Jet Substructure : Selected Short Stories

2024 RHIC/AGS Annual Users' Meeting

Dhanush Hangal (he/him)

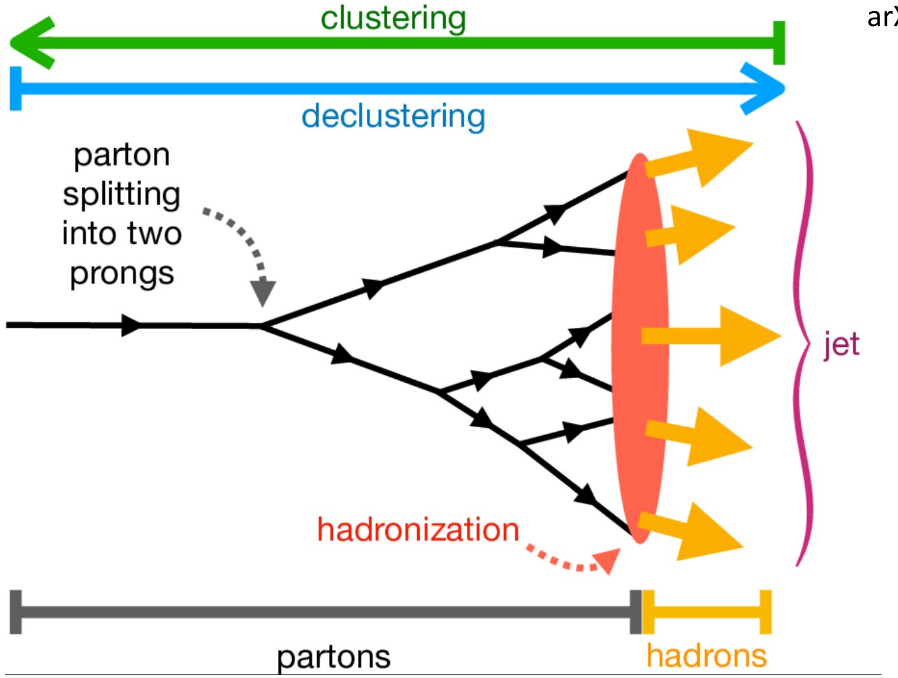
June 12, 2024

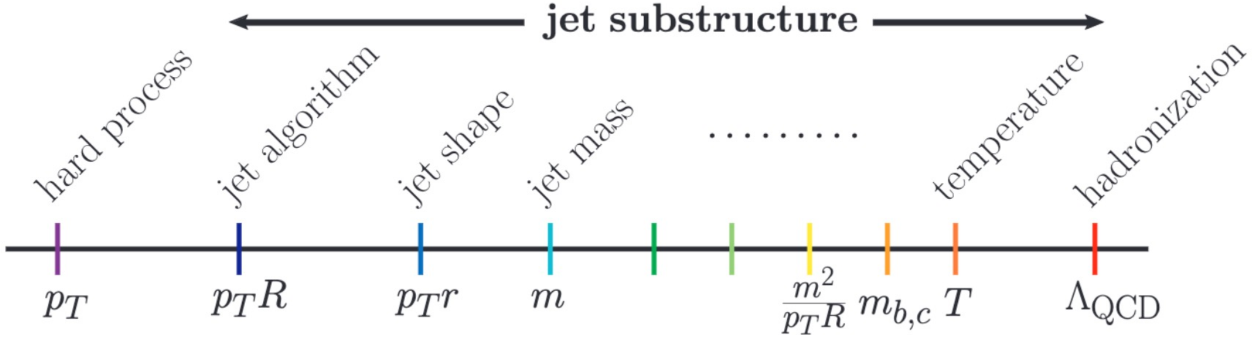
Lawrence Livermore National Laboratory

Why Jets?

- Jets are rich objects whose formation involves rich QCD dynamics

arXiv:2303.13347



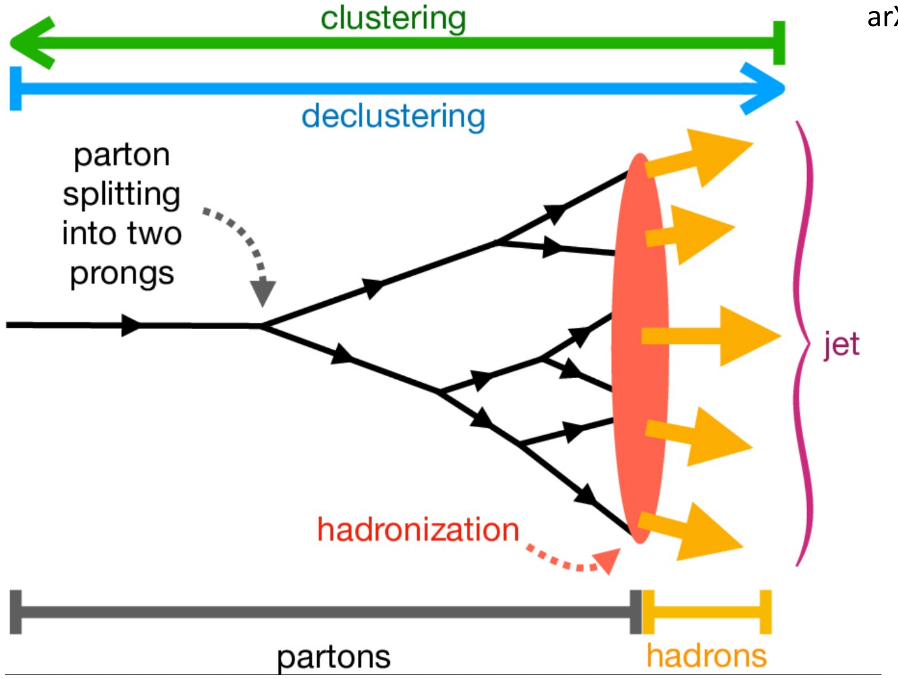


Yang Ting Chien
QM'19

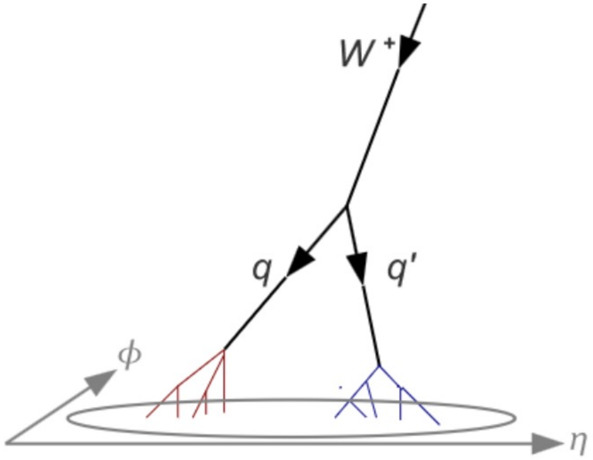
Jet Substructure: Powerful tools in QCD

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

arXiv:2303.13347



JHEP 1103:015.2011



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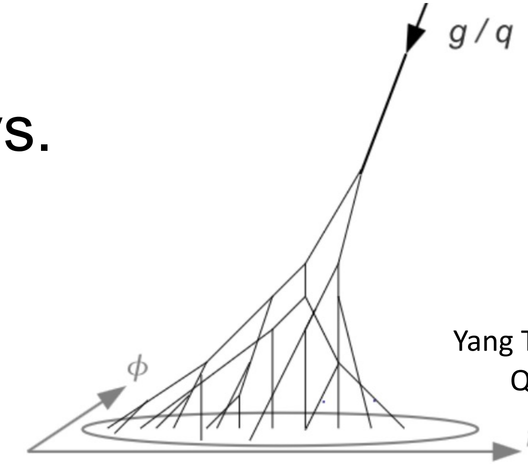

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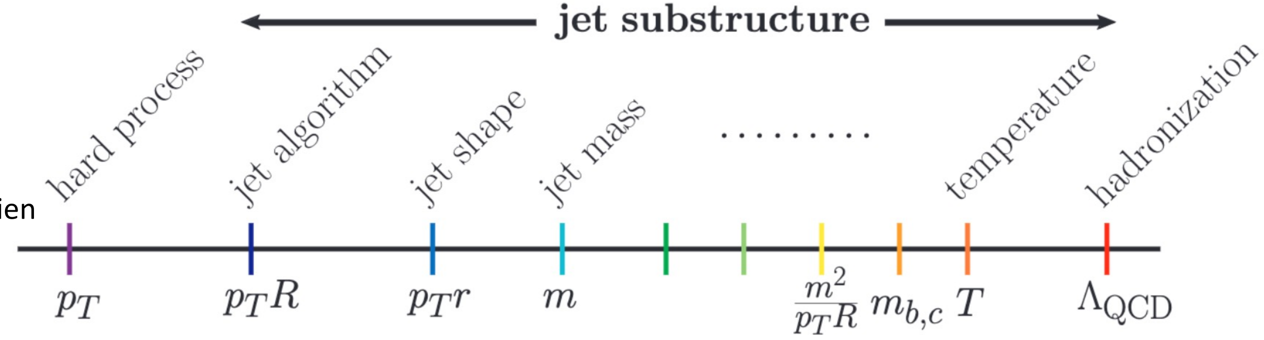
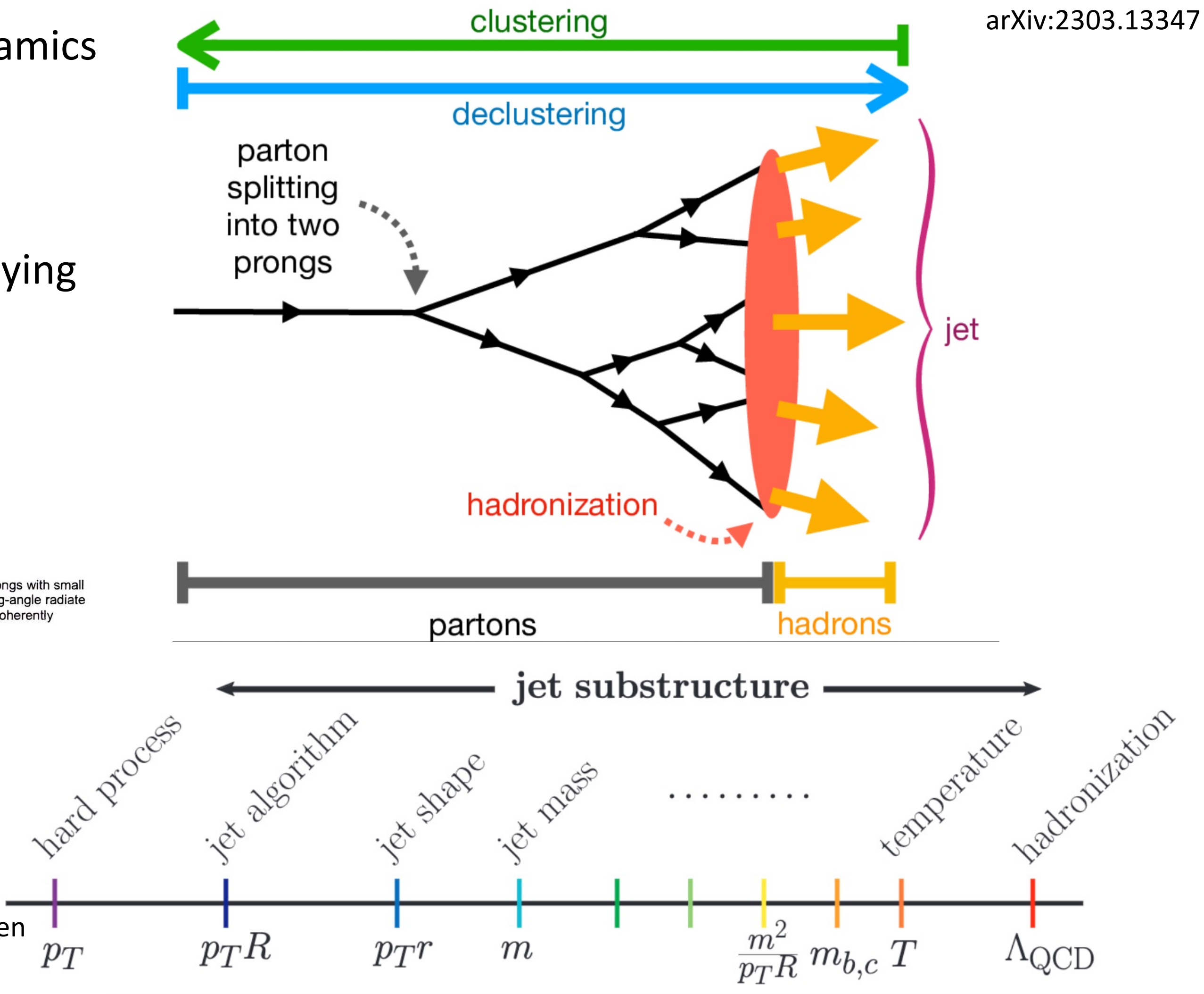
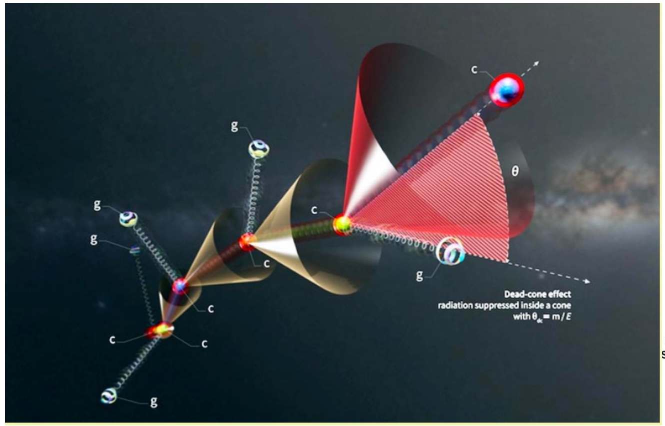


Jet Substructure: Powerful tools in QCD

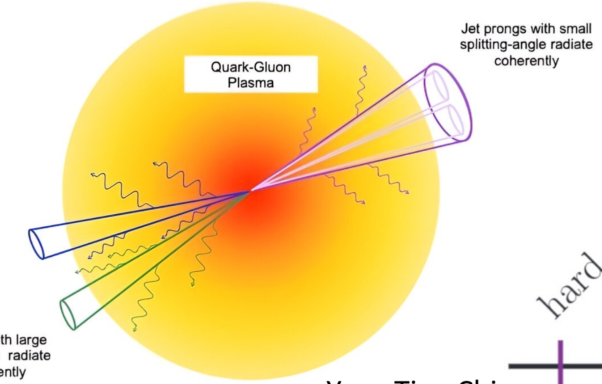
- Jets are rich objects whose formation involves rich QCD dynamics
- Jet Substructure first used to tag and differentiate boosted objects from QCD jets
- Jet substructure has since been critical in analyzing and studying
  - Parton Showers and hadronization processes
  - Heavy flavor physics
  - Quark-Gluon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

arXiv:2303.13347





[ALICE 2022]



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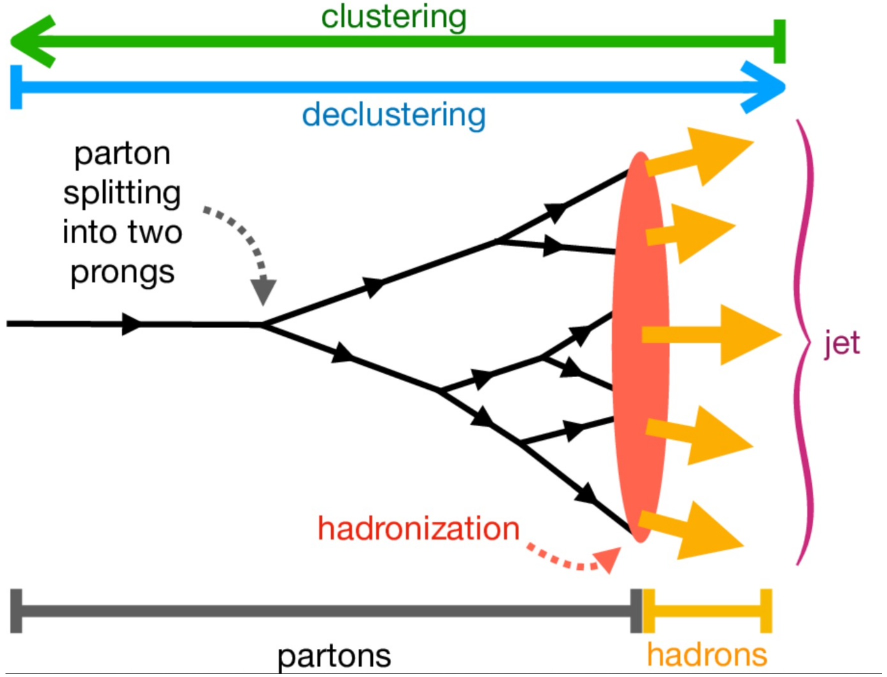
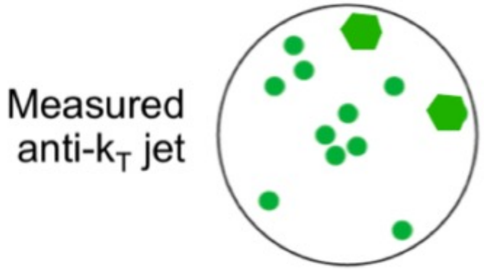
Jet Substructure: Grooming

- How can we make a jet robust against contamination from pileup and UE effects?

arXiv:2303.13347





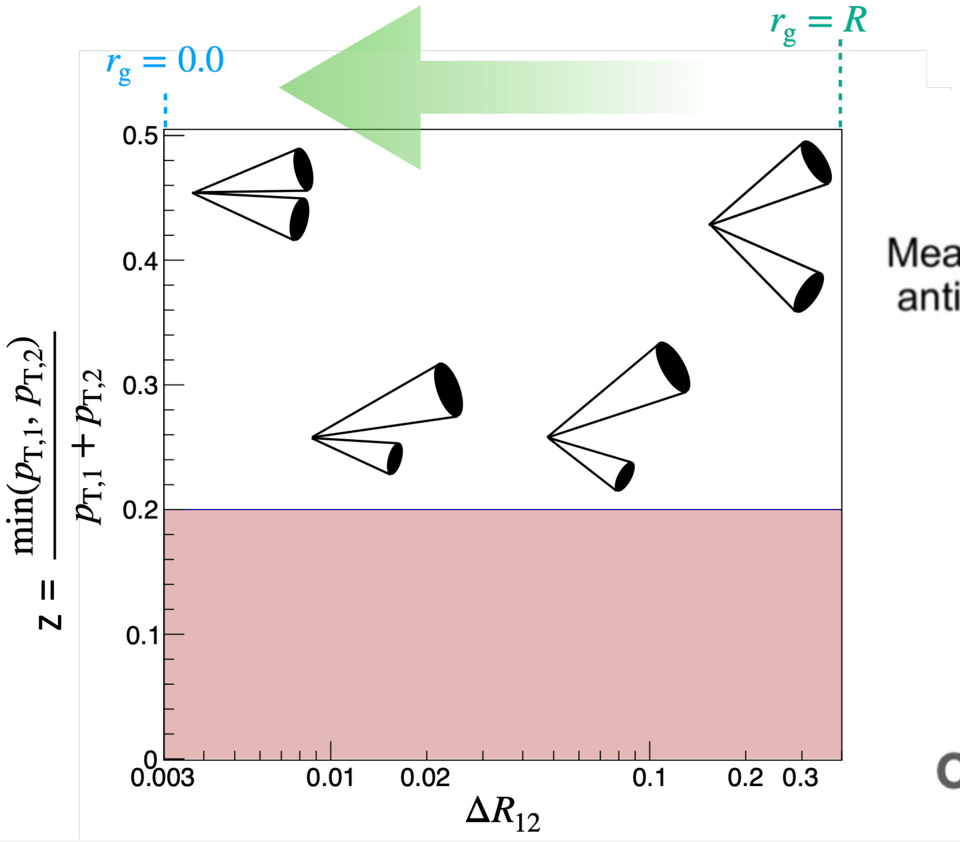
Jet Substructure: Grooming

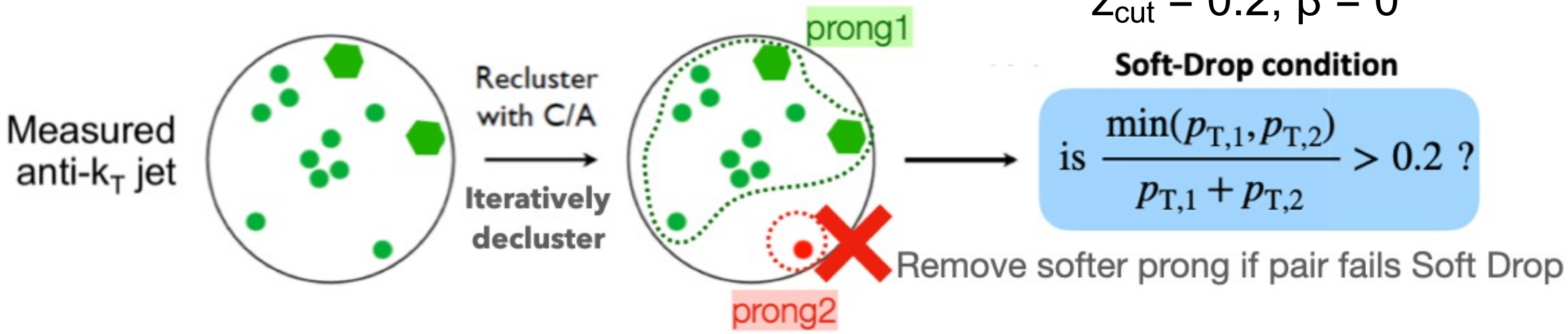
- Grooming techniques systematically remove soft and wide-angle radiation
- Using C/A algorithm to recluster the jet imposes angular ordering

