Heavy-flavour production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE

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Outline

- Physics motivations
- Detector and data sample
- D mesons
- Electrons from heavy-flavour hadron decays
- Single muons from heavy-flavour hadron decays
- Conclusions

Physics motivations

- Heavy flavour production provides an excellent QCD test tool.
  - pp : test perturbative QCD predictions, baseline for p-Pb and Pb-Pb

    see talk of *Matthias Richter, this conference*
  - p-A : disentangle initial from final state effects, PDFs at small-x, gluon saturation, ...
  - A-A : probe the high density medium (QGP)

☑ Heavy quarks produced at the early stage of the collision (*large mass requires high* Q^2)

☑ Produced before Quark-Gluon-Plasma formation, experience the full collision history

→ Good probes of the QCD medium.

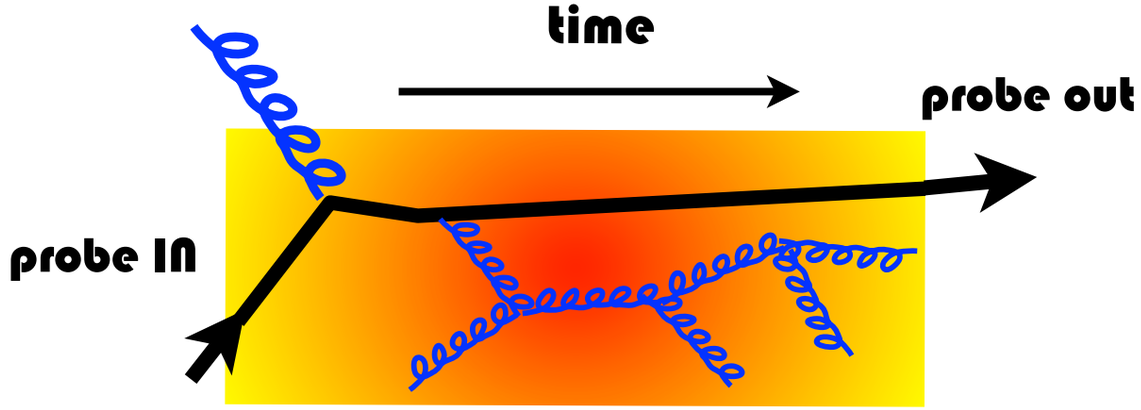
In-medium effects

- Heavy quarks are expected to lose less energy than light quarks and gluons due to color-charge and dead cone effect (radiative energy loss) → higher penetrating power into QCD medium.
  Observable: Nuclear modification factor R_{AA}

$$R_{AA}^{D}(p_T) = \frac{dN_{AA}^{D}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}^{D}/dp_T}$$

Expectations

$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$



Yu. Dokshitzer and D.E. Kharzeev, Phys.Lett. B 519 199–206 (2001). N. Armesto, C. A. Salgado and U. A. Wiedemann. PRD 69 (2004) 114003

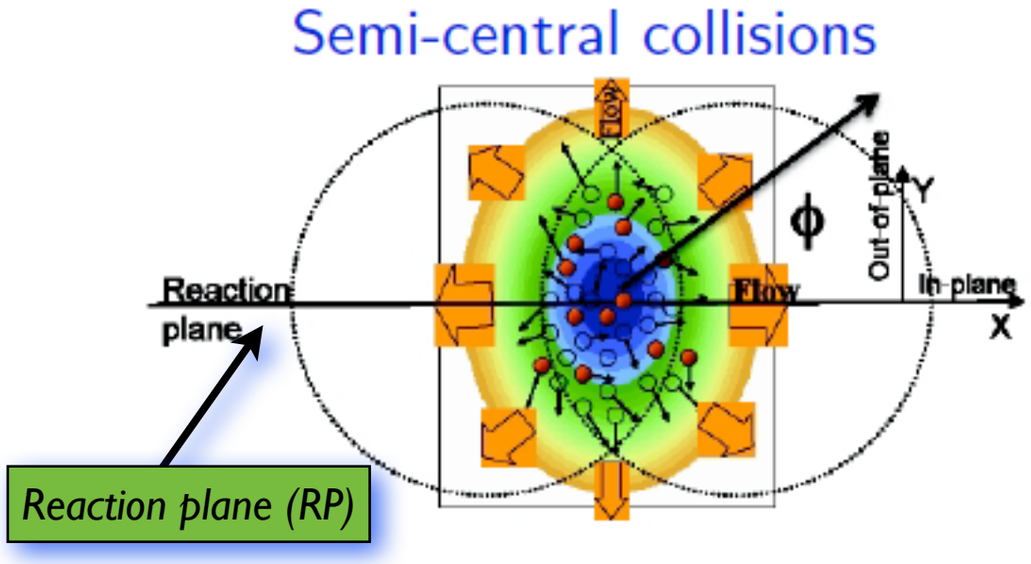
M. Djordjevic, M. Gyulassy, Nucl. Phys. A733 (2004) 265.

- If in-medium quark re-combination dominant mechanism of charm hadron formation at low p_T → strange charm hadrons (D_s) expected to be largely enhanced.

I. Kuznetsova and J. Rafelski, Eur.Phys.J. C51 (2007) 113-133.

M. He, R. J. Fries and R. Rapp, Phys.Rev.Lett. 110 (2013) 112301, arXiv:1204.4442 [nucl-th].

Thermalization and path length dependence



☑ Interaction among medium constituents convert the initial geometrical anisotropy into momentum anisotropy of final state particles

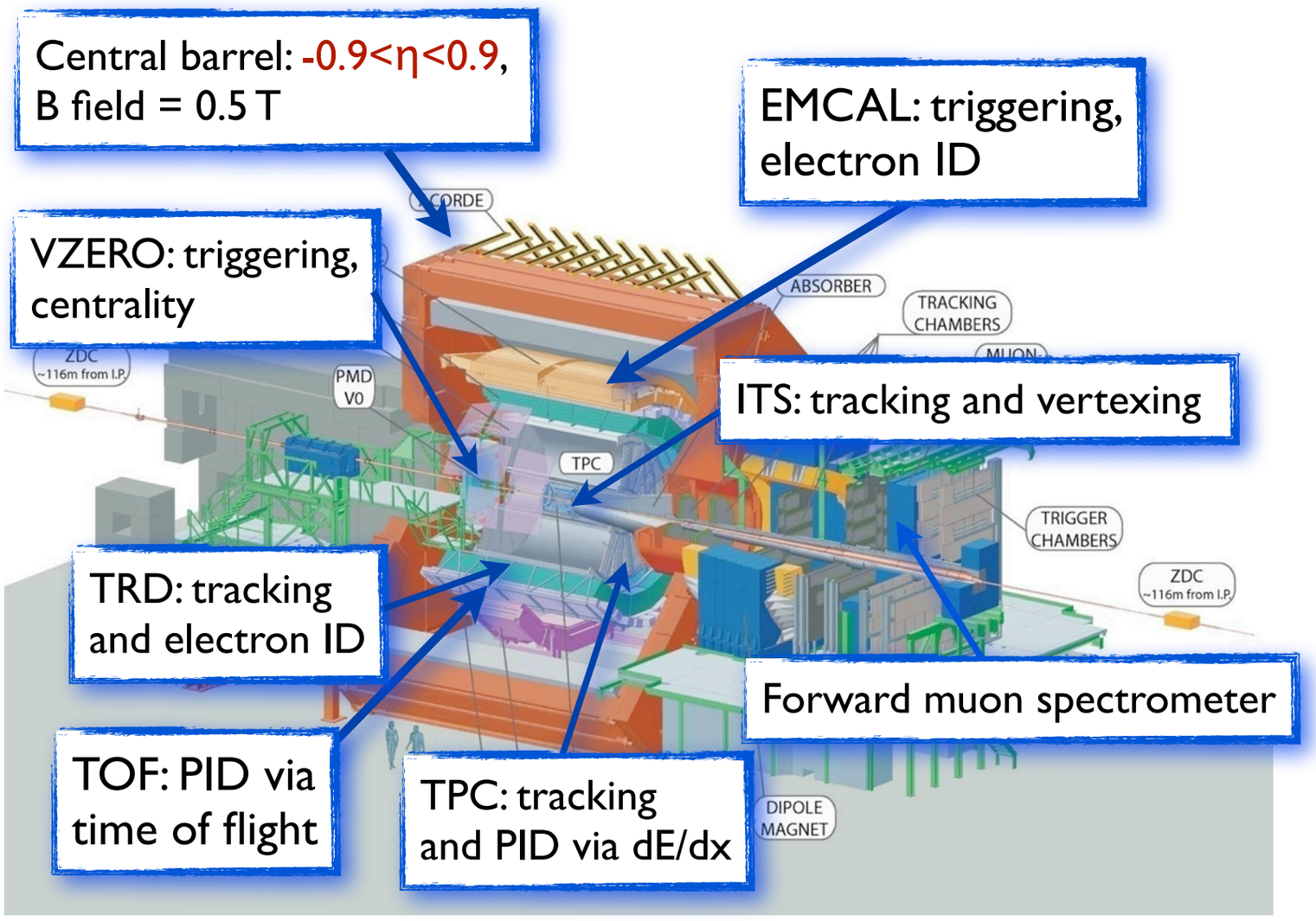
☑ Quantified via the 2nd order Fourier coefficient **v_2 (Elliptic flow)**

$$\frac{dN}{d\phi} = \frac{N_0}{2\pi}(1+2v_1\cos(\phi-\Psi_{RP})+2v_2\cos 2(\phi-\Psi_{RP})+.....)$$

☑ Carries informations on medium transport properties (*viscosity, energy loss*)

- Degree of thermalization of heavy quarks in QGP (low p_T)
- Path length dependence of parton energy loss (high p_T)

Detector and data sample



☑ Data sample Pb-Pb

2011: Central and semi-central trigger, based on VZERO scintillators. MB using VZERO

☑ Data sample: p-Pb

Minimum bias based on VZERO

☑ Centrality

Determined event-by-event from the measured VZERO amplitude.

System	c.m.s energy (TeV)	events analyzed
Pb-Pb	2.76	~1.6×10^7 (0-10%)
Pb-Pb	2.76	~1.8×10^7 (10-50%)
p-Pb	5.02	~10.2×10^7

New! 2013 run

D mesons via hadronic decay channels

☑ In this talk:

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

$D^+ \rightarrow K^-\pi^+\,\pi^+$

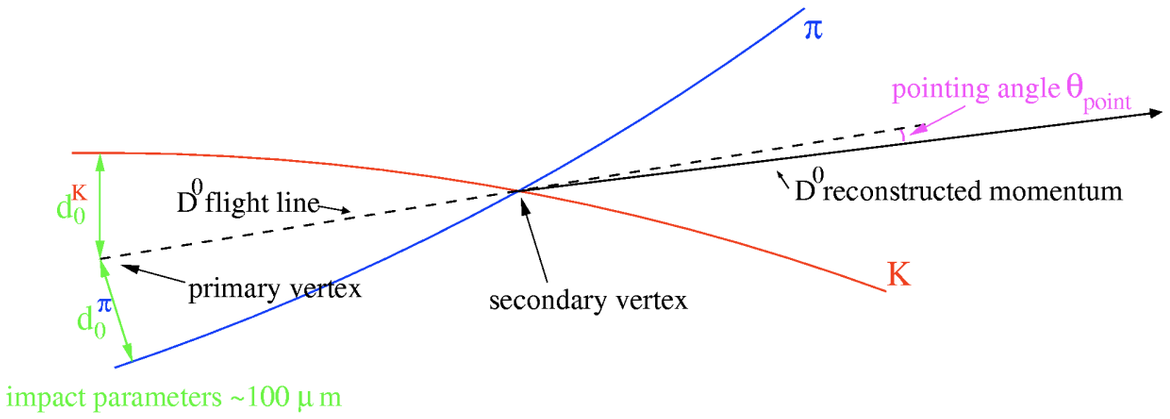
$D^{*+} \rightarrow D^0\,\pi^+ \rightarrow K^-\pi^+\,\pi^+$

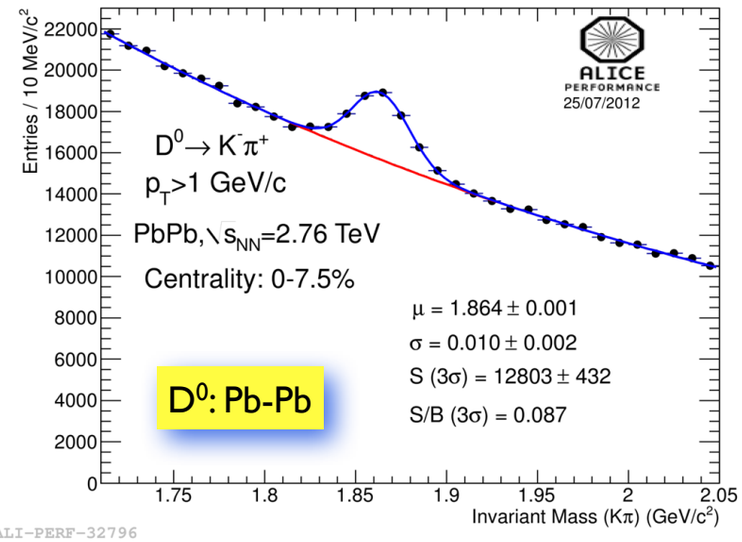
$D^+_s \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$

Except for D^{*+}, the $c\tau$ of the other D mesons ranges from ~123 to 312 μm

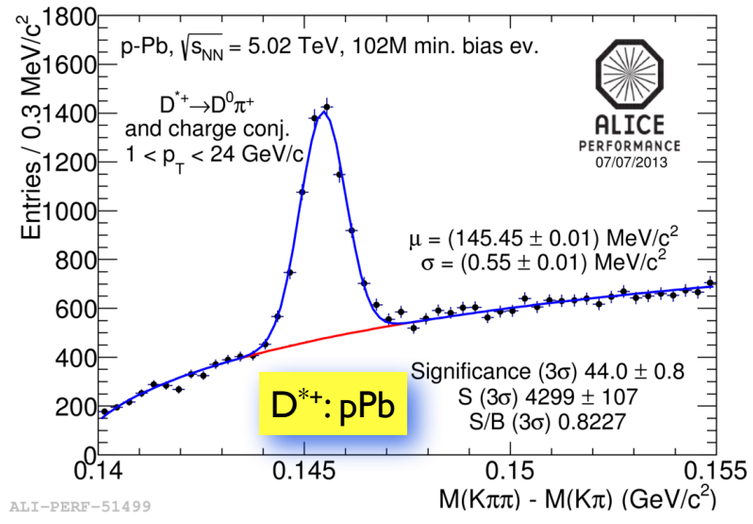
→ Decay vertices displaced by few hundreds of μm from the primary vertex.

