



# Measurement of Branching Fractions of $\chi_{c0,1,2} \rightarrow \Sigma^- \bar{\Sigma}^+$ at BESIII

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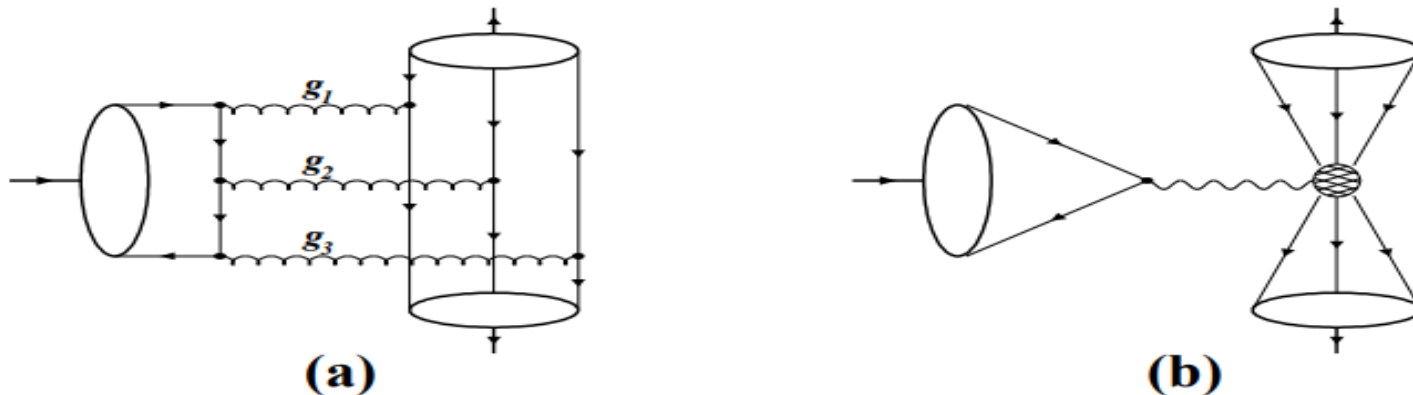
*University of Science and Technology of China*

# Outline

- **Motivation**
- **Data Analysis**
  - ✓ Event Selection
  - ✓ Comparison between Data and MC
  - ✓ Background Study
- **Systematic Uncertainty**
- **Fitting Results**
- **Summary**

# Motivation

- Exclusive P-wave Charmonium states  $\chi_{cJ}$  ( $J=0,1,2$ )  $\rightarrow \Sigma^- \bar{\Sigma}^+$  into baryon-antibaryon pairs ( $B\bar{B}$ ) are considered to be a favorable test of pQCD theory and also to test the color octet mechanism (COM).
- The  $\chi_{cJ}$  mesons are not produced directly in  $e^+e^-$  annihilations but assumed to process via annihilations of the constituents  $\bar{c}c$  pairs into three gluons or virtual photon.



**Figure:** Feynman graphs for  $\psi(2S)$  decay into  $B\bar{B}$  (a) Three-gluon contribution  
(b) Electromagnetic contribution.

- The large BFs of  $\psi(2S) \rightarrow \gamma \chi_{cJ}$  make  $e^+ e^-$  collision at the  $\psi(2S)$  energy a very clean environment for  $\chi_{cJ}$  investigation.
- BF of  $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$  had been well measured by BESIII and CLEO. [<https://arxiv.org/abs/1710.07922>, PhysRevD.78.031101].
- Experimentally, no measurements for  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$  have been performed yet.

# Data Sets

- **Boss Version:**
  - **Analysis Environment:** Boss 664p03
- **Data Sets:**
  - 107.0 M  $\psi'$  of 2009 year and 341.1 M  $\psi'$  of 2012 year
- **Signal MC :** Generated 1M Events.
  - **MC Sample:** Use KKMC Event Generator.
  - **Decay Chain :**
    - ✓  $\psi' \rightarrow \gamma \chi_{cJ}$  in *P2GC0*, *P2GC1* and *P2GC2*.
    - ✓  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$  in *PHSP*.
    - ✓  $\Sigma^- \rightarrow n \pi^-$  and  $\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+$  are in *PHSP*.
- **Inclusive MC :** 506 M  $\psi'$  MC ,  $\psi' \rightarrow$  Anything

# Pre-Selection

- **Good Charged Tracks:**

- $|V_z| < 30cm, |V_r| < 10cm$  and  $|\cos\theta| \leq 0.93, p > 1.0 \text{ GeV}/c$
- $N_{Good} = 2$  and  $\sum Q_i = 0$ .

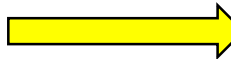
- **PID** :  $dE/dX + TOF$

- $Prob_{\pi} > Prob_p, Prob_{\pi} > Prob_k$  and  $N_{\pi^-} = N_{\pi^+} = 1$

- **Good Neutral Tracks:**

- $E_{barrel} > 80MeV; E_{endcap} > 80MeV$
- At least 2 photons tracks  $N_{\gamma} \geq 2$  (1 for Gamma, 1 for Anti-Neutron).
- The most energetic shower consider as  $\bar{n}$  candidate,  $E_{\bar{n}} > 0.2 \text{ GeV}$ ,  
numHits > 20, Secmom > 20.

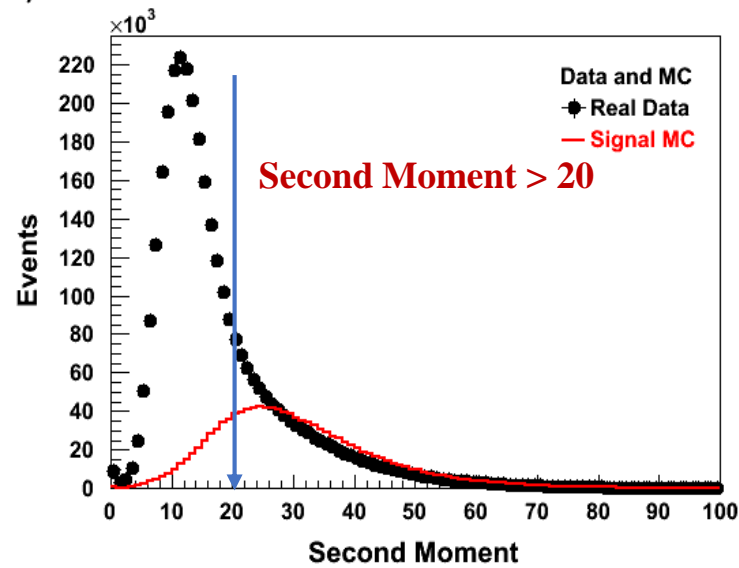
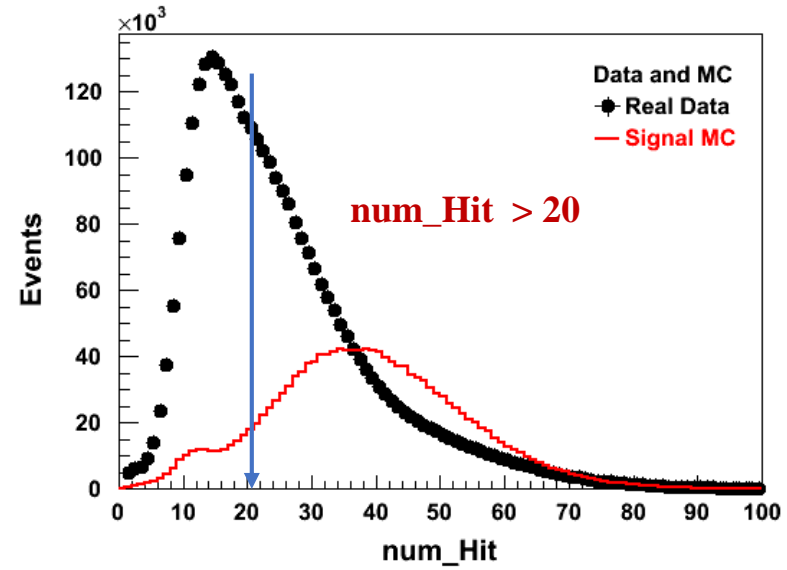
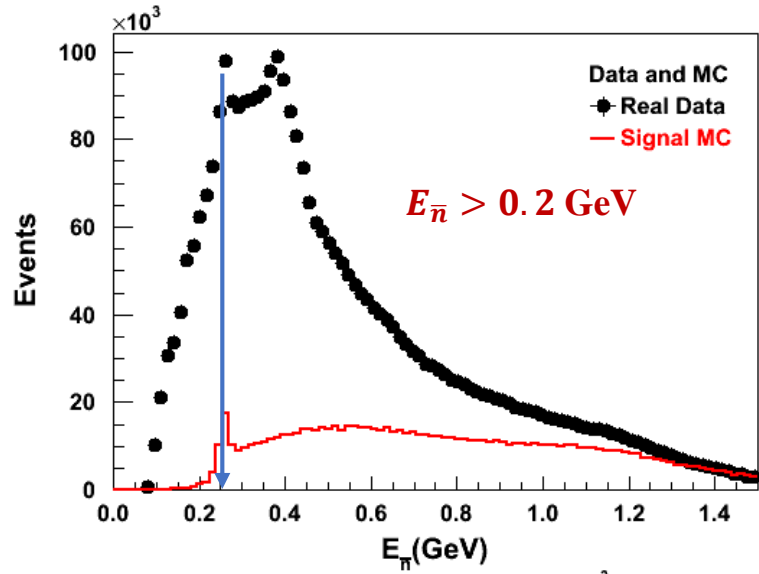
- **Further Slection** :

- Do Kinematics Fit 1C :  $\gamma \chi_{c0,1,2} \rightarrow \gamma \Sigma^- \bar{\Sigma}^+$  
- For  $N_{\gamma} \geq 2$ : Minimum  $\chi^2_{1C}(\gamma \Sigma^- \bar{\Sigma}^+)$  is chosen

**Kinematic fit:** Loop all the neutral tracks and minimum  $\chi^2$

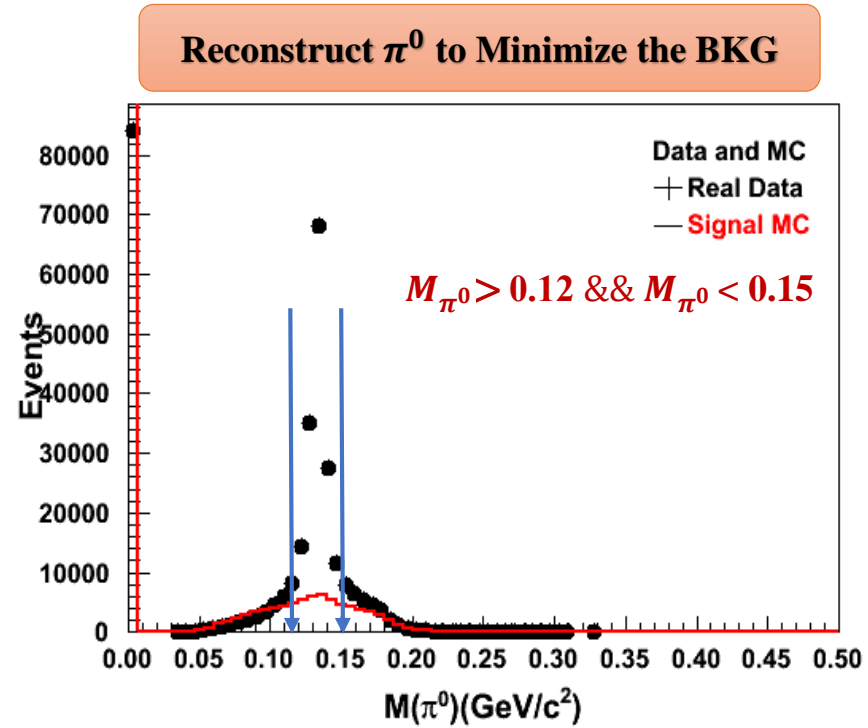
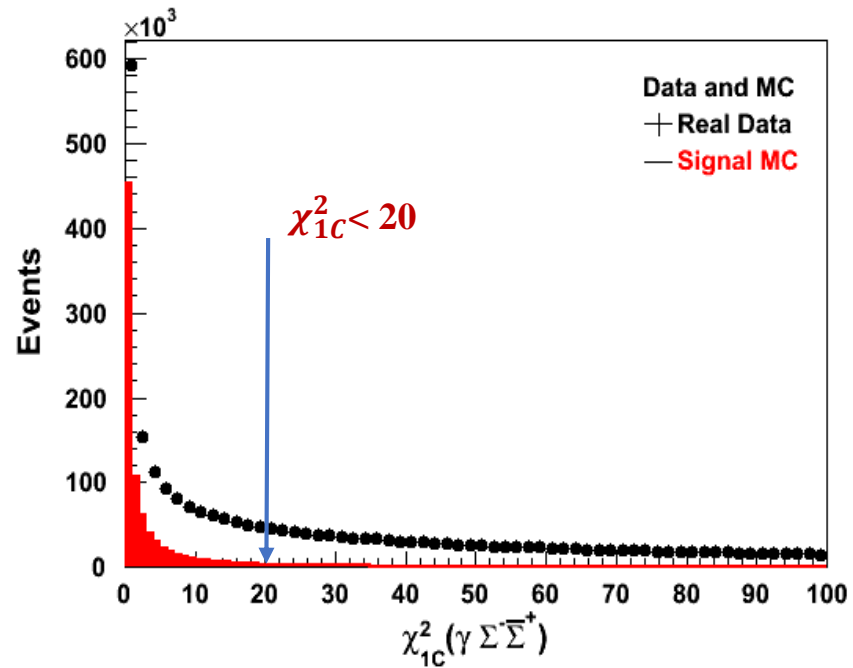
- ✓ Miss Neutron 3-momentum
- ✓ Miss Anti-Neutron Energy
- ✓ Mass constraint on  $\bar{n}\pi^-$
- ✓ 4-momentum constraint on  $\psi'$ .

