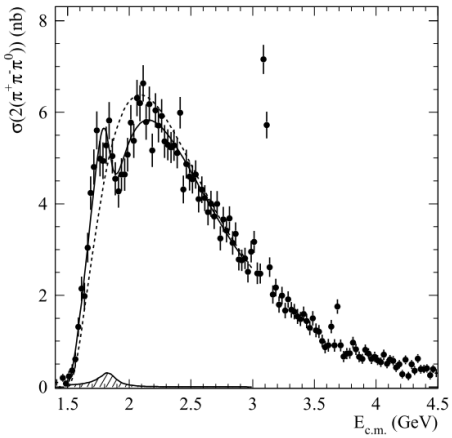
DM2 PLB 107 145



FOCUS PLB 514 240

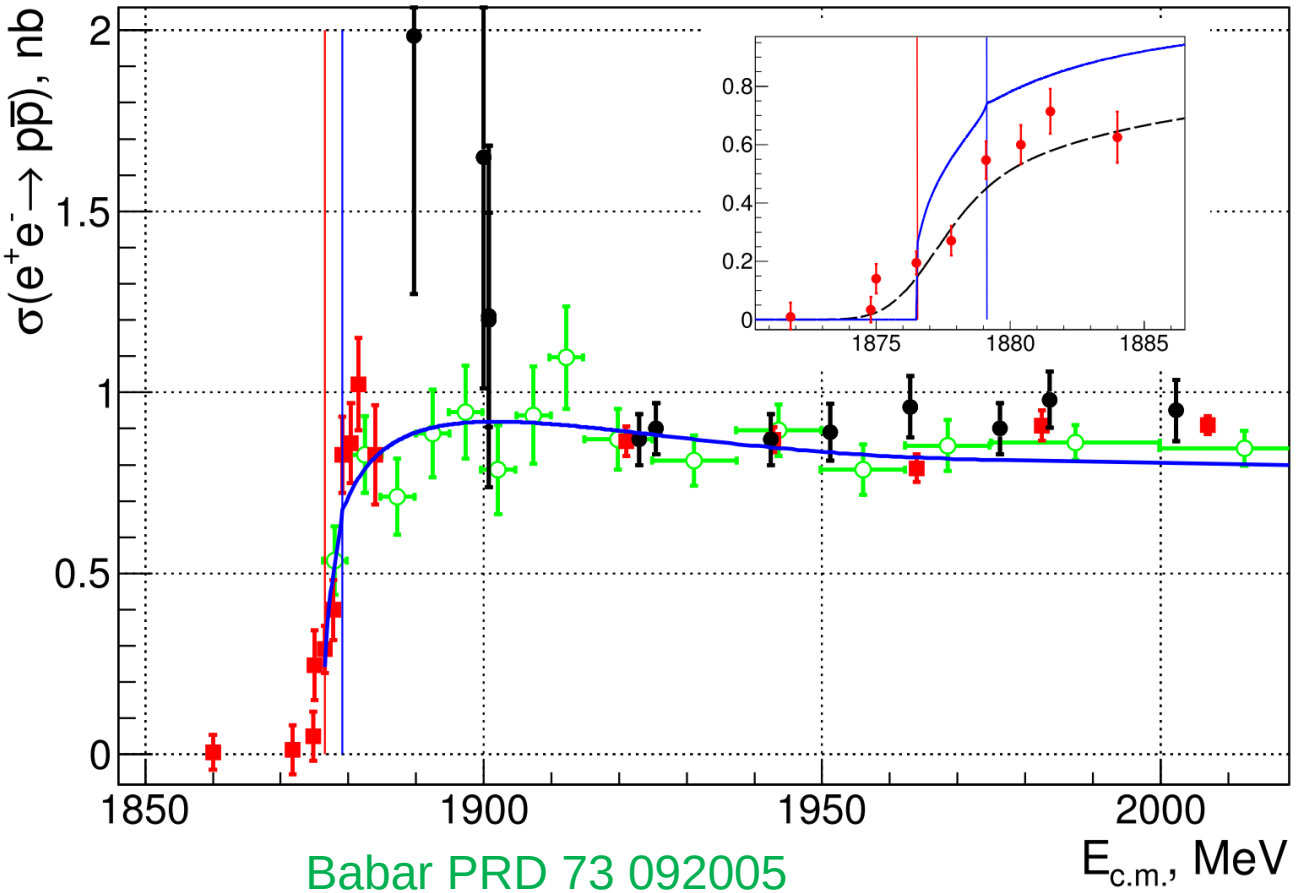






A resonance? e.g. ρ(1900)

