# Studying the jet angularities with ALICE

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# Our definition of the jet angularities

- **Substructure observable** dependent on $\boldsymbol{p}_{\mathbf{T}}$ and **angular** distributions of tracks within jets

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} \left( \frac{p_{\mathrm{T},i}}{p_{\mathrm{T,jet}}} \right)^{\kappa} \left( \frac{\Delta R_{i,\text{jet}}}{R} \right)^{\alpha}$$

*Tunable, continuous parameters for relative weighting*

*Constituent angle in $(\eta, \phi)$ space*

*Constituent $p_T$*

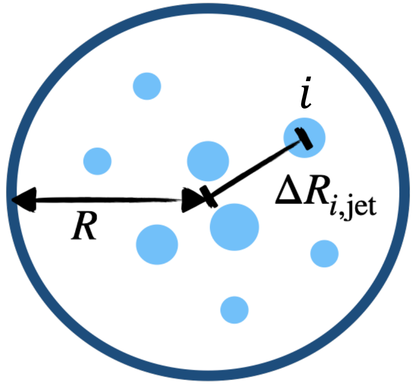


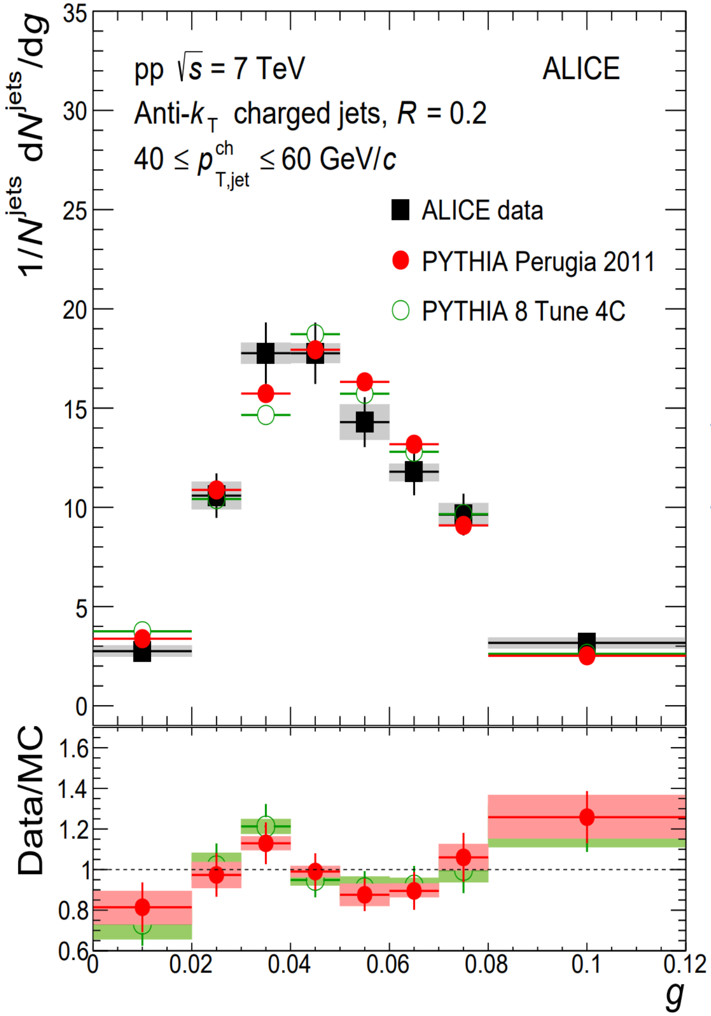

*diagram: James Mulligan, LBNL*

- IRC-safe observable for $\kappa = 1$, $\alpha > 0$ → calculable from pQCD
- Each $\kappa$, $\alpha$, and radius $R$ defines a different observable capable of probing some phase space of jet structure
  - Provides a systematic way to test certain aspects of theory

# Angularities in pp collisions

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \mathrm{jet}} z_i^\kappa \theta_i^\alpha$$

- Girth $g$: $\kappa = 1, \alpha = 1$




JHEP 10 (2018) 139

- Also related to jet mass $m_{\mathrm{jet}}$: $\kappa = 1, \alpha = 2$

$$\left(\lambda_{\alpha=2}^{\kappa=1} \sim \frac{m_{\mathrm{jet}}^2}{p_{\mathrm{T,jet}}^2}\right)$$

- These observables have been measured several times by ATLAS, CMS, ALICE, CDF, …

**Goals of our recent studies:**

- Provide a more systematic study with various $R$ and $\alpha$ to test perturbative & nonperturbative QCD
  - Explore both with and without grooming
  - Test validity of nonperturbative shape functions
- Provide a baseline for comparison to Pb-Pb

# Motivation for Pb-Pb studies

- **Quark-Gluon Plasma (QGP)** believed to form in heavy ion collisions

- Modifies jet interactions:
  - Jet quenching (see figure on right)
  - Momentum broadening

  - Open questions:
    - Lumpy or smooth? What are the d.o.f.? q / g fraction? Hadronization? Factorization breaking? …

- How does the QGP modify the jet angularities?
  - → how can we study the QGP with the jet angularities?

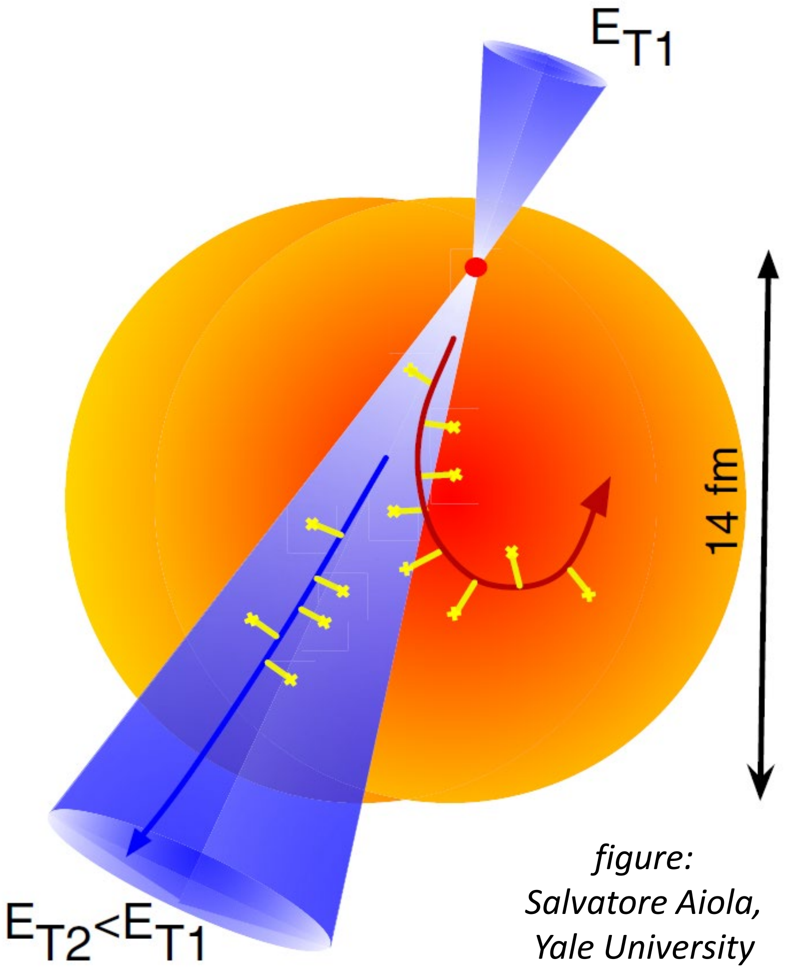
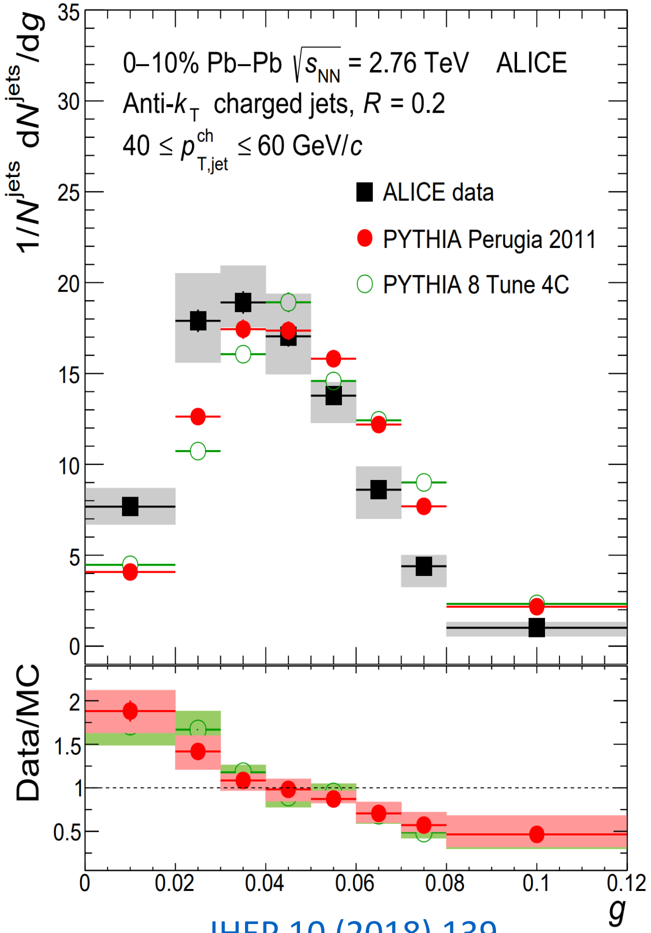



*figure: Salvatore Aiola, Yale University*

# Motivation for Pb-Pb studies

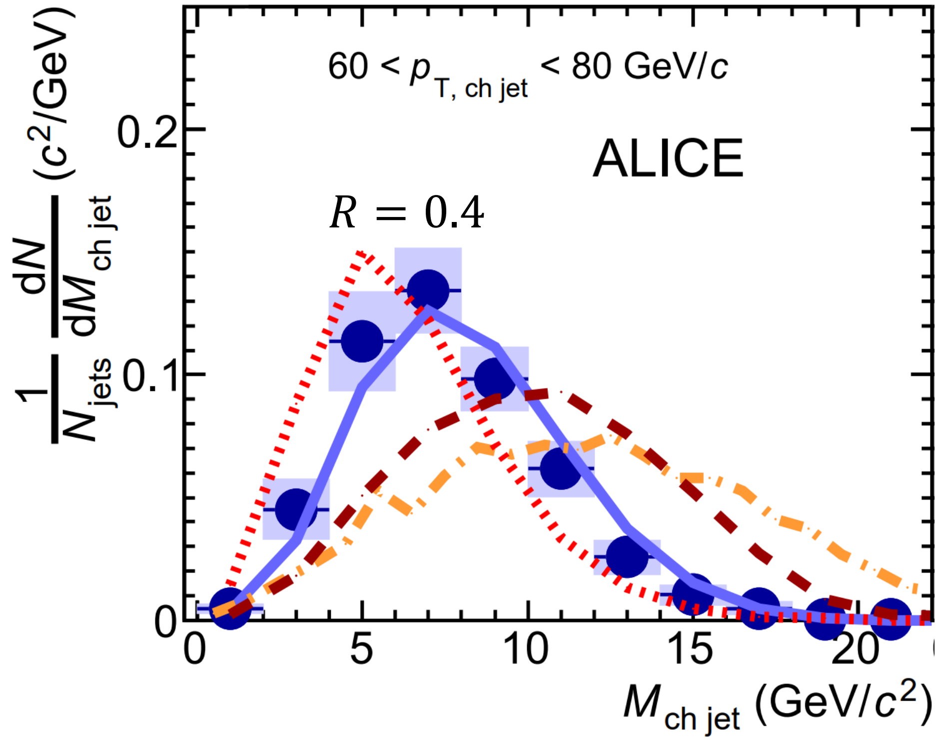
$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

$\alpha = 1, R = 0.2$: significant modification




[JHEP 10 (2018) 139]

