First measurement of $\chi_{cJ} \to \Sigma^0\bar{p}K^+ + c.c.$(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. We can search for excited baryon states via $\chi_{cJ} \to \Sigma^0 \bar{p} K^+$.**
- **The world's largest statistics of $\psi(3686)$ 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 $\chi_{cJ} \to \Sigma^0 \bar{p} K^+ + c.c.$ decays via the E1 radiative transition $\psi(3686) \to \gamma\, \chi_{cJ}$.**

Data Sets

- **Boss Version: 664p03;**
- **Data: 448.1× 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

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

($\Sigma^0 \to \gamma\Lambda$, $\Lambda \to p\pi^-$)

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

Event Selection

➢ **Charged tracks**

- |Rxy |<1cm and |Rz|<10cm for the free ant-proton and K^+;
- |cosθ|<0.93;
- Ngood =4 & ΣQ=0;

➢**Neutral tracks**

- Default;
- Nγ≥2;

➢**PID**

- PID for proton, pion and kaon;
- N(p)=N($\bar{p}$)=N(k^+) =N(π^-)

➢**Λ is reconstructed by Second VertexFit**

$$L/\sigma_L > 0$$

➢**4C kinematic fit**

- With the smallest χ^2
- Obtain $\gamma\gamma p\bar{p}\pi^- K^+$

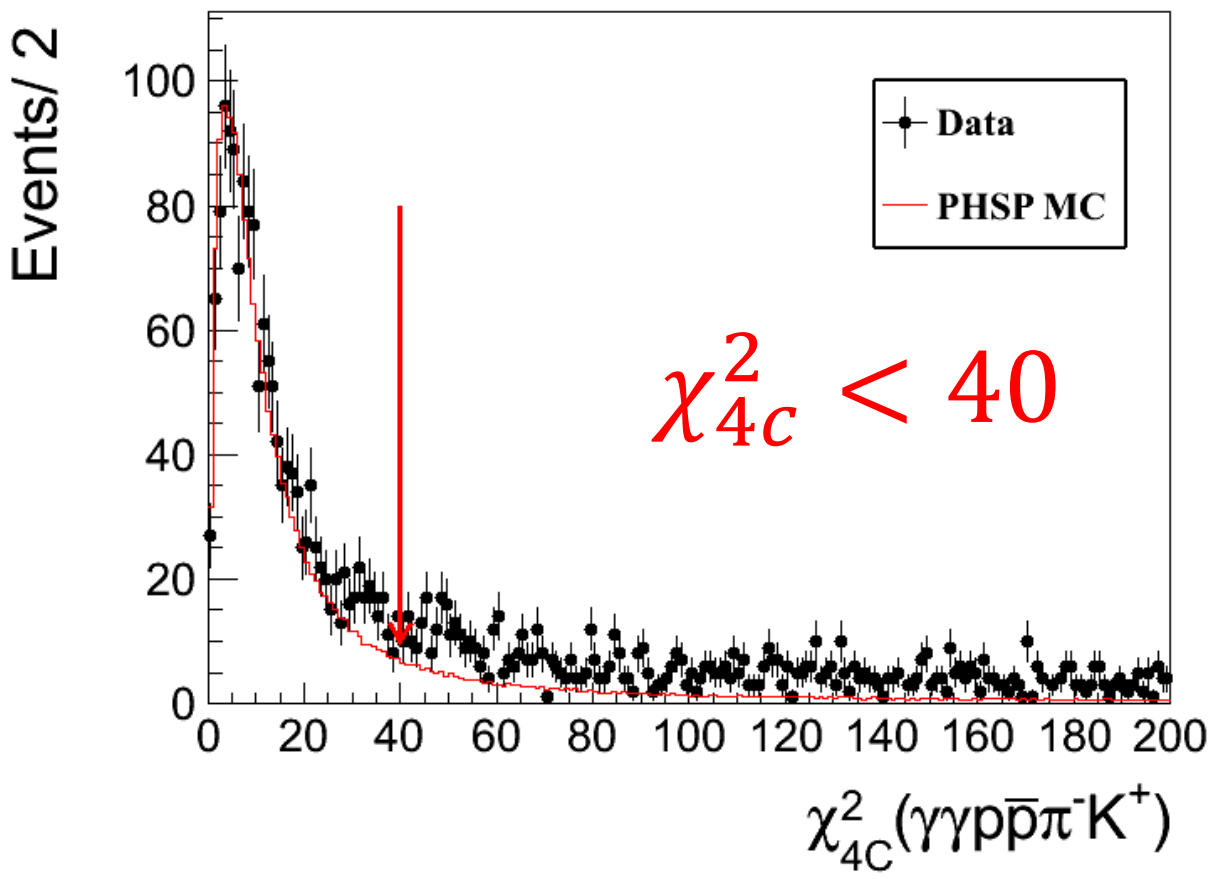
➢**Σ^0:**

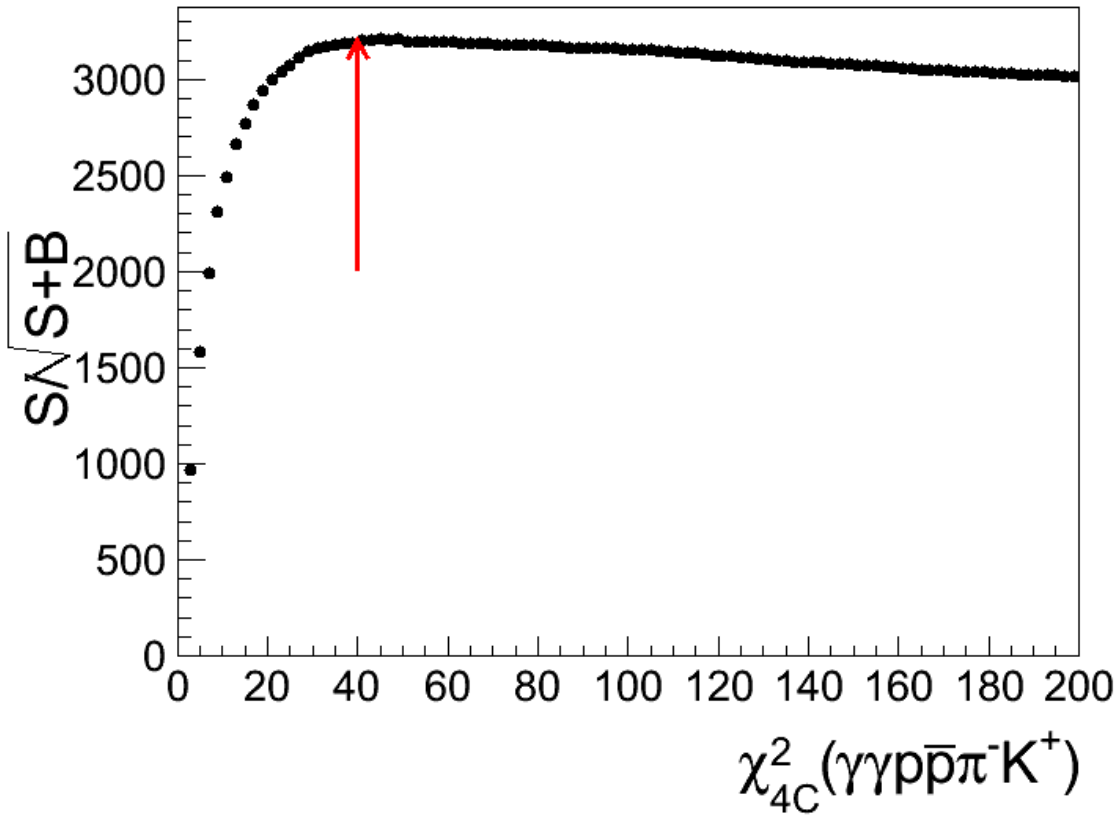
$$\chi^2 = \left(\frac{M(\gamma_1\Lambda) - M(\Sigma^0)}{\sigma_{\Sigma^0}}\right)^2$$

➢**Suppress background with γ :**

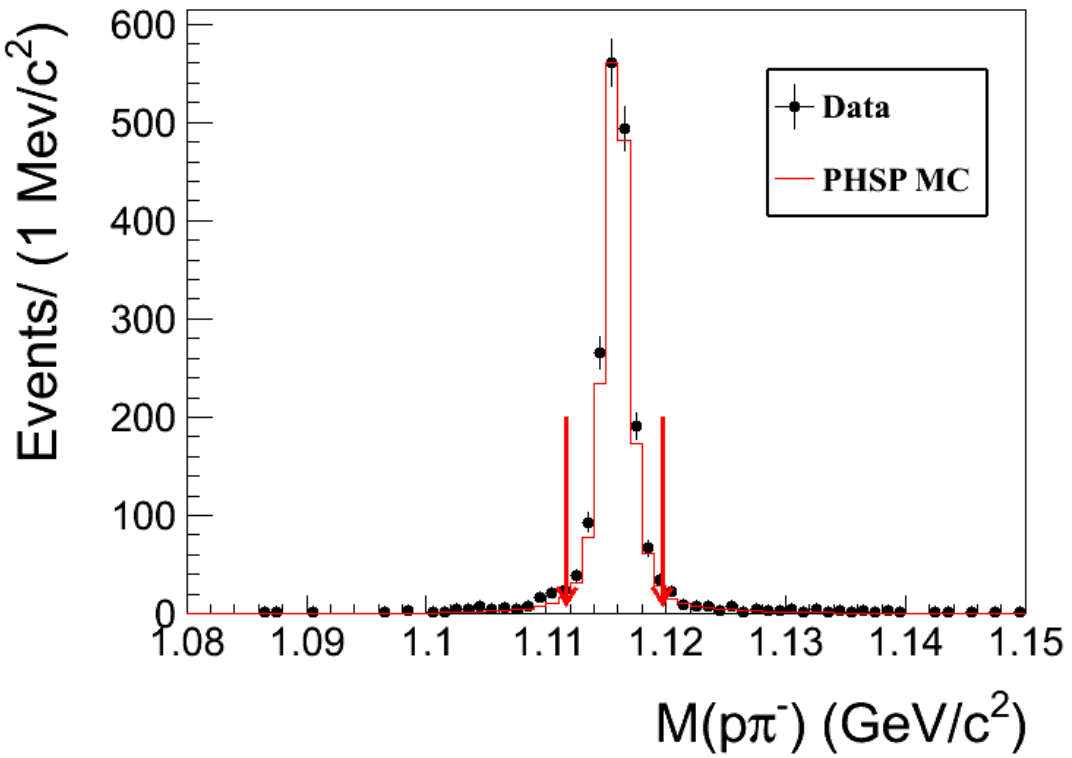
$$\chi^2(\gamma\gamma p\bar{p}\pi^- k^+) < \chi^2(\gamma p\bar{p}\pi^- k^+)$$

