

BOSS version : 6.6.4 p03(09,12) 707p01(21)

Dataset :

1 million DIY Signal MC (21) for $\gamma \pi^+ \pi^-$

1 million DIY Signal MC(21) 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 pi+ pi- gamma DIY_Etap2gpipi_box 0;
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 pi+ pi- eta DIY_pipieta;
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 η') vertex fit:

- $|V_z| < 10\text{cm}, |V_{xy}| < 1\text{cm}$;
- PID for selecting p and π : $\text{prob}(p) > \text{prob}(\pi) \&\& \text{prob}(p) > \text{prob}(K)$ saved as proton , else saved as π ;

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°
- $N_{\text{shower}} \geq 1$ for $\gamma \pi^+ \pi^-$, and ≥ 2 for $\eta \pi^+ \pi^-$;

5.4C Kinematic fit($\gamma \pi^+ \pi^-$): constrain to $\psi(2s)$'s four momenta;

6.5C Kinematic fit($\eta \pi^+ \pi^-$): 1C for η nominal mass, 4C for $\psi(2s)$'s four momenta;

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

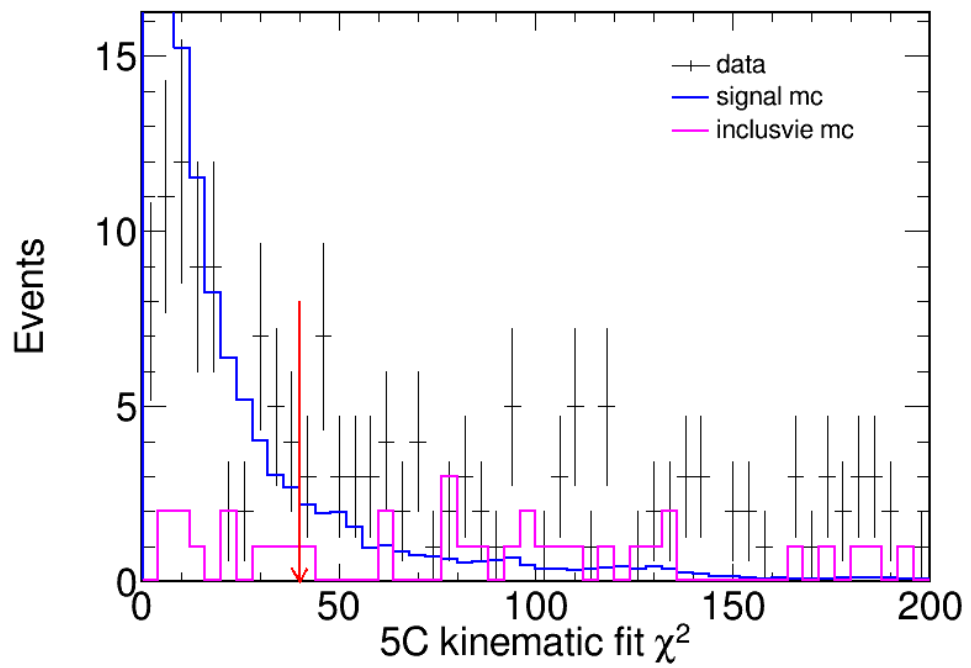
Cut:

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

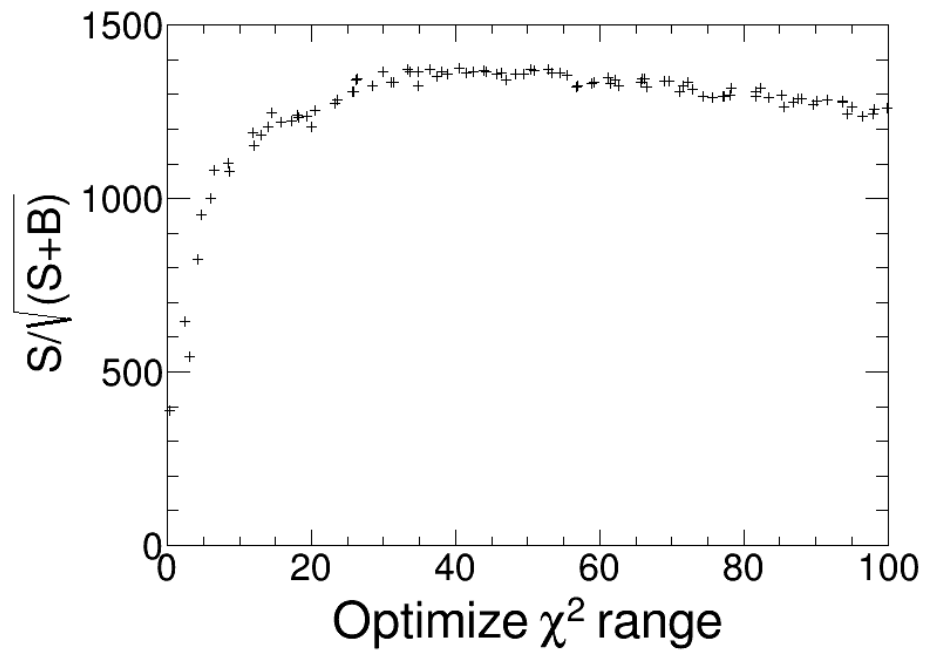
$$\chi^2(5c) < 40;$$

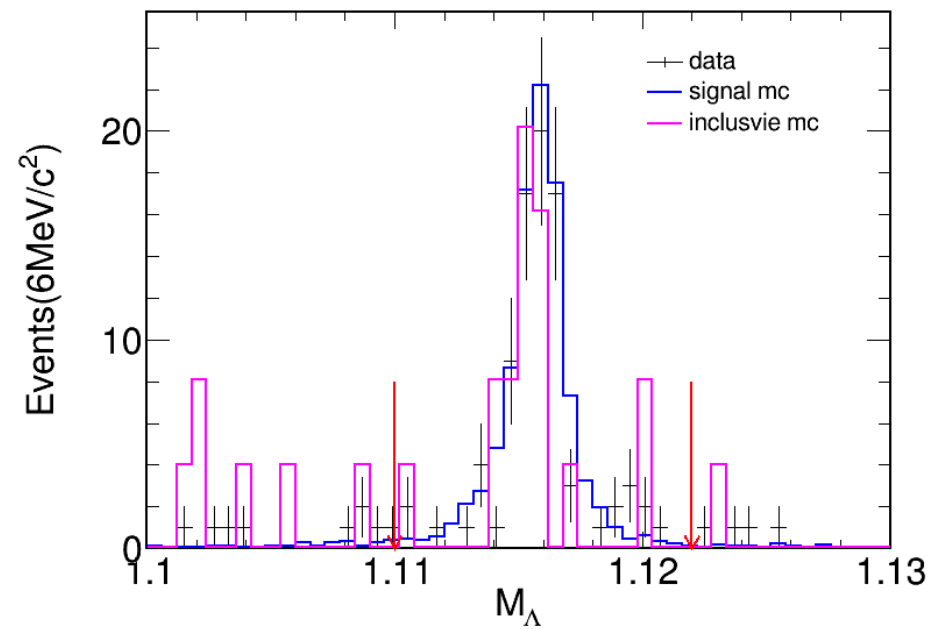
$$M_{\eta'} \in (0.94, 0.96) \text{ GeV};$$

