First measurement of $\chi_{cJ} \to \Sigma^{+}\overline{p}K_{S}^{0} + c.c$ (J=0, 1, 2) decays

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Outline

- **Introduction**
- **Data Sets**
- **Event Selection**
- **Background analysis**
- **Systematic uncertainties**
- **Summary**

Introduction

- Obtaining more experimental data on exclusive decays of χ_{cJ} state is important for a better understanding of their nature and decay mechanisms, as well as for testing QCD – based calculations.
- Searching for new excited baryon states is still motivated for us to enrich the relatively poor knowledge of the baryon spectrum. Search for excited baryon states via $\chi_{cJ} \to \Sigma^+ \bar{p} K_S^0$.
- The world's largest statistics of ψ(3686) events collected with the BESIII detector provides a unique opportunity for a detailed study of χ_{cJ} decays.
- This analysis report the first measurements of the branching fractions of $\chi_{cJ} \to \Sigma^+ \bar{p} K_S^0 + \mathrm{C.C.}$ decays via the E1 radiative transition $\psi(3686) \to \gamma\, \chi_{cJ}$.

Data Sets

- **Boss Version: 664p03;**
- **Data: 447.9× 10^6(2009+2012)$\psi(3686)$;**
- **Inclusive MC: 506× 10^6 $\psi(3686)$;**
- **Exclusive MC: 2 × 10^5 events for every decay mode.**

Event topology

$$\psi(3686) \to \gamma\chi_{cJ}, \chi_{cJ} \to \Sigma^{+}\bar{p}K_{S}^{0} + c.c$$

$\Sigma^{+} \to p\pi^{0}$, $K_{S}^{0} \to \pi^{+}\pi^{-}$

- Final states of signal: $\gamma\gamma\gamma p\bar{p}\pi^{+}\pi^{-}$.
- In the next slides, the charge-conjugated channel is included by default.

Event Selection

- **Charged tracks**
- No |Rxy | and |Rz| requirements;
- |cosθ|<0.93;
- Ngood =4 & ΣQ=0;

- **Neutral tracks**
- E≥25 MeV for barrel (|cosθ|< 0.8);
- E≥50 MeV for endcap (0.86<|cosθ|< 0.92) ;
- θmin(γ,charge)>10°;
- 0<TDC<14 (50ns) ;
- Nγ≥3;

- **PID**
- PID for proton;

- **4C kinematic fit**
- Obtain $\gamma\gamma\gamma p\bar{p}\pi^+\pi^-$

- **K_S is reconstructed by Second VertexFit**

$$L/\sigma_L > 2$$

- **π^0 and radiative γ_3:**

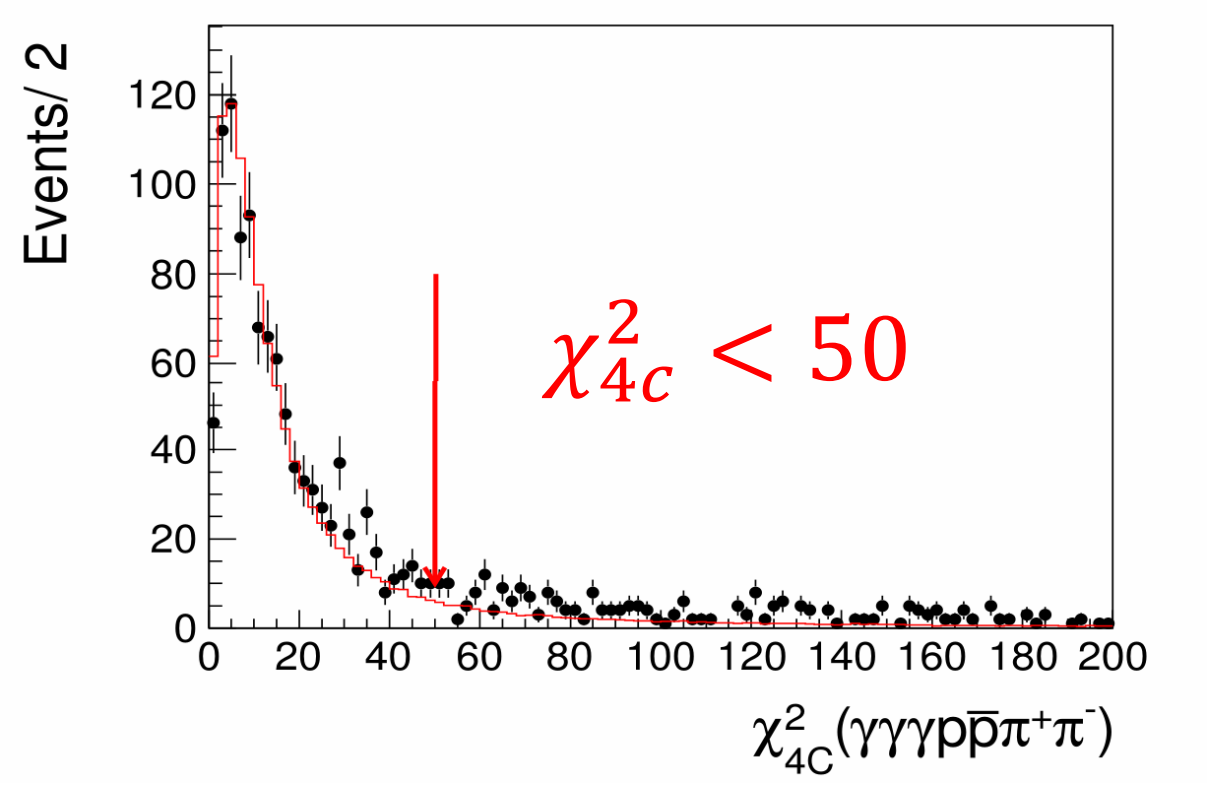
$$\chi^2 = \left(\frac{M(\gamma_1\gamma_2) - M(\pi^0)}{\sigma_{\pi^0}}\right)^2$$

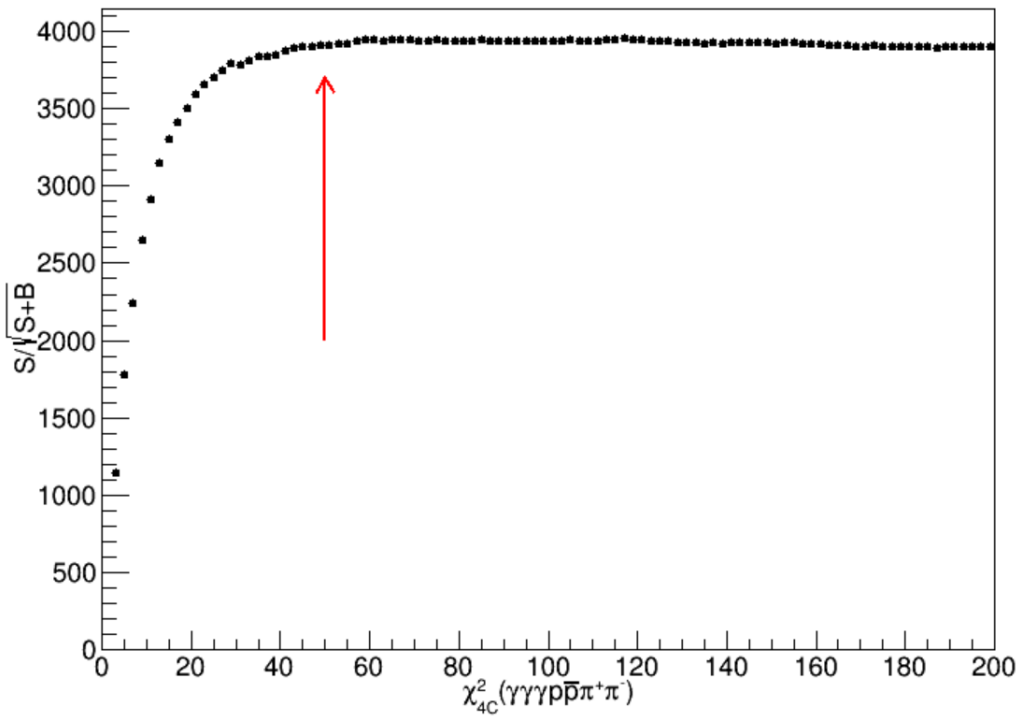
The left γ_3 is as the radiative γ from $\psi(3686)$.

- **Suppress background with $\gamma\gamma$ or $\gamma\gamma\gamma\gamma$ in final states:**

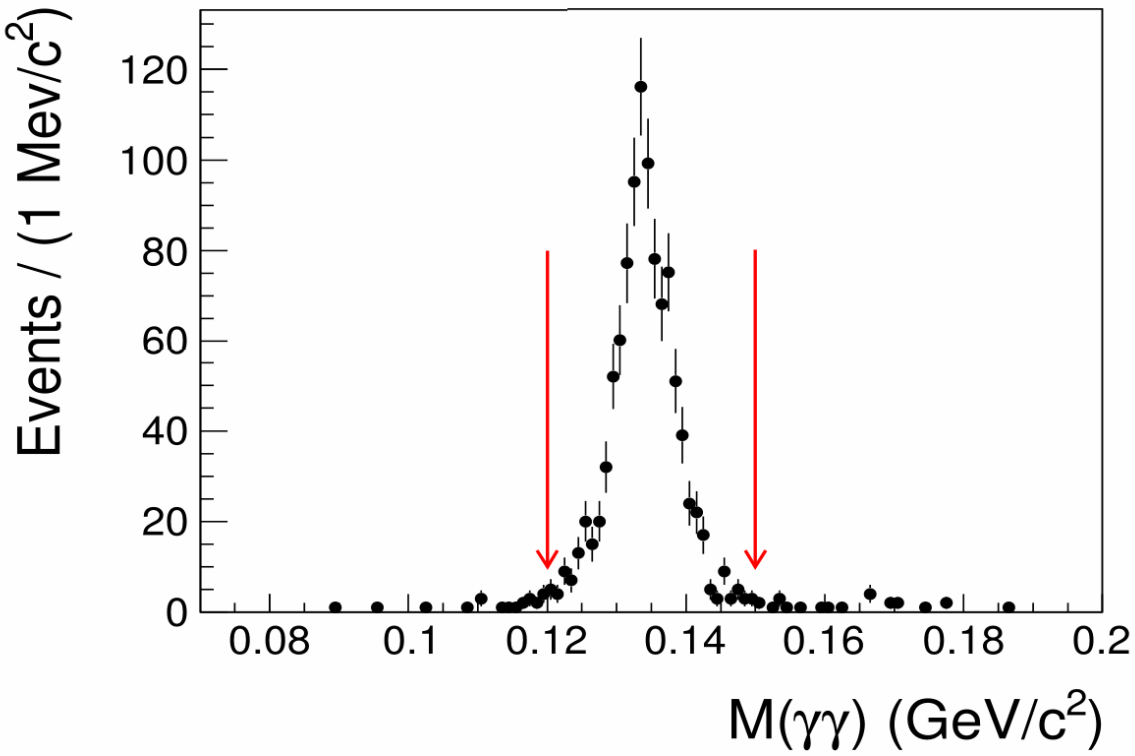
$$\chi^2(\gamma\gamma\gamma\pi^+\pi^-) < \chi^2(\gamma\gamma\gamma\gamma\pi^+\pi^-)$$
$$\&\& \ \chi^2(\gamma\gamma\gamma\pi^+\pi^-) < \chi^2(\gamma\gamma\pi^+\pi^-)$$

