D-meson production at central rapidity in p-p and Pb-Pb collisions with the ALICE detector

International Conference on the Initial Stages in High-Energy Nuclear Collisions
Ila da Toxa, Galizia, Spain

Gian Michele Innocenti
for the ALICE Collaboration
Università degli Studi di Torino

Outline of the talk

- Physics motivation
- D-meson analysis strategy
- pp measurement
- Nuclear modification factor R_{AA}
- Elliptic flow: v_2 measurement
- Comparison with models
- Conclusions

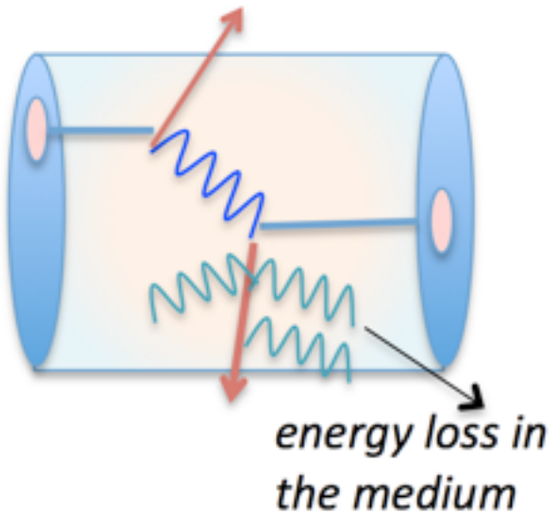
Why open charm?

Heavy quarks produced in the early stages of the collisions in high-Q^2 processes

→ in pp: test for perturbative calculations and reference for heavy-ion measurements

→ in Pb-Pb: probe to study the properties of the medium

→ in p-Pb : study cold nuclear matter effects (See A. Festanti Talk)

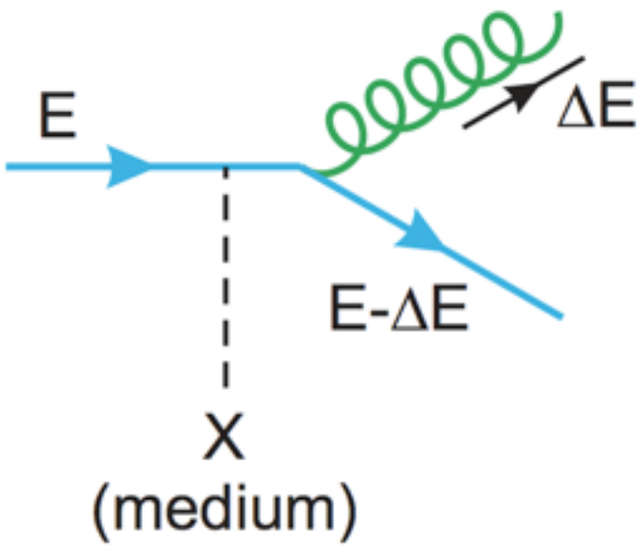


Heavy quarks can interact with the medium via:

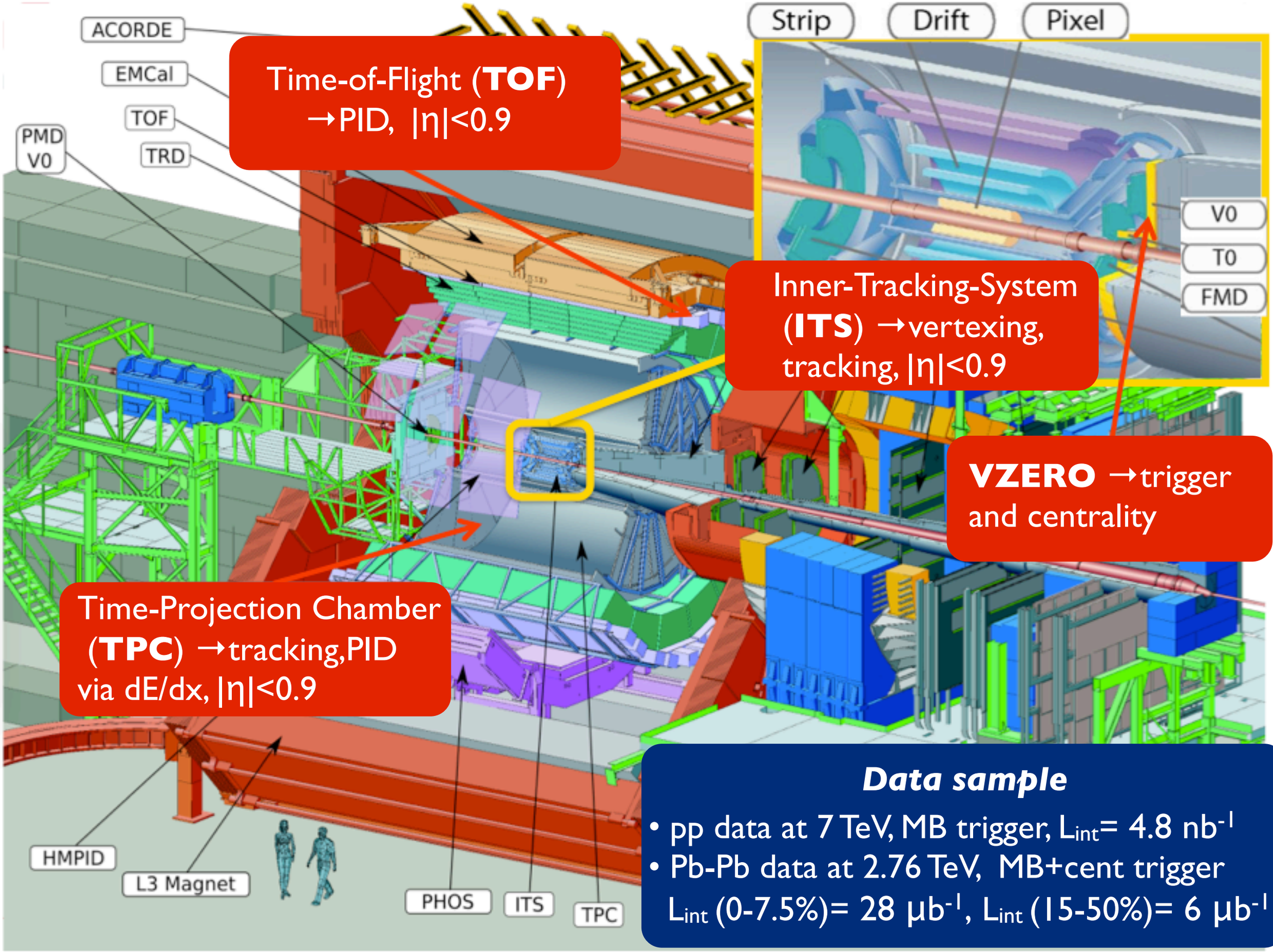
- elastic collisions
- inelastic collisions:
  medium-induced gluon radiation

Radiative energy loss (e.g. **BDMPS):** $\Delta E_{loss} \propto \alpha_s C_R \hat{q} L^2$

- depends on the in-medium path length L
- transport coefficient $\hat{q}$ related to the density of the medium
- expected to be smaller for heavy quarks than for light quarks and gluons due to color charge and dead cone effect [1]
  $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$



[1] Y. L. Dokshitzer, D. E. Kharzeev, Phys. Lett. B519 (2001)
[2] BDMPS: Baier et al.: Nucl. Phys. B484 (1997) 265
Armesto et al. PRD71(2005) 054027



Time-of-Flight (**TOF**) →PID, $|\eta|<0.9$

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

VZERO →trigger and centrality

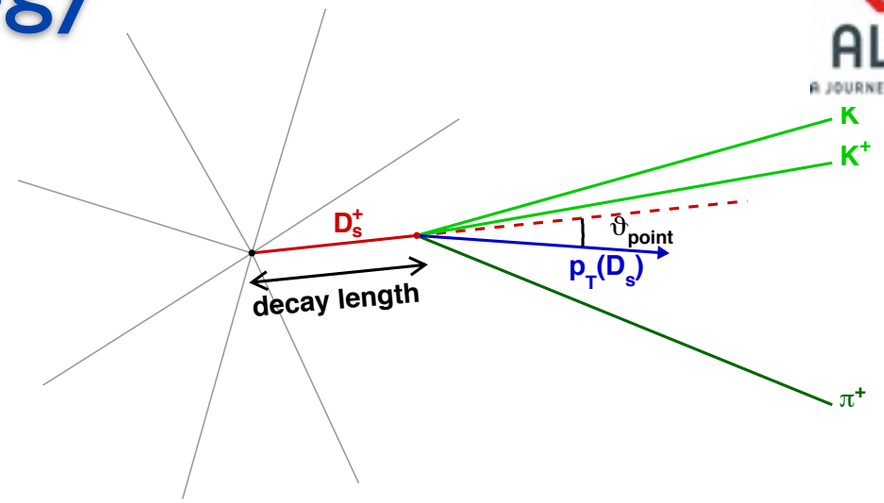
Time-Projection Chamber (**TPC**) →tracking,PID via dE/dx, $|\eta|<0.9$

Data sample

- pp data at 7 TeV, MB trigger, L_{int}= 4.8 nb^{-1}
- Pb-Pb data at 2.76 TeV, MB+cent trigger
  L_{int} (0-7.5%)= 28 μb^{-1}, L_{int} (15-50%)= 6 μb^{-1}

Analysis Strategy

- Reconstruction of displaced secondary vertices
- Track selection criteria:
  - p_T and impact parameter of single track
- Candidate selection:
  - distance between primary and secondary vertex
  - pointing angle
- Particle Identification (PID) based on TOF-TPC
  → strong background rejection at low p_T

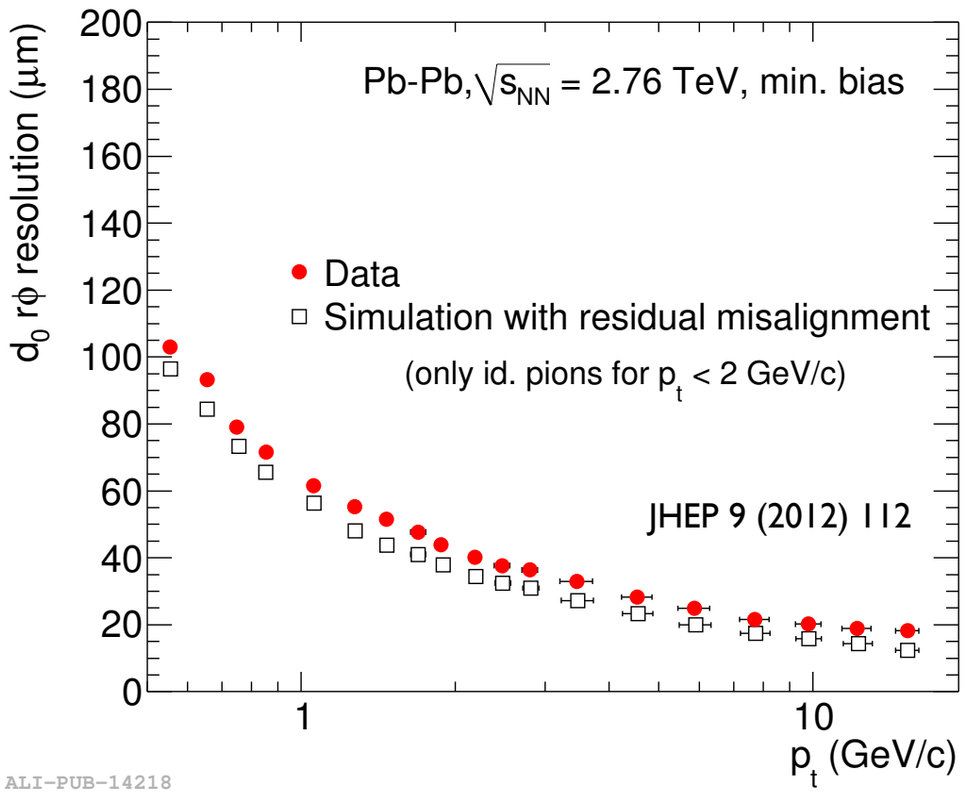


$D^0 \rightarrow K^-\pi^+$ BR: 3.88%

$D^+ \rightarrow K^-\pi^+\pi^+$ BR: 9.13%

$D_s^+ \rightarrow \Phi(\rightarrow K^+K^-)\pi^+$ BR: 2.28%

$D^{*+} \rightarrow D^0\pi^+$ BR: 67.7%

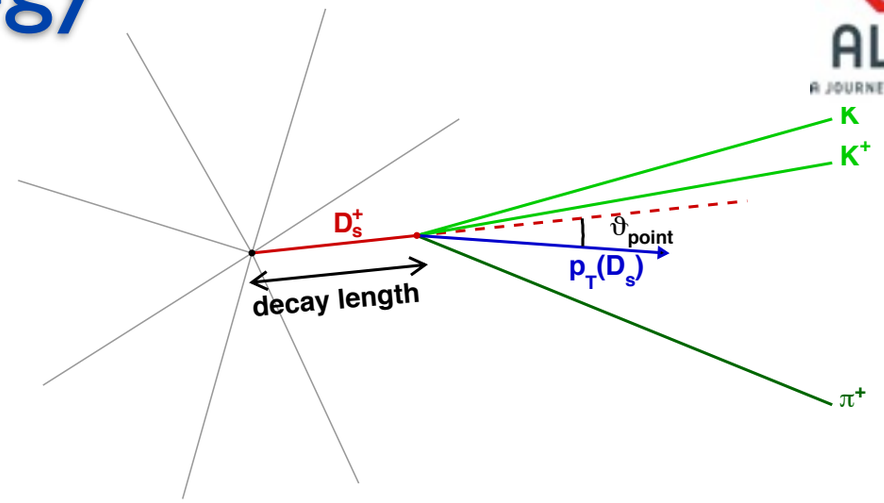


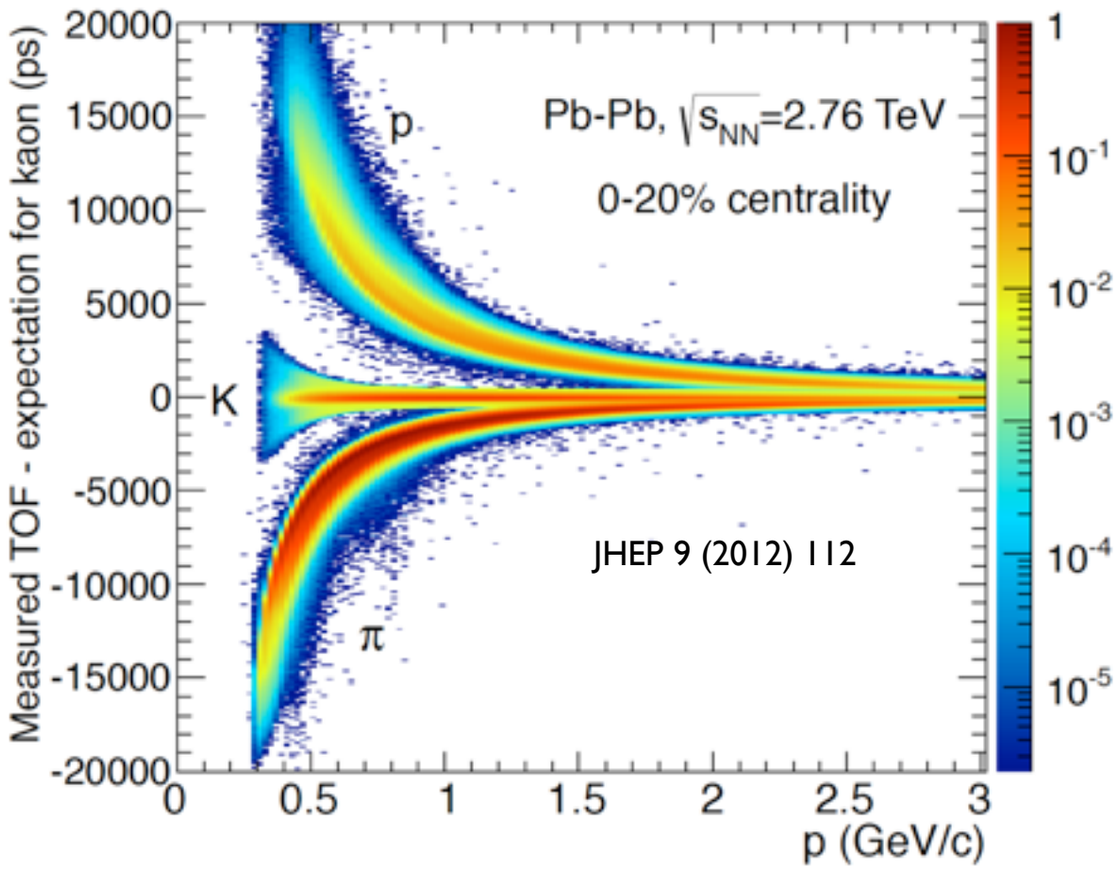
- Signal extraction via fits to invariant mass distributions in different p_T bins
- Efficiency x acceptance correction
- Subtraction of B feed-down based on FONLL[1] and in Pb-Pb also on a hypothesis on R_{AA} of D mesons from B meson decays

[1] M. Cacciari, M. Greco, P. Nason, JHEP 9805 (1998) 007

Analysis Strategy

- Reconstruction of displaced secondary vertices
- Track selection criteria:
  - p_T and impact parameter of single track
- Candidate selection:
  - distance between primary and secondary vertex
  - pointing angle
- Particle Identification (PID) based on TOF-TPC
  → strong background rejection at low p_T





