Characterizing system dynamics with short- and long-range correlations in pp, p–Pb, and Pb–Pb collisions at ALICE

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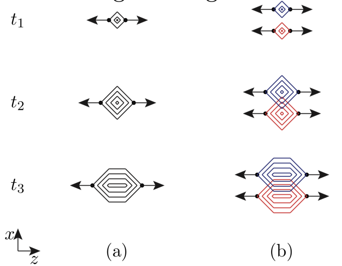
Initial Stages 2021

- **Initial state effects:** CGC + fluctuation
  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

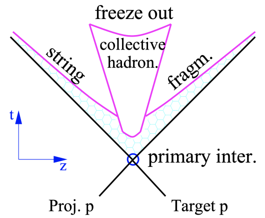
Alternatively,

- **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, 034906

String Shoving



EPOS LHC

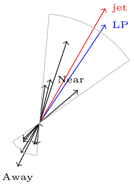


Experimental Challenges, outline

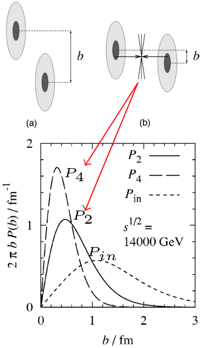
- **Pseudorapidity dependent** v_n observed in Pb–Pb collisions, How about **in small systems**?

- 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
  - **Ridge yield (ALICE, arXiv:2101.03110) and** v_n **(Preliminary) in tagged events with jets or leading particle**

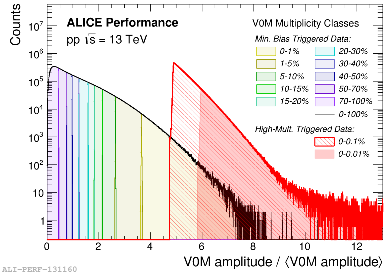
- **Two-particle charge independent** p_{T} **correlations** to access shear viscosity **in small systems**

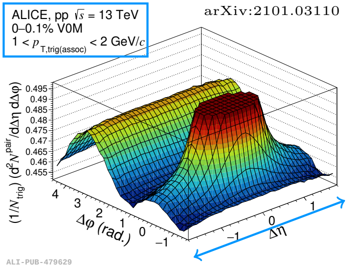


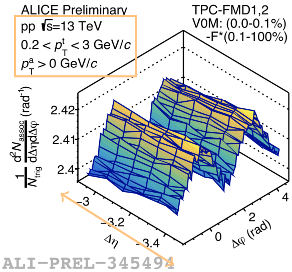
M. Strikman *et. al*
Phys. Rev. D 69, 114010 (2004)



Correlation measurements in ALICE







High-multiplicity events : 700 M

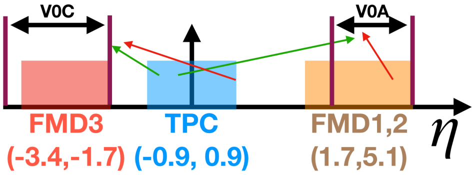
TPC-TPC

- Pro: Good p_T resolution
- Con: Small acceptance($|\Delta\eta| < 1.8$)
- number and p_T correlations

