Unraveling the Final-State Interactions and Correlations Inside High-Multiplicity Jets at LHC

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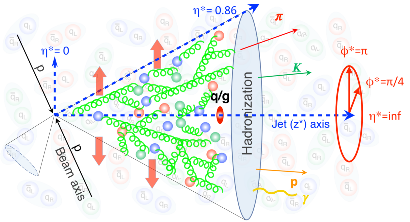
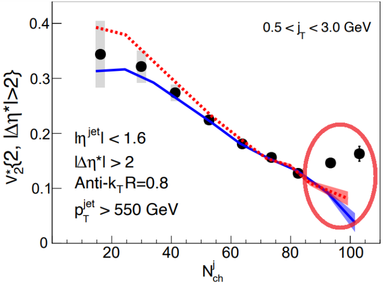
Non-Trivial Two-Particle Correlations in High-Multiplicity Jets





- A jet reference coordinate
- Redefine the constituents' momentum as: $\vec{p^*} = (j_T, \eta^*, \phi^*)$.
- For jets with $\langle N^j_{ch} \rangle \sim 100$, a near-side enhancement is observed, as seen in v_2 of two-particle correlations, which is absent in PYTHIA8 or SHERPA.

A. Hayrapetyan et al. [CMS], arXiv:2312.17103.

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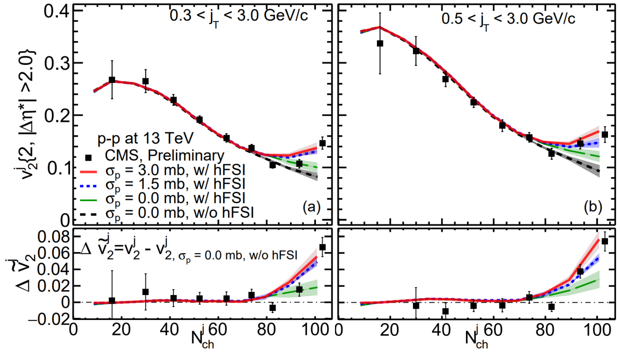
A Recent Work Suggests Importance of Final-State Interactions



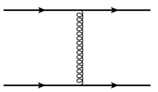
W. Zhao, Z. W. Lin and X. N. Wang, arXiv:2401.13137.

- Final-state partonic and hadronic interactions
- Partonic rescatterings are crucial for reproducing such behavior, while hadronic rescatterings alone are insufficient.

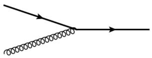
Our Work: Systematic Study of Various Sources of FS Correlations

1. Examine effects of parton shower components in PYTHIA:
   - Multiple Parton Interactions (MPI)
   - Initial-State Radiation (ISR)
   - Final-State Radiation (FSR)

   After parton shower, we apply the following processes:
2. Build a relatively consistent spacetime picture.
3. 2→2 partonic rescattering process

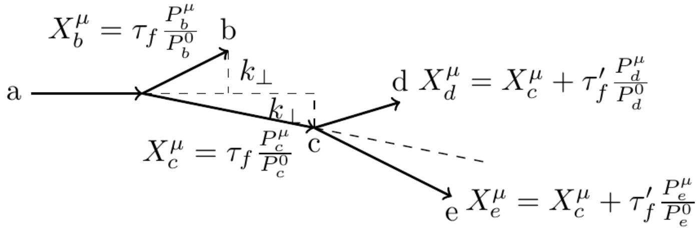


4. 2→1 partonic fusion process



5. Trace color flow and keep color neutral
6. Hadronic rescattering process

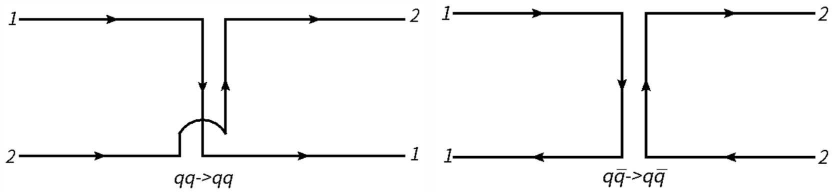
Build a Relatively Consistent Spacetime Picture



