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

September 6, 2023

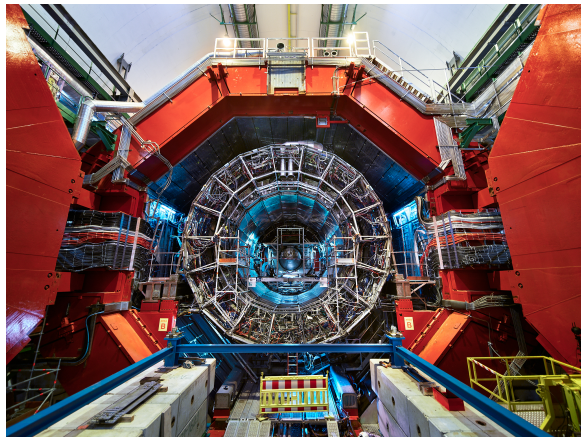- Precision measurements of jet production in small systems at
  - 2017 pp 5.02 TeV
  - 2016 p–Pb 5.02 TeV
  - 2012 pp 8 TeV
  - 2016 p–Pb 8.16 TeV
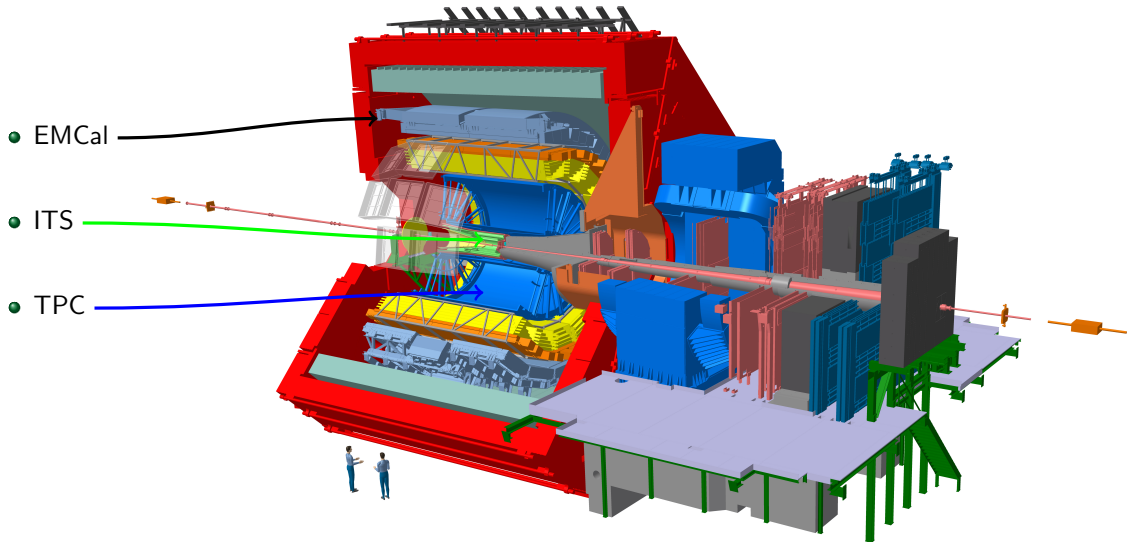- Detailed comparison to MC models/QCD calculations

