Heavy-flavour production as a function of multiplicity in pp collisions at the LHC

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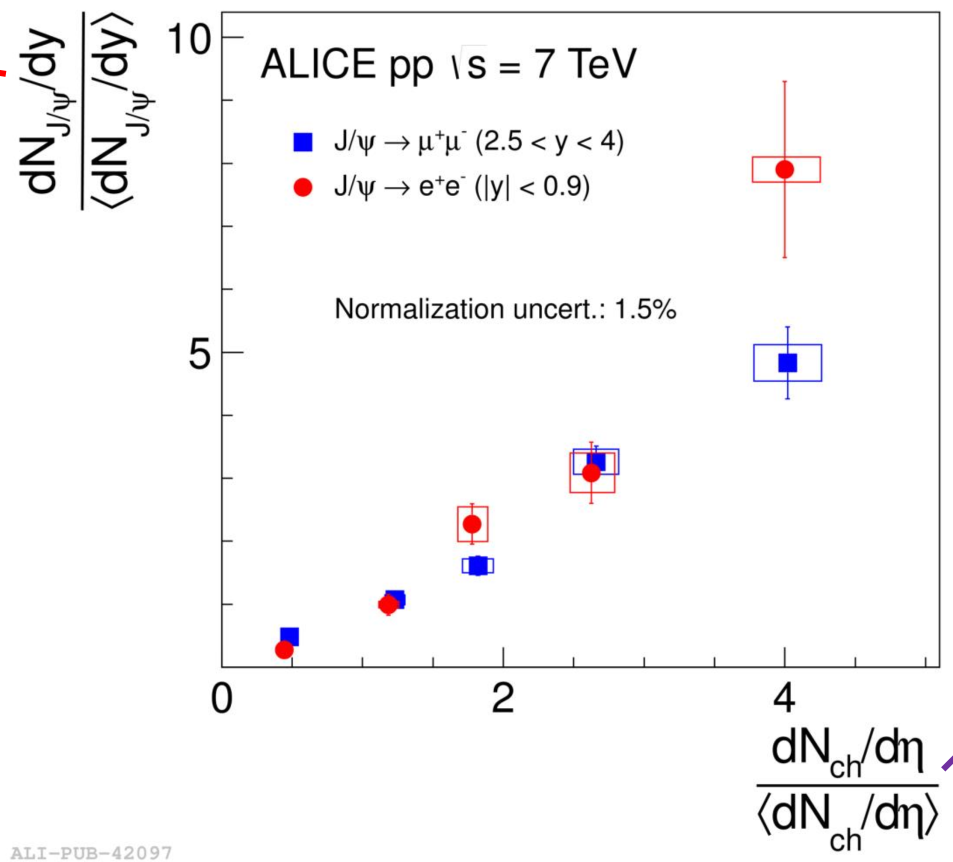
J/ψ production vs. multiplicity

📖 **ALICE, PLB 712 (2012) 165**

Hard process yield



Charged particle multiplicity

- Dominated by soft processes ?
- Coincides with KNO scaling variable

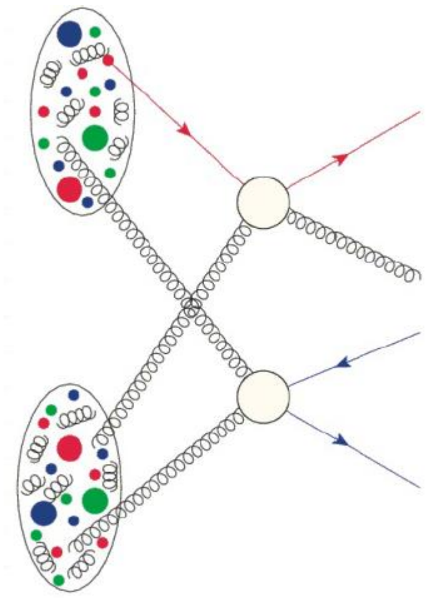
📖 **Koba, Nielsen, Olesen, Nucl.Phys. B40 (1972) 317**

- Per-event J/ψ yield increases approximately linearly with multiplicity
  - ⇨ Hadronic activity accompanying J/ψ production?
  - ⇨ Multi-Parton interactions?

Multi Parton Interactions

- Naïve picture
  - ⇨ Several interactions at the partonic level occur in parallel
    - ✓ ***At LHC energies: cross section for 2-2 parton scatterings with $\sqrt{Q^2}$ ~ few GeV/c exceed the total hadronic cross section***

      📖 **Bartalini, Fano, arXiv:1003.4220**
  - ⇨ Yield of particles from hard processes should increase with multiplicity



- More complex picture
  - ⇨ Role of collision geometry (impact parameter + transverse structure of proton)

    📖 **Frankfurt, Strikman, Weiss, PRD 83 (2011) 054012**

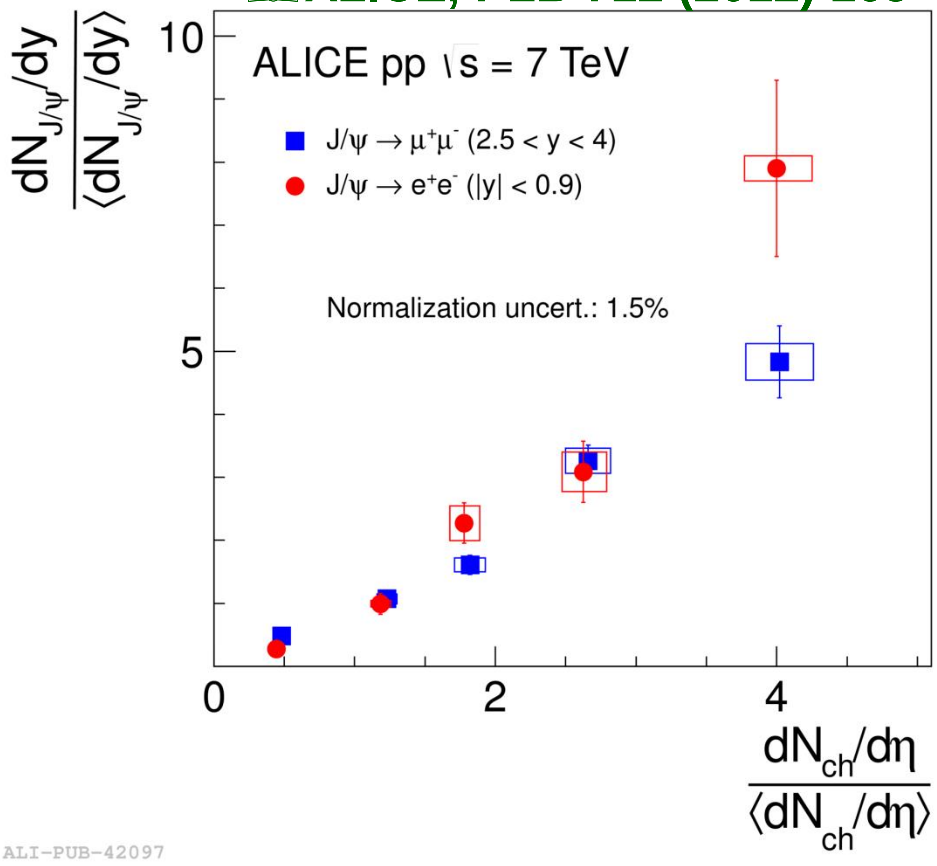
    📖 **Azarkin, Dremin, Strikman, PLB 735 (2014) 244**
  - ⇨ Final state: color reconnections, saturation, string percolation

    📖 **Ferreiro, Pajares, PRC 86 (2012) 034903**
  - ⇨ Collectivity in pp for sufficiently high multiplicities?
    - ✓ ***Multiplicities in high multiplcity pp collisions at the LHC similar to peripheral Cu-Cu at RHIC***