# Comparison b/w Data and Signal MC



# $\chi^2_{1C}$ and $\pi^0$ Reconstruction

For Further Selection: Other criteria are used

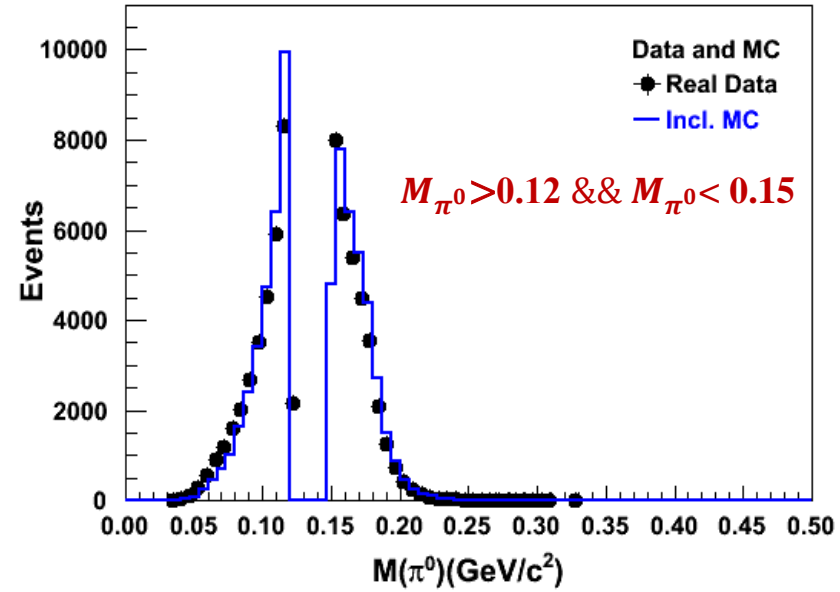
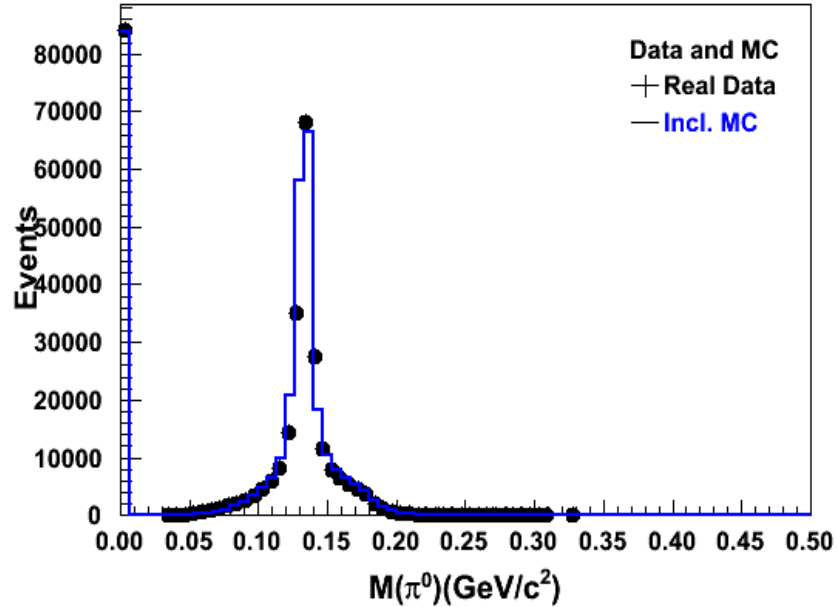




**Study of Peaking and Non- Peaking Background in**  
 **$\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$**

# Event Selection to Minimized the Background

## ➤ Event Selection: $\psi' \rightarrow \pi^0 \pi^0 J/\psi$ :



Extracted BKG Channel In Inclusive MC

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	2	10511	10511
1	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^0 \bar{\Delta}^- \Delta^-, \bar{\Delta}^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	4	9966	20477
2	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{\Delta}^- \pi^- n, \bar{\Delta}^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	1	6526	27003
3	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	0	4547	31550
4	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{\Delta}^- \Delta^-, \bar{\Delta}^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	5	2815	34365
5	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^- \Delta^0 \bar{\Delta}^-, \Delta^0 \rightarrow n \pi^0, \bar{\Delta}^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	6	2526	36891
6	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \gamma \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	10	2120	39011
7	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \pi^0 \Sigma^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	7	2088	41099
8	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{n} \pi^+ \Delta^-, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	8	1896	4295
9	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \Sigma^0, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^0 \rightarrow \Lambda \pi^-, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	3	1615	44610
10	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{\Delta}^{++} \pi^0 \Delta^{++}, \bar{\Delta}^{++} \rightarrow \bar{p} \pi^-, \Delta^{++} \rightarrow p \pi^+$	$\pi^- \bar{p} \pi^0 \pi^0 \pi^0 \pi^+ p$	11	1426	46036
11	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \pi^+ \bar{\Delta}^0, \Delta^- \rightarrow n \pi^-, \bar{\Delta}^0 \rightarrow \bar{n} \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	9	1156	47192
12	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{n} \pi^- \Delta^+, \Delta^+ \rightarrow n \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	12	1101	48293

# Event Selection to Minimized the Background

➤ Event Selection :  $\psi' \rightarrow \pi^+ \pi^- J/\psi$

✓  $M_{\pi^+ \pi^-} < 1.2$

✓  $|M_{\pi^+ \pi^-} - M_{ks}| > 0.01 \text{ GeV}$

✓  $|M_{recoil}(\pi^+ \pi^-) - M_{J/\psi}| > 0.01 \text{ GeV}$

Extracted BKG Channel In Inclusive MC

decay chain

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow n \bar{n}$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{n} \pi^0 n$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \eta n \bar{n}, \eta \rightarrow \pi^0 \pi^0 \pi^0$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \eta \bar{n} n, \eta \rightarrow \gamma \gamma$

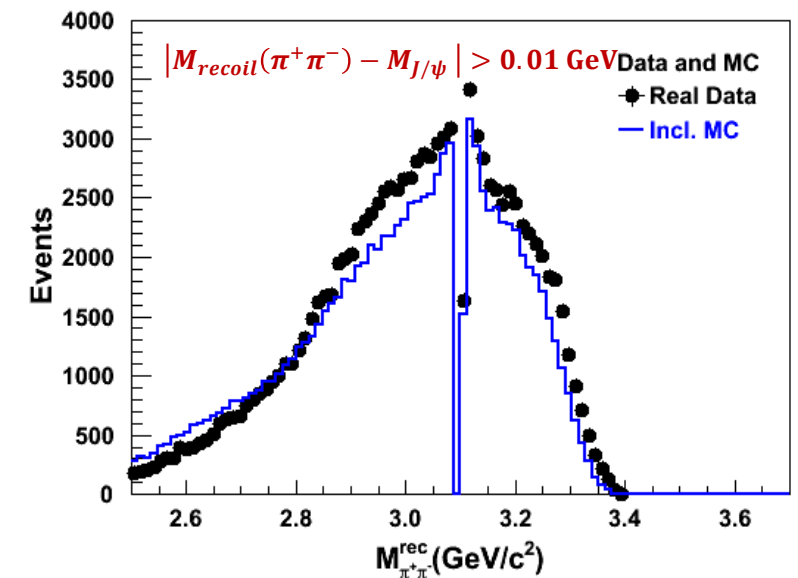
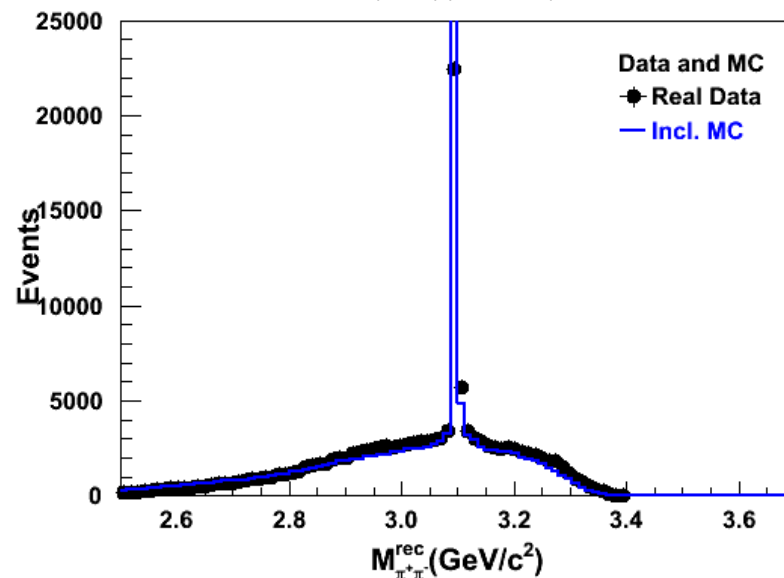
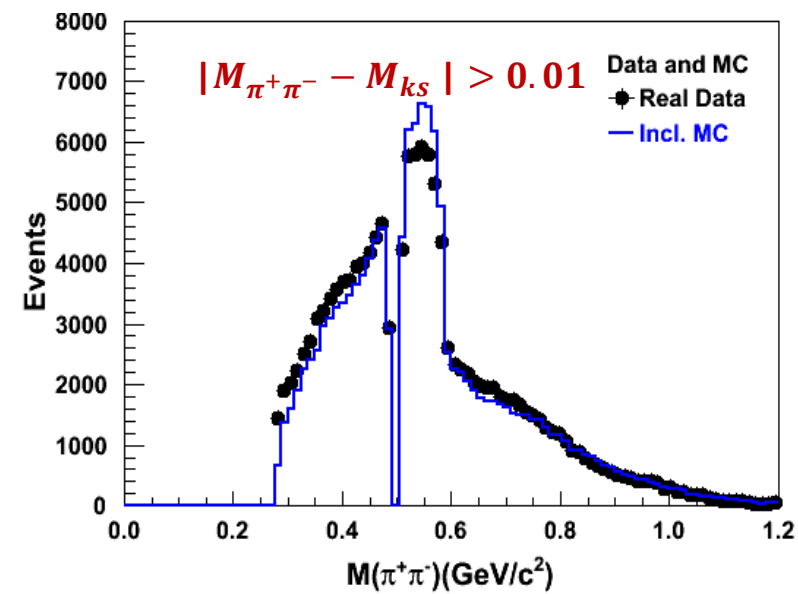
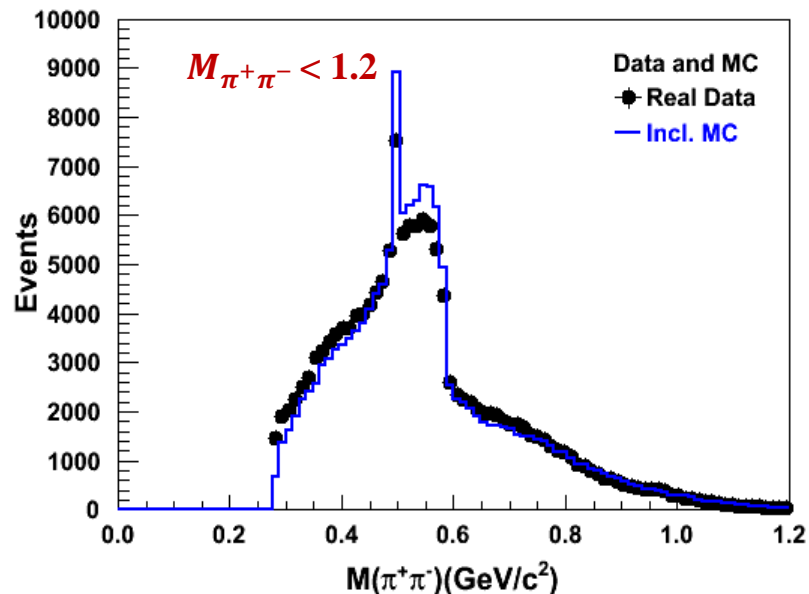
$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{\Delta}^0 \pi^0 \Delta^0, \bar{\Delta}^0 \rightarrow \bar{n} \pi^0, \Delta^0 \rightarrow n \pi^0$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \pi^0 n \bar{n} \pi^0$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Lambda \bar{\Lambda}, \Lambda \rightarrow n \pi^0, \bar{\Lambda} \rightarrow \bar{n} \pi^0$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{\Delta}^0 \Delta^0, \bar{\Delta}^0 \rightarrow \bar{n} \pi^0, \Delta^0 \rightarrow n \pi^0$

$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \gamma \bar{\Lambda} \Lambda, \bar{\Lambda} \rightarrow \bar{n} \pi^0, \Lambda \rightarrow n \pi^0$



## Event Selection to Minimized the Background

➤ Event Selection :  $\psi' \rightarrow \Sigma^- \bar{\Sigma}^+ \text{ OR } \pi^0 \Sigma^- \bar{\Sigma}^+$

$$\checkmark \chi_{\Sigma^+ \bar{\Sigma}^-}^2 > \chi_{\gamma \Sigma^+ \bar{\Sigma}^-}^2$$

### Extracted BKG Channel In Inclusive MC

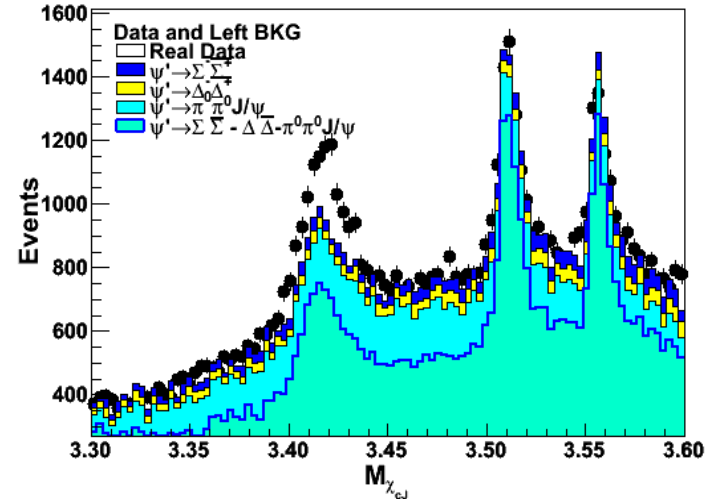
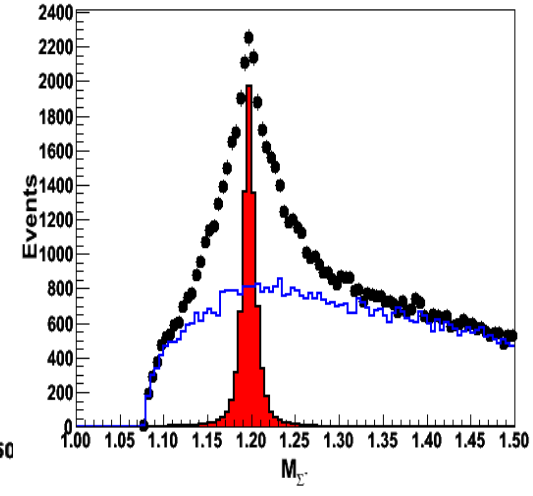
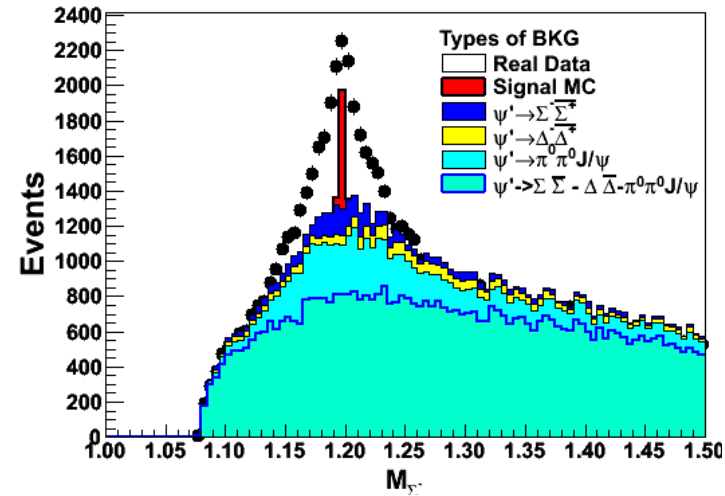
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \rightarrow \Sigma^- \bar{\Sigma}^+ \pi^0, \Sigma^- \rightarrow n \pi^-, \bar{\Sigma}^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n$	0	3148	3148
1	$\psi' \rightarrow \gamma \Sigma^- \bar{\Sigma}^+, \Sigma^- \rightarrow n \pi^-, \bar{\Sigma}^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma$	2	487	3635
2	$\psi' \rightarrow \Sigma^- \bar{\Sigma}^+, \Sigma^- \rightarrow n \pi^-, \bar{\Sigma}^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n$	1	476	4111

