# Summary of jet track

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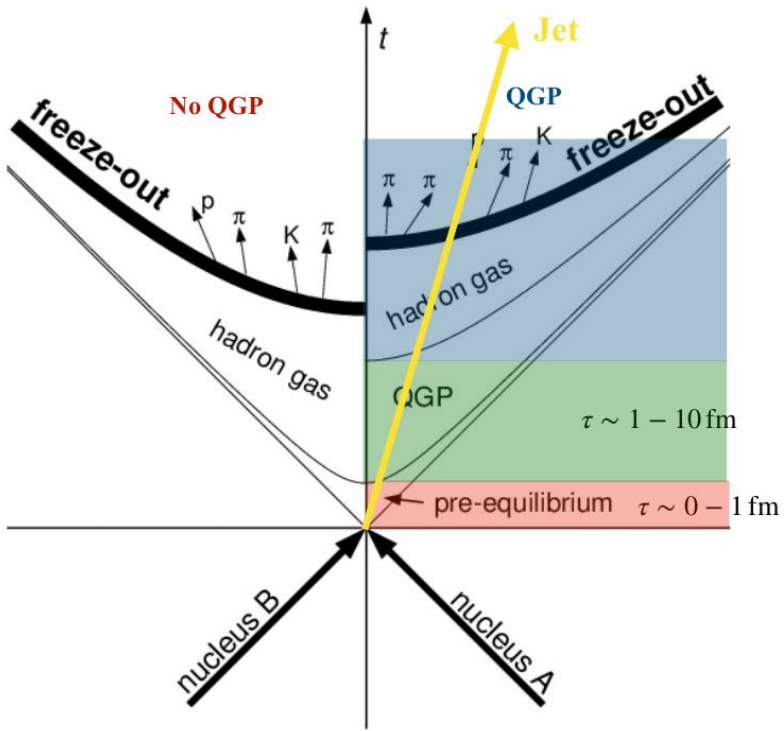
w/
João Barata, Leonardo Barreto, Yi Chen, Guilherme Milhano

# Introduction

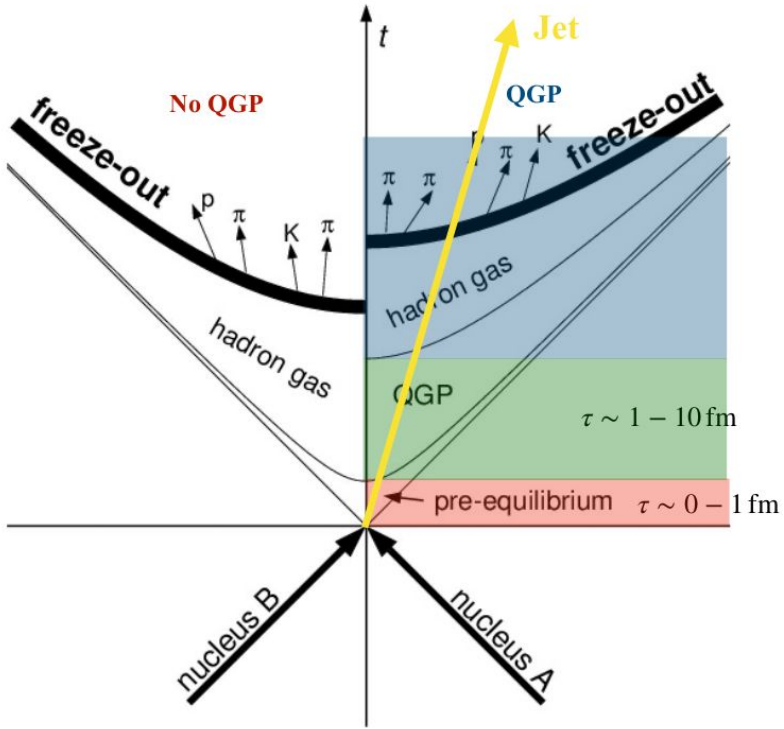
- Jet propagation through the medium: **multiscale problem**




cartoon by Joao Barata

# Introduction

- Jet propagation through the medium: **multiscale problem**
- Some components **cannot be described perturbatively**:
  - Initial conditions (e.g. almost classical glasma)
  - Hydro medium expansion
  - Response of the medium to the jet (back-reaction, wake)

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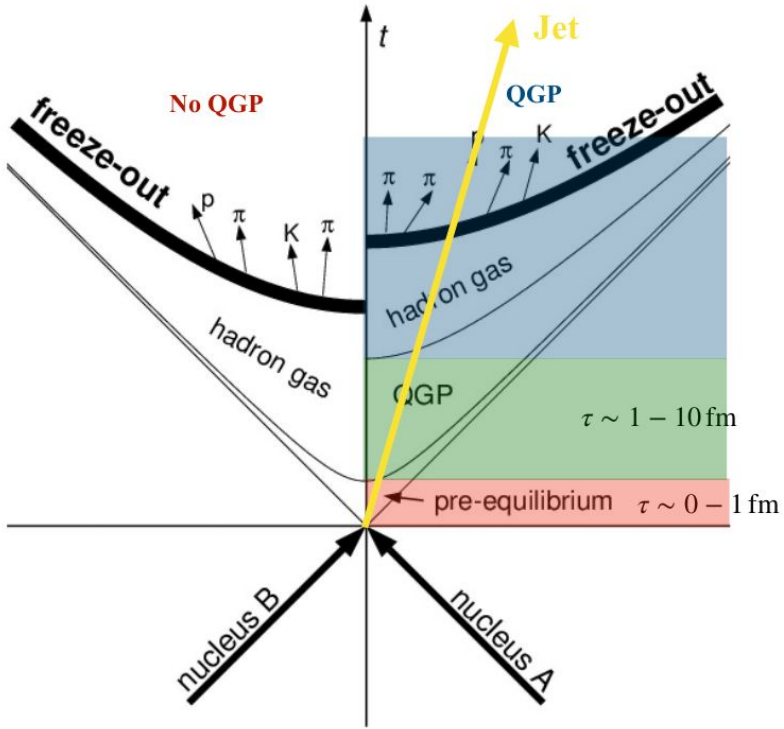
=> understanding is not just a matter of increasing precision

=> understanding is also a matter of designing **approaches to factorize the problem**

