Note: all the results shown here are preliminary and not published. Please keep them privatively !

Study of the two-photon processes $\gamma\gamma \to VV$ ($V = \omega$ or ϕ) and search for dibaryon resonance in $\Upsilon(1S)$ and $\Upsilon(2S)$ data

C. P. Shen[1], T. Iijima[1]

[1] Nagoya University, Nagoya

August 4, 2011

Who am I ?

Name: Chengping Shen

EDUCATION

- Ph. D. Major: Particle Physics Experiments
  2004.7 – 2007.7 Institute of High Energy Physics, Beijing, China.
- M. Sc. Major: Theoretical Physics
  2001.9 – 2004.7 Nanjing Normal University, Nanjing, Jiangsu, China.
- Bachelors Major: Physics Education
  1997.9 – 2001.7 Anhui Normal University, Wuhu, Anhui, China.

PROFESSIONAL EMPLOYMENT

- Assistant Professor: Particle Physics Experiments
  2011.5 – Department of Physics, Nagoya University, Nagoya, Japan
- Postdoctoral Research Assistant: Particle Physics Experiments
  2007.7 – 2011.4 University of Hawaii, Honolulu, Hawaii, USA

Personal website: http://www.phys.hawaii.edu/~shencp

At Nagoya Univ., I mainly do the hadron physics analysis using Belle data. I enjoy the life here very much!

Study of the two-photon processes $\gamma\gamma \to VV$ ($V = \omega$ or ϕ)

Motivation

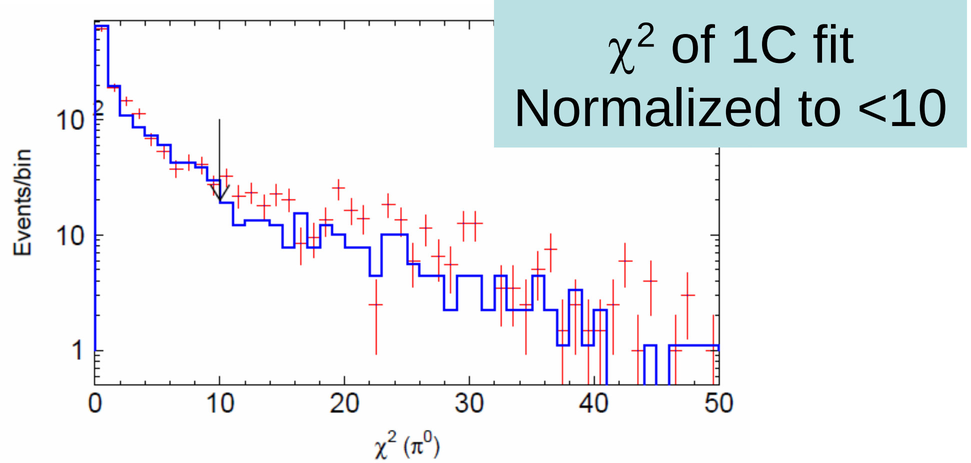
- X(3915)→$\omega J/\psi$, X(4350)→$\phi J/\psi$ observed in two-photon processes could be tetraquark states, with a pair of charm quarks and a pair of light quarks
- The XYZ (charmonium-like states) have mass above the open charm threshold, but usually we do not find a place for them in the charmonium model
- Recently Belle observed two charged Z states Zb(10610) and Zb(10650) in Y(5s) decays
- Is there state X decays into two pairs of light quarks: $\omega\omega$, $\omega\phi$, $\phi\phi$? It is a nature extenation to the low energy region around 2 GeV/c^2
- BES observed an X(1812)→$\omega\phi$ in J/ψ radiative decays, but not confirmed in other mode.

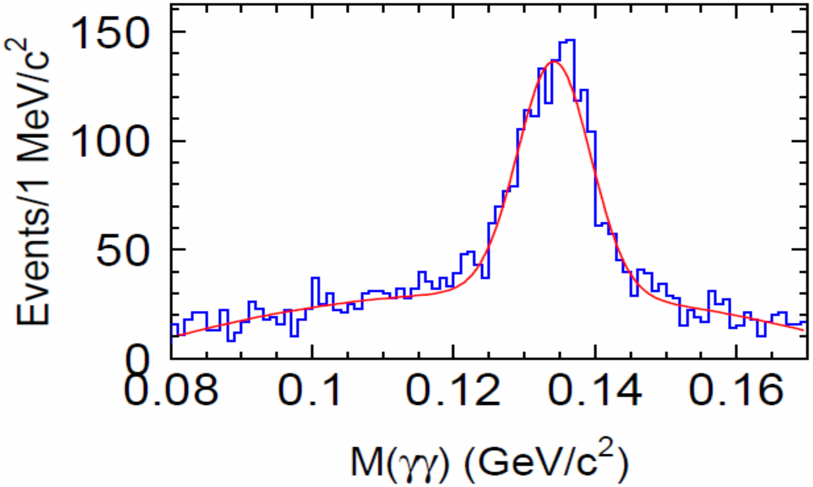
Data Sample

- Lowmulti-skim
- Exps.7-67 (Case B)
- Luminosity=870.41/fb
- MC: TREPS
  - $J^P=0^+/2^+/0^-/2^-$
  - $\omega\phi$, $\phi\phi$ and $\omega\omega$: Mass fixed to a few energy points to obtain the efficiency curve
  - Width fixed to be zero

$\gamma\gamma \rightarrow \omega\phi$ Selection Criteria

- N_{trk}=4, Net_chrg=0
- |dr|<0.5 cm, |dz|<4 cm
- P_t>100 MeV/c
- Pion ID (both tracks)
- Kaon ID (both tracks)
- π^0 reconstruction from $\gamma\gamma$, and 1C-fit to nominal mass
- $|\Sigma \, pt^*|$<0.1 GeV/c

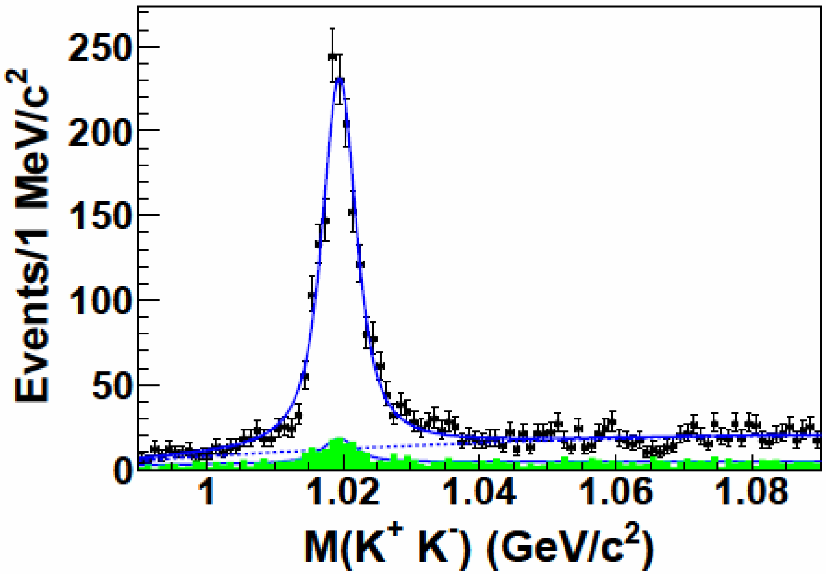


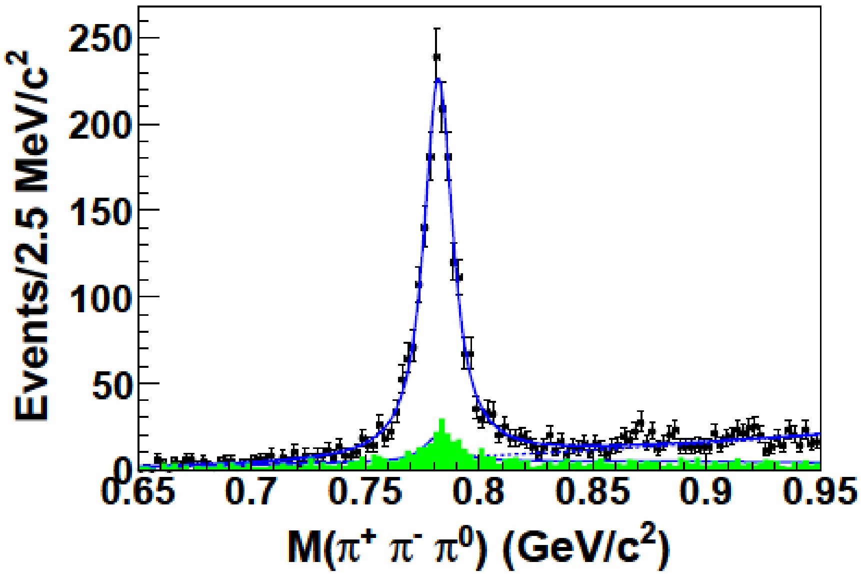


π^0 signal:

- $M(\gamma\gamma)$: 0.120 – 0.15 GeV
- χ^2 of 1C π^0 reconstruction<10

ω and ϕ signals





ϕ resolution ~ 3 MeV

ω resolution ~ 9 MeV

ω signal:

- M(πππ): 0.762 – 0.802 GeV

ϕ signal:

- M(KK): 1.012 – 1.027 GeV

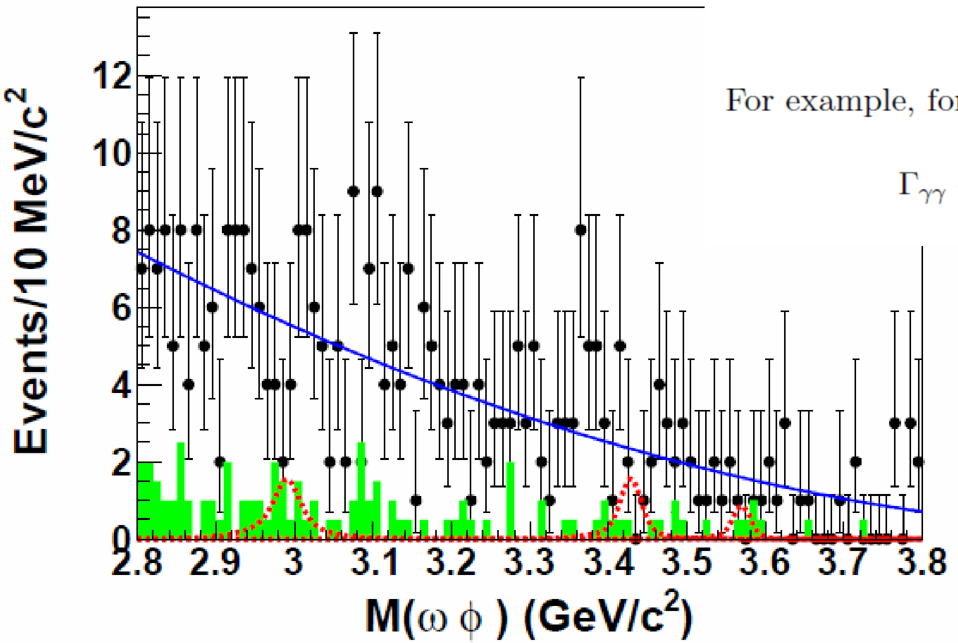
ω Sidebands (twice signal range):

- M(πππ): 0.702 – 0.742 GeV
  or 0.822 – 0.862 GeV

ϕ Sidebands (twice signal range):

- M(KK): 0.990 – 1.005 GeV
  or 1.034 – 1.049 GeV

ωϕ invariant mass



$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(R \to X_i) = \frac{N}{(2J+1)\epsilon \mathcal{K} \mathcal{L}_{int}}.$$

For example, for $e^+e^- \to \omega\phi$,

$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(R \to \omega\phi)\mathcal{B}(\phi \to K^+K^-)\mathcal{B}(\omega \to \pi^+\pi^-\pi^0) = \frac{N}{(2J+1)\epsilon \mathcal{K} \mathcal{L}_{int}}.$$

the proportionality factor $\mathcal{K}$ could be obtained from Monte Carlo integration

- No significant charmonium states
- The red dotted shapes show the upper limit sizes of the signals

$\Gamma_{\gamma\gamma} \cdot Br(X \to \omega\phi)$ Results:

