Light hadron spectroscopy at BESIII

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- $X(p\bar{p}), X(1835)$,X(2370), X(2120) [$\eta(1440)$]
- Search for a strangeonium-like state Zs
- Observation of $a_0(980)$-$f_0(980)$ Mixing
- Amplitude analysis: $J/\psi \to \gamma K_s K_s$
- (Exclusive cross section $e^+e^- \to hadrons$ and polarization in $B\bar{B}$)

$J/\psi \to \gamma K\bar{K}\eta'$

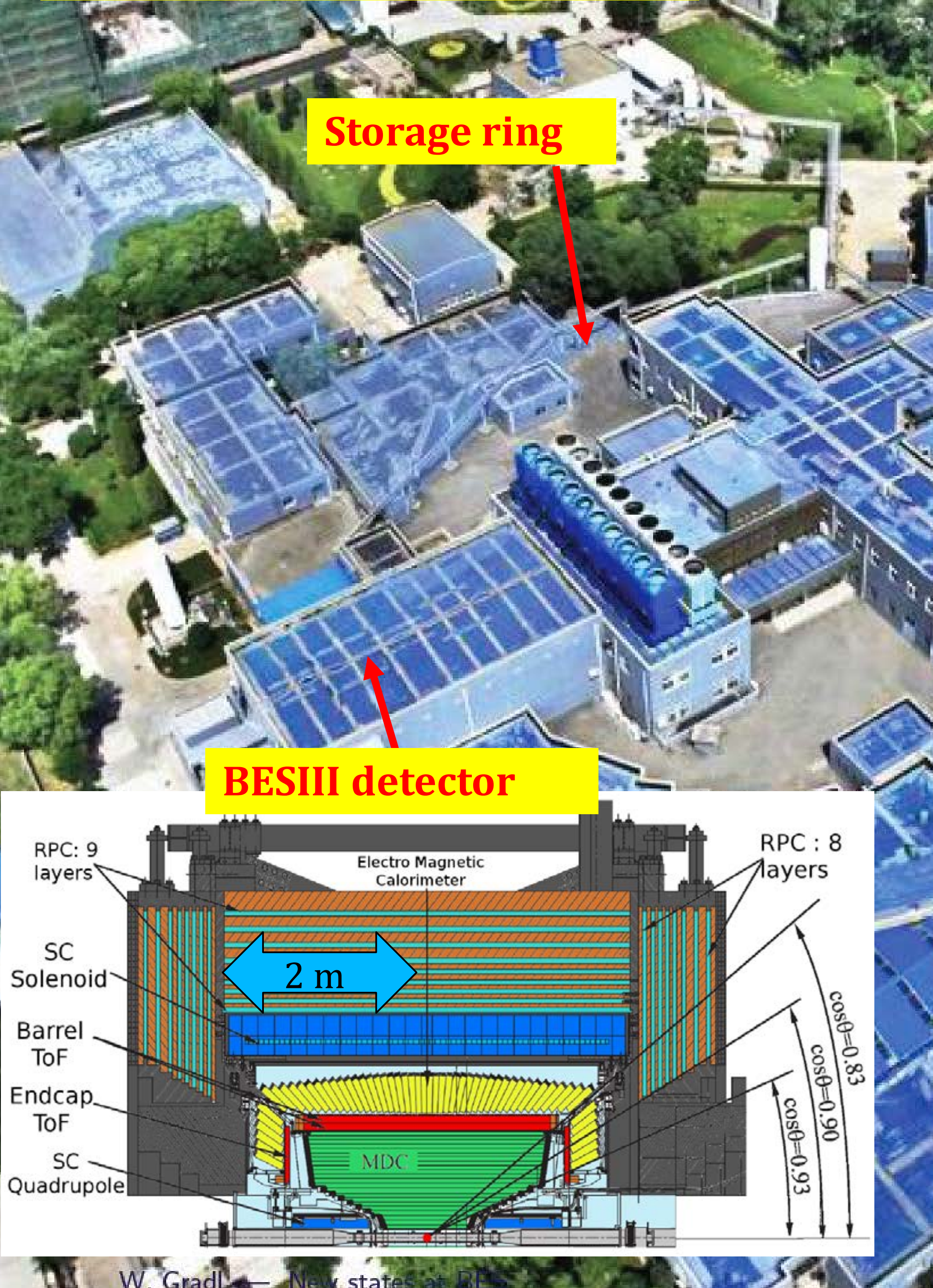
$J/\psi \to \omega\pi^+\pi^-\eta'$

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

UPPSALA UNIVERSITET

Excited QCD, Krynica, February 4th, 2020

BEPCII (Beijing)

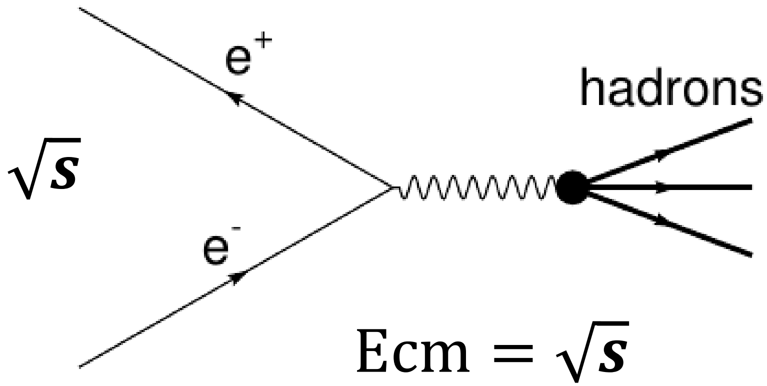


τ –charm factory 2<$\sqrt{s}$<4.7 GeV:

- Charmonium spectroscopy/decays
- Light hadrons
- Charm
- τ physics
- R-scan

electron – positron colliders

BESIII



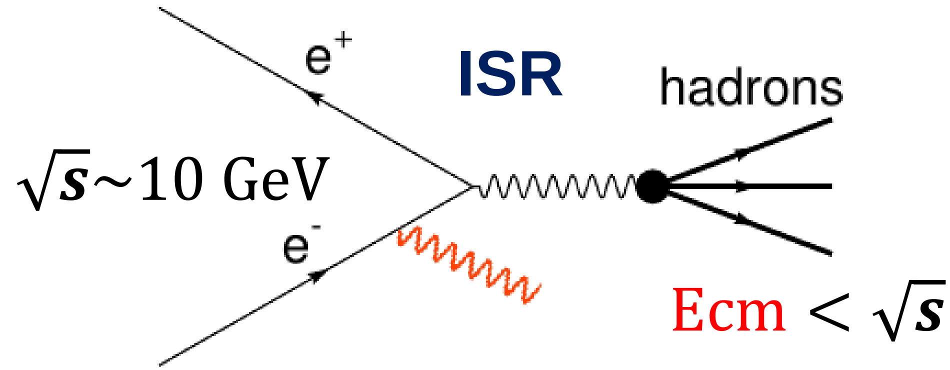
- (very) high luminosity at selected c.m. energies
- better resolution: at J/ψ 0.9 MeV:

BEPCII L= 10^{33} cm^{-2}s^{-1} at Ψ(3.77)

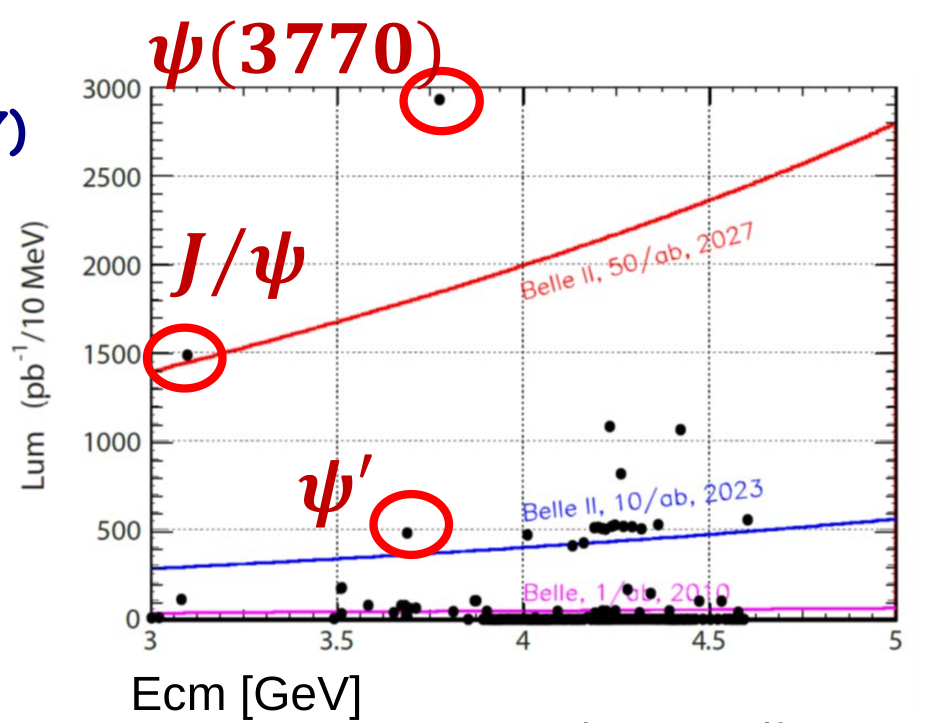
10^{10} J/ψ Feb 2019

Plans for more ψ' and $\psi(3.77)$ data

BelleII



- ISR: many Ecm simultaneously
- also hadrons from B and τ decays



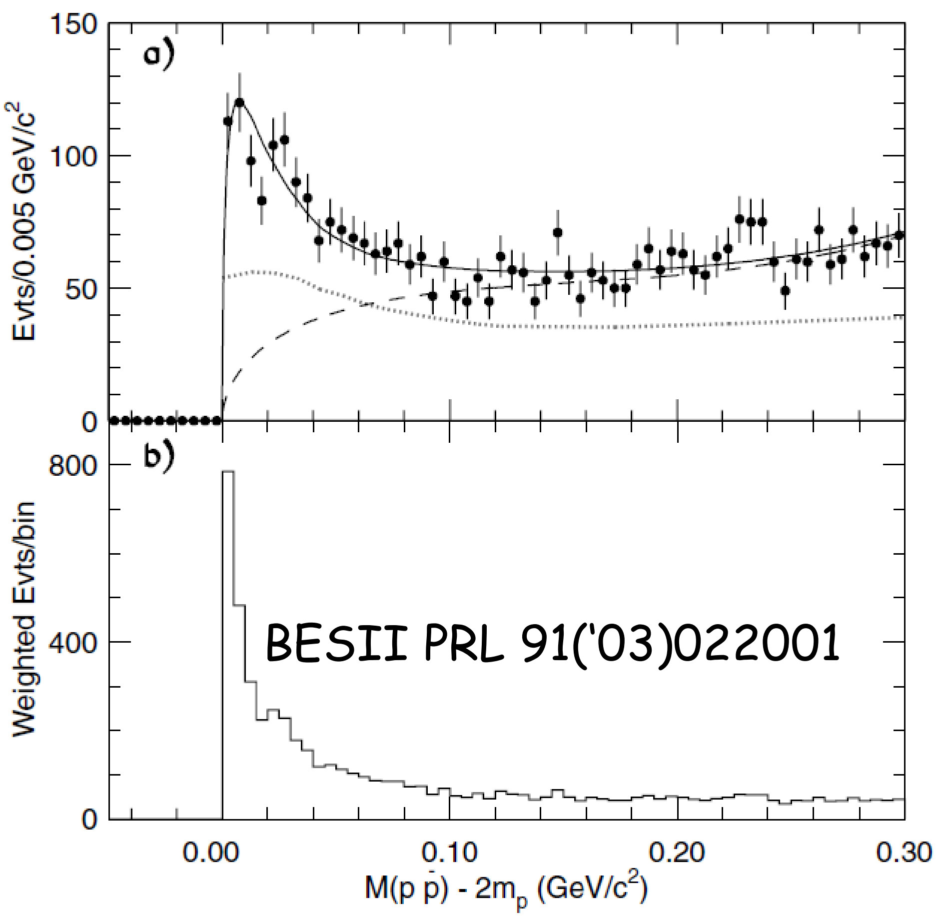
Picture:Wolfgang Gradl

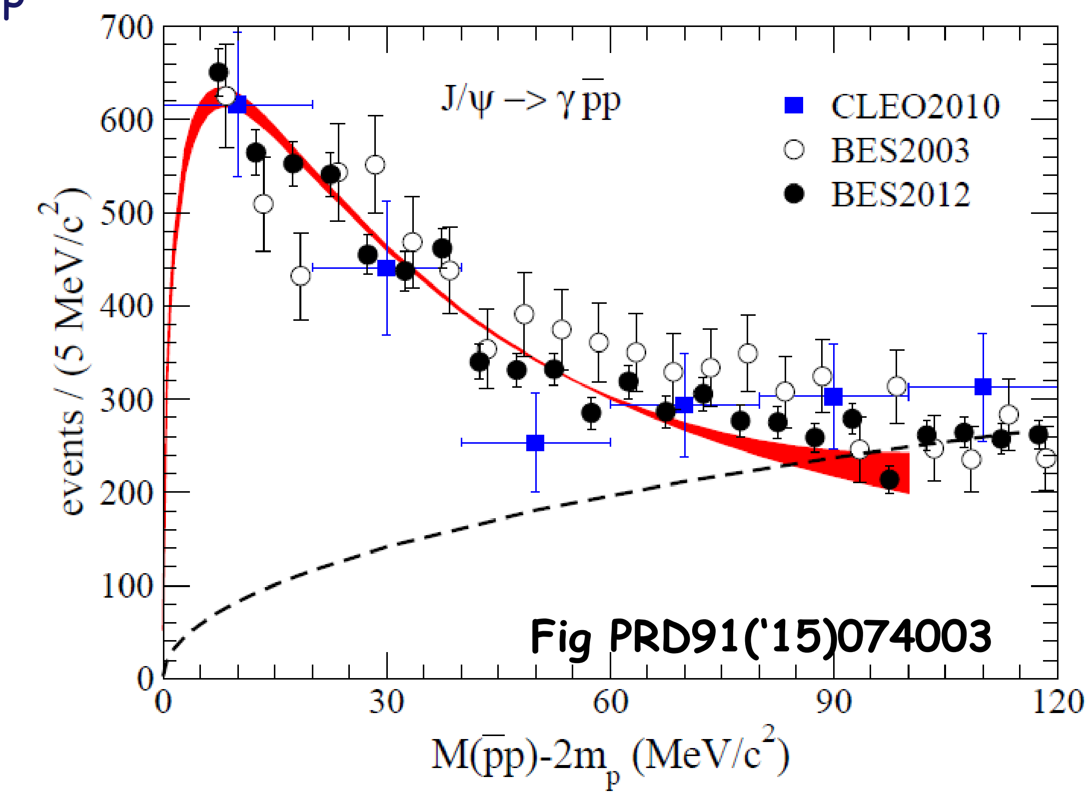
$X(\bar{p}p)$

Observed by BESII in the decay $J/\psi \to \gamma\bar{p}p$

confirmed by BESIII and CLEO

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





$p\bar{p}$ FSI ? Resonance?