$\alpha = 2, R = 0.4$: no significant modification

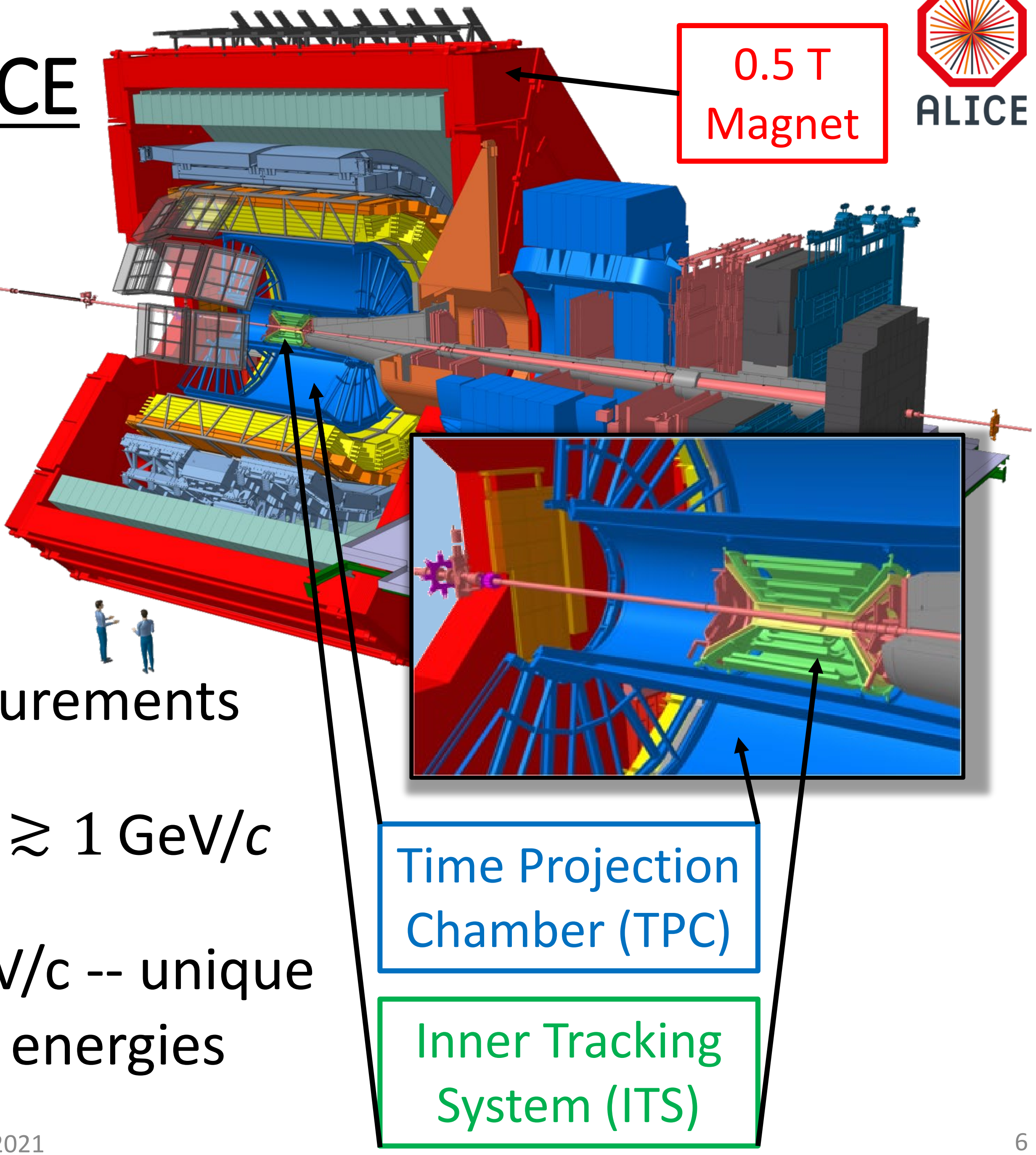



[Phys. Lett. B776 (2018) 249-264]

**Goals of future Pb-Pb measurements:**

- Understand observables with different $\alpha$ (e.g. 1.5) and $R$
- Differentiate between models of jet quenching

# Measuring charged jets with ALICE




- Charged tracks reconstructed using silicon inner tracking system (ITS) and gaseous TPC in a 0.5 Tesla $\vec{B}$-field
- **High-precision spatial and momentum resolution**, ideal for substructure measurements
- Good tracking efficiency (~85%) for $p_{\mathrm{T}} \gtrsim 1$ GeV/$c$
- Measure tracks down to $p_{\mathrm{T}} \sim 150$ MeV/c -- unique ability for low-$p_{\mathrm{T}}$ tracks and jets at LHC energies

# Our measurements of the jet angularities

- Use $\sqrt{s} = 5.02$ TeV data since it exists for both pp and Pb-Pb collisions

- Perform measurement for charged anti-$k_\mathrm{T}$ jets with parameters $\kappa = 1$, $\alpha \in \{1, 1.5, 2, 3\}$, and $R \in \{0.2, 0.4\}$.
  - With and without Soft Drop grooming: ($z_\mathrm{cut} = 0.2$, $\beta = 0$)

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \mathrm{jet}} z_i^\kappa \theta_i^\alpha$$

- New paper is submitted to the arXiv:
  - https://arxiv.org/abs/2107.11303
  - Currently undergoing journal review (JHEP)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP-2021-145
18 July 2021

**Measurements of the groomed and ungroomed jet angularities in pp collisions at $\sqrt{s} = 5.02$ TeV**

ALICE Collaboration*

**Abstract**

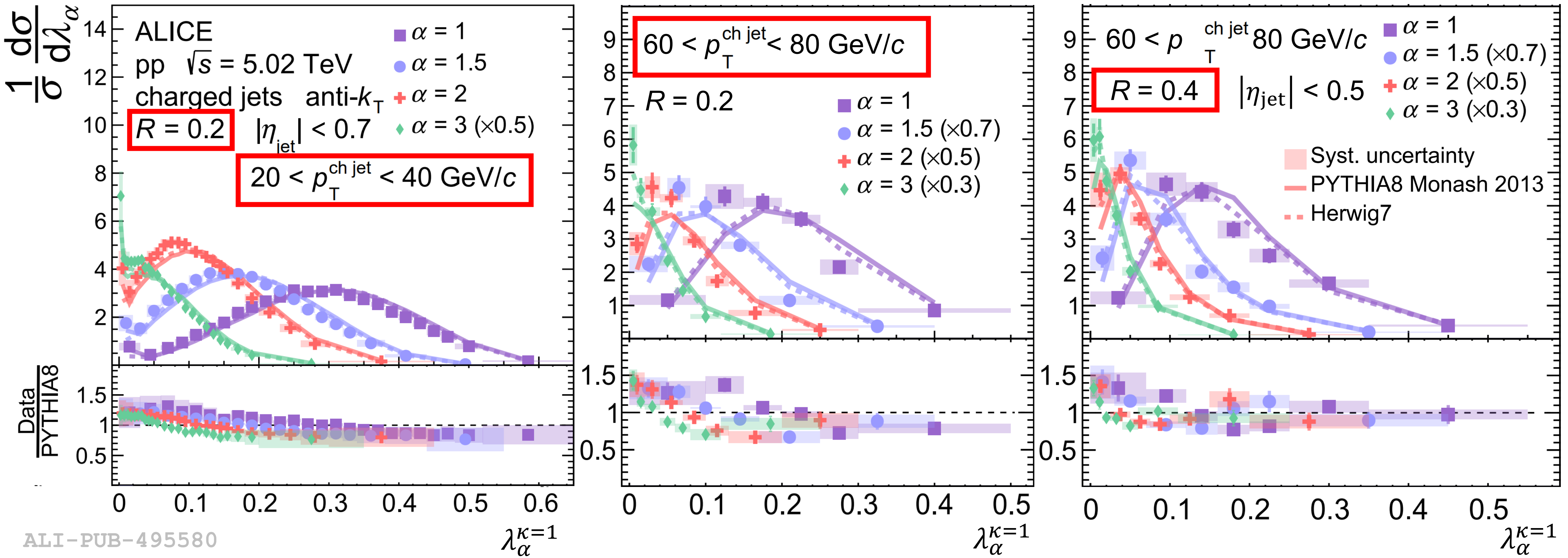
The jet angularities are a class of jet substructure observables which characterize the angular and momentum distribution of particles within jets. These observables are sensitive to momentum scales ranging from perturbative hard scatterings to nonperturbative fragmentation into final-state hadrons. We report measurements of several infrared- and collinear-safe jet angularities in pp collisions at $\sqrt{s} = 5.02$ TeV with the ALICE detector. Jets are reconstructed using charged particle tracks at midrapidity. The anti-$k_\mathrm{T}$ algorithm is used with jet resolution parameters $R = 0.2$ and $R = 0.4$ for several transverse momentum $p_\mathrm{T}^\mathrm{ch\,jet}$ intervals in the 20–100 GeV/$c$ range. Using the jet grooming algorithm Soft Drop, the sensitivity to softer, wide-angle processes, as well as the underlying event, can be reduced in a way which is well-controlled in theoretical calculations. We report the ungroomed jet angularities, $\lambda_\alpha$, and groomed jet angularities, $\lambda_{\alpha,\mathrm{g}}$, to investigate the interplay between perturbative and nonperturbative effects at low jet momenta. Various angular exponent parameters $\alpha = 1$, 1.5, 2, and 3 are used to systematically vary the sensitivity of the observable to collinear and soft radiation. Results are compared to analytical predictions at next-to-leading-logarithmic accuracy, which provide a generally good description of the data in the perturbative regime but exhibit discrepancies in the nonperturbative regime. Moreover, these measurements serve as a baseline for future ones in heavy-ion collisions by providing new insight into the interplay between perturbative and nonperturbative effects in the angular and momentum substructure of jets. They supply crucial guidance on the selection of jet resolution parameter, jet transverse momentum, and angular scaling variable for jet quenching studies.

# Example ungroomed measurements

$$\lambda_\alpha^\kappa \equiv \sum_{i\in \text{jet}} z_i^\kappa \theta_i^\alpha$$

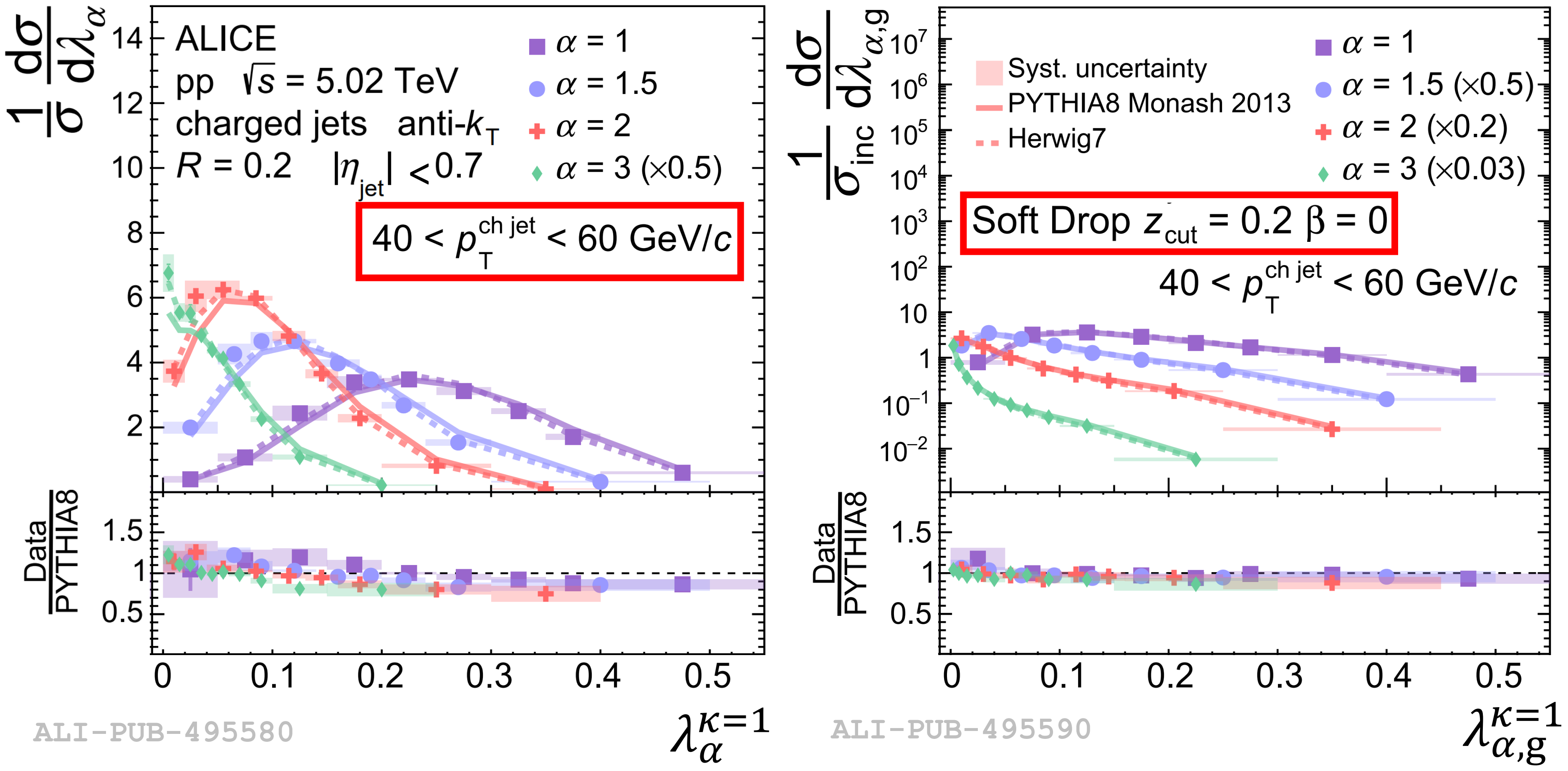
- Distributions shift to the left for higher $\alpha$, $p_\mathrm{T}^{\text{ch jet}}$

