Charmed baryon Λ_c^+ at the SPD NICA experiment

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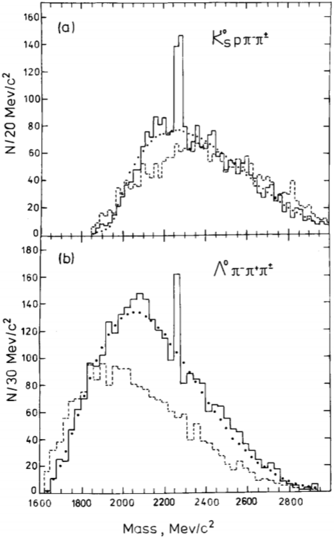
Motivation

An open charm production in proton-proton collisions at medium and low energy provides:

- QCD predictions test;
- Study in detail heavy quark hadronization processes;
- The better understanding of the proton structure;
- Clarify detector performance.



BIS-2 1984

Events simulation

Signal

- Hard subprocesses $gg \to c\bar{c}$ and $q\bar{q} \to c\bar{c}$ events have been generated within the Pythia8 as a signal:
  10 GeV: $\sim 1 \cdot 10^6$ events; 27 GeV: $\sim 1 \cdot 10^6$ events;
- The events with Λ_c^+ has been selected;
- All Λ_c^+ baryons have been forced to decay as follows:
  10 GeV: $\Lambda_c^+ \to (K_s^0 \to \pi^+\pi^-)p^+$;
  27 GeV: $\Lambda_c^+ \to p^+K^-\pi^+$;

Background

SoftQCD(MB) events have been generated within Pythia8 as a background:
10 GeV: $\sim 2 \cdot 10^6$ events; 27 GeV: $\sim 2.25 \cdot 10^6$ events;

Analysis

SPDROOT 4.1.6.

PID (10 GeV)

Since there is no Time-of-Flight (TOF) system in the first stage, an alternative method for PID is required.

In the current analysis for 10 GeV, PID was assigned based on the following algorithm:

If particle momentum < 0.5 GeV and Straw Tracker available:

- using TS PID;

else:

If (charge < 0):

- PID = -211;

else:

- PID = 2212;

If (Chi2ToPV >= 10 and charge > 0)

- PID = 211

PID (27 GeV)

For 27 GeV analysis PIDs were assigned based on the following algorithm:

- Using TOF PID;
- If no TOF PID available(rare cases) set PID = 211;

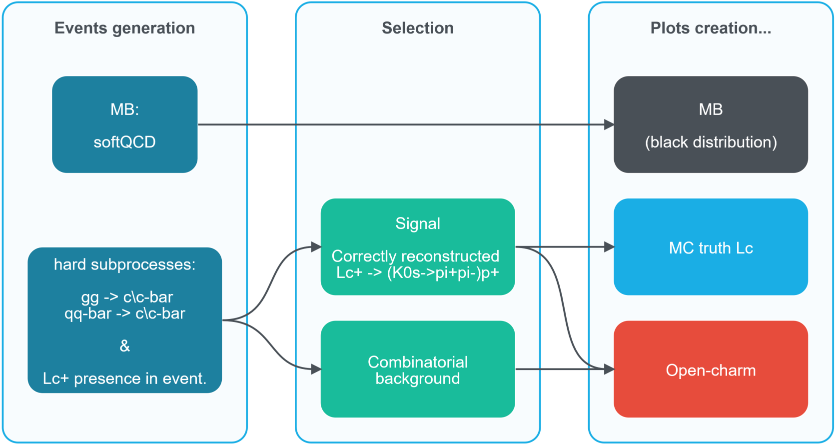
In the future, application of FARICH PID for high momenta supposed here.
TOF End-Cap separation up to energy of:

- π / K : 1.67 GeV;
- K / p : 2.73 GeV;

FARICH End-Cap separation up to energy of:

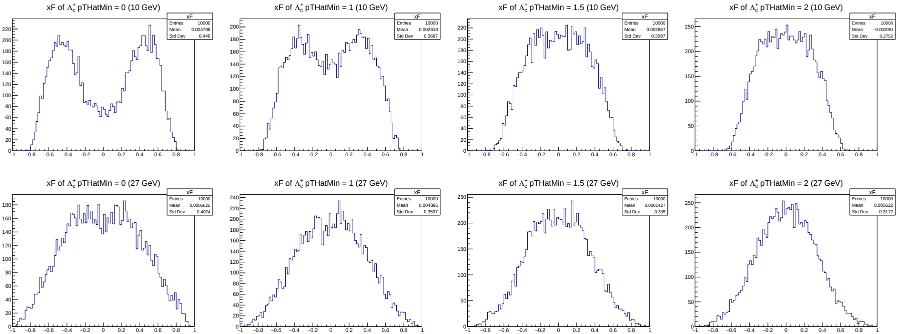
- π / K : 5.5 GeV;
- K / p : 8 GeV;

Designations

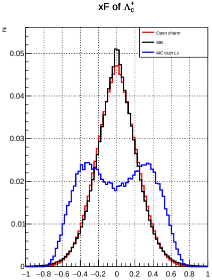


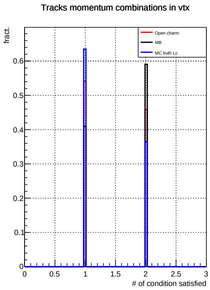
pTHatMin choice (currently set 1)

Now there is no definitively optimal value for the pTHatMin parameter in our case, due to the lack of experimental data to compare with.



