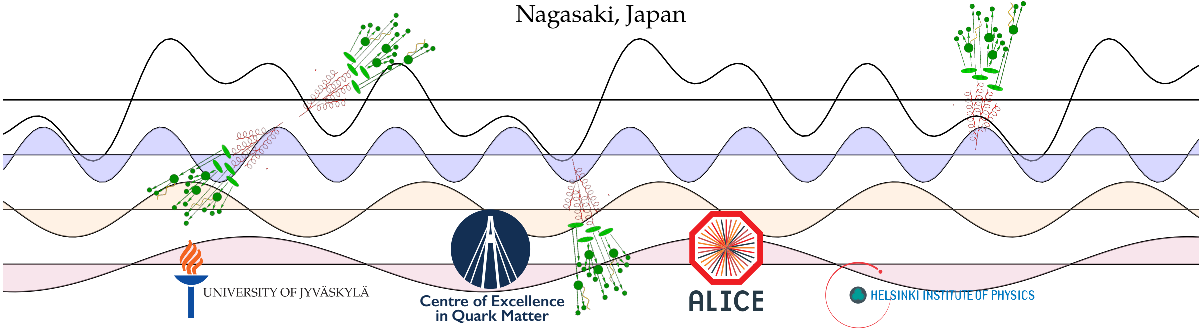
Exploring jet quenching effects via di-hadron correlations in 13 TeV proton-proton collisions with ALICE

Maxim Virta[1] on behalf of ALICE

1. University of Jyvaskyla, Finland

23. September 2024

Hard Probes,
Nagasaki, Japan



UNIVERSITY OF JYVÄSKYLÄ

Centre of Excellence
in Quark Matter

ALICE

HELSINKI INSTITUTE OF PHYSICS

MOTIVES OF THE ANALYSIS

Motive 1: *Can we find signals of jet quenching in high-multiplicity pp?*

Motive 2: *Are the assumptions in current flow extraction methods valid?*

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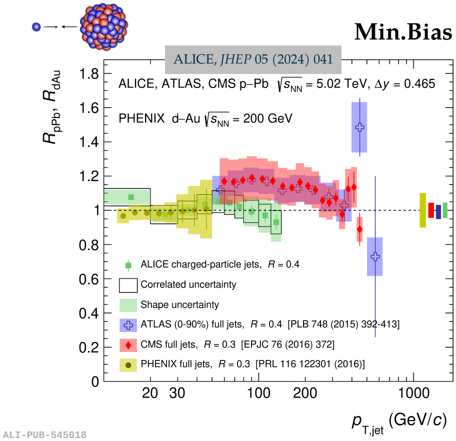
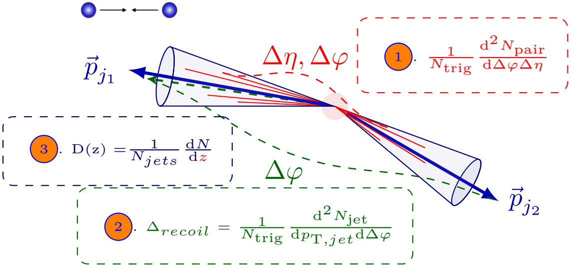
M1 Search for jet quenching effects in high-multiplicity pp collisions



- No sign of jet quenching in small systems
- Even though flow signatures are observed



① $\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2 N_{\mathrm{pair}}}{\mathrm{d}\Delta\varphi\Delta\eta}$

③ $\mathrm{D}(z) = \frac{1}{N_{jets}}\frac{\mathrm{d}N}{\mathrm{d}z}$

② $\Delta_{recoil} = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T},jet}\mathrm{d}\Delta\varphi}$

What about pp collisions at $\sqrt{s} = 13$ TeV?

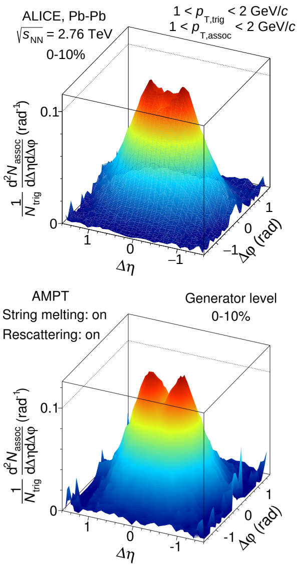
Study multiplicity dependence

① hadron-hadron correlations? (**This analysis**)

② hadron-jet correlations? (di-jets: *JHEP* 05 (2024) 229)

③ intra-jet correlations? (Intra-jet: arXiv:2311.13322)

Double peak structure in $\Delta\eta$ is from Shock Wave?

