The jet Lund plane in pp collisions and prospects for a PbPb measurement with CMS

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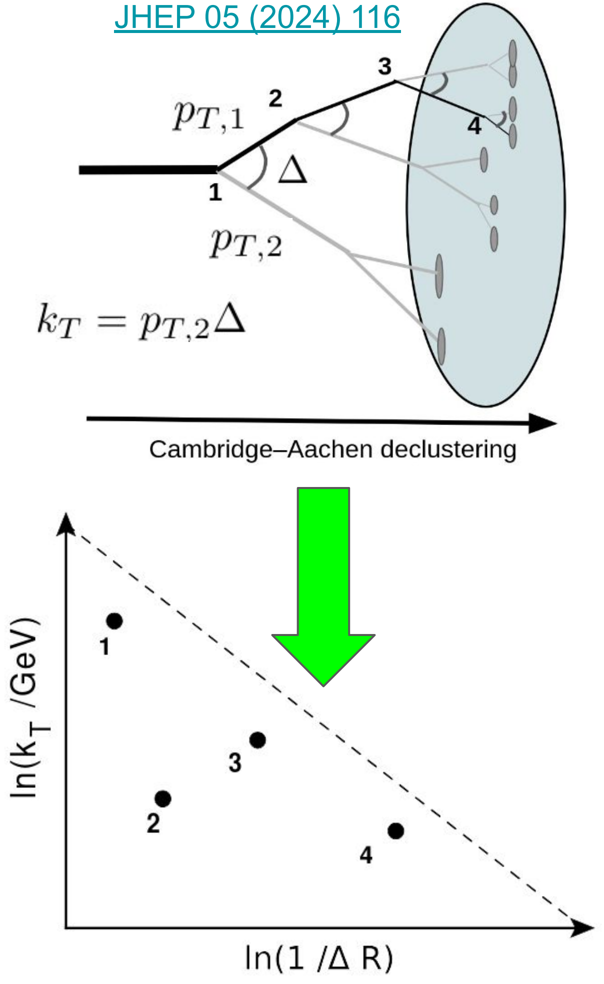
The (primary) jet Lund plane

JHEP 05 (2024) 116

- Representation of the emissions within a jet
- Recluster jet constituents using the **Cambridge–Aachen (C–A) algorithm**
  - ➢ only angle dependence in clustering
  - ➢ following the primary (hardest) branch
- 2D plane filled with each emission's **angle (Δ)** and **momentum relative to the emitter (k_T)**



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- 2D plane filled with each emission's **angle (Δ)** and **momentum relative to the emitter (k_T)**
- Different regions of the LP dominated by different physics
- Observable is calculable JHEP 10 (2020) 170

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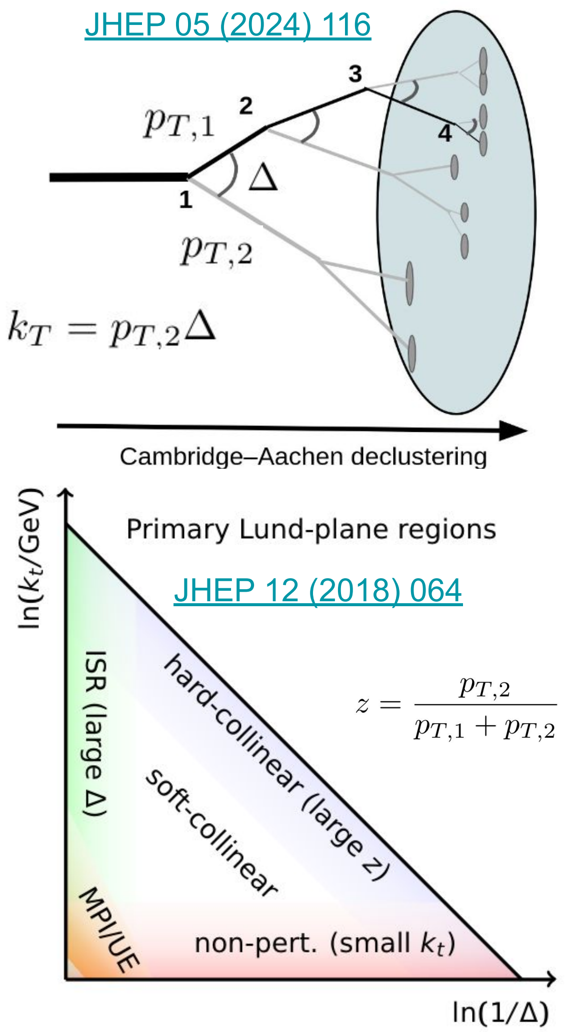
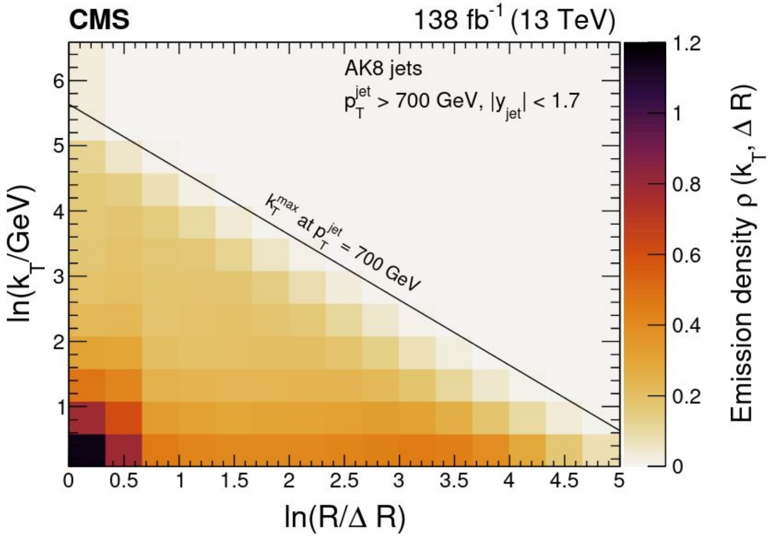
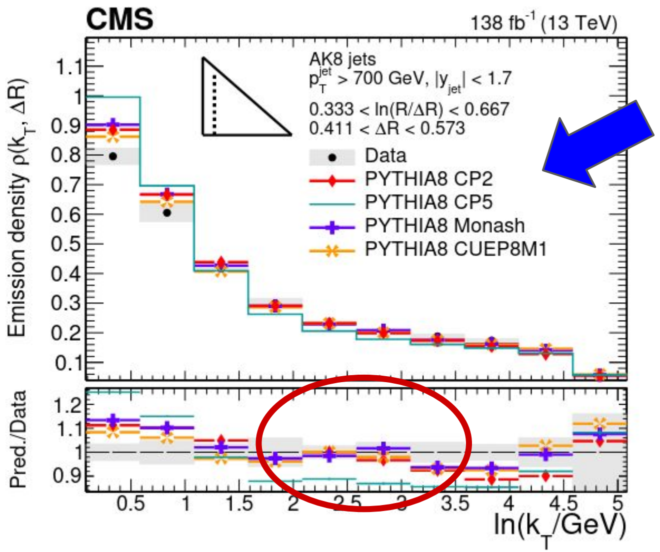


