Soft and hard interactions in high multiplicity PP collisions at LHC energies

Particles & Plasmas Symposium

HZDR Dresden & Kulturforum Synagoge Görlitz

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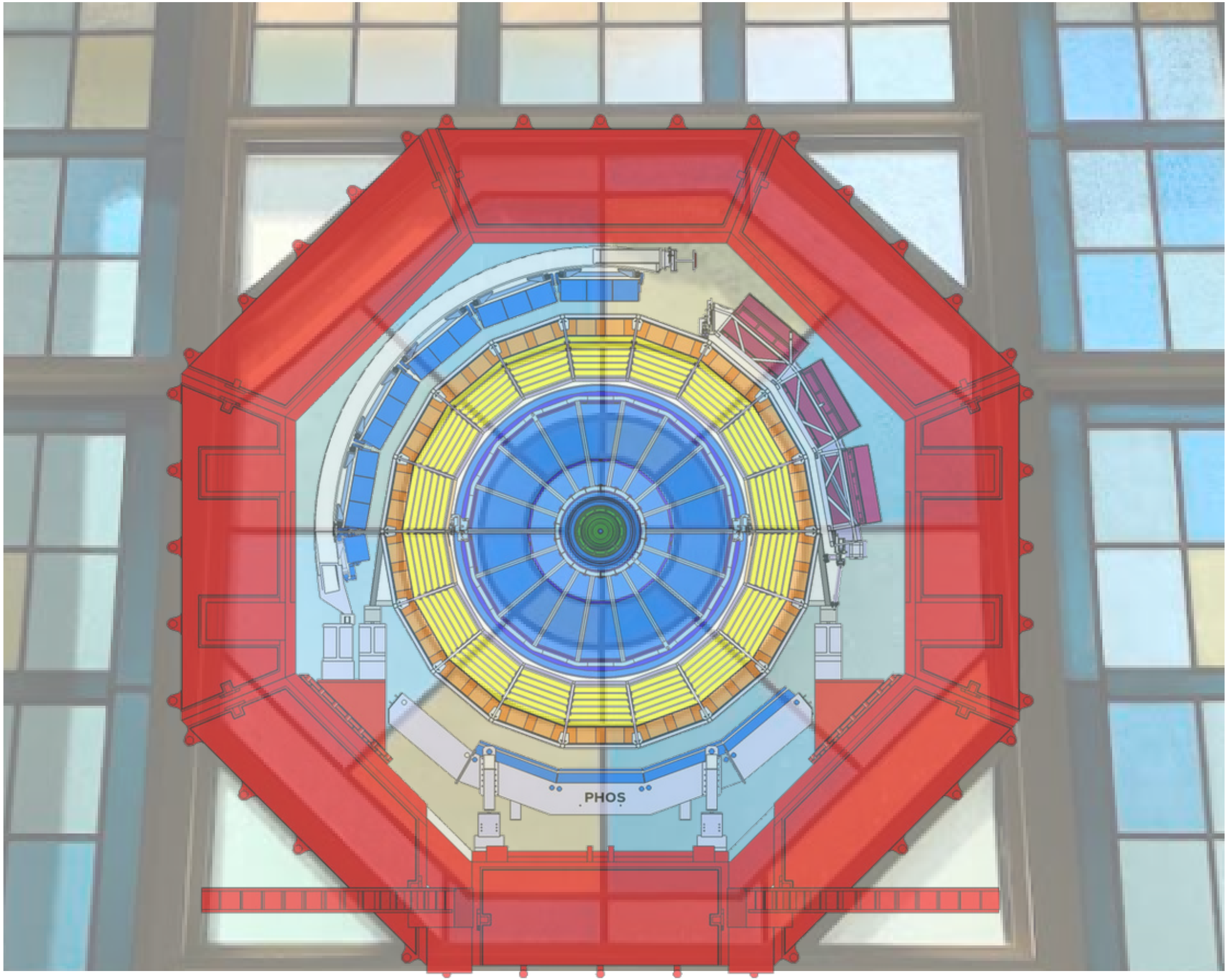
arXiv:2403.07512

arXiv:25XX.XXX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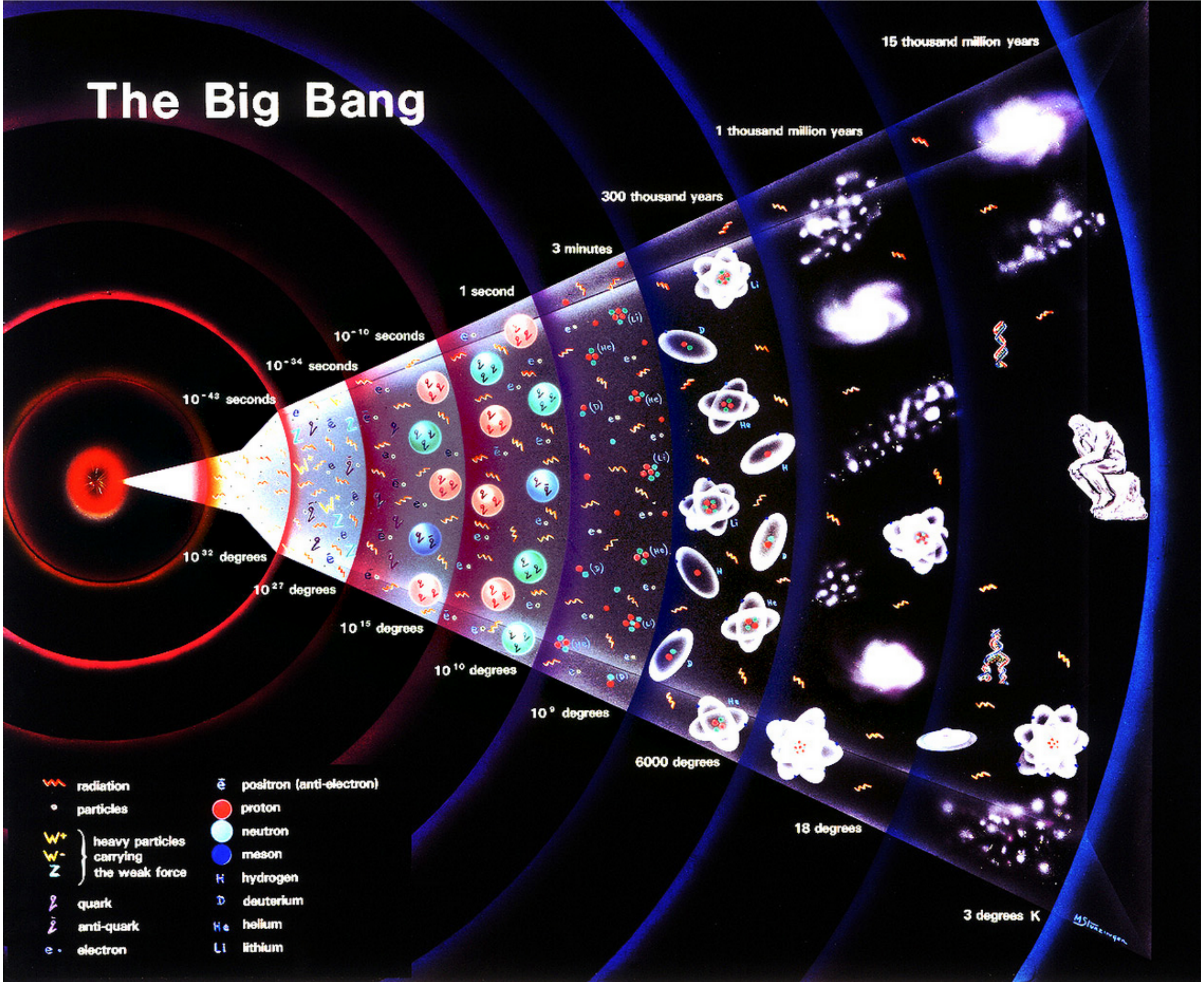
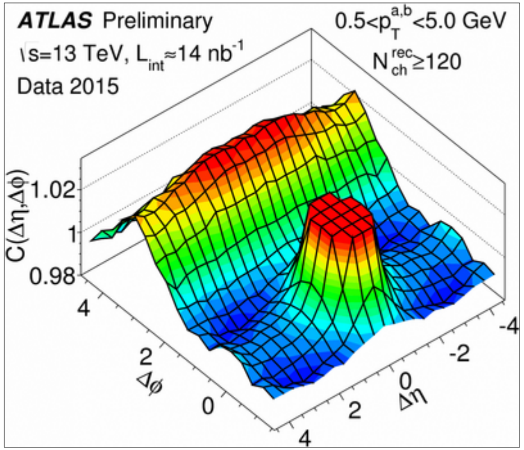

The Big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10⁻¹⁰ seconds
10⁻³⁴ seconds
10⁻⁴³ seconds
10³² degrees
10²⁷ degrees
10¹⁵ degrees
10¹⁰ degrees
10⁹ degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

CERN

QGP – QGP everywhere...



Phys. Rev. Lett. 116, 172301 (2016)

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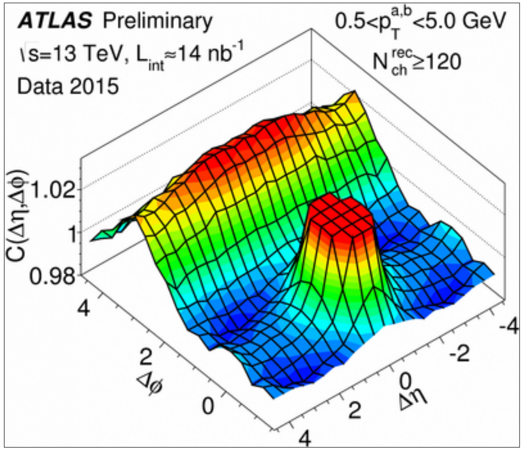