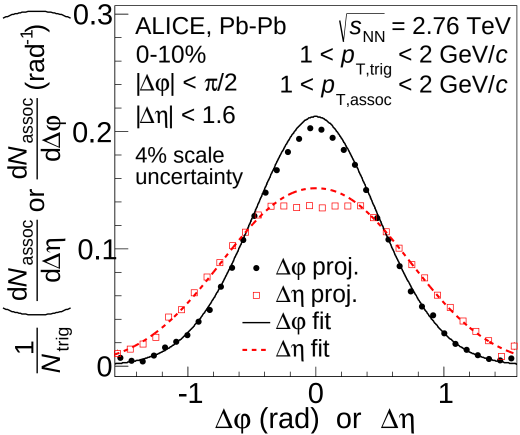


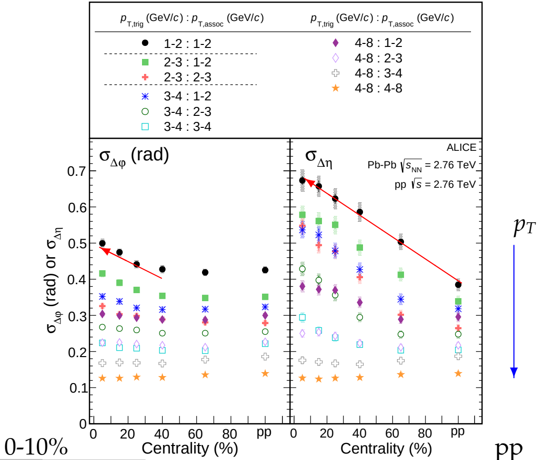
ALICE, *Phys. Rev. Lett.* 119 (2017) 102301

- Also seen in AMPT String melting model
- Double hump peaks around $\Delta\eta \approx 2$ from γ-jets and is also sensitive to EoS (X.N. Wang et al. *Phys. Lett. B* 777 (2018) 86-90)
  - ▸ See Yeonju's talk on Thursday morning

- **Is the origin the same?**
- **Can be seen in HM pp collisions?**

BROADENING OF JETS IN Pb – Pb COLLISIONS

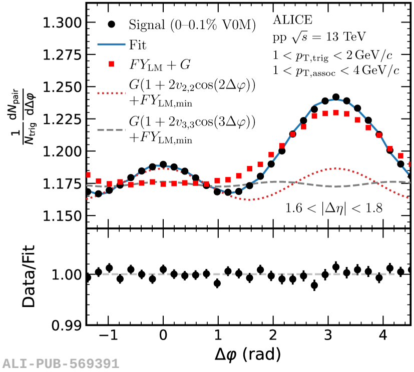




ALICE, *Phys. Rev. Lett.* 119 (2017) 102301

- **Broadening** of the jet fragmentation peak in various kinematic regions observed in HI collisions
- Abnormal and wider in $\Delta\eta$ direction than $\Delta\varphi$
- The origins are still being debated

M2 FLOW EXTRACTION METHOD - HOW TO REMOVE REMAINING JET CONTRIBUTIONS



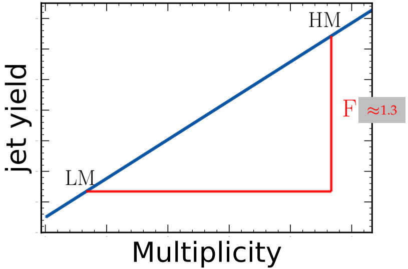
ALICE, *JHEP03* (2024) 092

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

① No ridge or flow in **Near-side** in the LM-template

② No **Away-side** jet shape modifications in HM events

Jet yield is 30% stronger in HM compared to LM



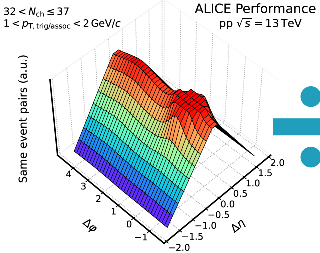
① $\Delta\eta$ **can be measured (weak η-dependence) and can be used as a proxy for away-side.**

② $\Delta\eta$ and $\Delta\varphi$ symmetry in jets.

③ $\Delta\varphi$ **width can't be measured because of the existence of the flow.**

Analysis strategy for near-side peak width and jet fragmentation

ALICE, *Phys. Rev. Lett.* 132, 172302



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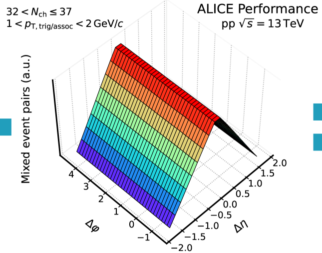

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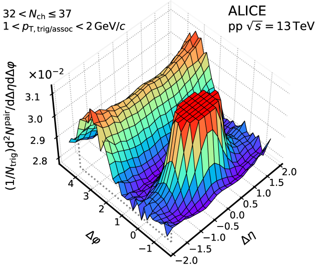


