Partial wave analysis of Singly Cabibbo Suppressed Decays $\Lambda_c^+ \to p\,\pi^+\pi^-$ at BESIII

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Dec. 16, 2022

Outline

- Motivation
- Data and MC Sample
- Analysis Strategy
- Summary

Motivation

- Pan Yue et. al. have measured the SCS process $\Lambda_c^+ \to p\pi^+\pi^-$, and found the existence of the intermediate states like $\sigma, \rho^0, f_0(980), \Delta$ and Δ^* in the individual process, but didn't give their branching fraction results.

- Using the new taken $\Lambda_c\overline{\Lambda}_c$ data samples above mass threshold, it has potential to perform Partial Wave Analysis (PWA) on the hadronic decay $\Lambda_c^+ \to p\pi^+\pi^-$ and measured the branching fractions of the intermediate states processes.

- The increase of the data samples would help us to search more exotic intermediate states, like N^*.

- More precise measurement can help to deepen our understanding of the charm hadronic decays. Especially for the SCS decay $\Lambda_c^+ \to p\pi^+\pi^-$, which have the nonfactorizable contributions W-exchange and internal W emission diagrams.

Data Sample

◆ Data sets:

Seven energy points, from 4.600-4.700 GeV
Total integrated luminosity: 4.5 fb^{-1}
Boss version: 7.0.6

◆ Signal MC:

- Samples dedicated for single-tag efficiency: Λ_c to 10 tag modes, the other Λ_c inclusively decays.
- Samples dedicated for single-tag shape: Λ_c to 10 tag modes, the other Λ_c decays to eν.
- Samples dedicated for signal: Λ_c to 10 tag modes, the other Λ_c decays to signal.

◆ Inclusive $\Lambda_c\overline{\Lambda}_c$ MC:

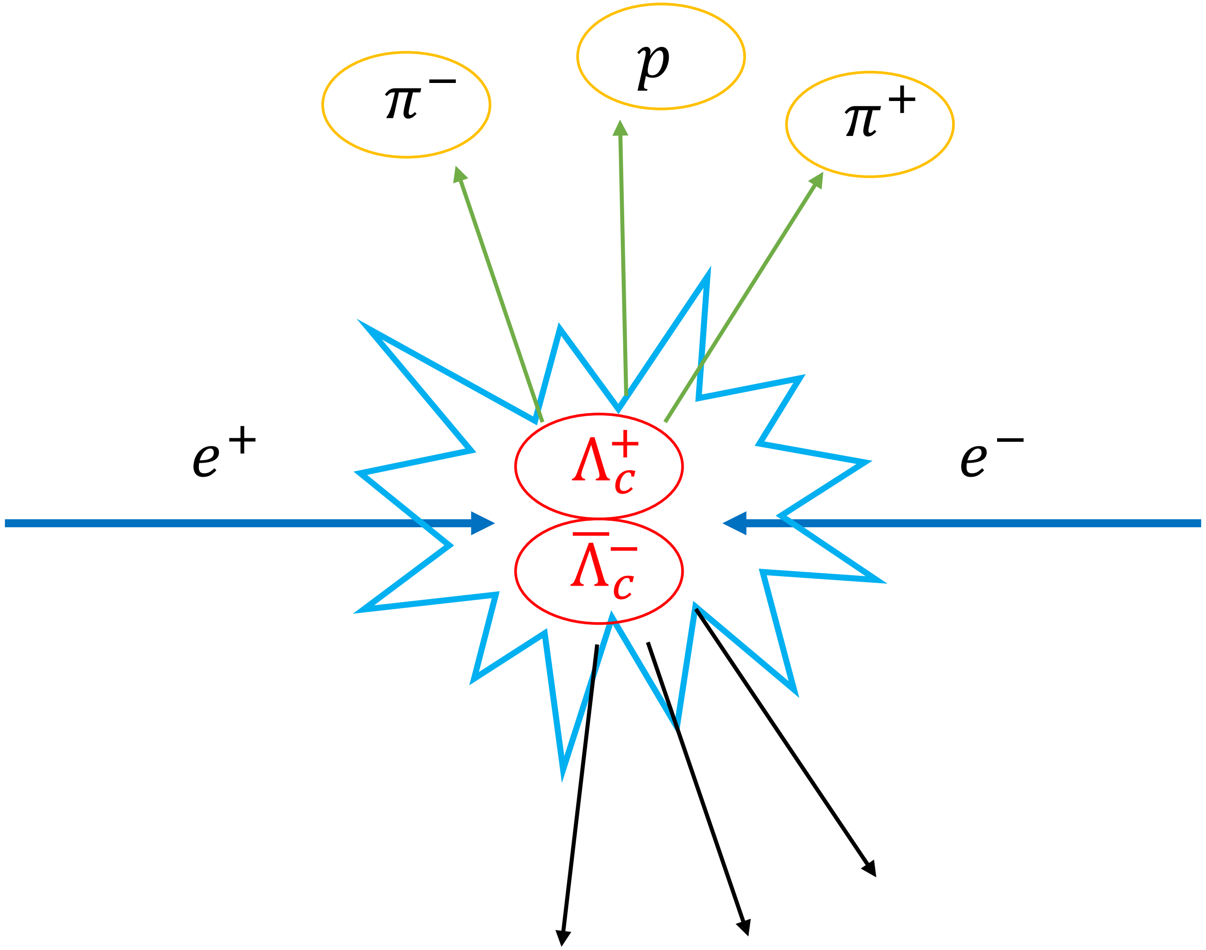
The production of Λ_c pair.

Phys. Rev. Lett. 128, 142001 (2022)
Phys. Rev. D 106, 072002 (2022)
Phys. Rev. D 106, 072008 (2022)

◆ Inclusive hadron MC:

The production of hadron , which excludes Λ_c pair.

Double Tag method



Ten hadronic decay mode

10 significant hadronic modes of Λ_c decays are chosen for single tag side:

Modes	Branching Fractions (%)
$\Lambda_c^+ \to pK^-\pi^+$	6.23 ± 0.33
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	4.42 ± 0.31
$\Lambda_c^+ \to pK_S$	1.58 ± 0.08
$\Lambda_c^+ \to pK_S\pi^0$	1.96 ± 0.13
$\Lambda_c^+ \to pK_S\pi^+\pi^-$	1.59 ± 0.12
$\Lambda_c^+ \to \Lambda\pi^+$	1.29 ± 0.07
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	7.0 ± 0.4
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	3.61 ± 0.29
$\Lambda_c^+ \to \Sigma^+\pi^0$	1.28 ± 0.07
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	4.42 ± 0.28

Event selections of single tag side

Good charged tracks:

- $|V_r| < 1.0\text{cm}, |V_z| < 10\text{cm}, |\cos\theta| < 0.93$

PID:

- K: $\text{prob}(K) > \text{prob}(p)\&\&\text{prob}(K) > \text{prob}(\pi)$
- P: $\text{prob}(p) > \text{prob}(\pi)\&\&\text{prob}(p) > \text{prob}(K)$
- π: $\text{prob}(\pi) > \text{prob}(K)\&\&\text{prob}(\pi) > \text{prob}(p)$

K_S:

- π^+ and π^-: $|V_z| < 20\text{cm}, |\cos\theta| < 0.93$
- Do vertex fit: $\chi^2 < 100$
- Do second vertex fit: $\frac{L}{\sigma} > 2$
- $0.487 < M(\pi^+\pi^-) < 0.511$ GeV

Λ :

- p and π^-: $|V_z| < 20\text{cm}, |\cos\theta| < 0.93$
- $\text{prob}(p) > \text{prob}(\pi)\&\&\text{prob}(p) > \text{prob}(K)$
- Do vertex fit: $\chi^2 < 100$
- Do second vertex fit: $\frac{L}{\sigma} > 2$
- $1.111 < M(p\pi^-) < 1.121$ GeV

π^0 :

- Showers: $0 < \text{TDC} < 14\&\&\ E > 50\text{MeV}, 0.86 < |\cos\theta| < 0.92\&\&E > 25\text{MeV}, |\cos\theta| < 0.8$
- $0.115 < M(\gamma\gamma) < 0.15$ GeV
- 1C kinematic && $\chi^2 < 200$

Σ^0 :

- Showers: $0 < \text{TDC} < 14\&\&\ E > 50\text{MeV}, 0.86 < |\cos\theta| < 0.92\&\&E > 25\text{MeV}, |\cos\theta| < 0.8$
- $1.179 < M_\Sigma < 1.203$ GeV

Σ^+:

- $1.176 < M_{\Sigma^+} < 1.2$ GeV

Same as pair Λ_C pair cross section measurement

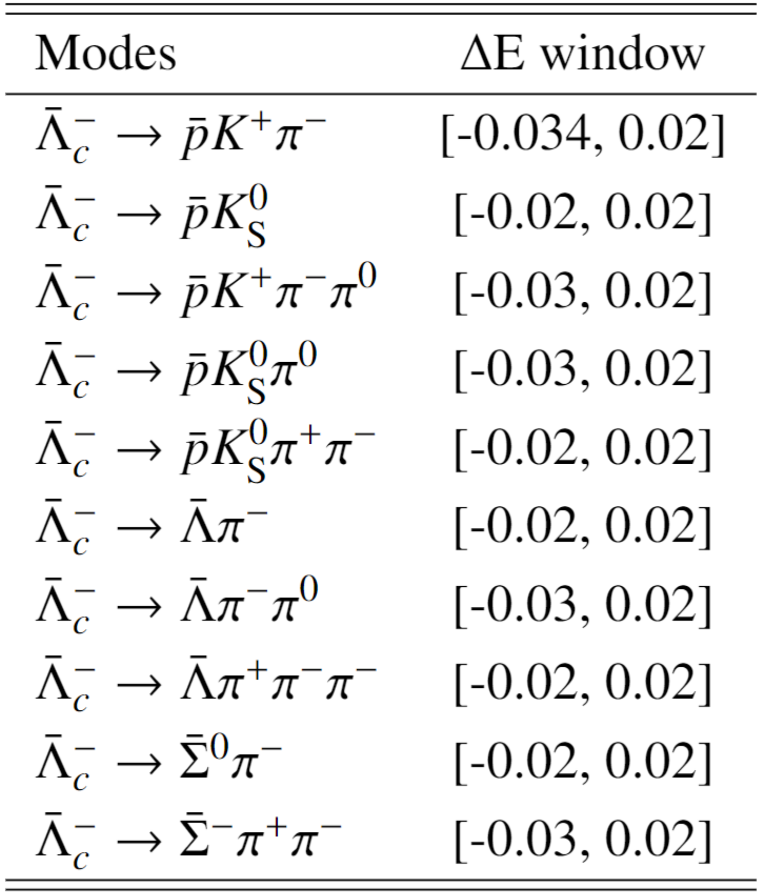
Phys.Rev.Lett,120,132001,(2018)
Phys. Rev. Lett. 128, 142001 (2022)
Phys. Rev. D 106, 072002 (2022)
Phys. Rev. D 106, 072008 (2022)