☑ Topology of the decay resolved via the reconstruction of the secondary vertex. PID to further reduce the combinatorial background.

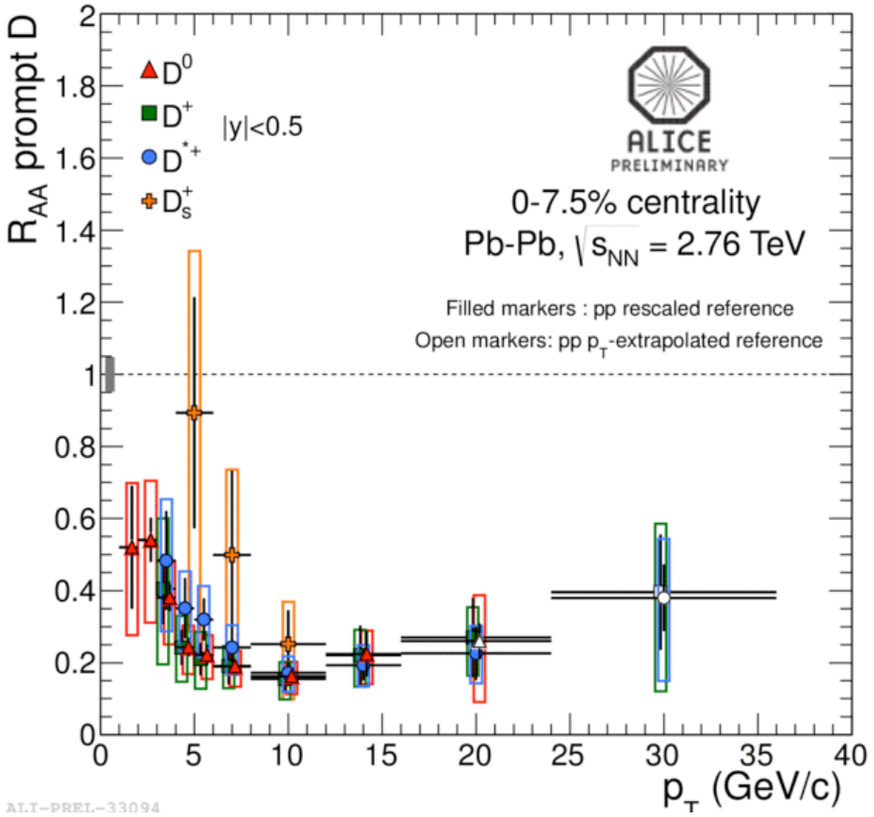


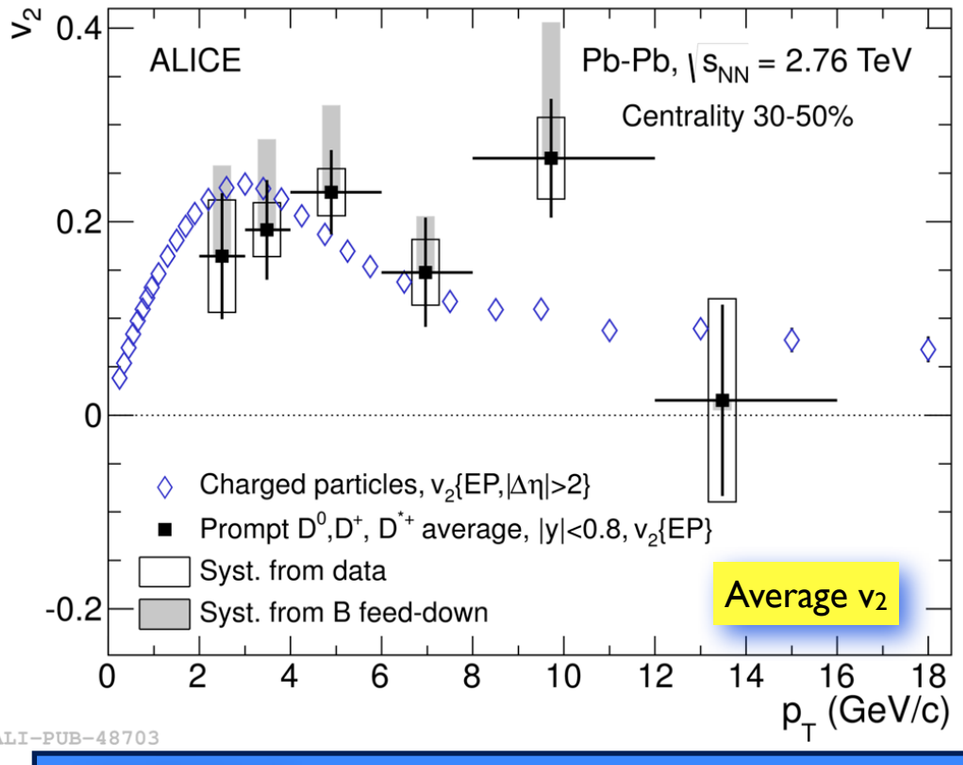


☑ Invariant mass analysis (Similar strategy for pp, p-Pb and Pb-Pb collisions)



p_T-differential nuclear modification factor and v_2





Nuclear modification factor (R_{AA})

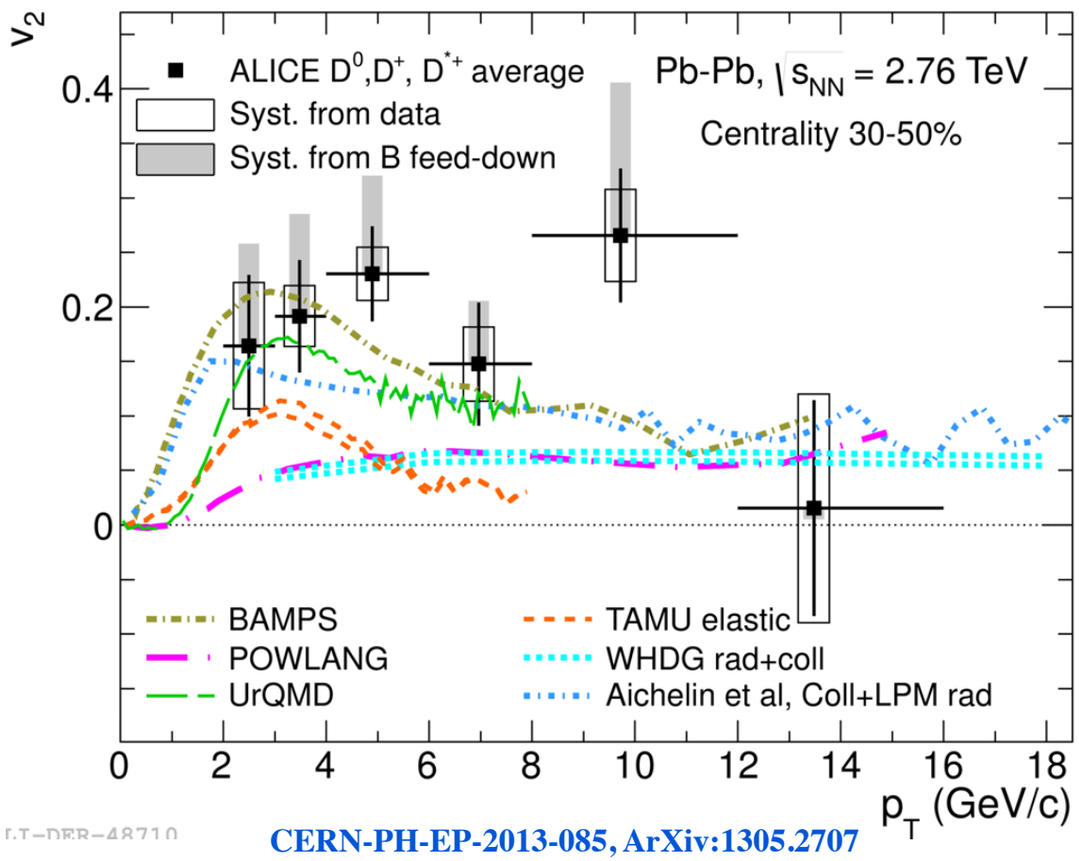
- ☑ D^0, D^+ and D^{*+} R_{AA} measured in the range [1,36] GeV/*c* with 2011 data. Compatible within uncertainties
- ☑ Suppression up to a factor 5 for D^0, D^+ and D^{*+} at p_T~10 GeV/*c*
- ☑ Enhancement of D^+_s due to strangness content? data not conclusive yet.

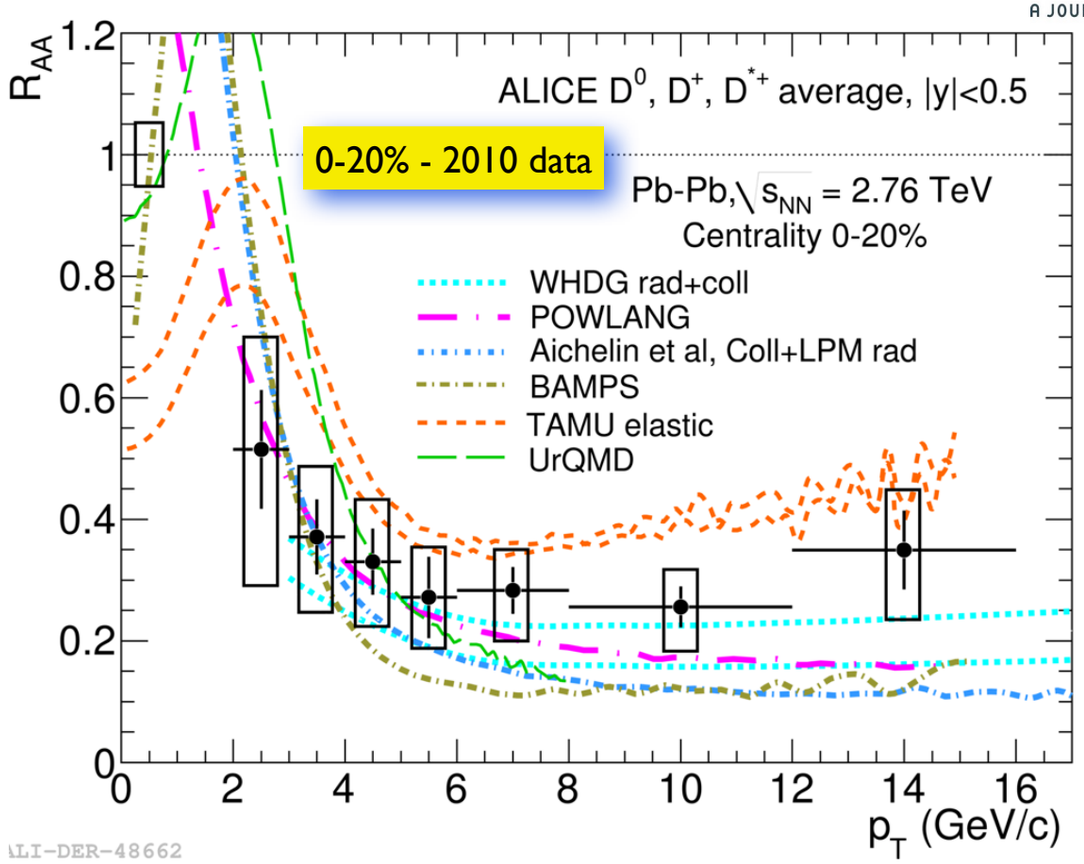
Elliptic flow v_2 New!

