中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

BESIII

Spin-Parity determination of $X(2370)$ in $J/\psi \rightarrow \gamma K_s^0 K_s^0 \eta'$

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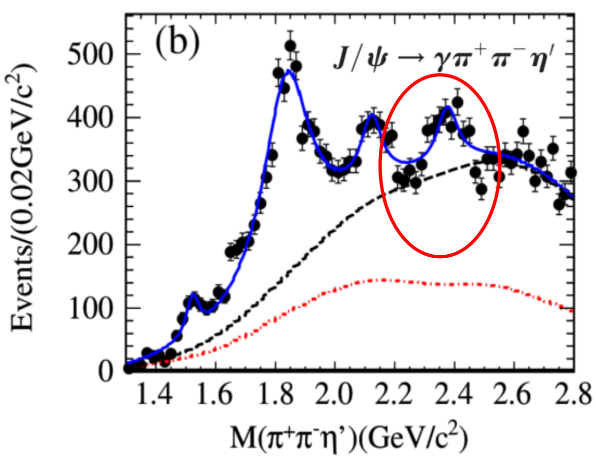
Motivation

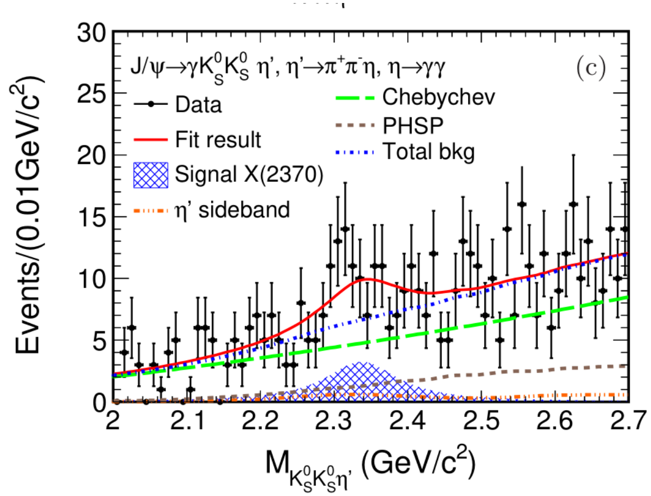
- The X(2370) was first observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$ channel and confirmed in $J/\psi \to \gamma K\bar{K}\eta'$ channel.

Mass (MeV/c²)	Width (MeV/c²)	Decay channel	Reference
$2376.3 \pm 8.7(stat.)^{+3.2}_{-4.3}(syst.)$	$83 \pm 17(stat.)^{+44}_{-6}(syst.)$	$J/\psi \to \gamma\pi^+\pi^-\eta'$	PhysRevLett.106.072002
$2341.6 \pm 6.5(stat.) \pm 5.7(syst.)$	$117 \pm 10(stat.) \pm 8(syst.)$	$J/\psi \to \gamma K\bar{K}\eta'$	Eur. Phys. J. C 80, 746 (2020)

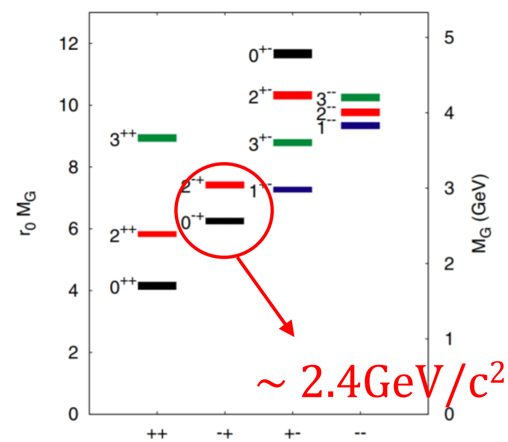
- Determine the Spin-Parity of X(2370) in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ with combined two η' decay modes: $\eta' \to \pi^+\pi^-\eta$ and $\eta' \to \gamma\rho^0$



PhysRevLett.106.072002



Eur. Phys. J. C 80, 746 (2020)



PhysRevD.73.014516

Content

- Data set
- $J/\psi \to \gamma K_S^0 K_S^0 \eta',\ \eta' \to \pi^+\pi^-\eta$
    - Event selection
    - Background analysis
- $J/\psi \to \gamma K_S^0 K_S^0 \eta',\ \eta' \to \gamma\rho^0$
    - Event selection
    - Background analysis
- Partial wave analysis
- Summary

Data set

- BOSS version: 7.0.8
- Data samples: 2009+2012+2018+2019
- Inclusive MC samples: 2009+2012+2018+2019
- $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ signal MC samples (10M)
  - $\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ channel:
    - $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ PHSP
    - $K_S^0 \to \pi^+\pi^-$ PHSP
    - $\eta' \to \pi^+\pi^-\eta$ PHSP
    - $\eta \to \gamma\gamma$ PHSP
  - $\eta' \to \gamma\rho^0, \rho^0 \to \pi^+\pi^-$ channel:
    - $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ PHSP
    - $K_S^0 \to \pi^+\pi^-$ PHSP
    - $\eta' \to \pi^+\pi^-\gamma$ DIY_Etap2gpipi_box

$\eta' \to \pi^+\pi^-\eta$: Object Selection

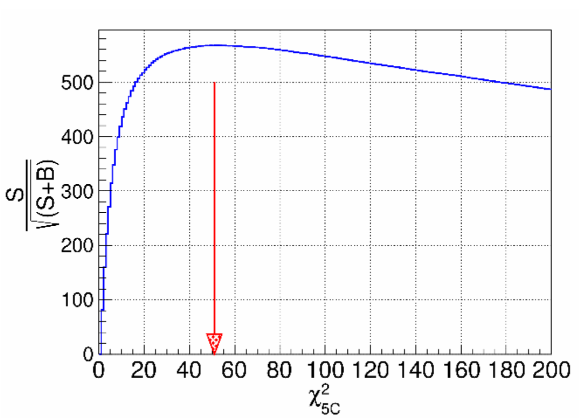
- Good Charged track
  - $R_{xy} < 1cm, R_z < 10cm$
  - $|\cos\theta|$<0.93
  - Ngood>=6, net charge=0
  - Without PID, all charged tracks are considered to be pion.

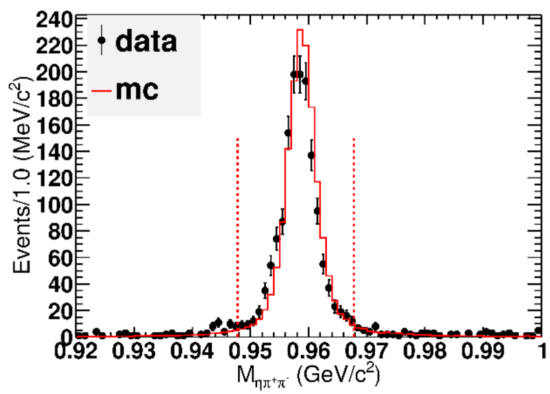
- Good photons
  - Energy>=25Mev/c^2 ($|\cos\theta|$<0.8)
  - Energy>=50Mev/c^2 (0.86<$|\cos\theta|$<0.92)
  - 0<time<14(50ns)
  - N_good >=3
  - $\theta_{\gamma-ch} > 5°$

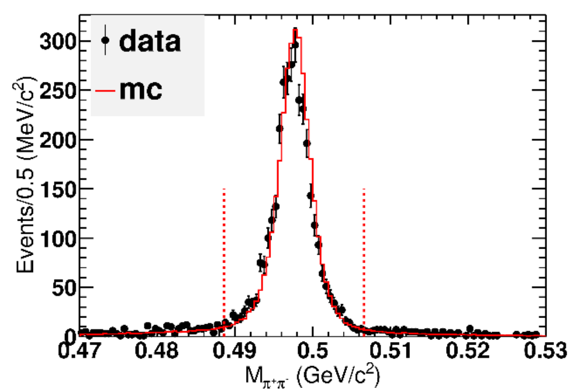
- K_S^0 candidate
  - The vertex fit and the subsequent secondary vertex fit are performed to the all possible $\pi^+\pi^-$ combinations with the invariant mass satisfying $|M_{\pi^+\pi^-} - M_{K_S^0}| \leq 0.04\mathrm{GeV/c^2}$.
  - The number of K_S^0 is required to be not less than two.
  - $L/\sigma_L > 2$
  - There's no requirement of R_{xy} and R_z for the pions from K_S^0

$\eta' \to \pi^+\pi^-\eta$: Event Selection

- $\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ channel:
  - Photon energy: > 0.1 GeV/c^2
  - 5C Kinematic fit: $\chi^2_{5c} < 50$ (S/sqrt(S+B) optimization)
  - $\left|M_{\pi^+\pi^-} - M_{K_S^0}\right| < 0.009$ GeV/c^2 (select K_S^0)
  - $\left|M_{\gamma\gamma} - M_{\pi^0}\right| > 0.02$ GeV/c^2 (veto $\pi^{\mathbf{0}}$)
  - $\left|M_{\gamma\gamma\pi^+\pi^-} - M_{\eta'}\right| < 0.010$ GeV/c^2 (select η')
  - 7C Kinematic fit: successful. K_S^0 and η' candidates should be constrained to their known masses by for further PWA

