The Imprint of Preequilibrium in Jet Flow and Suppression

[2101.01742, 2103.14676, 2402.07869]

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with: Daniel Pablos,

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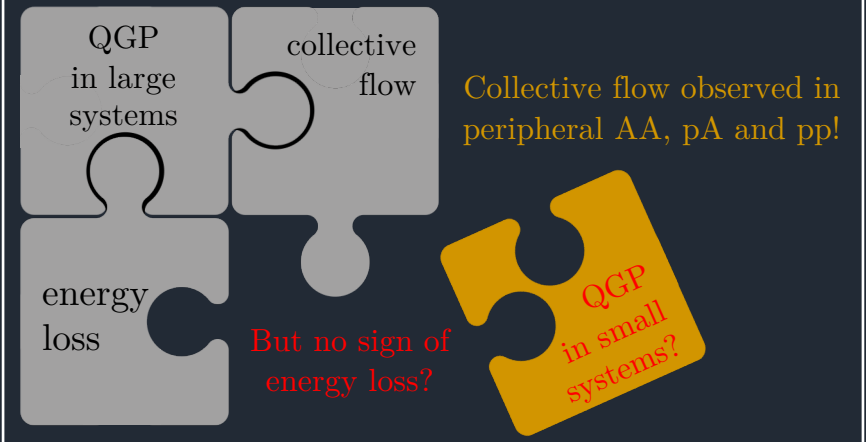
Motivation: jet quenching based on coherence

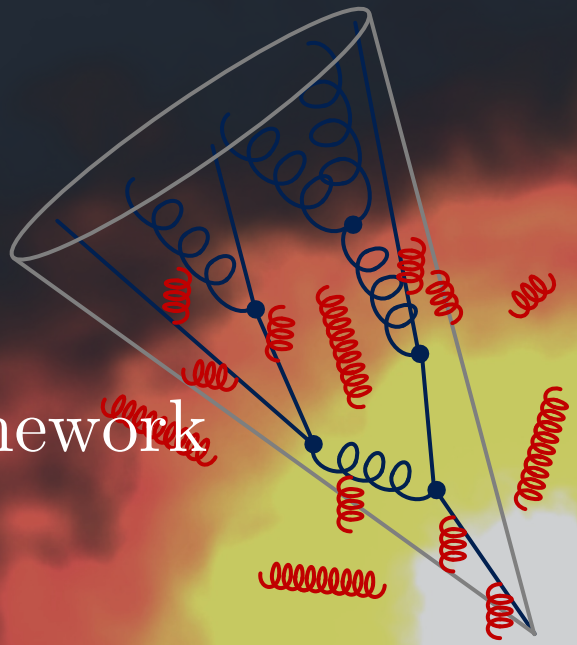
1. Stress-testing the framework

- Inclusive observables: R_{AA}, v_2, …
- System scan: Pb, Au, %, $\sqrt{s}$
- Substructure

2. Pushing boundaries



Jet energy loss framework



Energy loss

- Jet spectrum:

$$\frac{d\sigma_{jet}^{med}}{dp_T} = \int_0^\infty d\varepsilon\, \mathcal{P}\,(\varepsilon, p_T, R)\, \frac{d\sigma_{jet}^{vac}}{d(p_T+\varepsilon)}$$

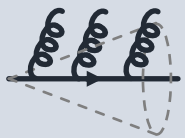
$$R_{AA} = \frac{d\sigma^{med}/dp_T}{d\sigma^{vac}/dp_T}$$

jet loose ϵ energy

jet is created in vacuum (factorization: $Q_{med} \ll p_T R$)

- 1-parton losing energy:

$$\mathcal{P}^{(0)}(\varepsilon) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_j^n \int \mathrm{d}\omega_j\, I_>(\omega_j) \right] \delta\left(\varepsilon - \sum_{j=1}^{n} \omega_j \right)$$



single emission out of cone

Energy loss

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jet loose ϵ energy

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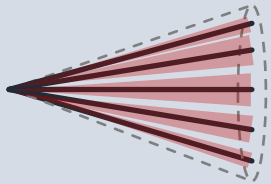
- Jets = many partons: more energy loss.

  Only resolved and color decohered ones lose energy.

[Mehtar-Tani, Tywoniuk, 1707.07361]



Quenching framework

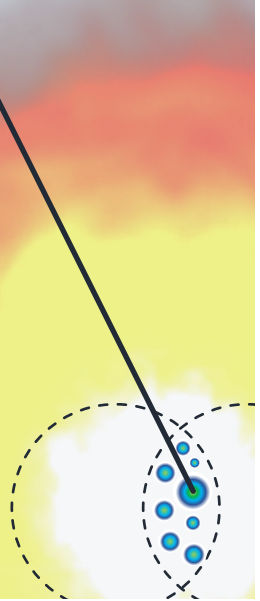
[Mehtar-Tani, Pablos, Tywoniuk, 2101.01742, 2402.07869]
[AT, Tywoniuk, 2103.14676]

- Vacuum jets: EPPS21 NLO nPDF + MadGraph NLO pQCD + LL Pythia (+ NPC23 NLO FF).
- Induced radiations: LO HTL (brick) + Improved opacity expansion.
- Elastic energy loss & medium response.
- Fluctuating hydro and path lengths

  JIMWLK + IP-Glasma + MUSIC + UrQMD [Mantysaari,Schenke,Shen,Zhao 2502.05138]
- Preequilibrium quenching:

  Hydro attractor form EKT
- Bayesian fit of all R_{AA} and v_2 data. [JETSCAPE/STAT]
- Predictions for hadrons.

new



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new

Pre-equilibrium quenching

- Usually: no quenching before $\tau_{hyd} = 0.4$ fm.

  v_2 is known to be sensitive to starting time!

