Measurement of Branching Fractions of $\chi_{cJ} \to \Sigma^- \bar{\Sigma}^+$ with BES*III*

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Outline

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- **Data Analysis**
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Motivation

- Exclusive P-wave Charmonium states χ_{cJ} (J=0,1,2)→ $\Sigma^{-}\bar{\Sigma}^{+}$ into baryon-antibaryon pairs (B$\bar{B}$) are considered to be a favorable test of pQCD models and QCD based calculations.
- The χ_{cJ} meason 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.

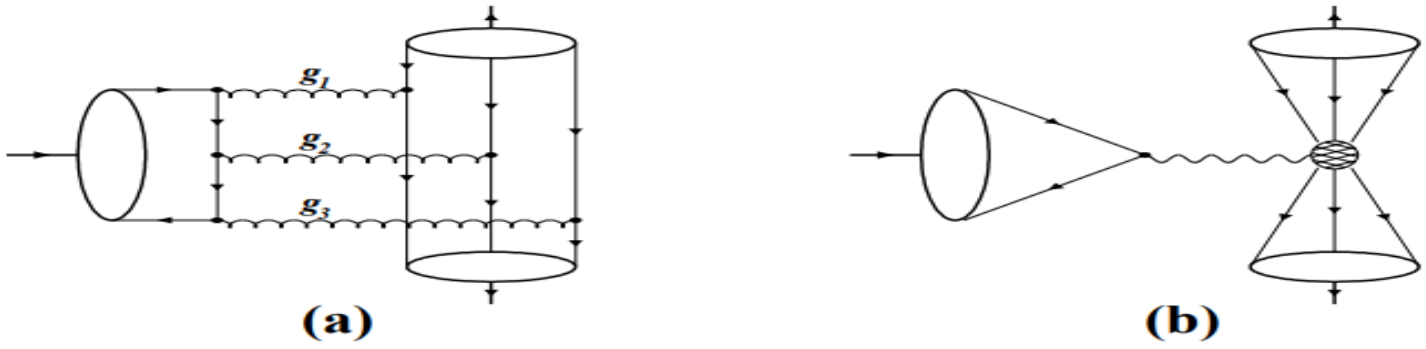


Figure: Feynman graphs for ψ(2S) decay into B$\bar{B}$ **(a)** Three-gluon contribution **(b)** Electromagnetic contribution.

- The large BFs of $\psi(2S) \rightarrow \gamma\chi_{cJ}$ make e^+e^-collision at the $\psi(2S)$ energy a very clean environment for χ_{cJ} investigation.
- The COM play an important role to describing these P-wave quarkonium decays and predictions of this model χ_{cJ} to pair of mesons and baryons are in agreement with earlier experiment.
- BF of $\chi_{cJ} \rightarrow \Sigma^+\bar{\Sigma}^-$ had been well measured by BesIII [1] and CLEO [2].
  [1].Phys. Rev. D 97, 052011, [2].PhysRevD.78.031101
- Experimentally, no measurements for $\chi_{cJ} \rightarrow \Sigma^-\bar{\Sigma}^+$ have been performed yet.

Data Sets

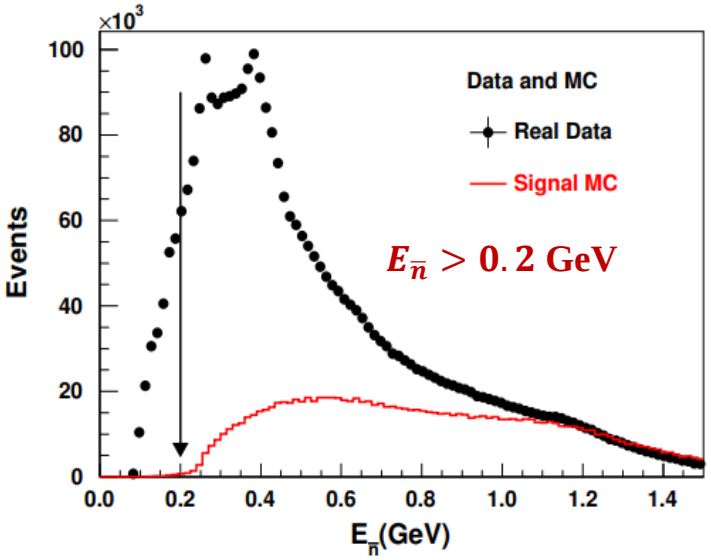
- **Boss Version:**
  - **Analysis Environment:** Boss 664p03
- **Data Sets:**
  - 107.0 M ψ' of 2009 year and 341.1 M ψ' of 2012 year
- **Signal MC :** Generated 1M Events.
  - **MC Sample:** Use KKMC Event Generator.
  - **Decay Chain :**
    - ✓ $\psi' \rightarrow \gamma\chi_{cJ}$ in *P2GC0*, *P2GC1* 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 ψ' MC, $\psi' \longrightarrow$ Anything

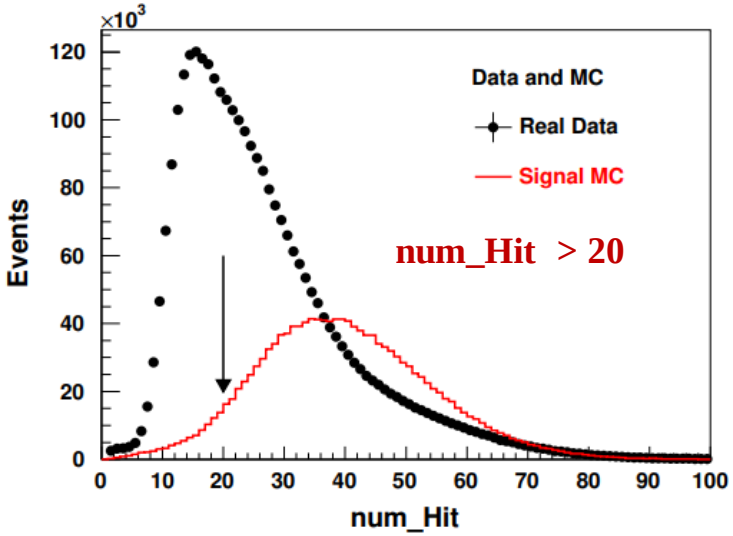
Pre-Selection

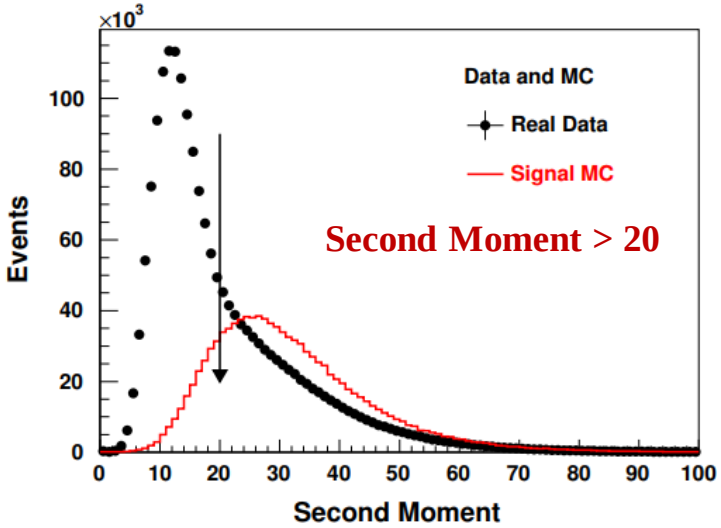
- **Good Charged Tracks:**
  - $|V_z| < 30cm$, $|V_r| < 10cm$ and $|\mathrm{Cos}\theta| \leq 0.93$, p>1.0 GeV/c
  - $N_{Good} = 2$ and $\sum Q_i = 0$.
- **PID : *dE/dX + TOF***
  - $Prob_\pi > Prob_p, Prob_\pi > Prob_K$ *and* $N_{\pi^-} = N_{\pi^+} = 1$
- **Good Neutral Tracks:**
  - $E_{barrel} > 80MeV; E_{endcap} > 80MeV$ (Phys. Rev. D **83**, 112009 – Published 27 June 2011)
  - Opening angle: $\theta_{(\gamma,Chge)} > 20^\circ$
  - At least 2 photons tracks $N_{shower} \geq 2$ (1 for Gamma, 1 for Anti-Neutron).
- **$\bar{n}$ candidate:**
  - The most energetic shower consider as $\bar{n}$ candidate.
  - Variable to the further selection for $\bar{n}$.
    - ✓ $E_{\bar{n}}$: Deposited energy of $\bar{n}$ in EMC; $E_{\bar{n}}$> 0.2 GeV.
    - ✓ Second Moment of $\bar{n}$ in EMC; Secmom>20
    - ✓ $\bar{n}$ number of hit in EMC within 40 degree cone; numHits>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 χ^2
- ✓ **Miss Neutron 3-momentum**
- ✓ **Miss Anti-Neutron Energy**
- ✓ **Mass constraint on $\bar{n}\pi^+$**
- ✓ **4-momentum constraint on ψ'.**

Comparison b/w Data and Signal MC

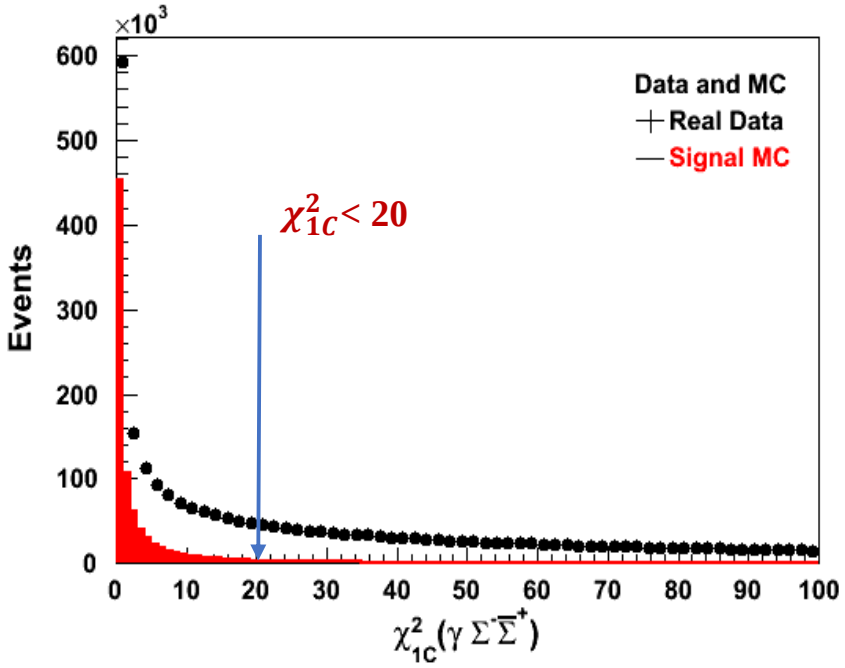




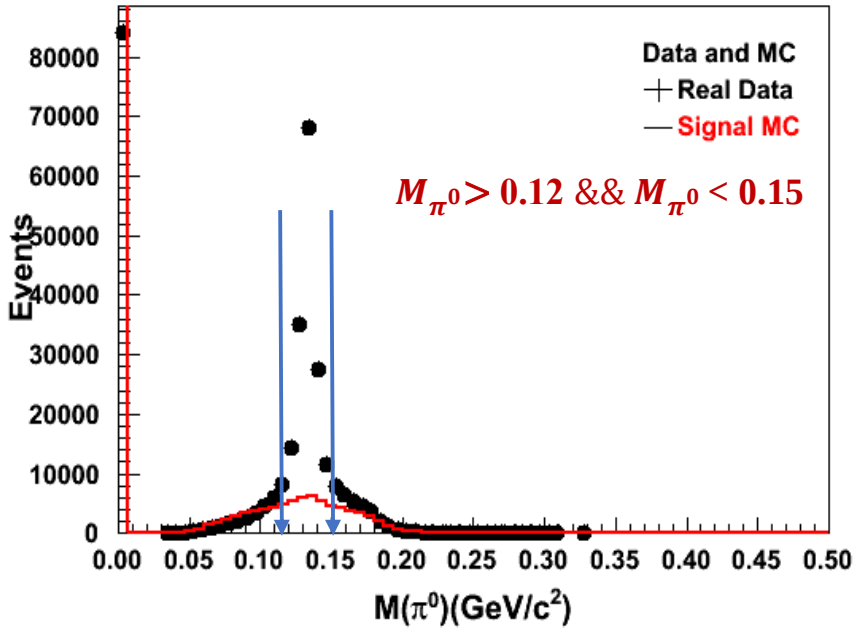


χ^2_{1C} and π^0Reconstruction

For Further Selection: Other criteria are used



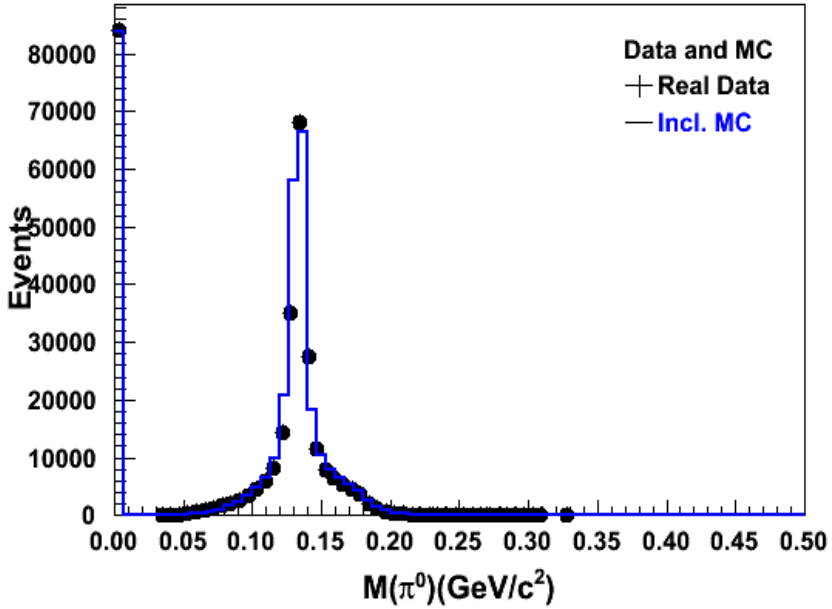
Reconstruct π^0 to Minimize the BKG

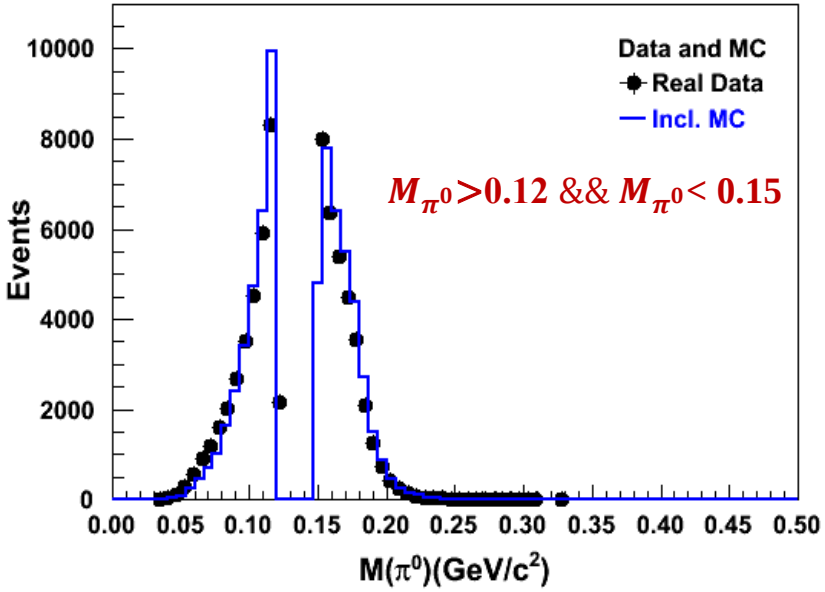


Study of Peaking and Non- Peaking Background in $\chi_{cJ} \rightarrow \Sigma^{-}\overline{\Sigma}^{+}$

Event Selection to Minimized the Background

- **Event Selection:** $\psi' \to \pi^o\pi^o J/\psi$:





Extracted BKG Channel In Inclusive MC

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Sigma^-\Sigma^+, \Sigma^- \to n\pi^-, \Sigma^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	2	10511	10511
1	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^0\bar{\Delta}^-\Delta^-, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	4	9966	20477
2	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^-\pi^-n, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	1	6526	27003
3	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to n\bar{n}\pi^+\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	0	4547	31550
4	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^-\Delta^-, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	5	2815	34365
5	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^-\Delta^0\bar{\Delta}^-, \Delta^0 \to n\pi^0, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	6	2526	36891
6	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \gamma\Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n\gamma$	10	2120	39011
7	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Sigma}^+\pi^0\Sigma^-, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	7	2088	41099
8	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{n}\pi^+\Delta^-, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	8	1896	42995
9	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Sigma}^+\Sigma^{*-}, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^{*-} \to \Lambda\pi^-, \Lambda \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	3	1615	44610
10	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^{++}\pi^0\Delta^{++}, \bar{\Delta}^{++} \to \bar{p}\pi^-, \Delta^{++} \to p\pi^+$	$\pi^-\bar{p}\pi^0\pi^0\pi^0\pi^+p$	11	1426	46036
11	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^-\pi^+\bar{\Delta}^0, \Delta^- \to n\pi^-, \bar{\Delta}^0 \to \bar{n}\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	9	1156	47192
12	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{n}\pi^-\Delta^+, \Delta^+ \to n\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	12	1101	48293

