Exploring QCD with Jet Substructure Measurements

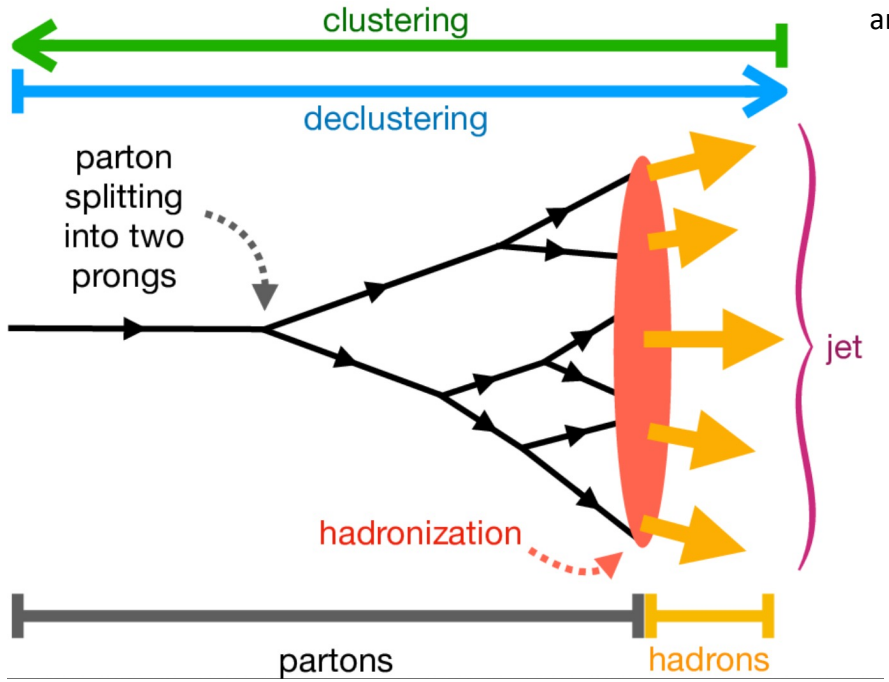
Workshop of the APS Topical Group on Hadronic Physics 2025

Dhanush Hangal

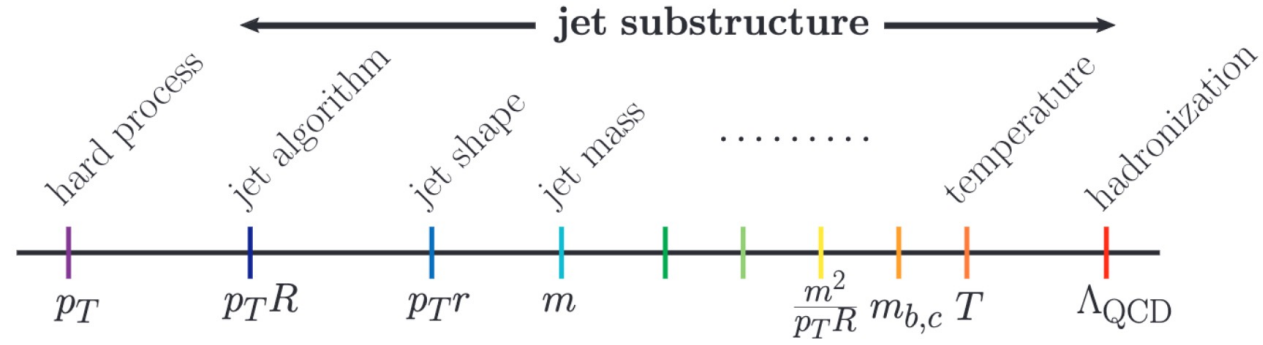
March 15, 2025

Why Jets?

- Jets are rich objects whose formation involves rich QCD dynamics



arXiv:2303.13347



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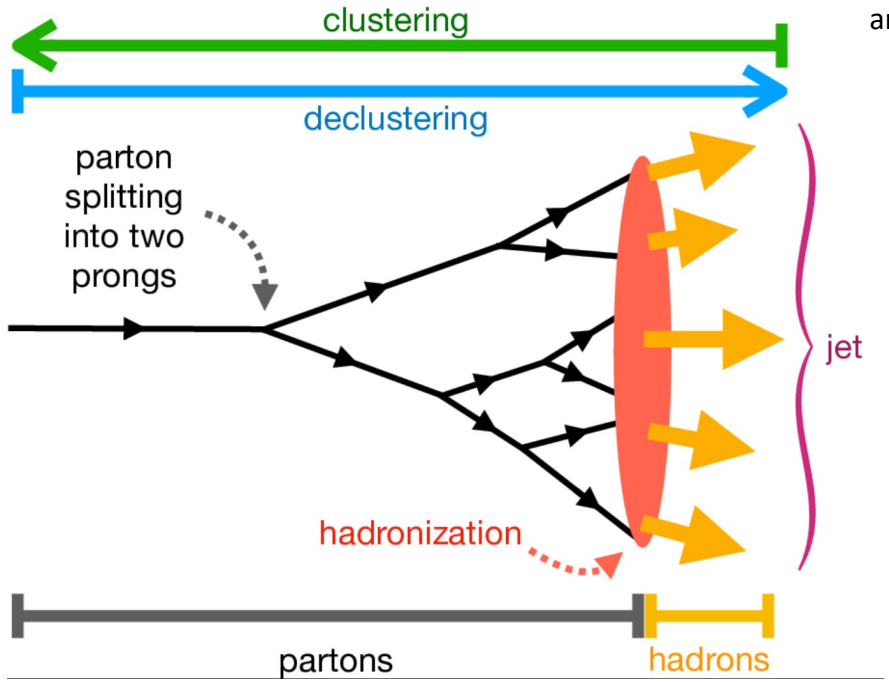
QM'19

Jet Substructure: Powerful tools in QCD

- Jets are rich objects whose formation involves rich QCD dynamics
- Jet Substructure first used to tag and differentiate boosted objects from QCD jets



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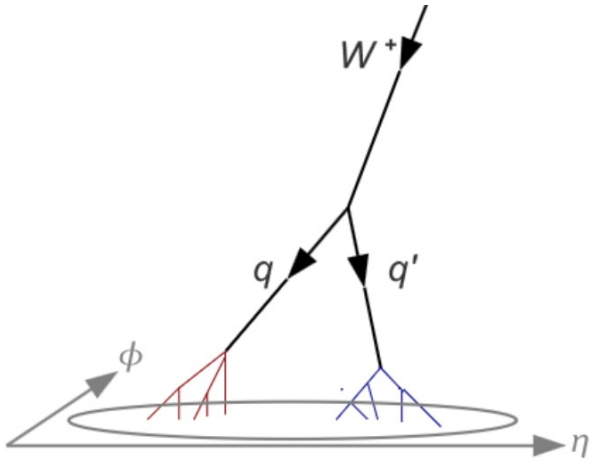
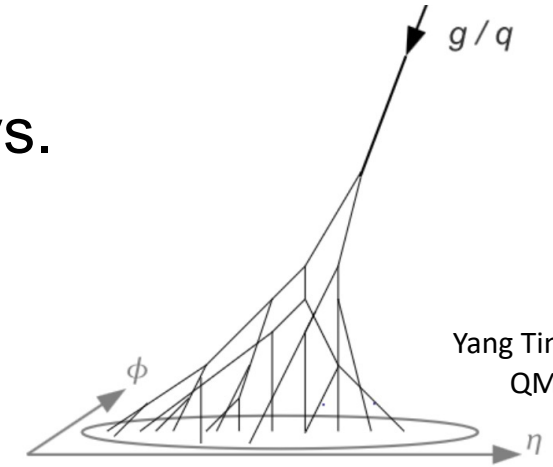
JHEP 1103:015.2011



vs.



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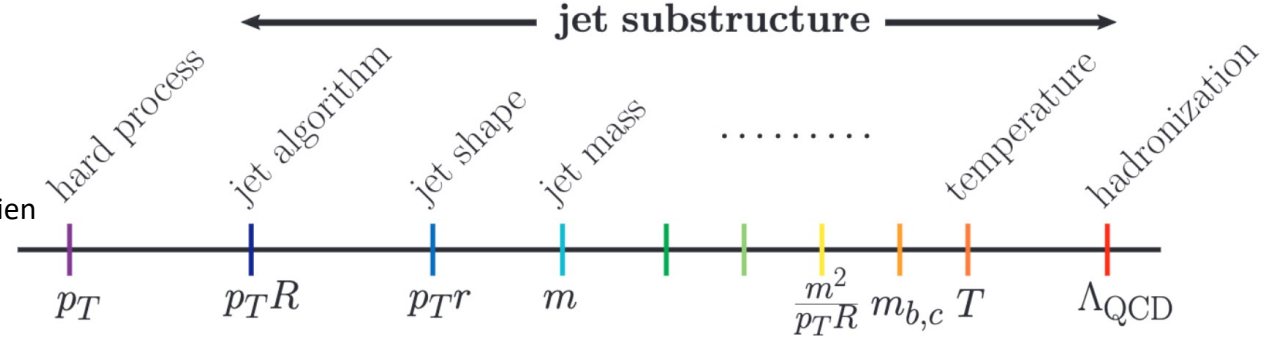
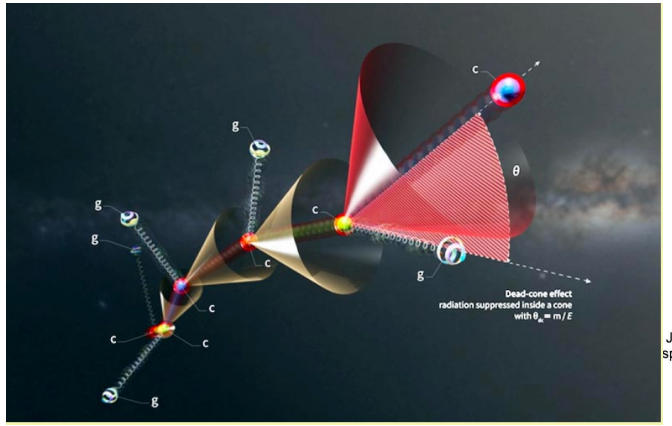
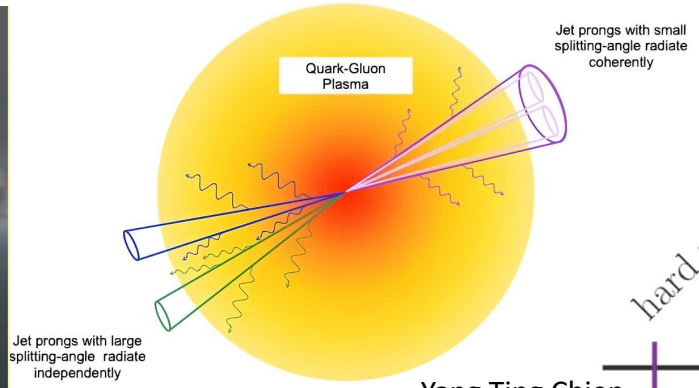


Jet Substructure: Powerful tools in QCD

- Jets are rich objects whose formation involves rich QCD dynamics
- Jet Substructure first used to tag and differentiate boosted objects from QCD jets
- Jet substructure has since been critical in analyzing and studying
  - Parton Showers and hadronization processes
  - Heavy flavor physics
  - Quark-Gluon Plasma physics among many others!