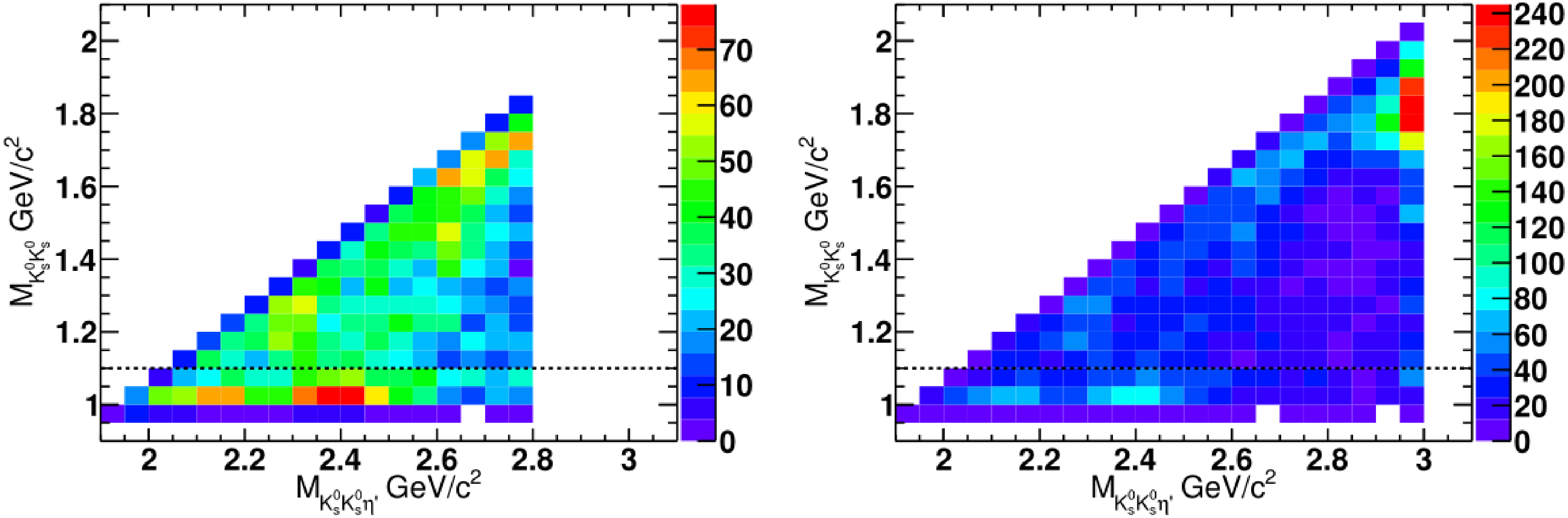






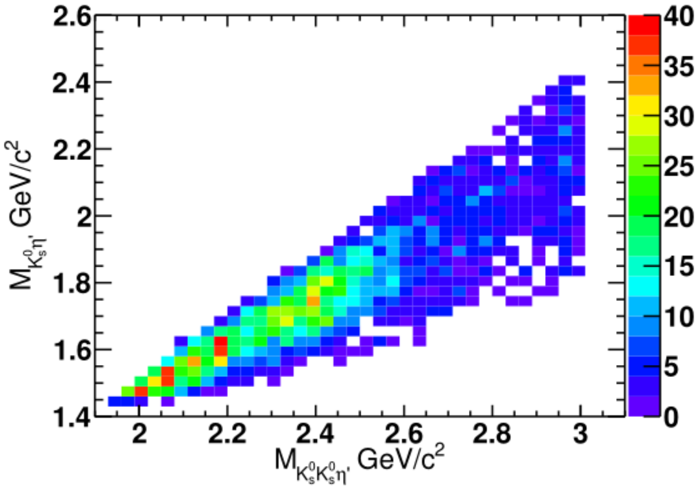
$\eta' \to \pi^+\pi^-\eta$: 2D plots

- $m_{K_S^0 K_S^0 \eta'}$ VS $m_{K_S^0 K_S^0}$

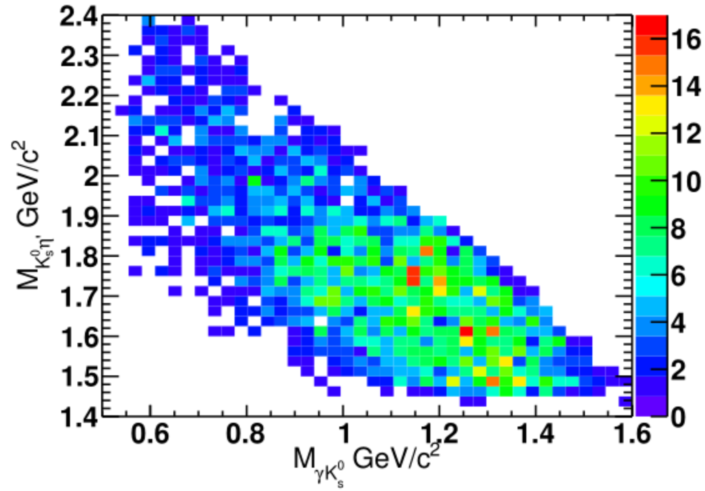


- There is a strong correlation between the X(2370) and $f_0(980)$ in the $K_S^0 K_S^0$ mass spectrum below 1.1 GeV/c^2.

$\eta' \rightarrow \pi^+\pi^-\eta$: 2D plots



(a)



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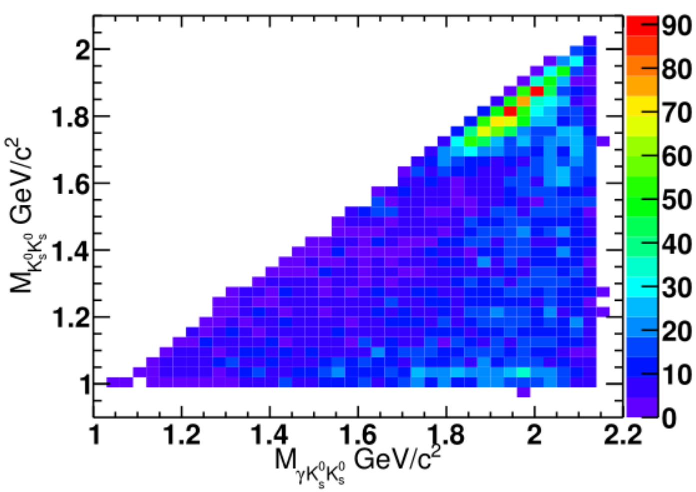

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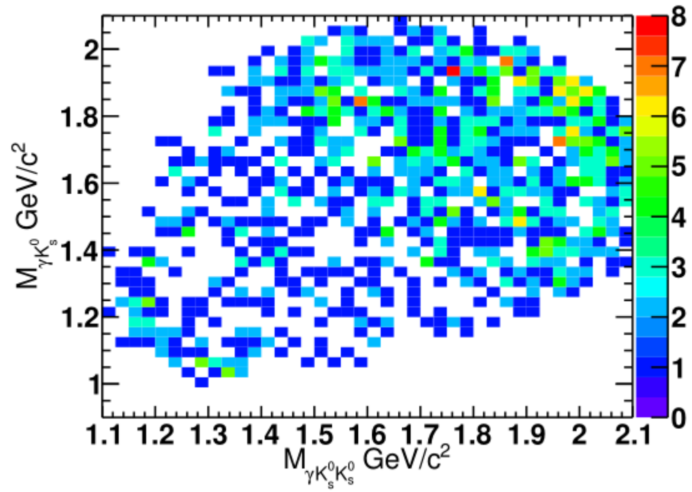
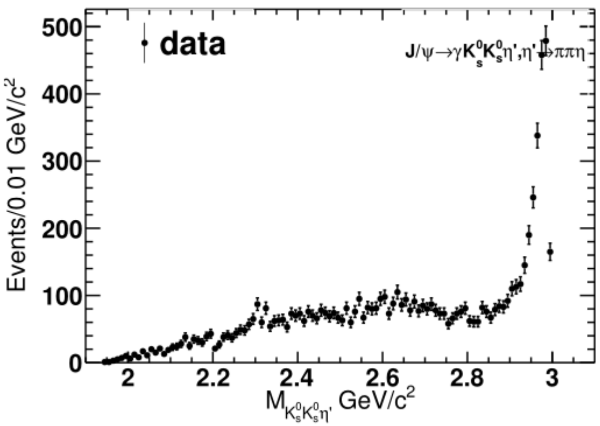
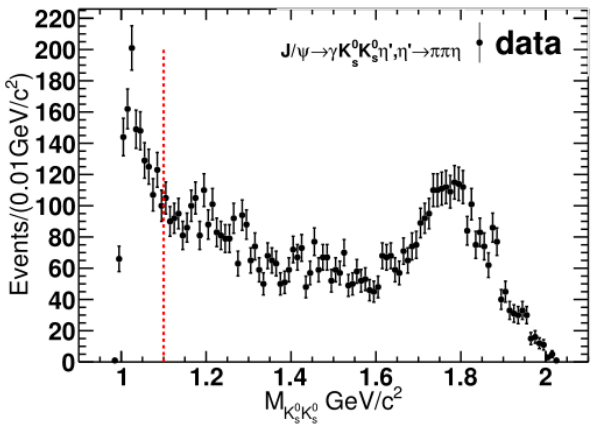


