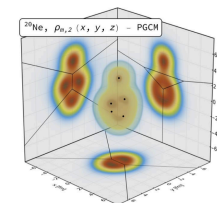


Centrality determination in light-ions at the LHC

Anthony Timmins (with much help from my LHC and theory colleagues)



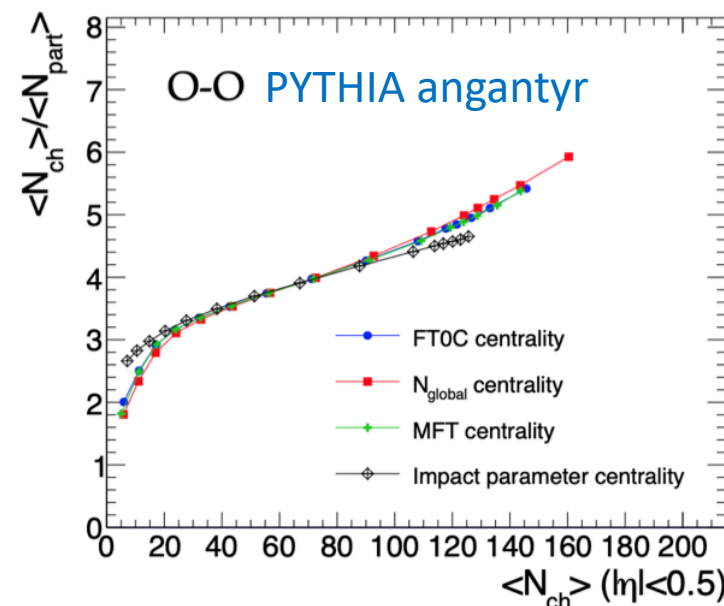
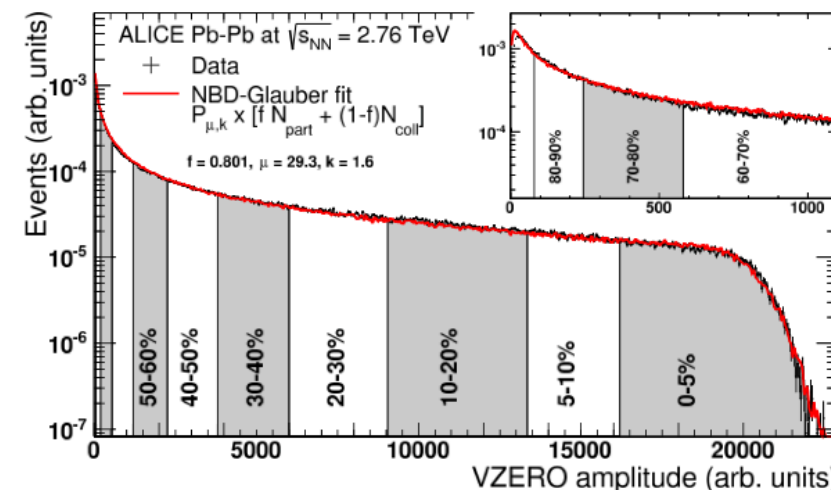
Kicking off (we're sure) a fruitful discussion

What will mainly be **shown in these slides**:

- ✓ Methods for centrality determination
- ✓ Why corrections needed for centrality determination are important in light-ions
- ✓ Comparison across LHC experiments

What **is also very important**:

- ✓ Centrality resolution
- ✓ Biases in particle production processes due to centrality estimator
- ✓ Comments welcome in the discussion session!



Experimental centrality determination

Not everyone likes the word in small systems, but for today:

$$C(N_{\text{ch}} \text{ or } E_{\text{T}}) = \frac{\sum_{N_{\text{ch}} \text{ or } E_{\text{T}} \geq \infty} N_{\text{events}}(N_{\text{ch}} \text{ or } E_{\text{T}})}{N_{\text{events}}(\text{total})}$$

$$\varepsilon_{had} (\text{pp at 7 TeV}) = \underline{74\% (+5\% -2\%)}$$

$$\varepsilon_{had} (\text{Pb-Pb at 2.76 TeV}) = \underline{99\% (\pm 1\%)}$$

Inefficiencies due to hadronic event selection criteria mean experiments don't observe $N_{\text{events}}(\text{total})$

Hadronic selection efficiency:

$$\checkmark \varepsilon_{had} = N_{\text{events}}(\text{observed})/N_{\text{events}}(\text{total}) = \sigma_{AA}(\text{visable})/\sigma_{AA}(\text{total})$$

