Multiplicity dependence of open and hidden heavy-flavour production in pp and p-Pb collisions with ALICE

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INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

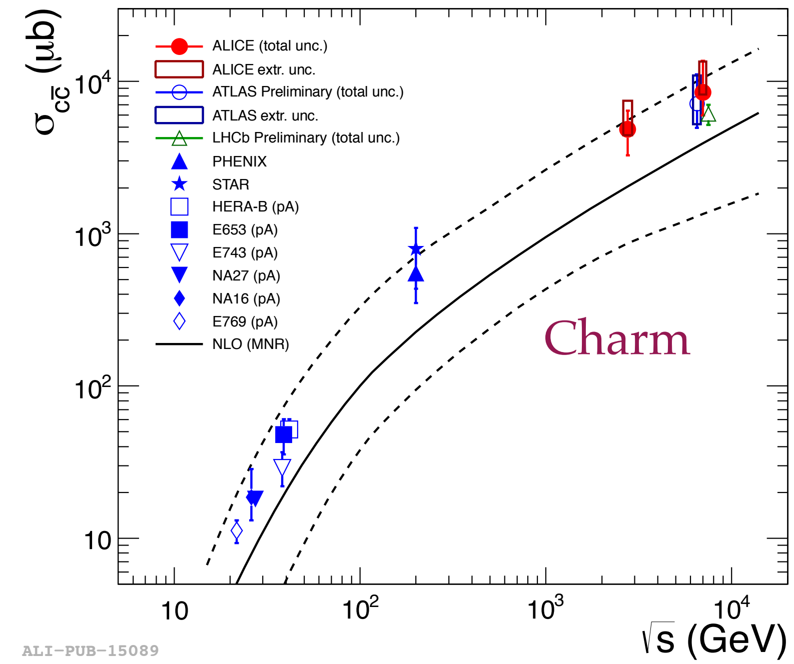
ALICE

Outline

- Motivation
- The ALICE experiment
- Results: measurements of
  - charmonium (J/ψ) production at central and forward rapidity,
  - and open (prompt D, $c \rightarrow J/\psi$, $b \rightarrow J/\psi$) heavy-flavour production at central rapidity
  - vs. multiplicity at central and forward rapidity,
  - in pp and p-Pb collisions.
- Comparison with models

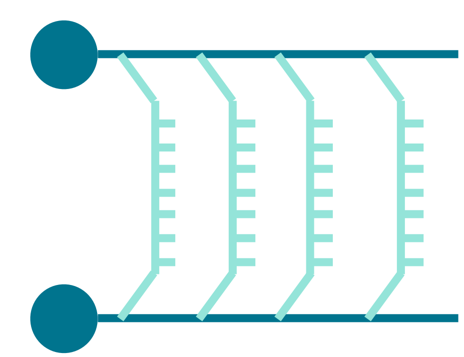
Motivation

- **Charm and beauty are produced in hard partonic collisions**
  - Tool to tag hard processes with $Q^2 > (2m)^2 \sim 10\ \mathrm{GeV}^2$.
  - Cross section **calculable with pQCD** based on the factorisation approach.

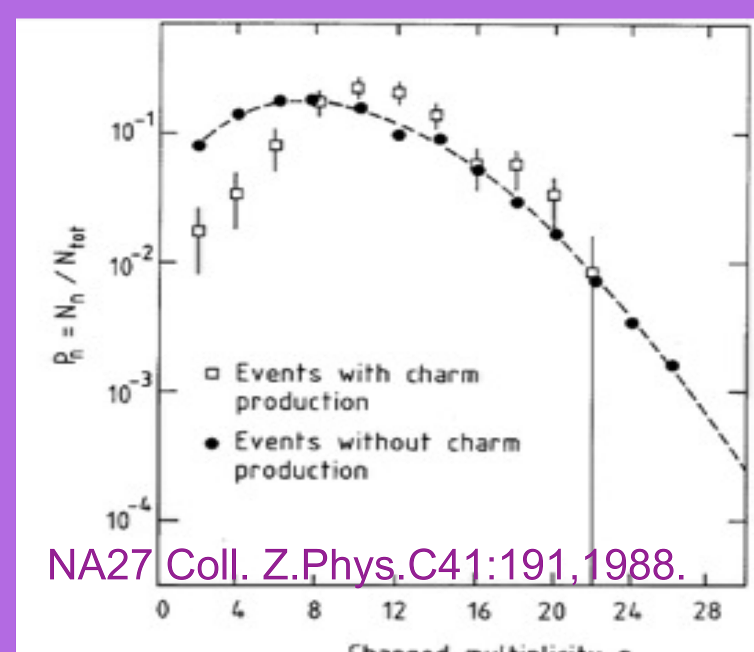


- **Test multiple parton interactions (MPI)**
  - A not so simple picture… (see other talks in the workshop)

- **Investigate the interaction between the hard and soft components in the full pp collision;**
  - the underlying event final-state particles are not associated to the hard scattering.



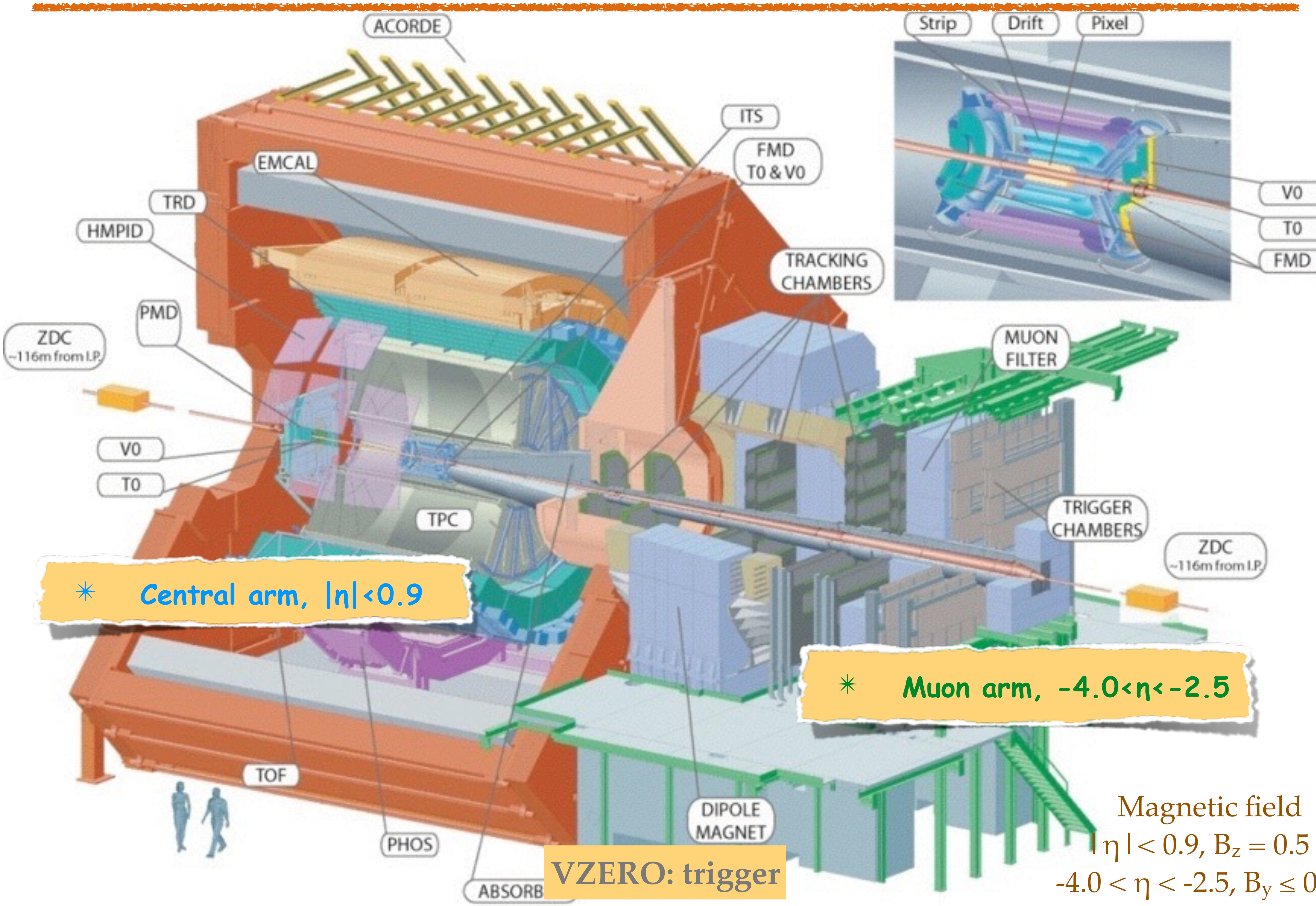
Ex.: NA27 observed that events with charm have on average a larger charged-particle multiplicity, in pp collisions at 400 GeV.



NA27 Coll. Z.Phys.C41:191,1988.

R. Bernhard et al, DESY-PROC-2009-06; arXiv:1003.4220
L. Frankfurt et al., Phys. Rev. Lett. 101, 202003 (2008).
M. Strikman, Prog. Theor. Phys. Suppl. 187, 289 (2011).
M. Strikman, Phys. Rev. D84, 011501(R) (2011).
E. G. Ferreiro et al, Phys.Rev. C86 (2012) 034903.
PHOBOS, Phys. Rev. C 83, 024913 (2011)
K. Werner at al. Phys. Rev. C83:044915, 2011
K. Werner at al. J. Phys. Conf. Ser.316:012012, 2011

The ALICE Experiment



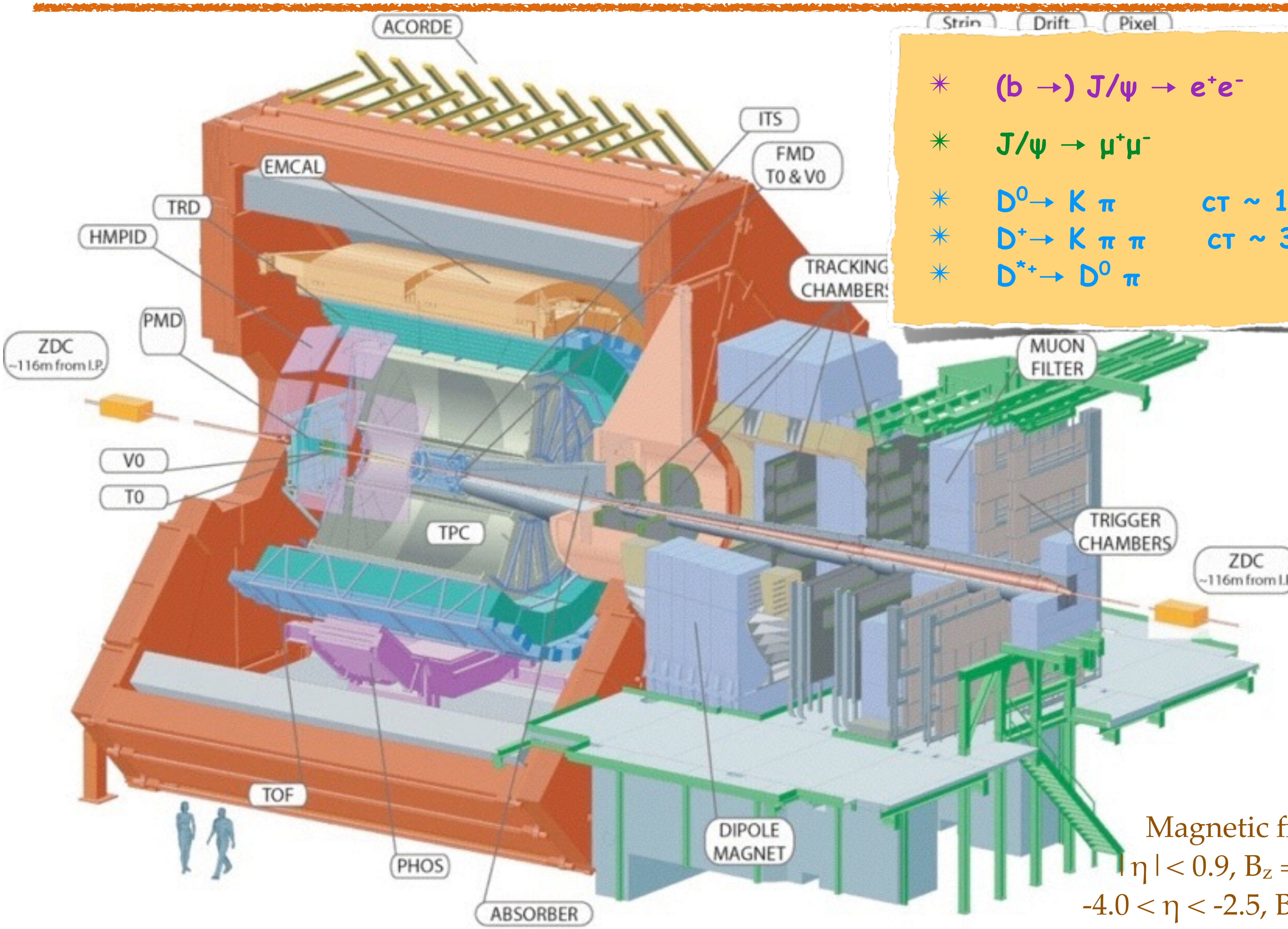
✳ Central arm, |η|<0.9

✳ Muon arm, -4.0<η<-2.5

VZERO: trigger

Magnetic field
$|\eta| < 0.9$, $B_z = 0.5$ T
$-4.0 < \eta < -2.5$, $B_y \leq 0.7$ T

The ALICE Experiment



- ✳ $(b \rightarrow)\ J/\psi \rightarrow e^+e^-$
- ✳ $J/\psi \rightarrow \mu^+\mu^-$
- ✳ $D^0 \rightarrow K\ \pi$ $c\tau \sim 122.9\ \mu m$
- ✳ $D^+ \rightarrow K\ \pi\ \pi$ $c\tau \sim 311.8\ \mu m$
- ✳ $D^{*+} \rightarrow D^0\ \pi$

