New measurements of inclusive jet suppression in Pb-Pb collisions with ALICE

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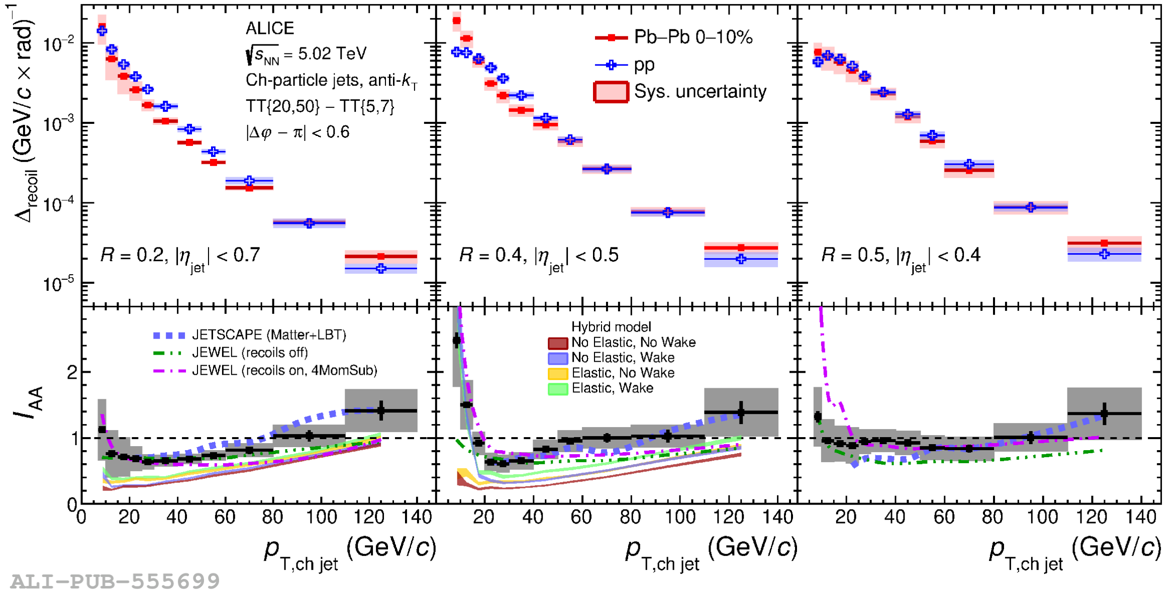
on behalf of the ALICE collaboration

Hard Probes 2024, Nagasaki, Japan – 24/09/2024

Jets as probe of the QGP

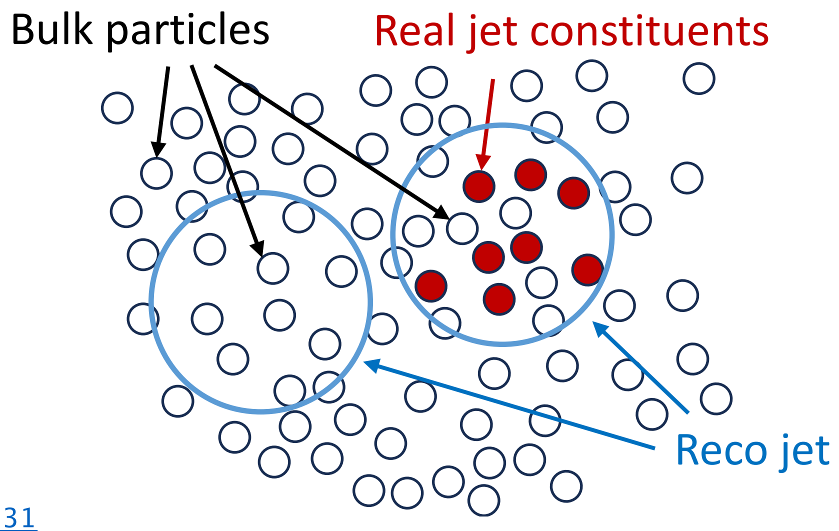
- Jets – hard probes:
  - Access to kinematics of partons scattered in initial stages of the collision (very well described by pQCD)
  - Probe QGP through:
    - **Collisional and radiative energy loss** (this talk)
    - Changes to jet substructure (Bas Hofman 23/09 14:40)
    - Hadrochemistry modification (Sierra Lisa Weyhmiller 24/09 11:10)
- ALICE detector: low p_{T} reach
- This talk covers energy loss:
  - **Statistical approach** to extend inclusive jet measurement to **very low p_{T}**
  - Performance of ALICE in Run 3 data
  - v_2 measurement did not converge in time, no results to show

arXiv:2308.16131



Distributions of recoil jets with R=0.2, 0.4, and 0.5 in pp and central Pb-Pb collisions
Upper panels: corrected Δ_{recoil} distributions. Lower panels: I_{AA}.

Jet measurements at low p_{T}



- Jet measurements in Pb-Pb challenging due to large **non-uniform uncorrelated background**
- Combinatorial ("fake") jet yield from jets clustered wholly around products of many soft (low Q^2) interactions
- Smearing of p_{T} of true jets arising from detector effects and bkg fluctuations

- Current ALICE jet R_{AA} measurement: low p_{T} reached with Machine Learning based background subtraction (10.1016/j.physletb.2023.138412)
- **Data-driven statistical approach** to push to even lower p_{T}
  - semi-inclusive: hadron correlations
  - can we also extend the low p_{T} reach for inclusive jets?
    This analysis

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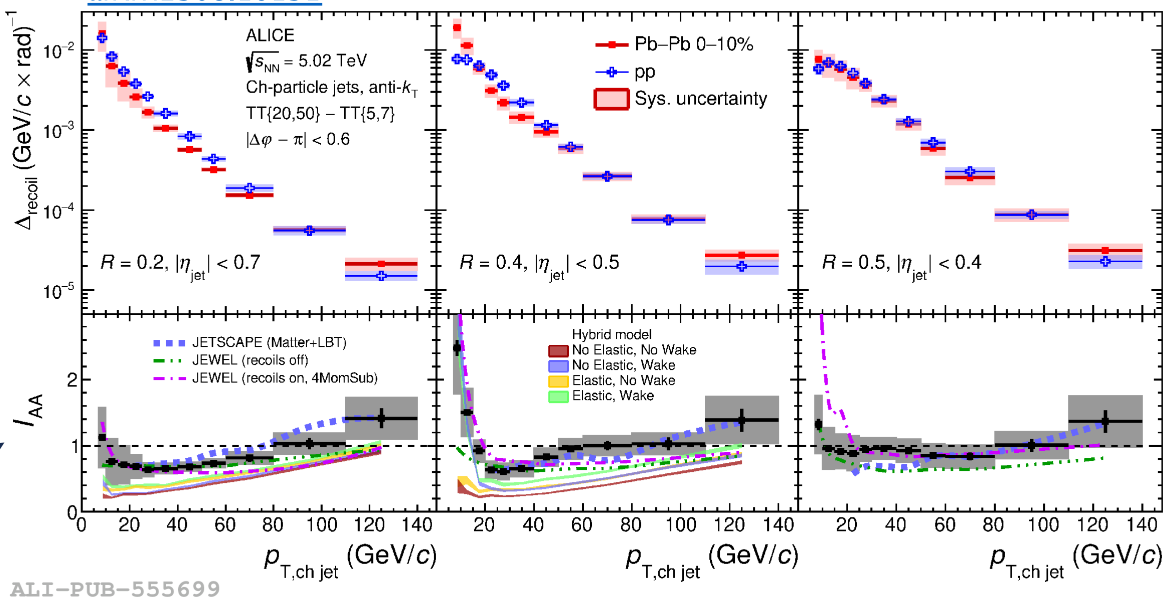
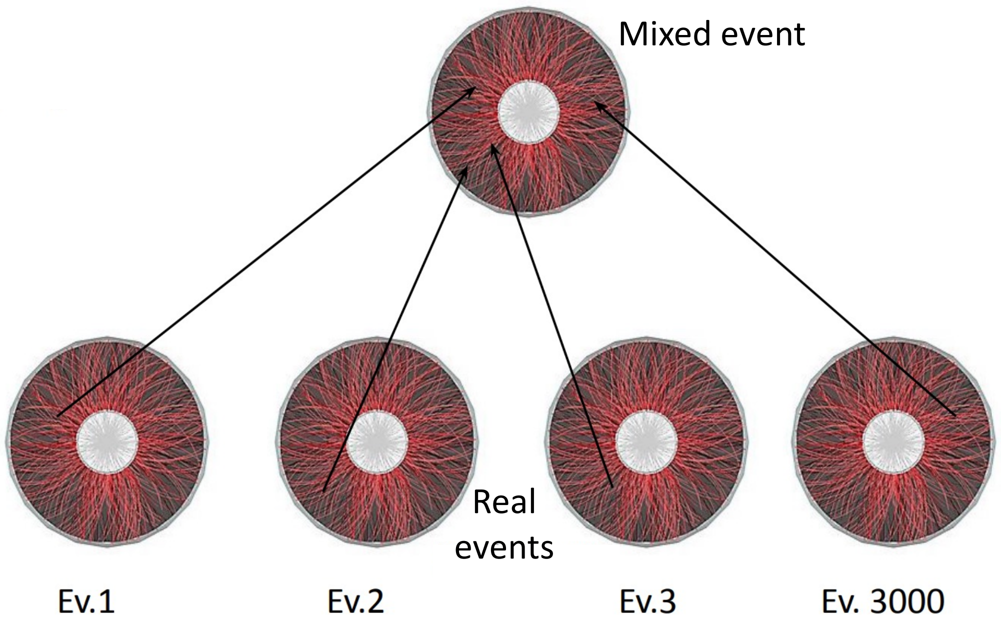


Distributions of recoil jets with R=0.2, 0.4, and 0.5 in pp and central Pb-Pb collisions
Upper panels: corrected Δ_{recoil} distributions. Lower panels: I_{AA}.