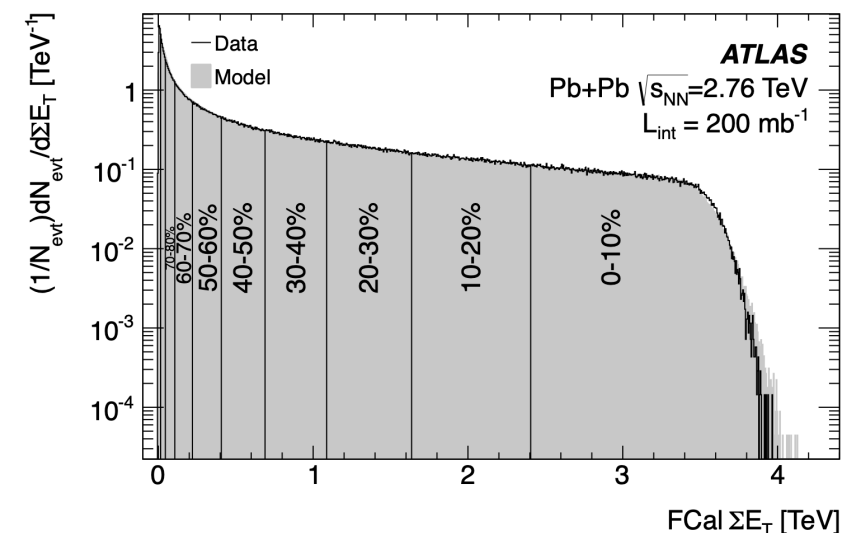
✓ Different nomenclature and **model-dependent**

Centrality determination
requires corrections
which have uncertainties

Methods used to determine missing events

Method 1

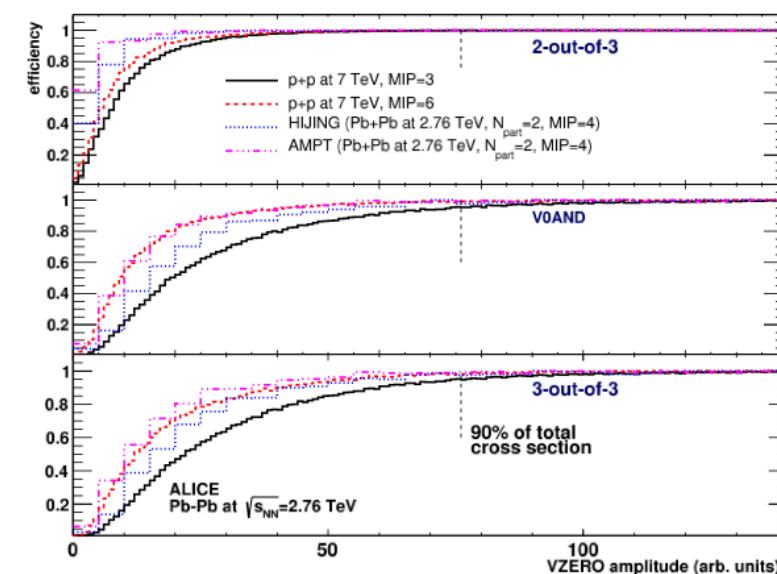
- ✓ Fit measured distribution with Glauber-type model using scaling hypothesis to map the centrality estimator
- ✓ Glauber with two-component (soft and hard scaling) popular
- ✓ $\varepsilon_{had} = N_{events}(observed)/N_{events}(model)$



Method 2

- ✓ Correct measured distribution using model folded with detector effects to recover event loss/subtract background
- ✓ $\varepsilon_{had} = N_{events}(observed)/N_{events}(corrected)$

Useful to define **anchor point** → Minimum centrality/centrality estimator value where event loss negligible