Soft-Drop condition

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

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





JHEP 1405 (2014) 146

Cambridge/Aachen (C/A) is an angular-ordered clustering algorithm

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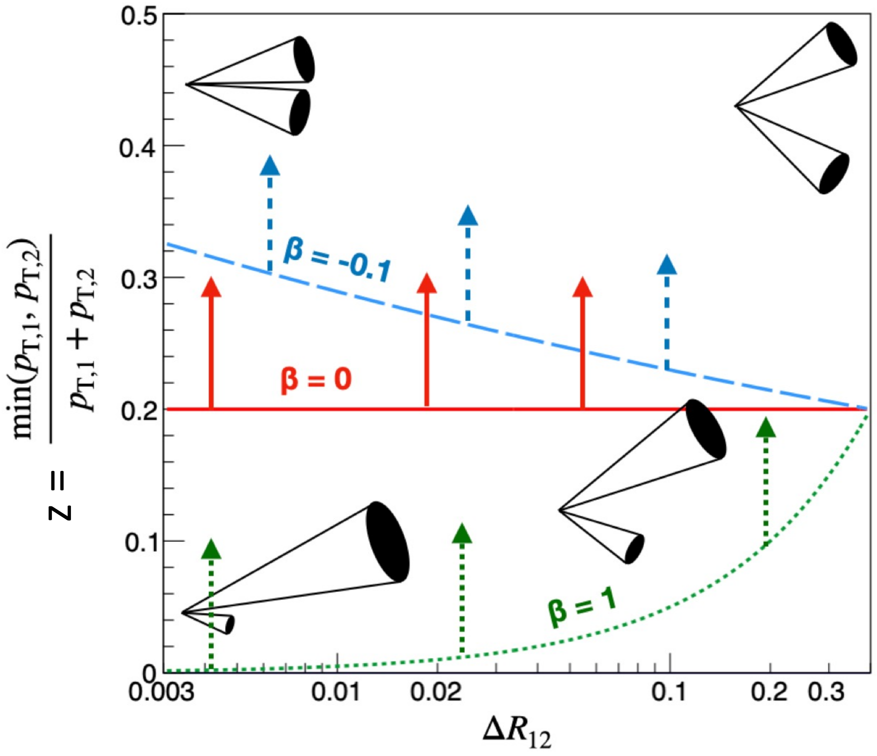
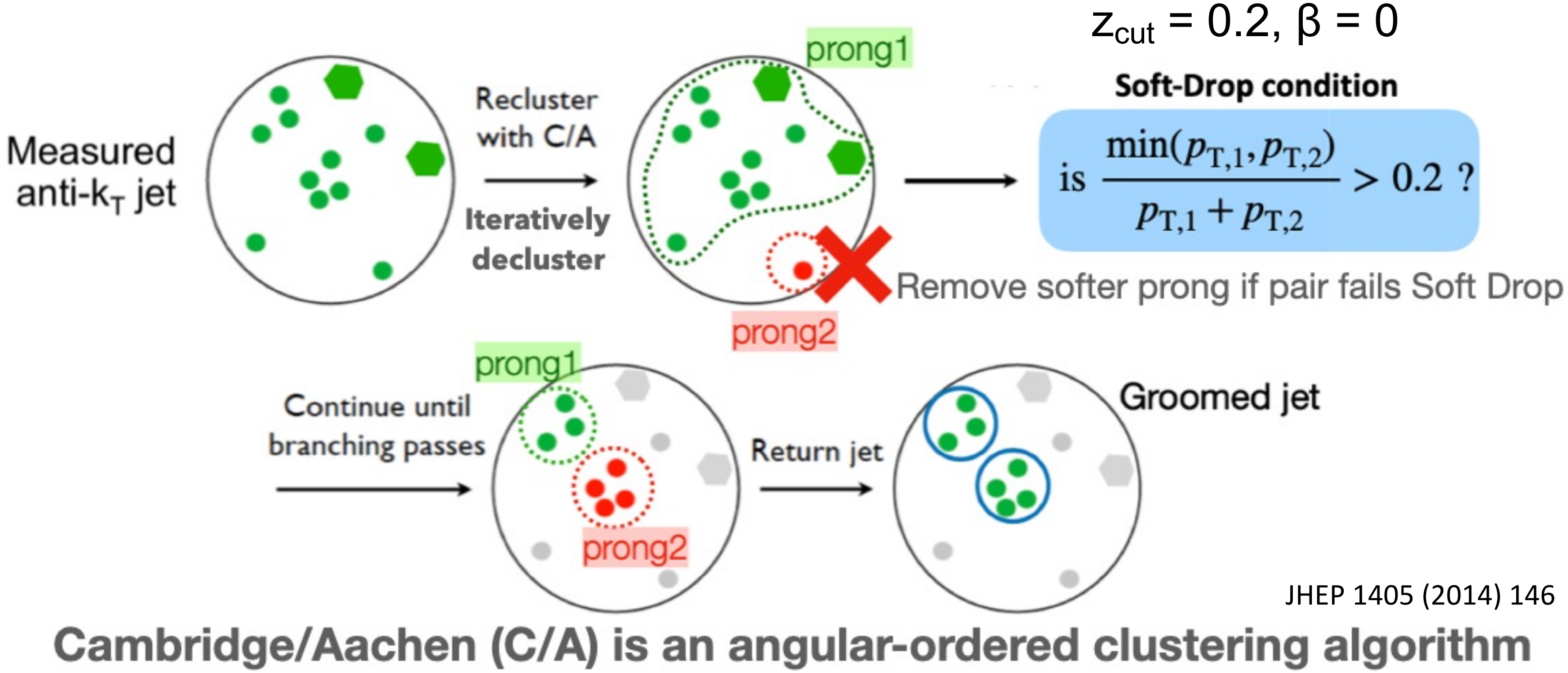
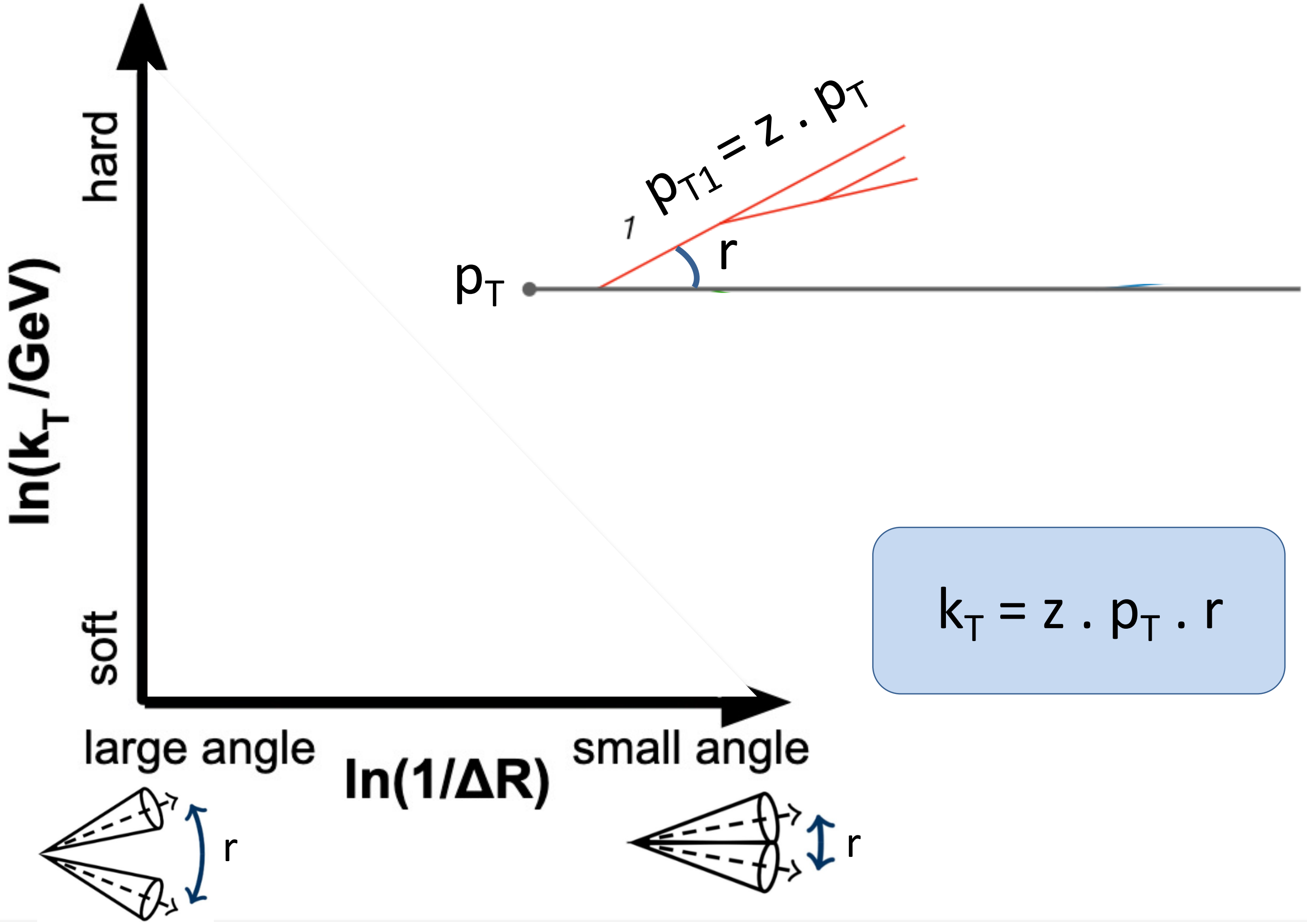




JHEP 1405 (2014) 146

Mapping the Evolution of a Jet

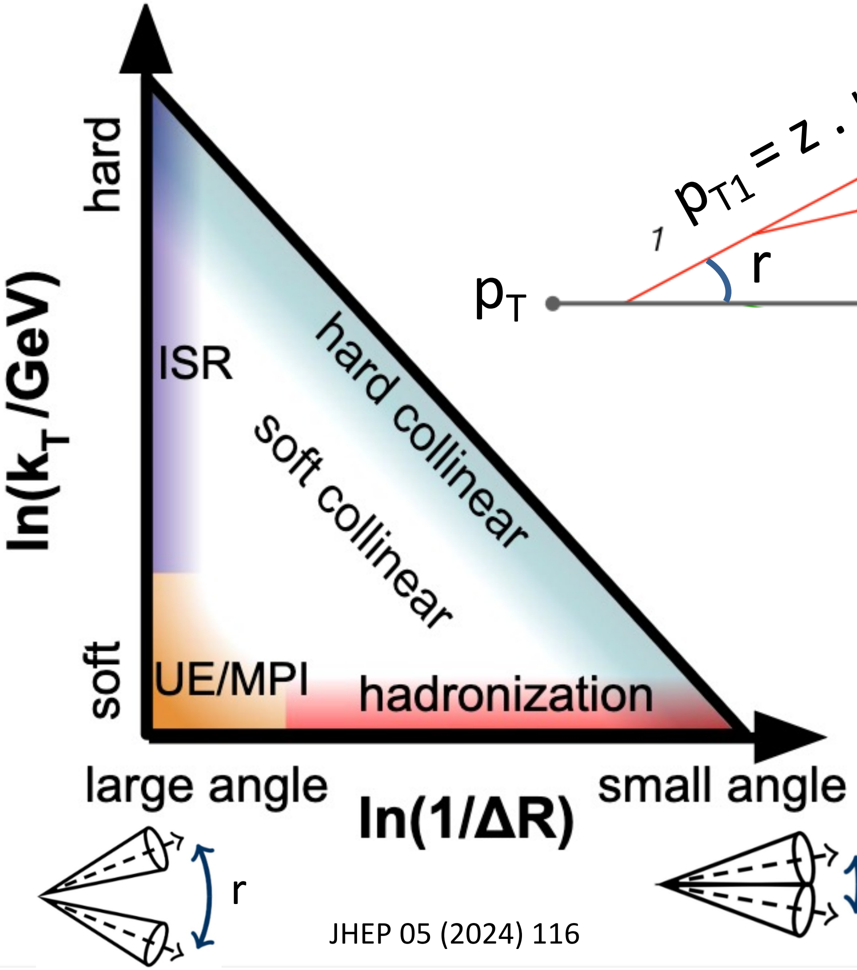
JHEP12(2018)064



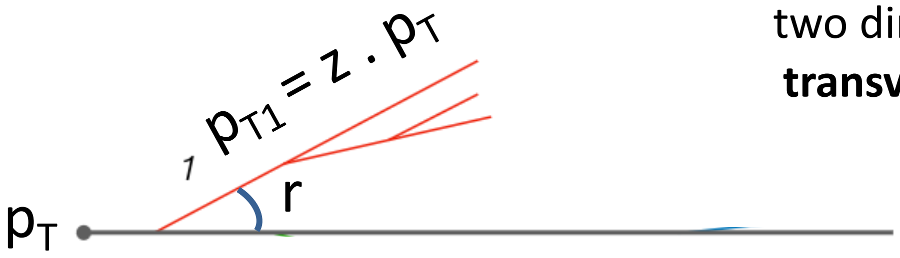
$k_T = z \cdot p_T \cdot r$

The (Primary) Lund Jet Plane

JHEP12(2018)064



JHEP 05 (2024) 116

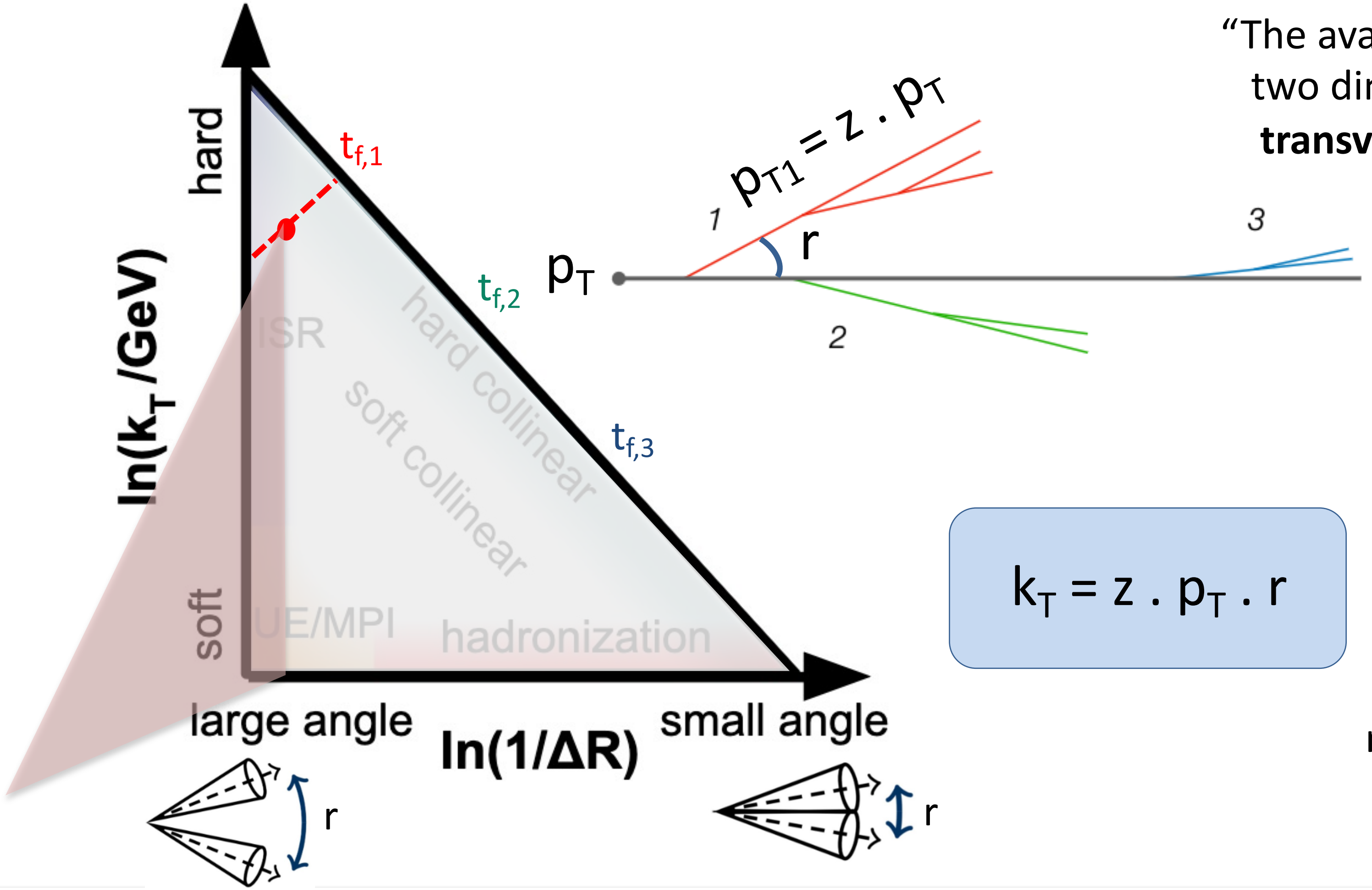


"The available phase-space is mapped to a triangle in a two dimensional (logarithmic) plane that shows the **transverse momentum and the angle of any given emission with respect to its emitter.**"

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

The Lund Jet Plane

JHEP12(2018)064



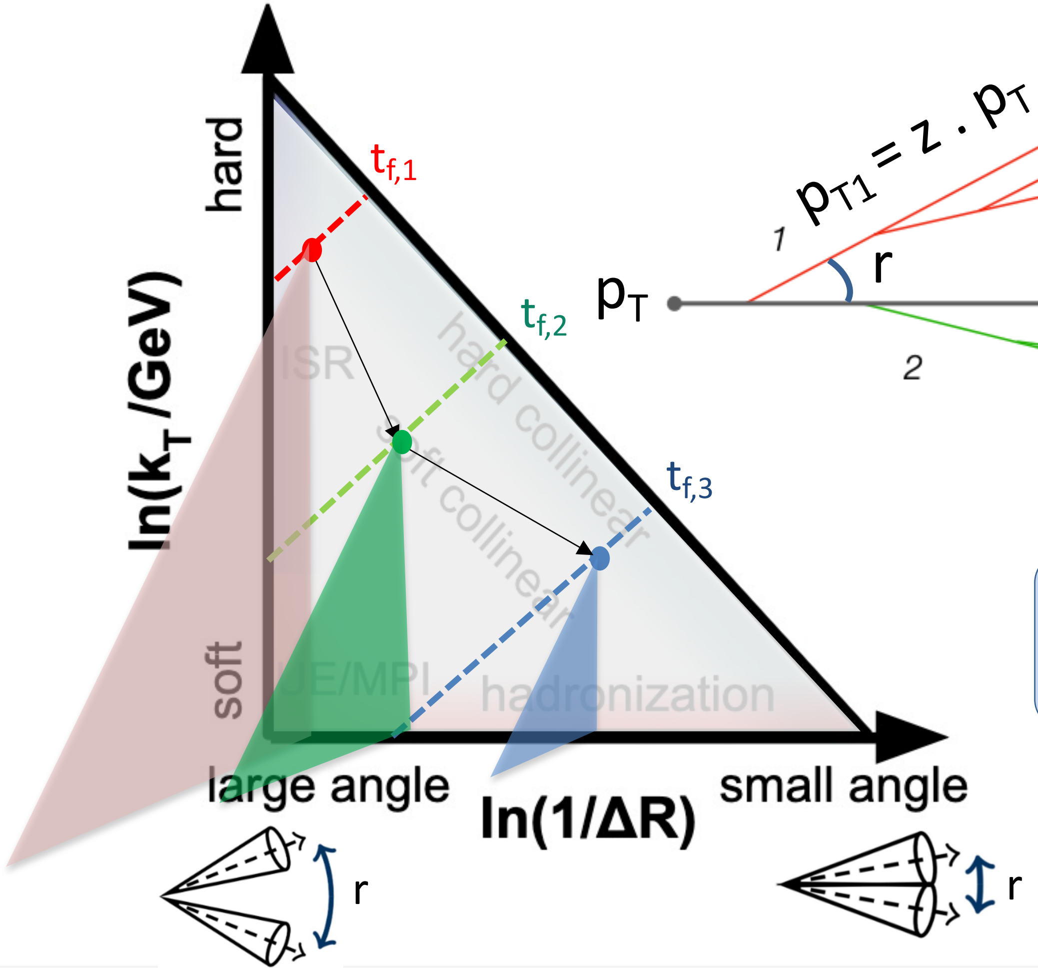
"The available phase-space is mapped to a triangle in a two dimensional (logarithmic) plane that shows the **transverse momentum and the angle of any given emission with respect to its emitter.**"

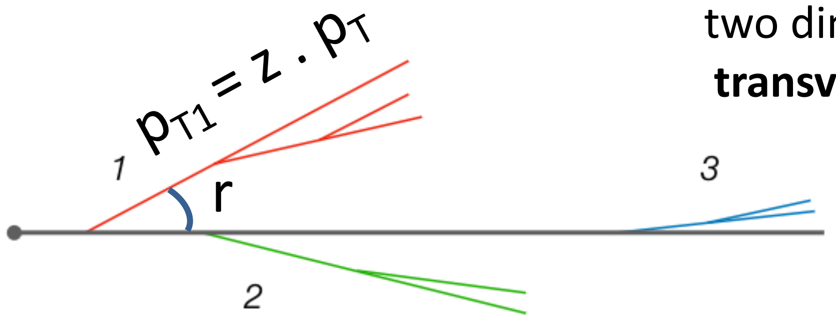
Each given emission creates new phase space (a triangular leaf) for further emissions.