## Background channel Extracted from Inclusive MC Sample

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	44	3616	3616
1	$\psi' \rightarrow \Delta^- \pi^0 \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n$	19	2137	5753
2	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \pi^- n, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	0	1922	7675
3	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^0 \Delta^- \Delta^-, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	8	1841	9516
4	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	31	1185	10701
5	$\psi' \rightarrow \Sigma^- \Sigma^+ \pi^0, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n$	2	865	11566
6	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	73	775	12341
7	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Sigma^0 \Sigma^+ \pi^-, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^+ \rightarrow \bar{n} \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	59	661	13002
8	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \gamma \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	163	628	13630
9	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow n \bar{n}$	$\pi^- \bar{n} \pi^+ n$	406	624	14254
10	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \Delta^0 \pi^-, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^0 \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	25	590	14844
11	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma$	33	569	15413
12	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \pi^+ \bar{n}, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	117	555	15968
13	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Sigma^- \Sigma^+, \eta \rightarrow \gamma \gamma, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	36	486	16454
14	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \Sigma^+ \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^+ \rightarrow \Lambda \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	112	448	16902
15	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \pi^0 \Delta^- \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	20	434	17336
16	$\psi' \rightarrow \Delta^0 \Delta^- \pi^-, \Delta^0 \rightarrow n \pi^0, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n$	7	433	17769
17	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \pi^0 \Sigma^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	52	410	18179
18	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Sigma^+ \Sigma^- \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	133	409	18588
19	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{n} n, \eta \rightarrow \gamma \gamma$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	150	385	18973
20	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \Delta^- \pi^- n, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma$	110	358	19331
21	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{n} \pi^+ \Delta^+, \Delta^+ \rightarrow n \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	114	339	19670
22	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \Sigma^0 \Sigma^+ \pi^-, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^+ \rightarrow \bar{n} \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	207	330	20000
23	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \Sigma^0 \pi^- \Sigma^+, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^+ \rightarrow \bar{n} \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	181	330	20330
24	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \eta \bar{n} n, \eta \rightarrow \pi^- \pi^+ \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	10	316	20646
25	$\psi' \rightarrow \Delta^- \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n$	68	314	20960
26	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \pi^- \Lambda \Sigma^+, \Lambda \rightarrow n \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	22	310	21270
27	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Delta^- \Delta^- \pi^0, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \pi^- \bar{n} \pi^0 \pi^+ \pi^+ n$	142	307	21577
28	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Delta^- \Delta^- \pi^0, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	97	272	21849
29	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Xi^+ \Xi^-, \Xi^+ \rightarrow \bar{\Lambda} \pi^+, \Xi^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow \bar{n} \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	120	270	22119

No.	decay chain	final states	iTopology	nEvt	nTot
30	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \pi^- \Delta^- \Delta^0, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^0 \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	37	270	22389
31	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^0 \Delta^+ \Delta^+, \Delta^+ \rightarrow \bar{p} \pi^+, \Delta^+ \rightarrow p \pi^+$	$\pi^- \bar{p} \pi^0 \pi^0 \pi^+ p$	229	263	22652
32	$\psi' \rightarrow \Delta^- \pi^- n, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n$	225	257	22909
33	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Delta^- \pi^0 \Delta^-, \eta \rightarrow \gamma \gamma, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	139	250	23159
34	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{\Delta}^0 \pi^+ \Delta^-, \bar{\Delta}^0 \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	293	247	23406
35	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \pi^0 \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	174	247	23653
36	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \pi^0 n \bar{n}$	$\pi^- \bar{n} \pi^0 \pi^+ n$	327	245	23898
37	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \pi^- \bar{n} \pi^+ \pi^+ n$	320	245	24143
38	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \eta \bar{n} n, \eta \rightarrow \pi^0 \pi^0 \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	130	243	24386
39	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma$	55	241	24627
40	$\psi' \rightarrow \gamma \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma$	186	239	24866
41	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Delta^- \pi^- n, \eta \rightarrow \gamma \gamma, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	146	230	25096
42	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \Sigma^- \Sigma^+ \pi^0, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	30	227	25323
43	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow n \pi^- \Delta^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n \gamma$	215	224	25547
44	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow p \bar{\Lambda} K^+, \bar{\Lambda} \rightarrow \bar{p} \pi^+, K^+ \rightarrow \bar{K}^0 \pi^-$	$\pi^- \bar{p} K_L \pi^+ \gamma p$	86	215	25762
45	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \phi K^+ K^+, \phi \rightarrow K^+ K^-, K^+ \rightarrow \bar{K}^0 \pi^-, K^+ \rightarrow K^0 \pi^+$	$\pi^- K^- K_L K_L \pi^+ \gamma K^+$	69	204	25966
46	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \pi^0 K^+ K^+, K^+ \rightarrow K^0 \pi^+, K^+ \rightarrow \bar{K}^0 \pi^-$	$\pi^- \pi^0 K_L K_L \pi^+ \gamma$	135	201	26167
47	$\psi' \rightarrow \Sigma^- \Sigma^+ \pi^-, \Sigma^- \rightarrow n \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n$	692	196	26363
48	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow n \pi^- \Delta^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \pi^- \bar{n} \pi^+ \pi^+ n$	621	190	26553
49	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^+ \pi^- \Delta^0, \Delta^+ \rightarrow n \pi^+, \Delta^0 \rightarrow \bar{n} \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	663	189	26742
50	$\psi' \rightarrow p K^+ \bar{\Lambda}, K^+ \rightarrow \bar{K}^0 \pi^-, \bar{\Lambda} \rightarrow \bar{p} \pi^+$	$\pi^- \bar{p} K_L \pi^+ p$	78	187	26929
51	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \Delta^- \pi^0 \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	173	187	27116
52	$\psi' \rightarrow K^+ n \Sigma^+, K^+ \rightarrow \bar{K}^0 \pi^-, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} K_L \pi^+ n$	65	186	27302
53	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Sigma^+ \Sigma^-, \eta \rightarrow \pi^0 \pi^0 \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	103	186	27488
54	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \gamma J/\psi, J/\psi \rightarrow \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	640	183	27671
55	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \Lambda \Sigma^+ \pi^-, \Lambda \rightarrow n \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	5	179	27850
56	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \Lambda \Sigma^+ \pi^-, \Lambda \rightarrow n \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	165	170	28020
57	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow p \bar{\Lambda} K^+, \bar{\Lambda} \rightarrow \bar{p} \pi^+, K^+ \rightarrow \bar{K}^0 \pi^-$	$\pi^- \bar{p} K_L \pi^+ p$	502	169	28189
58	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Delta^- \pi^0 \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	71	168	28357
59	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-, \eta \rightarrow \gamma \gamma$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	491	160	28517

## Categorization of the BKG In Inclusive MC



# Signal MC Efficiency

No. of Obs.	Selection Criteria	Survived Events	Percentage Efficiency %	Percentage Total Efficiency %
01.	Total Number	1000000	100	100
02.	Charge Track cut	644720	65	65
03.	EMC Shower cut	513507	79.6	51.4
04.	Nbar Shower cut	513507	79.6	51.4
05.	Pass PID	484992	75.3	48.6
06.	Pass KM Fit	319121	62.1	31.9

Rate of Cut Flow for chi\_c0 After KM Fit

```
All: = 319121
mpi0<0.12 && >0.15: = 275206
mpippim<1.2: = 275198
|mpippim-0.497|>0.01: = 263681
|mrecpip-3.097|>0.01: = 254987
msigmam<1.5: = 251648
mchicJ <3.6||mchicJ >3.3:= 244733
mchisq<20: = 221767
mchisq1>chisq: = 169194
nbar_energy>0.2: = 168840
nbar_hit_40d>20: = 154326
nbar_secmom >20: = 128423
gam_match>10: = 96015
```

**Tot. Signal MC Efficiency = 9.6 %**

Rate of Cut Flow for chi\_c1 After KM Fit

```
All: = 322617
mpi0<0.12 || >0.15: = 267986
mpippim<1.2: = 267979
|mpippim-0.497|>0.01: = 257420
|mrecpip-3.097|>0.01: = 249849
msigmam<1.5: = 246681
mchicJ <3.6||mchicJ >3.3:= 239433
mchisq<20: = 220967
mchisq1>chisq: = 155709
nbar_energy>0.2: = 153363
nbar_hit_40d>20: = 141591
nbar_secmom >20: = 118077
gam_match>10: = 86134
```

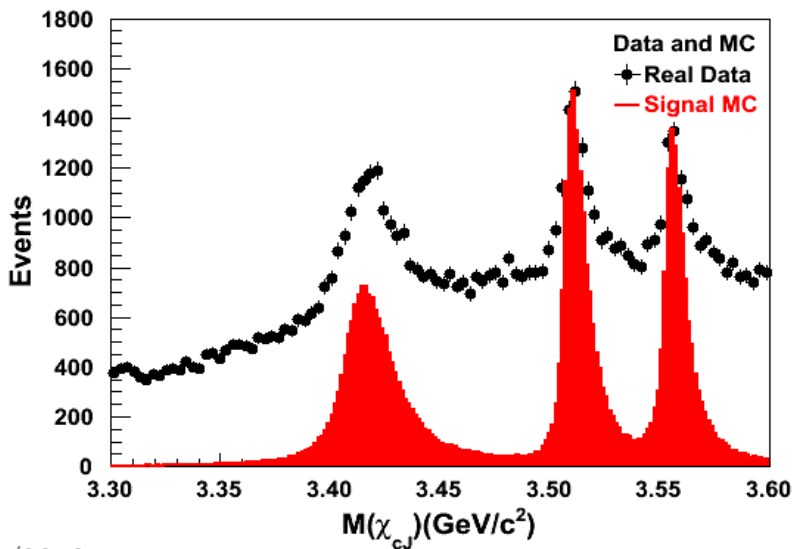
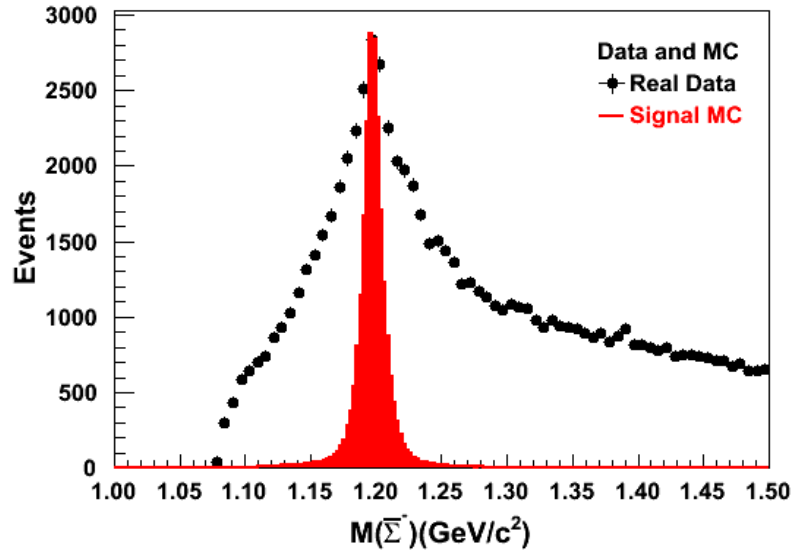
**Tot. Signal MC Efficiency = 8.6 %**

Rate of Cut Flow for chi\_c2 After KM Fit

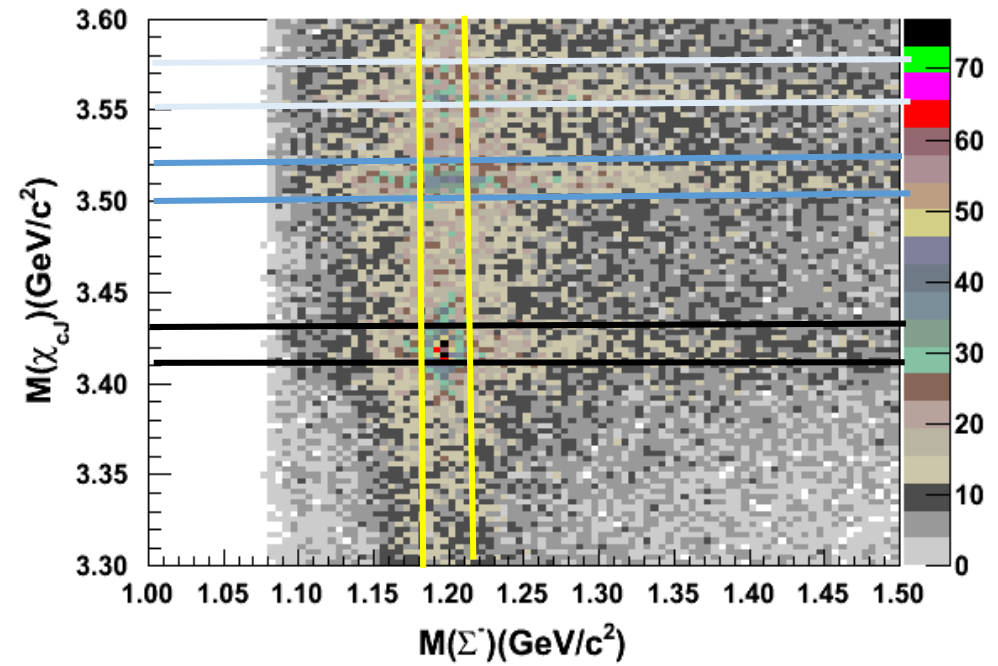
```
All: = 308394
mpi0<0.12 || >0.15: = 249435
mpippim<1.2: = 249421
|mpippim-0.497|>0.01: = 239804
|mrecpip-3.097|>0.01: = 233059
msigmam<1.5: = 230300
mchicJ <3.6||mchicJ >3.3:= 221963
mchisq<20: = 205695
mchisq1>chisq: = 137617
nbar_energy>0.2: = 135018
nbar_hit_40d>20: = 125058
nbar_secmom >20: = 104089
gam_match>10: = 69986
```

**Tot. Signal MC Efficiency = 6.9 %**

# Invariant Mass of $\chi_{cJ}$ and $\Sigma^-$



2D Scatter Plot for Data



# Measurement of Branching Fractions of

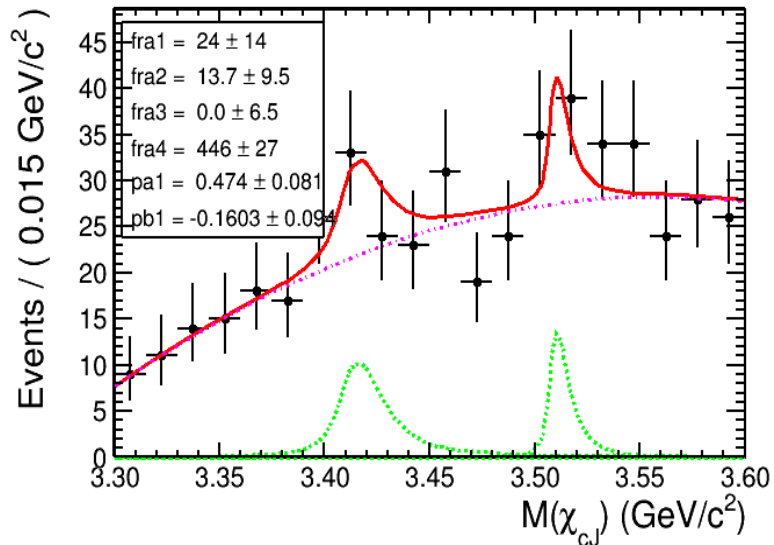
$$\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$$