Selection parameters (10 GeV : $\Lambda_c^+ \to (K_s^0 \to \pi^+\pi^-)p^+$) (I)



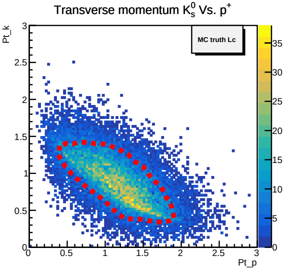


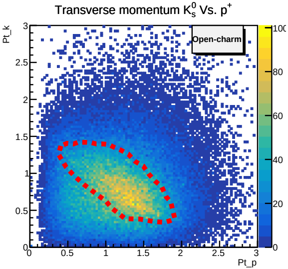
Note:

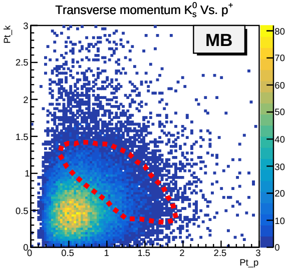
Using PID, all the p^+, π^+, π^- combinations in the event are then treated as possible candidates for Λ_c^+(and K_s^0) decay products.

Conditions for the right plot:

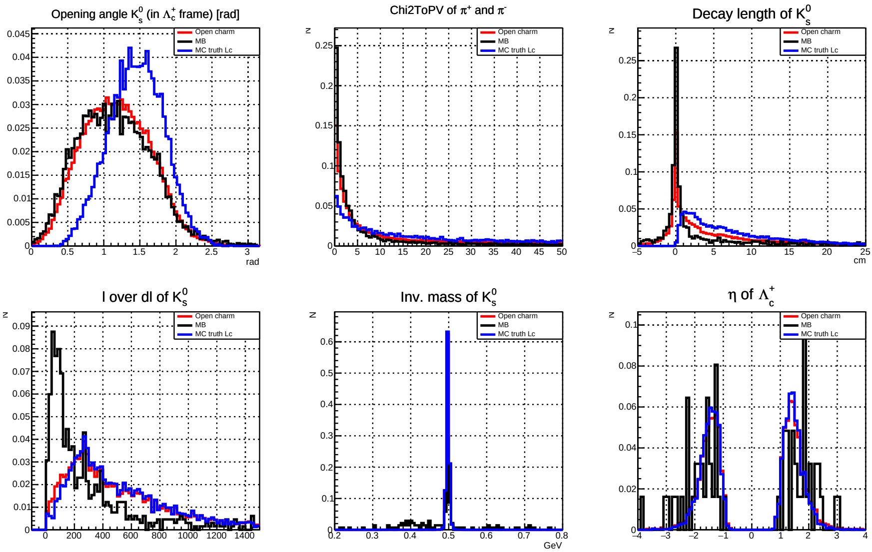
- 1) $P_p > P_{\pi^+}$ & $P_p > P_{\pi^-}$;
- 2) Else;



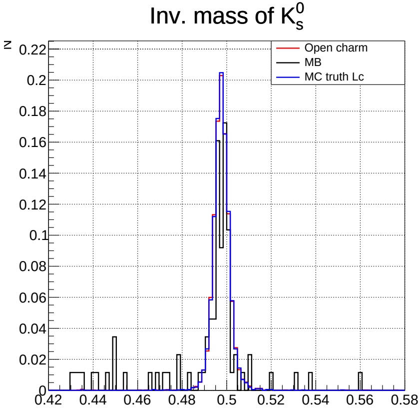


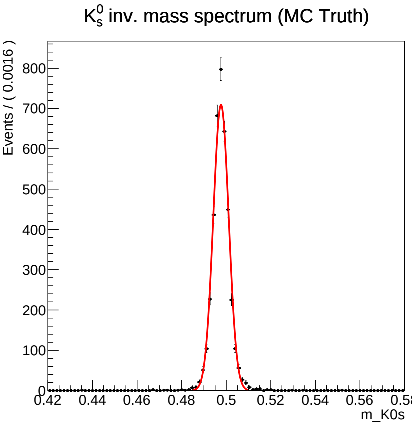


Selection parameters (10 GeV : $\Lambda_c^+ \rightarrow (K_s^0 \rightarrow \pi^+\pi^-)p^+$) (II)



K_s^0 reconstructed mass at K_s^0 mass range cut step





FIT INFO:

- $m_{K_s^0} = 0.49765 \pm 0.00006$ GeV;
- $\sigma = 0.00347 \pm 0.00004$ GeV;

Selection criteria (10 GeV) (I)

Tracks selection:

- PID according to algorithm above;
- GetNHitsIts > 1;
- GetIsFitted -> ok;
- GetConvergency() != 0;
- Chi2overNDF < 6 for pions;

Combinatorial selection:

- p^+, π^+, π^- combinations in event;
- Proton has max. momentum in p^+, π^+, π^- combination;

Selection criteria (10 GeV) (II)

2D selection:

- Pt_{p^+} VS. $Pt_{K_s^0}$ region selection;

Vertices & kinematics selection:

K_s^0 selection:

- chi2ToPV of pions > 4;
- K_s^0 decay length > 4 cm;
- l/dl > 400 for K_s^0;
- Opening angle > 1 rad for K_s^0;
- $M_{K_s^0} \in (0.49; 0.51) GeV$;

Λ_c^+ selection:

