Open heavy flavour and quarkonium production as a function of the multiplicity in pp and p-Pb collisions with ALICE at the LHC

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For the ALICE Collaboration

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Physics motivation

The ALICE detector

Results:

- proton-proton
- proton-lead

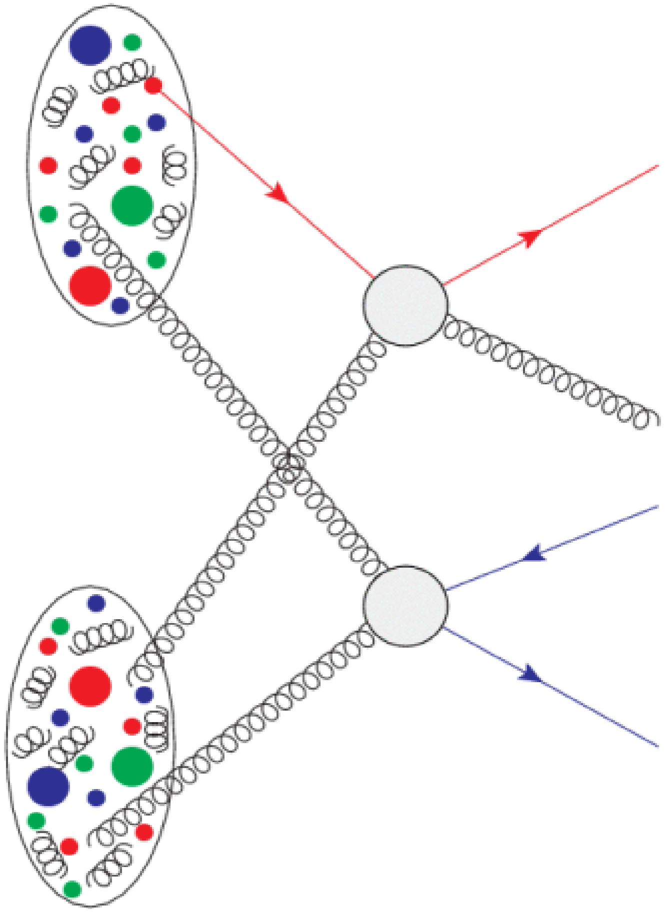
Summary

San Cristóbal de las Casas

PHYSICS MOTIVATION

Production vs multiplicity

Can provide insight into the processes occurring in the collision at the partonic level and the interplay between the hard and soft mechanisms in particle production.



Multiplicities in pp collisions at the LHC can reach values similar to those measured in HI collisions at lower energies ➔ collectivity in pp for high multiplicities?

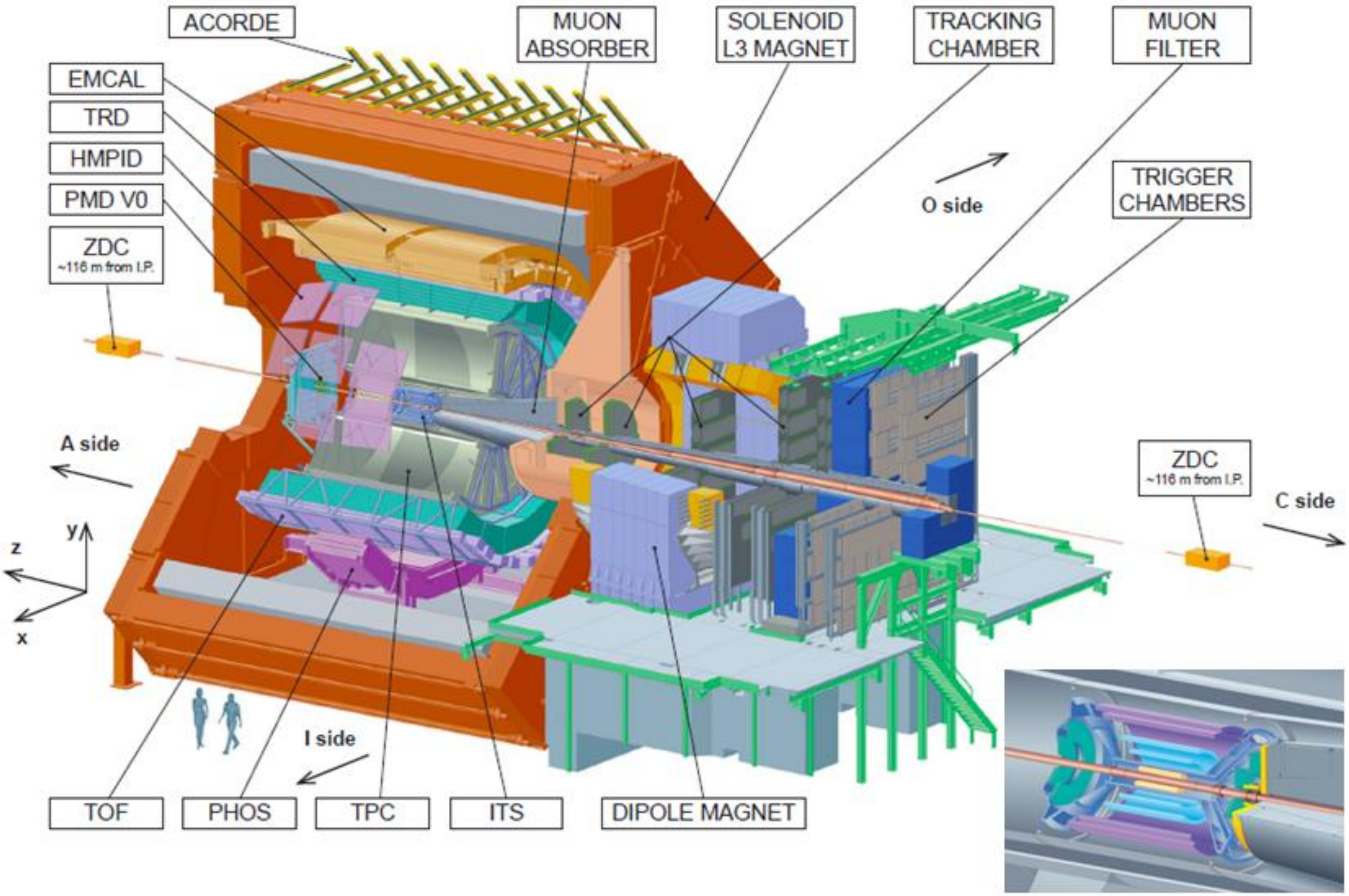
Possible explanations:

- Several interactions at the partonic level occur in parallel (MPI).
- Role of the collision geometry.
- Final-state effects (color reconnection or string percolation).