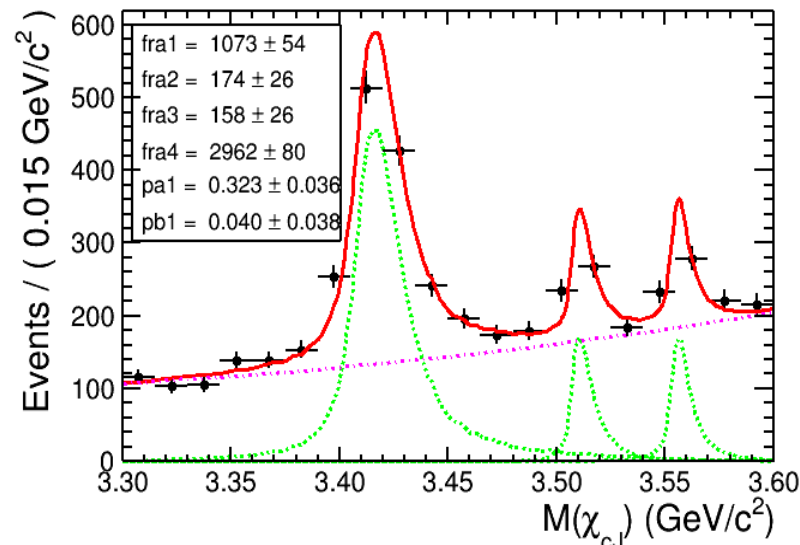
# Extraction of Signal $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$

- The peaking background have been seen in both  $\Sigma^-$  and  $\chi_{cJ}$  mass spectrum.
- The constitution of peaking backgrounds are complex.
- Here, we fit the  $M(\chi_{cJ})$  in each  $\Sigma^-$  mass interval of data and extracted the number of signal events of  $N_{\chi_{c0}}$ ,  $N_{\chi_{c1}}$ ,  $N_{\chi_{c2}}$ .

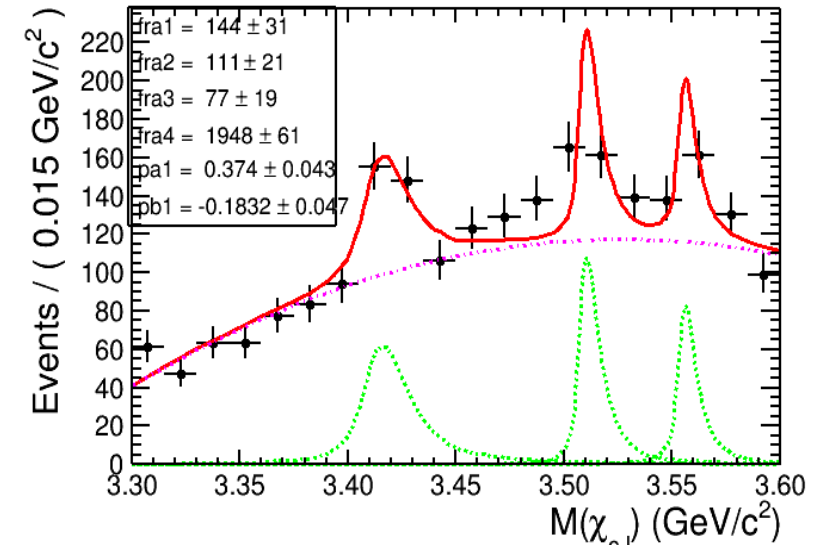
$M_{\Sigma^-} \in (1.08, 1.09)$



$M_{\Sigma^-} \in (1.19, 1.2)$

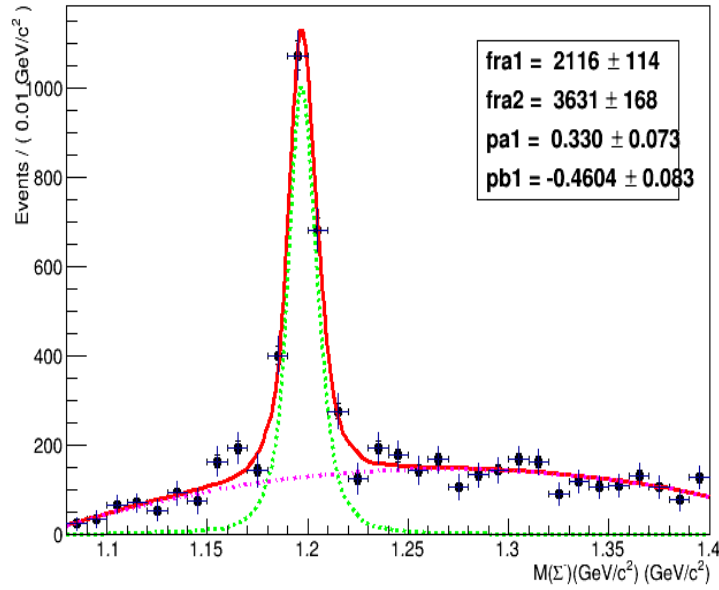


$M_{\Sigma^-} \in (1.25, 1.26)$



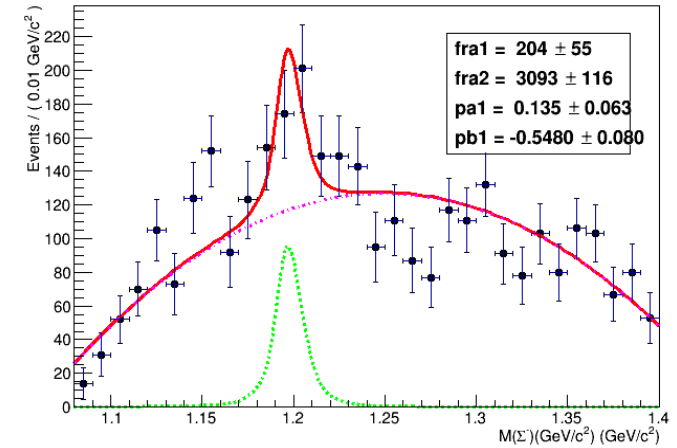
# Fitting Result

$$N_{\chi_{c0}}^{obs.} = 2116 \pm 114$$

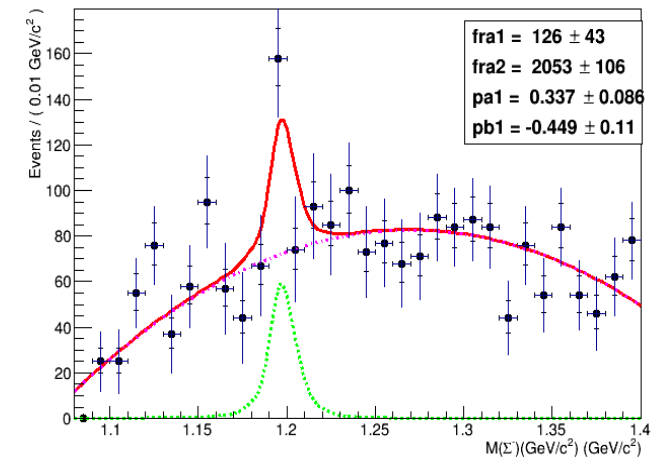


- Version 5.34/19 – 2014
- Version 5.34/34 – 2015
- Version 5.34/36 – 2016

$$N_{\chi_{c1}}^{obs.} = 204 \pm 55$$



$$N_{\chi_{c2}}^{obs.} = 126 \pm 43$$



**Resolve Problem:** Fix the computation of fit parameters errors in weighted Extended Maximum likelihood fit since root version 5.34-19 till up to now.

# Numerical Result for Branching Fractions of $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$

$$\bullet \mathfrak{B}(\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+) = \frac{N_{\chi_{cJ}}^{Obs.}}{N_{\psi'_{data}} \mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ}) \mathfrak{B}(\Sigma^- \rightarrow n \pi^-) \mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+) \epsilon_J}$$

## Number used to Calculate the Branching Fractions:

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2116 \pm 114$	$204 \pm 55$	$126 \pm 43$
Efficiency( $\epsilon_J$ ) %	9.6	8.6	6.99
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})$ %	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)$ %	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)$ %	99.848	99.848	99.848

1.  $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.94 \pm 0.27 * 10^{-4}$  in PDG  $3.9 * 10^{-4}$

2.  $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.6 \pm 1.5 * 10^{-5}$  in PDG  $< 6 * 10^{-5}$

3.  $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.4 \pm 1.5 * 10^{-5}$  in PDG  $< 7 * 10^{-5}$

➔ This result taken from  $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$  just as a reference

Channel	This work	PDG	Previous BESIII [6]	CLEO [5]	Theory	$\mathcal{B}_{prod}$
$\chi_{c0} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$50.4 \pm 2.5 \pm 2.7$	$39 \pm 7$	$43.7 \pm 4.0 \pm 2.8$	$32.5 \pm 5.7 \pm 4.3$	5.5-6.9 [3]	$4.99 \pm 0.24 \pm 0.24$
$\chi_{c1} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$3.7 \pm 0.6 \pm 0.2$	$< 6$	$5.2 \pm 1.3 \pm 0.5 (< 8.3)$	$< 6.5$	3.3 [4]	$0.35 \pm 0.06 \pm 0.02$
$\chi_{c2} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$3.5 \pm 0.7 \pm 0.3$	$< 7$	$4.7 \pm 1.8 \pm 0.7 (< 8.4)$	$< 6.7$	5.0 [4]	$0.32 \pm 0.06 \pm 0.03$

Ref: <https://arxiv.org/abs/1710.07922>

# Measurement of Systematic Uncertainty

# Systematic Uncertainty in $M(\pi^0)$ Rejection

$M(\pi^0) \in [0.115, 0.155] \text{ GeV}$

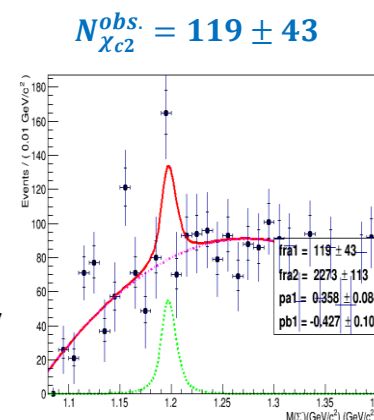
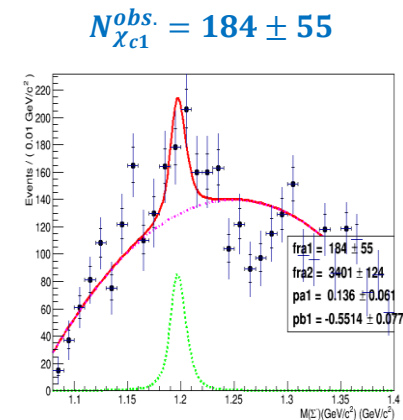
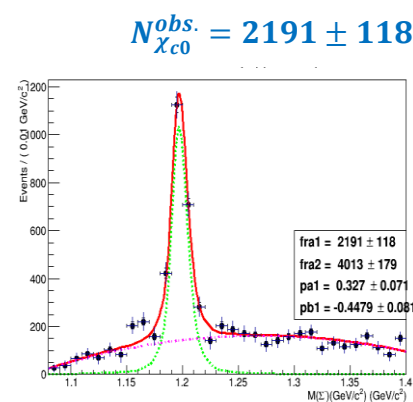
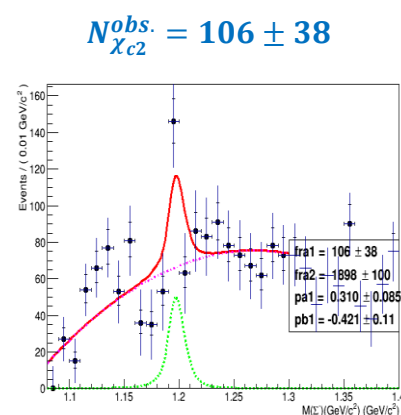
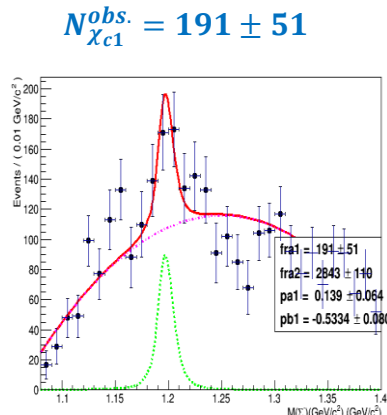
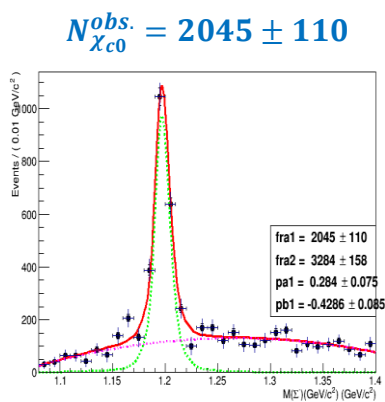
$M(\pi^0) \in [0.125, 0.145] \text{ GeV}$

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2045 \pm 110$	$191 \pm 51$	$106 \pm 38$
Efficiency( $\epsilon_j$ ) %	9.3	8.3	6.68
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{c_j})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2191 \pm 118$	$184 \pm 55$	$119 \pm 43$
Efficiency( $\epsilon_j$ ) %	9.94	8.98	7.36
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{c_j})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.93 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.4 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 3.9 * 10^{-5}$

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.94 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.80 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 3.97 * 10^{-5}$



# Systematic Uncertainty in $M(\pi^- \pi^+)$ Rejection

$$|M(\pi^- \pi^+) - 0.497| > 0.015 \text{ GeV}$$

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2063 \pm 112$	$198 \pm 54$	$116 \pm 42$
Efficiency( $\epsilon_J$ ) %	9.40	8.45	6.87
$N_{\psi'_{data}} (M)$	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

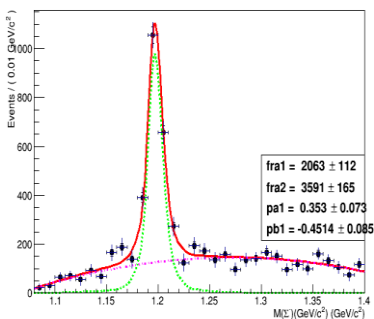
- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.92 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.49 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.15 * 10^{-5}$

$$|M(\pi^- \pi^+) - 0.497| > 0.20 \text{ GeV}$$

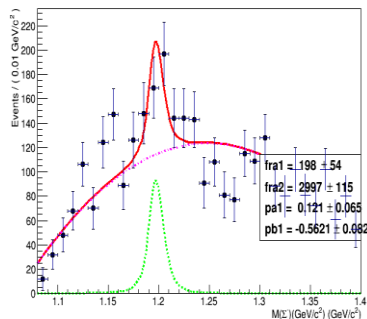
Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$1996 \pm 109$	$186 \pm 53$	$110 \pm 40$
Efficiency( $\epsilon_J$ ) %	9.20	8.28	6.74
$N_{\psi'_{data}} (M)$	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.86 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.27 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.01 * 10^{-5}$