Importance of these corrections for light-ions

Most extreme case $dN_{ch}/d\eta$ vs. centrality

✓ Varies exponentially therefore very prone to shifts in x-axis

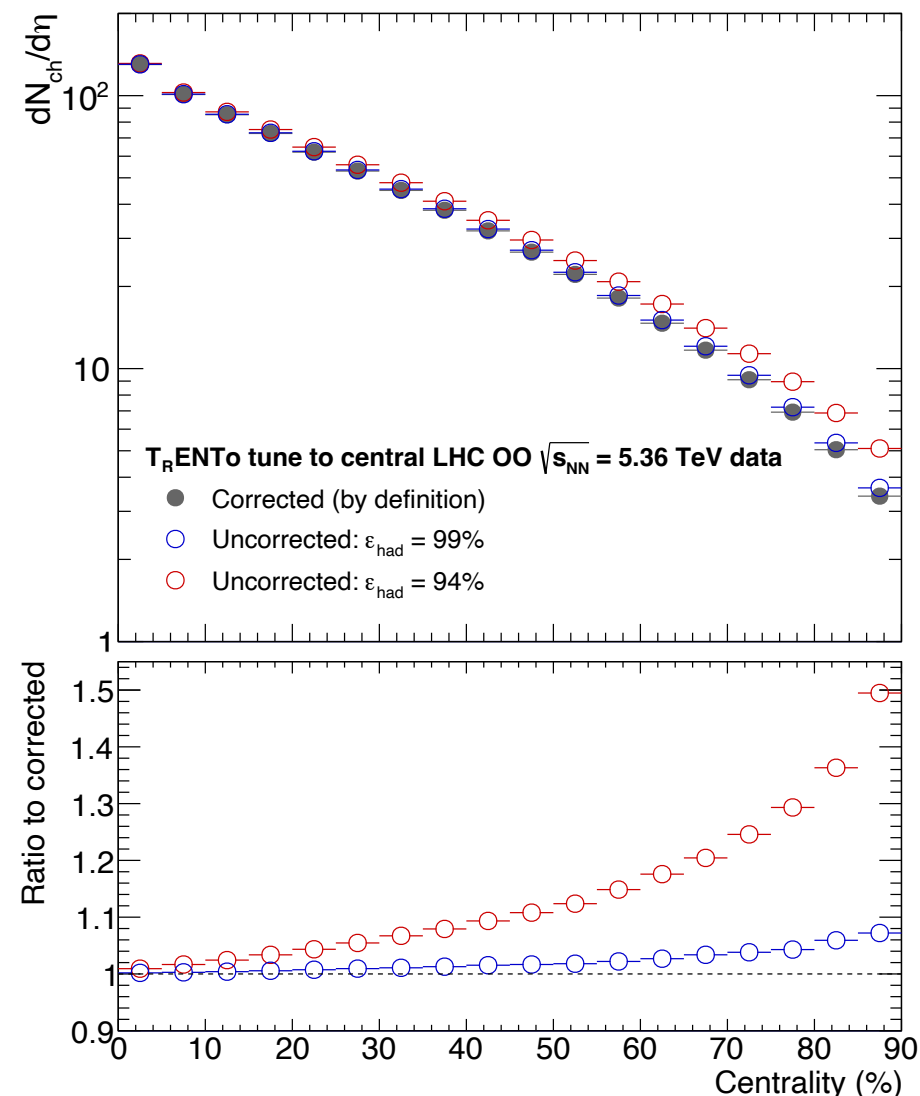
Simple exercise with TRENTo

✓ Use measured $dN_{ch}/d\eta$ to determine entropy scaling factor

✓ Artificially impose event-loss in centrality determination

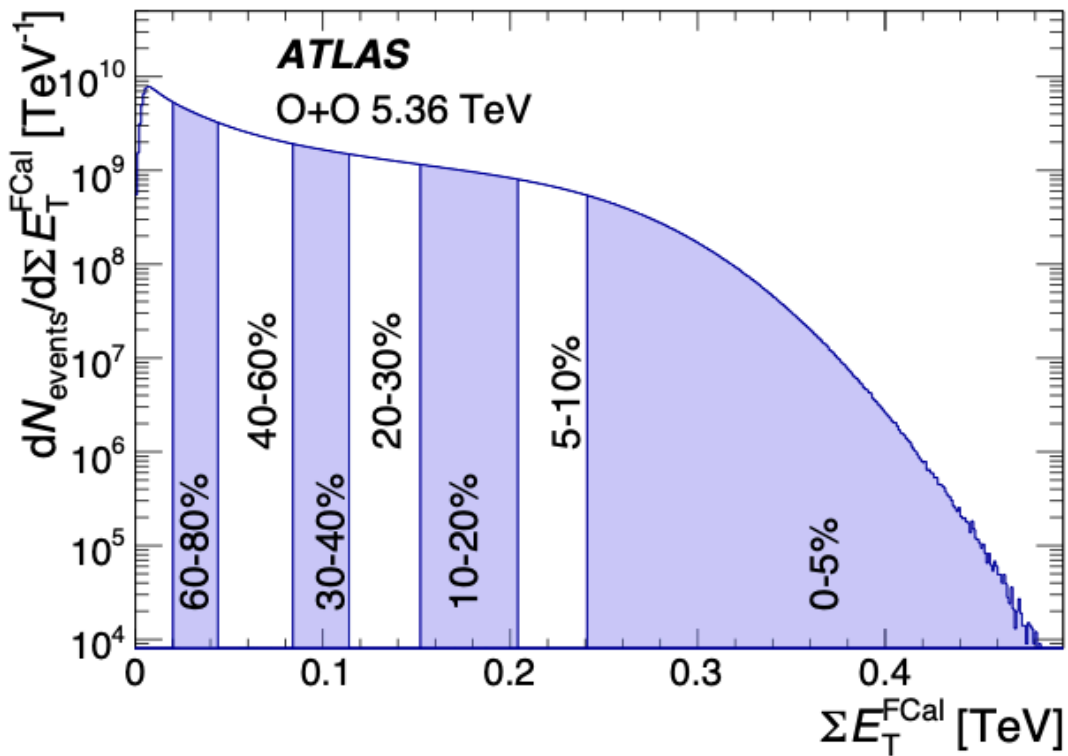
1% corrections lead to 10% changes in $dN_{ch}/d\eta$ for peripheral collisions

✓ Up to 50% for 6% correction...



ATLAS evaluation in OO collisions

[ATLAS light-ion flow paper](#)



Detectors used for default centrality classification:

✓ FCal ($3.2 < |\eta| < 4.9$) → Energy-based ($h^\pm$ and neutrals)

Method 1 and model used for centrality evaluation:

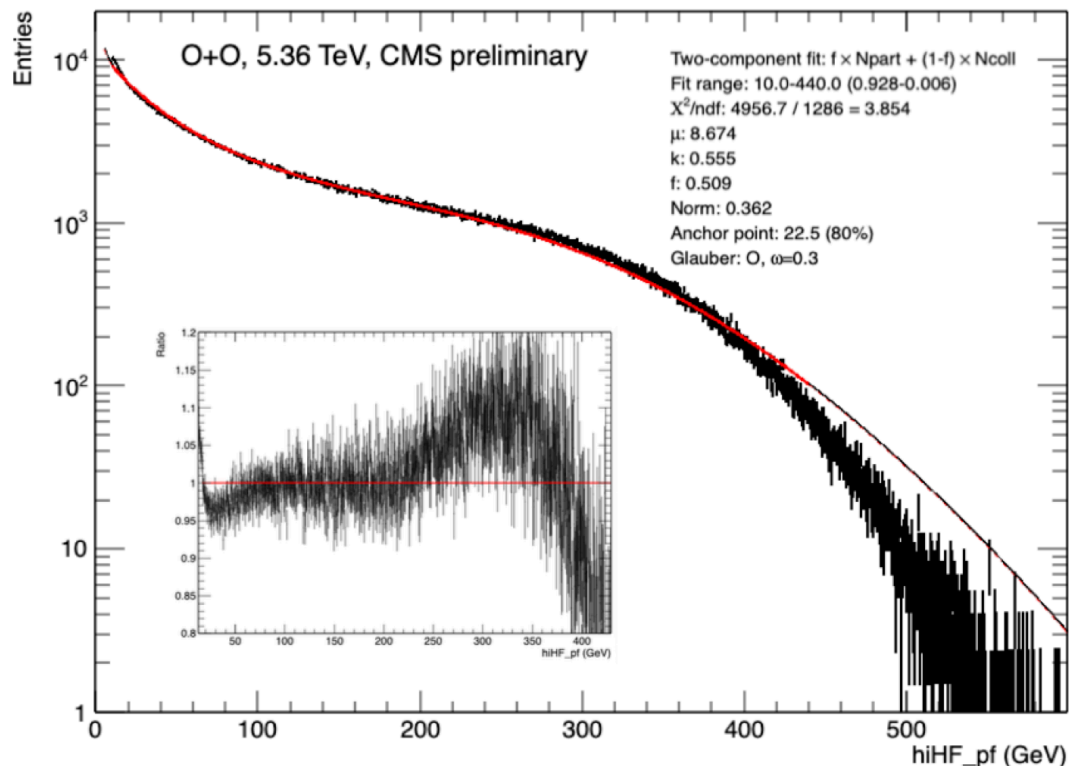
✓ MC Glauber + two-component with gamma folding

$$\Sigma E_T^{\text{FCal}} = E_T^{pp} \left\{ (1 - x) \frac{N_{\text{part}}}{2} + x N_{\text{coll}} \right\}$$

Uncertainty at 80% centrality $\pm 1\%$

✓ *Sources*: Event selection, oxygen profiles, anchor point location, x parameter

CMS evaluation in OO collisions



[Initial Stages 2025 talk](#)

Detectors used for centrality classification:

✓ HF ($2.9 < |\eta| < 5.2$) → Energy-based ($h^\pm$ and neutrals)

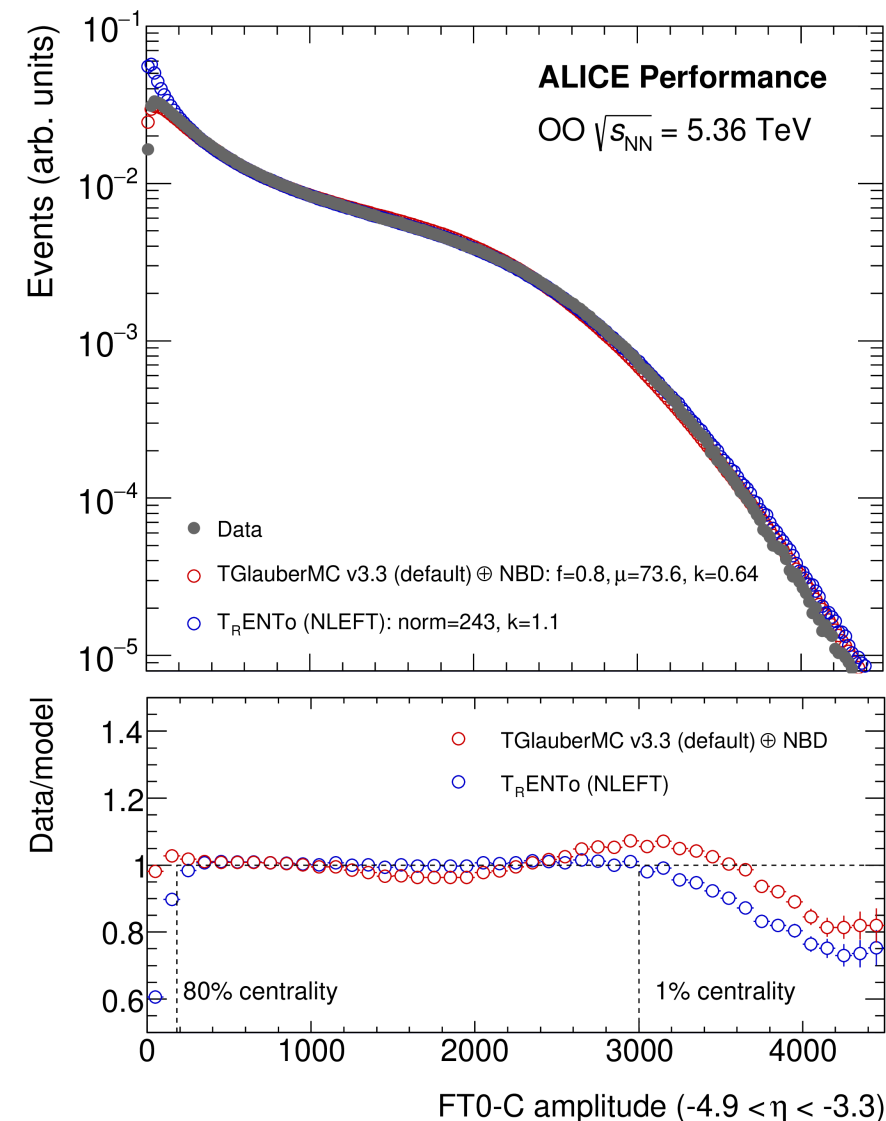
Method 2 and models used for centrality evaluation:

