Particle production vs. multiplicity in pp collisions with ALICE

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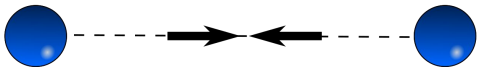
Particle production as a function of multiplicity

High-multiplicity pp and p–Pb collisions have shown features reminiscent of those observed in Pb–Pb: **azimuthal correlations and mass-dependent hardening of p_T distributions.**

- High-multiplicity pp collisions reach similar number of charged-particles as in peripheral Pb-Pb collisions.

- Look for possible collective behaviour in small systems.
- Investigate the possible influence of multiple partonic interactions (MPI) to the particle production.
- Study the interplay between soft and hard processes:
  - Heavy flavour:
    - D and B mesons, quarkonia
  - Light flavour:
    - Charged particles and identified particles: strangeness
  - Multiplicity is defined as the number of charged particles per event.



➢ **p_T spectra in multiplicity classes**
➢ **Self-normalized yield as a function of charged-particle multiplicities**

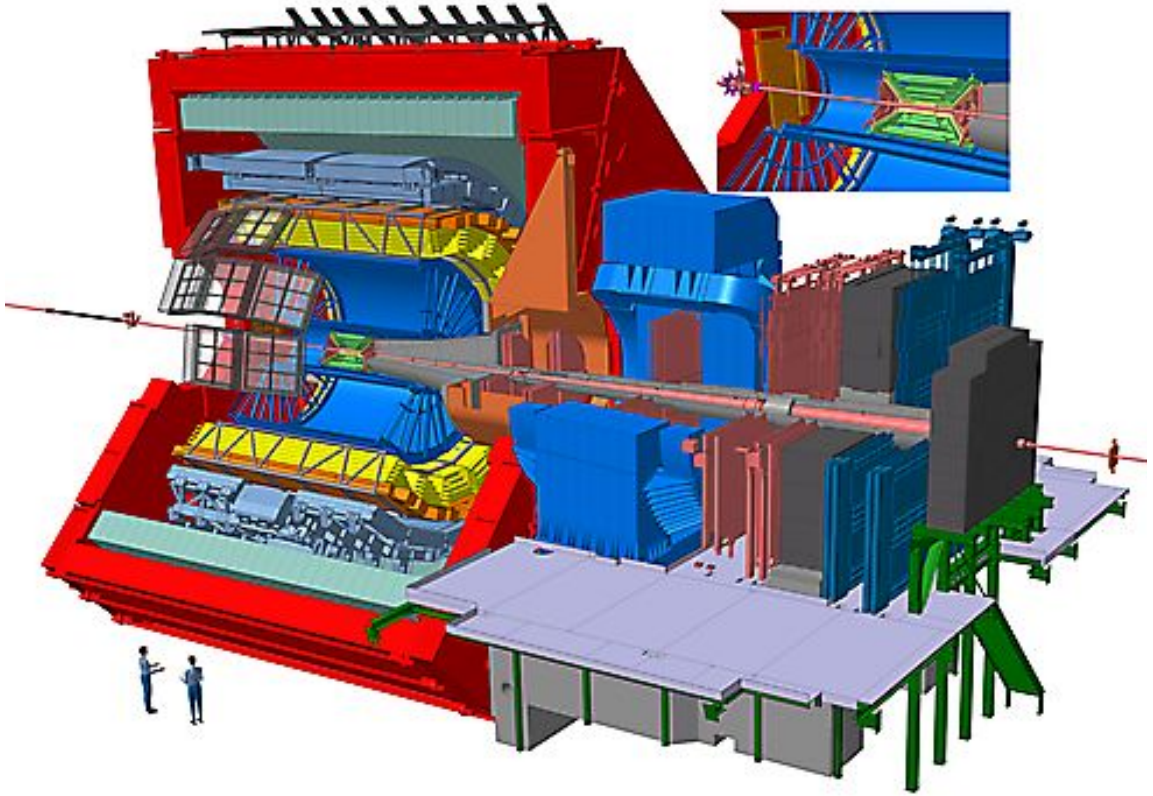
ALICE detector

Mid-rapidity ($|\eta| < 0.9$)

