Measurements of SCS process $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ with double-tag method

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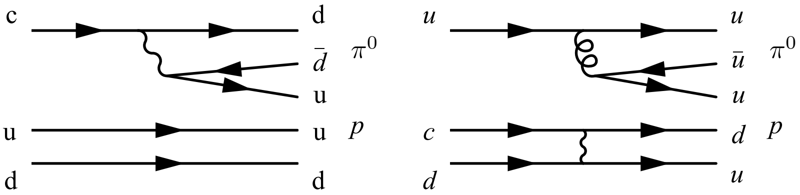
Motivation

- Two-body nonleptonic weak hadronic decay: understand the mechanism of charm baryons, test different theoretical models
  $\rightarrow$ the Cabibbo Suppressed (CS) decays
  Cabbibo suppression $\rightarrow \mathcal{B} \sim 10^{-3}$ - 10^{-4} $\rightarrow$ difficult to measure
- The hadronic decay amplitudes of Λ_c^+:
  - factorizable
  - nonfactorizable: W-exchange, internal W-emission

  SCS decays containing both contributions provide information about their interference.
  Validate different phenomenological models.
  Feynman diagrams of $\Lambda_c \rightarrow p\pi^0$ at lowest order is shown below



(a) W-emission (b) W-exchange

Motivation

- Experimentally, the absolute BFs of 12 CF Λ_c^+ decays were measured by BESIII with much improved precision in 2016.
- Various phenomenological models prediction for $\mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$:
  - SU(3) flavorsymmetry model : 2
  - Constituentquark model : 4.5 or 8.0
  - Dynamical calculation basedon pole model and current-algebra : 3.5
  - SU(3) flavor symmetry including the contributions from $\mathcal{O}(1\bar{5})$: 4.7

Data Sets

- Boss version: 7.0.6
- Data: XYZ data, E_{cms} from 4.6 - 4.7GeV
- MC for single-tag(ST) efficiency:
  $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$, $\Lambda_c^+(\bar{\Lambda}_c^-)$ decays to one of the tag modes, $\bar{\Lambda}_c^-(\Lambda_c^+)$ decays inclusively.
- MC for double-tag(DT) efficiency:
  $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$, $\Lambda_c^+(\bar{\Lambda}_c^-)$ decays to one of the tag modes, $\bar{\Lambda}_c^-(\Lambda_c^+)$ decays to $p\pi^0(\gamma\gamma)$ and $p\eta(\gamma\gamma)$.
- Inclusive MC:
  - 40x $\Lambda_c^+\bar{\Lambda}_c^-$ MC.
  - 40x Hadron MC.

Energy point	E_{cms}(MeV)	$\mathcal{L}(pb^{-1})$	Run number
4600	4599.53	$586.9 \pm 0.1 \pm 3.9$	35227-36213
4626	4628.00	$521.52 \pm 0.11 \pm 2.76$	63075-63515
4640	4640.91	$552.41 \pm 0.12 \pm 2.93$	63516-63715
4660	4661.24	$529.63 \pm 0.12 \pm 2.81$	63718-63852
4680	4681.92	$1669.31 \pm 0.21 \pm 8.85$	63867-64015, 64365-65092
4700	4698.82	$536.45 \pm 0.12 \pm 2.84$	64028-64313

Analysis strategy

- use double-tag(DT) method, tag side: 9 tag modes, signal side: $\Lambda_c^+ \to p\pi^0 (\Lambda_c^+ \to p\eta)$

Modes	Absolute $\mathcal{B}$ (%)	subsequent $\mathcal{B}$ (%)	total $\mathcal{B}$ (%)
$\Lambda_c^+ \to pK^-\pi^+$	6.28±0.32	-	6.28±0.32
$\Lambda_c^+ \to pK_S^0$	1.59±0.08	69.2	1.10±0.06
$\Lambda_c^+ \to \Lambda\pi^+$	1.30±0.07	63.9	0.83±0.04
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	4.46±0.30	98.8	4.41±0.30
$\Lambda_c^+ \to pK_S^0\pi^0$	1.97±0.13	69.2×98.8	1.35±0.06
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	7.1±0.4	63.9×98.8	4.48±0.25
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	1.60±0.12	69.2	1.11±0.08
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	3.64±0.29	63.9	2.33±0.19
$\Lambda_c^+ \to \Sigma^0\pi^+$	1.29±0.07	63.9	0.82±0.04

