# Measurement of jet suppression down to low $p_{\mathrm{T}}$ in Pb-Pb collisions with ALICE

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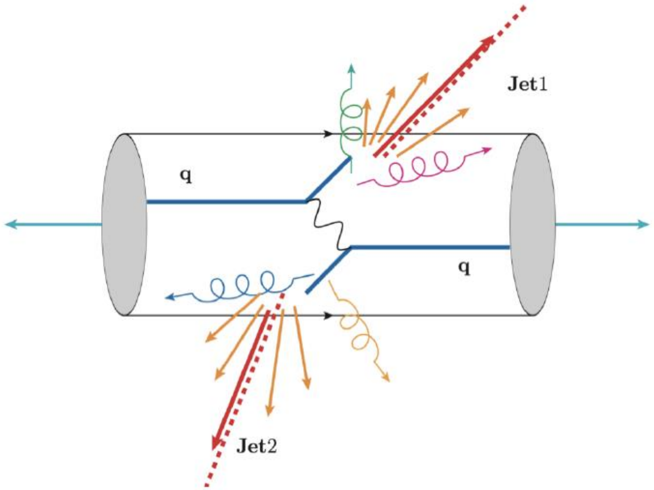
# Jets as a probe of the quark-gluon plasma

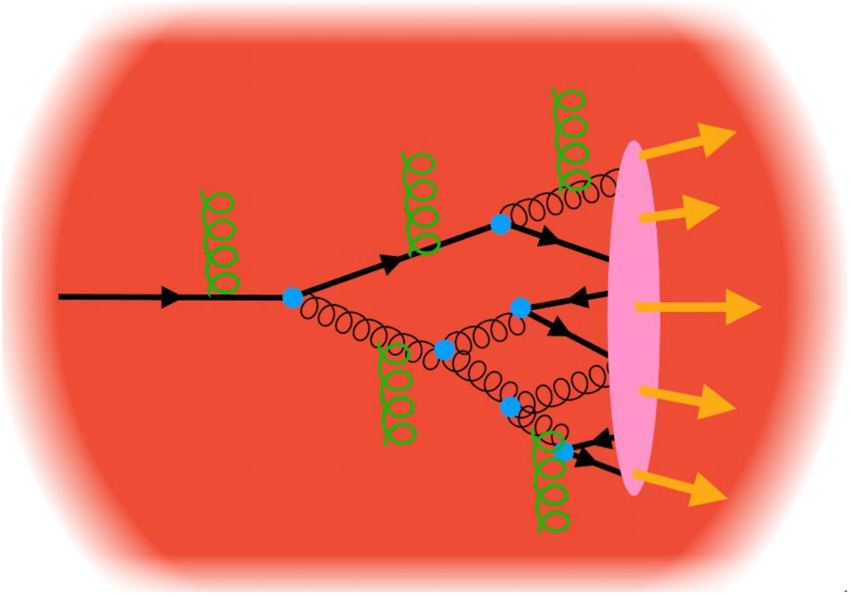
- **Jet:** a collimated cluster of hadrons produced by the fragmentation of high-energy quarks or gluons

- **Jet quenching:** jet energy loss caused by interaction between jet and QGP medium

- Jet nuclear modification factor:

$$R_{AA} = \frac{1}{< T_{AA} >} \frac{d^2 N_{jets}^{AA} / dp_T d\eta}{\sigma_{jets}^{pp} / dp_T d\eta}$$



# Jets measurements down to low $p_T$

- Jet measurements in Pb-Pb challenging due to large non-uniform uncorrelated background

- Current ALICE jet $R_{AA}$ measurement: low $p_T$ reached with Machine Learning based background subtraction
  - jet $R_{AA}$ measurement only down to about 30 GeV/c