  [Andres,Nestor,Luzum,Salgado,Zurita, 1606.04837]
  [Andres,Armesto,Niemi,Paatelainen,Salgado, 1902.03231]

- $\hat{q}$ increases going backwards in time.

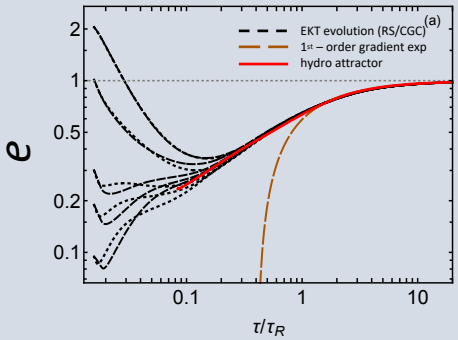
  [Ipp,Muller,Schuh, 2009.14206]
  [Avramescu,Baran,Greco,Ipp,Muller,Ruggieri 2303.05599]
  [Boguslavski,Kurkela,Lappi,Lindenbauer,Peuron 2303.12595]

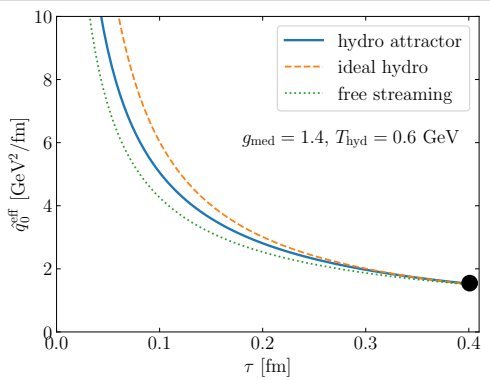
- Extrapolate T with hydro. attractors:

$$T(\tau < \tau_{hyd}) = f_{\text{attr}}(\tau, T_{hyd})$$

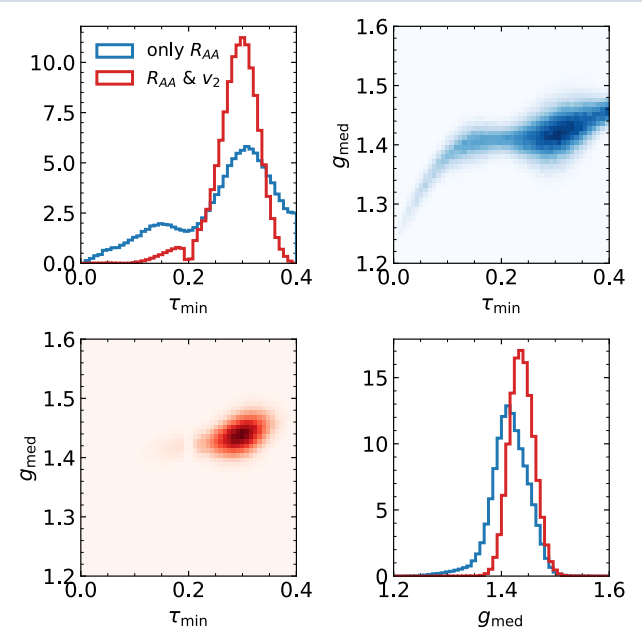
  [Giacalone,Mazeliauskas, Schlichting, 1908.02866]

[Almaalol,Kurkela,Strickland, 2004.05195]





Bayesian parameter estimation



Fitting only jet R_{AA}:

- little constraint on preeq!
- later quenching ⟷ smaller g_{med}.

Simultaneous fit of jet R_{AA} & v_2:

- constraint on preeq!
- Quenching starting time

$$\tau_{min} \lesssim \tau_{hyd}$$

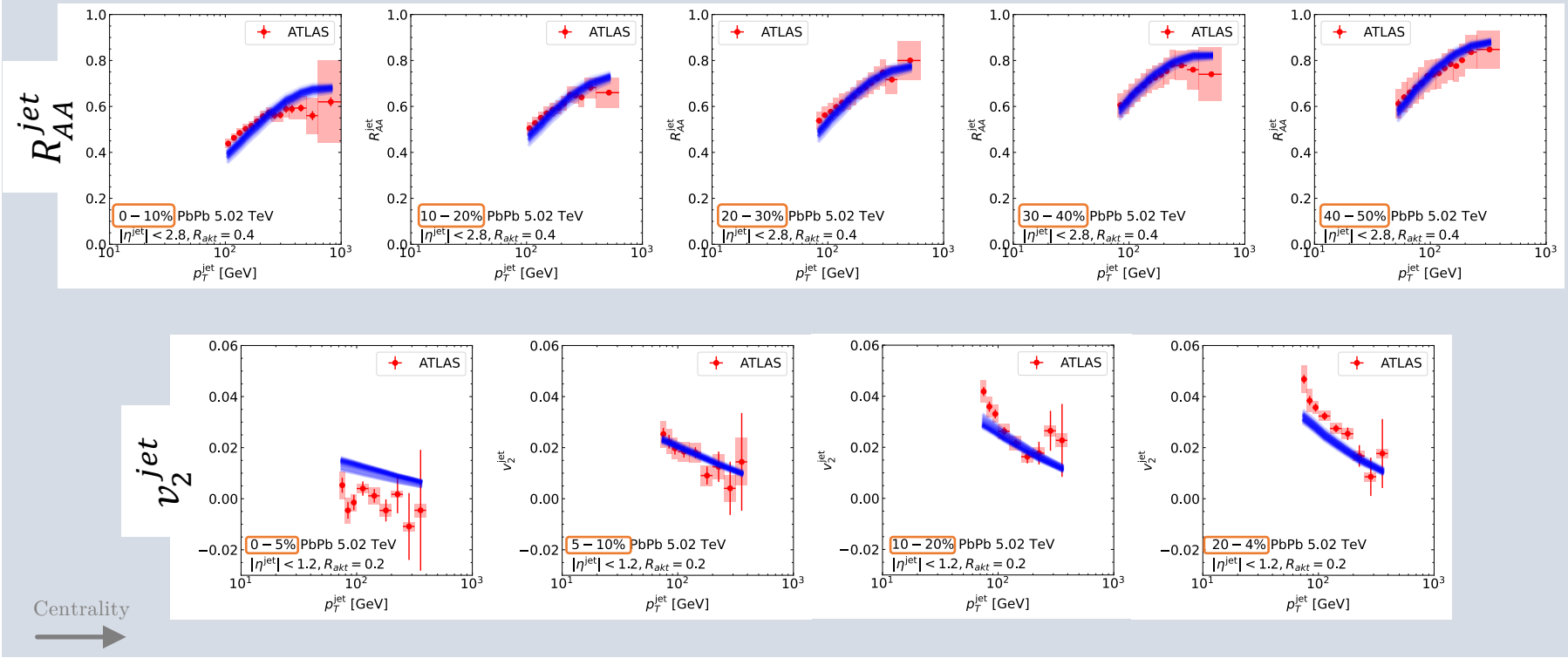
τ_{min}: earlies quenching

g_{med}: jet-medium coupling

(Sensitivity to other parameters is in 2402.07869)

Posteriors

[ATLAS, 1805.05635, 2211.15257, 2111.06606]
[CMS, 1611.01664, 2102.13080]
[ALICE, 1802.09145, 2303.00592]
[STAR 2006.00582]



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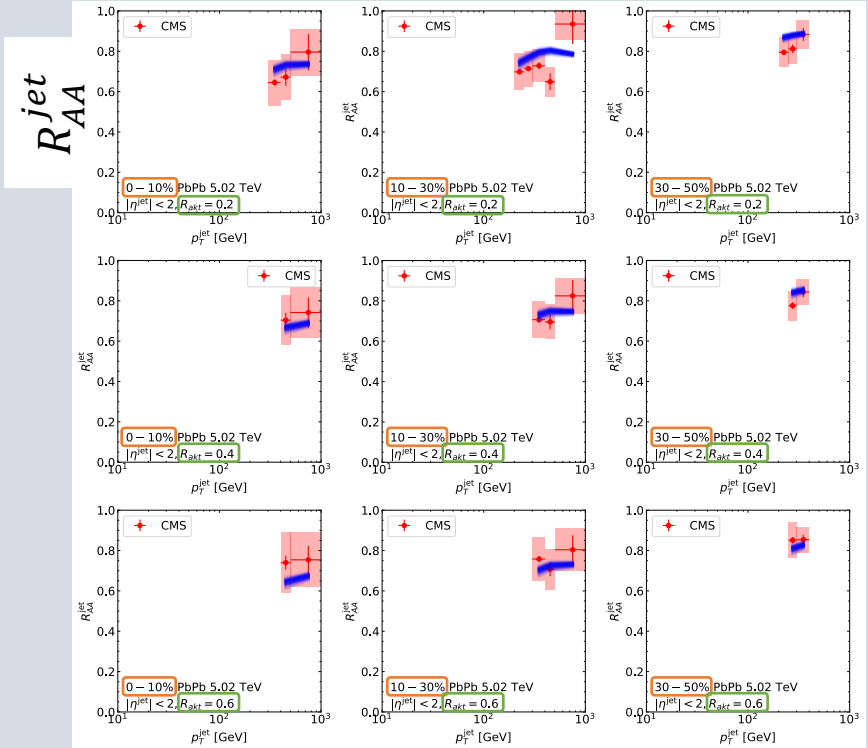

Centrality →
Jet cone ↓

→ centrality →
↓ jet cone ↓

Posteriors and predictions

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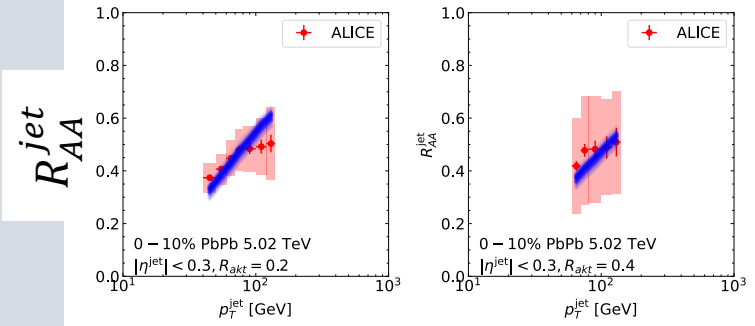
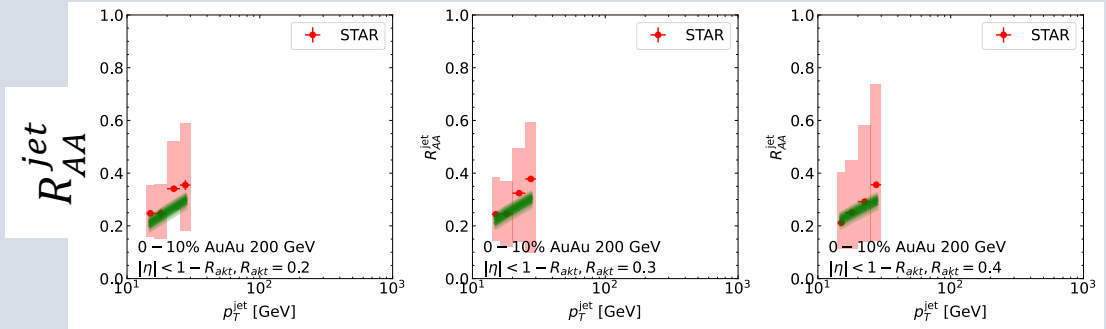
Fits