✓ HIJING, AMPT and ANGANTYR to correct HF distribution, MC Glauber + NBD fit for N_{part} etc.

Uncertainty at 80% centrality $\pm 2\%$

✓ *Sources*: Different model corrections (with and without residual corrections for UPC contributions)

ALICE evaluation in OO collisions



Detector used for default centrality classification:

✓ FT0-C ($-4.9 < \eta < -3.3$) $\rightarrow N_{ch}$ based

Method 1 and models used for centrality evaluation:

✓ MC Glauber + two component with NBD folding (default),
TRENTo, PYTHIA angantyr

Uncertainty at 80% centrality $\pm 5\%$

✓ *Sources:* Different models, 8 variations of oxygen nucleus profile parameters, and fits central barrel centrality estimator.

✓ Preliminary determination of $\varepsilon_{had} = 93.5 \pm 6\%$

LHCb evaluation in Pb-Ne collisions

Detectors used for default centrality classification:

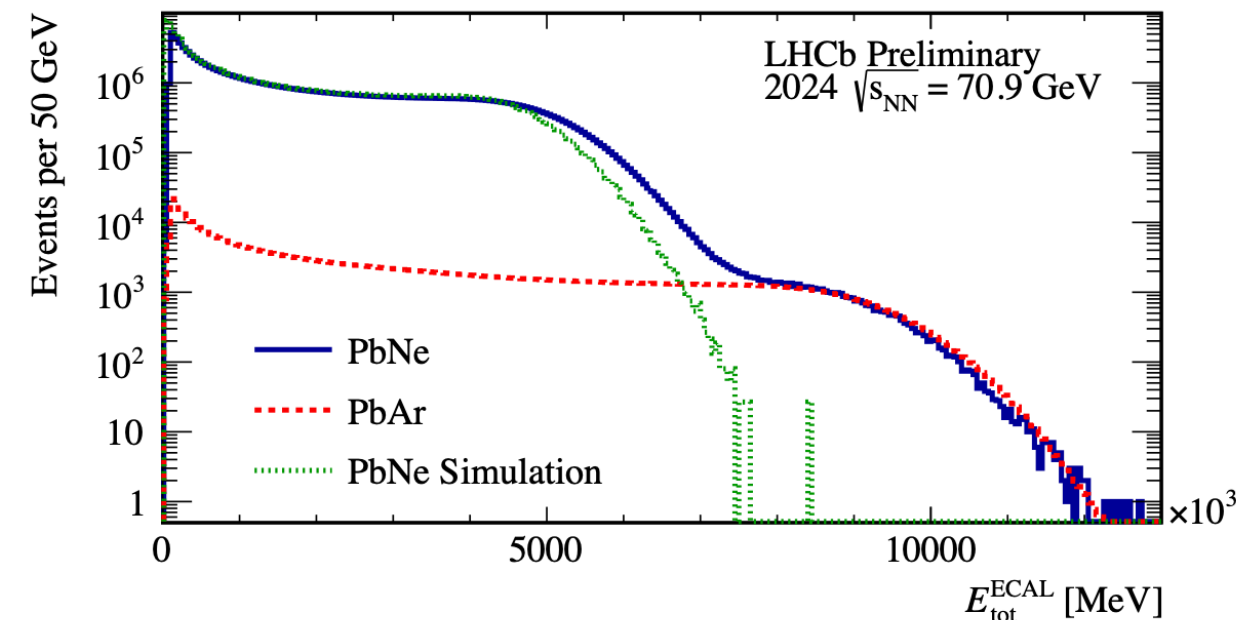
✓ $E_{\text{tot}}^{\text{ECAL}}$ ($2 < \eta < 4.38$) → Energy-based (neutrals only)

Methods 1/2 and models used for centrality evaluation:

✓ MC Glauber + NBD, EPOS folded with detector effects

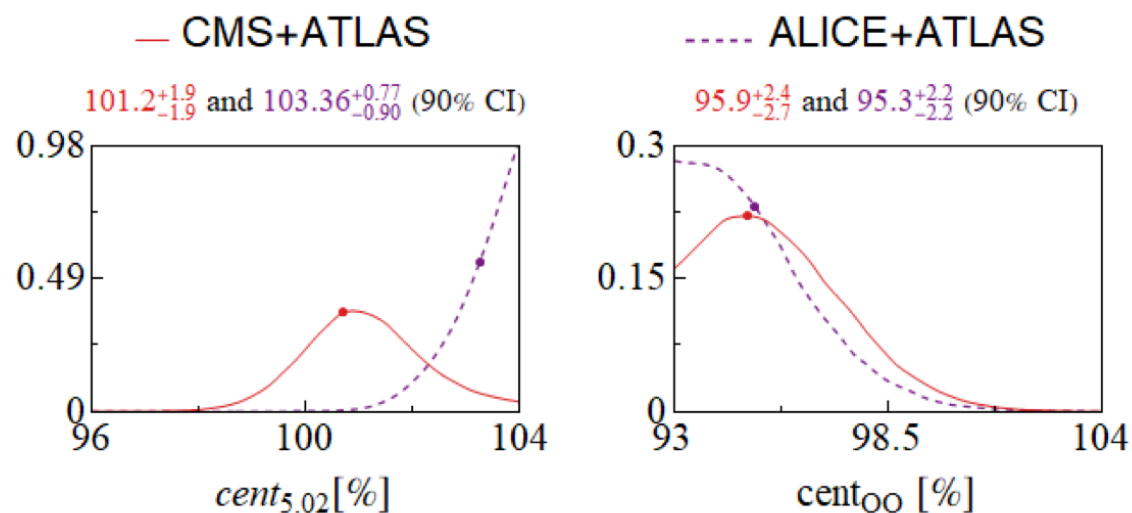
Uncertainties in centrality are still being determined:

✓ VELO estimator (N_{ch} based with $-2.3 < \eta < 0.5$), additional models (TRENTo etc.)



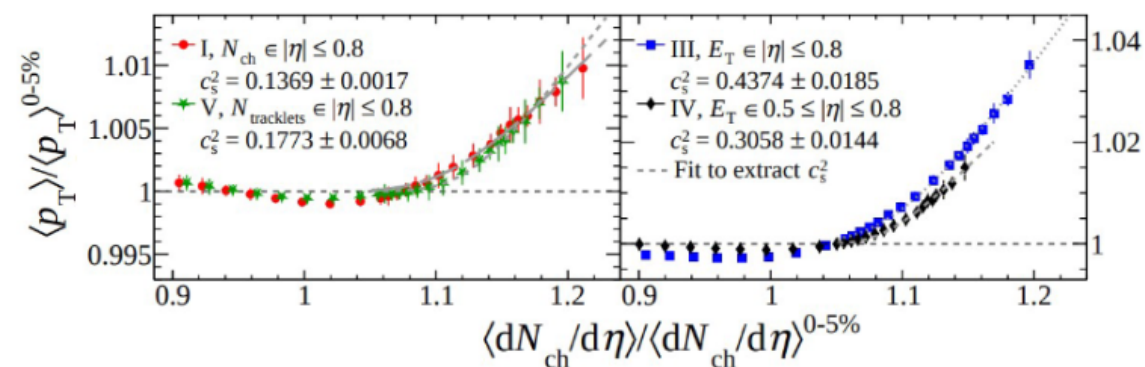
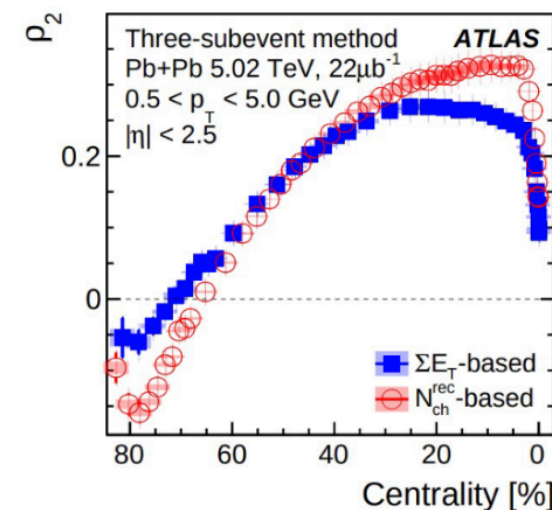
[LHCb PbNe and PbAr flow conference note](#)

Impact on data analysis and interpretation



Cross-experiment Bayesian posterior determination of ε_{had}

✓ [Shown by Wilke yesterday](#)



Centrality selection bias in soft sector

✓ Influence nuclear structure and QGP properties extraction ([Giuliano](#))...

Some key points for discussion?

Variety of approaches for centrality determination

✓ Can/should experiments agree on a common method(s)?

