

Exploring jet interactions in the quark-gluon plasma using jet substructure measurements in Pb-Pb collisions with ALICE

Raymond Ehlers¹ for the ALICE Collaboration

08 July 2022

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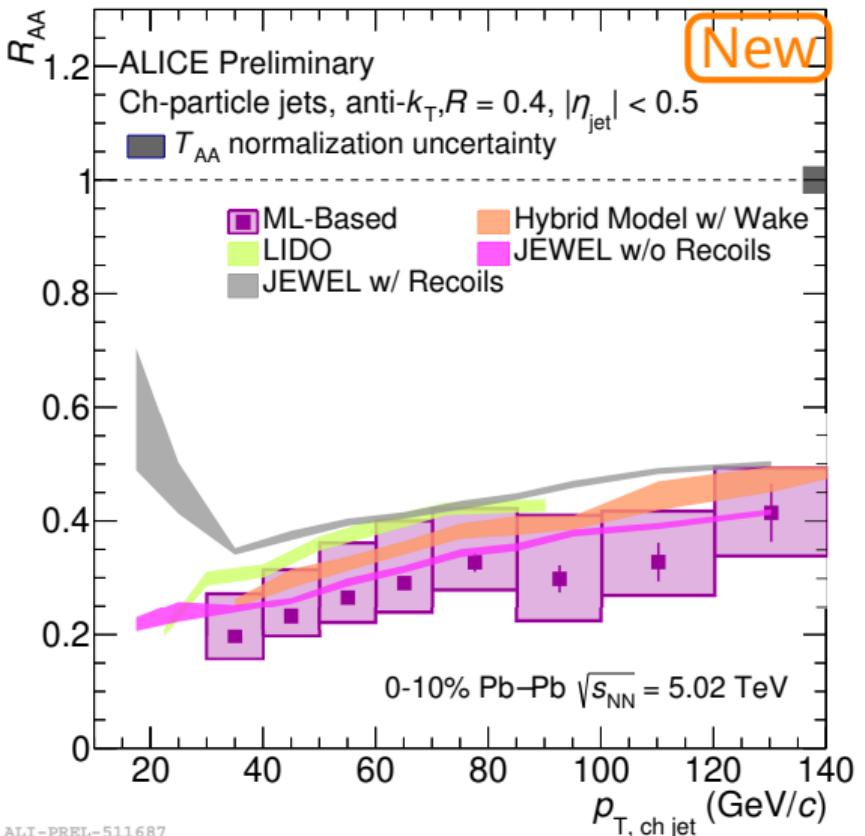
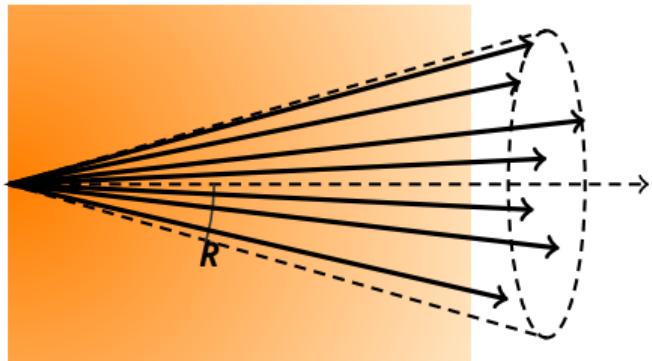


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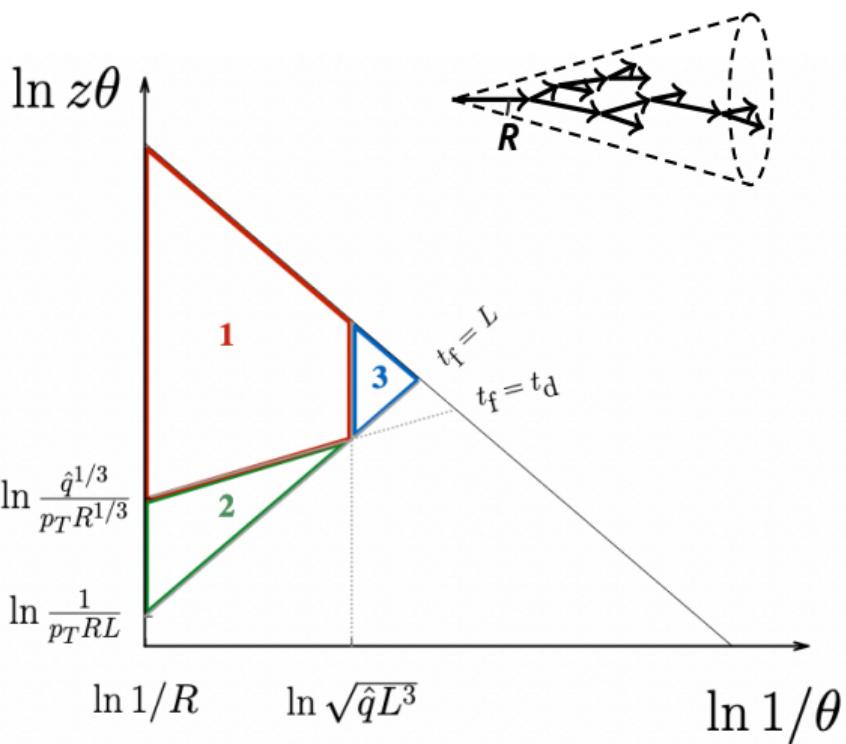
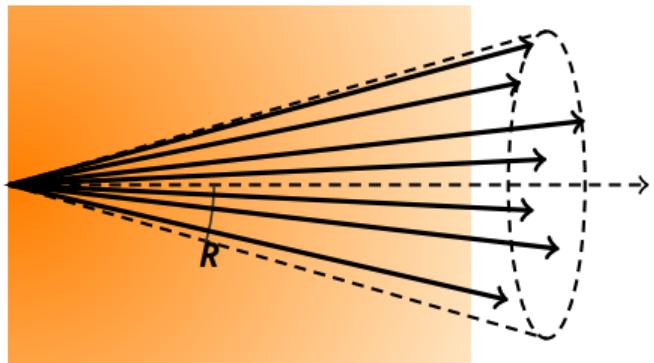
Jets and their substructure

- Jets are in situ probes of QGP dynamics
 - Modifications while traversing the medium collectively known as “jet quenching”
 - Jet-medium interactions modify the **internal jet structure**
- How to quantify this modification?



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H. Andrews et al., J.Phys.G 47 (2020) 6, 065102

Experimentally accessing substructure

1. Ungroomed substructure

Sensitive to the whole splitting phase space, including soft emissions

2. Groomed substructure

Dynamical Grooming (DyG)

Mehtar-Tani et al., [PhysRevD.101.034004](#)

$$\kappa^a \propto \max_{i \in C/A} [z_i(1-z_i)p_{Ti}(\theta_i/R)^a]$$

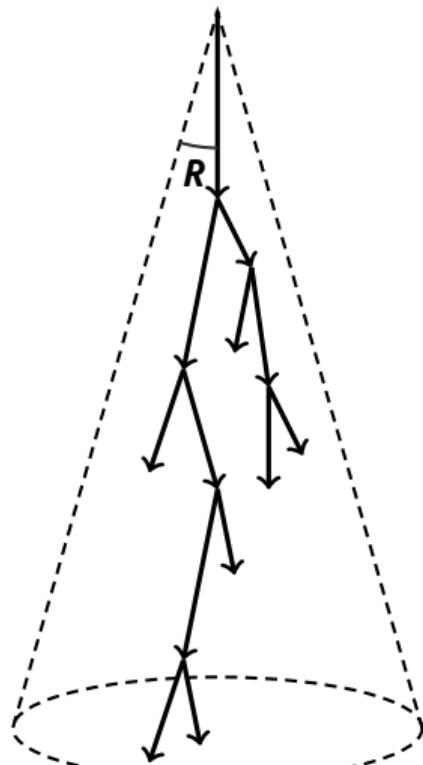
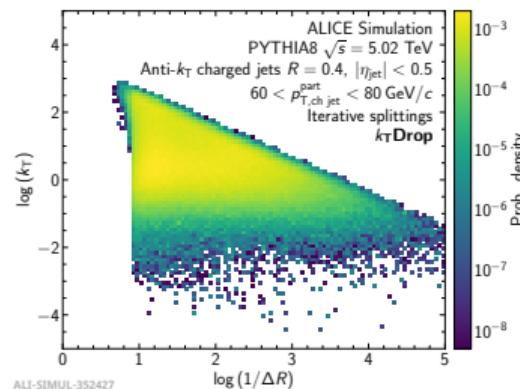
- $a = 0.5$: "core" - more symmetric, narrow
- $a = 1$: " k_T " - largest $k_T \sim \kappa^1 p_T$
- $a = 2$: "time" - shortest splitting time $t_f^{-1} \sim \kappa^2 p_T$

