Ξ_c^0 production in p-Pb collisions at 5.02 TeV

January 4th 2022

KoALICE National Workshop 2021

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  - Ξ_c^0 production in p+Pb collisions
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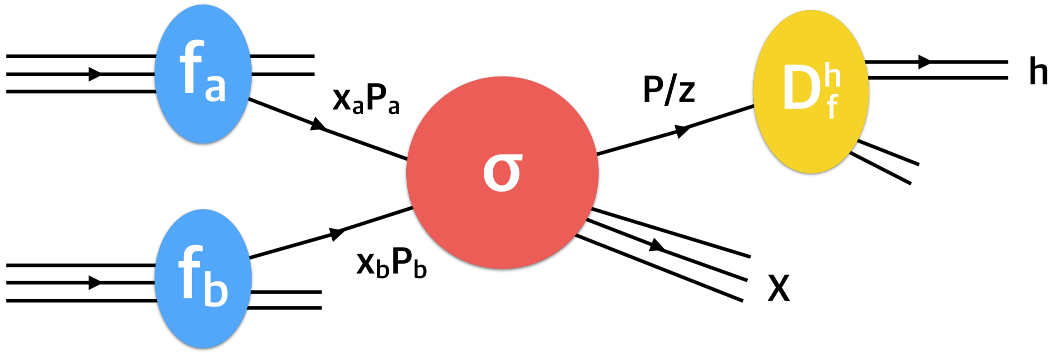
Ξ_c^0 production in p+Pb collisions

- Heavy quarks are
  - Sensitive probes to study the Quark-Gluon Plasma in heavy-ion collisions.
  - Due to their large masses, they are formed in initial hard scattering of parton before the timescale of QGP formation
    - produced early in the collision, live long enough to sample QGP
  - Experience the whole system evolution
- Measurements in proton-nucleus collisions is crucial
  - For the interpretation of the results in nucleus-nucleus collisions, the measurement in proton-nucleus collisions is also crucial.
  - In such a system cold-nuclear-matter (CNM) effects can affect the production of charm hadrons: disentangle them from the effects related to the formation of the QGP (hot-medium effects)

Ξ_c^0 production in p+Pb collisions

- Measurement of charmed baryon production could play an important role in studying hadronization process.
  - In pQCD calculations, the hadronisation process is modeled via a fragmentation function
  - Fragmentation functions are tuned on electron-positron data under the assumption that they are universal
  - Among other observables, the relative production of baryons and mesons (baryon/meson ratio) is sensitive to the fragmentation process
- The interaction with the medium constituents could modify the hadronisation:
  - a significant fraction of low and intermediate-momentum charm and beauty quarks could hadronise via recombination (coalescence) with other quarks from the medium
  - Models including coalescence predict an enhanced baryon-to-meson ratio at low and intermediate p_T relative to pp's

Heavy flavour hadronisation in small systems



$$\frac{d\sigma^{\mathrm{D}}}{dp_{\mathrm{T}}^{\mathrm{D}}}(p_{\mathrm{T}};\mu_{\mathrm{R}};\mu_{\mathrm{F}}) = PDF(x_1,\mu_{\mathrm{F}})PDF(x_2,\mu_{\mathrm{F}}) \otimes \frac{d\sigma^{\mathrm{c}}}{dp_{\mathrm{T}}^{\mathrm{c}}}(x_1,x_2,\mu_{\mathrm{R}},\mu_{\mathrm{F}}) \otimes D_{\mathrm{c}\to\mathrm{D}}(z = p_{\mathrm{D}}/p_{\mathrm{c}},Q^2)$$

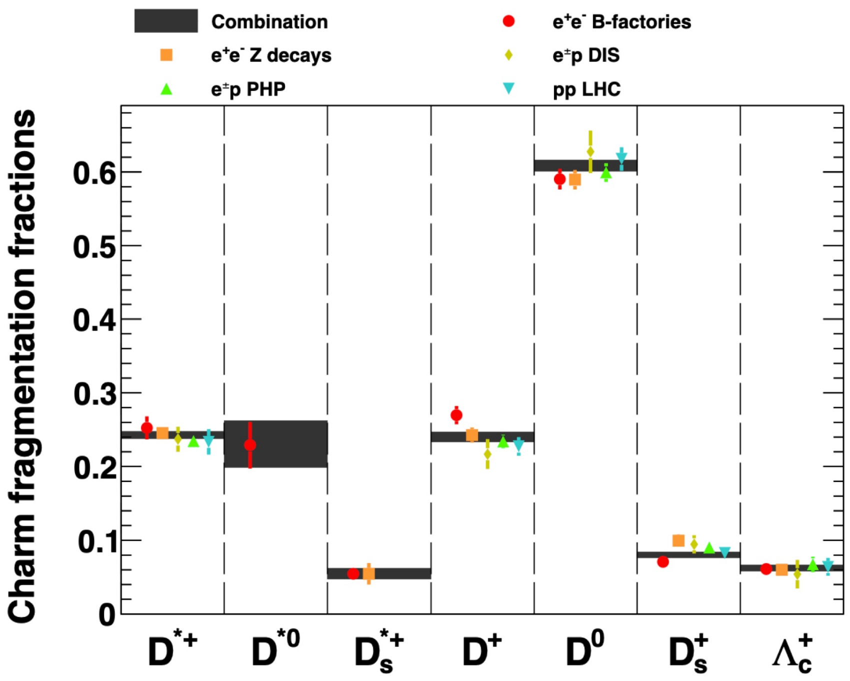
Initial State Parton Distribution Function (PDF) (non-perterbative)

pQCD partonic cross section (pertervative)

Hadronization by fragmentation (non-pertervative)

- pQCD models based on the factorisation appoach:
  - use fragmentation fractions parametrised on e+e- and ep collision data
  - assume universality of fragmentation fractions versus collision systems and energies
- Recent measurements of heavy-flavour baryon production challenge this assumption
- Additional mechanisms at play in pp collisions beyond simple string fragmentation?

Charm Fragmentation Fraction



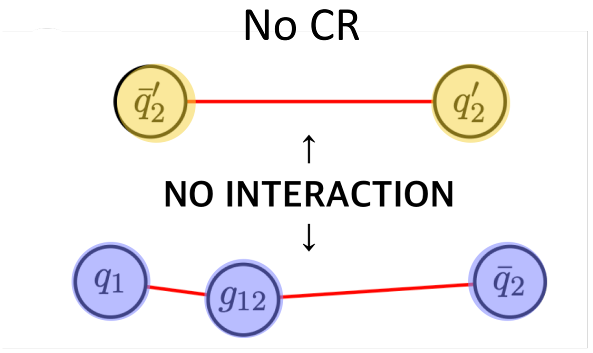
Eur. Phys. J. C76 (2016) no.7, 397

- Charm fragmentation fraction

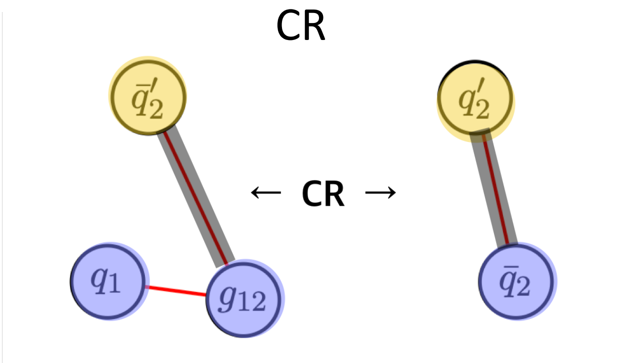
$$f(\mathrm{c} \to \mathrm{H}) = \sigma(\mathrm{H})/\Sigma_{\mathrm{H}}\sigma(\mathrm{H})$$

- Measurements in different collision systems and at different energies agree within uncertainties.
- Support the hypothesis:
  - pQCD models based on factorisation approach use fragmentation fractions (FF) tuned on e+e- and consider them universal? Independent of collision systems?
- However,
  - σ(Σc), σ(Ξc) and σ(Ωc) were not included.
    - In 2015, only LHCb Λc+ measurement was available.
  - Rapidity range : 2.0 < y < 4.5
- Measurements of charm baryons are essential for total charm cross section and FF measurement
  - Charm baryon-to-meson & baryon-to-baryon yield ratio sensitive to hadronization

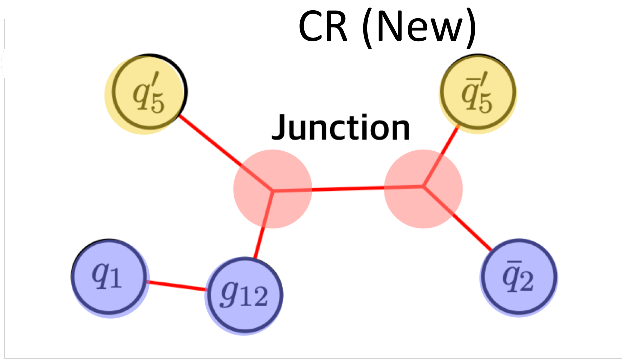
Models of HF Baryon Enhancement – PYTHIA8 CR tunes



- Partons created in different MPIs do not interact each other



- CR allowed between partons from different MPIs to minimize the string length.
- Monash tune



- Minimization of string length over all possible configurations
- Enhancement of hadrons
- CR mode X tunes

- PYTHIA 8 with Colour Reconnection (CR) tunes
  - Colour reconnection mode with QCD SU(3) algebra + string-length minimization
  - Junction connection topologies enhance baryon formation

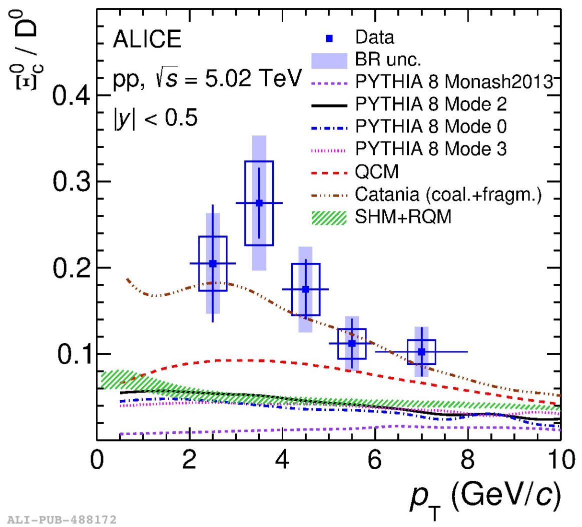
Models of HF Baryon Enhancement

- Statistical Hadronisation Model (SHM) + additional baryon states *PLB 795 (2019) 117-121*
  - PDG : 5 Λc (I=0), 3 Σc (I=1), 8 Ξc (I=1/2), 2 Ωc (I=0)
  - RQM (Relativistic Quark Model) : Add 18 Λc, 42 Σc, 62 Ξc, 34 Ωc *PRD 84 (2011) 014025*

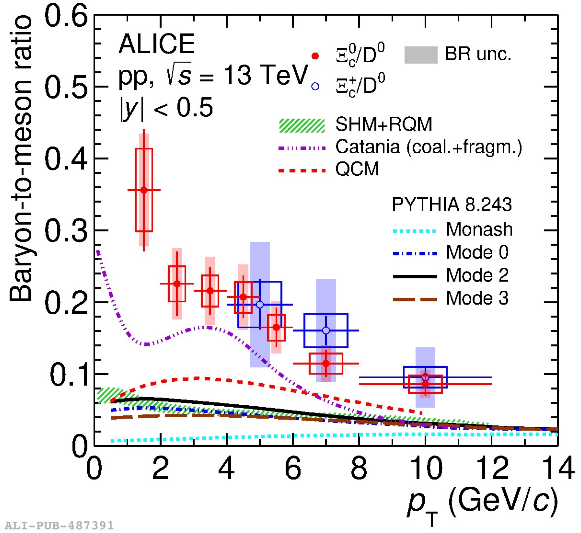
- Quark Recombination Mechanism (QCM)
  - Combination of charm quarks with co-moving light quarks

