UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

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Recent progress in inclusive jet measurements with ALICE

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Jets as probe of the QGP

- Jet quenching effects from the interaction of high energetic partons with the medium:

Jet energy loss — This talk

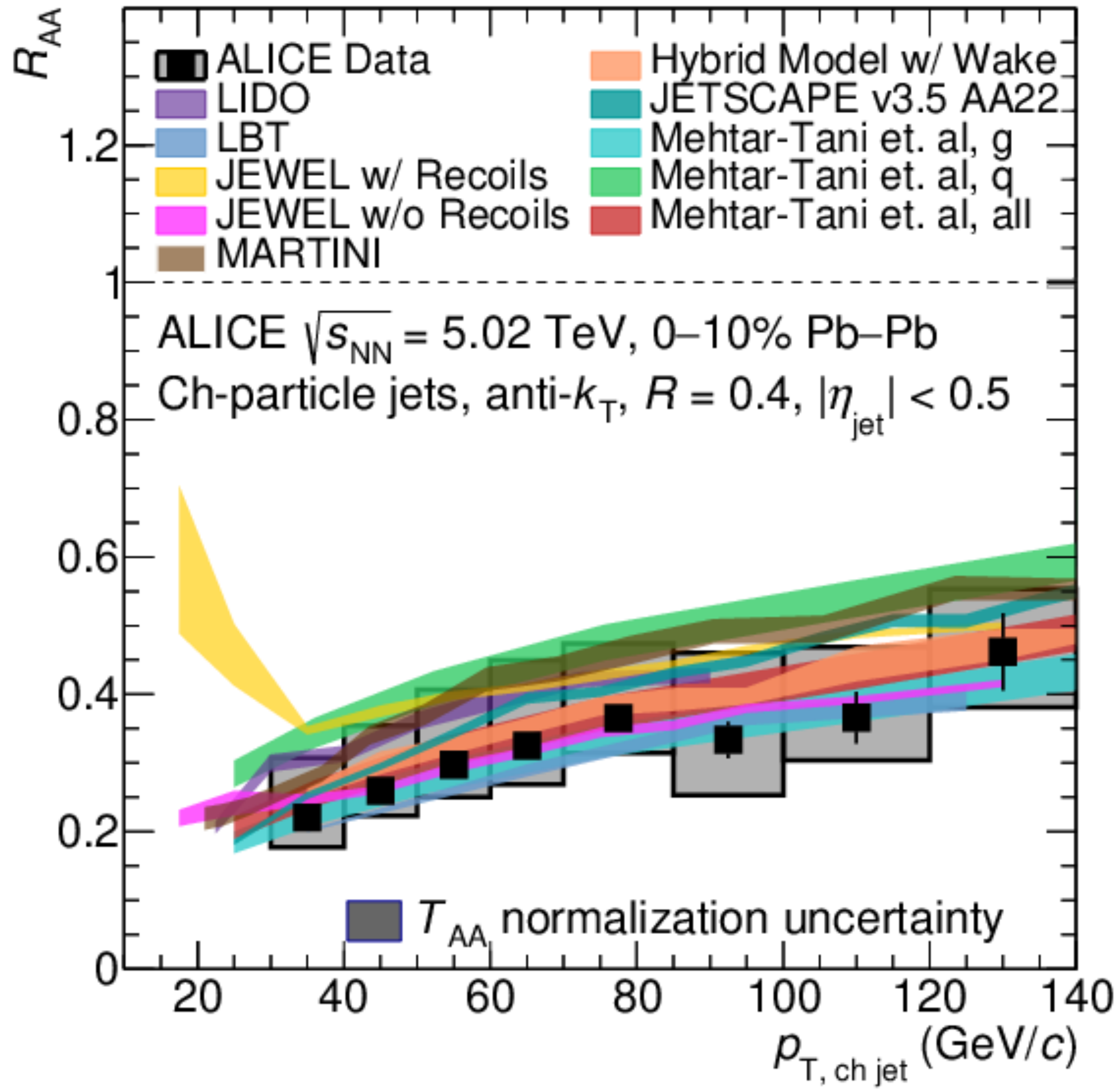
Jet substructure modifications

Jet deflection — Talk by Peter Jacobs today, 11:30

- Measurement of reconstructed jets in heavy-ion collisions is challenging due to huge non-uniform uncorrelated background, especially for very low p_T jets

- Current ALICE jet R_{AA} measurement: low p_T reach achieved using Machine Learning

- **Goal of this analysis: extend inclusive jet measurement to lower p_T & smaller uncertainties**



ALICE Collaboration, *Phys.Lett.B* 849 (2024) 138412

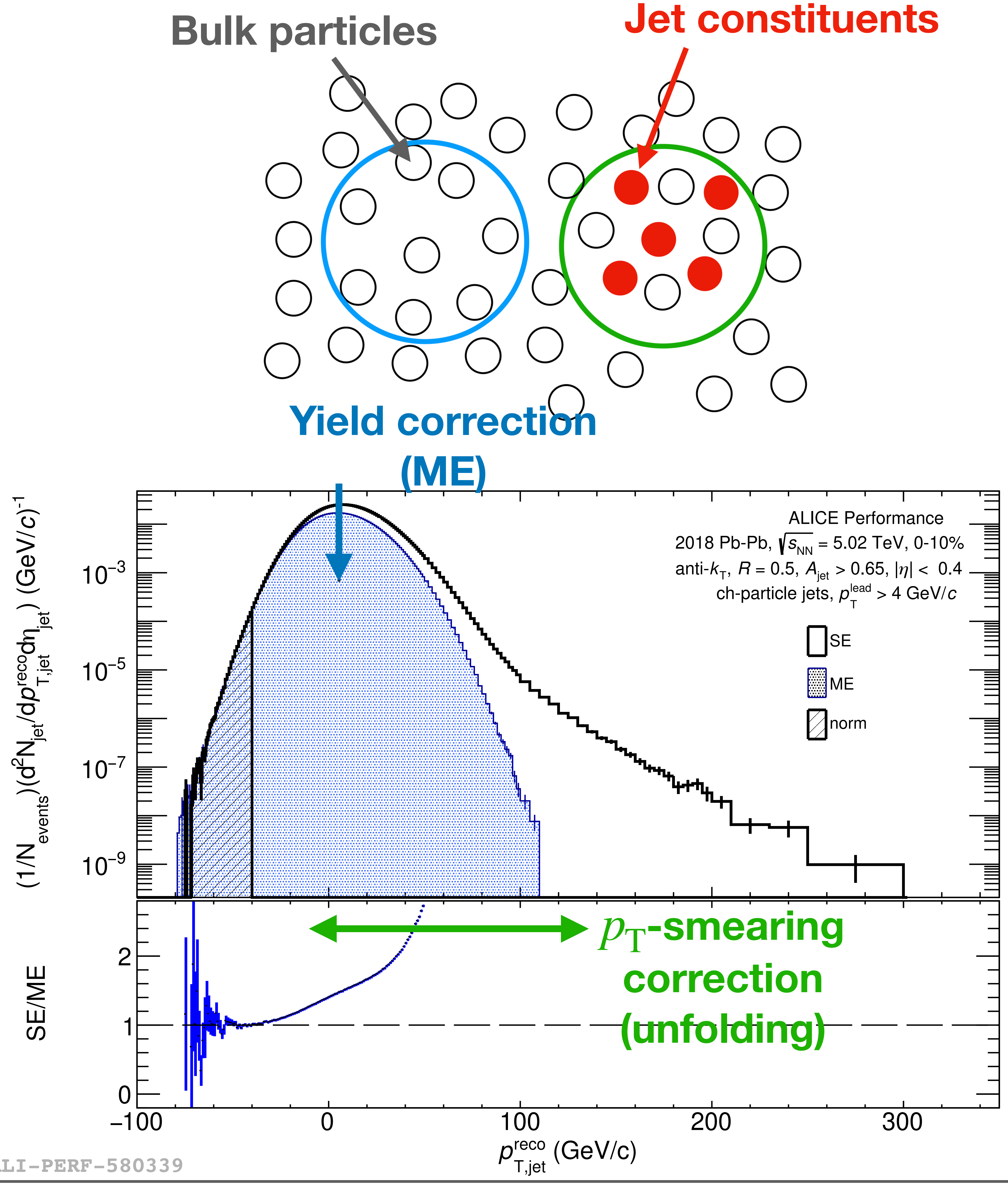
Inclusive jet measurements

Background has two distinct effects:

- **Combinatorial ("fake") jet yield** arising from random combination of products from soft (low Q^2) interactions
- **Smearing of p_T** of **true jets** arising from hard processes

Background correction methods:

