$\boldsymbol{Study\ of\ \psi(2S) \rightarrow\ \overline{\Sigma^0}\Lambda + c.c.}$

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Motivation

- The branching fraction $B\left(\psi(2S) \rightarrow \overline{\Sigma^0}\Lambda + c.c.\right) = (1.87 \pm 0.37 \pm 0.30) \times 10^{-6}$ measured at BESIII by Yujun Mo, etc., BAM-00213 (close to CWR)

- The branching fraction in PDG is $B\left(\psi(2S) \rightarrow \overline{\Sigma^0}\Lambda + c.c.\right) = (1.23 \pm 0.24) \times 10^{-5}$ Only one measurement using CLEOc data (PRD 96 (2017) 092004)

- The difference between two results was nearly seven times. So we make a cross check independently.

Data set

- Boss Version: 664p03
- Signal MC :$\psi(2S) \to \bar{\Sigma}^0\Lambda + c.c., \bar{\Sigma}^0 \to \gamma\overline{\Lambda}, \Lambda \to p\pi^-, \overline{\Lambda} \to \bar{p}\pi^+$
- Data sets and MC sample

Year	2009	2012
Data	106.9M	341.1M
Inclusive MC	106M	400M
Exclusive MC of $\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.$	0.11M	0.34M
Exclusive MC of $\psi(2s) \to \overline{\Sigma^0}\Sigma$	0.20M	0.60M

Table 1: Data sets used in this analysis.

Initial event selection

- Good charge tracks

  $|cos\theta|$<0.93

  $|V_r| < 10$cm, $|V_z|$<30cm

  $N_{Good} = 4$ N_{charge} =0

  If momenta>0.7 GeV/c is p , Else π

- Good Photon

  Barrel : 0.8<$|cos\theta|$<0.86 || $|cos\theta|$>0.92

  E_γ>25MeV, $|cos\theta|$<0.8

  Endcap : $E_\gamma > 50MeV, 0.86 < |cos\theta| < 0.92$

  0≤T≤14 (50ns)

  1≤ N_γ≤ 10

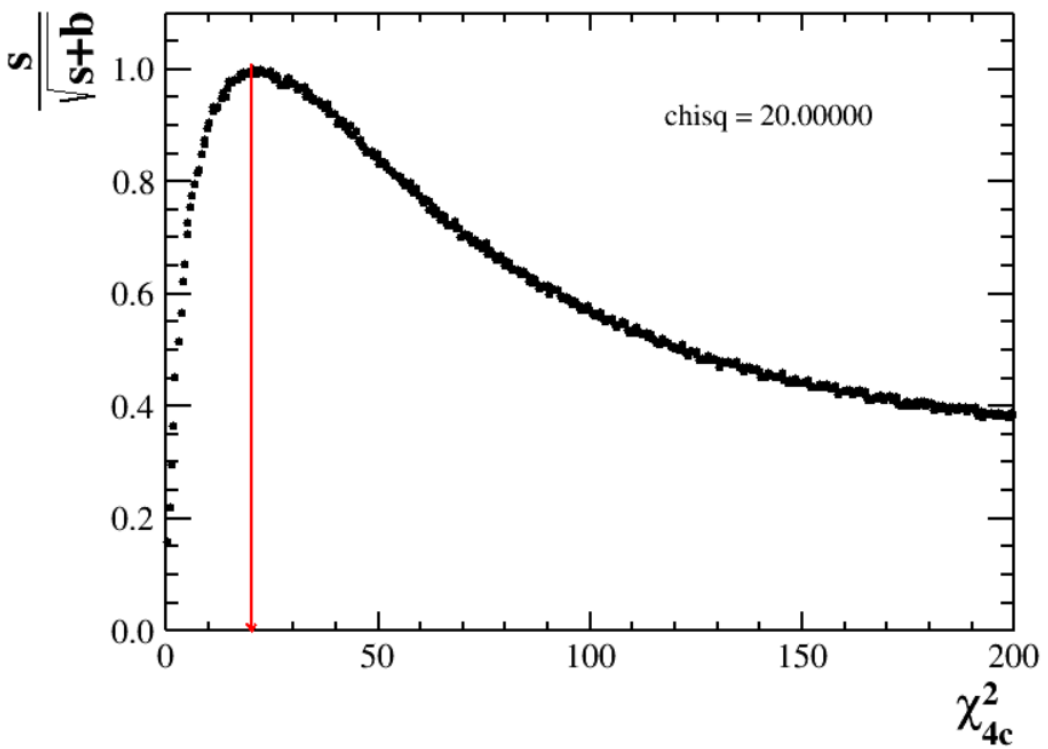
- Reconstruct $\Lambda\bar{\Lambda}$

We require the secondary vertex fit is successful for both Λ and $\bar{\Lambda}$

- 4C kinematic fit

Loop in all $\gamma\Lambda\bar{\Lambda}$ combinations with 4C kinematic fit and the one with minimum χ^2_{4c} is chosen.

