Unbiased quantification of jet energy loss

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LIP

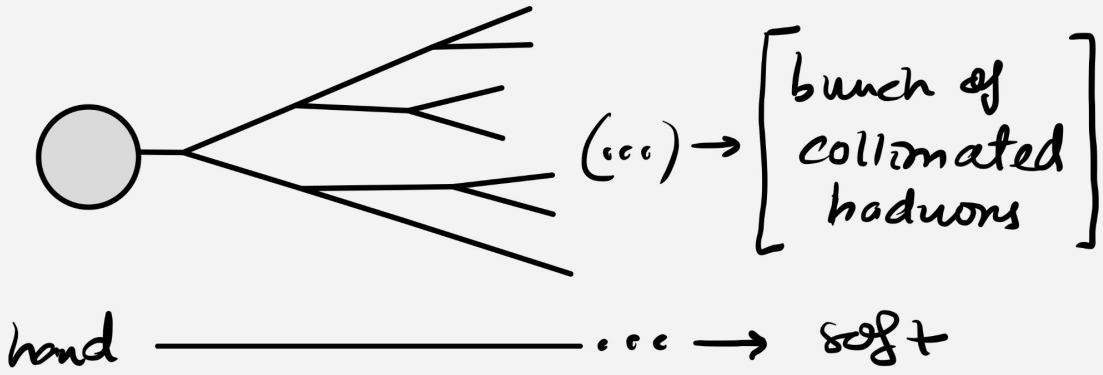
FCT Fundação para a Ciência e a Tecnologia

erc European Research Council Established by the European Commission

Probing the QGP with jets

➔ The QGP is very **short-lived** - lifetime of roughly **10 fm/c.** How do we probe it?

➔ **Hadronic jets** are produced **concurrently with the QGP**!



Vacuum (pp) jets

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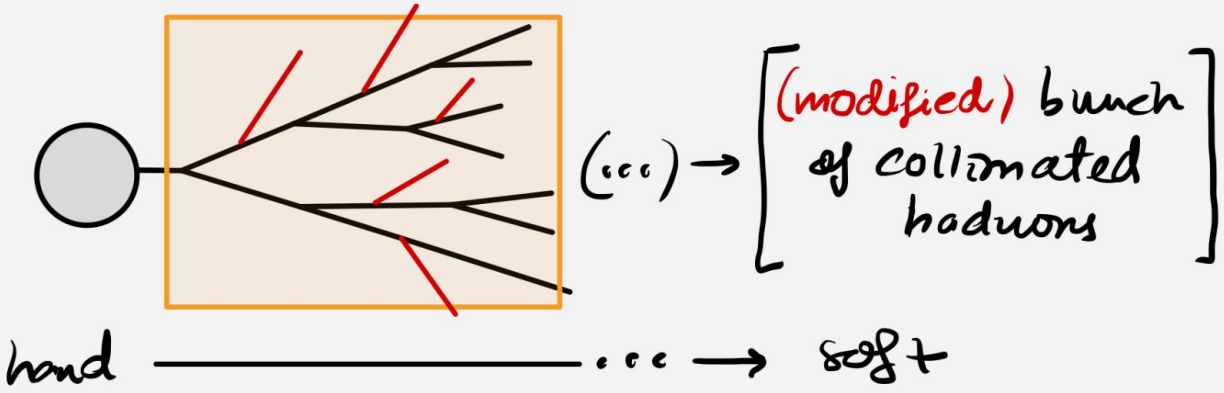


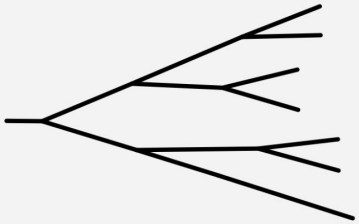
In-medium (AA) jets

Probing the QGP with jets

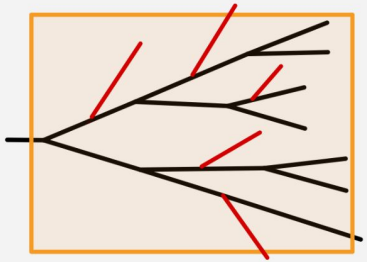
➔ Jets in **AA** collisions have to **propagate through the QGP and interact** with it - imprinted modifications (**jet quenching+medium response**) tell a story.