Cross section of $e^+e^- \to p\bar{p}$



Babar PRD 73 092005

CMD-3 PLB 759 634

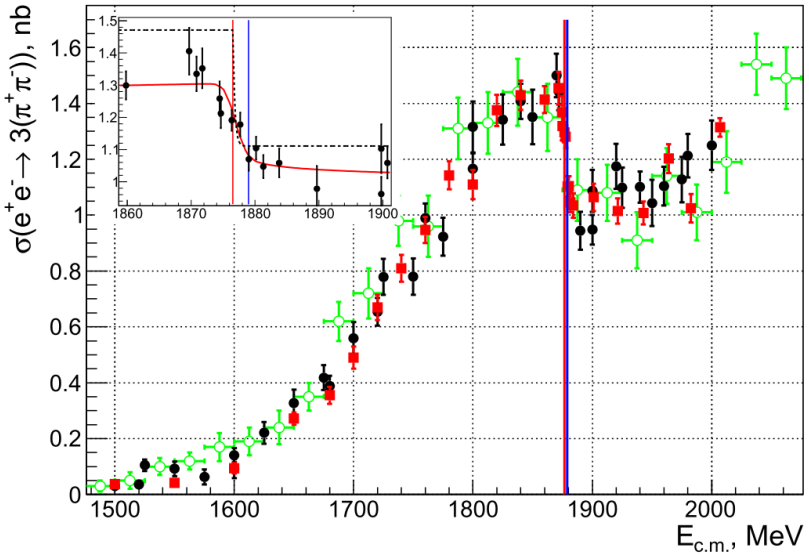
CMD-3 PLB 794 64

Cross sections of e^+e^- →multi hadrons

Babar PRD 73 052003

CMD-3 PLB 723 82

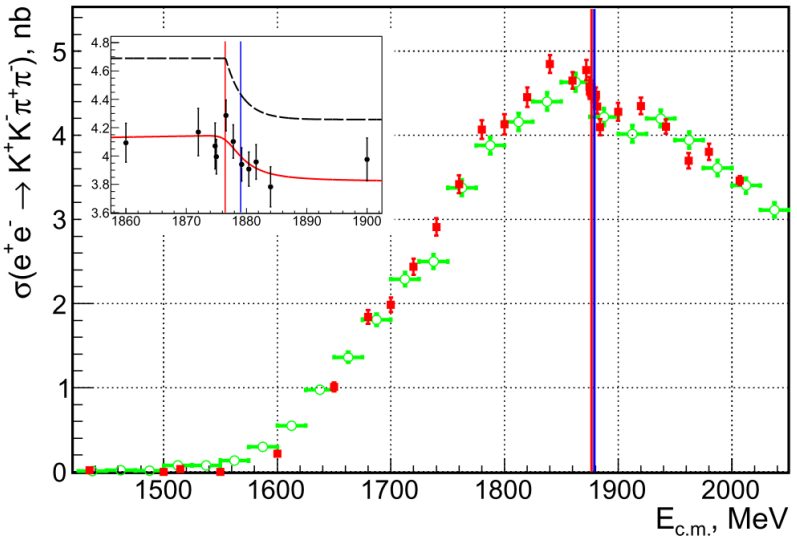
CMD-3 PLB 794 64



$e^+e^- \to 3(\pi^+\pi^-)$

Babar PRD 76 072008

CMD-3 PLB 794 64



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

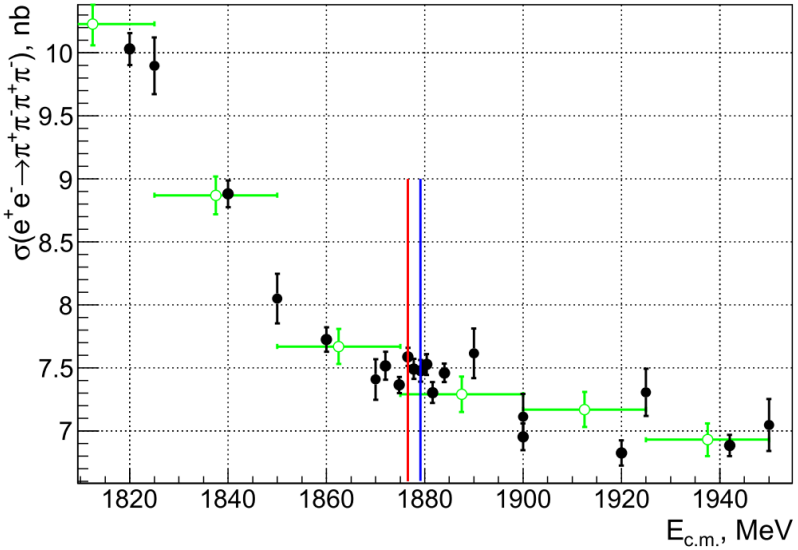
Too narrow to be a ρ resonance (~1 MeV)

Can be described via optical $N\bar{N}$ potentials

Non-observations

