Charged-particle multiplicity dependence of open heavy-flavour production in pp collisions with ALICE at the LHC

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Shimla, 14/12/2017

Open heavy flavours at the LHC

- Open heavy-flavour (HF) particles are mesons and baryons containing c and b quarks (D, B, Λ_c, Λ_b):
  - c and b are produced in hard partonic scatterings;
  - they have large masses and short formation times;
- HF production cross sections are calculable with pQCD.
- Heavy flavours are abundantly produced at LHC energies.

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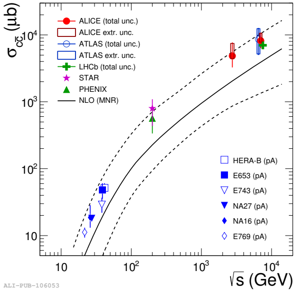
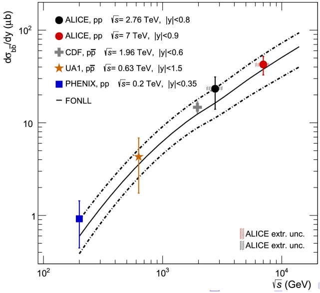
PLB 738 (2014) 97

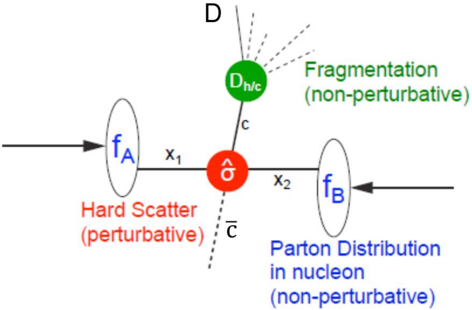




Production cross section can be calculated with perturbative QCD calculations based on the factorization approach:

- parton distribution functions (PDF);
- hard-parton scattering cross section;
- fragmentation function.

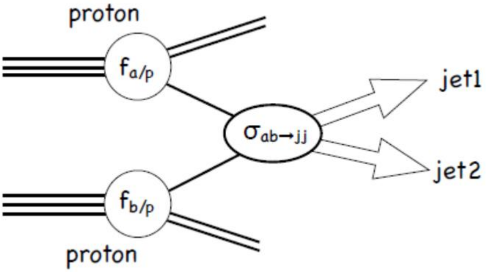
$$\sigma_{hh \to Hx} = PDF(x_a, Q^2) \cdot PDF(x_b, Q^2) \times \hat{\sigma}_{ab \to q\bar{q}} \times D_{q \to H}(z_q, Q^2)$$



Hard scattering and underlying event

Two component approach of a hadron collision:

- Initial hard scattering: large transferred Q^2, pQCD applicable $\rightarrow$ important for heavy-flavour, di-jet...
- Underlying event: production not associated with the hard scattering process $\rightarrow$ softer Multiple Parton Interactions still relevant at LHC energies, fragmentation of beam remnants...



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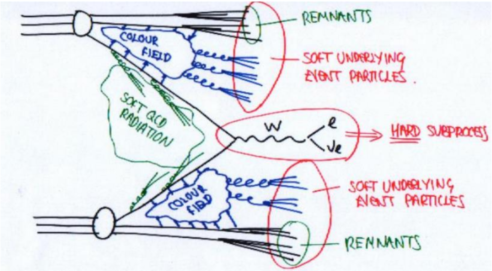

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Multiple Parton Interactions

Multiple Parton Interactions (MPI)

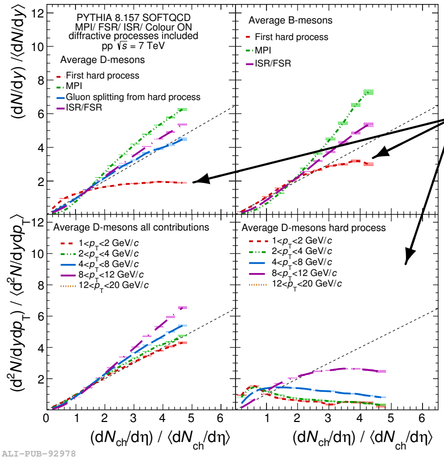
Class of events in which two or more distinct parton interactions occur simultaneously in a single hadron-hadron collision. arXiv:1111.0469

Production dependence on charged-particle multiplicity provides insight into processes occurring in the collision at the partonic level:

- is a key observable for addressing Multiple Parton Interactions;
- constrains MPI-based models where pQCD is not applicable;
- probes the interplay between soft and hard particle production mechanisms.