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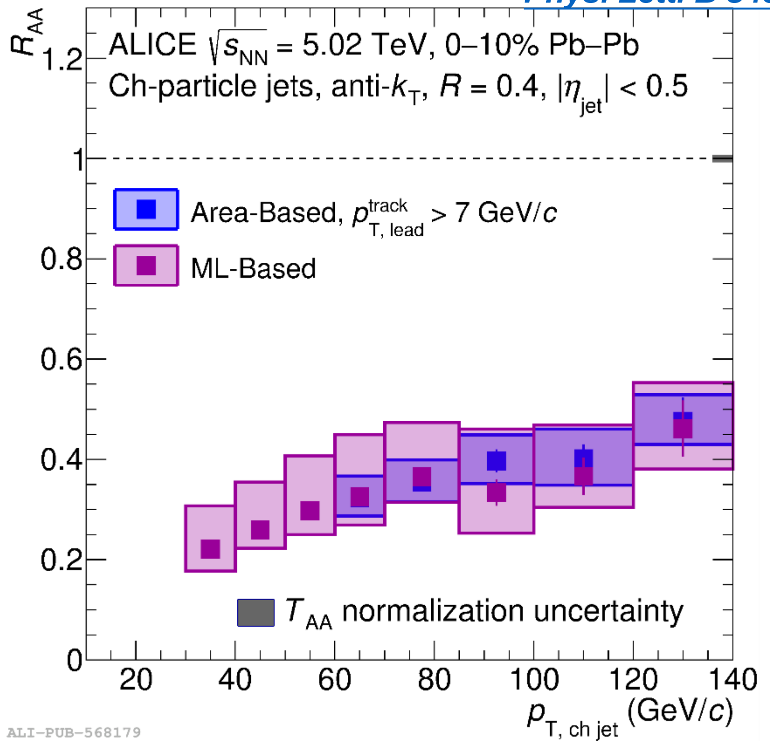
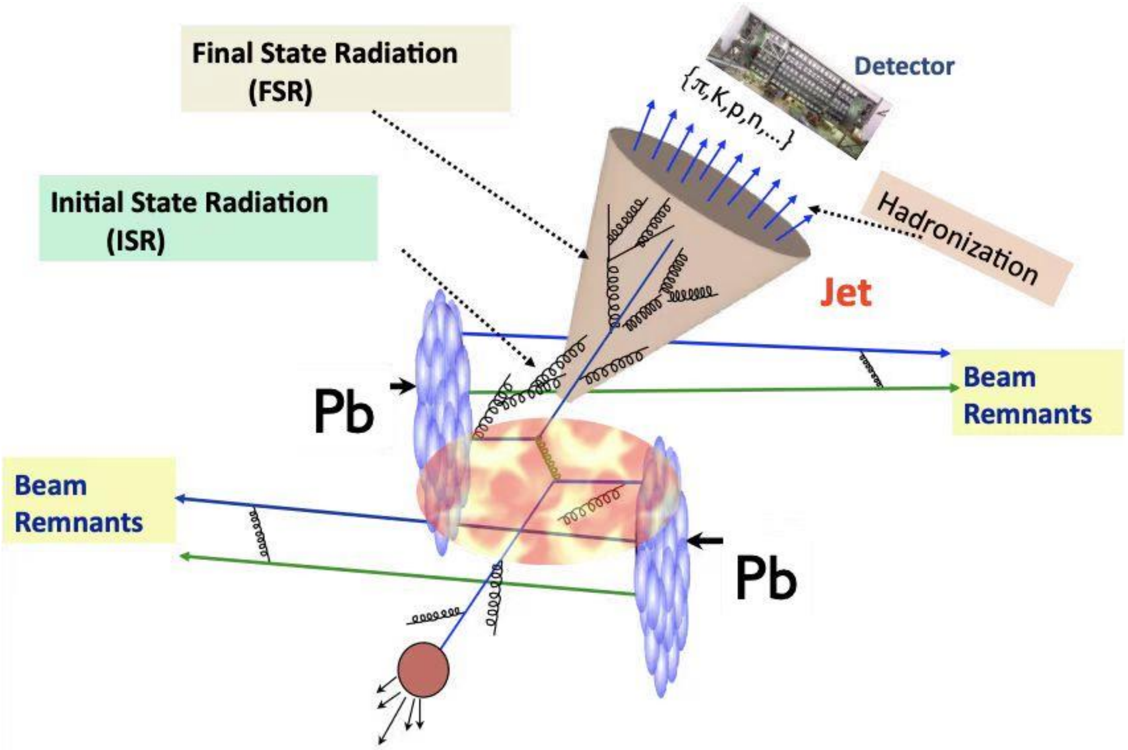
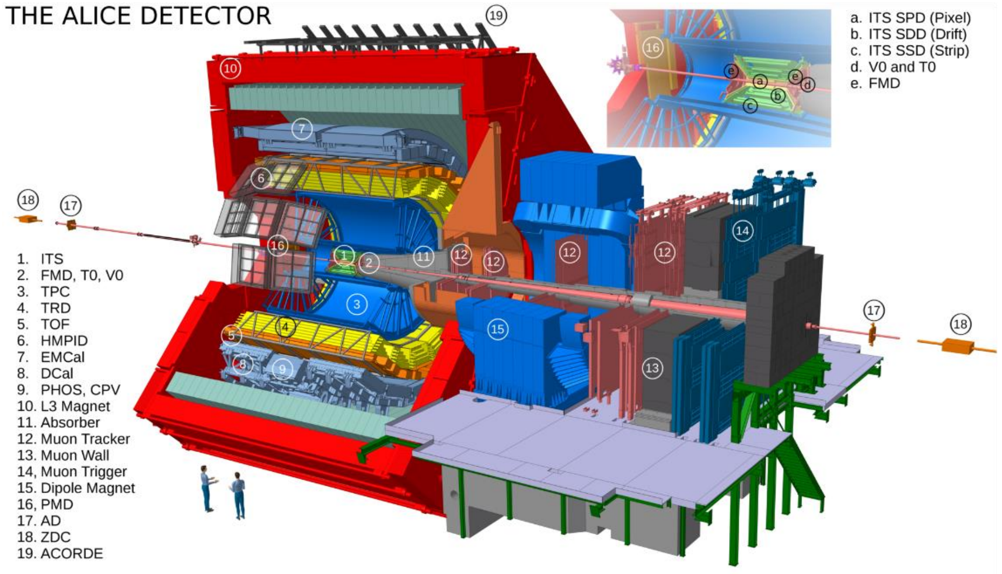


# ALICE in Run 2 & Run 3

Run 2



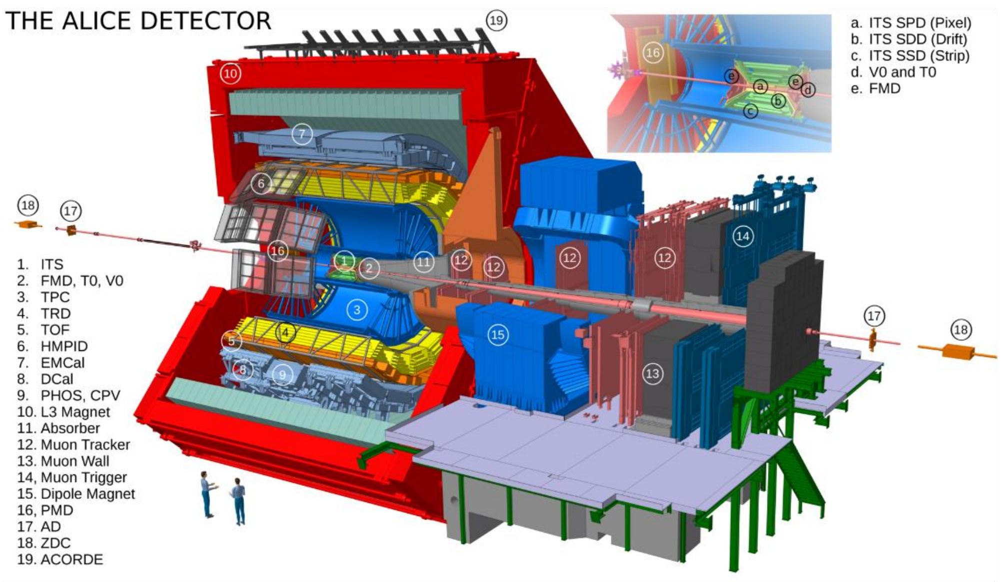

- **ITS** (Inner Tracking System)
  - Primary vertex reconstruction
  - Charged particle tracking
- **TPC** (Time Projection Chamber)
  - Charged particle tracking
  - Particle identification