ΔE and background veto/check

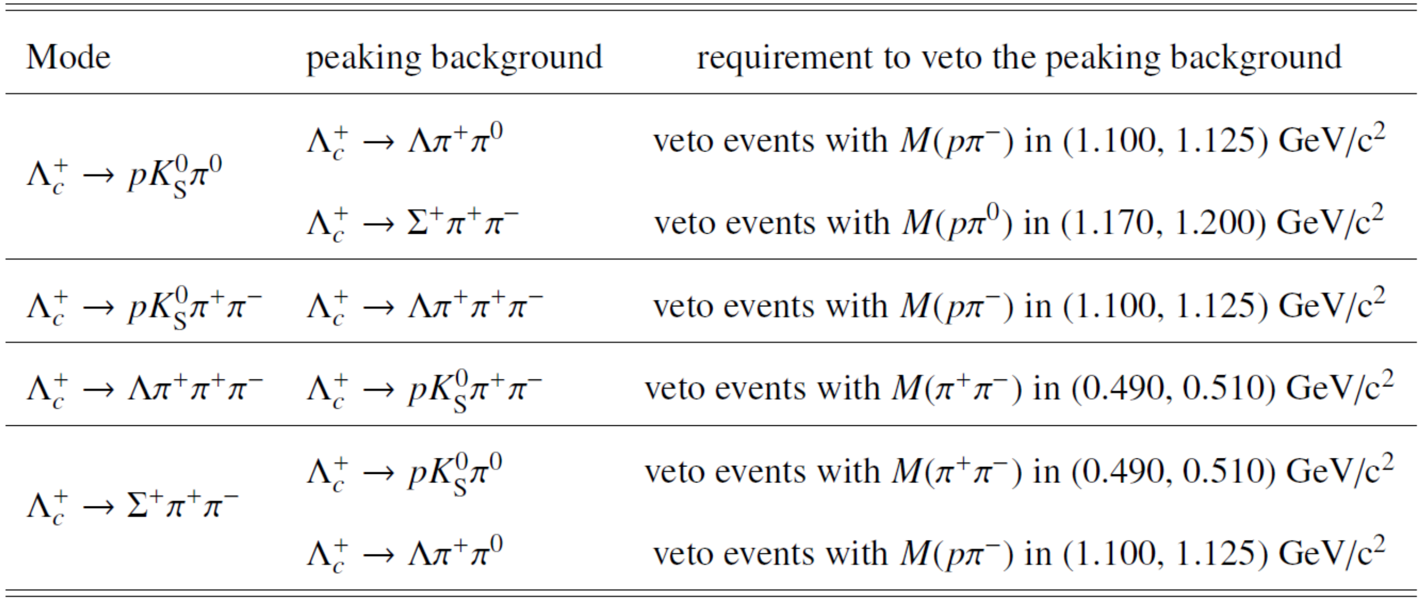
- To improve the signal significance, we use

$$\Delta E_{ST} = E_{\bar{\Lambda}_c^-} - E_{\mathrm{beam}}$$

where $E_{\bar{\Lambda}_c^-}$ is the sum of the measured energies for all particles from $\bar{\Lambda}_c^-$ decays.



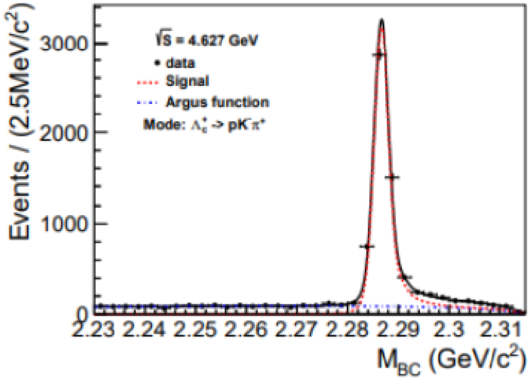
Modes	ΔE window
$\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$	[-0.034, 0.02]
$\bar{\Lambda}_c^- \to \bar{p}K_S^0$	[-0.02, 0.02]
$\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-\pi^0$	[-0.03, 0.02]
$\bar{\Lambda}_c^- \to \bar{p}K_S^0\pi^0$	[-0.03, 0.02]
$\bar{\Lambda}_c^- \to \bar{p}K_S^0\pi^+\pi^-$	[-0.02, 0.02]
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-$	[-0.02, 0.02]
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0$	[-0.03, 0.02]
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^+\pi^-\pi^-$	[-0.02, 0.02]
$\bar{\Lambda}_c^- \to \bar{\Sigma}^0\pi^-$	[-0.02, 0.02]
$\bar{\Lambda}_c^- \to \bar{\Sigma}^-\pi^+\pi^-$	[-0.03, 0.02]

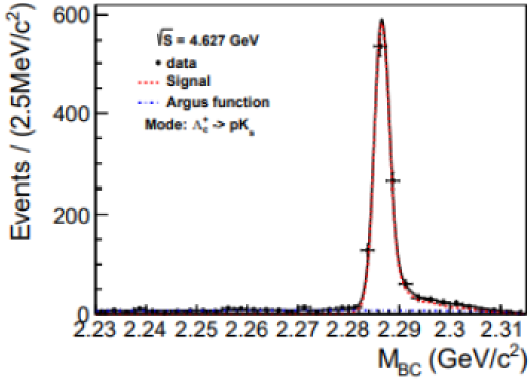


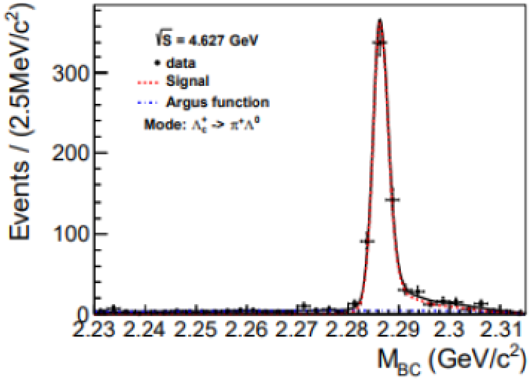
Mode	peaking background	requirement to veto the peaking background
$\Lambda_c^+ \to pK_S^0\pi^0$	$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	veto events with $M(p\pi^-)$ in (1.100, 1.125) GeV/c^2
	$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	veto events with $M(p\pi^0)$ in (1.170, 1.200) GeV/c^2
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	veto events with $M(p\pi^-)$ in (1.100, 1.125) GeV/c^2
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	veto events with $M(\pi^+\pi^-)$ in (0.490, 0.510) GeV/c^2
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	$\Lambda_c^+ \to pK_S^0\pi^0$	veto events with $M(\pi^+\pi^-)$ in (0.490, 0.510) GeV/c^2
	$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	veto events with $M(p\pi^-)$ in (1.100, 1.125) GeV/c^2

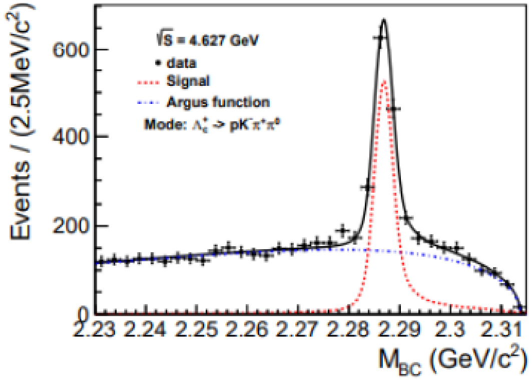
- Minimum the ΔE_{ST} for the best Λ_c candidates from the ten tag modes

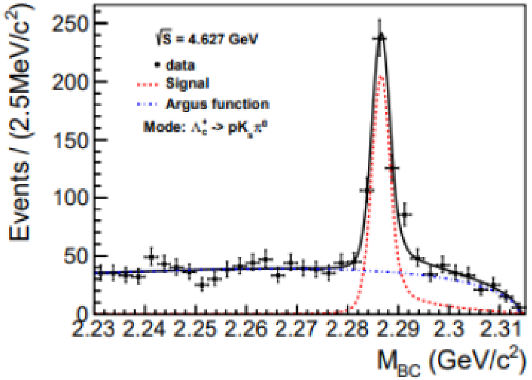
Single Tagged Yields at $\sqrt{s} = 4.620$ GeV

