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Measurement of open-charm hadrons with ALICE at LHC

For the ALICE Collaboration

XI International Conference
On hyperons, charm and beauty hadrons

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- Open heavy-flavour results
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  - Focus on D mesons reconstructed from their hadronic decays

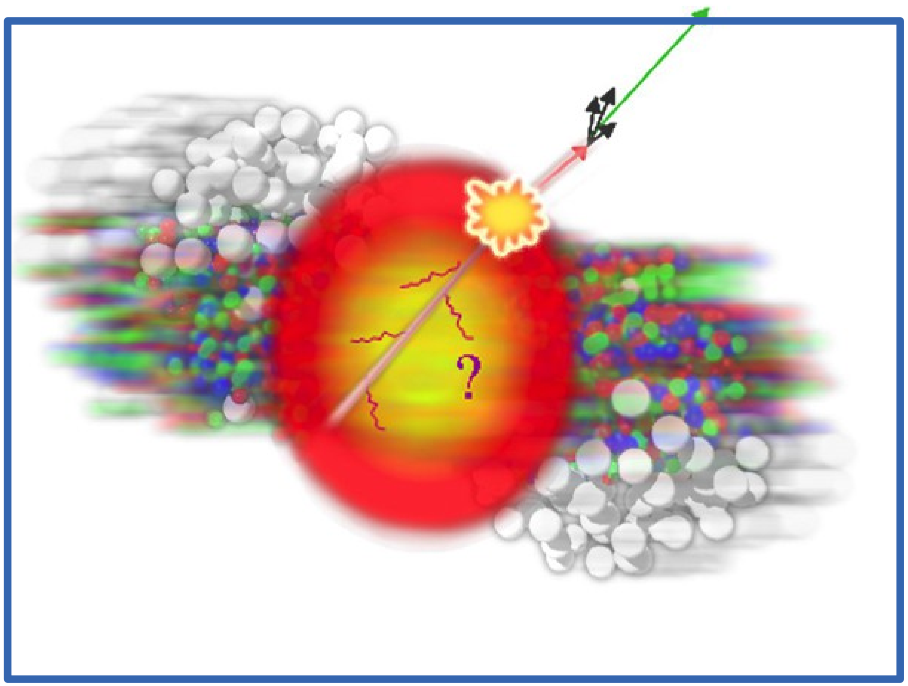
- Perspectives for open heavy-flavour measurements with the ALICE upgrade

Results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

Heavy-flavour production in Pb-Pb I

ALICE

Heavy quarks → produced in hard partonic scatterings in the early stages of the collision (before Quark-Gluon Plasma (QGP) formation)
Open charm and beauty hadrons are very good probes of the QGP.



R_{AA} → Nuclear modification factor

$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \times \frac{d^2 N_{AA} / dp_T d\eta}{d^2 N_{pp} / dp_T d\eta}$$

N_{coll} → Number of binary collisions

$R_{AA} \neq 1$ → Medium effects:

Energy loss in the QGP → $R_{AA} < 1$

Cold Nuclear Matter (CNM) effects → $R_{AA} \neq 1$

Energy loss, expected from theory:

Mass hierarchy → $\Delta E_g > \Delta E_{uds} > \Delta E_c > \Delta E_b$

Should be reflected in the R_{AA} (with caveats):

→ R_{AA}(B) > R_{AA}(D) > R_{AA}(π)

Dokshitzer and Kharzeev, PLB 519 (2001) 199.

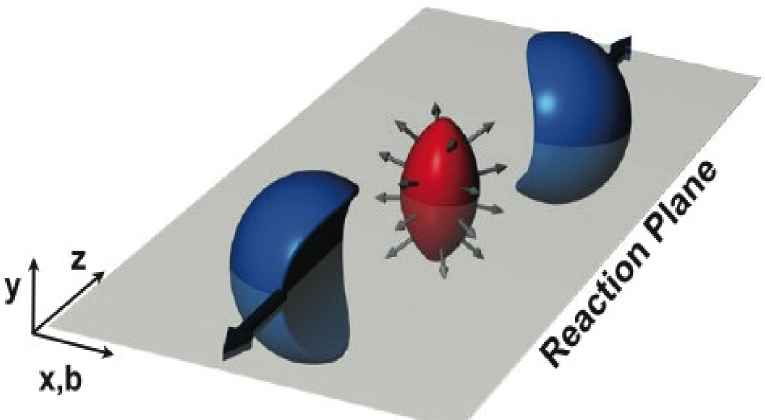
Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003.

Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493.

Heavy-flavour production in Pb-Pb II

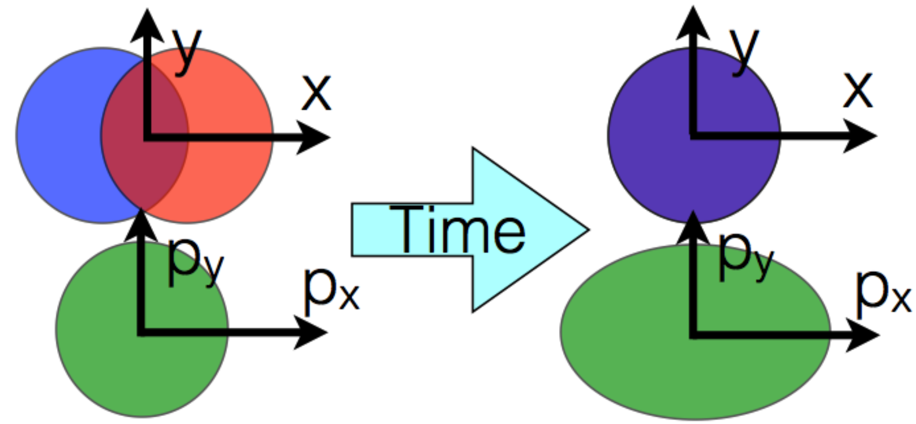
Flow = collective expansion of the medium created in heavy-ion collisions, established due to multiple interactions among its constituents

Non-central collisions



New Journal of Physics 13 (2011) 055008

Initial spatial anisotropy → momentum anisotropy
Pressure gradient (different in-plane and out-of-plane)



Anisotropy studies via the Fourier coefficients of the particles azimuthal distribution relative to the reaction plane:

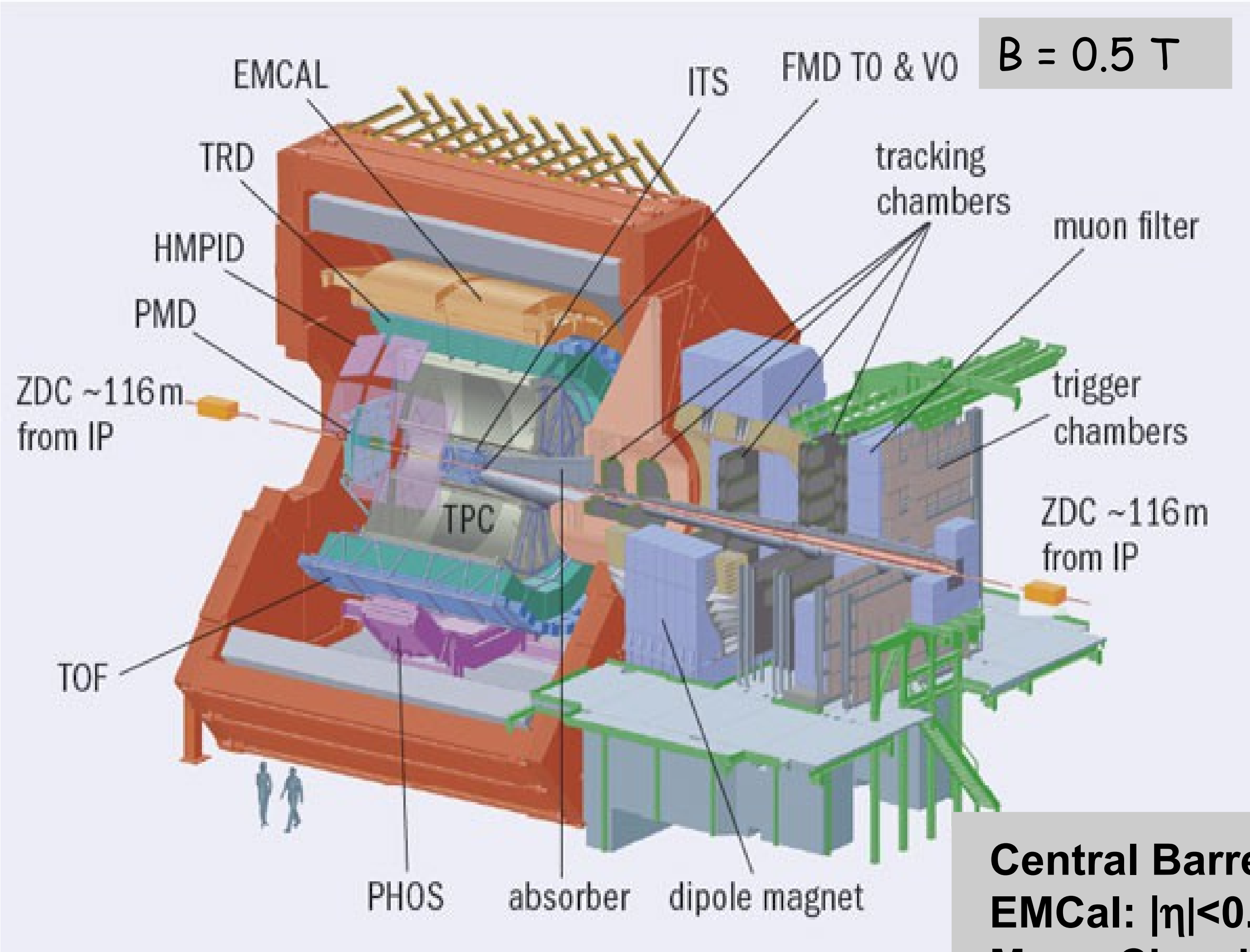
$$E\frac{d^3N}{d^3\mathbf{p}} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})]\right) \qquad v_n(p_t, y) = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

v_2 is called elliptic flow (n=2) and it is sensitive to:

Participation of charm quarks in the collective motion of the medium (low p_T)

Path-length dependence of in-medium energy loss (high p_T)

ALICE Experiment



Open-charm into hadronic decays:
Central Barrel detectors ($|\eta|<0.9$):

$D^0 \to K^- \pi^+$

$D^+ \to K^- \pi^+ \pi^+$

$D^{*+} \to D^0 \pi^+$

$D_s^+ \to \pi^+ \phi \to K^+ K^- \pi^+$

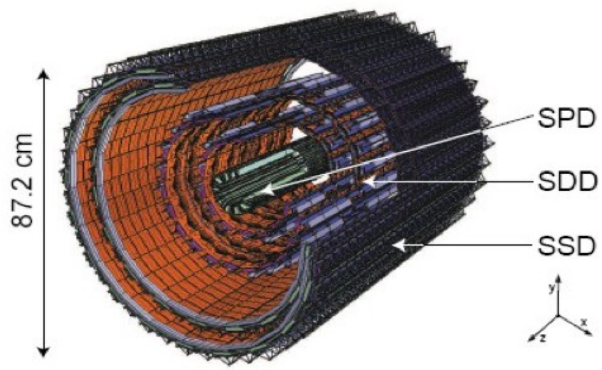
$\Lambda_c^+ \to pK^+\pi^-$ and pK_s^0

Central Barrel detectors → $|\eta|<0.9$
EMCal: $|\eta|<0.7$
Muon Chamber: $-4 < \eta < -2.5$