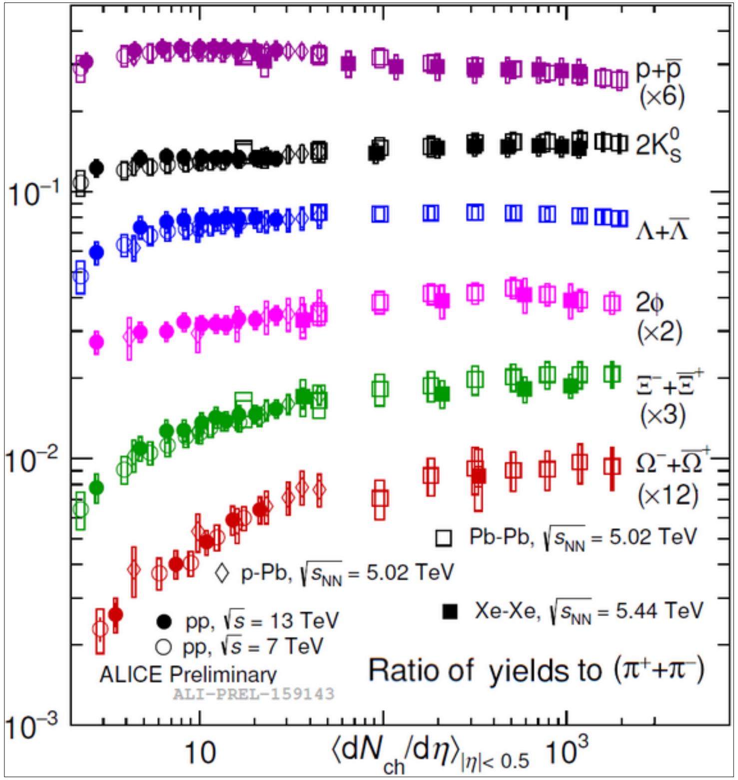

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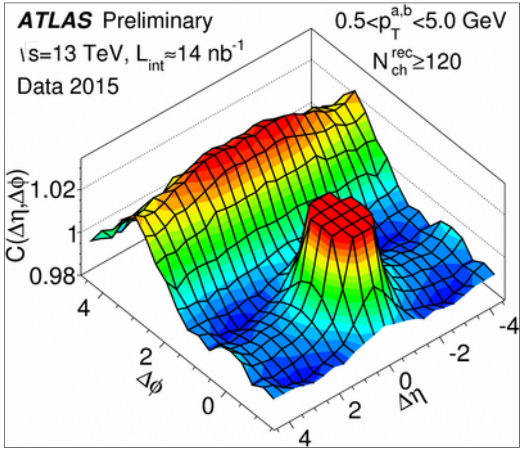
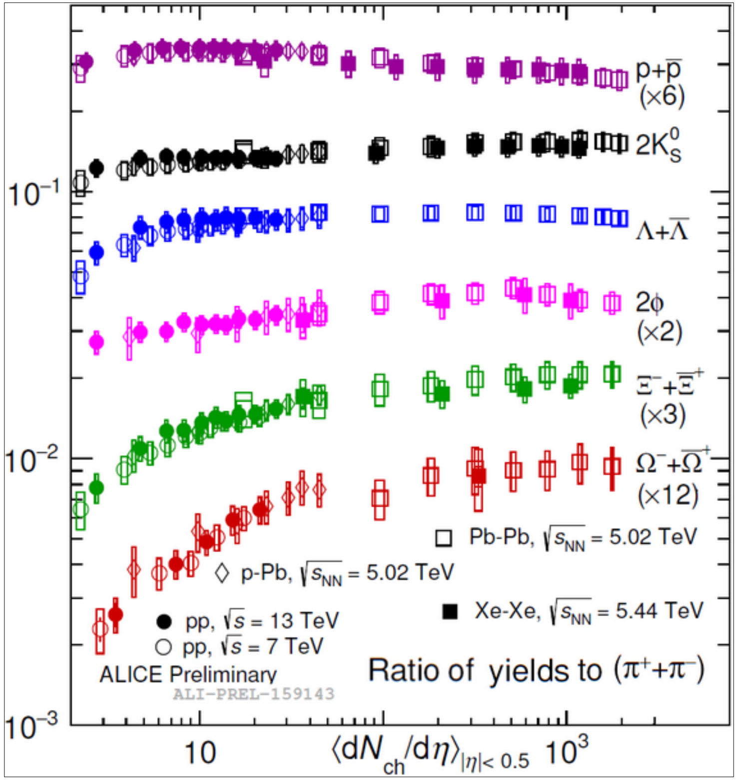
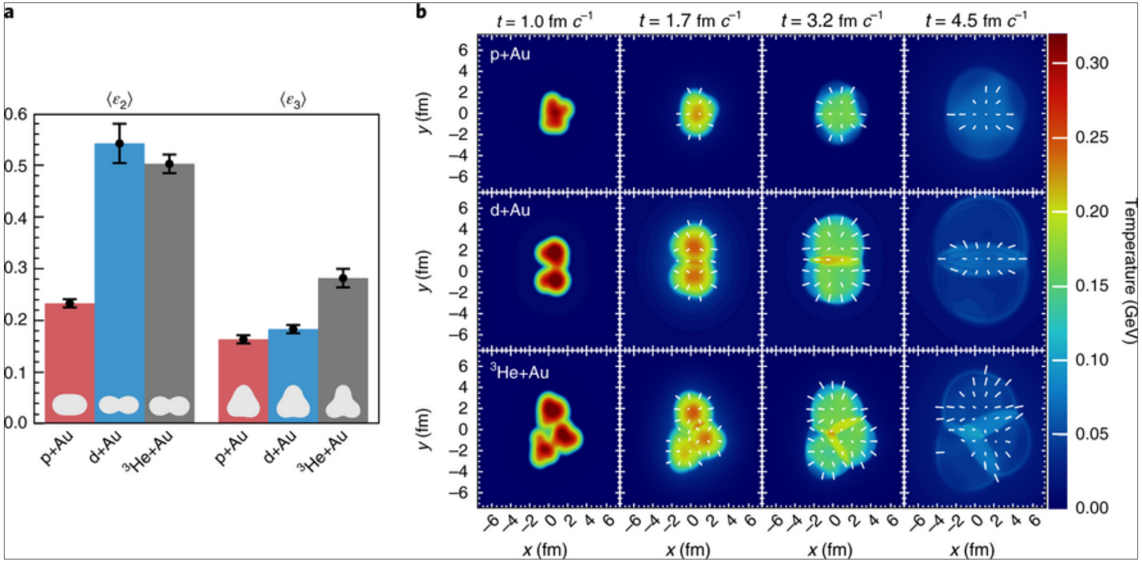






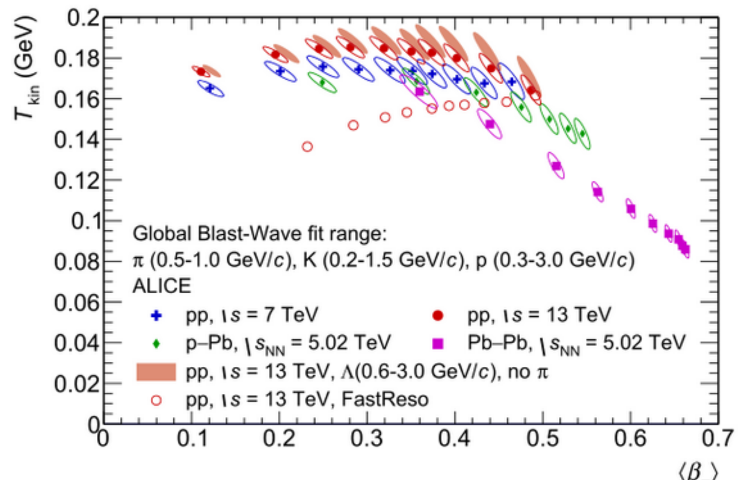
Phys. Rev. Lett. 116, 172301 (2016)
Nature Physics volume 13, 535-539 (2017)
Nature Physics volume 15, 214–220 (2019)

Collective flow in every system

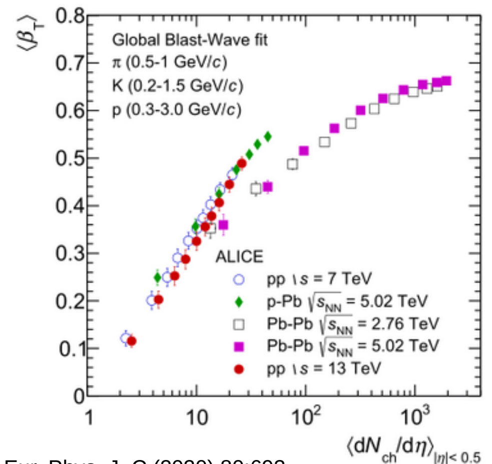
- High quality, multiplicity dependent (PID) data for various collision systems
- Traditional Blast-wave fits (Phys. Rev. C, 48 (1993), pp. 2462-2475):

$$\frac{dN}{p_T\ dp_T} \propto \int_0^R r\ dr\ m_T\ I_0\left(\frac{p_T \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{kin}}\right)$$

where $\rho = \tanh^{-1}(\beta_T)$



Eur. Phys. J. C (2020) 80:693



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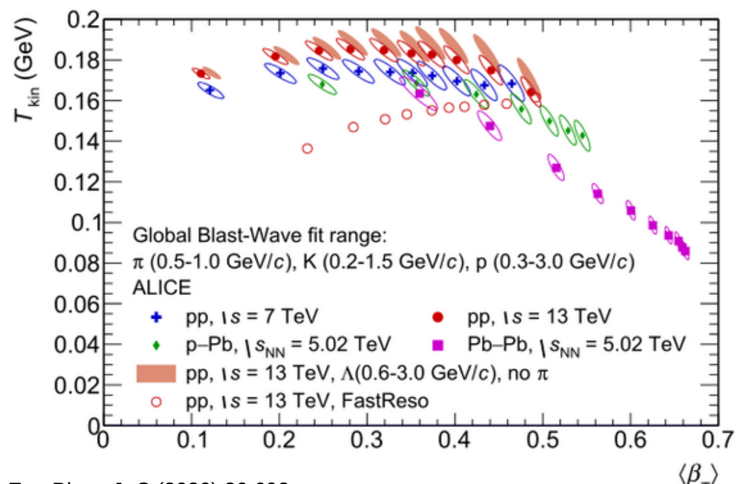

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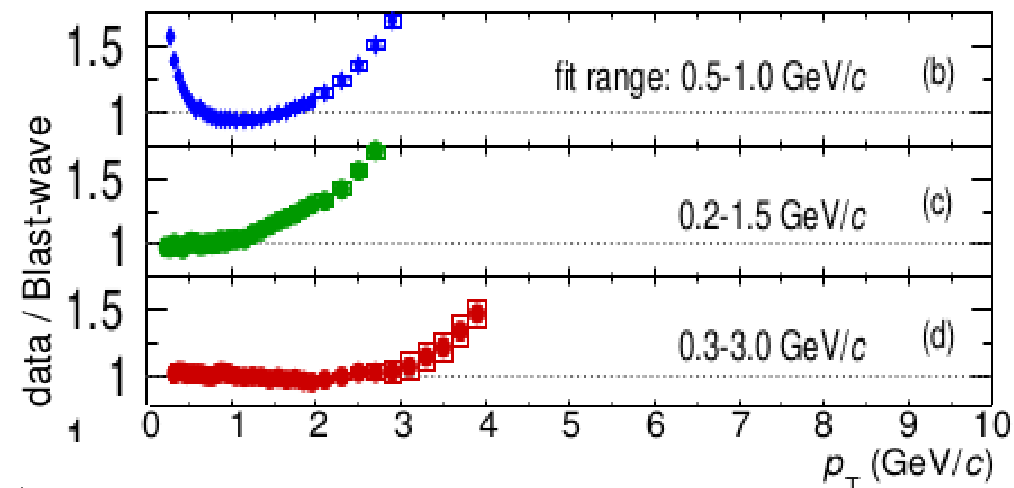
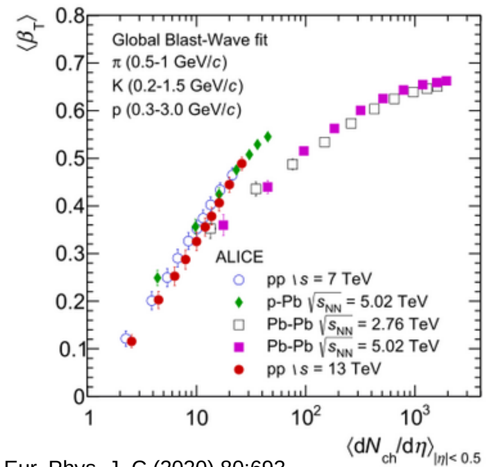


