Discoveries and Open Puzzles in Particle Physics and Gravitation
23-28 June 2019 Kitzbühel

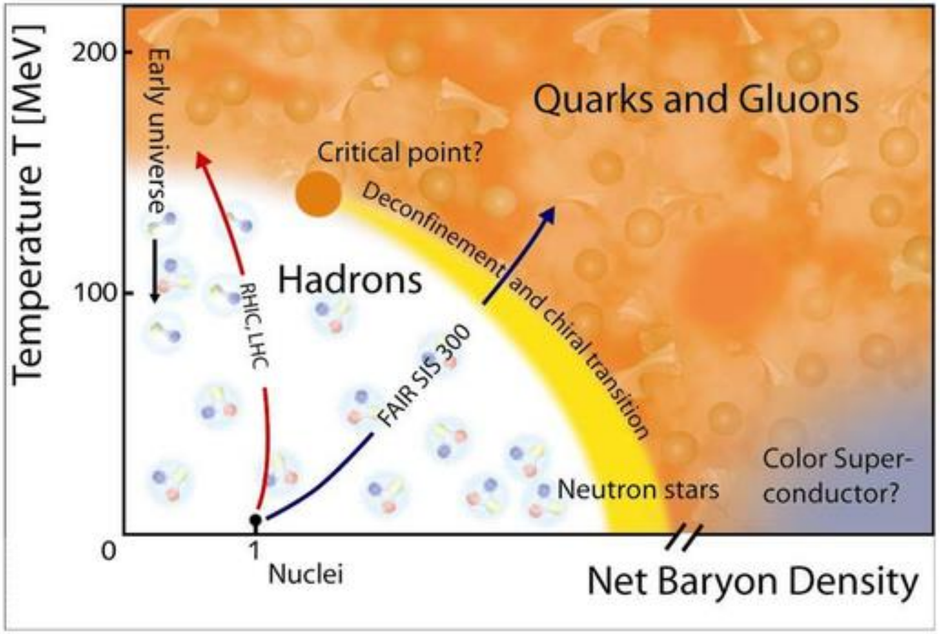
Charm baryon production in pp, p-Pb and Pb-Pb collsions with ALICE at the LHC

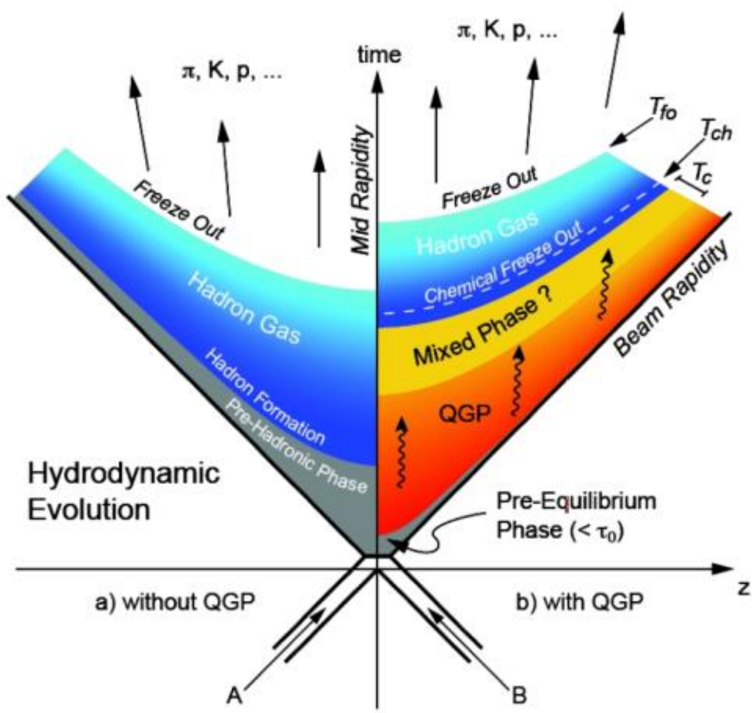
E. Meninno* on behalf of the ALICE Collaboration

* Stefan Meyer Institut für subatomare Physik

QUARK-GLUON PLASMA

- At very high temperature and/or density, a phase transition from ordinary matter to a colour-deconfined medium is predicted
- New state of matter called
  Quark-Gluon Plasma (QGP)

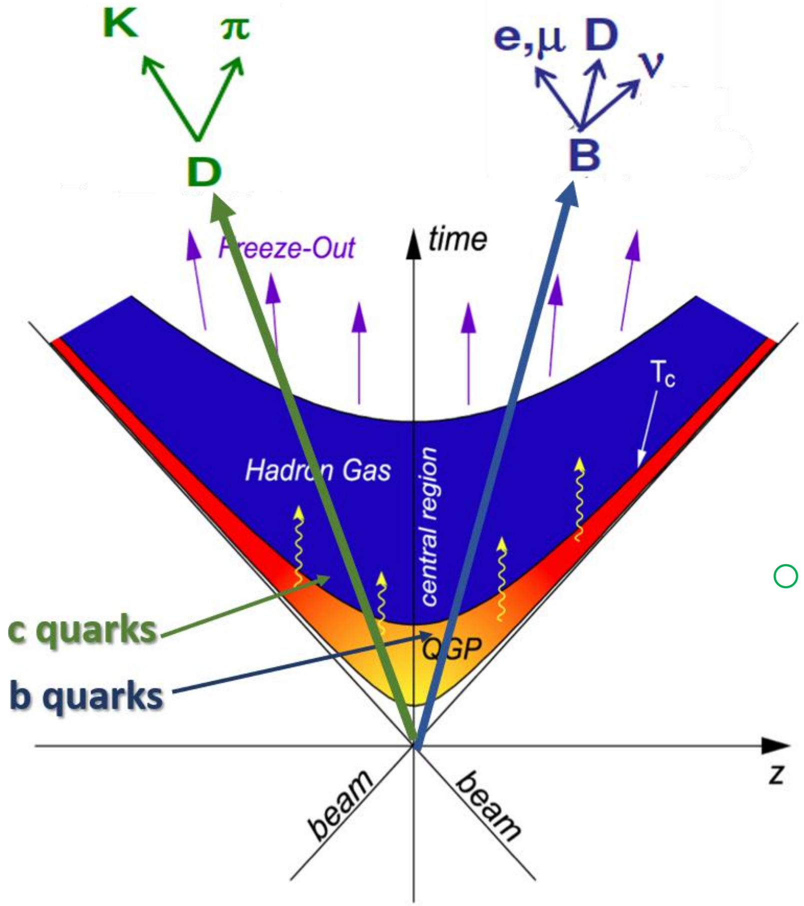




- The QGP can be recreated in laboratory via ultra-relativistic Heavy-Ion (HI) collisions.
  Different phases:
  - pre-equilibrium
  - QGP
  - hadronization
  - freeze out
- Experimental investigation of the QGP with HI collisions celebrated its 30th anniversary last year (SPS, RHIC,LHC)

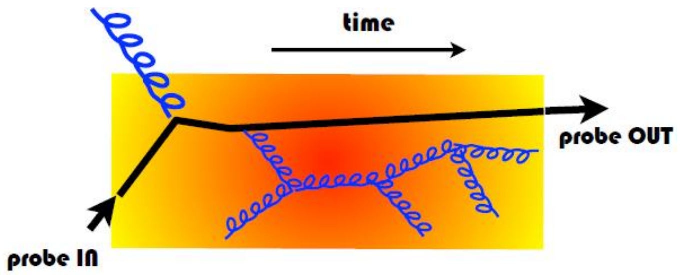
HEAVY-FLAVOUR PRODUCTION

ALICE



- **Heavy (charm and beauty) quarks**: powerful probes for the Quark Gluon Plasma created in HI collisions
  - Produced in the early stages of the collision, they experience the whole evolution of the medium, interacting with its constituents via elastic scatterings and gluon radiations.

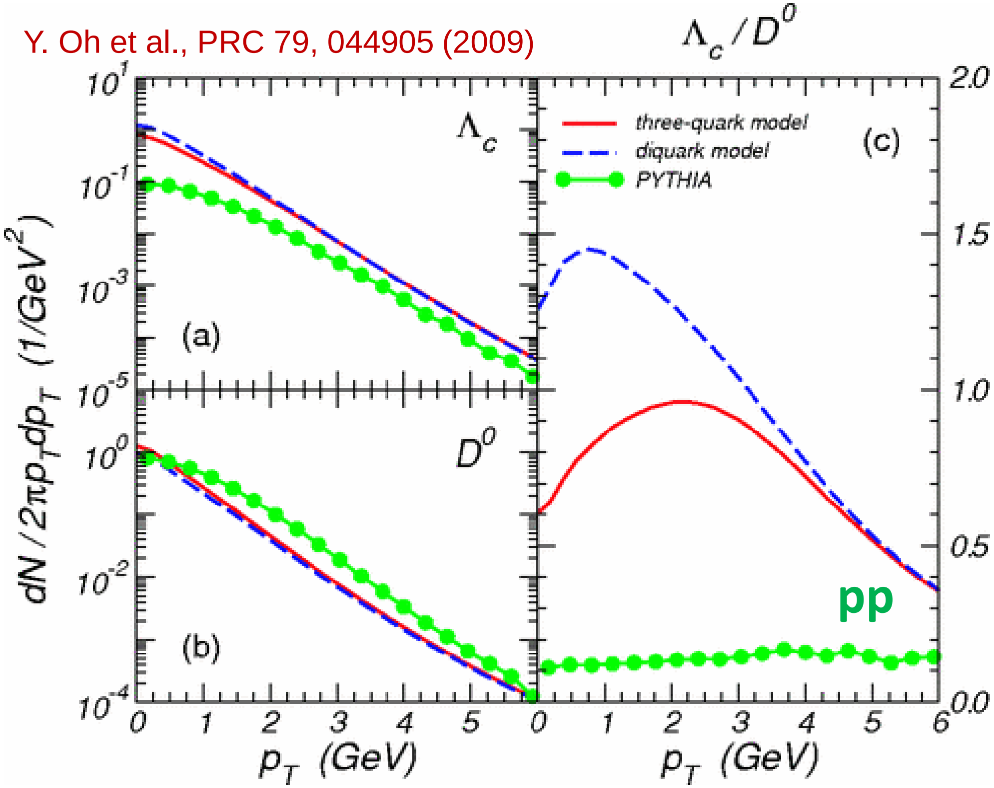
- Expected less energy loss w.r.t. light quarks and gluons in the QCD medium
  → Higher penetrating power



HEAVY BARYON PRODUCTION

- Understand **hadronisation processes** in the QGP: measuring the baryon/meson ratio

Y. Oh et al., PRC 79, 044905 (2009)



- Enhancement of Λ_c^+/D^0 (and $\Lambda_b^+/\bar{B}^0$) ratio predicted in coalescence models.
- Further enhancement expected if thermalised light diquark states exist in the QGP.

HEAVY FLAVOUR PRODUCTION

ALICE

..HF studies important also in small systems!

In pp collisions

- Production cross section computed using perturbative QCD (*p*QCD) calculations down to low p_T

$$d\sigma^{hard}_{AB\to h} = f_{b/B}(x_1,Q^2)\otimes f_{a/A}(x_2,Q^2)\otimes d\sigma^{hard}_{ab\to c}(x_1,x_2,Q^2)\otimes D_{c\to h}(z,Q^2)$$

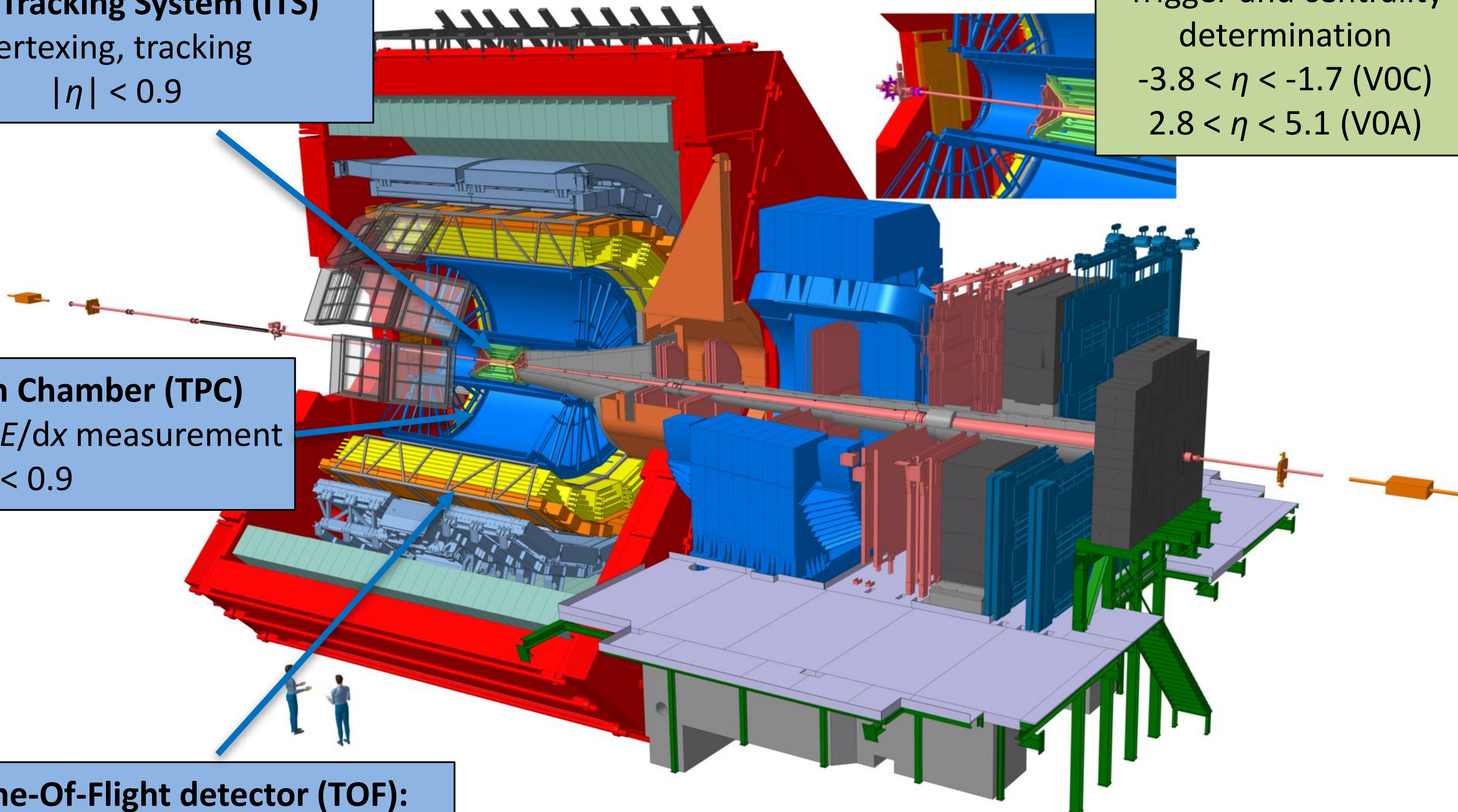
Parton Distribution Functions (not perturbative) — *p*QCD — Fragmentation Function (not perturbative)

- Test of *p*QCD calculations at the TeV domain
- Reference for p-Pb and Pb-Pb collisions
- Baryon /meson ratio sensitive to the hadronisation mechanisms.