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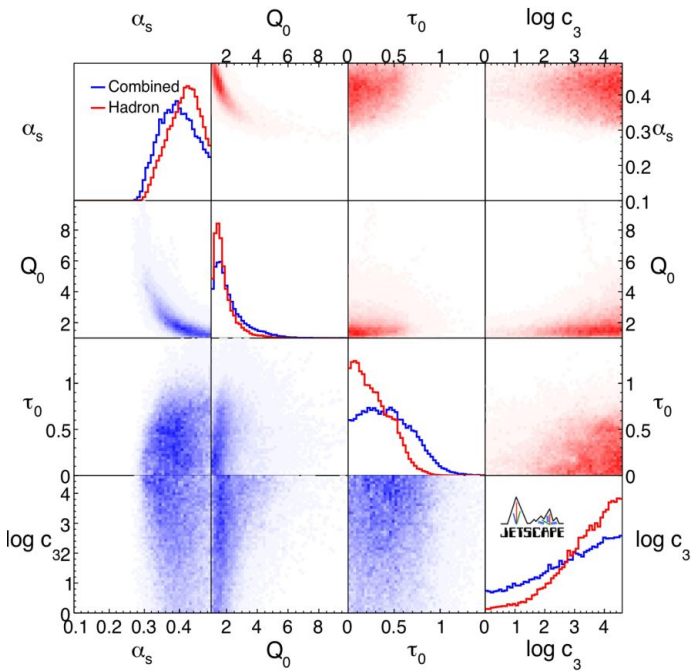
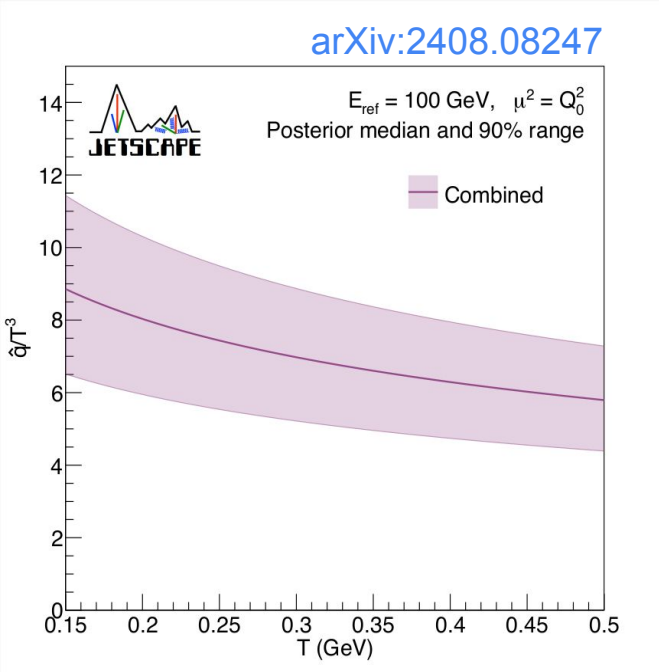
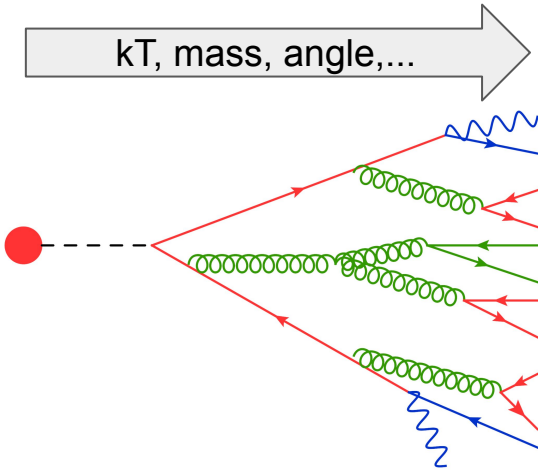
# More precision => more understanding?



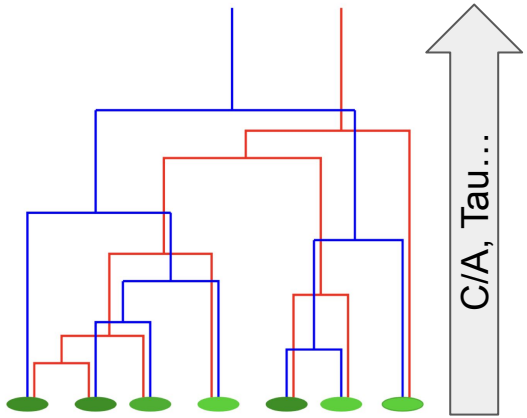




- **Ultimate precision**, e.g. JETScape project … very important but cannot tell us all.
  - **Meaning of extracted parameters** connected with given implementation of energy loss.
  - Not simple to decide if a given **physical mechanism** is present or absent.

# Less precision => more understanding I.: Space-time structure of jet




- **PS ordering**: certain level of arbitrariness since intermediate states are not directly measurable:
  - Current in-medium PS ordering based on vacuum: Pythia6 – virtuality;  Pythia8, Herwig … kT or angular ordering (accounts for interference effects => NLL precision)
- Additionally, several **jet re-clustering** schemes can be used when studying jets in the medium
  - Generalized-kt: Angular ordered, kT order, time ordered
- In both cases we **need to assign a space-time structure to interact with the QGP**

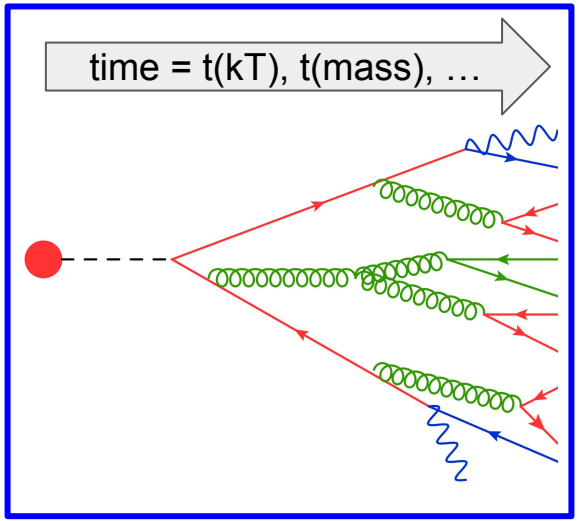


# Less precision => more understanding I.: Space-time structure of jet

- Impact on jet quenching studied via:

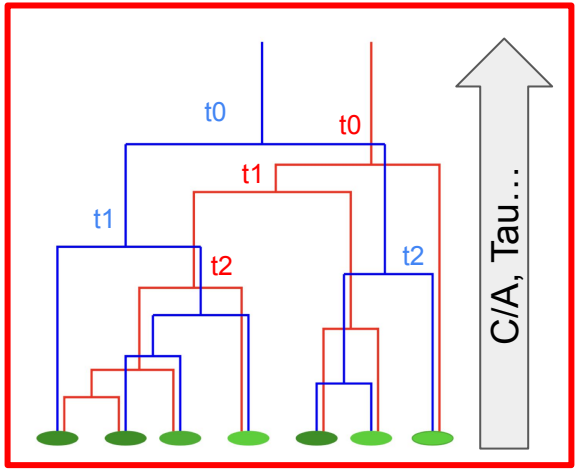
  - Different PS ordering with toy-model (L. Apolinário et al - *to appear soon in arXiv*)

  => different intrinsic jet time structure




  - Different reclustering from final list of particles using different ordering prescriptions …
    **an exercise being done at the workshop**

  => different assignments of time structure to the same jet




- Is the energy loss going to be different? (Yes)