Phys. Rev. C 99, 024906



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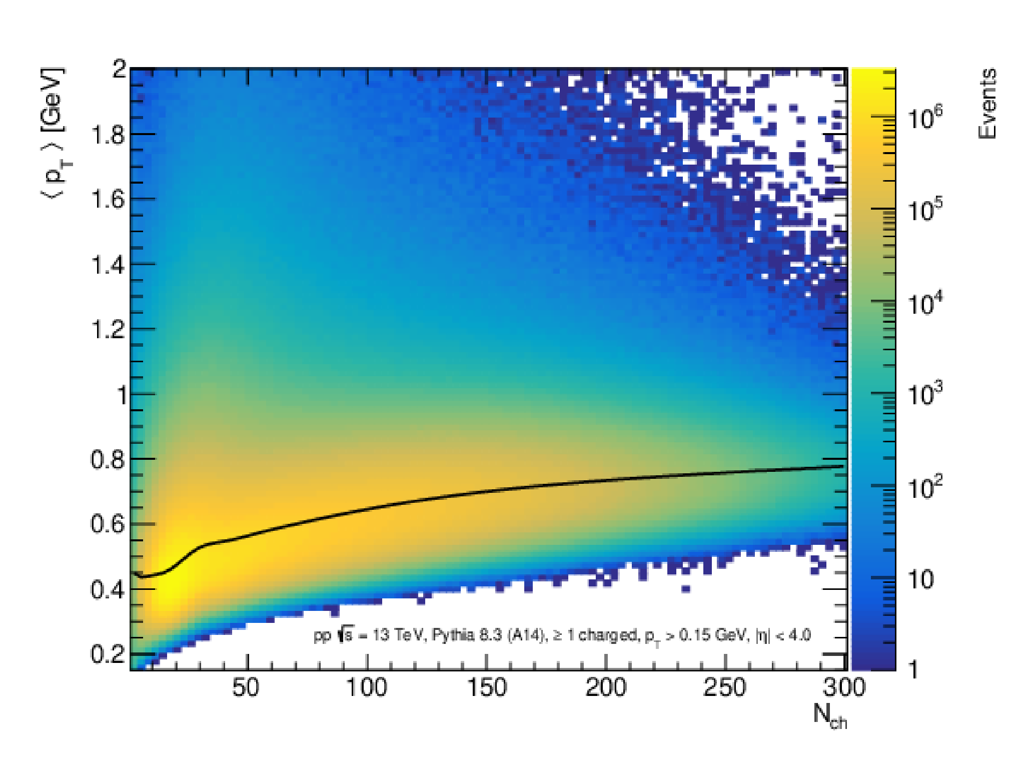
Problem of means

- the observations we are doing and the accompanying theories are based on “means”

  - mean multiplicity, transverse, momentum, anisotropy, strangeness…

- The models can get the most prominent features but never all the details of the interactions if there are multiple sources that contribute



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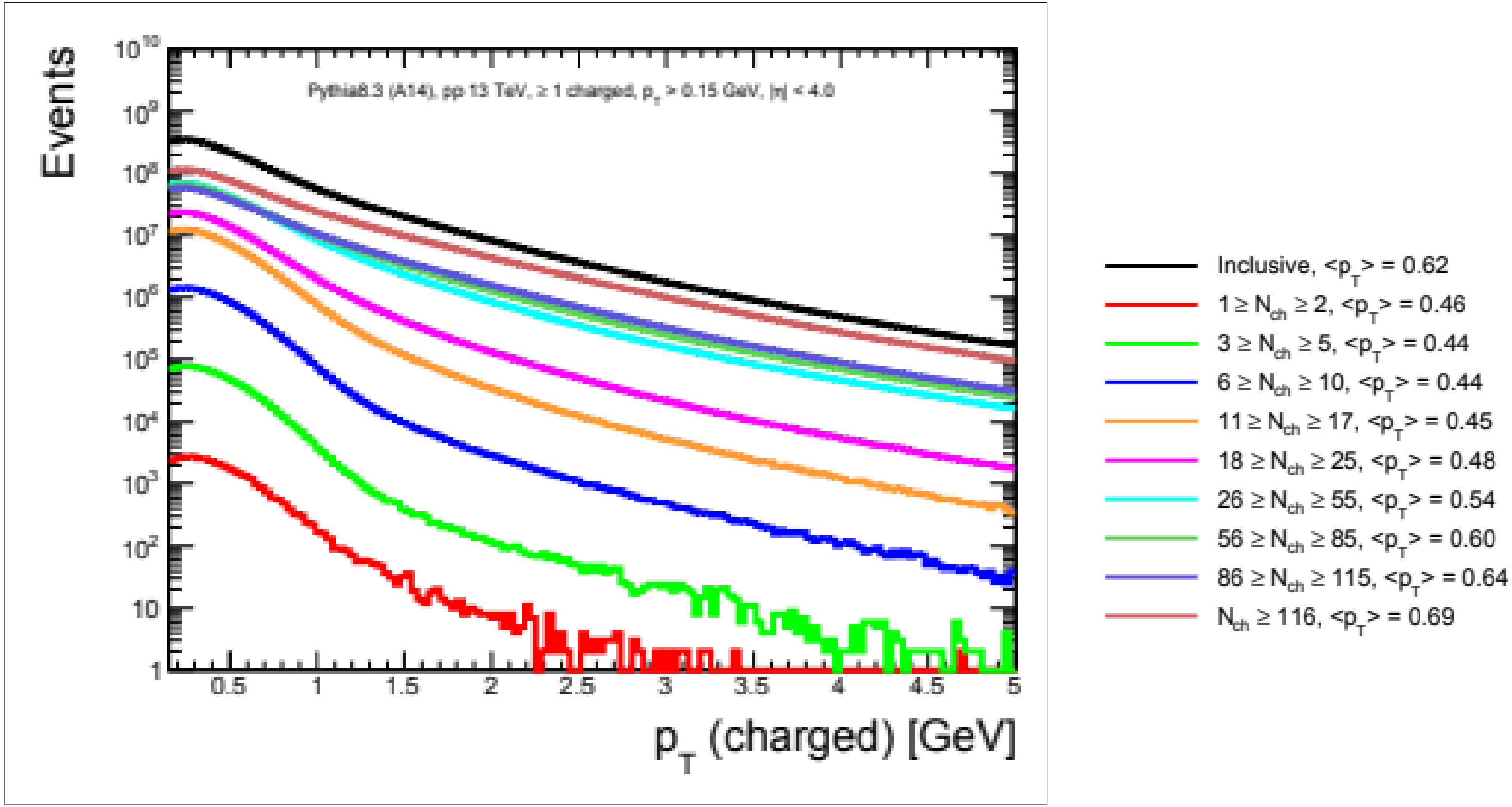
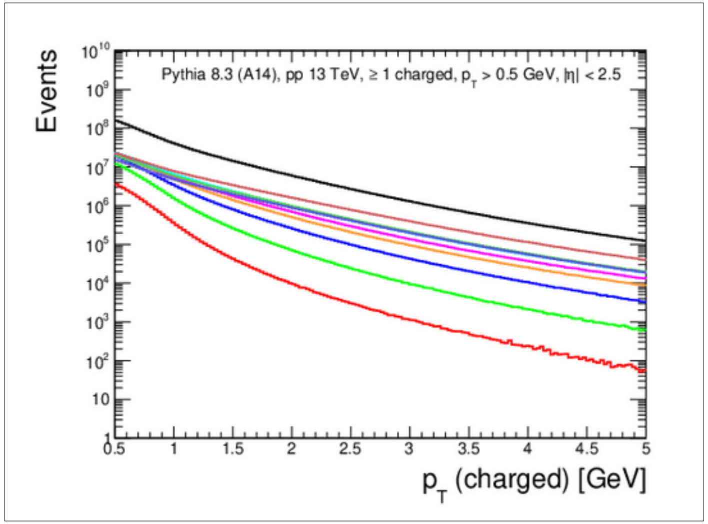
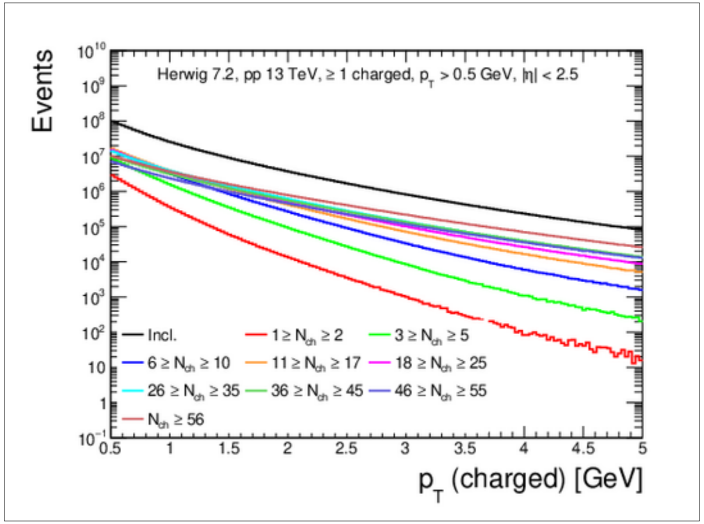
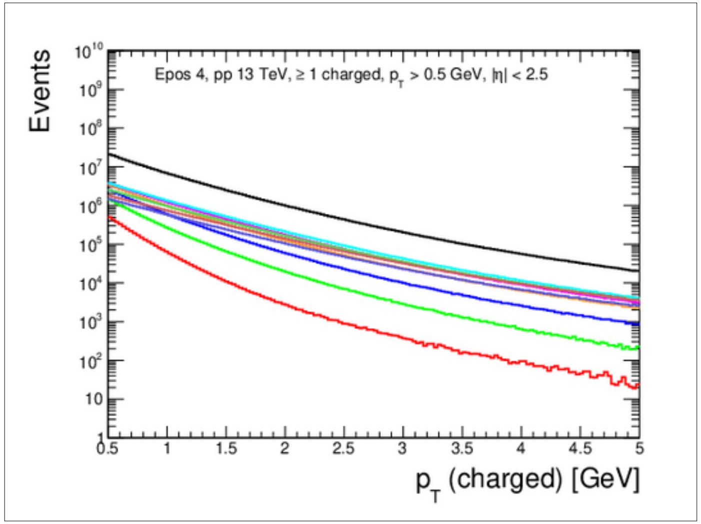


Problem of means

- Small differences in the mean pt's but important differences in the spectra!