- A proper spacetime evolution is key to uncovering the correlations.
- For a 1→2 parton splitting, estimate the formation time $\tau_f = \frac{2E}{Q^2}$ based on the virtuality.
- Test the impact of parton's vertex of MPI:
  1. same as hard process
  2. finite $\vec{x}_\perp$ displacement

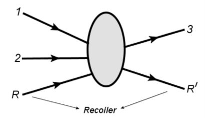
2→2 Partonic Rescattering Process

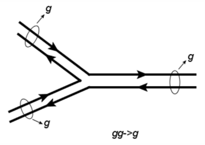
- Assume t-channel dominates: $\frac{d\sigma}{dt} \propto \frac{\alpha_s^2}{(t-\Lambda^2)^2}$.
- Apply a geometrical collision scheme: scattering occurs if $d_{ij} < \sqrt{\sigma/\pi}$.
- Exchange color in each collision in the large-N_c limit.

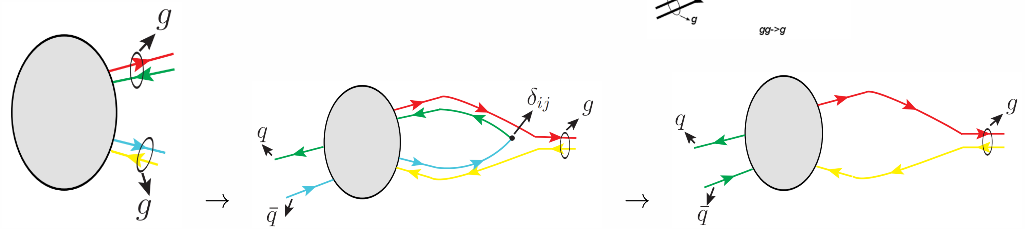


2→1 Partonic Fusion Process

- Keep momentum conservation.
- Fusion happens if $(P_1 + P_2)^2 < m^2_{\text{fusion}}$ and $d_{ij} < d_{\text{fusion}}$.
- Trace color flow to ensure neutrality.

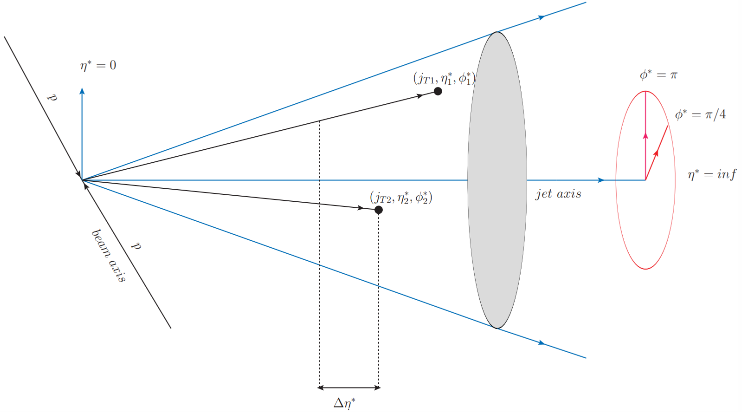






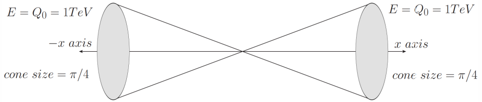
Hadronization, Hadronic Rescattering and v_2

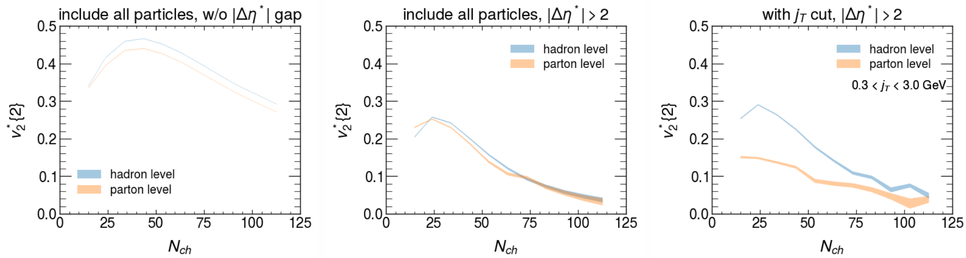
- PYTHIA8 assigns spacetime production vertices to all primary hadrons from string breakups and includes a hadronic rescattering framework as well.
- Calculate v_2 in ϕ^* with the Q-cumulant method include a $|\Delta\eta^*|$ gap.