Predictions



Jet cone

→ jet cone →

Predictions: hadron R_{AA}

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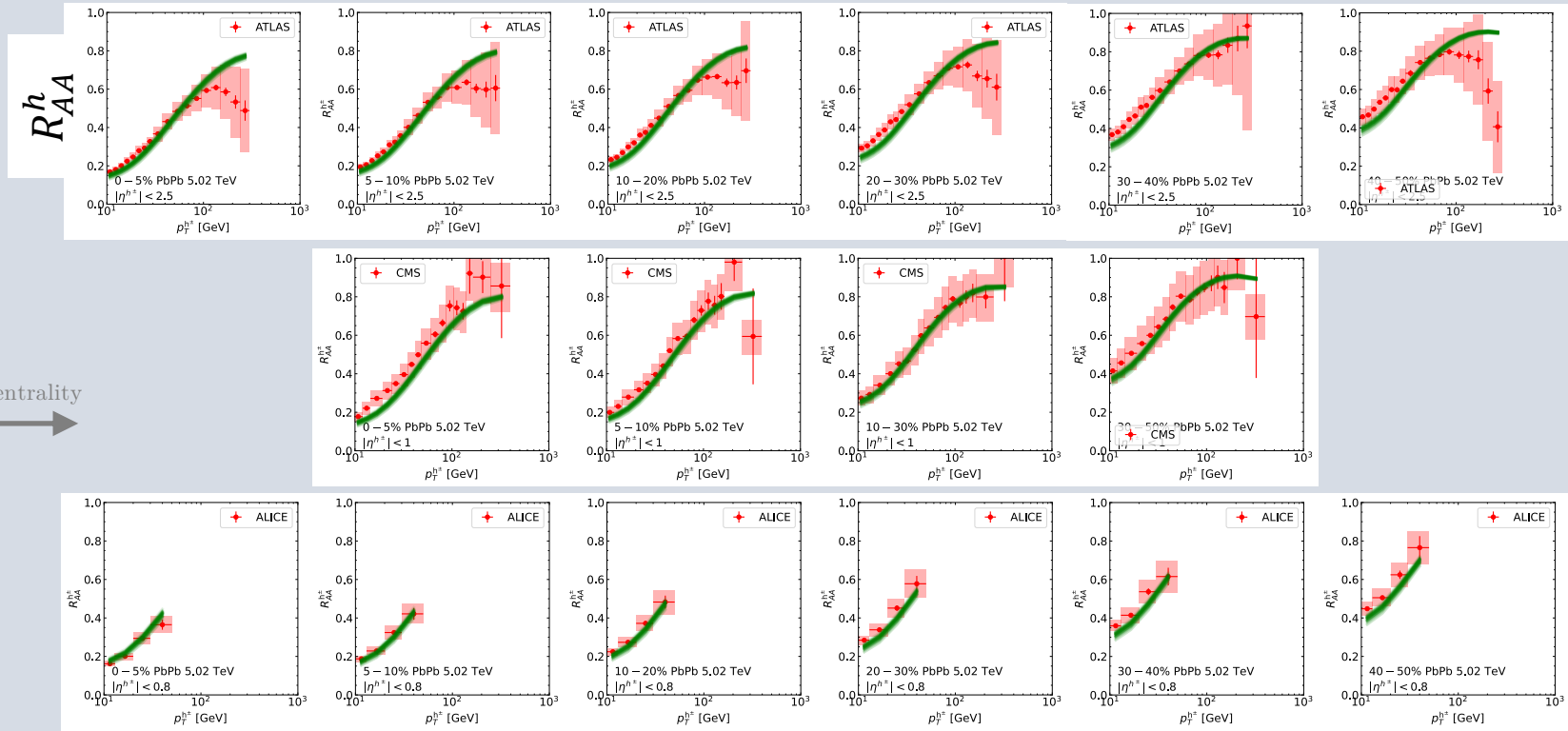

Predictions: hadron v_2

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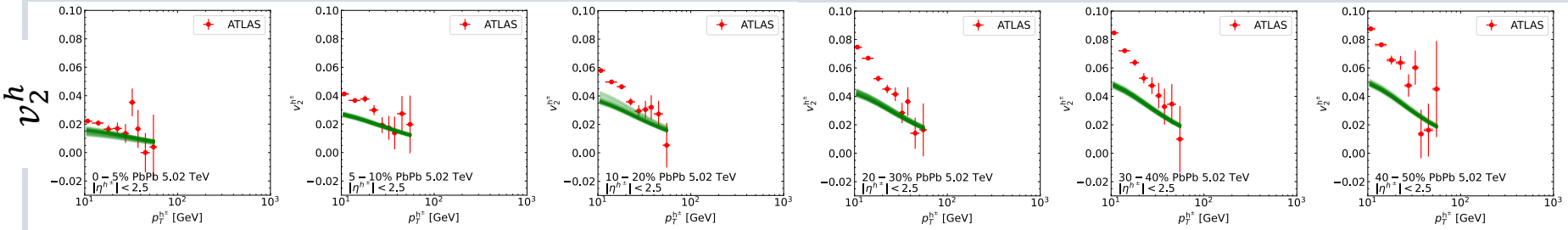
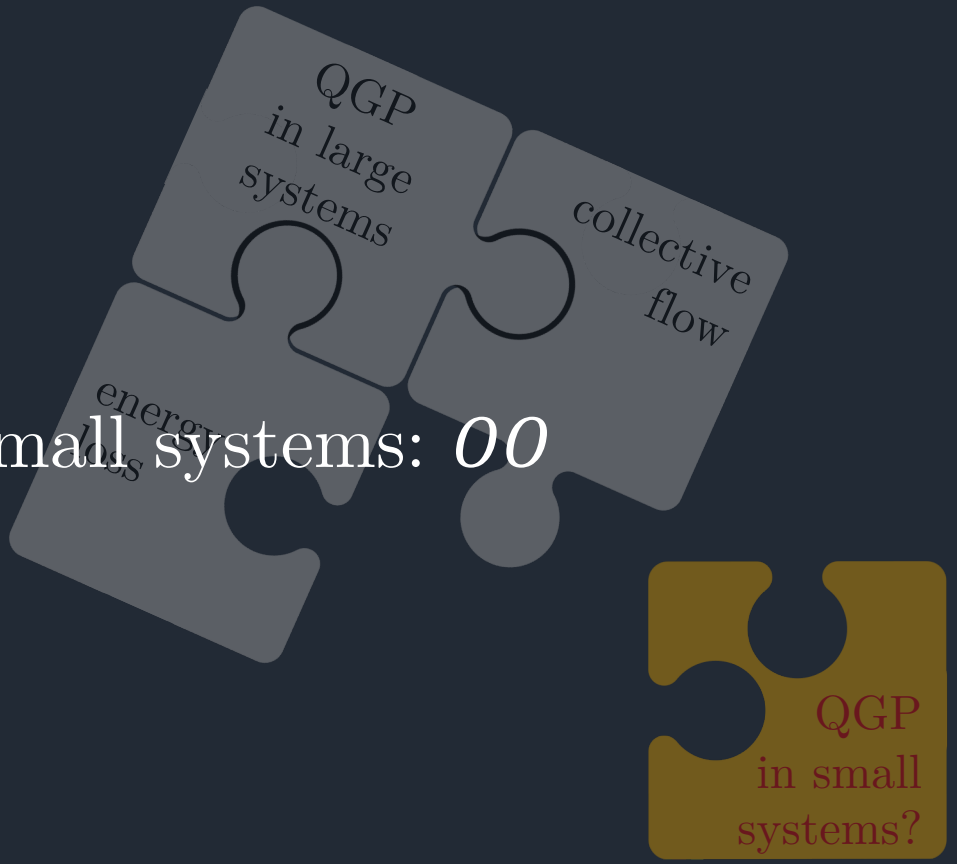