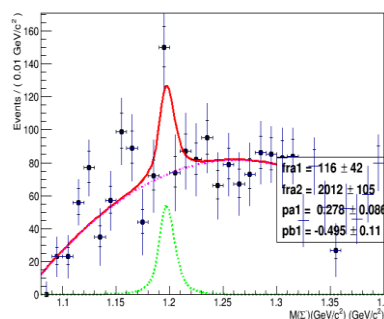
$$N_{\chi_{c0}}^{Obs.} = 2063 \pm 112$$



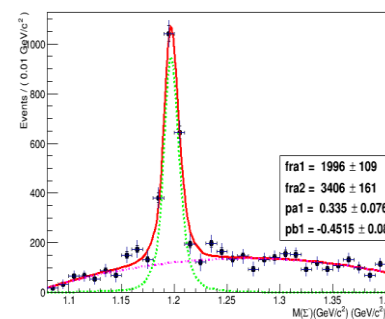
$$N_{\chi_{c1}}^{Obs.} = 198 \pm 54$$



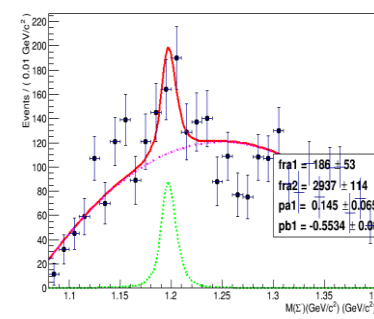
$$N_{\chi_{c2}}^{Obs.} = 116 \pm 42$$



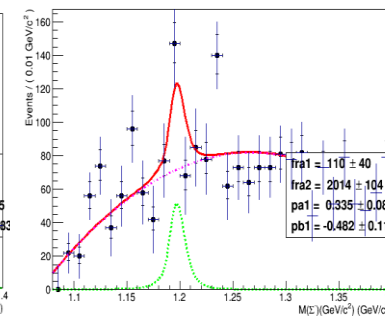
$$N_{\chi_{c0}}^{Obs.} = 1996 \pm 109$$



$$N_{\chi_{c1}}^{Obs.} = 186 \pm 53$$



$$N_{\chi_{c2}}^{Obs.} = 110 \pm 40$$



# Systematic Uncertainty in $M_{rec}(\pi_-\pi^+)$ Rejection

$$|M_{rec}(\pi_-\pi^+) - 3.097| > 0.015$$

Channel	$\chi_{c0} \rightarrow \Sigma^-\bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^-\bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^-\bar{\Sigma}^+$
$N_{fit}^{Obs.}$	2052 ± 113	207 ± 55	124 ± 42
Efficiency( $\epsilon_J$ ) %	9.45	8.49	6.91
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma\chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n\pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n}\pi^+)\%$	99.848	99.848	99.848

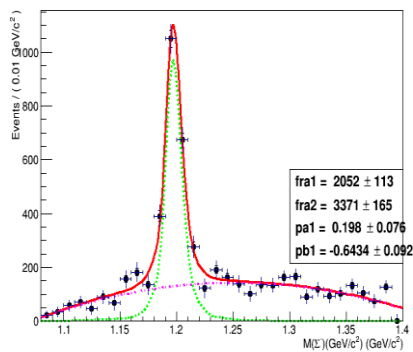
- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^-\bar{\Sigma}^+) = 4.87 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^-\bar{\Sigma}^+) = 5.71 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^-\bar{\Sigma}^+) = 4.41 * 10^{-5}$

$$|M_{rec}(\pi_-\pi^+) - 3.097| > 0.20$$

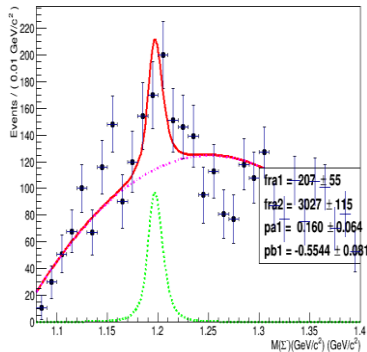
Channel	$\chi_{c0} \rightarrow \Sigma^-\bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^-\bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^-\bar{\Sigma}^+$
$N_{fit}^{Obs.}$	1996 ± 110	211 ± 54	137 ± 44
Efficiency( $\epsilon_J$ ) %	9.30	8.36	6.82
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma\chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n\pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n}\pi^+)\%$	99.848	99.848	99.848

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^-\bar{\Sigma}^+) = 4.81 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^-\bar{\Sigma}^+) = 5.92 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^-\bar{\Sigma}^+) = 4.94 * 10^{-5}$

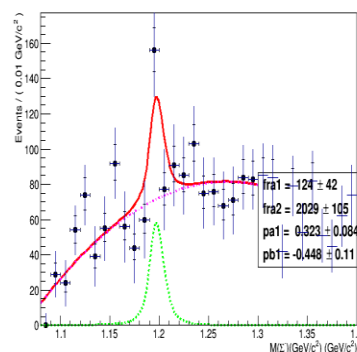
$$N_{\chi_{c0}}^{Obs.} = 2052 \pm 113$$



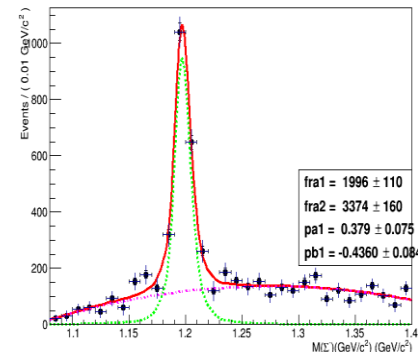
$$N_{\chi_{c1}}^{Obs.} = 207 \pm 55$$



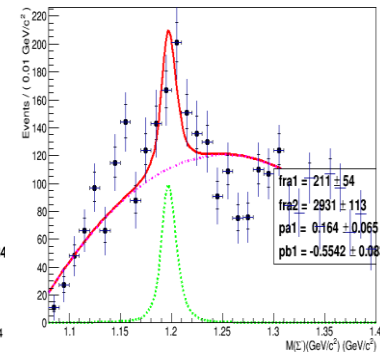
$$N_{\chi_{c2}}^{Obs.} = 124 \pm 42$$



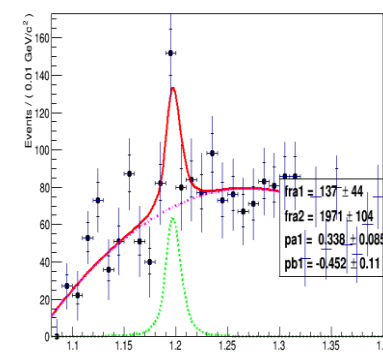
$$N_{\chi_{c0}}^{Obs.} = 1996 \pm 110$$



$$N_{\chi_{c1}}^{Obs.} = 211 \pm 54$$



$$N_{\chi_{c2}}^{Obs.} = 137 \pm 44$$



# Systematic Uncertainty in Fitting Method

For Bin Size 5 MeV

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2162 \pm 114$	$223 \pm 56$	$123 \pm 41$
Efficiency( $\epsilon_J$ ) %	9.6	8.6	6.99
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

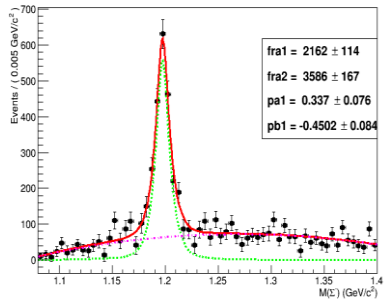
- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.05 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 6.08 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.32 * 10^{-5}$

For Bin Size 15 MeV

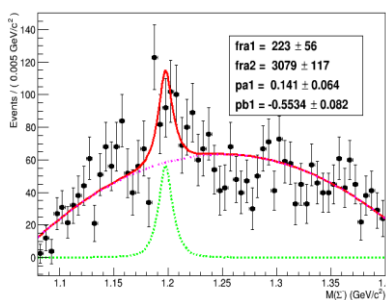
Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2134 \pm 57$	$269 \pm 31$	$108 \pm 22$
Efficiency( $\epsilon_J$ ) %	9.6	8.6	6.99
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.98 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 7.33 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 3.80 * 10^{-5}$

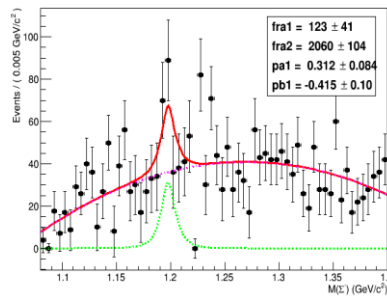
$N_{\chi_{c0}}^{Obs.} = 2162 \pm 114$



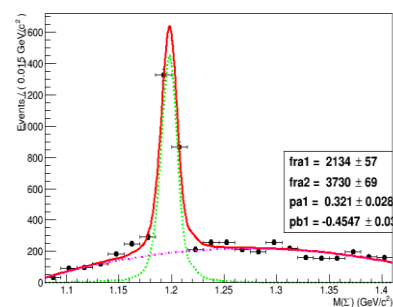
$N_{\chi_{c1}}^{Obs.} = 223 \pm 56$



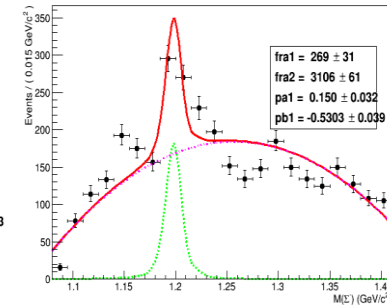
$N_{\chi_{c2}}^{Obs.} = 123 \pm 41$



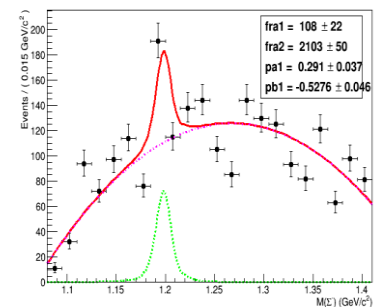
$N_{\chi_{c0}}^{Obs.} = 2134 \pm 57$



$N_{\chi_{c1}}^{Obs.} = 269 \pm 31$



$N_{\chi_{c2}}^{Obs.} = 108 \pm 22$





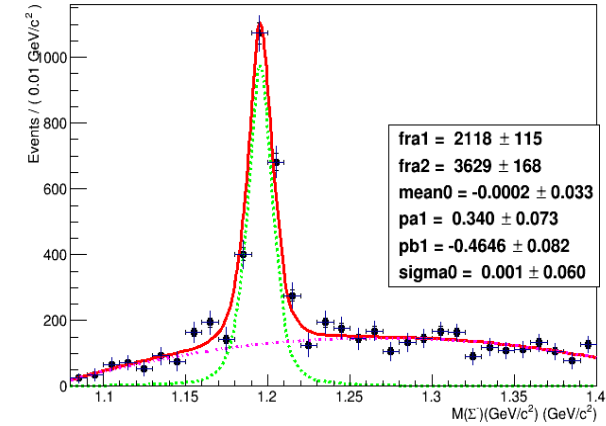
# Systematic Uncertainty in Signal Shape

By Signal MC  $\otimes$  Gaussian

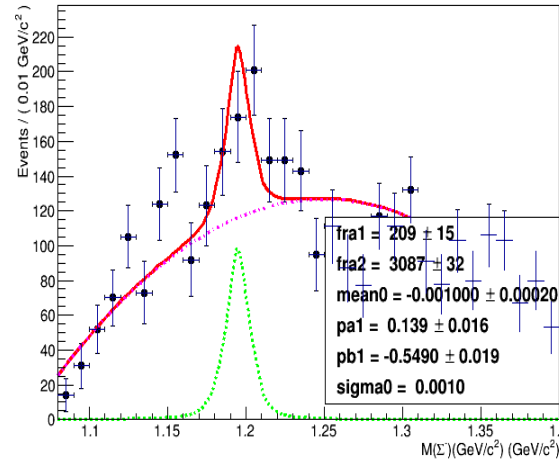
Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	$2118 \pm 115$	$209 \pm 15$	$130 \pm 11$
Efficiency( $\epsilon_f$ ) %	9.6	8.6	6.99
$N_{\psi'_{data}} (M)$	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

- $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.94 * 10^{-4}$
- $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 5.69 * 10^{-5}$
- $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.57 * 10^{-5}$

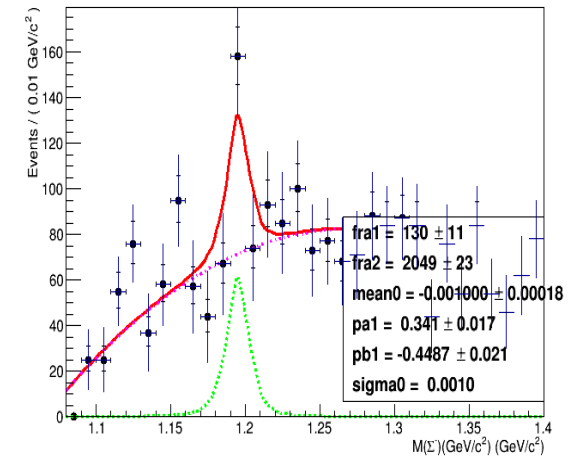
$N_{\chi_{c0}}^{Obs.} = 2118 \pm 115$



$N_{\chi_{c1}}^{Obs.} = 209 \pm 15$



$N_{\chi_{c2}}^{Obs.} = 130 \pm 11$

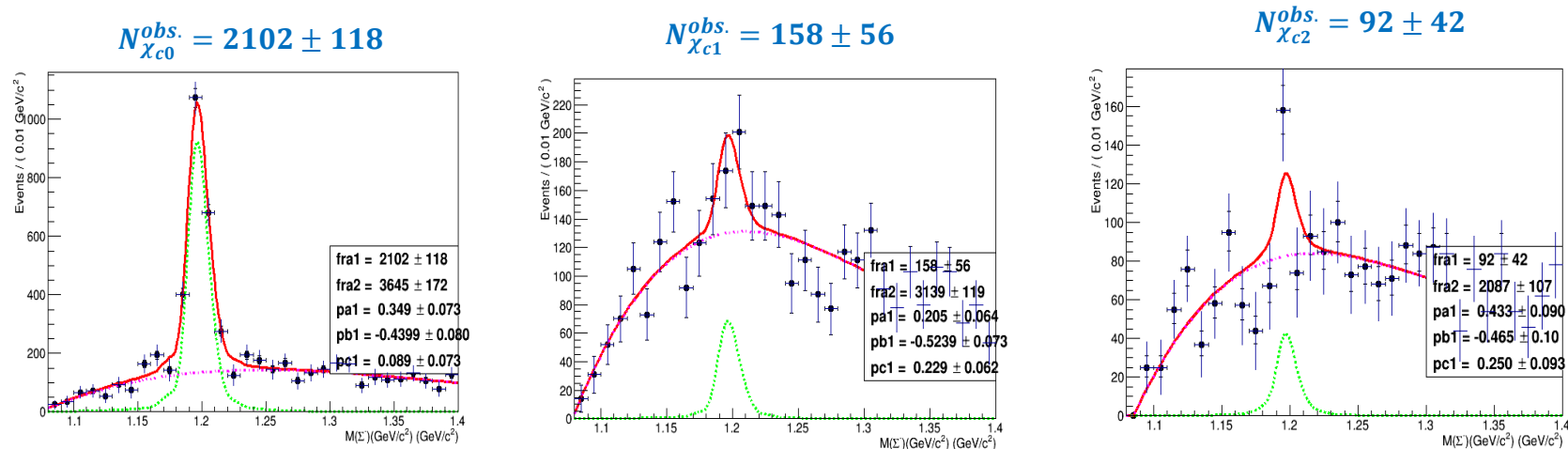


# Systematic Uncertainty in Background Shape

By Changing 2<sup>nd</sup> Order polynomial to 3<sup>rd</sup> Order polynomial.