# Less precision => more understanding II.: Basic features of jet quenching

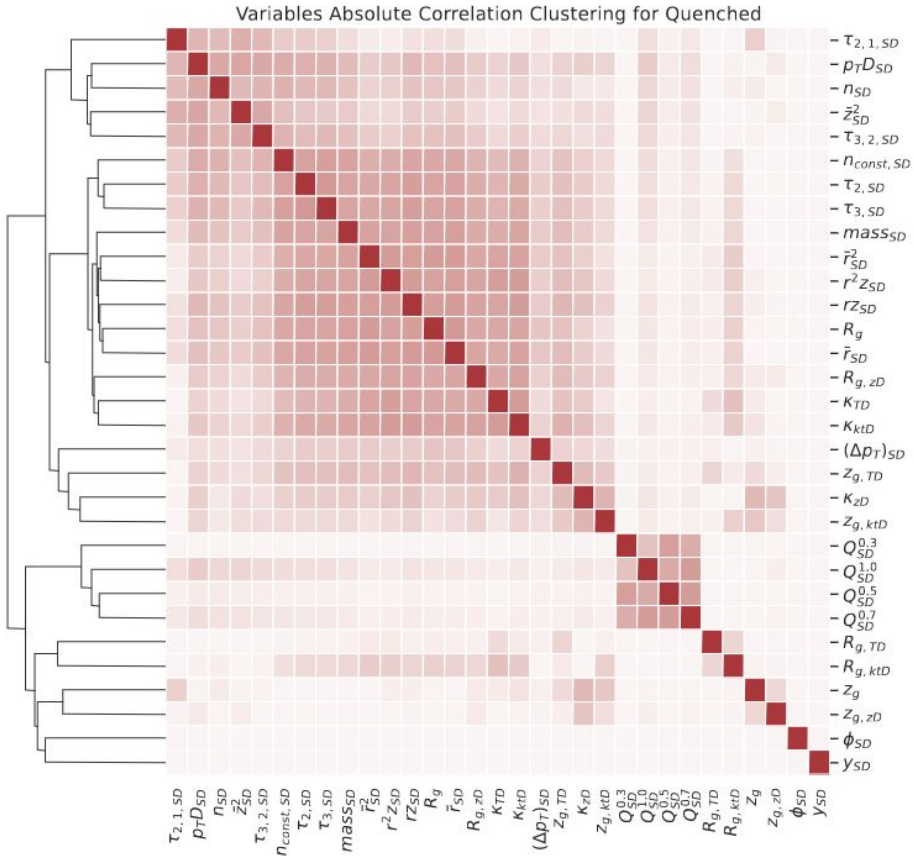
Design a set of **orthogonal observables** accessible to simple **analytic calculations** of energy loss implementing important basic features:

- Color coherence (or a lack of it)
- Radiative-only, collisional-only, or L^3 energy loss
- Modifications to the in-medium splitting functions (or lack of it)
- …

=> Comparison with the data may then help establishing the presence / absence of a given feature in the nature

How to find the set of orthogonal observables?

# Set of orthogonal observables



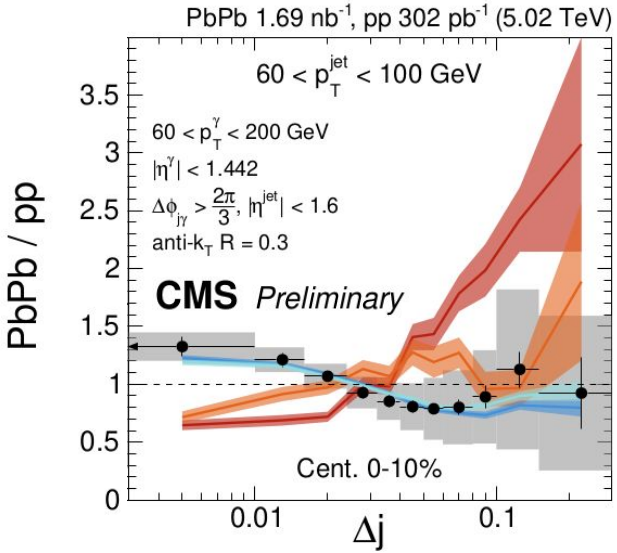

Analysis of correlations between “jet shape” observables [arxiv:2304.07196]

=> 31 obserables reduced to about 5 + jet kinematics

… clearly, need to add inter-jet observables, non-integrated jet shapes, etc.

# Set of orthogonal observables

- Needed also to **avoid re-inventing the measurements**
- LHC provided 90+ papers on jet quenching => keep inventing new observables, e.g. WTA axis and E-scheme axis difference



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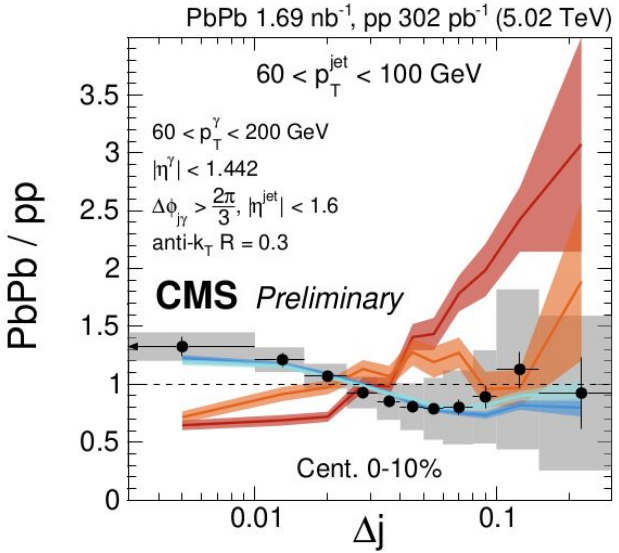
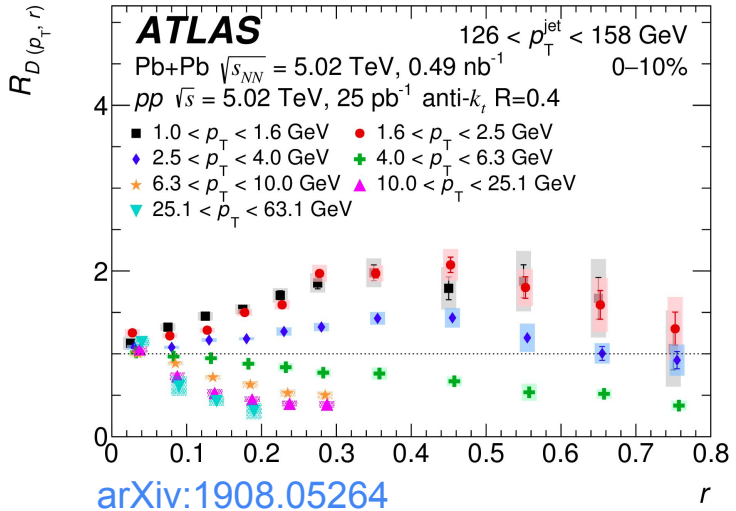


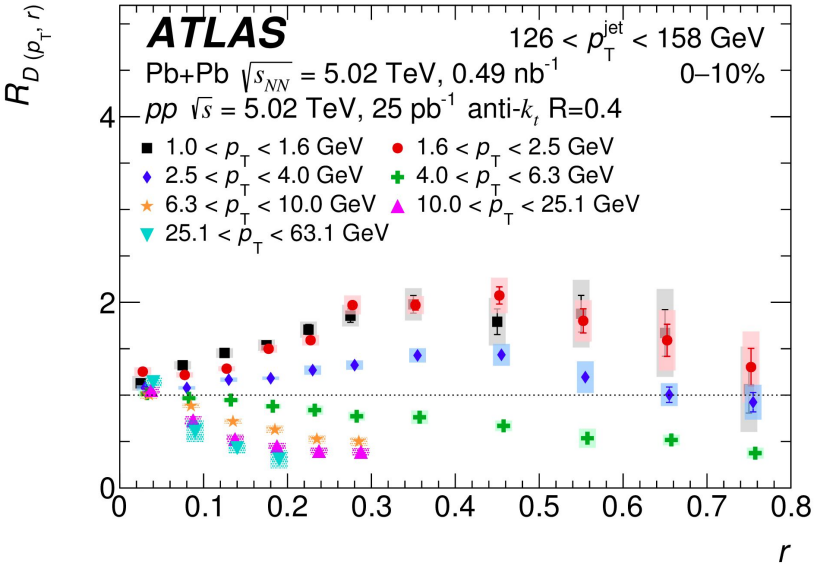

CMS-HIN-21-019

… is it orthogonal e.g. to <u>differential jet profiles</u>?