- Inner Tracking System (ITS):
  - Vertex determination
  - Tracking
  - Multiplicity estimator (SPD)
- Time Projection Chamber (TPC):
  - Tracking
  - PID
- ElectroMagnetic Calorimeter (EMCal):
  - PID
  - Trigger
- V0:
  - Trigger
  - Multiplicity estimator
- TOF:
  - PID
- TRD:
  - PID
  - Trigger

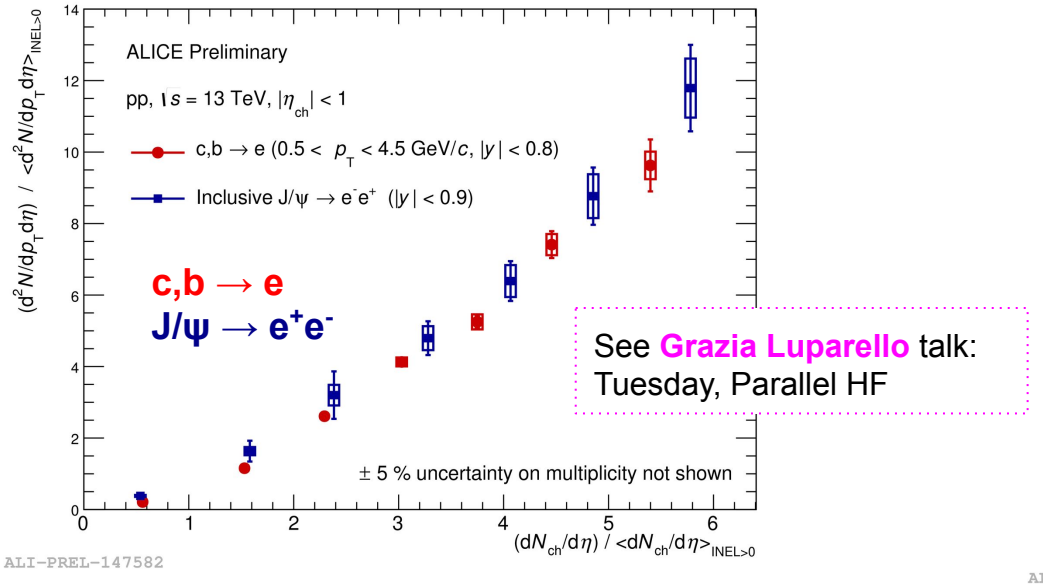
Forward rapidity ($-4 < \eta < -2.5$)

- Muon arm:
  - Tracking
  - Trigger

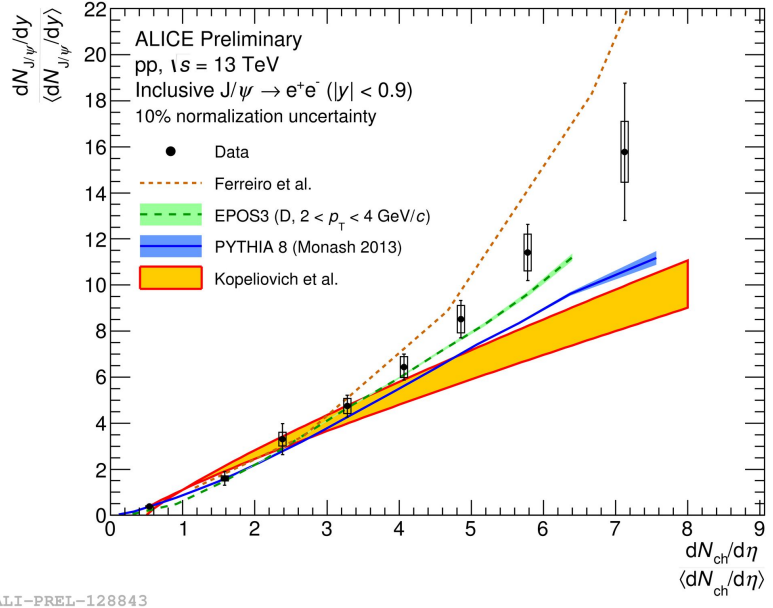


Heavy flavour results at mid rapidity

Self normalized yield at mid rapidity: open heavy flavour (c,b → e) vs hidden heavy flavour (J/ψ → e^+e^-)



