EuNPC Groningen /// 2015

Open heavy-flavour production as a function of multiplicity in pp and p-Pb collisions

Riccardo Russo for the ALICE Collaboration

Heavy-flavour measurements…

In pp collisions:

- provide a test for pQCD models based on different theoretical frameworks
  - ✦Fixed Order Next-to-Leading Log resummation (**FONLL**) *Phys. Rev. Lett. 95, 122001, 2005*
  - ✦General-Mass Variable-Flavour-Number Scheme (**GM-VFNS**) *Phys. Rev. Lett. 96, 012001, 2006*
  - ✦Non collinearly-factorized frameworks: k_{T} factorization *Journal of Physics: Conference Series 509, 012007, 2014*
- provide a reference for heavy-ion studies

In p-Pb collisions:

- sensitive to Cold Nuclear Matter (CNM) effects
  - ✦nuclear modification of the PDFs *Phys.Rev. C76 (2007) 065207*
  - ✦k_{T} broadening and Cronin enhancement *Phys.Rev. D11 (1975) 3105*
  - ✦energy loss in cold nuclear matter *Nucl. Phys. B 484, 265-282, 1997*
  - ✦possible final-state effects
- necessary for a complete understanting of results from Pb-Pb collisions (control experiment)

In Pb-Pb collisions:

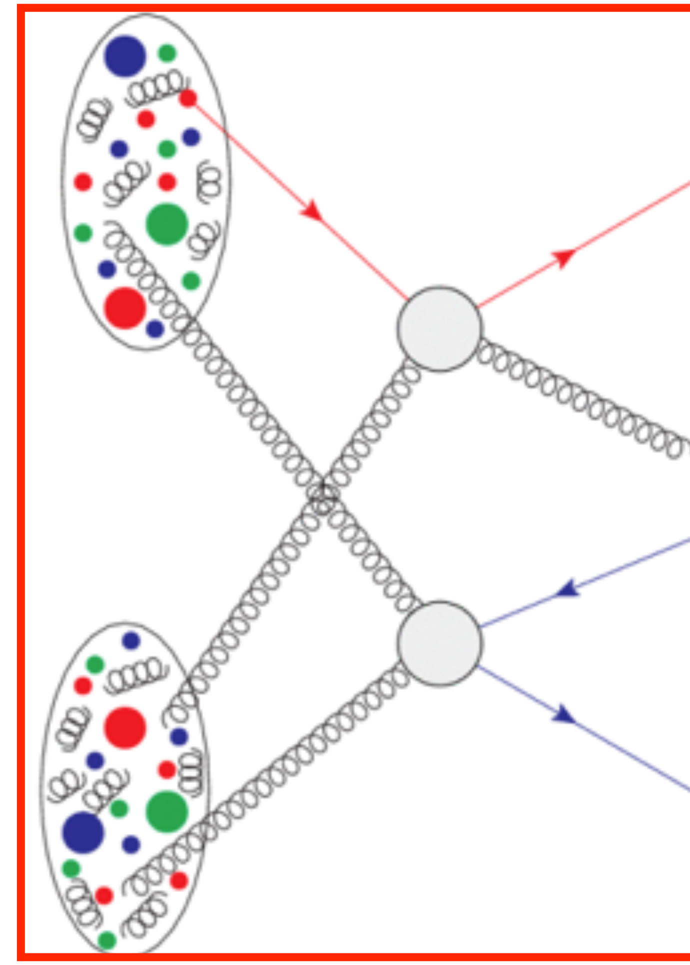
see talk of S. Altinpinar

…as a function of event multiplicity

In pp collisions:

- provide a tool to verify:
  - ✦if hard parton scatterings leading to charm-quark production are associated to a larger QCD radiation
  - ✦the possible presence of Multi-Parton Interactions (MPI), i.e. **several hard partonic scatterings occurring in a single pp interaction**

Double hard partonic scattering



- main experimental observations so far
  - ✦NA27 (pp collisions at $\sqrt{s}$ = 28 GeV): events with charm have larger charged-particle multiplicity **NA27 Coll. Z.Phys.C41:191**
  - ✦CMS: studies on jet and underlying event → better agreement with models including MPIs **Eur. Phys. J. C 73 (2013) 2674**
  - ✦LHCb: double charm production agrees better with models including double hard partonic scatterings **J. High Energy Phys., 06 (2012) 141**

In p-Pb collisions

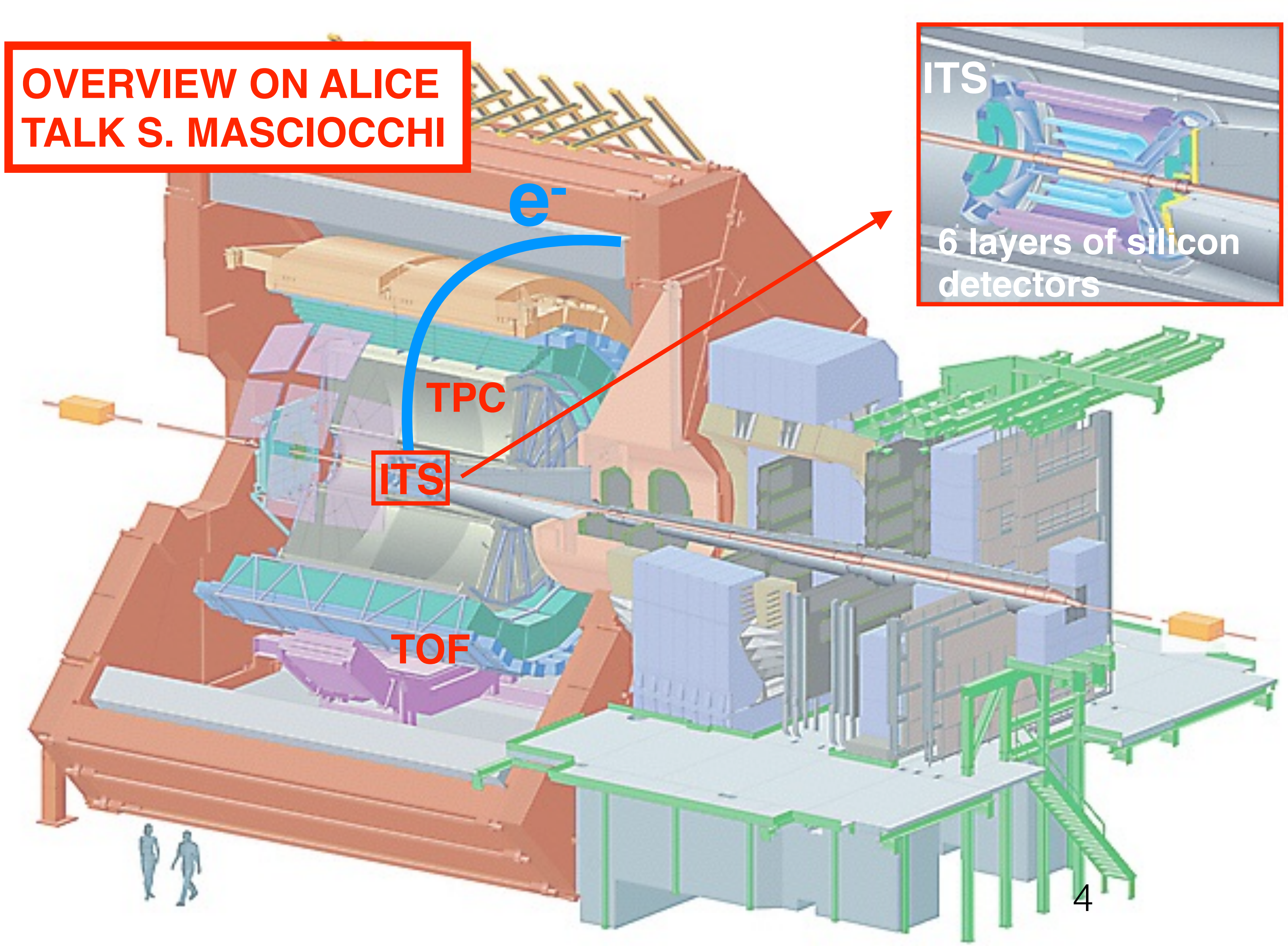
- ✦in principle the rate of multi-parton interactions depends on the **initial-state partonic multiplicities** in the colliding system and on the **density of partons** in the transverse space, both higher in nuclei
- ✦investigate the possible presence of final-state effects such as hydrodynamic expansion and jet quenching in events with higher final-state charged-particle multiplicities

HF-decay electrons

- **From semileptonic decays of heavy-flavoured hadrons:**
  - ✦ **B mesons → e + X**, branching ratio 11%
  - ✦ **D mesons → e + X**, branching ratio 10%

- **Electron reconstruction and identification with ALICE**
  - ✦ track reconstructed using Inner Tracking System (ITS) and Time Projection Chamber (TPC) in $|\eta|<0.8$
  - ✦ electron identification (**eID**) via ionization energy loss (dE/dx) in the TPC and time of flight in the TOF
  - ✦ background electrons from Dalitz decays and γ conversions
  - ✦ separation of electrons from beauty and from charm quark done via different impact parameter (**d_0**) distributions

OVERVIEW ON ALICE
TALK S. MASCIOCCHI



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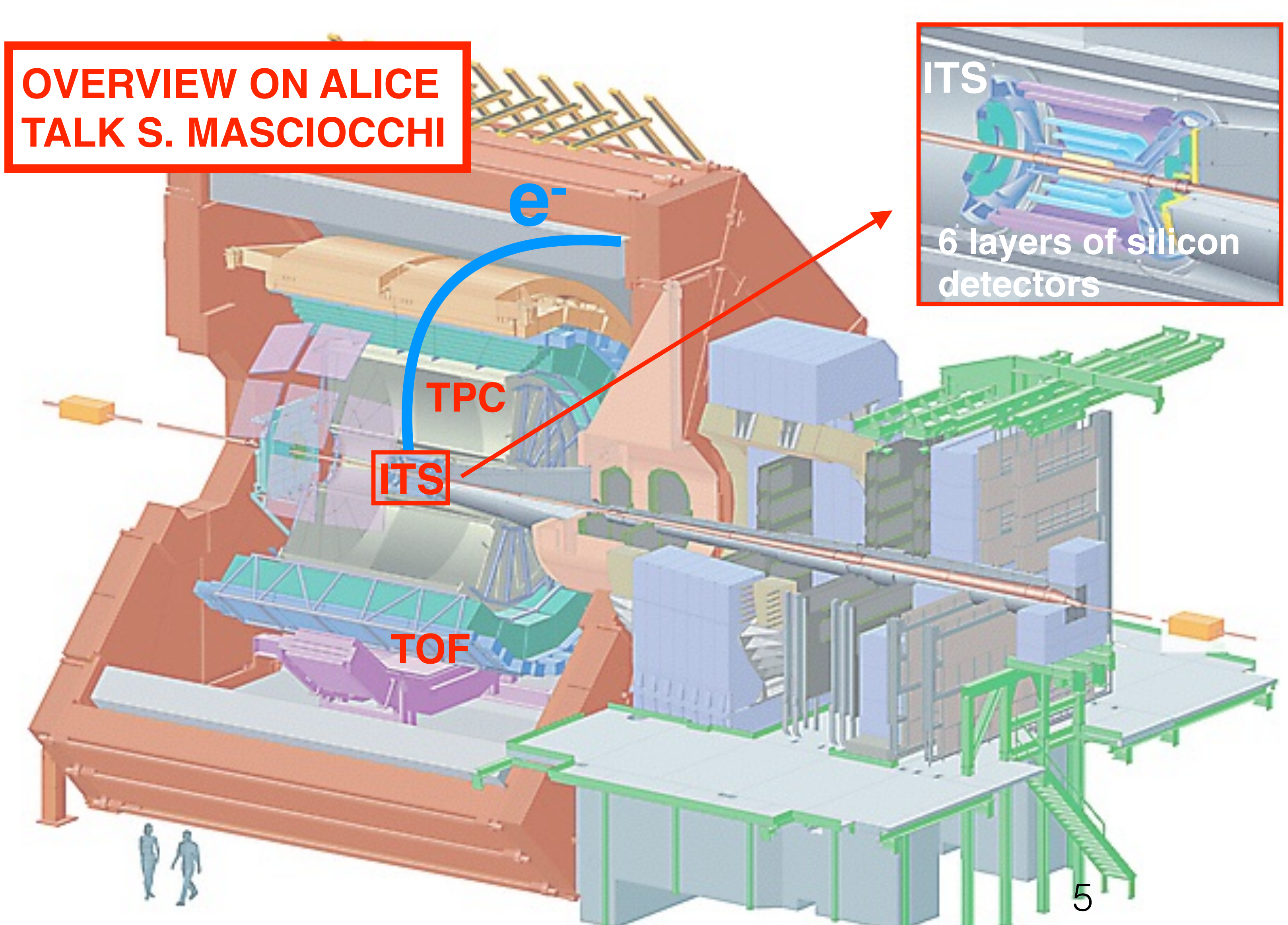
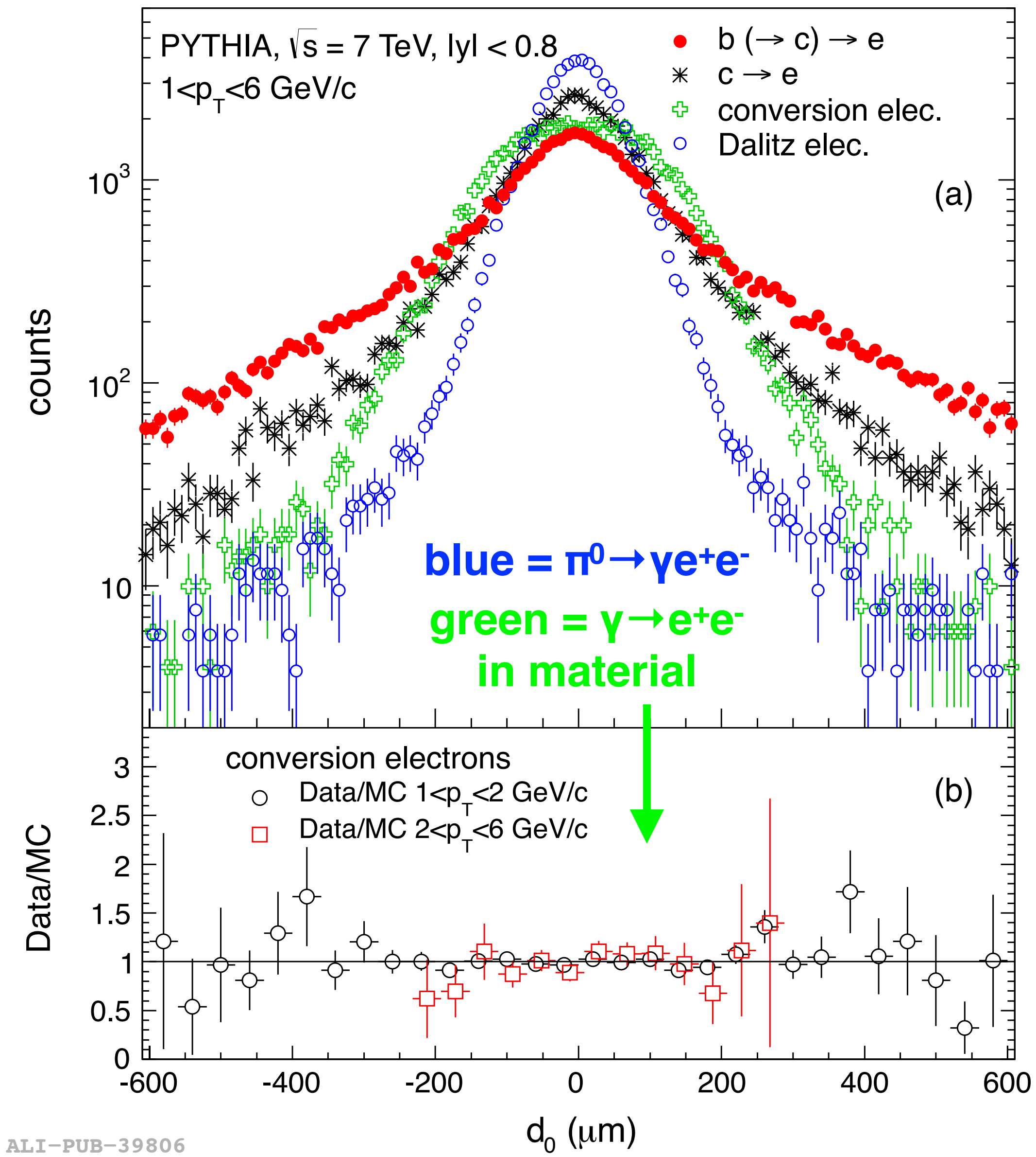
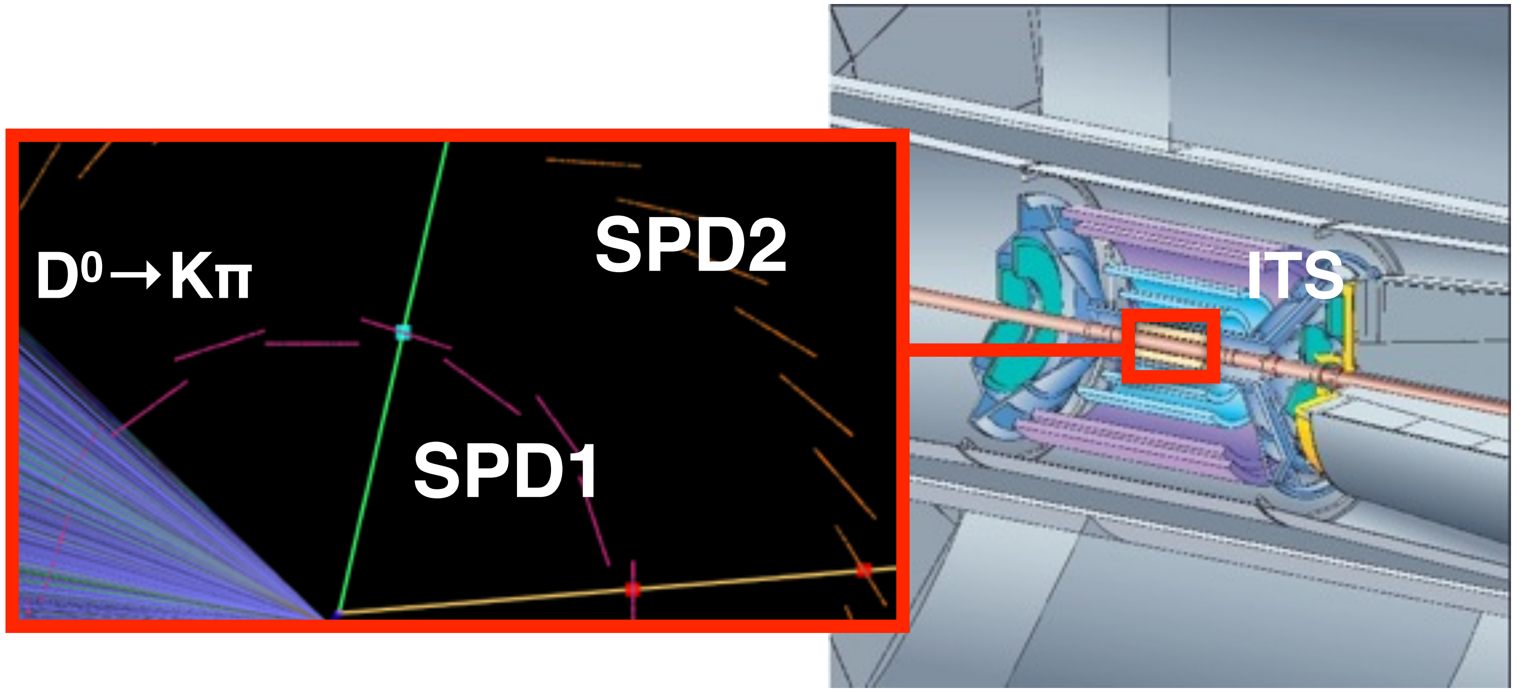




