# Jet production and the nuclear modification factor in pp and p−Pb collisions with ALICE

**Austin Schmier** on behalf of the ALICE collaboration
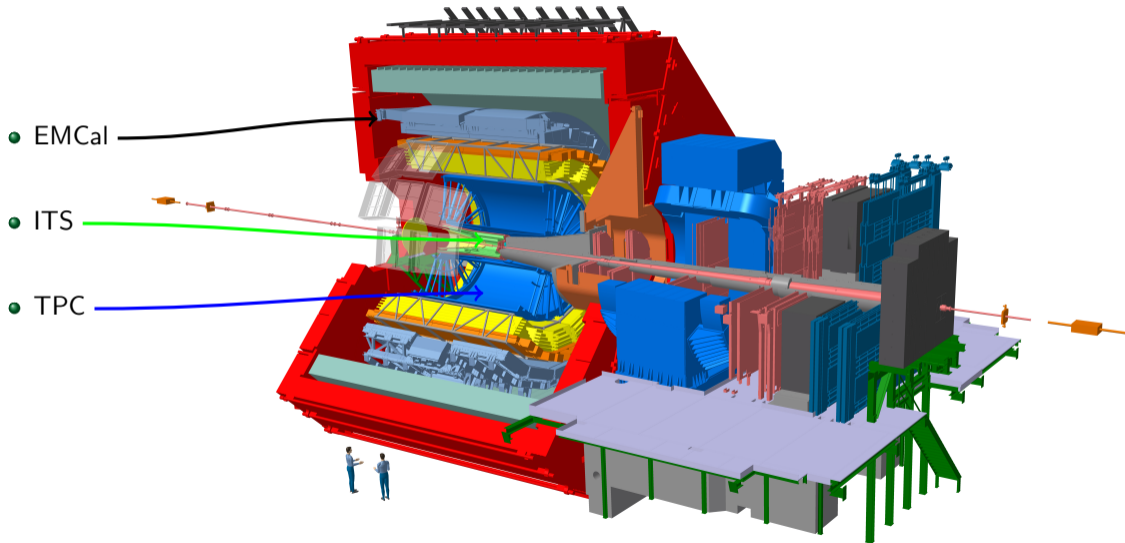University of Tennessee Knoxville