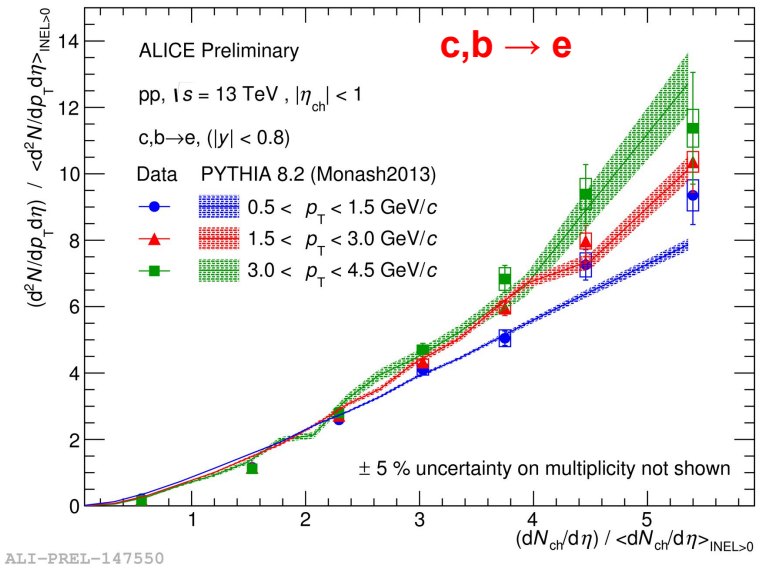
See **Grazia Luparello** talk: Tuesday, Parallel HF

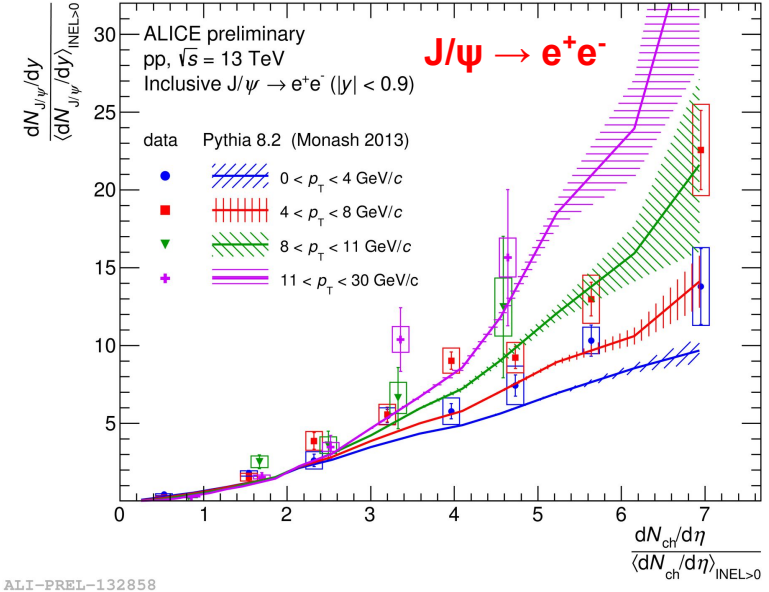


- A stronger than linear enhancement is observed for both open and hidden heavy flavour.
- Similar trend for both open and hidden heavy flavour.
- J/ψ results compared to string percolation, hydrodynamical evolution, PYTHIA8, Higher Fock states.
- ***Multiplicity*** *and* ***particle yield*** *are measured in the* ***mid rapidity range****: possible autocorrelation effect (jet bias).*

Heavy flavour results at mid rapidity

Model comparison and p_T dependence of (c,b → e) and (J/ψ → e^+e^-)