1. α_s (0.35)
2. Λ (0.5GeV)
3. m_{fusion} (0.5GeV)
4. d_{fusion} (0.5fm)

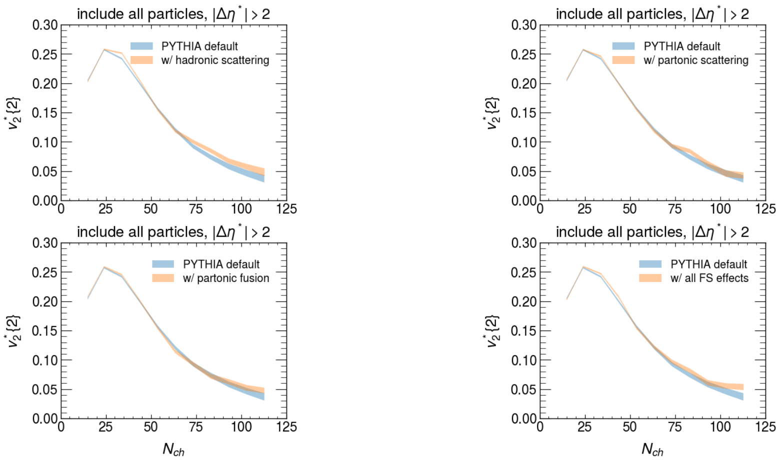
Case 1: A $q\bar{q}$−initiated Shower, No Underlying Event





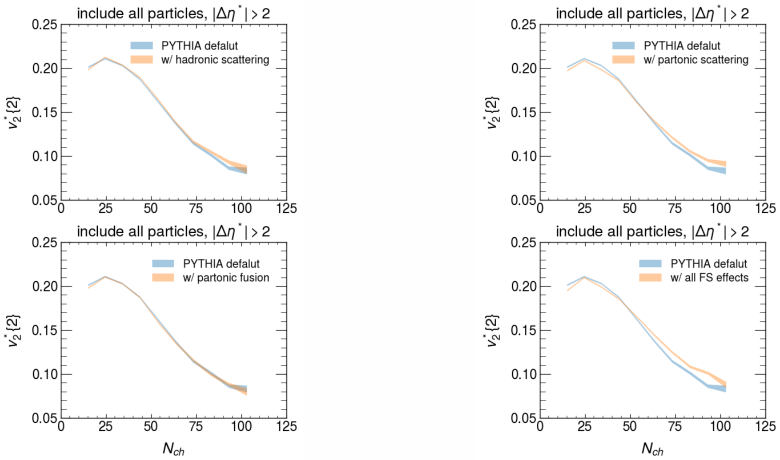
- Hadronization mainly contributes to short-range correlations and has a slight impact on long-range correlations.
- v_2 at partonic and hadronic levels are similar for long-range correlation but changes with j_T cuts due to different j_T distributions.

Case 1: A $q\bar{q}-$initiated Shower, No Underlying Event



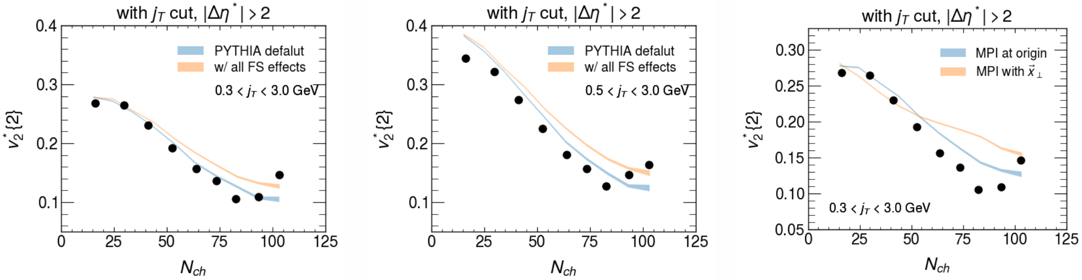
- Hadronic rescattering increase v_2 at high-multiplicity, and partonic interactions have a smaller but still notable influence.