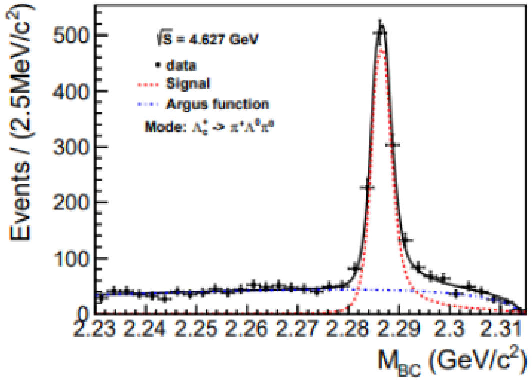


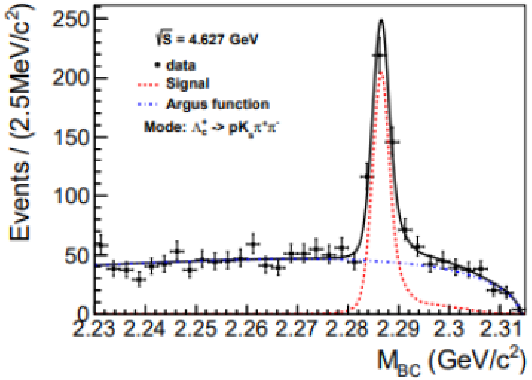


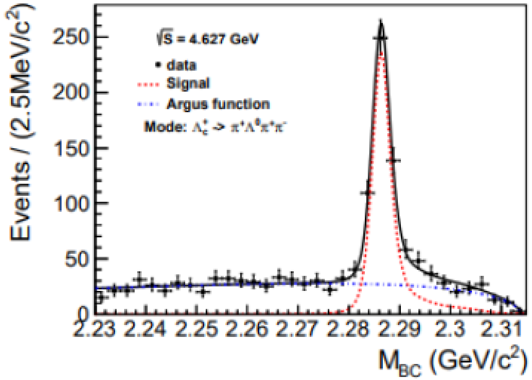


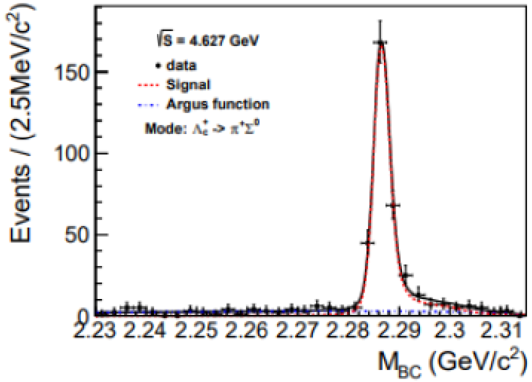


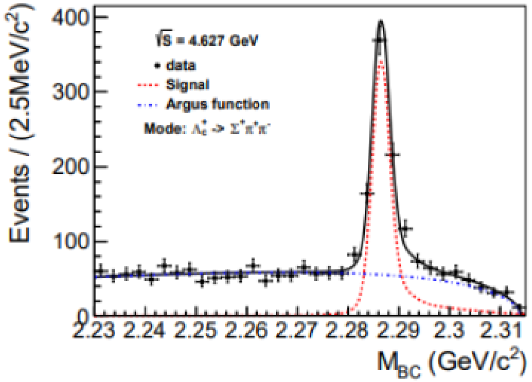












$$M_{BC} = \sqrt{\frac{p_{\Lambda_c^+}^2}{c^2} - \frac{E_{beam}^2}{c^4}}$$

Single Tagged Yields

Modes	4.600	4.612	4.620	4.640	4.660	4.680	4.700
$\Lambda_c^+ \to pK^-\pi^+$	6705 ± 90	1158 ± 38	5911 ± 87	6229 ± 90	5884 ± 86	17415 ± 145	5156 ± 80
$\Lambda_c^+ \to pK_S$	1268 ± 37	241 ± 16	1063 ± 35	1110 ± 35	1117 ± 35	3353 ± 61	964 ± 33
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	741 ± 28	281 ± 13	1239 ± 50	1307 ± 52	1349 ± 54	4005 ± 95	1116 ± 51
$\Lambda_c^+ \to pK_S\pi^0$	1539 ± 57	109 ± 13	460 ± 29	485 ± 30	479 ± 30	1454 ± 52	386 ± 26
$\Lambda_c^+ \to pK_S\pi^+\pi^-$	485 ± 29	103 ± 13	423 ± 28	455 ± 28	458 ± 28	1261 ± 49	417 ± 27
$\Lambda_c^+ \to \Lambda\pi^+$	1382 ± 49	120 ± 11	662 ± 28	691 ± 28	651 ± 27	2012 ± 47	519 ± 24
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	512 ± 29	226 ± 18	1161 ± 42	1328 ± 45	1165 ± 41	3576 ± 71	1045 ± 39
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	646 ± 31	128 ± 13	512 ± 29	667 ± 32	624 ± 30	1818 ± 52	548 ± 28
$\Lambda_c^+ \to \Sigma^+\pi^0$	404 ± 22	77 ± 9	329 ± 20	345 ± 21	343 ± 20	1047 ± 34	283 ± 18
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	872 ± 38	155 ± 16	738 ± 37	812 ± 38	751 ± 36	2275 ± 63	699 ± 35

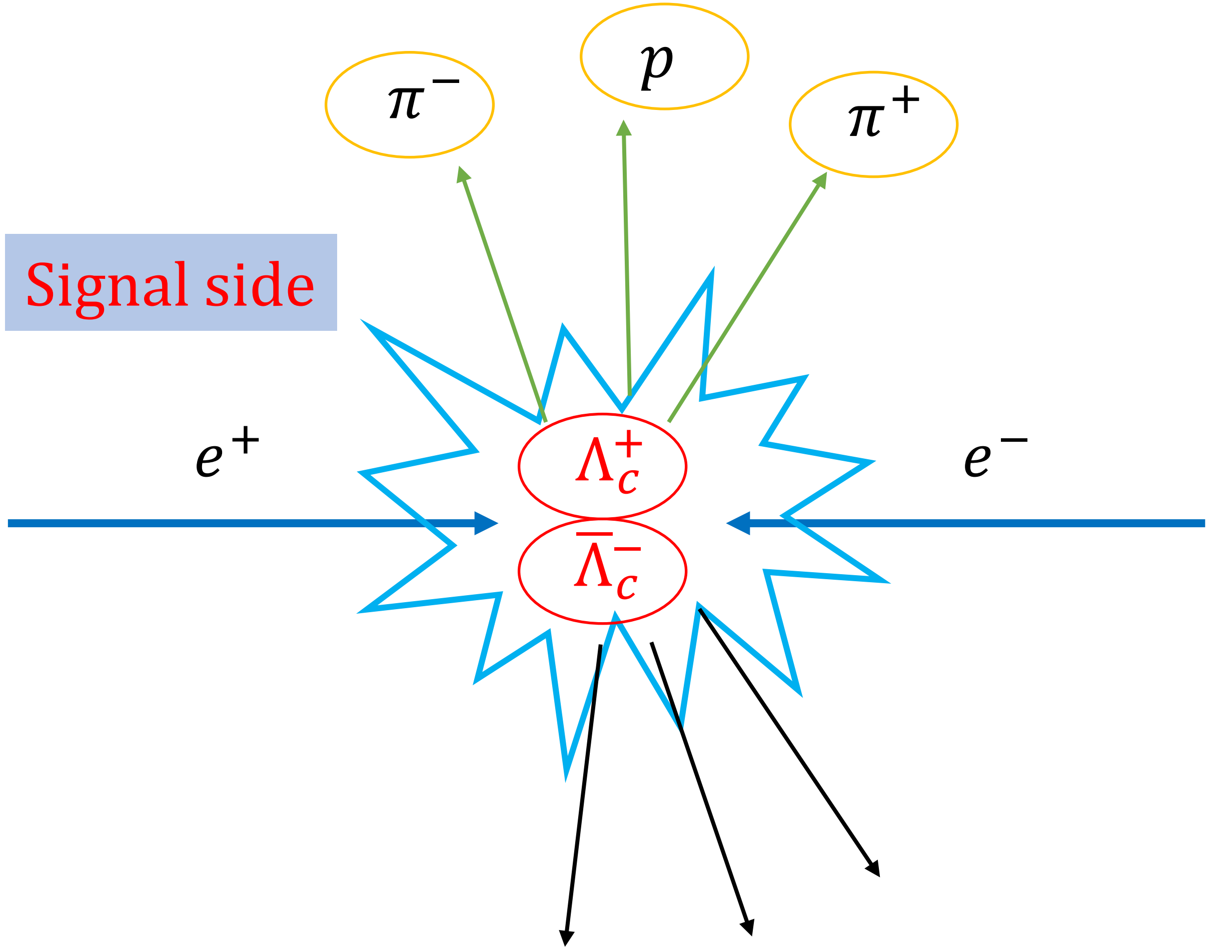
Same as those in the measurement of $\Lambda_c^+ \to n\pi^+$.
The uncertainty in the ST yield is statistical only.

Single Tagged Yields and Efficiencies

Modes	4.600	4.612	4.620	4.640	4.660	4.680	4.700
$\Lambda_c^+ \to pK^-\pi^+$	51.0%	50.2%	49.5%	49.0%	48.0%	47.3%	46.4%
$\Lambda_c^+ \to pK_S$	56.2%	53.2%	51.6%	50.9%	49.7%	48.1%	47.3%
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	15.4%	14.9%	15.0%	14.8%	14.6%	14.5%	14.2%
$\Lambda_c^+ \to pK_S\pi^0$	18.4%	17.2%	17.0%	17.0%	16.5%	16.5%	16.1%
$\Lambda_c^+ \to pK_S\pi^+\pi^-$	19.9%	19.0%	18.4%	18.4%	18.2%	17.7%	17.6%
$\Lambda_c^+ \to \Lambda\pi^+$	47.7%	42.5%	40.8%	40.4%	39.1%	37.8%	37.1%
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	16.6%	15.6%	15.2%	15.3%	14.9%	14.6%	14.2%
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	13.7%	12.7%	12.5%	12.5%	12.7%	12.3%	12.5%
$\Lambda_c^+ \to \Sigma^+\pi^0$	22.5%	21.0%	20.2%	20.5%	19.6%	19.3%	18.8%
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	18.1%	17.6%	17.4%	17.1%	16.7%	16.2%	16.1%

Same as those in the measurement of $\Lambda_c^+ \to n\pi^+$.

