

D-meson and charmed-baryon measurements in pp and p-Pb collisions with ALICE at the LHC



ALICE

A. De Caro (University and INFN of Salerno)
on behalf of the ALICE Collaboration



Outline

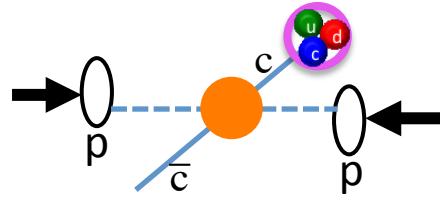
- Physics motivations for charmed-hadron studies
- The ALICE detector
- Results for charmed hadrons in pp:
 - D-meson cross sections and ratios
 - **First Λ_c^+ and Ξ_c^0 measurement in hadronic collisions at mid-rapidity**
- Results for charmed hadrons in p-Pb:
 - **First Λ_c^+ measurement at mid-rapidity**
- Conclusions and prospects



Why charmed hadrons?

Created in hard partonic scattering processes (early stage of hadronic collisions)

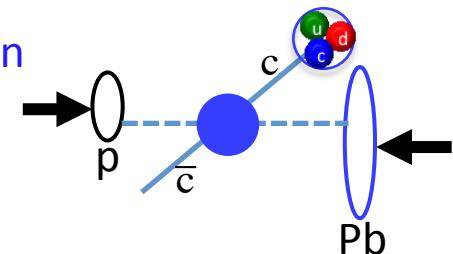
In pp:



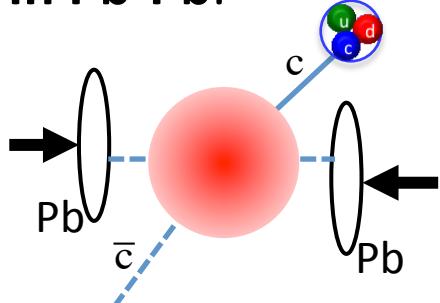
- Useful test of perturbative QCD calculations at LHC energies
- With charmed baryons: shed light on c-quark hadronisation mechanism
- Baseline for Quark-Gluon Plasma (QGP) study in Pb-Pb collisions

In p-Pb:

- Study cold nuclear matter (CNM) effects not due to the QGP formation
 - Modification of Parton Distribution Functions, gluon saturation at low x
 - Energy loss in the initial- and final- state of the collisions
 - k_T broadening (Phys.Rev.D36 (1987) 2019; Nucl.Phys.Proc.Suppl.214 (2011) 181–184)



In Pb-Pb:

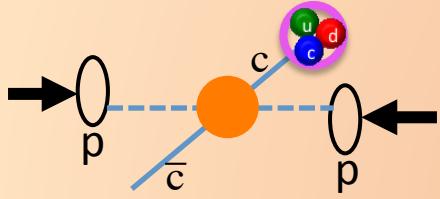


- Modification of the c-quark hadronisation mechanism due to its interaction with the medium constituents
 - Possible enhancement of Λ_c^+/Λ^0 ratio in heavy ion collisions with respect to pp collisions

Why charmed hadrons?

Created in hard partonic scattering processes (early stage of hadronic collisions)

In pp:

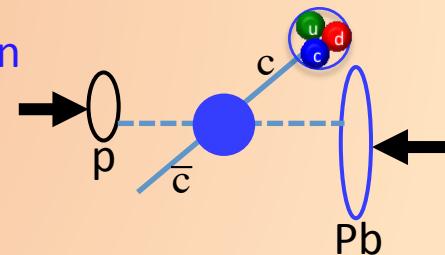


- Useful test of perturbative QCD calculations at LHC energies
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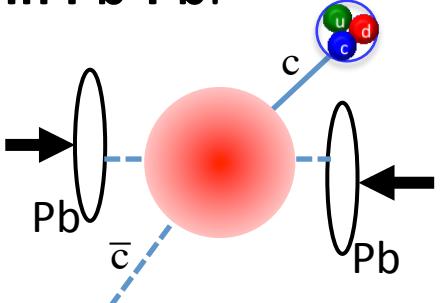
In this talk

In p-Pb:

- Study cold nuclear matter (CNM) effects not due to the QGP formation
 - Modification of Parton Distribution Functions, gluon saturation at low x
 - Energy loss in the initial- and final- state of the collisions
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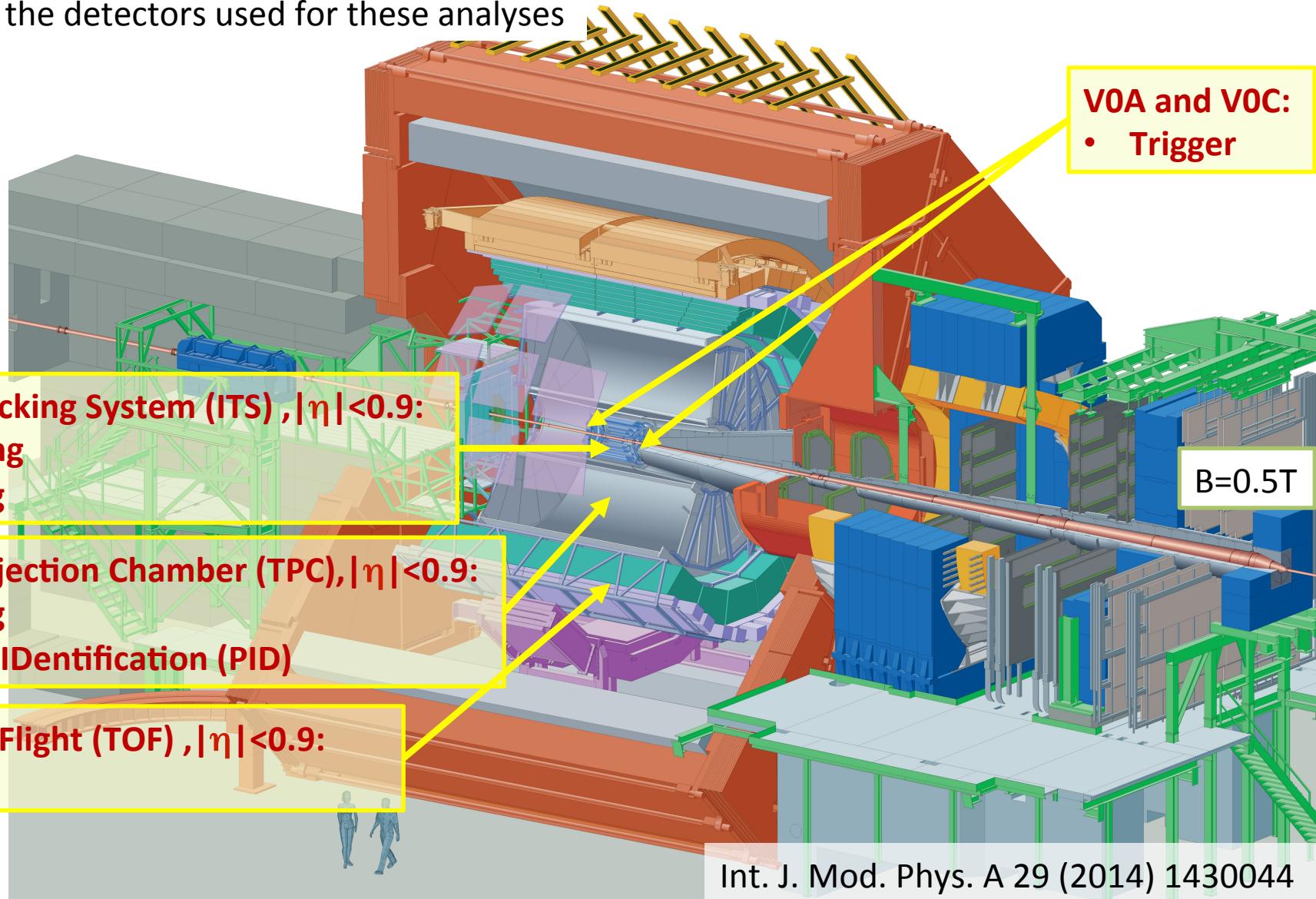
In Pb-Pb:



- Modification of the c-quark hadronisation mechanism due to its interaction with the medium constituents
 - Possible enhancement of Λ_c^+/\bar{D}^0 ratio in heavy ion collisions with respect to pp collisions