$D^0 \rightarrow K^-\pi^+$ BR: 3.88%

$D^+ \rightarrow K^-\pi^+\pi^+$ BR: 9.13%

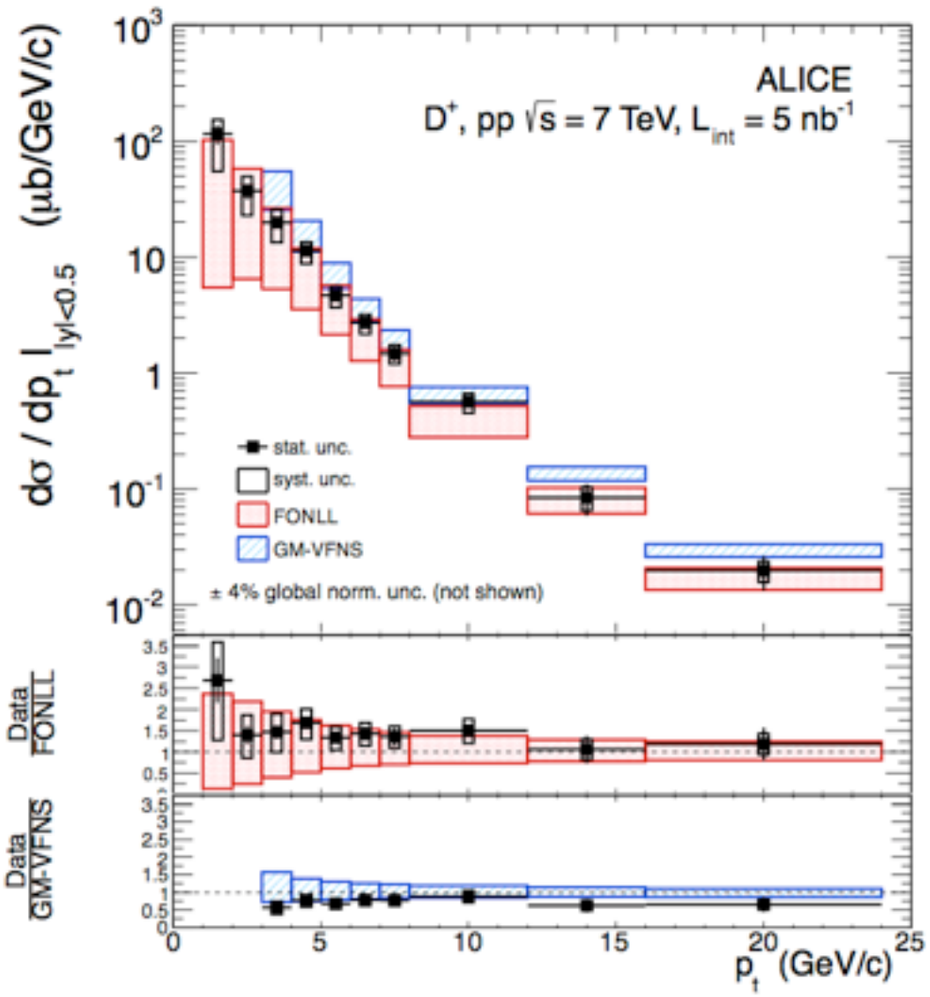
$D_s^+ \rightarrow \Phi(\rightarrow K^+K^-)\pi^+$ BR: 2.28%

$D^{*+} \rightarrow D^0\pi^+$ BR: 67.7%

- Signal extraction via fits to invariant mass distributions in different p_T bins
- Efficiency x acceptance correction
- Subtraction of B feed-down based on FONLL[1] and in Pb-Pb also on a hypothesis on R_{AA} of D mesons from B meson decays

[1] M. Cacciari, M. Greco, P. Nason, JHEP 9805 (1998) 007

proton-proton measurement



- D-meson production measured at $\sqrt{s}$=7 TeV in a wide p_T range (300 x 10^6 MB events)
- Measurement performed also on a smaller data sample at $\sqrt{s}$= 2.76 TeV (Pb-Pb energy)

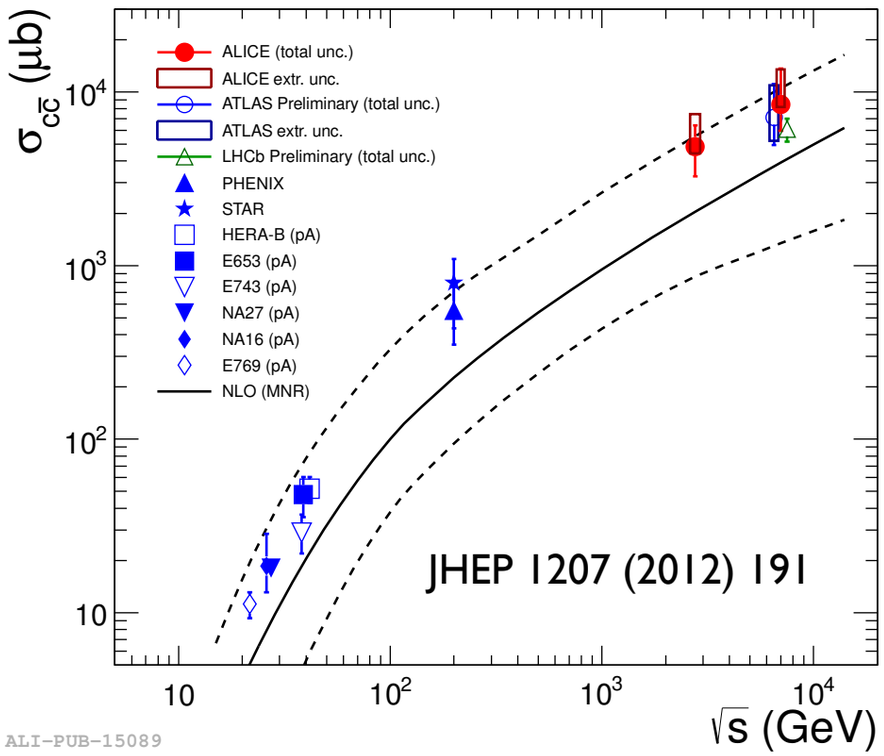
→ well reproduced by pQCD calculations FONLL [1] and GM-VFNS [2]

→ reference for the Pb-Pb measurement.

Extrapolation to Pb-Pb energy performed with FONLL calculations

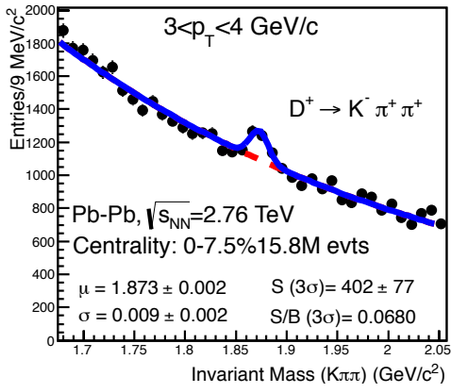
Total charm cross section compatible with NLO prediction over 3 orders of magnitude

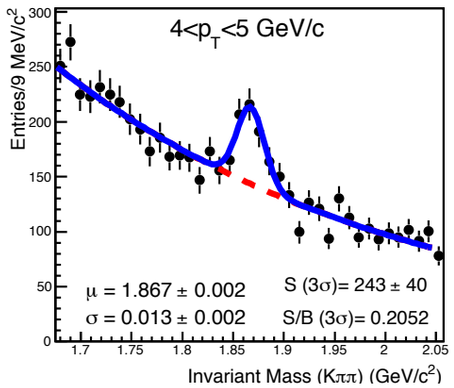
→ extrapolation to zero p_T and full rapidity coverage performed with FONLL

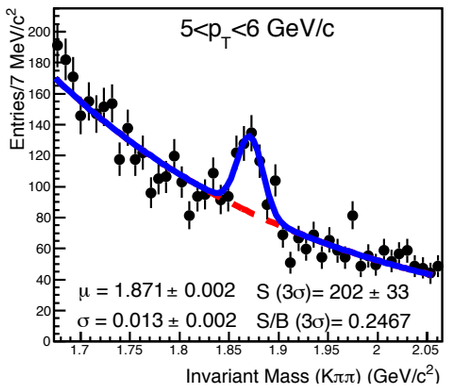


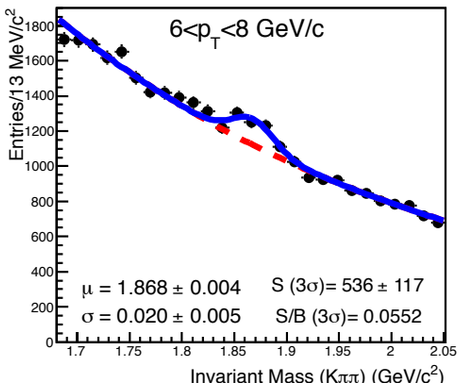
[1] M. Cacciari, M. Greco, P. Nason, JHEP 9805 (1998) 007
[2] B. A. Kniehl, G. Kramer, I. Schienbein and H. Spiesberger, arXiv:1202.0439 [hep-ph]

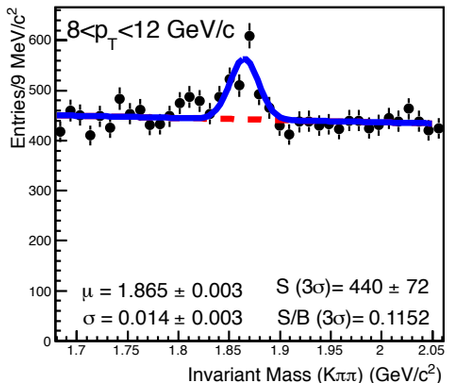
Signal extraction for central Pb-Pb events

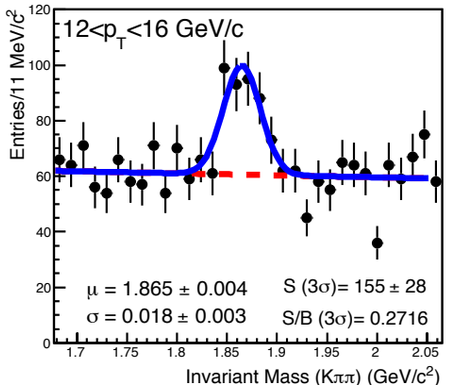


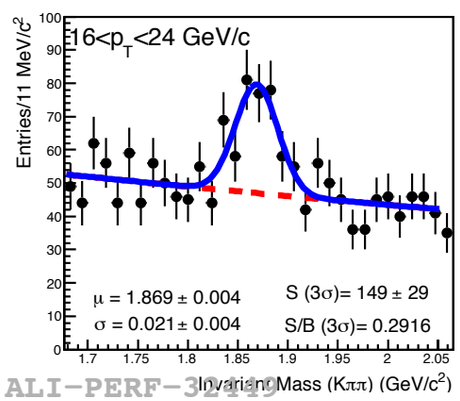


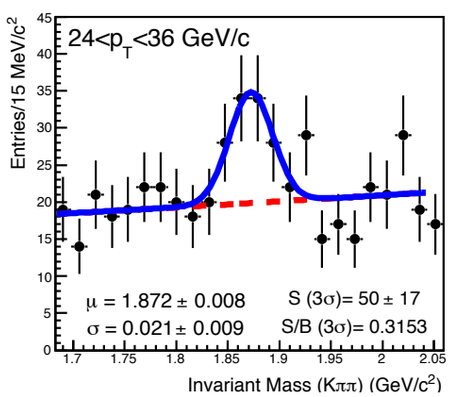












- **D^0** $1<p_T<24$ GeV/c
- **D^+, D^{*+}** $3<p_T<36$ GeV/c
- **D_s^+** $4<p_T<12$ GeV/c

≈ 16 Million central events from 2011 Pb-Pb run at 2.76 TeV

→ MB + centrality trigger

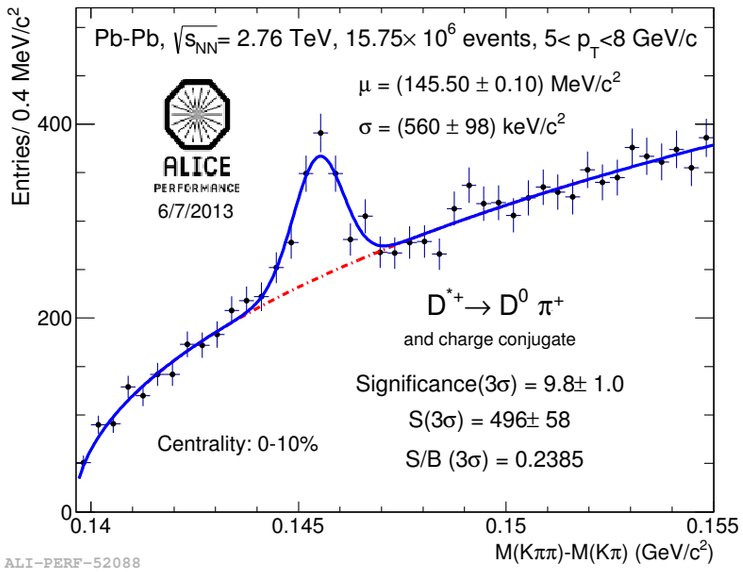
→ **Centrality 0-7.5%**

Signal extraction vs centrality

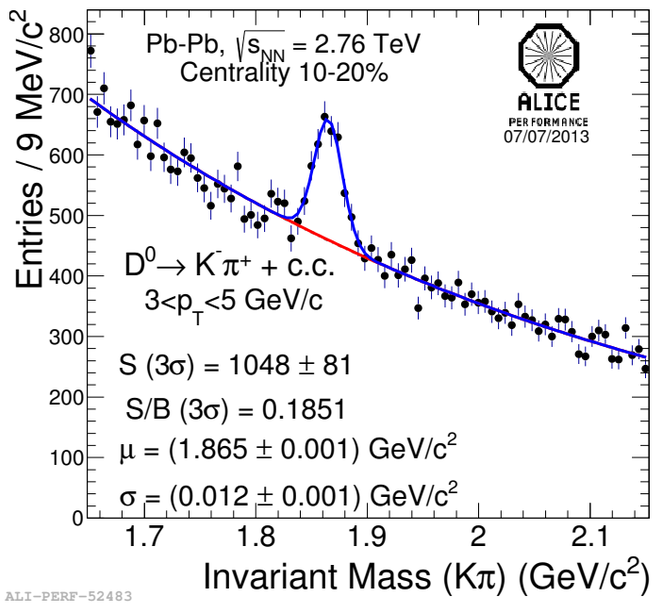
Centrality ranges: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-80%