Charged-particle jet reconstruction

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

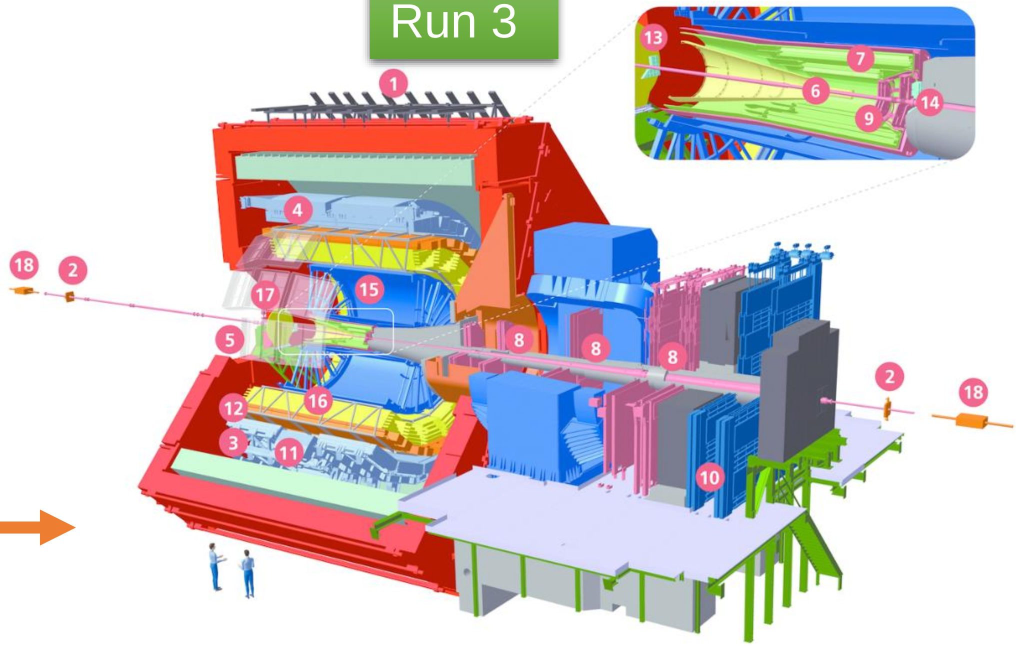
# ALICE in Run 2 & Run 3

Run 2




Upgraded

Run 3



- **ITS** (Inner Tracking System)
  - Primary vertex reconstruction
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Charged-particle jet reconstruction

- **Upgraded ITS**
  - Vertex reconstruction
- **Upgraded TPC**
  - Continuous readout

- Pb-Pb data taking 50kHz at $\sqrt{s_{NN}} = 5.36\ \text{TeV}$
- Collected 12B minimum bias events

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

*Use a new technique to push to even low $p_T$*

# Jets analysis with event mixing technique

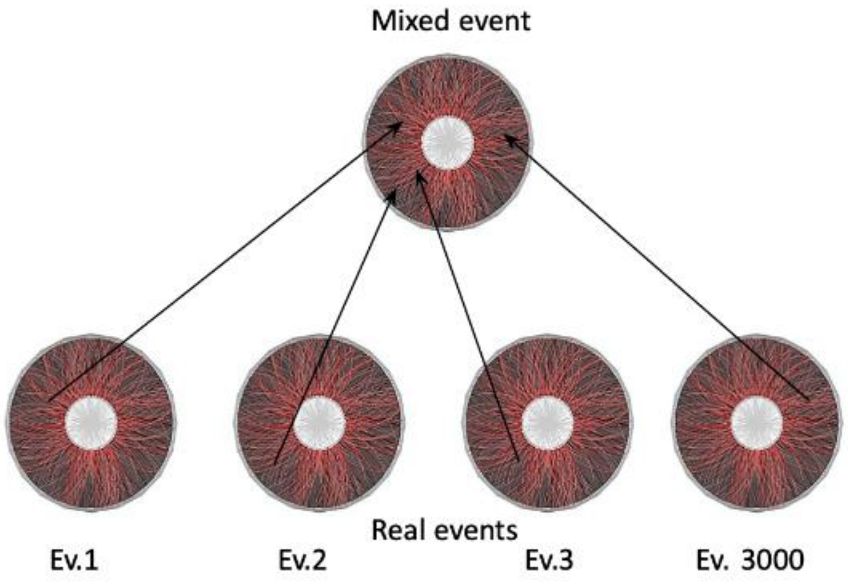
- Assembly of mixed events (ME):
  - Categorisation of events into 9600(multiplicity, z-vertex, event plane, $p_{\mathrm{T,tracks}}^{\mathrm{sum}}$) categories
  - One track form each real event
    - Remove multi-hadron correlations in ME
- Same events (SE): real events

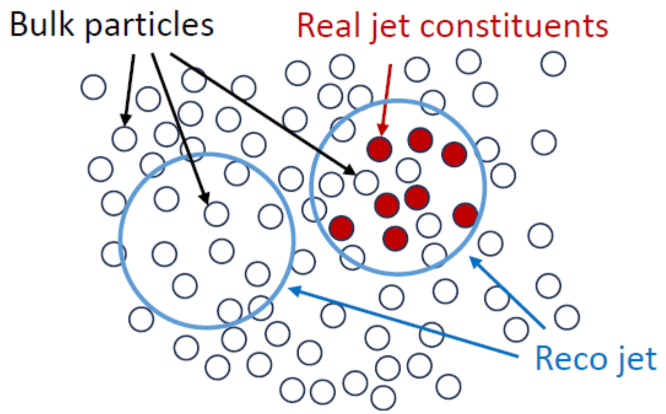
- Jet analysis:
  - Charged particle jets: anti-$k_{\mathrm{T}}$, R = 0.3, $|\eta| < 0.6$
- Background correction:
  - Remove pedestal underlying event from the jets:

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

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

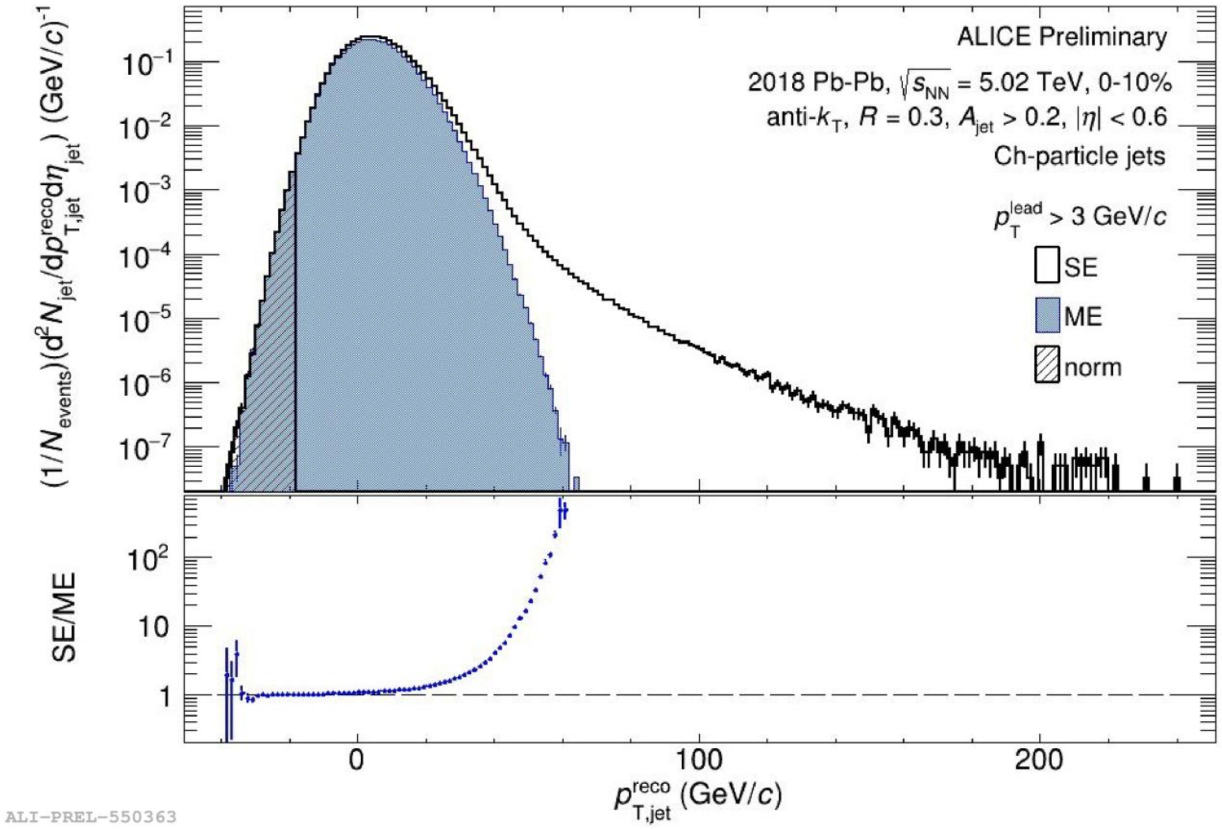
First use of ME technique: in STAR (PRC 96 (2017) 2, 024905)