Event selections of signal side



Ten hadronic decay mode

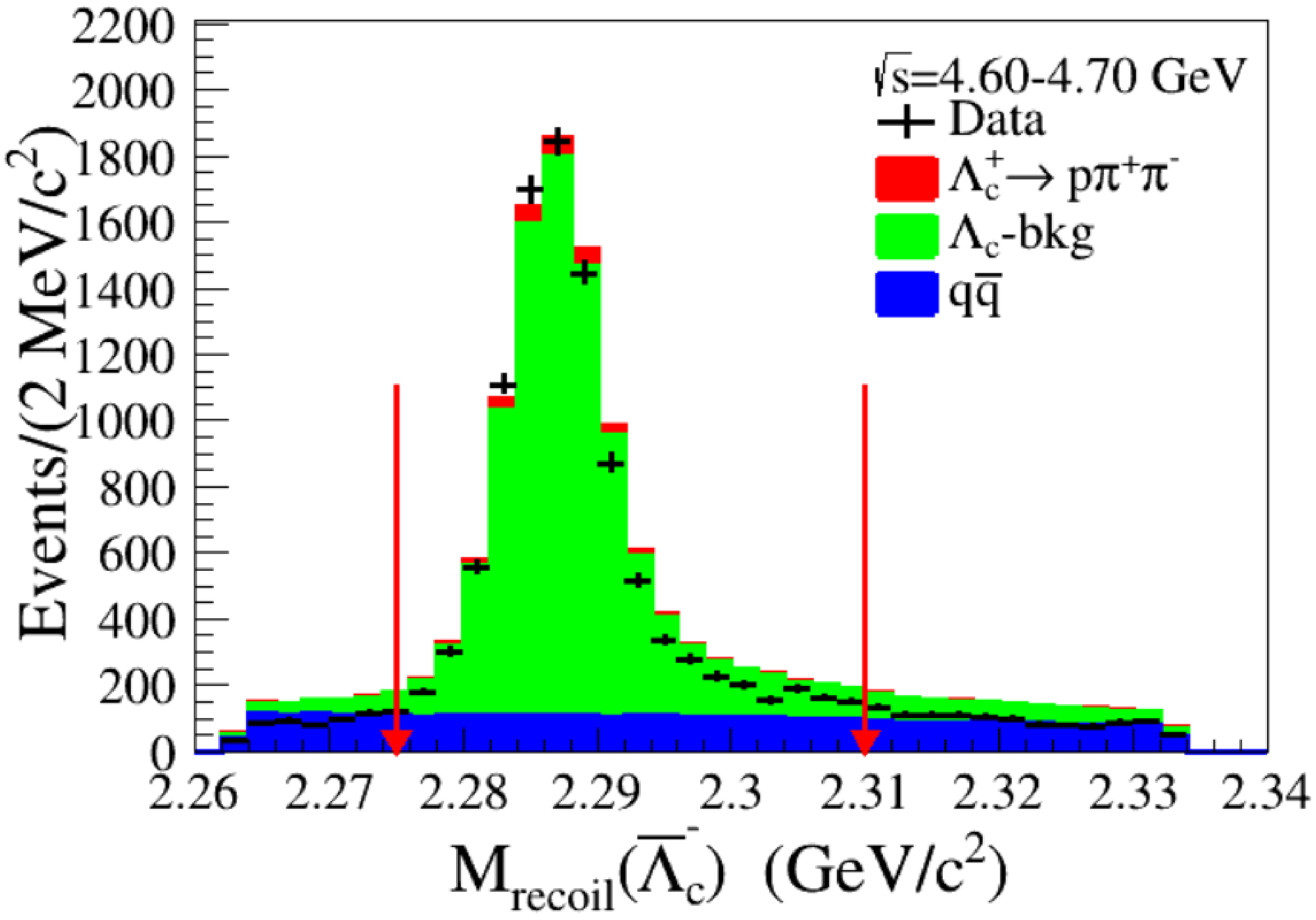
Signal side selected:

- ☐ Charged track:
  - ✓ p and $\boldsymbol{\pi}^{\pm}$ in: $|V_r| < 1cm, |V_z| < 10cm, cos\theta < 0.93$
  - ✓ Only three tracks.
- ☐ PID:
  - ✓ p : $prob$(p)>0&$prob$(p)>$prob(K)$>$prob(\pi)$
  - ✓ π : $prob(\pi)$>0&$prob(\pi)$>$prob$(p)>$prob(K)$
- ☐ M_{BC} of the tag Λ_c and recoil Λ_c :
  - ✓ $2.275 < M_{BC} < 2.31$
- ☐ Veto most of non-signal $\Lambda_c\Lambda_c$ background :
  - ✓ $\Delta E_{DT} = E_{p\pi^+\pi^-} - E_{beam}$;
  - ✓ ΔE_{DT}>-0.05.
- ☐ Veto the peaking background:
  - ✓ Peaking background from $\boldsymbol{\Lambda_c^+} \rightarrow \boldsymbol{\Lambda\pi^+}$:
    veto event in $1.103 < M(p\pi^-) < 1.129$ MeV.
  - ✓ Peaking background from$\boldsymbol{\Lambda_c^+} \rightarrow \boldsymbol{pK_S^0}$:
    veto event in $0.47 < M(\pi^+\pi^-) < 0.51$ MeV.

Mass window on recoiling mass of $\bar{\Lambda}_c^-$

The requirement of invariant mass of recoil Λ_c:

$2.275 < m_{recoil}^{\bar{\Lambda}_c^-} < 2.31$



The definition of invariant mass of recoil Λ_c :

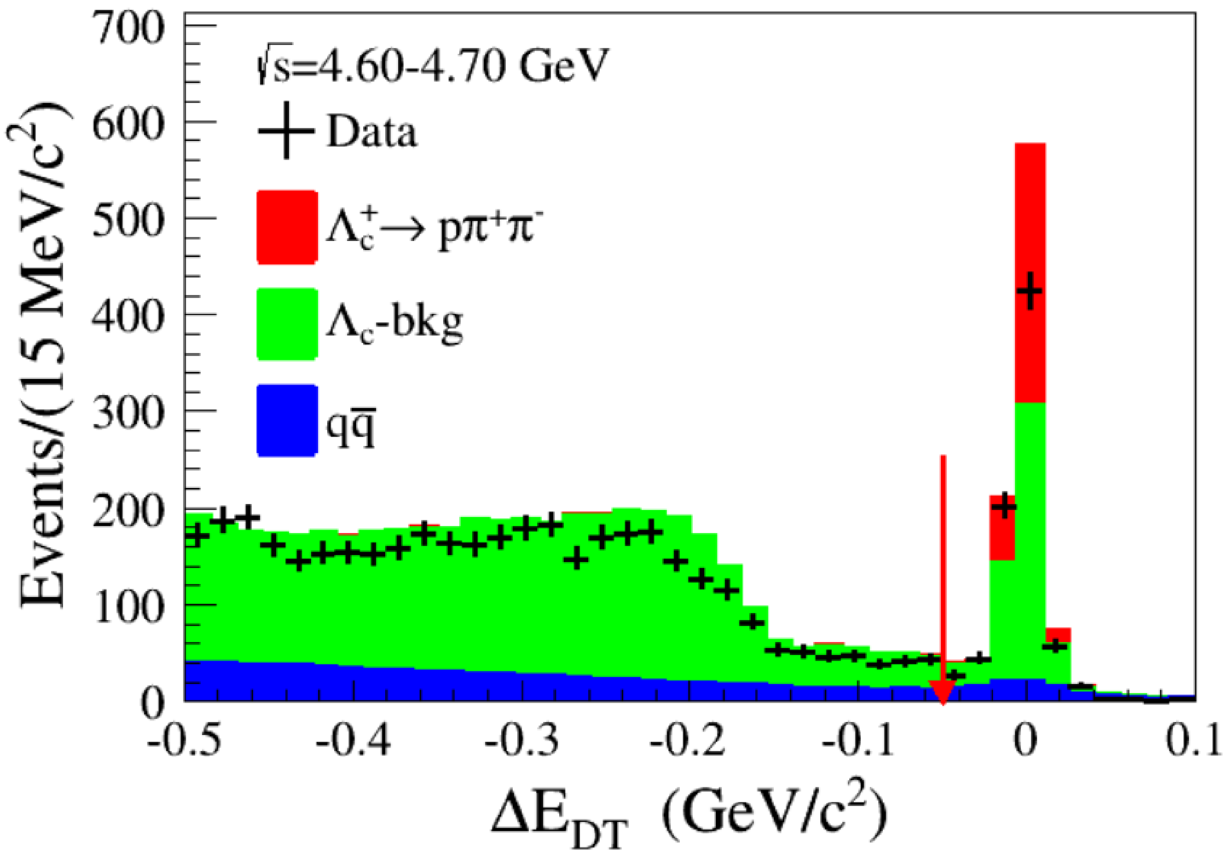
$$m_{\text{recoil}}^{\Lambda_c^+} = \sqrt{(E_{\text{beam}} - E_{\bar{\Lambda}_c^-})^2 - (\vec{P}_{\bar{\Lambda}_c^-})^2},$$

The mass window of this cut is consistent with that in the single tag side.