The ALICE detector

Focus on the detectors used for these analyses



Int. J. Mod. Phys. A 29 (2014) 1430044

RESULTS IN PP COLLISIONS

D-meson cross sections

$D^0 \rightarrow K^- \pi^+$ ($c\tau = 123 \mu\text{m}$, $\text{BR} = 3.93 \pm 0.04 \%$)
 $D^+ \rightarrow K^- \pi^+ \pi^+$ ($c\tau = 312 \mu\text{m}$, $\text{BR} = 9.46 \pm 0.24\%$)

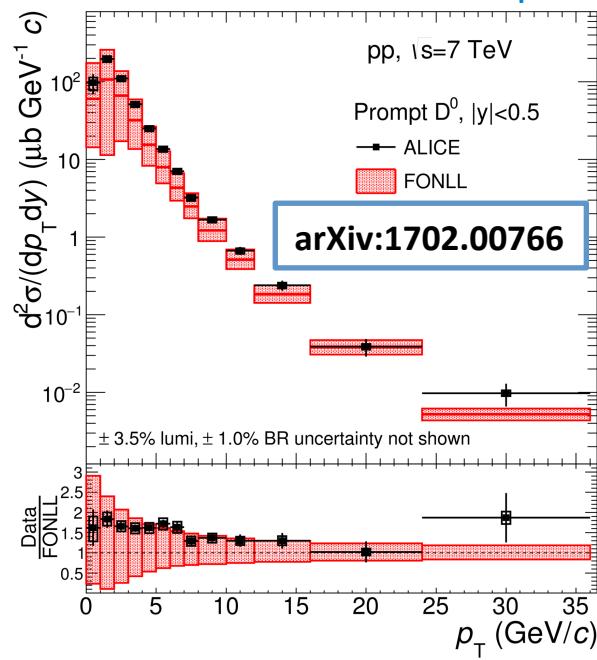
$D^{*+} \rightarrow D^0(\rightarrow K^- \pi^+) \pi^+$ (strong decay, $\text{BR} = 2.66 \pm 0.03 \%$)
 $D_s^+ \rightarrow \phi(\rightarrow K^- K^+) \pi^+$ ($c\tau = 150 \mu\text{m}$, $\text{BR} = 2.27 \pm 0.08 \%$)

Analysis technique: topological and kinematical cuts + PID

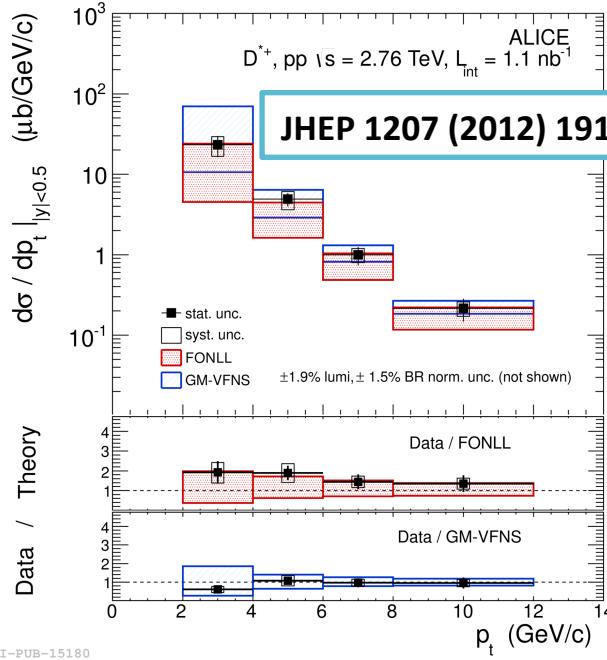
D^0 in $0 < p_T < 1 \text{ GeV}/c$, no topological selections
 correction for beauty feed-down (based on FONLL)

Analysis performed over wide p_T range ($0 < p_T < 36 \text{ GeV}/c$ for D^0 @ 7 TeV)

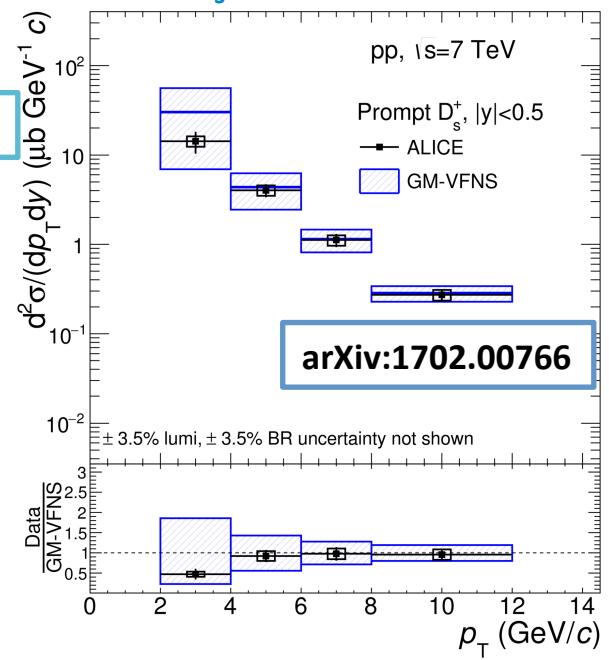
D^0 , pp @ 7TeV, down to $p_T=0$



D^{*+} , pp @ 2.76TeV



D_s^+ , pp @ 7TeV



p_T -differential cross sections reproduced within uncertainties by theoretical predictions based on pQCD calculations, i.e. FONLL[1] and GM-VFNS[2]

[1]: JHEP 05 (1998) 007; JHEP 10 (2012) 137; [2]: Eur. Phys. J. C41 (2005) 199–212; Eur. Phys. J. C72 (2012) 2082

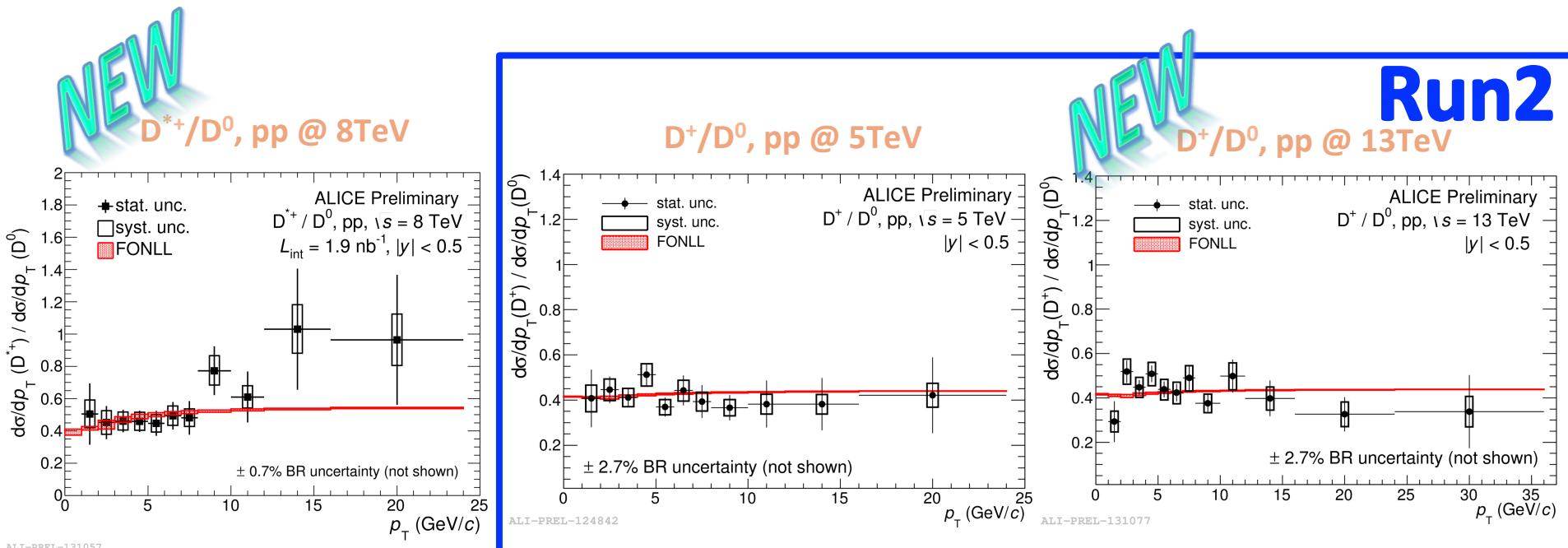
D-meson ratios

$D^0 \rightarrow K^- \pi^+$ ($c\tau = 123 \mu\text{m}$, BR = $3.93 \pm 0.04 \%$)
 $D^+ \rightarrow K^- \pi^+ \pi^+$ ($c\tau = 312 \mu\text{m}$, BR = $9.46 \pm 0.24\%$)