Soft Drop (SD)

Larkoski et al., [JHEP 05 \(2014\) 146](#)

$$\frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{\text{cut}} \left(\frac{\Delta R}{R} \right)^\beta$$

- $z_{\text{cut}} = 0.2, \beta = 0$



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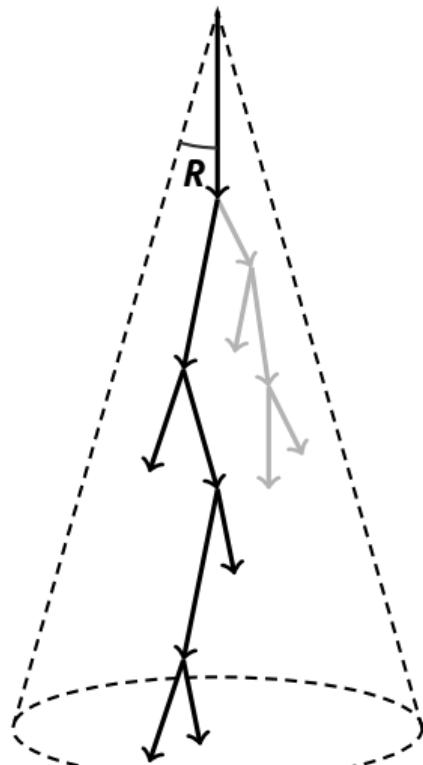
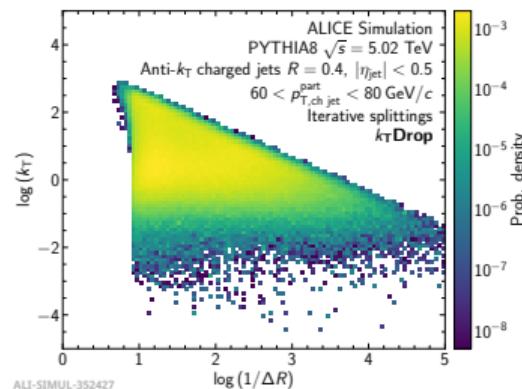
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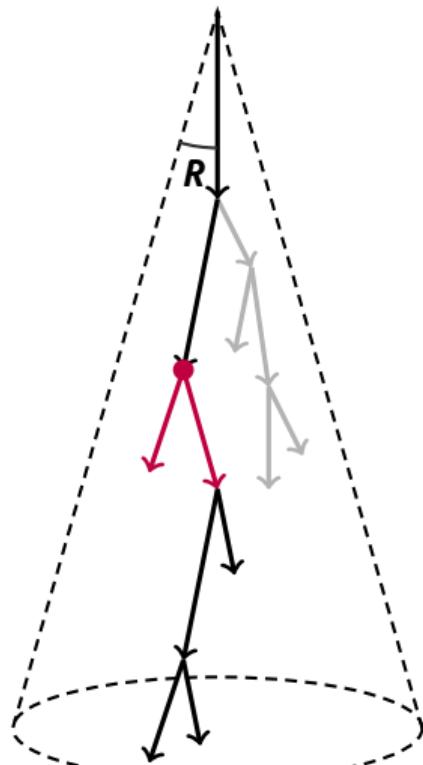
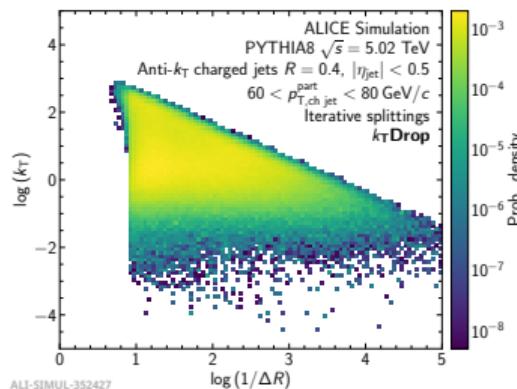
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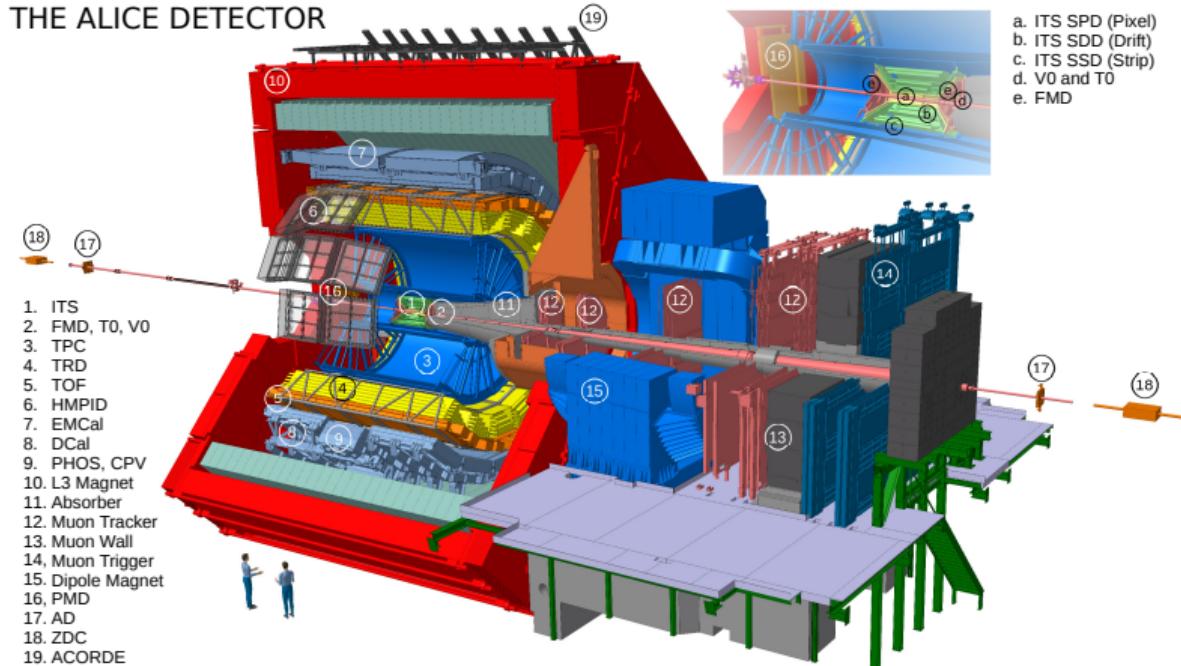
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Jets and their substructure in ALICE



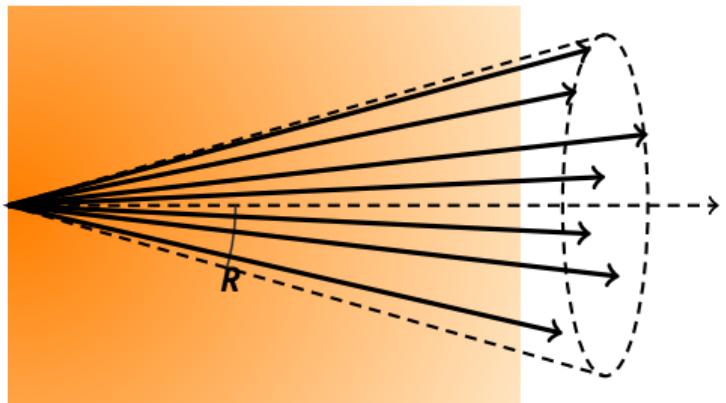
- ALICE well suited for measuring:
 - **Low p_T** jets
 - **Small splitting angles** at high efficiency
- Enables **strong substructure program**
- Anti- k_T **charged-particle jets** measured in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$



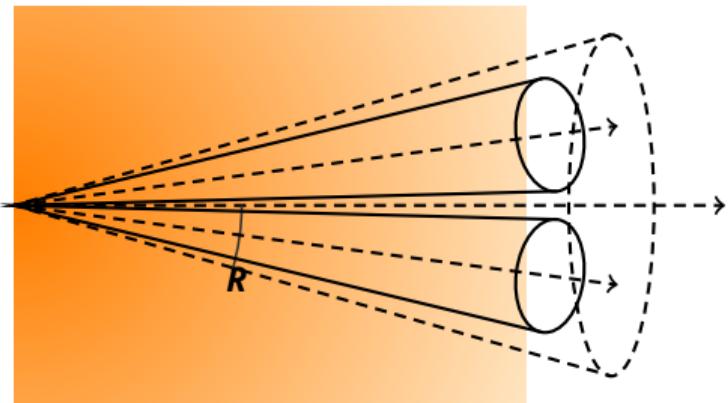
- See also:
- Artem Kotliarov on jet quenching search in pp (7 July, 11:30)
- Yongzhen Hou on jet acoplanarity (8 July, 15:05)