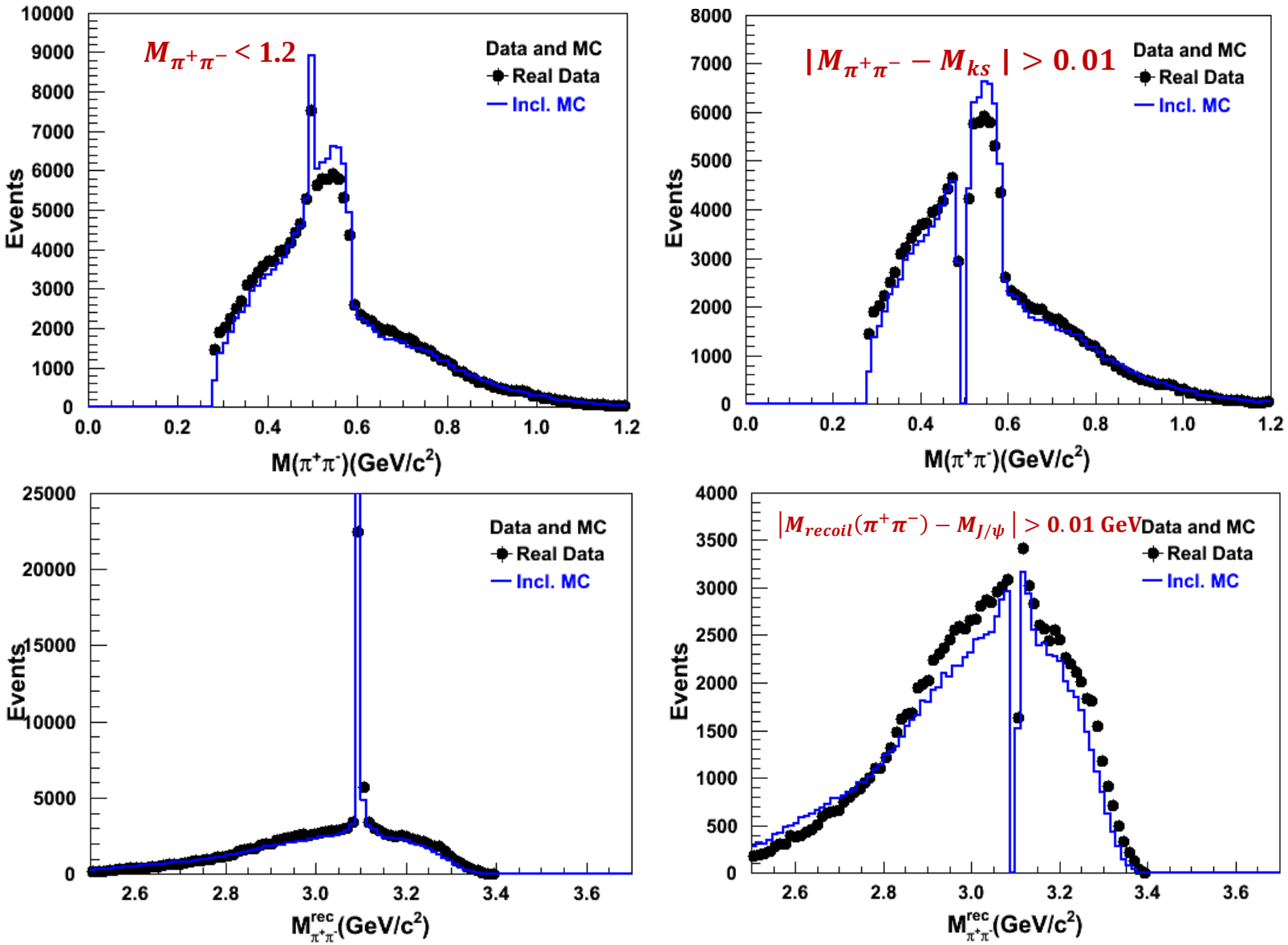
Minimized the Background

➢**Event Selection :** $\psi' \to \pi^+\pi^- J/\psi$

- ✓$M_{\pi^+\pi^-} < 1.2$
- ✓$|M_{\pi^+\pi^-} - M_{ks}| > 0.01\text{GeV}$
- ✓$|M_{recoil}(\pi^+\pi^-) - M_{J/\psi}| > 0.01\ \text{GeV}$

Extracted BKG Channel In Inclusive MC

decay chain
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to n\bar{n}$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{n}\pi^0 n$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \eta n\bar{n}, \eta \to \pi^0\pi^0\pi^0$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \eta\bar{n}n, \eta \to \gamma\gamma$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{\Delta}^0\pi^0\Delta^0, \bar{\Delta}^0 \to \bar{n}\pi^0, \Delta^0 \to n\pi^0$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \pi^0 n\bar{n}\pi^0$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to n\pi^0, \bar{\Lambda} \to \bar{n}\pi^0$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{\Delta}^0\Delta^0, \bar{\Delta}^0 \to \bar{n}\pi^0, \Delta^0 \to n\pi^0$
$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \gamma\bar{\Lambda}\Lambda, \bar{\Lambda} \to \bar{n}\pi^0, \Lambda \to n\pi^0$



Minimized the Background

➢**Event Selection :** $\psi' \to \Sigma^-\bar{\Sigma}^+$ **OR** $\pi^0\Sigma^-\bar{\Sigma}^+$

✓ $\chi^2_{\Sigma^+\bar{\Sigma}^-} > \chi^2_{\gamma\Sigma^+\bar{\Sigma}^-}$

Extracted BKG Channel In Inclusive MC

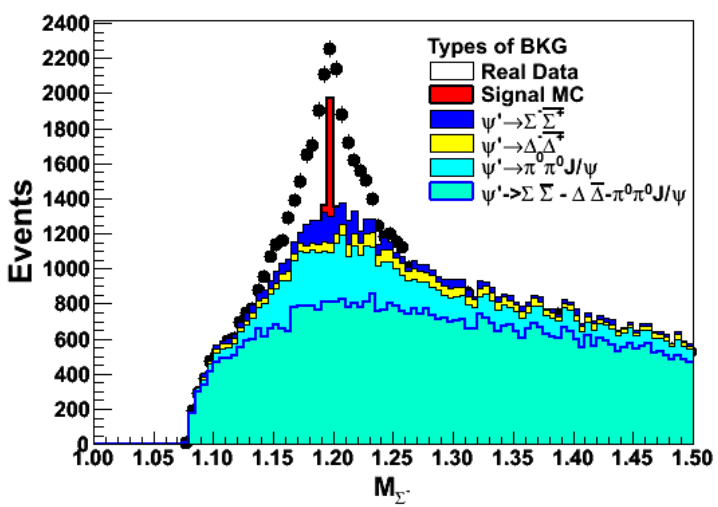
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \Sigma^-\bar{\Sigma}^+\pi^0, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n$	0	3148	3148
1	$\psi' \to \gamma\Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n\gamma$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

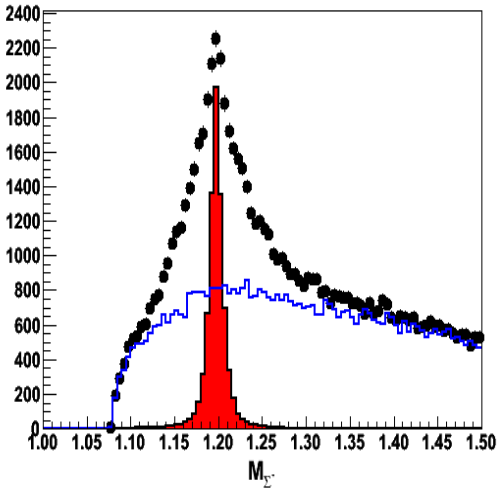
Background channel Extracted from Inclusive MC Sample

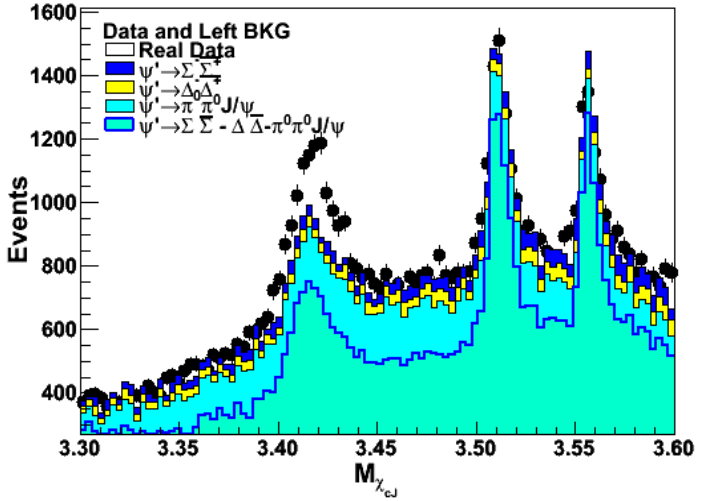
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	44	3616	3616
1	$\psi' \to \Delta^-\pi^0\bar{\Delta}^-, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$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

No.	decay chain	final states	iTopology	nEvt	nTot
30	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^-\bar{\Delta}^-\Delta^0, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^0 \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	37	270	22389
31	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^0\bar{\Delta}^{++}\Delta^{++}, \bar{\Delta}^{++} \to \bar{p}\pi^-, \Delta^{++} \to p\pi^+$	$\pi^-\bar{p}\pi^0\pi^0\pi^0\pi^+p$	229	263	22652
32	$\psi' \to \bar{\Delta}^-\pi^-n, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n$	225	257	22909
33	$\psi' \to J/\psi\eta, J/\psi \to \bar{\Delta}^-\pi^0\Delta^-, \eta \to \gamma\gamma, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	139	250	23159
34	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^0\pi^+\Delta^-, \bar{\Delta}^0 \to \bar{n}\pi^0, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	293	247	23406
35	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \pi^0\bar{\Sigma}^+\Sigma^-, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	174	247	23653
36	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \pi^0n\bar{n}$	$\pi^-\bar{n}\pi^0\pi^+n$	327	245	23898
37	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\pi^-\bar{n}\pi^+\pi^+n$	320	245	24143
38	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \eta\bar{n}n, \eta \to \pi^0\pi^0\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	130	243	24386
39	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to n\bar{n}\pi^+\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	55	241	24627
40	$\psi' \to \gamma\Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n\gamma$	186	239	24866
41	$\psi' \to J/\psi\eta, J/\psi \to \bar{\Delta}^-\pi^-n, \eta \to \gamma\gamma, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	146	230	25096
42	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \Sigma^-\bar{\Sigma}^+\pi^0, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	30	227	25323
43	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to n\pi^-\bar{\Delta}^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n\gamma$	215	224	25547
44	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to p\bar{\Lambda}K^{*-}, \bar{\Lambda} \to \bar{p}\pi^+, K^{*-} \to \bar{K}^0\pi^-$	$\pi^-\bar{p}K_L\pi^+\gamma p$	86	215	25762
45	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \phi K^{*-}K^{*+}, \phi \to K^+K^-, K^{*-} \to \bar{K}^0\pi^-, K^{*+} \to K^0\pi^+$	$\pi^-K^-K_LK_L\pi^+\gamma K^+$	69	204	25966
46	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^0K^{*+}K^{*-}, K^{*+} \to K^0\pi^+, K^{*-} \to \bar{K}^0\pi^-$	$\pi^-\pi^0K_LK_L\pi^+\gamma$	135	201	26167
47	$\psi' \to \Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n$	692	196	26363
48	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to n\pi^-\bar{\Delta}^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\pi^-\bar{n}\pi^+\pi^+n$	621	190	26553
49	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^+\pi^-\bar{\Delta}^0, \Delta^+ \to n\pi^+, \bar{\Delta}^0 \to \bar{n}\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	663	189	26742
50	$\psi' \to pK^{*-}\bar{\Lambda}, K^{*-} \to \bar{K}^0\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$\pi^-\bar{p}K_L\pi^+p$	78	187	26929
51	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \Delta^-\pi^0\bar{\Delta}^-, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	173	187	27116
52	$\psi' \to K^{*-}n\bar{\Sigma}^+, K^{*-} \to \bar{K}^0\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}K_L\pi^+n$	65	186	27302
53	$\psi' \to J/\psi\eta, J/\psi \to \bar{\Sigma}^+\Sigma^-, \eta \to \pi^0\pi^0\pi^0, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	103	186	27488
54	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \gamma J/\psi, J/\psi \to \bar{\Sigma}^+\Sigma^-, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	640	183	27671
55	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \Lambda\bar{\Sigma}^+\pi^-, \Lambda \to n\pi^0, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	5	179	27850
56	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \Lambda\bar{\Sigma}^+\pi^-, \Lambda \to n\pi^0, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	165	170	28020
57	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to p\bar{\Lambda}K^{*-}, \bar{\Lambda} \to \bar{p}\pi^+, K^{*-} \to \bar{K}^0\pi^-$	$\pi^-\bar{p}K_L\pi^+\gamma p$	502	169	28189
58	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \gamma J/\psi, J/\psi \to \Delta^-\pi^0\bar{\Delta}^-, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	71	168	28357
59	$\psi' \to J/\psi\eta, J/\psi \to n\bar{n}\pi^+\pi^-, \eta \to \gamma\gamma$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	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
nbar_match>10:              = 127562
gam_match>10:               = 95562
```

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
nbar_match>10:              = 117323
gam_match>10:               = 85754
```

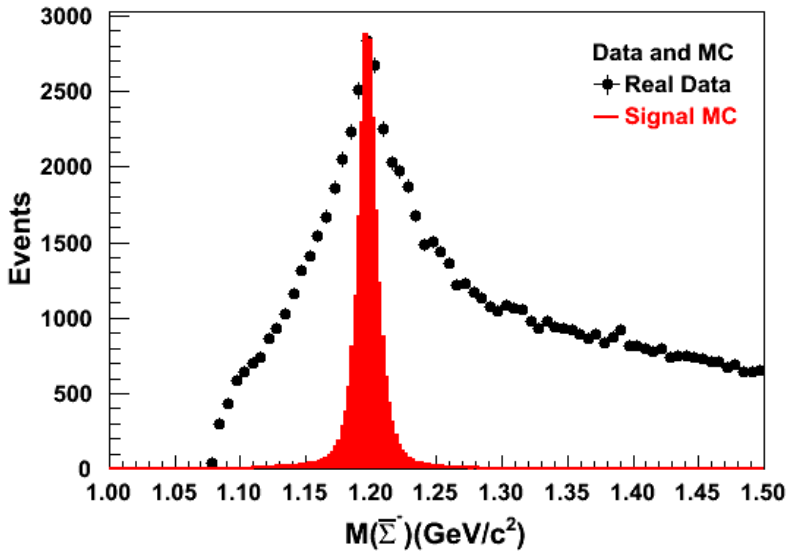
Tot. Signal MC Efficiency = 8.6 %

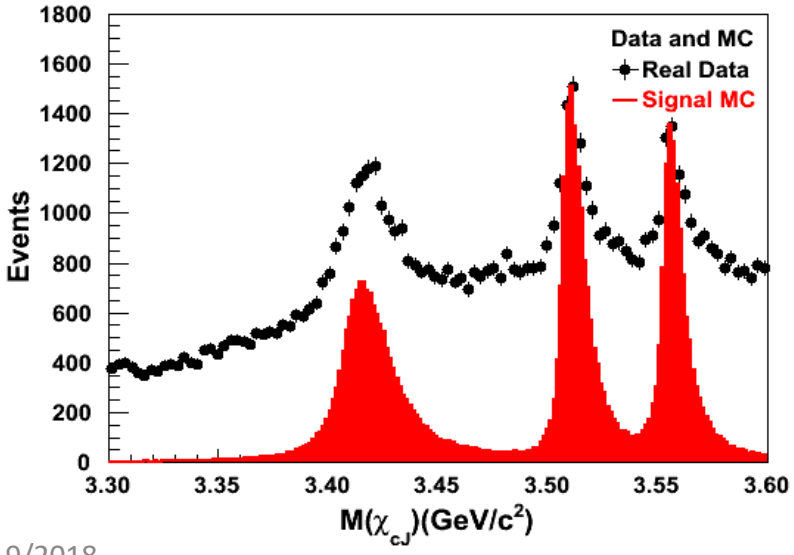
Rate of Cut Flow for chi_c2 After KM Fit

```
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
nbar_match>10:              = 103395
gam_match>10:               = 69679
```