The (primary) jet Lund plane in pp

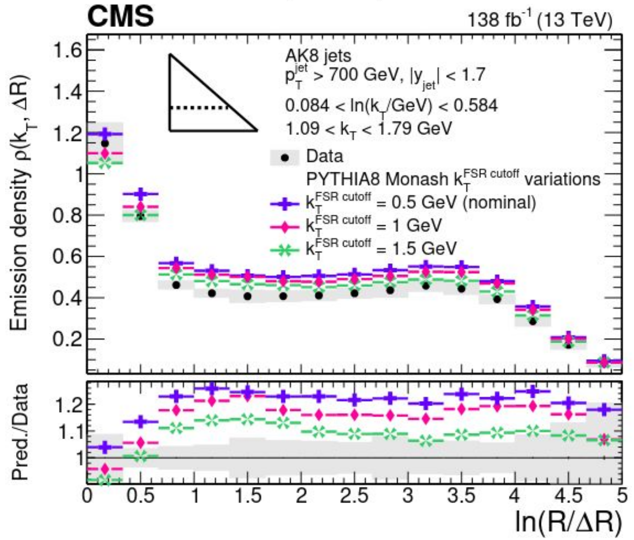
- Measured at 13 TeV pp collisions with CMS and other experiments JHEP 05 (2024) 116
- Reclustering **charged** particles
- Powerful tool for providing constraints on current models





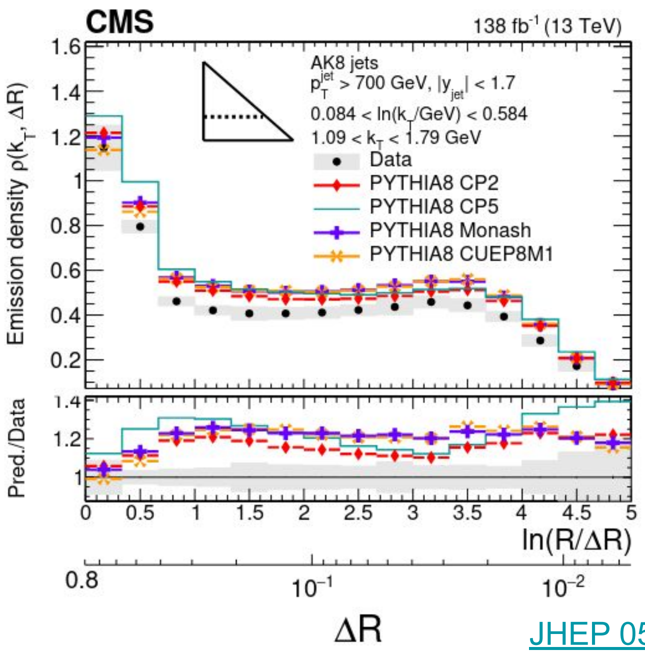
PYTHIA8 tunes: better agreement with data at higher $\alpha_s^{FSR}(m_Z)$

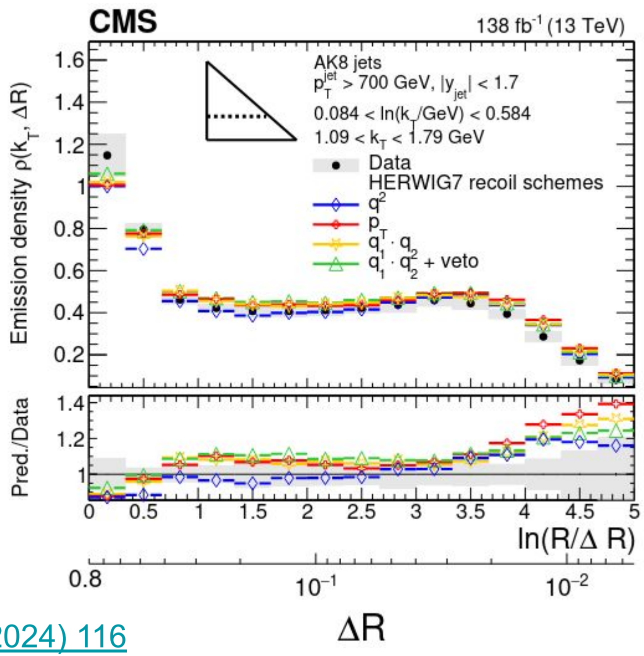
Parton shower cutoff: better agreement with higher shower cutoff