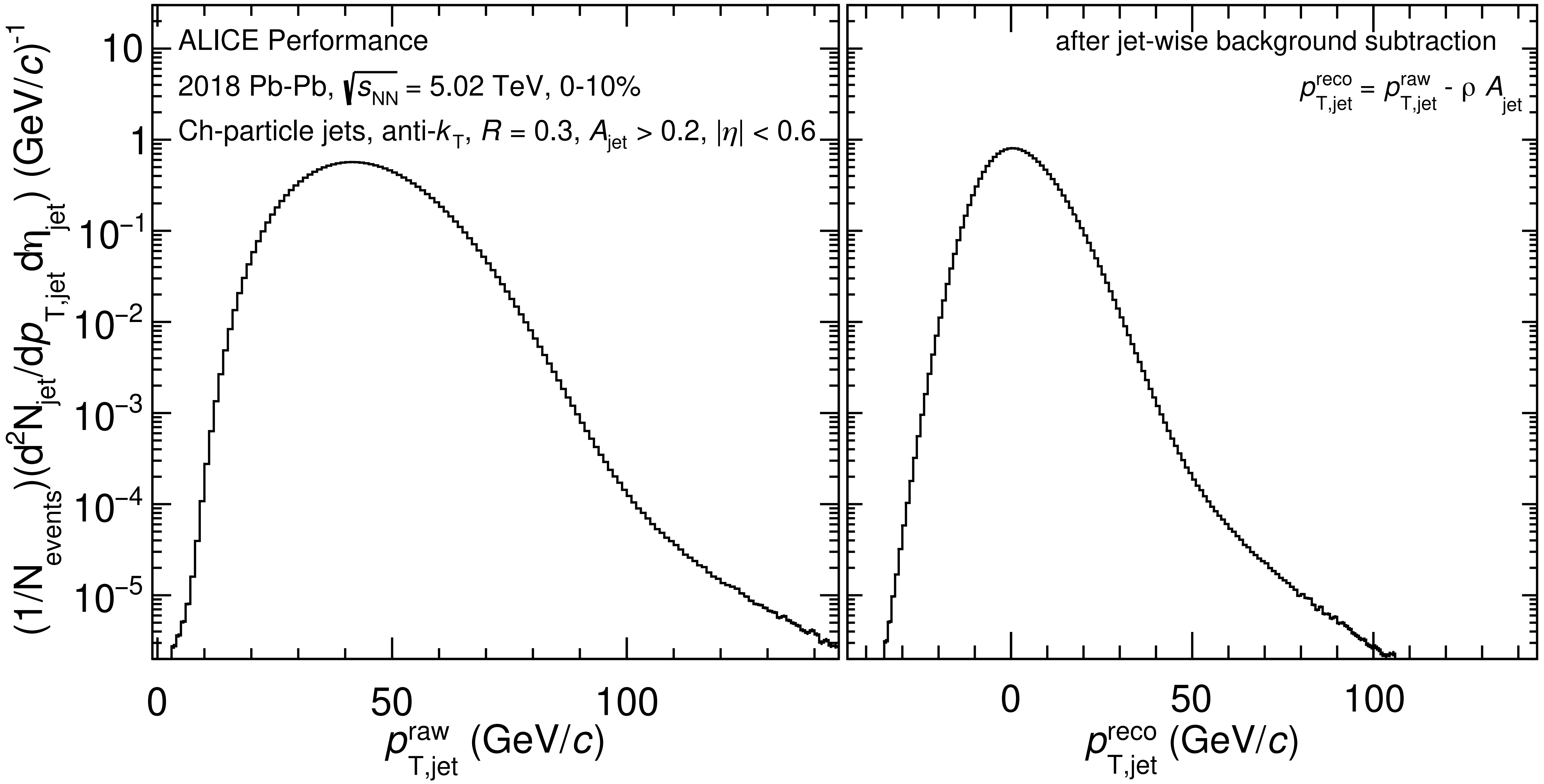
- **Use Mixed Events (ME) to determine the distribution of the combinatorial jets**
  - Purely statistical approach
  - ME successfully used at STAR (Phys.Rev.C 96 (2017) 2, 024905)



Dataset & technical details

ALICE 2018 Pb-Pb data, $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, 0-10%

- Charged particle jet reconstruction
- FastJet, jet reconstruction algorithm:
  - anti-k_{T} (jet finding) & k_{T} (background)
  - $R = 0.3$ ($R = 0.5$ is work in progress)
  - Fiducial cut: $|\eta| < 0.9 - R$
  - Area cut: $A_{\mathrm{jet}} > 0.2$ for $R = 0.3$
- "Jet-wise" background subtraction: $p_{\mathrm{T,jet}}^{\mathrm{reco}} = p_{\mathrm{T,jet}}^{\mathrm{raw}} - \rho A_{\mathrm{jet}}$



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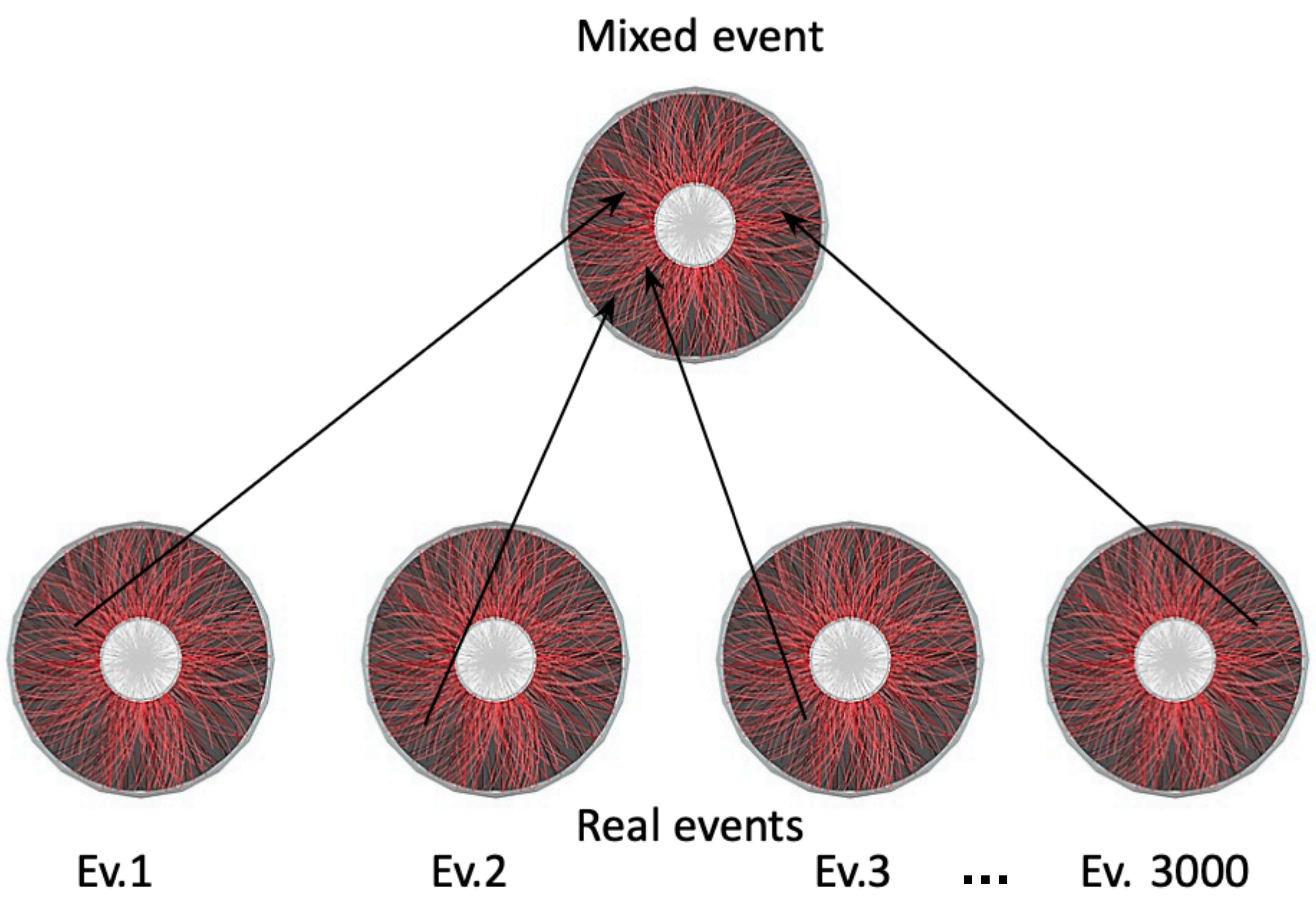
Creating the mixed events

- How to create the mixed events:
  - Categorisation of events into multiplicity, z-vertex, event plane & $p_{\mathrm{T}}^{\mathrm{sum}}$ (9600 categories)
  - Assembling of full events: same event (SE) multiplicity distribution and acceptance effects from real data are reproduced in the ME
  - For one ME only one random track from each real event → by construction **no multi-hadron correlations in ME**

Important aspects of the ME production:

- Mixing categories
- How to normalise ME to SE
- How to avoid jet-like high p_{T} tracks in ME