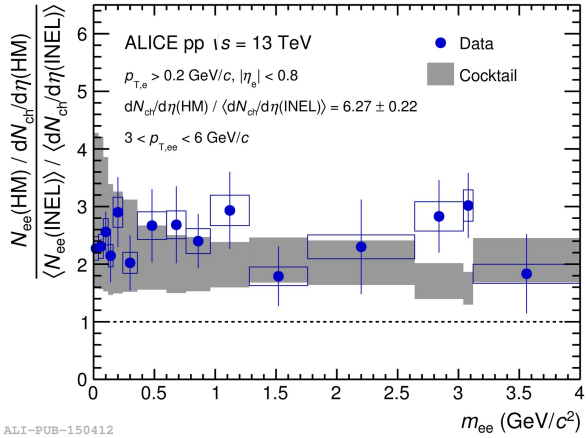


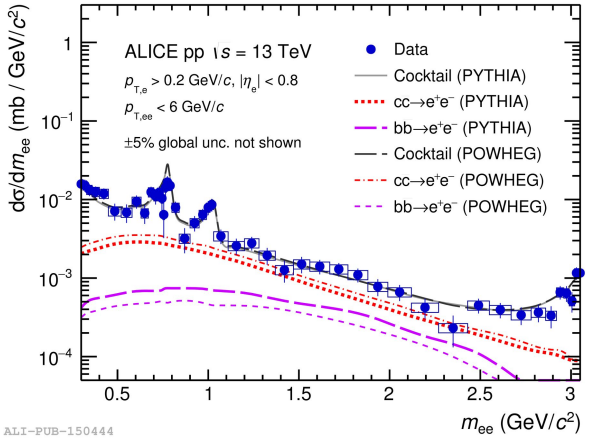


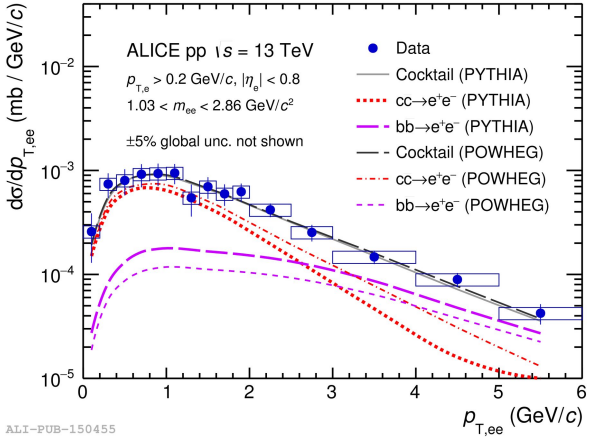
- A stronger than linear enhancement is observed for both open and hidden heavy flavour.
- Stronger rise for higher p_T.
- p_T dependent result qualitatively described by PYTHIA8, including MPI, for both (c,b → e) and (J/ψ → e^+e^-).
- ***Multiplicity*** *and* ***particle yield*** *are measured in the* ***mid rapidity range****: possible autocorrelation effect (jet bias).*

Heavy flavour results at mid rapidity

- Low mass dielectrons measured in high multiplicity pp collisions.
- $1.03 < m_{ee} < 2.86$ GeV/c^2 is dominated by open heavy-flavour decays:
  - Beauty and charm cross section are obtained via PYTHIA and POWHEG fits.







- Enhancement of charm and beauty cross section relative to the charged-particle multiplicity.
- Charm and beauty with compatible scaling.

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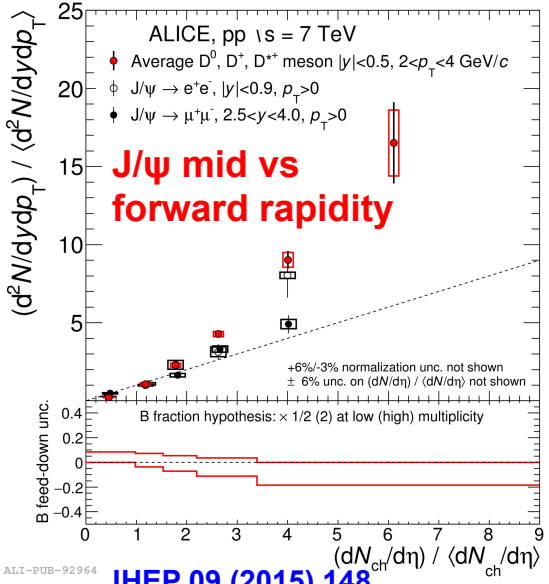
- ***Multiplicity*** *and* ***signal*** *are measured in the* ***mid rapidity range.***

Heavy flavour results at forward rapidity

Self normalized yield at forward rapidity ($J/\psi \rightarrow \mu^+\mu^-$ and $\Upsilon \rightarrow \mu^+\mu^-$).



