D meson nuclear modification factors in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV measured with the ALICE detector

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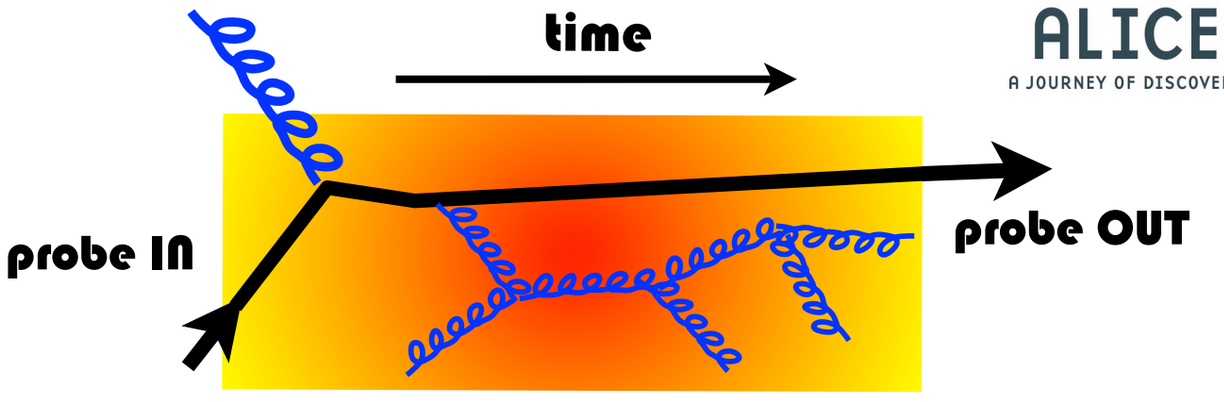
Outline

- Heavy quarks in heavy-ion collisions
- D^0, D^{*+}, D^+ and D^+_s reconstruction
- Proton-proton reference
- Pb-Pb analysis
  - ✓ Summary of results published in 2010
  - ✓ 2011 D meson spectra in 0-7.5% centrality class.
- D meson nuclear modification factor
- Conclusions

Heavy quarks in heavy-ion collisions

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



- Heavy quarks are expected to lose less energy than light quarks and gluons due to color-charge and dead cone effect → higher penetrating power into QCD medium.

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.

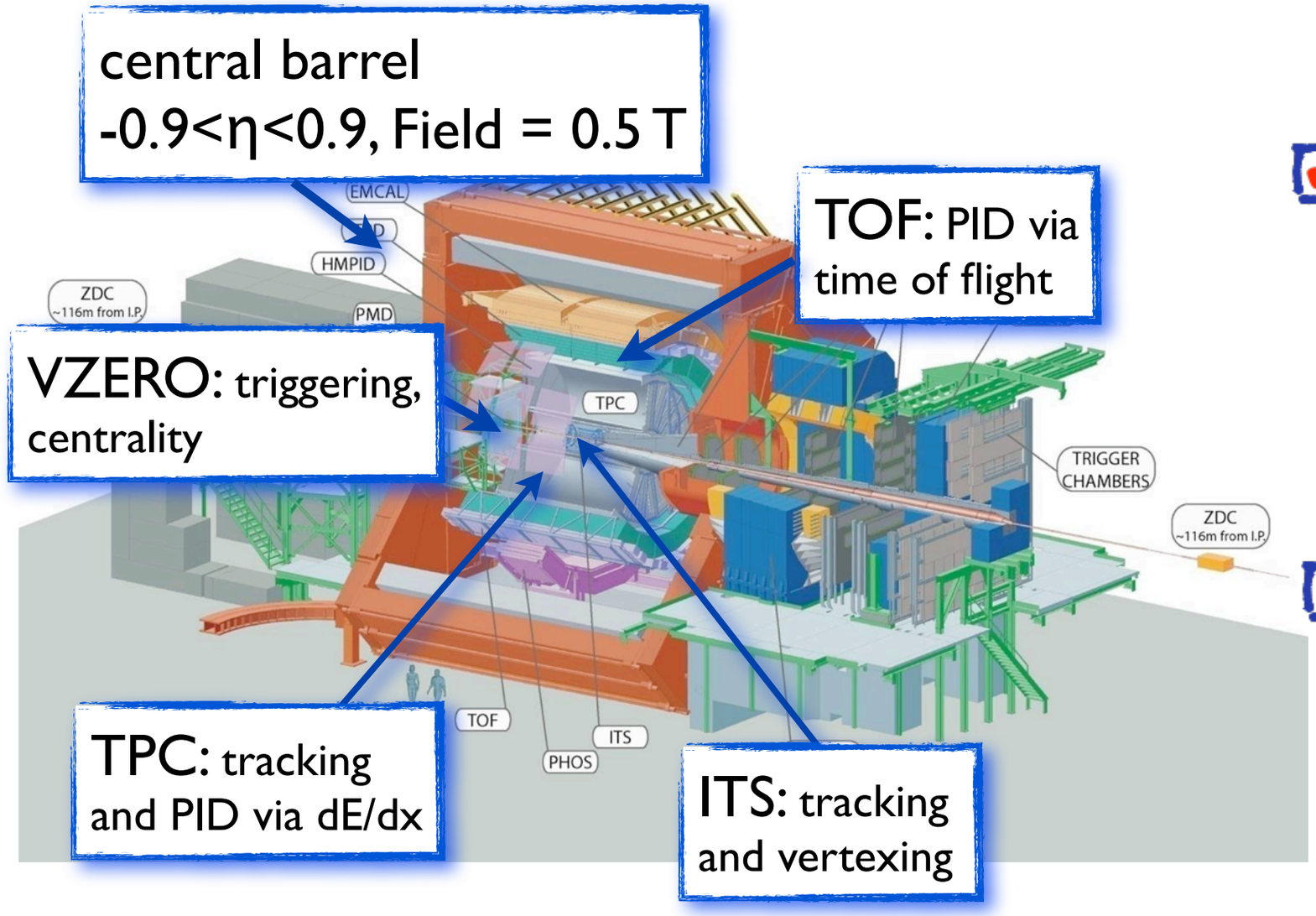
E_{loss}(light) > E_{loss}(D) > E_{loss}(B)

- What about charm strange hadrons (D_s)? If in-medium hadronization dominant mechanism of charm hadron formation at low p_T→ strange charm hadrons largely enhanced.

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

→ Allow testing of pQCD models of quark energy loss.
→ Good probes of the QCD medium.

Detector and data sample



Data sample

OR between central and minimum bias trigger, based on ITS pixel and VZERO scintillators.

Centrality

- Determined via geometrical Glauber model fit of the VZERO amplitude.

System	c.m.s energy (TeV)	events analyzed
PP	7	~3.16×10^{8}
PP	2.76	~6.8×10^{7}
Pb-Pb	2.76	~3.0×10^{6} (0-20%)
Pb-Pb	2.76	~1.6×10^{7} (0-7.5%)

New! 2011 run

D mesons via hadronic decays

- Fully reconstructed D mesons in hadronic decay channels.
- In this talk:

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

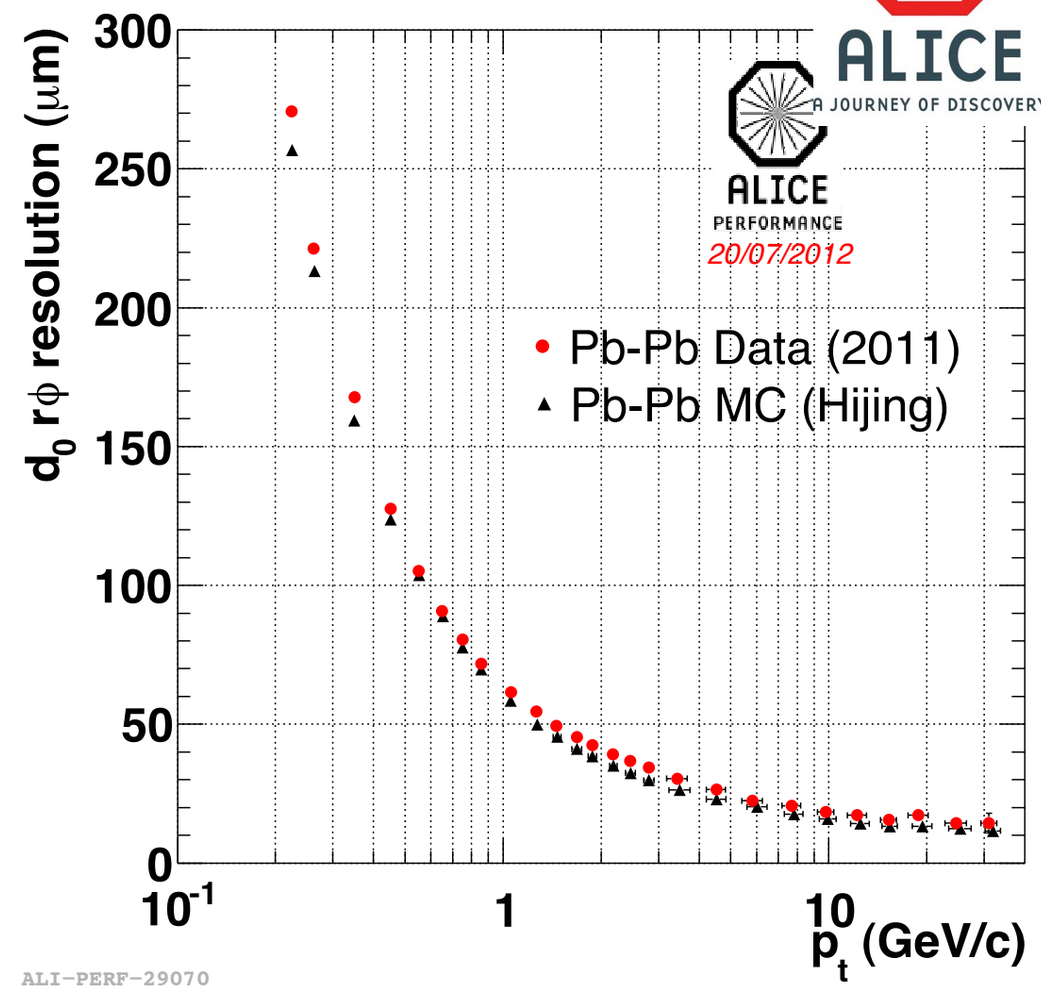
Except for D^{*+}, the $c\tau$ of the other D mesons ranges from ~123 to 312 μm

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

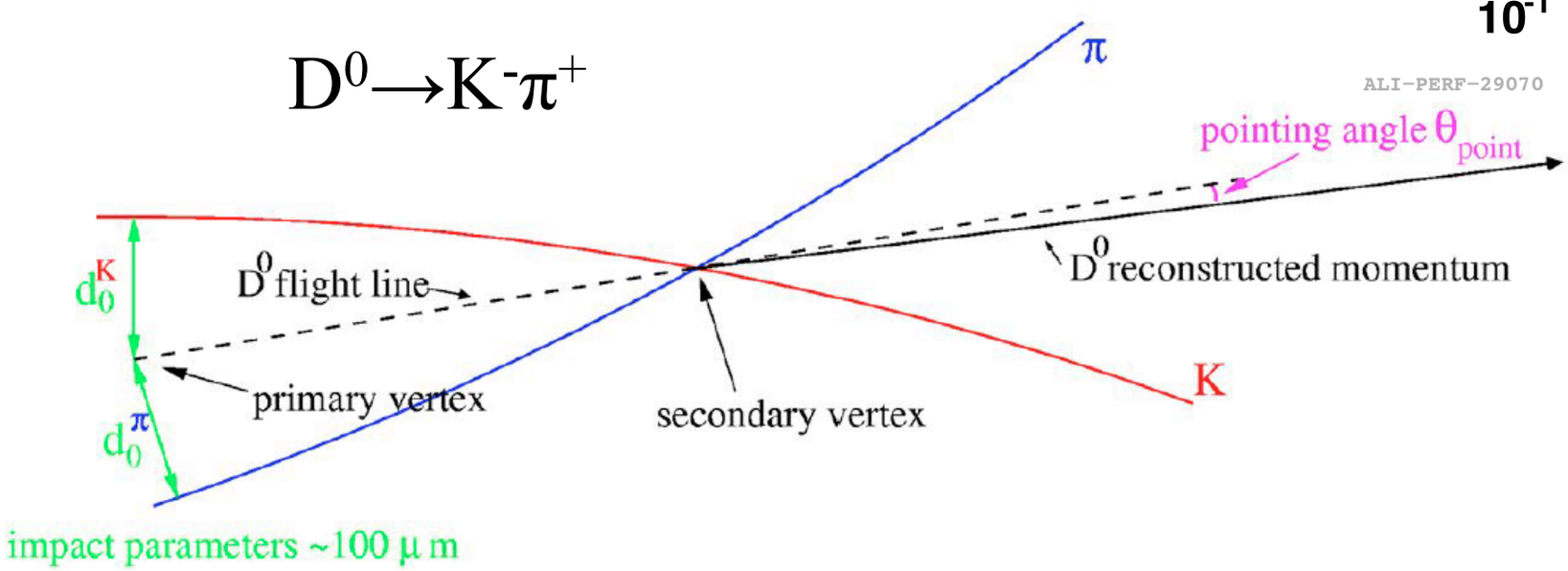
- Additional information on D^+_s and D^+ in:
  - → D^+_s talk by Gian Michele Innocenti
  - → D^+ poster by Riccardo Russo

D meson reconstruction

- Topology of the decay resolved via the reconstruction of the secondary vertex.
- Combinatorial background reduced via topological selections.
- PID using TOF and TPC to further suppress background.
- Invariant mass analysis.