- Catania model *PLB 821 (2021) 136622*
  - Blast wave parametrization for light quarks spectra, FONLL calculation for heavy quarks spectra
  - Coalescence process of heavy quarks with light quark based on the Wigner formalism + fragmentation process

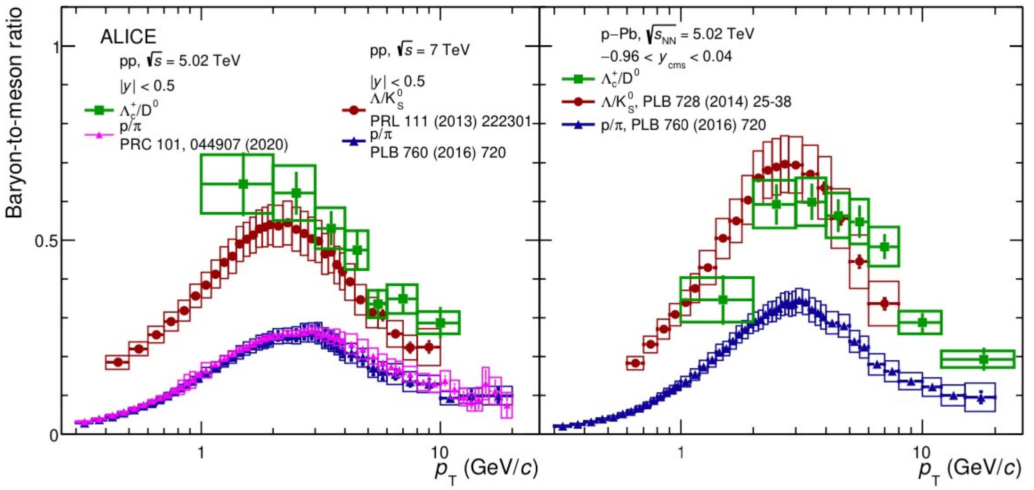
Charmed baryon/meson ratio in ALICE



Ξ_c^0/D^0 pp 5TeV
arXiv:2105.05616
JHEP 10 (2021) 159



Ξ_c^0/D^0 pp 13TeV
arXiv:2105.05187
PRL accepted : Jinjoo Seo

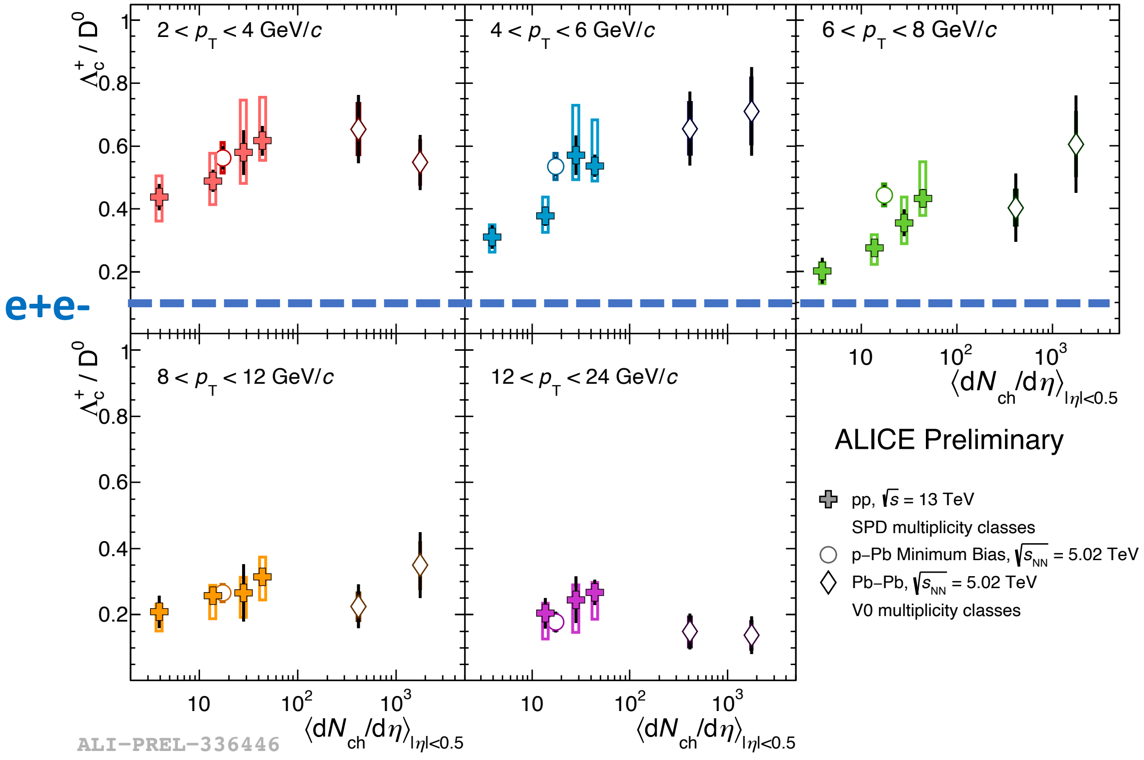


Λ_c^+/D^0 pp

Λ_c^+/D^0 p-Pb

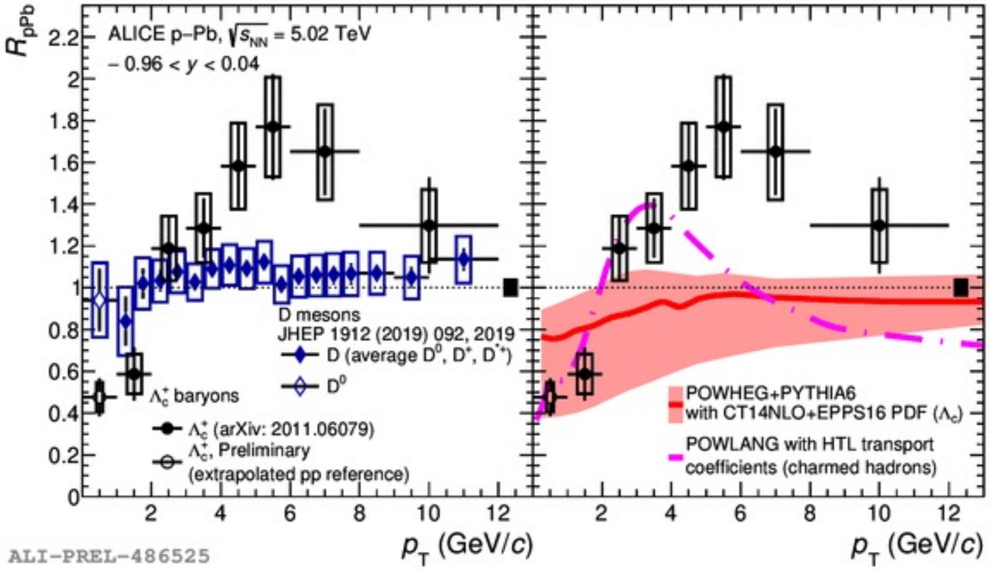
- Baryon-to-meson ratio in pp collisions at 5.02TeV and 13TeV
  - PYTHIA 8 Monash, PYTHIA 8 CR tunes, SHM+RQM and QCM underestimate the ratios significantly.
  - Catania shows better descriptions on the ratios in the measured p_T range.
- Baryon/Meson ratio comparison with light flavor
  - Λ_c^+ : seems to have similar trend in both collision systems,
  - Decreasing p_T >2,3 in both pp pA, Peak at 2< p_T <4 in both HF,LF

Multiplicity dependence of Λ_c^+/D^0



- Smooth increasement from p+p, p+Pb to Pb+Pb multiplicities.
  - Λ_c^+/D^0 at low multiplicity already higher than e+e-
  - Λ_c^+/D^0 at high multiplicity reaching to Pb+Pb
  - In qualitative agreement with the hypothesis that recombination saturates already in high multiplicity p+p?
- Related analysis: Ξ_c^0 at pp 13 TeV (Dr. Chong Kim), Ξ_c^+ at pp 13 TeV (Jaeyoon Cho)

Chamrd baryon R_{pPb} (Λ_c^+) in p-Pb

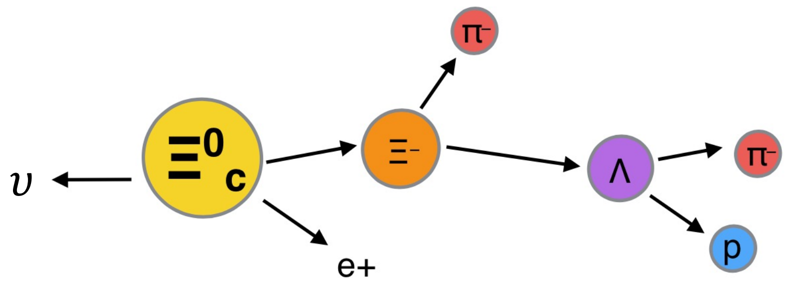


ArXiv: 2011.06079

- POWHEG+PYTHIA6
  - *EPJC 77 no. 3,(2017) 163, JHEP 09 (2007) 126*
  - CNM effect + PYTHIA 6 Parton shower + EPPS16 parameterization for PDFs
- POWLANG
  - *JHEP 03 (2016) 123*
  - Hot deconfined medium in p-Pb collisions.
  - Describe the suppression at low p_T.

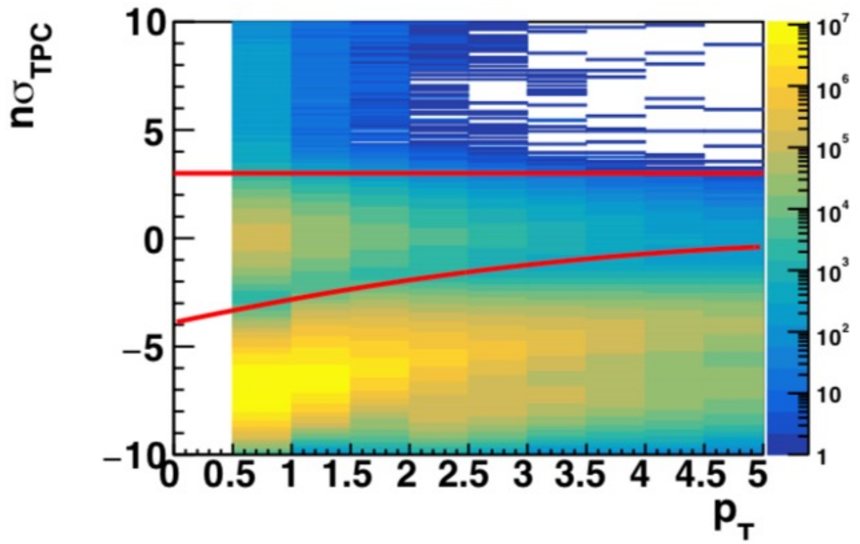
- Nuclear effects can be investigated measuring a nuclear modification factor R_{pPb}, defined as the ratio of particle yield in p-Pb collisions to those in pp collisions scaled by the average number of binary nucleon-nucleon collisions
- R_{pPb} (Λ_c^+) down to p_T = 0 GeV/c in p+Pb collisions
  - Above unity in $p_T > 2$ GeV/c
  - Below unity in $p_T < 2$ GeV/c
    - Possible modification due to radial flow or hadronisation mechanisms