D-meson reconstruction

- ✦ D mesons are fully reconstructed in the following hadronic decay modes
  - ➢ **$D^0 \rightarrow K^- \pi^+$ (BR 3.88%, cτ 123 μm)**
  - ➢ **$D^+ \rightarrow K^- \pi^+ \pi^+$ (BR 9.13%, cτ 312 μm)**
  - ➢ **$D^{*+} \rightarrow D^0 \pi^+$ (BR 68%, strong decay)**
- ✦ they decay before reaching the beam-pipe



- ✦ invariant mass analysis of **fully reconstructed decay topologies displaced from the primary vertex**

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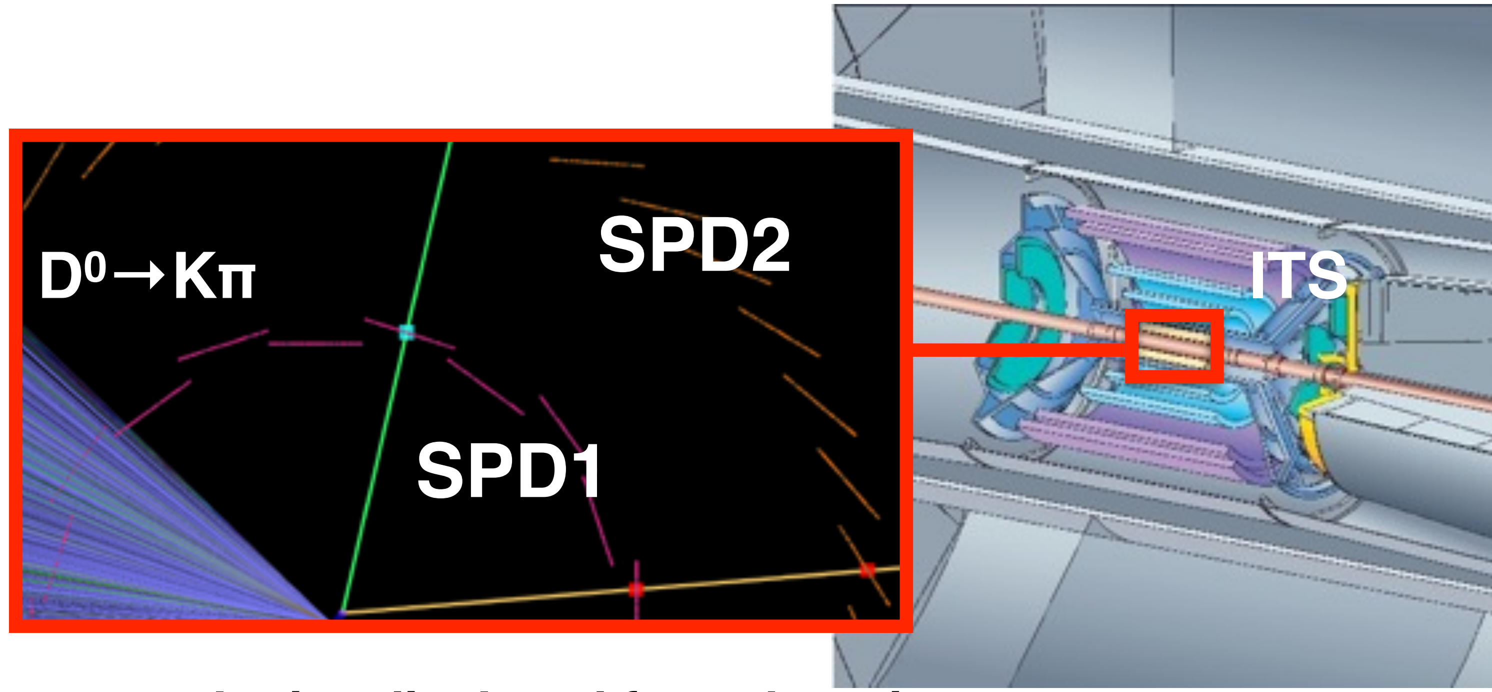
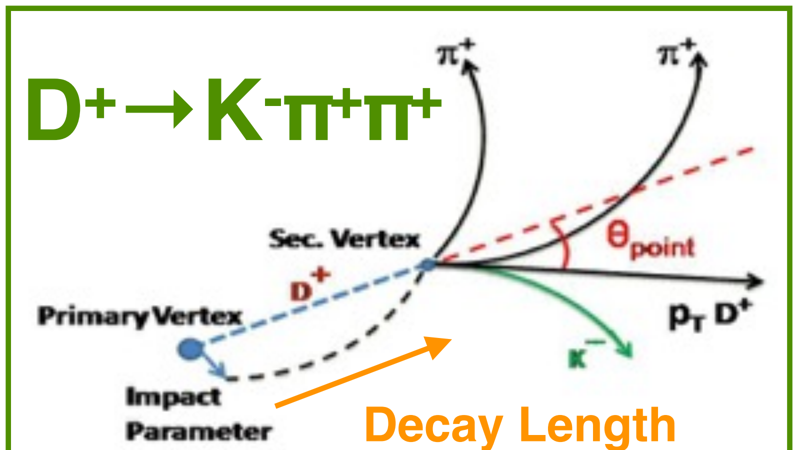
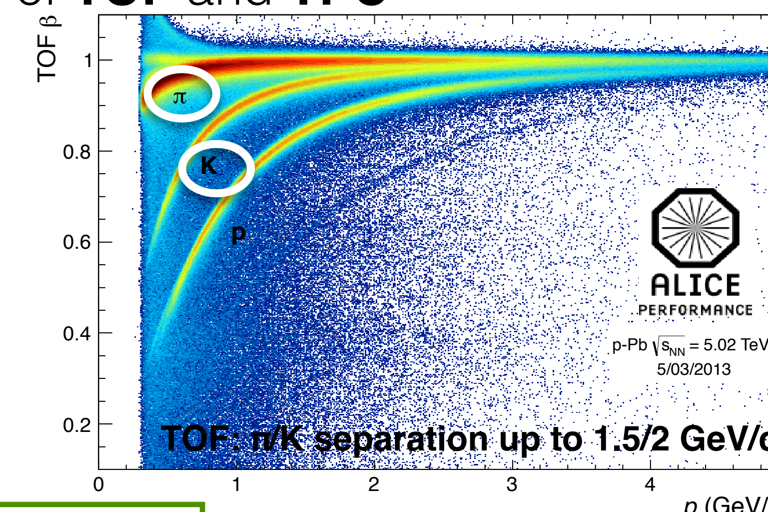
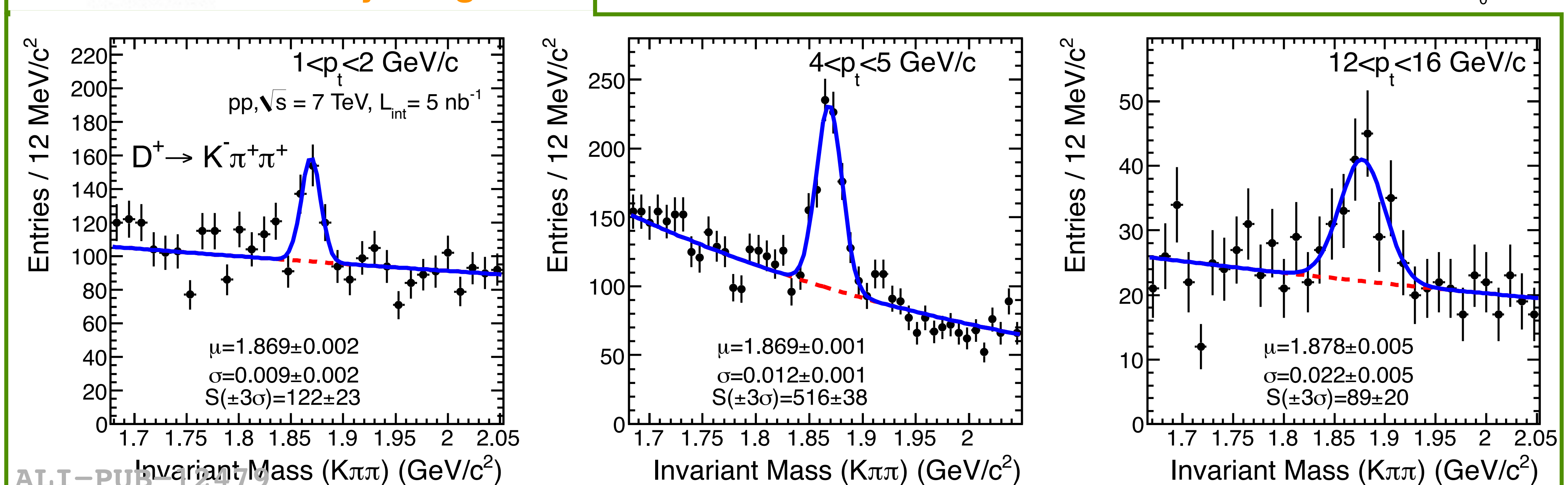


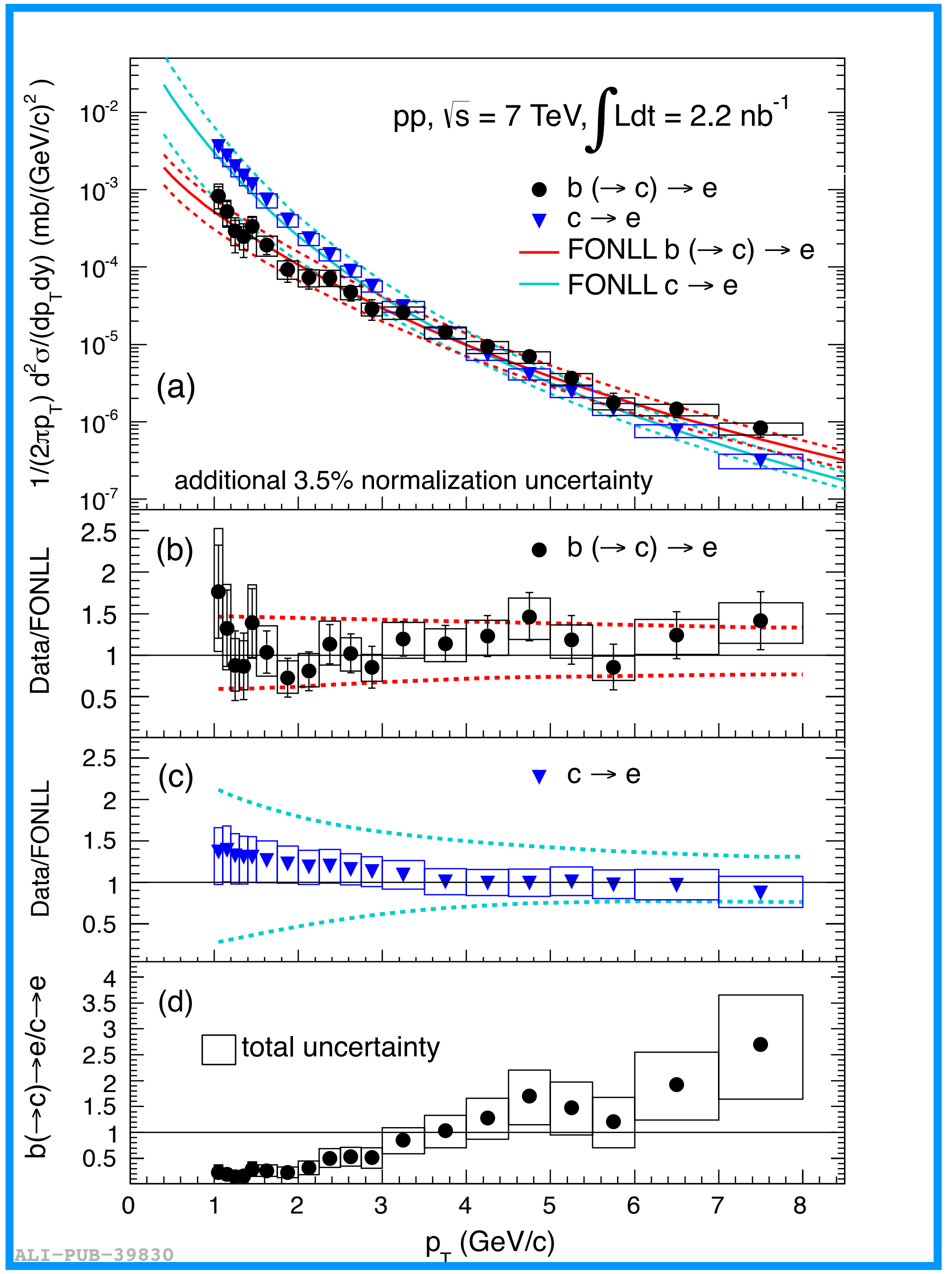
- invariant mass analysis of **fully reconstructed decay topologies displaced from the primary vertex**
- selections on reconstructed topological quantities applied to reduce combinatorial background
- further background rejection achieved exploiting the combined PID capabilities of **TOF** and **TPC**







Invariant cross sections in pp collisions at $\sqrt{s}$ = 7 TeV



Invariant cross sections of electrons from beauty and from charm

- ✦ Invariant cross section of electrons from beauty and charm compatible with predictions from FONLL
- ✦ Similar agreement observed for HF-decay muons

Physics Letters B 721 (2013) 13–23

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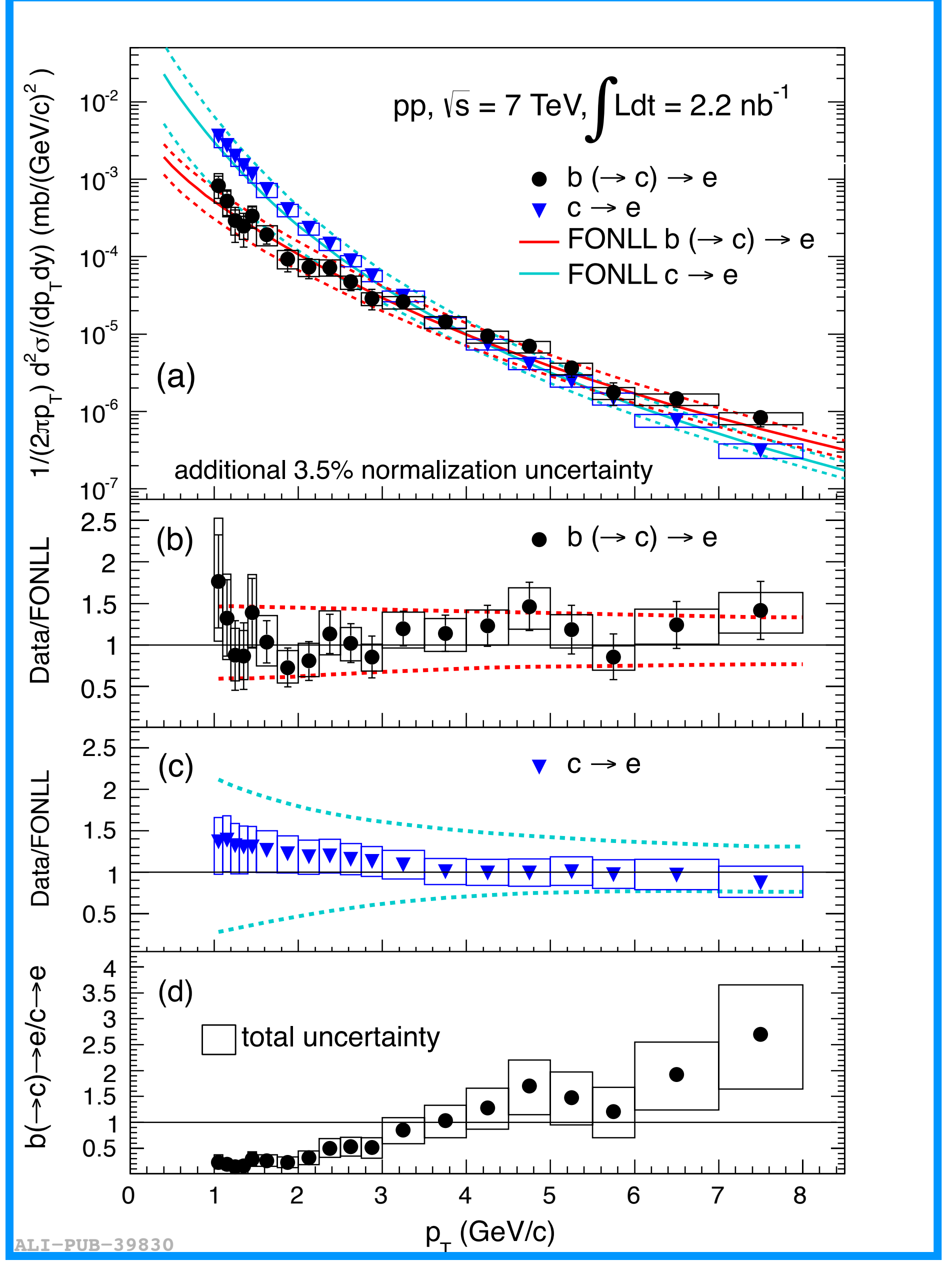