$D^{*+} \rightarrow D^0(\rightarrow K^- \pi^+) \pi^+$ (strong decay, BR = $2.66 \pm 0.03 \%$)
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Analysis technique: topological and kinematical cuts + PID
 correction for beauty feed-down (based on FONLL)

Analysis performed over wide p_T range ($1 < p_T < 36 \text{ GeV}/c$ for D^0 and D^+ @ 13 TeV)



Results reproduced within uncertainties by **FONLL** theoretical predictions

First Λ_c^+ measurements @ mid-rapidity



$$\Lambda_c^+ \rightarrow \begin{cases} pK^-\pi^+, & \text{B.R.} = 6.84 \pm 0.40 \% \\ pK^0_S, & \text{B.R.} = 1.09 \pm 0.06 \% \\ \Lambda e^+ \nu_e, & \text{B.R.} = 3.6 \pm 0.4 \% \end{cases}$$

$c\tau \sim 60 \mu\text{m}$

Challenging!

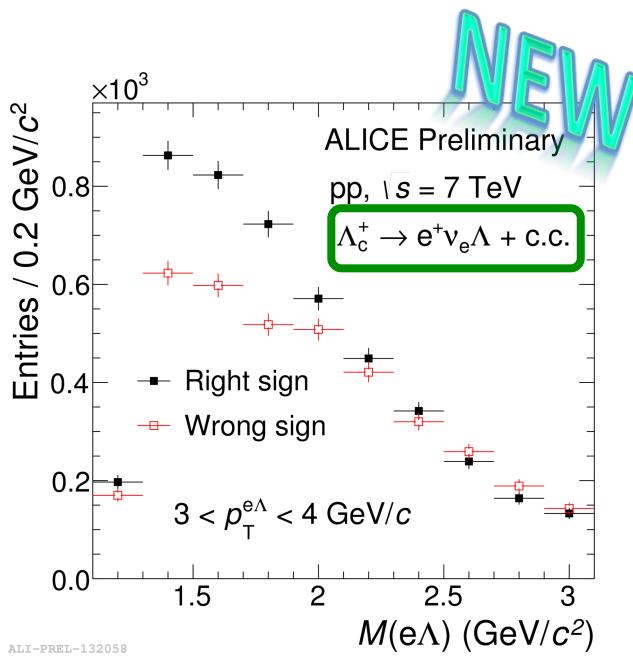
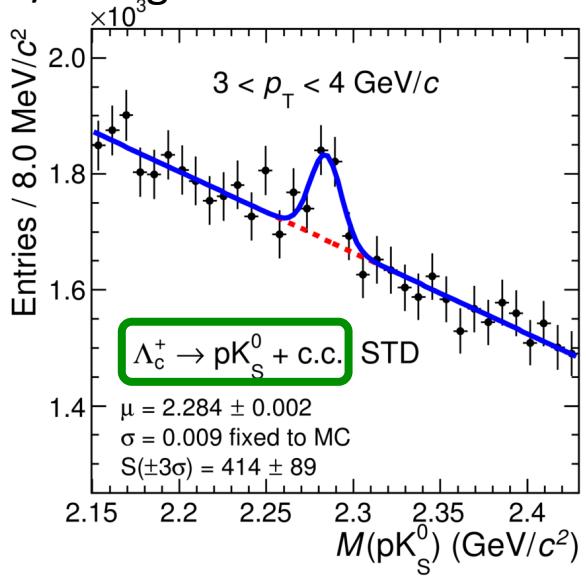
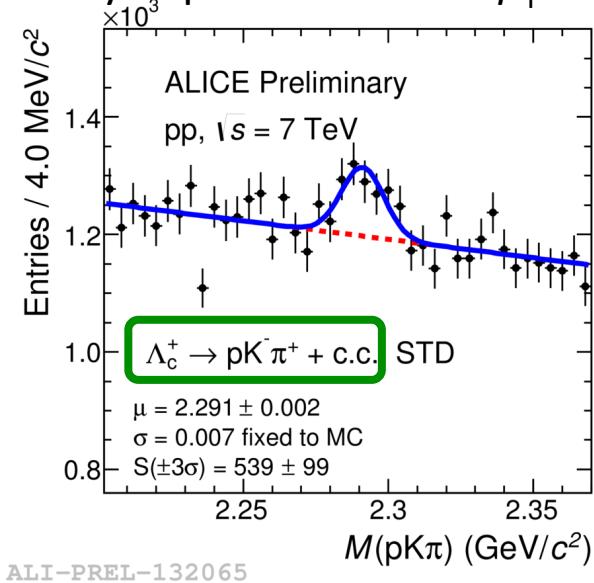
Analysis techniques:

hadronic decays: as done for D mesons

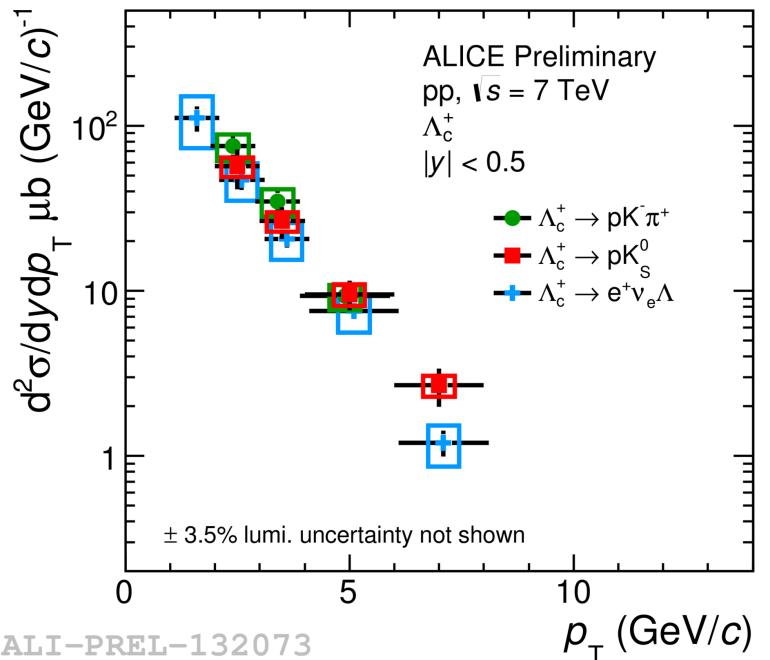
semileptonic decay - neutrino not measured:

subtract the **WS** ($e^- \Lambda$) spectrum from the **RS** ($e^+ \Lambda$) spectrum;
 correct for oversubtraction by Λ_b^0 and overestimate by Ξ_c^+ ;
 unfold reconstructed $p_T^{e\Lambda}$ into $p_T^{\Lambda_c}$.