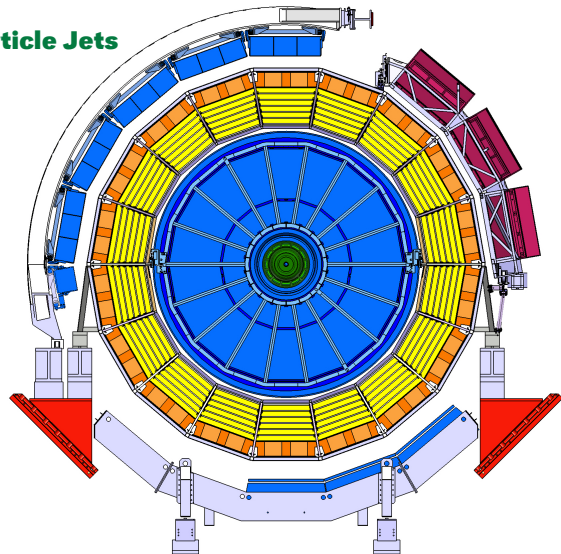* **New Publication**

* **New Measurement**

- EMCal
- ITS
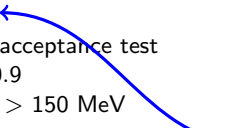- TPC

Jet Reconstruction

Charged-Particle Jets

- ITS+TPC
  - Full ϕ acceptance test
  - $|\eta| < 0.9$
  - $p_{T,track} > 150$ MeV
- EMCal
  - Run 1/2: $\Delta\phi = 100°/107°$
  - $|\eta| < 0.7$
  - Provides a trigger for high momentum jet events
  - $E_{cluster} > 300$ MeV
- Reconstructed using the anti-k_T algorithm
- Can use different jet radii: $R = \sqrt{\eta^2 + \phi^2}$

Jet Reconstruction
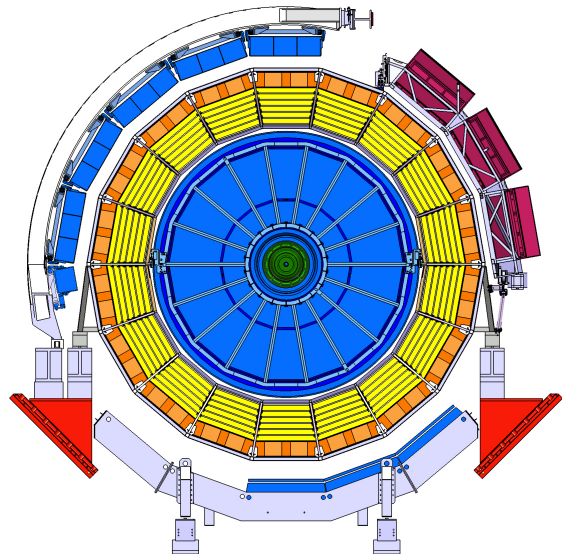

- ITS+TPC
  - Full ϕ acceptance test
  - $|\eta| < 0.9$
  - $p_{T,\text{track}} > 150$ MeV
- EMCal
  - Run 1/2: $\Delta\phi = 100°/107°$
  - $|\eta| < 0.7$
  - Provides a trigger for high momentum jet events
  - $E_{\text{cluster}} > 300$ MeV
- Reconstructed using the anti-k_T algorithm
- Can use different jet radii: $R = \sqrt{\eta^2 + \phi^2}$

Full Jets

- ITS+TPC
  - Full ϕ acceptance test
  - $|\eta| < 0.9$
  - $p_{T,\text{track}} > 150$ MeV
- EMCal
  - Run 1/2: $\Delta\phi = 100°/107°$
  - $|\eta| < 0.7$
  - Provides a trigger for high momentum jet events
  - $E_{\text{cluster}} > 300$ MeV
- Reconstructed using the anti-k_T algorithm
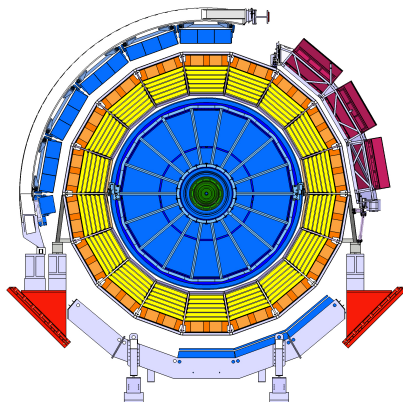- Can use different jet radii: $R = \sqrt{\eta^2 + \phi^2}$