      📖 **Werner et al., PRC 83 (2011) 044915**

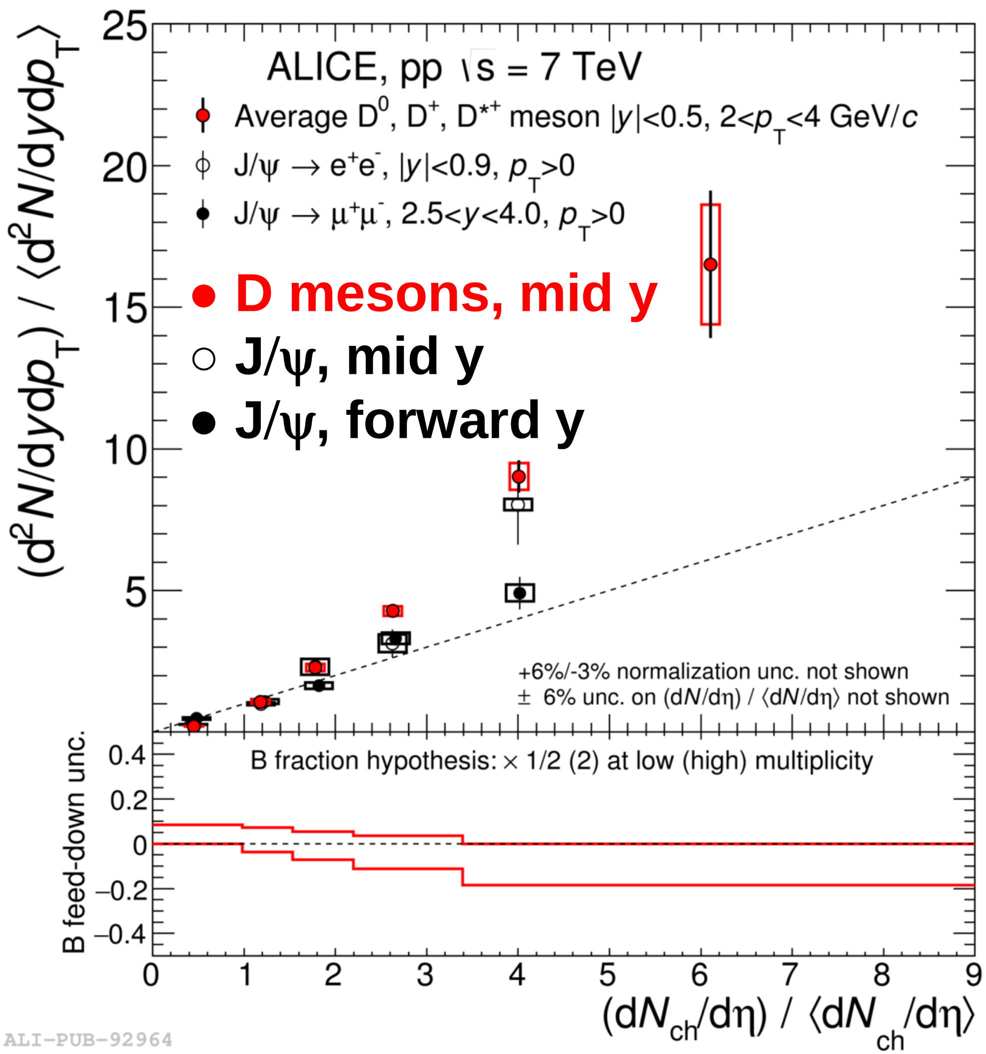
How to gain more insight?

📖 **ALICE, PLB 712 (2012) 165**



- Extend to **open charm** (D mesons)
  - ⇨ Compare open/hidden charm production -> insight in the role of **hadronization**?
  - ⇨ Study yield of D mesons vs. multiplicity in p_T **intervals** -> handle on Q^2 of hard scattering?
- Extend to **higher multiplicities**
  - ⇨ Clearer picture of the trend. Linear? Stronger than linear? Saturation due to a maximum number of MPI for collisions at zero impact parameter?

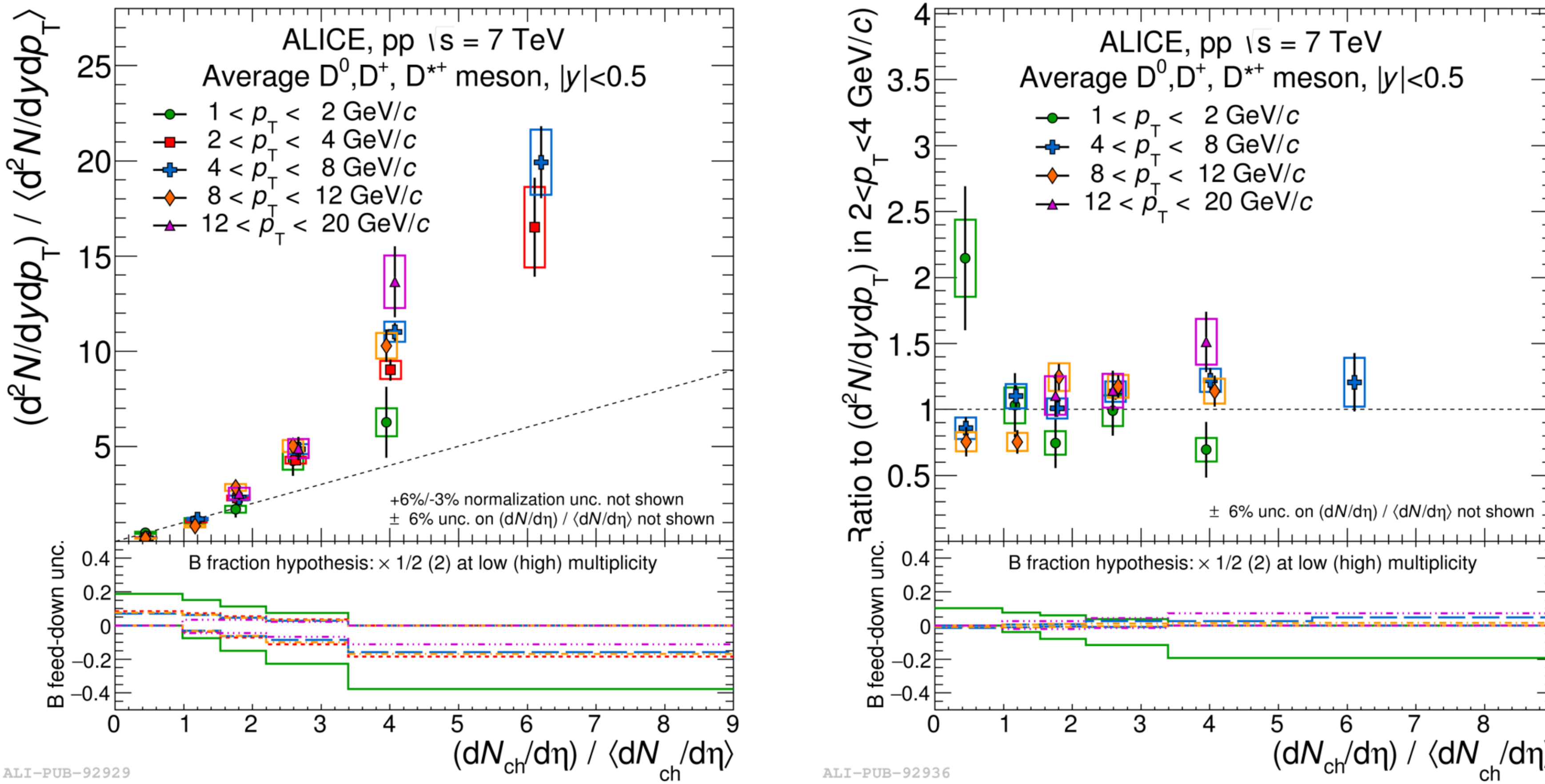
D mesons vs. inclusive J/ψ



- Similar increase with multiplicity of per-event yield of open and hidden charm
- Inclusive J/ψ measured at mid (e^+e^-) and forward ($\mu^+\mu^-$) rapidity
  - ⇨ Forward rapidity J/ψ and charged multiplicity measured in different η regions