arXiv:1908.05264

# Unused observables




- Precise multi-differential jet substructure: differential in centrality, r, particle-pt, jet-pt.
- Published in PRC 100 (2019) 064901 (i.e. 5 years ago).
- Collected nice 41 citations:
  - Experimental work: 10
  - Review: 5
  - Proceedings: 13
  - Theory intro section: 13
  - **Theory results: 0**

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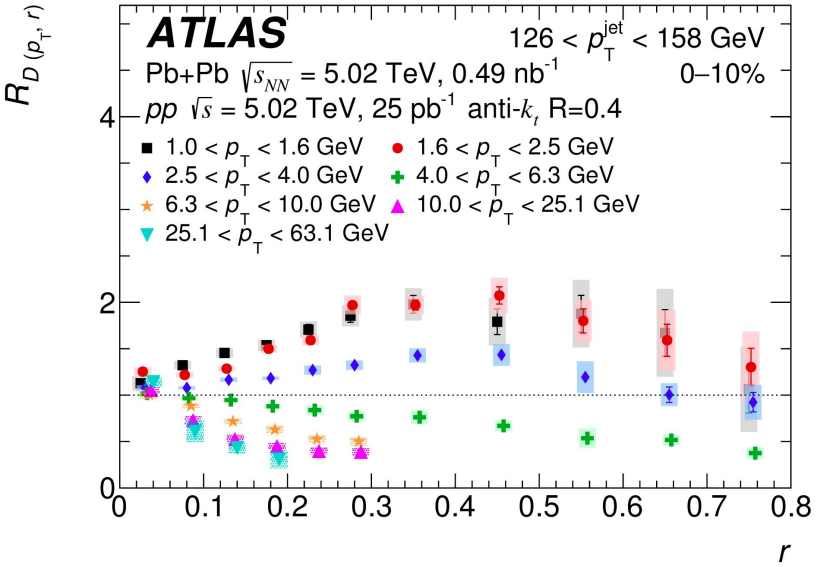


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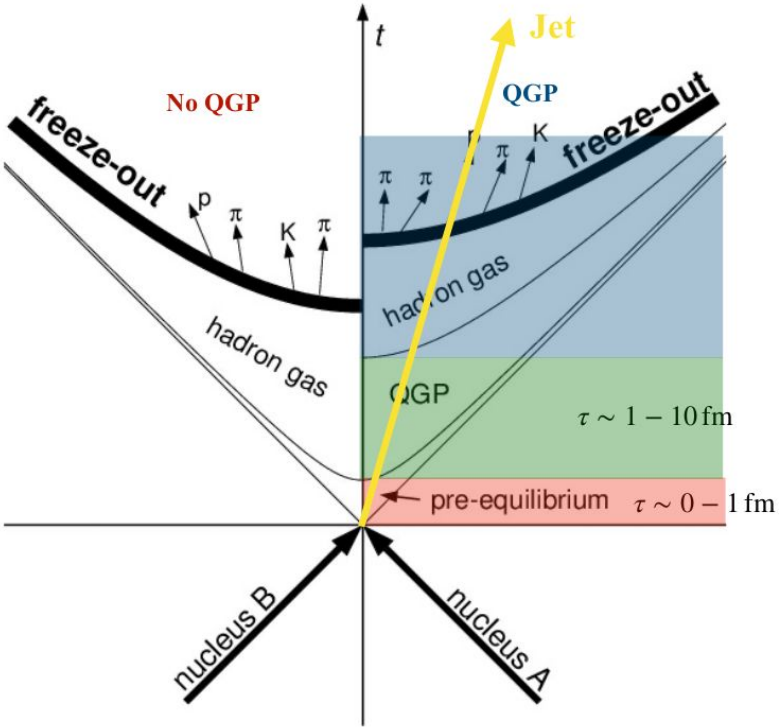
- How to avoid such situations?
  - Again, understanding if my new observables is orthogonal to previously measured (not problem of this one)
  - Delivering **RIVET analysis** is important!

# Probing multi-scale jet quenching

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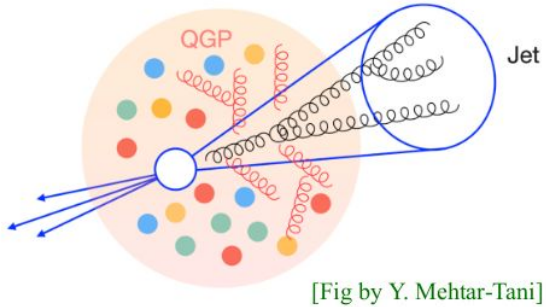
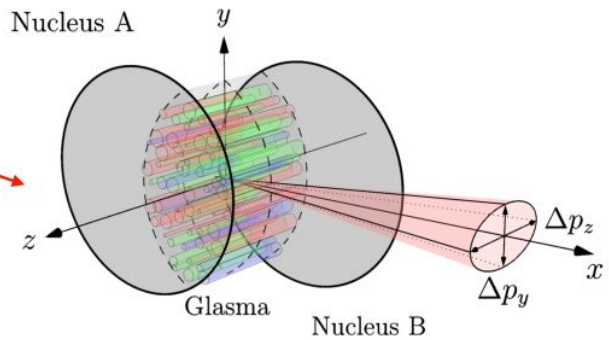



[Fig by Y. Mehtar-Tani]



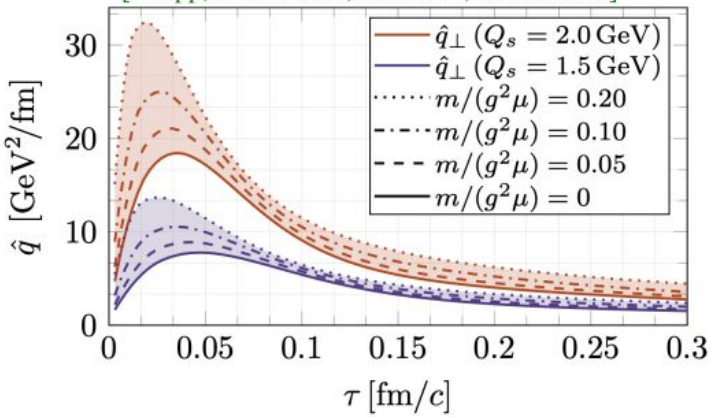

[A. App, D. I. Muller, D. Schuh, 2009.14206]

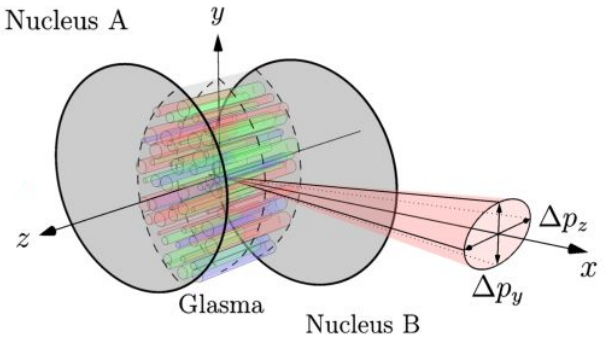
# Probing multi-scale jet quenching

$$\hat{q}_{\text{early}} \gg \hat{q}_{\text{hydro}}\,,\, \tau_{\text{hydro}} \gg \tau_{\text{early}}$$