Jet substructure observables

1. Summary substructure observables

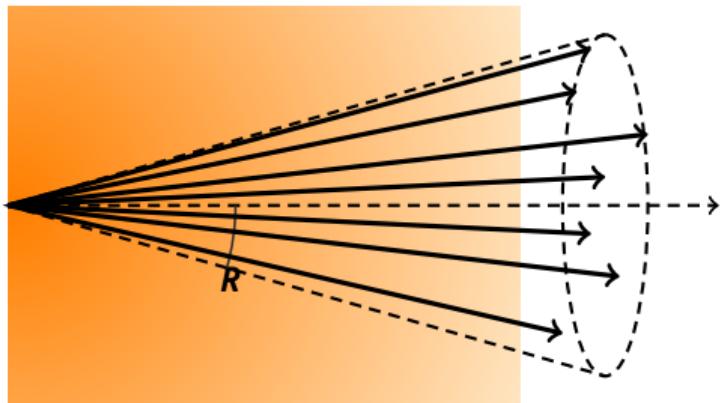


2. Subjet observables

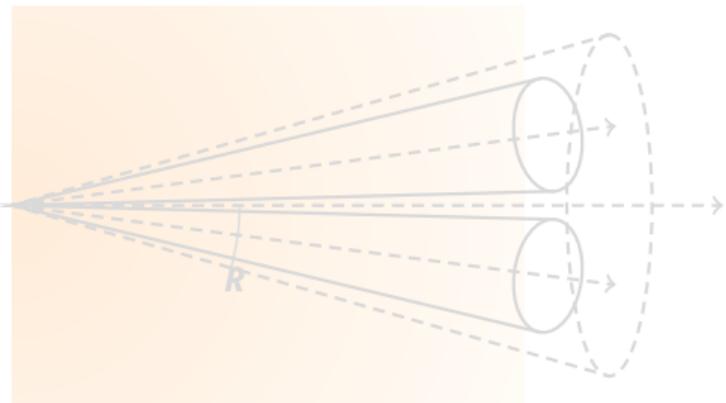


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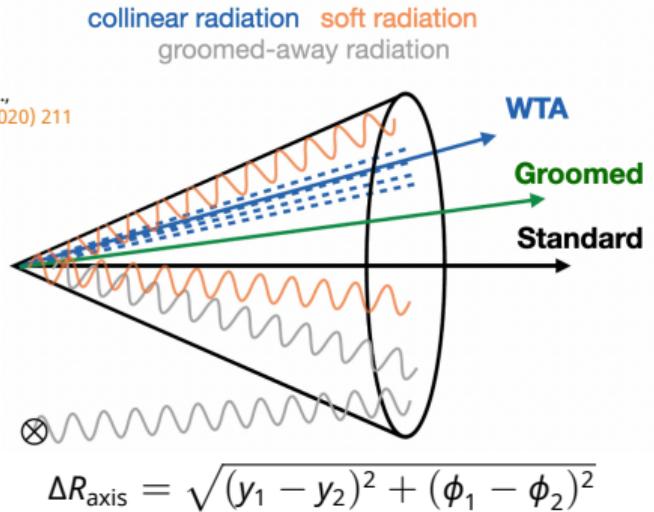


Angle between jet axes

New

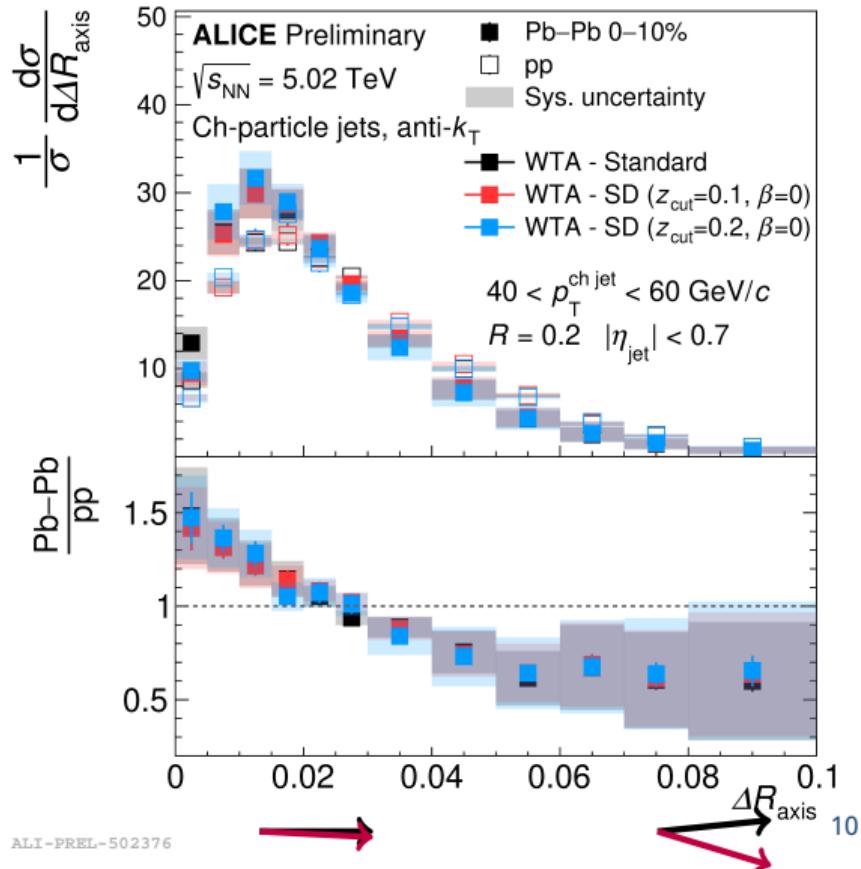


P. Cal et al.,
JHEP 04 (2020) 211



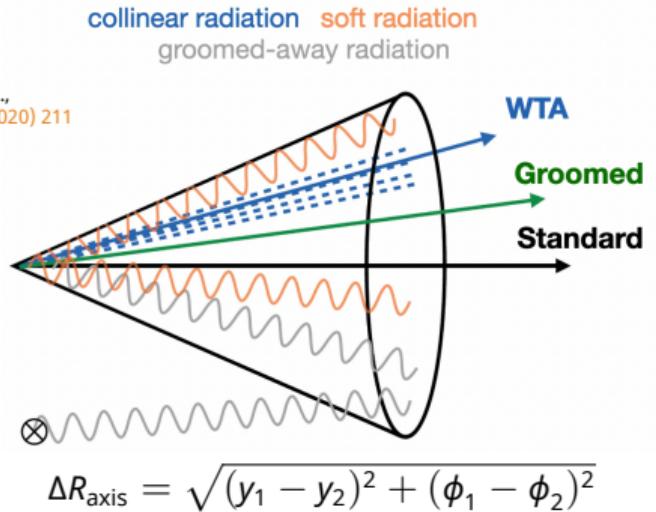
- Study impact of soft radiation via jet axis
- **Narrower jets** found in Pb-Pb relative to pp
- Jet axis is **insensitive to grooming**
- **Qualitatively describe by models**, except one
- Role of **changing q/g fraction? Coherence?**