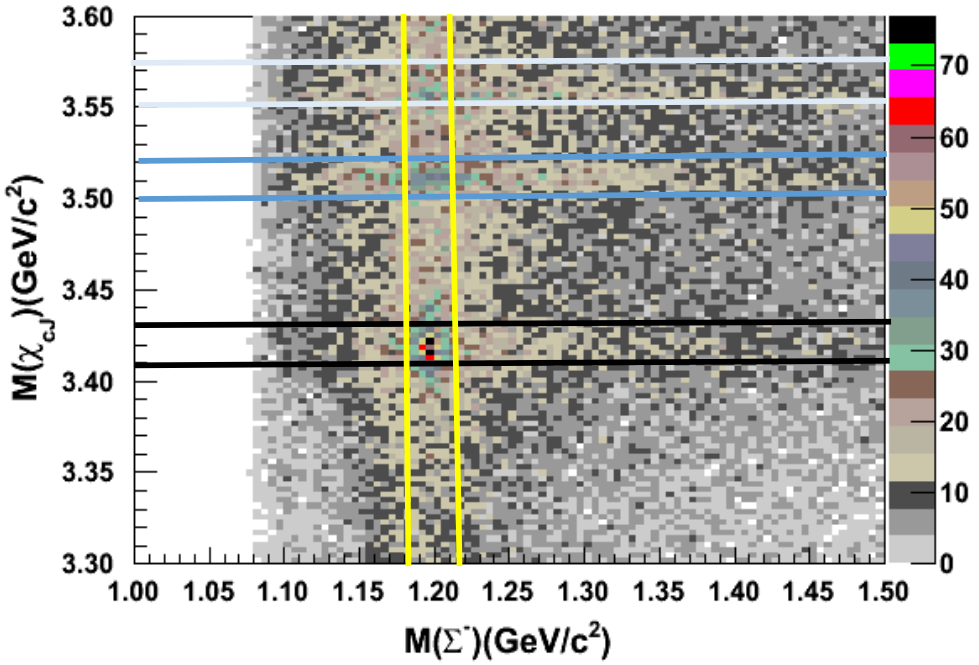
Tot. Signal MC Efficiency = 6.9 %

Invariant Mass of χ_{cJ} and Σ^-





2D Scatter Plot for Data

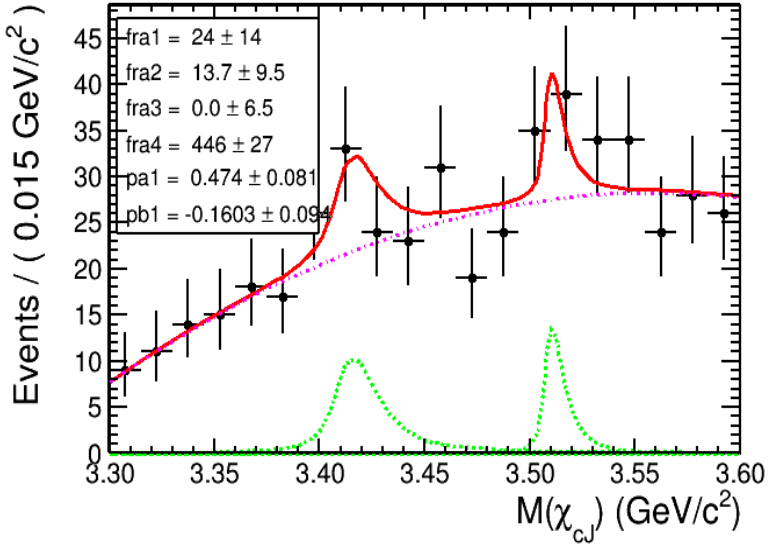


Measurement of Branching Fractions of $\chi_{cJ} \to \Sigma^{-}\overline{\Sigma}^{+}$

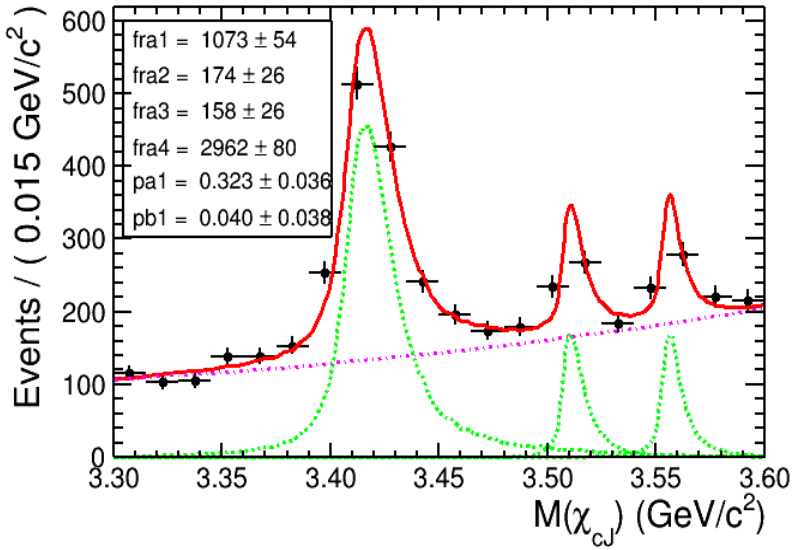
Extraction of Signal $\chi_{cJ} \to \Sigma^-\bar{\Sigma}^+$

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

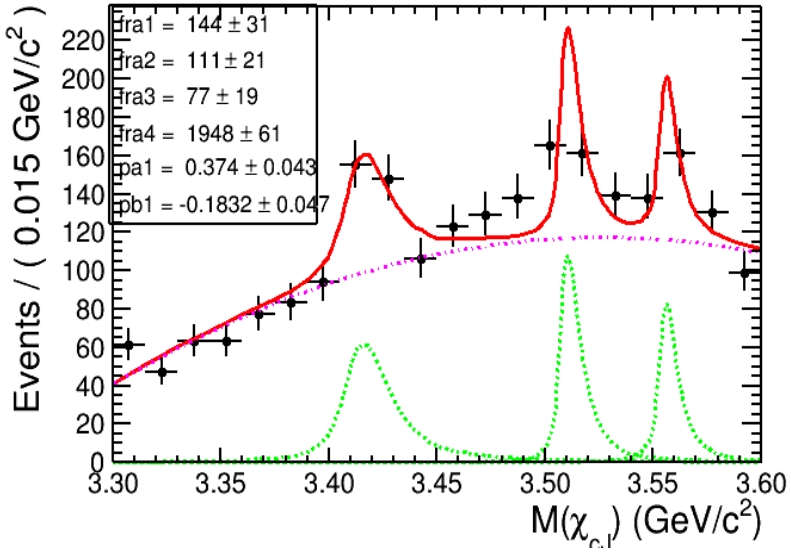
$\boldsymbol{M_{\Sigma^-}\epsilon(1.08, 1.09)}$



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

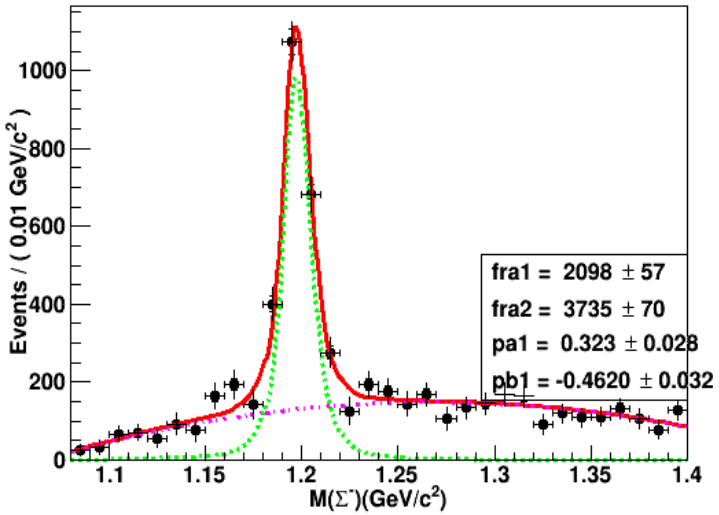


$\boldsymbol{M_{\Sigma^-}\epsilon(1.25, 1.26)}$

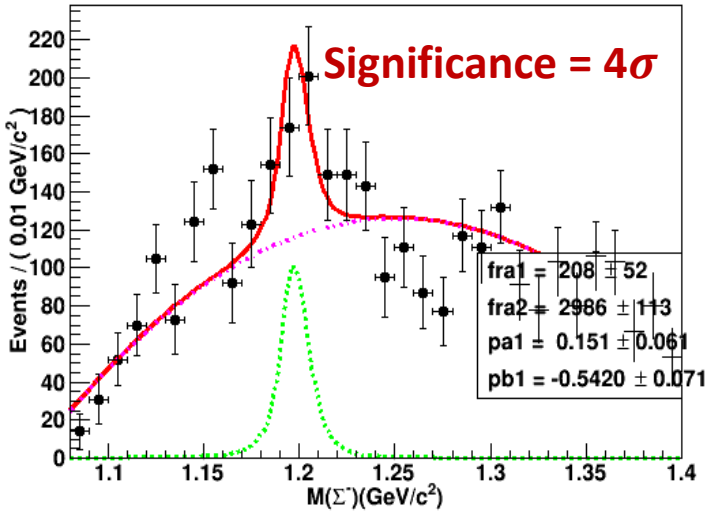


Fitting Result

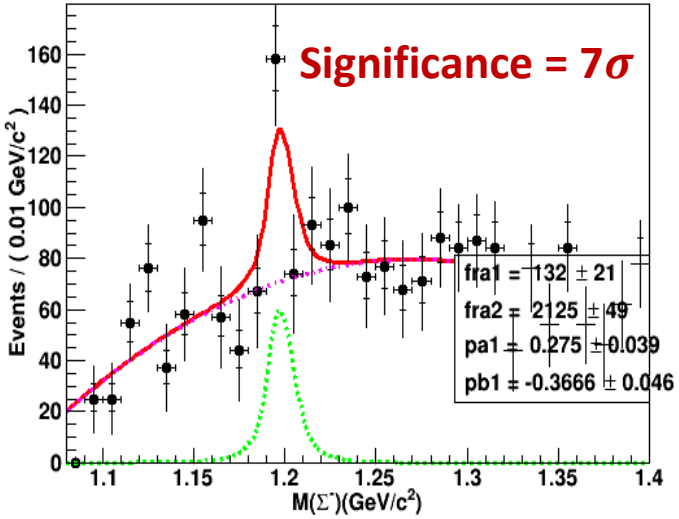
$N_{\chi_{c0}}^{obs.} = 2098 \pm 57$



$N_{\chi_{c1}}^{obs.} = 208 \pm 52$



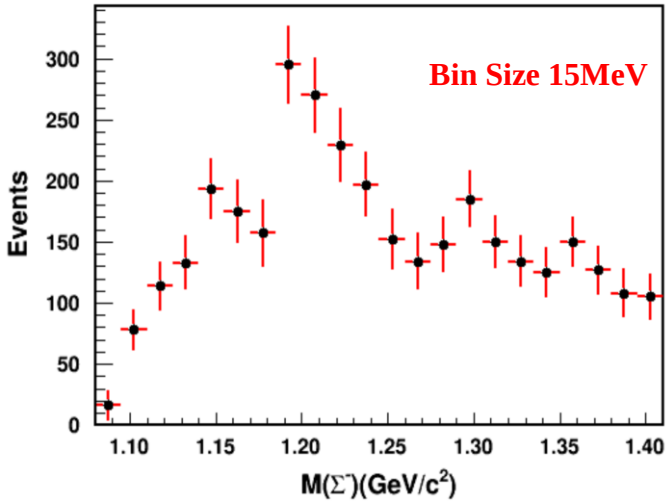
$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



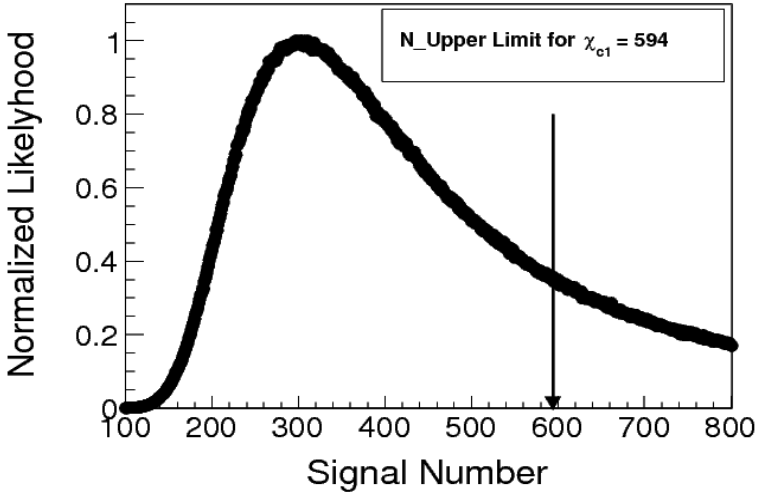
- Root Version 5.34/14 – 2013
- Root Version 5.34/19 – 2014
- Root Version 5.34/34 – 2015
- Root Version 5.34/36 – 2016

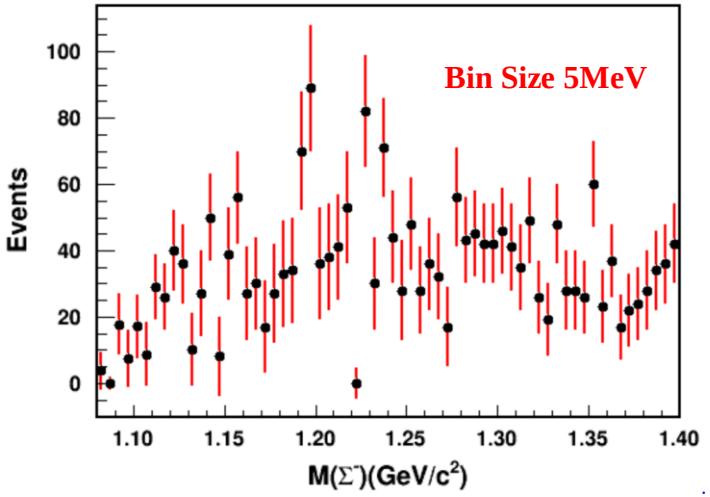
Resolve Problem: Fix the computation of fit parameters errors in χ^2goodness of fit, since root version 5.34 -14 till up to now.

Fitting Result for Upper Limit

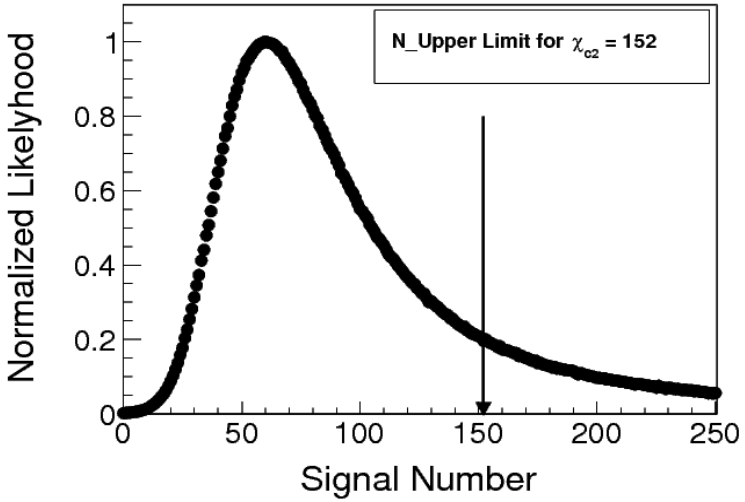


$N_{\chi_{c1}}^{obs.} = 594$ with 90% C.L





$N_{\chi_{c2}}^{obs.} = 152$ with 90% C.L



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

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

Number used to Calculate the Branching Fractions:

Channel	$\chi_{c0} \to \Sigma^- \bar{\Sigma}^+$	$\chi_{c1} \to \Sigma^- \bar{\Sigma}^+$	$\chi_{c2} \to \Sigma^- \bar{\Sigma}^+$
$N^{Obs.}_{fit}$	2098 ± 57	208 ± 52 594 (90%C.L)	132 ± 21 152 (90%C.L)
Efficiency(ϵ_J) %	9.6	8.6	6.97
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma \chi_{cJ})$%	9.99	9.55	9.11
$\mathfrak{B}(\Sigma^- \to n\,\pi^-)$%	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^- \bar{\Sigma}^+) = 4.90 \pm 0.13 * 10^{-4}$ in PDG $3.9 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^- \bar{\Sigma}^+) = 5.67 \pm 1.42 * 10^{-5} < 16.2 * 10^{-5}$ in PDG $< 6 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^- \bar{\Sigma}^+) = 4.65 \pm 0.74 * 10^{-5} < 5.6 * 10^{-5}$ in PDG $< 7 * 10^{-5}$

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

Channel	This work	PDG	Previous BESIII [6]	CLEO [5]	Theory	$\mathcal{B}_{prod}$
$\chi_{c0} \to \Sigma^+ \bar{\Sigma}^-$	$50.4 \pm 2.5 \pm 2.7$	39 ± 7	$43.7 \pm 4.0 \pm 2.8$	$32.5 \pm 5.7 \pm 4.3$	5.5-6.9 [3]	$4.99 \pm 0.24 \pm 0.24$
$\chi_{c1} \to \Sigma^+ \bar{\Sigma}^-$	$3.7 \pm 0.6 \pm 0.2$	< 6	$5.2 \pm 1.3 \pm 0.5 (< 8.3)$	< 6.5	3.3 [4]	$0.35 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \Sigma^+ \bar{\Sigma}^-$	$3.5 \pm 0.7 \pm 0.3$	< 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: M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D 97, 052011

Measurement of Systematic Uncertainty

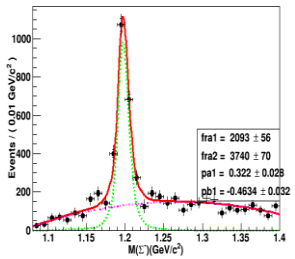
Systematic Uncertainty in $M(\pi^o)$ Rejection

Channel	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.115, 0.155]$GeV	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.125, 0.145]$GeV	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.115, 0.155]$GeV	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.125, 0.145]$GeV	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.115, 0.155]$GeV	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $M(\pi^o) \in [0.125, 0.145]$GeV
$N_{fit}^{Obs.}$	2093 ± 56	2102 ± 57	207 ± 52	209 ± 52	132 ± 21	132 ± 21
Efficiency(ϵ_J) %	9.3	9.9	8.3	8.9	6.65	7.32
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.55	9.55	9.11	9.11
$\mathfrak{B}(\Sigma^- \to n\,\pi^-)$%	99.848	99.848	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848	99.848	99.848

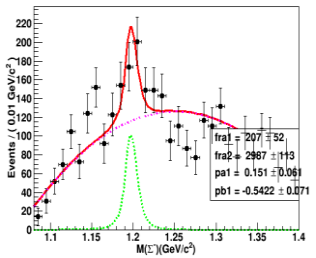
$M(\pi^o) \in [0.115, 0.155]$GeV

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 5.04 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.85 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.89 * 10^{-5}$