- Distributions fully corrected
  - Unfolded via bayesian unfolding
- Dominant uncertainties
  - Tracking efficiency
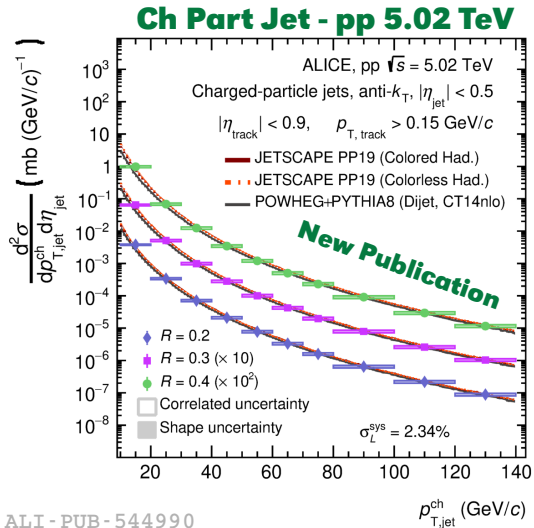 - Correlated unfolding uncertainties

- 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)

New Publication

- ◆ $R = 0.2$
- ■ $R = 0.3$ ($\times 10$)
- ● $R = 0.4$ ($\times 10^2$)

□ 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)

ALI-PUB-544990

[arXiv:2307.10860]

Full Jet - pp 8 TeV
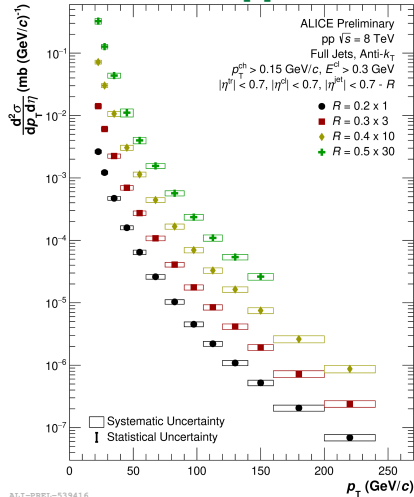
- Closer to the theoretical definition of a jet
  - Less sensitive to fragmentation and other non-perturbative effects
- Can go to high p_T using EMCal triggers
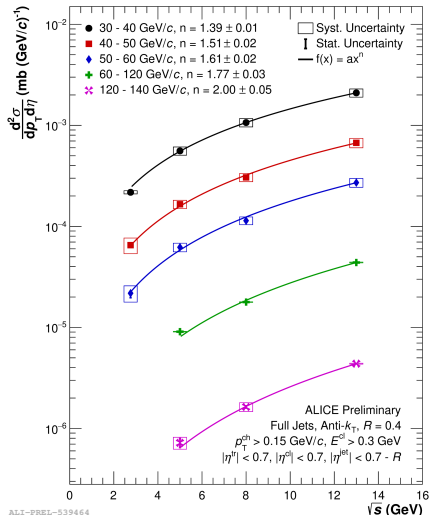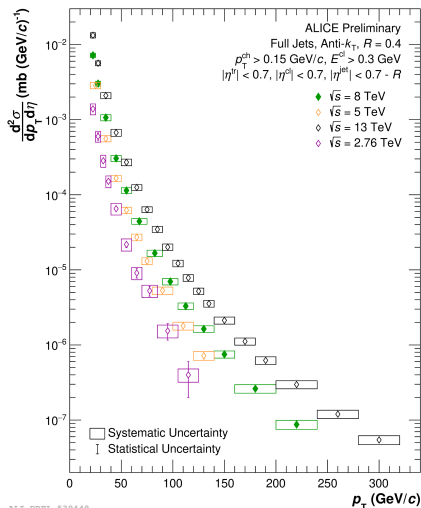- Jet required to be fully contained in EMCal

- Spectra get harder with increased collision energy

- Follow a power law dependence: $(\sqrt{s})^n$

- Different power law for different momenta

- **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
$|\eta^{trj}|$ < 0.7, $|\eta^{cl}|$ < 0.7, $|\eta^{jet}|$ < 0.7 - R