Event Selection

Good Charged Tracks

- $|V_r| < 1cm$, $|V_z| < 10cm$, $|cos\theta| < 0.93$

PID

- p :p(p)>p(π), p(p)>p(K)
- π :p(π)>p(p), p(π)>p(K)
- K :p(K)>p(p), p(K)>p(π), p(K)>0.0005

Good photons

- $0 \leq T \leq 700$ ns
- $E_\gamma > 25$MeV, $|cos\theta| < 0.8$ for barrel
- $E_\gamma > 50$MeV, $0.86 < |cos\theta| < 0.92$ for endcap

π^0 reconstruction

- 1C kinematic fit: $\chi^2_{KF} < 200$
- $0.115 < M_{\gamma\gamma} < 0.150\text{GeV}/c^2$

K^0_S reconstruction

- A pair of charged tracks with opposited charge: $|V_z| < 20cm$, $|cos\theta| < 0.93$
- Vertex fit, $\chi^2 < 100$
- Second vertex fit, $L/\delta L > 2$
- $0.487 < M_{K^0_S} < 0.511\text{GeV}/c^2$

Λ reconstruction

- charged tracks with opposited charge: $|V_z| < 20cm$, PID for p
- Vertex fit, $\chi^2 < 100$
- Second vertex fit, $L/\delta L > 2$
- $1.111 < M_\Lambda < 1.121\text{GeV}/c^2$

Σ^0 reconstruction

- $1.179 < M_{\Lambda\gamma} < 1.203\text{GeV}/c^2$

ΔE cut and background veto on tag side

- Extract Λ_c^+ with minimum ΔE, and ΔE requirements are shown in the right table
- $2.0 < M_{\Lambda_c^+} < 2.6\mathrm{GeV}/c^2$
- For modes with same final states, add veto cuts shown below:

Tag mode	ΔE window (GeV)
$\Lambda_c^+ \to pK^-\pi^+$	[-0.034, 0.02]
$\Lambda_c^+ \to pK_S^0$	[-0.02, 0.02]
$\Lambda_c^+ \to \Lambda\pi^+$	[-0.02, 0.02]
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	[-0.03, 0.02]
$\Lambda_c^+ \to pK_S^0\pi^0$	[-0.03, 0.02]
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	[-0.03, 0.02]
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	[-0.02, 0.02]
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	[-0.02, 0.02]
$\Lambda_c^+ \to \Sigma^0\pi^+$	[-0.02, 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

ST yields and efficiencies

- ST yields and efficiency are extracted by the unbinned maximum likelihood fits performed to all M_{BC} distributions.
  Total fit = MC shape $\otimes$ Gaussian(Signal) + ARGUS function(Background)
  Yield region: (2.275,2.31)GeV$/c^2$
- ST yields

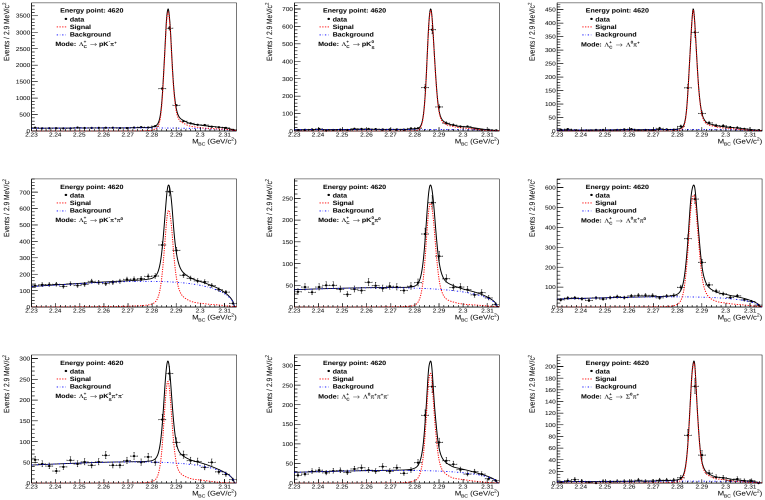
Modes	4.60GeV	4.626GeV	4.64GeV	4.66GeV	4.68GeV	4.70GeV
$\Lambda_c^+ \to pK^-\pi^+$	6463±86	5741±85	5936±87	5706±84	16890±143	5024±78
$\Lambda_c^+ \to pK_S^0$	1270±37	1062±35	1106±35	1113±35	3353±61	967±33
$\Lambda_c^+ \to \Lambda\pi^+$	742±28	659±28	690±28	649±27	2007±47	520±24
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	1487±52	1192±49	1256±50	1305±53	3854±92	1109±48
$\Lambda_c^+ \to pK_S^0\pi^0$	496±28	469±29	484±30	475±28	1462±51	388±26
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	1407±45	1162±42	1317±44	1157±41	3553±72	1054±40
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	498±28	428±28	457±29	465±28	1299±50	426±27
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	661±30	512±28	660±31	628±30	1802±51	557±28
$\Lambda_c^+ \to \Sigma^0\pi^+$	396±21	329±20	344±20	343±20	1038±34	284±18