Jet analysis with a mixed event technique

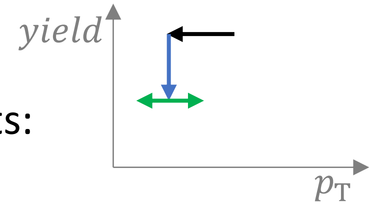
- ALICE 2018 Pb-Pb data, $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, 0-10% centrality
- Jet analysis:
  - charged particle jets: **anti-k_{T}, R = 0.3, $|\eta| < 0.6$**
- Assembly of mixed events (ME):
  - Categorisation of events into 9600 (multiplicity, z-vertex, event plane, $p_{\mathrm{T},tracks}^{sum}$) categories
  - One track from each real event of a same category (same event, SE)
  - ➜ Removes multi-hadron correlations

First use of ME technique: in STAR
10.1103/PhysRevC.96.024905



- Background correction:
  - Remove pedestal underlying event from the jets:

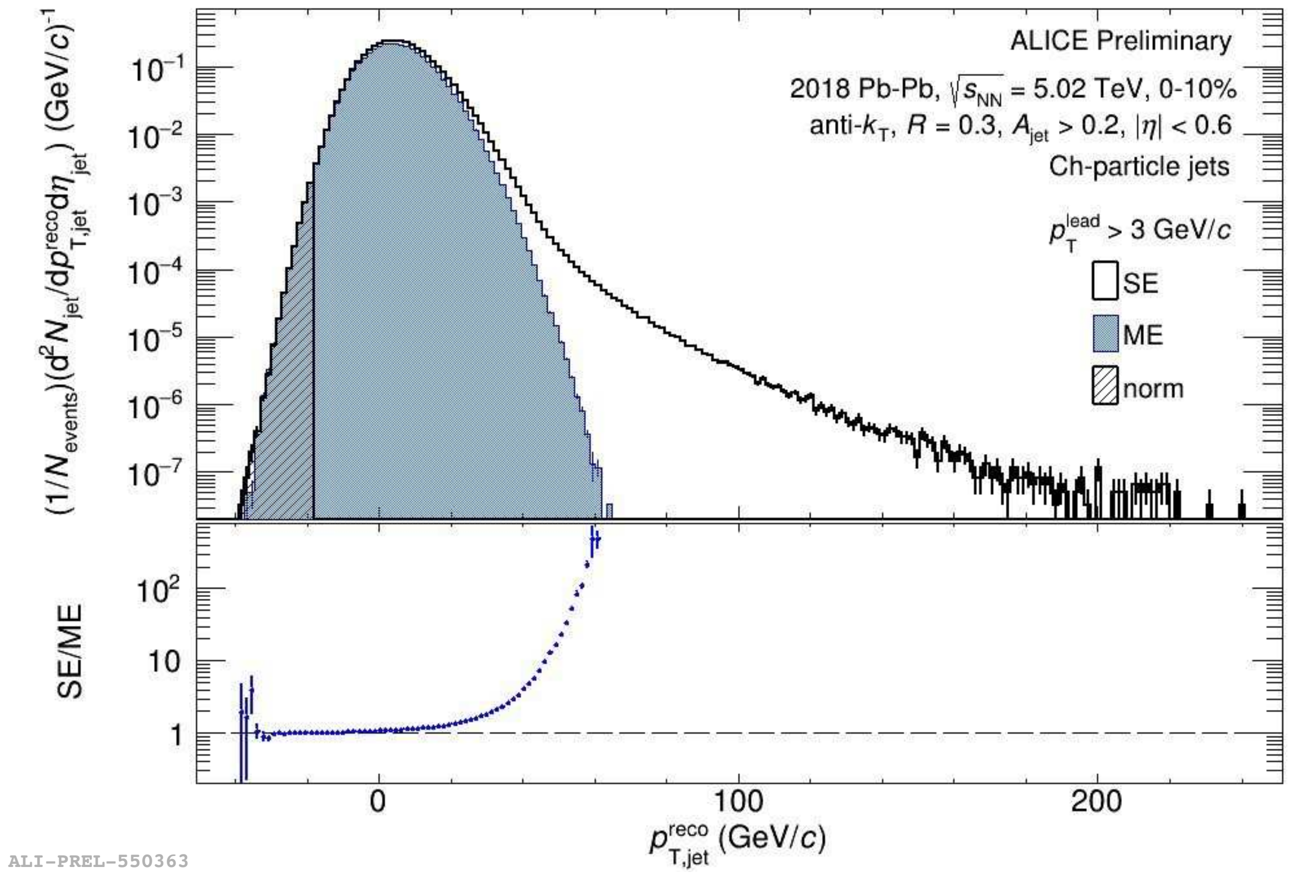
$$p_{\mathrm{T},jet}^{reco} = p_{\mathrm{T},jet}^{raw} - A_{jet} * \rho$$



  - Use Mixed Events (ME) to remove combinatorial jets from the yield
  - Unfolding to correct for smearing

Raw quasi-incl. jet distribution, R = 0.3

- Inclusive distribution of partons at low p_{T} : many overlapping objects, cannot reconstruct as distinct jets
  - ➜Introduce a small bias to define jet objects that can be interpreted in theory:
    - leading track cut 3 GeV/*c* or 4 GeV/*c*
  - ➜Vary the bias to measure its effect & determine the p_{T} region where the bias is negligible



Raw biased jet distribution, p_{T}^{lead} > 3 GeV/*c*

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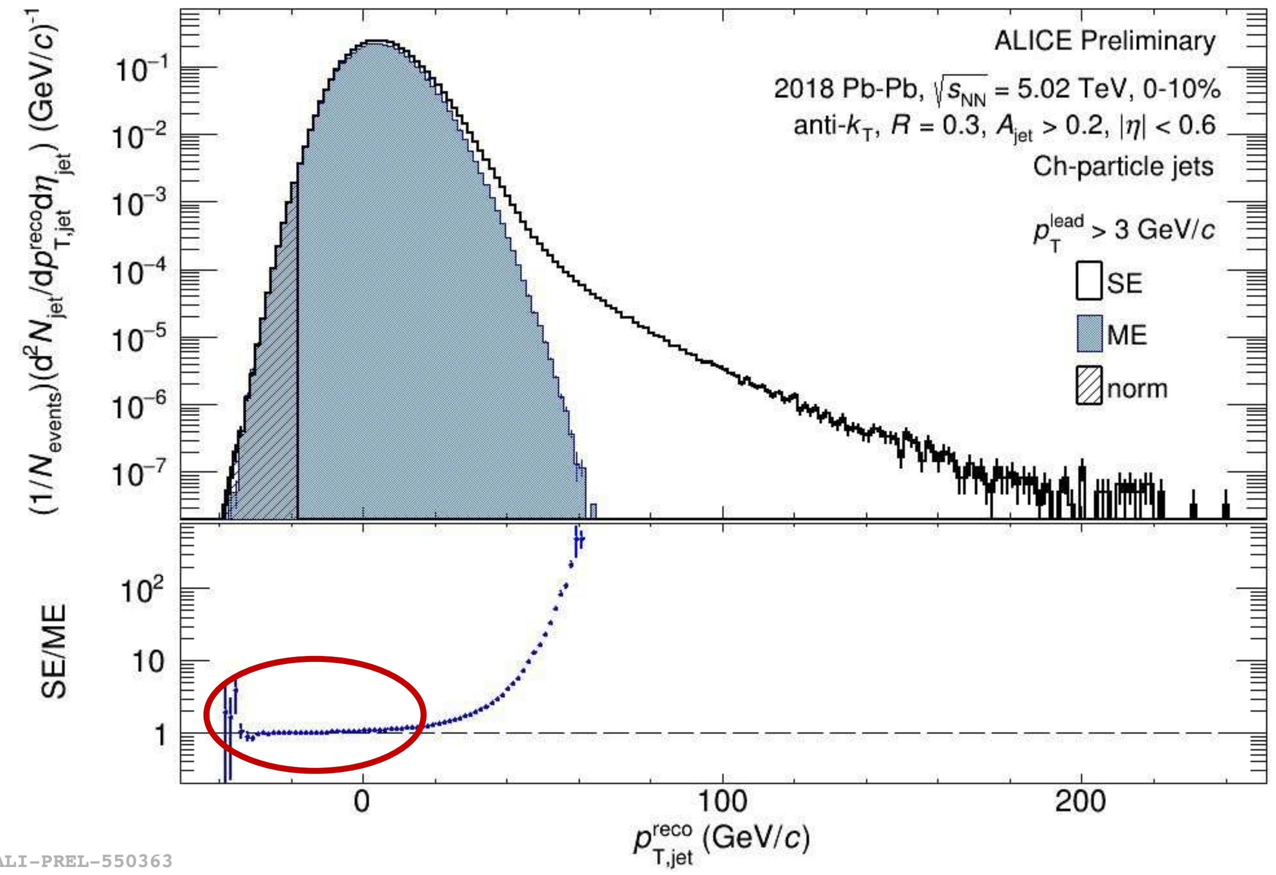
- Essential criterion for ME: ratio needs to be flat on the left-hand side (no jet signal)
- Normalisation of ME: data driven