ΔE window on DT side

The requirement of invariant mass of recoil Λ_c:

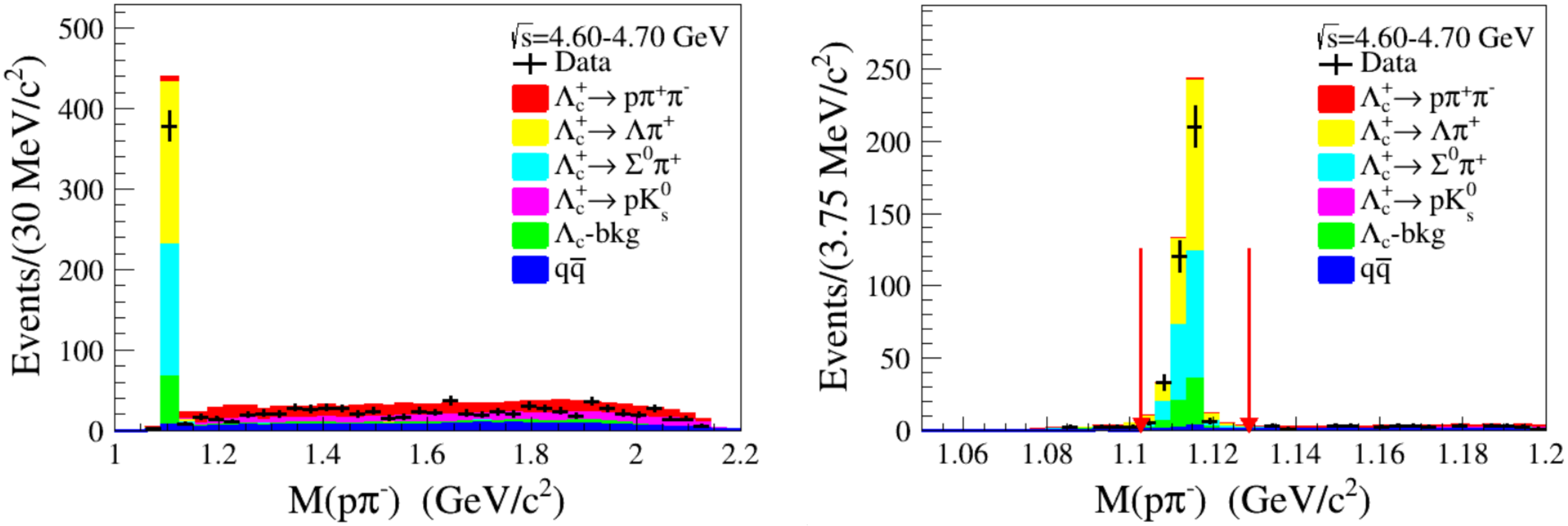
$\Delta E_{DT} = \mathrm{E}_{p\pi^+\pi^-} - \mathrm{E}_{\mathrm{beam}}$; ΔE_{DT}>-0.05.



The cut range is decided by keeping more than 97% of signal events.

Mass window on invariant mass of $p\pi^-$

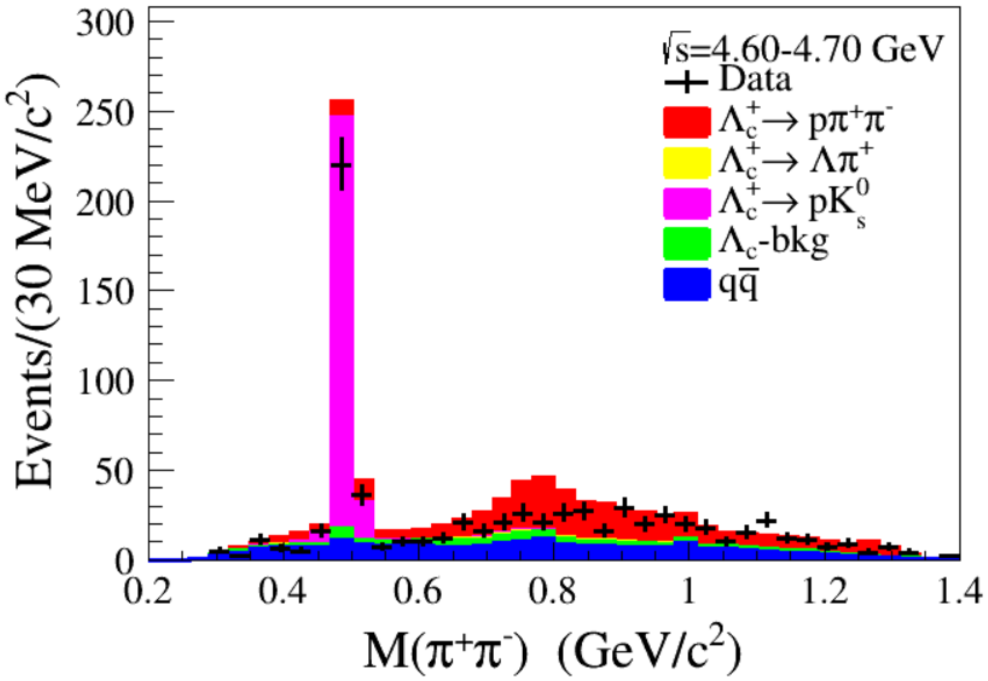
- ✓ Peaking background from $\Lambda_c^+ \to \Lambda\pi^+$:
  veto event in $1.103 < M(p\pi^-) < 1.129$ GeV.

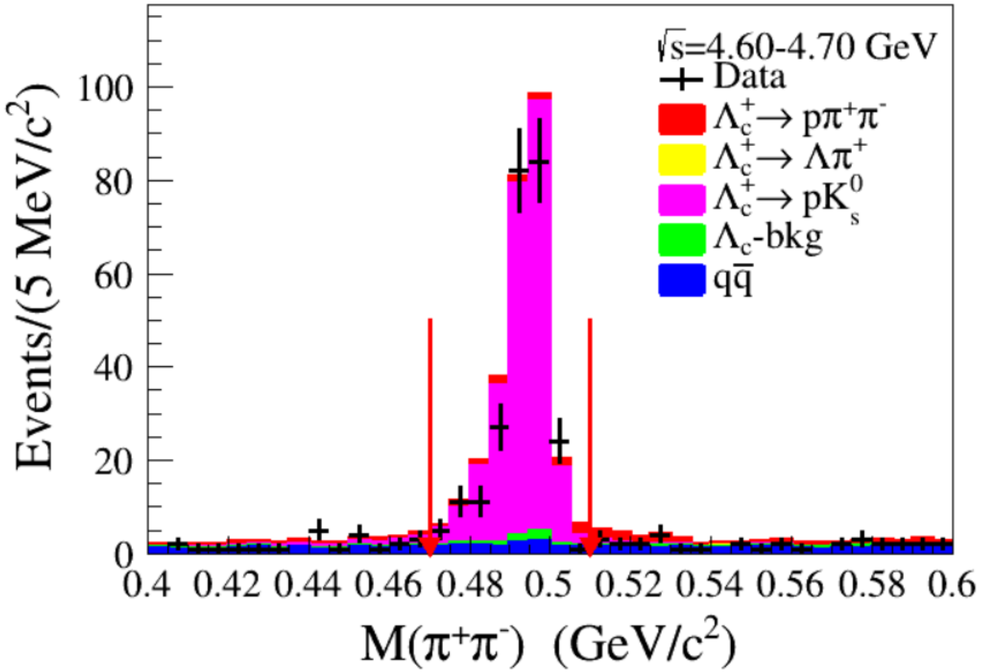


The cut range is decided by keeping more than 97% of $\Lambda_c^+ \to \Lambda\pi^+$ events.

Mass window on invariant mass of $\pi^+\pi^-$

- ✓ Peaking background from $\boldsymbol{\Lambda_c^+ \to pK_S^0}$:
  veto event in $0.47 < M(\pi^+\pi^-) < 0.51$ MeV.





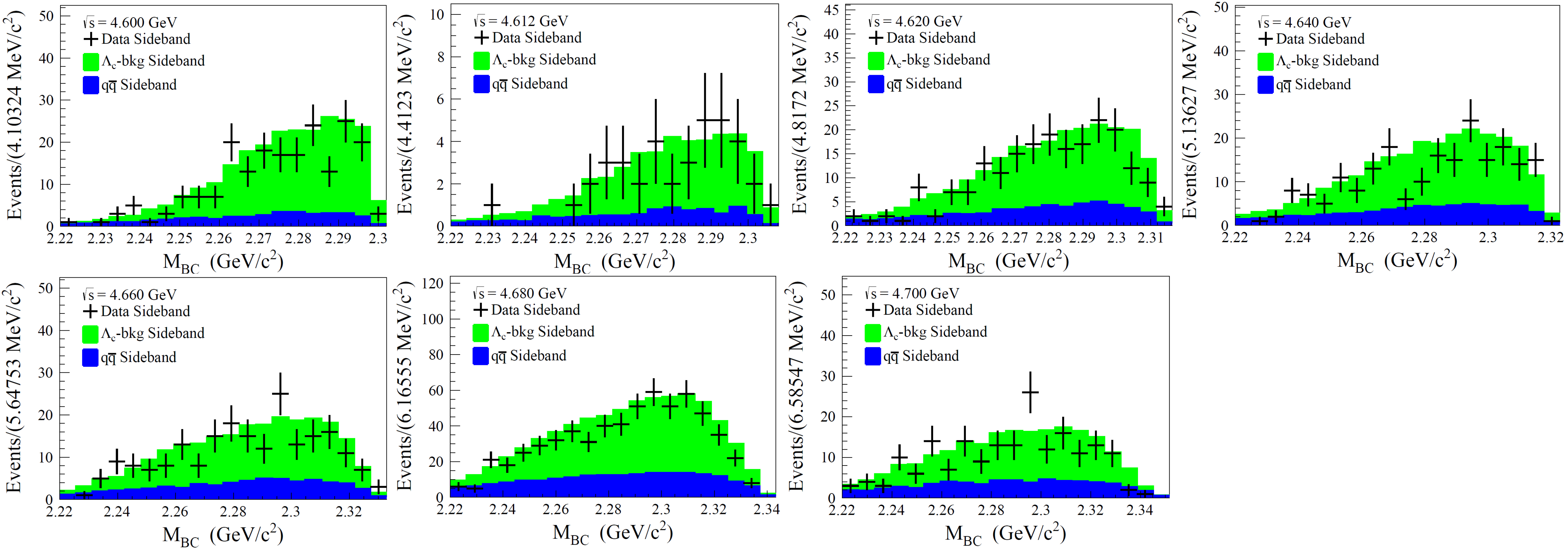
The cut range is decided by keeping more than 97% of $\Lambda_c^+ \to \mathrm{P}K_S^0$ events.