Magnetic field

$|\eta| < 0.9$, $B_z = 0.5$ T

$-4.0 < \eta < -2.5$, $B_y \leq 0.7$ T

The ALICE Experiment

<u>$J/\psi \rightarrow e^+e, |\eta|<0.8$</u>

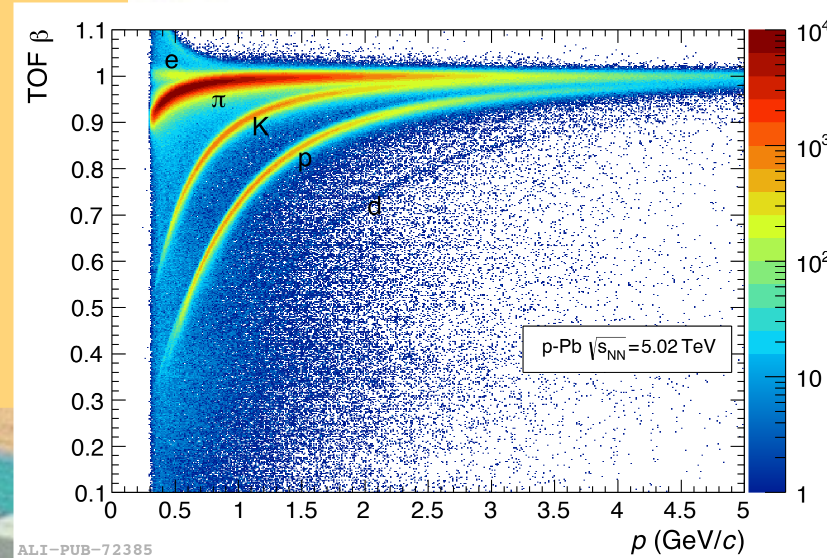
TOF: e PID

TPC: tracking, e PID

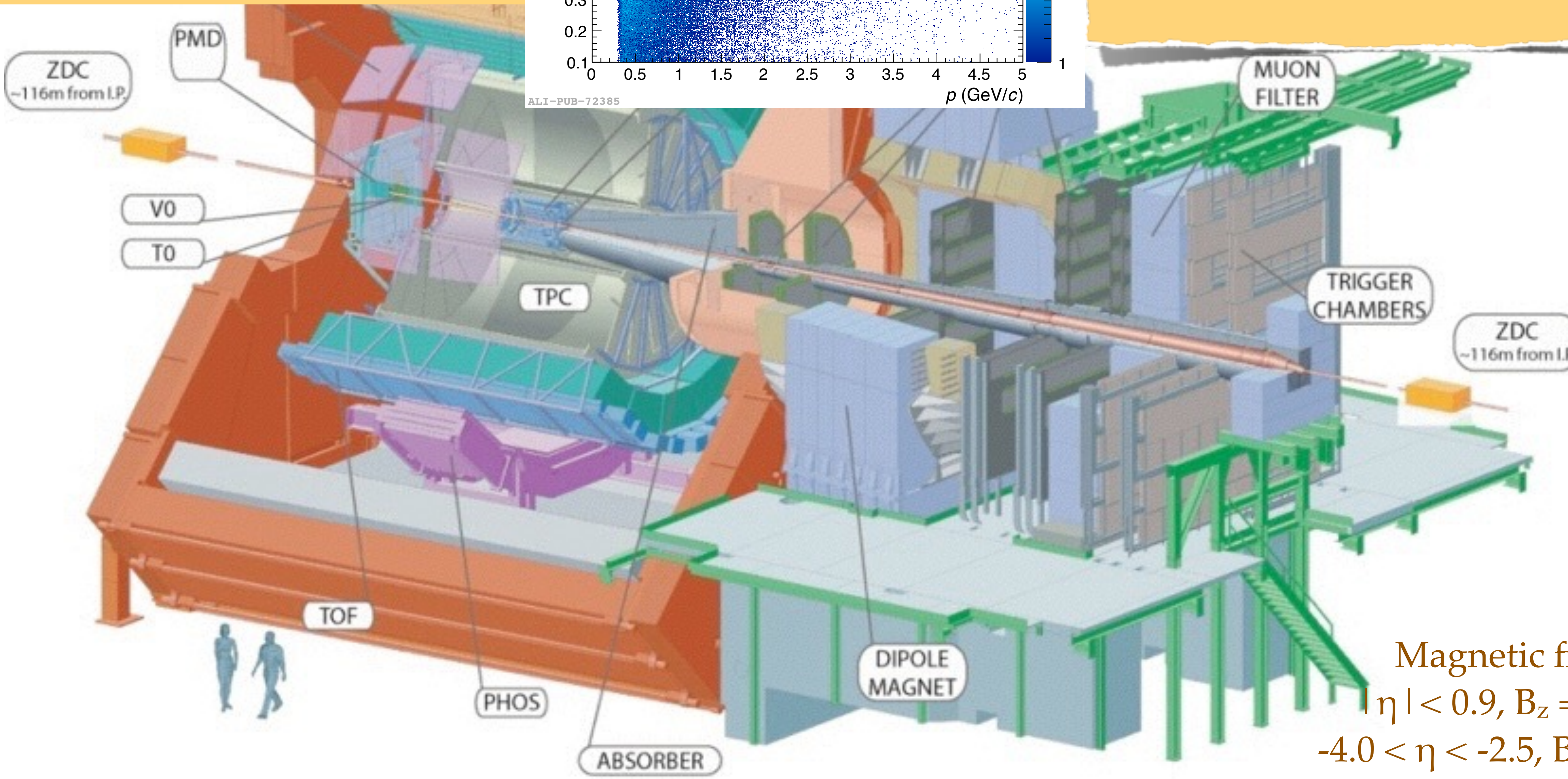
EMCAL: e PID, trigger

TRD: e PID

ITS: vertexing, tracking



- ✳ (b →) $J/\psi \rightarrow e^+e^-$
- ✳ $J/\psi \rightarrow \mu^+\mu^-$
- ✳ $D^0 \rightarrow K\,\pi$ cτ ~ 122.9 μm
- ✳ $D^+ \rightarrow K\,\pi\,\pi$ cτ ~ 311.8 μm
- ✳ $D^{*+} \rightarrow D^0\,\pi$



Magnetic field

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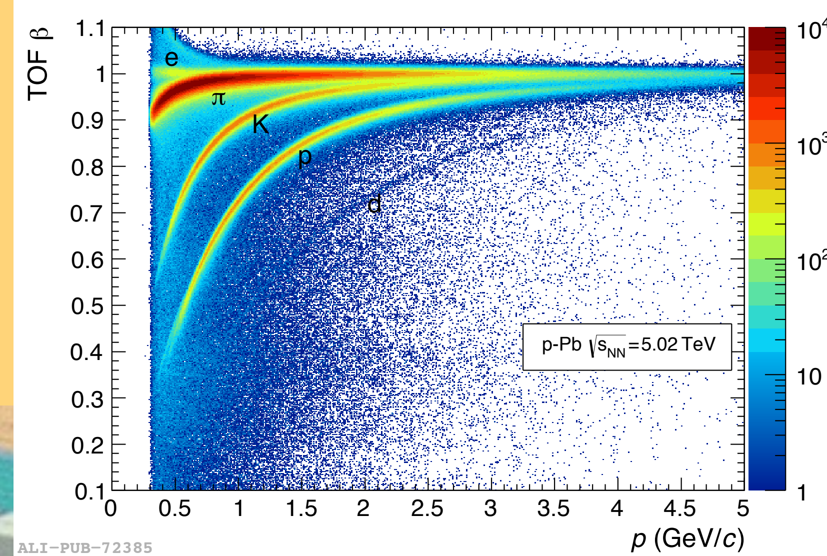

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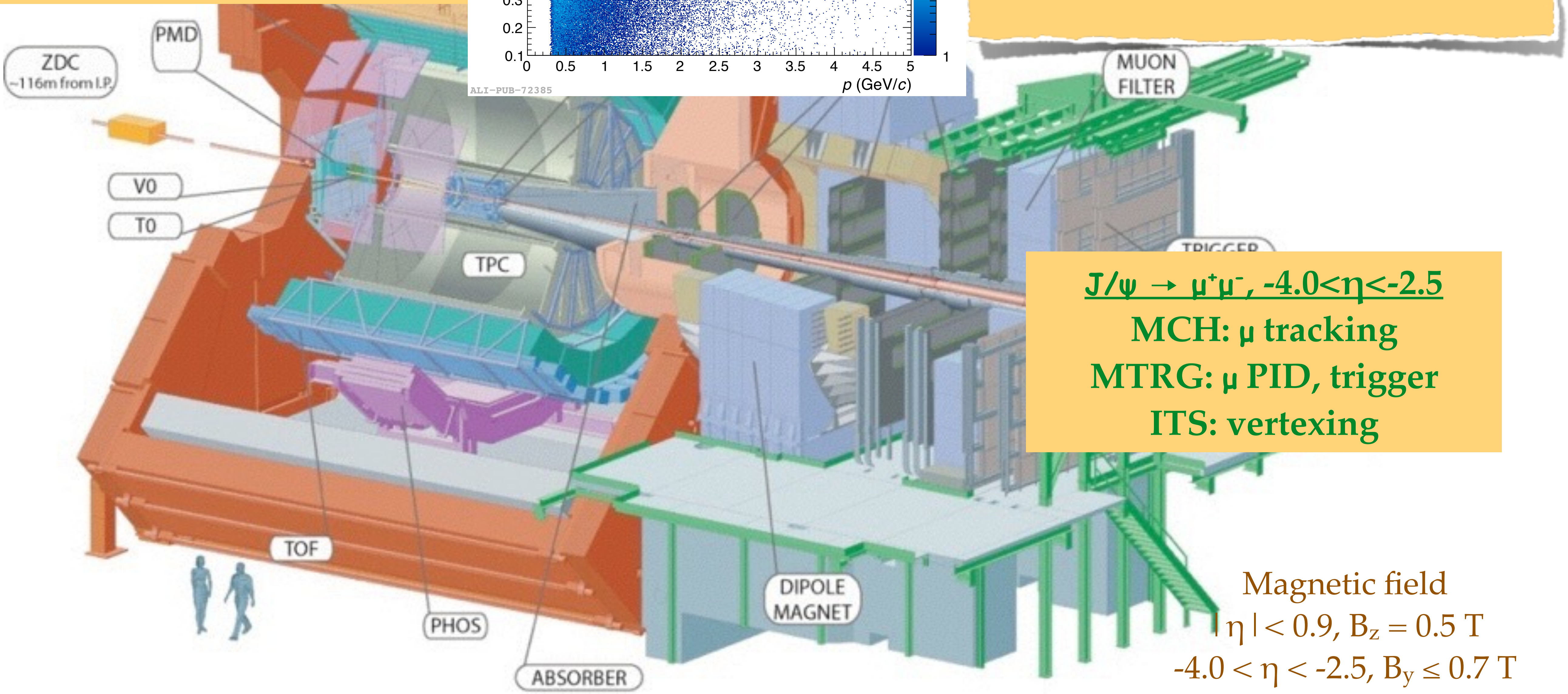

<u>$J/\psi \rightarrow \mu^+\mu^-$, $-4.0<\eta<-2.5$</u>
MCH: μ tracking
MTRG: μ PID, trigger
ITS: vertexing

Magnetic field
$|\eta| < 0.9$, $B_z = 0.5$ T
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The ALICE Experiment

<u>$J/\psi \to e^+e$, |η|<0.8</u>
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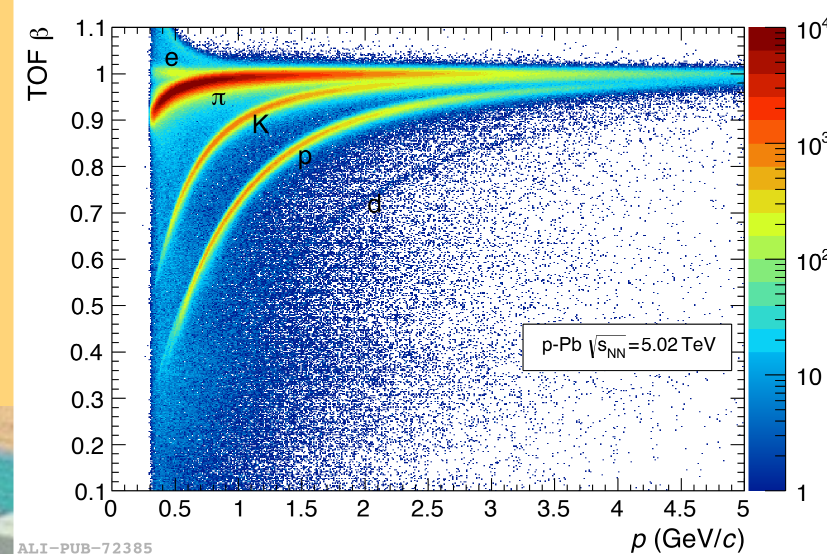

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- $D^0 \to K\,\pi$ cτ ~ 122.9 μm
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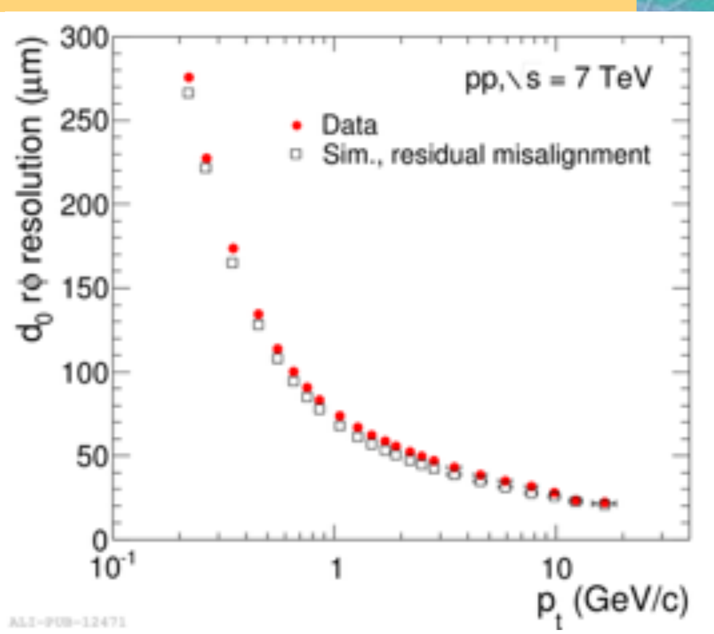
<u>D mesons, |y|<0.5</u>
TOF: K/p/π PID
TPC: tracking, K/p/π PID
ITS: vertexing, tracking



<u>$J/\psi \to \mu^+\mu^-$, -4.0<η<-2.5</u>
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Magnetic field
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The ALICE Experiment

$\underline{J/\psi \rightarrow e^+e, |\eta|<0.8}$
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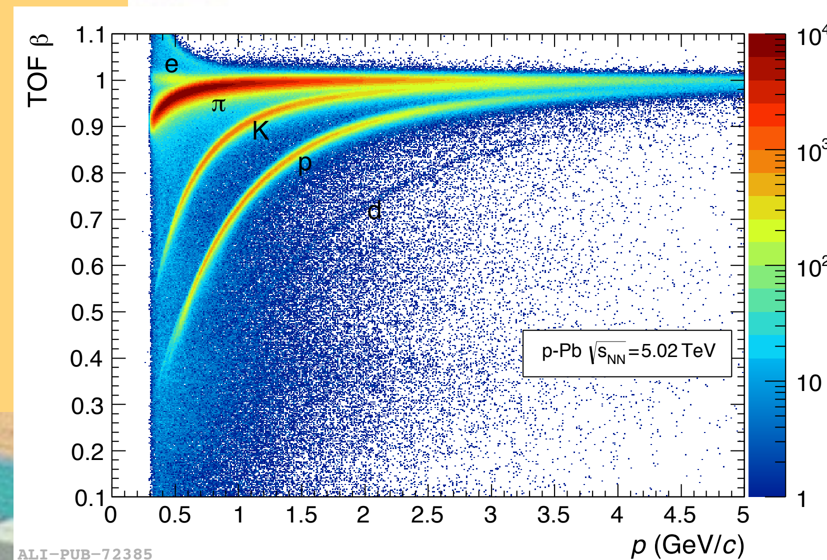