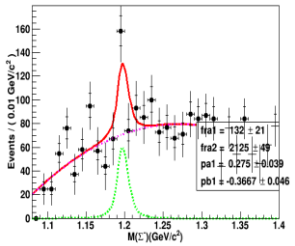
$N_{\chi_{c0}}^{obs.} = 2093 \pm 56$



$N_{\chi_{c1}}^{obs.} = 207 \pm 52$



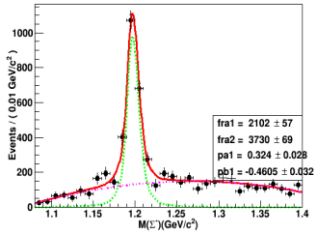
$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



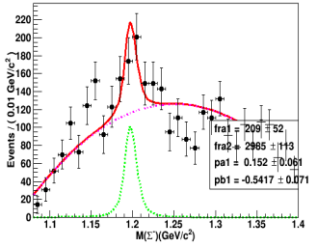
$M(\pi^o) \in [0.125, 0.145]$GeV

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 4.76 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.50 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.43 * 10^{-5}$

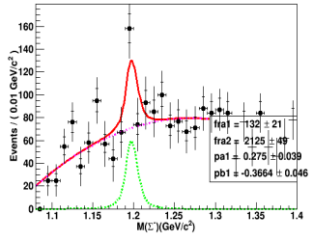
$N_{\chi_{c0}}^{obs.} = 2102 \pm 57$



$N_{\chi_{c1}}^{obs.} = 209 \pm 52$



$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



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

Channel	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.015$ GeV	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.02$GeV	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.015$ GeV	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.02$ GeV	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.015$ GeV	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M(\pi^-\pi^+) - 0.497\rvert > 0.02$GeV
$N_{fit}^{Obs.}$	2096 ± 56	2095 ± 56	208 ± 52	207 ± 52	132 ± 21	132 ± 21
Efficiency(ϵ_J) %	9.4	9.2	8.4	8.2	6.84	6.71
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.55	9.55	9.11	9.11
$\mathfrak{B}(\Sigma^- \to n\,\pi^-)$%	99.848	99.848	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848	99.848	99.848

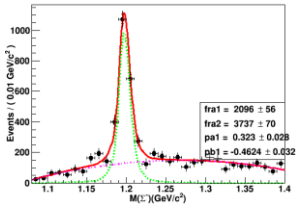
$|M(\pi^-\pi^+) - 0.497| > 0.015$ GeV

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 4.99 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.80 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.74 * 10^{-5}$

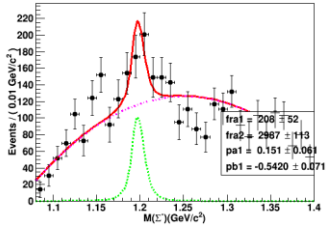
$|M(\pi^-\pi^+) - 0.497| > 0.02$ GeV

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 5.10 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.92 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.83 * 10^{-5}$

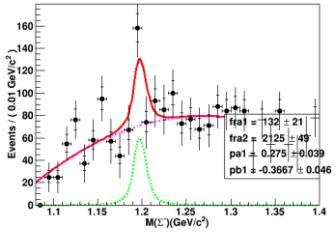
$N_{\chi_{c0}}^{obs.} = 2096 \pm 56$



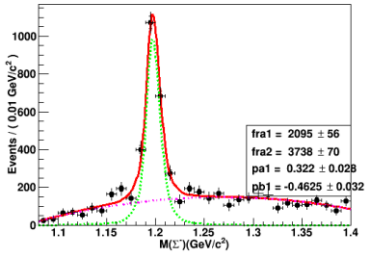
$N_{\chi_{c1}}^{obs.} = 208 \pm 52$



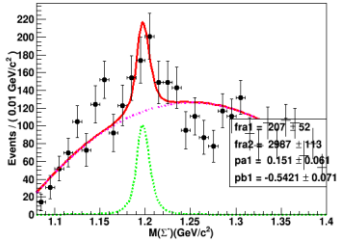
$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



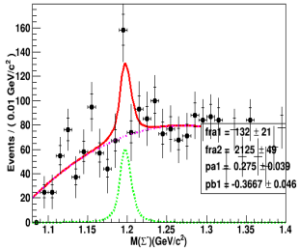
$N_{\chi_{c0}}^{obs.} = 2095 \pm 56$



$N_{\chi_{c1}}^{obs.} = 207 \pm 52$



$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



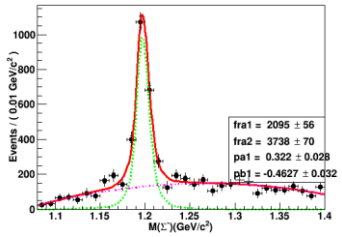
Systematic Uncertainty in $M_{rec}(\pi^+\pi^-)$Rejection

Channel	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.015$	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.02$	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.015$	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.02$	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.015$	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$ $\lvert M_{rec}(\pi^+\pi^-) - 3.097\rvert > 0.02$
$N_{fit}^{Obs.}$	2095 ± 56	2092 ± 56	208 ± 52	207 ± 52	132 ± 21	132 ± 21
Efficiency(ϵ_J) %	9.4	9.3	8.5	8.3	6.88	6.79
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.55	9.55	9.11	9.11
$\mathfrak{B}(\Sigma^- \to n\,\pi^-)$%	99.848	99.848	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848	99.848	99.848

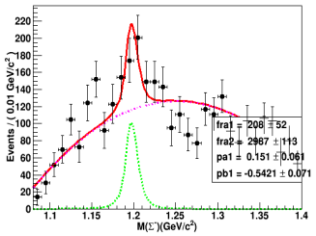
$|M_{rec}(\pi^+\pi^-) - 3.097| > 0.015$

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 4.99 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.74 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.71 * 10^{-5}$

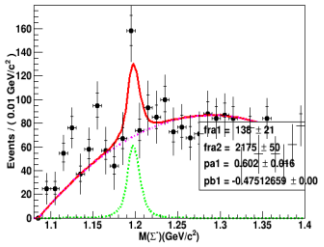
$N_{\chi_{c0}}^{obs.} = 2095 \pm 56$



$N_{\chi_{c1}}^{obs.} = 208 \pm 52$



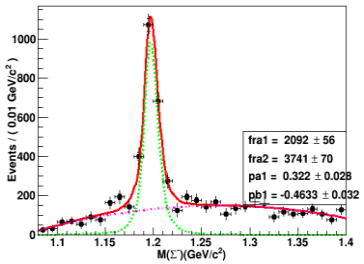
$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



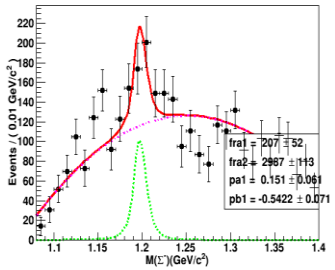
$|M_{rec}(\pi^+\pi^-) - 3.097| > 0.02$ GeV

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 5.04 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.85 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.78 * 10^{-5}$

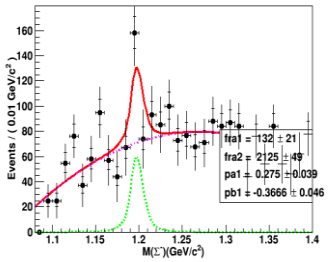
$N_{\chi_{c0}}^{obs.} = 2092 \pm 56$



$N_{\chi_{c1}}^{obs.} = 207 \pm 52$



$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



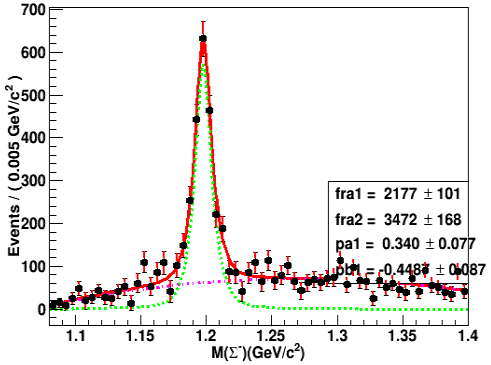
Systematic Uncertainty in Fitting Method

For χ_{c0}

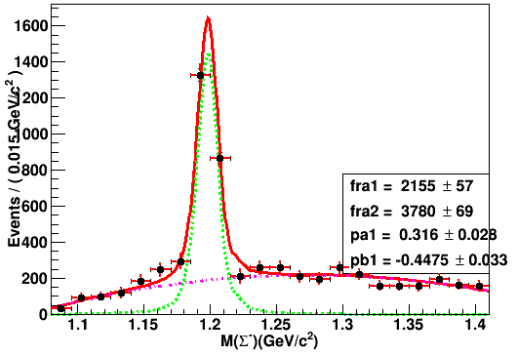
	Bin Size 5 MeV	Bin Size 15 MeV	Signal MC ⊗ Gaussian	2nd to 3rd Order poly.
Channel	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$
$N_{fit}^{Obs.}$	2177 ± 101	2155 ± 57	2097 ± 57	2053 ± 57
Efficiency(ϵ_J) %	9.6	9.6	9.6	9.6
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.99	9.99
$\mathfrak{B}(\Sigma^- \to$	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848

1. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 5.08 * 10^{-4}$
2. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 5.01 * 10^{-4}$
3. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 4.89 * 10^{-4}$
4. $\mathfrak{B}(\chi_{c0} \to \Sigma^-\bar{\Sigma}^+) = 4.79 * 10^{-4}$

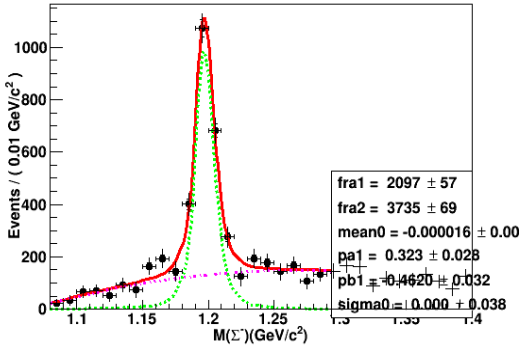
$N_{\chi_{c0}}^{obs.} = 2177 \pm 101$



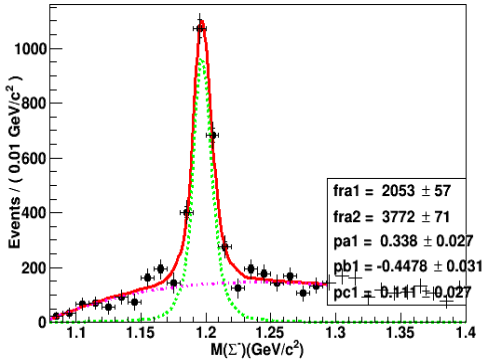
$N_{\chi_{c0}}^{obs.} = 2155 \pm 57$



$N_{\chi_{c0}}^{obs.} = 2097 \pm 57$



$N_{\chi_{c0}}^{obs.} = 2053 \pm 57$



The maximum difference on the No. of Signal Events are assigned as the systematic uncertainty in the fitting methods.

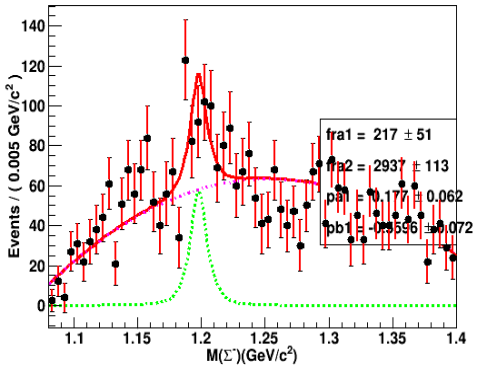
Systematic Uncertainty in Fitting Method

For χ_{c1}

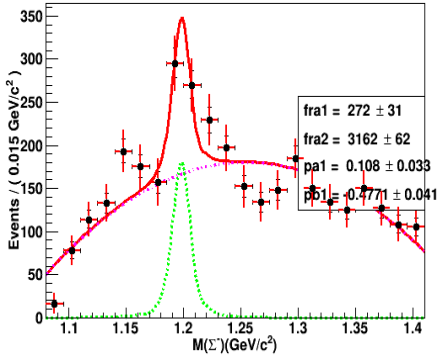
	Bin Size 5 MeV	Bin Size 15 MeV	Signal MC ⊗ Gaussian	2nd to 3rd Order poly.
Channel	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$
$N_{fit}^{Obs.}$	217 ± 51	272 ± 31	251 ± 57	154 ± 54
Efficiency(ϵ_J) %	8.6	8.6	8.6	8.6
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.99	9.99
$\mathfrak{B}(\Sigma^- \to$	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848

1. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 5.65 * 10^{-5}$
2. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 7.08 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 6.54 * 10^{-5}$
4. $\mathfrak{B}(\chi_{c1} \to \Sigma^-\bar{\Sigma}^+) = 4.01 * 10^{-5}$

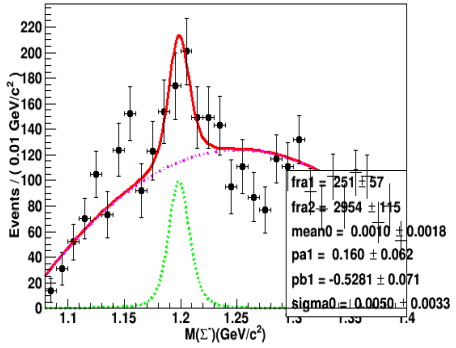
$N_{\chi_{c1}}^{obs.} = 217 \pm 51$



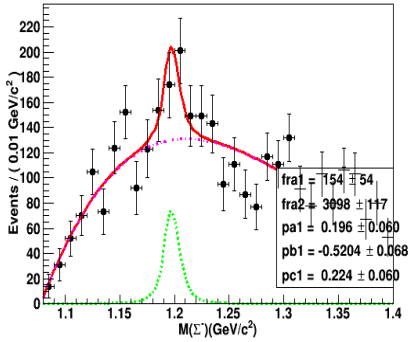
$N_{\chi_{c1}}^{obs.} = 272 \pm 31$



$N_{\chi_{c1}}^{obs.} = 251 \pm 57$



$N_{\chi_{c1}}^{obs.} = 154 \pm 54$



The maximum difference on the No. of Signal Events are assigned as the systematic uncertainty in the fitting methods.

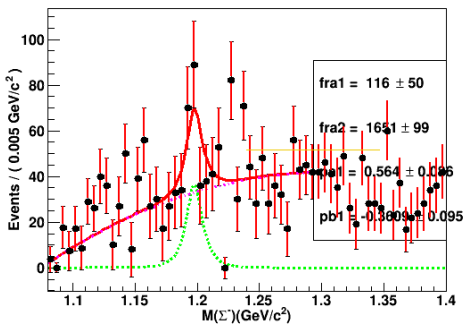
Systematic Uncertainty in Fitting Method

For χ_{c2}

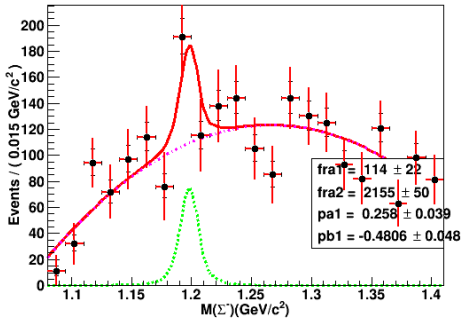
	Bin Size 5 MeV	Bin Size 15 MeV	Signal MC ⊗ Gaussian	2nd to 3rd Order poly.
Channel	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$	$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$
$N_{fit}^{Obs.}$	116 ± 50	114 ± 22	132 ± 21	103 ± 21
Efficiency(ϵ_J) %	6.97	6.97	6.97	6.97
$N_{\psi'_{data}}$ (M)	448.1	448.1	448.1	448.1
$\mathfrak{B}(\psi' \to \gamma\chi_{cJ})$%	9.99	9.99	9.99	9.99
$\mathfrak{B}(\Sigma^- \to$	99.848	99.848	99.848	99.848
$\mathfrak{B}(\bar{\Sigma}^+ \to \bar{n}\pi^+)$%	99.848	99.848	99.848	99.848

1. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 3.73 * 10^{-5}$
2. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 3.67 * 10^{-5}$
3. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 4.24 * 10^{-5}$
4. $\mathfrak{B}(\chi_{c2} \to \Sigma^-\bar{\Sigma}^+) = 3.31 * 10^{-5}$

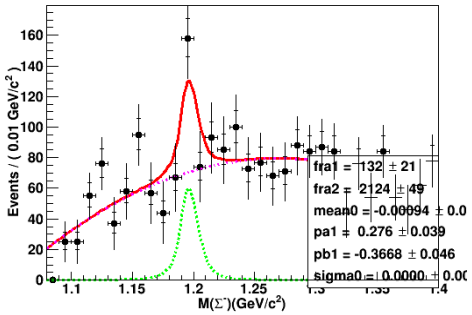
$N_{\chi_{c2}}^{obs.} = 116 \pm 50$



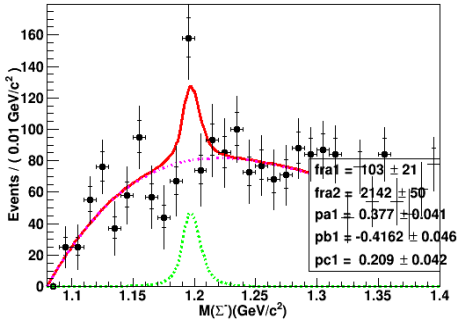
$N_{\chi_{c2}}^{obs.} = 114 \pm 22$



$N_{\chi_{c2}}^{obs.} = 132 \pm 21$



$N_{\chi_{c2}}^{obs.} = 103 \pm 21$



The maximum difference on the No. of Signal Events are assigned as the systematic uncertainty in the fitting methods.