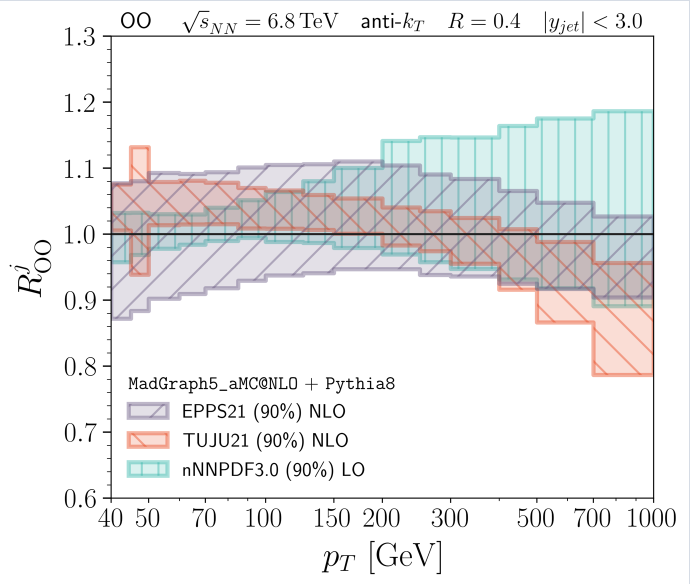
Centrality

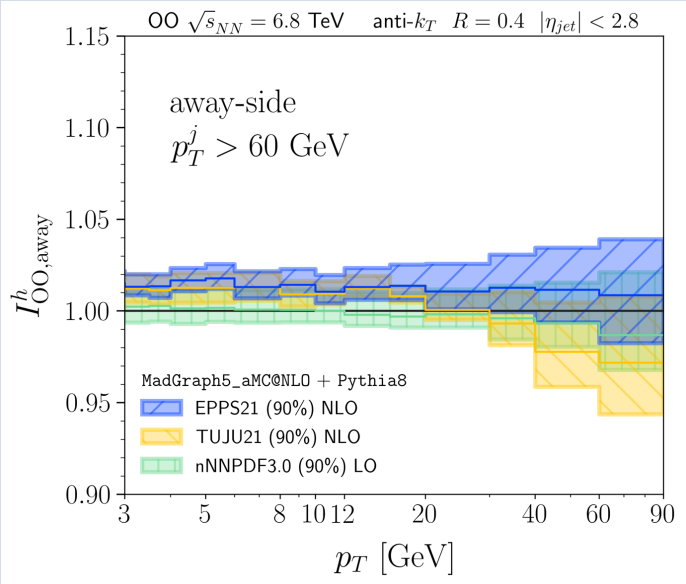
Refinements are necessary in the model, e.g. correlated jet production.