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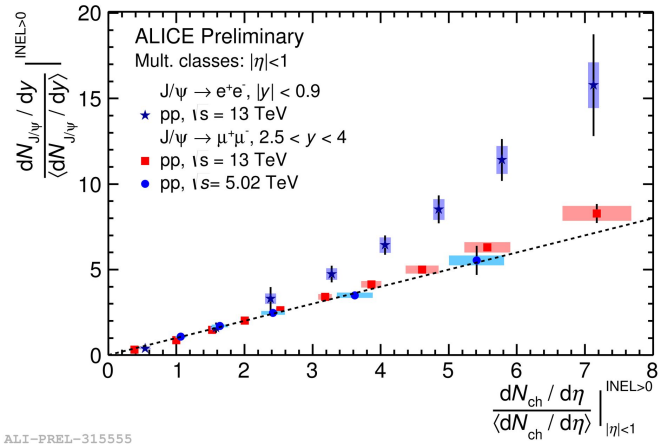
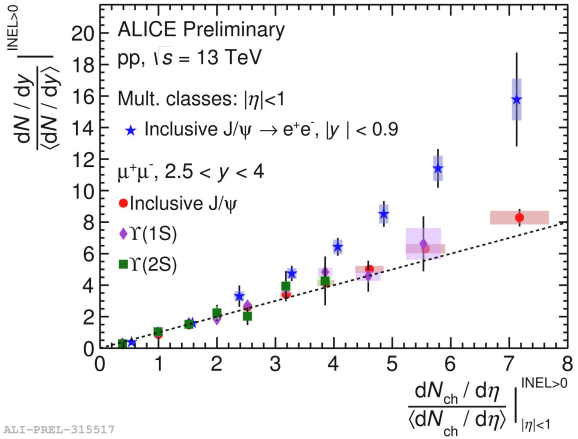
J/ψ mid vs forward rapidity



Υ at forward rapidity

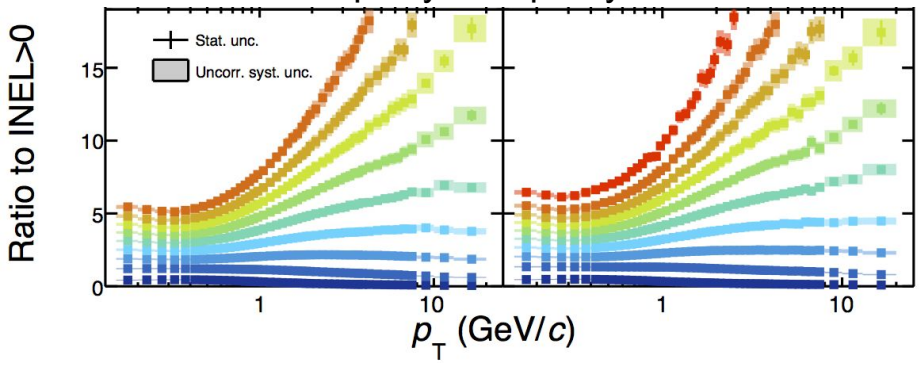


- Linear increase with multiplicity is observed for $J/\psi \rightarrow \mu^+\mu^-$ (forward rapidity).
- Similar trend is observed at forward rapidity for pp collisions at $\sqrt{s}$ = 5, 7 and 13 TeV.
- Υ self normalized yield shows a linear increase with multiplicity in pp at $\sqrt{s}$ = 13 TeV.
- ***Multiplicity*** *is measured at mid rapidity while* ***particle yield*** *is measured at forward rapidity: linear increase with multiplicity (no autocorrelation).*

