A multiplicity measurement by ALICE [1]

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Measurments of pp collisions

- 3 event classes
  - INEL
  - NSD
  - INEL>0
- 3 pseudorapidity intervals
  - $|\eta| < 0.5$
  - $|\eta| < 1.0$
  - $|\eta| < 1.5$
- 5 center-of-mass energies
  - $\sqrt{s} = 0.9$ TeV
  - $\sqrt{s} = 2.36$ TeV
  - $\sqrt{s} = 2.76$ TeV
  - $\sqrt{s} = 7$ TeV
  - $\sqrt{s} = 8$ TeV
- Pseudorapidity density of primary charged particles
- Multiplicity distributions
- Study both hard scattering and soft processes
- $\sqrt{s} = 8$ TeV and high multiplicity pp collisions
  - Energy densities comparable to Au-Au collisions (RHIC)
  - Volumes orders of magnitudes different

Multiplicity distributions

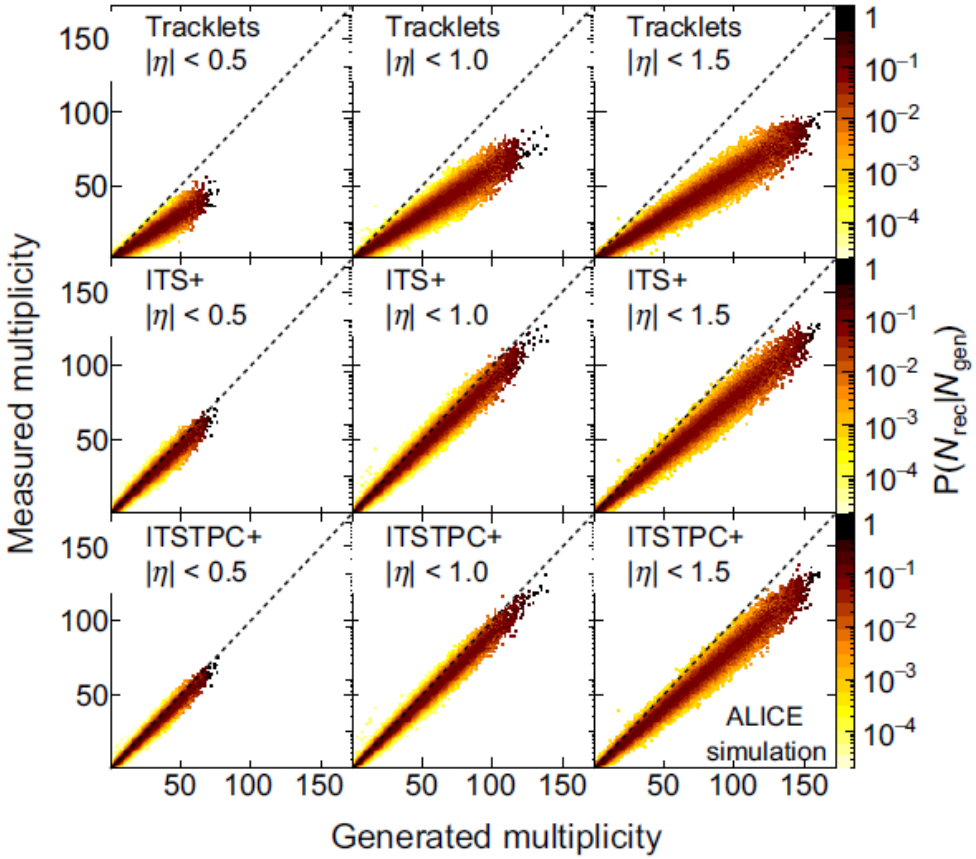
- KNO (Koba-Nielsen-Olesen) scaling: Probability distribution P(n) expressed as a function of the $\langle n \rangle$
- Sufficiently high energy: asymptotic shape $P(n) = \frac{1}{\langle n \rangle} \Psi \left(\frac{n}{\langle n \rangle} \right)$
- Ψ expected to be an energy invariant shape
- Violated for INEL at $\sqrt{s} \approx 50$ GeV
- For NSD holds up to $\sqrt{s} = 7$ TeV
- Fit function for measured multiplicity distributions: single and double NBD (negative binomial distribution)
- From $\sqrt{s} = 0.9$ TeV to $\sqrt{s} = 8$ TeV multiplicity distributions and pseudorapidity densities follow a smooth evolution