p_T ranges: 2-3, 3-5 GeV/c for D^0 only, 5-8,8-16 GeV/c for D^0, D^+, D^{+*}

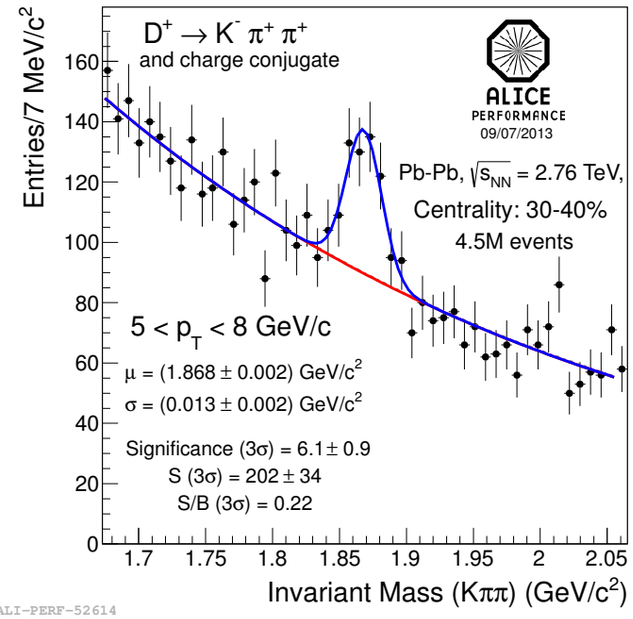
D^{*+} 5-8 GeV/c, 0-10%



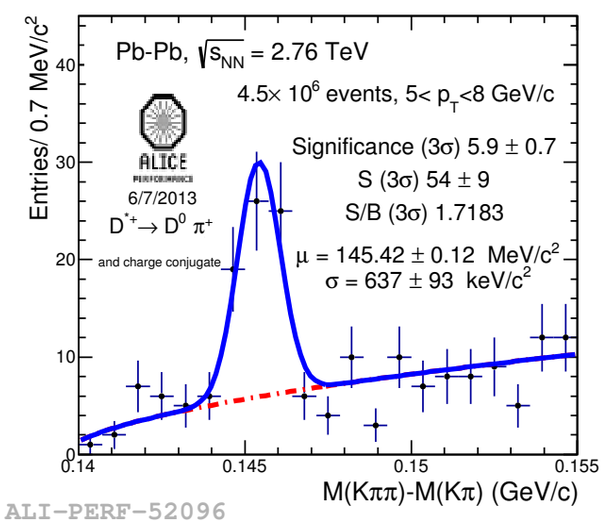
D^0 3-5 GeV/c, 10-20%

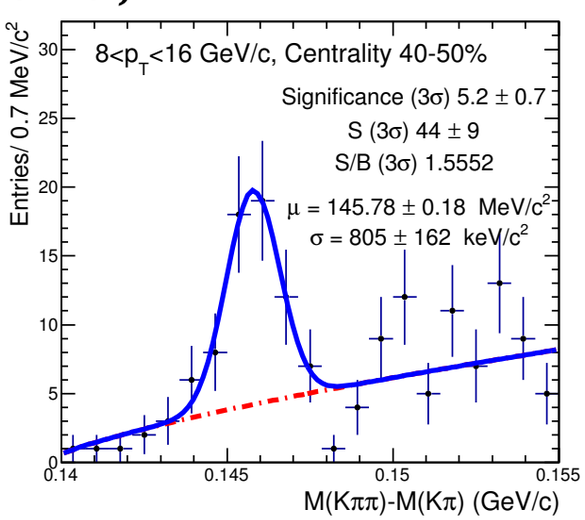


D^+ 5-8 GeV/c, 30-40%

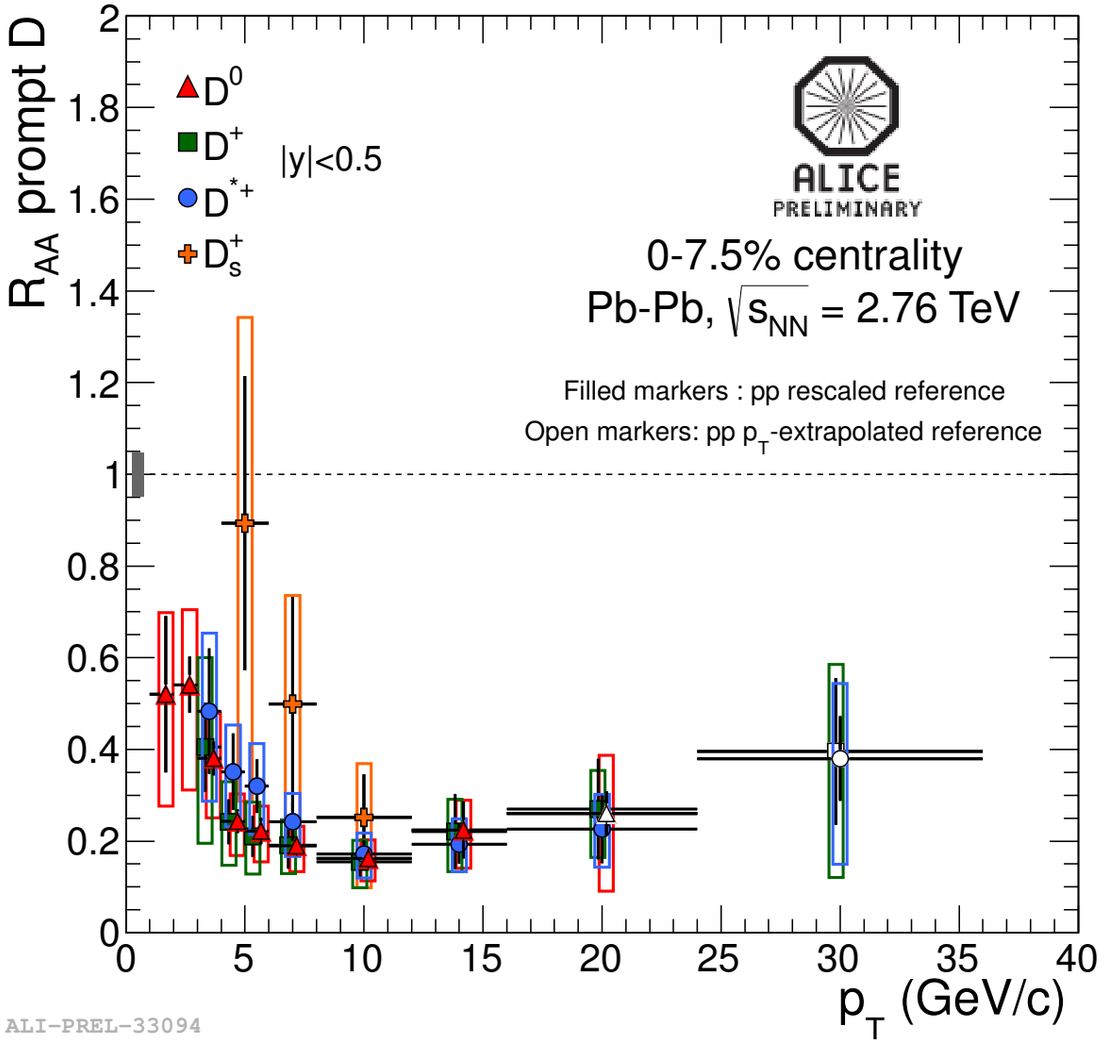


D^{*+} 5-8 and 8-16 GeV/c ,10-20%





R_{AA} vs p_T for central events



$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{< T_{\mathrm{AA}} >} \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- D^0, D^+, D^{*+} results compatible within the uncertainties
- Large suppression observed for p_T > 6-8 GeV/c (factor ≈4-5)

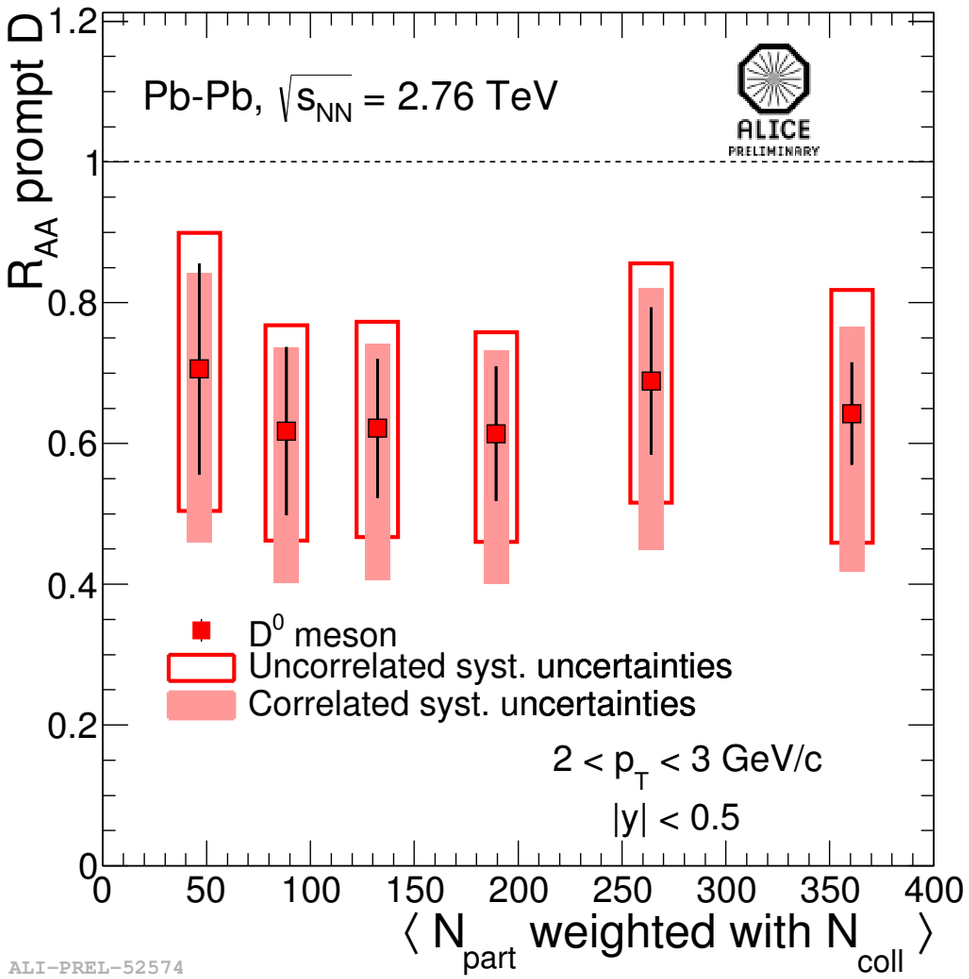
- First measurement of the D^+_s R_{AA} in Pb-Pb collisions in 4 < p_T < 12 GeV/c

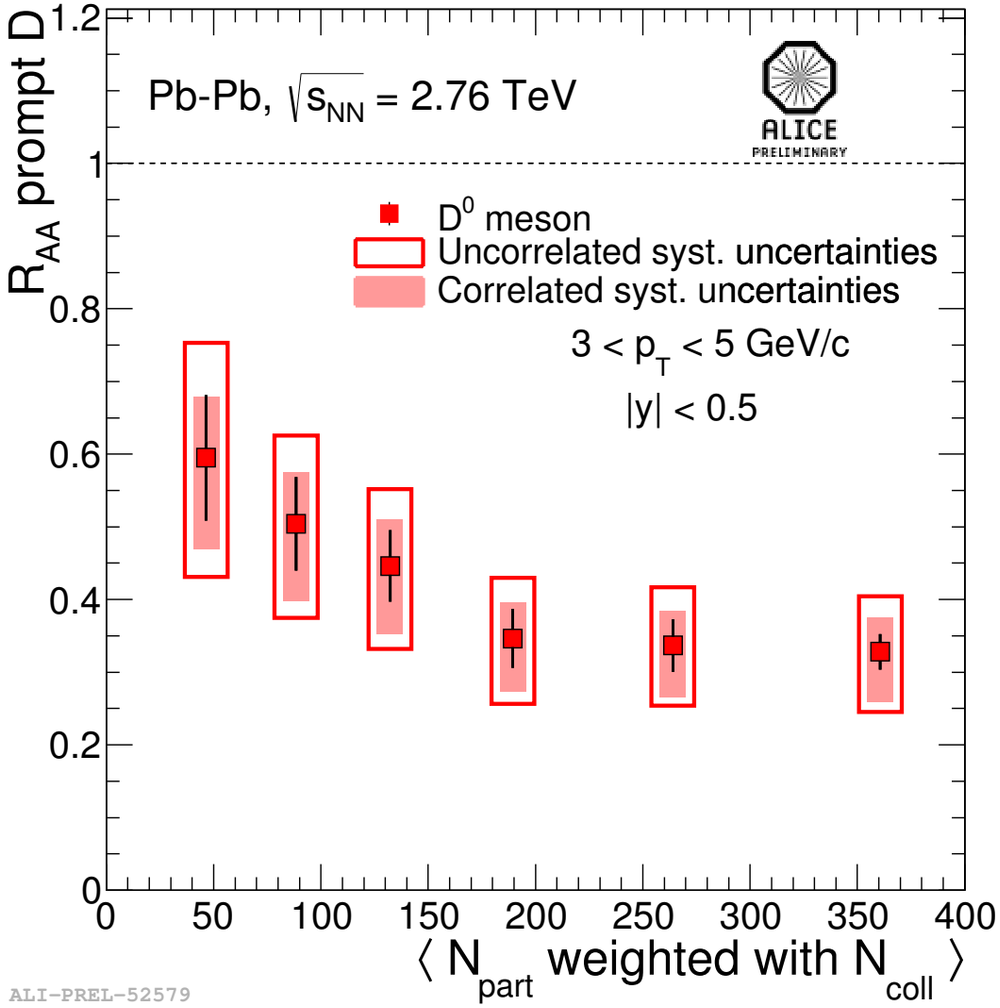
→ More precise measurement needed to conclude on the hypothesis of strangeness enhancement due to charm recombination in the medium[1,2]

[1] M. He, R. J. Fries and R. Rapp, arXiv:1204.4442 [nucl-th]
[2] I. Kuznetsova, J. Rafelski, Eur.Phys.J.C51:113-133,2007

R_{AA} vs centrality at low p_T

Centrality ranges: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-80%
p_T ranges: 2-3, 3-5 GeV/c for D^0 only



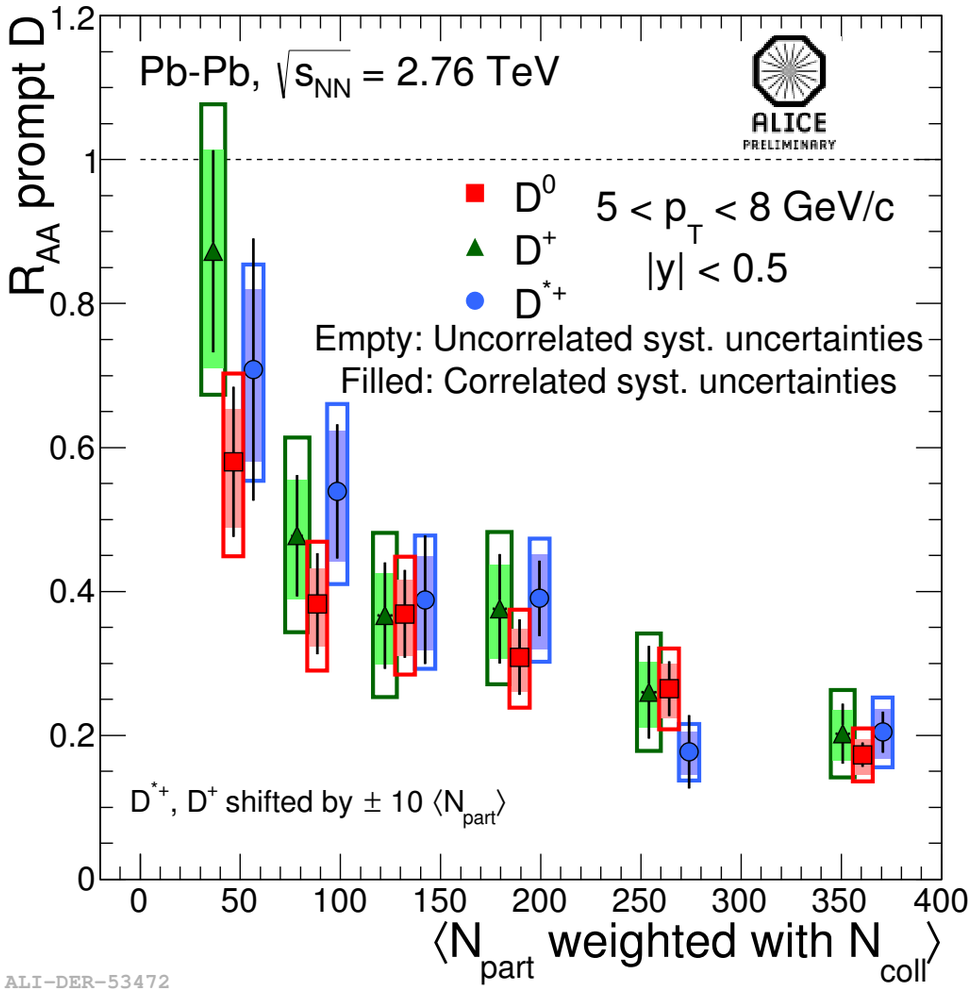


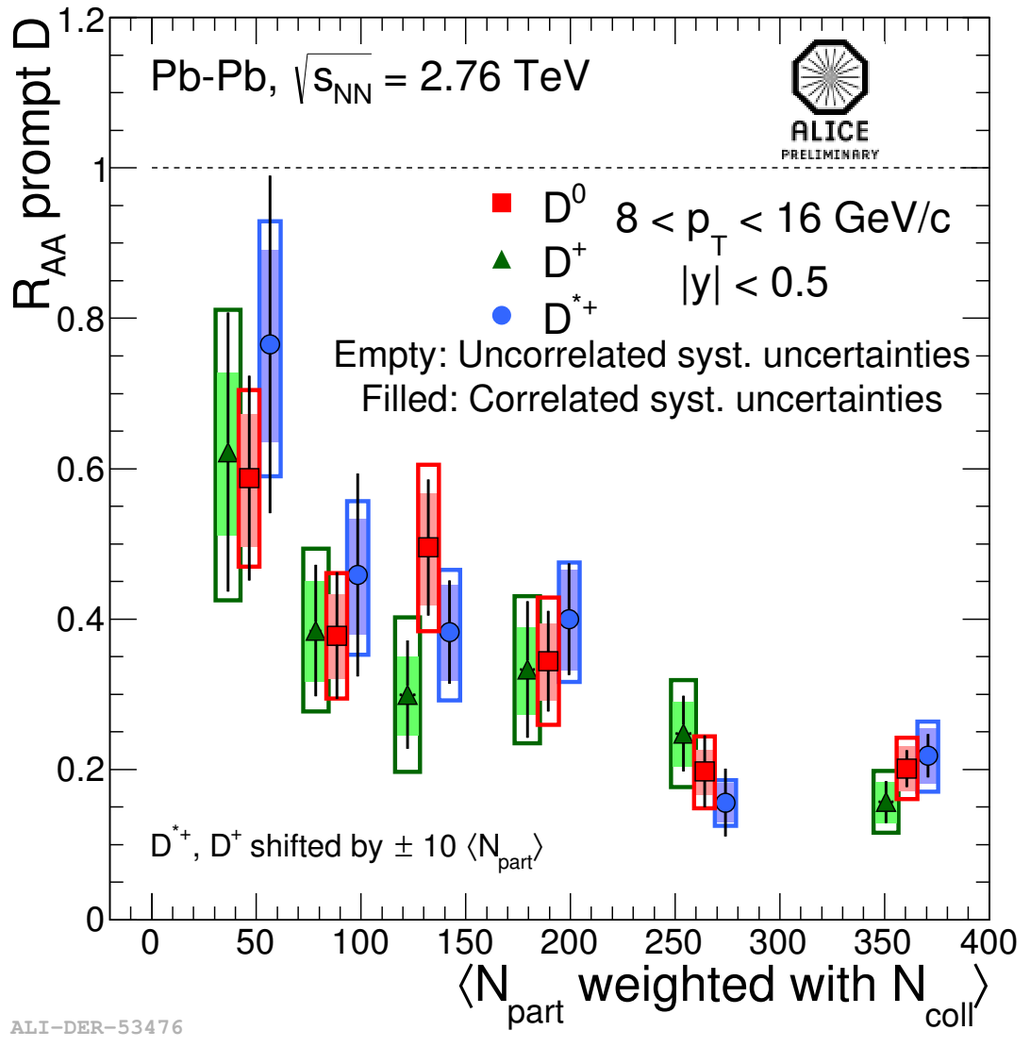
Indication of a different suppression pattern in 2-3 GeV/c and 3-5 GeV/c

