

BOSS version : 6.6.4 p03(09,12) 707p01(21)  
Dataset :1 million Signal MC (09) for  $\gamma \pi^+ \pi^-$   
1 million Signal MC(09) for  $\eta \pi^+ \pi^-$   
 $\psi(2S)$  data (09,12,21)  
 $\psi(2S)$  inclusive MC (09,12,21)

```
Decay psi(2S)
1.0 Lambda0 anti-Lambda0 eta' PHSP;
Enddecay

Decay Lambda0
1.0 p+ pi- PHSP;
Enddecay

Decay anti-Lambda0
1.0 anti-p- pi+ PHSP;
Enddecay

Decay eta'
1.0 gamma pi+ pi- PHSP;
Enddecay

End
```

```
Decay psi(2S)
1 Lambda0 anti-Lambda0 eta' PHSP;
Enddecay

Decay Lambda0
1 p+ pi- PHSP;
Enddecay

Decay anti-Lambda0
1 anti-p- pi+ PHSP;
Enddecay

Decay eta'
1 eta pi+ pi- PHSP;
Enddecay

Decay eta
1 gamma gamma PHSP;
Enddecay

End
```

## Event selection

### 1. Charged track :

- At least 3 positive and 3 negative charged track;
- Polar angle of each track in MDC:  $|\cos \theta| < 0.93$ ;

### 2. $\Lambda\bar{\Lambda}$ reconstruction:

- Vertex fit of one pair of opposite charged tracks save as  $\Lambda/\bar{\Lambda}$  candidate with  $\chi^2 < 50$ ;
- At least one pair of  $\Lambda\bar{\Lambda}$ ;
- The minimal value of  $(M_{\Lambda} - M_{\Lambda}^{PDG})^2 + (M_{\bar{\Lambda}} - M_{\bar{\Lambda}}^{PDG})^2$  kept;

### 3. $\pi^+ \pi^-$ (from $\eta'$ ) vertex fit:

PID for selecting p and  $\pi$ :  $\text{prob}(p) > \text{prob}(\pi) \&\& \text{prob}(p) > \text{prob}(K)$  saved as proton , else saved as  $\pi$ ;

### 4. Good shower:

- Shower energy:  $E_{\gamma} > 25\text{MeV}$  for the barrel EMC ( $|\cos \theta| < 0.8$ ),  $E_{\gamma} > 50\text{MeV}$  for the endcap EMC ( $0.86 < |\cos \theta| < 0.92$ );
- EMC time (0,700)ns;
- Opening angle between shower and the nearest charged track  $> 10^\circ$ ;
- angle between the direction of the photon and anti-proton is required to be greater than  $30^\circ$
- $N_{\text{shower}} \geq 1$  for  $\gamma \pi^+ \pi^-$ , and  $\geq 2$  for  $\eta \pi^+ \pi^-$ ;

5.4C Kinematic fit(1 gamma): constrain to  $\psi(2s)$ 's four momenta;

6.5C Kinematic fit(2 gamma): 1C for  $\eta$  nominal mass, 4C for  $\psi(2s)$ 's four momenta;

$$\eta' \rightarrow \gamma \pi^+ \pi^-$$

Cut:

$$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}$$

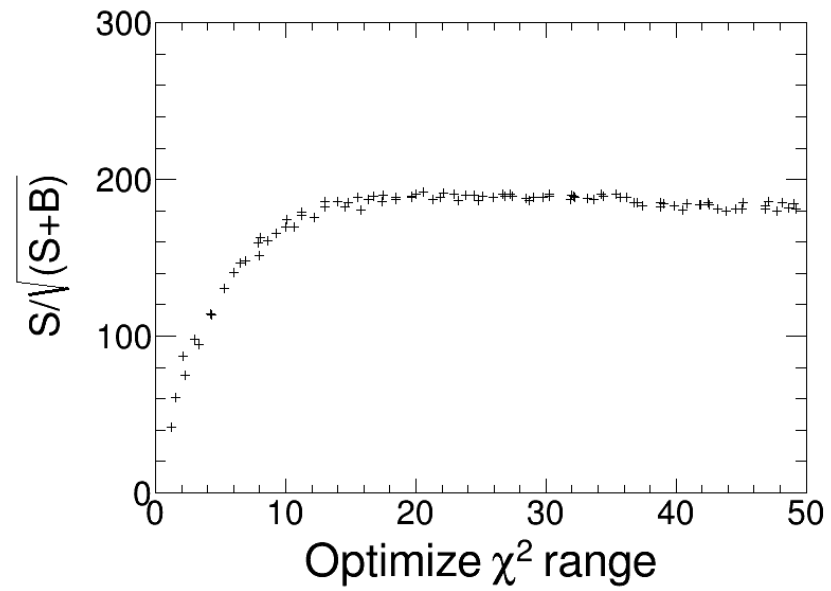
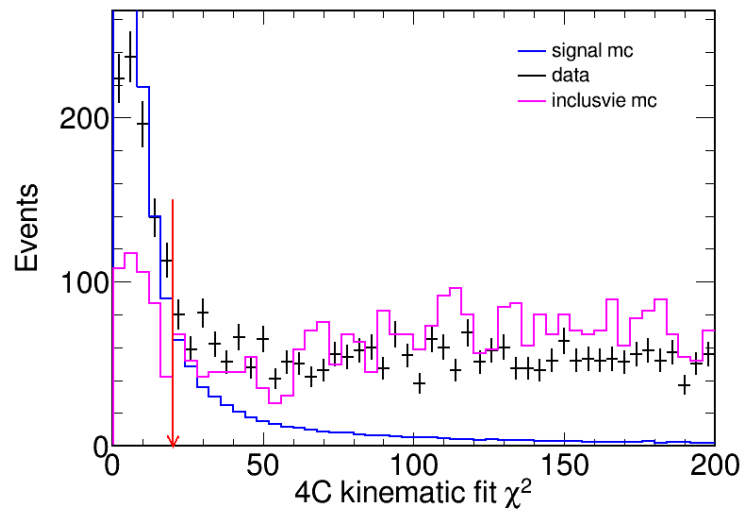
$$\chi^2(4c) < 20;$$