Comparison to previous studies

- Improved tracking and track counting algorithms
- Improved simulation generators
- Expanded pseudorapidity ranges
- At $\sqrt{s} = 0.9$ TeV and $\sqrt{s} = 7$ TeV better statistical precision (by a factor of 2)
- At $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 8$ TeV first results
- Comparison to results from CMS and UA5
- ATLAS and LHCb use different p_T and $|\eta|$ ranges: comparison not possible

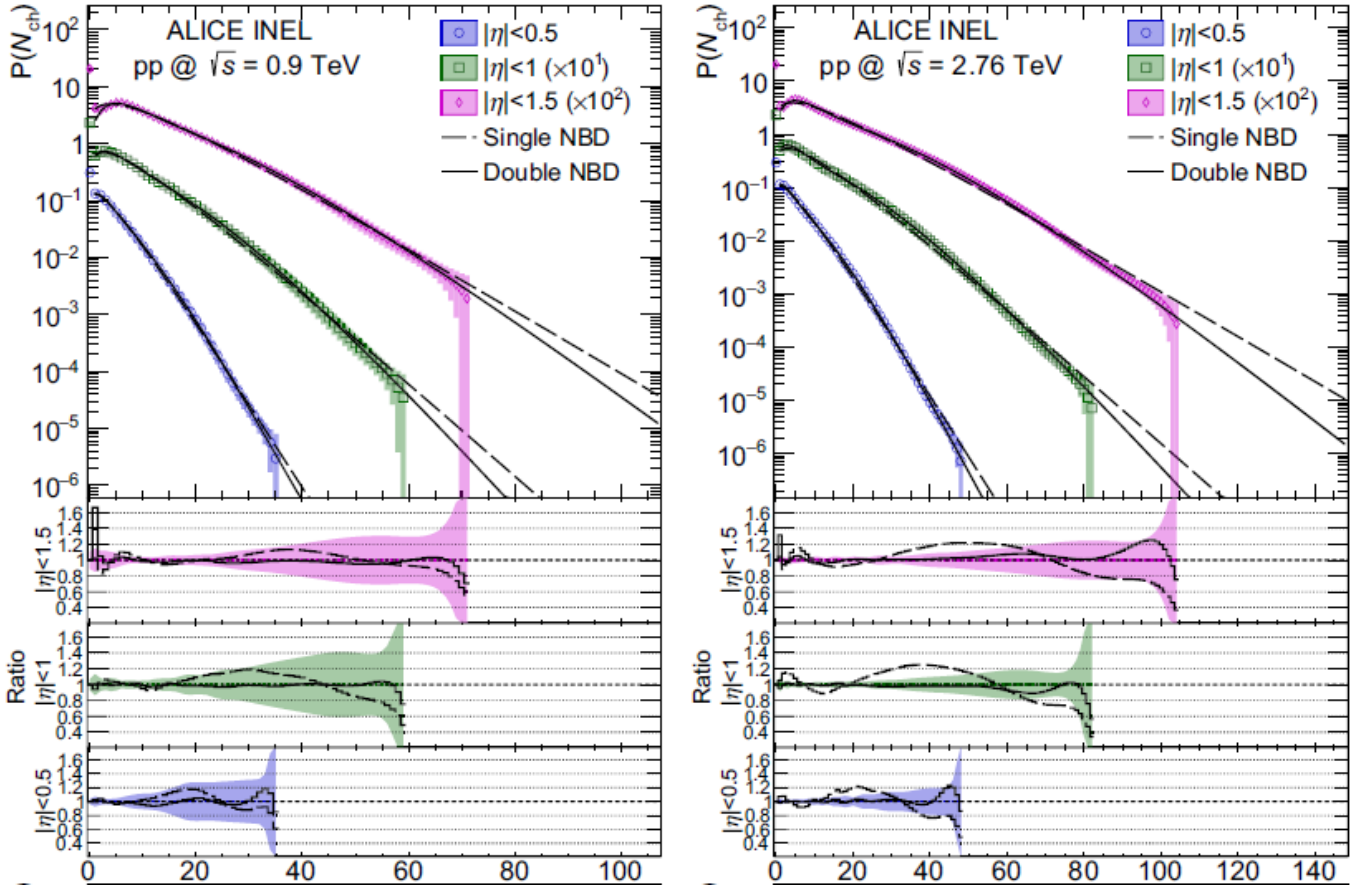
Track counting algorithms

- Tracklet: SPD $|\eta| < 2$
- ITS+: ITS tracks $|\eta| < 1.3$
- ITSTPC+: TPC $|\eta| < 0.9$



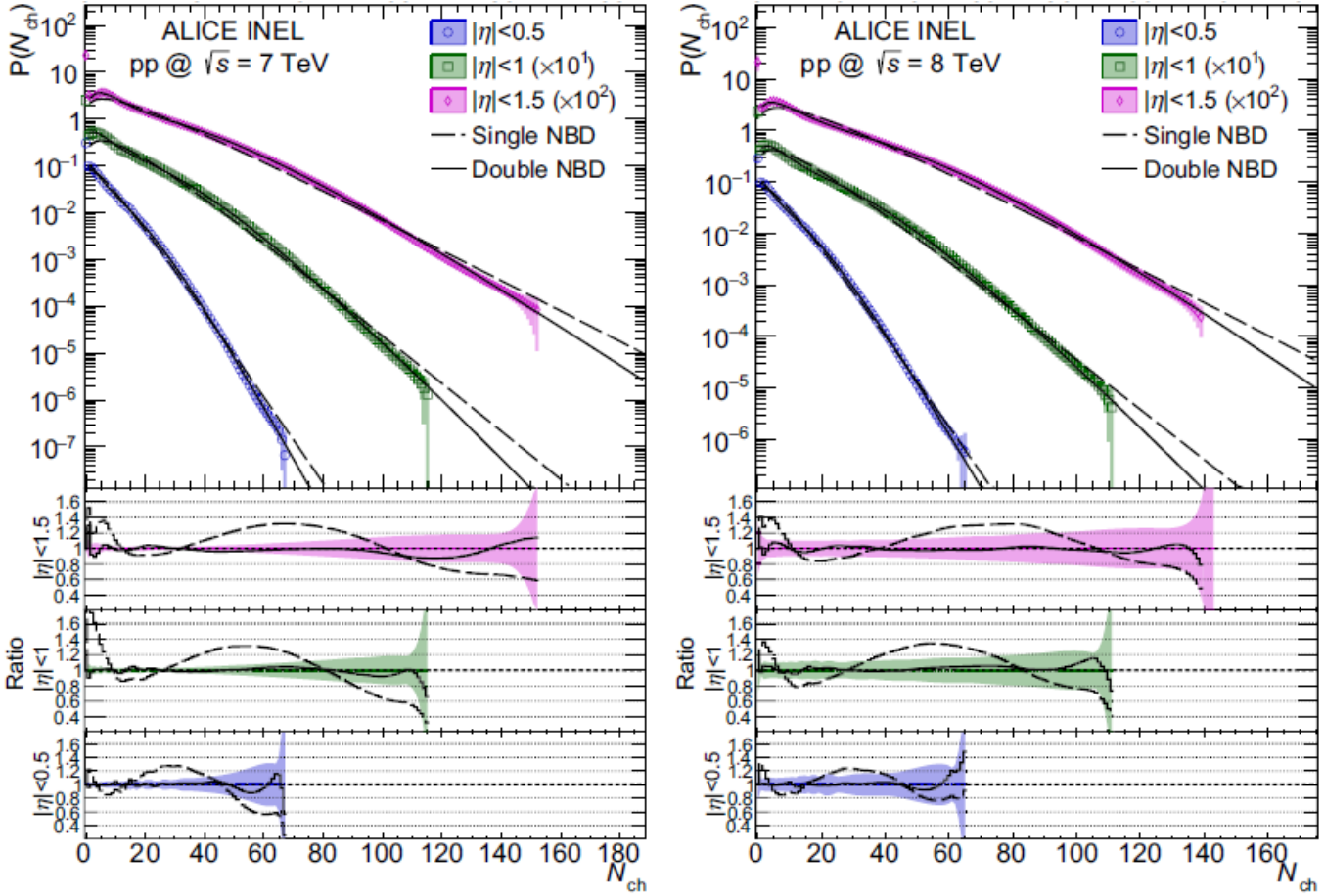
[1] Graphical representation of the detector response matrices obtained with PYTHIA6 CSC combined with a simulation of the ALICE detector at $\sqrt{s} = 7$ TeV