ALI-PUB-495575




- Full figures (including Herwig7 comparisons) are available publicly: https://alice-publications.web.cern.ch/node/7264

# Ungroomed vs. Groomed angularities ($R = 0.2$)




**Better agreement seen after grooming**

- Removing some nonperturbative effects from data and models increases the agreement, as would be expected

- Similar improvement in agreement is seen for all $\alpha$, $R$, and $p_{\mathrm{T}}^{\mathrm{ch\ jet}}$ bins

$$\lambda_\alpha^\kappa \equiv \sum_{i\in\mathrm{jet}} z_i^\kappa \theta_i^\alpha$$

# Comparing to pQCD predictions with SCET

- Theoretical predictions for **parton** jets by F. Ringer & K. Lee (LBNL) [3] at Next-to-Leading Log (NLL') perturbative accuracy

- Apply a "forward folding" procedure to correct for multi-parton interactions (MPI), hadronization, and **charged** jets
  - 2D folding with $p_{\mathrm{T,jet}}$ and $\lambda_\alpha$ axes; followed by bin-by-bin scaling for MPI

Parton-level pQCD prediction at NLL' → (Forward folding) → Charged hadron-level prediction, no MPI → (MPI scaling & renorm.) → Charged hadron-level prediction

- There is a model dependence introduced, which we address by repeating the folding procedure with both Herwig and PYTHIA

[3] JHEP 1804 (2018) 110

# Determining regions of interest

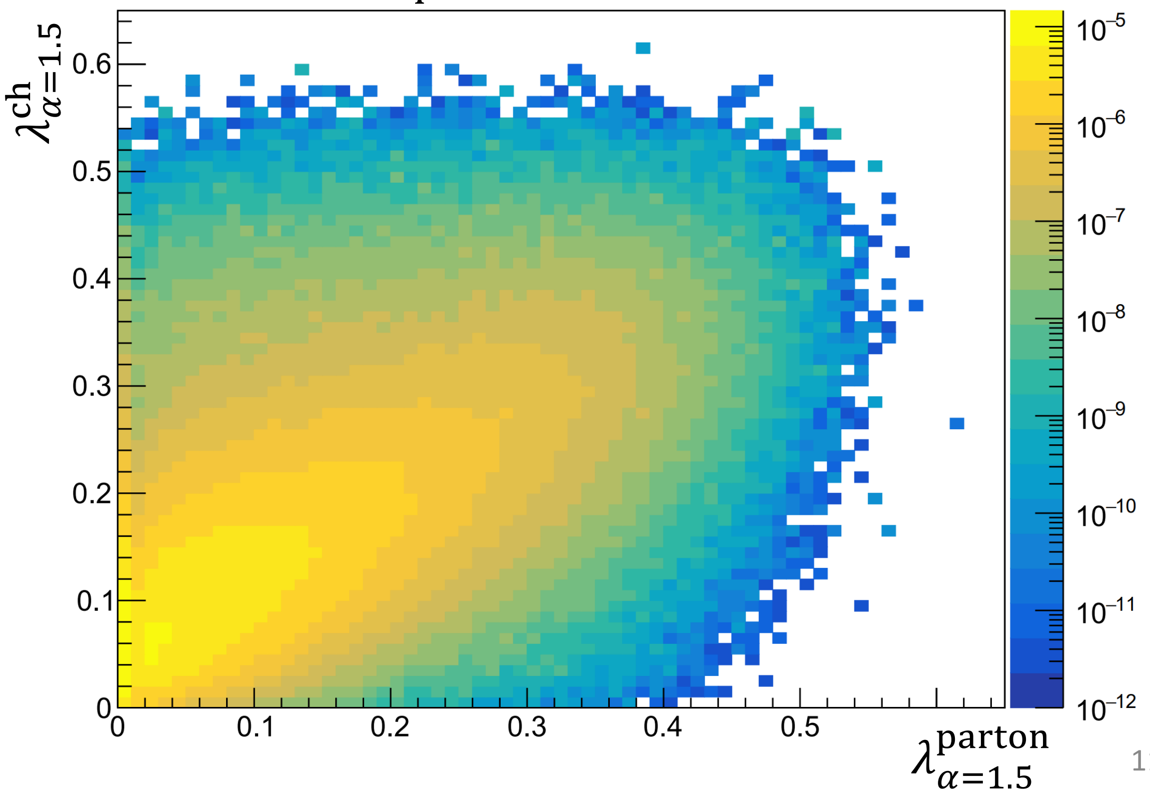
$$\lambda_\alpha^\kappa \equiv \sum_{i\in\text{jet}} z_i^\kappa \theta_i^\alpha$$

- Nonperturbative effects are larger at low $p_\mathrm{T}^\mathrm{jet}$ and small $R$:

$$\lambda_\alpha^\text{NP region} \lesssim \Lambda/(p_\mathrm{T}^\mathrm{jet} R) \text{ (we use } \Lambda = 1 \text{ GeV)}$$

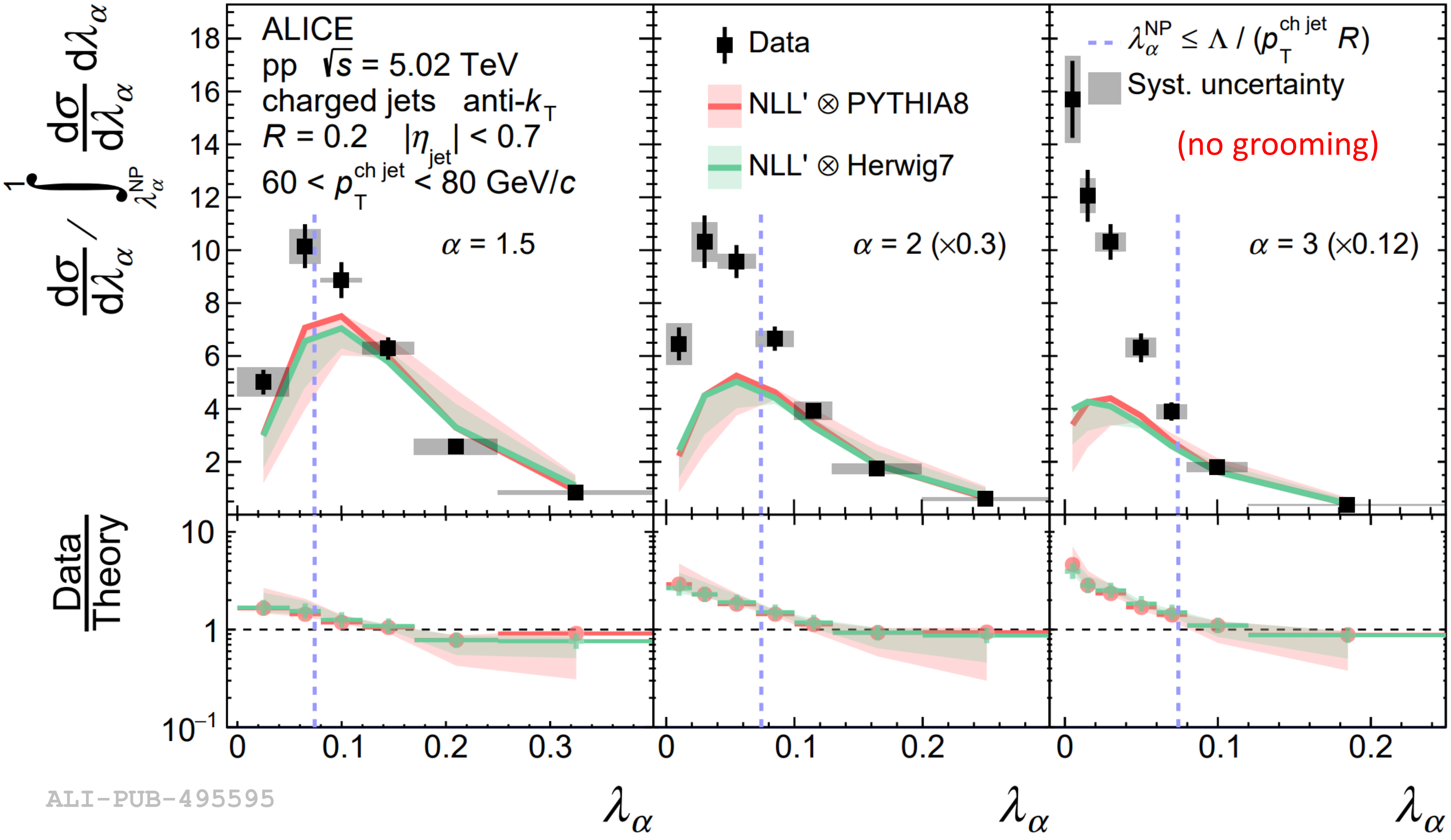
- Parton-to-charged response is largely non-diagonal for small $R$, low $p_\mathrm{T}^\mathrm{jet}$
  - Due primarily to hadronization
  - Corresponds to an increased dependence on the choice of hadronization model and tuning
  - These regions can be used for testing & tuning MC models

2D projection for $R = 0.2$, $p_\mathrm{T}^\text{ch jet} \in [60, 80]$ GeV/$c$ with **PYTHIA8**



