Measurements of D_s^+ production in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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Strangeness in Quark Matter 2015

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Dubna (Russia)

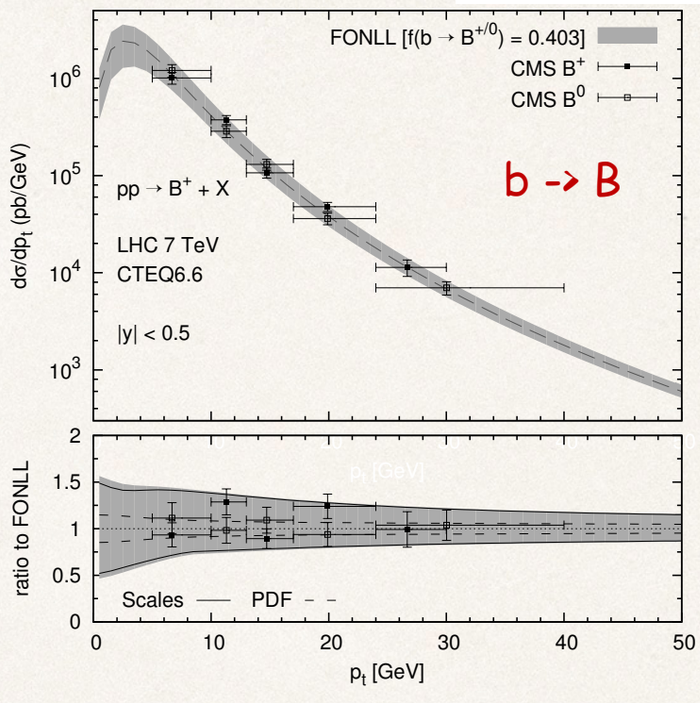
Outline of the talk

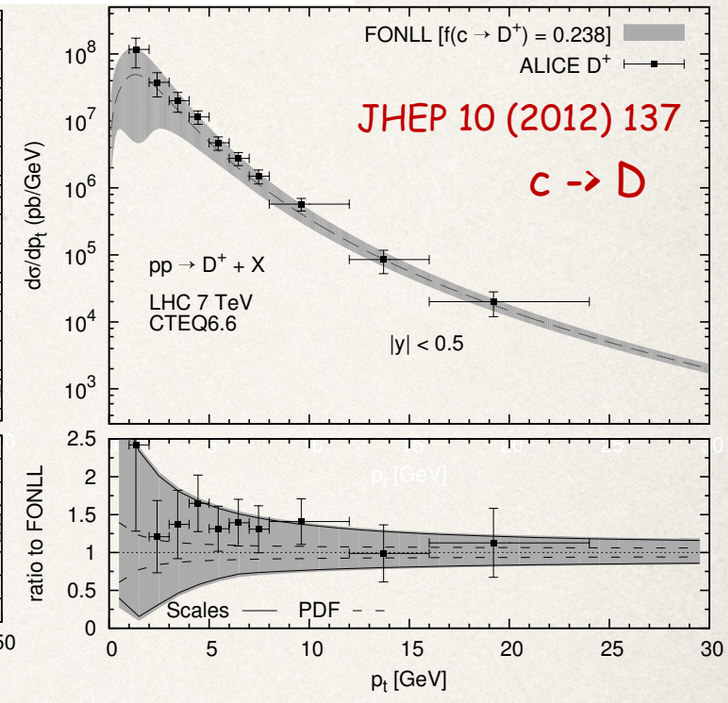
- **Physical interests in:**
  - ✓ heavy-flavour as probes of the Quark-Gluon Plasma (QGP)
  - ✓ D_s^+ measurements
- **Analysis strategy in ALICE**
- **Results in:**
  - ✓ pp, p-Pb and Pb-Pb collisions
- **Summary and conclusions**

Heavy flavours as probes of QGP

- Charm and beauty quarks produced in the early stages of the collision in high-Q^2 partonic scattering processes:
  - → pQCD description
  - → time scales $\propto 1/Q <$ QGP formation time

LHC 7 TeV, pp -> B^+/D^+ + X





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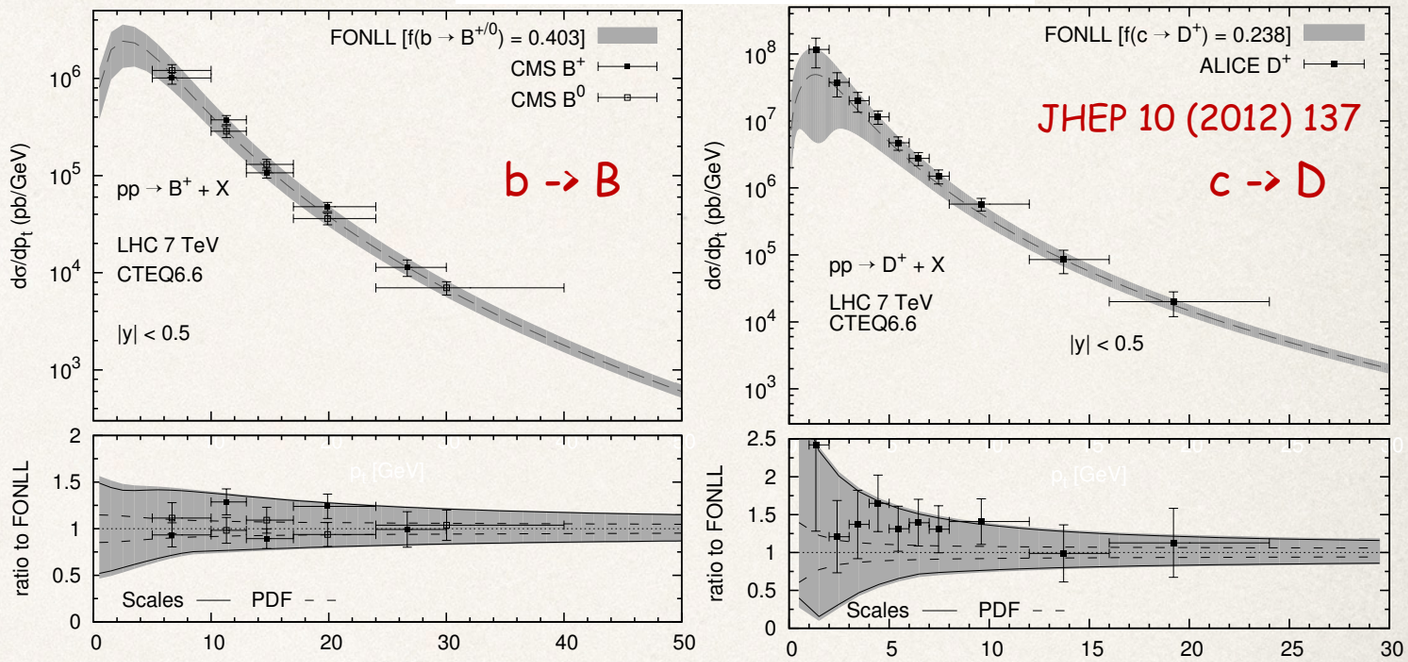

- Parton in-medium energy loss due to elastic and inelastic processes
  - **<u>colour-charge dependent:</u>** (only for energy loss via gluon radiation) stronger for gluons than for quarks (factor 9/4), BDMPS model [1]:

$$< \Delta E > \propto \alpha_s C_R \hat{q} L^2$$

  - **<u>quark-mass dependent:</u>** stronger for lighter than for heavier quarks [2]

[1]: R. Baier et al. Nucl.Phys. B483 (1997) 291-320
[2]: Dokshitzer, Kharzeev, PLB 519 (2001) 199

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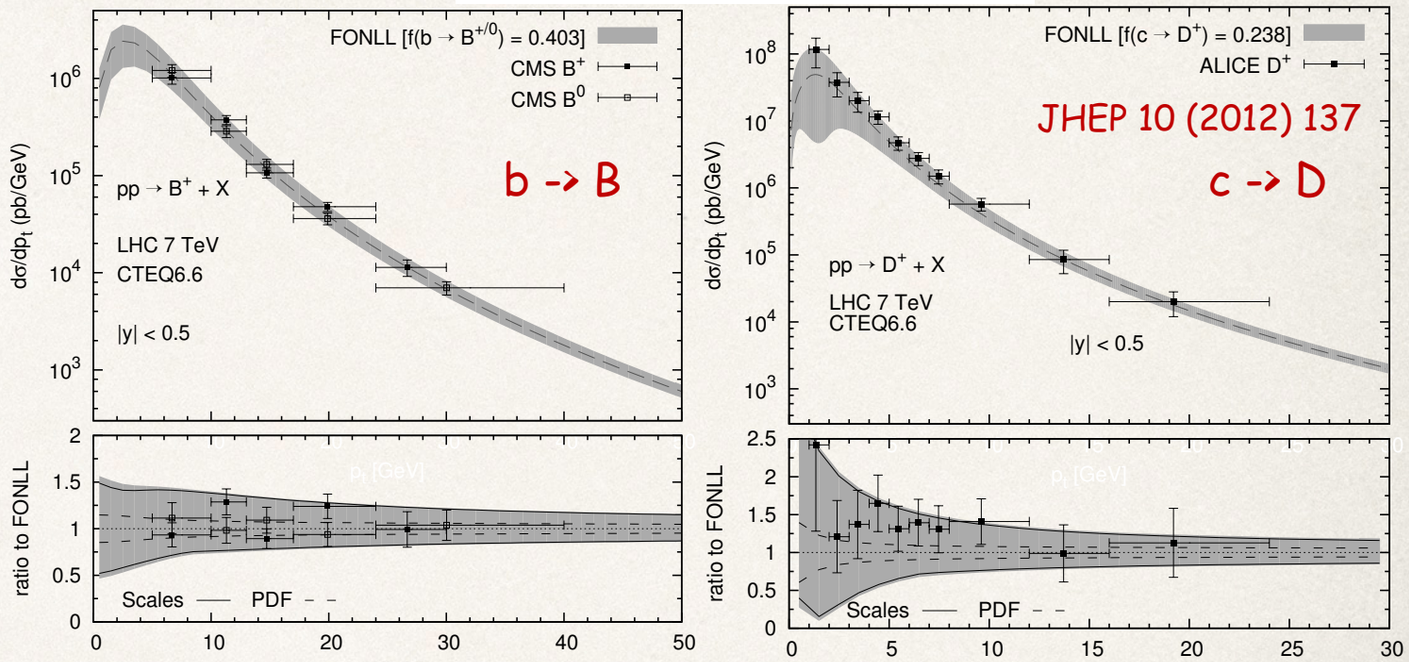

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- Modification of hadronization in presence of a medium?
  - → **fragmentation vs recombination**

[1]: R. Baier et al. Nucl.Phys. B483 (1997) 291-320
[2]: Dokshitzer, Kharzeev, PLB 519 (2001) 199

Strangeness and D_s^+ in QGP

Strange quarks are abundant in QGP:

- ✓ lower threshold for $s\bar{s}$ production w.r.t. a hadron gas
- ✓ lifting of canonical suppression for *strangeness* production from pp (p-A) to A-A collisions

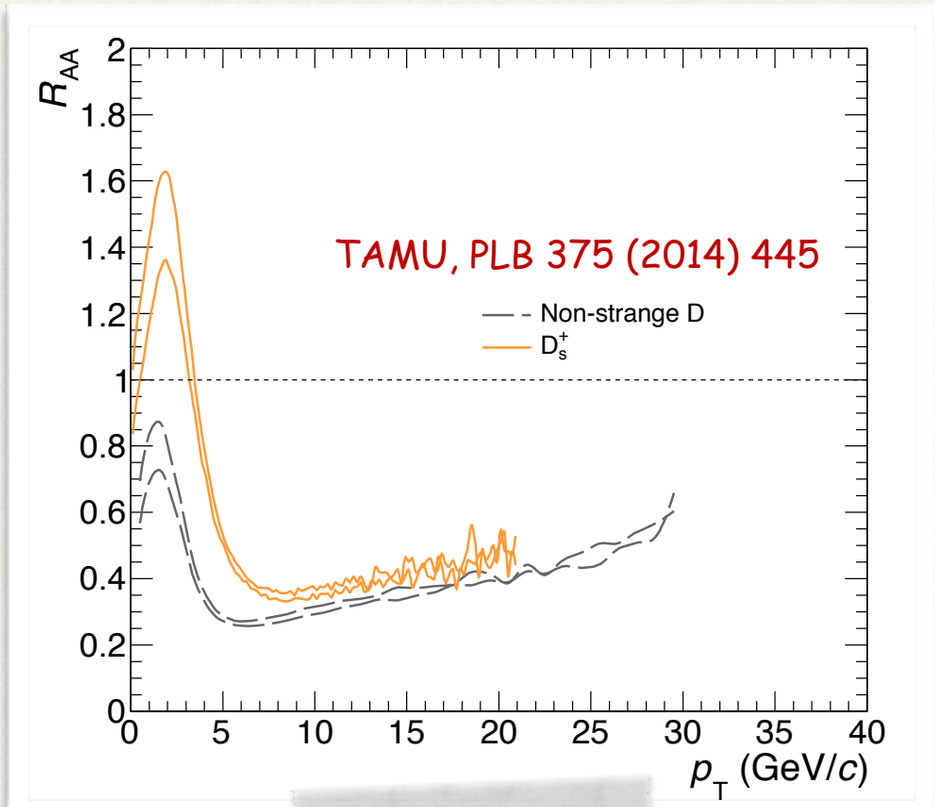
If hadronization of charm quark at low energy via recombination [1,2]

+

strangeness enhancement

→ enhanced D_s-meson production w.r.t. to non-strange D mesons in Pb-Pb collisions

→ interesting comparison with non-strange D mesons



Physical observable:

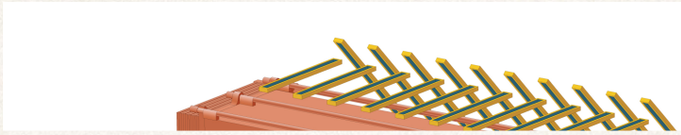
$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N_{\mathrm{AA}}^{\mathrm{D_s^+}}/\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{AA}}\rangle \,\mathrm{d}\sigma_{\mathrm{pp}}^{\mathrm{D_s^+}}/\mathrm{d}p_{\mathrm{T}}}$$

- $R_{AA} \neq 1$ -> binary scaling violation

[1] Kuznetsova, Rafelski, Eur.Phys.J.C51:113-133,2007

[2] He, Min et al. Phys.Rev.Lett. 110 (2013)

ALICE detector



TPC:
tracking and PID with dE/dx

ITS:
tracking and vertexing

TOF:
PID with time-of-flight

V0:
minimum bias trigger (from the signal in both V0s for p-Pb and Pb-Pb collisions)

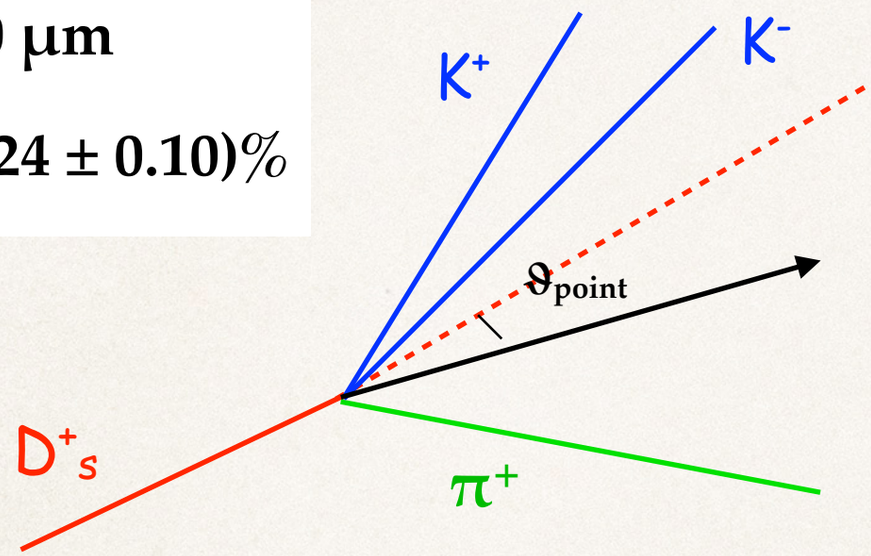
Collision system	$\sqrt{s_{NN}}$(TeV)	L_{int} (μb^{-1})	N_{events}
pp	7.0	4.8×10^3	3×10^8
p-Pb	5.02	48.6	97.3×10^6
0-7.5%, Pb-Pb	2.76	21.5	16.0×10^6
20-50%, Pb-Pb	2.76	5.9	13.5×10^6