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

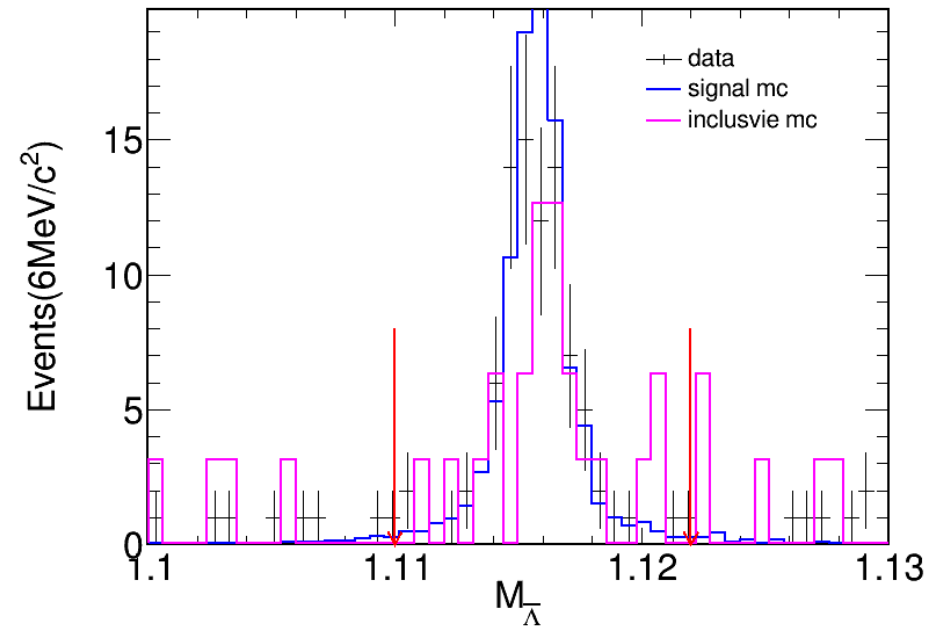


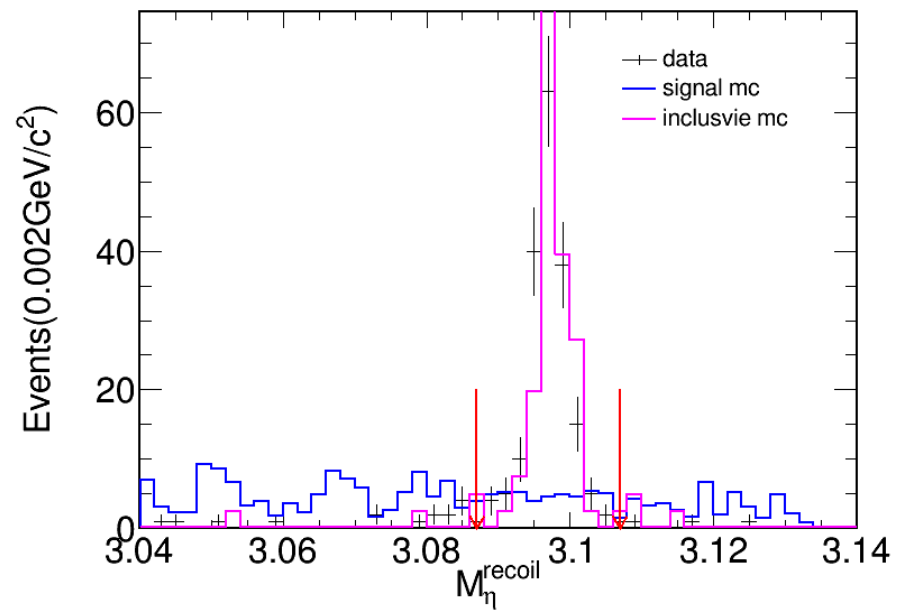
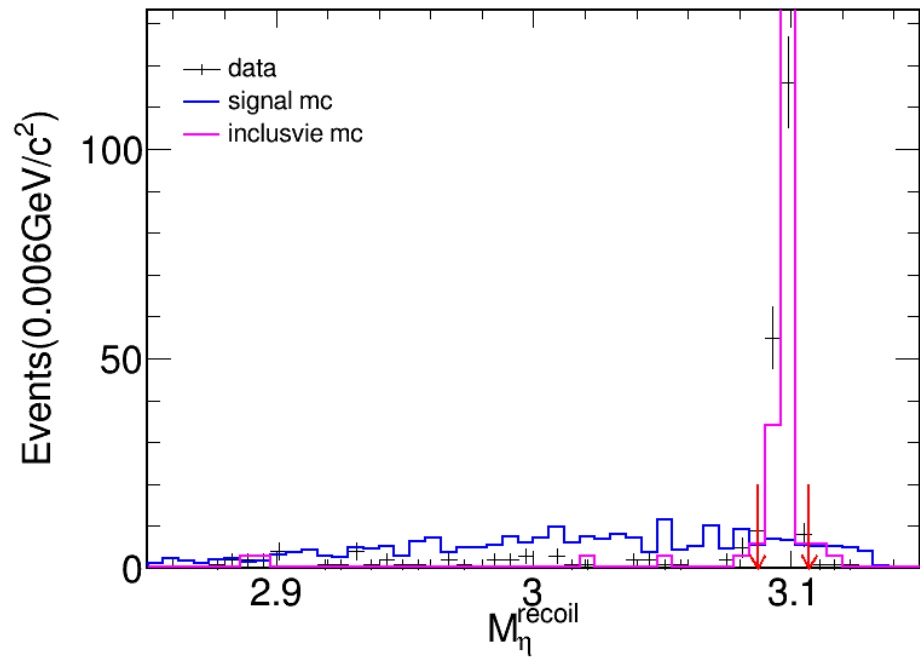
$\chi^2(5c) < 40$



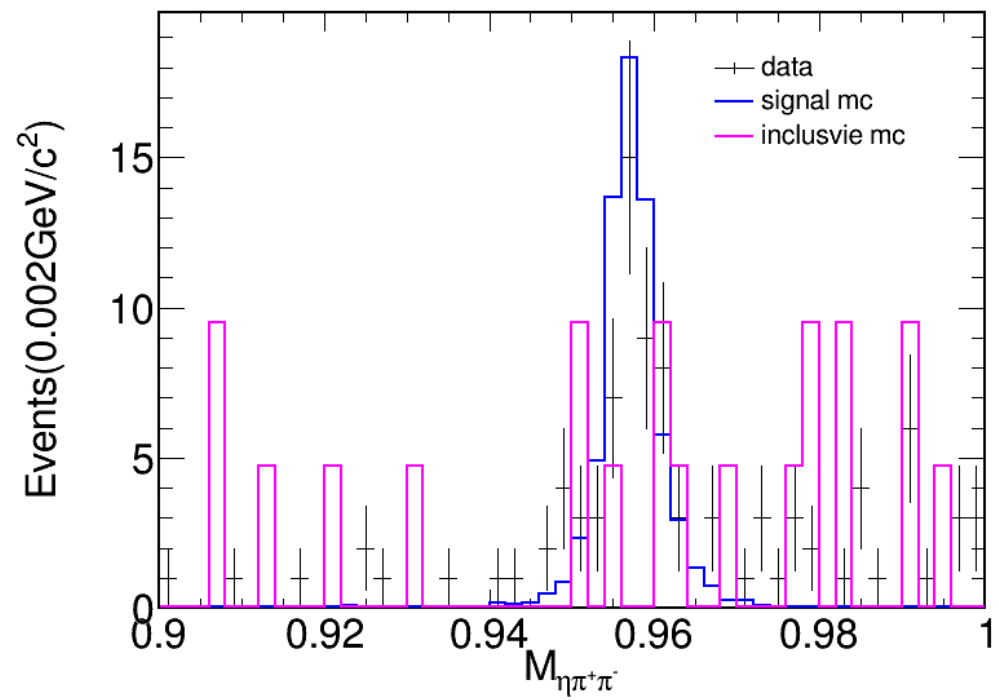


$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}$





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



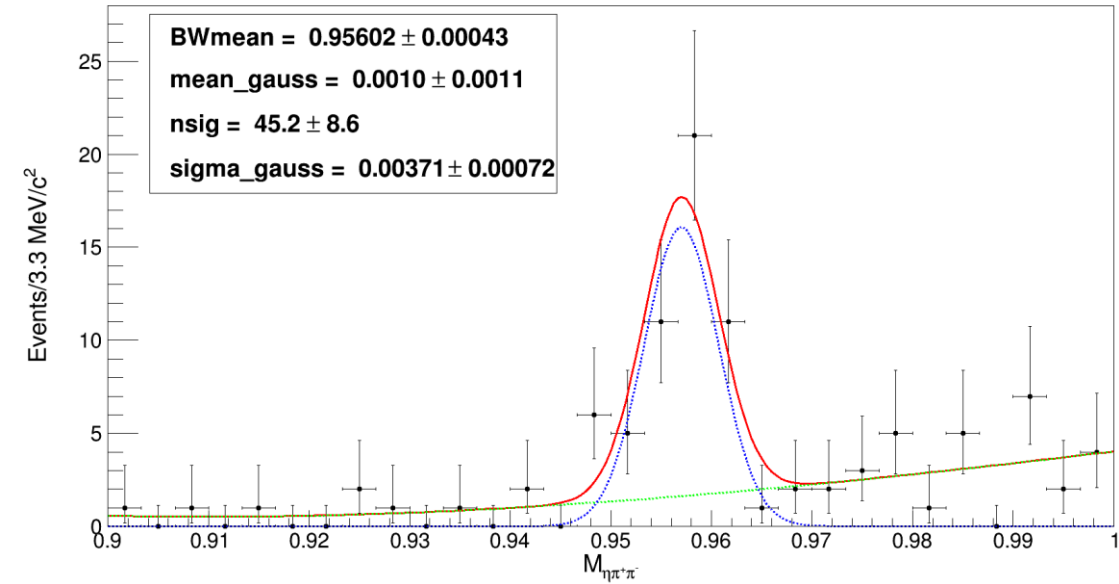
Cut flow

criteria	Efficiency (%)
$\Lambda(\bar{\Lambda})$ reconstruction	44.46
$\pi^+\pi^-$ vertex fit	21.07
Pass 5c kinematic fit	5.36
$\chi^2(5c) < 40$	4.08
$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}/c^2$	3.68
$M_{\eta'} \in (0.94, 0.98) \text{ GeV}/c^2$	3.61
$ M_{\eta}^{recoil} - 3.097 > 10 \text{ MeV}$	3.30

