ALICE results on long- and short-range correlations in high multiplicity pp collisions

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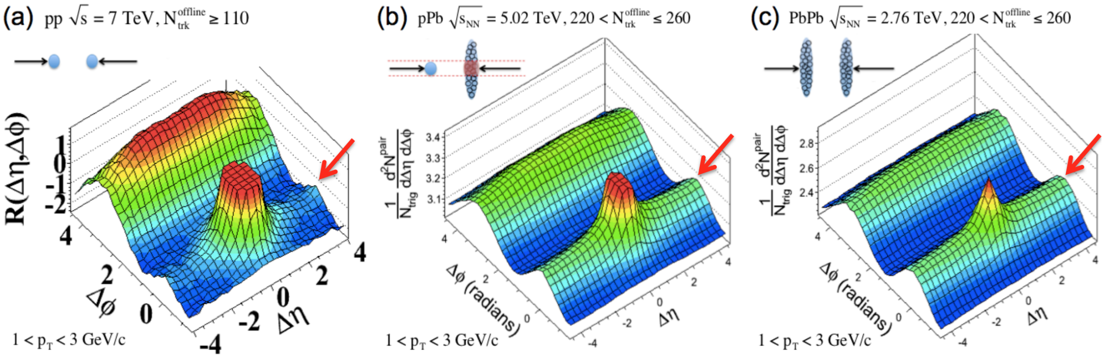
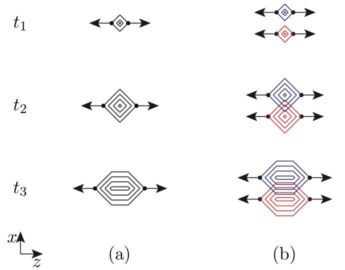


JHEP09(2010)091

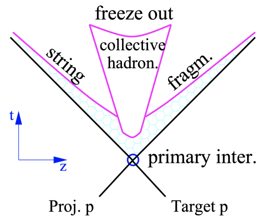
- 2-particle correlations measured as a function of $\Delta\eta$ and $\Delta\varphi$
- Structure that is long range in $\Delta\eta$ and generally shows two bumps in $\Delta\varphi \rightarrow$ "double-ridge"
- "Double-ridge" comes from dominant $\cos(2\Delta\varphi)$ contribution due to the mostly elliptic shape of the collision overlap zone
- Long-range correlations emerge from early times. In large systems, this is due to medium response to the initial transverse geometry (well described by hydrodynamics)

- **Initial-state effects:** CGC + fluctuations
  K. Dusling *et al.* PRD 87 5 (2013) 05150, A. Bzdak *et al.* PRC 87 6 (2013) 064906
- **Final-state effects:** Hydrodynamics
  R. D. Weller *et al.* PLB 774 (2017) 351–356, W. Zhao *et al.* PLB 780 (2018) 495–500
- **Hybrid models:** How quantitatively they interplay? Relative contributions?
  M. Greif *et al.* PRD 96 9 (2017) 091504, H. Mantysaari *et al.* PLB 772 (2017) 681–686



Alternatively,

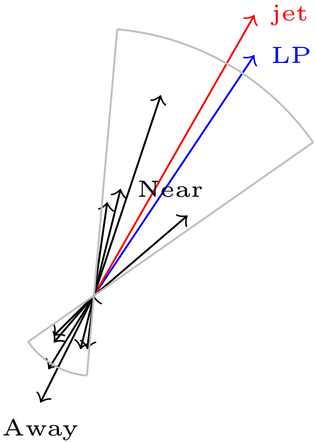
- **PYTHIA 8 String Shoving**: Pushing the strings resulting in transverse pressure
  C. Bierlich *et al.* PLB 779 (2018) 58-63
- **EPOS LHC**: Parameterized hydrodynamic evolution in core
  T. Pierog *et al.* PRC 92 (2015) 034906



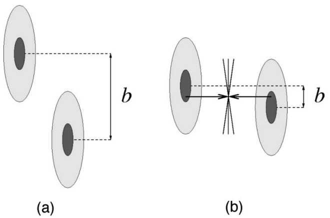
Experimental challenges

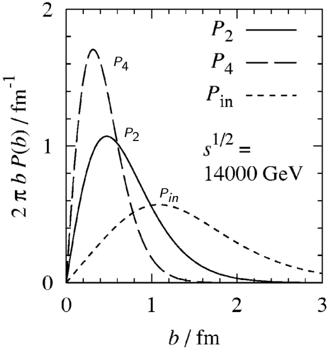
- Constraining the impact parameter of pp collisions to further understand origin of correlations in pp collisions by "event-scale" selection
  - Event scale is set to the momentum transfer in the hard-parton scattering

