Scaling properties of light and heavy-flavor jets in high-energy pp collisions

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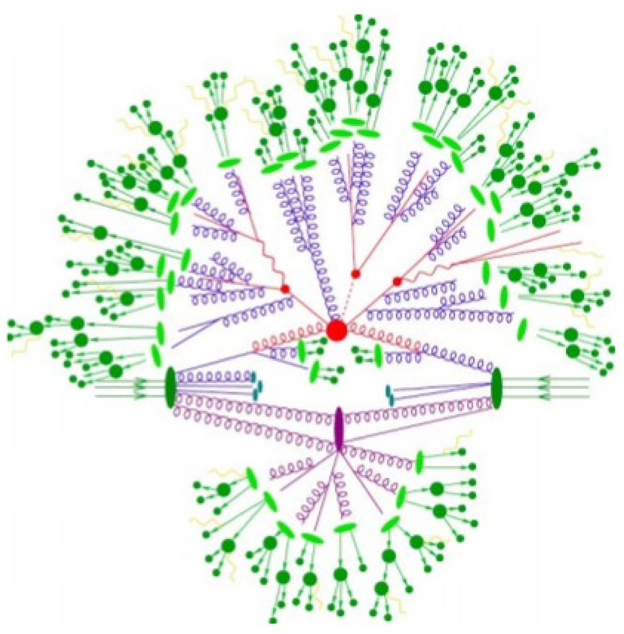
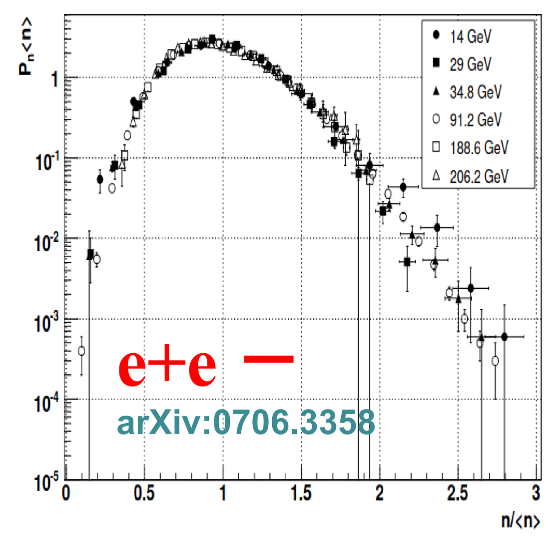
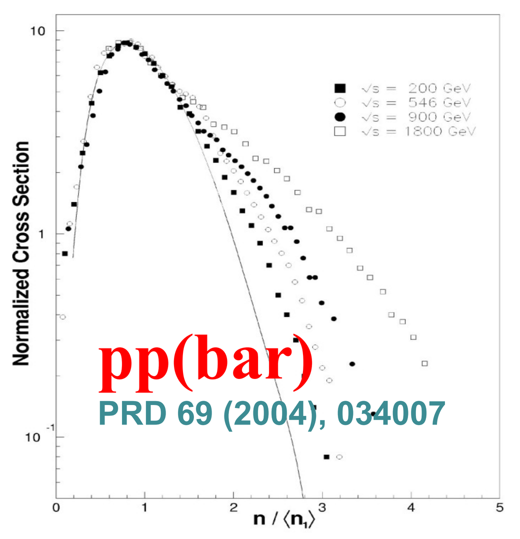
Background



- **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)]