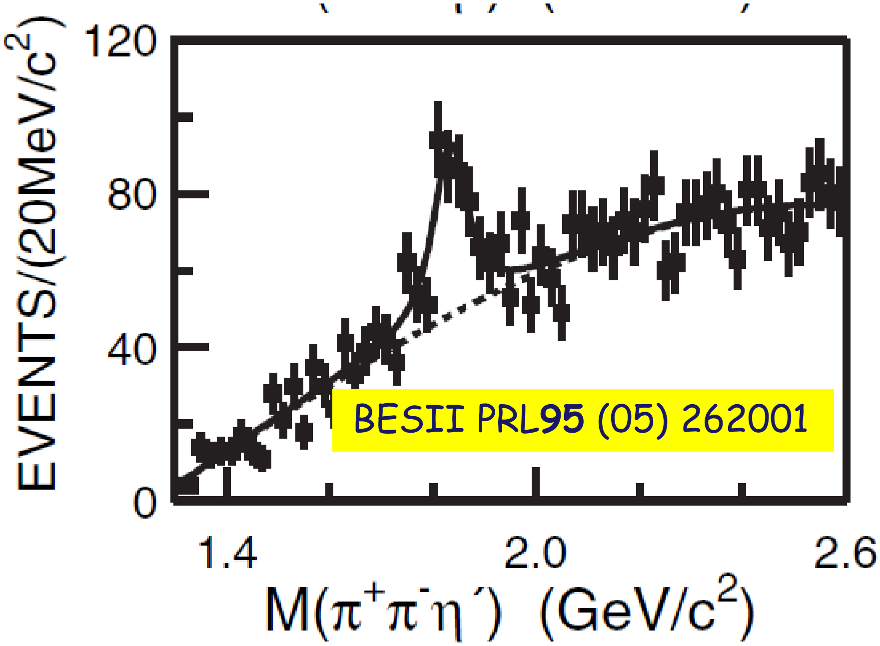
Studies of other channels BESIII:

$\psi' \to \gamma\bar{p}p$, $J/\Psi \to \pi\,\bar{p}p$,

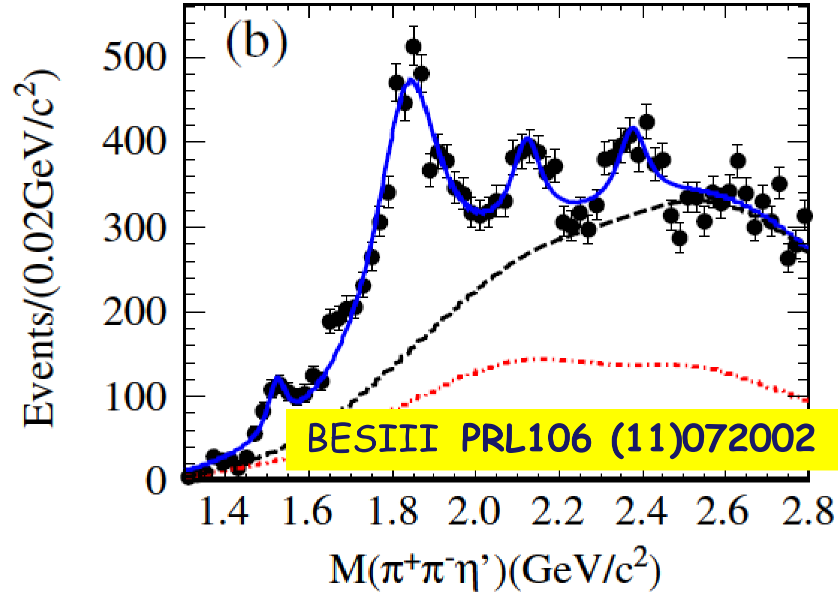
$J/\Psi \to \eta\,\bar{p}p$, $J/\Psi \to \omega\,\bar{p}p$

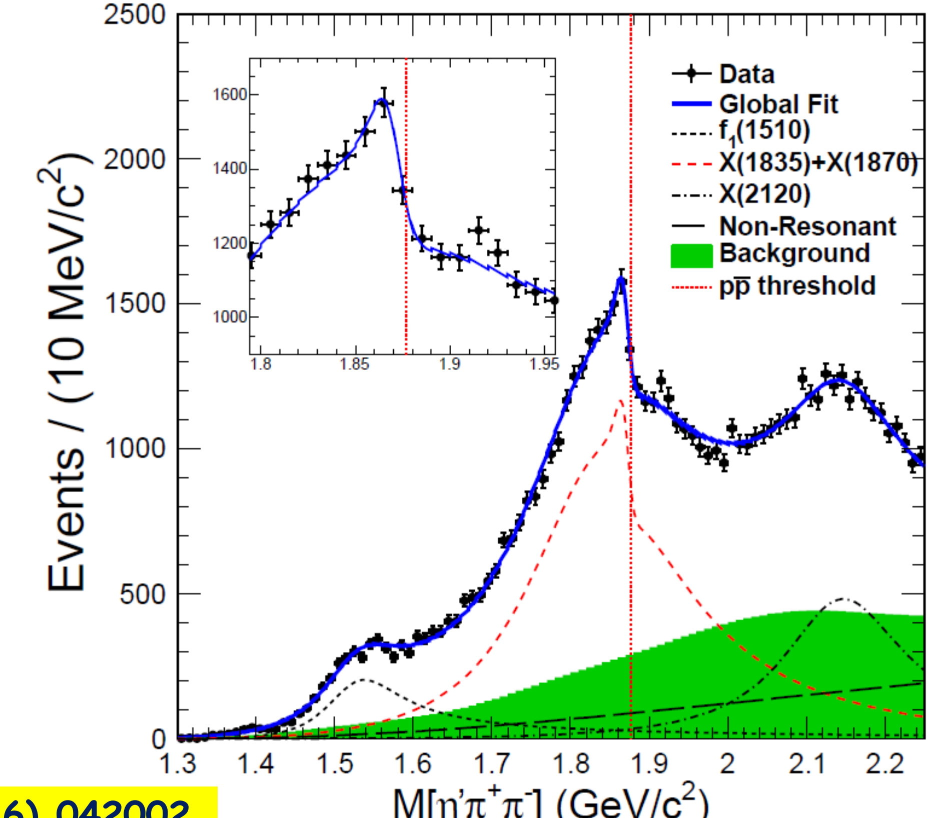
X(1835), X(2370), X(2120)

First observed in decay to π+π−η′ in J/ψ → γπ+π−η′



$J^P = 0^-$





BESIII PRL117 (2016) 042002

Possible interpretations
- p̄p bound state
- a second radial excitation of the η′
- pseudo-scalar glueball

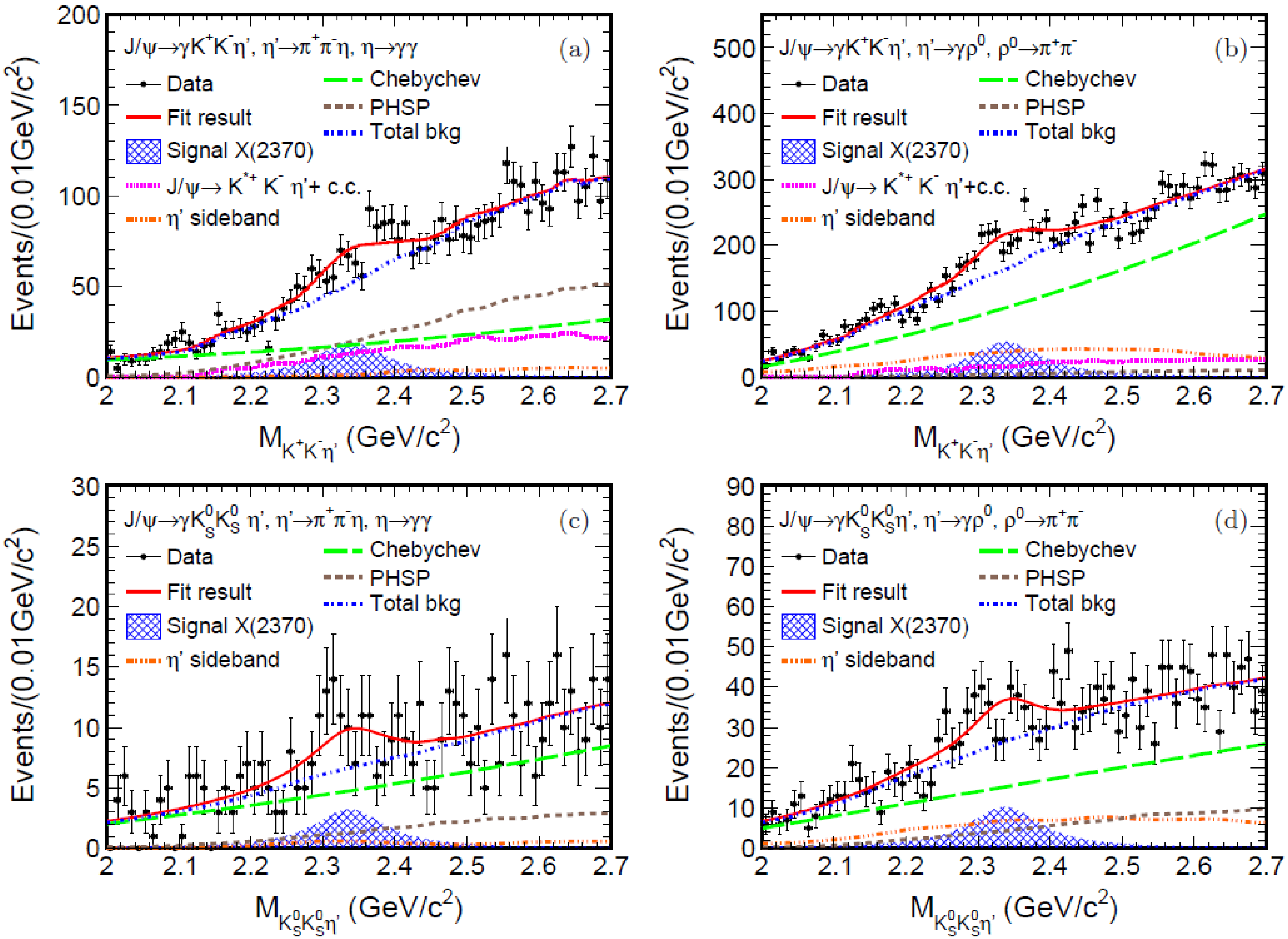
Relation to X(p̄p) enhancement,

Observation of X(2370) and search for X(2120) in $J/\psi \rightarrow \gamma K\bar{K}\eta'$