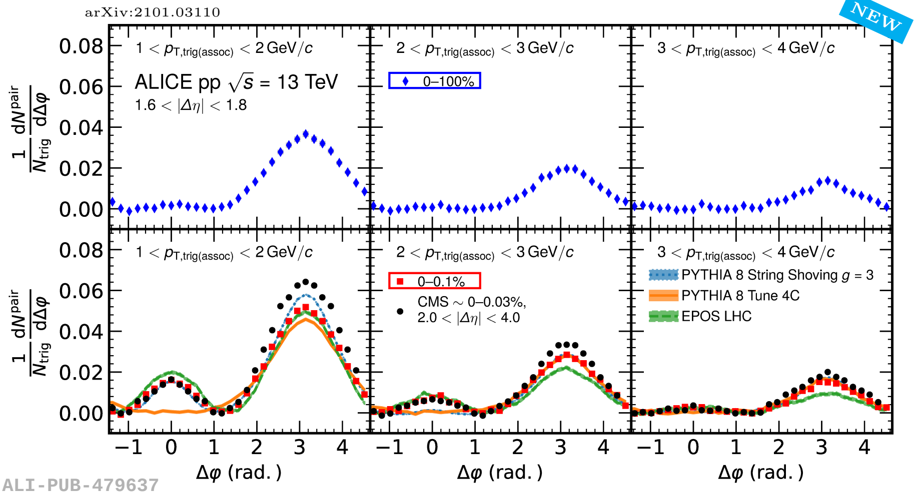
TPC (FMD)-FMD

- Pro: $\Delta\eta$ up to ~ 8
- Con: Large secondary contamination

V0M = V0A + V0C

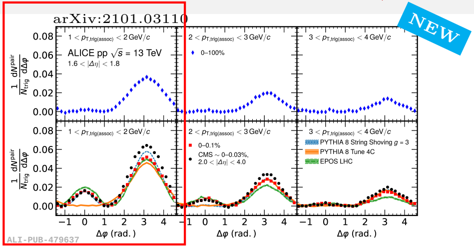


Long-range $\Delta\varphi$ correlations (TPC-TPC)



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

Long-range $\Delta\varphi$ correlations (TPC-TPC) and flow extraction

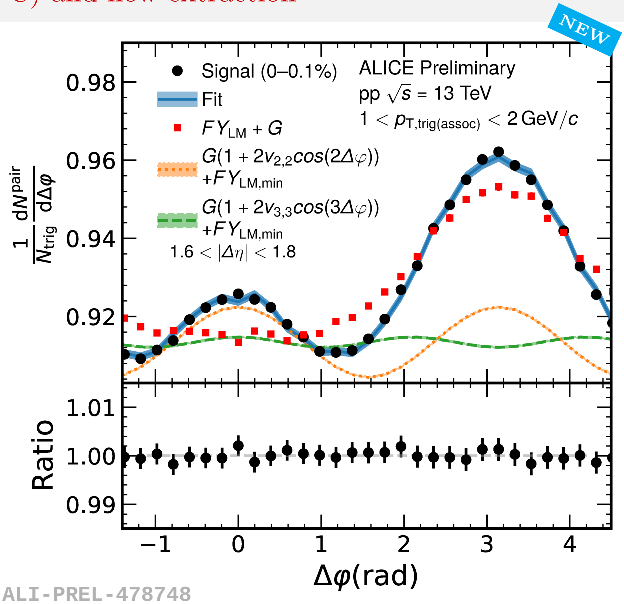


- Subtraction of low-multiplicity events and template fit to extract v_n

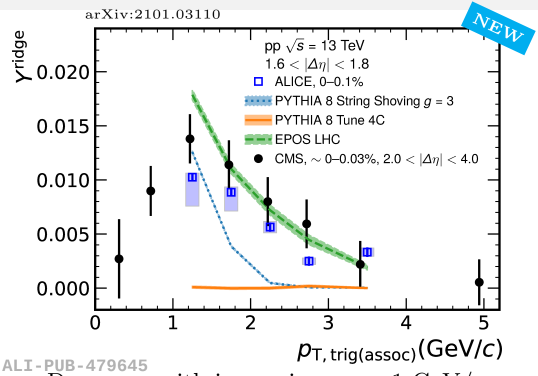
$$Y(\Delta\varphi) = G(1 + 2v_{2,2}\cos(2\Delta\varphi) + 2v_{3,3}\cos(3\Delta\varphi)) + FY_{\mathrm{LM}}(\Delta\varphi)$$

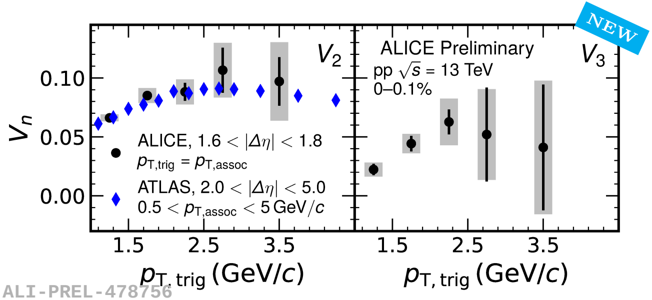
F: Ratio of away-side jet fragments in high-multiplicity to low-multiplicity events (60–100%), $F = 1.304 \pm 0.018$

N.B.:This method is not applicable to the models which have the ridge in low low-multiplicity events.