Systematic Uncertainty

Sources	Comments	Systematic Uncertainty (%)		
Charged Pions ($\pi^+\pi^-$)	1.4 per charged track	2.8 (By Dr.Xiaorong)		
Neutral particle (γ)	Ref: PhysRevD.83.112009	1.0		
Nbar ($\bar{n}$) Selections	Select control sample of $J/\psi \to \Sigma^{*-}\bar{\Sigma}^{+}$	5.0 (By Dr.Xiaorong)		
Kinematic Fit				
π^omass Window	Varying the region [0.12, 0.15] →[0.115, 0.155] (OR) [0.125, 0.145] GeV	χ_{c0}	χ_{c1}	χ_{c2}
		2.9	3.2	5.2
$\pi^+\pi^-$mass Window	Varying the region → 0.01 GeV → 0.015 GeV (OR) 0.02 GeV	4.1	4.4	3.9
Recoil $\pi^+\pi^-$ mass Window	Varying the region → 0.01 GeV → 0.015 GeV (OR) 0.02 GeV	2.9	3.2	2.8
Fitting Method	Using different bin size of χ_{cJ}mass spectrum 5 MeV (OR) 15 MeV	3.7	24.9	21.1
	By Changing MC to (Signal MC ⊗ Gaussian)	2.0	15.3	8.8
	By Changing 2nd Order Chebychev polynomial to 3rd order poly. function.	0.6	29.3	28.8
Branching Fraction	Uncertainty from $\psi(3686) \to \gamma\chi_{cJ}$	2.4	3.3	3.4
Number of $\psi(3686)$	Ref: Chin. Phys. C 42, 023001 (2018)	0.6		
Total		9.6	42.4	38.1

TABLE: Summary of Relative Systematic Uncertainties for the measurement of $\chi_{cJ} \to \Sigma^-\bar{\Sigma}^+$

Summary

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

Channel	This Work	PDG	Previous BESIII [1]		Theory
			$\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$	$\chi_{cJ} \to \Sigma^0\bar{\Sigma}^0$	
$\chi_{c0} \to \Sigma^-\bar{\Sigma}^+$	$(4.90 \pm 0.13 \pm 0.47) * 10^{-4}$	$(3.9 \pm 0.7) * 10^{-4}$	$(5.04 \pm 0.25 \pm 0.27) * 10^{-4}$	$(4.8 \pm 1.8 \pm 3.5) * 10^{-4}$	$(0.55 - 0.69) * 10^{-4}$ [2]
$\chi_{c1} \to \Sigma^-\bar{\Sigma}^+$	$(5.67 \pm 1.42 \pm 0.24) * 10^{-5}$ $< 16.2 * 10^{-5}$	$< 6 * 10^{-5}$	$(3.7 \pm 0.6 \pm 0.2) * 10^{-5}$	$(4.3 \pm 0.5 \pm 0.3) * 10^{-5}$	$3.3 * 10^{-5}$ [3]
$\chi_{c2} \to \Sigma^-\bar{\Sigma}^+$	$(4.65 \pm 0.74 \pm 0.14) * 10^{-5}$ $< 5.6 * 10^{-5}$	$< 7 * 10^{-5}$	$(3.5 \pm 0.7 \pm 0.3) * 10^{-5}$	$(3.9 \pm 0.5 \pm 0.3) * 10^{-5}$	$5.0 * 10^{-5}$ [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

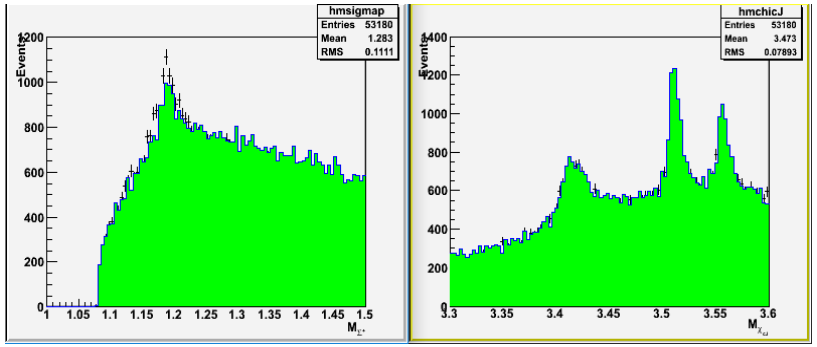
Measurement of Branching Fractions of $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$

Background channel Extracted from Inclusive MC Sample

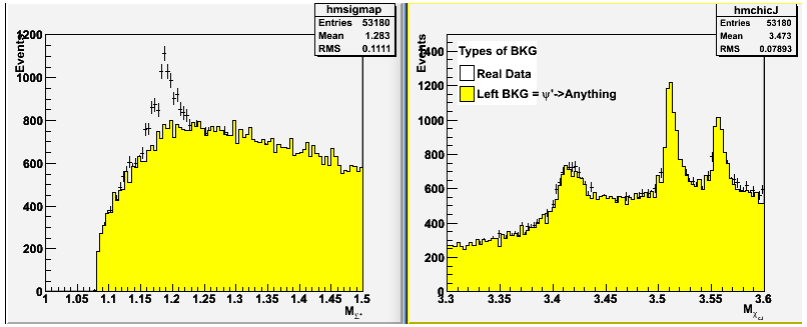
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^-\bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	17	1716	1716
1	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^-\Delta^-\pi^0, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	32	1292	3008
2	$\psi' \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^+n$	33	1262	4270
3	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to n\bar{n}\pi^+\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	11	1177	5447
4	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	70	897	6344
5	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to n\bar{n}$	$\pi^-\bar{n}\pi^+n$	15	652	6996
6	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^+\Delta^-\bar{\Delta}^0, \Delta^- \to n\pi^-, \bar{\Delta}^0 \to \bar{n}\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	4	529	7525
7	$\psi' \to \Delta^-\pi^0\bar{\Delta}^-, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n$	80	410	7935
8	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to n\pi^-\bar{\Delta}^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	200	379	8314
9	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to n\pi^+\bar{\Delta}^+, \bar{\Delta}^+ \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	90	375	8689
10	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{n}n\eta, \eta \to \gamma\gamma$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	122	368	9057
11	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to \Delta^-\pi^+\bar{n}, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	280	339	9396
12	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^0\Sigma^+\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	82	338	9734
13	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \eta n\bar{n}, \eta \to \pi^-\pi^+\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	116	289	10023
14	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to \pi^0\Delta^-\bar{\Delta}^-, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	9	284	10307
15	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Sigma^0\bar{\Sigma}^-\pi^+, \Sigma^0 \to \gamma\Lambda, \bar{\Sigma}^- \to \bar{n}\pi^-, \Lambda \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	104	265	10572
16	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{\Delta}^-\Delta^-\pi^0, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\pi^-\bar{n}\pi^0\pi^+\pi^+n$	118	246	10818
17	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \pi^0\bar{n}n$	$\pi^-\bar{n}\pi^0\pi^+n$	170	235	11053
18	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to n\bar{n}\pi^+\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	273	232	11285
19	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Delta^{++}\bar{\Delta}^{++}\pi^0, \Delta^{++} \to p\pi^+, \bar{\Delta}^{++} \to \bar{p}\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^0\pi^+p$	236	228	11513
20	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \Sigma^+\bar{\Sigma}^-\pi^0, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	43	227	11740
21	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \Sigma^+\bar{\Sigma}^-\pi^0, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	40	227	11967
22	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Sigma}^-\Sigma^{*+}, \bar{\Sigma}^- \to \bar{n}\pi^-, \Sigma^{*+} \to \Lambda\pi^+, \Lambda \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	27	221	12188
23	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{n}n\eta, \eta \to \pi^0\pi^0\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	25	217	12405
24	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K^{*+}\Lambda\bar{p}, K^{*+} \to K^0\pi^+, \Lambda \to p\pi^-$	$\pi^-\bar{p}K_L\pi^+\gamma p$	215	214	12619
25	$\psi' \to J/\psi\eta, J/\psi \to \bar{n}\Delta^-\pi^+, \eta \to \gamma\gamma, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	81	212	12831
26	$\psi' \to \Sigma^+\pi^0\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n$	343	211	13042
27	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^+\Delta^0\bar{\Delta}^+, \Delta^0 \to n\pi^0, \bar{\Delta}^+ \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	0	203	13245
28	$\psi' \to \Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \to \Lambda\pi^+, \bar{\Sigma}^{*-} \to \bar{\Lambda}\pi^-, \Lambda \to n\pi^0, \bar{\Lambda} \to \bar{n}\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	14	196	13441
29	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K^{*-}\pi^0K^{*+}, K^{*-} \to \bar{K}^0\pi^-, K^{*+} \to K^0\pi^+$	$\pi^-\pi^0K_LK_L\pi^+\gamma$	209	187	13628

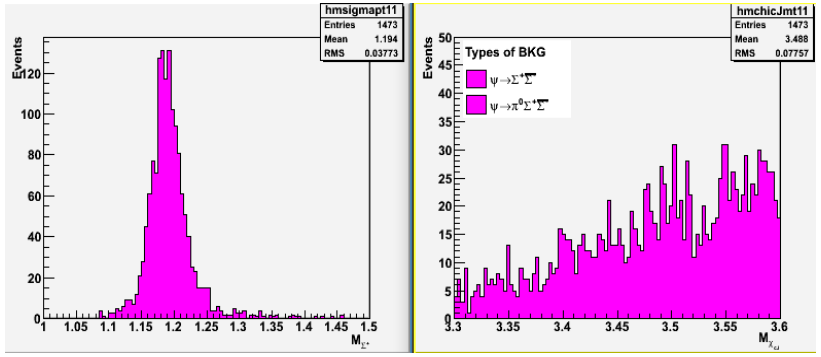
No.	decay chain	final states	iTopology	nEvt	nTot
30	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K^{*+}K^{*-}\phi, K^{*+} \to K^0\pi^+, K^{*-} \to K^0\pi^-, \phi \to K^+K^-$	$\pi^-K^-K_LK_L\pi^+\gamma K^+$	79	180	13808
31	$\psi' \to J/\psi\eta, J/\psi \to \Delta^-\pi^0\bar{\Delta}^-, \eta \to \gamma\gamma, \Delta^- \to n\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	206	178	13986
32	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \gamma\Sigma^-\bar{\Sigma}^+, \Sigma^- \to n\pi^-, \bar{\Sigma}^+ \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n\gamma$	114	174	14160
33	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \gamma\Sigma^+\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n\gamma$	195	174	14334
34	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Delta}^-\Delta^0\pi^-, \bar{\Delta}^- \to \bar{n}\pi^+, \Delta^0 \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	164	168	14502
35	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \Lambda\bar{\Sigma}^-\pi^+, \Lambda \to n\pi^0, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	102	167	14669
36	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \Delta^-\bar{n}\pi^+, \Delta^- \to n\pi^-$	$\pi^-\pi^-\bar{n}\pi^+\pi^+n$	78	165	14834
37	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^{*+}\Lambda\bar{p}, K^{*+} \to K^0\pi^+, \Lambda \to p\pi^-$	$\pi^-\bar{p}K_L\pi^+\gamma p$	283	164	14998
38	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \pi^+\Delta^-\bar{n}, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^+n\gamma$	342	155	15153
39	$\psi' \to \bar{n}n\eta', \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	12	154	15307
40	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \bar{\Delta}^0\pi^0\Delta^0, \bar{\Delta}^0 \to \bar{n}\pi^0, \Delta^0 \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	228	150	15457
41	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Sigma}^+\Sigma^-, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n$	296	148	15605
42	$\psi' \to J/\psi\eta, J/\psi \to n\bar{n}\pi^+\pi^-, \eta \to \gamma\gamma$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	44	147	15752
43	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \bar{\Sigma}^+\Sigma^-\pi^0, \bar{\Sigma}^+ \to \bar{n}\pi^+, \Sigma^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^0\pi^+n$	261	142	15894
44	$\psi' \to \pi^+\bar{\Delta}^0\Delta^-, \bar{\Delta}^0 \to \bar{n}\pi^0, \Delta^- \to n\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n$	558	142	16036
45	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \Sigma^0\pi^+\bar{\Sigma}^-, \Sigma^0 \to \gamma\Lambda, \bar{\Sigma}^- \to \bar{n}\pi^-, \Lambda \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	111	141	16177
46	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Lambda\pi^+\bar{\Sigma}^-, \Lambda \to n\pi^0, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	103	141	16318
47	$\psi' \to \Delta^0\bar{\Delta}^+\pi^+, \Delta^0 \to n\pi^0, \bar{\Delta}^+ \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n$	746	140	16458
48	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi, J/\psi \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	548	138	16596
49	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to n\bar{n}\pi^+\pi^-$	$\pi^-\pi^-\bar{n}\pi^+\pi^+n$	22	136	16732
50	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \pi^+\Sigma^0\bar{\Sigma}^-, \Sigma^0 \to \gamma\Lambda, \bar{\Sigma}^- \to \bar{n}\pi^-, \Lambda \to n\pi^0$	$\pi^-\bar{n}\pi^0\pi^+n\gamma\gamma$	225	136	16868
51	$\psi' \to J/\psi\eta, J/\psi \to \Sigma^+\bar{\Sigma}^-, \eta \to \gamma\gamma, \Sigma^+ \to n\pi^+, \bar{\Sigma}^- \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^+n\gamma\gamma$	520	133	17001
52	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to n\eta'\bar{n}, \eta' \to \rho^0\gamma, \rho^0 \to \pi^+\pi^-$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n\gamma$	420	133	17134
53	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \bar{p}\Lambda K^{*+}, \Lambda \to p\pi^-, K^{*+} \to K^0\pi^+$	$\pi^-\bar{p}K_L\pi^+\gamma p$	38	132	17266
54	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to \Delta^0\pi^+\bar{\Delta}^+, \Delta^0 \to n\pi^0, \bar{\Delta}^+ \to \bar{n}\pi^-$	$\pi^-\bar{n}\pi^0\pi^+n\gamma$	411	130	17396
55	$\psi' \to \Lambda\bar{p}K^{*+}, \Lambda \to p\pi^-, K^{*+} \to K^0\pi^+$	$\pi^-\bar{p}K_L\pi^+p$	47	128	17524
56	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to \pi^+\pi^-\pi^0K^+K^-$	$\pi^-K^-\pi^0\pi^0\pi^0\pi^+K^+$	115	128	17652
57	$\psi' \to J/\psi\pi^0\pi^0, J/\psi \to p\bar{p}\pi^+\pi^-$	$\pi^-\bar{p}\pi^0\pi^0\pi^+p$	39	125	17777
58	$\psi' \to \bar{\Delta}^-\pi^-n, \bar{\Delta}^- \to \bar{n}\pi^+$	$\pi^-\bar{n}\pi^+n$	109	122	17899
59	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to b_1^0\bar{n}n, b_1^0 \to \omega\pi^0, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\bar{n}\pi^0\pi^0\pi^+n\gamma$	318	120	18019

Data with Inclusive MC after All sections



Categorization of the BKG In Inclusive MC

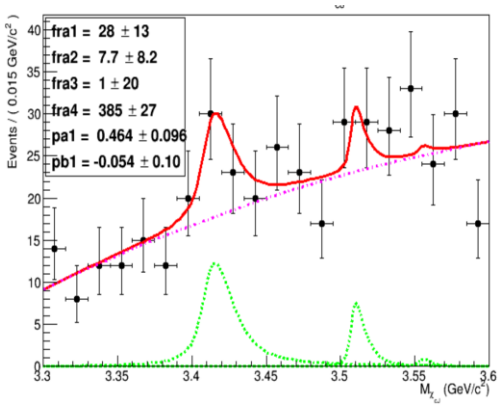




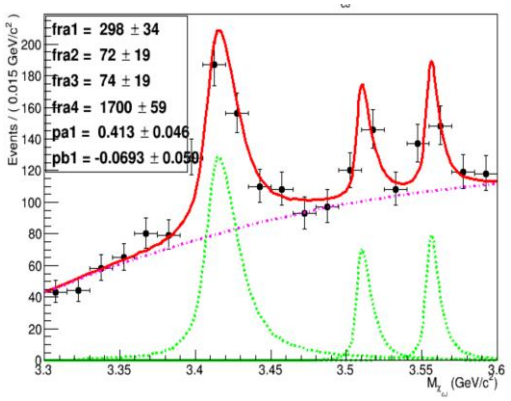
Extraction of Signal for $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$