[ALICE 2022]



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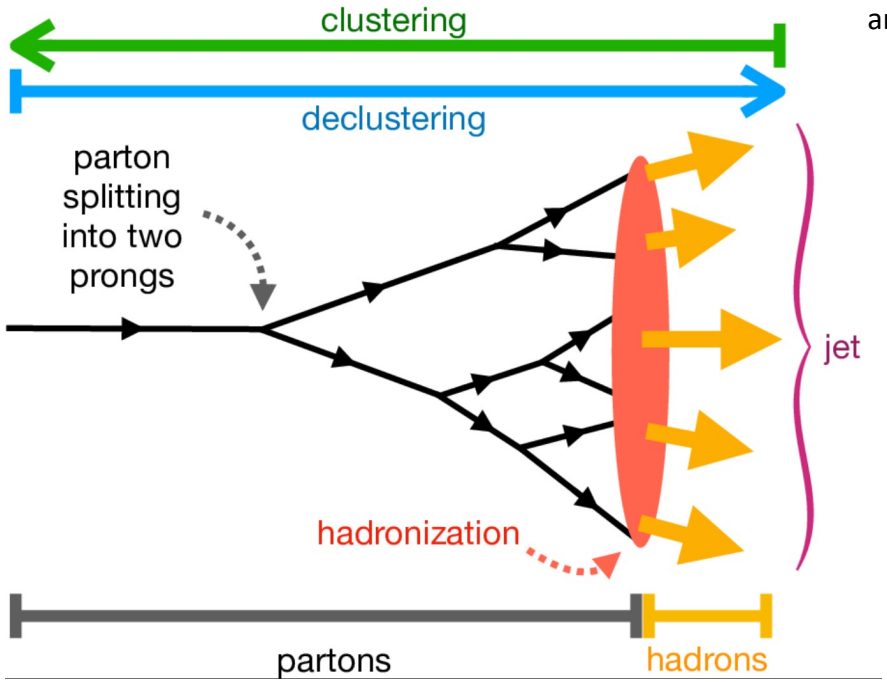
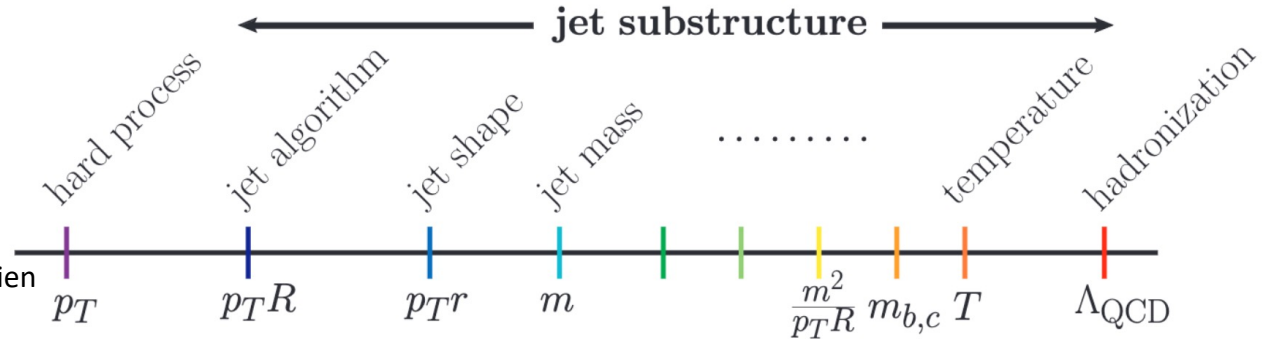
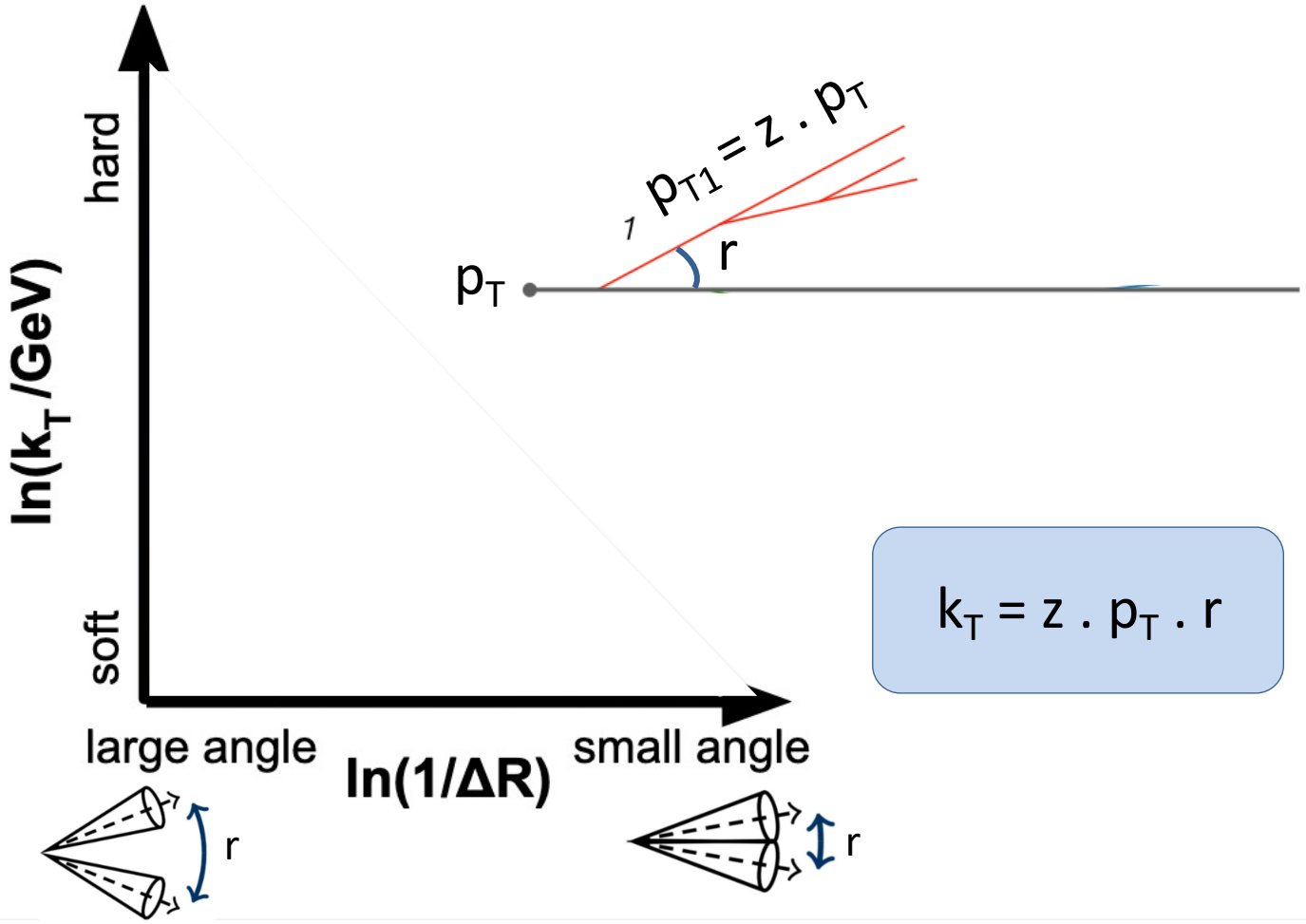