ST yields and efficiencies

- ST yields and efficiency are extracted by the unbinned maximum likelihood fits performed to all M_{BC} distributions.
  Total fit = MC shape $\otimes$ Gaussian(Signal) + ARGUS function(Background)
  Yield region: $(2.275, 2.31)\mathrm{GeV}/c^2$
- ST efficiencies(%)

Modes	4.60GeV	4.626GeV	4.64GeV	4.66GeV	4.68GeV	4.70GeV
$\Lambda_c^+ \to pK^-\pi^+$	49.13±0.10	47.62±0.10	47.20±0.10	46.17±0.10	45.49±0.09	44.69±0.09
$\Lambda_c^+ \to pK_S^0$	55.69±0.25	51.62±0.25	50.92±0.24	49.75±0.24	48.14±0.23	47.33±0.23
$\Lambda_c^+ \to \Lambda\pi^+$	45.02±0.27	40.81±0.25	40.38±0.25	39.05±0.24	37.84±0.24	37.09±0.23
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	14.95±0.08	14.33±0.08	14.10±0.07	13.94±0.07	13.80±0.07	13.59±0.07
$\Lambda_c^+ \to pK_S^0\pi^0$	18.17±0.14	17.13±0.14	17.11±0.14	16.56±0.13	16.55±0.13	16.22±0.13
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	16.72±0.08	15.23±0.07	15.28±0.07	14.93±0.07	14.62±0.07	14.23±0.07
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	20.44±0.16	18.51±0.16	18.48±0.16	18.31±0.15	17.84±0.15	17.75±0.15
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	13.72±0.09	12.48±0.09	12.49±0.09	12.67±0.09	12.26±0.08	12.47±0.08
$\Lambda_c^+ \to \Sigma^0\pi^+$	22.25±0.20	20.26±0.19	20.46±0.18	19.56±0.18	19.28±0.18	18.81±0.17

ST yields @4626 as demonstration



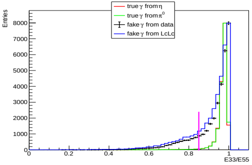
DT side analysis strategy

Search for $\Lambda_c \to p\pi^0(p\eta) \to p\gamma\gamma$ in the remaining objects recoiling against the ST Λ_c

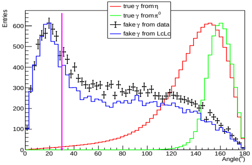
- The selection criteria for the good charged tracks and the good photon, as well as the PID for the proton are exactly same as those in the ST analysis.
- Only one good charged track identified as proton and at least two good photons are required.
- To suppress multi-track background， require only one charged track that satisfies |cosθ|<0.93 , $|V_r| < 1cm$, $|V_z| < 10cm$, and no other track in $|V_z| < 20cm$
- To veto noise photons from anti-proton or proton interacting with the material in the EMC, the good photons are further required:
  - Lateral moment < 0.4 : The lateral moment of shower shape is required to be less than 0.4.
  - $E_{3\times3}/E_{5\times5} > 0.85$: $E_{3\times3}/E_{5\times5}$ is required to be larger than 0.85, where the $E_{3\times3}$ and $E_{5\times5}$ are the shower energy summed of 3×3 and 5×5 crystal around seed crystal.
  - $Angle_{\gamma\bar{p}} > 30^\circ$: The photons are requred to be apart from anti-proton with an opening angle larger than 30°.