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D mesons, |y|<0.5
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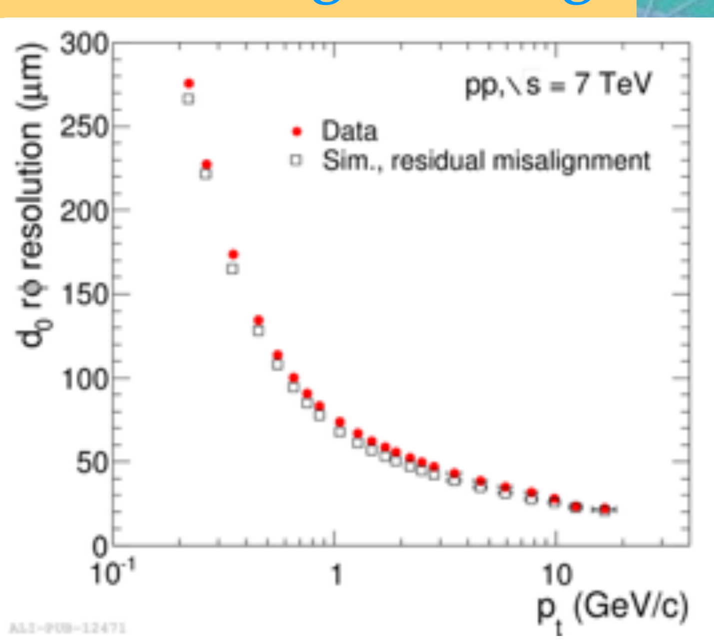


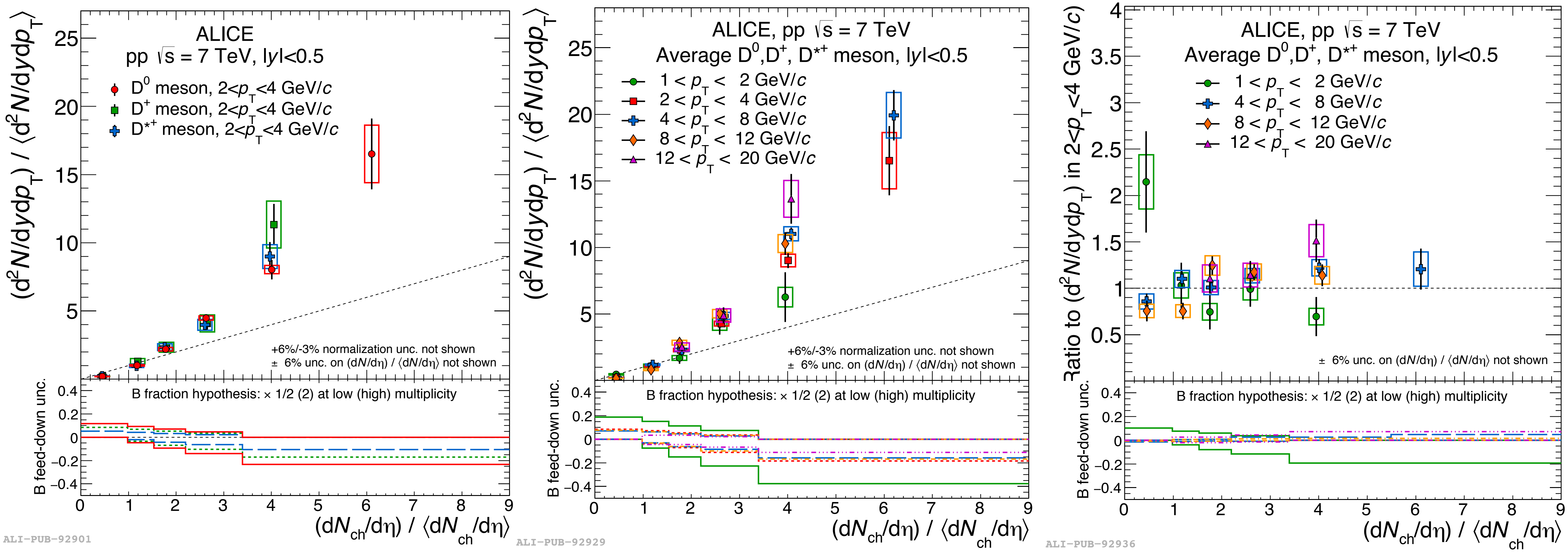
$\underline{J/\psi \rightarrow \mu^+\mu^-, -4.0<\eta<-2.5}$
MCH: μ tracking
MTRG: μ PID, trigger
ITS: vertexing

Multiplicity measurement
ITS (2 innermost layers)
VZERO

Magnetic field
$|\eta| < 0.9$, $B_z = 0.5$ T
$-4.0 < \eta < -2.5$, $B_y \leq 0.7$ T

Results in pp collisions at 7 TeV

Open charm vs. multiplicity

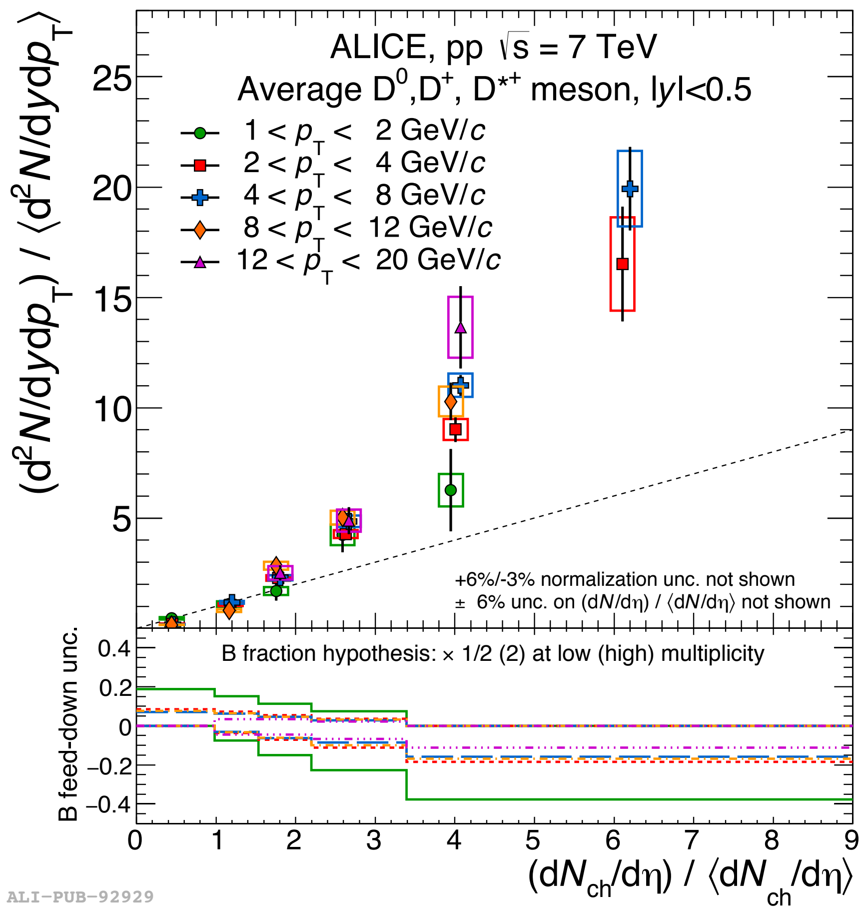


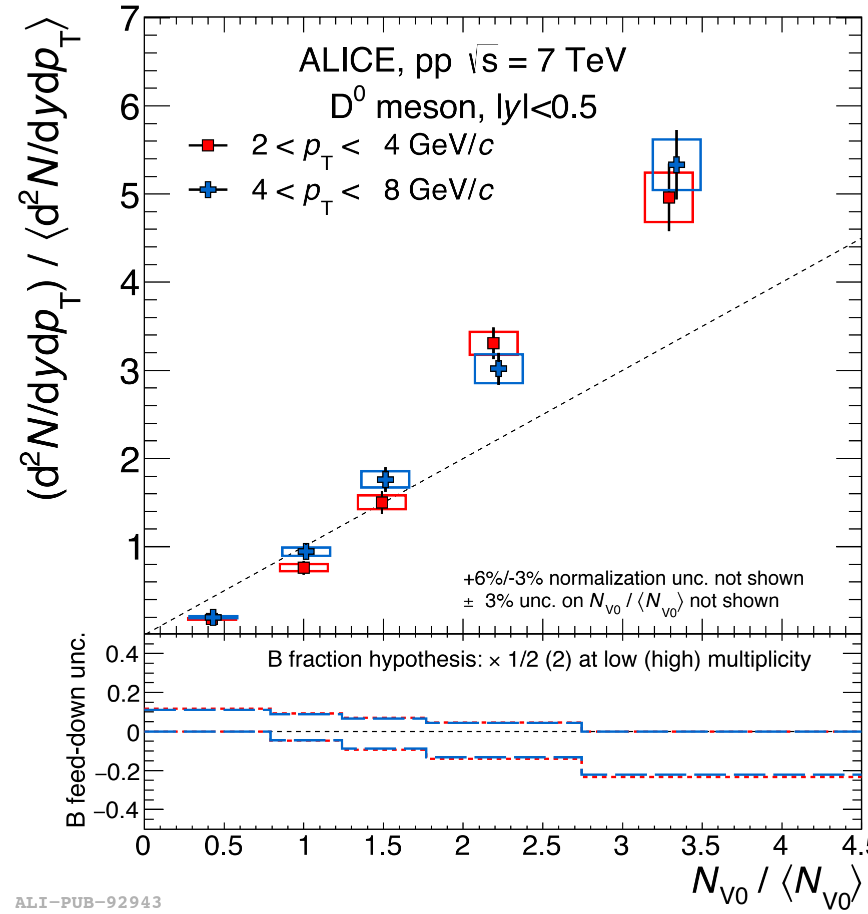
- **The results of D^0, D^+ and D^{*+} are consistent within uncertainties.**
- **Increase of D-meson yields with charged-particle multiplicity at mid rapidity:**
  - **faster-than-linear increase at large multiplicities,**
  - **independent of p_T within uncertainties.**

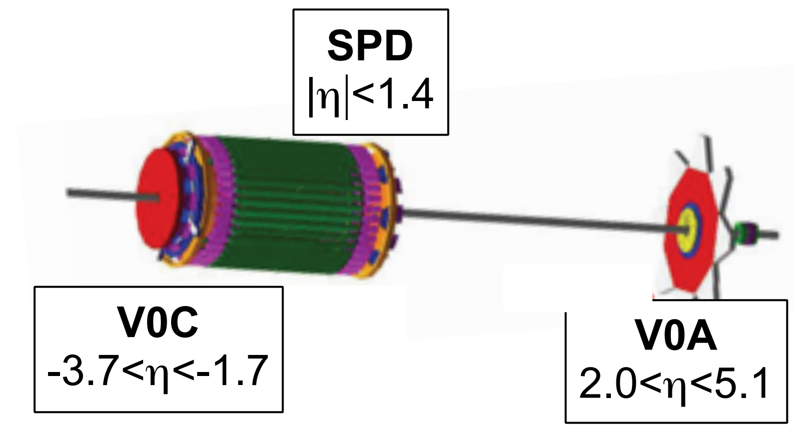
ALICE, JHEP 09 (2015) 148.

Error bars: statistical uncertainty.
Vertical size of boxes : systematic uncertainties but feed-down.
Bottom panels lines: relative feed-down systematic uncertainties.
Not shown : systematic uncertainty on $(dN/d\eta)/\langle dN/d\eta\rangle$. and normalisation.

Introducing an η gap on the multiplicity measurement







- Test possible auto-correlations using multiplicity measured in a different rapidity range than heavy-flavour yields (minimise the influence of heavy-quark fragmentation and heavy-flavour hadron decays in the multiplicity estimation).
- **Qualitatively similar increasing trend of D-meson yields when an η gap is introduced between the regions where the D mesons and the multiplicity are measured.**

ALICE, JHEP 09 (2015) 148.

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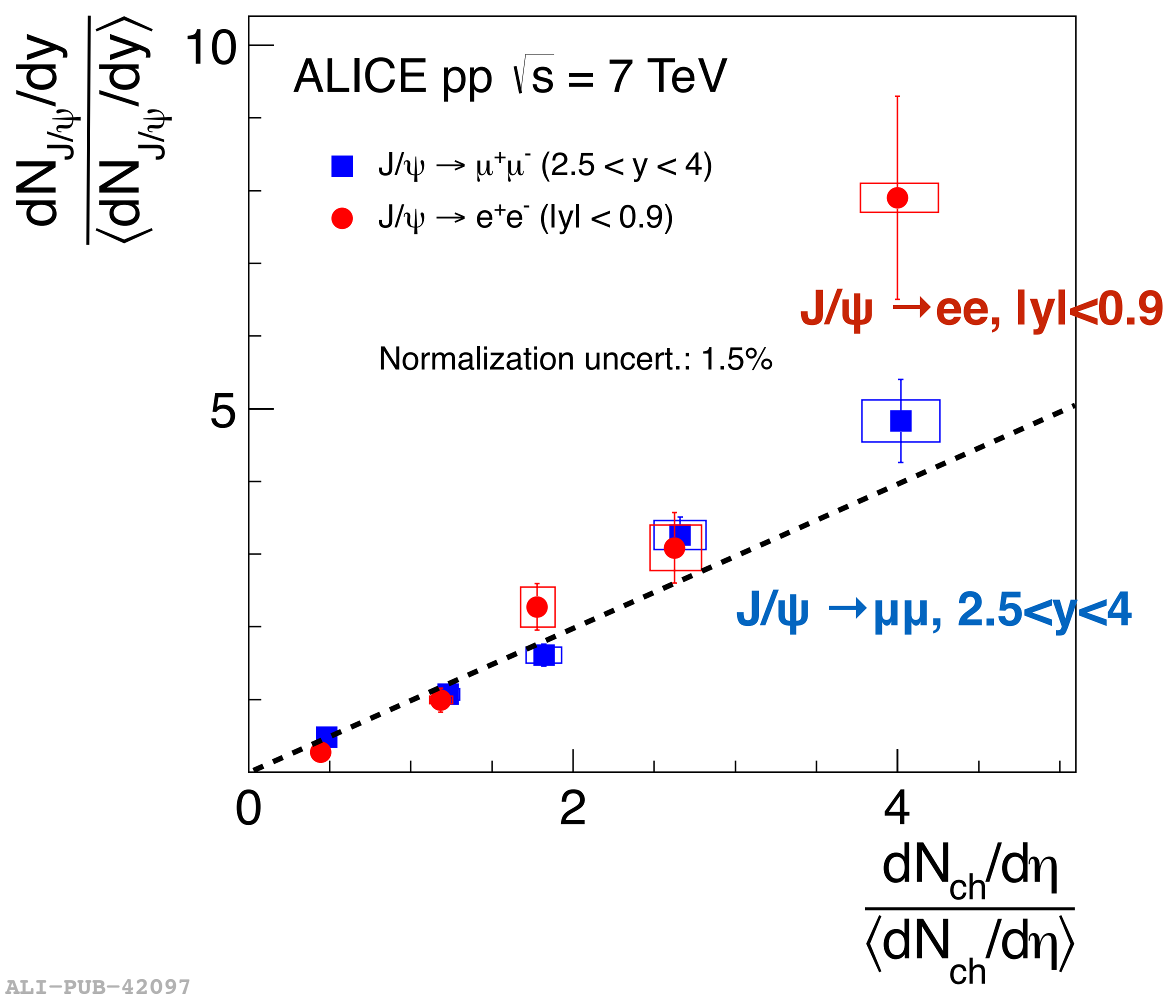
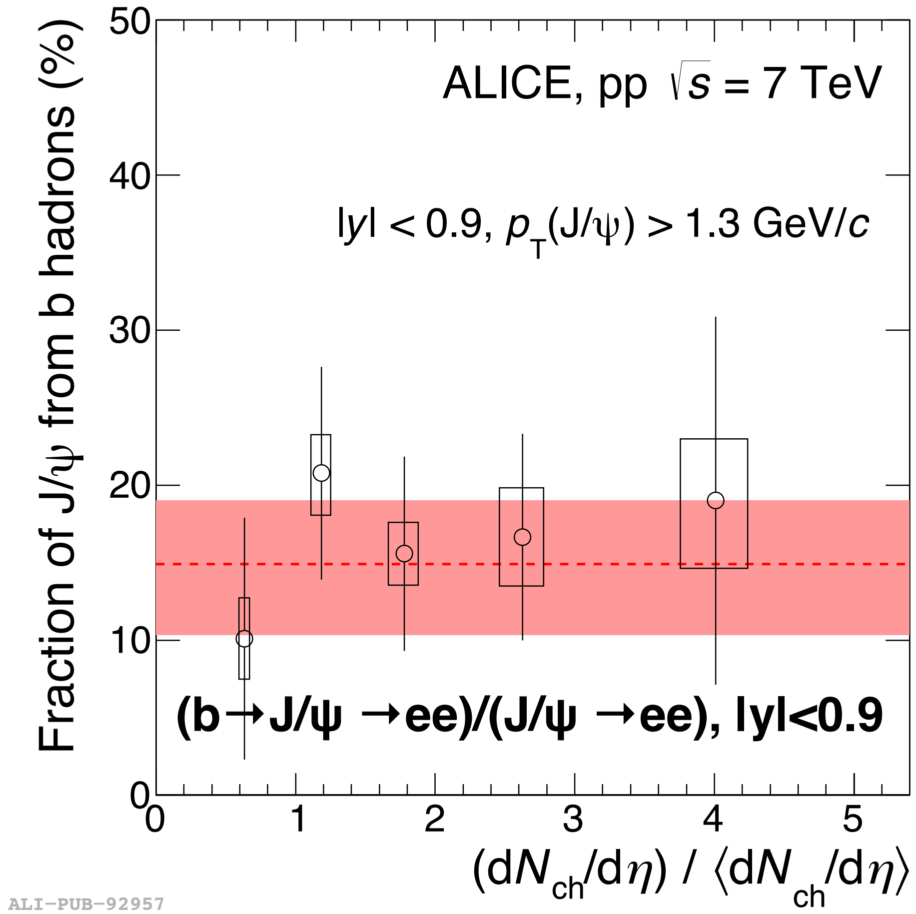
Quarkonia vs. multiplicity