[JHEP 2025 \(2025\) 76](#)

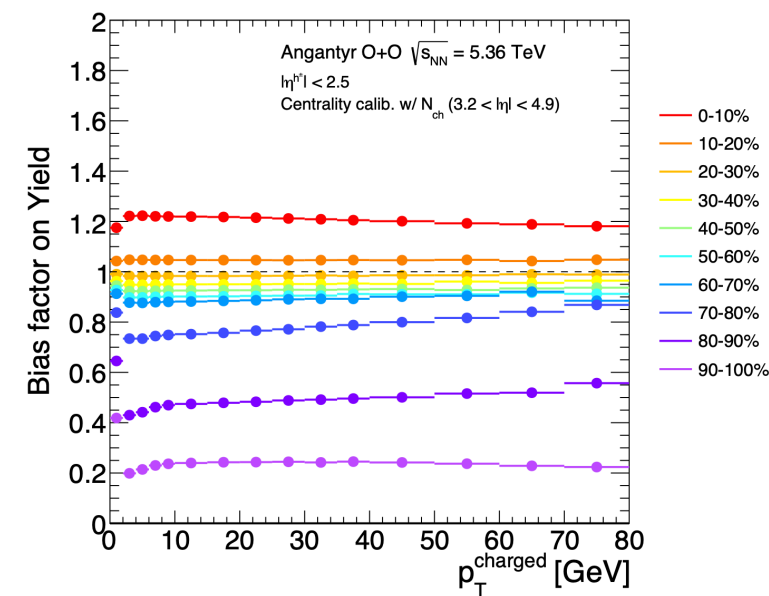
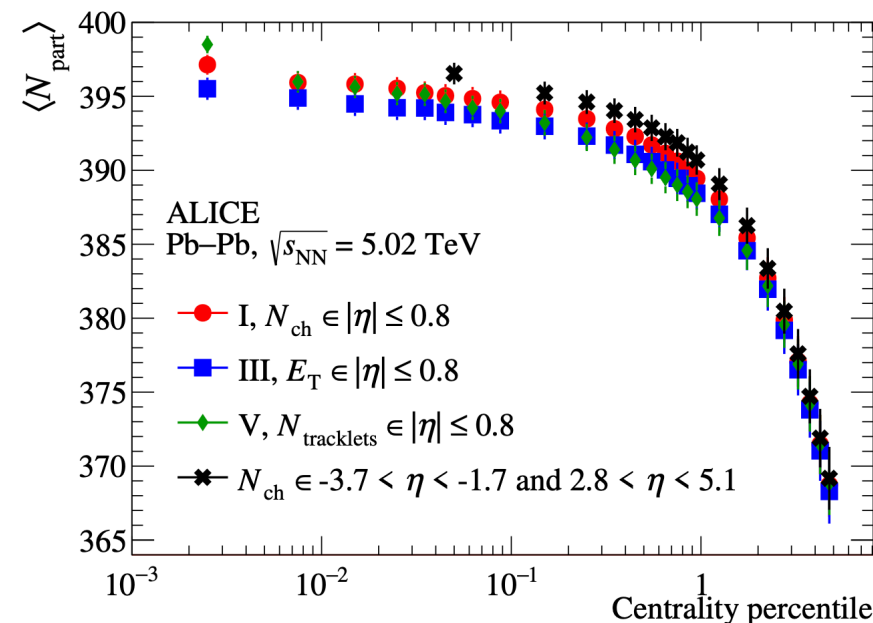
Centrality resolution is dependent on the system and estimator

✓ How should it be quantified?