Towards small systems: *OO*



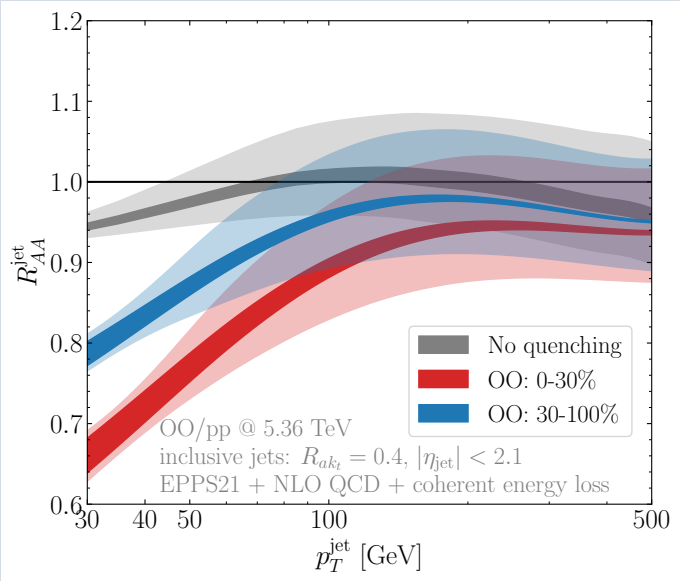
Baseline studies in OO

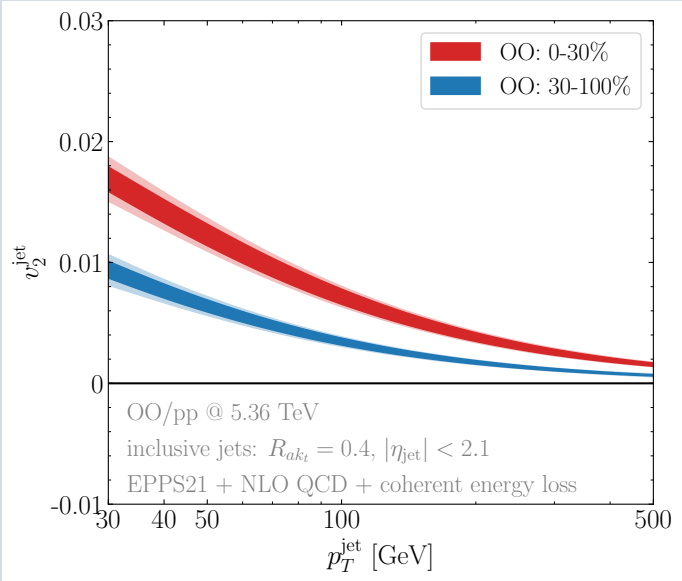




[J. Gebhard, A. Mazeliauskas, AT, 2410.22405]

Preequilibrium in OO





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- Clear quenching signal below 100 GeV!

- nPDF unc are less of a problem for v2!

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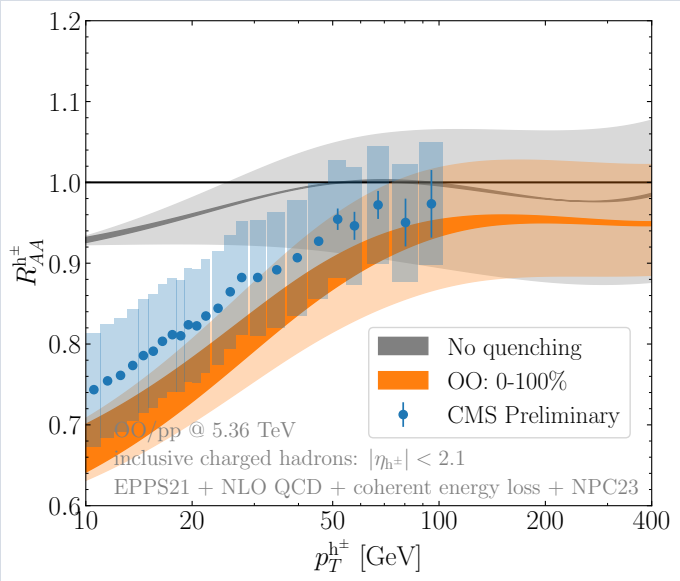
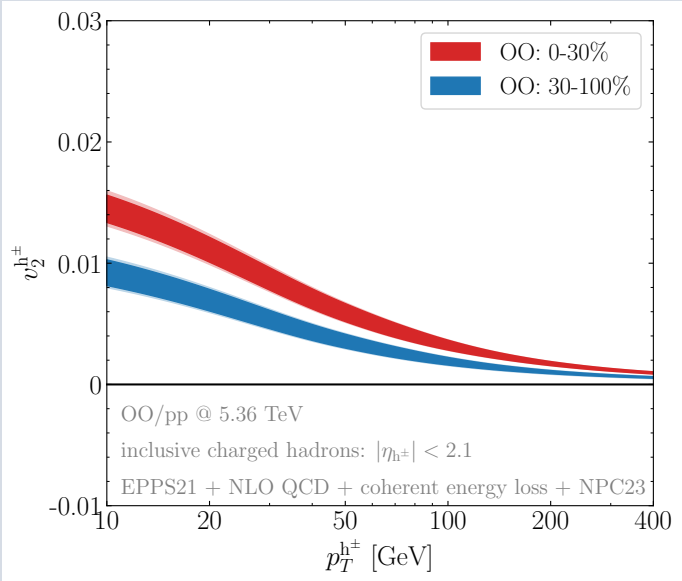




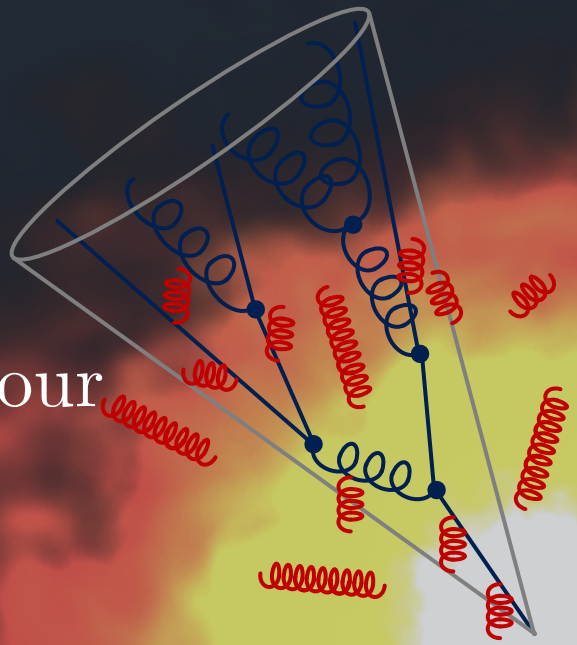
- 68% Bayesian parameter confidence
- 68% nPDF confidence
- Clear quenching signal below 30 GeV!

- nPDF unc are less of a problem for v2!