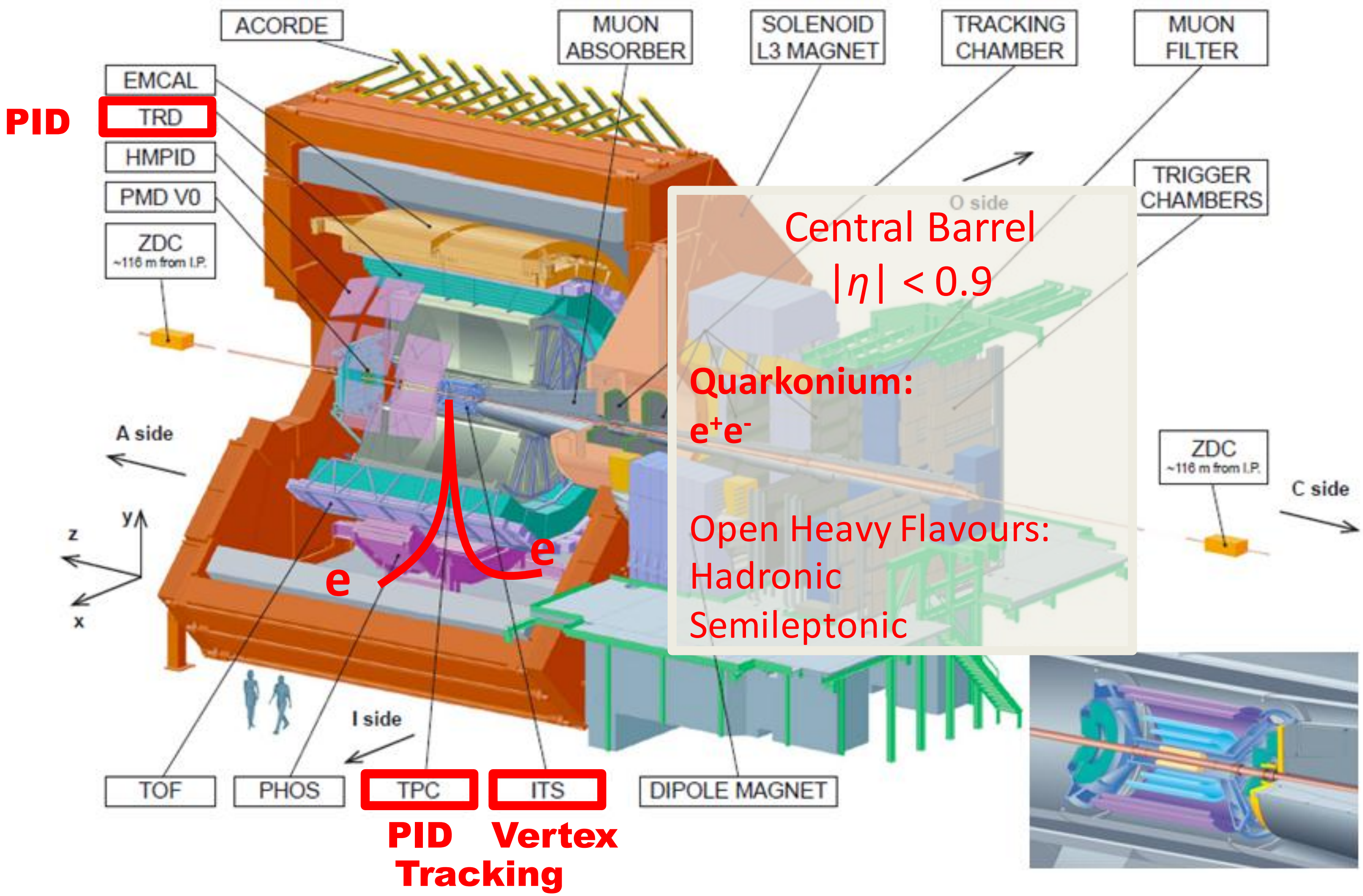
Caveat: in p-Pb the multiplicity dependence is also affected by the presence of multiple binary nucleon-nucleon interactions and the initial conditions modified by CNM effects.

THE ALICE DETECTOR

The ALICE detector



The ALICE detector

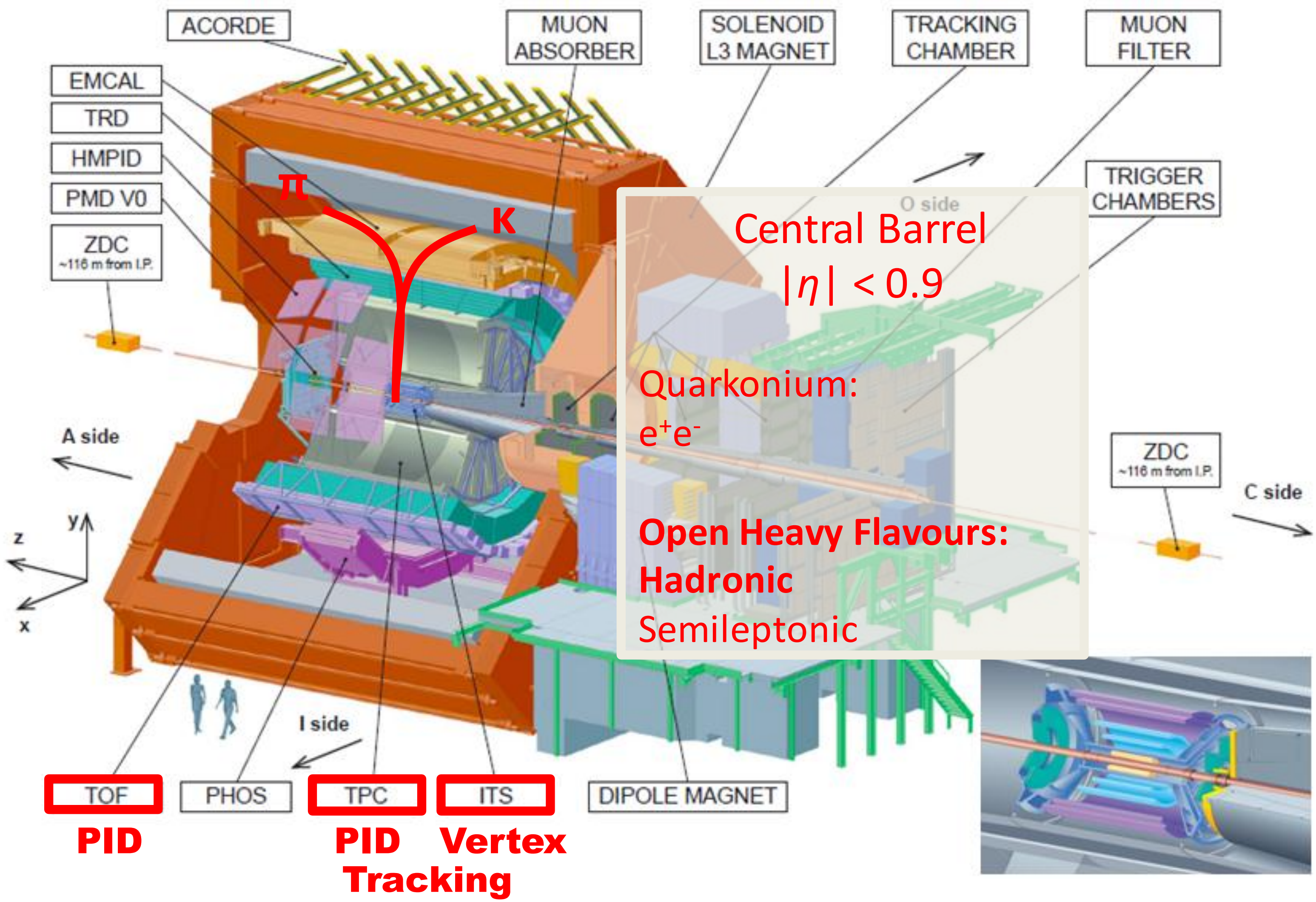


Central Barrel
$|\eta| < 0.9$

Quarkonium:
e^+e^-

Open Heavy Flavours:
Hadronic
Semileptonic

The ALICE detector



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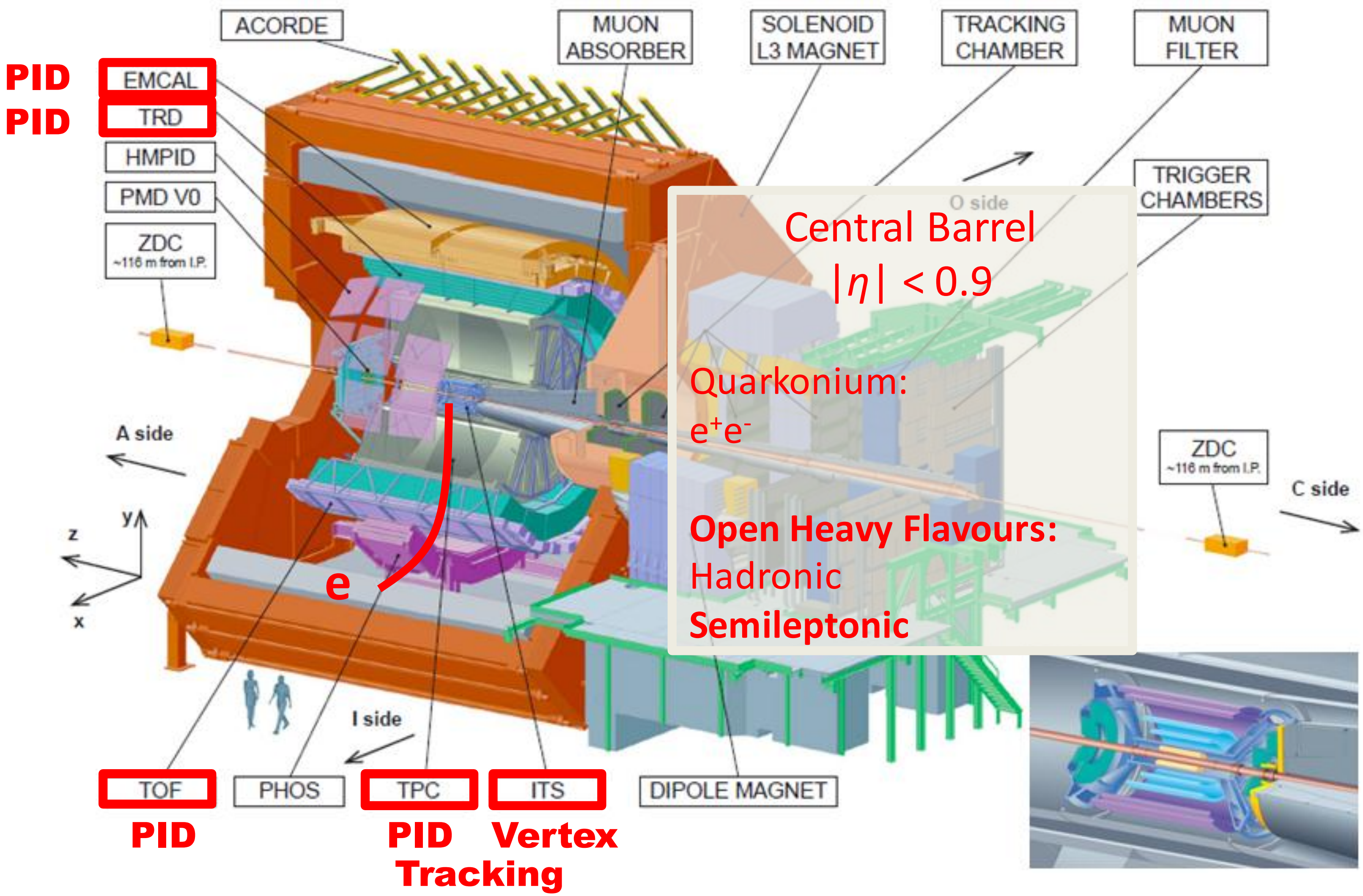