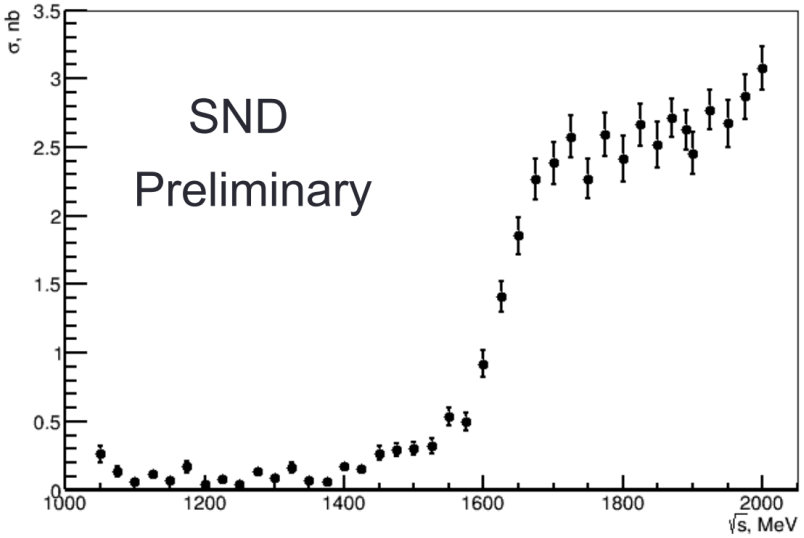
$e^+e^- \to 2(\pi^+\pi^-)$

CMD-3 PLB 794 64



$e^+e^- \to \pi^+\pi^- 4\pi^0$

E. Solodov@Moriond 2019



Cross section of $p\bar{p}$ anhilation : $4\pi > 6\pi \gg KK\pi\pi$

Why no structure in $e^+e^- \to 2(\pi^+\pi^-)$, but effect in $e^+e^- \to K^+K^-\pi^+\pi^-$ is at the same level as for 6π?

- Search for glueballs
- Scalars near $K\bar{K}$ threshold
  - $a_0(980) - f_0(980)$ mixing
- Structures near $N\bar{N}$ threshold
  - X($p\bar{p}$) and X(1835)
  - e^+e^- cross sections
- $\phi(2170)$