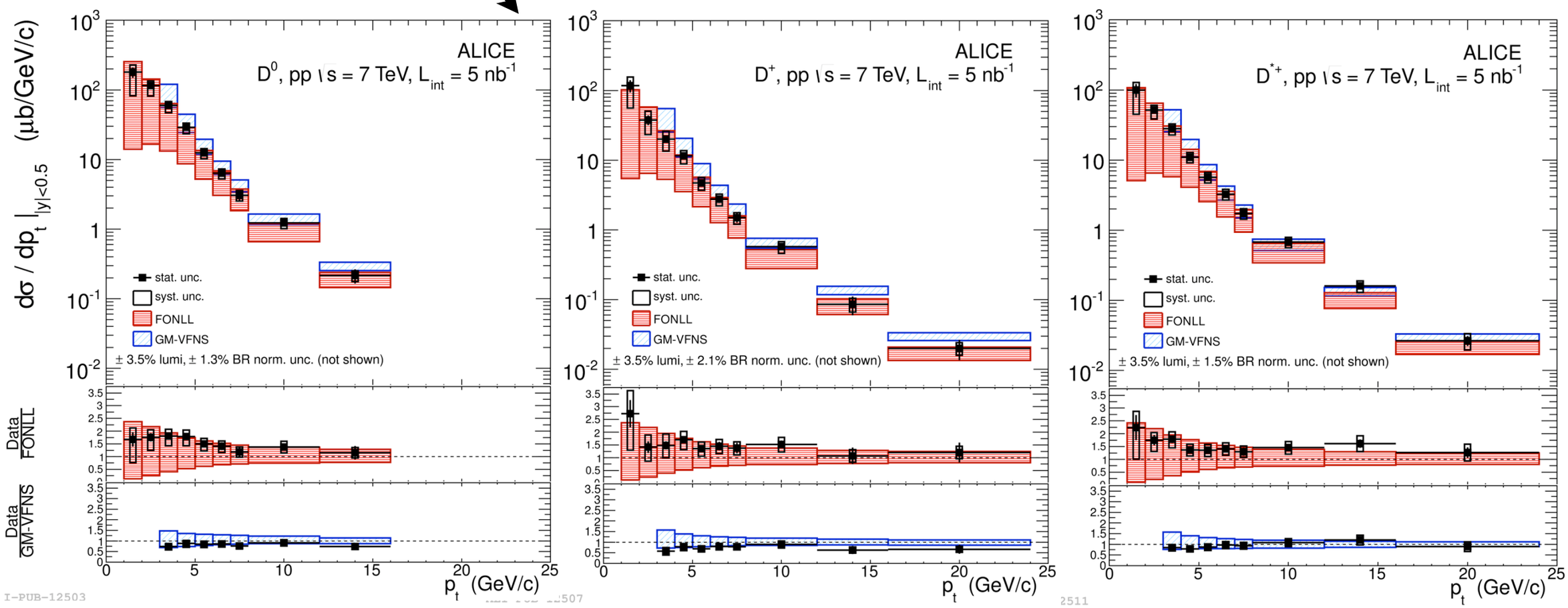
$D^0 \rightarrow K^- \pi^+$



Similar strategy for all D mesons both in pp and Pb-Pb collisions.

D meson cross sections in pp at √s = 7 TeV

D^0, D^+ and D^{*+} cross section at √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.

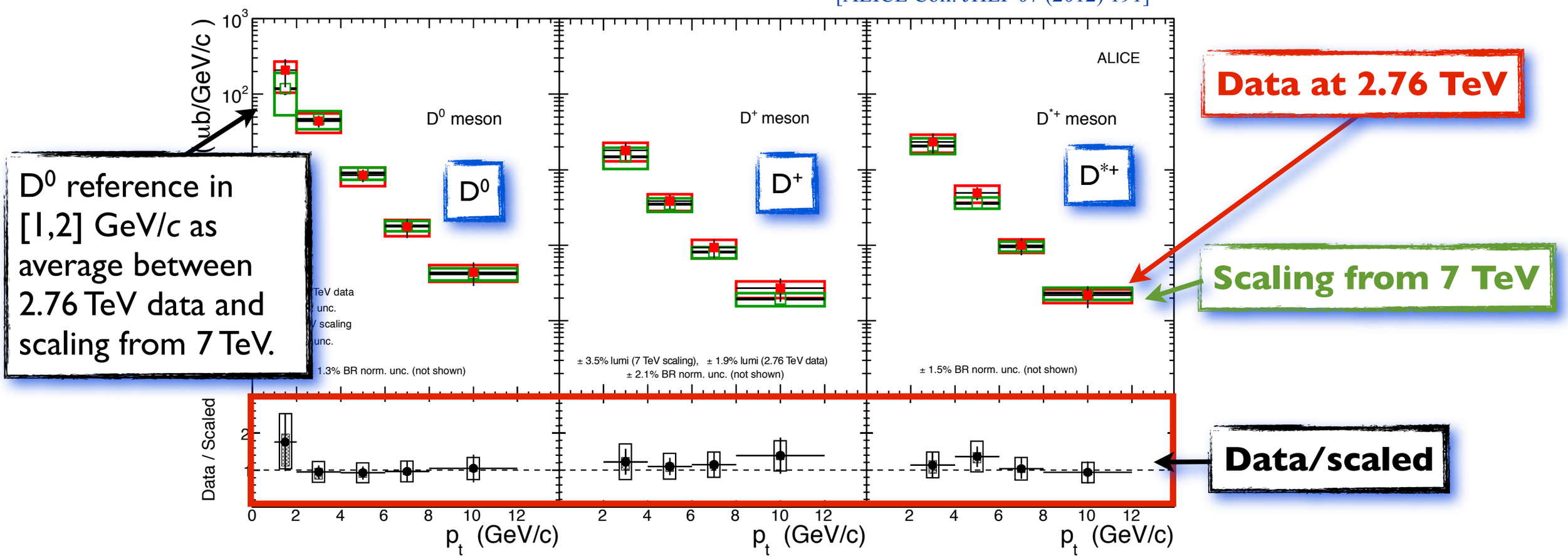
M. Cacciari, M. Greco and P. Nason, JHEP 9805 (1998) 007;
M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason, G. Ridolfi, arXiv:1205.6344

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

Scaling to 2.76 TeV and extrapolation to high p_T

- pp reference defined by scaling the 7 TeV measurement to 2.76 TeV
  - ✓ FONLL predictions at 7 and 2.76 TeV used for the scaling
  - ✓ Scaling uncertainty from ~50% (p_T = 1 GeV/c) to ~5% (high p_T)
- Direct measurement with short run at 2.76 TeV to validate the reference.

[ALICE Coll. JHEP 07 (2012) 191]



- At high p_T (>16 GeV/c for D^0 and >24 GeV/c for D^{*+} and D^+) reference extrapolated using the ratio data/theory (→**rely on FONLL p_T shape**)

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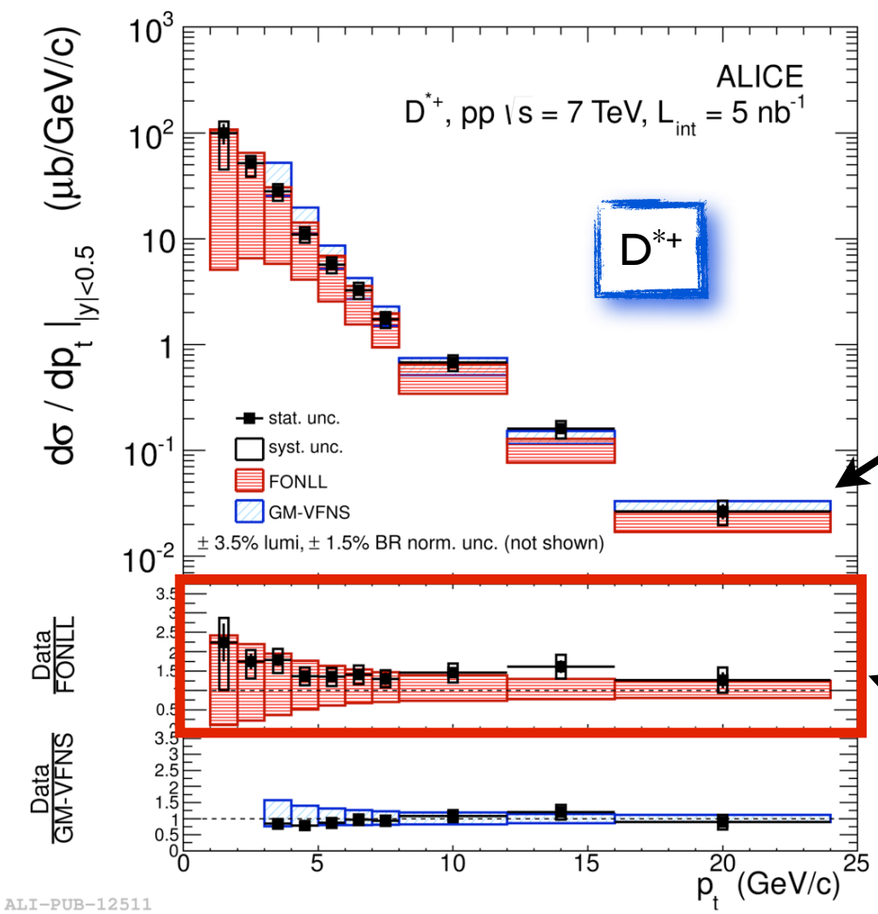
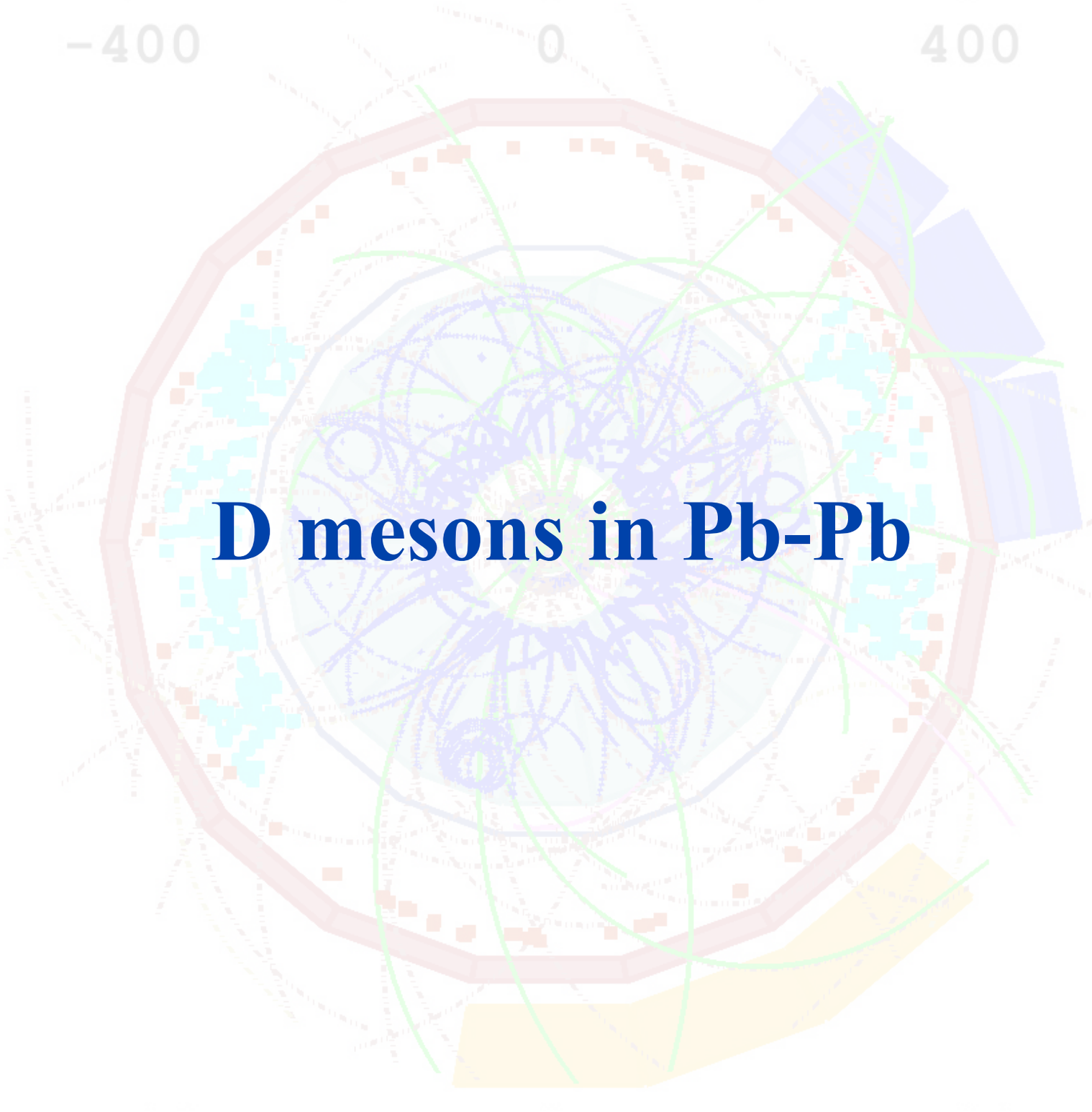


Measured cross-section up to 24 GeV/c

Data/theory constant above 5 GeV/c →rely on FONLL p_T shape.

At high p_T (>16 GeV/c for D^0 and >24 GeV/c for D^{*+} and D^+) reference extrapolated using the ratio data/theory (**→rely on FONLL p_T shape**)



