Heavy-flavour multiplicity dependence in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE at the LHC

Jan Wagner for the ALICE Collaboration

Content

Multiplicity dependent nuclear modification Q_{pPb}

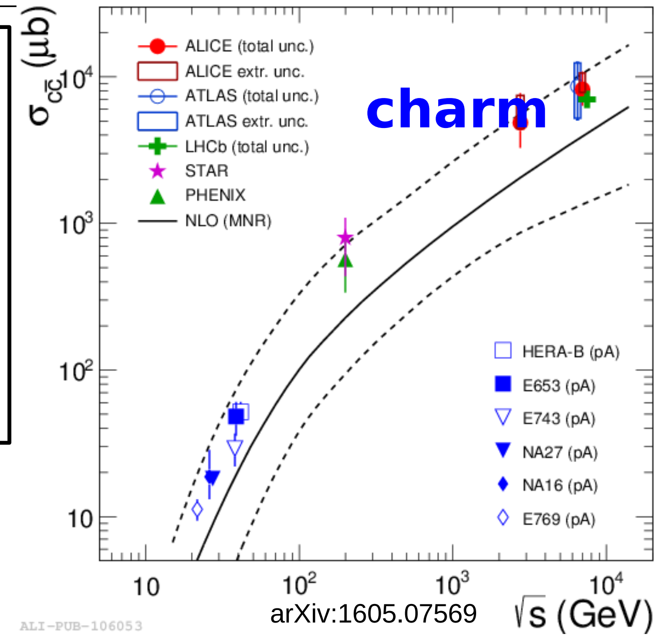
Relative open heavy-flavour yields in p-Pb collisions vs multiplicity

Comparison of results to models and pp collisions

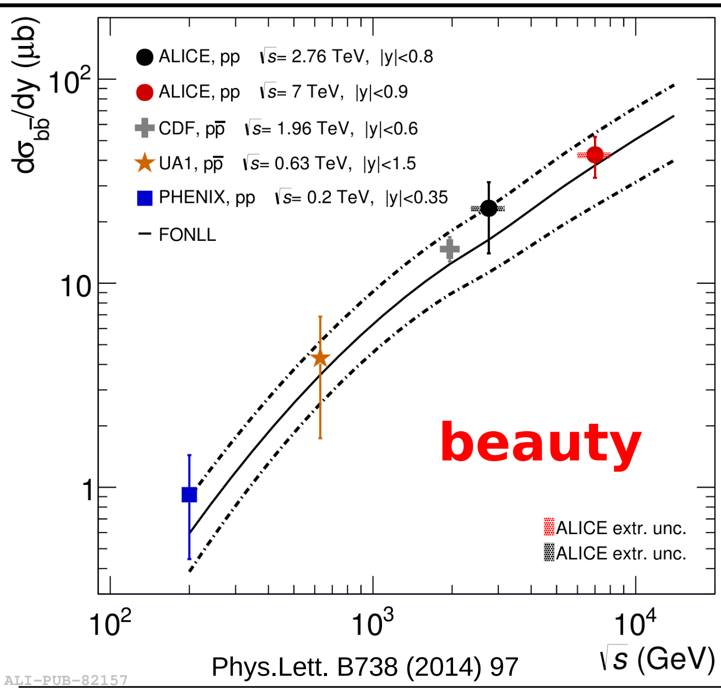
Supported by the Global Research Network (**GRN**) Program through the National Research Foundation (**NRF**) of Korea funded by the Ministry of Education, Science and Technology (Grant Number: 2013S1A2A2035612)

Open heavy flavours in p-Pb collisions

- Due to their large masses, **charm** and **beauty** quarks are produced in the **early stages** of the collision
  - Experience the **full evolution** of the system
  - Described well by **pQCD** calculations in pp collisions



arXiv:1605.07569



Phys.Lett. B738 (2014) 97

- p-Pb collisions ($\langle N_{coll} \rangle \approx 7$) **no medium** expected to be formed
- **cold nuclear matter** effects (shadowing, $\boldsymbol{k_T}$-broadening, *E*-loss**)**
- **Centrality** dependence? → $\boldsymbol{Q_{pPb}}$
- High **multiplicity events in p-Pb** collisions → relative yields

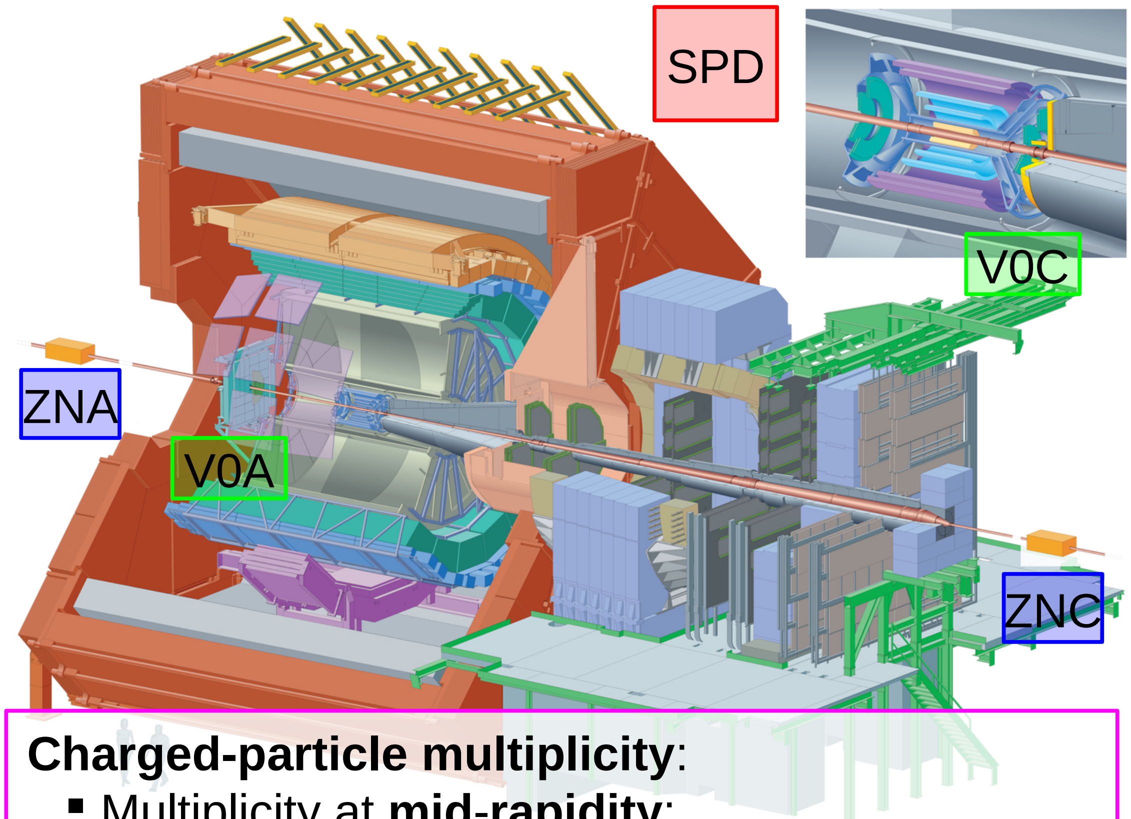
ALICE – centrality/multiplicity determination

Detectors used as centrality estimators:

- Zero Degree Neutral calorimeter (**ZNA** & **ZNC**):
  - Energy deposit in |η|> 8.7

- Forward scintillator arrays (**VZERO**):
  - 2.8 < η < 5.1 (**V0A**)
  - -3.7 < η < -1.7 (**V0C**)
  - Also used to trigger events

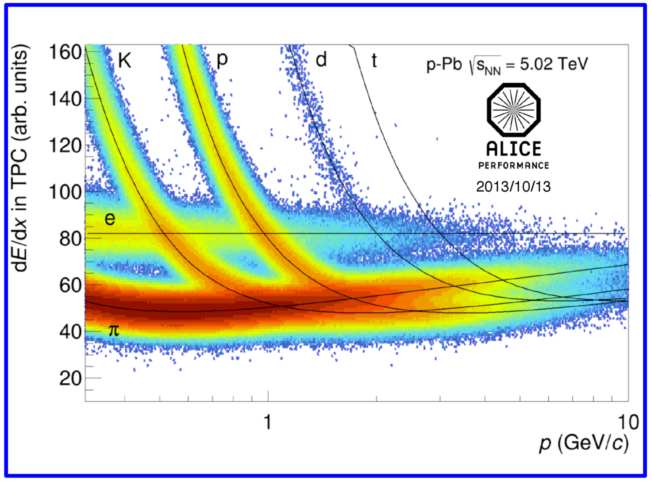
- Silicon Pixel Detector (**SPD**):
  - Two innermost layers of the Inner Tracking System
  - **|η| < 1**
  - Also used to trigger events



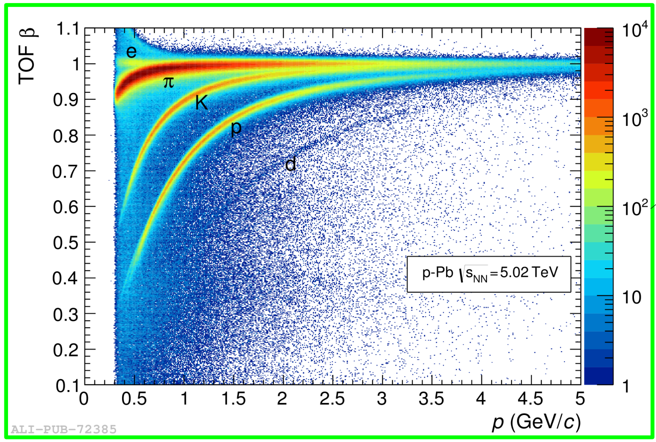
Charged-particle multiplicity:
- Multiplicity at **mid-rapidity**:
  - tracklets in SPD |η| < 1.0
- Multiplicity at **backward rapidity** (Pb-going direction):
  - V0A signal