R_{AA} vs centrality at high p_T

Centrality ranges: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-80%

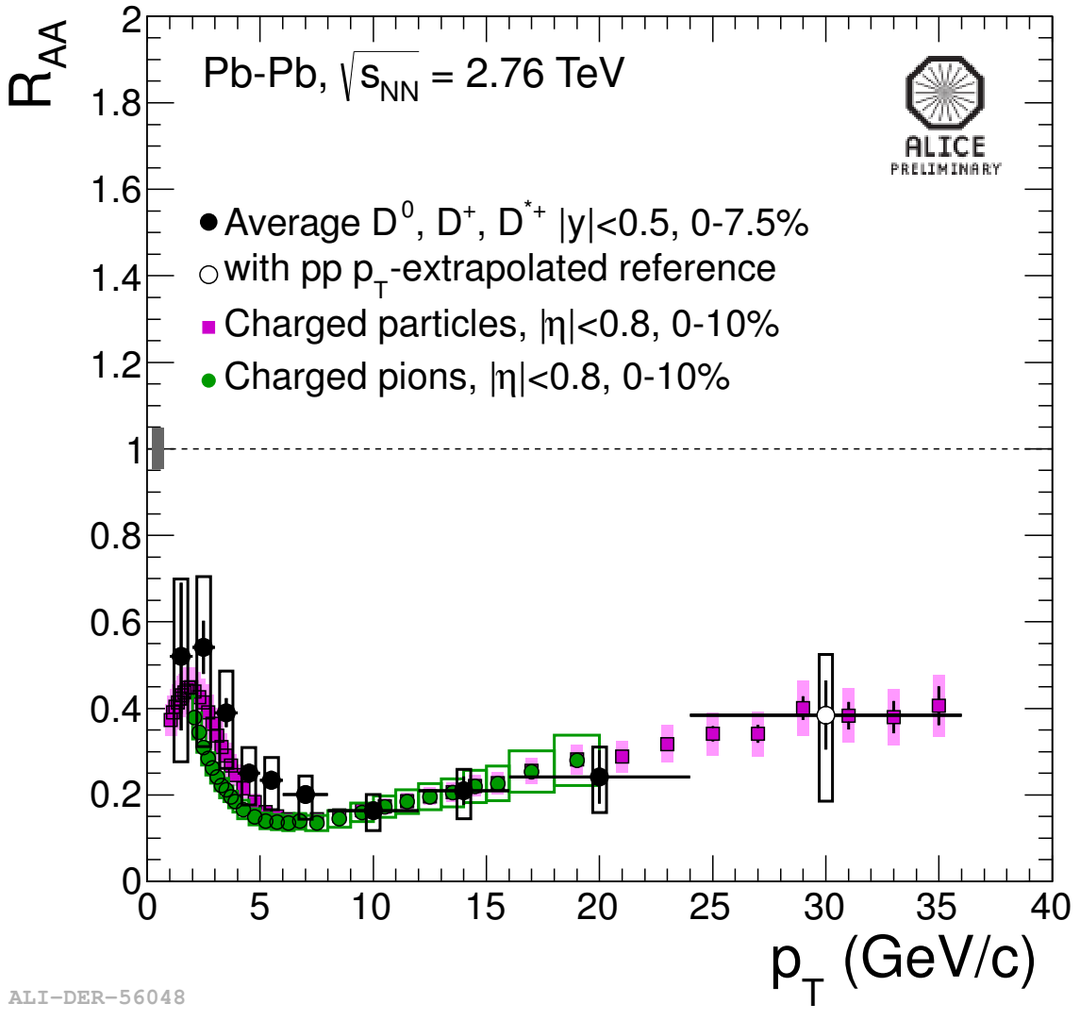
p_T ranges: 5-8, 8-16 GeV/c for D^0, D^+,D^{*+}

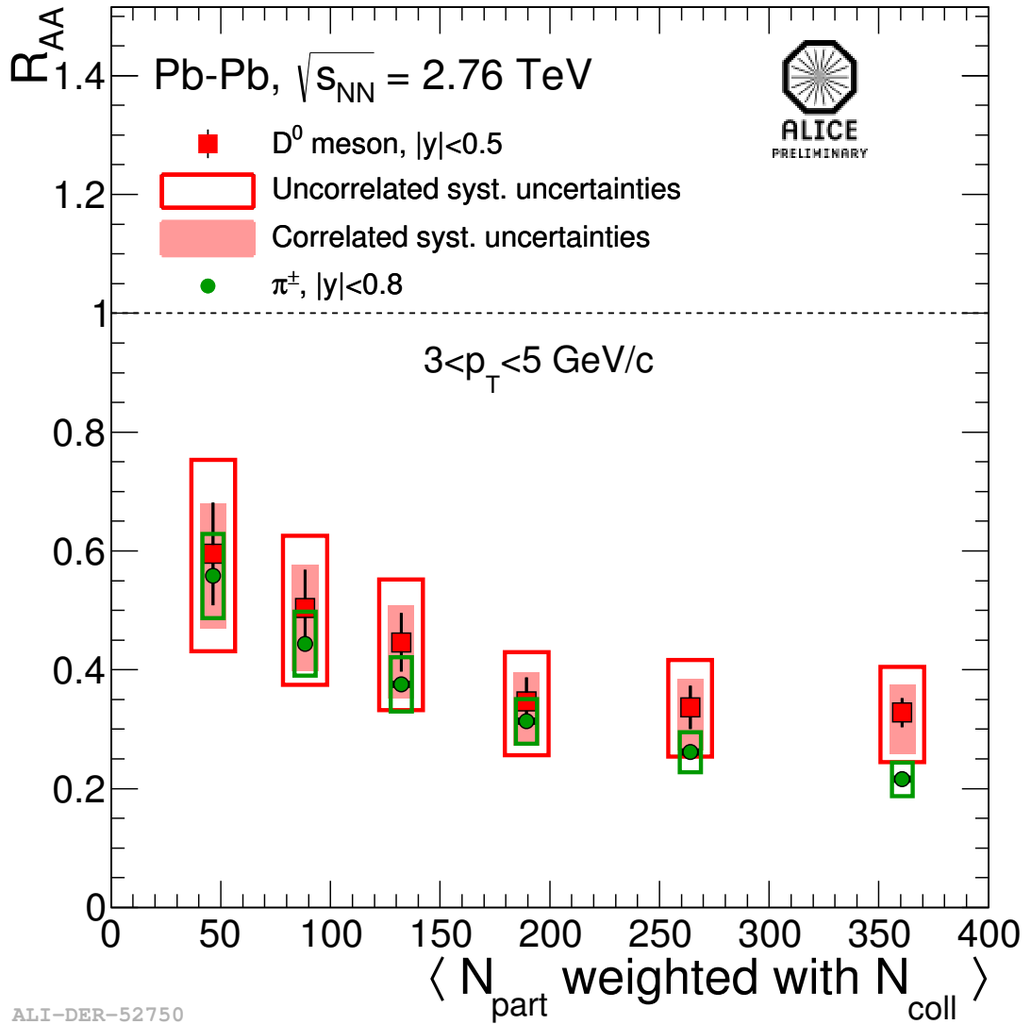




Similar evolution with centrality at intermediate and high p_T

Comparison to pion R_{AA}



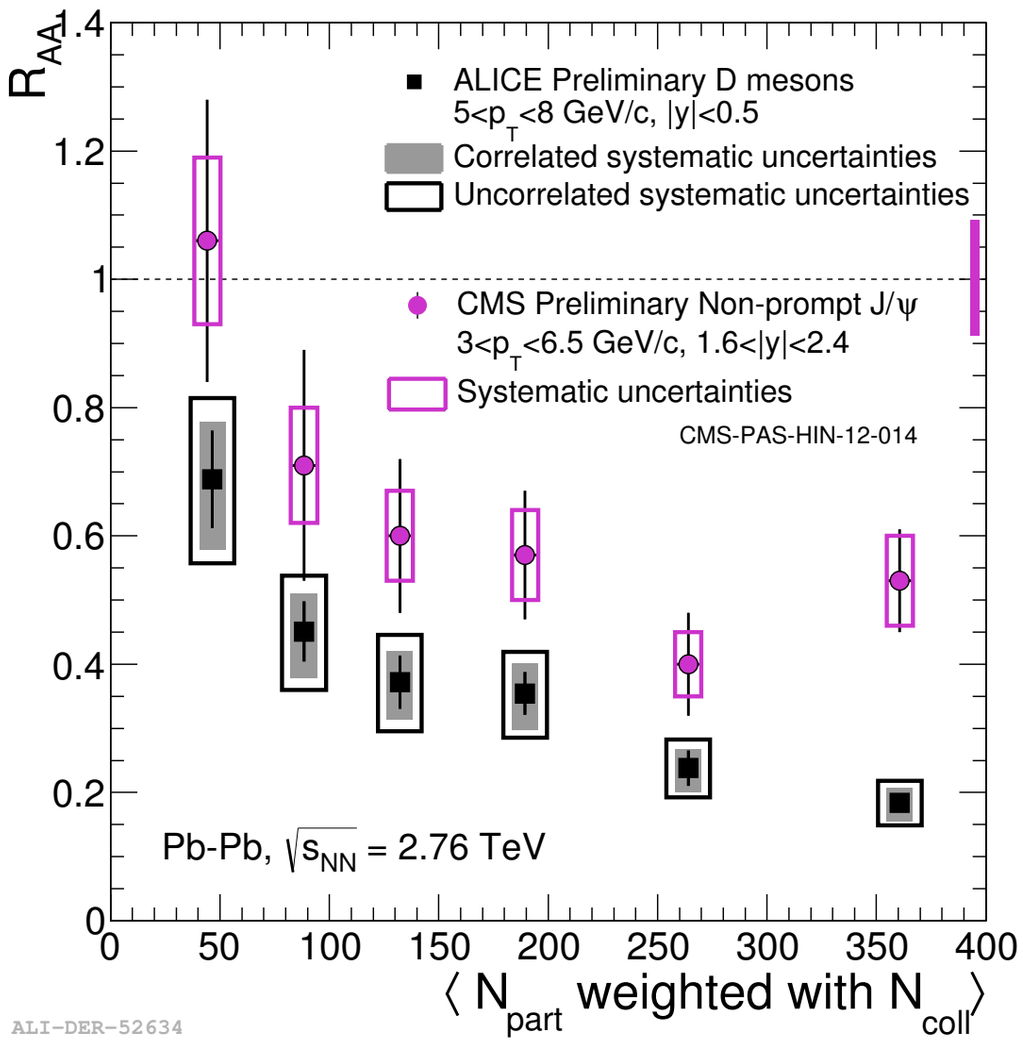


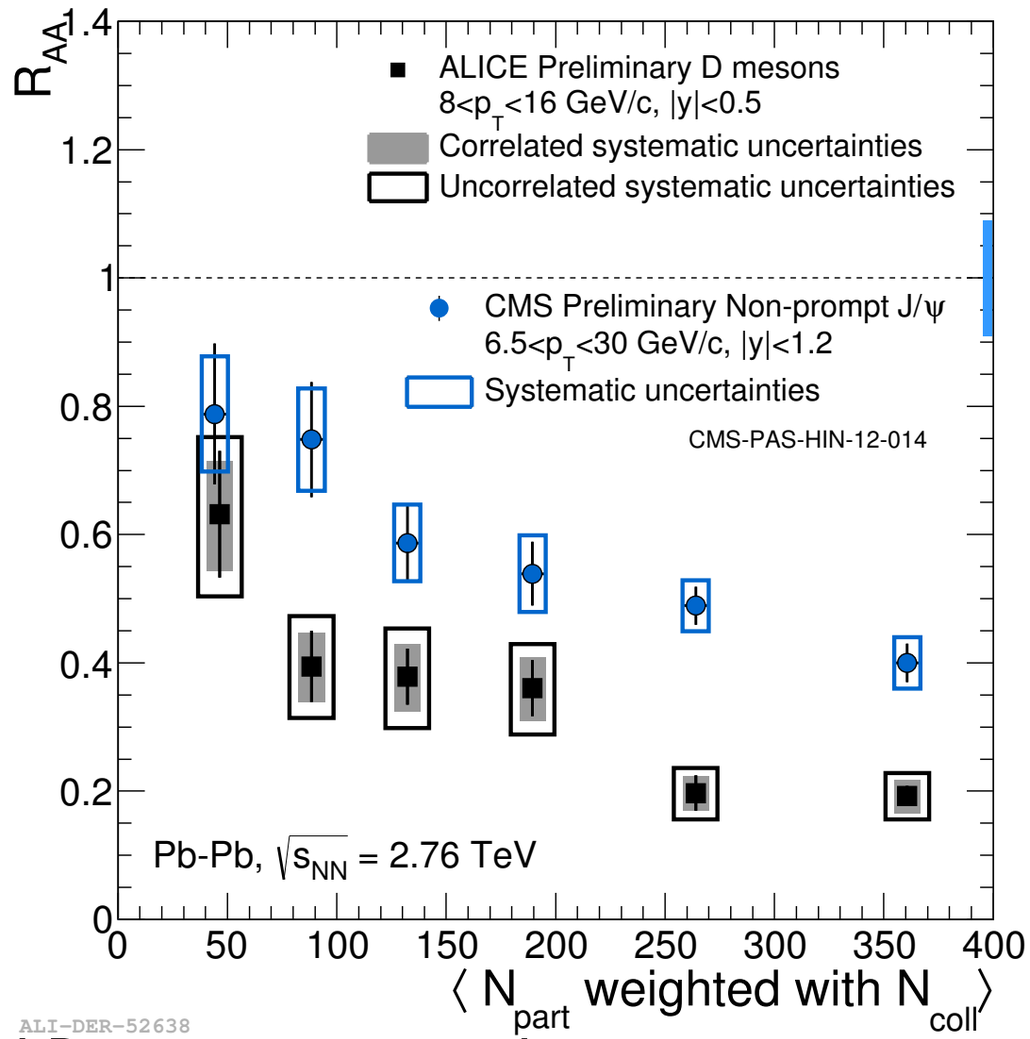
- Similar pattern for D meson and pion R_{AA} in central collisions w.r.t. transverse momentum p_T

- ***Expectation: $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$***

→ *Cannot conclude on this expected difference within present uncertainties!*

Comparison to non-prompt J/ψ by CMS

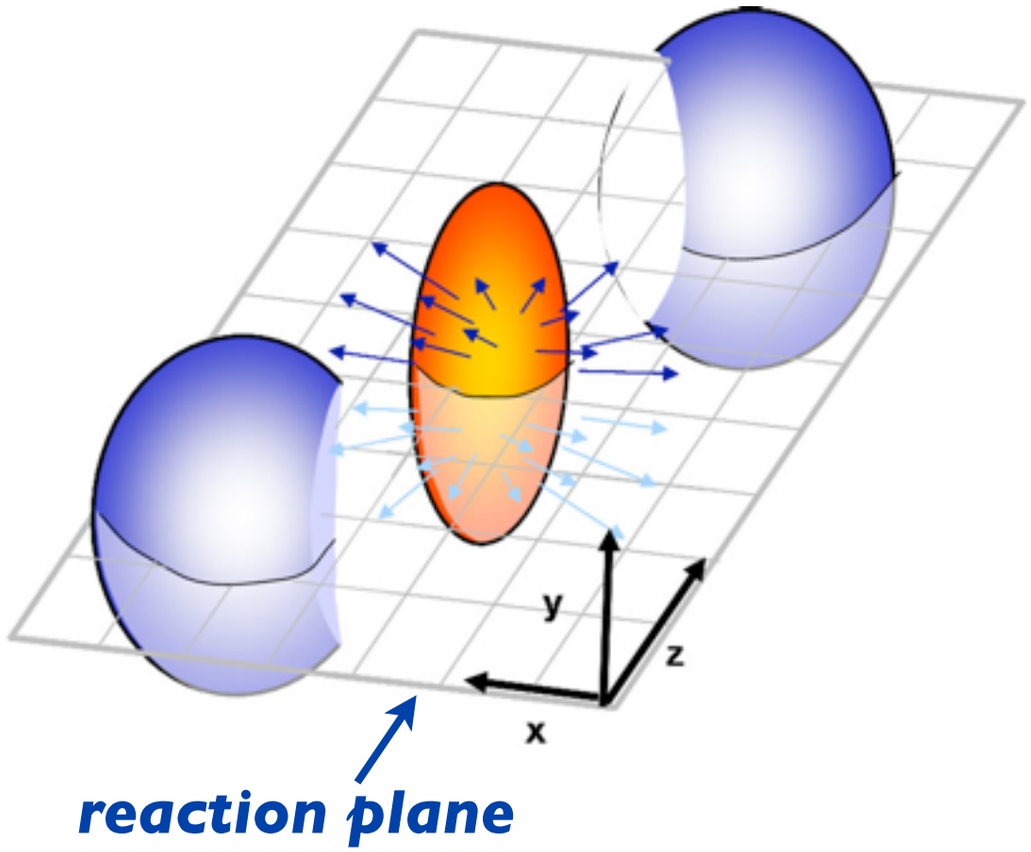




- p_T ranges chosen to allow a comparison of D and B mesons in a similar kinematic region (evaluated via simulation of the decay kinematic B → J/ψ+X)
- Different rapidity coverage

→ ***Indication of a difference between charm and beauty suppression in central collisions*** $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$

Elliptic flow of D mesons

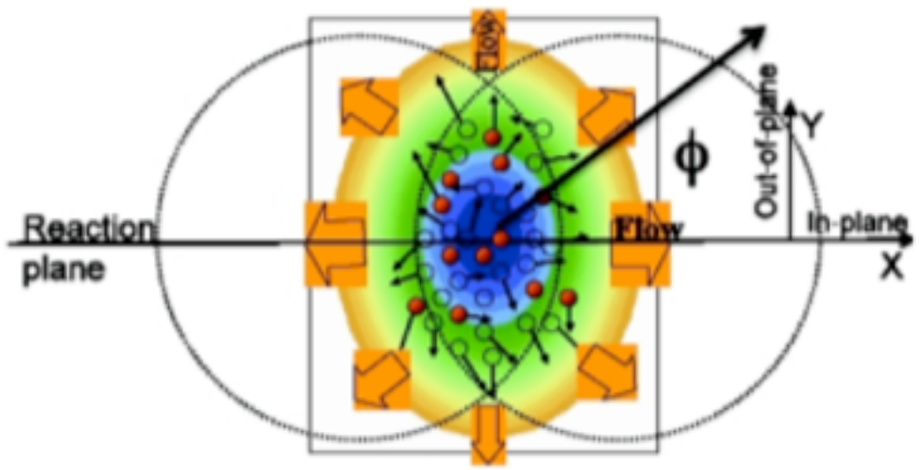


- Initial spatial anisotropy in peripheral collisions
  → momentum anisotropy of particles
- Anisotropy quantified via a Fourier expansion in the azimuthal angle φ measured with respect to the reaction plane Ψ_{RP}