- ☑ Non zero D meson v_2 for $2<p_T<6$ GeV/*c* (>5σ effect)
- ☑ D meson v_2 comparable with charged hadron v_2 measured by ALICE in the same centrality class (30-50%)

CERN-PH-EP-2013-085, ArXiv:1305.2707

Comparison with models



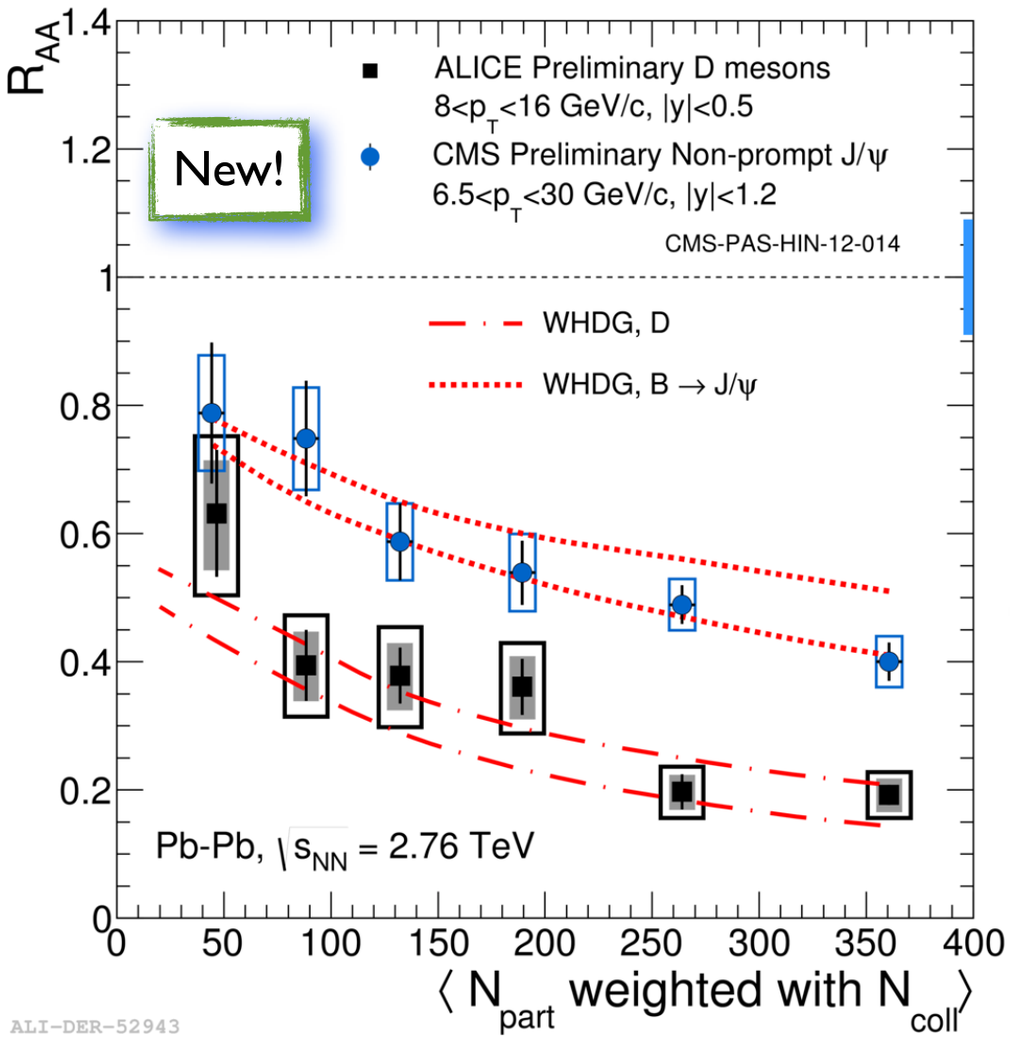


CERN-PH-EP-2013-085, ArXiv:1305.2707

☑ Simultaneous description of D meson R_{AA} and v_2 → understanding of heavy quark transport coefficients of the medium (challenging for models)

BAMPS: Uphoff et al. arXiv:1112.1559., O. Fochler, J. Uphoff, Z. Xu and C. Greiner, J. Phys. G38 (2011) 124152.
Aichelin et al. Phys. rev. C 79 (2009) 044906,
W.A. Horowitz et al. J. Phys. G38, 124064 (2011).,W. A. Horowitz and M. Gyulassy, J. Phys. G38 (2011) 124114.
W. M. Alberico et al. Eur. Phys. J. C 71, 1666 (2011). M. He, R.J Fries and R. Rapp, arXiv:1204.4442 [nucl-th]

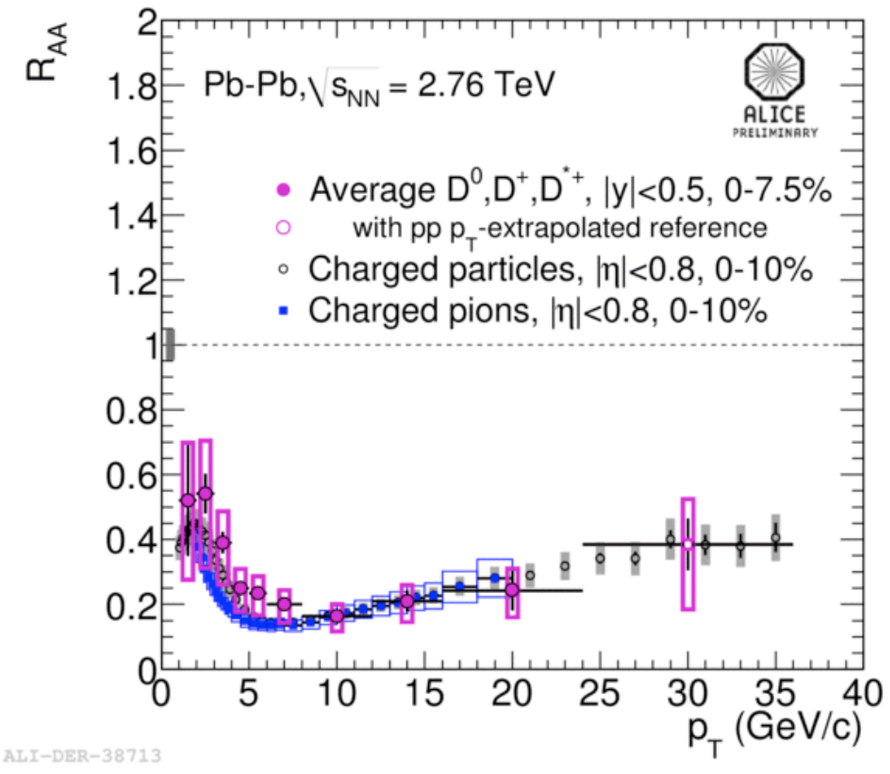
Centrality dependent R_{AA}: Mass hierarchy



☑ Average D^0, D^+ and D^{*+} R_{AA} vs N_{part} measured in the p_T range [8,16] GeV/*c*. Non-prompt J/ψ released by CMS collaboration Compatible average p_T between D mesons and B mesons from which the non-prompt J/ψ came from.

Clear indication of a more relevant suppression with respect non prompt J/ψ ($R_{AA}(D)<R_{AA}(J/\psi\leftarrow B)$)

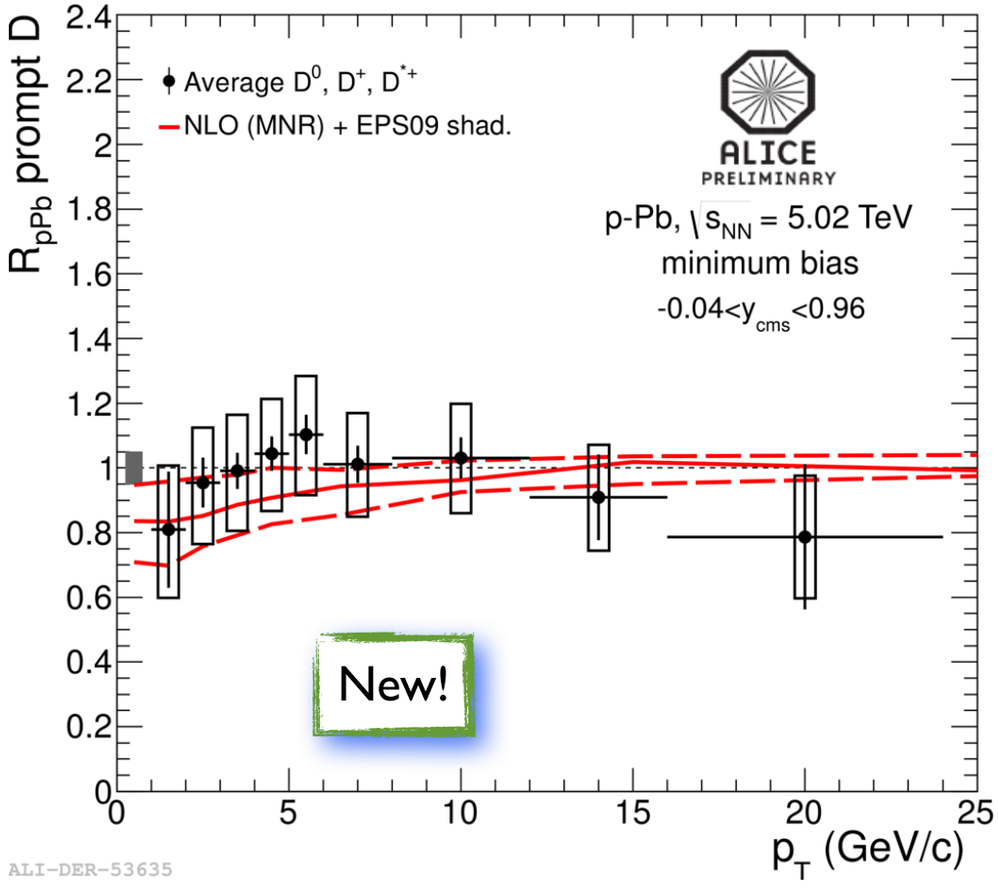
☑ The comparison with charged pions in the most central class it is not conclusive. There is an hint of a lower suppression of D mesons at low p_T (<4 GeV/*c*), but still compatible within systematics

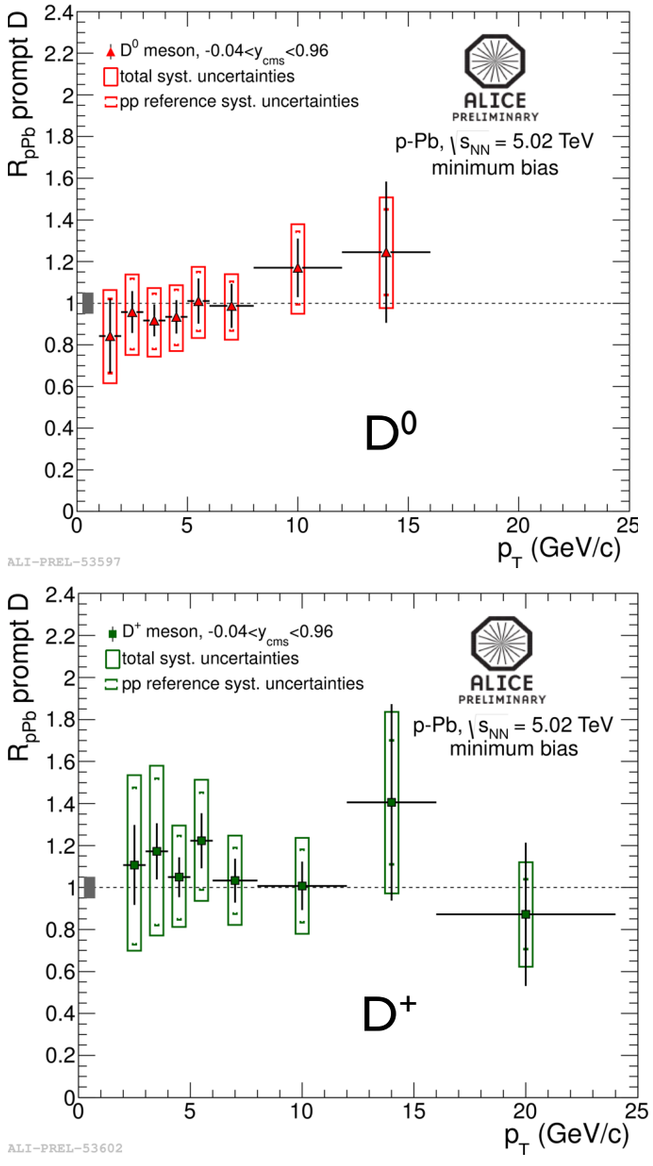


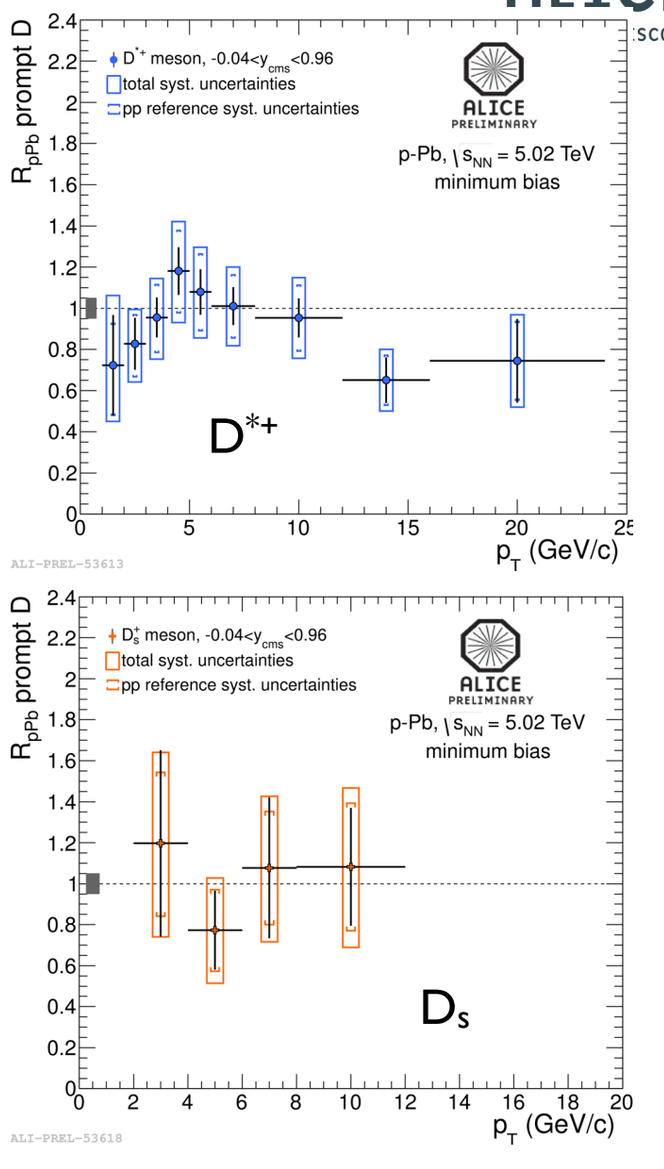
D meson R_{pPb}

- First measurement of the D meson R_{pPb} made using 2013 p-Pb ALICE data sample. D^0, D^+, D^{*+} and D_s show a compatible trend within uncertainties

$$R_{\mathrm{pPb}} = \frac{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pPb}}}{A \times \left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pp}}}$$