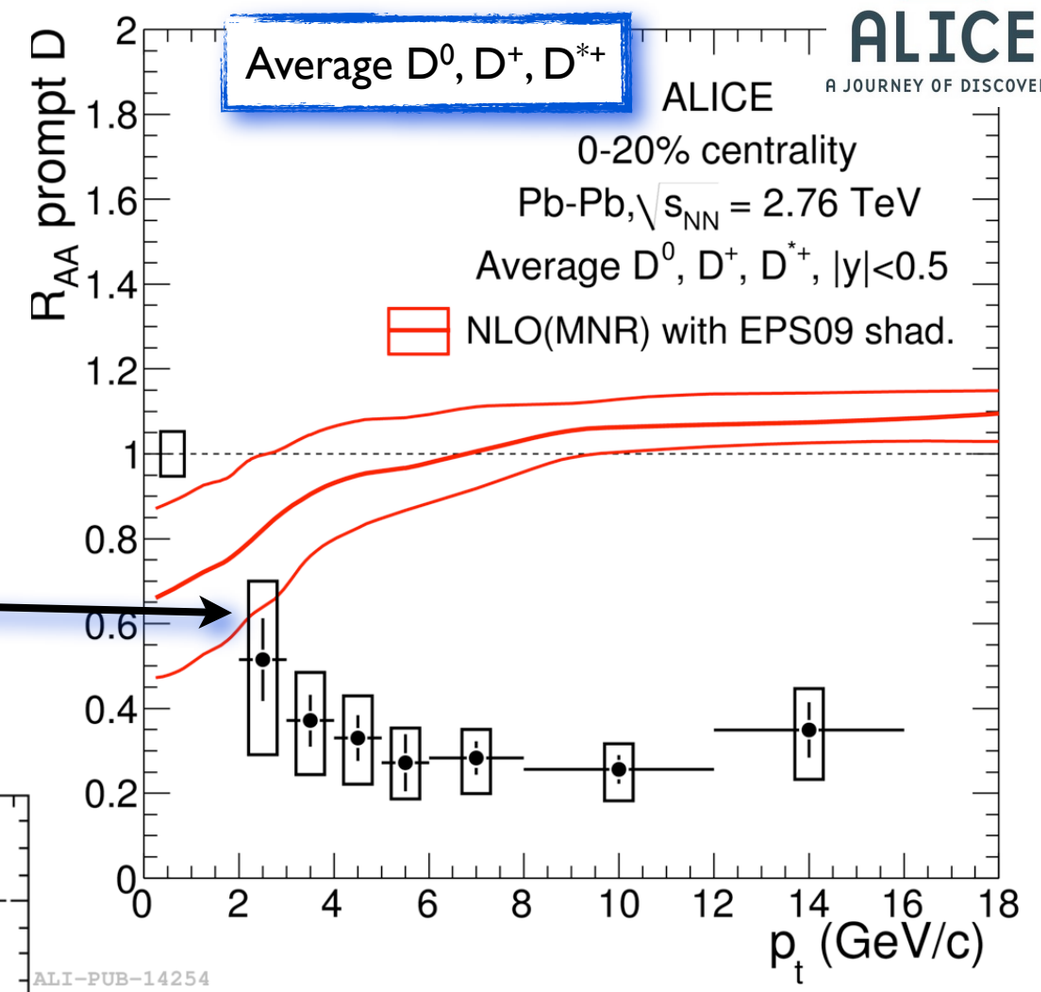
D mesons in Pb-Pb

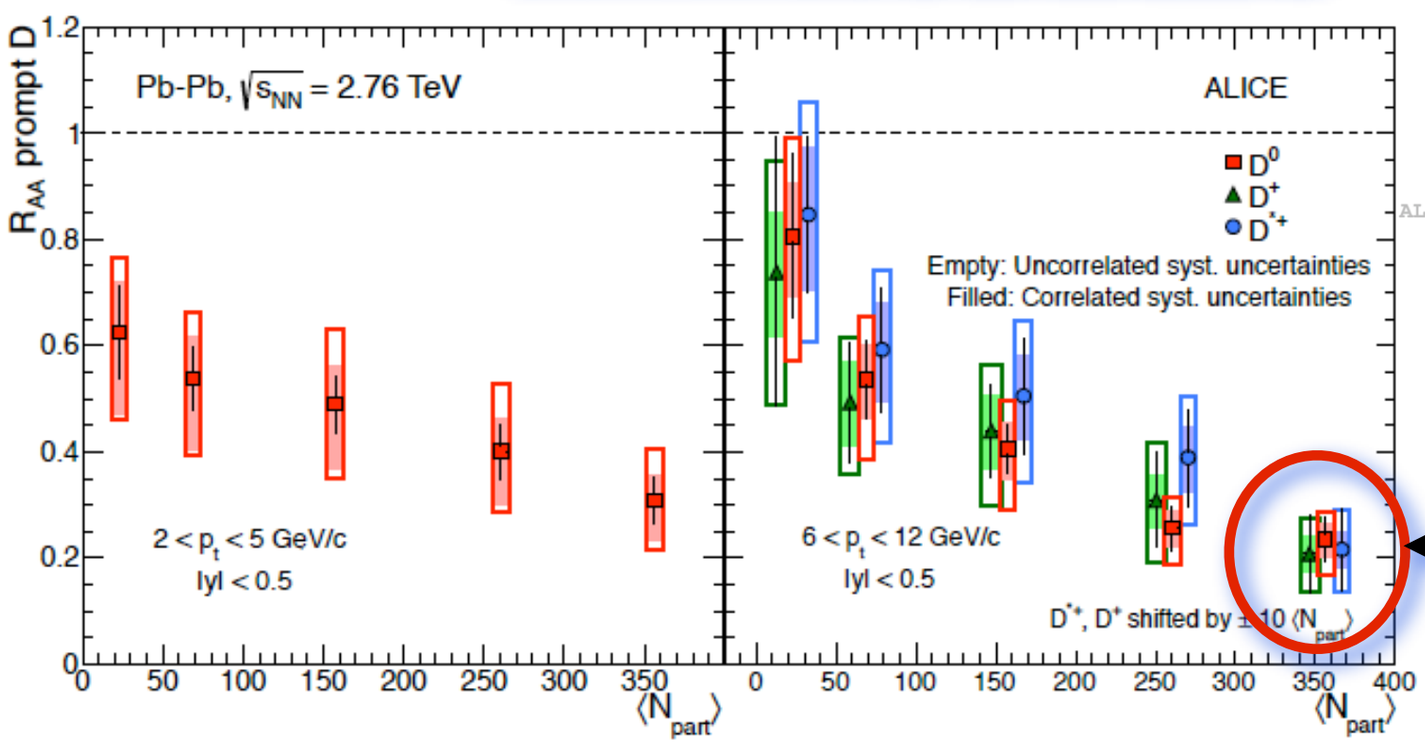
Pb-Pb results with 2010 data sample

B. Abelev et al. [ALICE Coll.], CERN-PH-EP-2012-069, arXiv:1203.2160 (2012).

- In 2010 the first measurement of D^0, D^+ and D^{*+} meson R_{AA} using ~3×10^6 events. Similar suppression for all the meson species.

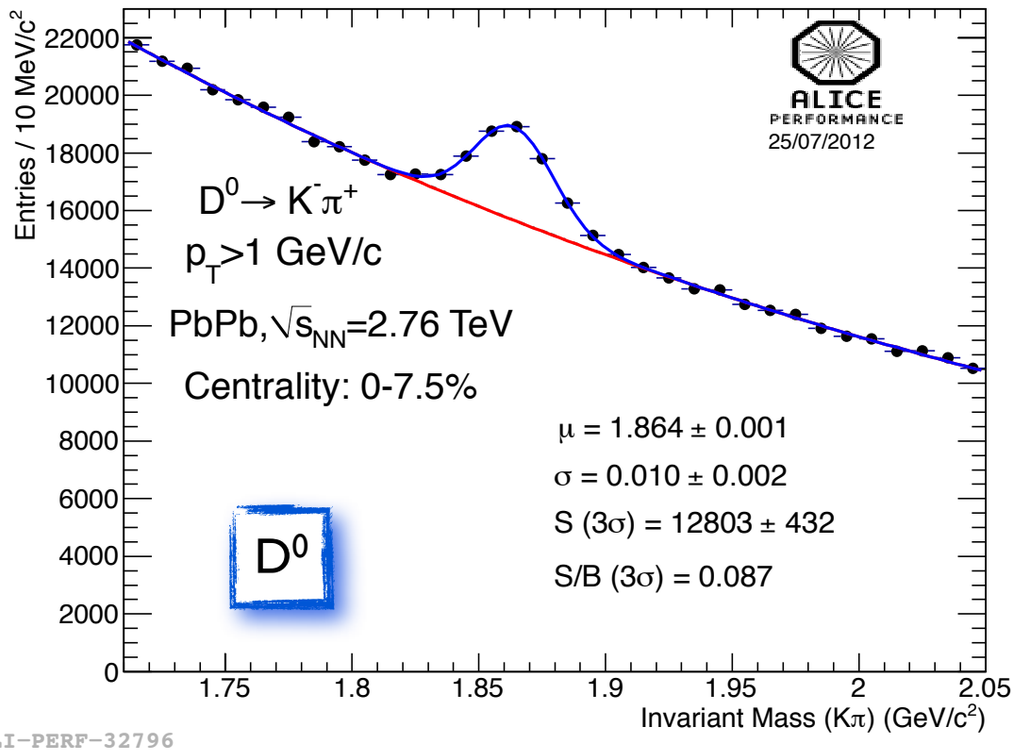
$R_{AA}(p_T)$ shows a tendency to increase at low p_T in the 20% most central class.



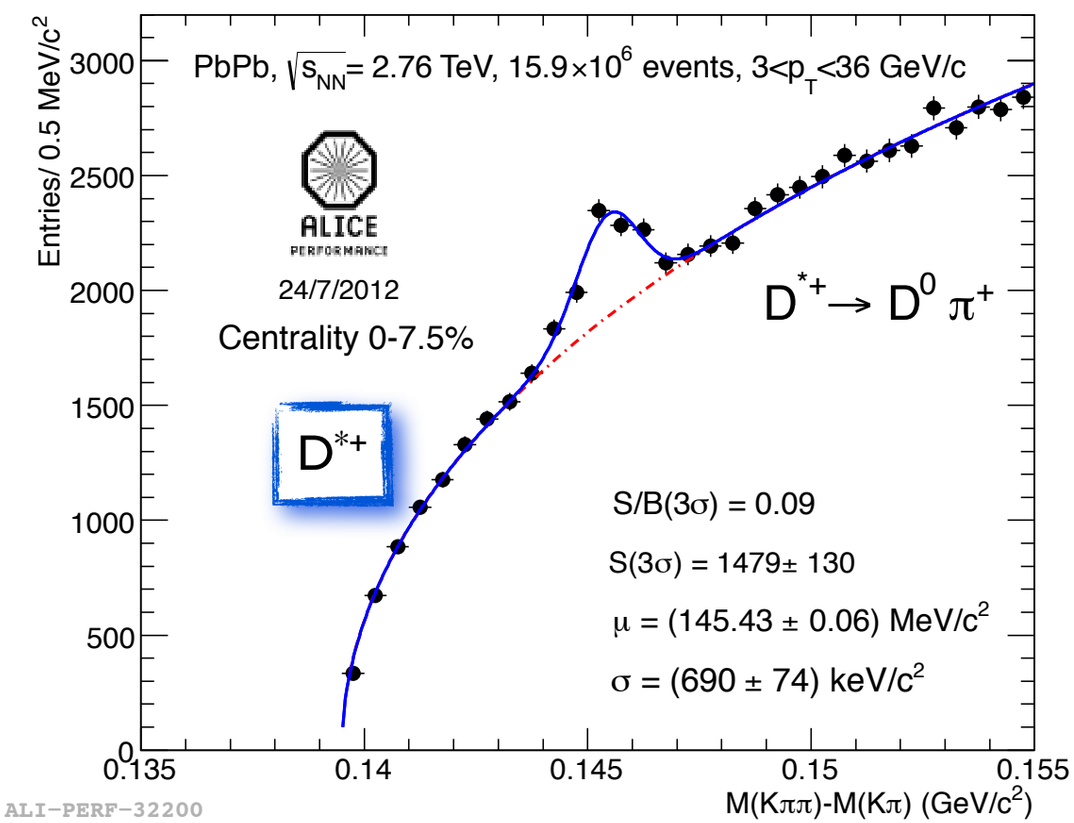


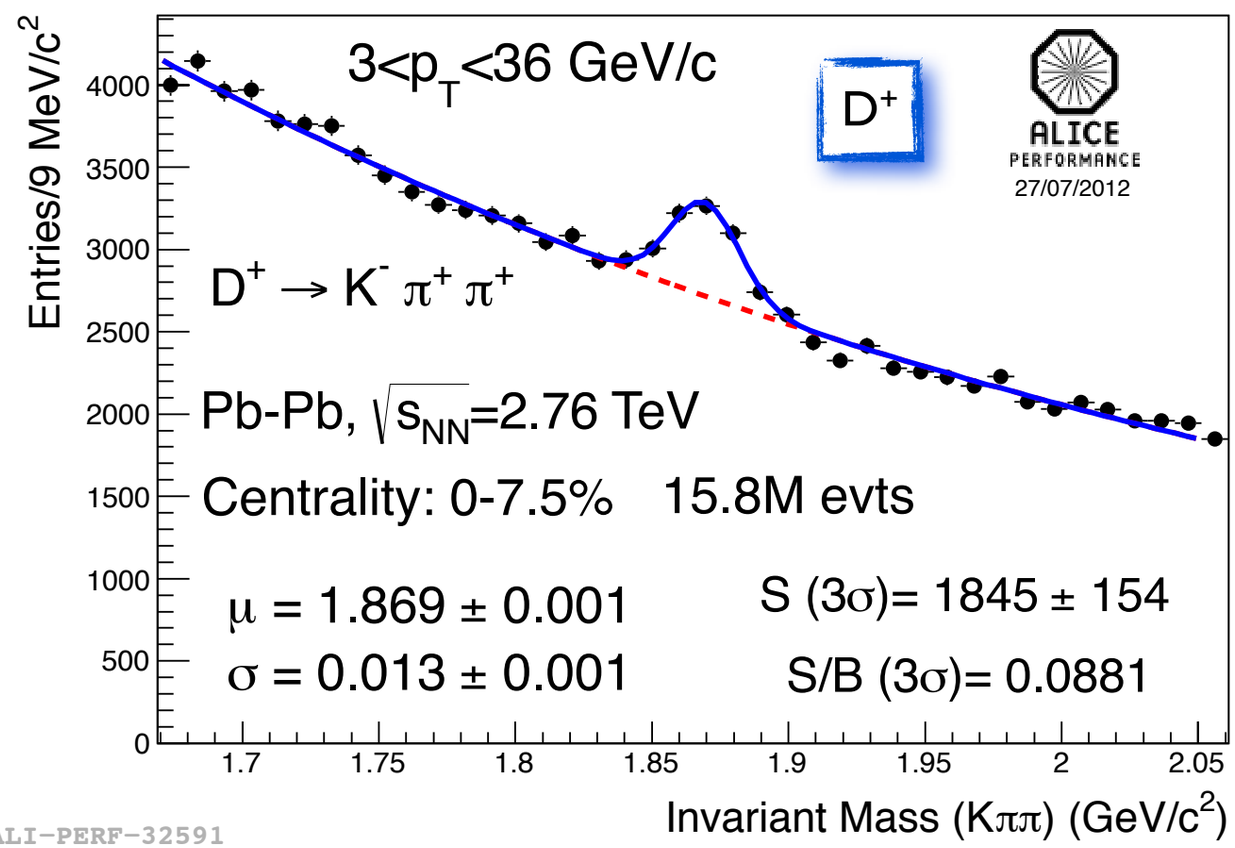
Large suppression in the 10% most central class.