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

Different regions are dominated by factorized processes, the LJP can be useful for tuning nonperturbative models and for constraining the model parameters of advanced parton shower (PS) Monte Carlo (MC) programs.

The Lund Jet Plane





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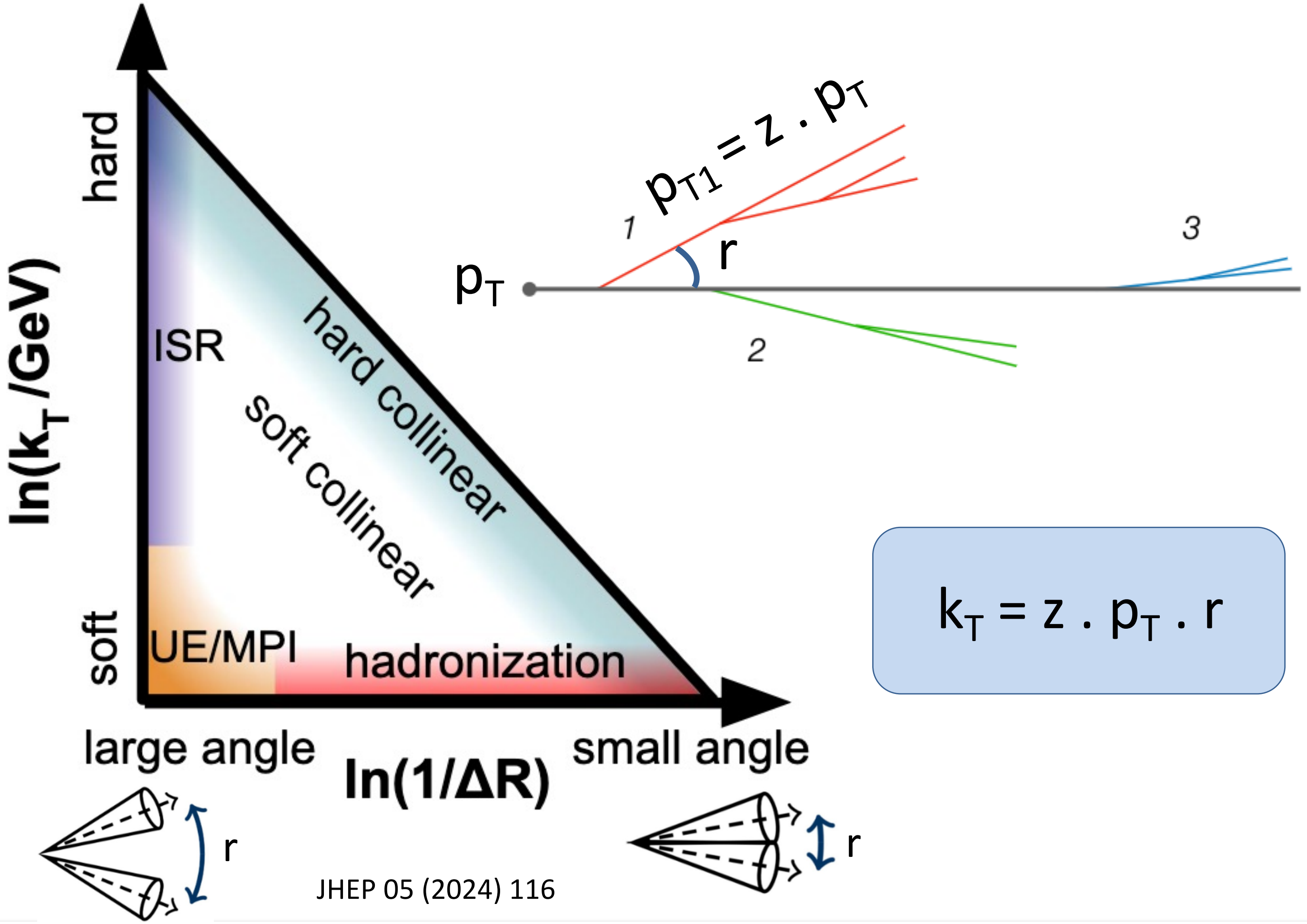
Each given emission creates new phase space (a triangular leaf) for further emissions.

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

The LJP can be used to improve different aspects of the physics modeling in event generators

The Lund Jet Plane



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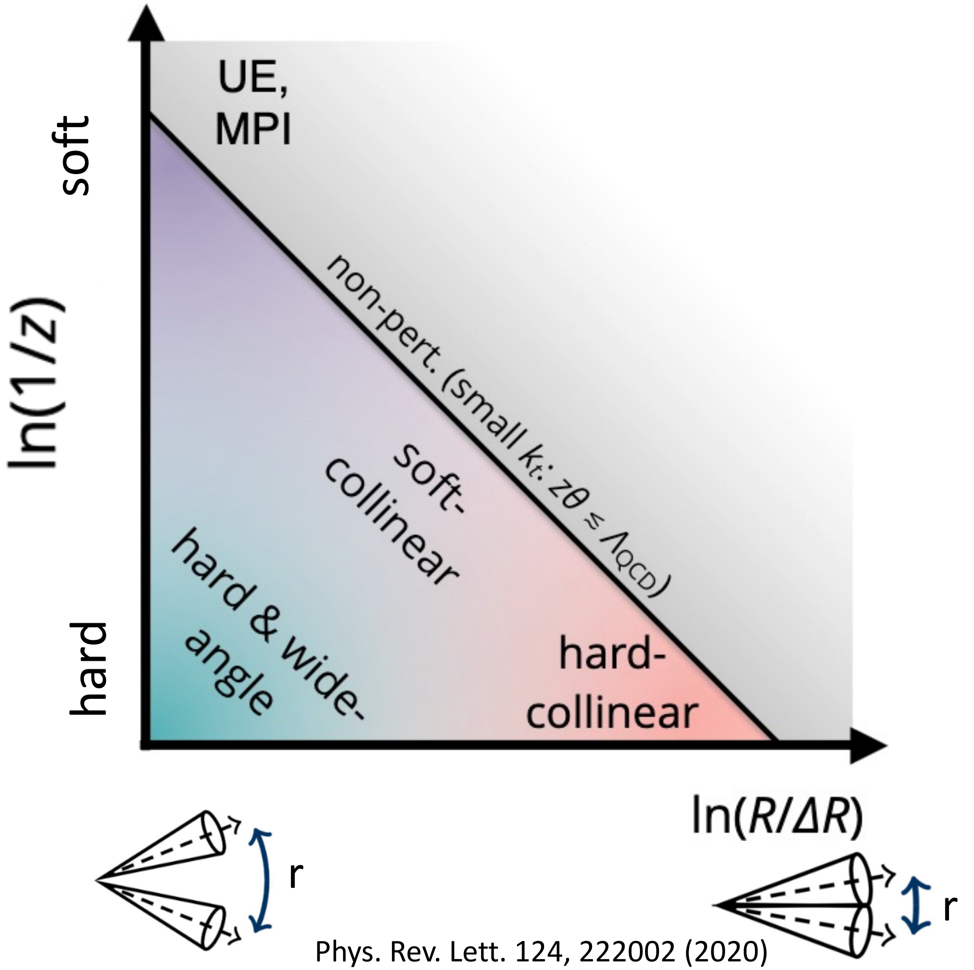
$k_T = z . p_T . r$

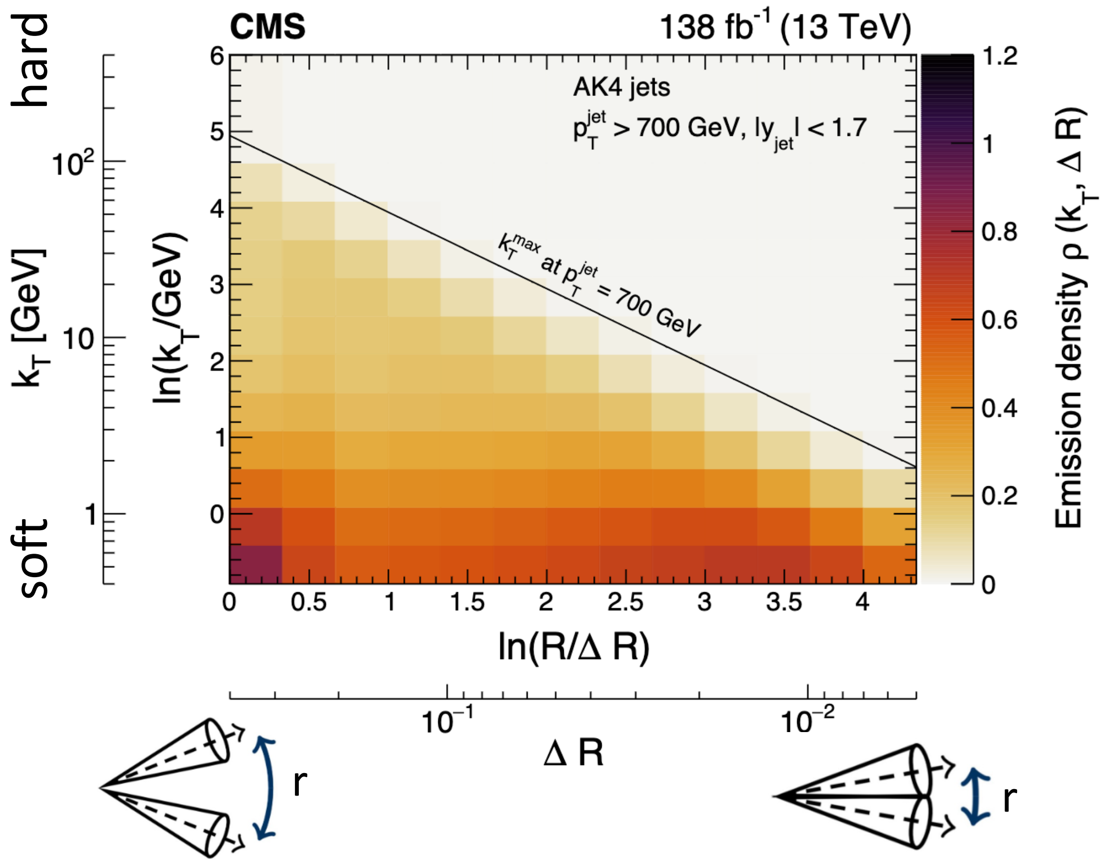


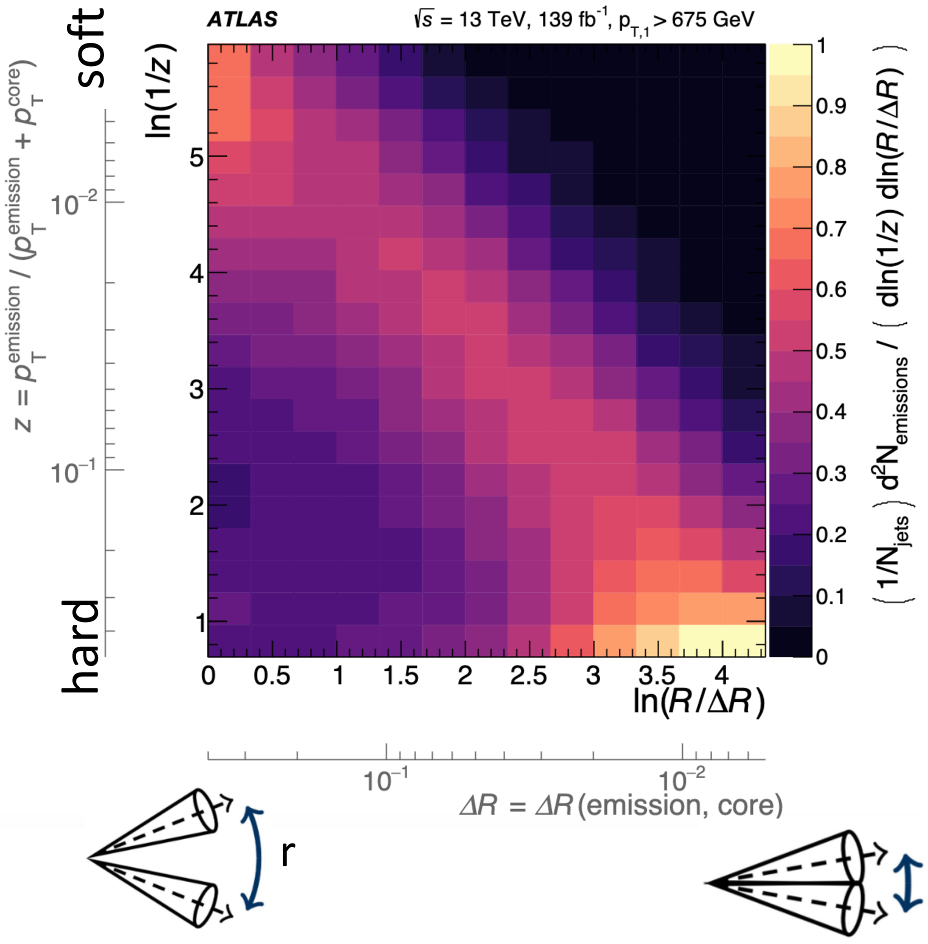
Phys. Rev. Lett. 124, 222002 (2020)

The (Primary) Lund Jet Plane Measurements

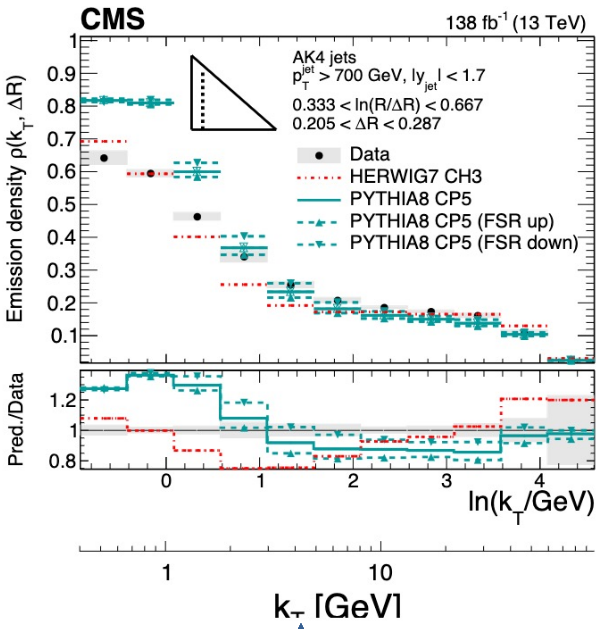
JHEP 05 (2024) 116

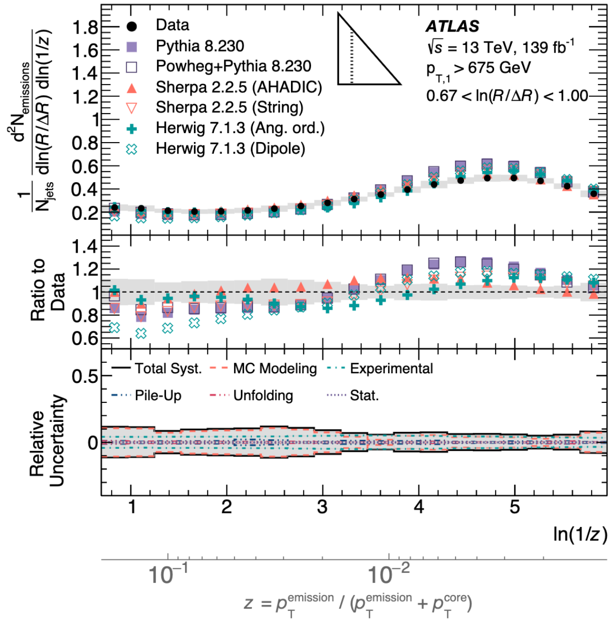
Phys. Rev. Lett. 124, 222002 (2020)

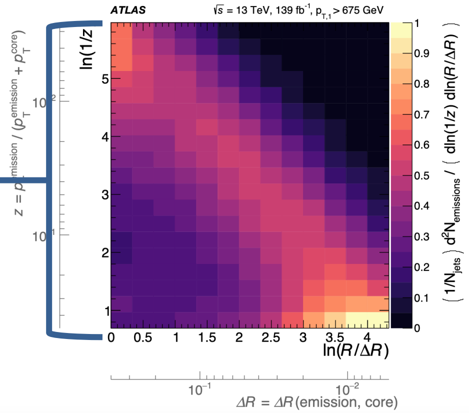




The (Primary) Lund Jet Plane Projections







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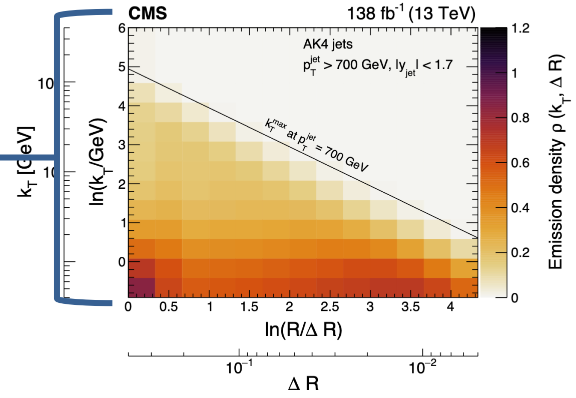

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The Lund Jet Plane Projections

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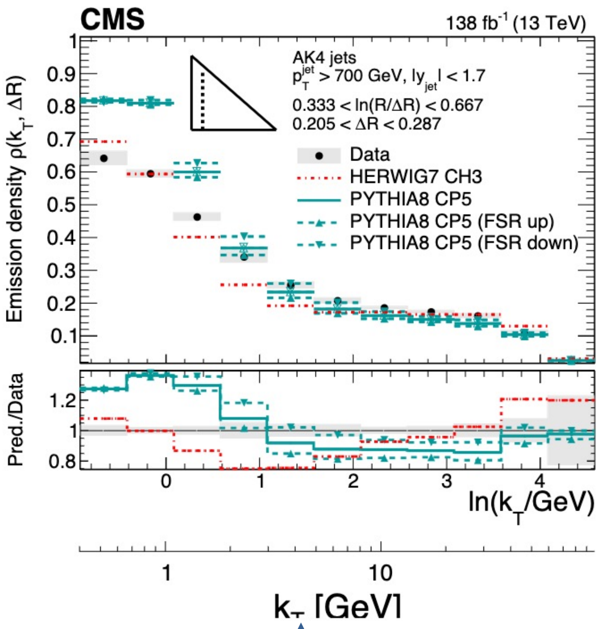