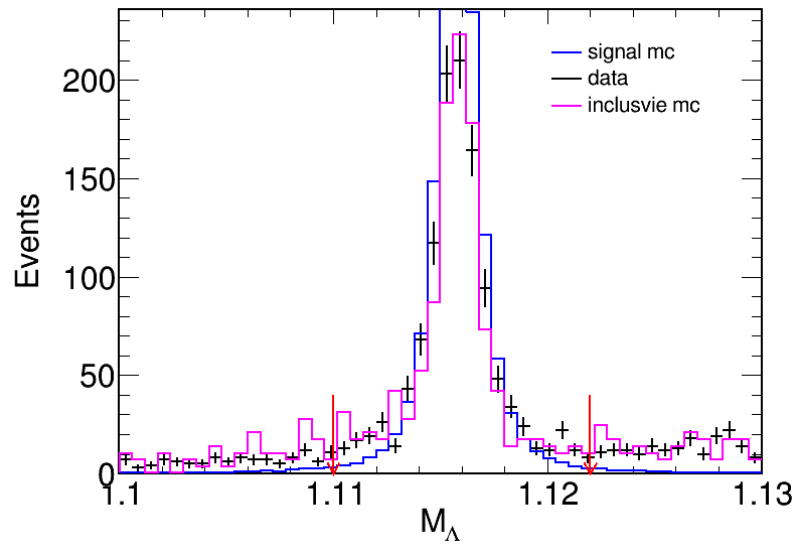
$$M_{\eta'} \in (0.93, 0.98) \text{ GeV};$$

$$|M_{\gamma\Lambda(\bar{\Lambda})} - 1.193 \text{ GeV}| > 10 \text{ MeV};$$

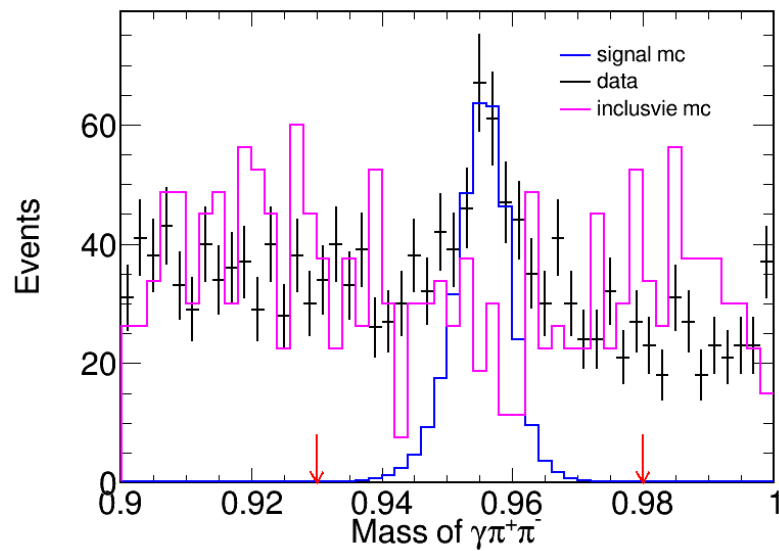
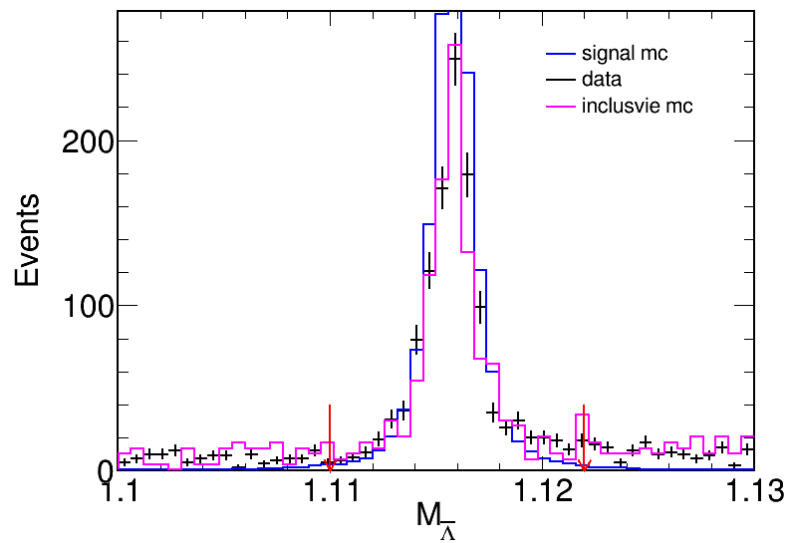
$$|M_{\gamma}^{\text{recoil}} - 2.984 \text{ GeV}| > 50 \text{ MeV}; |M_{\gamma}^{\text{recoil}} - M_{\chi_{c1}}| > 15 \text{ MeV}, |M_{\gamma}^{\text{recoil}} - M_{\chi_{c1(2)}}| > 10 \text{ MeV}$$