(d)

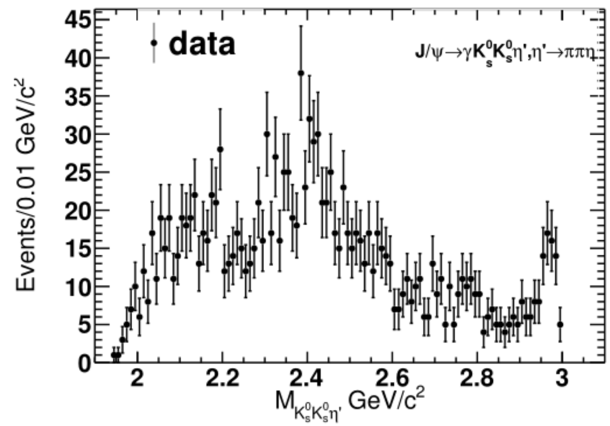
$\eta' \to \pi^+\pi^-\eta$: Mass spectrum

- Invariant mass spectra of $K_S^0K_S^0\eta'$ and $K_S^0K_S^0$





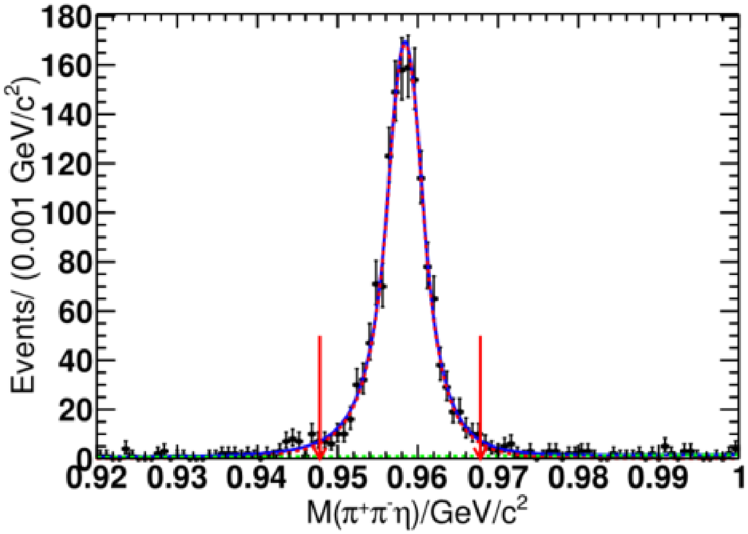
$M_{K_S^0K_S^0} < 1.1$ GeV/c^2

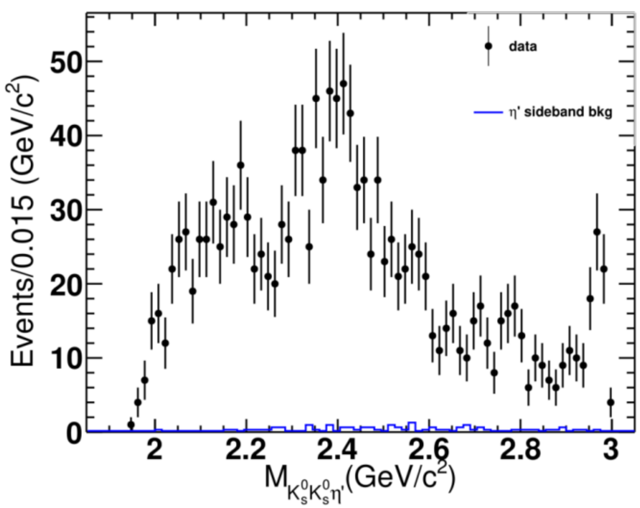


- Require $M_{K_S^0K_S^0} < 1.1$ GeV/c^2 to focus on X(2370).
- We can see the clear structures around 2.1 GeV , 2.4 GeV and 2.9 GeV.

$\eta' \to \pi^+\pi^-\eta$: Backgroud analysis

- Non-η' process background
  - Ratio of non-η' process background is 1.76%.
  - Other background is negligible. So we use the events in η' sideband region to describe backgroud in PWA.
  - Distribution of signal and background.





η' signal region: $\left|M_{\gamma\gamma\pi^+\pi^-} - M_{\eta'}\right| < 10\ \mathrm{MeV/c^2}$

$\eta' \to \gamma\rho^0$: Object Selection

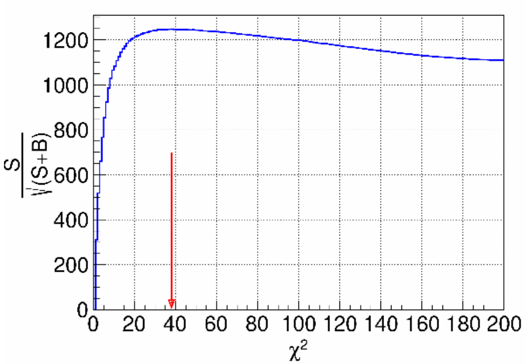
- Good Charged track
  - $R_{xy} < 1cm, R_z < 10cm$
  - |cosθ|<0.93
  - N_good>=6, net charge=0
  - Without PID, all charged tracks are considered to be π in this analysis.

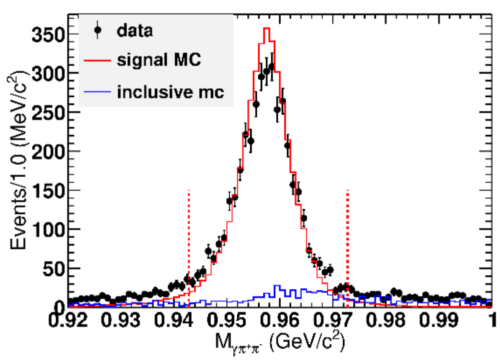
- Good photons
  - Energy>=25Mev/c^2 (|cosθ|<0.8)
  - Energy>=50Mev/c^2 (0.86<|cosθ|<0.92)
  - 0<time<14(50ns)
  - N_good >=2
  - $\theta_{\gamma-ch} > 5°$

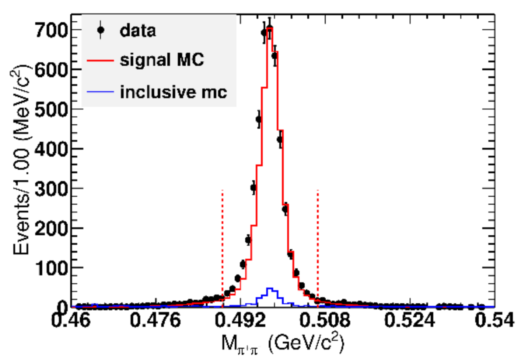
- K_S^0 candidate:
  - vertex fit and the subsequent secondary vertex fit are performed to the all possible $\pi^+\pi^-$ combinations with the invariant mass satisfying $|M_{\pi^+\pi^-} - M_{K_S^0}| \leq 0.04\text{GeV/c}^2$.
  - The number of K_S^0 is required to be not less than two.
  - $L/\sigma_L > 2$
  - There's no requirement of R_{xy} and R_z for the pions from K_S^0

$\eta' \to \gamma\rho^0$: Event Selection

- $\eta' \to \gamma\rho^0, \rho^0 \to \pi^+\pi^-$channel:
  - Photon energy: > 0.1 GeV/c^2
  - 4C Kinematic Fit: $\chi^2_{4c} < 38$ (S/sqrt(S+B) optimization)
  - $\left|M_{\pi^+\pi^-} - M_{K_S^0}\right| < 0.009$ GeV/c^2 (select K_S^0)
  - $\left|M_{\gamma\gamma} - M_{\pi^0}\right| > 0.02$ GeV/c^2 and $\left|M_{\gamma\gamma} - M_{\eta}\right| > 0.03$ GeV/c^2 (veto π^0)
  - $0.55 < M_{\pi^+\pi^-} < 0.9$ GeV/c^2 (select ρ^0)
  - $\left|M_{\gamma\pi^+\pi^-} - M_{\eta'}\right| < 0.015$ GeV/c^2 (select η')
  - 7C Kinematic fit: successful. K_S^0 and η' candidates should be constrained to their known masses by for further PWA