Veto noise photons

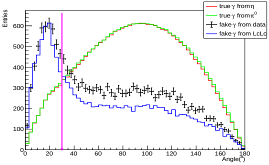
- Distributions of true photon and noise photon shower shape parameters.



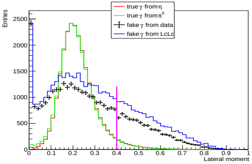
(l) E33/E55



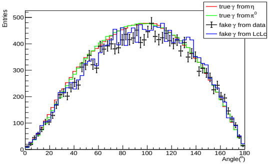
(m) angle between γ and $\bar{p}$, γ and $\bar{p}$ from DT $\bar{\Lambda}_C^-$



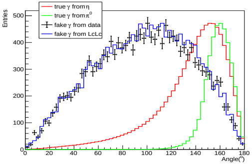
(n) angle between γ and $\bar{p}$, γ from DT Λ_c^+, $\bar{p}$ from ST $\bar{\Lambda}_C^-$



(o) Lateral moment



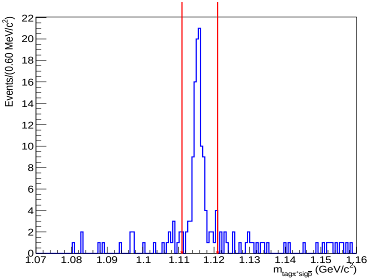
(p) angle between γ and p, γ from DT $\bar{\Lambda}_C^-$, p from ST Λ_c^+



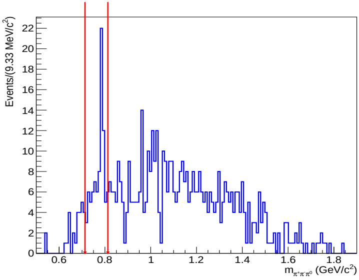
(q) angle between γ and p, γ and p from DT Λ_c^+

DT side analysis strategy

- To veto backgrounds with wrong combined Λ, $m_{tag\pi^- sig\bar{p}}$ in $(1.111, 1.121)$ GeV$/c^2$ is vetoed, where $m_{tag\pi^- sig\bar{p}}$ is the invariant mass of π^- from ST side and $\bar{p}$ from DT side.
- To veto backgrounds with wrong combined ω, $m_{\pi^+\pi^-\pi^0}$ in $(0.713, 0.813)$ GeV$/c^2$ is vetoed, where $m_{\pi^+\pi^-\pi^0}$ is the invariant mass of any combination of $\pi^+\pi^-\pi^0$ in both ST and DT final states.



(r) Distribution of $m_{tag\pi^- sig\bar{p}}$

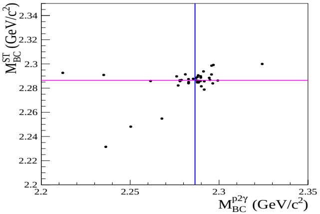


(s) Distribution of $m_{\pi^+\pi^-\pi^0}$

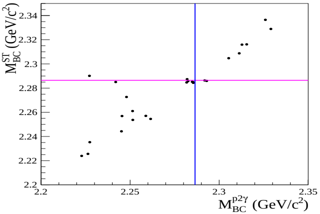
DT side analysis strategy

- With above selected proton and photons, the DT Λ_c signal is reconstructed with the proton and two photons with $\Delta E_{p2\gamma} = E_p + E_{\gamma 1} + E_{\gamma 2} - E_{\mathrm{beam}}$ be within $(-0.08, 0.035)$GeV.
- Combination with minimum $|\Delta E_{p2\gamma}|$ is kept for further analysis.
- After above selection criteria, three variables are used in the further analysis:
  - $M_{\gamma\gamma}$: the invariant mass of two photon
  - M_{BC}^{ST}: the ST side beam energy constrained mass
  - $M_{BC}^{p2\gamma}$: the signal side beam energy constrained mass
- Fit region:
  - $M_{\gamma\gamma}$: $0.115 < M_{\gamma\gamma} < 0.150\ \mathrm{GeV}/c^2$ for π^0; $0.49 < M_{\gamma\gamma} < 0.583\ \mathrm{GeV}/c^2$ for η
  - $M_{BC}^{ST} > 2.2\mathrm{GeV}/c^2$ and $M_{BC}^{p2\gamma} > 2.2\mathrm{GeV}/c^2$