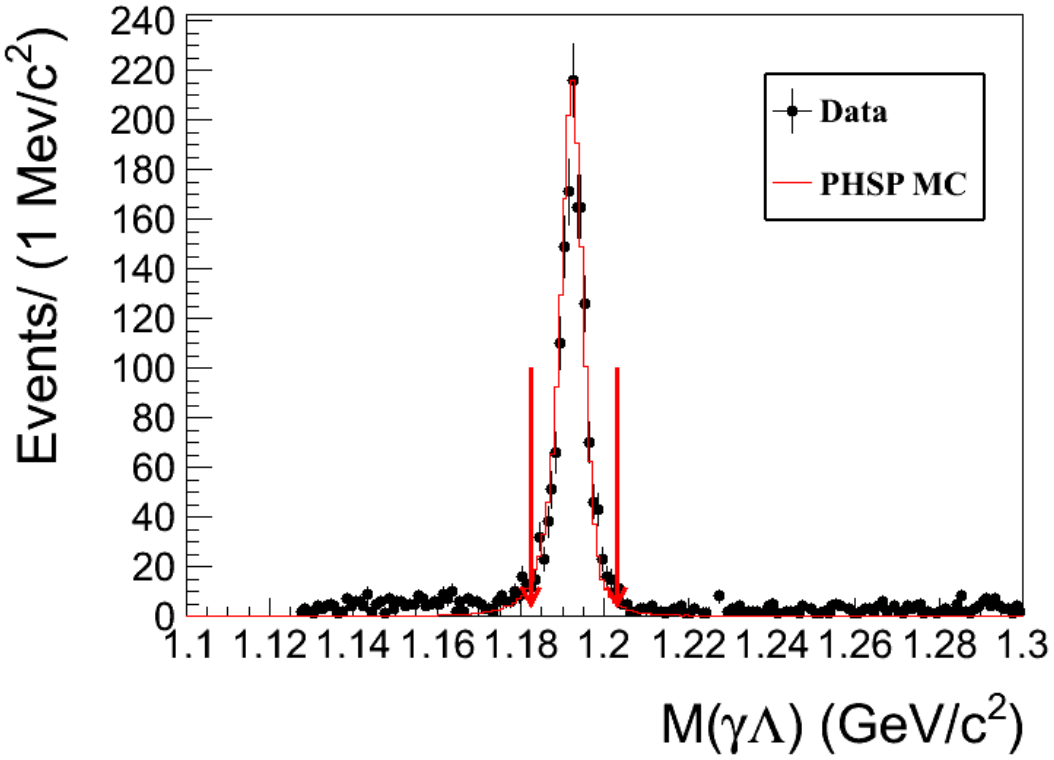
Event Selection





Event Selection

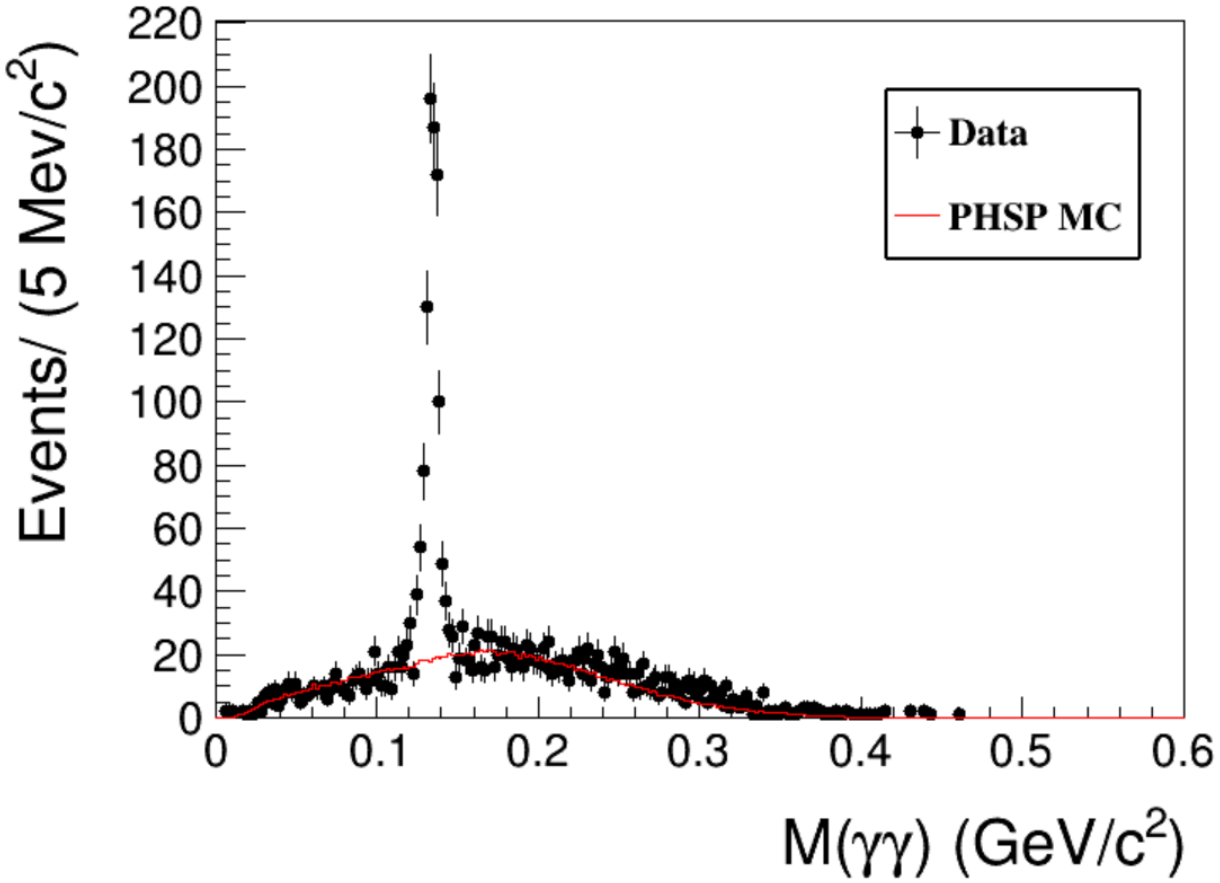


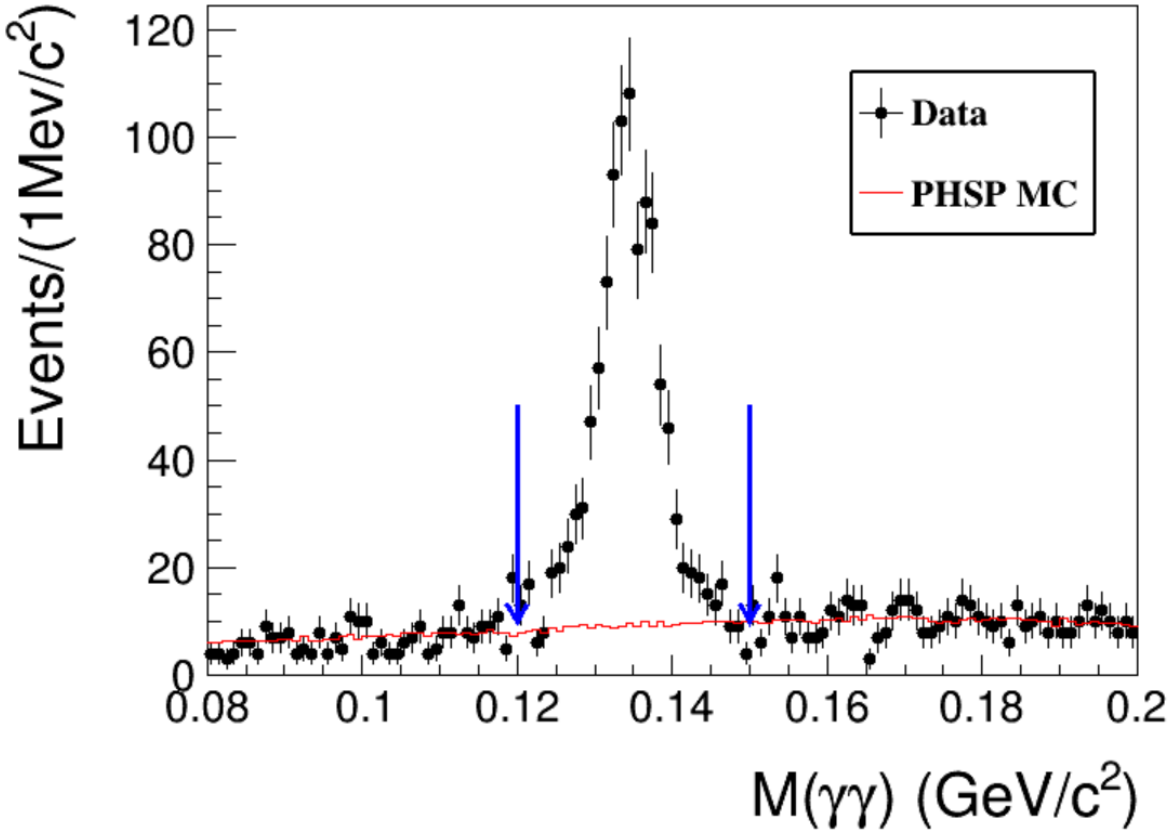


$|M_{p\pi^-} - m_{\Lambda}| < 0.004\text{GeV}$

$|M_{\gamma\Lambda} - m_{\Sigma^0}| < 0.01\text{GeV}$

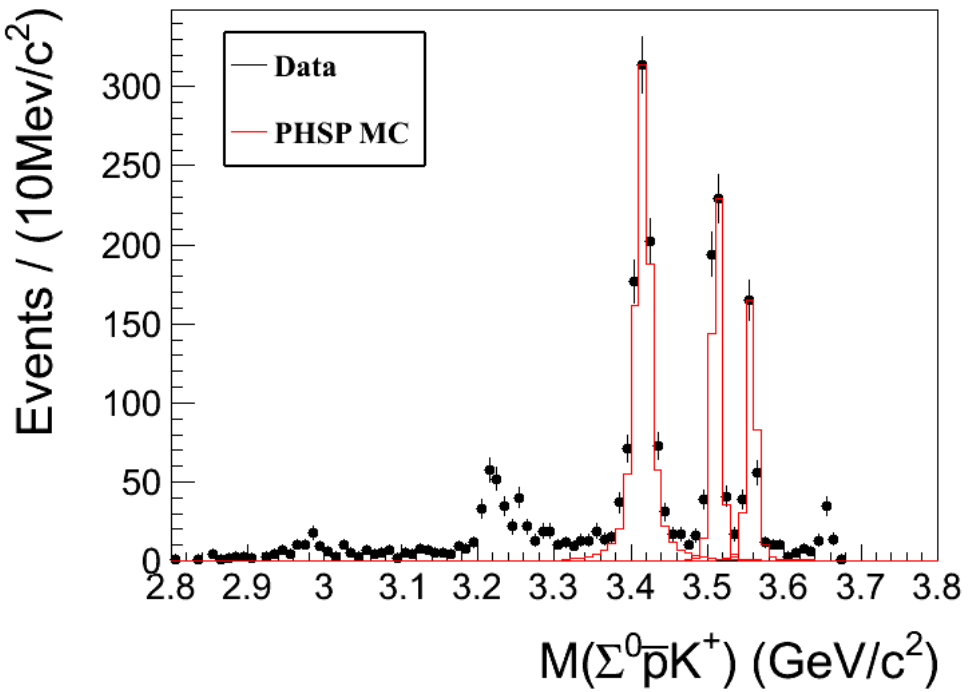
Event Selection



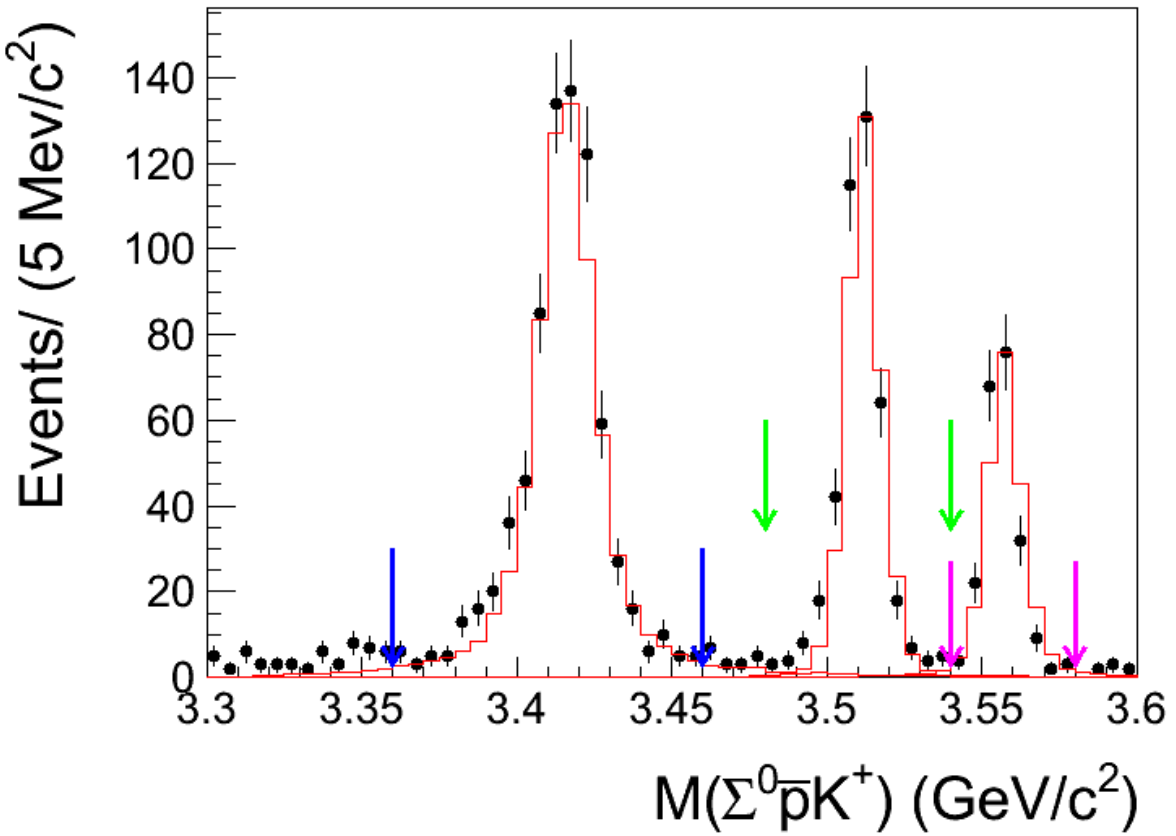


$|M_{\gamma\gamma} - m_{\pi^0}|$>0.015GeV

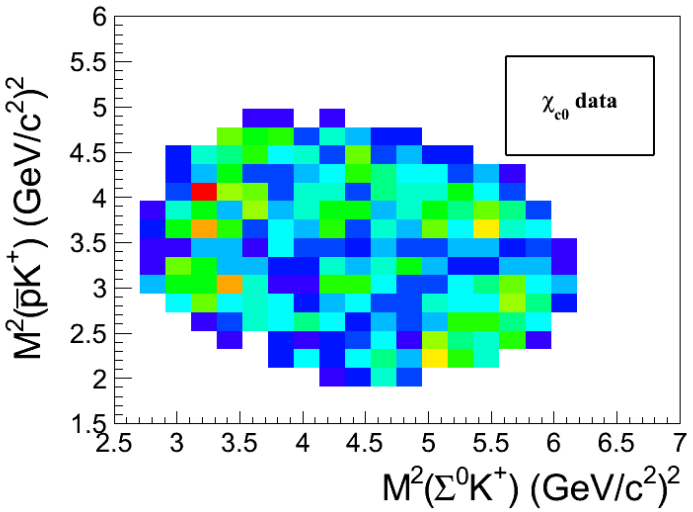
Total events