$\phi(2170)$

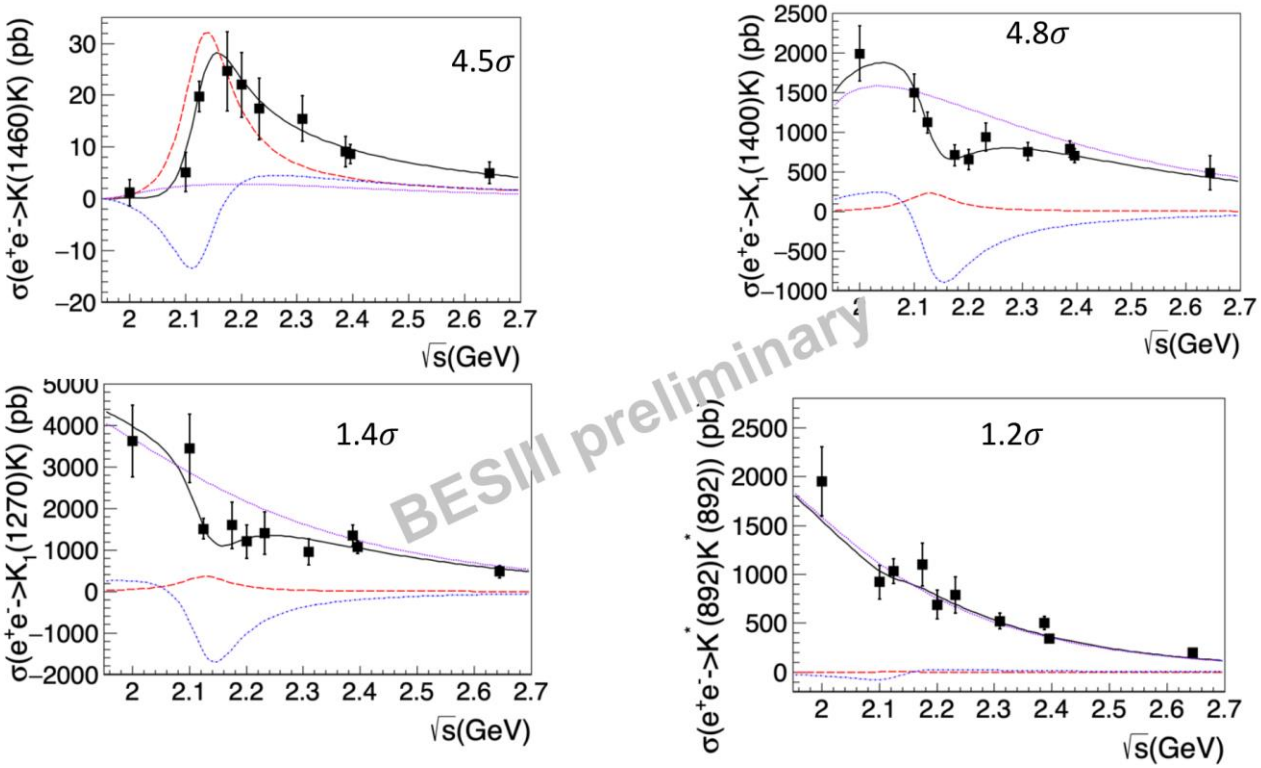
- Observed by Babar in $e^+e^- \to \gamma_{ISR}\phi f_0(980)$, confirmed by BESII and Belle
- Many interpretations
  - $s\bar{s}g$ hybrid
  - 3^3S_1 or 2^3D_1 strangeonium
  - Tetraquark
  - Molecular of $\Lambda\bar{\Lambda}$
  - $\phi f_0(980)$ resonance with FSI
  - Three body system of ϕKK

$e^+e^- \to K^+K^-\pi^0\pi^0$ at BESIII

- $\phi(2170) \to KK\pi\pi$ has good discriminate power to several models
  - $K^*(892)K^*(892)$: $s\bar{s}g$ (forbidden), 3^3S_1(favored)
  - $KK_1(1400)$: $s\bar{s}g$ (favored)
  - $KK\,(1460)$: $s\bar{s}g$ (forbidden), 2^3D_1(favored)

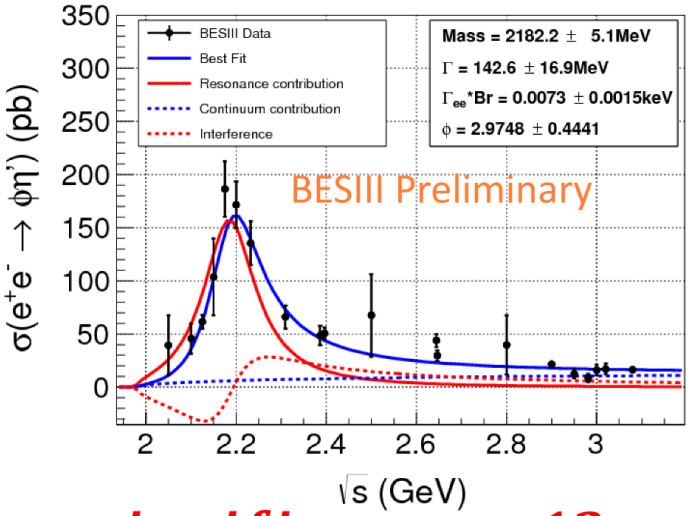
- Amplitude analysis has been performed to extract intermedia resonances