Ridge yield and v_n (TPC-TPC): 0–0.1%

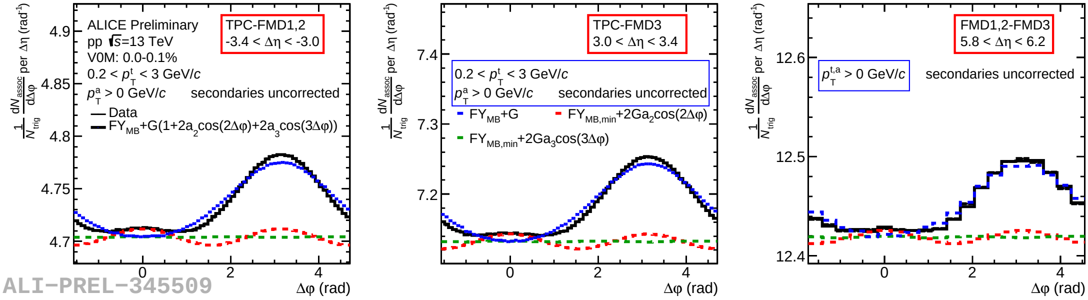




- Decreases with increasing $p_{\mathrm{T}} > 1$ GeV/c
- CMS yield is higher than ALICE mainly due to different multiplicity selection
- **EPOS LHC describes p_{T} dependence, over-estimating the yield**
- **String Shoving shows steeper p_{T} dependence, under-estimating it**

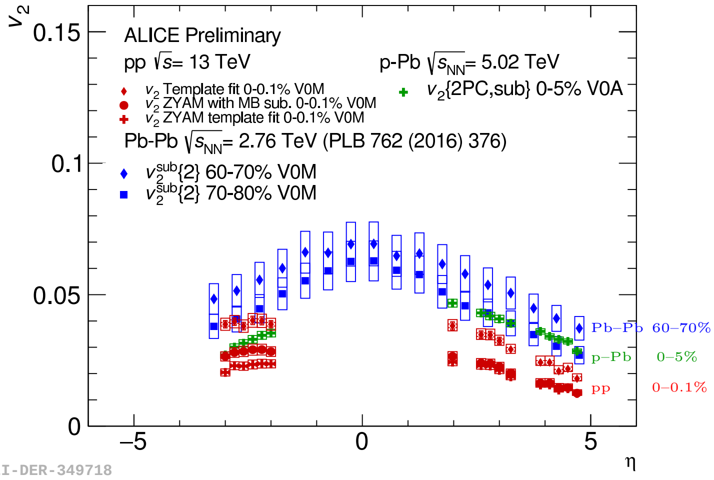
- Comparable with ATLAS result
- Note that multiplicity class for ATLAS is classified with central particles ($|\eta| < 2.5$, $p_{\mathrm{T}} > 0.4$ GeV/c), $N_{\mathrm{Mult}}^{\mathrm{ATLAS}} > 60$

pp $\sqrt{s} = 13$ TeV, 0–0.1%

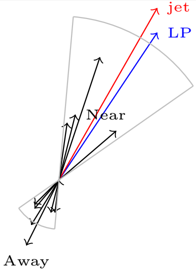


- Correlations measured up to $\Delta\eta \sim 8$ with forward subsystems (FMD)
- Elliptic flow extracted from assumed factorization
  - $v_{2,\eta_A}\{2\mathrm{PC},\mathrm{sub}\} = \sqrt{\frac{v_{2,2,\Delta\eta=\eta_A-\eta_B}\{2\mathrm{PC},\mathrm{sub}\}\, v_{2,2,\Delta\eta=\eta_A-\eta_C}\{2\mathrm{PC},\mathrm{sub}\}}{v_{2,2,\Delta\eta=\eta_B-\eta_C}\{2\mathrm{PC},\mathrm{sub}\}}}$