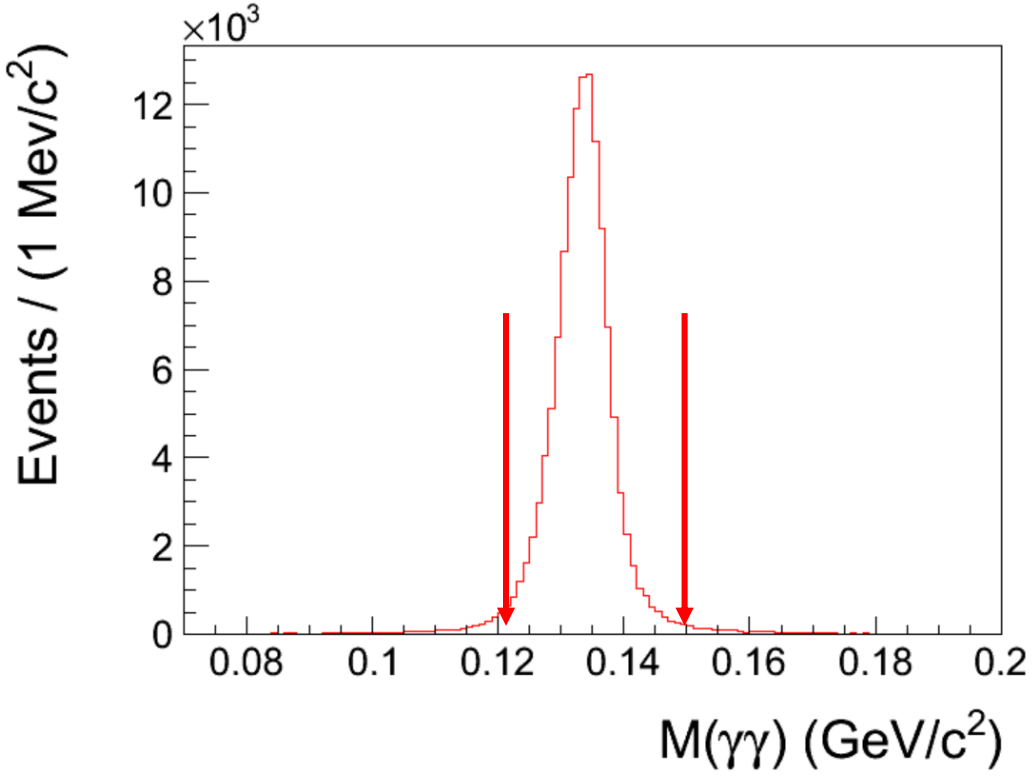
Event Selection





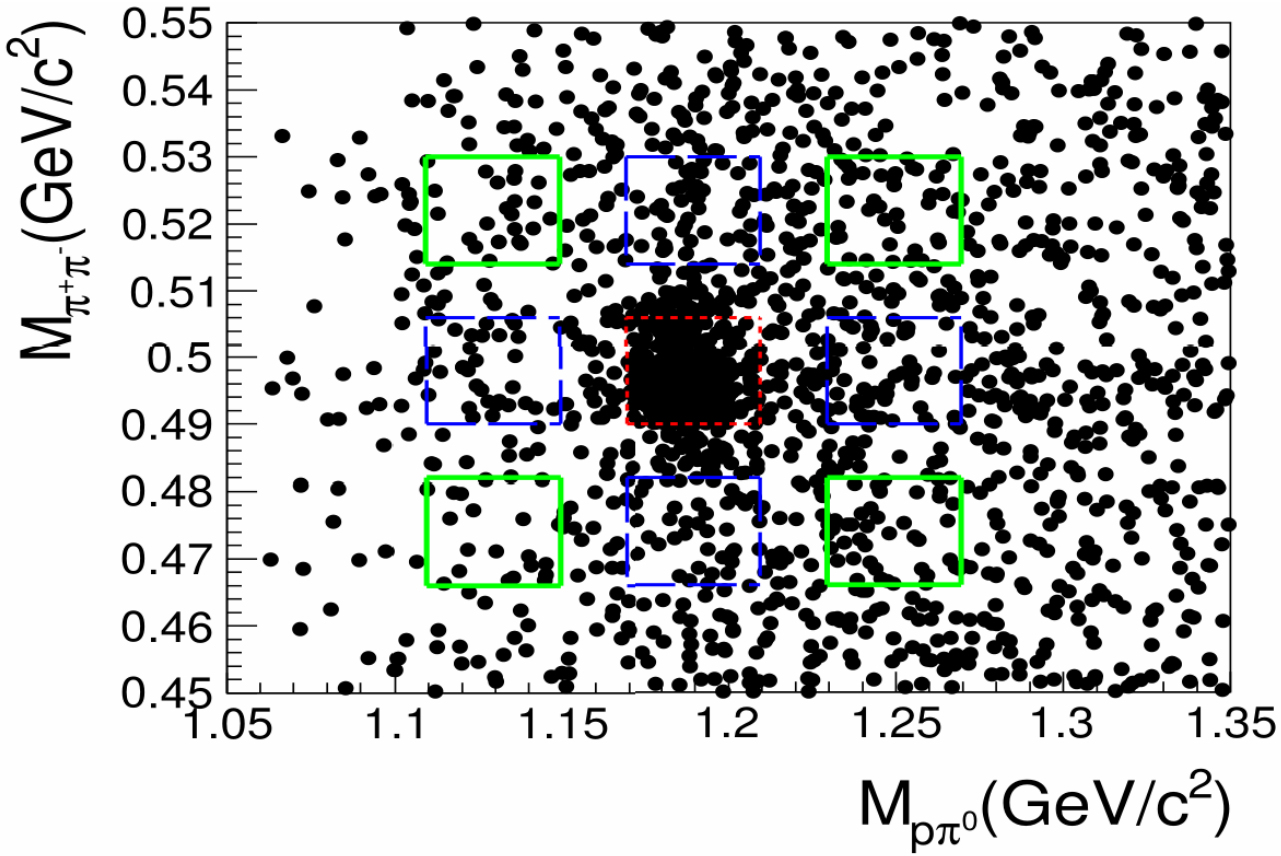
Event Selection

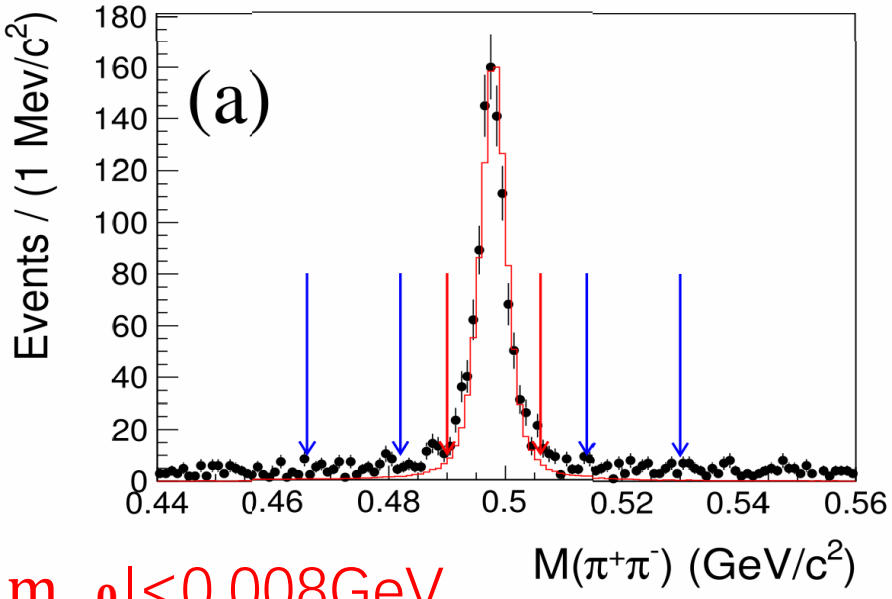




$$|m_{\gamma\gamma} - m_{\pi^0}| < 0.015\text{GeV}$$

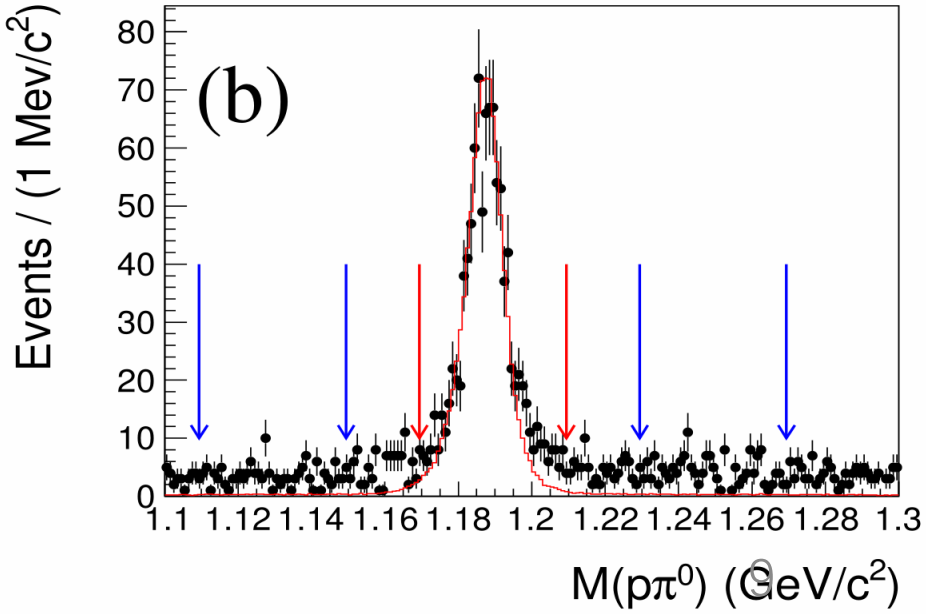
Event Selection



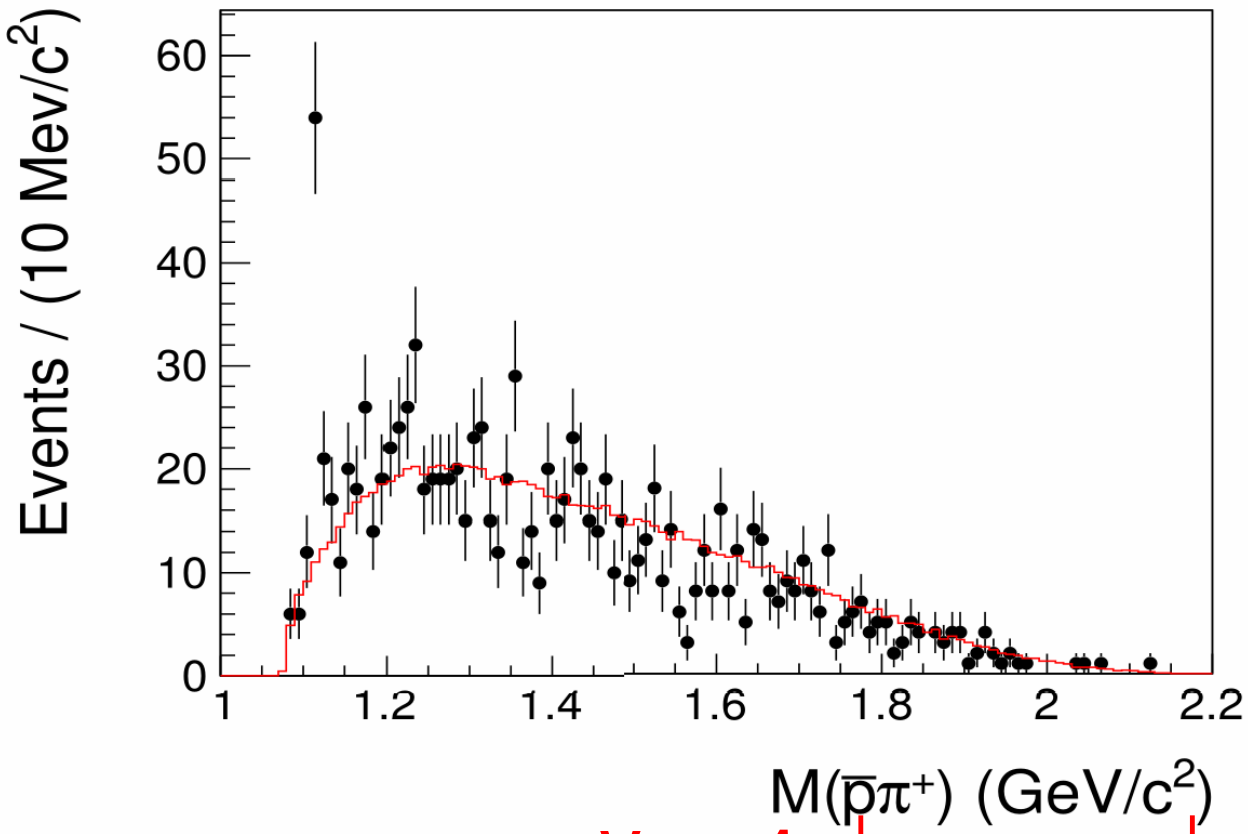


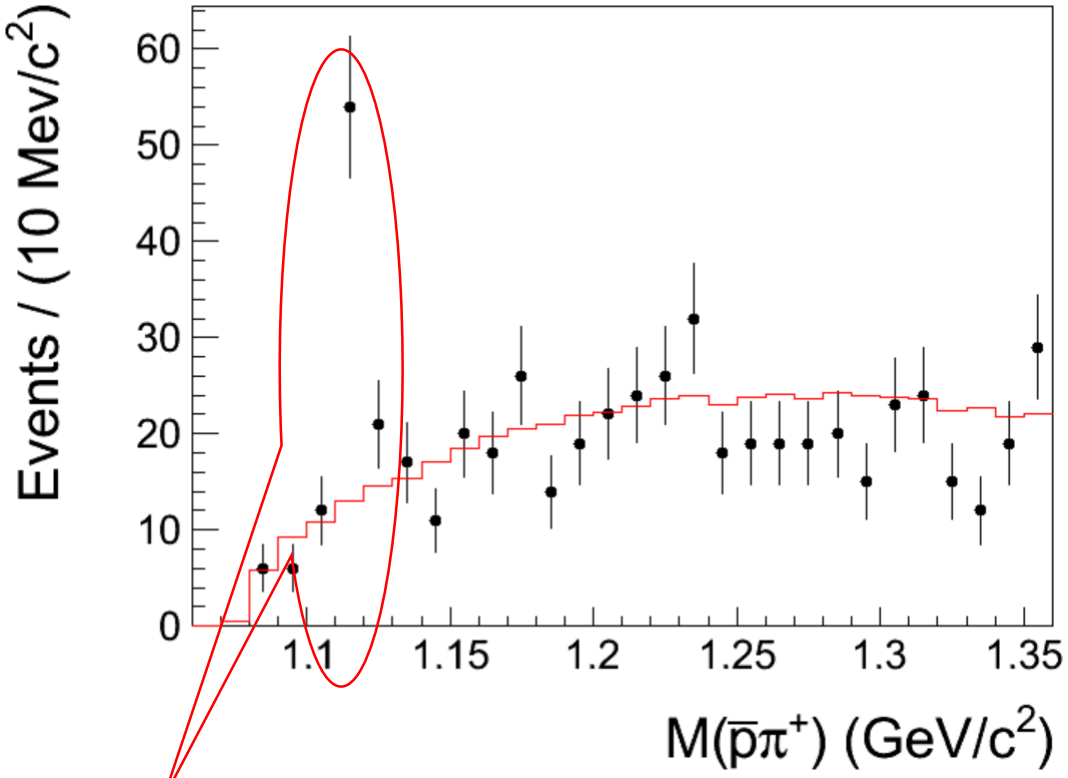
$|m_{\pi^+\pi^-} - m_{K_S^0}|$<0.008GeV

$|m_{p\pi^0} - m_{\Sigma^+}|$<0.02GeV



Event Selection