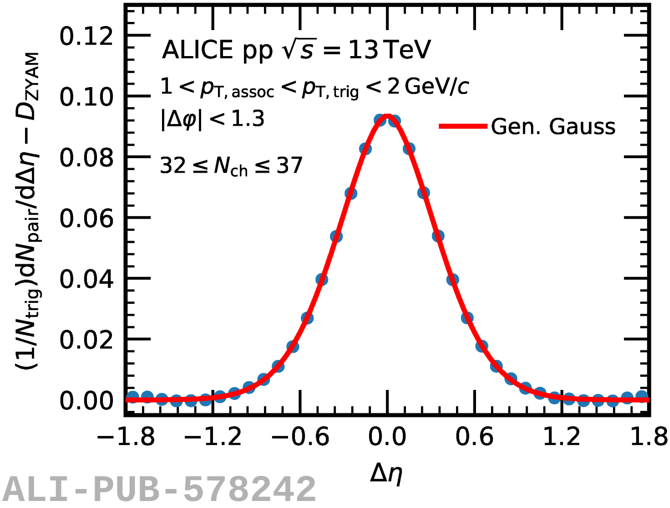
ALI-PUB-574465

$$\begin{aligned}\frac{1}{N^*_{\rm trig}(z)}\frac{{\rm d}^2N_{\rm pair}}{{\rm d}\Delta\eta\Delta\varphi}(\Delta\eta,\Delta\varphi,z) &= \frac{1}{N^*_{\rm trig}(z)}\frac{N^{*,\rm same}_{\rm pair}(\Delta\eta,\Delta\varphi,z)}{N^{*,\rm mixed}_{\rm pair}(\Delta\eta,\Delta\varphi,z)}N^{*,\rm mixed}_{\rm pair}(0,0,z),\\ \frac{1}{N_{\rm trig}}\frac{{\rm d}^2N_{\rm pair}}{{\rm d}\Delta\eta\Delta\varphi}(\Delta\eta,\Delta\varphi) &= \frac{1}{\sum_z N^*_{\rm trig}(z)}\sum_z N^*_{\rm trig}(z)\frac{{\rm d}^2N_{\rm pair}}{{\rm d}\Delta\eta\Delta\varphi}(\Delta\eta,\Delta\varphi,z)\end{aligned} \tag{1}$$

$$\frac{1}{N_{\rm trig}}\frac{{\rm d}N_{\rm pair}}{{\rm d}\Delta\eta} = \int_{|\Delta\varphi|<1.3}\left(\frac{1}{N_{\rm trig}}\frac{{\rm d}^2N_{\rm pair}}{{\rm d}\Delta\eta{\rm d}\Delta\varphi}\right)\frac{1}{\delta_{\Delta\varphi}}{\rm d}\Delta\varphi - D_{\rm ZYAM}. \tag{2}$$

NEAR SIDE $\Delta\eta$ IN PP 13 TEV

NEW! ALICE, arXiv:2409.04501



- Projection taken in range $\Delta\varphi \in [-1.3, 1.3]$
- Fitted with the generalized Gaussian function

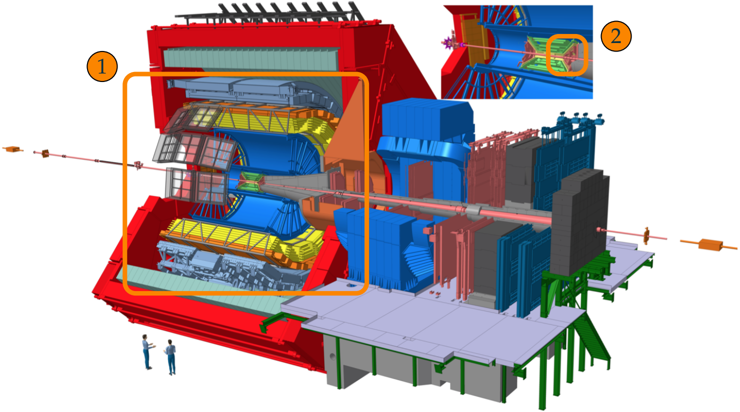
$$A + \frac{1}{2\alpha\Gamma(1/\beta)} \exp\left[-\left(\frac{|x|}{\alpha}\right)^{\beta}\right],$$

for which

$$\sigma = \sqrt{\frac{\alpha^2\Gamma(3/\beta)}{\Gamma(1/\beta)}}$$

- α and β define the scale and shape

MIDRAPIDITY VS. FORWARD MULTIPLICITY ESTIMATOR



More about ALICE
ALICE, *Eur. Phys. J. C* 84, 813 (2024)

① Midrapidity Multiplicity Estimator

- Event activity estimated with tracks
- Directly translates to $\langle N_{ch} \rangle$ with unfolding

ALICE, *JHEP03* (2024) 092

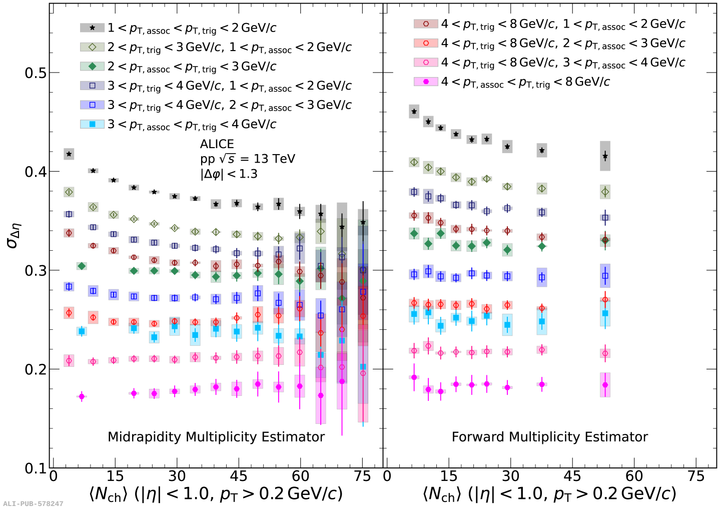
② Forward Multiplicity Estimator

- Event activity estimated with V0 detectors (V0M)
- Needs to be translated to $\langle N_{ch} \rangle$