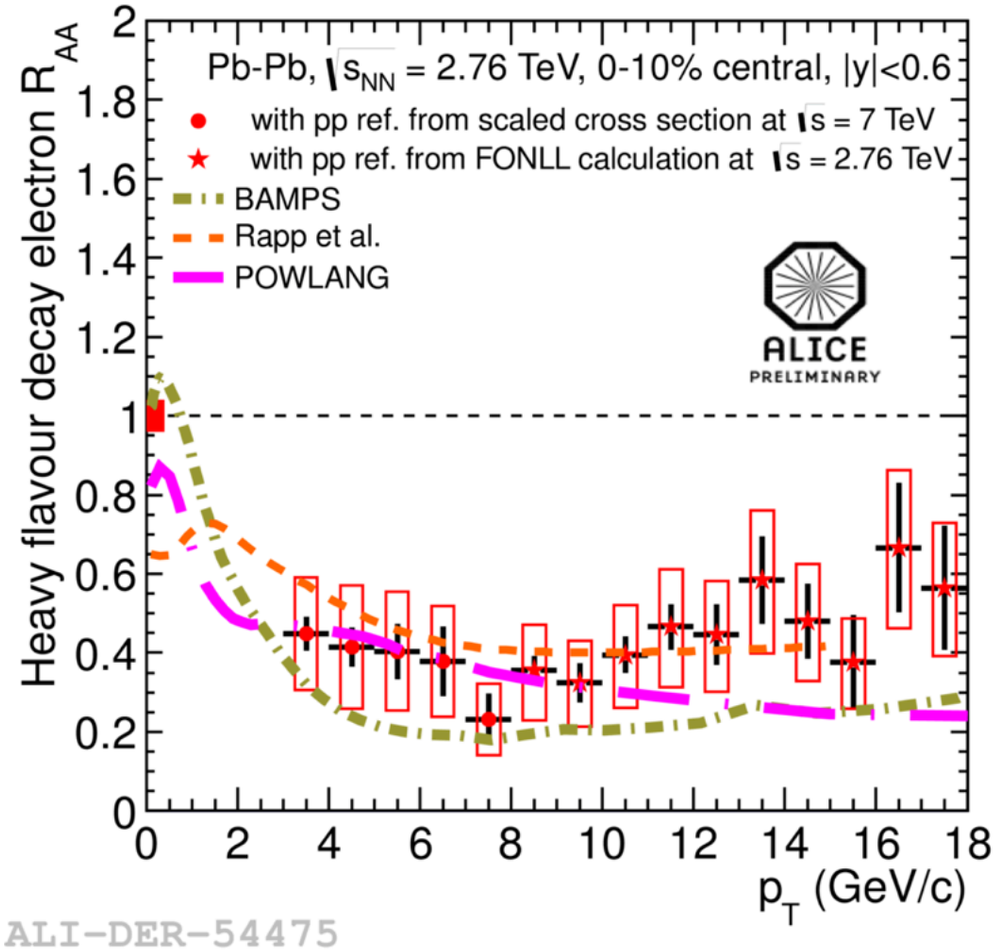


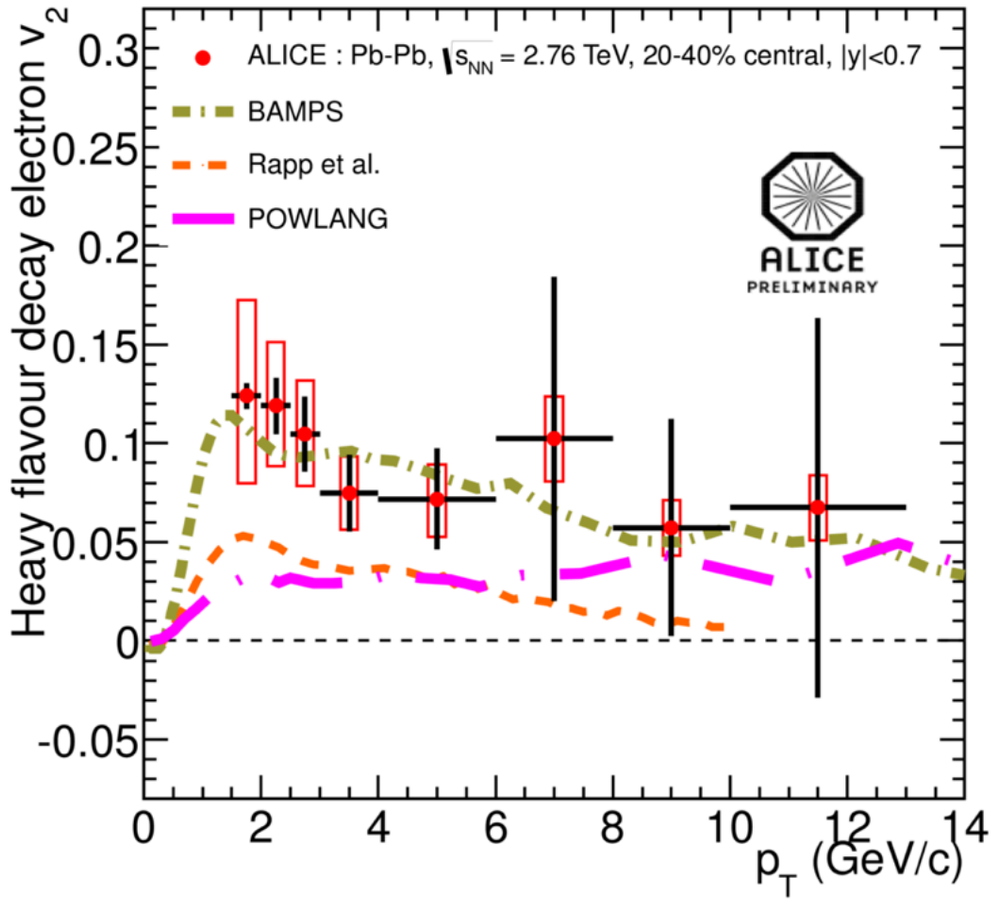
- Comparison with EPS09 nPDF calculations shows a good agreement within the whole p_T region covered by the measurement

Heavy flavour decay electrons

Heavy Flavour decay electrons R_{AA} and v_2: Pb-Pb, 0-10%

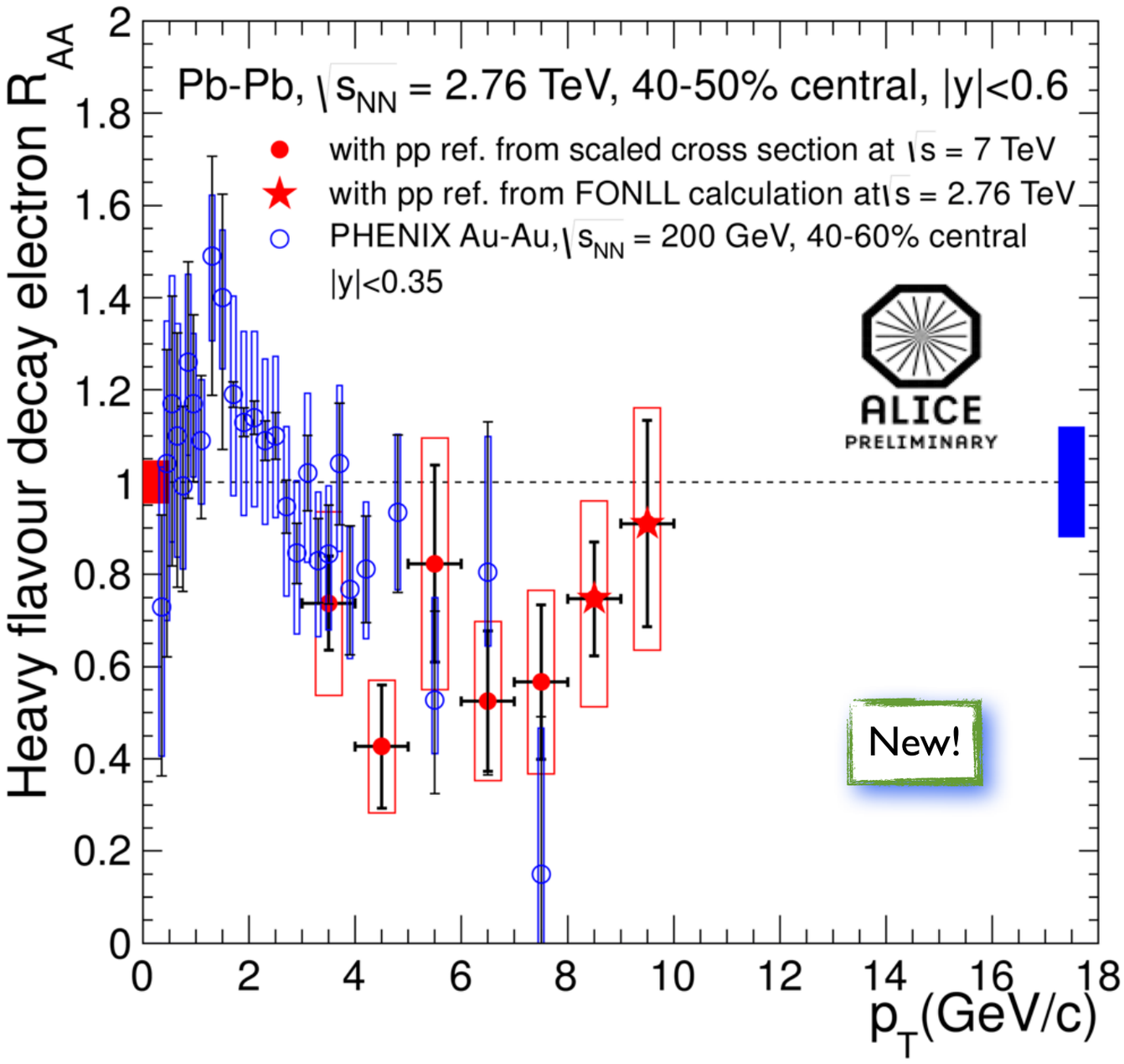
- High quality tracks in ITS+TPC. Electron identification using TOF, TPC, TRD and EMCal.





- R_{AA}: Suppression by a factor of ~3 in the centrality class 0-10%
- Challenging for models the simultaneus description of R_{AA} and v_2

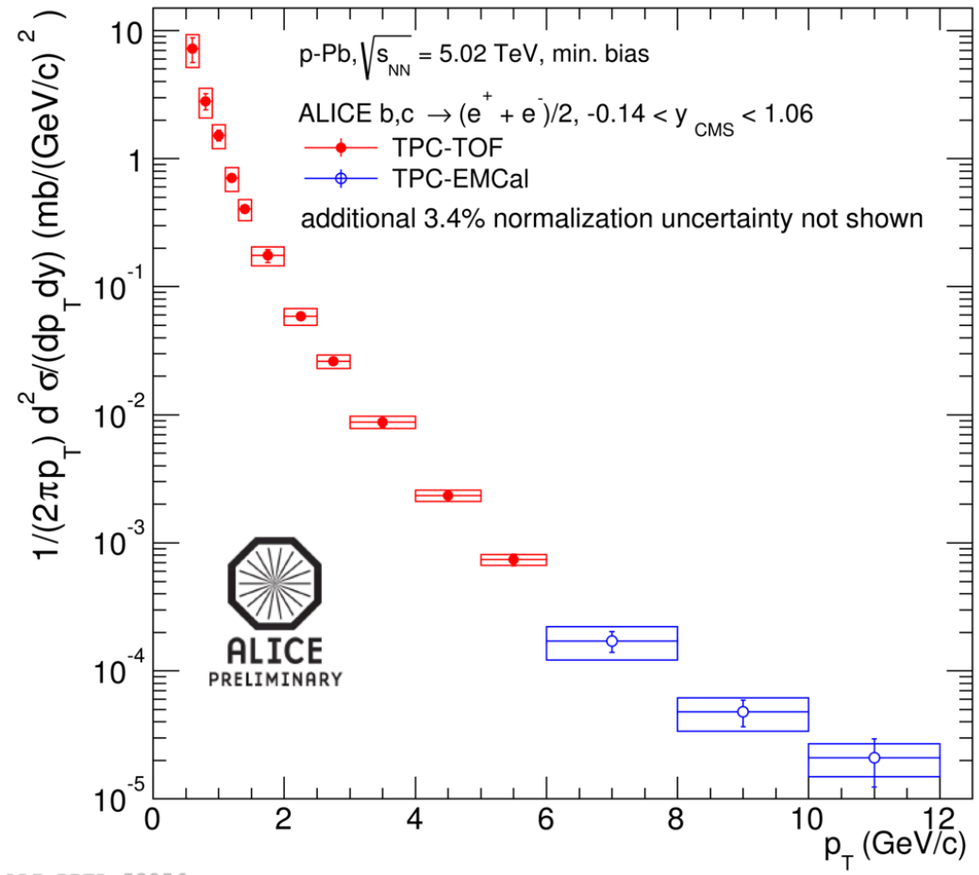
Heavy Flavour decay electrons R_{AA} : 40-50%