  2D distributions of $M_{BC}^{p2\gamma}$ VS M_{BC}^{ST} in fit region is shown below:



(t) $M_{BC}^{p2\gamma}$ VS M_{BC}^{ST} for $p\eta$



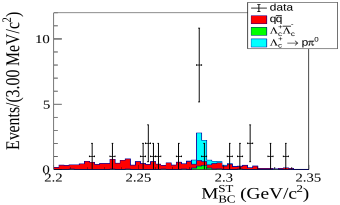
(u) $M_{BC}^{p2\gamma}$ VS M_{BC}^{ST} for $p\pi^0$

Background Study and some distributions

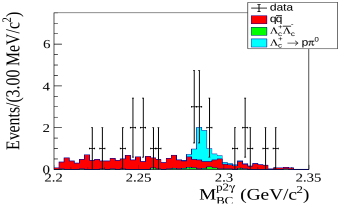
Fit region:

- $M_{\gamma\gamma}$: $0.115 < M_{\gamma\gamma} < 0.150$ GeV$/c^2$ for π^0; $0.49 < M_{\gamma\gamma} < 0.583$ GeV$/c^2$ for η
- $M_{BC}^{ST} > 2.2$GeV$/c^2$ and $M_{BC}^{p2\gamma} > 2.2$GeV$/c^2$

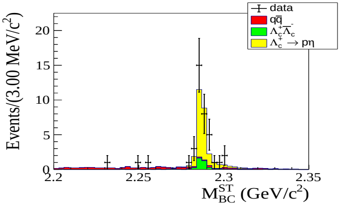
M_{BC}^{ST} and $M_{BC}^{p2\gamma}$ 1D distributions in fit region:



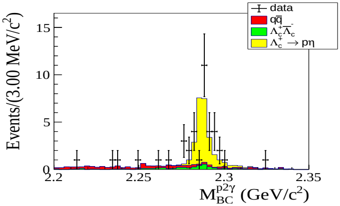
(v) M_{BC}^{ST} of $\Lambda_c \to p\pi^0$ process



(w) $M_{BC}^{p2\gamma}$ of $\Lambda_c \to p\pi^0$ process



(x) M_{BC}^{ST} of $\Lambda_c \to p\eta$ process



(y) $M_{BC}^{p2\gamma}$ of $\Lambda_c \to p\eta$ process

DT efficiencies of $\Lambda_c^+ \to p\pi^0$

Modes	4.60GeV	4.626GeV	4.64GeV	4.66GeV	4.68GeV	4.70GeV
$\Lambda_c^+ \to pK^-\pi^+$	23.88±0.06	23.39±0.06	23.36±0.06	22.99±0.06	22.68±0.06	22.32±0.06
$\Lambda_c^+ \to pK_S^0$	28.48±0.15	26.54±0.15	25.90±0.15	25.37±0.15	24.60±0.14	24.03±0.14
$\Lambda_c^+ \to \Lambda\pi^+$	23.79±0.17	21.70±0.16	21.12±0.16	20.91±0.16	19.72±0.15	19.50±0.15
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	8.27±0.05	8.02±0.05	8.05±0.05	7.88±0.05	7.89±0.05	7.83±0.05
$\Lambda_c^+ \to pK_S^0\pi^0$	8.65±0.09	8.02±0.08	8.27±0.08	8.14±0.08	7.89±0.08	7.84±0.08
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	8.93±0.05	8.18±0.05	8.21±0.05	7.97±0.05	7.78±0.04	7.68±0.04
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	8.54±0.09	7.78±0.09	7.80±0.09	7.79±0.09	7.66±0.09	7.51±0.09
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	5.51±0.05	5.11±0.05	5.12±0.05	5.18±0.05	5.26±0.05	5.22±0.05
$\Lambda_c^+ \to \Sigma^0\pi^+$	13.51±0.13	11.93±0.13	11.78±0.12	11.24±0.12	11.11±0.12	10.80±0.12