In p-Pb collisions

- Reference for Pb-Pb collisions
- Study cold nuclear matter (CNM) effects in the initial and final states.
- Address possible collective effects resembling what observed in heavy-ion collisions
- Small QGP formed also in p-Pb collisions?

The ALICE apparatus



Inner Tracking System (ITS)
vertexing, tracking
$|\eta| < 0.9$

V0
Trigger and centrality determination
$-3.8 < \eta < -1.7$ (V0C)
$2.8 < \eta < 5.1$ (V0A)

Time Projection Chamber (TPC)
Tracking, PID via dE/dx measurement
$|\eta| < 0.9$

Time-Of-Flight detector (TOF):
PID via time-of-flight measurement
$|\eta| < 0.9$

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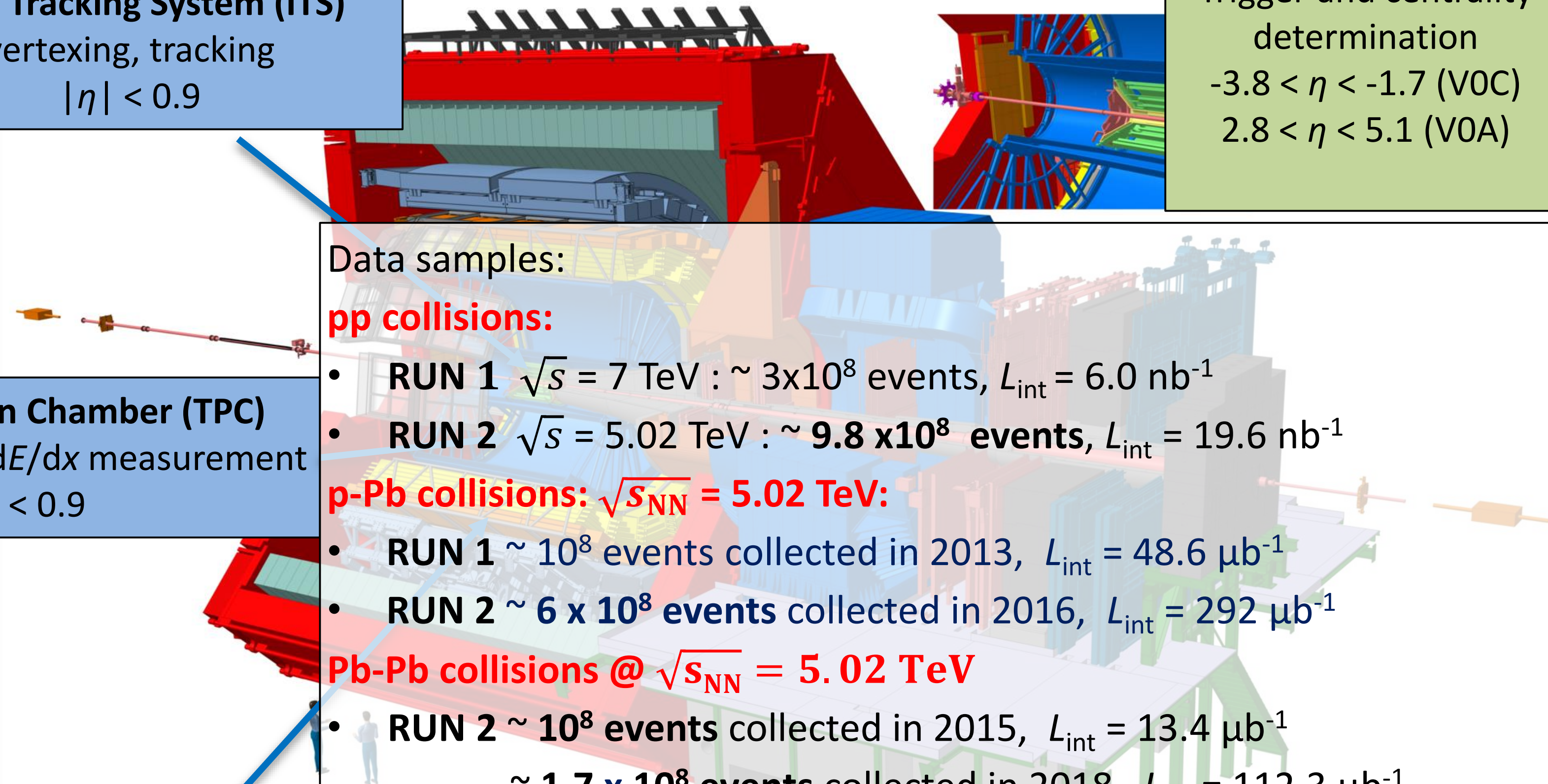

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Time-Of-Flight detector (TOF):
PID via time-of-flight measurement
$|\eta| < 0.9$

Data samples:

pp collisions:

- **RUN 1** $\sqrt{s}$ = 7 TeV : ~ 3x10^8 events, L_{int} = 6.0 nb^{-1}
- **RUN 2** $\sqrt{s}$ = 5.02 TeV : ~ **9.8 x10^8 events**, L_{int} = 19.6 nb^{-1}

p-Pb collisions: $\sqrt{s_{NN}}$ = 5.02 TeV:

- **RUN 1** ~ 10^8 events collected in 2013, L_{int} = 48.6 μb^{-1}
- **RUN 2** ~ **6 x 10^8 events** collected in 2016, L_{int} = 292 μb^{-1}

Pb-Pb collisions @ $\sqrt{s_{NN}} = 5.02$ TeV

- **RUN 2** ~ **10^8 events** collected in 2015, L_{int} = 13.4 μb^{-1}

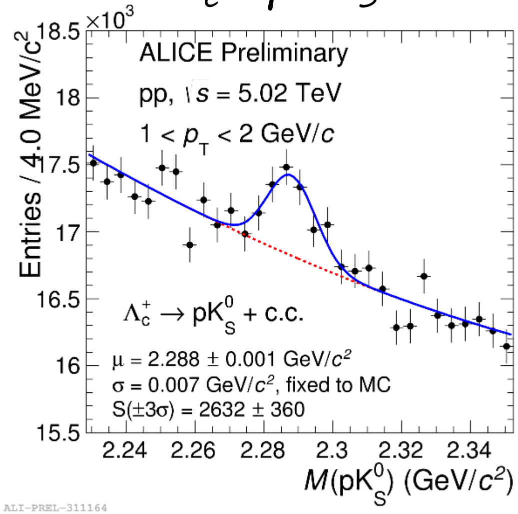
  ~ **1.7 x 10^8 events** collected in 2018, L_{int} = 112.3 μb^{-1} (0-10%centrality) and L_{int} = 49.0 μb^{-1} (30 -50%centrality)

Charmed-hadron reconstruction

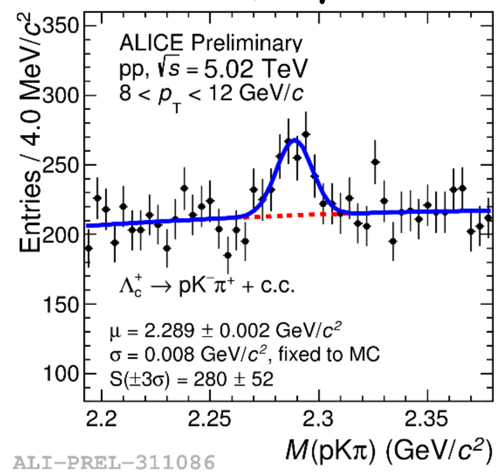
Hadronic decays

- **Reconstruction of secondary** vertex, displaced from primary vertex.
- Candidates selected applying topological selection and PID (using TPC and TOF)
- **Signal extraction** from invariant mass distribution, in each individual p_T interval.

$\Lambda_c \rightarrow pK^0_S$



$\Lambda_c \rightarrow pK\pi$



Baryon Λ_c^+
M = 2284 MeV/c^2
Quark: *udc*
cτ = 60 μm

Decay	Branching fraction (%)
$\Lambda_c^+ \rightarrow pK^-\pi^+$	6.35
$\Lambda_c^+ \rightarrow pK^0_S$	1.58

Charmed-hadron reconstruction

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- **Reconstruction of secondary** vertex, displaced from primary vertex.
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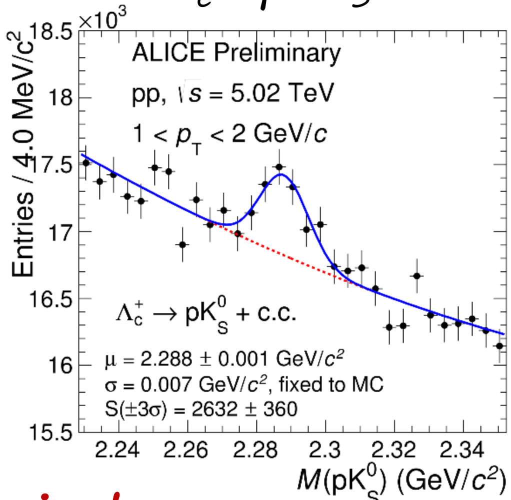
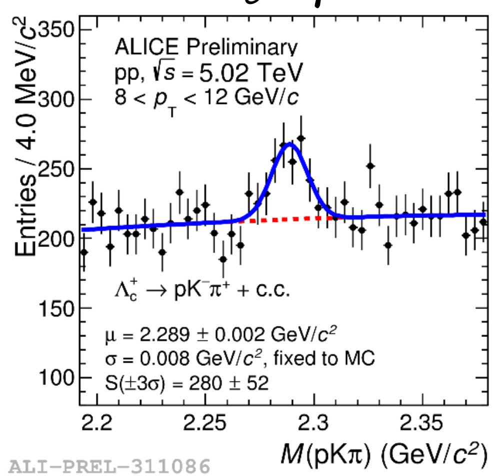
$\Lambda_c \to pK^0_S$



$\Lambda_c \to pK\pi$



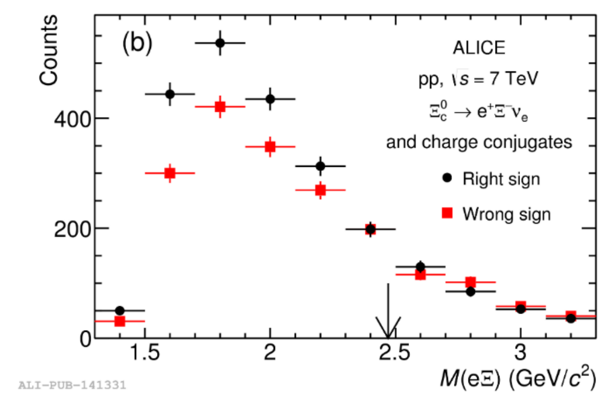
Baryon Λ_c^+
M = 2284 MeV/c²
Quark: *udc*
cτ = 60 µm

Baryon Ξ_c^+
M = 2471 MeV/c²
Quark: *usc*
cτ = 34 µm

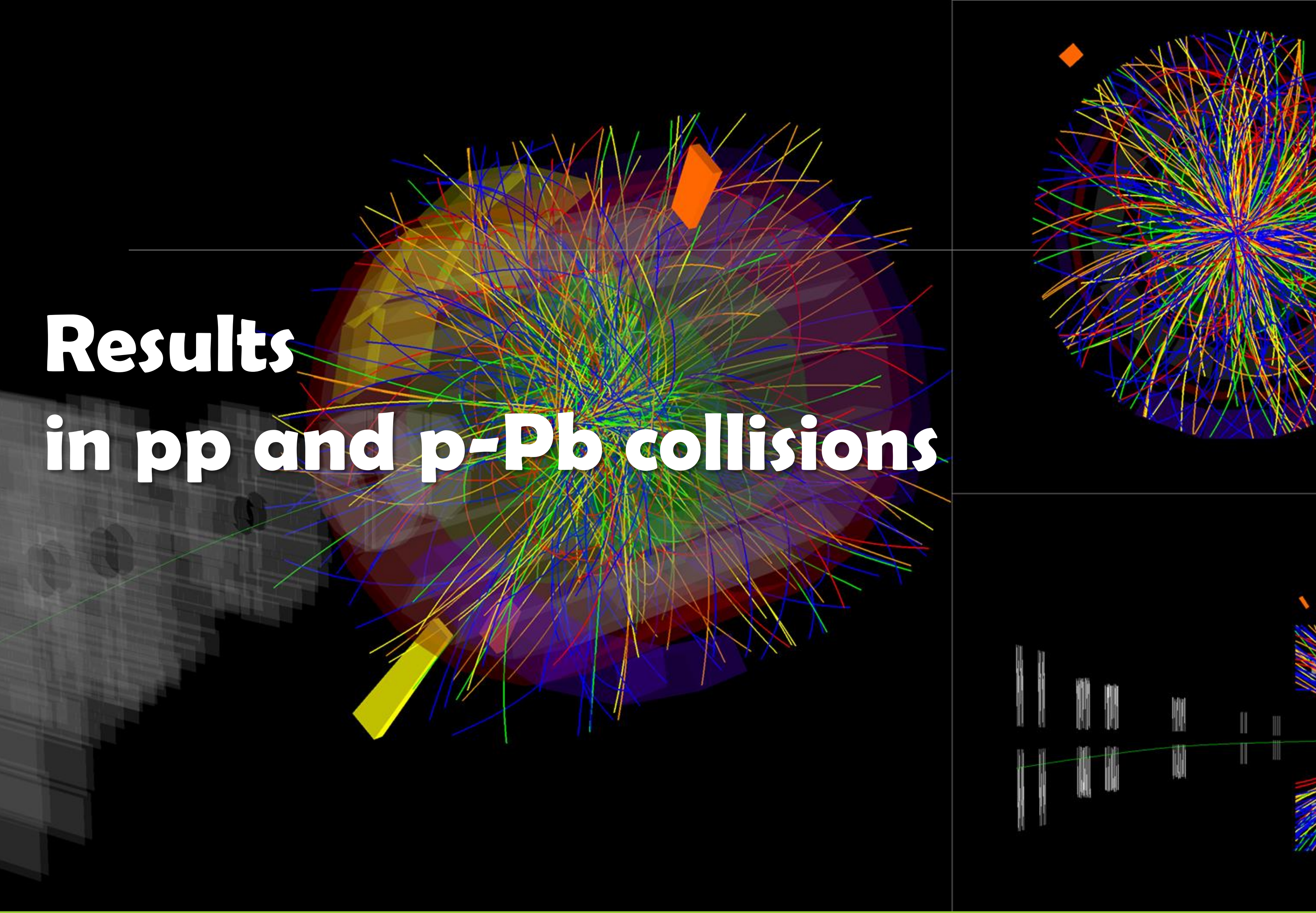
Decay	Branching fraction (%)
$\Lambda_c^+ \to pK^-\pi^+$	6.35
$\Lambda_c^+ \to pK^0_S$	1.58
$\Lambda_c^+ \to e^+\Lambda\nu_e$	3.6
$\Xi_c^0 \to e^+\Xi^-\nu_e$	Unknown