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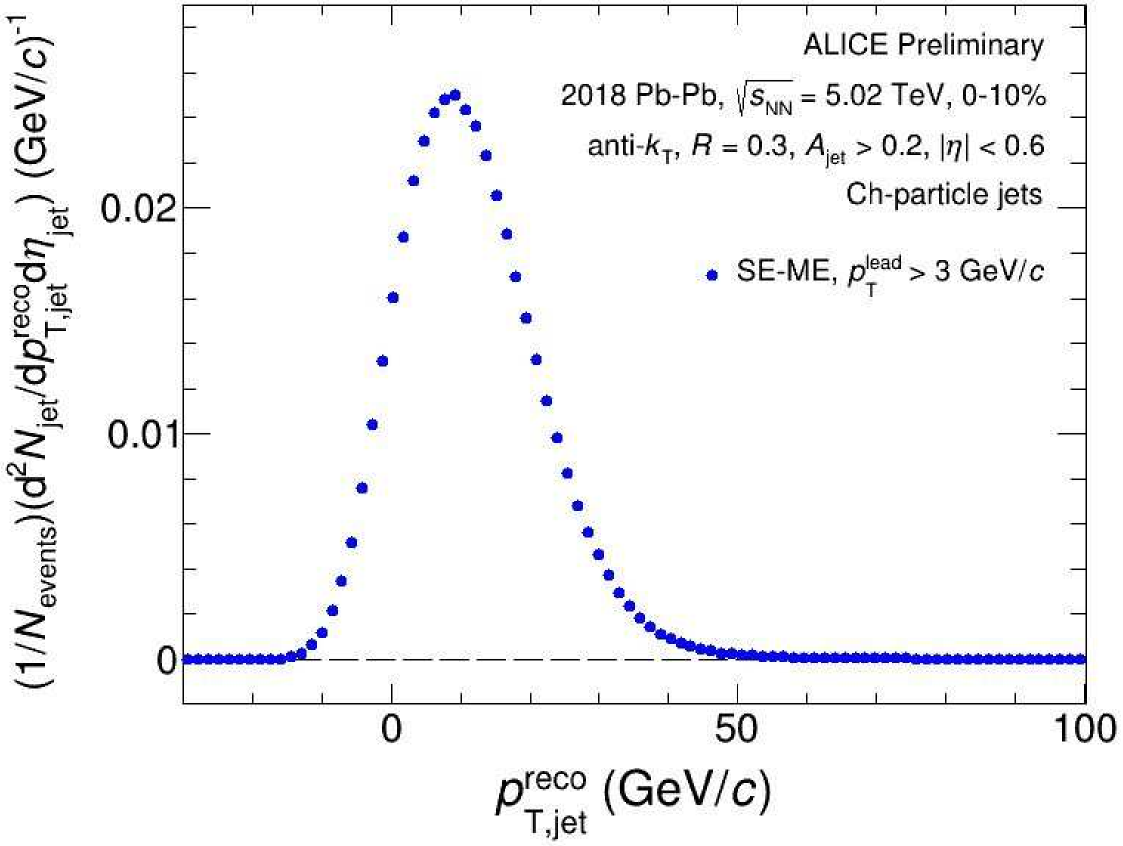
- Subtraction of combinatorial background yield using ME



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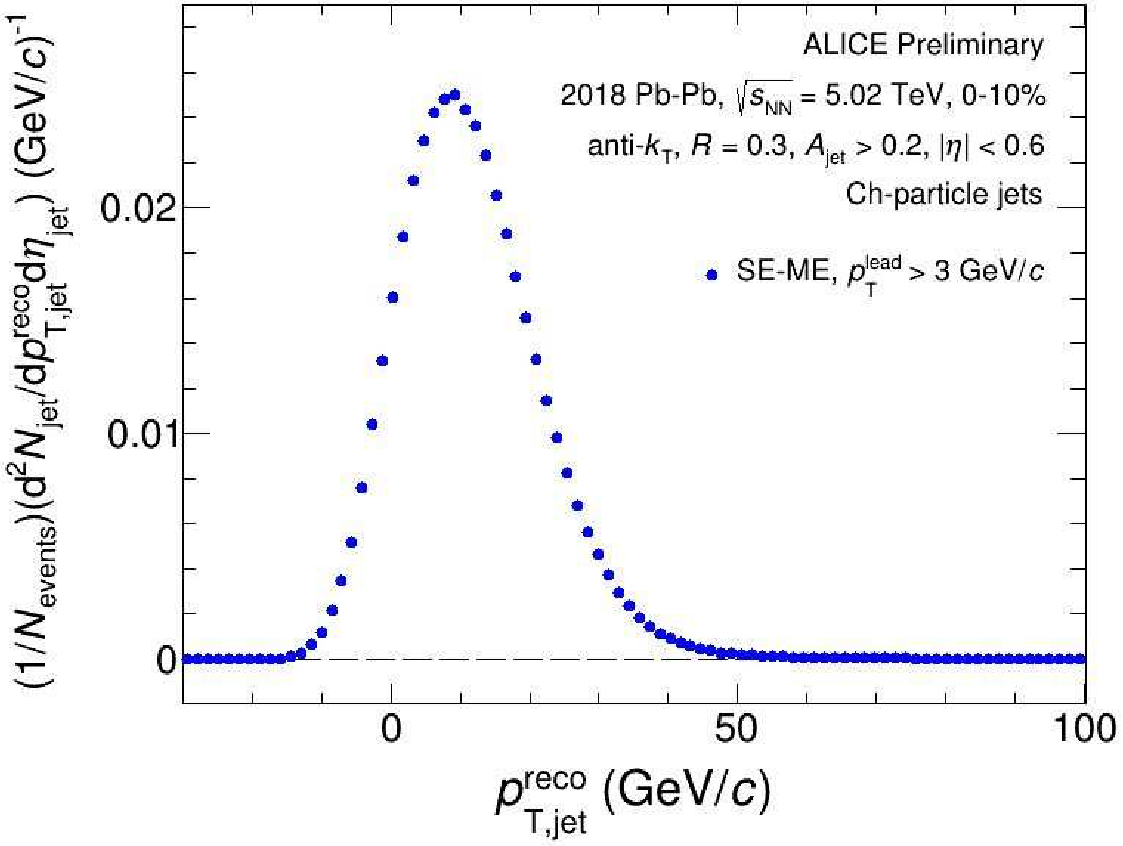
Raw correlated biased jet distribution, p_{T}^{lead} > 3 GeV/*c*: SE-ME

Raw quasi-incl. jet distribution, R = 0.3

- Inclusive distribution of partons at low p_{T} : many overlapping objects, cannot reconstruct as distinct jets
  - ➜Introduce a small bias to define jet objects that can be interpreted in theory:
    - leading track cut 3 GeV/c or 4 GeV/c
  - ➜Vary the bias to measure its effect & determine the p_{T} region where the bias is negligible
- Essential criterion for ME: ratio needs to be flat on the left-hand side (no jet signal)
- Normalisation of ME: data driven
- Subtraction of combinatorial background yield using ME

> ○ ME procedure removes uncorrelated bkg yield
> ○ Leading track p_{T} cut generates countable objects



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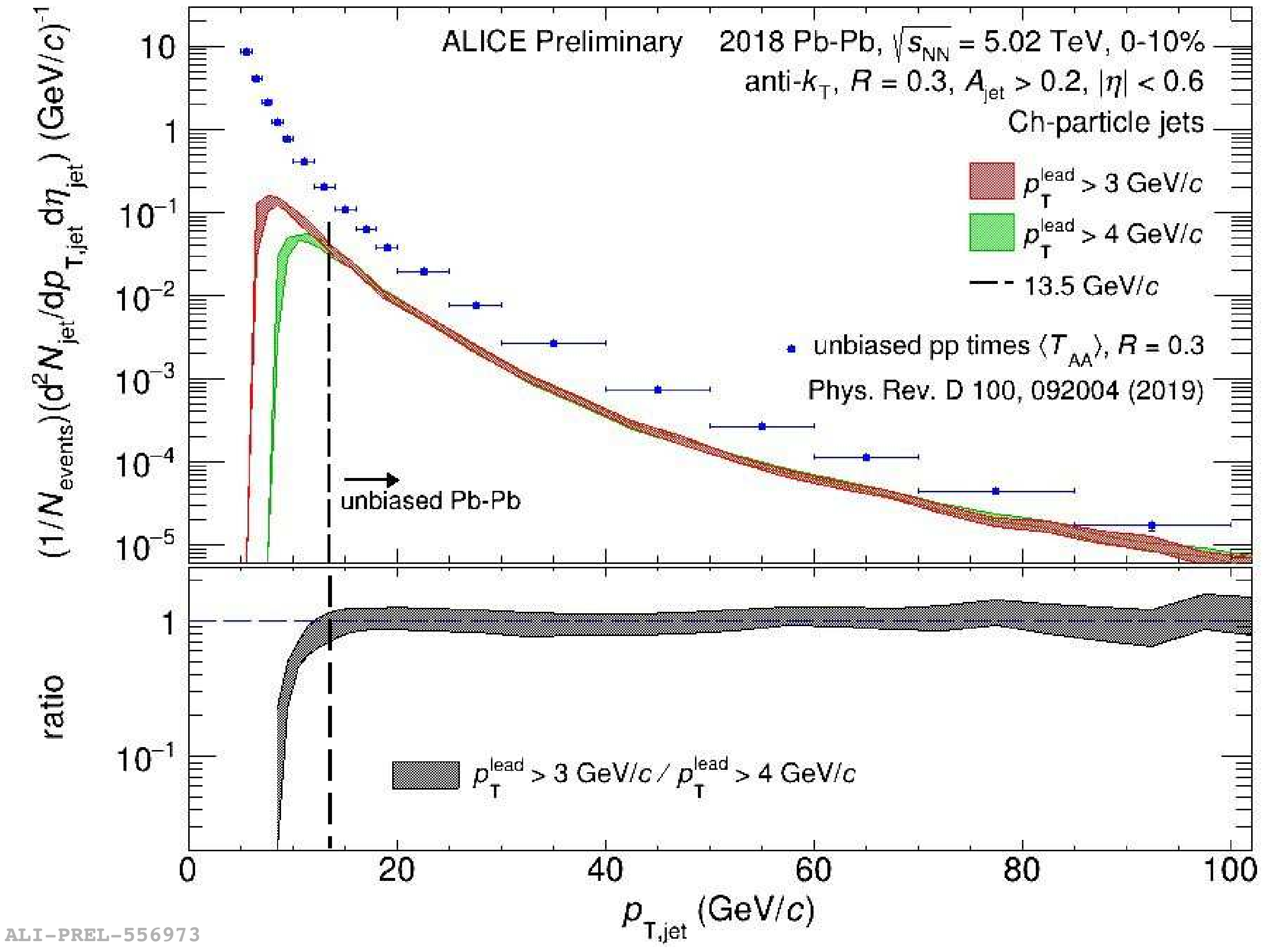
Raw correlated biased jet distribution, p_{T}^{lead} > 3 GeV/c: SE-ME