The (primary) jet Lund plane in pp

- Constraints on hadronisation models:
  - ➢ Data in better agreement with cluster fragmentation model predictions than with Lund string model
  - ➢ PYTHIA8 overestimates data by 15-20% across the region





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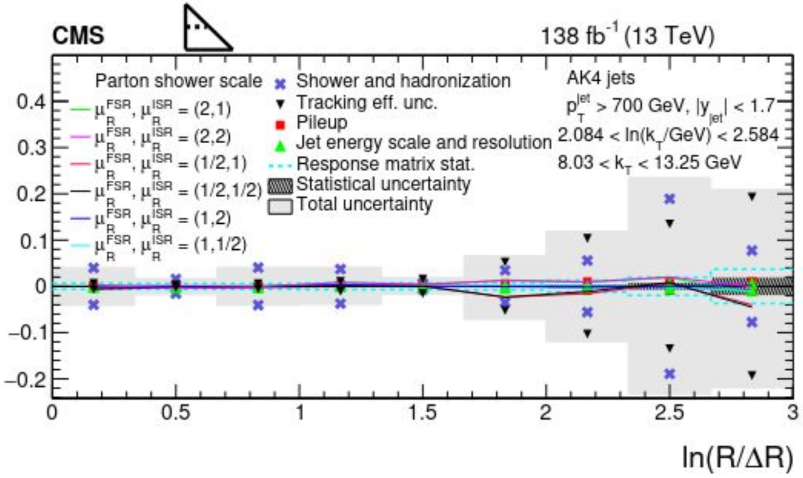
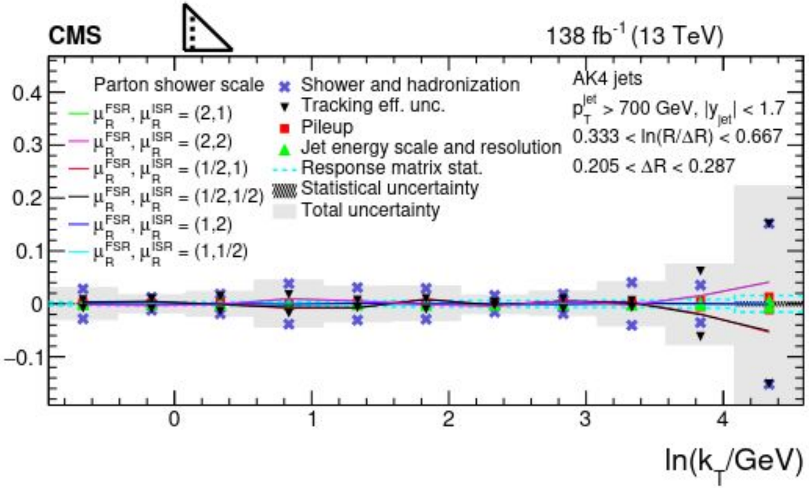
The (primary) jet Lund plane in pp

- Dominant uncertainties arise from:
  - ➢ Shower and hadronisation models effects on the unfolding through the prior and response matrix in unfolding
  - ➢ Tracking efficiency: as measurement is using only charged particles, the loss of a track results in a loss of a particle – more pronounced near LP edge, where departure from the pJLP are more probable





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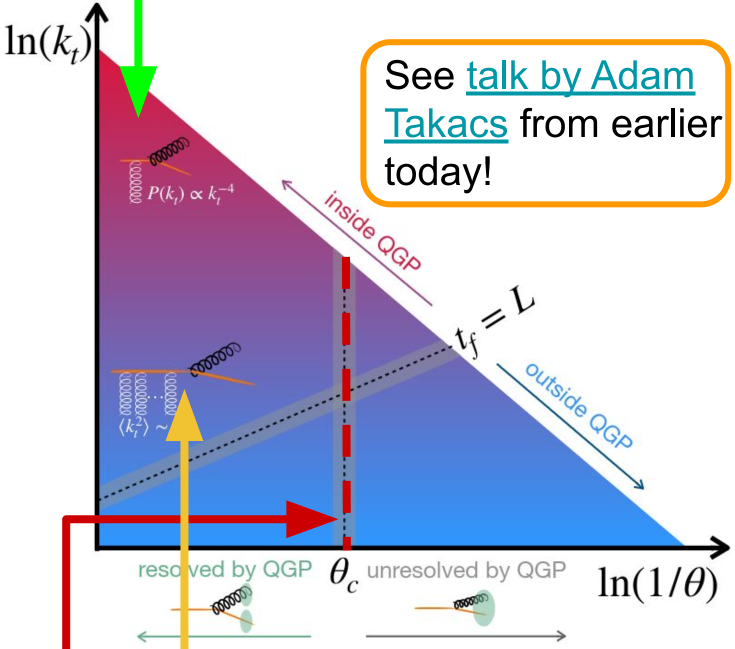
The jet Lund plane in PbPb

- Different effects due to QGP manifest in different regions of the Lund plane J.Phys.G 47 (2020) 6, 065102
- New approach: scanning LP from top to bottom allows for: Phys. Rev. D 110, 014015
  - ➢ k_T-ordered scan
  - ➢ Allows for gradual onset of colour coherence according to jet quenching models
  - ➢ Could constrain assumption of vacuum-like and in-medium factorisation

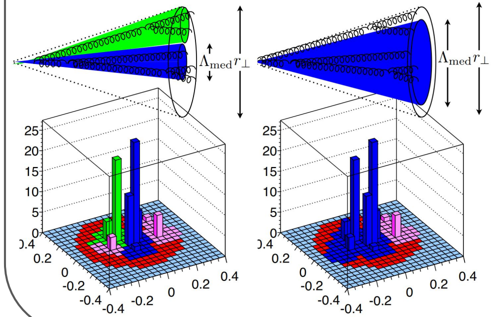
Expect vacuum-like emissions in high k_T region

See talk by Adam Takacs from earlier today!