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

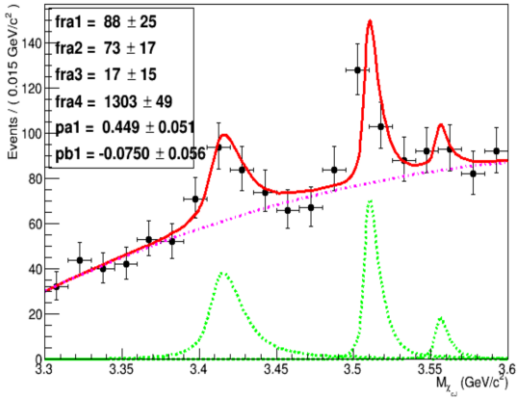
$M_{\Sigma^+}\epsilon(1.08, 1.09)$



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

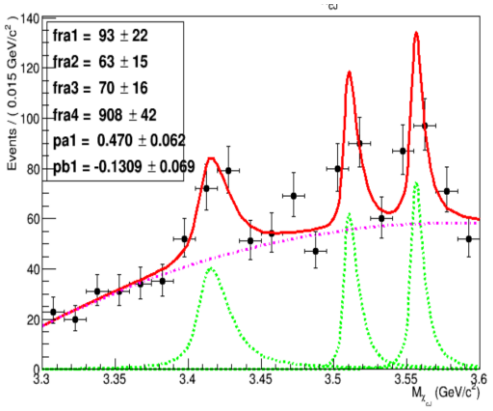


$M_{\Sigma^+}\epsilon(1.25, 1.26)$



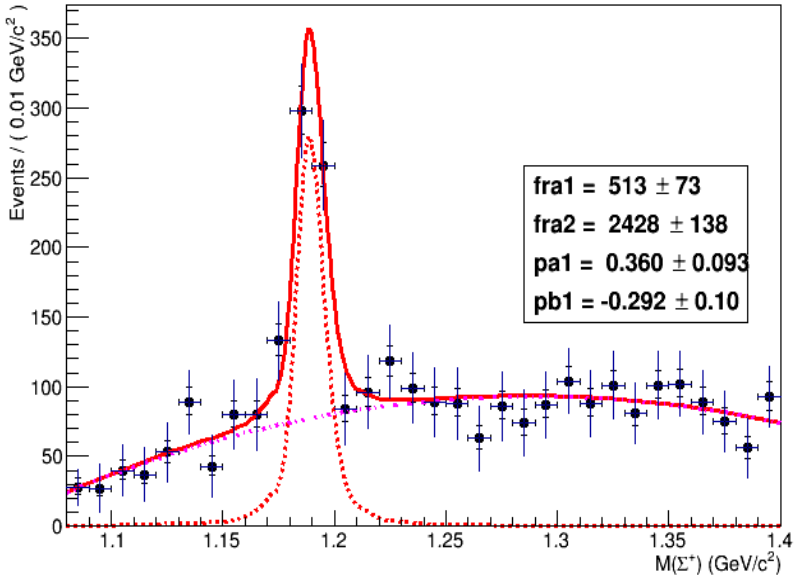
Continue …

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



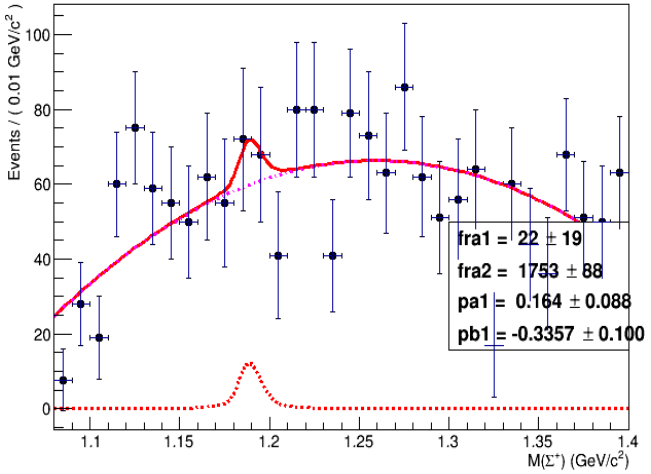
Fitting Result

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

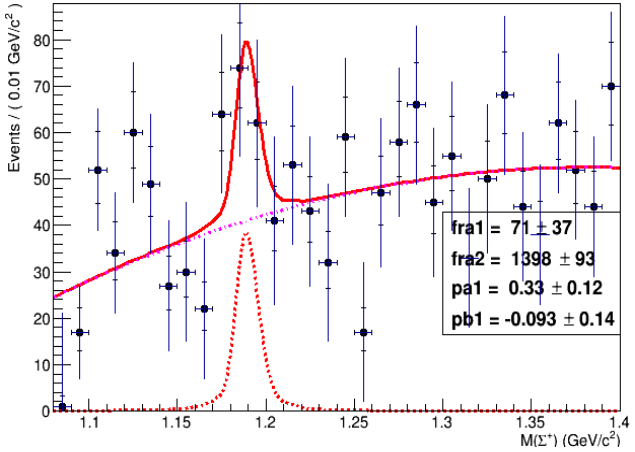


- Version 5.34/19-2014
- Version 5.34/34-2015
- Version 5.34/36-2016

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



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



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.

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

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

Number used to Calculate the Branching Fractions:

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

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

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

Signal MC Efficiency without chisq_sigma cut

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:              = 0
nbar_energy>0.2:            = 221347
nbar_hit_40d>20:            = 203292
nbar_secmom >20:            = 169354
nbar_match>10:              = 168075
gam_match>10:               = 119225
```

Tot. Signal MC Efficiency = 11.9 %

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:              = 0
nbar_energy>0.2:            = 218122
nbar_hit_40d>20:            = 202394
nbar_secmom >20:            = 168971
nbar_match>10:              = 167818
gam_match>10:               = 116882
```

Tot. Signal MC Efficiency = 11.7 %

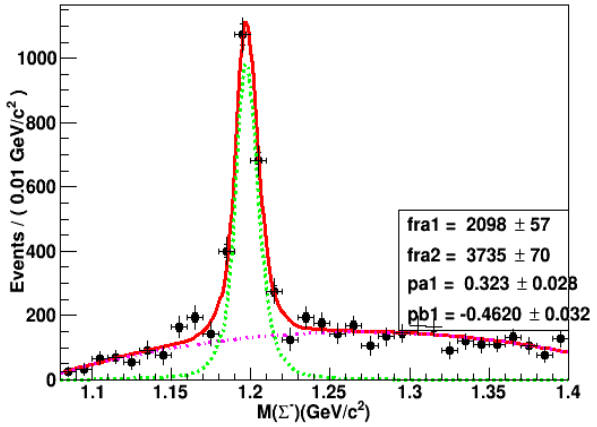
Rate of Cut Flow for chi_c2 After KM Fit

```
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:              = 0
nbar_energy>0.2:            = 202448
nbar_hit_40d>20:            = 188500
nbar_secmom >20:            = 157285
nbar_match>10:              = 156225
gam_match>10:               = 101855
```

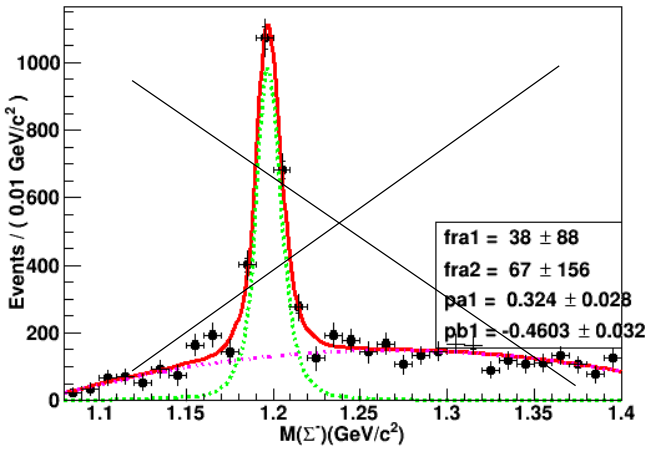
Tot. Signal MC Efficiency = 10.2 %

Latest Root Version Comparison with chi^2 method

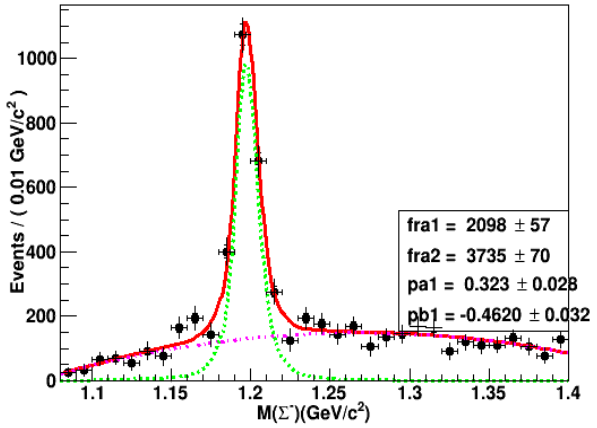
Version 5.34/36 5 April 2016



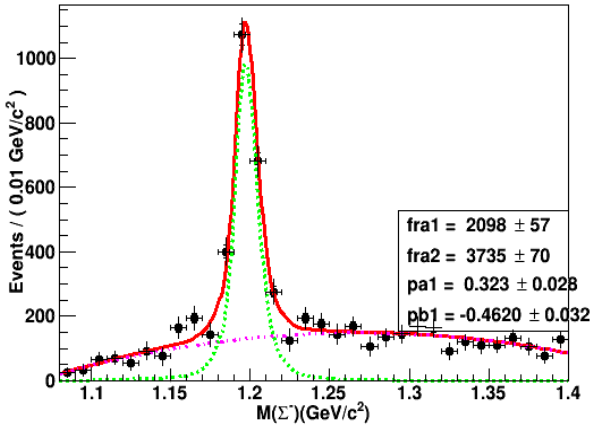
Version 5.34/09 26 June 2013



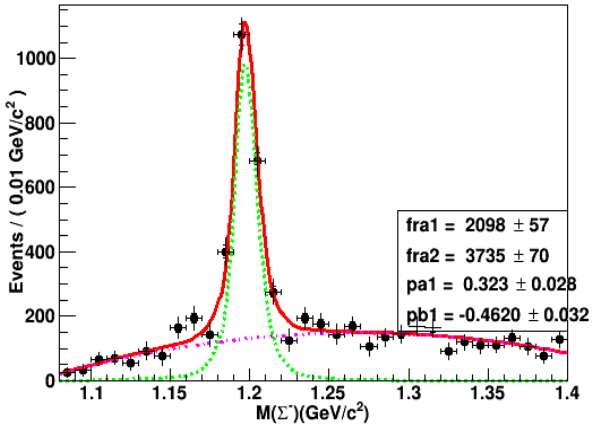
Version 5.34/34 2 October 2015



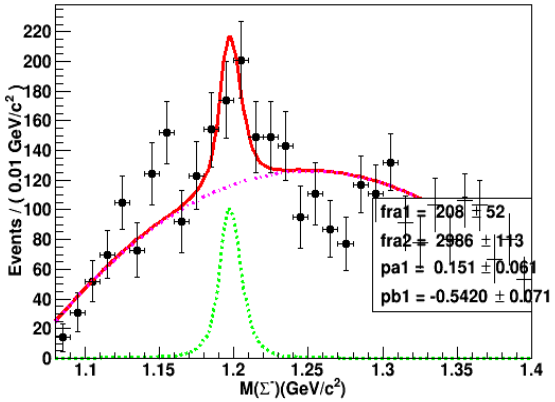
Version 5.34/19 9 July 2014



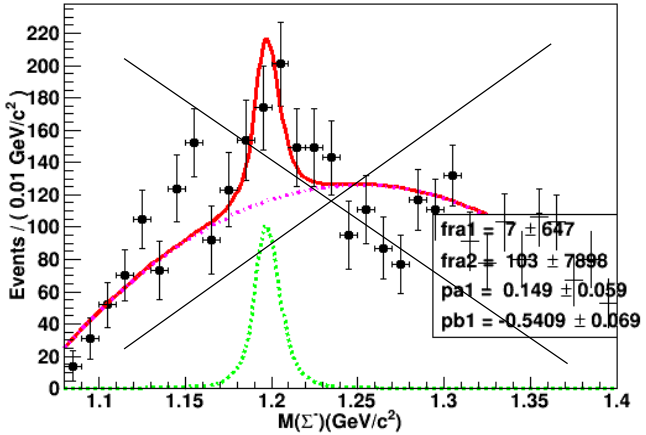
Version 5.34/14 16 December 2013



Version 5.34/36 5 April 2016



Version 5.34/09 26 June 2013

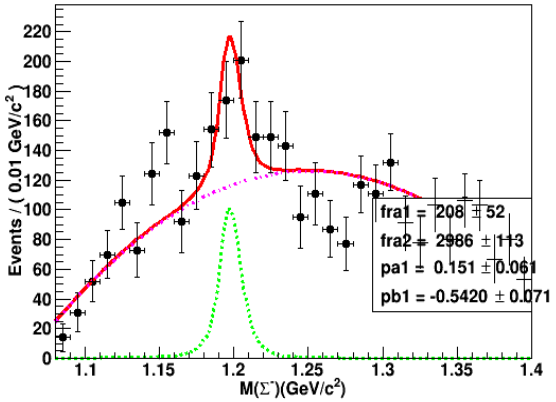


FCN = 46.24 ; Deg. Of Freedom = 4

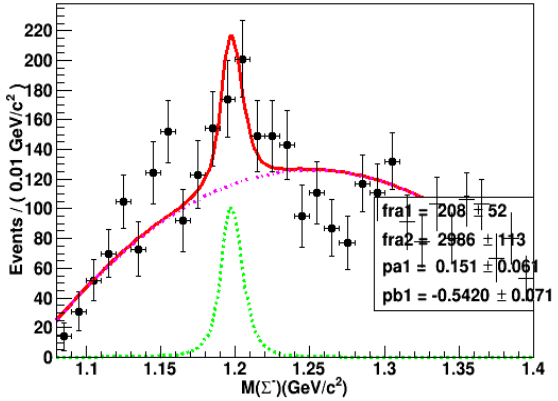
FCN = 62.39;Degree of Freedom = 3

Significance = 4σ

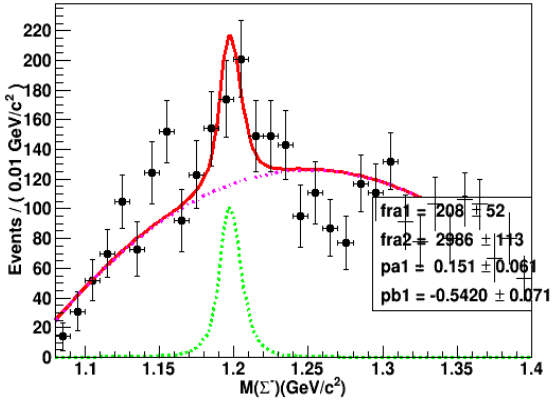
Version 5.34/34 2 October 2015



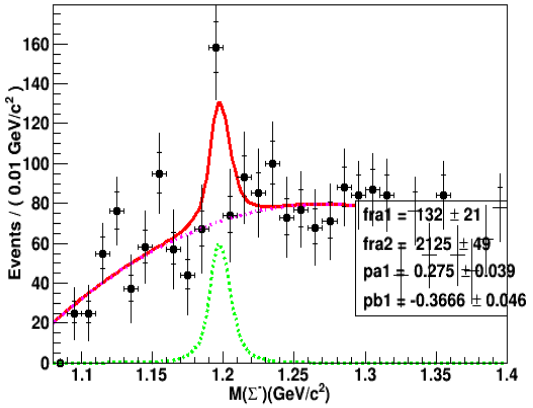
Version 5.34/19 9 July 2014



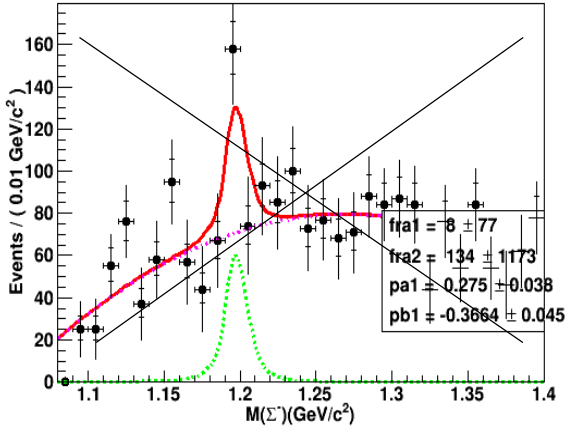
Version 5.34/14 16 December 2013



Version 5.34/36 5 April 2016



Version 5.34/09 26 June 2013

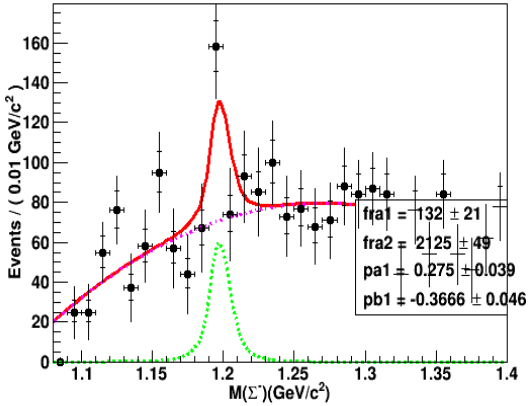


FCN = 158.37; Deg. Of Freedom = 4

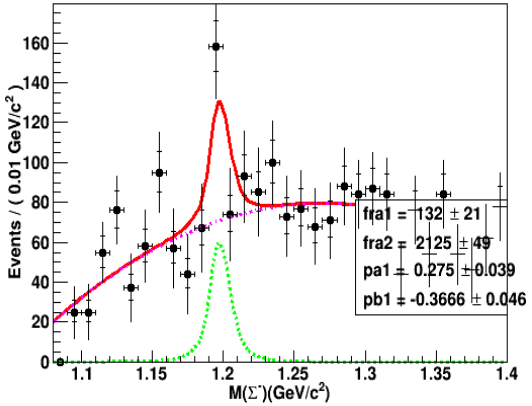
FCN = 217.51; Deg. Of Freedom = 3

Significance = 7σ

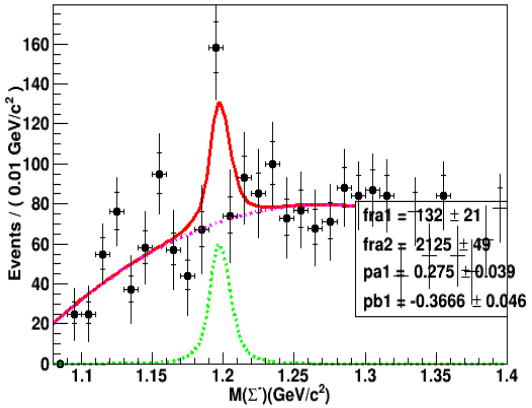
Version 5.34/34 2 October 2015



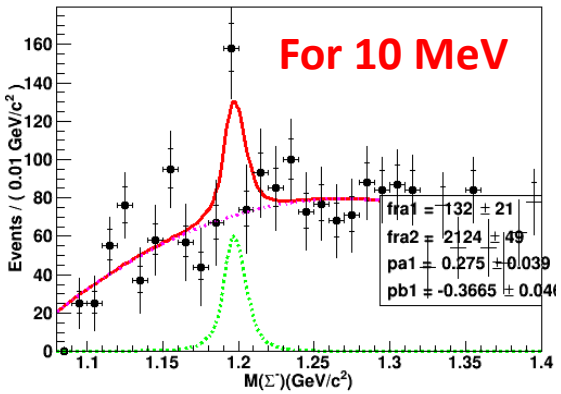
Version 5.34/19 9 July 2014



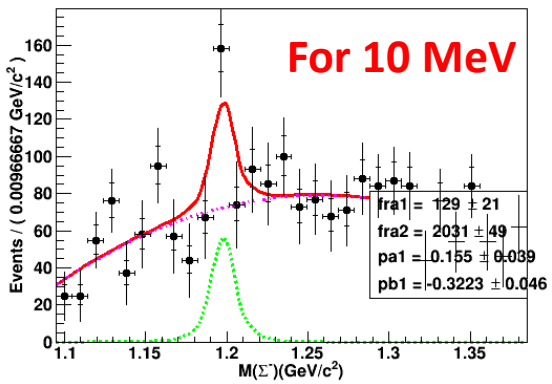
Version 5.34/14 16 December 2013



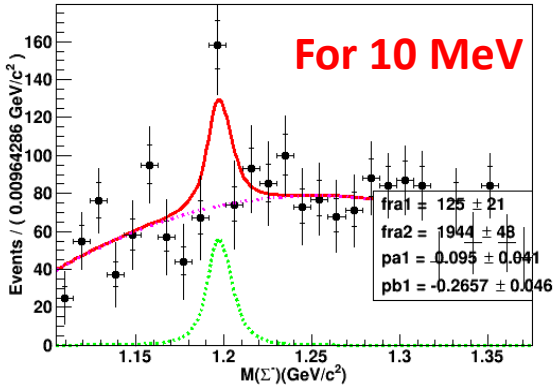
Range∈(1.08,1.40)