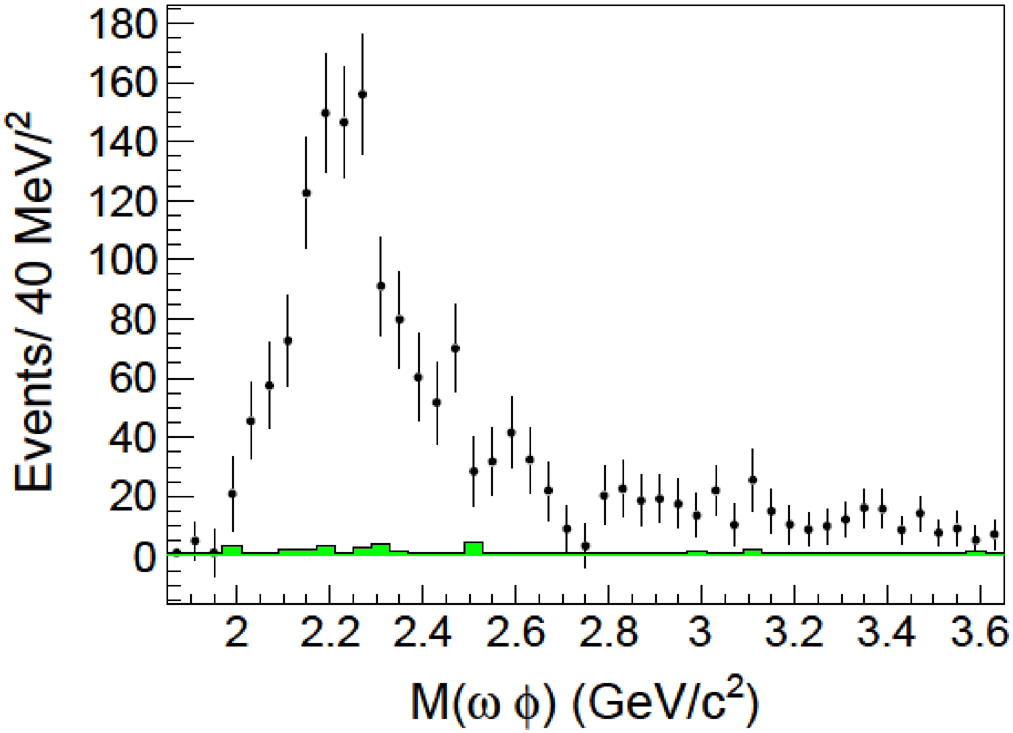
$$\Gamma_{\gamma\gamma}(\eta_c)\mathcal{B}(\eta_c \to \omega\phi) < 0.40 \text{ eV},$$

$$\Gamma_{\gamma\gamma}(\chi_{c0})\mathcal{B}(\chi_{c0} \to \omega\phi) < 0.38 \text{ eV},$$

$$\Gamma_{\gamma\gamma}(\chi_{c2})\mathcal{B}(\chi_{c2} \to \omega\phi) < 0.035 \text{ eV},$$

respectively, at the 90% C.L.

ωφ mass spectrum



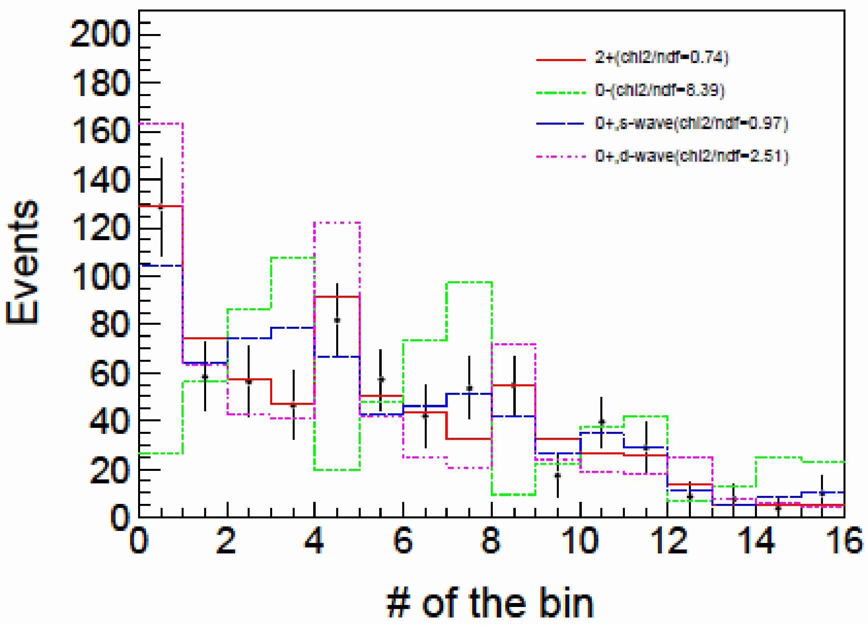
Method :

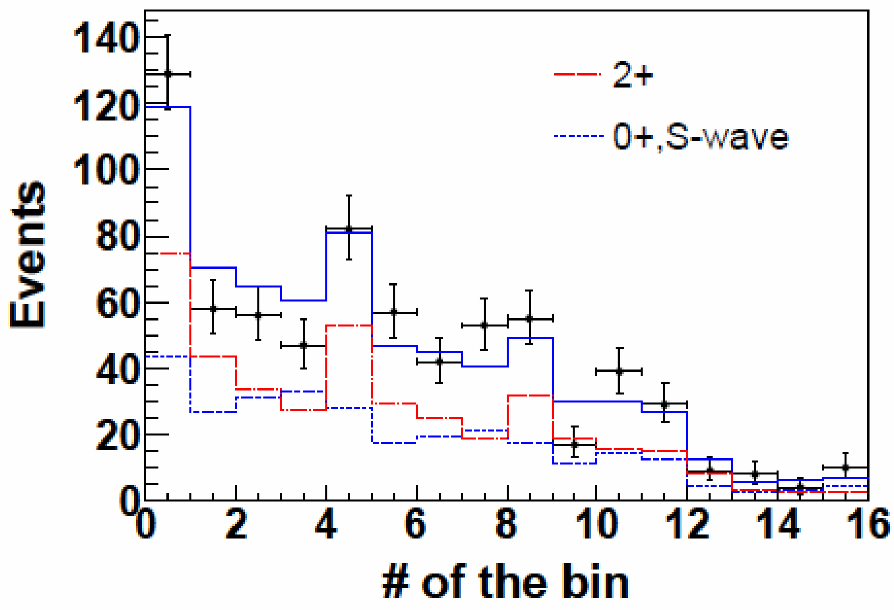
fit Σ Pt* distribution in each ωφ mass region

to extract γ γ → ωφ signal events.

- A new resonance have been observed around 2.2GeV??

2-d angular distribution analysis

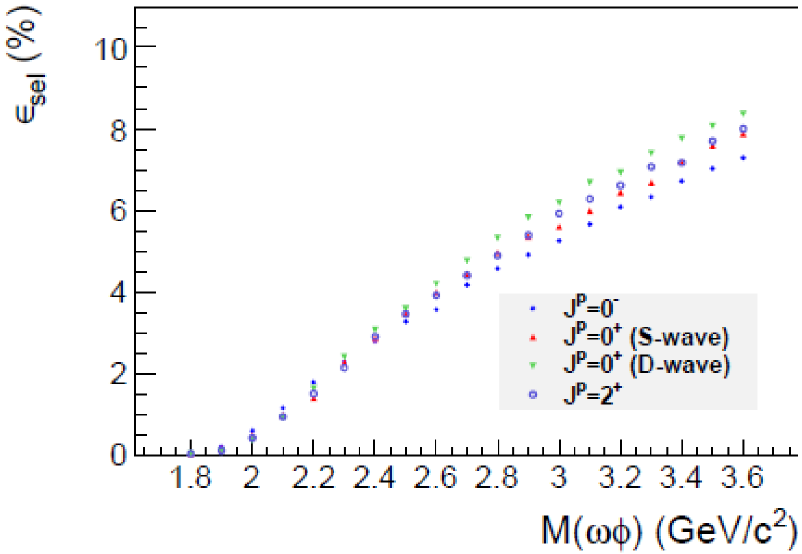


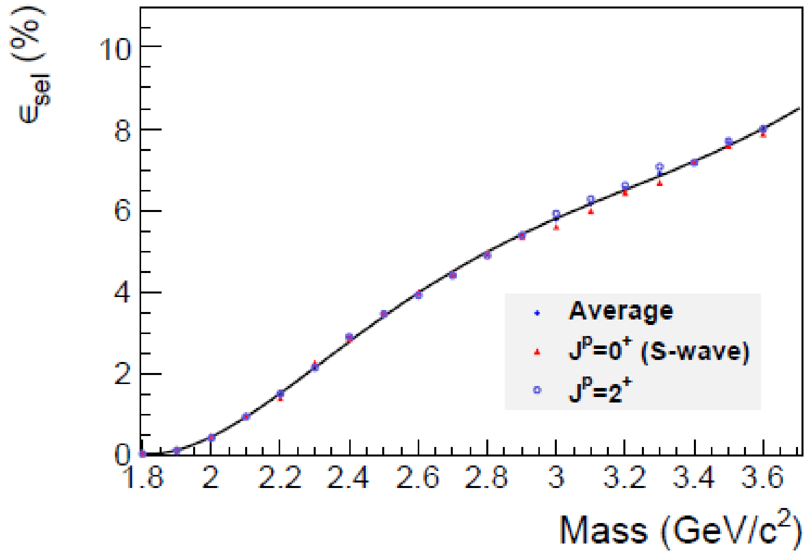


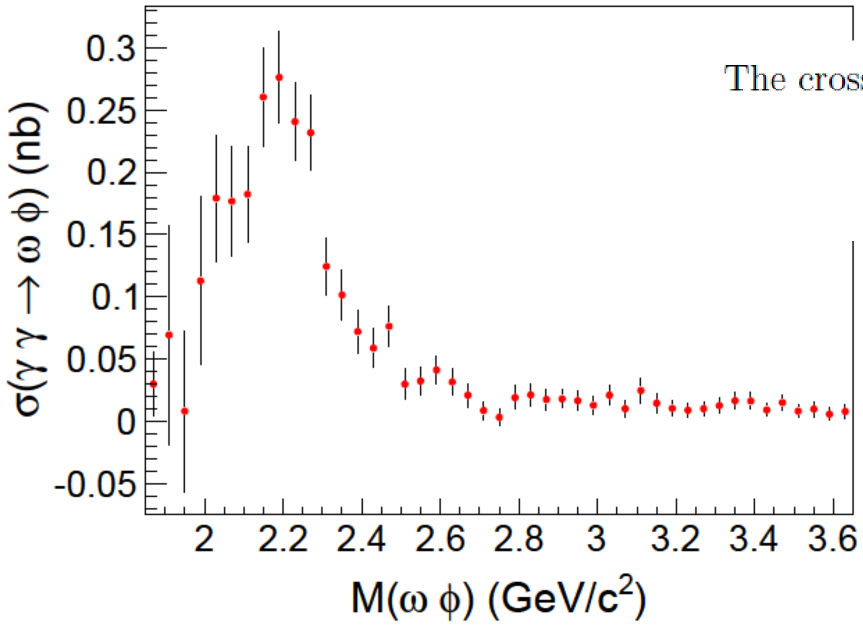
1. We divide transversity angle and polar angle in 2-d into 4x4 bins
2. The compared results are much better for 0+ (S-wave) and 2+
3. With the limited statistics, we can not draw a conclusion that J^P must be 0+ (S-wave) or 2+ yet.
4. We also show the fitted results with 0+ (S-wave) and 2+ components

For the define of angles, please see BN#250

cross section results







The cross section $\sigma_{\gamma\gamma\to R}(W)$ is calculated with the following equation:

$$\sigma_{\gamma\gamma\to R}(W) = \frac{\Delta n}{\mathcal{L}_{int}\frac{dL_{\gamma\gamma}}{dW}\epsilon(W)\Delta W},$$