ALICE, *Eur. Phys. J. C* 81, 630

MULTIPLICITY DEPENDENCE OF $\sigma_{\Delta\eta}$ IN PP 13 TEV: MAGNITUDE COMPARISON

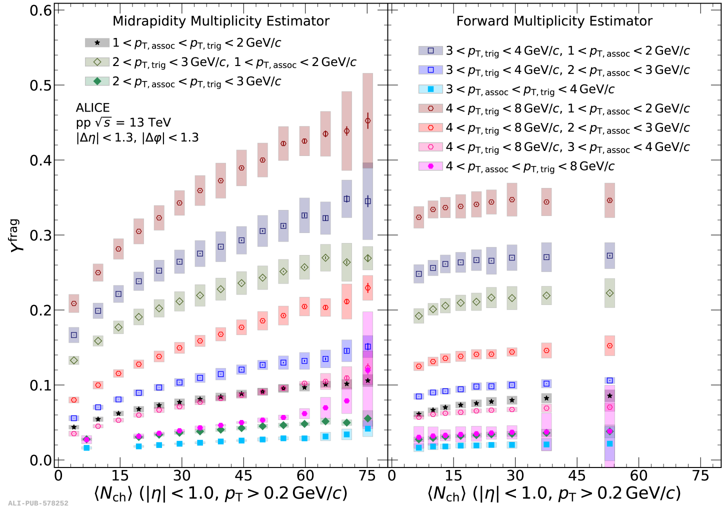
NEW! ALICE, arXiv:2409.04501



- Multiplicity dependence decreases for higher p_{T} and higher multiplicity
- V0M results have broader jets and weaker multiplicity dependence across almost all p_{T}-bins
- Clear ordering in the magnitude → narrower peaks towards higher p_{T}

MULTIPLICITY DEPENDENCE OF JET FRAGMENTATION YIELDS: MAGNITUDE COMPARISON

NEW! ALICE, arXiv:2409.04501



- Evaluate jet fragmentation yield:

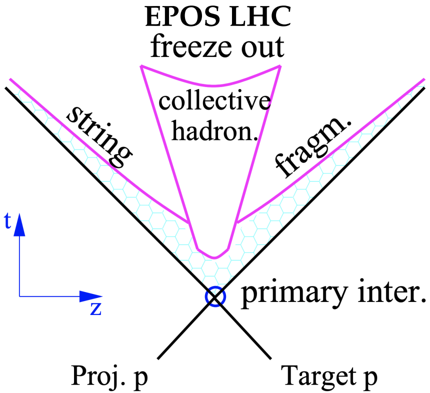
$$Y^{\text{frag}} = \int_{|\Delta\eta|} \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}N}{\mathrm{d}\Delta\eta} \mathrm{d}\Delta\eta.$$

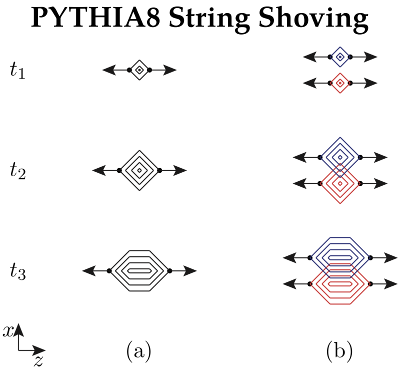
- Largest jet yields for $1 < p_{\mathrm{T,assoc}} < 2$ GeV/c bins
- Smallest yields for symmetric trig-assoc bins
- $F = 1.3\,(\sim 2.2)$ for forward rapidity (midrapidity) in low-p_{T}

Model comparisons

Model	Physics	Observations	Refs
(1) PYTHIA8 Monash	Jets only (2013)	No soft partonic or hadronic interactions	P. Skands *et al.*, *Eur. Phys. J. C* 74 3024
(2) PYTHIA8 4C	Jets only (2011)	No soft partonic or hadronic interactions	R. Corke & T. Sjöstrand, *JHEP* 03 032
(3) PYTHIA8 String Shoving	Jets and Flow	Uses strings to simulate soft interactions	C. Bierlich *et al.* *PLB* 779 58-63
(4) EPOS LHC	Jets and Flow	Uses core (hydrodynamic expansion) and corona (hadrons from string decays)	K. Werner *et. al* *Phys. Rev. C* 92 034906
(5) AMPT String Melting	Jets and Flow	Uses soft and hard partonic and hadronic interactions	Z.-W. Lin *et al.* *Phys. Rev. C* 72 064901

COLLECTIVITY IN THE MODELS

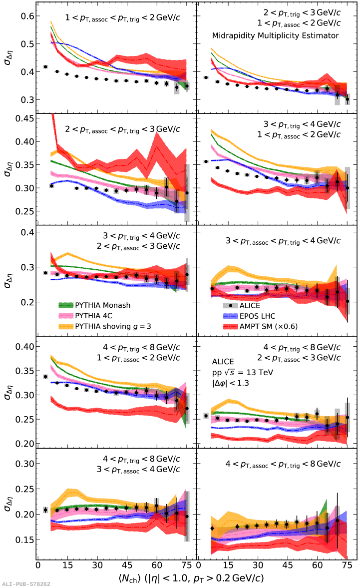




- Separation between core and corona with density
- Core undergoes collective hadronisation