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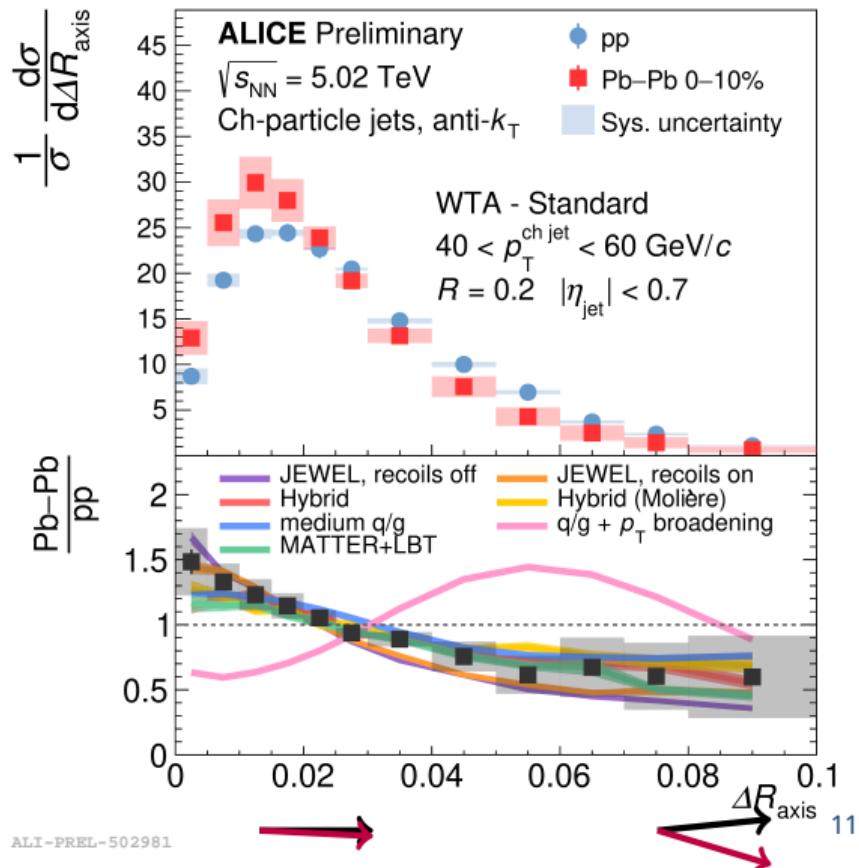
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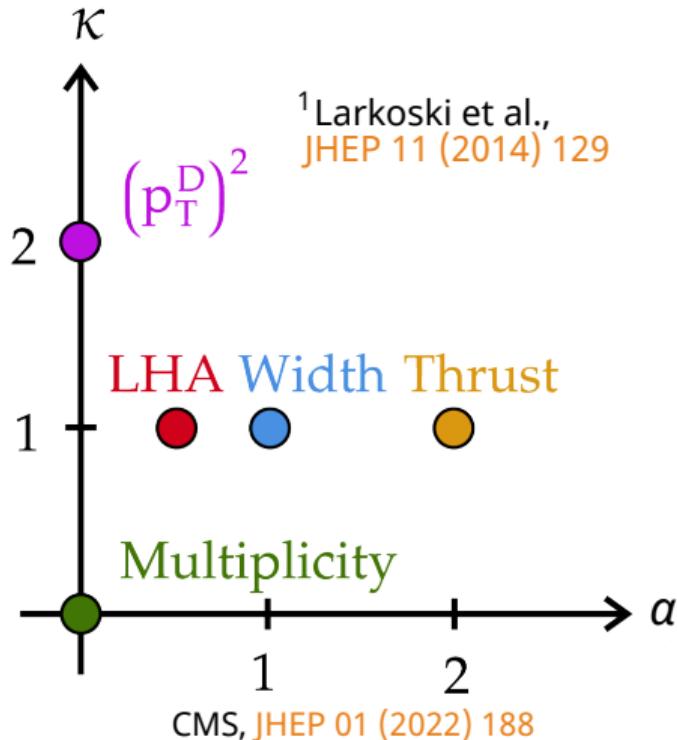
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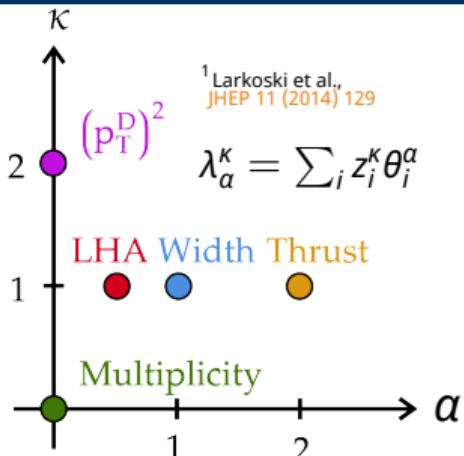
$$\lambda_a^\kappa = \sum_i z_i^\kappa \theta_i^\alpha$$

- IRC-safe observables to summarize substructure¹
- Focus on $\kappa = 1$
- Smaller uncertainties, **clear narrowing** in groomed
- Grooming **reduces** intra-jet broadening, recoils effects

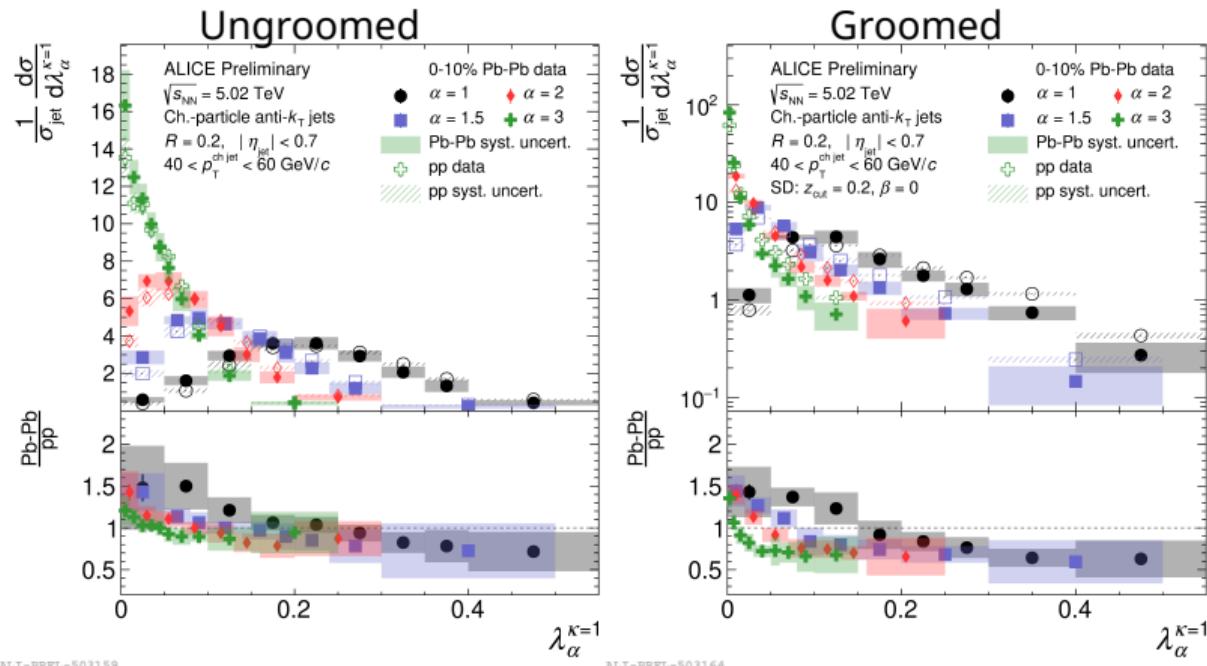


Jet shape via generalized angularities

New



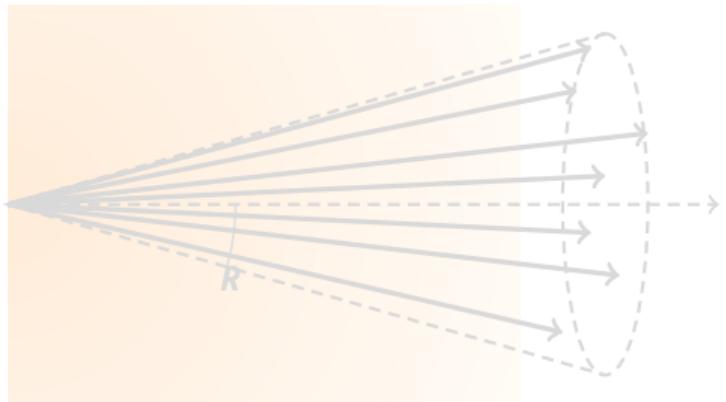
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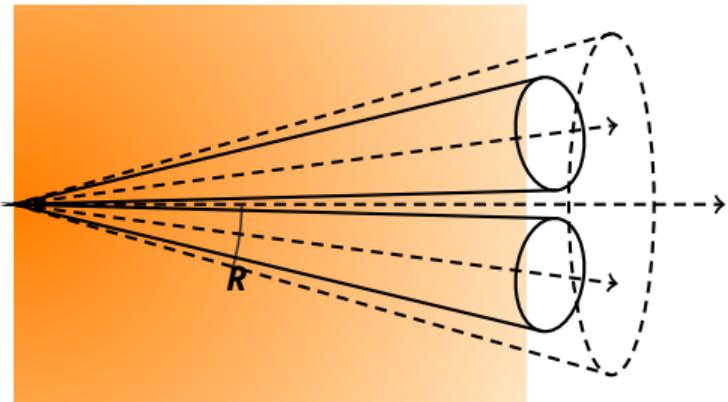
- Well described by **most models**, with some deviations (backup)