$$\text{Veto } M_{2\pi}^{\text{recoil}} \in (3.077, 3.117)$$

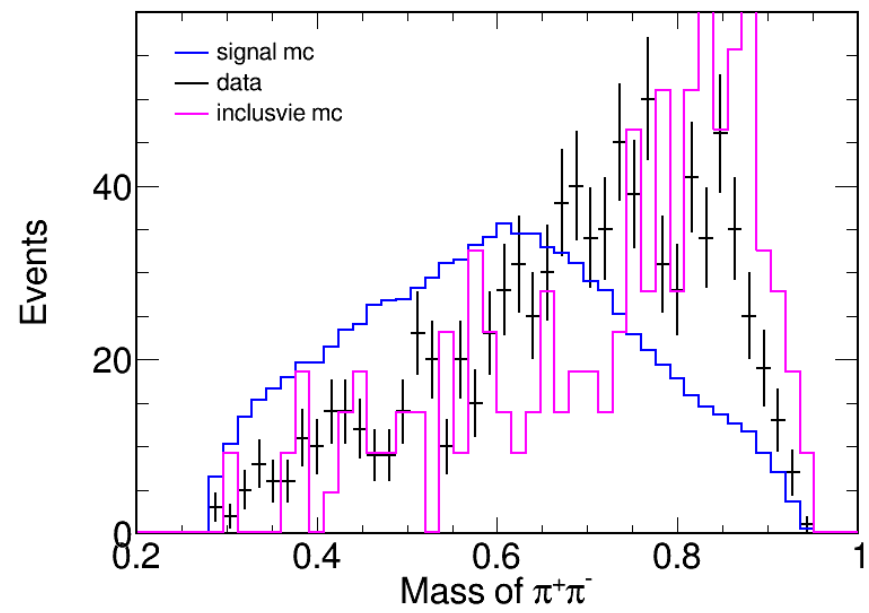


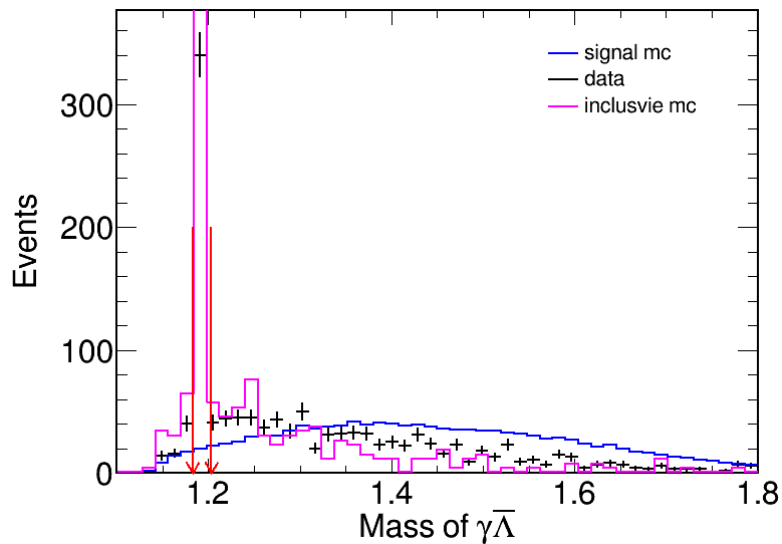
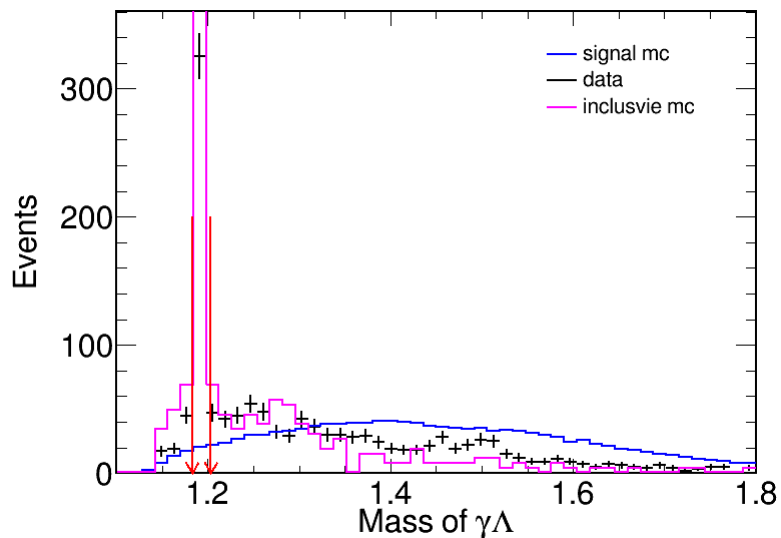


$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}$

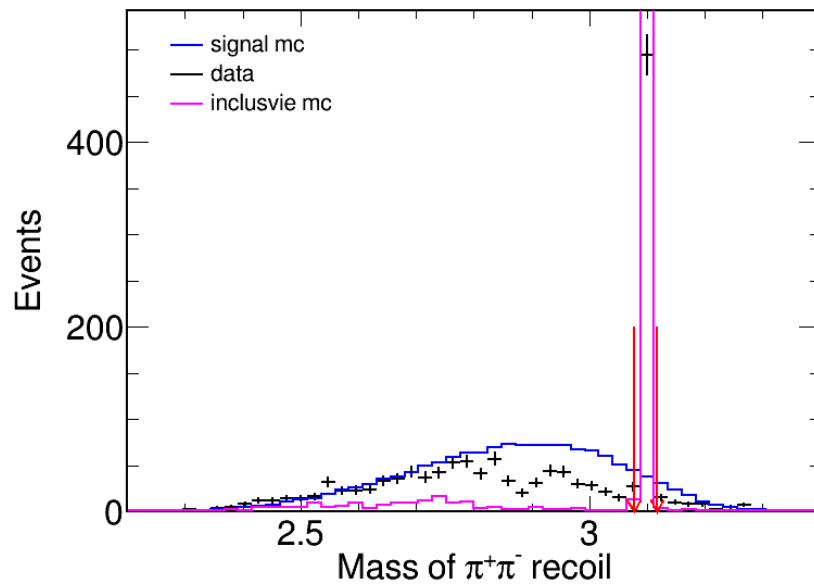
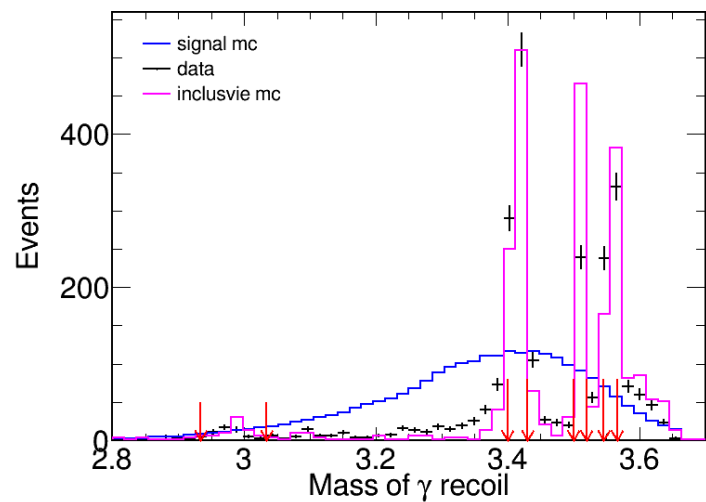


