Scaling properties of jets in high-energy pp collisions

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with

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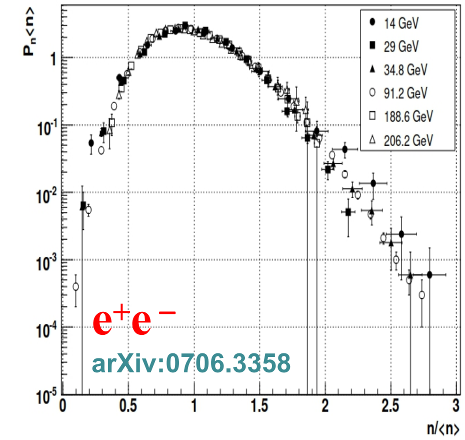
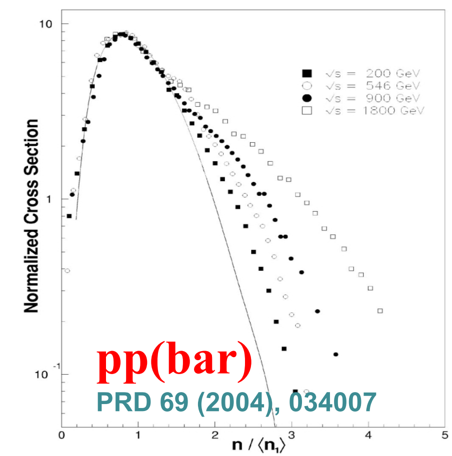
This work has been supported by the Hungarian NKFIH OTKA FK131979 and K135515 as well as the NKFIH 2019-2.1.11-TÉT-2019-00078, 2019-2.1.11-TÉT-2019-00050, 2019-2.1.6-NEMZKI-2019-00011, 2020-1.2.1-GYAK-2020-00013 grants and the Wigner distinguished research group program

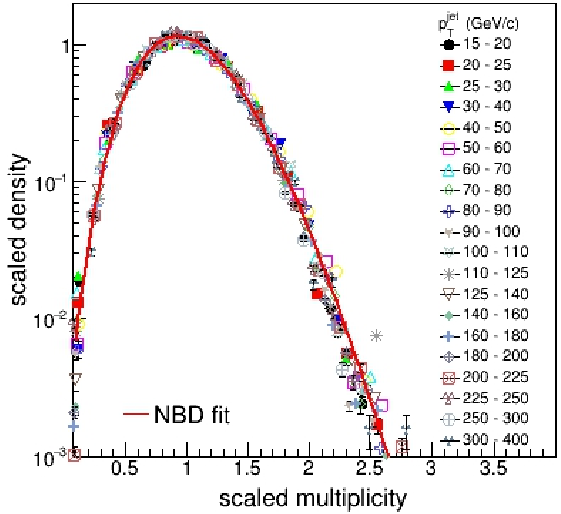
Background

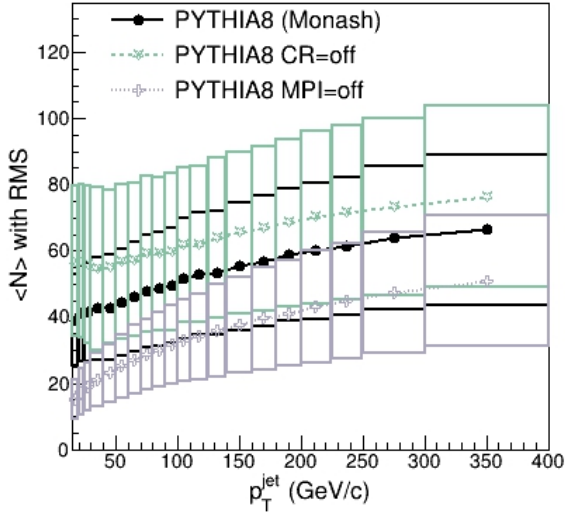
- **Substantial collectivity in small-system collisions with high multiplicity** [Yan-Ollitrault, PRL 112, 082301 (2014).]
  - Current understanding: QGP is not necessary to explain it; Vacuum-QCD effects at the soft-hard boundary, e.g. **multiple-parton interactions (MPI)** [Schlichting, arXiv:1601.01177] with **color reconnection (CR)** [Ortiz-Bencédi-Bello, J.Phys.G 44 (2017)]
  - **Jet structure** may be sensitive to the soft-hard interplay [Z.V. R.V, G.G.B, Adv.HEP 2019, 6731362 (2019)]
- KNO scaling: the multiplicity distribution scales with $\sqrt{s}$ [Koba-Nielsen-Olesen, NPB 40, 317 (1972); Polyakov, Sov.Phys.JETP 32, 296 (1971)]
  - The KNO scaling breaks down at high $\sqrt{s}$
  - Reason of violation not fully understood. KNO may be violated by the presence of multiple-parton interactions or overlapping color strings [Walker PRD 69, 034007 (2004); Abramovsky et al., arXiv:0706.3358]
- **Is KNO-scaling valid within a single jet?**
  - **Origin of scaling?** How is it affected by MPI and CR?
  - Flavor dependence: Initial pQCD process or parton shower?