DT efficiencies of $\Lambda_c^+ \to p\eta$

Modes	4.60GeV	4.626GeV	4.64GeV	4.66GeV	4.68GeV	4.70GeV
$\Lambda_c^+ \to pK^-\pi^+$	21.83±0.06	21.46±0.06	21.45±0.06	21.08±0.06	20.83±0.06	20.65±0.06
$\Lambda_c^+ \to pK_S^0$	26.14±0.15	24.11±0.14	23.96±0.14	22.94±0.14	22.33±0.14	21.76±0.14
$\Lambda_c^+ \to \Lambda\pi^+$	21.78±0.16	19.77±0.15	19.36±0.15	18.71±0.15	17.98±0.15	17.76±0.15
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	7.56±0.04	7.26±0.04	7.29±0.04	7.27±0.04	7.17±0.04	7.16±0.04
$\Lambda_c^+ \to pK_S^0\pi^0$	8.89±0.09	8.33±0.08	8.39±0.08	8.20±0.08	7.95±0.08	7.89±0.08
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	8.35±0.05	7.74±0.04	7.74±0.04	7.51±0.04	7.36±0.04	7.32±0.04
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	8.60±0.09	7.88±0.09	7.91±0.09	7.61±0.09	7.81±0.09	7.66±0.09
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	5.94±0.05	5.53±0.05	5.59±0.05	5.42±0.05	5.51±0.05	5.52±0.05
$\Lambda_c^+ \to \Sigma^0\pi^+$	12.01±0.13	10.76±0.12	10.43±0.12	10.23±0.12	10.04±0.12	9.81±0.12

Signal Extraction

- A simultaneous fit on 6 energy points is performed based on the 2D M_{BC} distributions.
  The total PDF used in the fit:

$$PDF = PDF_{\pi^0}(PDF_{\eta}) + PDF_{bkg}. \quad (1)$$

$PDF_{\pi^0}(PDF_{\eta})$ is described by signal MC simulation.
2D background is estimated by:

$$PDF_{bkg}(x,y) = \mathrm{Argus}(x; m_x, z_x, \rho_x) \times \mathrm{Argus}\,(y; m_y, z_y, \rho_y) \times \mathrm{Student}\,(x-y; \mu, \sigma(x+y), N). \quad (2)$$

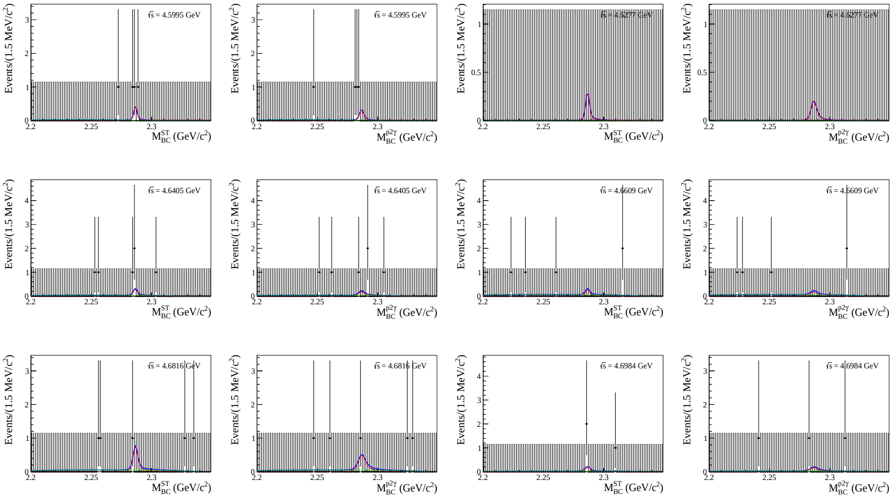
$$\mathrm{Student}\,(Q; \mu, \sigma, N) = \frac{\Gamma\left(\frac{N+1}{2}\right)}{\sigma\sqrt{N\pi}\Gamma\left(\frac{N}{2}\right)}\left[1 + \frac{1}{N}\left(\frac{Q-\mu}{\sigma}\right)^2\right]^{-\frac{N+1}{2}}. \quad (3)$$

$$\mathrm{Argus}(x; m, z, \rho) = Cx\left(1 - \frac{x^2}{m^2}\right)^{\rho} e^{z\left(1-\frac{x^2}{m^2}\right)} \quad (4)$$