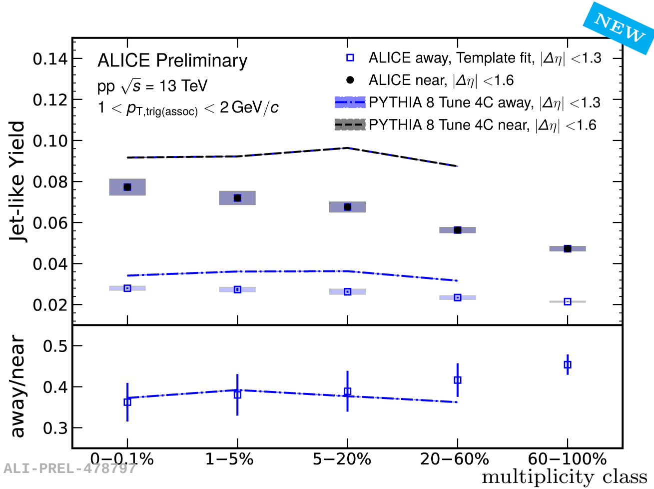
- Non-zero $v_2(\eta)$ has been measured in pp and p–Pb collisions
- **$v_2(\eta)$ in high-multiplicity p–Pb is comparable with peripheral Pb–Pb**
- $v_2(\eta)$ shows asymmetric behavior and is decreasing with increasing η in pp



Near-side and Away-side jet fragmentation

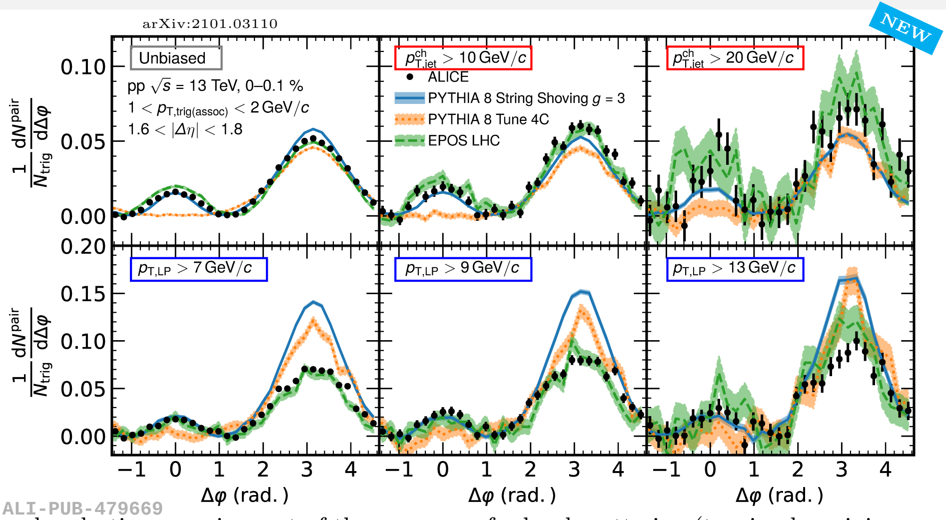


- Away-side jet yield : $Y_{\rm jet}^{\rm Away} = {\color{red}F} Y_{\rm jet}^{\rm Away,LM}$
- Near-side jet yield measured by short-range correlations (see the backup)
- Limited η acceptance as ratio (RPD 74, 0782002 (Oct 2006))
- **The relative away-side jet contribution, F, has been tested by comparing the ratios from the ALICE and the PYTHIA 8**



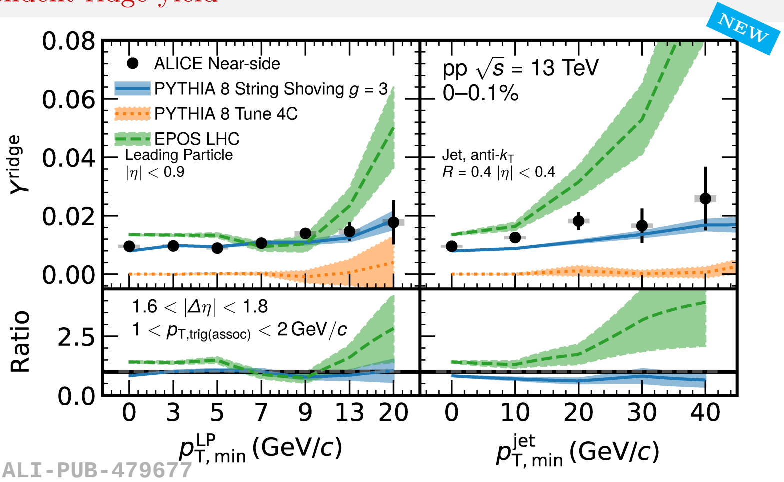
Event-scale dependent $\Delta\varphi$ correlations (event tagging)