Medium induced and UE combinatorial background

PLB 725 (2013) 357-360

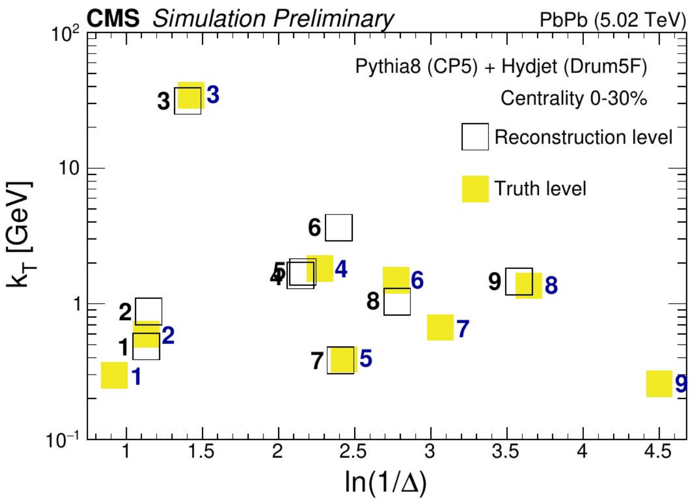


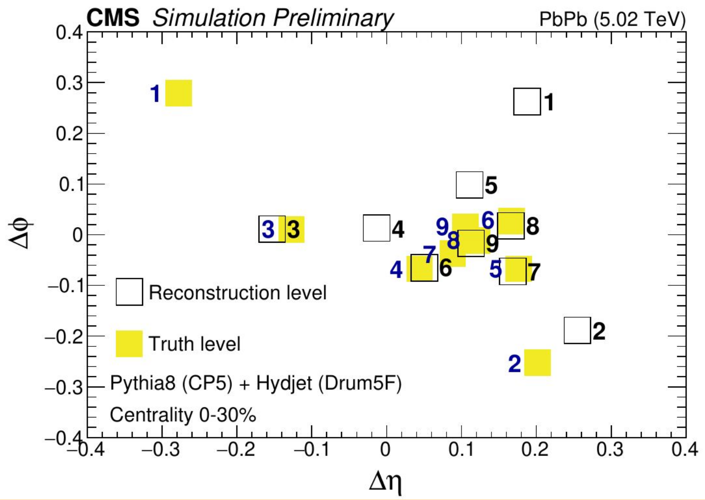
Colour coherence: below θ_c, particles act as a single source – less quenching

Selection procedure

- Select energetic jets – **p_T>200 GeV** to suppress non-perturbative effects
- **C–A** using **all** jet constituents
- Particle-level angular distribution for different values of k_T by **D'Agostini unfolding** in 3D - Δ, k_T, jet p_T
- Large underlying event and detector effects distort truth-reco correspondence of emissions
  - ➢ Only use the **hardest splitting at detector and truth level** which are **closest to each other in η–φ space**

Example jet pJLP satisfying the criteria, with highest split on both levels being the 3rd according to C–A