Mapping the Evolution of a Jet

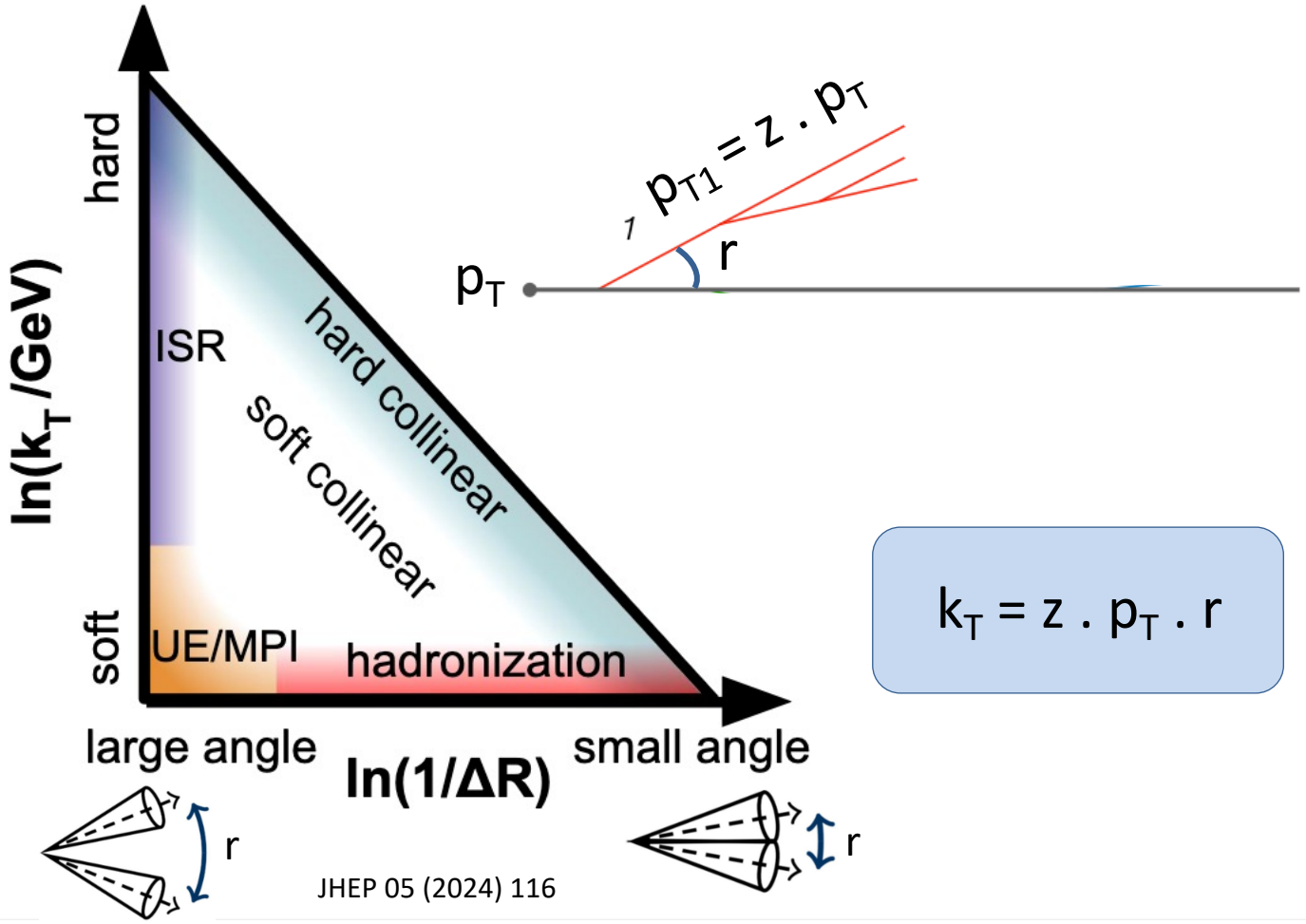
JHEP12(2018)064



$$k_T = z \cdot p_T \cdot r$$

The (Primary) Lund Jet Plane

JHEP12(2018)064



$k_T = z \cdot p_T \cdot r$

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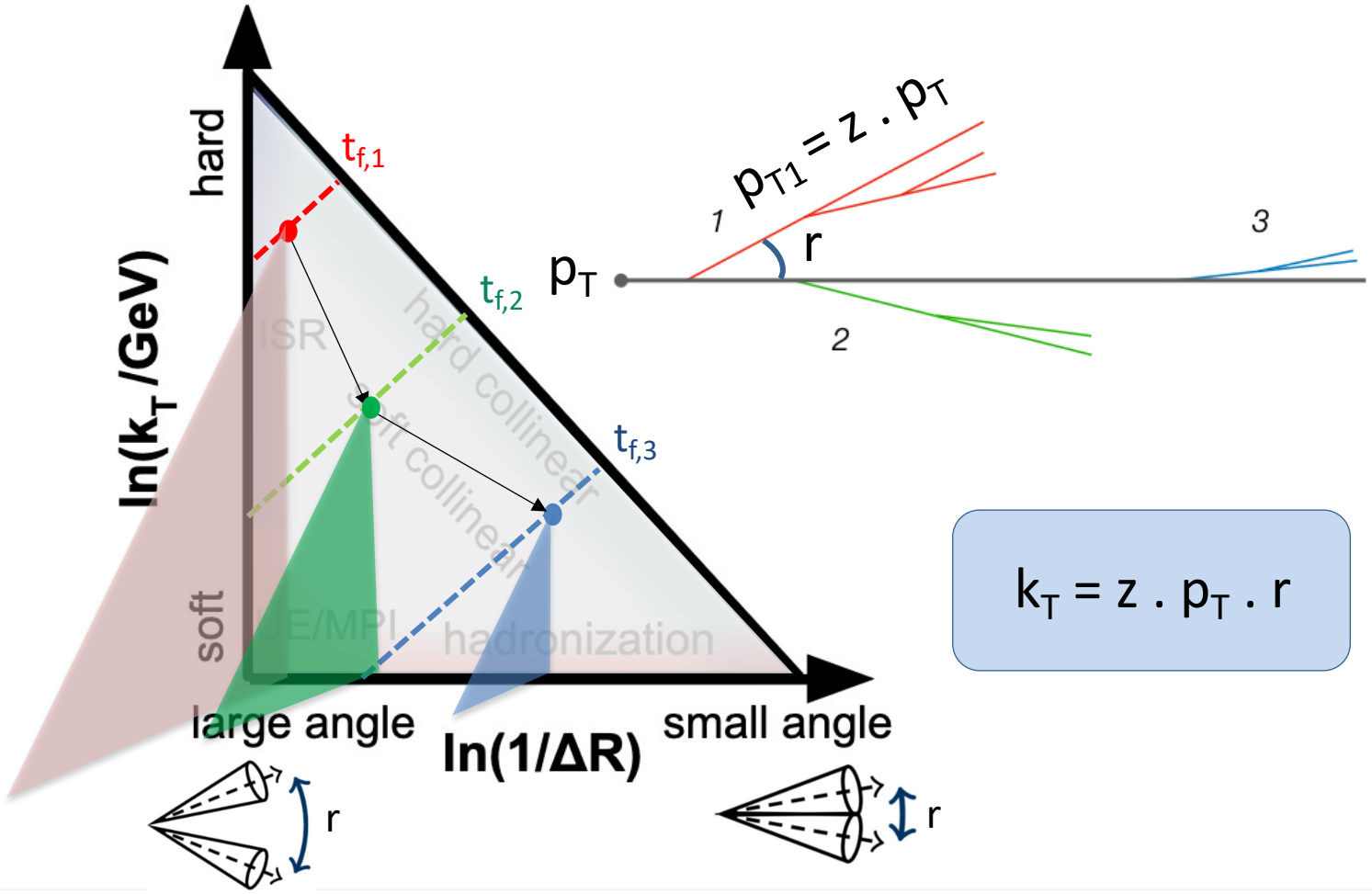
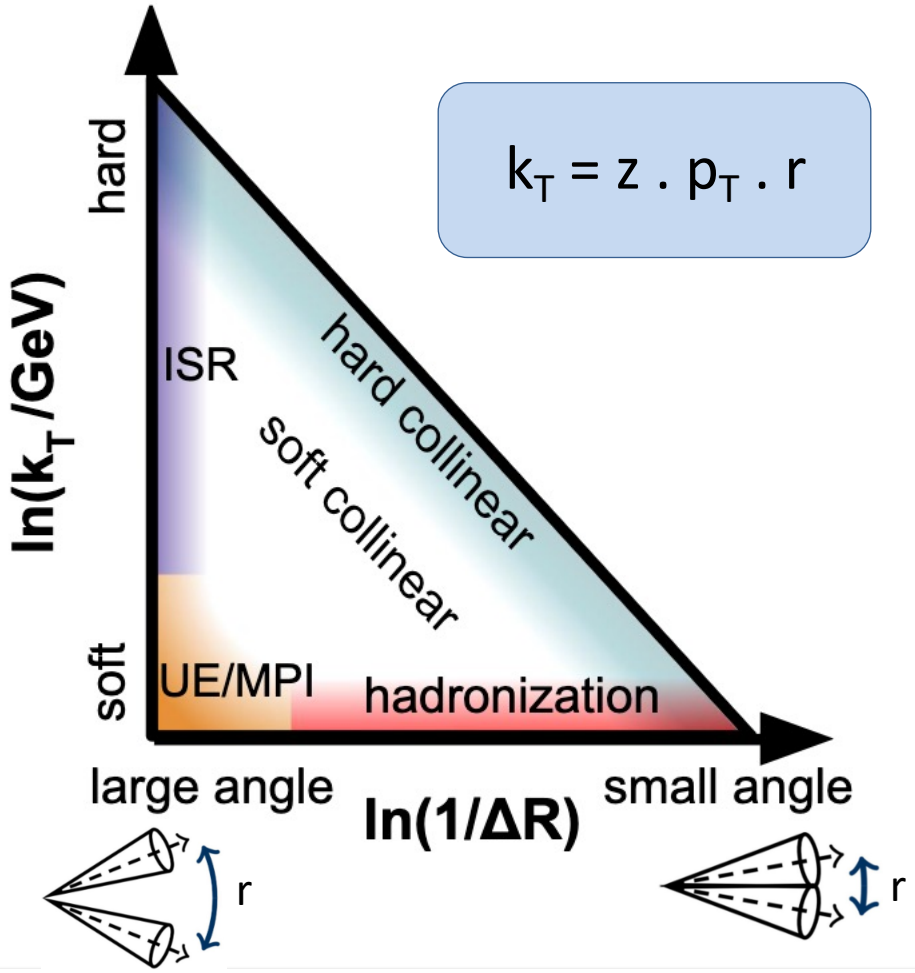
The Lund Jet Plane



Each given emission creates new phase space (a triangular leaf) for further emissions.