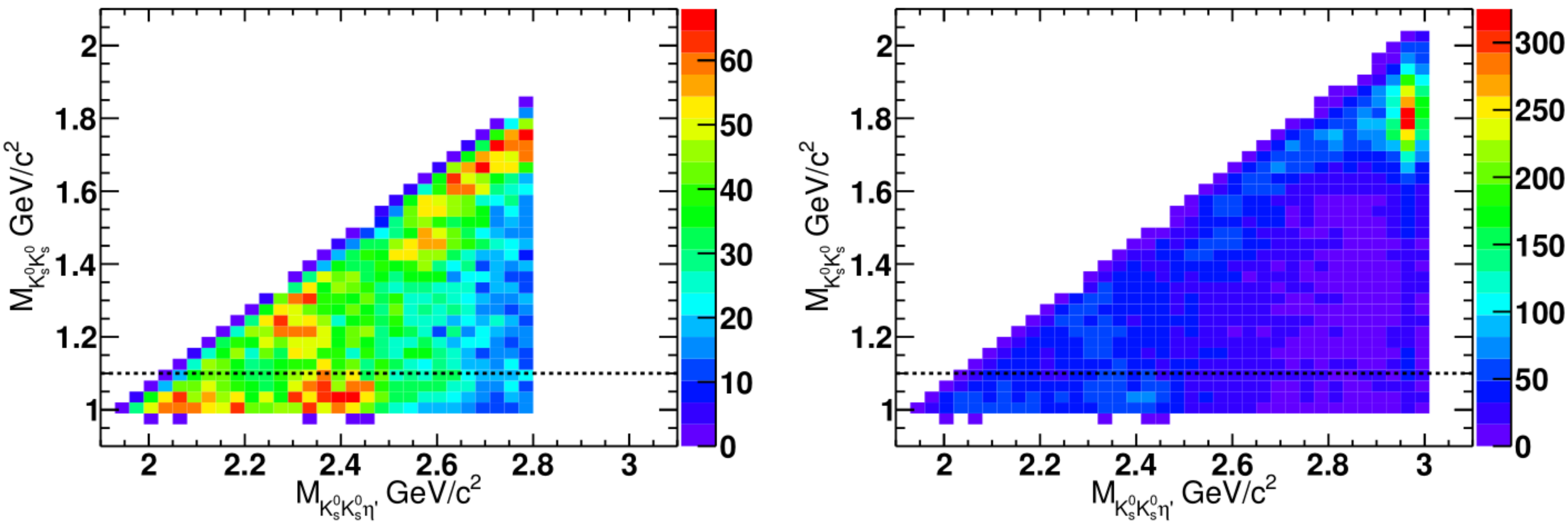






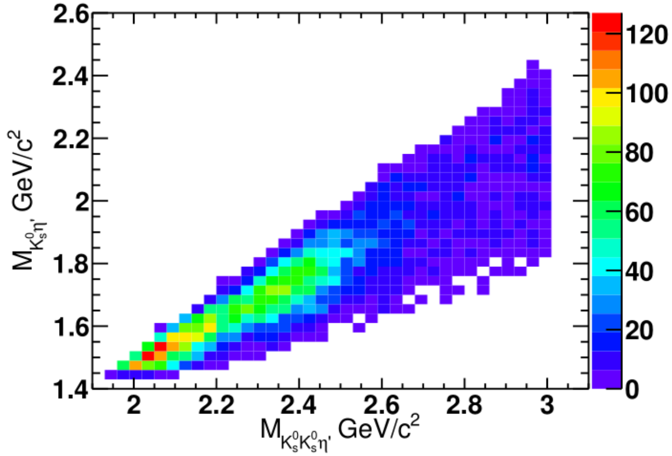
$\eta' \rightarrow \gamma \rho^0$: 2D plots

- $m_{K_S^0 K_S^0 \eta'}$ VS $m_{K_S^0 K_S^0}$

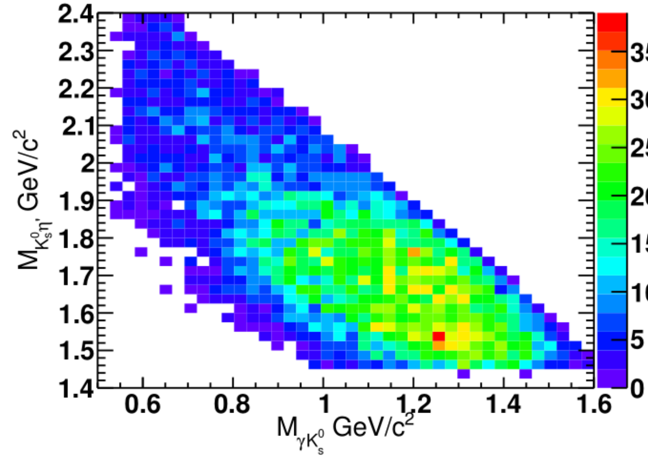


- There is a strong correlation between the X(2370) and $f_0(980)$ in the $K_S^0 K_S^0$ mass spectrum below 1.1 GeV/c^2.

$\eta' \to \gamma\rho^0$: 2D plots



(a)



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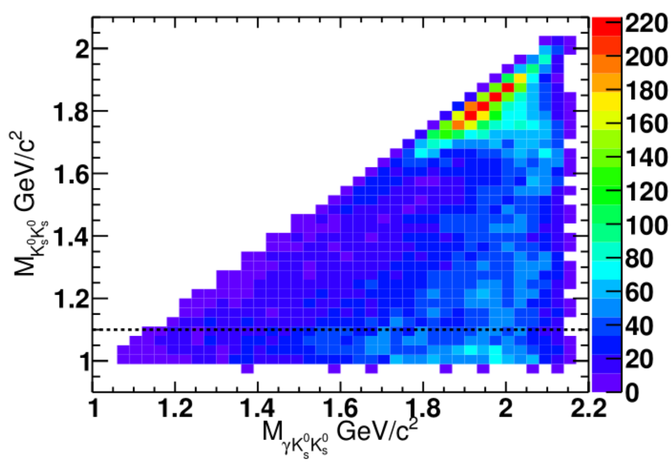

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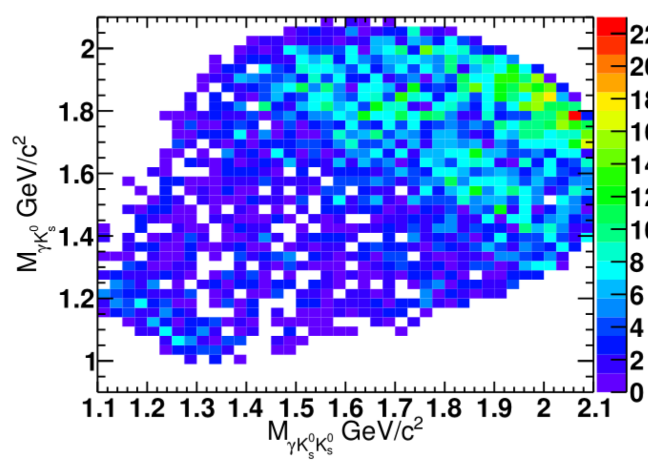
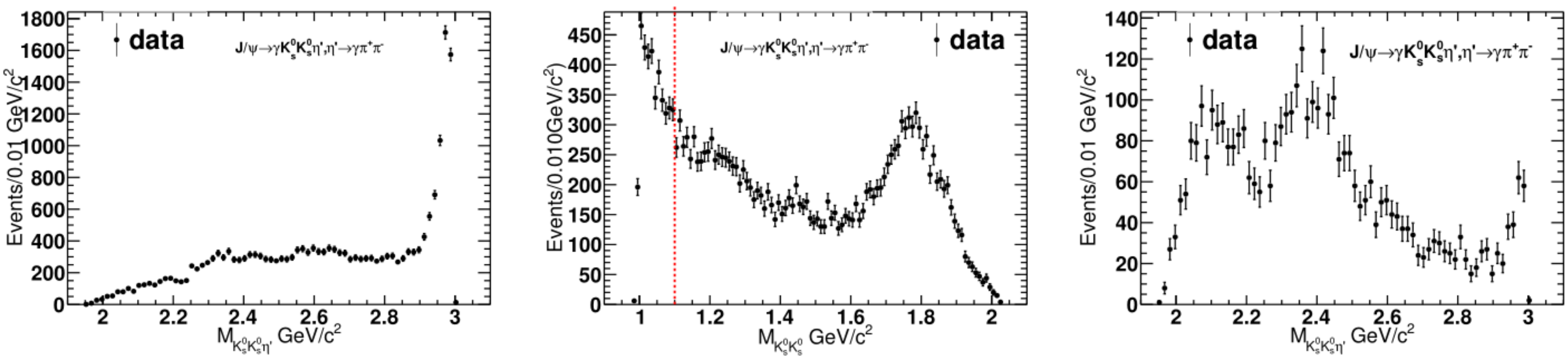