ALICE, arXiv:1505.00664
Inclusive J/ψ result from:
ALICE, PLB 712 (2012) 165

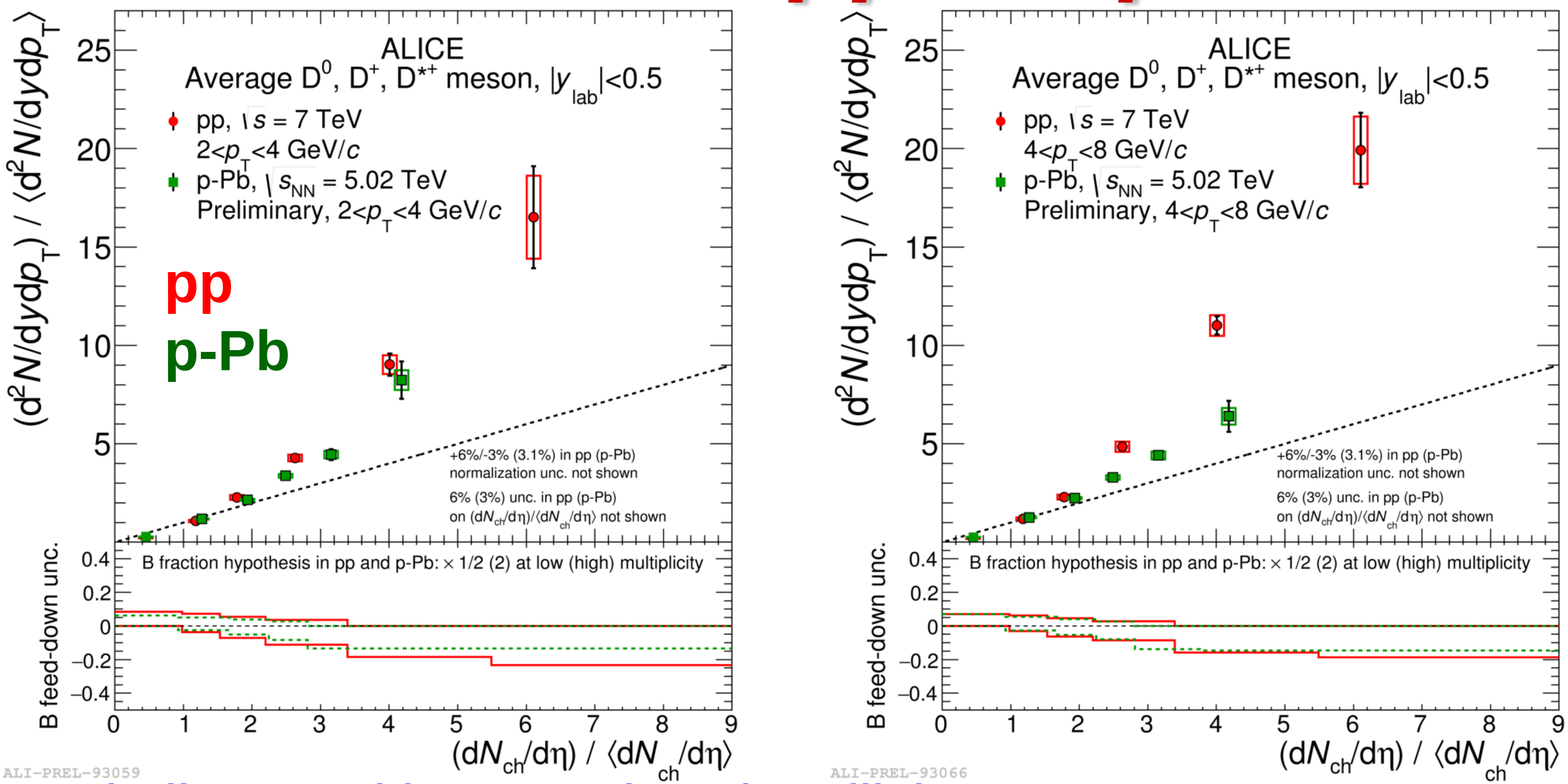
D-meson yield vs. multiplicity
p_T dependence?



- Trend of D-meson yield vs. multiplicity **independent of p_T** within uncertainties

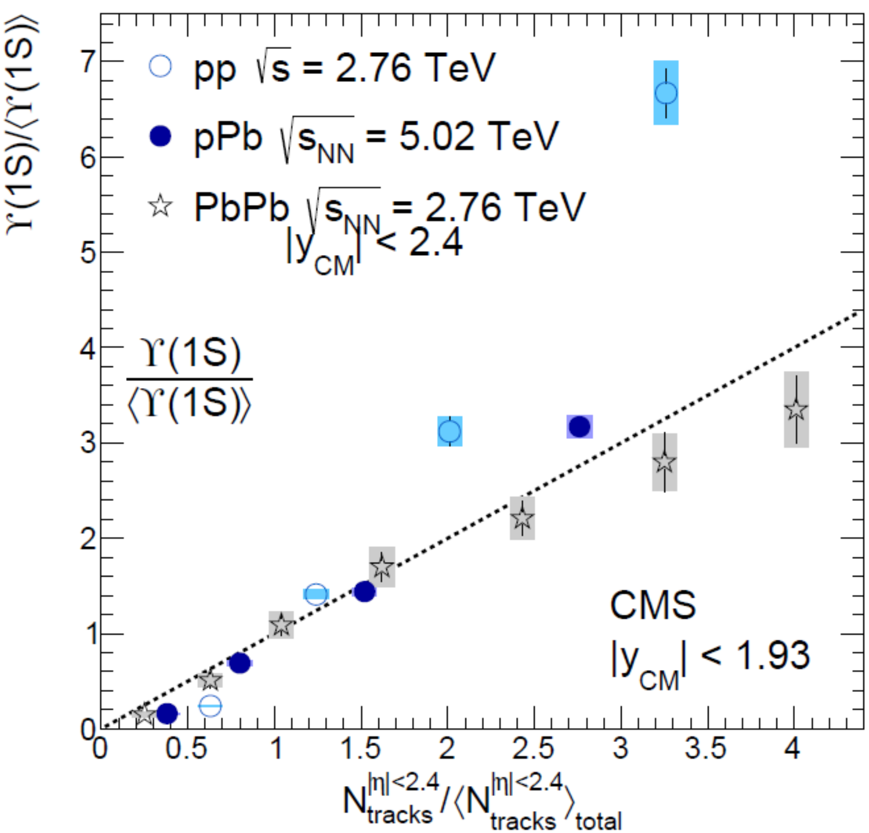
ALICE, arXiv:1505.00664

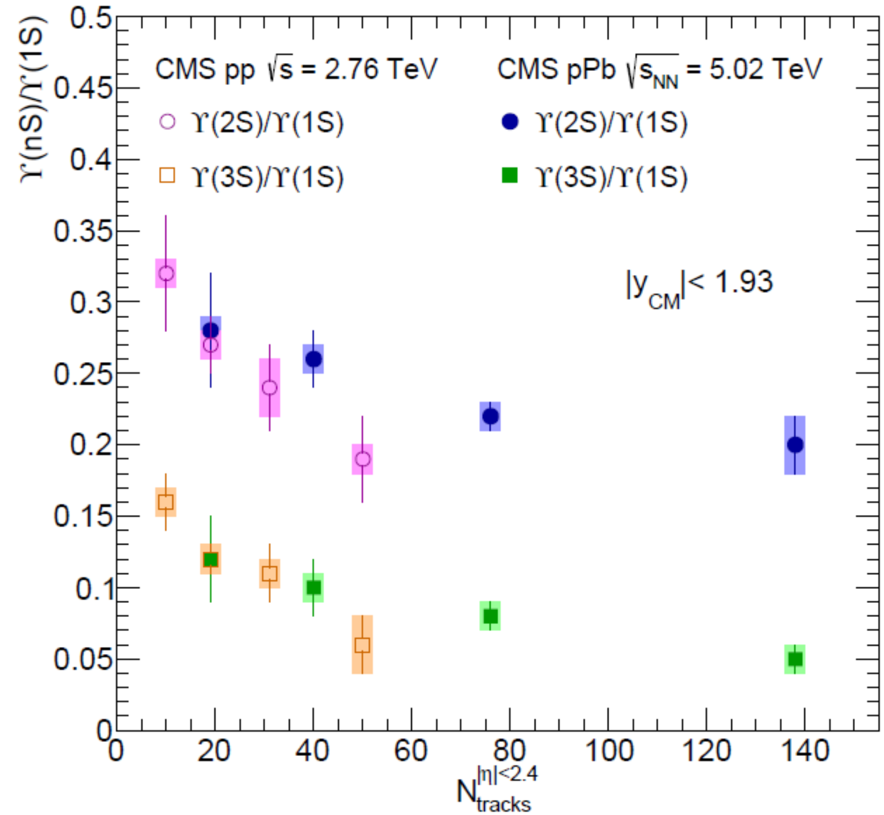
D mesons: pp vs. p-Pb



- Similar trend in pp and p-Pb collisions
- Caveat:
  - ⇨ dN/dη~4<dN/dη> in **pp** from many **MPIs** + high number of fragments per parton
  - ⇨ dN/dη~4<dN/dη> in **p-Pb** also from **multiple** (and softer) **nucleon-nucleon collisions**