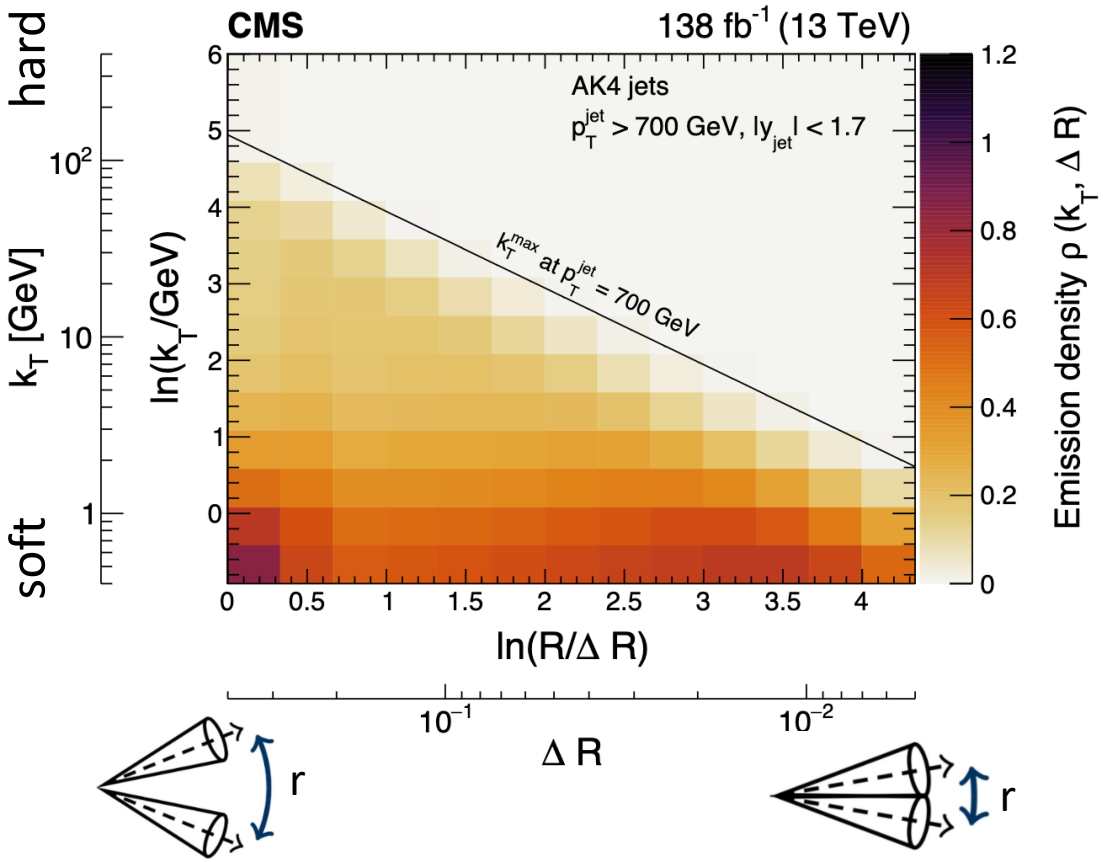
$$k_T = z \cdot p_T \cdot r$$

The Lund Jet Plane



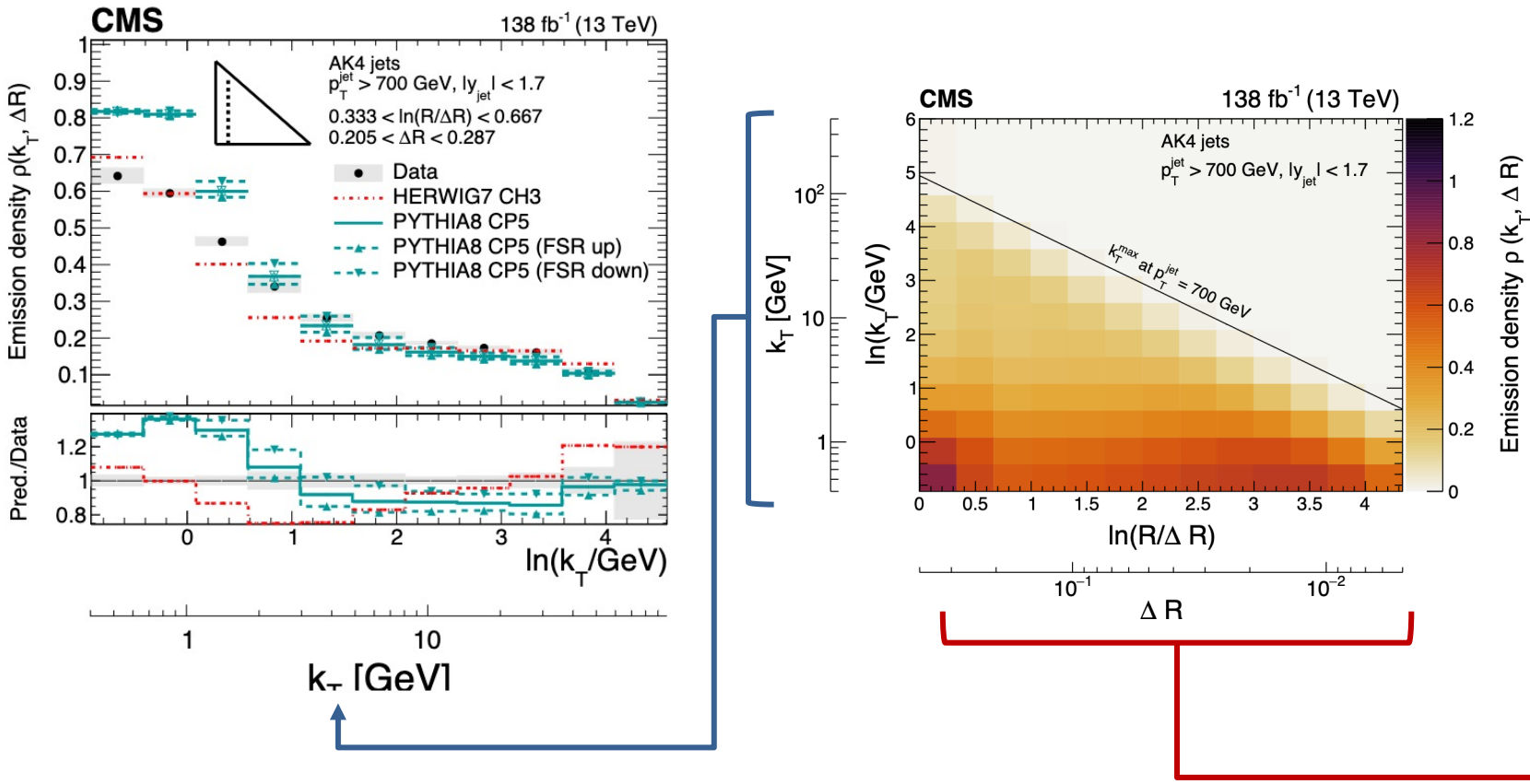
$k_T = z \cdot p_T \cdot r$

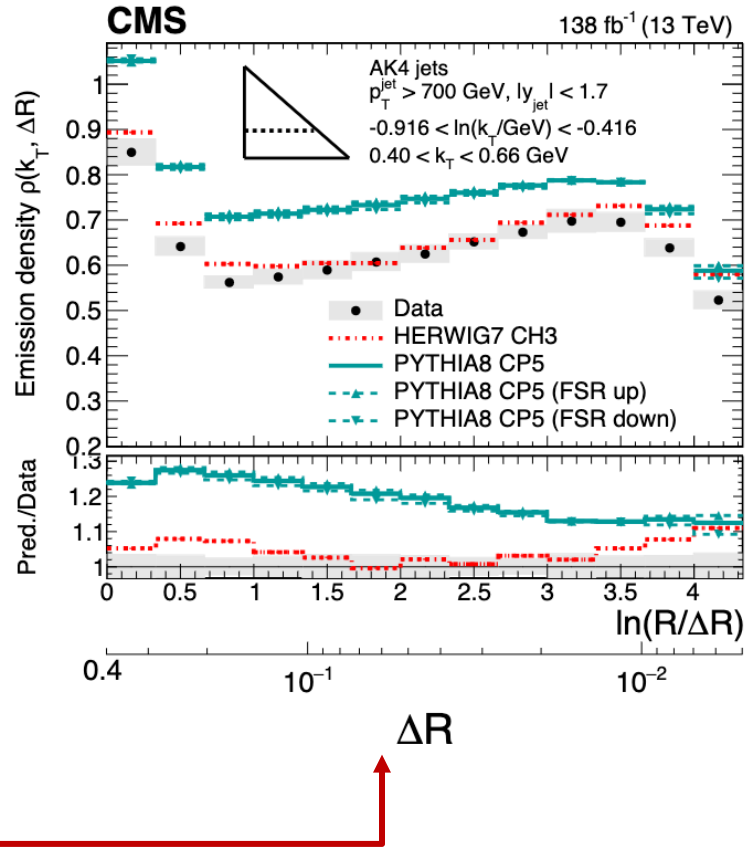
Unfolded measurements of the Primary Lund Jet plane in pp collisions



The Lund Jet Plane Projections

Unfolded measurements of the Primary Lund Jet plane in pp collisions





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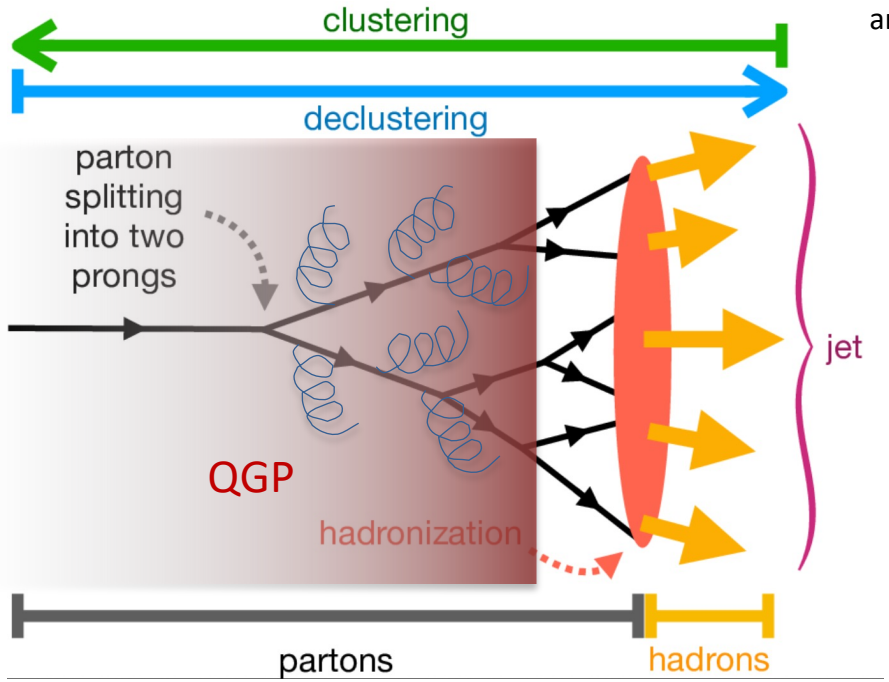
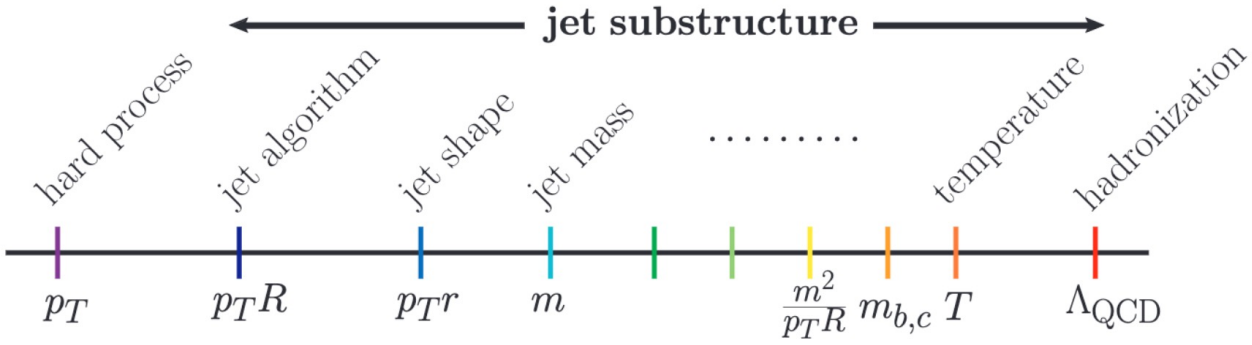
Jets in Heavy-Ion Collisions

- Collide nuclei at the LHC and RHIC to produce droplets of **hot, dense quark-gluon plasma**
- **Use jets as probes to study the properties of the QGP**



arXiv:2303.13347



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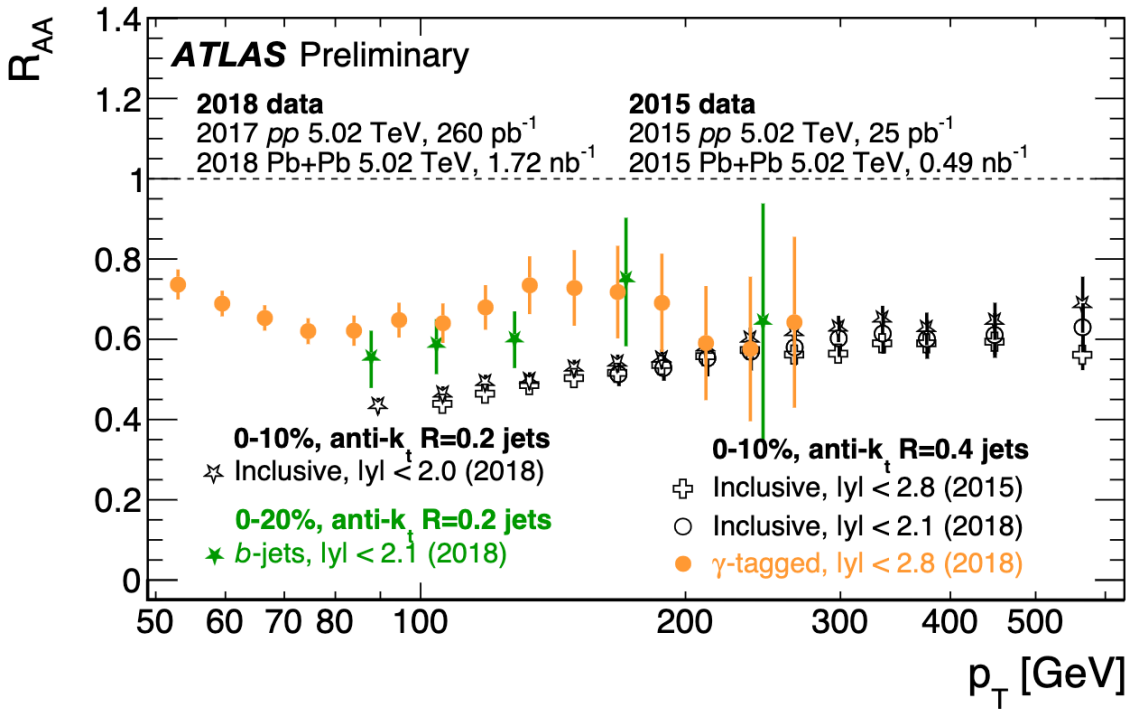
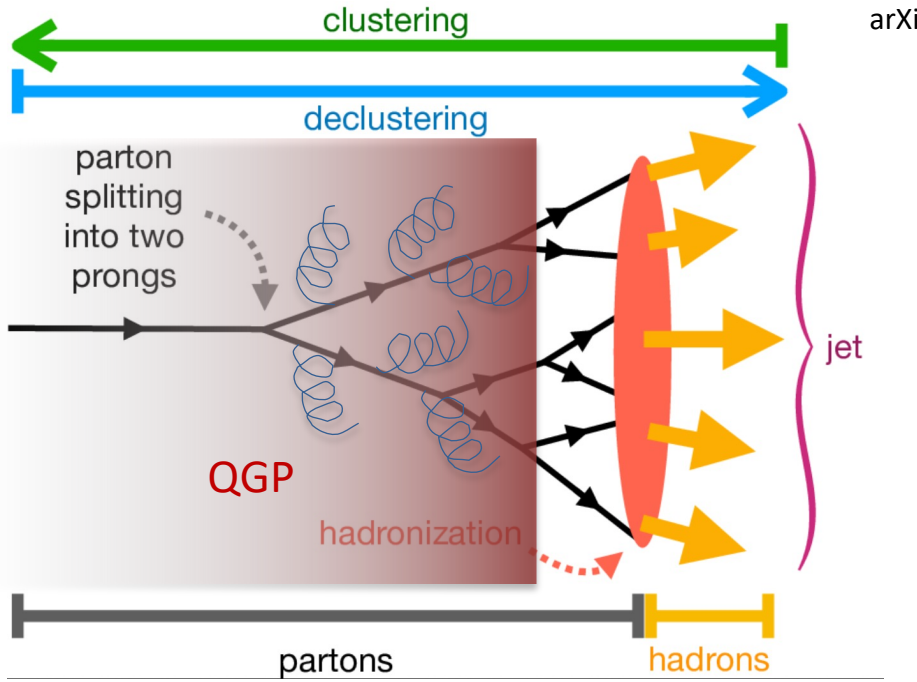