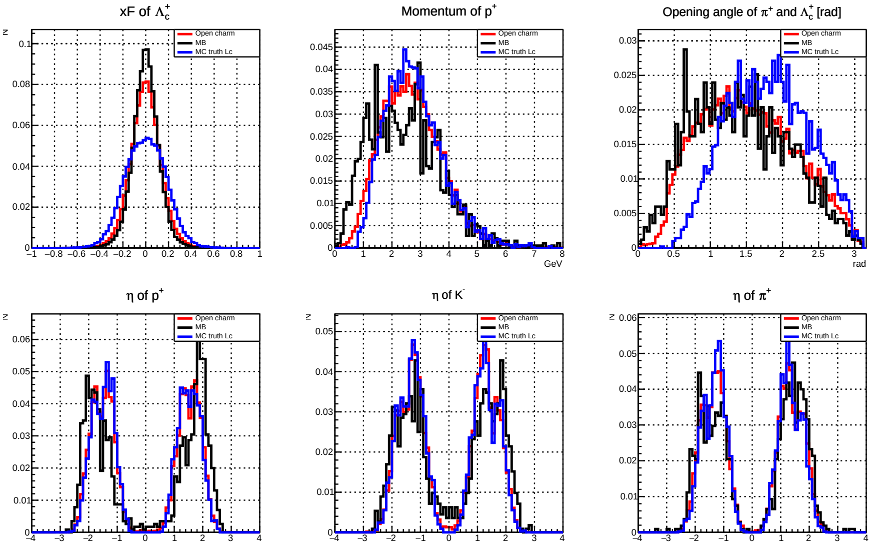
- |xF$_{\Lambda_c^+}$| > 0.4;
- $M_{\Lambda_c^+} \in (1.6; 3.0) GeV$;
- $\eta_{\Lambda_c^+} \in (-2; 2)$;

Cut reduction table (counts from (2.2; 2.4) GeV interval) (10 GeV)

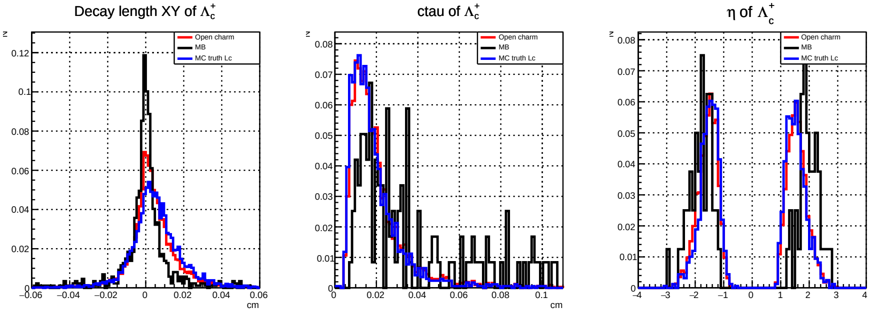
Fractions takes after/before each cut.

Num.	Ratios	MC Truth events	MB events
1	ITsHits > 1	1	1
2	IsFitted -> ok	1	1
3	GetConvergency() != 0	0.4459	0.2452
4	Chi2overNDF < 6 for pions	0.9236	0.8449
5	$\|xF_{\Lambda_c^+}\| > 0.4$	0.3090	0.0791
6	Max. momentum belongs to p^+	0.6344	0.4023
7	K_s^0 and p^+ Pt corr. cut	0.7433	0.2420
8	OA > 1 rad	0.8778	0.8155
9	chi2ToPV of pions > 4	0.8827	0.4972
10	K_s^0 decay length > 4 cm	0.6272	0.2980
11	l/dl > 400 for K_s^0	0.5598	0.2962
12	$M_{K_s^0} \in (0.49; 0.51) GeV$	0.9742	0.4250
13	$\eta_{\Lambda_c^+} \in (-2; 2)$	0.9119	0.5294
14	$M_{\Lambda_c^+} \in (1.6; 3.0) GeV$	1	1
	Total	$\mathbf{1.5 \cdot 10^{-2}}$	$\mathbf{1.3 \cdot 10^{-5}}$

Selection parameters (27 GeV : $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$) (I)



Selection parametersd (27 GeV : $\Lambda_c^+ \to p^+ K^- \pi^+$) (II)



Selection criteria (27 GeV) (I)

Tracks selection:

- PID according to algorithm above;
- GetNHitsIts > 3;
- GetIsFitted -> ok;
- GetConvergency() != 0;
- Chi2overNDF < 6 for pions;

Combinatorial selection:

- p^+, K^-, π^+ combinations in event;

Selection criteria (27 GeV) (II)

Kinematics of Λ_c^+ products selection:

- $\mathrm{P}_{p^+} > 1$ GeV;
- $\mathrm{OA}_{\pi^+} > 1$ rad;
- $\eta_{p^+} \notin (-0.6; 0.6)$;
- $\eta_{K^-} \notin (-0.4; 0.4)$;
- $\eta_{pip^+} \notin (-0.4; 0.4)$;

Λ_c^+ vertex & kinematics selection:

- $|\mathrm{xF}_{\Lambda_c^+}| > 0.3$;
- Λ_c^+ decay length XY > 0.0075 cm;
- $ctau_{\Lambda_c^+} < 0.04$;
- $\eta_{\Lambda_c^+} \in (-2; 2)$;
- $M_{\Lambda_c^+} \in (1.6; 3.0) GeV$;

Cut reduction table (counts from (2.2; 2.4) GeV interval) (27 GeV)

Fractions takes after/before each cut.