Experimental results: INEL



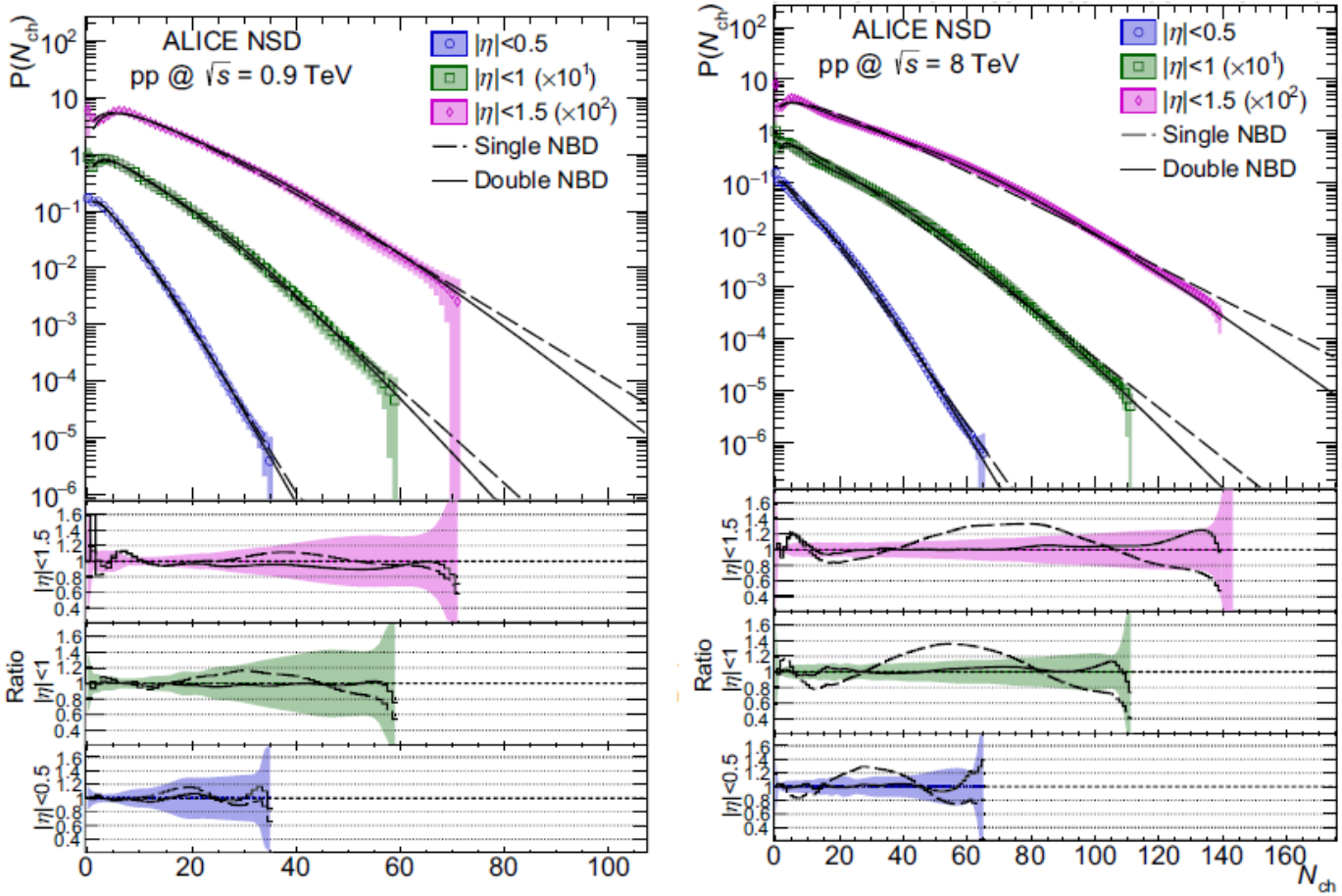
- Double NBD is a better fit
- Multiplicity grows with energy