Analysis strategy

$D_s^+ \rightarrow \Phi\, \pi^+ \rightarrow K^+\, K^-\, \pi^+$

$c\tau$ = 150 μm

BR = (2.24 ± 0.10)%



Reconstruction and selection based on:

1. Excellent vertex and impact parameter resolution
2. Particle Identification (PID)

Signal extraction requires:

1. **Specific selection of the decay channel → Invariant mass of the reconstructed Φ meson**
2. **Background reduction via topological selections**

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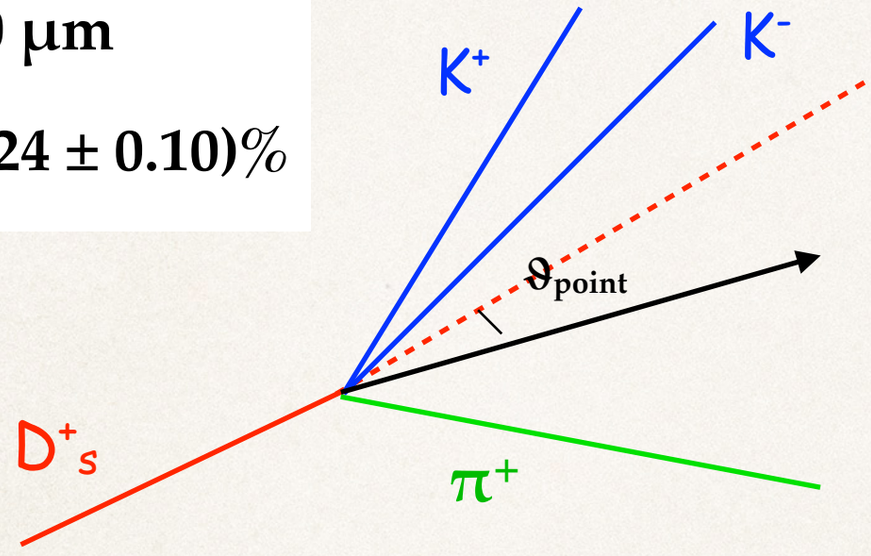

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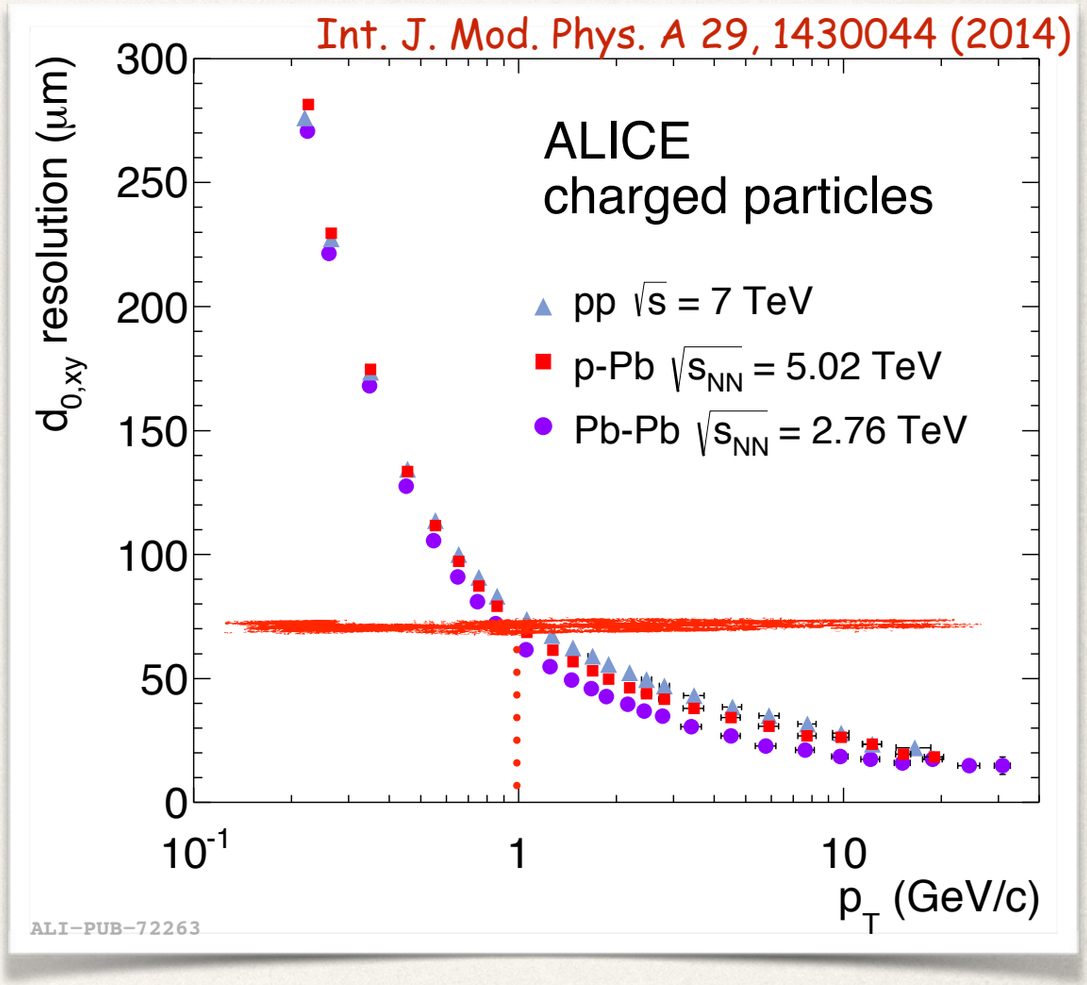

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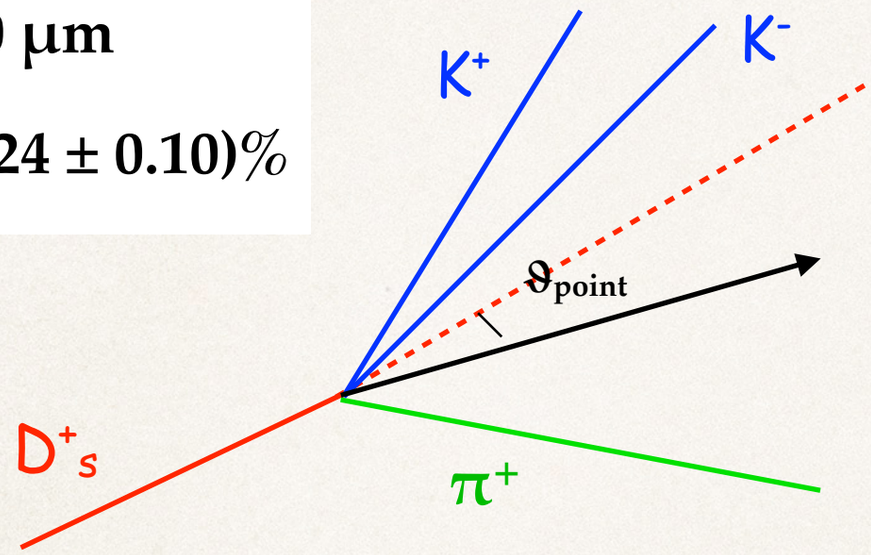

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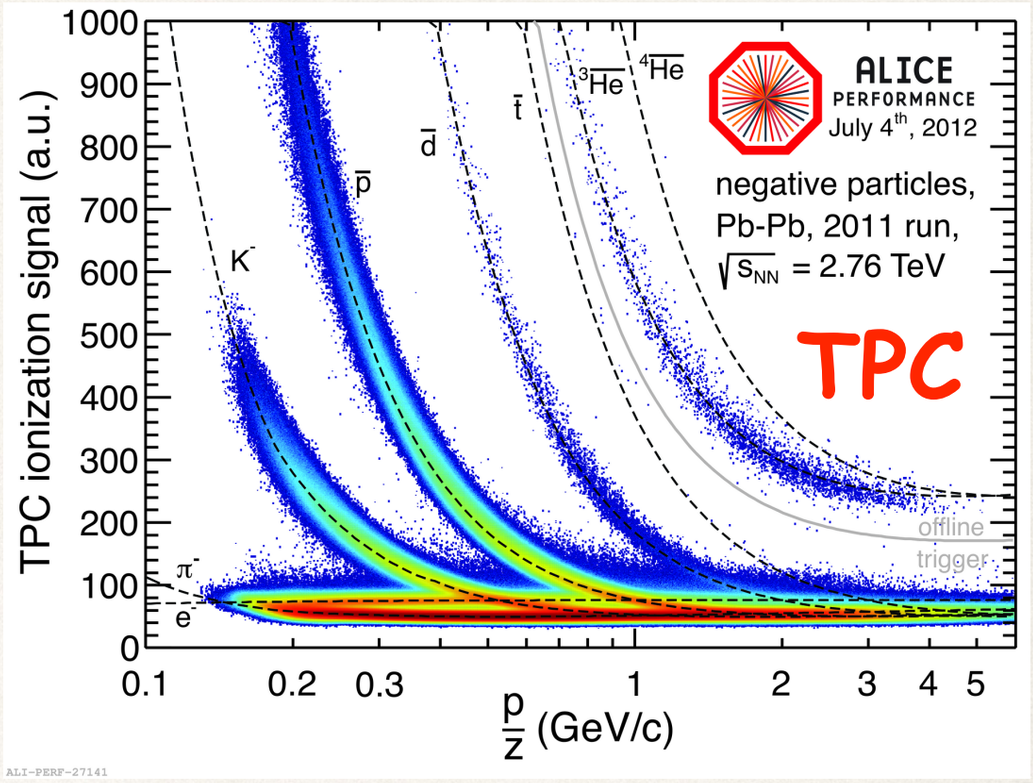
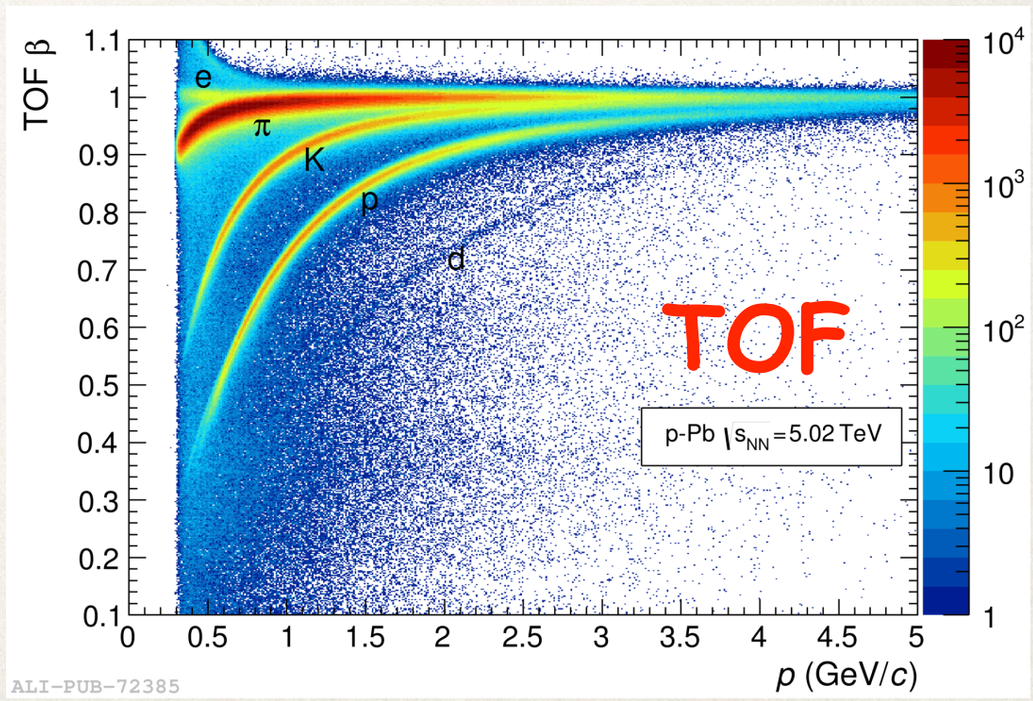




pp collisions @ $\sqrt{s} = 7$ TeV

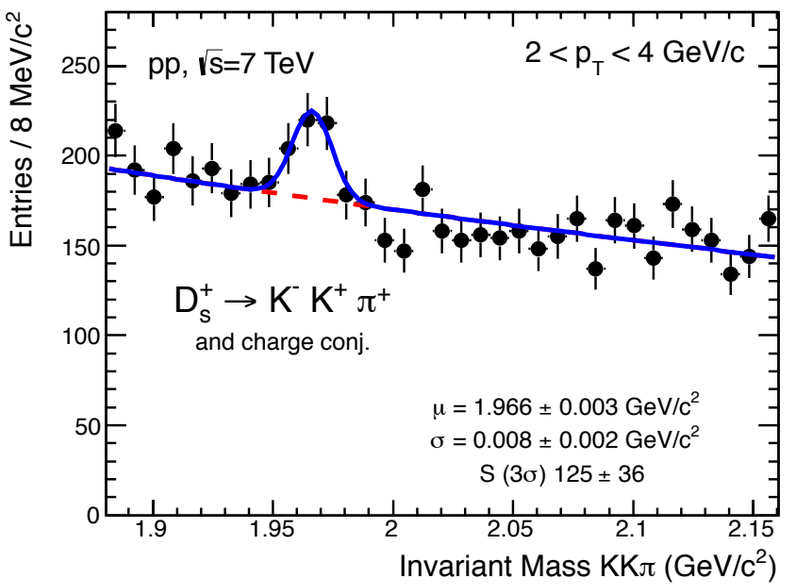
- 2010 data sample
- 3 x 10^8 minimum bias events

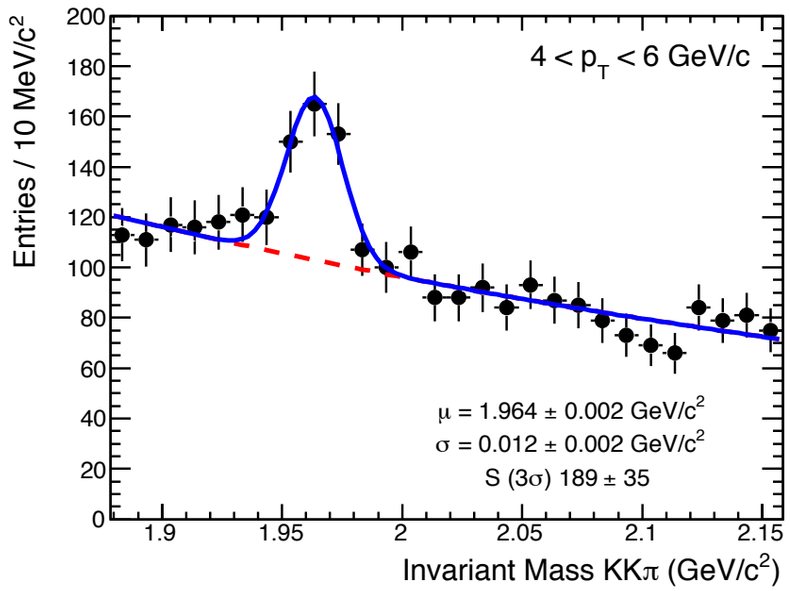
Goals:
1) pQCD tests at LHC energies
2) reference for p-Pb and Pb-Pb measurements