Channel	$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$
$N_{fit}^{Obs.}$	2102 ± 118	158 ± 56	92 ± 42
Efficiency( $\epsilon_J$ ) %	9.6	8.6	6.99
$N_{\psi'_{data}} (M)$	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \rightarrow n \pi^-)\%$	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \rightarrow \bar{n} \pi^+)\%$	99.848	99.848	99.848

1.  $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.91 * 10^{-4}$
2.  $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+) = 4.30 * 10^{-5}$
3.  $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+) = 3.23 * 10^{-5}$



# Systematic Uncertainty

Sources	Comments	Systematic Uncertainty (%)		
Charged Pions ( $\pi^+\pi^-$ )	1.4 per charged track	2.8 (By Liu Liang)		
Neutral particle ( $\gamma$ )	Ref: <b>PhysRevD.83.112009</b>	1.0		
Nbar ( $\bar{n}$ ) Selections	Select control sample of $J/\psi \rightarrow \Sigma^{*-}\bar{\Sigma}^+$	5.0 (By Liu Liang)		
Kinematic Fit				
$\pi^0$ mass Window	Varying the region [0.12, 0.15] $\rightarrow$ [0.115, 0.155] (OR) [0.125, 0.145] GeV	$\chi_{c0}$	$\chi_{c1}$	$\chi_{c2}$
		0.20	14.3	11.4
$\pi^+\pi^-$ mass Window	Varying the region $\rightarrow$ 0.01 GeV $\rightarrow$ 0.015 GeV (OR) 0.02 GeV	1.6	5.89	8.9
Recoil $\pi^+\pi^-$ mass Window	Varying the region $\rightarrow$ 0.01 GeV $\rightarrow$ 0.015 GeV (OR) 0.02 GeV	2.6	5.7	12.3
Fitting Method	Using different bin size of $\chi_{cJ}$ mass spectrum 5 MeV (OR) 15 MeV	2.2	30.1	13.6
	By Changing MC to (Signal MC $\otimes$ Gaussian)	0.0	1.6	3.9
	By Changing 2 <sup>nd</sup> Order Chebychev polynomial to 3 <sup>rd</sup> order poly. function.	0.6	23	26.5
Branching Fraction	Uncertainty from $\psi(3686) \rightarrow \gamma\chi_{cJ}$	2.4	3.3	3.4
Number of $\psi(3686)$	Ref: <b>Chin. Phys. C 42, 023001 (2018)</b>	0.6		
<b>Total</b>		<b>7.4</b>	<b>42</b>	<b>36</b>

# Summary

- By Reconstruction of  $\gamma n \bar{n} \pi^+ \pi^-$  final states, the process of  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$  are observed for the first time at BESIII.
- The signal is extracted by fitting of  $M(\chi_{cJ})$  mass spectra (*un-binned*) in each  $\Sigma^-$  mass interval (*bin-by-bin*).
- The branching fraction of  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$  to be given, which are consistent with  $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$  process.

Channel	This Work	PDG	Previous BESIII [1]		Theory
			$\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$\chi_{cJ} \rightarrow \Sigma^0 \bar{\Sigma}^0$	
$\chi_{c0} \rightarrow \Sigma^- \bar{\Sigma}^+$	$(4.94 \pm 0.27 \pm 0.36) * 10^{-4}$	$(3.9 \pm 0.7) * 10^{-4}$	$(5.04 \pm 0.25 \pm 0.27) * 10^{-4}$	$(4.8 \pm 1.8 \pm 3.5) * 10^{-4}$	$(0.55 - 0.69) * 10^{-4}$ [2]
$\chi_{c1} \rightarrow \Sigma^- \bar{\Sigma}^+$	$(5.6 \pm 1.5 \pm 2.3) * 10^{-5}$	$< 6 * 10^{-5}$	$(3.7 \pm 0.6 \pm 0.2) * 10^{-5}$	$(4.3 \pm 0.5 \pm 0.3) * 10^{-5}$	$3.3 * 10^{-5}$ [3]
$\chi_{c2} \rightarrow \Sigma^- \bar{\Sigma}^+$	$(4.4 \pm 1.5 \pm 1.6) * 10^{-5}$	$< 7 * 10^{-5}$	$(3.5 \pm 0.7 \pm 0.3) * 10^{-5}$	$(3.9 \pm 0.5 \pm 0.3) * 10^{-5}$	$5.0 * 10^{-5}$ [3]

## References:

- [1]. M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D 97, 052011  
 [2]. X. H. Liu and Q. Zhao, J. Phys. G 38, 035007 (2011)  
 [3]. S. M. H. Wong, Eur. Phys. J. C 14, 643 (2000).

Thank you for your Attention

# Backup

**Measurement of Branching Fractions of**

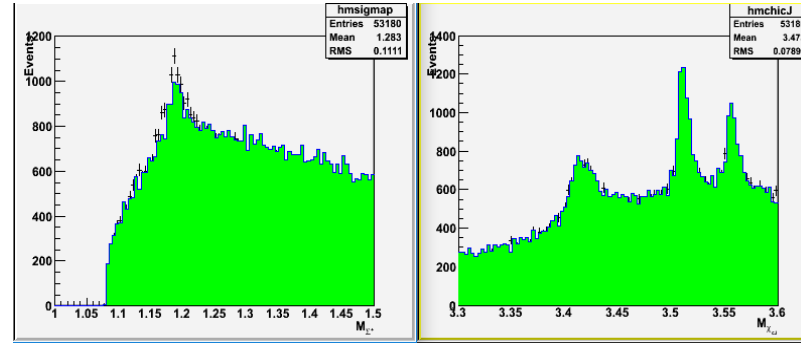
$$\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$$

# Background channel Extracted from Inclusive MC Sample

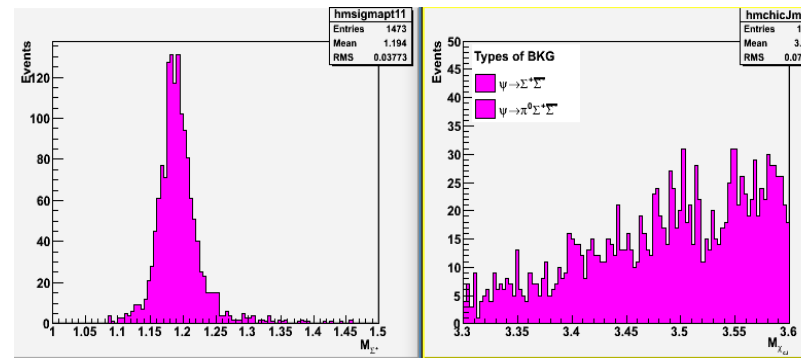
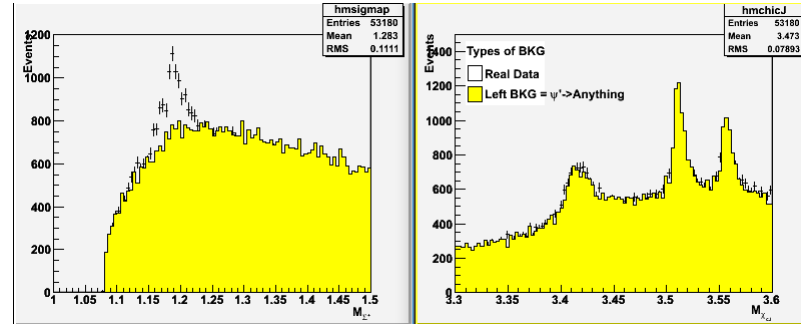
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	17	1716	1716
1	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \Delta^- \pi^0, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	32	1292	3008
2	$\psi' \rightarrow \Sigma^+ \Sigma^- \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^+ n$	83	1262	4270
3	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{n} \bar{n} \pi^+ \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	11	1177	5447
4	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	70	897	6344
5	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow n \bar{n}$	$\pi^- \bar{n} \pi^+ n$	15	652	6996
6	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^+ \Delta^- \Delta^0, \Delta^- \rightarrow n \pi^-, \Delta^0 \rightarrow \bar{n} \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	4	529	7525
7	$\psi' \rightarrow \Delta^- \pi^0 \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n$	80	410	7935
8	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow n \pi^+ \Delta^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	200	379	8314
9	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow n \pi^+ \Delta^+, \Delta^+ \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	90	375	8689
10	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{n} n \eta, \eta \rightarrow \gamma \gamma$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	122	368	9057
11	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \Delta^- \pi^+ \bar{n}, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	280	339	9396
12	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \pi^0 \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	82	338	9734
13	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \eta \bar{n}, \eta \rightarrow \pi^- \pi^+ \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	116	289	10023
14	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \pi^0 \Delta^- \Delta^-, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	9	284	10307
15	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Sigma^0 \Sigma^- \pi^+, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^- \rightarrow \bar{n} \pi^-, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	104	265	10572
16	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Delta^- \Delta^- \pi^0, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \pi^- \bar{n} \pi^0 \pi^+ \pi^+ n$	118	246	10818
17	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \pi^0 \bar{n} n$	$\pi^- \bar{n} \pi^0 \pi^+ n$	170	235	11053
18	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	273	232	11285
19	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^+ \Delta^+ \pi^0, \Delta^+ \rightarrow p \pi^+, \Delta^+ \rightarrow \bar{p} \pi^-$	$\pi^- \bar{p} \pi^0 \pi^0 \pi^0 \pi^+ p$	236	228	11513
20	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \Sigma^+ \Sigma^- \pi^0, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	43	227	11740
21	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \Sigma^+ \Sigma^- \pi^0, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	40	227	11967
22	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^- \Sigma^+, \Sigma^- \rightarrow \bar{n} \pi^-, \Sigma^+ \rightarrow \Lambda \pi^+, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	27	221	12188
23	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \bar{n} n \eta, \eta \rightarrow \pi^0 \pi^0 \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	25	217	12405
24	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow K^{*+} \Lambda \bar{p}, K^{*+} \rightarrow K^0 \pi^+, \Lambda \rightarrow p \pi^-$	$\pi^- \bar{p} K_L \pi^+ \gamma \bar{p}$	215	214	12619
25	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \bar{n} \Delta^- \pi^+, \eta \rightarrow \gamma \gamma, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	81	212	12831
26	$\psi' \rightarrow \Sigma^+ \pi^0 \Sigma^-, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n$	343	211	13042
27	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^+ \Delta^0 \Delta^+, \Delta^0 \rightarrow n \pi^0, \Delta^+ \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	0	203	13245
28	$\psi' \rightarrow \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow \Lambda \pi^+, \Sigma^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow n \pi^0, \Lambda \rightarrow \bar{n} \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	14	196	13441
29	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow K^{*+} \pi^0 K^{*+}, K^{*+} \rightarrow K^0 \pi^+, K^{*+} \rightarrow K^0 \pi^+$	$\pi^- \pi^0 K_L K_L \pi^+ \gamma$	209	187	13628

No.	decay chain	final states	iTopology	nEvt	nTot
30	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow K^{*+} K^{*+} \phi, K^{*+} \rightarrow K^0 \pi^+, K^{*+} \rightarrow K^0 \pi^-, \phi \rightarrow K^+ K^-$	$\pi^- K^- K_L K_L \pi^+ \gamma K^+$	79	180	13808
31	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Delta^- \pi^0 \Delta^-, \eta \rightarrow \gamma \gamma, \Delta^- \rightarrow n \pi^-, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	206	178	13986
32	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \gamma \Sigma^- \Sigma^+, \Sigma^- \rightarrow n \pi^+, \Sigma^+ \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	114	174	14160
33	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \gamma \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	195	174	14334
34	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta^- \Delta^0 \pi^-, \Delta^- \rightarrow \bar{n} \pi^+, \Delta^0 \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	164	168	14502
35	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Delta \Sigma^- \pi^+, \Delta \rightarrow n \pi^0, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	102	167	14669
36	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Delta^- \bar{n} \pi^+, \Delta^- \rightarrow n \pi^-$	$\pi^- \pi^- \bar{n} \pi^+ \pi^+ n$	78	165	14834
37	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow K^{*+} \Lambda \bar{p}, K^{*+} \rightarrow K^0 \pi^+, \Lambda \rightarrow p \pi^-$	$\pi^- \bar{p} K_L \pi^+ \gamma \bar{p}$	283	164	14998
38	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \pi^+ \Delta^- \bar{n}, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma$	342	155	15153
39	$\psi' \rightarrow \bar{n} n \eta, \eta \rightarrow \pi^+ \pi^- \eta, \eta \rightarrow \gamma \gamma$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	12	154	15307
40	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow \Delta^0 \pi^0 \Delta^0, \Delta^0 \rightarrow \bar{n} \pi^0, \Delta^0 \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	228	150	15457
41	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n$	296	148	15605
42	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-, \eta \rightarrow \gamma \gamma$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	44	147	15752
43	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \Sigma^+ \Sigma^- \pi^0, \Sigma^+ \rightarrow \bar{n} \pi^+, \Sigma^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^0 \pi^+ n$	261	142	15894
44	$\psi' \rightarrow \pi^+ \Delta^0 \Delta^-, \Delta^0 \rightarrow \bar{n} \pi^0, \Delta^- \rightarrow n \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n$	558	142	16036
45	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \Sigma^0 \pi^+ \Sigma^-, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^- \rightarrow \bar{n} \pi^-, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	111	141	16177
46	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Lambda \pi^+ \Sigma^-, \Lambda \rightarrow n \pi^0, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	103	141	16318
47	$\psi' \rightarrow \Delta^0 \Delta^+ \pi^+, \Delta^0 \rightarrow n \pi^0, \Delta^+ \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n$	746	140	16458
48	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow \Sigma^+ \Sigma^-, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	548	138	16596
49	$\psi' \rightarrow J/\psi \pi^+ \pi^-, J/\psi \rightarrow n \bar{n} \pi^+ \pi^-$	$\pi^- \pi^- \bar{n} \pi^+ \pi^+ n$	22	136	16732
50	$\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \pi^+ \Sigma^0 \Sigma^-, \Sigma^0 \rightarrow \gamma \Lambda, \Sigma^- \rightarrow \bar{n} \pi^-, \Lambda \rightarrow n \pi^0$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma \gamma$	225	136	16868
51	$\psi' \rightarrow J/\psi \eta, J/\psi \rightarrow \Sigma^+ \Sigma^-, \eta \rightarrow \gamma \gamma, \Sigma^+ \rightarrow n \pi^+, \Sigma^- \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^+ n \gamma \gamma$	520	133	17001
52	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \eta \bar{n} \eta, \eta \rightarrow \rho^0 \gamma, \rho^0 \rightarrow \pi^+ \pi^-$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	420	133	17134
53	$\psi' \rightarrow \gamma \chi_{c2}, \chi_{c2} \rightarrow \bar{p} \Lambda K^{*+}, \Lambda \rightarrow p \pi^-, K^{*+} \rightarrow K^0 \pi^+$	$\pi^- \bar{p} K_L \pi^+ \gamma \bar{p}$	98	132	17266
54	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \Delta^0 \pi^+ \Delta^+, \Delta^0 \rightarrow n \pi^0, \Delta^+ \rightarrow \bar{n} \pi^-$	$\pi^- \bar{n} \pi^0 \pi^+ n \gamma$	411	130	17396
55	$\psi' \rightarrow \Lambda \bar{p} K^{*+}, \Lambda \rightarrow p \pi^-, K^{*+} \rightarrow K^0 \pi^+$	$\pi^- \bar{p} K_L \pi^+ p$	47	128	17524
56	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \pi^+ \pi^- \pi^0 K^+ K^-$	$\pi^- K^- \pi^0 \pi^0 \pi^0 \pi^+ K^+$	115	128	17652
57	$\psi' \rightarrow J/\psi \pi^0 \pi^0, J/\psi \rightarrow \bar{p} \bar{p} \pi^+ \pi^-$	$\pi^- \bar{p} \pi^0 \pi^0 \pi^+ p$	39	125	17777
58	$\psi' \rightarrow \Delta^- \pi^- n, \Delta^- \rightarrow \bar{n} \pi^+$	$\pi^- \bar{n} \pi^+ n$	109	122	17899
59	$\psi' \rightarrow \gamma \chi_{c0}, \chi_{c0} \rightarrow \omega \bar{n} n, \omega \rightarrow \pi^+ \pi^- \pi^0$	$\pi^- \bar{n} \pi^0 \pi^0 \pi^+ n \gamma$	318	120	18019