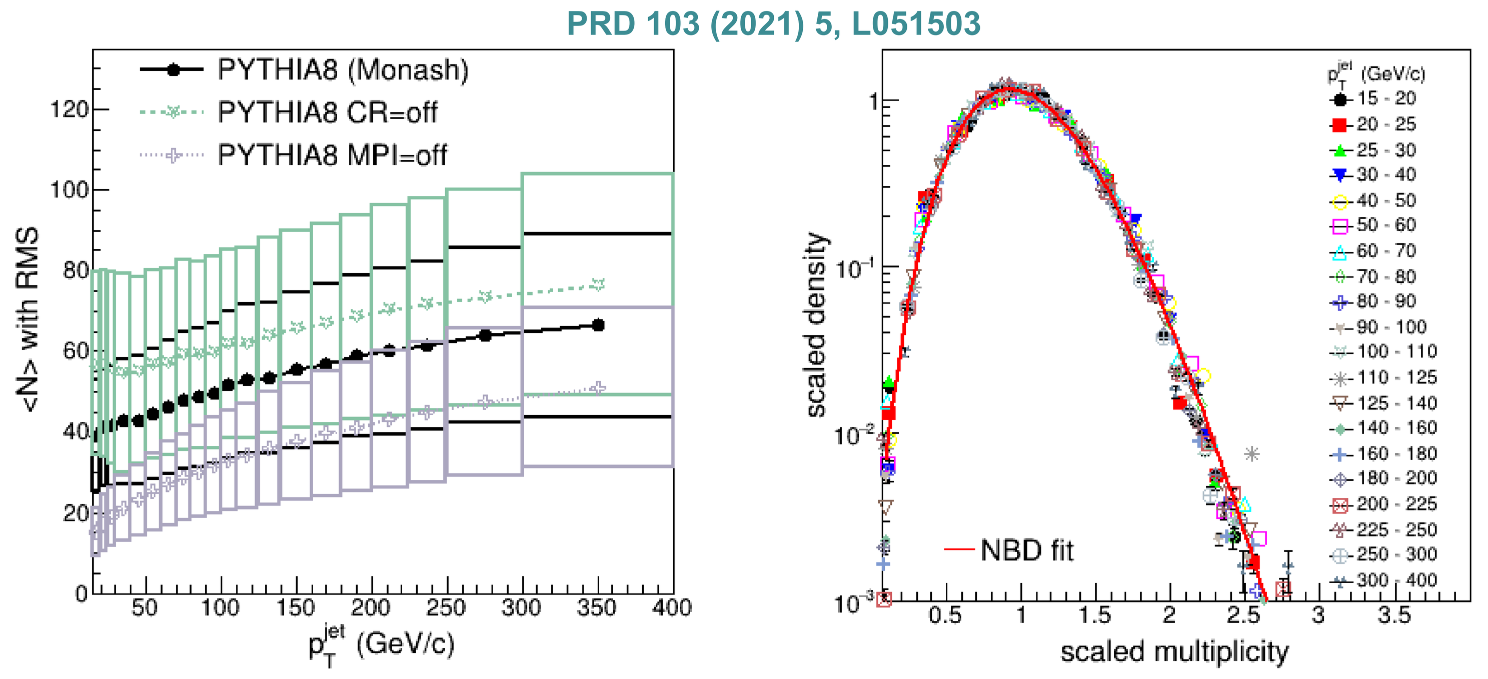
- **Koba-Nielsen-Olesen (KNO) scaling**: the multiplicity distribution scales with $\sqrt{s}$ [Koba-Nielsen-Olesen, NPB 40, 317 (1972); Polyakov, Sov.Phys.JETP 32, 296 (1971)]
  - The KNO scaling breaks down at high $\sqrt{s}$
  - Reason of violation not fully understood. KNO may be violated by the presence of multiple-parton interactions or overlapping color strings [Walker PRD 69, 034007 (2004); Abramovsky et al., arXiv:0706.3358]