Num.	Ratios	MC Truth events	MB events
1	ITsHits > 3	0.6369	0.5193
2	IsFitted -> ok	1	1
3	GetConvergency() != 0	0.4377	0.2104
4	Chi2overNDF < 6 for pions	0.9478	0.9400
5	$\lvert xF_{\Lambda_c^+}\rvert > 0.3$	0.0797	0.0150
6	$P_{p^+} > 1GeV$	0.9914	0.8899
7	$OA_{\pi^+} > 1$ rad	0.9255	0.6981
8	$\eta_{p^+} \notin (-0.6; 0.6)$	0.9993	0.9739
9	$\eta_{K^-} \notin (-0.4; 0.4)$	0.9948	0.9625
10	$\eta_{\pi^+} \notin (-0.4; 0.4)$	0.9986	0.9944
11	Λ_c^+ decay length XY > 0.0075 cm	0.3831	0.2290
12	$c\tau_{\Lambda_c^+} < 0.04$	0.9269	0.4146
13	$\eta_{\Lambda_c^+} \in (-2; 2)$	0.9009	0.6470
	Total	$\mathbf{6 \cdot 10^{-3}}$	$\mathbf{5.5 \cdot 10^{-5}}$

Data scaling (left – 10 GeV, right – 27 GeV)

Parameters for the total inv. mass spectrum calculation:

- $\sigma_{\Lambda_c^+} \sim 0.11\ \mu b$ (optimistic $\sim 14\ \mu b$) (Pythia8 $\sim 0.096\ \mu b$);
- $\sigma_{MB} \sim 38\ mb$;
- $L \sim 10^{30}\ cm^{-2}c^{-1}$;
- $\tau \sim \frac{1}{3} \cdot 10^7\ c$;
- branching ratio ~ 0.011;

- $\sigma_{\Lambda_c^+} \sim 3\ \mu b$ (optimistic $\sim 80\ \mu b$) (Pythia8 $\sim 0.86\ \mu b$);
- $\sigma_{MB} \sim 38$ mb;
- $L \sim 10^{32}\ cm^{-2}c^{-1}$;
- $\tau \sim 10^7$ c;
- branching ratio ~ 0.035 (nonresonant);

Events with Λ_c^+ and corresponding decay expects:

- $\sigma_{\Lambda_c^+} \sim 0.11\ \mu b$: $\sim 4 \cdot 10^3$;
- $\sigma_{\Lambda_c^+} \sim 14\ \mu b$: $\sim 5.1 \cdot 10^5$;

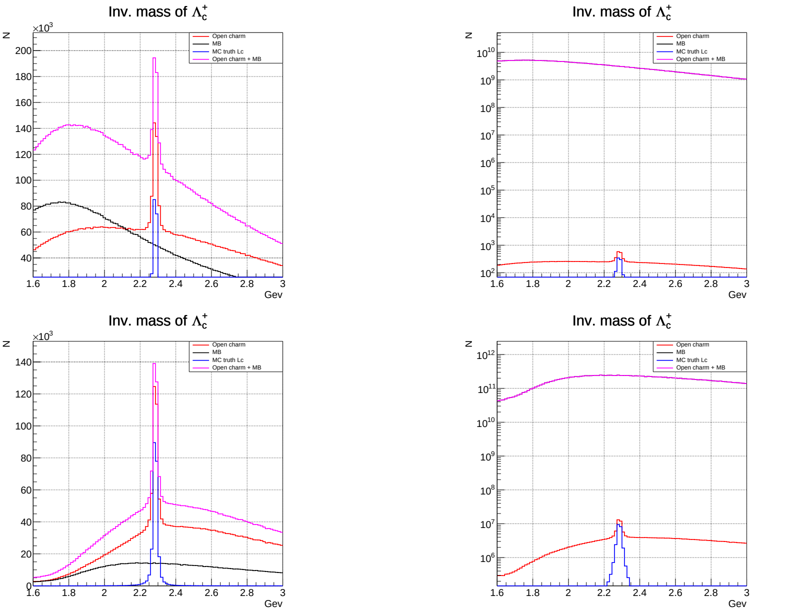
- $\sigma_{\Lambda_c^+} \sim 3\ \mu b$: $\sim 1.05 \cdot 10^8$;
- $\sigma_{\Lambda_c^+} \sim 80\ \mu b$: $\sim 2.8 \cdot 10^9$;

Events of MB expects:

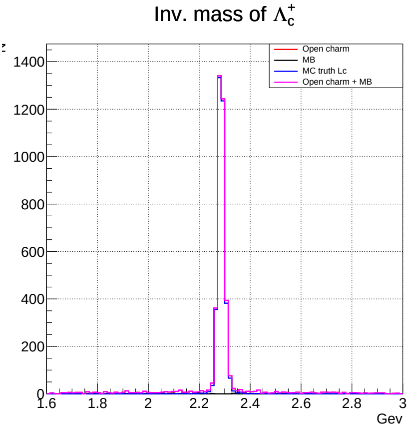
- $\sim 1.3 \cdot 10^{11}$;

- $\sim 3.8 \cdot 10^{13}$;

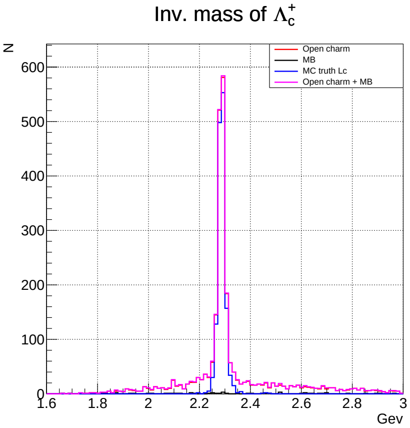
Λ_c^+ Inv. mass before any selections (top – 10 GeV, bottom – 27 GeV, left – unscaled, right – scaled)



Λ_c^+ Inv. mass after all selections (unscaled)