$M_{\eta'} \in (0.93, 0.98) \text{ GeV};$





$$|M_{\gamma\Lambda(\bar{\Lambda})} - 1.193\text{GeV}| > 10\text{ MeV};$$



$$|M_{\gamma}^{\text{recoil}} - 2.984\text{GeV}| > 50\text{MeV}; |M_{\gamma}^{\text{recoil}} - M_{\chi_{c1}}| > 15\text{MeV},$$

$$|M_{\gamma}^{\text{recoil}} - M_{\chi_{c1(2)}}| > 10\text{MeV}$$

$$\text{Veto } M_{2\pi}^{\text{recoil}} \in (3.077, 3.117)$$

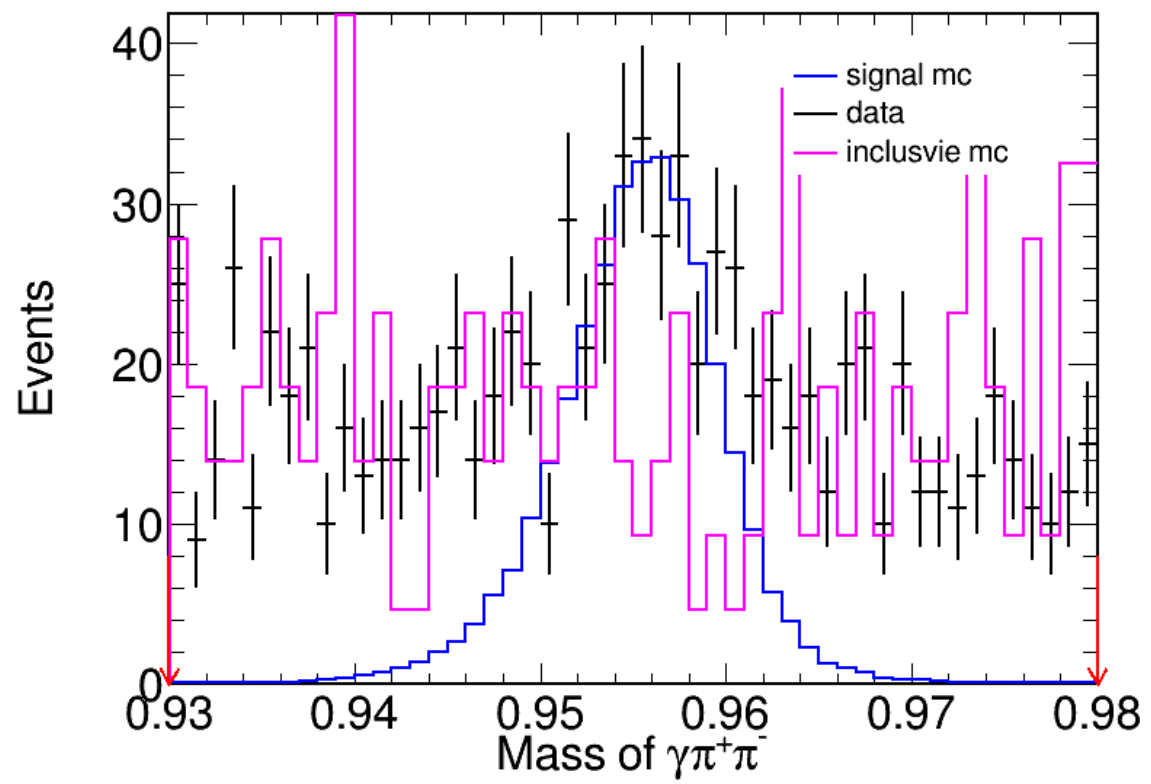




Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow \pi^+\Lambda\bar{\Sigma}^{*-}, \Lambda \rightarrow \pi^-p, \bar{\Sigma}^{*-} \rightarrow \pi^-\bar{\Lambda}, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	5	19	19
2	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow \pi^-\bar{\Sigma}^{*+}\Lambda, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	10	16	35
3	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow \pi^-\bar{\Lambda}\Sigma^{*+}, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Sigma^{*+} \rightarrow \pi^+\Lambda, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	17	16	51
4	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow \pi^+\Sigma^{*-}\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	8	11	62
5	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow K^{*-}p\bar{\Lambda}, K^{*-} \rightarrow \pi^-K^0, \bar{\Lambda} \rightarrow \pi^+\bar{p}, K^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+\pi^-$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	0	9	71
6	$\psi' \rightarrow \pi^+\pi^-J/\psi, J/\psi \rightarrow \Lambda\bar{\Lambda}\gamma, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	14	7	78
7	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow K^{*+}\bar{p}\Lambda, K^{*+} \rightarrow \pi^+K^0, \Lambda \rightarrow \pi^-p, K^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+\pi^-$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	11	4	82
8	$\psi' \rightarrow \chi_{c1}\gamma, \chi_{c1} \rightarrow \pi^+\Sigma^{*-}\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	12	4	86
9	$\psi' \rightarrow \Xi^+\Xi^-\gamma, \Xi^+ \rightarrow \pi^+\bar{\Lambda}, \Xi^- \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	42	4	90
10	$\psi' \rightarrow \eta_c\gamma, \eta_c \rightarrow \Xi^+\Xi^-, \Xi^+ \rightarrow \pi^+\bar{\Lambda}, \Xi^- \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	22	3	93
11	$\psi' \rightarrow \chi_{c1}\gamma, \chi_{c1} \rightarrow \pi^+\Lambda\bar{\Sigma}^{*-}, \Lambda \rightarrow \pi^-p, \bar{\Sigma}^{*-} \rightarrow \pi^-\bar{\Lambda}, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	29	3	96
12	$\psi' \rightarrow \chi_{c0}\gamma, \chi_{c0} \rightarrow \Xi^+\Xi^-, \Xi^+ \rightarrow \pi^+\bar{\Lambda}, \Xi^- \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	9	3	99
13	$\psi' \rightarrow \pi^0J/\psi, J/\psi \rightarrow \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	16	2	101
14	$\psi' \rightarrow \bar{\Sigma}^{*+}\Sigma^{*-}\gamma, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	2	2	103
15	$\psi' \rightarrow \pi^0\bar{\Sigma}^{*+}\Sigma^{*-}, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	18	2	105
16	$\psi' \rightarrow \pi^-\bar{\Sigma}^{*+}\Lambda\gamma^f, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma^f$	6	2	107
17	$\psi' \rightarrow \chi_{c1}\gamma, \chi_{c1} \rightarrow \pi^-\bar{\Sigma}^{*+}\Lambda, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	13	2	109
18	$\psi' \rightarrow \pi^+\Sigma^{*-}\bar{\Lambda}\gamma^f, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma^f$	34	2	111
19	$\psi' \rightarrow \pi^+\pi^-\Lambda\bar{\Lambda}\gamma^f, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma^f$	36	2	113
20	$\psi' \rightarrow \Sigma^{*+}\bar{\Sigma}^{*-}\gamma, \Sigma^{*+} \rightarrow \pi^+\Lambda, \bar{\Sigma}^{*-} \rightarrow \pi^-\bar{\Lambda}, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	38	2	115