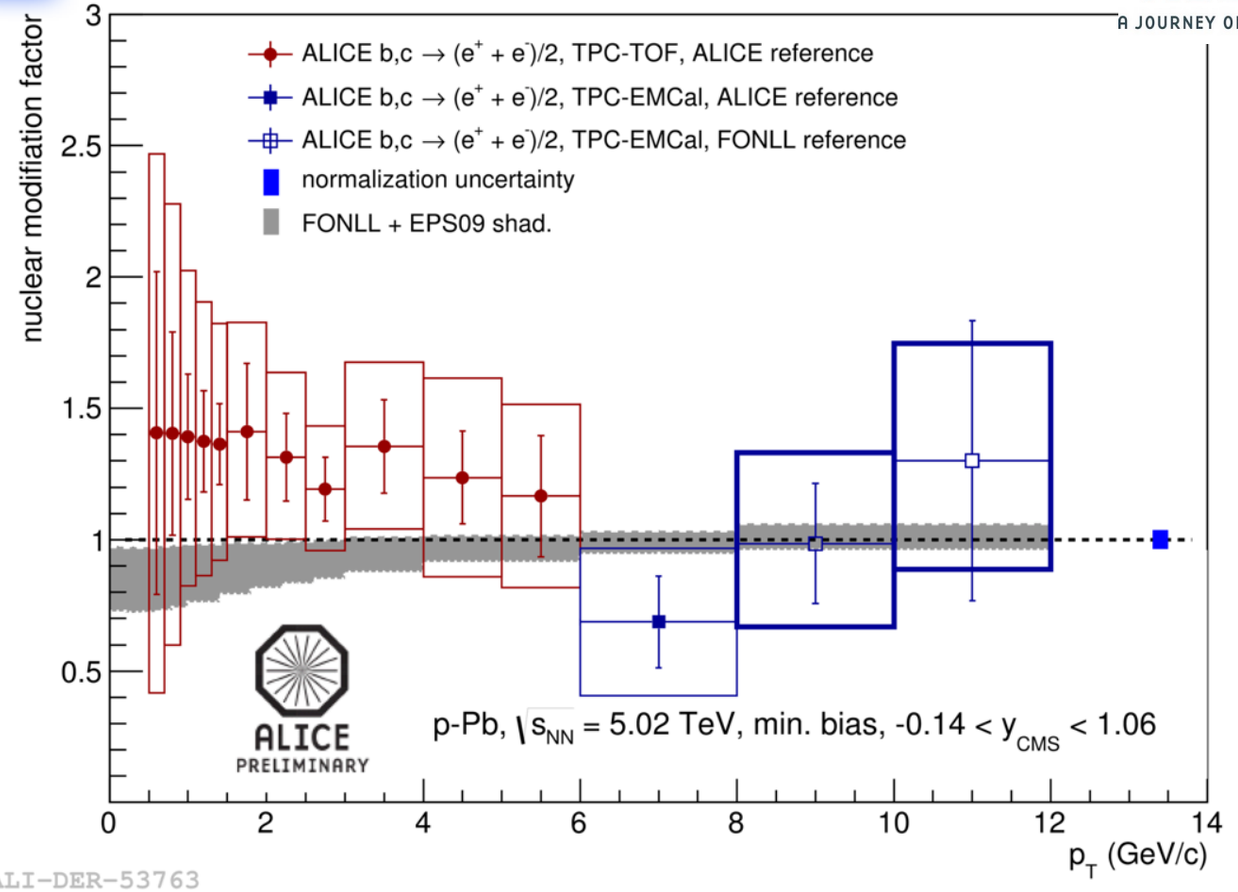


- Heavy flavour decay electron R_{AA} measured in semi-central (40-50%) centrality region at mid-rapidity
- Comparison with PHENIX measurement ($\sqrt{s_{NN}}$=0.2 TeV) in the centrality range 40-60% shows agreement within uncertanties.

Heavy flavour decay electrons R_{pPb}

New!

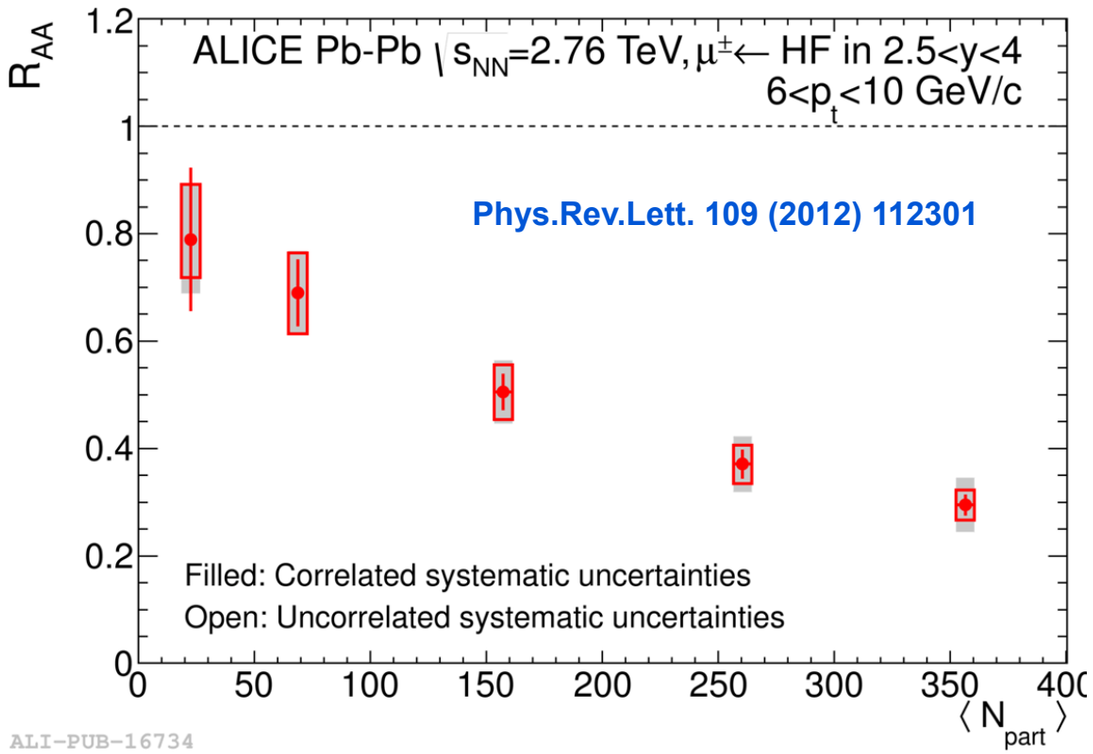




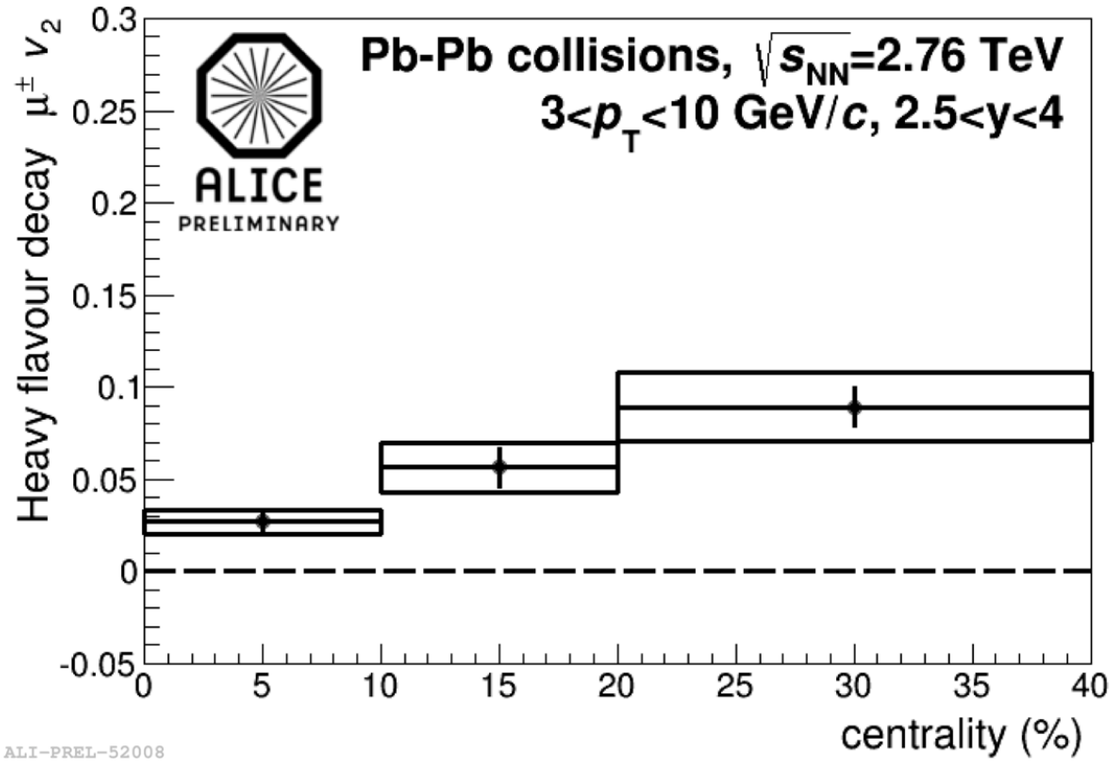
- Heavy flavours decay electron R_{pPb} measured using TPC+TOF electron identification for $p_T < 6$ GeV/*c* and TPC+EMCal electron identification at higher p_T
- Comparison with EPS09 parametrization of nuclear PDFs show agreement within systematics.

Heavy-flavour decay muons

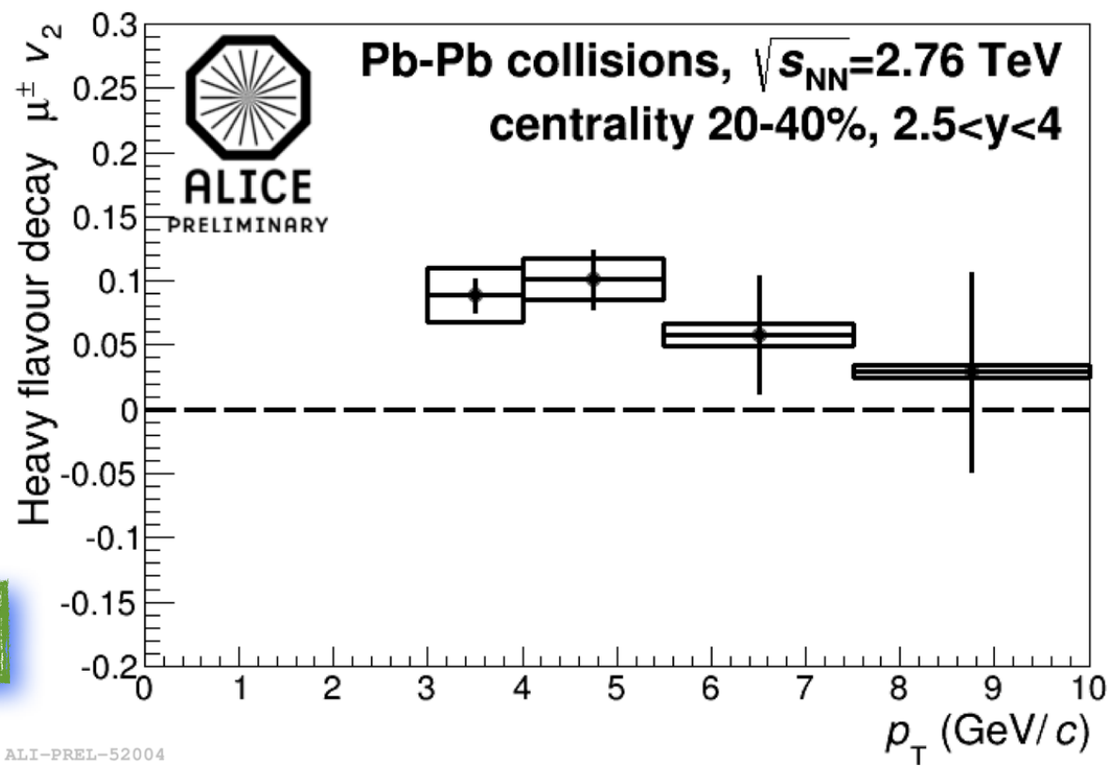
Heavy flavour decay muons: R_{AA} and v_2



- Clear dependence on centrality of the R_{AA}, suppression by a factor 4 in the most central class
- v_2 measured in 3 centrality classes. p_T differential measurement show a >3σ effect in the region 3<p_T<6 GeV/c
- Centrality dependence of the v_2



New!