D^0, D^+ and D^{*+} invariant mass in 2011 data 0-7.5%

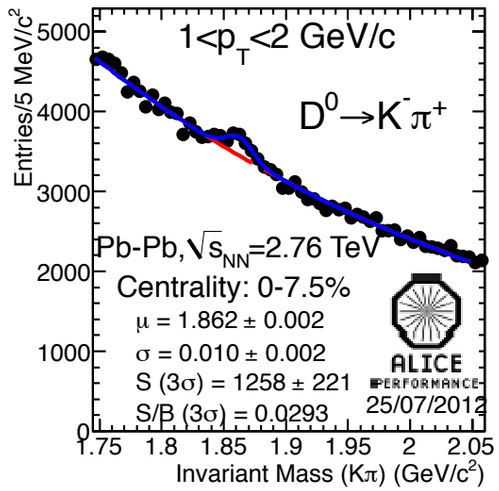


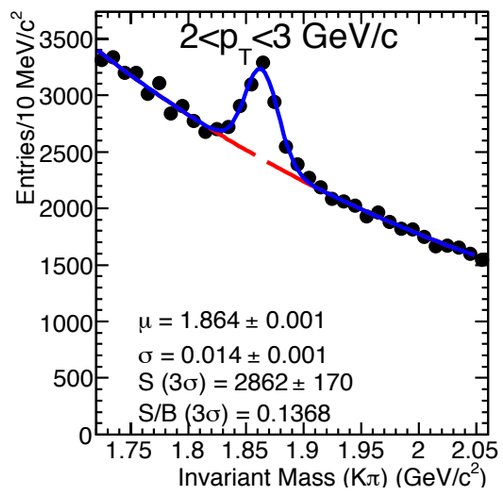
- ~16×10^6 Pb-Pb events in the centrality class 0-7.5%
- Significance > 30 (D^0) and >11 (D^{*+} and D^+)

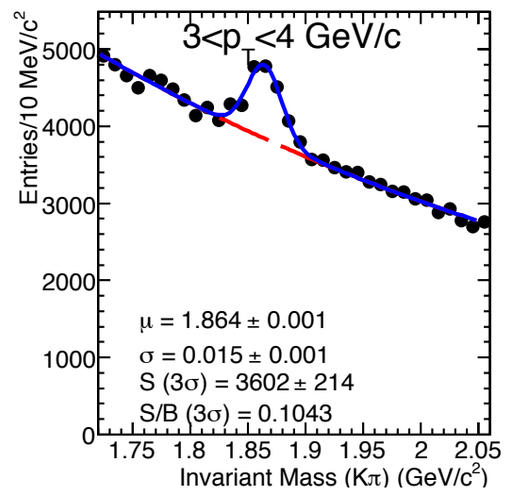




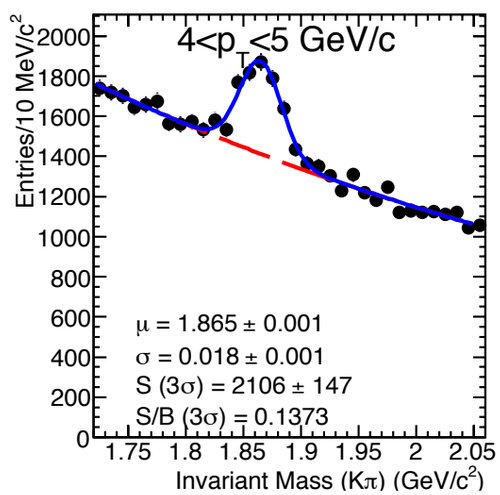
D meson signal in p_T bins (0-7.5%)

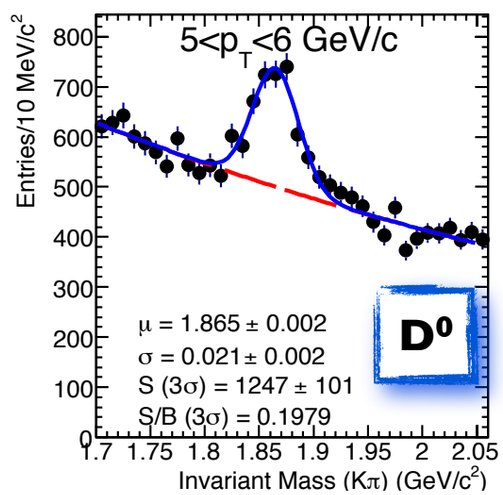


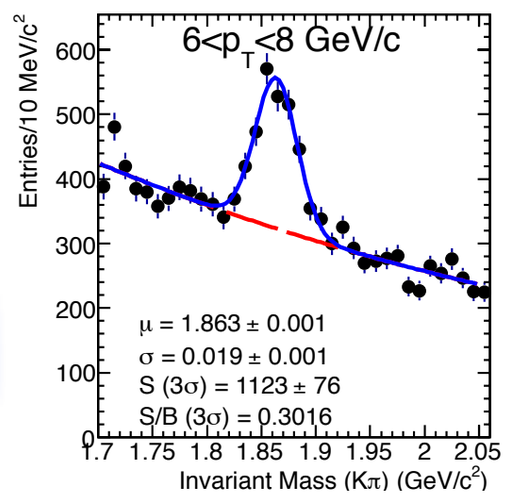




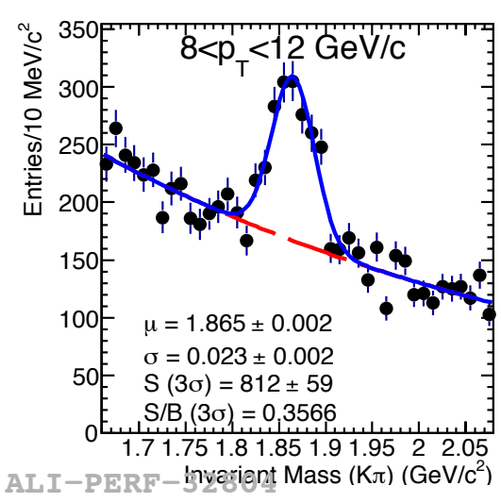
- D mesons cover a p_T range from 1 to 36 GeV/c with 10 p_T bins.

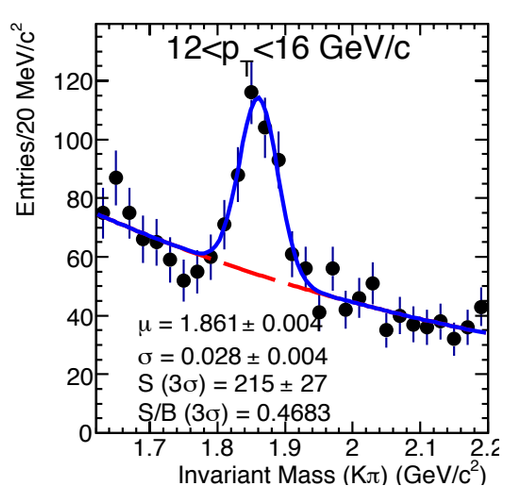


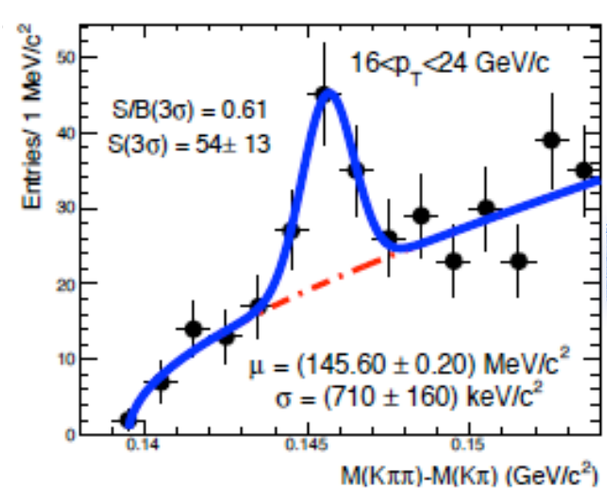




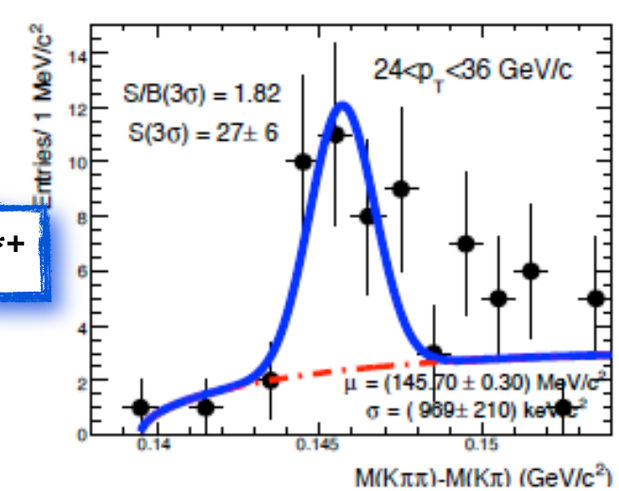
- **Note:** here as example the first 8 bins D^0 and last 2 bins D^{*+}.





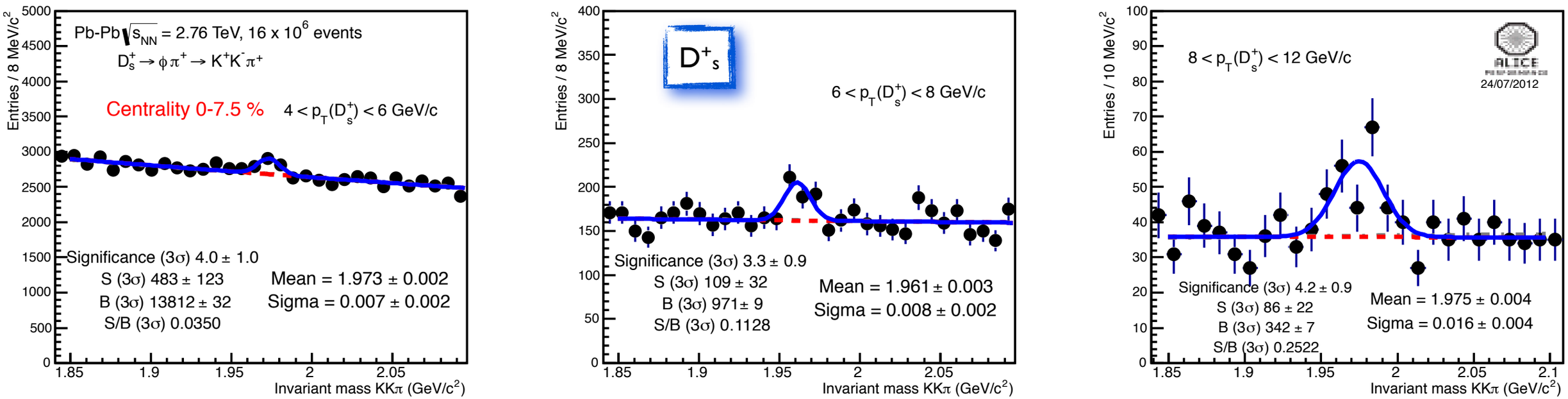


D*+



ALI-PERF-32804

D^+_s signal in p_T bins (0-7.5%)

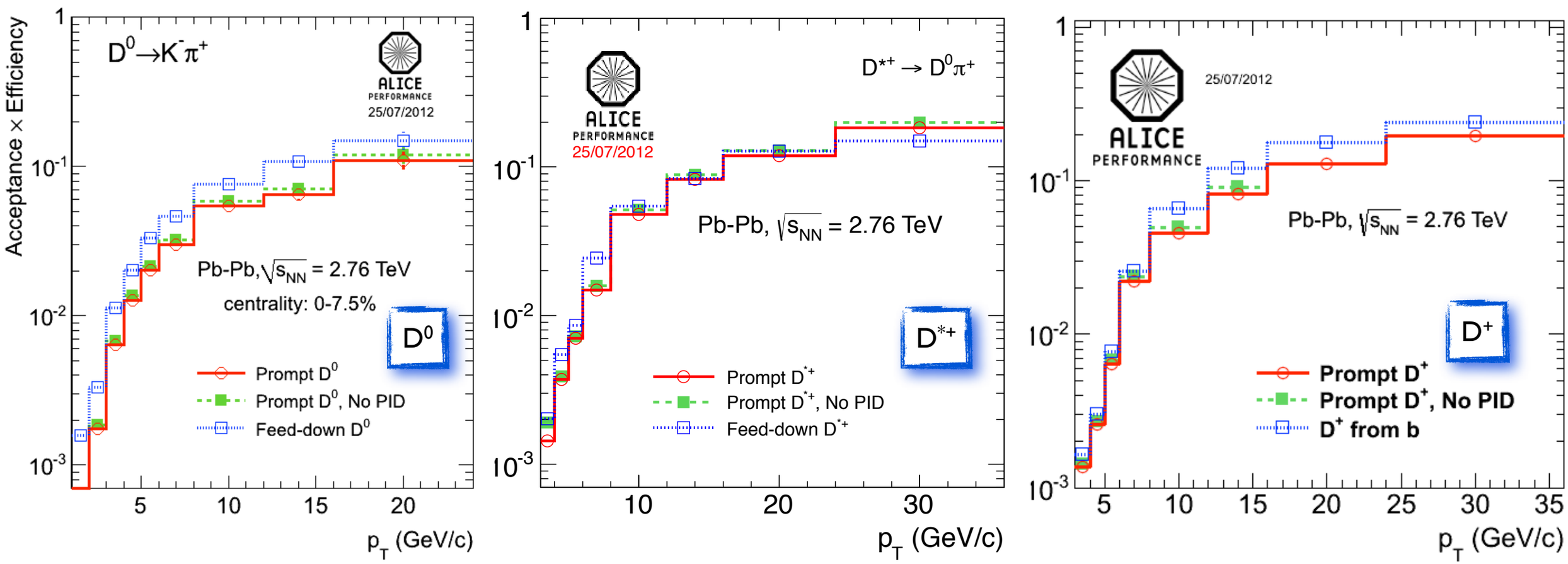


- ☑ Invariant mass analysis in the p_T range [4,12] GeV/c, centrality class 0-7.5%
- ☑ PID selection ensures large background reduction to the presence of two kaons in the final state.

D mesons efficiencies

Corrections from MC

- ✓ HIJING+Pythia (D meson enriched)
- ✓ Full description of detector status
- ✓ Detailed analysis of the systematic error sources (*MC p_T shape, PID, cut variation and yield extraction, particle-antiparticle ....*)



☑ Efficiencies up to 20% at high p_T.