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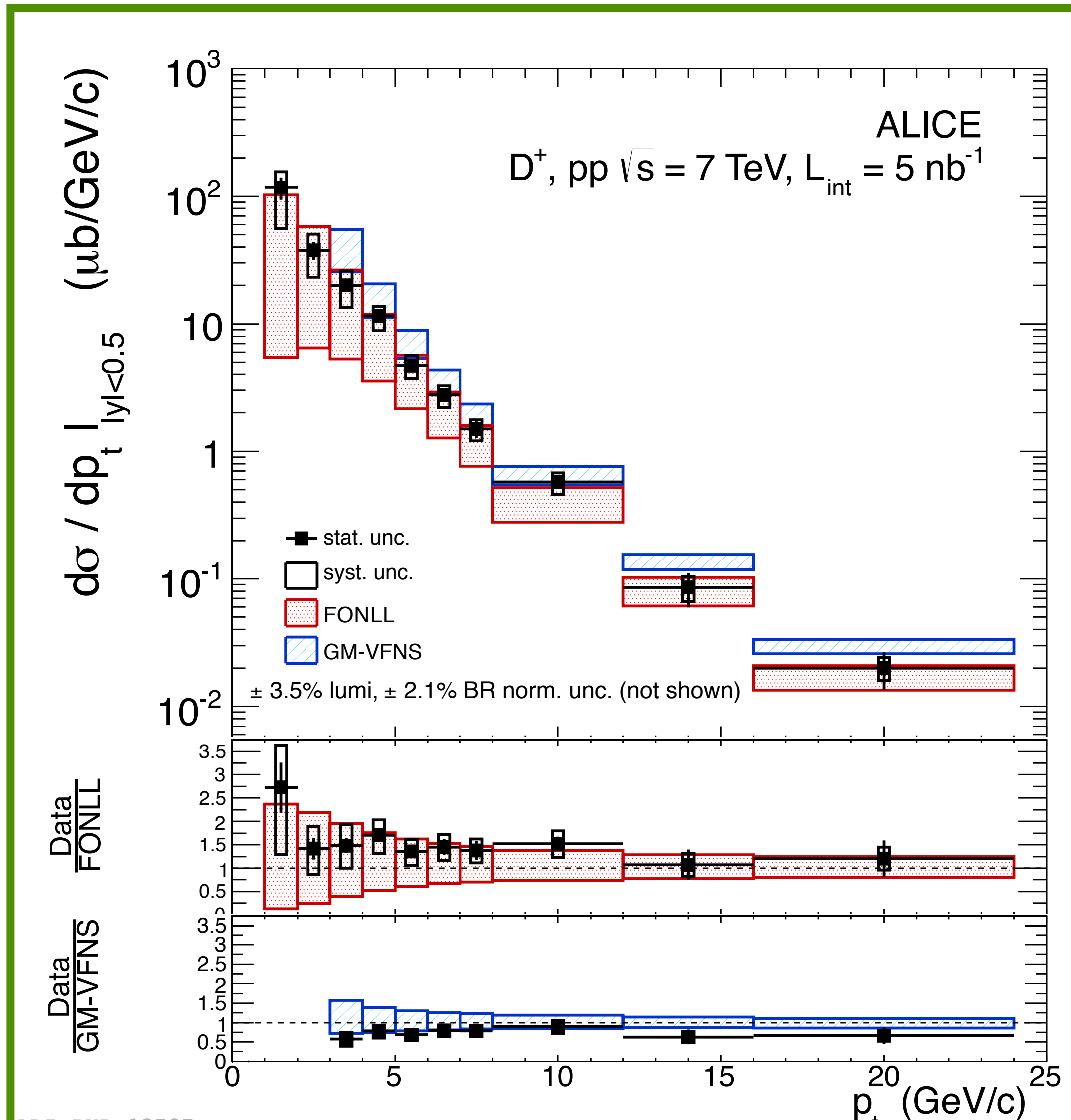
JHEP 01 (2012) 128

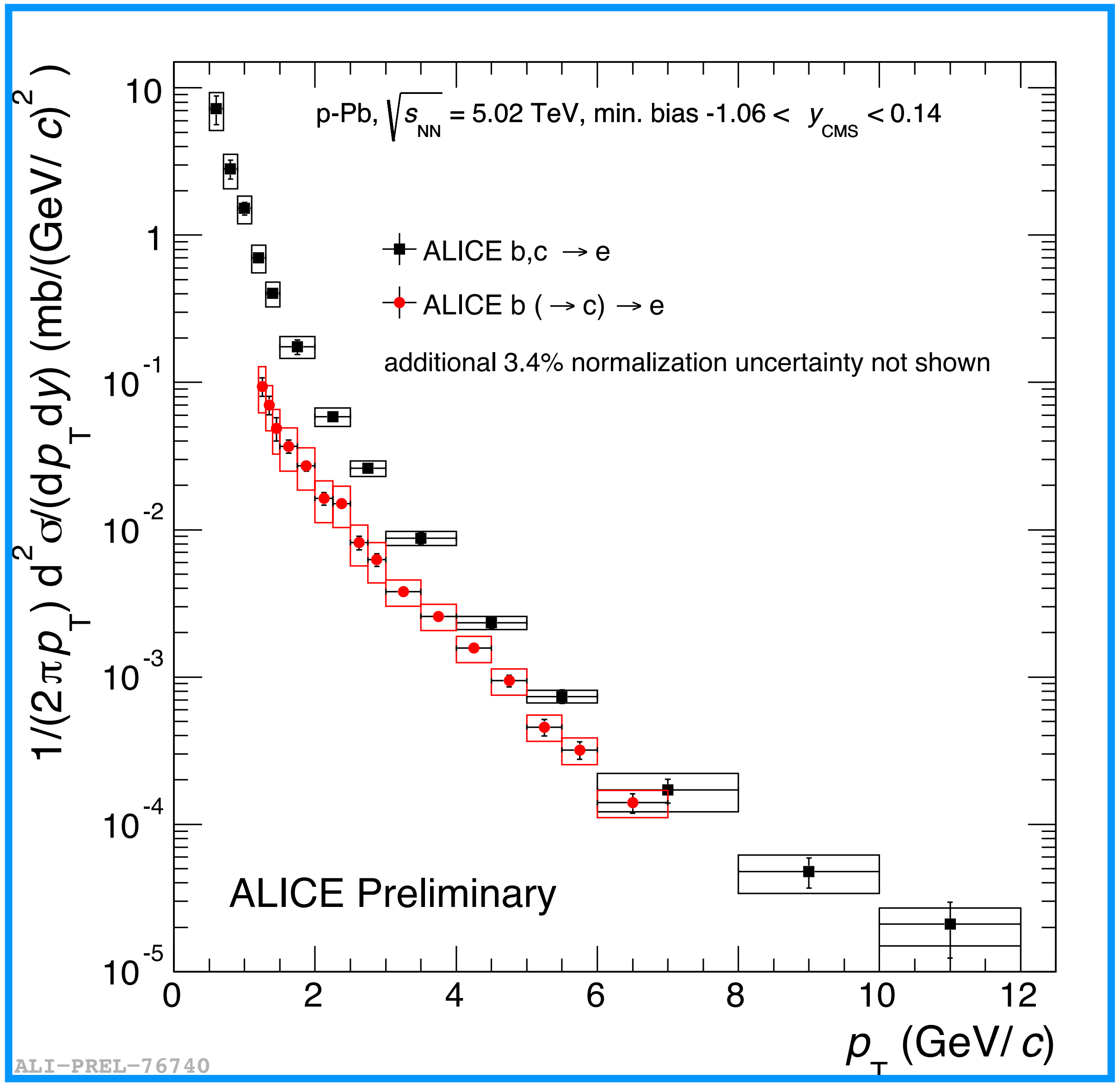
Prompt* D+ invariant cross section →

- ✦ Non-prompt (i.e.from beauty-hadron decays) D-meson yield subtracted by mean of FONLL predictions
- ✦ Invariant cross section compatible with predictions from different pQCD frameworks (FONLL, GM-VFNS)



***from c quark hadronization**

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



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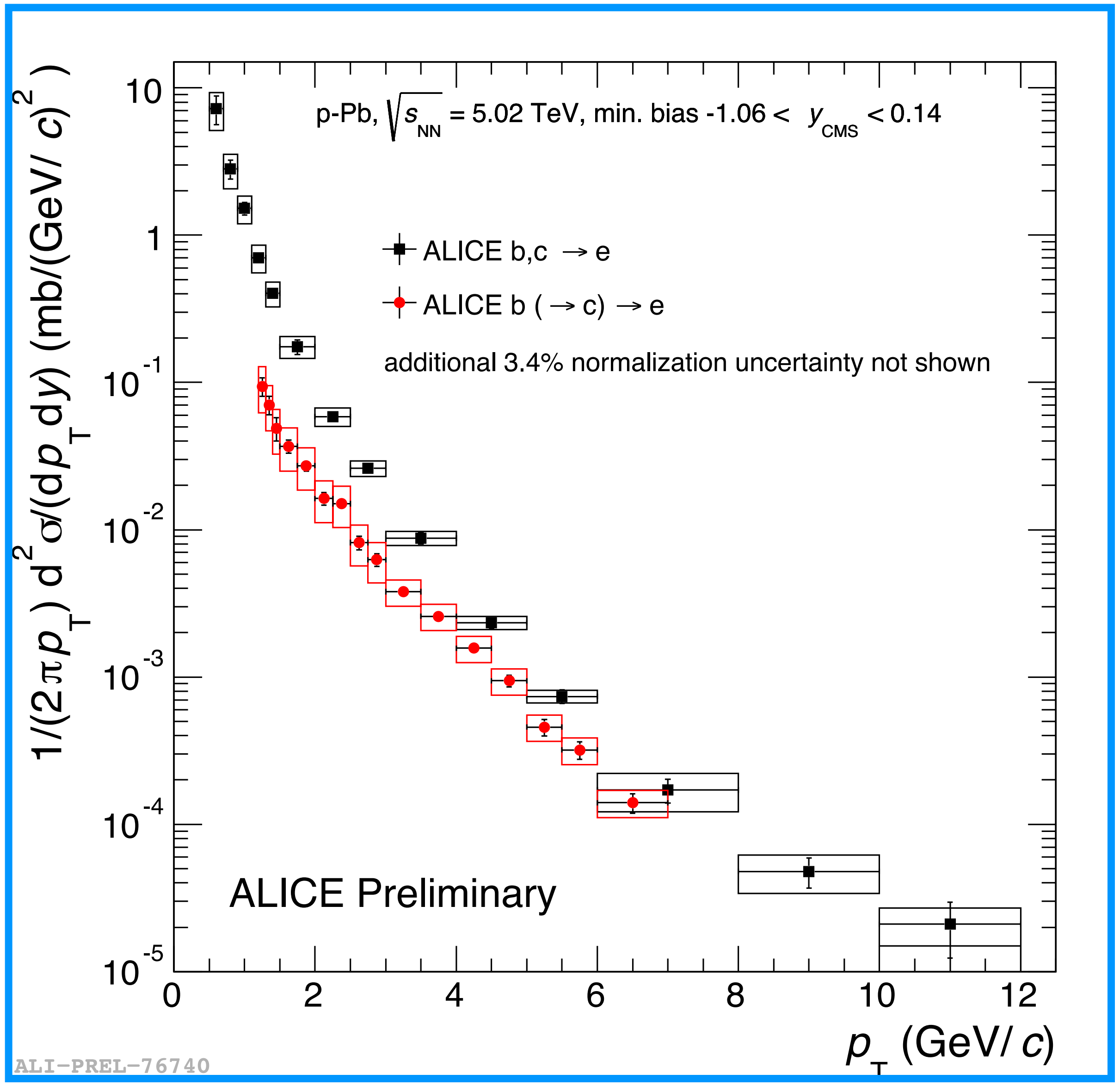

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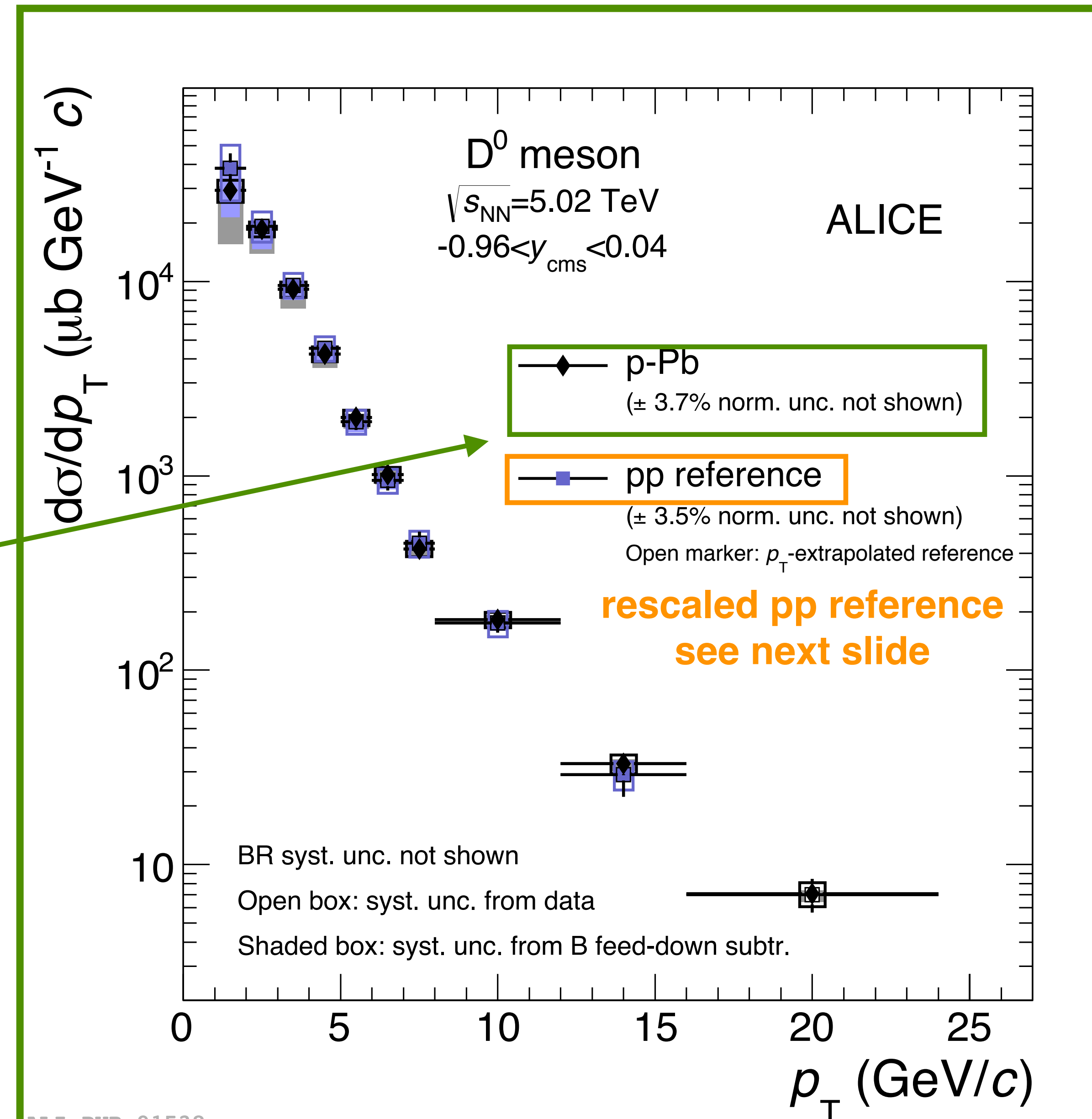

Prompt D⁰ invariant cross section

Phys. Rev. Lett. 113 (2014) 232301

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

✦ is heavy-flavour production in p-Pb collisions proportional to heavy-flavour production in pp collisions, if we scale the latter by the average number of binary collisions in minimum bias p-Pb collisions N_{coll} = 6.9 ?

$$R_{\mathrm{pA}}(p_{\mathrm{T}}) = \frac{dN^{\mathrm{pA}}/dp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle dN^{\mathrm{pp}}/dp_{\mathrm{T}}} = \frac{d\sigma^{\mathrm{pA}}/dp_{\mathrm{T}}}{\mathrm{A}\ d\sigma^{\mathrm{pp}}/dp_{\mathrm{T}}}$$

✦ $d\sigma_{pp}/dp_T$ has to be evaluated at the same centre of mass energy used for the p-Pb measurement $\sqrt{s}$ = 5.02 TeV

✦ since no pp data sample at $\sqrt{s}$ = 5.02 TeV is available, a theory-driven (FONLL) energy scaling has been applied to the pp cross section at 7 TeV *arXiv:1107.3243*