Conclusions

- The nuclear modification factor of heavy flavour was measured with ALICE via hadronic and semi-leptonic decay channels. A suppression by a factor 4-5 was found at high p_T, compatible with in-medium energy loss

- A non zero elliptic flow, was measured in the p_T region $2<p_T<6$ GeV/c for D mesons, compatible with the flow of charged hadrons

- The comparison of the average D meson R_{AA} vs centrality with non-prompt J/Ψ shows a clear indication of D mesons being more suppressed, in particular in the 2 most central centrality classes (0-10% ad 10-20%)

- First results from p-Pb measurements shown in this talk. Comparison with expectations from shadowing calcuations show a good agreement within uncertanties

- The statistical precision of heavy flavour measurements will profit dramatically of the ALICE upgrade - see talk of Chiara Bianchin, this conference

Backup

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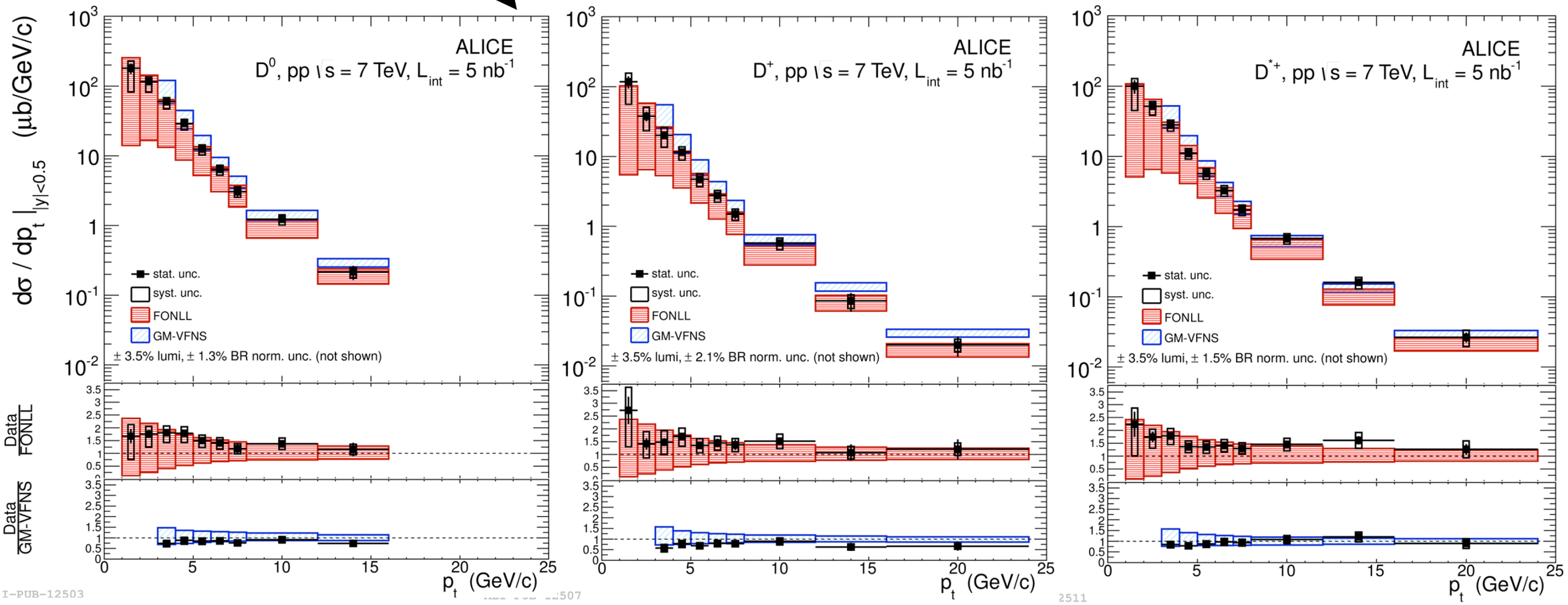
pp as baseline for Pb-Pb: D^0, D^+ and D^{*+}

D^0, D^+ and D^{*+} cross section at $\sqrt{s} = 7$ TeV, $|y|<0.5$



B. I. Abelev et al. [ALICE Collaboration], JHEP 01 (2012) 128.

☑ Large p_T coverage [1,24] GeV/c and well described by pQCD predictions.

M. Cacciari, M. Greco and P. Nason, JHEP 9805 (1998) 007;
M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason, G. Ridolfi, arXiv:1205.6344

B.A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger, arXiv:1202.0439, DESY-12-013, MZ-TH-12-07, LPSC-12019

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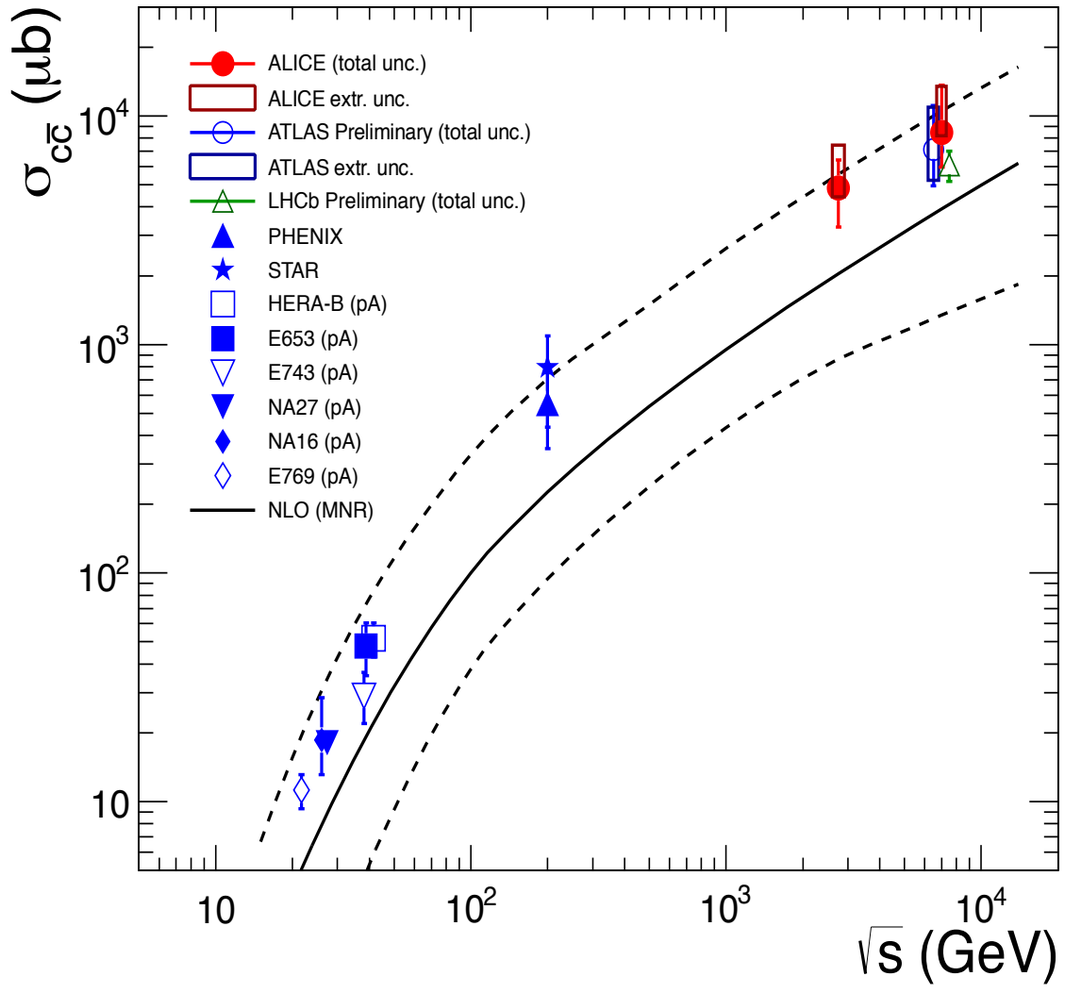
pp as baseline for Pb-Pb: D^0, D^+ and D^{*+}

B. I. Abelev et al. arXiv:1205.4007 [hep-ex].
JHEP 1207 (2012) 191.



FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

- p_T differential production cross sections of D^0, D^+ and D^{*+} measured @ 2.76 TeV. Good agreement with FONLL and GM-VFNS calculations
- Total nucleon-nucleon (pp) charm production cross section. In case of proton-nucleus collisions the measured cross section have been scaled down by the number of binary nucleon-nucleon collisions. Results are compared with NLO MNR calculation

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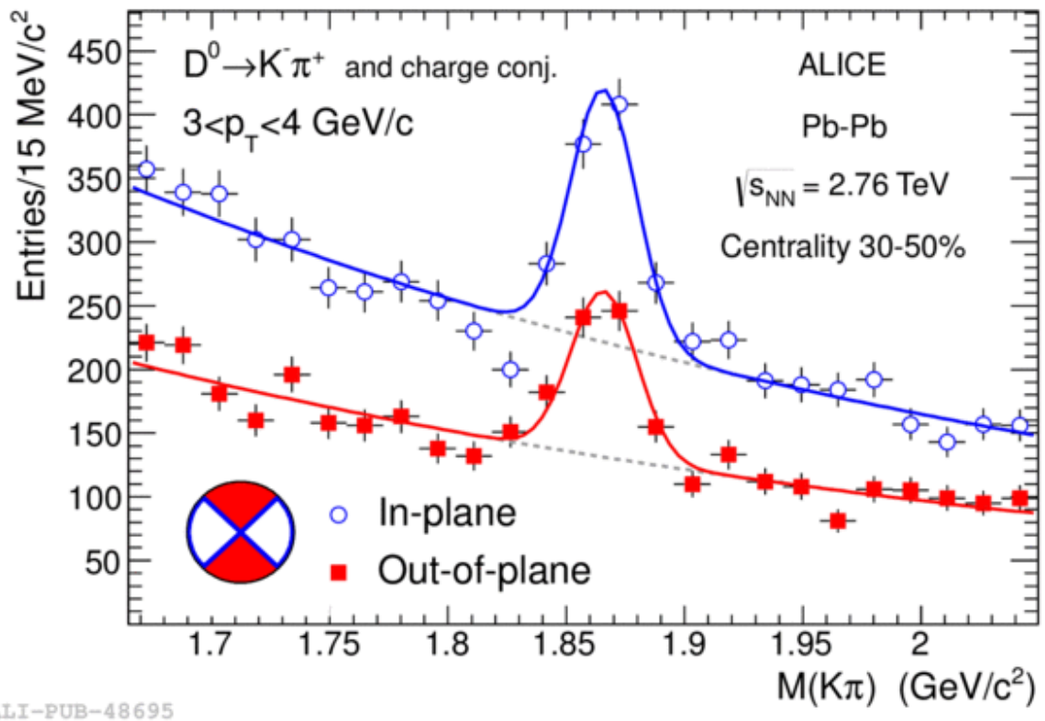
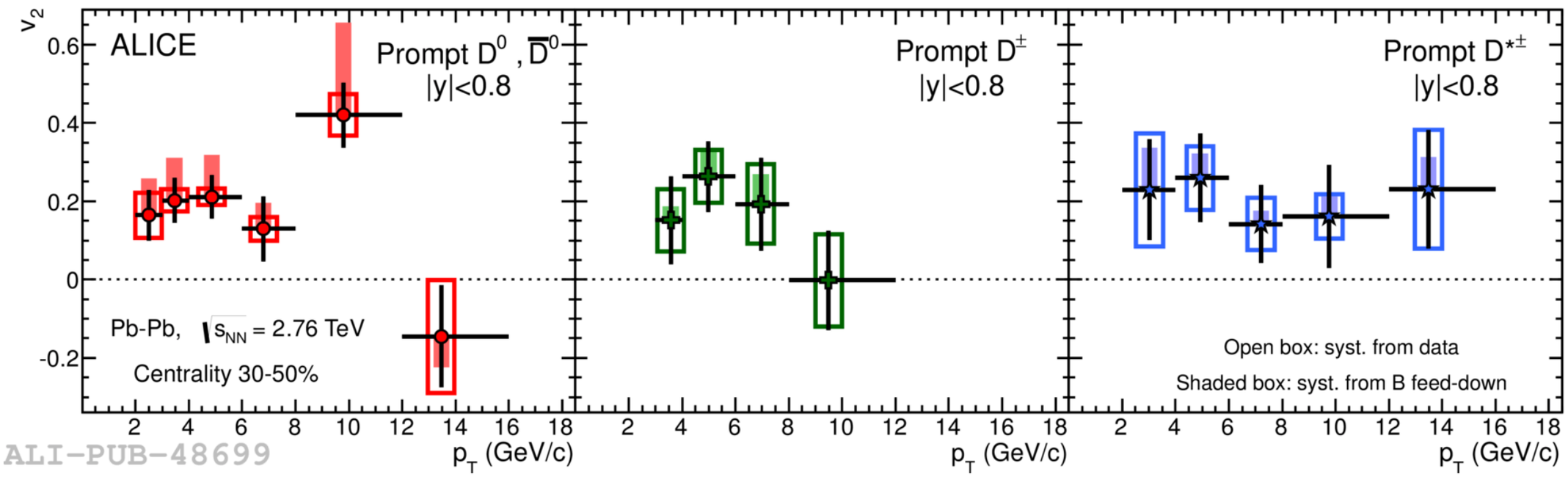
D mesons v2