$\frac{dL_{\gamma\gamma}}{dW}$ is two-photon luminosity

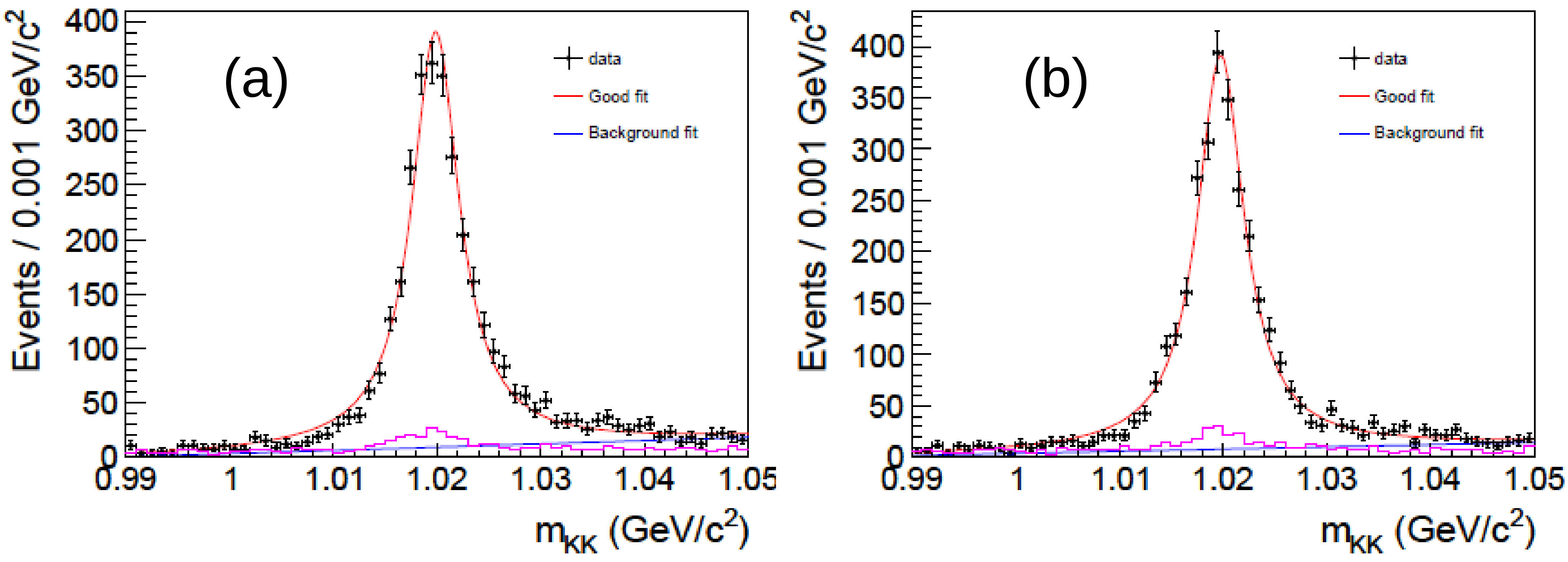
$\gamma\gamma \rightarrow \phi\phi$ Event Selection

- Good track: P_t>0.1GeV, |dr|<0.5cm, |dz|<4cm
- N_{good}=4,N_{charge}=0
- Kaon ID: prob(K;pi)>0.4
- At least 3 kaons are identified to reject possible $\pi\pi$kk, Kskπ backgrounds.
- Initial selection: |ΣPt*|<0.9 GeV/c in e^+e^- c.m. frame.
- Select two ϕ candidates: Choose the minimal value

$$\delta_{min} = \sqrt{(m^1_{kk} - m_\phi)^2 + (m^2_{kk} - m_\phi)^2}$$

to determine the best combination.

- eid<0.9 for each track to reject $\gamma^* \rightarrow$ e+e- events.

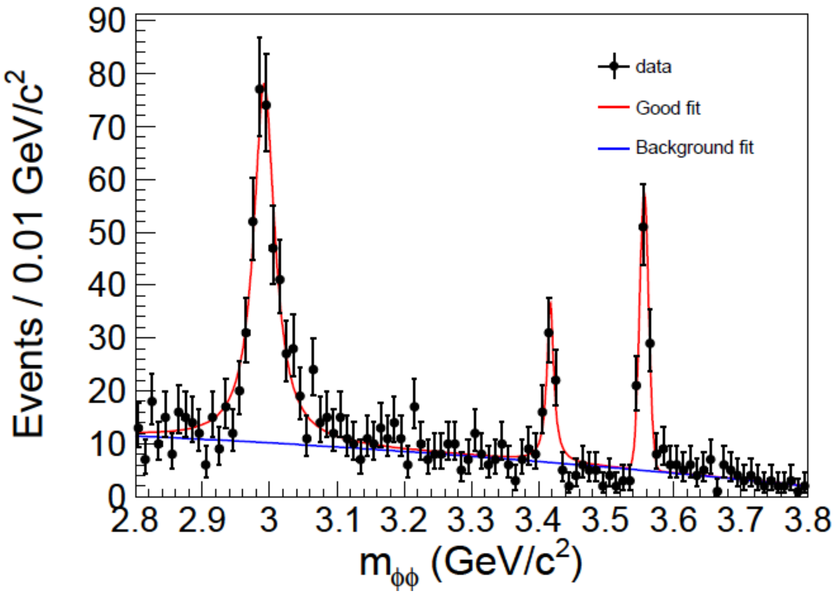


1. $\phi 2(\phi 1)$ invariant mass distribution when $\phi 1(\phi 2)$ in signal region and sideband region
2. A little peak in sideband (blank histogram) distribution indicate there are some ϕKK events.

ϕ mass window: [1.012,1.027] GeV/c^2

ϕ mass sidebands (twice signal region): [0.99,1.005] GeV/c^2 or [1.034,1.049] GeV/c^2

$\phi\phi$ invariant mass



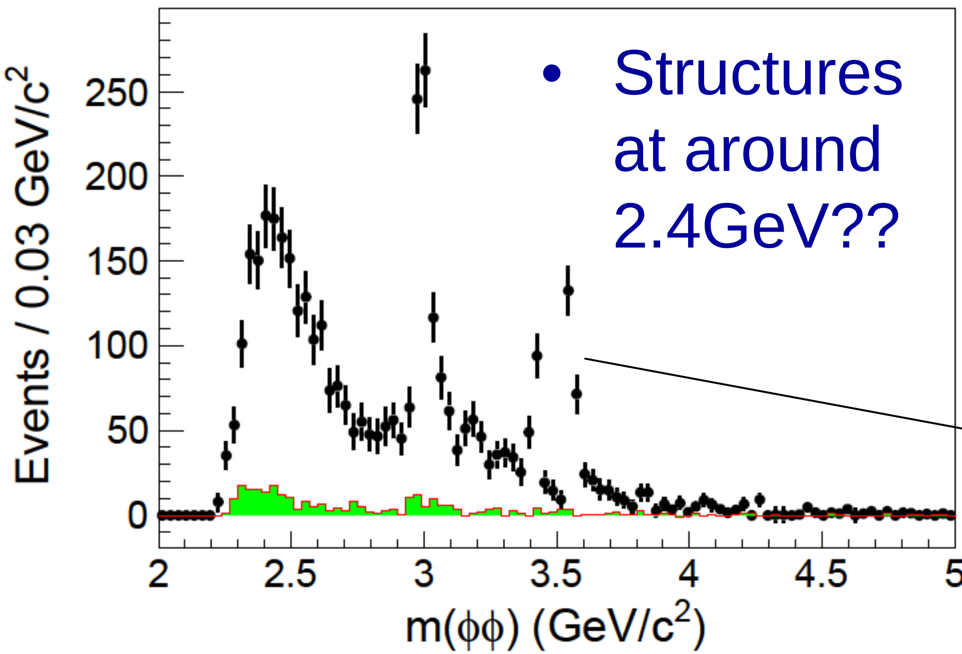
Here we require $|\Sigma Pt^*|<0.1$ GeV/c and subtract the normalized ϕ_1 and ϕ_2 mass sidebands events.

TABLE I: Results of $\Gamma_{\gamma\gamma}\mathcal{B}(X \to \phi\phi)$ for η_c, χ_{c0} and χ_{c2} from our measurements and Ref. [33]. Here for our measurements, the erros are statistical only.

$\Gamma_{\gamma\gamma}\mathcal{B}(X \to \phi\phi)$	Our measurements (eV)	S. Uehara's measurements (eV) [33]
η_c	7.72 ± 0.66	$6.8 \pm 1.2 \pm 1.3$
χ_{c0}	1.72 ± 0.33	$2.3 \pm 0.9 \pm 0.4$
χ_{c2}	0.62 ± 0.07	$0.58 \pm 0.18 \pm 0.16$

[33] S. Uehara *et al.* [Belle Collaboration], Eur. Phys. J. C **53**, 1 (2007)

BN# 921



Method : fit ΣP_t^* distribution to extract $\gamma\gamma \to \phi\phi$ signal events.

$\Gamma_{\gamma\gamma} \cdot Br(X \to \phi\phi)$ Results:

- η_c: 7.48 ± 0.64 eV
- χ_{c0}: 1.70 ± 0.34 eV
- χ_{c2}: 0.60 ± 0.08

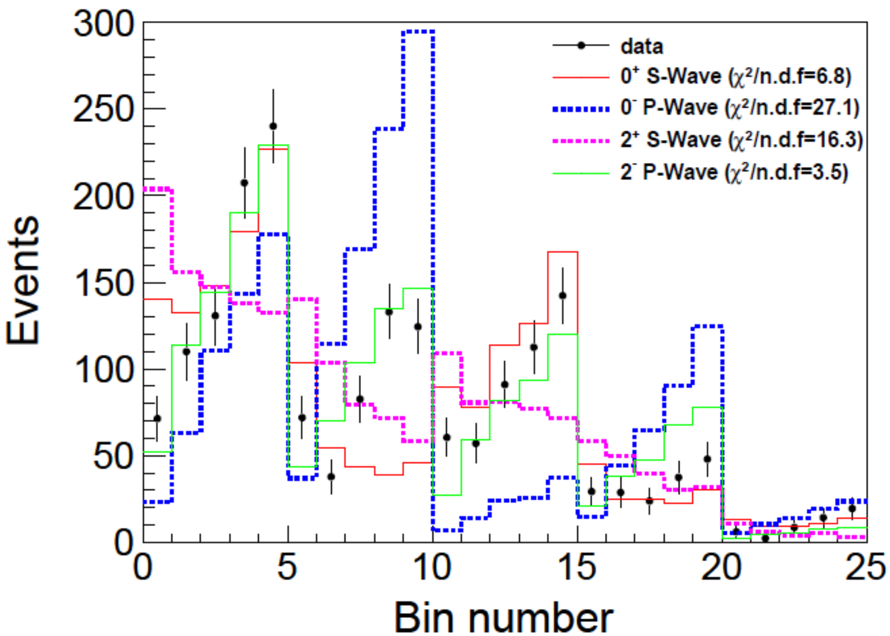
TABLE I: Results of $\Gamma_{\gamma\gamma}\mathcal{B}(X \to \phi\phi)$ for η_c, χ_{c0} and χ_{c2} from our measurements and Ref. [33]. Here for our measurements, the erros are statistical only.

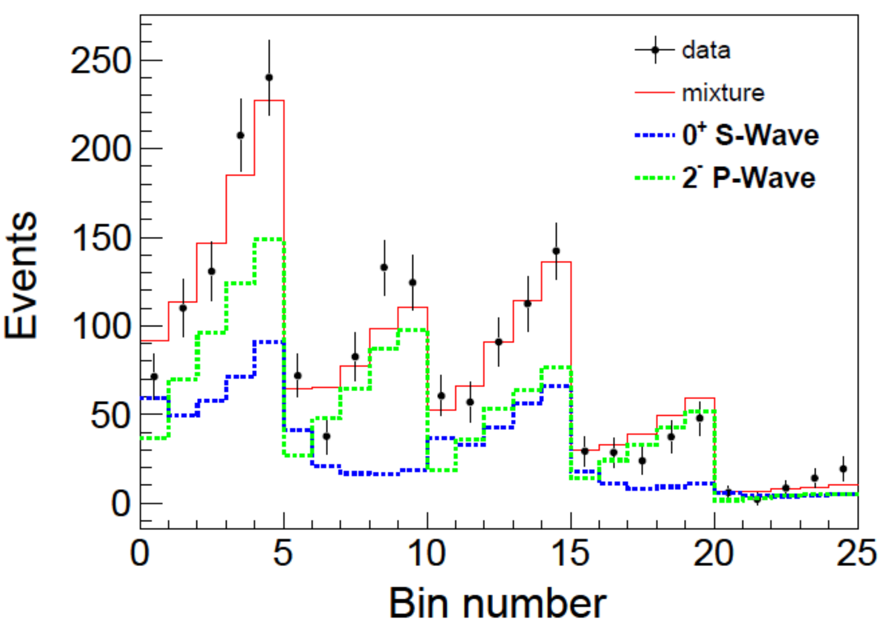
$\Gamma_{\gamma\gamma}\mathcal{B}(X \to \phi\phi)$	Our measurements (eV)	S. Uehara's measurements (eV) [33]
η_c	7.72 ± 0.66	$6.8 \pm 1.2 \pm 1.3$
χ_{c0}	1.72 ± 0.33	$2.3 \pm 0.9 \pm 0.4$
χ_{c2}	0.62 ± 0.07	$0.58 \pm 0.18 \pm 0.16$

Good consistence between each other!