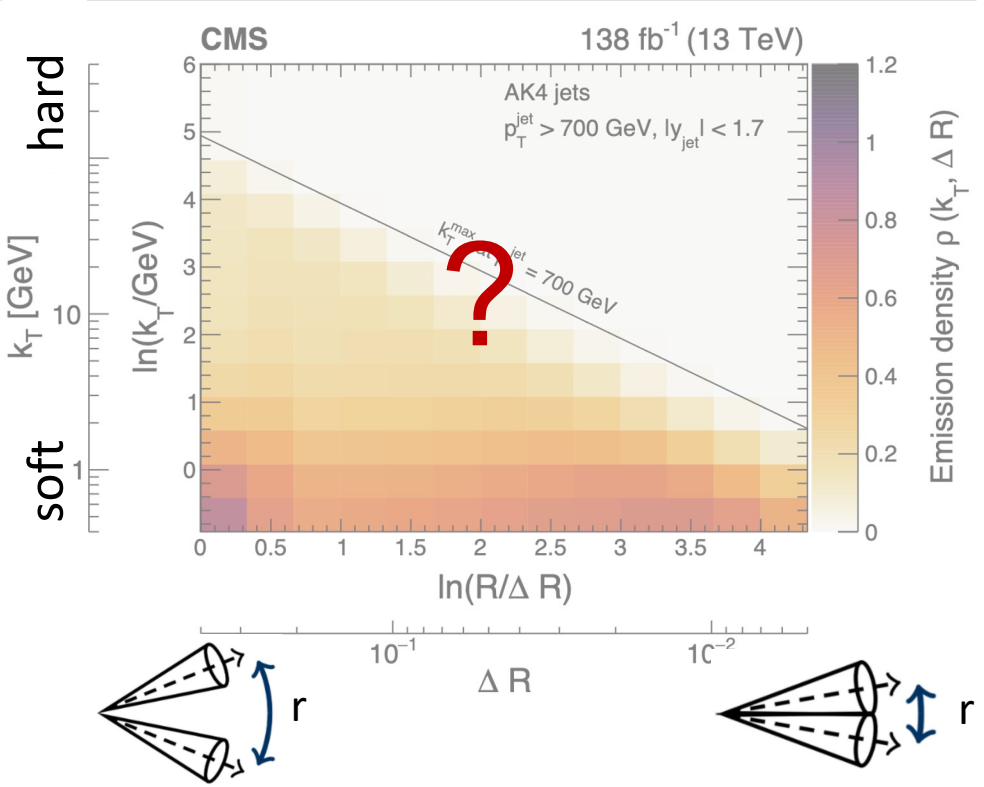


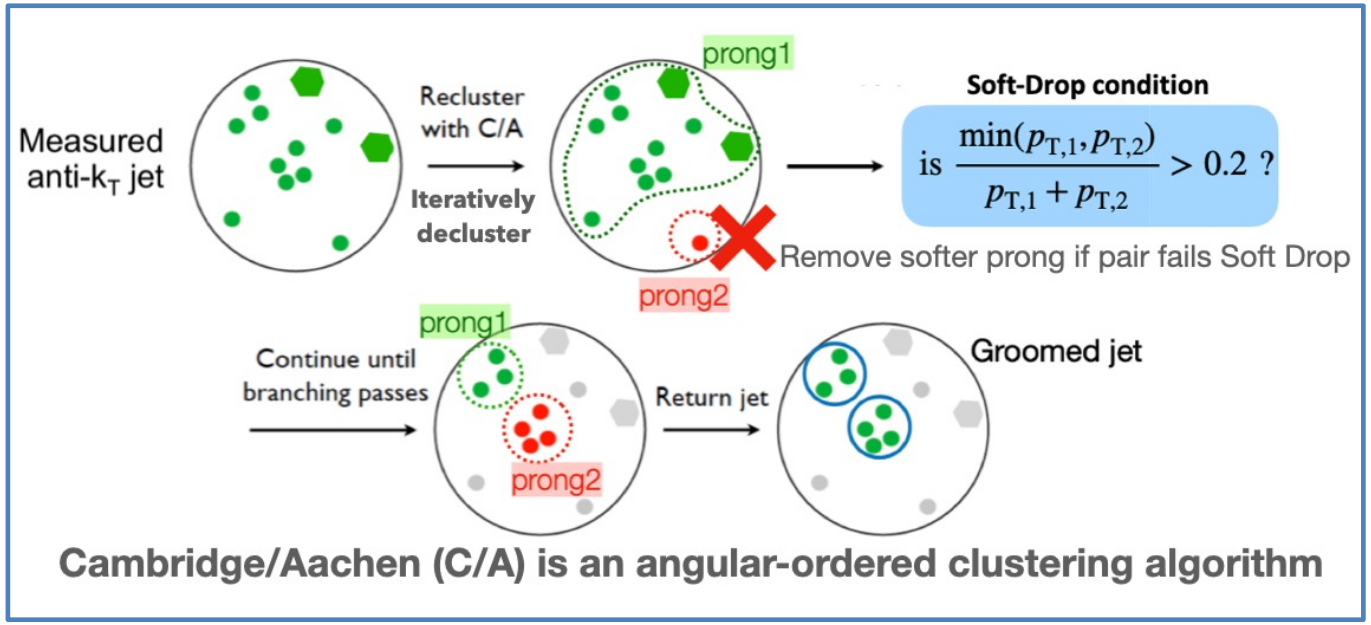
arXiv:2303.13347

$$R_{AA} = \frac{\text{per-NN yields in PbPb}}{\text{yields in } pp}$$

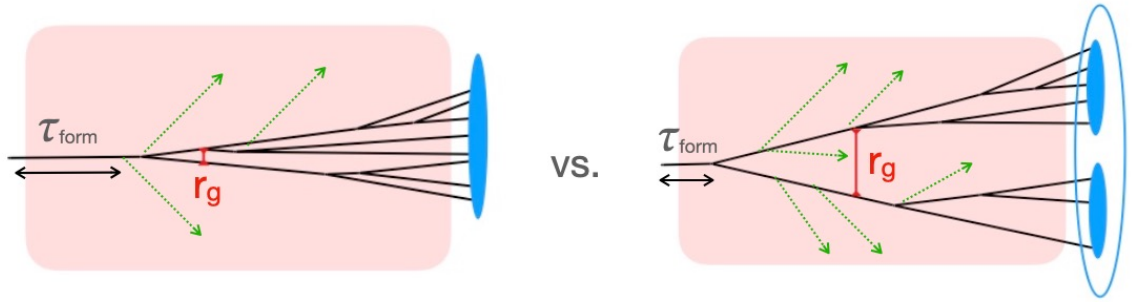
Jet Substructure in Heavy-Ion Collisions

What does the multiscale evolution of jets look like in presence of the QGP?



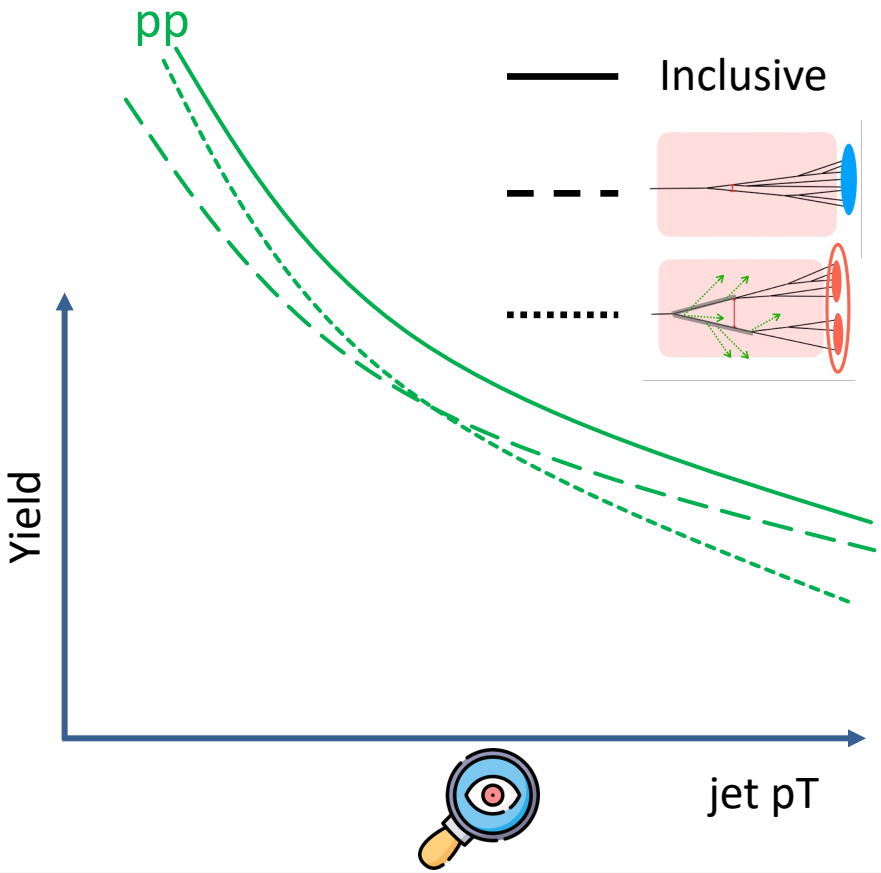


Can the medium resolve splittings below a threshold angle?