# pQCD predictions with SCET ($R = 0.2$)

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

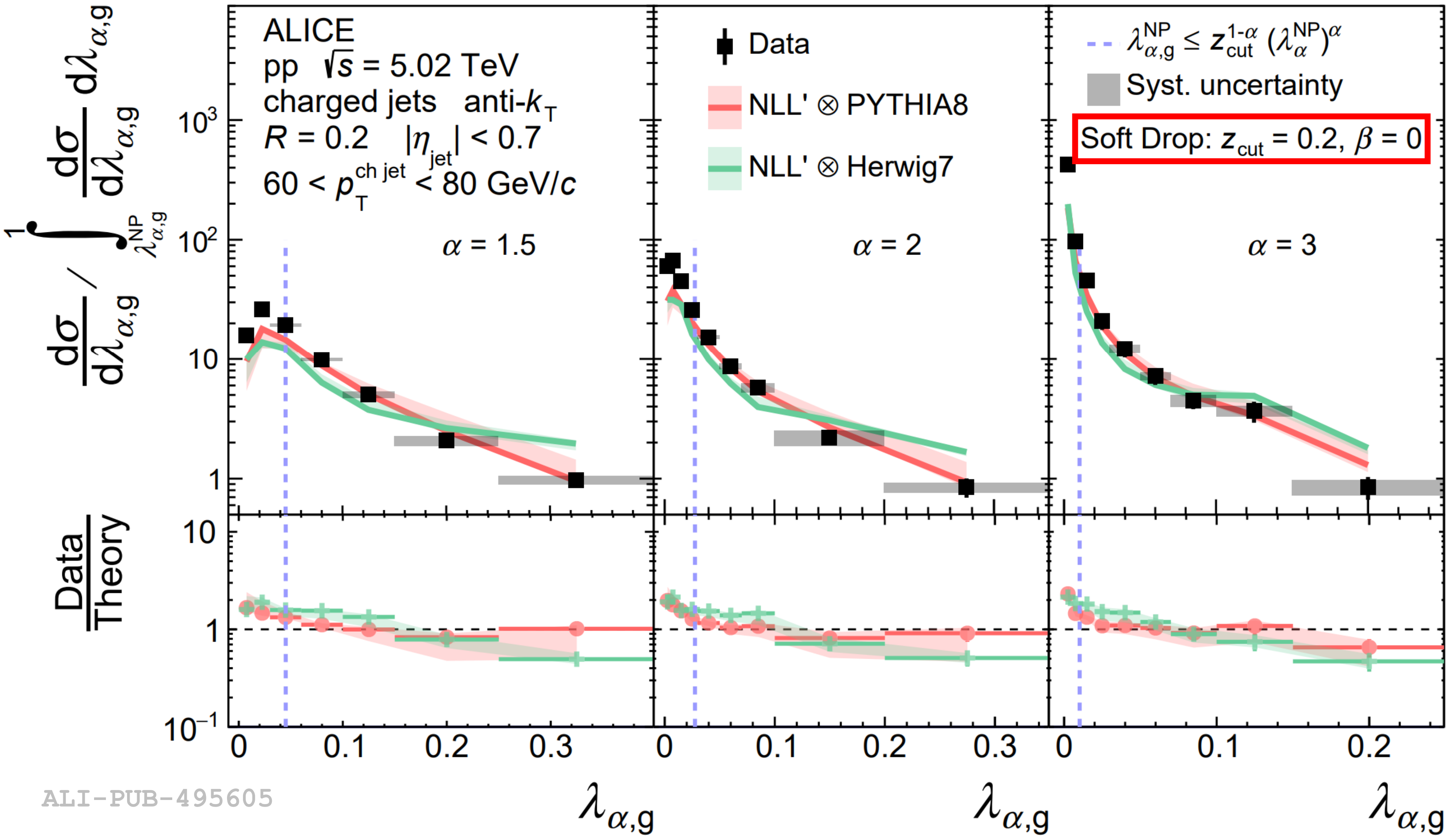



Distributions dominated by nonperturbative effects at large $\alpha$

Agreement within perturbative region is reasonable

# pQCD predictions with SCET ($R = 0.2$)

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \mathrm{jet}} z_i^\kappa \theta_i^\alpha$$

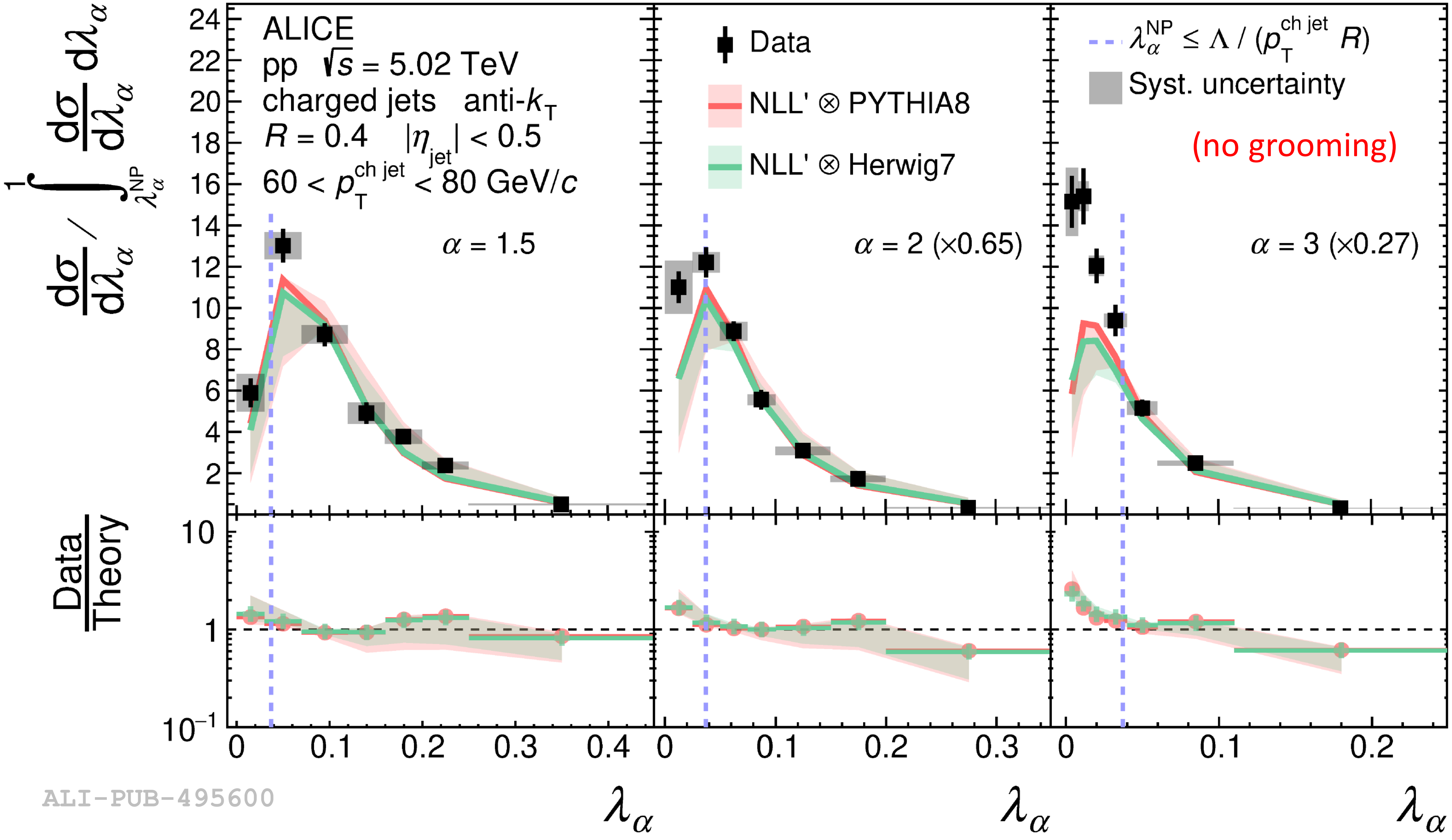



SD grooming greatly increases the perturbative region for predictions

Reasonable agreement still seen within uncertainties

# pQCD predictions with SCET ($R = 0.4$)

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$




For larger $R$ we see increased tension at large values of $\lambda_\alpha$

This could hint at the importance of higher-order terms (for example, power corrections in $\lambda_\alpha$)

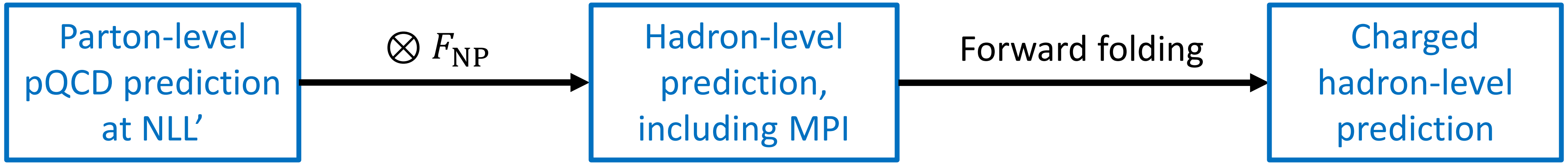
# Alternate hadronization correction

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

- Comparisons to Monte Carlo predictions are limited in interpretation
  - Highly-tuned phenomenological models
- Apply nonperturbative shape function $F$ [4] from first principles: $\Omega_\alpha = \frac{\Omega}{\alpha - 1}$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}\lambda_\alpha} = \int \mathrm{d}k\, F(k) \frac{\mathrm{d}\sigma^\mathrm{pert}}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}\lambda_\alpha}\left(\lambda_\alpha - \frac{k}{p_T R}\right) \sim \left(F * \frac{\mathrm{d}\sigma^\mathrm{pert}}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}\lambda_\alpha}\right)(\lambda_\alpha) \quad \text{where} \quad F(k) = \frac{4k}{\Omega_\alpha^2} \exp\left(-\frac{2k}{\Omega_\alpha}\right)$$

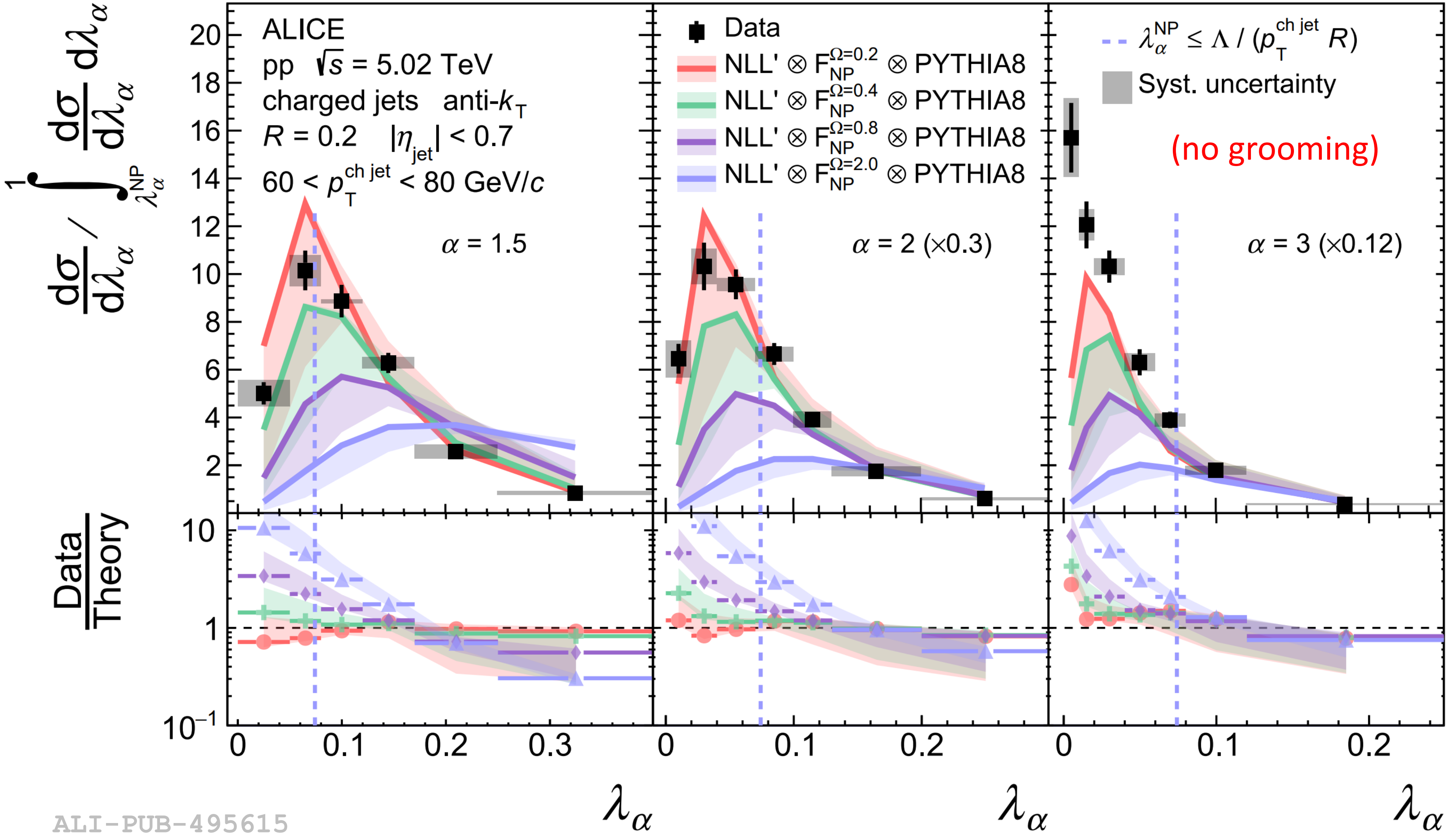
  - Single-parameter ($\Omega$) function: hadronization effects should be described by one (unknown to pQCD) parameter, expected to be universal
  - Still requires folding to charged level, which is mostly well-described $p_\mathrm{T}$ shift