Bottomonia vs. multiplicity

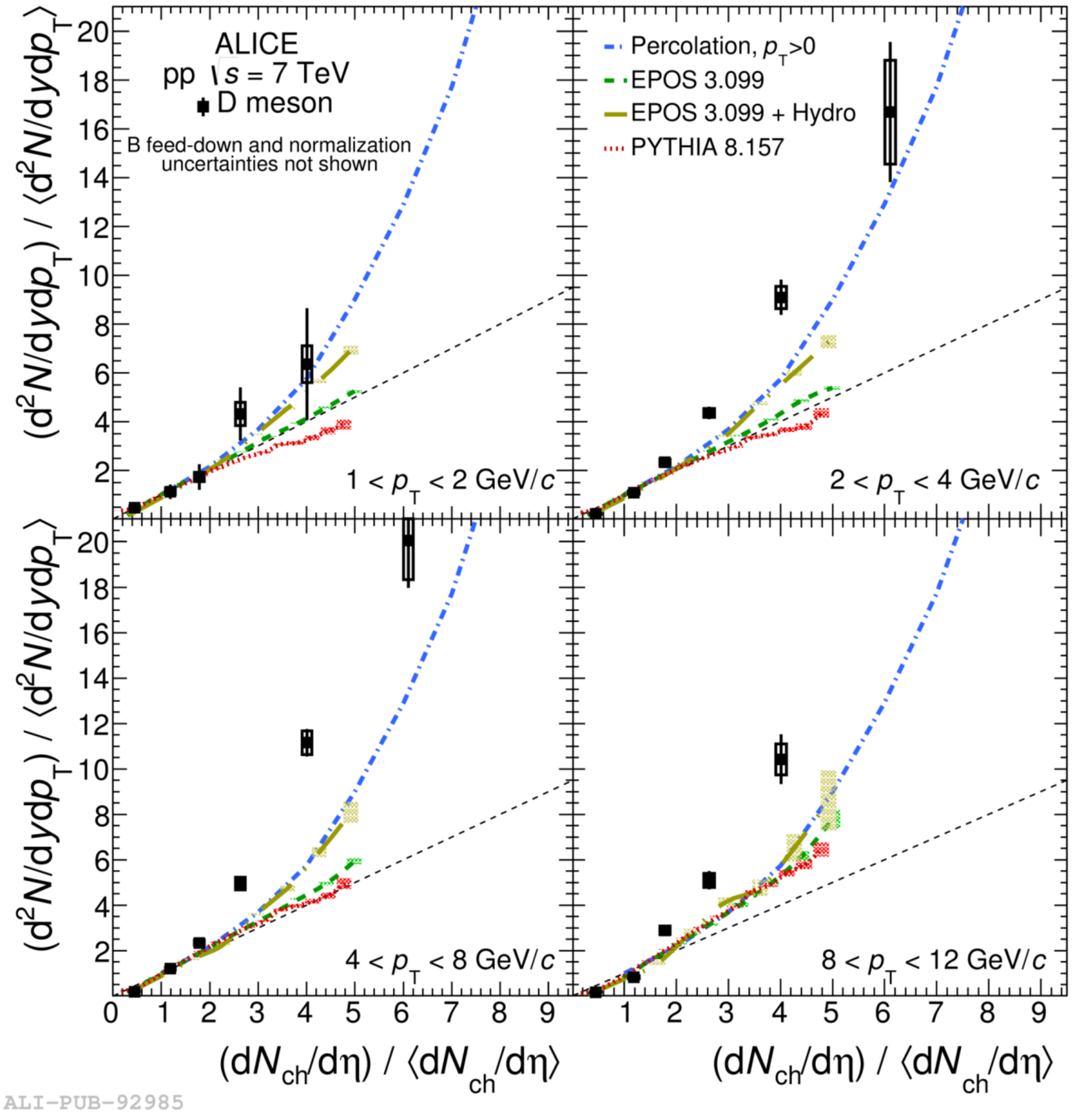




- Yield of Υ increases with multiplicity
  - ⇨ Similar in pp, p-Pb and Pb-Pb
  - ⇨ In Pb-Pb (and p-Pb) number of nucleon-nucleon collisions increases with multiplicity
- Υ(nS) production ratios depend on multiplicity
  - ⇨ Ground state Υ(1S) systematically produced with more particles?
  - ⇨ Excited states more easily dissociated by interactions with other particles?

📖 **CMS, JHEP 1404 (2014) 103**

Outlook (with more stats)



- Reduce uncertainties, extend to **higher multiplicities** and **higher p_T**
- More differential studies (vs. sphericity?)
- Angular correlations (D-hadron) in high multiplicity events

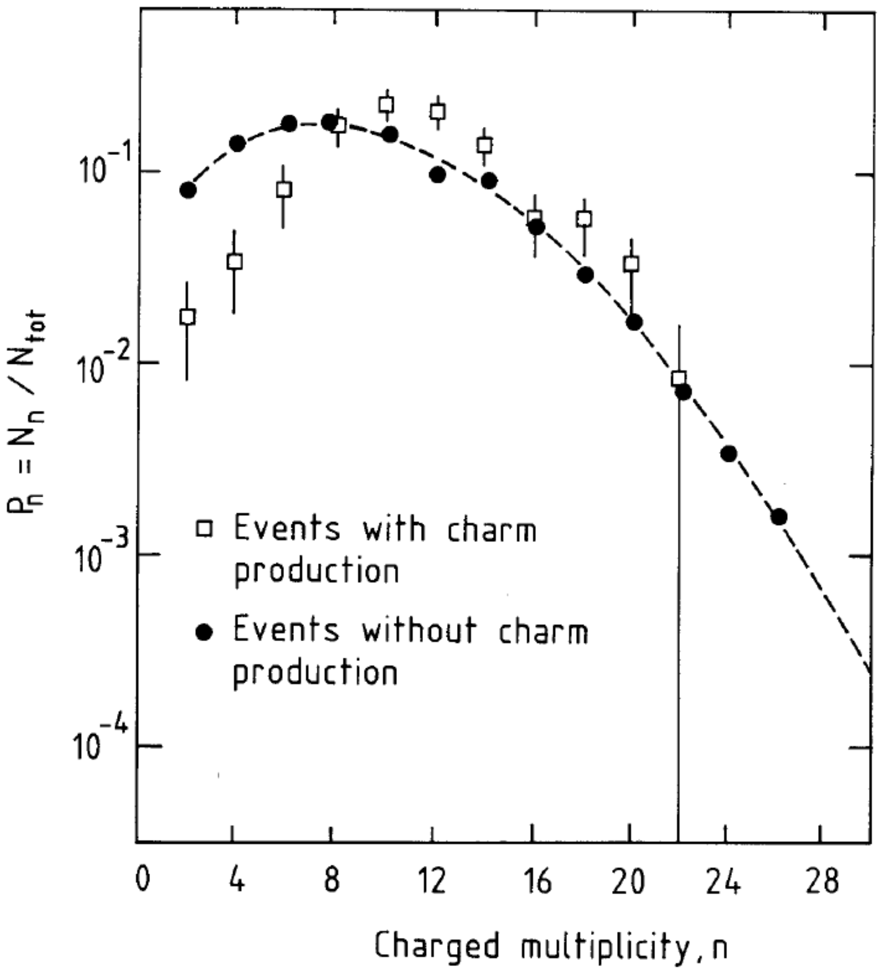
📖 **ALICE, arXiv:1505.00664**

📖 **Werner et al., PRC 89 (2014) 064903** 📖 **Ferreiro, Pajares, PRC 86 (2012) 034903**

Additional material

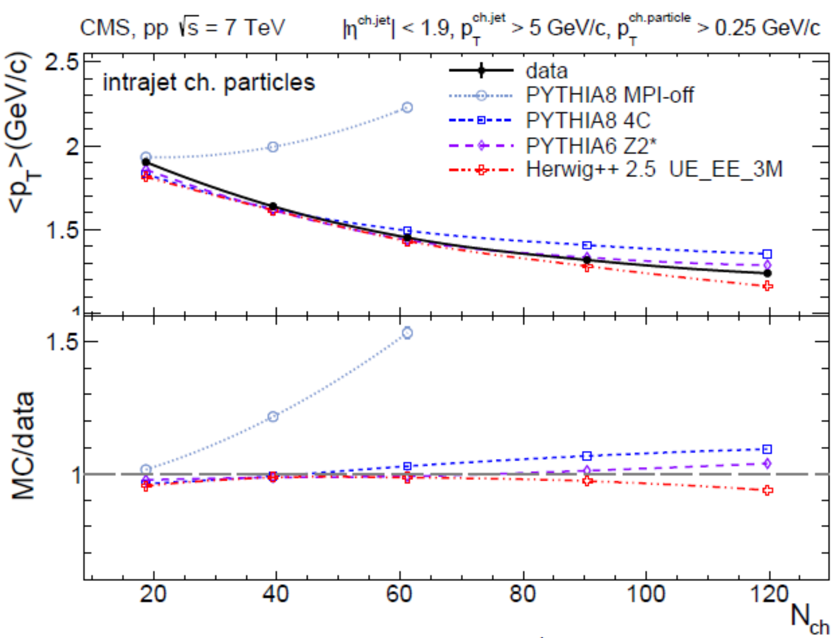
Charm production vs. multiplicity at the SPS