→ Alternative mixing procedures were tested but rejected

Mixing categories: ME dependence on correlations

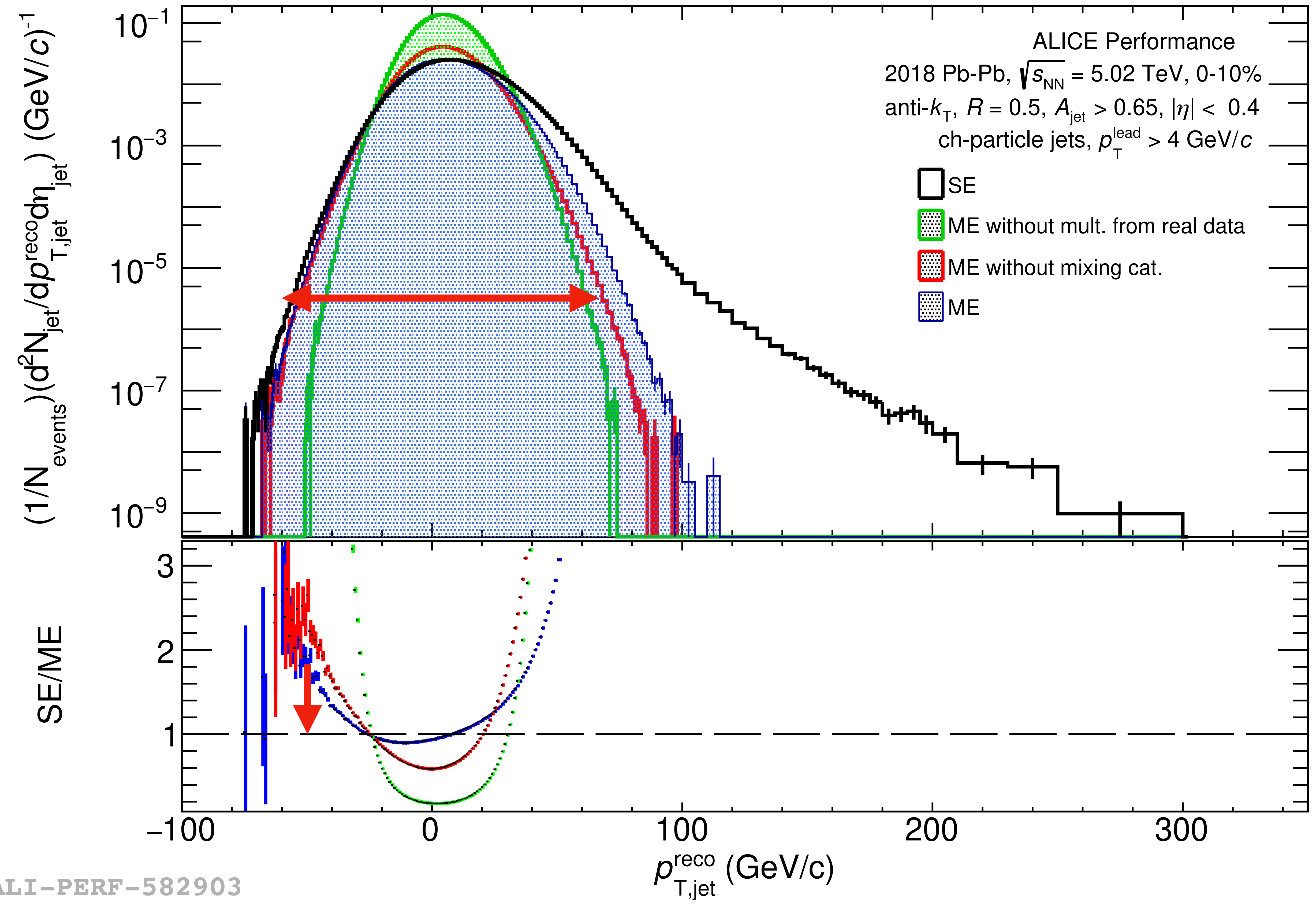
- ME shape/width depends strongly on different correlations

→ Additional correlations increase the width of the ME

- **Essential criterion of the ME: identical shape of SE & ME at the left-hand side**
- Already included in 9600 categories:
  - 10 multiplicity bins
  - 4 z-vertex bins
  - 10 Ψ_2 bins
  - 6 Ψ_3 bins
  - 4 p_T^{sum} bins (sum of track p_T within an event)
- Number of categories is limited by statistics & physical resolution

  → Remaining contributions are absorbed in a scaling factor for the ME width

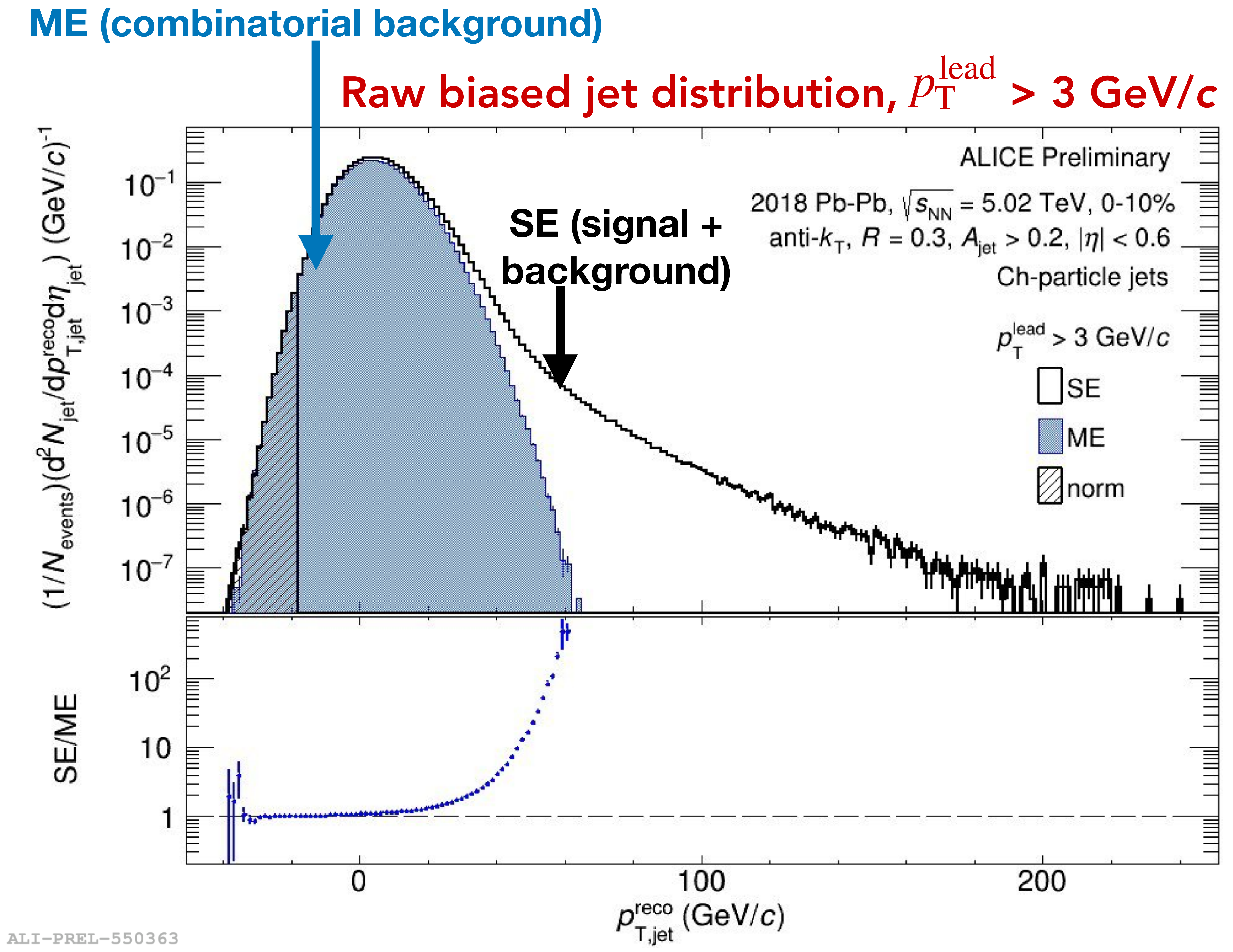
Mixing only within categories, mixing without categories & without sampling from real multiplicity dist.



Effect of individual categories: Master thesis, Nadine Grünwald: https://www.physi.uni-heidelberg.de/Publications/MasterThesis_NadineGruenwald.pdf

Raw quasi-incl. jet distribution, $R = 0.3$

- Same jet reconstruction for SE and ME
- Leading track cut of 3 GeV/c and 4 GeV/c:
  - Introduce a small bias to define jet object that can be interpreted in theory
  - Vary the bias to measure its effect and determine the p_T region where the bias is negligible



Raw quasi-incl. jet distribution, $R = 0.3$

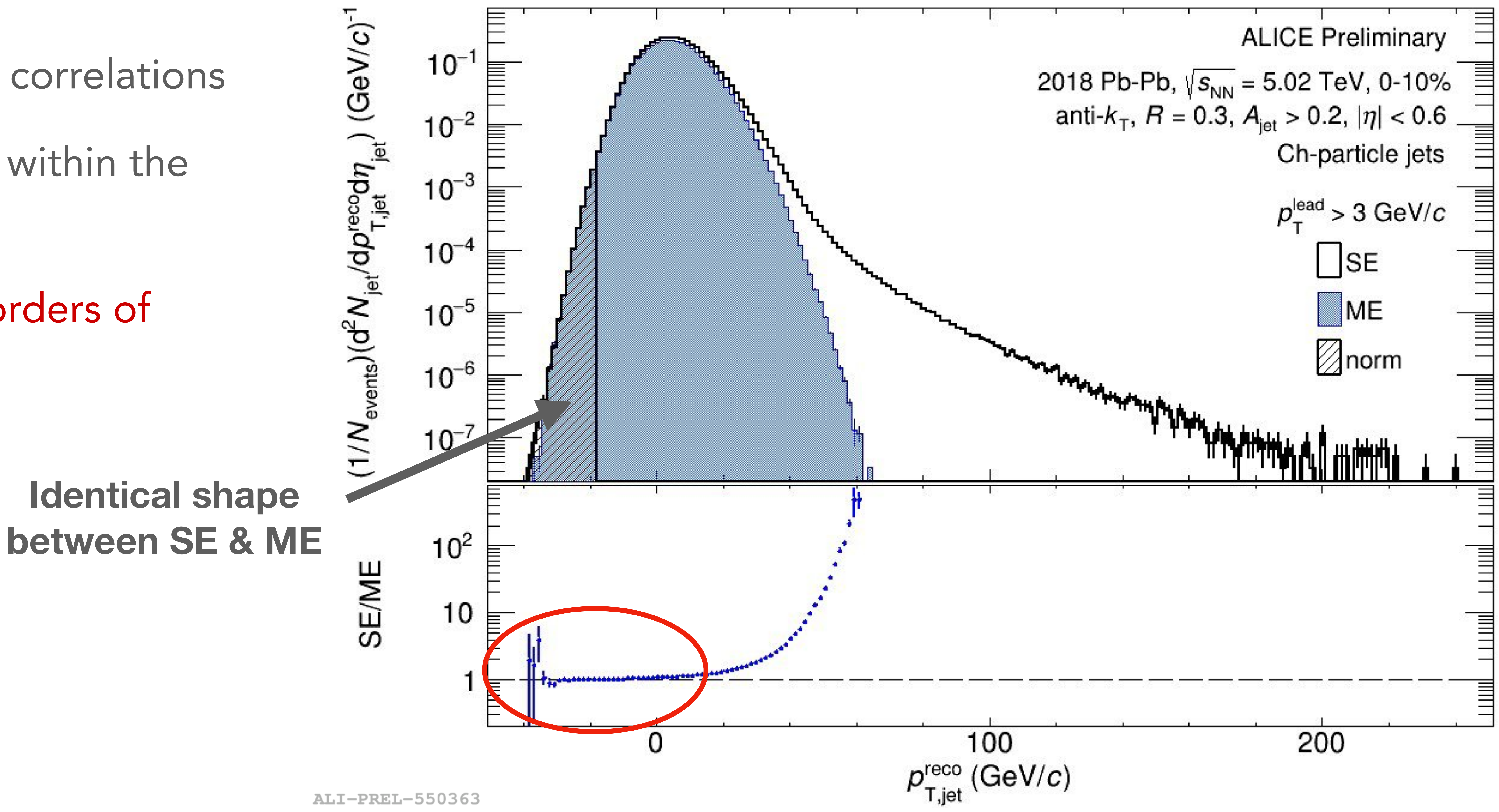
- Essential criterion of the ME: identical shape of SE & ME at the left-hand side