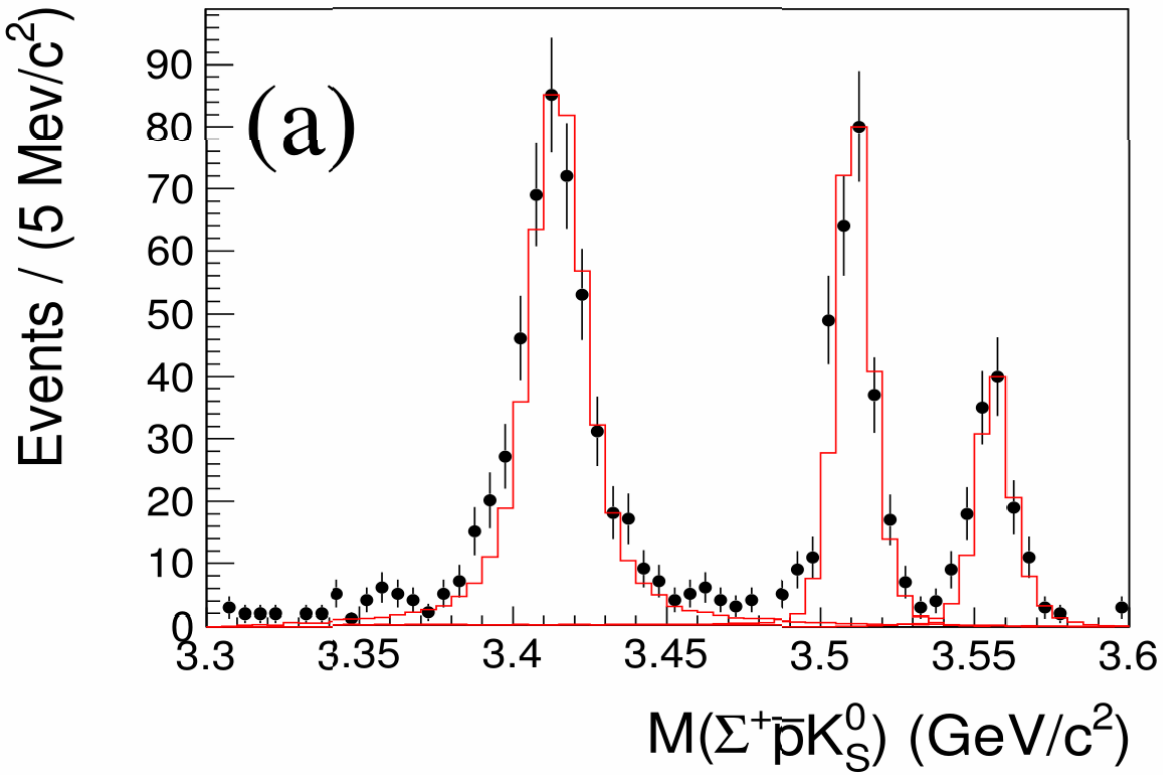


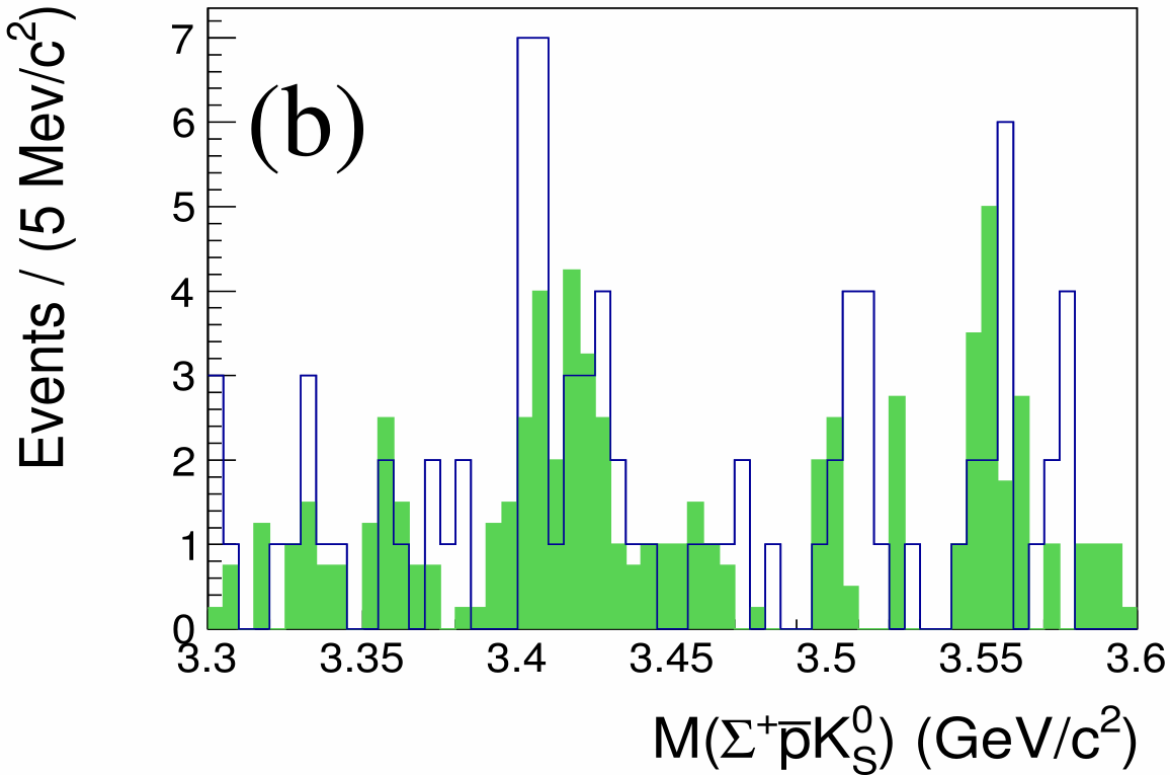


Veto Λ : $\left|m_{\bar{p}\pi^+} - m_\Lambda\right| > 0.006\text{GeV}$

to suppress the backgrounds from $\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to \Sigma^+\bar{\Lambda}\pi^-, \Sigma^+ \to p\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$. The cut efficiency is 98.8% .

$\Sigma^+\bar{p}K_S^0$ mass



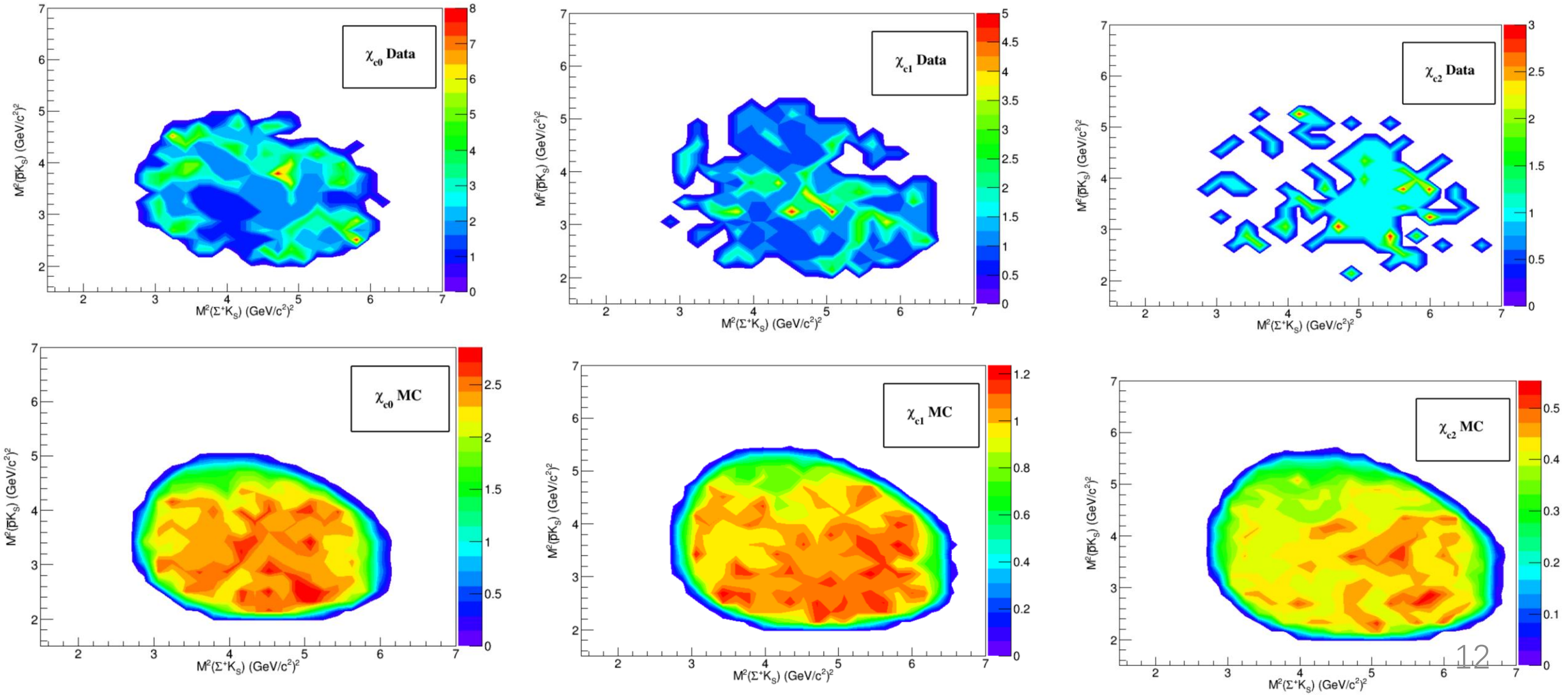