Semileptonic decays

- **Wrong-Sign (WS)** $e^-\Lambda$ ($e^-\Xi^-$) pairs subtracted from **Right-Sign (RS)** $e^+\Lambda$ ($e^+\Xi^-$) spectra, to estimate the combinatorial background.
- **Unfolding technique** used to convert the $e^+\Lambda$ ($e^+\Xi^-$) p_T spectrum in Λ_c^+ (Ξ_c^0)



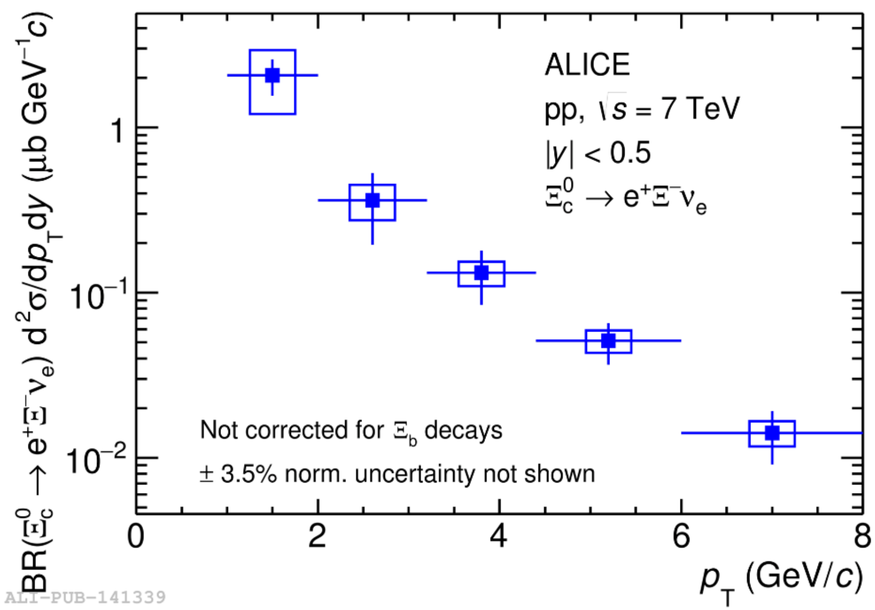
Results in pp and p-Pb collisions

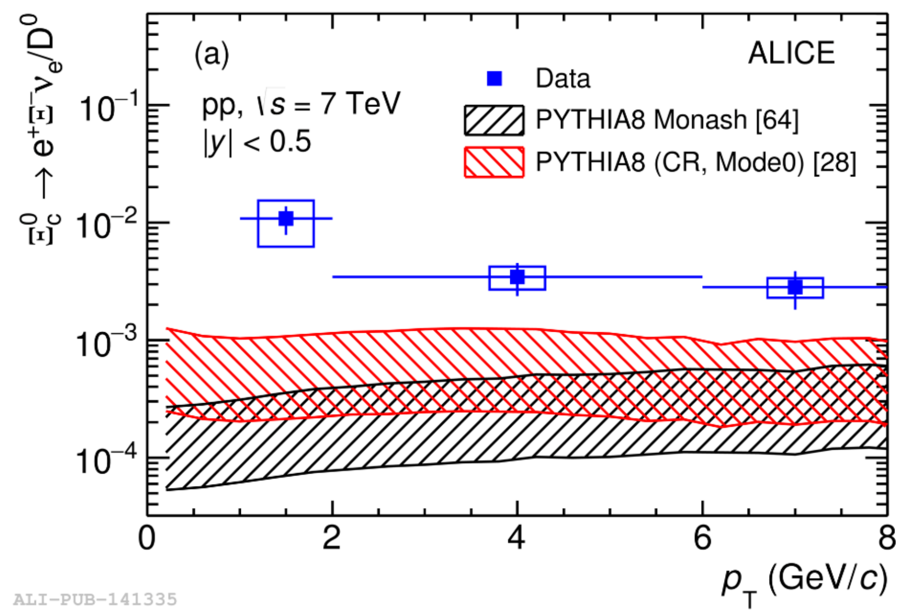


Results from Run1 for Ξ_c^0

First measurement of Ξ_c^0 production in pp collisions at $\sqrt{s}$ = 7 TeV

Phys. Lett. B 781 (2018) 8-19





PYTHIA8 Monash: P. Skands et al., Eur. Phys. J. C (2014) 74:3024
Colour reconnection (CR): J. R. Christiansen and P. Skands, JHEP 08 (2015) 003

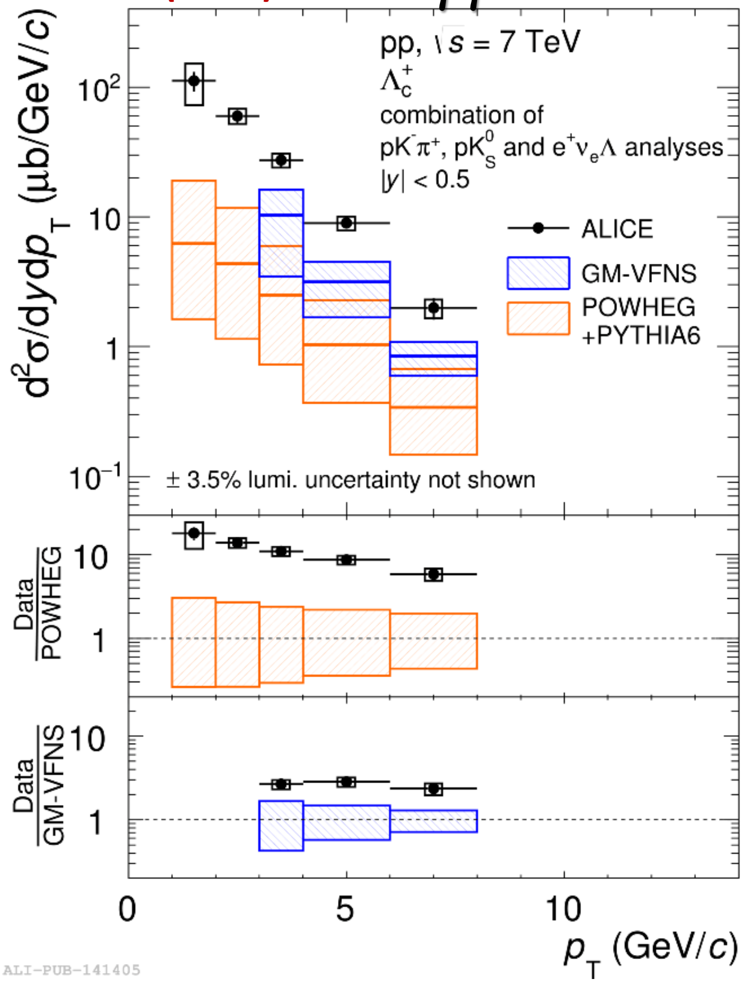
- Ξ_c^0 cross section x B.R.($\Xi_c^0 \to e^+\Xi^-\nu_e$) in 1 < p_T < 8 GeV/c

  B.R.($\Xi_0^c \to e^+\Xi^-\nu_e$) not known, high uncertainty bands in the theoretical predictions.

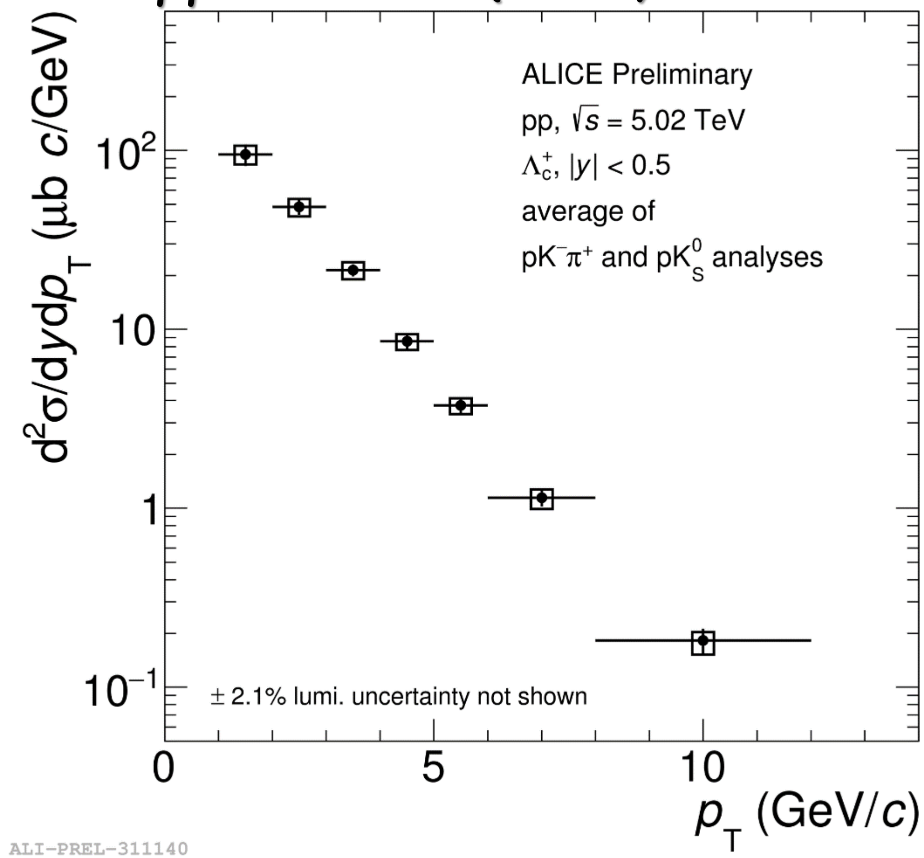
- Baryon/meson $\Xi_c^0 \to e^+\Xi^-\nu_e\,/D^0$ ratio higher than theoretical predictions.
- **PYTHIA8** with enhanced colour reconnection mechanisms closer to data.

Λ_c^+ cross section in pp collisions

JHEP 04 (2018) 108 pp@7TeV



pp@5.02TeV (Run2)



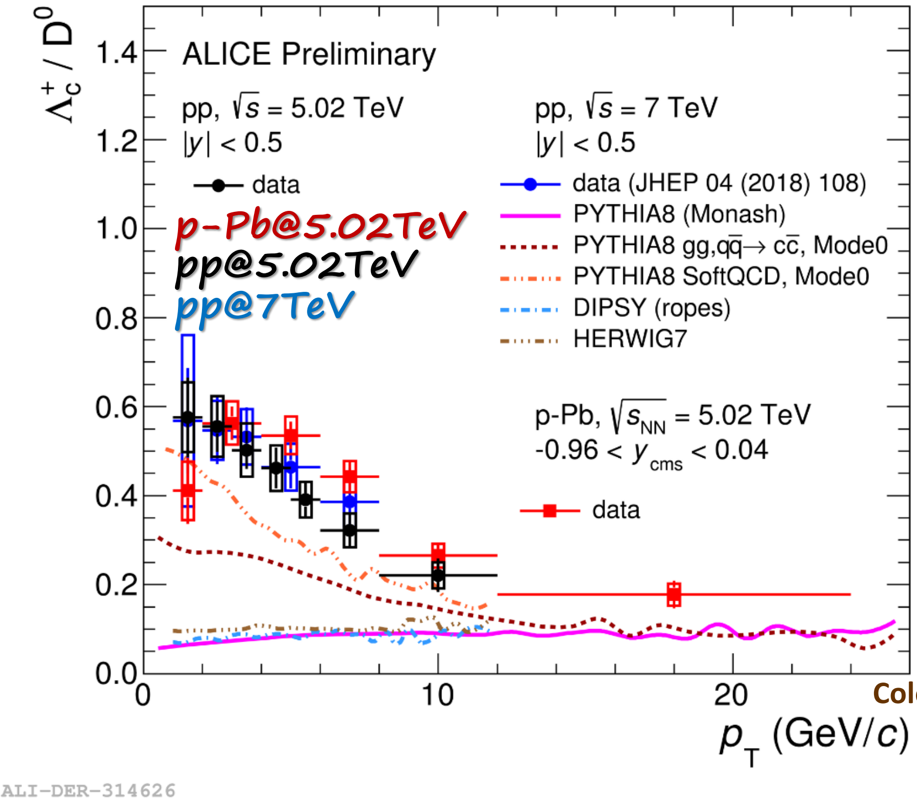
Measurements in pp@5TeV in wider p_T range

Important reference for Pb-Pb and p-Pb collisions.

- Λ_c^+ p_T-differential cross section **underestimated** by theoretical models in pp (and p-Pb, see backup) collisions

GM-VFNS
Eur. Phys. J. C41, 199 (2005)
POWHEG
JHEP0709, 126 (2007)

Results for Λ_c^+/D^0



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Colour reconnection (CR): J. R. Christiansen and P. Skands, JHEP 08 (2015) 003
DIPSY: JHEP 08 (2011) 103
HERWIG7: Eur. Phys. J. C58 (2008) 639-707

- All the models underestimate data.
  - PYTHIA8 with enhanced colour reconnection mode closer to data.
- p-Pb results agree with pp ones within uncertainties.