Jet substructure observables

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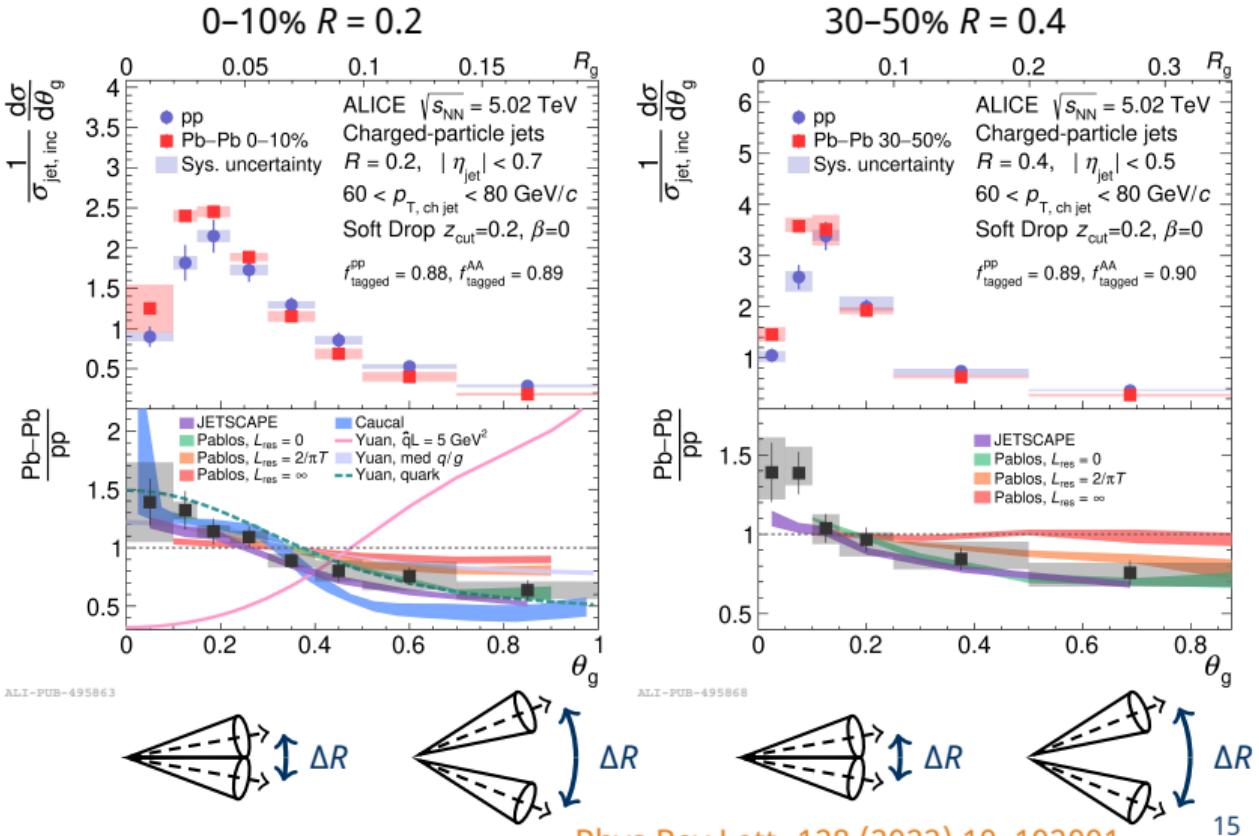
2. Subjet observables



Exploring angular dependence via groomed substructure



- **Suppression of large angles and enhancement of small angles**
- **Promotes narrow or filters out wider subjets**
- **Qualitative description** by most of the models
- Medium has **resolving power** for splittings
- No modification of shared momentum fraction, z_g

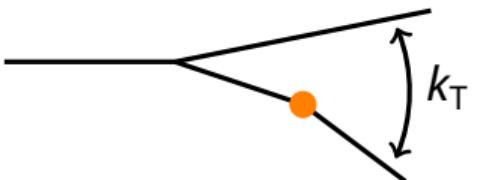


Search for hardest $k_{T,g}$ splittings in Pb-Pb

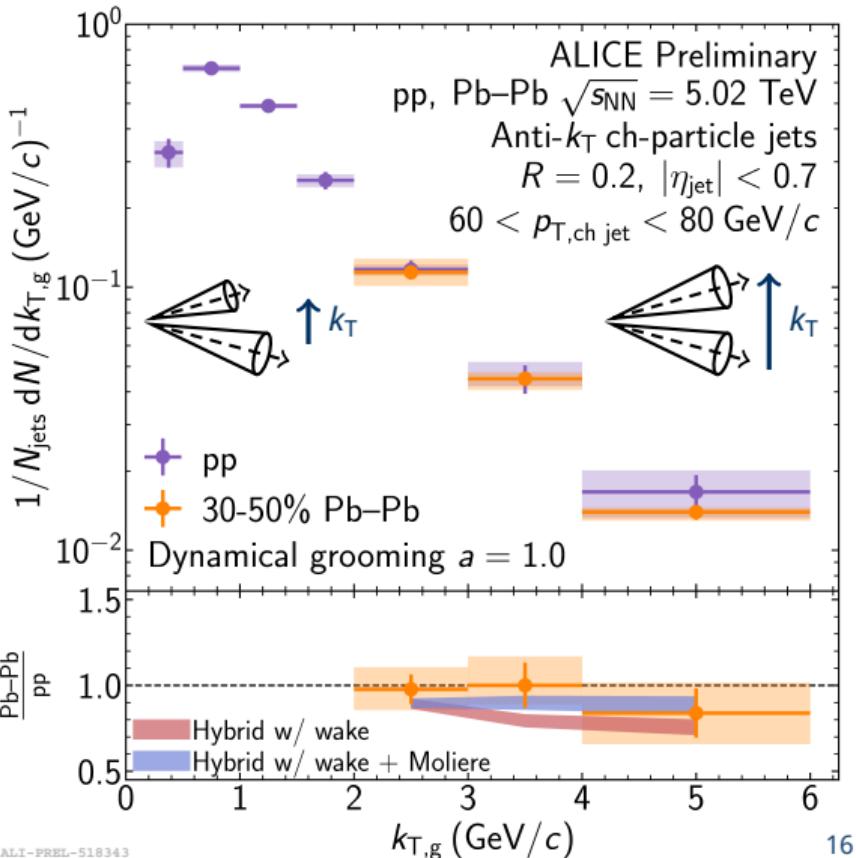
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- Search for high k_T emissions as **signature of point-like (Moliere) scattering**



- Search via groomed jet substructure
 - **First measurement with DyG in Pb-Pb**
 - Set of **consistent set of splittings** at high $k_{T,g}$
 - SD $z_{cut} = 0.2$ removes soft component
- Measure over **larger k_T range**
- Convolved with **narrowing effects**
 - Measurement **not yet sensitive** to impact of Moliere scattering