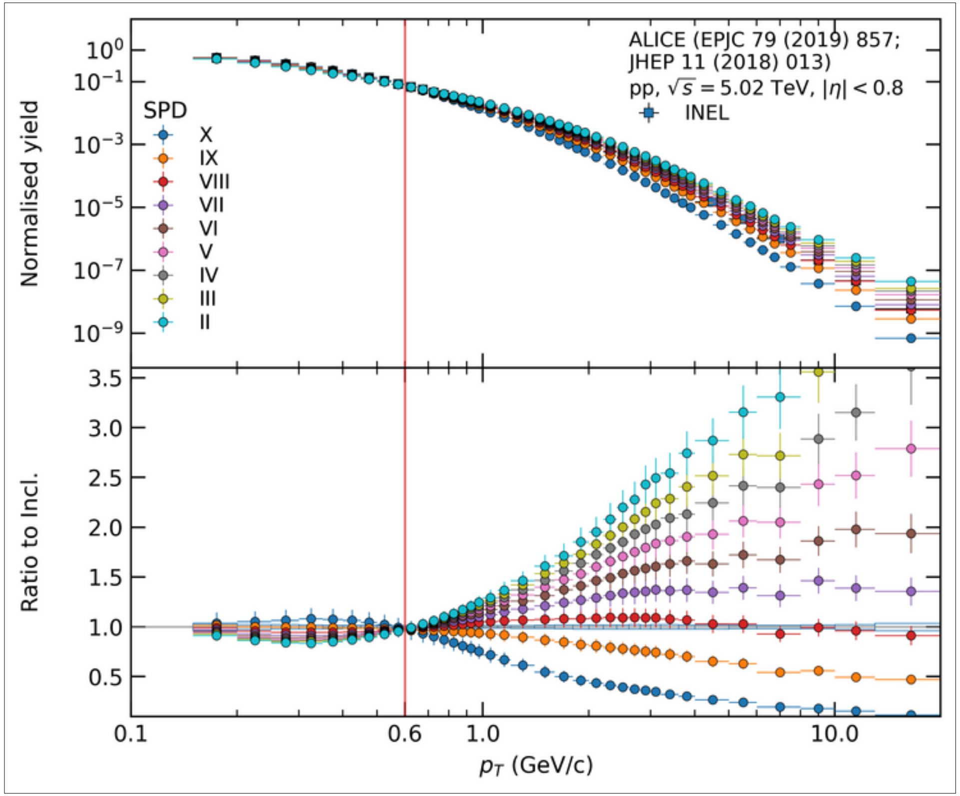
1) the mean is always close to the threshold in fast diminishing spectra

2) by getting a "mean" value we learn very little about the high p_T behavior

3) an agreement in the means among various models does not ***mean*** that they agree on the details!

Normalized yields and event multiplicity

Normalized yield ratios of charged hadrons: common crossing for all LHC energies → hint for soft limit?



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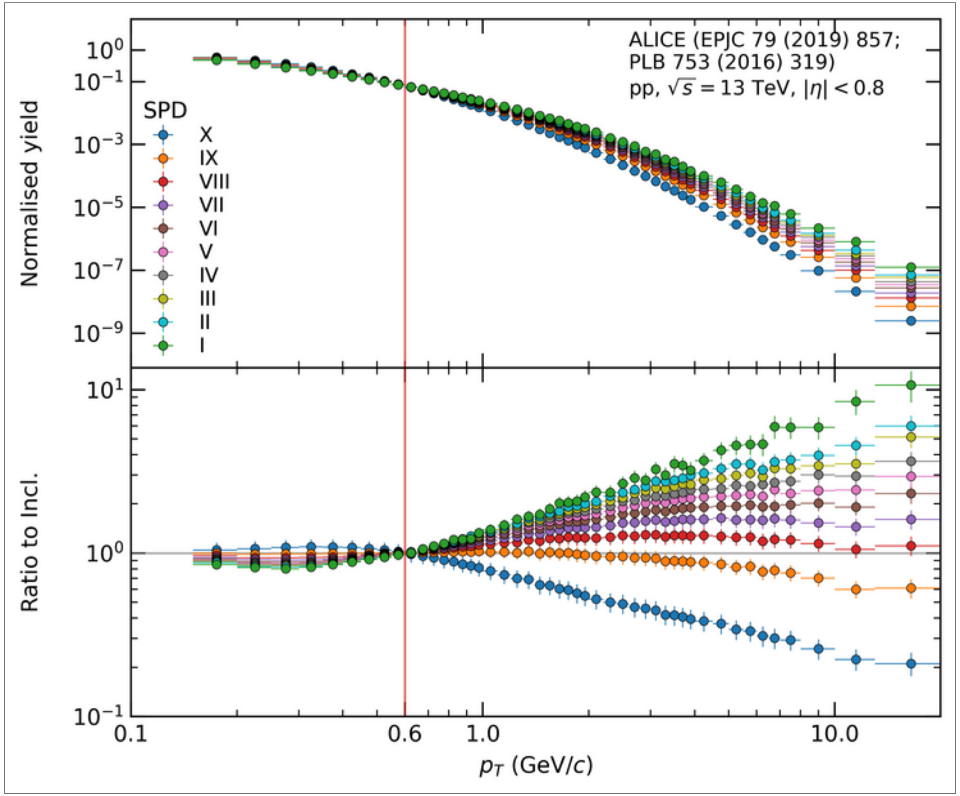

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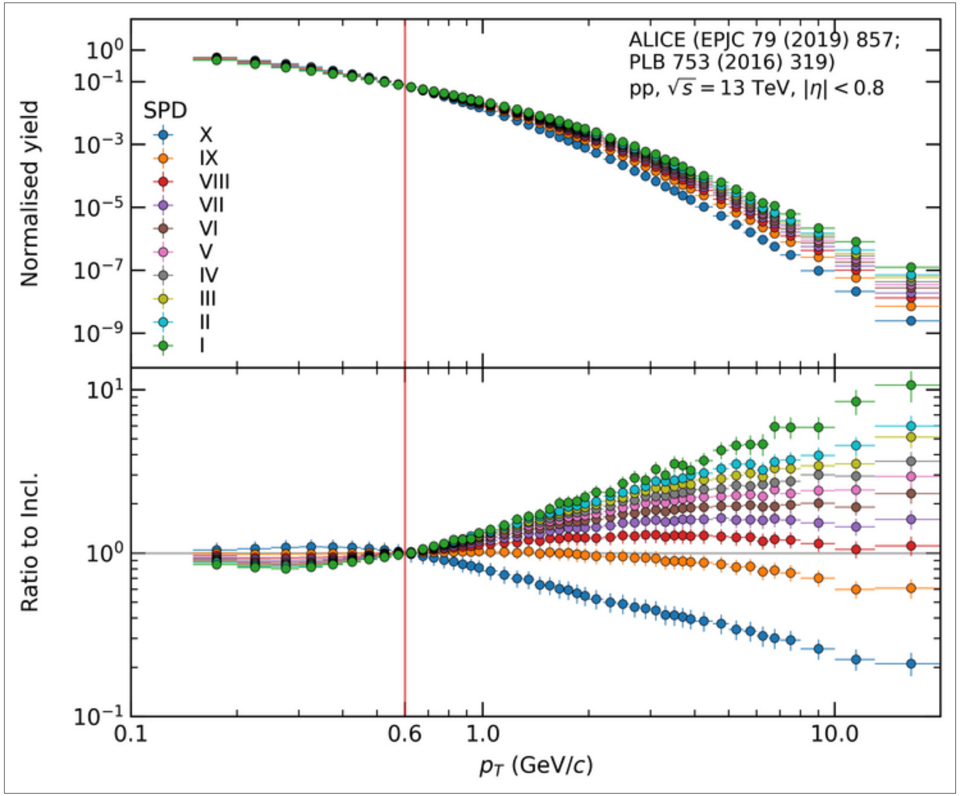
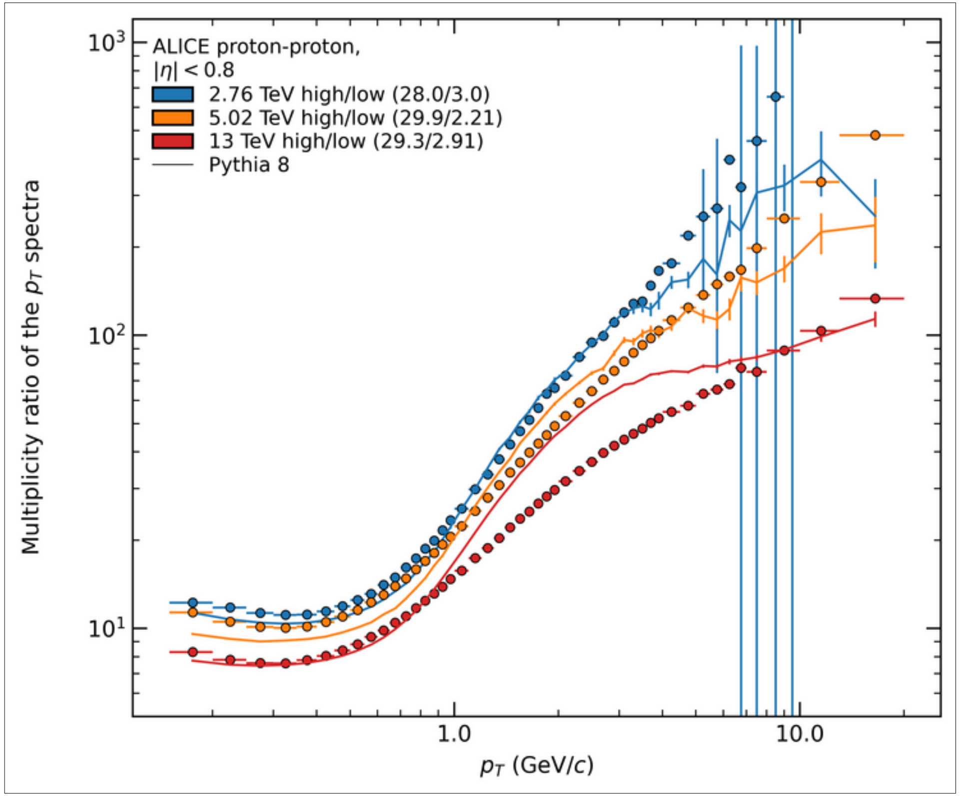
p_T ratio of high/low multiplicities → common scaling