Corrected jet distributions, R = 0.3

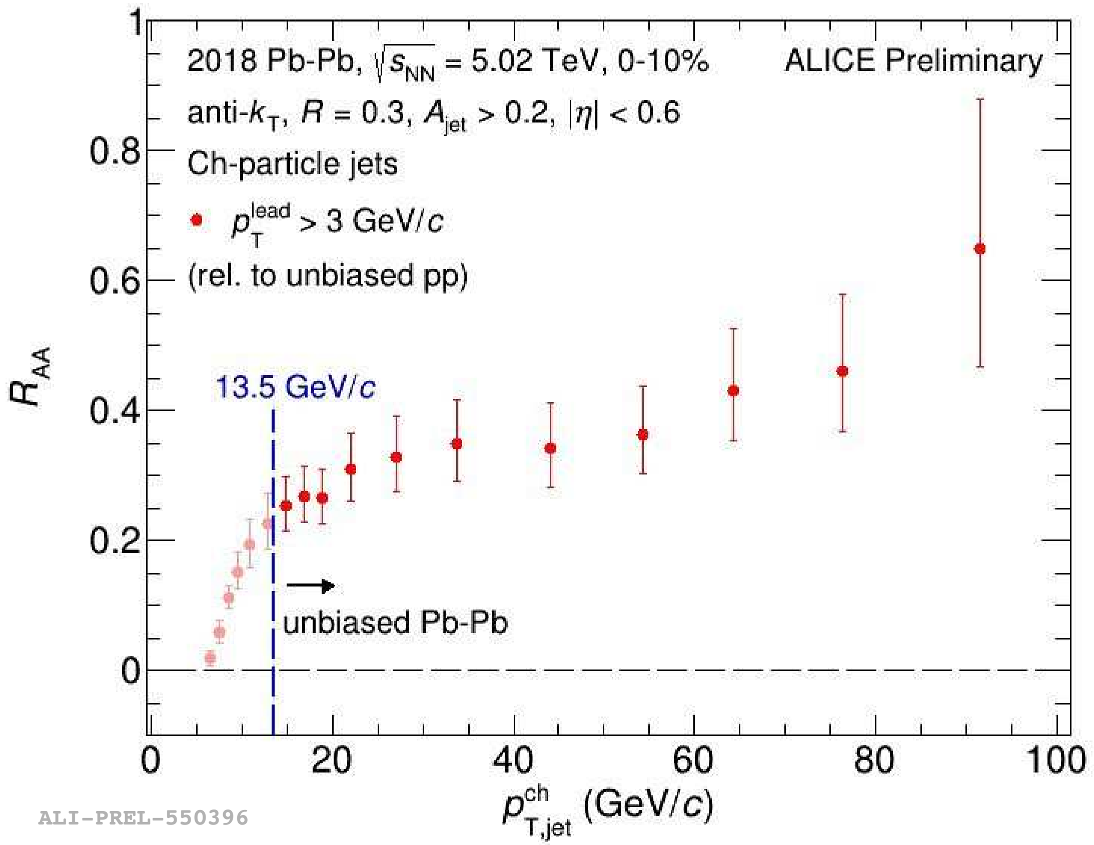
- Once the yield is subtracted, smearing of jets due to residual background fluctuations and detector effects is corrected ➜ **Unfolding**
- Fully corrected quasi-incl. charged-particle jet distributions with p_{T}^{lead} > 3 GeV/c and p_{T}^{lead} > 4 GeV/c
- Systematic uncertainties from ME, DCA, tracking efficiency & unfolding

- Determining where the bias is small
- Effect of the leading track bias: **no bias within uncertainties for $p_{\mathrm{T},\,jet}$ > 13.5 GeV/c**

➜ unbiased Pb–Pb at $p_{\mathrm{T},\,jet}$ > 13.5 GeV/c



Charged-particle jet R_{AA}



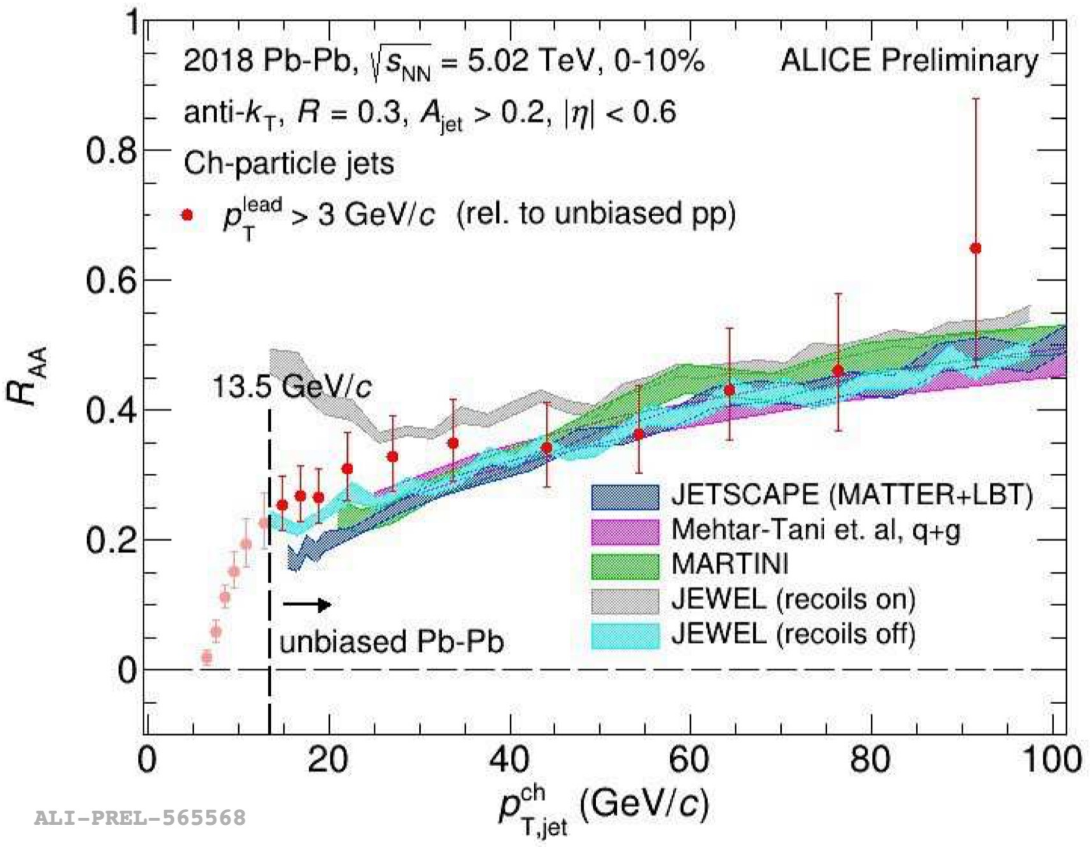
$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \frac{\mathrm{d}^2 N_{jets}^{\mathrm{AA}} / \mathrm{d}p_{\mathrm{T}} \mathrm{d}\eta}{\mathrm{d}^2 \sigma_{jets}^{\mathrm{pp}} / \mathrm{d}p_{\mathrm{T}} \mathrm{d}\eta}$$

- R_{AA} is calculated relative to unbiased pp charged-particle jets[1]
- Combined pp and Pb–Pb uncertainties
- Syst. + stat. uncertainties added in quadrature

→ unbiased Pb–Pb R_{AA} at $p_{\mathrm{T},jet}$ > 13.5 GeV/c

[1] Unbiased pp: ALICE collaboration, Phys. Rev. D, 100, 092004, 2019. arXiv: 1905.02536 [nucl-ex].