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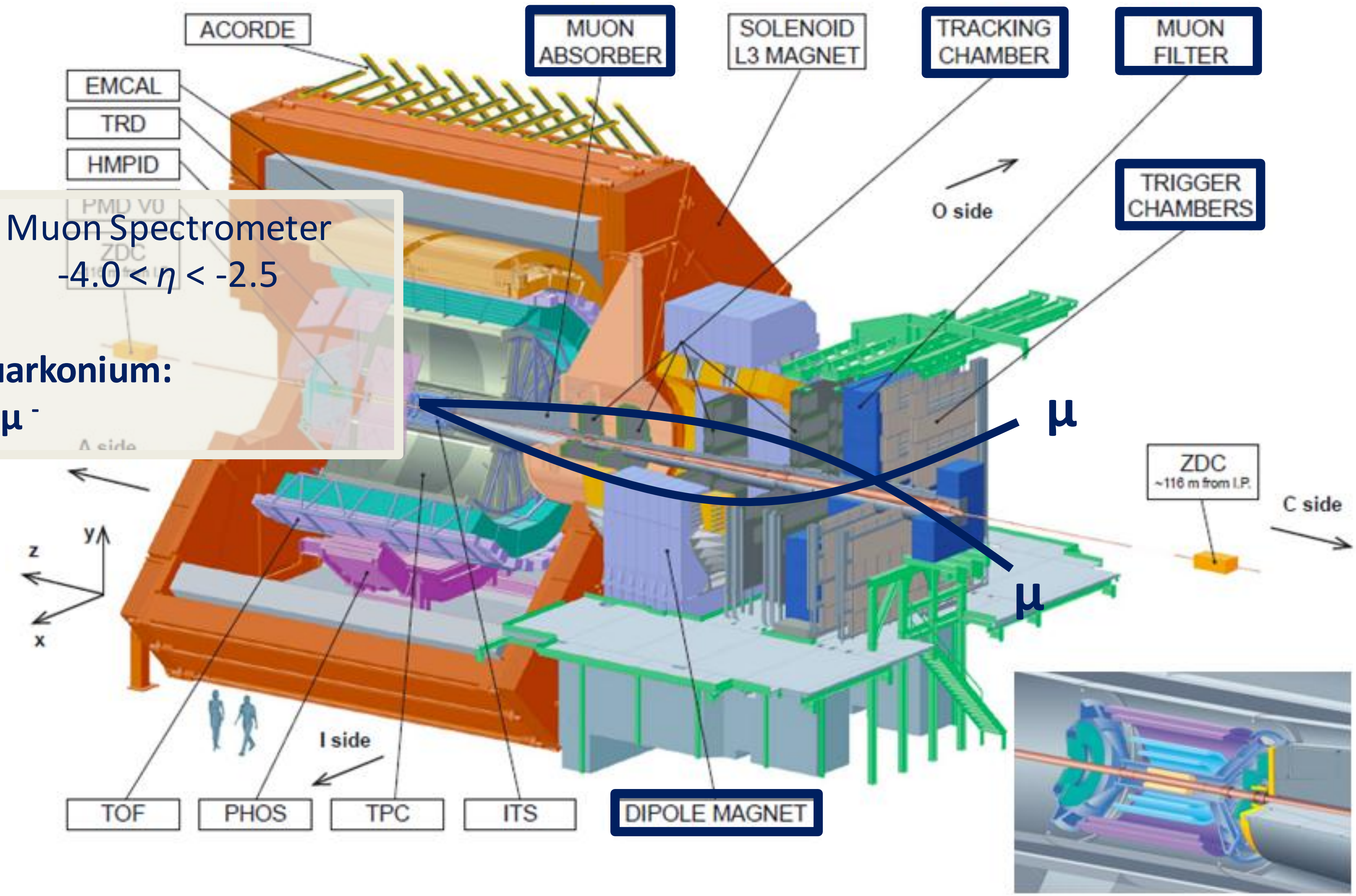
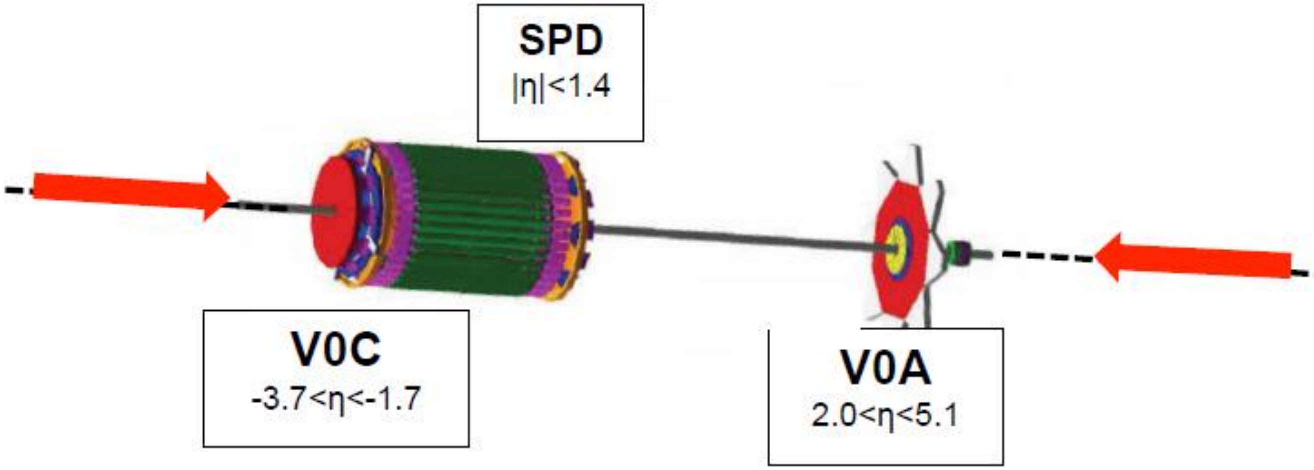


Muon Spectrometer
$-4.0 < \eta < -2.5$

Quarkonium:
$\mu^+ \mu^-$

Multiplicity estimators



Number of track segments (or tracklets) of the Silicon Pixel Detector (SPD).

- Pixel detectors of radii of 3.9 cm and 7.6 cm with intrinsic spatial resolution of 100 μm along the *z* axis and 12 μm in the *r*φ plane.