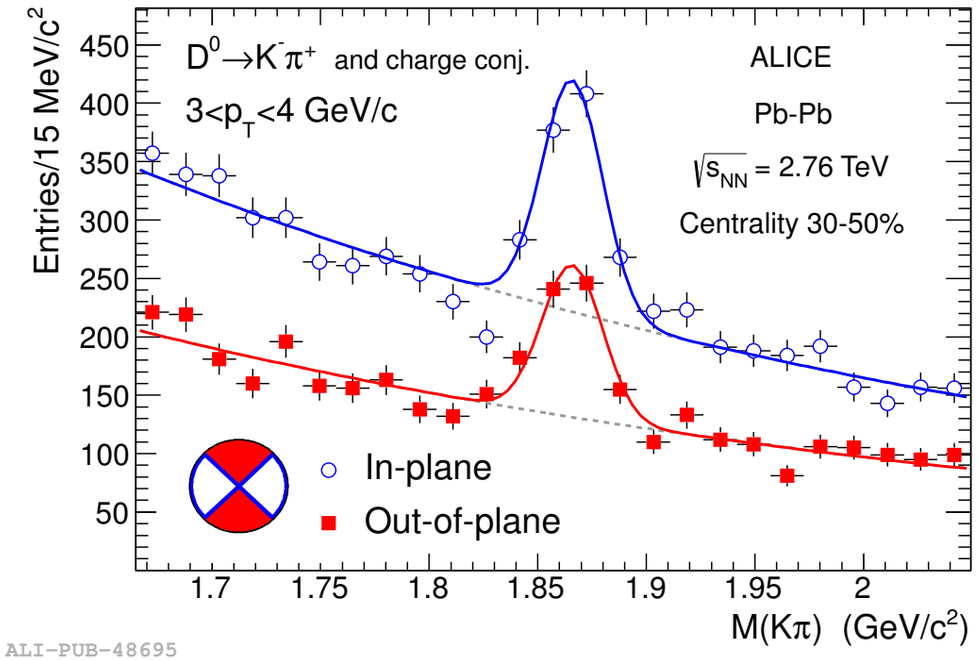
$$\frac{dN}{d(\varphi-\Psi_{RP})}=\frac{N_0}{2\pi}\left(1+2v_1\cos(\varphi-\Psi_{RP})+2v_2\cos(2(\varphi-\Psi_{RP}))+....\right)$$

D meson v_2 measurement:

- provides information on the degree of thermalization of charm quarks in the medium at low / intermediate p_T
- At high-p_T sensitive to path length dependence of heavy quark energy loss



D meson v_2 measurement



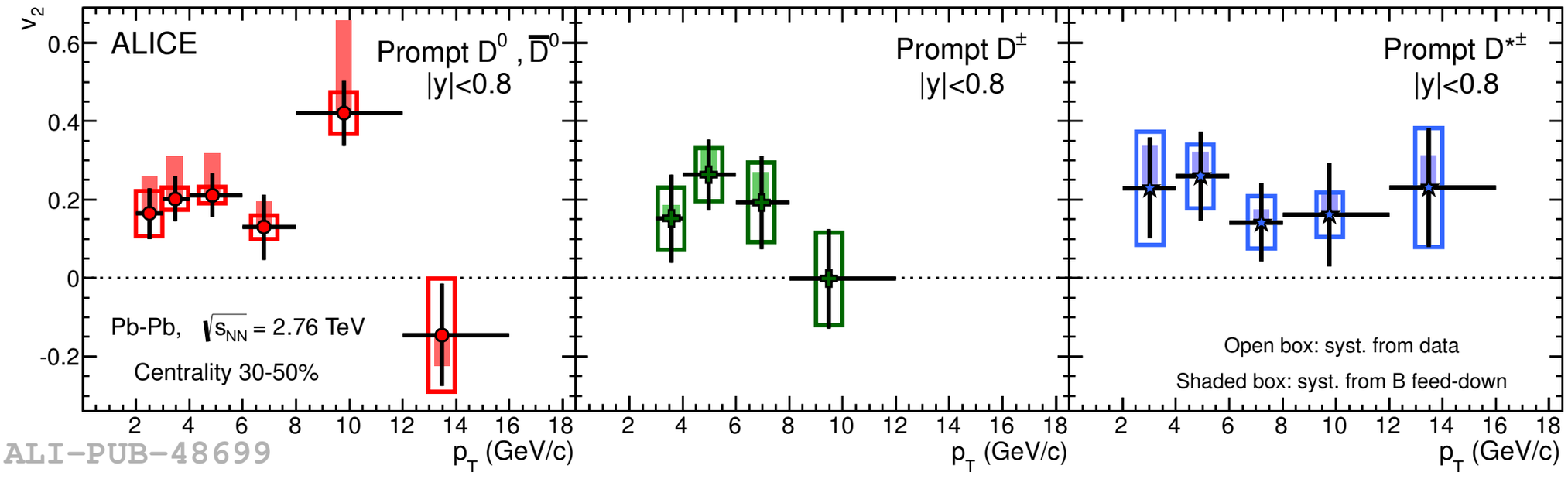
ALI-PUB-48695

v_2 of D mesons measured with event plane method in the centrality range 30-50%

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

R_2 correction for event plane resolution

Phys. Rev. Lett. 111, 102301 (2013)

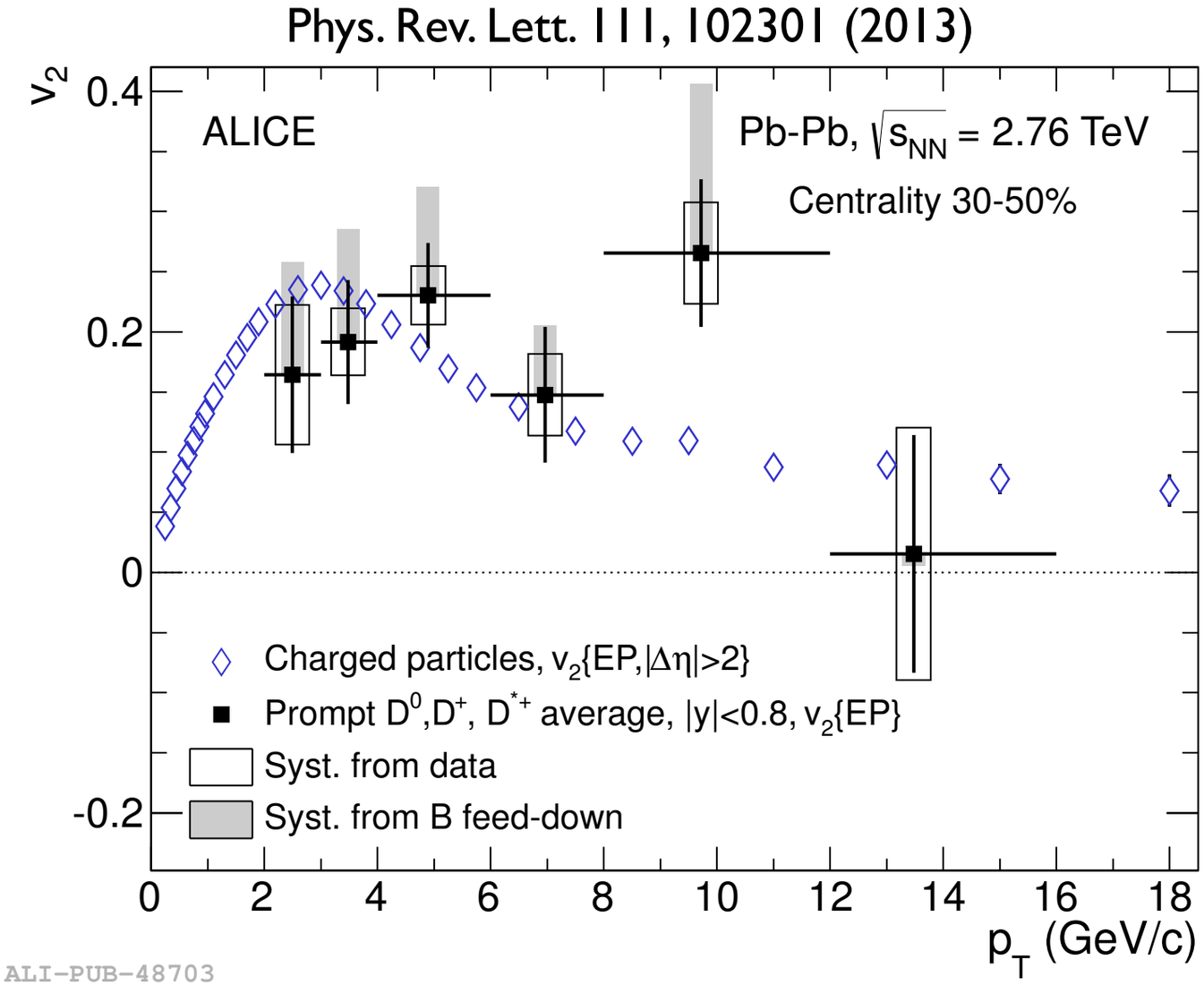


ALI-PUB-48699

- Results for the three mesons consistent within the uncertainties

D meson v_2 >0 at low p_T (~5σ effect in the p_T range 2-6 GeV/c)

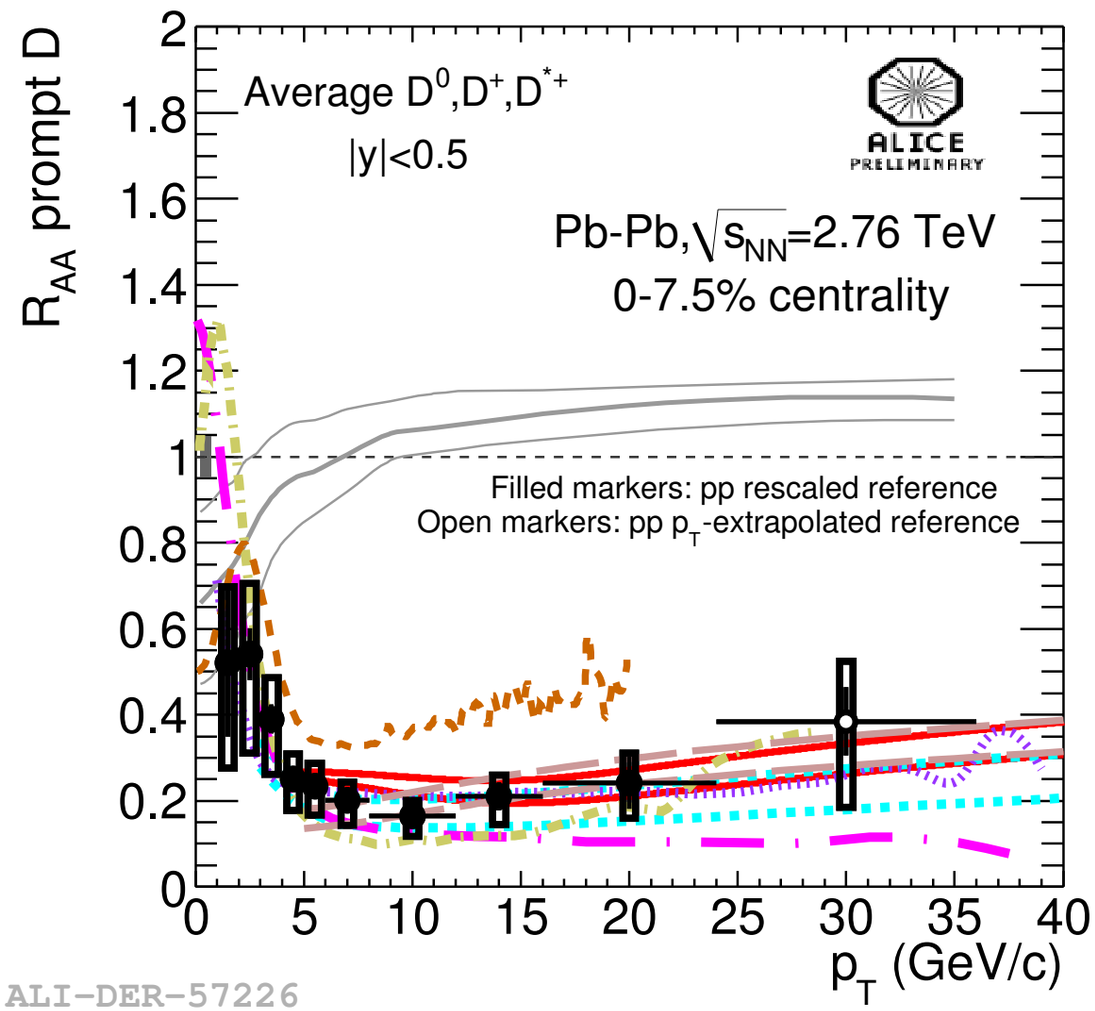
Comparison with charged particle v_2

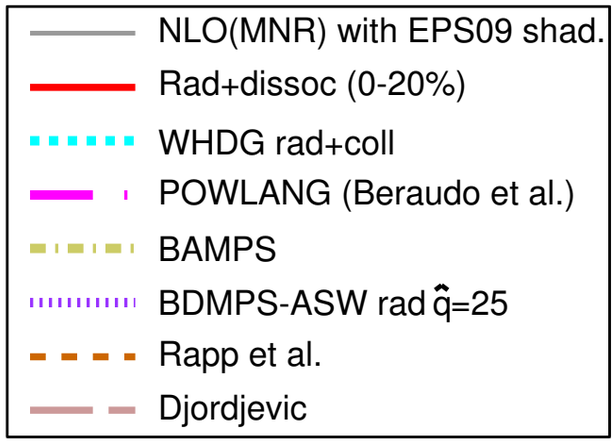


v_2 of D-mesons comparable in magnitude to that of light-flavour hadrons

→ALICE measurement of D-meson elliptic flow suggests that heavy quarks take part in the collective motion of the system

Comparison to models: R_{AA} for central events



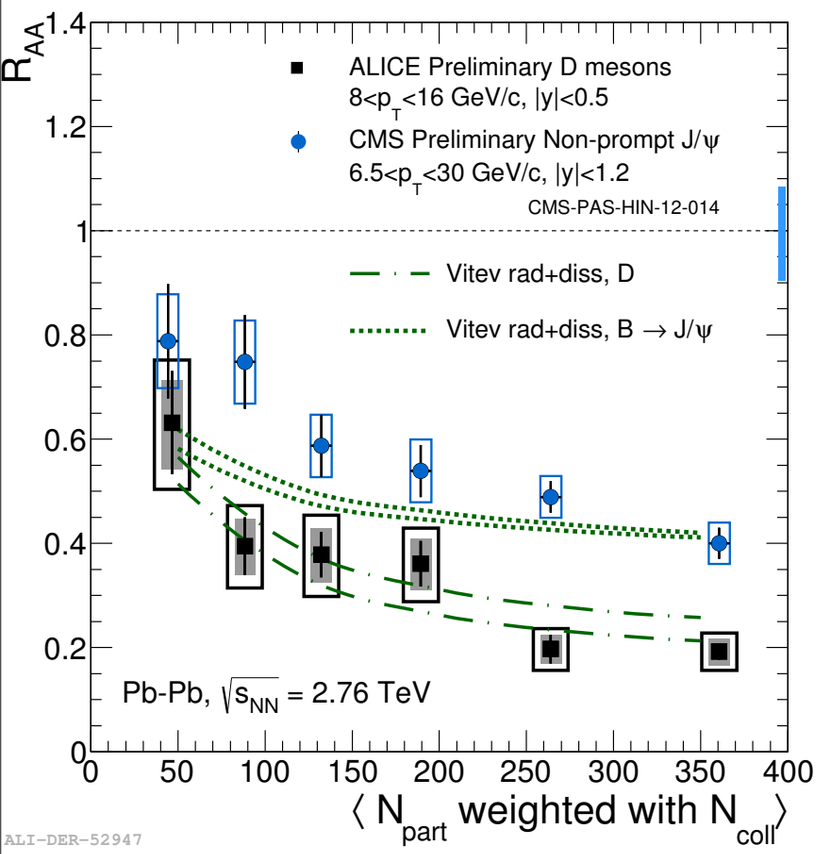


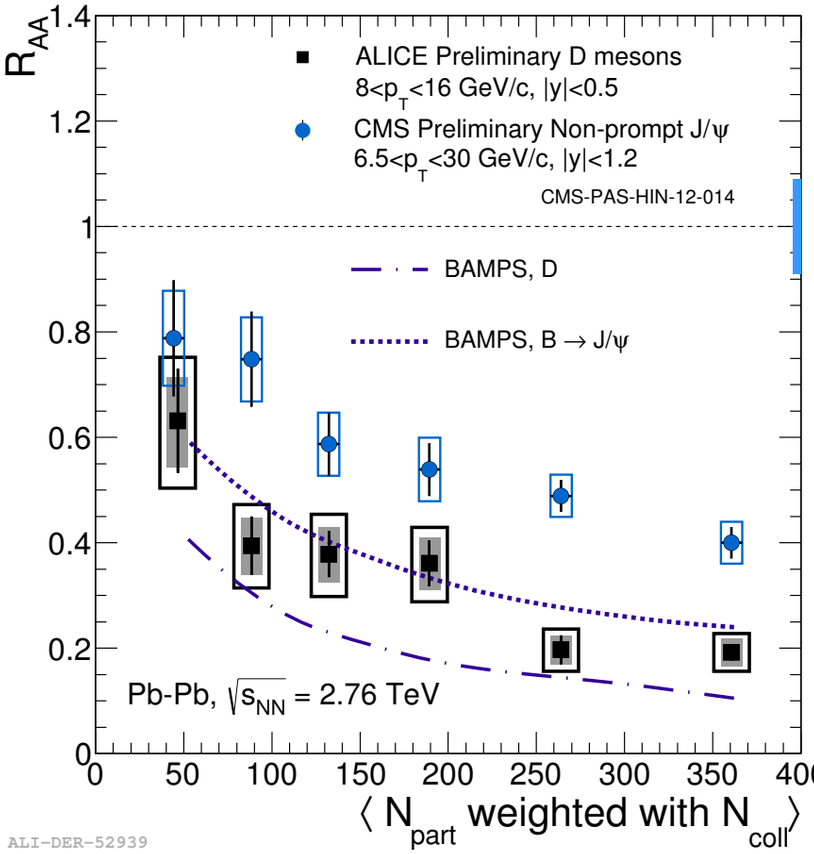
BAMPS: Fochler et al., J. Phys. G38 (2011) 124152
BDMPS: Armesto et al. PRD71(2005) 054027
POWLANG: Alberico et al., Eur.Phys.J C71 (2011) 1666
UrQMD: T. Lang et al, arXiv:1211.6912 [hep-ph];
T. Lang et al., arXiv:1212.0696 [hep-ph].
TAMU: Rapp, He et al., Phys. Rev. C 86 (2012) 014903
WHDG: Horowitz et al., JPhys G38 (2011) 124114
Aichelin et al.:Phys. Rev. C79 (2009) 044906
J. Phys. G37 (2010) 094019
Djordjevic et al.: arXiv:1307.4098
Vitev et al.: Phys. Rev. C80 (2009) 054902,
Phys. Lett. B 713 (2012) 224