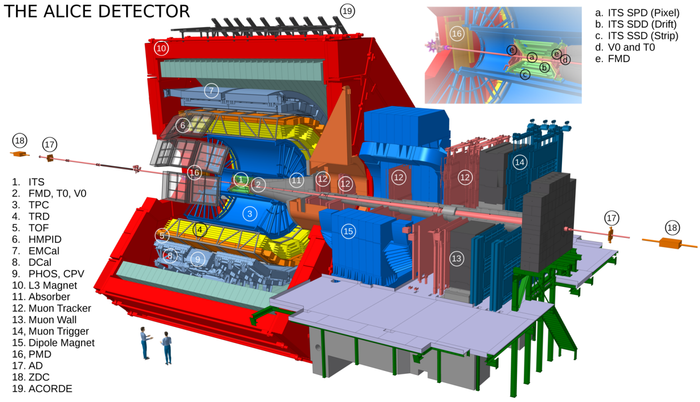
→ Measurements of ridge yield (ALICE JHEP05(2021)290) and v_n (Preliminary) in events tagged with jets or leading particle

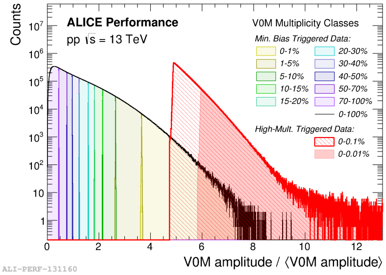


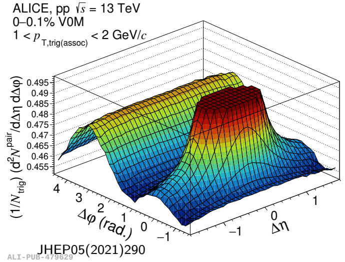
M. Strikman *et al.*
PRD 69 (2004) 114010







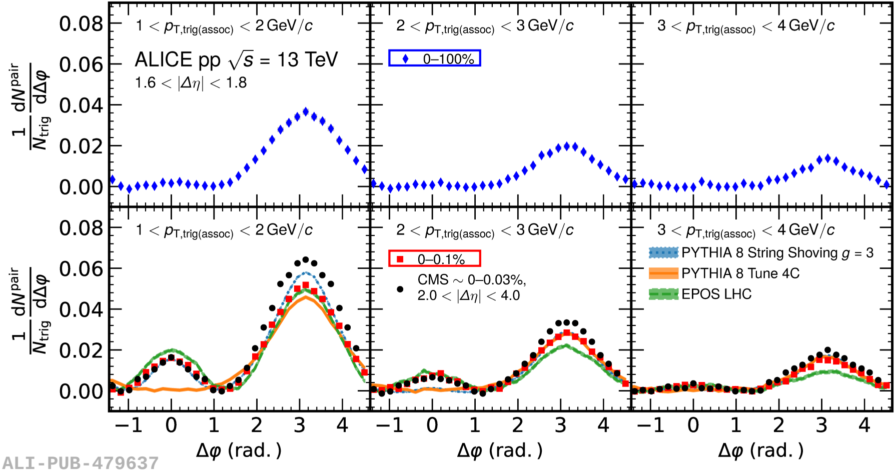




- V0: Minimum bias and high multiplicity triggering
- ITS: vertexing and reconstruction
- TPC: particle tracking (charged particles) at $|\eta| < 0.9$

High-multiplicity events: 700M (High-multiplicity trigger)

Long-range $\Delta\varphi$ correlations (TPC-TPC)