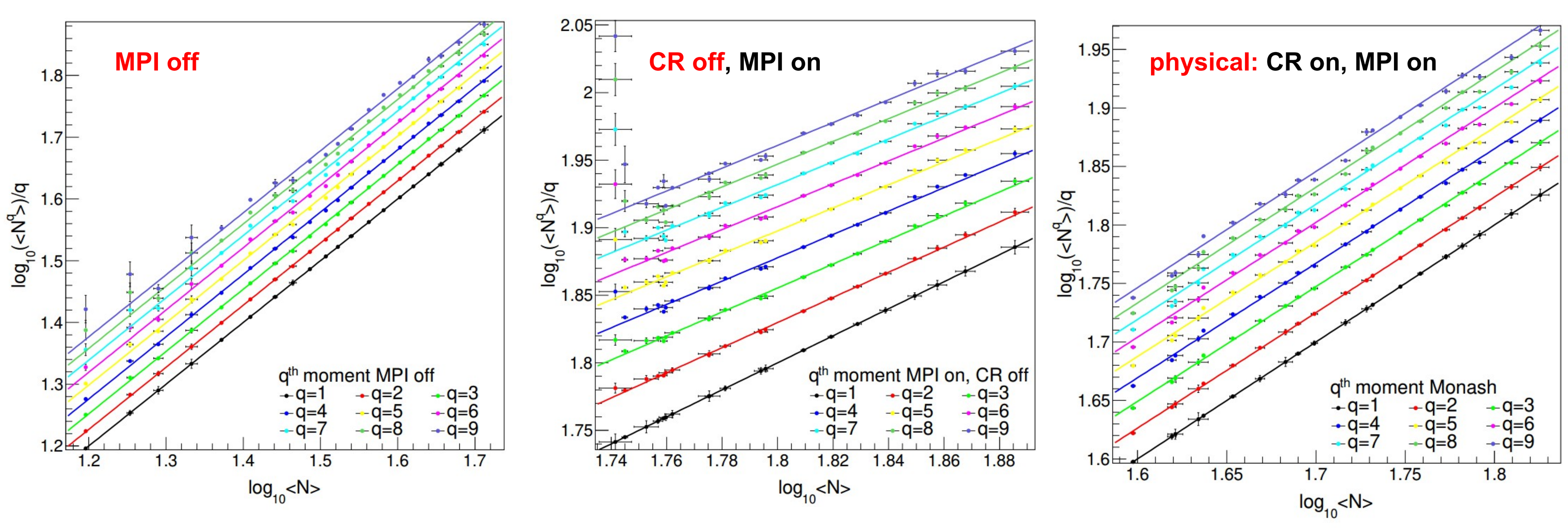
- **Is KNO-scaling valid within a single jet?**
  - **Origin of scaling?** How is it affected by MPI and CR?
  - **Flavor dependence:** Initial pQCD process or parton shower?

KNO scaling within a jet

PRD 103 (2021) 5, L051503



- **KNO-scaling is present within a jet**
  - PYTHIA 8 simulations with the Monash tune: Multiplicity (dominated by the jet multiplicity) vs. jet momentum p_T^{jet}
  - Parametrized with a Negative Binomial Distribution $$P_N = \frac{\Gamma(Nk+a)}{\Gamma(a)\Gamma(Nk+1)} p^{Nk}(1-p)^a$$
  - Distributions at all p_T^{jet} fit well on a single NBD curve
- **Quantify the scaling:** q^{th} statistical moment $$\langle N^q \rangle = \sum_{N=1}^{\infty} P_N N^q$$
  - insensitive to fluctuations
  - no need for parametrization
  - Scaling <=> $\langle N^q(p_T^{jet}) \rangle = \lambda^q(p_T^{jet}) \langle N^q(p_0) \rangle \quad \lambda(p_0) = 1$
  - $\log\langle N^q \rangle / q \approx \log\langle N \rangle$