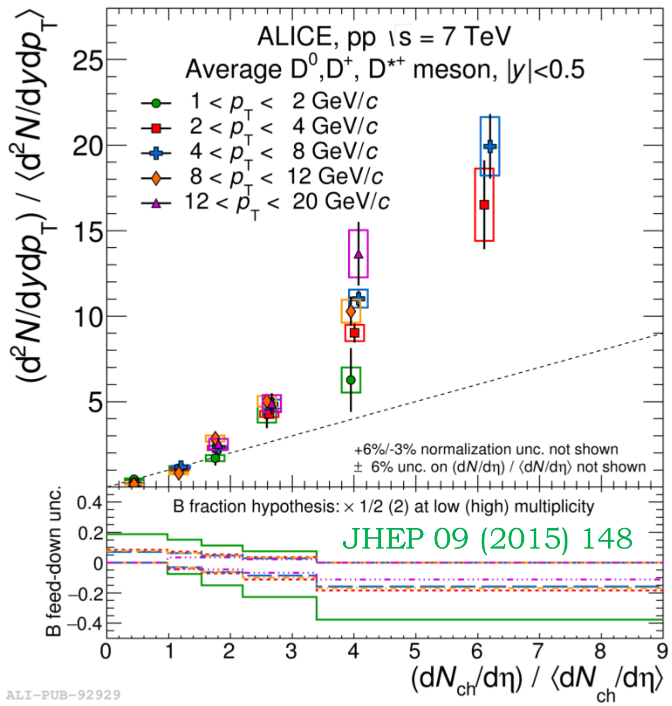
Sum of the amplitudes in the V0 scintillators arrays (V0A and V0C). For p-Pb collisions only V0A amplitude is used (backward rapidity multiplicity estimator).

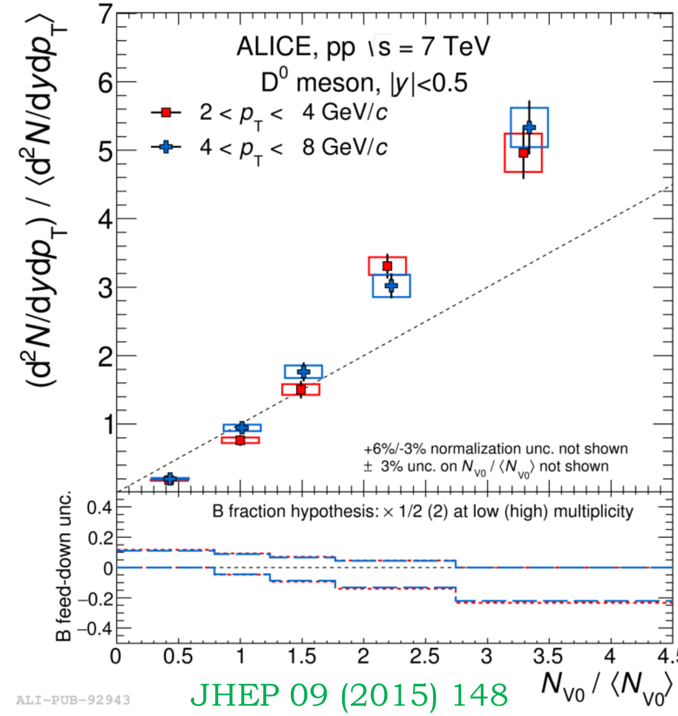
- Plastic scintillators located at both sides of the interaction point at a distance of 330 cm (V0A) and 90 cm (V0C).

Rapidity gap between SPD and V0: mid and forward rapidity multiplicity estimators.

PROTON-PROTON COLLISIONS

Open charm



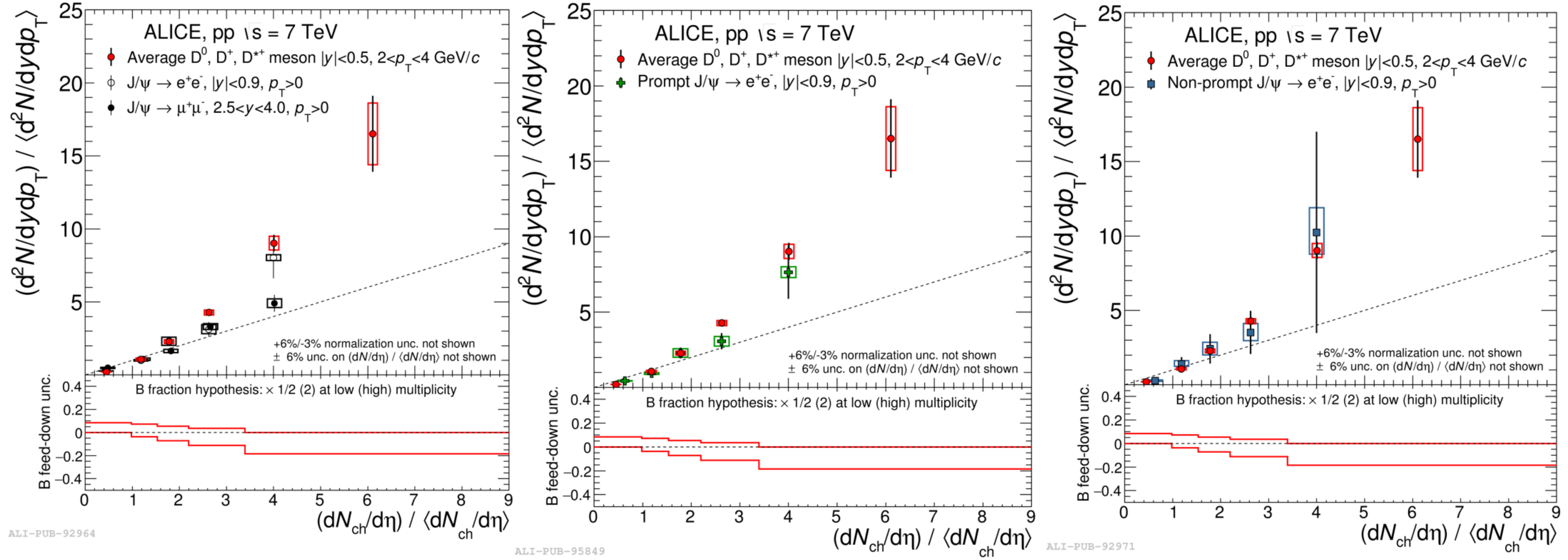


Mid-rapidity multiplicity estimator (left): faster than linear increase and independent of p_T.

Forward rapidity multiplicity estimator (right): minimise influence of particles produced in the charm fragmentation and *D*-meson decay in mult. estimation.

Qualitatively similar increasing trend of *D*-meson yields in both pseudo-rapidity regions.

Quarkonium and Open Heavy Flavours



Faster than linear increase with multiplicity for inclusive J/ψ, open charm and open beauty, within the uncertainties.

Indication that this behavior is related to heavy-flavour production processes and not significantly influenced by hadronisation mechanisms.

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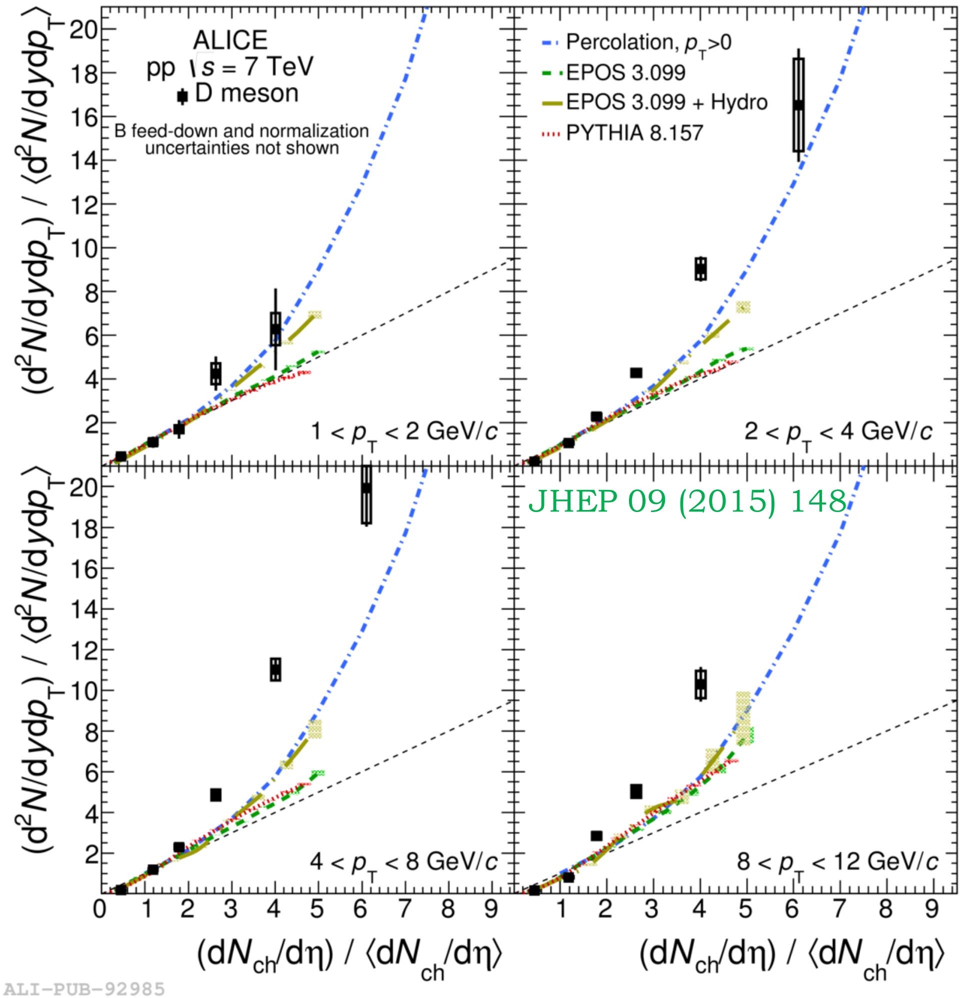
Caveat: different p_T and y intervals of the measurements.