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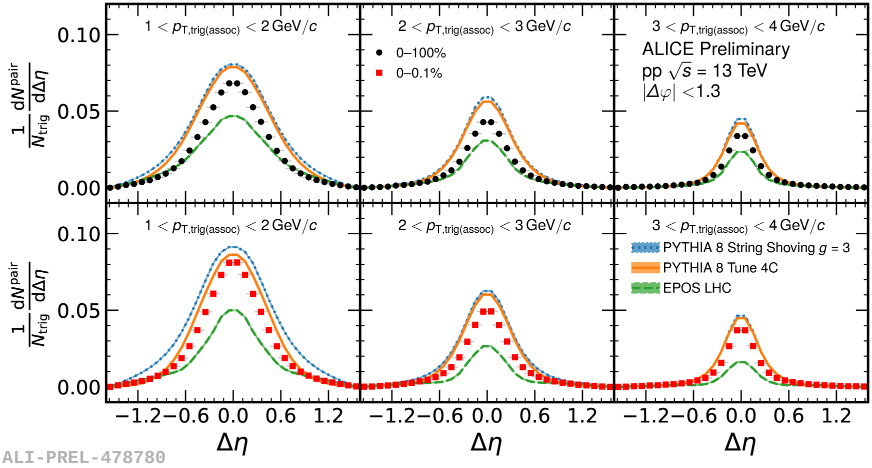
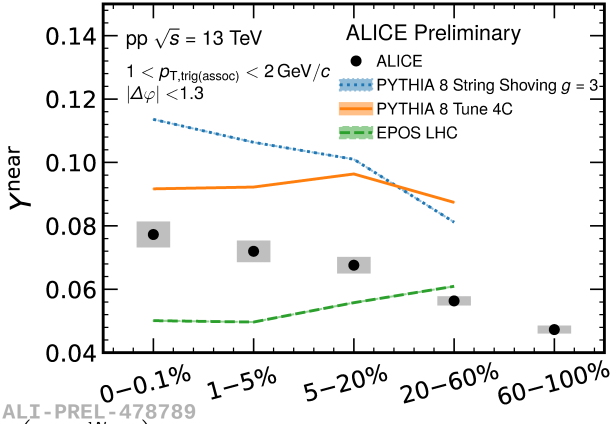
- Large rapidity gap ($1.6 < |\Delta\eta| < 1.8$) to avoid nonflow contribution
- **Clear ridge in high-multiplicity events, while no ridge in minimum bias events**

Near-side jet fragmentation



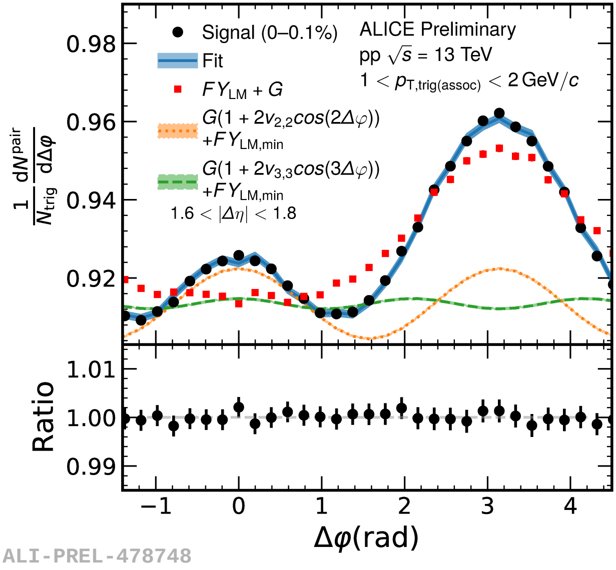
- $$\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta} = \int_{|\Delta\varphi|<1.3}\left(\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi}\right)\frac{1}{\delta_{\Delta\varphi}}\mathrm{d}\Delta\varphi - D_{\mathrm{ZYAM}}$$
- Description of jet fragmentation is compared with models: qualitative agreement of PYTHIA 8 Tune 4C



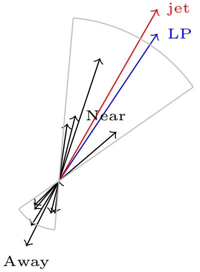
- $Y^{\mathrm{near}} = \int_{|\Delta\eta|<1.6} \mathrm{d}\Delta\eta \left(\frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta} \right)$
- Data and String Shoving show increasing near-side yield with increasing multiplicity, while that is not the case for EPOS LHC and PYTHIA 8 Tune 4C

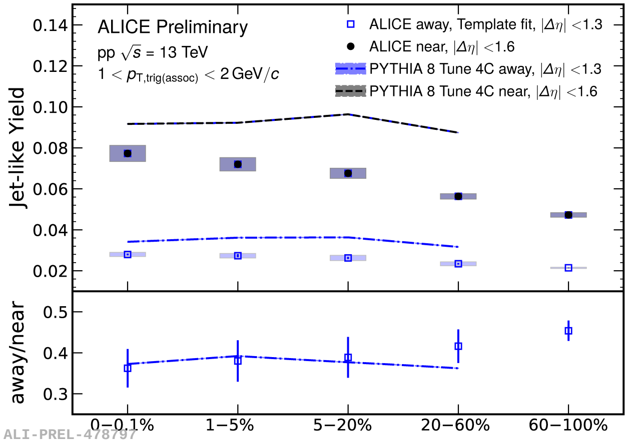
$$Y(\Delta\varphi) = G(1 + 2v_{2,2}\cos(2\Delta\varphi) + 2v_{3,3}\cos(3\Delta\varphi)) + F\,Y_{\mathrm{LM}}(\Delta\varphi)$$