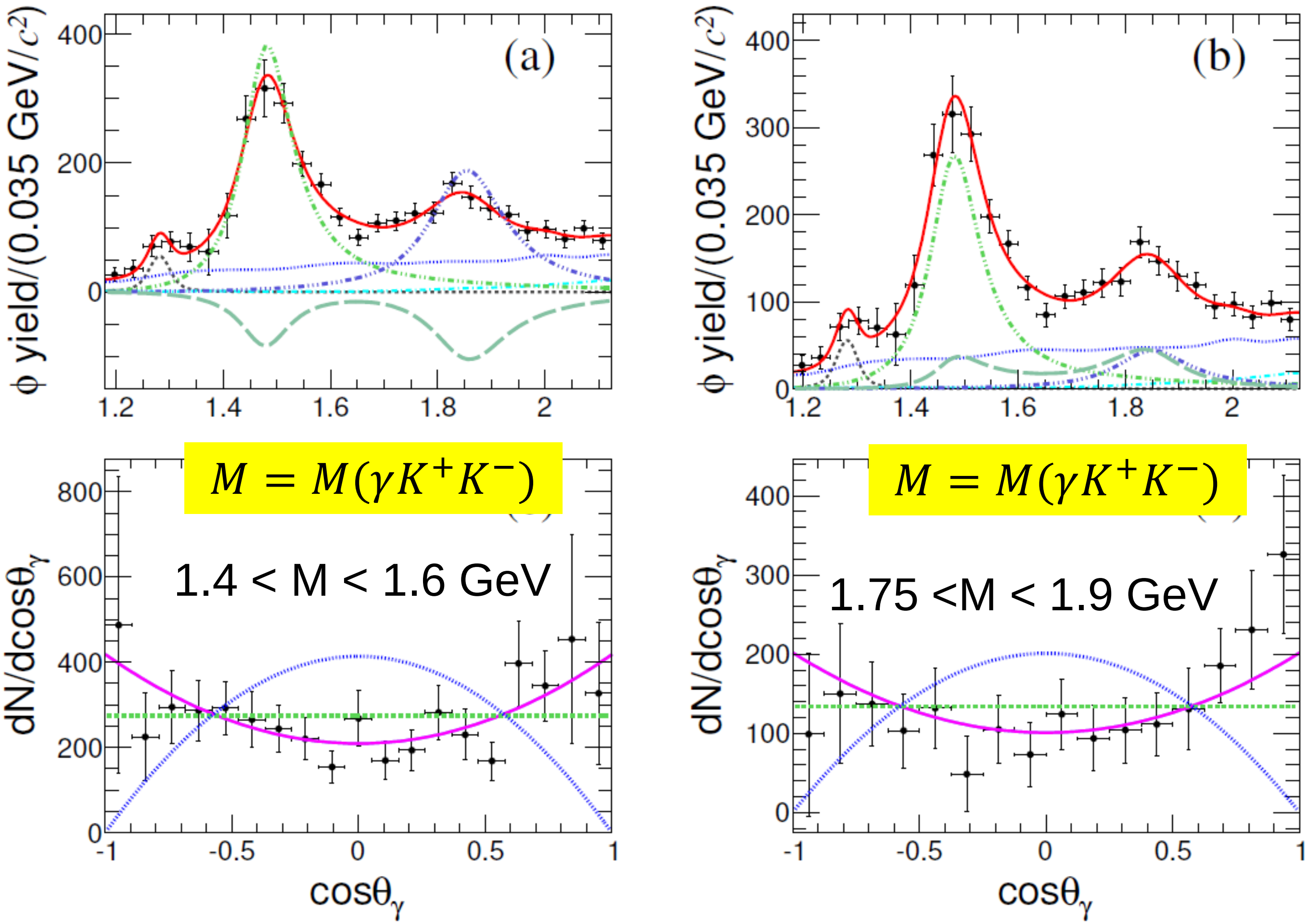
X(2370): stat significance 8.3 σ

$M_X = 2341.6 \pm 6.5(\text{stat.}) \pm 5.7(\text{syst.})$ MeV
$\Gamma_X = 117 \pm 10(\text{stat.}) \pm 8(\text{syst.})$ MeV,

BESIII arXiv:1912.11253



Study of η(1475) and X(1835) in $J/\psi \rightarrow \gamma(\gamma\phi)$

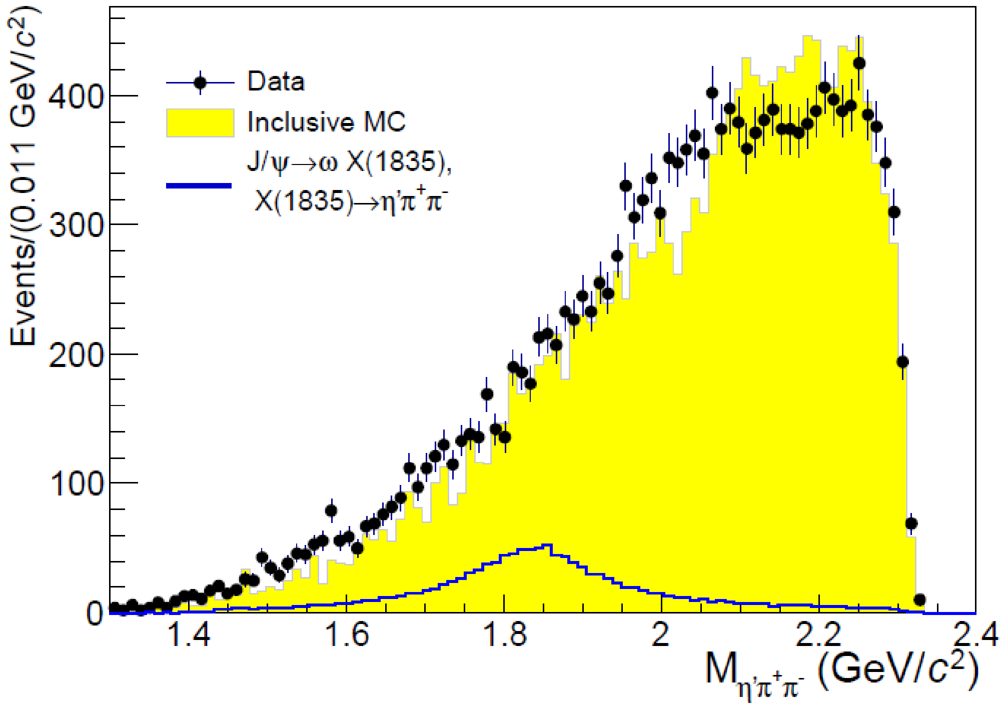


Angular distributions consistent with $J^{PC} = 0^{-+}$

Phys.Rev. D97 (2018) 051101

Search for J/ψ→ωX(1835),X(1835)→η′π+π−

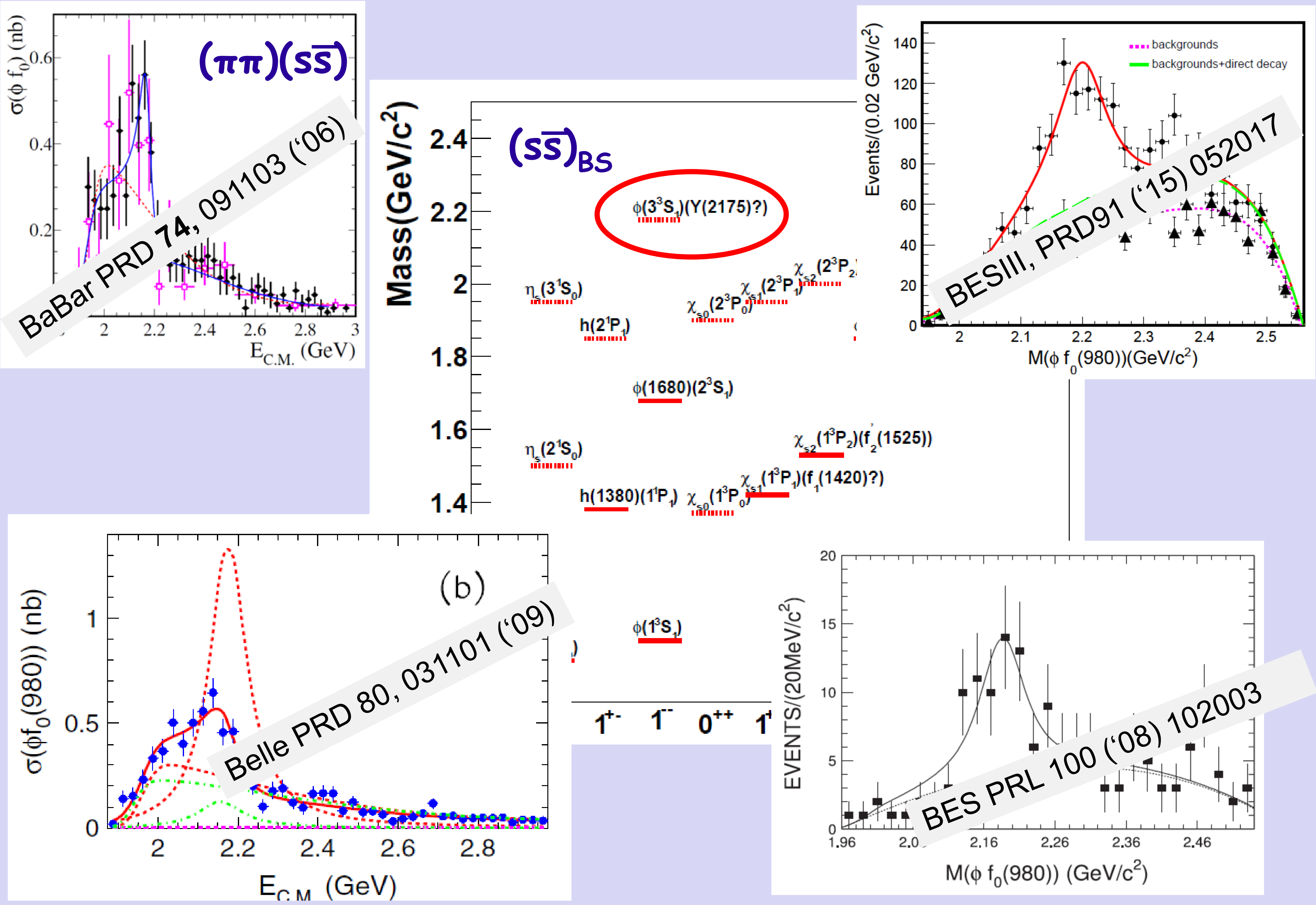
J/ψ→ωη′π+π−



No signal:
UL 90% CL B(J/ψ -> ωX(1835), X(1835) -> η′π+π−) < 6.2 × 10^{-5}

Phys.Rev. D99 (19) 071101

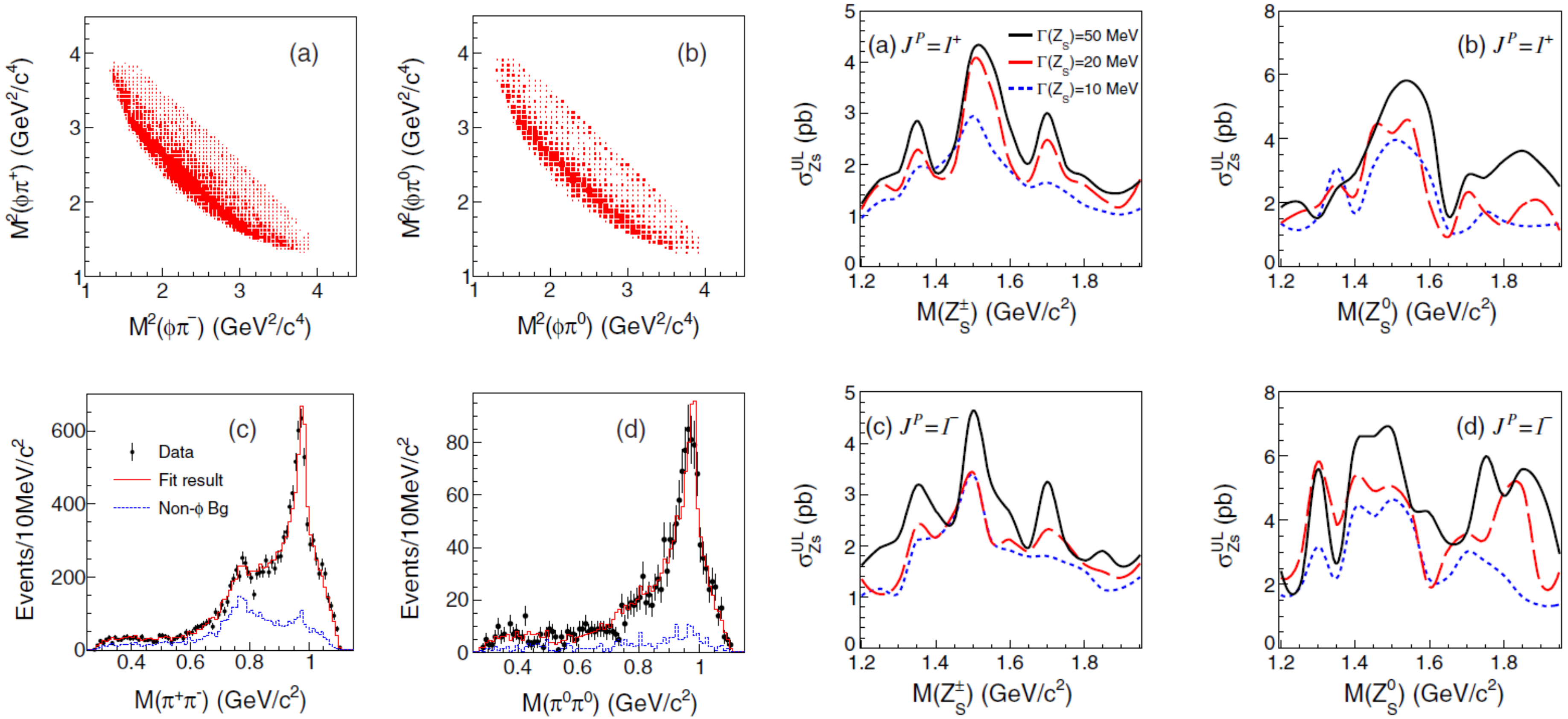
$\phi(2170)$: analog to $\psi(4260)$?