Case 2: Jets in p-p Collision With Underlying Event



- Partonic rescattering appears to have a larger effect than hadronic rescattering, while the impact of partonic fusion is negligible in this complex environment.

Case 2: Jets in p-p Collision With Underlying Event



- Including all final-state interactions increases v_2, but the very strong enhancement of v2 at high multiplicity observed in CMS data is still not reproduced.
- Introducing a finite transverse displacement in MPI coordinates sharply increases v_2 at high multiplicity due to more collisions at patonic level.

Summary

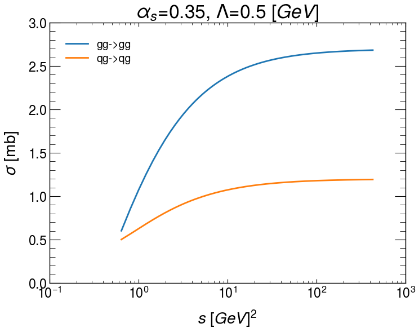
- Spacetime is important for studying correlations inside high-multiplicity jets.
- Partonic rescattering, partonic fusion, and hadronic rescattering all contribute to correlations in high-multiplicity jets, but their relative importance varies based on the underlying event.
- The strength of the correlations changes depending on the j_T of the particles.
- The current setup does not exhibit the v_2 enhancement seen at high multiplicity, as shown in CMS data. We aim to advance our study with a focus on:
  - To Refine the spacetime picture
  - To increase the strength of scattering
  - To optimize fusion strategies to enhance fusion probability

Back Up

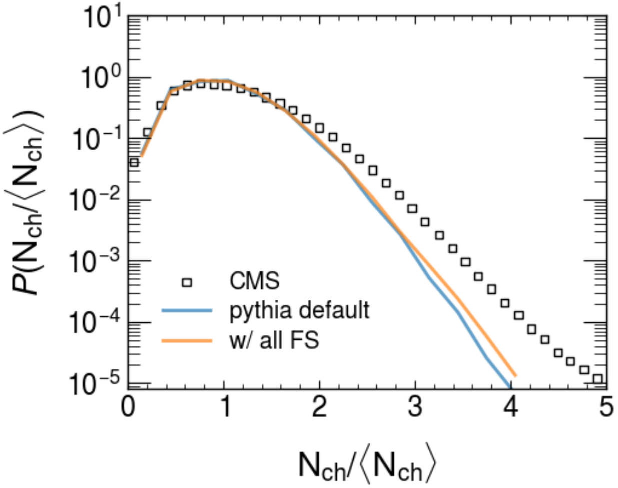
Model Parameters

The key model parameters are:

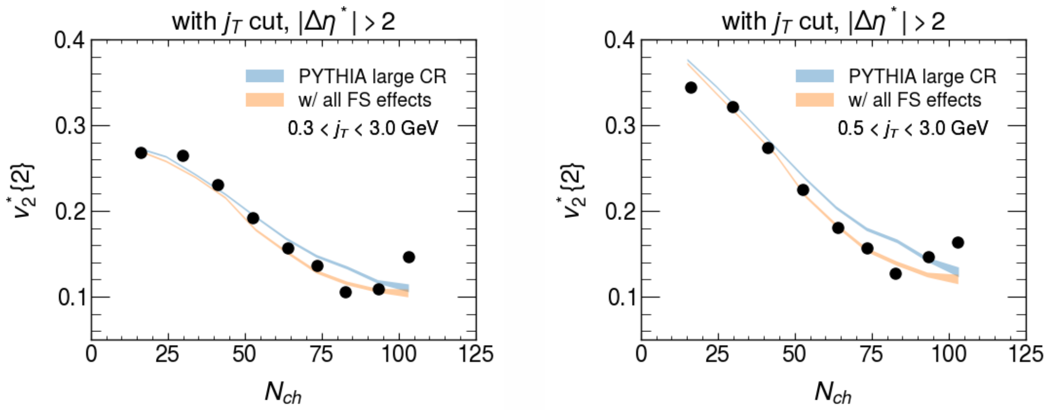
1. α_s (0.35): strong coupling constant for the collision process
2. Λ (0.5GeV): regularization scale for the differential cross section
3. m_{fusion} (0.5GeV): invariant mass boundary for fusion pairs
4. d_{fusion} (0.5fm): distance threshold for fusion to occur