(a)Dots with error bars are data, the solid line histogram is the χ_{cJ} line shape from the signal MC simulation.

(b) The solid line is the background estimated from inclusive MC sample, and the green-shaded histograms are the 2-D sideband events of K_S^0 and Σ^+ invariant mass from inclusive MC sample.

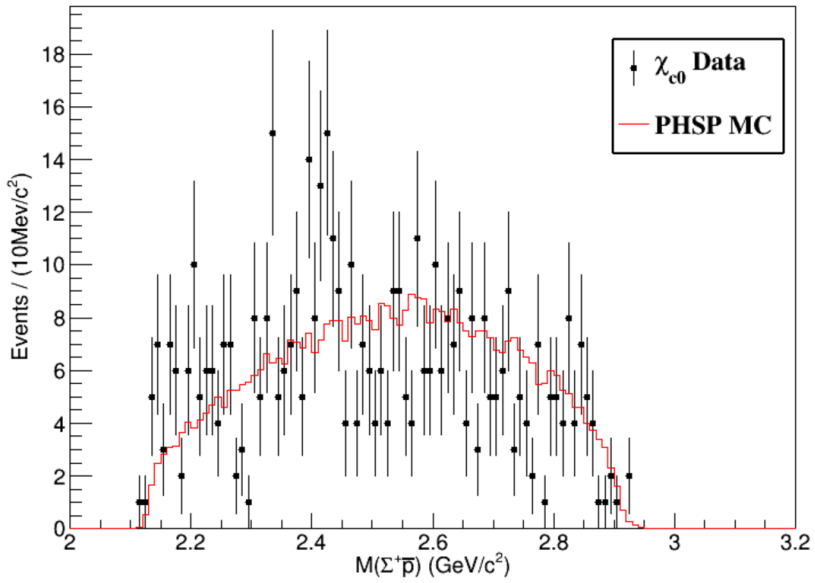
Distributions

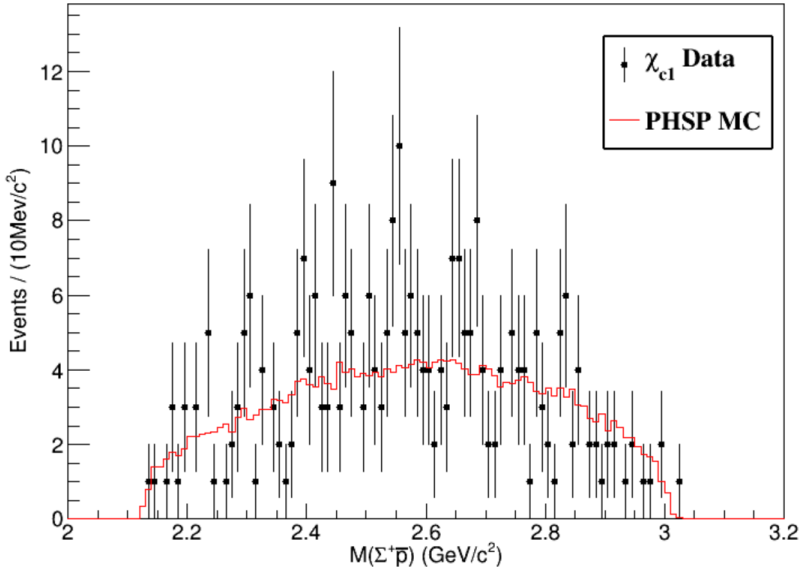
$\chi_{c0,1,2}$ regions are defined as [3.36, 3.46] , [3.48, 3.54] and [3.54, 3.58] GeV/c ^{2} .