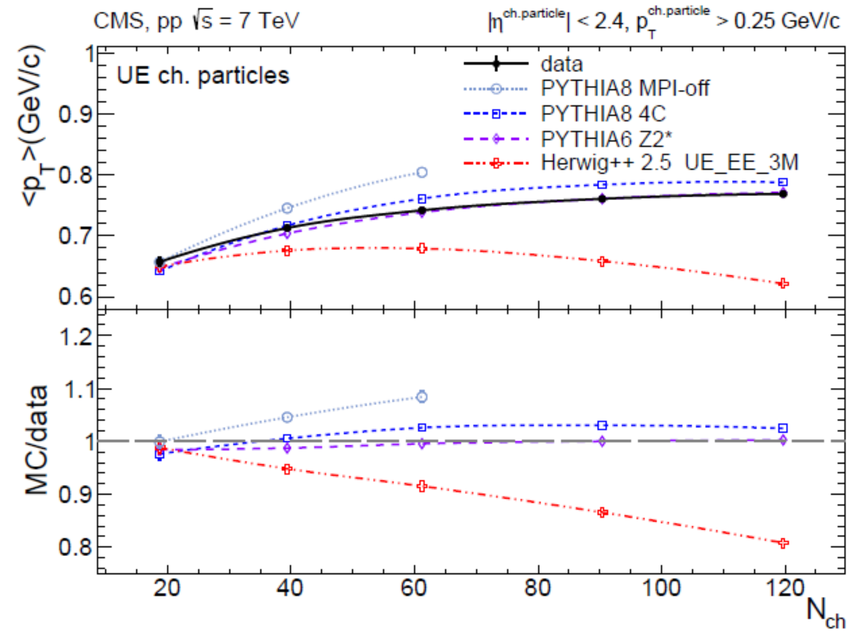
- NA27 and LEBC-EHS Collaboration
  - ⇨pp collisions at SPS
  - ⇨p_{BEAM} = 400 GeV
- Different multiplicity distributions for events with and without charm production
- "… It is natural to interpret these differences by the more *central* nature of collisions leading to charm production."

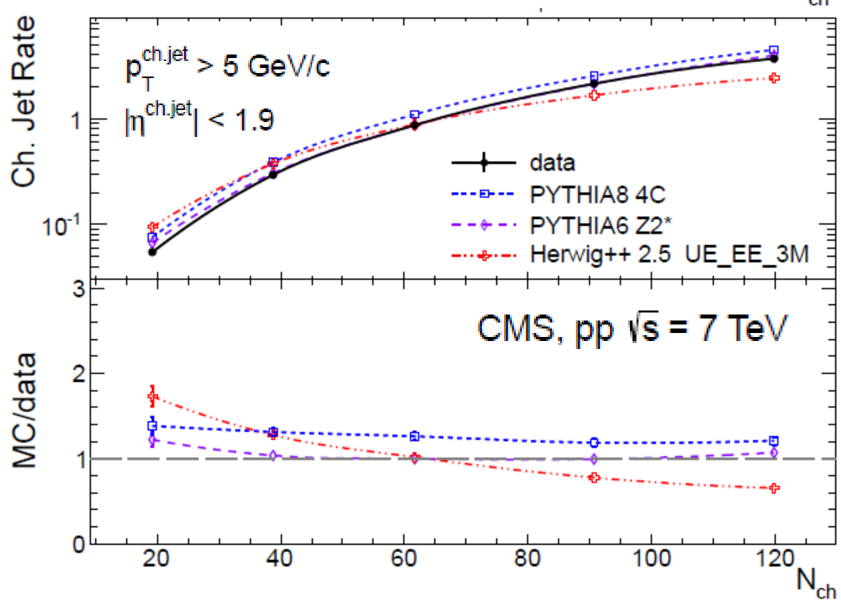


📖 **Aguilar-Benitez et al., Z. Phys C41 (1988) 191**

Jets and UE vs. multiplicity







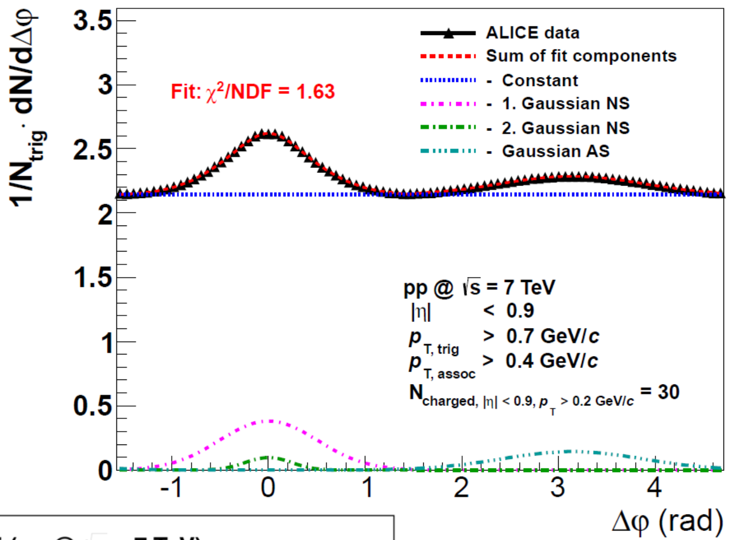
- High-multiplicity events:
  - ⇨ Larger number of (semi) hard parton interactions, (mini)jets
  - ⇨ Softer distribution of hadrons inside jets
- Multi-Parton Interaction (MPI) mechanism critical to reproduce the features of the data

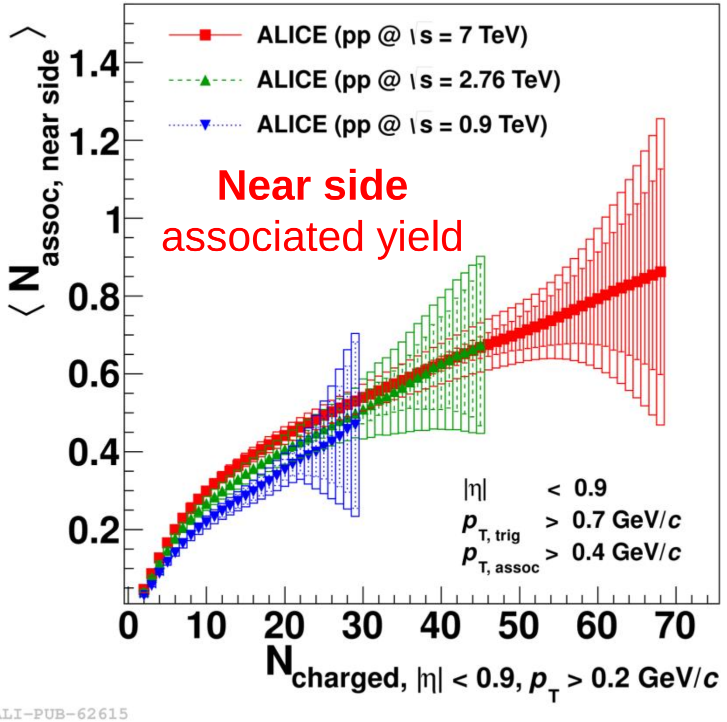
CMS, EPJ C73 (2013) 2674

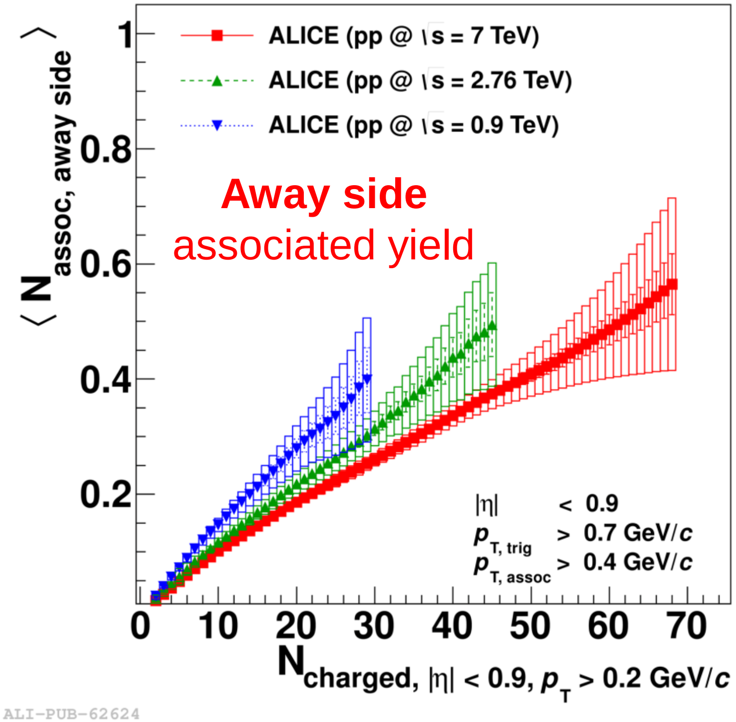
Mini jets in pp vs. multiplicity

- **Mini jets**: bundles of particles from semi-hard partonic scatterings
- **How**: from 2-particle correlations, associated yields in near and away sides