Model comparisons



- Models describe R_{AA} at high p_T, **disagree with each other at low p_T**

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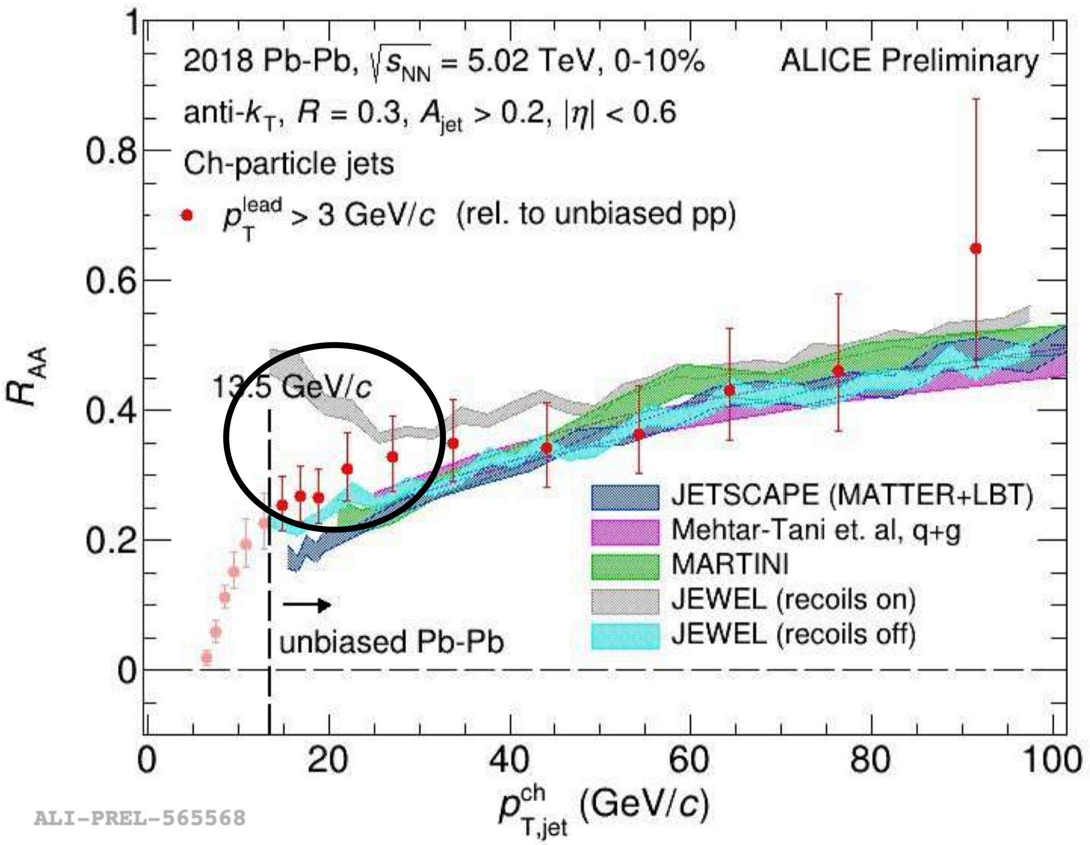
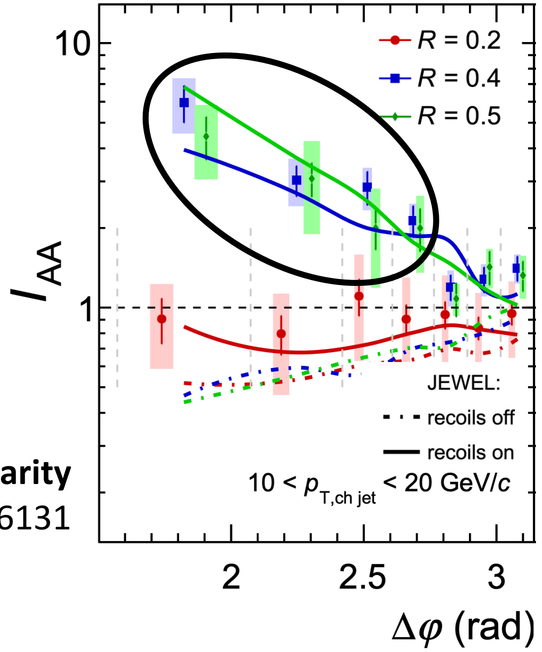


- Models describe R_{AA} at high p_T, **disagree with each other at low p_T**
- Jewel with recoil ON at low p_T:
  - reproduces features in semi-inclusive
  - fails in inclusive