Multiplicity-dependent studies in small colliding systems show remarkable similarities with AA collisions → phenomena considered signatures of deconfinement have been observed in high-multiplicity pp collisions!

Heavy-flavour production mechanisms in PYTHIA 8



- First hard process shows weak dependence on multiplicity (D and B mesons).
- Other processes contribute to the increasing trend vs. multiplicity.

Self-normalized quantities on x and y axes → some uncertainties cancel out; possibility to compare different experiments, systems, energies...

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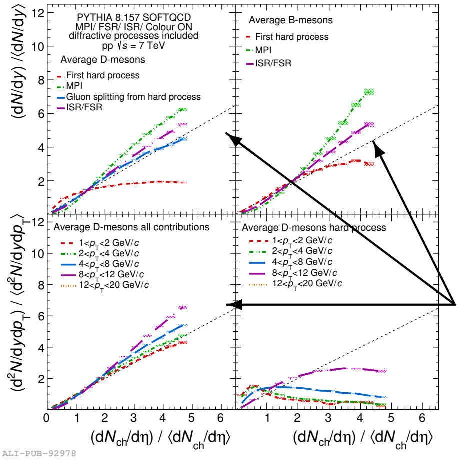
Heavy-flavour production mechanisms in PYTHIA 8



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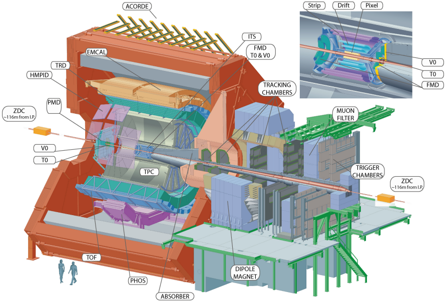


- ALICE is the LHC experiment dedicated to the study of ultrarelativistic heavy-ion collisions.

- It is composed of:
  - a central barrel for vertex reconstruction (ITS), tracking (ITS, TPC) and PID (EMCAL, ITS, TOF, TPC, TRD);
  - forward detectors for triggering purposes, luminosity, multiplicity and centrality determination (T0, V0, ZDC);
  - a forward muon spectrometer.

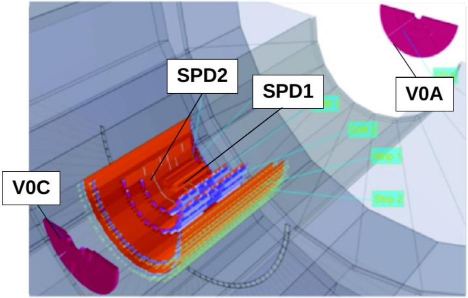
Multiplicity selection in ALICE

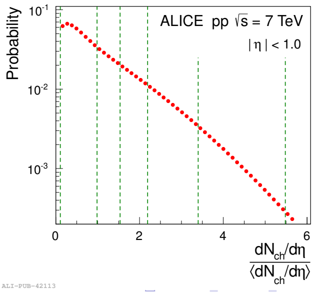
Two multiplicity estimators:

- mid-y: number of track segments (tracklets) in the two innermost layers of the ITS (SPD);
- forward-y: sum of amplitudes in the V0 scintillator arrays.

Different trigger configurations exploited over the years:

- minimum bias: coincidence of V0A, V0C and SPD;
- high multiplicity: threshold on number of hits in SPD.

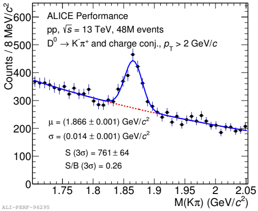




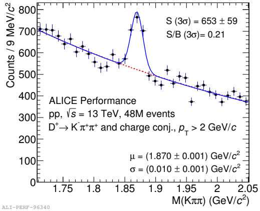
D-meson reconstruction

- D mesons are reconstructed at midrapidity ($|y| < 0.5$) via their hadronic decays (invariant mass of decay products exploiting the "displaced" topology of the decay vertex to remove combinatorial background).
- Different background subtraction techniques exploited to go down to $p_{\rm T} = 0$.
- TOF and dE/dx techniques used to identify p, K and π.