Glasma phase may be connected with **significant qhat** => but no clear consensus (interference effects, certain level of arbitrariness) – may have rather small impact on the magnitude of energy loss

[A. Ipp, D. I. Muller, D. Schuh, 2009.14206]

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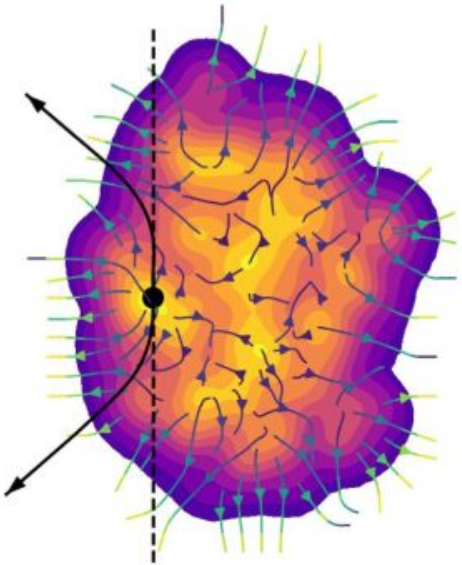
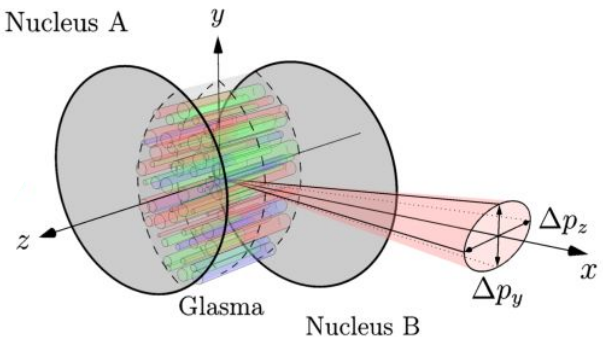


… but what could have an impact are **early time anisotropies**
=> should study intra-jet azimuthal structure, e.g. **inter-jet v2**
… clearly an **orthogonal observable** to any previously measured, sensitive e.g. to size of temperature gradients

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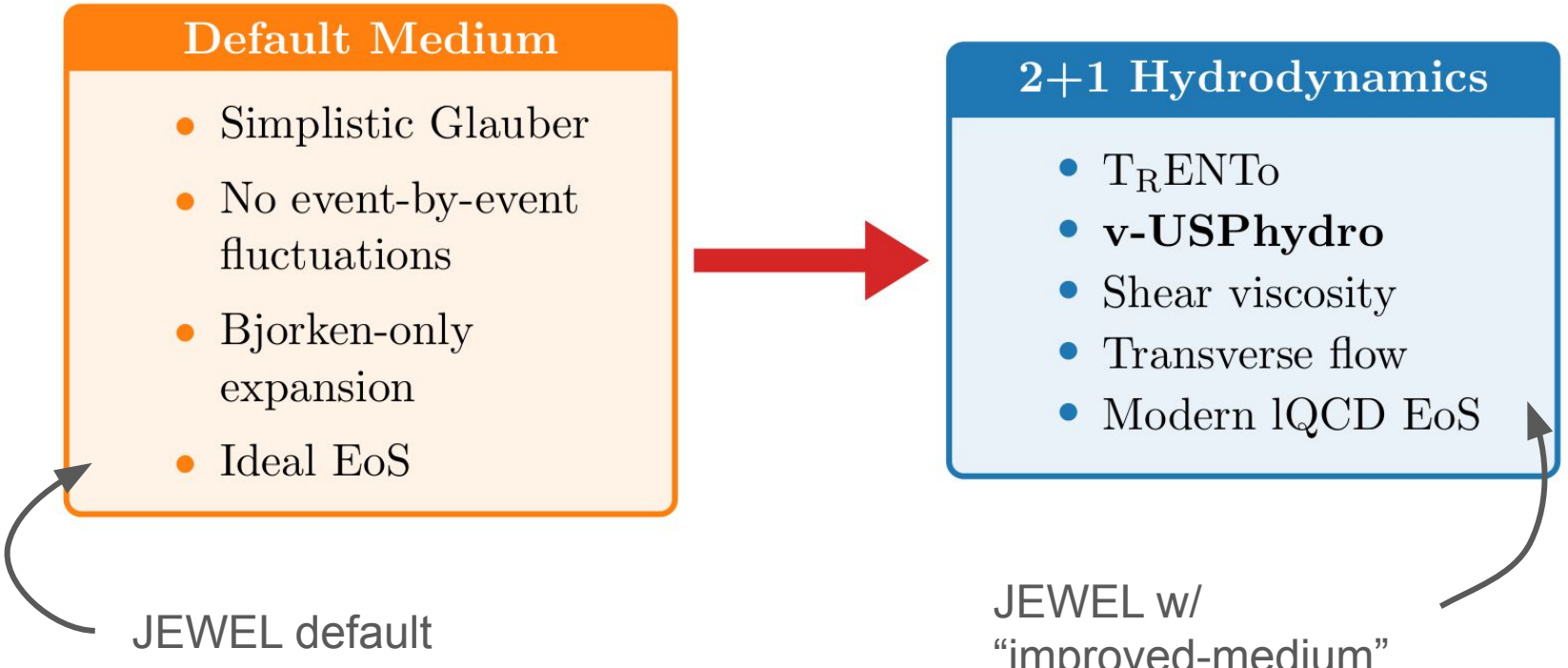
# Probing multi-scale jet quenching: Probing two extremes with JEWEL