criteria	Efficiency (%)
$\Lambda(\bar{\Lambda})$ reconstruction	44.46
$\pi^+\pi^-$ vertex fit	21.07
Pass 4c kinematic fit	11.46
$\chi^2(4c) < 20$	7.63
$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}/c^2$	7.18
$M_{\eta'} \in (0.93, 0.98) \text{ GeV}/c^2$	7.15
$ M_{\gamma\Lambda(\bar{\Lambda})} - 1.193 \text{ GeV}  > 10 \text{ MeV}/c^2$	6.88
$ M_{\gamma}^{\text{recoil}} - M_{\chi_{cj}}  > 10 \text{ MeV}, \eta_c$	5.84
Veto $M_{2\pi}^{\text{recoil}} \in (3.077, 3.117) \text{ GeV}/c^2$	5.55

$$\eta' \rightarrow \eta \pi^+ \pi^-$$

Cut:

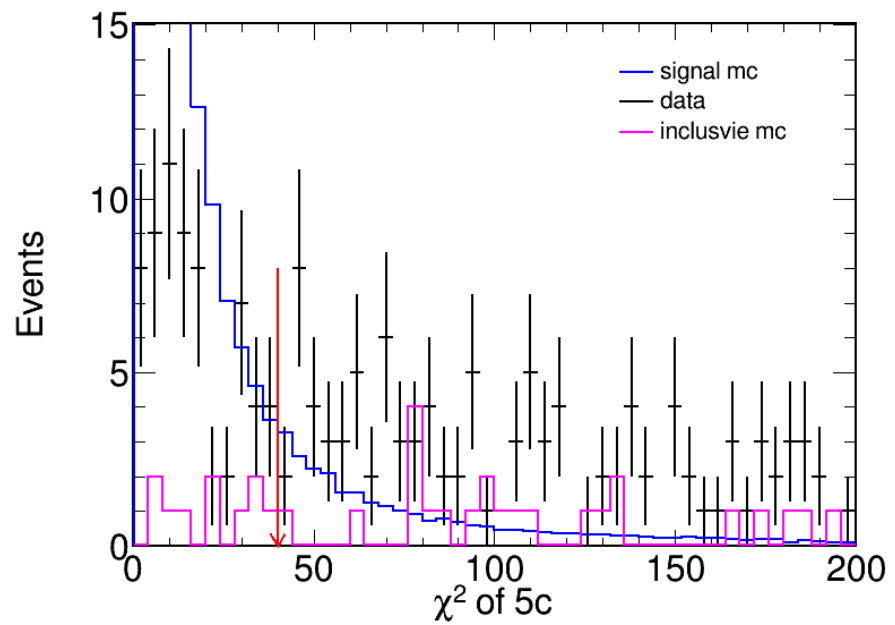
$$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}$$

$$\chi^2(5c) < 20;$$

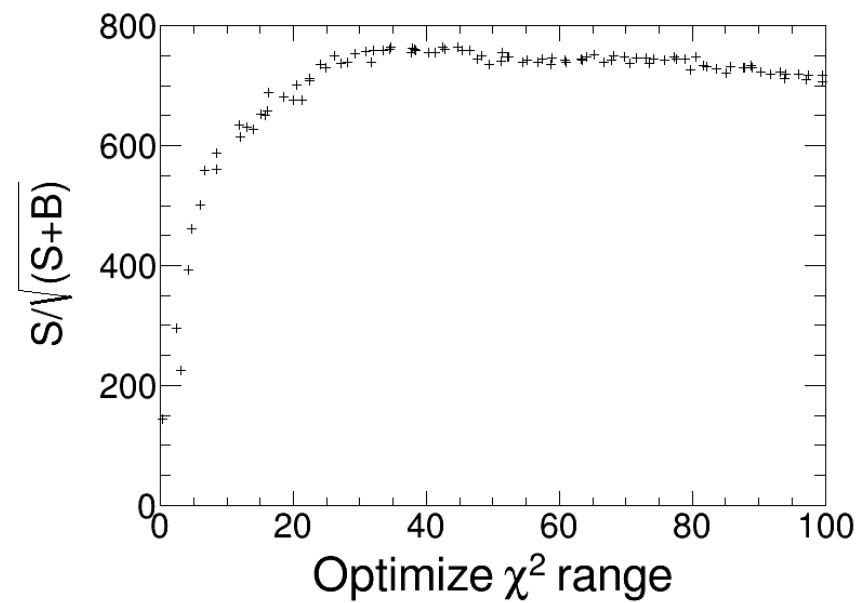
$$M_{\eta'} \in (0.93, 0.98) \text{ GeV};$$