2-d angular distribution analysis

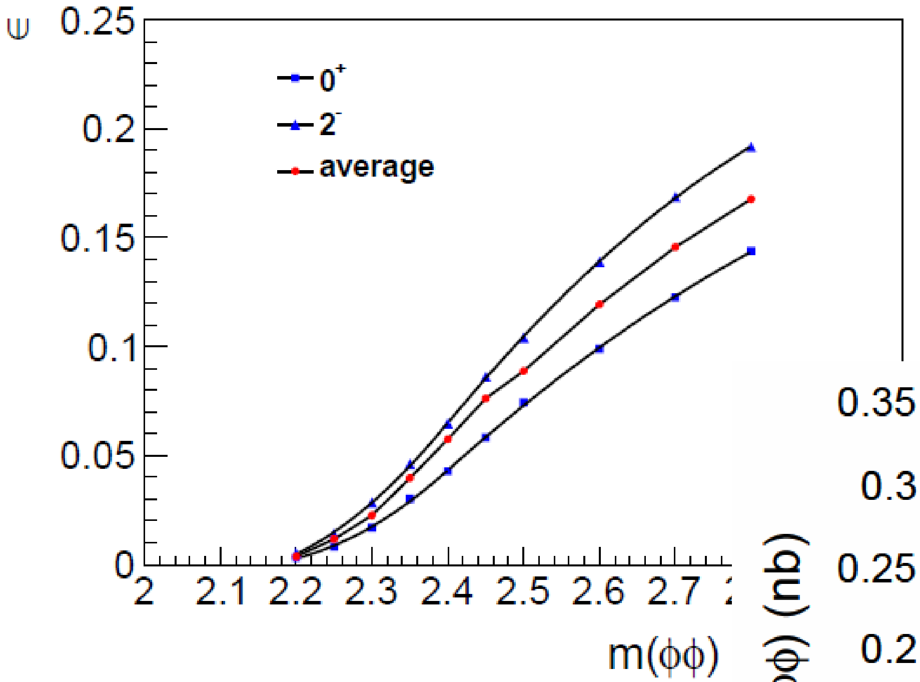
ϕϕ mass < 2.8 GeV



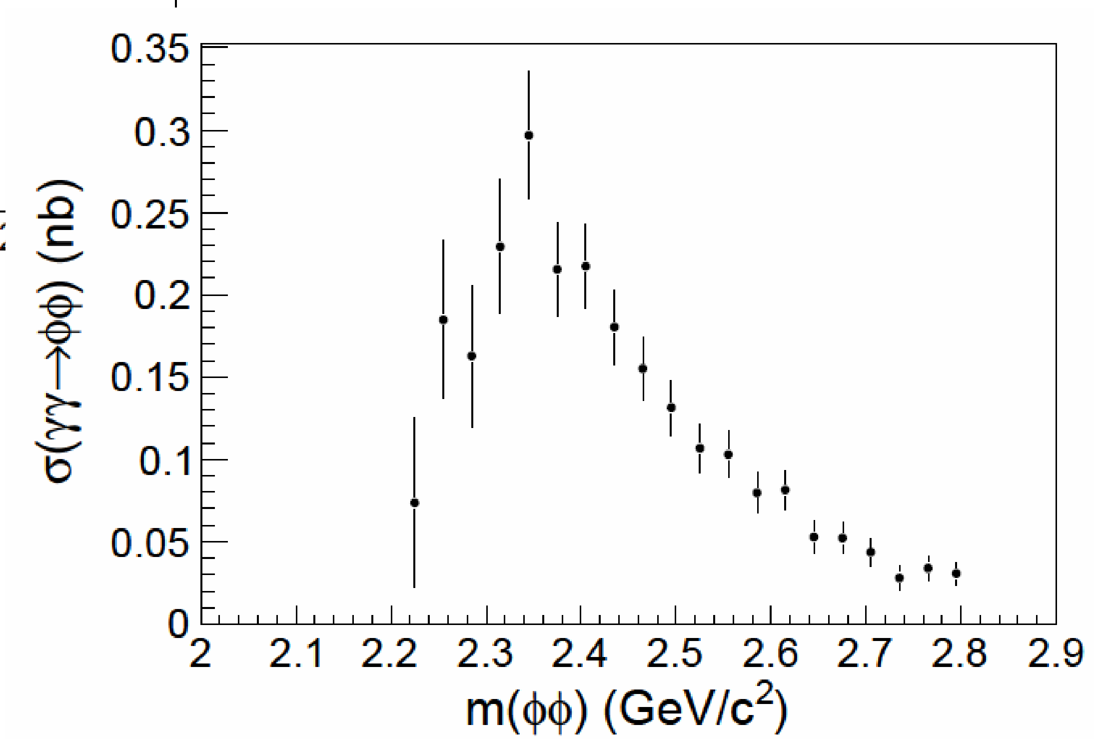


1. **We divide transversity angle and polar angle in 2-d into 5x5 bins**
2. Only one simple component can not describe the data well
3. **We tried to fit use different J^P component and found the mixture of 0+ S-wave and 2- P-wave can describe the data well with chi2/ndf=1.3**

cross section results



$$\sigma_{\gamma\gamma\to R}(W) = \frac{\Delta n}{\mathcal{L}_{int}\frac{dL_{\gamma\gamma}}{dW}\epsilon(W)\Delta W}$$



$\gamma\gamma \rightarrow \omega\omega$

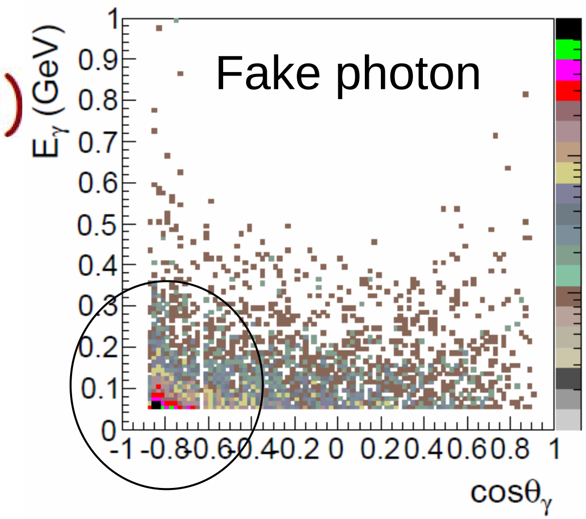
Event Selection

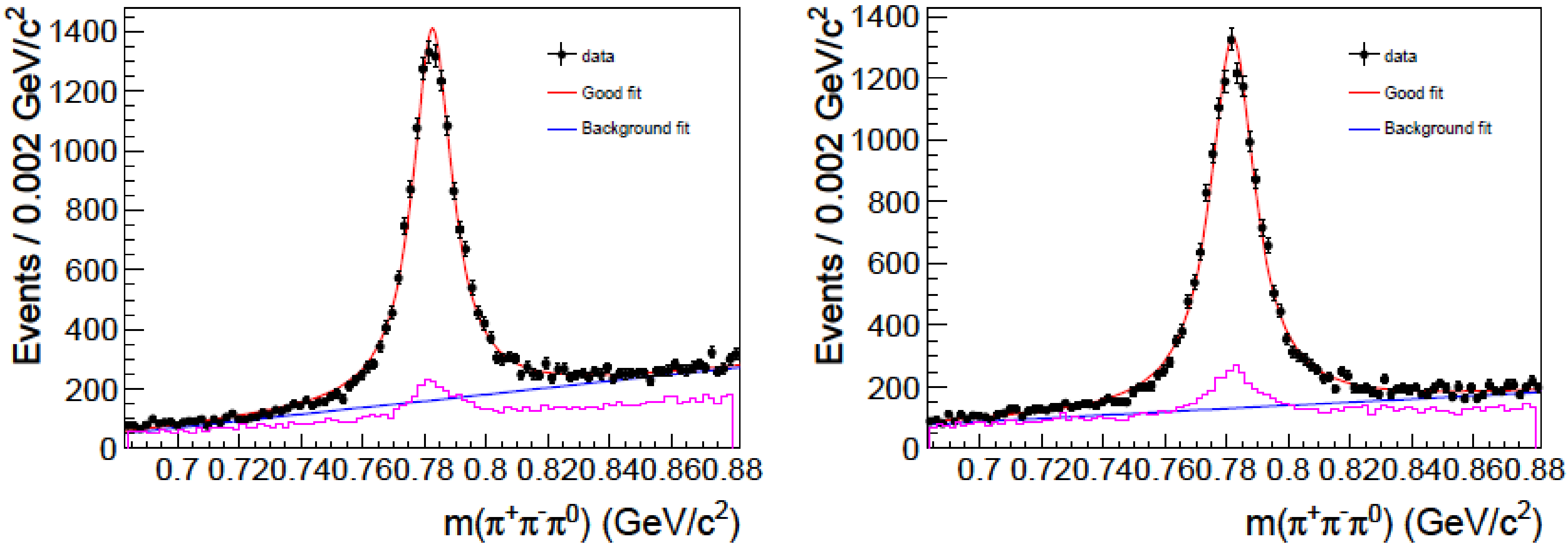
1. Good track: Pt>0.1GeV,|dr|<0.5cm,|dz|<4.0cm
- N_{trk}=4,N_{charge}=0

2. Pion identification: Prob(K:pi)<0.4
- 4 pions need to be identified.

3. π^0 list.
- $E(\gamma_1,\gamma_2)$>50MeV, mass window: [0.05,0.35]GeV
- $E(\gamma_1,\gamma_2)$>75MeV if $\cos(\theta_{\gamma1\gamma2})<-0.65$: fake photon rejection.
- $N(\pi^0)>=2$ in π^0 list
- select two π^0 with least χ^2 sum ($\chi^2<10$)

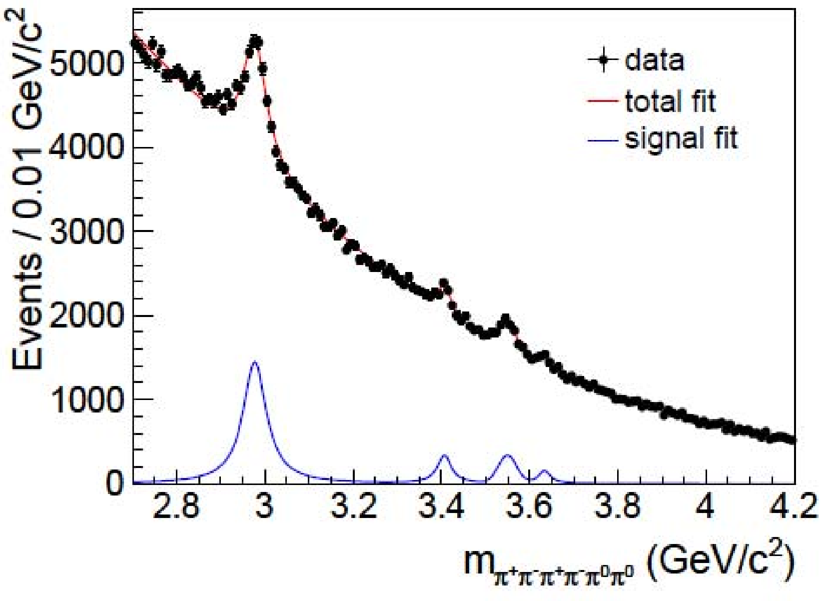
4. select two photon events.
- $|\Sigma P_t^*|<0.9$GeV in e^+e^- c.m frame