Total charm cross section

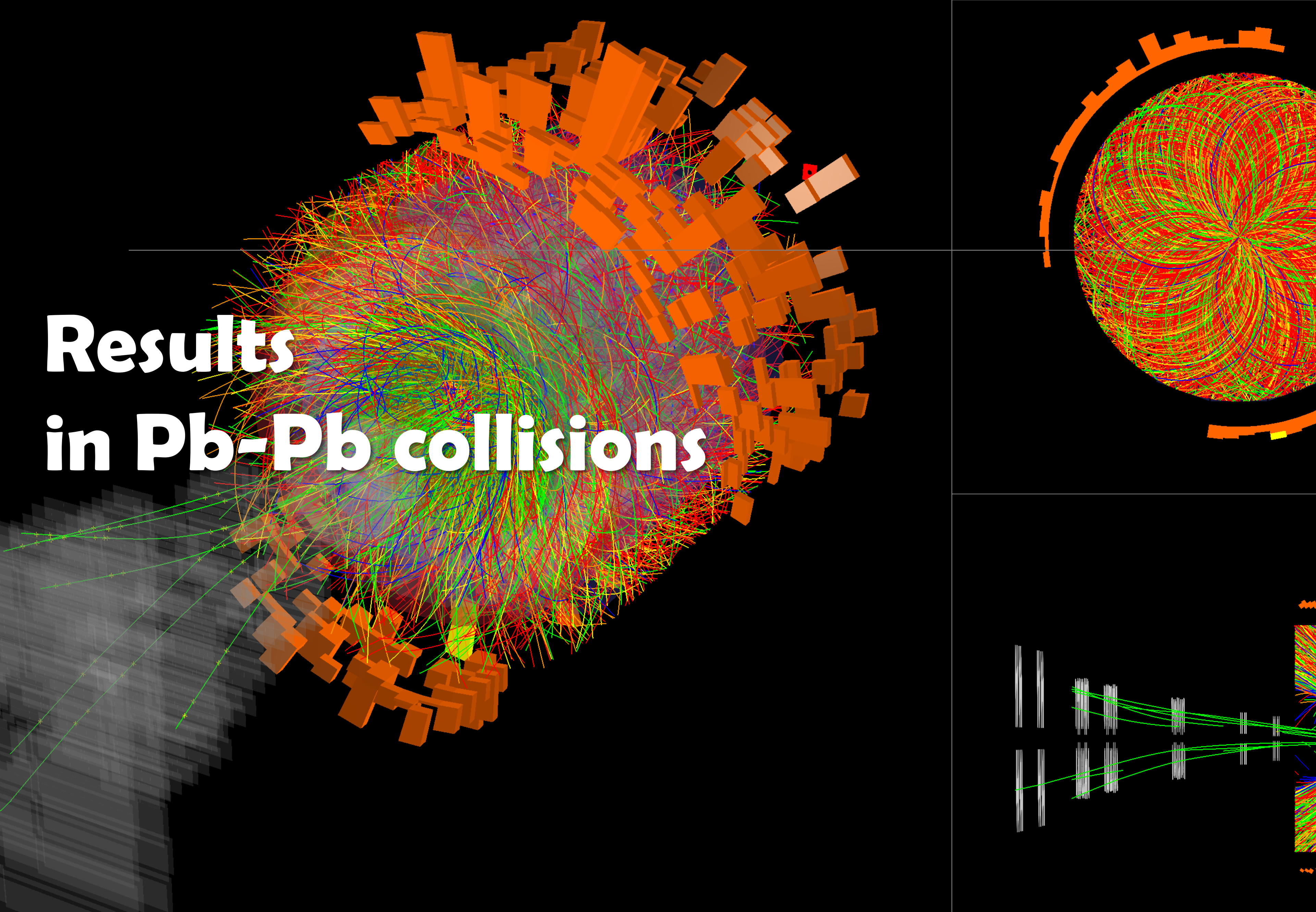
Eur. Phys. J. C77 (2017) 550

	Extr. factor to $p_T > 0$	$d\sigma/dy\,\|_{\|y\|<0.5}$ (μb)
D^0	$1.0002^{+0.0004}_{-0.0002}$	$500 \pm 36(\mathrm{stat}) \pm 39(\mathrm{syst}) \pm 18(\mathrm{lumi}) \pm 5(\mathrm{BR})$
D^+	$1.25^{+0.29}_{-0.09}$	$227 \pm 18(\mathrm{stat}) \pm 25(\mathrm{syst}) \pm 8(\mathrm{lumi}) \pm 6(\mathrm{BR})^{+52}_{-16}(\mathrm{extrap})$
D^{*+}	$1.21^{+0.28}_{-0.08}$	$251 \pm 29(\mathrm{stat}) \pm 24(\mathrm{syst}) \pm 9(\mathrm{lumi}) \pm 3(\mathrm{BR})^{+58}_{-16}(\mathrm{extrap})$
D_s^+	$2.23^{+0.71}_{-0.65}$	$89 \pm 18(\mathrm{stat}) \pm 11(\mathrm{syst}) \pm 3(\mathrm{lumi}) \pm 3(\mathrm{BR})^{+28}_{-26}(\mathrm{extrap})$

$$d\sigma^{c\bar{c}}_{pp,7\,\mathrm{TeV}}/dy\Big|_{|y|<0.5} = 954 \pm 69\,(\mathrm{stat}) \pm 97\,(\mathrm{tot.\ syst.})\,\mu b\,.$$

- Λ_c cross section measurement will allow to estimate the total charm production cross section at mid-rapidity in pp collisions @ 5TeV

Λ_c cross section extrapolation down to $p_T = 0$ in progress



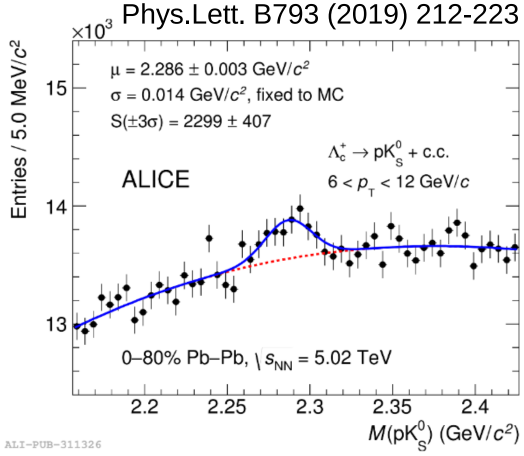
Results in Pb-Pb collisions

Λ_c production in Pb-Pb collisions at the LHC

ALICE

- First analysis of $\Lambda_c^+ \rightarrow pK^0_S$ with topological cut selection in 0-80 % centrality and for $6 < p_T < 12$ GeV/c.

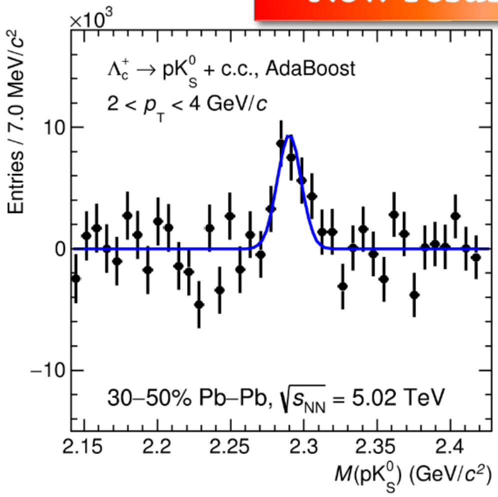
Phys.Lett. B793 (2019) 212-223

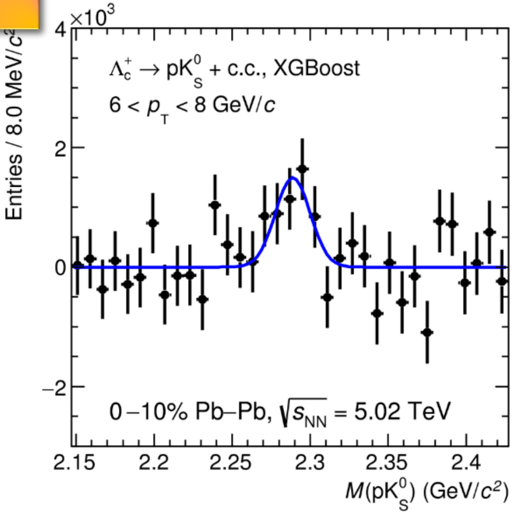


- **Analysis of the latest Run 2 Pb-Pb 2018 data**
- Machine Learning algorithms used to reduce the background

New results

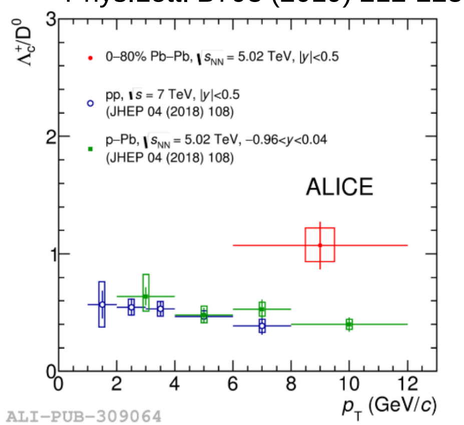
Topological, kinematical and PID variables used as training for ML



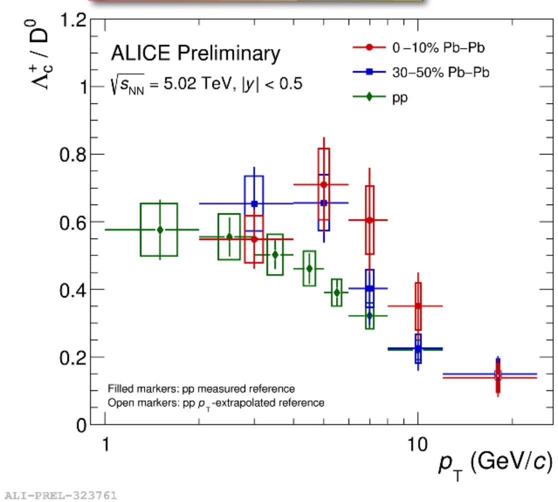


Baryon to meson ratio: Λ_c^+ / D^0

Phys.Lett. B793 (2019) 212-223



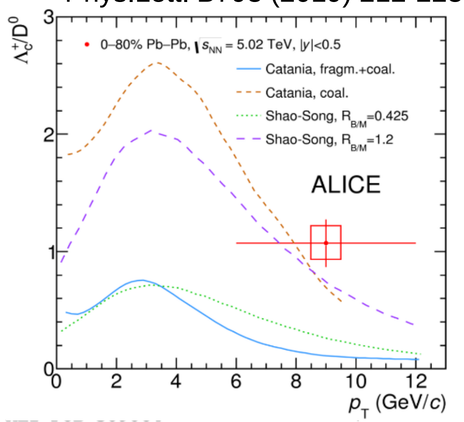
New results



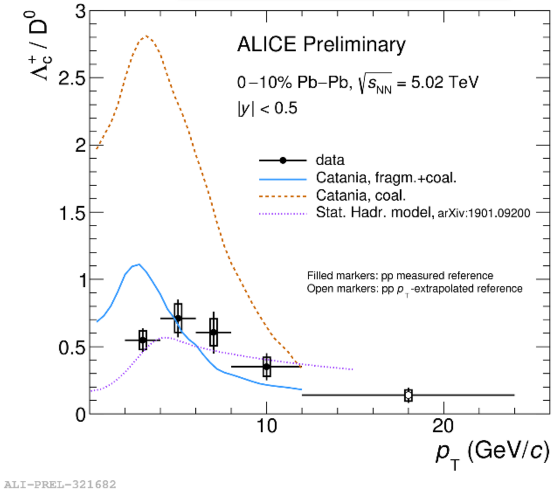
- Hint of higher Λ_c^+/D^0 than in pp (and p-Pb) collisions.
- Λ_c^+/D^0 ratio in central collisions higher than in peripheral collisions

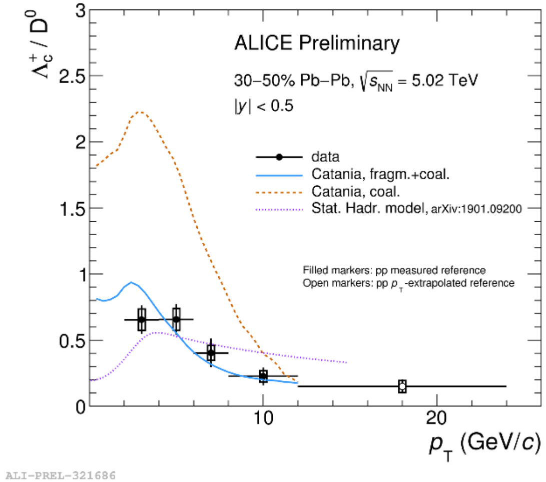
Baryon to meson ratio: Λ_c^+ / D^0

Phys.Lett. B793 (2019) 212-223



New results





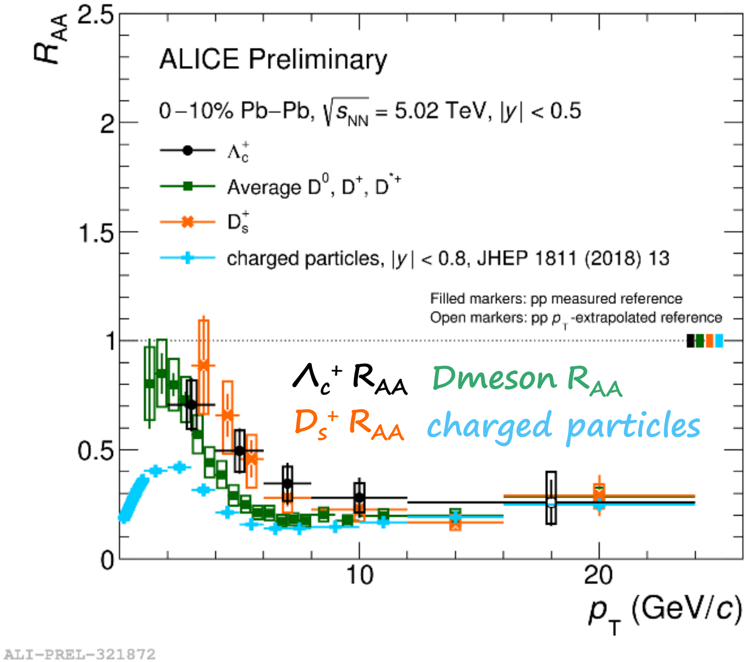
- Λ_c^+/D^0 results compatible with model calculations including both coalescence and fragmentation.