Experimental results: INEL



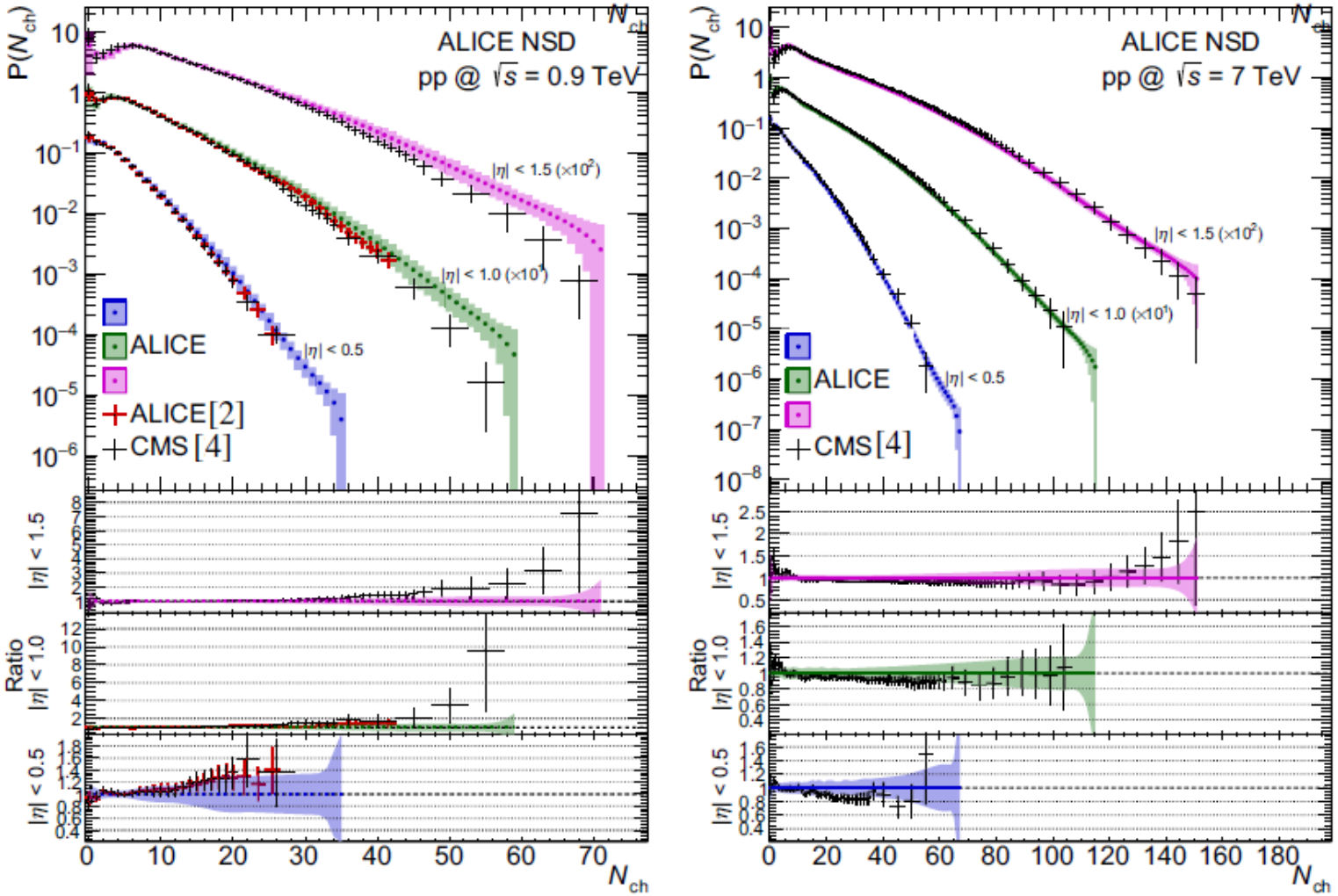
- Discrepancy between NBD and data gets bigger with higher energy