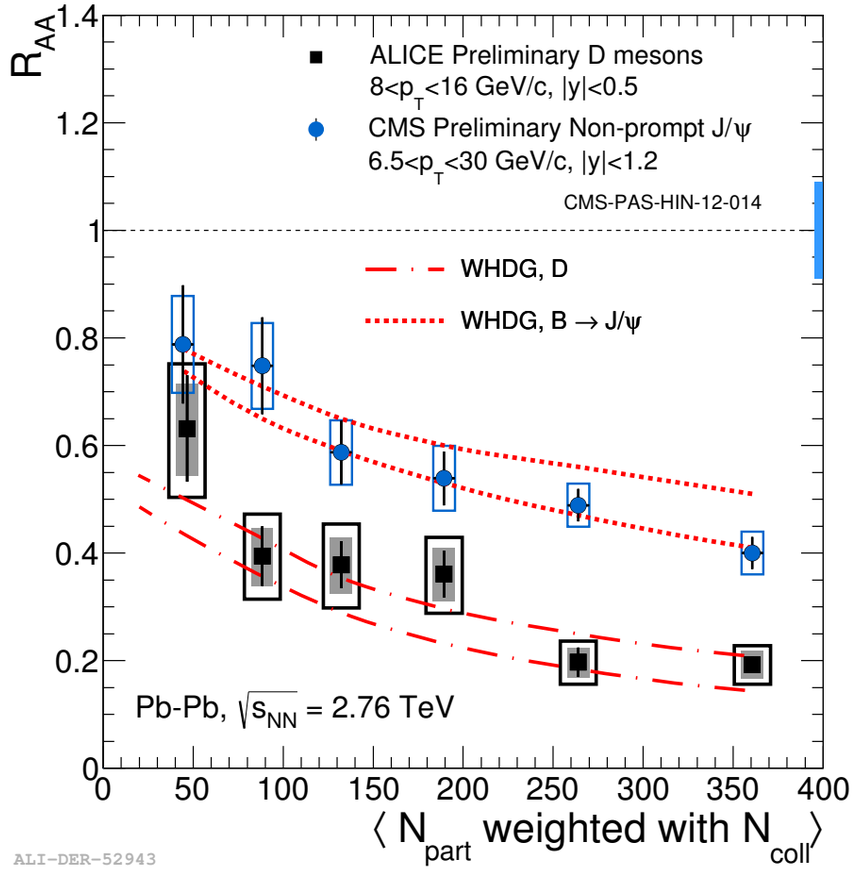
Different models based on in-medium energy loss (radiative and collisional) provide a reasonable description of the R_{AA} measurement

→ for p_T >3-4 GeV/c suppression cannot be described by cold nuclear matter effects
(See A. Festanti Parallel Talk for details on the p-Pb D meson measurement)

Comparison to models: R_{AA} vs centrality







Vitev et al.:
Good description of D meson R_{AA}. Non prompt J/ψ suppression underestimated

Vitev et al.: Phys. Rev. C80 (2009) 054902, Phys. Lett. B 713 (2012) 224

BAMPS:
both the measurements seem to be slightly underestimated

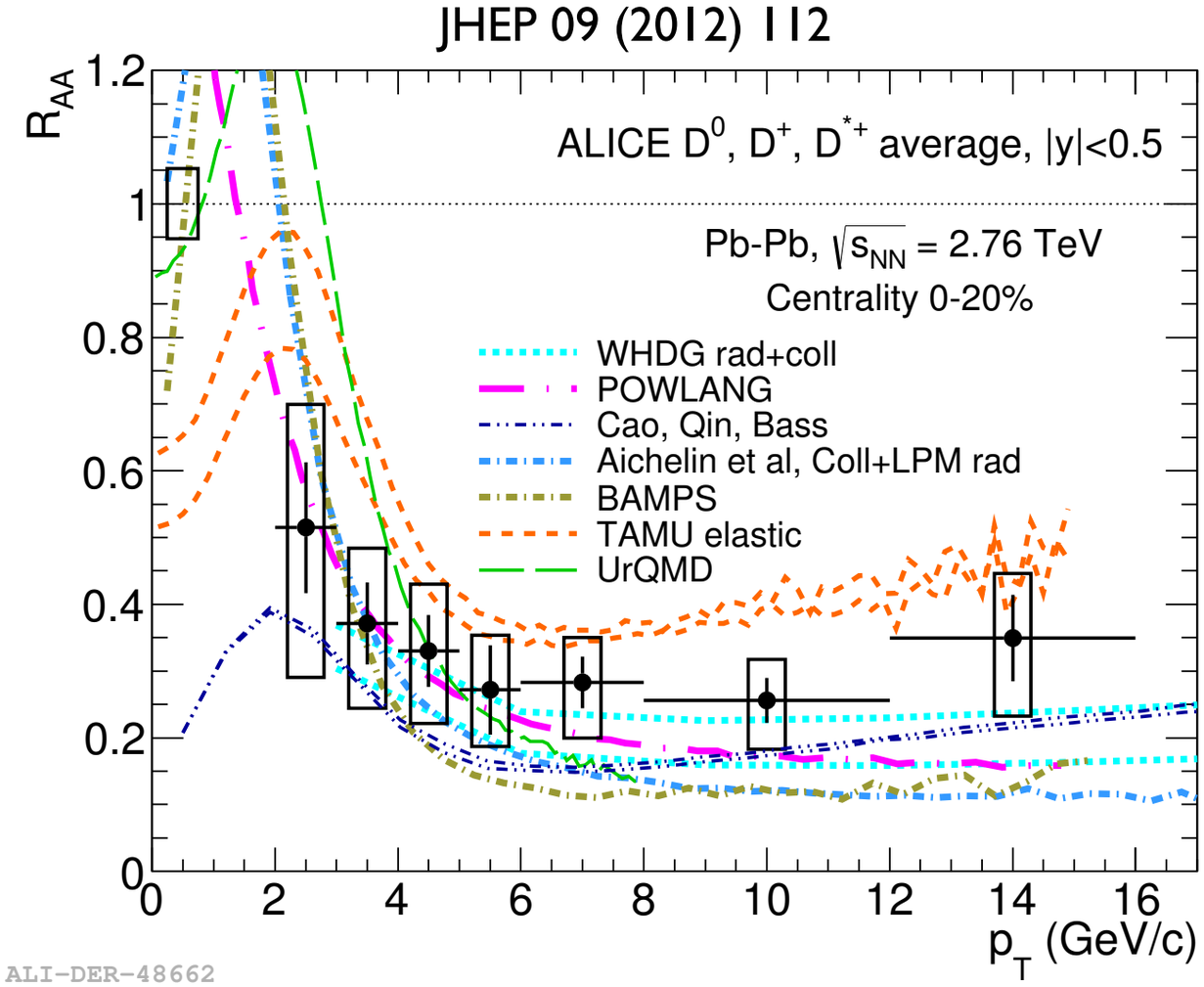
BAMPS: Fochler et al., J. Phys. G38 (2011) 124152

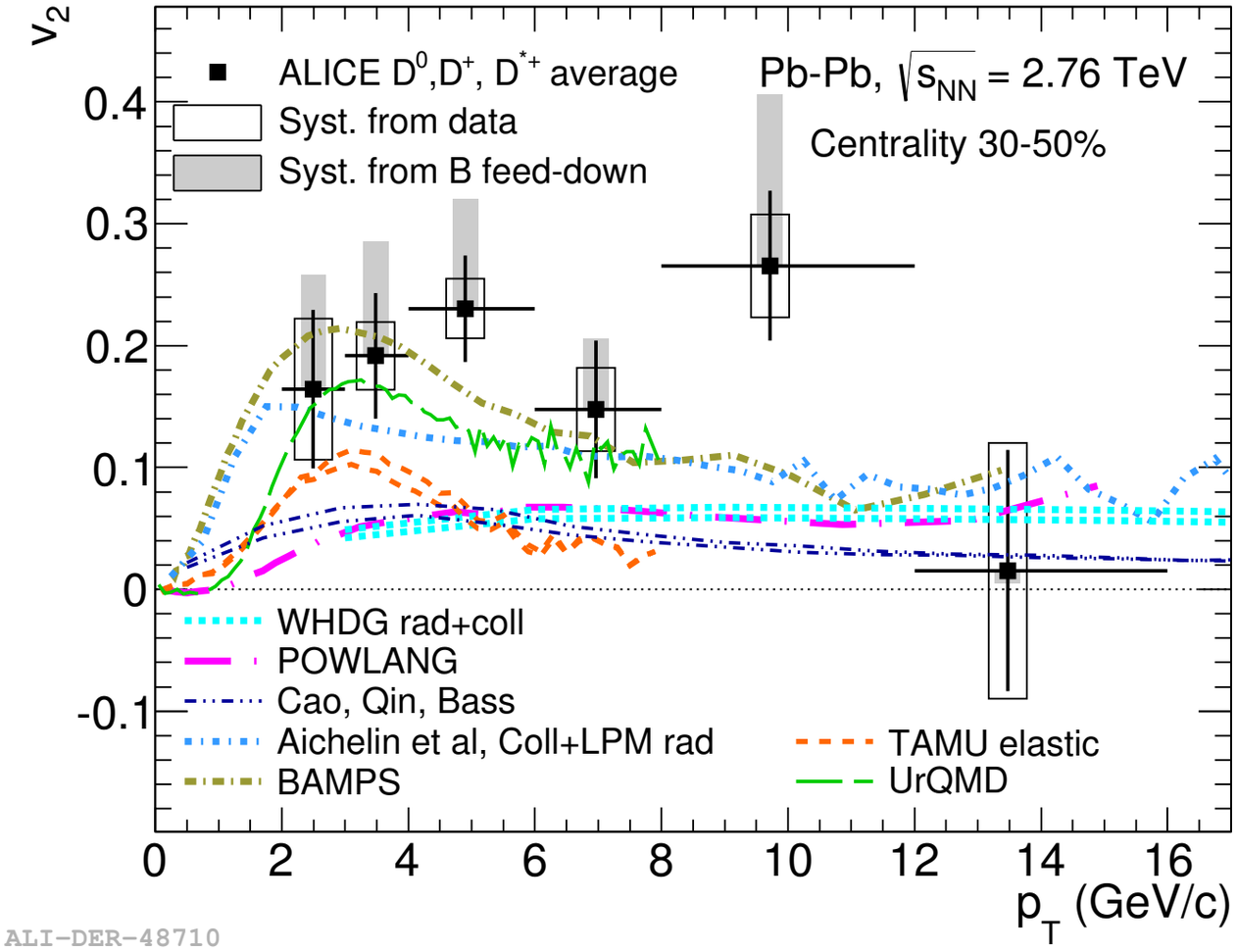
WHDG.:

Good description of both D meson and non-prompt J/ψ R_{AA} in the full p_T range

Horowitz et al., J Phys G38 (2011) 124114

Comparison to models: R_{AA} and v_2





Several models reproduce R_{AA} and v_2 separately. However, a simultaneous description of the two measurements is still challenging.

BAMPS: Fochler et al., J. Phys. G38 (2011) 124152
POWLANG: Alberico et al., Eur.Phys.J C71 (2011) 1666
UrQMD: T. Lang et al, arXiv:1211.6912 [hep-ph];
T. Lang et al., arXiv:1212.0696 [hep-ph].
TAMU: Rapp, He et al., Phys. Rev. C 86 (2012) 014903
WHDG: Horowitz et al., JPhys G38 (2011) 124114
Aichelin et al.:Phys. Rev. C79 (2009) 044906
J. Phys. G37 (2010) 094019
Cao, Qin, Bass arXiv: 1308.0617 [hep-ph]

Conclusions

D meson R_{AA} vs p_T in central Pb-Pb collisions:

- Large suppression observed at high p_T compatible for D^0, D^+, D^{+*}
- D_s^+ R_{AA} compatible with non-strange D meson R_{AA} at high p_T
- Intriguing result for D_s^+ R_{AA} at low p_T (recombination?)
  Measurement to be improved with the next runs and with the ALICE upgrade.

D meson R_{AA} vs centrality in Pb-Pb collisions:

- Strong increase of suppression w.r.t. centrality at high p_T 3-5, 5-8, 8-16 GeV/c while tends to be flat in the lowest p_T bin (2-3 GeV/c)
- The difference between D meson R_{AA} and CMS results for non-prompt J/ψ observed at high p_T in central collisions seems to confirm the expected hierarchy $R_{AA}(D)<R_{AA}(B)$

Non-zero D meson v_2 observed in semi-peripheral Pb-Pb collision

- 5 σ effect in the p_T range 2-6 GeV/c
  →hint for heavy quarks to take part in the collectivity


ALICE
A JOURNEY OF DISCOVERY

Backup Slides

B feed down subtraction in Pb-Pb analyses

The same approach has been used for the four D mesons studied in ALICE
D^+_s ,D^0,D^+ and D^{*+}

Fraction of prompt D_s^+ mesons f_{prompt} estimated as:

$$f_{\text{prompt}} = 1 - \langle T_{\text{AA}} \rangle \cdot \left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\,\mathrm{d}p_{\text{t}}} \right)^{\text{FONLL}}_{\text{feed-down}} \cdot R_{\text{AA}}^{\text{feed-down}} \cdot \frac{(\text{Acc} \times \varepsilon)_{\text{feed-down}} \cdot \Delta y\, \Delta p_{\text{t}} \cdot \text{BR} \cdot N_{\text{evt}}}{N^{\text{D}^{\pm}\ \text{raw}}/2}$$

average nuclear overlap function in the centrality class considered

beauty production cross section from ***FONLL***[1] calculations

Hypothesis on the R_{AA} of D_s^+ from B:

Assumption on B suppression:

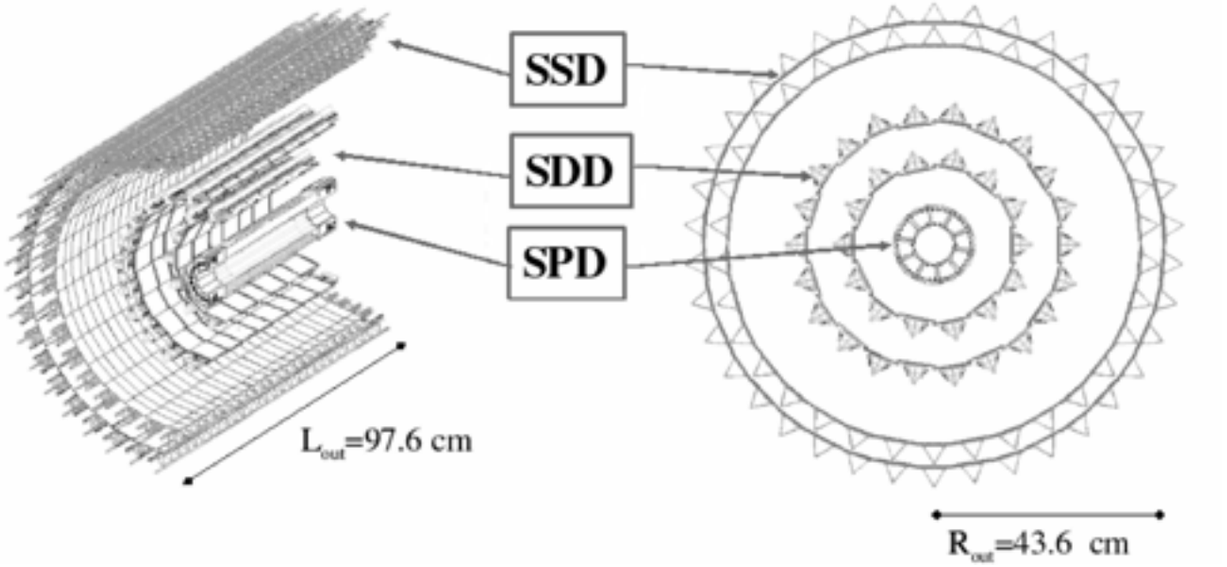
- R_{AA} vs p_T: Central hypothesis: R_{AA} (D from B)=R_{AA} (prompt D) ,
  Variation range: R_{AA} (D from B) from 0.3 to 3 x R_{AA} (prompt D)