♦ ALICE Data
⬦ PYTHIA8 Monash

☐ Systematic Uncertainty
I Statistical Uncertainty

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
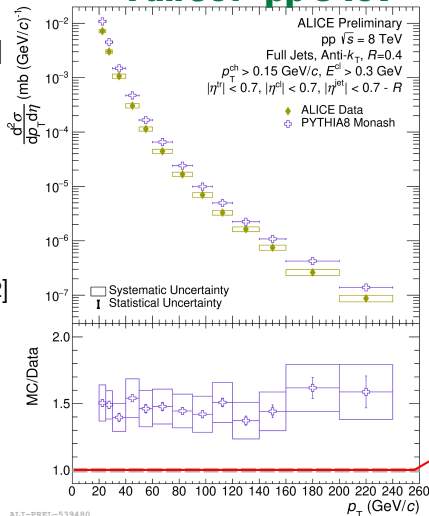▨ Shape uncertainties

Ch Part Jet - pp 5.02 TeV

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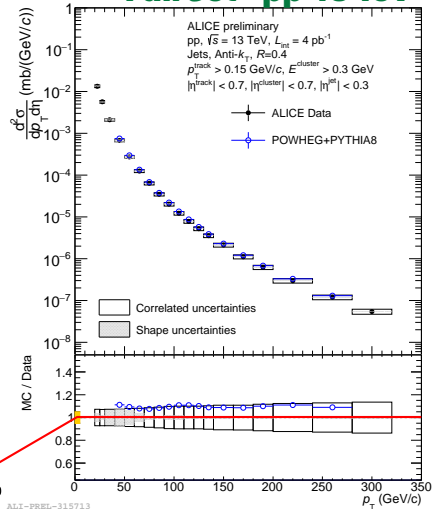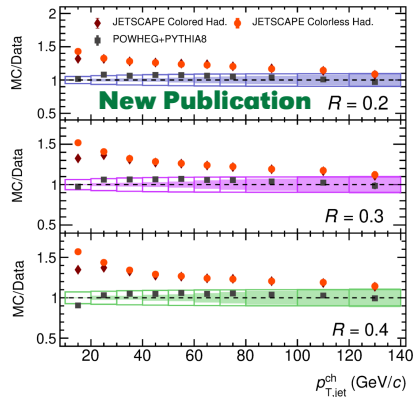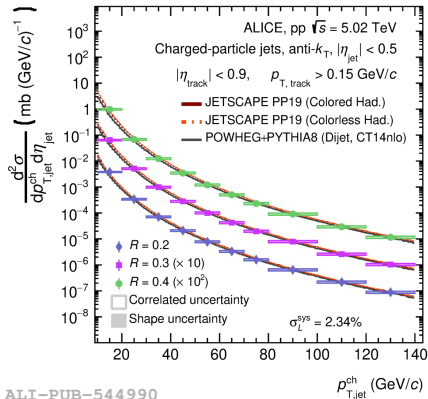- Similar behavior seen at other collision energies
- Predictions including POWHEG [arXiv:0709.2092] agree with data within uncertainties
- → **Needs NLO correction**

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)

ALI-PUB-544990

JETSCAPE Colored Had.   JETSCAPE Colorless Had.
POWHEG+PYTHIA8

New Publication $R = 0.2$

MC/Data

$R = 0.3$

$R = 0.4$

$p_{T,jet}^{ch}$ (GeV/c)
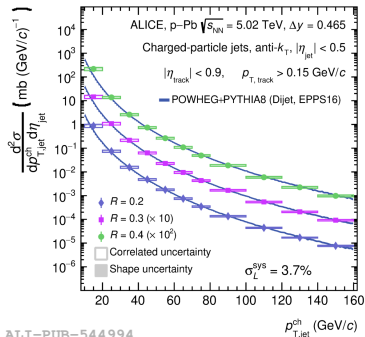
JETSCAPE [arXiv:1903.07706]
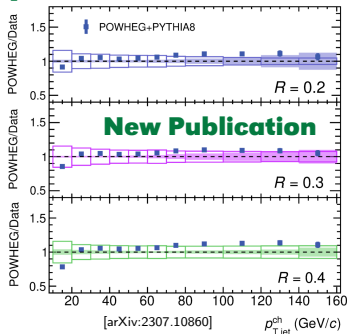
[arXiv:2307.10860]