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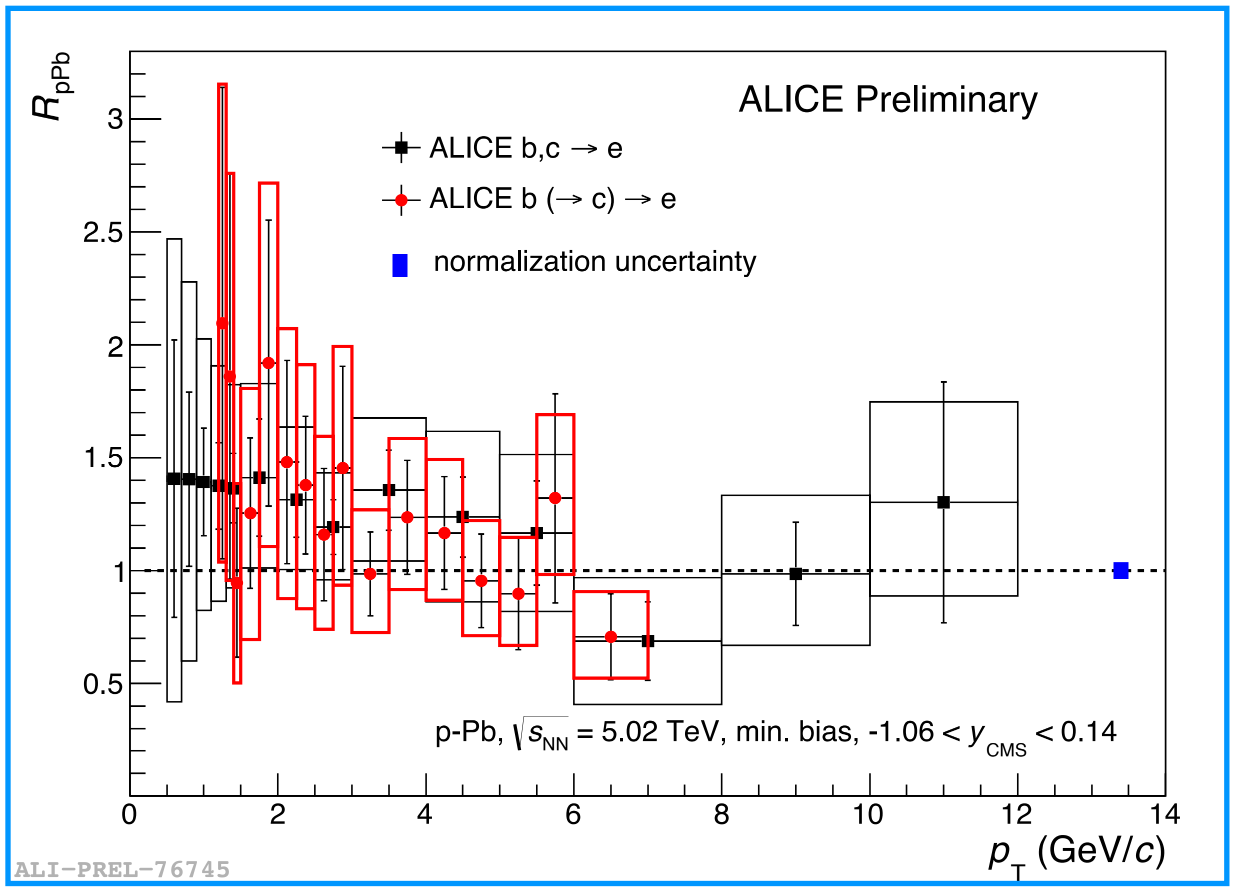
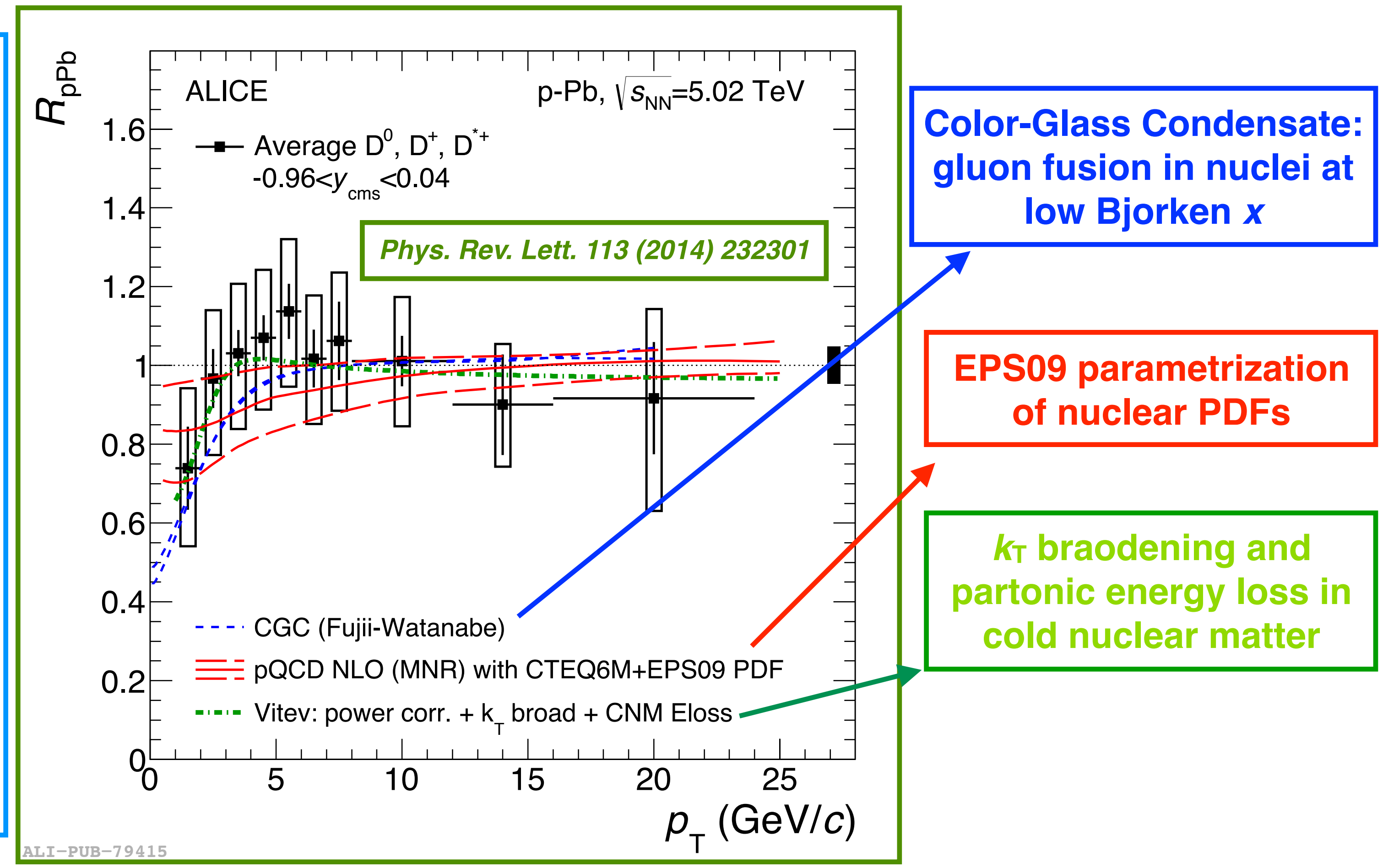
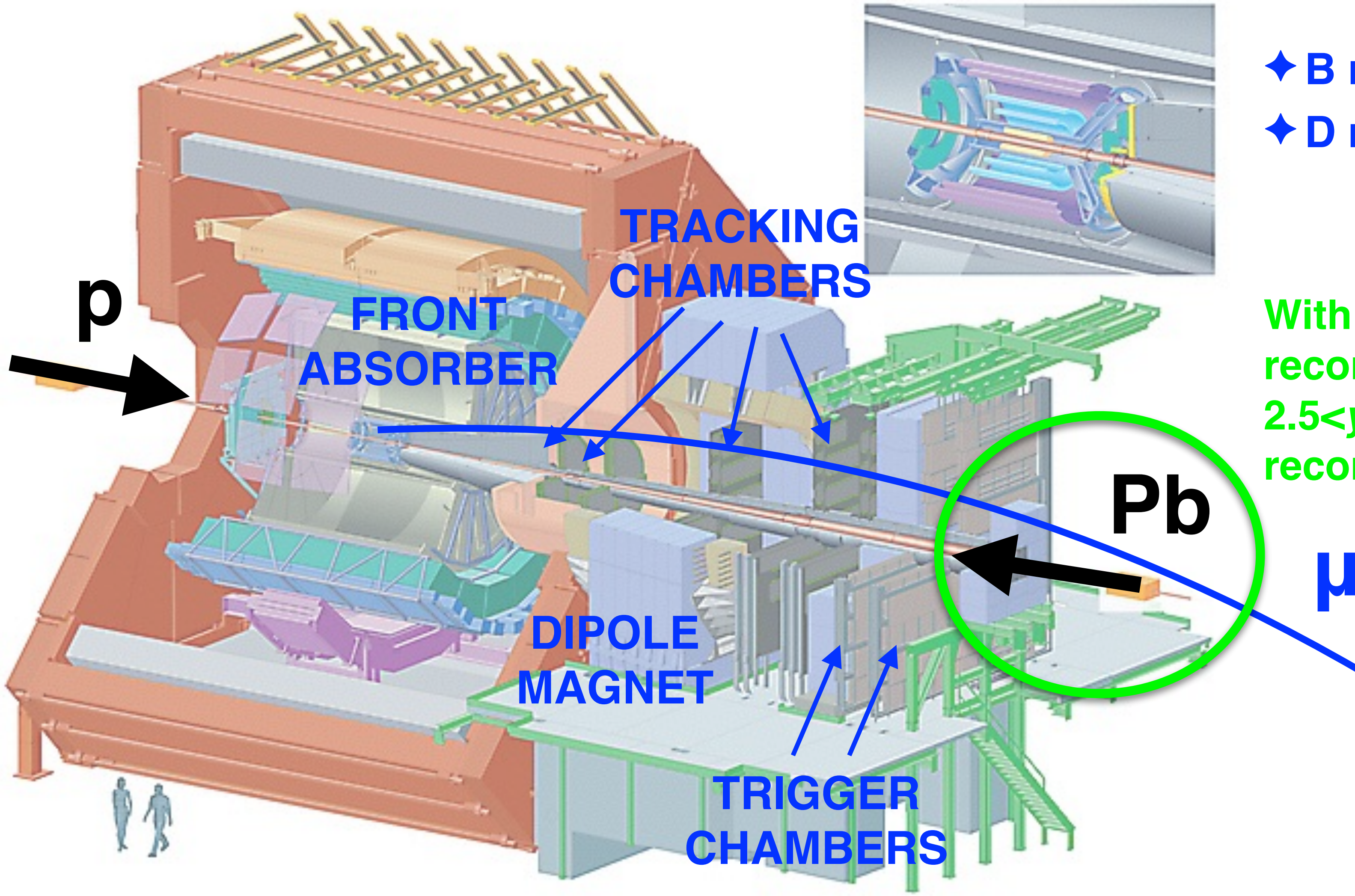




✦ R_{pPb} of both D mesons (D^0,D^+ and D^{*+} average) and heavy-flavour decay electrons (inclusive and from beauty) are compatible with unity

✦ D-meson results are compatible with models from different theoretical frameworks including initial-state effects

Nuclear modification factor of muons from HF decays



- **B mesons → μ + X**, branching ratio 11%
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With this beam configuration muons are reconstructed in the centre-of-mass rapidity range $2.5 < y_{cms} < 3.54$. Inverting the beams muons are reconstructed in $-4 < y_{cms} < -2.96$

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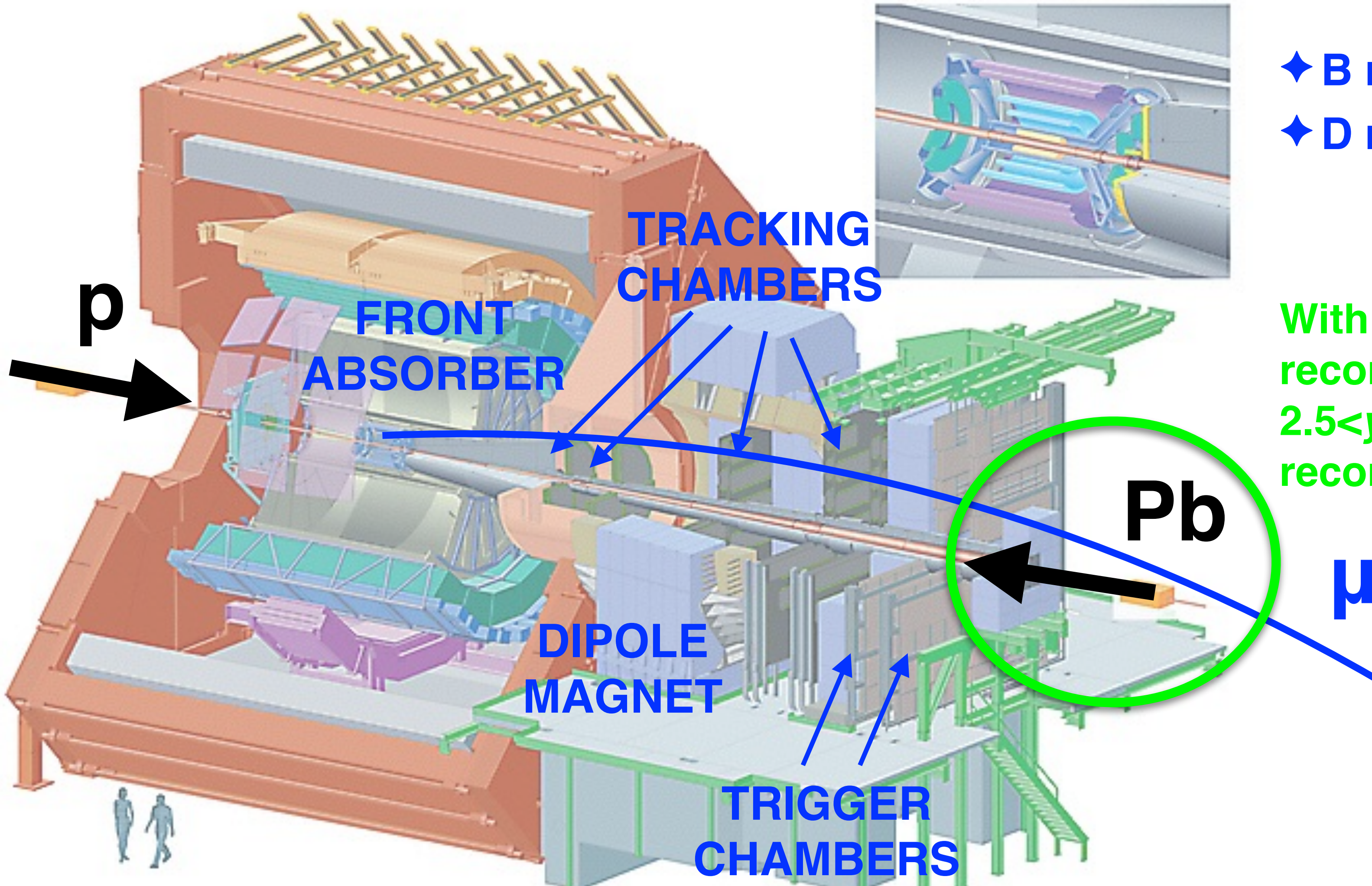

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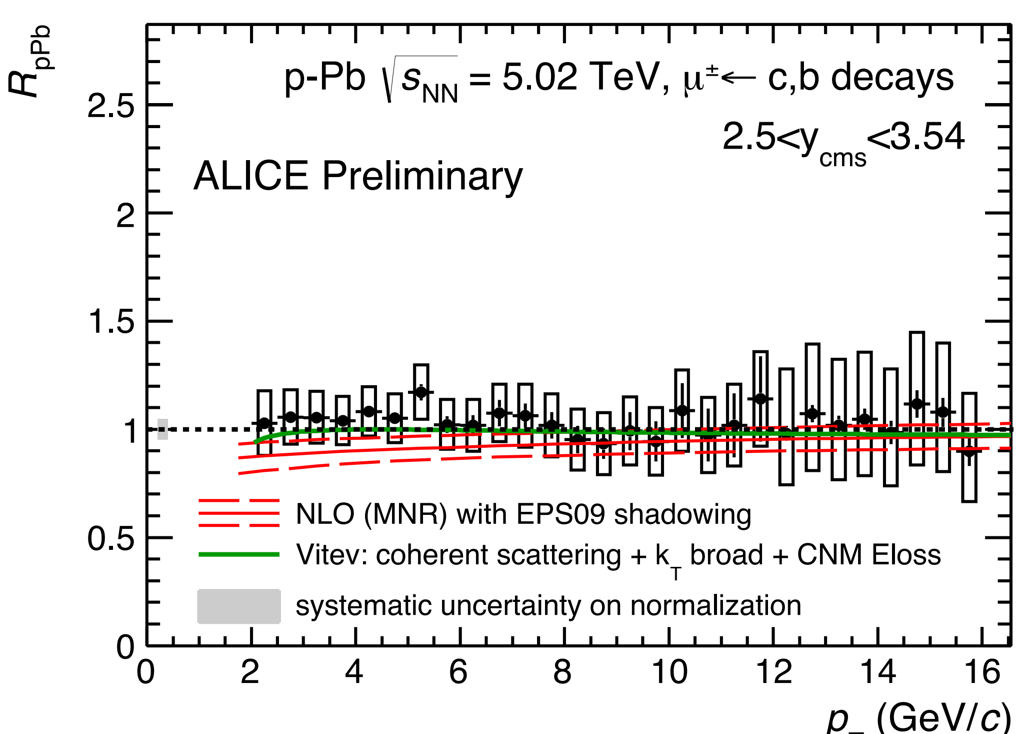
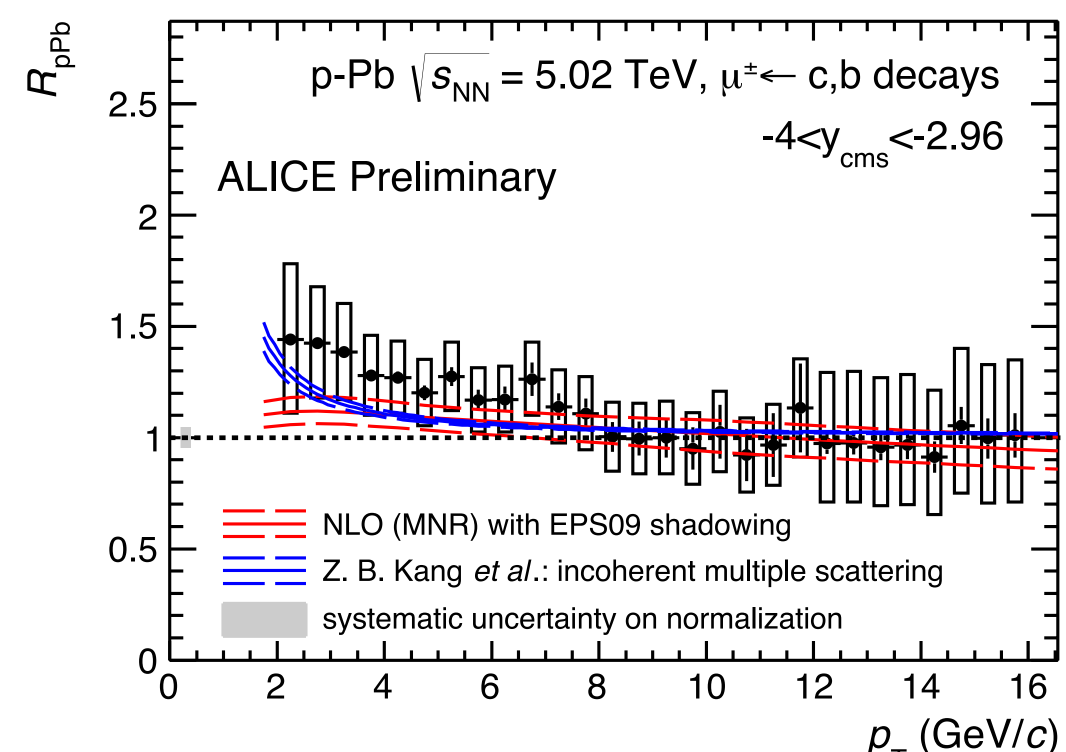
- R_{pPb} is consistent with unity in $2.5<y_{cms}<3.54$, slightly larger than unity in $-4<y_{cms}<-2.96$ for $2<p_T<4$ GeV/c
- data can be described by perturbative QCD calculations including cold nuclear matter effects