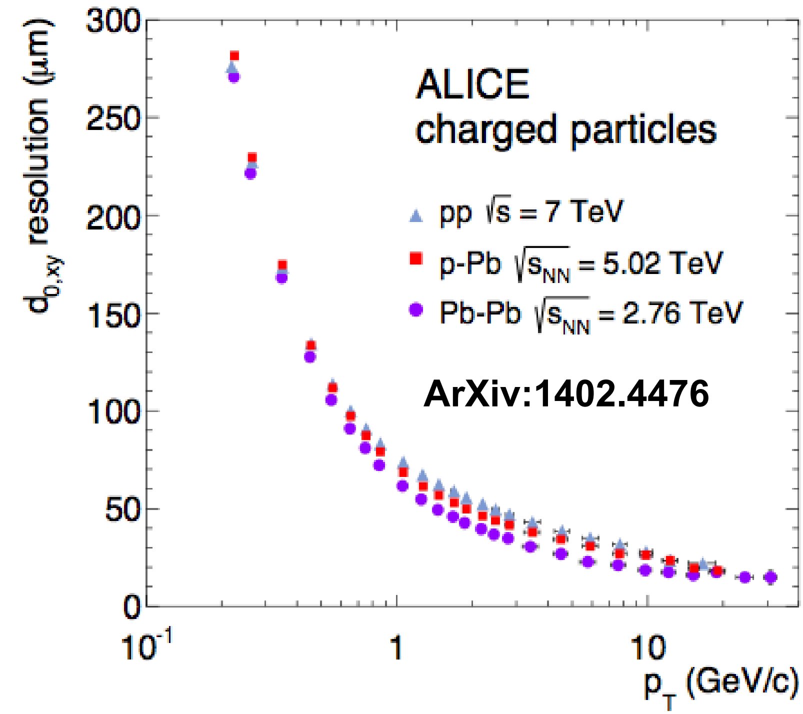
TPC(Time Projection Chamber) → Tracking and Particle Identification (PID)
ITS (Inner Tracking System) → Vertex reconstruction, tracking and PID
TOF(Time of Flight) → PID

Open charm reconstruction from hadronic decays

Inner tracking system (ITS)

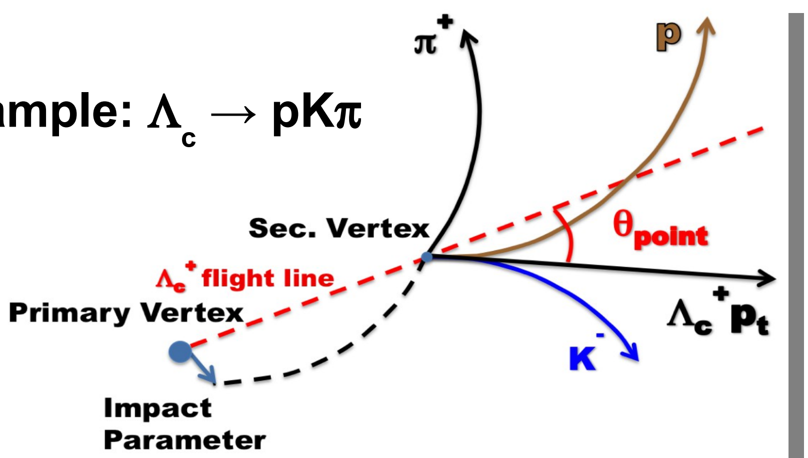


Impact parameter resolution (ITS)