**December 13, 2023**

- EMCal
- ITS
- TPC

# Jet Reconstruction

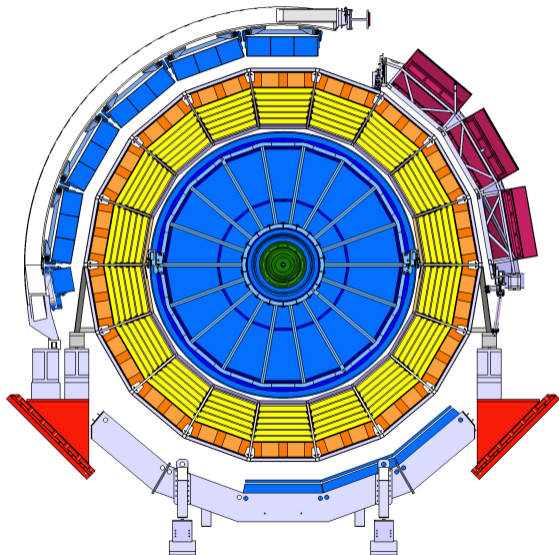**Charged-Particle Jets**

- ITS+TPC
  - Full $\phi$ acceptance
  - $|\eta| < 0.9$
- EMCal
  - Run 1/2: $\Delta\phi = 100°/107°$
  - $|\eta| < 0.7$
  - Provides a trigger for high momentum jet events
- Reconstructed using the anti-$k_{\text{T}}$ algorithm with different jet radii ($R = \sqrt{\eta^2 + \phi^2}$)
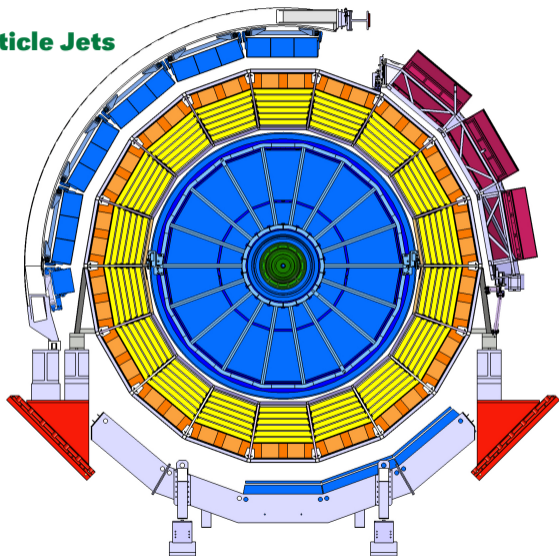
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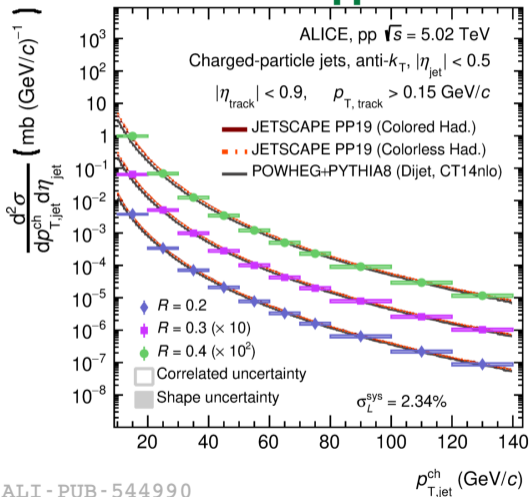- Reconstructed using the anti-$k_T$ algorithm with different jet radii ($R = \sqrt{\eta^2 + \phi^2}$)

**Full Jets**

- Possible to go to large jet radii
- High precision of tracking detectors
- Small uncertainties allow for tighter model constraints
- Momentum limited by ALICE high-$p_T$ tracking

## Ch Part Jet - pp 5.02 TeV



ALICE, pp $\sqrt{s}$ = 5.02 TeV
Charged-particle jets, anti-$k_T$, $|\eta_{jet}| < 0.5$
$|\eta_{track}| < 0.9$, $p_{T, track} > 0.15$ GeV/$c$

JETSCAPE PP19 (Colored Had.)
JETSCAPE PP19 (Colorless Had.)
POWHEG+PYTHIA8 (Dijet, CT14nlo)

$R$ = 0.2
$R$ = 0.3 ($\times$ 10)
$R$ = 0.4 ($\times$ 10$^2$)

Correlated uncertainty
Shape uncertainty

$\sigma_L^{sys}$ = 2.34%

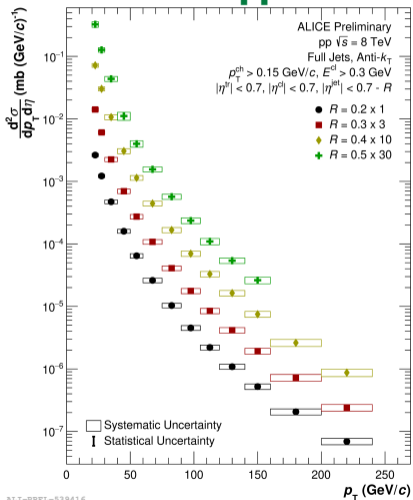$\frac{d^2\sigma}{dp_{T,jet}^{ch} d\eta_{jet}}$ (mb (GeV/$c$)$^{-1}$)

$p_{T,jet}^{ch}$ (GeV/$c$)

[arXiv:2307.10860]

## Full Jet - pp 8 TeV



- Closer to the theoretical definition of a jet
- Less sensitive to fragmentation and other non-perturbative effects
- Can go to high $p_T$ using EMCal triggers
- Jet required to be fully contained in EMCal