Experimental results: NSD



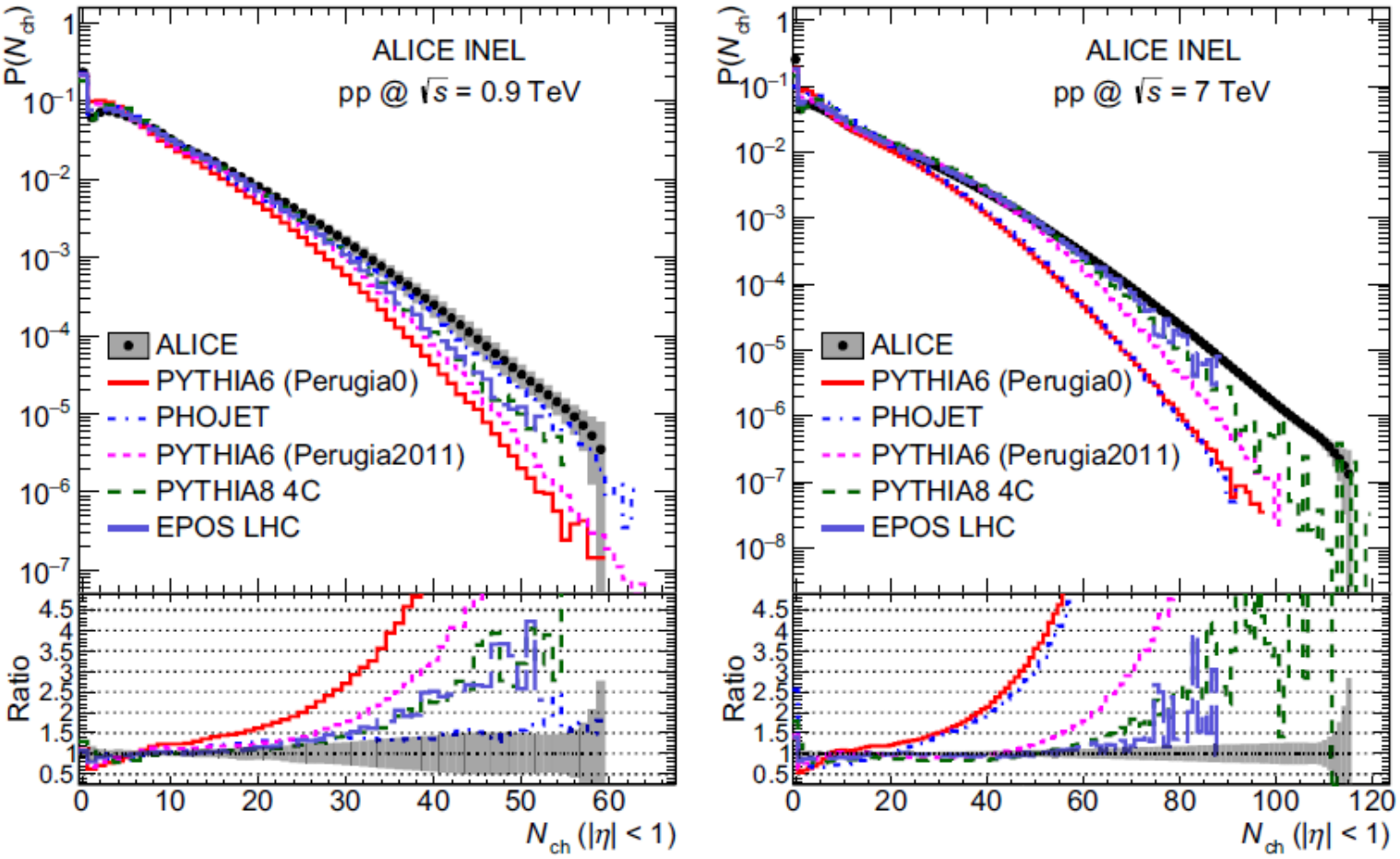
- Single NBD fits the NSD at $\sqrt{s} = 0.9$ TeV in low multiplicity region