Comparison to theoretical models



Good description from Percolation Model.

Percolation model:

- Assumes collisions are driven by the exchange of colour sources between projectile and target.
- Colour sources have a finite spatial extension and can interact.

EPOS 3:

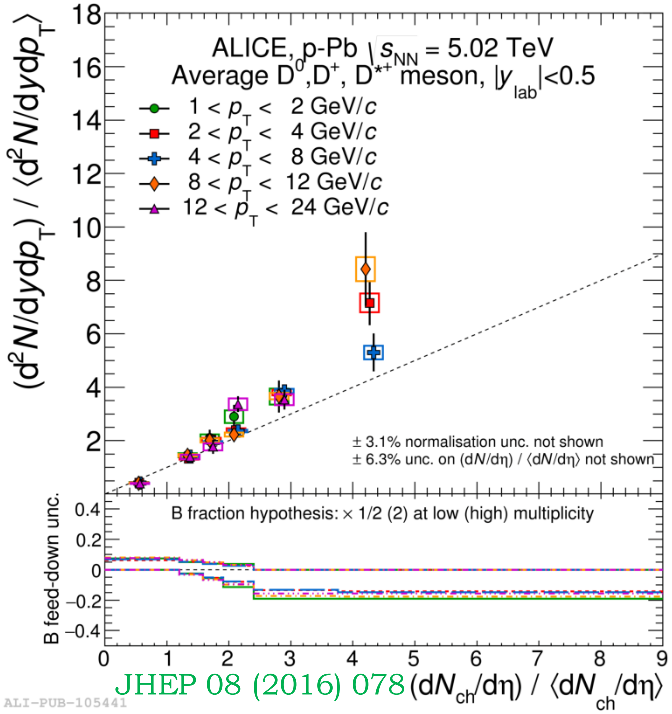
- Assumes hydro evolution.
- Hadronization via string fragmentation.

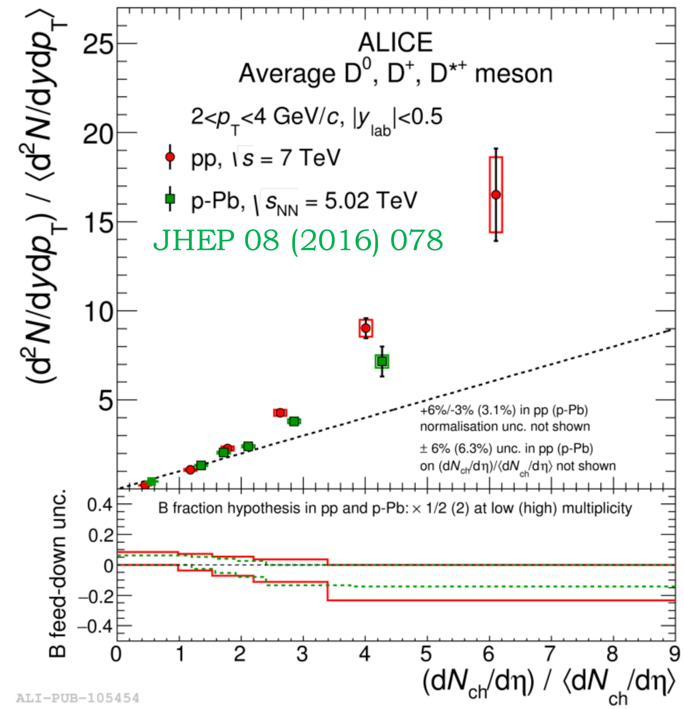
Pythia 8:

- Simulation includes colour reconnection and diffractive processes.
- SoftQCD process selection.
- Also MPI and ISR/FSR.

PROTON-LEAD COLLISIONS

Open charm

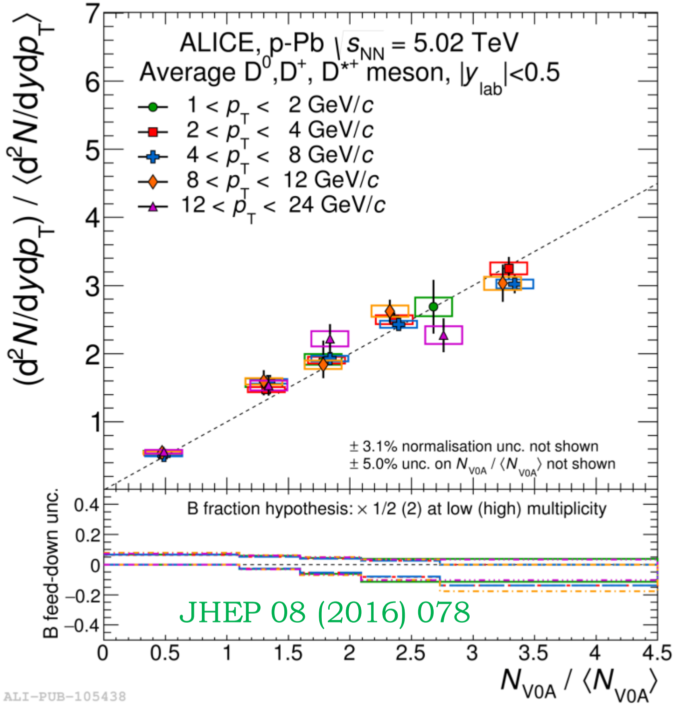


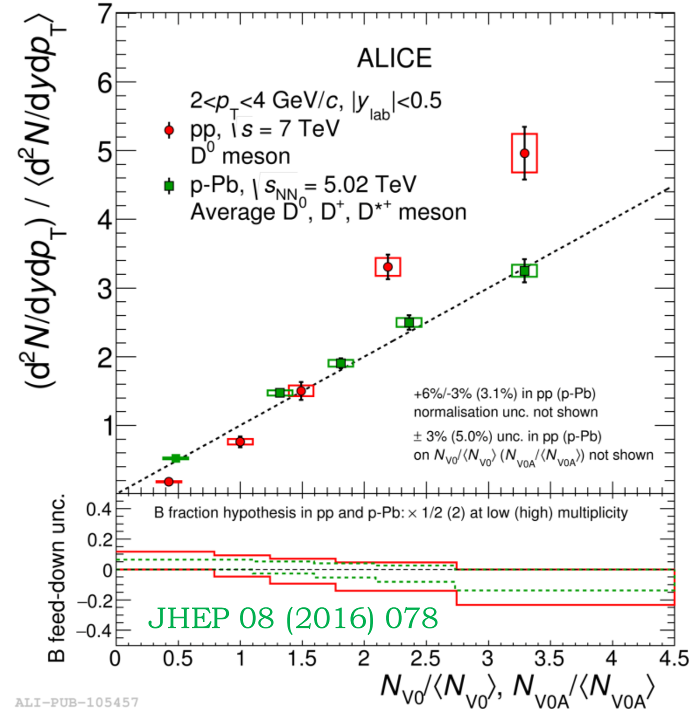


Mid-rapidity multiplicity estimator: faster than linear increase and independent of p_T. Similar relative increasing trend of *D*-meson yields with charged-particle multiplicity observed both in pp and p-Pb collisions.

In p-Pb collisions, measurement is affected by multiple binary nucleon-nucleon interactions and CNM effects.