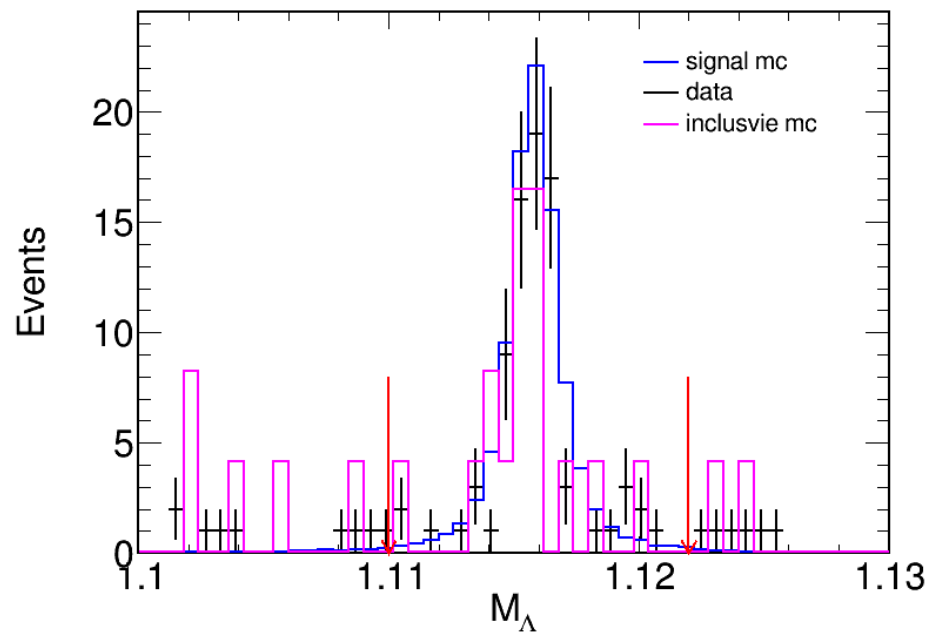
$$|M_{\eta}^{recoil} - 3.097| > 10 \text{ MeV}$$

$$|M_{2\pi}^{recoil} - 3.097| > 20 \text{ MeV}$$

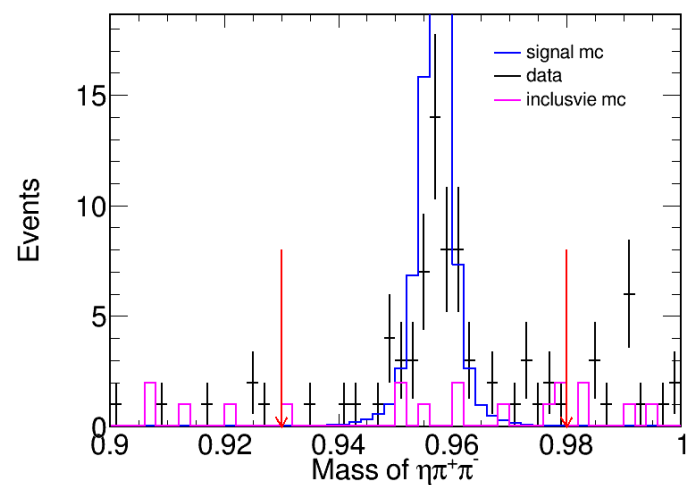
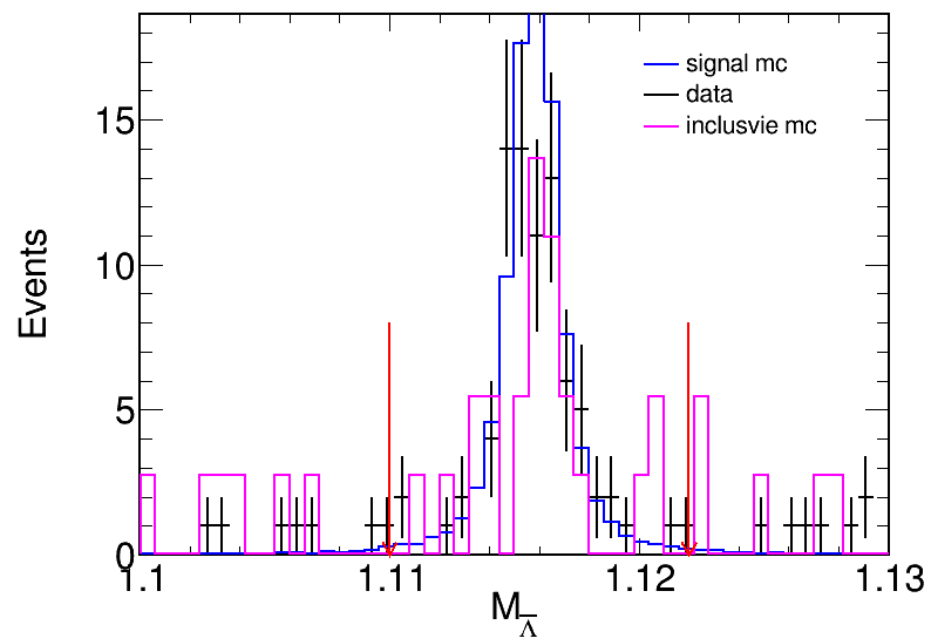