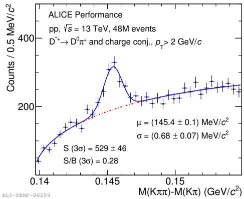
$D^0 \to K^-\pi^+$



$D^+ \to K^-\pi^+\pi^-$



$D^{*+} \to D^0\pi^+$



$D_s^+ \to \phi\pi^+ \to K^+K^-\pi^+$ also studied.

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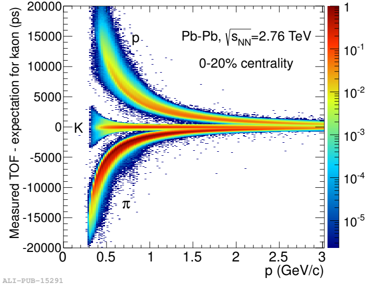
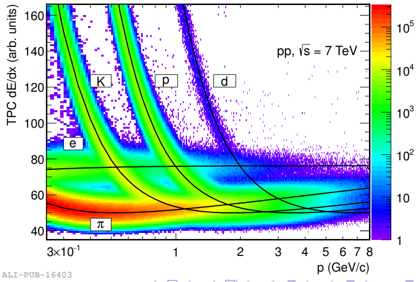
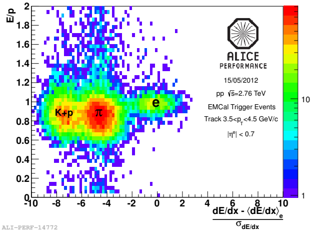




- e from HF decays reconstructed at midrapidity ($|\eta| < 0.9$).
- Electron identified with TPC, TOF, EMCAL and/or TRD.



- Possibility to separate e←B studying the impact parameter.

- μ from HF decays reconstructed at forward rapidity ($2.5<y<4$).
- p_{T}-based trigger allows the rejection of low-p_{T} muons.
- Tracking+trigger tracks matching required to identify muons.

Semileptonic decays: electron and muon reconstruction

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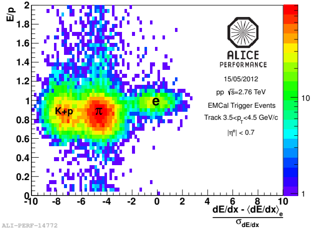

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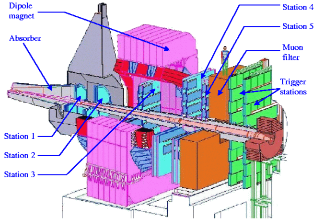

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D-meson results in pp collisions

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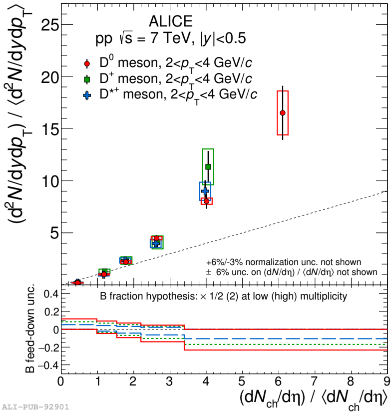

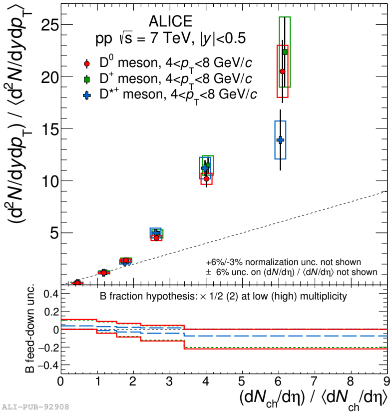

- The results of D^0, D^+ and D^{*+} are consistent within uncertainties.
- The yields of D mesons increase with charged-particle multiplicity at mid-rapidity: it is faster than linear at high multiplicity.