(d)

$\eta' \to \gamma\rho^0$: Mass spectrum

❖ Invariant mass spectra of $K_S^0 K_S^0 \eta'$ and $K_S^0 K_S^0$

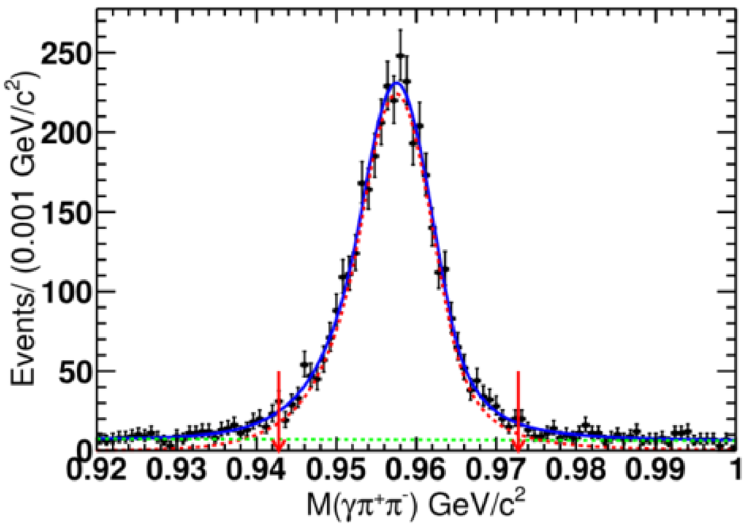
$M_{K_S^0 K_S^0} < 1.1\ \mathrm{GeV/c^2}$

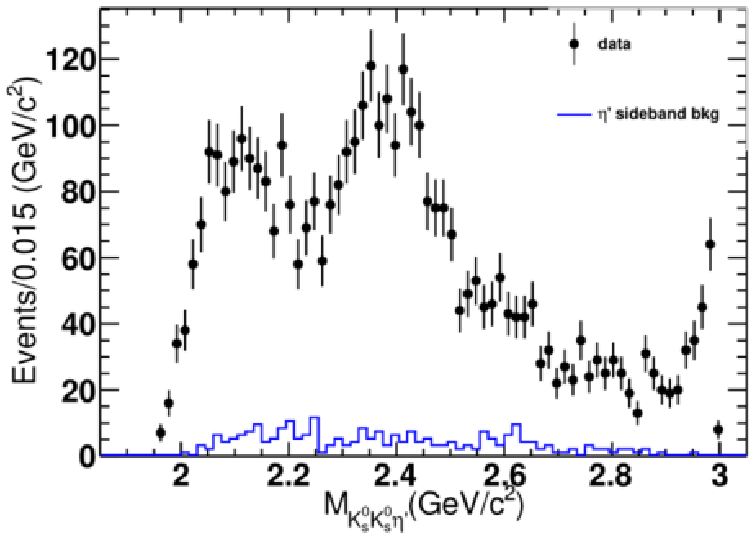


- Require $M_{K_S^0 K_S^0} < 1.1\ \mathrm{GeV/c^2}$ to focus on X(2370).
- We can see the clear structures around 2.1 GeV , 2.4 GeV and 2.9 GeV.

$\eta' \to \gamma\rho^0$: Backgroud analysis

- Non-η' process background
  - Non-η' process background fraction is 6.76%.
  - Other background is negligible. So we use the events in η' sideband region to describe backgroud in PWA.
  - Distribution of signal and background.





η' signal region: $|M_{\gamma\pi^+\pi^-} - M_{\eta'}| < 15\ \mathrm{MeV/c^2}$

PWA strategy

- Perform a combined fit on the candidate events of the two η' decay modes to improve the sensitivity.
- Combined log likelihood value:

$$S = S_1 + S_2$$
$$= \left(-ln\mathcal{L}_{sig1} + f_{norm1} \cdot ln\mathcal{L}_{bkg1}\right) + \left(-ln\mathcal{L}_{sig1} + f_{norm1} \cdot ln\mathcal{L}_{bkg2}\right)$$

  - Here, S_1 and S_2 are the log likelihoods of the two decay modes, respectively. f_{norm1} and f_{norm2} are the normalization factors from η' sideband to η' signal region.
- Two individual phase space MC samples are combined according to the normalized intergral of the two η' decay modes.
- Background treatment: After normalization, the events in η' sideband region are used to describe non-η' background in η' signal region.

PWA strategy

❖ Combined log likelihood value:

$$
\begin{aligned}
S &= \left(-\ln \mathcal{L}_{sig1} + f_{norm1} \cdot \ln \mathcal{L}_{sideband1}\right) + \left(-\ln \mathcal{L}_{sig1} + f_{norm2} \cdot \ln \mathcal{L}_{sideband2}\right) \\
&= -\left(\sum_{i=1}^{N_{sig1}} \ln \frac{\omega(\xi_i)}{\sigma}\right) - \left(\sum_{i=1}^{N_{sig2}} \ln \frac{\omega(\xi_i)}{\sigma}\right) \\
&\qquad + f_{norm1} \cdot \left(\sum_{i=1}^{N_{sideband1}} \ln \frac{\omega(\xi_i)}{\sigma}\right) + f_{norm2} \cdot \left(\sum_{i=1}^{N_{sideband2}} \ln \frac{\omega(\xi_i)}{\sigma}\right)
\end{aligned}
$$

decay mode	$N_{event}^{selected\ data}$	$N_{event}^{selected\ MC}$	$N_{event}^{sideband}$	f_{norm}
$\eta' \to \pi^+\pi^-\eta$	1395	22873	31	1.05
$\eta' \to \gamma\pi^+\pi^-$	3979	78729	338	1.07

Resonance parameterization

- The ordinary intermediate resonance is parameterized by the Breit-Wigner propagator:

$$BW(s) = \frac{M_R \Gamma_R}{s - M_R^2 + i M_R \Gamma_R}$$

- According to the result of CLEO collaboration, the η_c signal is parameterized following formula:

$$f^{(\eta_c)}_{propagator} = \sqrt{f_{damp}(E_\gamma)} \times BW(s)$$

$$f_{damp}(E_\gamma) = e^{-\frac{E_\gamma^2}{8\beta^2}}, \ \beta = 0.065 \ GeV$$

$$E_\gamma = \frac{m^2_{J/\psi} - s}{2 m_{J/\psi}}$$

Nominal solution

- Combined channels: $J/\psi \to \gamma K_S^0 K_S^0 \eta', \eta' \to \pi^+\pi^-\eta$ and $\eta' \to \gamma\rho^0$
- Data: all $M_{K_S^0 K_S^0 \eta'}$ with $M_{K_S^0 K_S^0} < 1.1\ \mathrm{GeV}/c^2$, momenta from 7C kimimatic fit
- Background: η' sideband
- Justification: significance > 5σ, interference<100%
- Current nominal pwa solution

state	J^{PC}	Decay mode	Mass (MeV/c^2)	Width (MeV/c^2)	Significance
X(2370)	0^{-+}	$f_0(980)\eta'$	2395^{+11}_{-11}	188^{+18}_{-17}	14.9σ
X(1835)	0^{-+}	$f_0(980)\eta'$	1844	192	$> 20\sigma$
X(2750)	0^{-+}	$f_0(980)\eta'$	2815^{+53}_{-54}	641^{+181}_{-108}	16.4σ
η_c	0^{-+}	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	0^{-+}	$\eta'(K_S^0 K_S^0)_{S-wave}$	$---$	$---$	9.0σ
		$\eta'(K_S^0 K_S^0)_{D-wave}$	$---$	$---$	16.3σ

Nominal solution

- Interference for all combinations of two components:

Table 12: The fractions of each components and their interferences

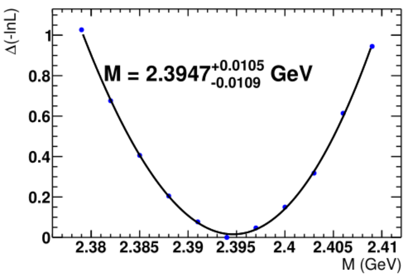
component(%)	$X(2370) \to f_0(980)\eta'$	$X(1835) \to f_0(980)\eta'$	$X(2750) \to f_0(980)\eta'$	$\eta_c \to f_0(980)\eta'$	$PHSP \to \eta'(K_S^0K_S^0)_{S-wave}$	$PHSP \to \eta'(K_S^0K_S^0)_{D-wave}$
$X(2370) \to f_0(980)\eta'$	15.4	26.2	27.2	0.7	-19.2	0.1
$X(1835) \to f_0(980)\eta'$		35.6	11.5	-0.9	-33.3	0.1
$X(2750) \to f_0(980)\eta'$			36.2	4.4	-28.1	0.1
$\eta_c \to f_0(980)\eta'$				5.0	1.0	0.0
$PHSP \to \eta'(K_S^0K_S^0)_{S-wave}$					15.7	-0.1
$PHSP \to \eta'(K_S^0K_S^0)_{D-wave}$						2.4