  → ME shape/width depends on correlations

- Yield normalisation of ME to SE within the shaded region up to -18 GeV/c

  → excellent agreement over 5 orders of magnitude

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



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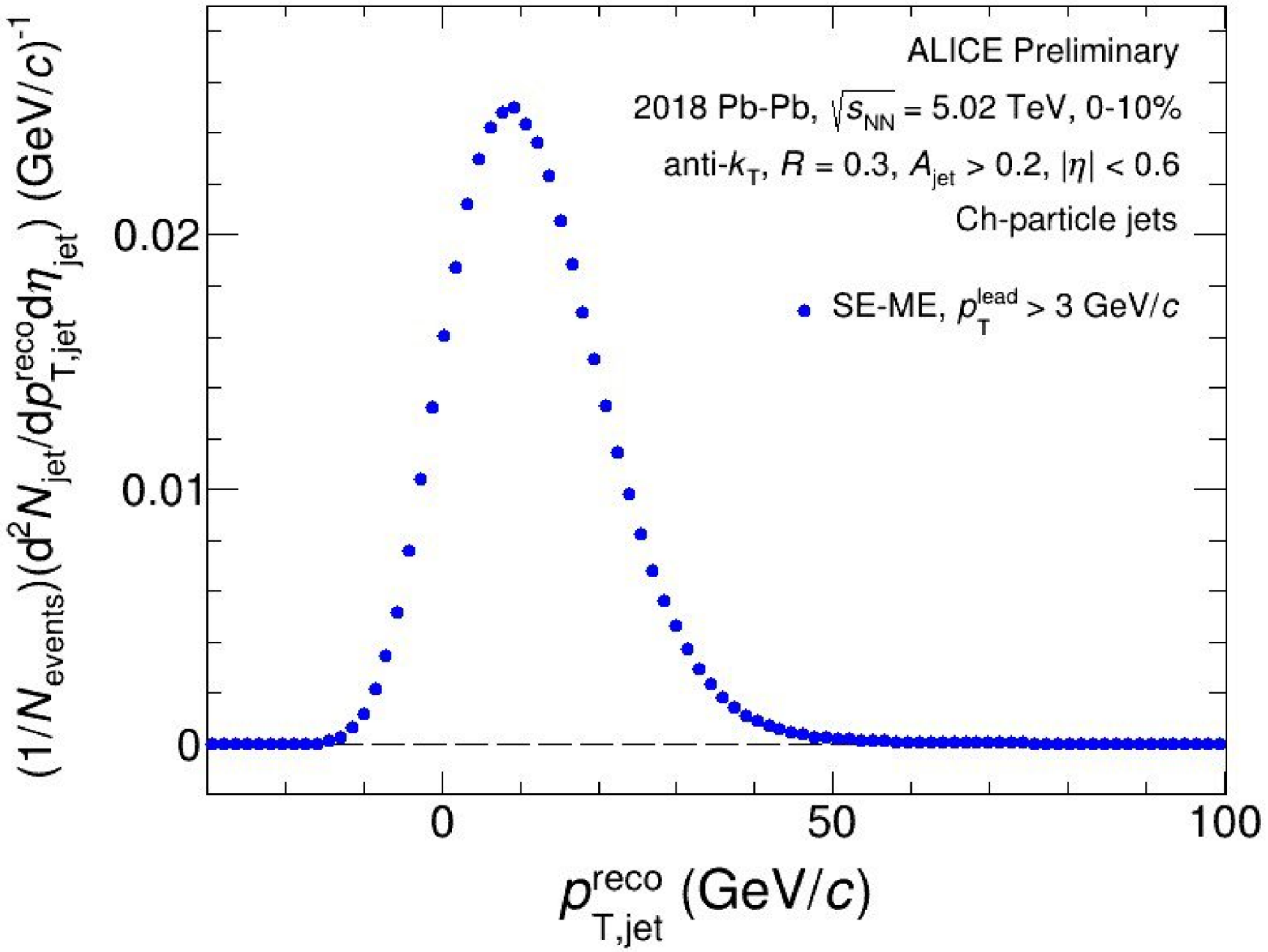
- Subtraction of combinatorial background yield using ME

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



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Raw quasi-incl. jet distribution, $R = 0.3$

- Essential criterion of the ME: identical shape of SE & ME at the left-hand side

  → ME shape/width depends on correlations

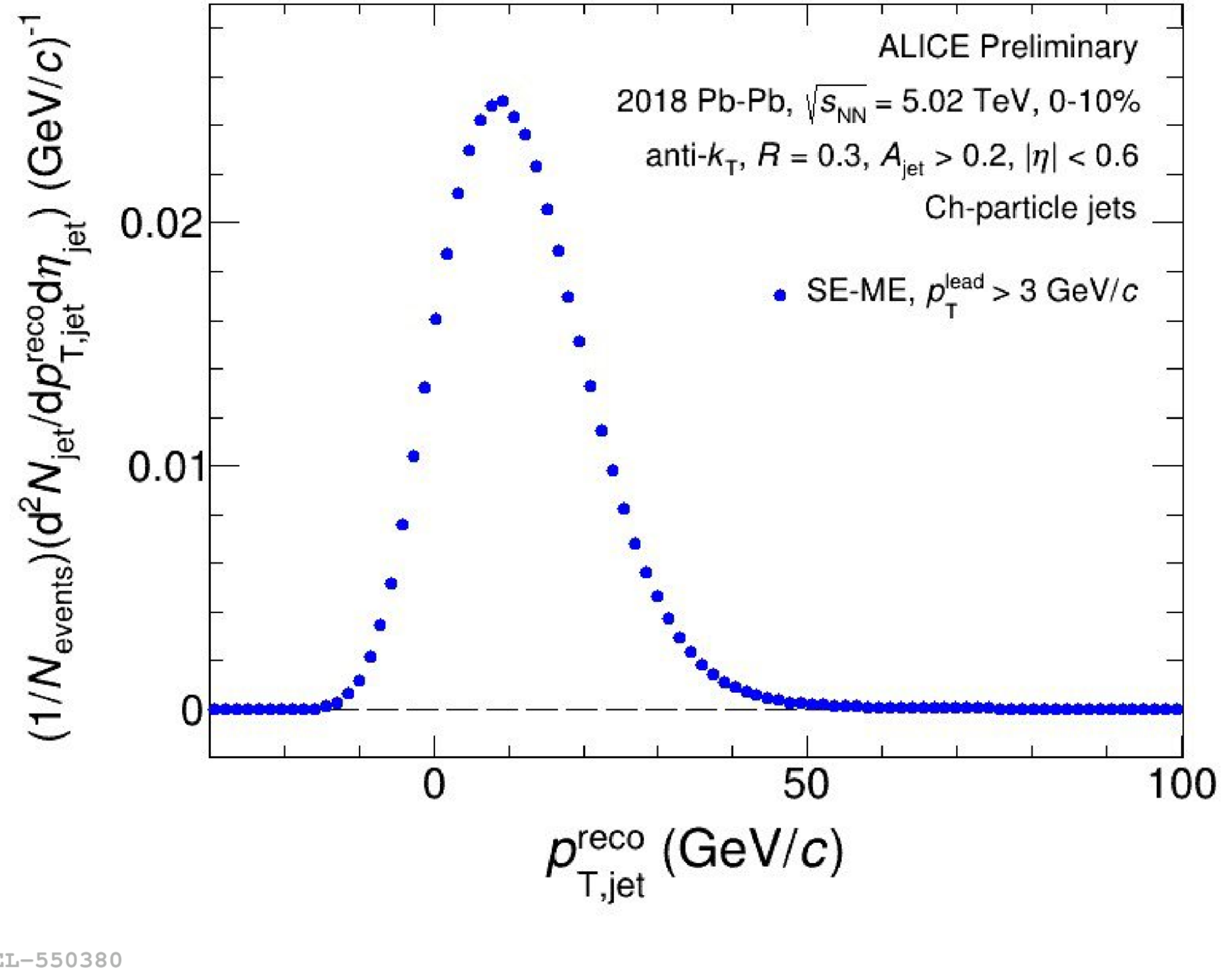
- Yield normalisation of ME to SE within the shaded region up to -18 GeV/c