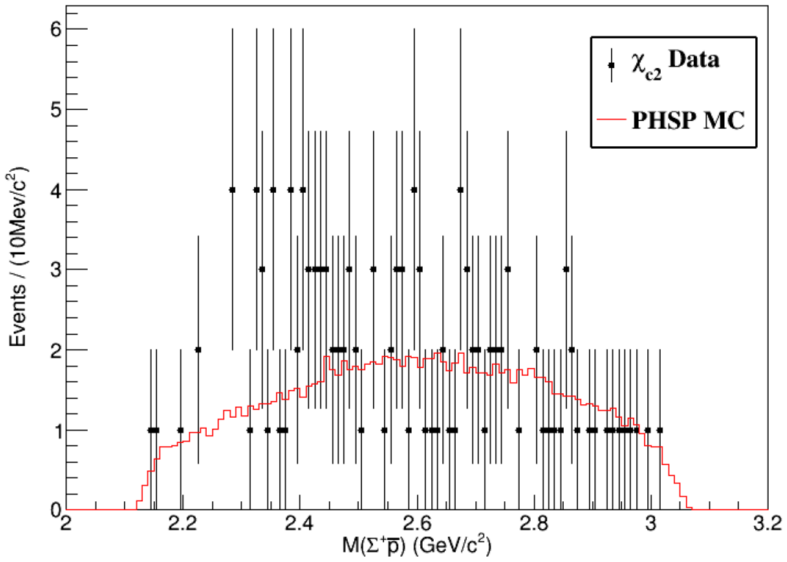


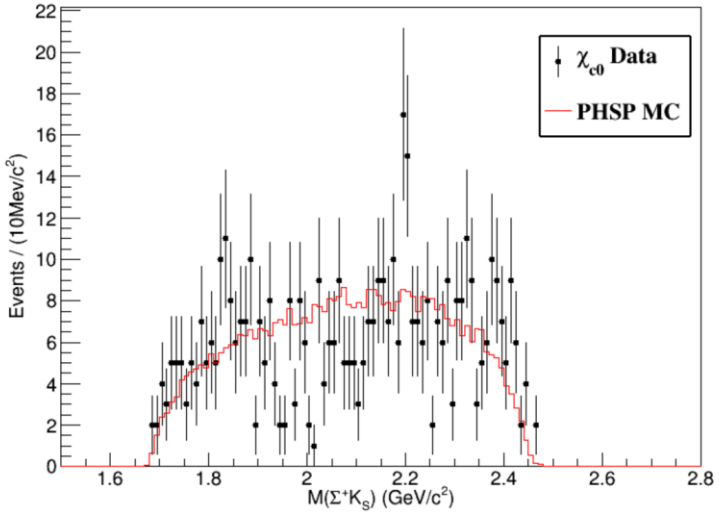
Distributions

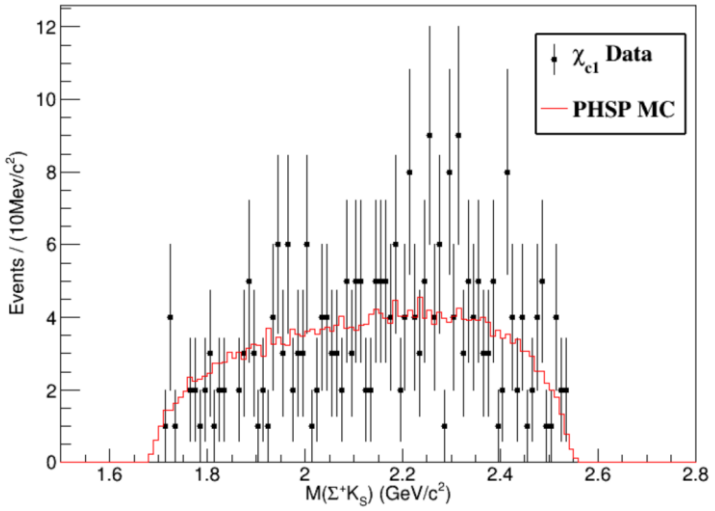
No clear structure can be seen from them.

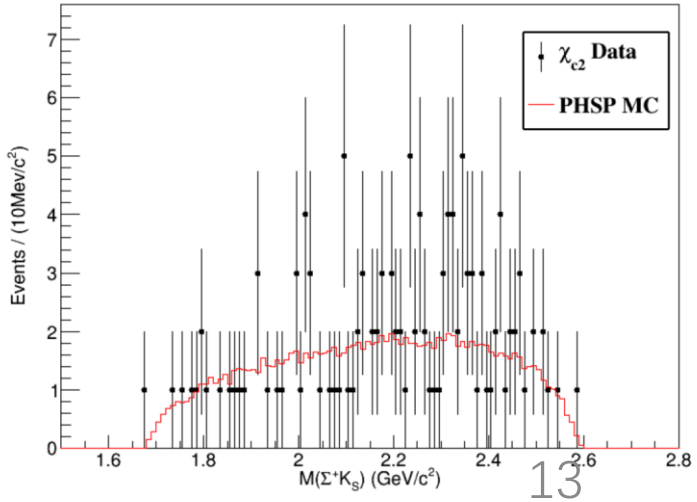




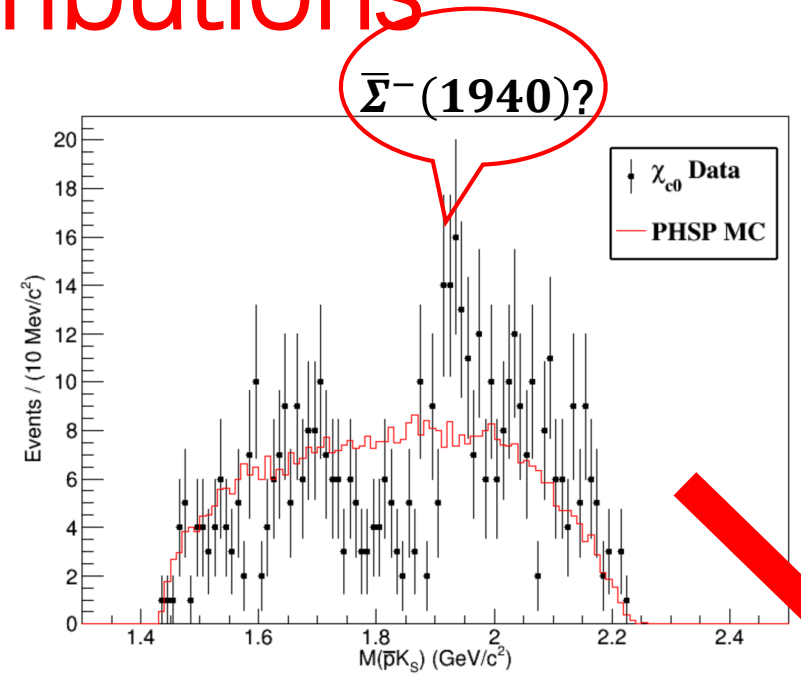


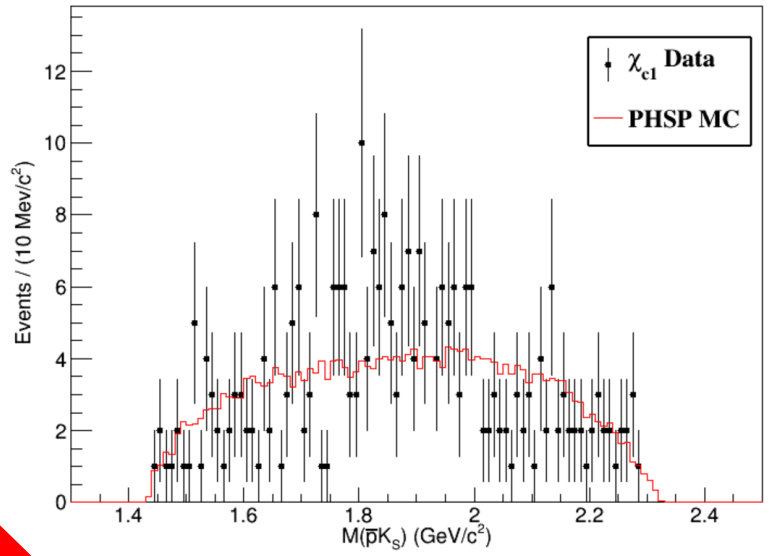


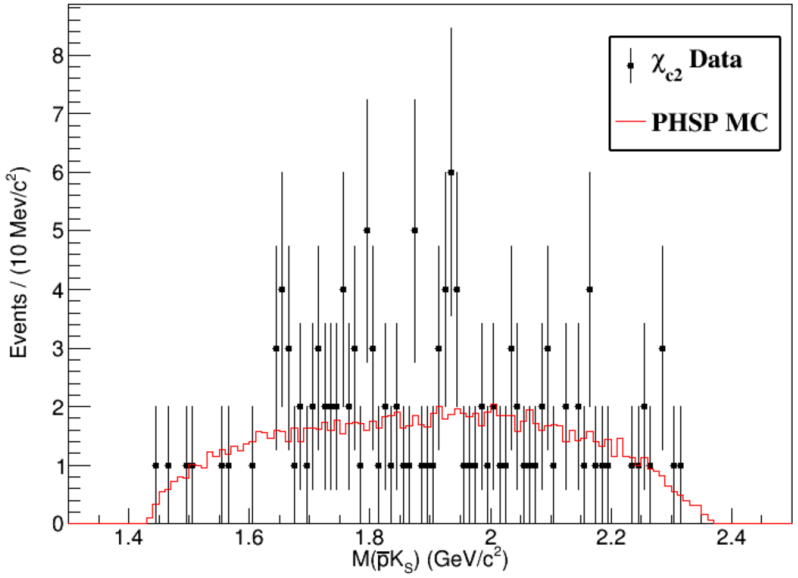


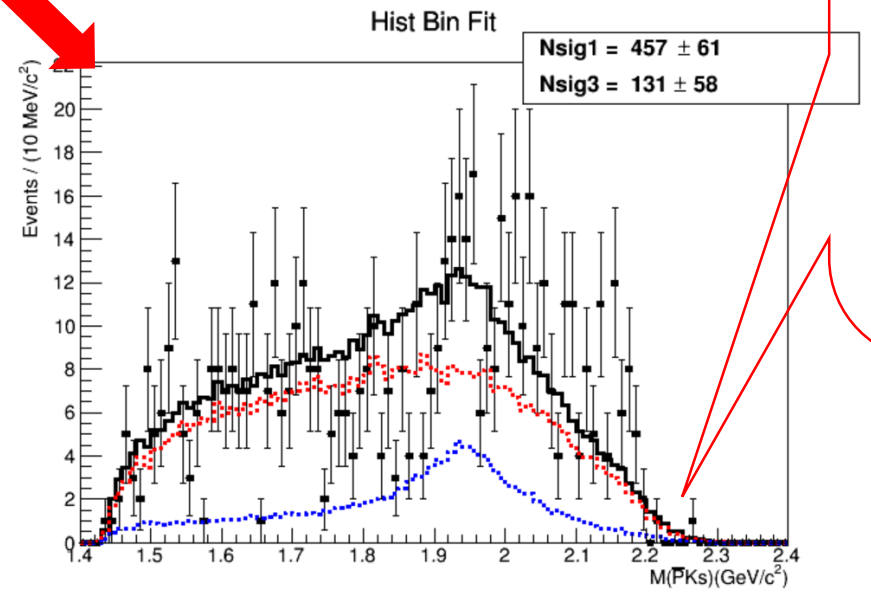


Distributions







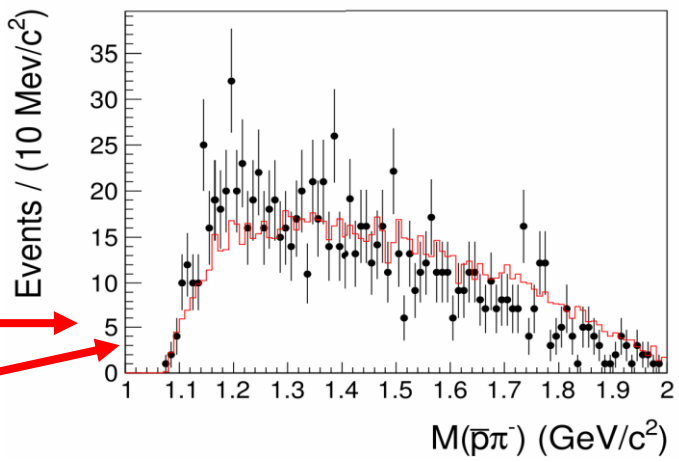


Use $\chi_{c0} \rightarrow \Sigma^+\bar{\Sigma}^-(1940)$ MC and the Phase Space MC to fit it.