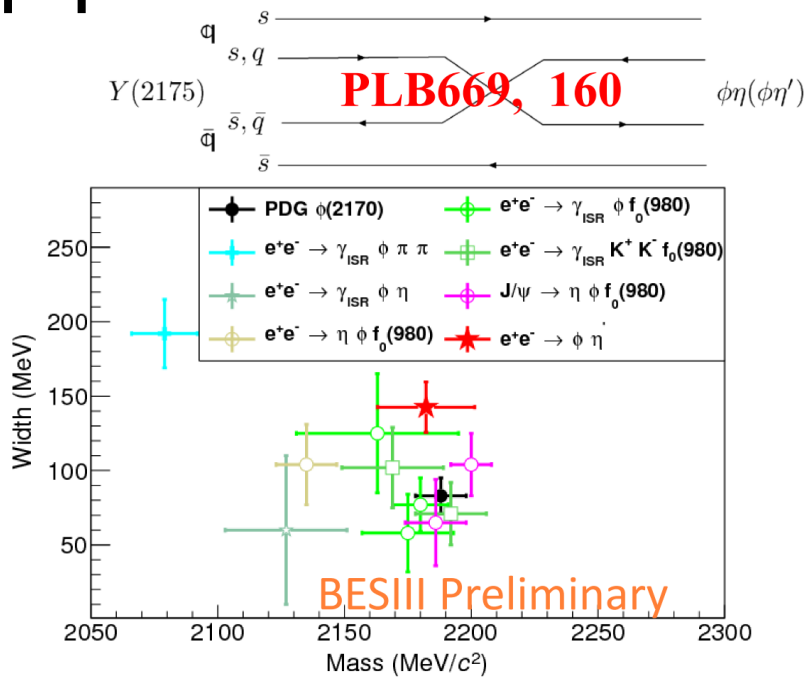
$e^+e^- \to K^+K^-\pi^0\pi^0$ at BESIII



- M = (2127 ± 17 ±12) MeV/c^2 and Γ = (107 ± 32 ±28) MeV
- Non-observation in $K^*(892)K^*(892)$: deviates from the prediction of 3^3S_1 $s\bar{s}$
- Observation in $KK(1460)$: inconsistent with the prediction of hybrid interpretation

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





***significance* > 12σ**

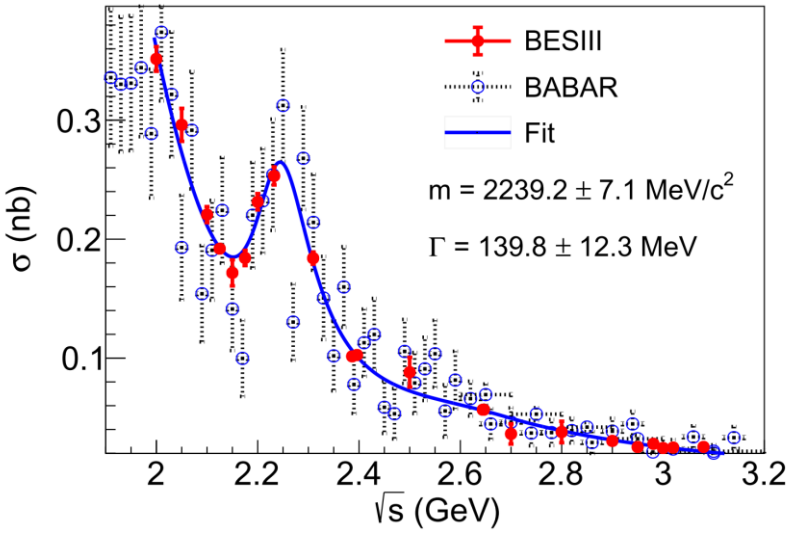
$$\frac{\Gamma_{ee} \cdot Br^{\phi\eta}}{\Gamma_{ee} \cdot Br^{\phi\eta'}} = \frac{1.7 \pm 0.7^*}{7.3 \pm 1.5} = 0.23 \pm 0.11$$