Apply a **realistic description** using a **jet-hydro** interface



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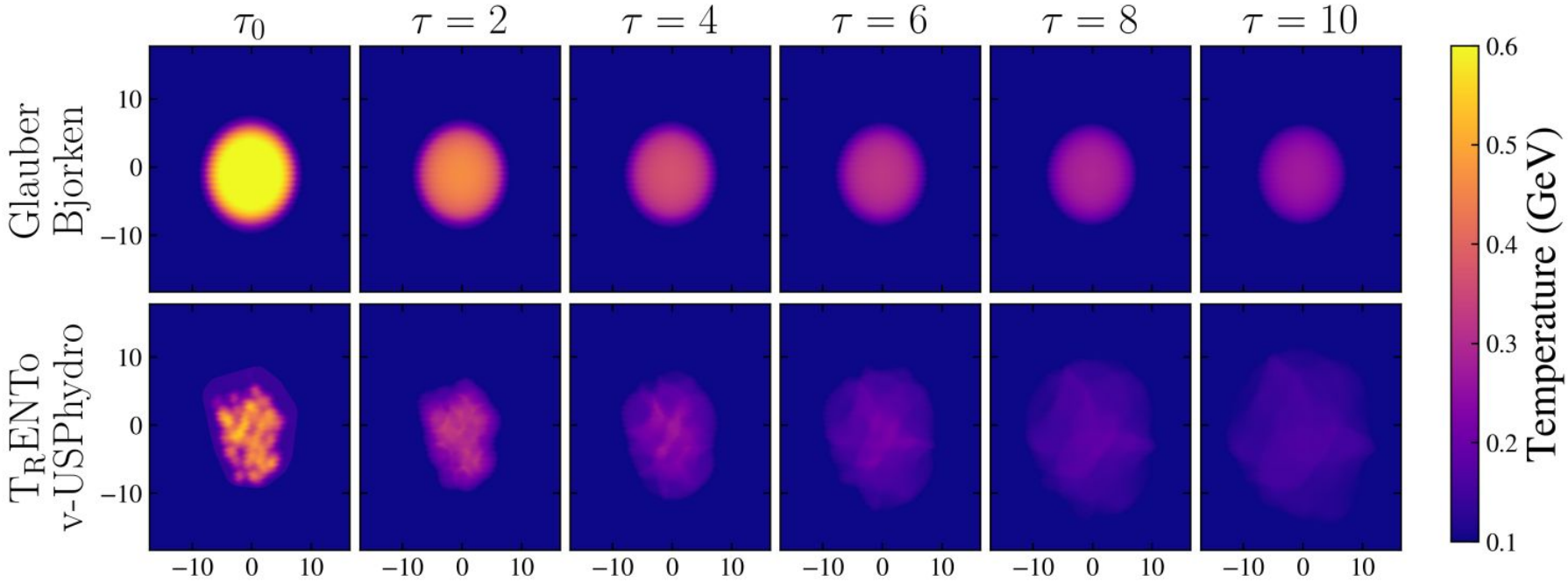
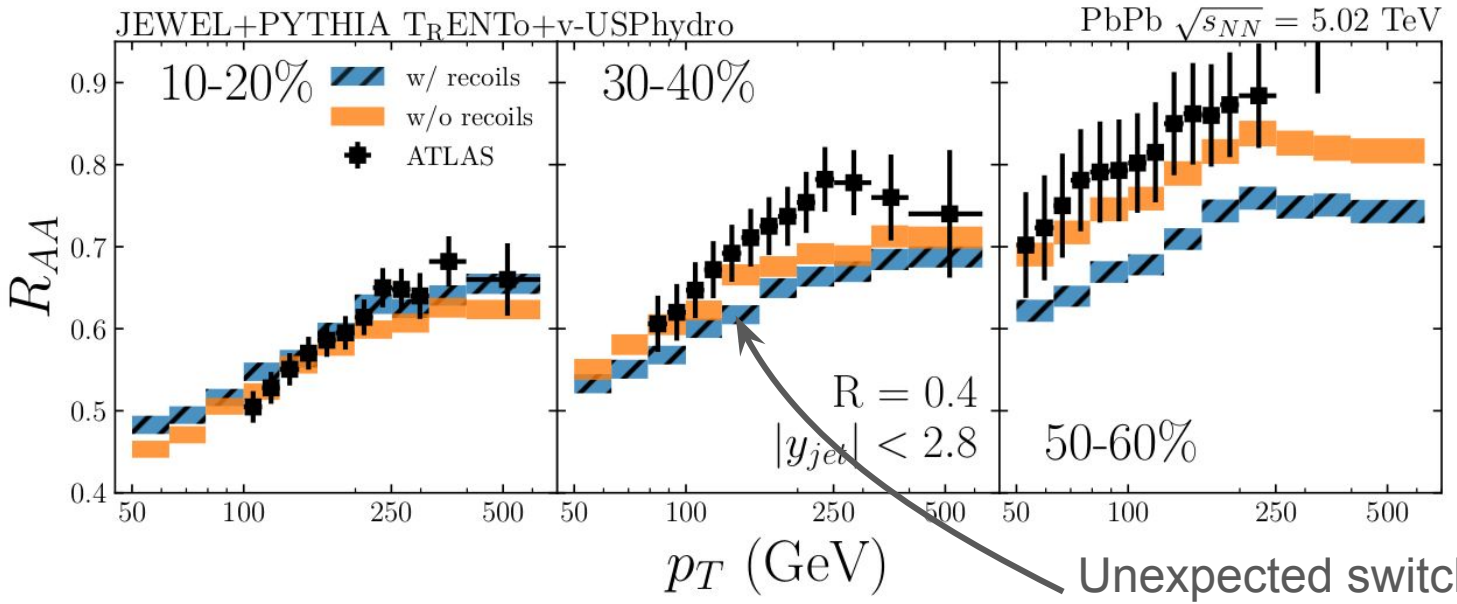


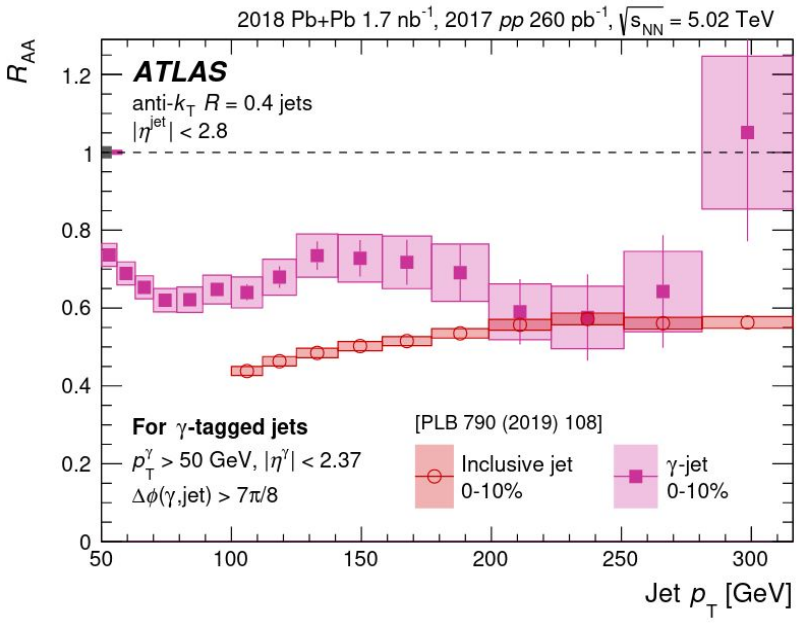
# Probing multi-scale jet quenching: Probing two extremes with JEWEL

Goal: compare impact of improved medium modelling on observables
… ongoing effort – not all understood yet

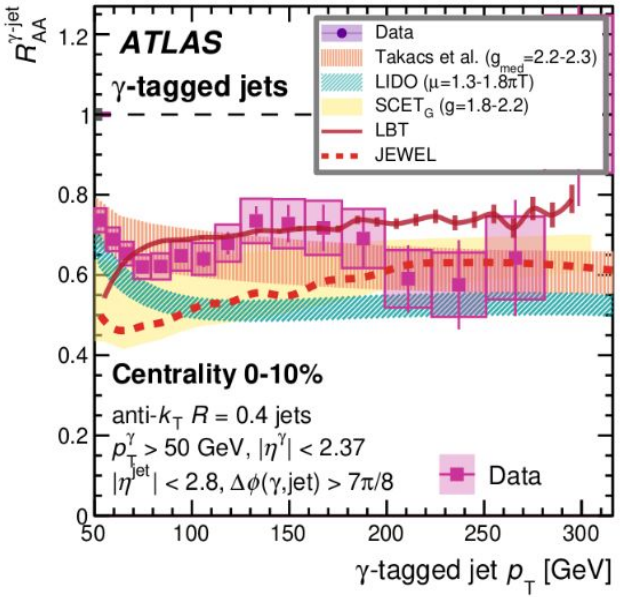



Unexpected switch of the order of suppression

# Jet quenching: need for understanding the reference




arXiv:2303.10090




- Gamma-jets often viewed as optimal system to probe jet quenching
- However, theory has problems reproducing the data => **reference may be an important** part of the story