Search for a strangeonium-like Zs decaying into ϕπ

$$e^+e^- \rightarrow \phi(2170) \rightarrow \phi\pi\pi$$

$\sqrt{s} = 2.125$ GeV L=(108.49 ±0.75) pb^{-1}



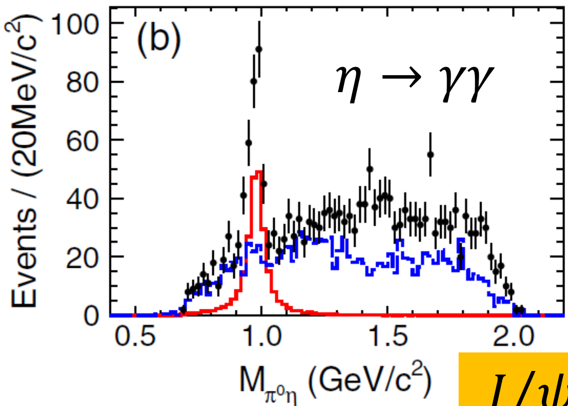
Phys.Rev. D99 (2019) 011101

$D^*\overline{D} \Longrightarrow K^*\overline{K}$ (threshold 1.4 GeV)

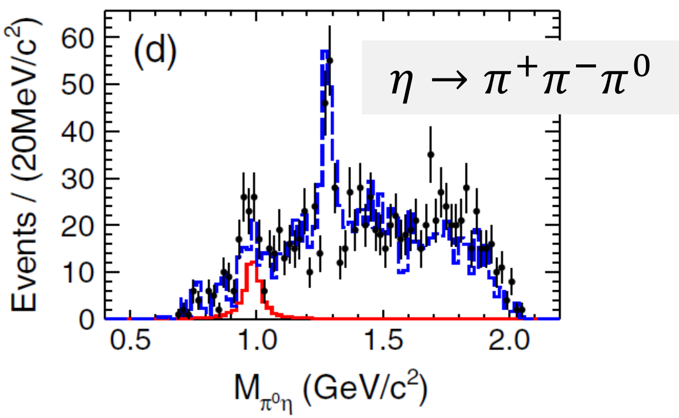
Observation of $a_0(980)$-$f_0(980)$ mixing

$J/\psi \to \phi\eta\pi^0$
$\psi' \to \gamma\chi_{c1} \to \gamma\pi^+\pi^-\pi^0$

Phys.Lett. B489 (2000) 24
Phys.Lett. B515 (2001) 13
Phys.Rev. D76 (2007) 074028
Phys.Rev. D75 (2007) 114012
Phys.Rev. D78 (2008) 074017



$J/\psi \to \phi\eta\pi^0$



$$\xi_{fa} = \frac{\mathcal{B}[J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0]}{\mathcal{B}[J/\psi \to \phi f_0(980) \to \phi\pi\pi]},$$

$$\xi_{af} = \frac{\mathcal{B}[\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-]}{\mathcal{B}[\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0\pi^0\eta]}$$

$$|A_{\text{mix}}(m)e^{i\varphi}\alpha + A_a(m)|^2(pq)$$

$$A_{\text{mix}}(m) = D_{fa}/D_aD_f$$

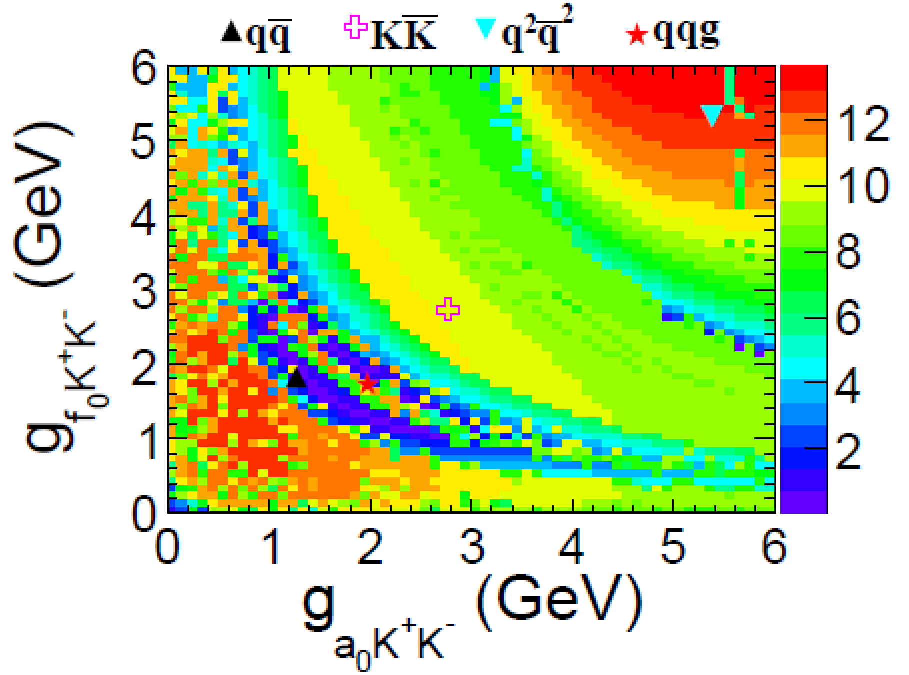
$$D_{fa} = (g_{a_0K^+K^-} \cdot g_{f_0K^+K^-}/16\pi)i[\rho_{K^+K^-}(s) - \rho_{K^0\bar{K}^0}(s)]$$

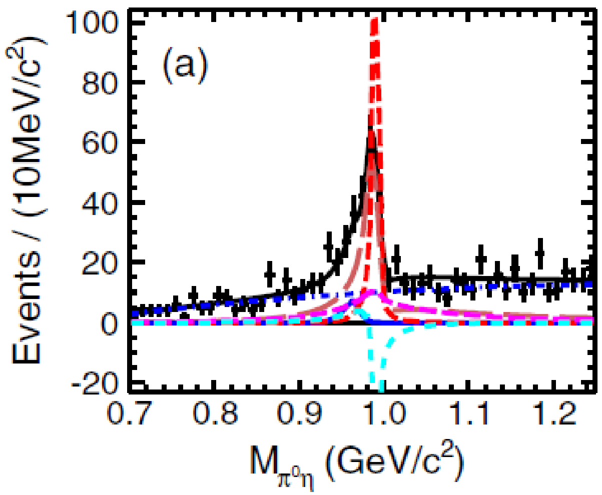
Phys.Rev.Lett. 121 (2018) 022001

Using of 1.31×10^9 J/ψ and 4.48×10^8 ψ(3686)

In $\eta \to \pi^+\pi^-\pi^0$ bkg from $f_1(1285)$

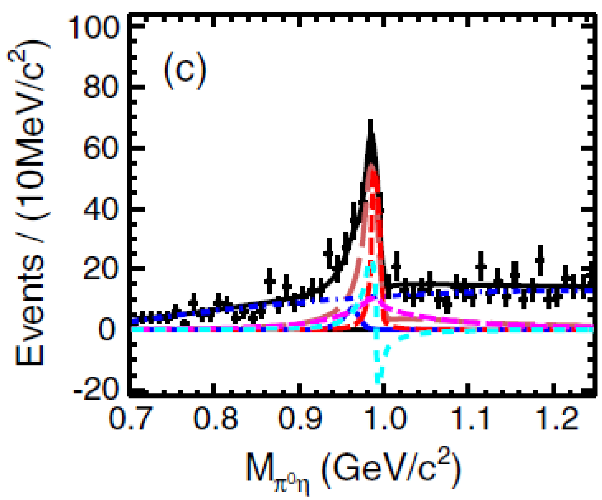
$a_0(980)$-$f_0(980)$ mixing





$$|A_{\text{mix}}(m)e^{i\varphi}\alpha + A_a(m)|^2(pq)$$

$$A_{\text{mix}}(m) = D_{fa}/D_aD_f$$



	$J/\psi \to \phi\eta\pi^0$		
Channel	Solution I	Solution II	$\chi_{c1} \to 3\pi$
N (mixing)	$161 \pm 26 \| 45 \pm 7$	$67 \pm 21 \| 19 \pm 6$	42 ± 7
N (EM)	$162 \pm 54 \| 46 \pm 16$	$130 \pm 51 \| 37 \pm 14$	...
φ (degree)	23.6 ± 11.3	-51.5 ± 21.3	...
S (mixing)	7.4σ		5.5σ
S (EM)	4.6σ		...

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

Light scalar meson spectrum ($J^{PC} = 0^{++}$):

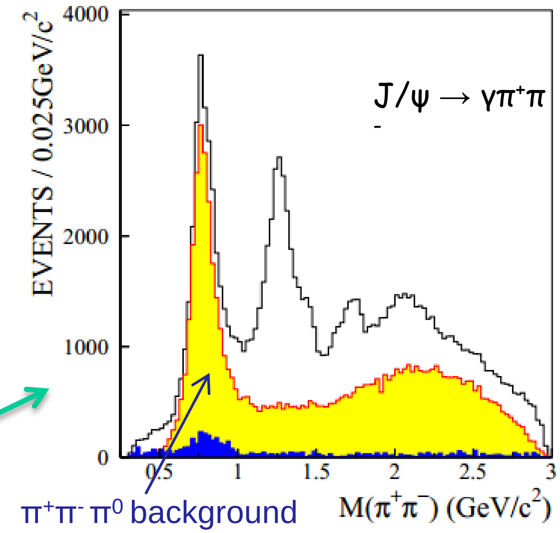
- Broad, overlapping states
- Lightest glueball state

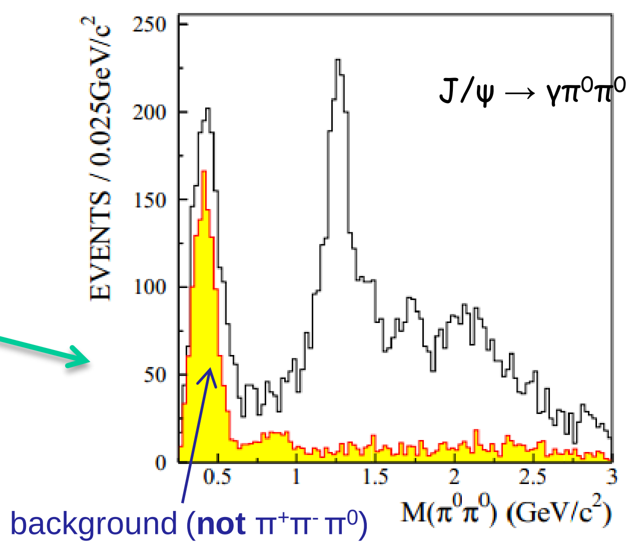
J/ψ radiative decay to $\pi^0\pi^0$ provides a clean environment to study this spectrum

- Radiative decays to two pseudoscalars, angular momentum + parity restricts the quantum numbers to $J^{PC}=0^{++}, 2^{++}, 4^{++}$...
- Neutral channel is cleaner than the charged channel

Amplitude analysis:

- Mass independent fits → final state interactions of $\pi^0\pi^0$
- Mass dependent fits → extracting masses, widths, etc. of intermediate states





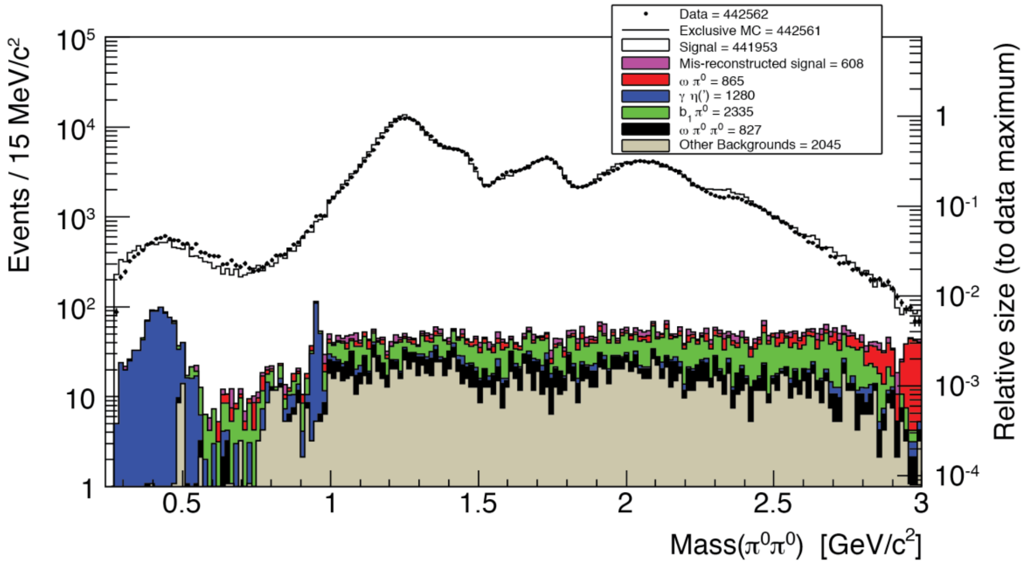
BESII: PLB 642,441 (2006)