- 4C kinematic fit :
  - $\chi^2_{4C}\left(\psi(2s) \to \overline{\Sigma^0}\Lambda\right) < 20$ (optimized with $S/\sqrt{S+B}$)



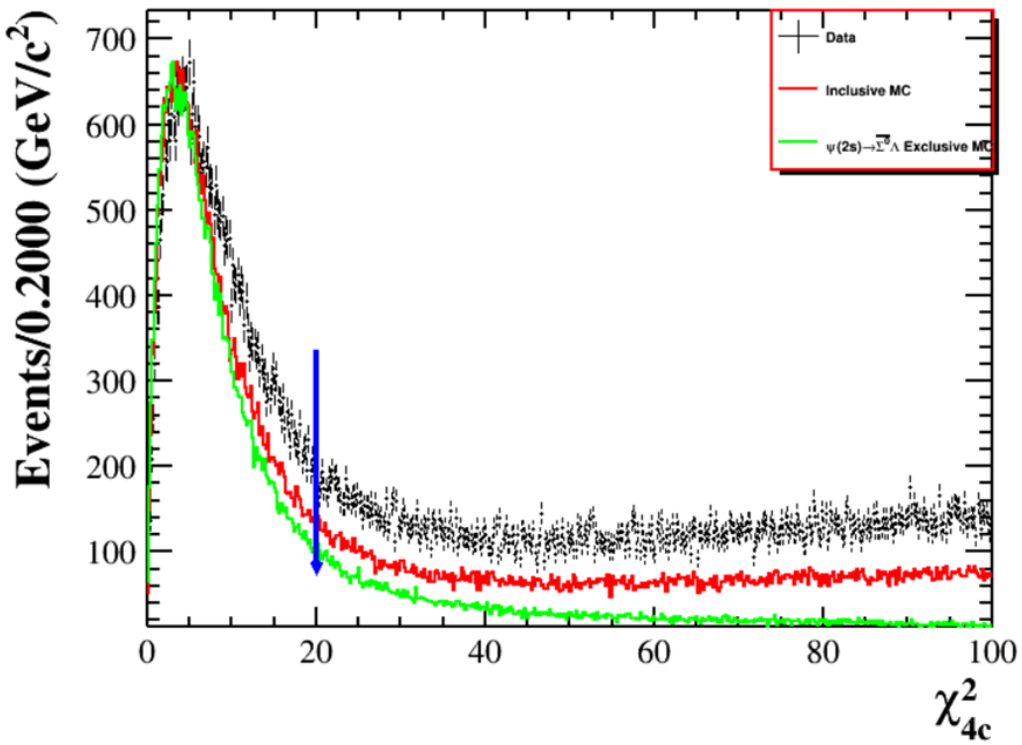
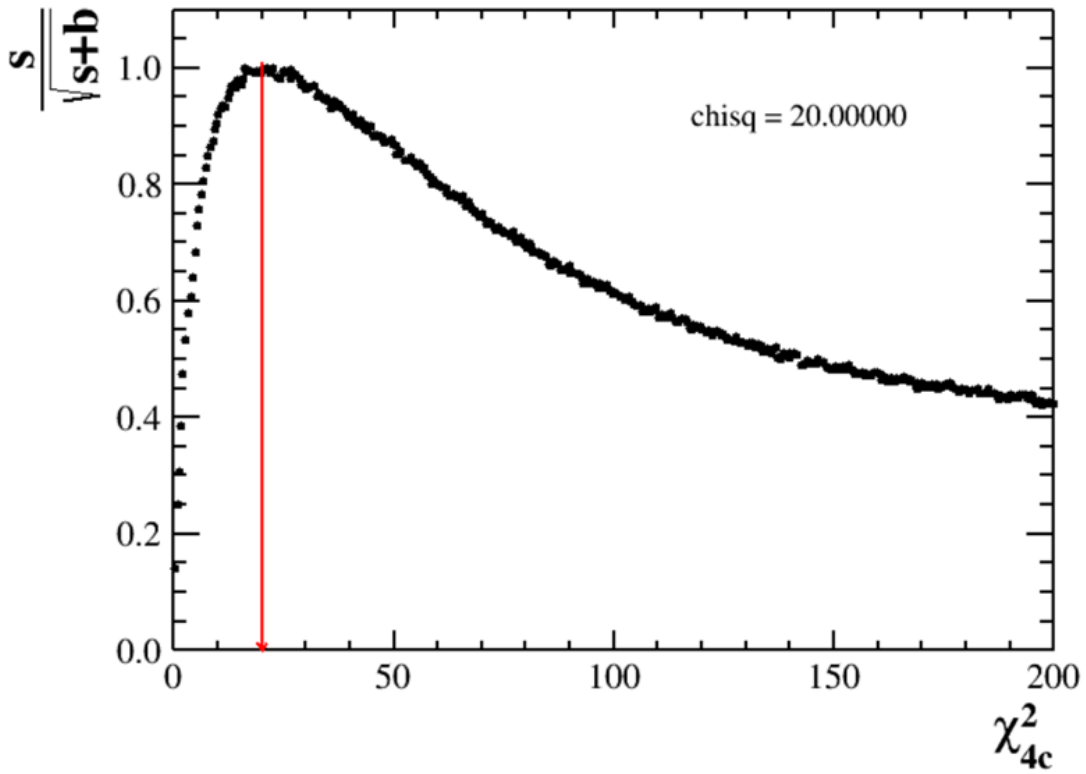


Figure 1: (left) shows the $S/\sqrt{S+B}$ versus x^2_{4C} , where S and S+B are the numbers of Exclusive MC and Inclusive MC , which are in the signal rang ($|M_{\gamma\bar{\Lambda}} - 1.19| < 18MeV/c^2$). (right) shows the distribution of the 4C kinematic fit.