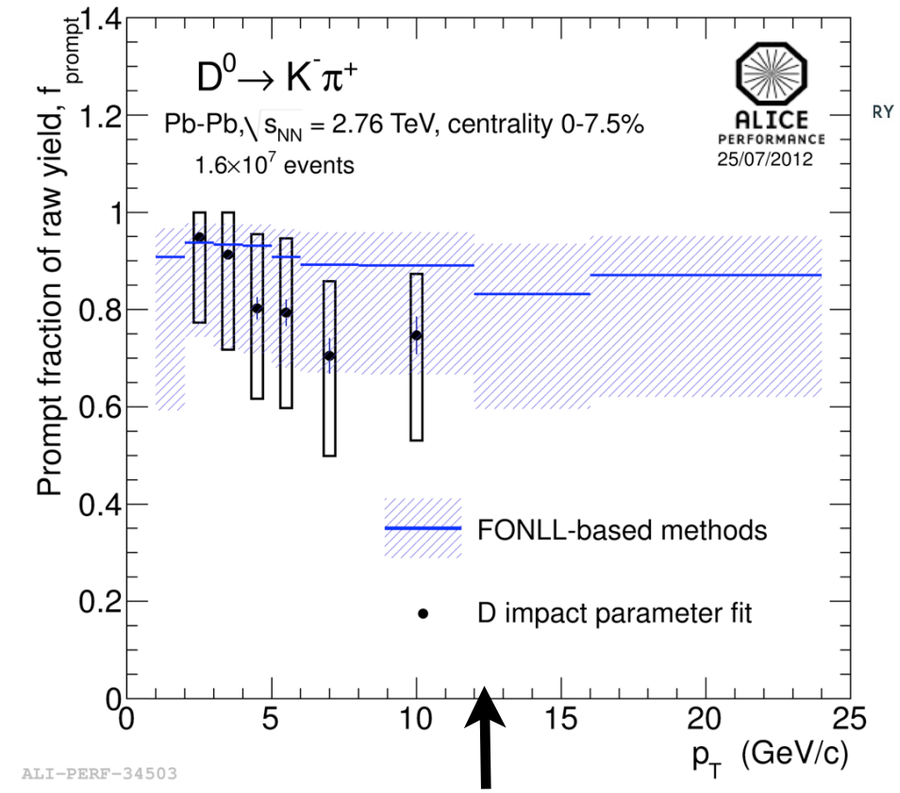
B feed down subtraction in Pb-Pb

- Subtraction of secondary D from B needed to compute prompt D-meson R_{AA}
  - ✓ Rely on FONLL predictions as done for D meson cross section in pp at √s=7 TeV and 2.76 TeV
  - ✓ Hypothesis on R_{AA} of D from B mesons

$$N^{\text{theory, uncorrected}}_{\text{D from B}} = \Delta p_t \times \epsilon_{\text{D from B}} \times \frac{dN^{\text{theory}}_{\text{D from B}}}{dp_t}$$

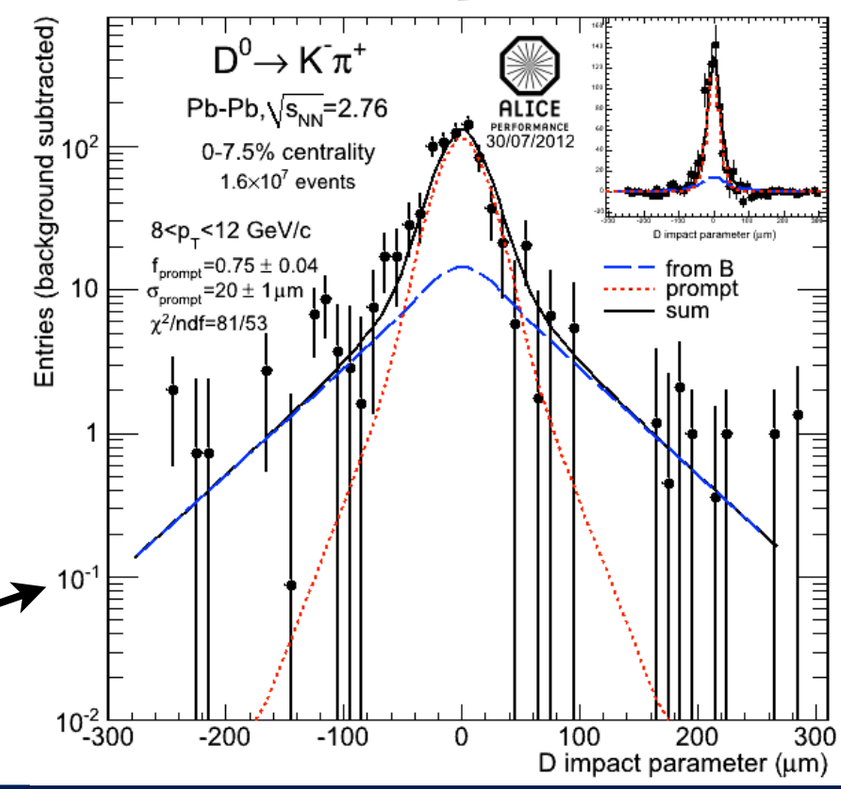
$$\frac{dN^{\text{theory}}_{\text{D from B}}}{dp_t} = R_{AA}^{\text{D from B}} \times T_{AA} \times \frac{d\sigma^{\text{pp,theory}}_{\text{D from B}}}{dp_t}$$

$R_{AA}^{\text{DfromB}}/R_{AA}^{\text{promptD}}$ ranges from 0.3 to 3.0

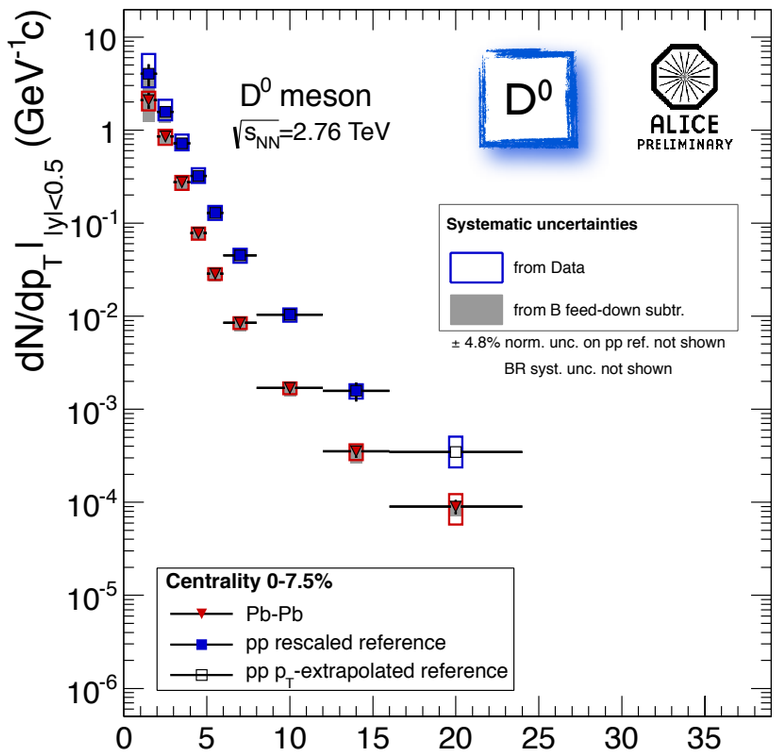


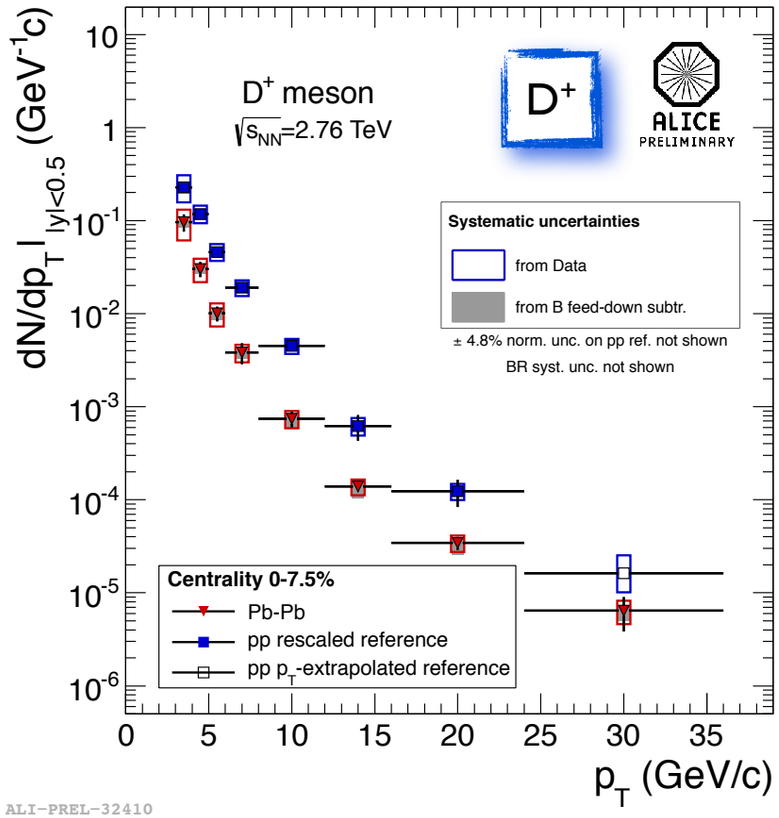
- Data driven method in development:

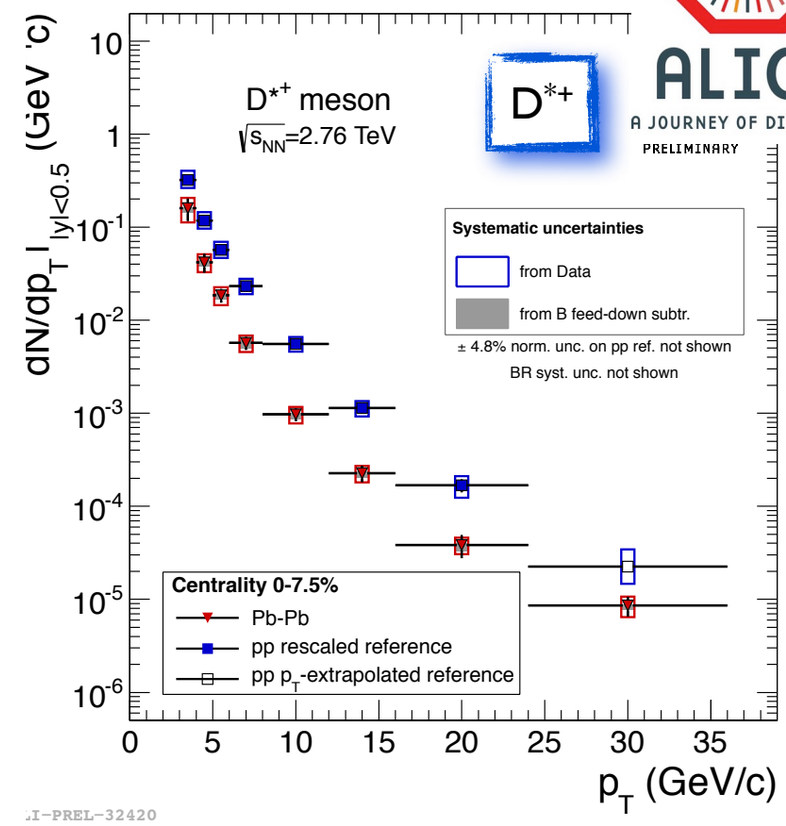
fit the impact parameter of D to measure the prompt charm fraction

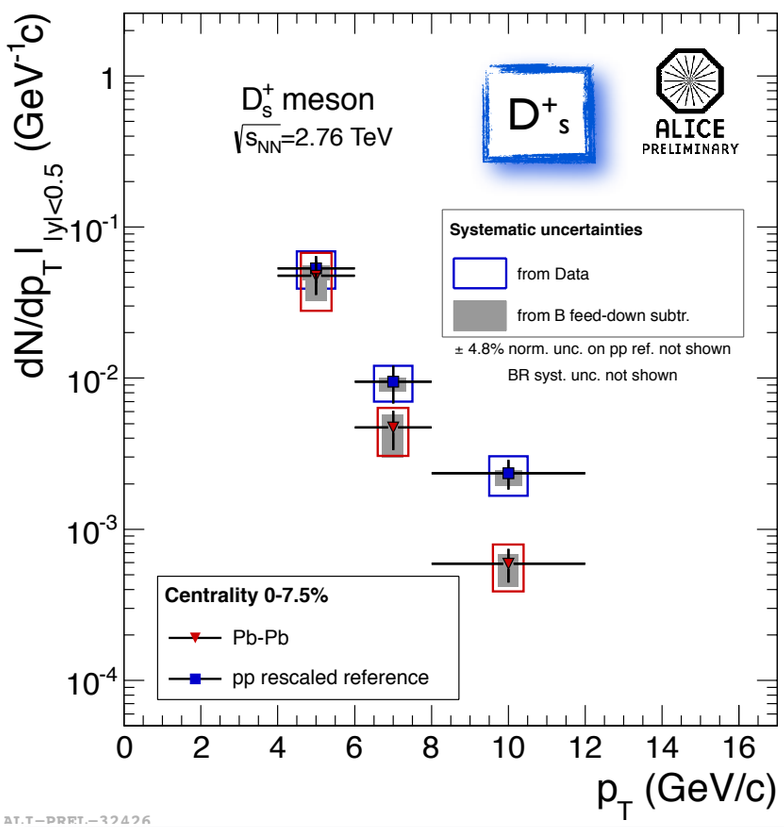


D meson dN/dp_T in pp and Pb-Pb (0-7.5%)



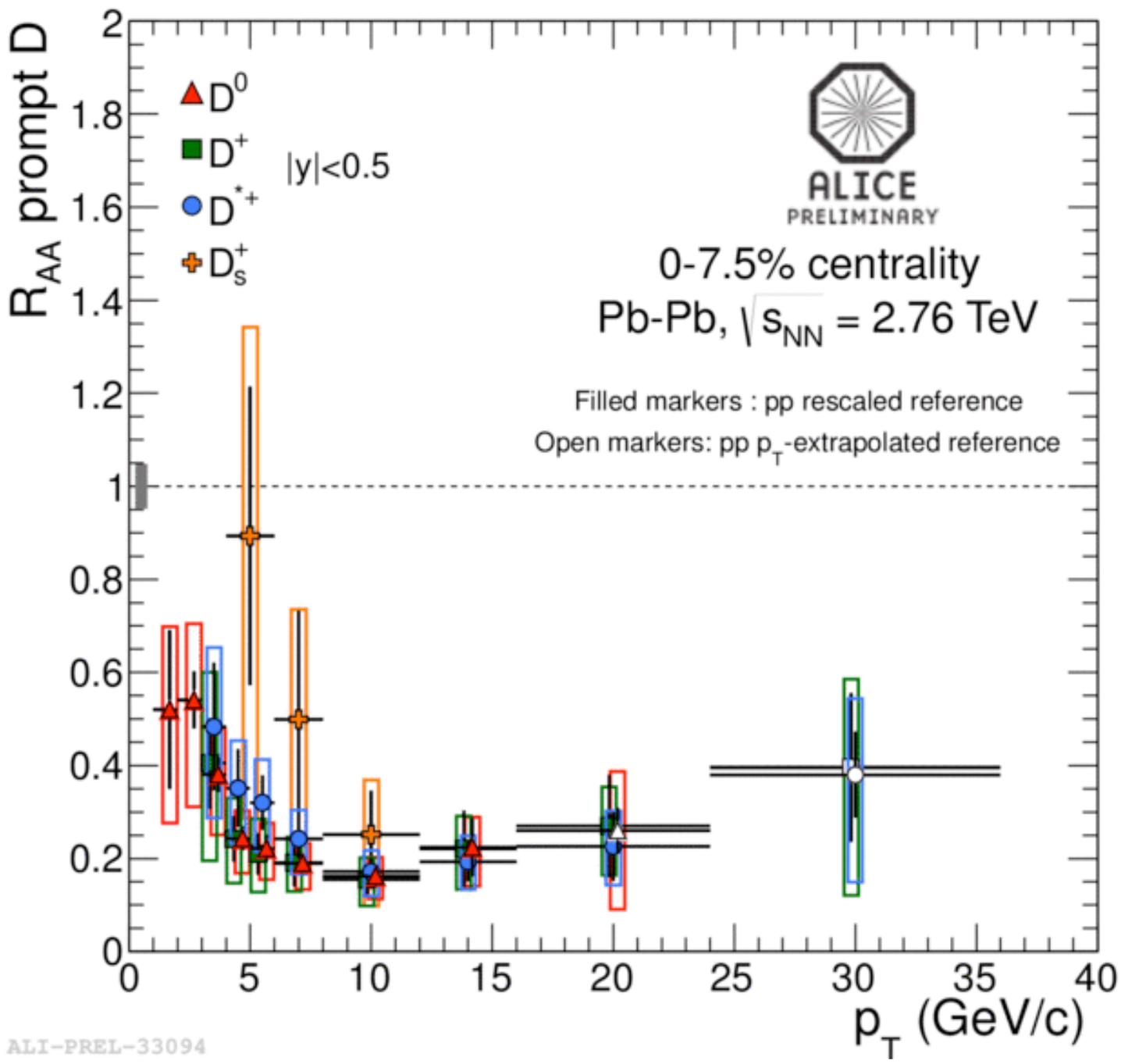






- ☑ **pp data** from √s=7 TeV scaled to 2.76 TeV and multiplied by <T_{AA}>.
- ☑ **Pb-Pb data** show large suppression at high p_T.