KNO within jet: multiplicity scaling with p_T^{jet}





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- Multiplicity (dominated by the jet multiplicity) vs. jet momentum p_T^{jet}
- Parametrized with a NBD $$P_N = \frac{\Gamma(Nk+a)}{\Gamma(a)\Gamma(Nk+1)} p^{Nk}(1-p)^a$$
- Distributions at all p_T^{jet} fit well on a single NBD curve
- **KNO-like scaling observed within a jet**
  - In the following we quantify how well it is fulfilled

Multiplicity vs. p_T^{jet}: moments

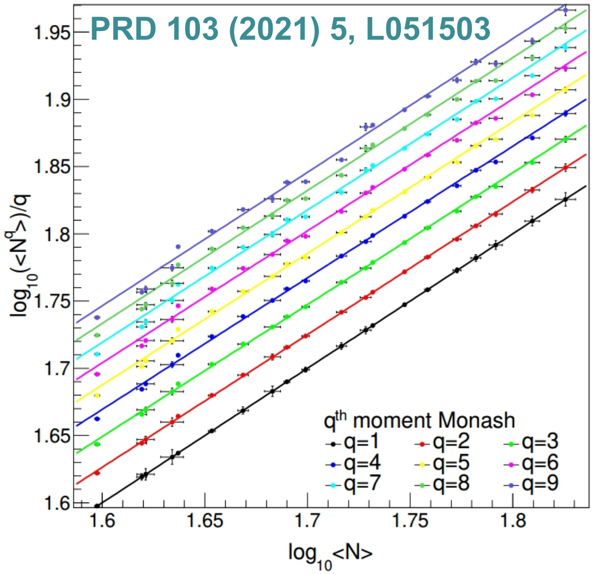
- q^{th} statistical moment
  - insensitive to fluctuations
  - no need for parametrization

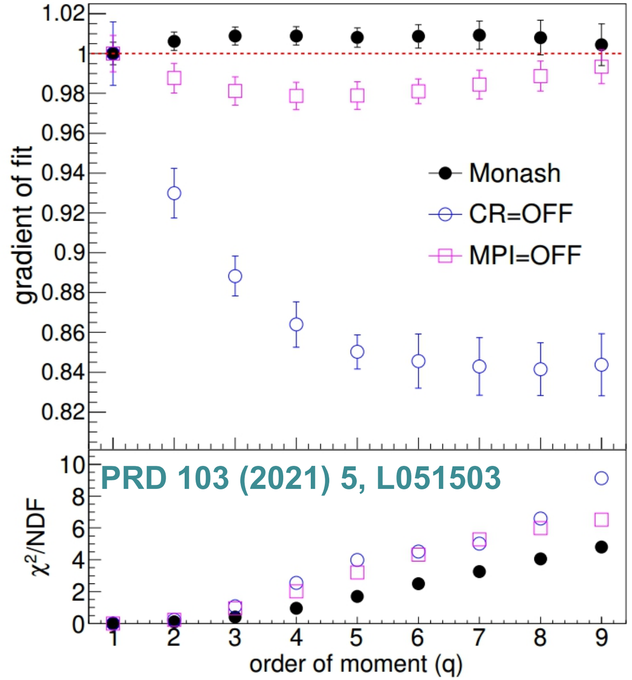
$$\langle N^q \rangle = \sum_{N=1}^{\infty} P_N N^q$$