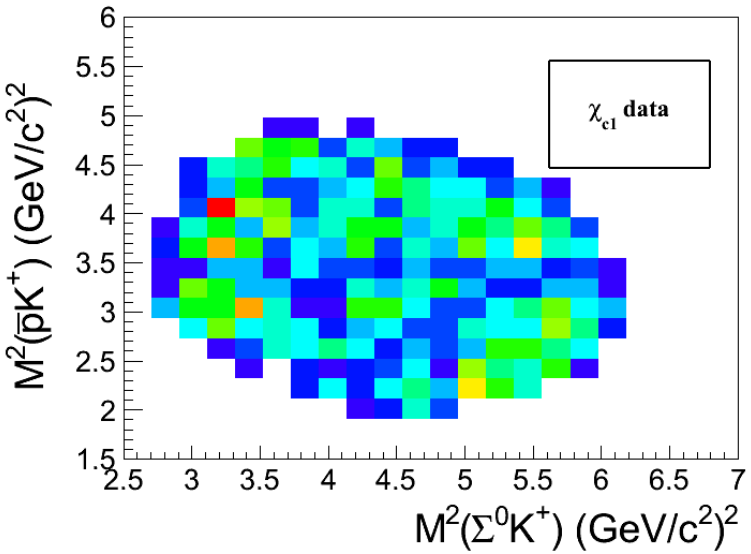


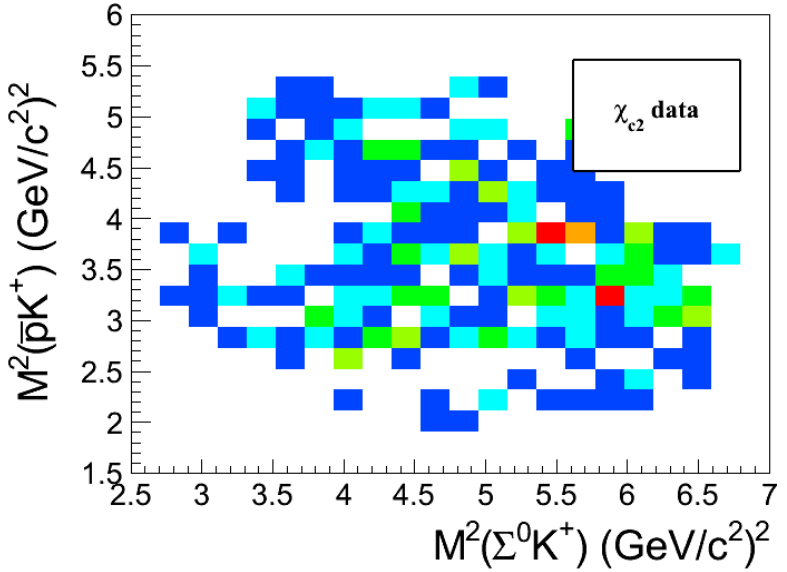
1556 events left

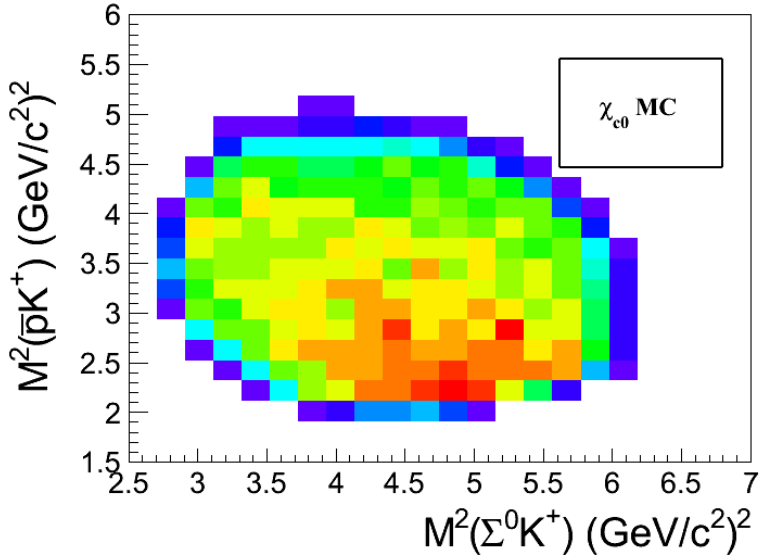


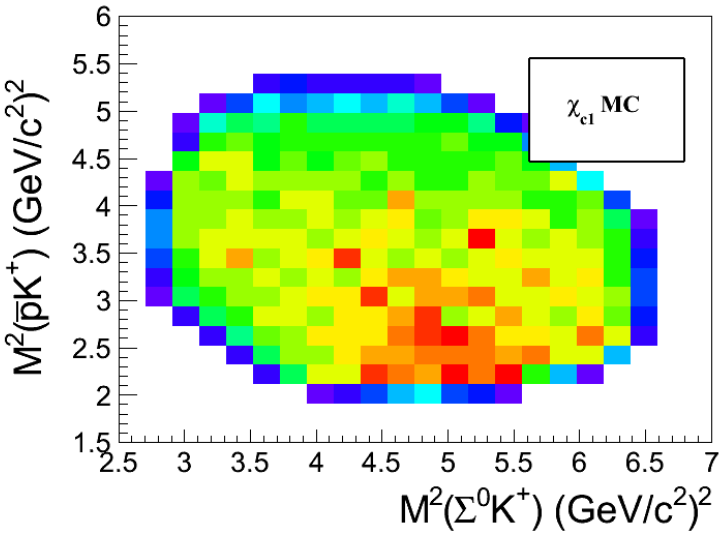
Dalitz plot distributions of the intermediate states

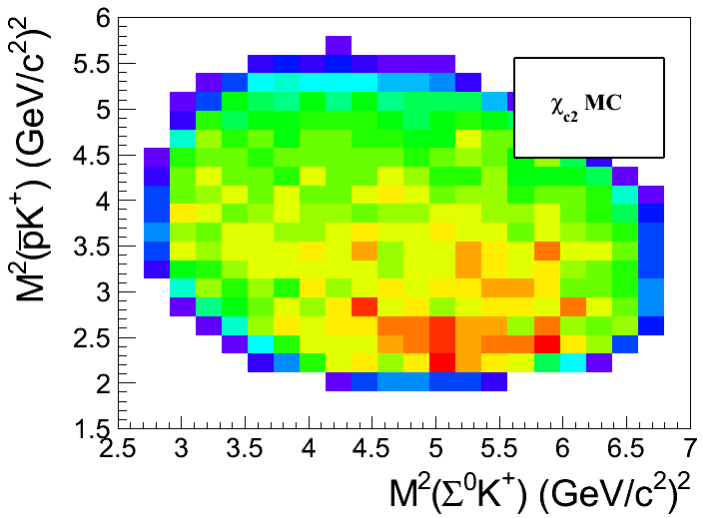




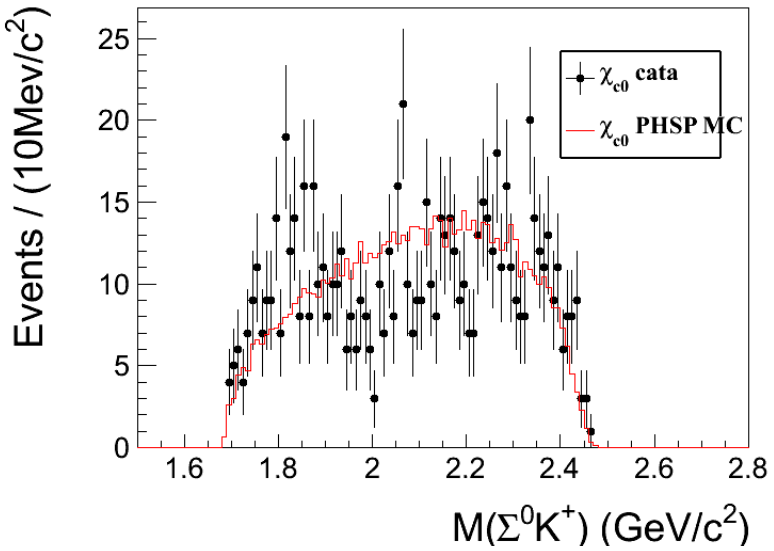


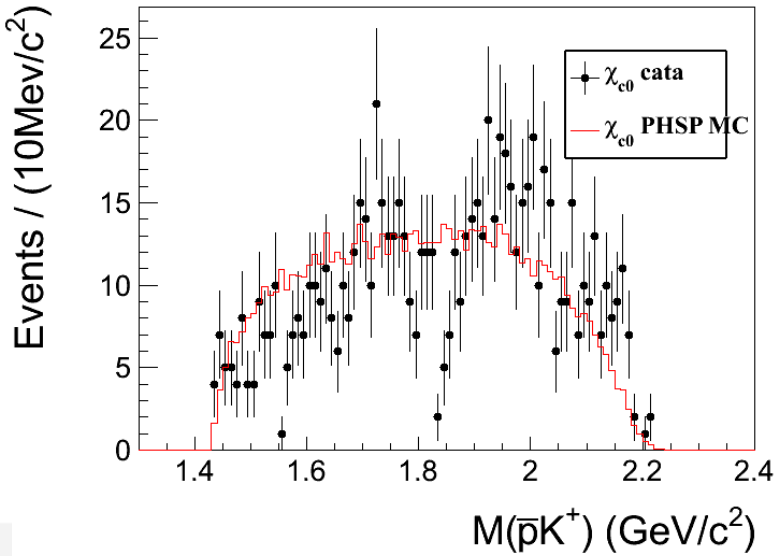


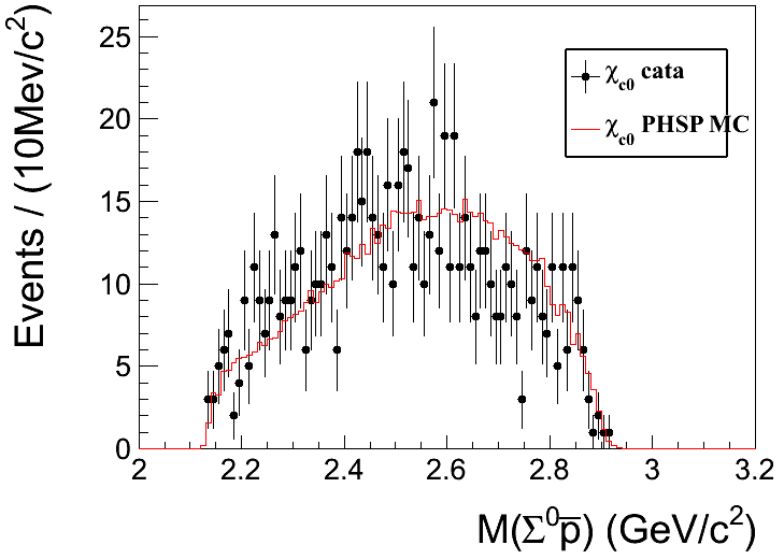