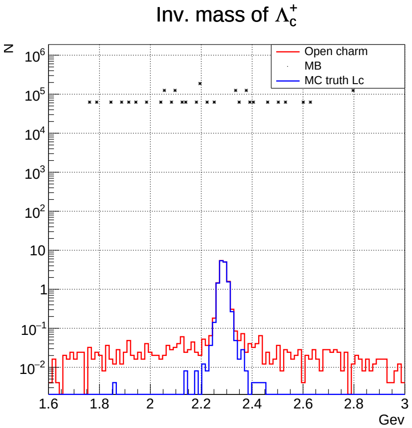


10 GeV

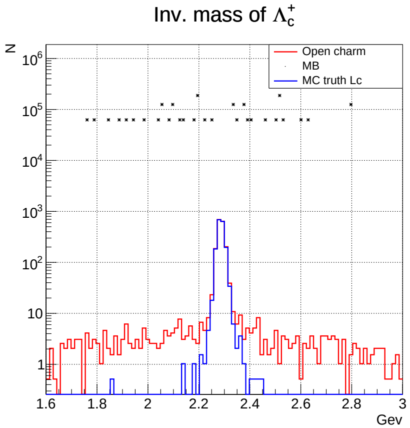


27 GeV

Λ_c^+ Inv. mass after all selections (scaled) (10 GeV)

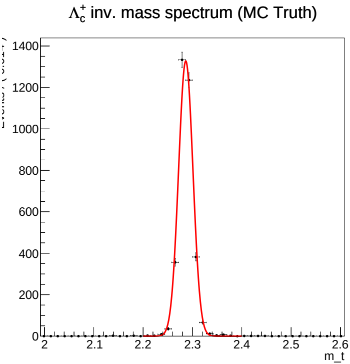


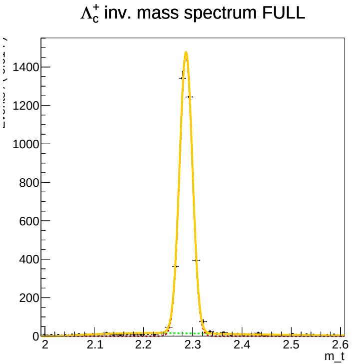
$$\sigma_{\Lambda_c^+} \sim 0.11\ \mu b$$



$$\sigma_{\Lambda_c^+} \sim 14\ \mu b$$

Inv. mass after all selections fit (no scaling) (10 GeV)





Fit info(MC Truth):

- Gauss;
- $m_{\Lambda_c} = 2.2865 \pm 0.00025$ GeV;
- $\sigma = 0.01449 \pm 0.00018$ GeV;

Fit info(including MB):

- Gauss + $(x - b_0)^{b_1} exp(-x \cdot b_2)$;
- $m_{\Lambda_c} = 2.2863 \pm 0.00023$ GeV;
- $\sigma = 0.01289 \pm 0.00018$ GeV;

Sig efficiency and Bg suppression (2.2; 2.4) GeV interval (10 GeV)

Total signal efficiency:

- $\frac{N_{\textsf{sel.}}}{N_{\textsf{no sel.}}} = 1.5 \cdot 10^{-2}$;

Total background suppression:

- $\frac{N_{\textsf{sel.}}}{N_{\textsf{no sel.}}} = 1.3 \cdot 10^{-5}$;

Estimates

$\sigma_{\Lambda_c^+} \sim 0.11\ \mu b$:

Signal over background:

- $\frac{N_{sig}}{N_{bg}} \sim 1.9 \cdot 10^{-5}$

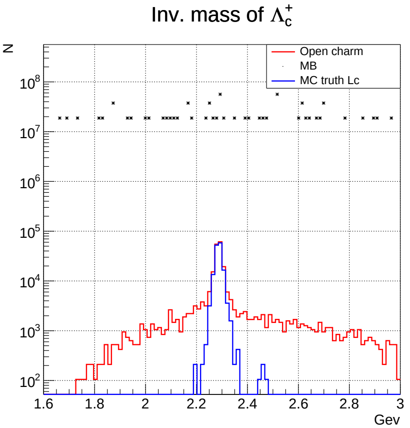
Signal significance(6 sigma area):

- $\frac{N_{sig}}{\sqrt{N_{sig}+N_{bg}}} \sim 0.06$;

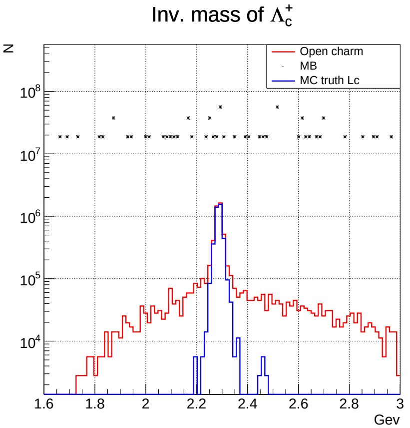
$\sigma_{\Lambda_c^+} \sim 14\ \mu b$:

- $\frac{N_{sig}}{N_{bg}} \sim 2.4 \cdot 10^{-3}$

- $\frac{N_{sig}}{\sqrt{N_{sig}+N_{bg}}} \sim 7.02$;

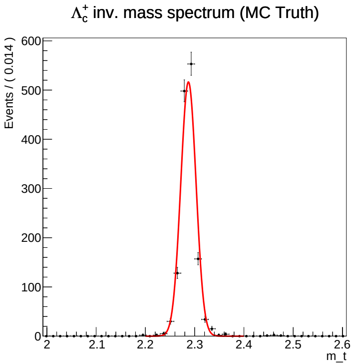


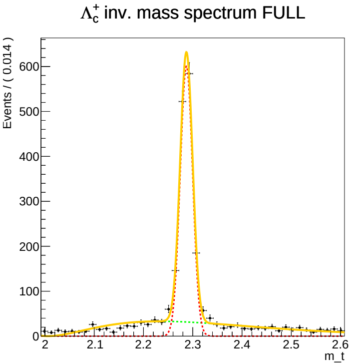
$$\sigma_{\Lambda_c^+} \sim 3\ \mu b$$



$$\sigma_{\Lambda_c^+} \sim 80\ \mu b$$

Inv. mass after all selections fit (no scaling) (27 GeV)





Fit info(MC Truth):