Current ITS
Resolution of track impact parameter
~100-300 μm at low p_T

Example: $\Lambda_c \rightarrow pK\pi$

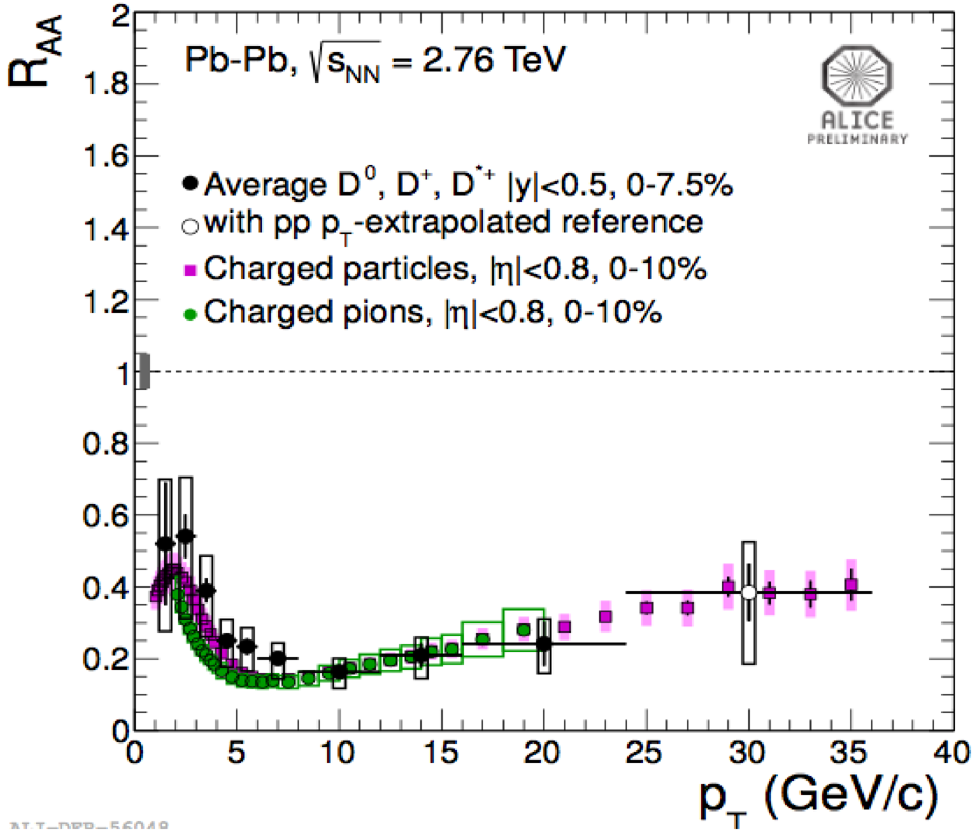


Topological cuts based
on displaced vertex analysis
→ ITS detector

PID with TOF and TPC
Select protons, kaons and pions

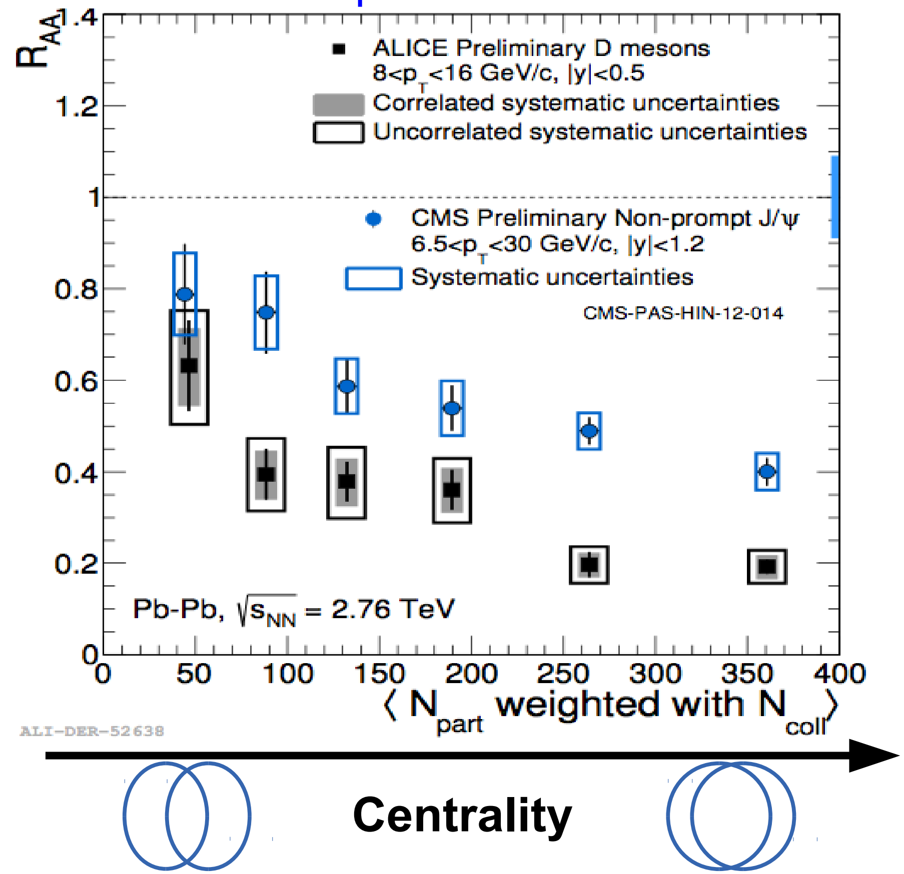
R_{AA} of D Mesons

D^0, D^+, D^{*+} in their hadronic channels



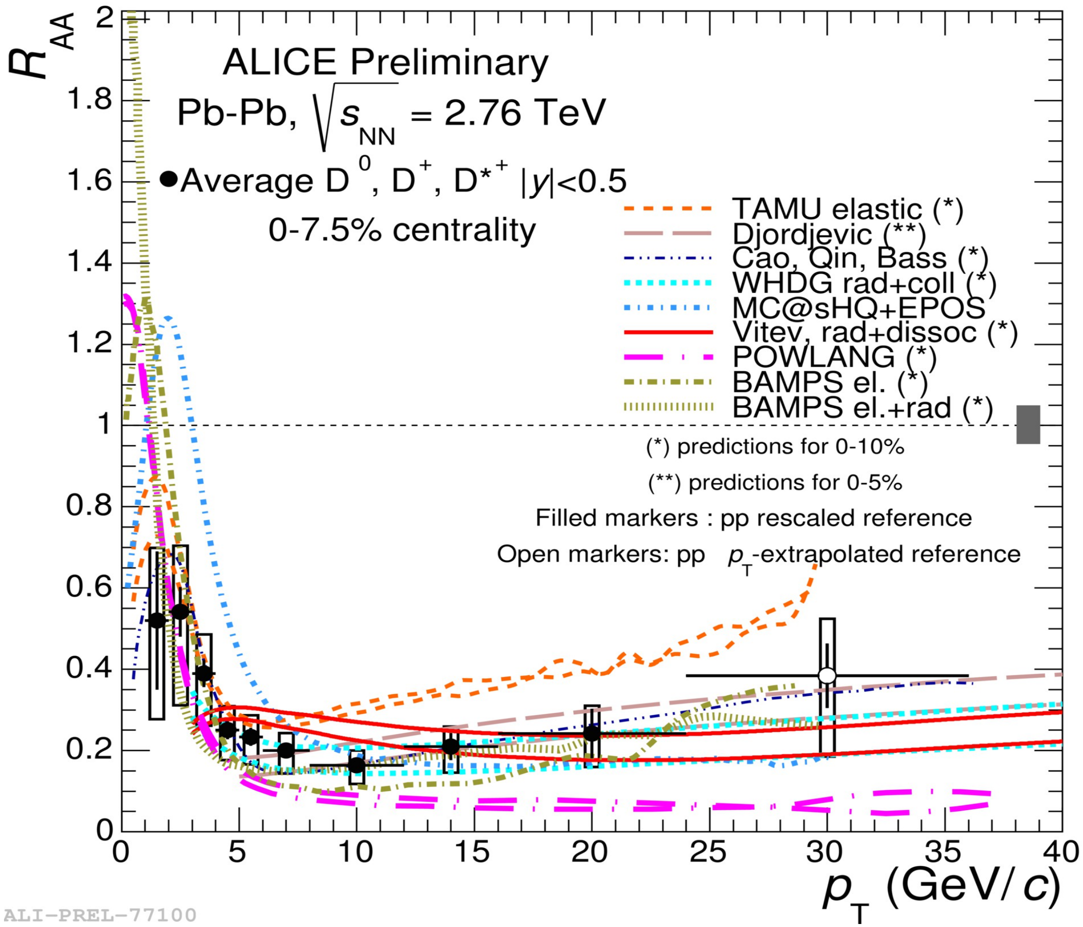
D $\langle p_T \rangle$ ~10 GeV/c

B $\langle p_T \rangle$ ~11 GeV/c



- **D-meson yield is strongly suppressed at high p_T**
- **R_{AA}(D) compatible with $R_{AA}(\pi)$ within current uncertainties**
  - **More statistics needed to conclude on the expected hierarchy $R_{AA}(D) > R_{AA}(\pi)$**
- **At high p_T: R_{AA}(D) < R_{AA} (J/ψ) from B decays measured by CMS**
  - **Consistent with expectation due to mass-dependent energy loss**

Comparison of R_{AA} with models



TAMU elastic: arXiv:1401.3817

Djordjevic: arXiv:1307.4098

Cao, Qin, Bass: PRC 88 (2013) 044907

WHDG: J. Phys. G 38 (2011) 124114

MC@sHQ+EPOS: PRC 89 (2014) 014905

Vitev, rad+dissoc: PRC 80 (2009) 054902

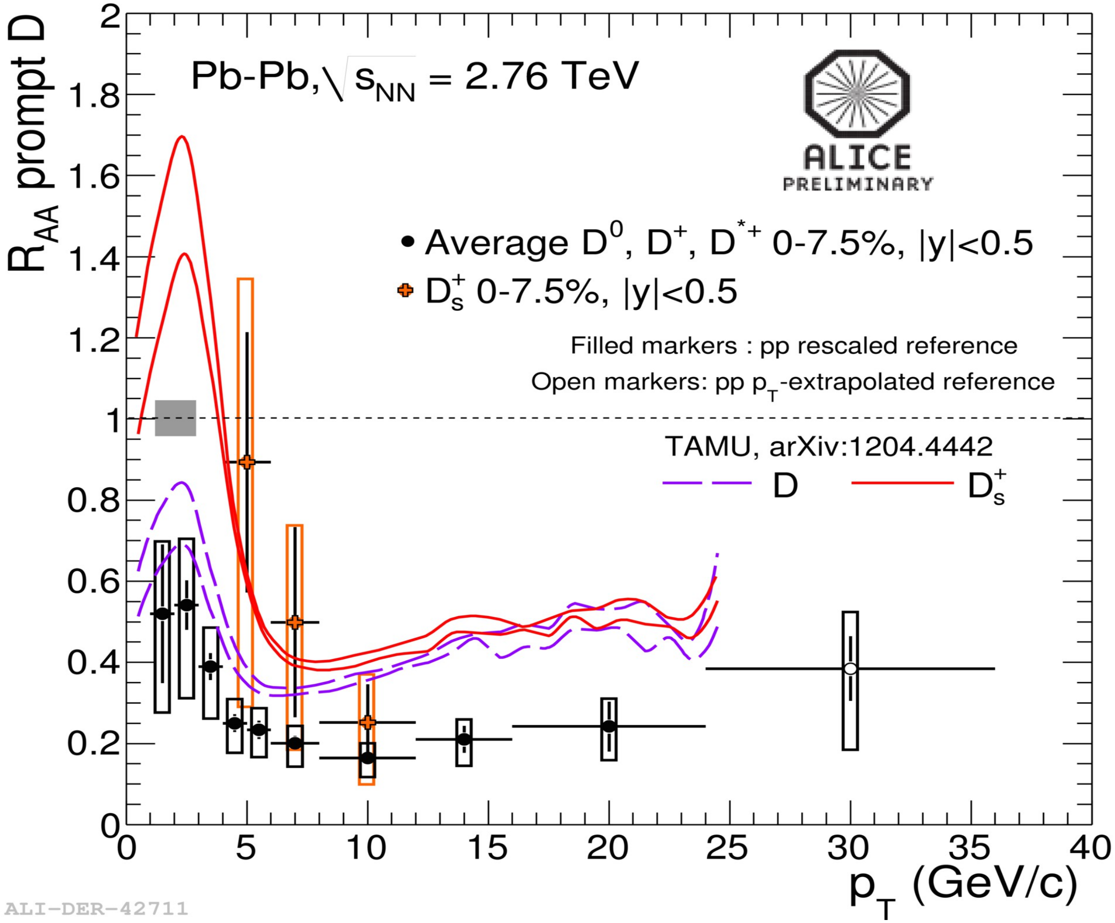
POWLANG: Eur. Phys. J C 71 (2011)1666]

BAMPS: Phys. Lett. B 717 (2012) 430

Some models can describe the measured R_{AA} within the uncertainties

More statistics are needed to further constrain the models

R_{AA} of D_s^+ mesons



At low/intermediate p_T

From predictions:

Strange D mesons enhanced relative to non-strange ones due to recombination

Kuznetsova, Rafelski, EPJ C 51 (2007) 113

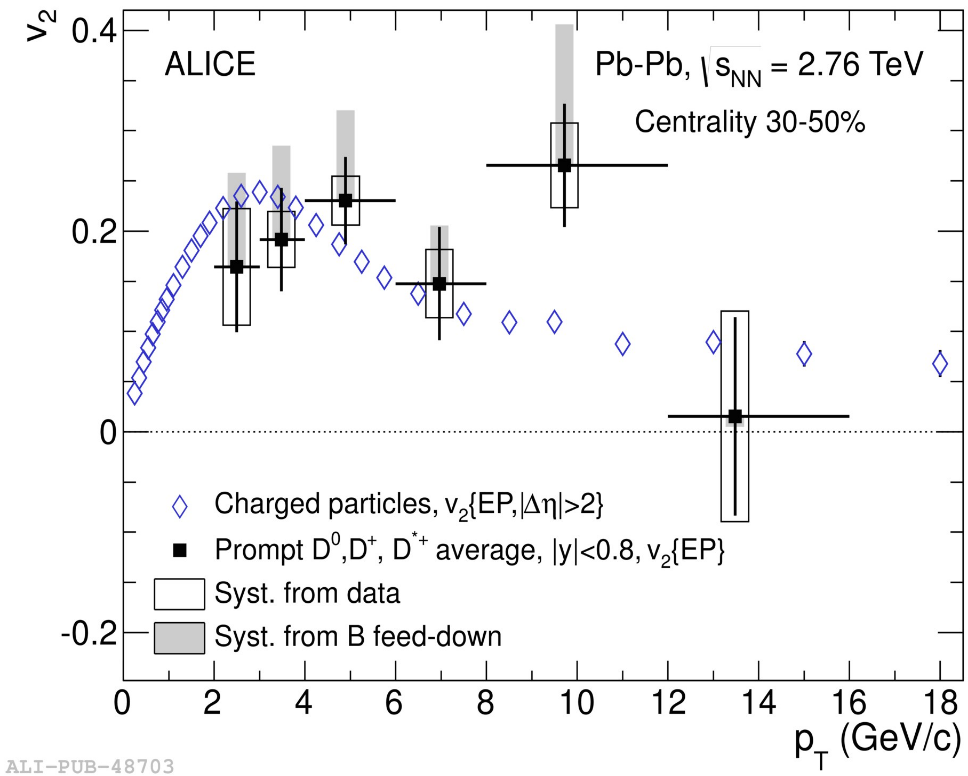
He, Fries, Rapp, PRL 110 (2013) 112301

At low p_T, central value of $R_{AA}(D_s^+)$ > R_{AA} (non-strange D):

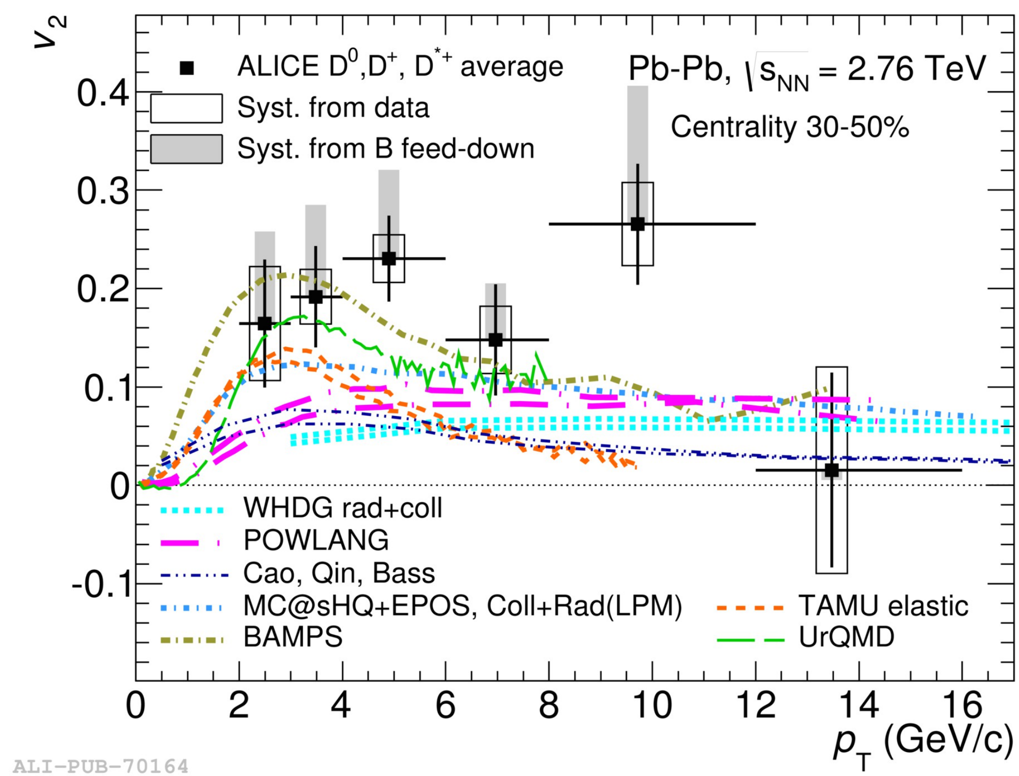
Compatible within uncertainties
More statistics needed to conclude on this subject.