→ Modelling still needs work

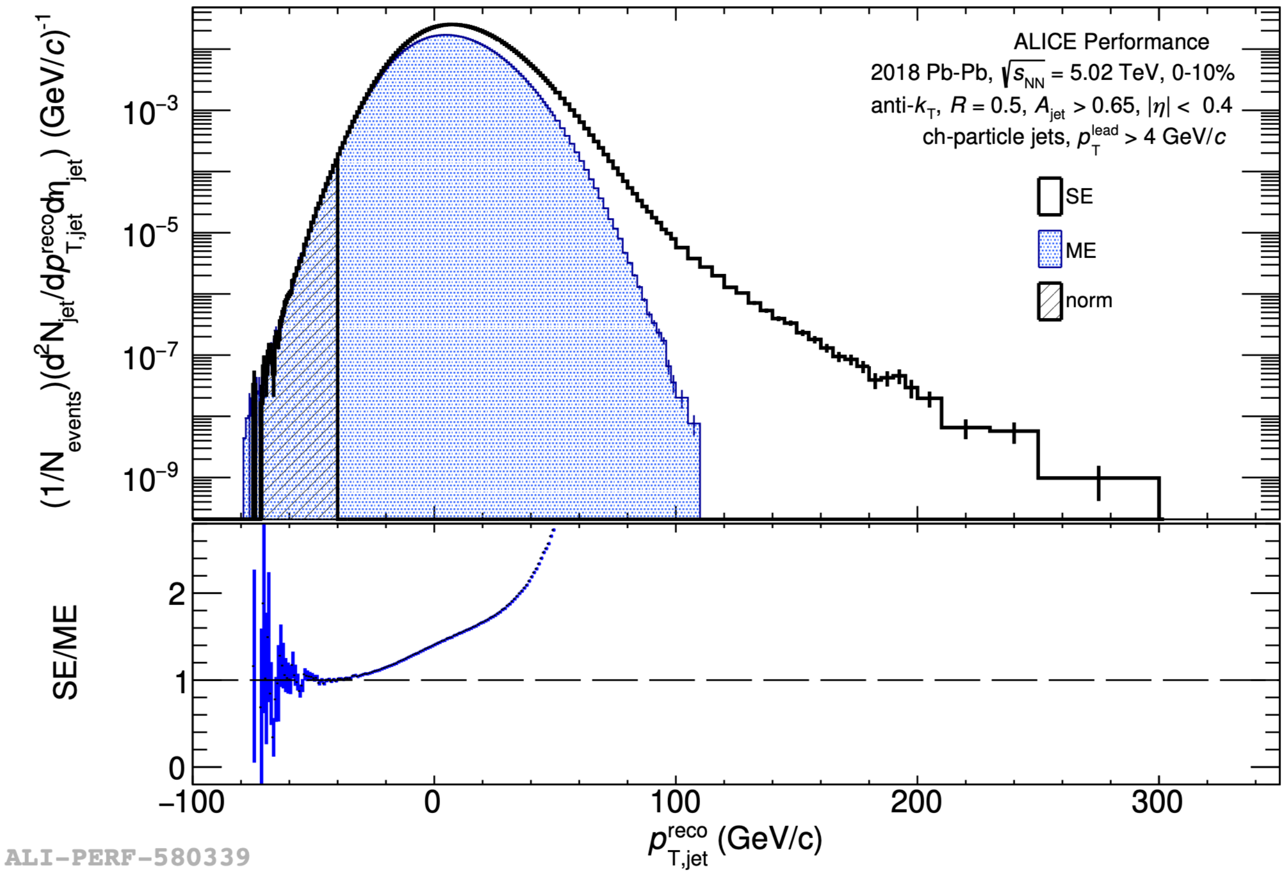
h-jet acoplanarity
arXiv:2308.16131



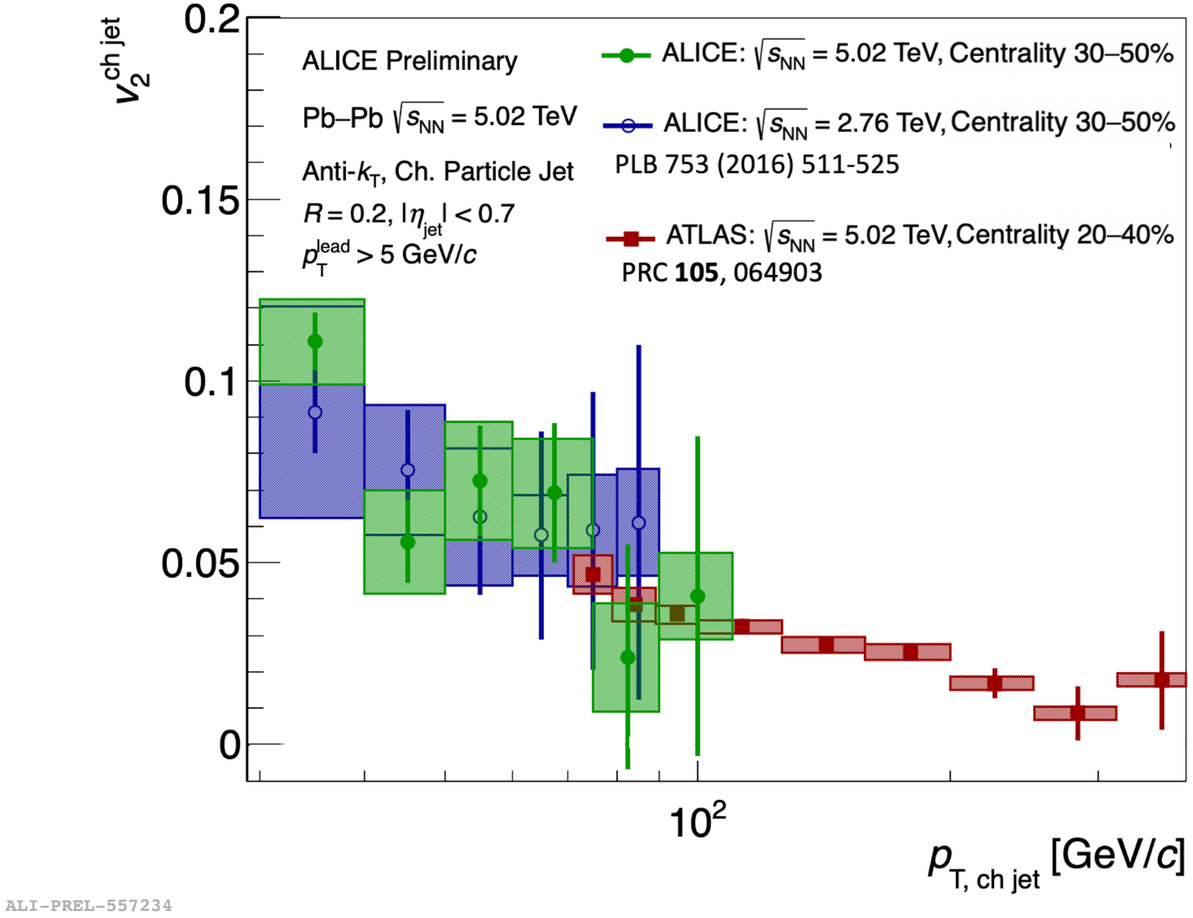
Raw quasi-incl. jet distribution, R = 0.5

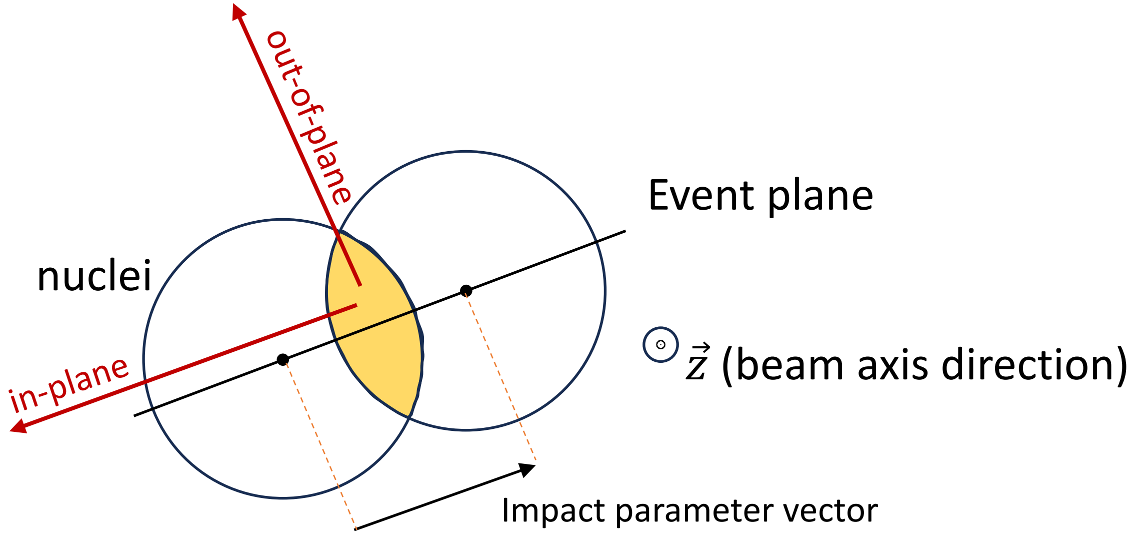
Ongoing work:

- Pushing measurement to large radius **R = 0.5**
- More challenging due to larger background in jet area
- Unbiased above 23 GeV/*c*



Charged-particle jet v_2





$$v_2 = \frac{N_{in} - N_{out}}{N_{in} + N_{out}}$$

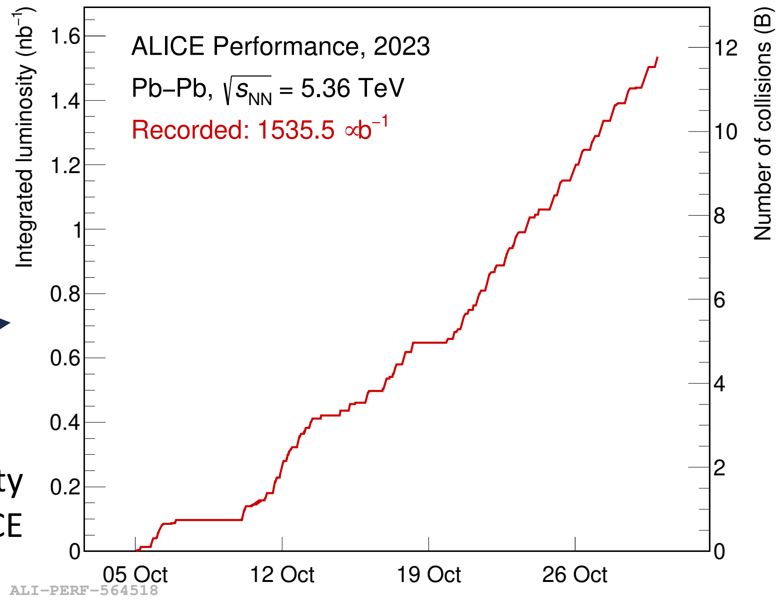
- Suppression of out-of-plane jets
- Larger positive charged-particle jet v_2 at low p_T
- Consistent with ATLAS in the p_T overlap

- Run 3 measurement will come with increased statistics:
  - smaller stat. errors
  - **more centrality intervals**

Run 3 Analysis is ongoing

Run 3 Pb-Pb analysis

- Increased statistics with Run 3**: x30 more** min. bias collision
- pp reference run in November



Collected min. bias Pb-Pb luminosity
recorded in Run 3 with ALICE

Run 3 Pb-Pb analysis

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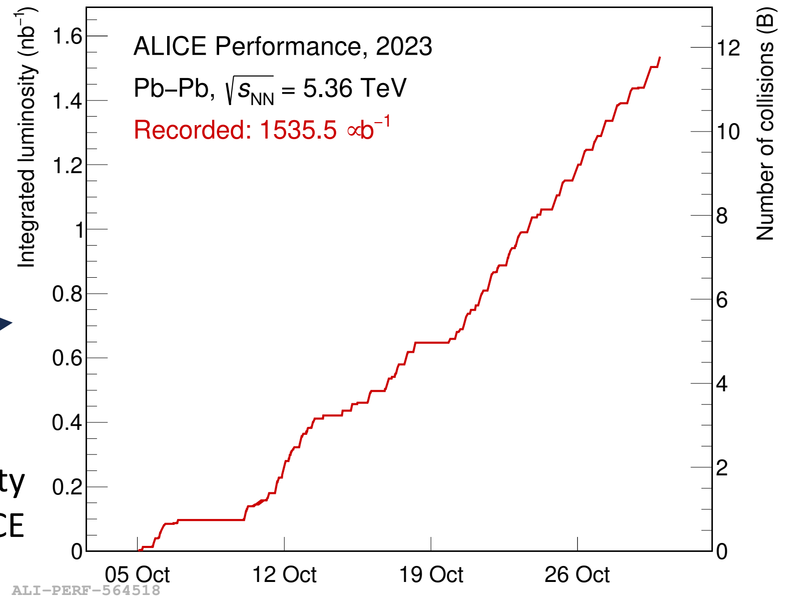
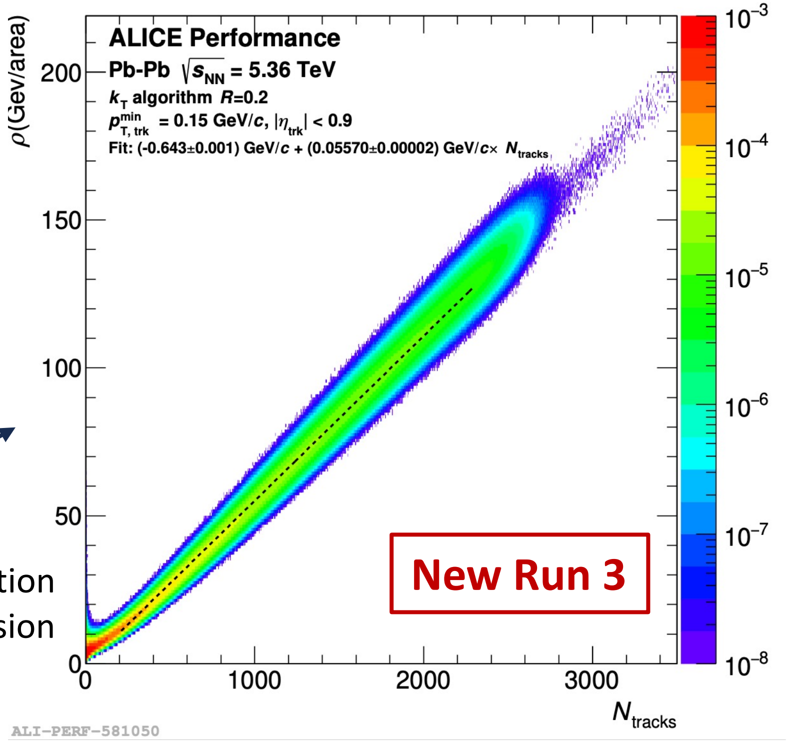