- Gauss;
- $m_{\Lambda_c} = 2.2874 \pm 0.0004$ GeV;
- $\sigma = 0.01544 \pm 0.00029$ GeV;

Fit info(including MB):

- Gauss + $(x - b_0)^{b_1} exp(-x \cdot b_2)$;
- $m_{\Lambda_c} = 2.2871 \pm 0.0004$ GeV;
- $\sigma = 0.0126 \pm 0.0004$ GeV;

Sig efficiency and Bg suppression (2.2; 2.4) GeV interval (27 GeV)

Total signal efficiency:

- $\frac{N_{\text{II sel.}}}{N_{\text{no sel.}}} = 6 \cdot 10^{-3}$;

Total background suppression:

- $\frac{N_{\text{sel.}}}{N_{\text{no sel.}}} = 5.5 \cdot 10^{-5}$;

Estimates

$\sigma_{\Lambda_c^+} \sim 3\ \mu b$:

Signal over background:

- $\frac{N_{sig}}{N_{bg}} \sim 7 \cdot 10^{-4}$

Signal significance(6 sigma area):

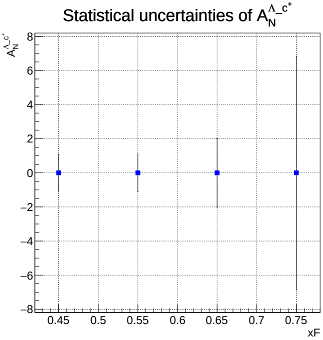
- $\frac{N_{sig}}{\sqrt{N_{sig}+N_{bg}}} \sim 14$;

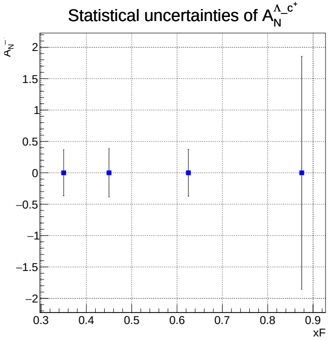
$\sigma_{\Lambda_c^+} \sim 80\ \mu b$:

- $\frac{N_{sig}}{N_{bg}} \sim 1.9 \cdot 10^{-2}$

- $\frac{N_{sig}}{\sqrt{N_{sig}+N_{bg}}} \sim 365$;

Statistical uncertainties of TSSA (left – 10 GeV, right – 27 GeV)





(data scaled from tracks sel. & |absxF| > 0.4 step)

xF gaps:

- (0.4; 0.5);
- (0.5; 0.6);
- (0.6; 0.7);
- (0.7; 0.8);

data scaled from no selection step

xF gaps:

- (0.3; 0.4);
- (0.4; 0.5);
- (0.5; 0.7);
- (0.7; 1);

To Do and Summary

To do:

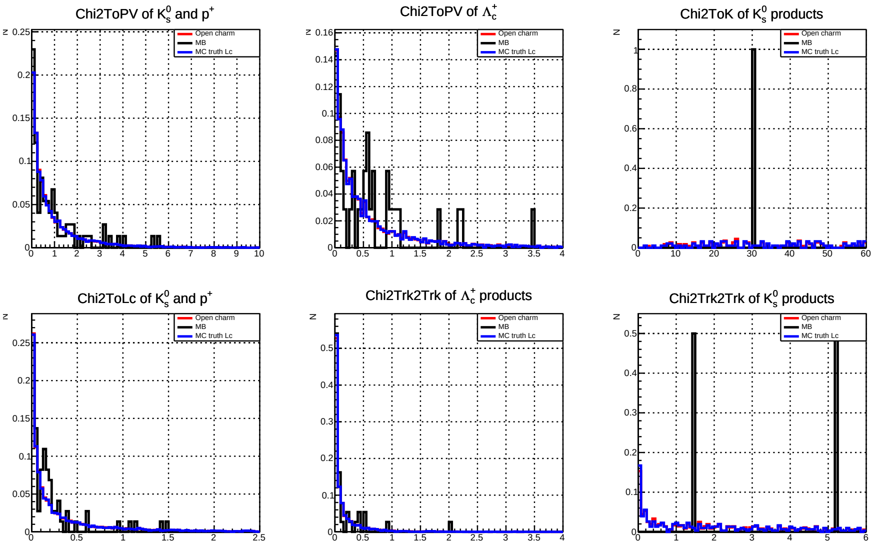
- Examine $\Lambda_c^+ \to \Lambda^0 \pi^+$ for 10 GeV;
- Apply FARICH for high momentum at 27 GeV;
- Clarify PtHatMin value at Pythia generation step;
- Examine region of low xF for all energies.
- Improve selection quality using numerical approach.

Summary:

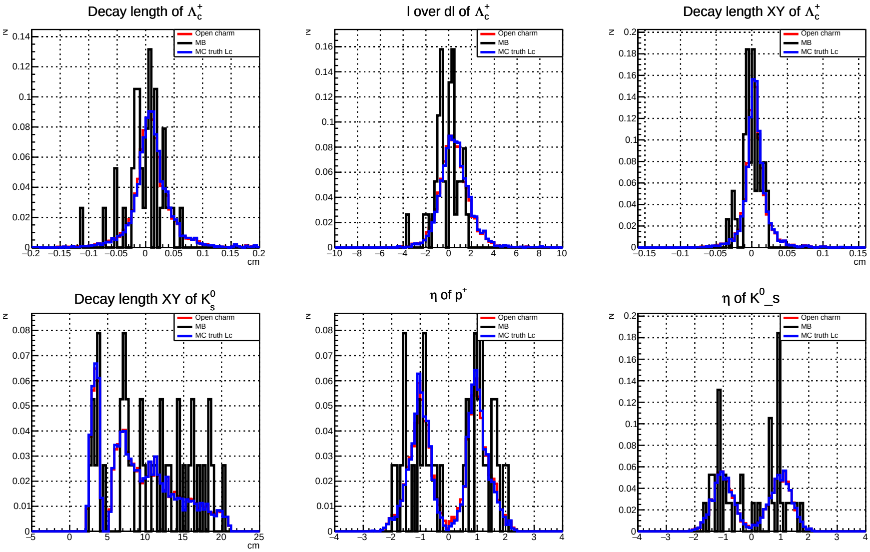
- Current results support the possibility of observing the signal ($\Lambda_c^+ \to p^+ K^- \pi^+$) at $\sqrt{S} = 27$ GeV energy and high |xF|;
- The signal ($\Lambda_c^+ \to (K_s^0 \to \pi^+ \pi^-) p^+$) at $\sqrt{S} = 10$ GeV energy and high |xF| remains too weak for reliable observation and study after selection.
- Have significant discrepancies with Protvino results in my 10 GeV analysis.