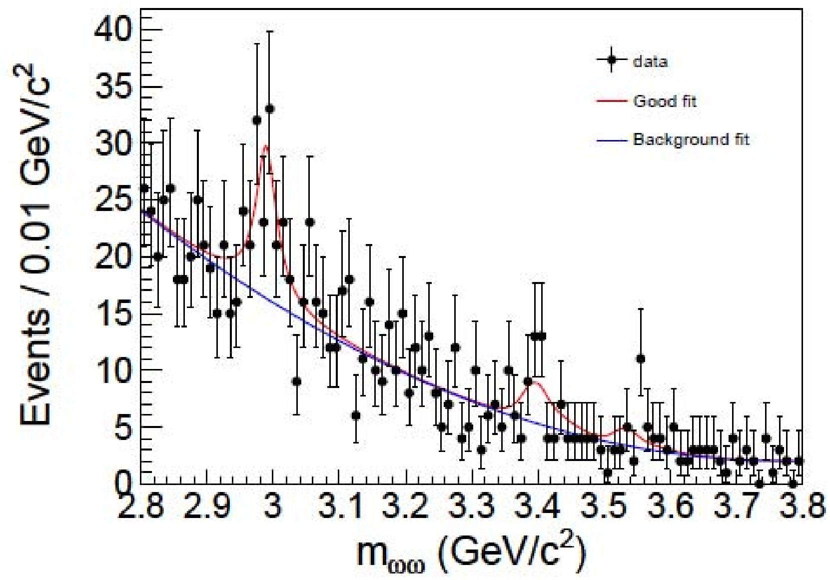




1. ω mass window: [0.762,0.802]GeV
2. ω sideband: [0.702,0.742]GeV && [0.822,0.862]GeV

ωω invariant mass





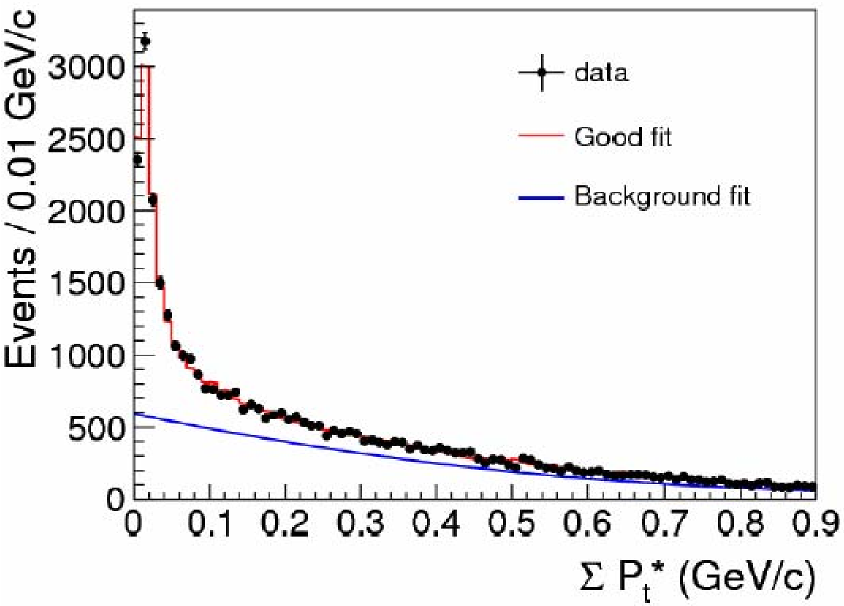
It is the first time we observed $\eta_c(2S)$ signal in $2(\pi^+\pi^-\pi^0)$ mode

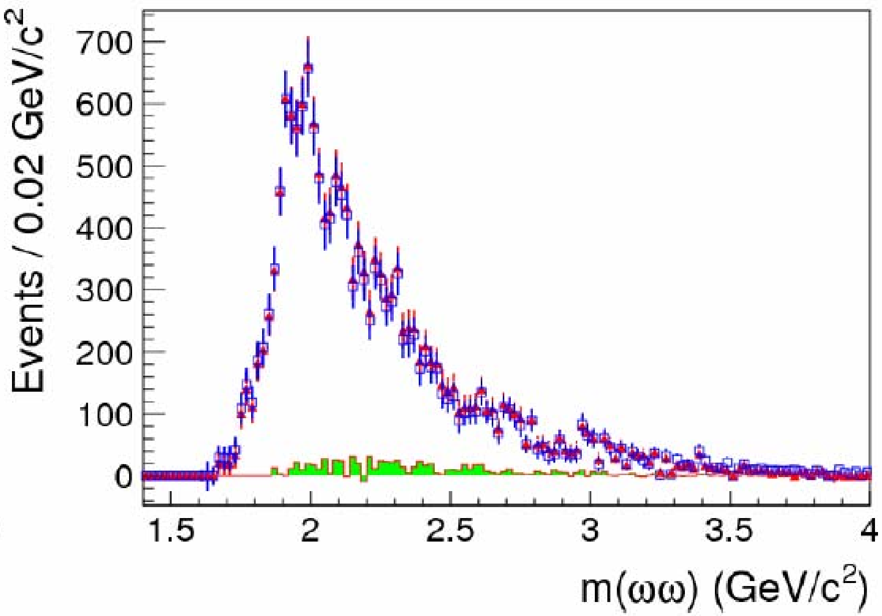
$$\Gamma_{\gamma\gamma}(\eta_c)\mathcal{B}(\eta_c \to \omega\omega) = 8.64 \pm 2.92 \text{ eV},$$

$$\Gamma_{\gamma\gamma}(\chi_{c0})\mathcal{B}(\chi_{c0} \to \omega\omega) < 4.9 \text{ eV},$$

$$\Gamma_{\gamma\gamma}(\chi_{c2})\mathcal{B}(\chi_{c2} \to \omega\omega) < 0.53 \text{ eV},$$

ωω mass spectrum

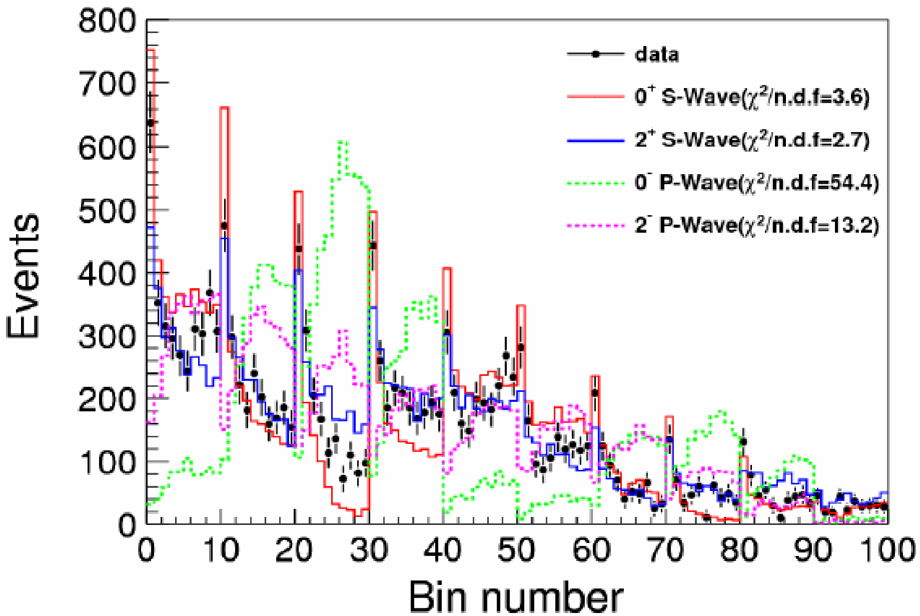


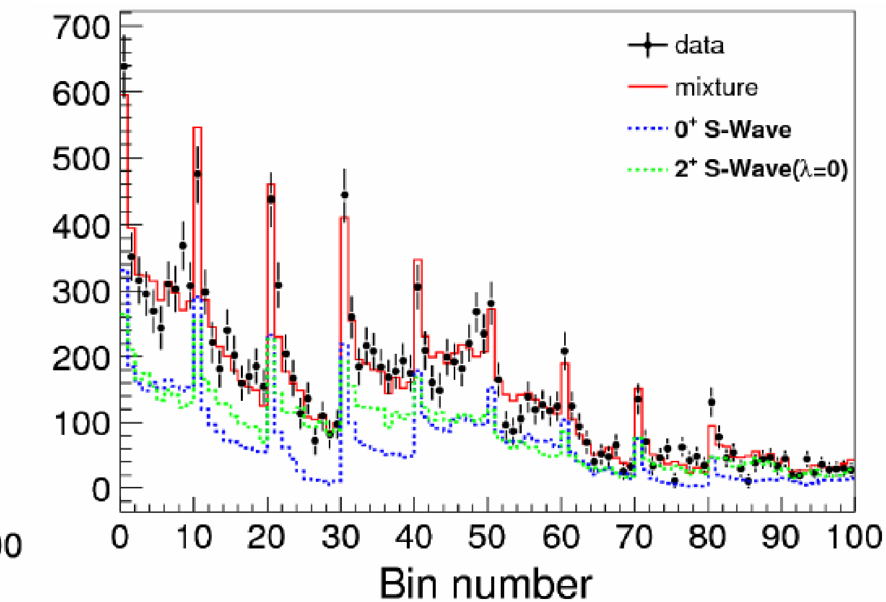


If we do not require $|\Sigma Pt^*|<0.1$GeV/c:

1. Fit $|\Sigma Pt^*|$ distribution to extract $\gamma\gamma \rightarrow \omega\omega$ events.
2. (left plot) show $|\Sigma Pt^*|$ fit with MC signal shape+2nd bkg.
3. (right plot) the $m(\omega\omega)$ invariant mass distribution from $|\Sigma Pt^*|$ fit.

Spin-parity analysis





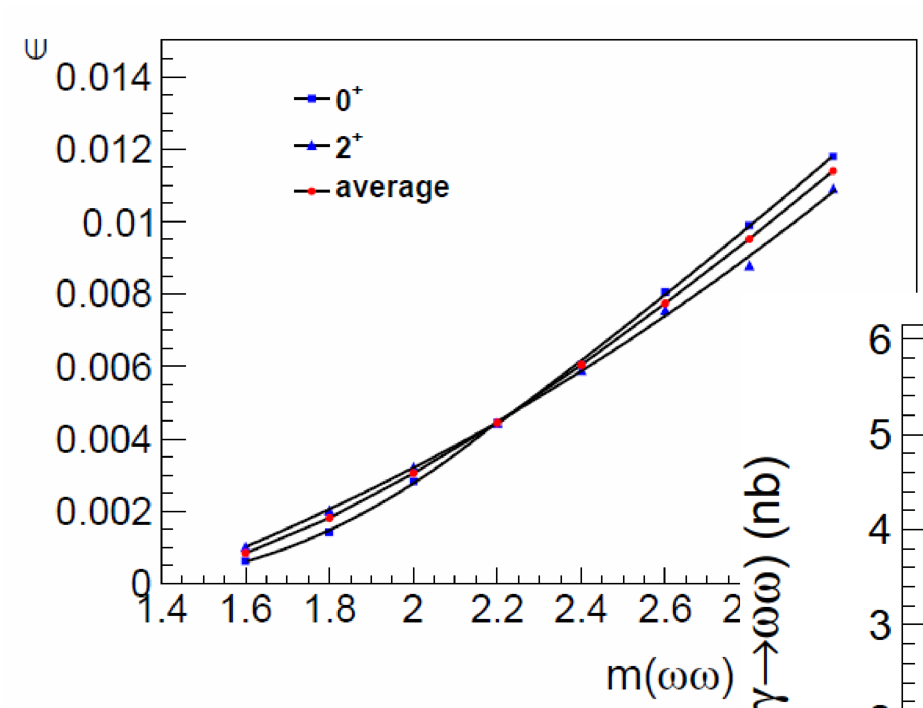
Angular distribution: divide (polar-angle product, transversity angle) into 10×10 bins.