The invariant mass spectra of the intermediate states in χ_{c0}mass regions([3.36, 3.46] GeV/c^2)







Ξ(1690)		***
Ξ(1820)	3/2⁻	***
Ξ(1950)		***

Σ(1690)		**
Σ(1730)	3/2⁺	*
Σ(1750)	1/2⁻	***
Σ(1770)	1/2⁺	*
Σ(1775)	5/2⁻	****
Σ(1840)	3/2⁺	*
Σ(1880)	1/2⁺	**
Σ(1900)	1/2⁻	*
Σ(1915)	5/2⁺	****
Σ(1940)	3/2⁺	*
Σ(1940)	3/2⁻	***
Σ(2000)	1/2⁻	*
Σ(2030)	7/2⁺	****
Σ(2070)	5/2⁺	*
Σ(2080)	3/2⁺	**

Ξ BARYONS

($S = -2$, $I = 1/2$)

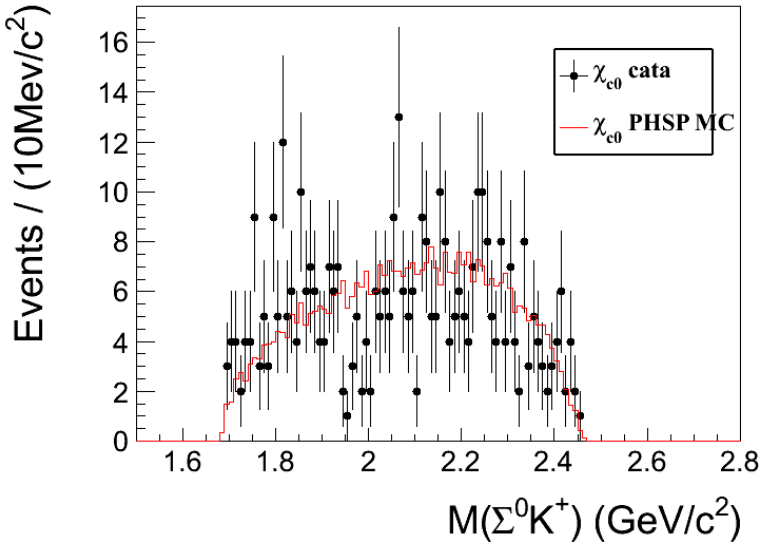
$\Xi^0 = u\,s\,s$, $\Xi^- = d\,s\,s$ → No Ξ^+