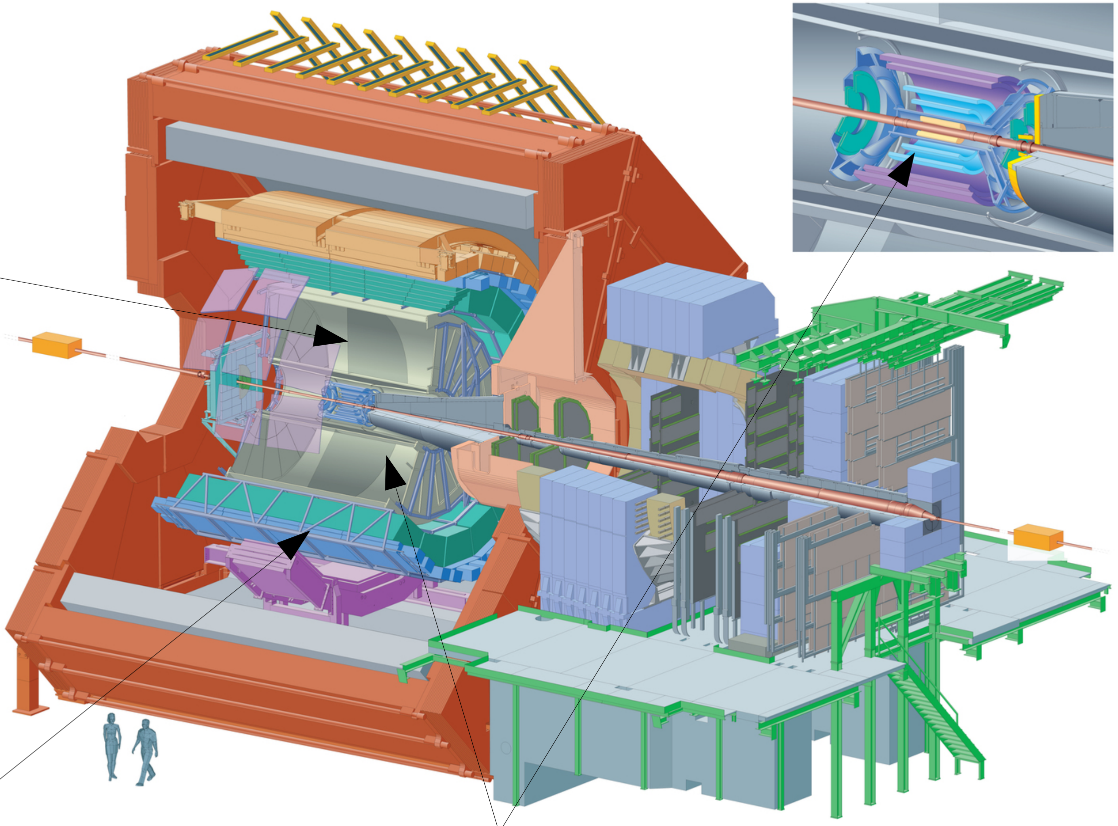
ALICE – particle identification

TPC PID via dE/dx vs p



Time Of Flight (TOF) vs p

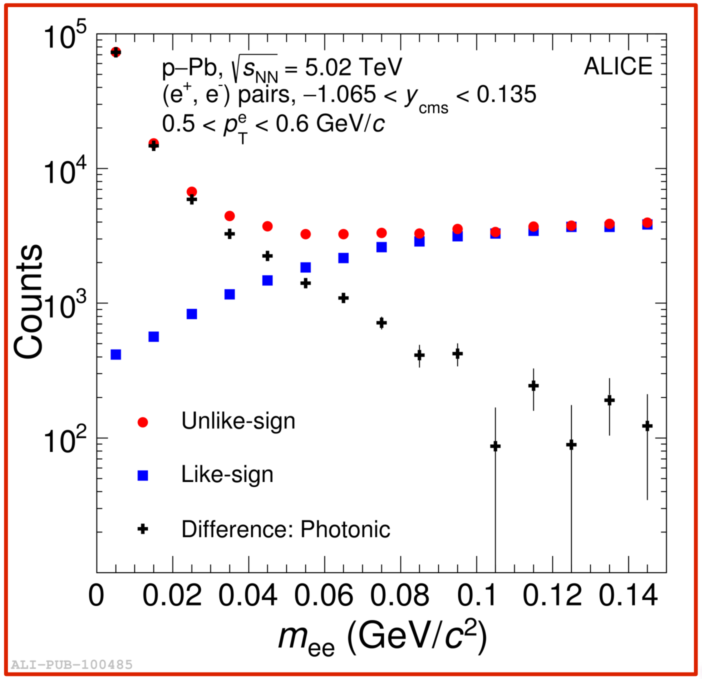




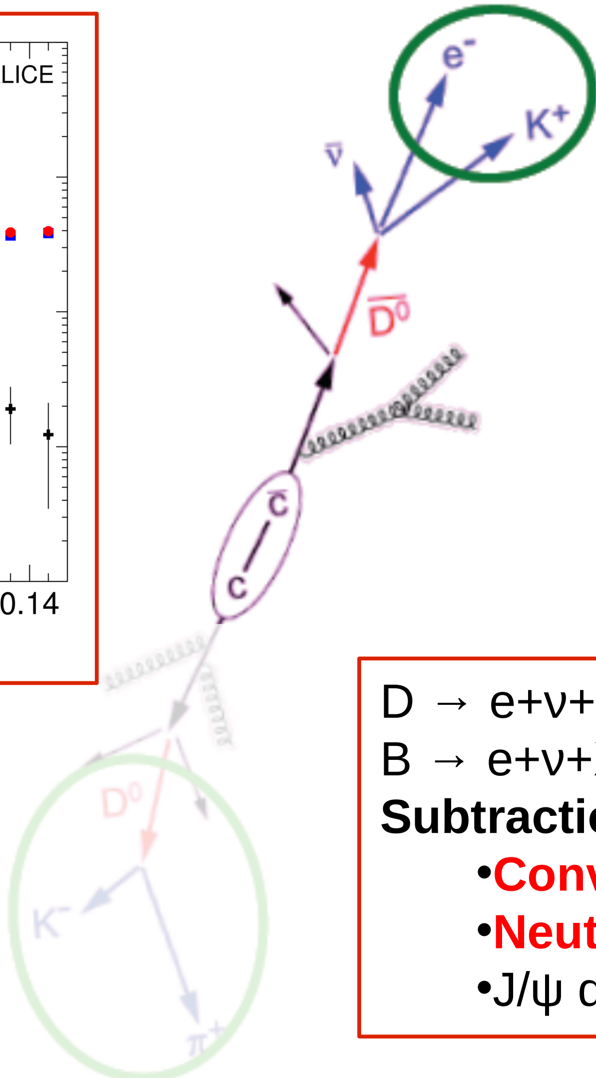
Tracking & Vertexing:
ITS + TPC

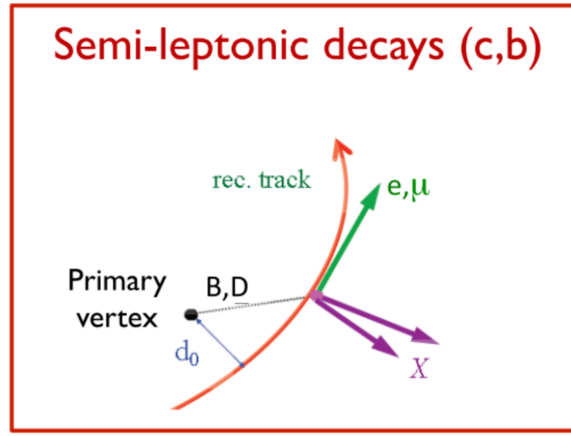
p-Pb: 103 M (MB)
$\sqrt{s_{NN}}$ = 5.02 TeV
$L_{int} \approx 50\ \mu b^{-1}$