📖 ALICE, JHEP 09 (2013) 049







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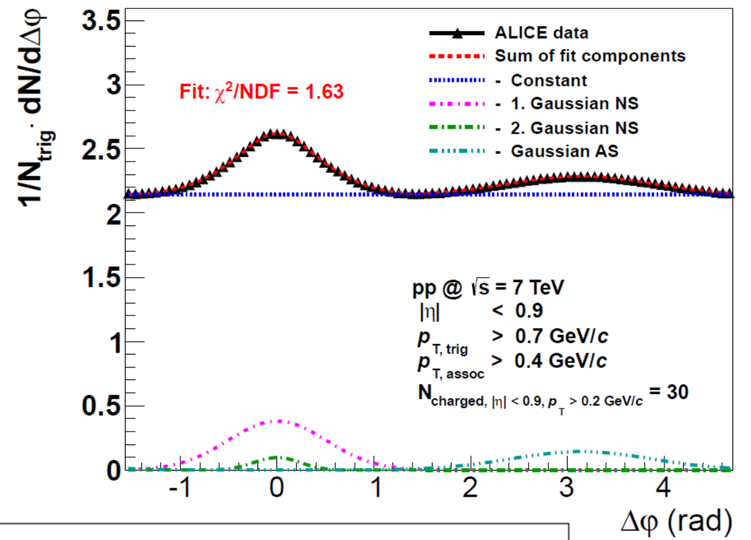
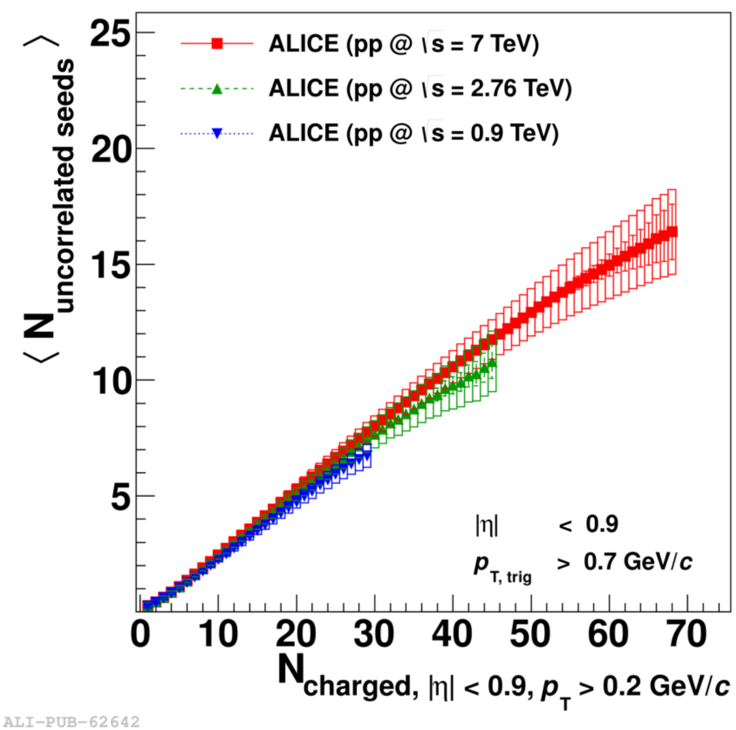


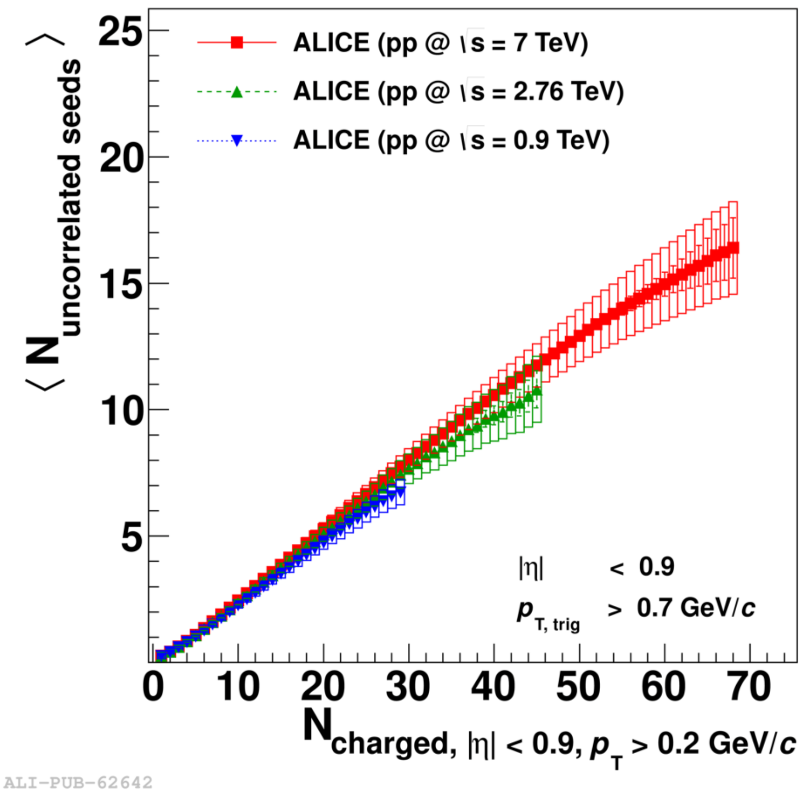
- Uncorrelated seeds = number of independent sources of particle production

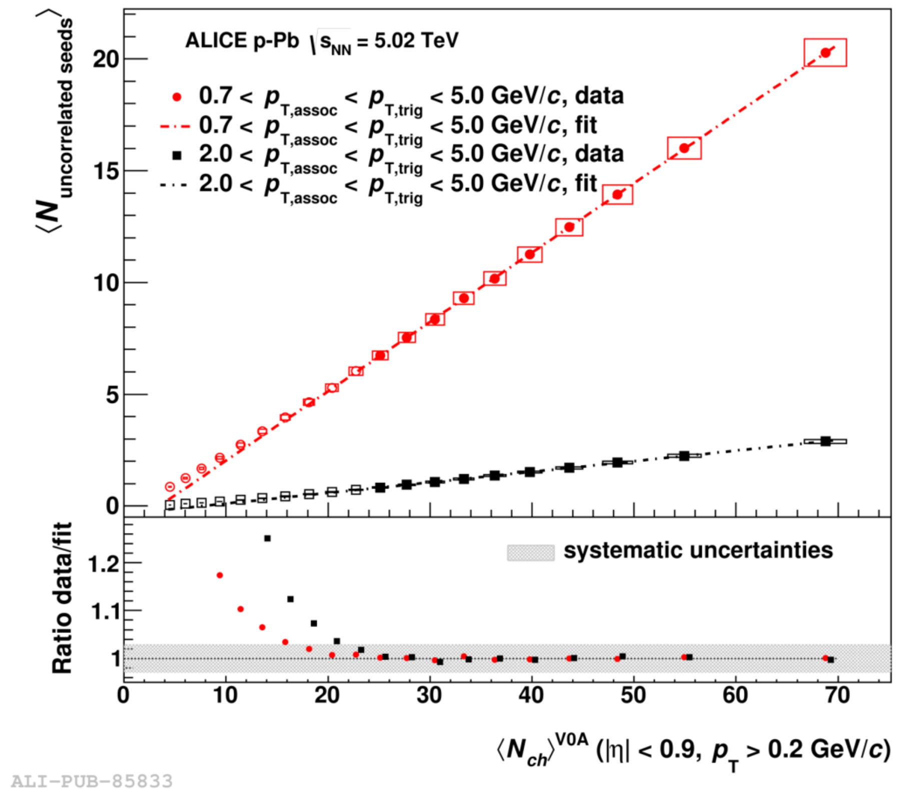
$$< N_{\text{uncorrelated seeds}} >= \frac{< N_{\text{trigger}} >}{< 1 + N_{\text{assoc, near+away}} >}$$

  - ⇨ In PYTHIA strongly correlated with number of MPIs
  - ⇨ Linearly increasing with multiplicity at low multiplicity
  - ⇨ Levels off at high multiplicities