  → excellent agreement over 5 orders of magnitude

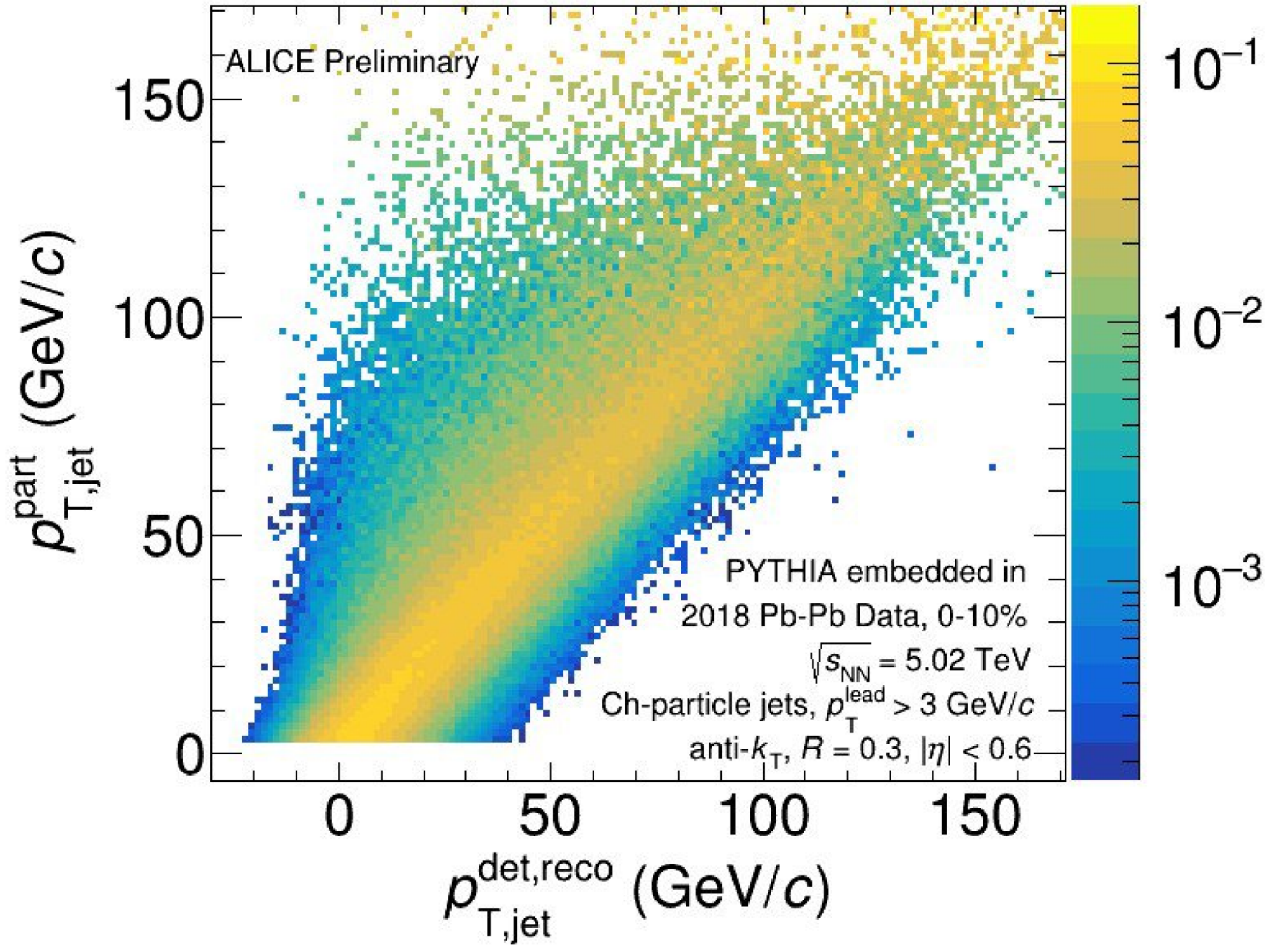
- Subtraction of combinatorial background yield using ME

1. ME procedure removes uncorrelated background yield
2. Leading track p_T cut generates countable objects
3. Leading track p_T cut is decoupled from background suppression

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



Corrections for p_T-smearing



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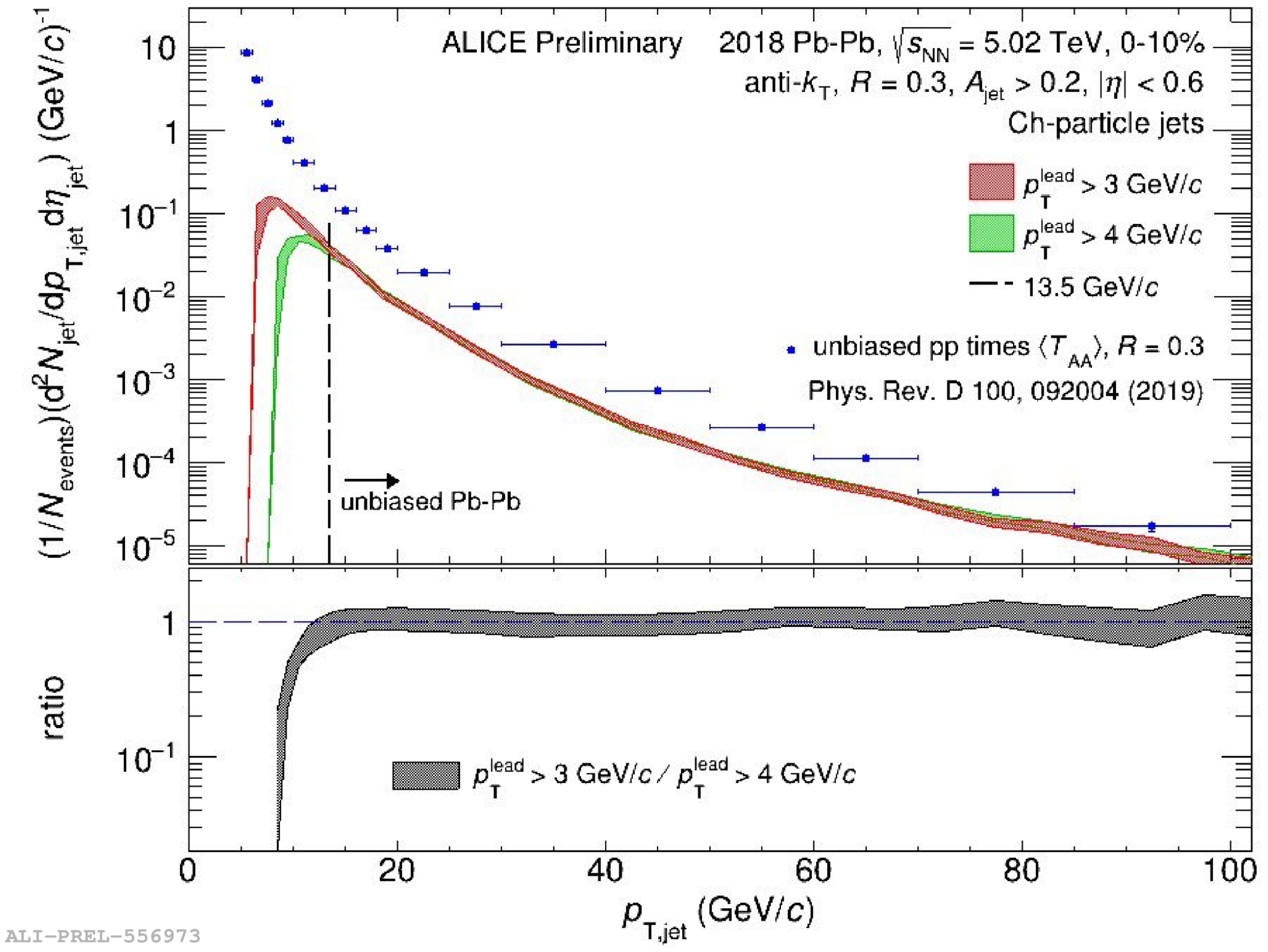
- In addition to yield correction: correction of p_T-smearing due to background and instrumental effects → **Unfolding**
- **Instrumental effects:** correction for efficiency and p_T -resolution
- **Background effects:** correction for local fluctuations
- Response matrix calculation with embedding of PYTHIA jets: fragmentation modification for systematic studies of the response matrix
- ROOT unfolding framework RooUnfold with Bayesian unfolding method
- Additional correction for jet reconstruction efficiency after the unfolding

Corrected jet distributions, $R = 0.3$

- Fully corrected quasi-incl. charged-particle jet distributions with $p_{\mathrm{T}}^{\mathrm{lead}} > 3$ GeV/c & $p_{\mathrm{T}}^{\mathrm{lead}} > 4$ GeV/c
- Systematic uncertainties from ME, DCA, tracking efficiency & unfolding
- Measuring where the bias is small
- Effect of the leading track bias: **less than 10% difference for $p_{\mathrm{T,jet}} > 13.5$ GeV/c**