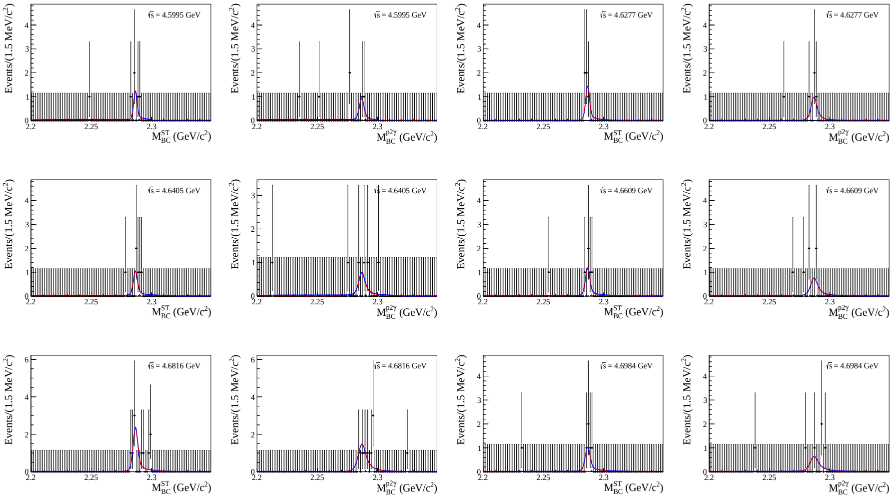
Fit 40x $q\bar{q}$ inclusive MC to get PDF_{bkg} parameters.
PDF_{bkg} parameters are shared between each energy point.
Parameters are set as follow:

- m_x, m_y: cutoff of Argus function, fixed to $\mathrm{E}_{\mathrm{beam}}$
- z_x and z_y float in the fit
- ρ_x and ρ_y are fixed to 0.5.
- In the Student function, μ, σ and N is float in the fit.
- Argus function parameters in PDF_{bkg} is fixed when fitting data, while Student function parameters float.

Fitting results $\Lambda_c^+ \to p\pi^0$



Fitting results $\Lambda_c^+ \to p\eta$



Systematic Uncertainty

Sources	$\Lambda_c^+ \to p\pi^0$(%)	$\Lambda_c^+ \to p\eta$(%)
p tracking	1.0	1.0
p PID	1.0	1.0
π^0 reconstruction efficiency, including the photon detection efficiency	0.8	1.0
shower requirements	1.7	0.8
ST yield	0.5	0.5
Intermediate states	0.03(negligible)	0.5
ΔE requirement	1.7	1.7
M(tagπ^+signal$\bar{p}$) mass window	1.8	5.8
M_ω mass window	0.3	-
2D Fitting (signal shape and background shape, fit range)	14.7	1.5
MC statistics	0.1	0.1
Sum	15.1	6.6

Dominant Systematic Uncertainty

- ΔE requirement
  The systematic uncertainty for ΔE requirement in DT side is studied by ST control sample $\Lambda_c \to pK^-\pi^+\pi^0$ and $\Lambda_c \to \Lambda\pi^+\pi^0$. A combined result is 1.7%.
- veto DT background: mass window requirement
  - Nominal: require $M(p\pi^0) < 1.111GeV$ or $M(p\pi^0) > 1.121GeV$
    Change mass window: $| M(p\pi^0) - M(\Lambda) |> 4MeV$ or $| M(p\pi^0) - M(\Lambda) |> 6MeV$.
  - Nominal: require $M_{\pi^+\pi^-\pi^0} - M_\omega < 70MeV$ or $M_{\pi^+\pi^-\pi^0} - M_\omega > 30MeV$.
    Change mass window: $| M_{\pi^+\pi^-\pi^0} - M_\omega |> 50MeV$ or $| M_{\pi^+\pi^-\pi^0} - M_\omega |> 90MeV$.