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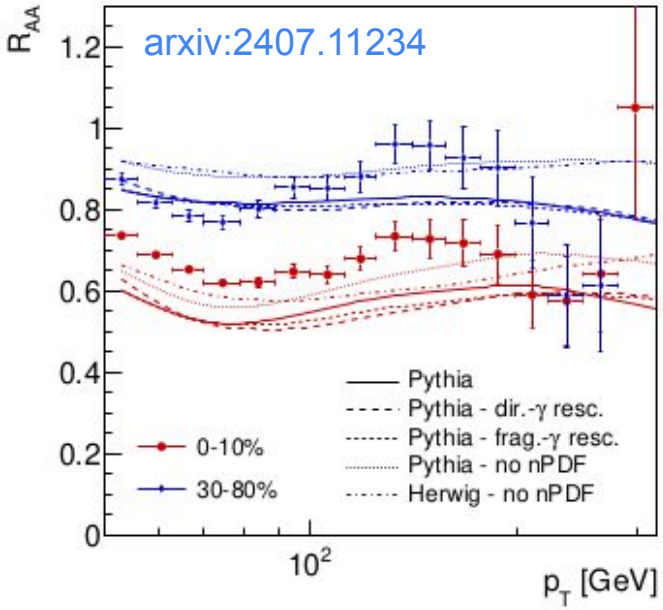


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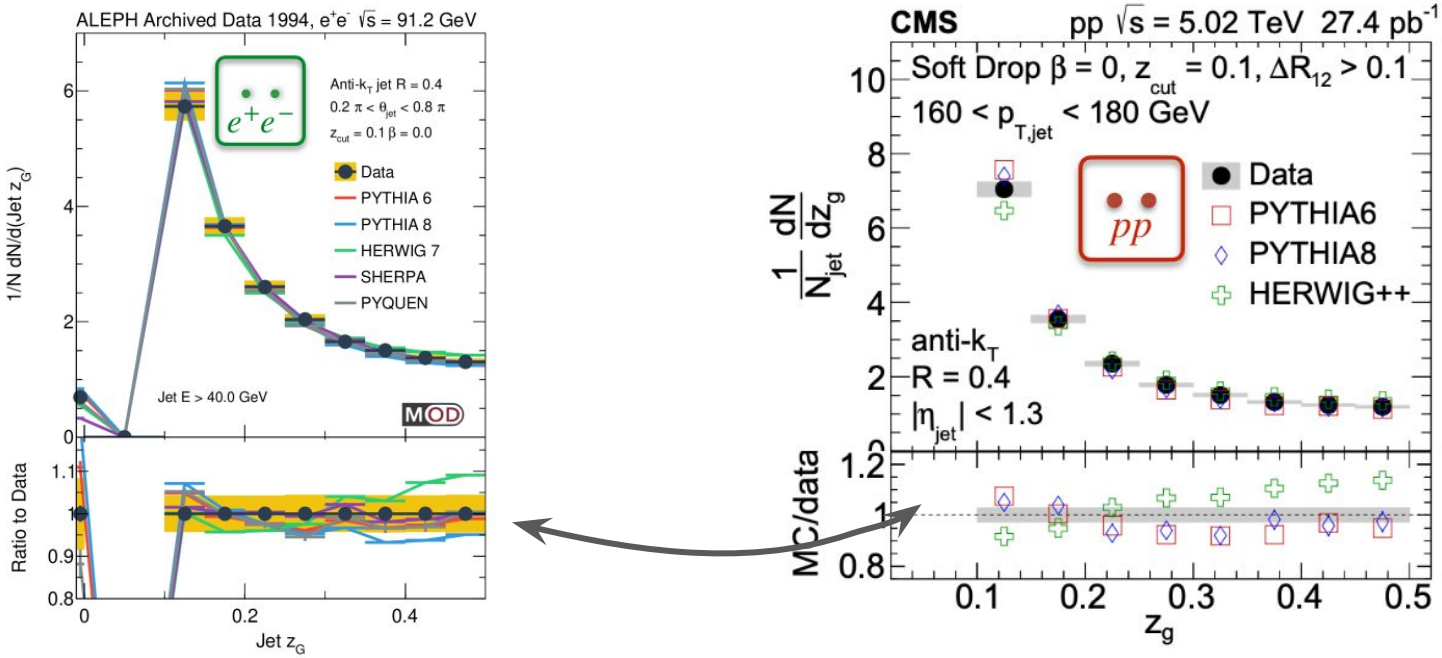


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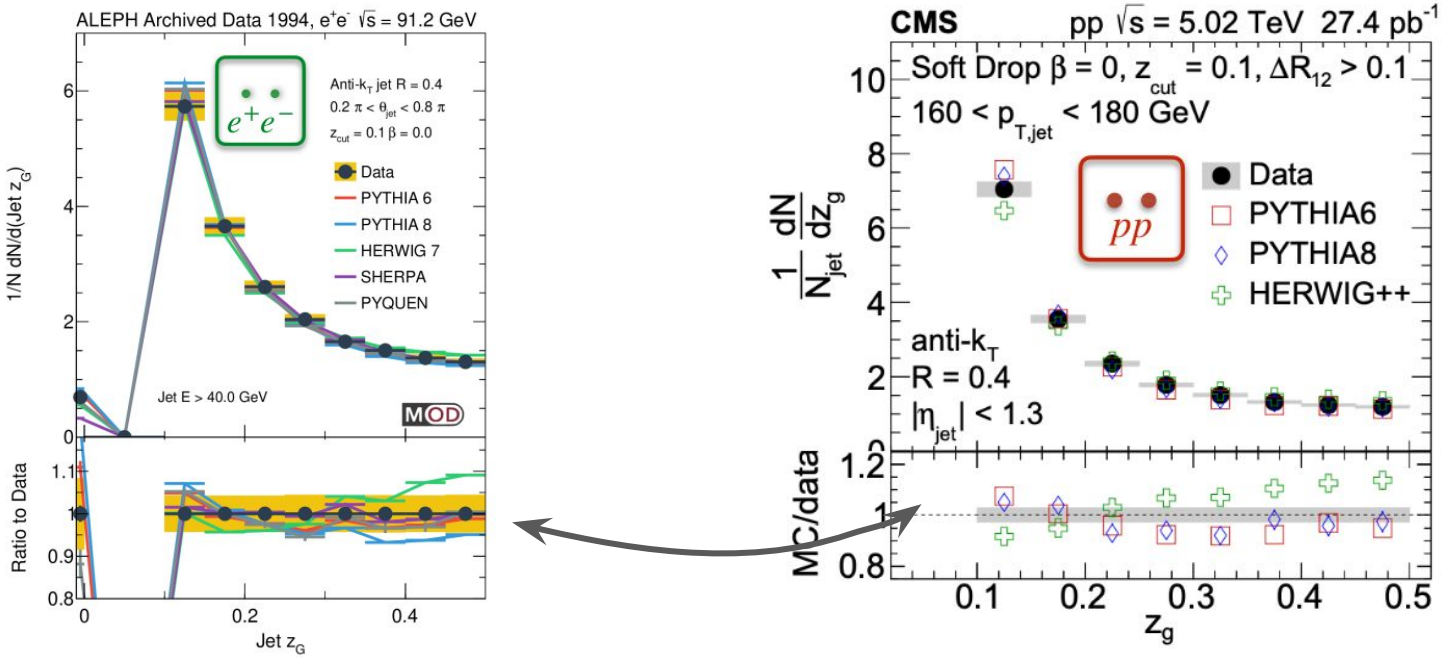