Open charm

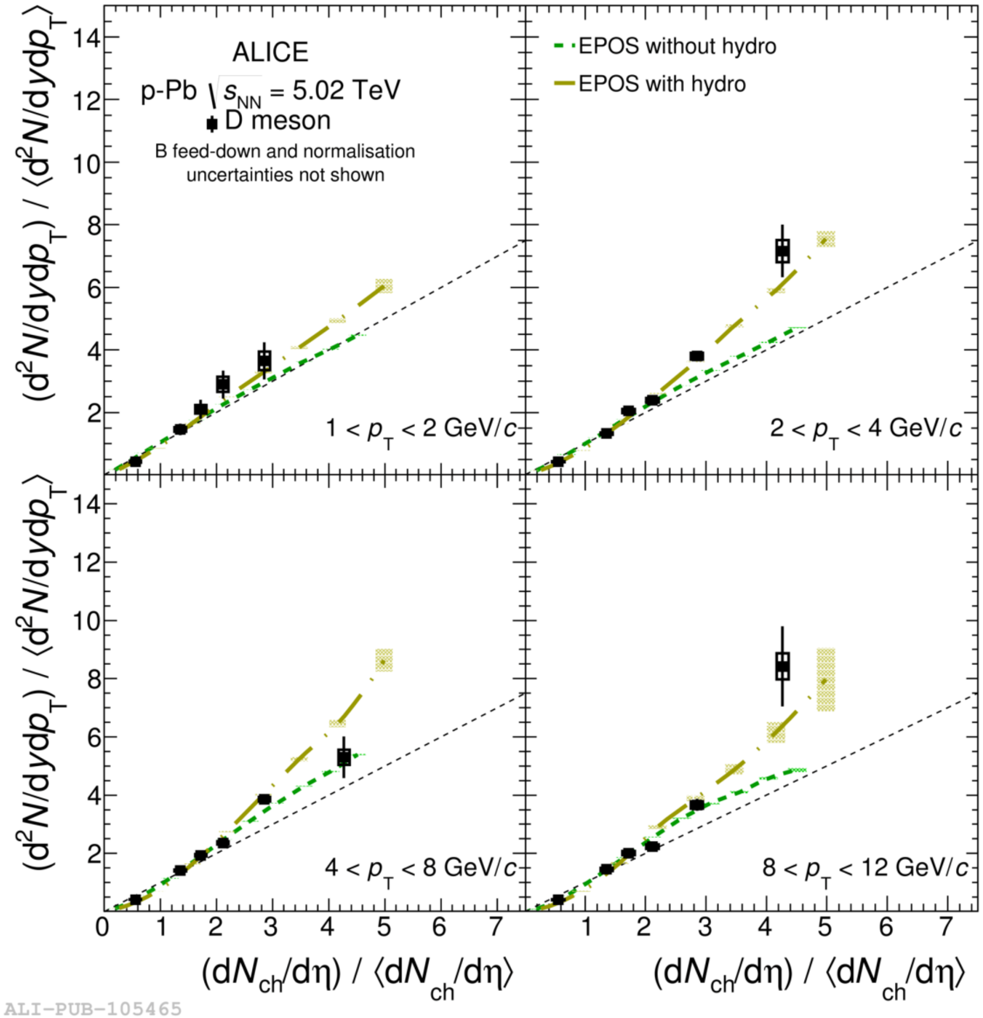




Charmed-meson yields are independent of p_T within uncertainties and they increase linearly with the multiplicity, as measured with the backward rapidity multiplicity estimator.

D-meson yields increase faster in pp than in p-Pb collisions. Different pseudorapidity intervals of the multiplicity measurement may contribute to this observation. In p-Pb, measurement is affected by multiple binary nucleon-nucleon interactions and CNM effects.

Comparison to theoretical models



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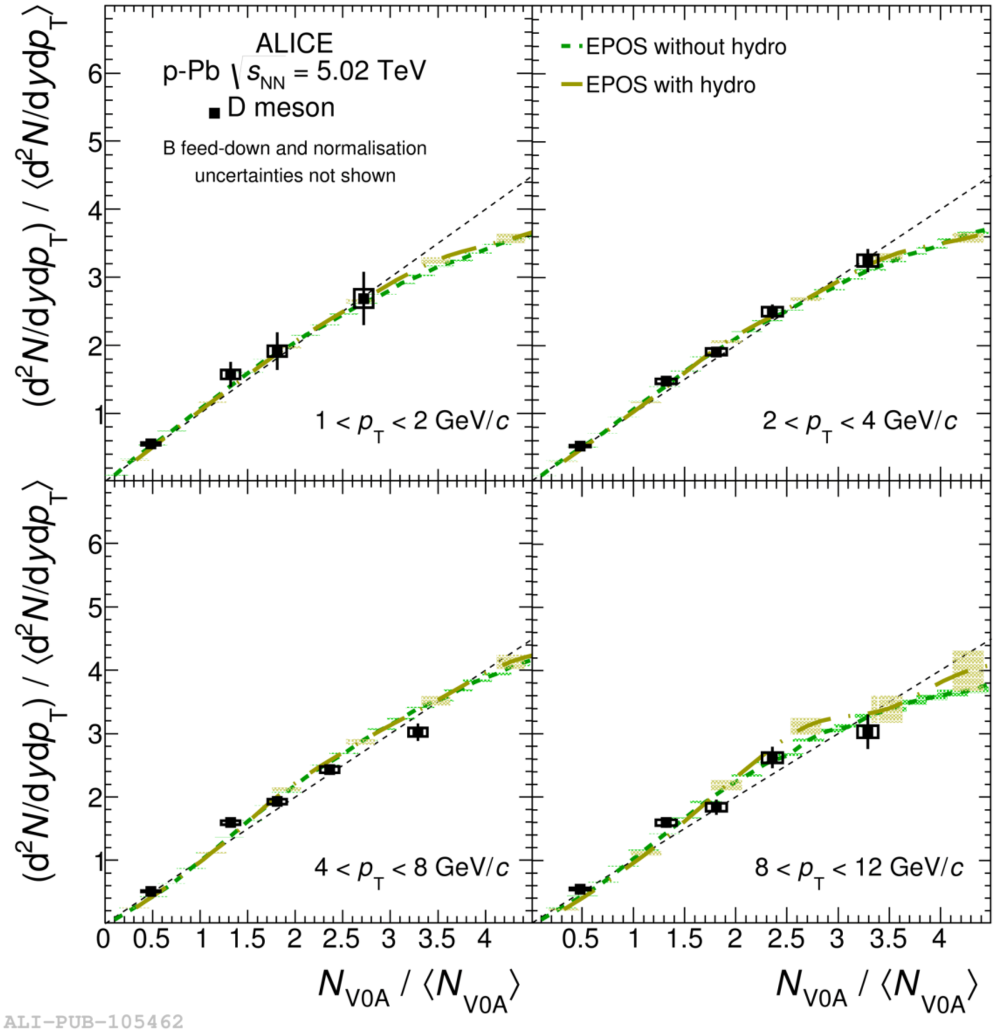
EPOS 3 event generator:

- Same theoretical framework for pp, p-A and A-A collisions.
- Initial conditions using the Gribov-Regge formalism of multiple scattering.
- Each scattering is identified with a parton ladder, composed of a pQCD hard process with ISR/FSR.

EPOS 3 can correctly describe the result, whether mid or backward rapidity multiplicity estimator is used.

High multiplicity measurements are better reproduced by calculations including viscous hydrodynamical evolution of the collision.

Comparison to theoretical models



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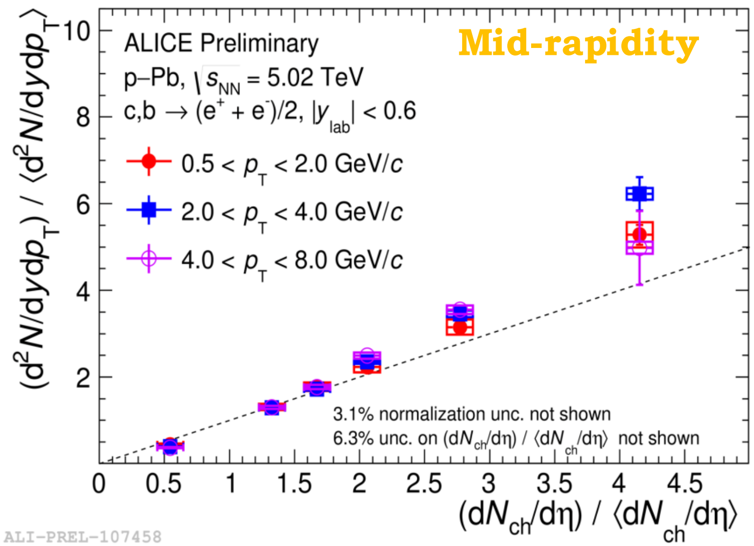
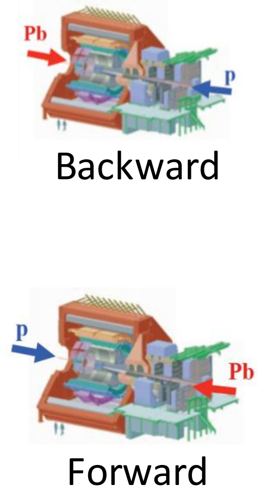
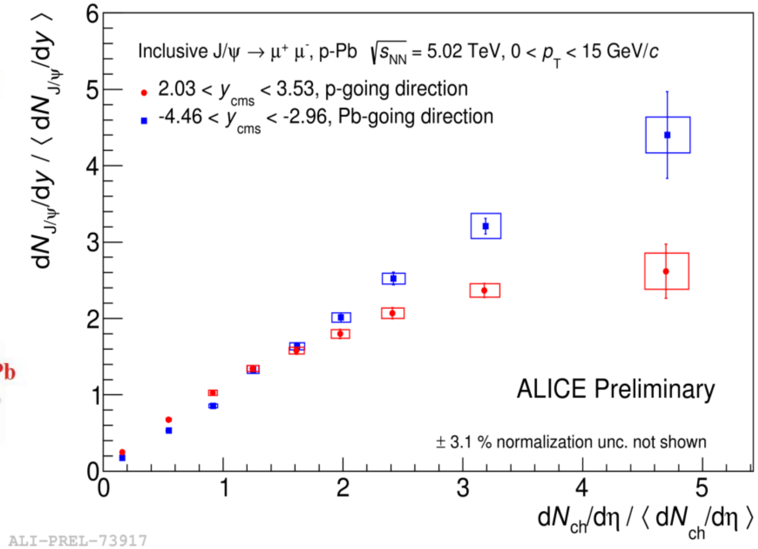
Quarkonia and Open Heavy Flavours