  The larger difference is assigned as the systematic uncertainty.
  The uncertainty of ω veto is 0.3% for $\Lambda_c^+ \to p\pi^0$. For Λ veto, the uncertainties are 1.8% and 5.8% for $\Lambda_c^+ \to p\pi^0$ and $p\eta$, respectively.
- Fitting
  The systematic uncertainty from 2D Fitting includes signal shape, background shape and fitting range.
  - Signal MC shape: Convolute a Gaussion function with a fixed width. The result is 3.1% for $\Lambda_c^+ \to p\pi^0$ and 0.4% for $\Lambda_c^+ \to p\eta$.
  - Background shape: change background PDF parameter in 1σ deviation. The result is 9.3% for $\Lambda_c^+ \to p\pi^0$ and 1.4% for $\Lambda_c^+ \to p\eta$.
  - Fitting range: change the fitting range. Nominal: M_{BC}^{ST} range $[2.2, 2.35]$ GeV$/c^2$ and $M_{BC}^{p2\gamma}$ range $[2.2, 2.35]$ GeV$/c^2$. The range is changed to be $[2.25, 2.35]$ GeV$/c^2$. The result is 11% for $\Lambda_c^+ \to p\pi^0$ and negligible for $\Lambda_c^+ \to p\eta$.

  Thus, the combined result for fitting systematic uncertainty is 14.7% for $\Lambda_c^+ \to p\pi^0$ and 1.5% for $\Lambda_c^+ \to p\eta$.

Result

- $\mathcal{B}$ is determined by:

$$\mathcal{B} = \frac{N_{\rm obs}}{\Sigma_i \left(N_i^{\rm single-tag}/\epsilon_i^{\rm single-tag}\right) \cdot \epsilon_i^{\rm double-tag}},$$

  - $N_{\rm obs}$: number of observed events for the signal process
  - $N_i^{\rm single-tag}$ denotes the number of events of each single-tag channel of Λ_c^+ decays
  - $\epsilon_i^{\rm single-tag}$ and $\epsilon_i^{\rm double-tag}$: ST and DT efficiencies
- Preliminary result:
  $\mathcal{B}(\Lambda_c^+ \to p\pi^0): (1.73 \pm 0.67 \pm 0.26) \times 10^{-4}, 4.9\sigma$
  $\mathcal{B}(\Lambda_c^+ \to p\eta): (1.77 \pm 0.33 \pm 0.12) \times 10^{-3}, 11.2\sigma.$
  The results of this work and measurments from other works are summarized as follow:

Decay modes	$\Lambda_c^+ \to p\pi^0$	$\Lambda_c^+ \to p\eta$
$\mathcal{B}$(this analysis)	$(1.73 \pm 0.67 \pm 0.26) \times 10^{-4}$	$(1.77 \pm 0.33 \pm 0.12) \times 10^{-3}$
$\mathcal{B}$(BESIII previous result)	$< 2.7 \times 10^{-4} @ 90\% C.L.$	$(1.24 \pm 0.28 \pm 0.10) \times 10^{-3}$
$\mathcal{B}$(BESIII ST method)	-	$(1.56 \pm 0.11 \pm 0.04) \times 10^{-3}$
$\mathcal{B}$(Belle result)	$< 8 \times 10^{-5} @ 90\% C.L.$	$(1.42 \pm 0.05 \pm 0.11) \times 10^{-3}$

Summary and next to do

- $\mathcal{B}$ of SCS process $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ have been measured with double-tag method, and the result is:
  $\mathcal{B}(\Lambda_c^+ \to p\pi^0) : (1.73 \pm 0.67 \pm 0.26) \times 10^{-4}$ with 4.9σ
  $\mathcal{B}(\Lambda_c^+ \to p\eta) : (1.77 \pm 0.33 \pm 0.12) \times 10^{-3}$ with 11.2σ.
  The result is consistent with various phenomenological models' predictions.
- Memo has been prepared
- Next to do:
  - Check datasets at $E_{cms} > 4.7\text{GeV}$
  - Check $\Lambda_c^+ \bar{\Lambda}_C^-$ backgrounds
  - More validation of background *PDF*
  - Upper limit