- Includes a repulsive force between colour strings
- Can predict some long-range correlations

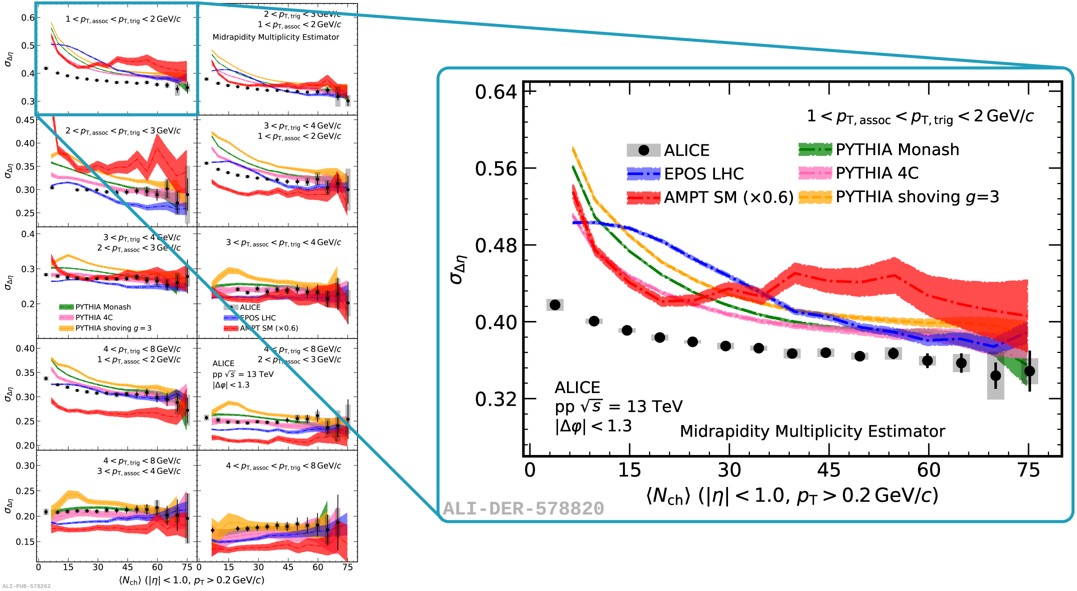
Model comparions: Near-side width $\sigma_{\Delta\eta}$



NEW! ALICE, arXiv:2409.04501

Too many p_{T}-intervals?
Let's zoom in!

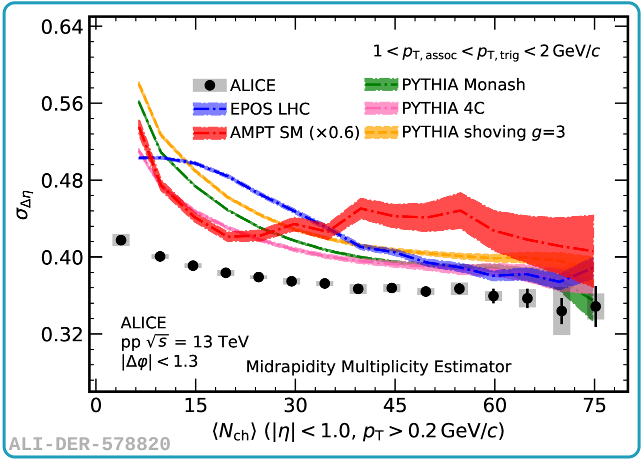
Model comparions: Near-side width $\sigma_{\Delta\eta}$, low-p_{T}



Model comparions: Near-side width $\sigma_{\Delta\eta}$, low-p_{T}

- Models overestimate the data in the lower-p_{T}
- Overestimation stronger in low multiplicity
- Trend is captured by most models
- AMPT scaled with 0.6