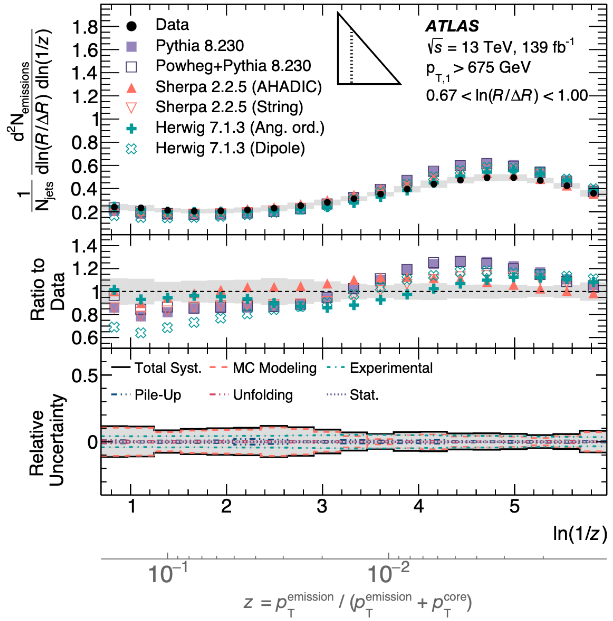

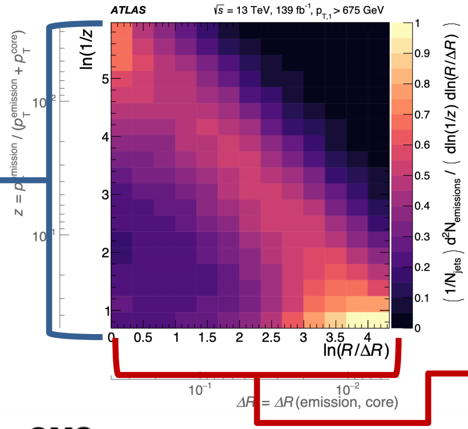

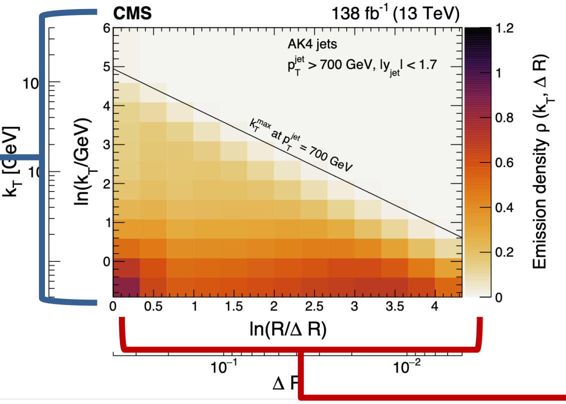

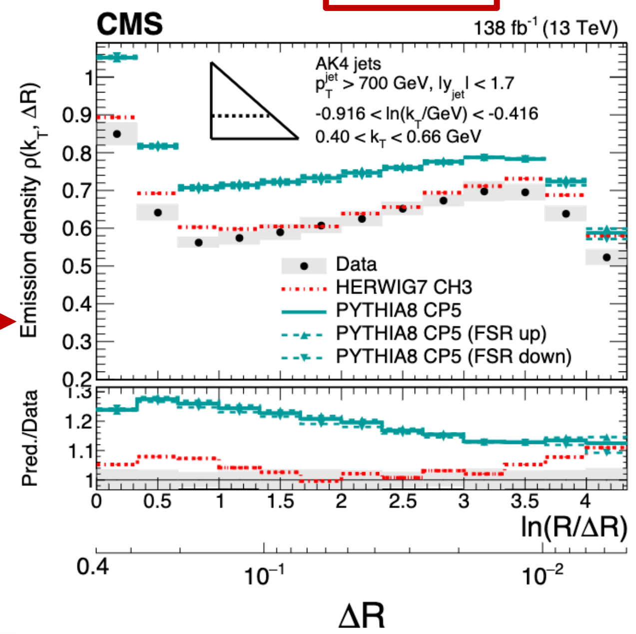

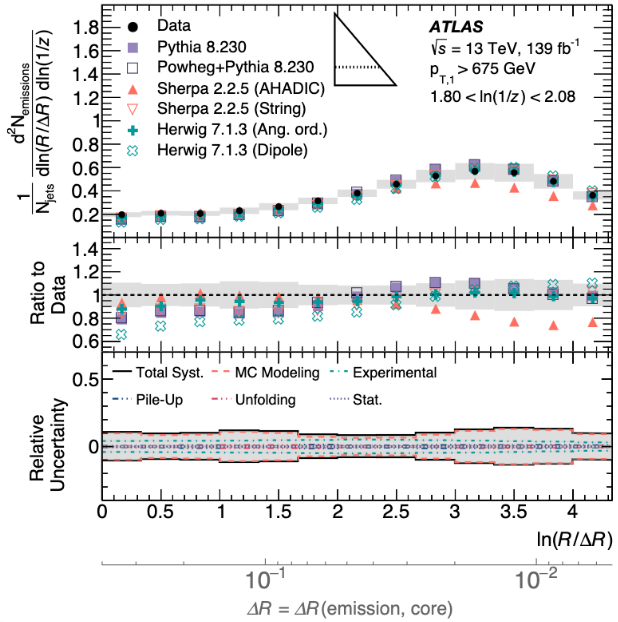

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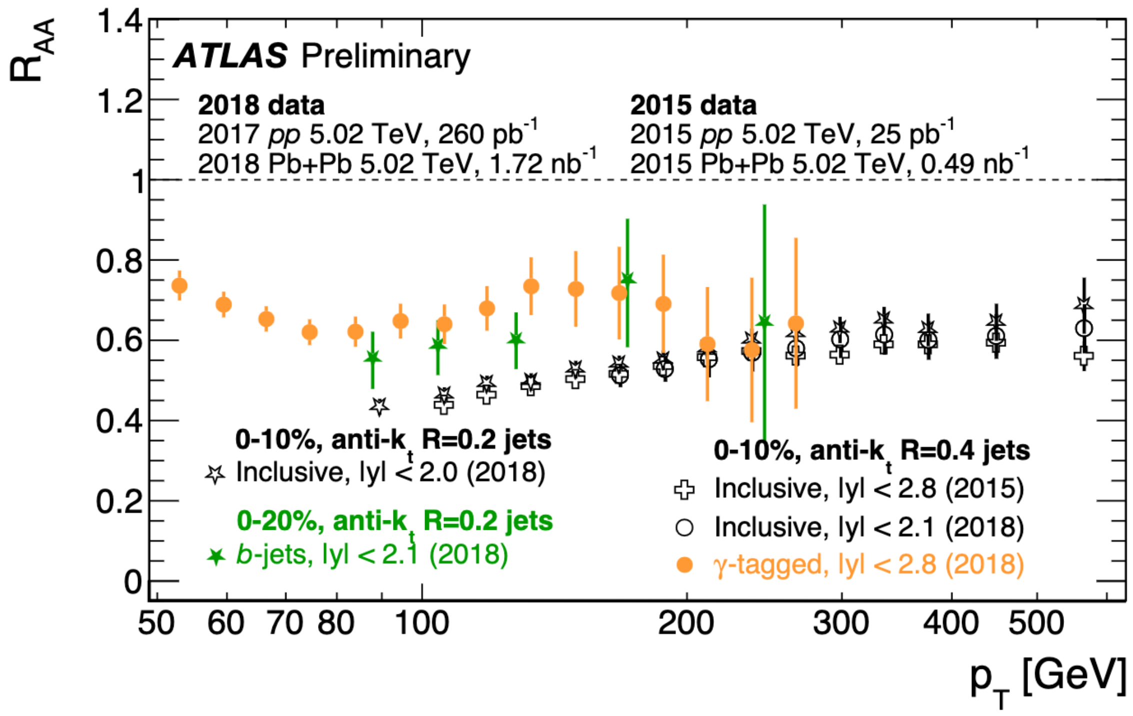
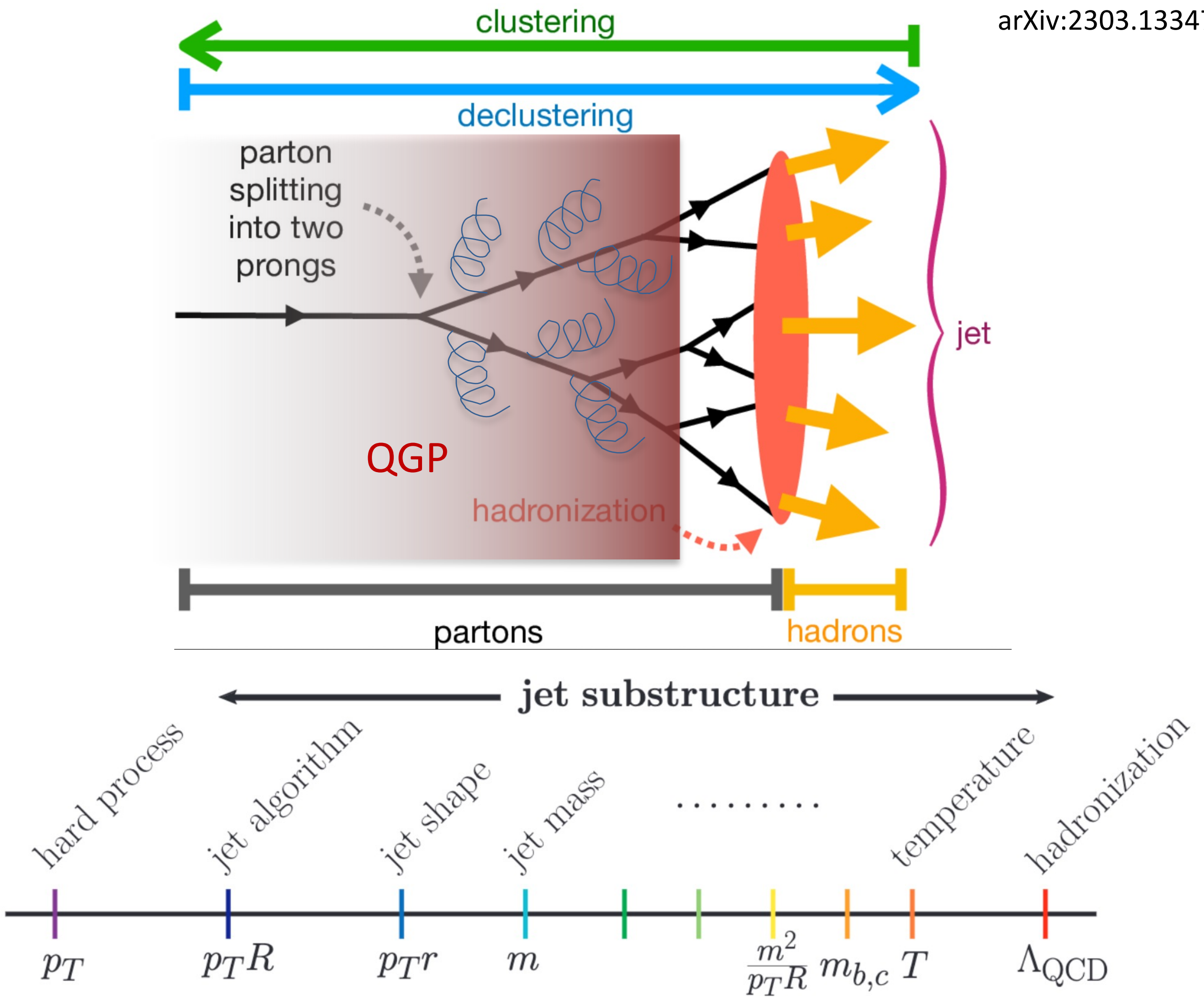
Jets in Heavy-Ion Collisions

- 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**

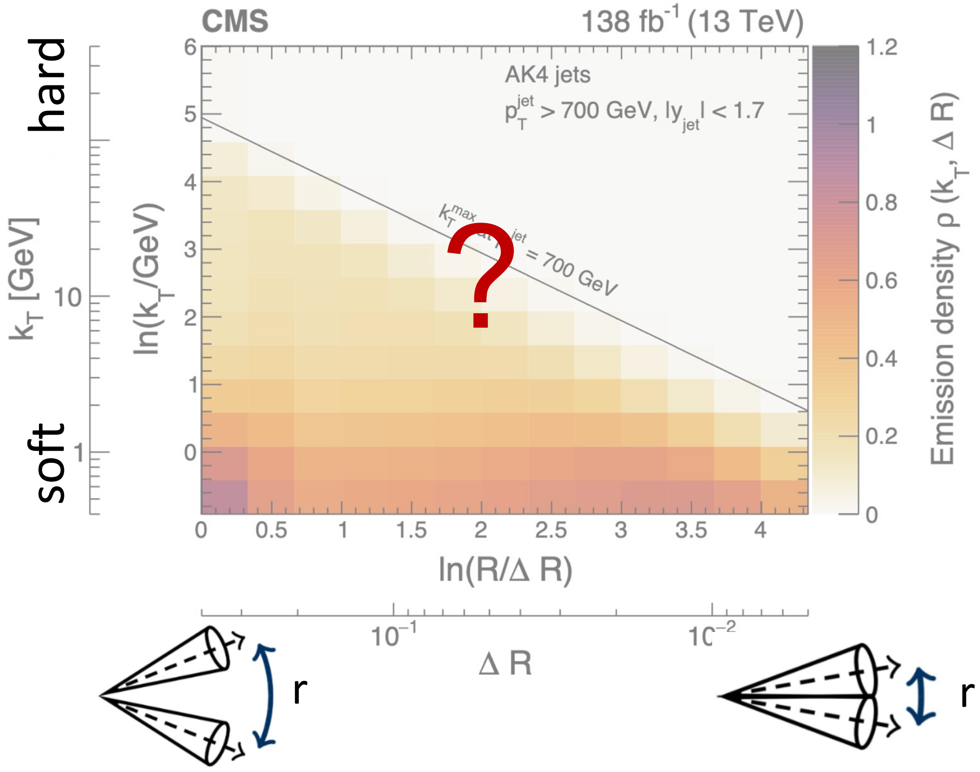


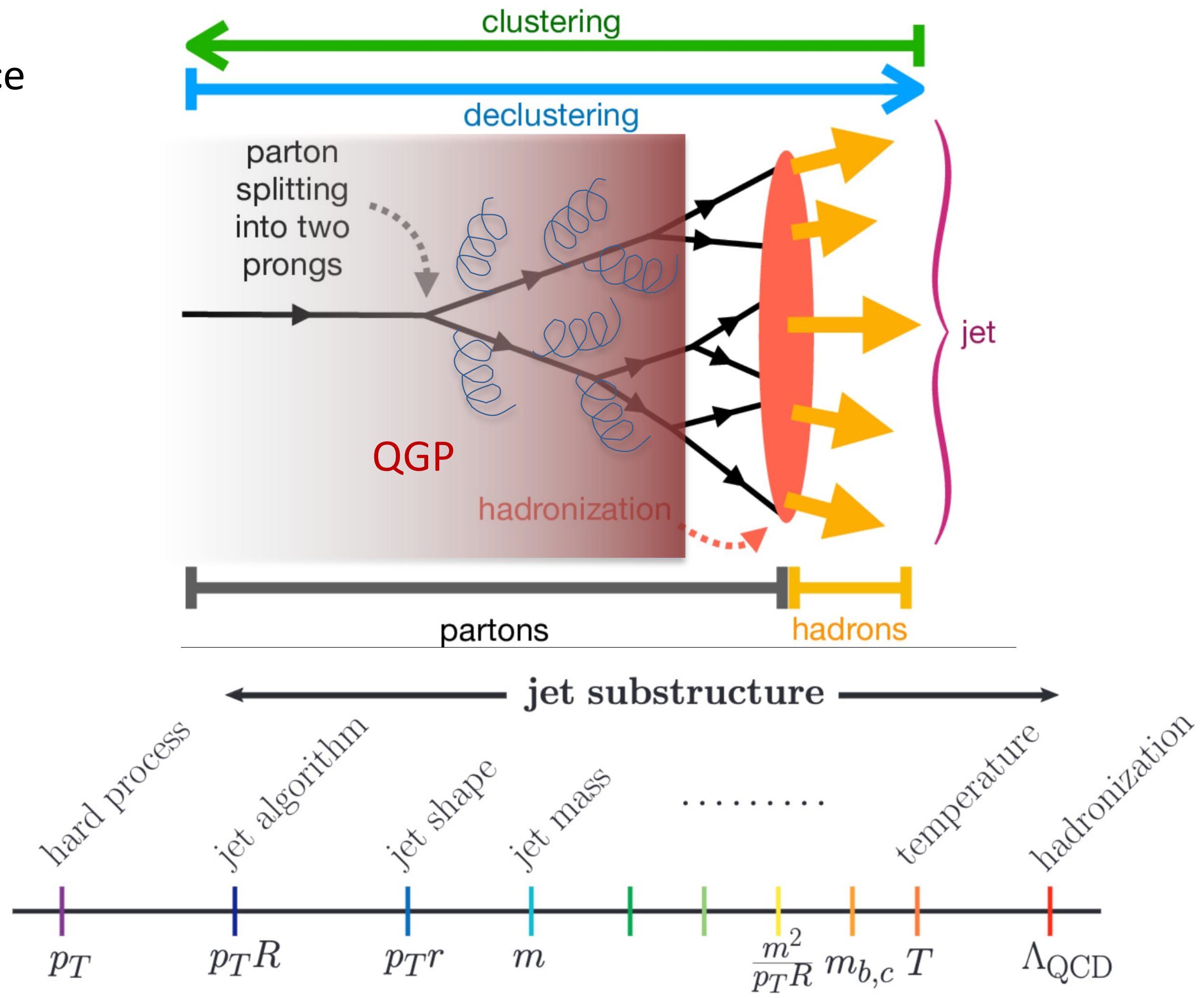
arXiv:2303.13347



Jet Substructure in Heavy-Ion Collisions

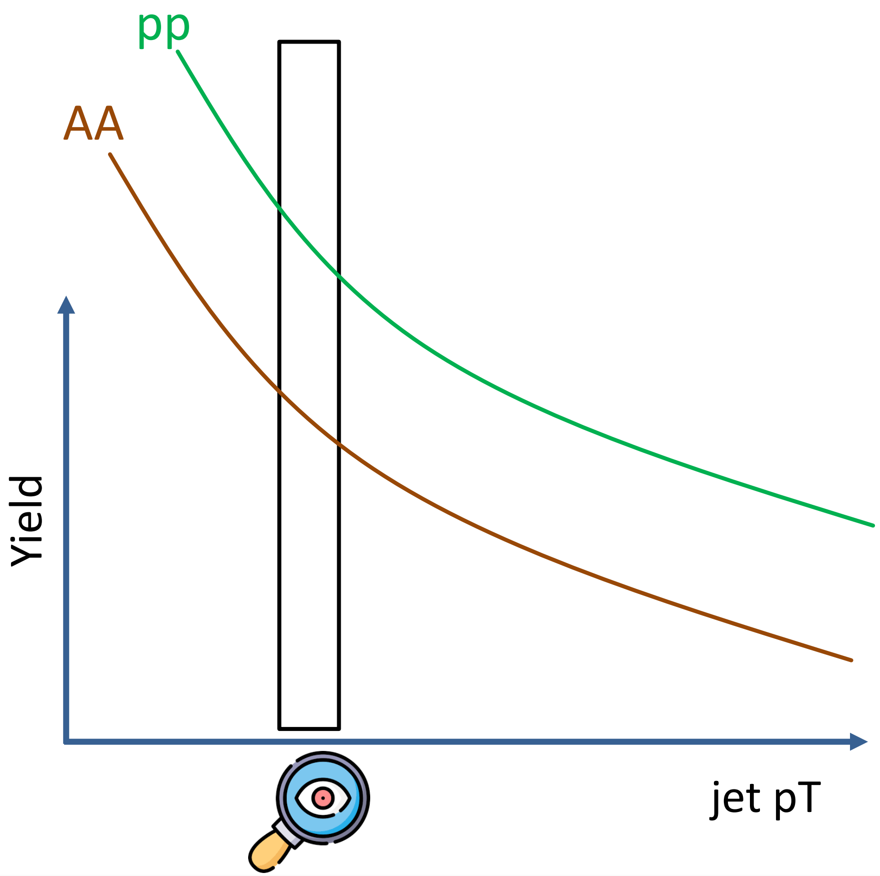
What does the multiscale evolution of jets look like in presence of the QGP?