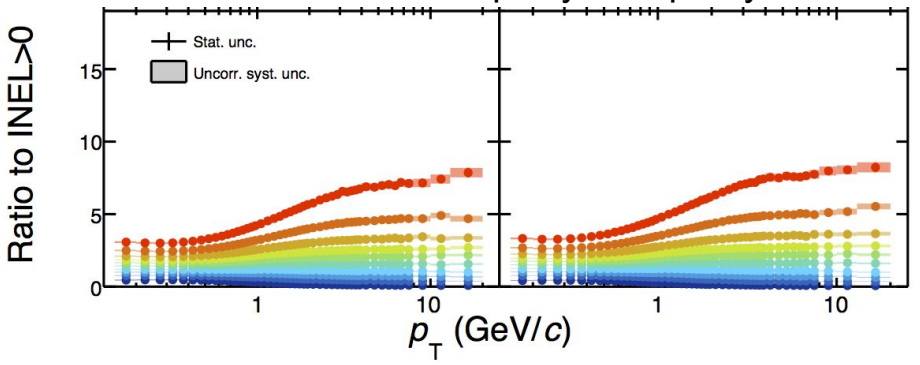
Light flavour results: charged particles

Transverse momentum spectra as a function of charged-particle multiplicity. **ALICE, arXiv: 1905.07208**

Mid rapidity multiplicity



Forward rapidity multiplicity

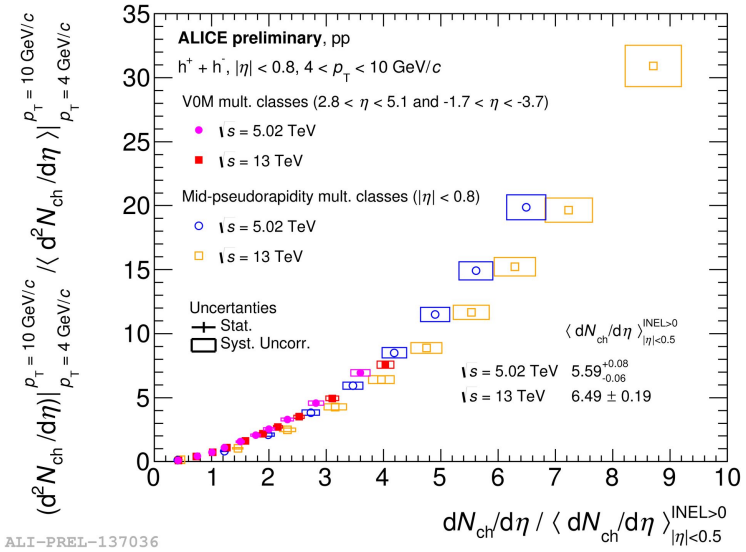


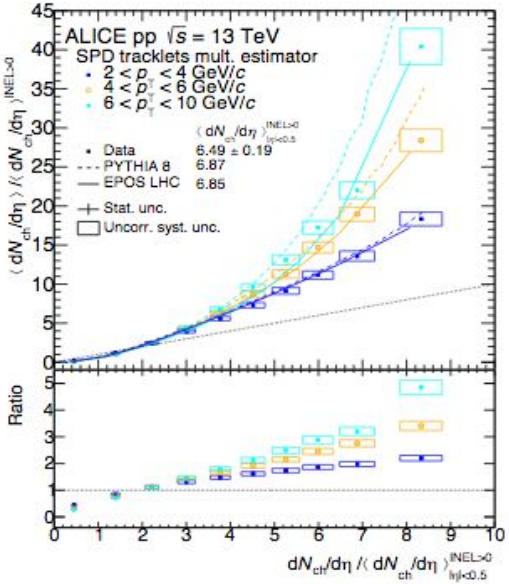
- Mid rapidity multiplicity:
  - The p_T spectra become harder as the multiplicity increases.
  - The ratios to INEL > 0 strongly depend on multiplicity and p_T
- Forward rapidity multiplicity:
  - p_T hardening with multiplicity not so evident as in mid rapidity.
- The change of the spectral shape going from low- to high-multiplicity values are qualitatively same for pp collisions at $\sqrt{s}$ = 5 and 13 TeV.

See **Antonio O. Velasquez** talk: Tuesday, Plenary IV

Light flavour results: charged particles

Self normalized yield of charged particles as a function of charged-particle multiplicity: multiplicity estimator at mid rapidity vs. forward rapidity.