$\bar{\Sigma}^-(1940)$:
M = 1940 MeV,
Γ= 150 MeV,
I(J^P) = 1(3/2$^-$)).
Significance: 2.3σ

Background analysis

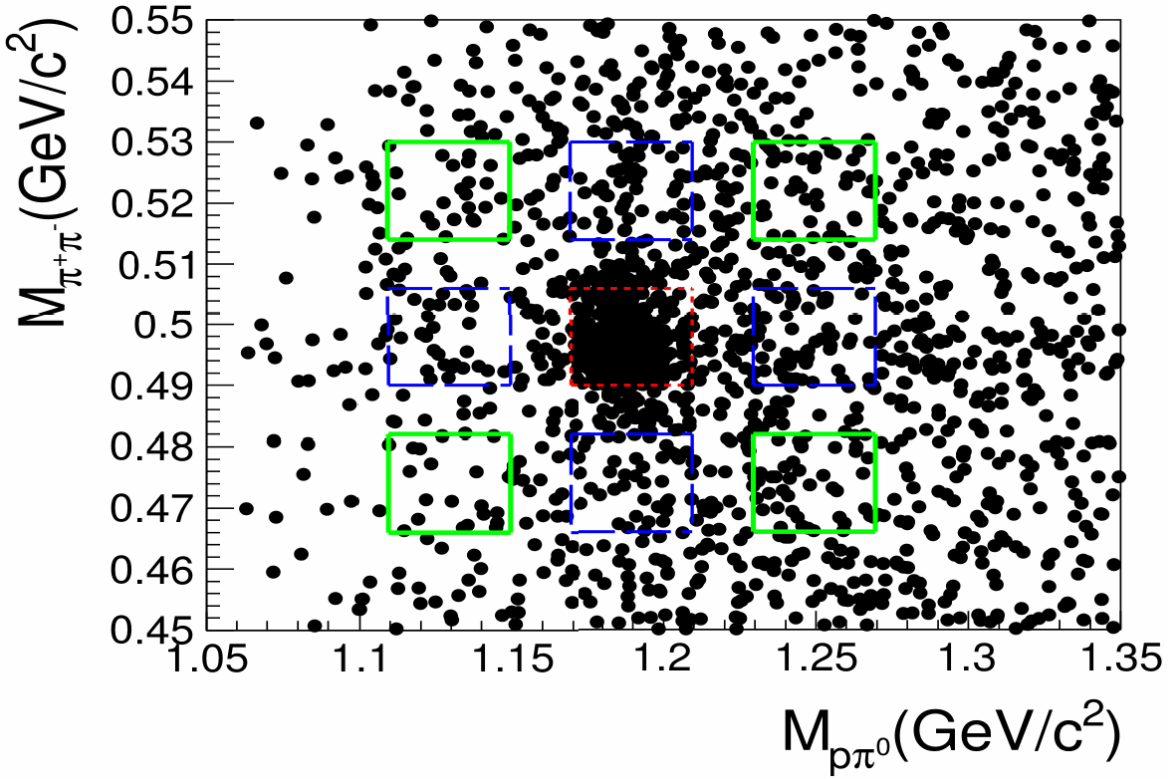
No.	decay chain	final states	iTopology	nEvt
7	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to p\bar{p}\pi^+\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	5	3
8	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^{++}\bar{p}\pi^-, \Delta^{++} \to p\pi^+$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	21	3
9	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \Delta^+\pi^+\bar{\Delta}^{--}, \Delta^+ \to p\pi^0, \bar{\Delta}^{--} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	0	3
10	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \Delta^{++}\pi^-\bar{\Delta}^-, \Delta^{++} \to p\pi^+, \bar{\Delta}^- \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	18	3
11	$\psi' \to \bar{\Sigma}^- p\bar{K}^*, \bar{\Sigma}^- \to \bar{p}\pi^0, \bar{K}^* \to \bar{K}^0\pi^0, K_S \to \pi^+\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	42	3
12	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \omega p\bar{p}, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	12	2
13	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \pi^0\Delta^{++}\bar{\Delta}^{--}, \Delta^{++} \to p\pi^+, \bar{\Delta}^{--} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	15	2
14	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^+\Delta^+\bar{\Delta}^{++}, \Delta^+ \to p\pi^0, \bar{\Delta}^{--} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	4	2
15	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \bar{\Delta}^{--}\pi^0\Delta^{++}, \bar{\Delta}^{--} \to \bar{p}\pi^-, \Delta^{++} \to p\pi^+$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	17	2
16	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to h_1(1170)p\bar{p}, h_1(1170) \to \rho^+\pi^-, \rho^+ \to \pi^+\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	25	2
17	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^+\Lambda\bar{\Sigma}^-, \Lambda \to p\pi^-, \bar{\Sigma}^- \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	26	2
18	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^{++}\bar{\Delta}^{--}, \Delta^{++} \to p\pi^+, \bar{\Delta}^{--} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	27	2
19	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \bar{\Delta}^{--}p\rho^+, \bar{\Delta}^{--} \to \bar{p}\pi^-, \rho^+ \to \pi^+\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	28	2
20	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to p\pi^0, \bar{\Sigma}^- \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	29	2
21	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \pi^0\Delta^{++}\bar{\Delta}^{--}, \Delta^{++} \to p\pi^+, \bar{\Delta}^{--} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	31	2
22	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^-\rho^+\bar{p}p, \rho^+ \to \pi^+\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	32	2
23	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to p\bar{\Delta}^0\pi^-, \bar{\Delta}^0 \to \bar{p}\pi^+$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	33	2
24	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Delta^{++}\pi^-\bar{\Delta}^-, \Delta^{++} \to p\pi^+, \bar{\Delta}^- \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	36	2
25	$\psi' \to \bar{K}^0\Delta^+\bar{\Sigma}^-, \Delta^+ \to p\pi^0, \bar{\Sigma}^- \to \bar{p}\pi^0, K_S \to \pi^+\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	37	2
26	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \bar{\Delta}^-\pi^+\Delta^0, \bar{\Delta}^- \to \bar{p}\pi^0, \Delta^0 \to p\pi^-$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	41	2
27	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Delta^+\pi^-\bar{\Delta}^0, \Delta^+ \to p\pi^0, \bar{\Delta}^0 \to \bar{p}\pi^+$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	3	2
28	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to h_1(1170)p\bar{p}, h_1(1170) \to \rho^-\pi^+, \rho^- \to \pi^-\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	44	2
29	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to p\bar{p}\pi^+\pi^-$	$\pi^-\bar{p}\pi^+\gamma\gamma p$	45	2



no clear $\bar{\Delta}^{--}$ peak

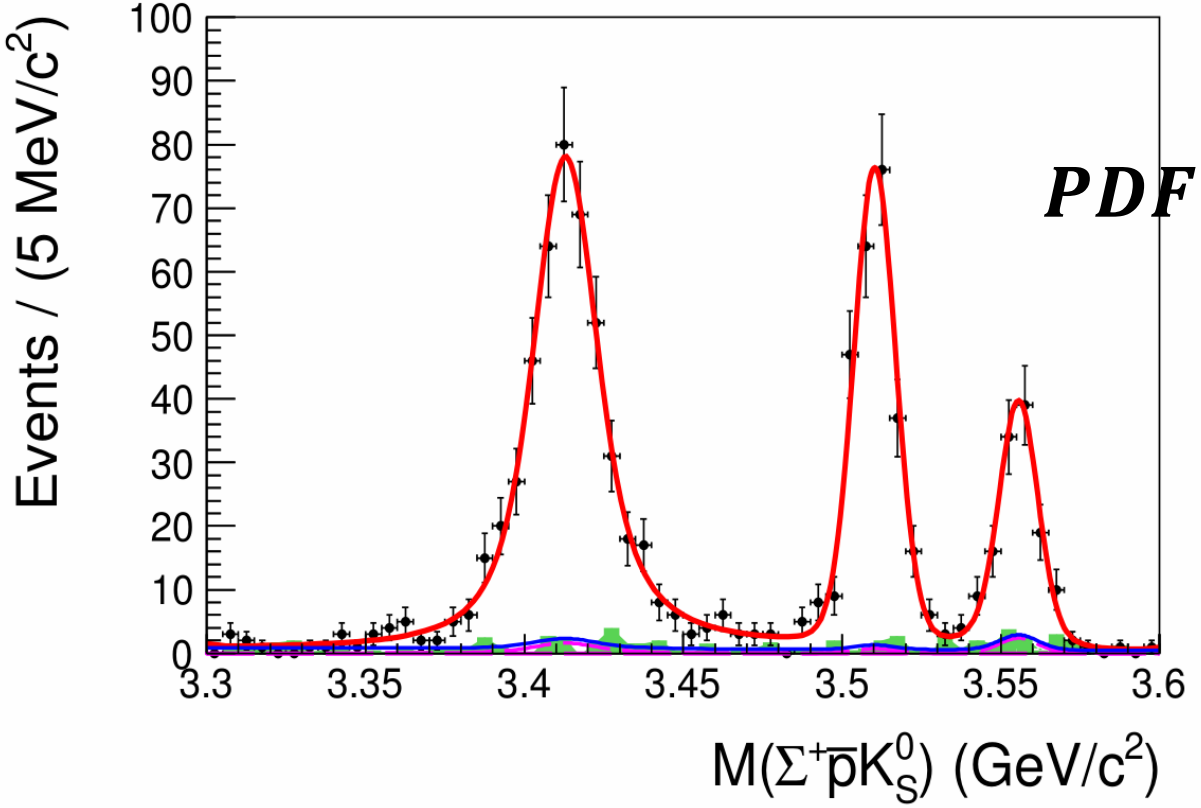
estimated by K_S^0 and Σ^+ 2-D sideband

Background analysis



$$\mathrm{Nbkg} = \frac{1}{2}\,\mathrm{Nblue} - \frac{1}{4}\,\mathrm{Ngreen}$$

Unbinned simultaneous fit to M($\Sigma^+\bar{p}K_S^0$)



$$PDF = (\mathrm{BW}(\mathrm{m}) \times \mathrm{E}_\gamma^3 \times \mathrm{D}(E_\gamma)) \otimes \mathrm{Gaussion}$$

$$E_\gamma = \frac{M_{\psi(3686)}^2 - m^2}{2M_{\psi(3686)}}$$

$$\mathrm{D}(E_\gamma) = e^{-\frac{E_\gamma^2}{8\beta^2}}$$ [1]