D-meson results in pp collisions

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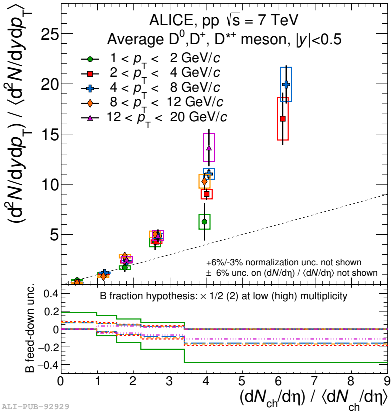

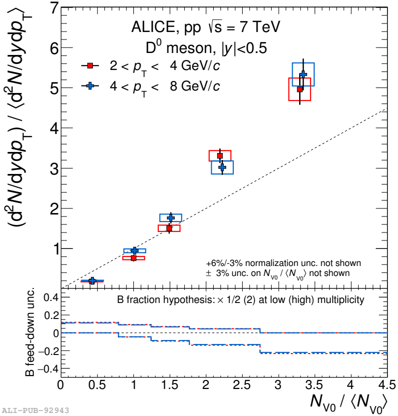

- The increase is independent of p_T within uncertainties.
- Test possible auto-correlations using multiplicity measured in a different rapidity range than D yields → qualitatively similar increasing trend of D-meson yields when a η gap is introduced.

Comparison with J/ψ production

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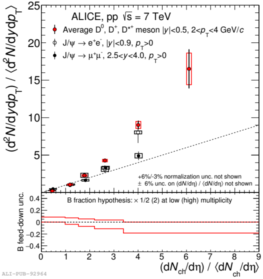
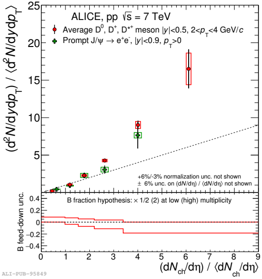
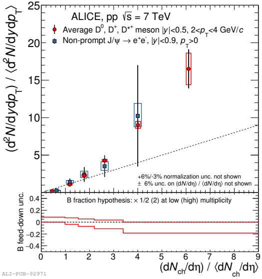
all J/ψ



prompt J/ψ



non-prompt J/ψ



- Similar increase of open charm, open beauty and charmonia with charged-particle multiplicity at mid-rapidity (different y and p_T intervals considered).
- See D. Takur's talk for more results on quarkonia in ALICE.

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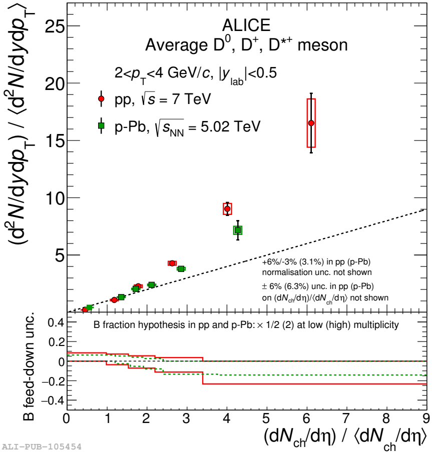
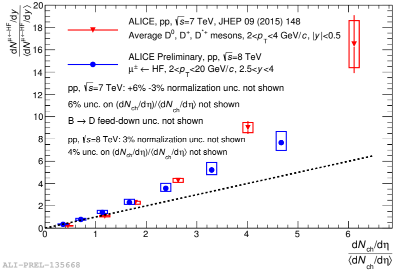
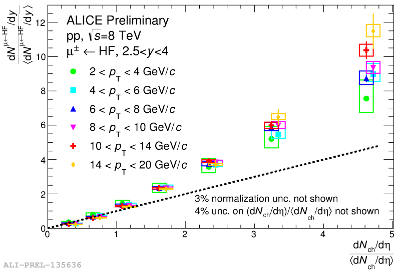


- At low and intermediate multiplicity a similar increase is visible for pp and p–Pb collisions.
- Event multiplicity in p–Pb collisions determined also by multiple nucleon-nucleon collisions.
- See S. De's talk for more results on open heavy flavours in p–Pb collisions in ALICE.