Measuring heavy-flavour hadrons: inclusive electrons



Phys. Lett. B 754 (2016) 81-93

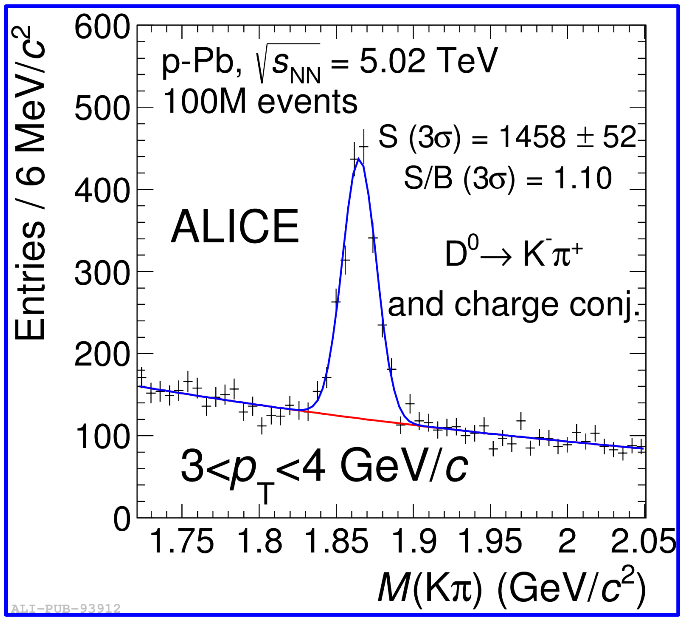


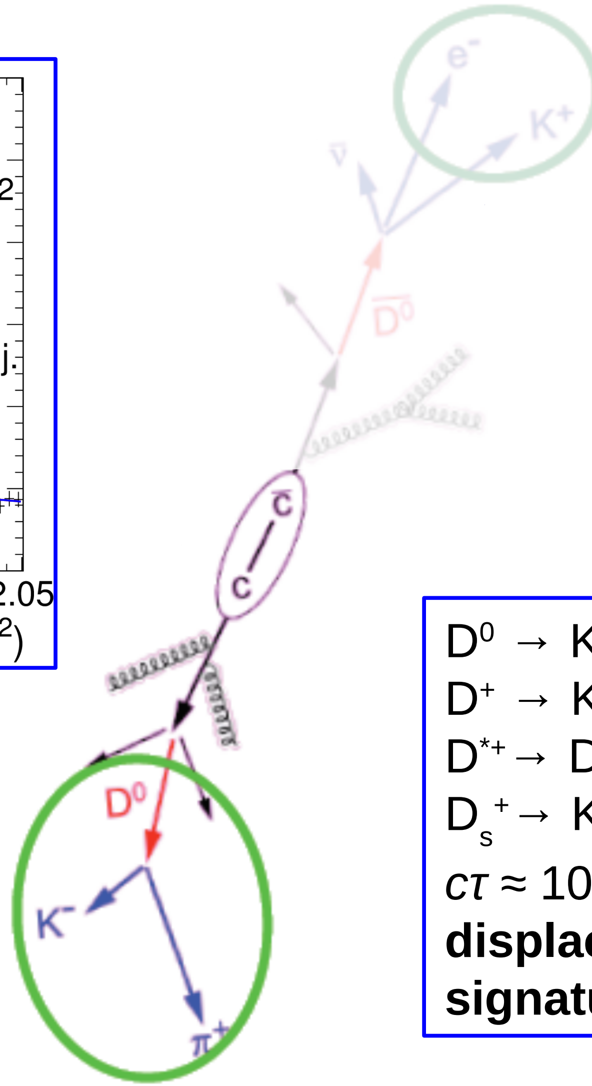


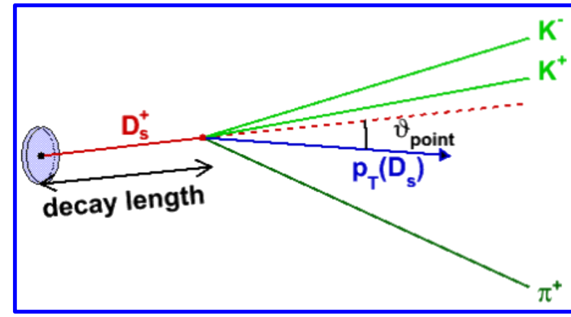
D → e+ν+X (BR ~ 10%)
B → e+ν+X (BR ~ 11%)
Subtraction of background from:
- **Conversion γ**
- **Neutral-meson Dalitz decays**
- J/ψ decays

Measuring heavy-flavour hadrons: reconstruction of hadronic decays

PRL 113 (2014) 232301



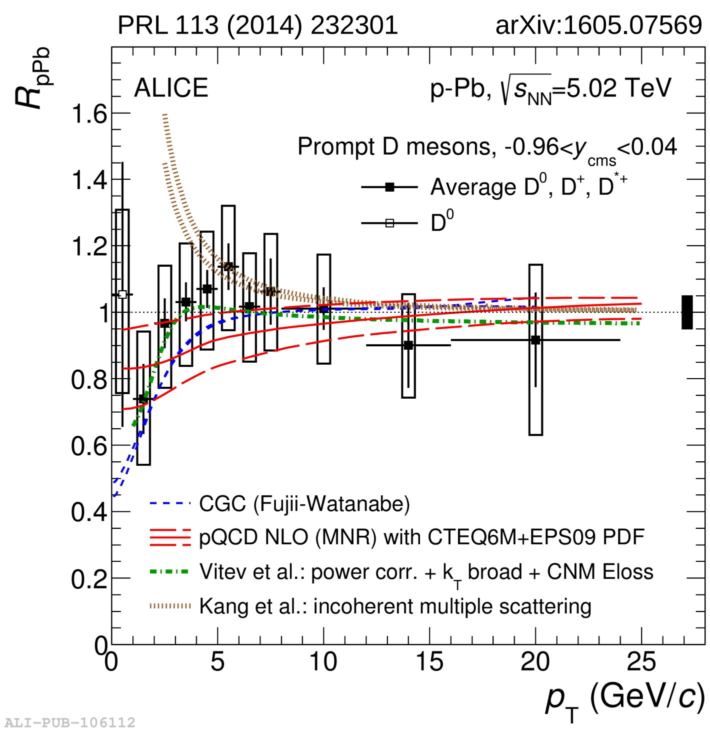


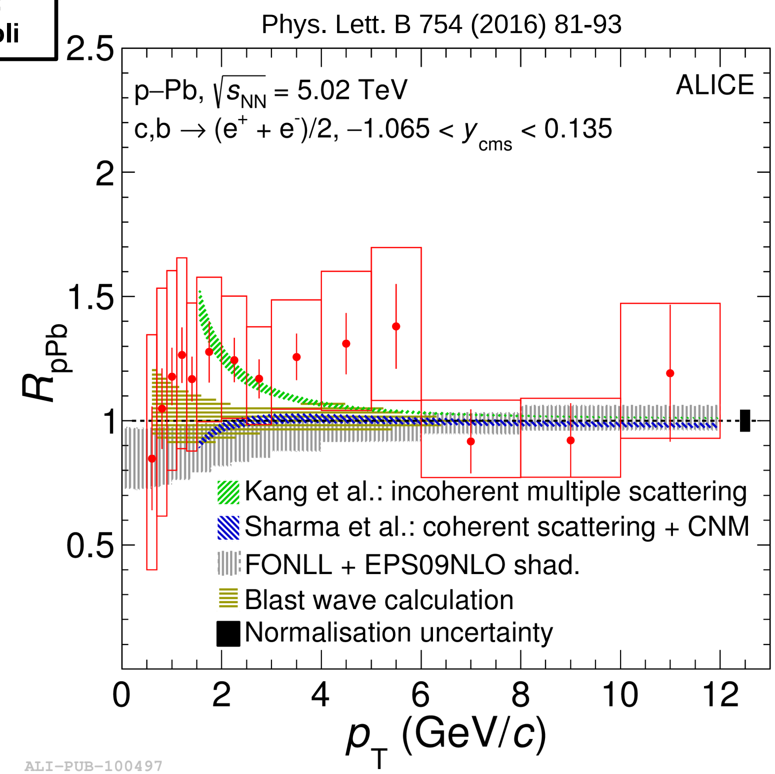


$D^0 \rightarrow K^- \pi^+$ (BR ~ 3.9%)
$D^+ \rightarrow K^- \pi^+ \pi^+$ (BR ~ 9.1%)
$D^{*+} \rightarrow D^0 \pi^+$ (BR ~ 68%)
$D_s^+ \rightarrow K^+ K^- \pi^+$ (BR ~ 2.3%)
$c\tau \approx$ 100-300 μm:
displaced decay **vertex** is a **signature** of **D-meson** decay

Reminder:
cold nuclear matter effects

2:40 pm:
C. Terrevoli





- R_{pPb} for D mesons and (c+b)→e compatible with unity
- Compatible with different models simulating cold nuclear matter effects

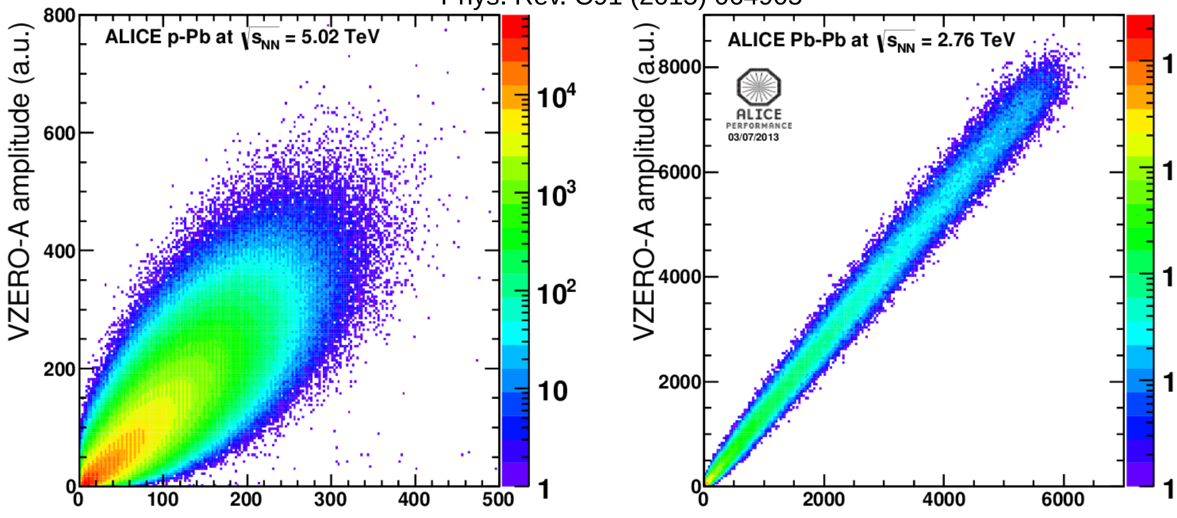
Multiplicity dependence on R_{pPb}

- Test **multiplicity dependent** modification of the p_T spectra in **p-Pb** collisions w.r.t. **pp** collisions:

$$Q_{\mathrm{pPb}}^{\mathrm{multi}}(p_{\mathrm{T}})=\frac{(\mathrm{d}N_{\mathrm{pPb}}^{\mathrm{multi}}/\mathrm{d}p_{\mathrm{T}})_i}{\langle N_{\mathrm{coll}}\rangle_i \, \mathrm{d}N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- But in p-Pb collisions **biases** are present in the determination of $\langle N_{\mathrm{coll}}\rangle$:
  - **Multiplicity** bias
  - **Jet** veto bias
  - **Geometrical** bias
- **Bias** depends on the **estimator** used for the multiplicity determination