Thank you for your attention!

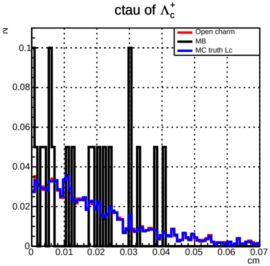
BackUps(I): parameters not in selection (10 GeV)



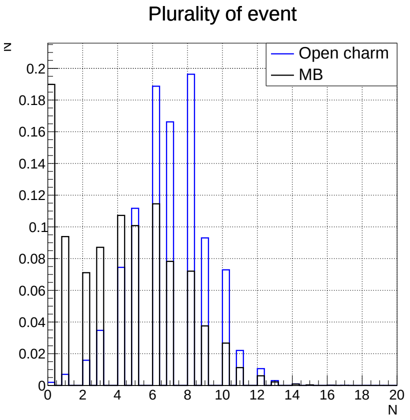
BackUps(II): parameters not in selection (10 GeV)

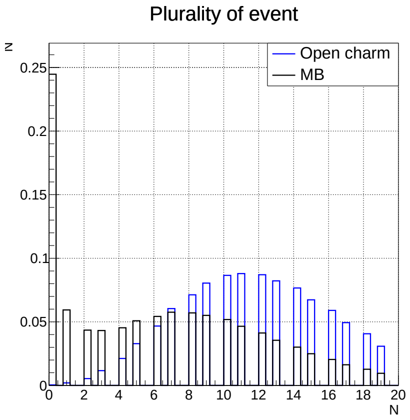


BackUps(III): parameters not in selection (10 GeV)

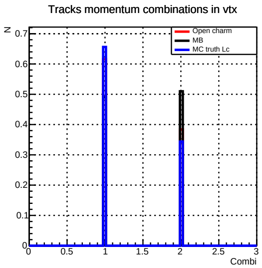


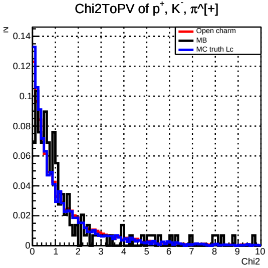
BackUps(IV): multiplicity of events (left – 10 GeV, right – 27 GeV)

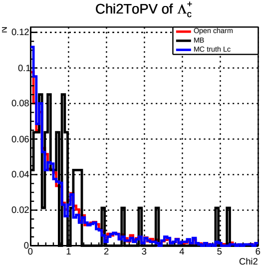


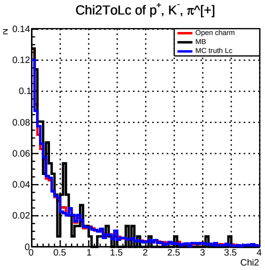


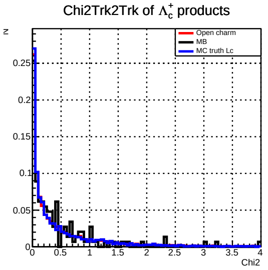
BackUps(V): parameters not in selection (27 GeV)



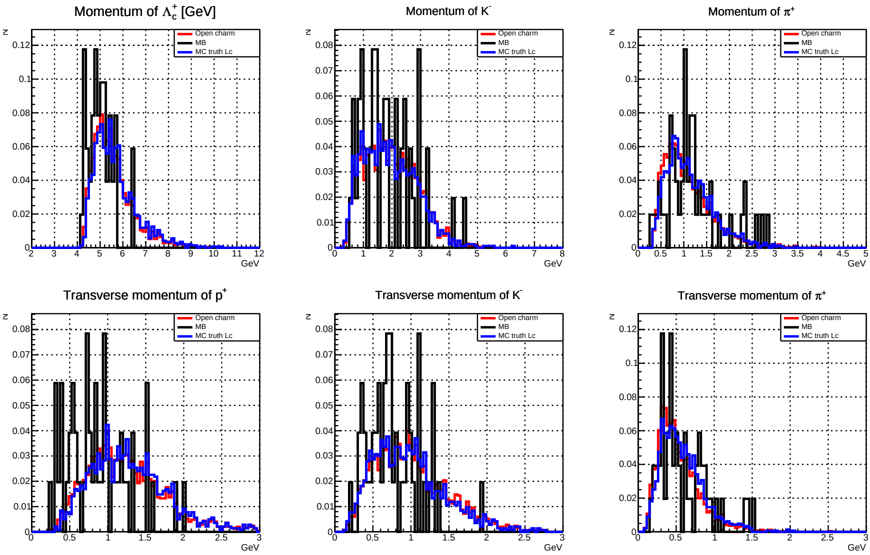






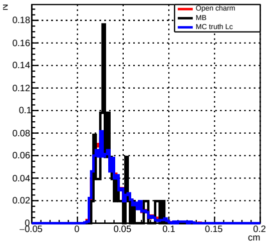


BackUps(VI): parameters not in selection (27 GeV)