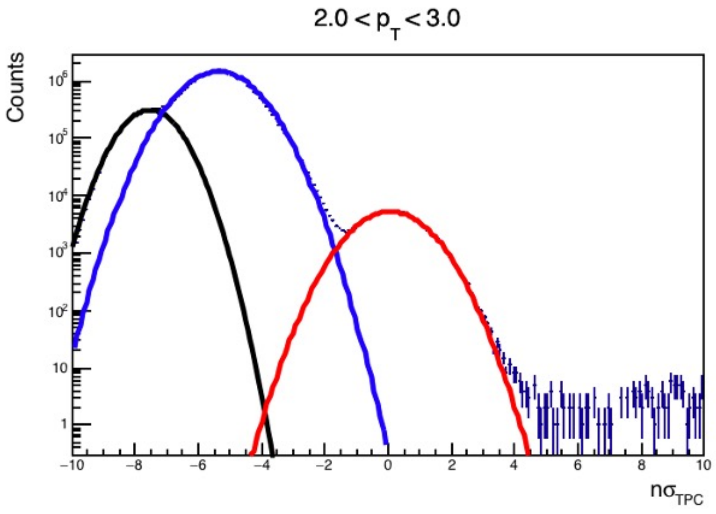
Analysis procedure



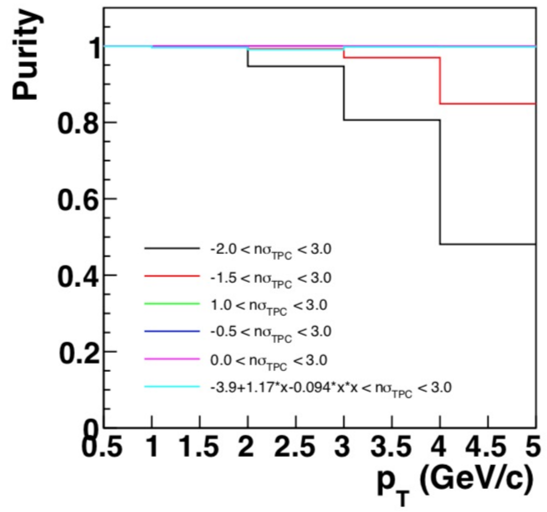
- Select *e* and Ξ
- Make Right-Sign (RS) pairs (*e*-Ξ+ , *e*+Ξ-) and Wrong-Sign (WS) pairs (*e*+Ξ+ , *e*-Ξ-) which are selected to satisfy conditions
- Signal extraction by subtracting the WS spectra from the RS spectra
- Correct for the efficiency caused by the ”prefilter” of electron candidates.
- Convert $p_T(e\Xi)$ into $p_T(\Xi_c^0)$ using unfolding technique.
- Efficiency correction
- Compute *dσ*

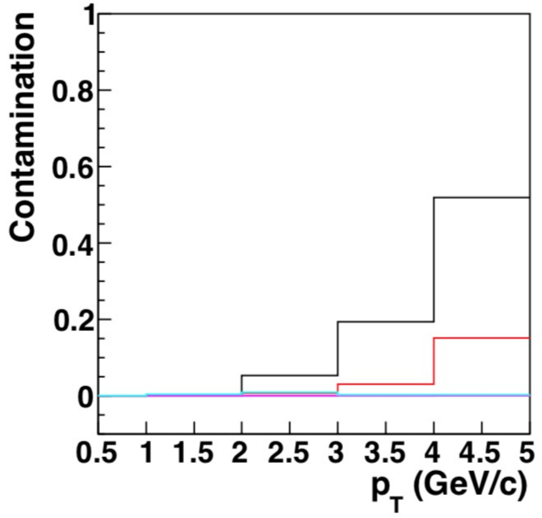
Analysis Detail: Electron selection



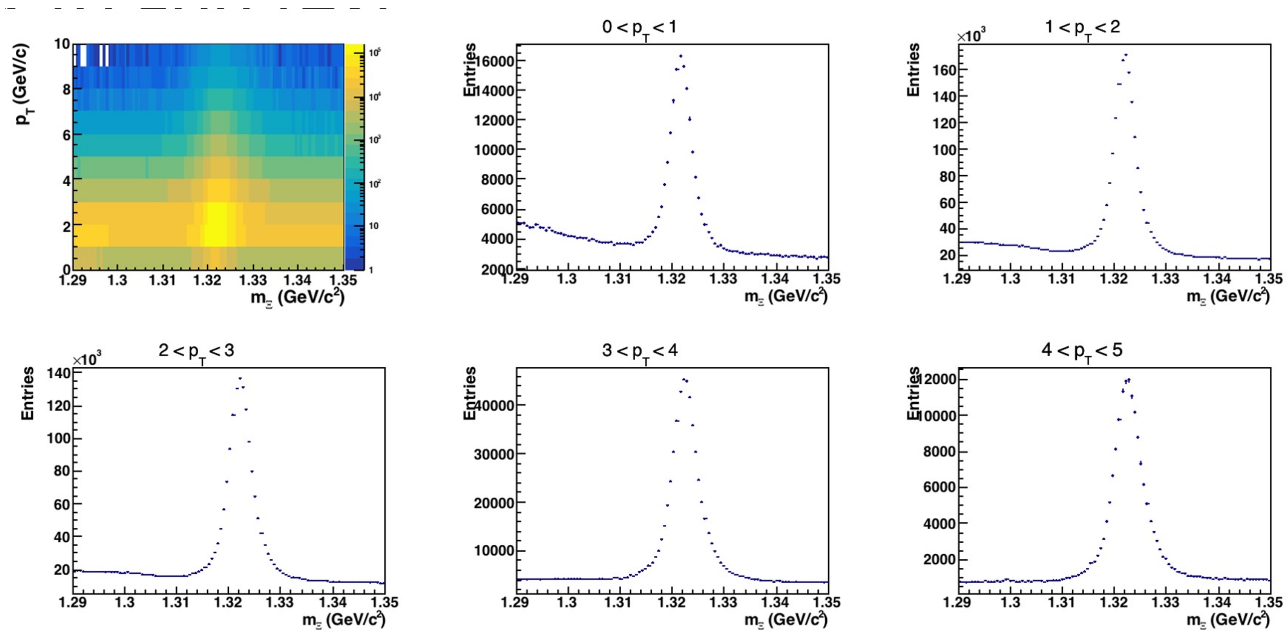


- Particle identification for electron : TPC
- Cut is optimized for electron
- High purity, low contamination after p_T - dependent cut





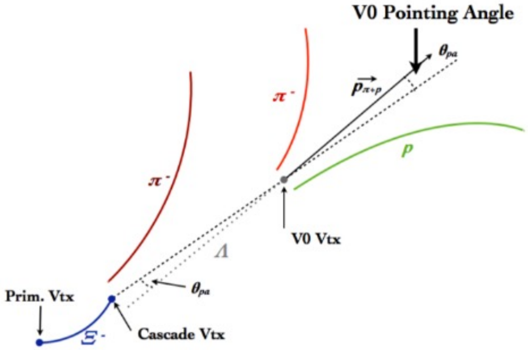
Analysis Detail: Ξ selection : Ξ mass



- Ξ mass distribution.

$$\Xi_c^0 \rightarrow e^+ \Xi^- \nu \rightarrow e^+(\pi^- \Lambda)\nu \rightarrow e(\pi p \pi)\nu$$

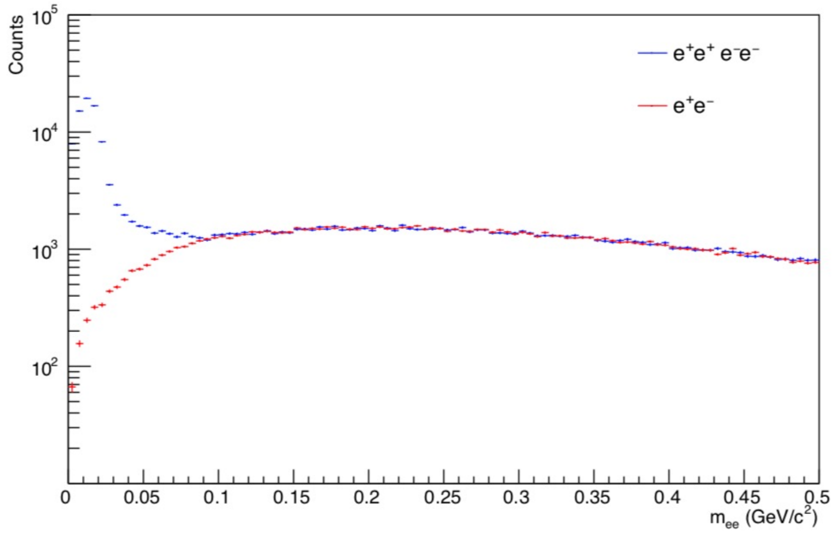
- Other cut variables

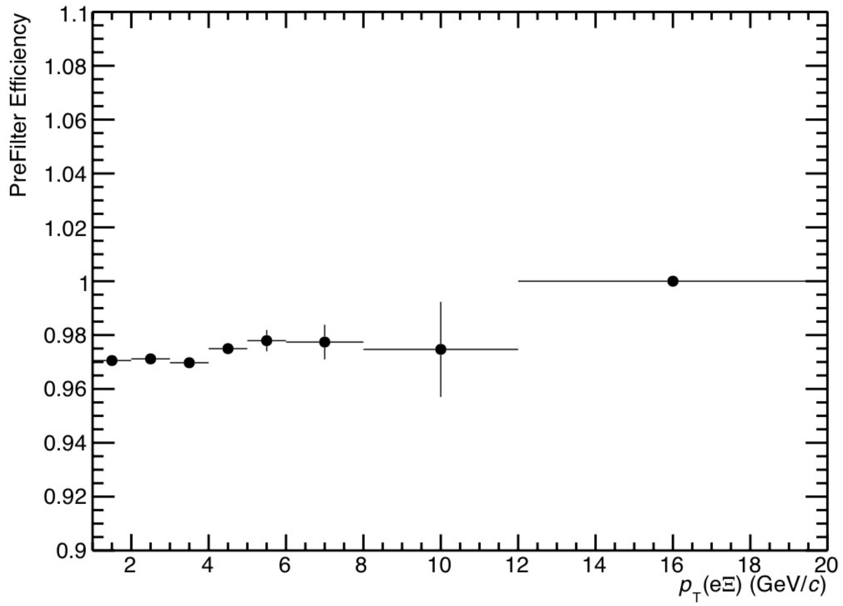


Cuts variables	cuts
Number of CrossedRows	>70
CrossedRows Over Findable Cluster	>0.77
Λ Mass tolerance (MeV/c^2)	7.5
Ξ Mass tolerance (MeV/c^2)	8
DCA of V0 to PV (cm)	>0.03
DCA of V0 daughters to PV (cm)	>0.073
V0 cosine of pointing angle to Ξ vertex	>0.983
Ξ cosine of pointing angle to PV	>0.983
DCA of bachelor track to PV (cm)	>0.0204
V0 decay length (cm)	>2.67
Ξ decay length (cm)	>0.38
$\lvert n\sigma_{TPC}\rvert$ (proton)	<4
$\lvert n\sigma_{TPC}\rvert$ (pion)	<4