Table 13: The interference intensity ($\frac{N_{ij}}{\sqrt{N_i \cdot N_j}}$) of two components

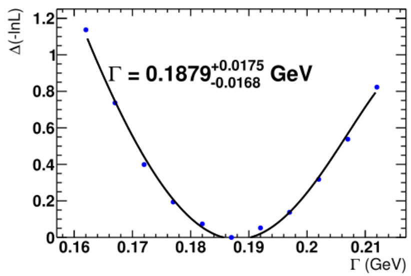
component	$X(2370) \to f_0(980)\eta'$	$X(1835) \to f_0(980)\eta'$	$X(2750) \to f_0(980)\eta'$	$\eta_c \to f_0(980)\eta'$	$PHSP \to \eta'(K_S^0K_S^0)_{S-wave}$	$PHSP \to \eta'(K_S^0K_S^0)_{D-wave}$
$X(2370) \to f_0(980)\eta'$	1.00	1.12	1.15	0.08	-1.23	0.02
$X(1835) \to f_0(980)\eta'$		1.00	0.32	-0.07	-1.41	0.01
$X(2750) \to f_0(980)\eta'$			1.00	0.33	-1.18	0.02
$\eta_c \to f_0(980)\eta'$				1.00	0.11	0.00
$PHSP \to \eta'(K_S^0K_S^0)_{S-wave}$					1.00	-0.02
$PHSP \to \eta'(K_S^0K_S^0)_{D-wave}$						1.00

Scanning curves of nominal solution

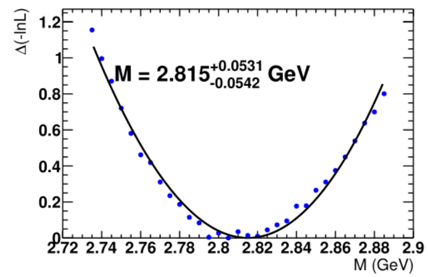
- left: X(2370)
- right: X(2750)



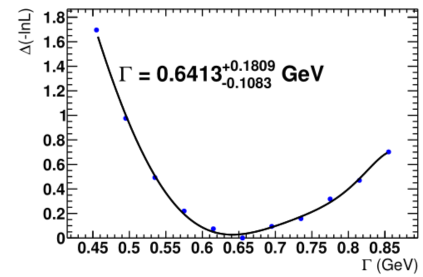
(a) Mass of the X(2370)



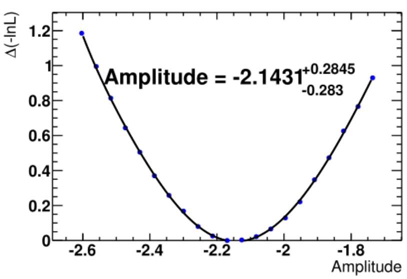
(b) Width of the X(2370)



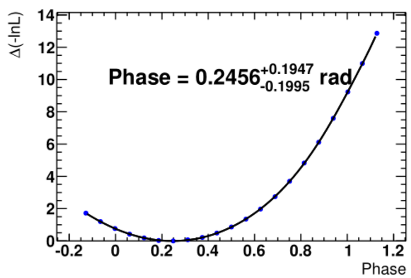
(a) Mass of the X(2750)



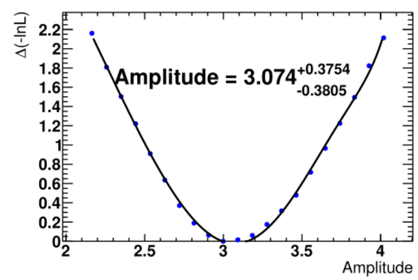
(b) Width of the X(2750)



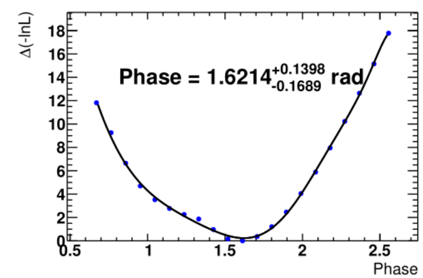
(c) Amplitude of the X(2370)



(d) Phase of the X(2370)



(c) Amplitude of the X(2750)



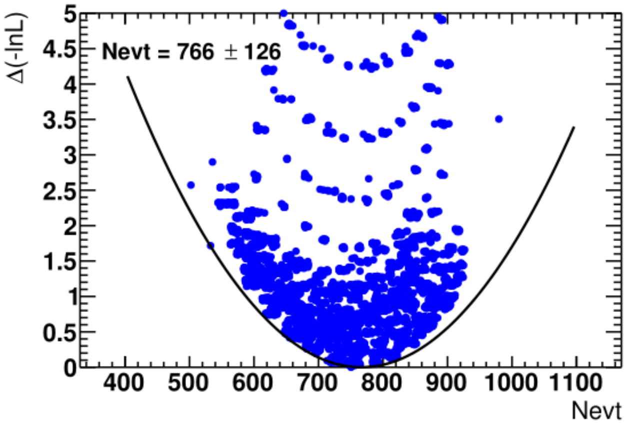
(d) Phase of the X(2750)

Branch fraction measurement

- The corresponding product branching fraction can be calculated as the following formula

$$\mathcal{B}[J/\psi \to \gamma X(2370)] \times \mathcal{B}[X(2370) \to f_0(980)\eta'] \times \mathcal{B}[f_0(980) \to K_S^0 K_S^0]$$
$$= \frac{N_{X(2370)}}{N_{J/\psi} \cdot \left(\mathcal{B}[K_S^0 \to \pi^+\pi^-]\right)^2 \cdot \left(\mathcal{B}[\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma] \cdot \varepsilon_{X(2370)}^{\eta' \to \pi^+\pi^-\eta} + \mathcal{B}[\eta' \to \gamma\pi^+\pi^-] \cdot \varepsilon_{X(2370)}^{\eta' \to \gamma\pi^+\pi^-}\right)}$$

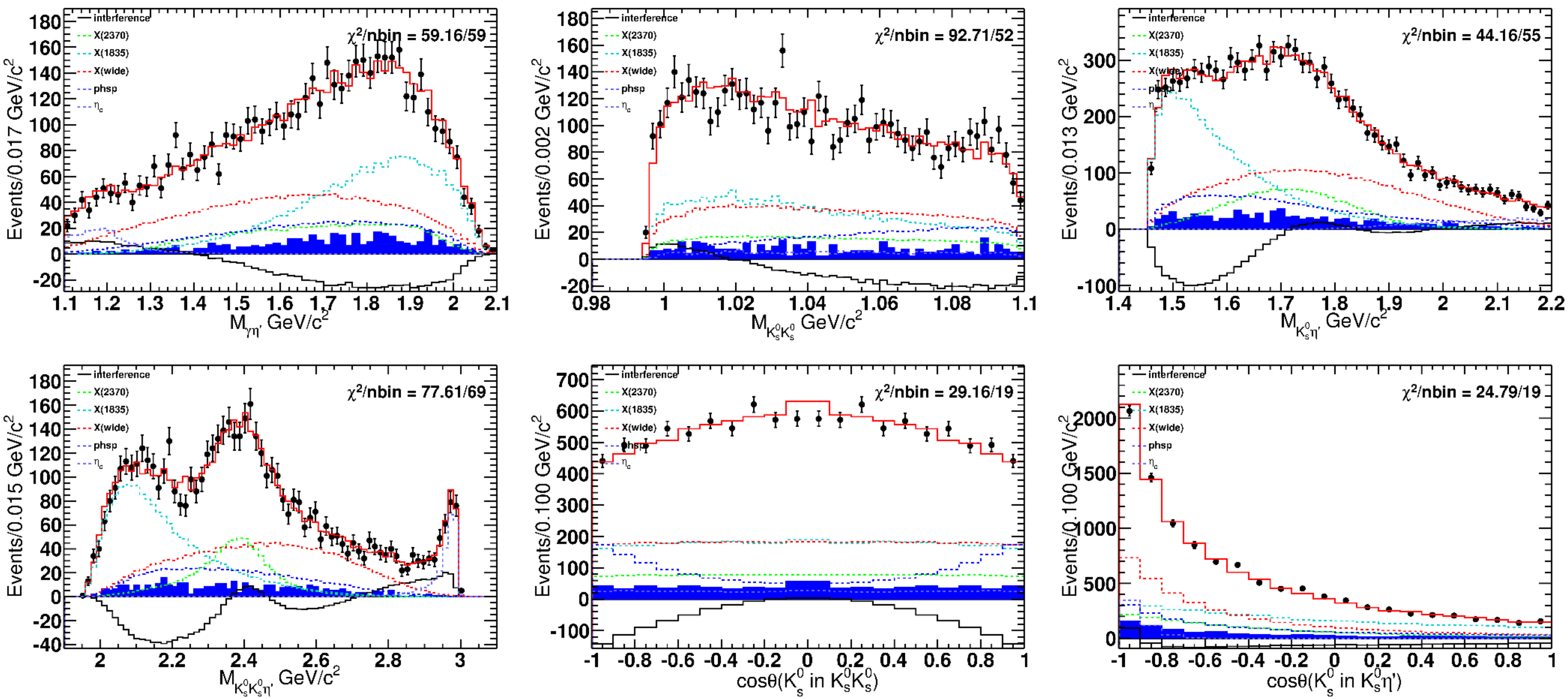
- We change the mass and width of X(2370) by one standard statistical deviation and each mass-width combination is performed PWA fit 300 times.