- $\chi^2_{4C}(\psi(2s) \to \Sigma^0\overline{\Lambda}) < 20$ (optimized with $S/\sqrt{S+B}$)



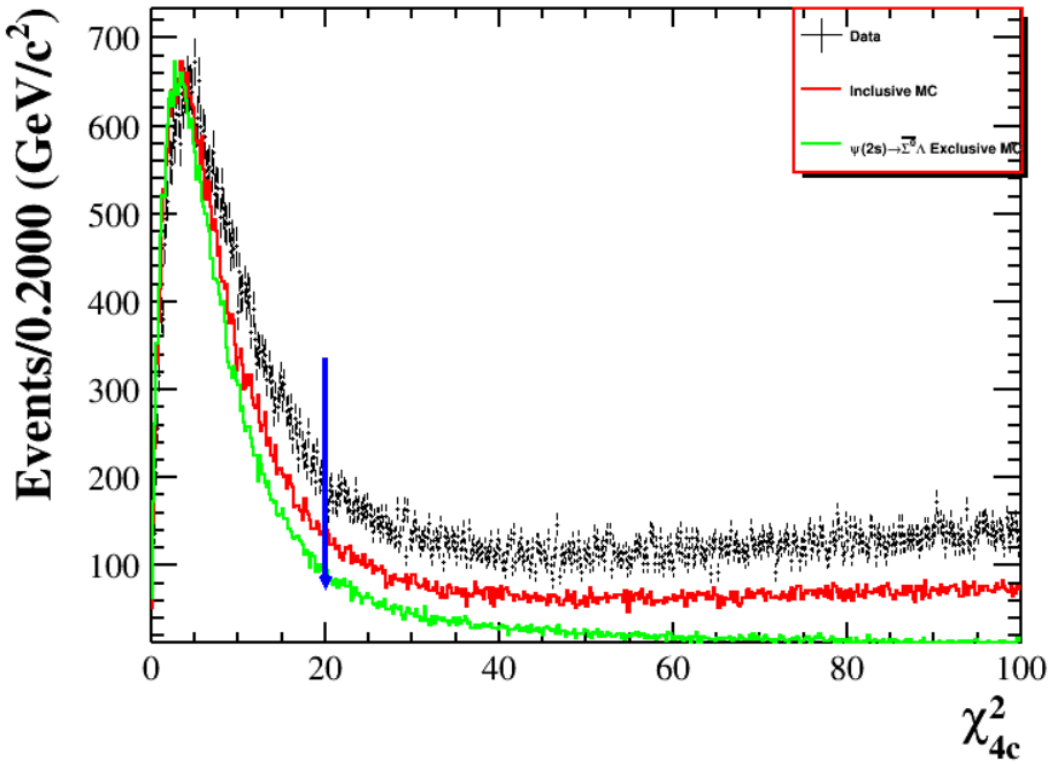
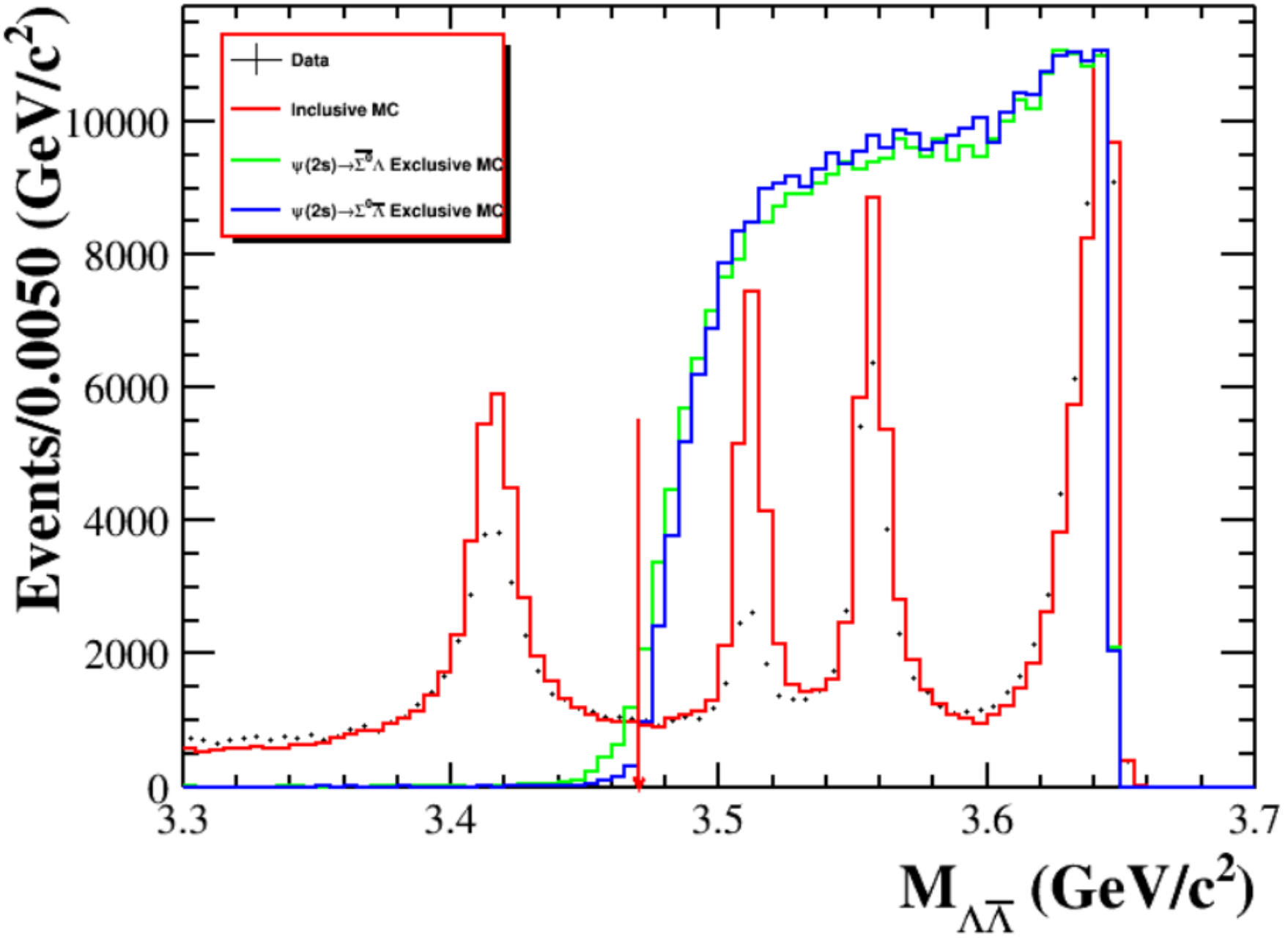


Figure 2: (left) shows the $S/\sqrt{S+B}$ versus x^2_{4C} , where S and S+B are the numbers of Exclusive MC and Inclusive MC , which are in the signal rang ($|M_{\gamma\Lambda} - 1.19| < 18MeV$). (right) shows the distribution of the 4C kinematic fit.