Phys. Rev. C91 (2015) 064905



ALI-PERF-51411

p-Pb Pb-Pb

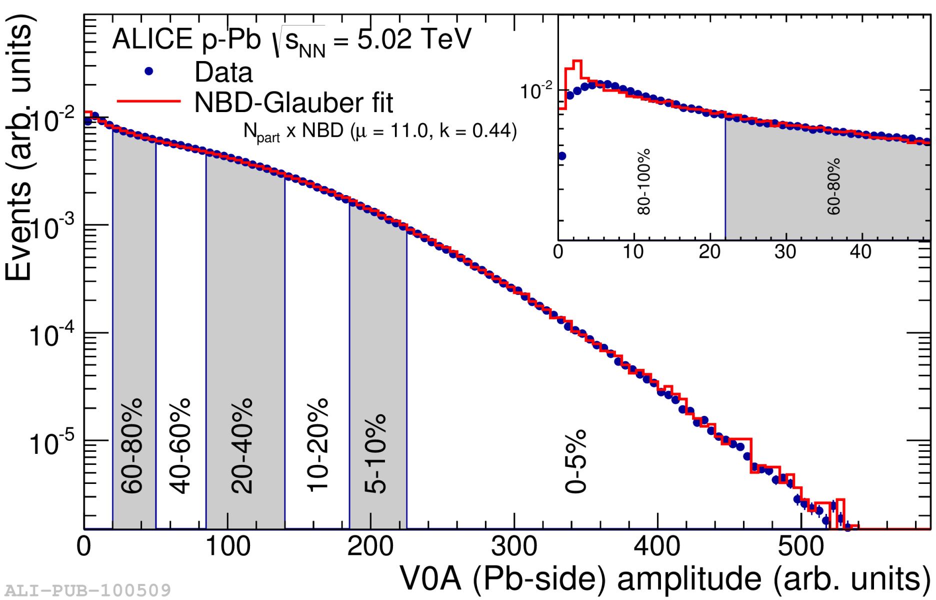
Centrality estimators: V0A / ZN

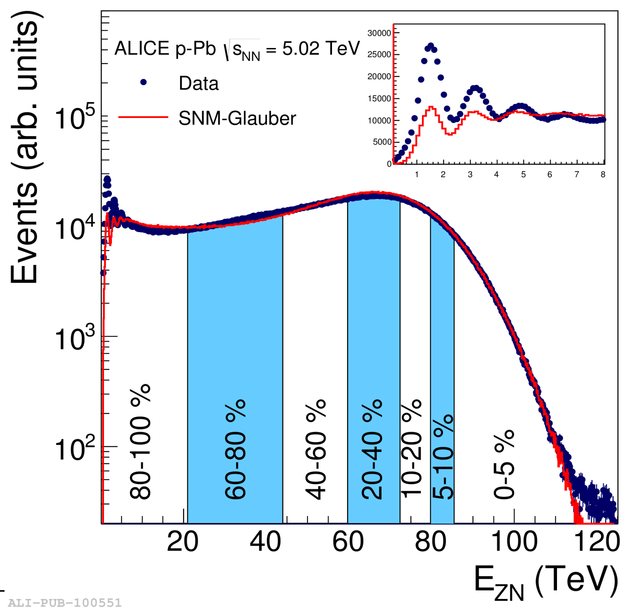
- **V0A:** ⟨N_{coll}⟩ from **Glauber** fit to V0A **amplitude** (Pb-going direction)
  - **Multiplicity** from Negative Binomial Distribution (**NBD**)

- **ZN**: ⟨N_{coll}⟩ from **hybrid** approach
  - Event classes defined by **energy deposited** in the ZNA (Pb-spectator neutrons)
  - ⟨N_{coll}⟩ obtained by **scaling** with **multiplicity** the minimum-bias value

$$\langle N_{coll}\rangle_i = \langle N_{coll}\rangle_{MB}\left(\frac{\langle dN/d\eta\rangle_i}{\langle dN/d\eta\rangle_{MB}}\right)-1$$

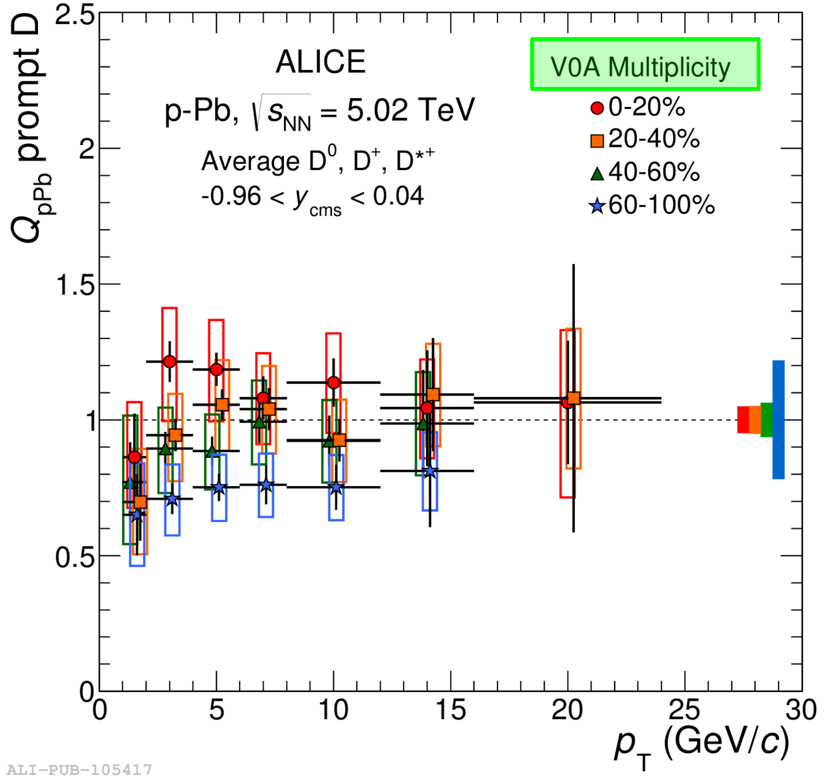
Phys. Rev. C91 (2015) 064905

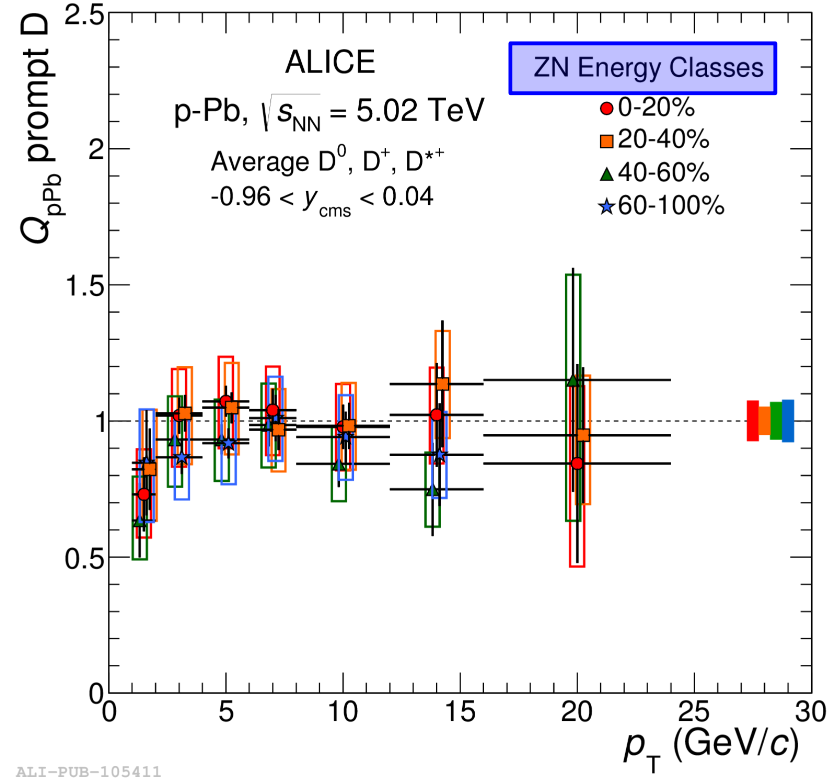




Q_{pPb} vs p_T for D mesons

arXiv:1602.07240





- Q_{pPb} from average D mesons shows a **residual bias** with the **V0A** estimator; **less bias for ZN**
- With ZN estimator: **no** significant **multiplicity dependent modification** of D-meson production is observed in p-Pb collisions w.r.t. pp collisions
- **Consistent** with **charged hadrons** at **high p_T** Phys. Rev. C91 (2015) 064905

Heavy-flavour production in high multiplicity events

pp: **heavy-flavour** dependence vs charged-particle **multiplicity**:

- **Interplay** between **hard** and **soft** contributions to particle production
- More-than-linear **increase** can be **explained** by Multi-Parton Interactions (**MPIs**)

p-Pb: multiplicity dependence of heavy-flavour production in **p-Pb** collisions **also** through **large** $\langle N_{coll} \rangle$