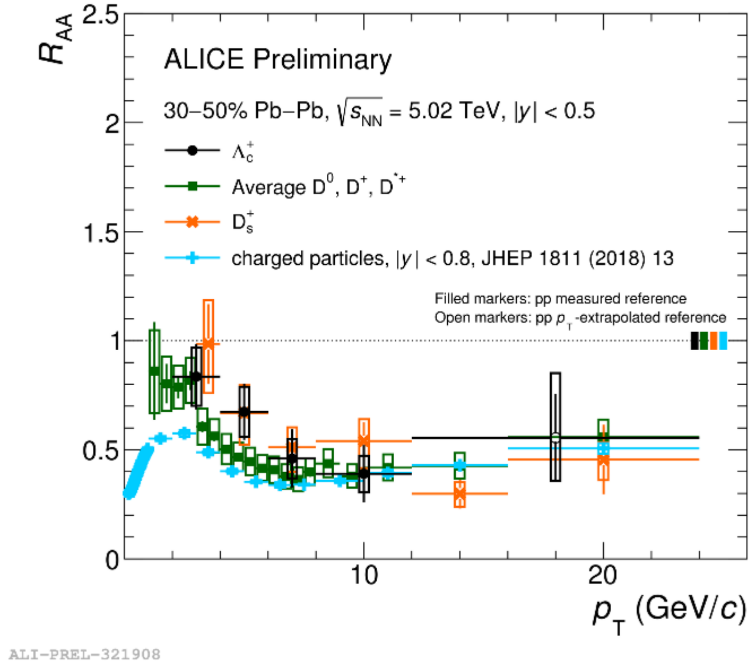
Catania: Eur.Phys.J.C (2018) 78:348
Shao-Song: Phys. Rev. C 97, 064915

$\Lambda_c^+ R_{AA}$

New results

$$R_{AA}(p_T) = \frac{dN_{AA}/dp_T}{< T_{AA} > d\sigma_{pp}/dp_T}$$





- Hint for a nuclear modification factor smaller for central collisions.
- Suggested hierarchy Λ_c^+ R_{AA} > (non strange) *D*-meson R_{AA} > charged particles R_{AA}
- Comparison with D_s^+ not straightforward, due to still high uncertanties

Conclusions

Measurements of charmed baryons with ALICE in pp and p-Pb collisions

- First measurement of Ξ_c^0 production in pp collisions @7 TeV
- Recent Λ_c^+ measurements in pp@5 TeV (Run2) more p_T –differential and covering a wider p_T range. Important reference for Pb-Pb
- Charm bearyon production higher than theoretical predictions, tuned on e^+e^- measurements.

Paper writing in progress

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Paper writing in progress

Λ_c in Pb-Pb collisions

- Λ_c^+/D^0 : Hint of enhancement with respect to pp and p-Pb collisions.
- Λ_c^+/D^0 in Pb-Pb compatible by models including hadronisation via coalescence and fragmentation
- Λ_c^+ R_{AA} measured in $2 \leq p_T \leq 24$ GeV/c in 0-10% and 30-50% centrality intervals.

  - *Further constraint on charmed baryon production mechanisms with higher precision: waiting for ALICE upgrade in RUN 3 + 4*


Thank You!

Backup

Open HF in A-A collisions: Observables

Parton energy loss

- ΔE depends on the parton color charge and mass, in-medium energy density, path length

- Investigated through the **Nuclear Modificaton Factor**

$$R_{AA}(p_T) = \frac{dN_{AA}/dp_T}{< T_{AA} > d\sigma_{pp}/dp_T}$$

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_{charm} > \Delta E_{beauty}$ → $R^{\pi}_{AA}(p_T) < R^{D}_{AA}(p_T) < R^{B}_{AA}(p_T)$?

PLB 519 (2001) 199, PLB 649 (2007)139

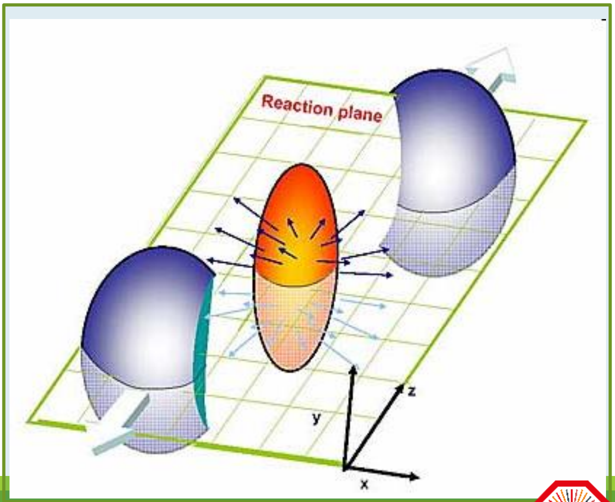
Azimuthal anisotropy

- Initial spatial anisotropy → azimuthally anisotropic momentum distribution
- non-central collisions

  → anisotropy dominated by **elliptic flow** v_2

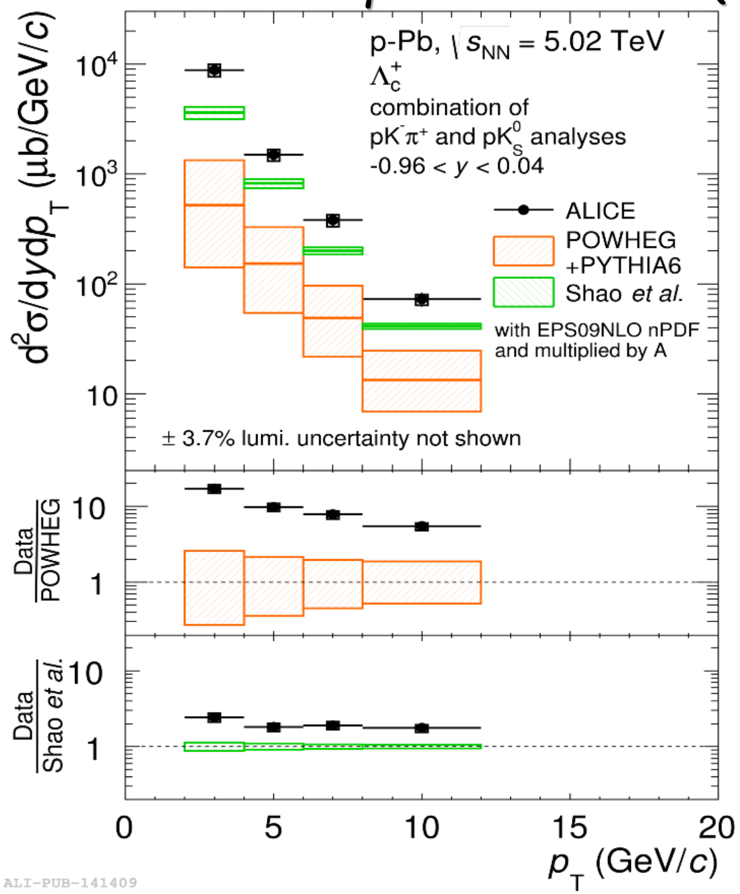
  - **low p_T**: v_2 sensitive to collective expansion
  - **high p_T**: v_2 sensitive to path-length dependence of in-medium parton energy loss

$$\frac{2\pi}{N}\frac{dN}{d\varphi} = [1 + 2v_1 \cos(\varphi - \Psi_{RP}) + 2v_2 \cos[2(\varphi - \Psi_{RP})] + \cdots]$$

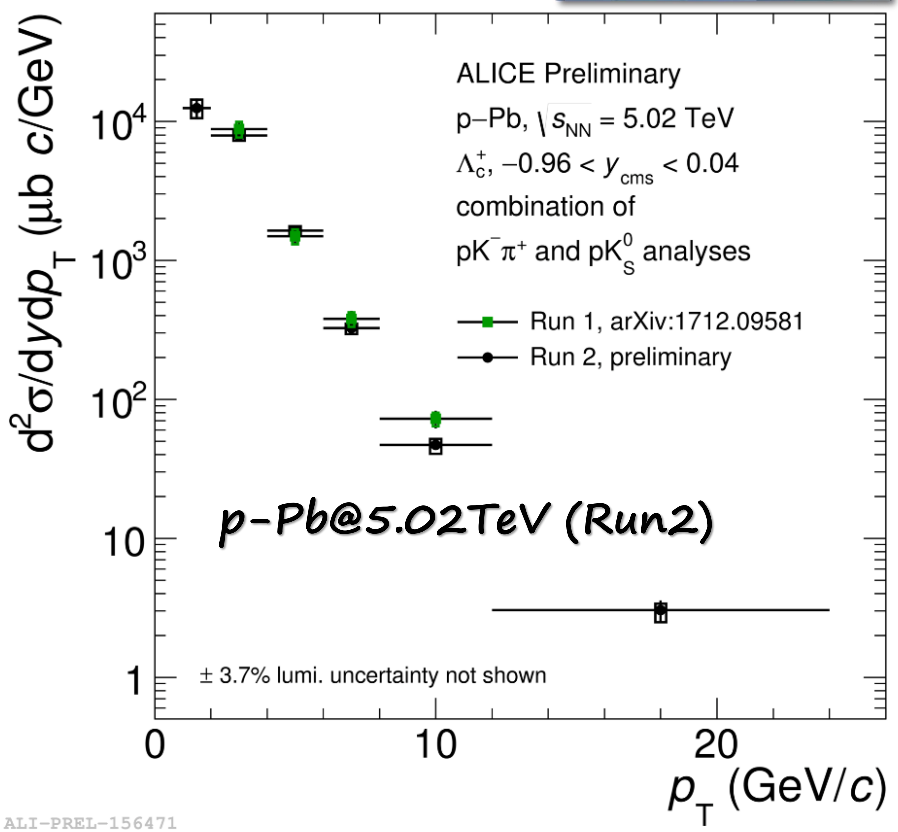


Λ_c^+ cross section in p-Pb collisions

JHEP 04 (2018) 108 p-Pb@5.02TeV (Run1)



Recent results from RunII

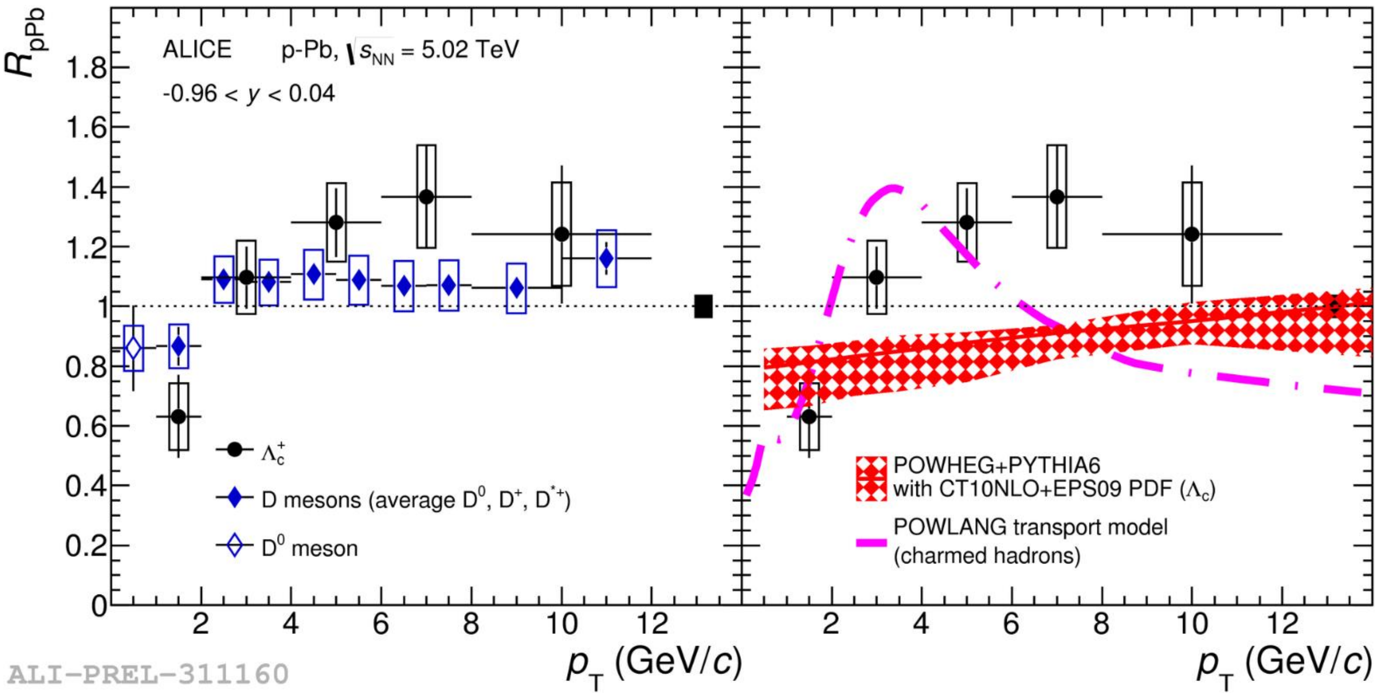


- Λ_c^+ p_T-differential cross section **underestimated** by theoretical models in p-Pb (and pp) collisions
- Improved precision and extended p_T range with Run II data.