Origin of scaling: Role of CR and MPI

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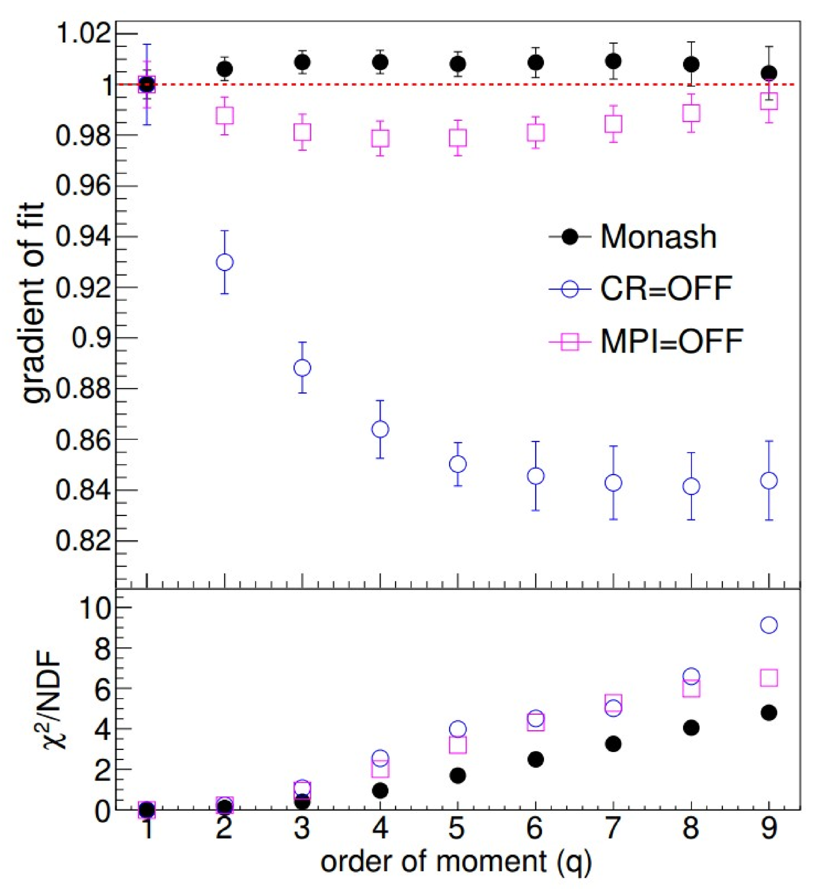
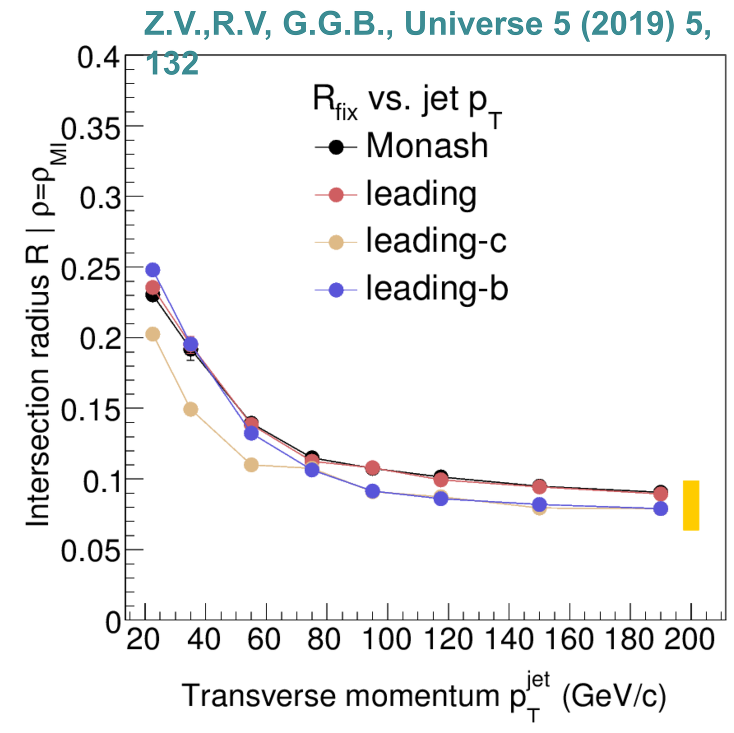