Analysis performed in $1 < p_T < 8 \text{ GeV}/c$ range

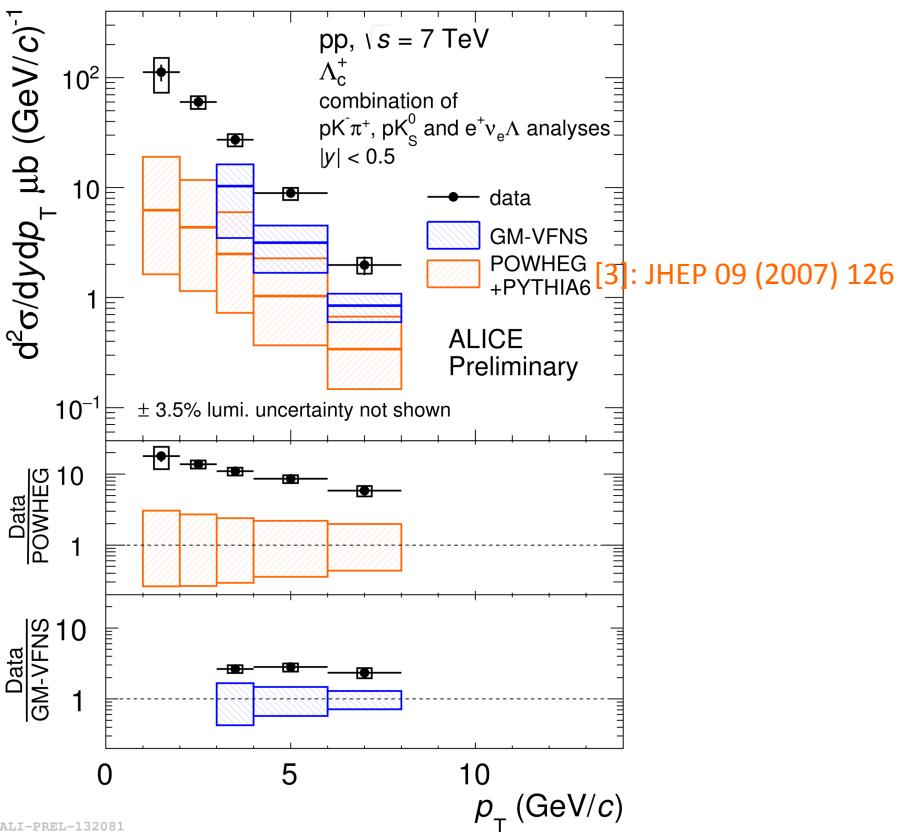


First Λ_c^+ measurements @ mid-rapidity



NEW

All measurements averaged together
(correlation in the uncertainties taken into account)



All the measured cross sections compatible within statistical and systematic uncertainties
(BR uncertainties included)

GM-VFNS underestimates by a factor 2.5

and POWHEG+PYTHIA6[3] significantly underpredicts (by more than a factor 18 at lower p_T) the data

GM-VFNS well describes the ALICE and LHCb measurements of D mesons and LHCb measurements of Λ_c^+ , $2 < y < 4.5$ (Nucl.Phys. B 871 (2013) 1-20), but it underestimates the ALICE measurements of Λ_c^+ , $|y| < 0.5$



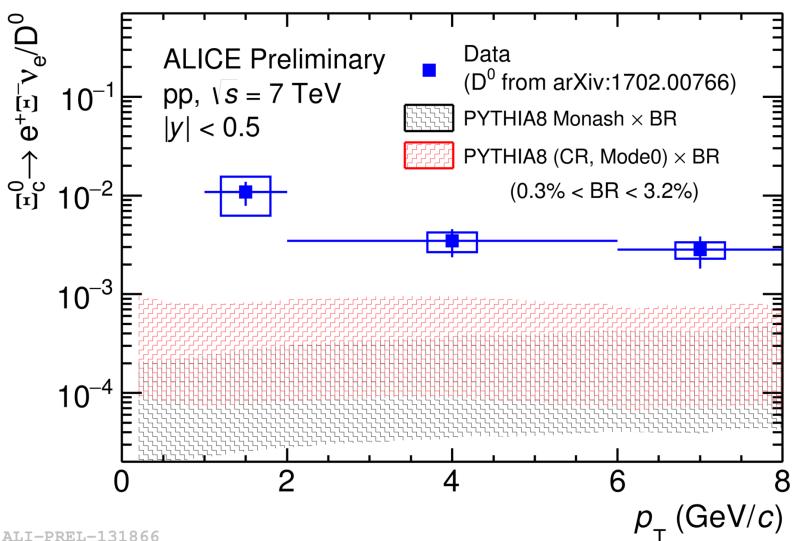
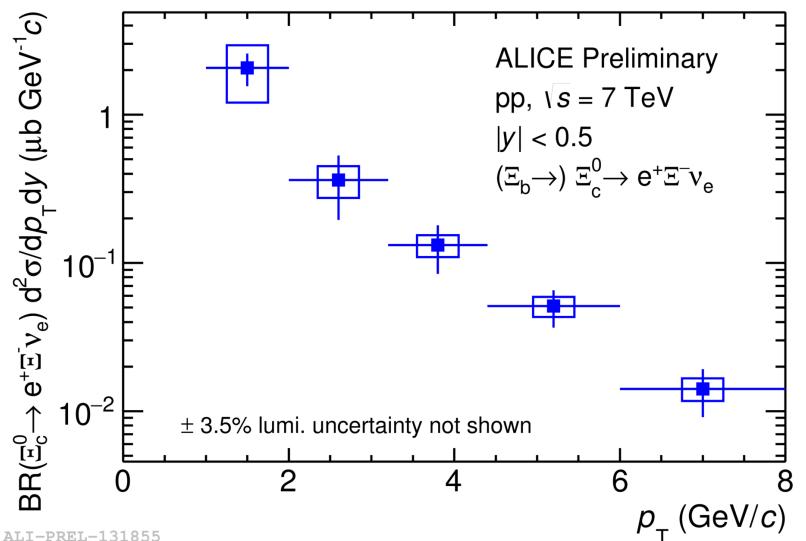
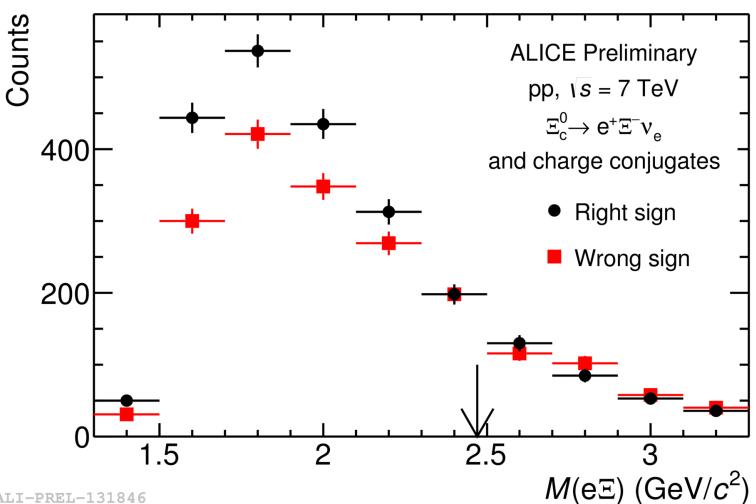
First Ξ_c^0 measurements in hadronic collisions



$\Xi_c^0 \rightarrow \Xi^- e^+ \bar{\nu}_e \rightarrow \Lambda \pi^- e^+ \bar{\nu}_e$
 $(\sigma \sim 30 \mu\text{m}, \text{BR unknown})$

NEW

Analysis techniques: as done for $\Lambda_c^+ \rightarrow e^+ \bar{\nu}_e \Lambda$
 Analysis performed in $1 < p_T < 8 \text{ GeV}/c$ range
 No feeddown subtraction from Ξ_b
 lack of knowledge of the absolute BR of $\Xi_b \rightarrow \Xi_c^0 + X$



Various PYTHIA8 tunes for the hadronisation mechanism, underestimate the measured Ξ_c^0/D^0
 Uncertainty bands due to the range assumed for the Ξ_c^0 branching ratio (0.3-3.2%)

RESULTS IN P-PB COLLISIONS (2013 DATA)