- Veto χ_{c0}：

  $M_{\Lambda\bar{\Lambda}}$>3.47 GeV



Further event selection $\psi(2S) \rightarrow \overline{\Sigma^0}\Lambda + c.c.$

- ✓ kinematic fit
  - ✓ $\chi^2_{4c}(\gamma) < \chi^2_{4c}(\gamma\gamma)$ && $\chi^2_{4c}(\gamma) < \chi^2_{4c}(0\gamma)$
  - ✓ $\chi^2_{4c} < 20$ ($|M_{\gamma\bar{\Lambda}} - 1.19| < 18\mathrm{MeV/c^2}$)

- ✓ Veto decay length of L_Λ/σ（$\bar{\Lambda}$）:
  Decay length of L_Λ/σ >2 （$\bar{\Lambda}$）

- ✓ The angle of γ from $p\,\bar{p}\,\pi^+\pi^-$
  Angle (γ, π^+/π^-/p)>10°
  Angle (γ, $\bar{p}$) > 20°

- ✓ Mass window of $\Lambda/\bar{\Lambda}$
  $1.075 < M_{\bar{p}\pi^+}/M_{p\pi^-} < 1.150 GeV/c^2$

- ✓ Veto χ_{c0}
  $M_{\Lambda\bar{\Lambda}}$>3.47 GeV

- ✓ $M_{\gamma\Lambda} - 1.19264 < 0.018 GeV/c^2 (M_{\gamma\bar{\Lambda}})$

Table 2: cut flow of $\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.$ (09+12)

Criteria	$\psi(2s) \to \overline{\Sigma^0}\Lambda$	$\psi(2s) \to \Sigma^0\overline{\Lambda}$
Total Events	440000	440000
Good Charged track	250339	250920
$1< N_\gamma < 10$	218539	217402
Λ、$\overline{\Lambda}$ reconstruction	205102	203914
Pass 4c $\gamma\Lambda\overline{\Lambda}$	160869	158285
$\chi^2_{4c}(\gamma) < \chi^2_{4c}(\gamma\gamma/0\gamma)$	153914	152773
$\chi^2_{4c} < 20$	106590	109562
L_Λ/σ >2 （$\overline{\Lambda}$）	91872	94373
Angle $(\gamma, \bar{p}) > 20^\circ$	75200	77966
$1.075 < M_{\bar{p}\pi^+} < 1.150 GeV/c^2 (M_{p\pi^-})$	74899	77675
$M_{\Lambda\,\overline{\Lambda}} > 3.47 GeV/c^2$	74752	77646
$M_{\gamma\Lambda} - 1.19264 < 0.018 GeV/c^2 (M_{\gamma\overline{\Lambda}})$	69509	72473
Efficiency (ε %)	15.8%	16.5%