D meson nuclear modification factor

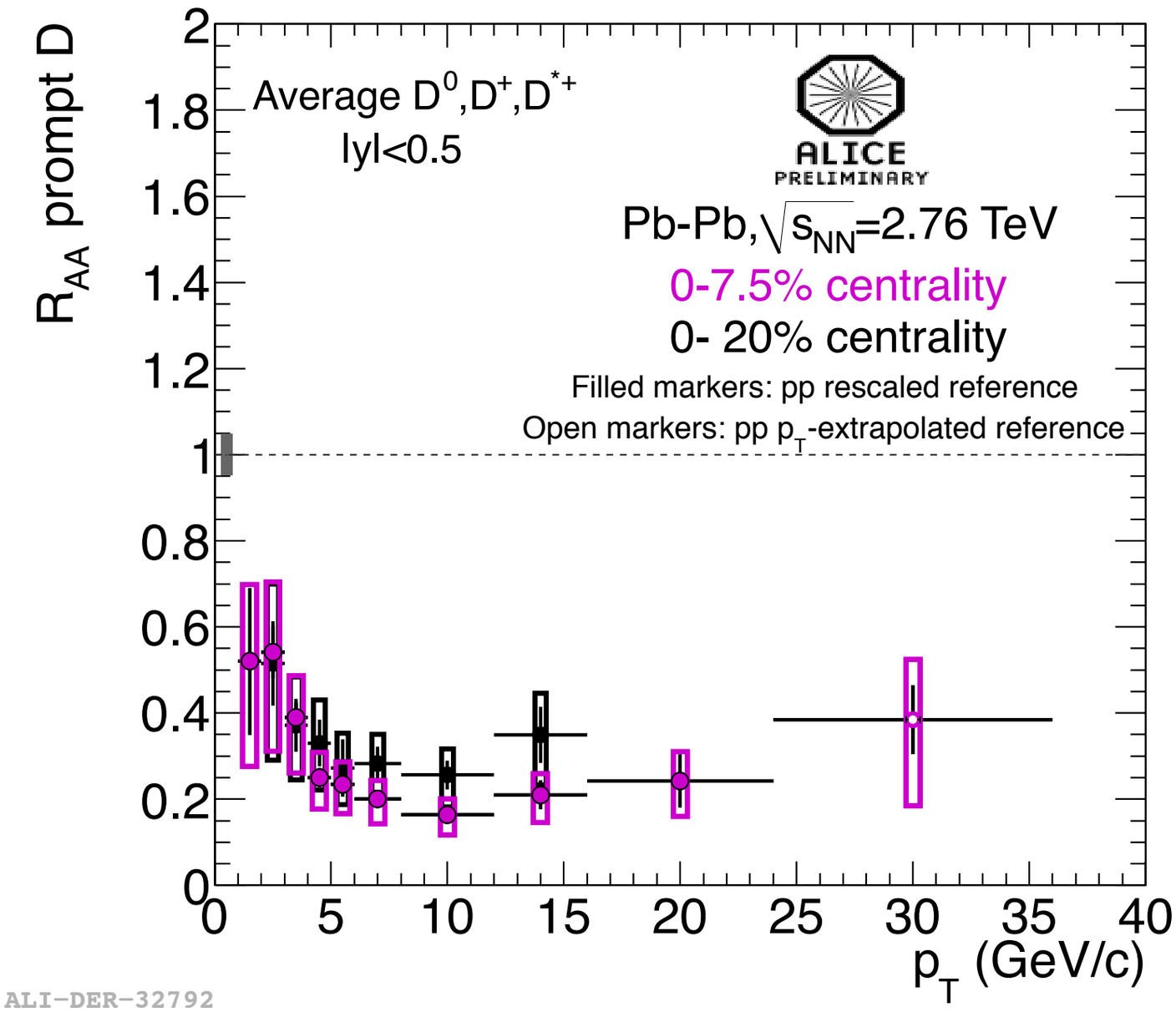


$$R_{AA}^{D}(p_T) = \frac{dN_{AA}^{D}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}^{D}/dp_T}$$

Glauber model

- ☑ 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*.
- ☑ First measurement of D^+_s R_{AA}, data not conclusive on comparison with other mesons.

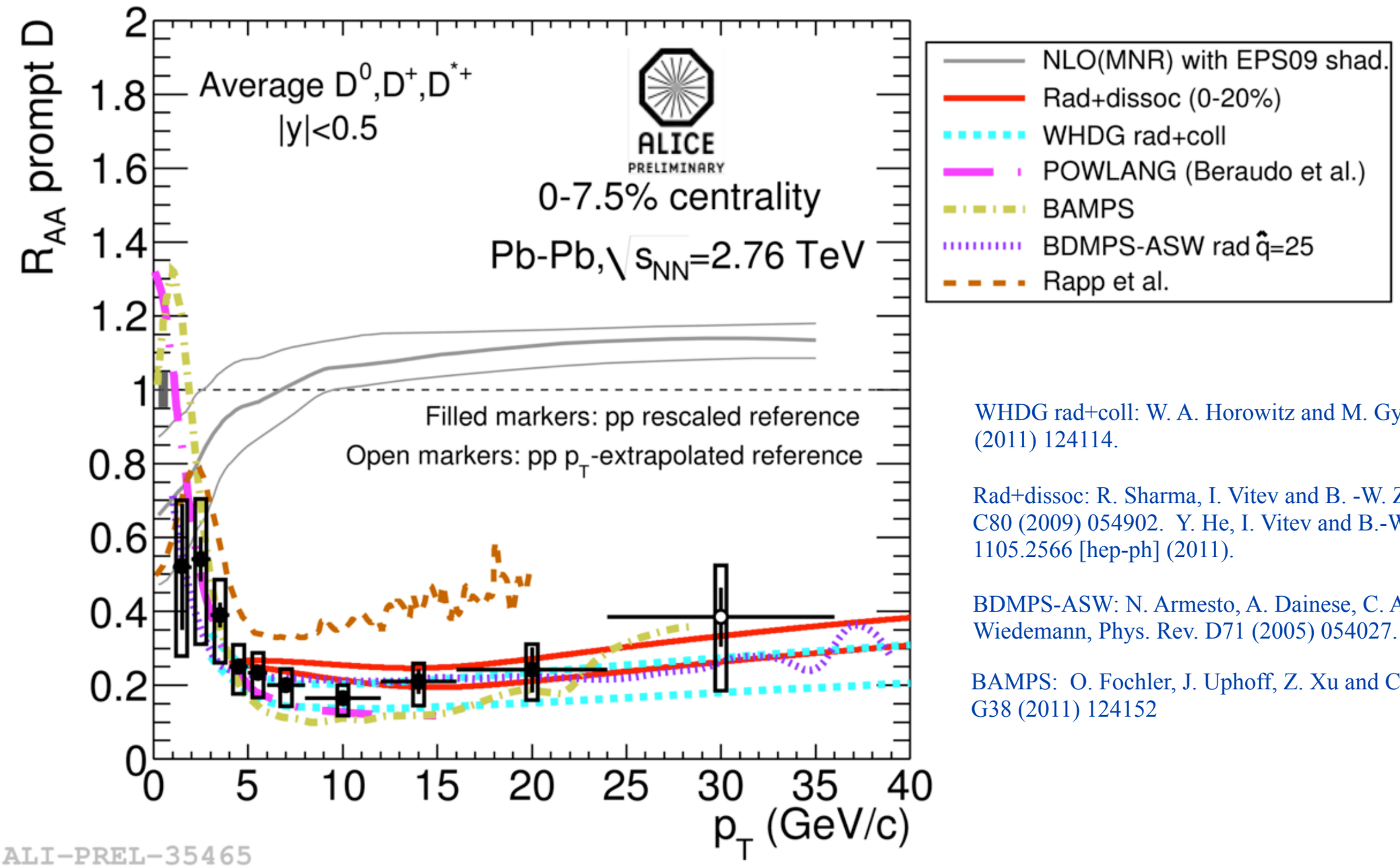
Average D^0, D^+ and D^{*+} R_{AA}



- Comparison of the 2010 and 2011 results. Hint of a larger suppression going to more central events, but compatible within uncertainties.
- At low p_T indication of a $R_{AA}<1$
- At high p_T data are consistent both with a rising and flat shape
- pPb run beginning of 2013 to study the shadowing effect.

Comparison with models

- Radiative energy loss supplemented with in-medium D meson dissociation and radiative plus collisional energy loss in the WHDG and BDMPS-ASW implementations describe reasonably well our average R_{AA}.



WHDG rad+coll: W. A. Horowitz and M. Gyulassy, J. Phys. G38 (2011) 124114.

Rad+dissoc: R. Sharma, I. Vitev and B. -W. Zhang, Phys. Rev. C80 (2009) 054902. Y. He, I. Vitev and B.-W. Zhang, arXiv: 1105.2566 [hep-ph] (2011).

BDMPS-ASW: N. Armesto, A. Dainese, C. A. Salgado and U. A. Wiedemann, Phys. Rev. D71 (2005) 054027.

BAMPS: O. Fochler, J. Uphoff, Z. Xu and C. Greiner, J. Phys. G38 (2011) 124152

Conclusions

- D meson R_{AA} measured in 0-7.5% centrality with 2011 data sample. p_T reach extended with respect to the 2010 analysis. Now [1,36] GeV/c Large suppression, factor of 5 at about p_T = 10 GeV/c for D^0, D^+ and D^{*+}

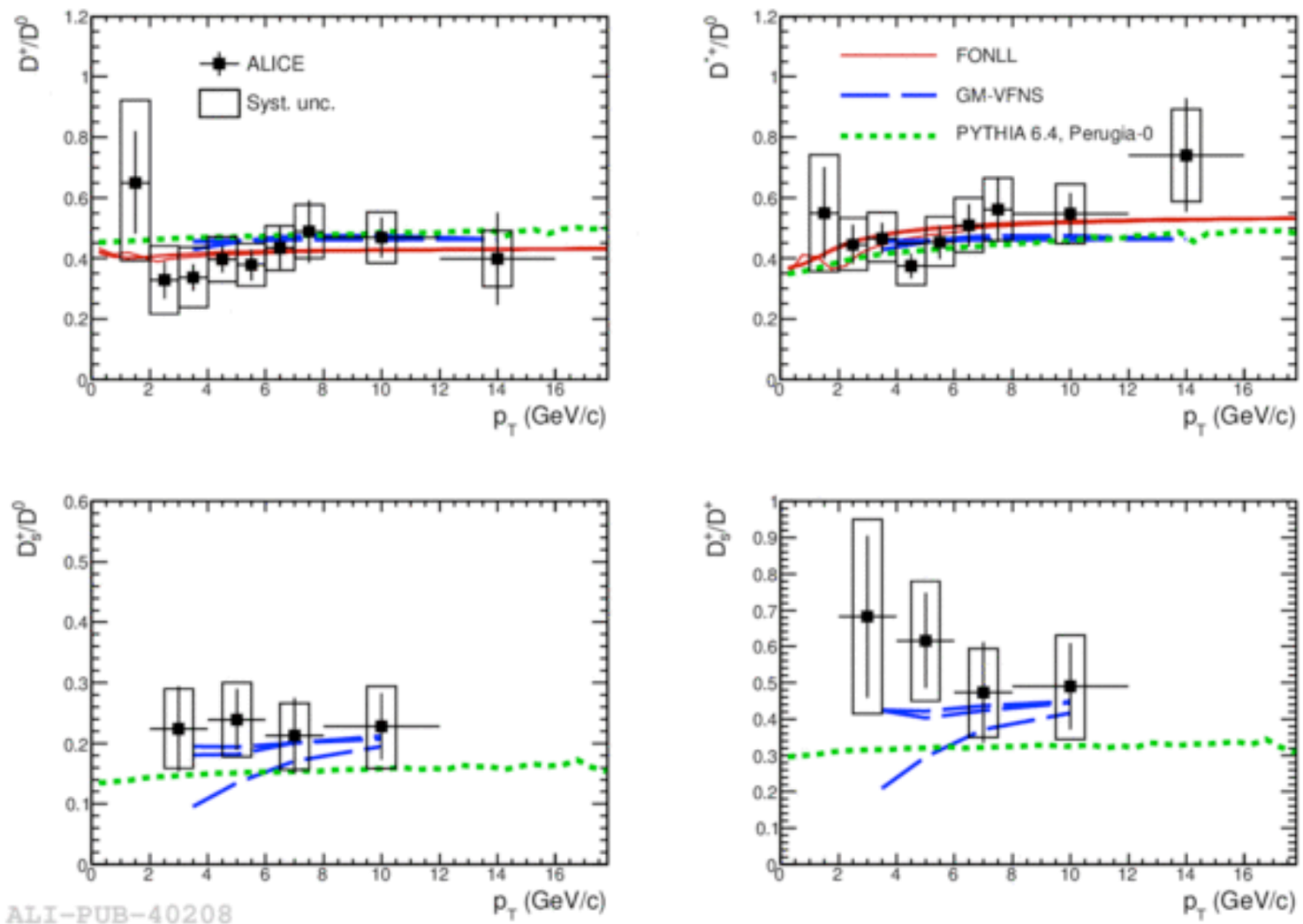
- First measurement of D^+_s R_{AA}: intriguing result, in view of future LHC Pb-Pb runs.