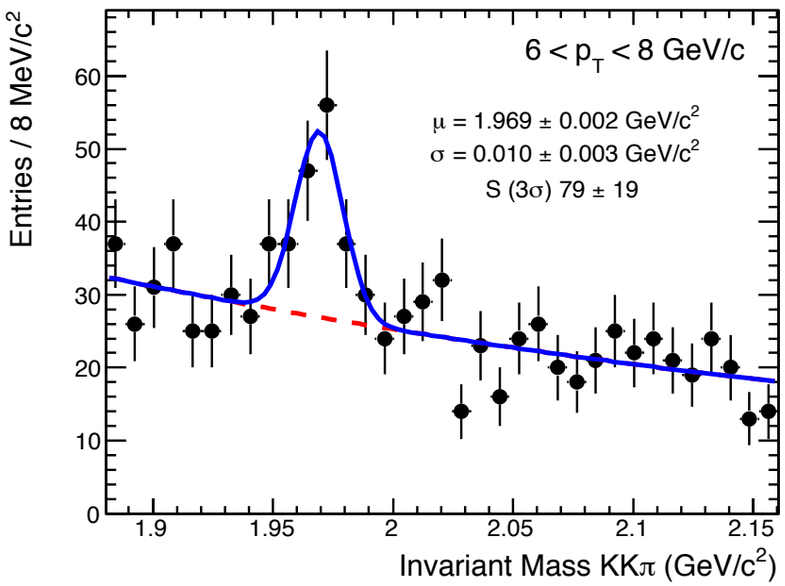
$D_s^{\pm}$ signal in pp collisions

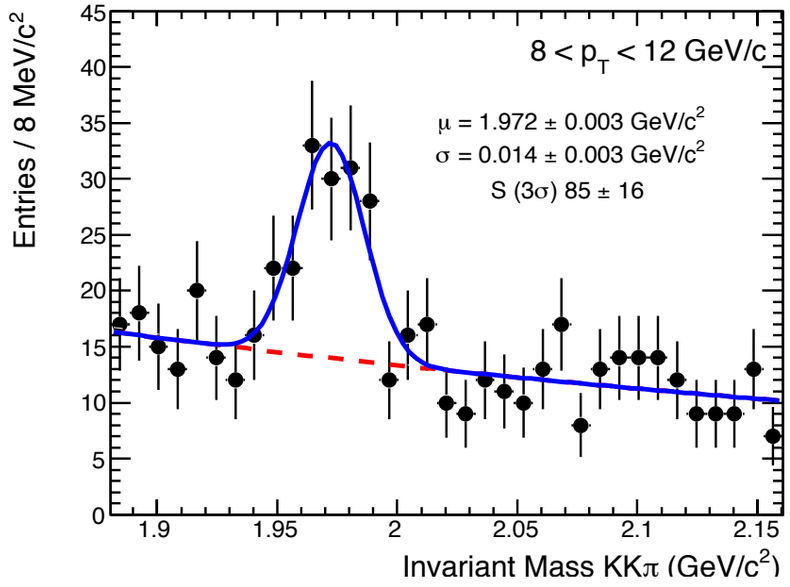
Invariant mass distributions of $D_s^{\pm}$ candidates in **4 p_T intervals: [2,4], [4,6], [6,8], [8,12] GeV/*c***

Gaussian + exponential fit function







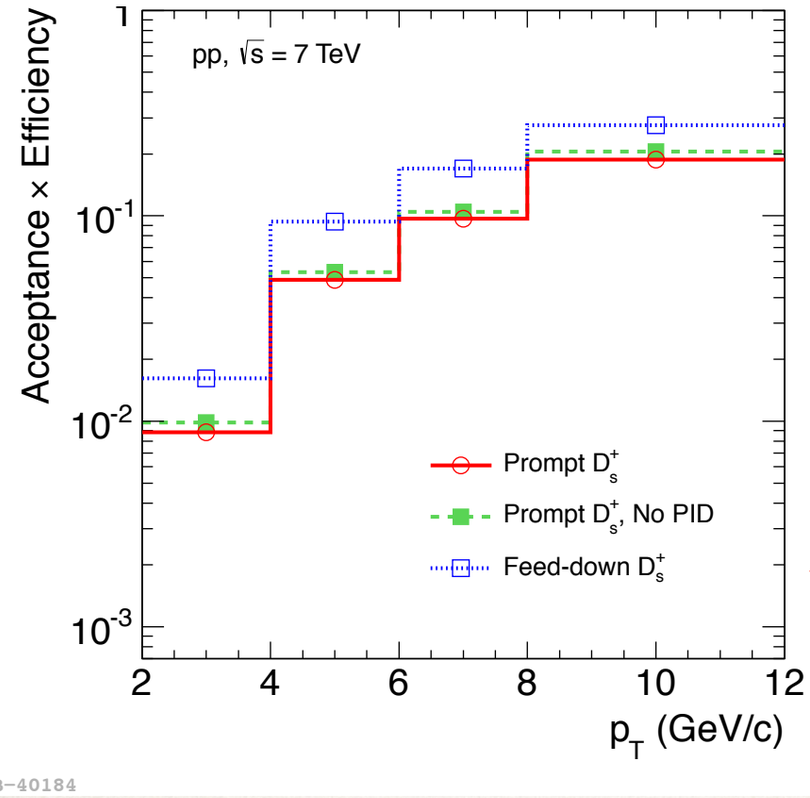


ALI-PUB-40180

Phys.Lett. B718 (2012) 279-294

Corrections

Phys.Lett. B718 (2012) 279-294



ALI-PUB-40184

- Acceptance x efficiency for **prompt and feed-down D_s^+**
- **Higher efficiencies for D_s^+ from beauty feed-down** than for prompt
- Efficiencies increasing with p_T

$$\left.\frac{\mathrm{d}\sigma^{D_s^+}}{\mathrm{d}p_T}\right|_{|y|<0.5} = \frac{1}{2}\,\frac{1}{\Delta y\,\Delta p_T}\,\frac{\left.f_{\mathrm{prompt}}\cdot N^{D_s^\pm\ \mathrm{raw}}\right|_{|y|<y_{\mathrm{fid}}}}{(\mathrm{Acc}\times\varepsilon)_{\mathrm{prompt}}\cdot \mathrm{BR}\cdot L_{\mathrm{int}}}$$

Corrections

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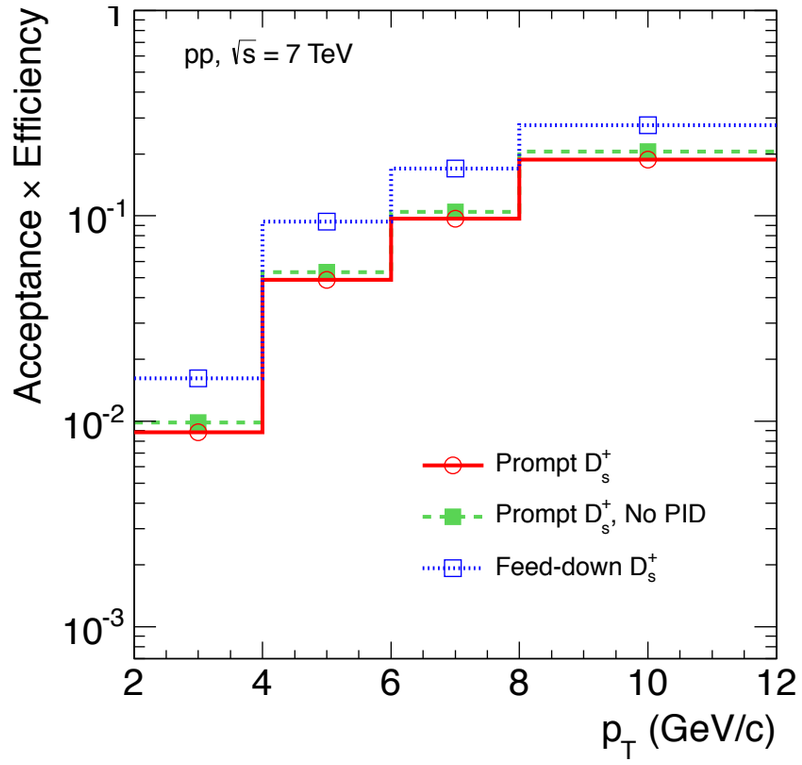

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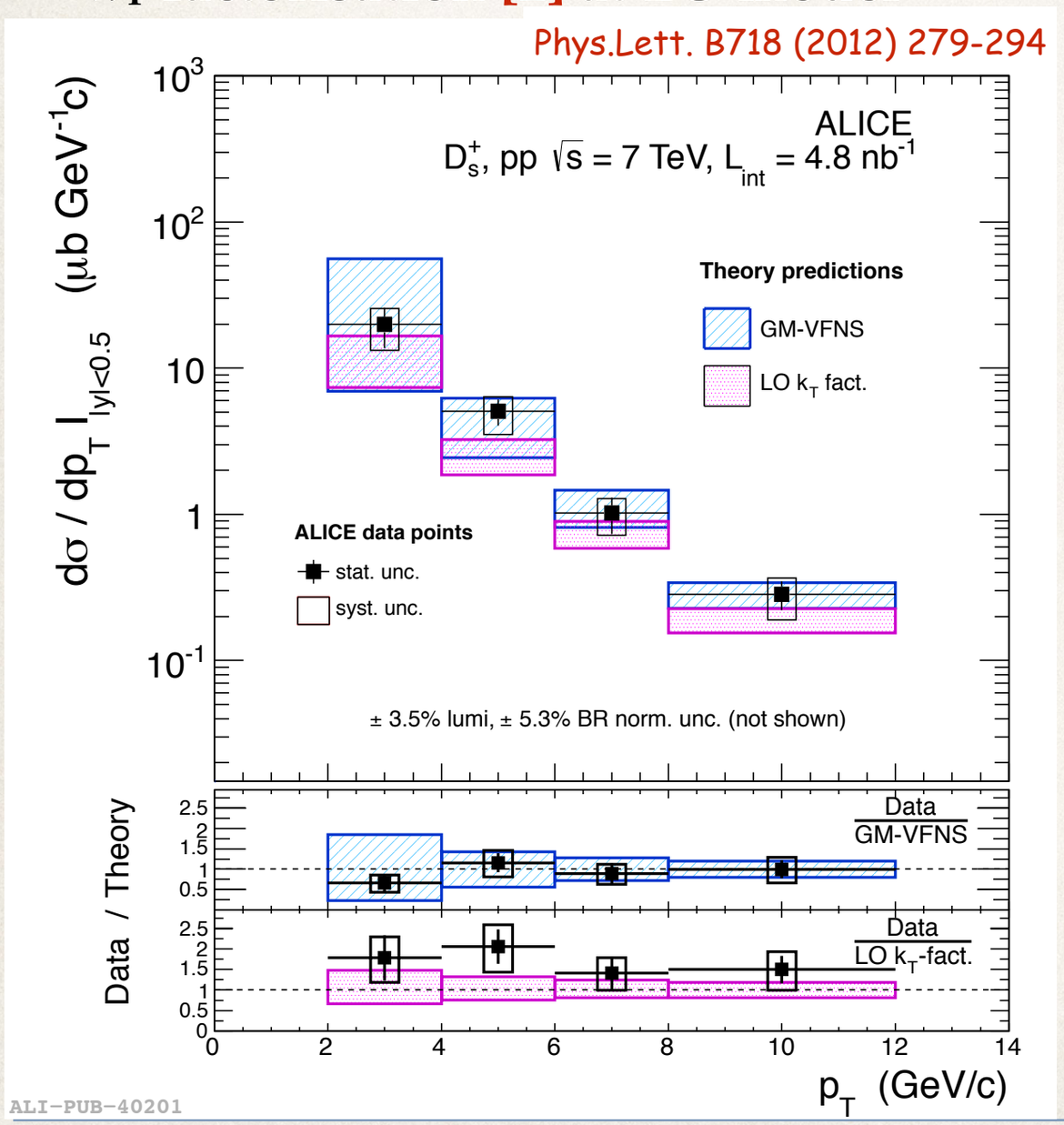
- Fraction of prompt D_s calculated as: $f_{prompt} = 1 - (N^{D_s^\pm fromB,raw}/N^{D_s^\pm raw})$
  - ✓ beauty-production cross section from FONLL [1] calculations
  - ✓ feed-down D_s^+ efficiency from MC
- f_{prompt} ranges from 0.93 to 0.87 depending on the p_T of the D_s^+ meson

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

D^+_s p_T-differential cross section in pp collisions

- p_T-differential cross section described within uncertainties by **GM-VFNS** [1] **(collinear factorisation NLO)** and k_T **factorisation** [2] **at LO model**

Phys.Lett. B718 (2012) 279-294



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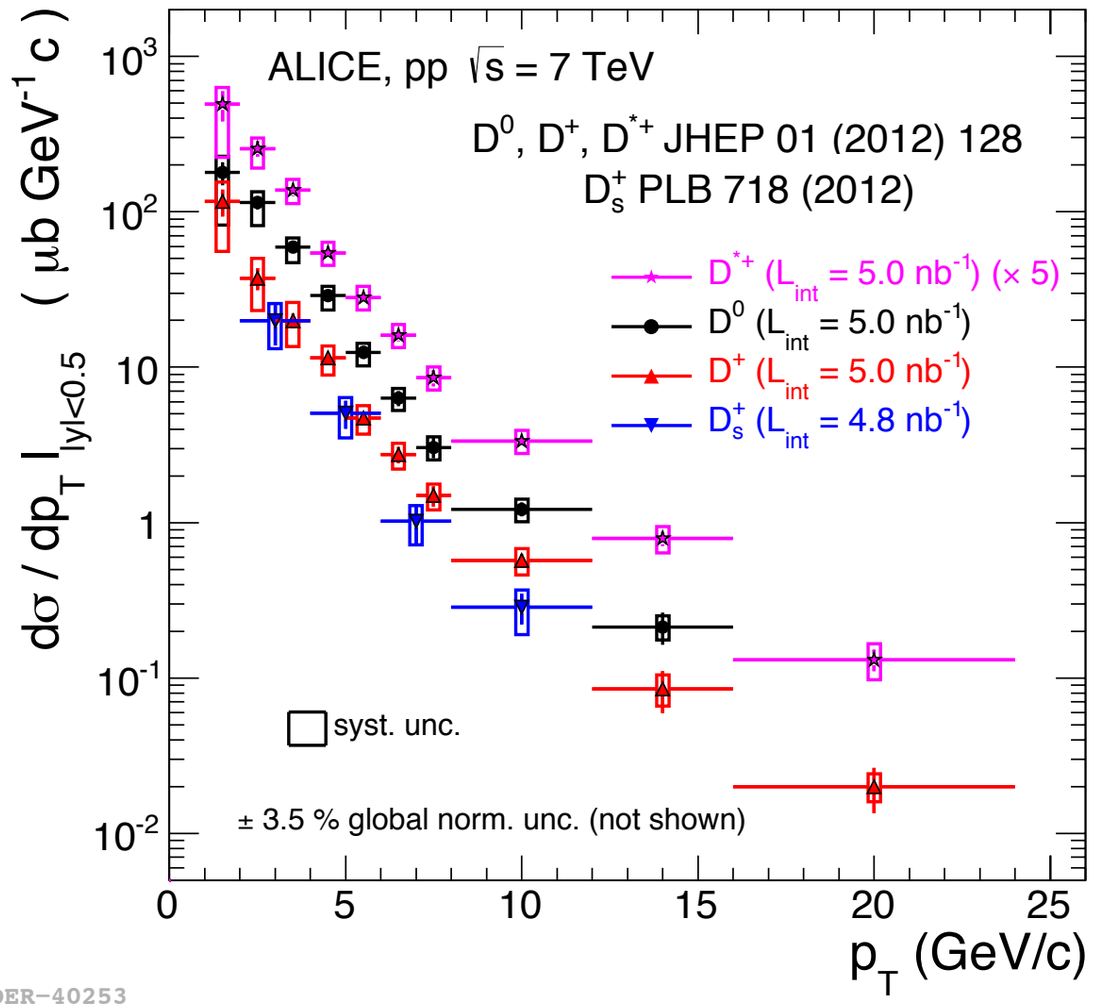


ALI-DER-40253

- **D^0, D^+ and D^{*+}** p_T-differential cross section also measured at the same energy

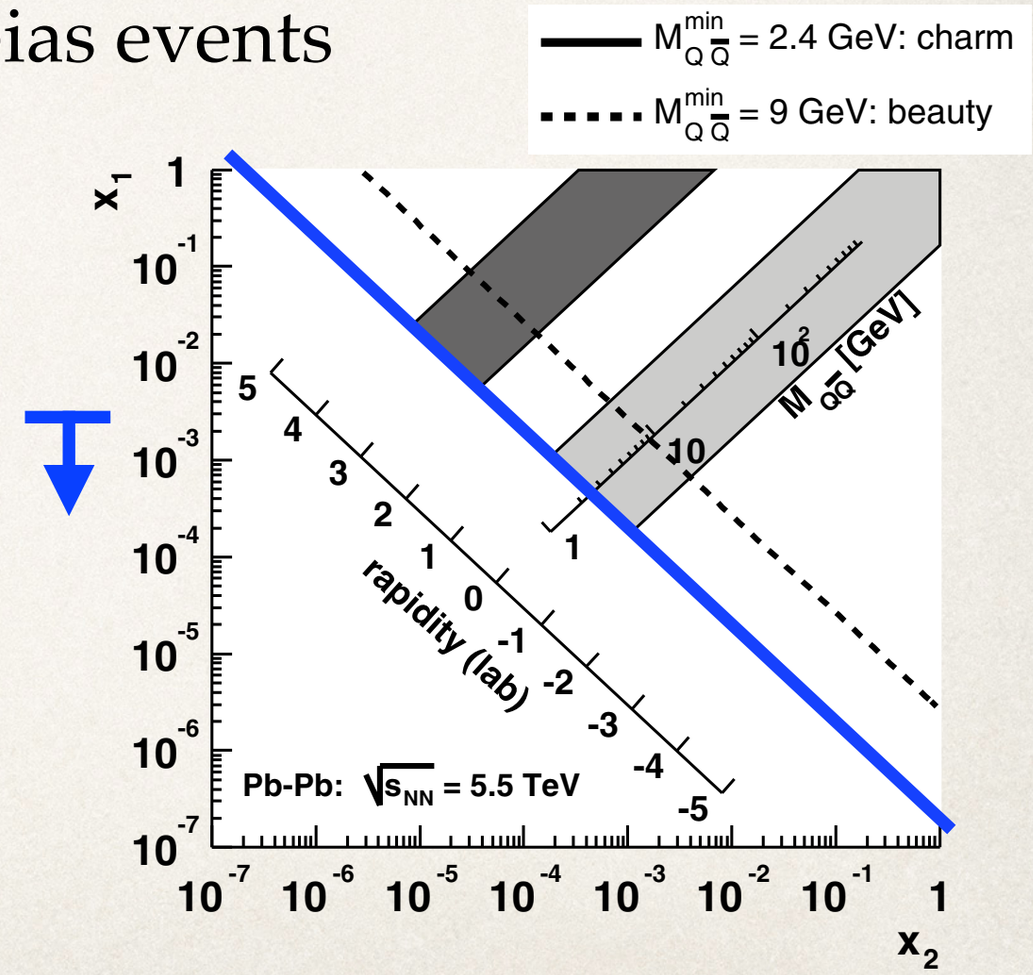
[1] Kniehl, B.A. et al. Eur.Phys.J. C72 (2012) 2082