# Raw jet distribution – R = 0.3

- Inclusive distribution of partons at low $p_{\mathrm{T}}$: many overlapping objects, cannot reconstruct as distinct jets
  - Introduce a small bias to define physics jet
  - Vary the bias to measure its effect and determine the $p_{\mathrm{T}}$ region where the bias is negligible




Raw biased jet distribution, $p_T^{lead} > 3$GeV/$c$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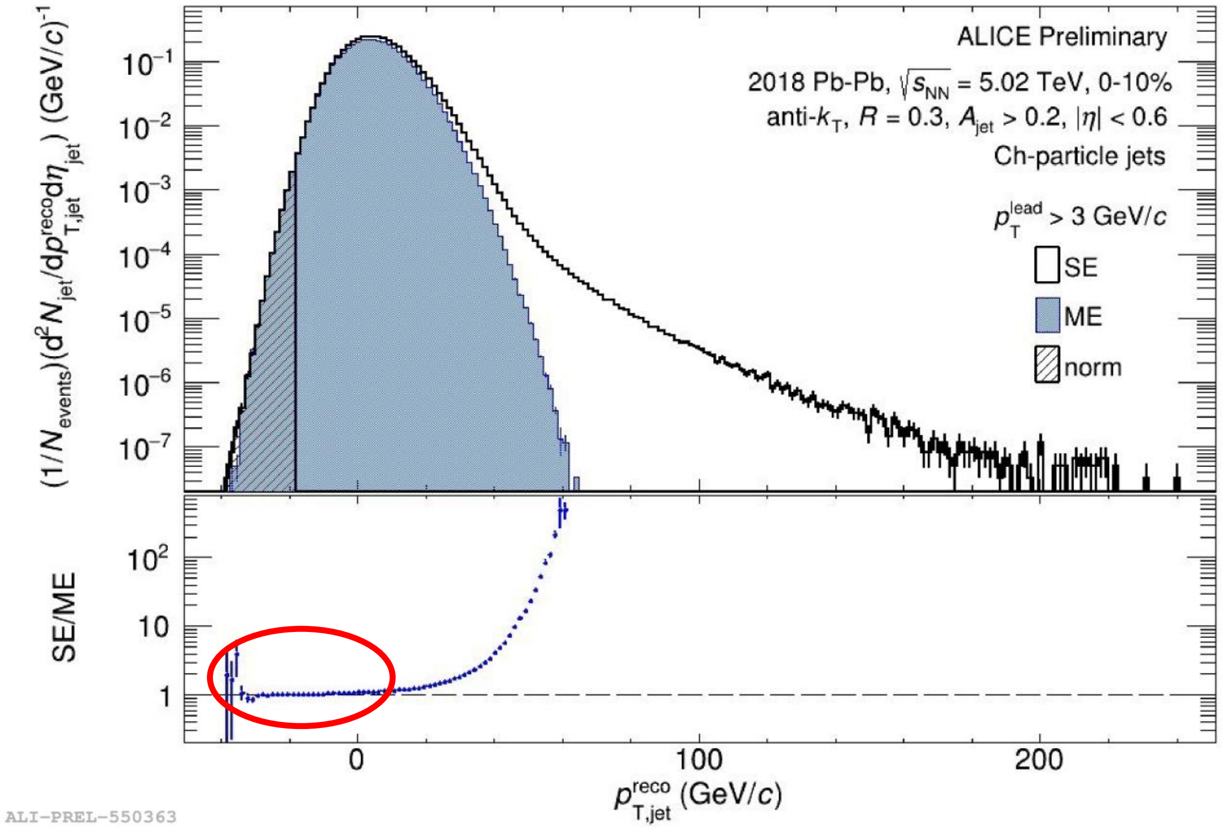
- Essential criterion for ME: ratio needs to be flat on the left-hand side (not jet signal)