[4] Phys. Rev. D 101, 054028 (2020)

# pQCD predictions with SCET $(R = 0.2)$

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \mathrm{jet}} z_i^\kappa \theta_i^\alpha$$




Best agreement seen with smaller values of $\Omega = 0.2$ or 0.4 GeV/$c$

Tension with previous result of $\Omega = 3.5$ GeV/$c$ ($R = 0.4$ full jets, higher $p_T^{\mathrm{jet}}$, and for jet mass) [5]

[5] JHEP 1810 (2018) 137

# What we've learned so far

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

- We have systematically measured the generalized jet angularities for a variety of $R$, $\alpha$, and $p_{\mathrm{T}}^{\text{ch jet}}$
  - Sensitive to widely different physics with different configurations
- Looking at groomed-jet angularities is useful for reducing nonperturbative effects and more directly testing pQCD predictions

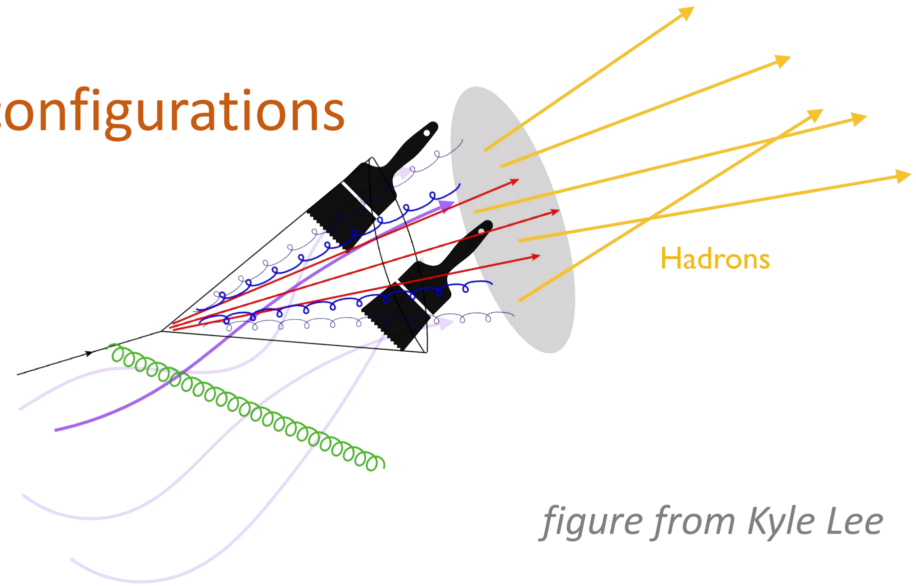
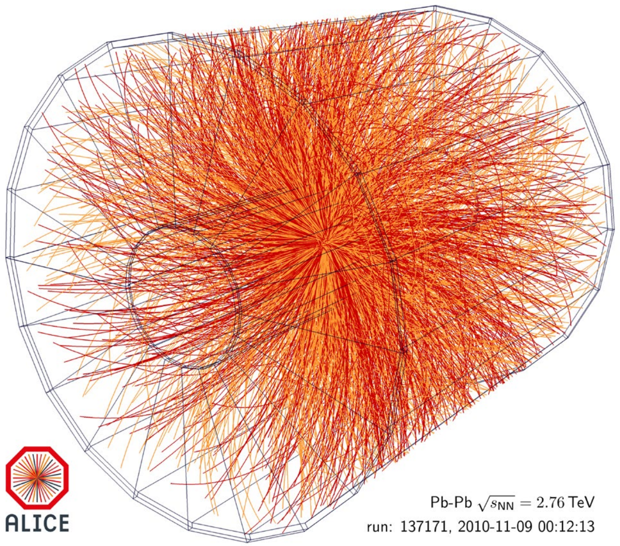



*figure from Kyle Lee*

- It will be important to consider the perturbative versus non-perturbative regions also when looking at Pb-Pb data and jet quenching models

# Outlook



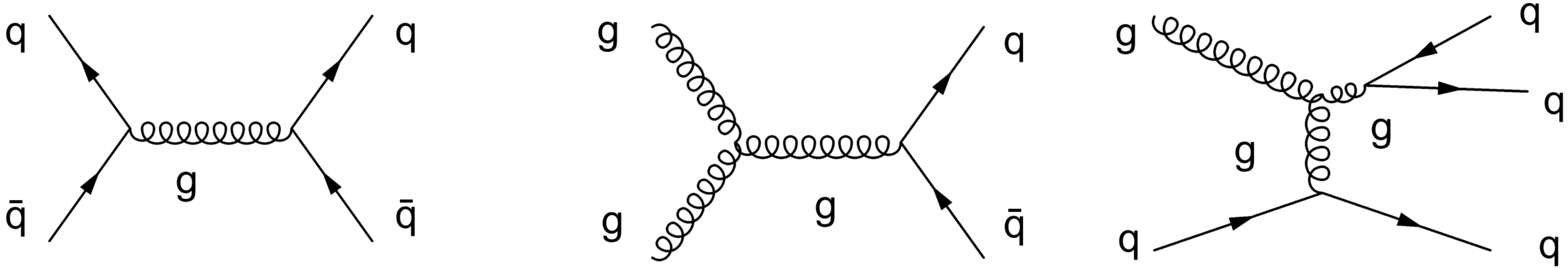

- Repeating with Pb-Pb data requires some changes:
  - Pb-Pb has a high background
    - Example: $R = 0.4$ jet has roughly $p_{\mathrm{T}} = 100\ \mathrm{GeV}/c$ of background!
    - We have to perform event-by-event background subtraction
  - For MC, we will use pp MC embedded in Pb-Pb background from data

- Fantastic opportunity to learn about how the QGP develops and interacts with "intermediate"-$p_{\mathrm{T}}$ (~60-100 GeV/$c$) particles
  - Compare to jet quenching models: Jet broadening? In/Coherent? Factorization breaking? Weak or strong?

- Which other observables are most useful for probing different stages of jet / QGP evolution?

# Backup

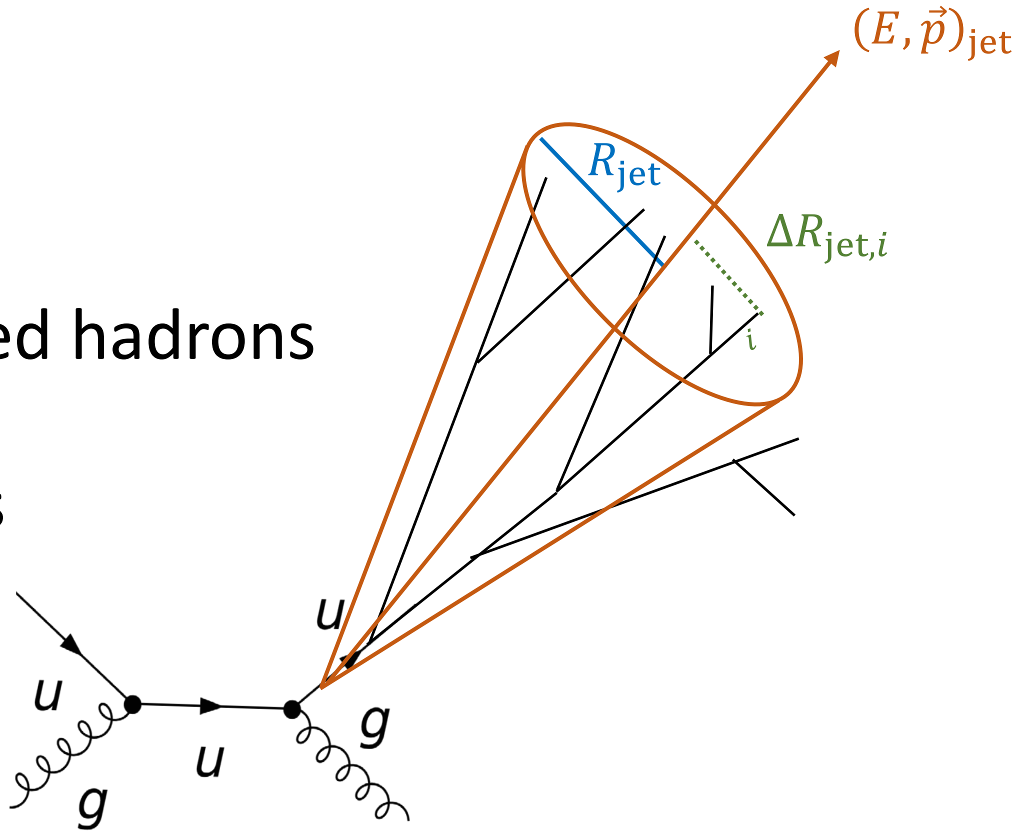
# QCD jets




- Interesting probe for various scales of strong interactions:
  - Initial, hard (high-$Q^2$) scattering
  - Parton shower
  - Fragmentation into hadrons

- Experimentally reconstructed from grouped hadrons

- **Dynamically recombined, tunable** objects which can be sensitive to either/both perturbative and nonperturbative physics



# Analysis procedure

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

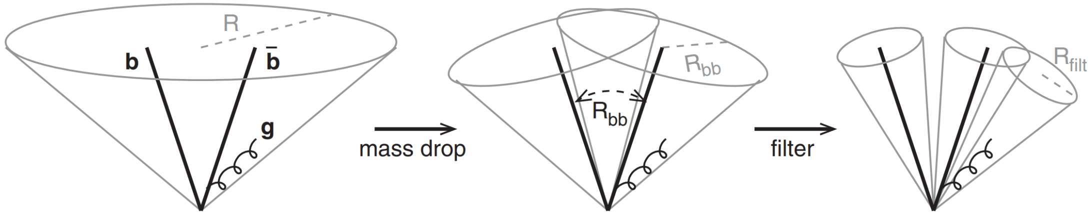
- Generate **4D response matrix** using PYTHIA8 Monte Carlo simulation followed by GEANT3 detector simulation

$$\left[p_{\mathrm{T,det}}^{\mathrm{ch\ jet}}, \quad p_{\mathrm{T,tru}}^{\mathrm{ch\ jet}}, \quad \lambda_\alpha^{\mathrm{det}}, \quad \lambda_\alpha^{\mathrm{tru}}\right]$$

- Apply unfolding procedure to correct for detector effects (tracking efficiency, particle-detector interactions)
- Quality assurance checks:
  - Response matrix projections
  - Kinematic efficiency
  - Unfolding tests

# Jet substructure

- Looking at the structure composed from constituents inside of reconstructed jets, e.g.:
  - What does the (transverse) momentum distribution look like?
  - What are most of the particles located?
  - Are there smaller "subjets" inside? (Higgs/BSM searches: $H \rightarrow b\bar{b}$) [1]
  - …




- With such a large space, what questions are most useful to ask? Meaning, what observables are most useful to study?
  - We want to be able to:
    - 1) Test our theoretical predictions from QCD (on the lattice, pQCD, effective theories, …)
    - 2) Gain some overarching intuition and measure nonperturbative physics

[1] Phys. Rev. Lett. 100, 242001 (2008)

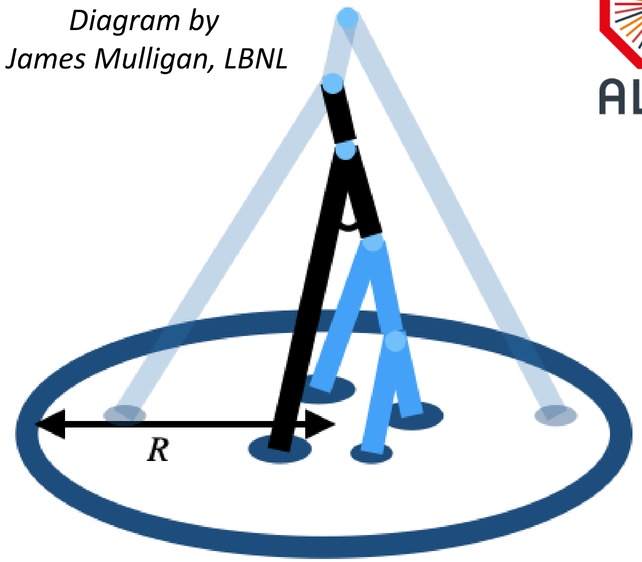
# Jet grooming

- Procedure used to modify jet structure after the initial reconstruction

- Often aimed at removing soft, wide-angle radiations, which are strongly affected by underlying event and nonperturbative effects