ATLAS : r_g yield in pp

The r_g distributions are observed to peak at lower values of r_g with increasing jet p_T



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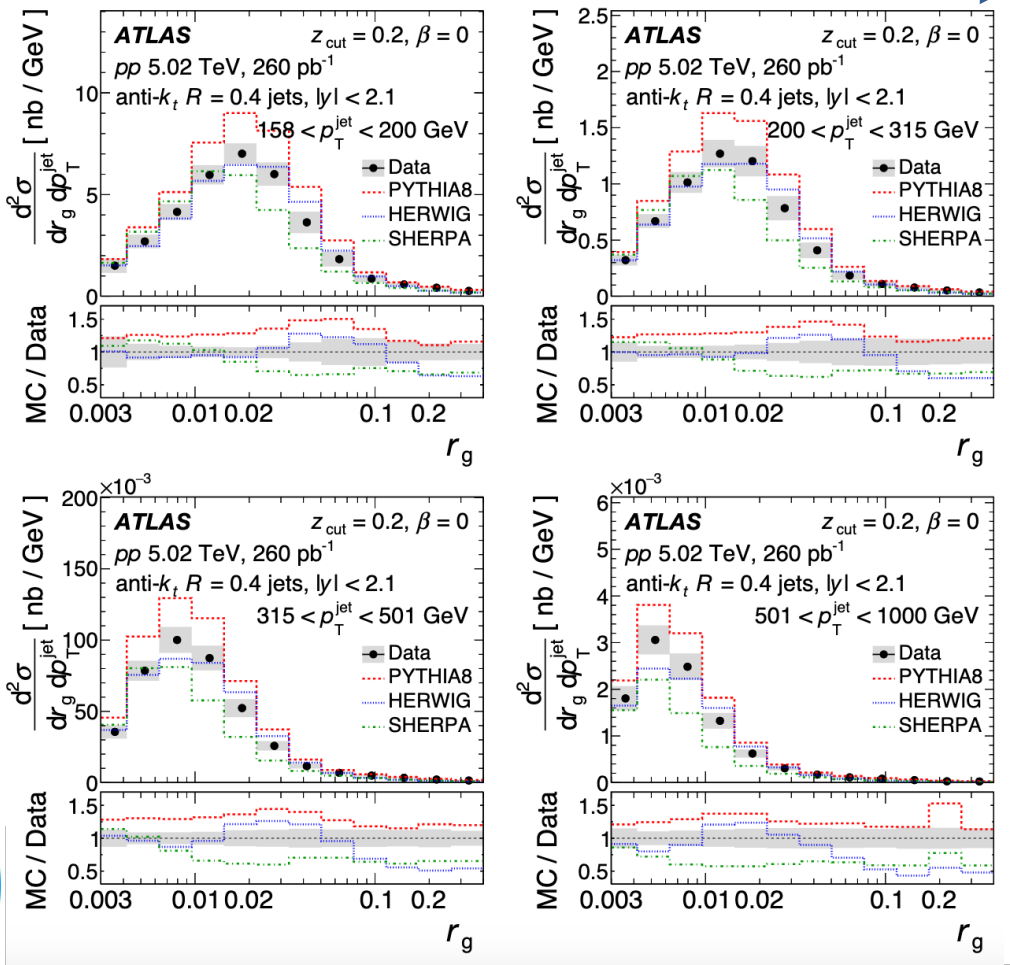
Increasing jet p_T

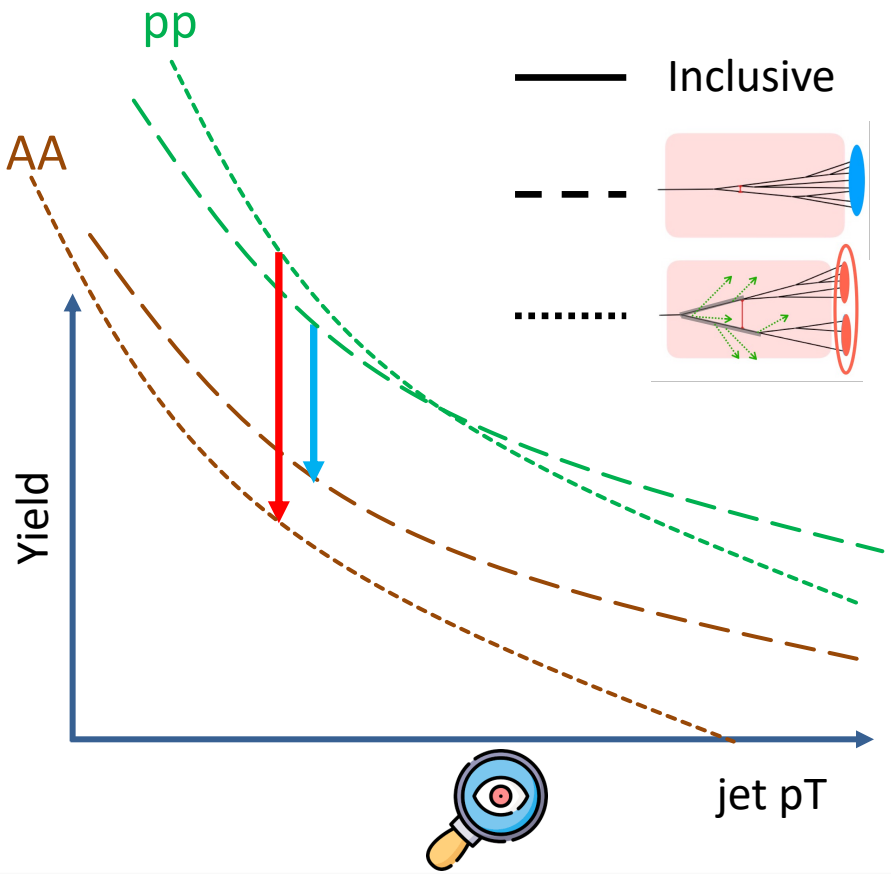
Increasing jet p_T

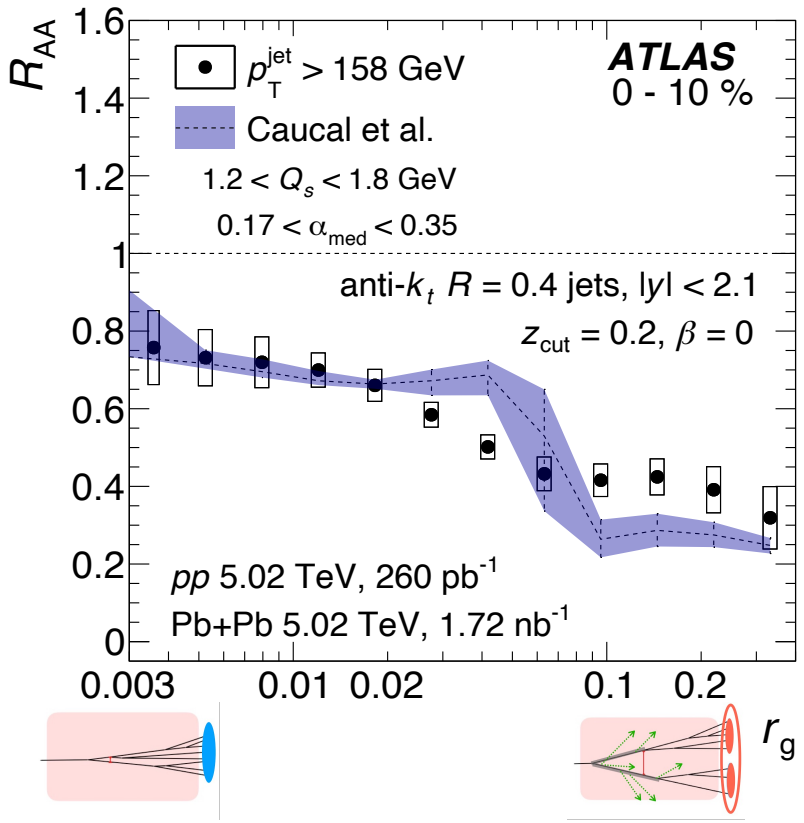


ATLAS : R_{AA} vs. r_g

$$R_{AA} = \frac{\text{per-NN yields in PbPb}}{\text{yields in } pp}$$

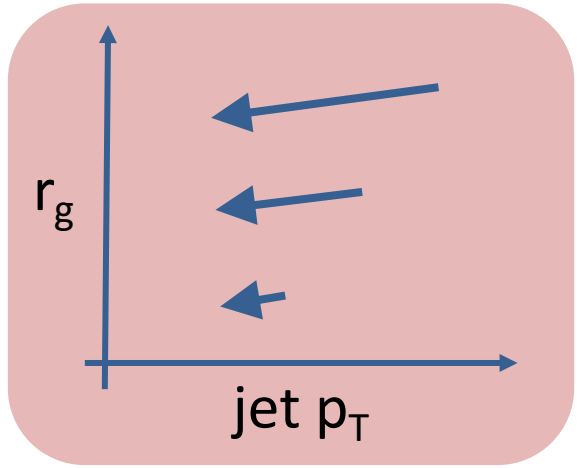
- The R_{AA} value is observed to depend significantly on jet r_g
- Jets with largest r_g are twice as suppressed as those with the smallest r_g in central Pb+Pb collisions





Soft-Drop condition

$$z_g = \frac{min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut}(R_g/R_{jet})^{\beta}$$