- Normalisation of ME: data driven



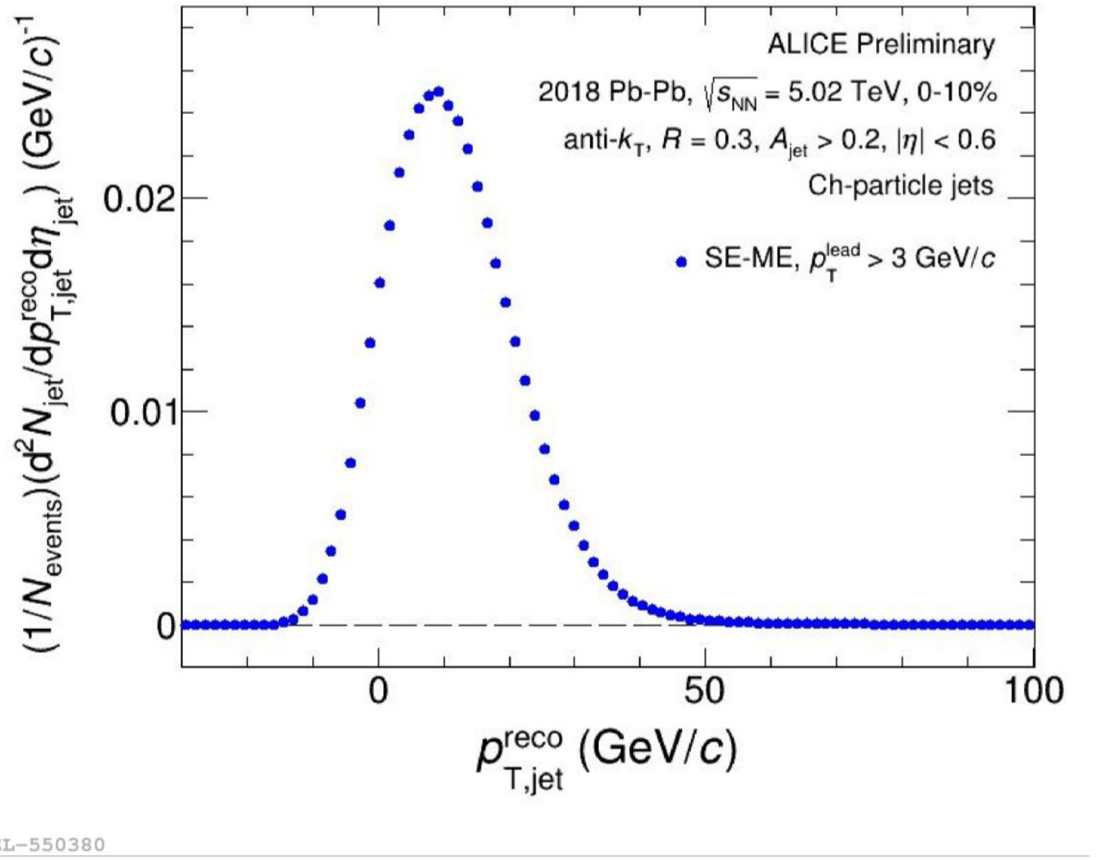

Raw biased jet distribution, $p_T^{lead} > 3$GeV/c

# Raw jet distribution – after subtraction

- Inclusive distribution of partons at low $p_{\mathrm{T}}$: many overlapping objects, cannot reconstruct as distinct jets
  - Introduce a small bias to define physics jet
  - Vary the bias to measure its effect and determine the $p_{\mathrm{T}}$ region where the bias is negligible

- Essential criterion for ME: ratio needs to be flat on the left-hand side (not jet signal)
- Normalisation of ME: data driven
- Subtraction of combinatorial background yield using ME

- ME procedure removes uncorrelated bkg yield
- Leading track $p_{\mathrm{T}}$ cut generates countable objects