→ **Unbiased Pb-Pb at $p_{\mathrm{T,jet}} > 13.5$ GeV/c**



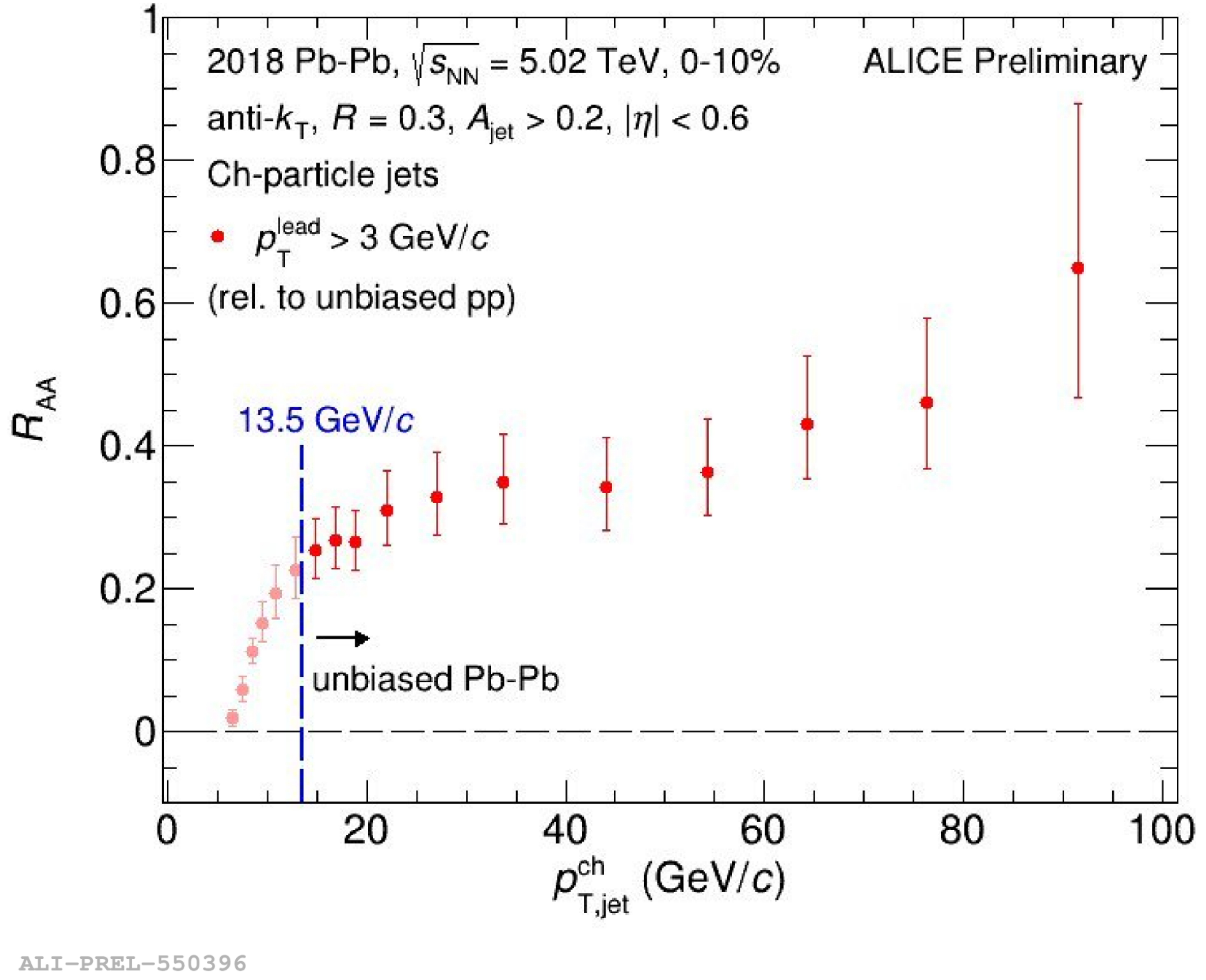
Unbiased pp: ALICE Collaboration, *Phys.Rev.D* 100 (2019) 9, 092004 ($R = 0.3$)

Charged-particle jet R_{AA}: $R = 0.3$

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}_{\mathrm{jets}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}{\langle T_{\mathrm{AA}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}_{\mathrm{jets}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}$$

- R_{AA} is calculated relative to unbiased pp charged-particle jets
- Combined pp & Pb-Pb uncertainties
- Syst. + stat. uncertainty added in quadrature

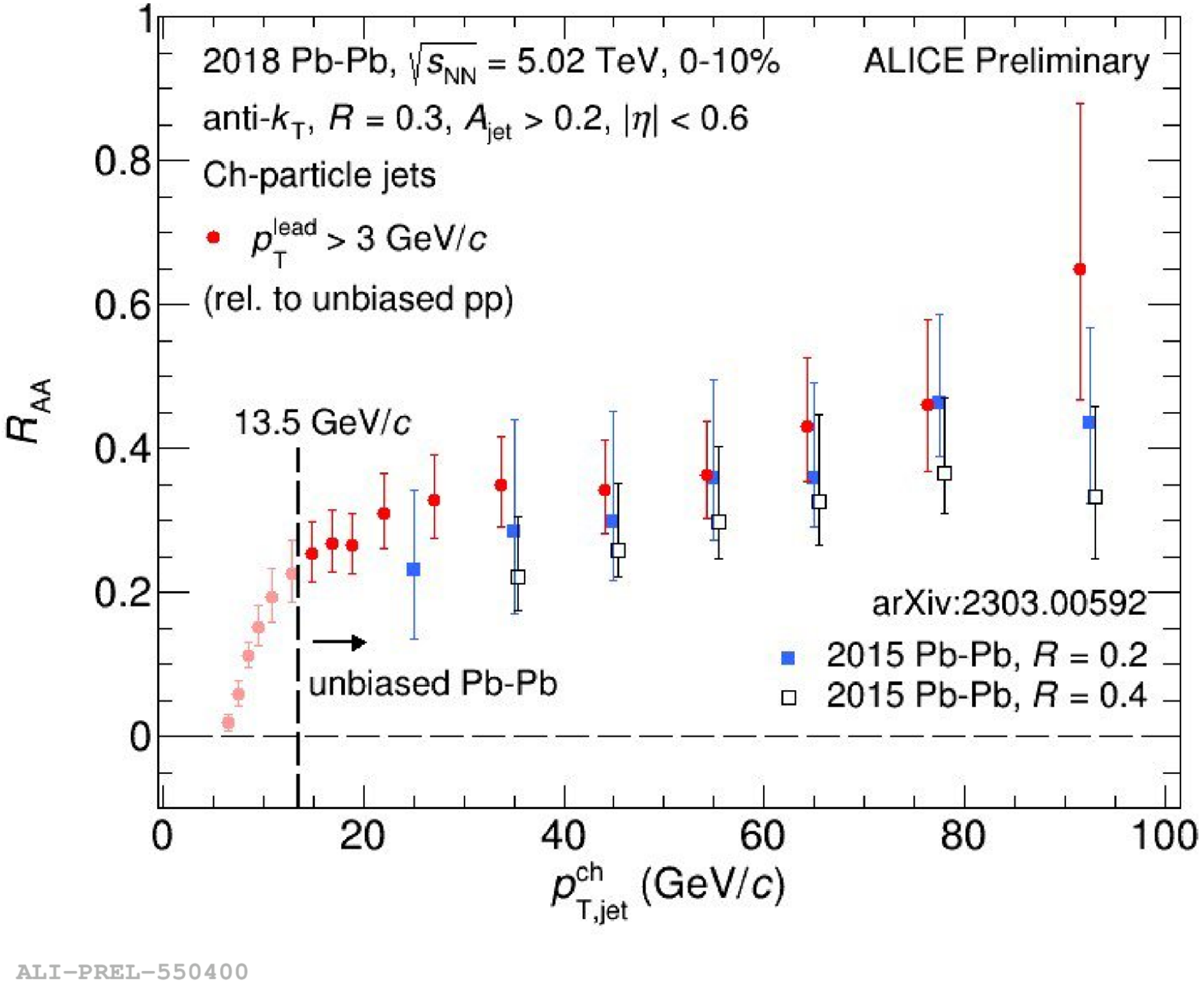
→ Unbiased Pb-Pb R_{AA} down to **13.5 GeV/*c*** (conservative estimate)



Unbiased pp: ALICE Collaboration, *Phys.Rev.D* 100 (2019) 9, 092004 (R = 0.3)

Comparison to previous ALICE R_{AA}

- Consistent with previous ALICE R_{AA} measurement with 2015 Pb-Pb data
- Lower in p_T & smaller uncertainties at low p_T