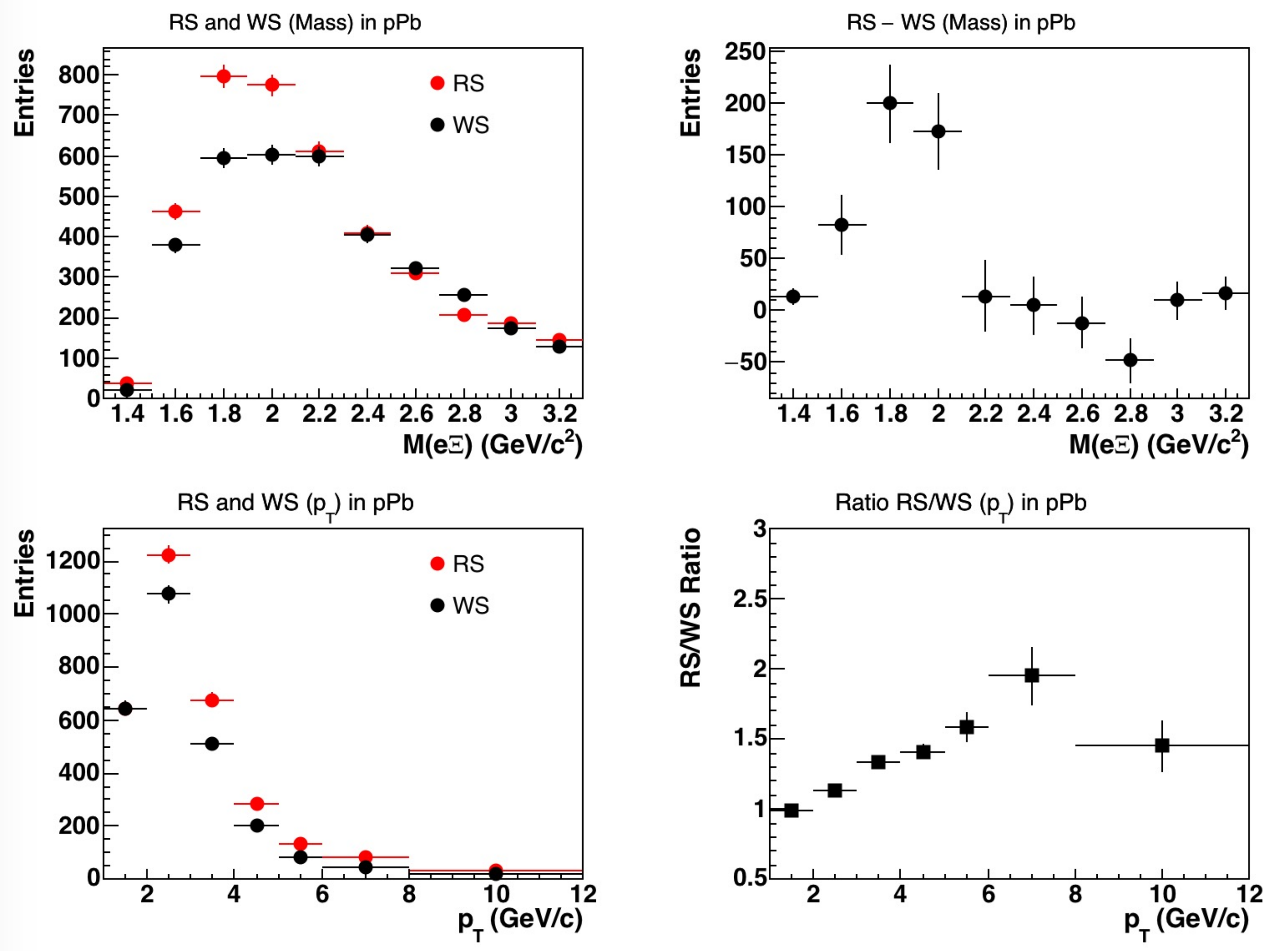
Analysis Detail: prefilter: e-pair mass cut

- the number of $e\Xi$ pairs having the same-sign for which the electron has a same-sign partner which from a pair with invariant mass lower than 0.05 GeV.
  - peak at $m_{ee} \sim 0$ GeV/c^2 in the invariant mass distribution of such pairs, which clearly shows the contributions from the π^0 Dalitz decays and γ





Analysis Detail: Background subtraction

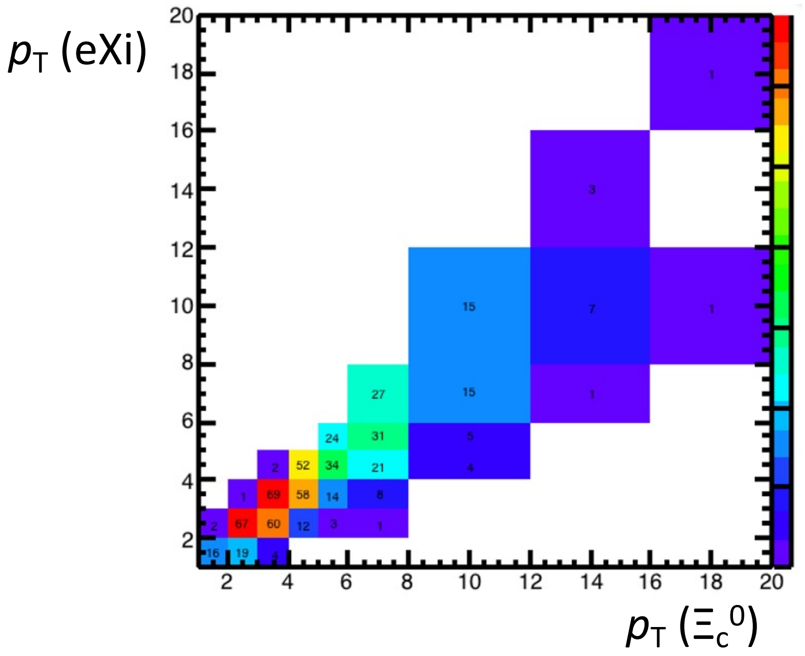


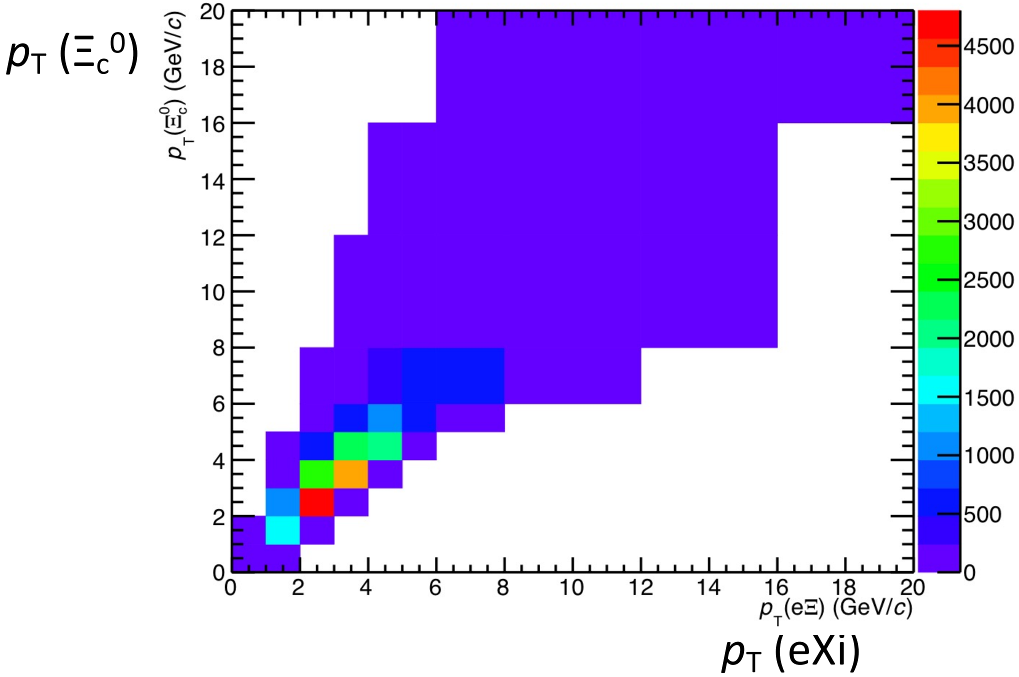
- Right-Sign(RS)
  - *e*+Ξ- , *e*-Ξ+
- Wrong-Sign (WS) pairs
  - *e*+Ξ+ , *e*-Ξ-
- we assume that most of the background sources contribute equally to WS and RS pairs
- Subtract WS same-sign pair from RS opposite-sign pair
- Invariant Mass cut
  - M(*e*Ξ)<2.5 GeV/c^2

MC production

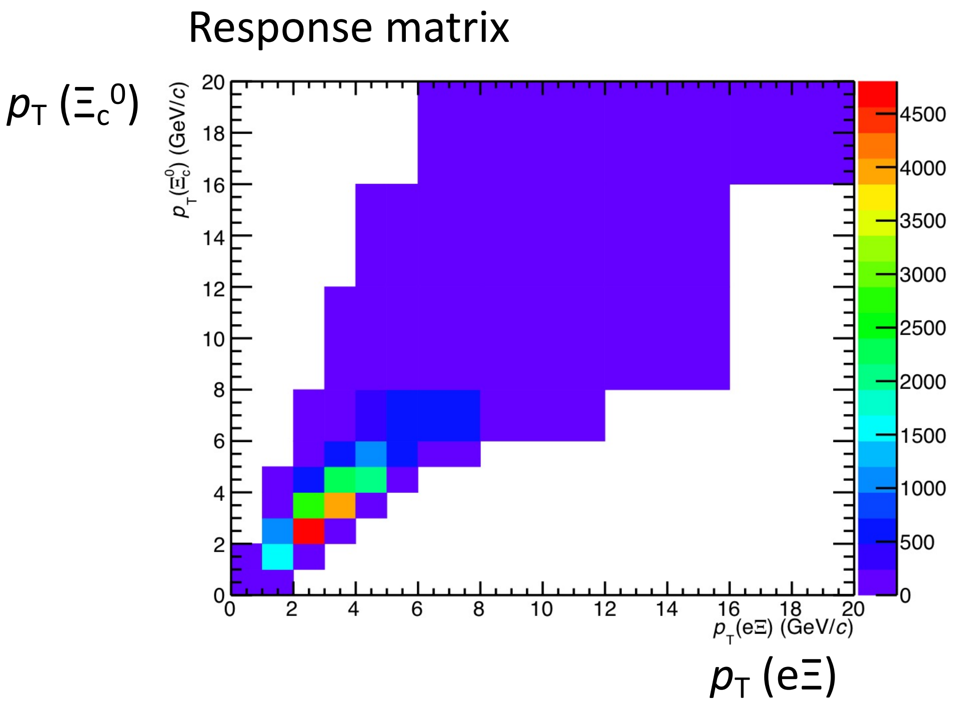
- MC production is under final QA
- Xic-dedicated MC using PYTHIA8+HIJING
- Much more statistics than previous MC for electron from heavy flavor decay.