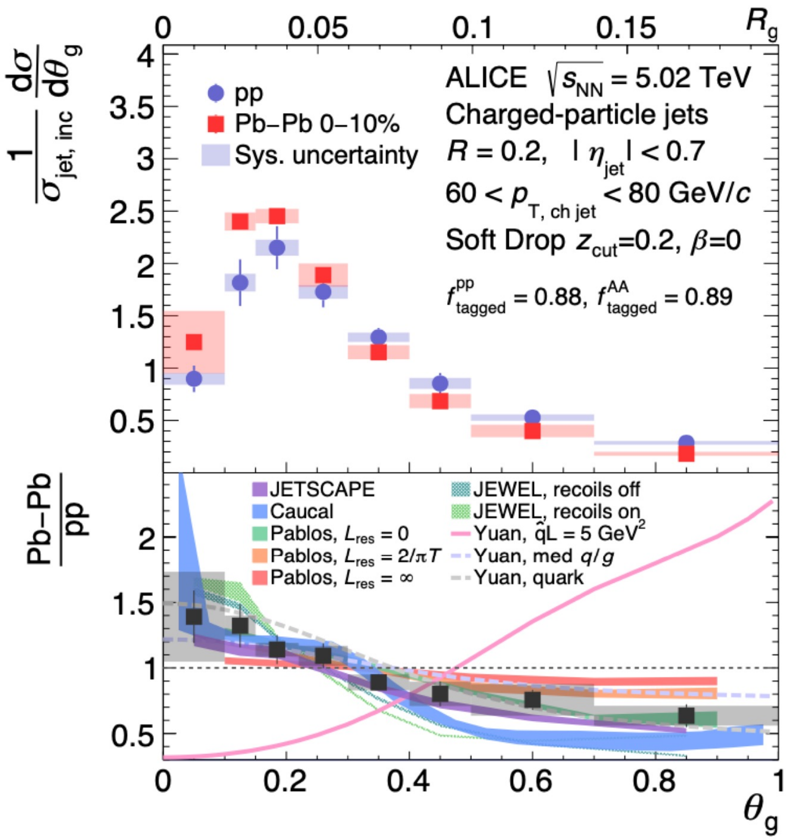




ALICE : r_g measurement

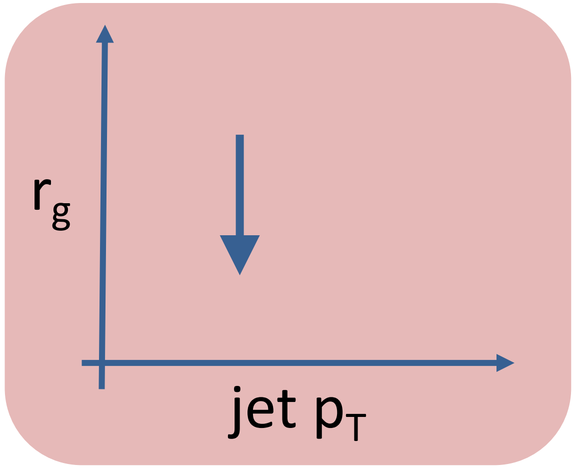
“A narrowing of the θ_g distribution in Pb−Pb collisions compared to pp collisions is seen, which provides direct evidence of the modification of the angular structure of jets in the quark−gluon plasma.”





Soft-Drop condition

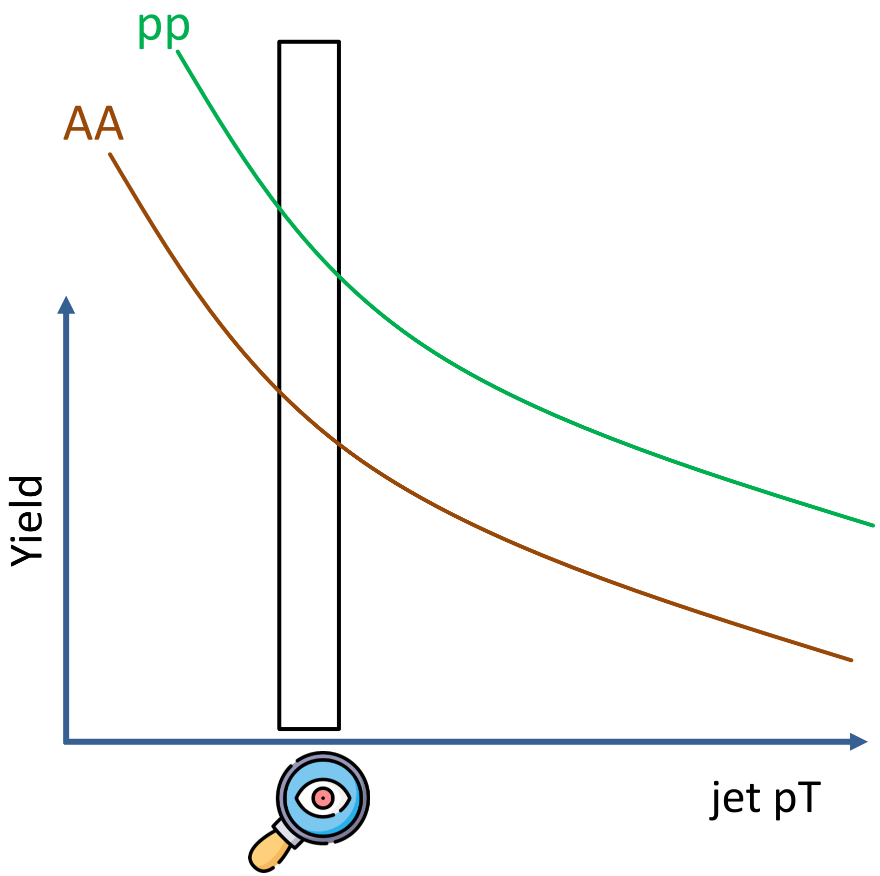
$$z_g = \frac{min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut}(R_g/R_{jet})^{\beta}$$

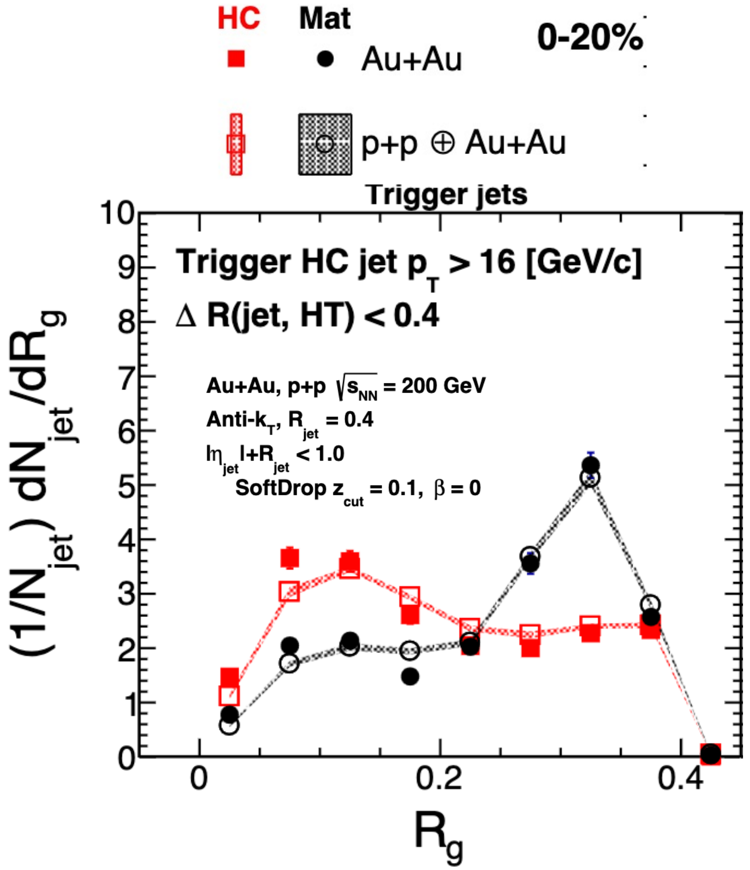


Phys. Rev. Lett. 128 (2022) 102001

STAR : r_g measurement

"We observe no significant modifications of the subjet observables within the two highest-energy, back-to-back jets, resulting in a distribution of opening angles and the splittings that are vacuum-like."





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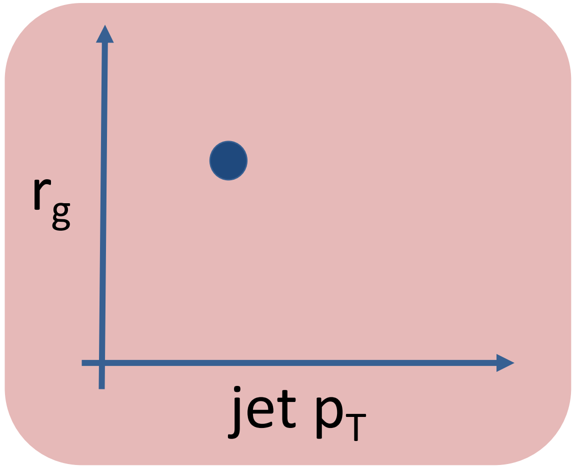
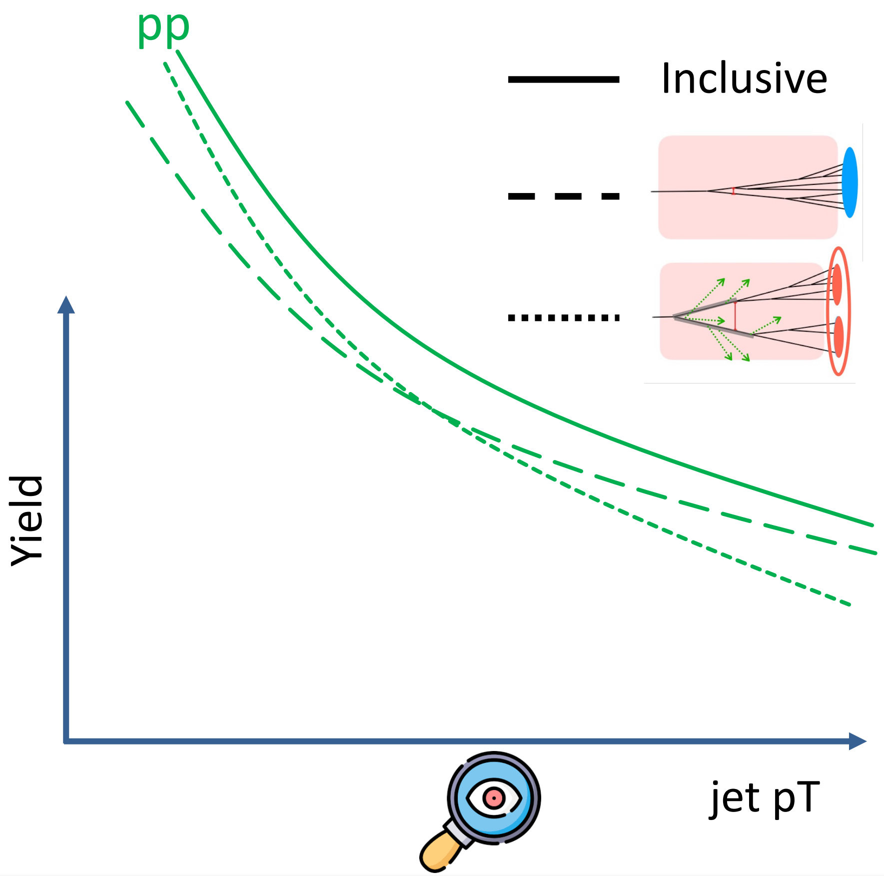