$\chi^2(5c) < 40$

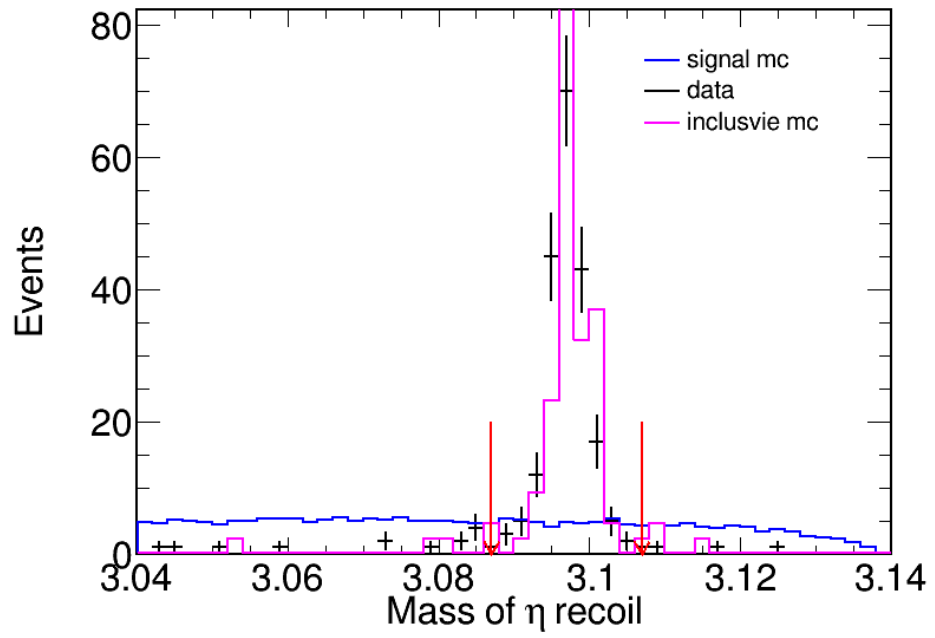




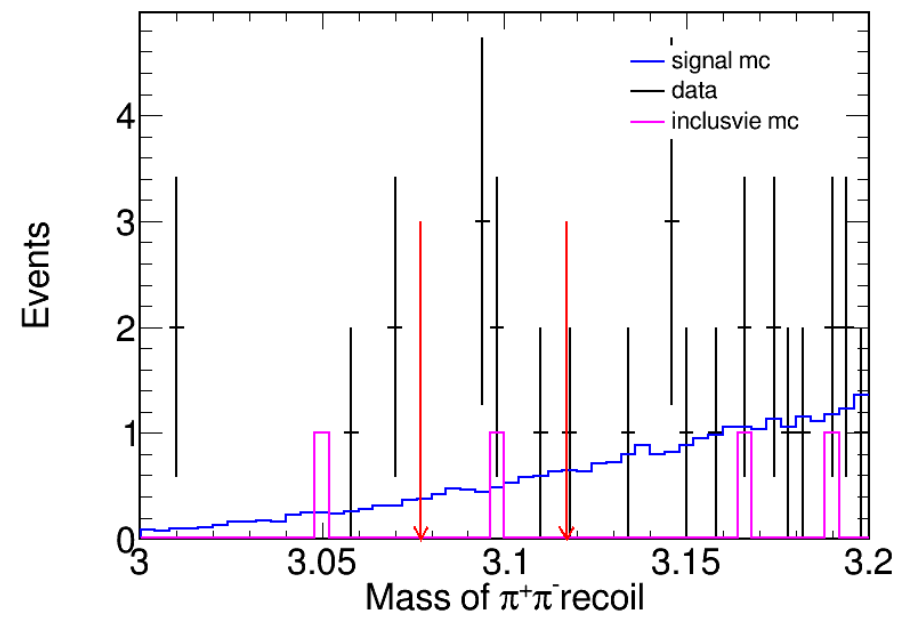
$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}$