BW \otimes gauss + 3nd -chebychevnomial

Significance: 6.68

BR = 7.38e-6



```

FCN=-608.977 FROM HESSE      STATUS=OK          61 CALLS          236 TOTAL
                        EDM=2.02088e-05    STRATEGY= 1      ERROR MATRIX ACCURATE
EXT  PARAMETER              INTERNAL          INTERNAL
NO.  NAME                   VALUE            ERROR           STEP SIZE      VALUE
  1  BWmean                  9.56025e-01     4.29839e-04    3.18030e-05   -3.00394e-01
  2  a1                      9.74884e-01     4.46937e-01    5.35066e-04    1.34620e+00
  3  b1                      2.64454e-01     2.80381e-01    6.46045e-04    2.67638e-01
  4  c1                      -2.68209e-02    2.24033e-01    4.90697e-04   -2.68241e-02
  5  mean_gauss              1.04058e-03    1.13865e-03    2.35764e-04    1.04246e-01
  6  nbkg                   4.98441e+01     8.90115e+00    1.10013e-04    4.93705e-02
  7  nsig                   4.51547e+01     8.63979e+00    1.05558e-04   -4.93950e-02
  8  sigma_gauss            3.71204e-03     7.21340e-04    4.29442e-05    3.80305e-01
    
```

```

chisq/ndf: 0.998862
chi= 91.8953
Ndof= 92
NbinsX= 30
nParsToFit= 8
    
```

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

Cut:

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

$$\chi^2(4c) < 28;$$

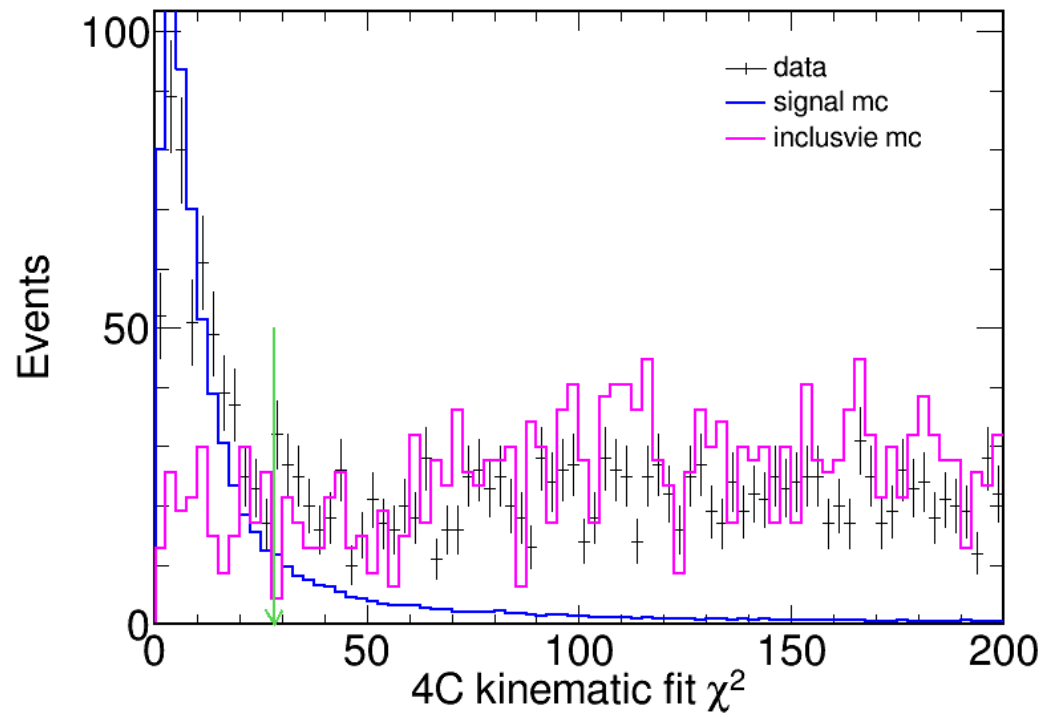
$$M_{\eta'} \in (0.94, 0.98) \text{ GeV};$$

$$|M_{\gamma\Lambda(\bar{\Lambda})} - 1.193 \text{ GeV}| > 20 \text{ MeV};$$

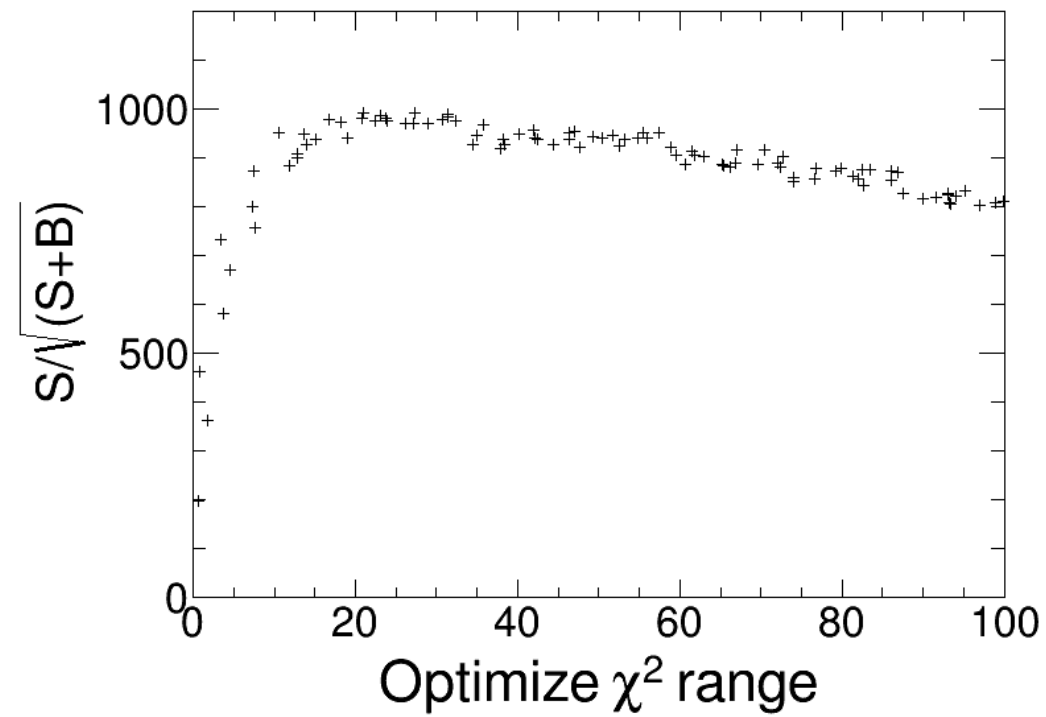
$$|M_{\gamma}^{\text{recoil}} - 2.984 \text{ GeV}| > 40 \text{ MeV}; |M_{\gamma}^{\text{recoil}} - M_{\chi_{c0}}| > 15 \text{ MeV}, |M_{\gamma}^{\text{recoil}} - M_{\chi_{c1}}| > 10 \text{ MeV}; |M_{\gamma}^{\text{recoil}} - M_{\chi_{c2}}| > 10 \text{ MeV}$$