- One of the most popular algorithms is called **Soft Drop**
  - **1)** Recluster jet with C/A algorithm into tree (~angularly ordered);
  - **2)** Remove branches until the Soft Drop Condition is satisfied, then stop
  - Process can also be applied to theoretical calculations

*Diagram by James Mulligan, LBNL*



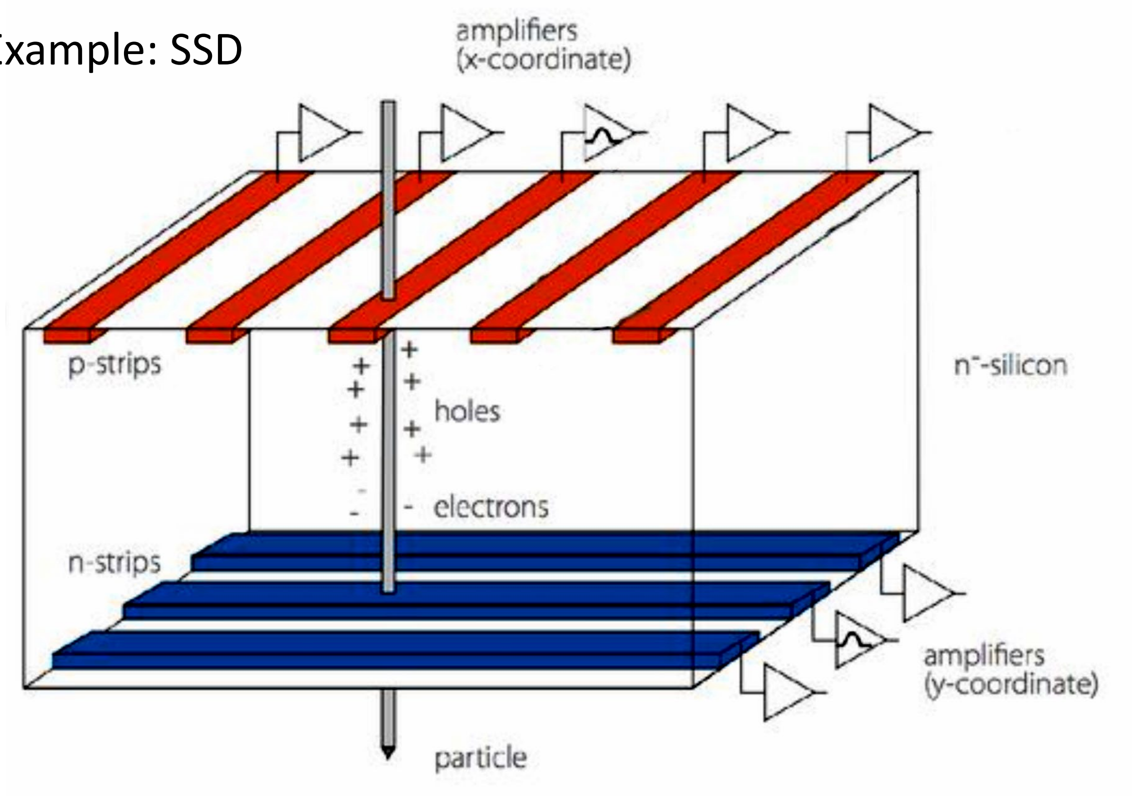

Soft Drop Condition: $\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$

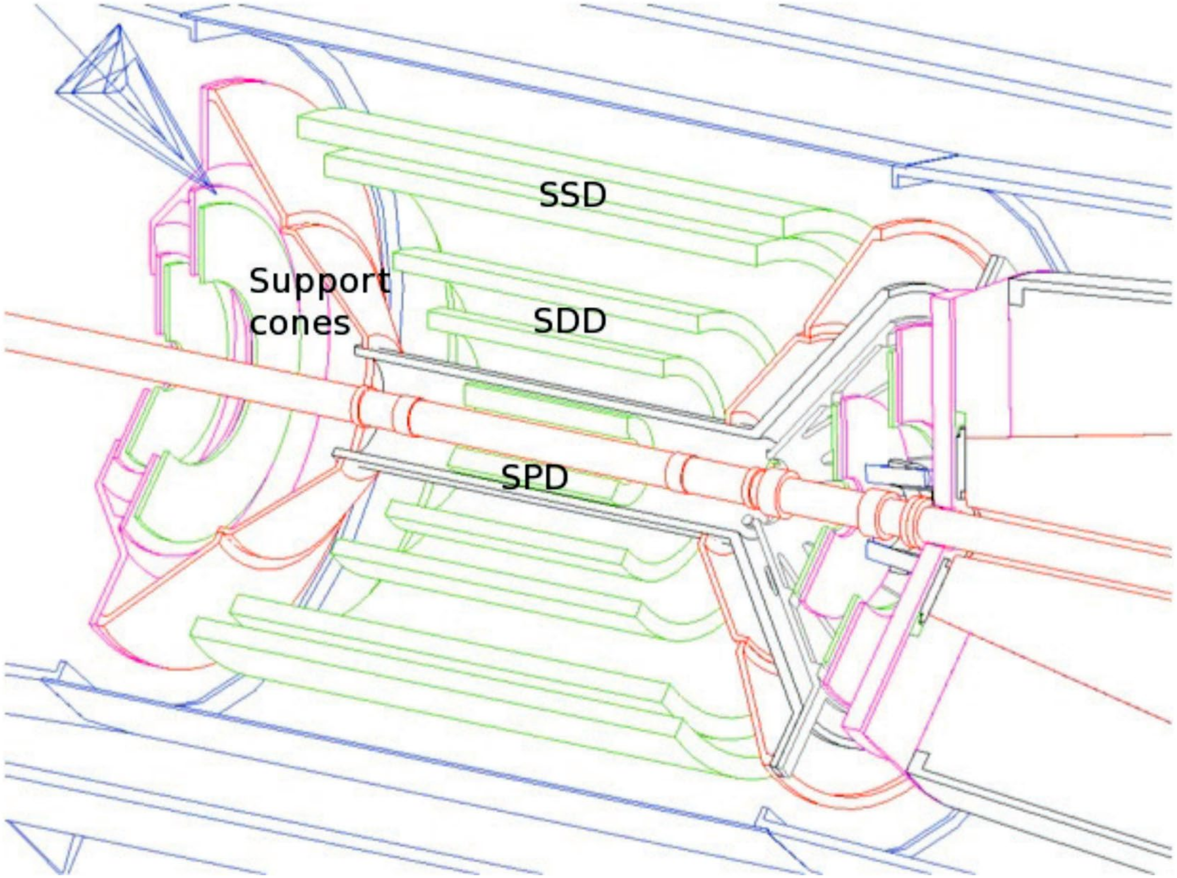
*Larkowski et al.*, JHEP 1405 (2014) 146

# ALICE Inner Tracking System (ITS)

- 6 layers (two each of pixel, drift, and strip detectors)
- SSD & SDD can measure charge → $\frac{\mathrm{d}E}{\mathrm{d}x}$

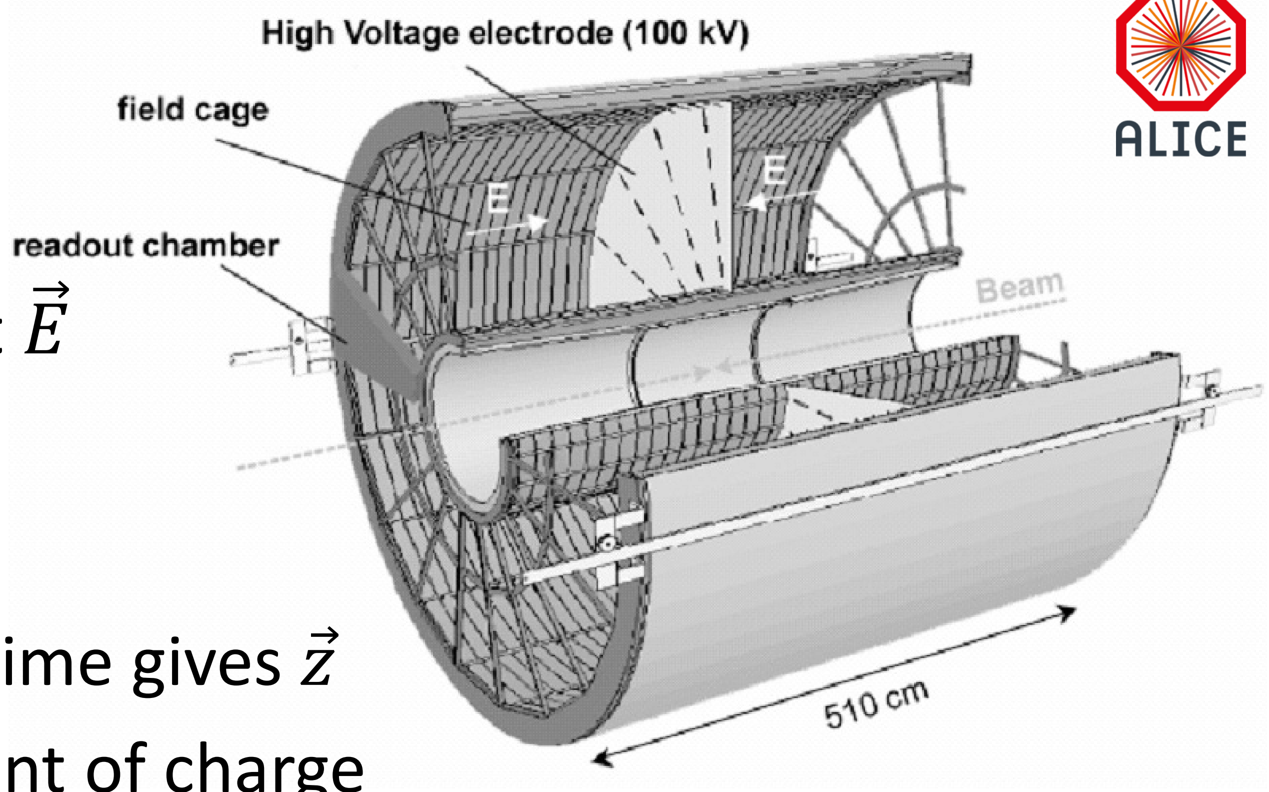
Example: SSD

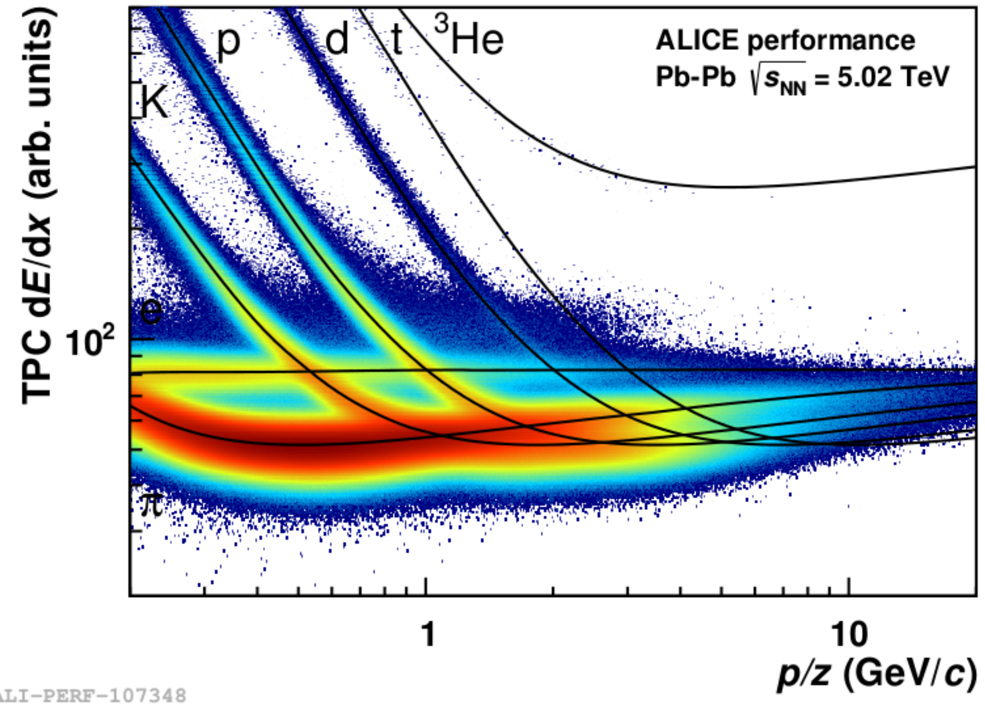


# ALICE TPC

- HV electrode creates high-gradient $\vec{E}$
- Ionization electrons drift to wire chamber readout