D-meson v_2 in Pb-Pb

Phys. Rev. Lett. 111 (2013) 102301



arXiv:1405.2001



v_2 of D Mesons → Positive in 2 < p_T < 6 GeV/c (5 σ significance)

Suggests that c quarks participate in the collective motion

With current statistics → No conclusion on path-length dependence of energy loss at high p_T

Some models describe the data within uncertainties

Simultaneous description of v_2 and R_{AA} challenging for models

Results in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Heavy-flavour in p-Pb

In order to interpret the Pb-Pb data and conclude about the energy loss mechanisms:
– Understand the role of initial state effects
– Disentangle them from the dense medium effects

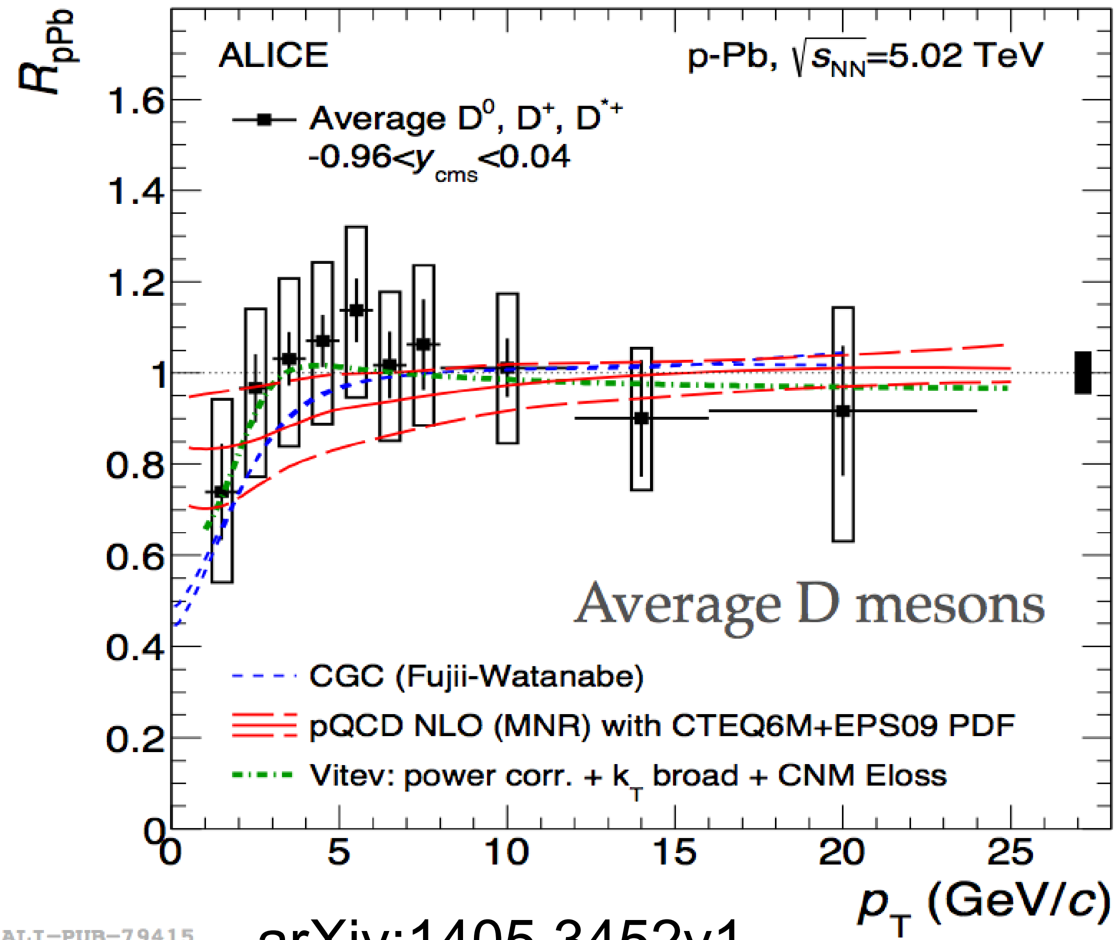
p-Pb collisions to understand cold nuclear matter effects:
– k_T broadening
– PDF modifications, mainly shadowing/gluon saturation at low x

Nuclear Modification Factor in p-Pb

$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$

Production in p-Pb collisions compared with pp
$R_{pPb} \neq 1 \rightarrow$ Cold Nuclear Matter (CNM) effects

R_{pPb} of D Mesons



arXiv:1405.3452v1

In p-A collisions:

– R_{pPb} compatible with 1 for p_T > 2 GeV/c

→ Small cold nuclear matter effects for p_T < 2 GeV/c

– Suggests suppression in Pb-Pb due to dense medium

→ Models of CNM effects describe the data within uncertainties

[M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B 373 (1992) 295;

K. Eskola, H. Paukkunen and C. Salgado, JHEP 04467 (2009) 065.;

H. Fujii and K. Watanabe, arXiv:1308.1258.

R. Sharma, I. Vitev and B. -W. Zhang, Phys. Rev. C 80461 (2009) 054902.]

The ALICE Upgrade

ALICE Upgrade

ITS (Inner Tracking System):

→ **Closer to interaction point**
  – 39 mm → 22 mm

→ **Lower material budget**
  – ~1.14% → ~0.3 % (for inner layers)

→ **Pixel size reduced**
  – 50 µm x 425 µm → 30 µm x 30 µm

→ **More layers (7 instead of 6)**

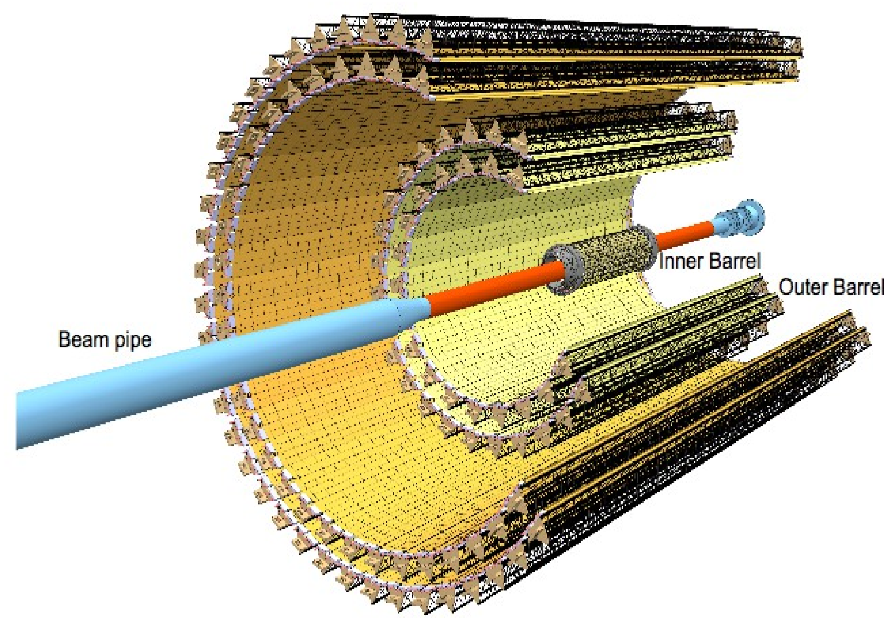
→ **Only pixels**
  – No more drift and strips

→ **Impact parameter resolution:**
  – ~3x better in the transverse plane

TPC + ITS:

→ **Faster readout:**

→ **Pb-Pb at 50 kHz, pp at 200 kHz**
  – Currently limited at 1 kHz with full ITS



TDR (Technical Design Report)
→ CERN-LHCC-2013-024 ; ALICE-TDR-017

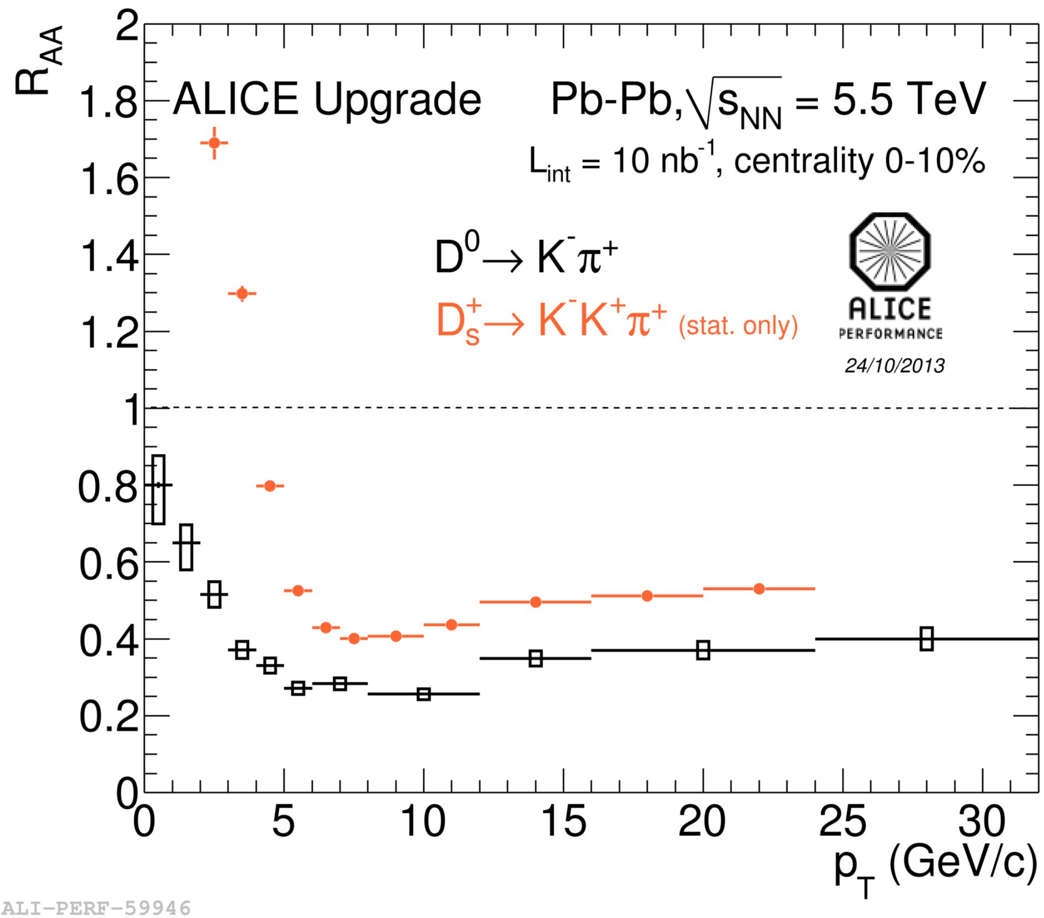
Targets:

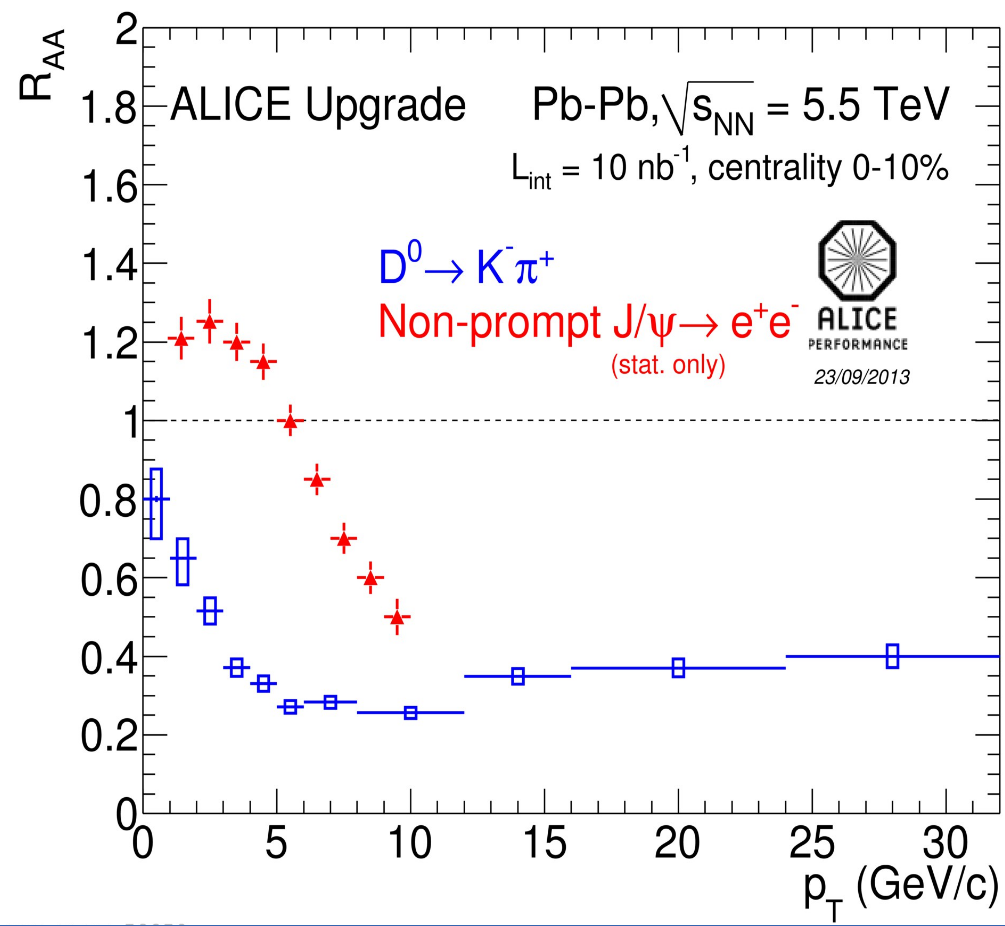
L_{int} → 10 nb^{-1} with minimum bias events

Upgrade planned for shutdown 2 (2018-19)

R_{AA} of D mesons

From Simulations of Pb-Pb collision with the ALICE upgrade





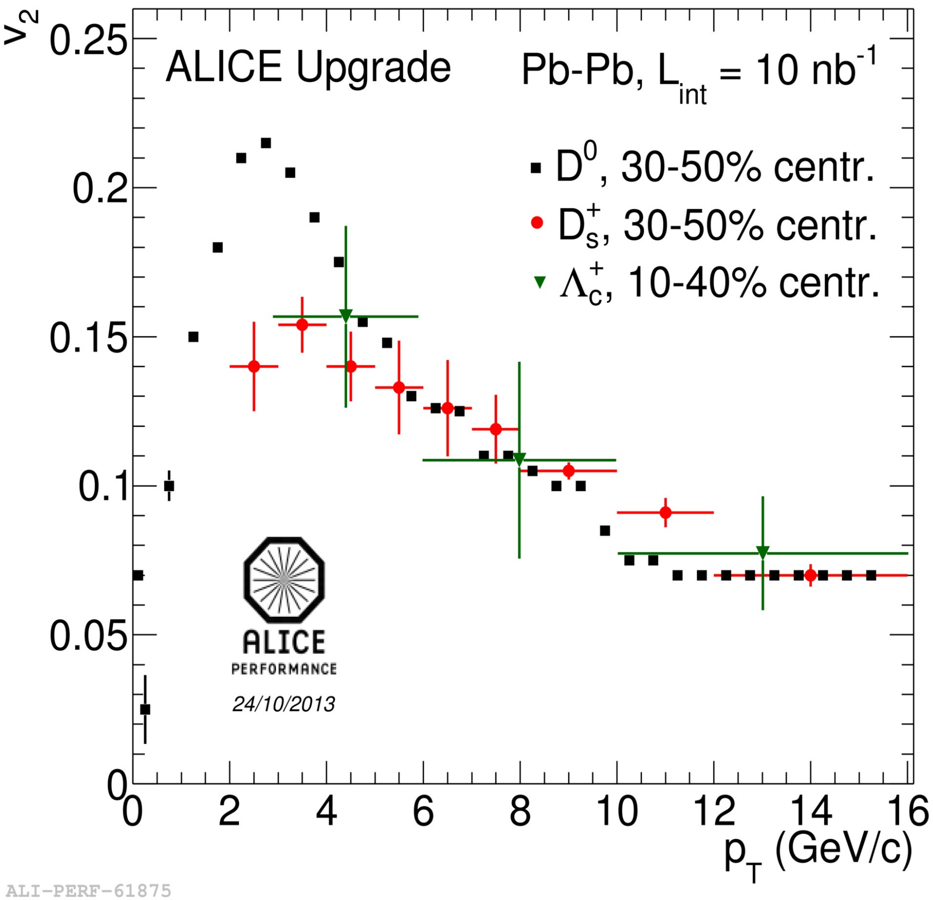
R_{AA} of charmed mesons with percent-level precision → down to low p_T

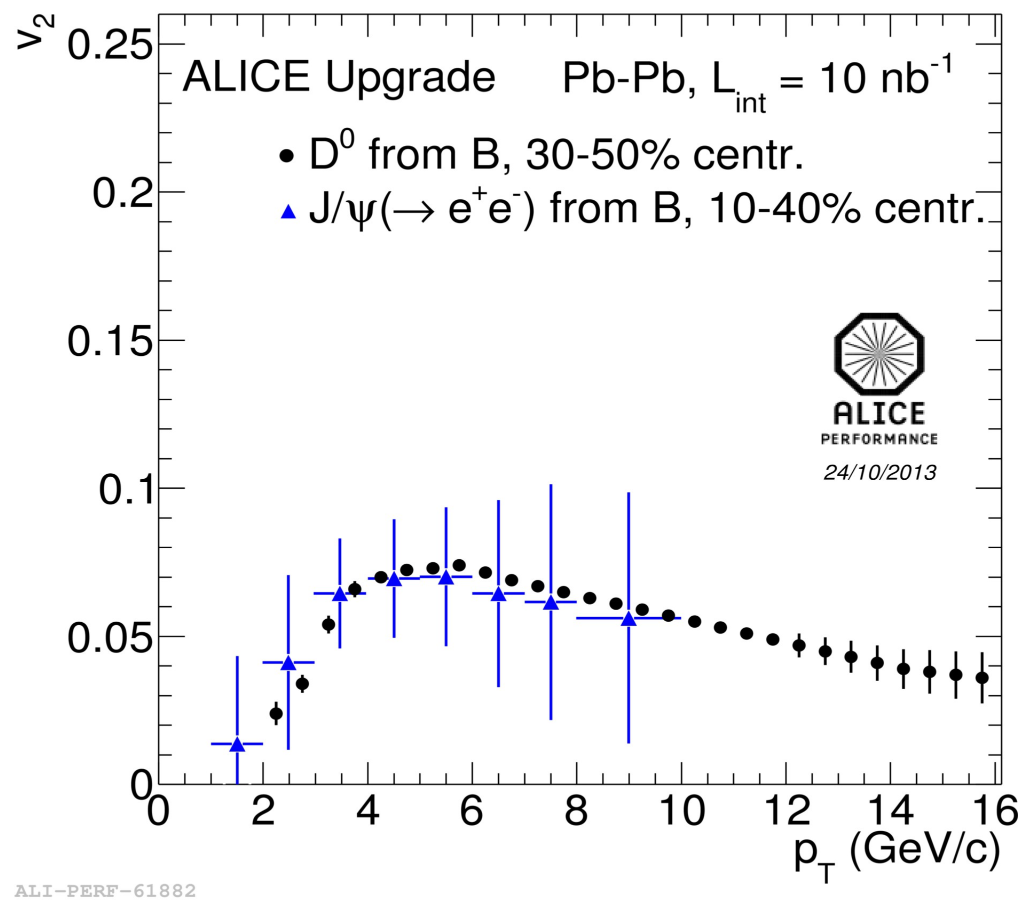
Precise comparison between strange and non-strange D mesons.

– Hadronisation mechanism and strangeness enhancement in QGP.

Comparison between open beauty and charm will be possible.

v_2 with the ITS upgrade





v_2 measurements for open charm and open beauty

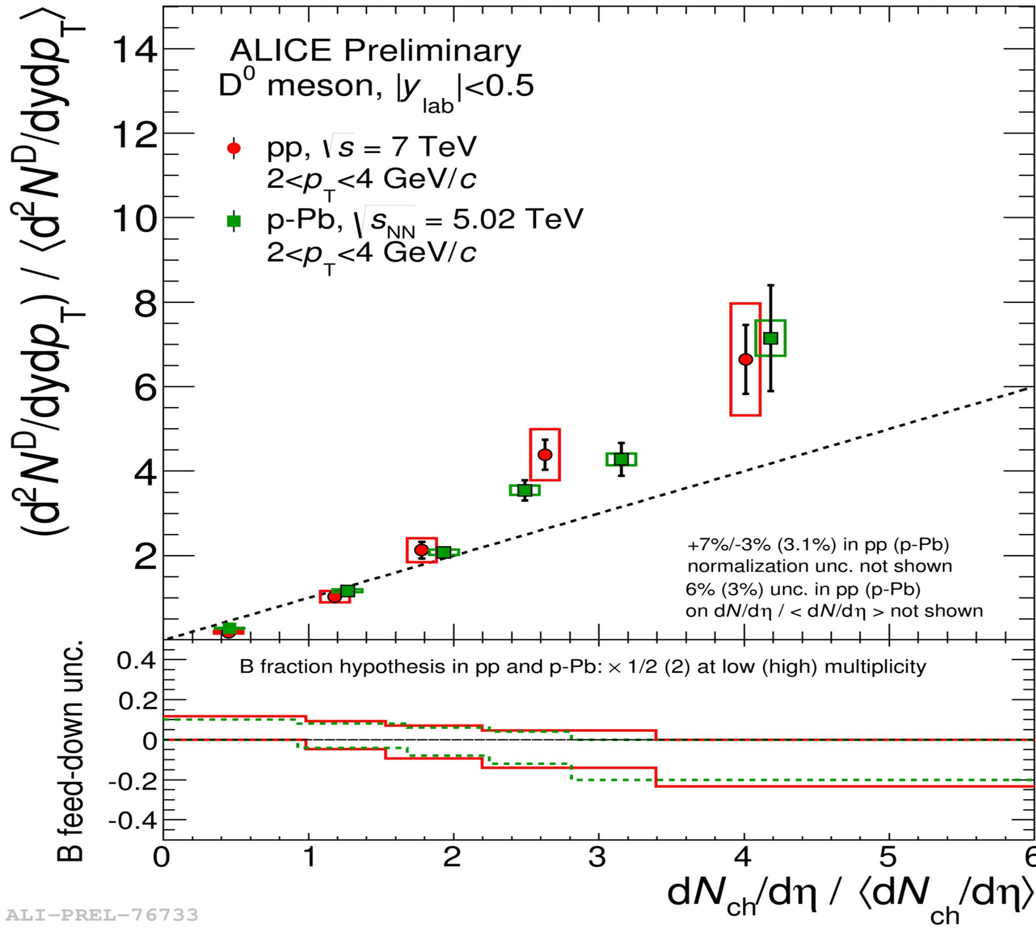
First measurements of Λ_c and v_2 of D_s^+ will be feasible!