First Λ_c^+ measurements @ mid-rapidity



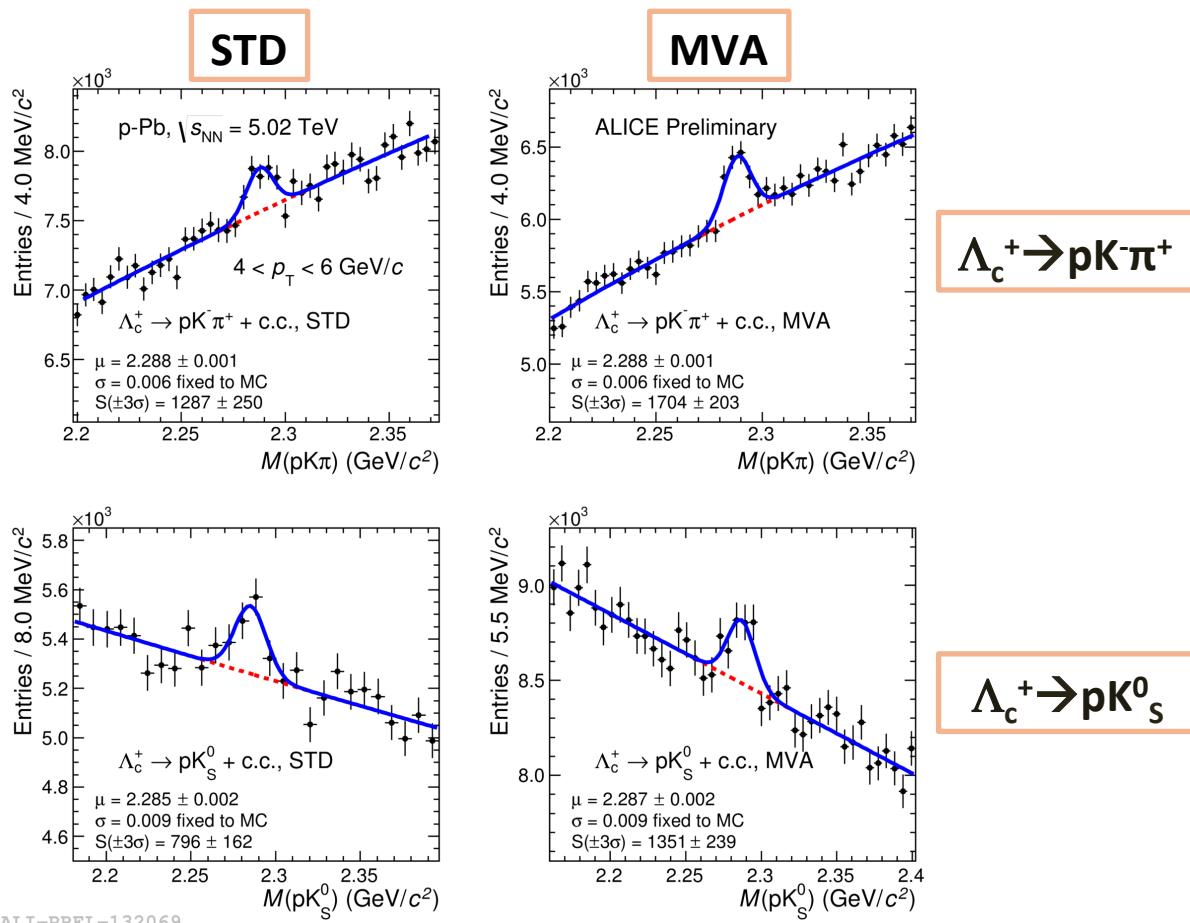
Two hadronic decay channels studied, $\Lambda_c^+ \rightarrow pK^-\pi^+$ and $\Lambda_c^+ \rightarrow pK_S^0$

Analysis techniques: topological and kinematical cuts + PID (**STD**)

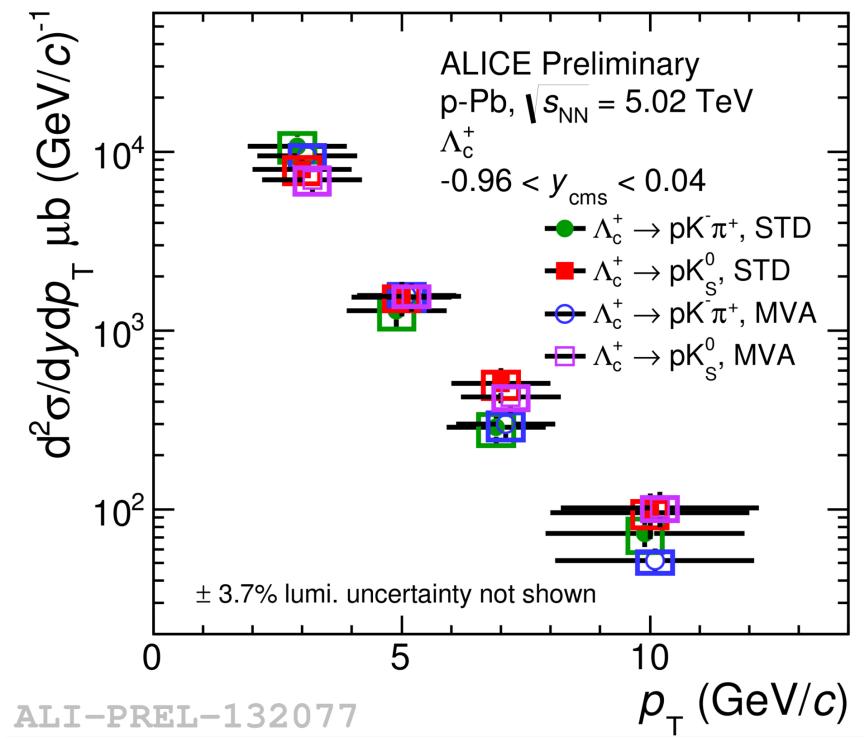
MultiVariate Analysis (**MVA**) based on Boosted Decision Tree (BDT)

Analysis performed in $2 < p_T < 12$ GeV/c range

NEW

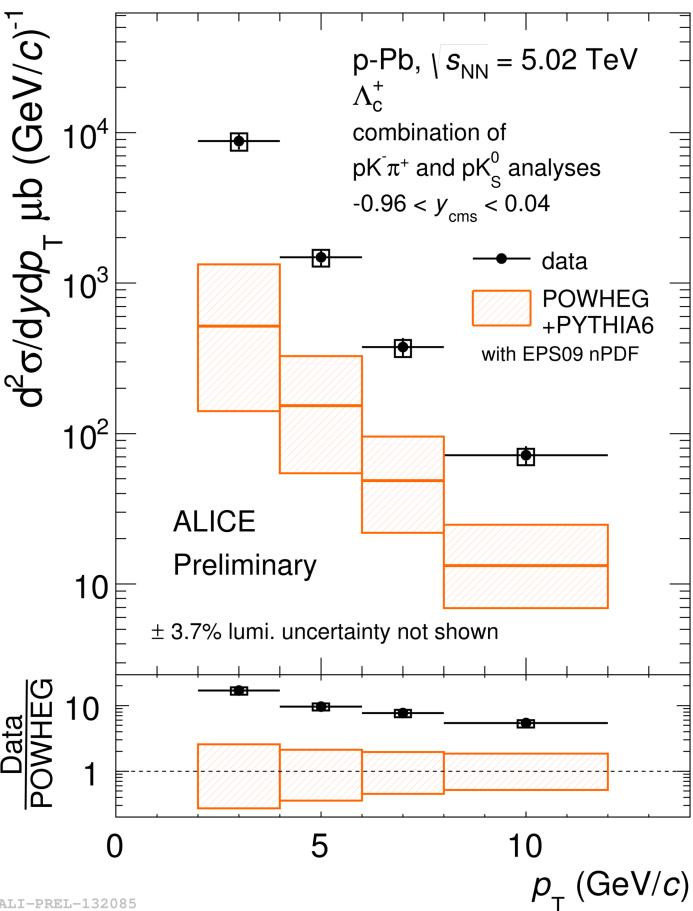


First Λ_c^+ measurements @ mid-rapidity



NEW

All measurements averaged together
 (correlation in the uncertainties taken into account)



All the measured cross sections compatible within statistical and systematic uncertainties (BR uncertainties included)

POWHEG+PYTHIA6 significantly underestimates (by more than a factor 18 at low p_T) the data