NEW! ALICE, arXiv:2409.04501



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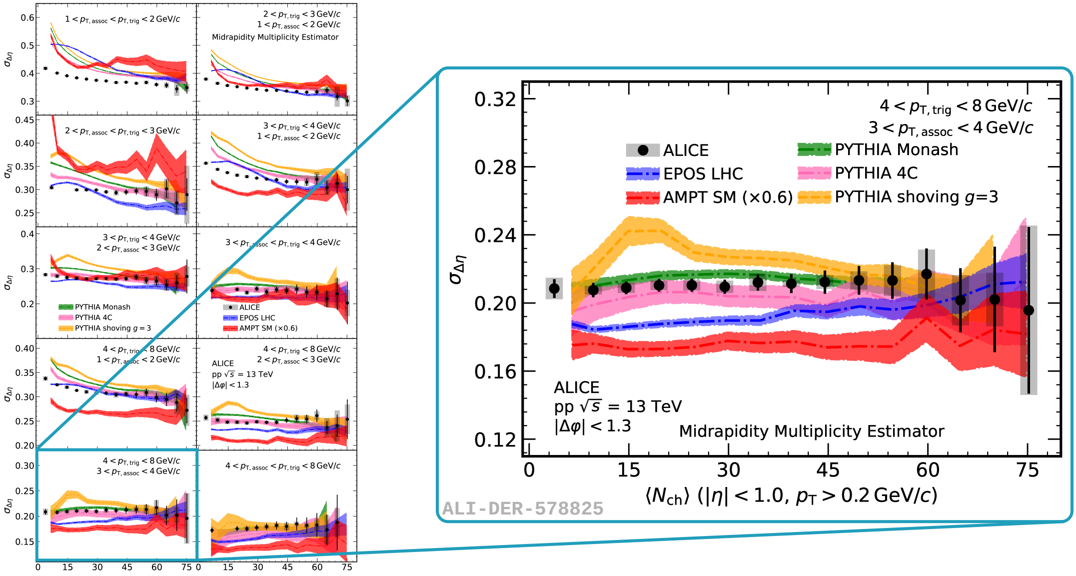
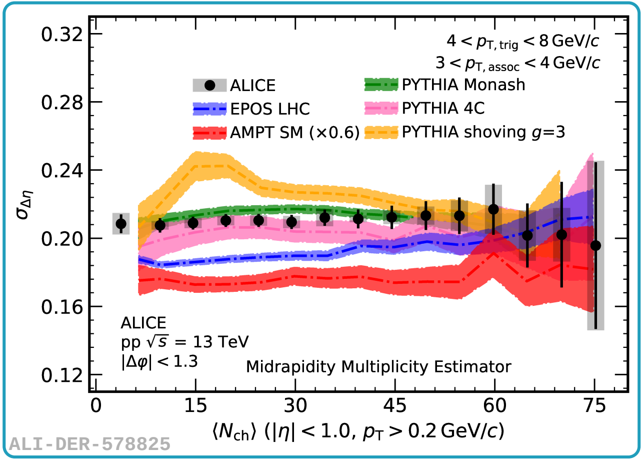


ALI-PUB-578262

MODEL COMPARIONS: NEAR-SIDE WIDTH $\sigma_{\Delta\eta}$, HIGH-p_T

- Models can estimate the data better in higher-p_T
- The multiplicity dependence vanishes
- AMPT scaled with 0.6

NEW! ALICE, arXiv:2409.04501



Motive 1:

- No broadening of jet peak found

→ no signal of jet quenching

- Measured narrowing may result from kinematic biases
- Disentangle QCD biases to search for QGP effects in small systems
  - Core vs. corona contributions (Y. Kanakubo et al., *Phys. Rev. C* 106, 054908)
  - Refining both QCD and initial condition models (eg. MC-EKRT Kuha et al., arXiv:2406.17592)

CONCLUSIONS

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Motive 2:

- Clear distinction with Midrapidity Multiplicity Estimator

→ need to use forward estimators

- Flow measurements need to account for shape modifications in low-p_T
- May differ for different kinematic selections

→ effects need to be quantified separately

CONCLUSIONS

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Run 3 analysis has been started!

Probe for the low multiplicity limit of flow and correlations
Reduce the statistical and systematical uncertainties

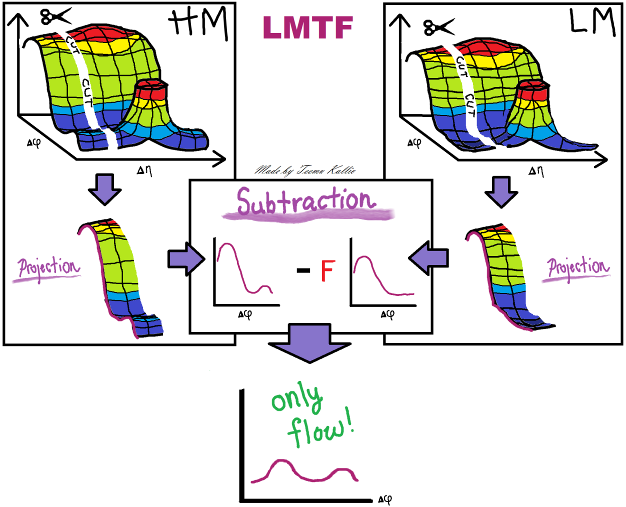
QUESTIONS?

Thank you!
Questions?