# Data with Inclusive MC after All sections



# Categorization of the BKG In Inclusive MC



# Extraction of Signal for $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$

- The peaking background have been seen in both  $\Sigma^+$  and  $\chi_{cJ}$  mass spectrum.
- The constitution of peaking backgrounds are complex.
- Here, we fit the  $M(\chi_{cJ})$  mass spectra in each  $\Sigma^+$  mass interval of data and extracted the number of signal events for  $N_{\chi_{c0}}$ ,  $N_{\chi_{c1}}$ ,  $N_{\chi_{c2}}$ .

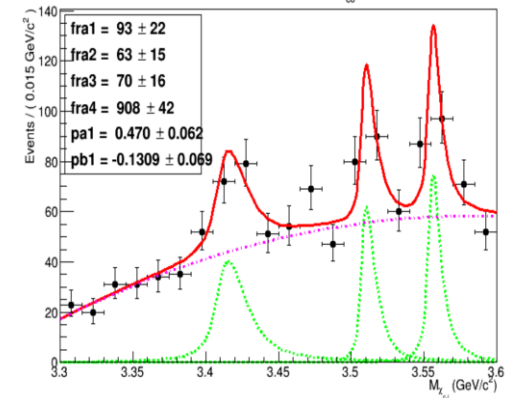
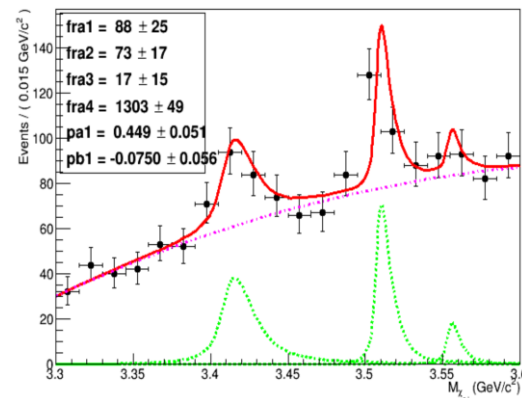
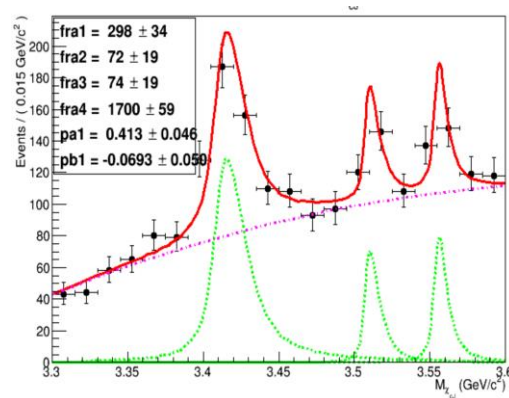
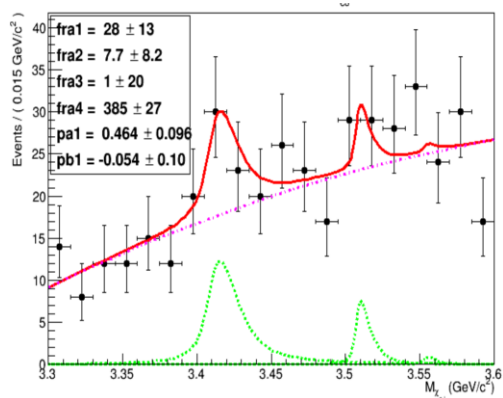
$M_{\Sigma^+} \in (1.08, 1.09)$

$M_{\Sigma^+} \in (1.19, 1.2)$

$M_{\Sigma^+} \in (1.25, 1.26)$

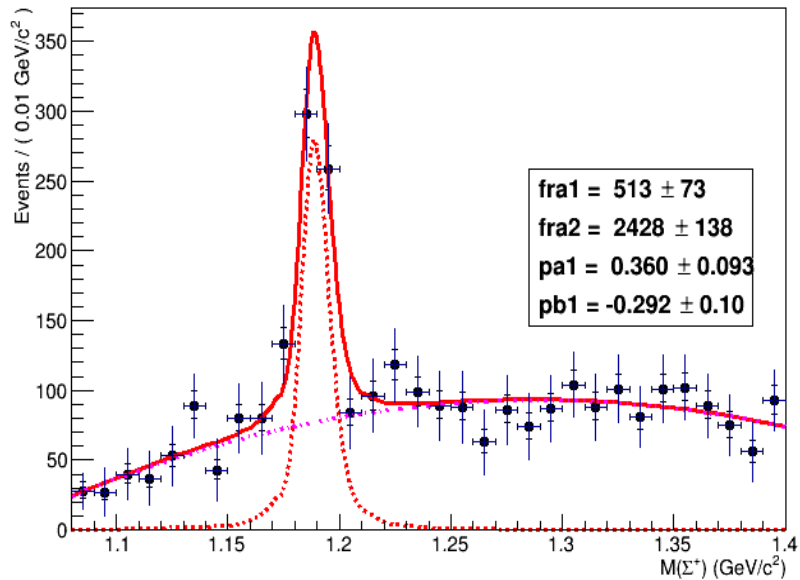
Continue ...

$M_{\Sigma^+} \in (1.39, 1.40)$



# Fitting Result

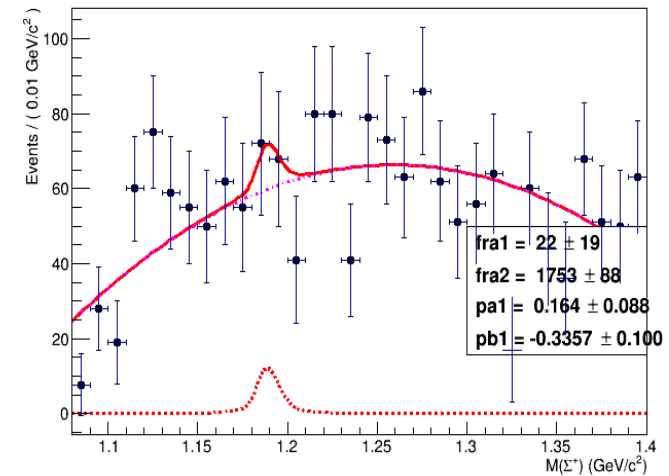
$N_{\chi_{c0}}^{obs.} = 513 \pm 73$



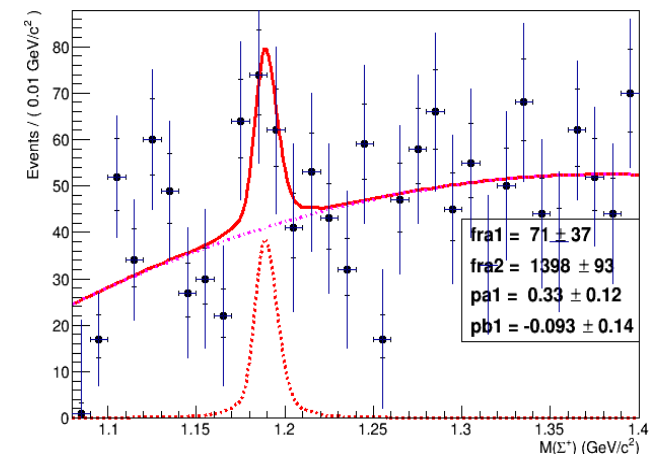
- Version 5.34/19-2014
- Version 5.34/34-2015
- Version 5.34/36-2016

**Resolve Problem:** Fix the computation of fit parameters errors in weighted Extended Maximum likelihood fit since root version 5.34-19-2014 till up to now.

$N_{\chi_{c1}}^{obs.} = 22 \pm 19$



$N_{\chi_{c2}}^{obs.} = 71 \pm 37$





# Numerical Result for Branching Fractions of $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$

$$\bullet \mathfrak{B}(\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-) = \frac{N_{\chi_{cJ}}^{Obs.}}{N_{\psi'_{data}} \mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ}) \mathfrak{B}(\Sigma^+ \rightarrow n \pi^+) \mathfrak{B}(\bar{\Sigma}^- \rightarrow \bar{n} \pi^-) \epsilon_J}$$

## Number used to Calculate the Branching Fractions:

Channel	$\chi_{c0} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$\chi_{c1} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$\chi_{c2} \rightarrow \Sigma^+ \bar{\Sigma}^-$
$N_{fit}^{Obs.}$	$513 \pm 73$	$22 \pm 19$	$71 \pm 37$
Efficiency( $\epsilon_J$ ) %	9.97	8.94	7.27
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \rightarrow \gamma \chi_{cJ})\%$	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^+ \rightarrow n \pi^+)\%$	48.31	48.31	48.31
$\mathfrak{B}(\bar{\Sigma}^- \rightarrow \bar{n} \pi^-)\%$	48.31	48.31	48.31

1.  $\mathfrak{B}(\chi_{c0} \rightarrow \Sigma^+ \bar{\Sigma}^-) = (4.9 \pm 0.7) * 10^{-4}$  in PDG  $3.9 * 10^{-4}$
2.  $\mathfrak{B}(\chi_{c1} \rightarrow \Sigma^+ \bar{\Sigma}^-) = (2.5 \pm 2.1) * 10^{-5}$  in PDG  $< 6 * 10^{-5}$
3.  $\mathfrak{B}(\chi_{c2} \rightarrow \Sigma^+ \bar{\Sigma}^-) = (10.2 \pm 5.3) * 10^{-5}$  in PDG  $< 7 * 10^{-5}$

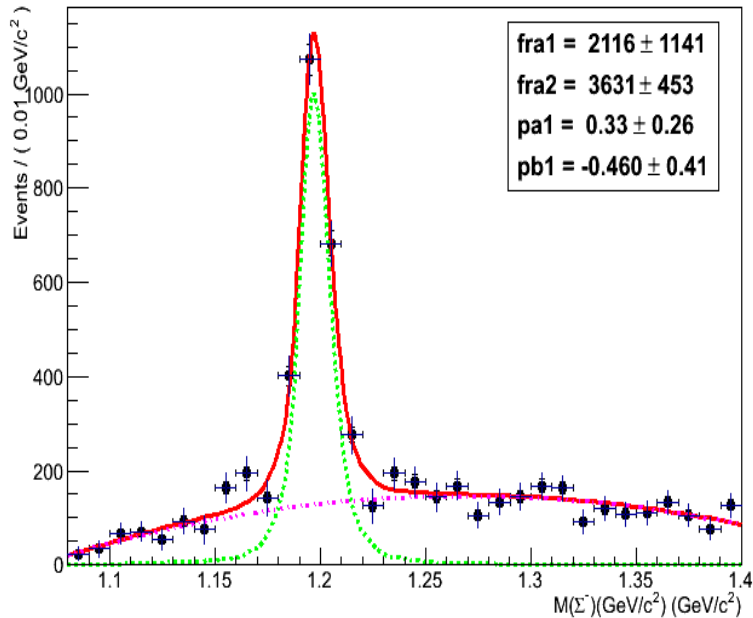
Channel	This work	PDG	Previous BESIII [6]	CLEO [5]	Theory	$\mathcal{B}_{prod}$
$\chi_{c0} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$50.4 \pm 2.5 \pm 2.7$	$39 \pm 7$	$43.7 \pm 4.0 \pm 2.8$	$32.5 \pm 5.7 \pm 4.3$	5.5-6.9 [3]	$4.99 \pm 0.24 \pm 0.24$
$\chi_{c1} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$3.7 \pm 0.6 \pm 0.2$	$< 6$	$5.2 \pm 1.3 \pm 0.5 (< 8.3)$	$< 6.5$	3.3 [4]	$0.35 \pm 0.06 \pm 0.02$
$\chi_{c2} \rightarrow \Sigma^+ \bar{\Sigma}^-$	$3.5 \pm 0.7 \pm 0.3$	$< 7$	$4.7 \pm 1.8 \pm 0.7 (< 8.4)$	$< 6.7$	5.0 [4]	$0.32 \pm 0.06 \pm 0.03$