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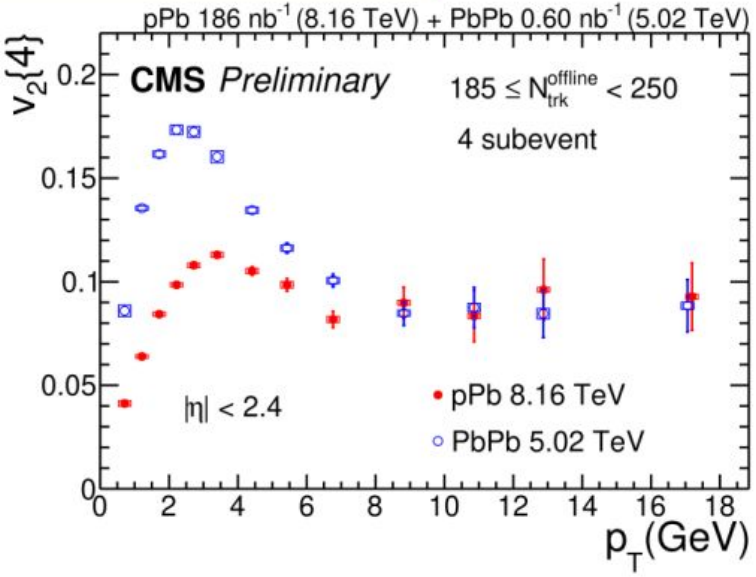
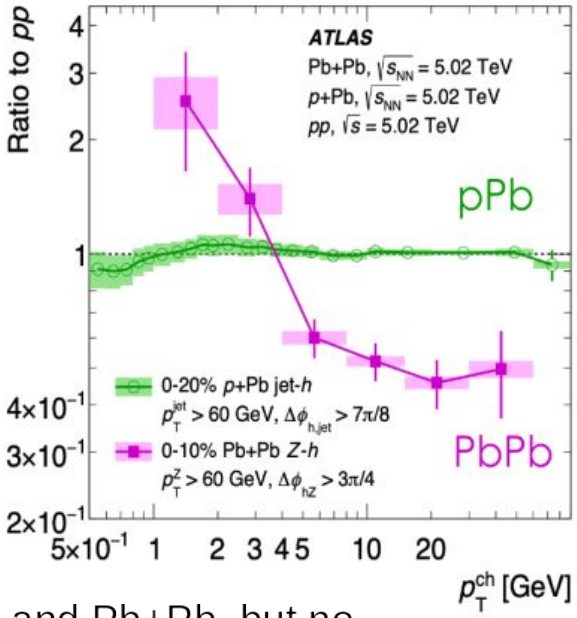
- However, theory has problems reproducing the data => **reference is important** part of the story => for some observables one can use **e+e- data** to improve tuning … and use of **NLO generators** (Powheg) also important

# High-pt v2 and energy loss

CMS-PAS-HIN-23-002




PRL 131 (2023) 072301




- **Charged particle v2** at high-pt consistent between p+Pb and Pb+Pb, but no energy loss seen in p+Pb => puzzle?

Measured p+Pb to pp ratio of **yields of hadrons** produced

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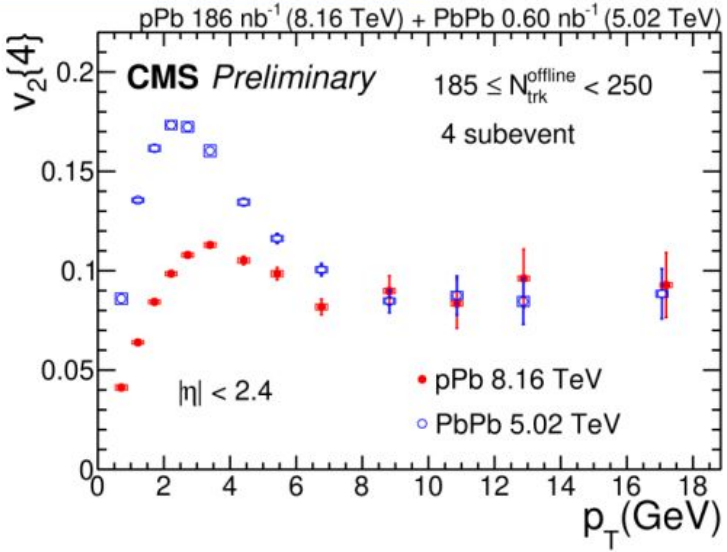
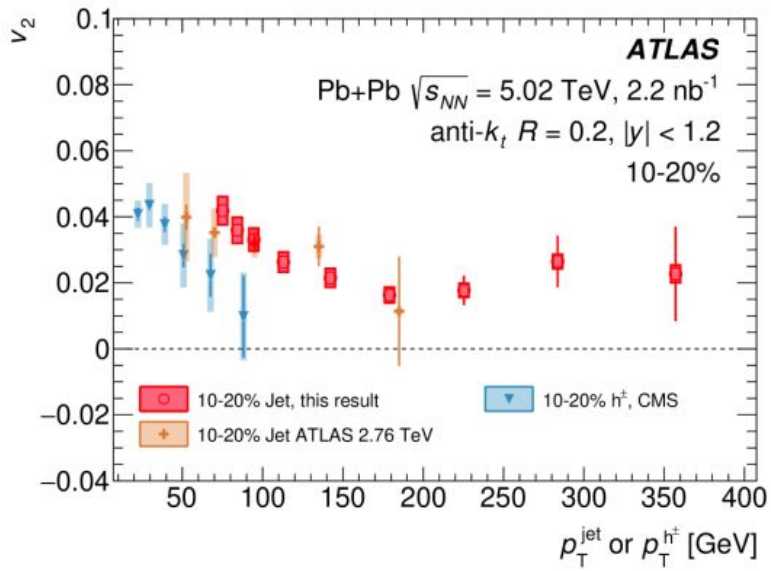



PRC 105 (2022) 064903




- **Charged particle v2** at high-pt consistent between p+Pb and Pb+Pb, but no energy loss seen in p+Pb => puzzle?
- Non-zero **jet v2** measured **up to high jet pt** in Pb+Pb => natural would be to measure jet v2 in p+Pb as well … but biases by soft-hard correlations?
  => use MC to explore

# Summary

- Jet quenching is a multiscale complex problem
- Important is to discuss approaches how to factorize the problem. Examples:
  - **PS ordering**: Toy PS MC can tell us the impact of PS ordering on observable jet quenching (**complementary efforts via the workshop)**.
  - Finding set of orthogonal observables accessible t**o analytic calculations** to test important basic features of quenching (e.g. coherence)
- Experiment:
  - Knowing **how orthogonal** is my new observable to the old one is important
  - Delivering Rivet for analyses is important
- New orthogonal observable: **inter-jet v2** … important to understand impact of early time anisotropies on jet quenching
- Impact of **precise medium modelling** tested by comparing two “extremes” within JEWEL MC
- Understanding jet quenching <=> understanding **reference** (tunings of MC, NLO MC, reweighting –> systematics)