Experimental results: Comparison



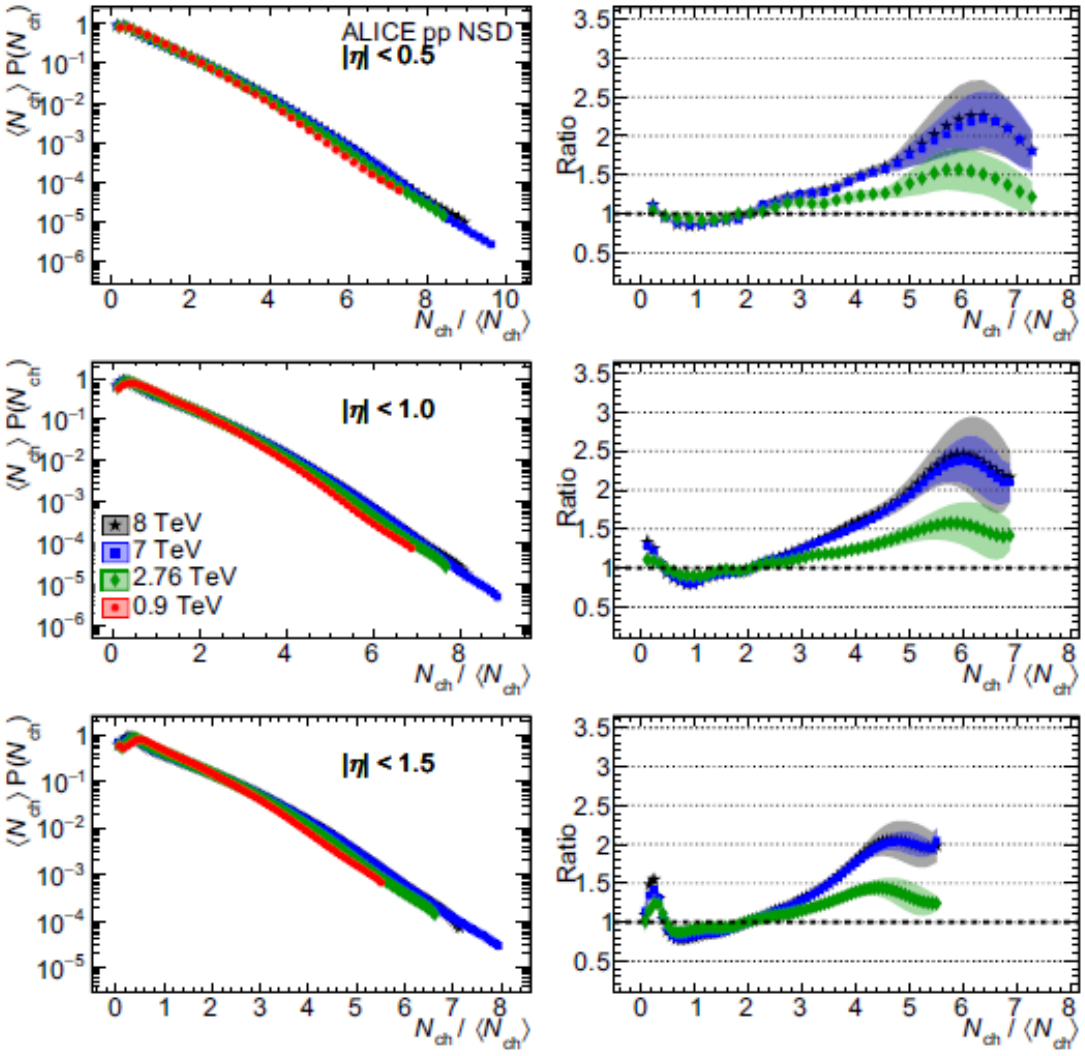
- Consistent results, with higher precision