[2] R. Maciula, M. Luszczak and A. Szczurek, arXiv:1207.6533 [hep-ph]

p-Pb collisions @ $\sqrt{s_{NN}} = 5.02$ TeV

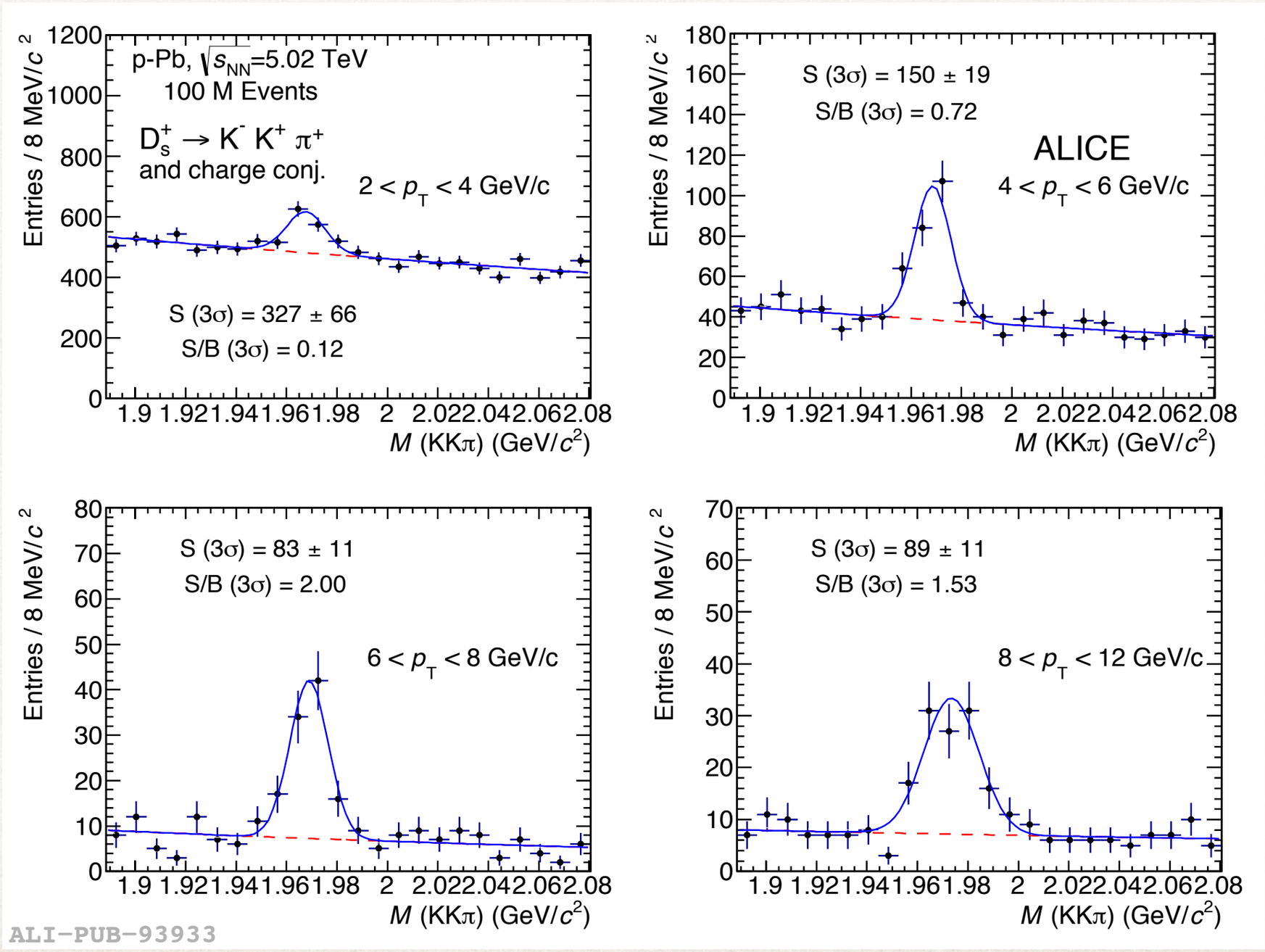
- 2013 data sample
- 97.3 x 10^6 minimum bias events

Goal:
establish the role of cold nuclear matter effects
- **nuclear PDFs**
- **k_T-broadening**
- **…**



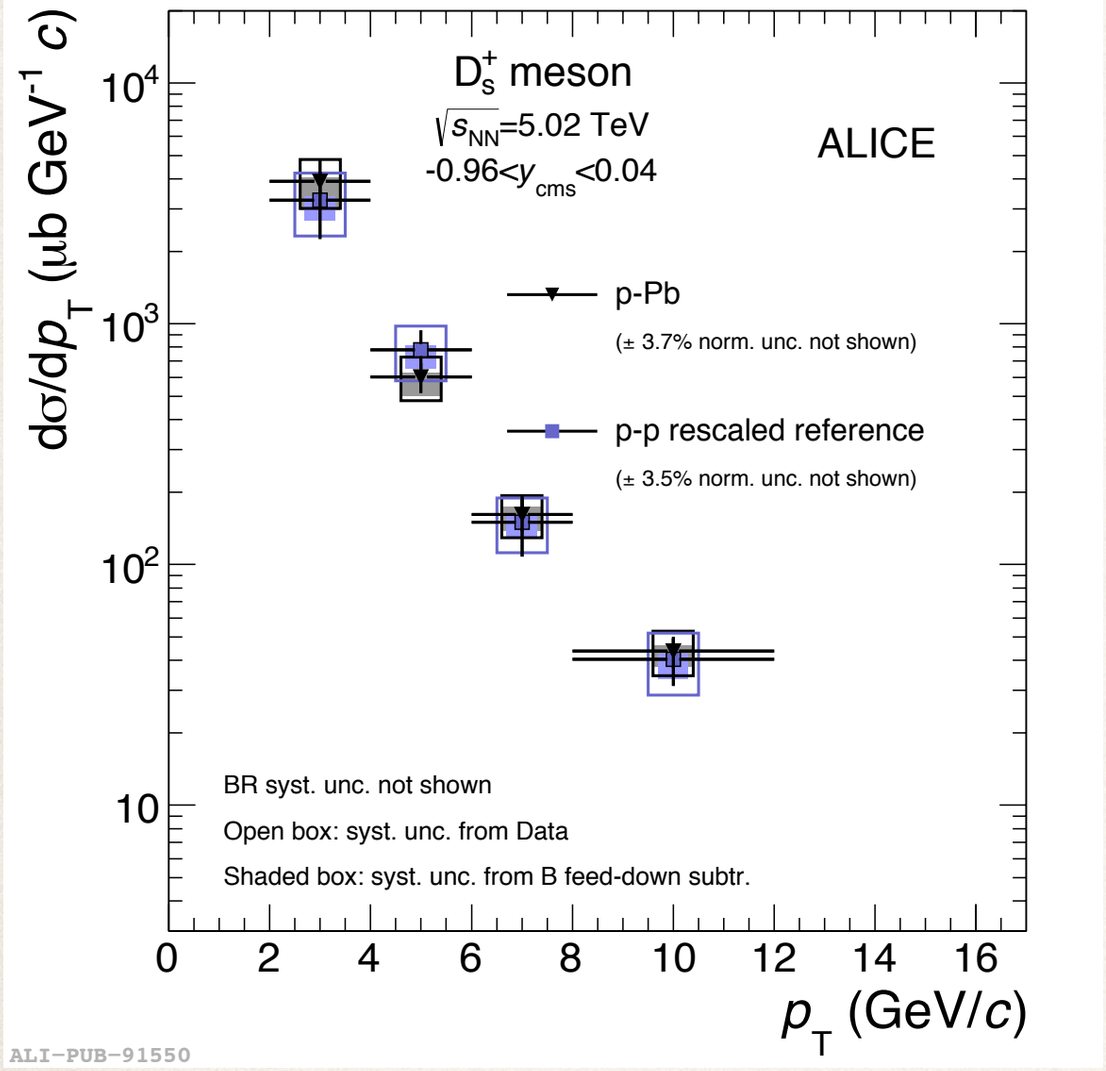
$D^{\pm}_s$ signal in p-Pb collisions

Invariant mass distributions of $D_s^{\pm}$ candidates in **4 p_T intervals: [2,4], [4,6], [6,8], [8,12] GeV/*c***

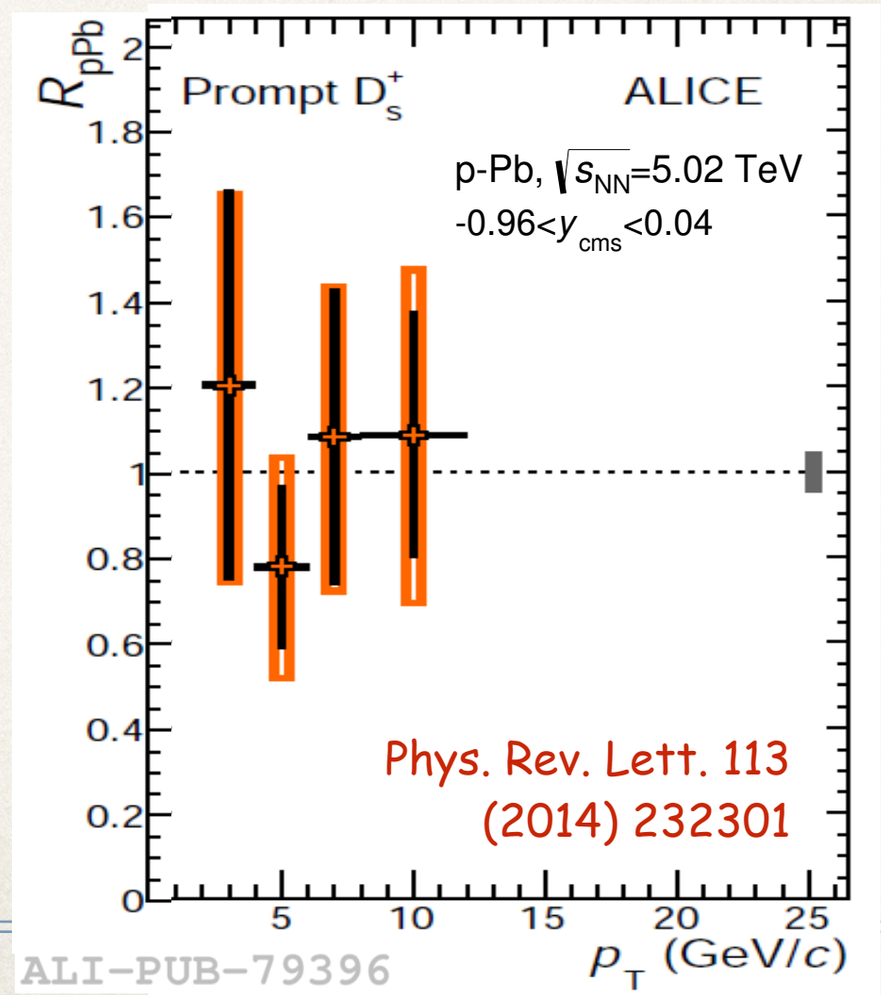


D^+_s p_T-differential cross section and R_{pPb}

Phys. Rev. Lett. 113 (2014) 232301



- R_{pPb} compatible with unity within uncertainties
- No indication for modification due to cold nuclear matter effects, crucial for the interpretation of the Pb-Pb results



- **Similar observations for D^0, D^+, D^{*+} (see talk by C. Terrevoli)**

Pb-Pb collisions @ $\sqrt{s_{\rm NN}} = 2.76$ TeV

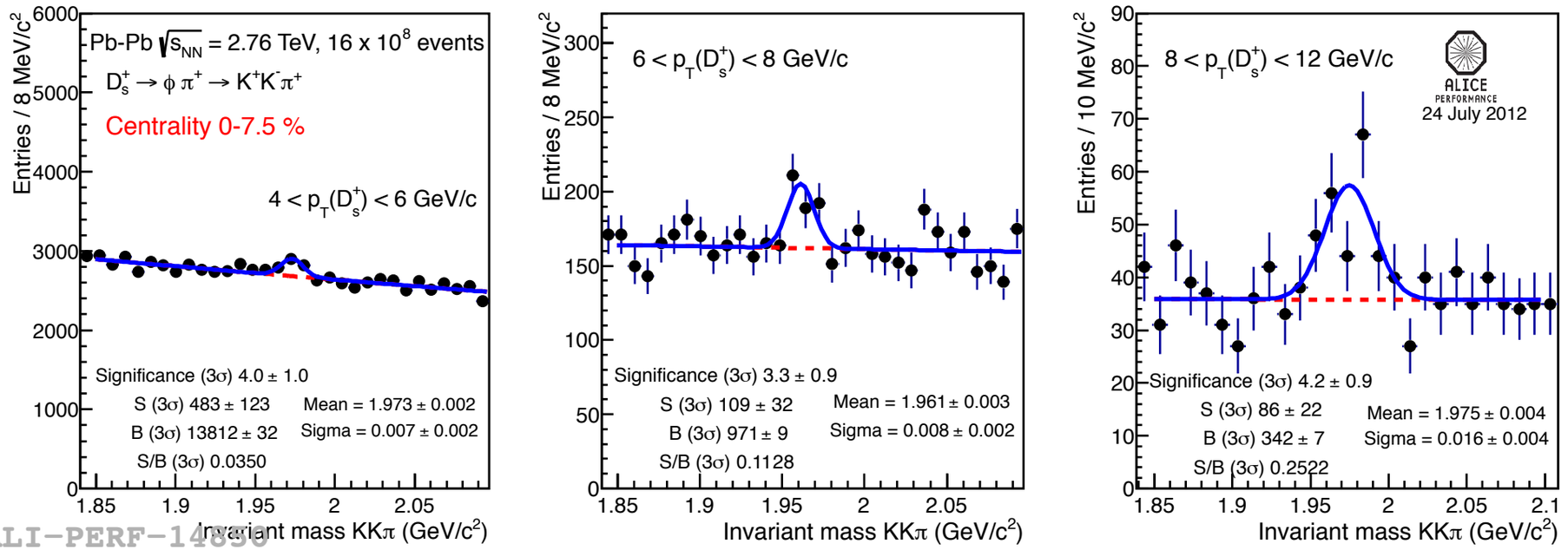
- 2011 data sample
- 16.0 x 10^6 events in the 0-7.5% centrality class

- 13.5 x 10^6 events in the 20-50% centrality class

Goals:
to study heavy-quark in-medium energy loss, hadronization mechanism …

$D^{\pm}_s$ signal in Pb-Pb collisions

Invariant mass distribution of $D_s^{\pm}$ candidates in:



centrality 0-7.5 %:

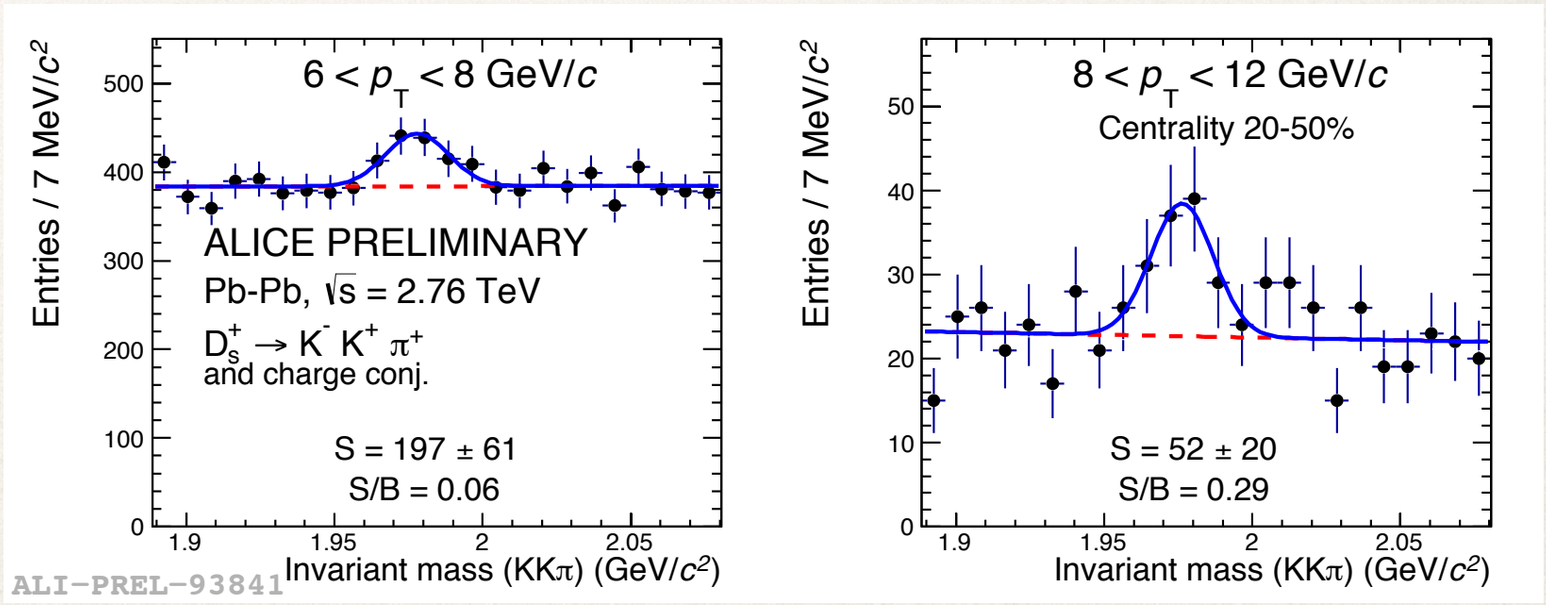
3 p_T **intervals**

[4,6], [6,8], [8,12] GeV/*c*

centrality 20-50 %:

2 p_T **intervals**

[6,8], [8,12] GeV/*c*



Corrections

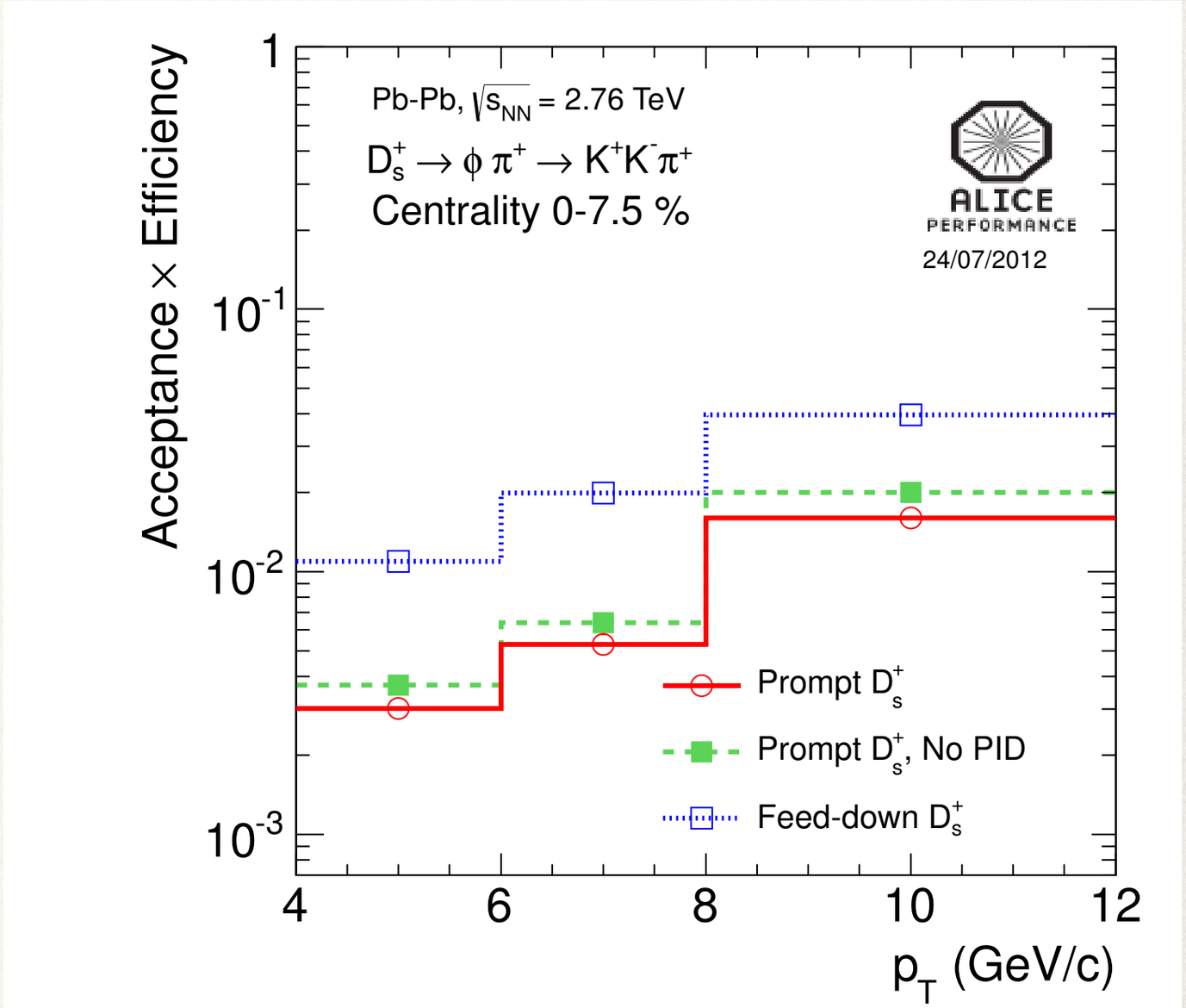
- **Efficiencies lower than in pp and in p-Pb** → tighter selections needed in Pb-Pb collisions

- In the **20-50%** centrality class looser selections than in 0-7.5% can be used

- $\mathbf{f_{prompt}}$ in Pb-Pb requires an **hypothesis on R_{AA} of D_s from beauty feed-down:**

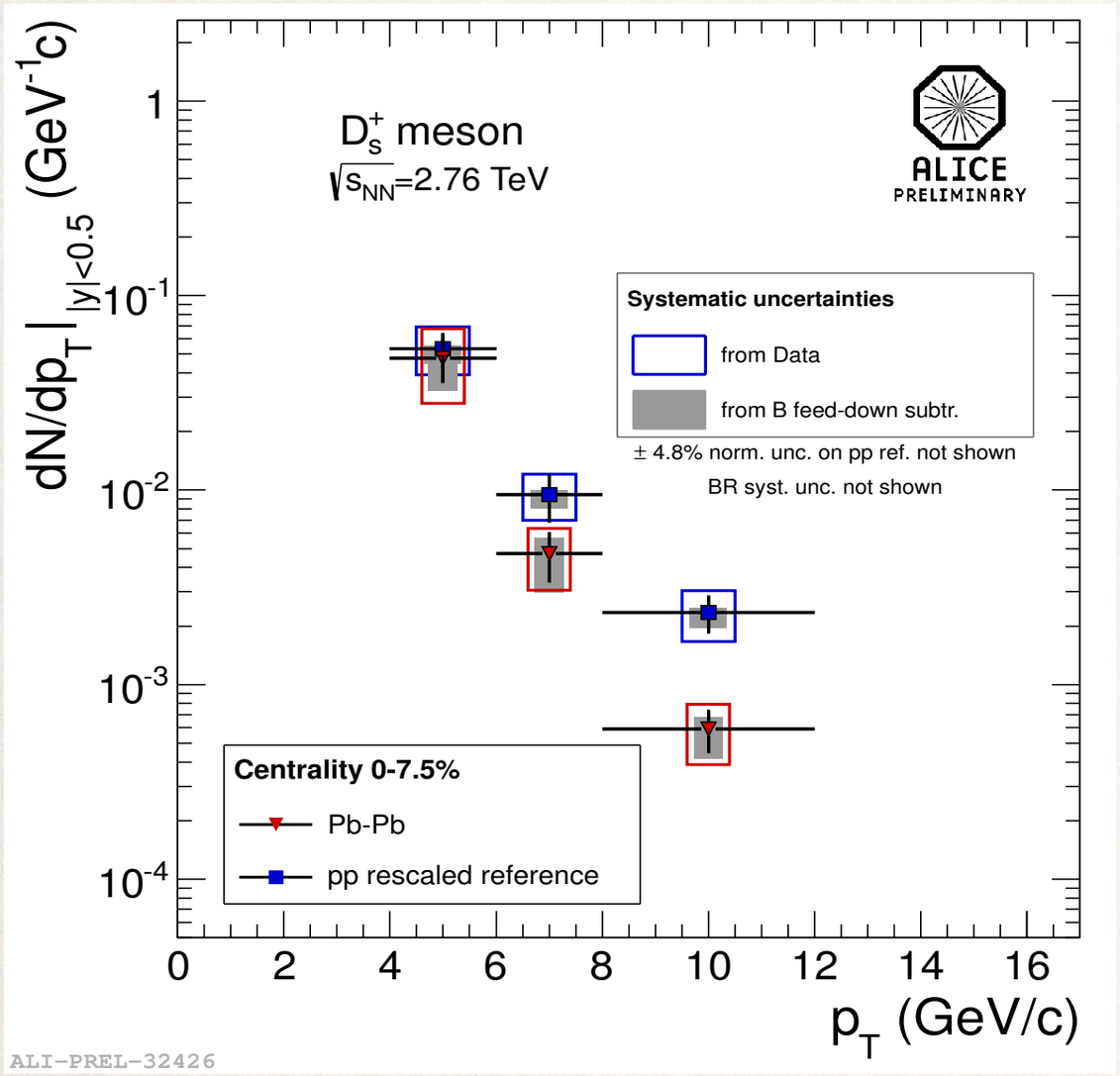
  - $R_{AA}^{\text{feed-down}}/R_{AA}^{\text{prompt}} = 1$ for central values;
  - systematic uncertainty varying:

    $1/3 < R_{AA}^{\text{feed-down}}/R_{AA}^{\text{prompt}} < 3$

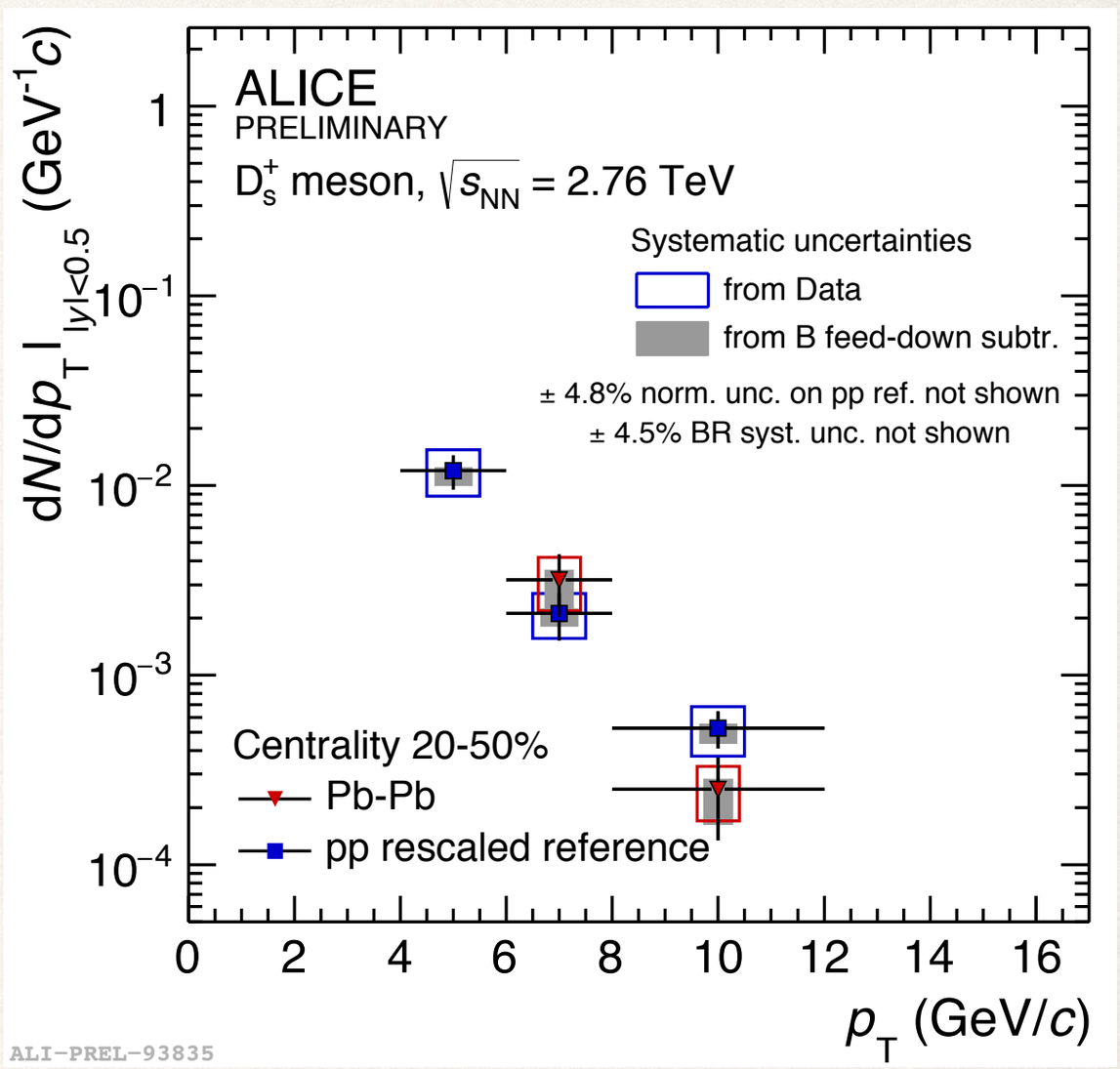


D_s^+ dN/dp_T

0-7.5%



20-50%



pp reference cross section:

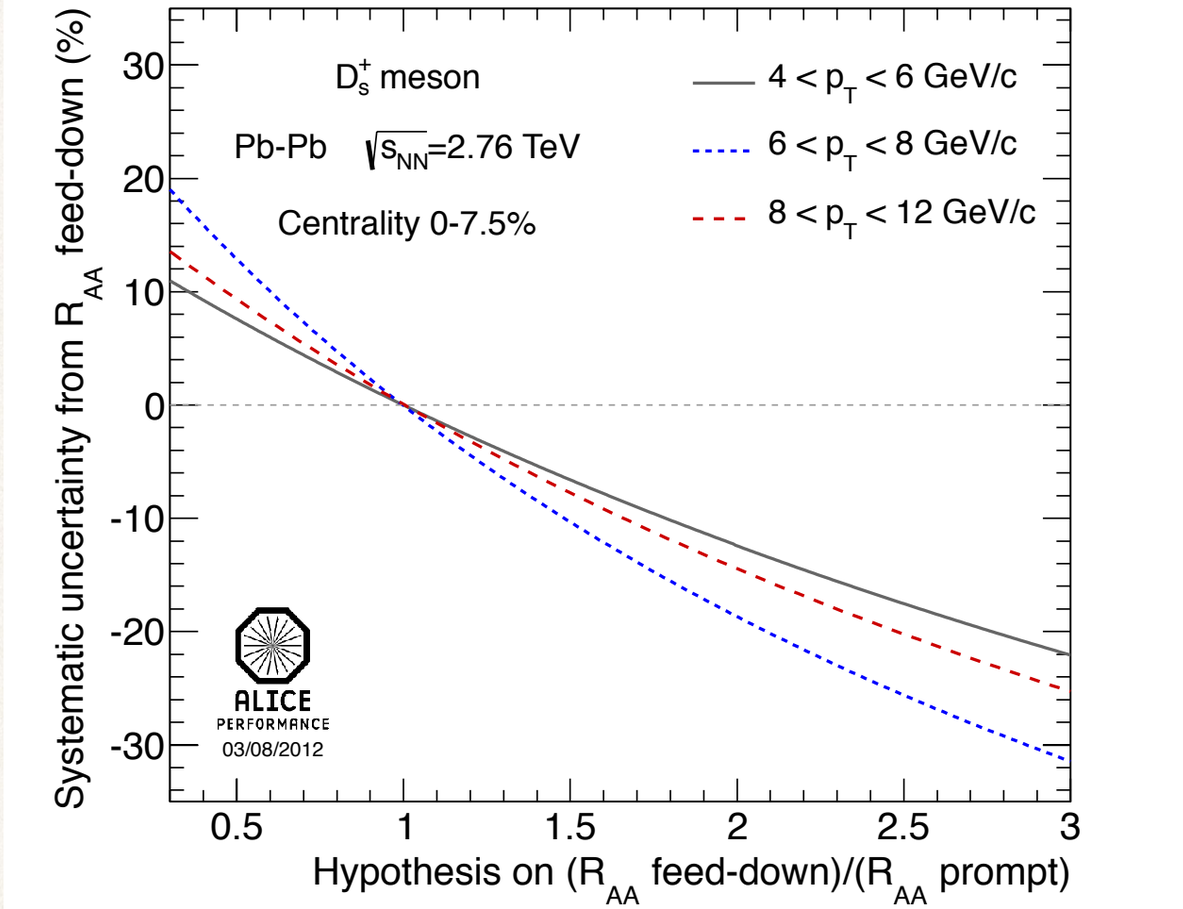
- measured cross section at $\sqrt{s} = 7$ TeV scaled to 2.76 TeV with pQCD calculations [1]
- multiplied by the nuclear overlap function $\langle T_{AA} \rangle$