Semi-leptonic decay: $\mu \leftarrow$HF





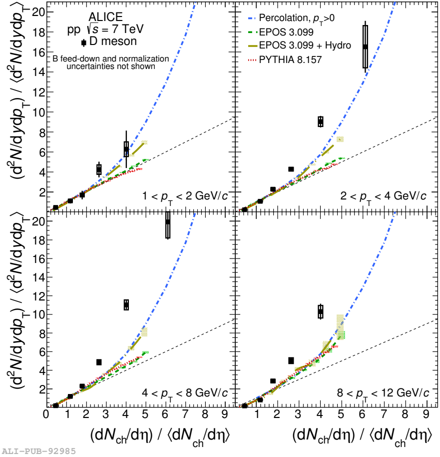
- New results in pp collisions: $\mu \leftarrow$HF at forward y.
- D-meson and muon-based analyses (at different energy) show similar results especially at low multiplicity.
- At higher multiplicity the p_{T}-integrated muon trend is still linear.
- Also for muon decays the increase is independent of p_{T} at low multiplicity: hint of hierarchy at higher multiplicity?

Model predictions for D mesons

Ferreiro and Pajares, PRC 86 (2012) 034903

Sjostrand and Mrenna, Comput. Phys. Comm. 178 (2008) 852

Drescher, Hladik, Ostapchenko, Pierog and Werner, Phys. Rept. 350 (2001) 93

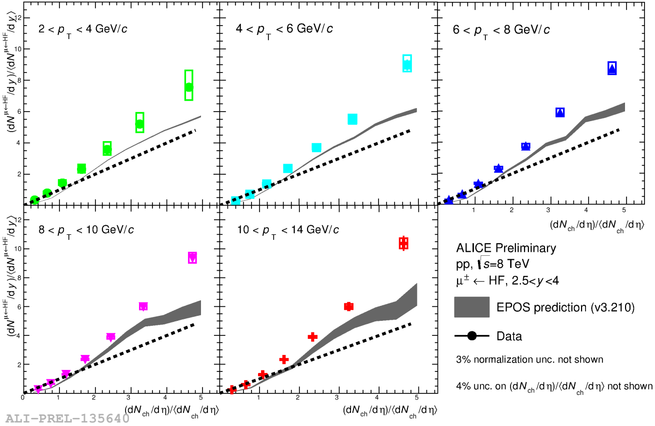


- **Percolation:**
  - interactions driven by the exchange of colour sources (strings ∼MPI scenario);
  - strings have finite spatial extension and can interact.
- **PYTHIA 8:**
  - soft QCD process selection;
  - color reconnection, MPI and diffractive processes.
- **EPOS 3:**
  - Gribov-Regge multiple-scattering formalism;
  - with and without hydrodynamic evolution.

General difficulty of the models to reproduce the data especially at high p_T.

Model predictions for $\mu \leftarrow$HF

Drescher, Hladik, Ostapchenko, Pierog and Werner, Phys. Rept. 350 (2001) 93



- Measurements in bins of p_T compared with EPOS predictions.
- EPOS doesn't include hydrodynamics.
- The prediction underestimates the yield of muons for all p_T bins

Summary

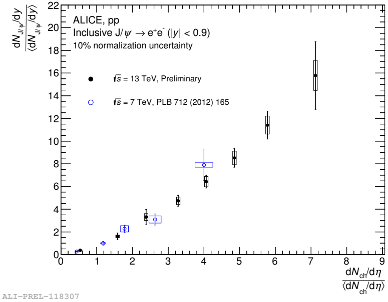
ALICE measured the open heavy-flavour production at several energies and colliding systems. The yields in all channels studied show a strong increase with charged-particle multiplicity.

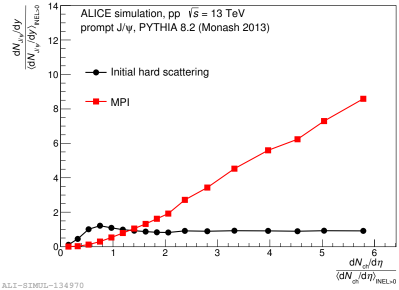
In pp collisions:

- for D mesons the increase is faster than linear at high multiplicity;
- a similar trend is observed for open and hidden heavy-flavour;
- models including MPI qualitatively predict an increasing trend, but underestimate it at high $p_{\rm T}$.