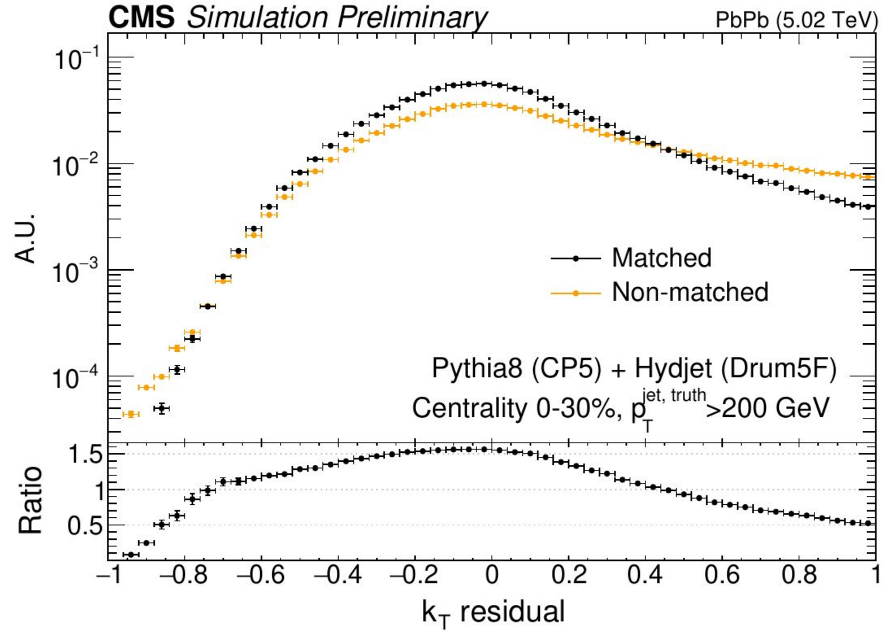


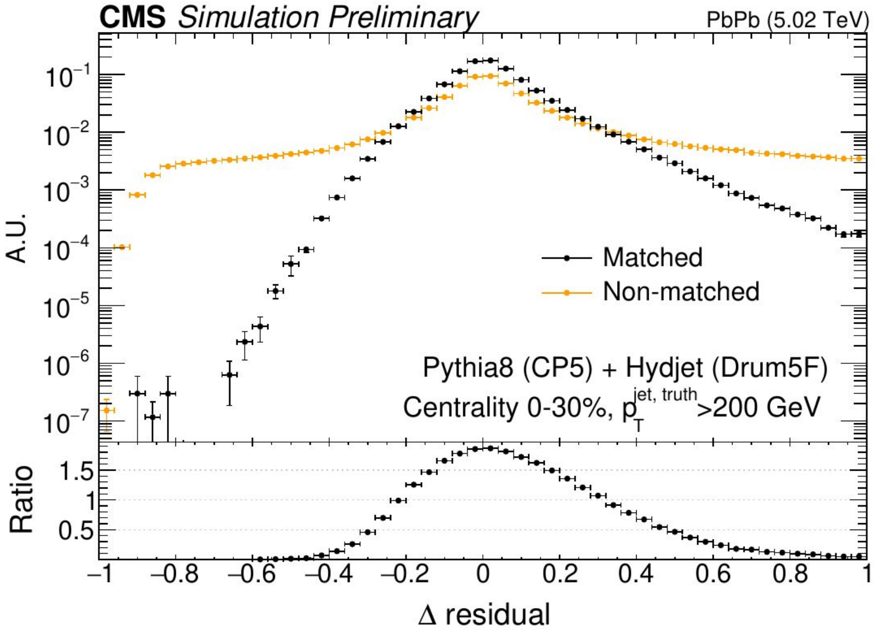


Truth-reco level correspondence

- Reconstruction-truth level matching leads to **improvement in Δ and k_T residual distributions** compared to non-matched case

$$\text{residual} = \frac{x^{reco} - x^{truth}}{x^{truth}}$$

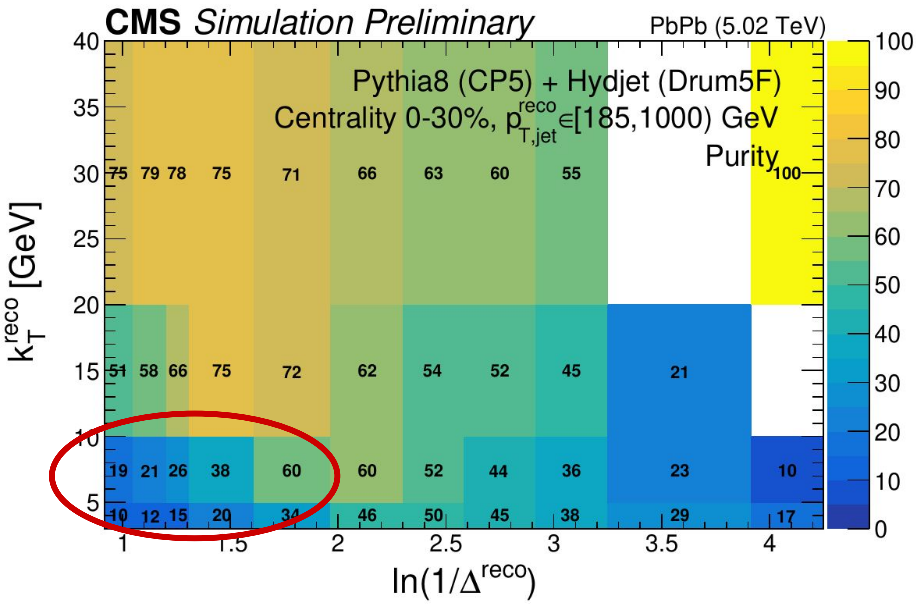




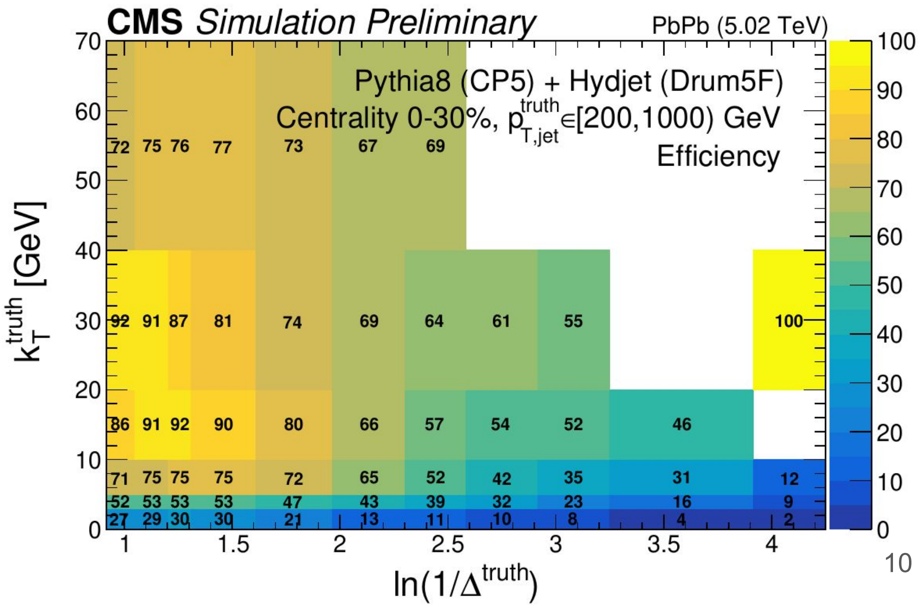
Matching of emissions

- Matching introduces a set of bin-by-bin **purity** and **efficiency** corrections applied to the detector level distribution before unfolding and to the unfolded distribution after
- Low purities at high angles and low k_T – combinatorial background from UE
- Facilitates unfolding but correction is fragmentation model dependent