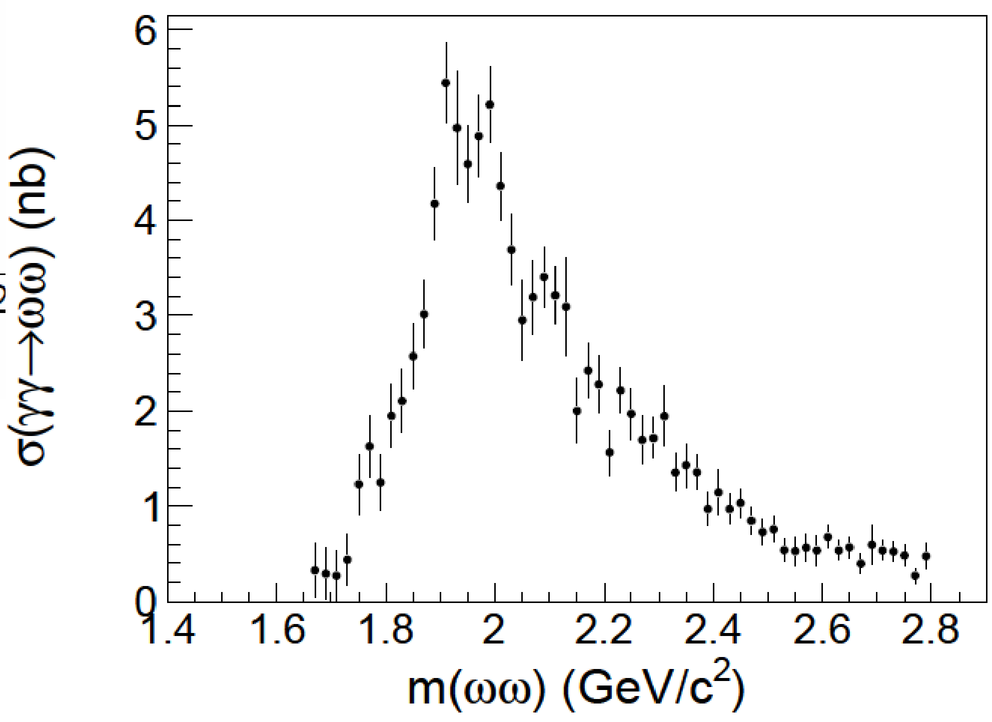
1. (left plot) data vs. MC for different spin-parity assumption.

   Most probable spin-parity is 2^+ and 0^+

2. A mixture with 2^+(~55%) and 0^+(~45%) can describe data much better: χ^2/n.d.f=1.2

cross section results





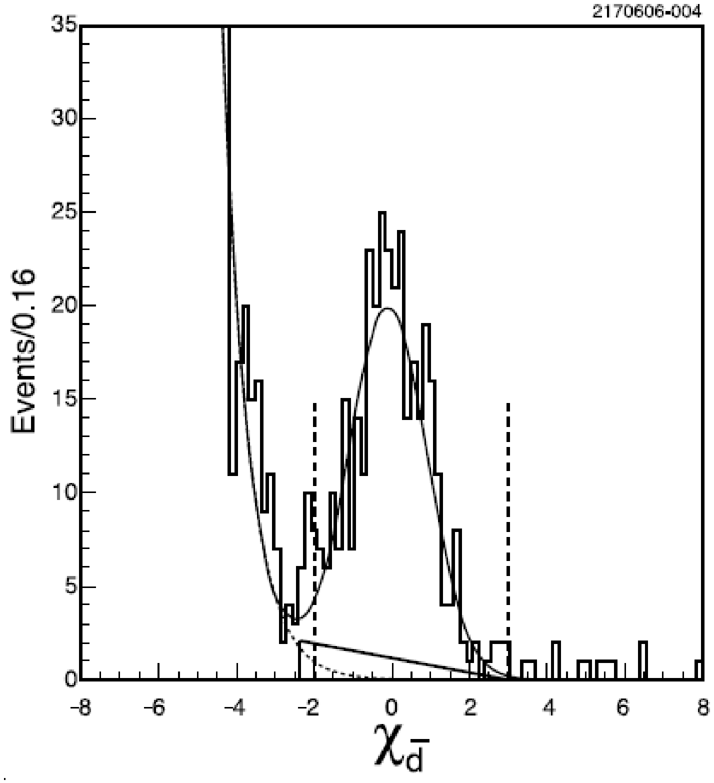
Summary

- X(1812): No signal in $\omega\phi$, efficiency low.
- events accumulate at 2.2 GeV in $\omega\phi$ mode, at 2.35 GeV in $\phi\phi$ mode, and at 2.0 GeV in $\omega\omega$ mode, some structures are significant
- Spin-parity analyses for those structures have been done. What are the natures of them? [X(3915), X(4350)-like?]
- $\Gamma_{\gamma\gamma}$B(X→$\omega\phi$, $\phi\phi$, $\omega\omega$) for η_c , χ_{c0}, χ_{c2} are given. For $\phi\phi$ mode, the results are consistent well with the published results. For $\omega\phi$, $\omega\omega$ modes, they are the first measurements
- Cross sections of $\gamma\gamma \to \omega\phi$, $\phi\phi$, $\omega\omega$ have been measured (most important)
- BN is completely ready and has been uploaded into BN web page (BN#1139). *Under referee stage.*

search for dibaryon resonance in $\Upsilon(1S)$ and $\Upsilon(2S)$ data

Motivation

- A few years ago, CLEO has studied anti-deuteron production from $\Upsilon(nS)$ resonance decays and the nearby continuum. The Brs of $\Upsilon(1S, 2S) \to \bar{d}X$ are not small. [PRD75, 012009, 2007].



$$\chi_d \equiv \frac{(dE/dx)_{measured} - (dE/dx)_{expected,d}}{\sigma_{dE/dx}}$$

So maybe dibaryon bound state production rate in Y(nS) is also not small.

- Many years ago, the first high resolution measurement of $pp \to K^+ + (\Lambda p)$ has been performed at SATURNE II [Nucl. Phys. A 567, 819, 1994]. The missing mass spectra of kaon show characteristic enhancements near the Λp threshold. A sharp peak anomaly has been observed in the missing mass spectrum at 2096.5 ± 1.5 MeV$/c^2$ with about 3.5 standard deviations.

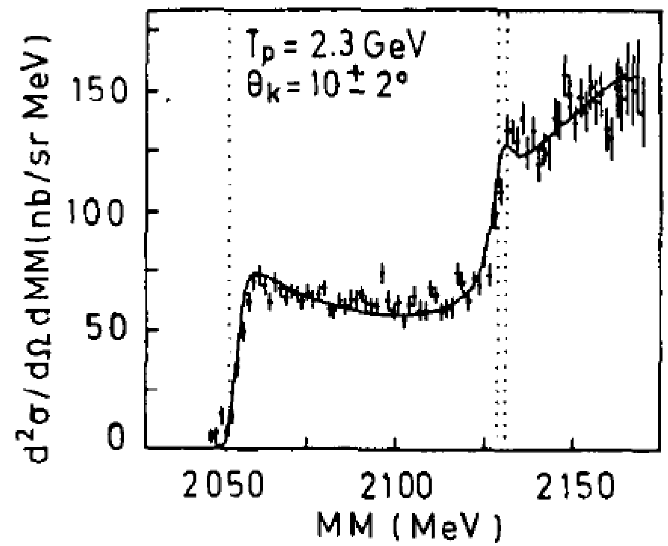
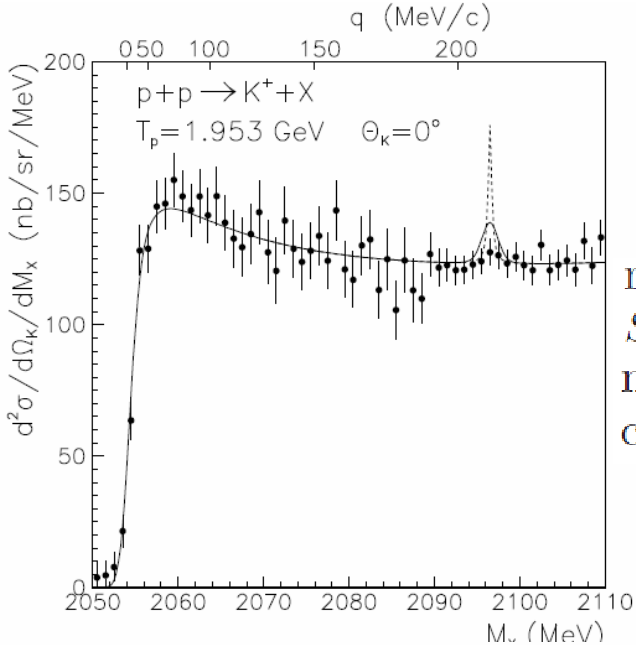


Fig. 11. Comparison of the experimental effective YN mass yields from pp → K⁺YN at $T_p = 2.3$ GeV, $\theta_k \approx 10° \pm 2°$ with the theoretical curves according to the Deloff model with the parameters of model A(+) from Table 10. The experimental resolution of 2 MeV is folded in.

- A high-resolution study of the reaction $pp \to K^+ + (\Lambda p)$ has been performed by the HIRES Collaboration. The aim of the experiment was to study the Λp final state interaction (FSI) and to search for narrow strangeness $S = -1$ resonances.

[arXiv:1105.2281].

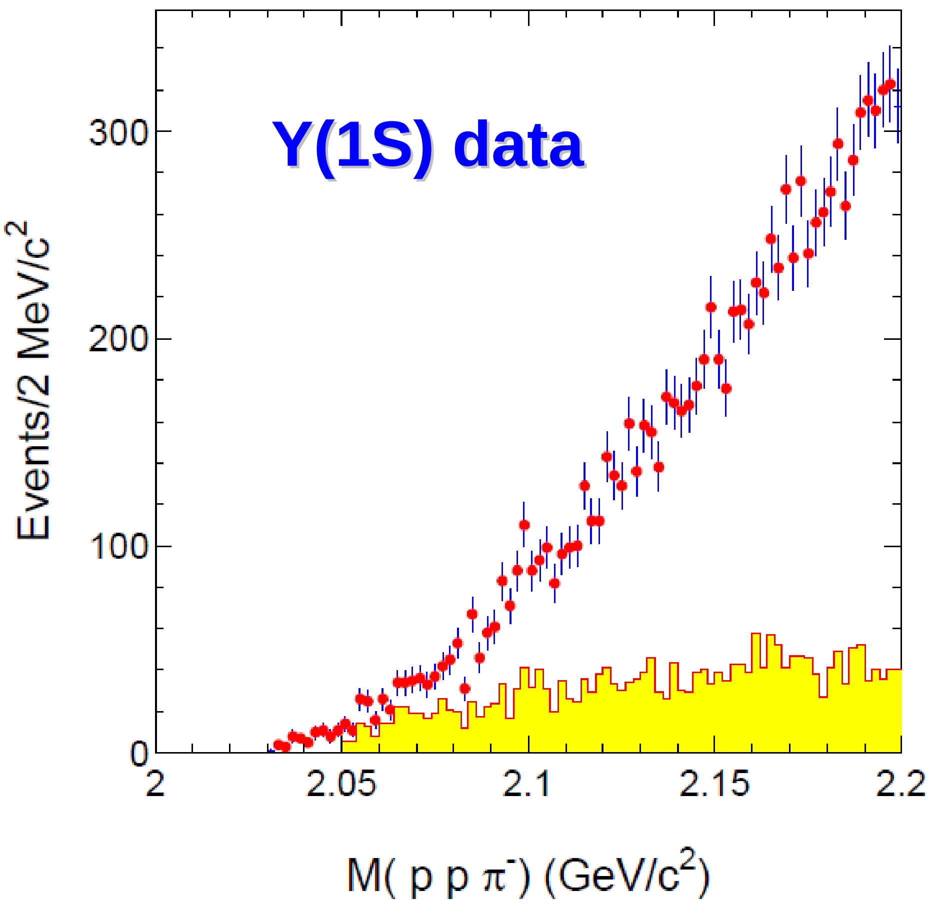


There may be two reasons for the nonobservation. (i) The predicted narrow $S = -1$ resonance D_s does not exist at all in the invariant mass region below 2110 MeV/c^2. (ii) The production cross section $d\sigma^r/d\Omega_K(pp \to K^+ D_s)$ is too small.

- The predictions of strange dibaryons are summarized in a recent review by Gal [arXiv:1011.6322].