4pm:
F. Colamaria

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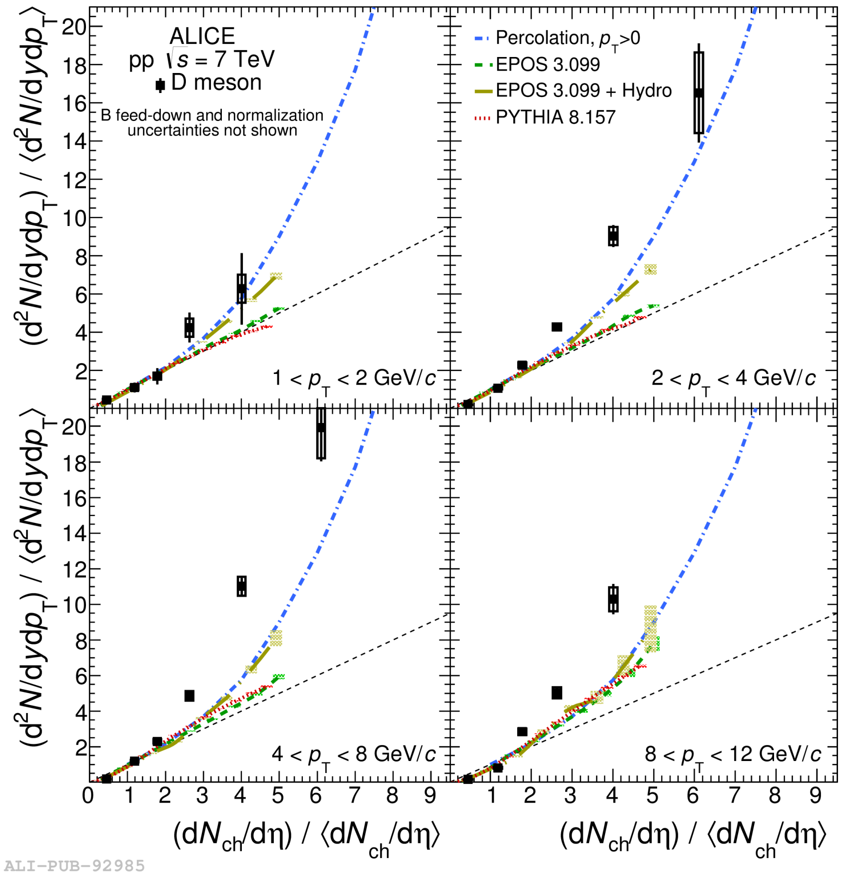
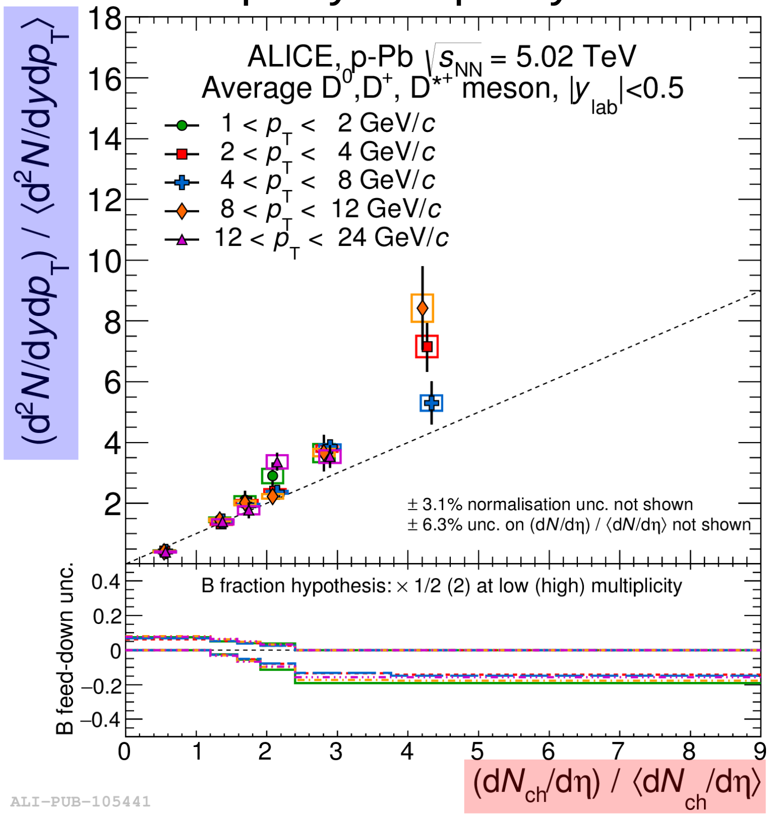
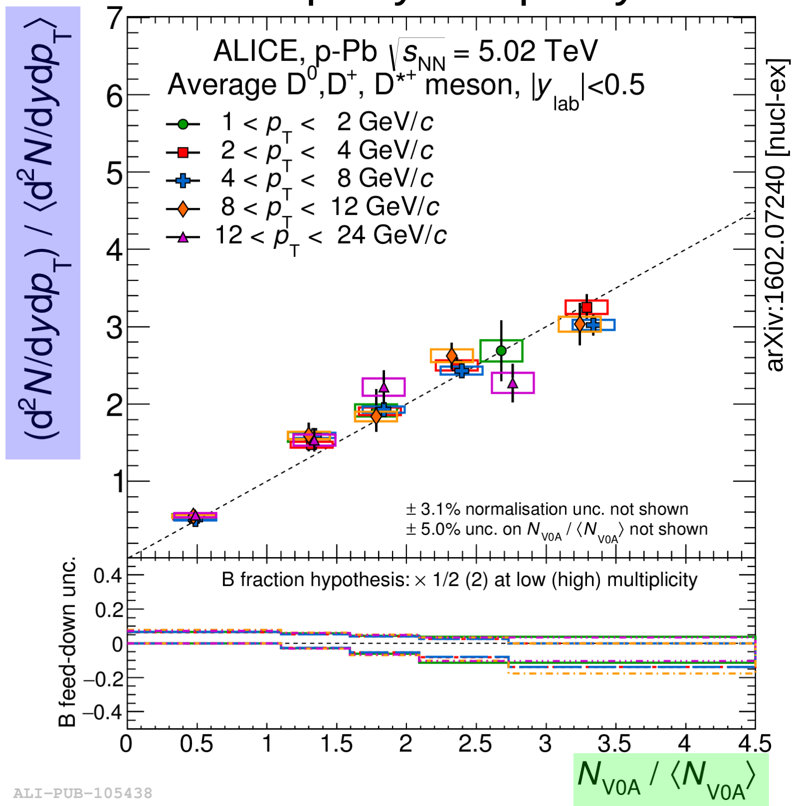


Relative D-meson yields vs multiplicity in p-Pb collisions

Mid-rapidity muliplicity estimator



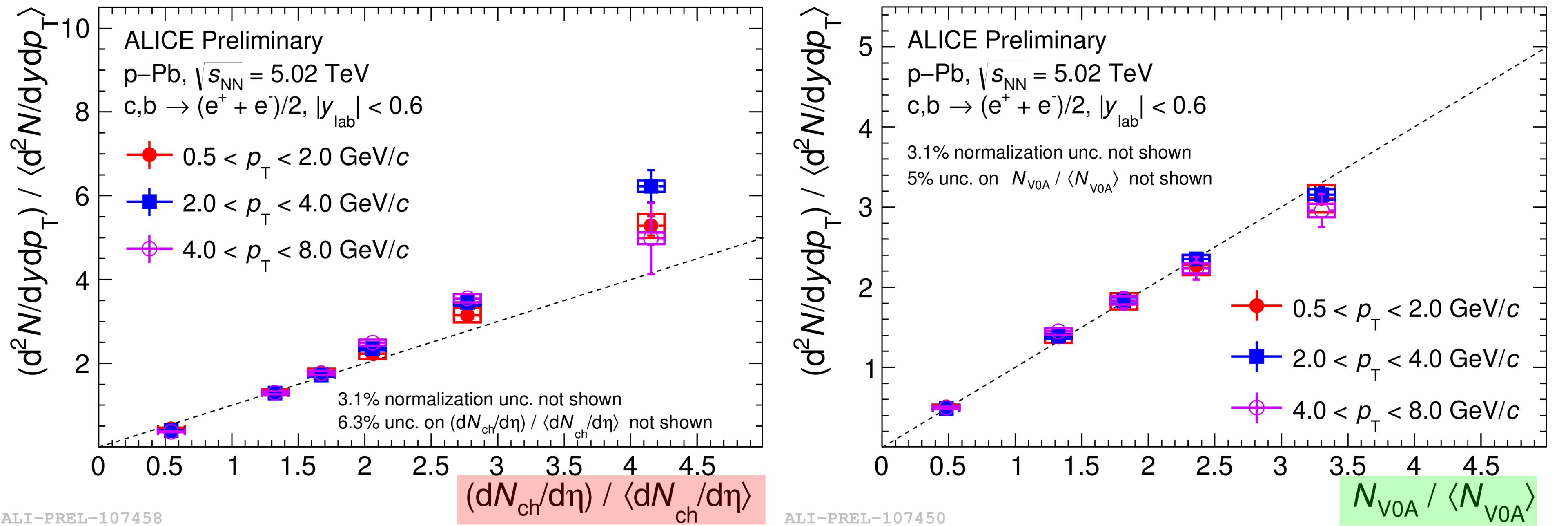
Backward rapidity muliplicity estimator



- **No p_T dependence** of relative yields
- **Faster**-than-**linear increase** vs $dN_{ch}/d\eta/\langle dN_{ch}/d\eta \rangle$
- **Linear increase** for relative yields vs $N_{V0A}/\langle N_{V0A} \rangle$