matching purity



matching efficiency



Prior dependency of the unfolding

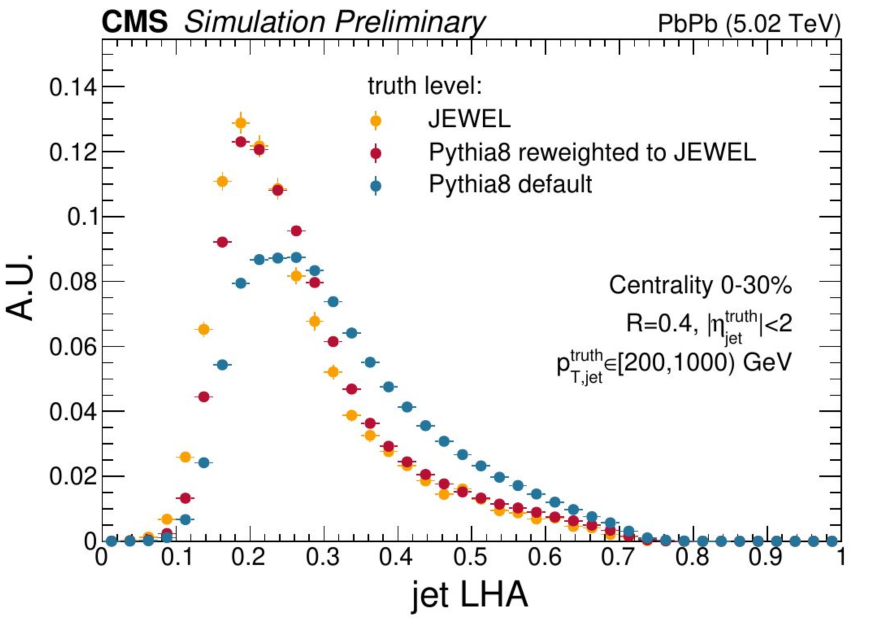
- In heavy ions, there are different strategies to estimate the prior uncertainty in PbPb
- The default sample used is PYTHIA8 embedded in HYDJET Minimum bias events
  - ➢ Does not contain jet quenching
- Attempt to reweigh the particle level radiation pattern of PYTHIA8 to match the one of a model which includes quenching – JEWEL (also Hybrid in backup slides)
  - ➢ Use primary JLP density as a proxy for the parton shower
  - ➢ By reweighting the pJLP density, expect to also affect observables which are not directly derived from the pJLP
  - ➢ Reweigh each jet by the product of each of its pJLP emission

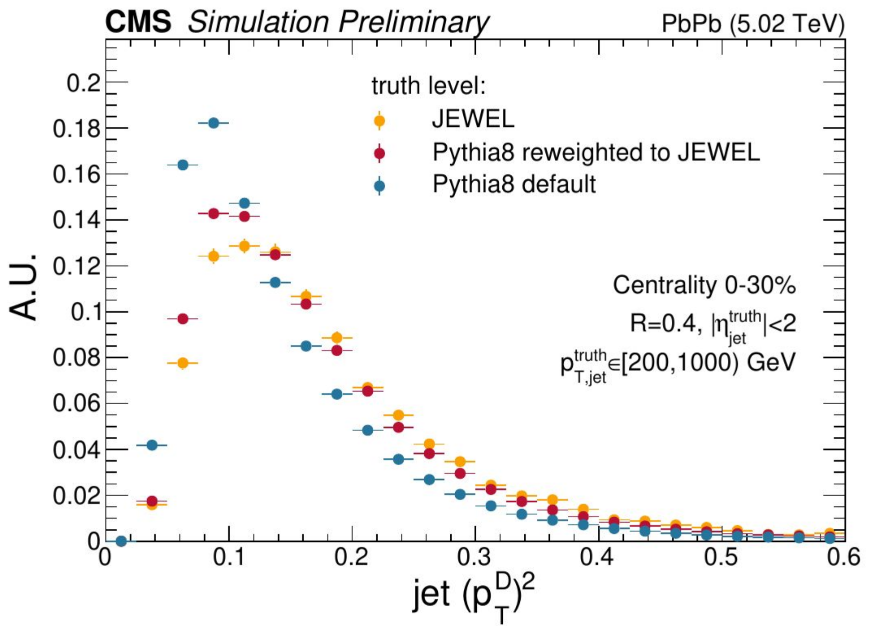
PYTHIA8 reweighting using JEWEL

- Test impact of reweighting on observables not directly connected to the pJLP
  - ➢ Jet angularities
- Normalised distributions of $\lambda_{0.5}^{1}$ (Les Houches angularity, **LHA**) and λ_{0}^{2} (momentum dispersion, **$(p_T^D)^2$**)

$$\lambda_\beta^\kappa = \Sigma_i z_i^\kappa (\Delta R_i/R)^\beta$$

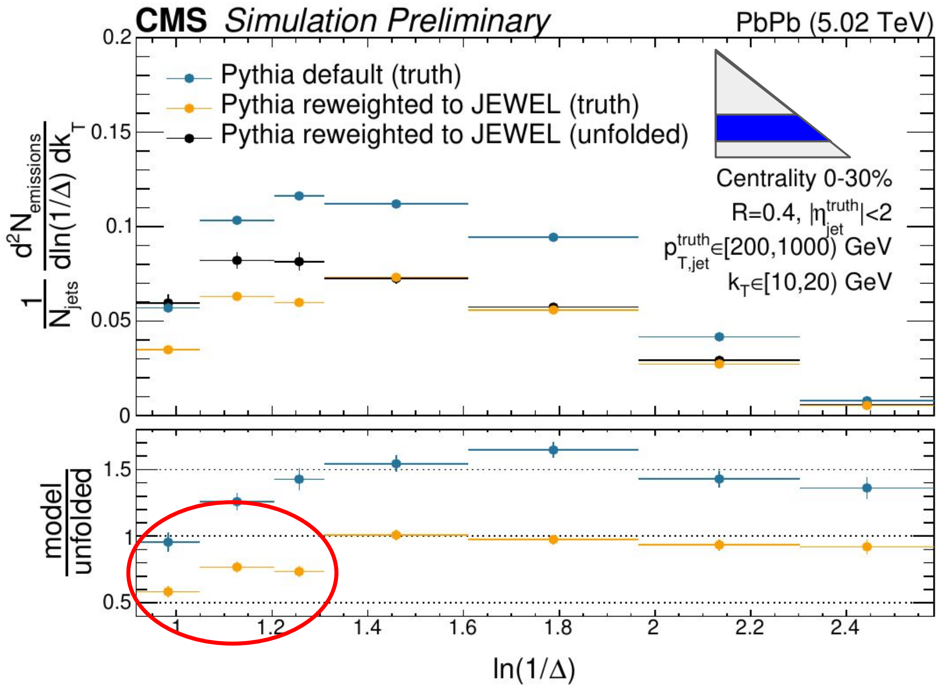
sum over all jet constituents i with fractional momentum z_i and distance to jet axis ΔR_i