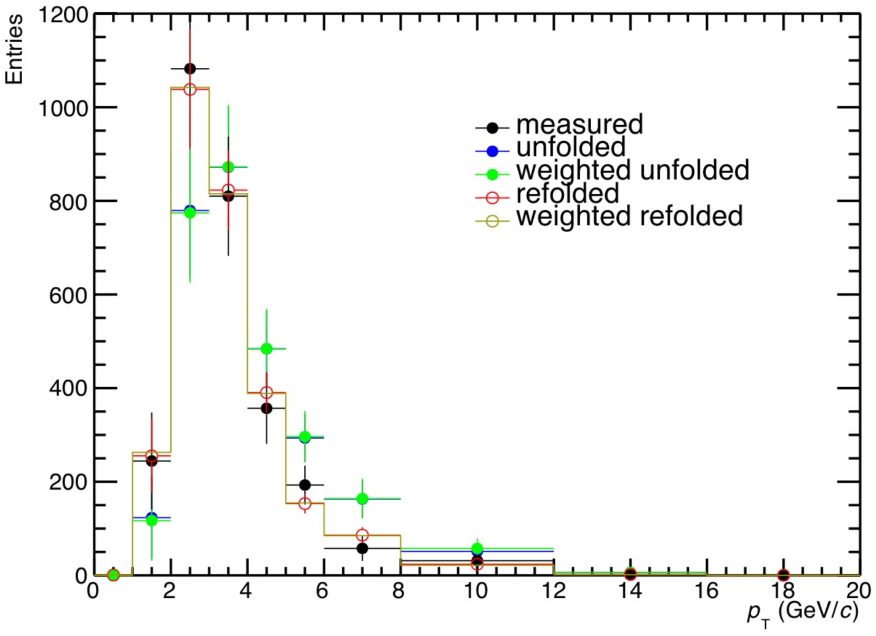
Old MC





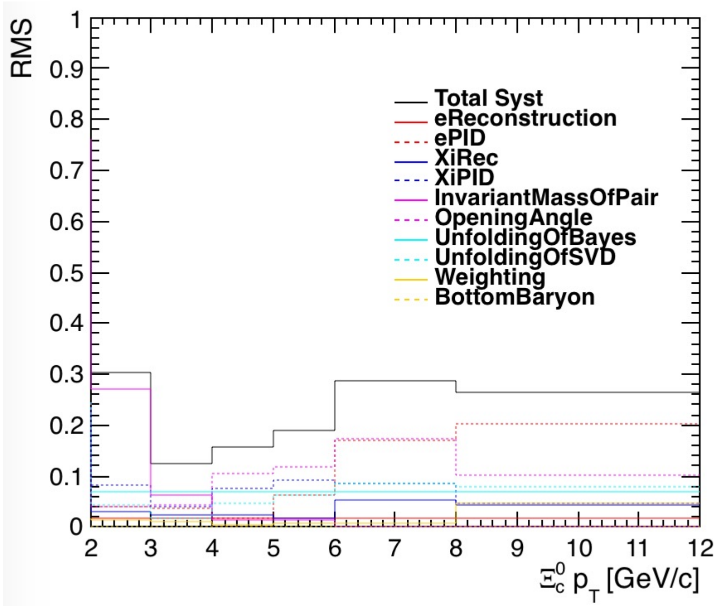
Unfolding

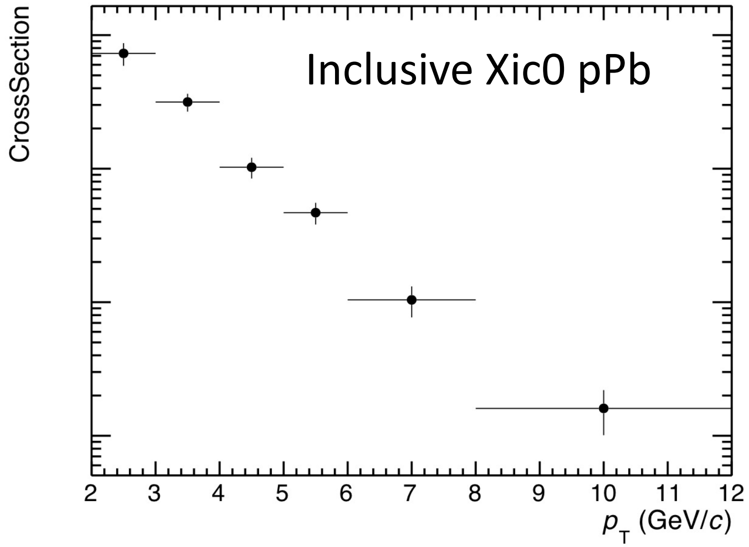




- Measured p_T is p_T of e-Ξ pair.
- missing momentum of neutrino $\Xi_c^0 \rightarrow e^+\Xi^-\nu \rightarrow e^+(\pi^-\Lambda)\nu \rightarrow e(\pi p \pi)\nu$.
- Bayesian unfolding to extract p_T of Ξ_c^0 from p_T of eXi pair
- crosscheck with SVD unfolding, varying the number of iteration

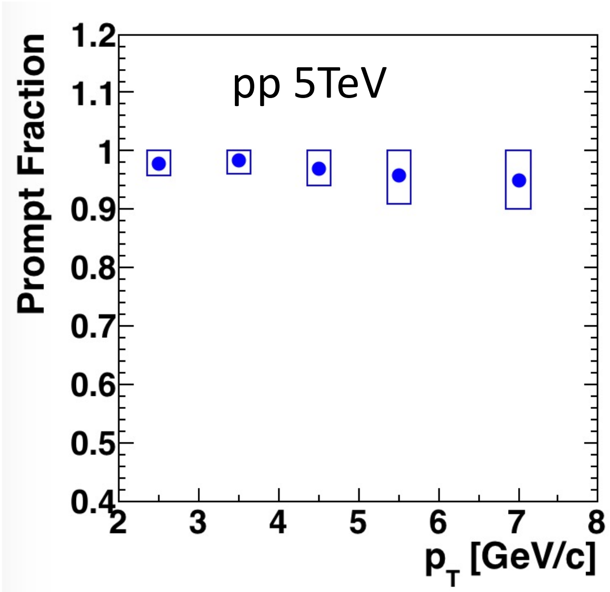
Systematic uncertainty

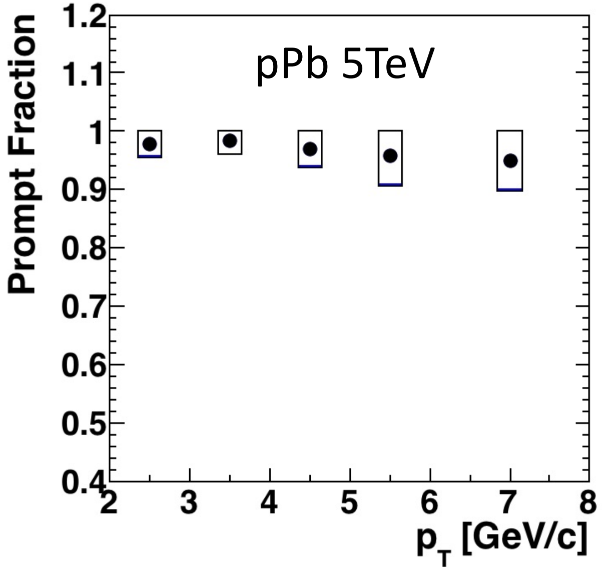




- Syst. Included
  - e, Xi PID, reco
  - Pair mass, opening angle
  - Unfolding
- Missing syst.
  - ITS-TPC matching
  - rapidity range
  - prompt fraction

prompt fraction





- Following Lc analysis
  - *ArXiv:2011.06079*
  - assumed that the R_{pPb} of prompt and feed-down Lc were equal

    $$0.9 < R_{pPb}^{\text{feed-down}} / R_{pPb}^{\text{prompt}} < 1.3$$

  - Prompt fraction from pp5TeV
  - Referred D-meson paper
    - *Phys. Rev. C94 no. 5, (2016) 054908*
    - Additional uncertainty was small

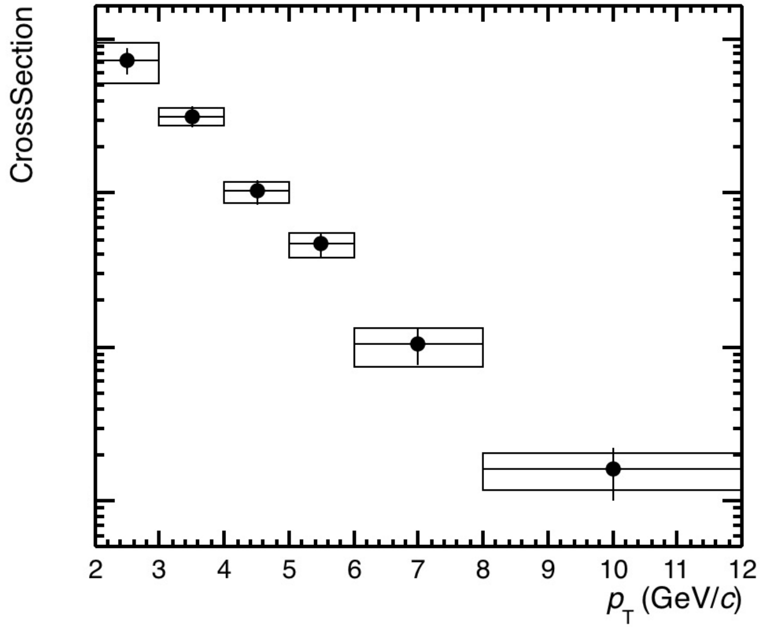
of D mesons from B decays. On the basis of calculations including initial-state effects through the EPS09 nuclear PDF parametrizations [20] or the color glass condensate formalism [27], it was assumed that the R_{pPb} of prompt and feed-down D mesons were equal and their ratio was varied in the range $0.9 < R_{pPb}^{\text{feed-down}} / R_{pPb}^{\text{prompt}} < 1.3$ to evaluate the systematic uncertainties. The resulting f_{prompt} values and their

Cross Section

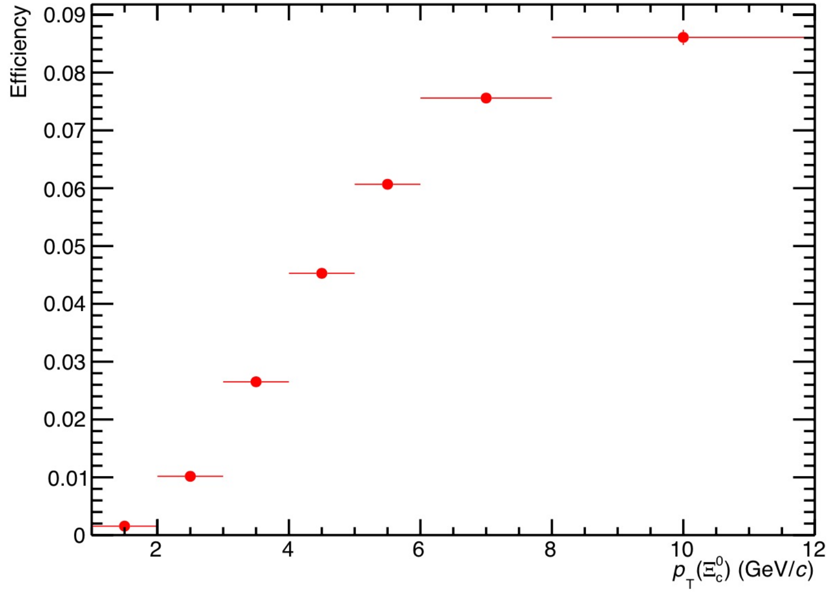
$$BR \cdot \frac{d\sigma^{\Xi_c^0}}{dp_T dy} = \frac{N_{\Xi_c^0}}{2 \cdot \Delta p_T \Delta y \cdot (A \times \varepsilon \times \varepsilon_{\Xi \mathrm{tag}}) \cdot L_{\mathrm{int}}}$$

$$L_{\mathrm{int}} = \frac{N_{\mathrm{evt}}}{\sigma_{\mathrm{pPb}}^{\mathrm{MBAND}}}$$

- σ_{pPb}^{MBAND} : cross section of MBAND trigger // 2.09e+06 ub
- $A \times \epsilon \times \epsilon_{\Xi \mathrm{tag}}$: product of the geometrical accepted (*A*) and the reconstruction and selection efficiency (ε) for $\Xi_c^0 \rightarrow e\Xi\nu$



(Prompt Xic0) Cross section (syst. not final)

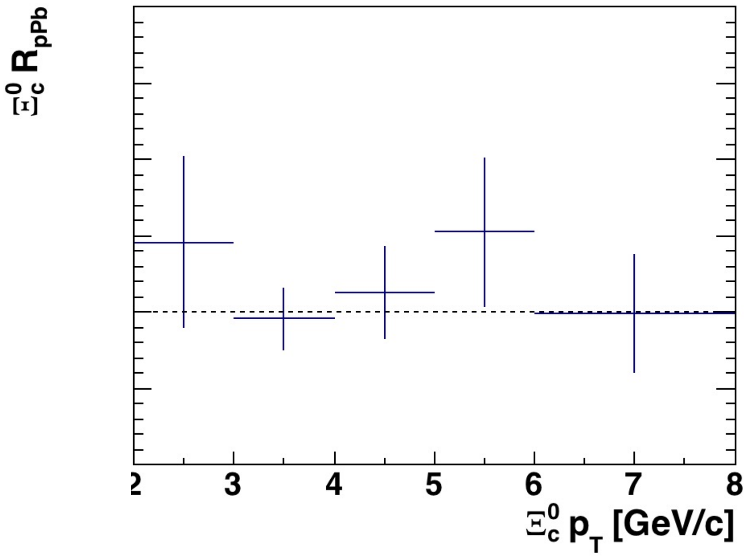


Acc*Efficiency

R_{pPb}

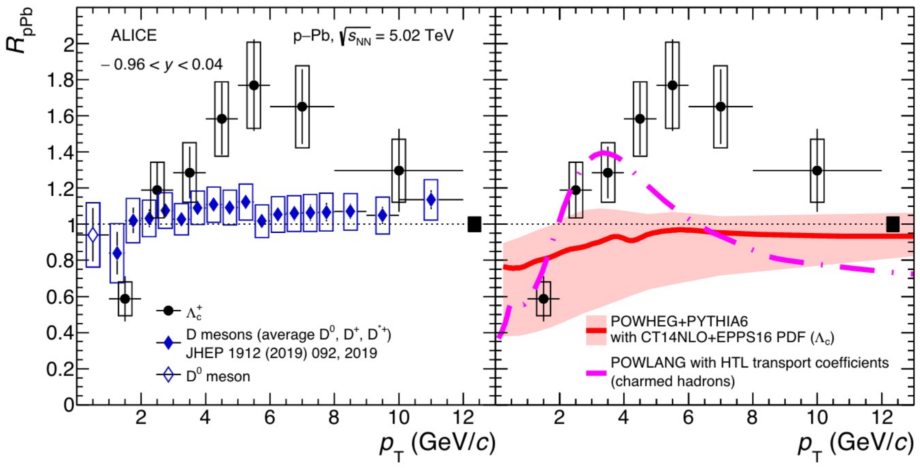
- Nuclear effects can be investigated measuring the nuclear modification factor R_{pPb}, defined as the ratio of the cross section in p-Pb collisions to that in pp interactions scaled by the average number of binary nucleon-nucleon collisions

$$R_{\rm pPb}(p_{\rm T},{\rm cent}) = \frac{{\rm d}N^{\rm pPb}_{\rm cent}/{\rm d}p_{\rm T}}{\langle N^{\rm cent}_{\rm coll}\rangle {\rm d}N^{\rm pp}/{\rm d}p_{\rm T}}$$