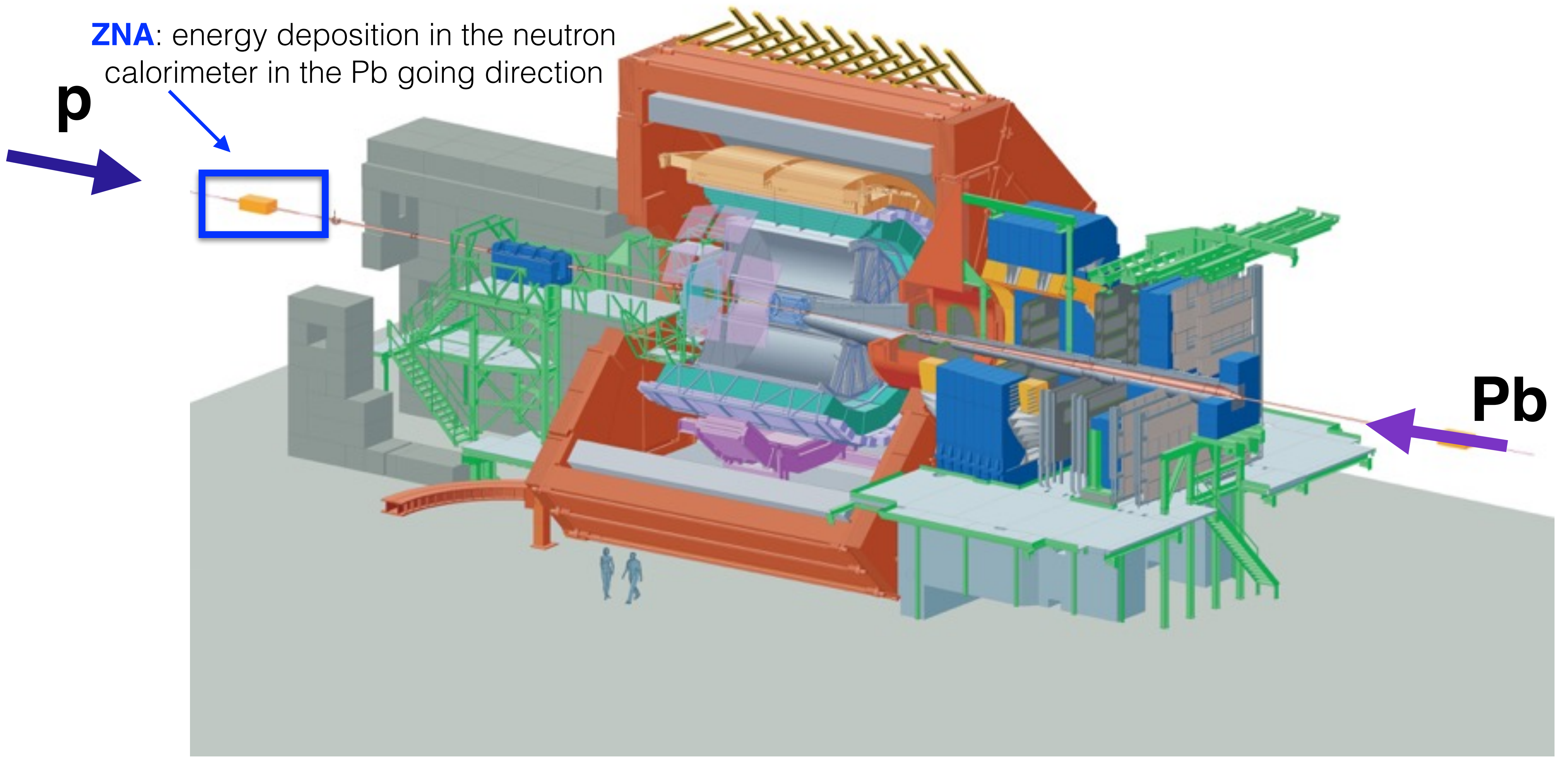
ALI-PREL-90686



ALI-PREL-90691

Q_{pPb}^{mult} - Event activity estimator

- it is also interesting to calculate the nuclear modification factor in different event activity classes (Q_{pPb}), to see if collective phenomena (flow, jet quenching) develop in p-Pb events with high event activity (~ centrality)
- event activity is evaluated according to the energy deposition in the ALICE Zero-Degree Neutron Calorimeter (ZDC)



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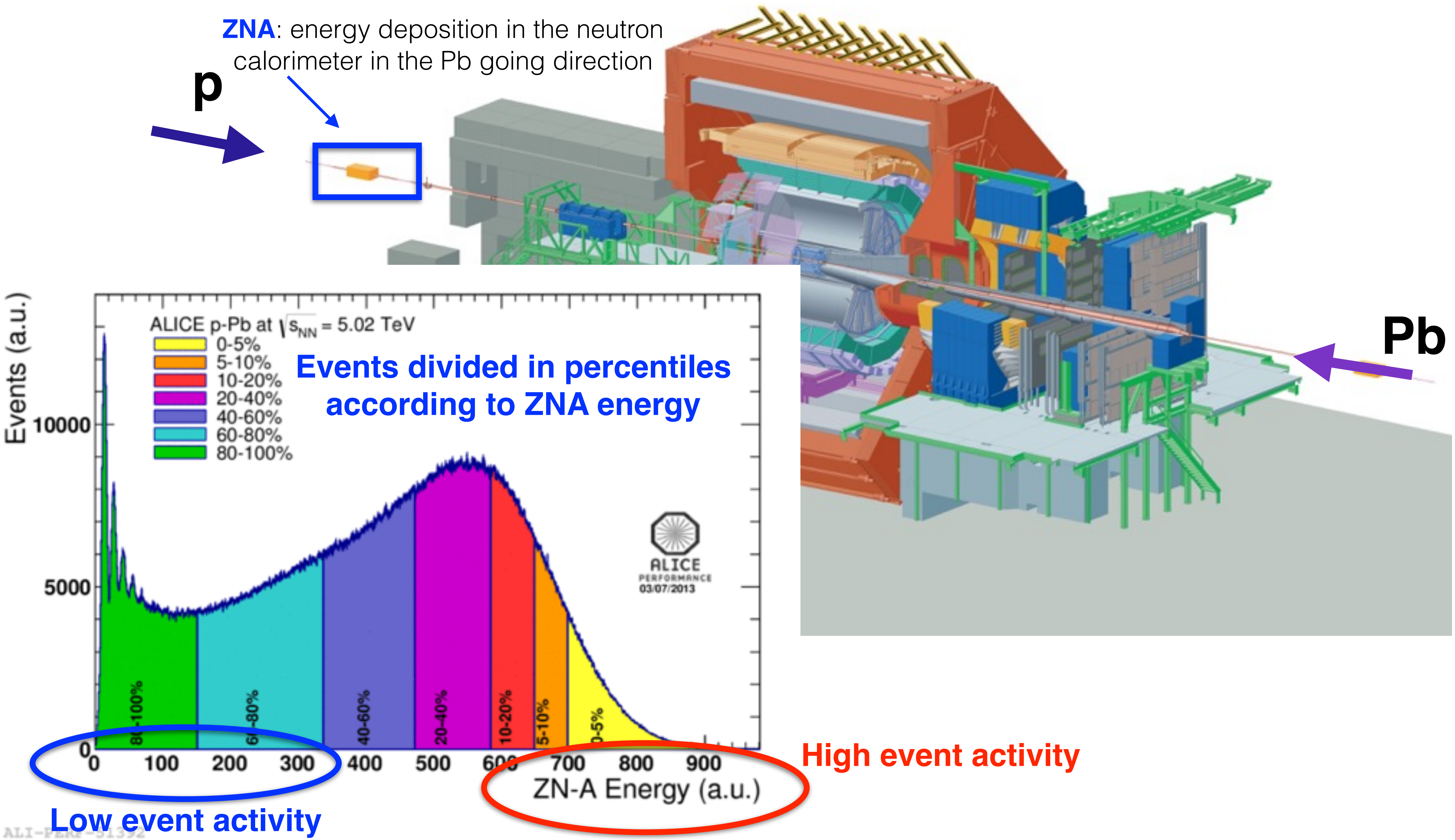

Q_{pPb}^{mult} - Results

$$Q_{\rm pPb}^{\rm mult}(p_{\rm T}) = \frac{dN^{\rm pPb}_{\rm ZNA}/{\rm d}p_{\rm T}}{\langle T^{\rm ZNA}_{\rm pA}\rangle^{\rm mult}\, d\sigma^{\rm pp}/{\rm d}p_{\rm T}}$$

D-meson yield corrected for efficiency in different event activity classes

T_{pA} = nuclear overlap function proportional to N_{coll} in the different event activity intervals

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D-meson yield corrected for efficiency in different event activity classes

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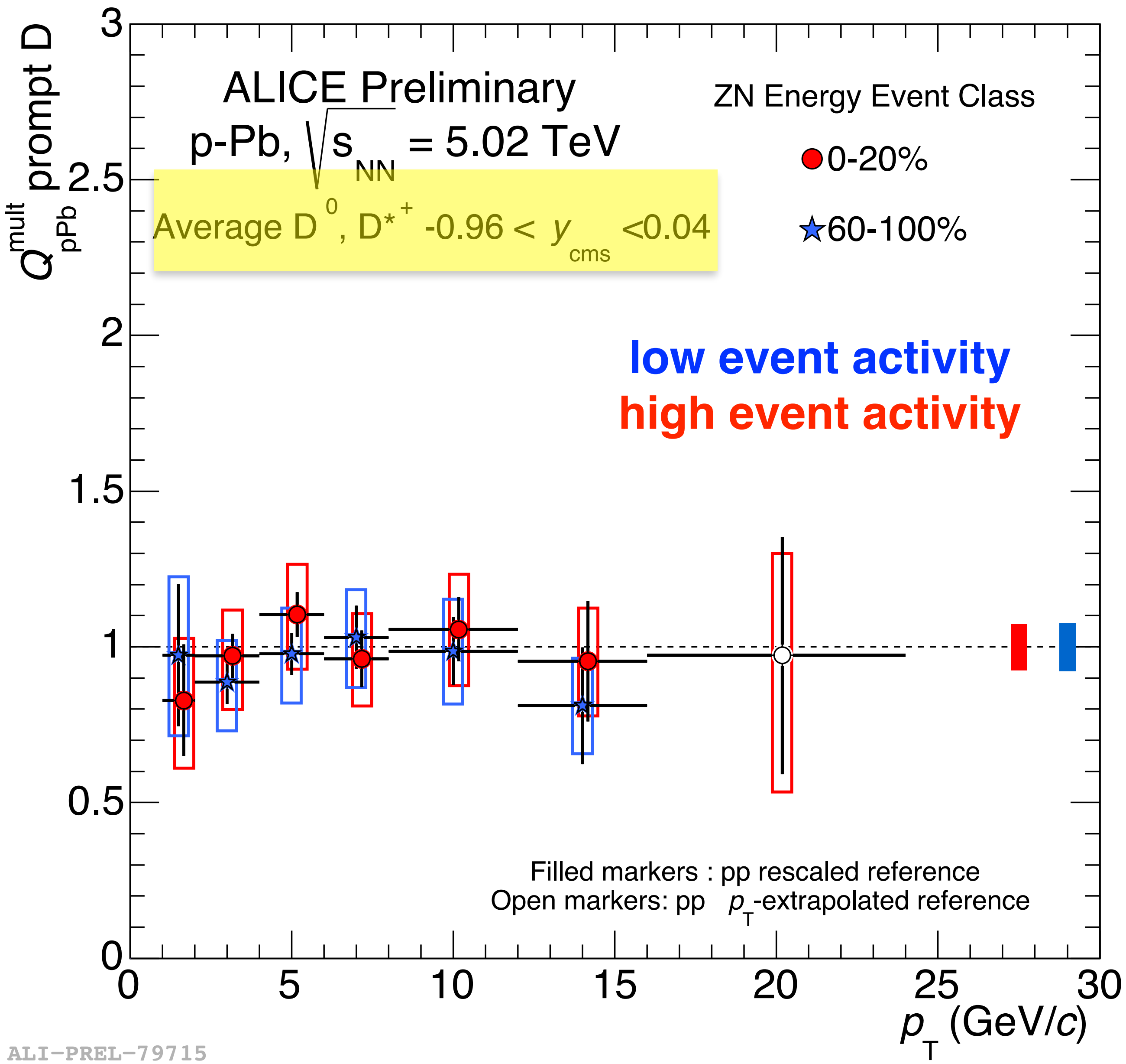
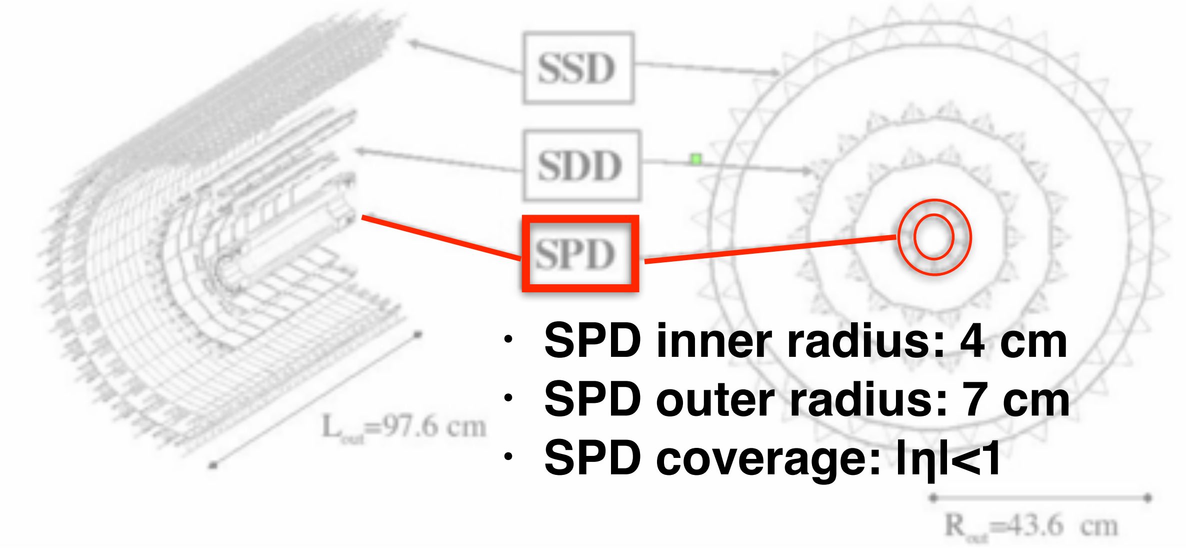
- ✦ Q_{pPb}^{mult} values are compatible with unity within uncertainties in all event activity intervals
- ✦ no-hint of collective behaviour or jet quenching is visible in the 0-20% event activity class
- ✦ D-meson production scales with the average number of nucleon-nucleon collisions $\langle N_{coll}\rangle$



D-meson yield vs multiplicity - Analysis strategy

✦ events are divided in multiplicity intervals depending on the number of tracklets $\boldsymbol{N_{tracklets}}$, i.e. track segments reconstructed using the two inner silicon layers of ITS (Silicon Pixel Detectors, **SPD**)

✦ results are shown in terms of corrected per-event yields normalised to the multiplicity-integrated values



- **SPD inner radius: 4 cm**
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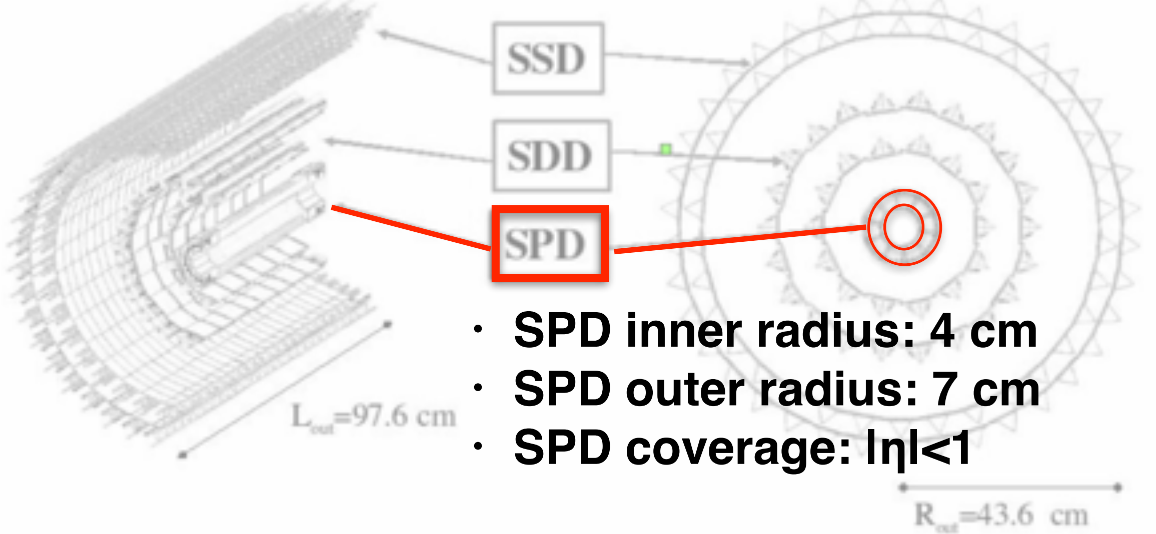
$$Y^{\rm corr} = \frac{({\rm d}^2N^{\rm D}/{\rm d}y{\rm d}p_{\rm T})}{\langle {\rm d}^2N^{\rm D}/{\rm d}y{\rm d}p_{\rm T}\rangle} = \frac{Y^{\rm mult}/(\epsilon^{\rm mult}\times N^{\rm mult}_{\rm event})}{Y^{\rm tot}/(\epsilon^{\rm tot}\times N^{\rm tot}_{\rm event}/\epsilon^{\rm trigger})}$$