POWHEG JHEP0709, 126 (2007)

Lansberg and Shao
Eur. Phys. J. C77, no. 1, 1 (2017)

Λ_c^+ nuclear modification factor R_{pPb}



$$R_{pPb} = \frac{d\sigma_{pPb}/dp_T}{A \times d\sigma_{pp}/dp_T}$$

pp reference:
last measurement at 5 TeV

- Λ_c^+ R_{pPb} **compatible with unity**
- Compatible with D-meson R_{pPb}

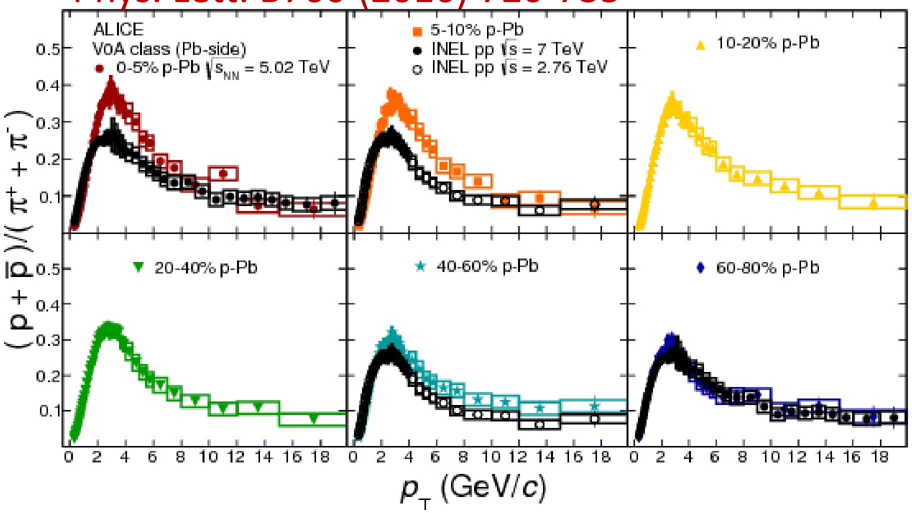
- **Compatible with models within uncertainties:**
  - **-POWHEG+PYTHIA6 with CT10NLO+EPS09 PDF - only CNM effects included**
  - **-POWLANG – small QGP formation included**

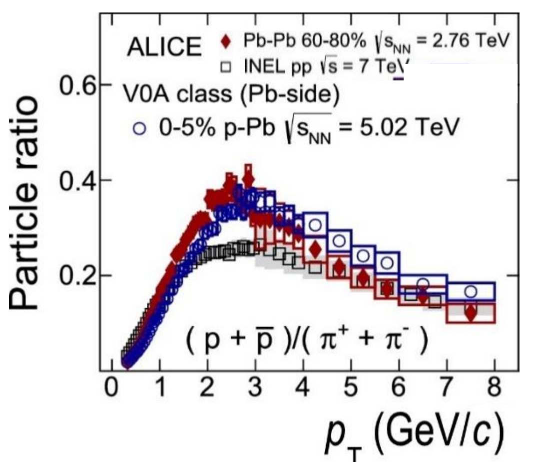
POWHEG +PYTHIA parton shower: JHEP 0709:126,2007
POWLANG: JHEP03(2016)123

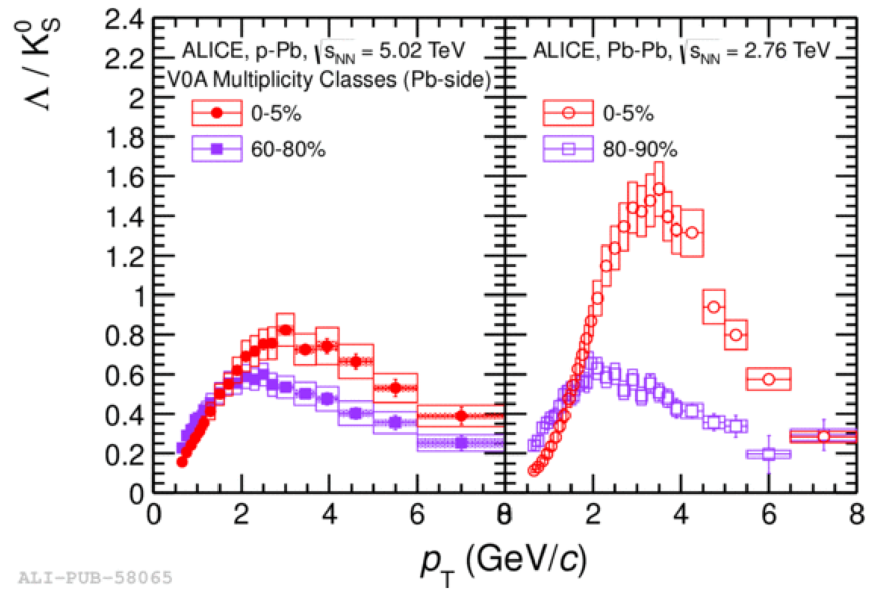
Physics motivations

- ALICE and CMS observed enhancement of baryon/meson ratio at intermediate p_T in High Multiplicity (HM) pp and p-Pb collisions.
  - Similar to what was observed in HI collisions

Phys. Lett. B760 (2016) 720-735







Physics motivations

- Measurement in pp collisions:
  - Important to test predictions from pQCD and the models of hadronisation in vacuum.
- Measurement in p-Pb collisions:
  - Important to distinguish cold-nuclear-matter (CNM) effects, that can affect the charm hadron production.

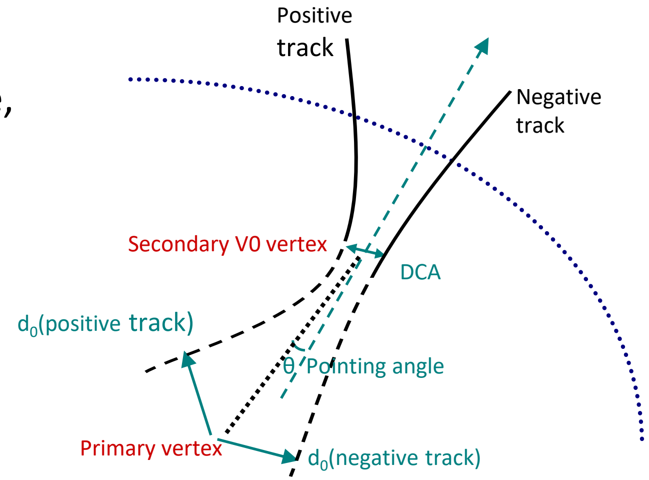
- Baryon/meson ratio particularly sensitive to the fragmentation process.
  - Differences observed in pp collisions (CDF+LHCb) with respect to e^+e^- collisions (LEP) in the beauty sector http://pdg.lbl.gov/2017/reviews/rpp2017-rev-b-meson-prod-decay.pdf

→ hint of non-universal fragmentation fractions for baryons in the beauty sector

$\Lambda_c \rightarrow pK^0_S$ analysis strategy

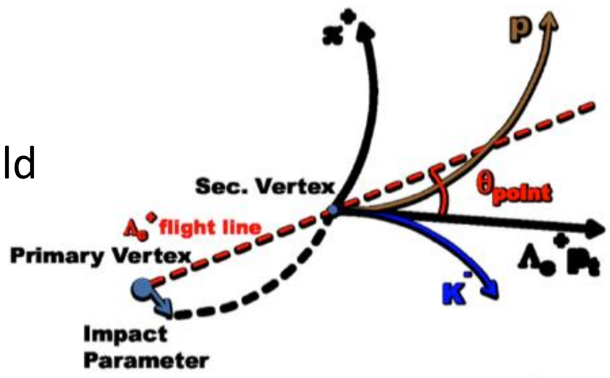
$\Lambda_c \rightarrow pK^0_S$ B.R = (1.58 ± 0.08)%
and $K^0_S \rightarrow \pi^+\pi^-$ B.R = (69.20 ± 0.05)%

- K^0_S candidate reconstructed from pairs of opposite-sign tracks forming a vertex displaced from the interaction vertex, according to track selection and topological cuts:
  - Distance of closest approach (DCA), Cosine of pointing angle, p_T(K^0_S daughters), d_0(K^0_S daughters) , $m_{inv}(\pi^+\pi^-)$
- Proton candidates are selected, according to track quality selection and **PID** (the main selection, using TPC and TOF)
- **Built Λ_c candidate, combining K^0_S and proton candidates**
- Further selection to improve signal extraction, via two methods:
  - **Topological cuts on several variables (standard analysis - STD)**
  - **Cut on multivariate discriminator (TMVA)**
- Feed-down correction
- Efficiency and acceptance corrections
- Cross section estimate



$\Lambda_c \to pK\pi$ analysis strategy

$\Lambda_c \to pK\pi$ B.R = (6.35 ± 0.33)%



- ***pKπ candidate building***

Pairs of opposite charge tracks selected. Third track added to build a triplet and secondary vertex of the triplet estimated.
Cuts applied: high-quality single track cuts,
cuts on p_T daughters, quality of reconstructed vertex,
DCA, cosine of Λ_c pointing angle (angle between the Λ_c flight line and the momentum of the reconstructed Λ_c candidate), Bayesian PID.

- Further selection to improve signal extraction, via two methods:
  - **Topological cuts on several variables (standard analysis - STD)**
  - **Cut on multivariate discriminator (TMVA)**

- Feed-down correction
- Efficiency and acceptance corrections
- Cross section estimate

Charmed-hadron reconstruction

Semileptonic decays

- **Wrong-Sign (WS)** $e^-\Lambda$ ($e^-\Xi^-$) pairs subracted from **Right-Sign (RS)** $e^+\Lambda$ ($e^+\Xi^-$) spectra, to estimate the combinatorial background.

Baryon Λ_c^+
M = 2284 MeV/c²
Quark: *udc*
cτ = 60 μm

Baryon Ξ_c^+
M = 2471 MeV/c²
Quark: *usc*
cτ = 34 μm

- PID for electrons using TOF and TPC.

Decay	Branching fraction (%)
$\Lambda_c^+ \to e^+\Lambda\nu_e$	3.6
$\Xi_c^0 \to e^+\Xi^-\nu_e$	Unknown

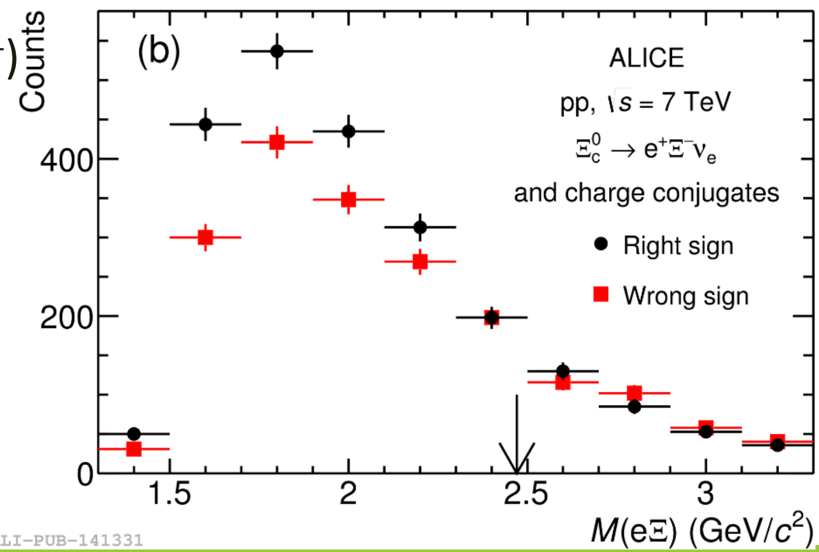
- Subtracted contributions from:
  - Λ_b^0 (Ξ_b^0) in WS spectra
  - Ξ_c^+ in RS spectra, for Λ_c^+ analysis.

- **Unfolding technique** used to convert the $e^+\Lambda$ ($e^+\Xi^-$) p_T spectrum in Λ_c^+ (Ξ_c^0)

- Subtraction of contribution from beauty hadrons **(only for Λ_c^+)**

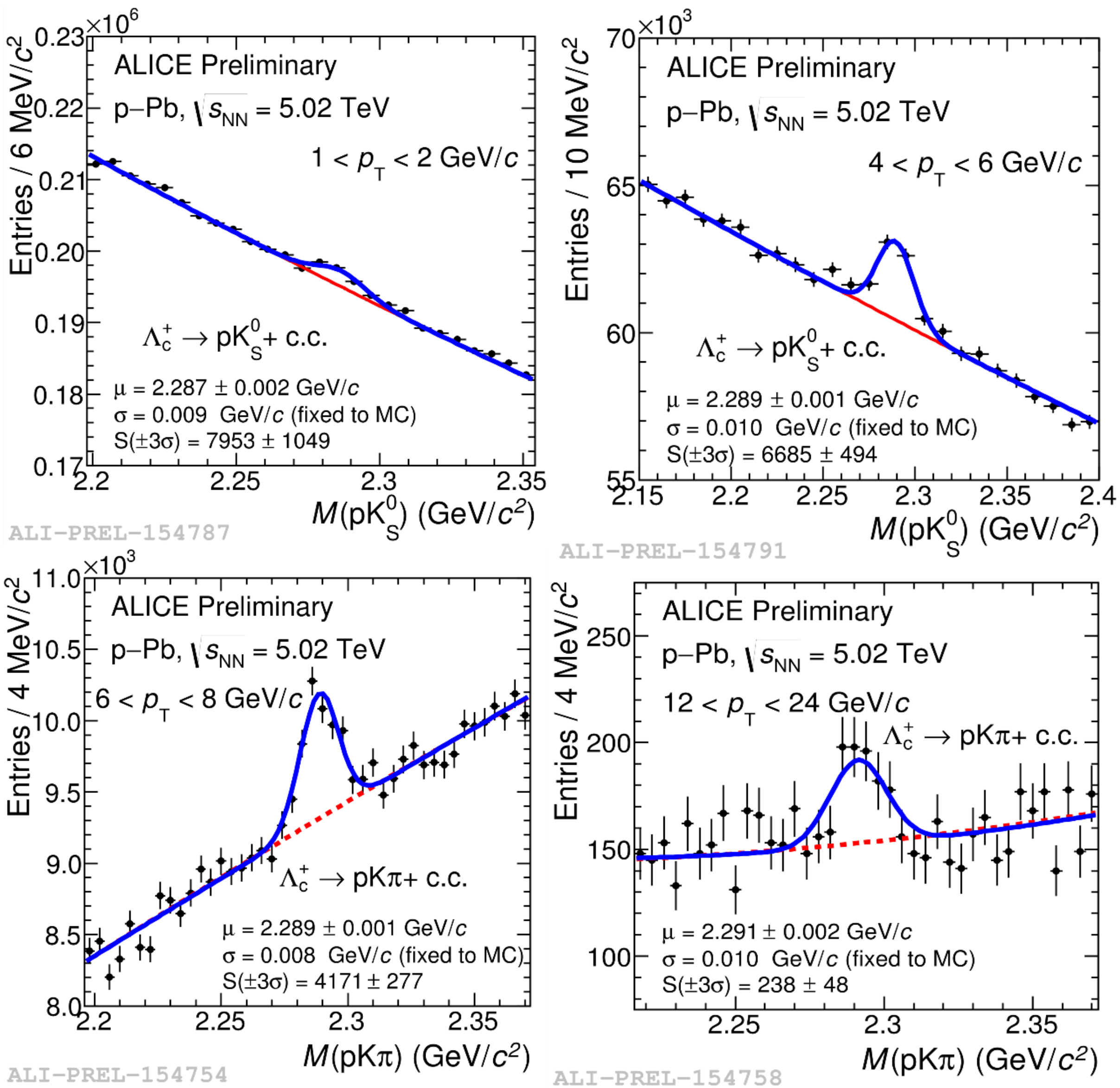
- Corrections for acceptance and efficiency

Phys. Lett. B 781 (2018) 8-19



$\Lambda_c^+ \rightarrow pK^0_S$ and $\Lambda_c^+ \rightarrow pK^+\pi^-$ signal extraction in p-Pb

Recent results from RunII



- Signal extracted via an invariant-mass analysis.
- Decay topology selection and Multivariate approach (Boosted Decision Tree) used.
- Signal extracted in 1-24 GeV/c
  - Wider and finer binning with respect to Run I.