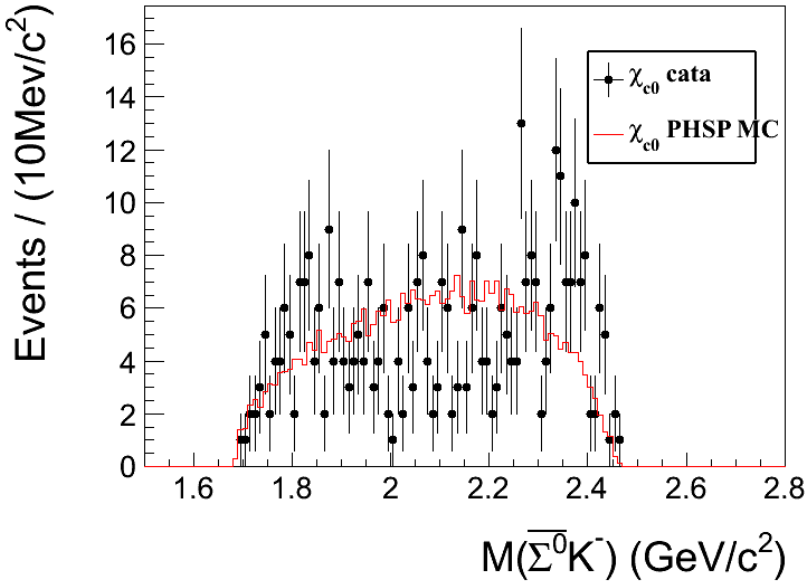
Ξ(1820) $I(J^P) = 1/2(3/2^-)$

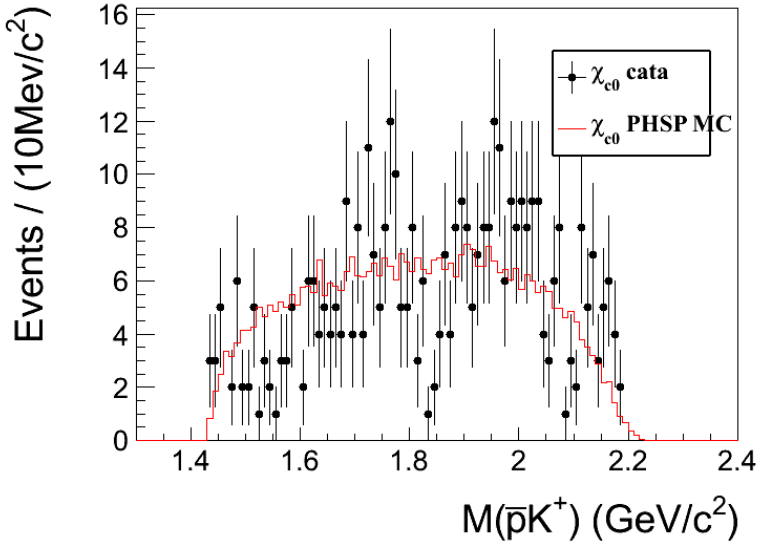
The clearest evidence is an 8-standard-deviation peak in ΛK^- seen by GAY 1976C. TEODOR cannot make a parity discrimination. BIAGI 1987C is consistent with $J = 3/2$ and favors negati

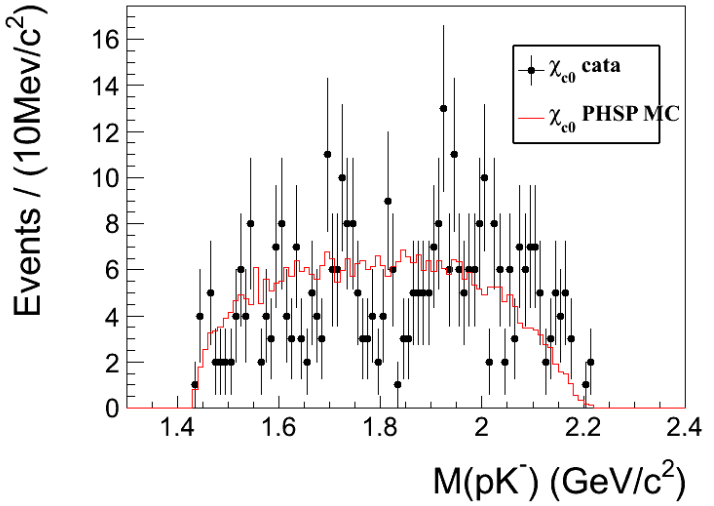
Ξ(1820) MASS	1823 ± 5 MeV

Check for the charge-conjugated decay

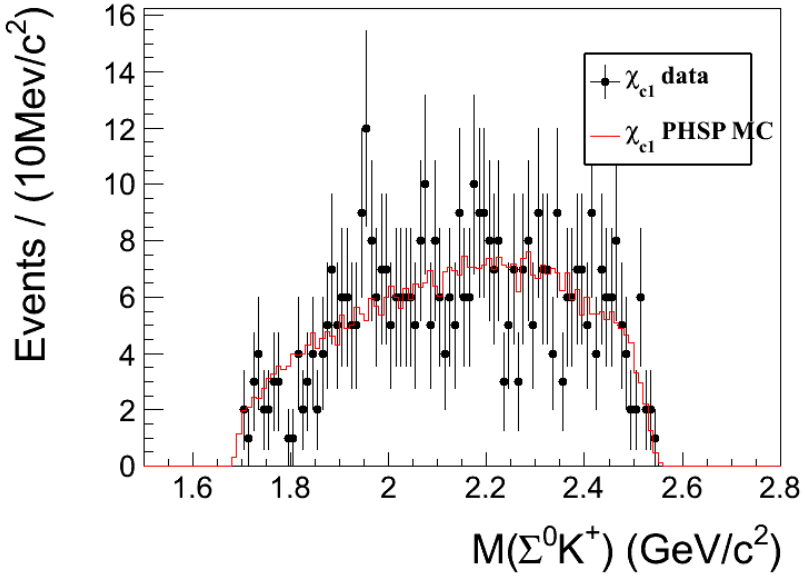


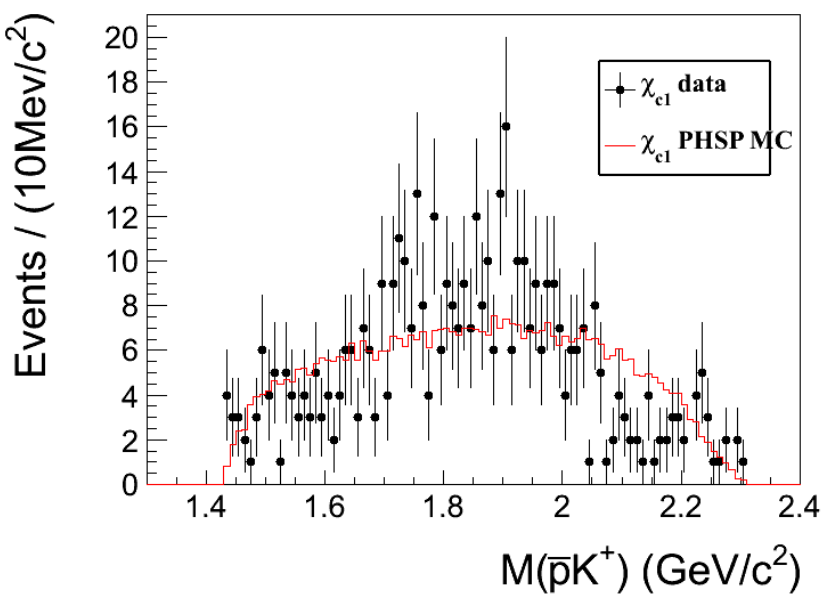


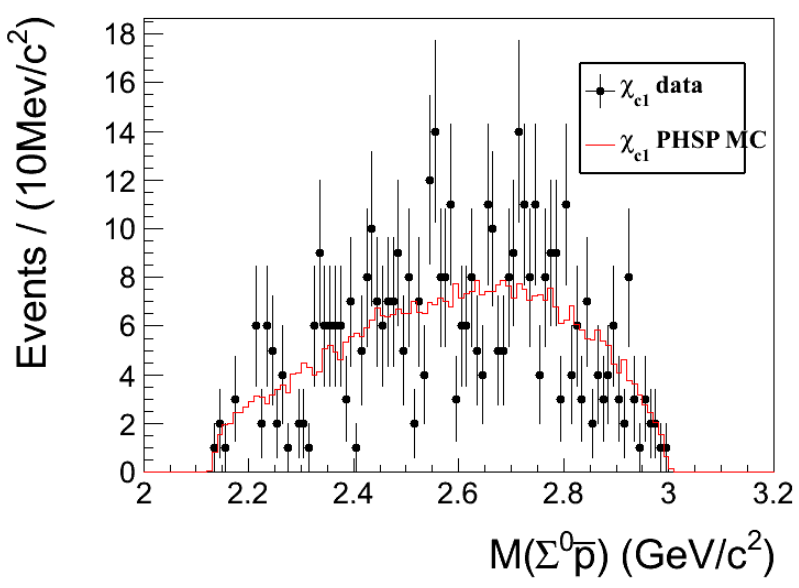




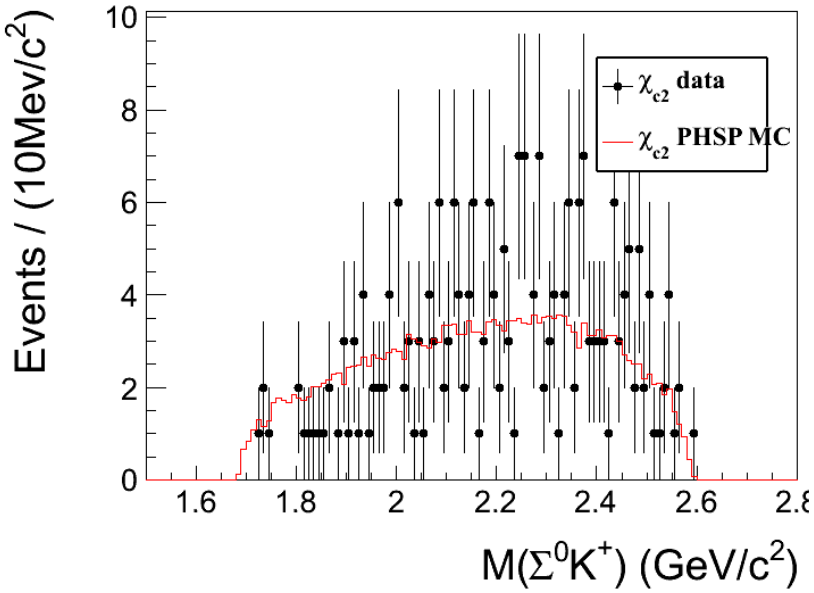
The invariant mass spectra of the intermediate states in χ_{c1} mass regions([3.48, 3.54] GeV/c^2)