Experimental results: Comparison to simulations



- Models do not describe data at high multiplicities
- Best description: generators adjusted using first LHC data

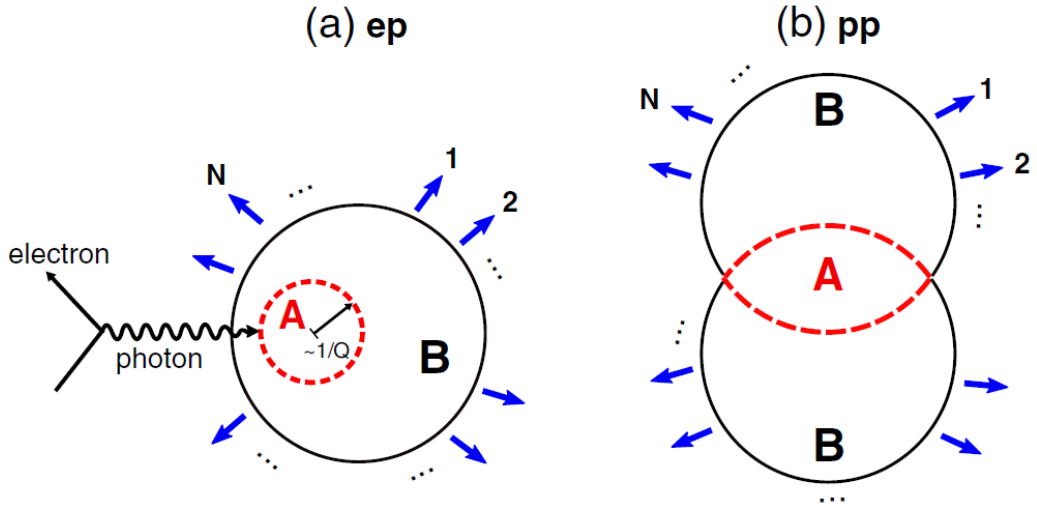
Experimental results: KNO



- KNO scaling violated for NSD events
- Violation increases with increasing energy and $|\eta|$

Quantum entanglement

- Einstein-Podolski-Rosen paradox: initially connected later separated systems: measurement should have an immeadiate effect
- Parton model: parton is independent for an external probe
- Infinite momentum frame: causally disconnected parton probed by a virtual photon: yet it has to form a color singlet state with the rest of the nucleon
- In contradiction with STR: information travelling faster than the speed of light
- [3]



Quantum entanglement - experiment

- Experimental test using data from pp collisions at LHC
- Boltzmann entropy reconstructed from final-state hadrons distributions $S_h = -\Sigma P(n) lnP(n)$
- Entanglement entropy computed from initiate-state partons $S_A = ln(xG(x)) = S_B$ at small x where gluons dominate
- Entanglement entropy S_B gives rise to the final-state entropy
- Tested relation $S_h = S_B$
- e-p collisions in simulation (PYTHIA6)
- e-p experiment does not cover the needed region $x < 10^{-3}$
- p-p experimental data in agreement with Q.E. in $|\eta| < 0.5, 1.0, 2.0$
- Q.E. at subnucleonic scales

Thank you for your attention

Sources

- ALICE Collaboration: Charged-particle multiplicities in proton-proton collisions at $\sqrt{s} = 0.9$ to 8 TeV, Eur. Phys. J. C, 77:33 (2017)
- ALICE Collaboration, K. Aamodt et al.: Charged-particle multiplicity measurement in proton–proton collisions at $\sqrt{s} = 0.9$ and $\sqrt{s} = 2.36$ TeV with ALICE, LHC. Eur. Phys. J. C 68, 89–108 (2010)
- Zhoudunming Tu, Dmitri E. Kharzeev, Thomas Ullrich: Einstein-Podolsky-Rosen Paradox and Quantum Entanglement at Subnucleonic Scales, Physical Review Letters 124, 062001 (2020)
- CMS Collaboration, R. Rougny: Charged particle multiplicities at $\sqrt{s} = 0.9$, $\sqrt{s} = 2.36$ and $\sqrt{s} = 7$ TeV with the CMS detector at LHC, PoS ICHEP2010, 358 (2010)