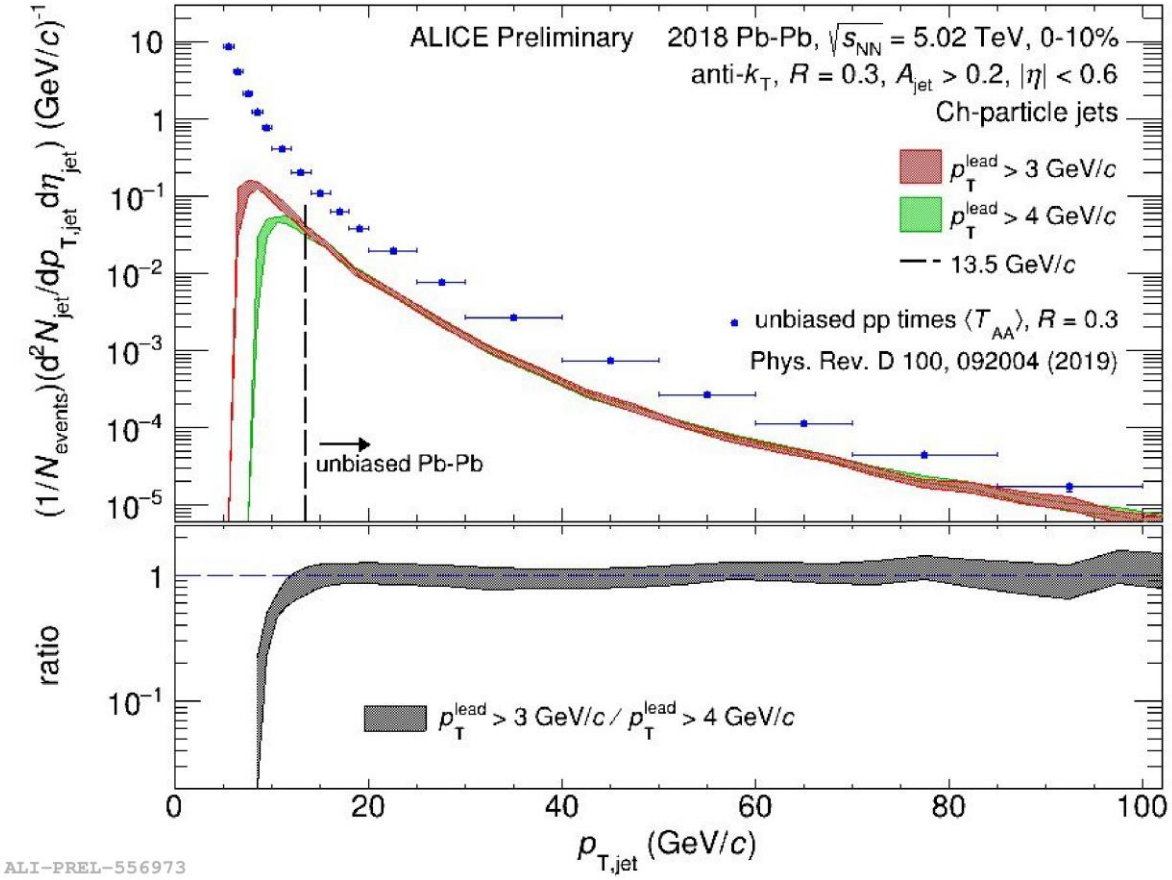



Raw correlated biased jet distribution, $p_T^{lead} > 3$GeV/$c$: SE-ME

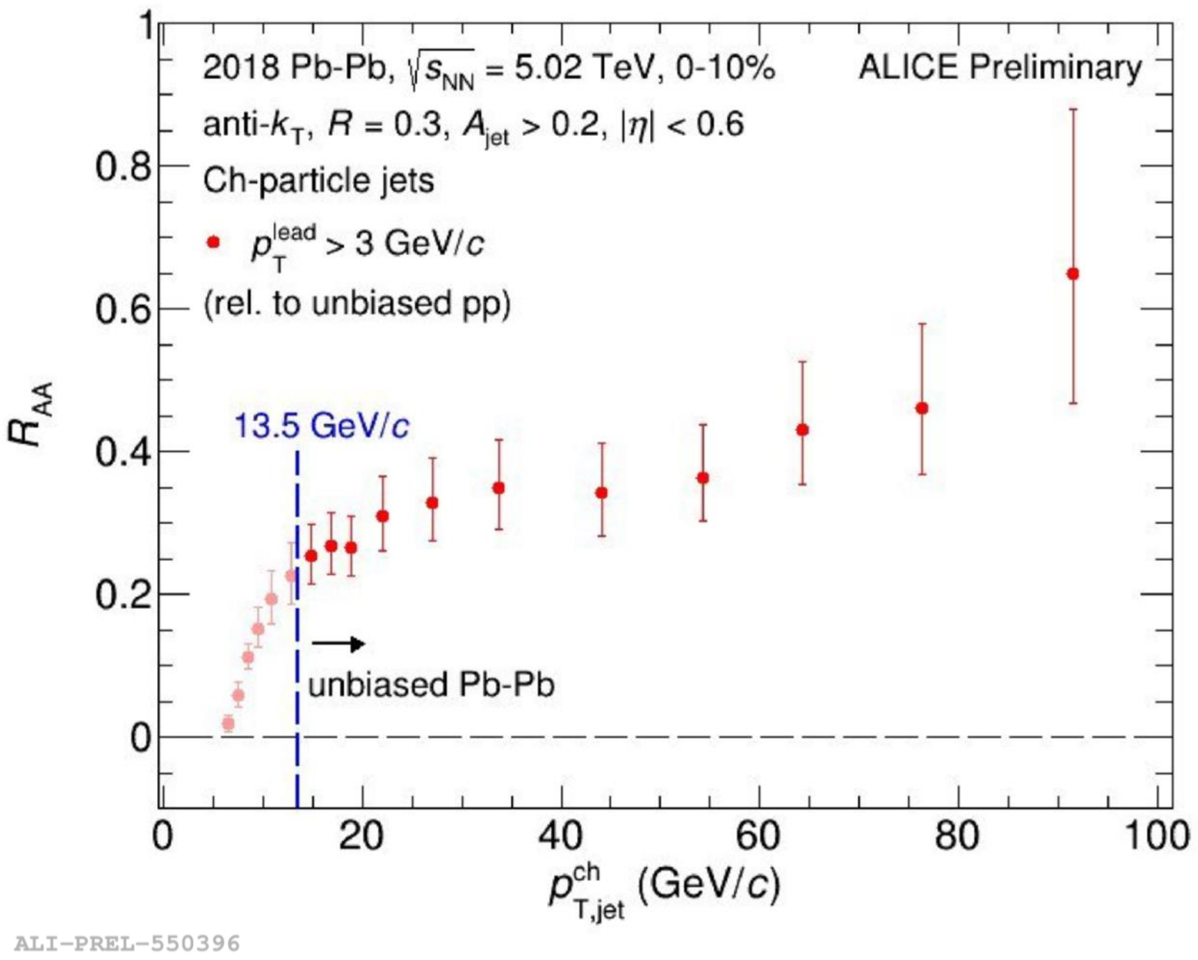
# Corrected jet distributions – R = 0.3

- Once the yield is subtracted, unfolding to correct the smearing of jets
- Fully corrected 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 and unfolding

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



# Charged-particle jet $R_{AA}$

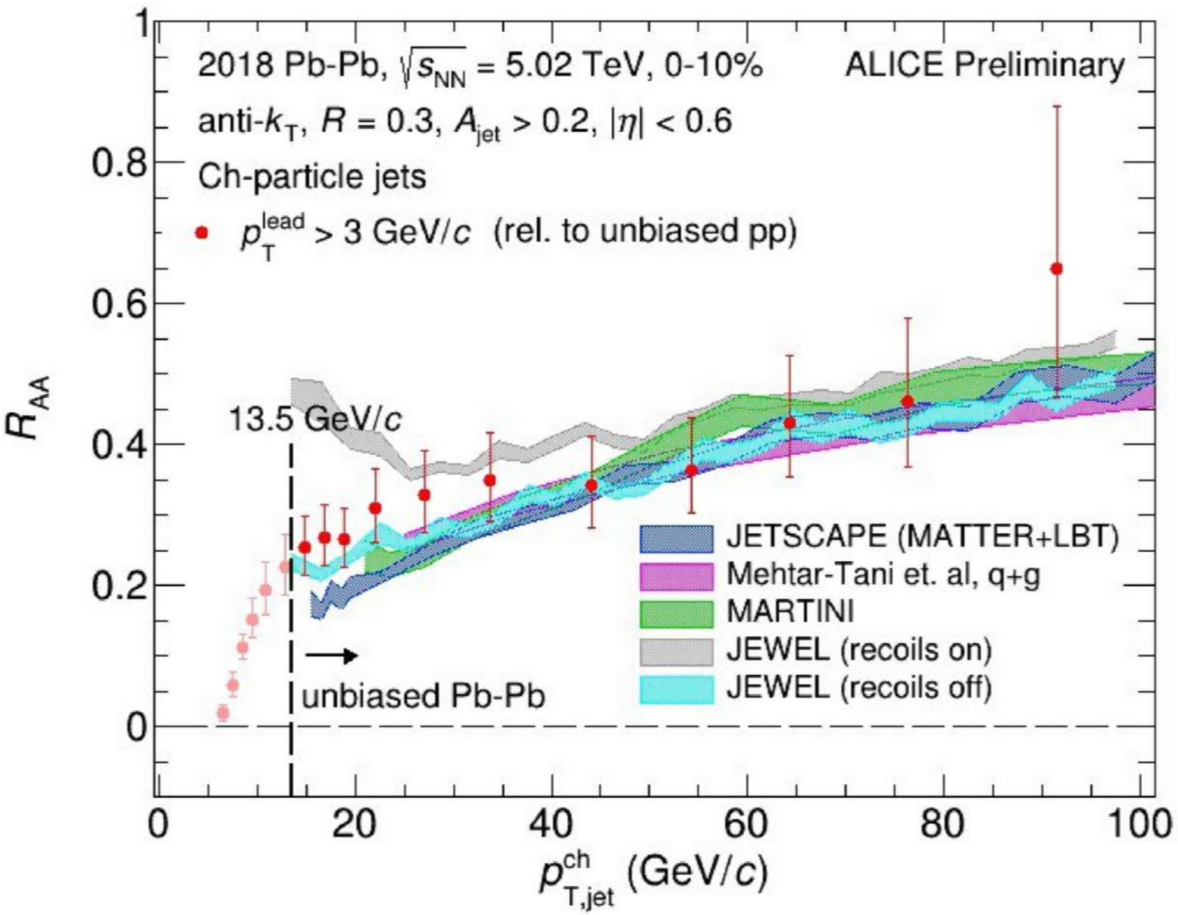



- $R_{AA}$ is calculated relative to unbiased pp charged-particle jets[1]
- Combined pp and Pb-Pb uncertainties
- Syst. + stat. uncertainties added in quadrature

  ➢ unbiased Pb-Pb $R_{AA}$ down to 13.5 GeV/$c$

[1]Unbiased pp: ALICE collaboration, Phys. Rev. D, 100, 092004, 2019.