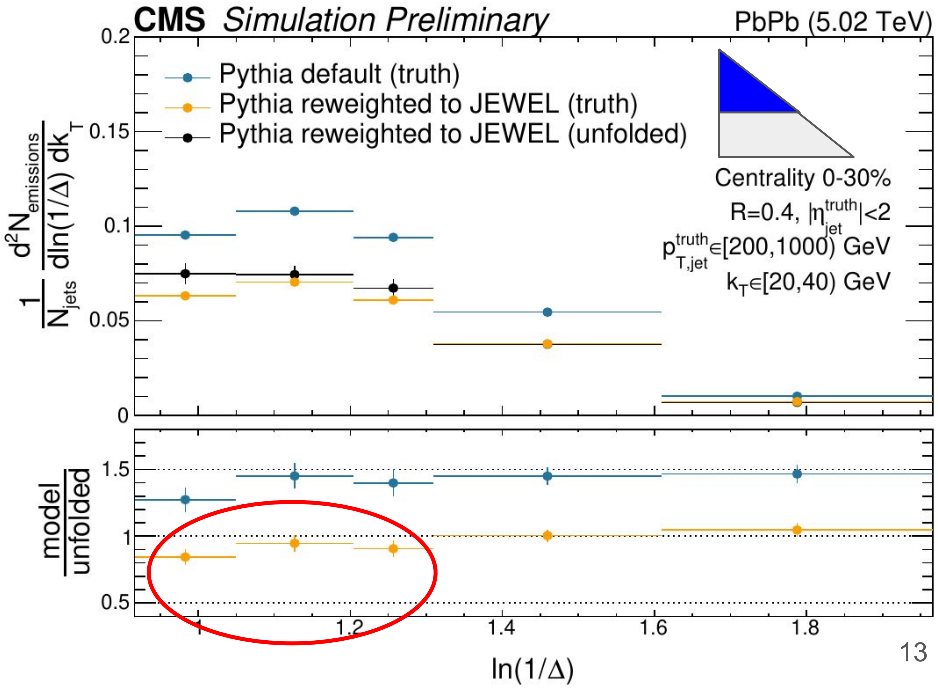




Estimate of prior uncertainty with reweighted PYTHIA8

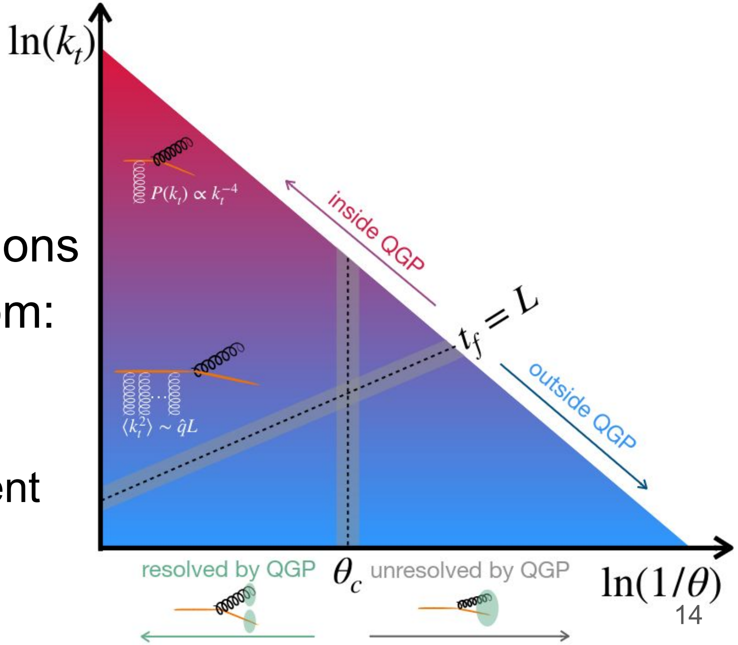
- Take the reweighted PYTHIA8 distribution and unfold it using the default PYTHIA8 prior and compare to the two particle level distributions in two different k_T bins
- **Large nonclosures** observed at **large angles** – should be of the same order of magnitude as prior uncertainty when unfolding the data