Summary: jet R_{AA} & v_2

1. Powerful semi-analytical framework:
   - Good agreement with data: R_{AA} & v_2 vs p_T, R, %, $\sqrt{s}$, (Pb, Au, O)
2. Bayesian extraction of initial quenching time $\approx$ 0.3 fm.
3. Jet quenching in small systems (OO):
   - R_{AA} prediction for CMS.
   - More measurements on the go.
4. Outlook:
   - Systematically improvable: e.g. elastic energy loss in small medium, MCMC
   - Other observables: NeNe, pA, substructure

Thank you for your attention!



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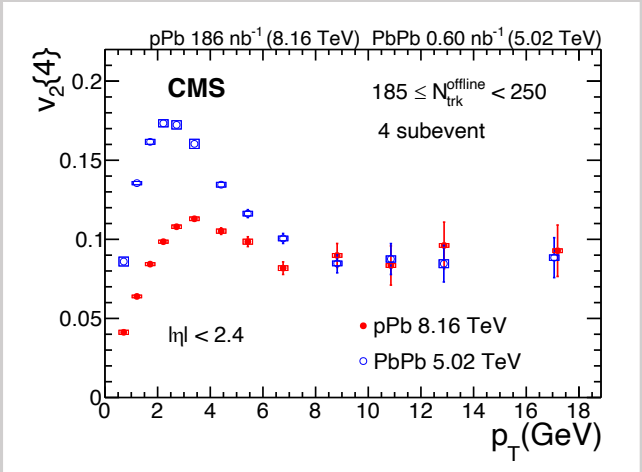


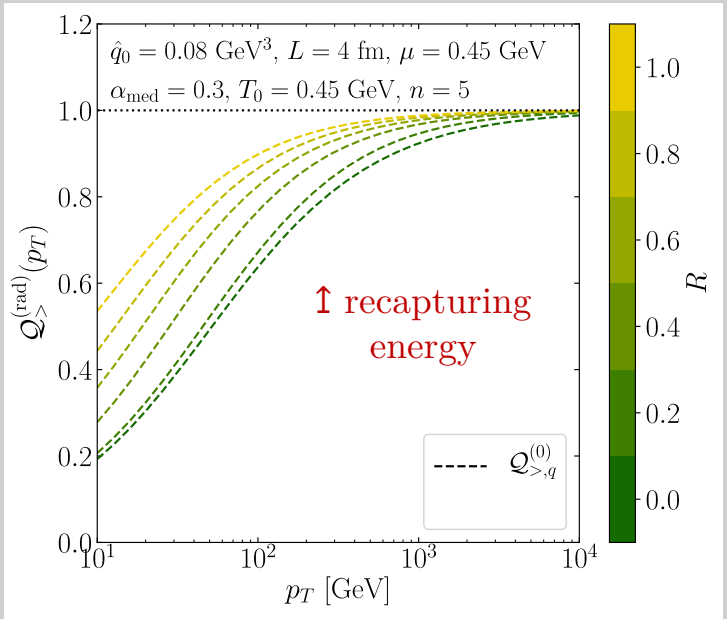
[CMS, 2502.07525]

Energy loss

- Jet spectrum:

$$R_{AA} = \frac{d\sigma^{med}/dp_T}{d\sigma^{vac}/dp_T}$$

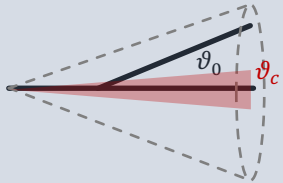
- 1-parton loosing



[AT, K. Tywoniuk, 2103.14676]

Energy loss

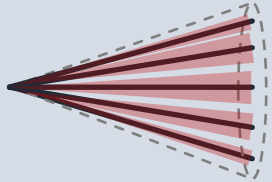
- Jet with 2 parton (medium resolution [Mehtar-Tani, Salgado, Tywoniuk, 1102.4317]):



$$= \begin{cases} \vartheta_c < \vartheta_0, & \text{two sources (more Eloss)} \\ \vartheta_0 < \vartheta_c, & \text{one source} \end{cases}$$

- all sources: collimator resummation [Mehtar-Tani, Tywoniuk, 1707.07361]

$$\partial_\vartheta \tilde{\mathcal{P}}_i(\nu,\vartheta) = \int dz \frac{dI^{vac}}{dz d\vartheta} \Theta_{res} \left[\tilde{\mathcal{P}}_j(z\nu,\vartheta) \tilde{\mathcal{P}}_k\big((1-z)\nu,\vartheta\big) - \tilde{\mathcal{P}}_i(\nu,\vartheta) \right]$$



Laplace tf: $\tilde{\mathcal{P}}_i(\nu,\vartheta) = \int_0^\infty d\varepsilon\, \mathcal{P}_i(\varepsilon) e^{-\nu\varepsilon}$

Energy loss

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(more Eloss)

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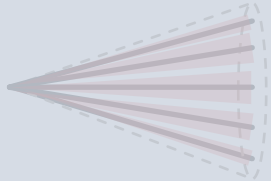

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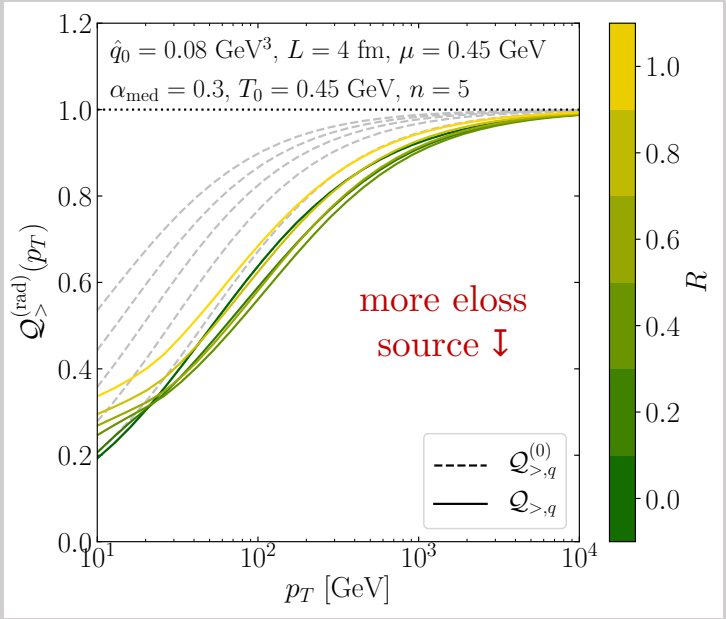