- **Increase of J/ψ yields as a function of multiplicity at mid rapidity.**
  - **Similar increase of J/ψ yields measured at central and forward rapidity.**
- **The fraction of non-prompt J/ψ in the inclusive yields shows no multiplicity dependence with multiplicity within uncertainties.**

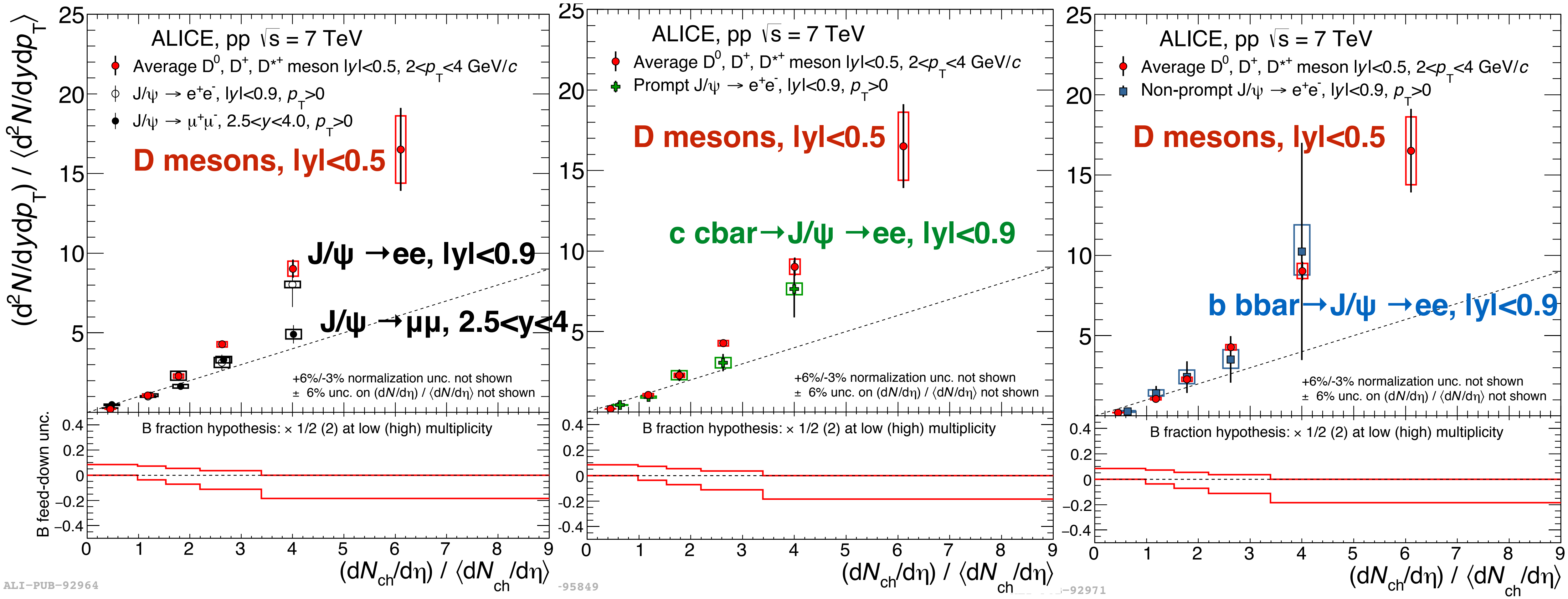
ALICE, Phys.Lett. B712 (2012) 165–175
ALICE, JHEP 09 (2015) 148.

Error bars: statistical uncertainty.

Horizontal size of boxes : systematic uncertainty on $(dN/d\eta)/\langle dN/d\eta\rangle$.

Vertical size of boxes : systematic uncertainties but feed-down.
Not shown : normalisation systematic uncertainty.

Comparison of open and hidden heavy flavours



- **Similar increase of open charm, open beauty and charmonia yields as a function of charged-particle multiplicity at mid rapidity.**
  - **Caveats: different rapidity and p_T interval of the measurements.**
  - **Likely related to heavy-flavour production processes, and not significantly influenced by hadronisation.**

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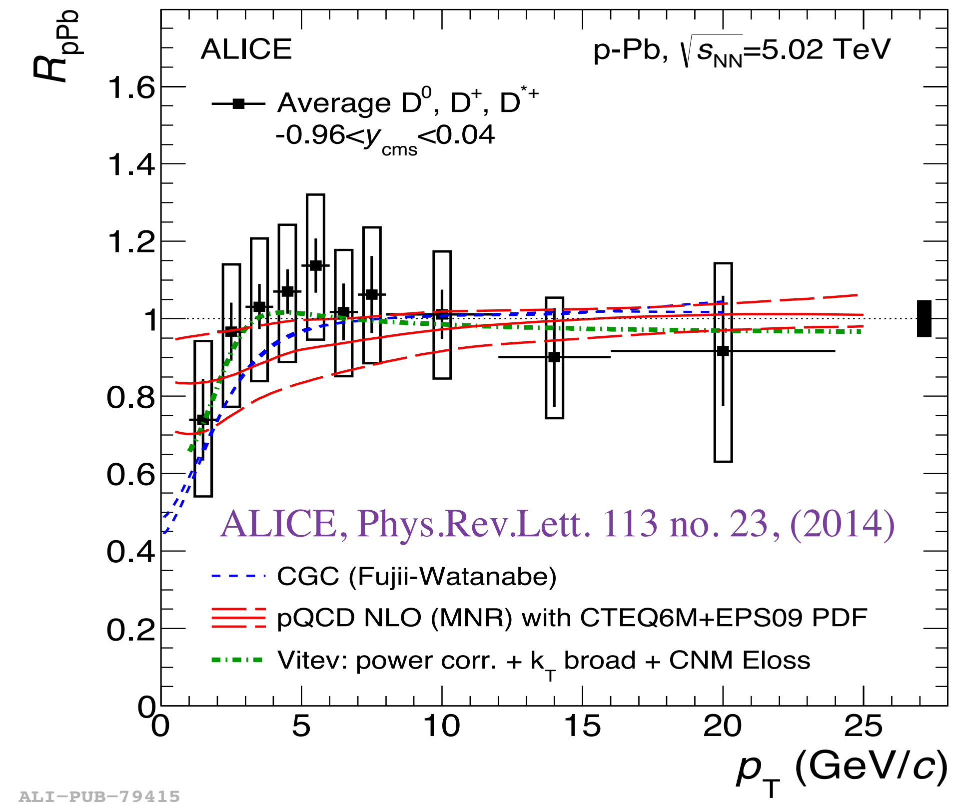
Results in p-Pb collisions at 5.02 TeV

Heavy-flavour production in p-Pb collisions

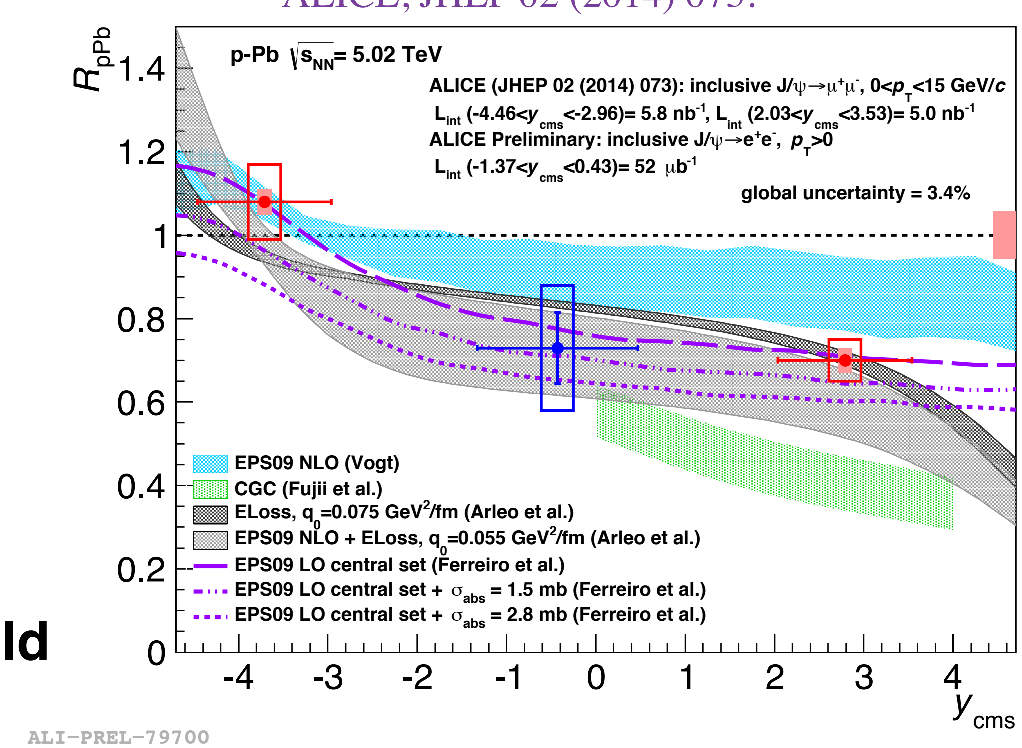
- As in pp collisions,
- **HF yield expected to scale with the number of binary nucleon-nucleon collisions.**
- **Nuclear environment influence (p-Pb collisions):**
    - **shadowing (PDF modifications in nuclei) and gluon saturation,**
    - **energy loss (initial/final state or coherent),**
    - **nuclear absorption.**



- Observable:

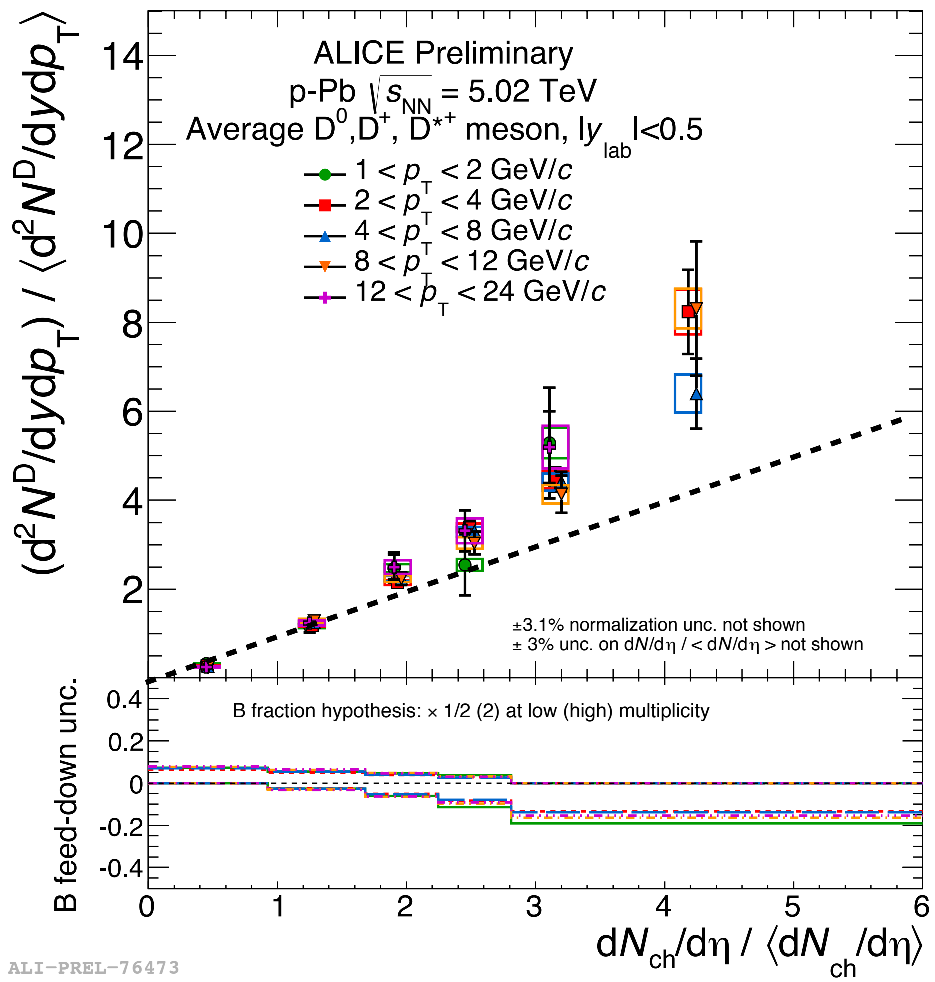
$$R_{AB} = \frac{1}{\langle T_{AB} \rangle} \frac{dN_{AB}/dp_T}{d\sigma_{pp}/dp_T} = \frac{1}{\langle N_{coll} \rangle_{AB}} \frac{dN_{AB}/dp_T}{dN_{pp}/dp_T}$$

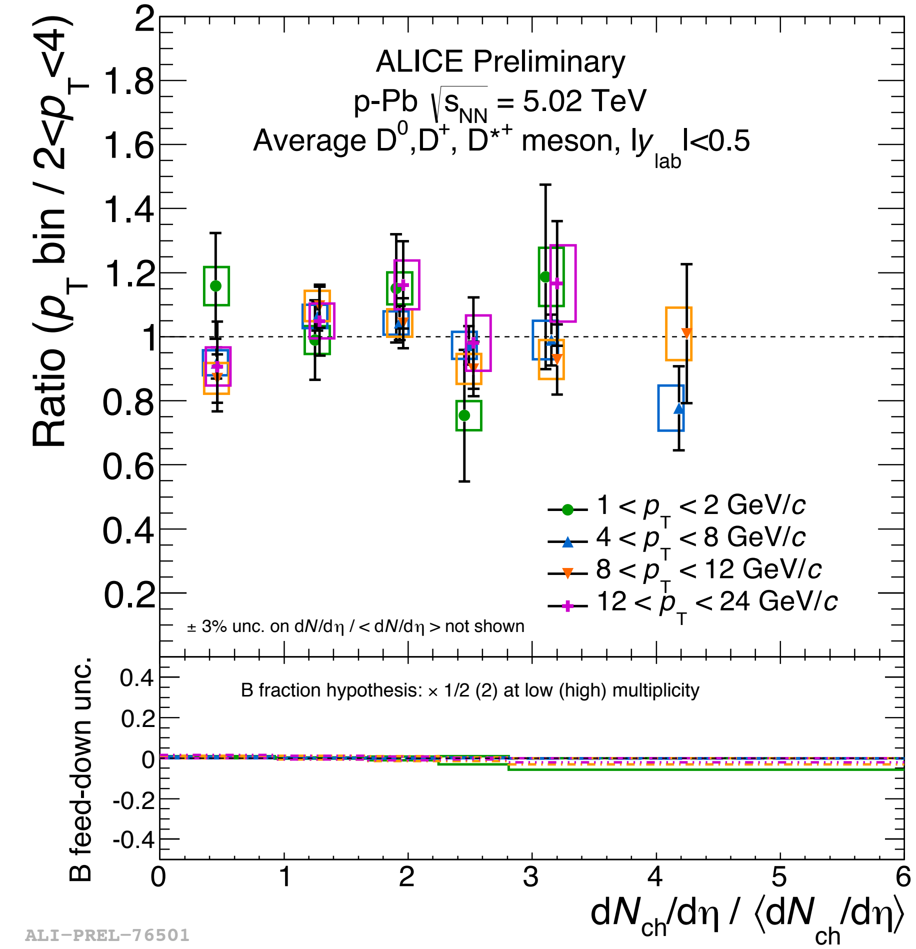
ALICE, JHEP 02 (2014) 073.