Uncorrelated seeds: pp vs. p-Pb

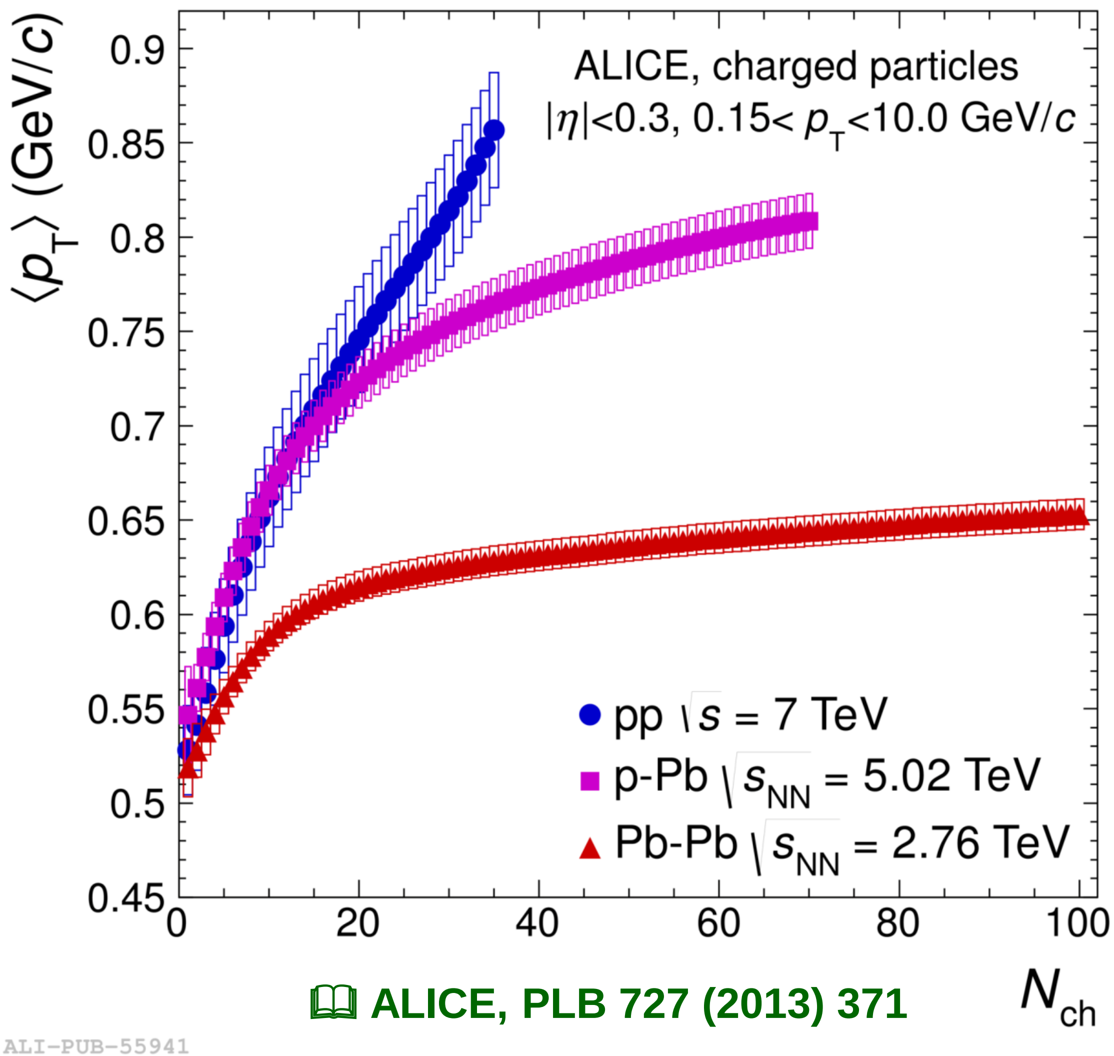




- Number of uncorrelated seeds grows linearly with multiplicity in p-Pb
- Levelling off in pp

📖 ALICE, JHEP 09 (2013) 049

Mean p_T in pp, p-Pb and Pb-Pb

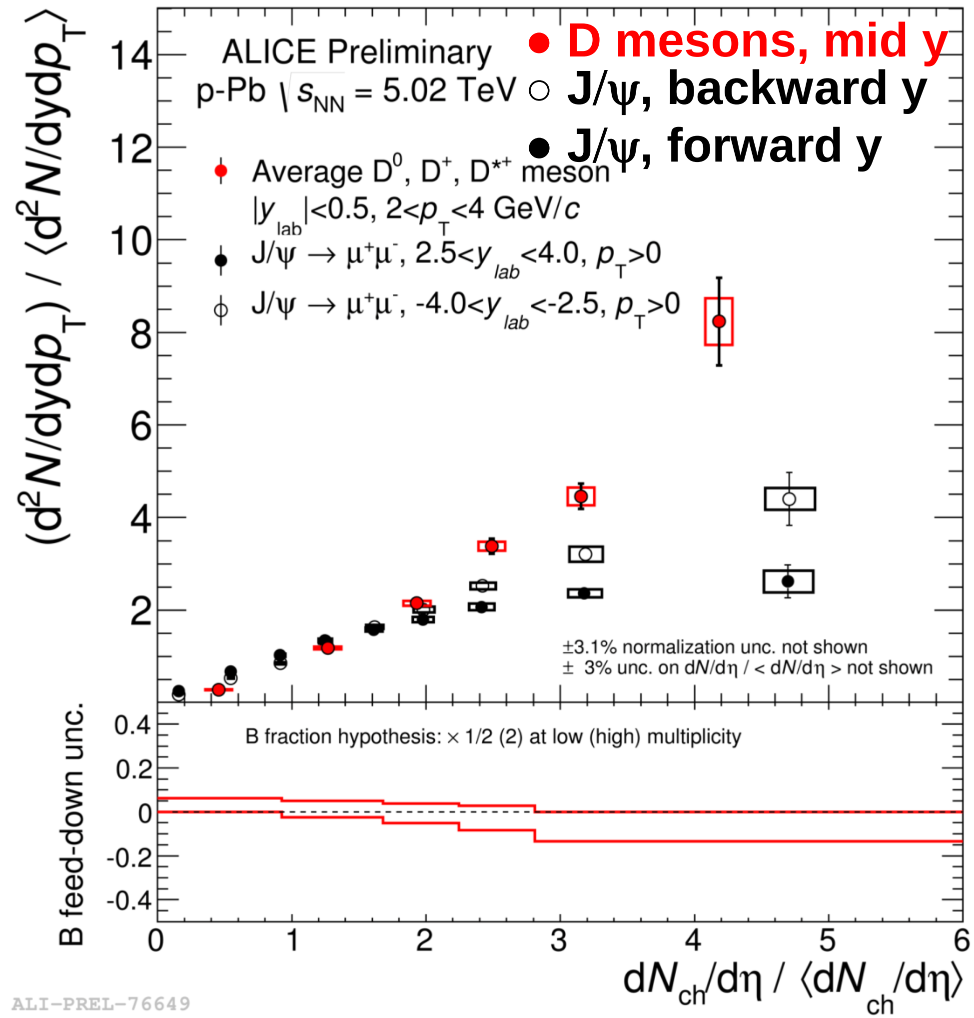


ALICE, PLB 727 (2013) 371

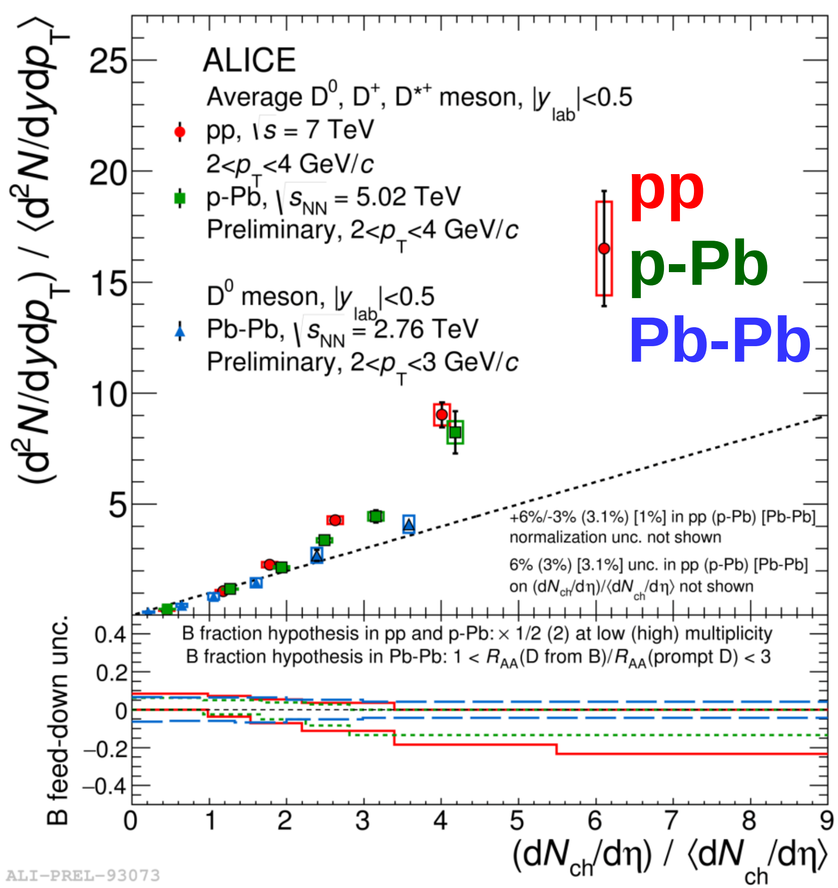
- Three different √s for pp, p-Pb and Pb-Pb
  - ⇨ but √s dependence expected to be weak
- Much stronger increase of <p_T> in p-Pb than in Pb-Pb
- p-Pb follows pp up to N_{ch}~14-15
- N_{ch}>14 corresponds to
  - ⇨ ~10% of pp x-section:
    - ✓ ***pp already highly biased***
  - ⇨ 50% of p-Pb x-section
    - ✓ ***only centrality bias***