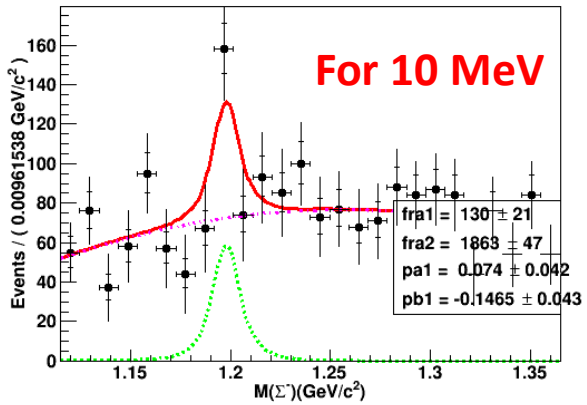
Range ∈(1.095,1.385)



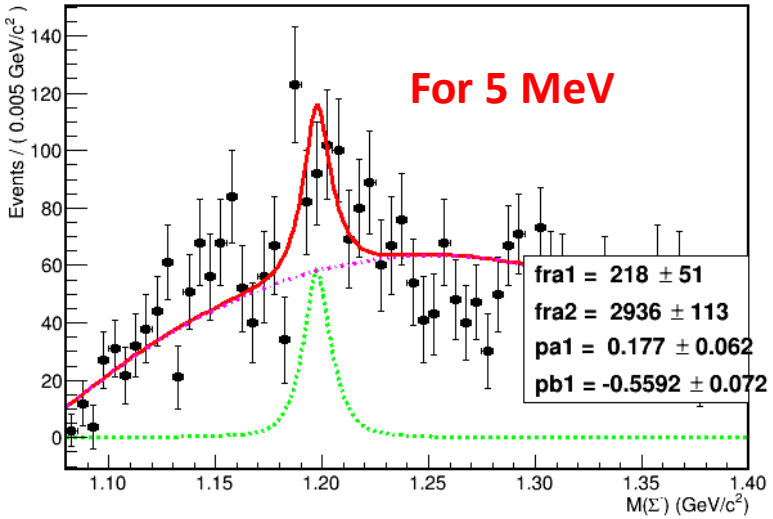
Range ∈(1.105,1.375)

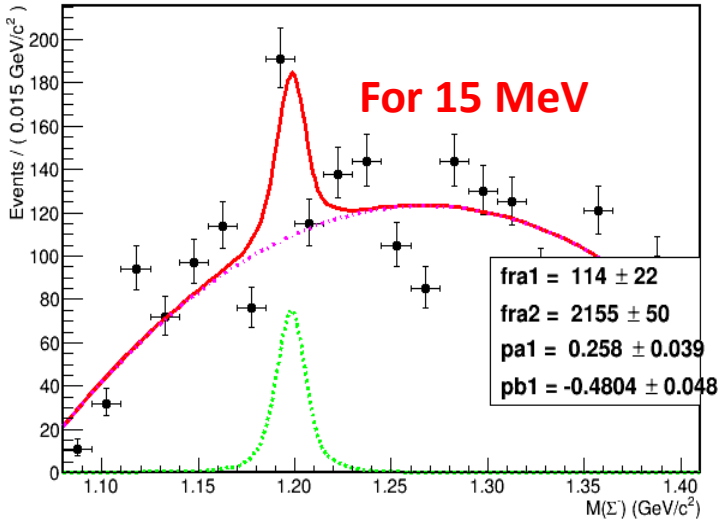


Range ∈(1.115,1.365)



Noted that if we cut the mass of sigma^-,Nominal value of chic_2 is not changes and statistical uncertainty also remain same, Also, we have seen that no. of observed events not increasing ,So we can say this is not cause in systematic uncertainty in fitting method