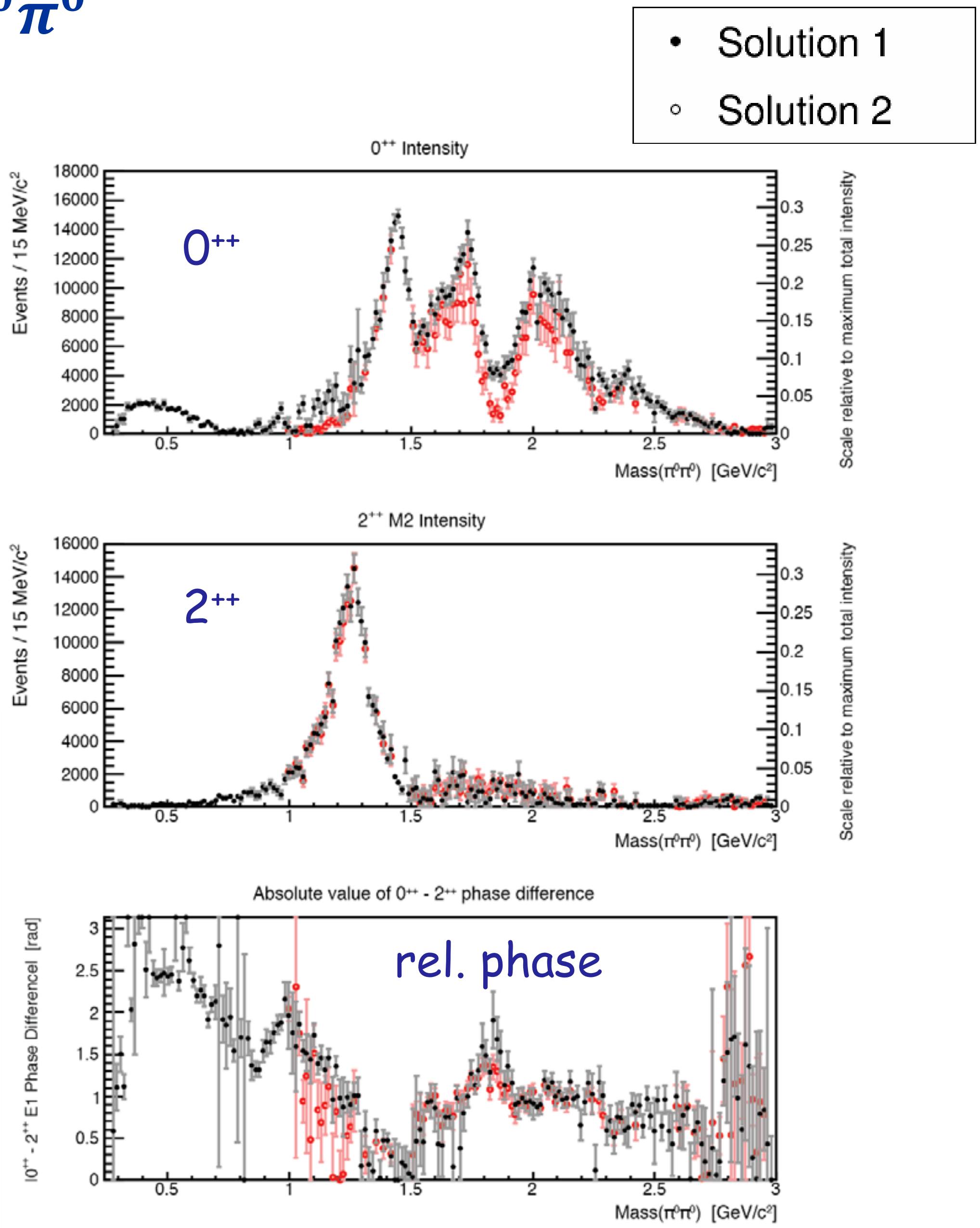
Amplitude analysis of $J/\psi \to \gamma\pi^0\pi^0$

0^{++} spectrum include structures near

1.5, 1.7, 2.0 GeV/c^2

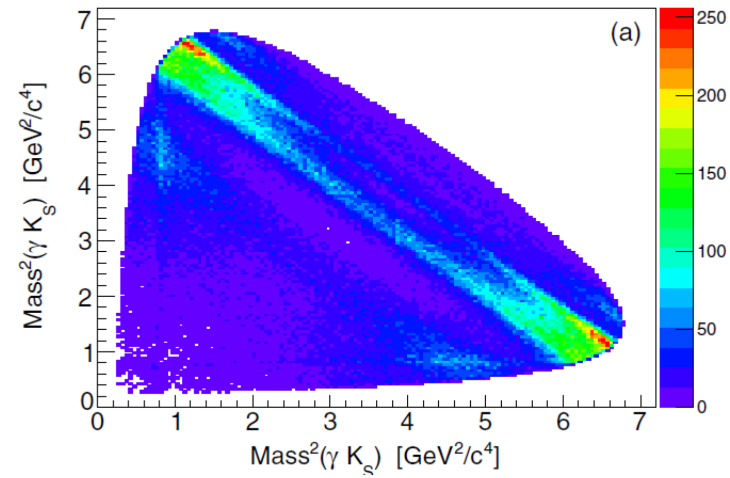
BESIII PRD92 (´15) 052003

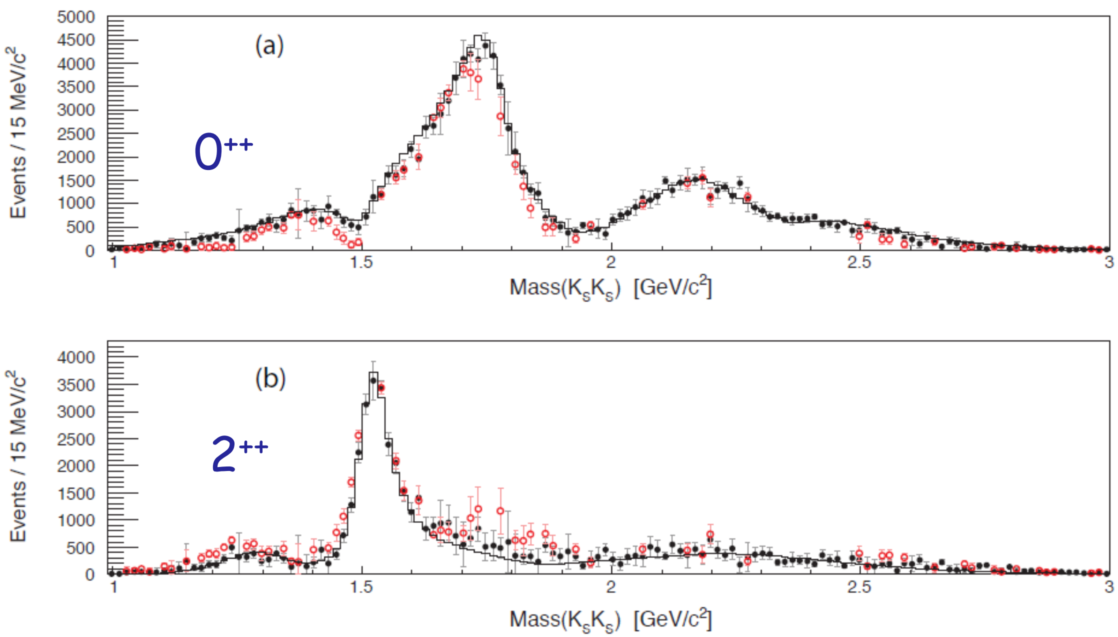


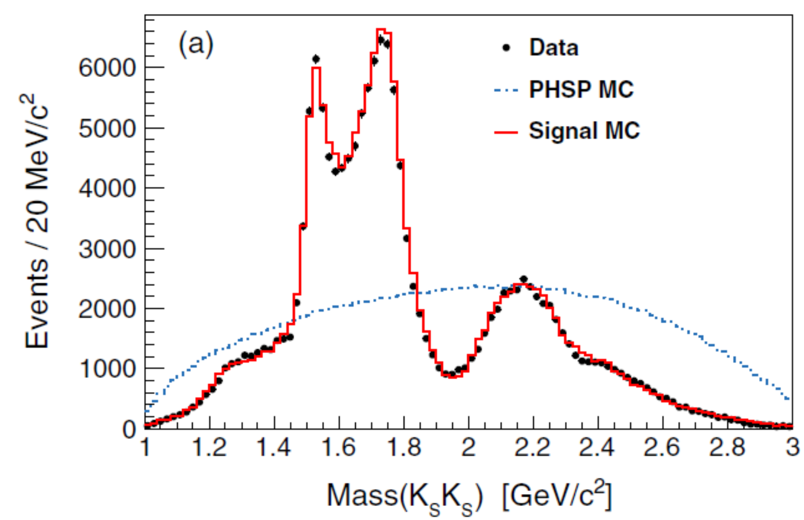


* Error bars are statistical only

Amplitude analysis of $J/\psi \rightarrow \gamma K_s K_s$





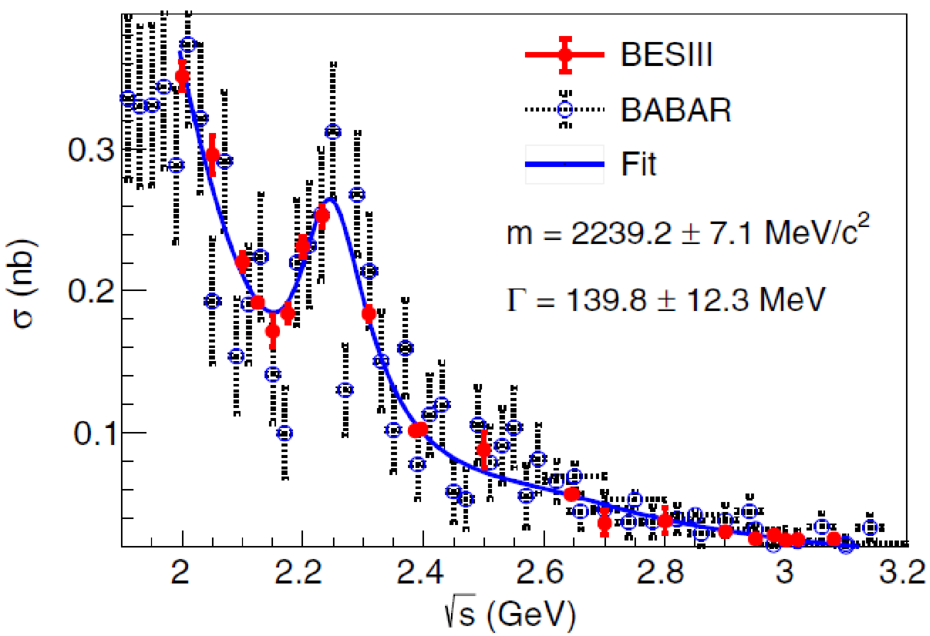


BESIII Phys.Rev. D98 (18) 072003

Exclusive cross sections $e^+e^- \to hadrons$

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

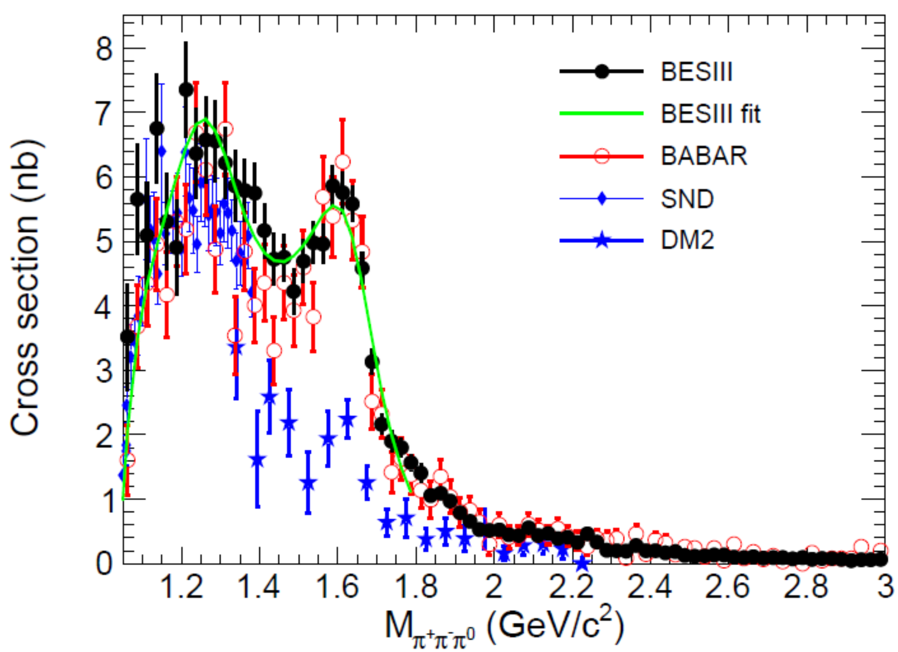
2.00−3.08 GeV



Phys.Rev. D99 (2019) 032001

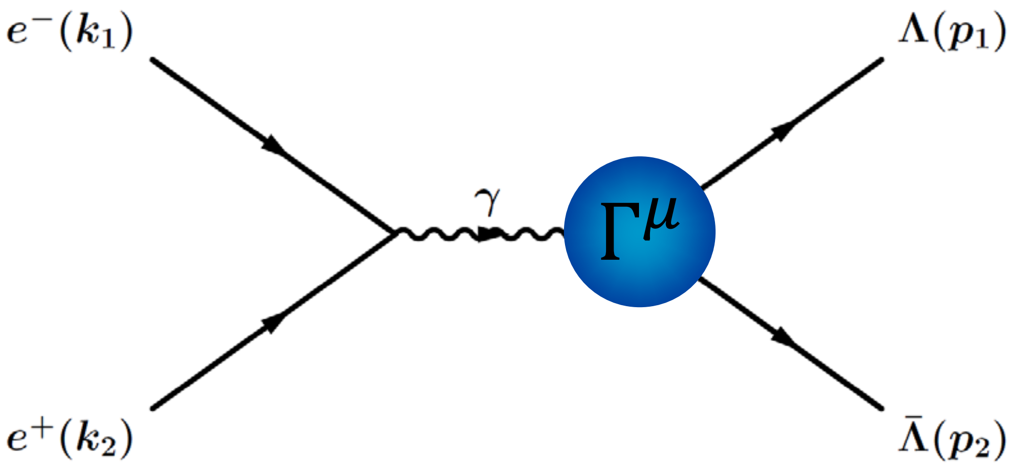
$e^+e^- \to \pi^+\pi^-\pi^0$

0.7-3.0 GeV via ISR



arXiv:1912.11208

$e^+e^- \to \gamma^* \to B\bar{B}$ (spin 1/2)



$$s = (p_1 + p_2)^2$$
$$q = p_1 - p_2$$

$$\Gamma^\mu(p_1, p_2) = -ie\left[\gamma^\mu F_1(s) + i\frac{\sigma^{\mu\nu}}{2M_B} q_\nu F_2(s)\right]$$

Sachs Form Factors (FFs) ⇔ helicity amplitudes:

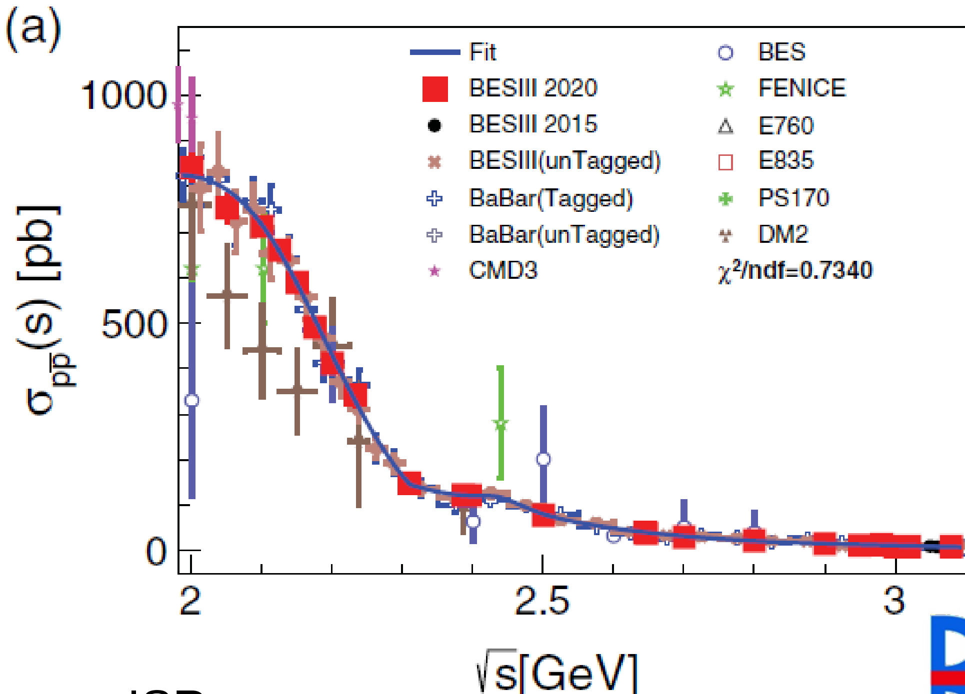
$$G_M(s) = F_1(s) + F_2(s), \quad G_E(s) = F_1(s) + \tau F_2(s)$$

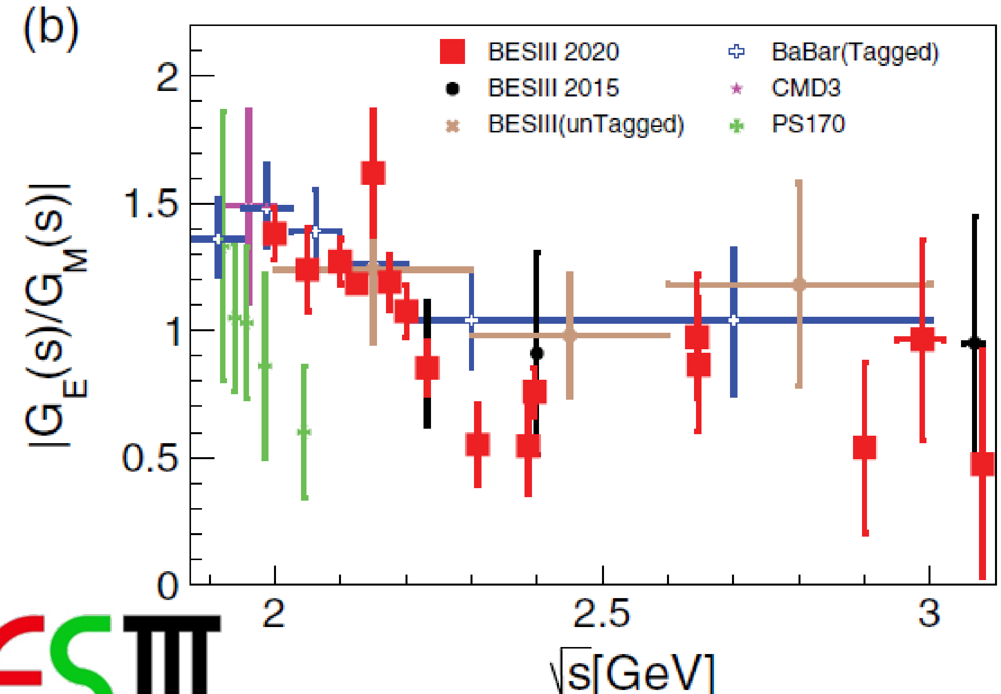
helicity non-flip　　　　helicity flip

$$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta \qquad -1 < \alpha_\psi < 1$$

$$R = \left|\frac{G_E}{G_M}\right| \qquad \left(\alpha_\psi = \frac{\tau - R^2}{\tau + R^2}\right) \qquad \tau = \frac{s}{4M_B^2}$$

$e^+e^- \to p\bar{p}$

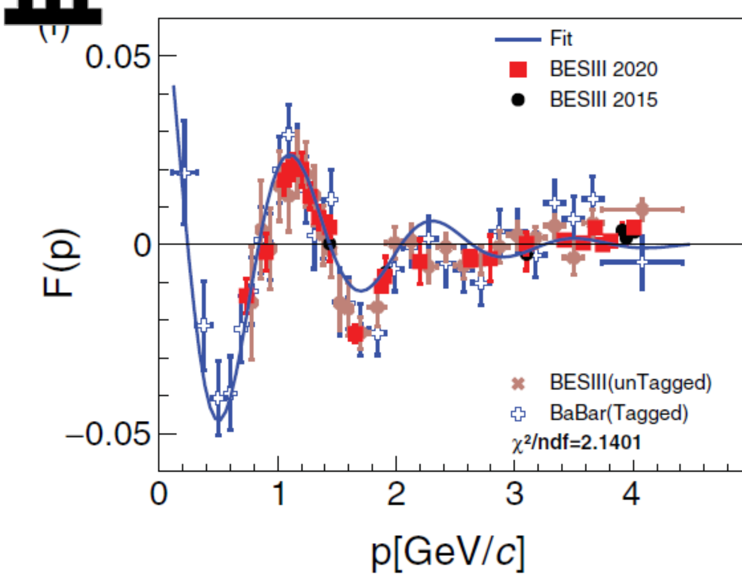




ISR
Phys.Rev. D99 (2019) 092002 (ISR)

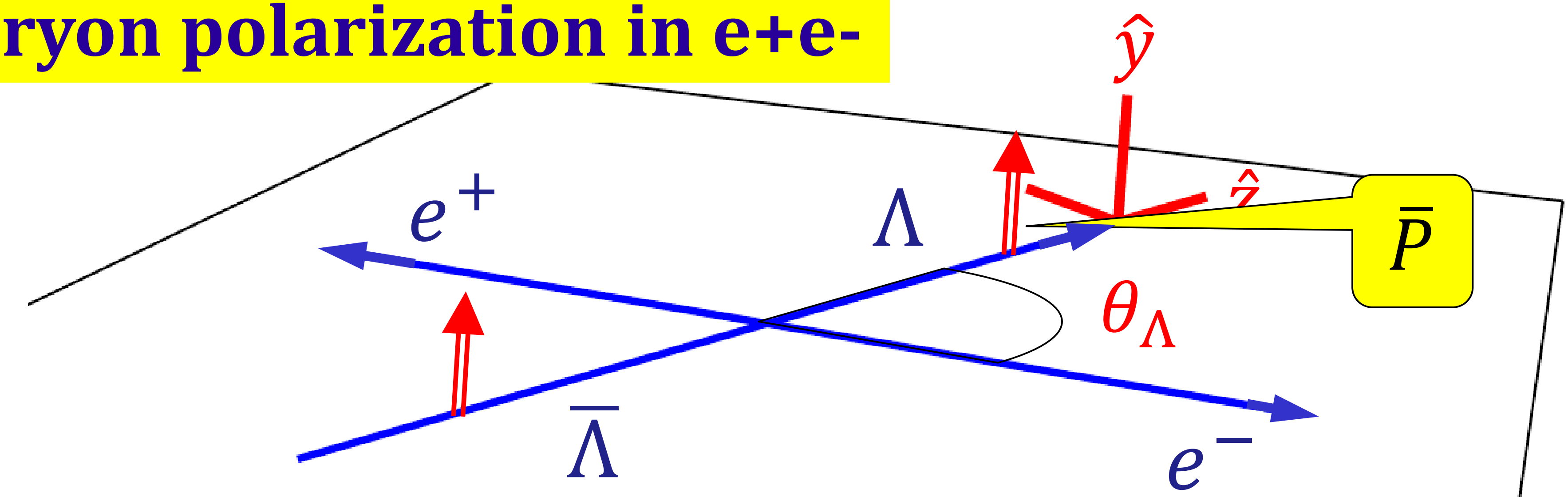
Phys.Rev.Lett. 124 (2020) 042001

$$|G_{\mathrm{eff}}| = \frac{\mathcal{A}}{(1+q^2/m_a^2)[1-q^2/q_0^2]^2}$$



Phys. Rev. C 93, 035201 (2016)

Baryon polarization in e+e-



Unpolarized e+e- beams ⇨ transverse polarization:

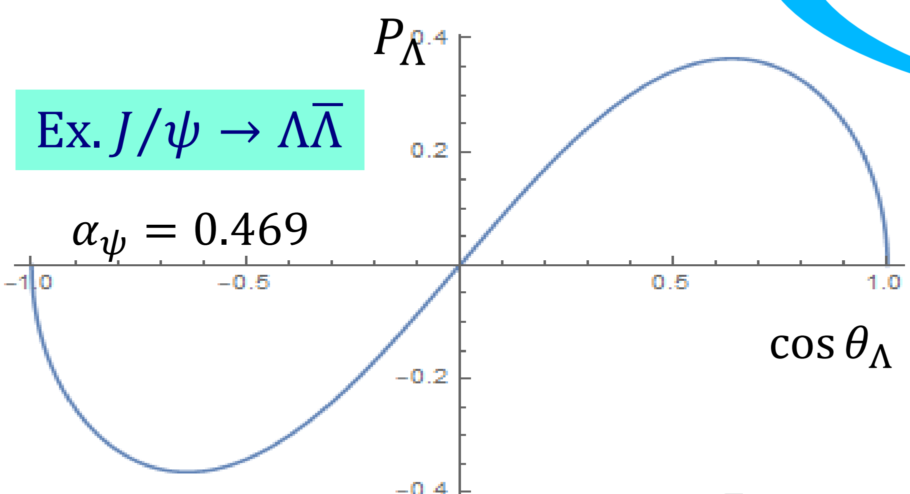
$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi{}^2}\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi \cos^2\theta_\Lambda}\sin(\Delta\Phi)$$

$\Delta\Phi \neq 0$

$$G_E = R G_M e^{i\Delta\Phi}$$

Ex. $J/\psi \to \Lambda\bar{\Lambda}$

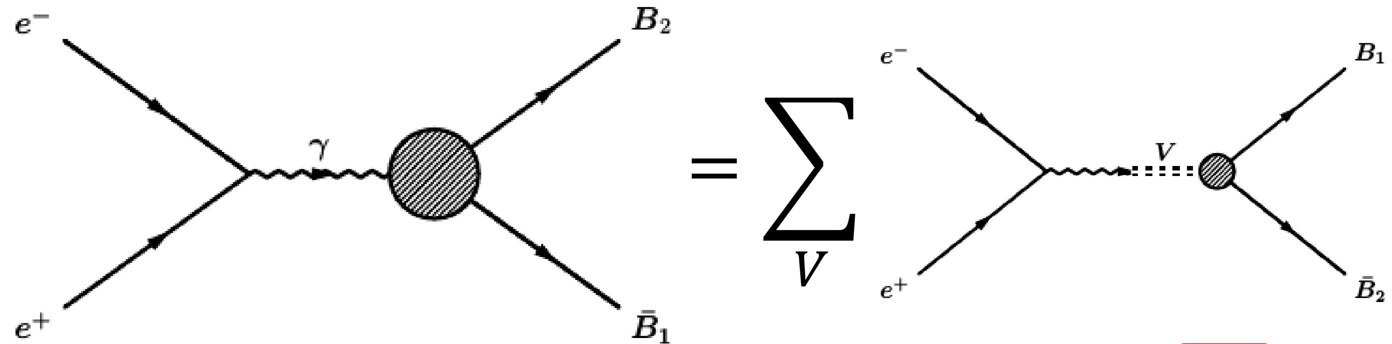
$\alpha_\psi = 0.469$



Max P_Λ= 36.4%

if $\Delta\Phi = \frac{\pi}{2}$

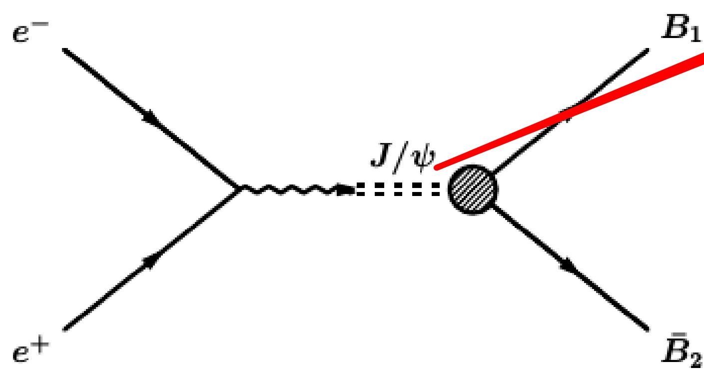
Baryon FFs (continuum):



Baryons B_1 and $\bar{B}_2$ (spin 1/2, ...)