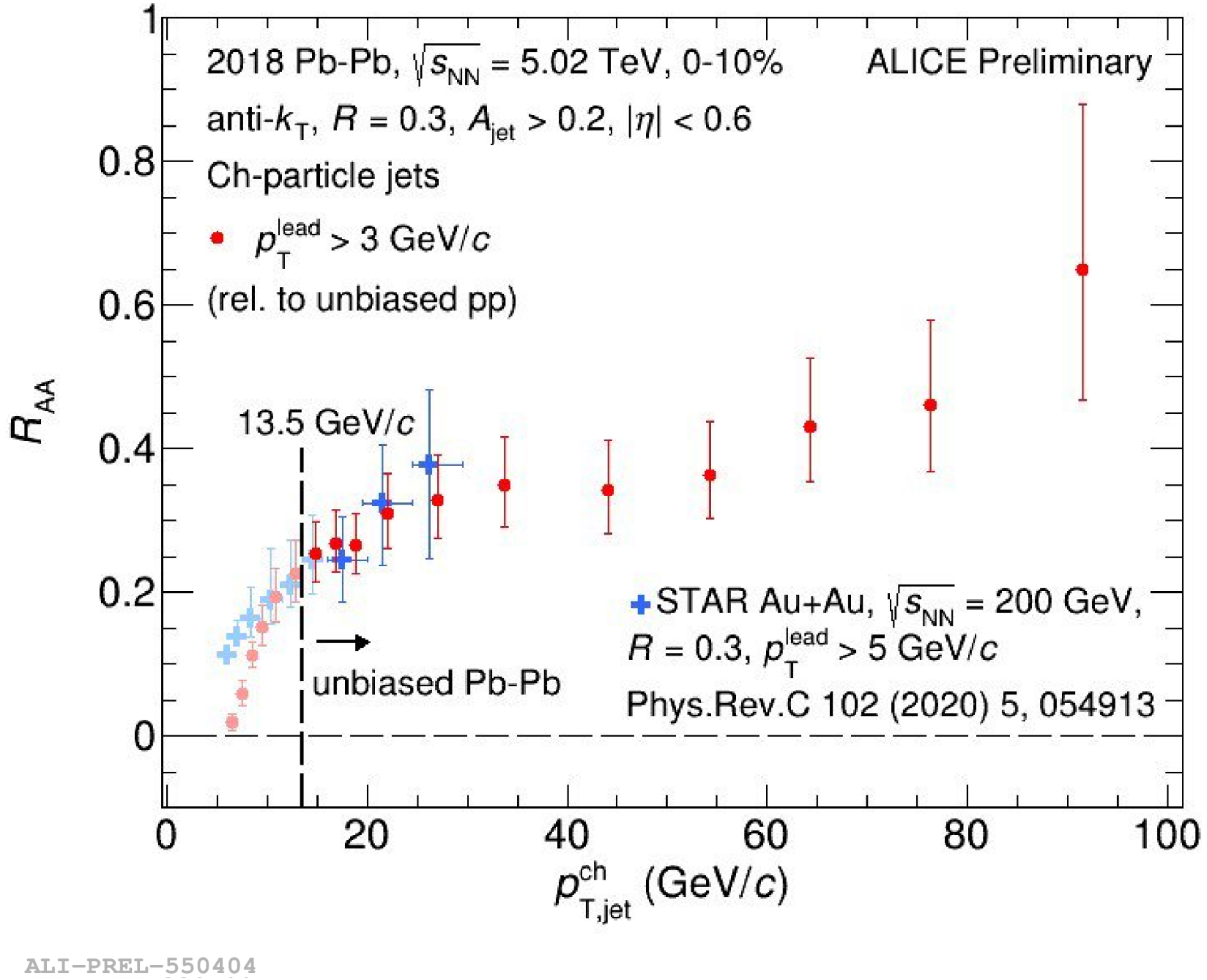


2015 Pb-Pb: ALICE Collaboration, *Phys.Lett.B* 849 (2024) 138412

Comparison to RHIC R_{AA}: R = 0.3

- First direct comparison of reconstructed jet suppression at LHC & RHIC in same kinematic range
- Unbiased Au+Au at $p_{T,jet} > 16$ GeV/c
- Comparable R_{AA} between $\sqrt{s_{NN}}$ = 5.02 TeV & $\sqrt{s_{NN}}$ = 200 GeV
  - Yield suppression is combined effect of spectrum shape and energy loss
  - Inclusive jet spectrum much harder at LHC than RHIC
  - q/g composition is different at LHC (gluon-dominated) & RHIC (larger quark fraction)

→ **Same R_{AA} does not mean same energy loss**



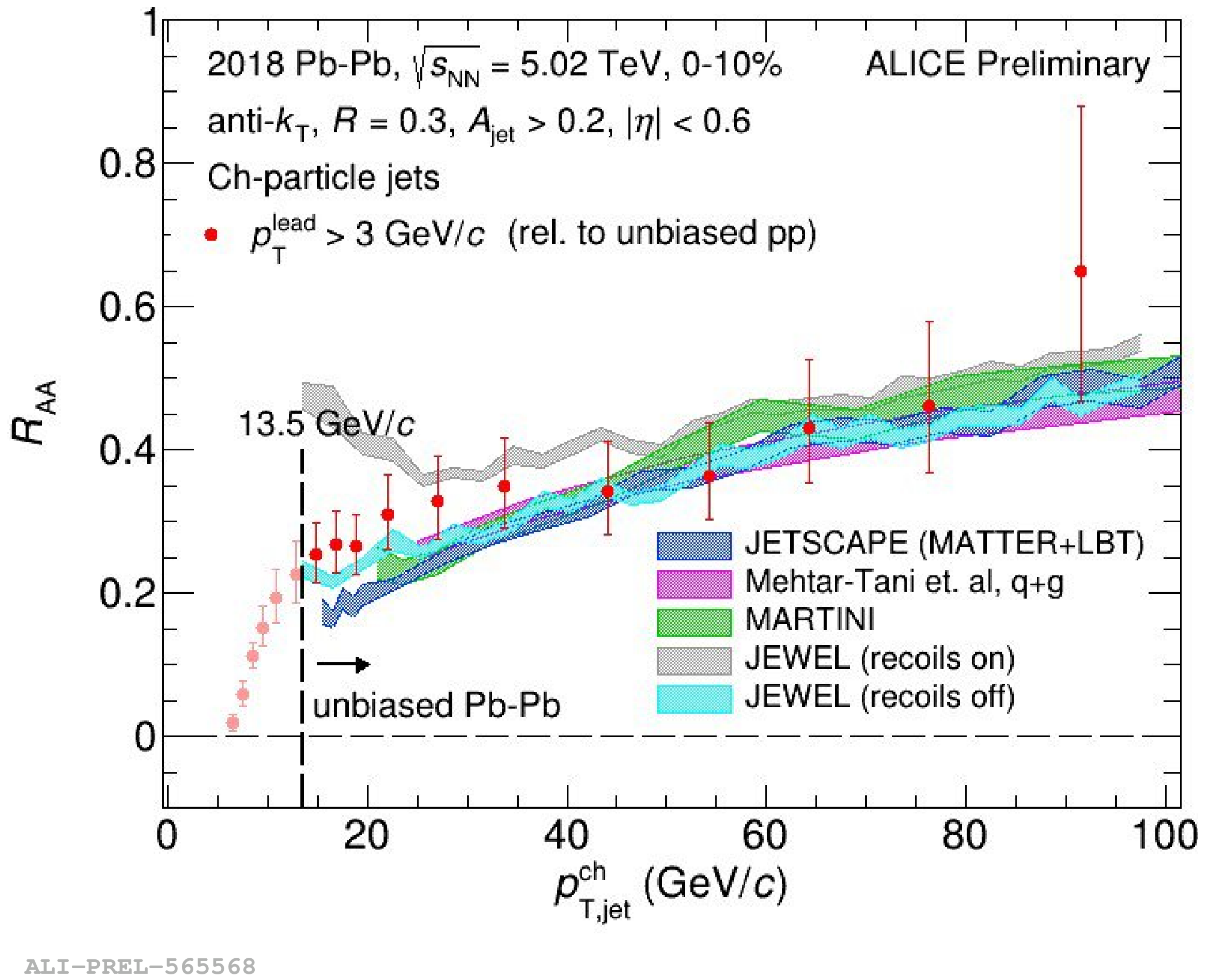
STAR: *Phys.Rev.C* 102 (2020) 5, 054913

Model comparisons: R = 0.3

- Models describe R_{AA} at high $p_{T,jet}$
- Models differ at low $p_{T,jet}$
- Acoplanarity is much better described with JEWEL recoils on

  → Inclusive & coincidence give opposite pictures

Talk by Peter Jacobs today, 11:30

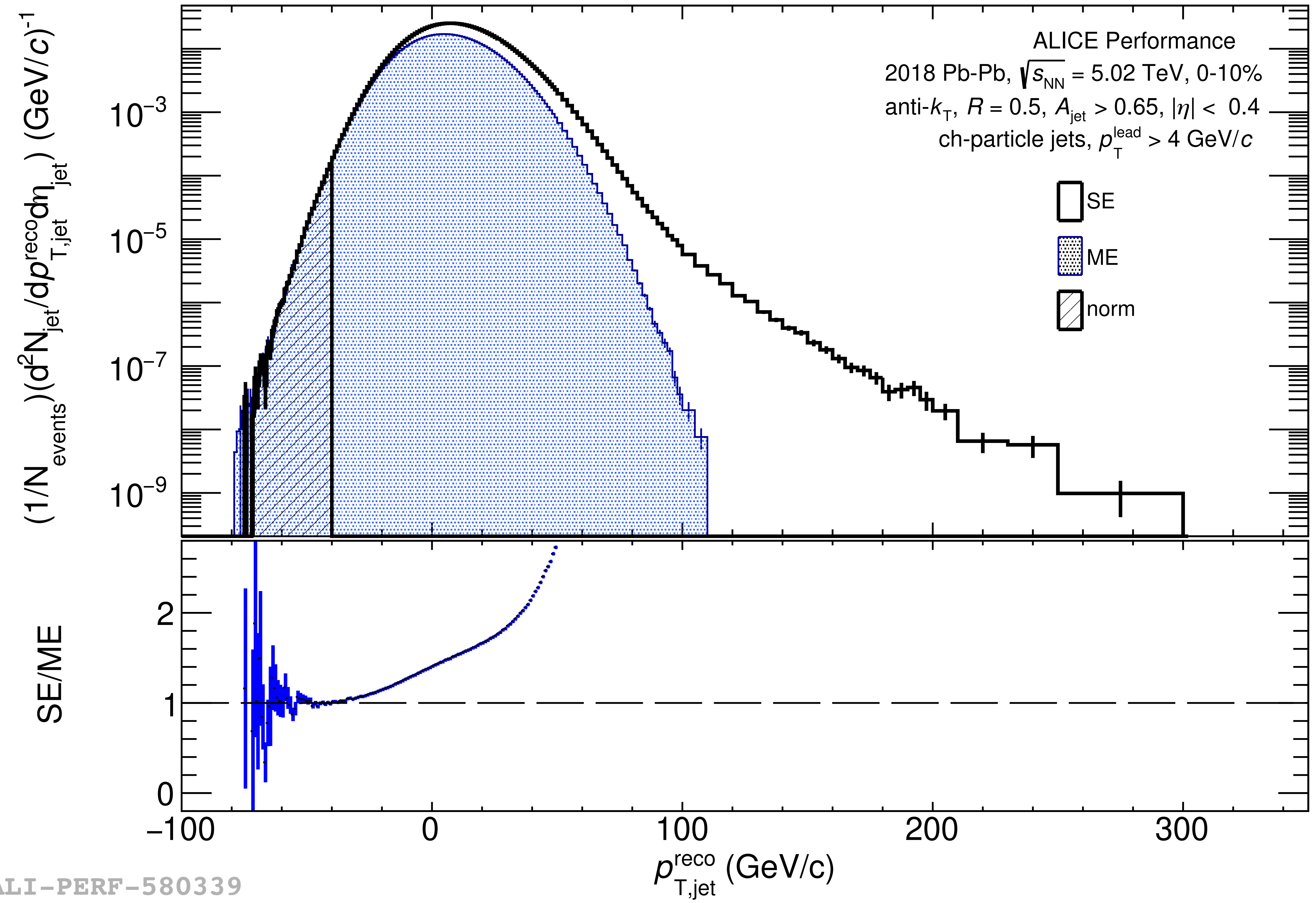


JETSCAPE: JETSCAPE Collaboration, Phys. Rev. C 107, 034911, 16 March 2023,arXiv:1903.07706
Mehtar-Tani et. al: Phys.Rev.Lett. 127 (2021) 25, 252301
JEWEL: JHEP 1707 (2017) 141
MARTINI: Phys.Rev.C 107 (2023) 3, 034908, arXiv:2212.05944