- Subtract the remaining away-side jet contribution in high multiplicity event relative to the low multiplicity term
- F: Ratio of away-side jet fragments in high-multiplicity to low-multiplicity events (60–100%), $F = 1.304 \pm 0.018$
- Assumptions
  - No ridge or flow in the LM-template
  - No away-side jet modifications (quenching) in HM events relative to the LM-template



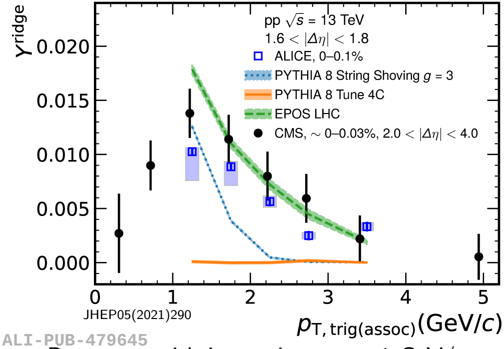
Near-side and away-side jet fragmentation

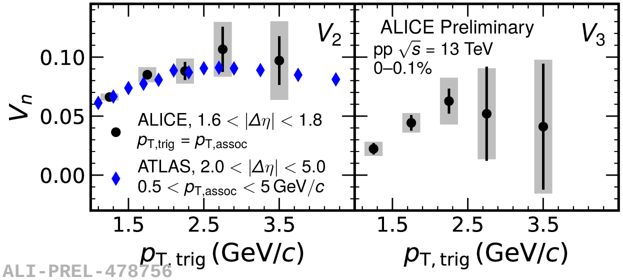




- Away-side jet yield : $Y_{\mathrm{jet}}^{\mathrm{Away}} = {\color{red}F}\, Y_{\mathrm{jet}}^{\mathrm{Away,LM}}$
- Near-side jet yield measured by short-range correlations (see the backup)
- Limited η acceptance as ratio
  PRD 74 (2006) 072002
- **The relative away-side jet contribution, F, has been tested by comparing the ratios from the ALICE and the PYTHIA 8**

Ridge yield and v_n (TPC-TPC): 0–0.1%

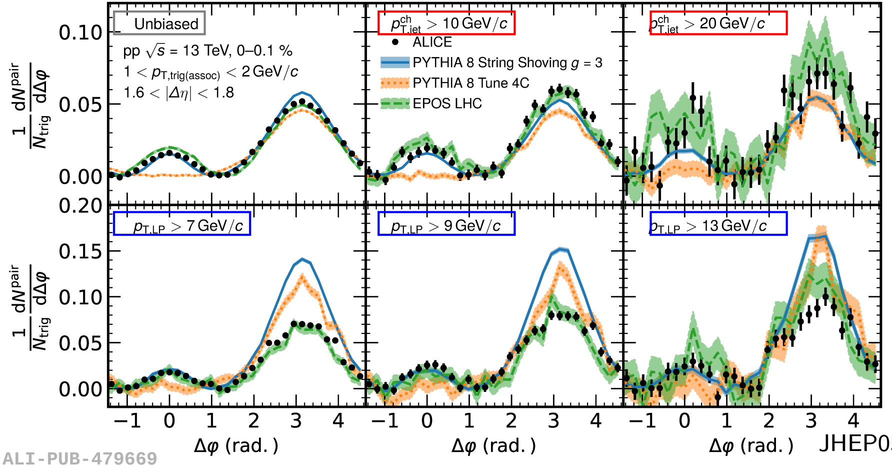




- Decreases with increasing $p_{\mathrm{T}} > 1$ GeV/c
- CMS yield is higher than ALICE mainly due to different multiplicity selection
- **EPOS LHC describes p_{T} dependence, overestimating the yield**
- **String Shoving shows steeper p_{T} dependence, underestimating it**