Summary

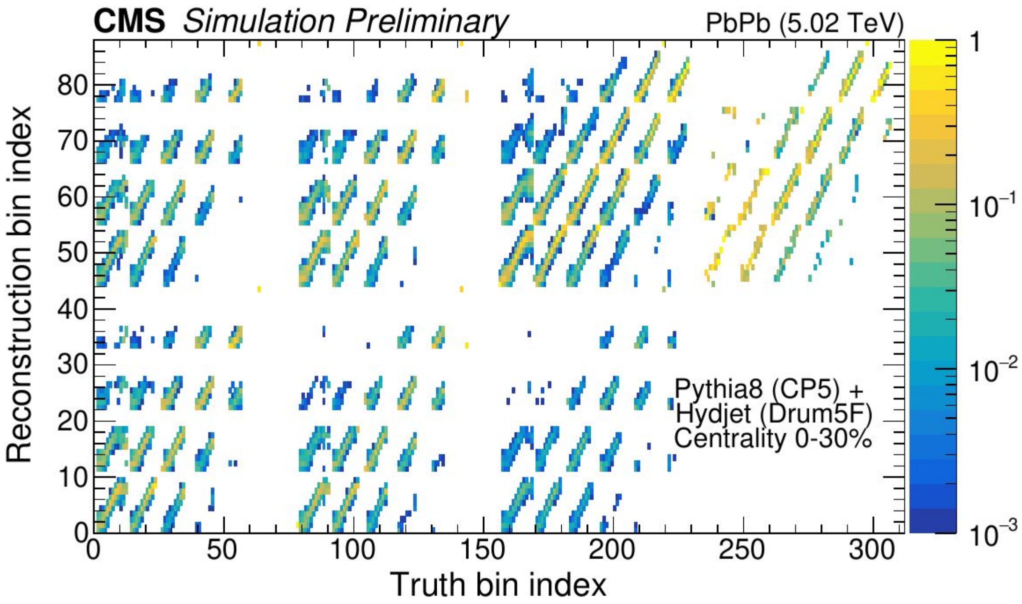
- The primary Lund plane has been used as a powerful tool for constraining different modelling parameters in pp collisions
- Could be used in PbPb collisions to put constraints on different jet-quenching and medium response models
- Challenges in PbPb measurement include large UE background and detector effects, as well as potentially large model dependence of the corrections
- Prospects for a k_T scan of the LP from top to bottom:
  - ➢ Need for emission matching
  - ➢ New techniques for the prior uncertainty assessment



BACKUP

Response matrix

- The response matrix used for the 3D unfolding
  - ➢ 8 largest blocks correspond to different p_T bins
  - ➢ containing cells of different k_T values
  - ➢ smallest structures representing the angle Δ



- Despite the effort to remove the combinatorial background through matching, non-diagonalities in the response matrix are still present in the low k_T region

PYTHIA8 reweighting using Hybrid

- Test impact of reweighting on observables not directly connected to the pLJP
  - ➢ jet angularities
- Normalised distributions of $\lambda_{0.5}^{1}$ (**LHA**) and λ_{0}^{2} (**$(p_T^D)^2$**)

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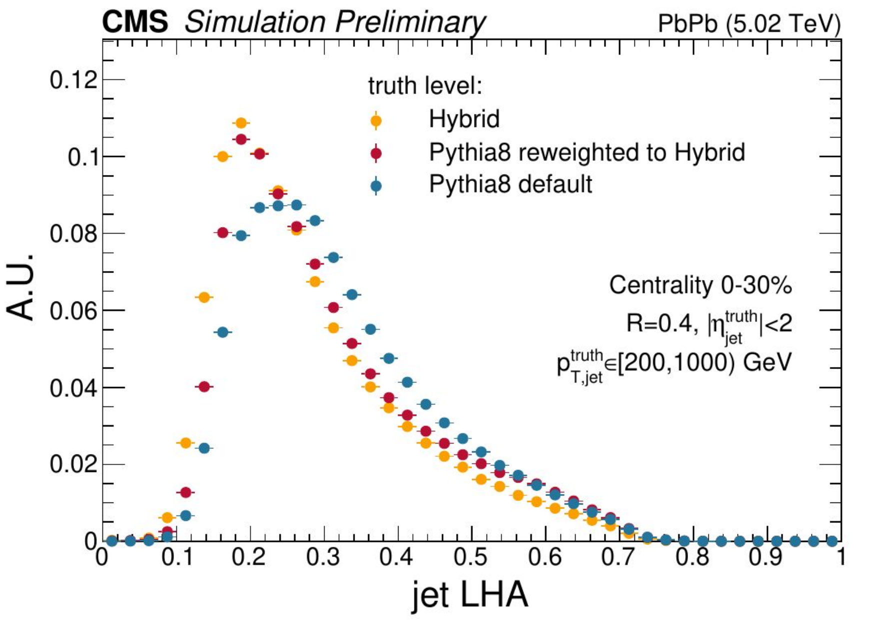

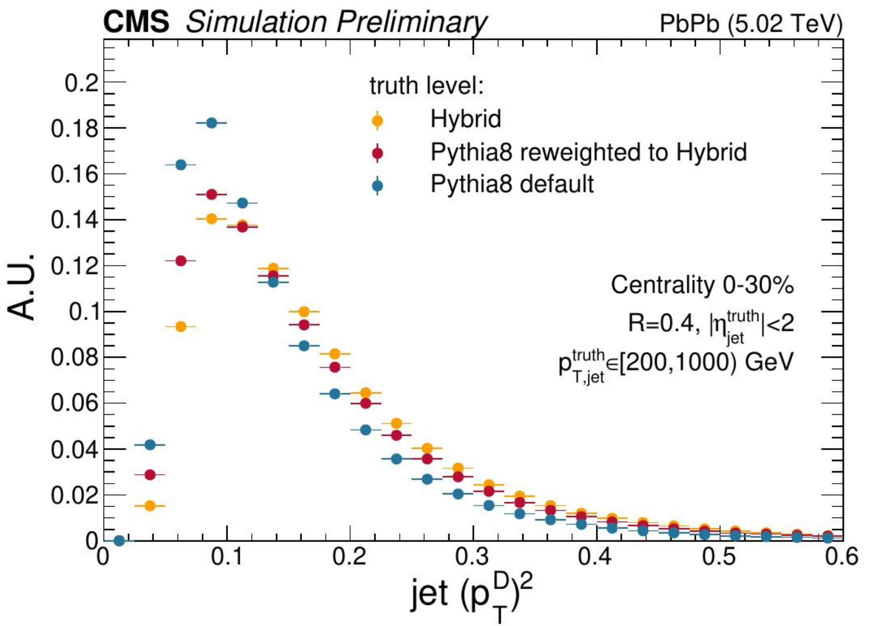

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