arXiv:2101.03110



- 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

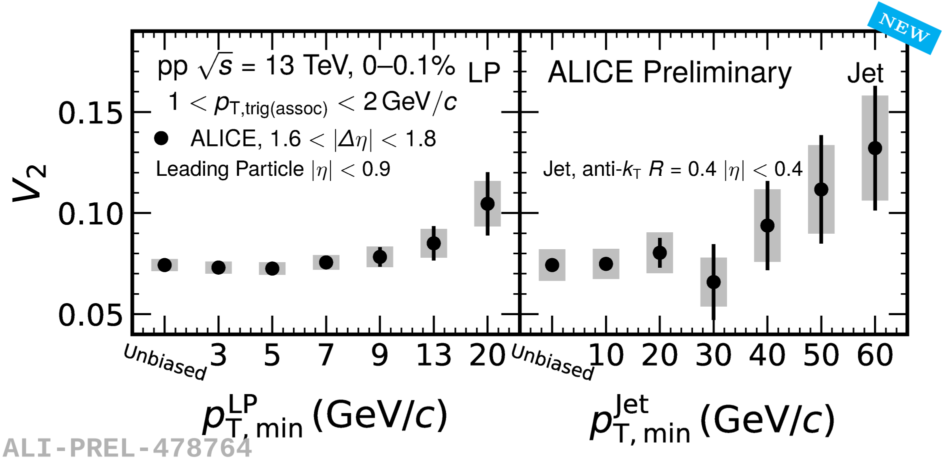
Event-scale dependent ridge yield



arXiv:2101.03110

- 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**

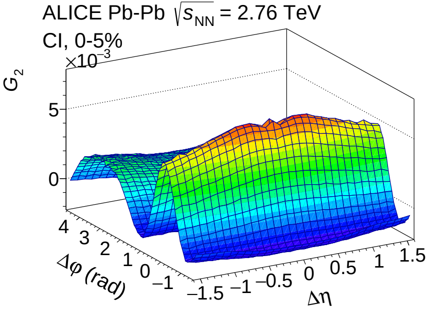


- Weak or no sensitivity to event-scale selection with the uncertainties
- Note that the template does not impose event-scale selection

Two-particle transverse momentum correlation function G_2

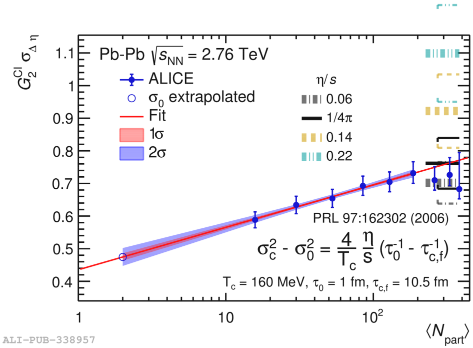
$$G_2(\Delta\eta,\Delta\varphi) = \frac{1}{\langle p_T\rangle^2}\left[\frac{\langle \sum_i^{n_{1,1}} \sum_{j\neq i}^{n_{1,2}} p_{T,i}\, p_{T,j}\rangle}{\langle n_{1,1}\rangle\langle n_{1,2}\rangle} - \langle p_{T,1}\rangle\langle p_{T,2}\rangle\right]$$

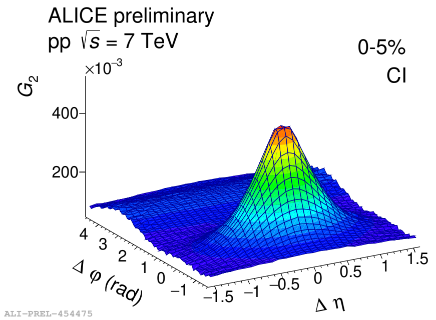
ALICE, PLB 804, 135375 (2020)