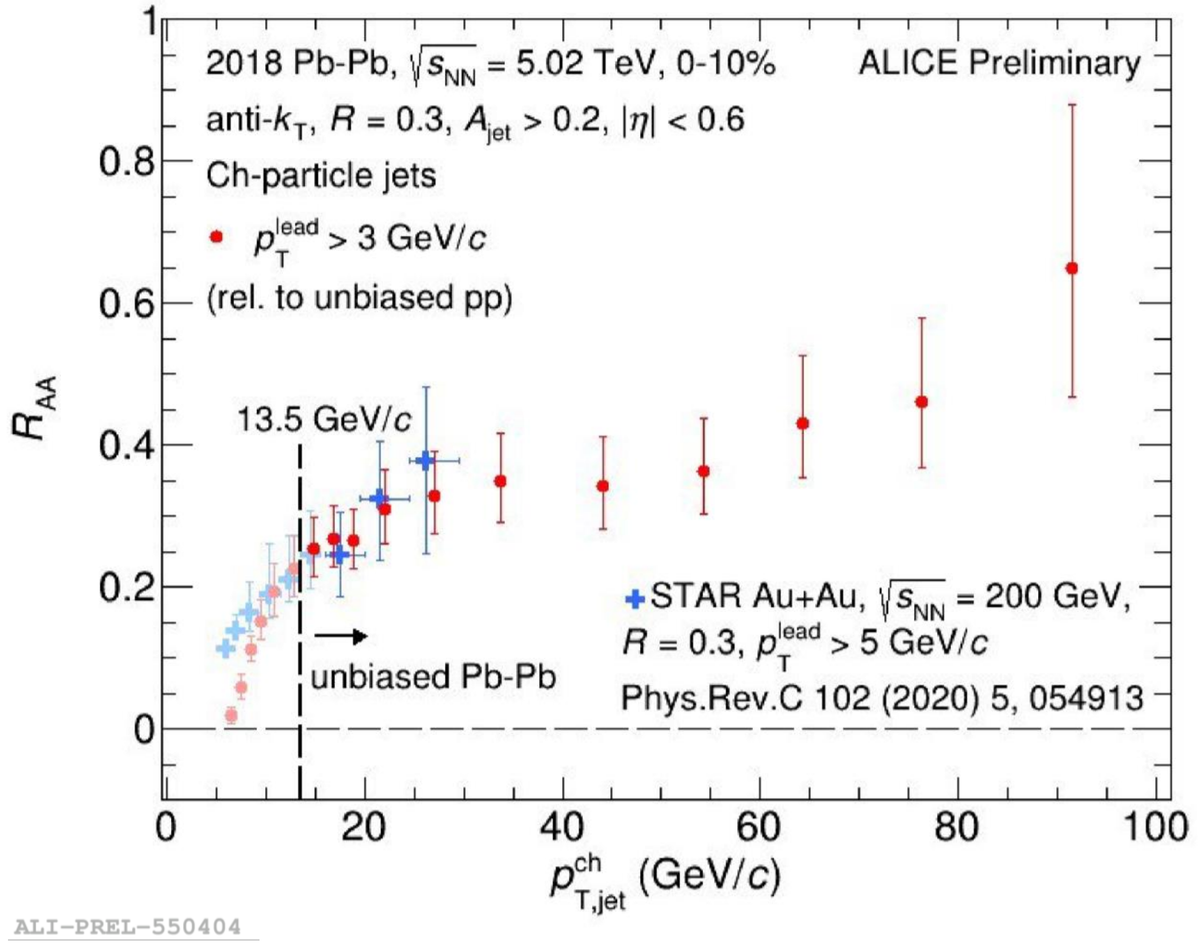
# Charged-particle jet $R_{\mathrm{AA}}$ – model comparisons




- $R_{\mathrm{AA}}$ 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 $R_{\mathrm{AA}}$ down to 13.5 GeV/$c$
- Models describe $R_{\mathrm{AA}}$ at high $p_{\mathrm{T}}$, **disagree with each other at low $p_T$**

[1]Unbiased pp: ALICE collaboration, Phys. Rev. D, 100, 092004, 2019.