trigger efficiency ~ 96%



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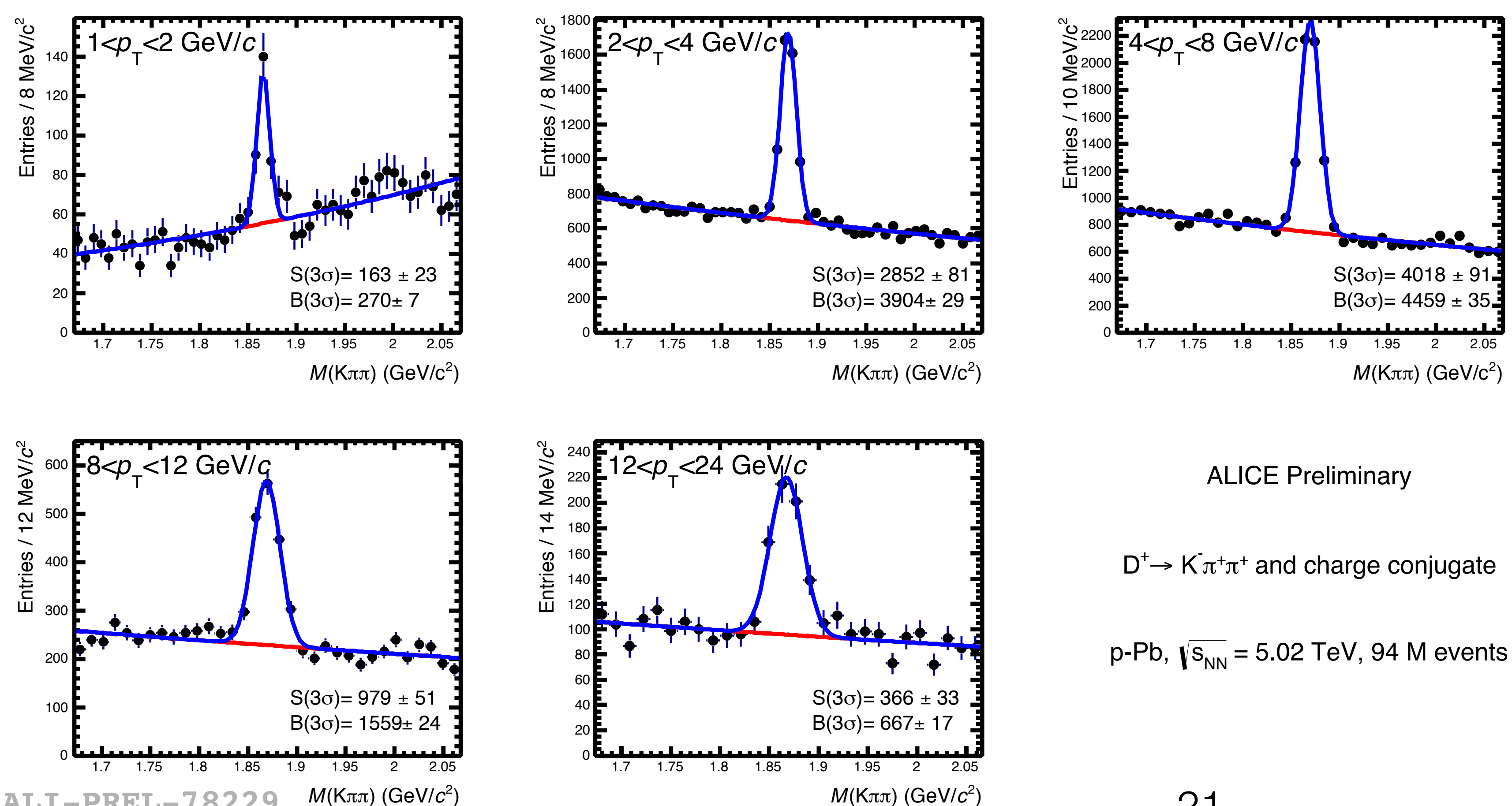
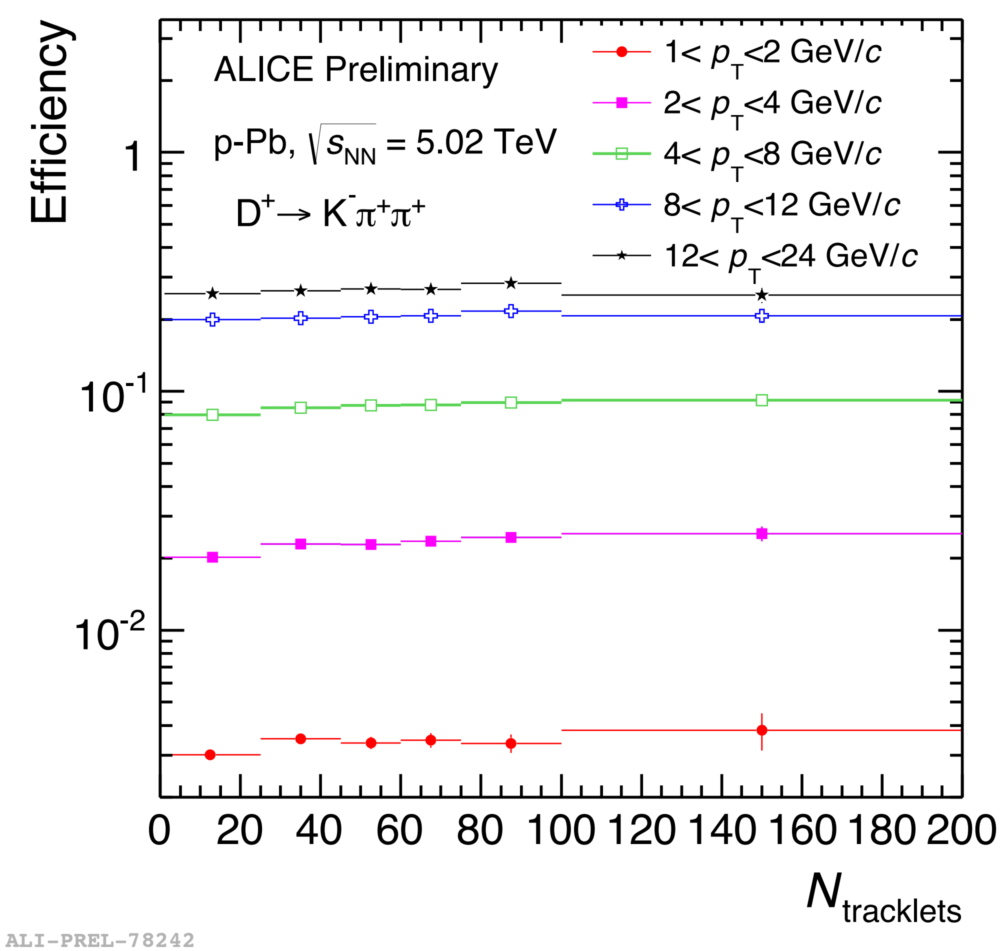
D-meson raw yields (multiplicity integrated and in *N*tracklets intervals)

reconstruction efficiencies (multiplicity integrated and in *N*tracklets intervals)

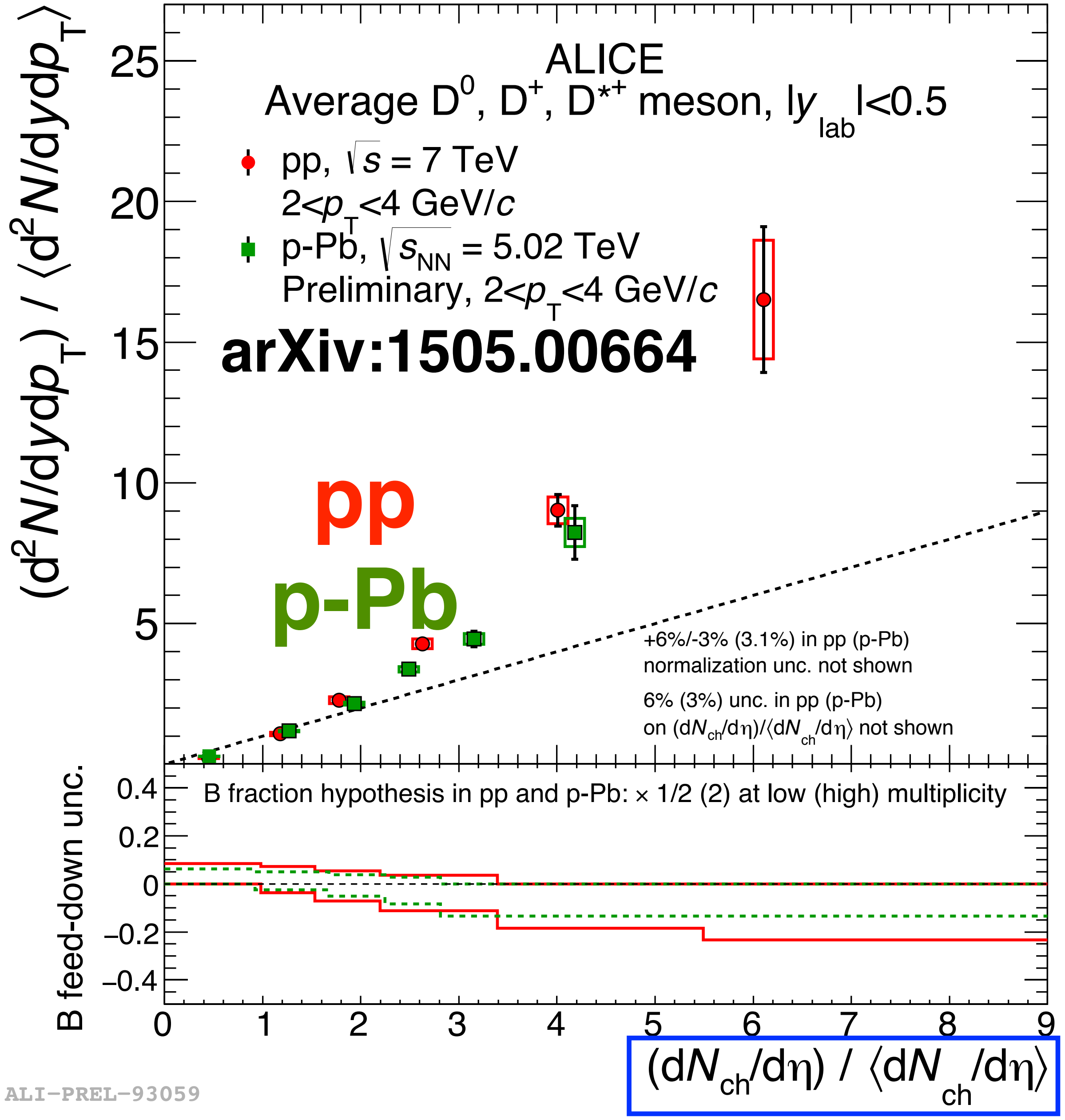




D-meson yields vs multiplicity - Results

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

✦ results are shown in $2<p_T<4$ GeV/c, similar results are obtained in the p_T range $1<p_T<24$ GeV/c



$N_{tracklets}$ converted to number of charged tracks N_{ch} in $|\eta|<1$

✦ similar increasing trend in pp and p-Pb collisions:

- interpreted as the presence of MPIs and of increased gluon radiation in events with charm production in pp collisions
- for p-Pb collisions this trend can also be caused by a higher $\langle N_{coll} \rangle$ for events with high charged-particle multiplicities

D-meson yields vs multiplicity - Results

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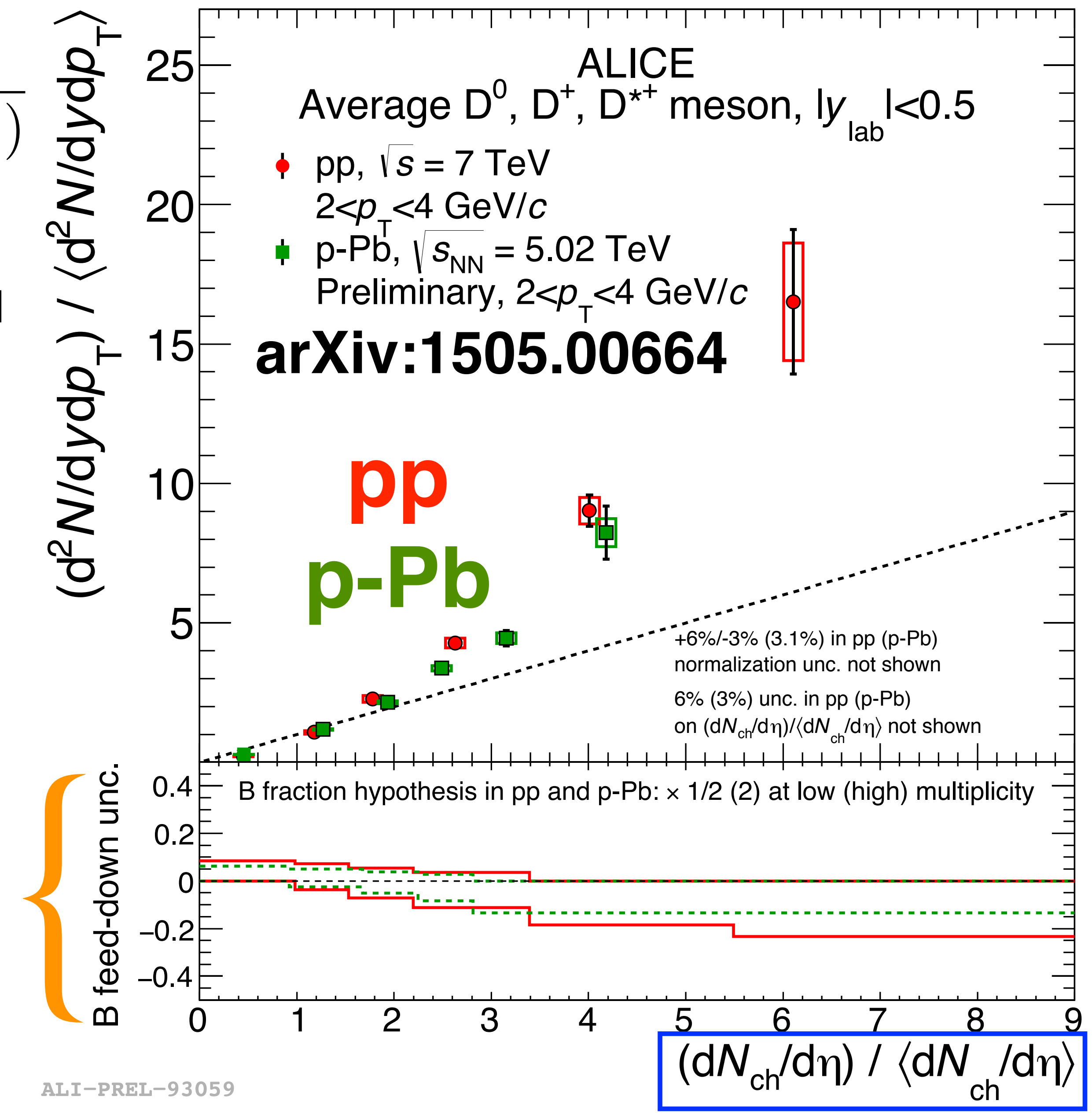
Beauty feed-down subtraction systematic uncertainty



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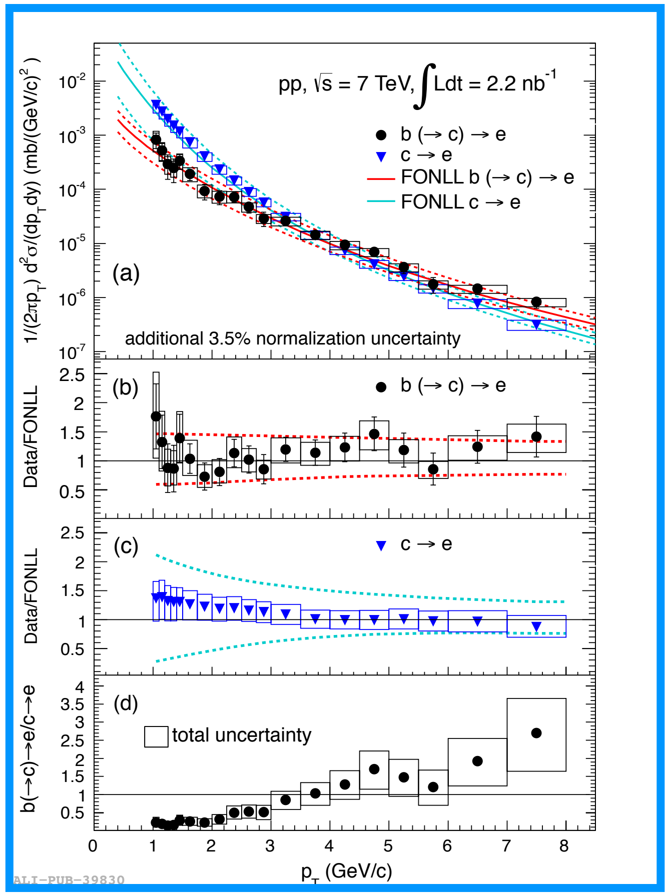
Conclusions

✦ p_T -differential invariant cross sections of D mesons and of leptons from HF decays are compatible with pQCD predictions



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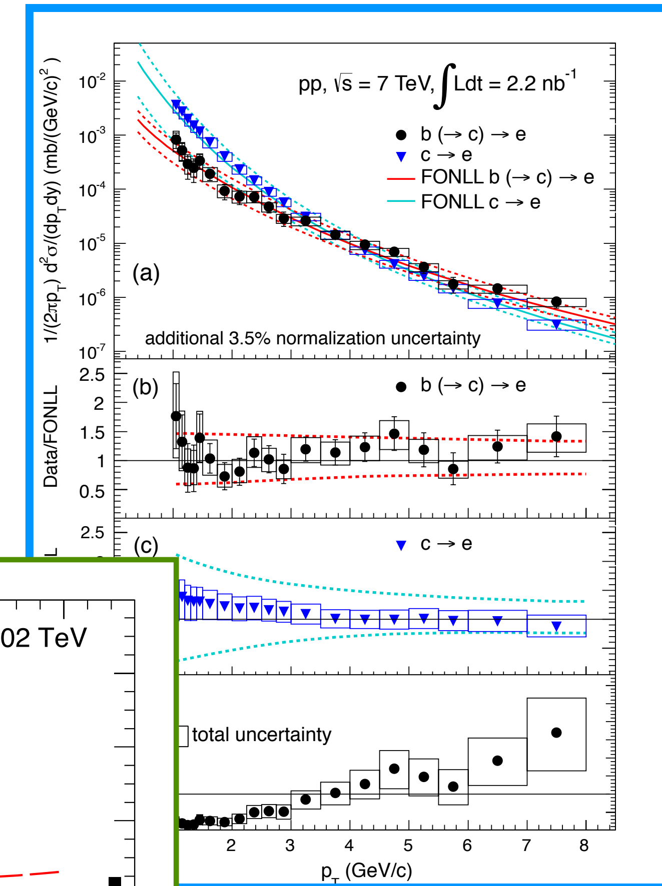
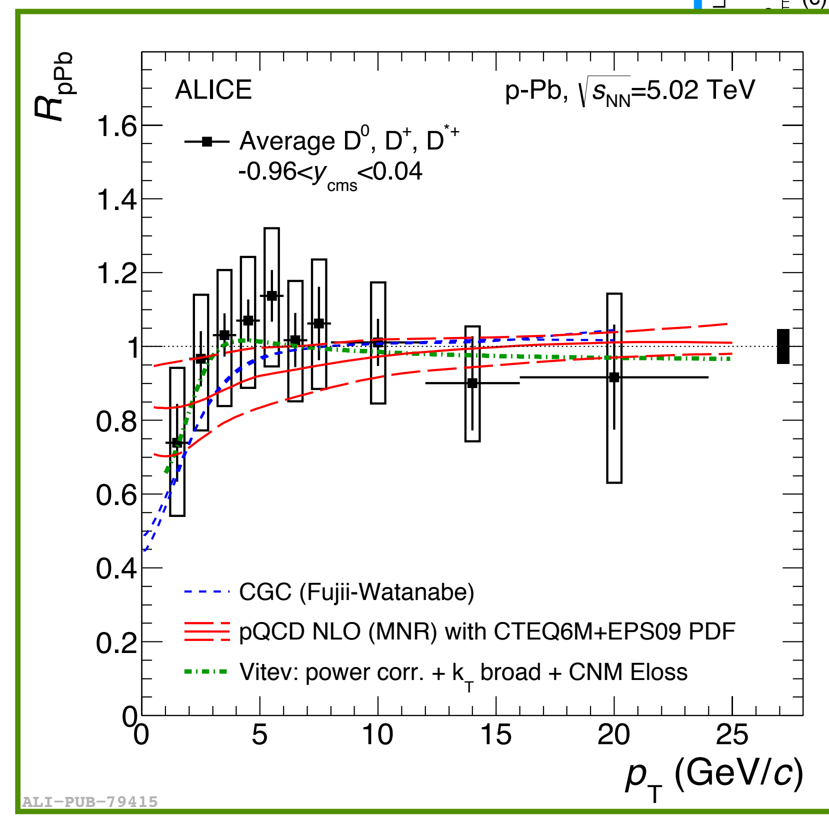