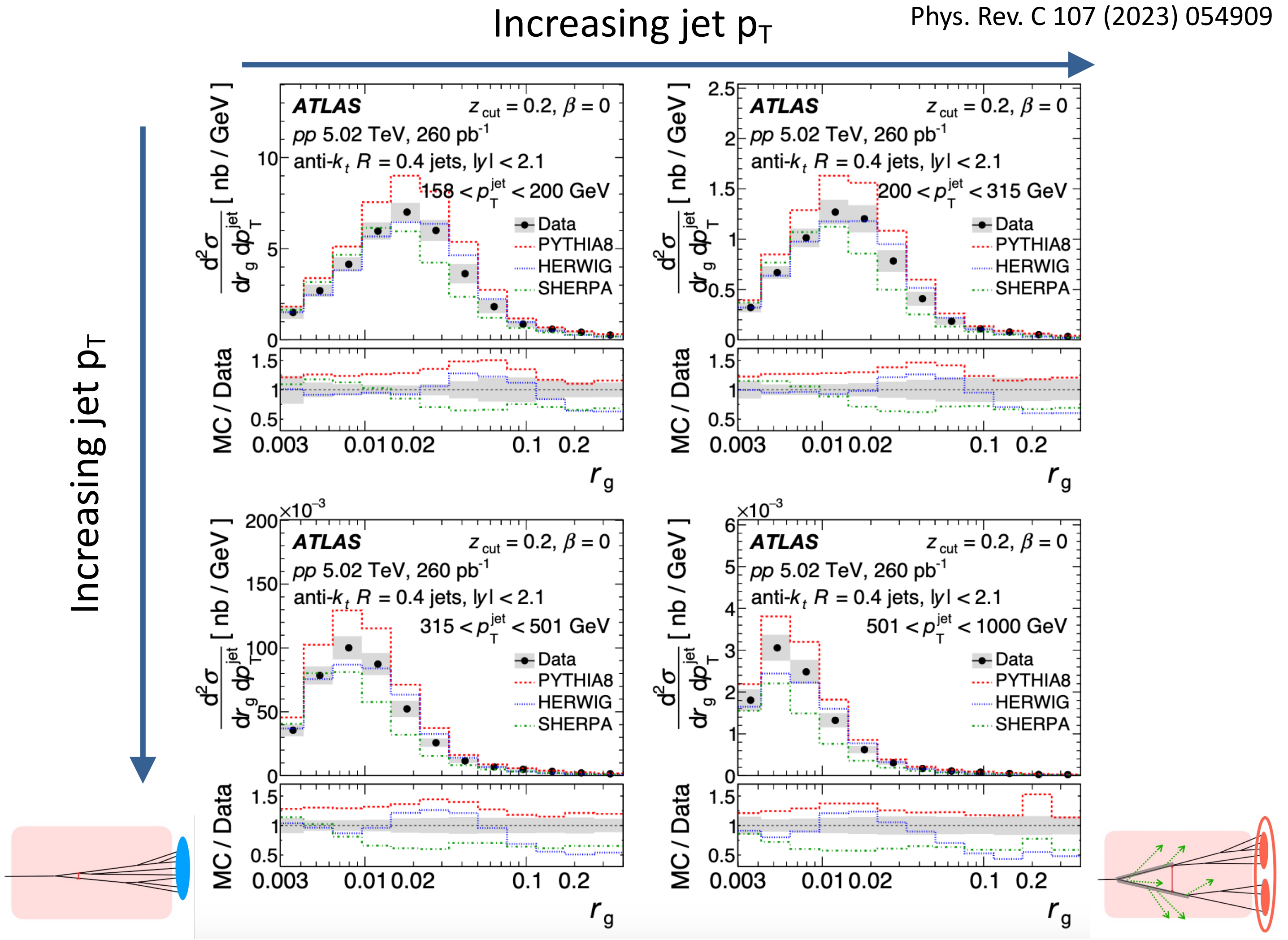
Phys. Rev. C **105** (2022) 44906

ATLAS : r_g yield in pp

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

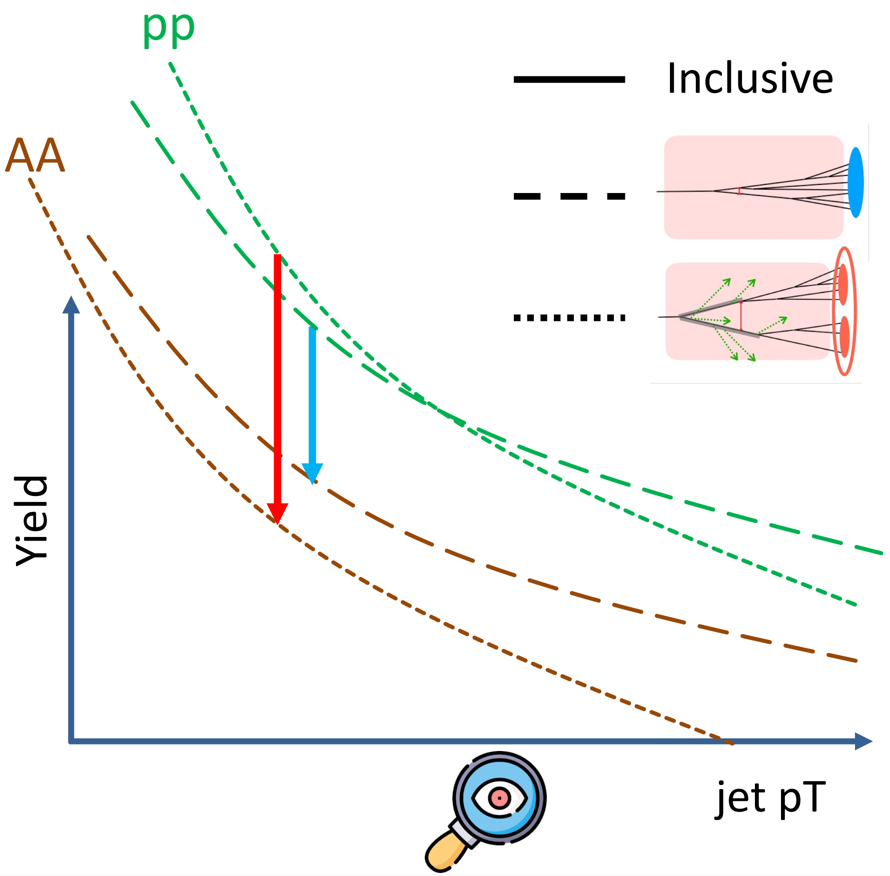


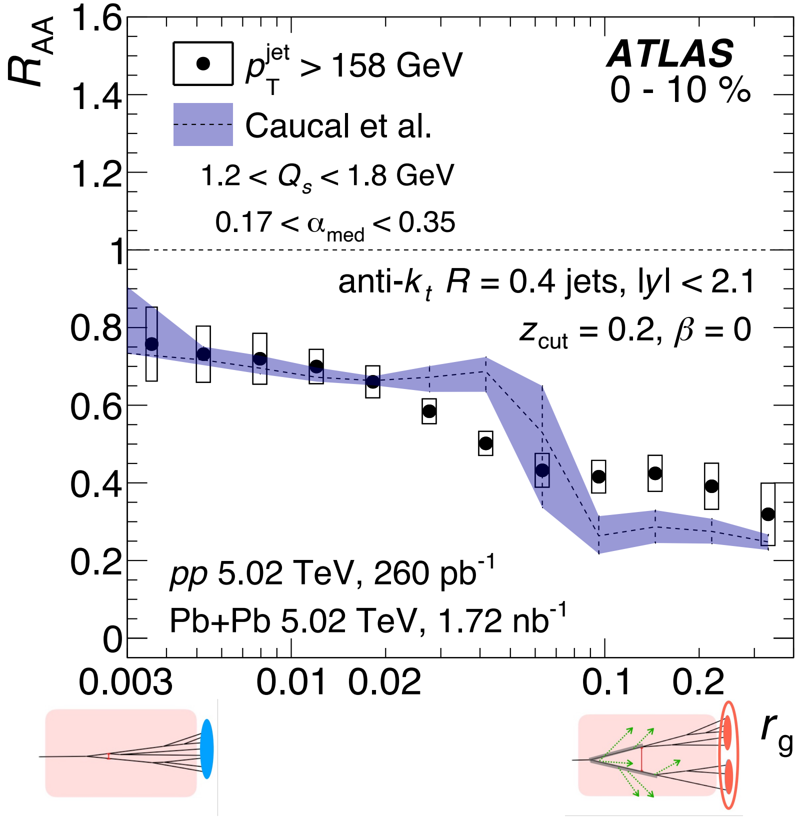
Phys. Rev. C 107 (2023) 054909



ATLAS : R_{AA} vs. r_g

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





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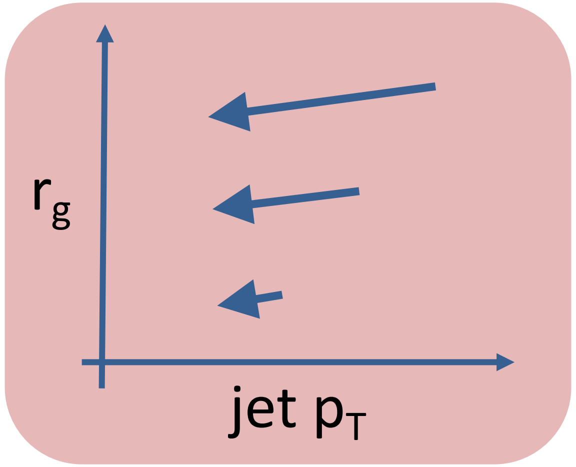
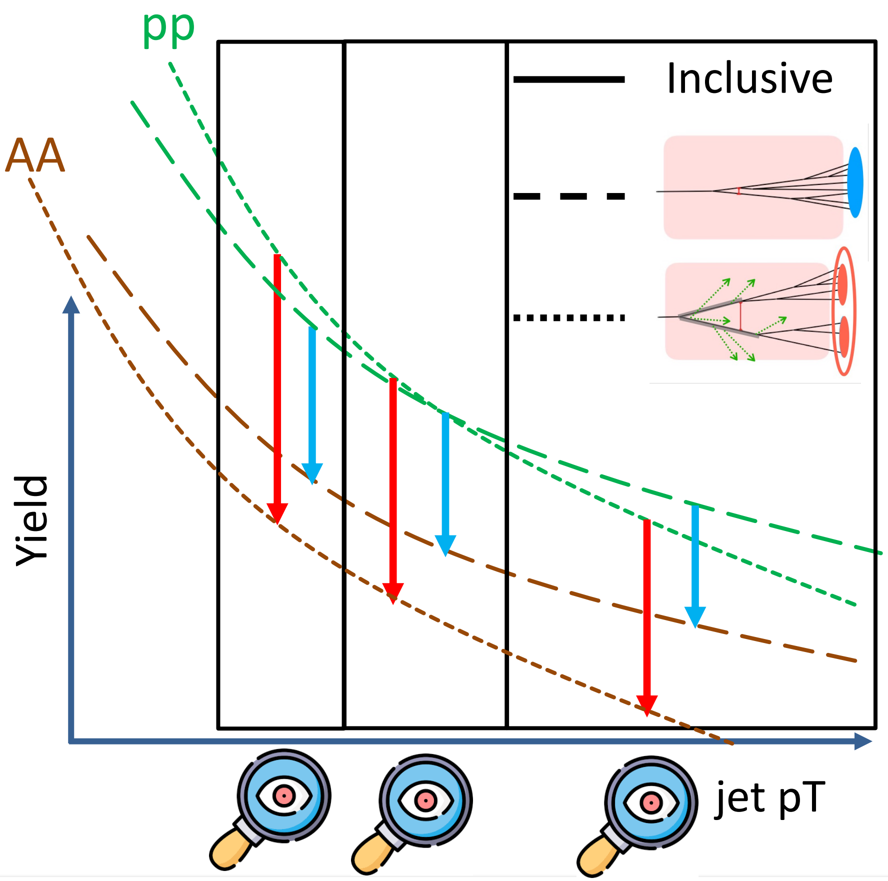
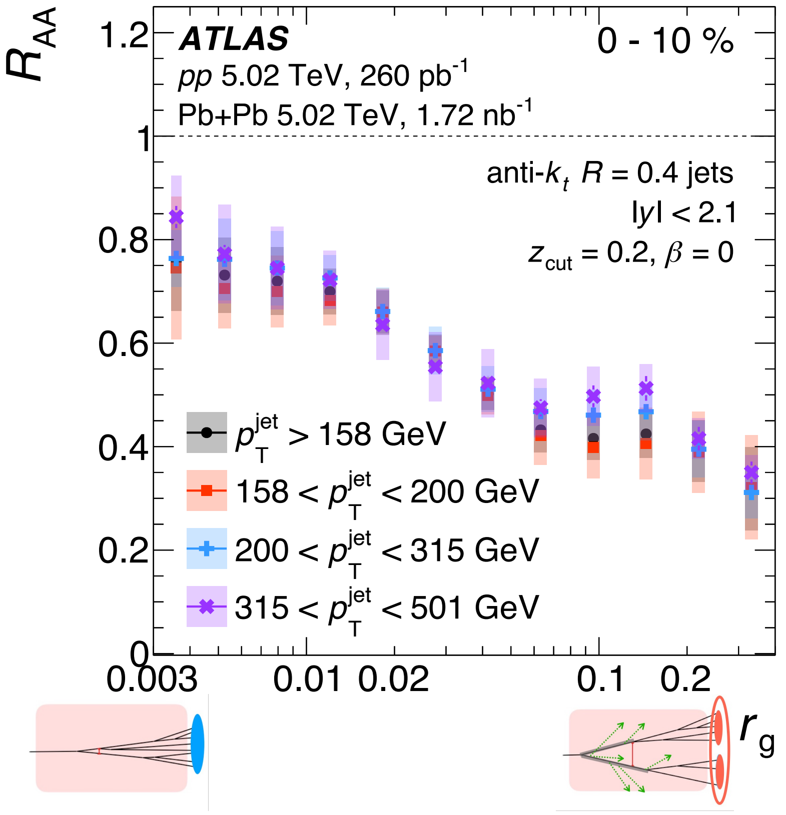


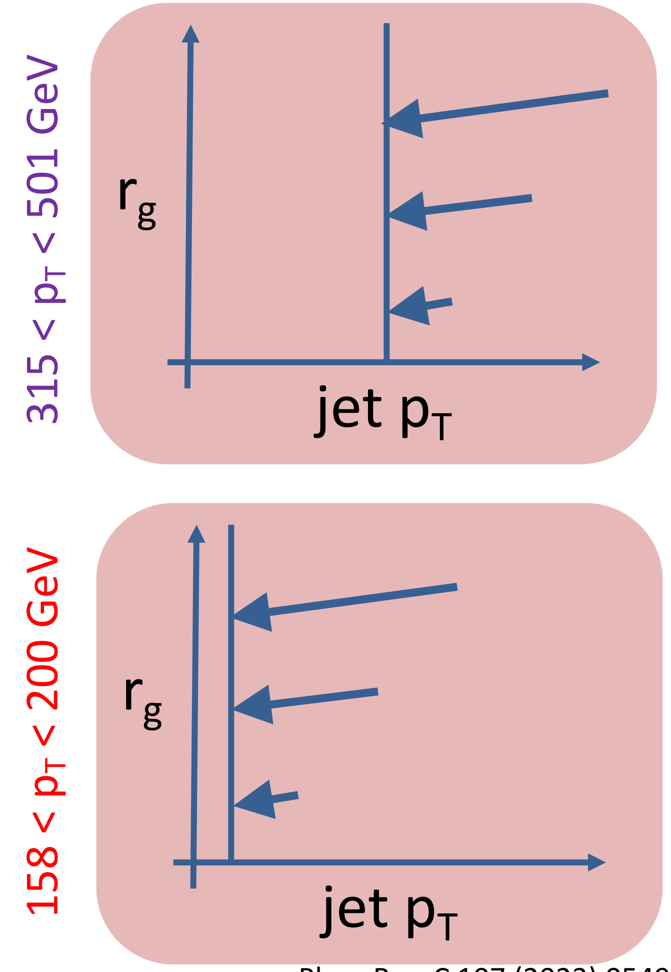
Phys. Rev. C 107 (2023) 054909

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

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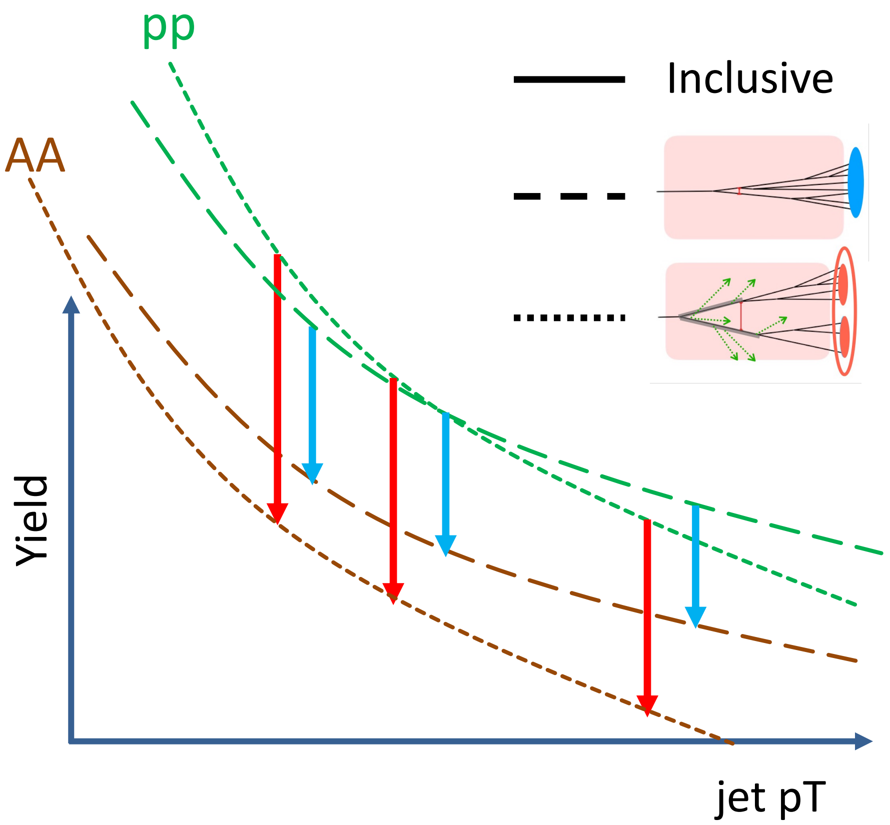
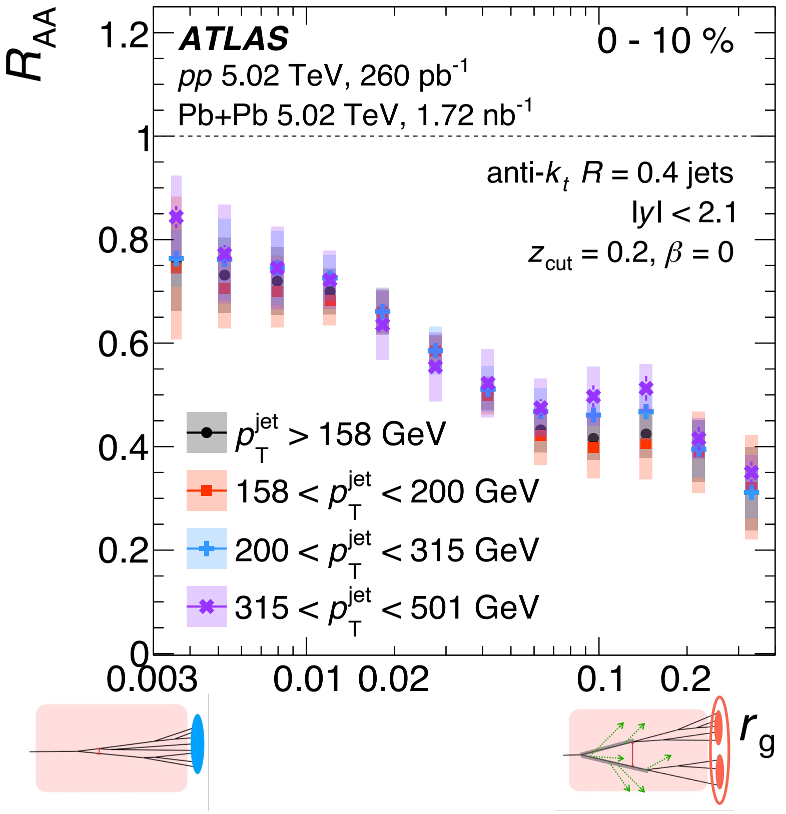
ATLAS : R_{AA} vs. (r_g and jet p_T)

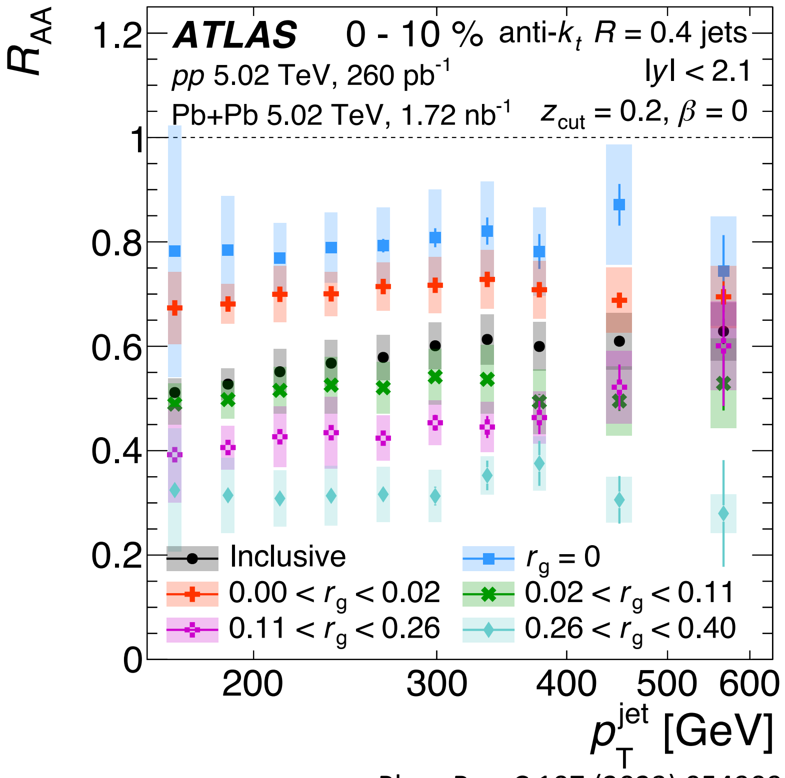
"The values of R_{AA} are observed to depend significantly on r_g, with a clear ordering with respect to the splitting angle."

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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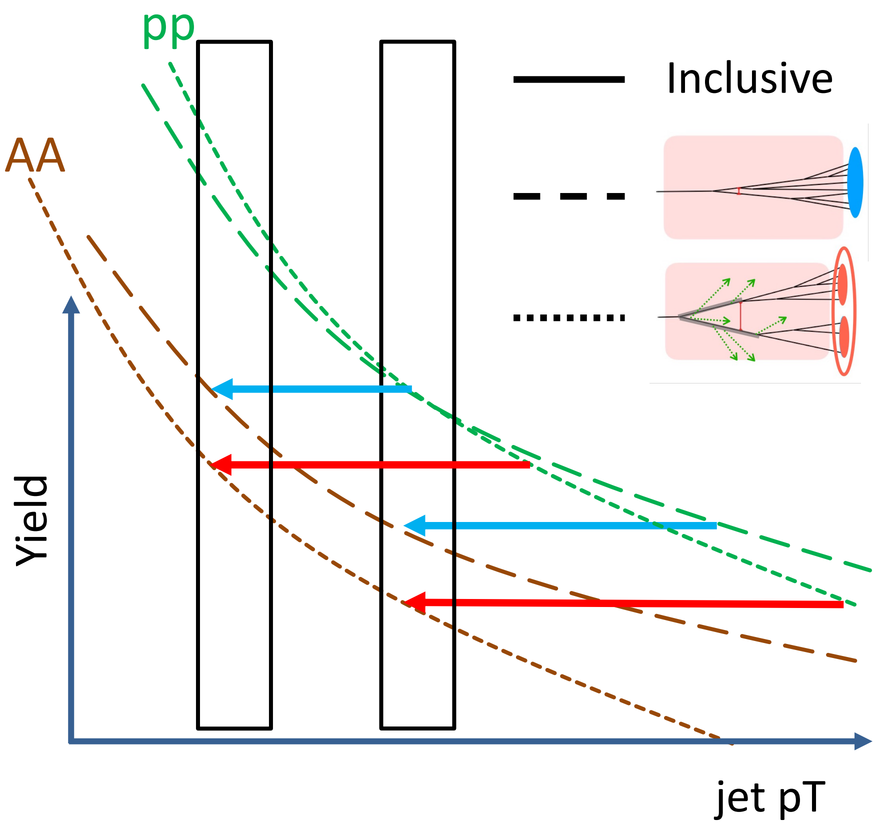