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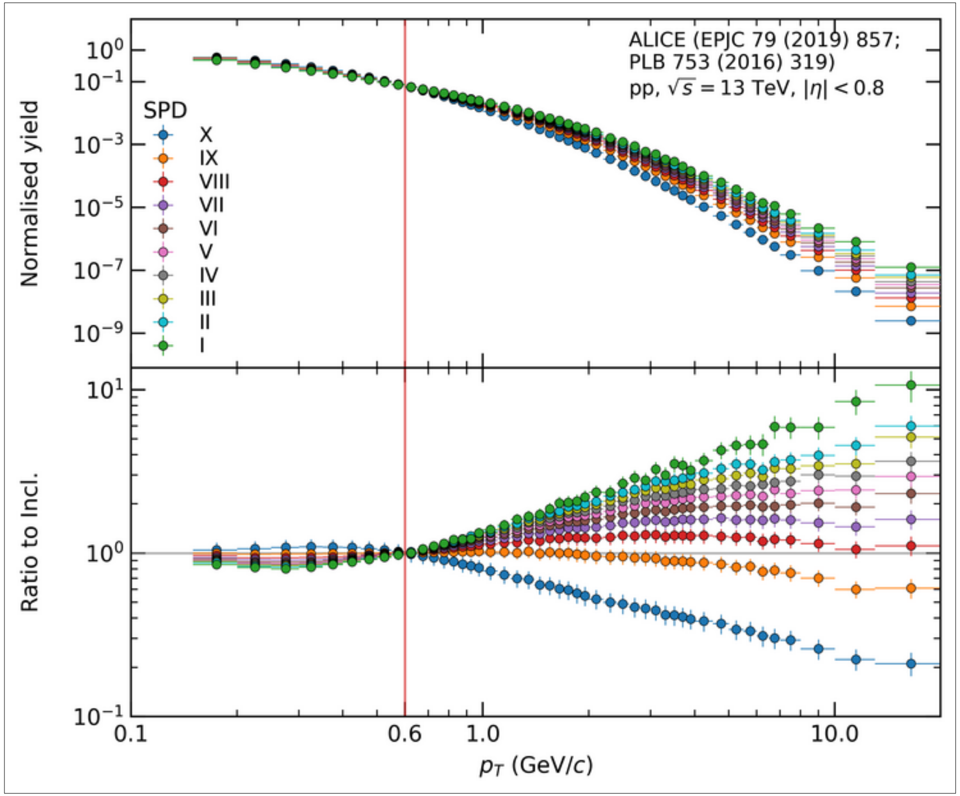
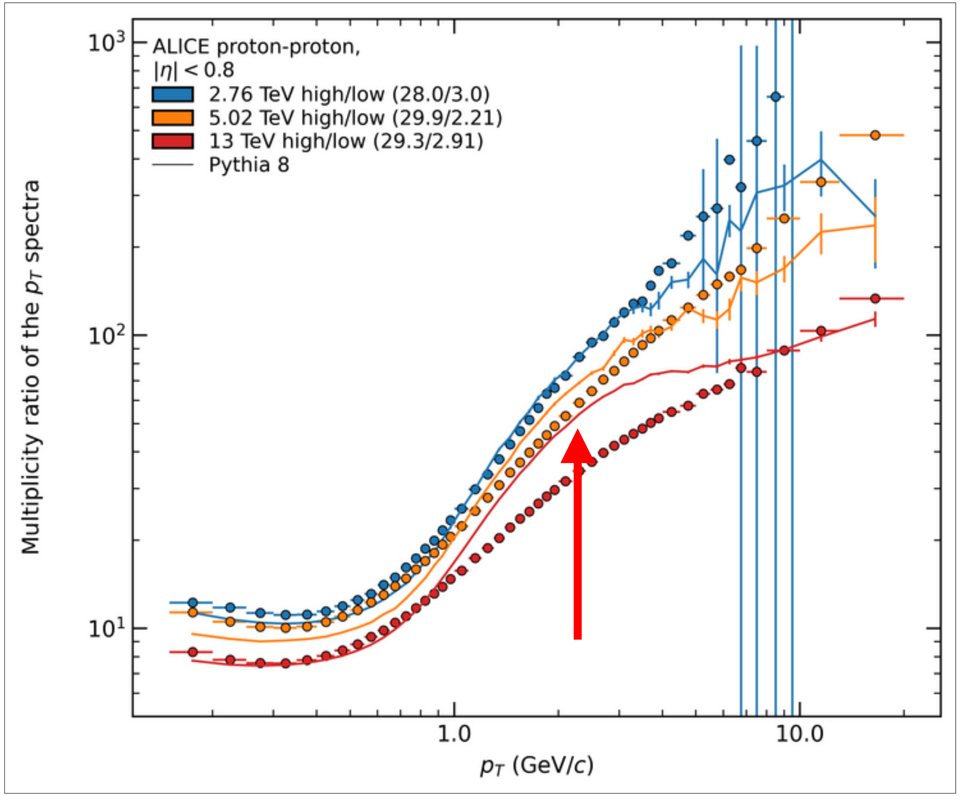
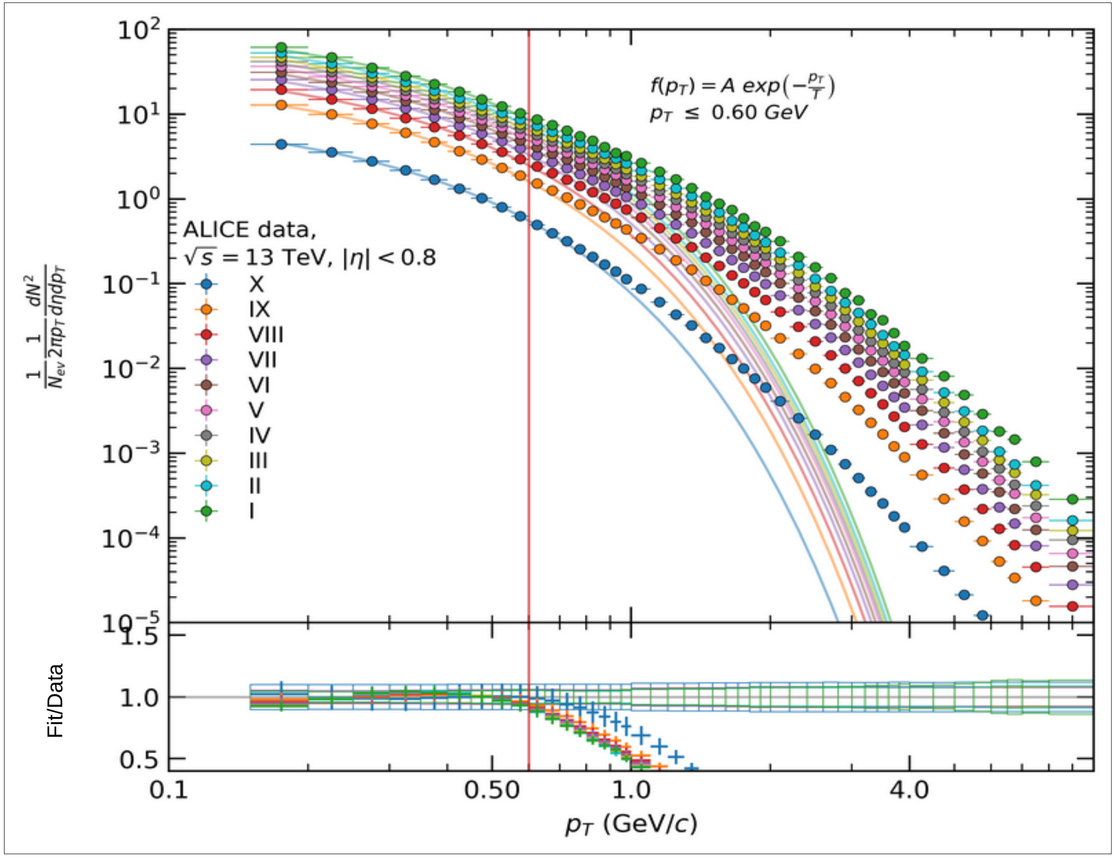




Systematic study of p_T ranges

- Systems:
  - 2.76 TeV, 5.02 TeV, 13 TeV (pp→ ch)
- p_T ranges:
  - 0.15 GeV ≤ p_T ≤ **p_0**
  - **p_0** in [0.4, 3.0], dp_T = 0.05
- Fit function: naive Boltzmann

$$f(p_T) = A\exp\left(-\frac{p_T}{T}\right)$$



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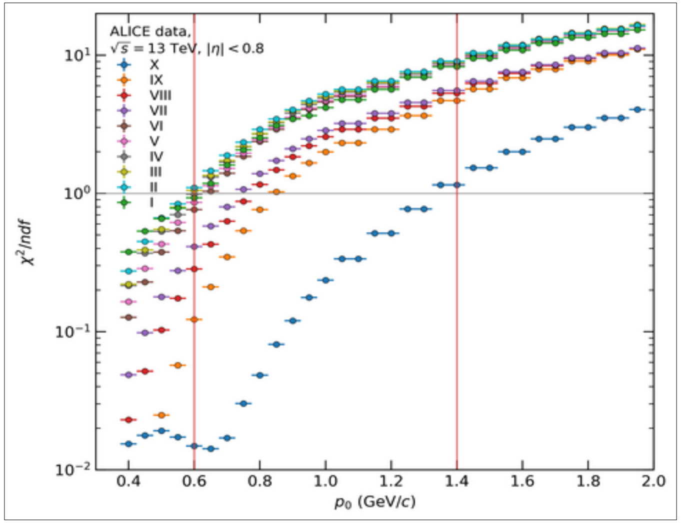