- Drift time gives $\vec{z}$
- Amount of charge (pulse height) correlates to the energy

- The first TPC was invented by David Nygren at LBNL

David Nygren

# Systematic uncertainties

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

- Primarily dominated by tracking efficiency and model dependence

- Unfolding uncertainty probed via variation of:
  - the regularization parameter
  - the prior distribution;

$$p_{\mathrm{T}}{}^{\pm 0.5} \times [1 \pm 0.5\ (2\lambda_\alpha - 1)]$$

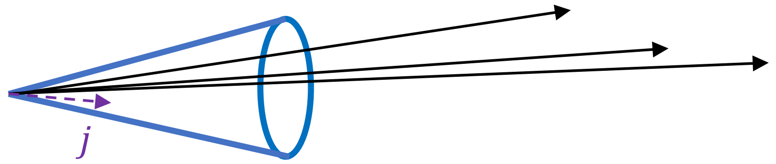
  - the binning of $\lambda_\alpha$;
  - truncation region for $p_{\mathrm{T,det}}^{\mathrm{ch\ jet}}$.
- The total unfolding systematic uncertainty is then the standard deviation of the variations

# What is IRC safety?

$$\lambda_\beta^\kappa \equiv \sum_{i\in\text{jet}} \left(\frac{p_{\text{T},i}}{p_{\text{T,jet}}}\right)^\kappa \left(\frac{\Delta R_{\text{jet},i}}{R}\right)^\alpha \equiv \sum_{i\in\text{jet}} z_i^\kappa \theta_i^\alpha$$

- Stands for Infra-Red and Collinear (IRC) safety
- Class of reconstruction algorithms & observables which satisfy certain conditions in order to avoid singularities from appearing in a well-defined path towards theoretical calculation

**Infra-Red safety**: the observable should not change if an infinitely-low-momentum particle is added to the event/jet




$$\lambda_{\beta,\text{new}}^\kappa = \sum_{i\in\text{jet}} z_i^\kappa \theta_i^\beta + z_j^\kappa \theta_j^\beta$$

$$z_j = 0 \rightarrow z_j^\kappa \theta_j^\beta = 0 \quad (\kappa > 0)$$

$$\lambda_{\beta,\text{new}}^\kappa = \lambda_{\beta,\text{old}}^\kappa$$

**Collinear safety**: the observable should not change if one particle splits into two collinear particles

$$\lambda_{\beta,\text{new}}^\kappa = \sum_{(i\neq j)\in\text{jet}} z_i^\kappa \theta_i^\beta + (\lambda z_j)^\kappa \theta_j^\beta + [(1-\lambda)z_j]^\kappa \theta_j^\beta$$

Need $\lambda^\kappa + (1-\lambda)^\kappa = 1 \quad \forall\{\lambda \in [0,1]\} \quad \rightarrow \quad \kappa = 1$

Consider 1-particle jet: $\lambda_{\beta,\text{new}}^\kappa = (\lambda z_j)^\kappa \theta_j^\beta + [(1-\lambda)z_j]^\kappa \theta_j^\beta$

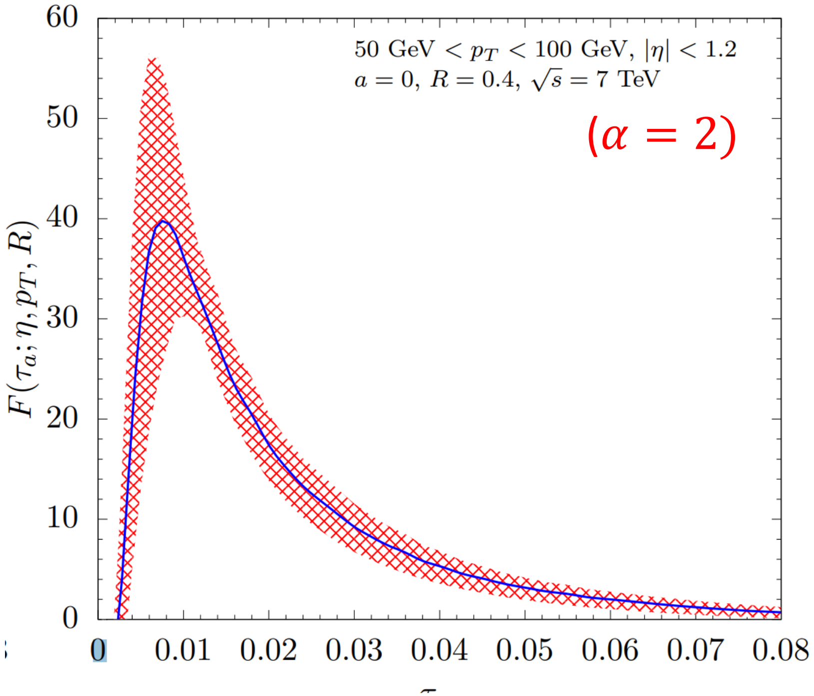
$$\theta_j = 0 \rightarrow z_j^\kappa \theta_j^\beta = 0 \quad (\beta > 0)$$

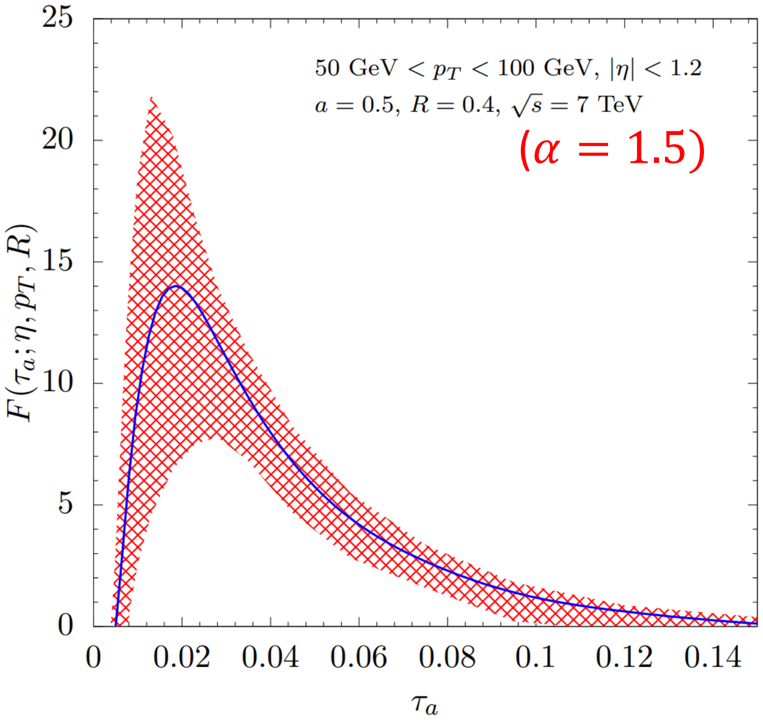
# Theoretical calculations

$$\lambda_\alpha^\kappa \equiv \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$$

ALICE

- Kang/Lee/Ringer: NLL' calculations within Soft Collinear Effective Theory [2]: JHEP 1804 (2018) 110




$$F(\tau_a;\eta,p_T,R) = \frac{d\sigma^{pp\to(\text{jet }\tau_a)X}}{d\eta\, dp_T\, d\tau_a} \Bigg/ \frac{d\sigma^{pp\to \text{jet}X}}{d\eta\, dp_T}$$

$$\frac{d\sigma^{pp\to(\text{jet }\tau_a)X}}{d\eta\, dp_T\, d\tau_a} = \sum_{abc} f_a(x_a,\mu) \otimes f_b(x_b,\mu) \otimes H_{ab}^c(x_a,x_b,\eta,p_T/z,\mu) \otimes \mathcal{G}_c(z,p_T,R,\tau_a,\mu)$$

PDFs (*NP*)

Hard Function (*P*)

siAJFs (*P / NP*)

$$\tau_a \equiv \tau_a^{pp} \equiv \frac{1}{p_T} \sum_{i\in J} p_T^i \left(\Delta\mathcal{R}_{iJ}\right)^{2-a} \equiv \lambda_{\alpha=2-a}^{\kappa=1} * R^{2-a}$$

**We can directly compare our data to predictions from theory**

[2] Phys. Rev. D 63 (2000) 014006

# Jet reconstruction

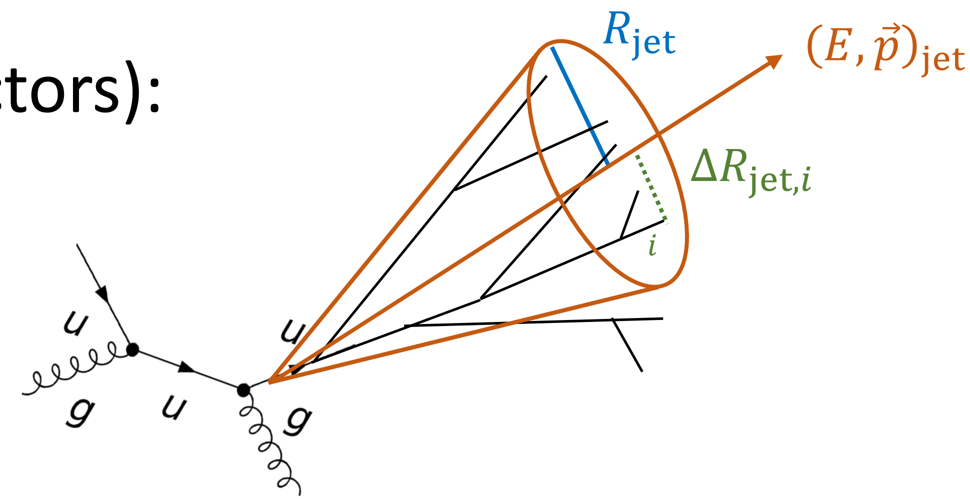
- Jets are reconstructed from charged particle tracks using the **anti-$k_\mathrm{T}$** sequential recombination algorithm [5]
  - From an **IRC-safe** class of algorithms
  - **Soft-resilient**: shape is not strongly affected by soft, wide-angle radiation

$$d_{ij} = \min\left(k_{\mathrm{T}i}^{2p}, k_{\mathrm{T}j}^{2p}\right)\frac{\Delta_{ij}^2}{R^2}$$
$$d_{i\mathrm{B}} = k_{\mathrm{T}i}^{2p}$$

$$p = \begin{cases} 1, & (\text{"inclusive"})\ k_\mathrm{T} \\ 0, & \text{Cambridge/Aachen} \\ -1, & \text{anti } k_\mathrm{T} \end{cases}$$

- ***E*-scheme** recombination (adding four vectors):

$$(E,\vec{p})_\mathrm{jet} = \sum_{i\in\mathrm{jet}} (E,\vec{p})_i$$




[5] JHEP 0804:063,2008

# Event / track selection requirements

- Minimum bias events (hit in both V0A and V0C)
  - Require there is a successfully reconstructed primary vertex within 10cm longitudinally of the nominal IP

- $p_{\mathrm{T}} > 0.15$ GeV/$c$
- 70 space points found in the TPC
- At least 3 hits in the ITS
- If no hits in SPD, add primary vertex to track fit (improves momentum resolution)

# Unfolding tests

- Convergence test: unfolding process must converge as $n_{iter}$ increases

- Refolding test: multiply RM by unfolded solution & compare to original

- Statistical closure test:
  - Smear MC det-level by statistical errors on measured data
  - Unfold the smeared MC det-level spectrum
  - Compare to MC truth-level

- Shape closure test:
  - Vary shape of input in some reasonable way
  - Do as above

# *Perturbative* versus *Non-Perturbative* regions

- In the theoretical calculations of the jet angularities, there are 5 different characteristic factorization **scales**
  - These are varied to produce the NLL' uncertainty bands