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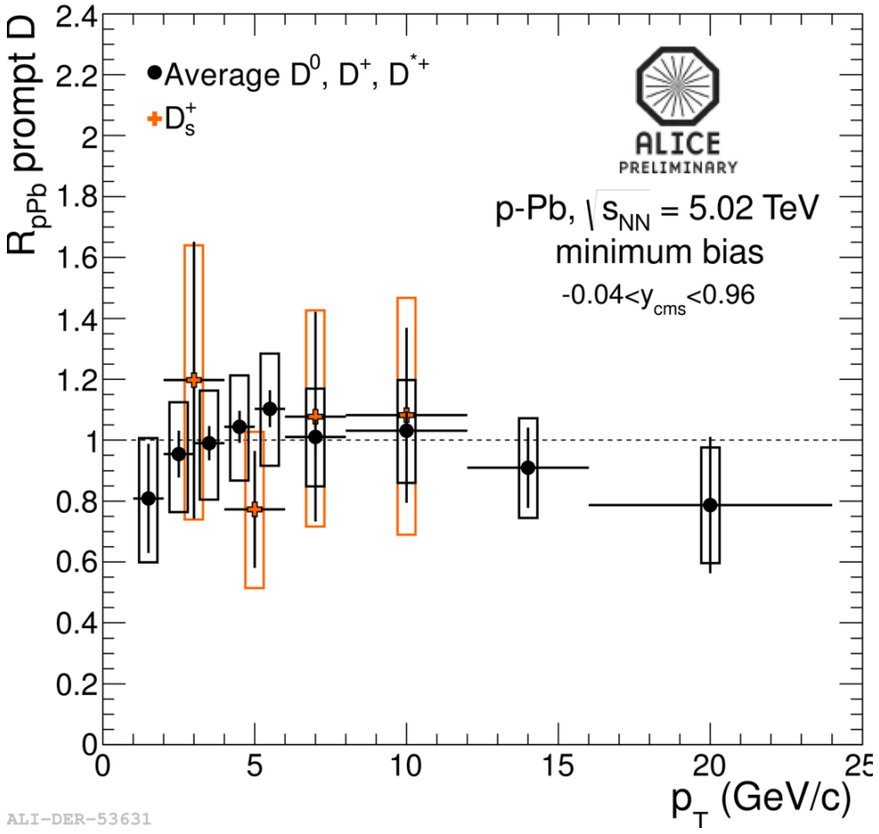
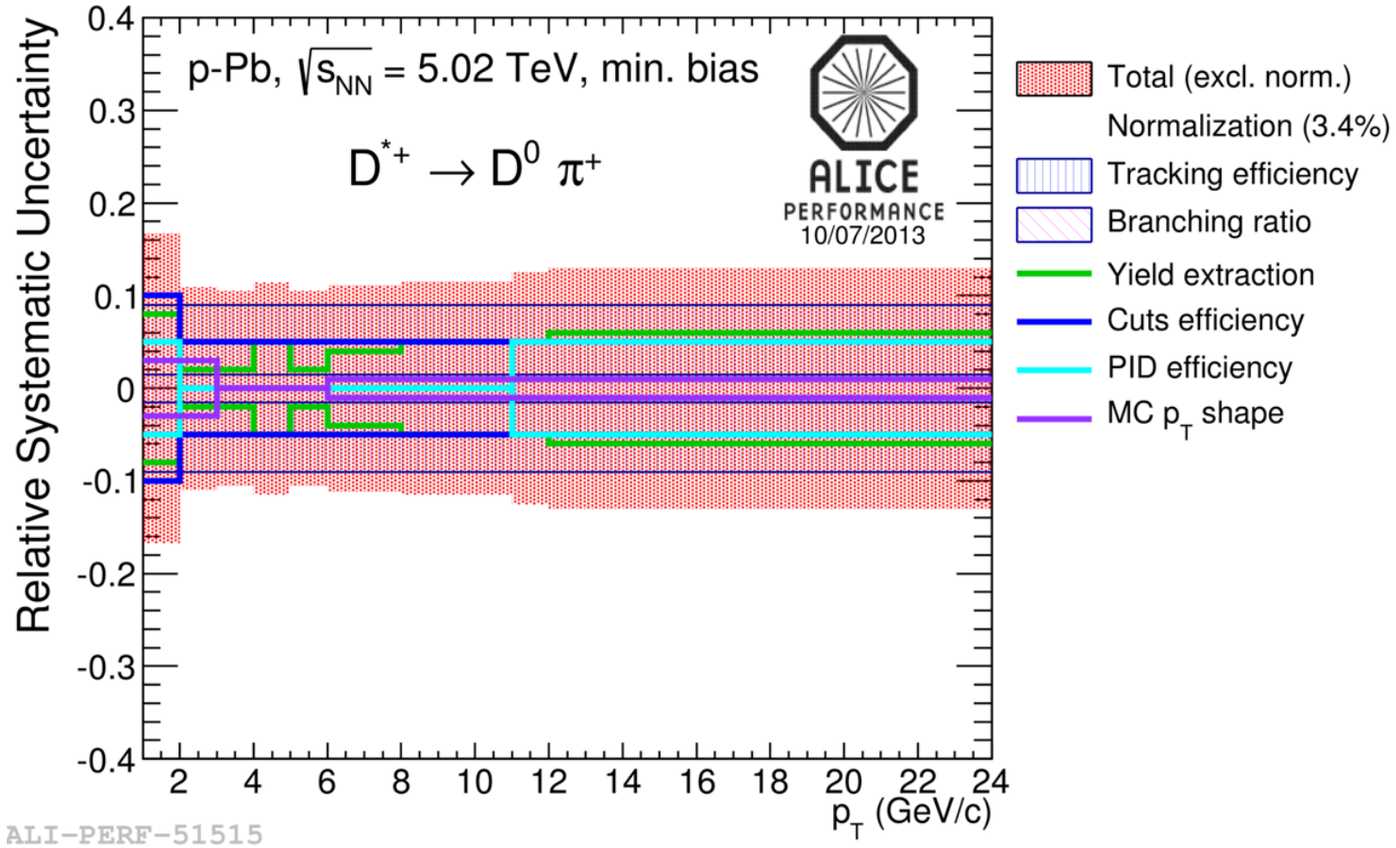
D mesons R_{pPb}





- D mesons R_{pPb} measured for D^0, D^+ and D^{*+} in the range $1<p_T<24$ GeV/c. The average is shown here
- D_s R_{pPb} measured in the range $2<p_T<12$ GeV/c
- Several sources of systematics investigated. D^{*+} as example

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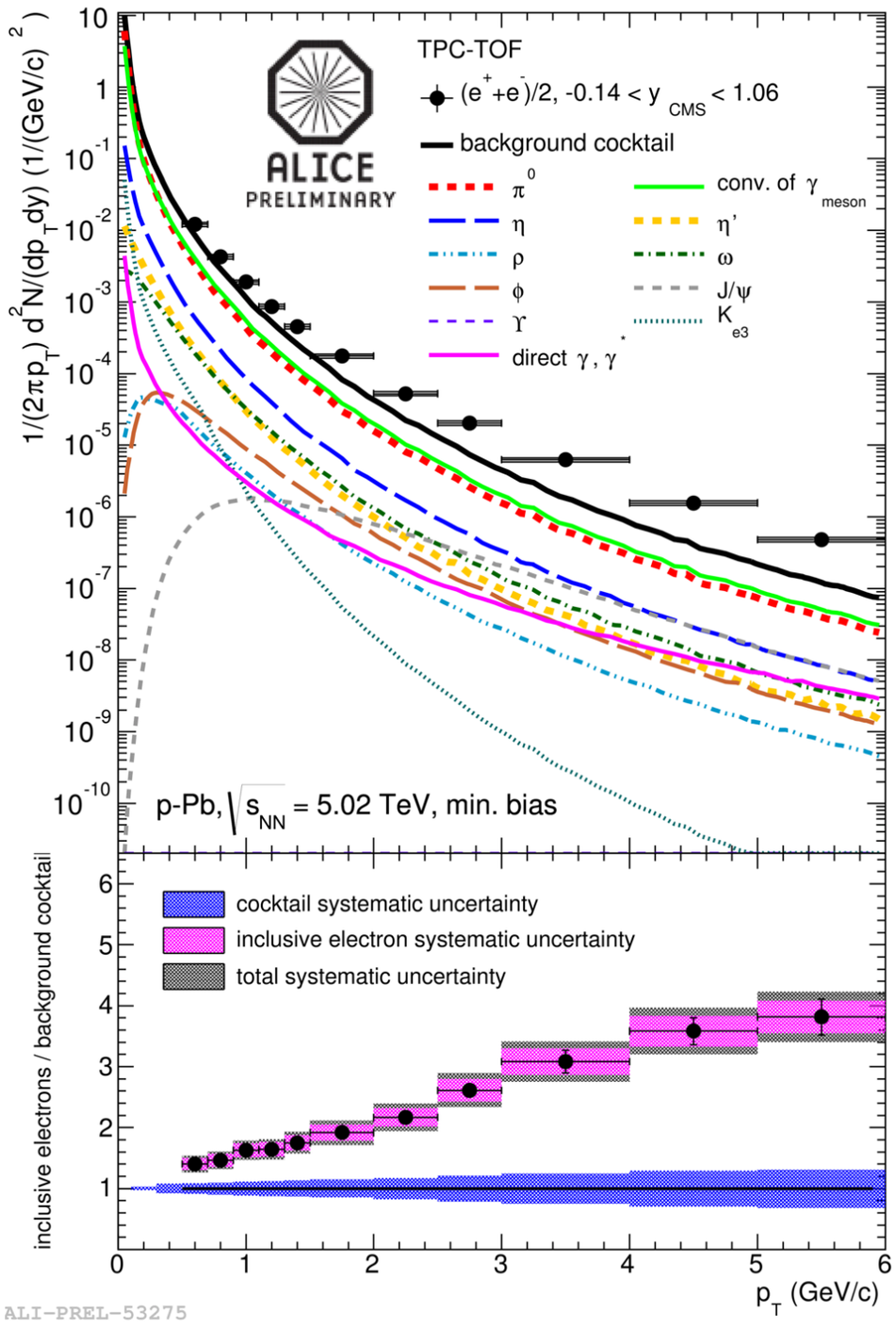
Inclusive electron yield and cocktail background: pPb



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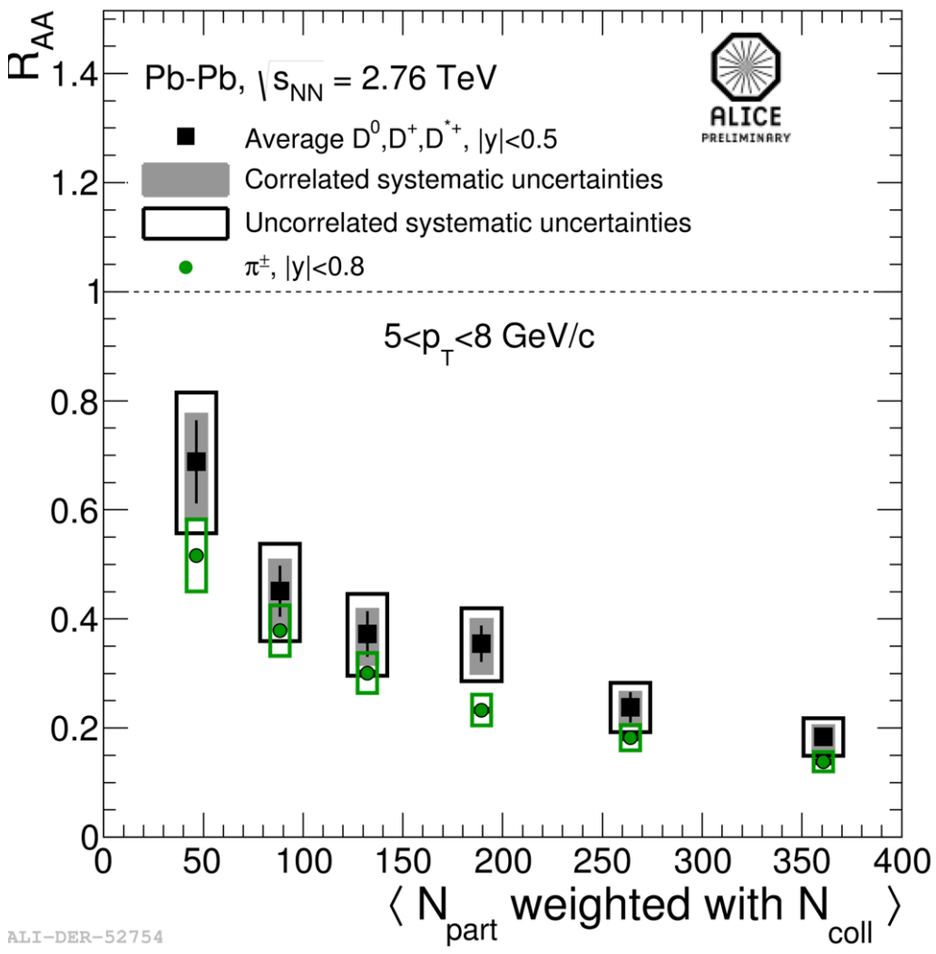
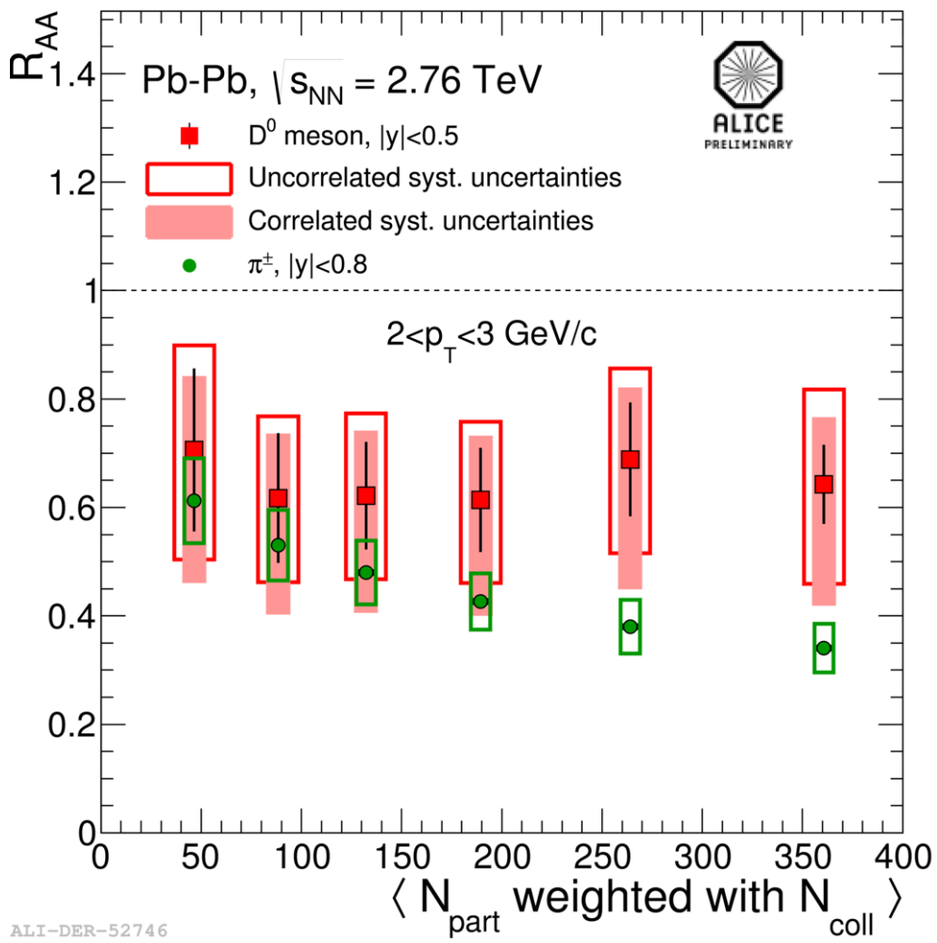
Centrality dependent R_{AA}: Mass hierarchy