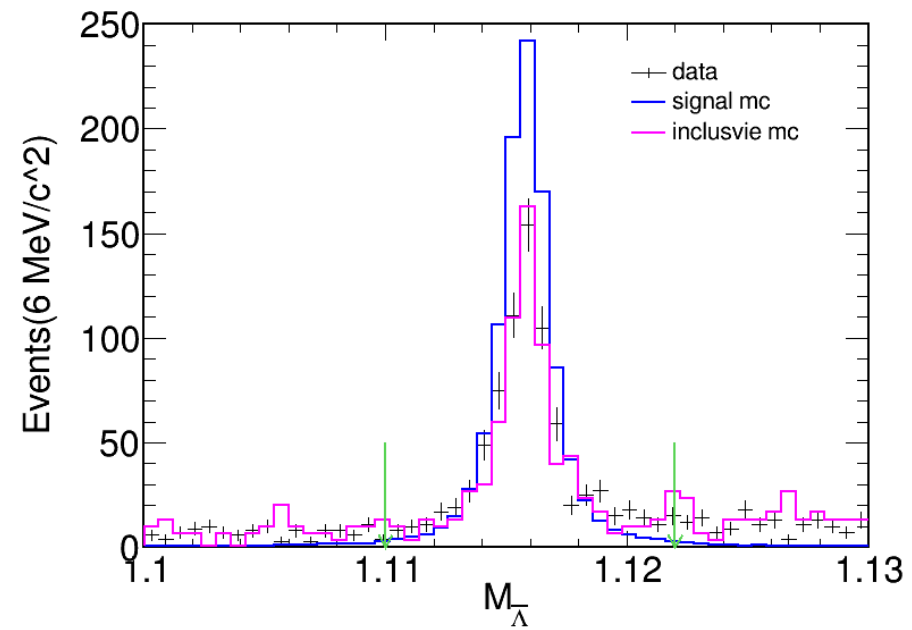
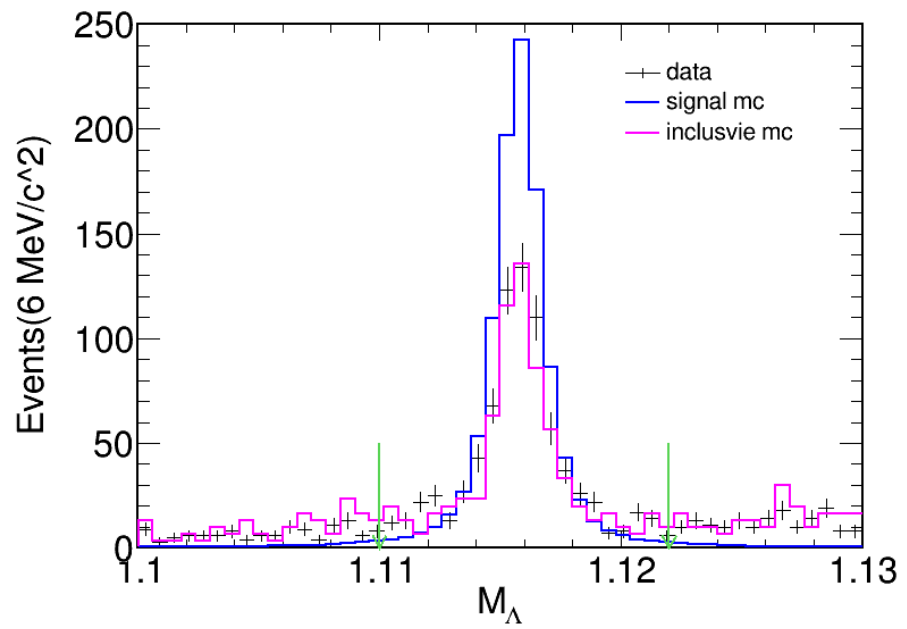
$$|M_{2\pi}^{\text{recoil}} - M_{j\psi}| > 10 \text{ MeV}$$

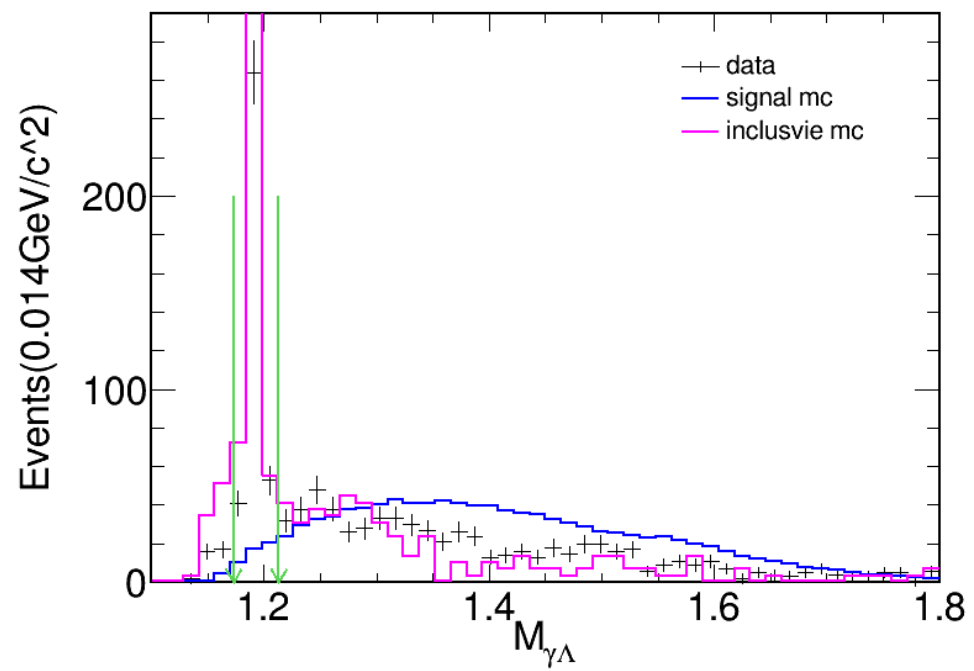
$$|M_{\Lambda\pi^-(\bar{\Lambda}\pi^+)} - M_{\chi_i}| > 8 \text{ MeV}; |M_{\Lambda\pi^-} - M_{\Sigma^*}| > 20 \text{ MeV};$$