↳ out-of-cone medium-induced radiation, momentum broadening, …

Compare **AA jets** with the well established vacuum baseline of **pp jets**



Infer properties of the QGP



Biased jet comparison

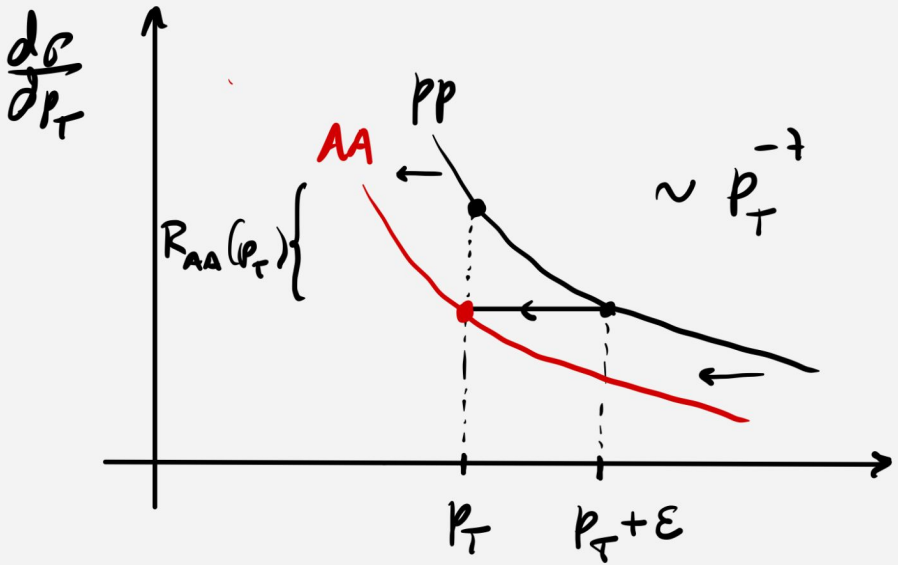
Which AA jets should I compare to a given set of pp jets?

- ➔ Common procedure: Choose a window of **reconstructed jet pT**.
- ➔ Common problems:
  - ◆ AA jets **migrate** to lower reconstructed pT (**out of cone radiation**)

    ⟹ We are comparing jets that **“started out” differently**.

Bin migration in RAA

$$p_T \rightarrow p_T - \epsilon$$



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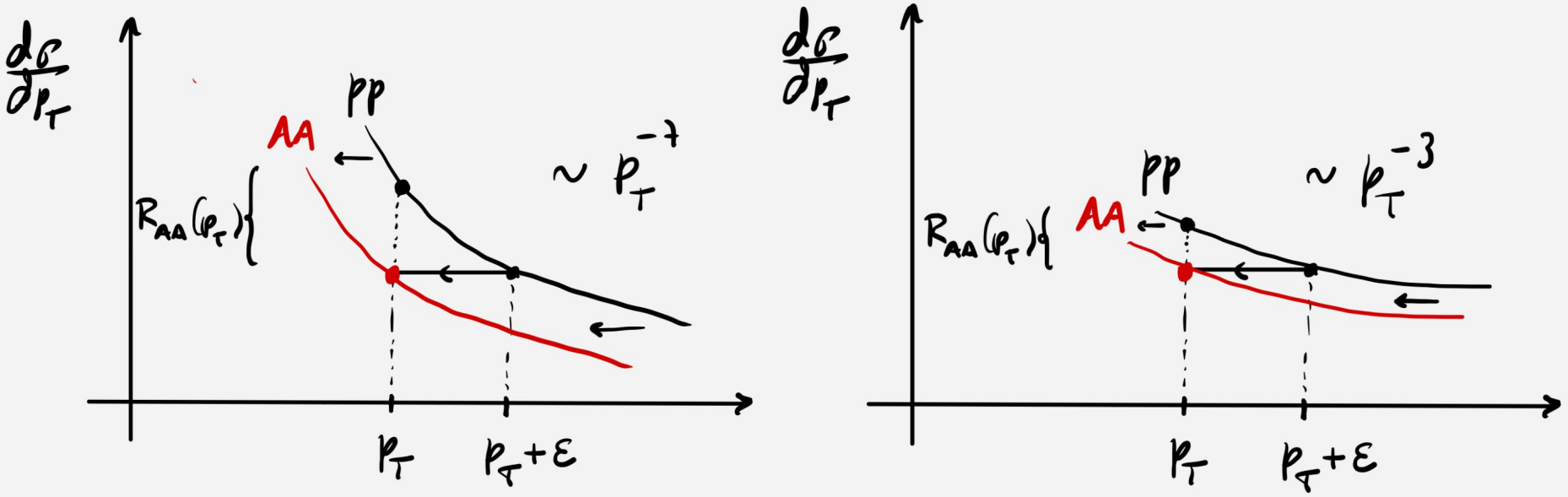

Same energy loss but **different RAA!**

Biased jet comparison

Which AA jets should I compare to a given set of pp jets?