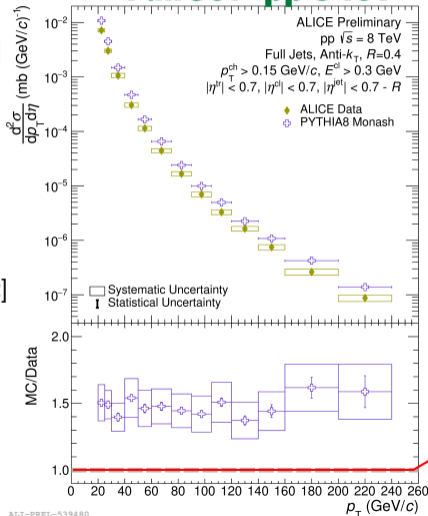- **PYTHIA** [arXiv:1907.09874] **alone over-predicts data** by ≈ 50%
- Similar behavior seen at other collision energies
- Predictions including POWHEG [arXiv:0709.2092] agree with data within uncertainties
→ **Needs NLO correction**



**Full Jet - pp 8 TeV**

ALICE Preliminary
pp $\sqrt{s}$ = 8 TeV
Full Jets, Anti-$k_T$, $R$=0.4
$p_T^{ch}$ > 0.15 GeV/c, $E^{cl}$ > 0.3 GeV
$|\eta^{tr}|$ < 0.7, $|\eta^{cl}|$ < 0.7, $|\eta^{jet}|$ < 0.7 - $R$

♦ ALICE Data
✛ PYTHIA8 Monash

☐ Systematic Uncertainty
Ⅰ Statistical Uncertainty

$\frac{d^2\sigma}{dp_T d\eta}$ (mb (GeV/$c$)$^{-1}$)

MC/Data

$p_T$ (GeV/$c$)

ALI-PREL-539480



**Full Jet - pp 13 TeV**

ALICE preliminary
pp, $\sqrt{s}$ = 13 TeV, $L_{int}$ = 4 pb$^{-1}$
Jets, Anti-$k_T$, $R$=0.4
$p_T^{track}$ > 0.15 GeV/c, $E^{cluster}$ > 0.3 GeV
$|\eta^{track}|$ < 0.7, $|\eta^{cluster}|$ < 0.7, $|\eta^{jet}|$ < 0.3

✛ ALICE Data
✛ POWHEG+PYTHIA8

☐ Correlated uncertainties
▨ Shape uncertainties

$\frac{d^2\sigma}{dp_T d\eta}$ (mb/(GeV/$c$))

MC / Data

$p_T$ (GeV/$c$)

ALI-PREL-315713
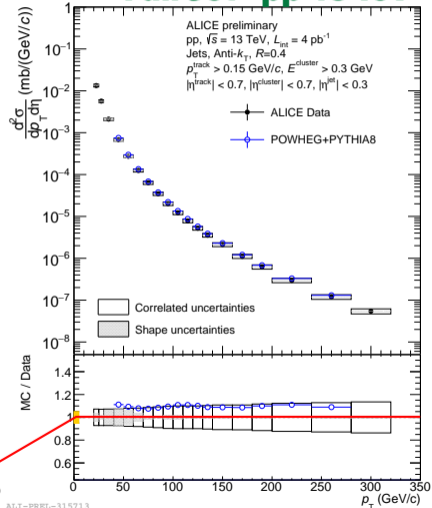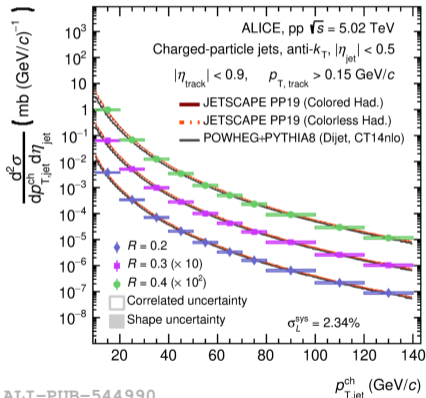
## Ch Part Jet - pp 5.02 TeV