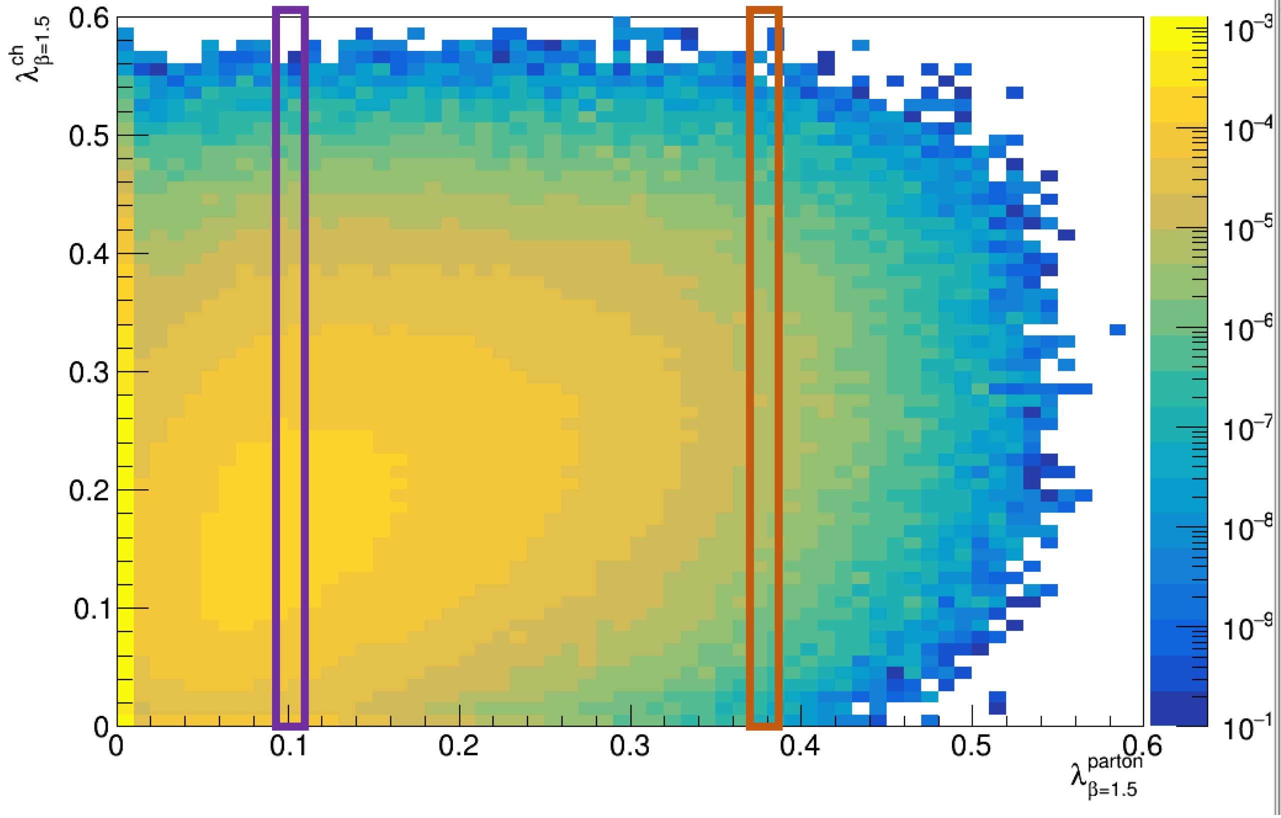
- The prediction can become NP-dominated if the "**soft scale**" ($\lambda_\beta p_\mathrm{T} R$) approaches a non-perturbative value (say, $\Lambda \sim 1\ \mathrm{GeV}$)
  - This divides plots into perturbative (P) and NP-dominated regions

- Similarly, the *entire distribution* can become NP-dominated if the "**hard scale**" ($p_\mathrm{T}$) or "**jet scale**" ($p_\mathrm{T} R$) approach some NP value
  - We don't have to worry about this for our (ungroomed) jet measurements

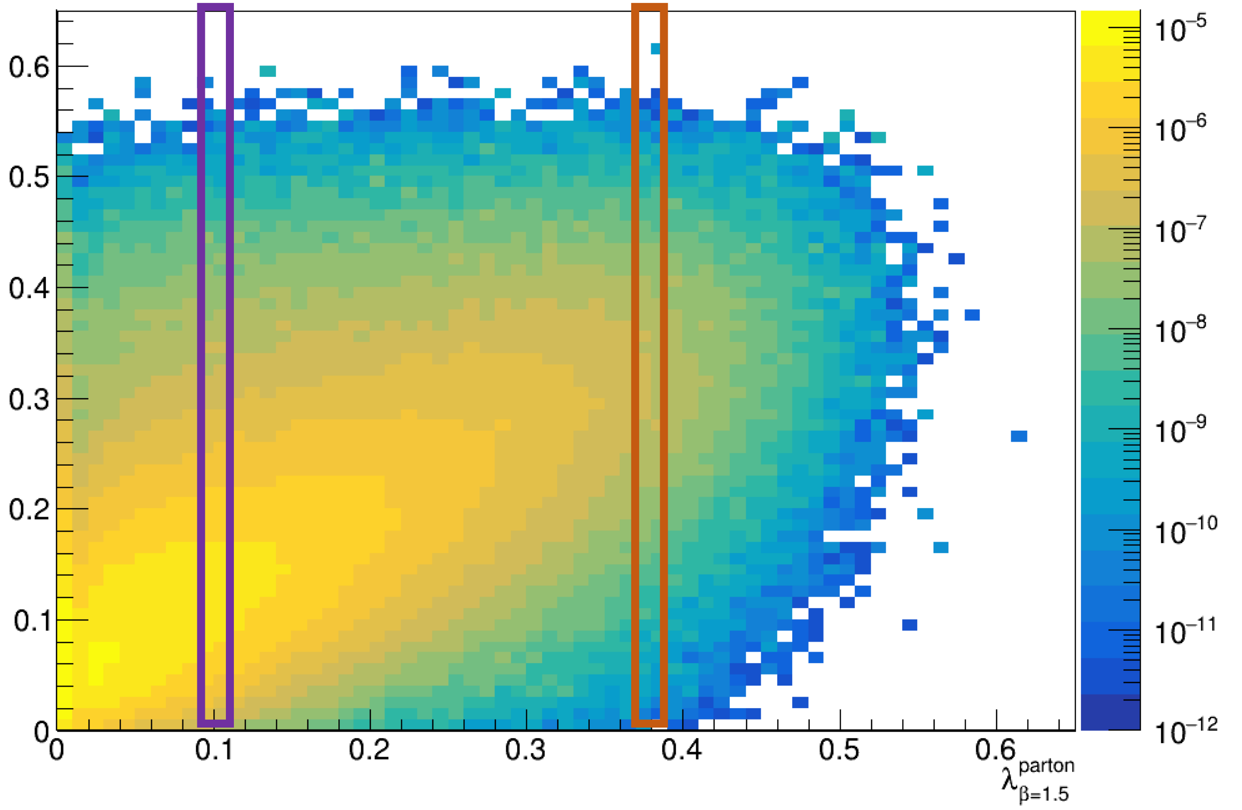
# Angularity response matrix projections

- PYTHIA
- $\lambda_{\beta=1.5}$; $R = 0.2$

$20 \leq p_{\mathrm{T}}^{\mathrm{ch\,jet}} < 40$ GeV/$c$




$60 \leq p_{\mathrm{T}}^{\mathrm{ch\,jet}} < 80$ GeV/$c$




Consider the (Green's function-like) response of a delta function at parton-level ...and for a second value

→ Output distributions are smeared & shifted from input distributions, and appear more similar at ch-level

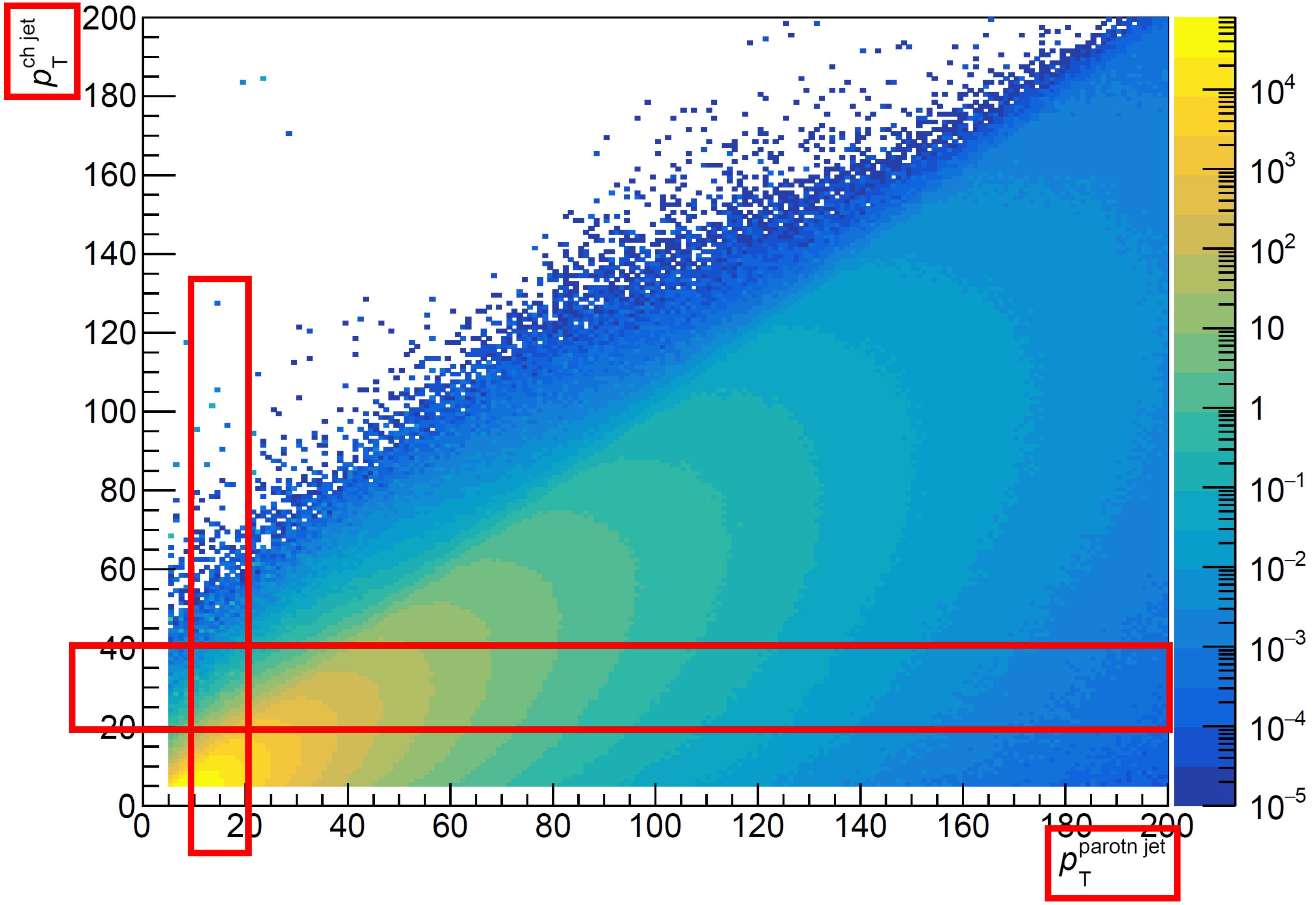
→ Large (but well-defined) model dependence & output shape bias, especially at lower $p_{\mathrm{T}}^{\mathrm{ch\,jet}}$



ALICE

# PYTHIA8 response matrix projection onto $p_{\mathrm{T}}$

- Some contribution at $p_{\mathrm{T,jet}}^{\mathrm{ch}} \in [20, 40]$ GeV/$c$ from $p_{\mathrm{T,jet}}^{\mathrm{parton}} < 20$ GeV/$c$
- Strongly emphasized by ~order-of-magnitude scaling per $p_{\mathrm{T,jet}}^{\mathrm{parton}}$ bin (increments of 10 GeV/$c$)
- Sensitive to low- $p_{\mathrm{T,jet}}^{\mathrm{parton}}$ distributions



# Parton-level distributions per $p_{\mathrm{T,jet}}^{\mathrm{parton}}$ bin

- Agreement improves with increased $R$ and increased $p_{\mathrm{T,jet}}$