ALICE, arXiv:2409.04501

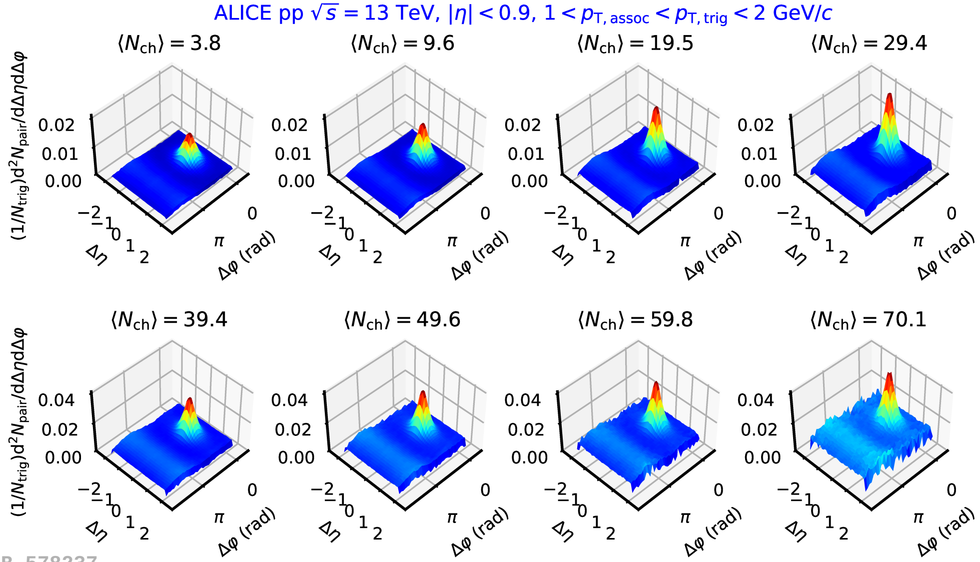
BACKUP

Low multiplcity template fit method



1. Measure correlation functions for both LM and HM
2. Cut with $1.6 < |\Delta\eta| 1.8$
3. Project to $\Delta\varphi$
4. Subtract LM from HM
5. Extract flow

Correlation functions in pp 13 TeV



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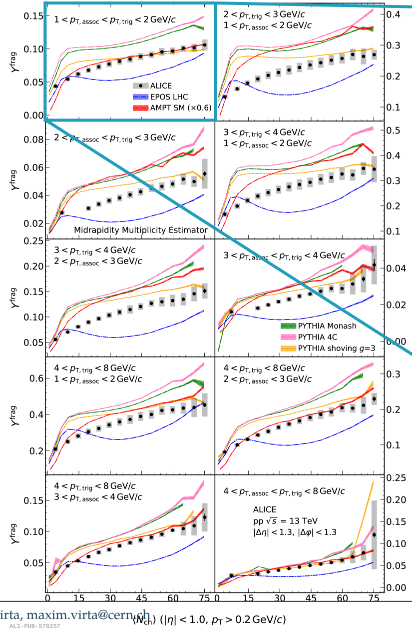
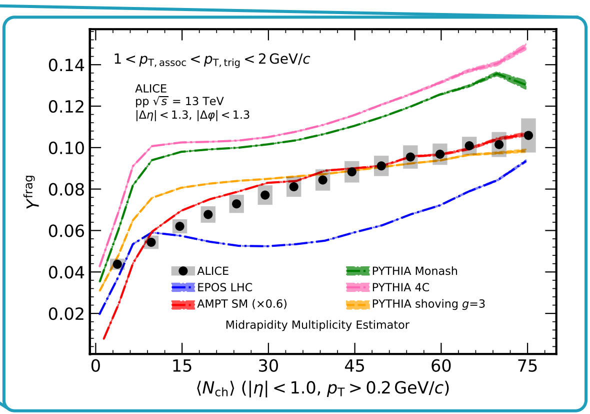
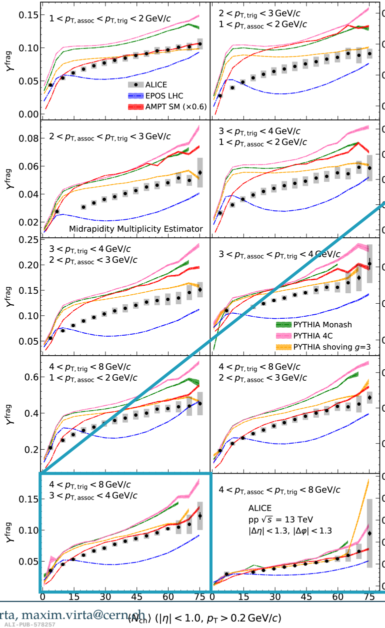
MODEL COMPARIONS: JET FRAGMENTATION YIELDS Y^{frag}, LOW-p_{T}



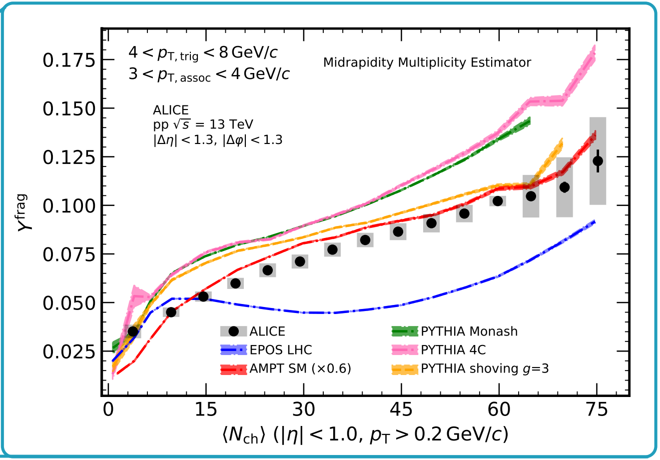


- All models except EPOS overestimate the data in the lower-p_{T}
- Small peak around $\langle N_{ch}\rangle = 10$
- Closest description by PYTHIA8 String shoving
- AMPT scaled with 0.5

MODEL COMPARIONS: JET FRAGMENTATION YIELDS Y^{frag}, HIGH-p_{T}



- Model description improves in higher-p_{T}
- Slight overestimation but trend is better captured
- AMPT scaled with 0.5



COLLECTIVITY IN SMALL SYSTEMS

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

  K. Dusling *et. al* PRD 87 5 (2013) 05150, A. Bzdak *et. al* PRC 87 6, (2013) 064906

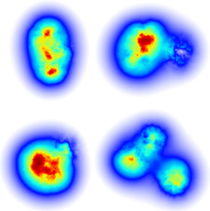
- **Final state effects:** Hydrodynamics

  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, MC-based models?