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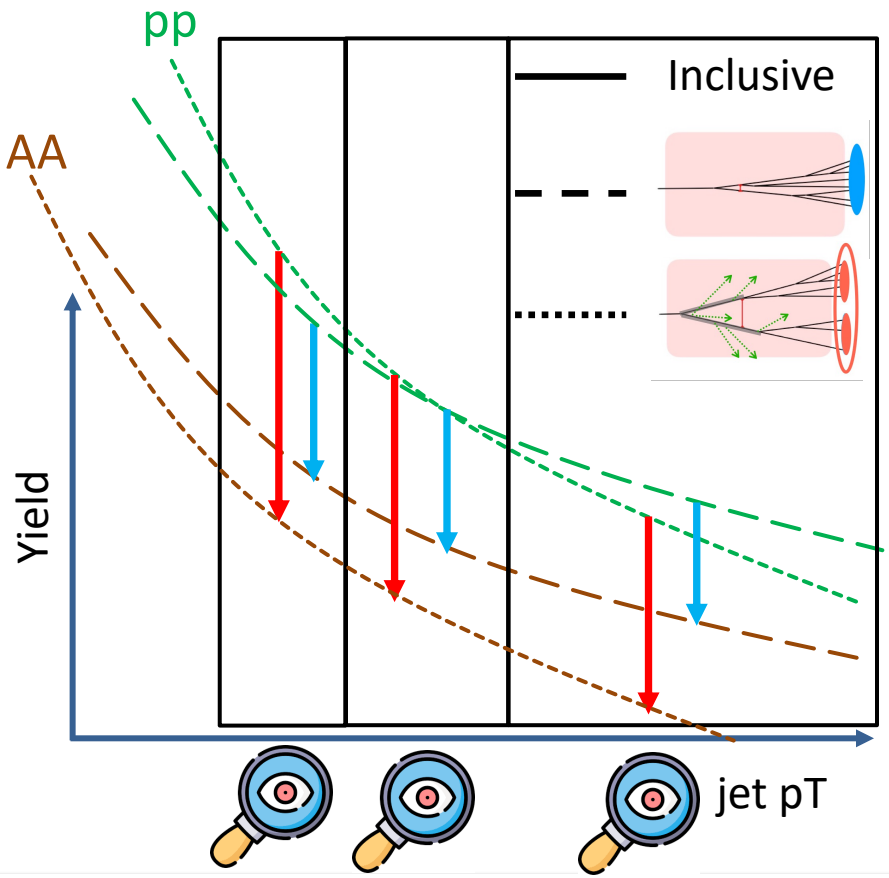
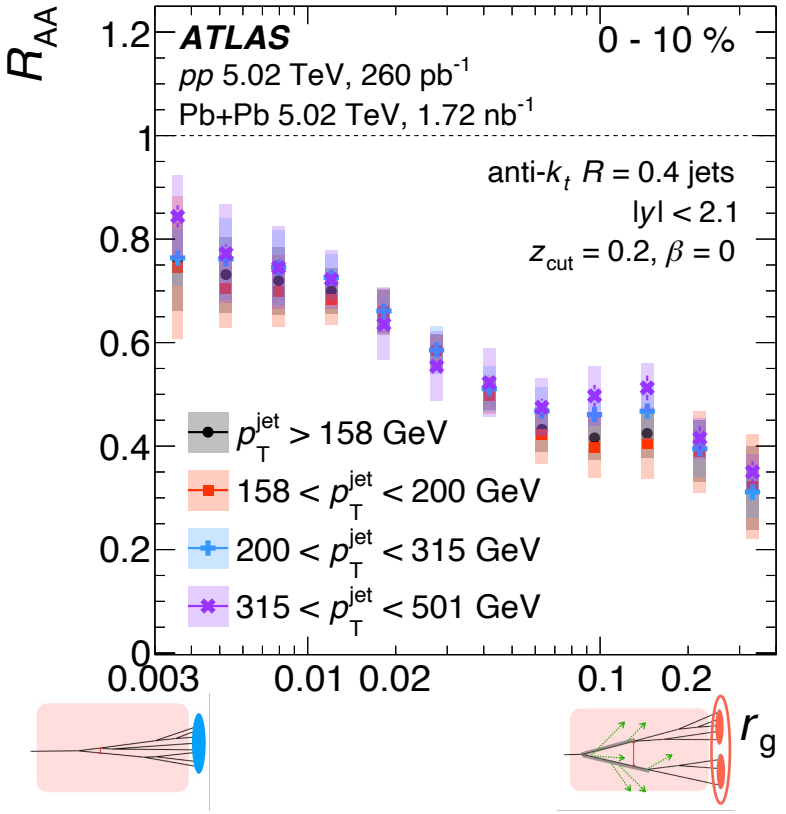
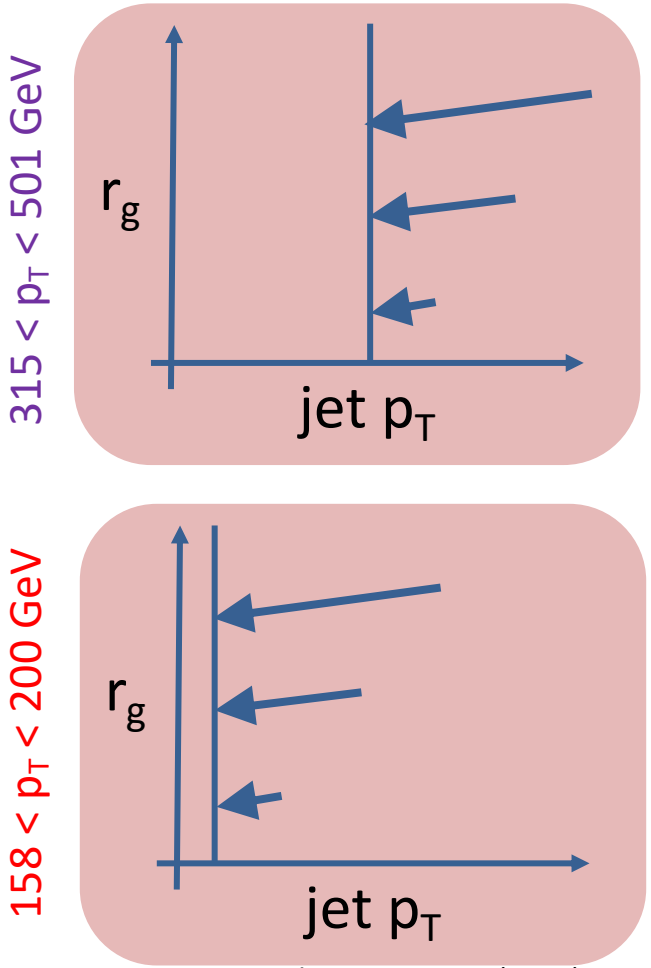
ATLAS : R_{AA} vs. (r_g and jet p_T)

$$R_{AA} = \frac{\text{per-NN yields in PbPb}}{\text{yields in } pp}$$

The R_{AA} values do not exhibit a strong variation with jet p_T in any of the r_g intervals







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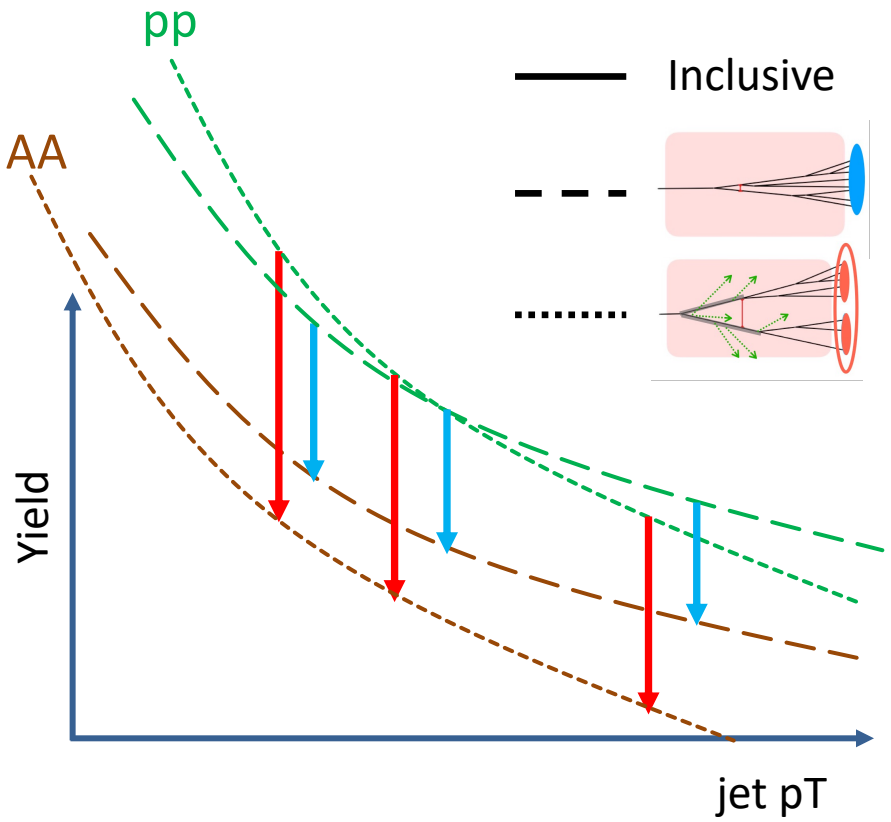
ATLAS : R_{AA} vs. (r_g and jet p_T)

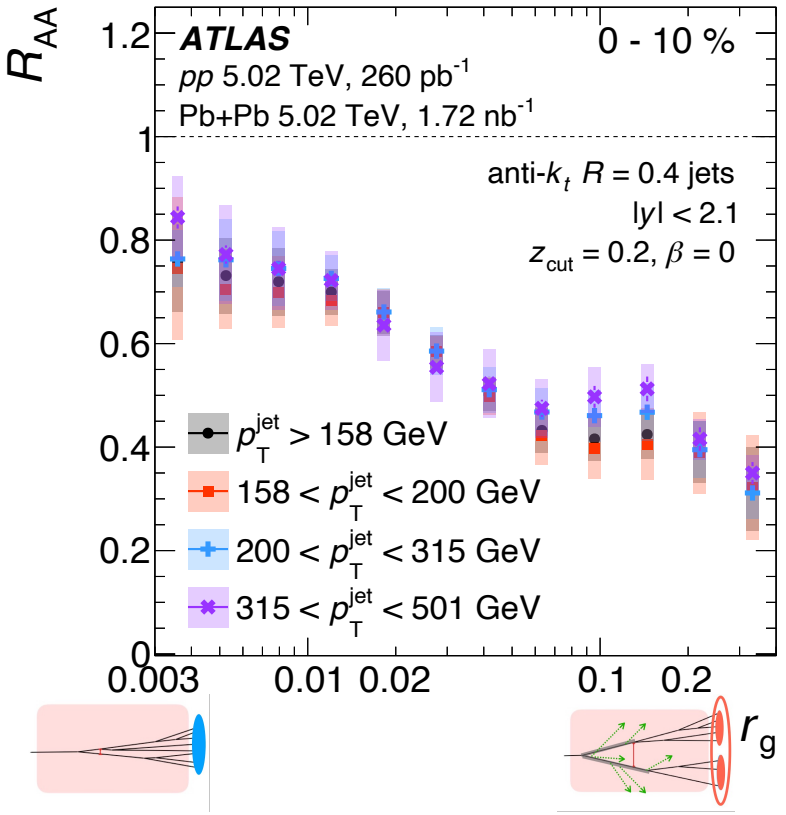
$$R_{AA} = \frac{\text{per-NN yields in PbPb}}{\text{yields in } pp}$$

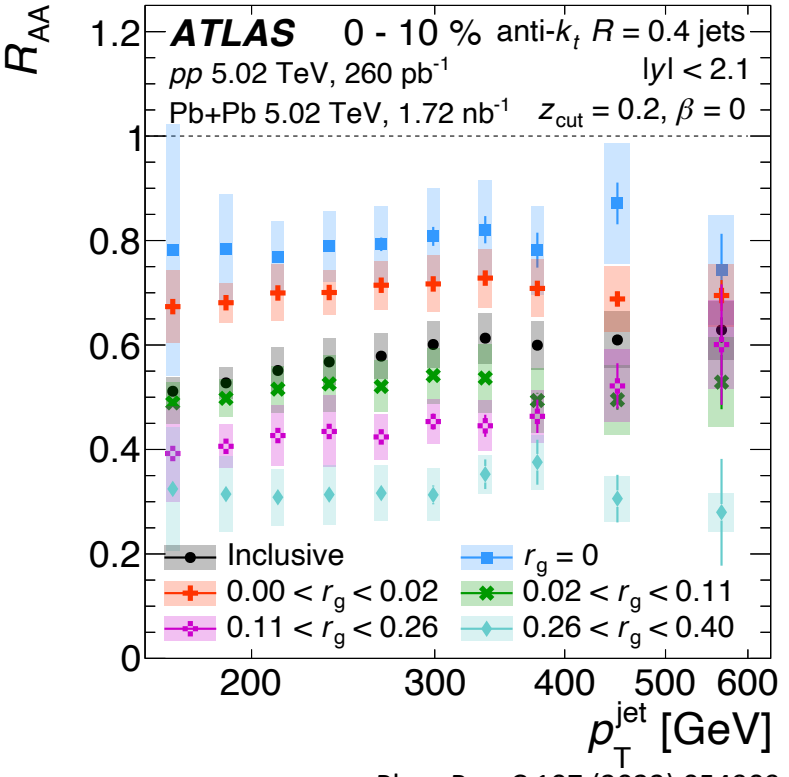
The R_{AA} is observed to have a clear ordering with respect to the splitting angle r_g