$$\frac{(d^2N/dy\,dp_T)}{\langle d^2N/dy\,dp_T \rangle}$$

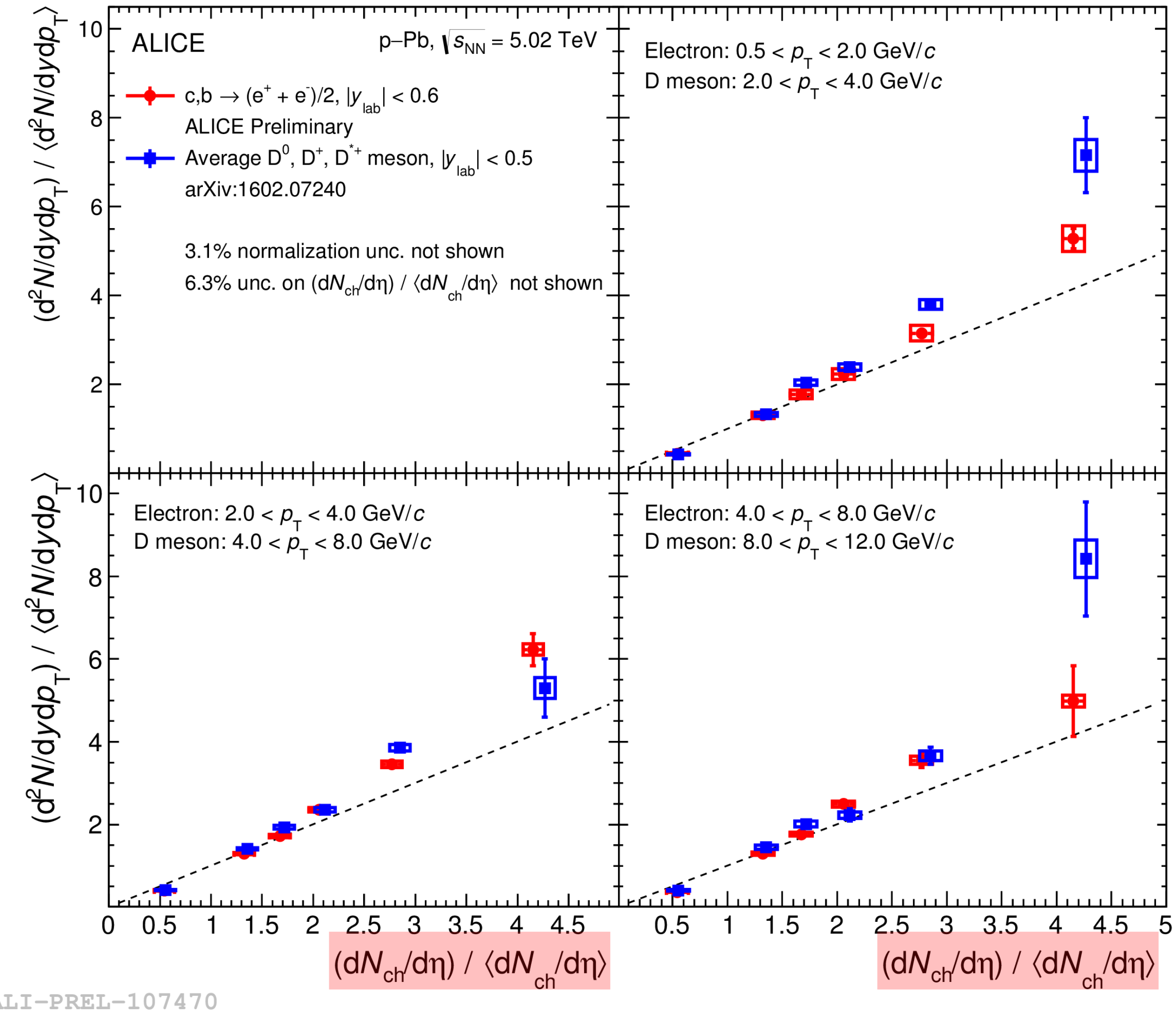
NEW: Relative yields of electrons vs multiplicity



- **New** measurement for **electrons** from **heavy-flavour** hadron decays
- **Similar** to results for D mesons (trend for **above-linear** / **linear**)
- **No** significant **change** for p_T>4 GeV/c (**>50% b→e** contribution)

Comparison between D mesons and (c+b)→e

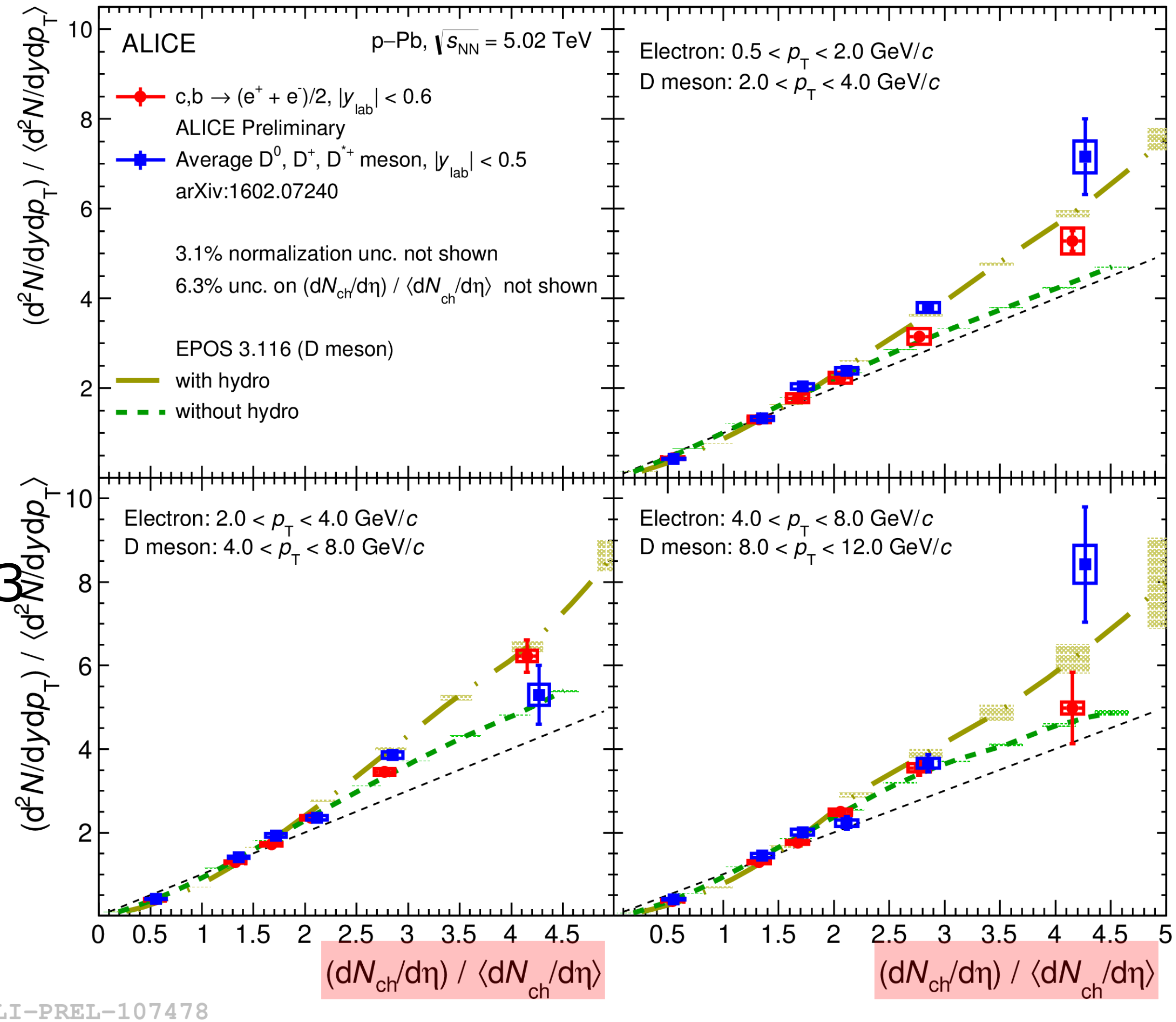
- **HF-decay electrons** and **D mesons** are **compatible** within their uncertainties
- different p_T range for better kinematic comparability



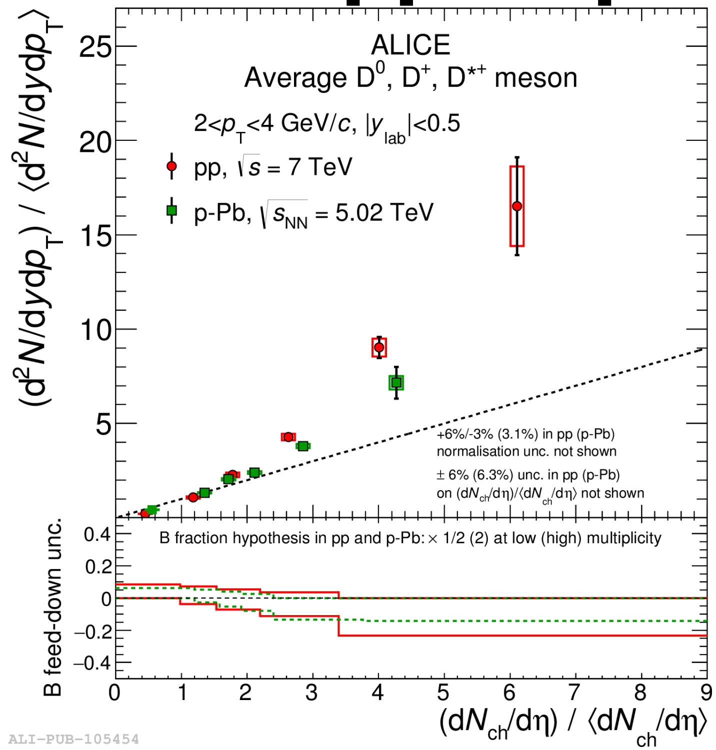
Comparison between D mesons and (c+b)→e with EPOS