- **PYTHIA** [arXiv:1907.09874] **alone over-predicts data** by $\approx 50\%$
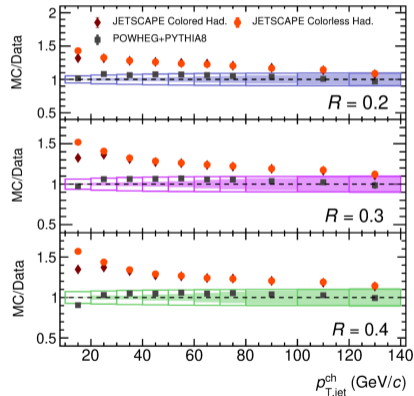- Similar behavior seen at other collision energies
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JETSCAPE Colored Had.    JETSCAPE Colorless Had.
POWHEG+PYTHIA8

$R = 0.2$
$R = 0.3$
$R = 0.4$

ALI-PUB-544990

JETSCAPE [arXiv:1903.07706]

[arXiv:2307.10860]
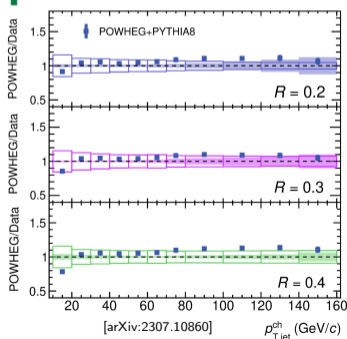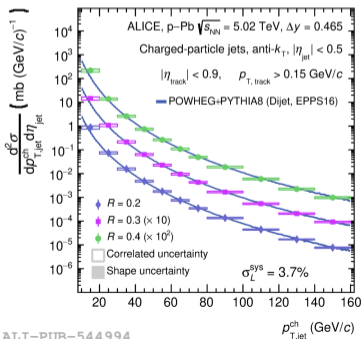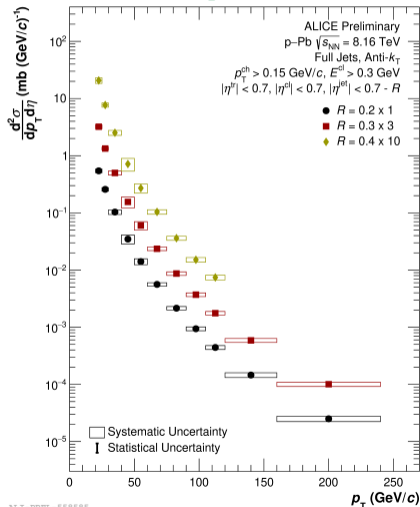
- Compare with pp to explore behavior
- Reference for Pb–Pb collisions
- POWHEG with nPDF still in agreement

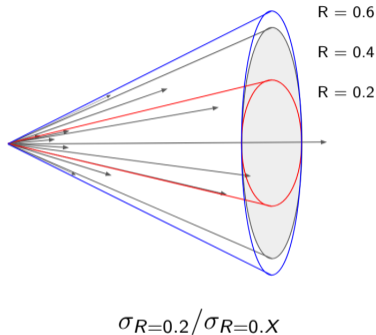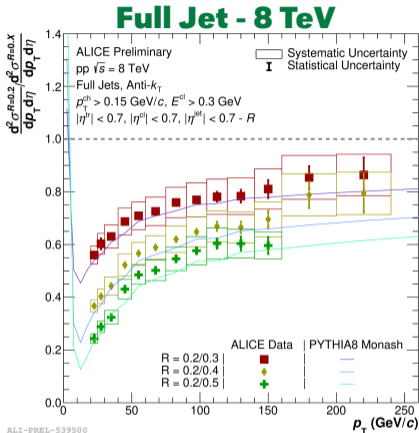## Ch Part Jet - p–Pb 5.02 TeV



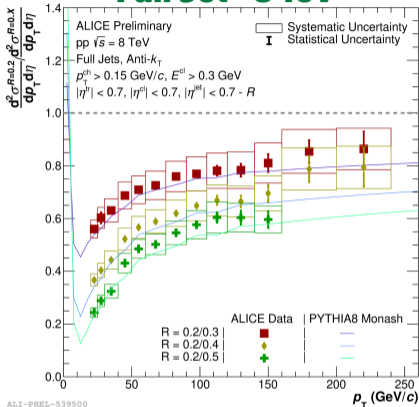## Full Jet - p–Pb 8.16 TeV



ALI-PUB-544994

[arXiv:2307.10860]