[1]: arXiv:1107.3243 [hep-ph]

Systematic uncertainties

Systematic on R_{AA} in 0-7.5% as a function of the hypothesis on the beauty feed-down:

$$1/3 < R^{\text{feed-down}}_{AA} / R^{\text{prompt}}_{AA} < 3$$



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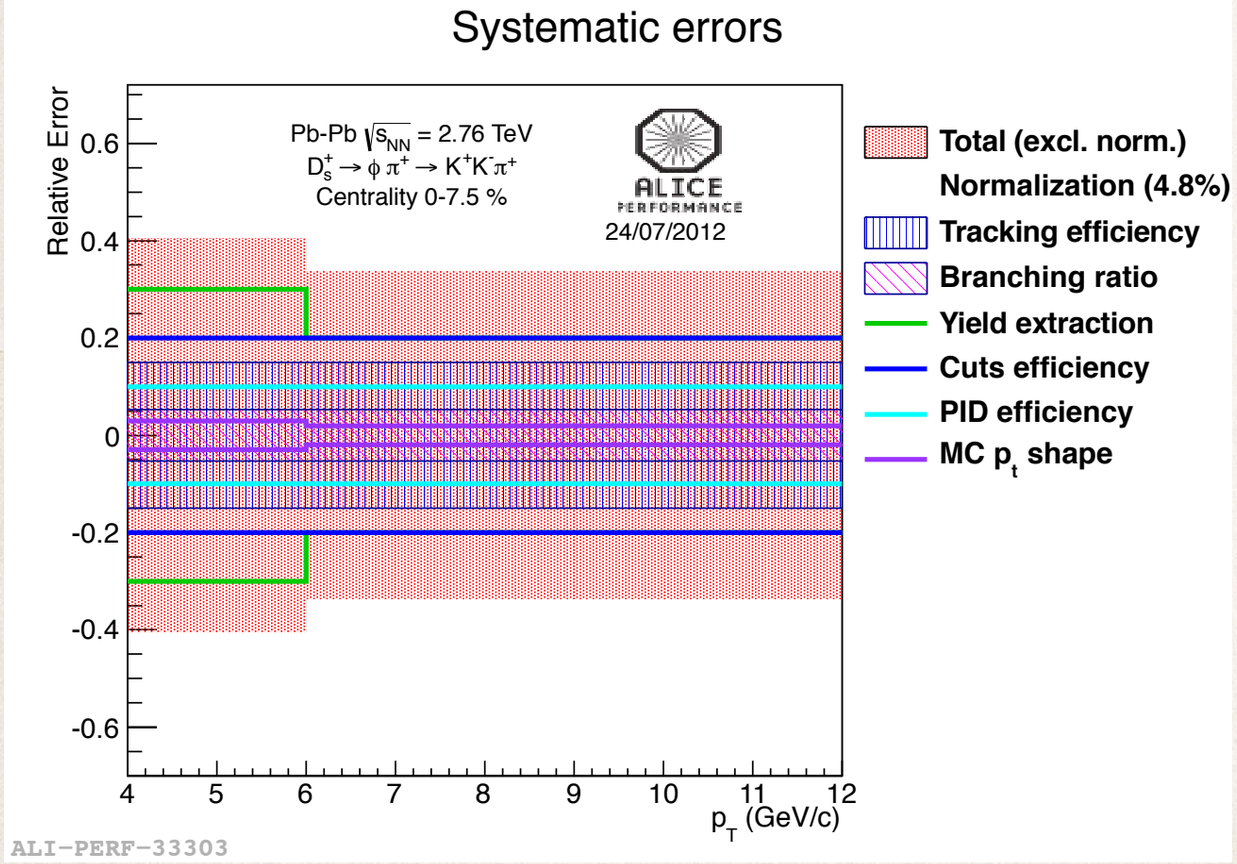


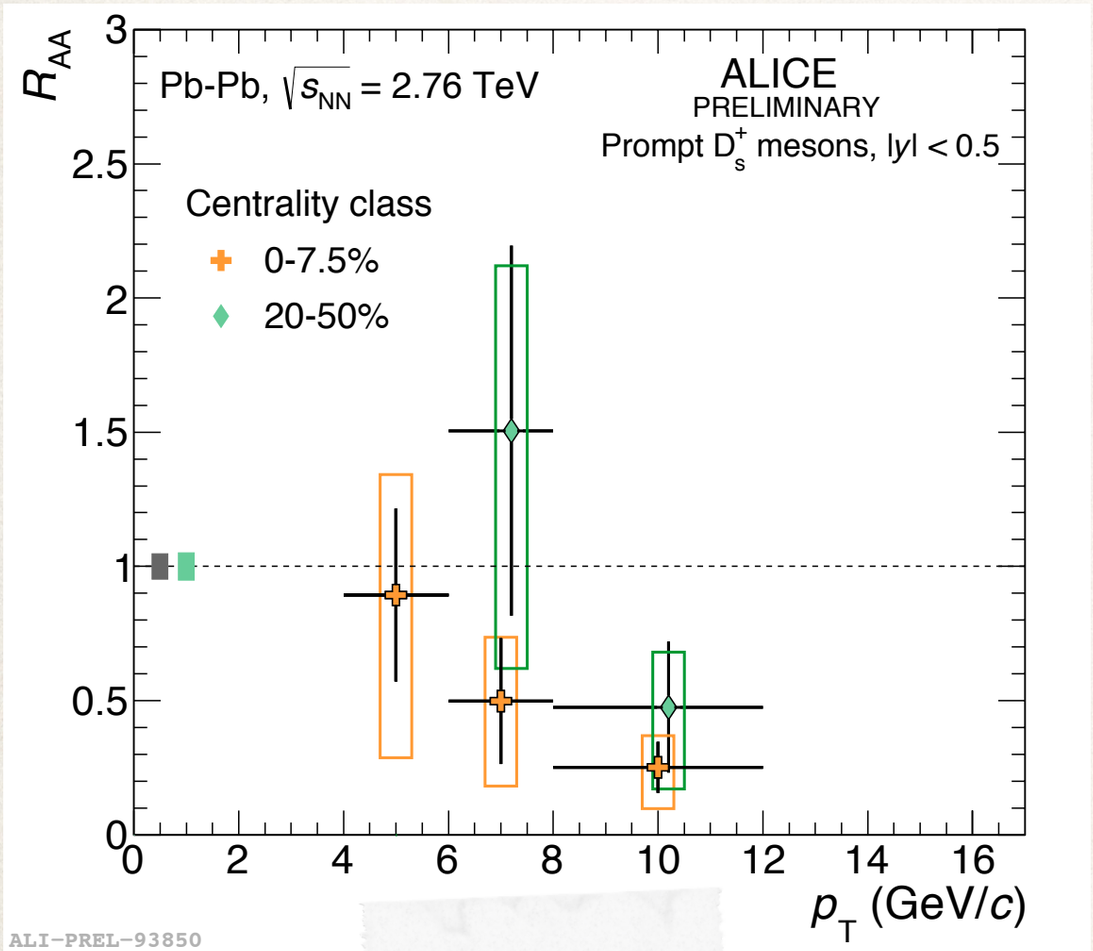
ALI-PERF-33303

Summary of the contributions to the systematic uncertainty on data in the 0-7.5% centrality class

←

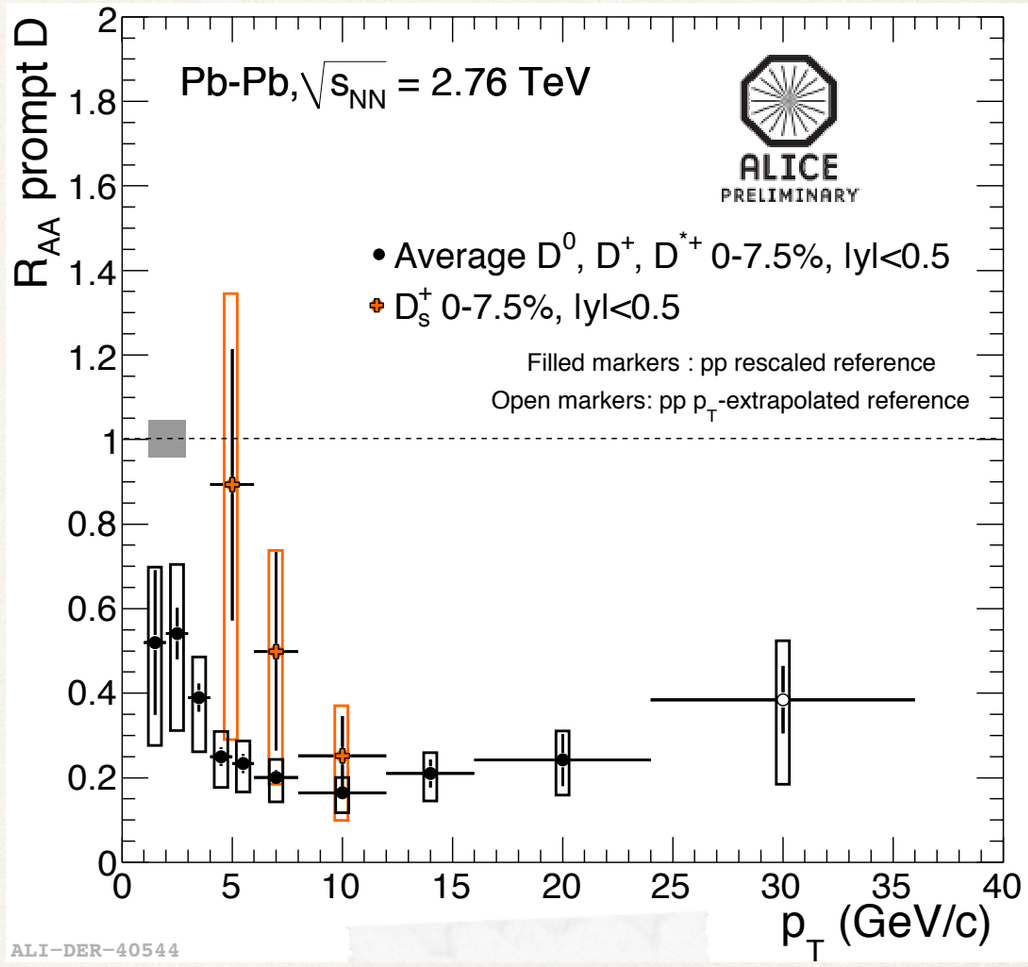
R_{AA} vs p_T

R_{AA} in central and semi-central events



- ✓**Significant suppression** in **0-7.5%** for p_T**>8 GeV/***c* due to **energy loss effects** (→ R_{pPb} compatible with 1!)
- ✓**Indication of suppression** for p_T>8 GeV/*c* **also in the 20-50%** centrality class

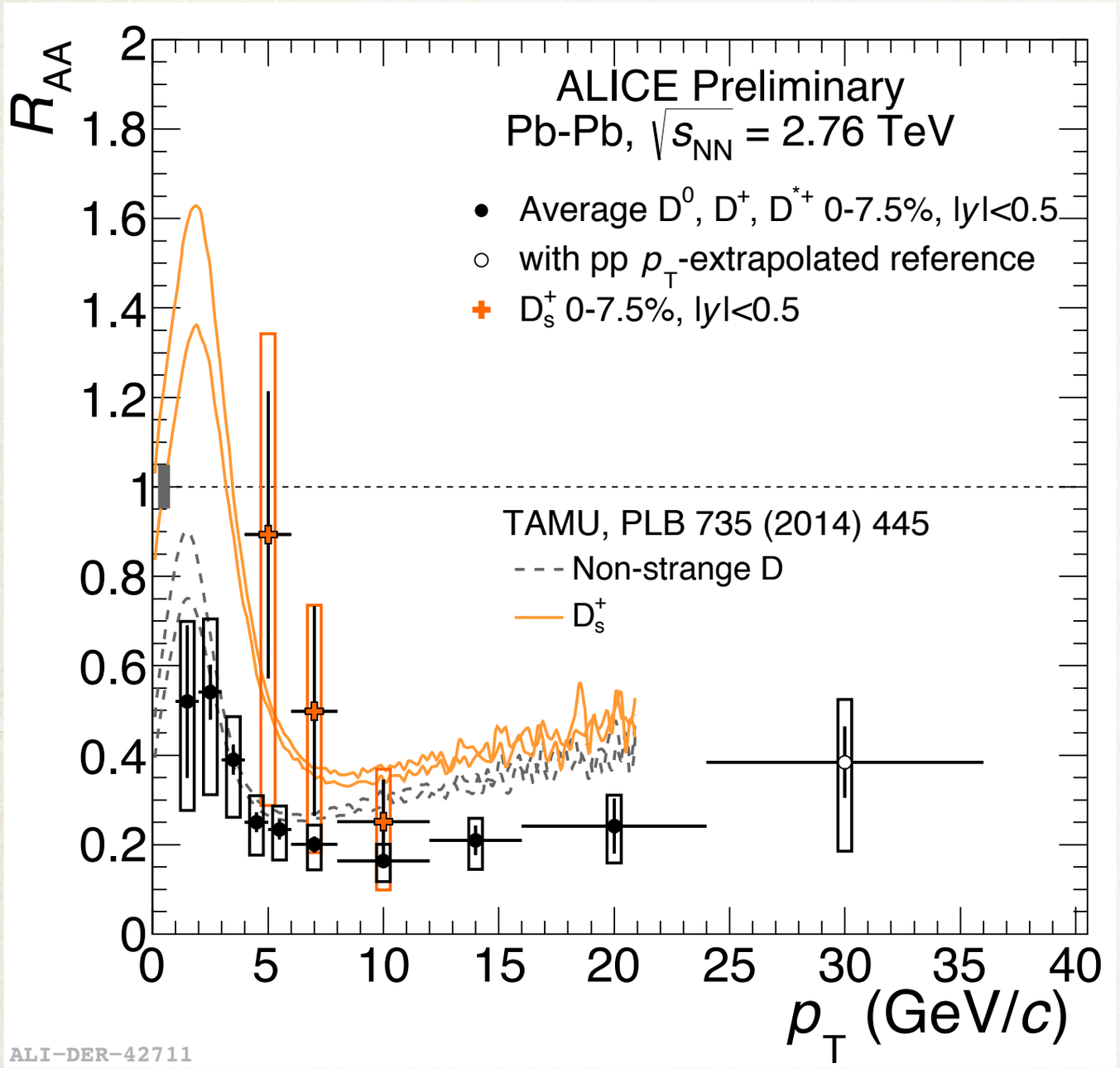
Comparison with R_{AA} of non-strange D meson (D^0, D^+, D^{*+})



Higher central values for D_s^+ in **4-6** and **6-8 GeV/***c* w.r.t non-strange D mesons, but still compatible within uncertainties

(see talk by A. Festanti)