- ✦ R_{pPb} of D mesons and of leptons from HF decays is compatible with unity in the p_T range $2<p_T<24$ GeV/c
- ✦ Q_{pPb} in different event activity class show similar results



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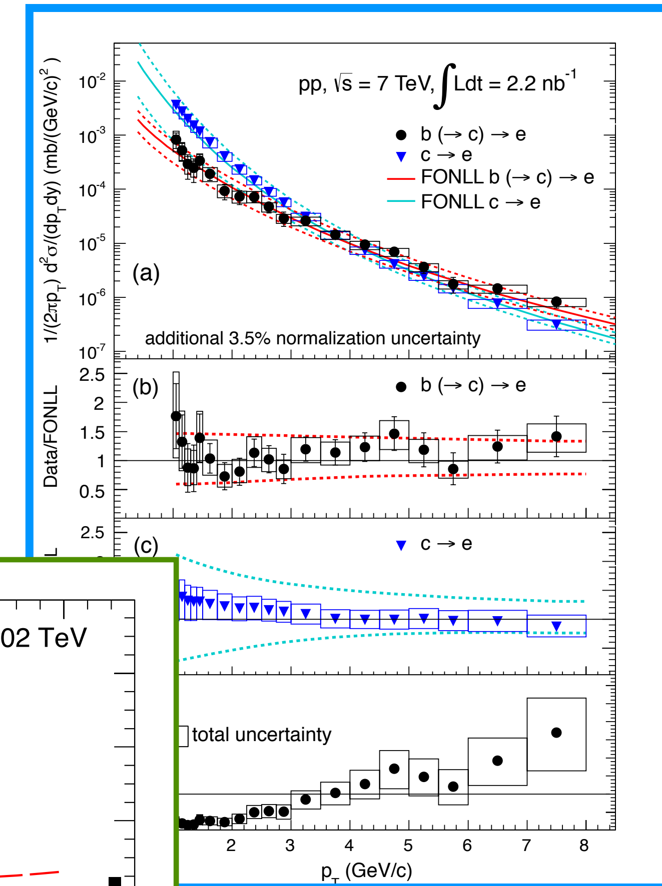

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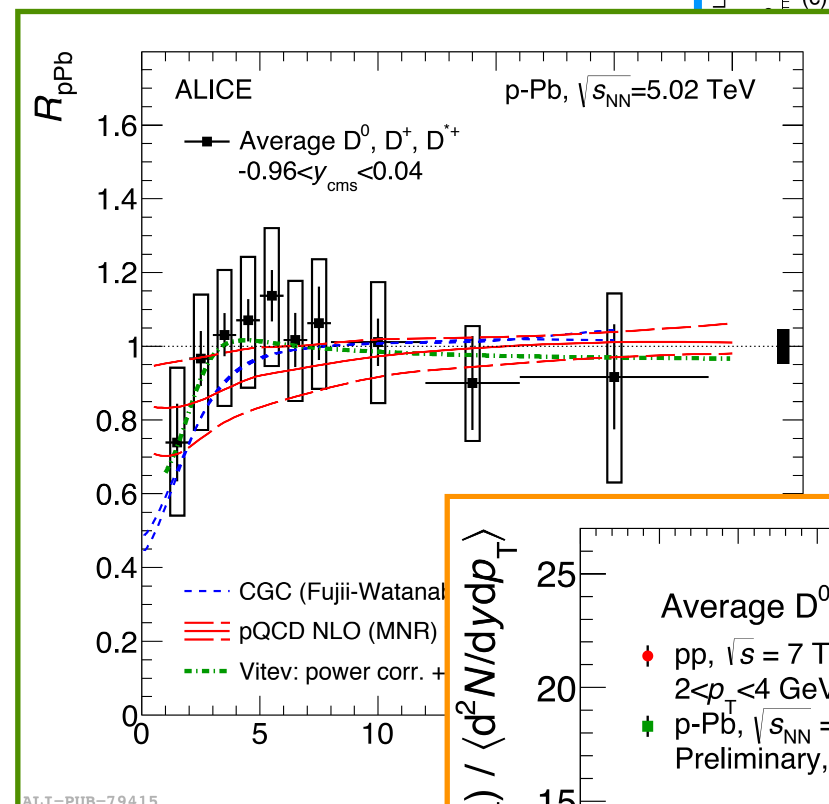
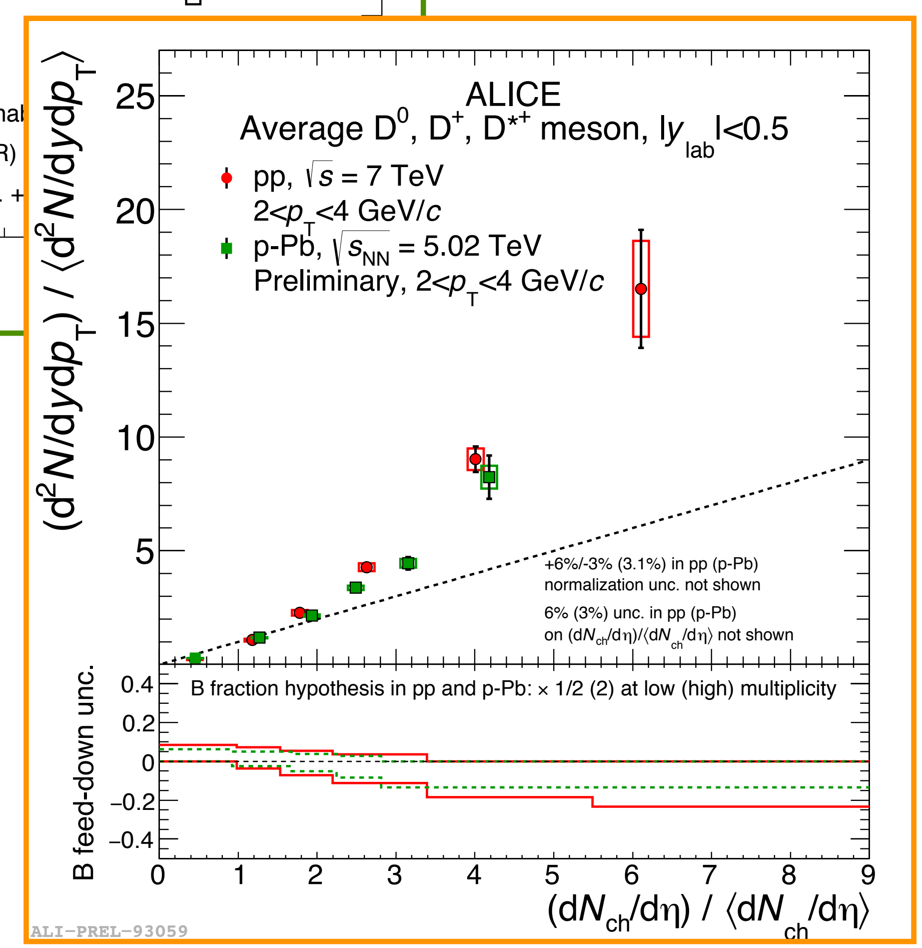
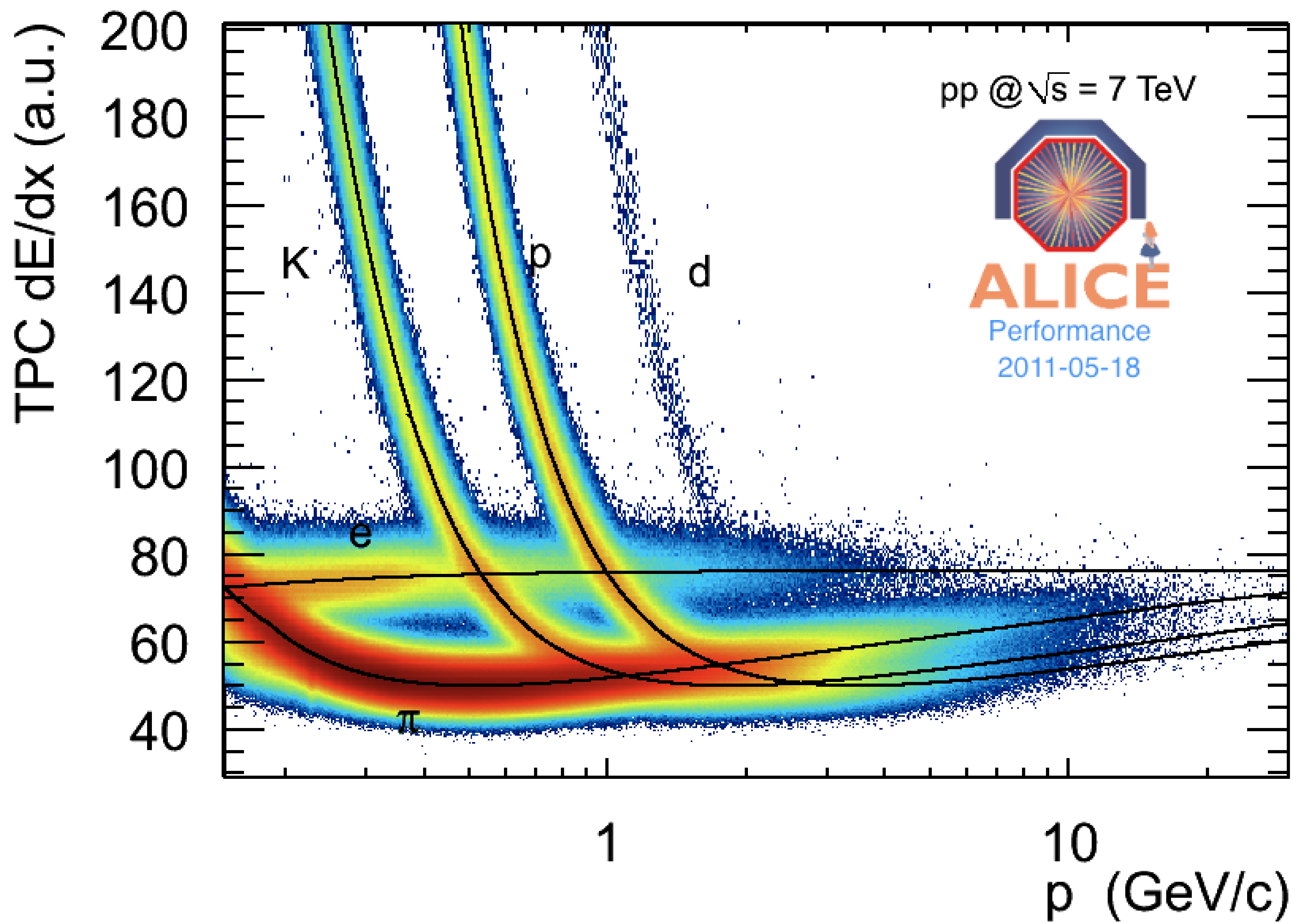


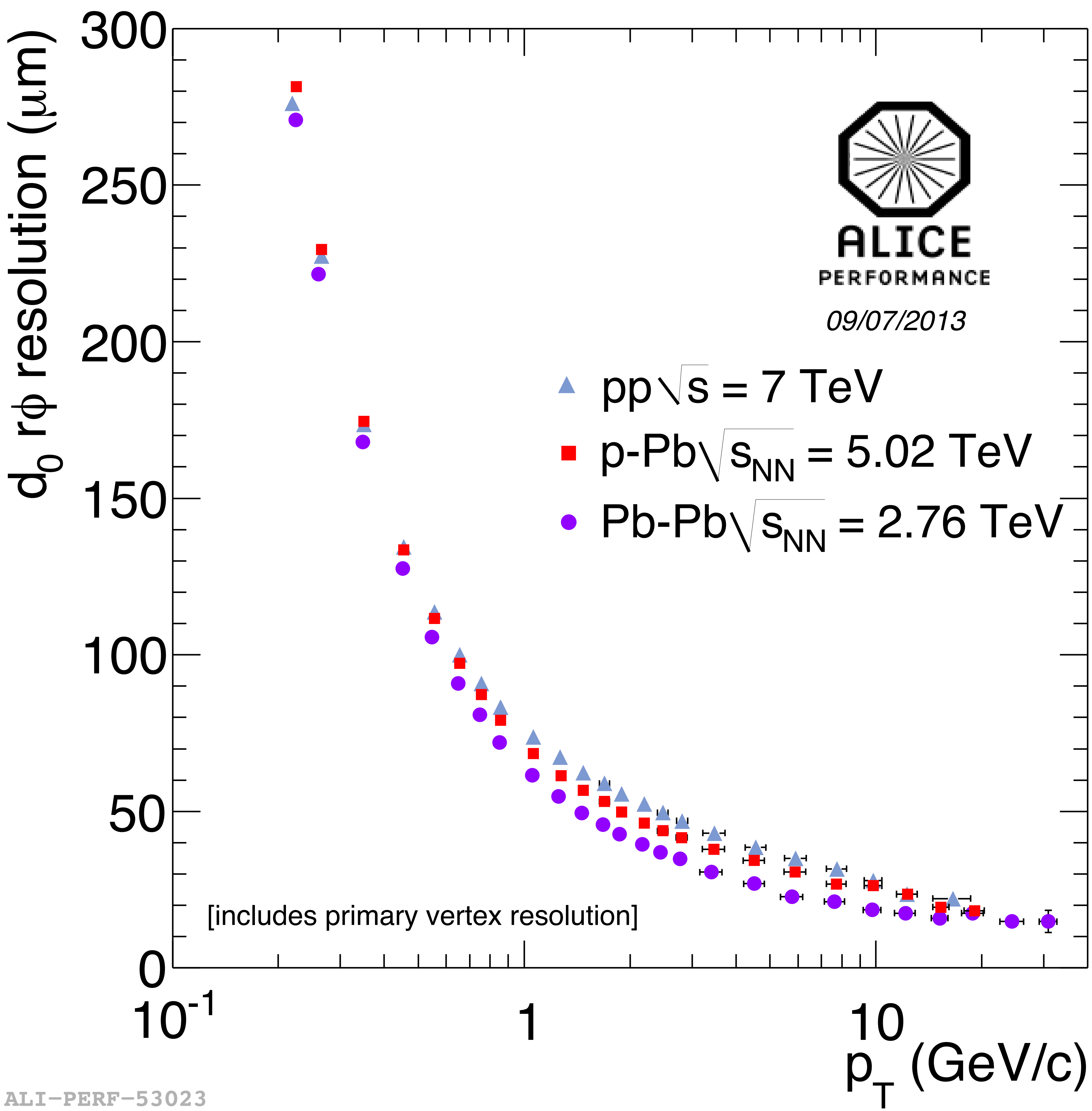
✦ D-meson production rate increases faster than linearly in events with high charged-particle multiplicities. In pp collisions this is attributed to the presence of MPIs and of increased gluon radiation in events with charm