- R_{AA} vs N_{part} : Central hypothesis: R_{AA} (D from B)=2 x R_{AA} (prompt D) ,
  Variation range: R_{AA} (D from B) from 1 to 3 x R_{AA} (prompt D)*

* new choice for R_{AA} for feed-down driven by the comparison with CMS results for non-prompt J/Ψ

[1] M. Cacciari, M. Greco, P. Nason, JHEP 9805 (1998) 007

Inner Tracking System

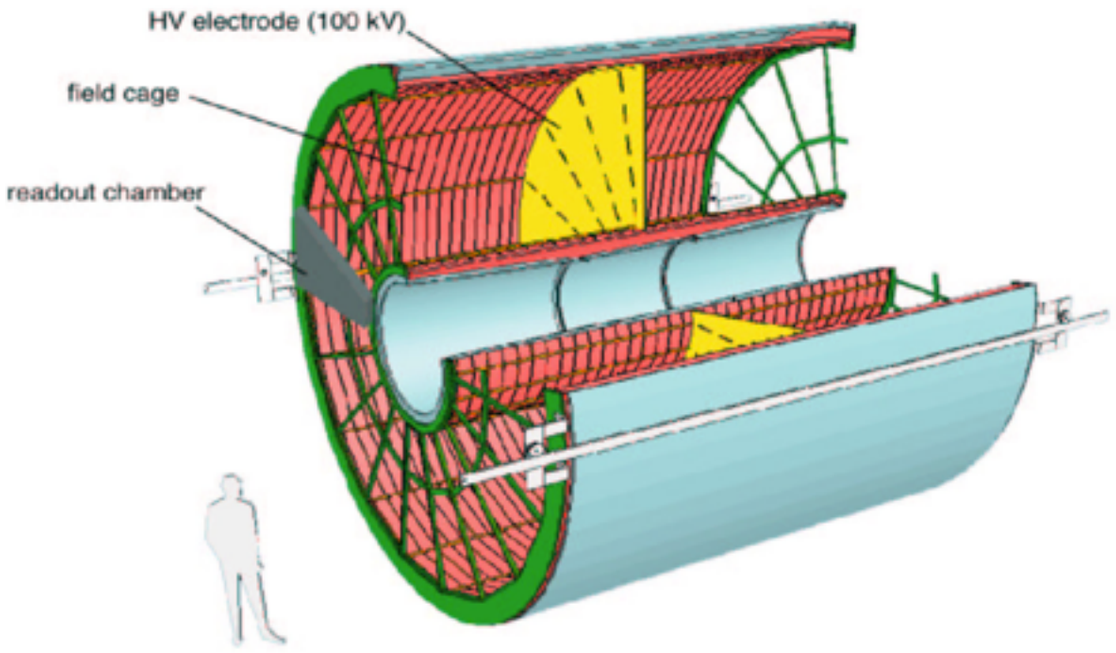


- 6 cilindrical layers of silicon detectors with radii from 3.9 to 43.0 cm
- two innermost layer are equipped with Silicon Pixel Detectors with radii 3.9 and 7.6 cm
- ITS has coverage $|\eta| < 0.9$ (1.98 for SPD)

Main goals:

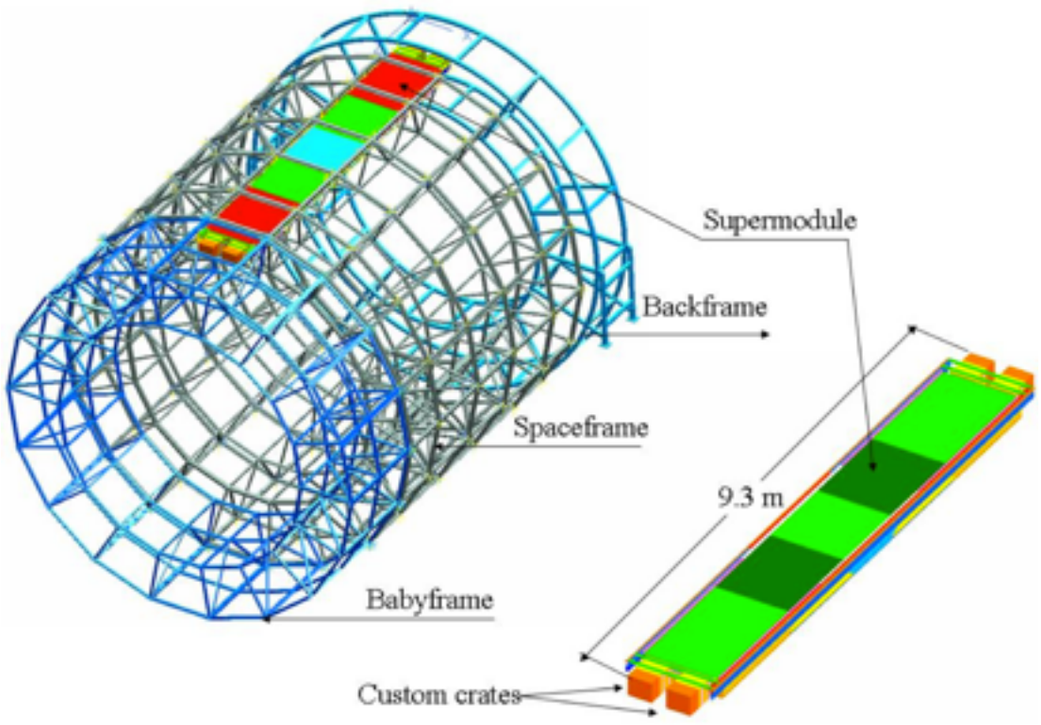
- primary and secondary vertex reconstruction with high resolution required for the detection of open charm and beauty
- measurement with resolution better than 100 μm of the impact parameter of the tracks
- reconstruction and identification of the low momentum tracks with p_T < 200 MeV/c

Time Projection Chamber and Time of Flight Detector



TPC

- 510 cm long cylindrical chamber filled with 90 m^3 of drift volume filled with a gas mixture
- TPC has coverage $|\eta| < 0.9$ for tracks with full radial length
- *main tracking detector of the ALICE central barrel (from 0.2 to 100 GeV/c)*
- *particle identification via specific energy deposit*



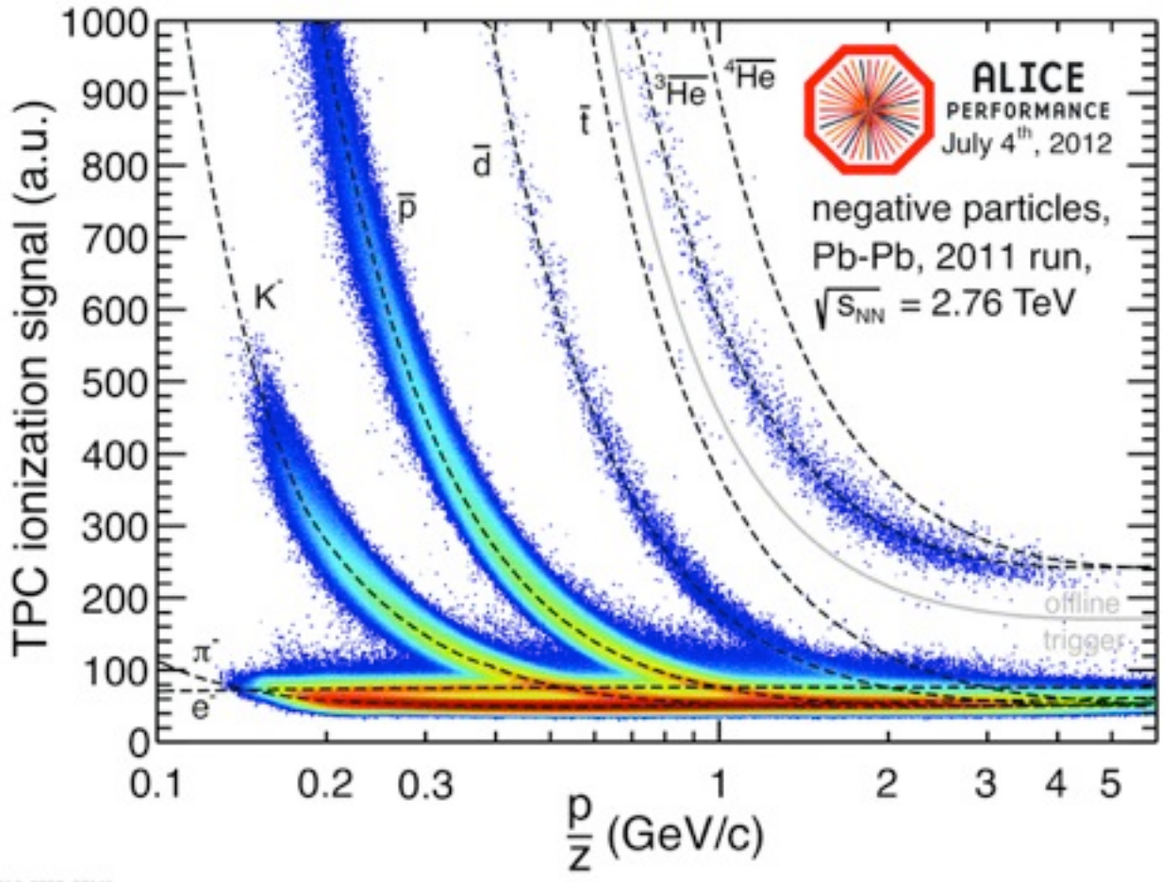
TOF

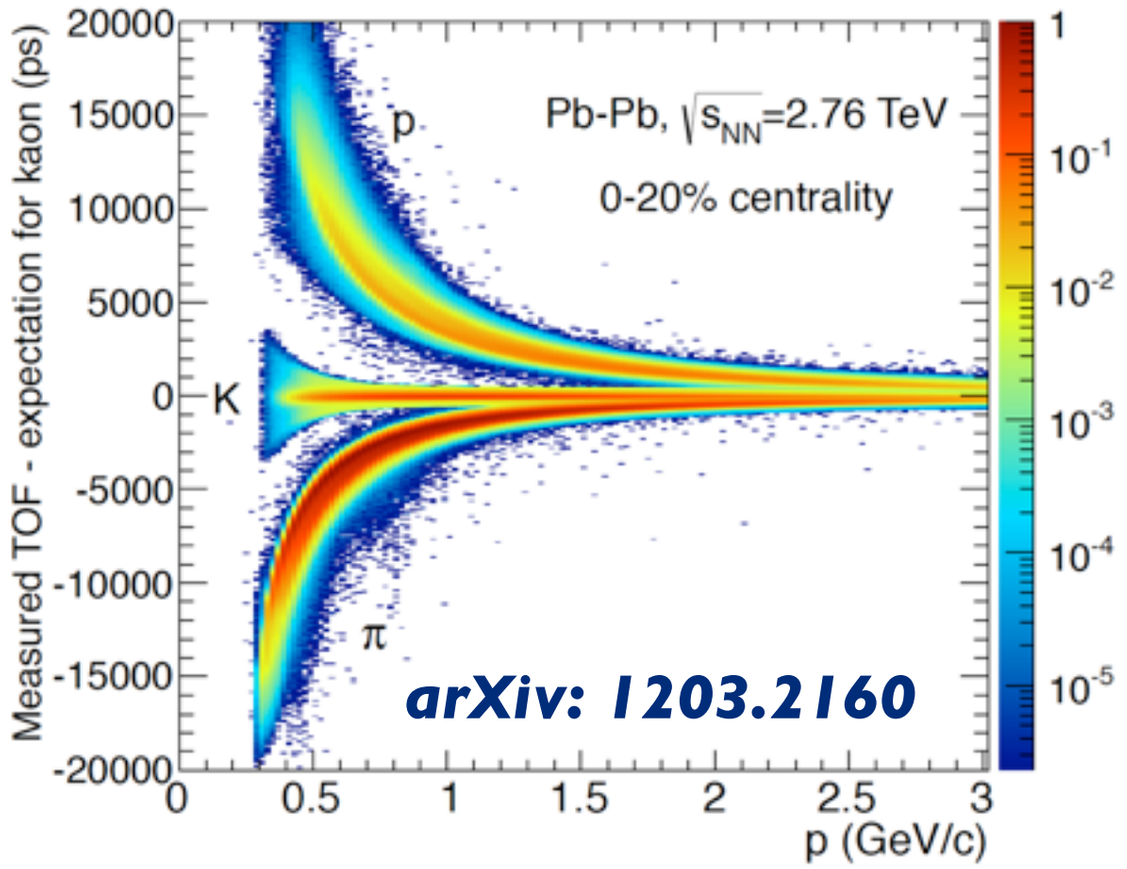
- large array area of MRPC that covers the full azimuthal angle and $|\eta| < 0.9$ in pseudorapidity at radii from 370-399 cm

- *particle identification in the intermediate momentum range via time of flight measurement*

  $p_T < 2.5$ GeV/c for pions and kaons
  $p_T < 4$ GeV/c for protons.

Particle identification selection (PID)