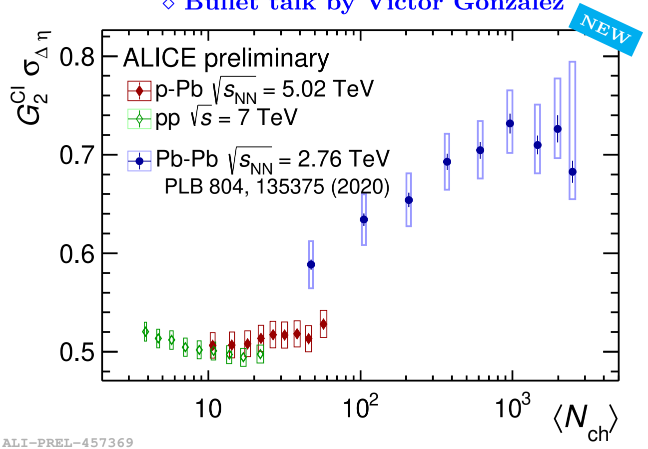
◇ **Bullet talk by Victor Gonzalez**

- Sensitive to momentum currents transfer
- The longitudinal dimension shape
  - The reach of the transfer
    proxy for the shear viscosity η/s
  - The mechanism of the transfer
    proxy for the relaxation time τ_π
- Charge Independent (CI) $G_2 = G_2^{CI}$





◇ Bullet talk by Victor Gonzalez



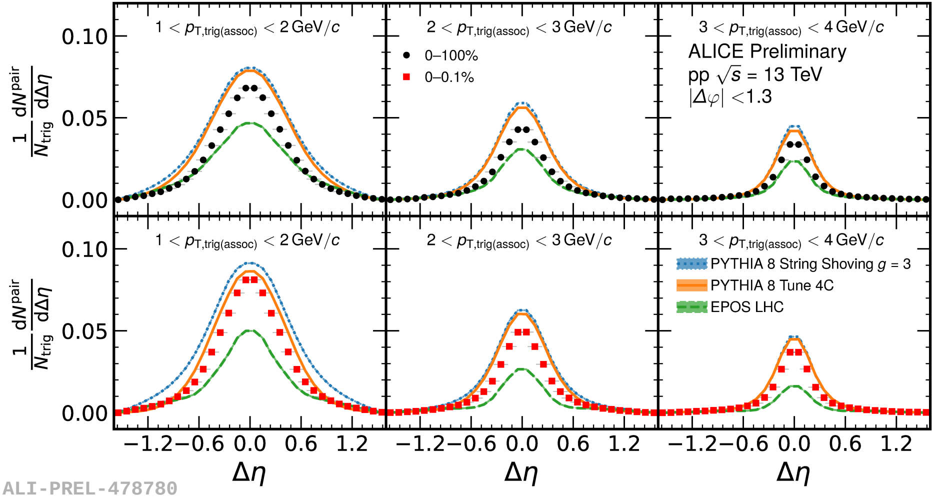
- **Evolution trend breaks in both dimensions in the transition from small systems**
- Consistent azimuthal narrowing trend along the three systems
- Completely different longitudinal evolution

Summary

- Ridge and flow coefficients in two-particle correlations in various pseudorapidity ranges
  - Comparable with measurements from other experiments
  - $v_2(\eta)$ in p–Pb collisions is comparable with peripheral Pb–Pb collisions
- 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.
- Furthermore, event-scale dependent ridge yields and v_n are studied
  - Increasing trend for the ridge yield and no significant dependence for v_n
  - Compared to EPOS LHC and PYTHIA 8 string shoving, leading to further improvement of each model.
- G_2^{CI} has been measured and found to be different from small systems to Pb–Pb, which potentially shed a light on the shear viscosity.