$$\mathcal{B}[J/\psi \to \gamma X(2370)] \times \mathcal{B}[X(2370) \to f_0(980)\eta']$$
$$\times \mathcal{B}[f_0(980) \to K_S^0 K_S^0] = \left(1.32^{+0.22}_{-0.22}(stat.)\right) \times 10^{-5}$$

Projection plots of nominal solution

- Combined two η' decay modes:
  - Total intensity of sum of all interference terms: -10.3%



Check list of nominal solution

- J^{pc} of the resonances in the nominal resolution
  - X(2370), PHSP, X(wide), X(1835) and η_c
- Significance of additional waves
- Significance of additional resonances
  - Addtional resonance($X_{K_S^0 K_S^0 \eta'}$) scanning
  - The X(2120) (observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$, Phys. Rev. Lett.117:042002)
  - The X(2600) (observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$, arXiv:2201.10796)

J^{pc} check of nominal solution

- J^{pc} check for the X(2370)/PHSP

Table 9: ΔS comparing to nominal solution for different J^{PC} of X(2370) and PHSP. The changes of S value (ΔS) and the number of degrees of freedom ($\Delta ndof$) are marked with black and blue respectively.

State		$X(2370)$		
	J^{PC} and decay mode	$0^{-+} \to f_0(980)\eta'$	$1^{++} \to f_0(980)\eta'$	$2^{-+} \to f_0(980)\eta'$
PHSP	$0^{-+} \to (K_S^0 K_S^0)_{S/D-wave}\eta'$	$\boxed{0\ (0)}$ $(\Delta S)_{\mathrm{min}}$	+89 (+2)	+50 (+4)
	$1^{++} \to (K_S^0 K_S^0)_{S/D-wave}\eta'$	+45 (+6)	+92 (+8)	+78 (+10)
	$2^{-+} \to (K_S^0 K_S^0)_{S/D-wave}\eta'$	+44 (+10)	+101(+12)	+56 (+14)
	$2^{++} \to (K_S^0 K_S^0)_{D-wave}\eta'$	+36 (+2)	+104(+4)	+69 (+6)

- J^{pc} check for the X(wide)

State	J^{PC}	Decay mode	ΔS	$\Delta ndof$
X(wide)	0^{-+}	$f_0(980)\eta'$	0	0
	1^{++}	$f_0(980)\eta'$	+108	+2
	2^{-+}	$f_0(980)\eta'$	+78	+4

- Both the X(2370) and the PHSP favor to 0^{-+}
- X(wide) favor to 0^{-+}

J^{pc} check of nominal solution

- J^{pc} check for the X(1835)

State	J^{PC}	Decay mode	ΔS	$\Delta ndof$
X(1835)	0^{-+}	$f_0(980)\eta'$	0	0
	1^{++}	$f_0(980)\eta'$	+150	+2
	2^{-+}	$f_0(980)\eta'$	+203	+4

- J^{pc} check for the η_c

State	J^{PC}	Decay mode	ΔS	$\Delta ndof$
η_c	0^{-+}	$f_0(980)\eta'$	0	0
	1^{++}	$f_0(980)\eta'$	+31	+2
	2^{-+}	$f_0(980)\eta'$	+26	+4

- The η_c and the X(1835) favor to 0^{-+}, which are consistent with previous study.

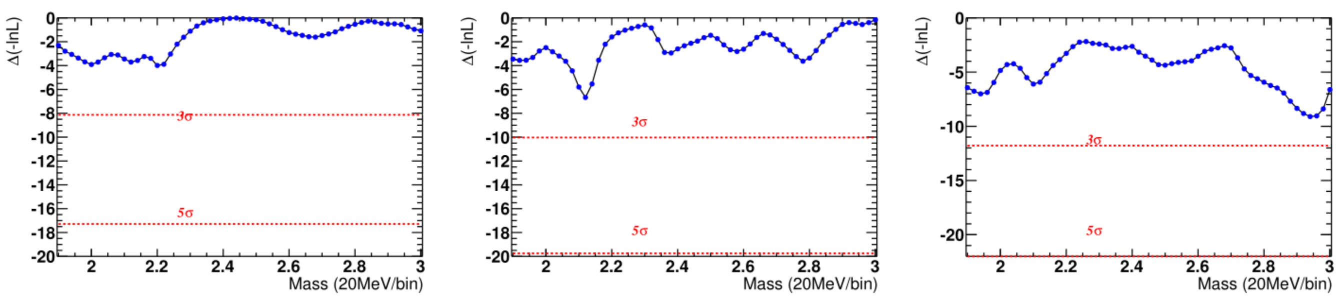
Additional wave check

- Significance of additional wave for each resonance in nominal solution
  - The significance of every additional wave $< 5\sigma$

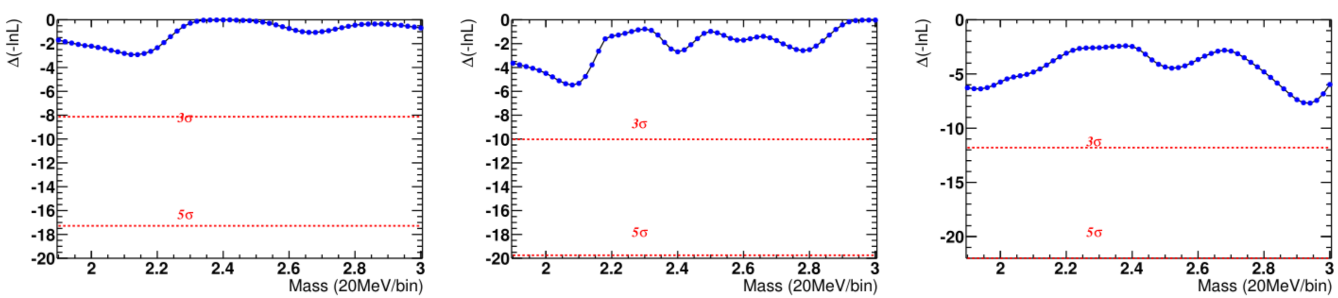
Decay mode \ state	$X(2370)$	$X(1835)$	$X(2750)$	η_c	$PHSP$
$0^{-+} \to f_0(980)\eta'$	$--$	$--$	$--$	$--$	2.0σ
$0^{-+} \to f_0(1500)\eta'$	1.1σ	3.0σ	2.2σ	1.2σ	2.3σ
$0^{-+} \to f_2(1270)\eta'$	2.8σ	3.2σ	1.5σ	2.0σ	1.8σ
$0^{-+} \to K^*(1410)K_s^0$	2.4σ	0.1σ	0.5σ	0.3σ	1.2σ
$0^{-+} \to K_0^*(1430)K_s^0$	1.8σ	1.0σ	2.8σ	2.0σ	1.5σ
$0^{-+} \to K_2^*(1430)K_s^0$	3.0σ	2.0σ	2.4σ	1.5σ	2.5σ
$0^{-+} \to K^*(1680)K_s^0$	1.3σ	2.7σ	1.9σ	1.1σ	2.6σ
$0^{-+} \to (K_S^0K_S^0)_{S-wave}\eta'$	1.5σ	3.6σ	1.7σ	1.0σ	$--$
$0^{-+} \to (K_S^0K_S^0)_{D-wave}\eta'$	2.7σ	2.6σ	1.2σ	1.6σ	$--$
$0^{-+} \to (K_S^0\eta')_{P-wave}K_S^0$	3.0σ	2.1σ	1.8σ	2.0σ	2.9σ
$0^{-+} \to (K_S^0\eta')_{D-wave}K_S^0$	1.4σ	3.6σ	1.7σ	1.1σ	2.4σ

Additional resonance check

- Addtional resonance($X_{K_S^0 K_S^0 \eta'}$) scanning with step=20MeV based on the nominal solution:
- In each plot, the upper and bottom red-color dashed lines represent for the ΔS corresponding to 3σ and 5σ respectively.
- The significance of every additional resonance $< 5\sigma$



(a) $0^{-+} \to f_0(980)\eta'$, $\Gamma = 0.1\ GeV/c^2$ (b) $1^{++} \to f_0(980)\eta'$, $\Gamma = 0.1\ GeV/c^2$ (c) $2^{-+} \to f_0(980)\eta'$, $\Gamma = 0.1\ GeV/c^2$



(d) $0^{-+} \to f_0(980)\eta'$, $\Gamma = 0.2\ GeV/c^2$ (e) $1^{++} \to f_0(980)\eta'$, $\Gamma = 0.2\ GeV/c^2$ (f) $2^{-+} \to f_0(980)\eta'$, $\Gamma = 0.2\ GeV/c^2$

The X(2120) contribution?