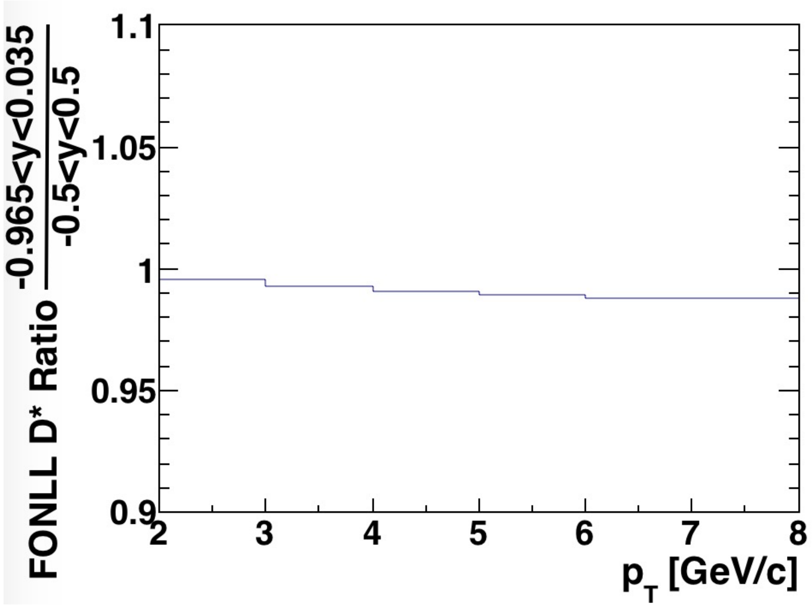


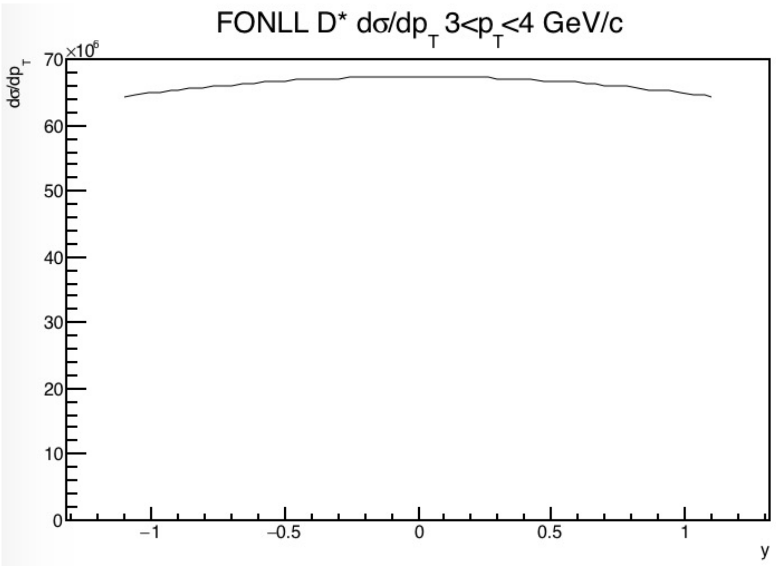
Stat. err. only

Lc result ArXiv: 2011.06079



Rapidity correction for R_{pPb}

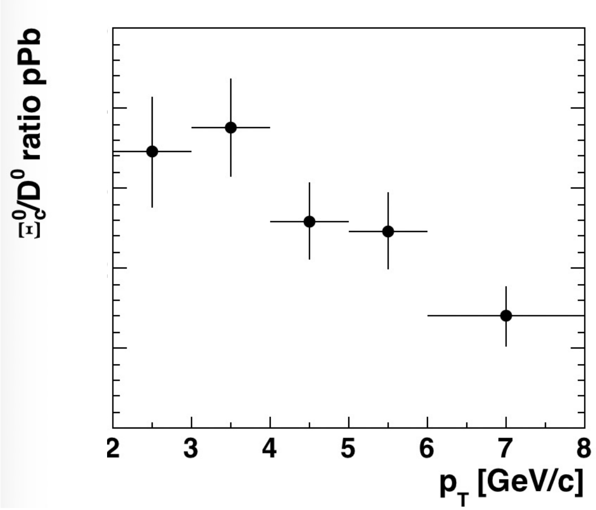




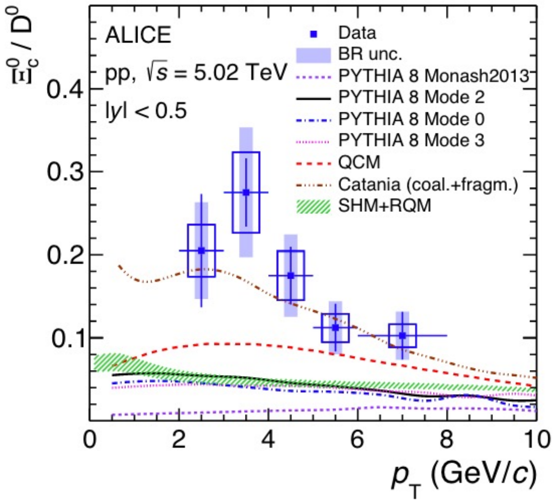
- FONLL rapidity ratio
  - Following Lc analysis https://alice-notes.web.cern.ch/node/811
  - pPb: $-0.5<y_{Lab}<0.5$
    - → (y_{cms} = $-y_{Lab}$ -0.465)
    - → $-0.965<y_{cms}<0.035$
  - Uncertainty not applied yet. D* Central value only in this slide.

$$\frac{d\sigma^{-0.965<y<0.035}/dp_T}{d\sigma^{-0.5<y<0.5}/dp_T}$$

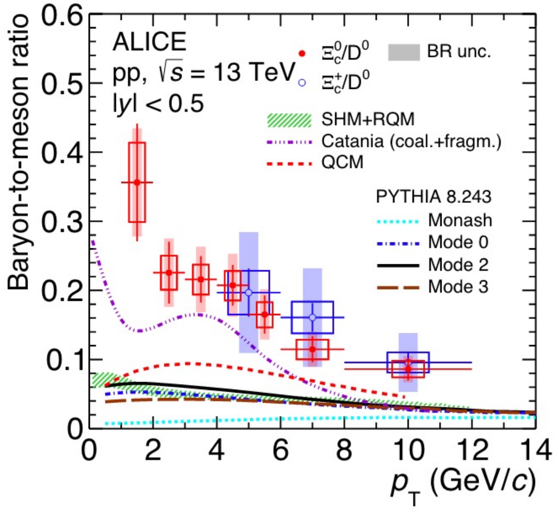
Baron/Meson ratio (Ξ_c^0/D^0)



Stat. err. only

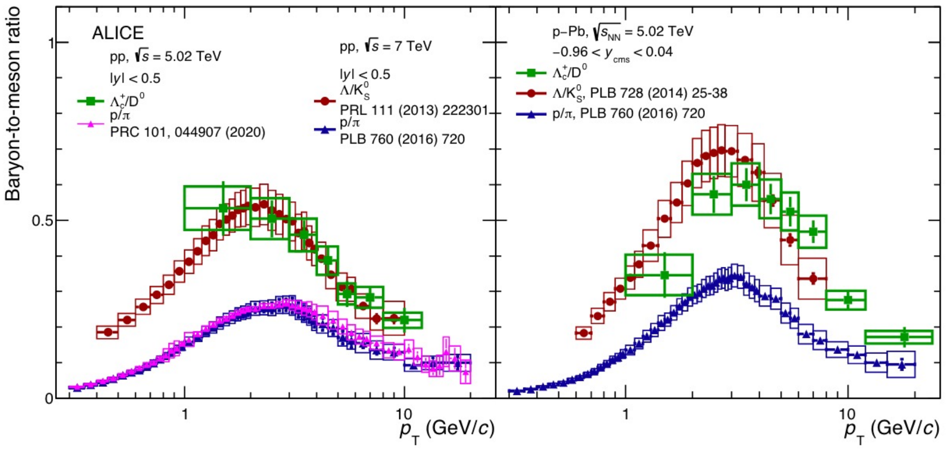


pp 5TeV



pp 13TeV

- Will be compared when the results come.



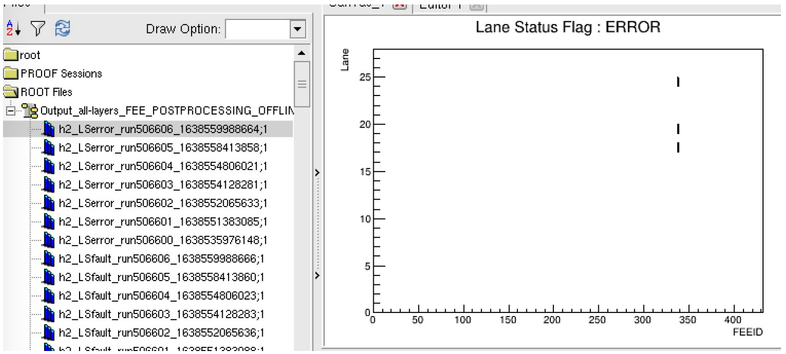
Lc p-Pb 5TeV

Summary and Outlook

- Studying charmed baryon in pPb collisions could play an important role in the investigation of strongly-interacting matter from heavy ion collisions and hadronization process.
- To do list in the analysis
  - Systematic uncertainty
  - Analysis note
- Expected results in January
  - R_{pPb}
  - Baryon/Meson ratio (Ξ_c^0/D^0) comparison with Λ_c^+
  - Baryon/Meson ratio with High Multiplicity pp result in terms of multiplicity

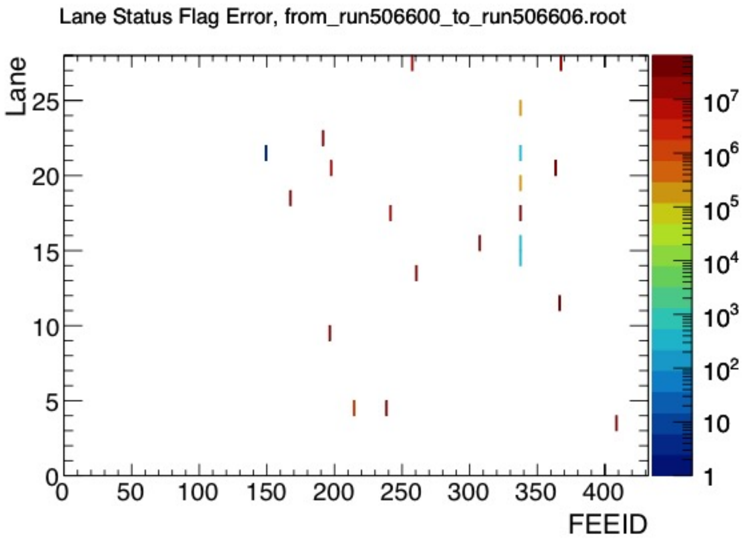
Activity in ALICE – ITS QC
(FEE post-processing offline)