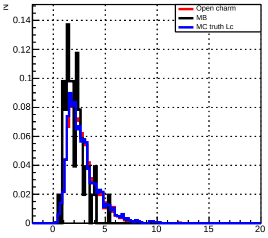


BackUps(VII): parameters not in selection (27 GeV)

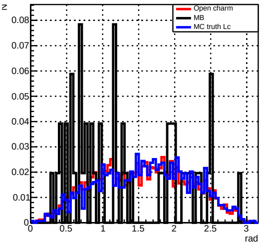
Decay length of Λ_c^+



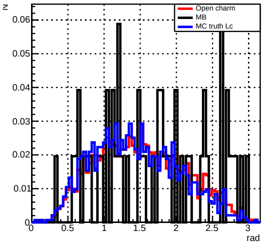
l over dl of Λ_c^+



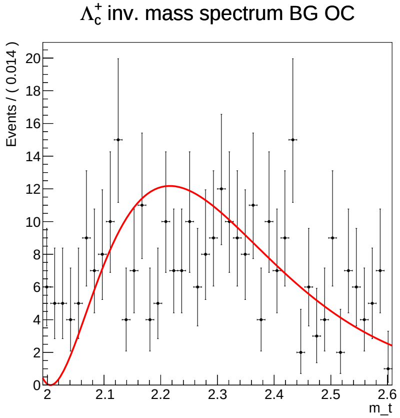
Opening angle of p^+ and Λ_c^+ [rad]

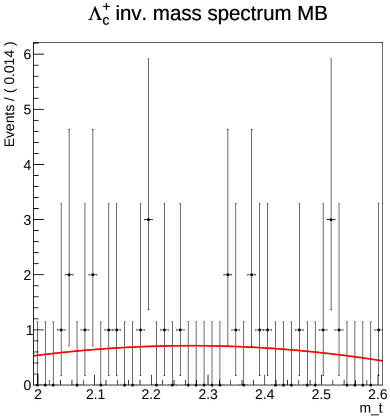


Opening angle of K^- and Λ_c^+ [rad]



Inv. mass BG fit after all selections (10 GeV)





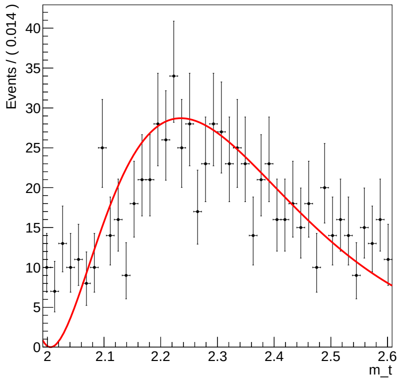
Fit function:

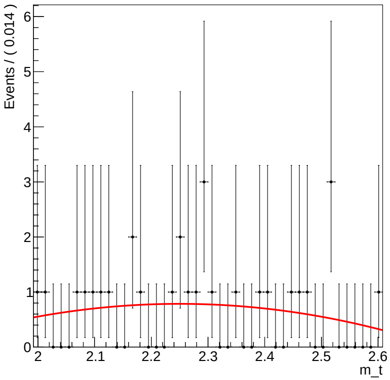
- BgFunc=$(x - b_0)^{b_1} exp(-x \cdot b_2)$

Fit function:

- MBFunc=$exp(-x \cdot c_0) + pol(2)$

Inv. mass BG fit after all selections (27 GeV)





Fit function:

- BgFunc=$(x - b_0)^{b_1} exp(-x \cdot b_2)$

Fit function:

- MBFunc=$exp(-x \cdot c_0) + pol(2)$

Protvino cross-sections

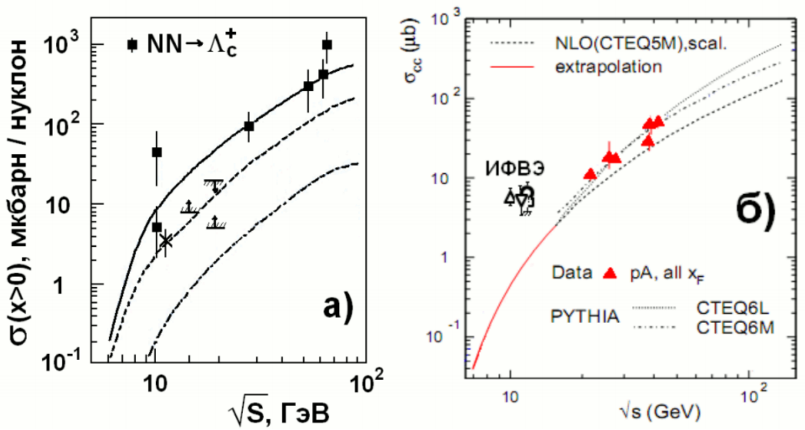


Рис. 6.11. а) Сечения рождения Λ_c^+-барионов для области $x_F > 0$. Экспериментальные данные взяты из работ [37,41,47,126–131], сечение из данной работы обозначено знаком Х. Теоретические кривые из работы [37]: сплошная линия – для периферической модели, пунктирные линии – для двух вариантов модели КХД. б) Полные сечения образования чарма в pA-взаимодействиях [7]. Экстраполяция (сплошная линия) и данные различных моделей (другие линии) взяты из работы [7] без учета точек ИФВЭ. Обозначения для данных ИФВЭ: круг – СВД, треугольник – БИС-2 [39], квадрат – СКАТ [23], обратный треугольник – «beam-damp» эксперимент [21].