  → D^+_s talk by Gian Michele Innocenti
  → Upgrade of ALICE: talk by Roy Lemmon

- Comparison of the average D^0, D^{*+} and D^+ R_{AA} with 2011 and 2010 data shows a hint of larger suppression for p_T>5 GeV/c with 2011 data consistent with the change in centrality from 0-20% to 0-7.5%

Backup

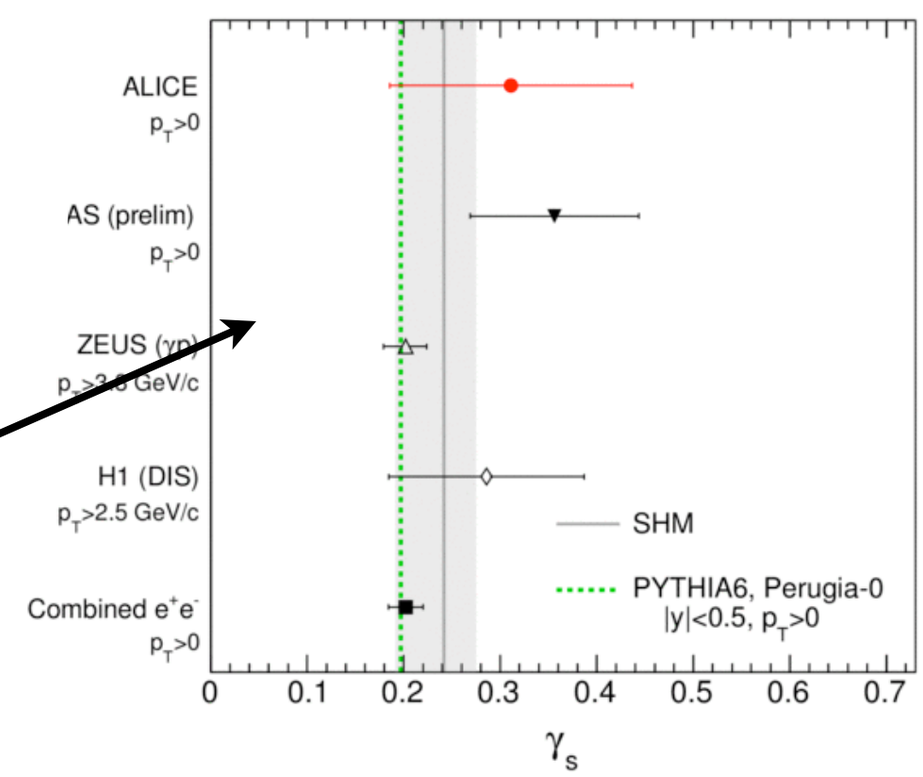
Proton-proton D mesons ratio and Gamma$_s$



arXiv:1208.1948

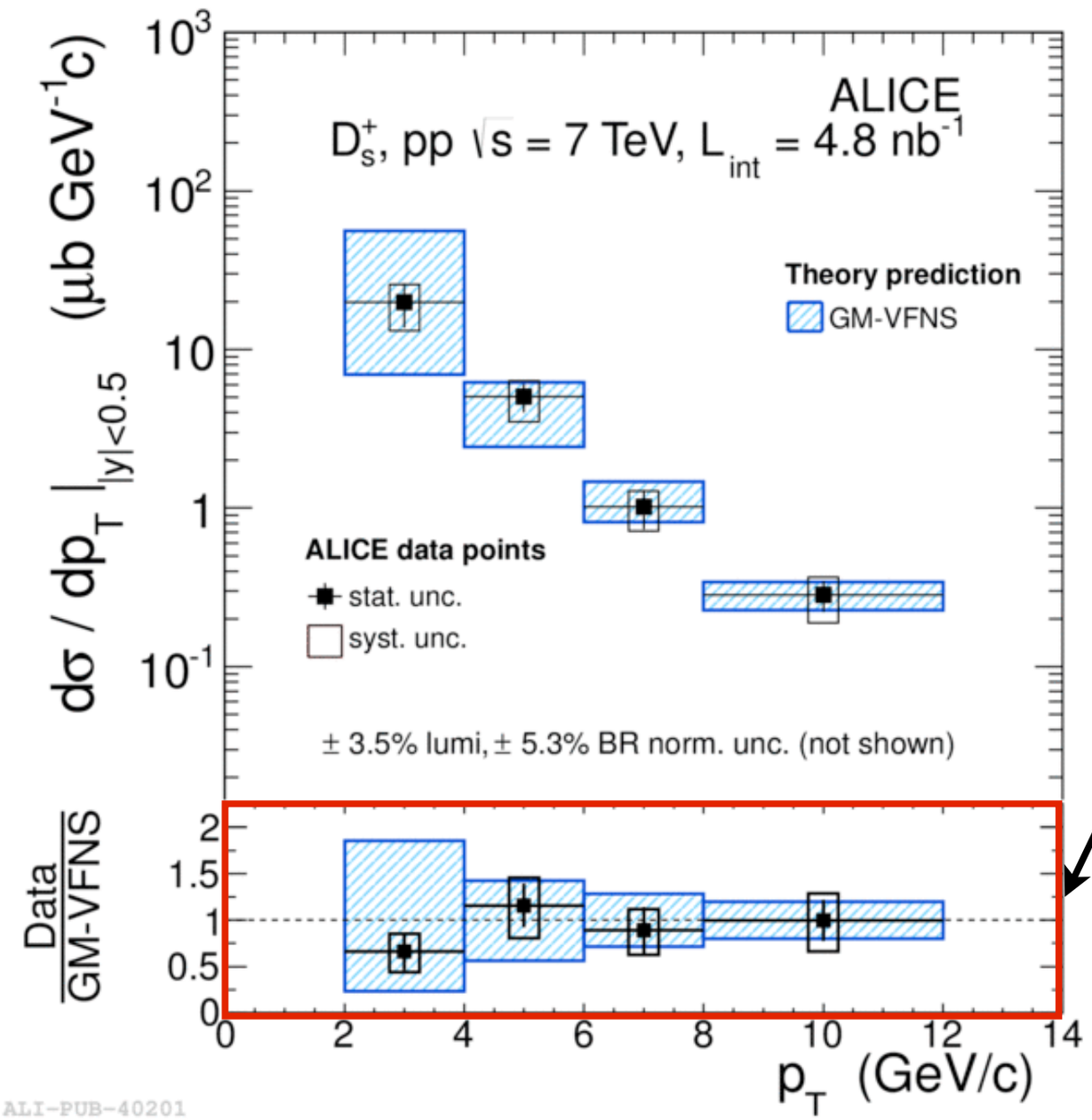
- Ratio of D mesons versus pt. FONLL, GM-VFNS and Pythia are also shown

- Strangeness suppression factor as measured by ALICE and compared with other experiments.



D^+_s cross section in pp at $\sqrt{s}$ = 7 TeV

arXiv:1208.1948

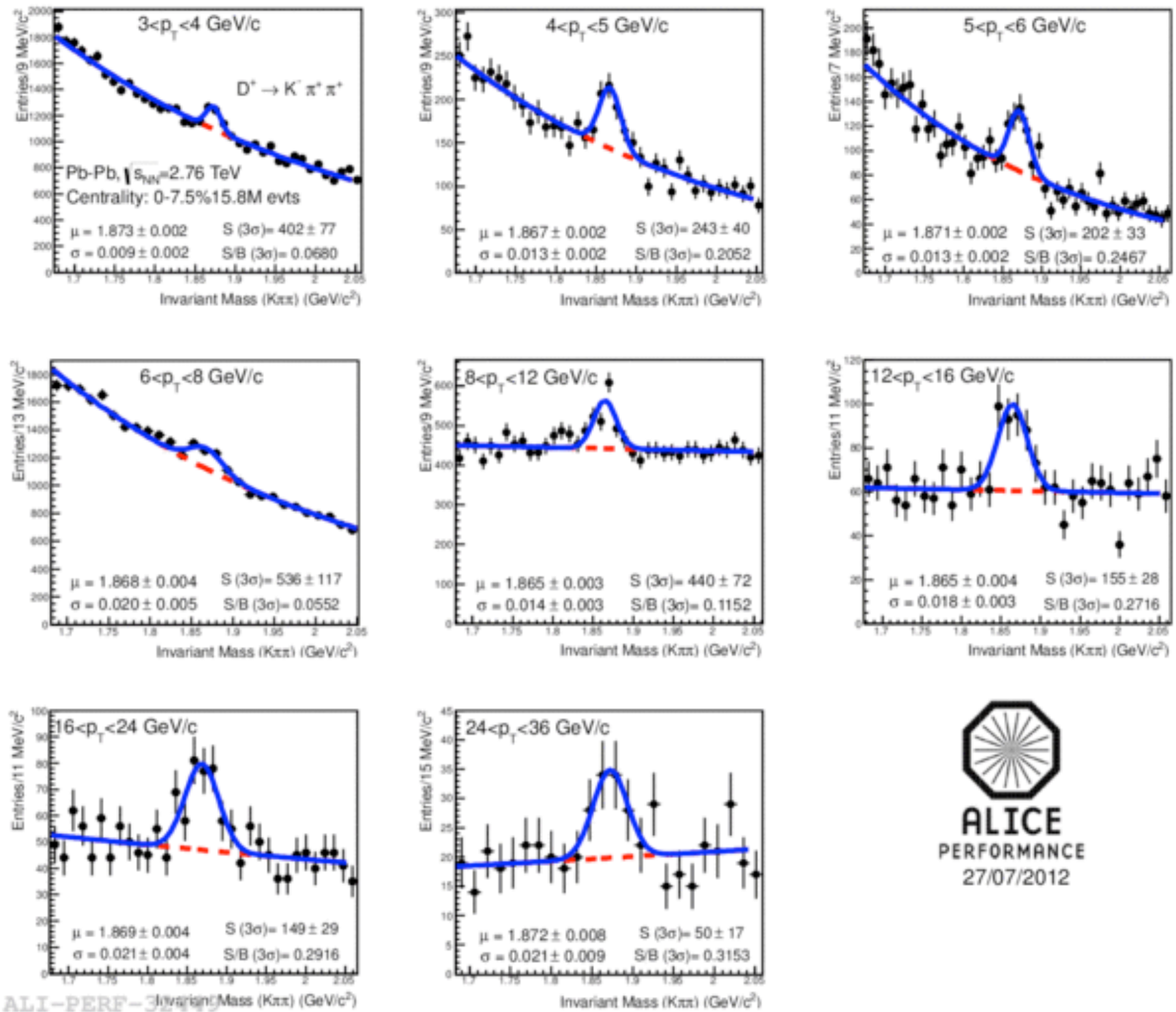


- D^+_s cross section in pp at 7 TeV in the p_T range [2,12] GeV/*c*.

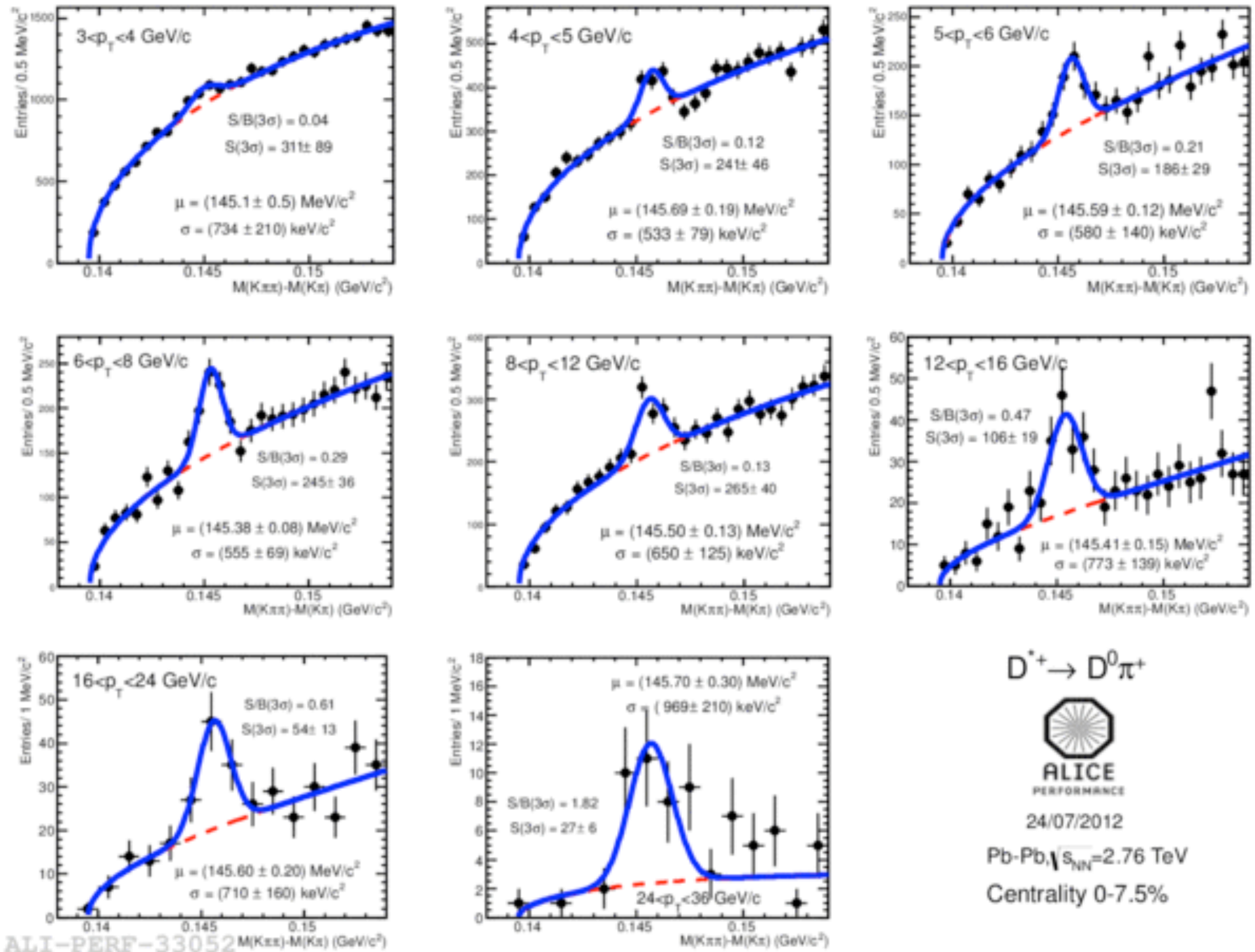
Well described by pQCD prediction.