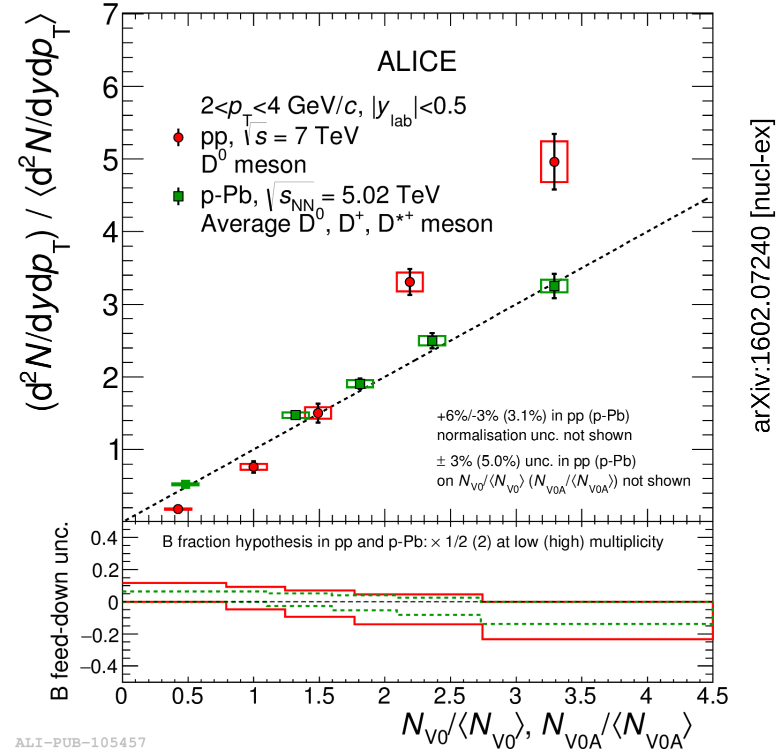
- **EPOS 3** with initial conditions and **hydro-dynamic** evolution **(includes MPIs):**

- D mesons **more** compatible with EPOS 3 **with hydro**



Multiplicity dependence of D mesons: pp vs p-Pb collisions





- Multiplicity at **mid**-rapidity: **comparable** relative D-meson yields in pp and p-Pb collisions
- Multiplicity at large (**backward**) rapidities:
  - Measured in **different η ranges** in pp and p-Pb collisions
  - **Faster increase** of D-meson yields in **pp** than in **p-Pb** collisions
- **MPIs & ⟨N_{coll}⟩>1 contributions** in **p-Pb** collisions not easy to disentangle

Trends for beauty hadrons vs multiplicity

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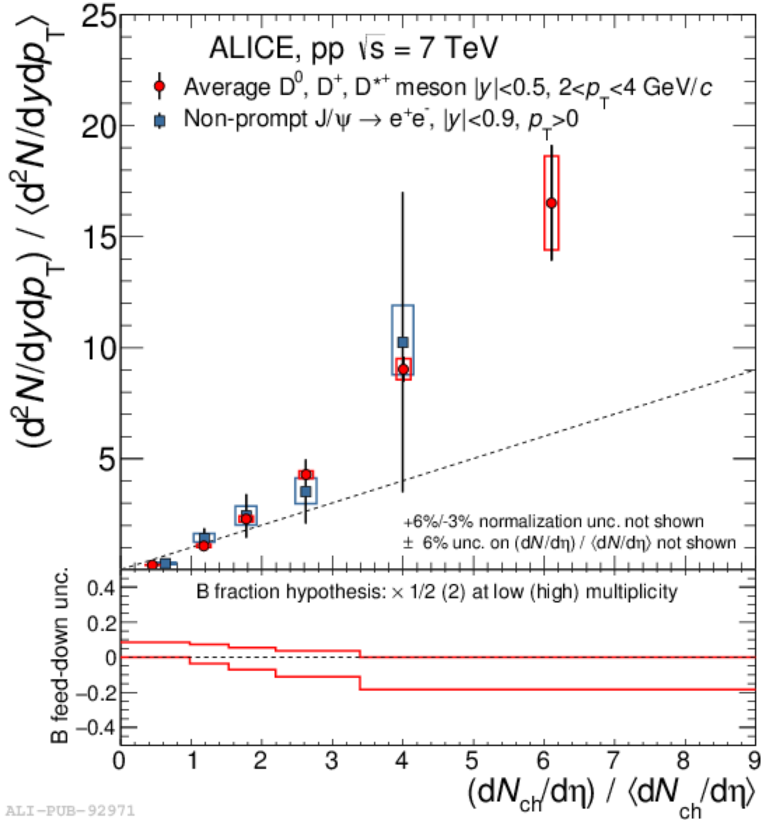

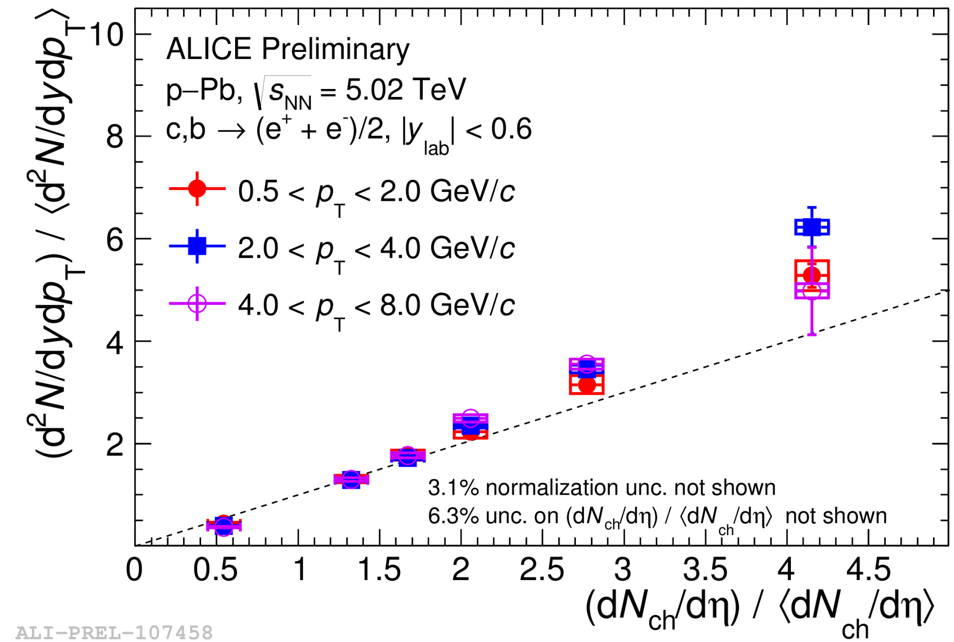

- **pp**: relative yields of **non-prompt J/ψ** compatible with **D mesons**
- **p-Pb**: no p_T dependence on relative yields of **(c+b)→e** (**significant** (>50%) b→e for p_T>4 GeV/c)

Conclusions 1/3

- Q_{pPb}^{multi} compatible with **unity**: heavy-flavour yields in p-Pb collisions consistent with **binary**-collision **scaling** of the yields in pp collisions, independent of multiplicity

- **Relative heavy-flavour** hadron yield **increases** with multiplicity (**D mesons** and decay **electrons**)
- **EPOS 3** (including $\langle N_{coll} \rangle$ and hydro) **reproduces D mesons** in p-Pb collisions

In **p-Pb** collisions contribution from **multiple**-**binary** collisions and **MPIs**

- **Dependence of collision system (pp** and **p-Pb** collisions):
  - Comparable yields for D mesons
  - Similar **trend** for beauty hadrons (caveat: limited statistics in pp collisions / mixing of b→e and c→e in p-Pb collisions)

Conclusions 2/3

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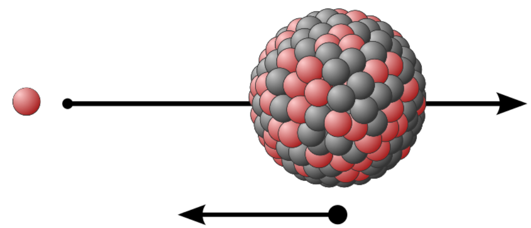
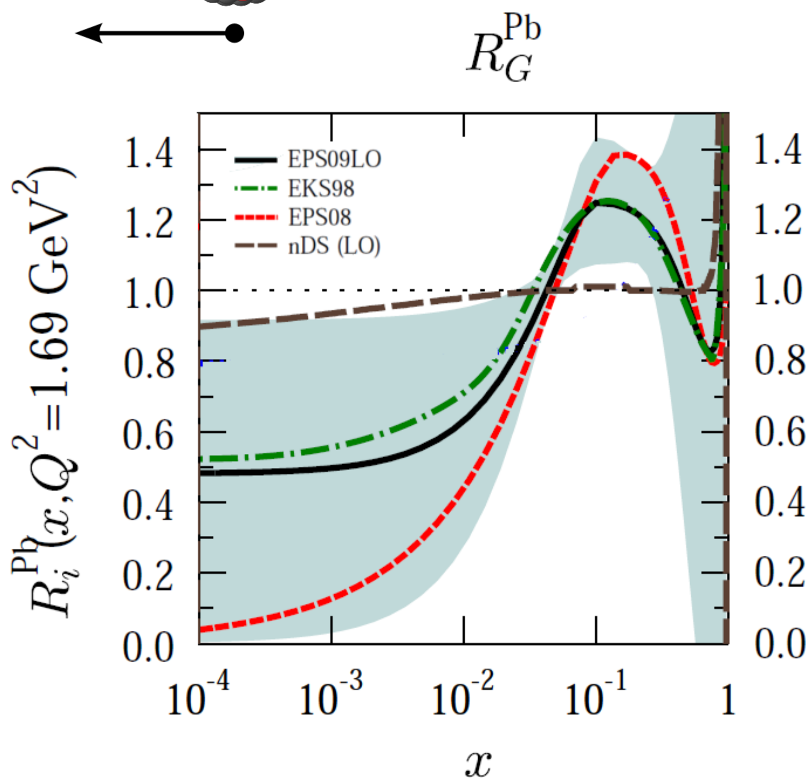
    (caveat: limited statistics in pp collisions / mixing of b→e and c→e in p-Pb collisions)