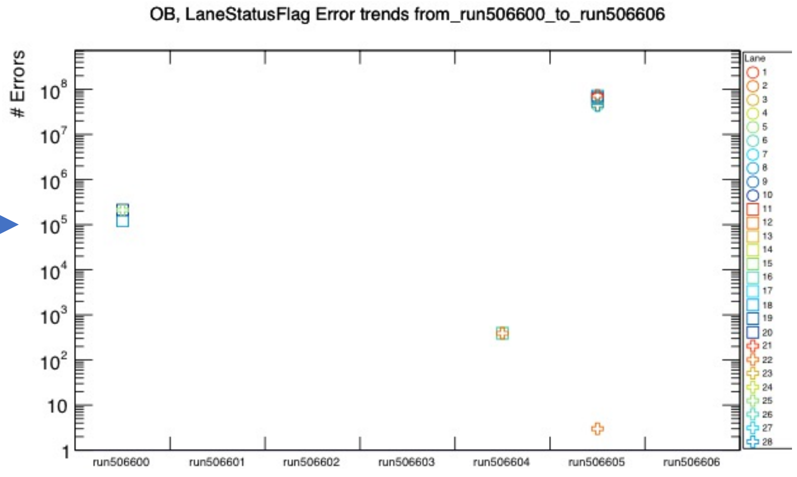
Lane Status Flag: ERROR
Run 506606



- FEE post-processing offline
- Jeongsu Bok, Jaeyoon Cho
- collecting Lane Status Flags
  - ERROR, FAULT, OK, WARNING
  - To check the trend quickly and easily

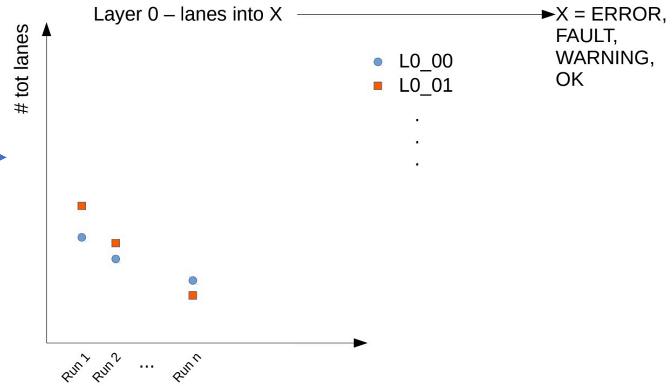
Lane Status Flag: ERROR
Run 506600~506606





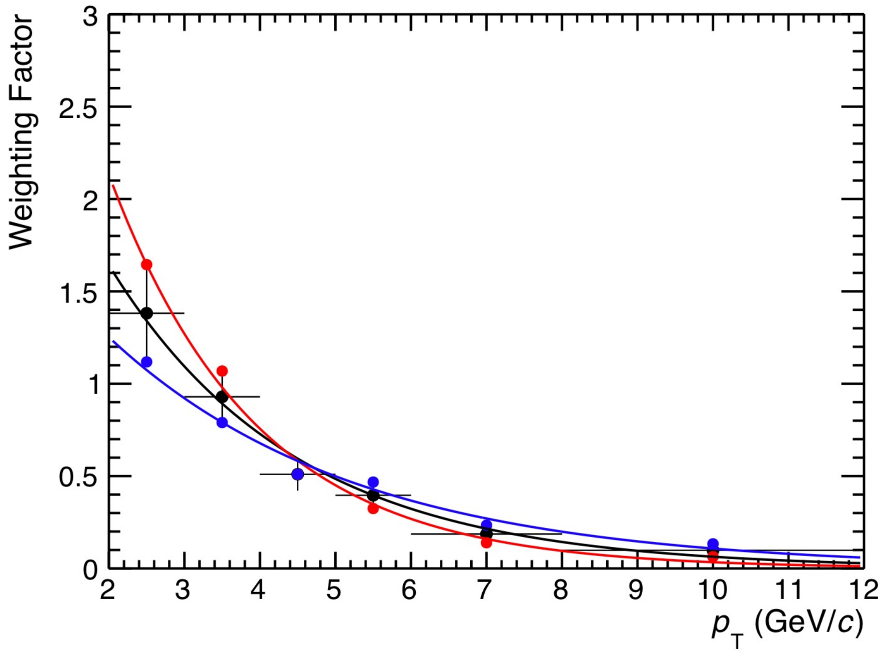
Projection to Yaxis(Lane). OB

Run



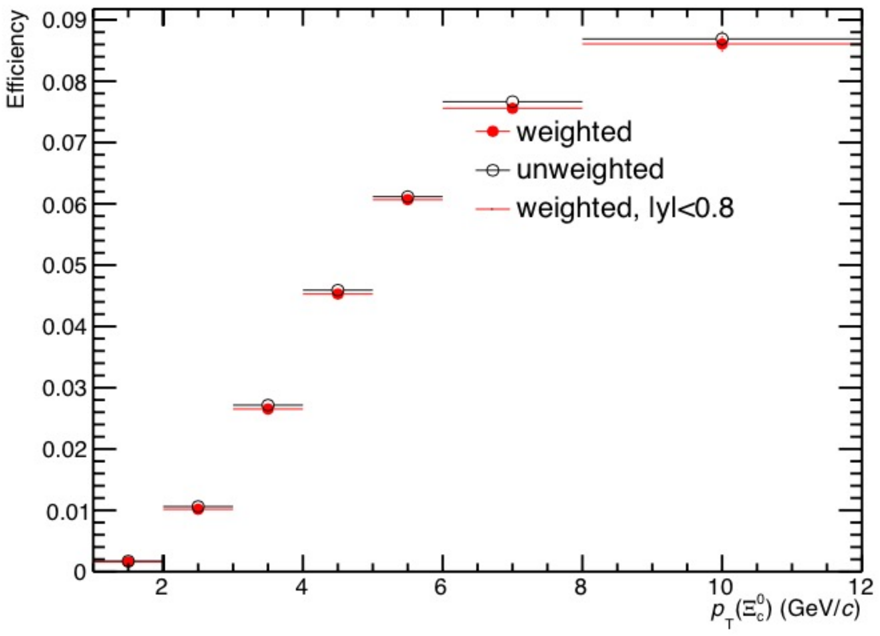
Backup slides

Weighting Factor



- Match shape of MC and unfolded (unweighted) spectra in $2<p_T<12$
  - Normalize within $2<p_T<12$, fit with exponential, then get the ratio between two functions → weighting factor
- Included in the systematic uncertainty.

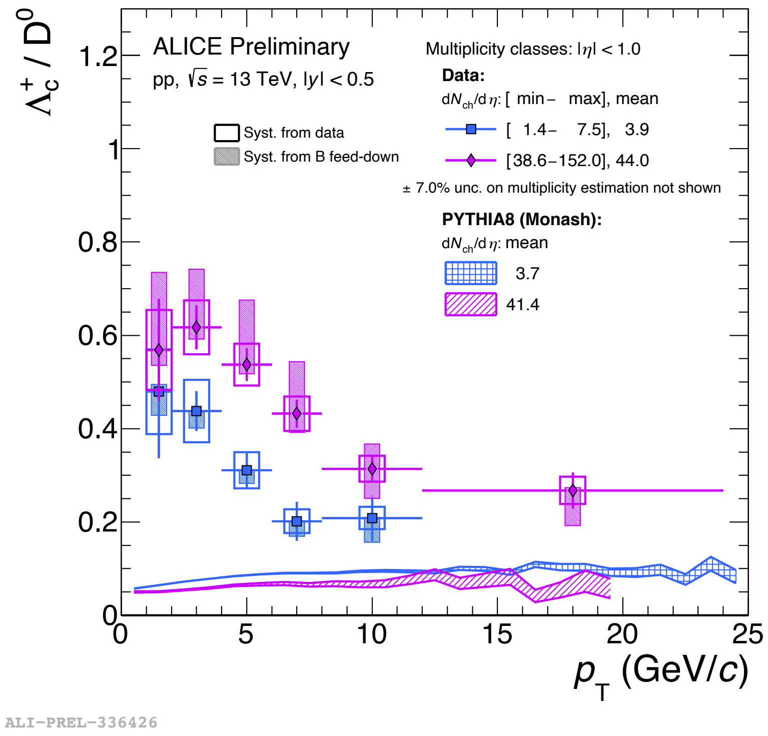
Efficiency

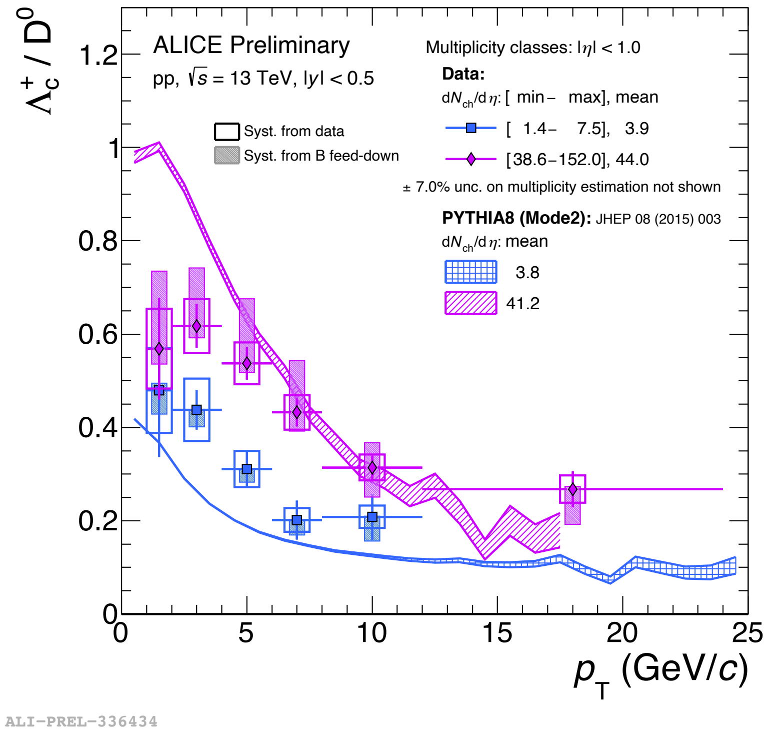


- Weighted, unweighted difference is included in syst.
- Rapidity variation(y<0.5,0.8) is not included yet.