ALI-PREL-558585

## Full Jet - 8 TeV

- Ratios allow for error cancellation
- Sensitive to fragmentation & hadronization
- Reproduced by MC models ([arXiv:1101.2665])
- Fragmentation patterns constant across collision energies



$$\sigma_{R=0.2}/\sigma_{R=0.X}$$

- Jets become more collimated with increasing momentum
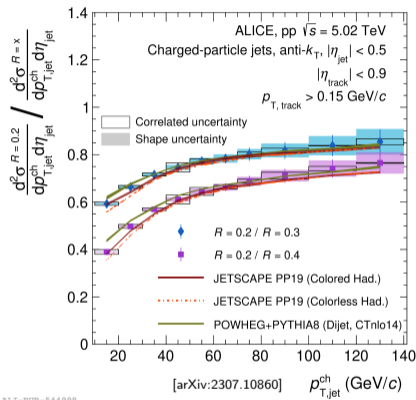- p–Pb consistent with pp within uncertainties

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**Full Jet - 8 TeV**

**Ch Part Jet - 5.02 TeV**

- Jets become more collimated with increasing momentum
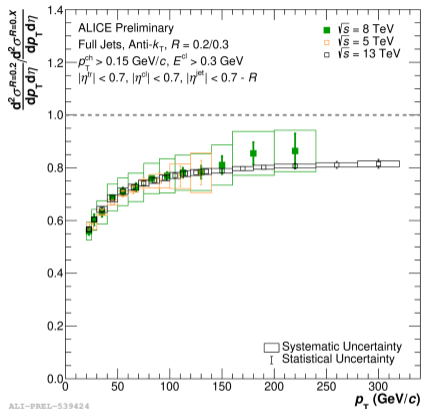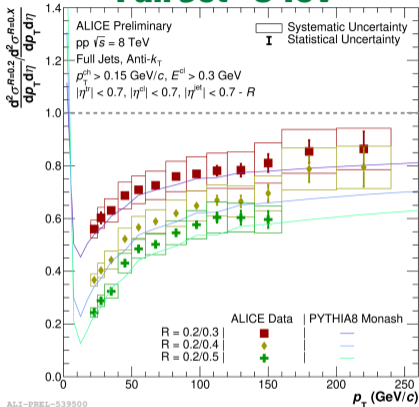- p–Pb consistent with pp within uncertainties

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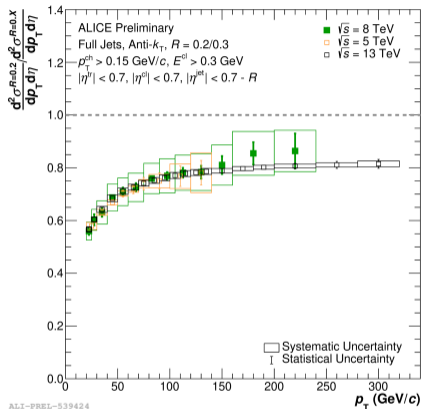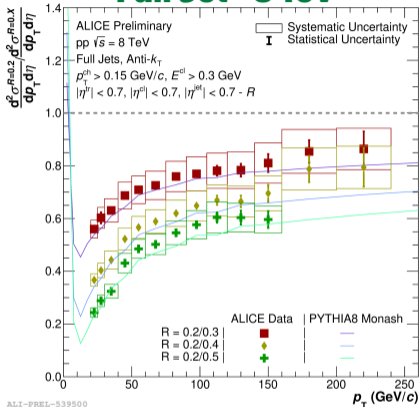- p–Pb  consistent with pp within uncertainties