Λ_c^+ nuclear modification factor measurement

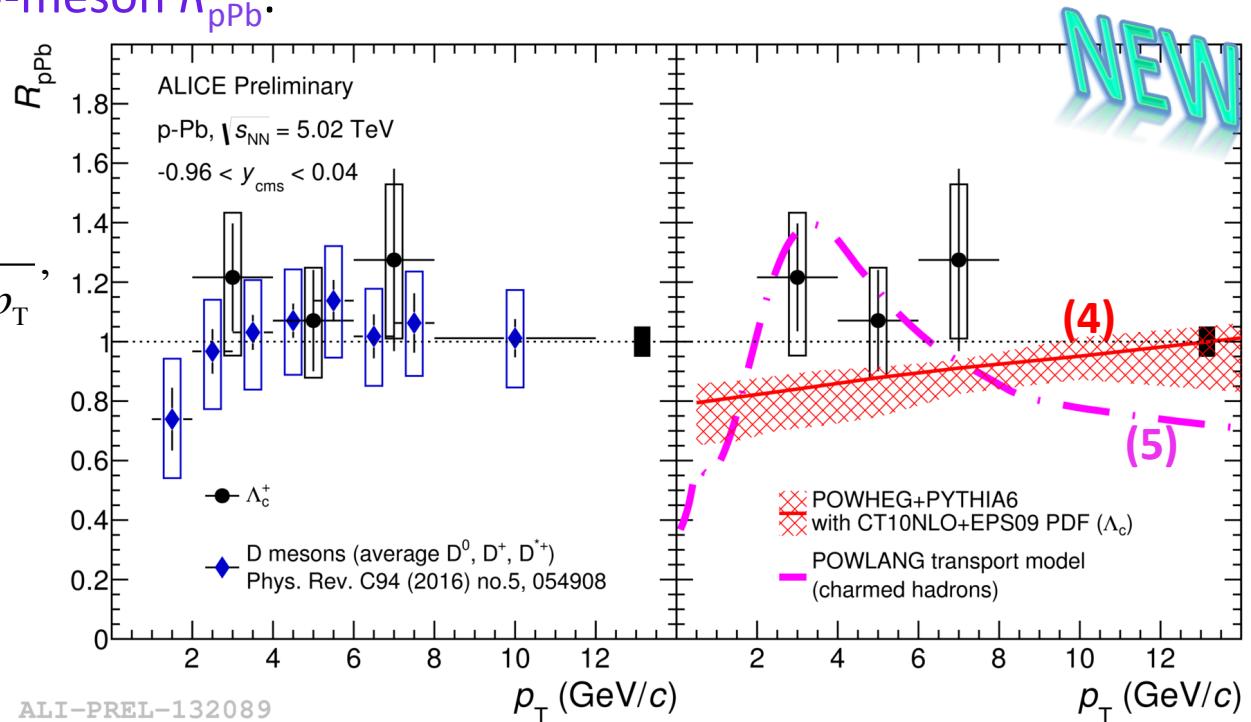
Λ_c^+ -baryon $R_{p\text{Pb}}$ measured in $2 < p_T < 8 \text{ GeV}/c$ range.

The measurement is

compatible with unity within the statistical uncertainties,
consistent with the D-meson $R_{p\text{Pb}}$.

$$R_{p\text{Pb}} = \frac{1}{A} \frac{d\sigma_{p\text{Pb}}^{5 \text{ TeV}}/dp_T}{f_{FONLL}(p_T) \cdot d\sigma_{pp}^{7 \text{ TeV}}/dp_T},$$

$$f_{FONLL}(p_T) = \frac{d\sigma_{FONLL}^{5 \text{ TeV}}/dp_T}{d\sigma_{FONLL}^{7 \text{ TeV}}/dp_T}$$

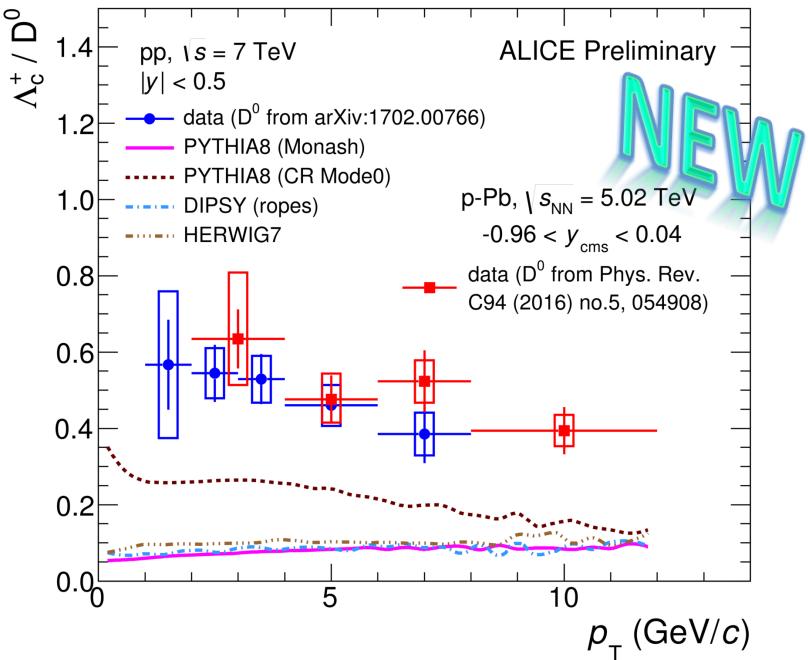


Measurement vs theoretical predictions:

- (4) POWHEG+PYTHIA6 with CT10NLO+EPS09 PDF (Λ_c): only CNM effects included,
- (5) POWLANG transport model: a hot deconfined medium formed also in p-Pb collisions.

The current precision of the measurement does not allow to constrain the models.

Λ_c^+/\bar{D}^0 measurements in pp and p-Pb collisions



All theoretical predictions underestimate our measurements

- PYTHIA8 with colour-reconnection tune Mode0 (hadronisation of multi-parton system) is closer to the measurements
- DIPSY generator predicts lower values
 - Similar predictions obtained by HERWIG and PYTHIA8 with the Monash 2013 tune (better description of the measured baryon-to-meson ratios in the light-flavour sector)

ALICE measurements higher than all previous measurements - not all in pure hadronic collisions, lower energies, different p_T and y ranges

CLEO Coll.: Phys. Rev. D43 (1991) 3599–3610

ARGUS Coll.: Phys. Lett. B207 (1988) 109–114;
Z. Phys. C52 (1991) 353–360

LEP average: L. Gladilin, Eur. Phys. J. C75 no. 1, (2015) 19

ZEUS Coll., DIS: JHEP 11 (2010) 009

ZEUS Coll., γp (HERA I): Eur. Phys. J. C44 (2005) 351–366

ZEUS Coll., γp (HERA II): JHEP 09 (2013) 058

LHCb Coll., pp $2.0 < y < 4.5$: Nucl.Phys. B871 (2013) 1–20

All theoretical predictions, that contain, fundamentally, LEP results as ingredients, reproduce previous measurements



Conclusions and prospects

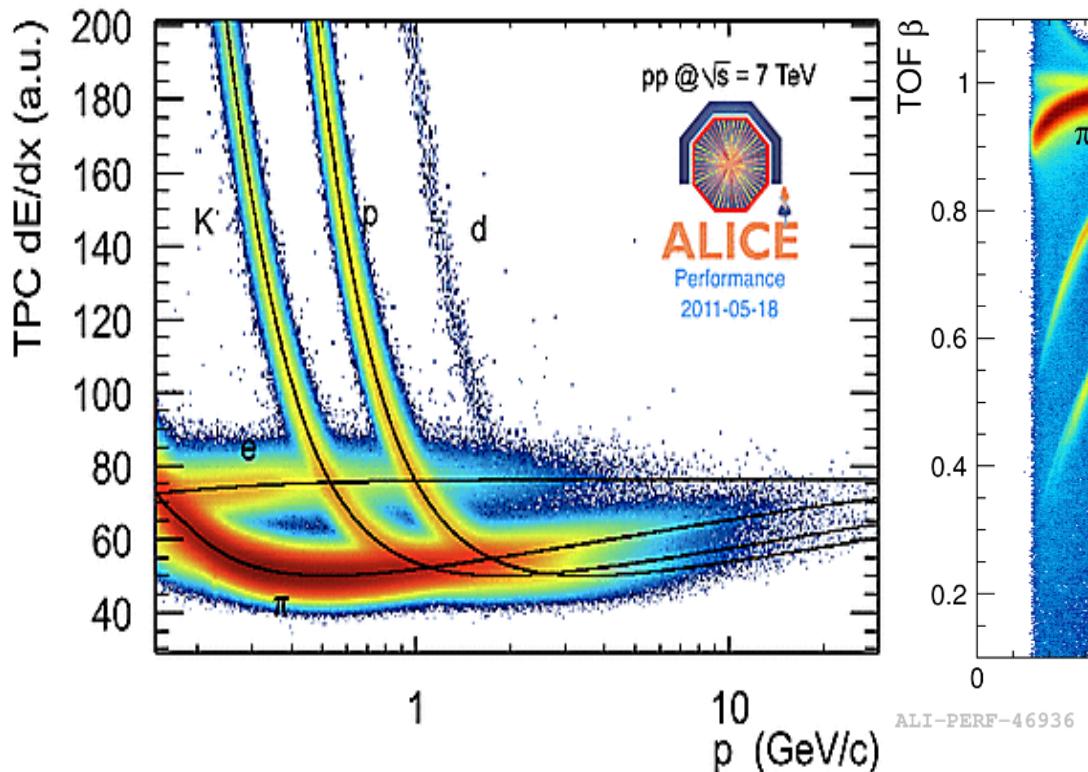
- Non-strange and strange D-meson production measured at several collision energies reproduced by pQCD calculations
- **First charmed-baryon measurements at mid-rapidity @ LHC energies and collisions** shown
 - Measured cross sections and Λ_c^+/D^0 ratios higher than all available theoretical predictions
- Run2 (M.Floris's talk, plenary session)
 - 13 and 5 TeV pp collisions: first results shown here
 - p-Pb collisions: 6xRun1 available statistics (C.Terrevoli's talk, Heavy-Ion Physics session)
- ALICE-ITS upgrade program (P.Camerini's talk, Detector R&D and Data Handling session)
 - More precise charmed-hadron measurements will be allowed