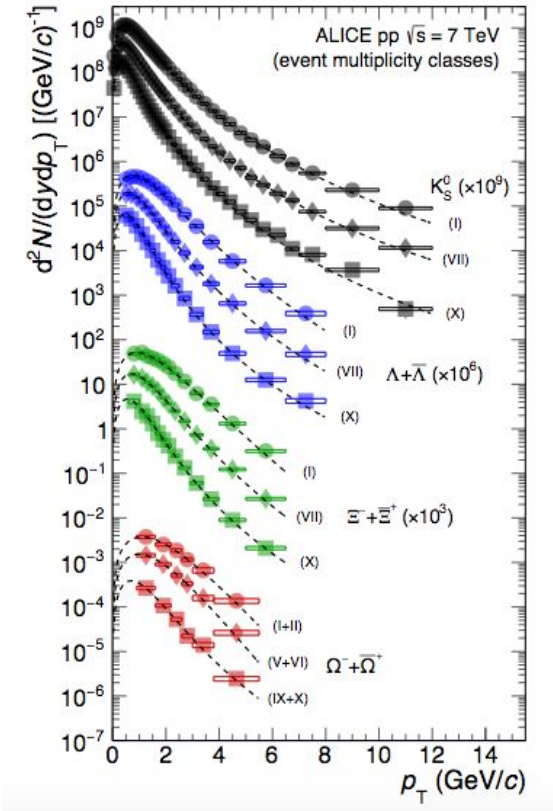
ALICE, arXiv: 1905.07208

- Mid rapidity and forward rapidity multiplicity estimators with similar trend.
- The yields of charged particles increase faster than linear with the charged-particle multiplicity.
- The trend of the data is qualitatively well reproduced by PYTHIA8 up to 6 GeV/*c*.
- EPOS model describes the results in the whole momentum range.

Light flavour results: strangeness

p_T differential yields of strange particles.

- The p_T spectra become harder as the multiplicity increases.
- Hardening is more pronounced for higher mass particles.
- In heavy-ion collisions these observations are described by models based on relativistic hydrodynamics.
- Appearance of collective behavior at high-multiplicity?

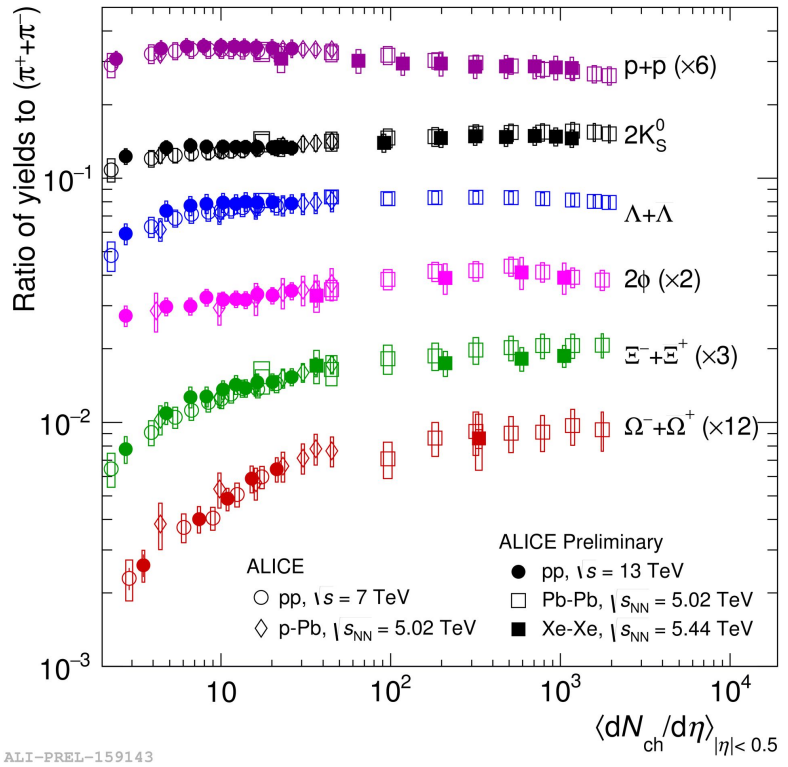


Nature Phys. 13 (2017) 535-539

Light flavour results: strangeness

p_T-integrated yield ratios to pions ($\pi^+ + \pi^-$) as a function of charged-particle multiplicity.