Soft-Drop condition

$$z_g = \frac{min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut}(R_g/R_{jet})^{\beta}$$







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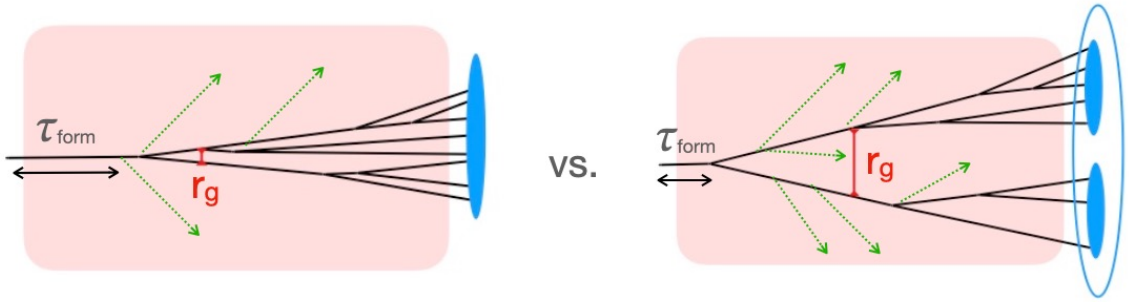
Formation time

$$R_{AA} = \frac{\text{per-NN yields in PbPb}}{\text{yields in } pp}$$

Look at formation time (τ) to select jets with different degrees of quenching without biasing their initial pT

Formation time

$$\tau_{\text{form}} \simeq \frac{1}{2Ez_1z_2(1-\cos\theta_{12})}$$



Soft-Drop condition

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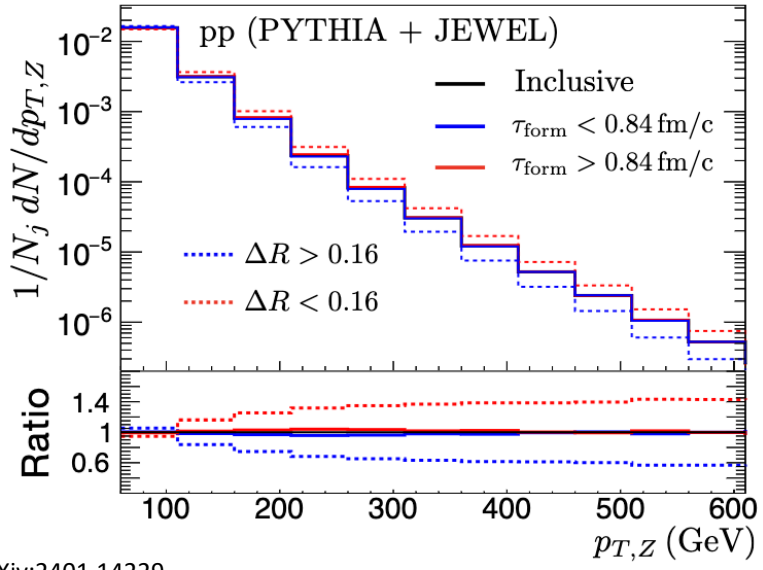
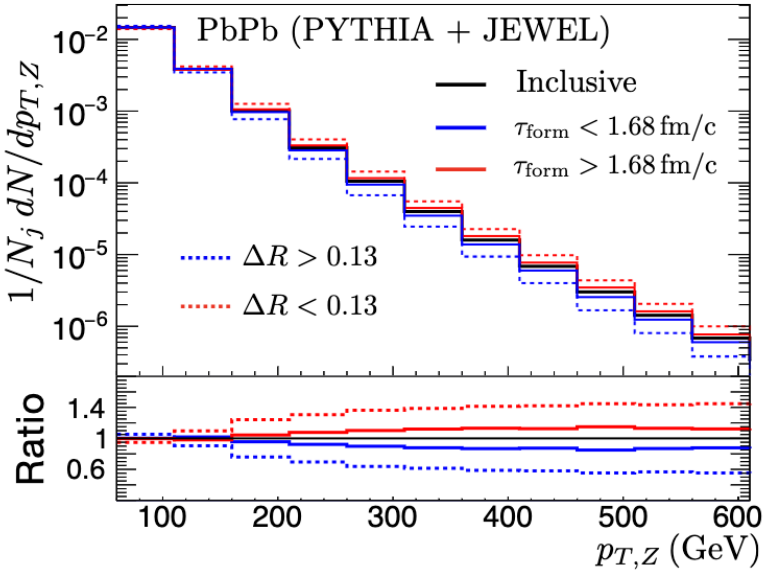
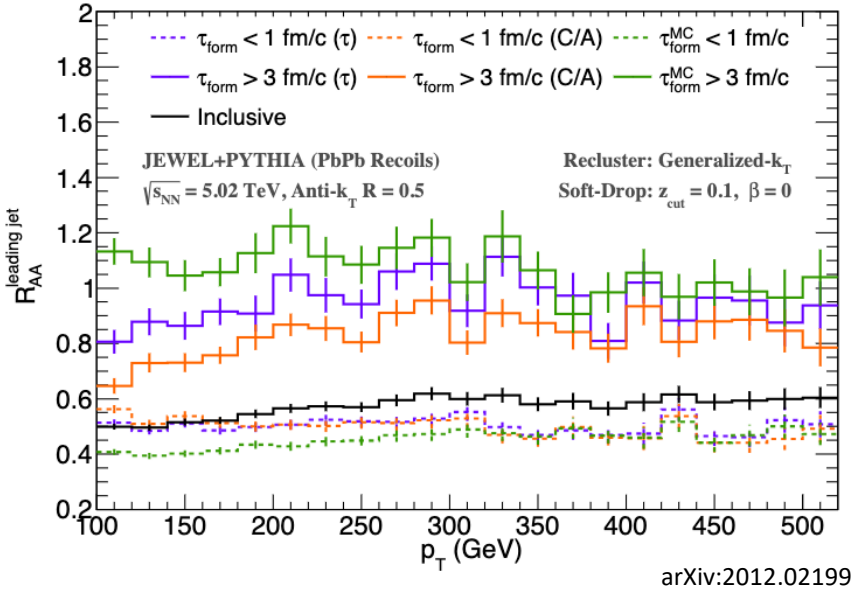




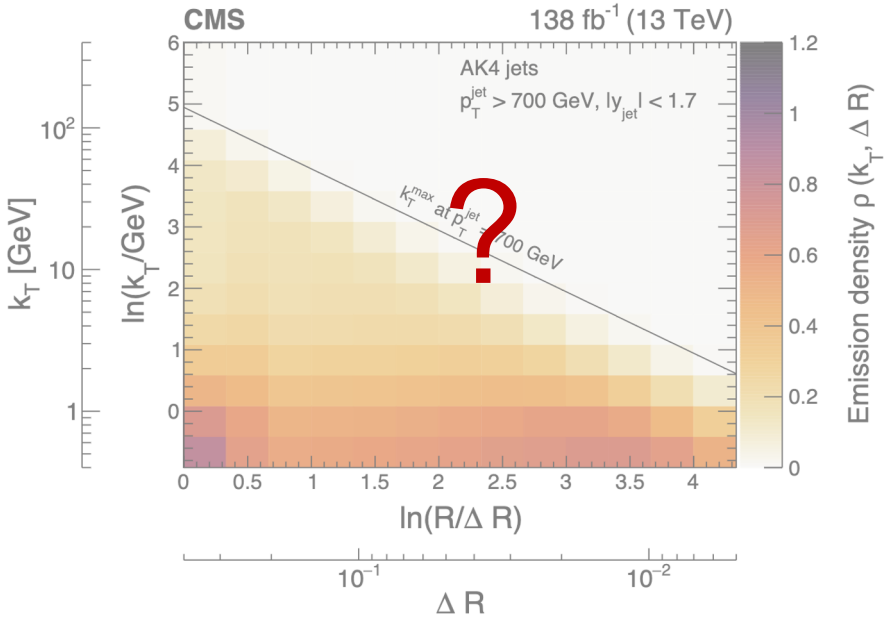


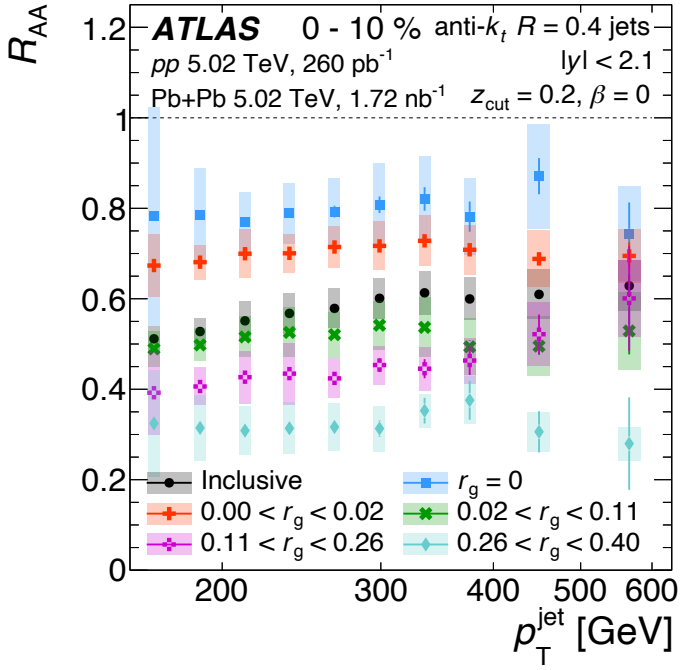
arXiv:2401.14229

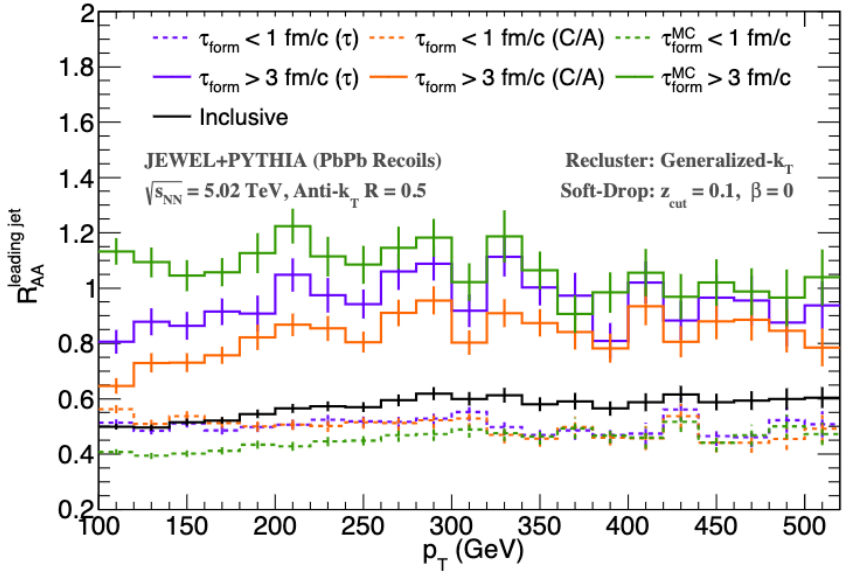
arXiv:2012.02199

Jet Substructure : Long Journey Ahead

- Jet evolution in a hot and dense QCD medium is a multiscale problem and requires a comprehensive characterization
- Need to better understand what we're measuring with the novel observables and analysis methods in the field







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