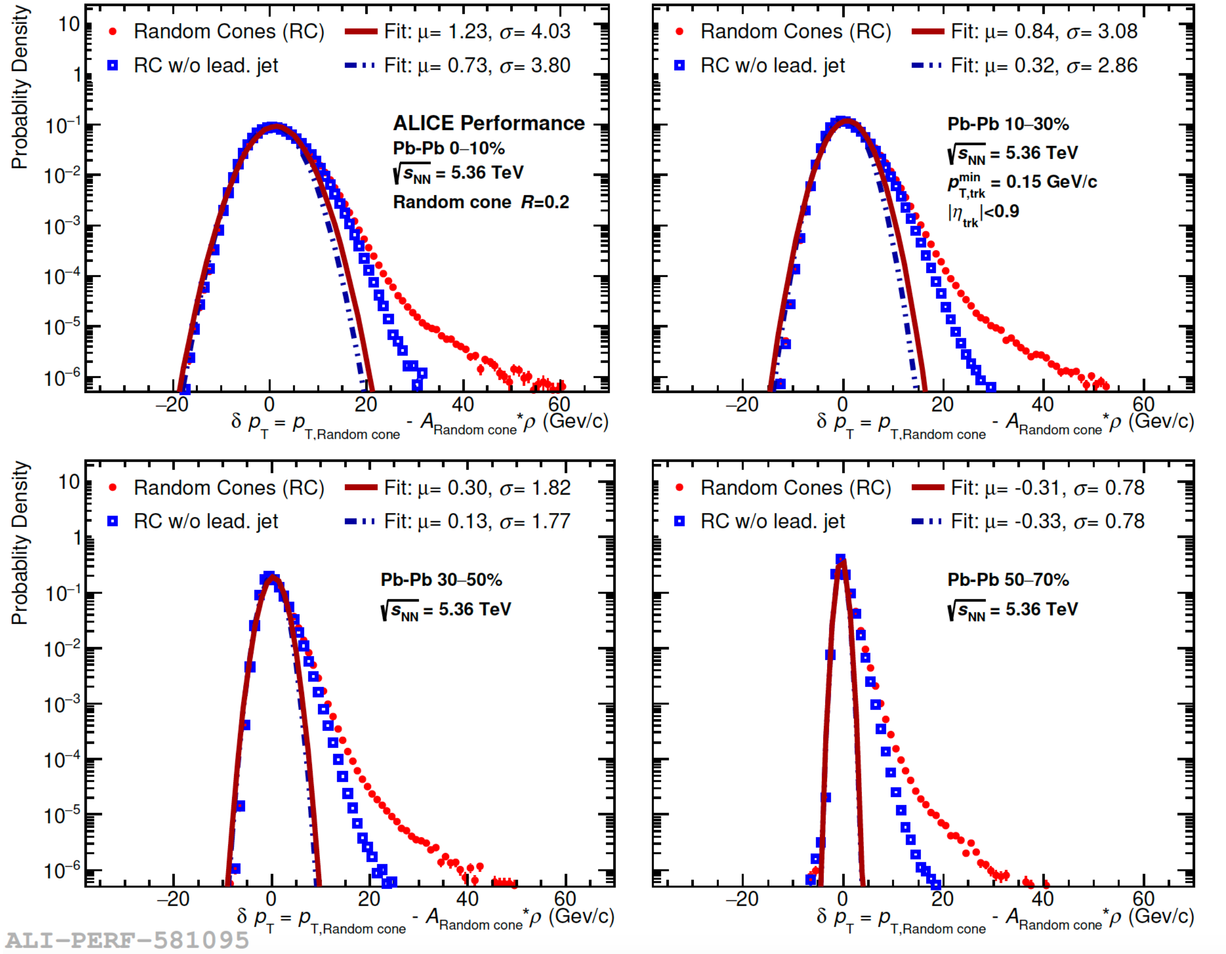
Collected min. bias Pb-Pb luminosity recorded in Run 3 with ALICE

- Ongoing jet yield analysis for R_{CP} and R_{AA} measurements in Pb-Pb at $\sqrt{s_{NN}}$ = 5.36 GeV
- Careful consideration of new challenges introduced by continuous readout
- **Background effects in Run 3: poster by Wenhui Feng**



Median background density per unit area ρ as a function of the number of selected tracks in the collision

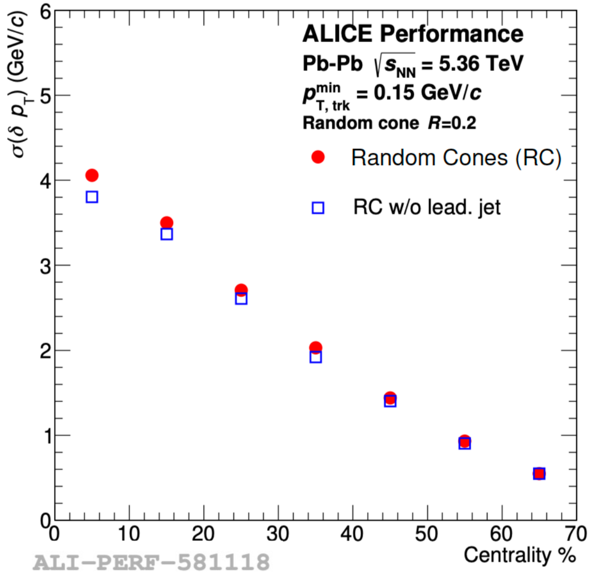
Background fluctuations in Run 3 Pb-Pb data



New Run 3

- Important assessment of detector response in heavy-ion collisions for jet studies
- Similar shapes and widths as in Run 2

➔progress in understanding detector behaviour for jets



Background effects in Run 3: poster by Wenhui Feng

Summary

- **ME technique:**

→ **Unbiased** exploration of jets at **very low $\boldsymbol{p}_{\mathbf{T}}$** in heavy-ion collisions

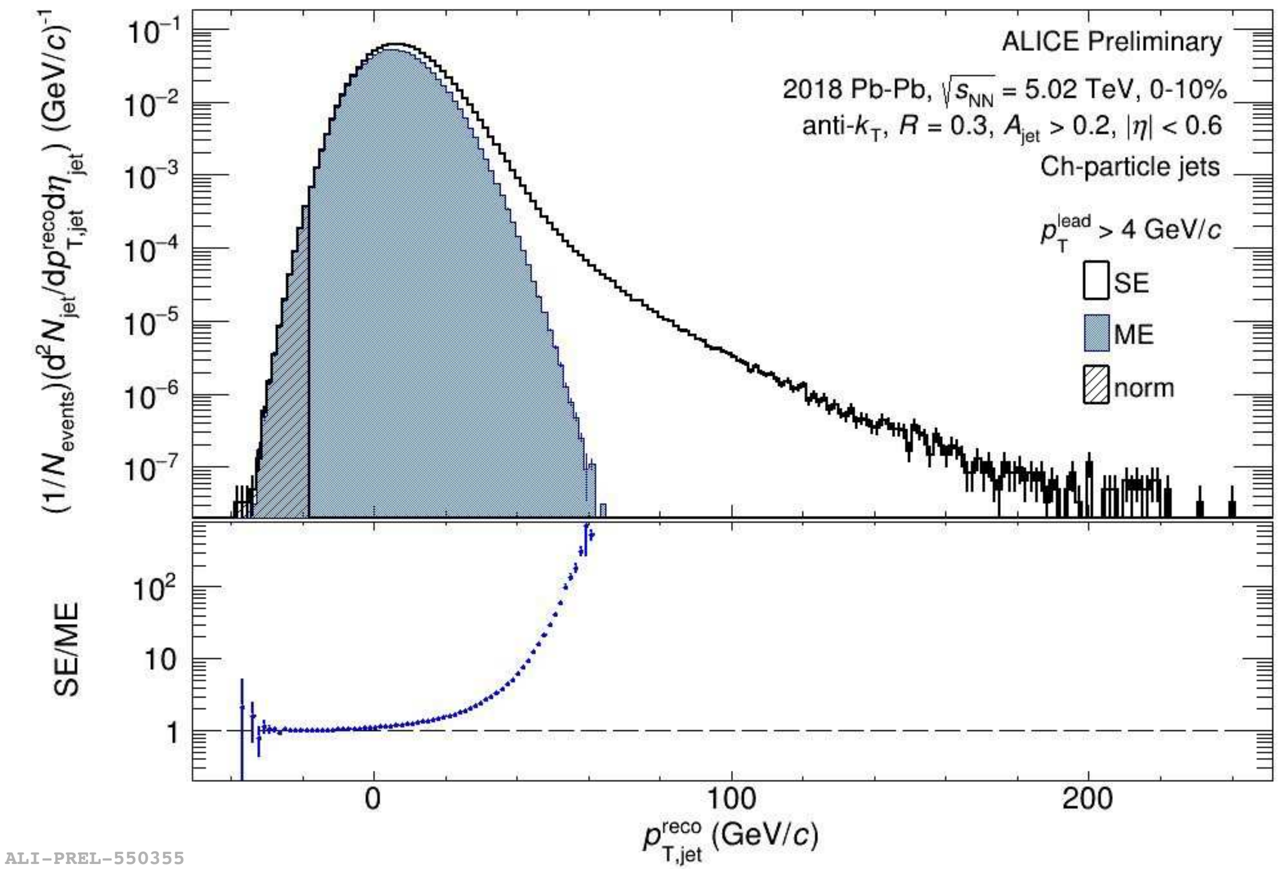
→ Upcoming measurement is pushing low $\boldsymbol{p}_{\mathbf{T}}$ jets to **large radius of R = 0.5**