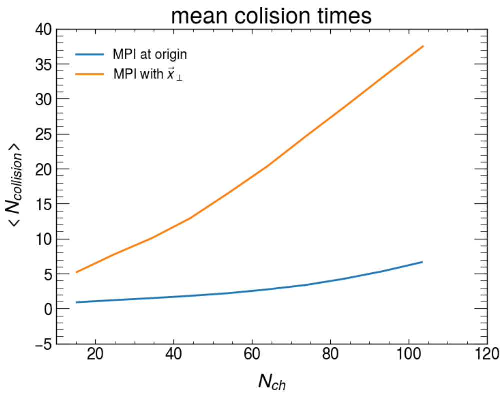
Multiplicity distribution

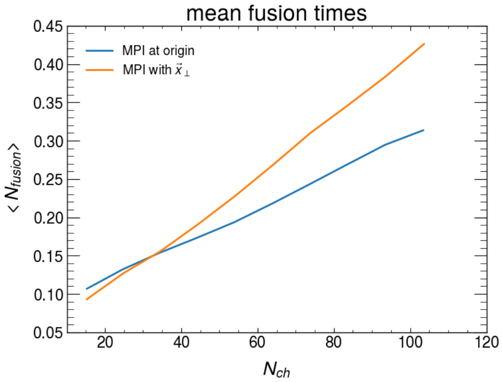


PYTHIA MPI-based Color Reconnection & Larger range

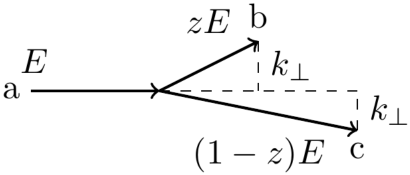


Mean Collision or Fusion Times





Formation Time



- For FSR, "a" get the virtuality:

$$Q^2 = \frac{k_T^2}{z(1-z)E}, \quad \tau_f = \frac{2E}{Q^2} = \frac{2z(1-z)E}{k_T^2}$$

- For ISR, "b" get the virtuality:

$$Q^2 = \frac{k_T^2}{(1-z)E}, \quad \tau_f = \frac{2zE}{Q^2} = \frac{2z(1-z)E}{k_T^2}$$

Large N_c Limit

- In this picture, the Fierz identity:

$$(T^a_{ij})(T^b_{kl}) = \frac{1}{2}(\delta_{il}\delta_{kj} - \frac{1}{N_c}\delta_{ij}\delta_{kl})$$

will be considered as:

$$(T^a_{ij})(T^b_{kl}) = \frac{1}{2}\delta_{il}\delta_{kj}$$

- The 3-gluon vertex:

$$gf^{abc}T^a_{ij}T^b_{kl}T^c_{mn}$$

will be considered as:

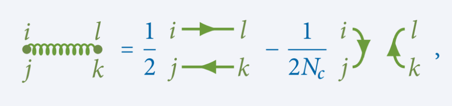
$$gf^{abc}T^a_{ij}T^b_{kl}T^c_{mn} = -\frac{i}{4}g(\delta_{il}\delta_{jm}\delta_{nk} - \delta_{in}\delta_{jk}\delta_{lm})$$

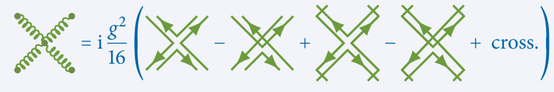
Large N_c Limit

- The 4-gluon vertex will be:

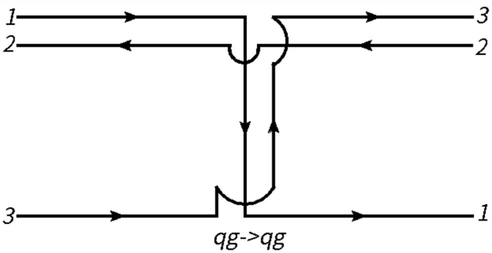
$$-ig^2 f^{abx} f^{xcd} T^a_{ij} T^b_{kl} T^c_{mn} T^d_{op} = i\frac{g^2}{16}(\delta_{il}\delta_{jo}\delta_{kn}\delta_{mp} - \delta_{in}\delta_{jk}\delta_{lo}\delta_{mp} - \delta_{il}\delta_{jm}\delta_{kp}\delta_{on} + \delta_{ip}\delta_{jk}\delta_{lm}\delta_{on})$$

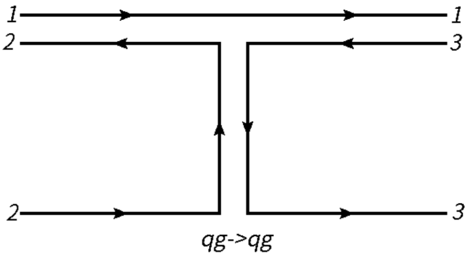
- Show with image



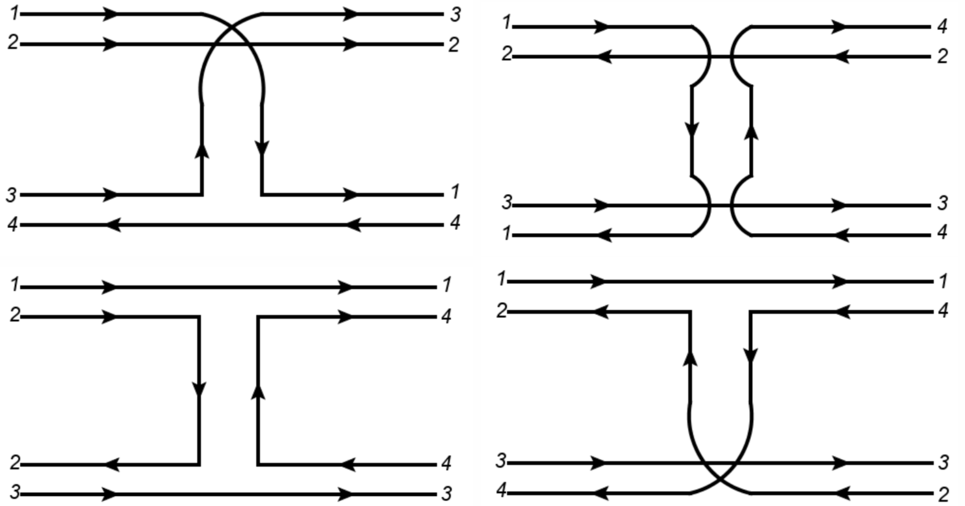


Color Information for qg→qg Scattering

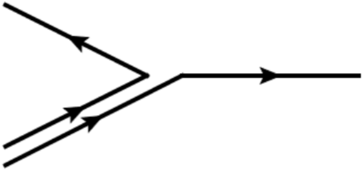




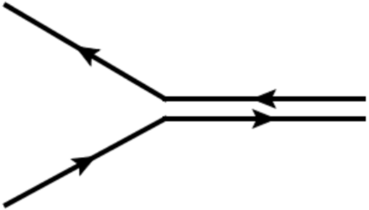
Color Information for gg→gg Scattering



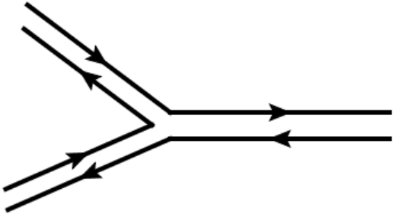
Color Information for Fusion



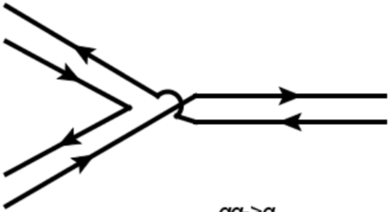
qg->g



q$\bar{q}$->g



gg->g



gg->g