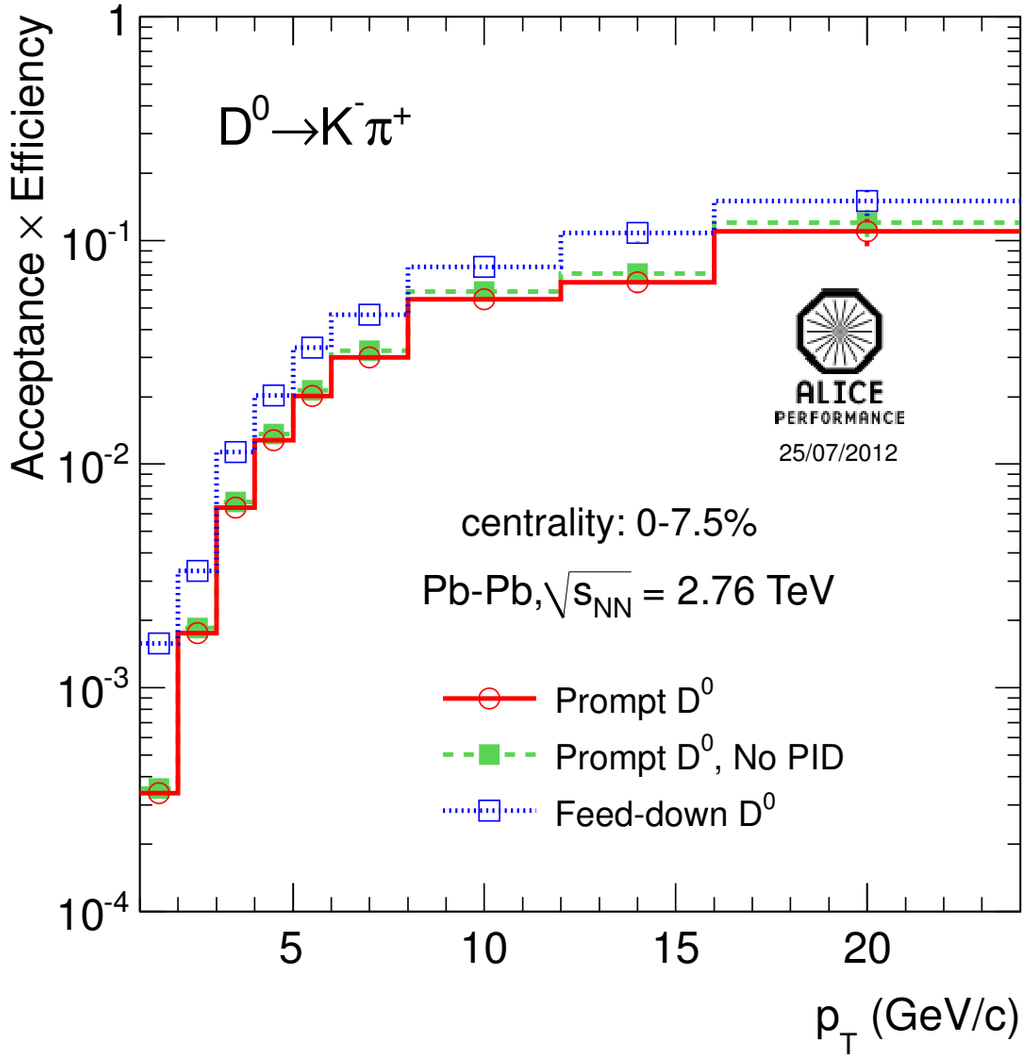


TPC: identification based on dE/dx:
- N*σ compatibility with Bethe-Bloch curves

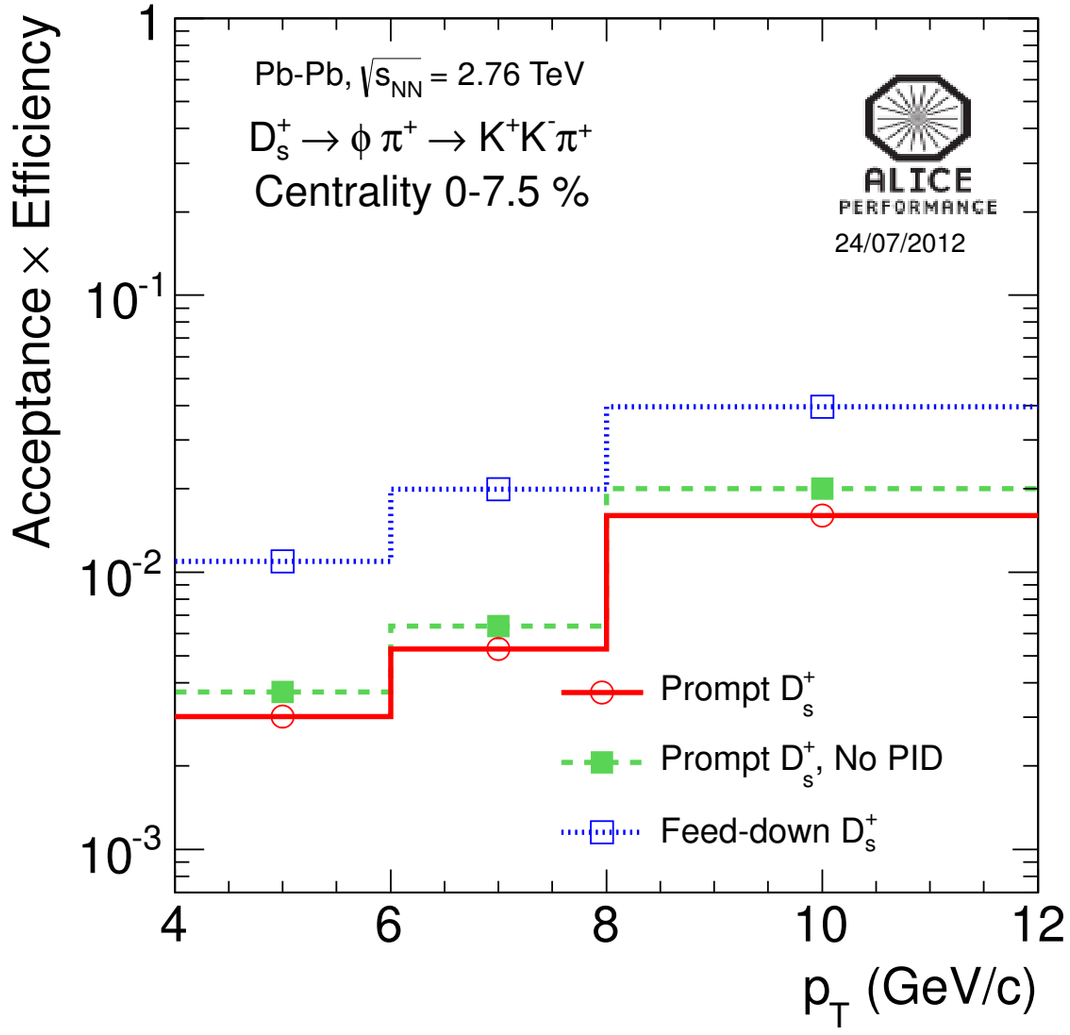
TOF: identification based on difference between the measured time-of-flight ($t_{MEAS} = t_{TOF} - t_{T0}$) and the one expected for a given particle species

Efficiency correction

$$\left.\frac{d\sigma^{D^0}}{dp_t}\right|_{|y|<0.5} = \frac{1}{2}\frac{1}{2y_{acc}\Delta p_t}\frac{f_{prompt}(p_t)\cdot N^{RawD^0}(p_t)}{\epsilon_{prompt}(p_t)\cdot BR\cdot L_{int}}\Bigg|_{|y|<y_{acc}}$$

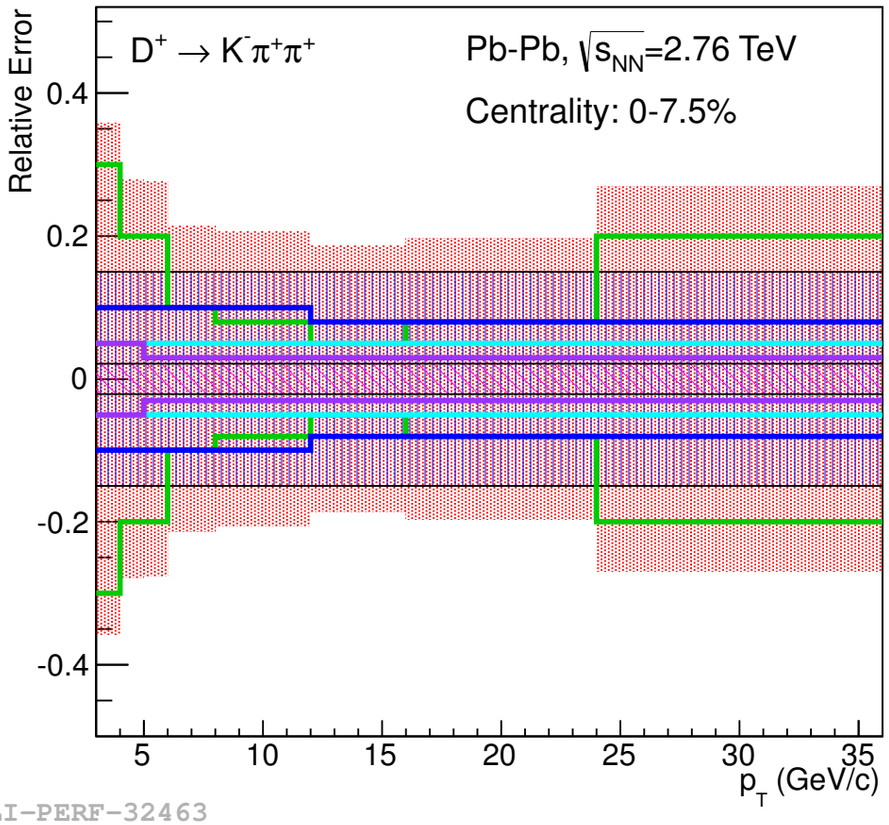


ALI-PERF-32809

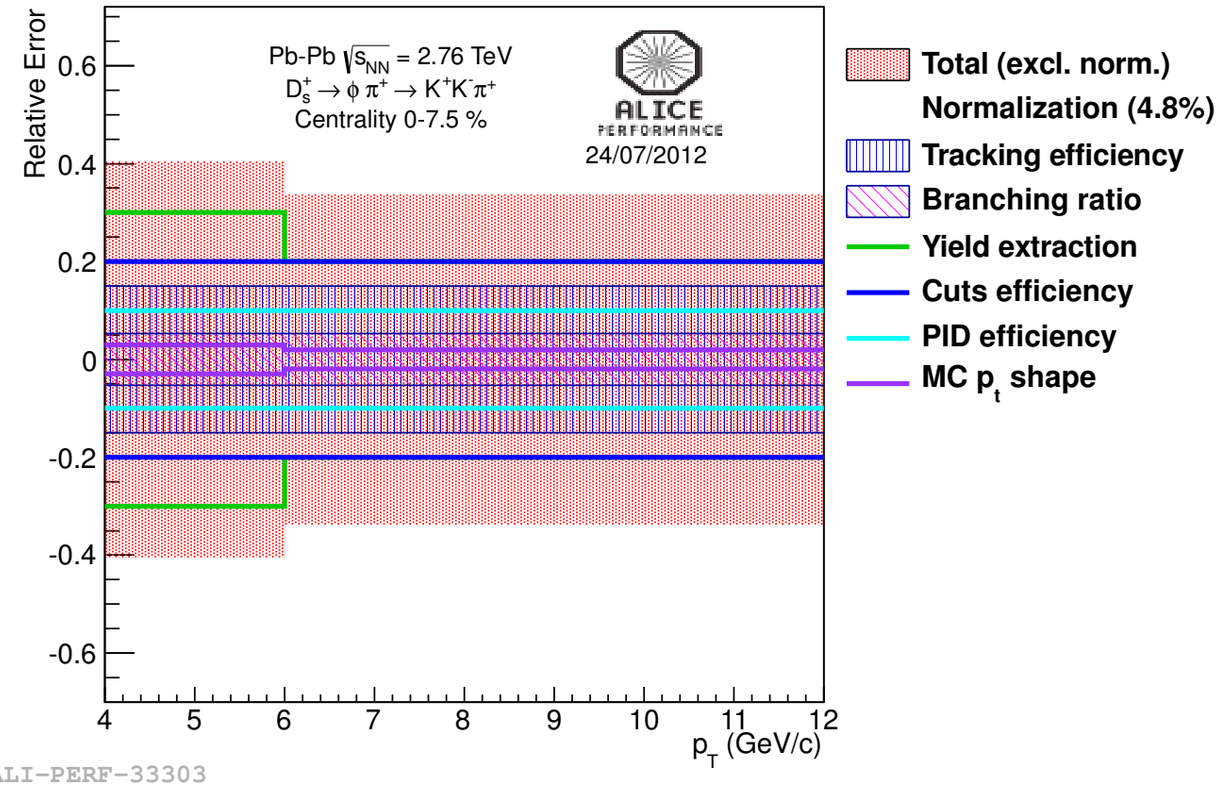


ALI-PERF-33605

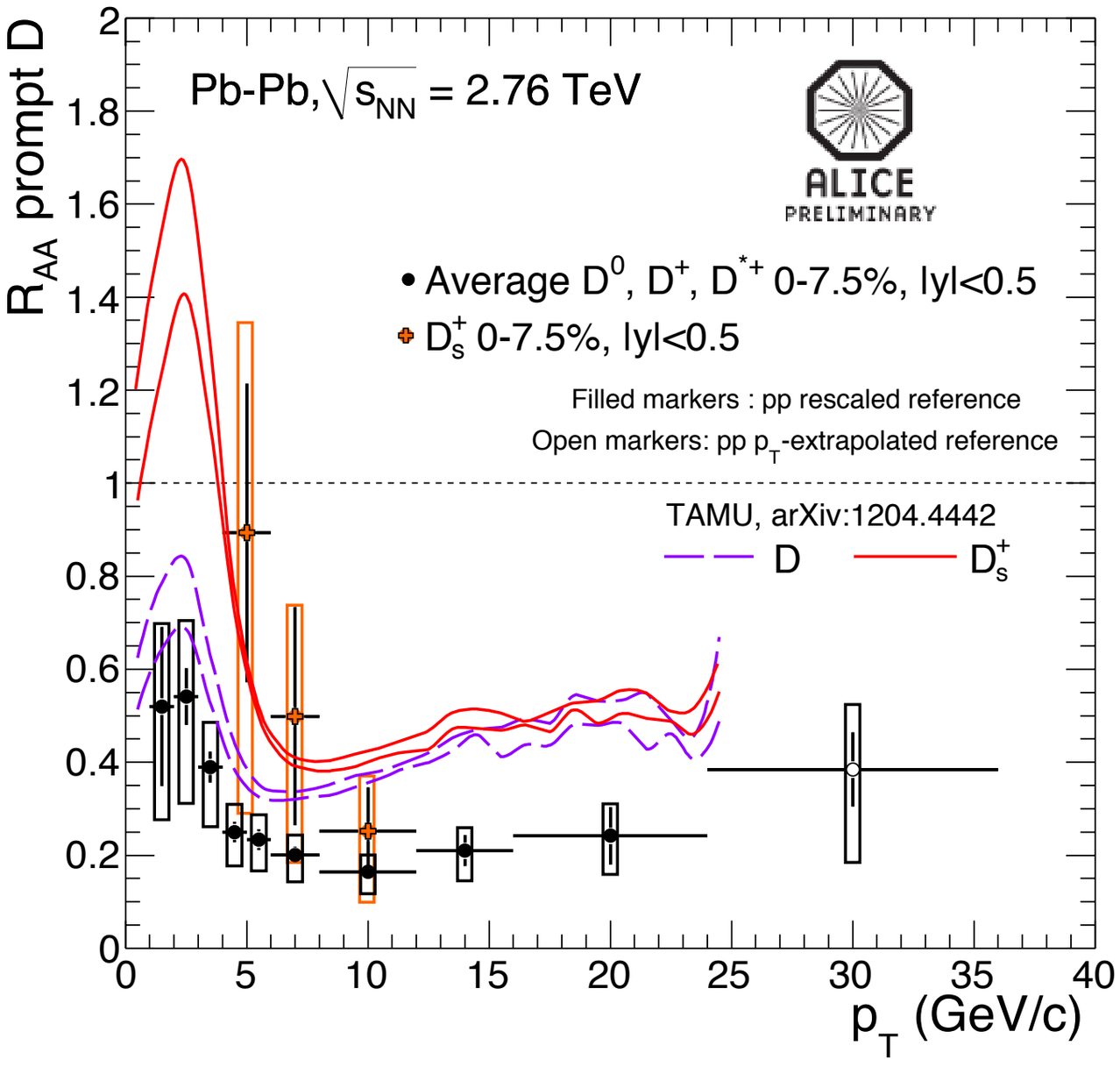
Systematic uncertainties



Systematic errors



Focus on D^+_s R_{AA}



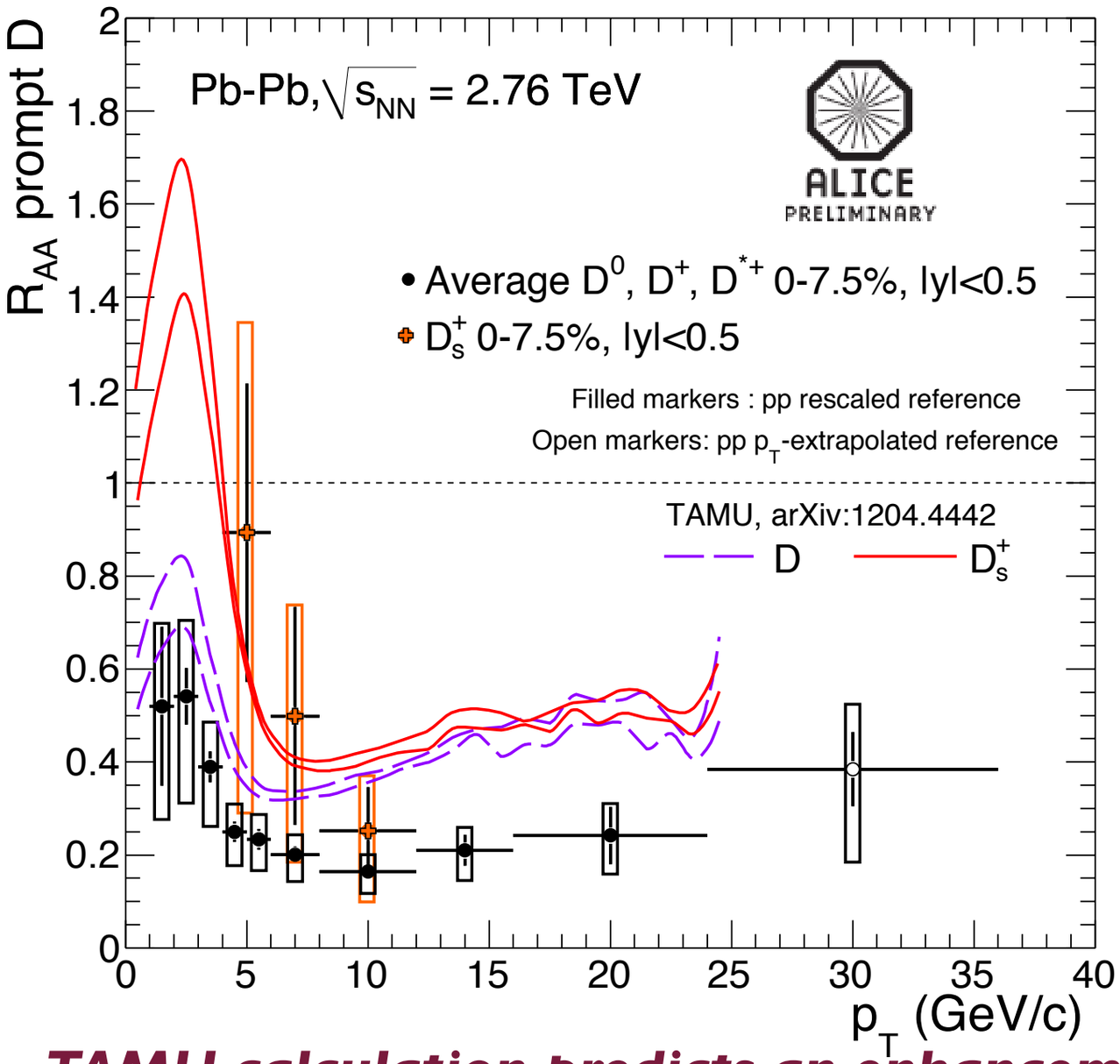
- R_{AA} of D_s^+ and average non-strange D meson compared to the prediction of the TAMU model [1] by He, Fries and Rapp

- This model employs a strong-coupling treatment with hydrodynamic bulk evolution for quark diffusion and hadronization in the QGP

- The model includes the mechanism of coalescence of the charm quark in the medium

[1] M. He, R. J. Fries and R. Rapp, arXiv:1204.4442 [nucl-th]

Focus on D^+_s R_{AA}



- R_{AA} of D_s^+ and average non-strange D meson compared to the prediction of the TAMU model [1] by He, Fries and Rapp

- This model employs a strong-coupling treatment with hydrodynamic bulk evolution for quark diffusion and hadronization in the QGP

- The model includes the mechanism of coalescence of the charm quark in the medium

TAMU calculation predicts an enhancement of the D_s^+ R_{AA} of a factor ≃2 in the low-intermediate transverse momentum region while it overpredicts the non-strange R_{AA} for p_T >5-6 GeV/c

[1] M. He, R. J. Fries and R. Rapp, arXiv:1204.4442 [nucl-th]

pp reference at 2.76 TeV

- pp reference obtained by scaling the ALICE pp measurement at 7 TeV to 2.76 using the ratio of the cross section at the two energies estimated with FONLL

- At high p_T (~16 GeV/c for D^0, > 24 GeV/c for D^+, D^{*+}) the pp measurement is not available. The pp reference obtained using relying on the FONLL p_T shape.