Background study

Table3:Topology of inclusive MC in $\psi(2s) \to \Sigma^0\bar{\Lambda}$ process

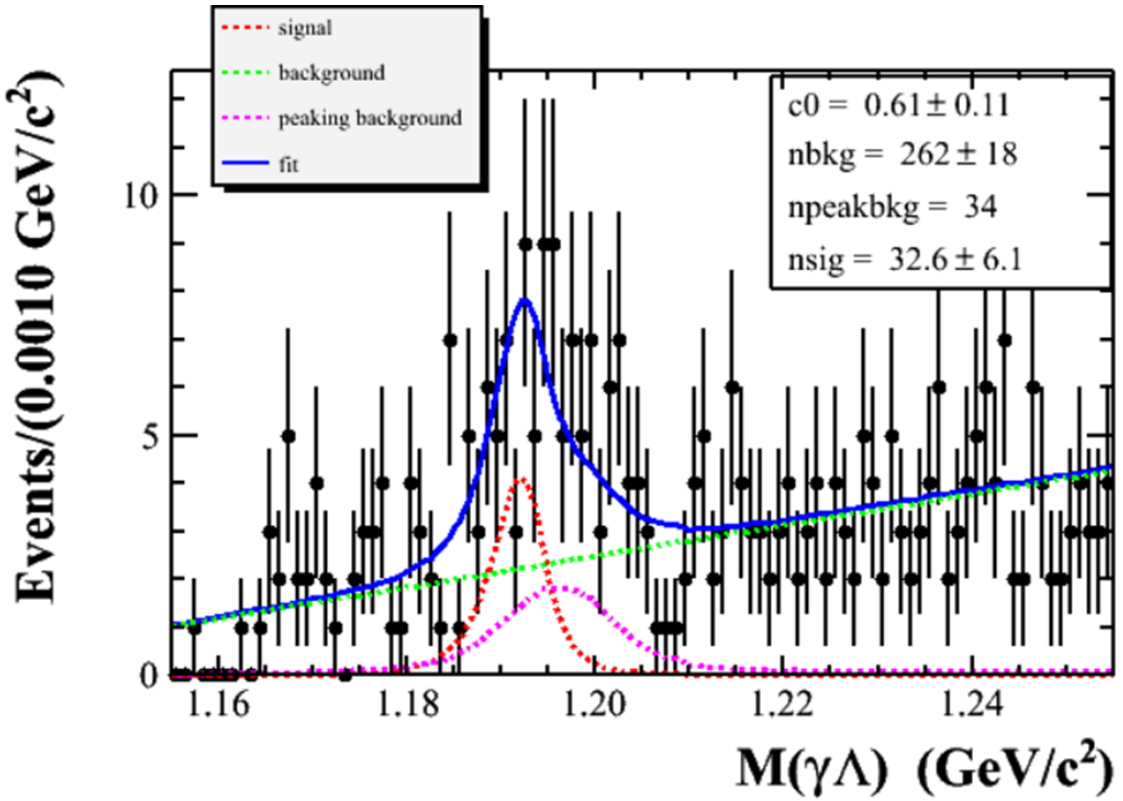
No.	decay chain	final states	iTopo	nEvt	nTot
0	$\psi' \to \gamma\chi_{c2},\ \chi_{c2} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	0	536	536
1	$\psi' \to \gamma\chi_{c1},\ \chi_{c1} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	1	415	951
2	$\psi' \to \bar{\Lambda}\Sigma^0,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	7	40	991
3	$\psi' \to \bar{\Sigma}^0\Sigma^0,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$\psi' \to \gamma\gamma p\pi^+\pi^-\bar{p}$	3	32	1023
4	$\psi' \to \gamma\chi_{c0},\ \chi_{c0} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	2	21	1044
5	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to p\pi^+\pi^-\bar{p}$	5	12	1056
6	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\gamma\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	6	8	1064
7	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\gamma_{FSR}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma_{FSR} p\pi^+\pi^-\bar{p}$	8	8	1072
8	$\psi' \to \gamma,\ \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	4	7	1079
9	$\psi' \to \bar{\Sigma}^0\Lambda,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	9	1	1080
10	$\psi' \to \gamma\chi_{c2},\ \chi_{c2} \to \bar{p}\pi^-\Delta^{++},\ \Delta^{++} \to \pi^+ p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	10	1	1081

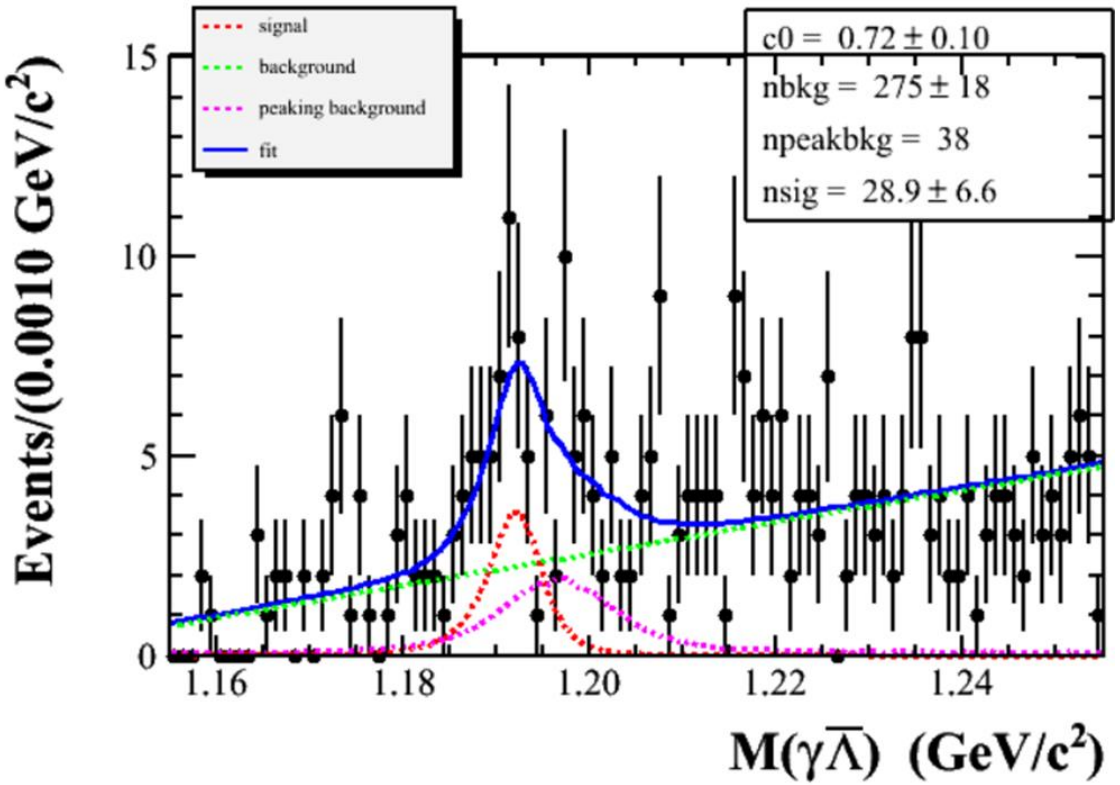
Table 4:topology of inclusive MC in $\psi(2s) \to \overline{\Sigma^0}\Lambda$ process