$M_{\eta' } \in (0.93, 0.98) \text{ GeV};$



$$|M_{\eta}^{recoil} - 3.097| > 10 \text{ MeV}$$



$$|M_{2\pi}^{recoil} - 3.097| > 20 \text{ MeV}$$

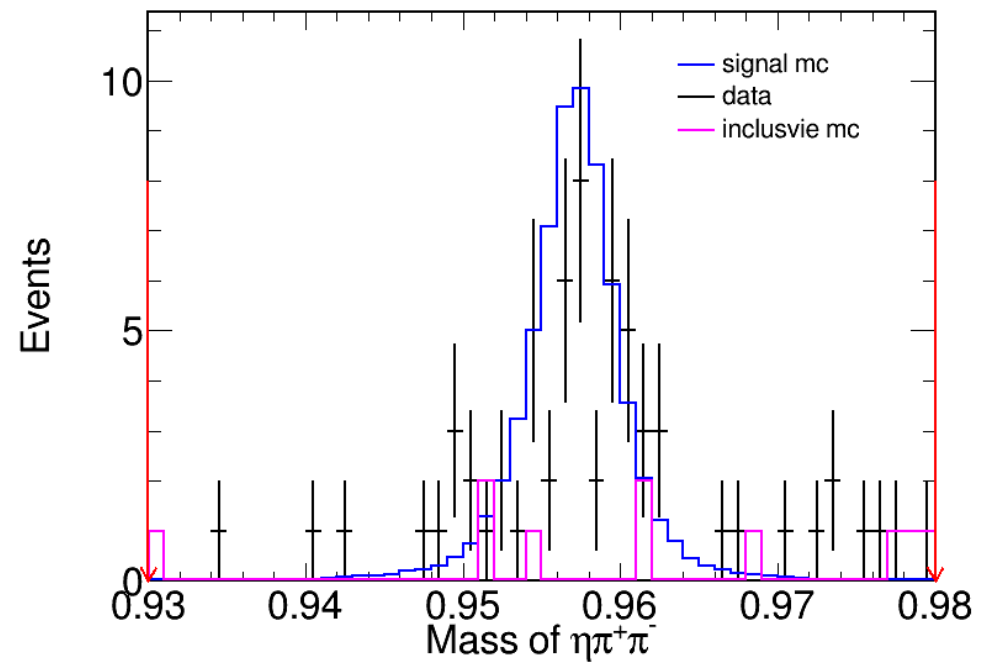


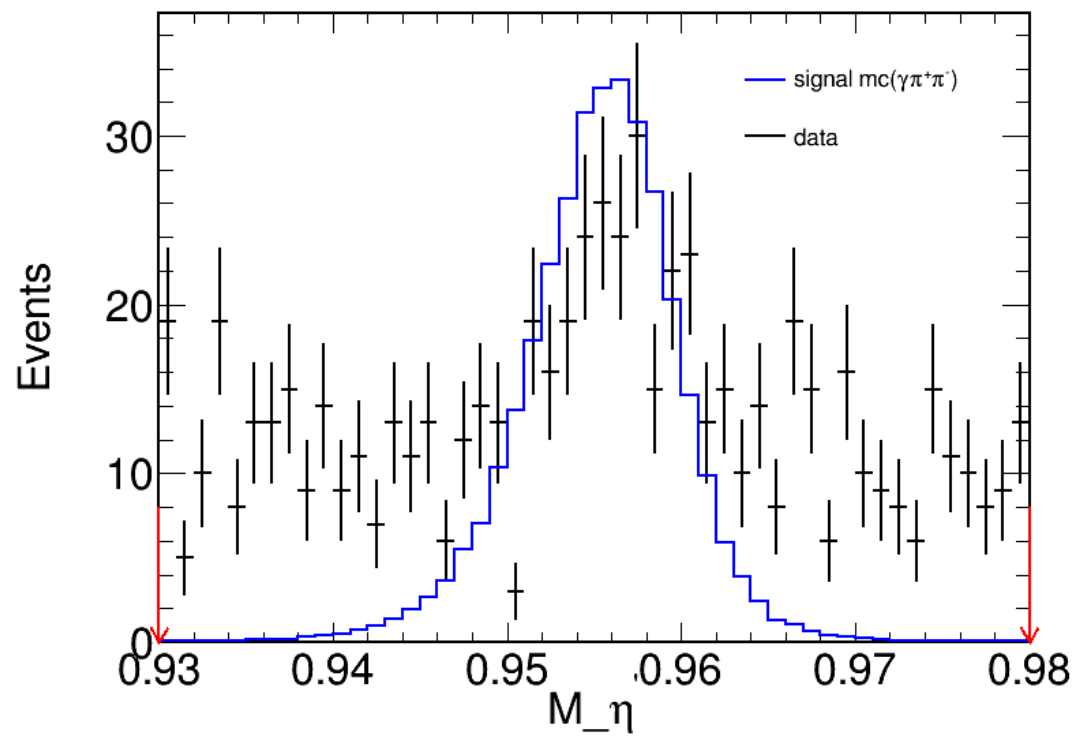
Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \rightarrow \chi_{c1}\gamma, \chi_{c1} \rightarrow J/\psi\gamma, J/\psi \rightarrow \Xi^+\Xi^-, \Xi^+ \rightarrow \pi^+\bar{\Lambda}, \Xi^- \rightarrow \pi^-\Lambda,$ $\bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	2	2	2
2	$\psi' \rightarrow \pi^0\pi^0J/\psi, J/\psi \rightarrow \pi^+\Sigma^{*-}\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	1	1	3
3	$\psi' \rightarrow \eta'\Lambda\bar{\Lambda}, \eta' \rightarrow \pi^+\pi^-\eta, \Lambda \rightarrow \pi^-p, \bar{\Lambda} \rightarrow \pi^+\bar{p}, \eta \rightarrow \gamma\gamma$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	0	1	4
4	$\psi' \rightarrow \chi_{c2}\gamma, \chi_{c2} \rightarrow \pi^0\bar{\Sigma}^+\Sigma^{*-}, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p},$ $\Lambda \rightarrow \pi^-p$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	3	1	5
5	$\psi' \rightarrow \eta J/\psi, \eta \rightarrow \gamma\gamma, J/\psi \rightarrow \bar{\Sigma}^{*+}\Sigma^{*-}, \bar{\Sigma}^{*+} \rightarrow \pi^+\bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^-\Lambda,$ $\bar{\Lambda} \rightarrow \pi^+\bar{p}, \Lambda \rightarrow \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	4	1	6
6	$\psi' \rightarrow \pi^+\pi^-J/\psi, J/\psi \rightarrow \eta'p\bar{p}, \eta' \rightarrow \pi^+\pi^-\eta, \eta \rightarrow \gamma\gamma$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	5	1	7
7	$\psi' \rightarrow \eta\Sigma^{*+}\bar{\Sigma}^{*-}, \eta \rightarrow \gamma\gamma, \Sigma^{*+} \rightarrow \pi^+\Lambda, \bar{\Sigma}^{*-} \rightarrow \pi^-\bar{\Lambda}, \Lambda \rightarrow \pi^-p,$ $\bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	6	1	8
8	$\psi' \rightarrow \chi_{c1}\gamma, \chi_{c1} \rightarrow \pi^0\Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \rightarrow \pi^+\Lambda, \bar{\Sigma}^{*-} \rightarrow \pi^-\bar{\Lambda}, \Lambda \rightarrow \pi^-p,$ $\bar{\Lambda} \rightarrow \pi^+\bar{p}$	$\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	7	1	9
9	$\psi' \rightarrow \pi^0\pi^0J/\psi, J/\psi \rightarrow \Xi^+\Xi^-, \Xi^+ \rightarrow \pi^+\bar{\Lambda}, \Xi^- \rightarrow \pi^-\Lambda, \bar{\Lambda} \rightarrow \pi^+\bar{p},$ $\Lambda \rightarrow \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	8	1	10



## Cut flow

criteria	Efficiency (%)
$\Lambda(\bar{\Lambda})$ reconstruction	44.46
$\pi^+\pi^-$ vertex fit	21.07
Pass 5c kinematic fit	5.08
$\chi^2(5c) < 40$	4.06
$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}/c^2$	3.78
$M_{\eta'} \in (0.93, 0.98) \text{ GeV}/c^2$	3.75
$ M_{\eta}^{recoil} - 3.097  > 10 \text{ MeV}$	3.39
$ M_{2\pi}^{recoil} - 3.097  > 20 \text{ MeV}$	3.16



$$M_{\eta'}(\gamma \pi^+ \pi^- + \eta \pi^+ \pi^-)$$