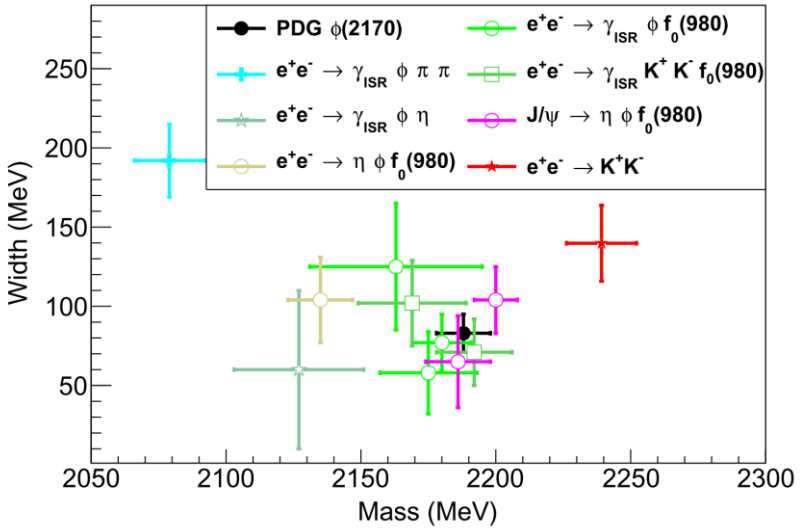
* Babar PRD 77 092002

Decay modes	$2^3D_1\ s\bar{s}$		$1^{--}\ s\bar{s}g$	$3^3S_1\ s\bar{s}$
Γ(MeV)	$^3P_0$ model	Flux tube	Flux tube	$^3P_0$ model
ϕη	0	0	1.2	21
ϕη'	2.9	2.8	0.4	11
Ratio(ϕη/ϕη')	0.0	0.0	3.0	2.0