More Complex Systems: p–Pb

- Compare with pp to explore behavior
- How do different inital states effect the final state?
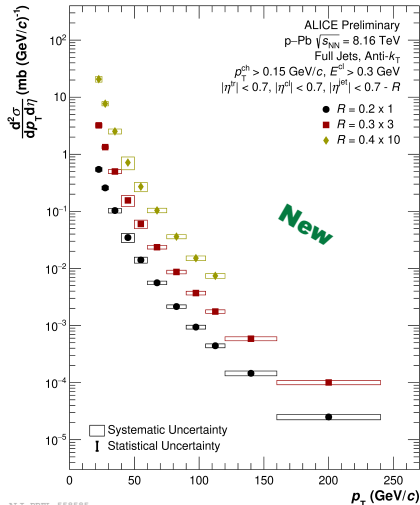- Reference for Pb–Pb collisions

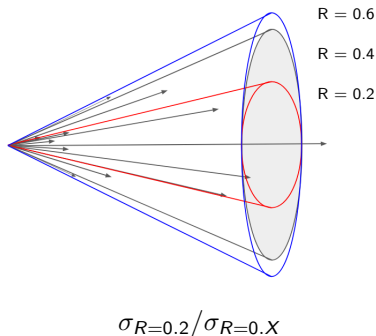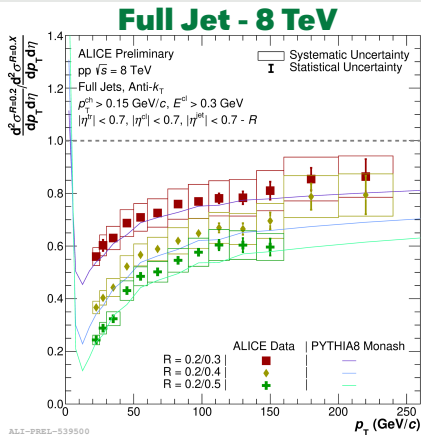## Ch Part Jet - p–Pb 5.02 TeV

[arXiv:2307.10860]

Full Jet - p–Pb 8.16 TeV

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

ALICE Preliminary
pp $\sqrt{s}$ = 8 TeV
Full Jets, Anti-k_T
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

Systematic Uncertainty
Statistical Uncertainty

ALICE Data | PYTHIA8 Monash
R = 0.2/0.3
R = 0.2/0.4
R = 0.2/0.5

ALI-PREL-539500

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

R = 0.6
R = 0.4
R = 0.2

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

* Christos Pliatskas' Poster - Energy Flow
* Wenqing Fan's Talk - EE Correlators
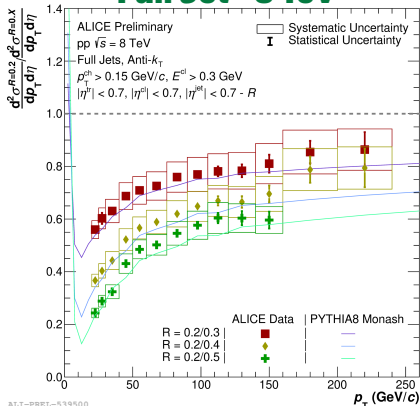* Jaehyeok Ryu's Poster - Jet Fragment j_T

- Ratios allow for error cancellation
- Sensitive to fragmentation & hadronization
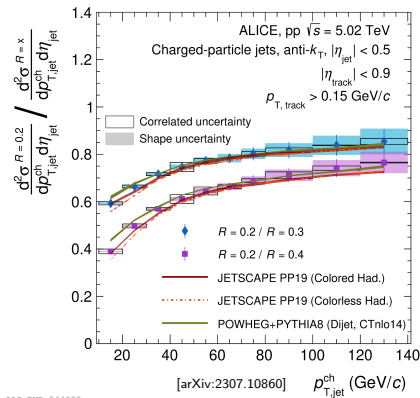- Reproduced by MC models ([arXiv:1101.2665])
- Fragmentation patterns constant across collision energies
- Jets become more collimated with increasing momentum
- p–Pb consistent with pp within uncertainties