BACKUP

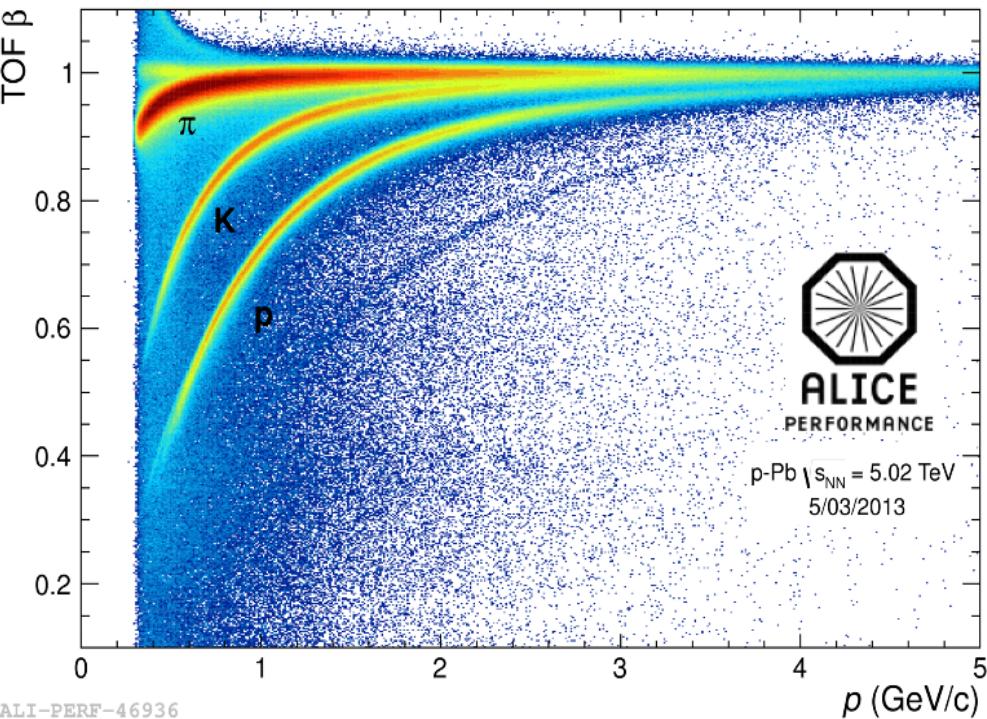
PID performance in pp and p-Pb collisions



TPC in pp



TOF in p-Pb



LHCb measurements in pp @ 7 TeV



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D⁰

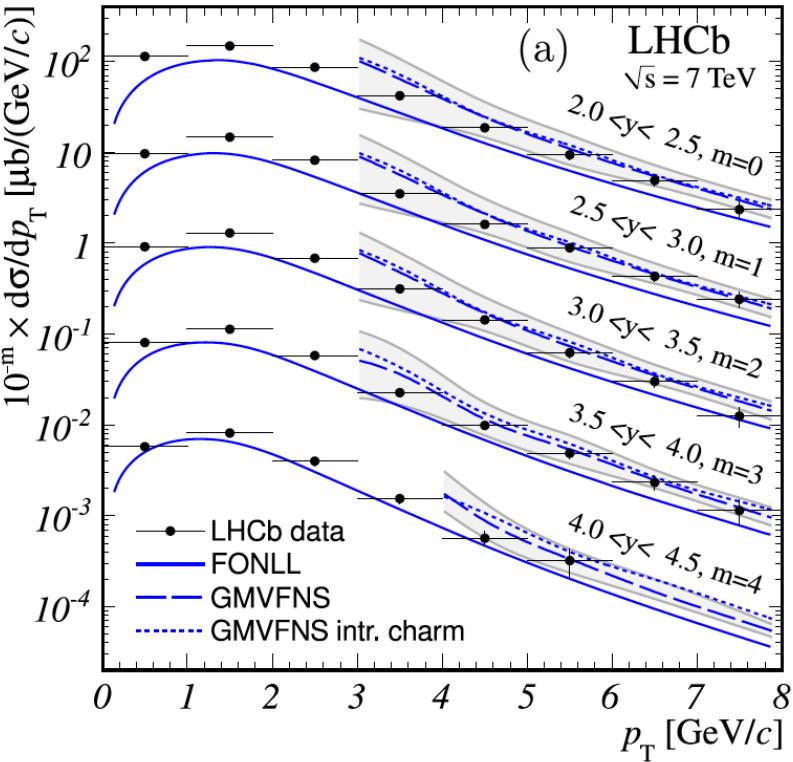
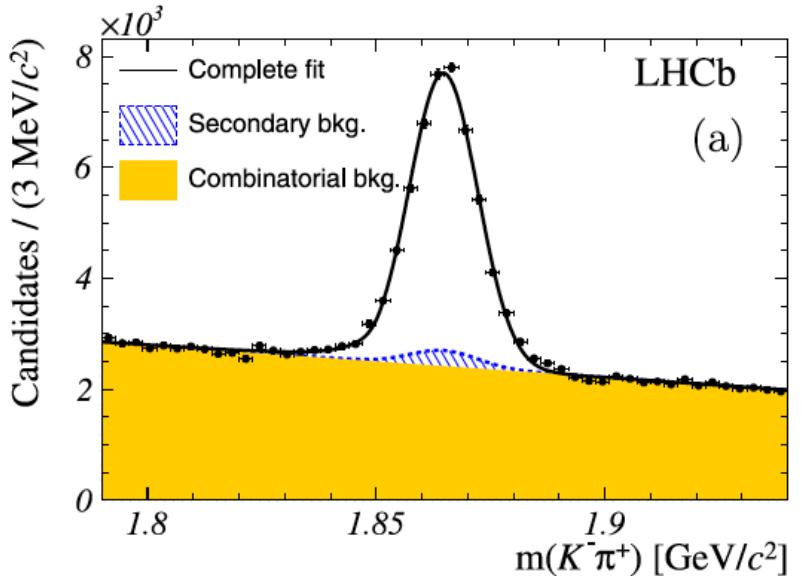


Table 7

Differential production cross-sections, $d\sigma/dp_T$, in $\mu\text{b}/(\text{GeV}/c)$ for prompt $D^0 + \text{c.c.}$ mesons in bins of (p_T, y) . The first uncertainty is statistical, and the second is the total systematic.