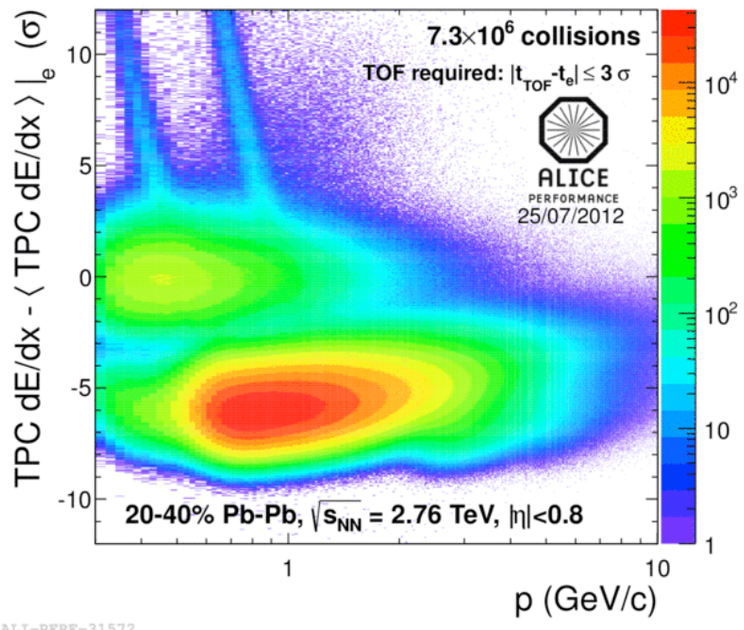
☑ In the transverse momentum range $2<p_T<3$ GeV/c the R_{AA} vs N_{part} of the D^0 shows a hint of $R_{AA}(\pi)<R_{AA}(D)$ in the 2 most central bins

Heavy Flavour decay electrons

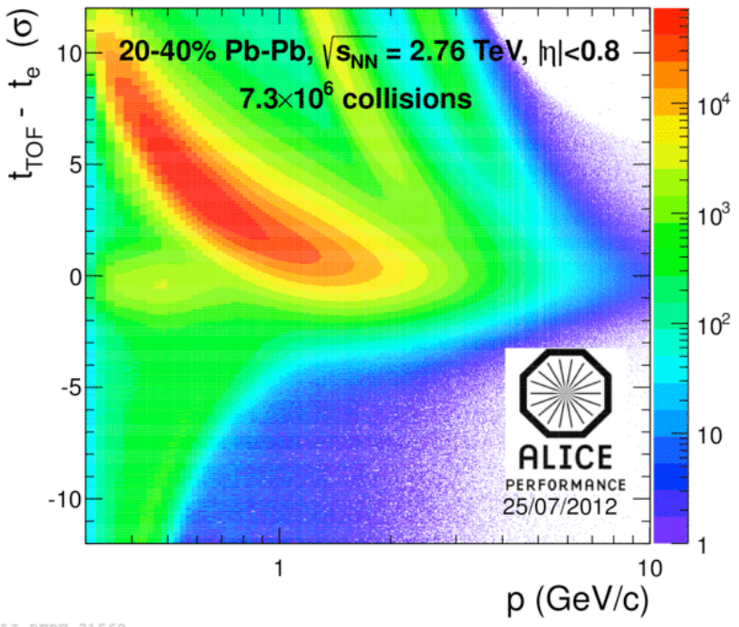
- ☑ High quality tracks in TPC and ITS.
  - Hit in the innermost pixel layer to reduce γ conversions.
- ☑ Electron identification using TOF, TPC, TRD and EMCal.
- ☑ Background subtraction methods.
  - MC cocktail of relevant background sources
    Photon conversions, Dalitz decay of π^0 and η and light mesons, Non-photonic sources
  - e^+e^- invariant mass method

Dalitz decay and photon conversion measured via invariant mass selection and subtracted statistically

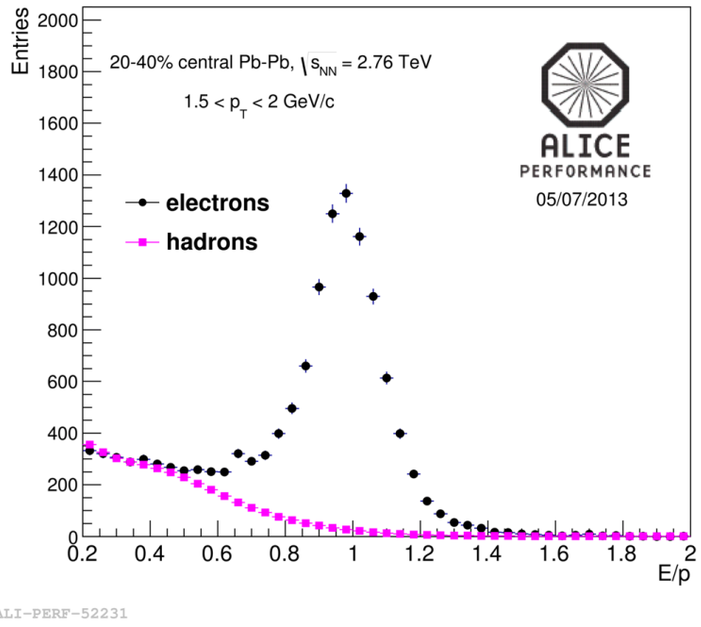
TPC



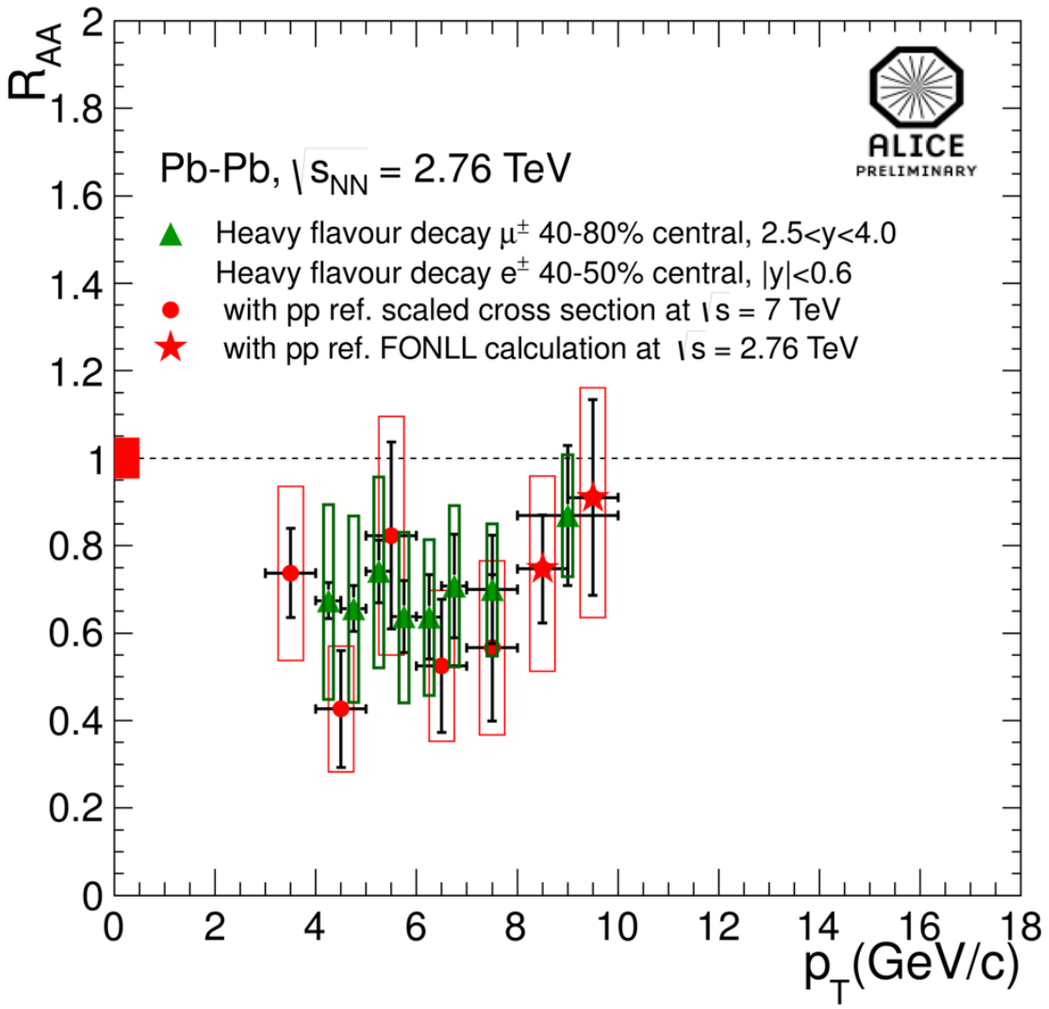
TOF



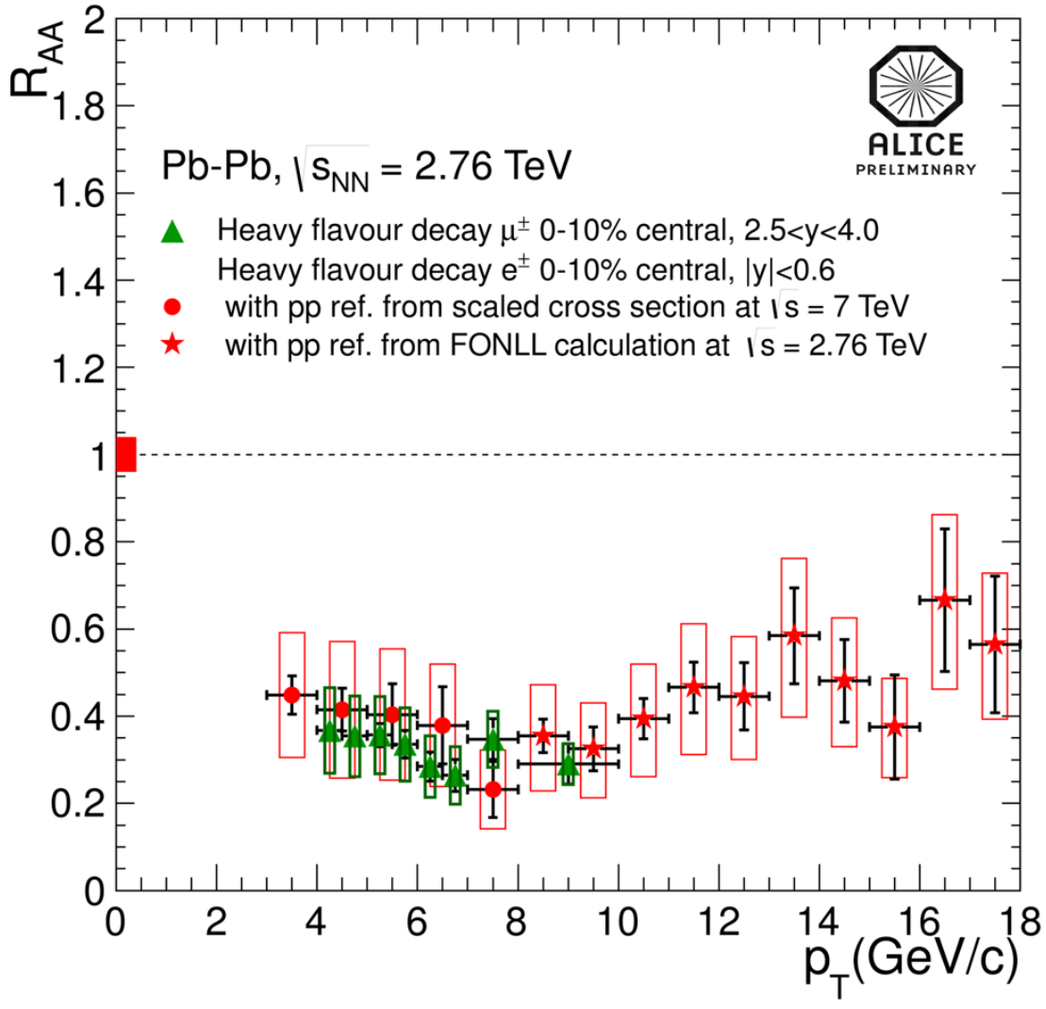
EMCal



HF decay electrons vs HF decay muons



ALI-DER-53851



ALI-DER-36791