- **Measurements:**
    - **prompt D-meson R_{pPb} is close to unity at high p_T**
    - **J/ψ suppression (R_{pPb}<1) at positive y (p-going, low-x in Pb nucleus) and low p_T.**
    - **Relatively well described by models including cold nuclear matter effects.**

Open charm vs. multiplicity





- **Increase of D-meson yields with charged-particle multiplicity at mid rapidity:**
  - **slightly faster-than-linear increase at large multiplicities,**
  - **independent of p_T within uncertainties.**

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Vertical size of boxes : systematic uncertainties but feed-down.
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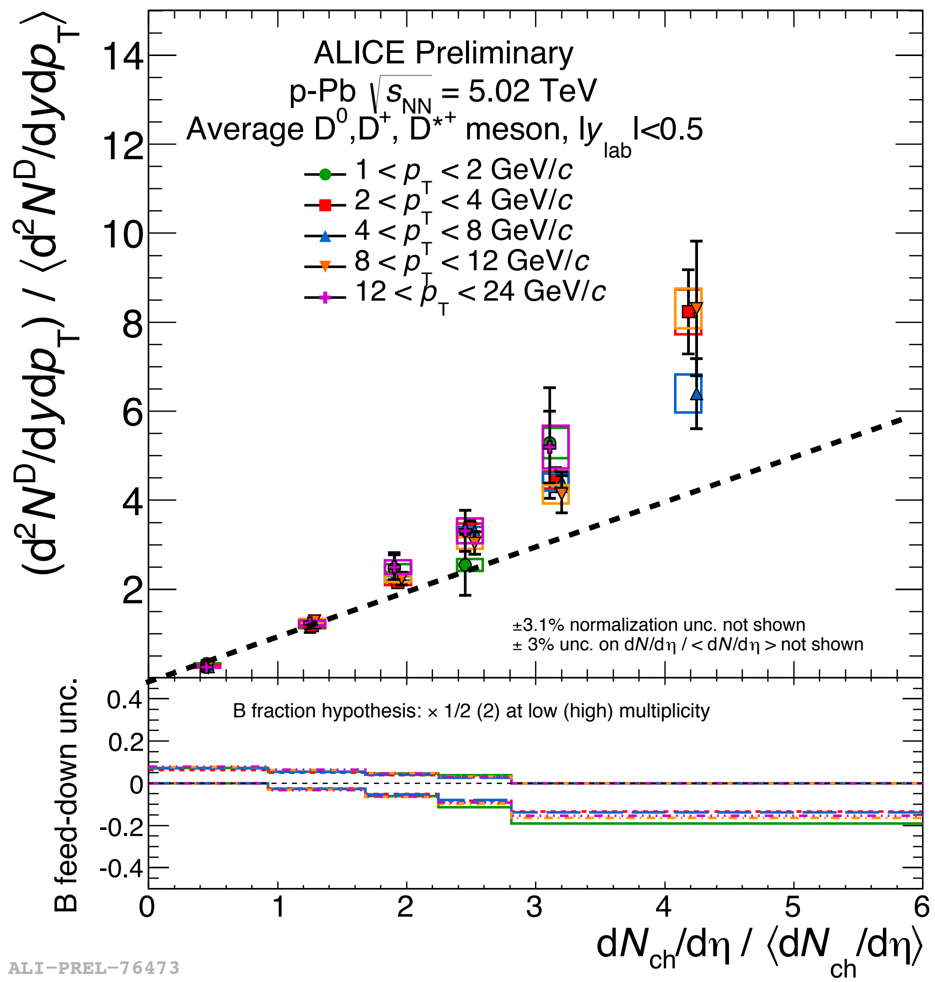
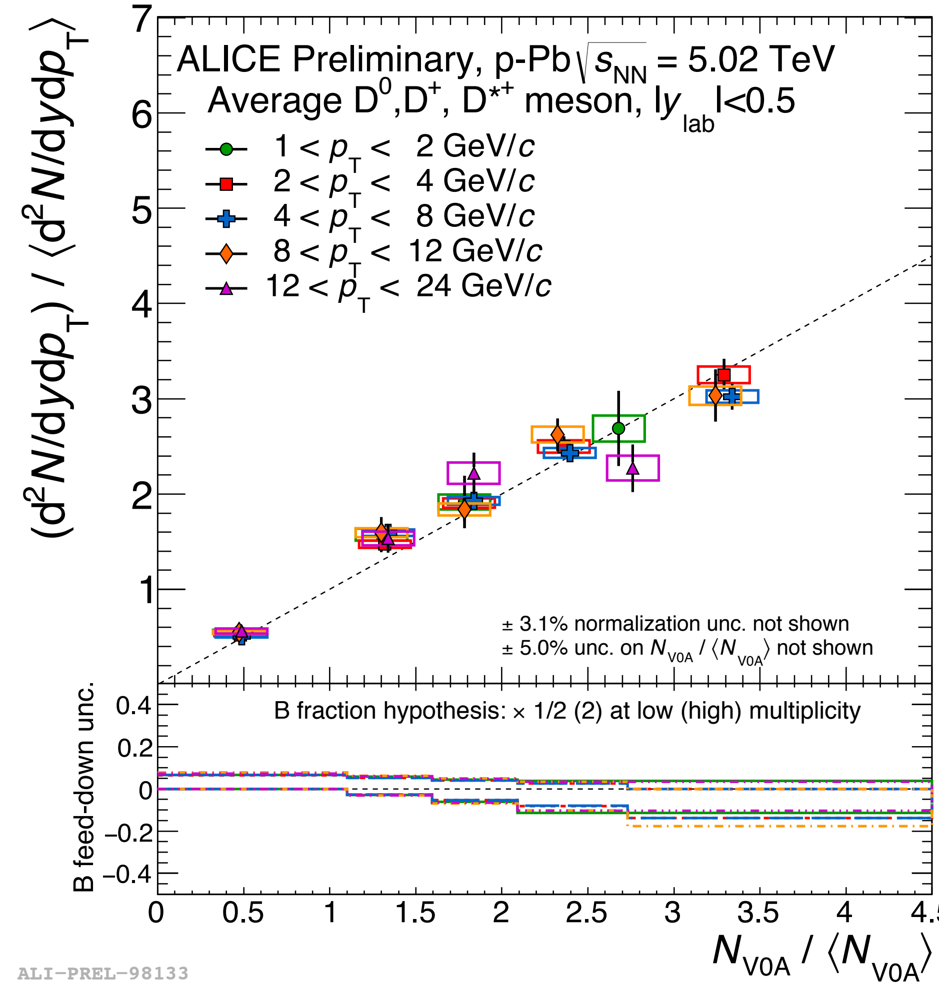
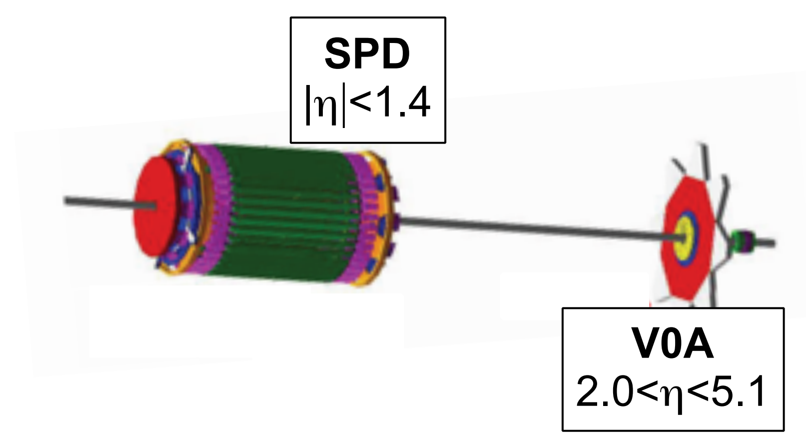
Not shown : systematic uncertainty on $(dN/d\eta)/\langle dN/d\eta \rangle$. and normalisation.

Introducing an η gap on the multiplicity measurement





- Test auto-correlations on the multiplicity estimation.
- **Nearly linear increase with multiplicity at backward rapidity (Pb-going direction).**
  Results consistent in the measured interval within uncertainties.



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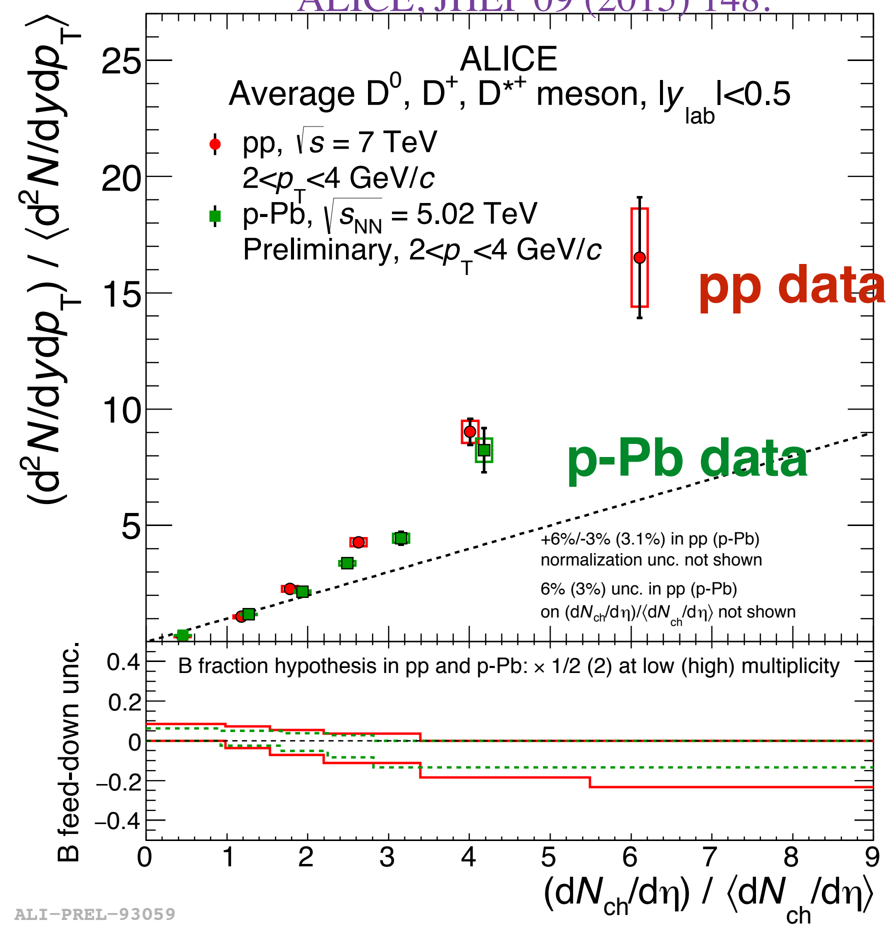
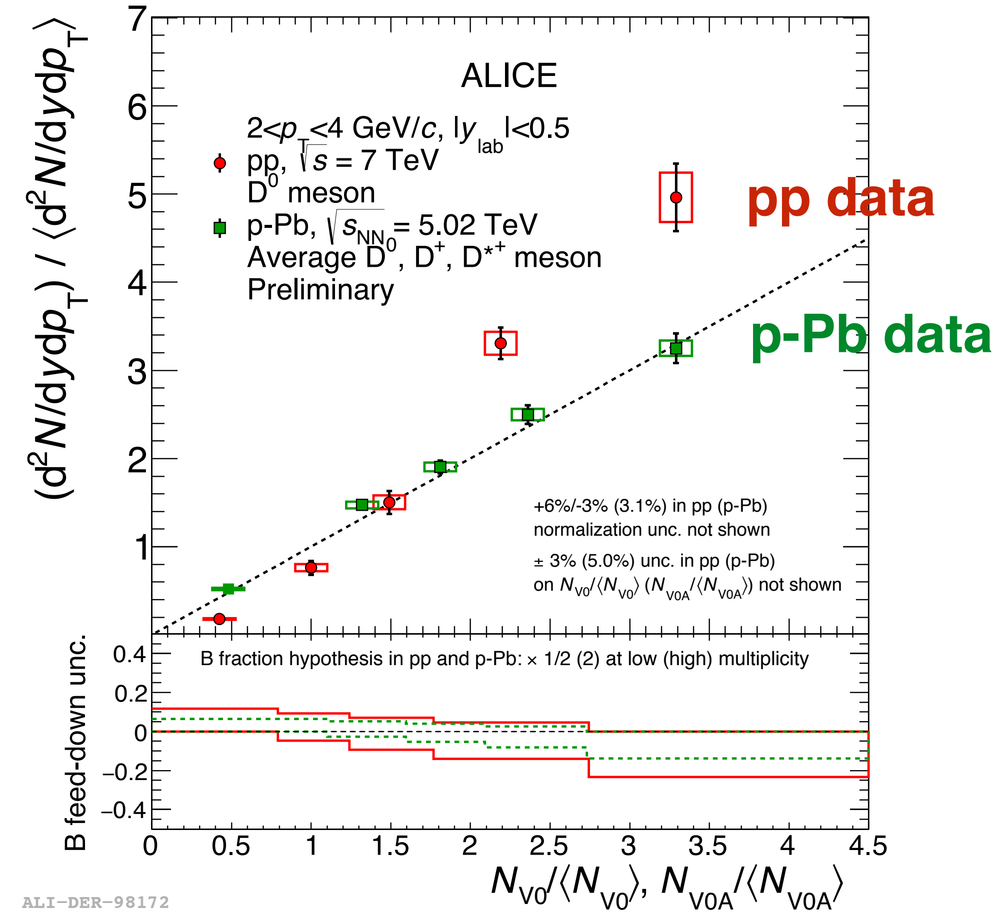
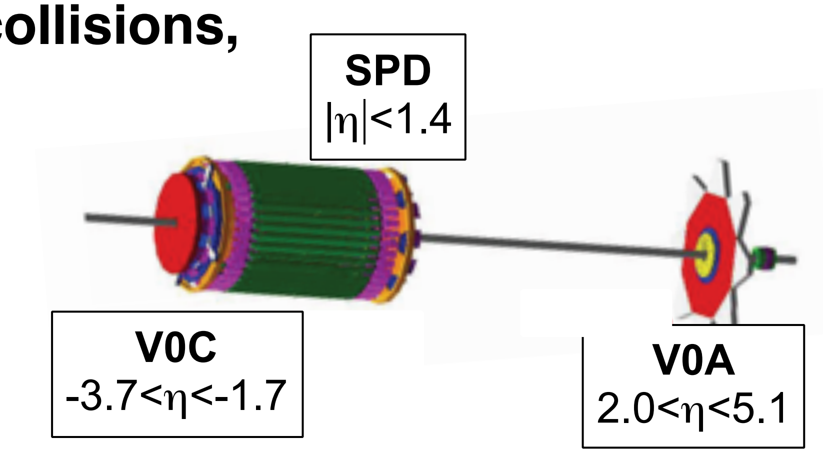
Open charm in pp and p-Pb collisions

ALICE, JHEP 09 (2015) 148.