Full Jet - 8 TeV

Ch Part Jet - 5.02 TeV

* Christos Pliatskas' Poster - Energy Flow
* Wenqing Fan's Talk - EE Correlators
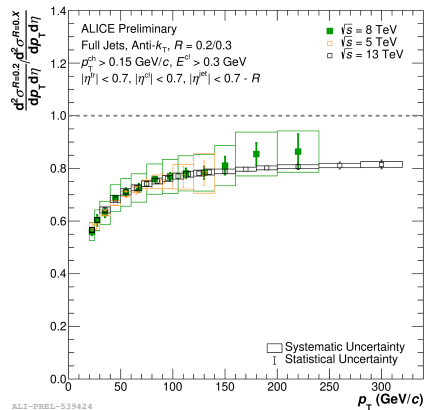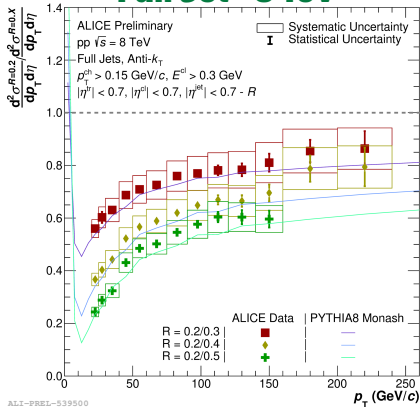* Jaehyeok Ryu's Poster - Jet Fragment j_T

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

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

* Christos Pliatskas' Poster - Energy Flow
* Wenqing Fan's Talk - EE Correlators
* Jaehyeok Ryu's Poster - Jet Fragment j_T

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

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

* Christos Pliatskas' Poster - Energy Flow
* Wenqing Fan's Talk - EE Correlators
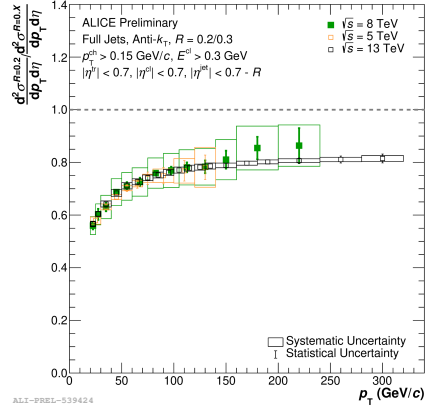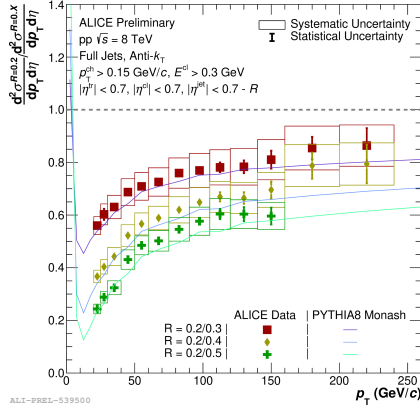* Jaehyeok Ryu's Poster - Jet Fragment j_T