p_T (GeV/c)	y (2.0, 2.5)	(2.5, 3.0)	(3.0, 3.5)	(3.5, 4.0)	(4.0, 4.5)
(0, 1)	$113.58 \pm 5.45 \pm 10.45$	$96.51 \pm 3.49 \pm 8.10$	$90.99 \pm 3.67 \pm 7.24$	$80.41 \pm 4.19 \pm 6.30$	$57.37 \pm 5.37 \pm 5.10$
(1, 2)	$147.06 \pm 5.78 \pm 12.45$	$146.54 \pm 4.08 \pm 12.16$	$129.43 \pm 3.89 \pm 10.19$	$112.64 \pm 4.52 \pm 8.95$	$81.57 \pm 5.20 \pm 7.02$
(2, 3)	$85.95 \pm 3.18 \pm 6.80$	$82.07 \pm 2.10 \pm 6.58$	$68.48 \pm 1.90 \pm 5.40$	$58.25 \pm 2.02 \pm 4.70$	$39.87 \pm 2.56 \pm 3.78$
(3, 4)	$41.79 \pm 1.78 \pm 3.82$	$34.86 \pm 1.10 \pm 2.82$	$31.30 \pm 1.05 \pm 2.47$	$22.65 \pm 1.00 \pm 2.13$	$15.50 \pm 1.29 \pm 1.51$
(4, 5)	$18.61 \pm 0.98 \pm 1.73$	$16.11 \pm 0.67 \pm 1.49$	$14.36 \pm 0.66 \pm 1.15$	$9.89 \pm 0.62 \pm 0.94$	$5.69 \pm 0.87 \pm 0.60$
(5, 6)	$9.35 \pm 0.66 \pm 0.90$	$8.85 \pm 0.48 \pm 0.84$	$6.23 \pm 0.41 \pm 0.60$	$4.88 \pm 0.43 \pm 0.48$	$3.22 \pm 0.98 \pm 0.46$
(6, 7)	$4.92 \pm 0.51 \pm 0.49$	$4.31 \pm 0.38 \pm 0.43$	$2.99 \pm 0.33 \pm 0.30$	$2.33 \pm 0.34 \pm 0.25$	
(7, 8)	$2.34 \pm 0.42 \pm 0.26$	$2.41 \pm 0.36 \pm 0.26$	$1.25 \pm 0.27 \pm 0.14$	$1.14 \pm 0.35 \pm 0.16$	

LHCb measurements in pp @ 7 TeV



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Λ_c^+

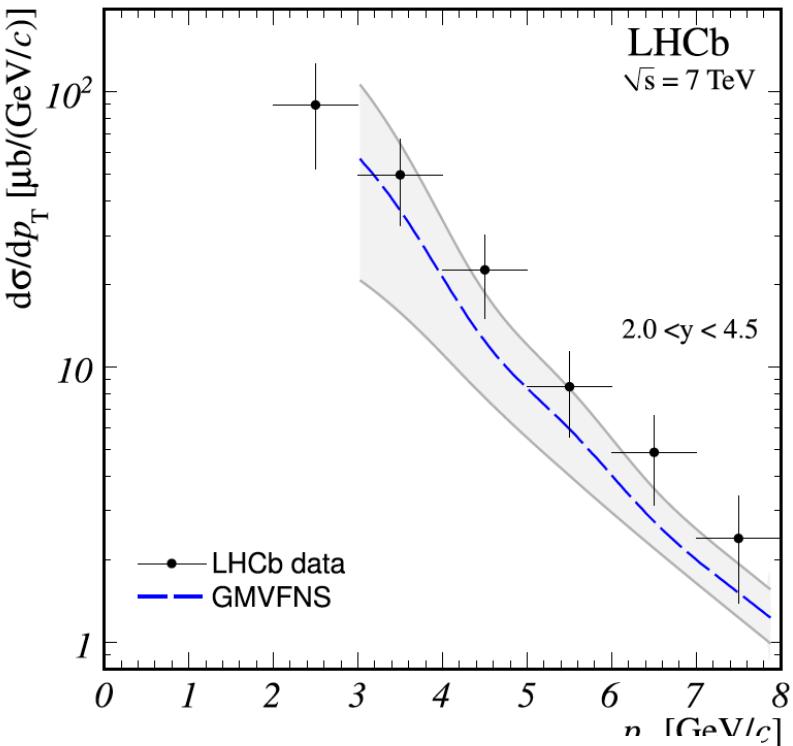
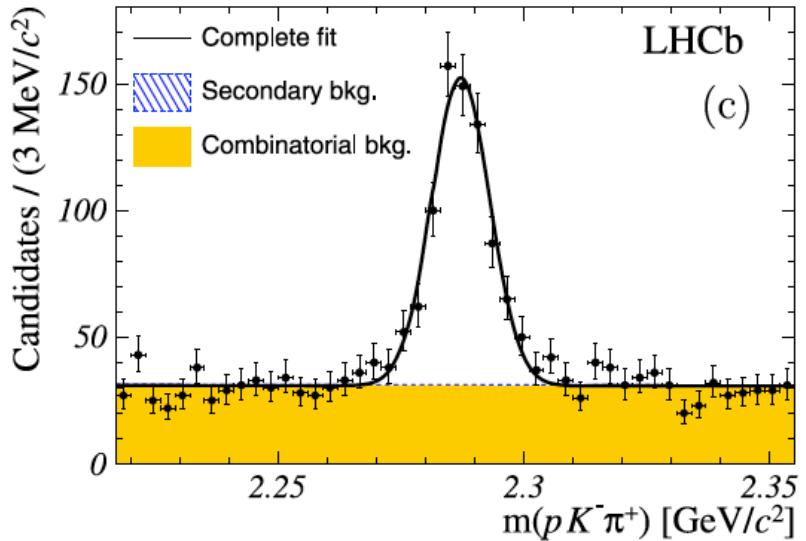
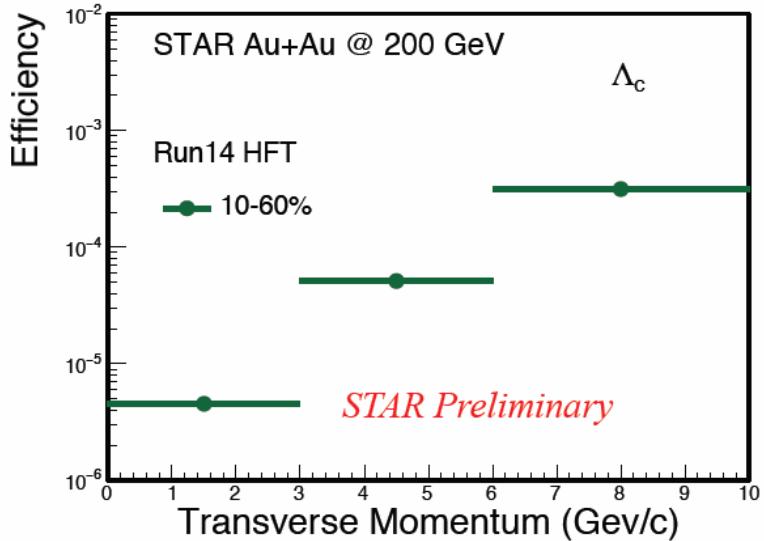
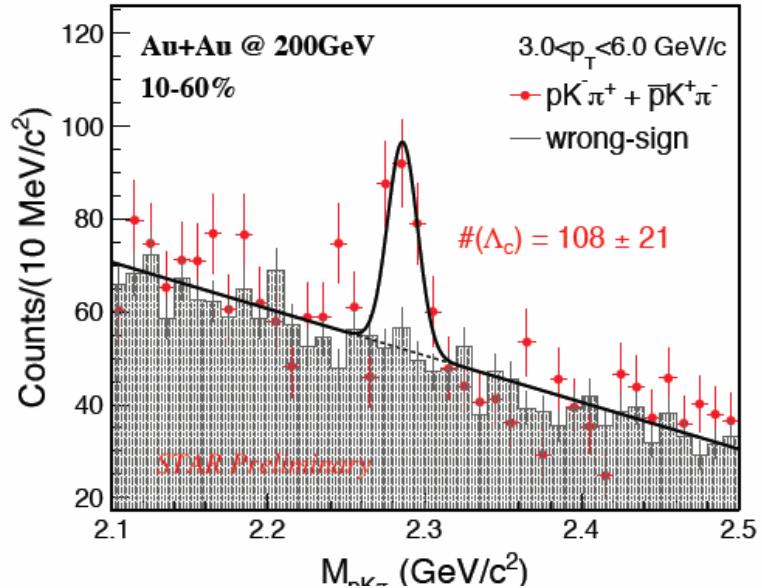


Table 5

Bin-integrated production cross-sections in μb for prompt $\Lambda_c^+ + \text{c.c.}$ baryons in bins of y integrated over the range $2 < p_T < 8 \text{ GeV}/c$. The first uncertainty is statistical, and the second is the total systematic.

p_T (GeV/c)	y				
		(2.0, 2.5)	(2.5, 3.0)	(3.0, 3.5)	(3.5, 4.0)
(2, 8)	$21.4 \pm 8.1 \pm 7.2$	$49.9 \pm 11.6 \pm 15.6$	$62.9 \pm 7.0 \pm 18.8$	$44.2 \pm 8.6 \pm 13.2$	

STAR measurements in Au-Au collisions



Results shown @ QM2017