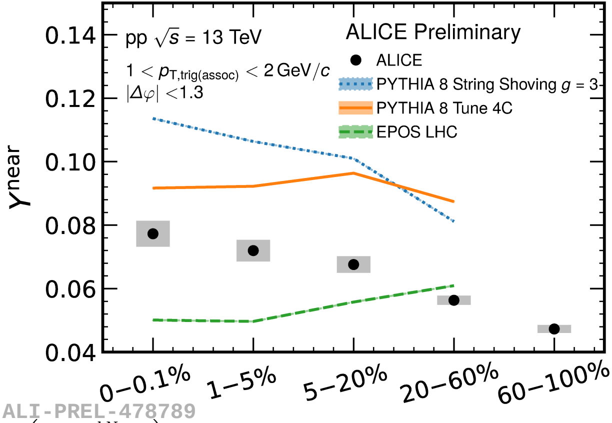
Thank You!

BACKUP



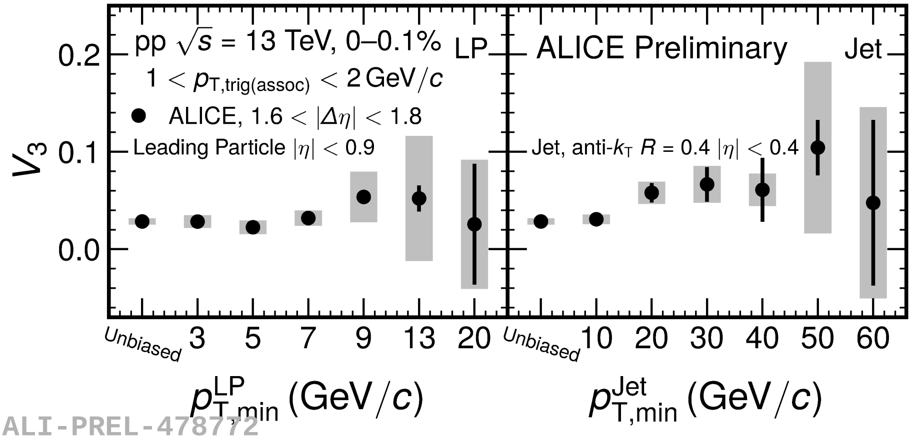
- $\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta} = \int_{|\Delta\varphi|<1.3}\left(\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi}\right)\frac{1}{\delta_{\Delta\varphi}}\mathrm{d}\Delta\varphi - D_{\mathrm{ZYAM}}$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

Multiplicity dependent near-side peak



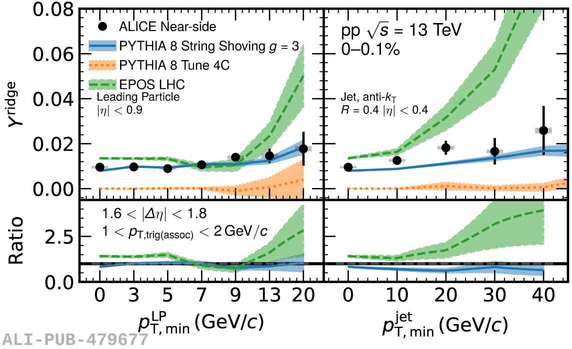
- $Y^{\rm near} = \int_{|\Delta\eta|<1.6} {\rm d}\Delta\eta \left(\frac{1}{N_{\rm trig}} \frac{{\rm d}N_{\rm pair}}{{\rm d}\Delta\eta} \right)$
- Data and String Shoving show increasing near-side yield with increasing multiplicity, while it is not the case for EPOS LHC and PYTHIA 8 Tune 4C.

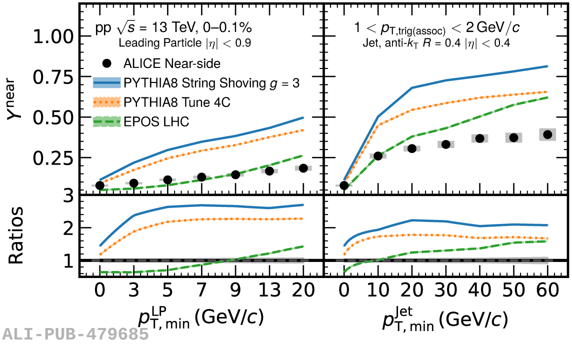
Event-scale dependent v_3



- 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.