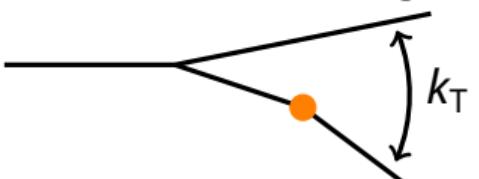


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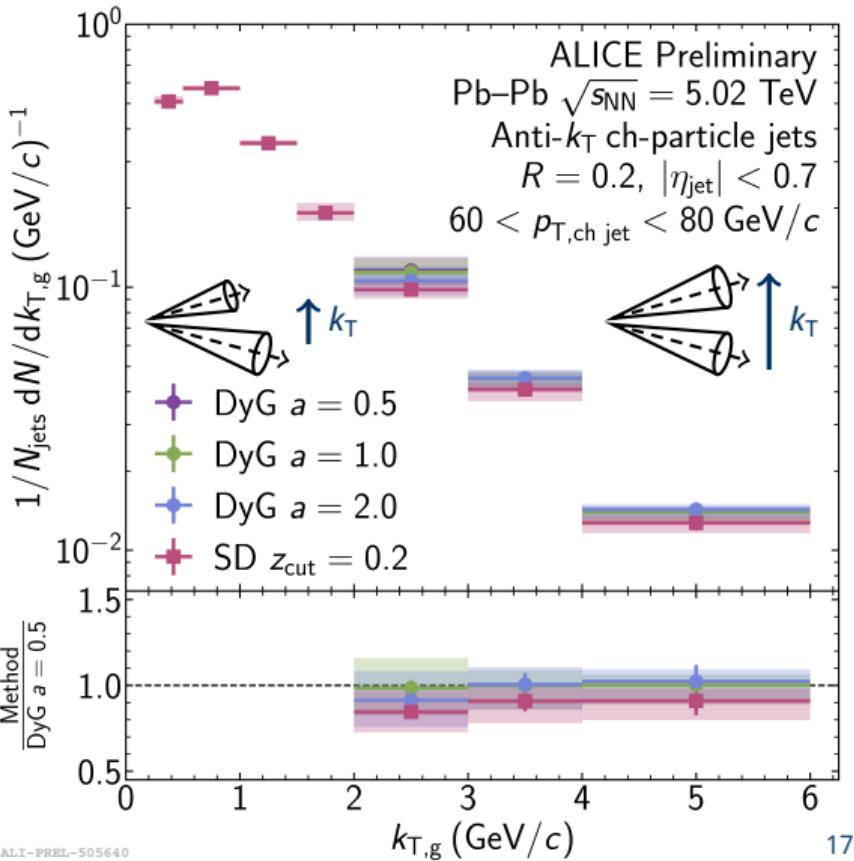
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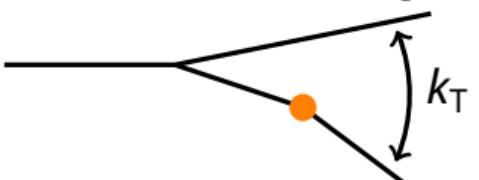


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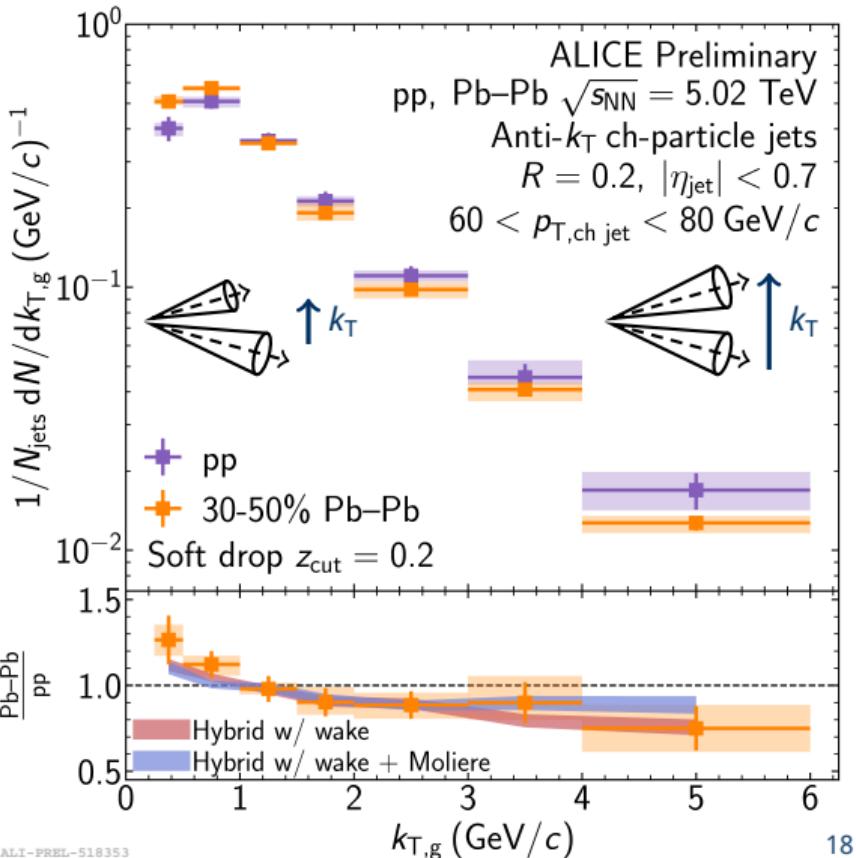
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Exploring fragmentation via subjets

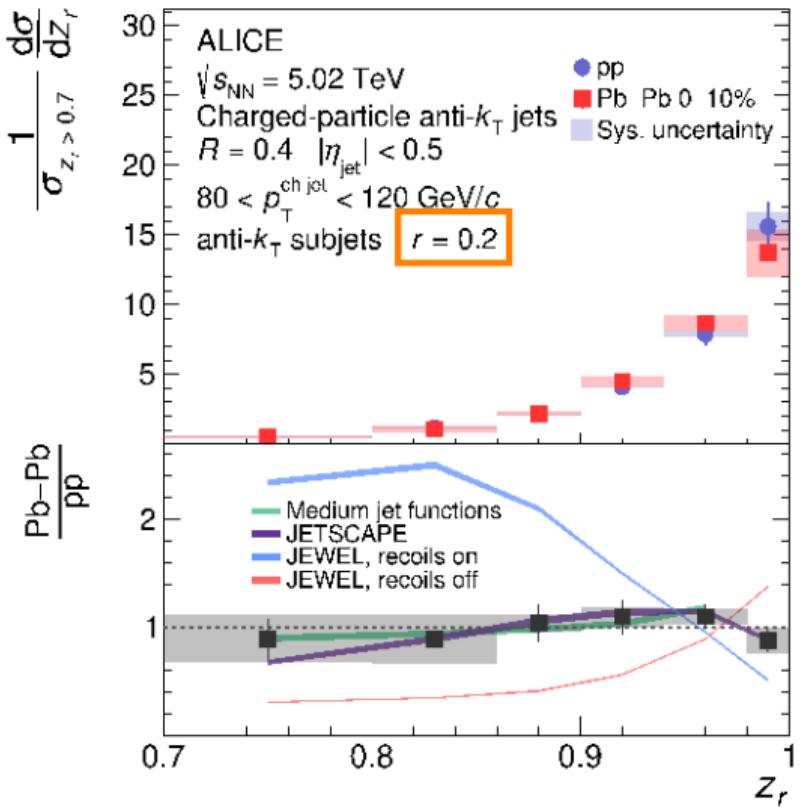
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- Access **harder fragmentation** via subjets
- Recluster inclusive jets using anti- k_T with resolution parameter $r < R$
- Characterize the subjet fragmentation via:

$$z_r = \frac{p_T^{\text{ch,subjet}}}{p_{T,\text{jet}}^{\text{ch}}}$$

- Leading subjets are measured for pp and Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$
- Consistent with **no modification** for $r = 0.1, 0.2$
- **Softening** due to **medium-induce radiation**
- **Hardening** for $z_r \rightarrow 1$ due to **g/q differences**
- **Interplay** yields non-trivial shape change
- Well described by medium jet functions, JETSCAPE