- Scaling $\left\langle N^q(p_T^{jet}) \right\rangle = \lambda^q(p_T^{jet}) \left\langle N^q(p_0) \right\rangle \qquad \lambda(p_0) = 1$

$$\log\langle N^q \rangle / q \approx \log\langle N \rangle$$

=> scaling is fulfilled in the whole p_T^{jet} range

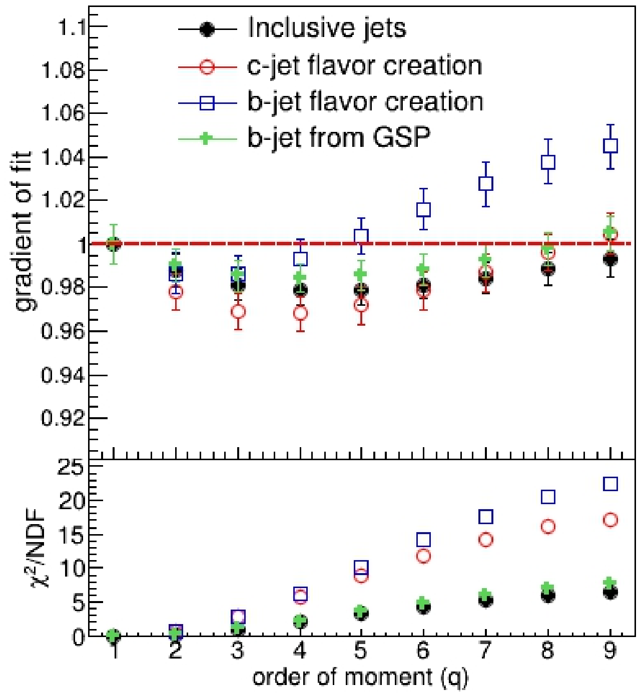


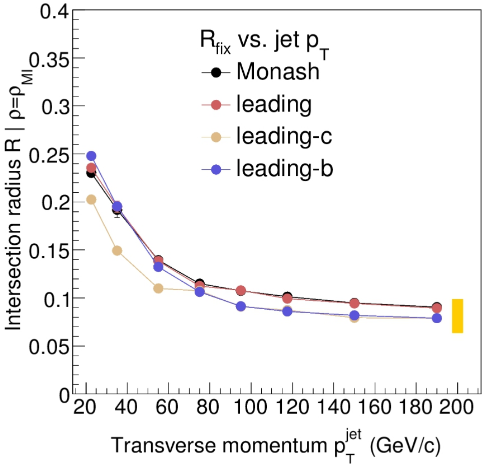


- Origin of scaling (PYTHIA)
  - Physical case (Monash): All 9 moments are consistent with unity, slope within ~1%
  - No CR: Scaling is broken by ~15%
  - No MPI (also no CR): Scaling fulfilled to ~2%.

Heavy-flavor

- HF created via hard pQCD processes
  LO flavor creation <=> **NLO** gluon splitting + flavor excitation
  - These contributions are of similar magnitudes
    [Cao et al., Phys.Rev.C 93 (2016) 2, 024912]
- Jet production depends on quark flavor:
  - Mass-dependence: harder fragmentation (dead-cone)
  - Color-dependence: HF initiated by quark jets only
- Comparison of scaling LO and NLO:
  - sensitivity to its origin (hard QCD vs. jet development)





Z.V.,R.V, G.G.B., Universe 5 (2019) 5, 132

- All slopes are around unity within 5%
  - Flavor creation (LO): mass-dependent deviation from inclusive jets
  - Gluon splitting (NLO): Follows inclusive (mostly g) jets
- **Scaling driven by initial hard process**

Summary

KNO-like scaling within a jet (scaling of multiplicities with jet momentum)

Vértesi, Gémes, Barnaföldi, Phys.Rev.D 103 (2021) 5, L051503 [arXiv:2012.01132]

- Multiplicity distributions are NBD and can be collapsed into a single distribution
- This scaling holds without MPI but breaks down without CR
- **KNO scaling is likely violated by complex QCD processes outside the jet development, such as single and double-parton scatterings or softer MPI**
- This statement holds as long as the multiplicities are described. Testing for this scaling behavior can be an important element in model development

KNO-like scaling in heavy-flavor jets

- LO flavor creation: quark-mass dependent, imperfect scaling
- NLO gluon splitting: follows (gluon-dominated) light-jet pattern
- **Jet scaling driven by the initial hard parton-production process**

See also: Scaling of radial jet-momentum profiles with multiplicity

Varga, Vértesi, Barnaföldi, Adv. High Energy Phys. 2019 (2019), 6731362 [arXiv:1805.03101]
Gémes, Vértesi, Papp, Barnaföldi, in Gribov-90 Memorial Volume: (2021) [arXiv:2008.08500]