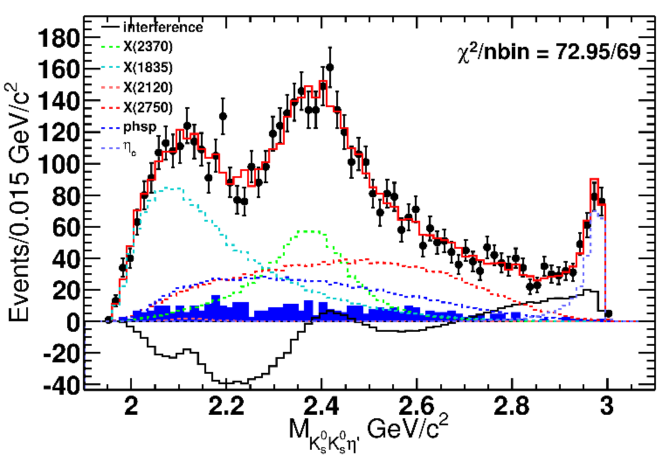
- The changes of resonance parameters

Phys. Rev. Lett.117:042002

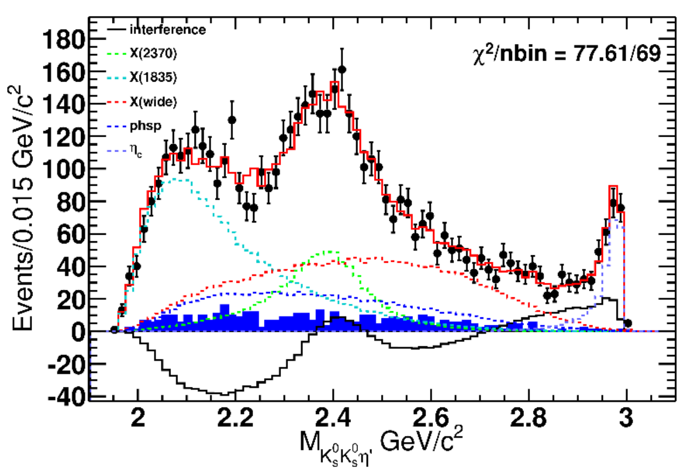
  - The mass and width of X(2120) are fixed to M = 2122 MeV/c^2,Γ = 84 MeV/c^2

Additional state	J^{PC}	Decay mode	Significance	Changes of resonance parameters of X(2370)		
				ΔM (MeV/c^2)	$\Delta\Gamma$ (MeV/c^2)	$\Delta\mathcal{B}/\mathcal{B}$ (%)
X(2120)	0^{-+}	$f_0(980)\eta'$	2.7σ	-10	$+10$	$+22.14$

- Projection plots



With the X(2120)



Without the X(2120)

The X(2600) contribution?

- The optimized result after adding the X(2600) arXiv:2201.10796

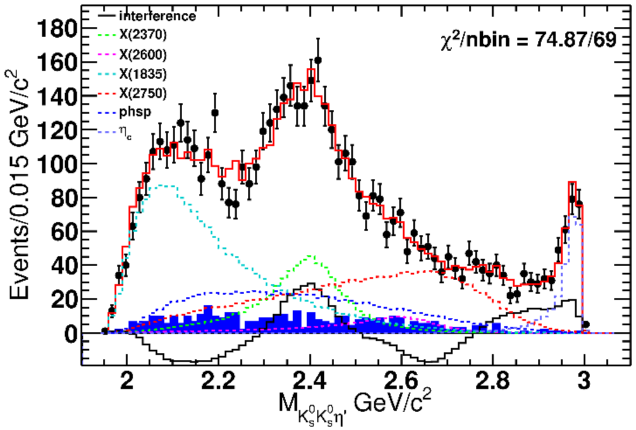
state	J^{PC}	Decay mode	Mass (MeV/c^2)	Width (MeV/c^2)	Significance
X(2370)	0^{-+}	$f_0(980)\eta'$	2405^{+13}_{-13}	167^{+20}_{-18}	12.7σ
X(2600)	0^{-+}	$f_0(980)\eta'$	2618.3	195	4.2σ
X(1835)	0^{-+}	$f_0(980)\eta'$	1844	192	$> 20\sigma$
X(2750)	0^{-+}	$f_0(980)\eta'$	2781^{+32}_{-35}	363^{+146}_{-81}	10.1σ
η_c	0^{-+}	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	0^{-+}	$(K^0_S K^0_S)_{S/D-wave}\eta'$	$---$	$---$	18.0σ

The X(2370) measurement results and nominal results are consistent within the margin of error.

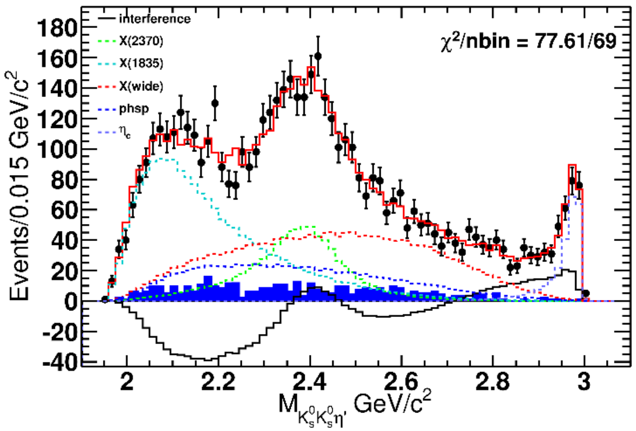
Changes of resonance parameters of X(2370)

ΔM (MeV/c^2)	$\Delta\Gamma$ (MeV/c^2)	$\Delta\mathcal{B}/\mathcal{B}$ (%)
+10	−21	−17.56

- Projection plots



With the X(2600)



Without the X(2600)

Systematic uncertainty

- The sources of systematic uncertainty are listed in table
  - For following assumptions, the difference with nominal PWA solution will be considered as an uncertainty on mass, width and branching ratio measurement.

source	ΔM $MeV/c^2)$	$\Delta\Gamma$ (MeV/c^2)	$\Delta\mathcal{B}/\mathcal{B}$ (%)
total number of J/ψ	$--$	$--$	± 0.44
K_S^0 reconstruction	$--$	$--$	± 3.0
Photon detection	$--$	$--$	± 3.0
4C kinematic fit	$--$	$--$	± 0.7
Intermediate branching fraction	$--$	$--$	± 0.5
Uncertainty from background estimation	$^{+5}_{-10}$	$+10$	$^{+13.79}_{-1.77}$
Uncertainty from the X(1835)	$+2$	$^{+4}_{-4}$	$^{+3.66}_{-5.06}$
Uncertainty from the X(2120)	-10	$+10$	$+22.14$
Uncertainty from the X(2600)	$+10$	-21	-17.56
Uncertainty from the $f_0(980)$ parameterization	-5	$+5$	$+5.31$
Total	$^{+11}_{-15}$	$^{+11}_{-21}$	$^{+23.18}_{-18.30}$

Summary

- Based on the measurement of the combined two η' decay modes, the J^{pc} of the X(2370) is 0^{-+}.
- In current nominal solution, the mass and width of the X(2370) are:
  - Mass $= 2395^{+11}_{-11}(stat.)^{+11}_{-15}(syst.)\ \mathrm{MeV}/c^2$
  - Width $= 188^{+18}_{-17}(stat.)^{+12}_{-21}(syst.)\ \mathrm{MeV}/c^2$
- $B[J/\psi \to \gamma \mathrm{X}(2370)] \cdot B[\mathrm{X}(2370) \to f_0(980)\eta'] \cdot B[f_0(980) \to K_s^0 K_s^0]$
  $= 1.32^{+0.22}_{-0.22}(stat.)^{+0.31}_{-0.25}(syst.) \times 10^{-5}$

- DocDB: Spin-Parity determination of the X(2370)
- Hypernews: BAM-00603

Thanks!