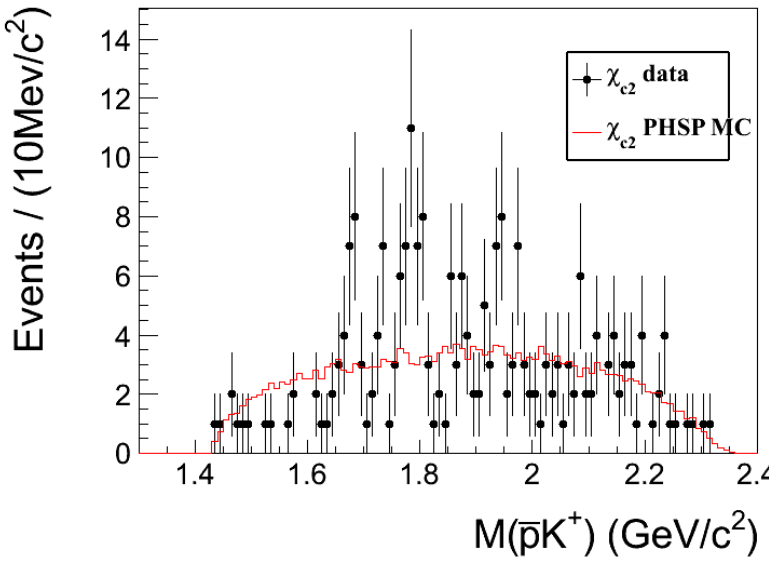


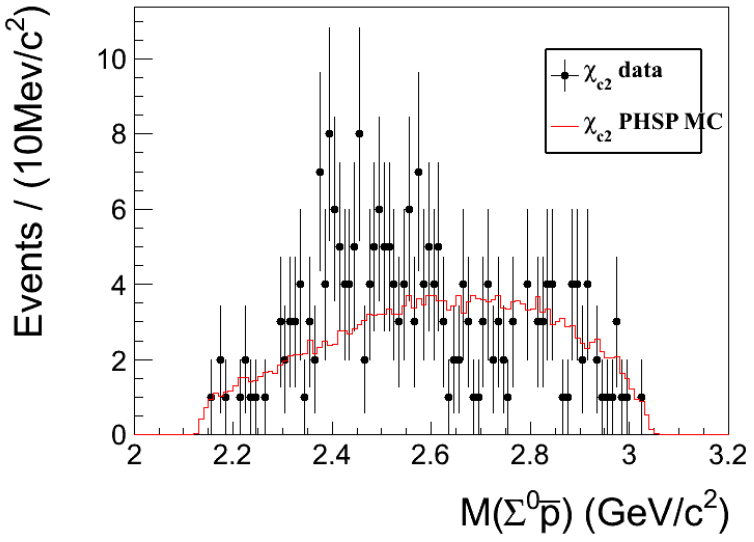




The invariant mass spectra of the intermediate states in χ_{c2} mass regions([3.54, 3.58] GeV/c^2)







Background study

Table 1: The information of the survived events from the $\psi(3686)$ inclusive MC sample in χ_{c0} region. nEvt means the number of the event from each decay chain, sum means the total number of the events in each category.

component	decay chain	final states	nEvt	sum
Signal	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to pK^-\bar{\Sigma}^0, \bar{\Sigma}^0 \to \gamma\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma\gamma p$	36	67
	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Sigma^0 K^+\bar{p}, \Sigma^0 \to \gamma\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma\gamma pK^+$	31	
K^{*-}	$\psi' \to K^{*-}p\bar{\Lambda}, K^{*-} \to K^-\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^0\pi^+p$	19	46
	$\psi' \to \Lambda K^{*+}\bar{p}, \Lambda \to p\pi^-, K^{*+} \to K^+\pi^0$	$\pi^-\bar{p}\pi^0 pK^+$	11	
	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K^{*+}\Lambda\bar{p}, K^{*+} \to K^+\pi^0, \Lambda \to p\pi^-$	$\pi^-\bar{p}\pi^0\gamma pK^+$	6	
	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K^{*-}\bar{\Lambda}p, K^{*-} \to K^-\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^0\pi^+\gamma p$	5	
	$\psi' \to \bar{p}\Sigma^0 K^{*+}, \Sigma^0 \to \gamma\Lambda, K^{*+} \to K^+\pi^0, \Lambda \to p\pi^-$	$\pi^-\bar{p}\pi^0\gamma pK^+$	3	
	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K^{*-}\bar{\Lambda}p, K^{*-} \to K^-\gamma, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma\gamma p$	1	
	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to p\bar{\Lambda}K^{*-}, \bar{\Lambda} \to \bar{p}\pi^+, K^{*-} \to K^-\pi^0$	$\bar{p}K^-\pi^0\pi^+\gamma p$	1	
peakingbkg	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K^+\bar{p}\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma pK^+$	5	8
	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to p\bar{\Lambda}K^-, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma p$	2	
	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K^+\bar{p}\Lambda\gamma_{FSR}, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma pK^+$	1	
flatbkg	$\psi' \to \Lambda K^+\Delta^+, \Lambda \to p\pi^-, \Delta^+ \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0 pK^+$	1	1

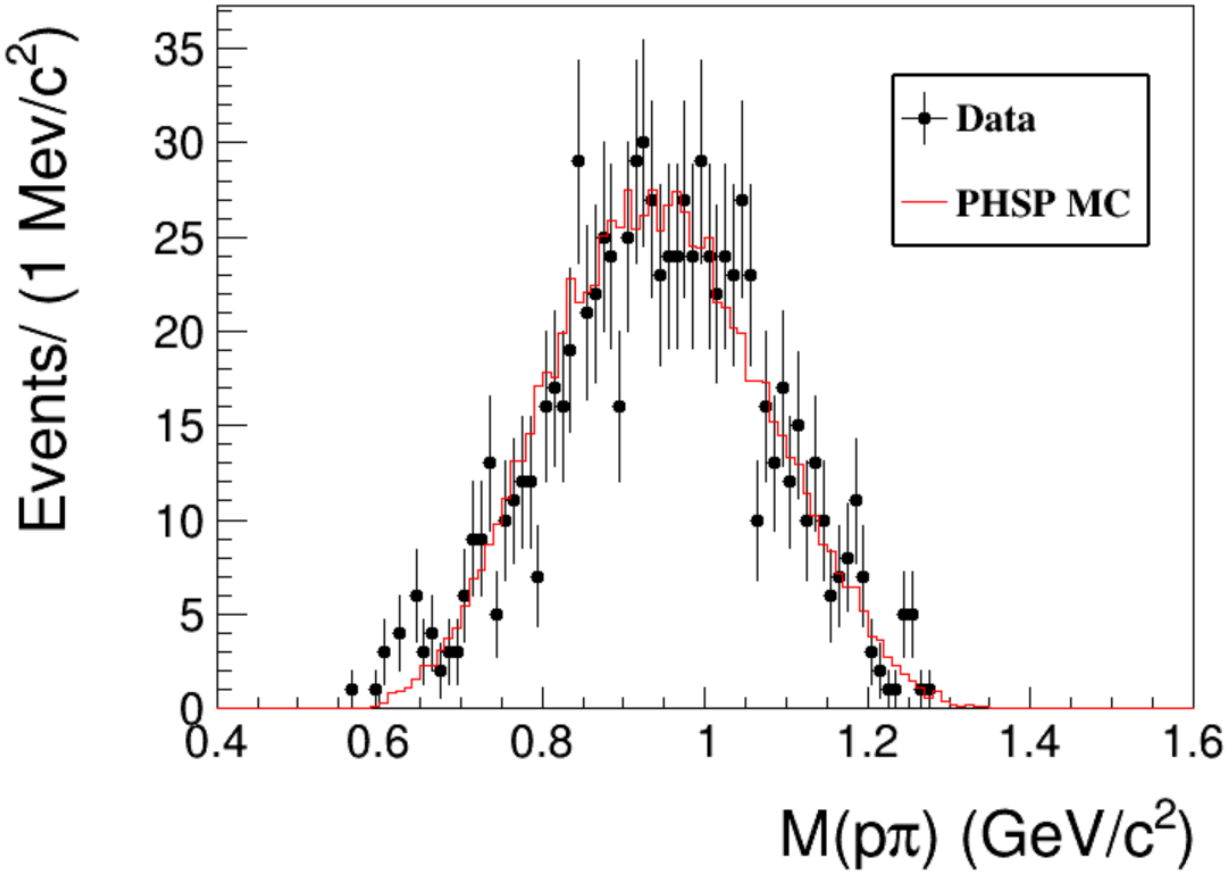
Table 2: The information of the survived events from the $\psi(3686)$ inclusive MC sample in χ_{c1} region. nEvt and sum stand for the same meaning as Table 1.