R_{AA}: comparison with models



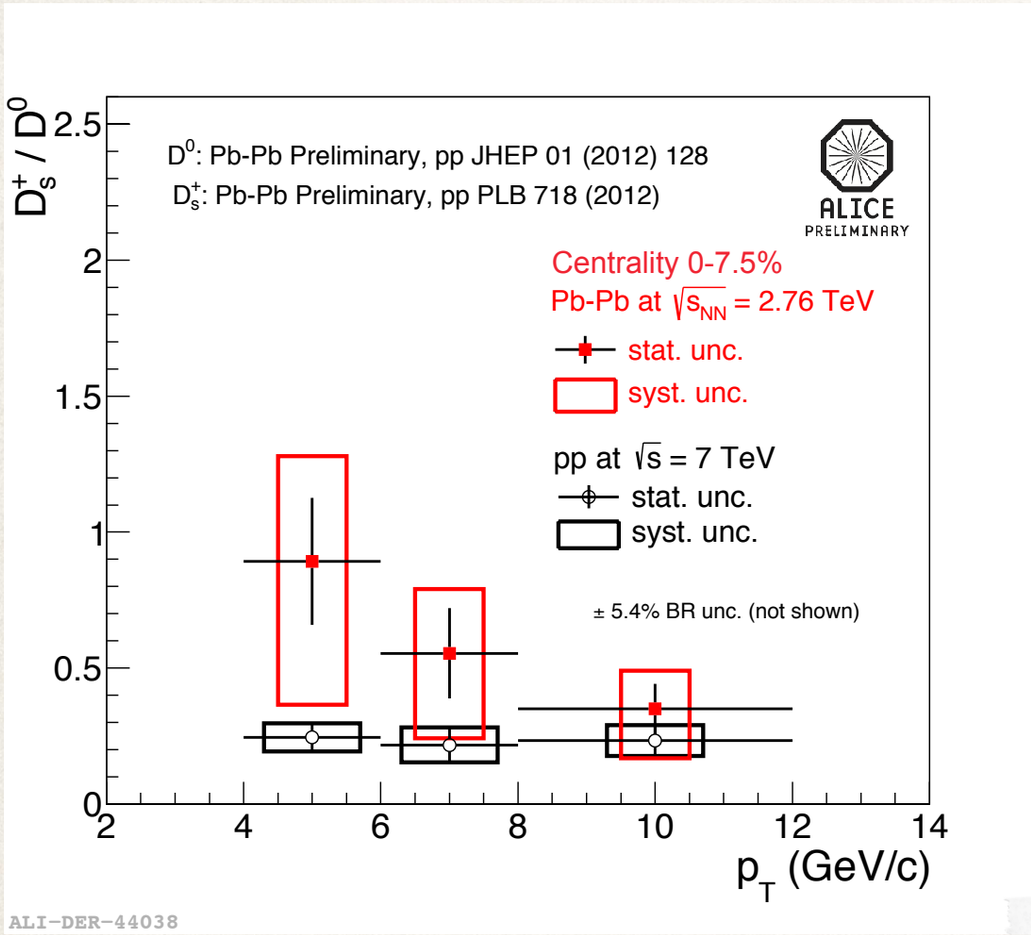
TAMU model:

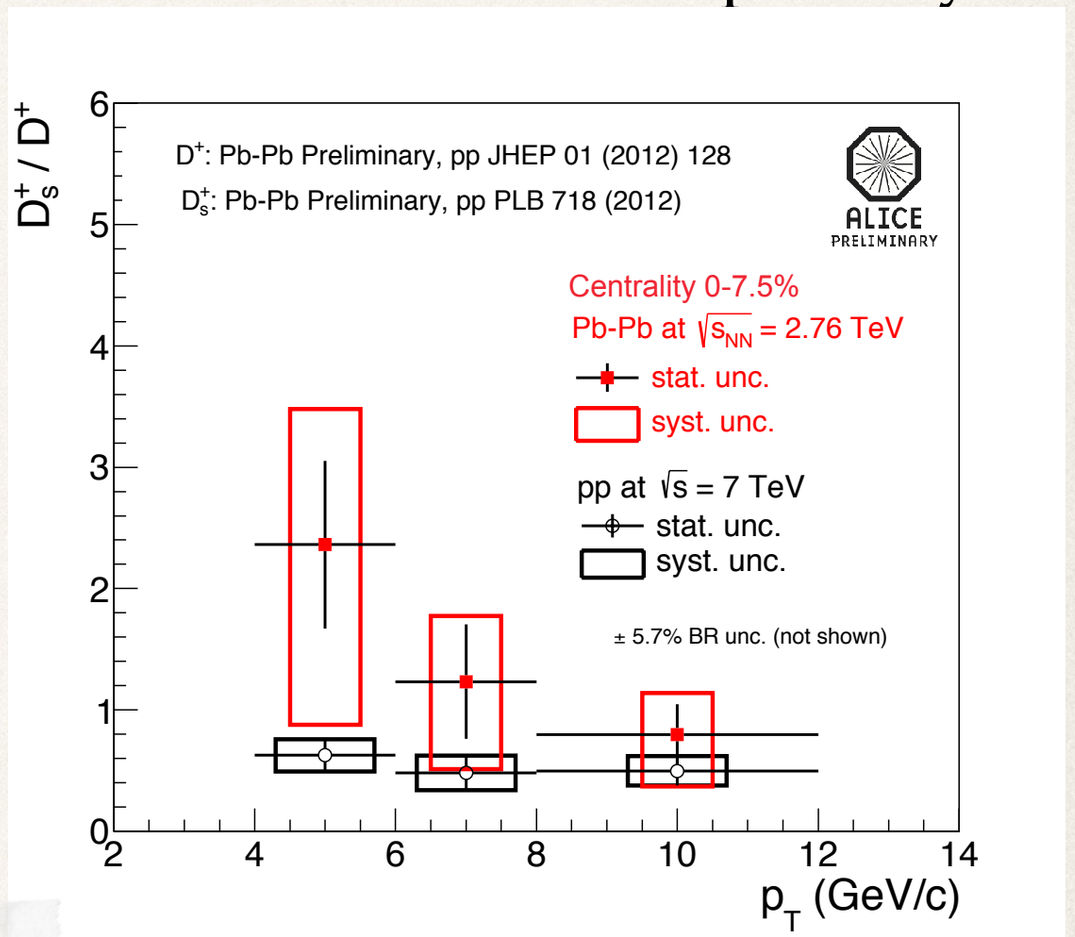
- **heavy-quark transport** in an expanding medium
- **elastic energy loss**
- interactions **via resonance** formation
- **recombination contribution** in the hadronization at low p_T

✓ Larger D_s^+ R_{AA} w.r.t. non-strange D meson R_{AA} predicted by TAMU at low and intermediate p_T

D_s^+/D^0 and D_s^+/D^+ ratios in pp and Pb-Pb collisions

- Correlated and uncorrelated sources of uncertainties treated separately



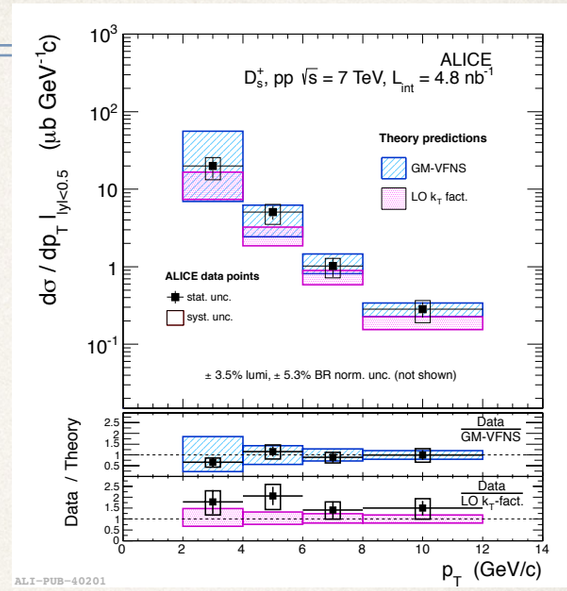


- **Central ratio values higher in Pb-Pb** than in pp collisions → as expected **if recombination contributes to charm quark hadronization**

- Need **smaller uncertainties to conclude**

Summary and conclusions

- D_s^+ mesons reconstructed in pp, p-Pb and Pb-Pb collisions
- pp measurements allow to test pQCD at LHC energies



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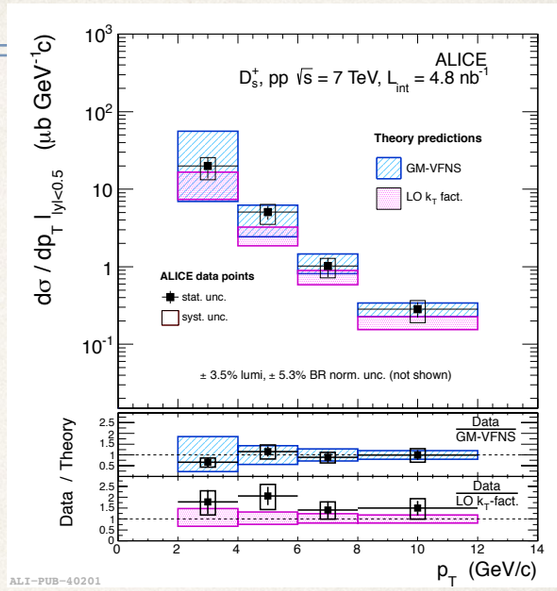

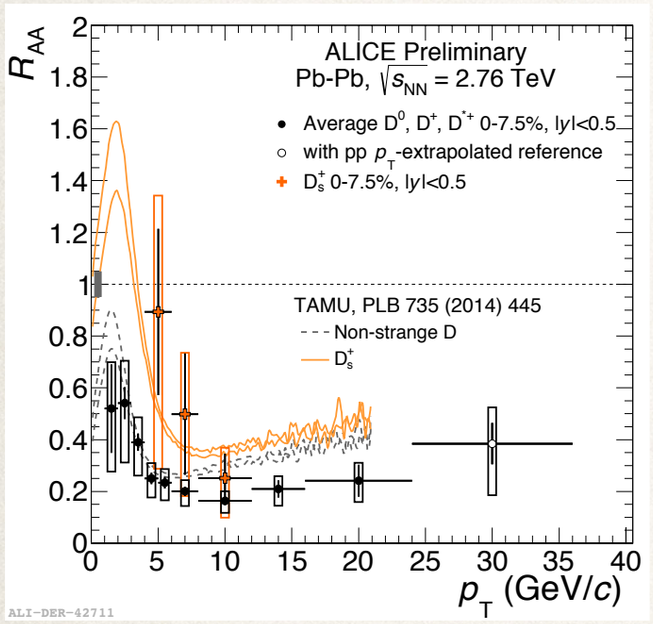

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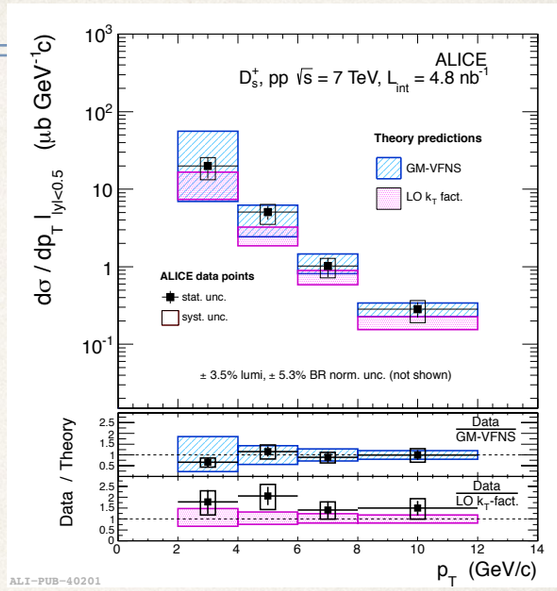

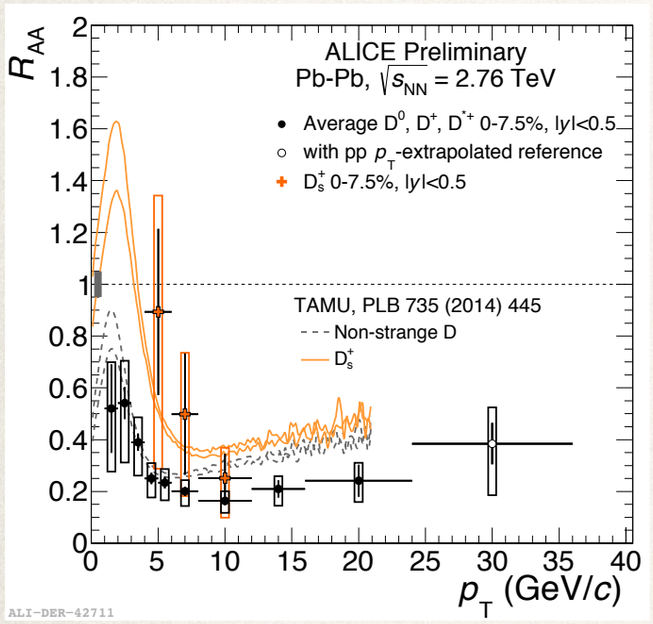

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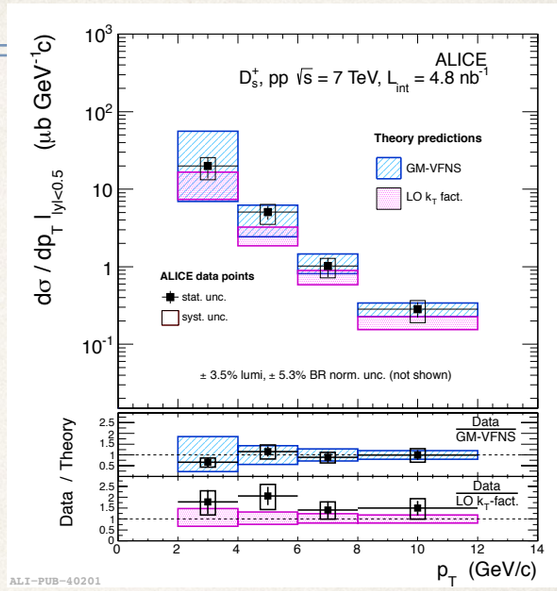