1

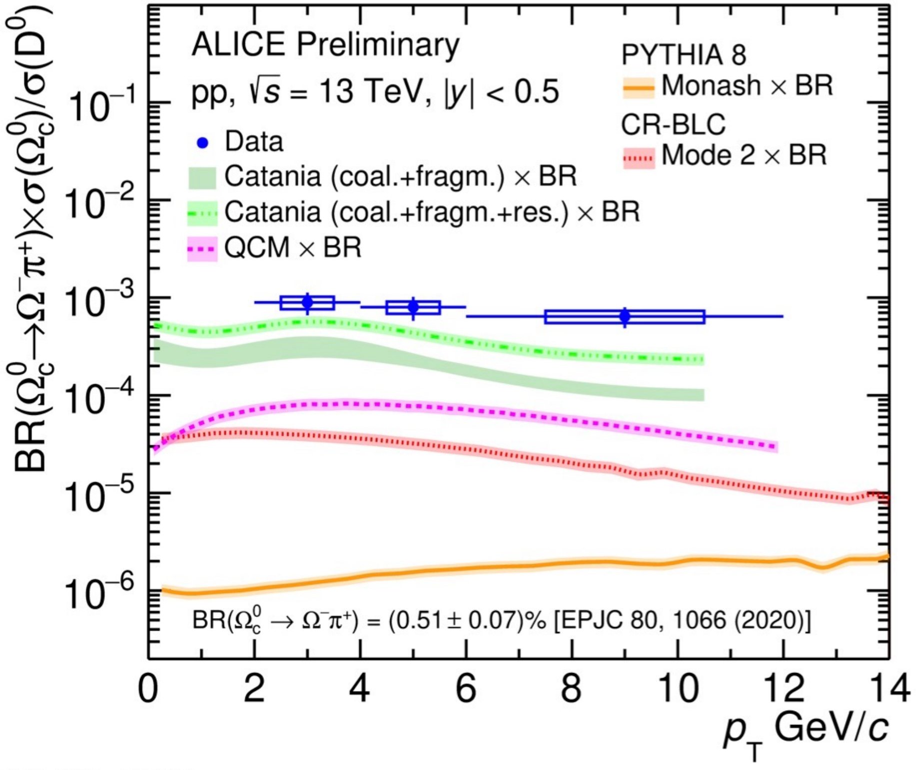
Multiplicity dependence of Λ_c^+/D^0





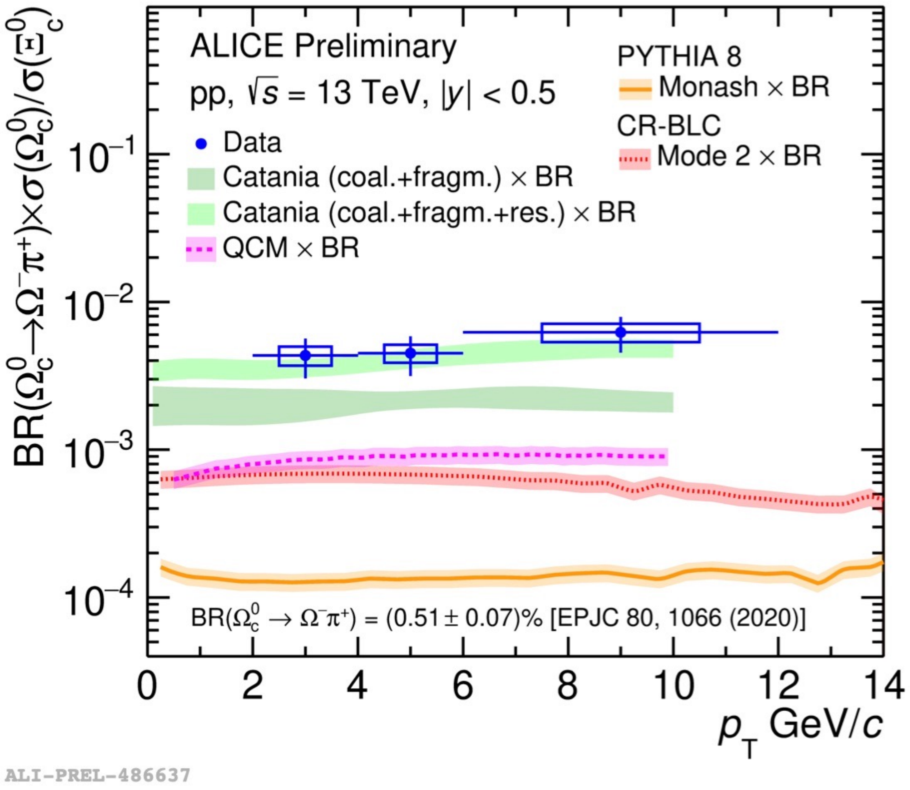
- Monash tune doesn't reproduce the pattern
- Enhanced CR mechanisms show a good agreement

Ω_c^0/D^0 results in ALICE



- BRxΩ_c^0/D^0 ratio in pp collisions at 13TeV
  - First measurement of Ω_c^0 production at LHC
  - BR ($\Omega_c^0 \rightarrow \Omega^- \pi^+$) = 0.51±0.07%
    - Theoretical calculation: *EPJC 80, 1066 (2020)*
- Model comparison
  - PYTHIA 8 Monash largely underestimate the measurement.
  - PYTHIA 8 CR tunes (Mode2) underestimate the measurement.
  - Catania and QCM
    - underestimate even though coalescence is included

Baryon-to-Baryon ratio: Ω_c^0 / Ξ_c^0 in ALICE



- BRxΩ_c^0/D^0 ratio in pp collisions at 13TeV
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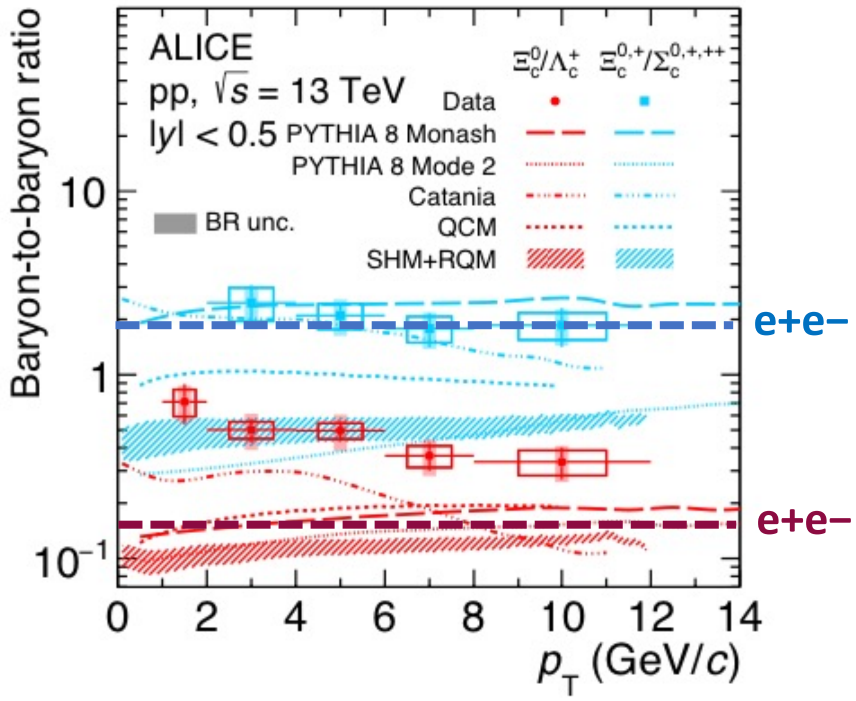
- Model comparison
  - Largely underestimate the measurement.
    - PYTHIA 8 Monash, PYTHIA 8 CR tunes (Mode2), QCM
  - Except the Catania model
    - considers coalescence, fragmentation, and additional resonance states

Baryon-to-Baryon ratio: Ξ_c^0/Λ_c^+, Ξ_c^0/Σ_c in ALICE



arXiv:2105.05187

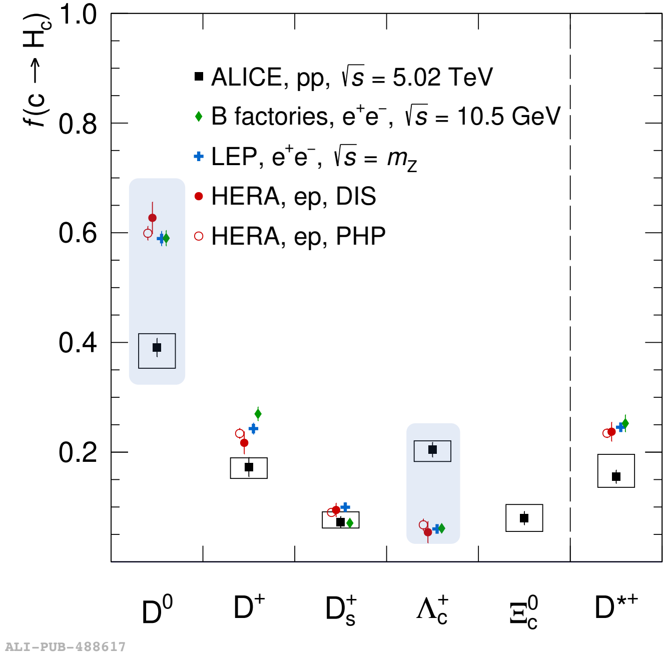
PYTHIA 8 Monash *(EPJC 74 (2014) 3024)*
PYTHIA 8 CR Modes *(JHEP 08 (2015) 003)*
SHM *(PLB 795 (2019) 117-121)*
RQM *(PRD 84 (2011) 014025)*
QCM *(EPJC 78 no.4, (2018) 344)*
Catania *(arXiv:2012.12001)*
Belle *(PRD 97, 072005 (2018))*

- Ξ_c^0/Λ_c^+, Ξ_c^0/Σ_c in p+p 13 TeV
- First measurement of charm baryon-to-baryon ratio yields at the LHC.
- Similar enhancement for Ξ_c^0, Σ_c with respect to e+e-
- Ξ_c^0/Σ_c : Catania describes the magnitude and p_T shape, Monash describes the magnitude.
  - Both underestimate the ratio

Charm Fragmentation Fractions in pp collisions at LHC

H_c	$f(c \rightarrow H_c)[\%]$
D^0	$39.1 \pm 1.7(\text{stat})^{+2.5}_{-3.7}(\text{syst})$
D^+	$17.3 \pm 1.8(\text{stat})^{+1.7}_{-2.1}(\text{syst})$
D_s^+	$7.3 \pm 1.0(\text{stat})^{+1.9}_{-1.1}(\text{syst})$
Λ_c^+	$20.4 \pm 1.3(\text{stat})^{+1.6}_{-2.2}(\text{syst})$
Ξ_c^0	$8.0 \pm 1.2(\text{stat})^{+2.5}_{-2.4}(\text{syst})$
D^{*+}	$15.5 \pm 1.2(\text{stat})^{+4.1}_{-1.9}(\text{syst})$

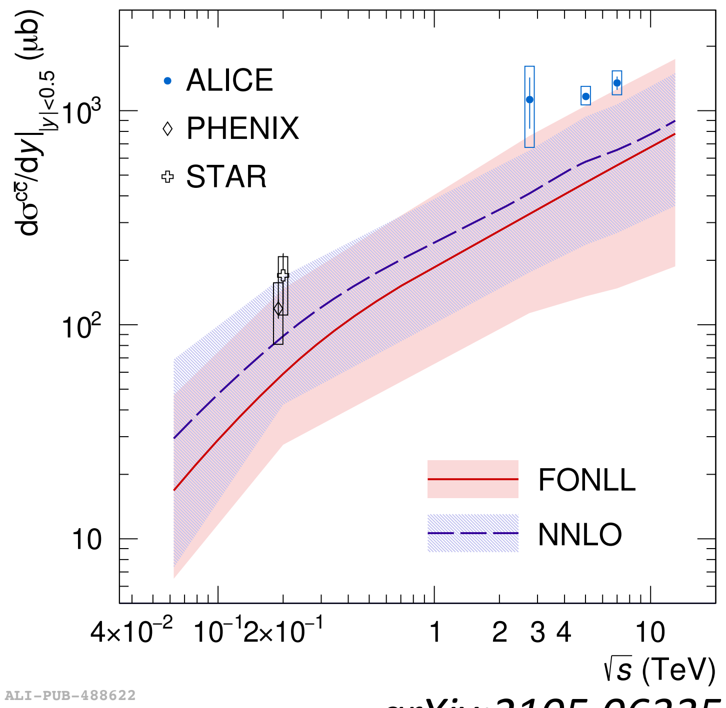
arXiv:2105.06335



B factories
(EPJC 76 no.7, (2016) 397)
LEP
(EPJC 77 no.1, (2015) 19)
HERA
(EPJC 76 no.7, (2016) 397)

- We measure now all single charm hadron ground states
  - For the first time, fragmentation fraction for the Ξ_c^0 baryon is measured
- Not counting D^{*+} contribution
  - Feed down into D^0,D^+
- charm fragmentation fractions:
  - Not universal

Total charm cross section



arXiv:2105.06335

STAR *(PRD 86 (2012) 072013)*
PHENIX *(PRC 84 (2001) 044905)*
FONLL *(JHEP 10 (2012) 137)*
NNLO *(PRL 118 (2017) 12, 122001)*

- Charm production cross section at the LHC
- First measurement of charm production cross section per unit of rapidity at midrapidity in pp collisions at 5.02 TeV

$$d\sigma^{c\bar{c}}/dy\,|_{|y|<0.5} = 1165 \pm 44(\text{stat})^{+134}_{-101}(\text{syst})\,\mu\text{b}$$

- According to new charm fragmentation fractions, updated charm cross section in pp 2.76, 7TeV are about 40% higher than previous publications
  - pp 2.76TeV *(JHEP 07 (2012) 191)*
  - pp 7TeV *(EPJC 77 no. 8, (2017) 550)*
- All ALICE results with new charm fragmentation fractions are at the upper edge of the pQCD calculations.