No.	decay chain	final states	iTopo	nEvt	nTot
0	$\psi' \to \gamma\chi_{c2},\ \chi_{c2} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	0	536	536
1	$\psi' \to \gamma\chi_{c1},\ \chi_{c1} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	1	410	946
2	$\psi' \to \bar{\Sigma}^0\Lambda,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	3	49	995
3	$\psi' \to \bar{\Sigma}^0\Sigma^0,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$\psi' \to \gamma\gamma p\pi^+\pi^-\bar{p}$	4	38	1033
4	$\psi' \to \gamma\chi_{c0},\ \chi_{c0} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	2	21	1054
5	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to p\pi^+\pi^-\bar{p}$	6	12	1066
6	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\gamma_{FSR}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma_{FSR}p\pi^+\pi^-\bar{p}$	8	9	1075
7	$\psi' \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\gamma\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	7	8	1083
8	$\psi' \to \gamma,\ \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	5	7	1090
9	$\psi' \to \gamma\chi_{c2},\ \chi_{c2} \to \bar{p}\pi^-\Delta^{++},\ \Delta^{++} \to \pi^+ p,$	$\psi' \to \gamma p\pi^+\pi^-\bar{p}$	9	1	1091
10	$\psi' \to \gamma\chi_{c2},\ \chi_{c2} \to \bar{\Lambda}\Lambda,\ \bar{\Lambda} \to \bar{p}\gamma\pi^+,\ \Lambda \to \pi^- p,$	$\psi' \to \gamma\gamma p\pi^+\pi^-\bar{p}$	10	1	1092

There are only one peaking background $\psi(2s) \to \overline{\Sigma^0}\Sigma$.

Fitting results





Dots with error bars are data, blue solid curves are fitting results, red dashed curves are the signal (shapes from MC), pink dashed lines are $\psi(2s) \to \overline{\Sigma^0}\Sigma$ backgrounds (shape from MC, amplitude fixed), and the green dashed lines show the other backgrounds (first order polynomial).

The observed events are $N_{\gamma\Lambda} = 32.6 \pm 6.1$ and $N_{\gamma\bar{\Lambda}} = 28.9 \pm 6.6$

Measurement of $\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.$ branching fraction

- $B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda\right) = \frac{\mathrm{N_{obs}}}{N(\psi')*\varepsilon\left(\psi' \to \overline{\Sigma^0}\Lambda\right)*B(\overline{\Lambda} \to \bar{p}\pi^+)*B(\overline{\Lambda} \to p\pi^-)*B(\overline{\Sigma^0} \to \gamma\overline{\Lambda})}$

  $= (1.00 \pm 0.23) \times 10^{-6}$

- $B(\psi(2s) \to \Sigma^0\overline{\Lambda}) = \frac{\mathrm{N_{obs}}}{N(\psi')*\varepsilon(\psi' \to \Sigma^0\overline{\Lambda})*B(\overline{\Lambda} \to \bar{p}\pi^+)*B(\overline{\Lambda} \to p\pi^-)*B(\Sigma^0 \to \gamma\Lambda)}$

  $= (1.08 \pm 0.20) \times 10^{-6}$

- $B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.\right) = B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda\right) + B(\psi(2s) \to \Sigma^0\overline{\Lambda})$

  $=(2.08 \pm 0.30) \times 10^{-6}$

Summary

- BAM-00213: $B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.\right) = (1.87 \pm 0.37 \pm 0.30) \times 10^{-6}$
- CLEOc data: $B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.\right) = (1.23 \pm 0.24) \times 10^{-5}$.
- Our results (only stat.): $B\left(\psi(2S) \to \overline{\Sigma^0}\Lambda + c.c.\right) = (2.08 \pm 0.30) \times 10^{-6}$.

Thanks for your attention!

Backups

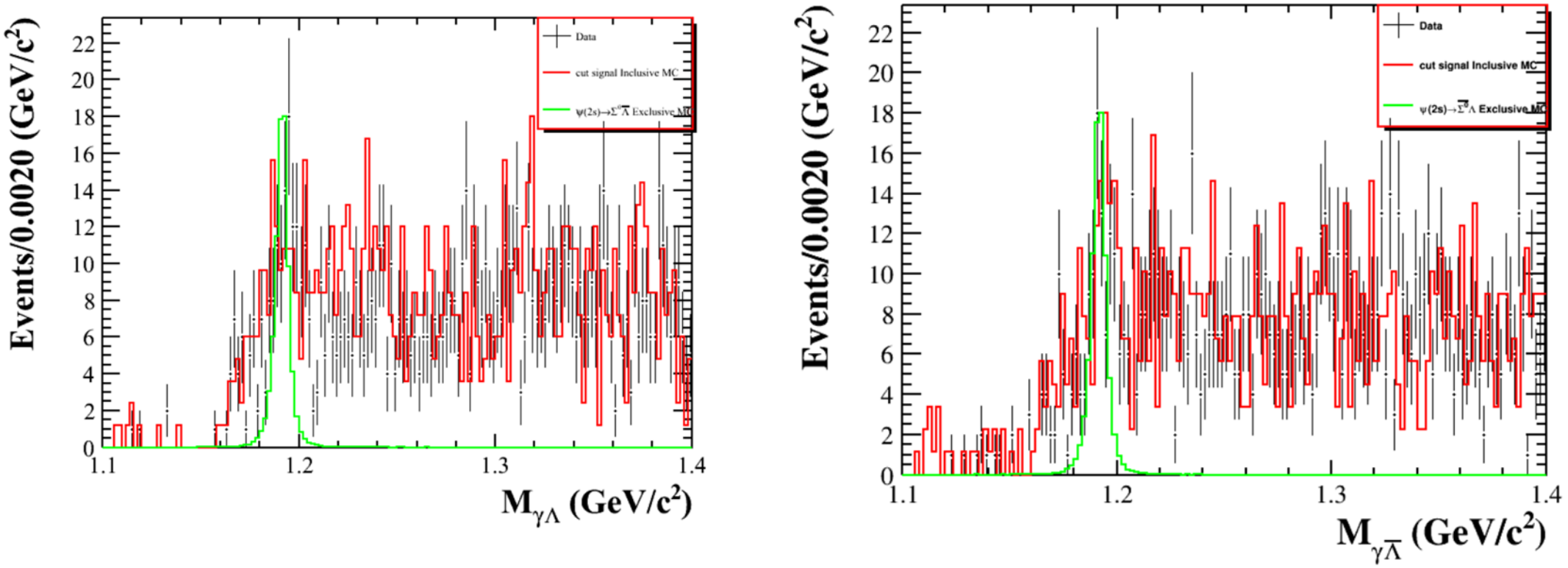


Figure 7: $M_{\gamma\Lambda}$ (left) and $M_{\gamma\bar{\Lambda}}$ (right) distributions from data and MC, the red histogram is sum of background (from inclusive MC), and signal (from exclusive MC), and dots with error bars are data.