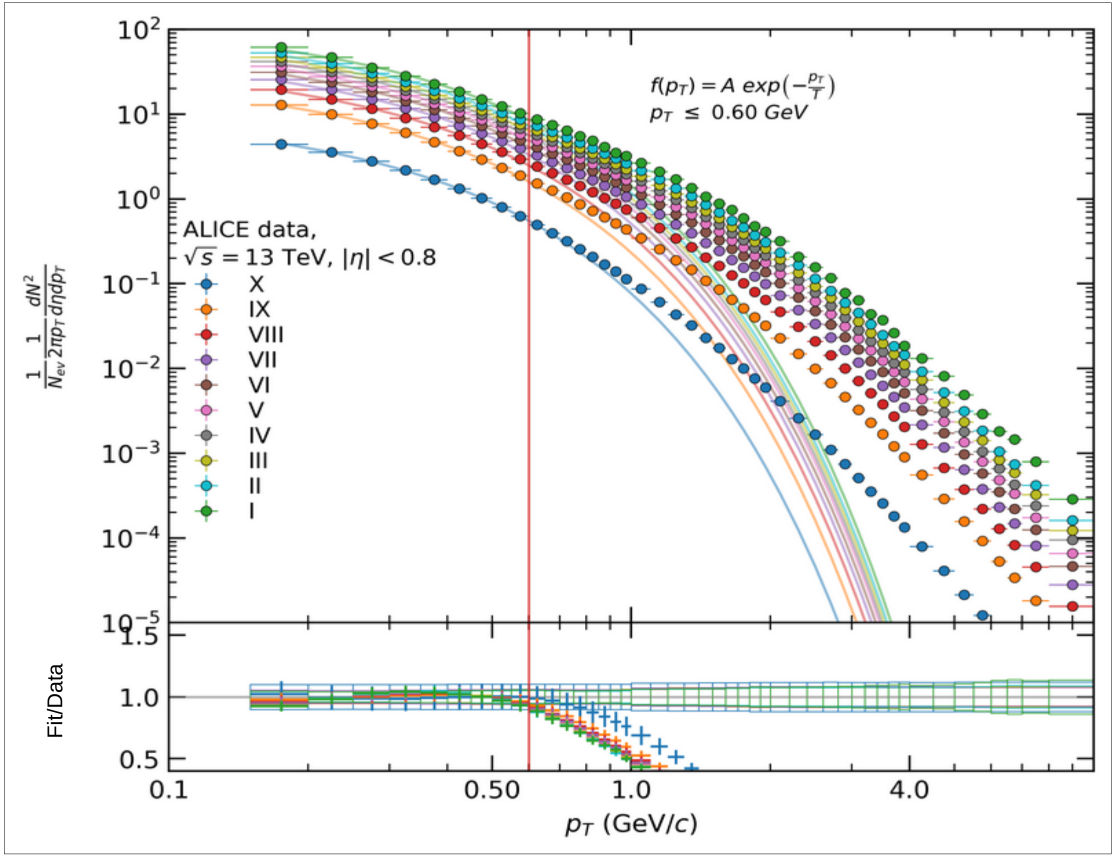

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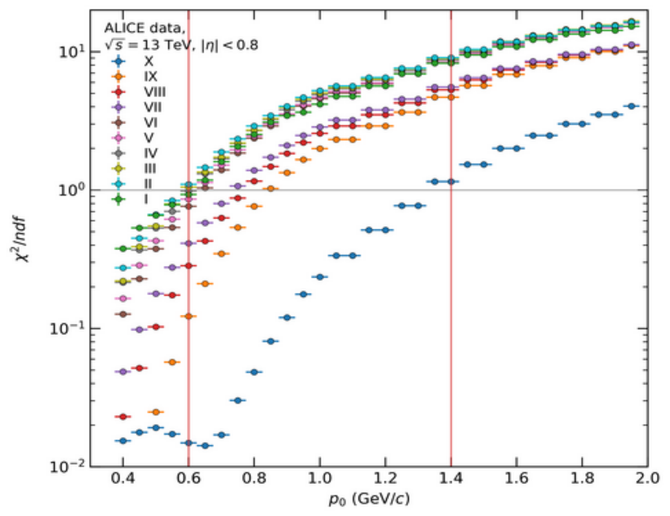

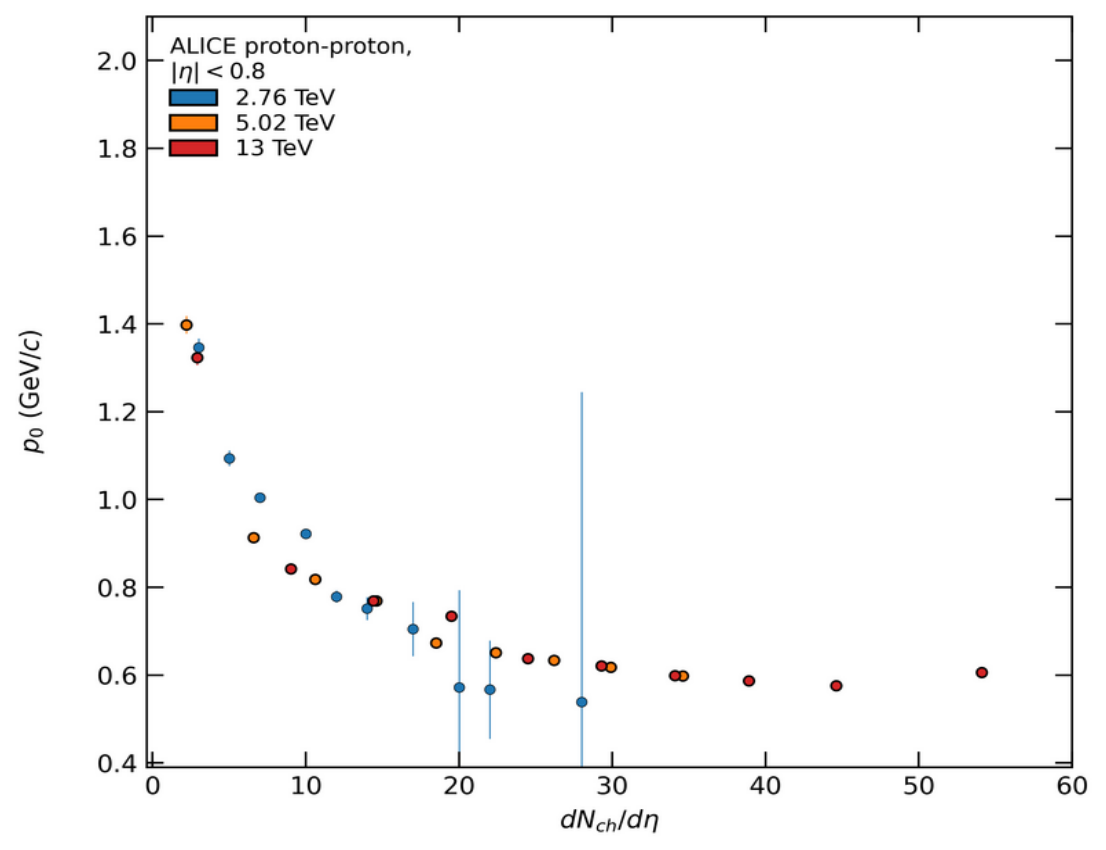

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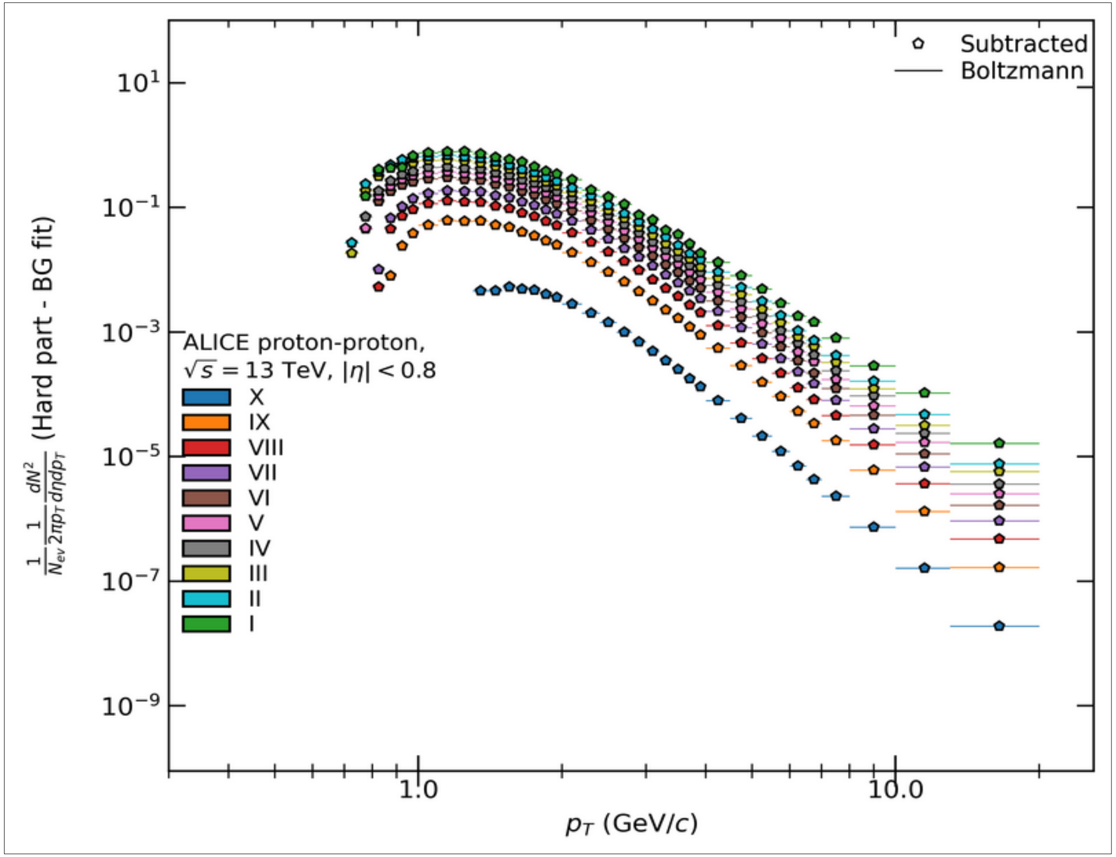
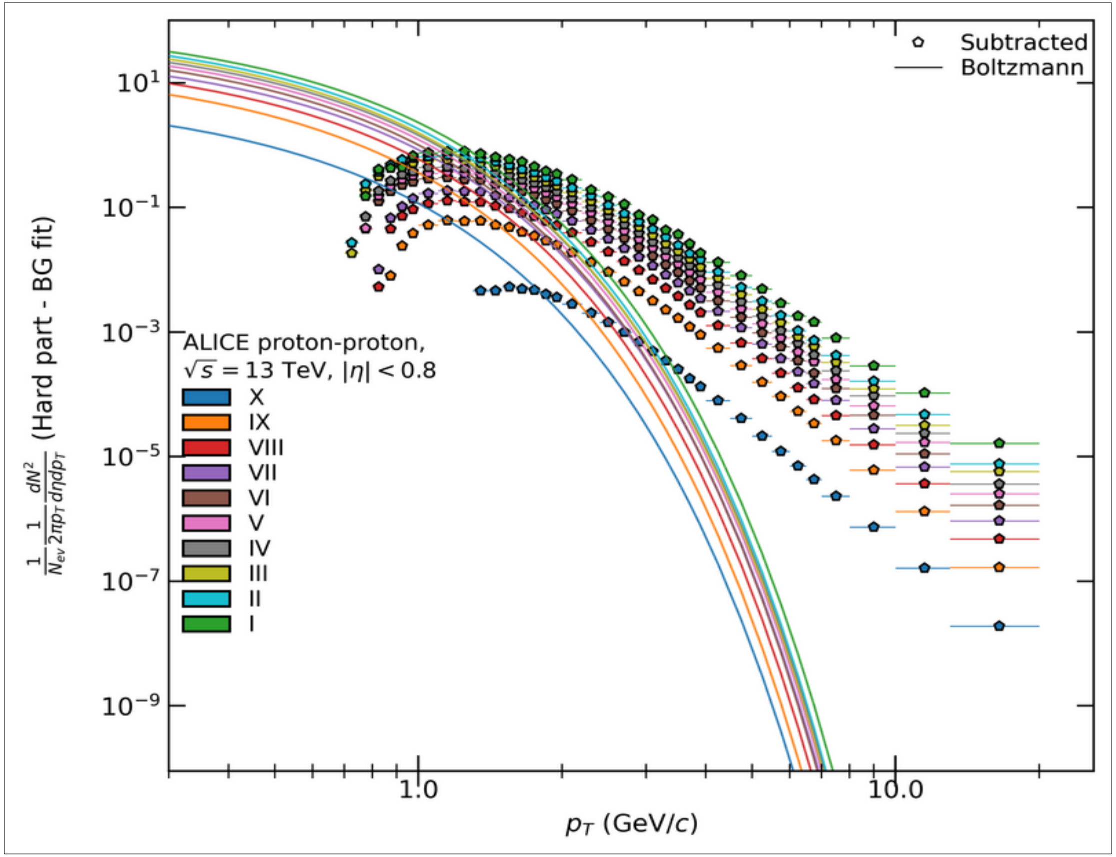
- Best value of p_0 is determined from the goodness of fit