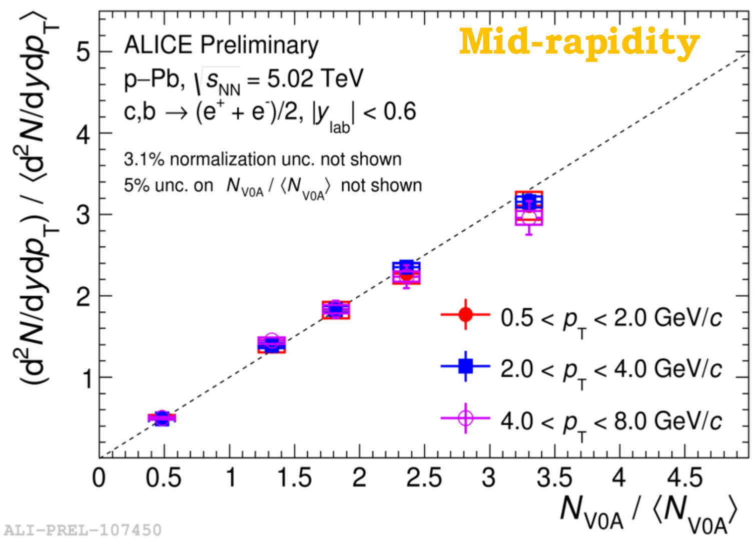


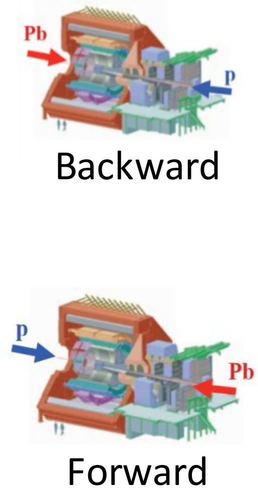
Measurements also performed for OHF decaying to single electrons (central barrel) and J/ψ via dimuons (muon spectrometer).

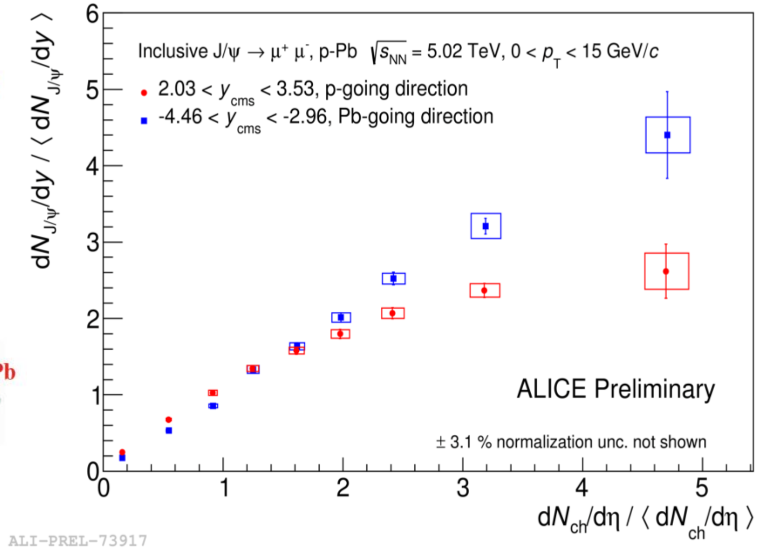
e ← OHF: faster than linear increase and independent of p_T. When backward multiplicity estimator is used: linear increase. Qualitatively similar behavior as *D* mesons.

In the muon spectrometer: different rapidity coverages for the two beam configurations. Linear increase of J/ψ yields measured at backward rapidity and deviation of the linear increase for J/ψ yields measured at forward rapidity.

Quarkonia and Open Heavy Flavours







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SUMMARY

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Open Heavy Flavour and quarkonium production as a function of the multiplicity are useful tests for Multiple Partonic Interaction scenario.

In pp collisions:

- Faster than linear increase at high multiplicities.
- Similar trend for quarkonia and Open Heavy Flavour indicates small influence of hadronisation.
- Models including MPI can reproduce the data.

In p-Pb collisions:

- Faster than linear increase at high multiplicities, but slower than in pp collisions.
- D-meson yields increase faster than J/ψ.
- Results for *D*-mesons can be described by EPOS 3 event generator.

For Run II: higher center of mass energy, higher mutiplicities, finer p_T intervals, etc.

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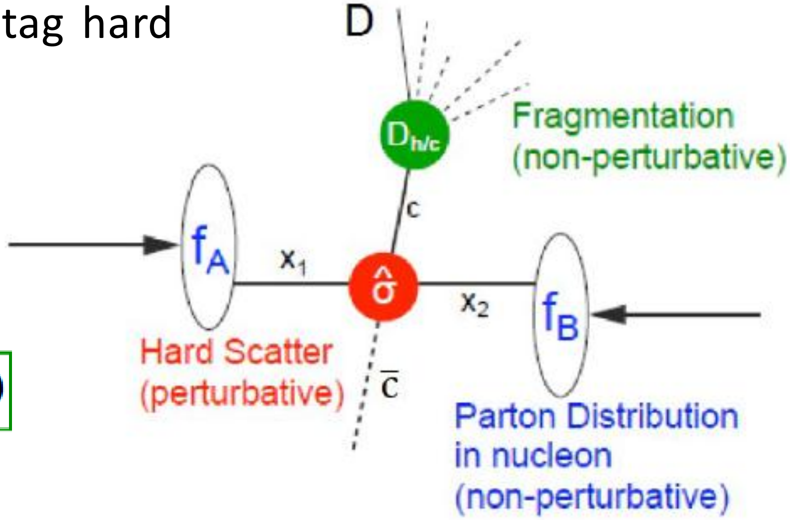
Thanks for your attention

BACKUP

Why Open Heavy Flavours and Quarkonium?

Charm and beauty quarks are produced in the initial hard scatterings of the collision, so they can be used to tag hard processes with $Q^2 > (2m)^2 \approx 10\ \text{GeV}^2$.

In pp collisions: test perturbative QCD-inspired models based on the factorization approach.



$$\sigma_{hh\to Hx} = PDF(x_a, Q^2)PDF(x_b, Q^2) \otimes \sigma_{ab\to q\bar{q}} \otimes D_{q\to H}(z_q, Q^2)$$

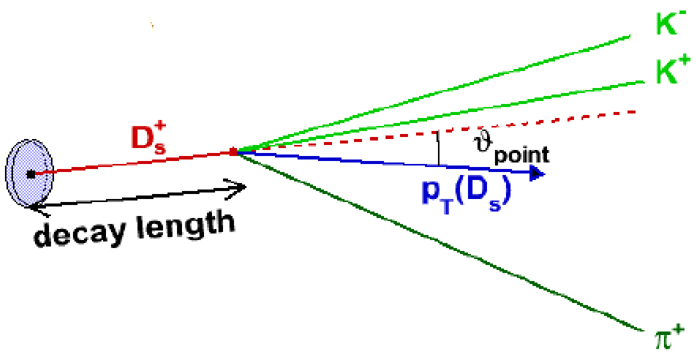
In p-Pb collisions: possibility to study the Cold Nuclear Matter (CNM) effects that can modify the particle production.