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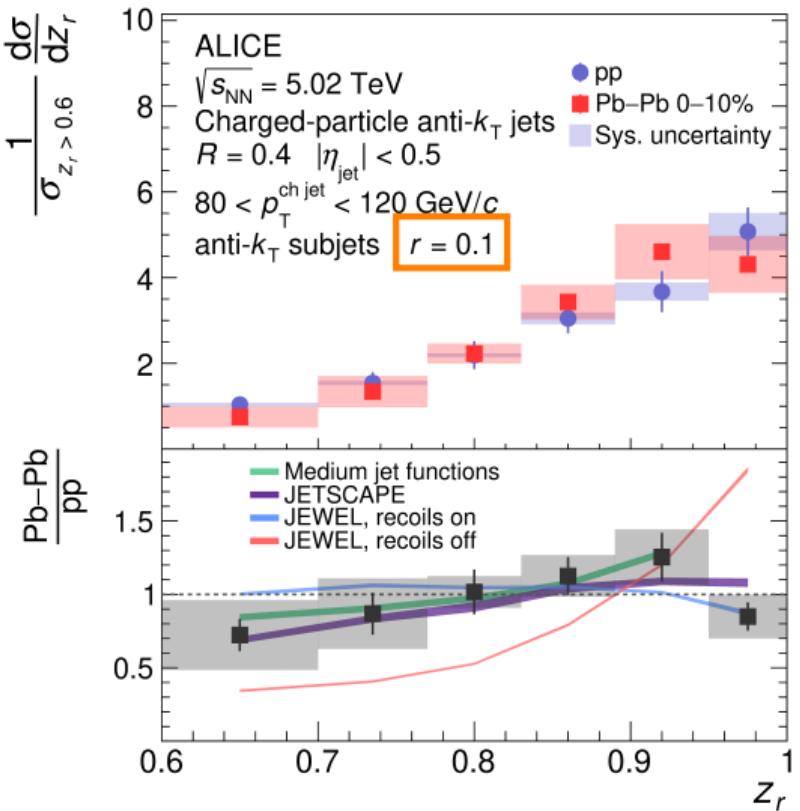
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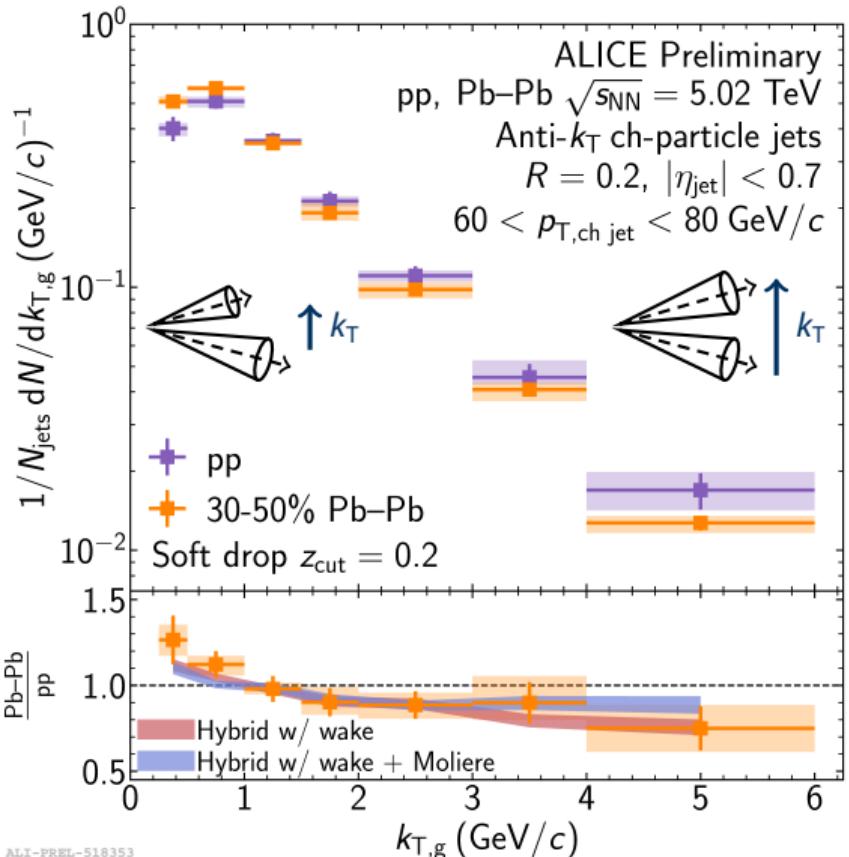
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Summary

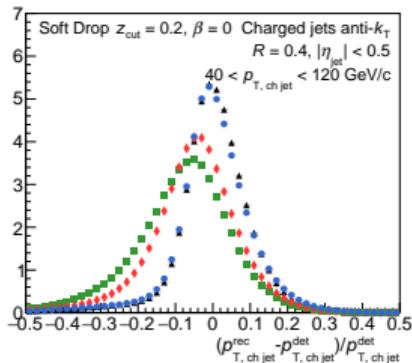
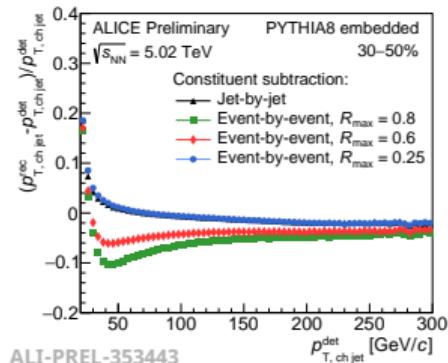
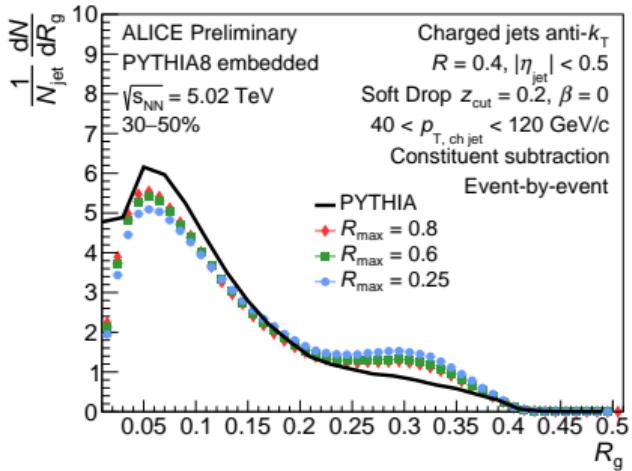
1. **No modification** to splitting function
2. **Narrowing effect** in substructure observables with angular dependence
 - Color coherence? q/g differences?
 - "Survival" bias?
3. Groomed relative transverse momentum $k_{T,g}$ **not yet sensitive** to Moliere scattering effects
 - **First DyG** measurement in Pb-Pb collisions



Backup

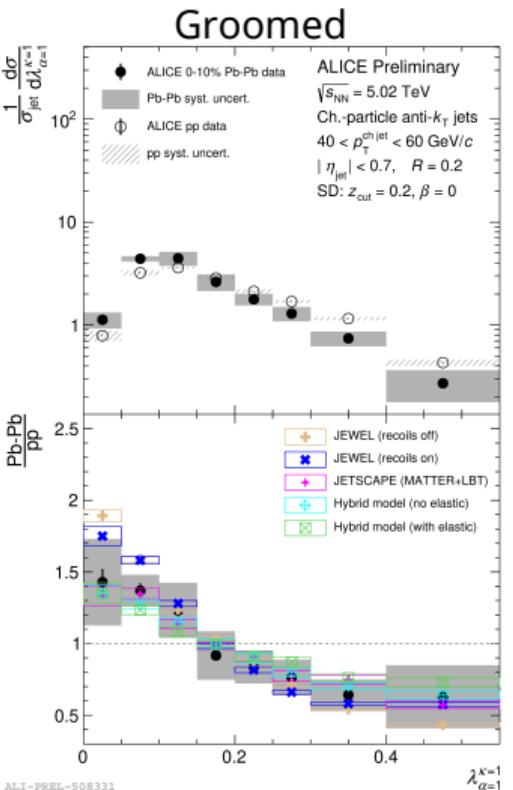
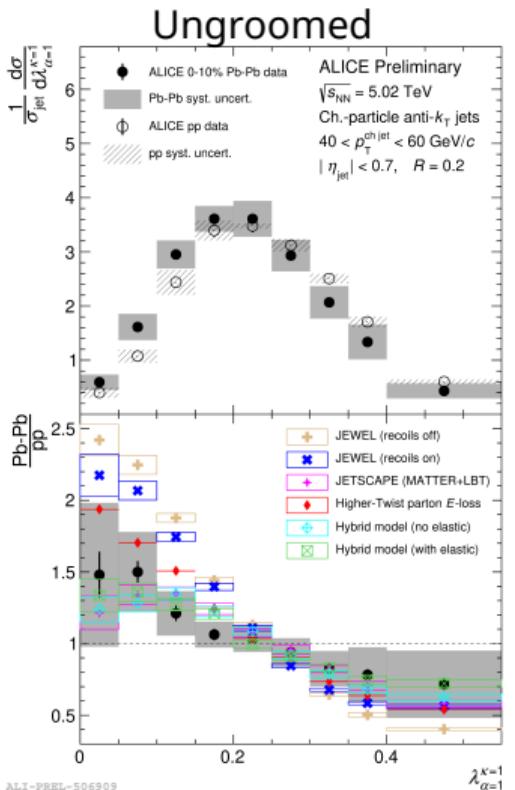
Understanding background contributions

- Different strategies used by ALICE to suppress combinatorial background:
 - Measure small R jets
 - Increase z_{cut}
 - Measure in semi-central collisions
 - Reduces jet quenching relative to central, but combinatorial background is heavily suppressed
- Strategies selected based on constraints of observable
- Utilize event-wise constituent subtraction [JHEP 08 \(2019\) 175](#).
 - Parameters optimized for Pb-Pb collisions