➔ Common procedure: Choose a window of **reconstructed jet pT**.

➔ Common problems:

- AA jets **migrate** to lower reconstructed pT (**wide angle out of cone radiation**)

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- **Selection bias** - samples of in-medium jets are biased towards **less modified jets**.

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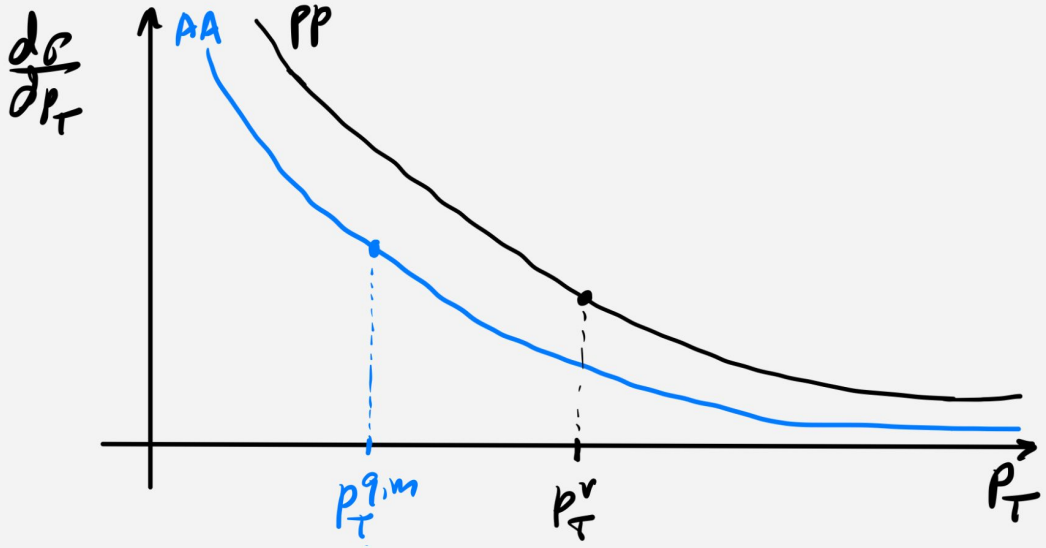
  - ◆ **Selection bias** - samples of in-medium jets are biased towards **less modified jets**.
- ➔ Possible solution: **electroweak boson + jet**? ⟹ Lower statistics

QAA - a possible way out



J. Brewer, G. Milhano, J. Thaler; Phys. Rev. Lett. 122 (2019) 22, 222301

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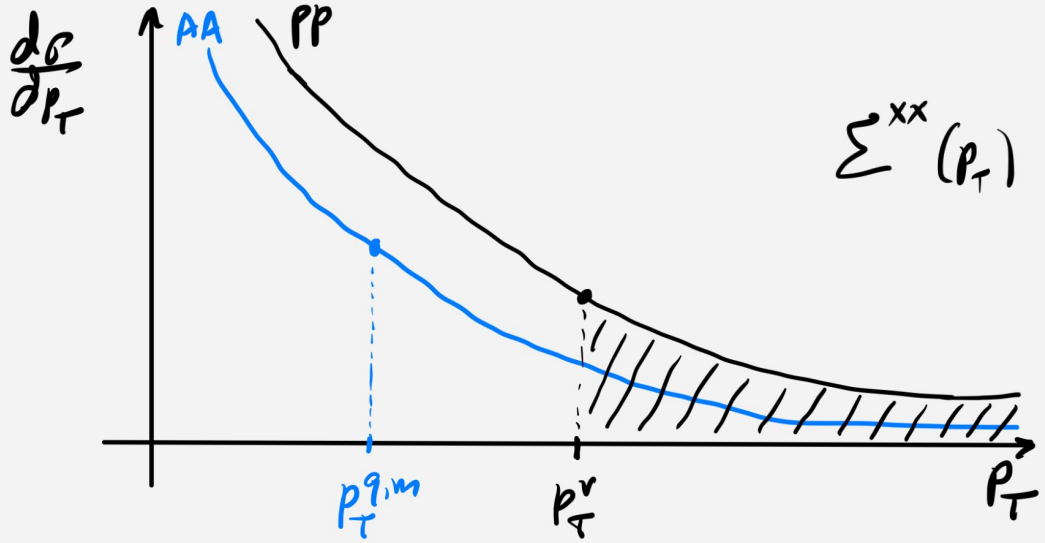
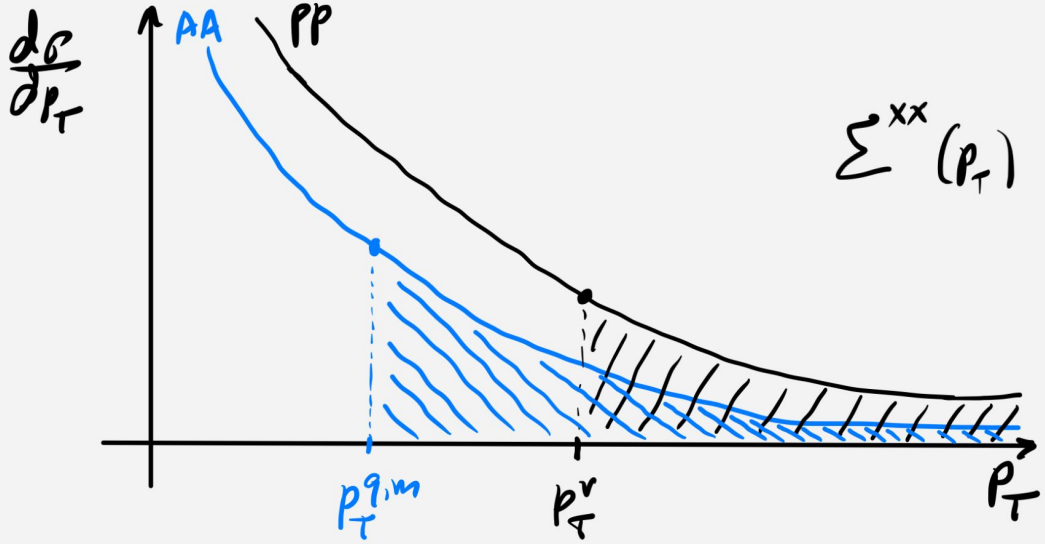