Summary and Outlook

- Open charm production cross sections in **pp** and **p-Pb** well described by **pQCD** calculations and **CNM effects** in **p-Pb**
- **Heavy-flavour hadrons in Pb-Pb collisions:**
  - Strongly suppressed in high p_T
  - $\boldsymbol{R_{pPb}}$ **close to unity** suggests that this is due to final state effects.
  - **Energy loss mechanisms** can describe this behaviour
    - Different R_{AA} of D (ALICE) and J/ψ from B (CMS) follows the expected quark mass dependence of energy loss
    - More statistics needed to draw conclusion on D vs. pion R_{AA}
  - Elliptic flow, $\mathbf{v_2 > 0}$ → indicates **collective motion** of charm in the medium.
    - More statistics needed to put more stringent constraints to models → Run 2015 and Upgrade
- **ITS + TPC Upgrades → Readout units will work much faster**
- **ITS upgrade** → Improve tracking and vertexing resolution
  - Improve significance and reduce background of the open charm reconstruction.
  - High precision measurements of $\boldsymbol{R_{AA}}$ **and** $\mathbf{v_2}$ of several HF hadron species.
  - Heavy-flavour baryons will become accessible in Pb-Pb collisions.

Backup Slides

Results p-Pb II



$$\frac{d^2N^D/dydp_T}{\langle d^2N^D/dydp_T\rangle} = \frac{Y^{mult}/(\epsilon^{mult} \times N^{mult}_{event})}{Y^{tot}/(\epsilon^{tot} \times N^{tot}_{event}/\epsilon^{trigger})}$$

D yield/event in a multiplicity range
Corrected by the reconstruction efficiency

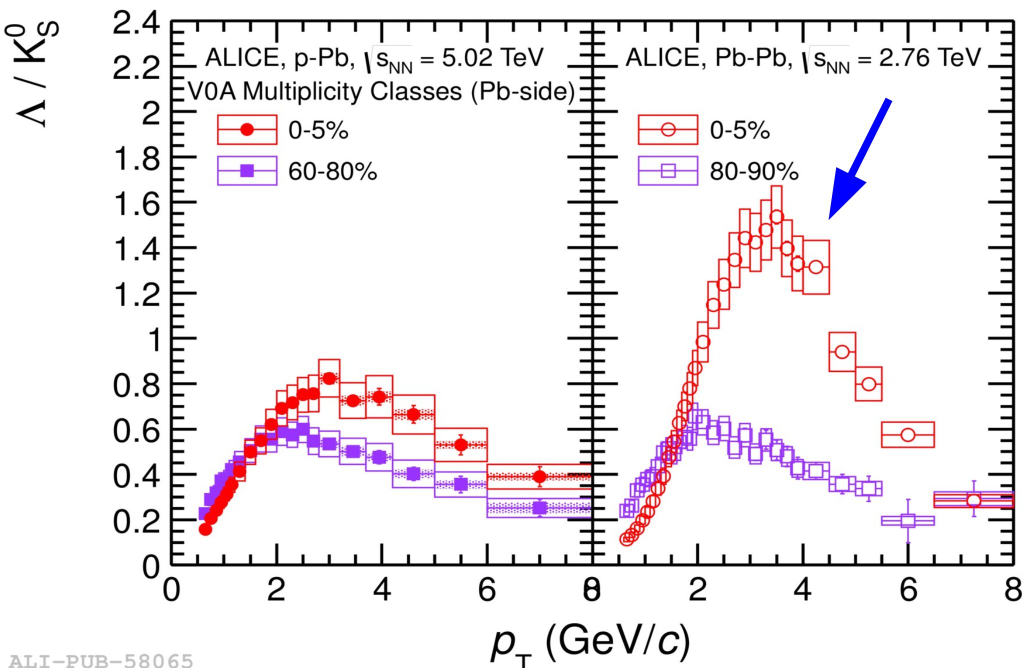
Self-normalized D-meson yields vs. multiplicity
– Increase with the charged particle multiplicity at mid-rapidity.
– Similar behaviour in p-Pb and pp collisions

Λ_C with the ITS upgrade

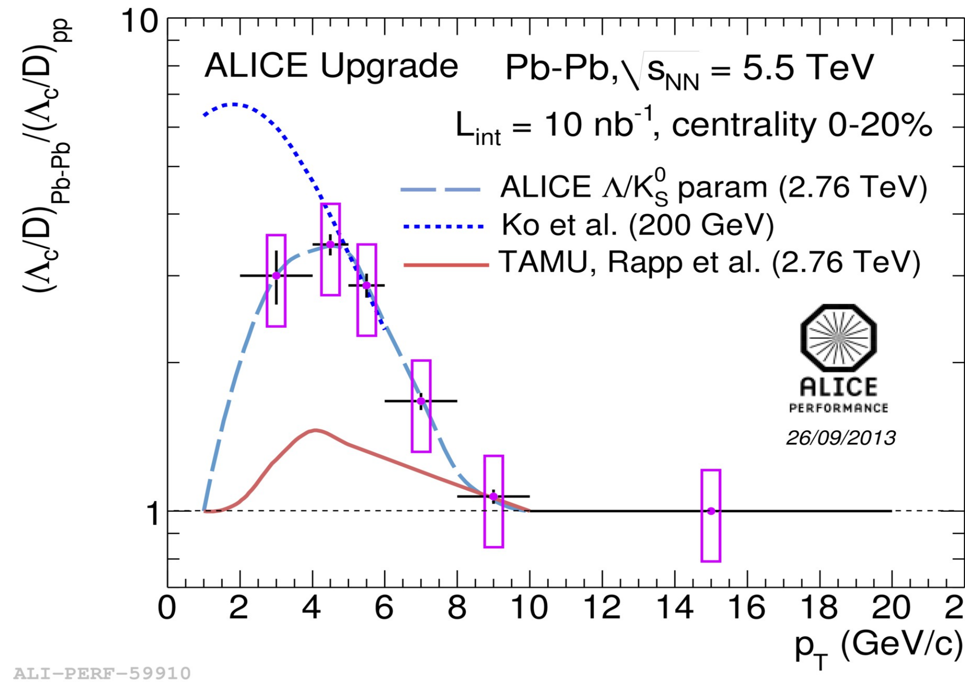
$\Lambda/K_S^0 \rightarrow 2 < p_T < 6$ GeV/c (current data):

Enhanced in most central collisions

Phys. Rev. Lett. 111, 222301 (2013)



Ratio Λ_c/D (ITS Upgrade)



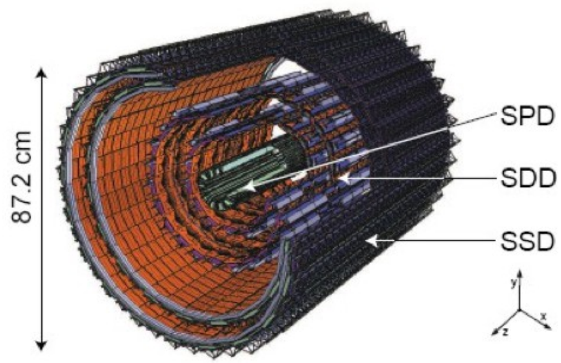
The baryon/meson ratio in the strangeness sector suggests:
Recombination, radial flow processes or hadronisation from di-quarks in the medium?
Does this persist in the charm sector? J/ψ R_{AA} at low p_T suggests that
Λ_c/D will clarify the origin of this effect.

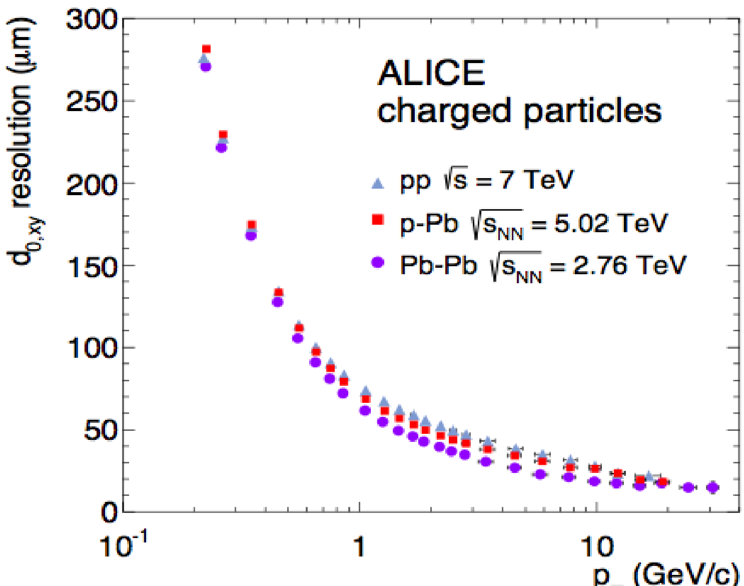
Sufficient statistics to disentangle different models.