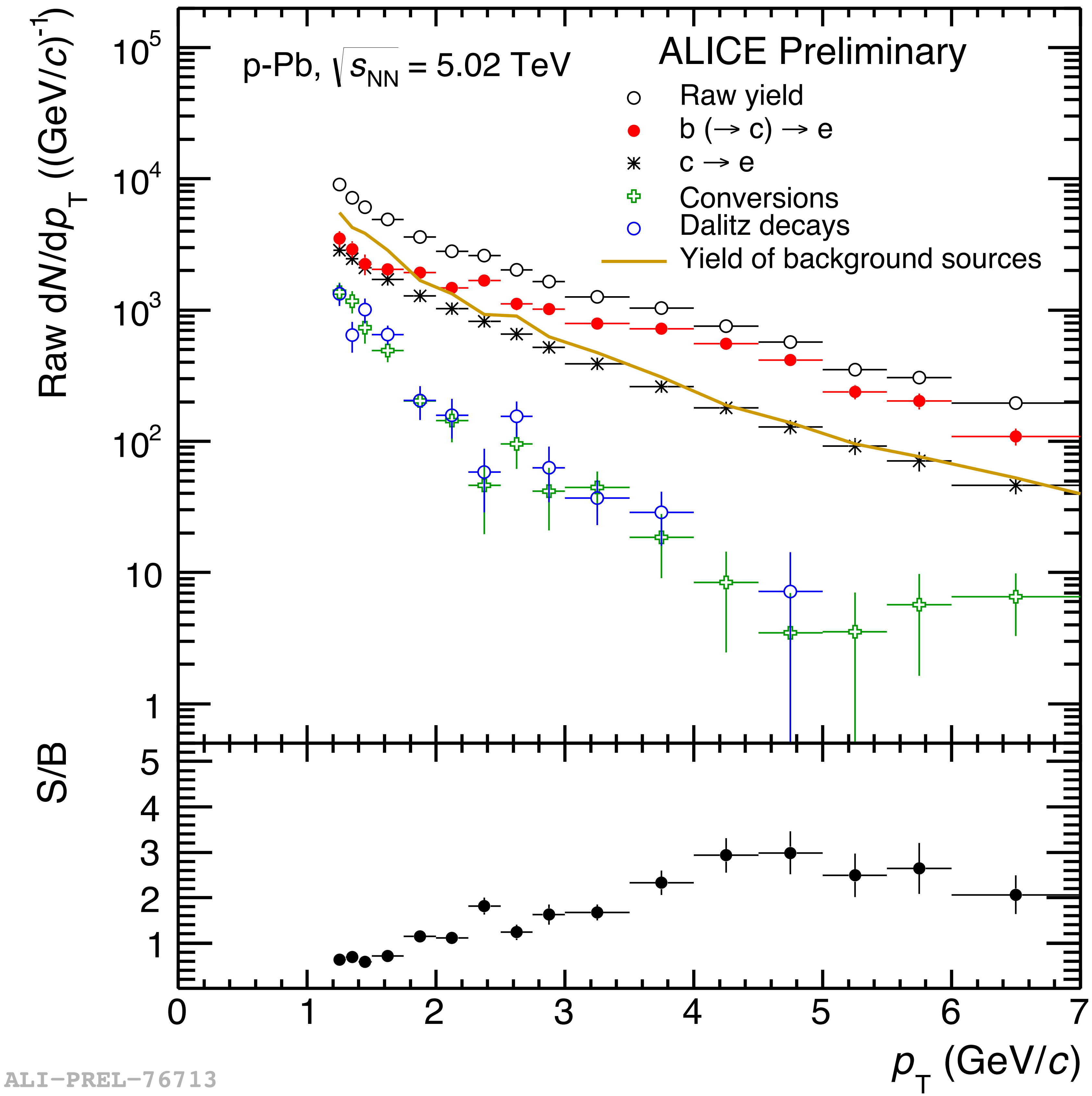
Backup



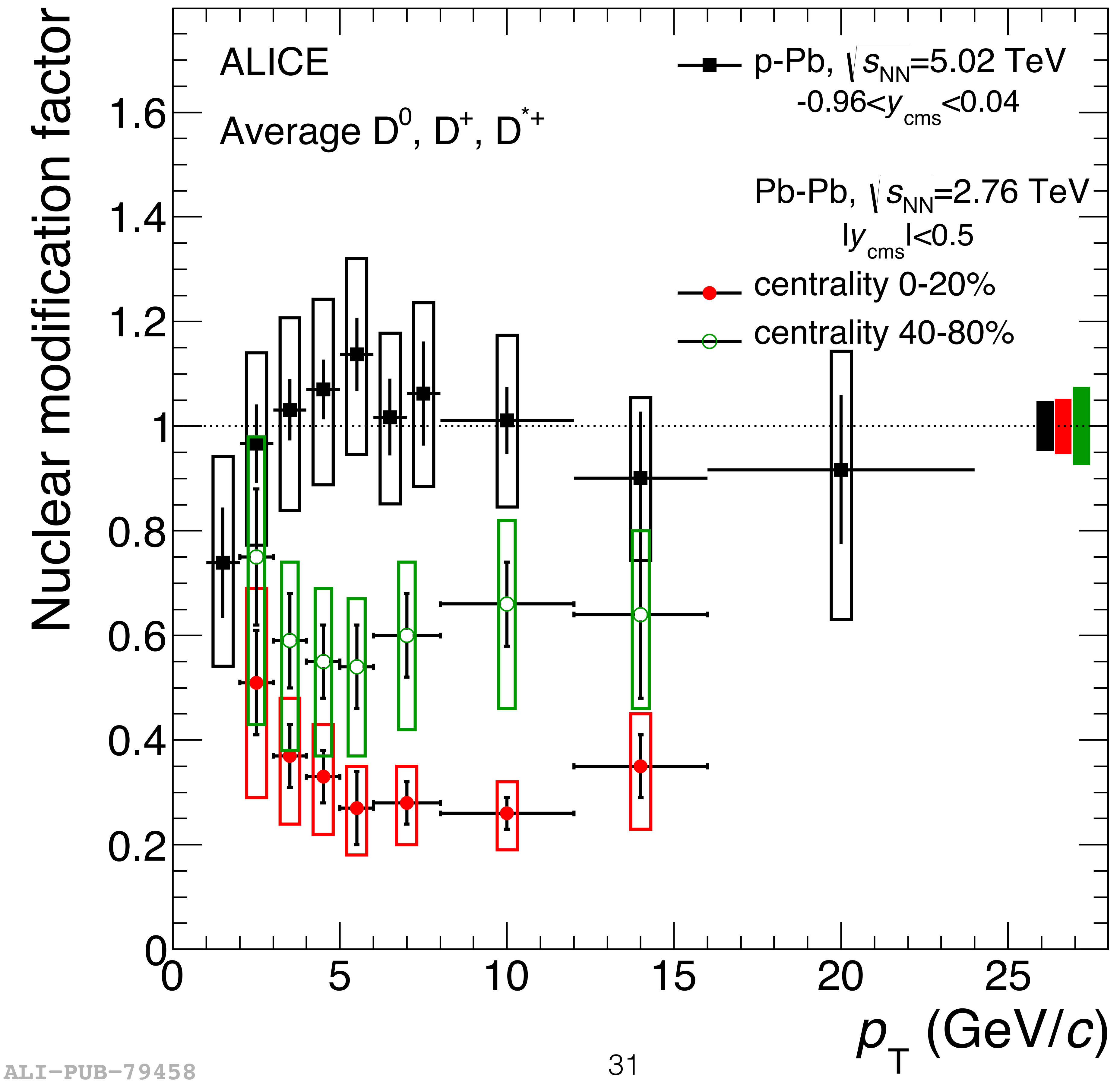
TPC dE/dx (a.u.)
200
180
160
140
120
100
80
60
40
1
10
p (GeV/c)
K
p
d
e
π
pp @ √s = 7 TeV
ALICE
Performance
2011-05-18



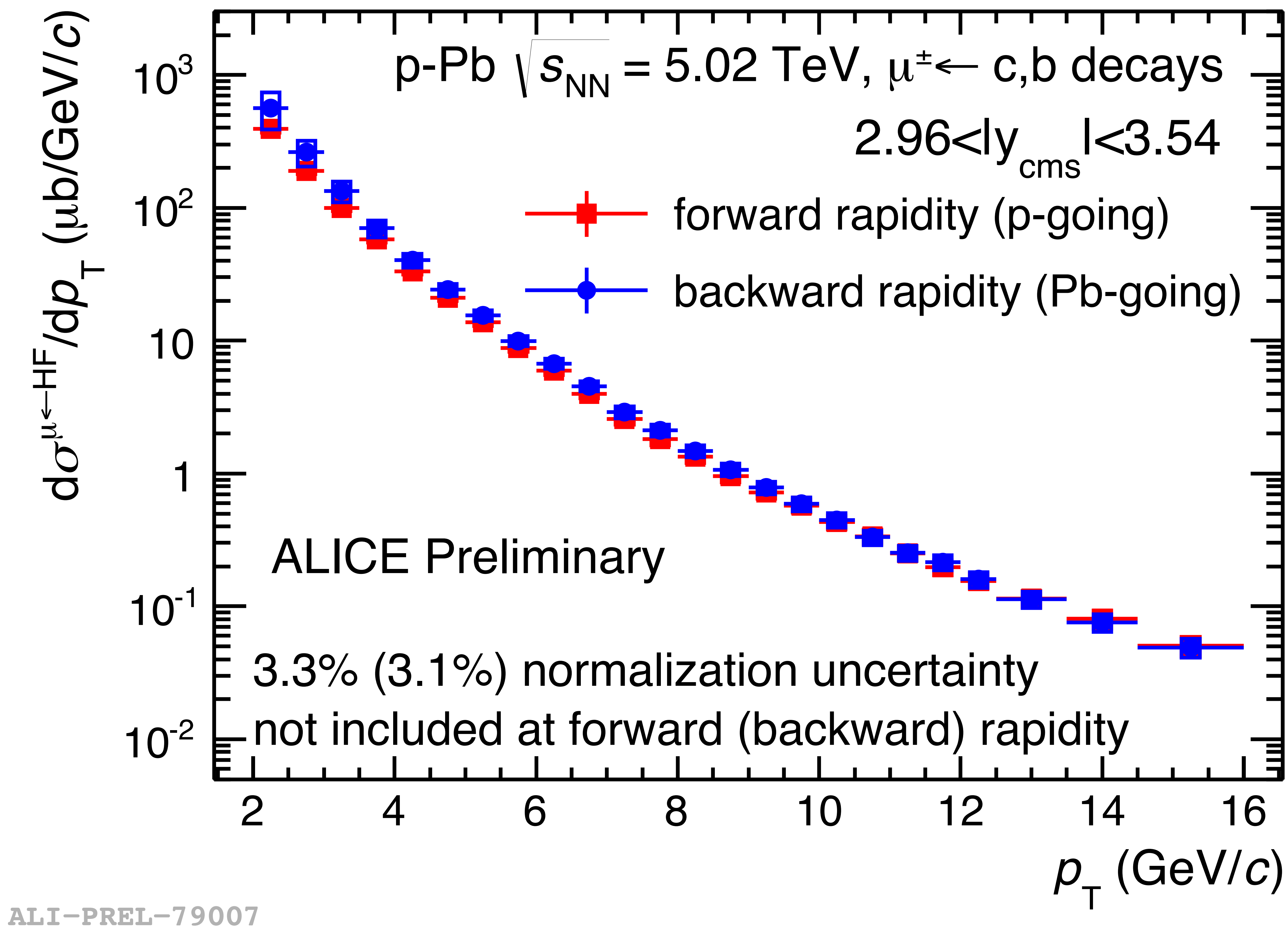
300
250
200
150
100
50
0
d_0 rϕ resolution (μm)
10^{-1}
1
10
p_T (GeV/c)
ALICE
PERFORMANCE
09/07/2013
pp $\sqrt{s}$ = 7 TeV
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
[includes primary vertex resolution]
ALI−PERF−53023



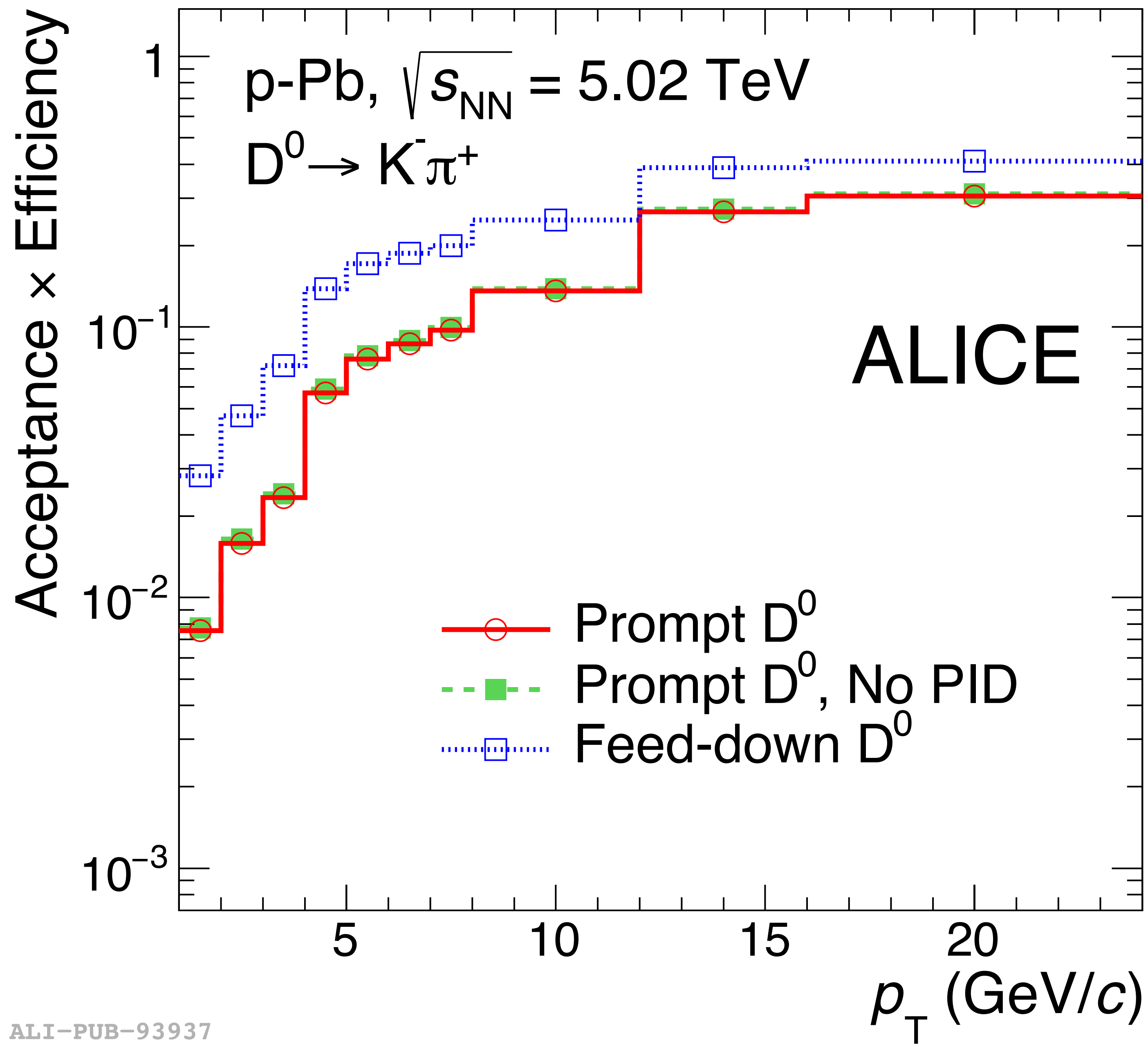
ALICE Preliminary
p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Raw yield
b (→ c) → e
c → e
Conversions
Dalitz decays
Yield of background sources
Raw dN/dp_T ((GeV/c)$^{-1}$)
S/B
p_T (GeV/c)
ALI-PREL-76713



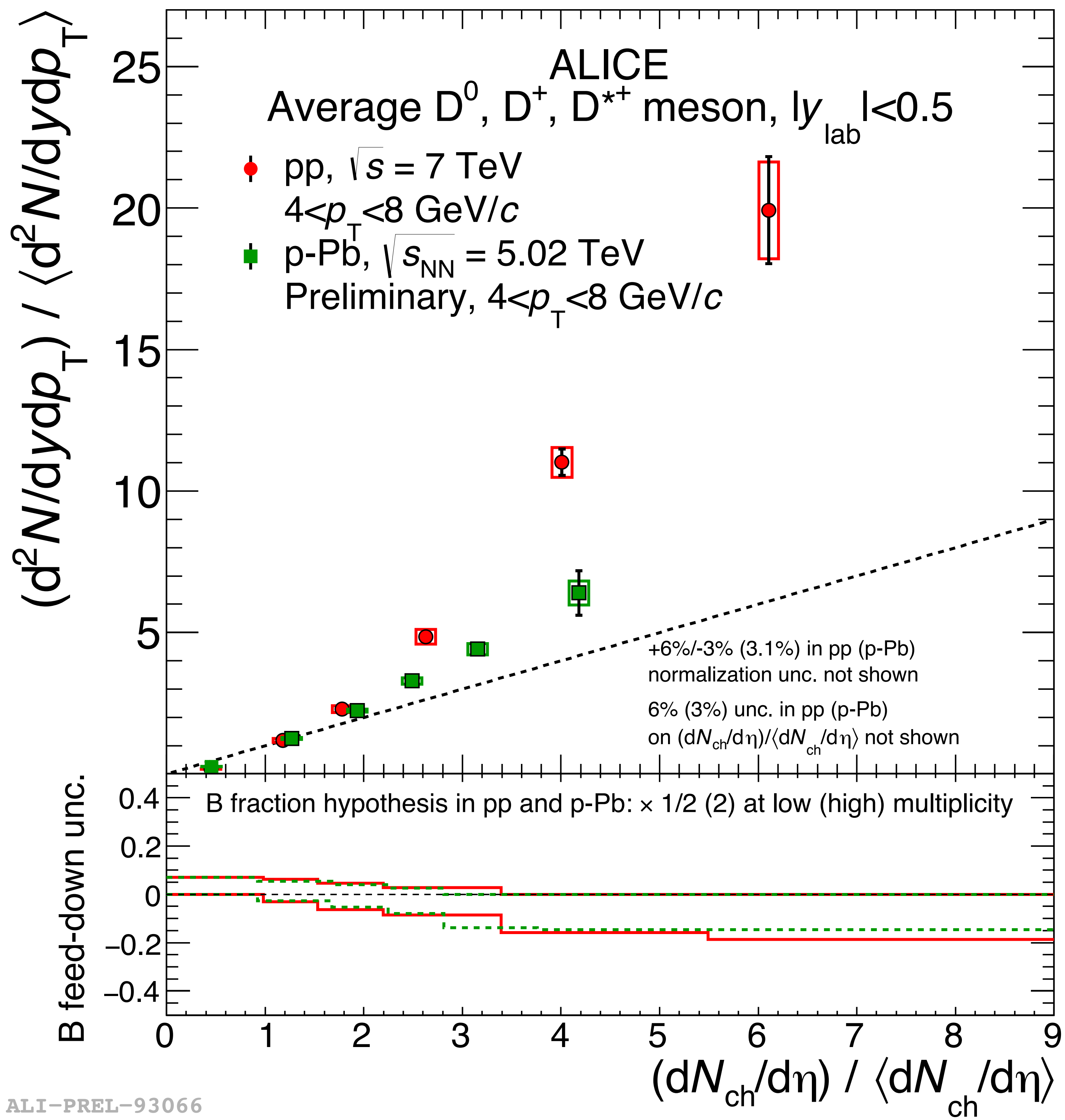
ALICE
Average D0, D+, D*+
p-Pb, √sNN=5.02 TeV
-0.96<ycms<0.04
Pb-Pb, √sNN=2.76 TeV
|ycms|<0.5
centrality 0-20%
centrality 40-80%
Nuclear modification factor
pT (GeV/c)
ALI-PUB-79458



p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV, μ±← c,b decays
2.96<|y_{cms}|<3.54
forward rapidity (p-going)
backward rapidity (Pb-going)
ALICE Preliminary
3.3% (3.1%) normalization uncertainty
not included at forward (backward) rapidity
$d\sigma^{\mu\leftarrow HF}/dp_T$ (μb/GeV/c)
p_T (GeV/c)
ALI-PREL-79007



p-Pb, √s_NN = 5.02 TeV
D0→ K-π+
ALICE
Prompt D0
Prompt D0, No PID
Feed-down D0
Acceptance × Efficiency
1
10−1
10−2
10−3
5
10
15
20
pT (GeV/c)
ALI-PUB-93937



ALICE
Average D0, D+, D*+ meson, |ylab|<0.5
pp, √s = 7 TeV
4<pT<8 GeV/c
p-Pb, √sNN = 5.02 TeV
Preliminary, 4<pT<8 GeV/c
+6%/-3% (3.1%) in pp (p-Pb)
normalization unc. not shown
6% (3%) unc. in pp (p-Pb)
on (dNch/dη)/⟨dNch/dη⟩ not shown
B fraction hypothesis in pp and p-Pb: × 1/2 (2) at low (high) multiplicity
(d2N/dydpT) / ⟨d2N/dydpT⟩
B feed-down unc.
(dNch/dη) / ⟨dNch/dη⟩
25
20
15
10
5
0.4
0.2
0
−0.2
−0.4
0
1
2
3
4
5
6
7
8
9
ALI-PREL-93066