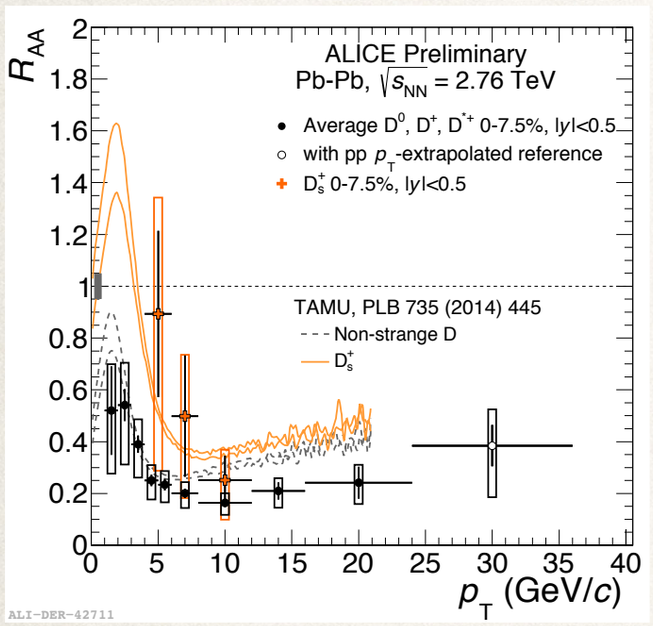

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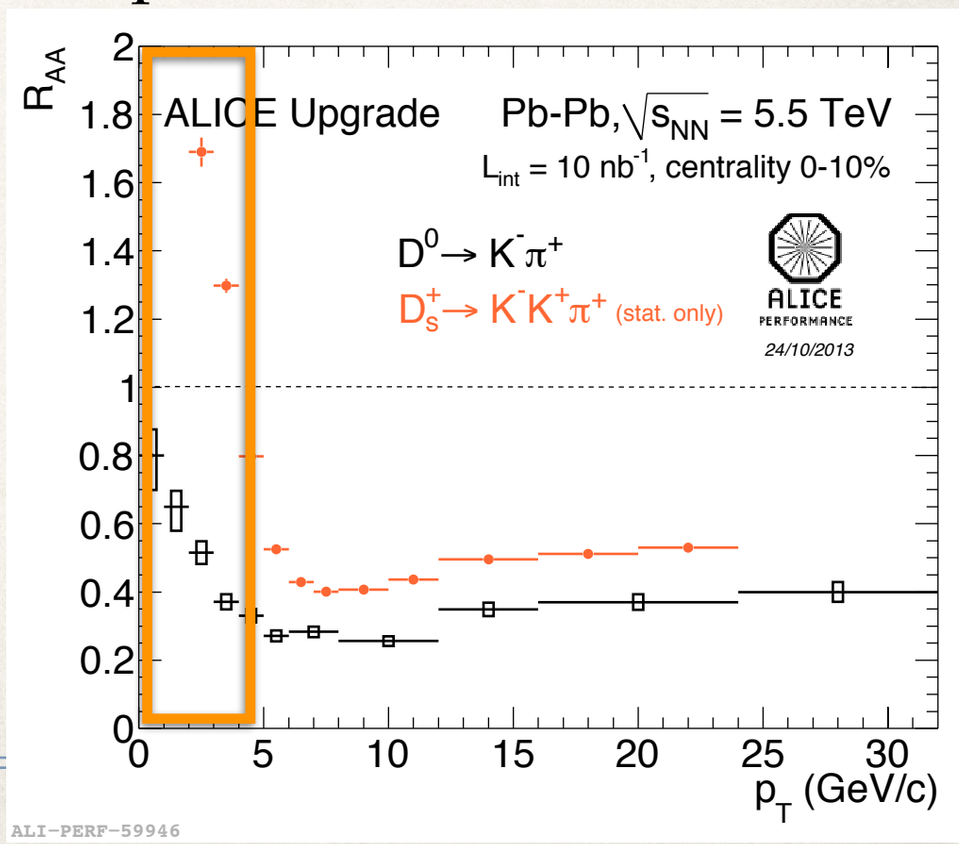
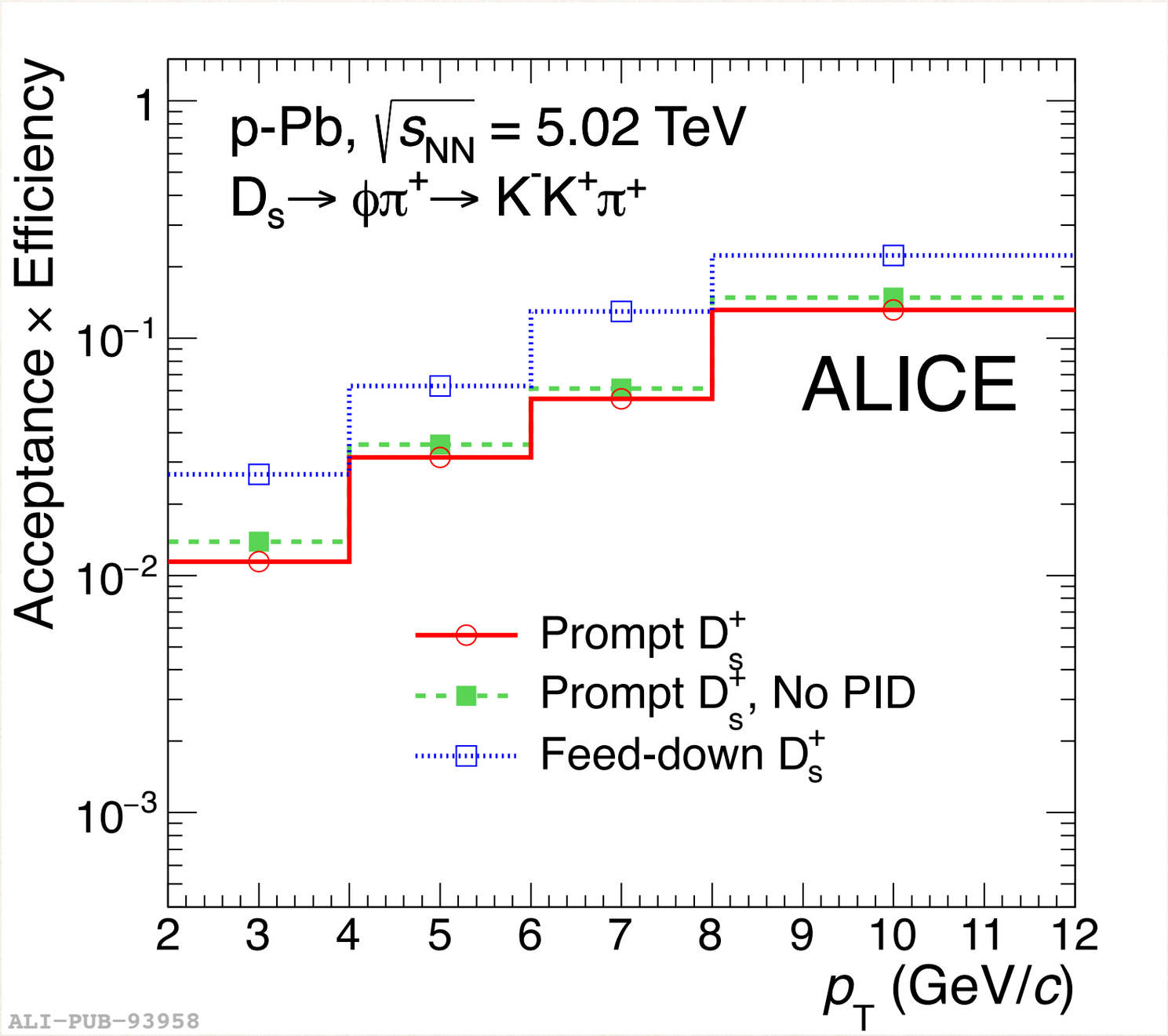
  → intriguing results to be improved!
- The larger data sample that will be collected during Run 2 will allow to substantially reduce the uncertainty
- Precision measurements with Run 3 after detector upgrade, particularly at low p_T



Backup

Corrections in p-Pb



B feed-down subtraction

To calculate prompt D_s meson fraction f_{prompt}:

beauty production from FONLL prediction

corrected using **our non-prompt efficiencies**

$$f_{\text{prompt}} = 1 - (N^{\text{D feed-down raw}}/N^{\text{D raw}}) =$$

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

rescaled with T_{AA}

Hypothesis on $R_{AA}^{\text{feed-down}}/R_{AA}^{\text{prompt}}$ assumed = 1 and varied between 1/3 and 3 for systematics

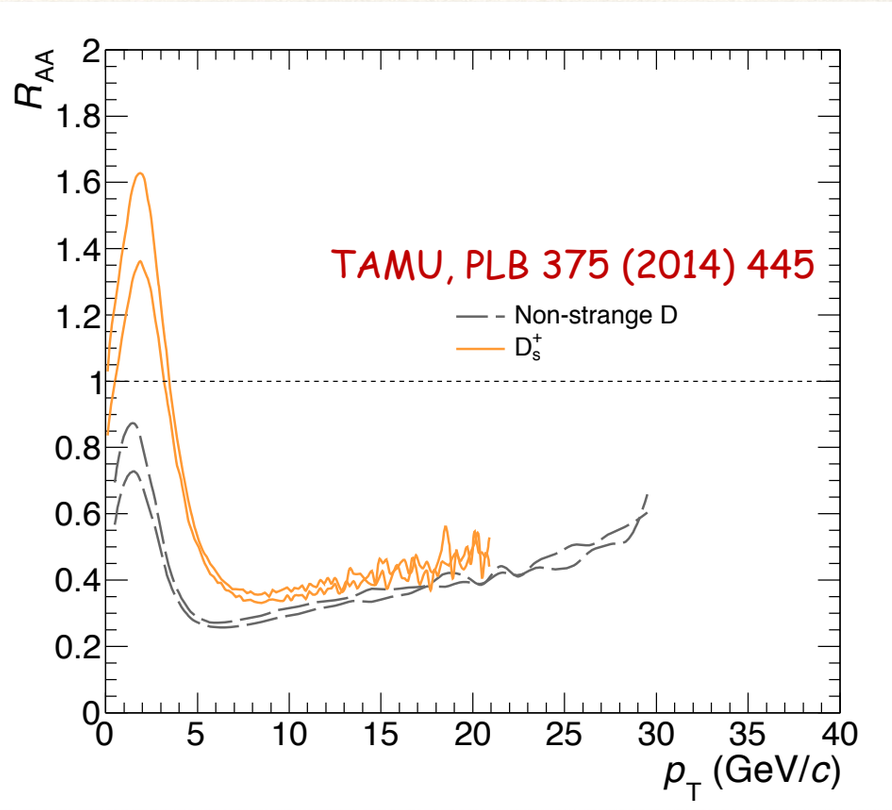
B feed-down subtraction

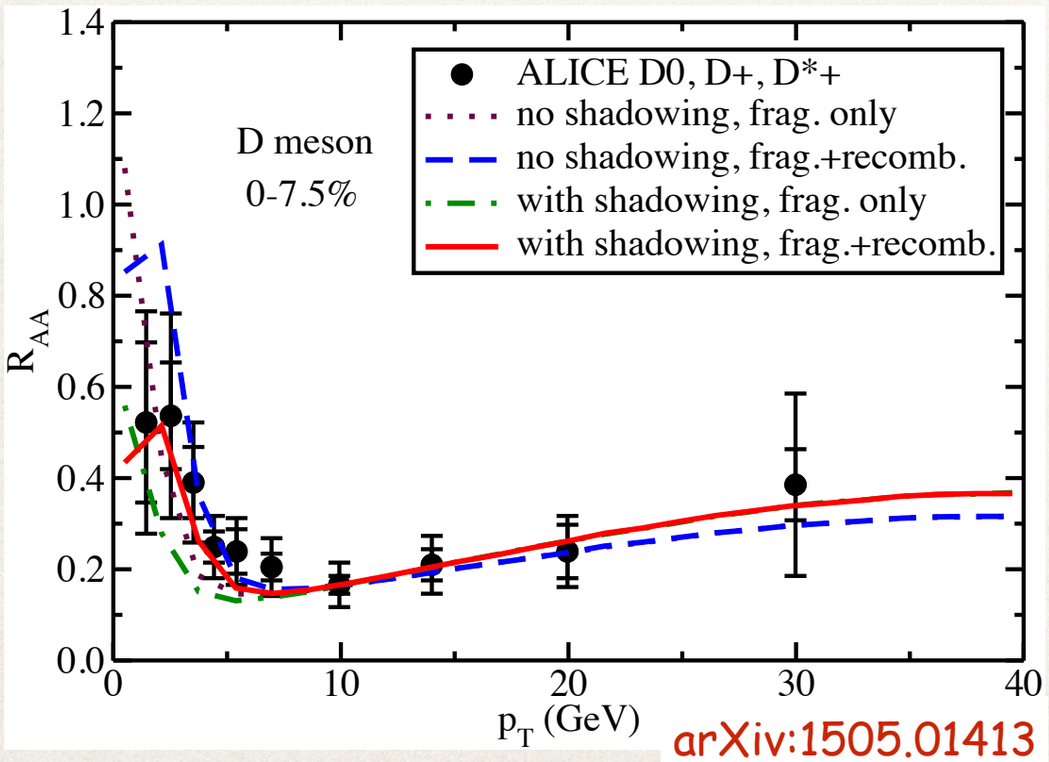
- f_{prompt} depends on hypothesis on

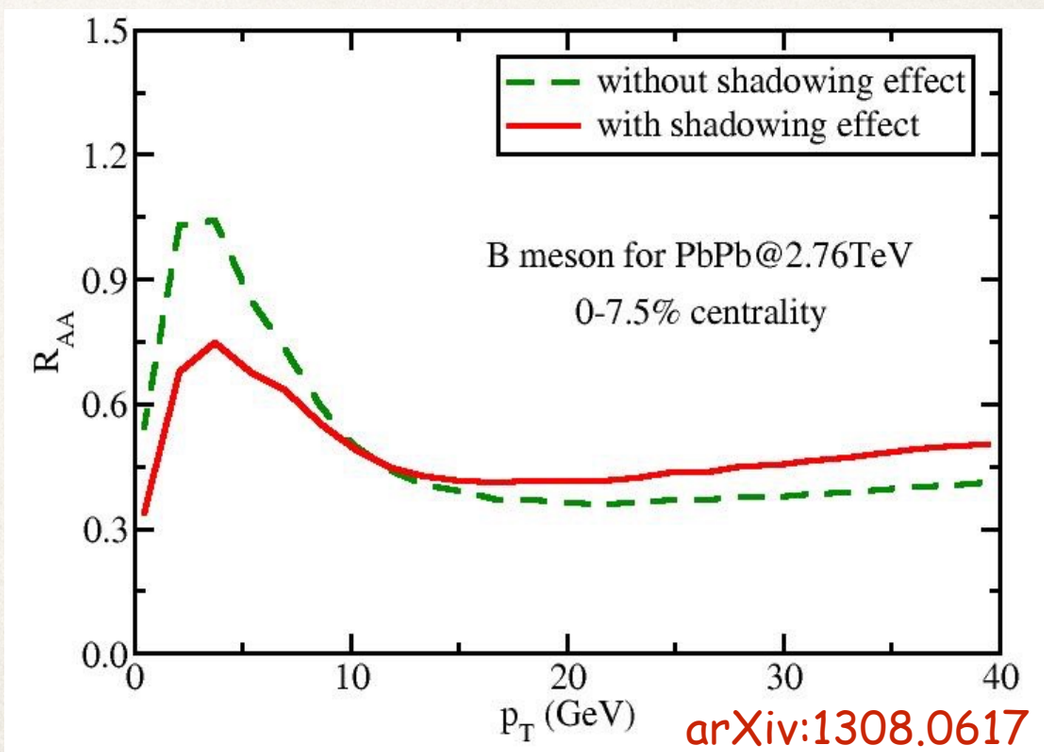
  $R^{\text{feed-down}}_{AA}/R^{\text{prompt}}_{AA}$

1. R_{AA} (B) > R_{AA} (D)
2. $R_{AA}(D^+_s) > R_{AA}(D)$ at intermediate-low p_t
3. $R_{AA}(B^0_s) > R_{AA}(B)$ if b recombines

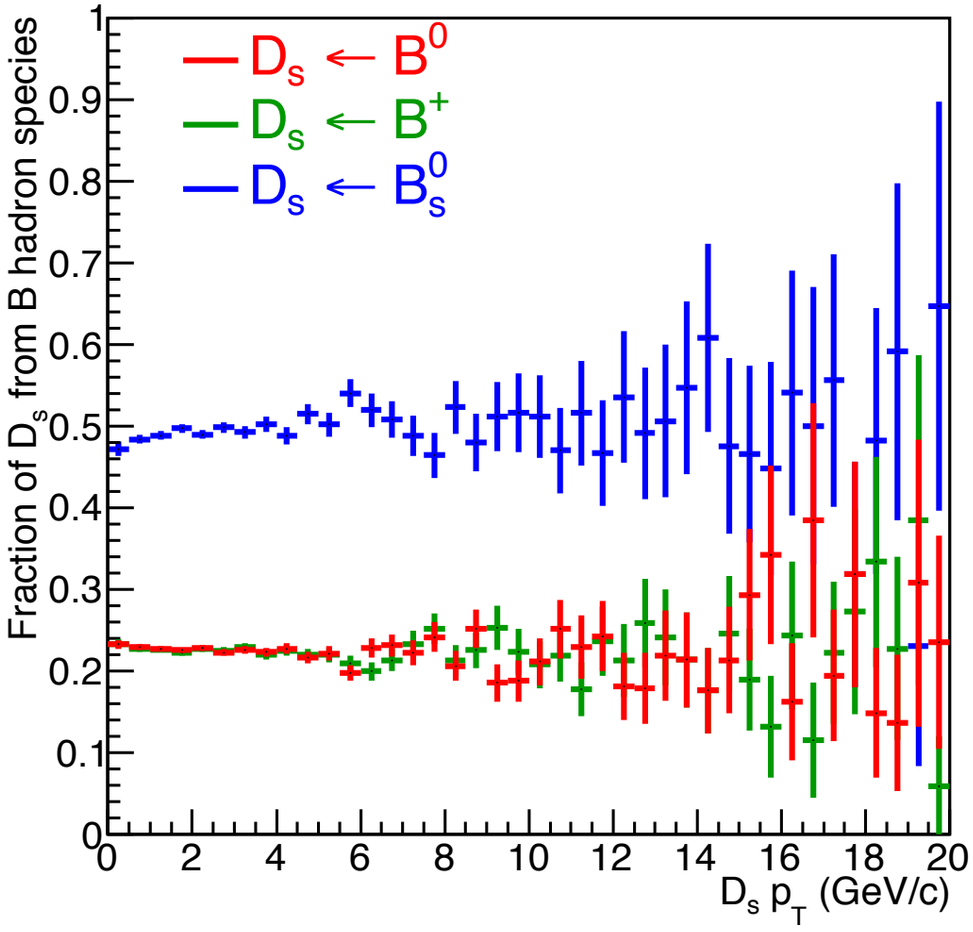
   -> $R_{AA}(B^0_s) > R_{AA}(D^+_s)$?







Energy-loss hypothesis



50% of feed-down D_s from B_s

50% from non-strange B

$$1/3 < R_{AA}^{\text{feed-down}} / R_{AA}^{\text{prompt}} < 3$$

S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, Nucl. Phys. A783 (2007) 493.
N. Armesto, A. Dainese, C. A. Salgado and U. A. Wiedemann, Phys. Rev. D71 (2005) 054027.