- Comparable with ATLAS result
- Note that multiplicity class for ATLAS is classified with central particles ($|\eta|$ <2.5, p_{T} >0.4 GeV/c), $N_{\text{Mult}}^{\text{ATLAS}} > 60$

Event-scale dependent $\Delta\varphi$ correlations (event tagging)



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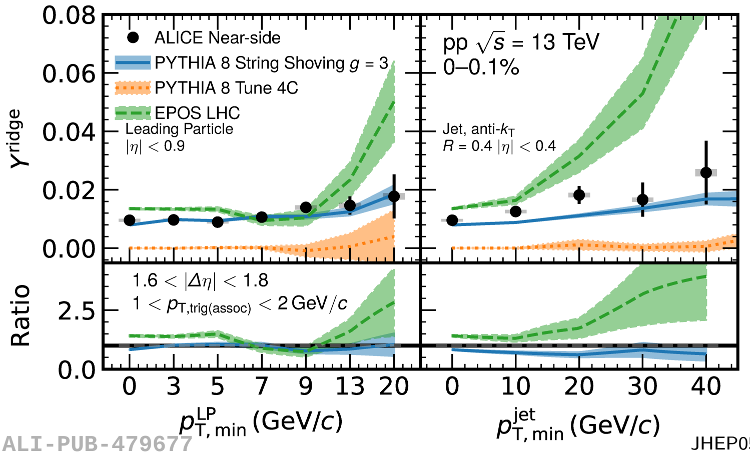
- Event-scale selection: requirement of the presence of a hard scattering (tagging by minimum p_T of reconstructed jet or leading particle)
- The ridge is still visible with event-scale selection

Event-scale dependent ridge yield



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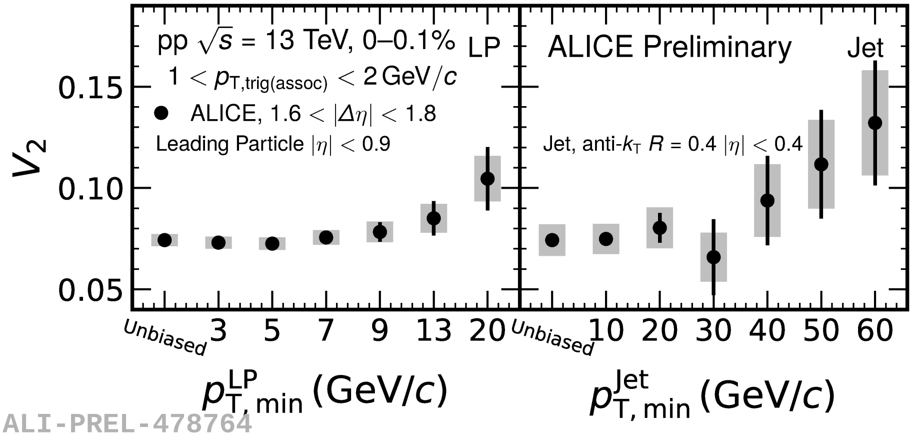
- Increase with increasing $p_{\mathrm{T,min}}^{\mathrm{LP}}$ or $p_{\mathrm{T,min}}^{\mathrm{jet}}$, similar for models, stronger for EPOS LHC
- **EPOS LHC** (**PYTHIA 8 String Shoving**) **overestimates** (**underestimates**) the ridge yield
  - Jet fragmentation (PYTHIA 8 with String Shoving, in contrast, overshoots the jet fragmentation in backup) → **Challenging existing models**

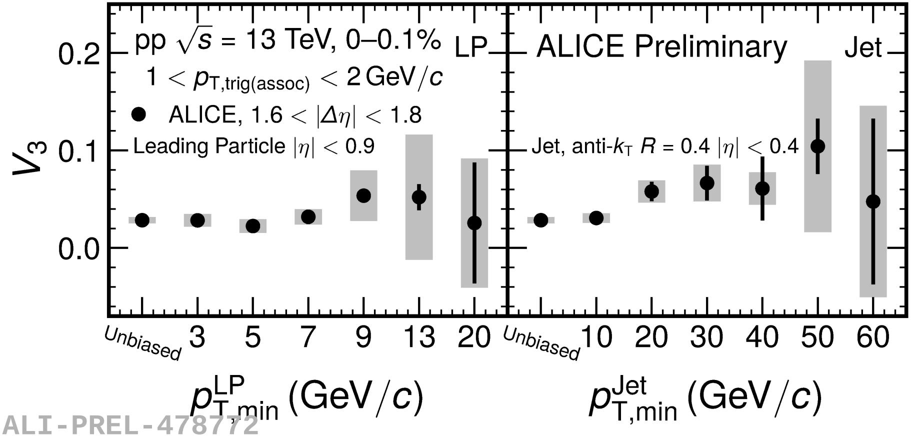


- Weak or no sensitivity to event-scale selection with the uncertainties
- Note that the template does not impose event-scale selection