Ref: <https://arxiv.org/abs/1710.07922>

# Comparison b/w different Root versions

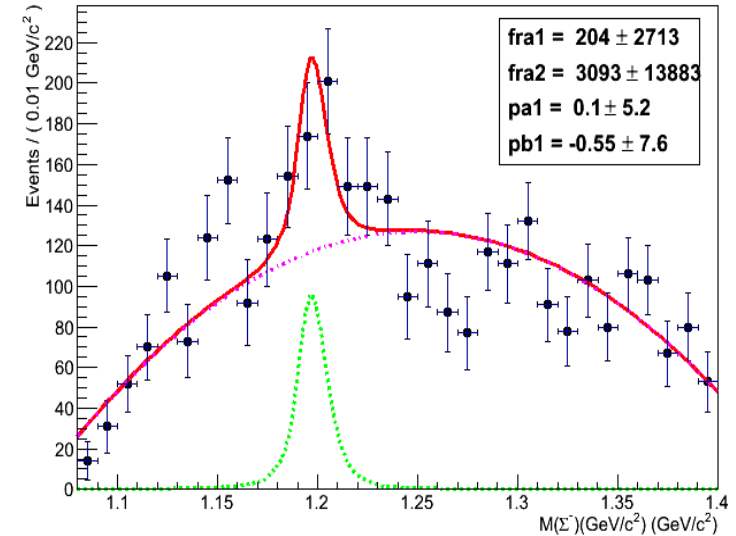
For  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$

$$N_{\chi_{c0}}^{obs.} = 2116 \pm 1141$$

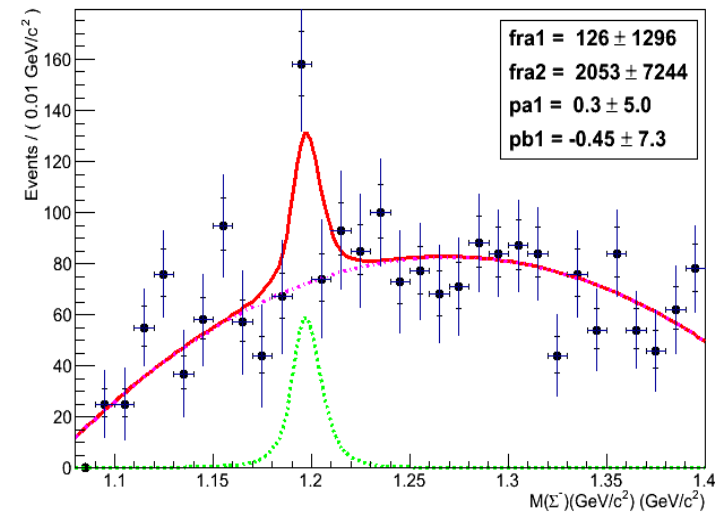


- Version 5.32/02 – 2012
- Version 5.32/03 – 2012
- Version 5.34/02 – 2012

$$N_{\chi_{c1}}^{obs.} = 204 \pm 2713$$



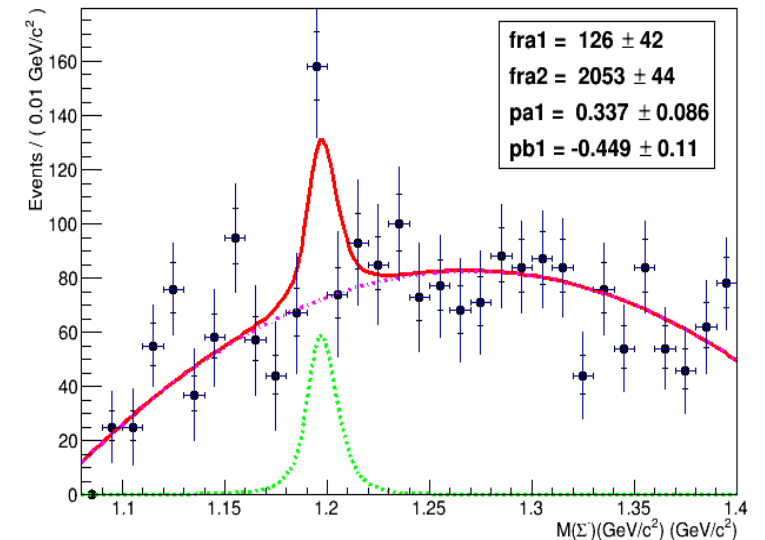
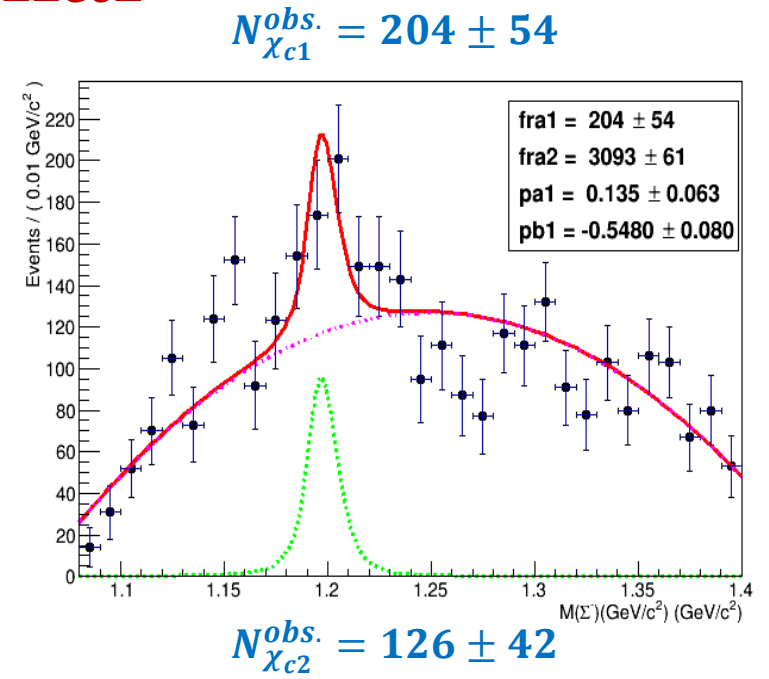
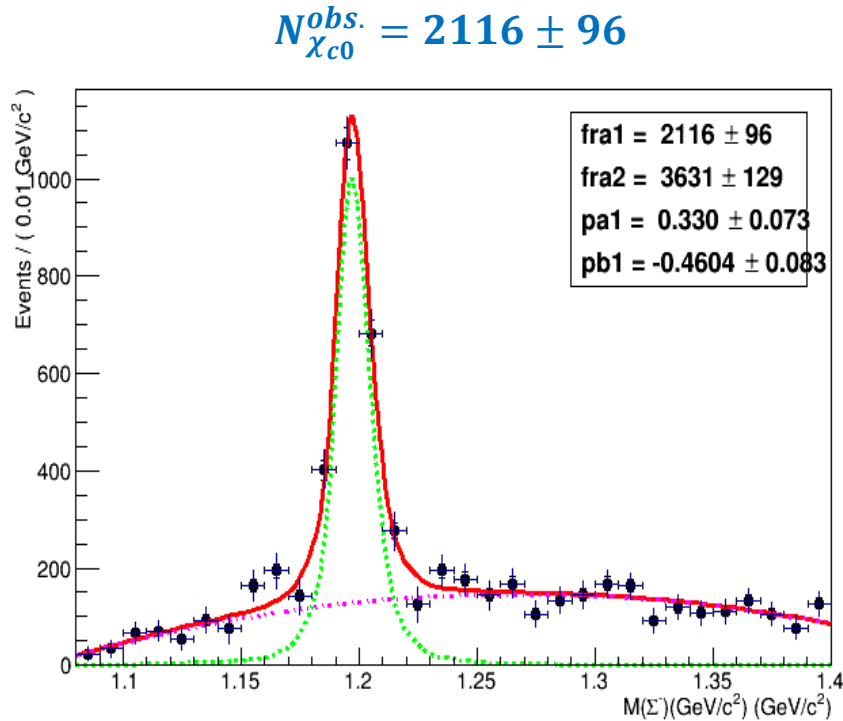
$$N_{\chi_{c2}}^{obs.} = 126 \pm 1296$$



**Problem:** To fit the parameters errors in weighted Extended Maximum likelihood fit

# Extraction of Signal

For  $\chi_{cJ} \rightarrow \Sigma^- \bar{\Sigma}^+$



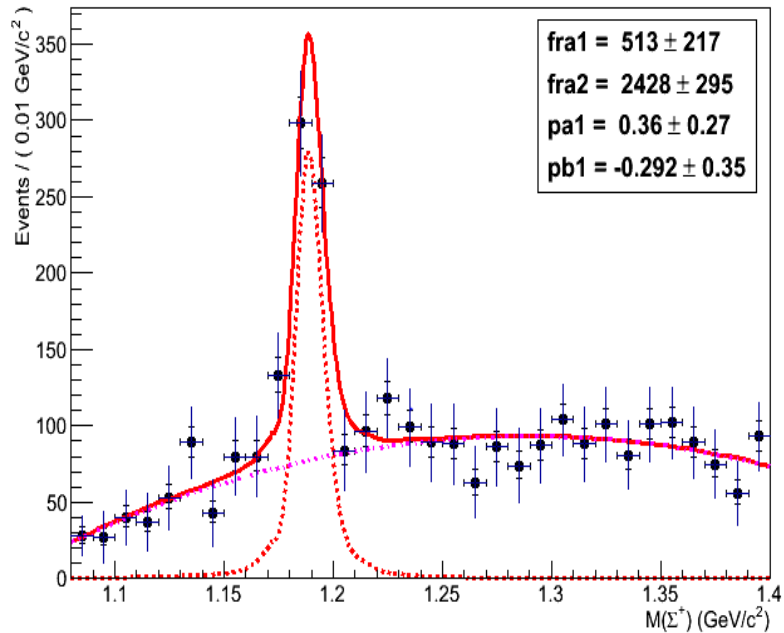
**Problem:** To fit the parameters errors in weighted Extended Maximum likelihood fit

- Version 5.34/14-2013
- Version 5.34/17-2014

# Comparison b/w different Root versions

For  $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$

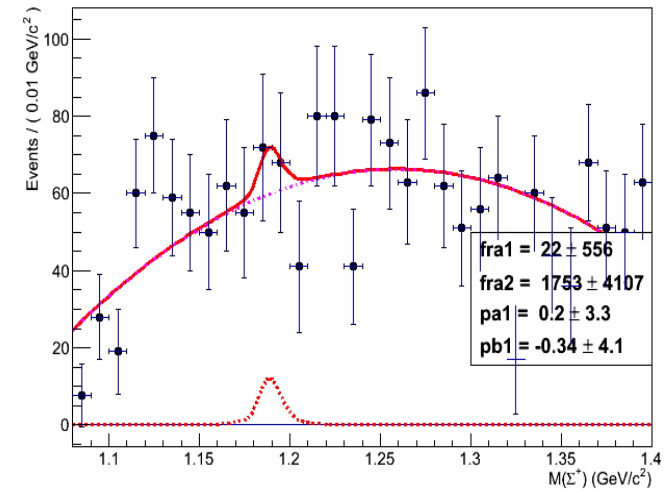
$$N_{\chi_{c0}}^{Obs.} = 513 \pm 217$$



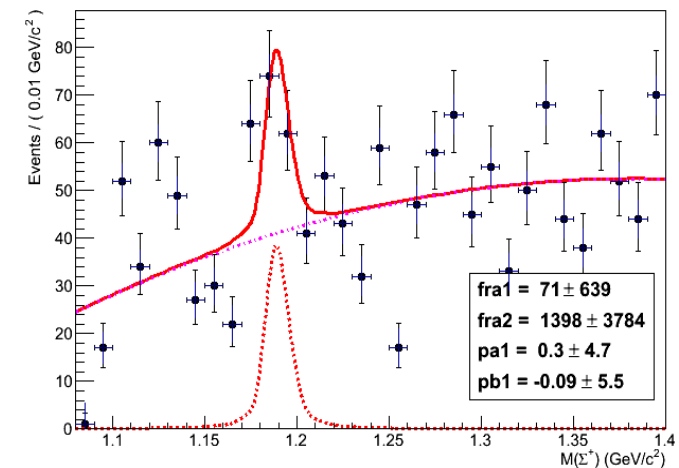
- Version 5.32/02 – 2012
- Version 5.32/03 – 2012
- Version 5.34/02 - 2012

**Problem:** To fit the parameters errors in weighted Extended Maximum likelihood fit

$$N_{\chi_{c1}}^{Obs.} = 22 \pm 556$$



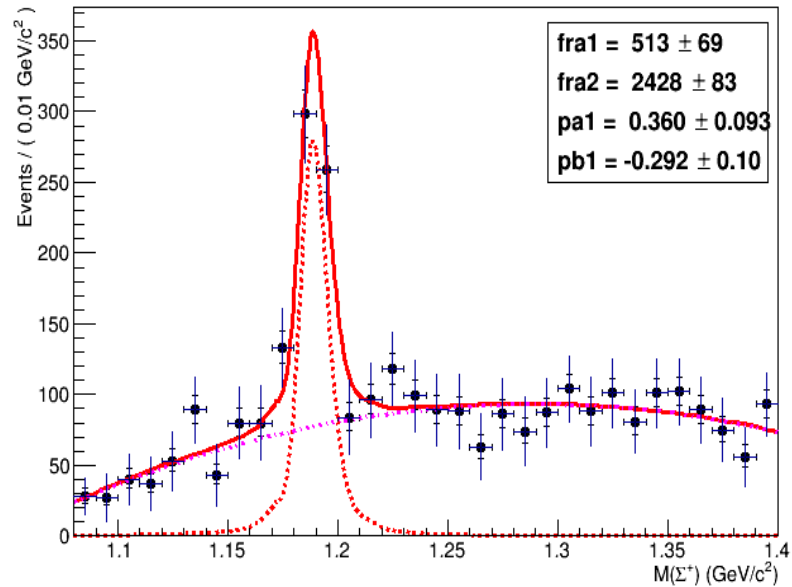
$$N_{\chi_{c2}}^{Obs.} = 71 \pm 639$$



# Extraction of Signal

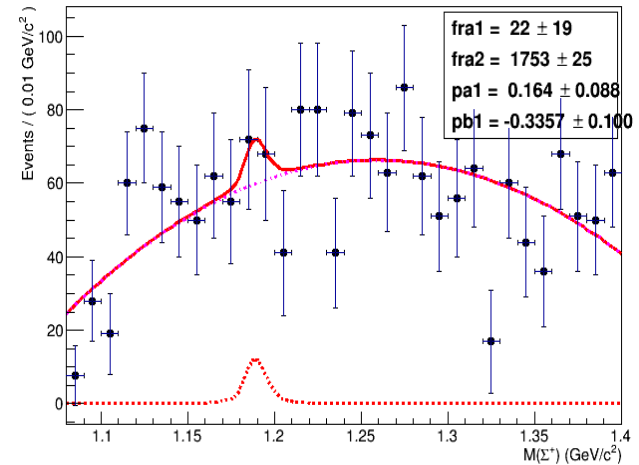
For  $\chi_{cJ} \rightarrow \Sigma^+ \bar{\Sigma}^-$

$$N_{\chi_{c0}}^{obs.} = 513 \pm 69$$

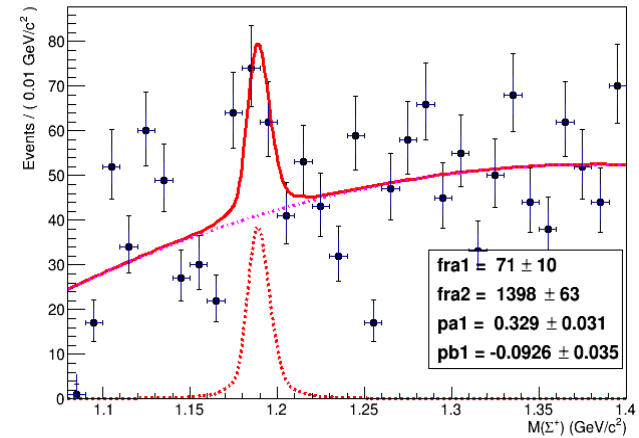


- Version 5.34/14-2013
- Version 5.34/17-2014

$$N_{\chi_{c1}}^{obs.} = 22 \pm 19$$



$$N_{\chi_{c2}}^{obs.} = 71 \pm 10$$



**Problem:** To fit the parameters errors in weighted Extended Maximum likelihood fit