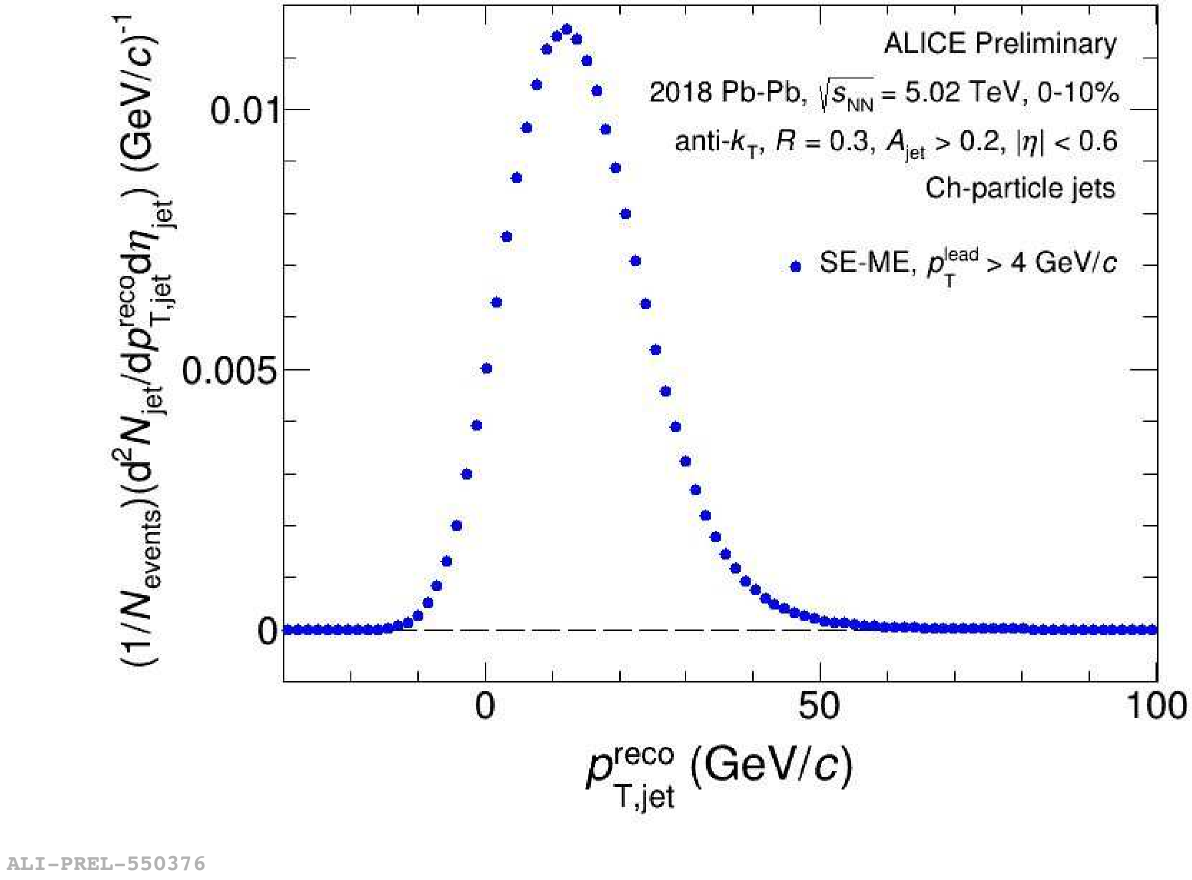
- **Jet $\boldsymbol{v_2 > 0}$ →** Out-of-plane jet suppression at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

- Run 3 Pb-Pb analysis:
  - response of new detector for jets being understood
  - jet yield, R_{AA}, v_2 soon

Backup

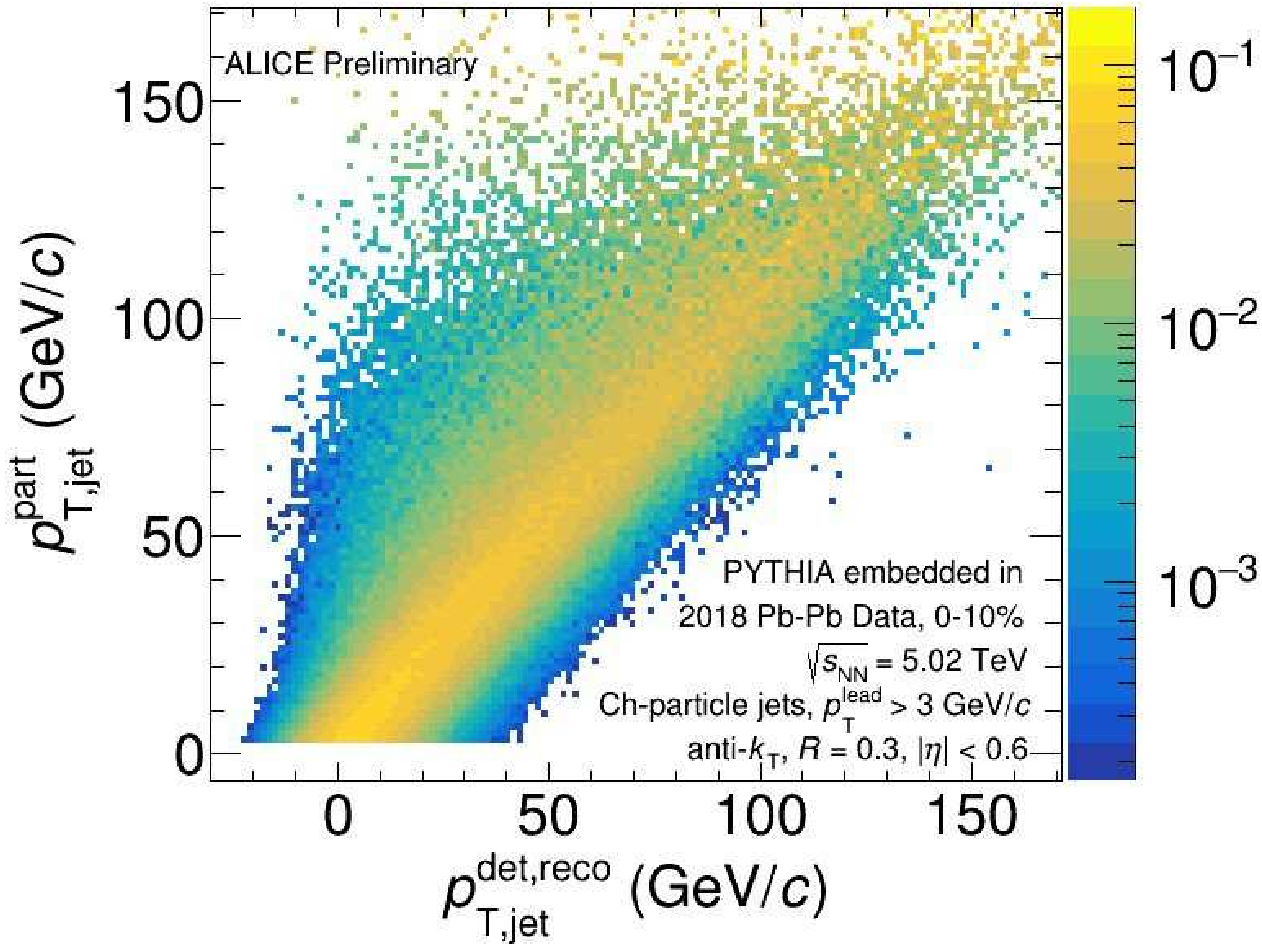
Backup, leading track cut 4 GeV/c





Correction of p_T-smearing

- After yield correction: Correction of p_T-smearing due to background and instrumental effects ➜ **Unfolding**
- **Instrumental effects:** Corrections for efficiency & pT resolution
- **Background effects:** Correction for local fluctuations
- Response matrix calculation with embedding of PYTHIA jets into SE
- ROOT unfolding framework **RooUnfold** with **Bayesian unfolding** method & 7 iterations
- Prior: PYTHIA particle level
- Additional correction after unfolding: **Jet reconstruction efficiency**



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Model comparisons

- **JETSCAPE:** Framework for pp and heavy-ion event simulation and Bayesian inference
- **Jet interactions, no medium response:**
  - **MATTER:** High virtuality shower
  - **MARTINI:** Low virtuality shower. Includes elastic scattering processes similar to LBT and radiative energy loss according to AMY formalism
- **Jet interactions with medium response:**
  - **LBT:** Transport of parton in QGP is described by linear Boltzmann equation. Medium particles can become part of the jet due to scattering: “recoiled partons”
  - **JEWEL:** PYTHIA based, microscopic response, energy-momentum locally conserved
  - **Hybrid:** PYTHIA based, hard (soft) jet-medium interaction based on DGLAP evolution (AdS/CFT)
- **Mehtar-Tani et. al:** Analytic calculation based on BDMPS/GLV and hydrodynamics