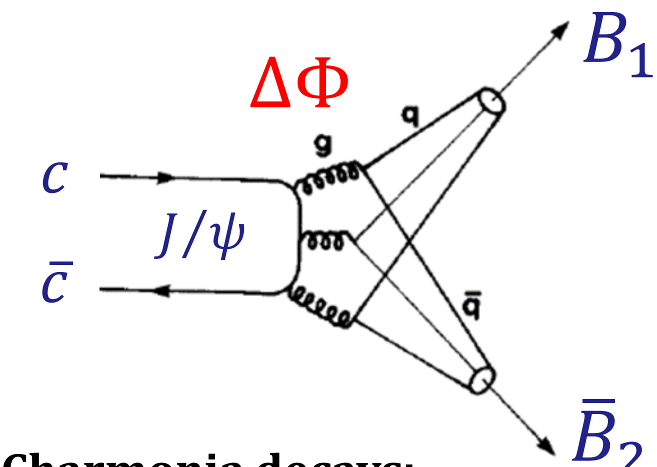
$V = \gamma, \rho, \omega, \varphi, \ldots, J/\psi, \psi(2S), \ldots$

vs J/ψ decay:



Both processes described by two complex FFs: relative phase $\Delta\Phi$

Cabibbo, Gatto PR124 (1961)1577



Time like spin ½ baryon FFs:
Dubnickova, Dubnicka, Rekalo
Nuovo Cim. A109 (1996) 241
Gakh, Tomasi-Gustafsson Nucl.Phys. A771 (2006) 169
Czyz, Grzelinska, Kuhn PRD75 (2007) 074026
Fäldt EPJ A51 (2015) 74; EPJ A52 (2016)141

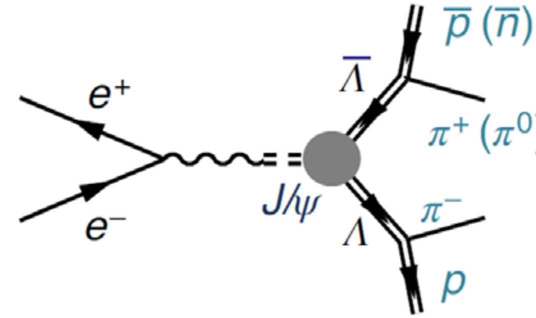
Charmonia decays:
Fäldt, Kupsc PLB772 (2017) 16

nature physics
LETTERS
https://doi.org/10.1038/s41567-019-0494-8

Polarization and entanglement in baryon-antibaryon pair production in electron-positron annihilation

The BESIII Collaboration*

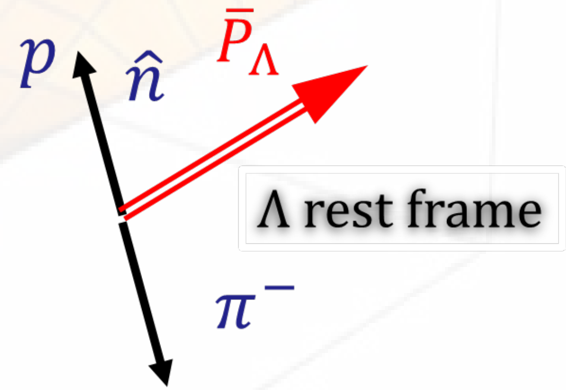
Nature Phys. 15 (2019) 631



BESIII

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$:

- Observation of Λ transverse polarization
- Determination of Λ decay asymmetry
- CP tests



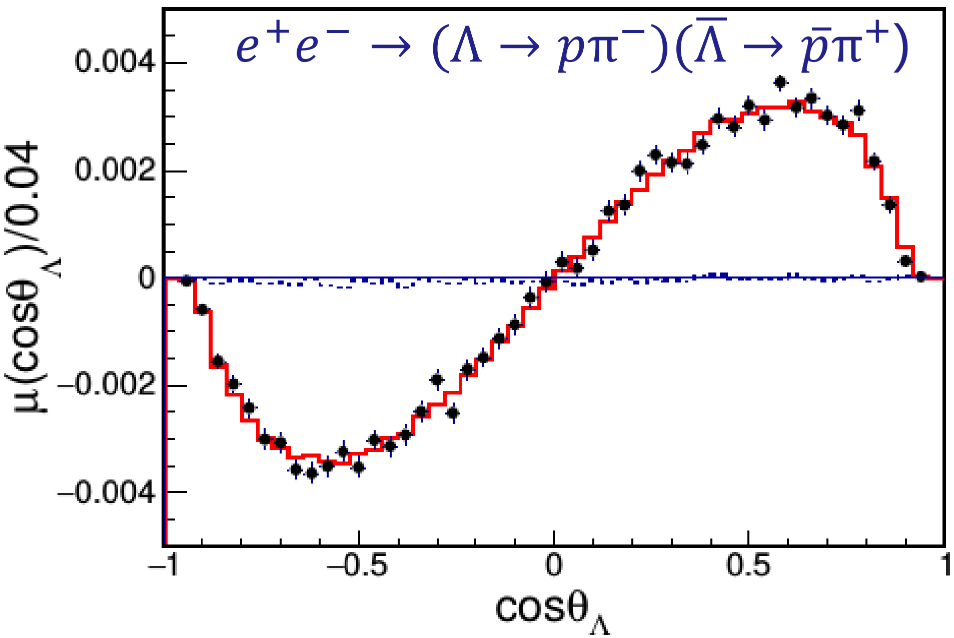
$$\frac{d\Gamma}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_{-}\hat{n}\,\bar{P}_\Lambda)$$

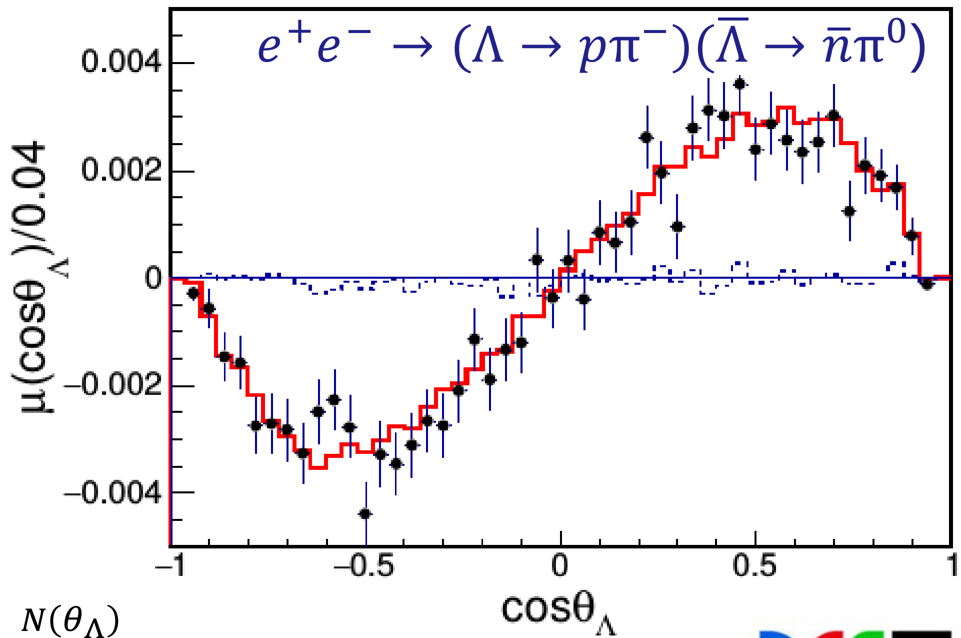
Methods(UU):

1. G.Fäldt, AK PLB772 (2017) 16
2. E.Perotti,G.Fäldt,AK,S.Leupold,JJ.Song PRD99 (2019)056008

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$ (0.4×10^6 events)

$\Delta\Phi = 42.3^{o} \pm 0.6^{o} \pm 0.5^{o}$





moment: $$\mu(\cos\theta_\Lambda) = \frac{1}{N}\sum_{i=1}^{N(\theta_\Lambda)}\left(n_{1,y}^{(i)} - n_{2,y}^{(i)}\right)$$

(uncorrected for acceptance)

Parameters	This work	Previous results
α_ψ	$\mathbf{0.461 \pm 0.006 \pm 0.007}$	0.469 ± 0.027 BESIII
$\Delta\Phi$ (rad)	$\mathbf{0.740 \pm 0.010 \pm 0.008}$	–
α_-	$\mathbf{0.750 \pm 0.009 \pm 0.004}$	0.642 ± 0.013 PDG
α_+	$\mathbf{-0.758 \pm 0.010 \pm 0.007}$	-0.71 ± 0.08 PDG
$\bar{\alpha}_0$	$\mathbf{-0.692 \pm 0.016 \pm 0.006}$	–

BESIII Nature Phys. 15 (2019) 631

PDG 2019 update:

$\alpha_- = 0.642 \pm 0.013$

$\alpha_- = 0.750 \pm 0.010$

α_- FOR $\Lambda \to p\pi^-$

INSPIRE search

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.750 ±0.009 ±0.004	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\bar{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.584 ±0.046	8500	ASTBURY	1975	SPEC	
0.649 ±0.023	10325	CLELAND	1972	OSPK	
0.67 ±0.06	3520	DAUBER	1969	HBC	From Ξ decay
0.645 ±0.017	10130	OVERSETH	1967	OSPK	Λ from $\pi^- p$
0.62 ±0.07	1156	CRONIN	1963	CNTR	Λ from $\pi^- p$

α_+ FOR $\bar{\Lambda} \to \bar{p}\pi^+$

INSPIRE search

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.758 ±0.010 ±0.007	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\bar{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.755 ±0.083 ±0.063	≈ 8.7k	ABLIKIM	2010	BES	$J/\psi \to \Lambda\bar{\Lambda}$
−0.63 ±0.13	770	TIXIER	1988	DM2	$J/\psi \to \Lambda\bar{\Lambda}$

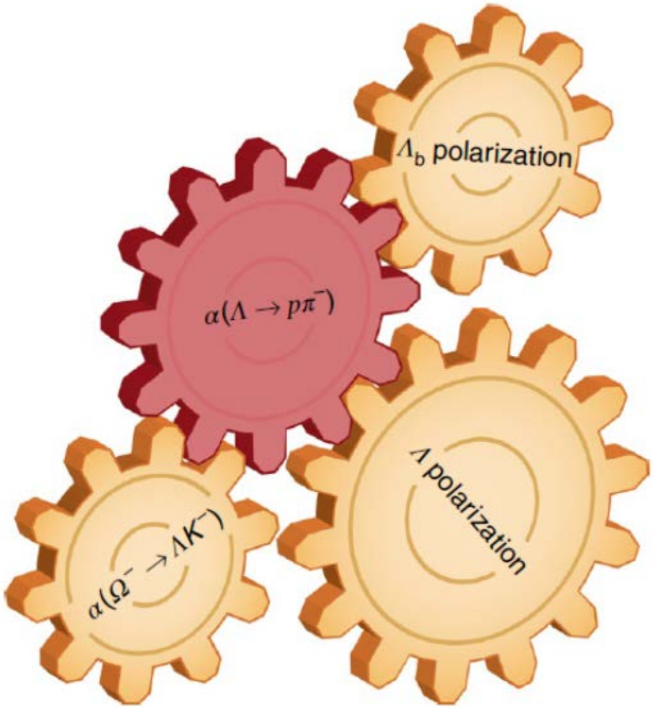
news & views

PARTICLE PHYSICS

Anomalous asymmetry

A measurement based on quantum entanglement of the parameter describing the asymmetry of the Λ hyperon decay is inconsistent with the current world average. This shows that relying on previous measurements can be hazardous.

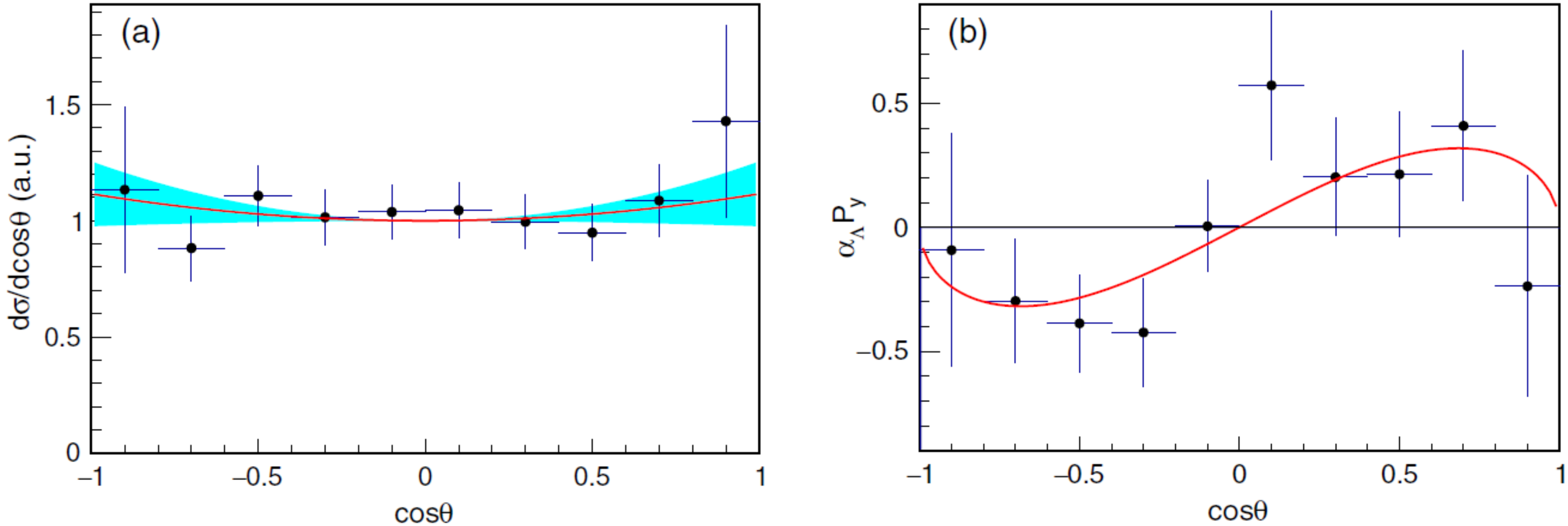
Ulrik Egede



$e^+e^- \to \gamma^* \to \Lambda\bar{\Lambda}$ (continuum: 2.396 GeV)

BESIII

PHYSICAL REVIEW LETTERS **123**, 122003 (2019)