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

BESIII PRD 99 032001

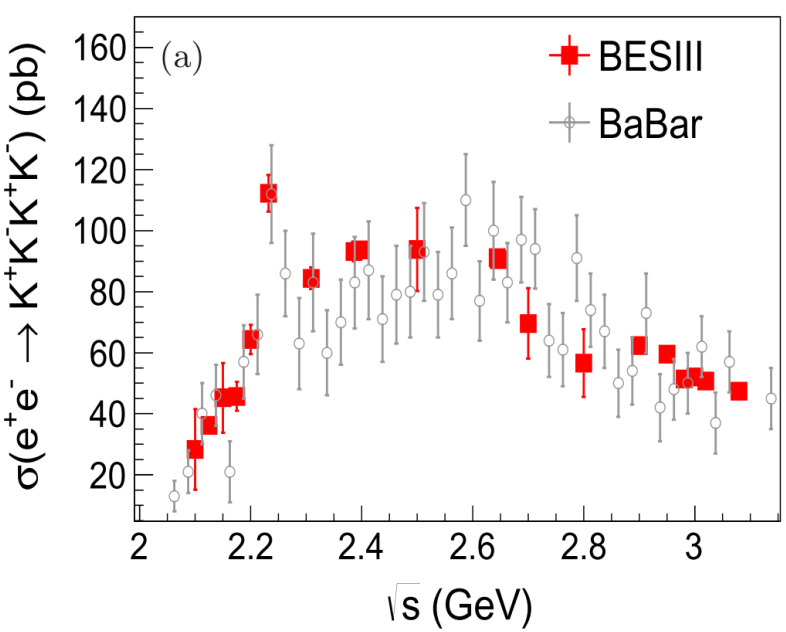


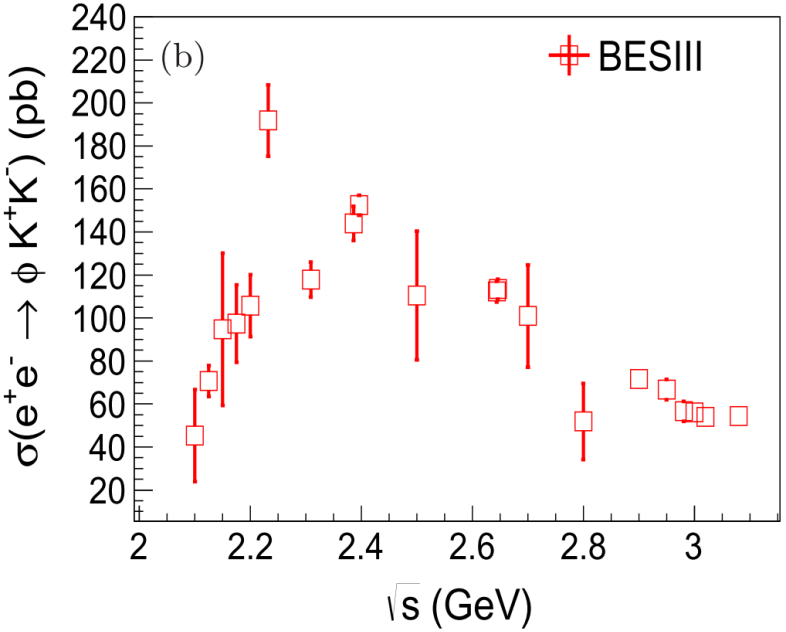


Mass (width) is different from the PDG values for $\phi(2170)$ or $\rho(2150)$ by 3(2)σ

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

BESIII arXiv:1907.06015





- Enhancement observed at $\sqrt{s} = 2.232$ GeV

Summary

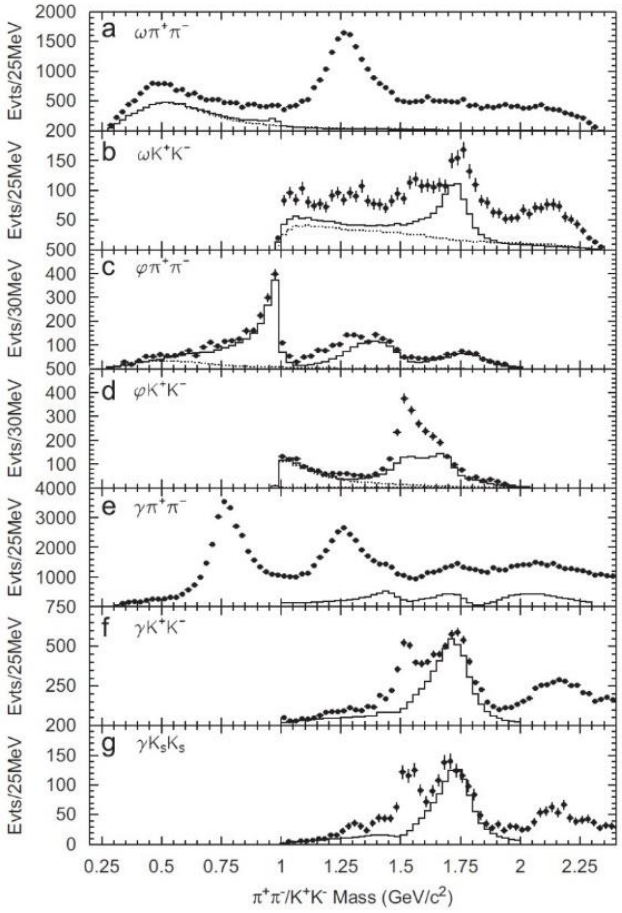
- Data from e^+e^- machines with unprecedented statistical accuracy provides great opportunities to map out light meson spectroscopy and study QCD exotics
  - Advantages: low background; clearly defined initial and final state
  - BESIII collected 10 billions of J/ψ and will continue to run for more years; BelleII started data taking; CMD-3,SND are running
- Many new results bring answers and new questions