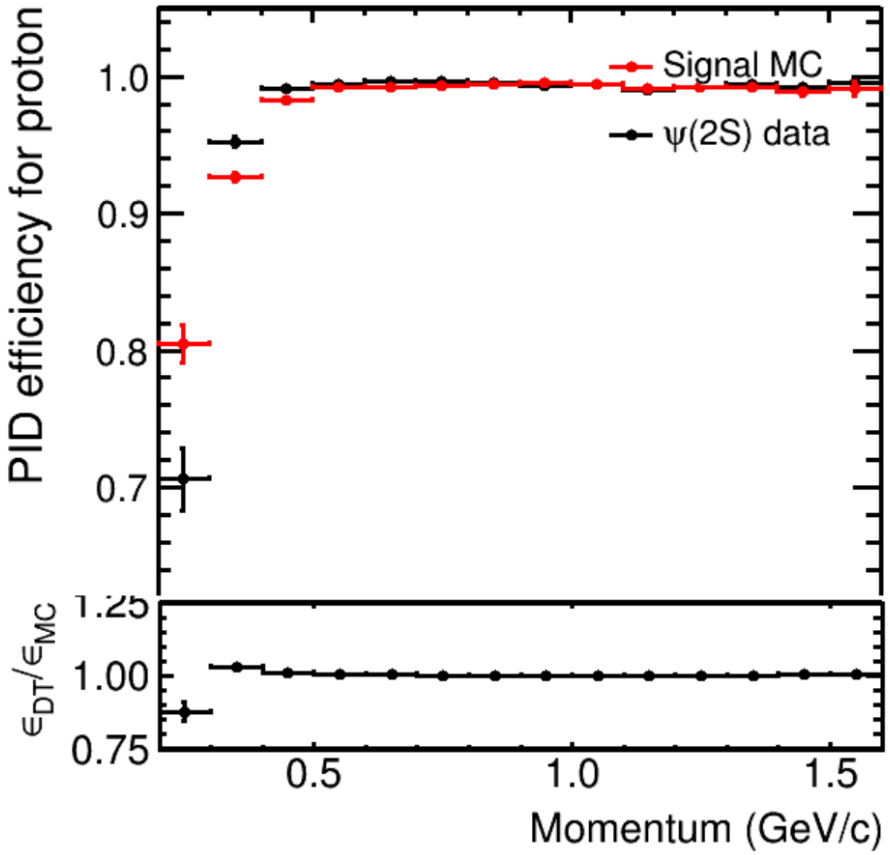
[1] R. E. Mitchell et al. (CLEO Collaboration), Phys. Rev. Lett. 102, 011801 (2009)

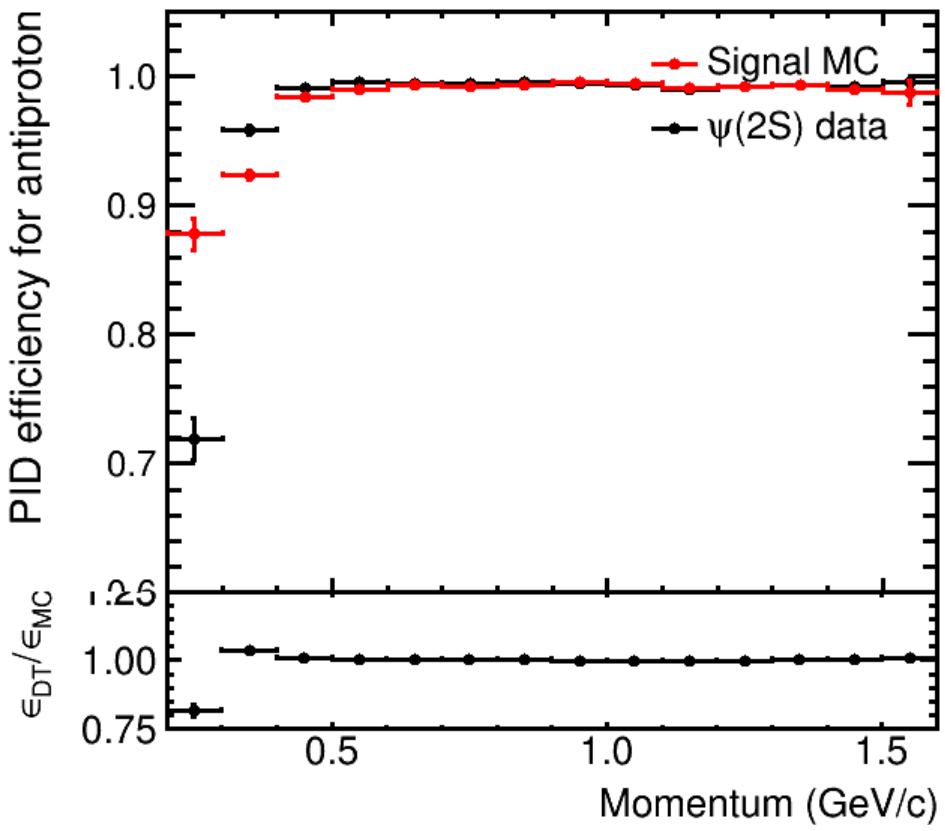
Dots with error bars are data, the red solid curve shows the result of fit, the green-shaded histograms are the events from 2-D sideband regions, the blue solid line is total background components of the fit, and the violet long dashed curve is the fit of the 2-D sideband events.

In the simultaneous fit, the shape of χ_{cJ} are the same between data and 2-D sideband events.

Systematic uncertainties

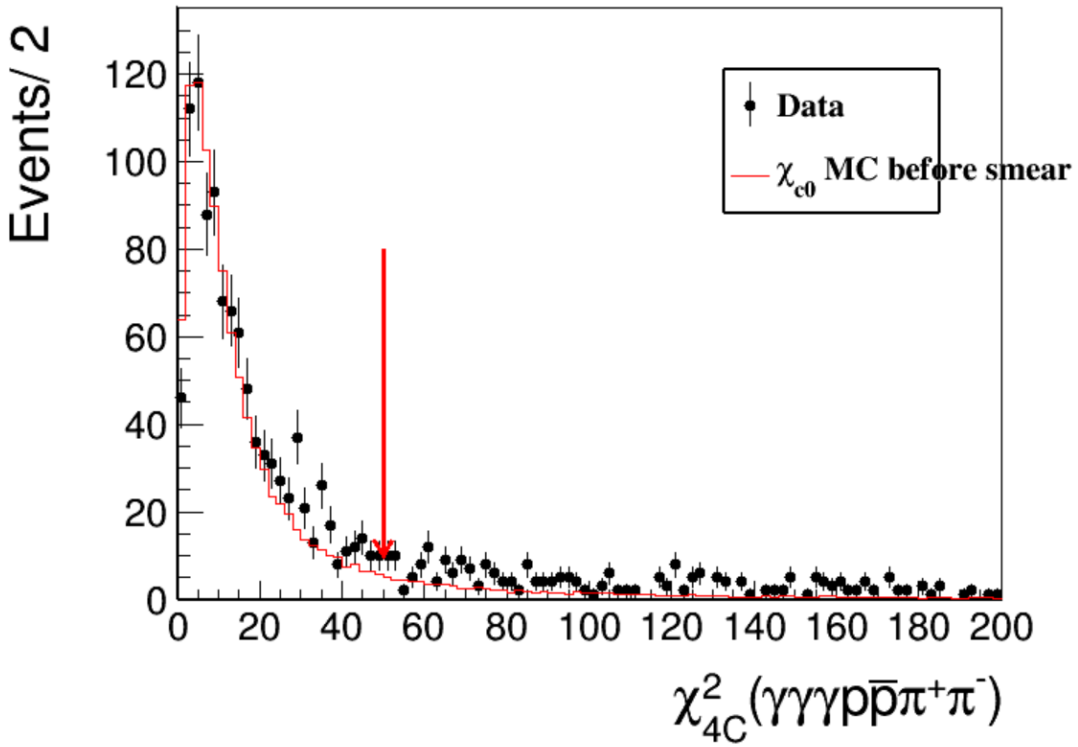
Particle identification using the control sample $\psi(3686) \rightarrow \bar{P}P\pi^+\pi^-$