- **Multiplicity at mid rapidity: similar trend for D-meson results 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.**



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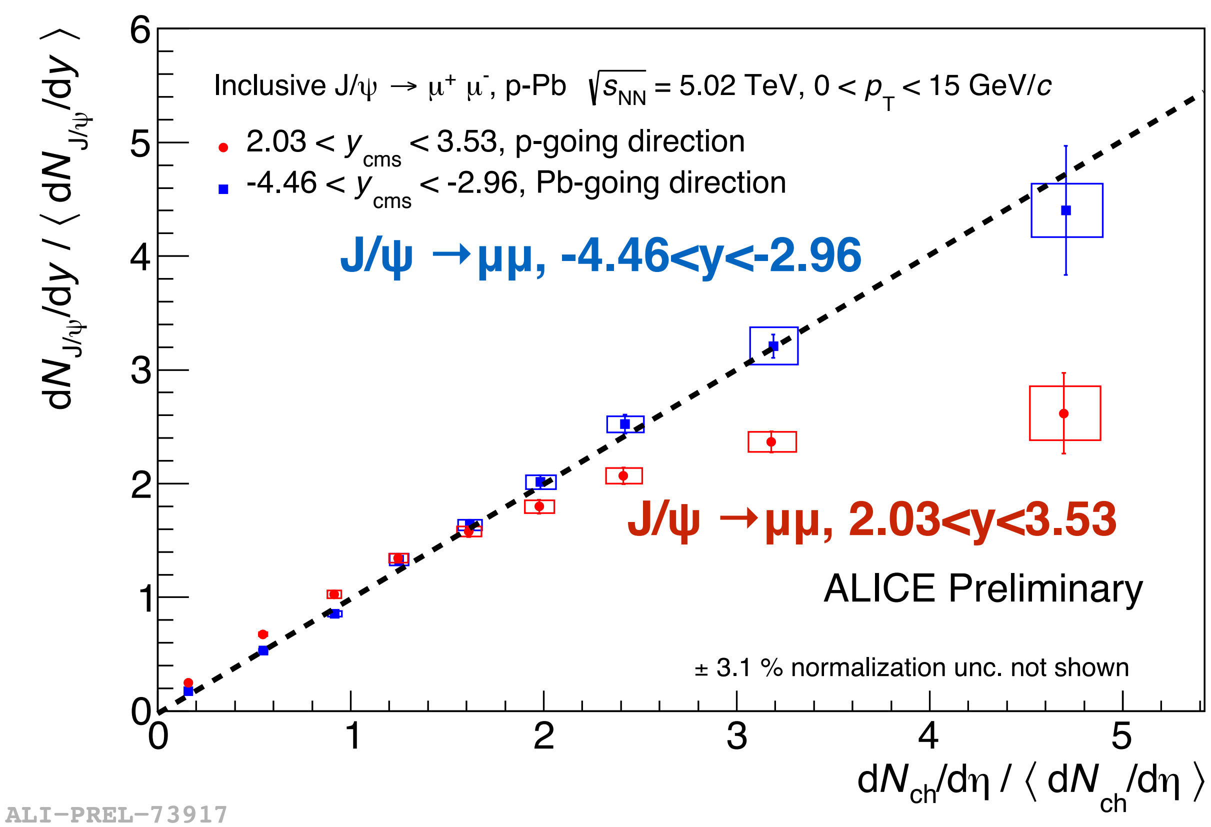
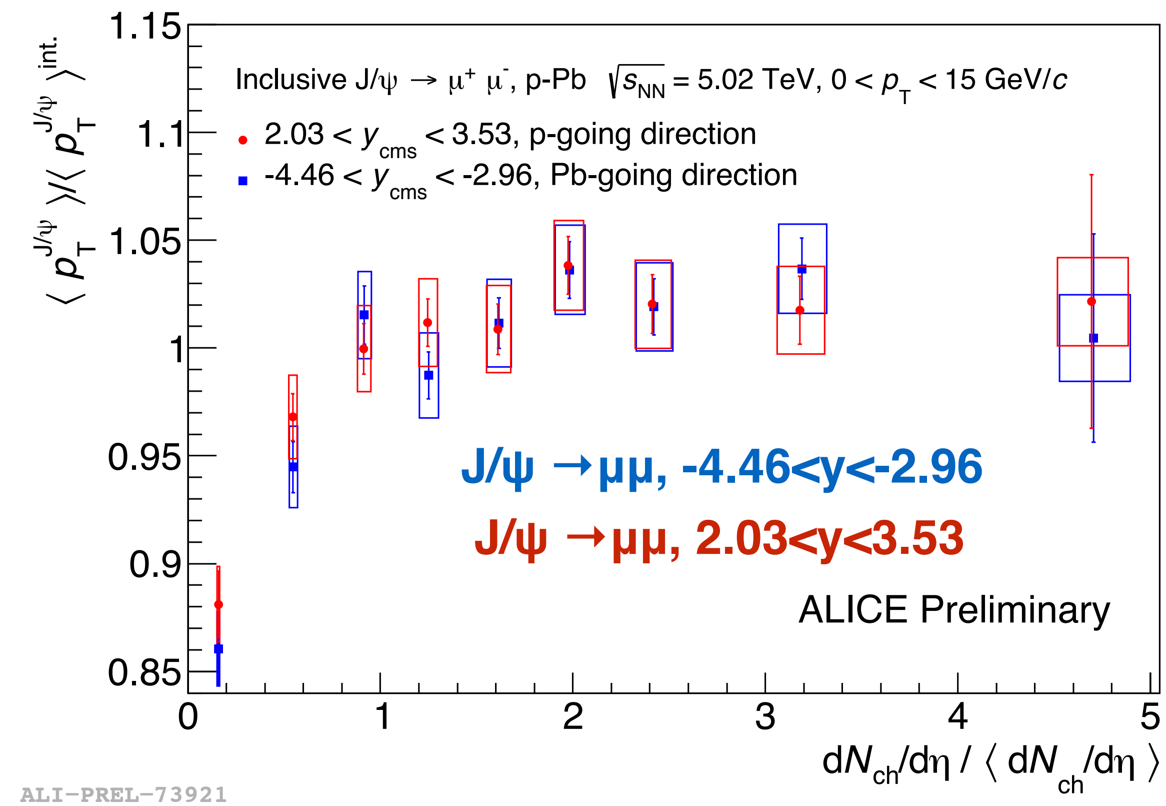
Quarkonia vs. multiplicity





- **J/ψ yields vs. multiplicity (with multiplicity measured at mid rapidity):**
  - **increase of J/ψ yields measured at backward rapidity (Pb-going direction),**
  - **deviation of the linear increase at forward rapidity (p-going direction).**
- **J/ψ average p_T, $p_T/\langle p_T \rangle$, increases with multiplicity and seems to saturate at about $(dN_{ch}/d\eta)/\langle dN_{ch}/d\eta \rangle \sim 1.5$, independently of J/ψ rapidity.**

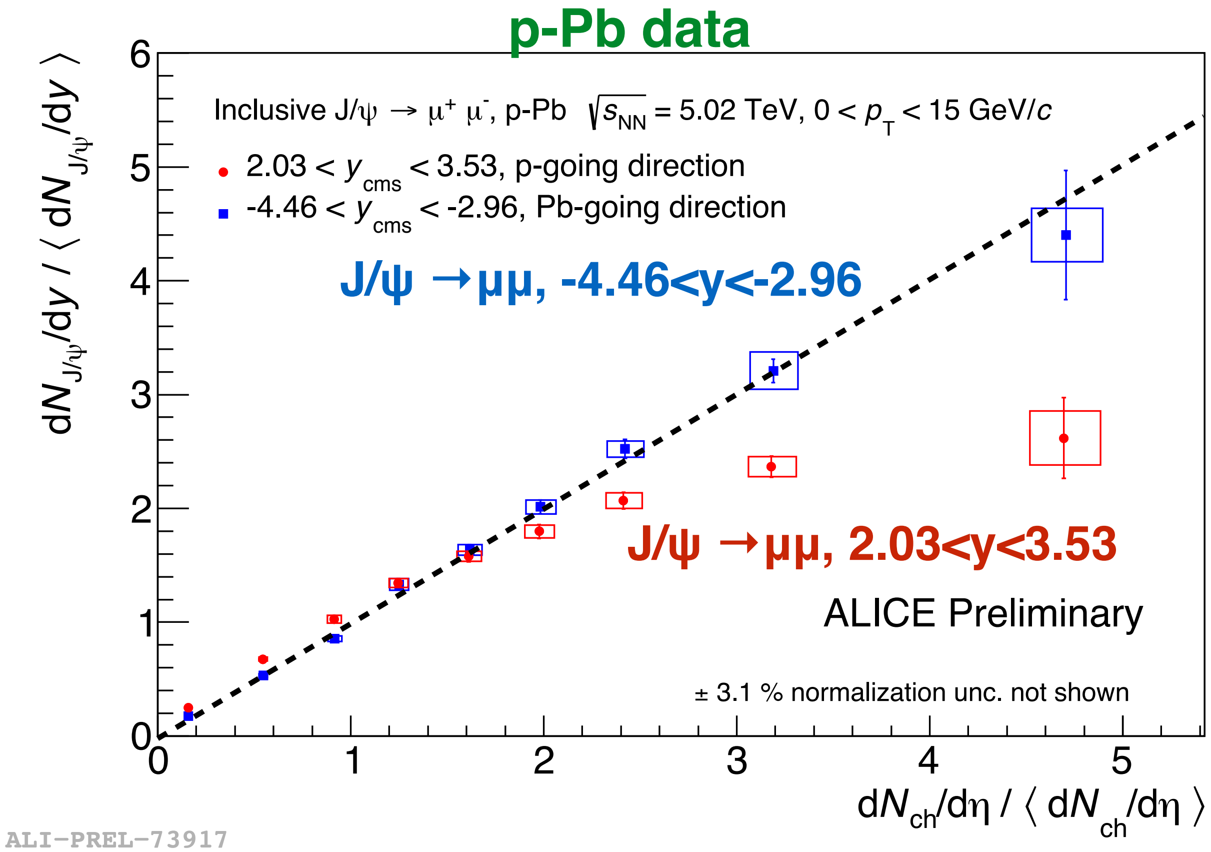
Note: J/ψ yields measured in the p-going direction probe low-*x* gluons

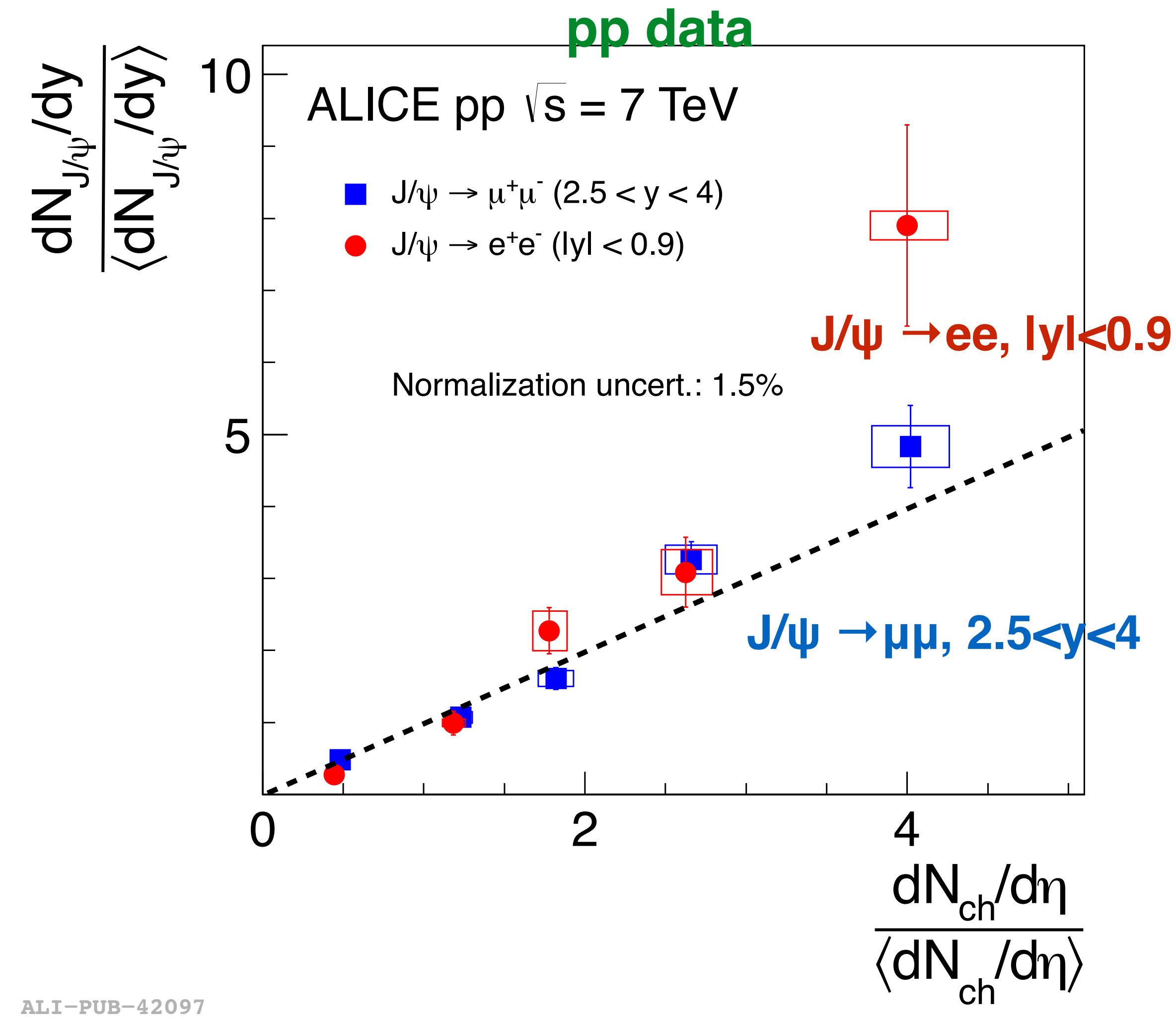
Error bars: statistical uncertainty.