Systematic study of p_T ranges

- Low p_T, soft part
  → traditional Boltzmann-fit

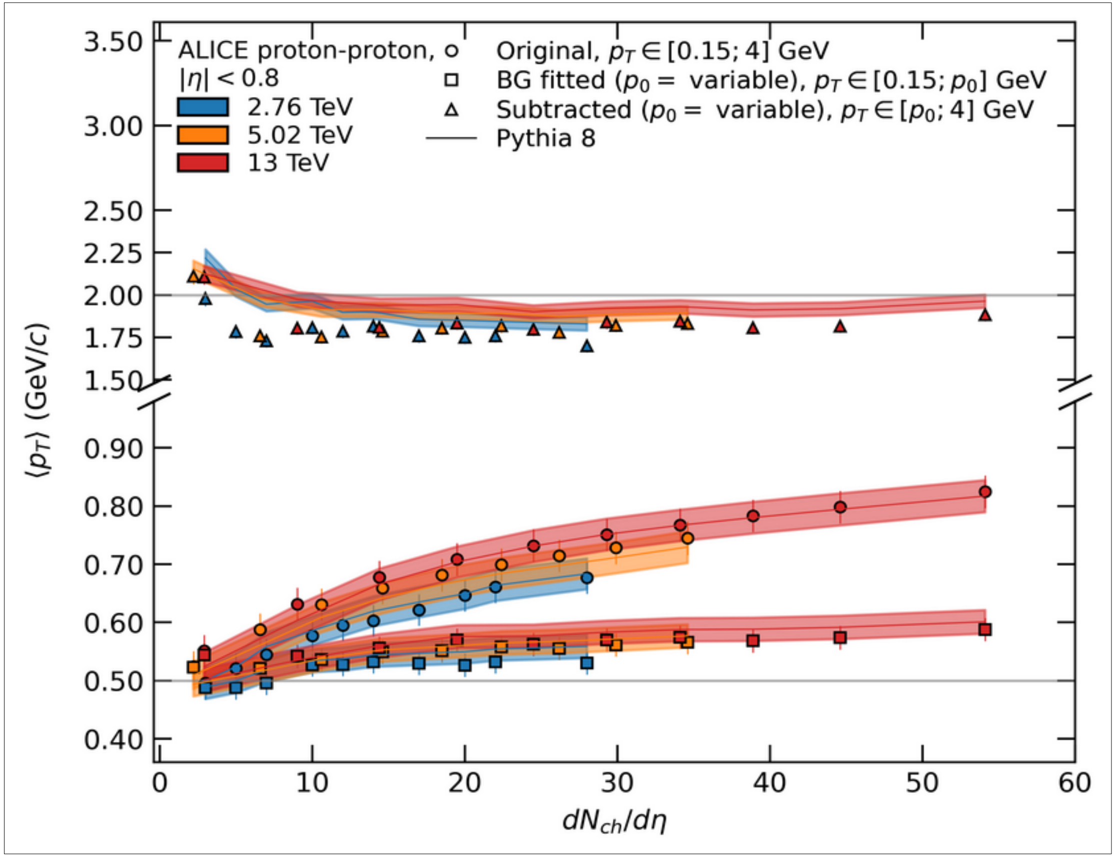
- High p_T part
  → (cut distribution - Boltzmann-fit)



Systematic study of p_T ranges

- "Inclusive" mean p_T: composite of two very different region

- Both the low p_T (collective, thermal part; from the Boltzmann fit) and high p_T (fragmentation; from subtracted spectrum) are ~constant of multiplicity and collision energy



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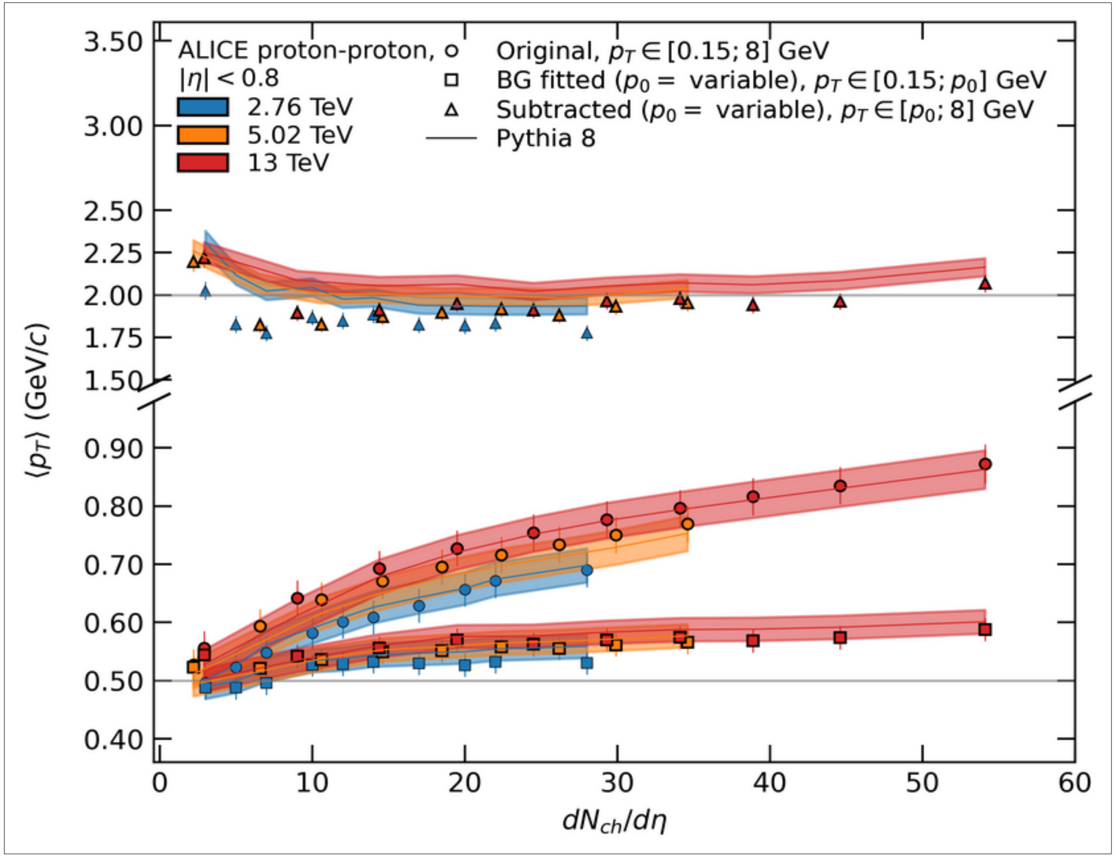

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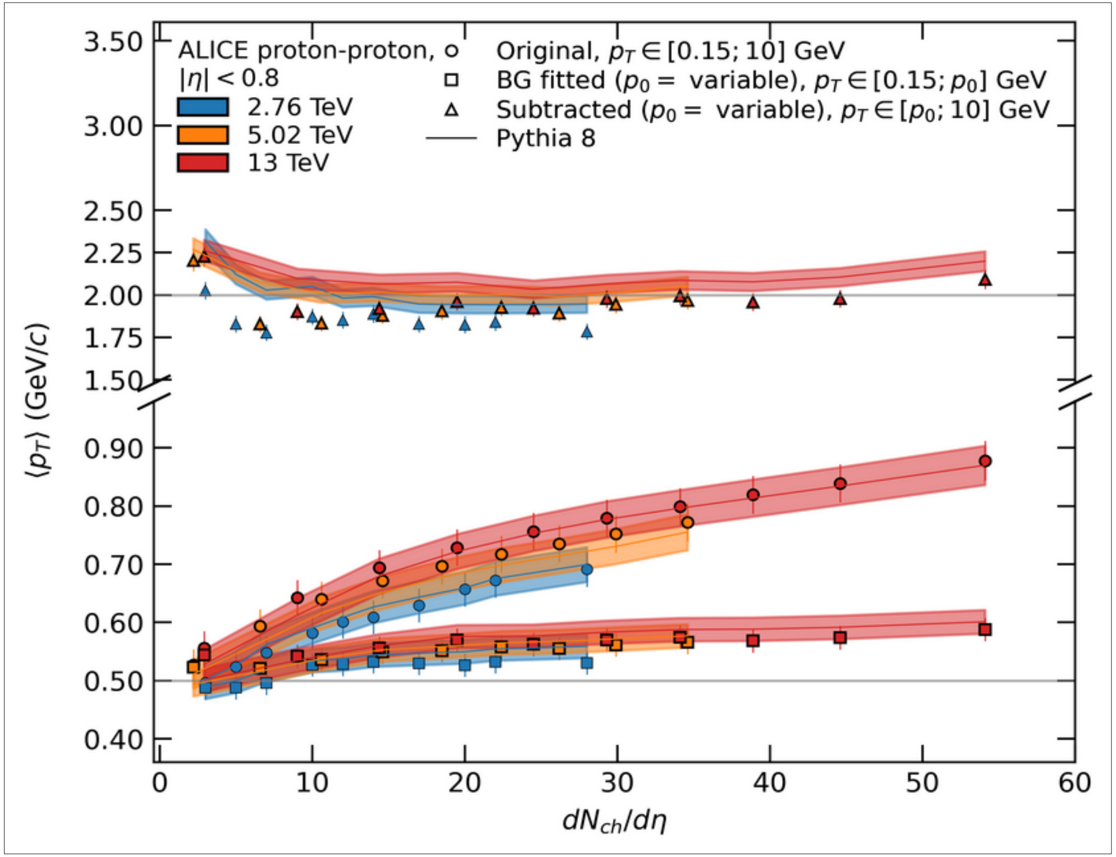