Double Tagged Yields and Efficiencies

Modes	4.600	4.612	4.620	4.640	4.660	4.680	4.700
$\Lambda_c^+ \to pK^-\pi^+$	28.23%	26.71%	25.49%	24.75%	24.78%	23.57%	23.20%
$\Lambda_c^+ \to pK_S$	32.12%	29.07%	27.69%	27.58%	26.02%	25.86%	24.94%
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	9.38%	8.77%	8.34%	7.56%	7.70%	7.81%	7.49%
$\Lambda_c^+ \to pK_S\pi^0$	11.20%	10.13%	9.70%	9.70%	9.52%	9.13%	8.46%
$\Lambda_c^+ \to pK_S\pi^+\pi^-$	11.79%	9.65%	9.20%	9.54%	9.07%	9.28%	8.86%
$\Lambda_c^+ \to \Lambda\pi^+$	26.19%	23.96%	22.92%	22.69%	21.23%	20.90%	19.44%
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	9.54%	8.65%	8.14%	8.03%	7.55%	7.53%	6.97%
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	7.55%	6.44%	6.89%	6.22%	6.24%	6.51%	6.10%
$\Lambda_c^+ \to \Sigma^+\pi^0$	14.39%	11.99%	11.51%	11.17%	11.24%	10.74%	10.53%
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	10.88%	9.93%	9.34%	9.19%	9.08%	8.61%	8.66%

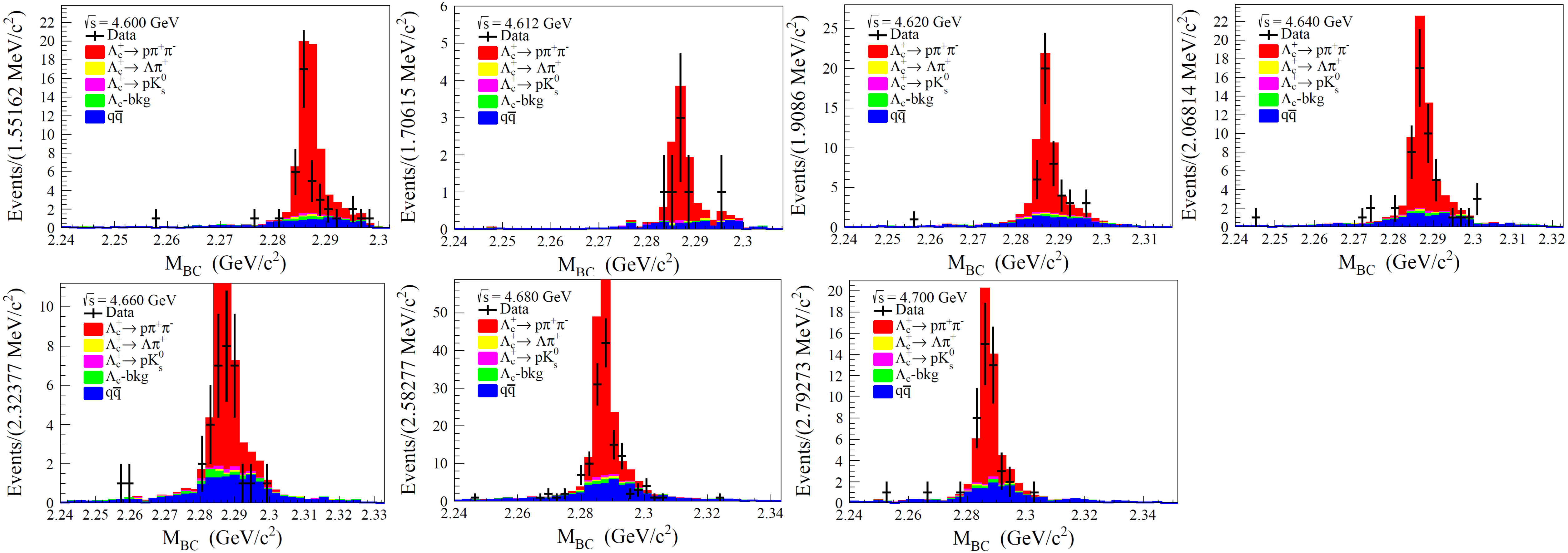
Comparison between Data and inclusive MC in sideband

✓ Sideband regions: -0.4 < ΔE_{DT} < -0.2



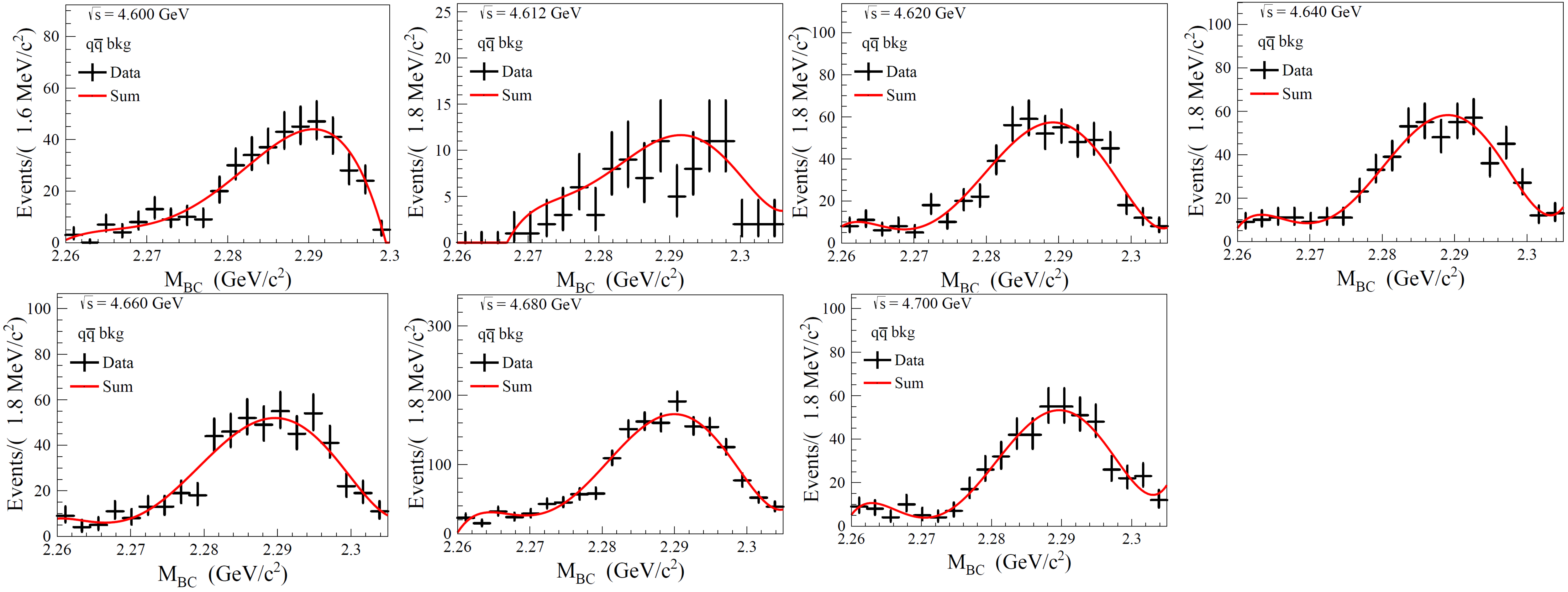
- The inclusive MC samples are consistent with the data within the statistical uncertainty.
- We could use the inclusive MC samples to model the backgrounds in data.

Distributions of M_{BC}



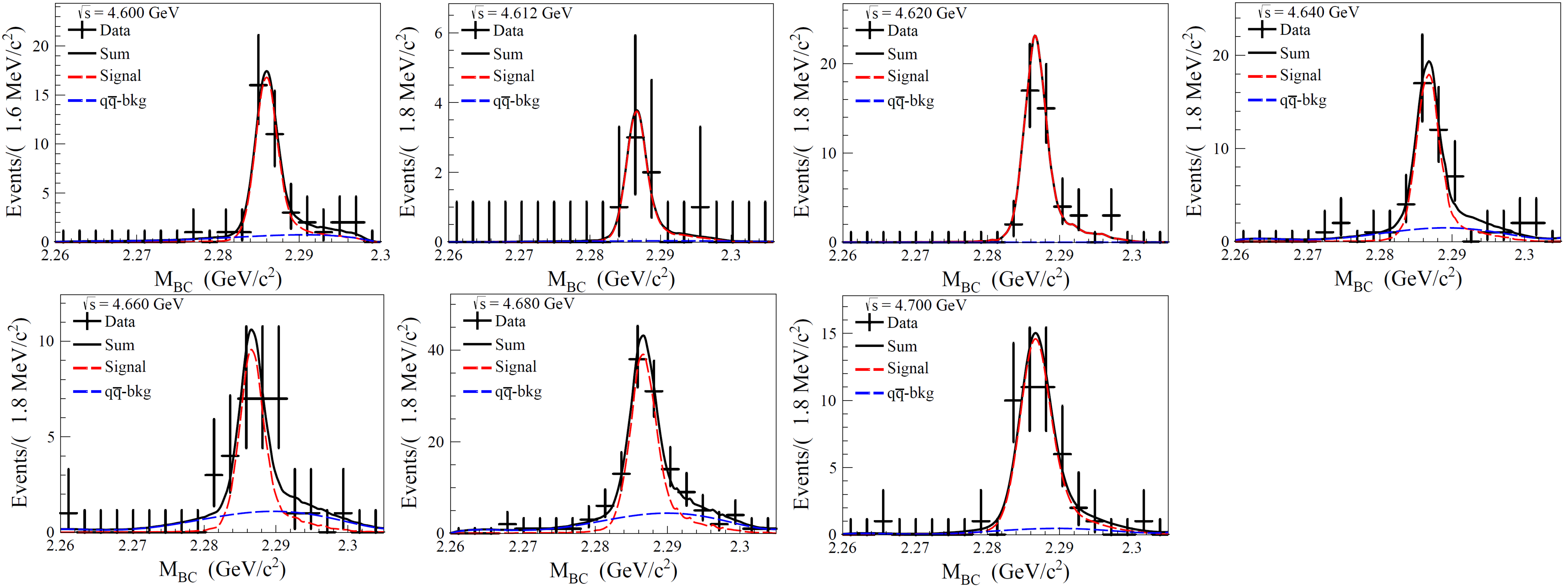
- The inclusive MC samples are normalized to the luminosity of data.
- The main background sources are from the $q\bar{q}$ backgrounds.
- The contributions from non-signal $\Lambda_c\bar{\Lambda}_c$ pair production backgrounds are negligible.