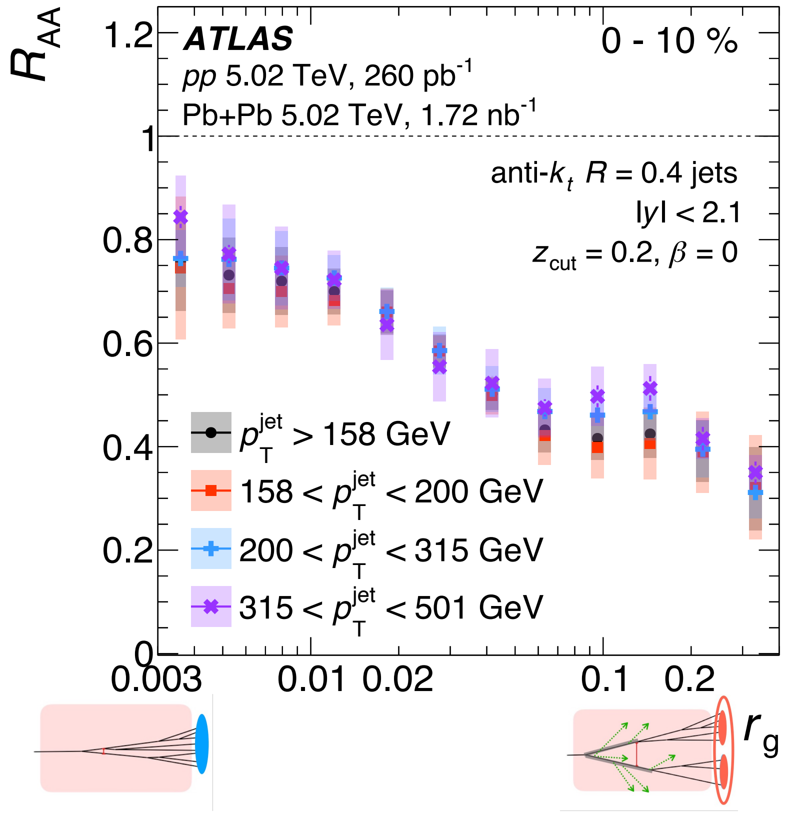

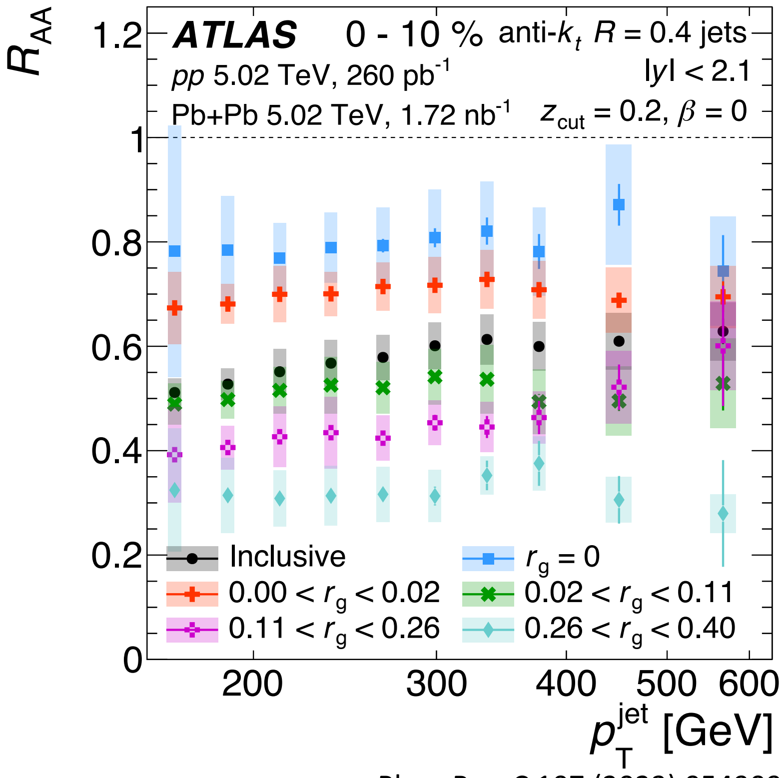

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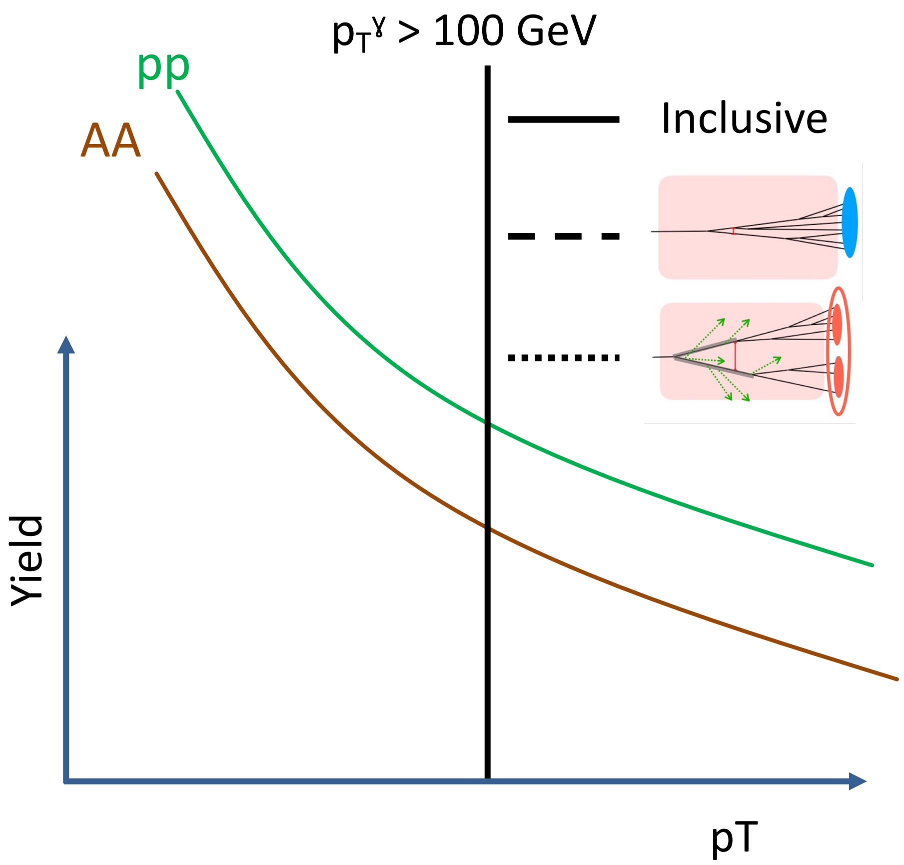
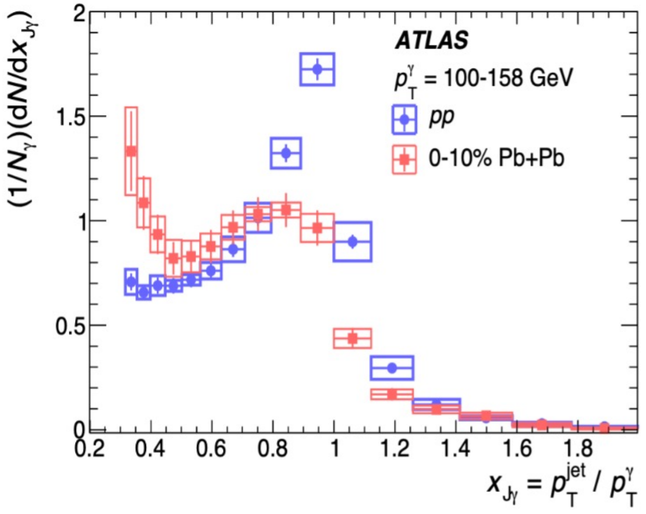
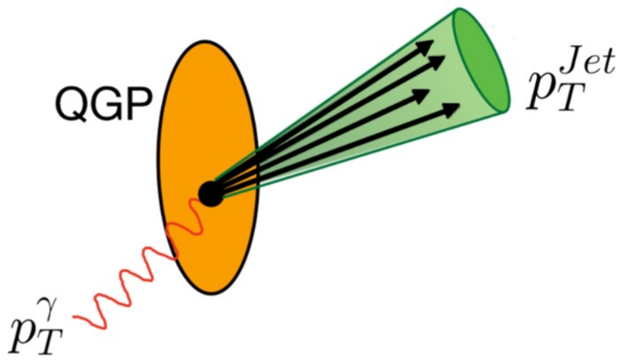
Photon-tagged Jets

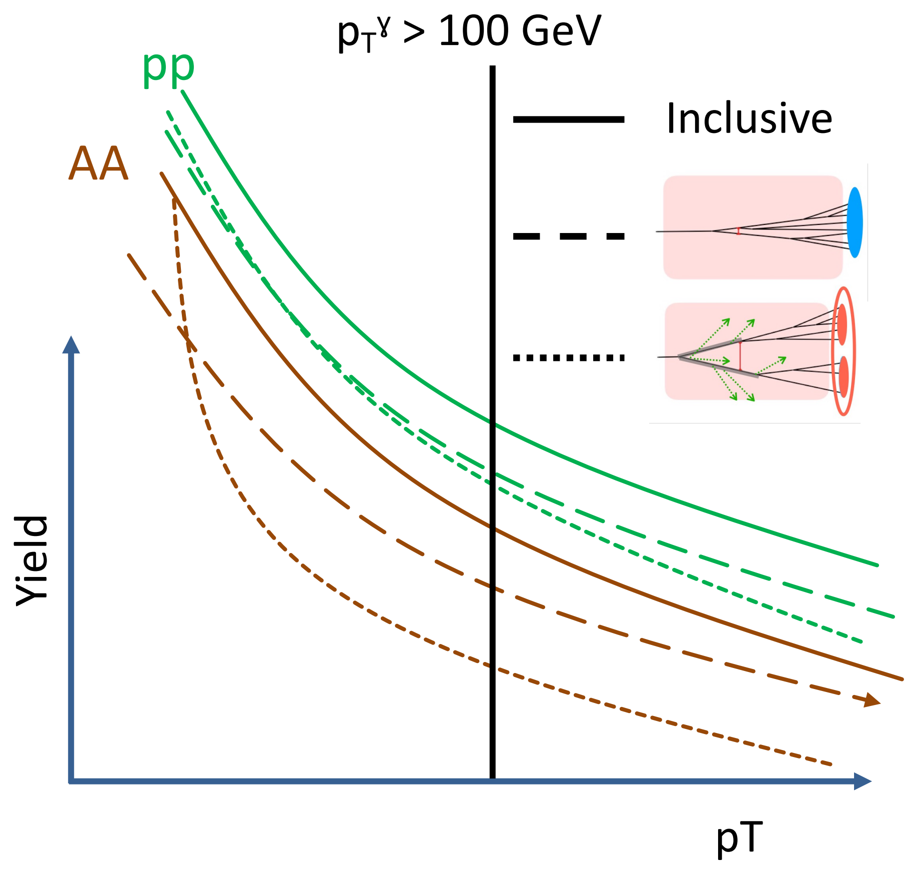


Phys. Rev. Lett. 123, 042001 (2019)





Photon-tagged Jet Substructure



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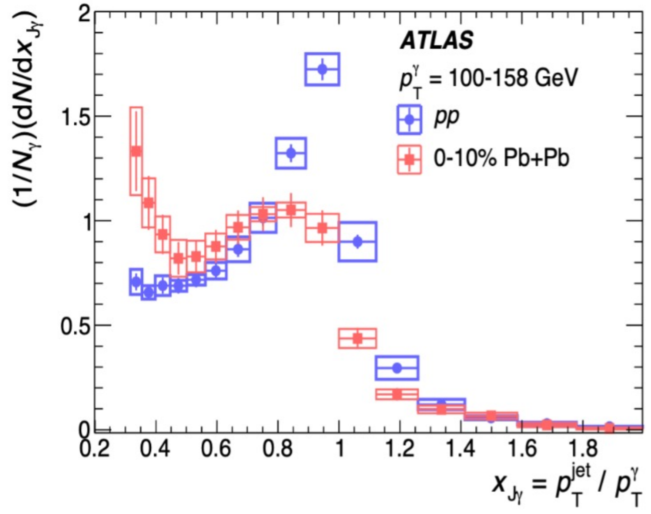
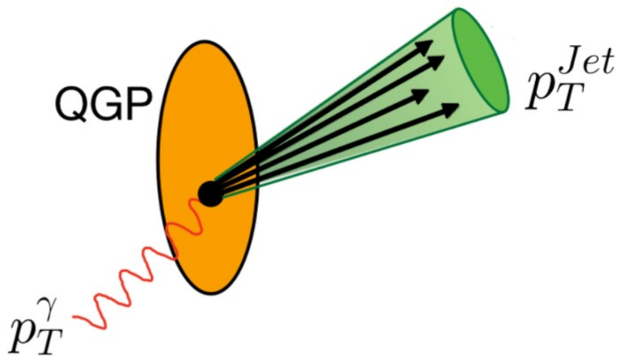
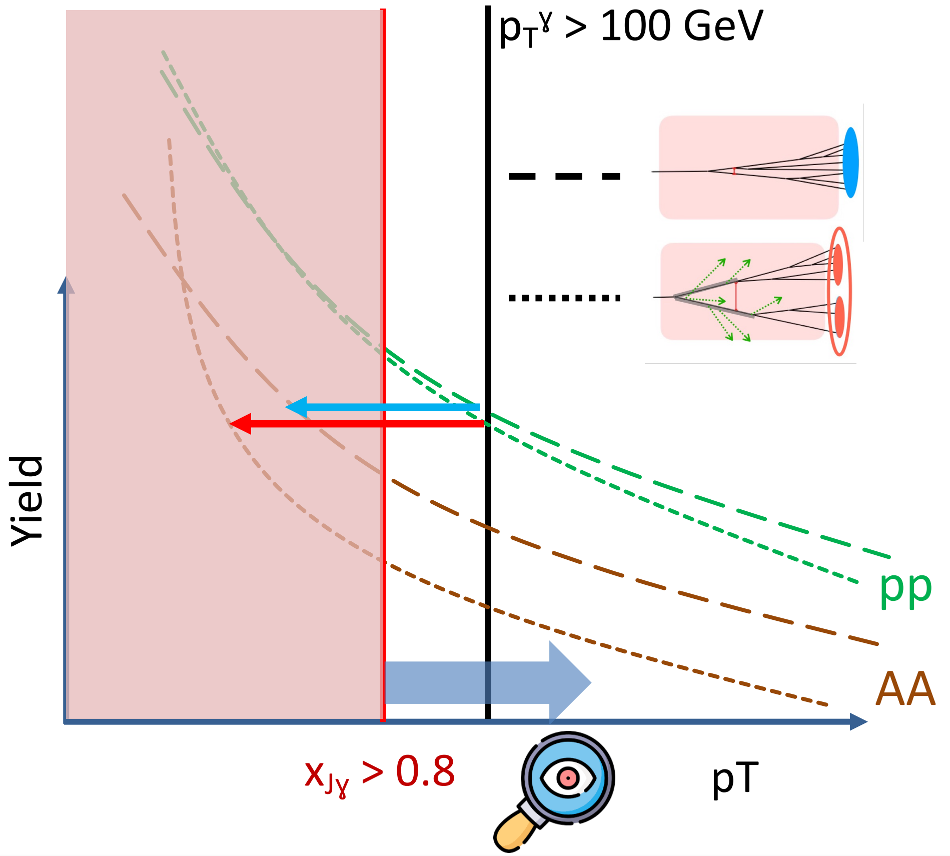
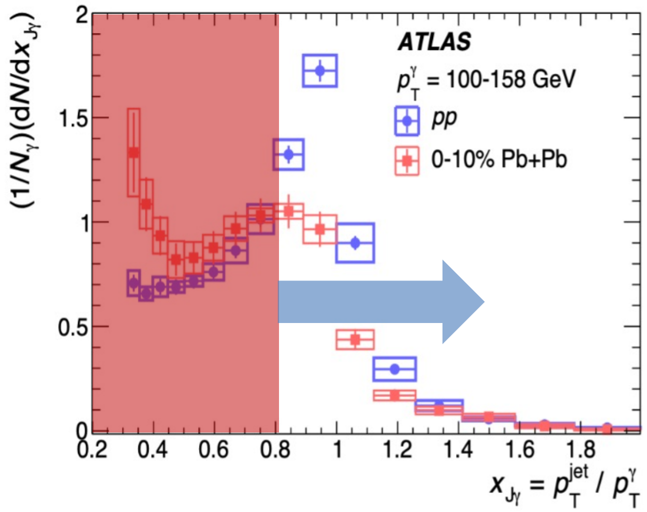


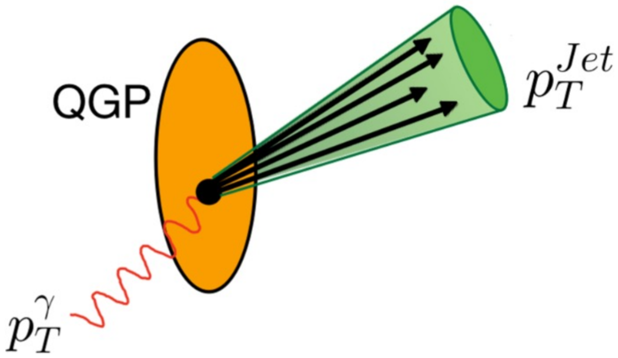


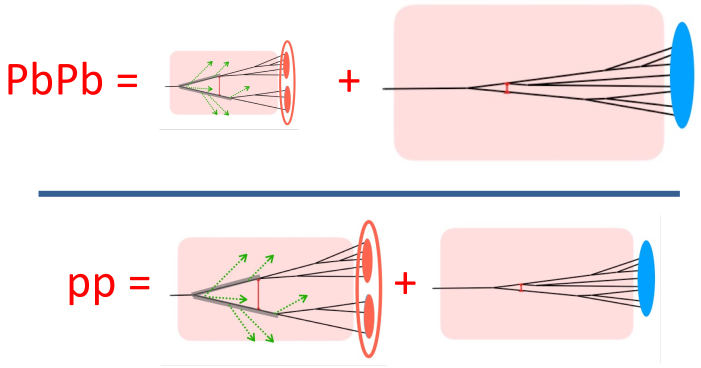
CMS : Photon-tagged jet r_g for $x_{J\gamma} > 0.8$

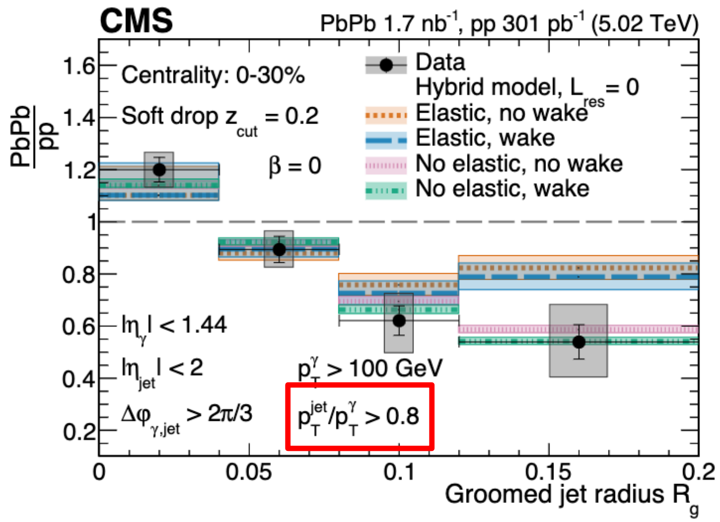
"It is found that jets with $p^{jet}_T / p^{\gamma}_T > 0.8$, i.e., those that closely balance the photon p^{γ}_T , are narrower in PbPb than in pp collisions."







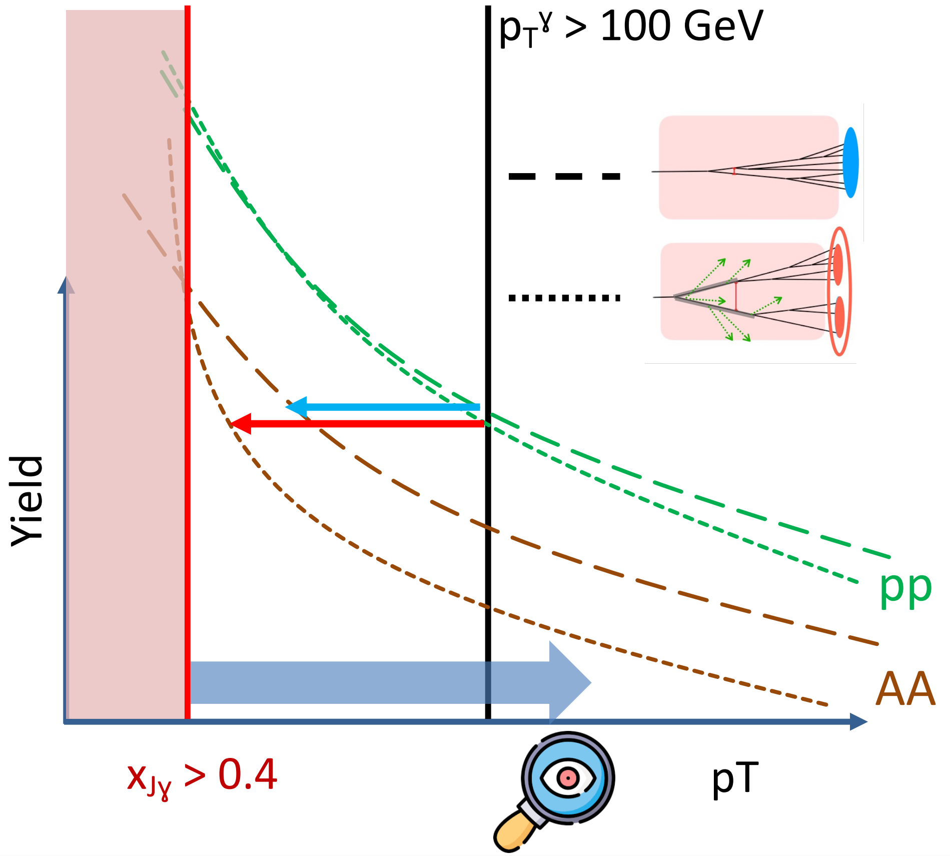


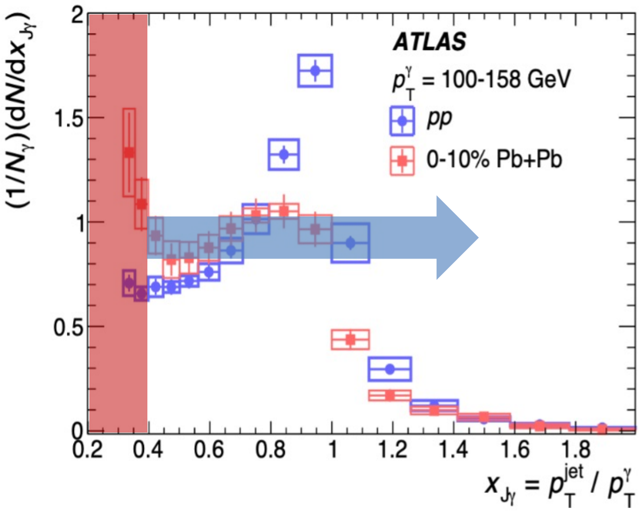


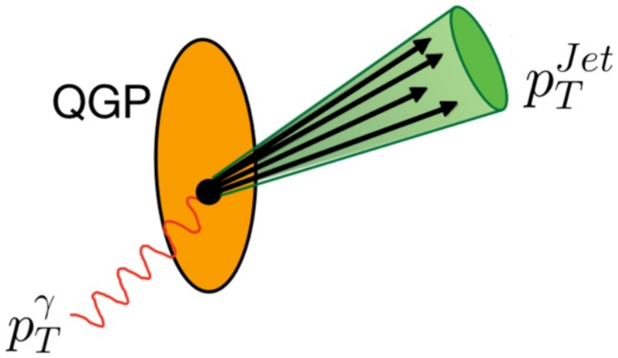
arXiv:2405.02737

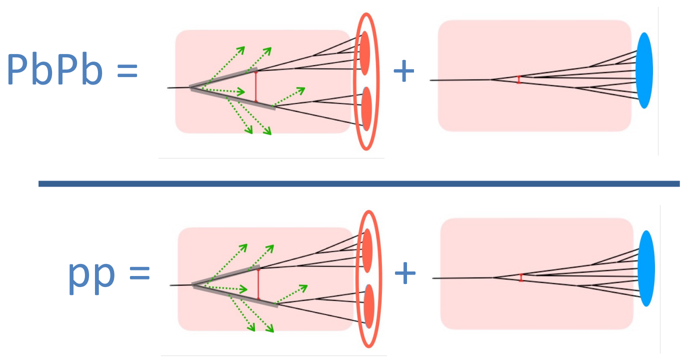
CMS : Photon-tagged jet r_g for $x_{J\gamma} > 0.4$

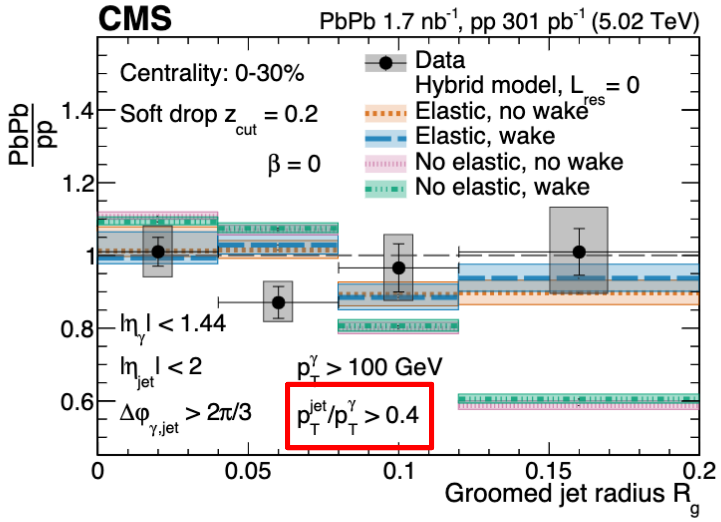
"Relaxing the selection to include jets with $p^{jet}_T / p^{\gamma}_T > 0.4$ reduces the narrowing of the angular structure of jets in PbPb relative to the pp reference."