ITS Upgrade

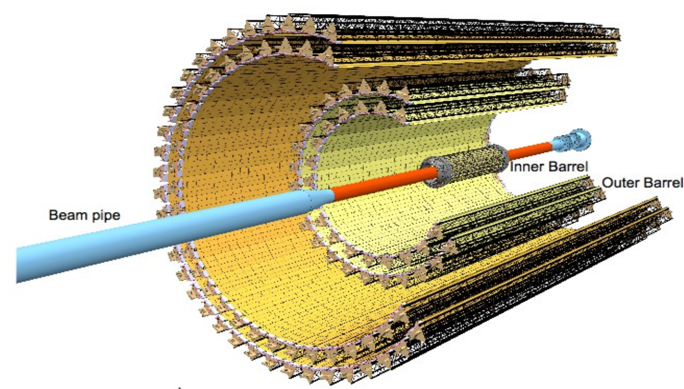
ITS (Inner Tracking System):
→ Very important for open charm analysis
- **Reconstruction depends upon secondary vertex analysis**

Current ITS

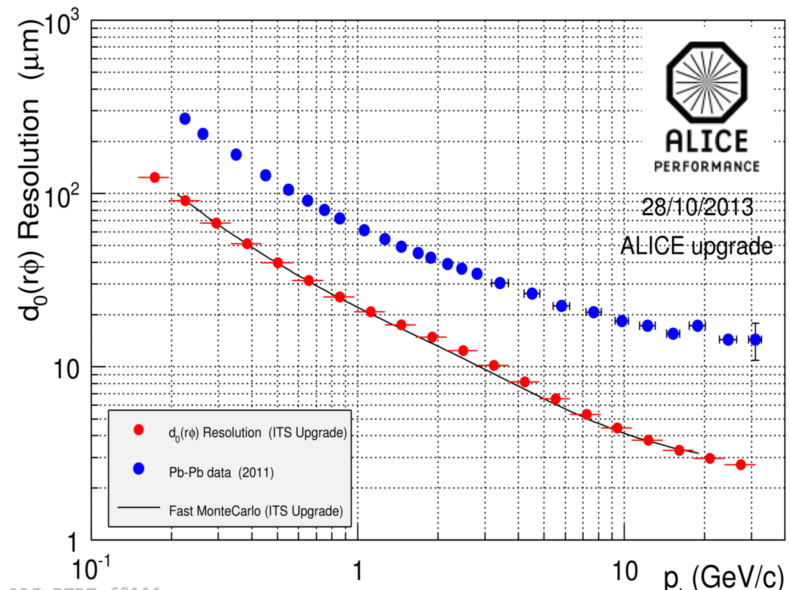




ITS Upgrade



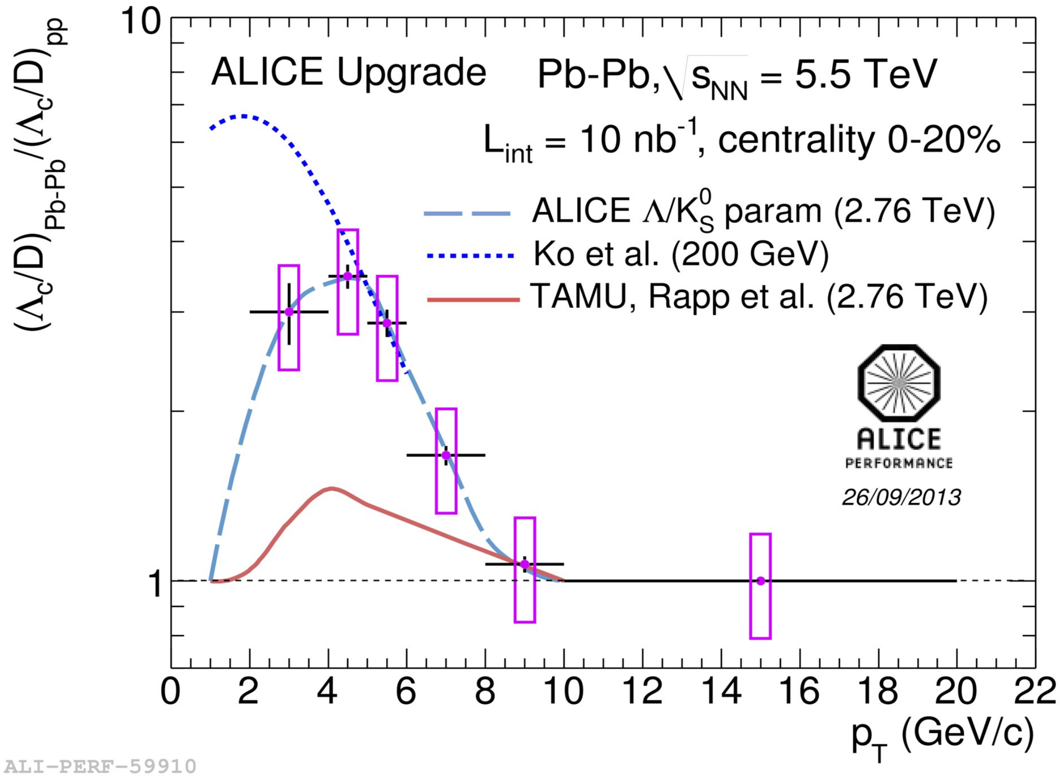
3x factor resolution in the transverse plane
6x in the z direction



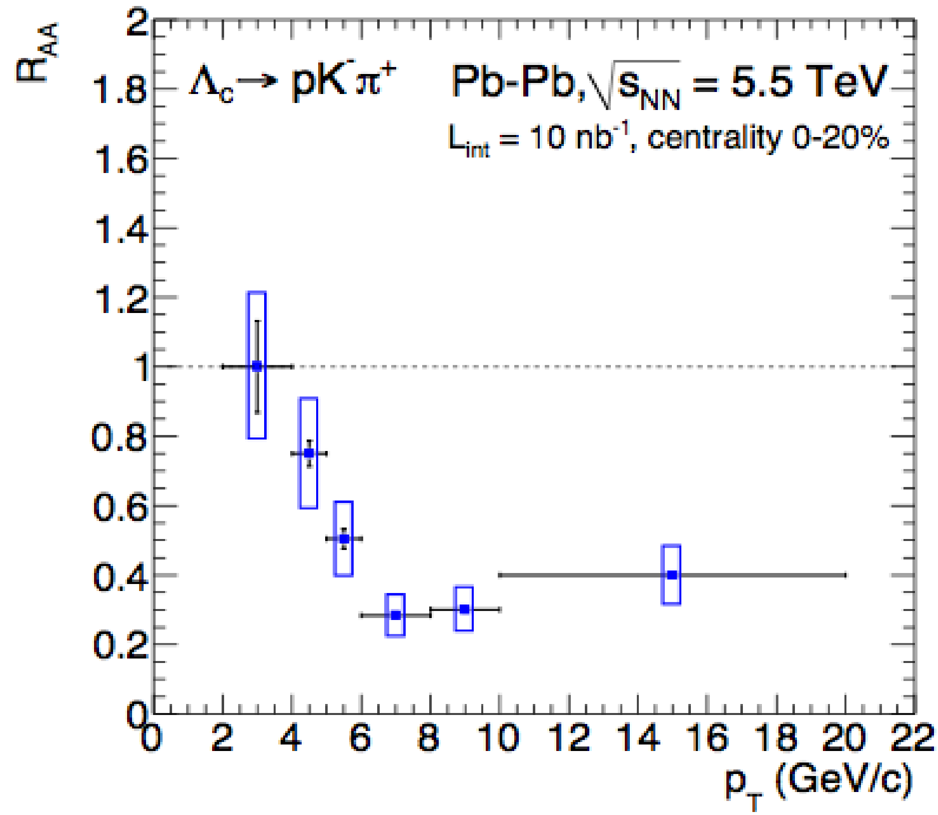
Λ_c with the ITS upgrade

ITS upgrade will improve background reduction

Ratio Λ_c/D



Λ_c R_{AA}:



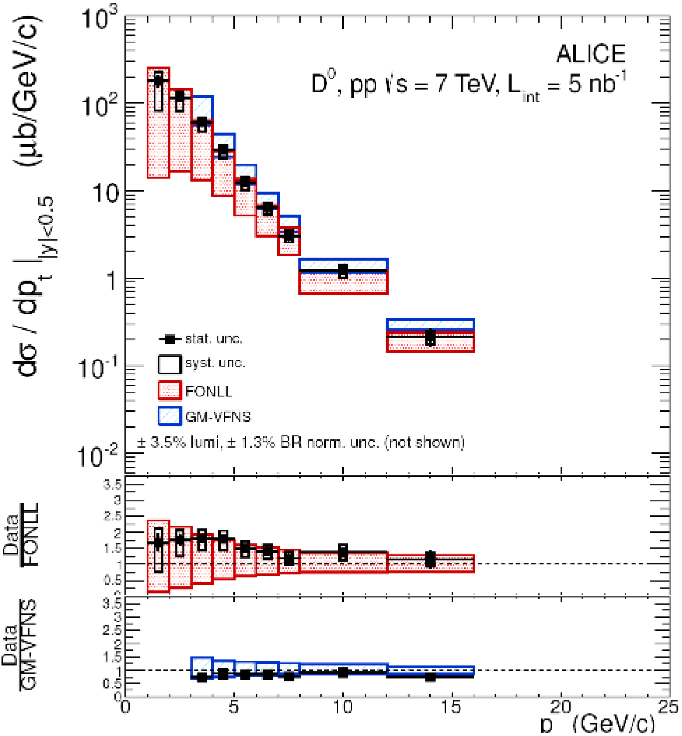
The Ratio Λ_c/D and Λ_c RAA will also be measured

Check baryon/meson ratio for heavy quarks as well.

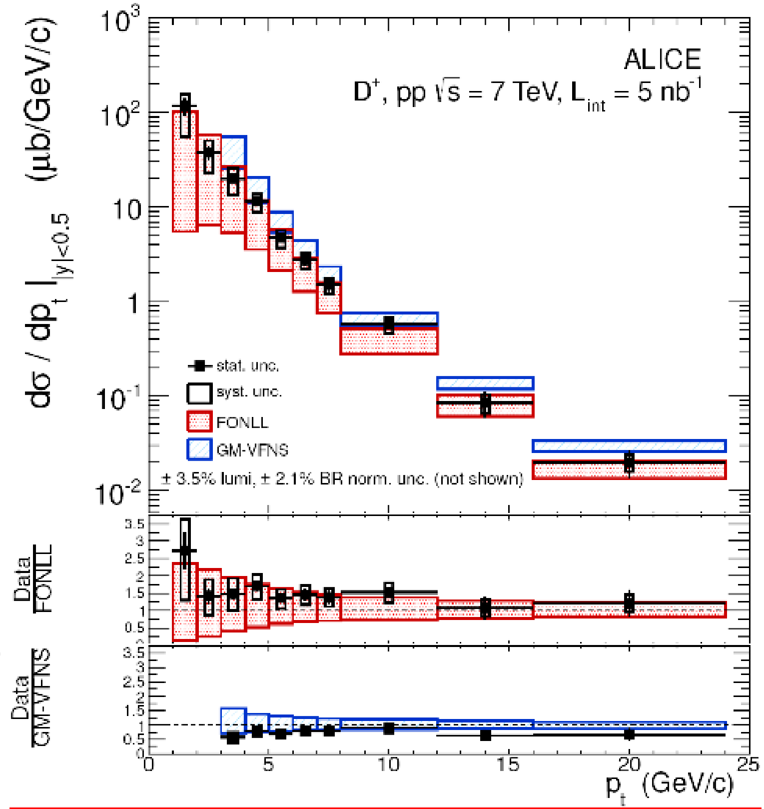
Hadronization mechanisms → Recombination processes for instance