Horizontal size of boxes : systematic uncertainty on $(dN/d\eta)/\langle dN/d\eta \rangle$.

Vertical size of boxes : systematic uncertainties but feed-down.
Not shown : normalisation systematic uncertainty.

Quarkonia in pp and p-Pb collisions





- **Multiplicity at mid rapidity:**
  - **similar trend for J/ψ yields measured in pp and p-Pb collisions at backward rapidity (Pb-going direction),**
  - **deviation of J/ψ yields measured at forward rapidity (p-going direction).**

ALICE, Phys.Lett. B712 (2012) 165–175

Note: J/ψ yields measured in the p-going direction probe low-*x* gluons

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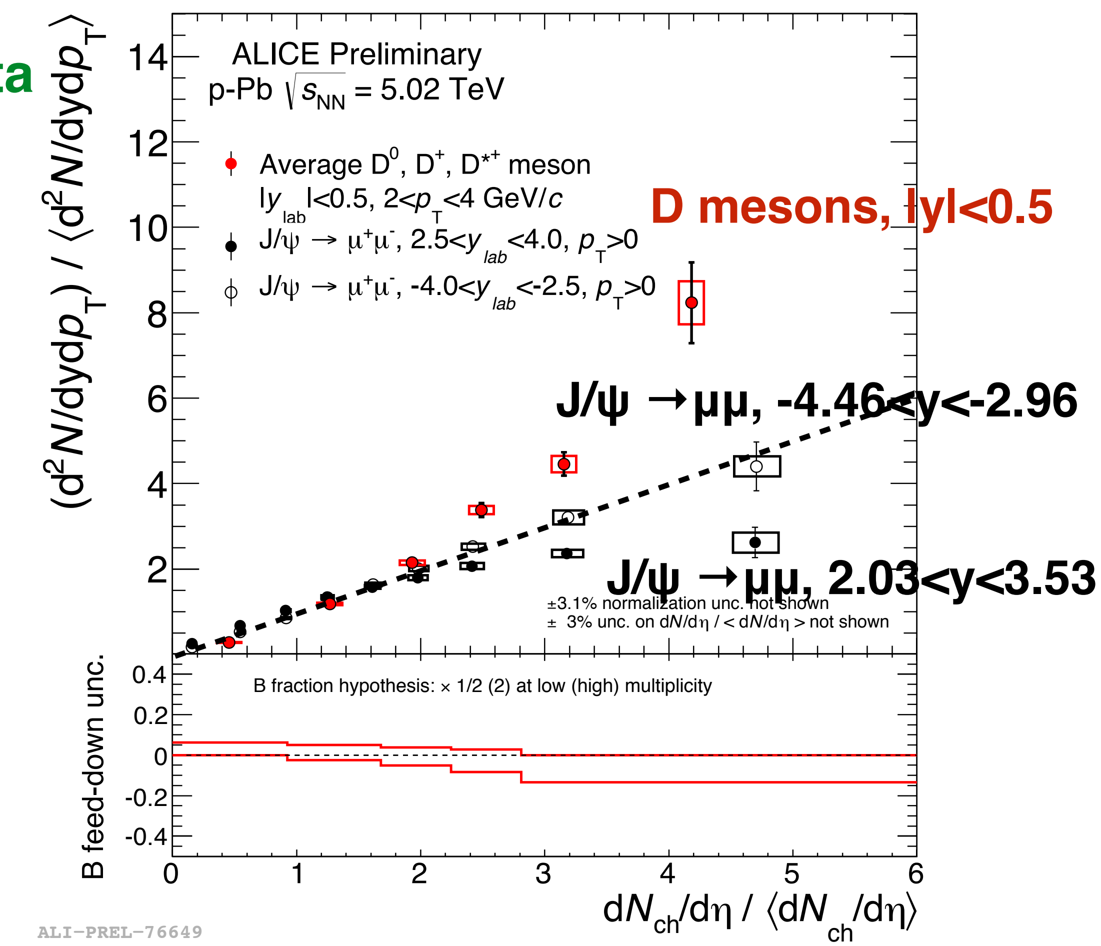
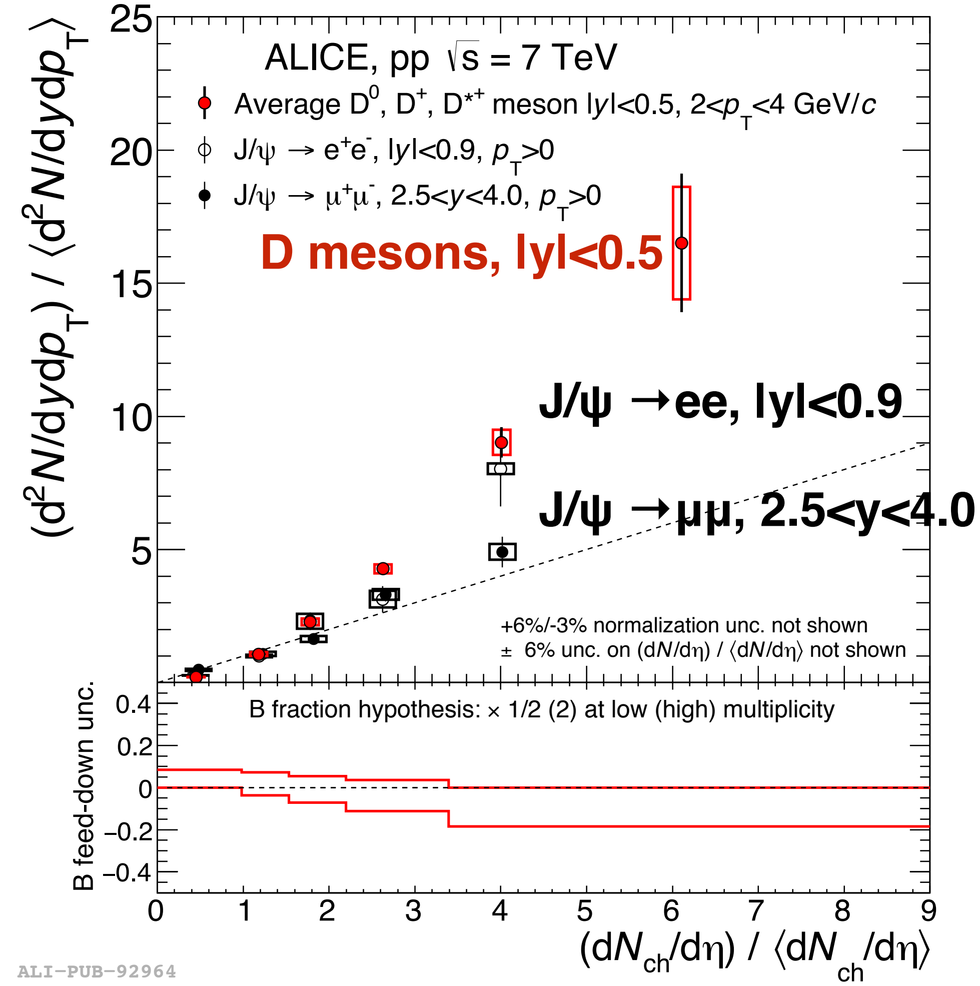
Comparison of open vs hidden heavy flavours

p-Pb data



pp data



- **Heavy-flavour yields increase with charged-particle multiplicity at mid rapidity;**
  - **similar trend in pp collisions,**
  - **in p-Pb collisions, D mesons increase faster than J/ψ.**
    In particular for J/ψ yields measured at forward rapidity (p-going direction).

ALICE, JHEP 09 (2015) 148.
ALICE, Phys.Lett. B712 (2012) 165–175

Note: J/ψ yields measured in the p-going direction probe low-*x* gluons

Error bars: statistical uncertainty.
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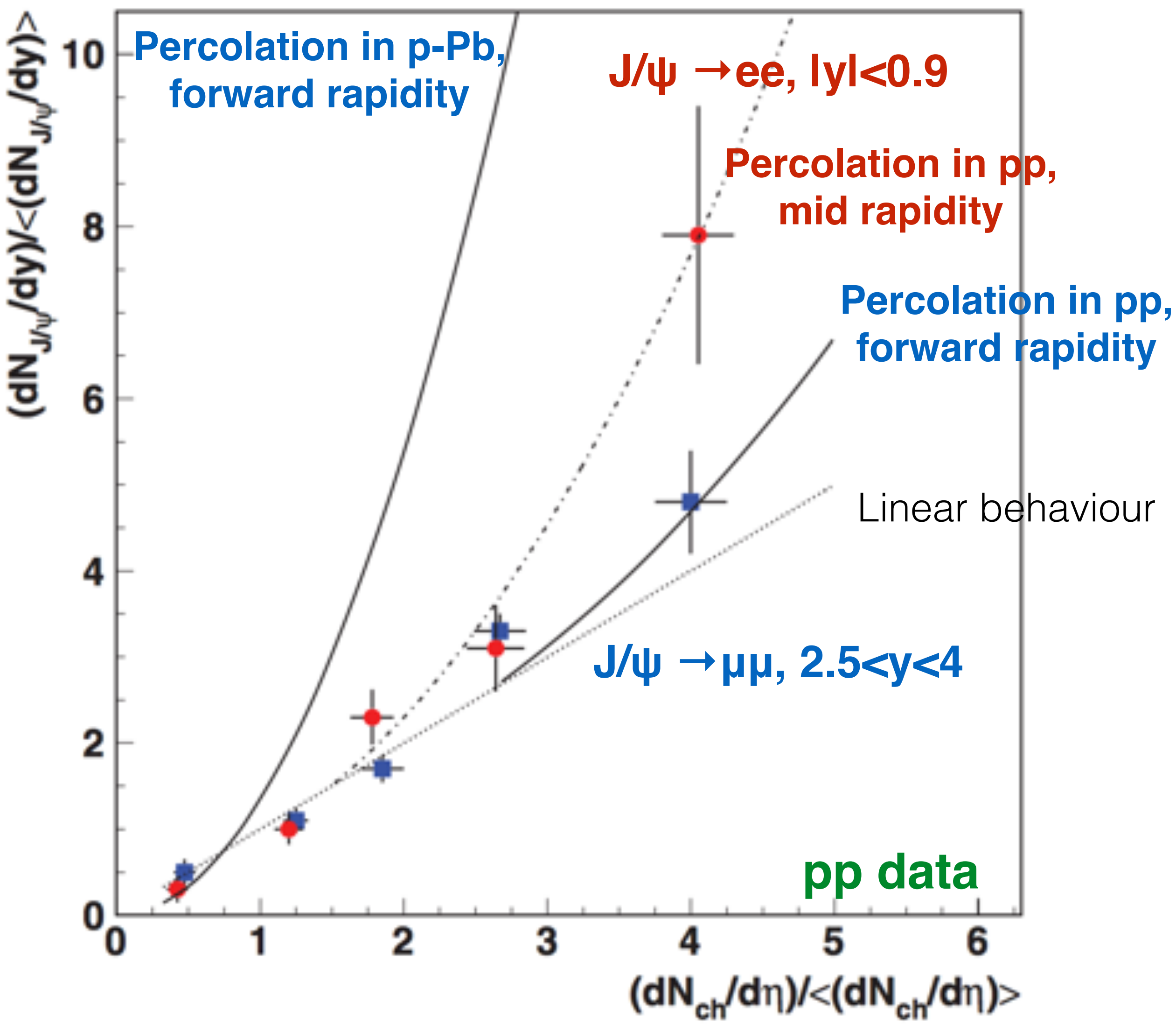
Comparison with models

J/ψ in pp collisions vs. percolation model



- **Percolation**:
  - interactions driven by the **exchange of colour sources** (strings ~ MPI scenario);
  - the strings **have a finite spatial extension and can interact**,
    - at high density the coherence leads to a reduction of their number, i.e. a reduction of charged-particle multiplicity,
    - heavy-flavours are less affected due to the smaller transverse size of hard sources;

✿ **faster-than-linear increase of J/ψ yield with multiplicity**

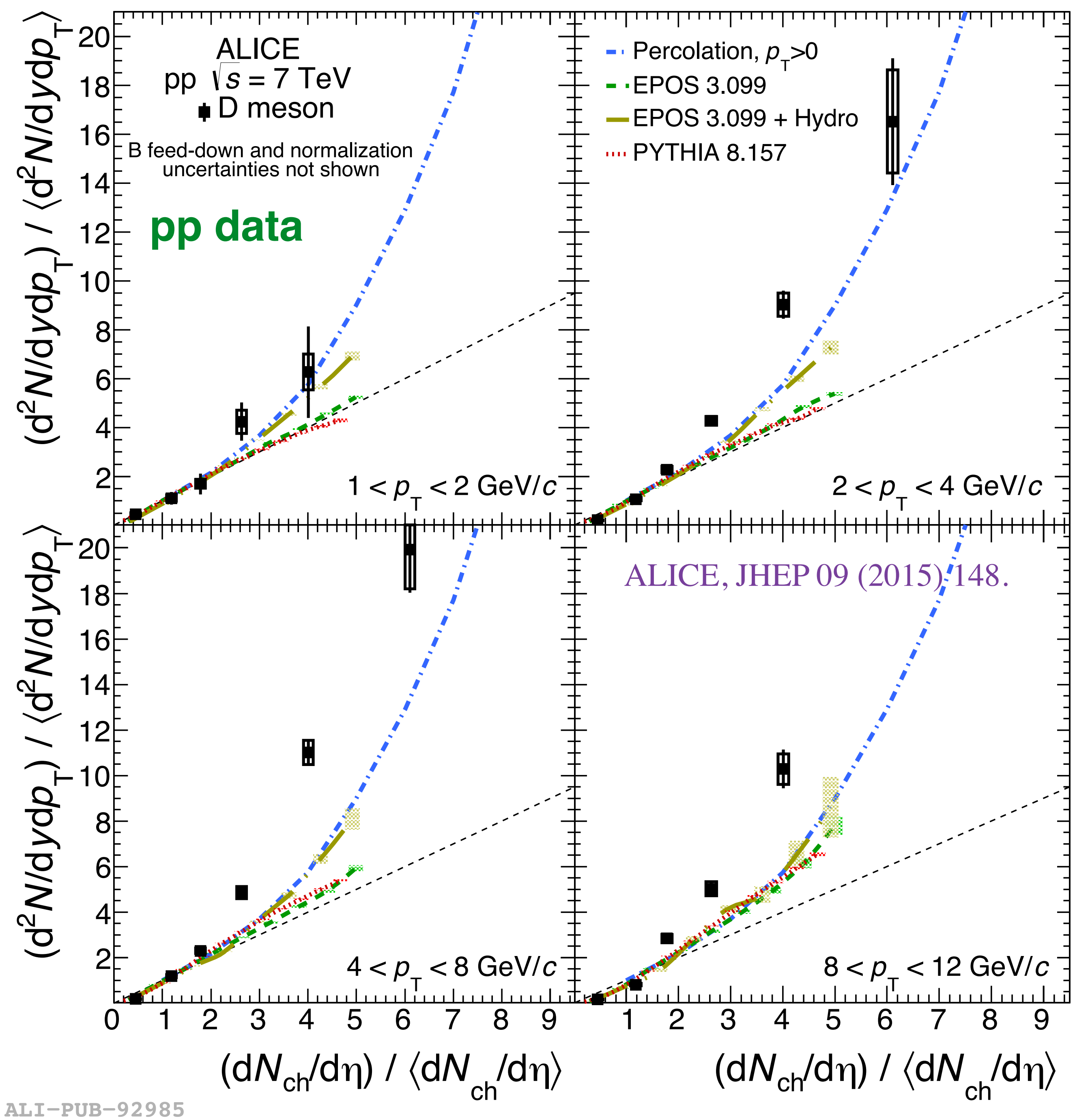
ALICE, Phys.Lett. B712 (2012) 165–175

E. G. Ferreiro and C. Pajares, Phys.Rev. C86 (2012) 034903.

D mesons in pp collisions vs. models

E. G. Ferreiro and C. Pajares, Phys.Rev. C86 (2012) 034903.

E. G. Ferreiro and C. Pajares, arXiv:1501.03381 (2015).



- **Percolation**:
  - interactions driven by the **exchange of colour sources** (strings ~ MPI scenario);
  - the strings **have a finite spatial extension and can interact**,
- **EPOS 3 (event generator)**
  - **Initial conditions**
  - **Hydrodynamical evolution:**
- **PYTHIA 8:**
  - SoftQCD process selection,
  - including colour reconnection,
  - as well as MPI,
  - and diffractive processes