Radius dependence: R = 0.5

- Measure larger R to be more sensitive to response of the medium
- R = 0.5 is already work in progress
- Larger R & small leading track cut is more challenging
  - Larger p_{T}-smearing
  - Normalisation ME to SE only up to -40 GeV/c
  - Lower statistics/smaller ME to SE ratio

Raw biased jet distribution, $p_{\mathrm{T}}^{\mathrm{lead}}$ > 4 GeV/c



Summary

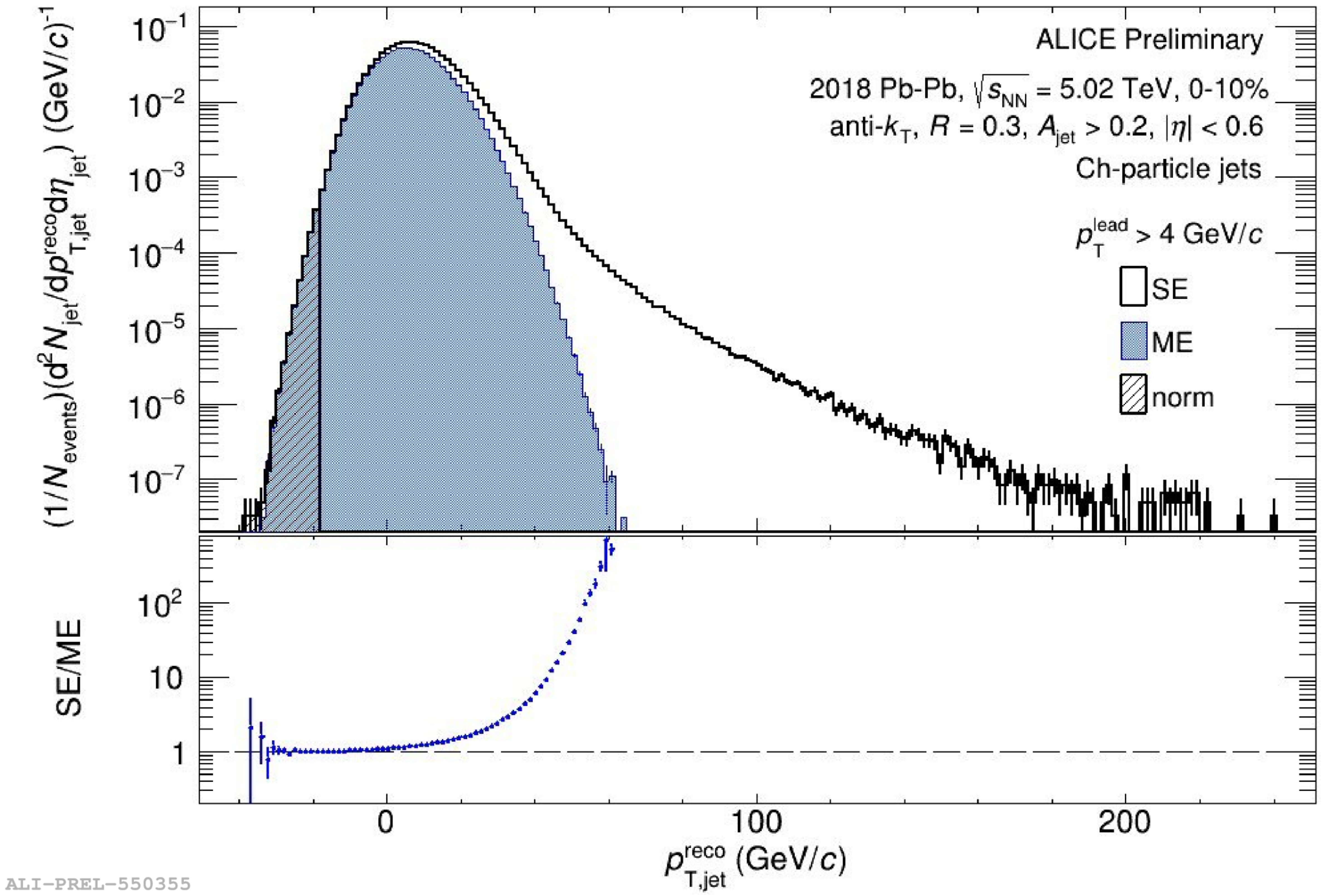
- With mixed-event technique we can push the inclusive jet measurement to very low $p_{\mathrm{T,jet}}$
- Unbiased charged particle jet R_{AA} down to 13.5 GeV/c (R = 0.3)

Next steps:

- Measurement of the radius dependence
- h-jet measurement
- Mixed events in Run3

Backup

Raw quasi-incl. jet distribution, *R* = 0.3



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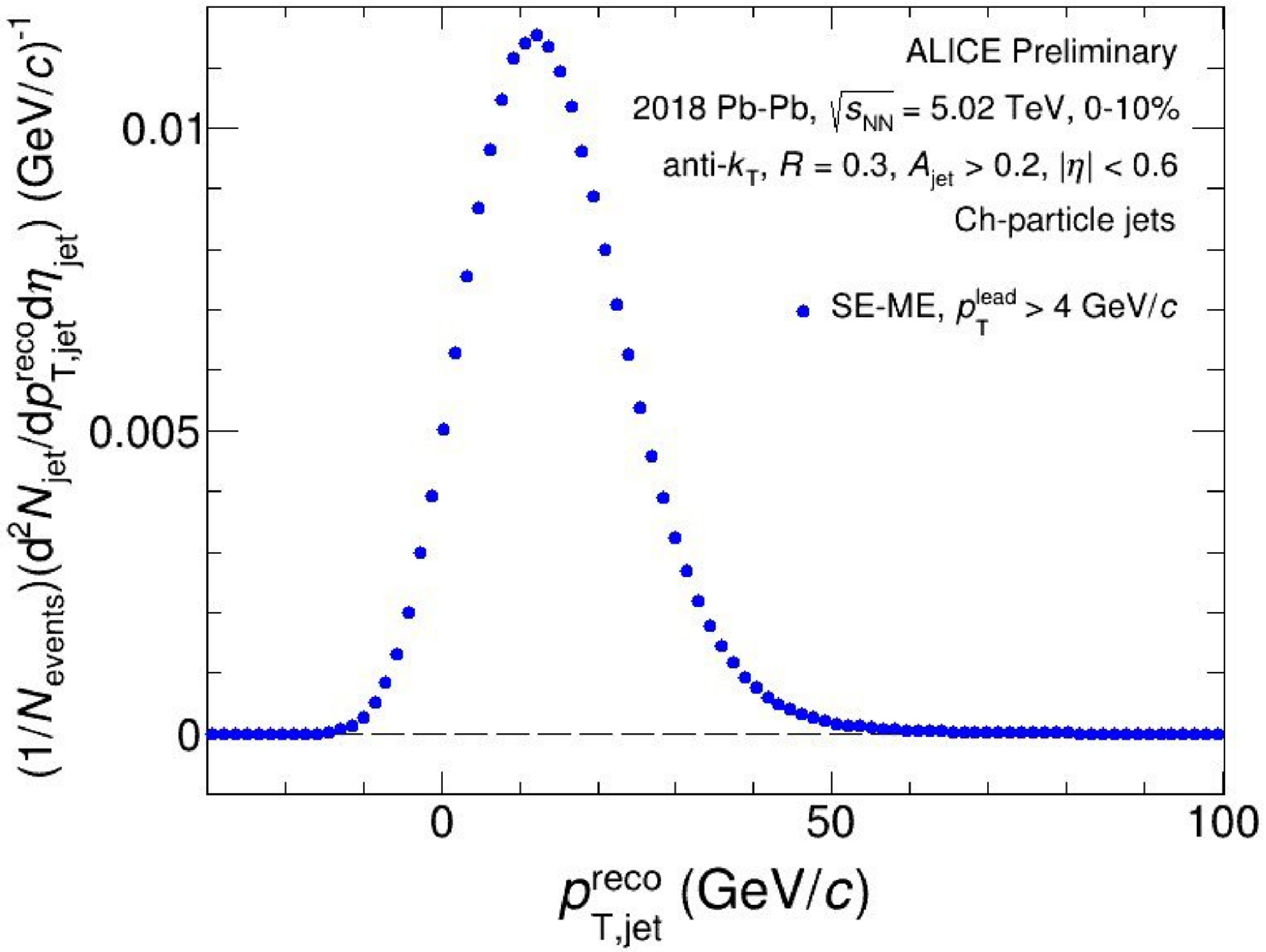

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Model comparisons

- 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/CTF)
- Mehtar-Tani et. al: Analytic calculation based on BDMPS/GLV and hydrodynamics