component	decay chain	final states	nEvt	sum
Signal	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to \Sigma^0 K^+ \bar{p}, \Sigma^0 \to \gamma\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma\gamma p K^+$	33	58
	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to pK^-\bar{\Sigma}^0, \bar{\Sigma}^0 \to \gamma\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma\gamma p$	25	
K^{*-}	$\psi' \to pK^{*-}\bar{\Lambda}, K^{*-} \to K^-\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^0\pi^+ p$	14	27
	$\psi' \to \bar{p}K^{*+}\Lambda, K^{*+} \to K^+\pi^0, \Lambda \to p\pi^-$	$\pi^-\bar{p}\pi^0 p K^+$	10	
	$\psi' \to K^{*+}\bar{p}\Sigma^0, K^{*+} \to K^+\pi^0, \Sigma^0 \to \gamma\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\pi^0\gamma p K^+$	2	
	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to \Lambda\bar{p}K^{*+}, \Lambda \to p\pi^-, K^{*+} \to K^+\gamma$	$\pi^-\bar{p}\gamma\gamma p K^+$	1	
peakingbkg	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to K^- p\bar{\Lambda}\gamma_{FSR}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma p$	2	4
	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to K^+\bar{p}\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma p K^+$	1	
	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to K^- p\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma p$	1	
flatbkg	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to \bar{\Sigma}^0 K^- p, \bar{\Sigma}^0 \to \gamma\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma\gamma p$	3	9
	$\psi' \to \gamma\chi_{c0},\chi_{c0} \to K^-\bar{\Lambda}p, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma p$	2	
	$\psi' \to \gamma\chi_{c0},\chi_{c0} \to K^+\bar{p}\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma p K^+$	1	
	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to \pi^+\Lambda\bar{\Sigma}^-, \Lambda \to p\pi^-, \bar{\Sigma}^- \to \bar{p}\pi^0$	$\pi^-\bar{p}\pi^0\pi^+\gamma p$	1	
	$\psi' \to \bar{\Sigma}^0 K^-\Delta^+, \bar{\Sigma}^0 \to \gamma\bar{\Lambda}, \Delta^+ \to p\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^0\pi^+\gamma p$	1	
	$\psi' \to \Sigma^+\pi^-\bar{\Sigma}^{*0}, \Sigma^+ \to p\pi^0, \bar{\Sigma}^{*0} \to \bar{\Lambda}\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\pi^-\bar{p}\pi^0\pi^0\pi^+ p$	1	

Table 3: The information of the survived events from the $\psi(3686)$ inclusive MC sample in χ_{c2} region. nEvt and sum stand for the same meaning as Table 1.

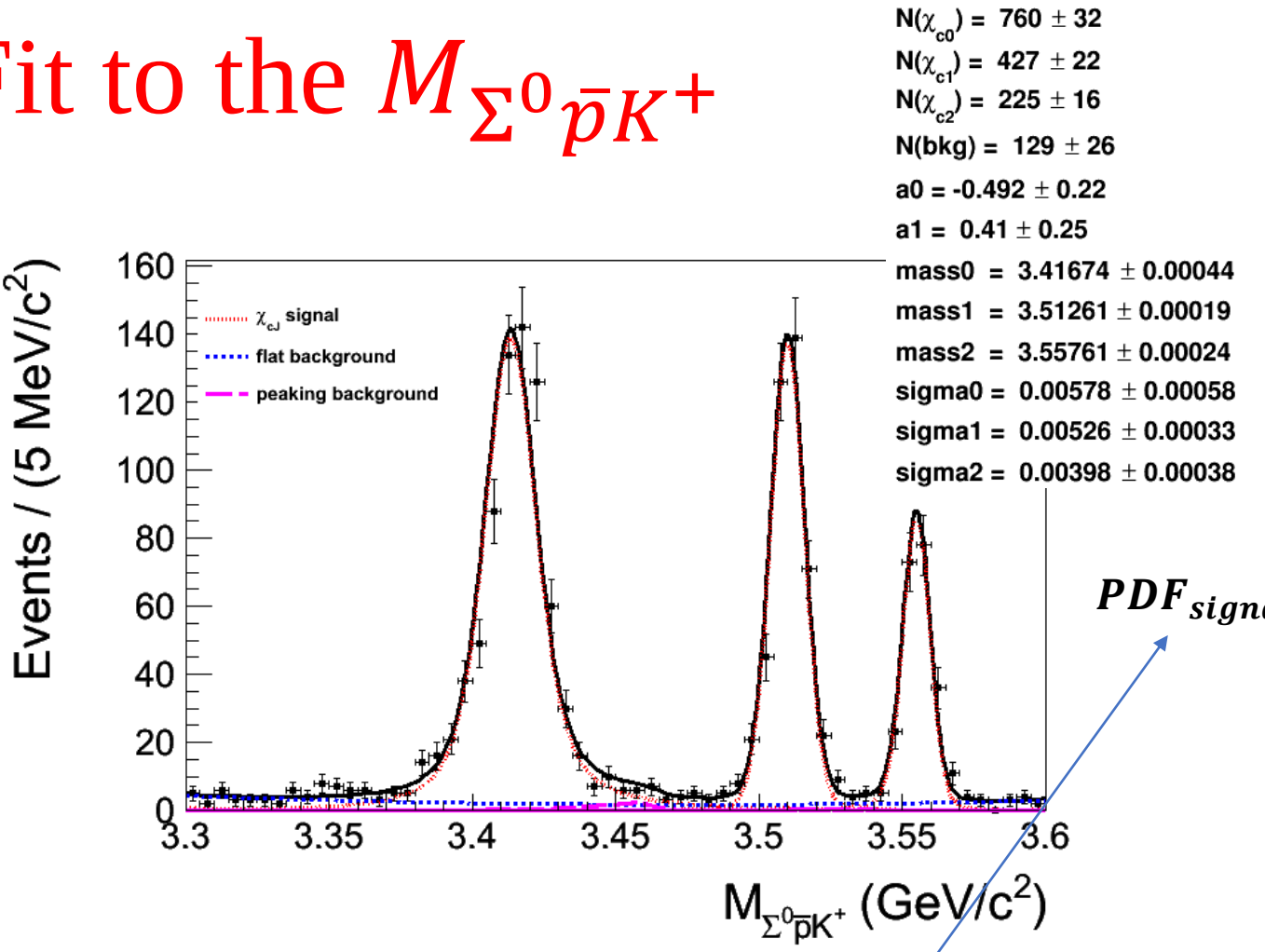
component	decay chain	final states	nEvt	sum
Signal	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to \Sigma^0 K^+ \bar{p}, \Sigma^0 \to \gamma\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma\gamma p K^+$	27	61
	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to pK^-\bar{\Sigma}^0, \bar{\Sigma}^0 \to \gamma\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma\gamma p$	24	
K^{*-}	$\psi' \to K^{*-}\bar{\Lambda}p, K^{*-} \to K^-\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^0\pi^+ p$	5	9
	$\psi' \to \Lambda K^{*+}\bar{p}, \Lambda \to p\pi^-, K^{*+} \to K^+\pi^0$	$\pi^-\bar{p}\pi^0 p K^+$	4	
peakingbkg	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to K^+\bar{p}\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma p K^+$	1	2
	$\psi' \to \gamma\chi_{c2},\chi_{c2} \to K^+\bar{p}\Lambda\gamma_{FSR}, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma p K^+$	1	
flatbkg	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to K^- p\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$	$\bar{p}K^-\pi^+\gamma p$	2	3
	$\psi' \to \gamma\chi_{c1},\chi_{c1} \to K^+\bar{p}\Lambda, \Lambda \to p\pi^-$	$\pi^-\bar{p}\gamma p K^+$	1	

check



No K^* signal.

Fit to the $M_{\Sigma^0\bar{p}K^+}$



Constrained to the PDG value

$$PDF_{signal} = (\mathbf{BW}(M) \times \mathbf{E_\gamma^3} \times \mathbf{D}(E_\gamma)) \otimes \mathbf{Gauss(0, sigma)}$$

$$BW(M) = \frac{1}{(M-m_{\chi_{cJ}})^2+0.25\Gamma_{\chi_{cJ}}^2}$$

$$E_\gamma = \frac{m_{\psi(3686)}^2 - M^2}{2m_{\psi(3686)}}$$

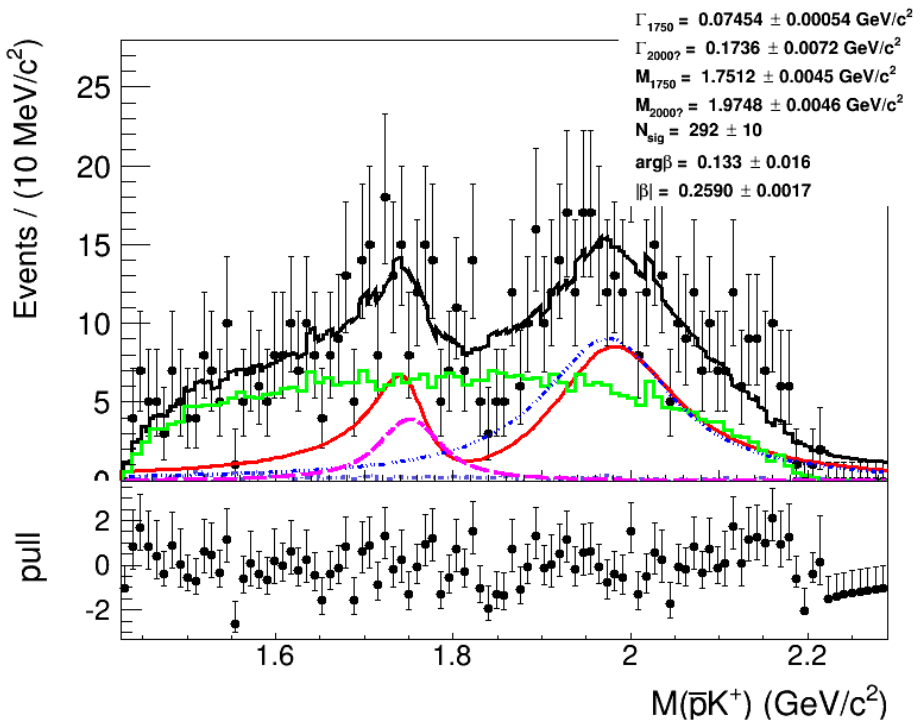
$$\mathbf{D}(E_\gamma) = e^{-\frac{E_\gamma^2}{8\beta^2}}$$