- A significant enhancement of strange to non-strange hadron production is observed with increasing particle multiplicity in pp collisions.
- Results in pp collisions at $\sqrt{s}$ = 7 and 13 TeV are compatible.
- The measurements are in agreement with p–Pb collision results indicating that the phenomenon is related to the final system created in the collision.
- In high-multiplicity events strangeness production reaches values similar to those observed in heavy ion collisions.



Nature Phys. 13 (2017) 535-539
Phys.Lett. B758 (2016) 389-401

Summary

- Heavy-flavour:
  - Mid rapidity: stronger than linear increase is observed.
    - Stronger rise for higher p_T.
    - p_T dependent result qualitatively described by PYTHIA8, including MPI.
    - Similar enhancement for charm and beauty cross section in high multiplicity.
    - *Particle yield and multiplicity measured at mid rapidity (possible autocorrelation).*
  - Forward rapidity: linear increase of J/ψ and Υ with charged-particle multiplicity.
    - *Particle yield measured at forward rapidity and multiplicity measured at mid rapidity.*
- Light-flavour:
  - Mid-rapidity multiplicity estimator: the p_T spectra become harder with multiplicity.
  - Stronger than linear increase of charged particle yield is observed for both mid and forward rapidity multiplicity estimator.
    - Stronger rise for higher p_T (mid-rapidity estimator).
  - Strangeness enhancement
    - Enhancement of strange to non-strange hadron production is observed with increasing multiplicity.
    - Strangeness production in high multiplicity pp events reaches values similar to those observed in heavy ion collisions.
- **Several hints of collectivity in high multiplicity pp collisions.**

Backup

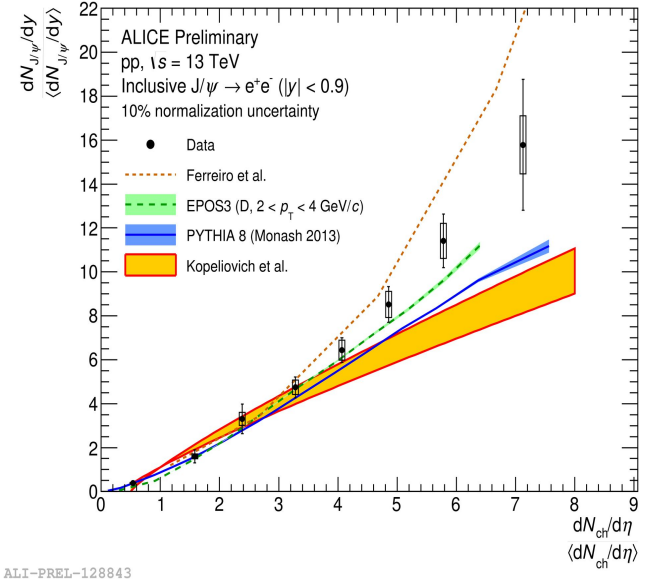
Heavy flavour results

Ferreiro et al: Saturation of soft particle production and string interactions (percolation model). It assumes that all projectiles have a finite spatial extension and collides at finite impact parameter by means of elementary parton-parton collisions. (Ferreiro, Pajares, PRC86 (2012) 034903)

EPOS3: MPI and hydrodynamic expansion of the system. Uses same formalism to calculate cross sections and particle production (QCD-inspired field theory). Uses a unified treatment of soft and hard scattering: no fundamental cutoff parameter is used to define a border between soft and hard scattering. (Werner et al., Phys.Rept.350 (2001) 93)

PYTHIA8: MPI and saturation of soft particle production via color reconnection. The colour reconnection is used in the final state, in which there is a certain probability for the partons of two sub-scatterings to have their colours inter arranged in a way that reduces the total string length. (Sjostrand et al.,Comput.Phys.Commun.178(2008)852)

Kopeliovich et al: higher Fock states. It assumes that hadron multiplicities larger than the mean value in pp collisions can be reached using higher Fock states in the proton, which contains an increased number of gluons. (Kopeliovich et al., PRD88 (2013) 116002)



Heavy flavour results

- Low mass dielectrons measured in high multiplicity pp collisions.
  - Ratio of high multiplicity and minimum bias events, in p_T bins.