Backup

J/ψ production mechanism in PYTHIA 8





- ALICE data at 7 and 13 TeV demonstrate a strong increase of the J/ψ yield with multiplicity.

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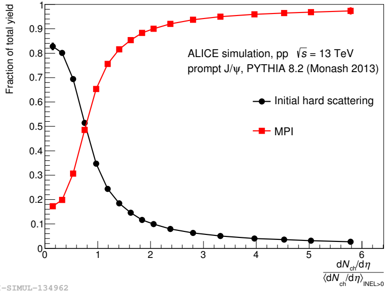
- In initial hard scattering no correlation of charmonium production with event activity.
- J/ψ production also due to other mechanisms.

More on J/ψ simulation



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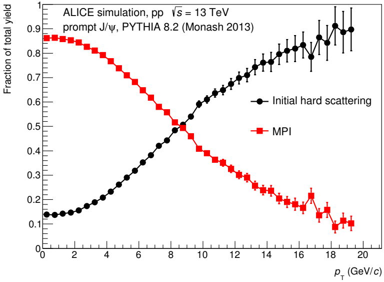

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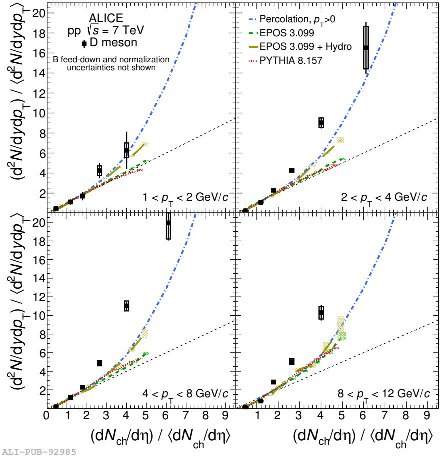
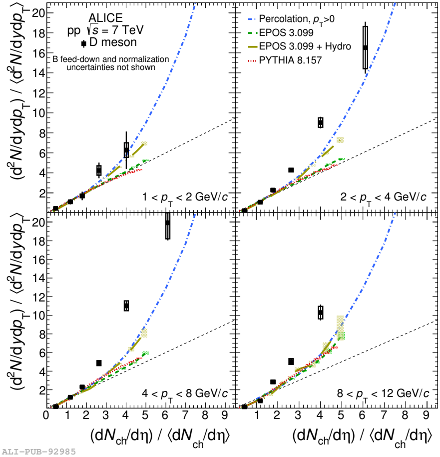


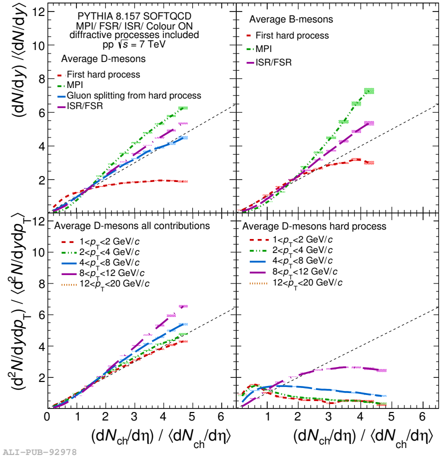
ALI-PUB-92985

- Percolation:
  - interactions driven by the exchange of colour sources (strings ∼MPI scenario);
  - strings have 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;



- EPOS 3 (event generator):
  - initial conditions
    - Gribov-Regge multiple-scattering formalism
    - saturation scale to model non-linear effects
    - hadronisation via string fragmentation
    - number of MPI directly related to multiplicity
  - hydrodynamic evolution.
    - can be applied to the dense core of the collision.

More details on PYTHIA 8



SoftQCD process selection, including colour reconnection and diffractive processes.

- First hard process $\cong$hardest process $\rightarrow$ weak dependence on multiplicity (slight increase at low multiplicities followed by a saturation).
- MPI $\cong$ subsequent hard process $\rightarrow$ increasing trend vs. multiplicity.
- gluon splitting from hard process $\rightarrow$ increasing trend vs. multiplicity.
- initial and final-state radiation $\rightarrow$ increasing trend vs. multiplicity.

ALICE