Fitting on $q\bar{q}$ Backgrounds



- The shapes of the $q\bar{q}$ backgrounds are described by the five order Chebyshev polynomial functions.
- The parameters of the five order Chebyshev polynomial functions are fixed by fitting the inclusive hadron MC samples.

Fitting on M_{BC} of Data



- The 1D un-binned maximum likelihood fits are performed on the M_{BC} distributions to extract the signal yields.
- The signal shapes are modeled by the MC simulation, convolved with a same Gaussian function accounting for the resolution difference between data and MC.

Signal Yields and Purity

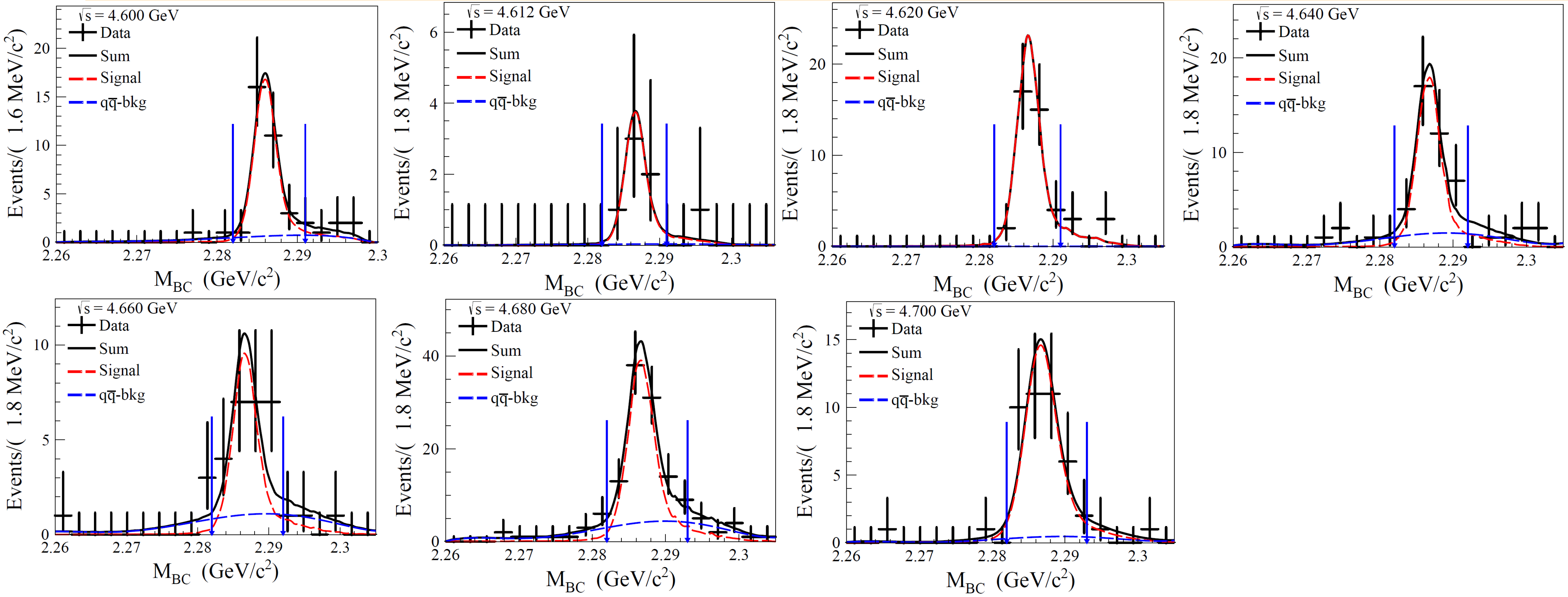
Data set	Signal yields	Bkg yields	Purity(%)
4600	33.0 ± 6.6	7.0 ± 4.2	82.6
4612	6.7 ± 2.7	0.3 ± 6.0	95.9
4620	44.0 ± 6.5	$5.2 \times 10^{-6} \pm 3.1$	≈ 100
4640	36.6 ± 7.2	14.4 ± 5.5	71.7
4660	20.6 ± 4.4	11.4 ± 6.3	64.4
4680	89.6 ± 6.7	43.4 ± 5.6	67.4
4700	39.6 ± 7.2	4.3 ± 4.2	90.1
Sum	270.1 ± 16.2	80.8 ± 13.5	77.0

- The equations for branching fraction calculation:

$$N_{obs} = B \cdot \sum_i N_i^{ST} \cdot (\epsilon_i^{DT} / \epsilon_i^{ST}).$$

- The measured branching fraction is $(4.87 \pm 0.29) \times 10^{-3}$, consistent with the previous result on BESIII.

Fitting on M_{BC} of Data



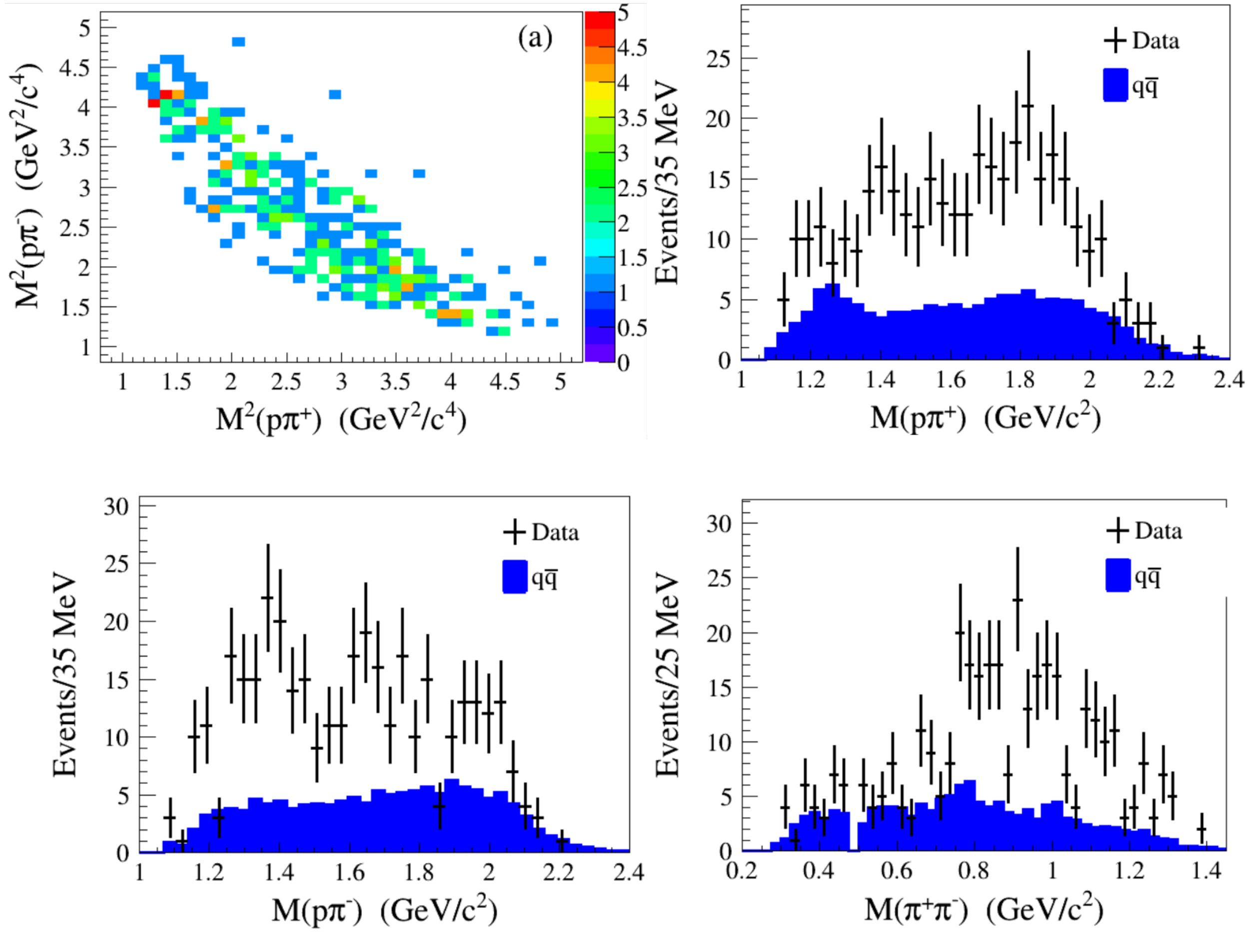
- Apply the requirements on M_{BC}.
- The window ranges are approximately 3 sigma Gaussian coverage.