Search for dibaryon state in $PP\pi$

- HadronBJ skim flag requirement (HadronBJ skim is suitable based on MC sample check)
- At least three charged tracks with $|dr| < 0.5$ cm, $|dz| < 5$ cm and $P_t > 0.1$ GeV/c
- For proton candidates: $L_p/L_p + L_\pi > 0.6$ and $L_p/L_p + L_K > 0.6$
- For pion candidates: $L_K/L_K + L_\pi < 0.4$
- For pion and proton candidates, they can not be identified as muon or electron.
- The number of charged tracks from charged track bank should be greater than 5.
- Do vertex fit to the selected p p π^- candidates, and require confidence level > 0.01

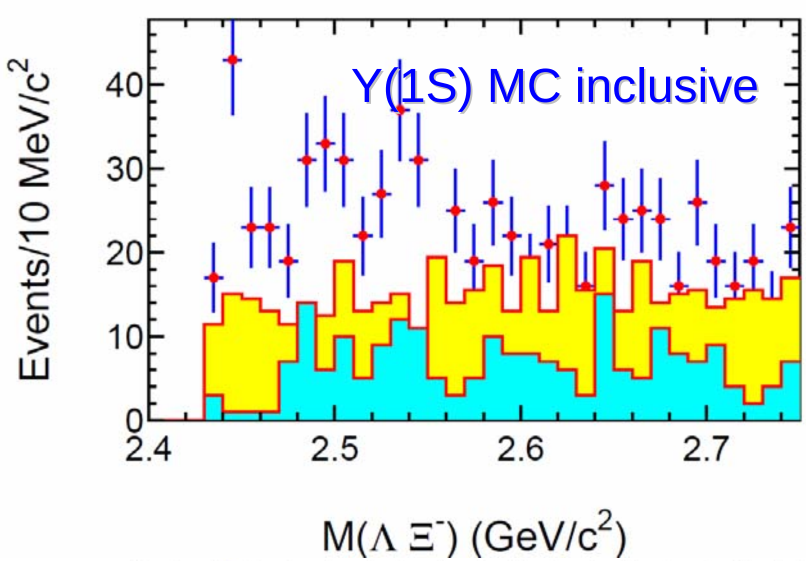


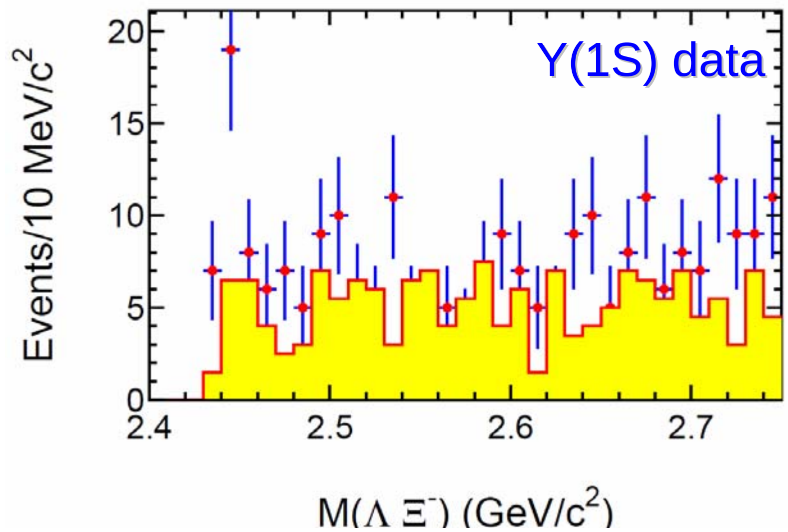
The shaded histograms is from $P\pi$ mass within Λ mass region

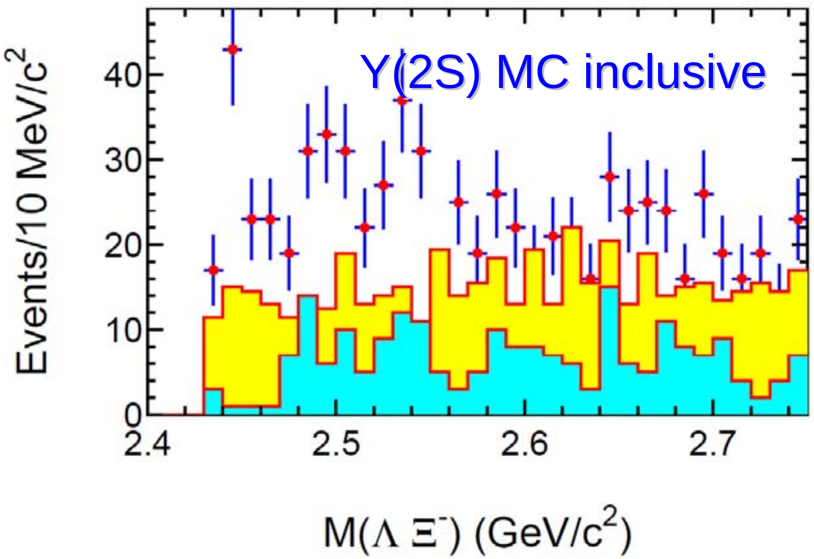
Search for dibaryon state in $\Lambda\Xi^-$

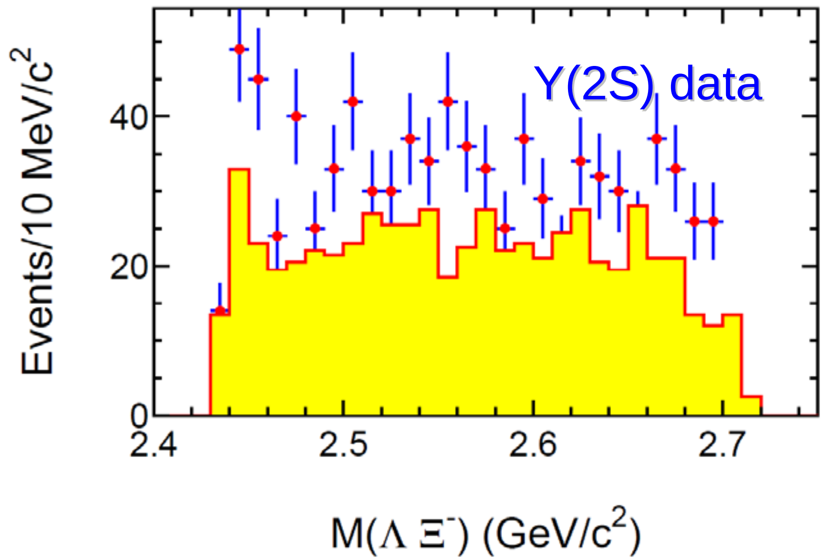
Event Selection:

- HadronBJ skim
- at least six charged tracks with $|dr| < 30$ cm, $|dz| < 50$ cm, $P_t > 0.1$ GeV$/c$
- For π^-, $\frac{L_K}{L_K+L_\pi} < 0.4$
- For P, $\frac{L_P}{L_P+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} > 0.6$
- at least two Λ candidates with $|m_{p\pi} - m_\Lambda|$ <3 MeV$/c^2$
- at least one Ξ^- candidates with $|m_{\Lambda\pi^-} - m_{\Xi^-}|$ <5 MeV$/c^2$. Ξ^- mass sidebands regions: [1.3017, 1.3117] or [1.3367, 1.3467] GeV$/c^2$ (two times wider)









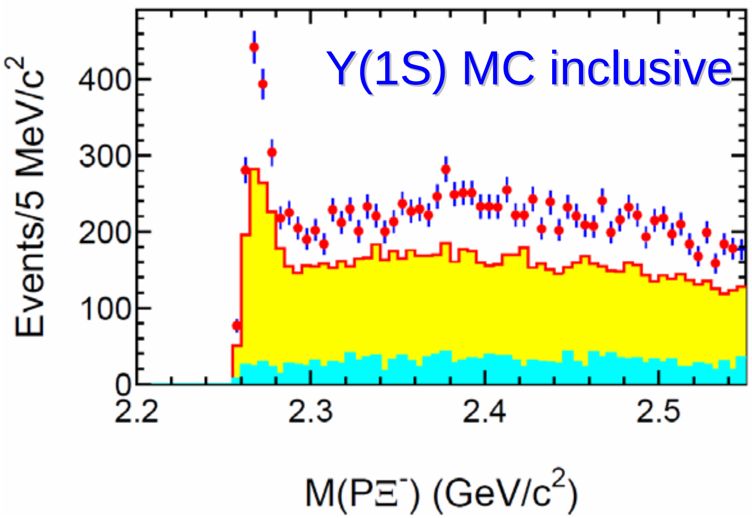
The green shaded histograms are from events with N(\Xi)>0 and N(Λ)>1 with MC Truth information. The peak at 2.45 GeV is fake!

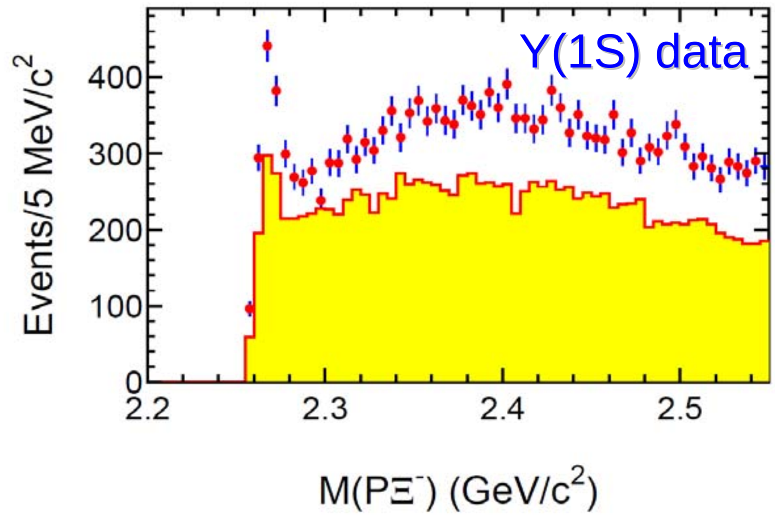
The shaded yellow histograms are normalized \Xi mass sidebands. No bound state !

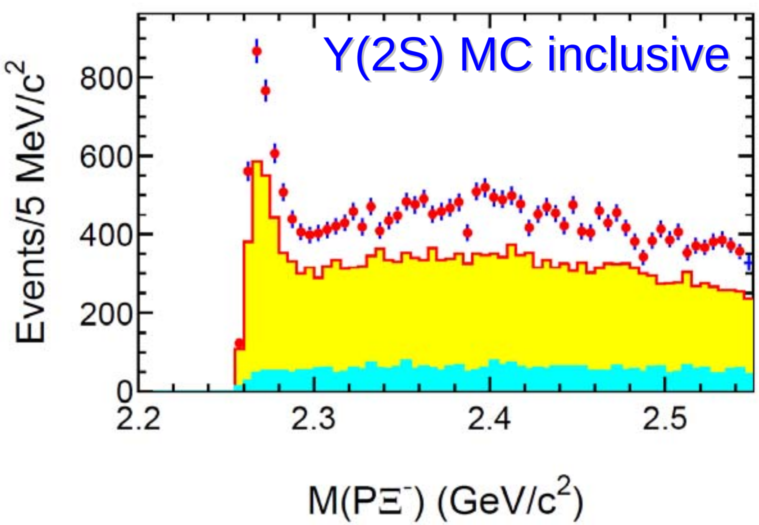
Search for dibaryon state in $P\Xi^-$

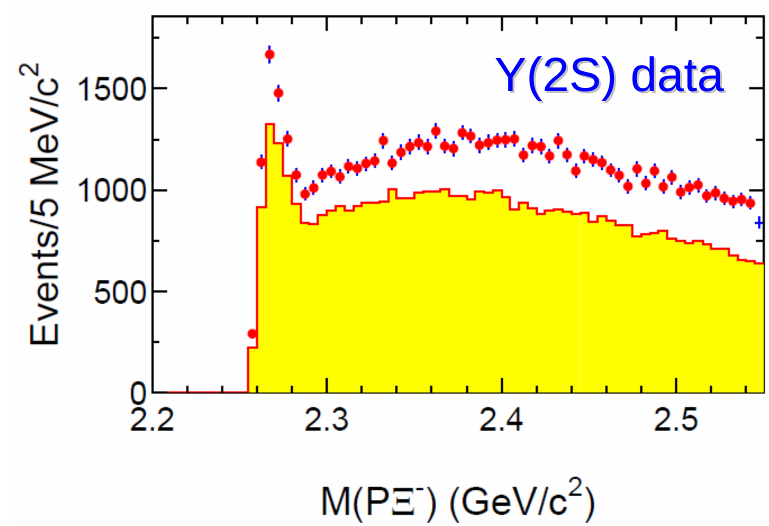
Event Selection:

- HadronBJ skim
- at least four charged tracks with $|dr| < 30$ cm, $|dz| < 50$ cm, $P_t > 0.1$ GeV/c
- For π^-, $\frac{L_K}{L_K+L_\pi} < 0.4$
- For P, $\frac{L_P}{L_P+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} > 0.6$
- at least one Λ candidate with $|m_{p\pi} - m_\Lambda|$ <3 MeV/c^2
- at least one Ξ^- candidates with $|m_{\Lambda\pi^-} - m_{\Xi^-}|$ <5 MeV/c^2. Ξ^- mass sidebands regions: [1.3017, 1.3117] or [1.3367, 1.3467] GeV/c^2 (two times wider)









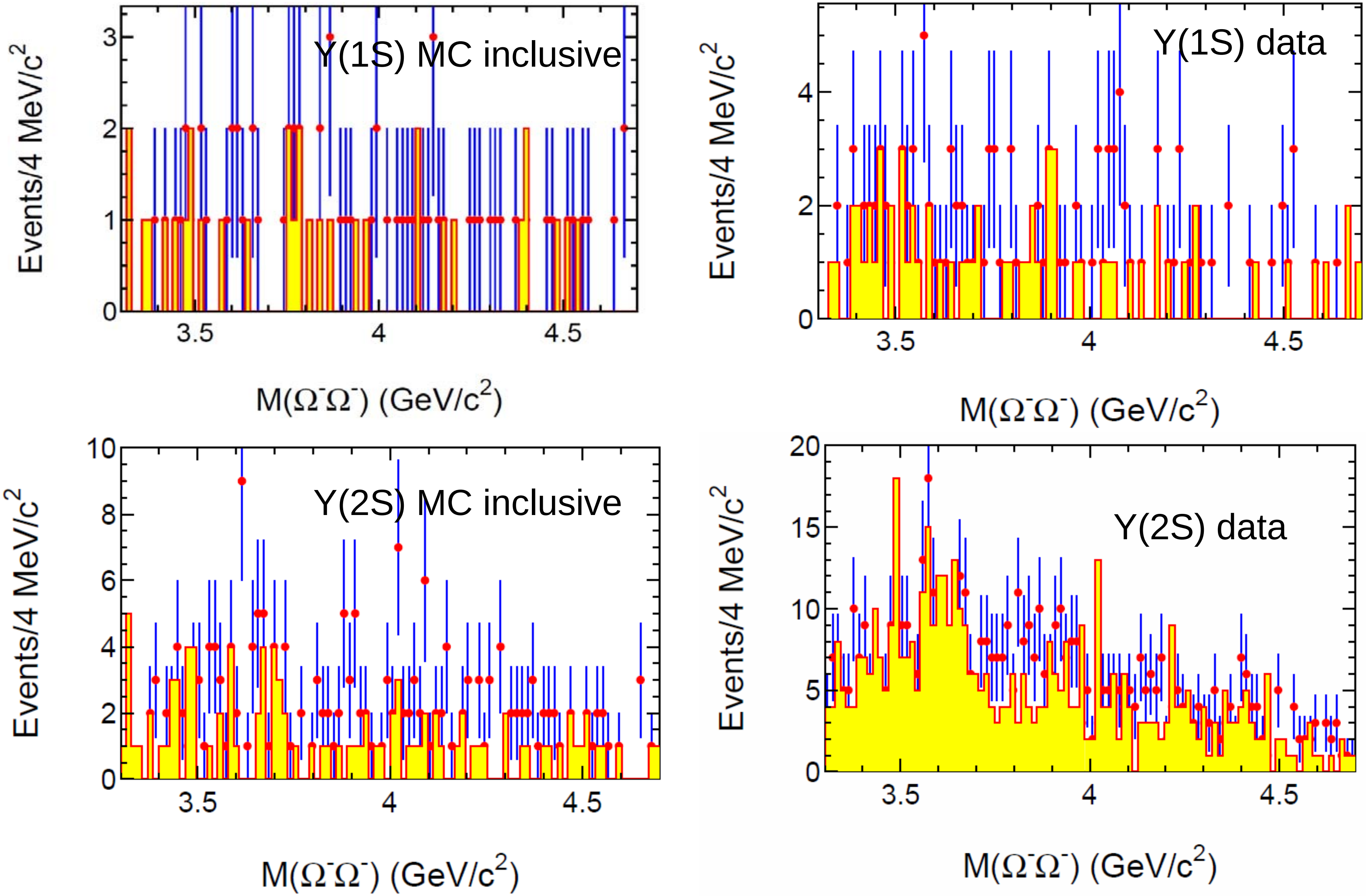
The green shaded histograms are from events with N(\Xi)>0 and N(P)>1 with MC Truth information. The peak at 2.27 GeV is fake!

The shaded yellow histograms are normalized \Xi mass sidebands. No bound state !

Search for dibaryon state in $\Omega^-\Omega^-$

Event Selection:

- HadronBJ skim
- at least five charged tracks with $|dr| < 30$ cm, $|dz| < 50$ cm, $P_t > 0.1$ GeV$/c$
- For π^-, $\frac{L_K}{L_K+L_\pi} < 0.4$
- For P, $\frac{L_P}{L_P+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} > 0.6$
- For K^-, $\frac{L_K}{L_K+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} < 0.6$
- at least two Λ candidates with $|m_{p\pi} - m_\Lambda|$ <5 MeV$/c^2$
- at least one Ω^- candidates with $|m_{\Lambda K^-} - m_{\Omega^-}|$ <25 MeV$/c^2$

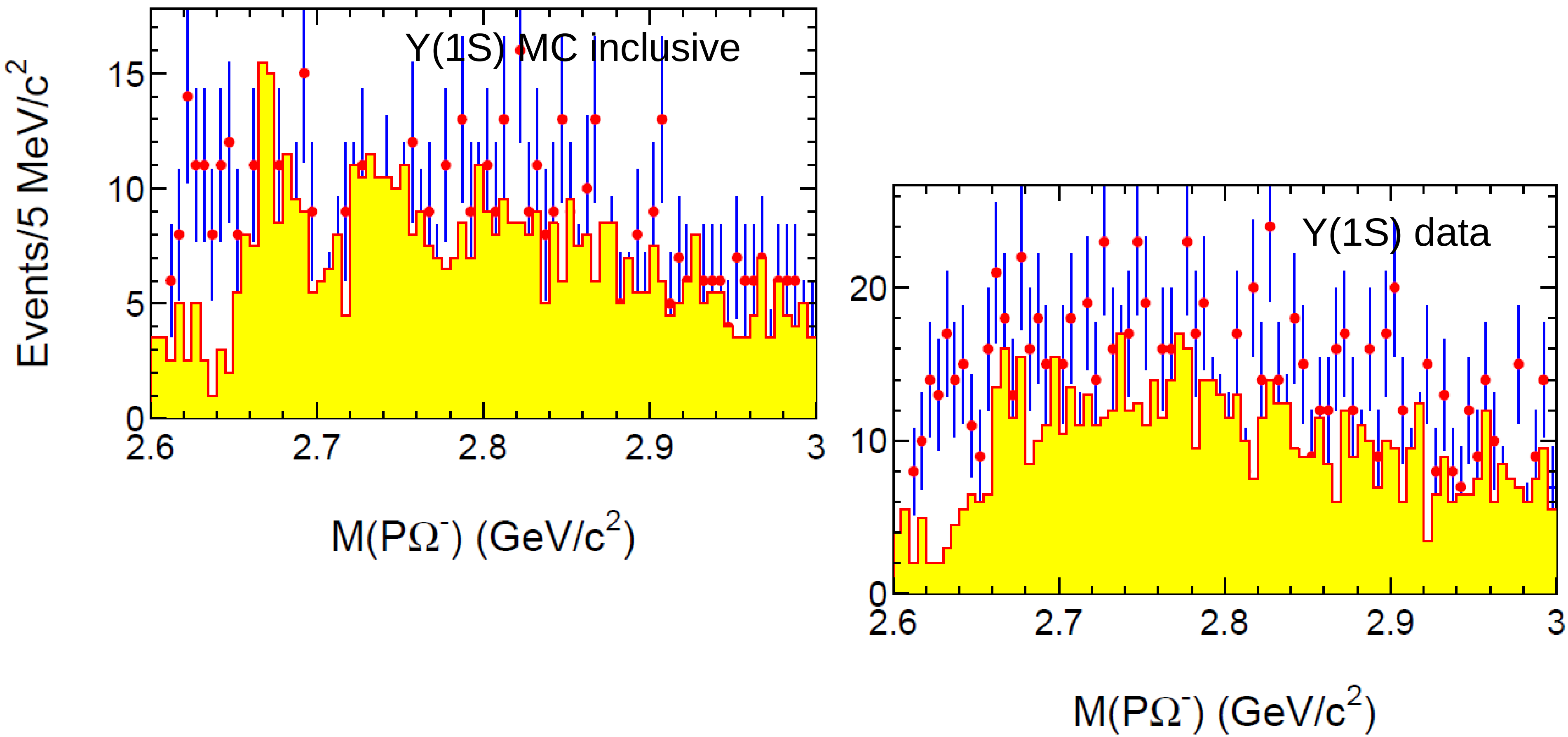


The normalized Lambda and Lambda masses sidebands can describe the data well. No bound state !

Search for dibaryon state in $P\Omega^-$

Event Selection:

- HadronBJ skim
- at least seven charged tracks with $|dr| < 30$ cm, $|dz| < 50$ cm, $P_t > 0.1$ GeV$/c$
- For π^-, $\frac{L_K}{L_K+L_\pi} < 0.4$
- For P, $\frac{L_P}{L_P+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} > 0.6$
- For K^-, $\frac{L_K}{L_K+L_\pi} > 0.6$ and $\frac{L_P}{L_P+L_K} < 0.6$
- at least one Λ candidates with $|m_{p\pi} - m_\Lambda|$ <4 MeV$/c^2$
- at least one Ω^- candidates with $|m_{\Lambda K^-} - m_{\Omega^-}|$ <10 MeV$/c^2$. Ω^- mass sidebands regions: [1.622, 1.642] or [1.692, 1.712] GeV$/c^2$ (two times wider)



The normalized \Omega mass
sidebands can describe the data well. No bound state !

Summary

Our conclusion: we have tried to search for dibaryon state (bound state) in $PP\pi$, ΛP, $\Omega\Omega$, ΩP, $\Lambda\Xi$, $\Lambda\Lambda\pi$, $P\Xi$ modes in $\Upsilon(1S)$ and $\Upsilon(2S)$ data. No obvious bound state can be seen.

Thank you!

University of Hawai'i Mānoa

Spin-parity analysis

In the two-photon process $\gamma\gamma \to VV$, five angles are kinematically independent. As one of choices of these variable sets, we choose z, z^*, z^{**}, ϕ^* and ϕ^{**}. These variables are defined, e.g., in the $\gamma\gamma \to \omega\phi$ process, as follows: z is the cosine of the scattering polar angle of ϕ in the $\gamma\gamma$ c.m. system, z^* and ϕ^* are the cosine of the helicity angle of K^+ in the ϕ decays and the azimuthal angle defined in the ϕ resonance c.m. frame with respect to the $\gamma\gamma \to \omega\phi$ scattering plane. z^{**} and ϕ^{**} are the cosine of the helicity angle of normal direction to the decay plane of the $\omega \to \pi^+\pi^-\pi^0$ decay and the azimuthal angle defined in the ω resonance c.m. frame.

Among these variables, we choose z, transversity angle and polar-angle product, where the latter two are defined by z^*, z^{**}, ϕ^* and ϕ^{**} as:

$$\text{transversity angle} = |\phi^* + \phi^{**}|,$$

and

$$\text{polar-angle produt} = (1 - (z^*)^2)(1 - (z^{**})^2),$$

where we took a plus operation of the two azimuthal angles since ϕ^* and ϕ^{**} are defined in each decay (helicity) coordinate. Note that the polar-angle product is, in reality, the product of the sine squared of the polar angles.

For more details, please see BN#250

- Thanks Uehara-san