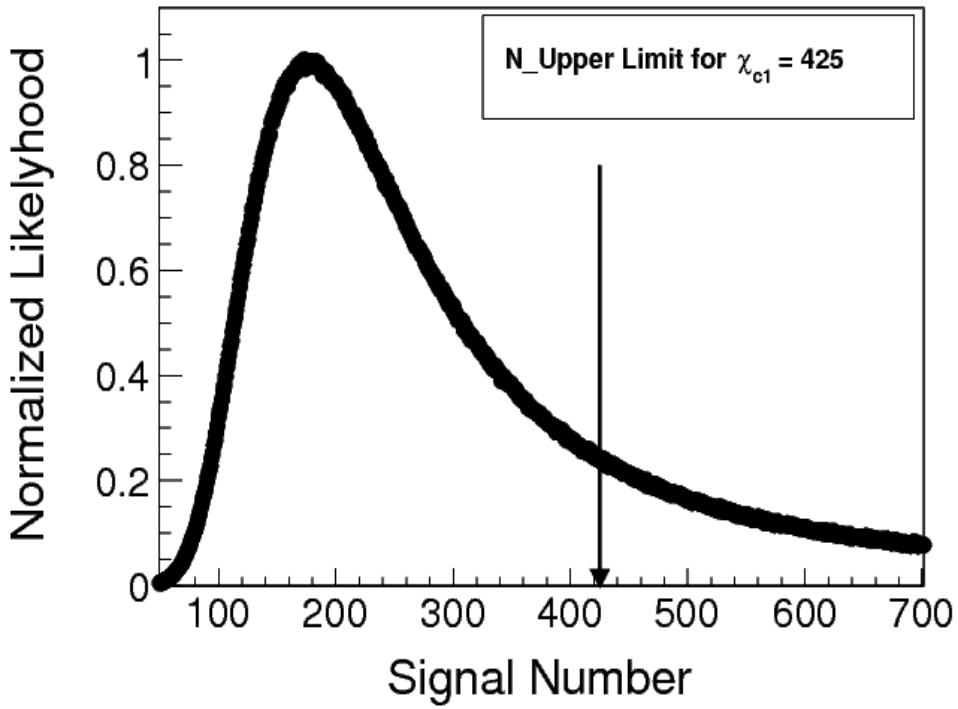


Results for Chic2

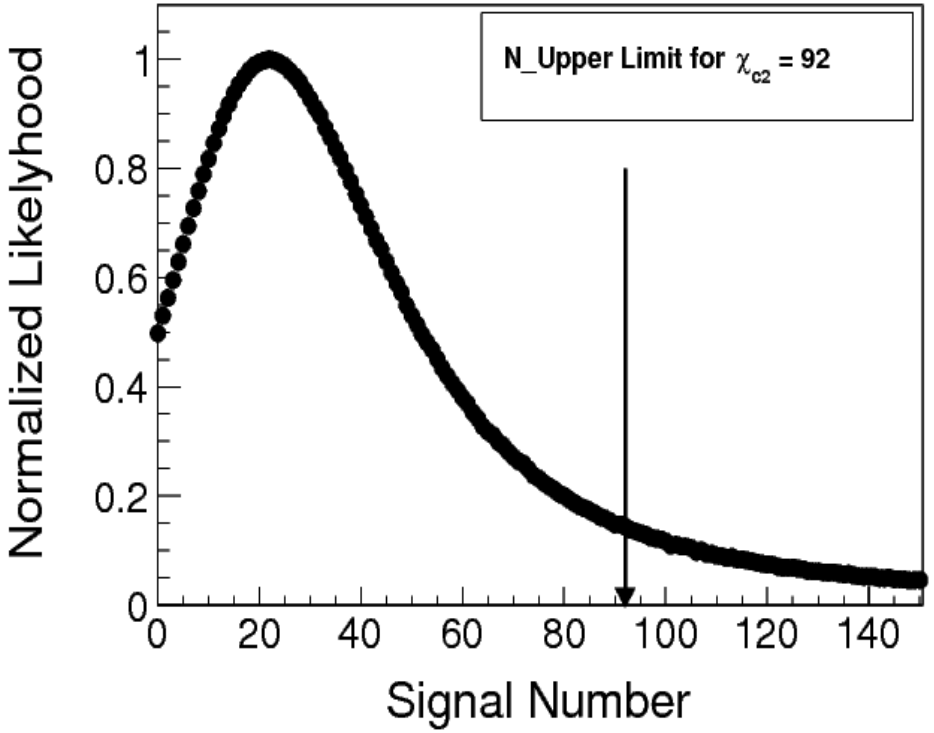
Upper Limit for chi_c1
&
chi_c2

Uncertainty in Fitting Methods

N_Signal for chi_c1 with 90% C.L
For bin size 10MeV

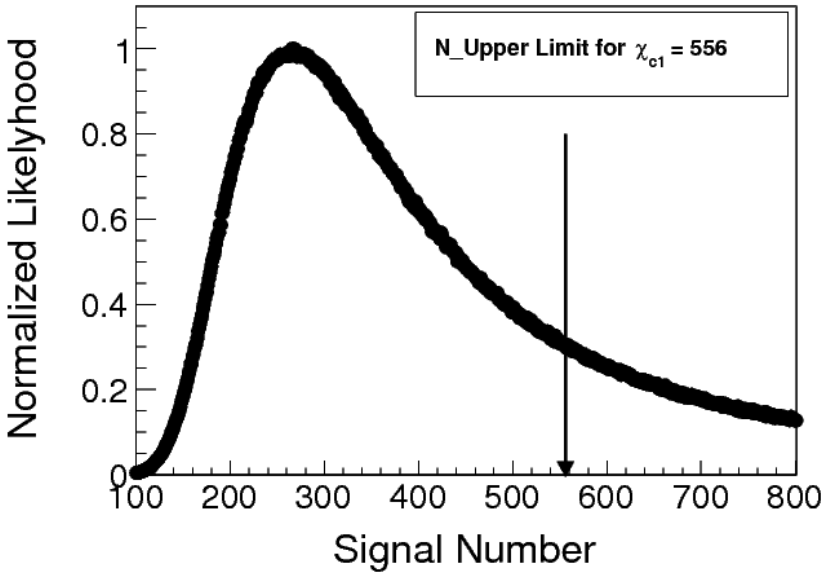


N_signal for chi_c2 with 90% C.L
For bin size 10MeV

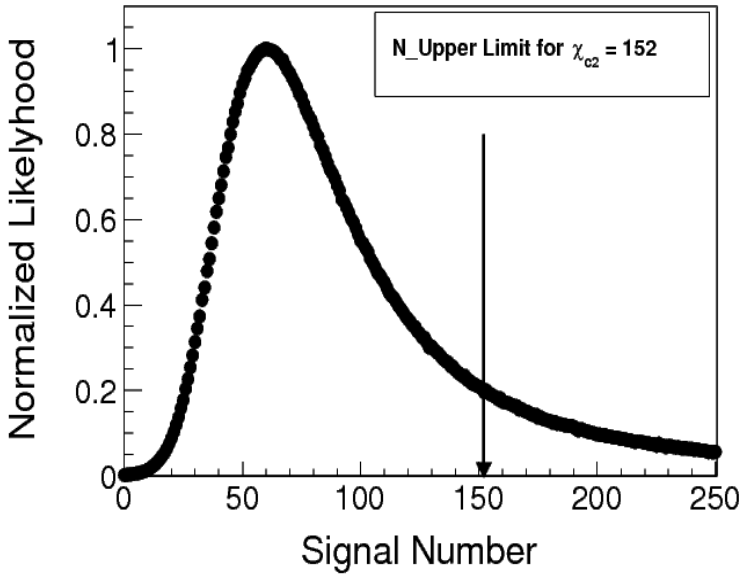


Uncertainty in Fitting Methods

N_Signal for chi_c1 with 90% C.L
For bin size 5MeV

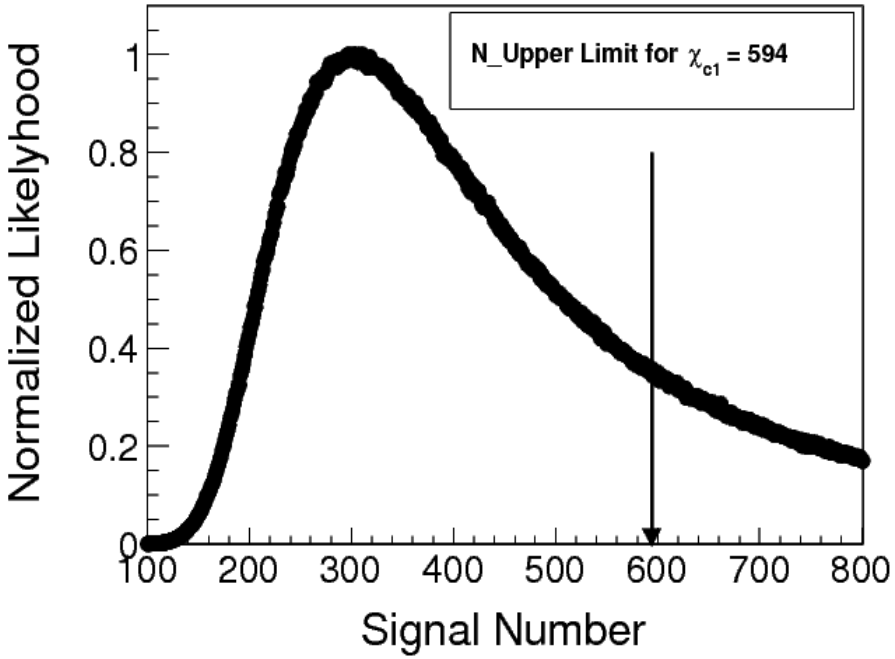


N_signal for chi_c2 with 90% C.L
For bin size 5 MeV

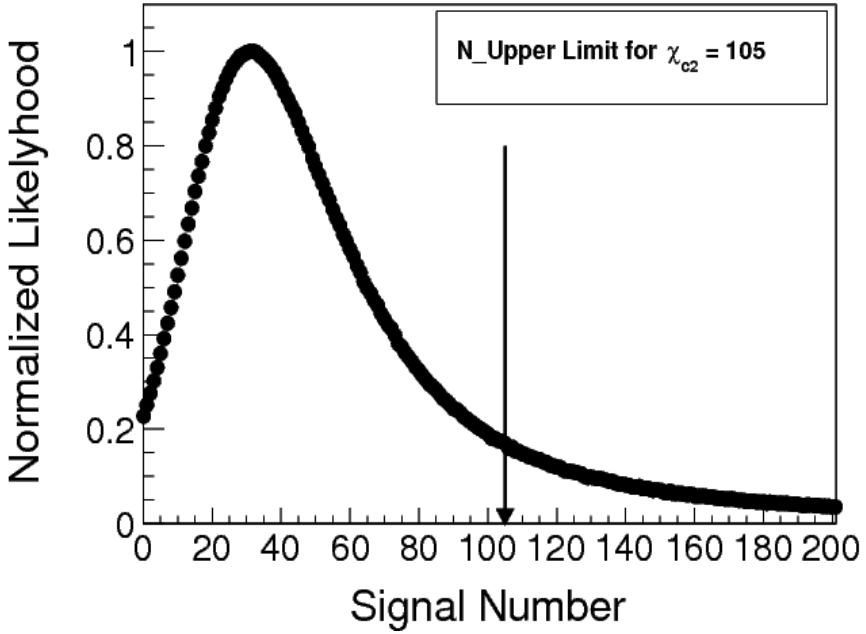


Uncertainty in Fitting Methods

N_Signal for chi_c1 with 90% C.L
For bin size 15MeV

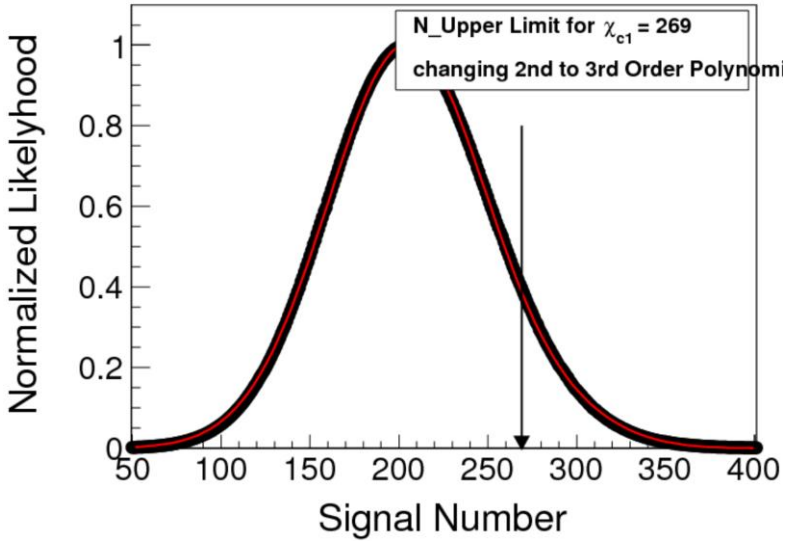


N_signal for chi_c2 with 90% C.L
For bin size 15 MeV

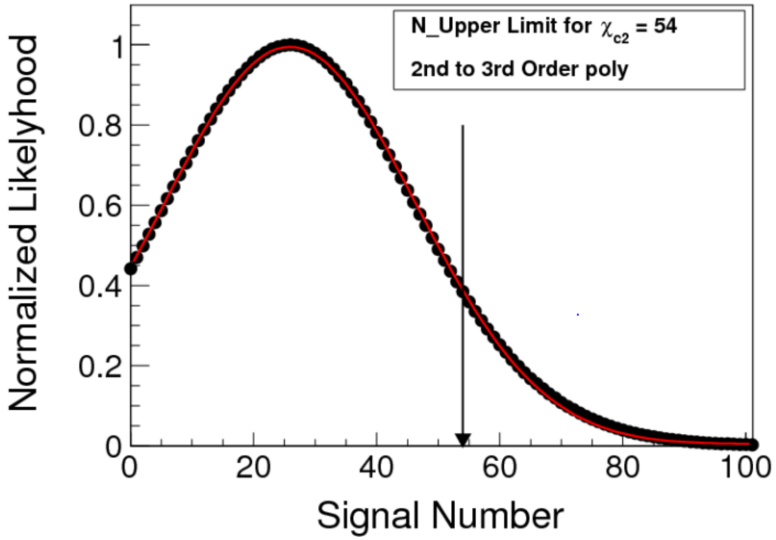


Uncertainty in Fitting Methods

N_Signal for chi_c1 with 90% C.L
By changing 2nd to 3rd order Poly.



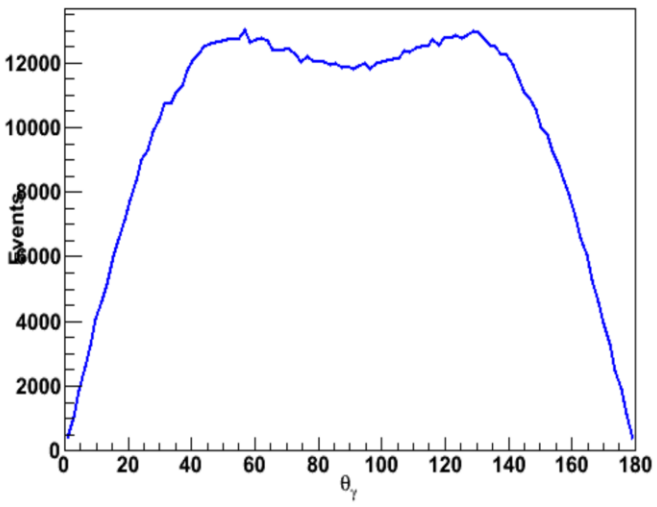
N_signal for chi_c2 with 90% C.L
By Changing 2nd to 3rd Order Poly.



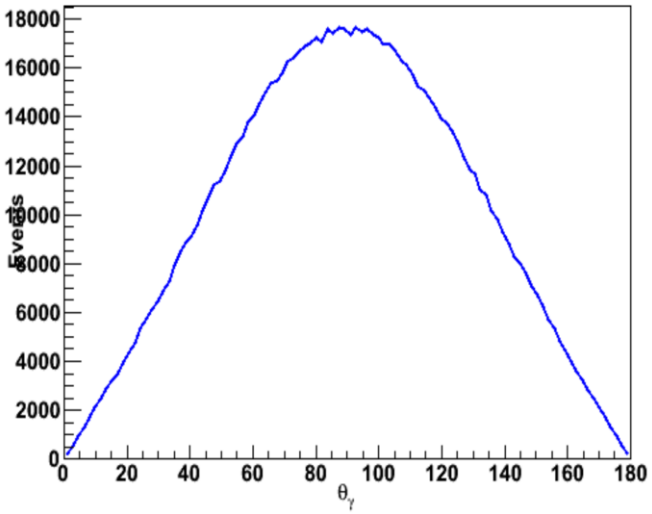
Angular Distribution of Chi_cJ in lab and C.M frame

MC_Truth Angle Gamma in C.M frame

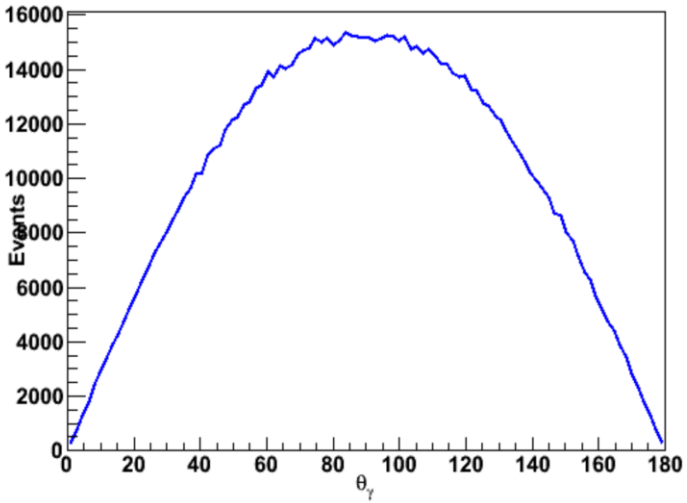
For Chi_c0



For Chi_c1

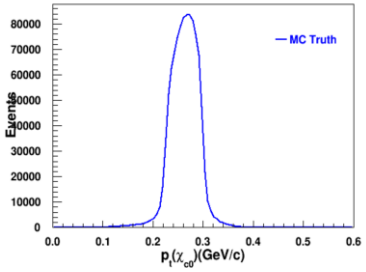


For Chi_c2

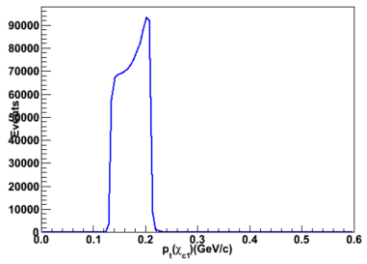


In Lab Frame

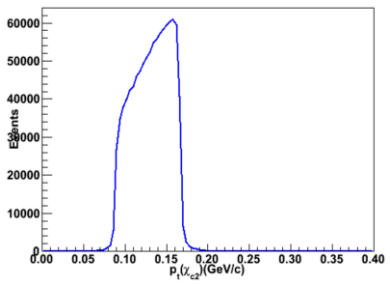
For Chi_c0



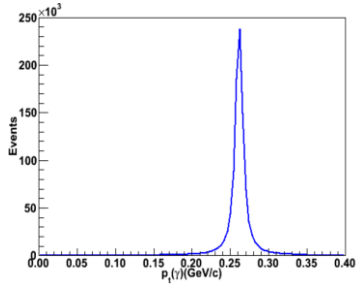
For Chi_c1



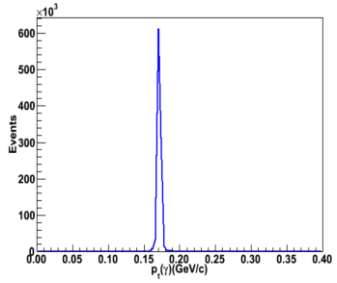
For Chi_c2



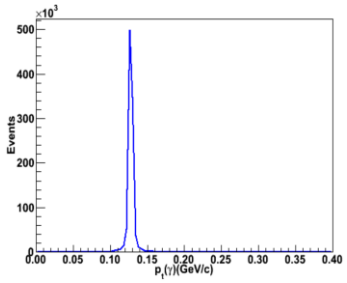
For gamma0

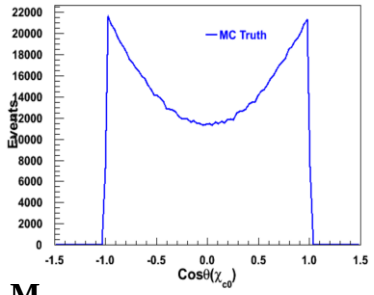


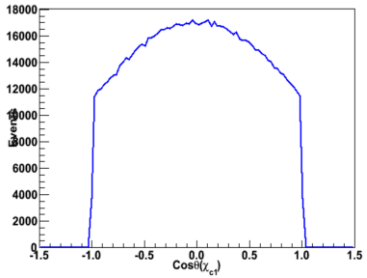
For gamma1

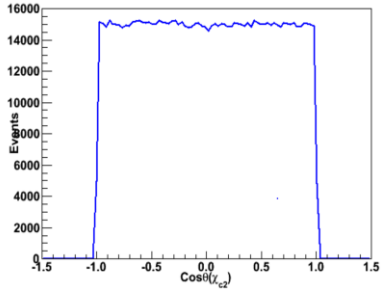


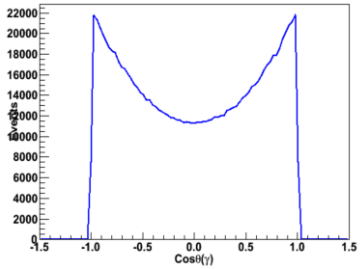
For gamma2

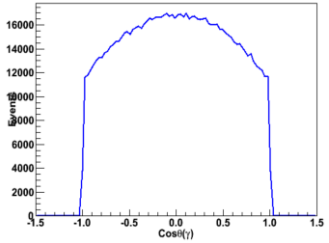


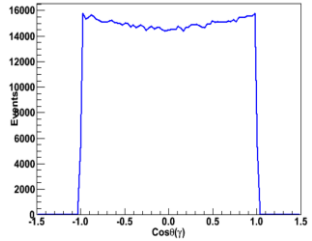






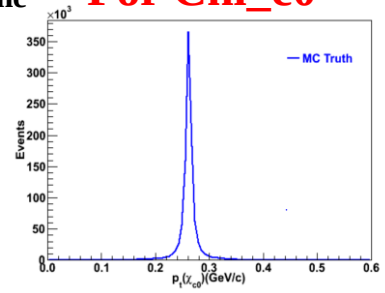




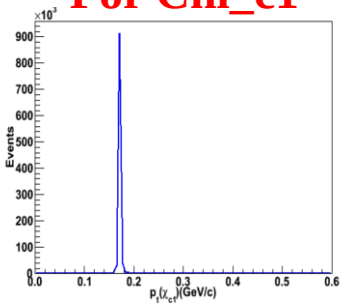


In C.M Frame

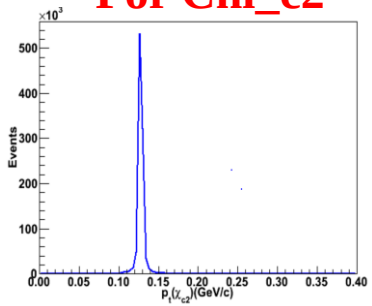
For Chi_c0



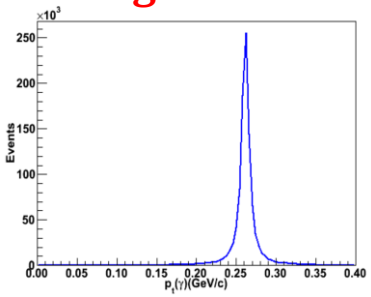
For Chi_c1



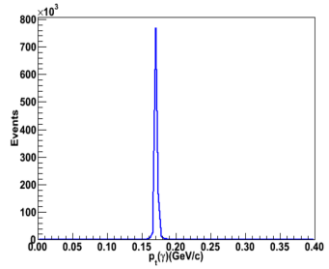
For Chi_c2



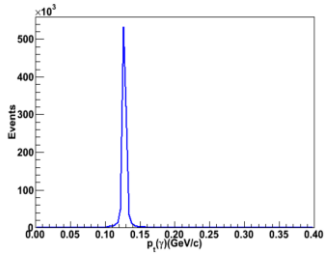
For gamma0

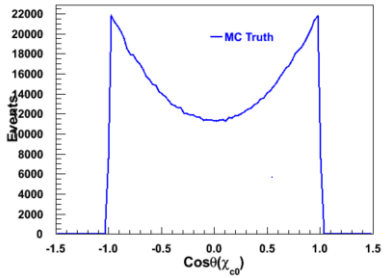


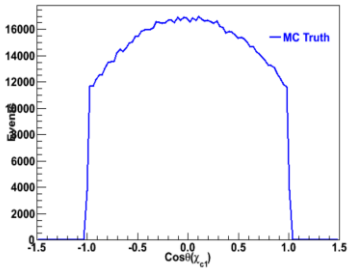
For gamma1

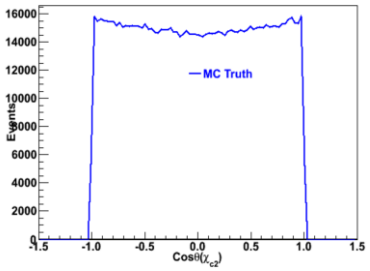


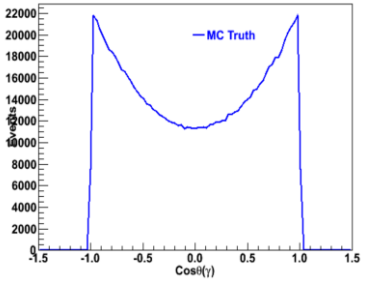
For gamma2

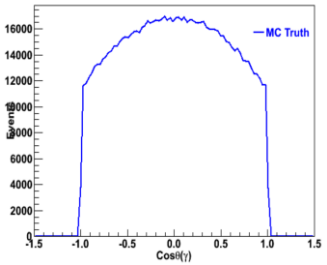


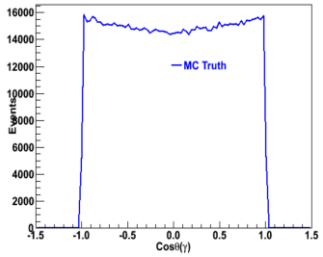






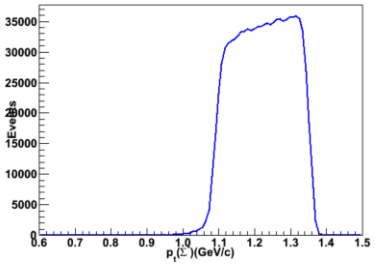




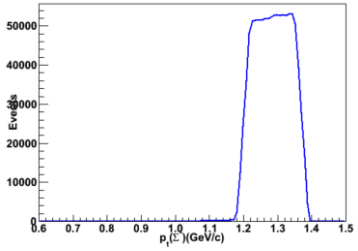


In Lab Frame

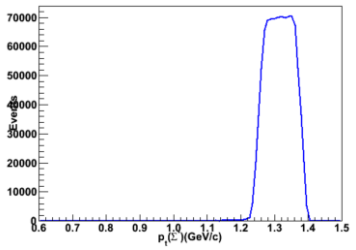
For Σ^-

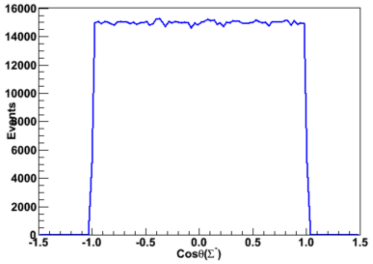


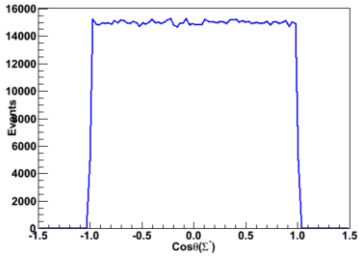
For Σ^-

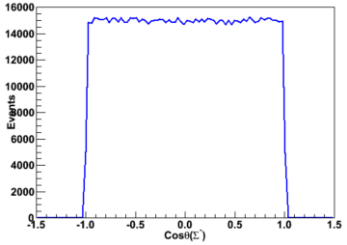


For Σ^-



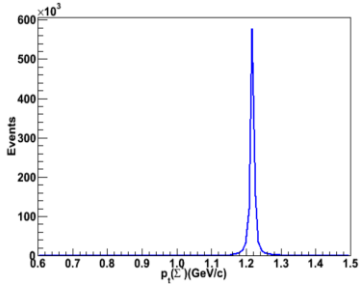




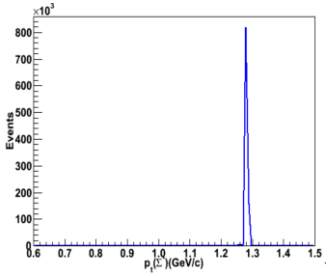


In C.M Frame

For Σ^-



For Σ^-



For Σ^-