Main CNM effects that can affect both open and hidden heavy flavours: shadowing/anti-shadowing, energy loss and gluon saturation.

However, more differential measurements can provide more insight into heavy quark production mechanisms.

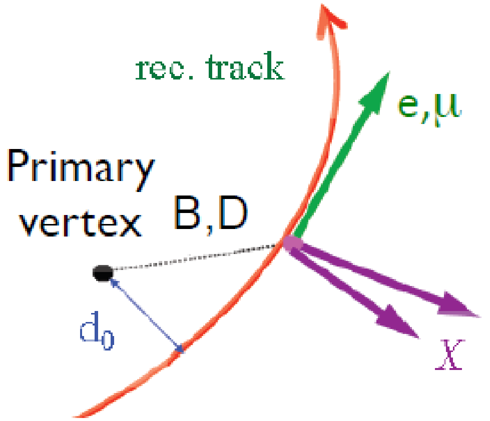
Open Heavy Flavours (OHF)

Full reconstruction of D mesons:



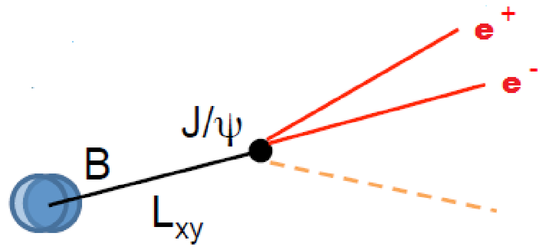
Invariant mass analysis based on displaced secondary vertices, selected with topological cuts and particle identification. Correction for beauty feed-down based on FONLL.

Semileptonic decays:



Background (neutral π and η Dalitz decays and photon conversions) subtracted with invariant mass method or a cocktail.

Beauty studies:



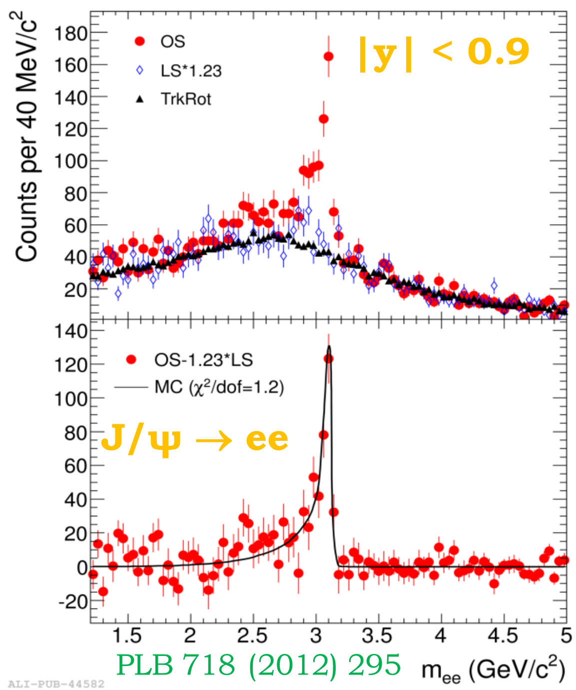
Separation of prompt and non-prompt J/ψ is performed by exploiting the pseudo-proper decay length. Beauty-decay electrons are extracted by exploiting the displaced track impact parameter.

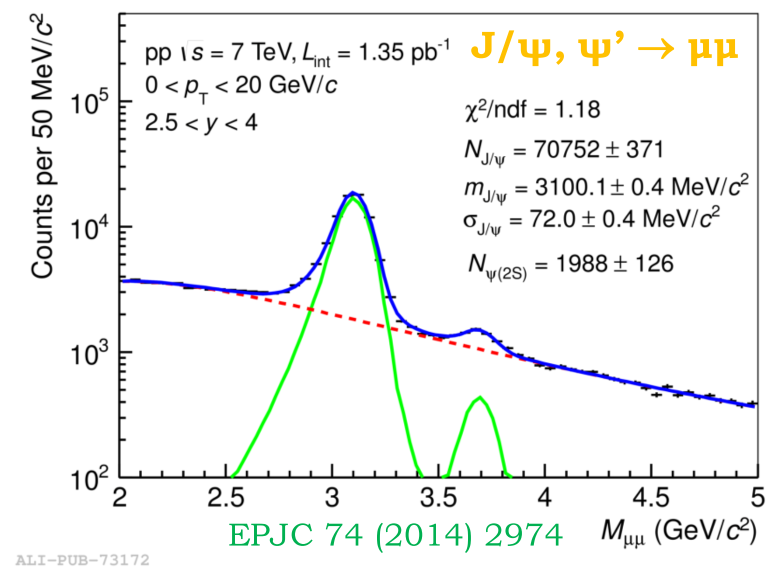
Quarkonia

ALICE is unique at the LHC: quarkonium measurements, both at mid and forward rapidity, are performed down to $p_T = 0$.

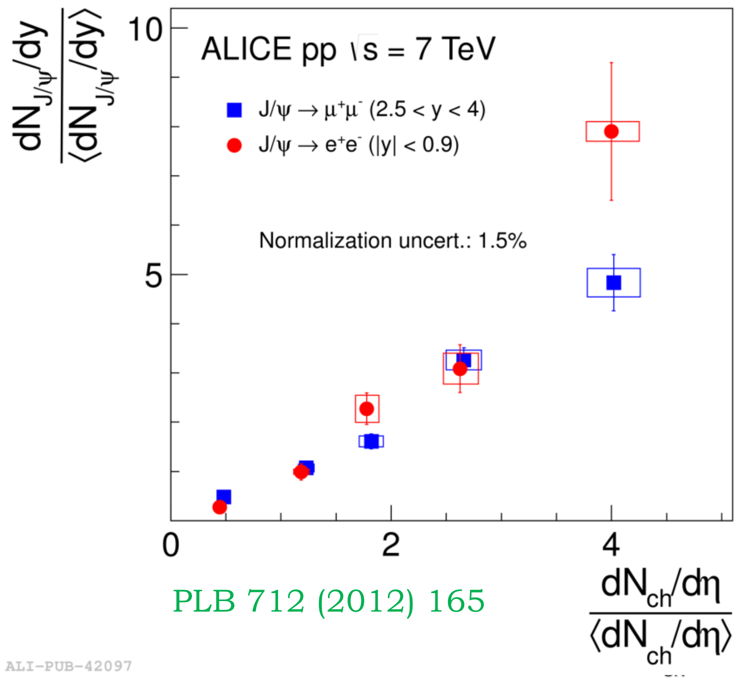
Mid rapidity: electron identification via the specific energy loss (dE/dx) in the TPC.

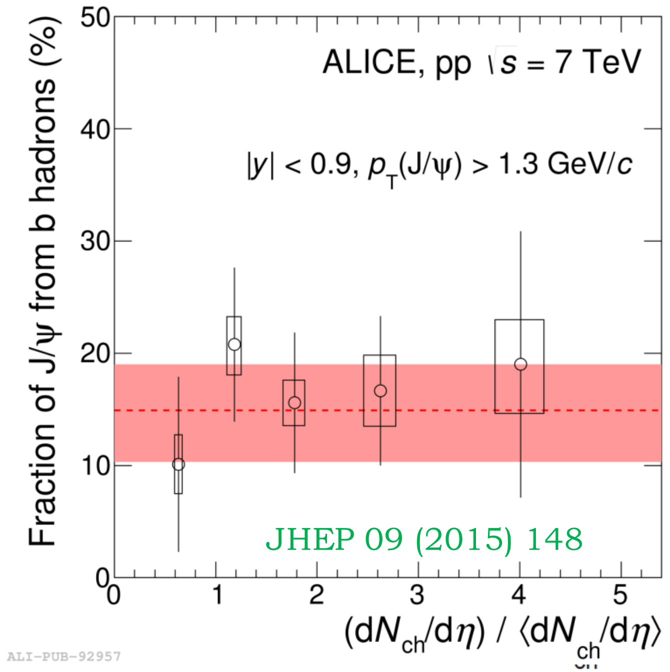
Forward rapidity: muons selected with specific triggers and identified thanks to a set of absorbers.





Inclusive and non-prompt J/ψ





Linear increase for J/ψ measured at mid and forward rapidity as a function of charged particle multiplicity. At high multiplicity there is a hint of a faster than linear increase of J/ψ.

Fraction of non-prompt J/ψ in the inclusive yield shows no dependence with multiplicity within statistical and systematic uncertainties.