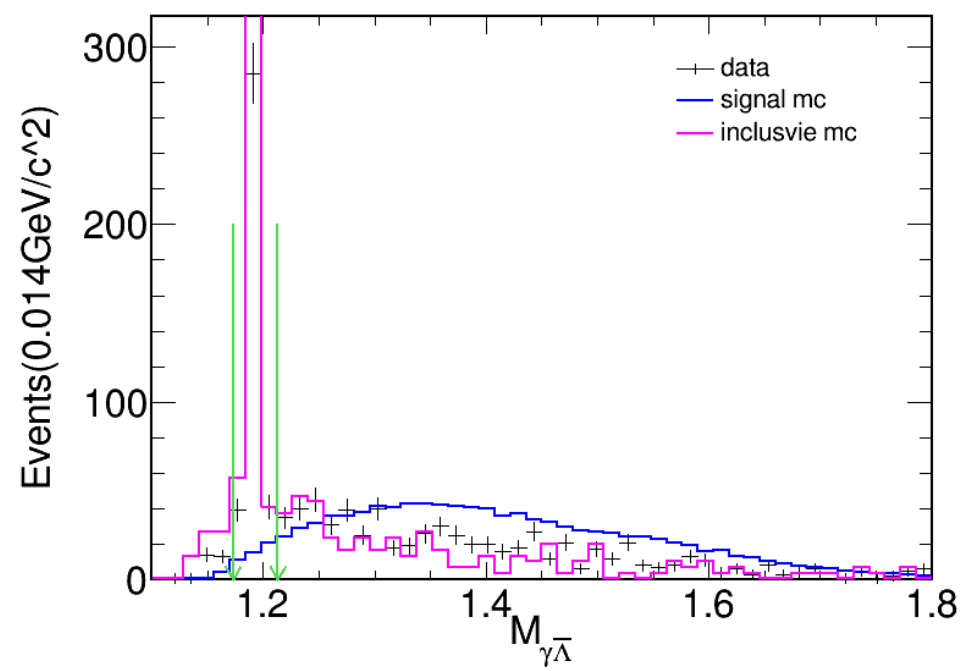
Chisq < 28

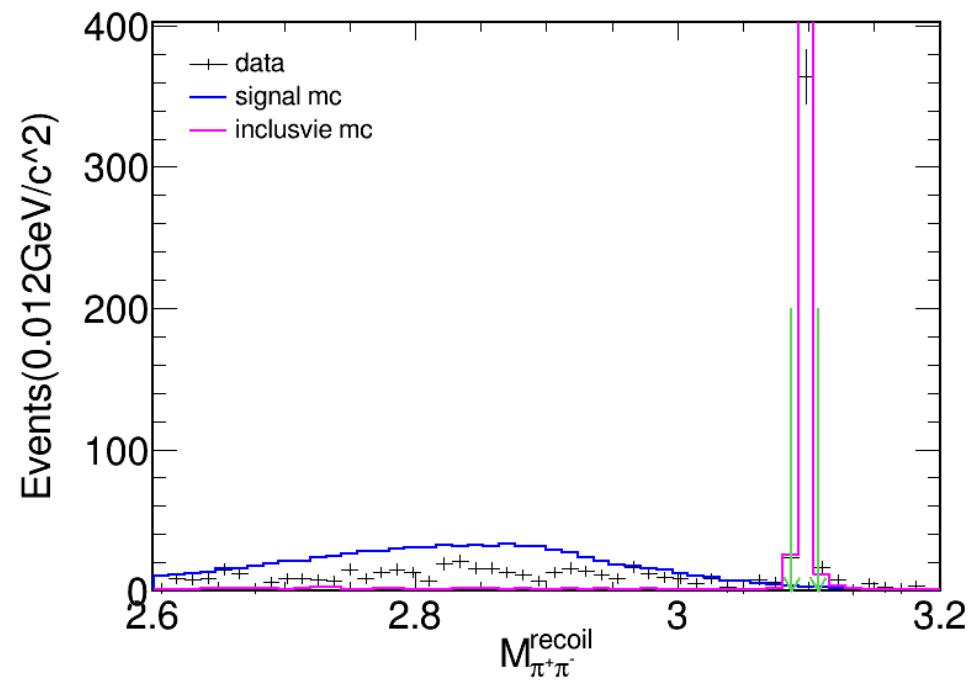




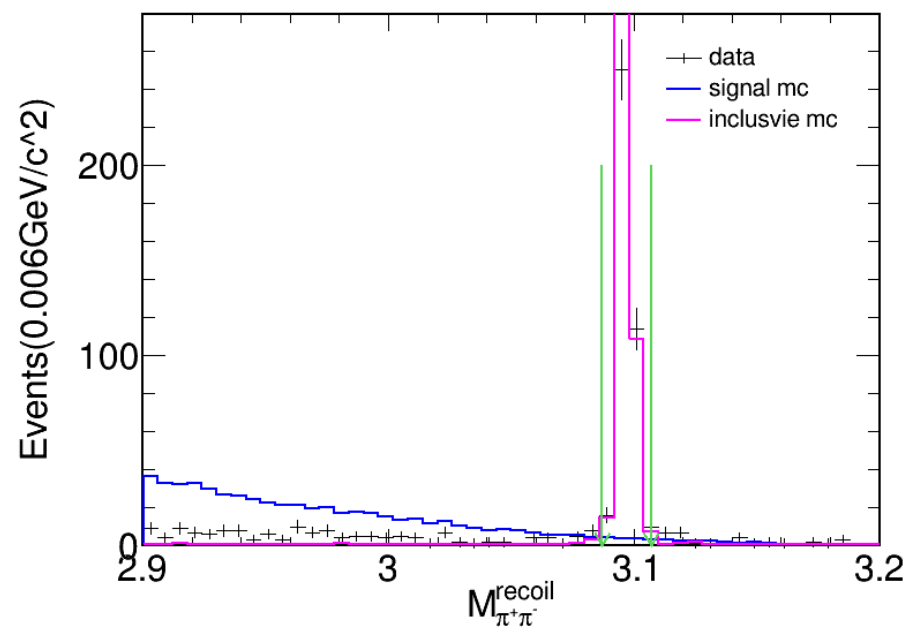


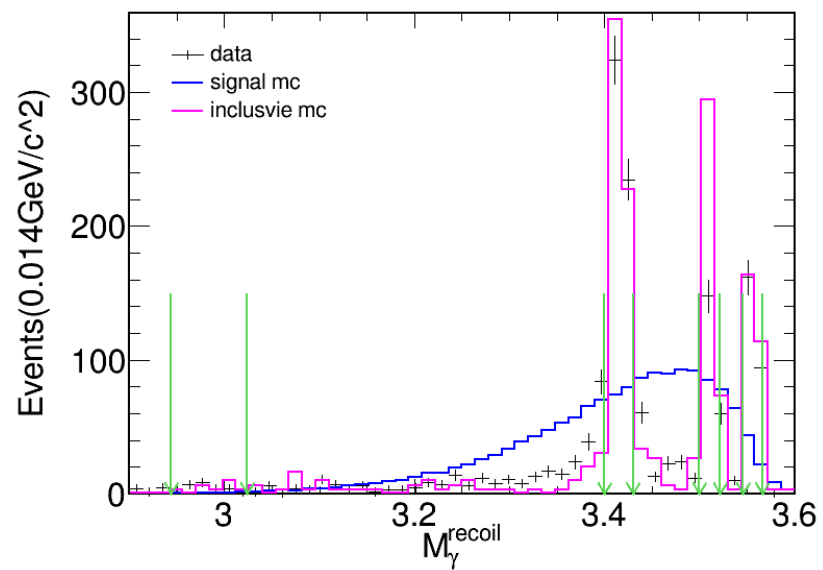
$$|M_{\gamma\Lambda(\bar{\Lambda})} - 1.193\text{GeV}| > 20\text{ MeV};$$





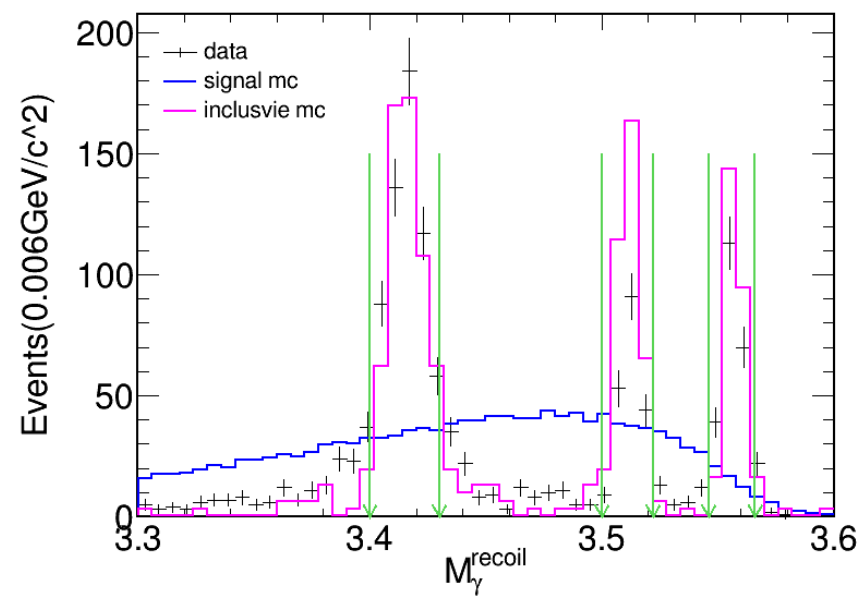
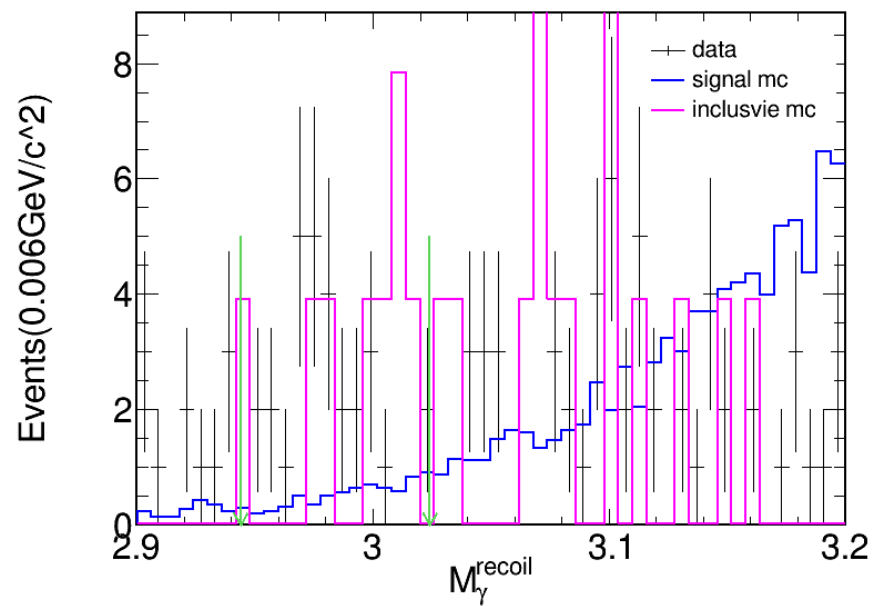
$$|M_{2\pi}^{recoil} - M_{jpsi}| > 10 \text{ MeV}$$