Signal Yields and Purity

Data set	M_{BC} requirement (GeV/c^2)	Signal yields	Bkg yields	Purity(%)
4600	(2.282,2.291)	30.4 ± 6.0	2.9 ± 1.7	91.4
4612	(2.282,2.291)	6.1 ± 2.4	0.1 ± 2.6	98.0
4620	(2.282,2.291)	39.5 ± 5.9	$2.0 \times 10^{-6} \pm 1.2$	≈ 100
4640	(2.282,2.292)	33.5 ± 6.6	6.1 ± 2.3	84.7
4660	(2.282,2.292)	18.7 ± 4.0	4.5 ± 2.5	80.5
4680	(2.282,2.293)	82.3 ± 6.1	19.6 ± 2.5	80.7
4700	(2.282,2.293)	36.0 ± 6.5	2.1 ± 2.0	94.6

- Ensure the signal purity is larger than 80% for each energy point.

Dalitz Plot of Data



- No obvious resonances are observed, a partial wave analysis need to be performed.
- For example, to verified the contributions of $\Lambda_c^+ \to pf_0(980)$.

	final states	iTopo	nEvt	nTot
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,$	$e^+e^- \to \gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	97	7118	7118
, $\bar{\Lambda}_c^- \to \Sigma^-\pi^-\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,\ \Sigma^- \to \bar{p}\pi^0,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	23	6975	14093
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-,\ \Lambda_c^+ \to K^-\pi^0\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	69	5410	19503
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^0\pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	12	5395	24898
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0\pi^-\pi^+ p,\ \bar{K}^0 \to K_L,$	$e^+e^- \to p K^+\pi^+ K_L e^-\pi^-\pi^-\bar{p}$	11	4241	29139
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,$	$e^+e^- \to \gamma\gamma\gamma_{FSR} p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	204	4192	33331
, $\bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^+ K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_L,$	$e^+e^- \to p\pi^+\pi^+ K_L e^-\pi^- K^-\bar{p}$	146	4010	37341
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \Sigma^-\pi^-\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,\ \Sigma^- \to \bar{p}\pi^0,$	$e^+e^- \to \gamma\gamma\gamma_{FSR} p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	5	3913	41254
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-,\ \Lambda_c^+ \to K^-\pi^0\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma_{FSR} p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	234	3226	44480
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^0\pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma\gamma_{FSR} p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	66	3185	47665
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^0\pi^+\Sigma^0,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	24	2871	50536
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \mu^-\nu_\mu\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to p K^+\nu_\mu e^-\mu^-\pi^-\pi^-\bar{p}$	95	2713	53249
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\bar{\nu}_\mu\mu^+,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to p\pi^+\pi^+\mu^+ e^-\bar{\nu}_\mu K^-\bar{p}$	1	2709	55958
, $\bar{\Lambda}_c^- \to \Sigma^0\pi^-\pi^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ \Sigma^0 \to \bar{\Lambda}\gamma,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	87	2689	58647
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0\pi^-\pi^+ p,\ \bar{K}^0 \to K_L,$	$e^+e^- \to \gamma_{FSR} p K^+\pi^+ K_L e^-\pi^-\pi^-\bar{p}$	144	2449	61096
, $\bar{\Lambda}_c^- \to \bar{p}\pi^0\pi^0 K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	246	2421	63517
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0\pi^0\pi^0 p,\ \bar{K}^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	47	2394	65911
$\bar{\Lambda}_c^-\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^+ K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_L,$	$e^+e^- \to \gamma_{FSR} p\pi^+\pi^+ K_L e^-\pi^- K^-\bar{p}$	111	2378	68289
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0,\ \Lambda_c^+ \to \pi^0\pi^+\Lambda,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^-\pi^-\bar{p}$	311	2288	70577
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0,\ \Lambda_c^+ \to K^-\pi^0\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	57	2175	72752
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \omega\Sigma^+,\ \omega \to \pi^-\pi^0\pi^+,\ \Sigma^+ \to \pi^0 p,$	$e^+e^- \to \gamma\gamma\gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	142	2150	74902
, $\bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^0 K^+,\ \Lambda_c^+ \to \pi^0\pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma\gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	273	2143	77045
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\bar{\nu}_e e^-,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to p\pi^+\pi^+ e^- e^-\bar{\nu}_e K^-\bar{p}$	25	2119	79164
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to e^+\nu_e\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to p K^+\nu_e e^- e^+\pi^-\pi^-\bar{p}$	104	2115	81279
, $\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0\pi^0 p,\ \bar{K}^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma p K^+\pi^+ e^-\pi^-\pi^-\bar{p}$	27	2065	83344
, $\bar{\Lambda}_c^- \to \bar{p}\pi^0 K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	96	2009	85353
, $\bar{\Lambda}_c^- \to \Sigma^-\omega,\ \Lambda_c^+ \to K^-\pi^+ p,\ \Sigma^- \to \bar{p}\pi^0,\ \omega \to \pi^-\pi^0\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	72	1990	87343
, $\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^-\pi^-\bar{p}$	143	1925	89268
, $\bar{\Lambda}_c^- \to \Sigma^-\pi^-\pi^+,\ \Lambda_c^+ \to \pi^0\pi^+\Lambda,\ \Lambda \to \pi^- p,\ \Sigma^- \to \bar{p}\pi^0,$	$e^+e^- \to \gamma\gamma\gamma\gamma p\pi^+\pi^+ e^-\pi^-\pi^-\bar{p}$	7	1878	91146
, $\bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,$	$e^+e^- \to p\pi^+\pi^+ e^-\pi^- K^-\bar{p}$	76	1666	92812

	final states	iTopo	nEvt	nTot
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to K^-\pi^+ p,$	$e^+e^- \to pK^+\pi^+e^-\pi^-K^-\bar{p}$	51	74	74
$\bar{\Lambda}_c^- \to \bar{p}K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	12	57	131
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0 p,\ \bar{K}^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	7	47	178
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	18	43	221
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^+\Sigma^0,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	26	41	262
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	76	39	301
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to K^-\pi^+ p,$	$e^+e^- \to \gamma_{FSR}pK^+\pi^+e^-\pi^-K^-\bar{p}$	54	37	338
$\bar{\Lambda}_c^- \to \bar{\Sigma}^0\pi^-,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	16	37	375
$\bar{\Lambda}_c^- \to \bar{p}\pi^-\gamma_{FSR}\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,$	$e^+e^- \to \gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	84	36	411
$\bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^0 K^+,\ \Lambda_c^+ \to \pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	9	35	446
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	32	35	481
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0 p,\ \bar{K}^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	27	33	514
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\gamma_{FSR}\pi^+ p,$	$e^+e^- \to \gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	5	32	546
$\bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	53	28	574
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^-\pi^0 K^+,\ \Lambda_c^+ \to \pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma\gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	39	24	598
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \bar{K}^0\pi^0 p,\ \bar{K}^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	1	24	622
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,$	$e^+e^- \to \gamma\gamma\gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	87	22	644
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^+\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	57	21	665
$\bar{\Lambda}_c^- \to \bar{\Sigma}^-\pi^-\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Sigma}^- \to \bar{p}\pi^0,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	45	21	686
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\gamma_{FSR}\pi^+ p,$	$e^+e^- \to \gamma_{FSR}\gamma_{FSR}pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	110	20	706
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-,\ \Lambda_c^+ \to K^-\pi^0\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	21	17	723
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{\Sigma}^0\pi^-,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Sigma}^0 \to \bar{\Lambda}\gamma,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	2	17	740
$\bar{\Lambda}_c^- \to \bar{p}K^0,\ \Lambda_c^+ \to \bar{K}^0 p,\ \bar{K}^0 \to K_S,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to p\pi^+\pi^+e^-\pi^-\pi^-\bar{p}$	162	17	757
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^0\pi^+\Sigma^0,\ \Sigma^0 \to \gamma\Lambda,\ \Lambda \to \pi^- p,$	$e^+e^- \to \gamma\gamma\gamma pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	77	16	773
$\bar{\Lambda}_c^- \to \bar{p}\pi^- K^+,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,$	$e^+e^- \to \gamma\gamma pK^+\pi^+e^-\pi^-\pi^-\bar{p}$	170	16	789
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{p}\pi^-\gamma_{FSR}\pi^+,\ \Lambda_c^+ \to K^-\pi^+ p,$	$e^+e^- \to \gamma_{FSR}\gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	92	15	804
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-,\ \Lambda_c^+ \to K^-\pi^+ p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma_{FSR}p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	79	15	819
$\bar{\Lambda}_c^- \to \bar{p}\pi^0 K^0,\ \Lambda_c^+ \to K^-\pi^+ p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+e^-\pi^-K^-\bar{p}$	38	13	832
$\bar{\Lambda}_c^- \to \bar{p}K^0,\ \Lambda_c^+ \to \pi^-\pi^+\Sigma^+,\ \Sigma^+ \to \pi^0 p,\ K^0 \to K_S,\ K_S \to \pi^-\pi^+,$	$e^+e^- \to \gamma\gamma p\pi^+\pi^+e^-\pi^-\pi^-\bar{p}$	132	13	845
$\Lambda_c^+,\ \bar{\Lambda}_c^- \to \bar{\Lambda}\pi^-\pi^0,\ \Lambda_c^+ \to \pi^+\Lambda,\ \Lambda \to \pi^- p,\ \bar{\Lambda} \to \bar{p}\pi^+,$	$e^+e^- \to \gamma\gamma\gamma_{FSR}p\pi^+\pi^+e^-\pi^-\pi^-\bar{p}$	68	13	858

Cut Flow