- Peaking background study

We generate 0.8 million MC events for the peaking background study, and there are 637 and 703 events survived after all event selection criteria.

- $\psi(2s) \to \Sigma^0\overline{\Lambda}$

The efficiencies calculation of $\psi(2s) \to \overline{\Sigma^0}\Sigma$ in process $\psi(2s) \to \Sigma^0\overline{\Lambda}$ is $\varepsilon_{\psi(2s)\to\overline{\Sigma^0}\Sigma} = 0.080\%$ and number of peaking background as follows:

$$
\begin{aligned}
&N_{peaking\ bkg} \\
&= N_{\psi(2s)} * B\left(\psi(2s) \to \overline{\Sigma^0}\Sigma\right) * B\left(\overline{\Sigma^0} \to \overline{\Lambda}\gamma\right) * B(\Sigma^0 \to \Lambda\gamma) * B(\Lambda \to p\pi^-) * B(\overline{\Lambda} \to \bar{p}\pi^+) * \varepsilon_{\overline{\Sigma^0}\Sigma^0} \\
&= 448 * 10^6 * 2.35 * 10^{-4} * 1 * 1 * 0.639 * 0.639 * 0.00080 \\
&= 34
\end{aligned}
$$

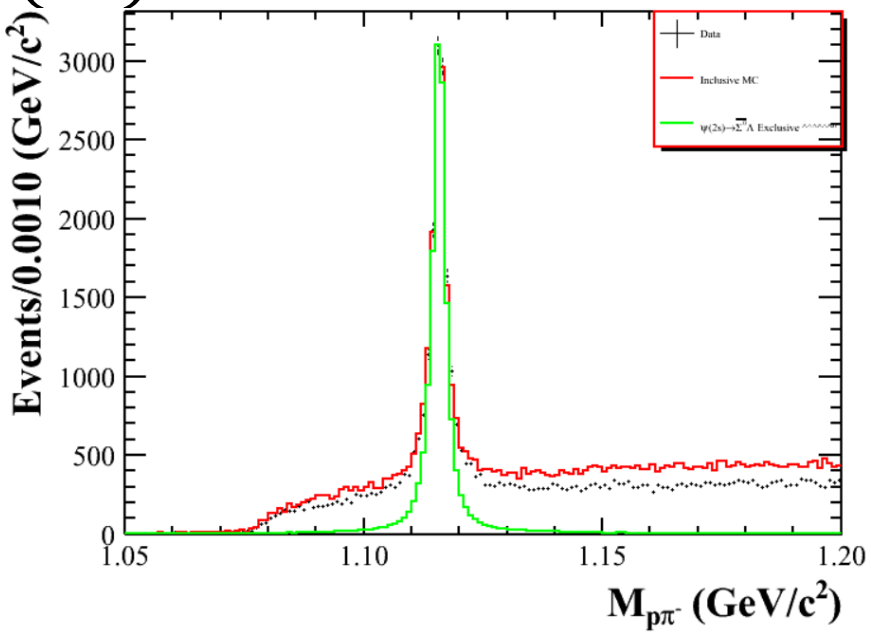
- $\psi(2s) \to \overline{\Sigma^0}\Lambda$

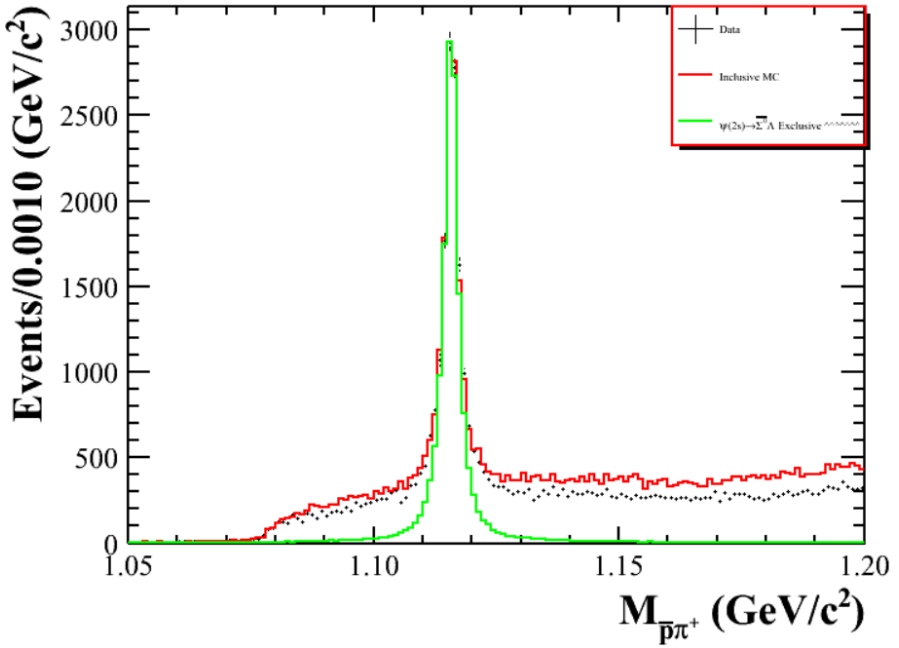
The efficiencies calculation of $\psi(2s) \to \overline{\Sigma^0}\Sigma$ in process $\psi(2s) \to \overline{\Sigma^0}\Lambda$ is $\varepsilon_{\psi(2s)\to\overline{\Sigma^0}\Sigma} = 0.088\%$