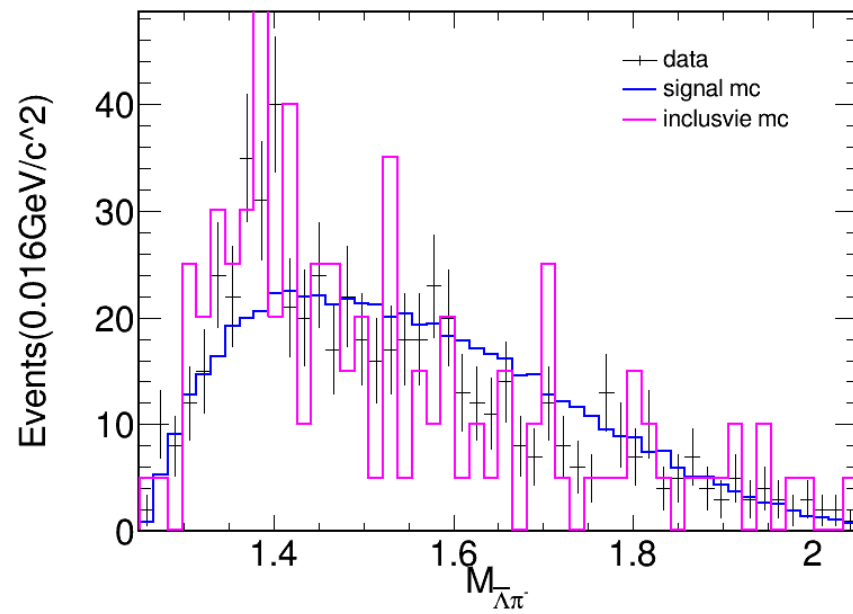
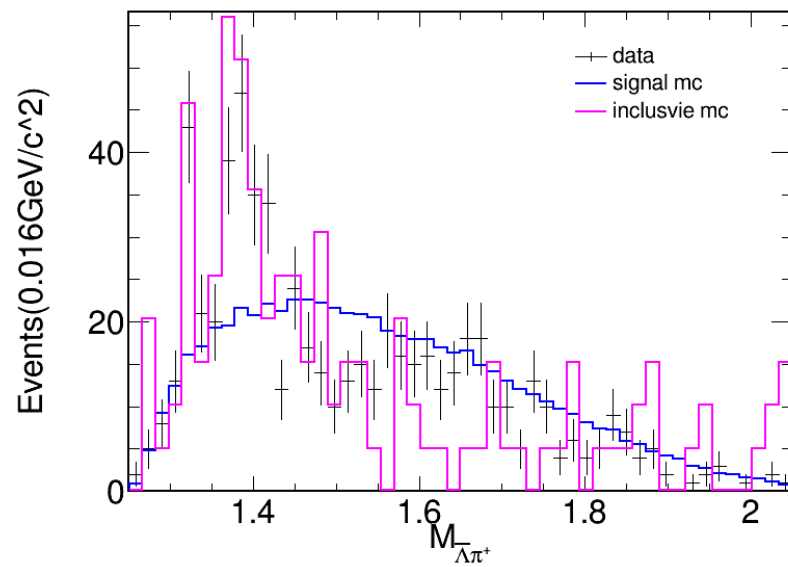
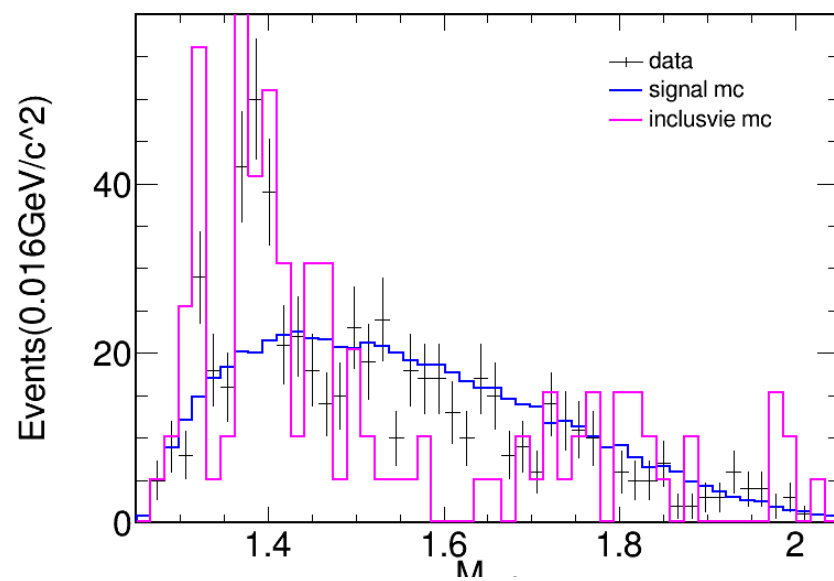
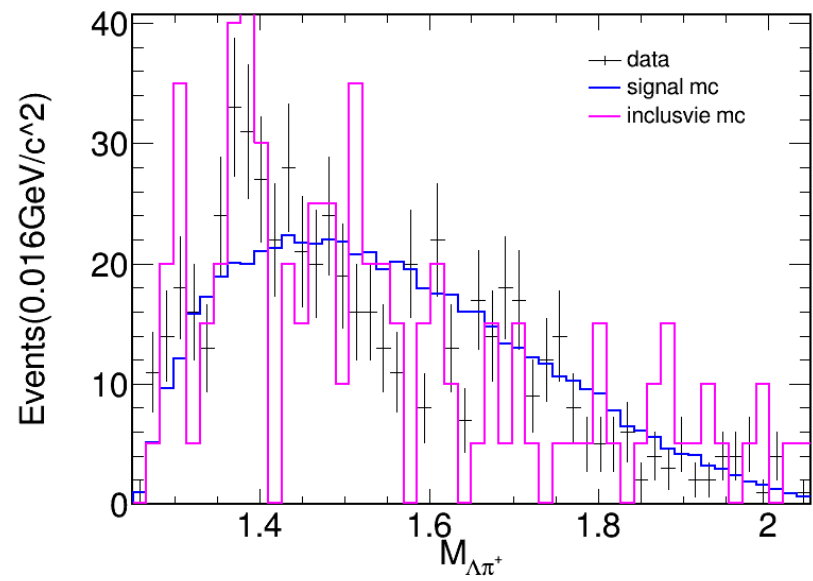


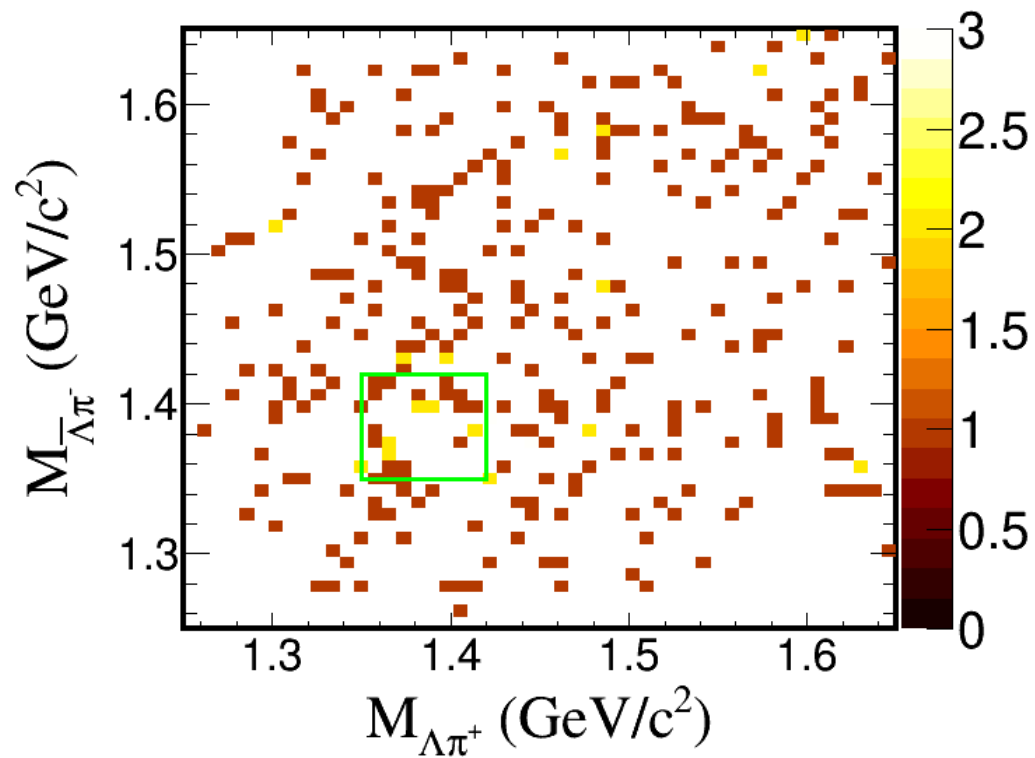
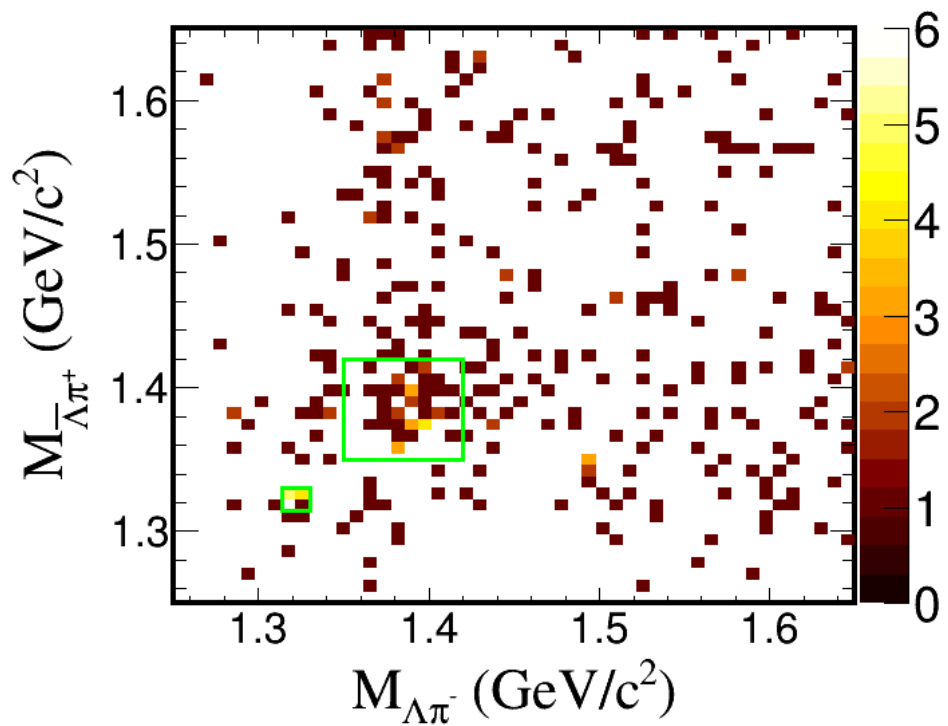