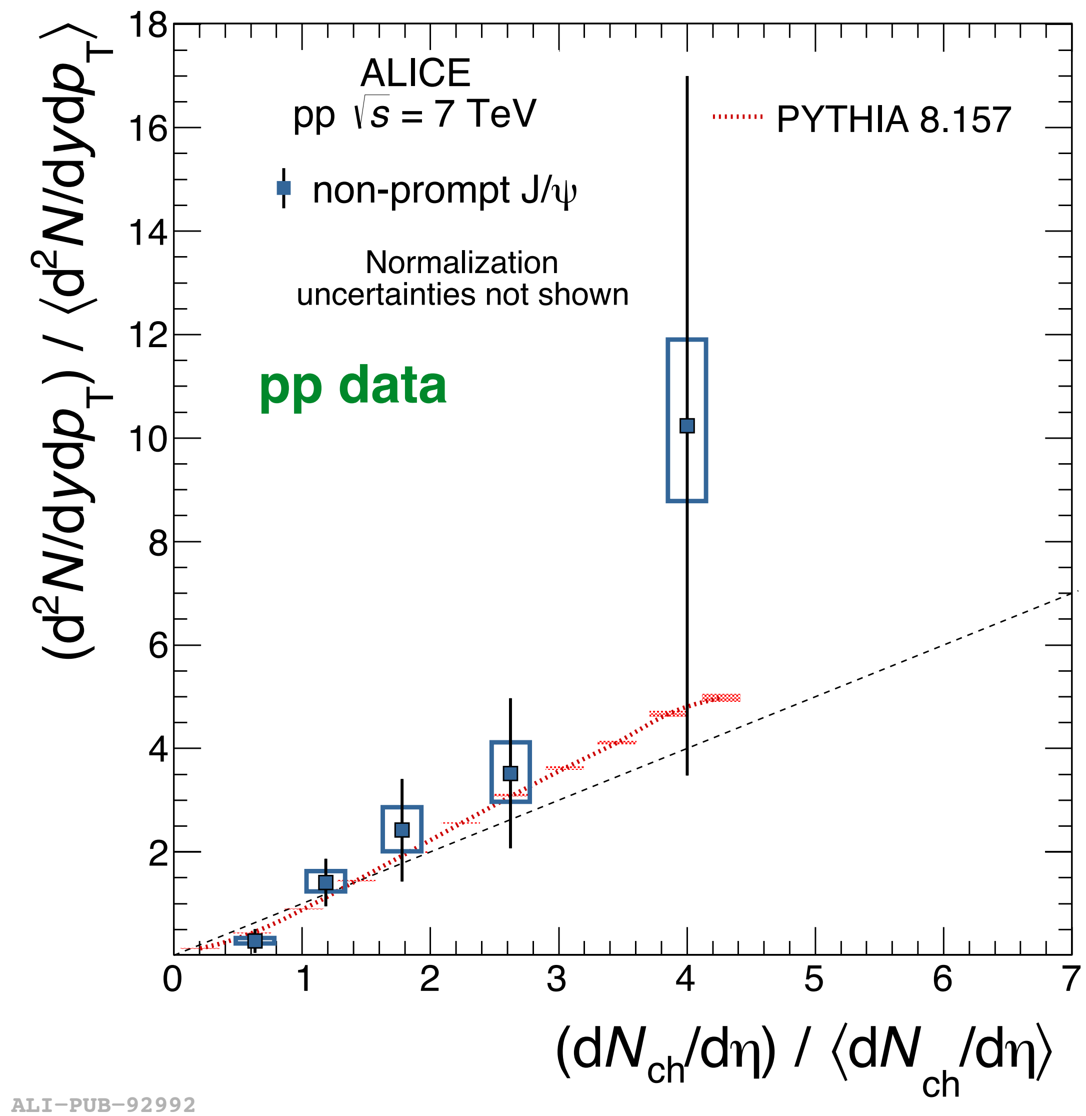
K. Werner talk

H. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, Phys.Rept. 350 (2001) 93–289

K. Werner, B. Guiot, I. Karpenko, and T. Pierog, Phys.Rev. C89 (2014) 064903

T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput.Phys.Commun. 178 (2008) 852–867

Non-prompt J/ψ in pp collisions vs. models



- **PYTHIA 8:**
  - SoftQCD process selection,
  - including colour reconnection,
  - as well as MPI,
  - and diffractive processes

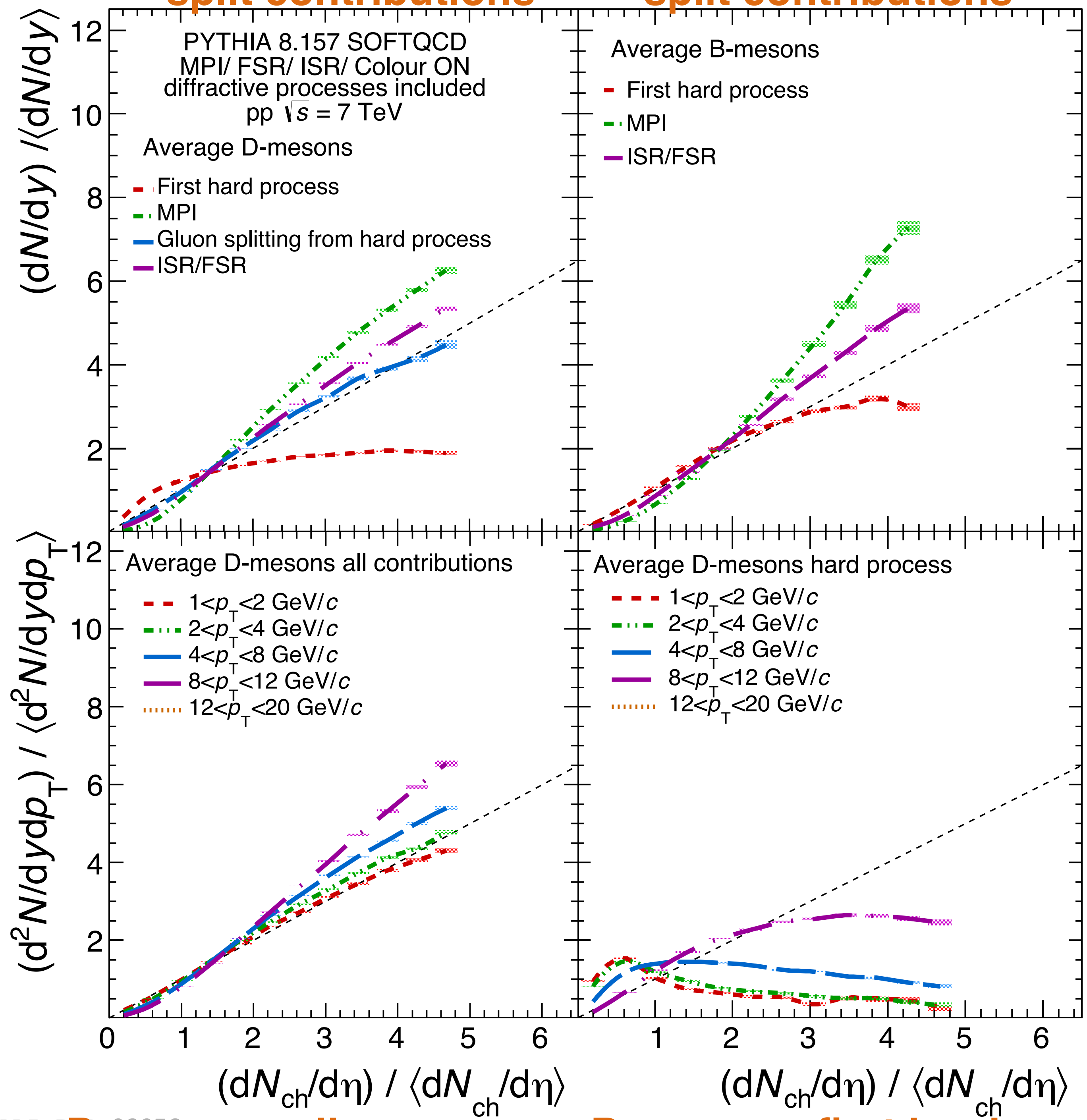
✿ **nearly linear trend of B-hadron yield with multiplicity.**

ALICE, JHEP 09 (2015) 148.

T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput.Phys.Commun. 178 (2008) 852–867

More details on PYTHIA 8

D hadrons, split contributions | **B hadrons, split contributions**

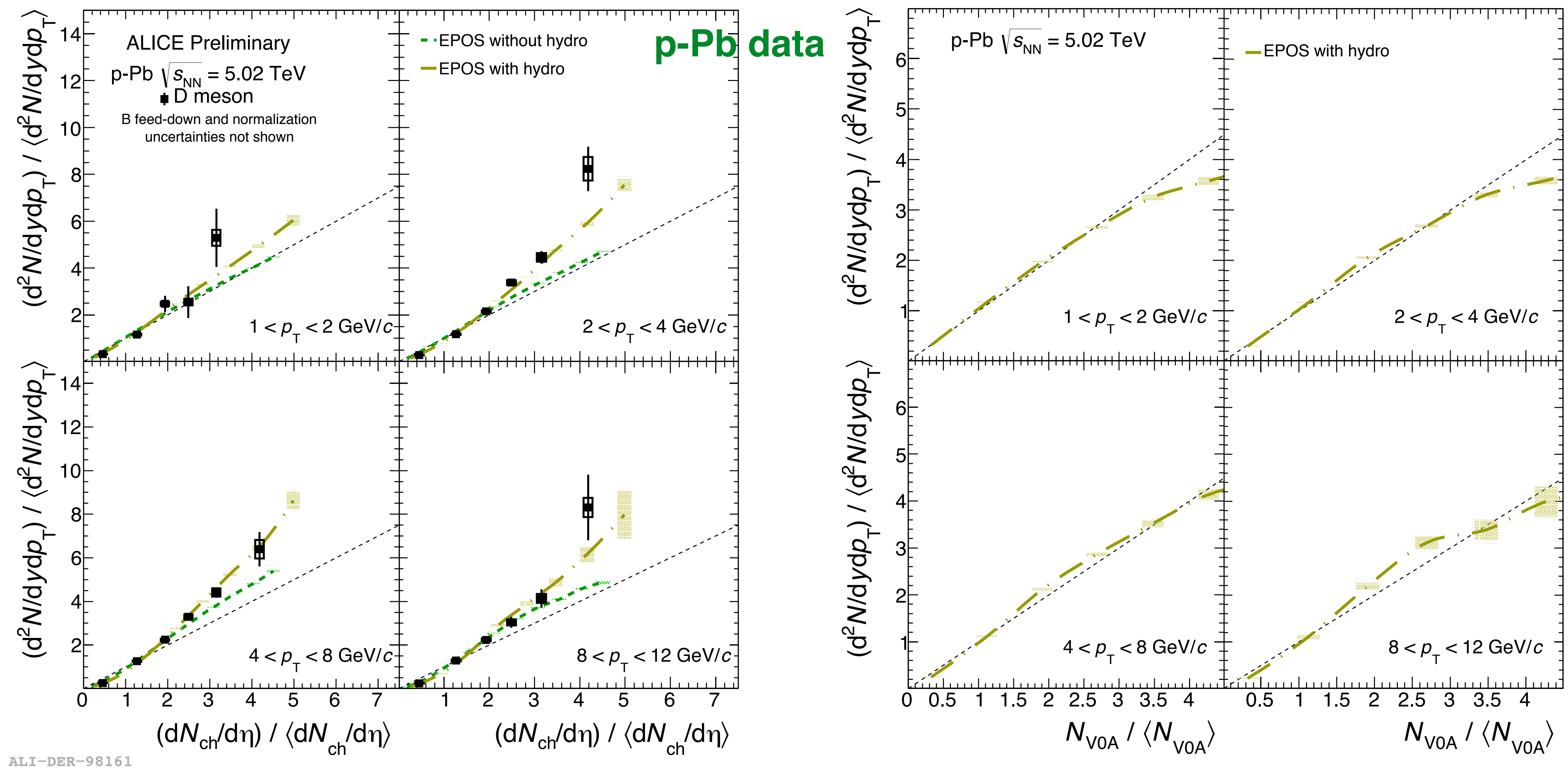


D mesons, all processes, p_T dependence | **D mesons, first hard process, p_T dependence**

- Calculation: SoftQCD process selection, including colour reconnection and diffractive processes.
- Contributions of:
  - **first hard process** ≈ hardest process
    ✿ **weak dependence on multiplicity** (slight increase at low multiplicities followed by a saturation)
  - **MPI** ≈ subsequent hard process
    ✿ **increasing trend vs. multiplicity**
  - **gluon splitting from hard process**
    ✿ **increasing trend vs. multiplicity**
  - **initial and final-state radiation**
    ✿ **increasing trend vs. multiplicity**

T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput.Phys.Commun. 178 (2008) 852–867

D mesons in p-Pb collisions vs. models



- **EPOS 3 with initial conditions and hydrodynamic evolution estimates:**
  - **a faster-than-linear increase of D-meson yields with multiplicity at mid rapidity,**
  - **approximately linear trend with multiplicity at backward rapidity (reduced influence of hydro on charged-particle production at forward rapidity).**

H. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, Phys.Rept. 350 (2001) 93–289
K. Werner, B. Guiot, I. Karpenko, and T. Pierog, Phys.Rev. C89 (2014) 064903

Summary

- Heavy-flavour hadron yield increases with charged-particle multiplicity in pp collisions
  - Faster-than-linear increase at high multiplicities.
  - Similar trend for open and hidden heavy-flavours
    ⇨ related to charm and beauty production mechanisms (small influence of hadronisation)
- Models including multiple parton interactions reproduce the measurements.

- In p-Pb collisions, heavy-flavour hadron yield increases with charged-particle multiplicity at mid rapidity
  - D mesons increase faster than J/ψ.
    In particular for J/ψ yields measured at forward rapidity (p-going direction).
  - J/ψ average p_T increases with multiplicity and seems to saturate at high multiplicities, independently of J/ψ rapidity.
- EPOS 3 calculations reproduce the observed D-meson trend.
  Missing model calculations for beauty-hadron and charmonia production.

- Future directions: higher multiplicities, higher √s, fine p_T intervals, angular correlations,…