Fluctuating gluon density in a proton

H. Mantysaari et al., PRL 117, 052301

Continuum eq. for fluids + partons

$$\partial_\mu\left(T^{\mu\nu}_{\text{fluid}} + T^{\mu\nu}_{\text{parton}}\right) = 0$$

Hydrodynamic eq. with source term

$$\partial_\mu T^{\mu\nu}_{\text{fluid}} = J^\nu$$

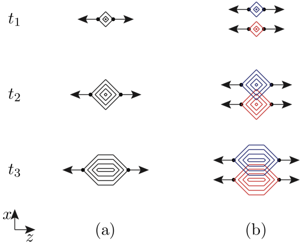
$$J^\nu \to -\sum_i \boxed{\frac{dp_i{}^\nu(t)}{dt}} G\left(x - x_i(t)\right)$$

Y. Kanakubo et al., Phys. Rev. C 105 (2022) 2, 024905

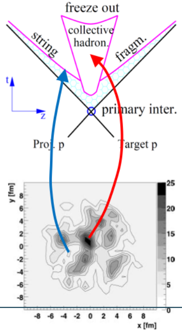
MC-BASED MODELS I

- **PYTHIA 8 String Shoving**: Pushing the strings resulting in transverse pressure
  C. Bierlich *et. al* PLB 779 (2018) 58-63 → strings produced from hard scatterings are also affected by the repulsive force, which then leads to observed long-range correlation even in low-multiplicity events
- **AMPT String Melting**: soft and hard partonic and hadronic interactions, Zi-Wei *et al.* → parton cross section value of 3 mb, fluid-like (hydrodynamic) excitations for Pb–Pb collisions and particle-like (or non-hydrodynamic) excitations for pp or p–Pb
- **Core vs. corona**
  - **EPOS LHC**: Parameterized hydrodynamic evolution in core
    T. Pierog *et. al* PRC 92, 034906
  - **DCCI2**: Equilibrium and non-equilibrium (e.g., Y. Kanakubo et al., *Phys. Rev. C* 106, 054908, 2022))
  - **MC-EKRT**: Refining/improving both QCD and initial condition models (e.g., M. Kuha et al., arXiv:2406.17592))

String Shoving

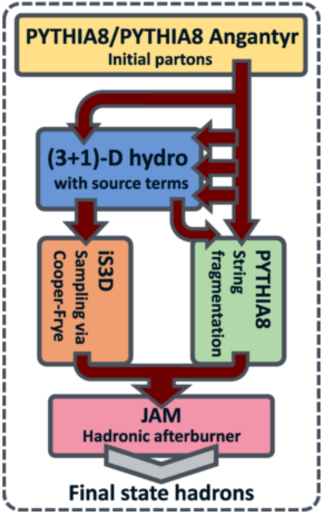


EPOS LHC



Equilibrium and non-equilibrium fractions in small systems

DCCI2



PYTHIA8/PYTHIA8 Angantyr
Initial partons

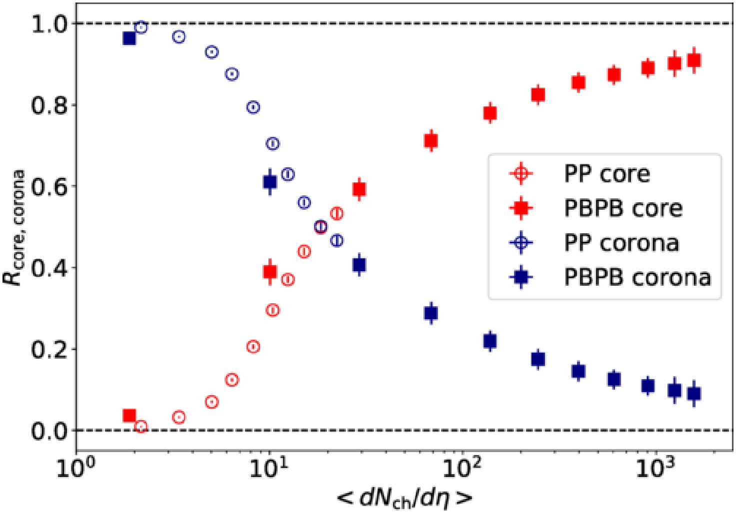
(3+1)-D hydro
with source terms

iS3D
Sampling via
Cooper-Frye

PYTHIA8
String
fragmentation

JAM
Hadronic afterburner

Final state hadrons



ALICE DETECTOR

More about ALICE

ALICE, *Eur. Phys. J. C* 84, 813 (2024)