https://arxiv.org/abs/1712.09581

Results from Run 1

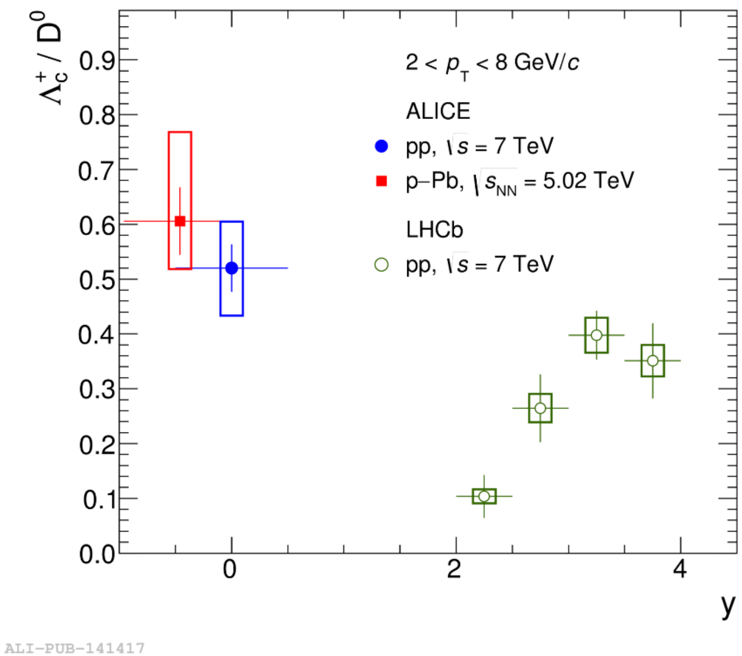
- $(\Lambda_c^+ / D^0)_{pp} = 0.543 \pm 0.061\ (stat) \pm 0.160\ (syst)$.
- $(\Lambda_c^+ / D^0)_{p\text{-}Pb} = 0.603 \pm 0.060\ ^{+0.159}_{-0.087}\ (syst)$

Λ_c^+ / D^0 ratio higher than previous measurements in e^+e^- and ep, and at lower centre-of-mass energies:

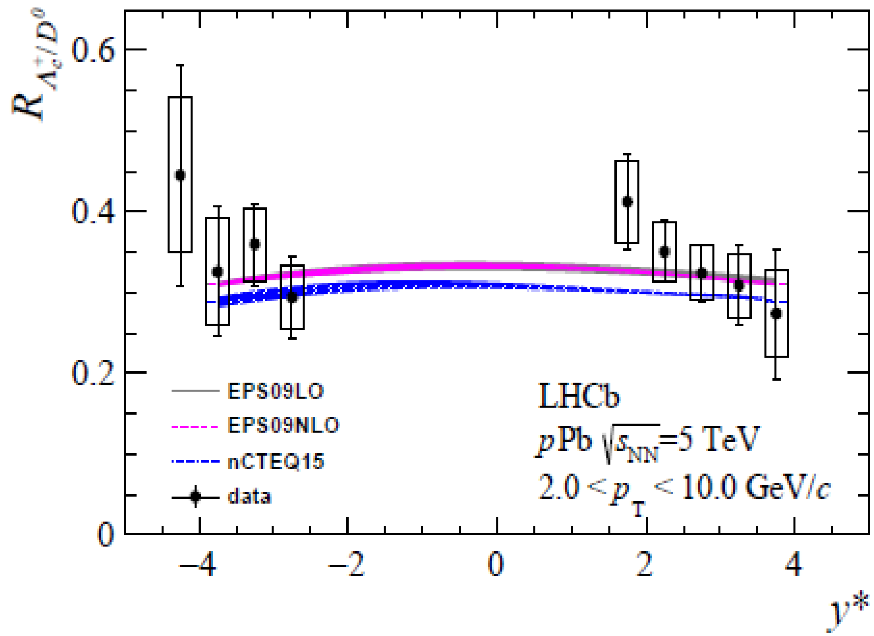
	$\Lambda_c^+/D^0 \pm$ stat. $\pm$ syst.	System	$\sqrt{s}$ (GeV)	Notes
CLEO	$0.119 \pm 0.021 \pm 0.019$	ee	10.55	
ARGUS	0.127 ± 0.031	ee	10.55	
LEP average	$0.113 \pm 0.013 \pm 0.006$	ee	91.2	
ZEUS DIS	$0.124 \pm 0.034^{+0.025}_{-0.022}$	ep	320	$1 < Q^2 < 1000$ GeV^2, $0 < p_T < 10$ GeV/c, $0.02 < y < 0.7$
ZEUS γp, HERA I	$0.220 \pm 0.035^{+0.027}_{-0.037}$	ep	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$
ZEUS γp HERA II	$0.107 \pm 0.018^{+0.009}_{-0.014}$	ep	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$

Λ_c^+ / D^0 ratio vs LHCb

arXiv:1712.09581v1

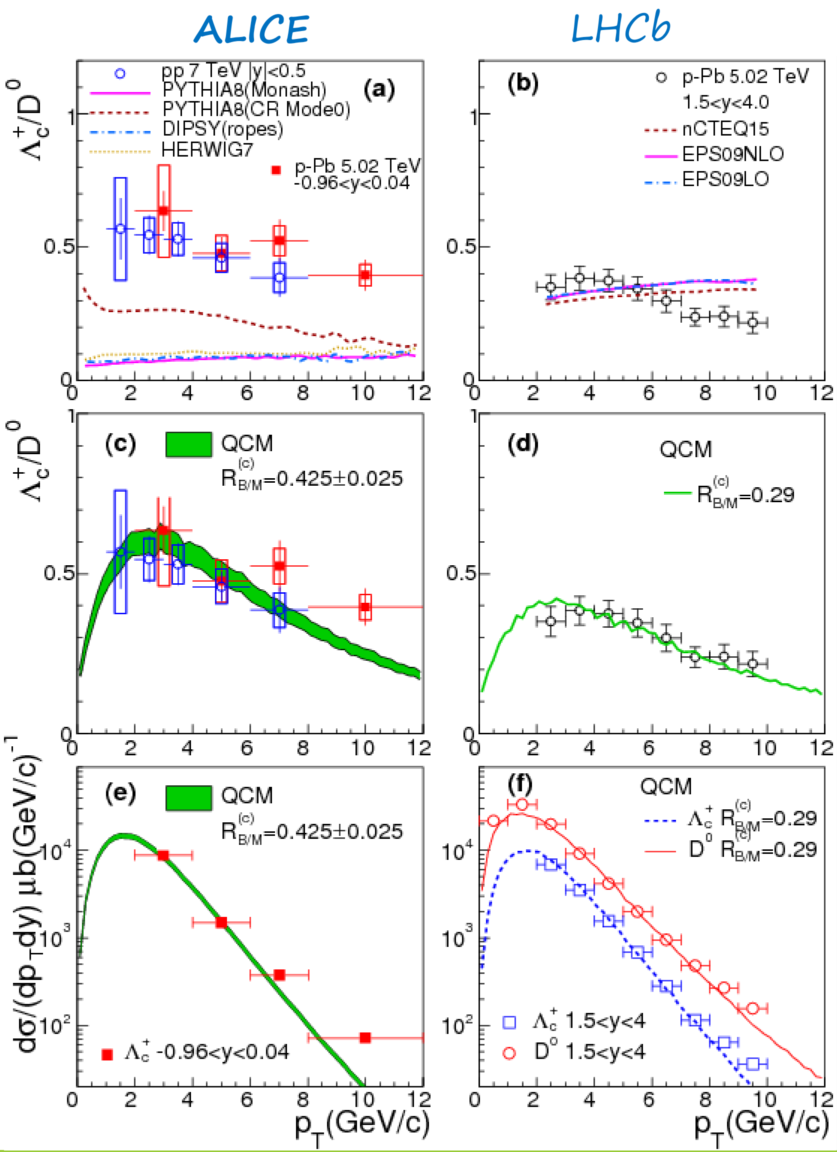


arXiv:1809.01404



- Λ_c^+/D^0 in p-Pb collisions recently measured by the LHCb experiment shows a flatter trend with rapidity, differently from pp results.
- Tendency for higher values at midrapidity (ALICE) than forward and backward rapidity (LHCb).

Theorists at work after our paper



Hai-hong Li et al., arXiv:1712.08921

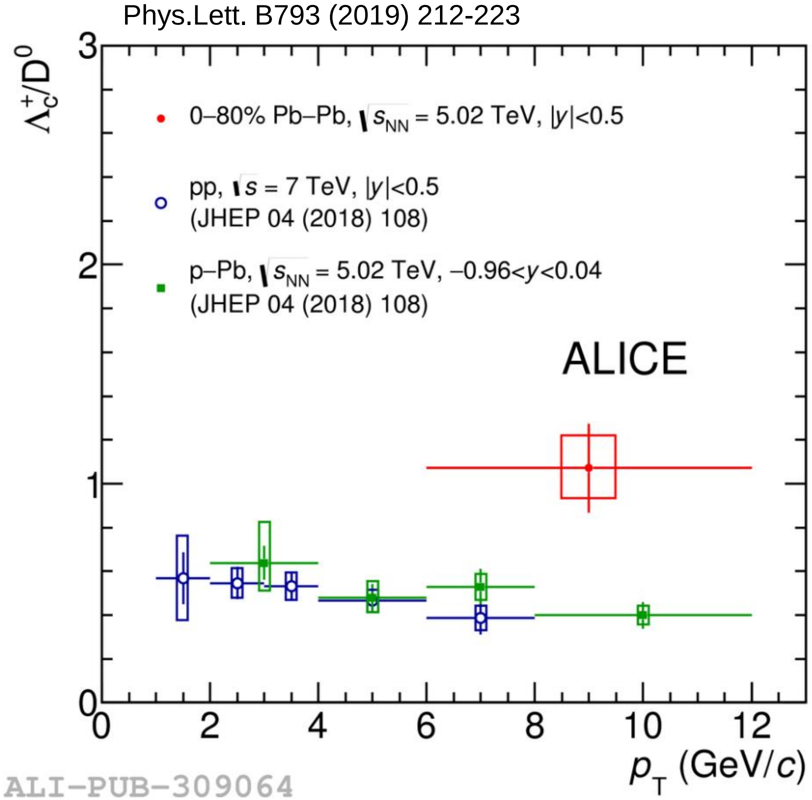
- Predictions using hadronization via recombination model reproduce ALICE results at central rapidity and the LHCb ones at forward rapidity in p-Pb collisions. LHCb-CONF-2017-005

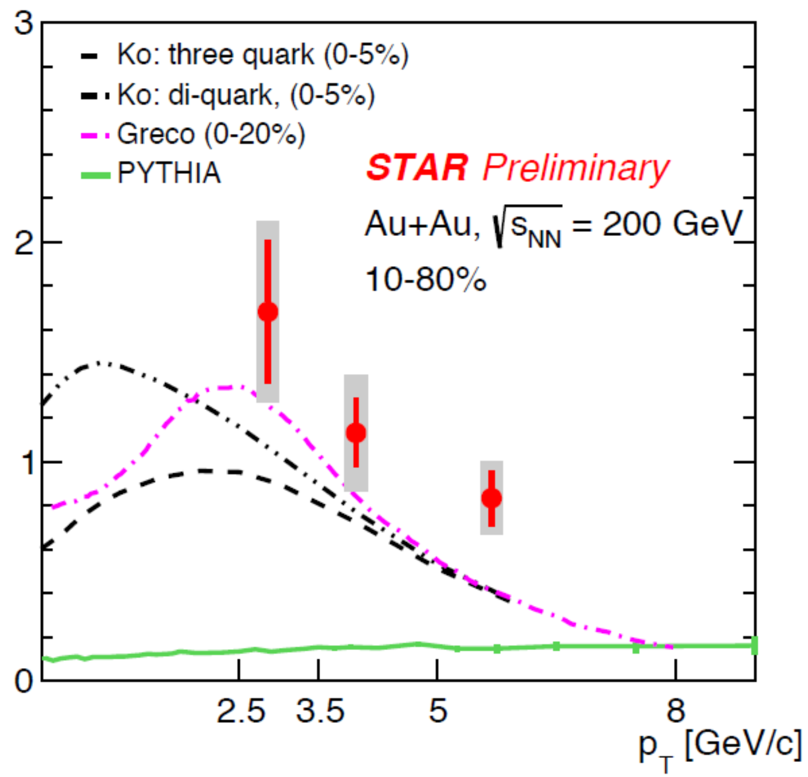
- $R^{(c)}_{B/M}$ relative production of single-charm baryons to single-charm mesons, treated as parameter of the model.

- Initial p_T distributions of light and charm quarks are input of the models.

First measurement of Λ_c production in Pb-Pb collisions at the LHC

ALICE



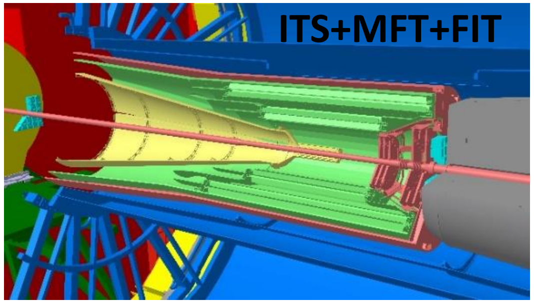


- Λ_c^+/D^0 higher (2σ) than that in pp and p-Pb collisions.
- Λ_c^+/D^0 results described by **model calculations including only coalescence.**
  Catania: Eur.Phys.J.C (2018) 78:348
- Λ_c^+/D^0 in $6 < p_T < 12$ GeV/*c* similar to STAR values in 3-6 GeV/*c*.