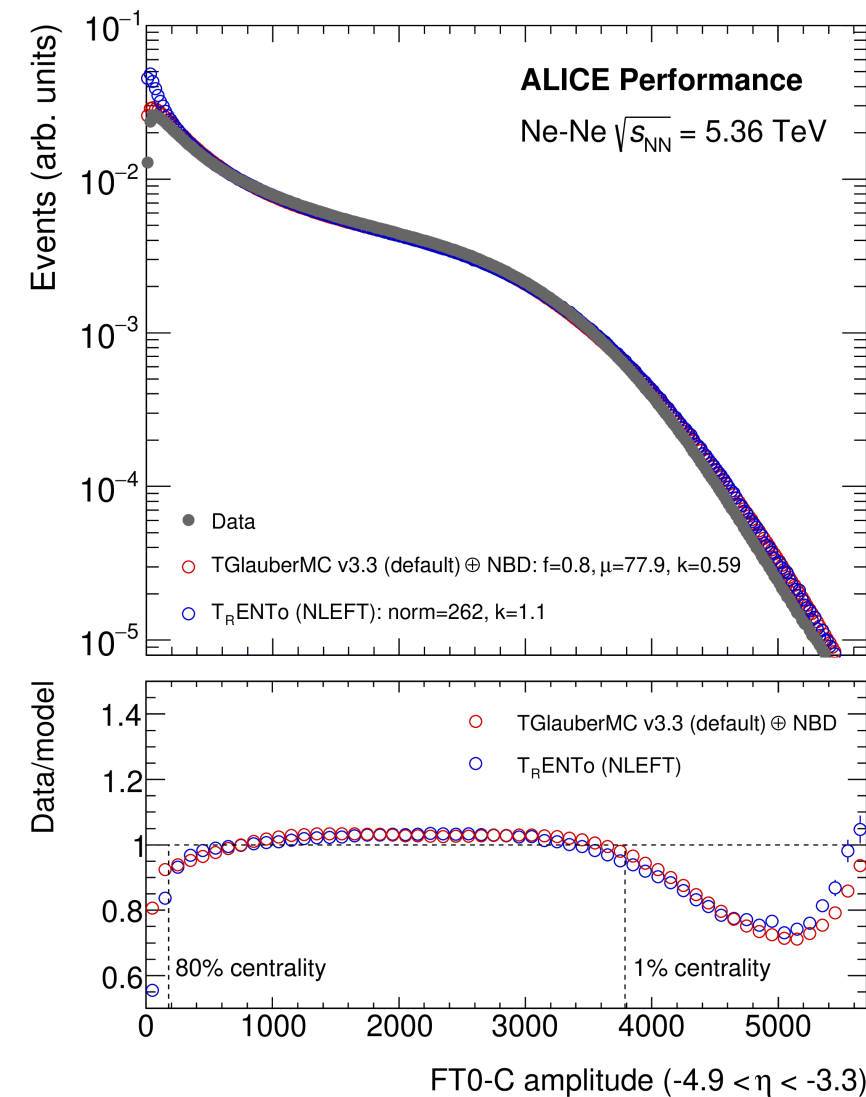
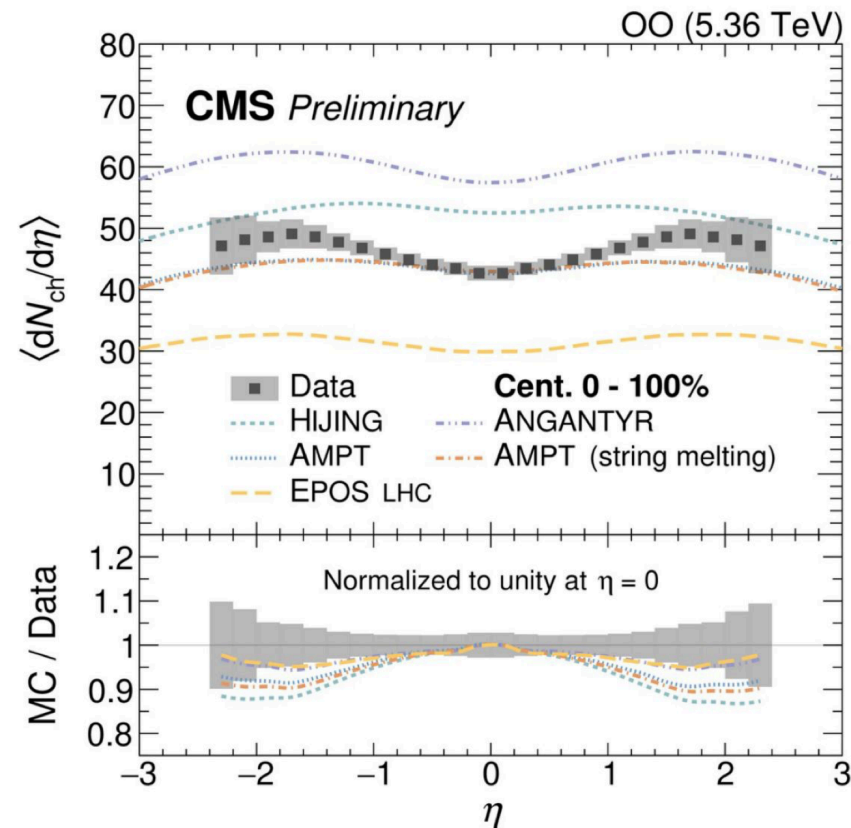
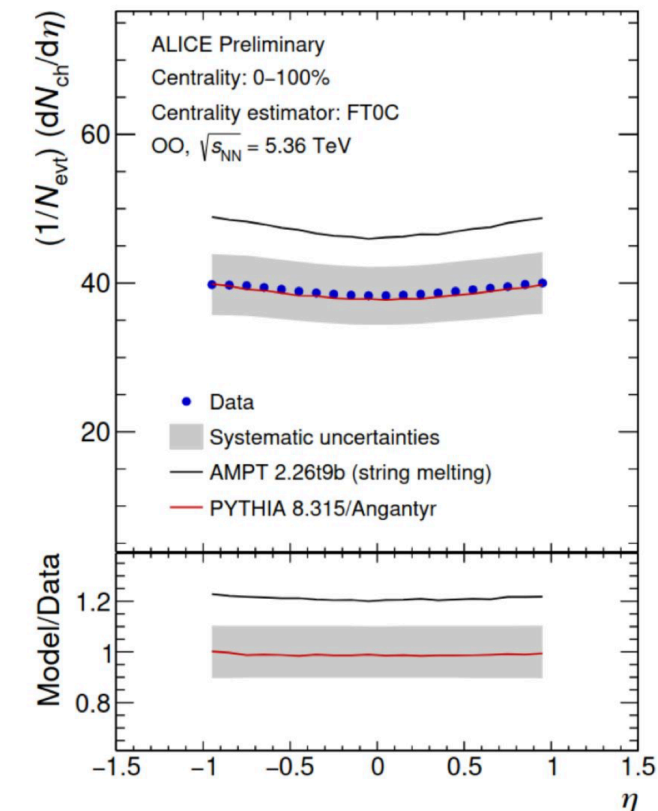
Centrality biases with respect to hard probes

✓ Irreducible or correctable for standard measurements?

[Park \(CU\) et al](#)



Backup



ALI-PERF-613669

Backup