$$|M_\gamma^{\text{recoil}} - 2.984 \text{ GeV}| > 40 \text{ MeV}; |M_\gamma^{\text{recoil}} - M_{\chi_{c0}}| > 15 \text{ MeV},$$

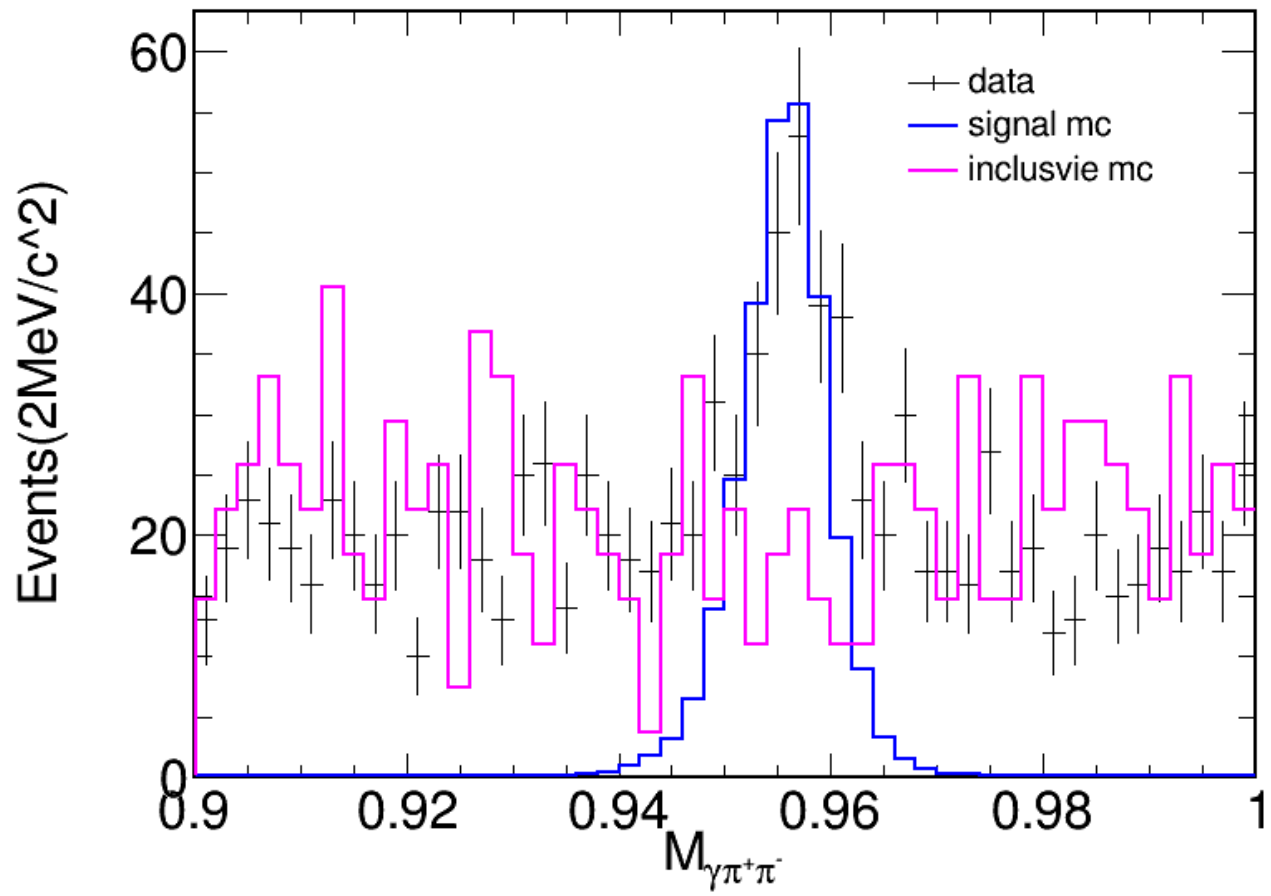
$$|M_\gamma^{\text{recoil}} - M_{\chi_{c1}}| > 10 \text{ MeV}; |M_\gamma^{\text{recoil}} - M_{\chi_{c2}}| > 10 \text{ MeV}$$







$$|M_{\Lambda\pi^-(\bar{\Lambda}\pi^+)} - M_{xi}| > 8\text{MeV}; |M_{\Lambda\pi^-} - M_{\Sigma^*}| > 35\text{MeV};$$

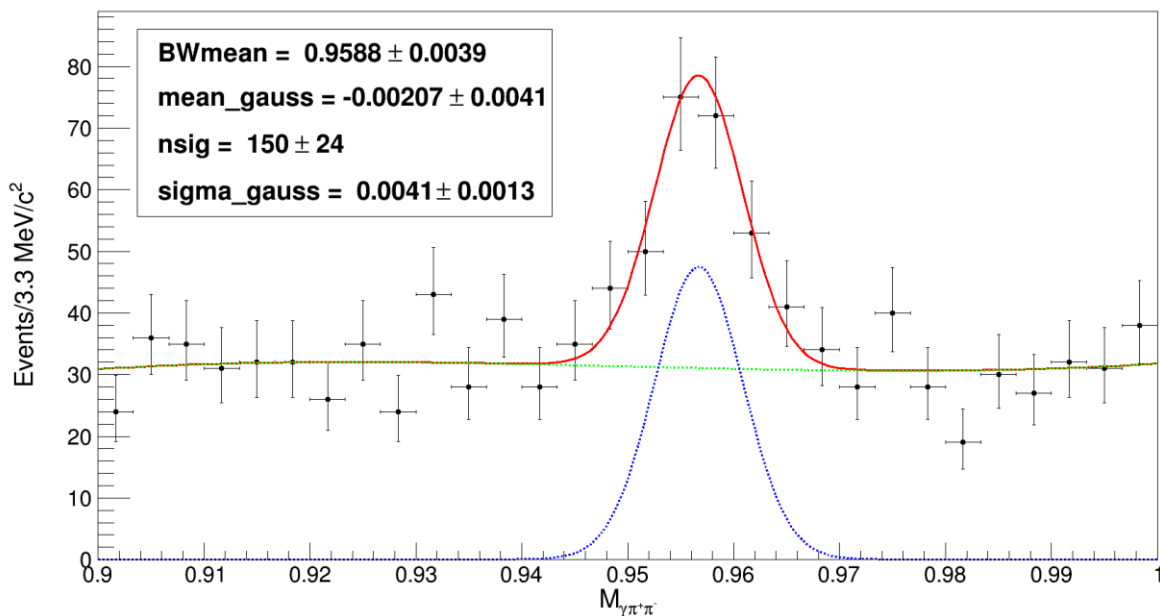


criteria	Efficiency (%)	Efficiency(%) / no pid
$\Lambda(\bar{\Lambda})$ reconstruction	44.46	44.46
$\pi^+ \pi^-$ vertex fit	21.07	26.84
Pass 4c kinematic fit	12.19	12.68
$\chi^2(4c) < 28$	8.75	9.05
$M_{\Lambda(\bar{\Lambda})} \in (1.11, 1.122) \text{ GeV}/c^2$	8.01	8.27
$M_{\eta'} \in (0.94, 0.98) \text{ GeV}/c^2$	7.94	8.20
$ M_{\gamma\Lambda(\bar{\Lambda})} - 1.193 \text{ GeV} > 20 \text{ MeV}/c^2$	7.32	7.55
Cut $M_{\gamma}^{\text{recoil}}$	5.70	5.88
$ M_{2\pi}^{\text{recoil}} - M_{jpsi} > 10 \text{ MeV}$	5.67	5.84
$ M_{\Lambda\pi^-(\bar{\Lambda}\pi^+)} - M_{xi} > 8 \text{ MeV};$ $ M_{\Lambda\pi} - M_{\Sigma^*} > 35 \text{ MeV};$	5.50	5.67

Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \Lambda \bar{\Lambda} \gamma, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	2	24	24
2	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow \pi^+ \Lambda \bar{\Sigma}^{*-}, \Lambda \rightarrow \pi^- p, \bar{\Sigma}^{*-} \rightarrow \pi^- \bar{\Lambda}, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	4	10	34
3	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow \pi^- \bar{\Sigma}^{*+} \Lambda, \bar{\Sigma}^{*+} \rightarrow \pi^+ \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	6	9	43
4	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow \pi^- \bar{\Lambda} \Sigma^{*+}, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Sigma^{*+} \rightarrow \pi^+ \Lambda, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	20	8	51
5	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow \pi^+ \Sigma^{*-} \bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^- \Lambda, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	17	6	57
6	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow K^{*-} p \bar{\Lambda}, K^{*-} \rightarrow \pi^- \bar{K}^0, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \bar{K}^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+ \pi^-$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	0	4	61
7	$\psi' \rightarrow \chi_{c1} \gamma, \chi_{c1} \rightarrow \pi^+ \Sigma^{*-} \bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^- \Lambda, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	11	4	65
8	$\psi' \rightarrow \pi^+ \Sigma^{*-} \bar{\Lambda} \gamma^f, \Sigma^{*-} \rightarrow \pi^- \Lambda, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma^f$	23	3	68
9	$\psi' \rightarrow \pi^+ \pi^- \Lambda \bar{\Lambda} \gamma^f, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma^f$	25	3	71
10	$\psi' \rightarrow \Lambda \bar{\Lambda} h_1(1170), \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, h_1(1170) \rightarrow \pi^- \rho^+, \rho^+ \rightarrow \pi^0 \pi^+$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	21	2	73
11	$\psi' \rightarrow \chi_{c1} \gamma, \chi_{c1} \rightarrow \pi^- \bar{\Lambda} \Sigma^{*+}, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Sigma^{*+} \rightarrow \pi^+ \Lambda, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	22	2	75
12	$\psi' \rightarrow \pi^- \bar{\Sigma}^{*+} \Lambda \gamma^f, \bar{\Sigma}^{*+} \rightarrow \pi^+ \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma^f$	5	2	77
13	$\psi' \rightarrow \chi_{c2} \gamma, \chi_{c2} \rightarrow \pi^- \bar{\Sigma}^{*+} \Lambda, \bar{\Sigma}^{*+} \rightarrow \pi^+ \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	14	2	79
14	$\psi' \rightarrow \chi_{c1} \gamma, \chi_{c1} \rightarrow \pi^+ \Lambda \bar{\Sigma}^{*-}, \Lambda \rightarrow \pi^- p, \bar{\Sigma}^{*-} \rightarrow \pi^- \bar{\Lambda}, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	29	2	81
15	$\psi' \rightarrow \pi^+ \pi^- \Lambda \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	30	2	83
16	$\psi' \rightarrow \pi^- \bar{\Lambda} \Sigma^{*+} \gamma^f, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Sigma^{*+} \rightarrow \pi^+ \Lambda, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma^f$	31	2	85
17	$\psi' \rightarrow \pi^+ \Sigma^{*-} \bar{\Lambda}, \Sigma^{*-} \rightarrow \pi^- \Lambda, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	16	1	86
18	$\psi' \rightarrow \chi_{c1} \gamma, \chi_{c1} \rightarrow \pi^+ \pi^- \Lambda \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	7	1	87
19	$\psi' \rightarrow \chi_{c0} \gamma, \chi_{c0} \rightarrow K^{*+} \bar{p} \Lambda, K^{*+} \rightarrow \pi^+ K^0, \Lambda \rightarrow \pi^- p, K^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+ \pi^-$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	18	1	88
20	$\psi' \rightarrow J/\psi \gamma \gamma, J/\psi \rightarrow \omega K^+ K^{*-}, \omega \rightarrow \pi^0 \pi^+ \pi^-, K^{*-} \rightarrow \pi^- \bar{K}^0, \bar{K}^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+ \pi^-$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- \pi^- K^+ \gamma \gamma$	19	1	89
21	$\psi' \rightarrow \Lambda \bar{\Lambda} h_1(1170), \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, h_1(1170) \rightarrow \pi^+ \rho^-, \rho^- \rightarrow \pi^0 \pi^-$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	8	1	90
22	$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \pi^+ \Delta^0 \bar{\Delta}^-, \Delta^0 \rightarrow \pi^- p, \bar{\Delta}^- \rightarrow \pi^0 \bar{p}$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	9	1	91
23	$\psi' \rightarrow \pi^0 J/\psi, J/\psi \rightarrow \pi^+ \pi^- \Lambda \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	10	1	92
24	$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \bar{\Lambda} \Sigma^0 \gamma, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Sigma^0 \rightarrow \Lambda \gamma, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	3	1	93
25	$\psi' \rightarrow \pi^- \bar{\Lambda} \Sigma^{*+}, \bar{\Lambda} \rightarrow \pi^+ \bar{p}, \Sigma^{*+} \rightarrow \pi^+ \Sigma^0, \Sigma^0 \rightarrow \Lambda \gamma, \Lambda \rightarrow \pi^- p$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma$	24	1	94
26	$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \pi^+ \pi^- p \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	12	1	95
27	$\psi' \rightarrow \eta' \Lambda \bar{\Lambda}, \eta' \rightarrow \pi^+ \pi^- \gamma^F, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^+ \pi^+ \pi^- \pi^- p \bar{p} \gamma^F$	26	1	96
28	$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \pi^0 \pi^0 \pi^+ \pi^+ \pi^- \pi^-$	$\pi^0 \pi^0 \pi^+ \pi^+ \pi^- \pi^- \pi^-$	27	1	97
29	$\psi' \rightarrow \pi^0 \Sigma^{*+} \bar{\Sigma}^{*-}, \Sigma^{*+} \rightarrow \pi^+ \Lambda, \bar{\Sigma}^{*-} \rightarrow \pi^- \bar{\Lambda}, \Lambda \rightarrow \pi^- p, \bar{\Lambda} \rightarrow \pi^+ \bar{p}$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^- p \bar{p}$	28	1	98

BW ⊗ gauss + 3nd -chebychevnomial



$\gamma \pi^+ \pi^-$

Significance :8.80

BR = 8.39e-6

```

FCN=-9090.74 FROM HESSE      STATUS=OK      71 CALLS      533 TOTAL
                        EDM=5.80653e-05  STRATEGY= 1      ERROR MATRIX ACCURATE
EXT  PARAMETER
NO.  NAME      VALUE      ERROR      INTERNAL      INTERNAL
      NAME      VALUE      ERROR      STEP SIZE     VALUE
  1  BWmean    9.58818e-01  3.89320e-03  2.21494e-01  1.70442e-01
  2  a1        -5.43362e-03  7.02317e-03  5.00000e-01  -2.56716e+00
  3  b1        2.62492e-04  1.46633e-03  1.00000e-01  2.65603e-01
  4  c1        1.99996e-02  7.17863e-03  2.38567e-02  1.56447e+00
  5  mean_gauss -2.07044e-03  4.11478e-03  8.27079e-05  -2.07059e-02
  6  nbkg      9.40120e+02  3.68790e+01  2.24705e-04  8.11022e-01
  7  nsig      1.49876e+02  2.41897e+01  6.13495e-04  -8.11032e-01
  8  sigma_gauss 4.12892e-03  1.34786e-03  1.78062e-04  4.25627e-01
ERR DEF= 0.5
EXTERNAL ERROR MATRIX.  NDIM= 25  NPAR= 8  ERR DEF=0.5
    
```

```

chisq/ndf: 0.9371
chi= 86.2132
Ndof= 92
NbinsX= 30
nParsToFit= 8
    
```