555 events selected

("α_ψ"=0.13±0.16)

$\Delta\Phi = 37^o \pm 12^o \pm 6^o$

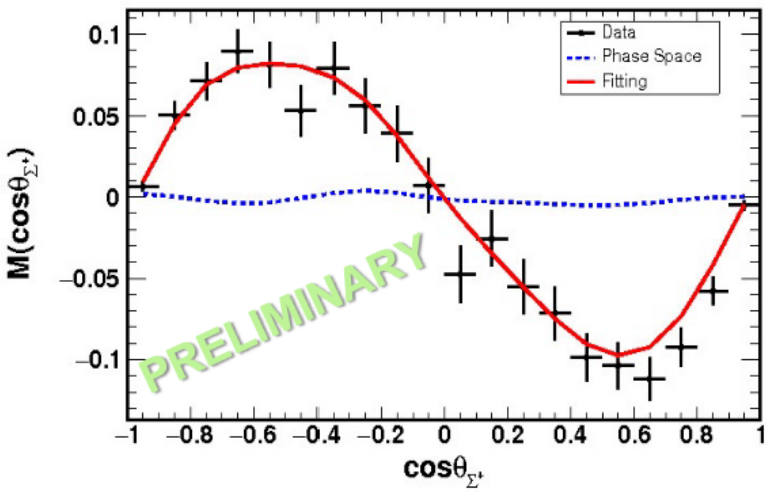
R = 0.94 ± 0.16(stat.) ± 0.03(sys.) ± 0.02(α_)

The same fit as for $J/\psi \to (\Lambda \to p\pi^-)(\bar{\Lambda} \to \bar{p}\pi^+)$ but $\alpha_- = \alpha_+$ and fixed

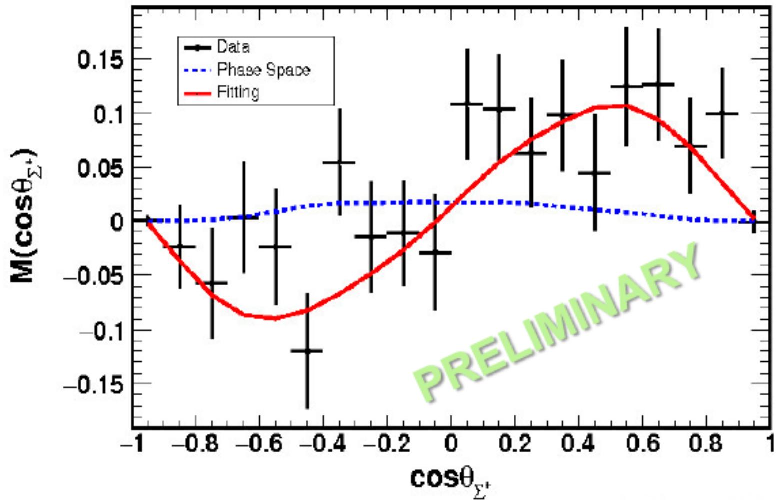
$e^+e^- \to J/\psi, \psi' \to \Sigma^+\bar{\Sigma}^- \to p\pi^-\bar{p}\pi^+$

The same formalism as for $J/\psi \to \Lambda\bar{\Lambda}$

$J/\psi \to \Sigma^+ \Sigma^-$



$\psi' \to \Sigma^+ \Sigma^-$



$\alpha_{J/\psi}/\alpha_{\psi}$ = -0.507±0.006±0.002 / 0.676±0.030±0.006

$\Delta\Phi(J/\psi, \psi)$ = (-15.4±0.7±0.3)° / (21.5 ± 0.4 ± 0.5)°

α_0 = -0.999±0.037±0.010

$\bar{\alpha}_0$ = 0.992±0.037±0.008

A_{CP} = -0.015±0.037±0.008

BESIII

Summary

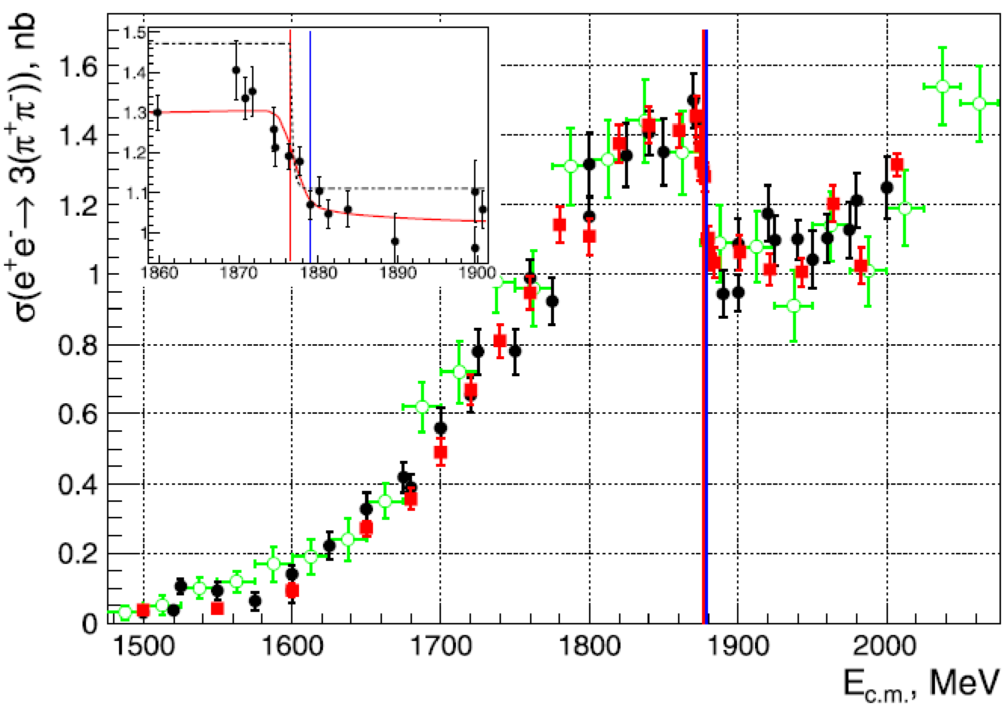
- Amplitude analyses from high statistics and J/ψ , ψ' data
  eg $J/\psi \to \gamma X$, three body decays $J/\psi \to K^+K^-\pi^0$, $\psi' \to K^+K^-\eta$
  … more to come from new 10^{10} J/ψ data.
- Hyperon spin physics…
- Semileptonic D decays with two hadrons in FS (Double tag method)
- Two gamma production …
- η' decays (5×10^7 events) e.g. $\eta' \to \pi^+\pi^-\gamma$, $\eta' \to \pi^+\pi^-\pi^0$

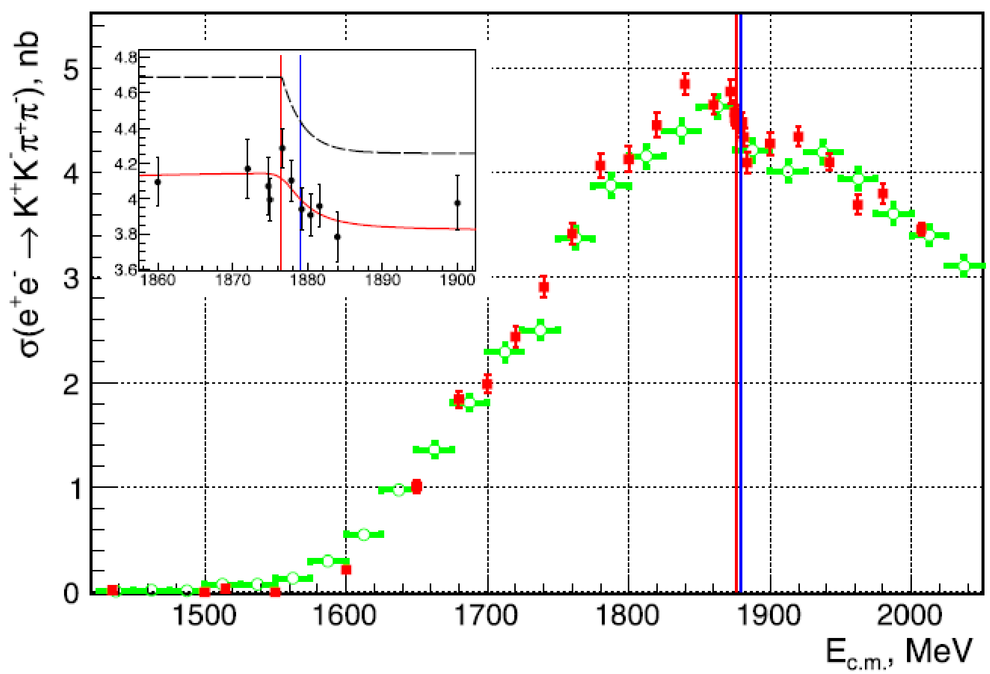
White Paper on the Future Physics Programme of BESIII
e-Print: arXiv:1912.05983

Extra slides

No structures in the $e^+e^- \to 2(\pi^+\pi^-)$

CMD3 Phys.Lett. B794 (2019) 64-68

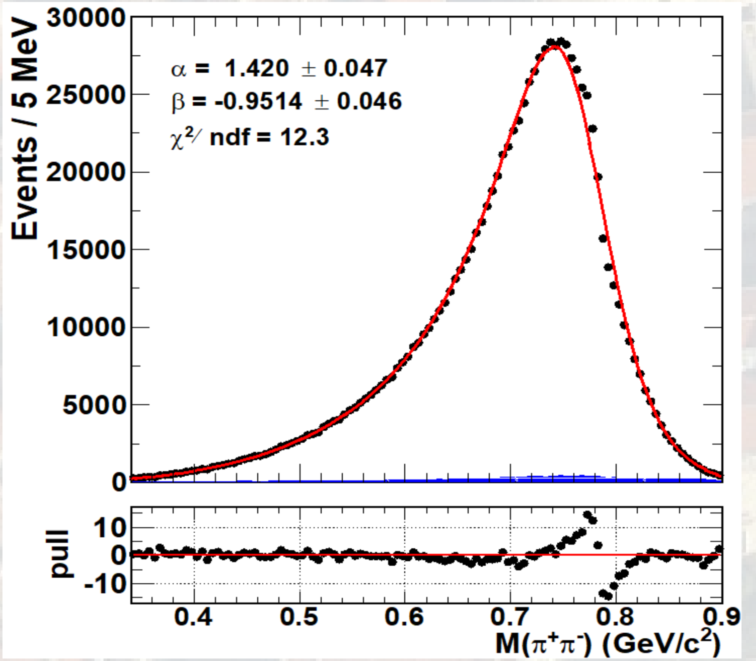


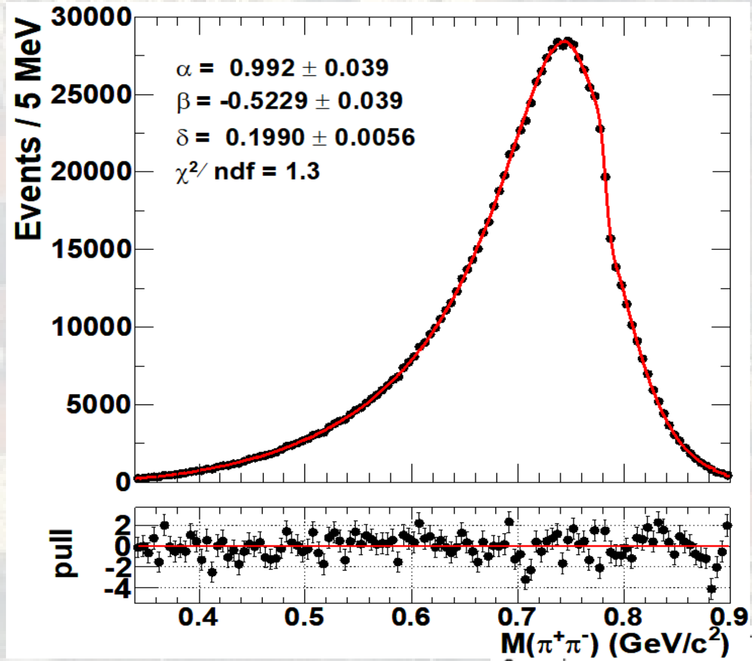


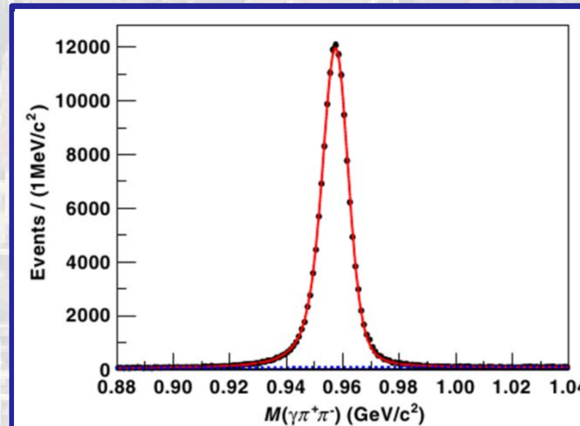
Prel. analysis based on 0.9 × 10^6 $\eta' \to \pi^+\pi^-\gamma$

$$\frac{d\Gamma}{ds_{\pi\pi}} = \left|AP(s_{\pi\pi})F_V(s_{\pi\pi})\right|^2 \Gamma_0(s_{\pi\pi})$$

$P(s_{\pi\pi}) = 1 + \alpha\, s_{\pi\pi} + \beta\, s^2_{\pi\pi}$ $P(s_{\pi\pi}) = 1 + \alpha\, s_{\pi\pi} + \beta\, s^2_{\pi\pi} + \delta\, BW_\omega$







PRD87,092001('13)

ω contribution necessary

Linear polynomial is insufficient...

Phys.Rev.Lett. 120 (2018) 242003