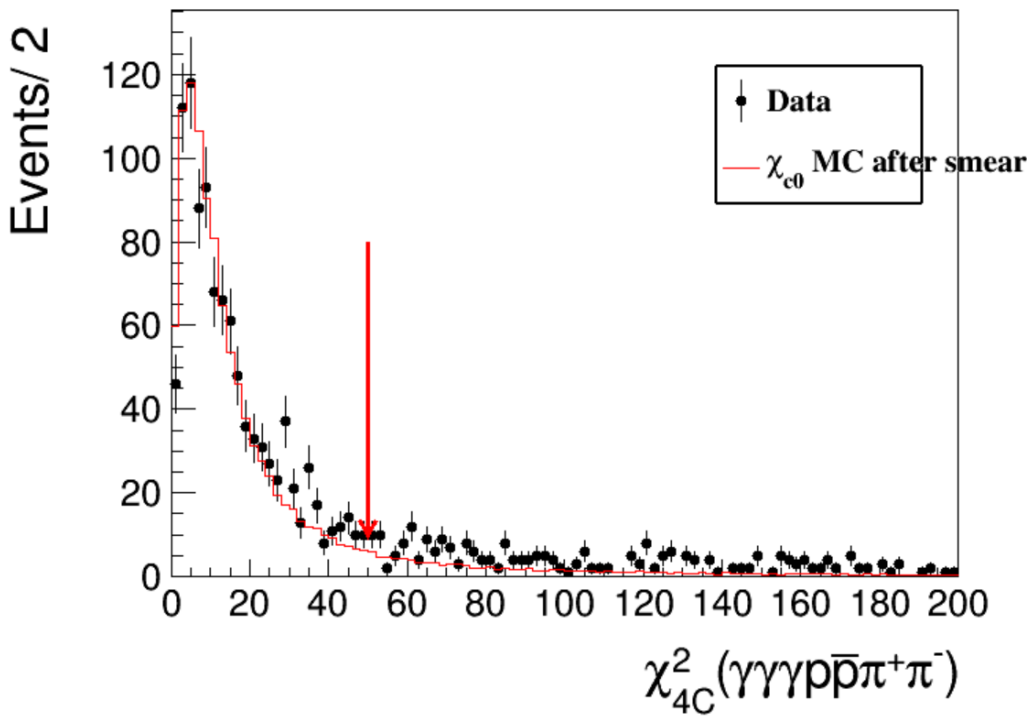




Systematic uncertainties

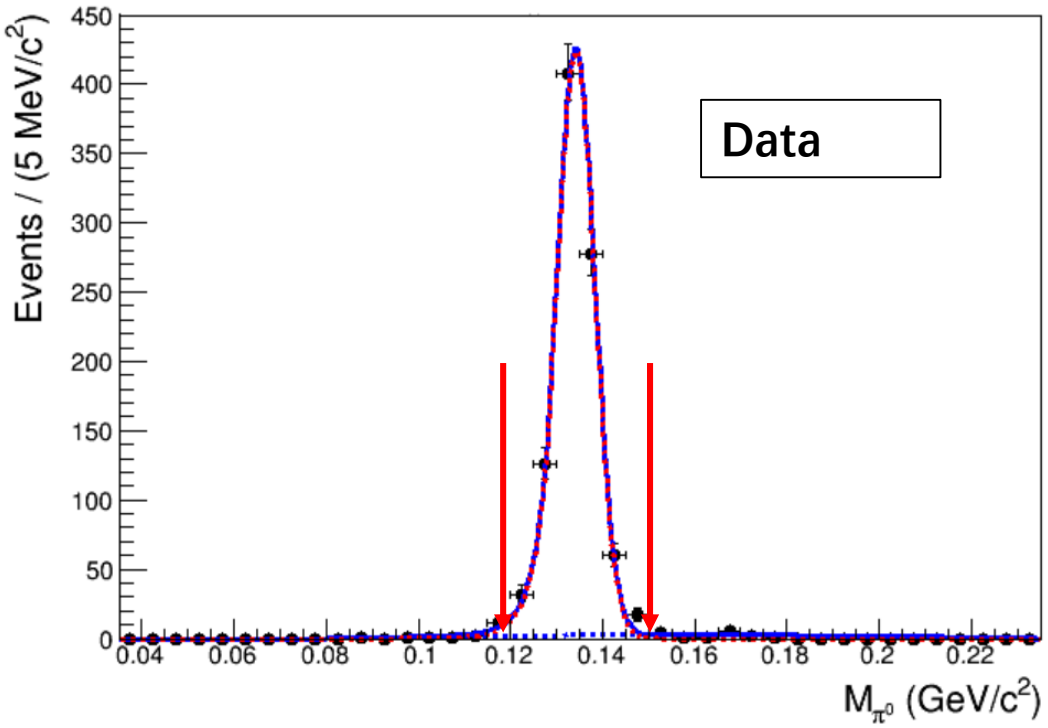
4C kinematic fit-take χ_{c0} as example.

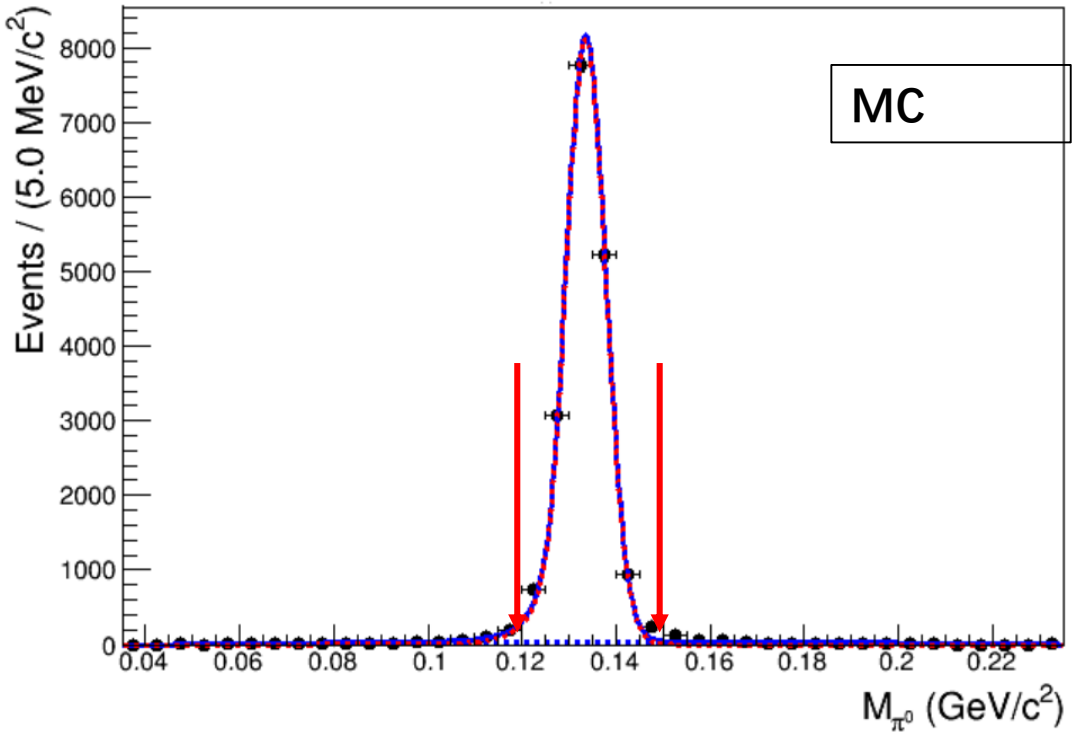




Systematic uncertainties

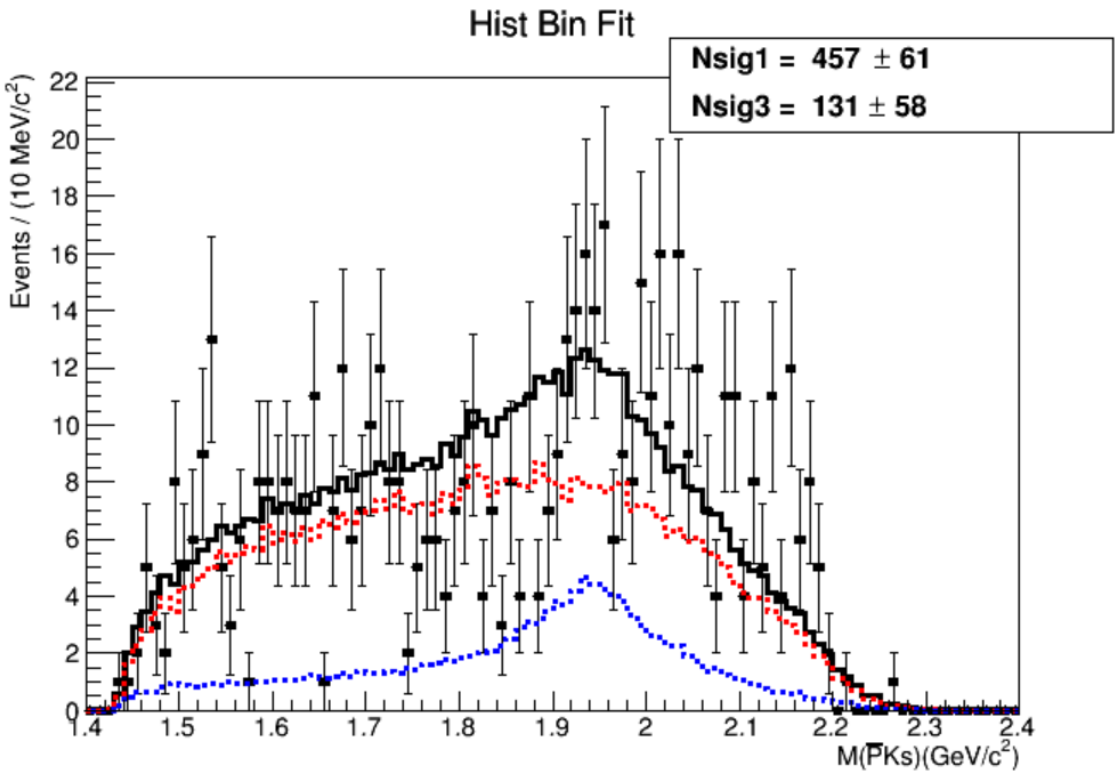
π^0, K_S^0 and Σ^+ mass window-take π^0 as example





Systematic uncertainties

$\bar{\Sigma}^{-}(1940)$ structure



Systematic uncertainties

$$\mathbf{D}(E_\gamma) = \frac{E_0^2}{E_0 E_\gamma + (E_0 - E_\gamma)^2}$$ [2]

[2]V. V. Anashin et al. (KEDR Collaboration), Int. J. Mod. Phys. Conf. Ser. 02, 188 (2011)

Summary of systematic uncertainty sources and their contributions (in %).

Source	$\mathcal{B}(\chi_{c0})$	$\mathcal{B}(\chi_{c1})$	$\mathcal{B}(\chi_{c2})$
MDC tracking	4.0	4.0	4.0
Photon detection	3.0	3.0	3.0
Particle ID	1.7	1.8	2.0
4C kinematic fit	0.5	0.6	0.7
π^0 mass window	0.4	0.4	0.4
K_S^0 mass window	0.3	0.3	0.3
Σ^+ mass window	0.1	0.1	0.1
$\bar{\Sigma}^-(1940)$ structure	0.2	...	...
Signal line shape	1.7	1.2	0.8
Fit range	1.0	1.2	1.6
2D-sideband	0.2	0.4	0.8
Remaining background shape	2.9	2.0	1.6
Intermediate decay	0.4	0.4	0.4
Number of $\psi(3686)$	0.6	0.6	0.6
Total	6.4	6.0	6.1

Summary

- $\chi_{cJ} \to \Sigma^+\bar{p}K_S^0 + c.c$ is performed for the first time, the branching fractions of them are

channel	Efficiency	Branching Fraction($\chi_{cJ} \to \Sigma^+\bar{p}K_S + c.c$) (*10^{-4})
χ_{c0}	9.26%	$3.32 \pm 0.17 \pm 0.21$
χ_{c1}	10.88%	$1.55 \pm 0.10 \pm 0.09$
χ_{c2}	10.26%	$0.845 \pm 0.082 \pm 0.052$

- We can not draw the conclusion there are any intermediate states existing in these decays.
- The memo is ready and will be released very soon.

Thank you !!!