$\mathbf{PDF_{total}} = \mathbf{PDF_{flat}} \times \mathbf{N1} + \mathbf{PDF_{peaking}} \times \mathbf{N2} + \mathbf{PDF_{signal}} \times \mathbf{N3}$

A second order Chebyshev polynomial function.

determined from the normalized $\psi(3686) \to \gamma\chi_{cJ}, \chi_{cJ} \to \Lambda pK^- + c.c.$

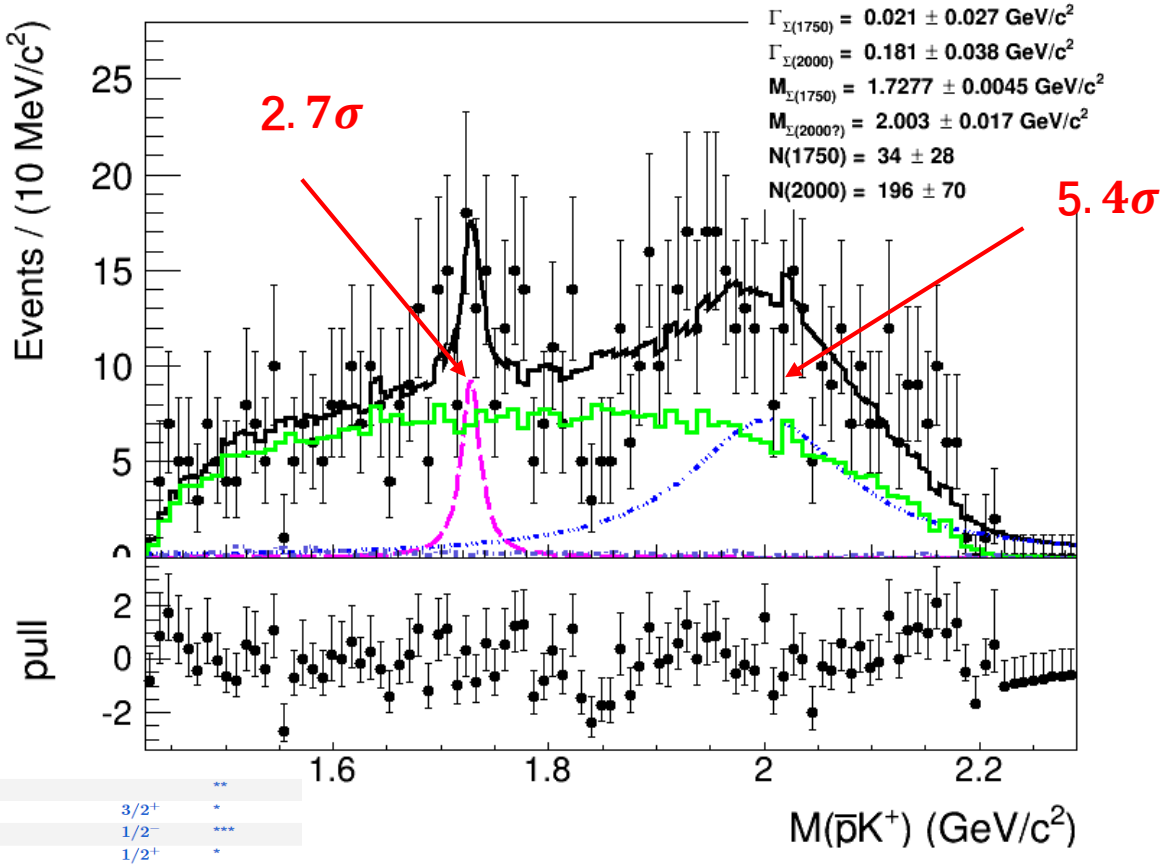
Fit to the $\bar{p}K^+$ invariant mass distributions in χ_{c0} mass regions



PHSP+BKG+(BW1,BW2)

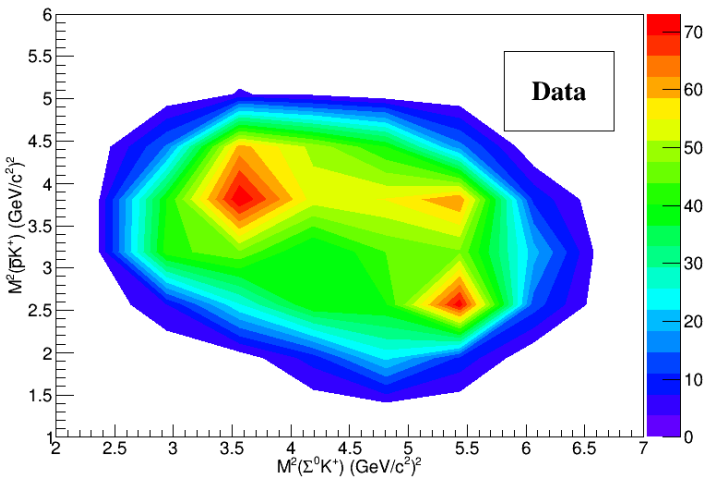
Significance of interference

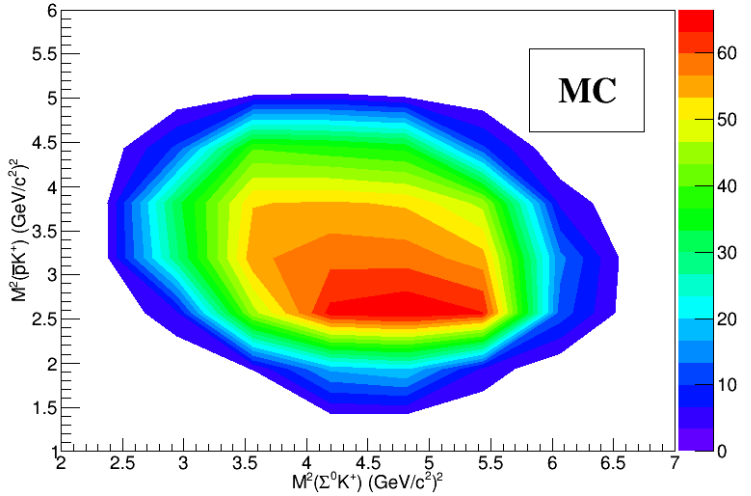
2.4σ

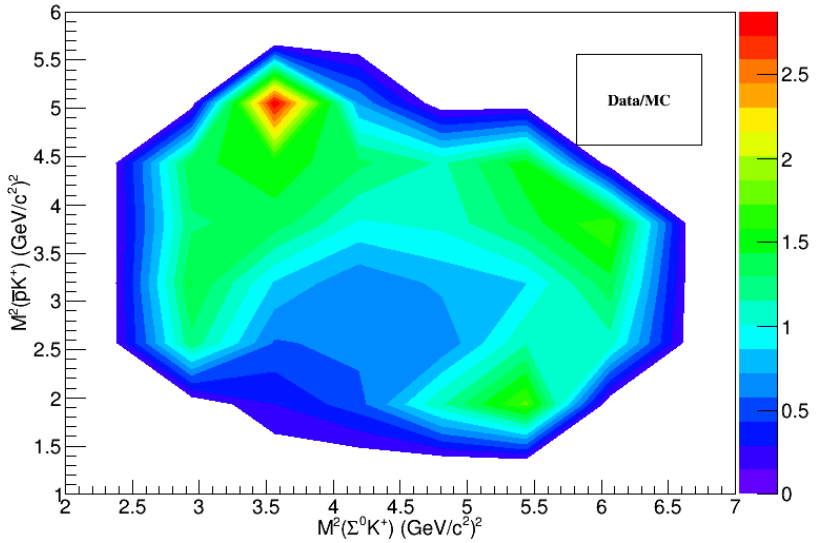


$\Sigma(1690)$		**
$\Sigma(1730)$	$3/2^+$	*
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1770)$	$1/2^+$	*
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1840)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	*
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**

Weighted Efficiency (Take χ_{c0} as an example)







Decay\Efficiency(%)	After smear	Weighted
$\chi_{c0} \to \Sigma^0\bar{p}k^+$	9.64	9.24
$\chi_{c1} \to \Sigma^0\bar{p}k^+$	10.85	10.82
$\chi_{c2} \to \Sigma^0\bar{p}k^+$	9.63	9.61

Systematic uncertainties

Source	Chic0(%)	chic1(%)	chic2(%)
Photon detection	2.0	2.0	2.0
PID and tracking	4.0	4.0	4.0
4C kinematicfit	0.9	0.9	1.5
Bkg(third_order)	1.2	1.4	1.3
KEDR	0.4	0.2	0.4
Fit range	1.2	1.2	1.3
Λ (Σ^0)mass window	0.2(0.2)	0.2(0.2)	0.2(0.2)
Weigted efficiency	0.3	0.3	0.5
Higher order contribution	-	0.2	0.6
Intermediate decay	2.0	2.5	2.1
Number of $\psi(3686)$	0.6	0.6	0.6
Total	5.3	5.6	5.6

Summary

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

channel	Efficiency	Nsignal	Branching Fraction($\chi_{cJ} \to \Sigma^0 \bar{p} k^+ + c.c$)
χ_{c0}	9.24%	760 ± 32	$(2.93 \pm 0.12 \pm 0.16) \times 10^{-4}$
χ_{c1}	10.82%	427 ± 22	$(1.41 \pm 0.07 \pm 0.08) \times 10^{-4}$
χ_{c2}	9.61%	225 ± 16	$(8.59 \pm 0.61 \pm 0.48) \times 10^{-5}$

- We can not study the intermediate states well now, comments are welcome!

Thank you !!!