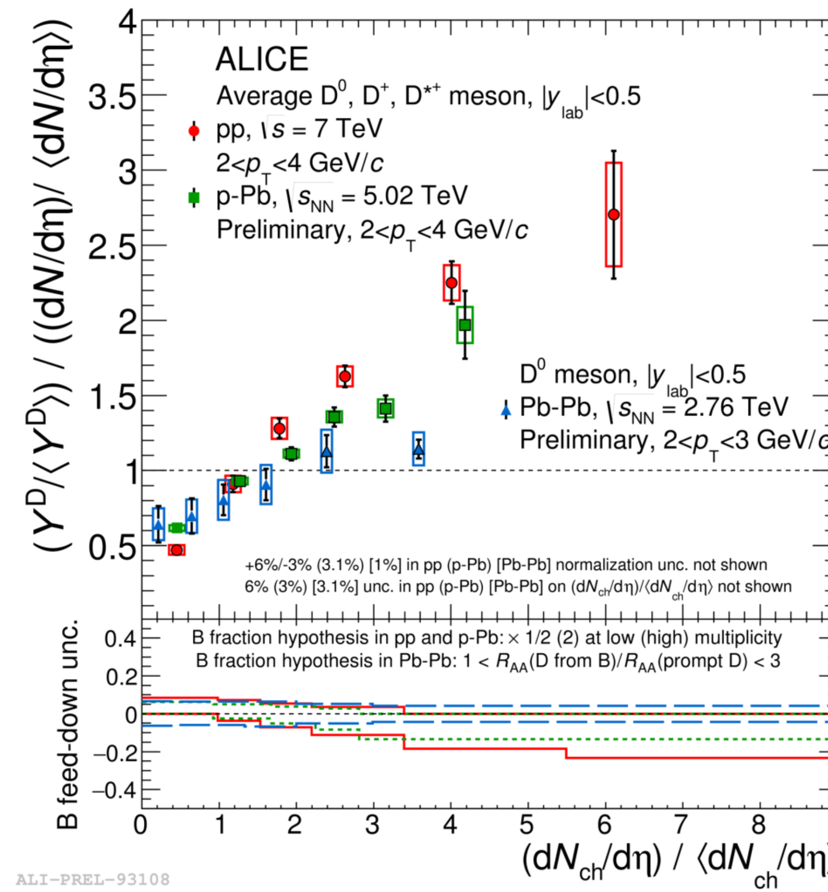
D mesons and J/ψ in p-Pb

- Similar increasing trend of D and J/ψ yields with multiplicity in p-Pb collisions at low multiplicities
- Deviation at high multiplicities
- NOTE:
  - Different p_T and *y* ranges for D's and J/ψ
  - Different probed values of Bjorken *x*
  - Different Cold Nuclear Matter effects



D mesons: pp vs. p-Pb vs. Pb-Pb

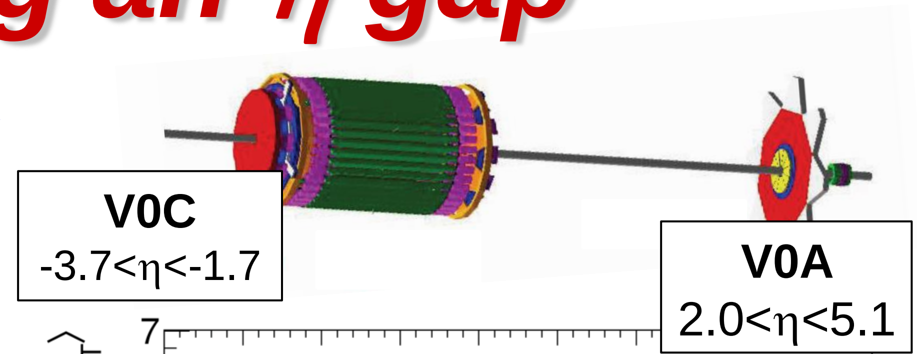


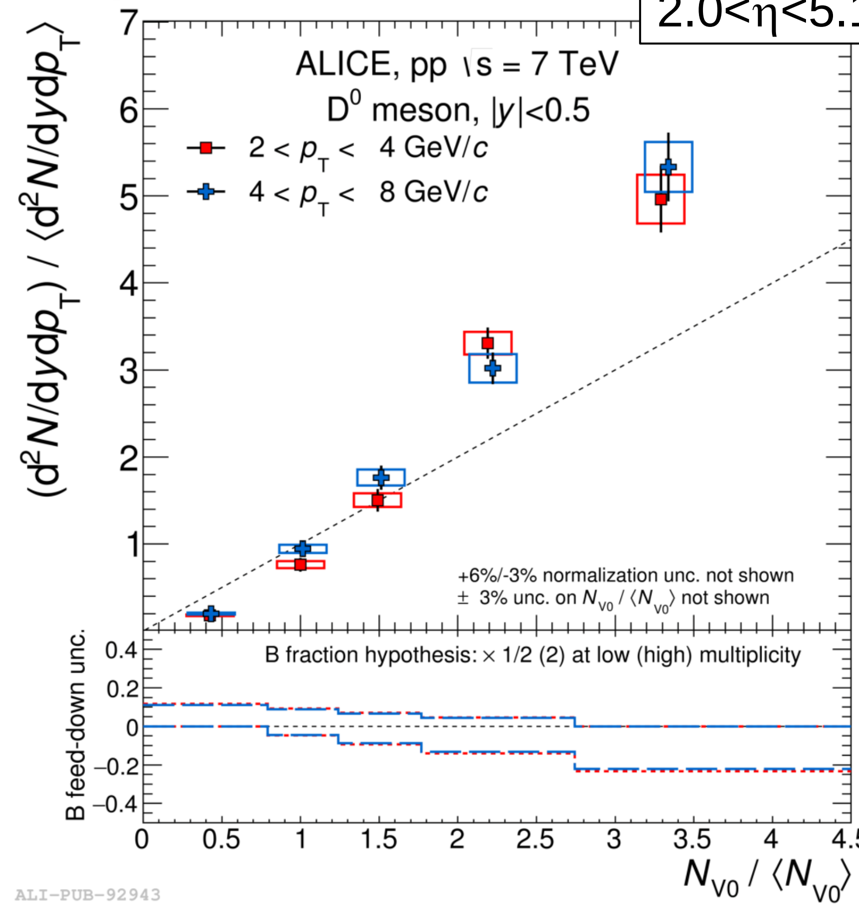


- Comparison to Pb-Pb
  - ⇨ NOTE: in-medium parton energy loss + radial flow modify the p_T distribution of D mesons in a centrality/multiplicity dependent way in Pb-Pb

Introducing an η gap

- Charged-particle multiplicity measured in the same η range as D mesons
- Multiplicity estimation includes:
  - ⇨ D-meson decay particles
  - ⇨ Particles produced in the charm-quark fragmentation
- Test effect of possible auto-correlations using the multiplicity measured in the V0 detector
  - ⇨ Qualitatively similar increasing trend when an η gap is introduced between the regions in which D mesons and multiplicity are measured





ALICE, arXiv:1505.00664

Going deeper into PYTHIA8

- Split by process:
  - First hard = hardest process
    - ✓ *~ flat D-meson yield with multiplicity*
  - MPI = subsequent hard processes
    - ✓ *Increasing D-meson yield with multiplicity*
  - Splitting of a gluon from a hard process
    - ✓ *Increasing D-meson yield with multiplicity*
  - Initial and Final state radiation (ISR/FSR)
    - ✓ *Increasing D-meson yield with multiplicity*