- **Physical case** (PYTHIA Monash): Moments up to 9 are consistent with unity, slope within ~1%
  - *Note:* scaling holds for different tunes & nPDFs (Monash, 4C, Monash*) and also for different jet algorithms (anti-k_T, C/A and k_T)
- **No CR**: Scaling is broken by ~15%
  - (non-physical scenario)
- **No MPI**: Scaling is fulfilled to ~2%. (also no CR by construction)
- All fits are statistically good (χ^2/NDF<8, ~proportional to the order of moment)

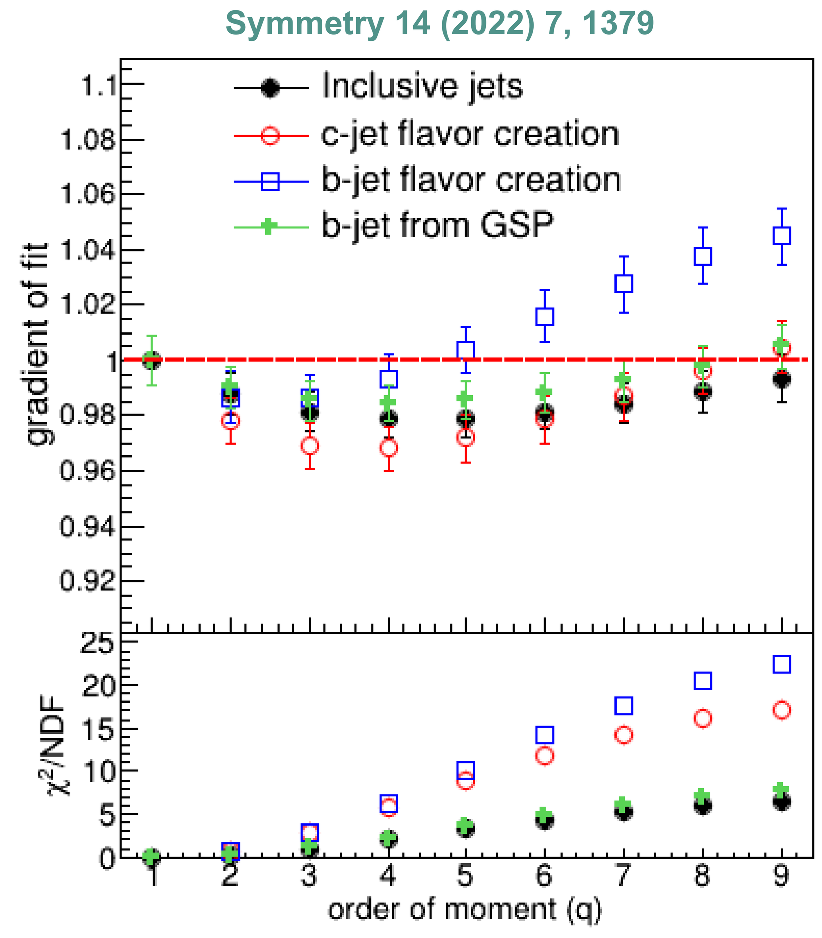
Origin of scaling: Heavy-flavor jets

- HF created via hard pQCD processes
  - **1) LO** flavor creation
  - **2) 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



Symmetry 14 (2022) 7, 1379



- All slopes around unity within 5%
- **LO** flavor-creation
  - Inferior quality fits (χ^2/ndf up to 22)
  - Deviation from inclusive jets, depending on the mass
- **NLO** gluon splitting
  - Follows inclusive jets (mostly gluon jets)
- **Scaling driven by the initial hard process**

Conclusion

KNO-like scaling within a jet: scaling of multiplicities with jet momentum
Phys.Rev.D 103 (2021) 5, L051503 [arXiv:2012.01132]

- Multiplicity distributions are NBD, 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
Symmetry 14 (2022) 7, 1379 [arXiv:2206.07544]

- 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**

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