Jet Shape: Cross-Section Ratios

Full Jet - 8, 8.16 TeV

Ch Part Jet - 5.02 TeV

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

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

* Christos Pliatskas' Poster - Energy Flow
* Wenqing Fan's Talk - EE Correlators
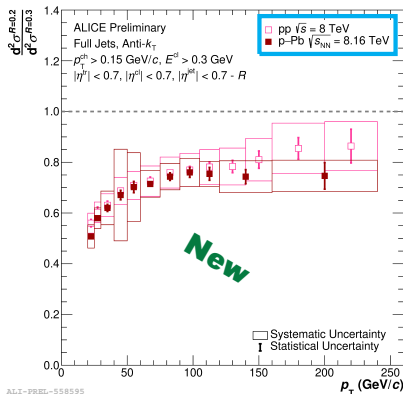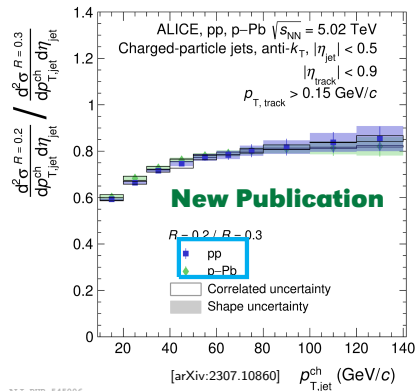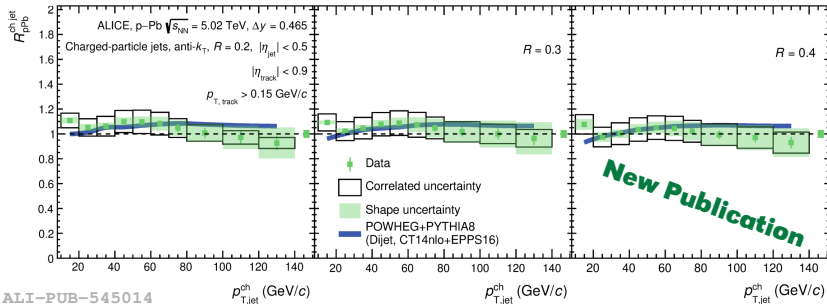* Jaehyeok Ryu's Poster - Jet Fragment j_T

Ch Part Jet - 5.02 TeV

[arXiv:2307.10860]

ALI-PUB-545014

$$R_{\text{p–Pb}} = \sigma_{\text{p–Pb}}/(\sigma_{\text{pp}} * 208)$$
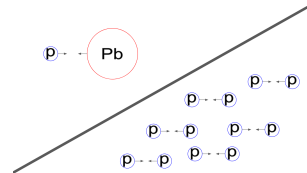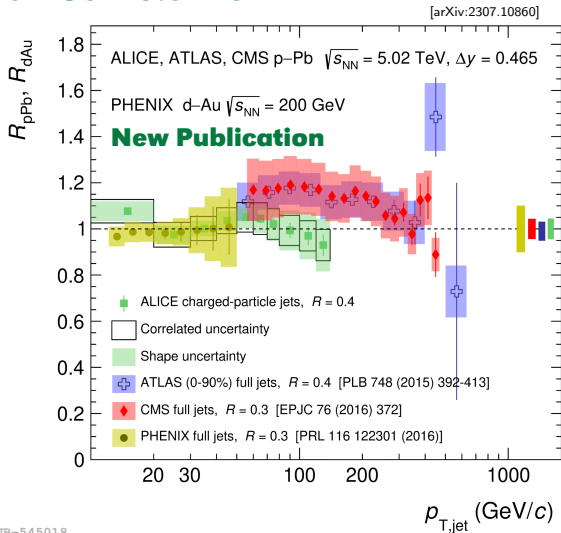
- Can we separate cold nuclear matter effects from those of a strongly interacting medium?
- Look for inital state effects
- This measurement: Consistent with unity

* Don Jo Kim's Poster - High Mult pp

* Nadine Grünwald's Talk - Pb–Pb

Ch Part Jet - 5.02 TeV

[arXiv:2307.10860]

- Consistent with unity

- Consistent with PHENIX and CMS within uncertainties

- Consistent with ATLAS within about 1σ

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

PHENIX d–Au $\sqrt{s_{NN}} = 200$ GeV

New Publication

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)

ALI-PUB-545018

- **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**?
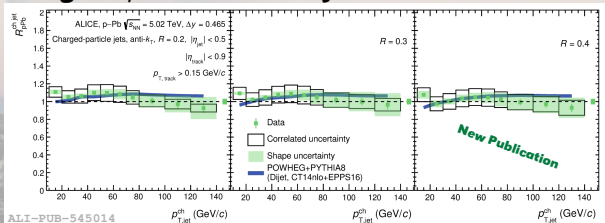
- PYTHIA8 used to generate the initial hard scattering and the underlying event
- Intermediate shower is handled by MATTER (includes parton virtuality)
- QCD strings are formed through colored or colorless hadronization
- Strings are fed into PYTHIA8 for string fragmentation
- JETSCAPE configuration: PP19 tune, implemented in JETSCAPE V3.4.1