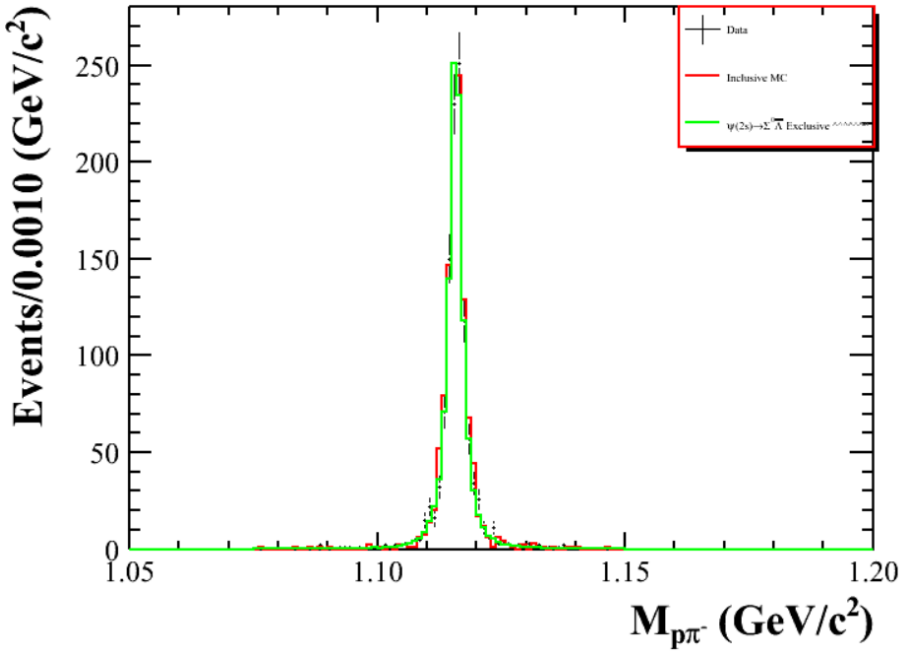
$$
\begin{aligned}
&N_{\ peaking\ bkg} \\
&= N_{\psi(2s)} * B\left(\psi(2s) \to \overline{\Sigma^0}\Sigma\right) * B\left(\overline{\Sigma^0} \to \overline{\Lambda}\gamma\right) * B(\Sigma^0 \to \Lambda\gamma) * B(\Lambda \to p\pi^-) * B(\overline{\Lambda} \to \bar{p}\pi^+) * \varepsilon_{\overline{\Sigma^0}\Sigma^0} \\
&= 448 * 10^6 * 2.35 * 10^{-4} * 1 * 1 * 0.639 * 0.639 * 0.00088 \\
&= 38
\end{aligned}
$$

the numbers of backgrounds of $\overline{\Sigma^0}\Sigma$ determined to be N =34 and N = 38 in $\Sigma^0\overline{\Lambda}$ and $\overline{\Sigma^0}\Lambda$ processes respectively. That numbers are fixed during the fit.

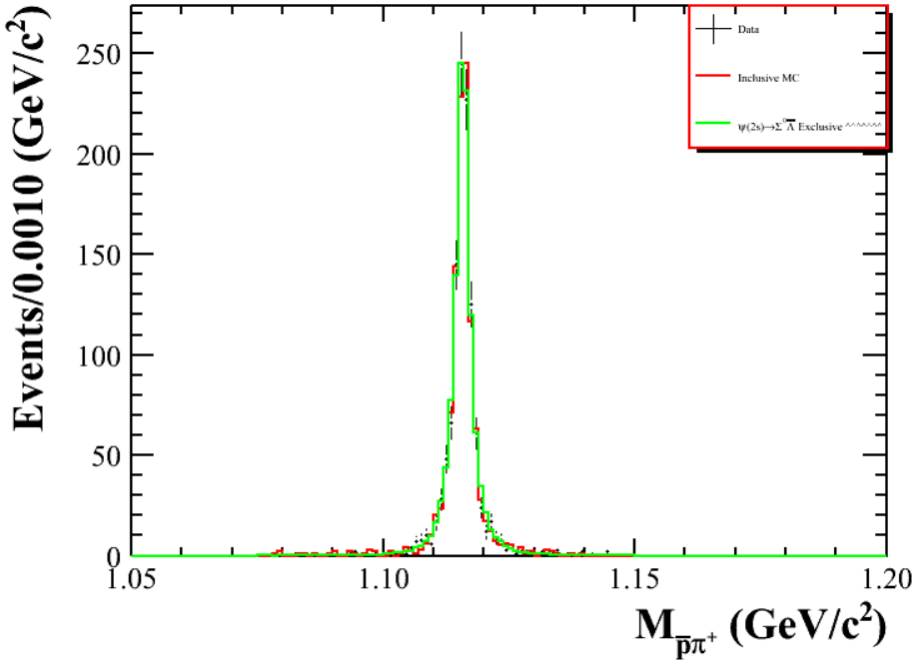
$\psi(2s) \to \Sigma^0\overline{\Lambda}$







Invariant mass distribution of Λ



Invariant mass distribution of $\overline{\Lambda}$

$\psi(2s) \to \overline{\Sigma^0}\Lambda$