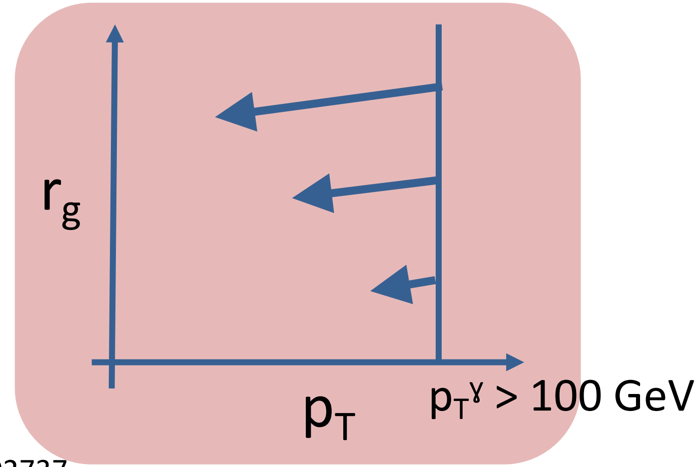




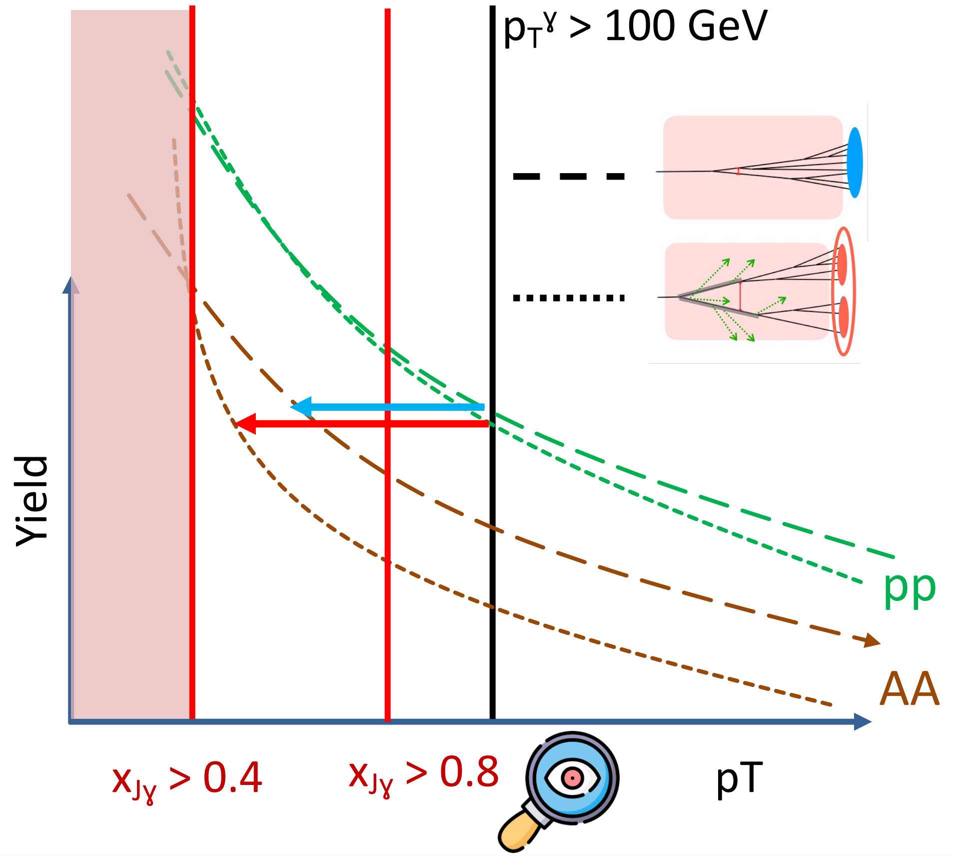
arXiv:2405.02737

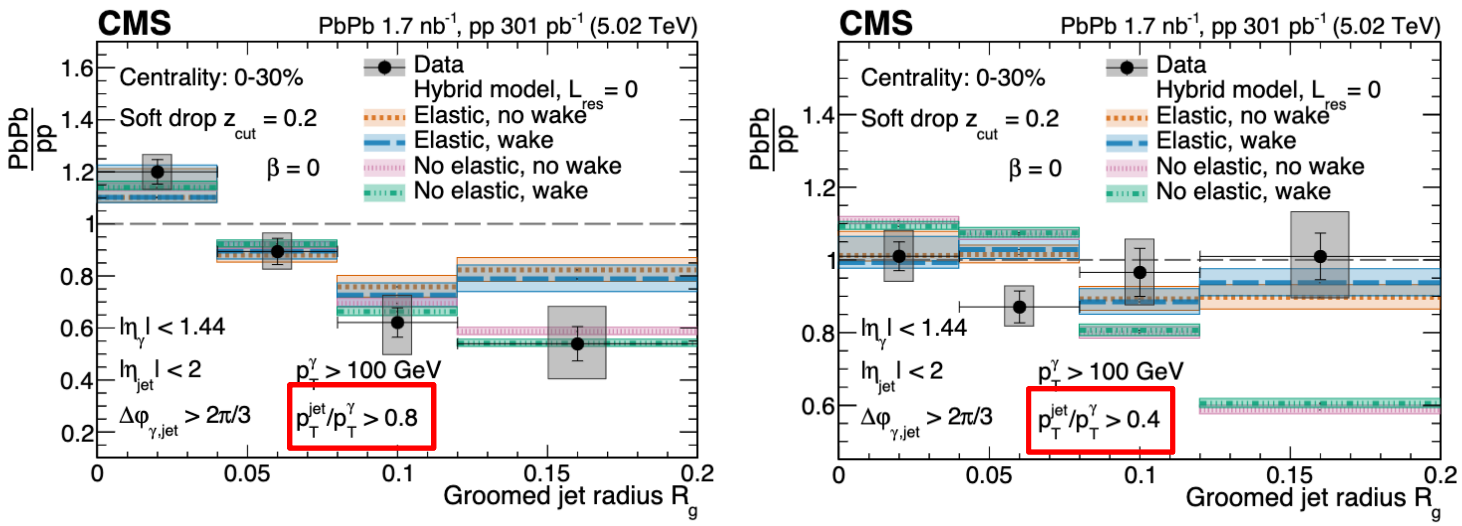
CMS : Photon-tagged jet r_g for ($x_{J\gamma}$ > 0.8 vs. $x_{J\gamma}$ > 0.4)

"In contrast to the trends observed by the ALICE and ATLAS Collaborations for R_g in inclusive jet events, we do not observe a narrowing of the substructure of jets in R_g within the experimental uncertainties when selecting jets with $x_{\gamma j}$ > 0.4 and $p_{\gamma T}$ > 100 GeV."

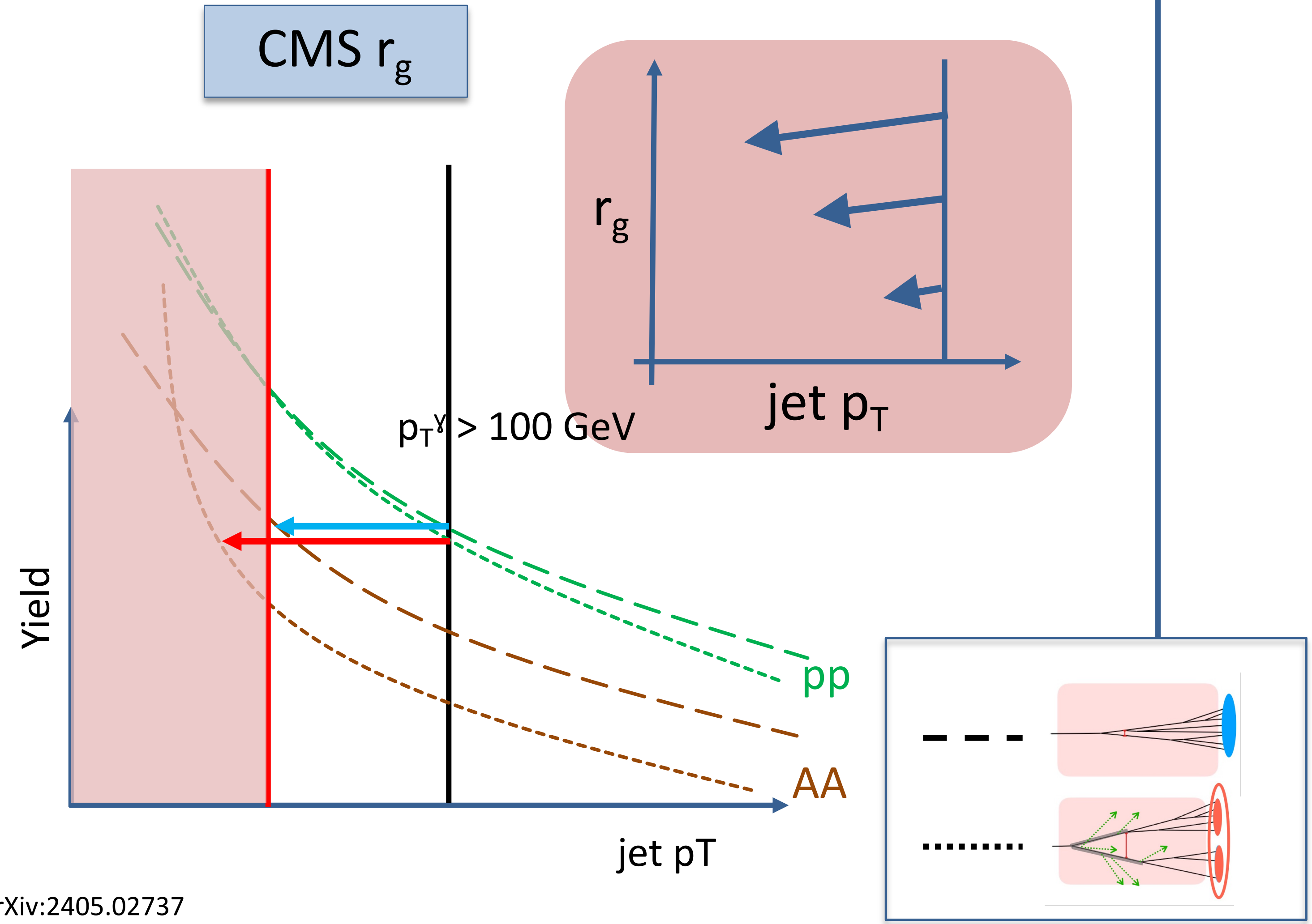


arXiv:2405.02737





CMS vs. ATLAS measurement interpretations



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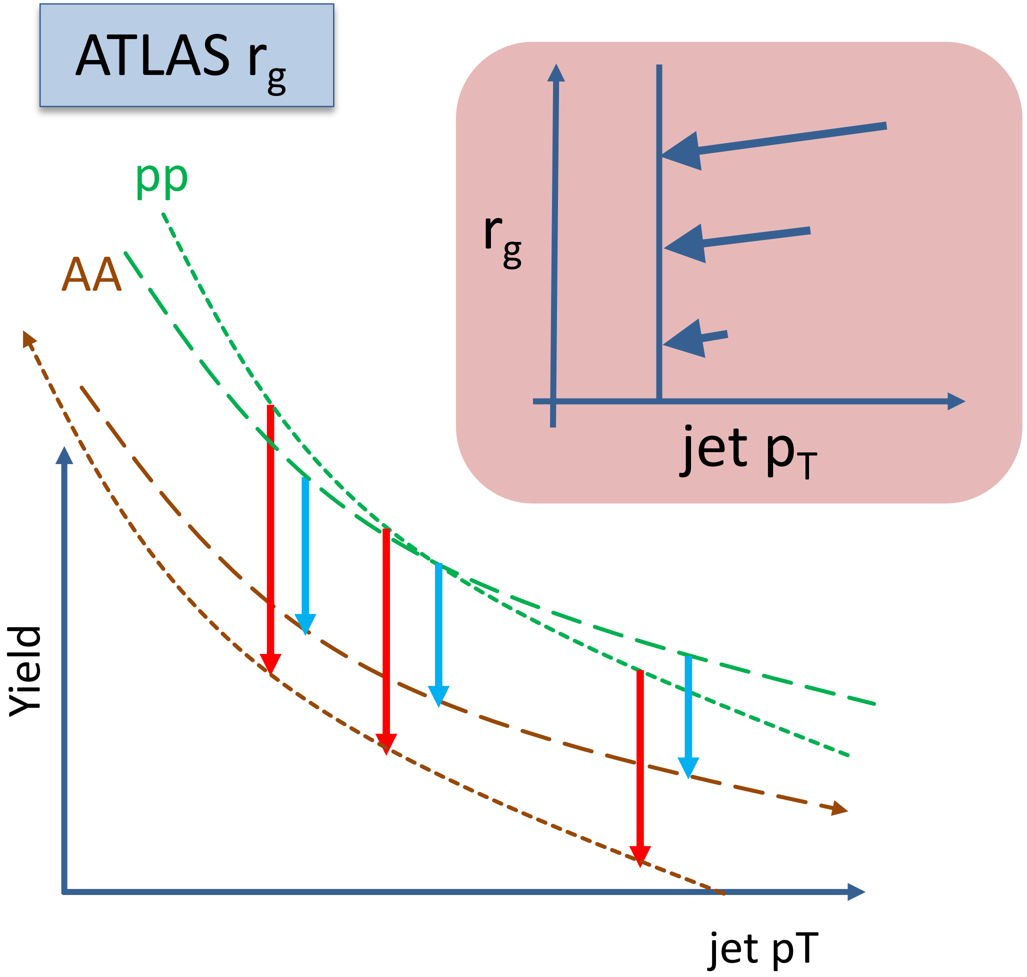

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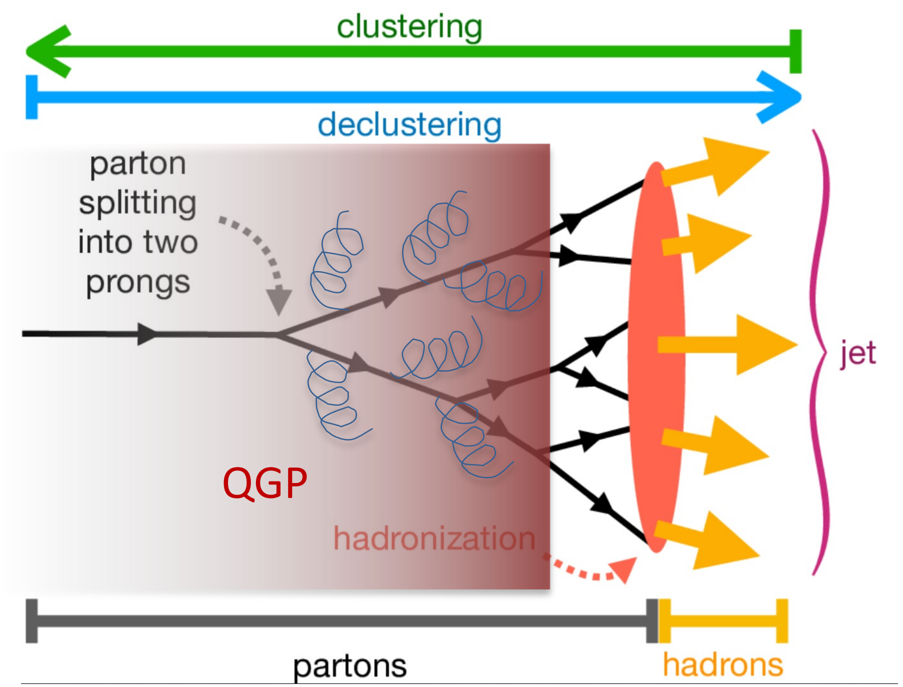
Next Generation Measurements?

Two-point energy correlators clearly identify the effective scales of the jet-QGP interactions determining the energy loss



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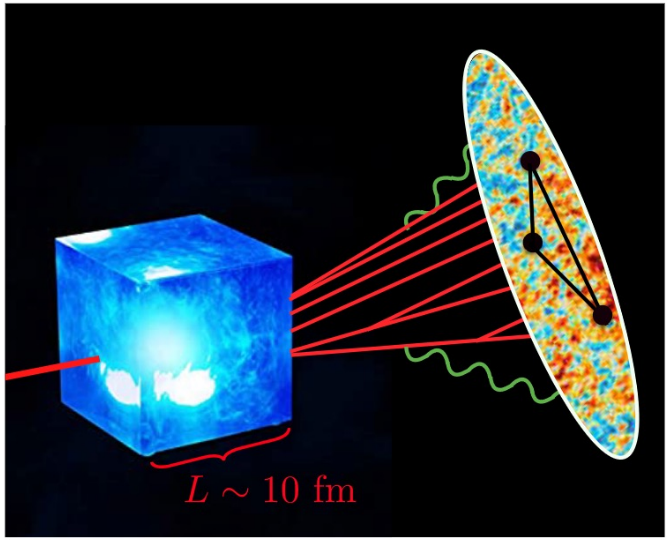
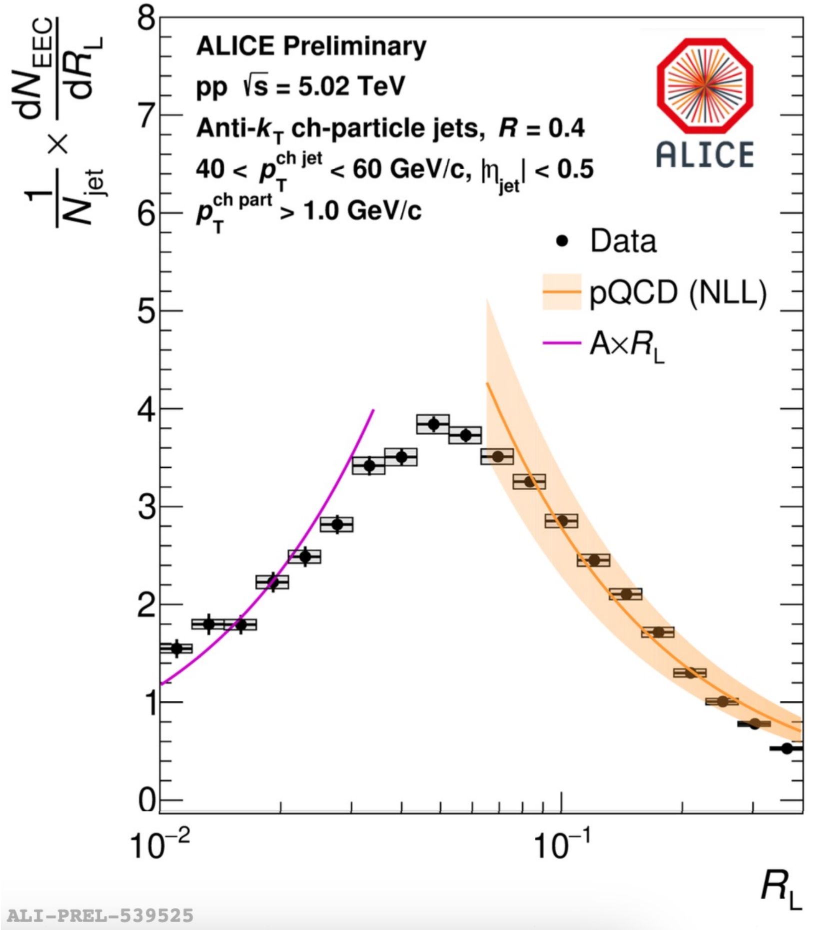


ALICE `23



Lawrence Livermore National Laboratory

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