Thank you

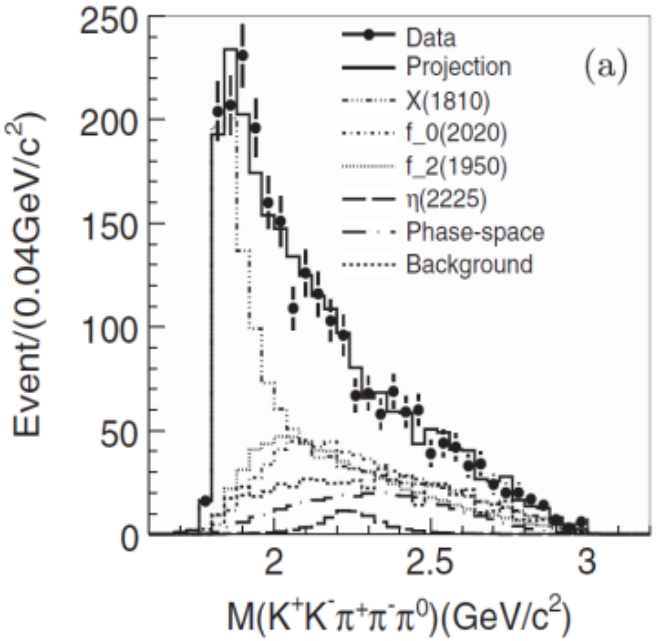
Nearby resonances around $f_0(1710)$

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

$f_0(1710)$ /$f_0(1790)$



BESIII PRD 87, 032008(2013)

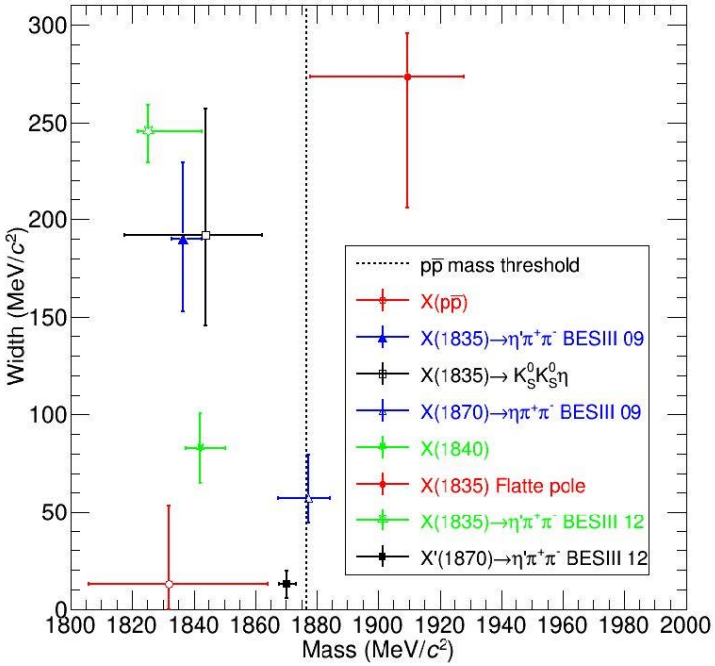


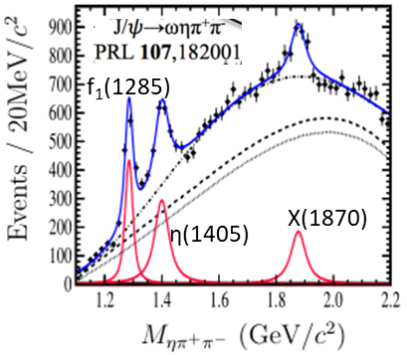
Scalar

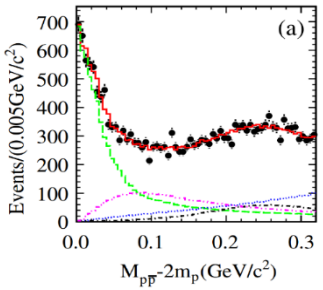
M= $1795\pm7^{+13}_{-5}\pm19$(model) MeV/c^2,

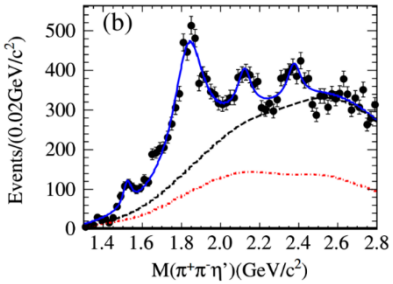
$\Gamma = 95\pm10^{+21}_{-34}\pm75$(model) MeV

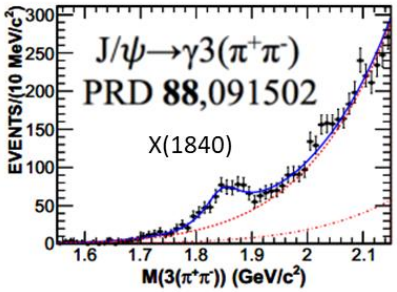
Structures around $p\bar{p}$ threshold











- **Any relations?**
- **What is the role of the $p\bar{p}$ threshold?**
- **Patterns in the production and decay modes**