Backup

p-Pb collisions: measuring initial state effects

- **Initial state effects** might play a role for Pb-Pb collisions
- p-Pb collisions:
  - **No** extended **hot** and dense **medium**
  - Only cold nuclear matter effects:
    - **Modified** (g)**PDF** in nuclei
      - **Shadowing**
      - saturation at low *x*
      - Multiple scattering / E-loss
    - $\boldsymbol{k_T}$ **broadening**
- Measure nuclear modification factor $\boldsymbol{R_{pPb}}$ of HF hadron yield to quantify **cold nuclear matter effects**

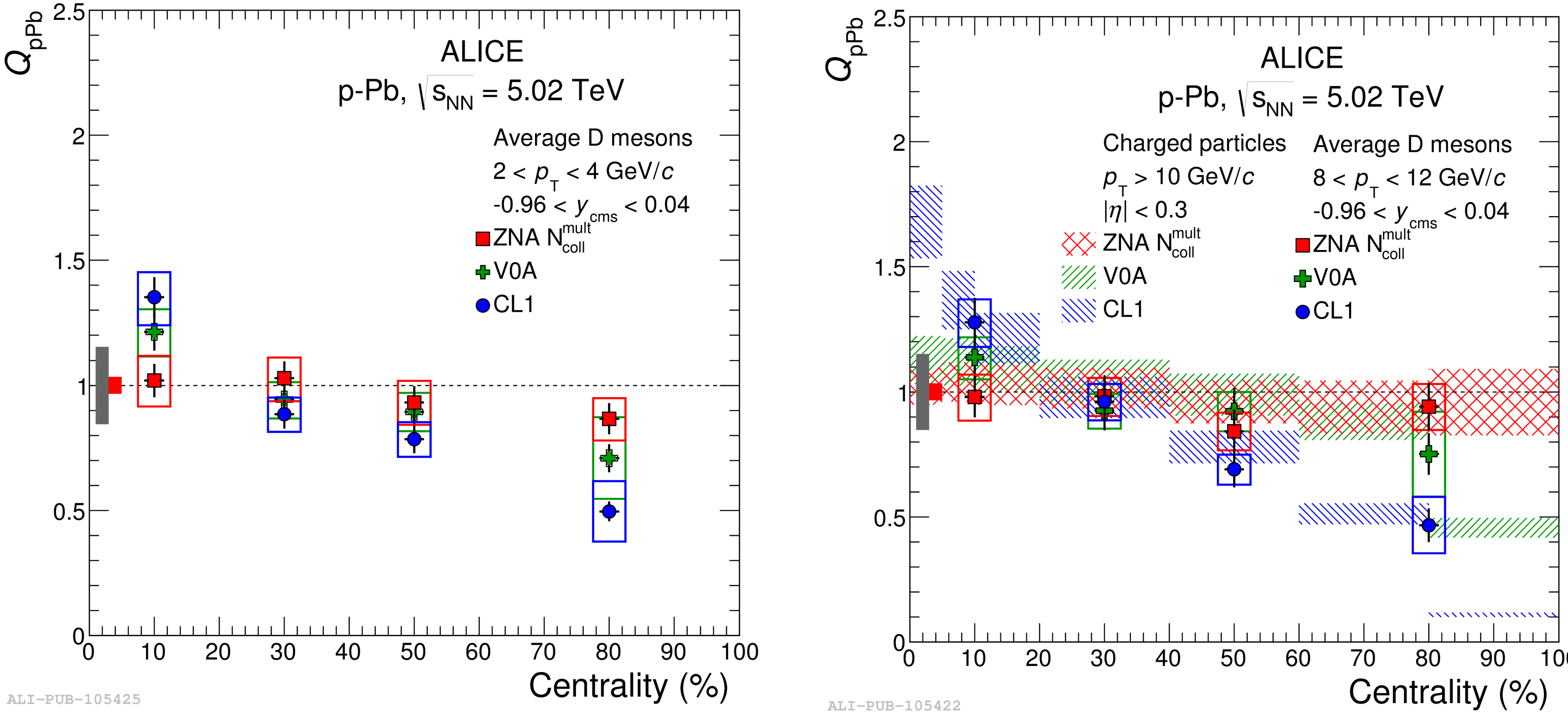




$$R_{pPb} = \frac{1}{A} \frac{d\sigma_{pPb}/dp_T}{d\sigma_{pp}/dp_T}$$

K.J. Eskola et al., JHEP, 0904:065, 2009.

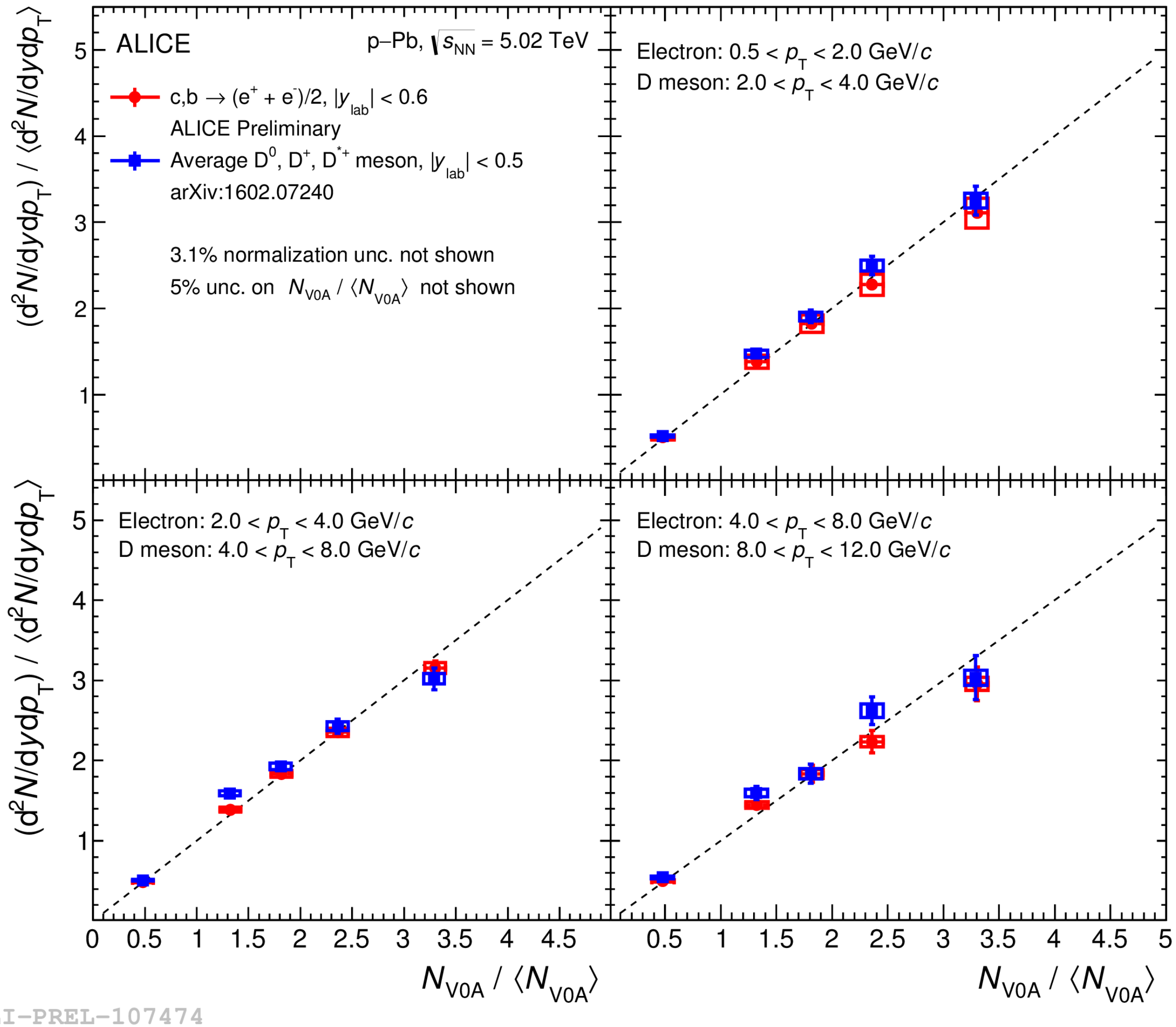
Q_{pPb} vs centrality for D mesons



- Bias for different multiplicity estimators
- Comparable bias for charged particles

Comparison between D mesons and (c+b)→e (V0A multiplicity)

- **HF-decay Electrons** and **D mesons** are very similar
- different p_T range for better kinematic comparability



Comparison with EPOS (V0A multiplicity)

- **EPOS 3** with initial conditions and **hydrodynamic** evolution **(includes MPIs):**
- EPOS 3 **with** and without **hydro agrees well** with the data