# Charged-particle jet $R_{\mathrm{AA}}$ - comparison to RHIC

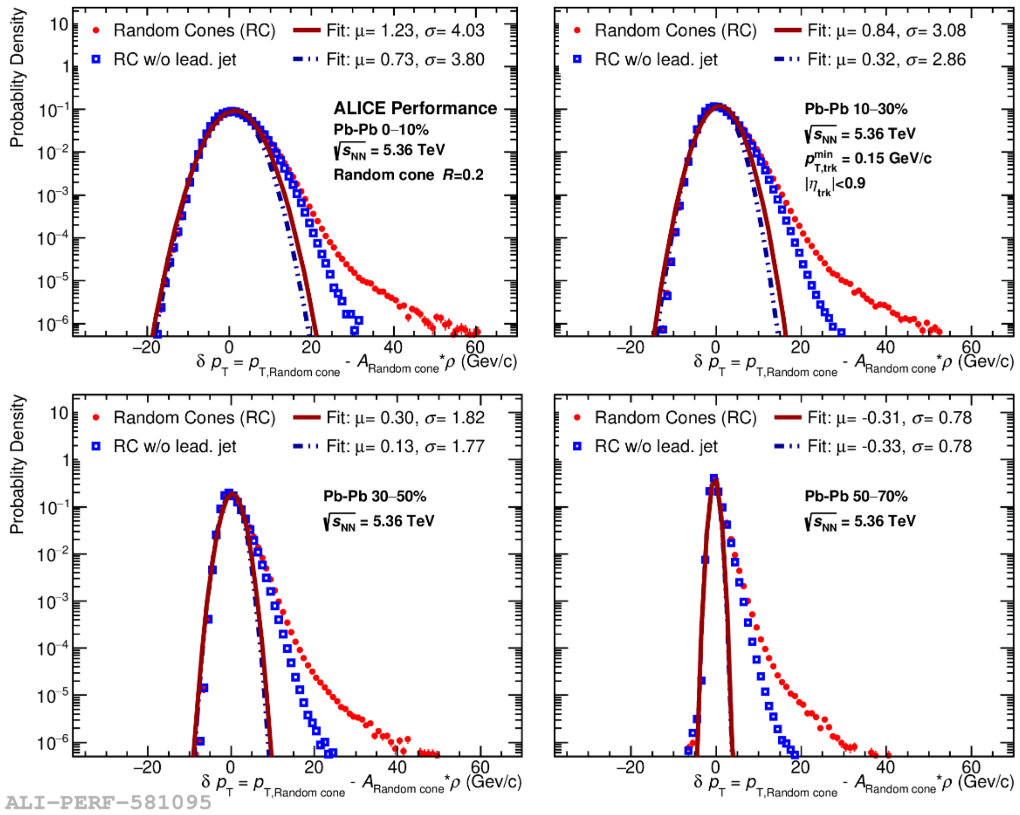


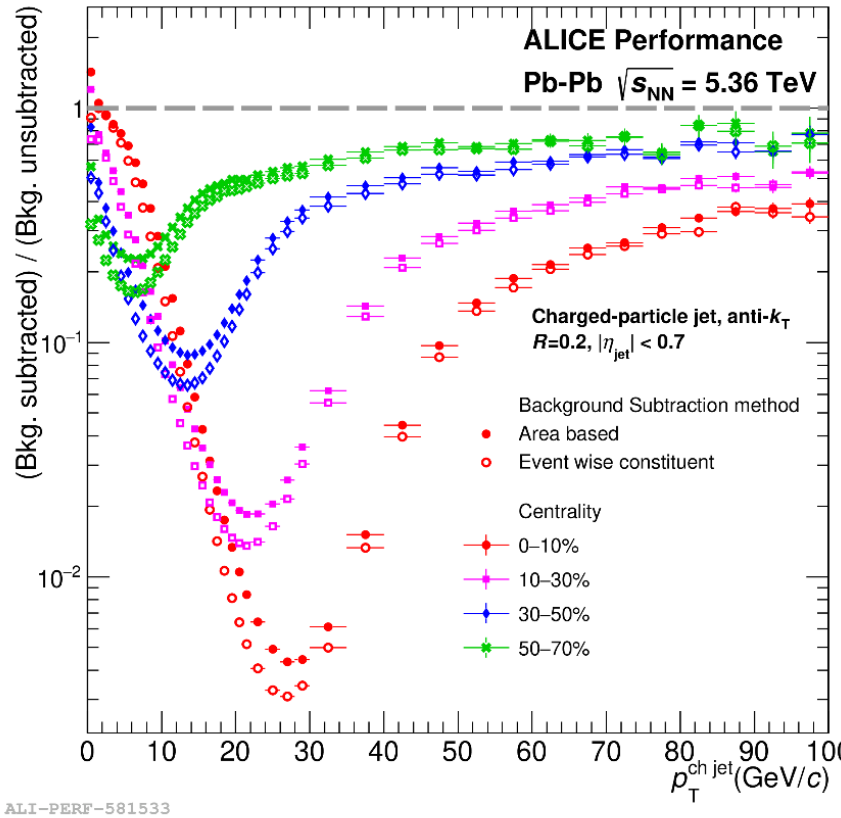

- Comparison of reconstructed jet suppression at LHC & RHIC in the same kinematic range
- Unbiased Au+Au at $p_{\mathrm{T,jet}} > 16$ GeV/$c$
- Comparable $R_{\mathrm{AA}}$ between $\sqrt{s_{NN}}$ = 200GeV and $\sqrt{s_{NN}}$ = 5.02TeV

➢ Same $R_{\mathrm{AA}}$ does not mean same energy loss

[1]Unbiased pp: ALICE collaboration, Phys. Rev. D, 100, 092004, 2019.
STAR: Phys.Rev.C 102 (2020) 5, 054913

# First background study with Run 3 Pb-Pb data




$$\delta p_{\mathrm{T}} = p_{\mathrm{T,Random\ cone}} - A_{\mathrm{Random\ cone}} * \rho$$

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

$$\mathrm{Ratio} = \frac{\mathrm{Bkg.\ subtracted}}{\mathrm{Bkg.\ unsubtracted}}$$

- Two pedestal background subtraction methods in four centrality classes

# Summary & outlook

- First application of event-mixing approach to inclusive jet measurements
- Unbiased Pb-Pb jet $R_{\mathrm{AA}}$ measurement down to lower $p_{\mathrm{T}}$
- Comparison of jet suppression at LHC & RHIC

## Outlook:

- Run 3 Pb-Pb analysis:
  - Jet $R_{\mathrm{AA}}$ measurement at $\sqrt{s_{NN}} = 5.36\ \mathrm{TeV}$
  - Study of path length dependent jet energy loss

**Thanks for your attention!**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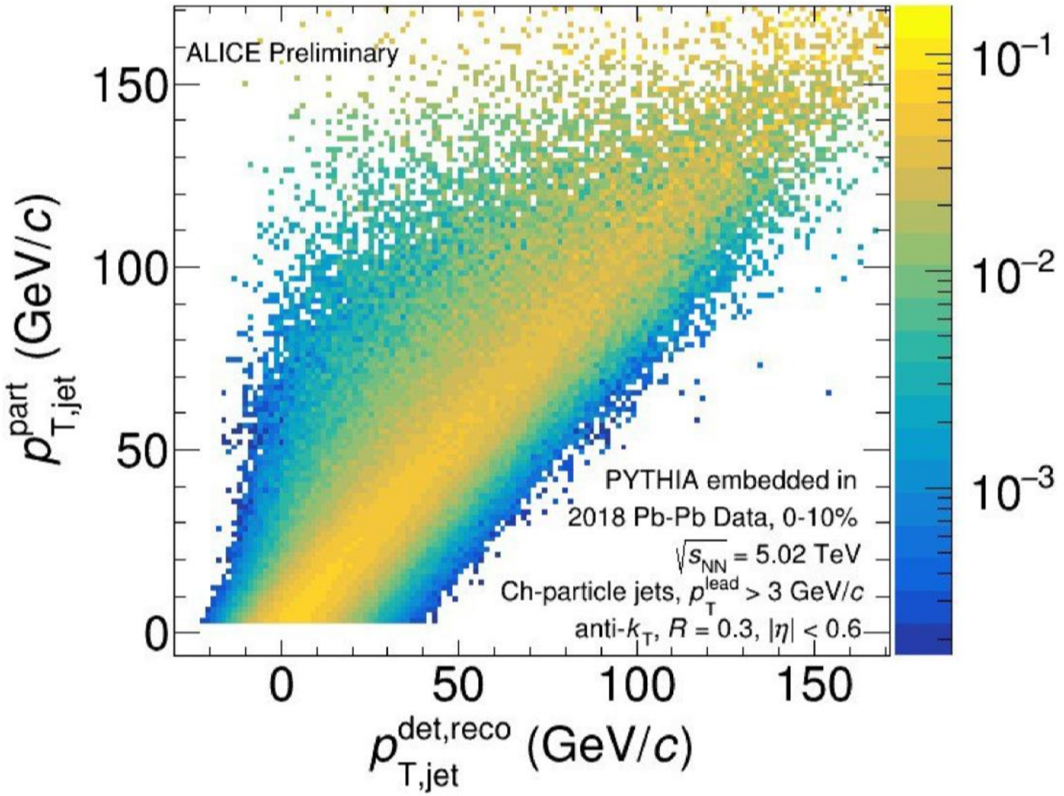
# BACK UP

# Corrections for $p_{\mathrm{T}}$ smearing

- Unfolding: correction of $p_{\mathrm{T}}$ smearing due to background and detector effects
- Background effects: corrections for local fluctuations
- Detector effects: corrections for efficiency and $p_{\mathrm{T}}$ resolution
- Response matrix calculation with embedding of PYTHIA jets into SE
- **ROOT** unfolding framework **RooUnfold** with **Bayesian unfolding** method
- Prior: PYTHIA particle level
- Correction for jet reconstruction efficiency after unfolding

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