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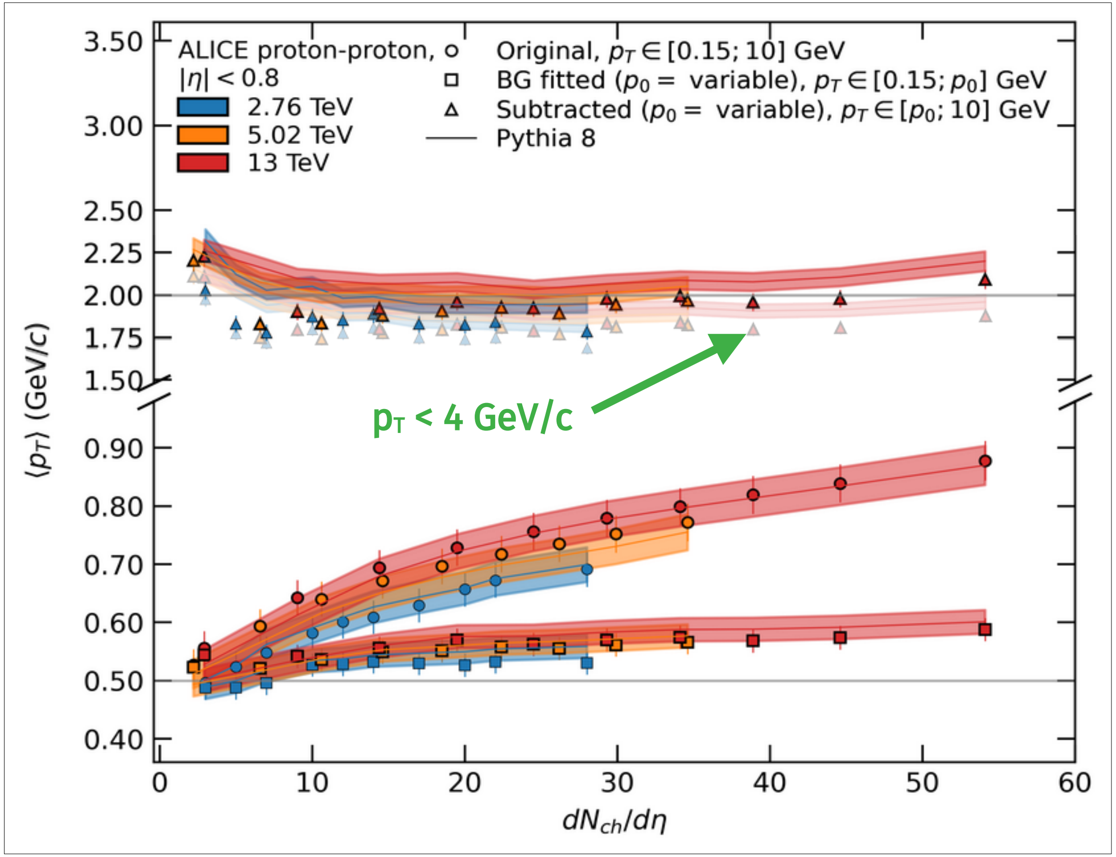
  ~12% for p_T < 4 GeV/c



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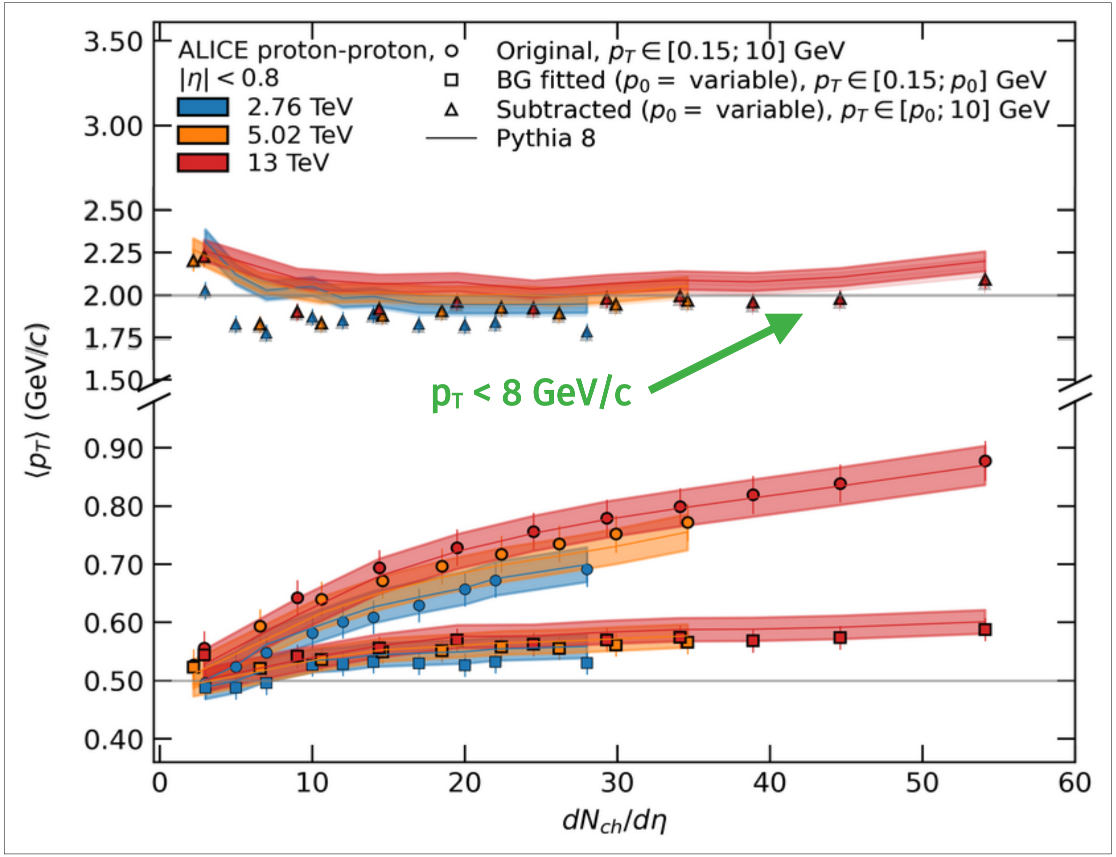
  ~12% for p_T < 4 GeV/c
  ~<1% for **p_T < 8 GeV/c**



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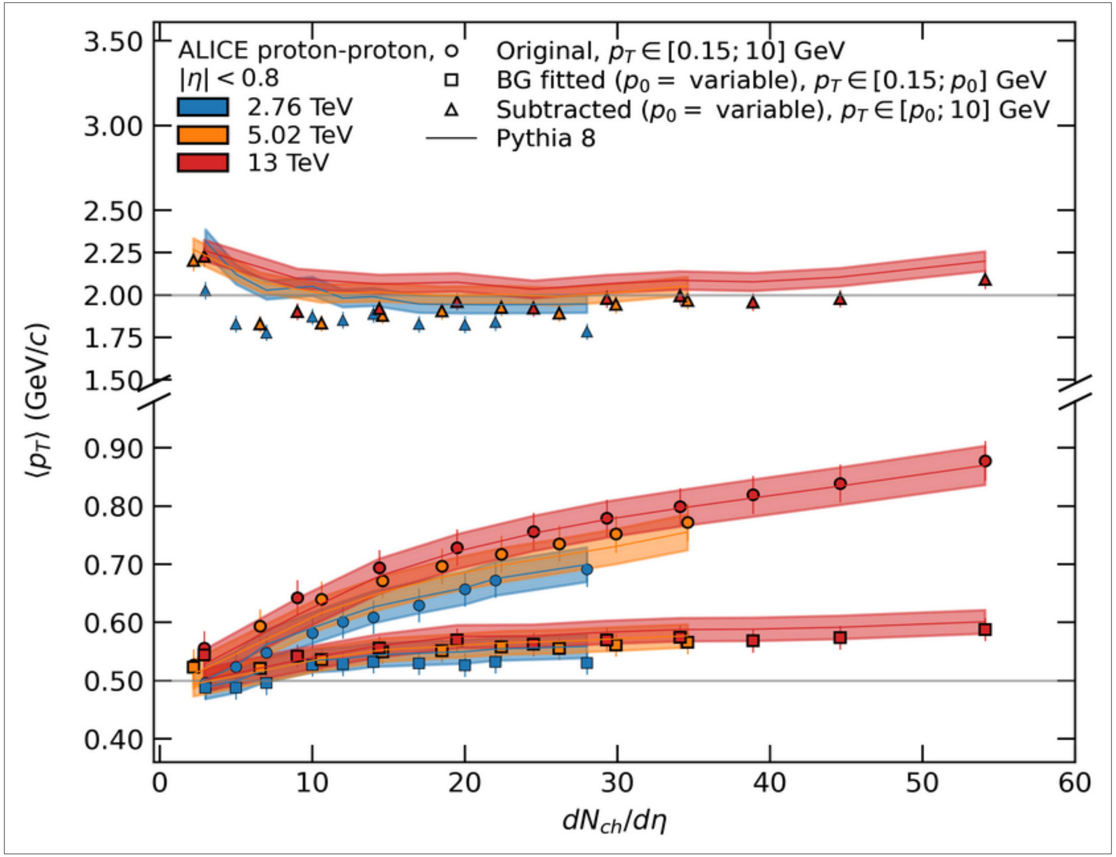
- Both the low p_T (collective, thermal part; from the Boltzmann fit) and high p_T (fragmentation; from subtracted spectrum) are ~constant of multiplicity and collision energy
- High p_T part: weak dependence above ~8 GeV/c
- **Questions the correct interpretation of the blast wave flow in pp collisions** → artifact of the constrained fit ranges..?



Summary

- The mean of the distributions can be **ill defined** (not to mention the extrapolations)
- The exponential-like Blast-wave fits (and the extracted flow properties) can be **ill defined**
- The extracted temperature (and therefore many other quantities) **strongly depends** on the applied definitions
- The soft/hard limit is controversial and question of interpretation

Thank you for your attention!

The research was supported by the **Wigner Scientific Computing Laboratory** (former Wigner GPU Laboratory).