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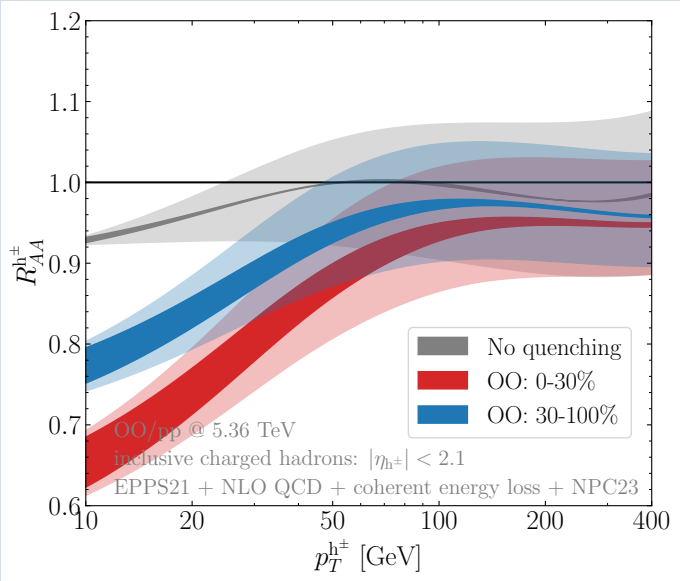
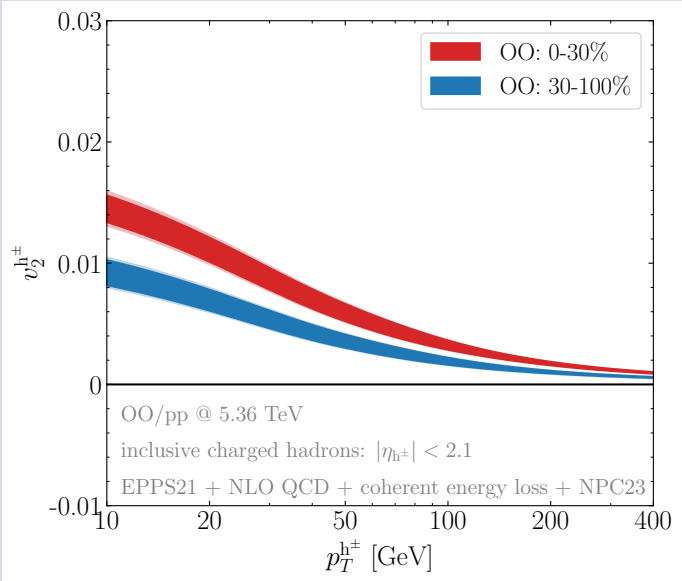
Preequilibrium in OO





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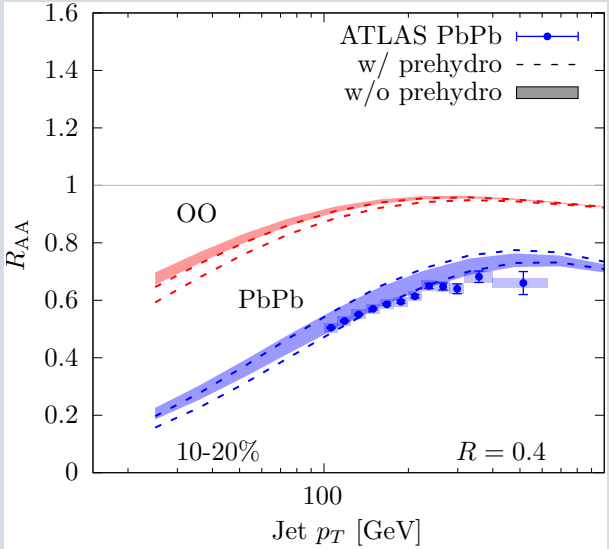
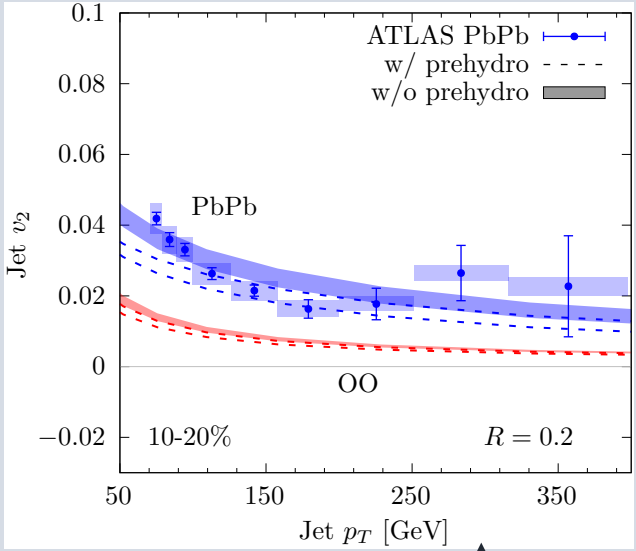
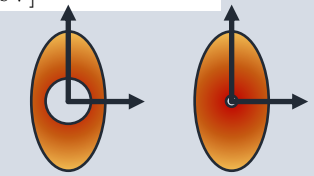
Preequilibrium in PbPb







Some changes in R_{AA}!

- More important for smaller systems