B.A. Kniehl, G. Kramer, I. Schienbein and H. Spiesberger, Phys. Rev. Lett. 96 (2006) 012001.

D^+ mass plots


3<p_T<4 GeV/c
D+ → K- π+ π+
Pb-Pb, √s_NN=2.76 TeV
Centrality: 0-7.5%15.8M evts
μ = 1.873 ± 0.002
σ = 0.009 ± 0.002
S (3σ)= 402 ± 77
S/B (3σ)= 0.0680
4<p_T<5 GeV/c
μ = 1.867 ± 0.002
σ = 0.013 ± 0.002
S (3σ)= 243 ± 40
S/B (3σ)= 0.2052
5<p_T<6 GeV/c
μ = 1.871 ± 0.002
σ = 0.013 ± 0.002
S (3σ)= 202 ± 33
S/B (3σ)= 0.2467
6<p_T<8 GeV/c
μ = 1.868 ± 0.004
σ = 0.020 ± 0.005
S (3σ)= 536 ± 117
S/B (3σ)= 0.0552
8<p_T<12 GeV/c
μ = 1.865 ± 0.003
σ = 0.014 ± 0.003
S (3σ)= 440 ± 72
S/B (3σ)= 0.1152
12<p_T<16 GeV/c
μ = 1.865 ± 0.004
σ = 0.018 ± 0.003
S (3σ)= 155 ± 28
S/B (3σ)= 0.2716
16<p_T<24 GeV/c
μ = 1.869 ± 0.004
σ = 0.021 ± 0.004
S (3σ)= 149 ± 29
S/B (3σ)= 0.2916
24<p_T<36 GeV/c
μ = 1.872 ± 0.008
σ = 0.021 ± 0.009
S (3σ)= 50 ± 17
S/B (3σ)= 0.3153
Entries/9 MeV/c²
Entries/7 MeV/c²
Entries/13 MeV/c²
Entries/11 MeV/c²
Entries/15 MeV/c²
Invariant Mass (Kππ) (GeV/c²)
ALICE
PERFORMANCE
27/07/2012
ALI-PERF-32449

D^{*+} mass plots



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

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24/07/2012

Pb-Pb, $\sqrt{s_{NN}}$=2.76 TeV

Centrality 0-7.5%

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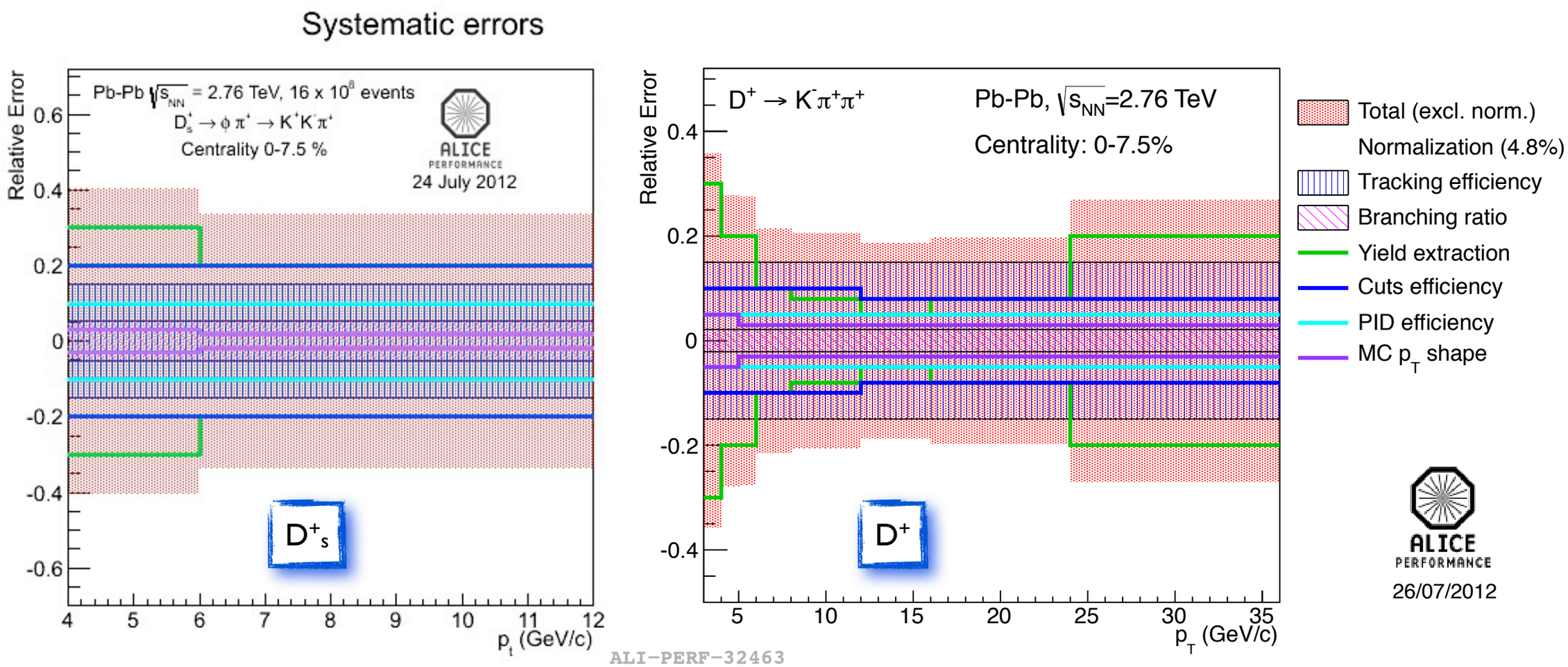
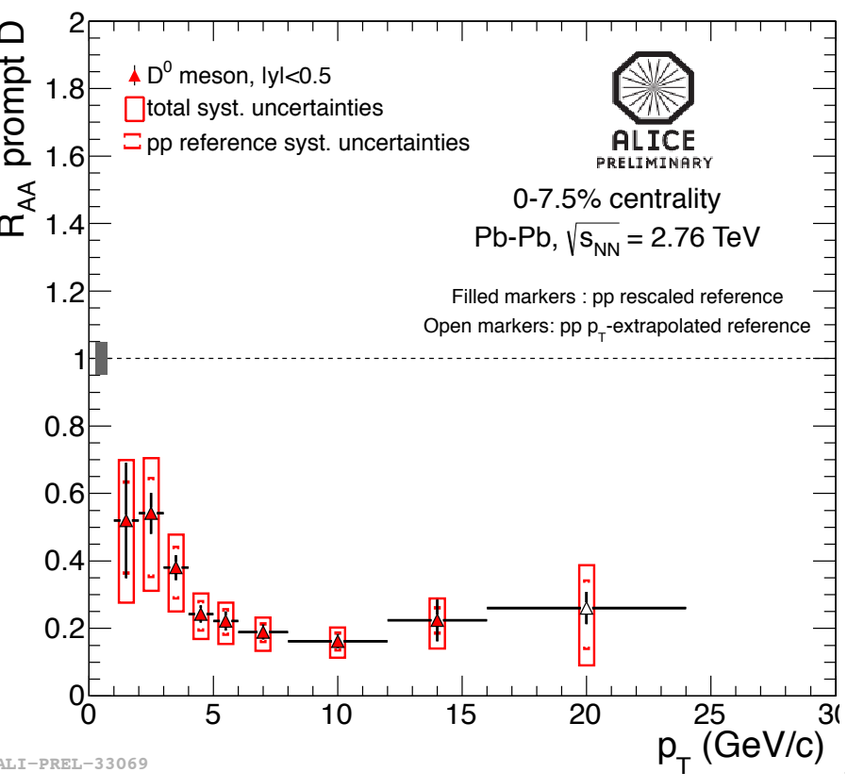
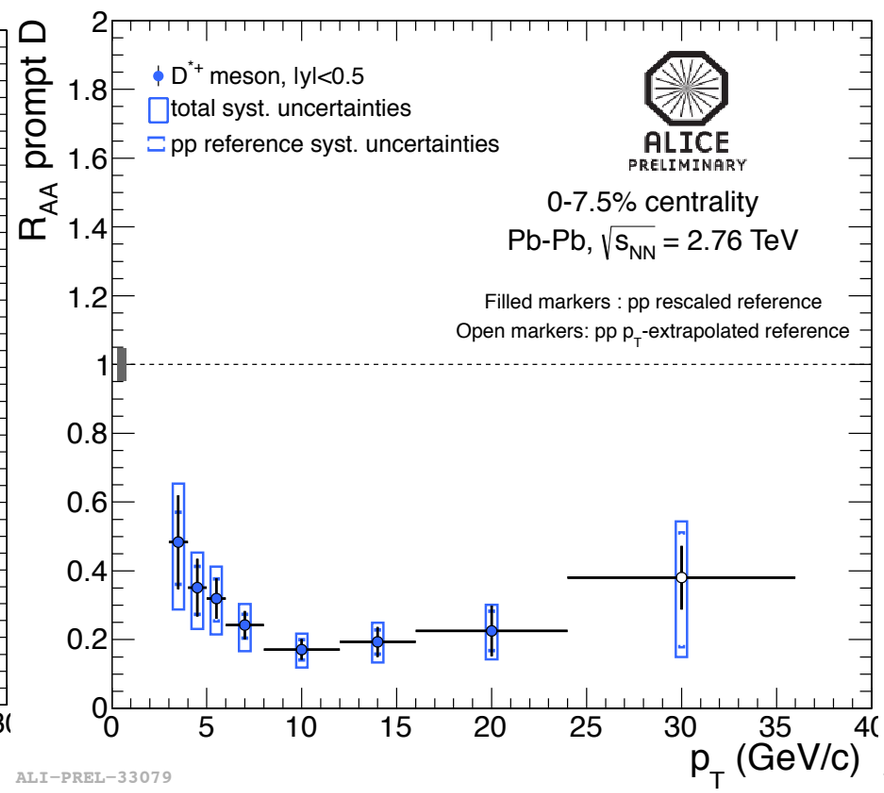
Systematic errors

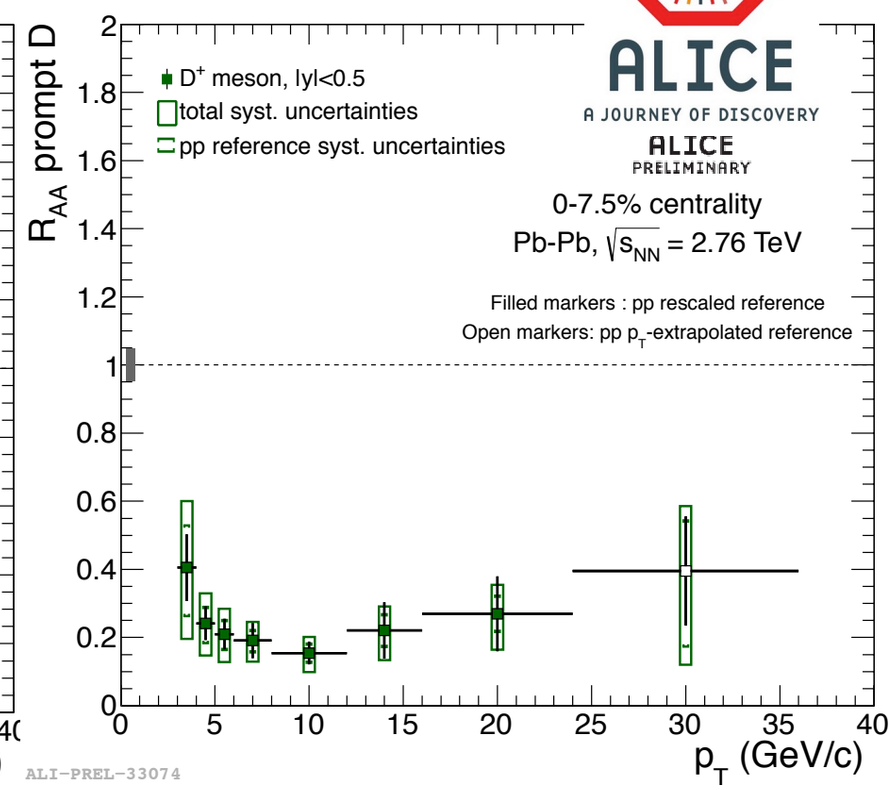
☑ D^+ and D^+_s as examples:

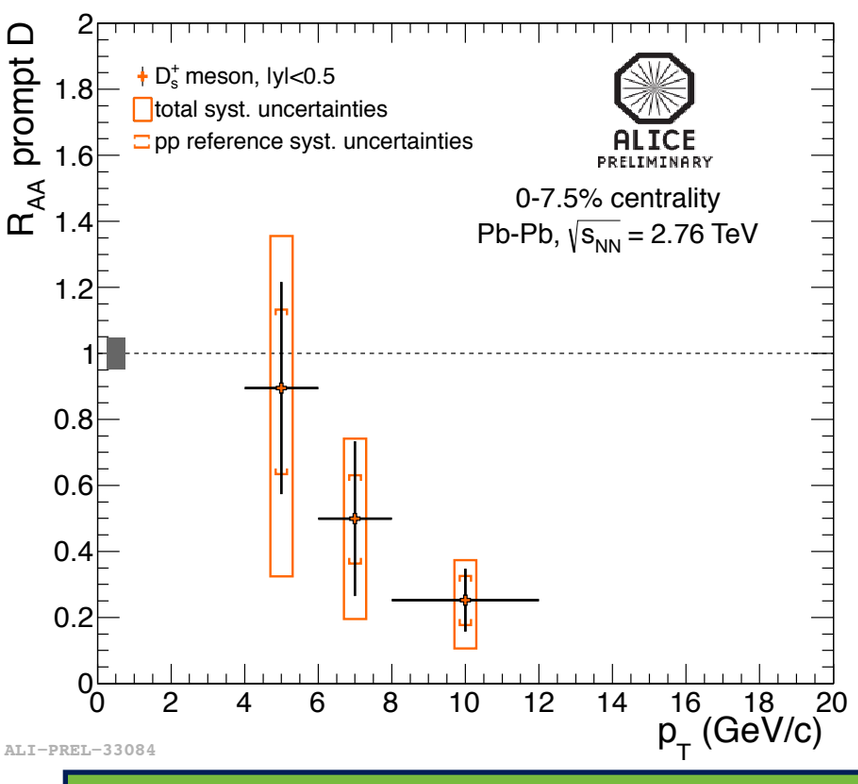


R_{AA} of D^0, D^+, D^{*+} and D^+_s









- R_{AA} of D^0 (red), D^+ (green), D^{*+} (blue) and D^+_s (orange)

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