ALICE upgrade

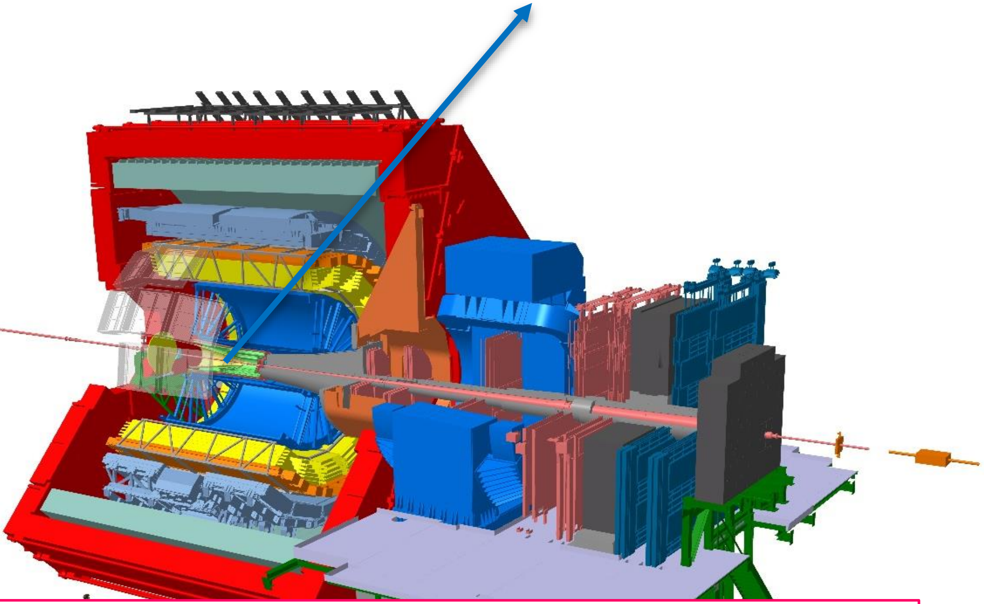
Data taking will start in 2021

- Significant upgrade forseen, aiming at:
  - Improve impact parameter resolution by a factor 3
  - Improve vertexing and tracking at low p_T
  - 50 kHz interaction rate in Pb-Pb (now < 10 kHz)



How?

- New smaller radius beam pipe
- New inner tracking system:
  - high resolution, low material budget
- Upgrade of the readout systems of most subdetectors to copy with the high rate
- New Muon Forward Tracker (MFT)

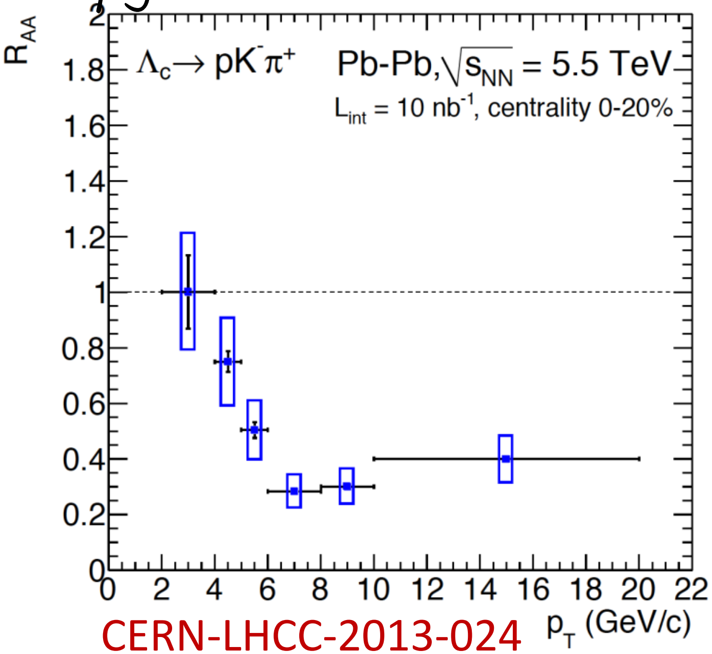


Main physics goal of the ALICE upgrade:

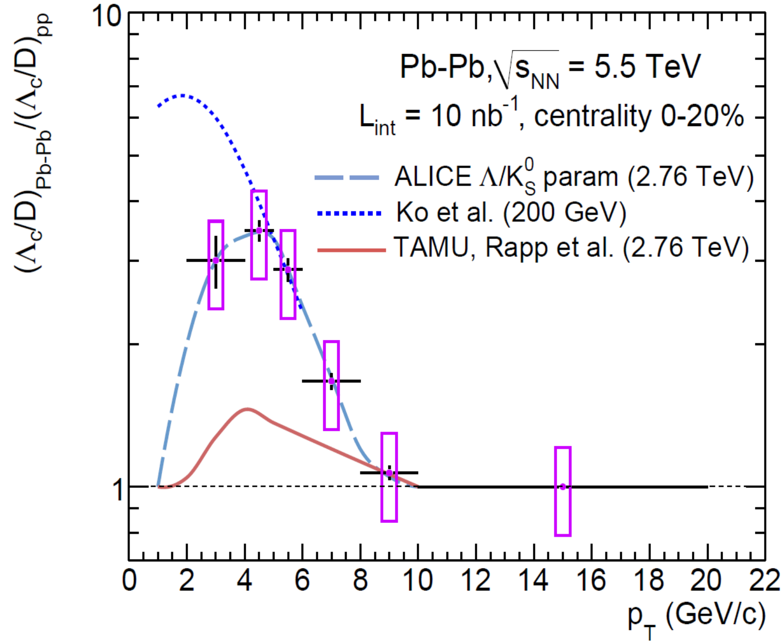
Charm and beauty-hadron measurements down to very low p_T

ALICE upgrade

- **Λ_c^+ measurement in Pb-Pb collisions:** one of the main goal of the ALICE upgrade



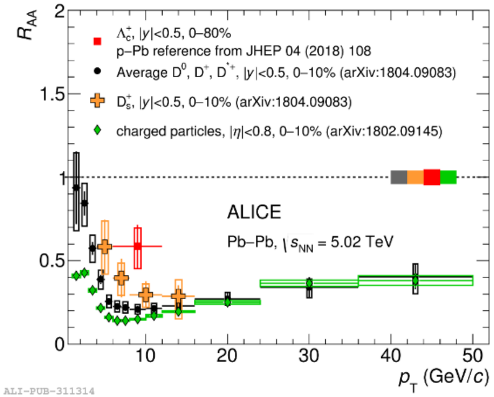
CERN-LHCC-2013-024



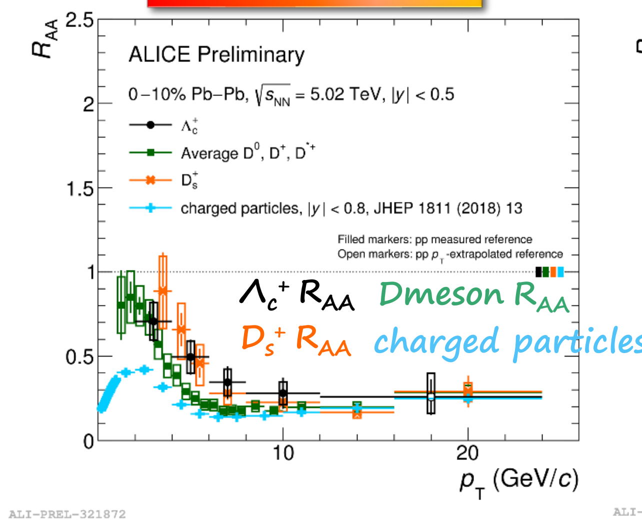
- Λ_c^+/D^0 baryon/meson ratio and Λ_c^+ baryon R_{AA} will be measured in charm sector with the upgraded ITS.
- Improvement in spatial resolution allows for a cleaner vertex identification.
  - ➡ **Λ_c^+ production measurable down to 2 GeV/*c*.**

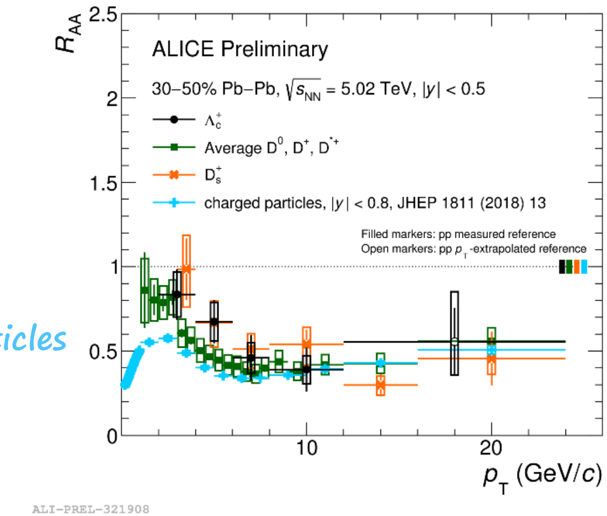
Λ_c^+ R_{AA}

Phys.Lett. B793 (2019) 212-223



New results

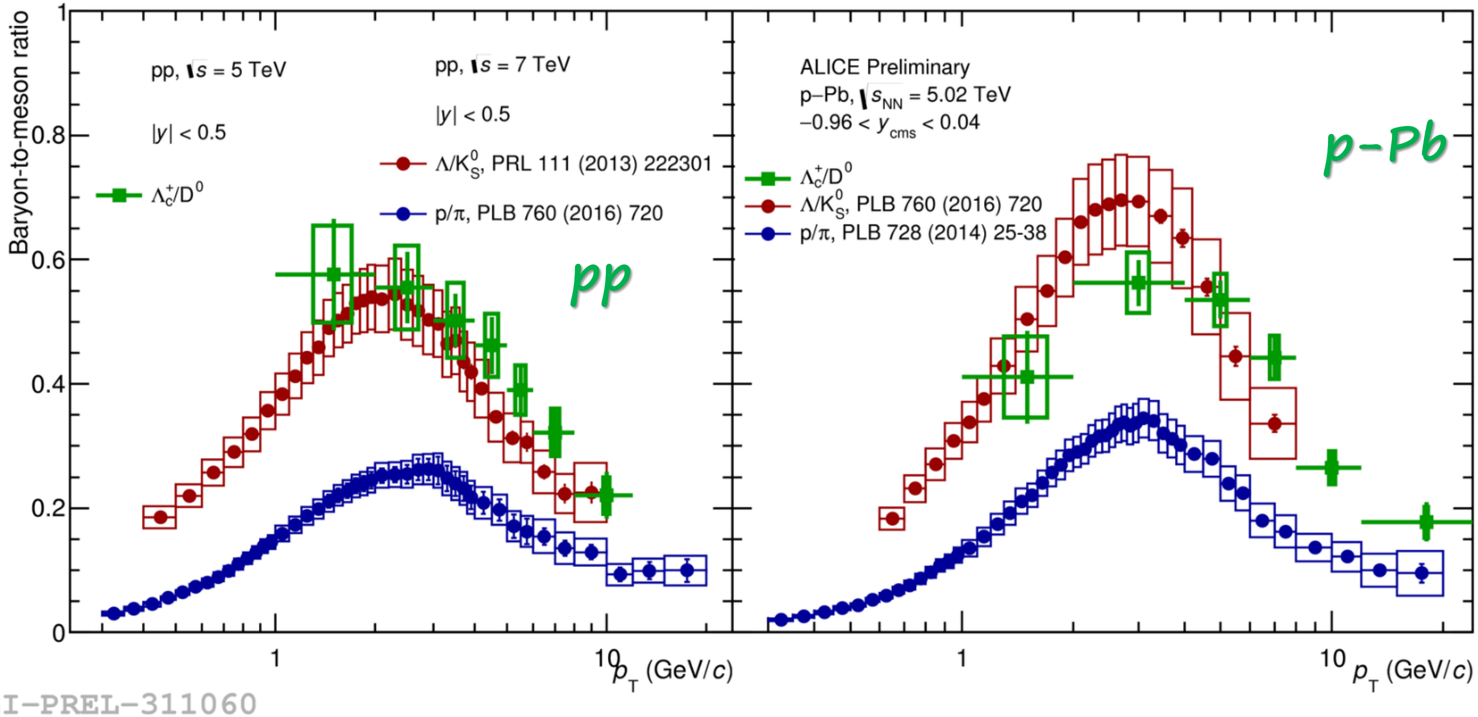




- Hint for a nuclear modification factor smaller for central collisions.
- Suggested hierarchy Λ_c^+ R_{AA} > (non strange) *D*-meson R_{AA} > charged particles R_{AA}
- Comparison with D_s^+ not straightforward, due to still high uncertanties

Results for Λ_c^+/D^0

Λ_c^+/D^0 vs Λ/K^0_S vs p/π



- Decreasing trend from p_T = 4 GeV/c observed in pp and p-Pb collisions.
- Similar trend to baryon-to-meson ratio in the light-flavour sector.
  - baryon-to-meson ratio independent of quark content?

Total cross section

ALICE

arxiv: 1901.07979, D meson production at 5 TeV

	Extr. factor to $p_T > 0$	$d\sigma/dy\,|_{|y|<0.5}$ (μb)
D^0	$1.0000^{+0.0003}_{-0.0000}$	$447 \pm 20(\mathrm{stat}) \pm 30(\mathrm{syst}) \pm 9(\mathrm{lumi}) \pm 5(\mathrm{BR})$
D^+	$1.28^{+0.35}_{-0.09}$	$184 \pm 13(\mathrm{stat}) \pm 13(\mathrm{syst}) \pm 4(\mathrm{lumi}) \pm 6(\mathrm{BR})^{+50}_{-13}(\mathrm{extrap})$
D^{*+}	$1.24^{+0.34}_{-0.08}$	$178 \pm 15(\mathrm{stat}) \pm 14(\mathrm{syst}) \pm 4(\mathrm{lumi}) \pm 2(\mathrm{BR})^{+48}_{-12}(\mathrm{extrap})$
D_s^+	$2.35^{+0.78}_{-0.66}$	$95 \pm 9(\mathrm{stat}) \pm 10(\mathrm{syst}) \pm 2(\mathrm{lumi}) \pm 3(\mathrm{BR})^{+31}_{-26}(\mathrm{extrap})$

Λ_c^+ = 245 ± 14 (stat.) ± 9 (syst.) $^{+33}_{-12}$ (extrap)
= 245 ± 14 (stat.) ± 9 (syst.) $^{+60}_{-30}$ (extrap)

Considering the Λ_c extrapolated cross section,
f(c->D^0) = 0.389 +- 0.033 (stat.) + 0.085 - 0.070 (syst.)
f(c->D^0) = 0.389 +- 0.030 (stat.) + 0.094 - 0.059 (syst.)
~ 20% lower than the value used in the previous total $c\bar{c}$ cross section (0.542 ± 0.024)

$c\bar{c}$ cross section per unit of rapidity at mid-rapidity calculated in arXiv:1702.00766 by dividing the prompt D^0-meson cross section by the f(c->D^0)

$$d\sigma^{c\bar{c}}_{\mathrm{pp,7\,TeV}}/dy\,\Big|_{|y|<0.5} = 954 \pm 69\,(\mathrm{stat}) \pm 74\,(\mathrm{syst}) \pm 33\,(\mathrm{lumi}) \pm 42\,(\mathrm{FF}) \pm 31\,(\mathrm{rap.shape})\ \mu\mathrm{b}.$$

@5TeV:

Total cross section ~ 1149 +- 33 (stat.) +- 94(syst.) + 162 - 116 (extrap.)
~ 1149 +- 33 (stat.) +- 94(syst.) + 135 - 81 (extrap.)

summing the hadron cross sections with the uncertaities