## Full Jet - 8, 8.16 TeV

## Ch Part Jet - 5.02 TeV

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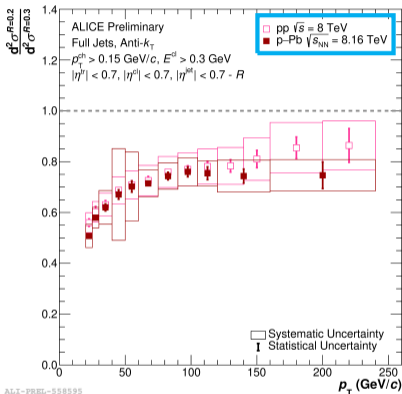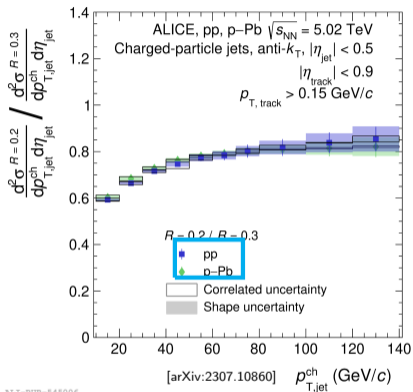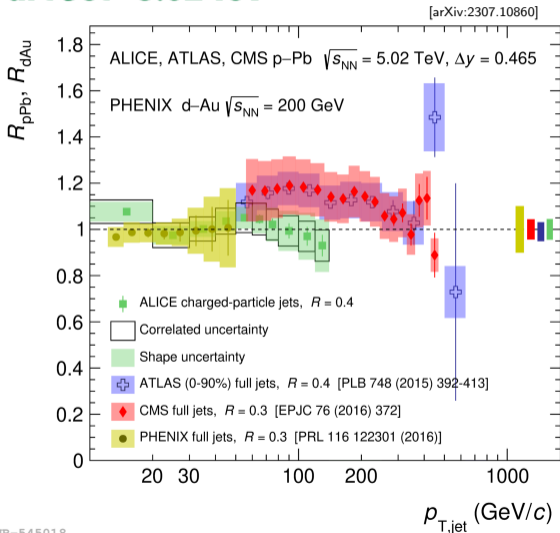- p–Pb consistent with pp within uncertainties

## Ch Part Jet - 5.02 TeV

[arXiv:2307.10860]

- Look for inital state effects due to presence of nucleus
- Consistent with unity
- Consistent with PHENIX and CMS within uncertainties
- Consistent with ATLAS within about $1\sigma$



ALICE, ATLAS, CMS p–Pb $\sqrt{s_{NN}} = 5.02$ TeV, $\Delta y = 0.465$

PHENIX d–Au $\sqrt{s_{NN}} = 200$ GeV

ALICE charged-particle jets, $R = 0.4$
Correlated uncertainty
Shape uncertainty
ATLAS (0-90%) full jets, $R = 0.4$  [PLB 748 (2015) 392-413]
CMS full jets, $R = 0.3$  [EPJC 76 (2016) 372]
PHENIX full jets, $R = 0.3$  [PRL 116 122301 (2016)]

$p_{T,jet}$ (GeV/$c$)

$R_{pPb}, R_{dAu}$

ALI-PUB-545018

# Summary

- **Inclusive jet cross-section measurements** can help us **understand jet formation** as a whole and **provide comparisons to theory**
- ALICE measurements with **charged-particle jets and full jets** have different strengths and are **complimentary to each other**
- **LO** (Pythia, etc) shows **good agreement with cross-section ratios**, but **NLO** (POWHEG, etc) is required to give a **good description of the cross-sections**
- **Nuclear modification factor** is **consistent with unity and shows general agreement** with other experiments
- Does the same hold at **higher-$p_T$ and with full jets**?
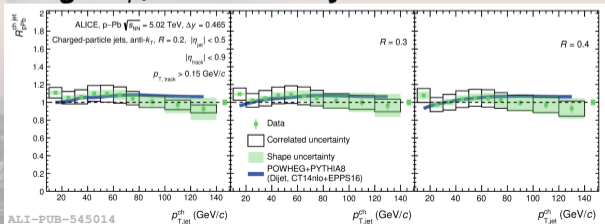
- PYTHIA8 used to generate the initial hard scattering and the underlying event
- Intermediate shower is handled by MATTER (includes parton virtuality)
- QCD strings are formed through colored or colorless hadronization
- Strings are fed into PYTHIA8 for string fragmentation
- JETSCAPE configuration: PP19 tune, implemented in JETSCAPE V3.4.1