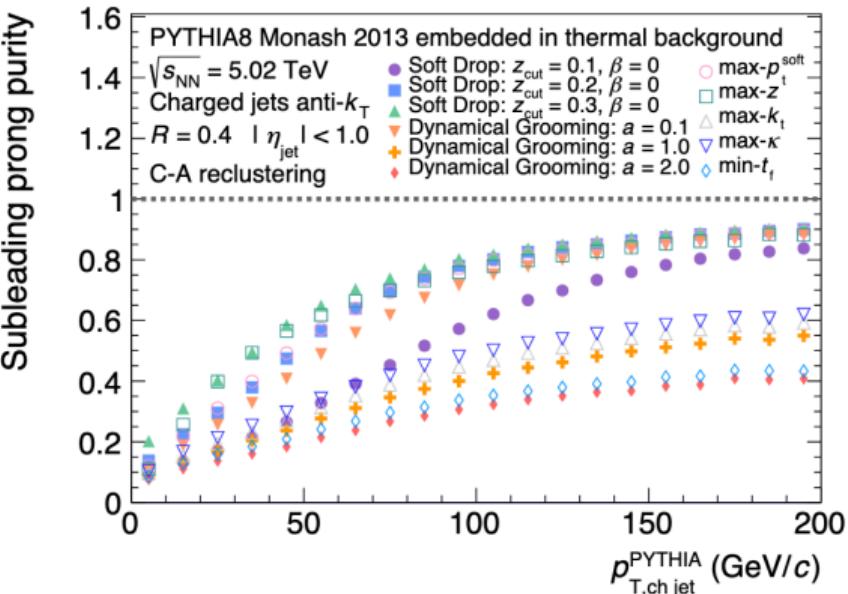
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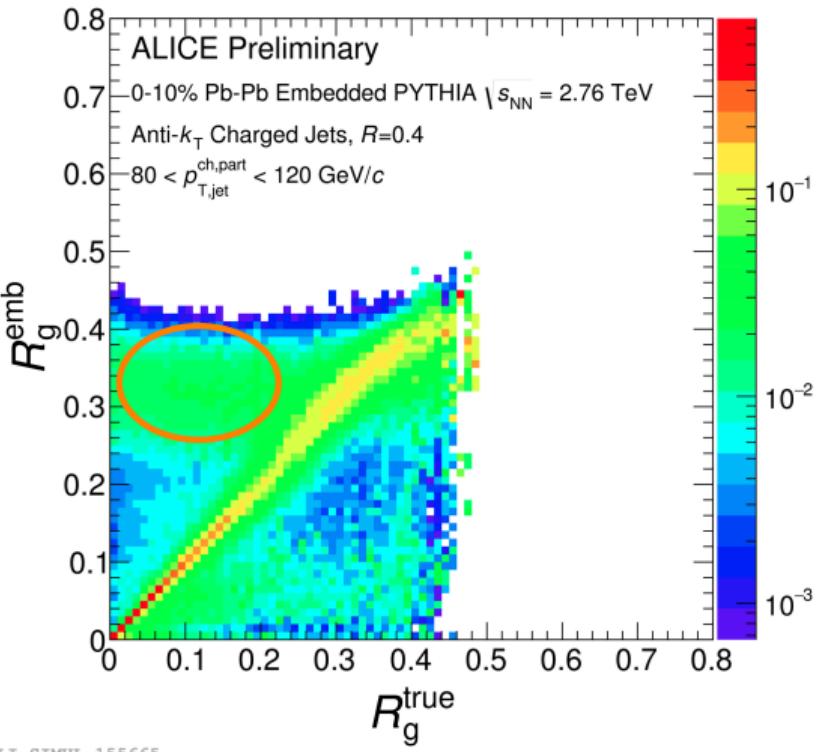
Extracting hardest $k_{T,g}$ splittings

- Attempt to select hardest k_T **directly** via Dynamical Grooming (DyG)
 - Grooming cutoff depends on jet properties
 - Can **change hardness measure** via parameter
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 - Use $a = 0.5, 1 (k_T), 2 (t)$
- Also measure with Soft Drop, $z_{\text{cut}} > 0.2$
- To measure $k_{T,g}$ (or other observables) in AA, need to deal with:
 - Subleading** subjet purity
 - Off-diagonal components** in the response



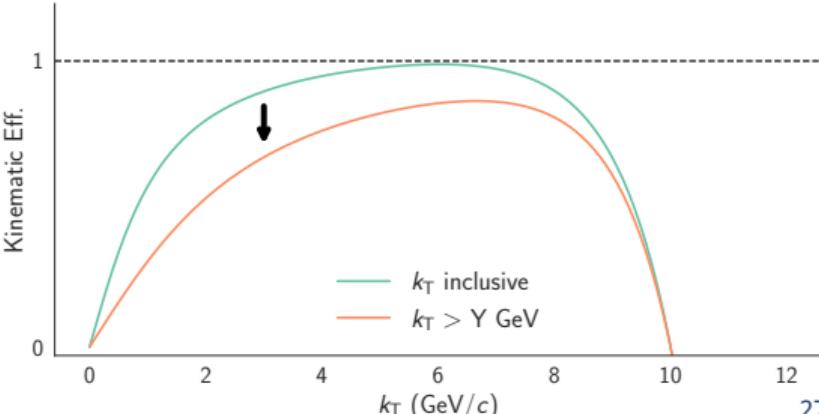
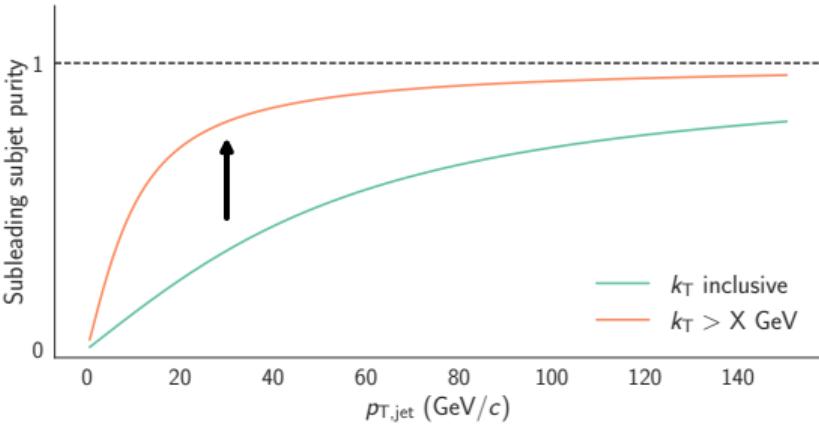
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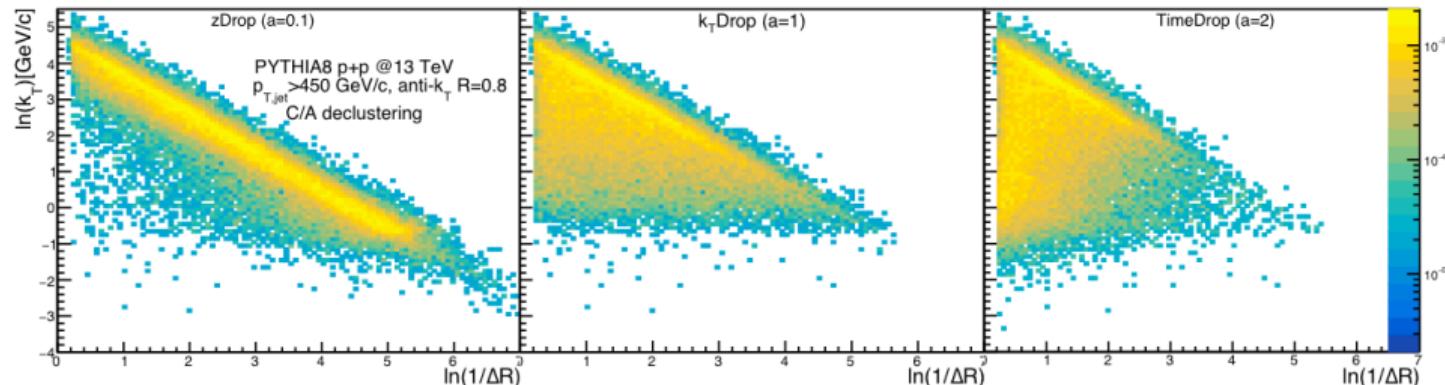


Using DyG for hardest $k_{T,g}$ splittings in Pb-Pb

- Subleading subjet purity must be **sufficiently high** to unfold
- Mismatched splittings** are major component of low k_T splittings
- Minimum k_T** requirement increases purity
- Sketch illustrates effects on purity and kinematic efficiency
 - Optimization problem
- Off-diagonal response components are driven by mismatch of subjet to low k_T
 - Reduced** via minimum k_T requirement
- Minimum z (SoftDrop) has **similar impact** for sufficiently small background (eg. smaller R)



Varying Dynamical Grooming hardness parameter



Mehtar-Tani et al., [PhysRevD.101.034004](#)