- Event-scale dependent ridge yields and v_n are studied
  - Increasing trend for the ridge yield with leading particle p_{T} and jet p_{T}, and no significant dependence for v_n
  - Compared to EPOS LHC and PYTHIA 8 String Shoving, leading to further improvement of these models
- Flow extraction with the template fit is tested
  - Relative increase of the jet yield for high multiplicity w.r.t low multiplicity template is properly considered

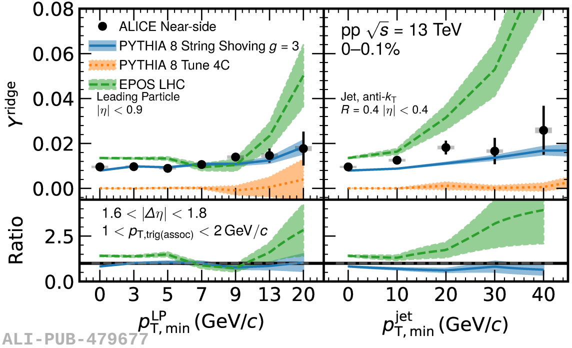
Thank You!

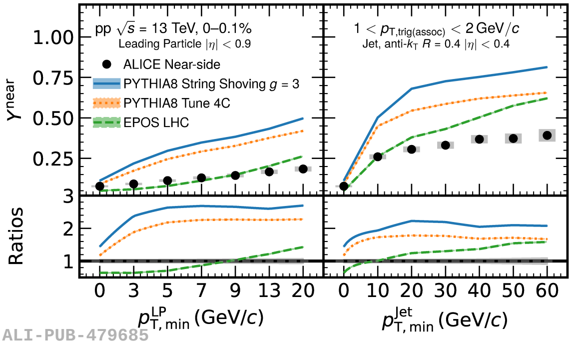
Event-scale dependent v_3



- Weak sensitivity for event-scale dependence
- Note that low-multiplicity events does not impose event-scale bias

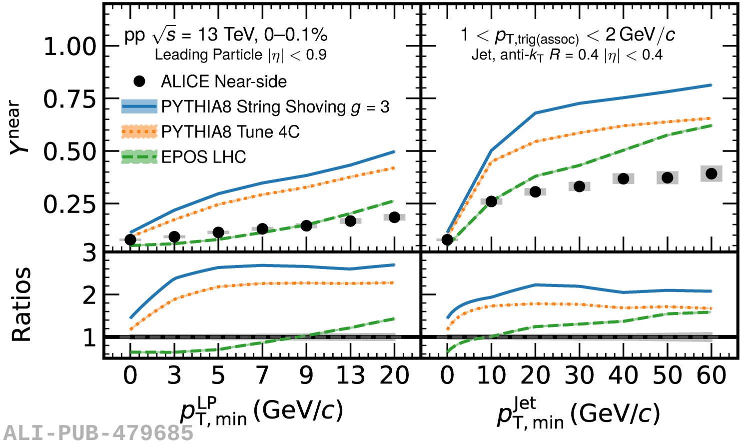
Event-scale dependent ridge yield





- The ridge yield tends to increase with increasing $p_{\mathrm{T,Lead}}$ or $p_{\mathrm{T,Jet}}$
- The increase of the ridge yield is also visible for two models
  - EPOS LHC largely overestimates the ridge yields while PYTHIA with String Shoving underestimates them
  - PYTHIA with String Shoving, in contrast, overshoots the jet fragmentation (in backup)

Event-scale dependent jet yield



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- Is the collective flow measured correctly in small systems?
  - Yes
  - Away-side jets are properly subtracted with the asumption that jets are not modified in high multiplicity events (counter intuitive?)
  - however, precise measurement on jet yields(quenching) will be needed
- How to probe a creation of the QGP in small systems?
  - precise determination of the η/s with larger systems is crucial but how precise?
  - further understanding on initial state before hydrodynamic takes place including sub-nucleon substructure(arXiv:2106.05019 etc)
    - revisit thermal photon production but hard to measure in small systems?
    - heavy quarks would help?