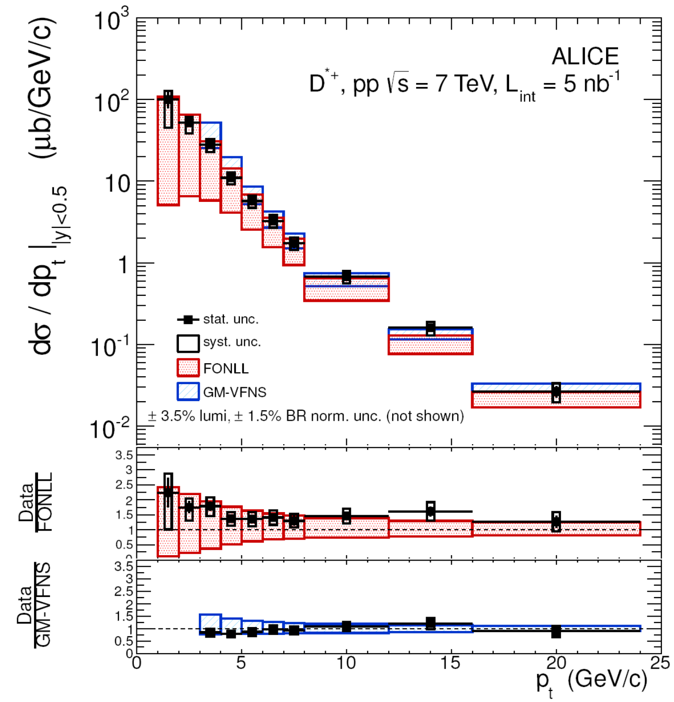
Open charm in pp collisions

D+



D^0





D*

rapidity

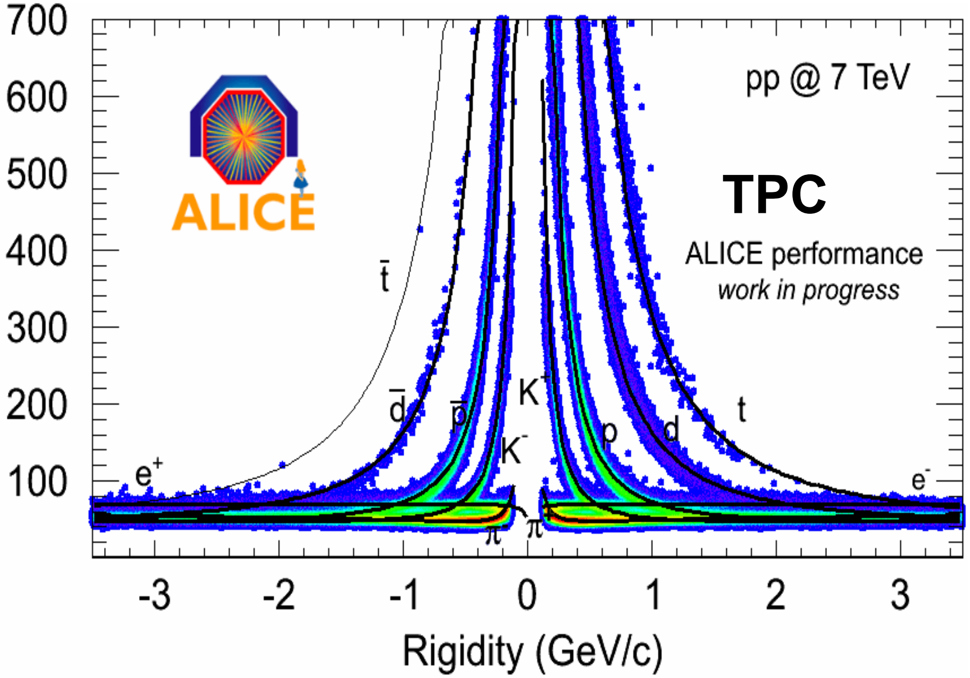
pQCD predictions in agreement with data

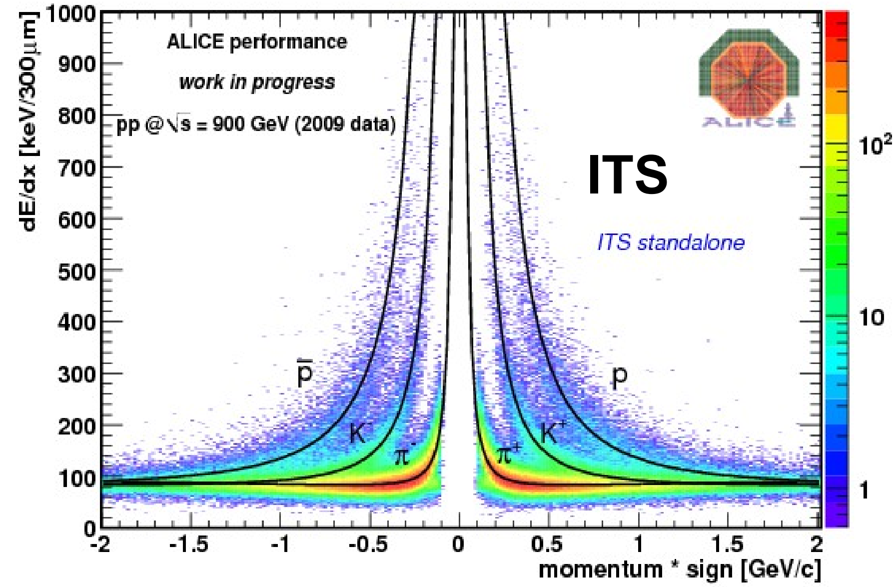
$$y = \frac{1}{2}\ln\left(\frac{E+P_L}{E-P_L}\right)$$

JHEP01(2012)128 (arXiv:1111.1553)

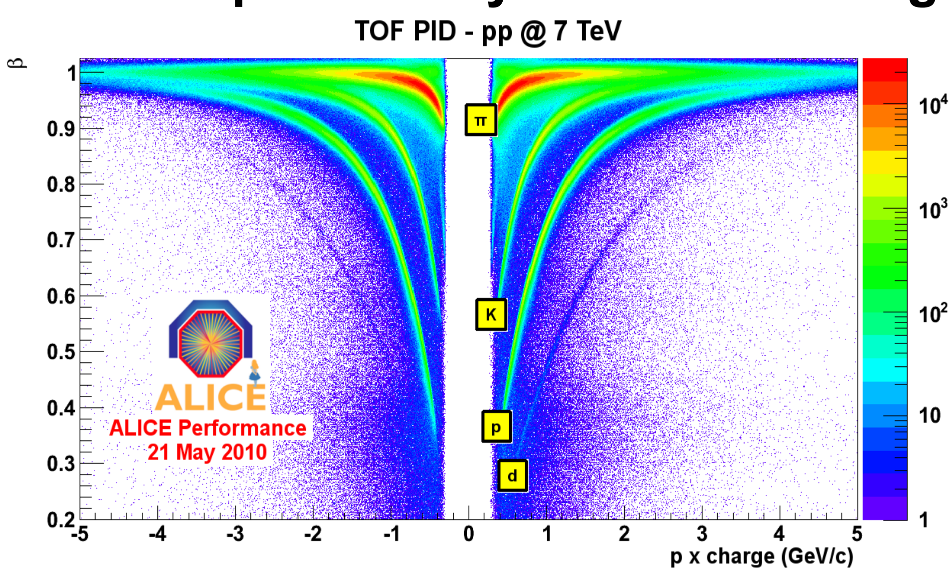
Predictions: FONLL (CERN-PHTH/2011-227) , GM-VFNS (arXiv:1202.0439)

Particle Identification – PID





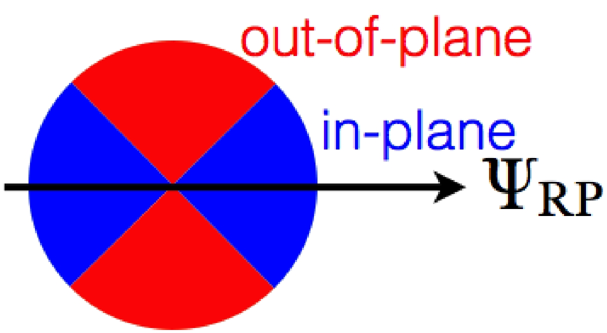
The detectors are complementary and cover a large p_T range



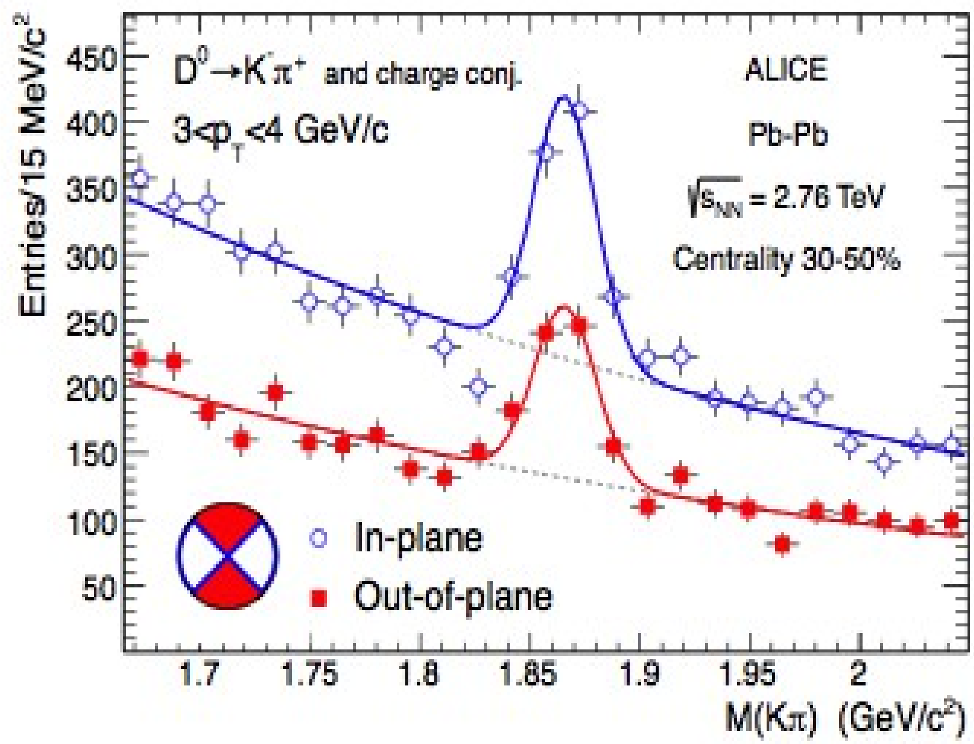
TOF

$V_2 \rightarrow$ E.P. Based Method

- in-plane: $(0, \pi/4] \cup [3\pi/4, \pi)$
- out-of-plane: $(\pi/4, 3\pi/4]$



$$v_2 = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{\text{in-plane}} - N_{\text{out-of-plane}}}{N_{\text{in-plane}} + N_{\text{out-of-plane}}}$$



Phys. Rev. Lett. 111 (2013) 102301