$$\Sigma^{xx}(p_T) \equiv \int_{p_T}^{+\infty} dp_T' \, \frac{d\sigma^{xx}}{dp_T'}$$

J. Brewer, G. Milhano, J. Thaler; Phys. Rev. Lett. 122 (2019) 22, 222301

$$\Sigma^{PP}(p_T^{v}) =$$

QAA - a possible way out



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$$\Sigma^{pp}(p_T^{v}) = \Sigma^{AA}(p_T^{q,m}) \rightarrow \boxed{p_T^{q,m} = p_T^{q,m}(p_T^{v})}$$

QAA - a possible way out

Let's say a pp jet reconstructed with a given p_T would lose energy as:

$$p_T \rightarrow p_T - f(p_T)$$

N most energetic pp jets
=
N most energetic AA jets

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Then,

$$\implies p_T^{q,m}(p_T^v) = p_T^v - f(p_T^v)$$

$$\implies 1 - Q_{AA}(p_T^v) = f(p_T^v), \qquad \boxed{Q_{AA}(p_T^v) = \frac{p_T^{q,m}(p_T^v)}{p_T^v}}$$

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"1-QAA is a proxy for the **average fractional jet energy loss**"

Event generation and analysis details

➔ Samples are obtained by running the **JEWEL event generator with medium response**

↳ **Constituent-wise background subtraction** as outlined in:
J.Milhano, K. Zapp, Eur.Phys.J.C 82 (2022) 11, 1010

➔ Vacuum samples are generated as nucleon-nucleon collisions including nuclear PDFs

↳ Differences between vacuum and medium samples are in principle **dominated by quenching effects**

In-medium jet spectrum

$$\frac{d\sigma^{med}}{dp_T} = \frac{1}{\langle N_{coll} \rangle} \frac{d\sigma^{PbPb}}{dp_T}$$

Vacuum jet spectrum

$$\frac{d\sigma^{vac}}{dp_T} = \left(\frac{d\sigma^{\mathrm{NN+nPDFs}}}{dp_T} \right) \Bigg|_{\mathrm{NN}=\{\mathrm{pp,pn,np,nn}\}}$$

Event generation and analysis details

➔ 10^6 medium and vacuum events (γ+jet and inclusive) with:

$$\sqrt{s_{NN}} = 5.02 \text{ TeV}$$

$$\text{Centrality: } [0\text{-}10] \ \%$$

➔ Kinematic cuts:

γ+jets	$p_T^{\gamma} > 50$ GeV	$\lvert y^{\gamma} \rvert < 2.37$	$\Delta\phi^{\gamma,jet} > 7\pi/8$
both γ+jets and inclusive jets	$p_T^{jet} > 30$ GeV	$\lvert y^{jet} \rvert < 2.8$	

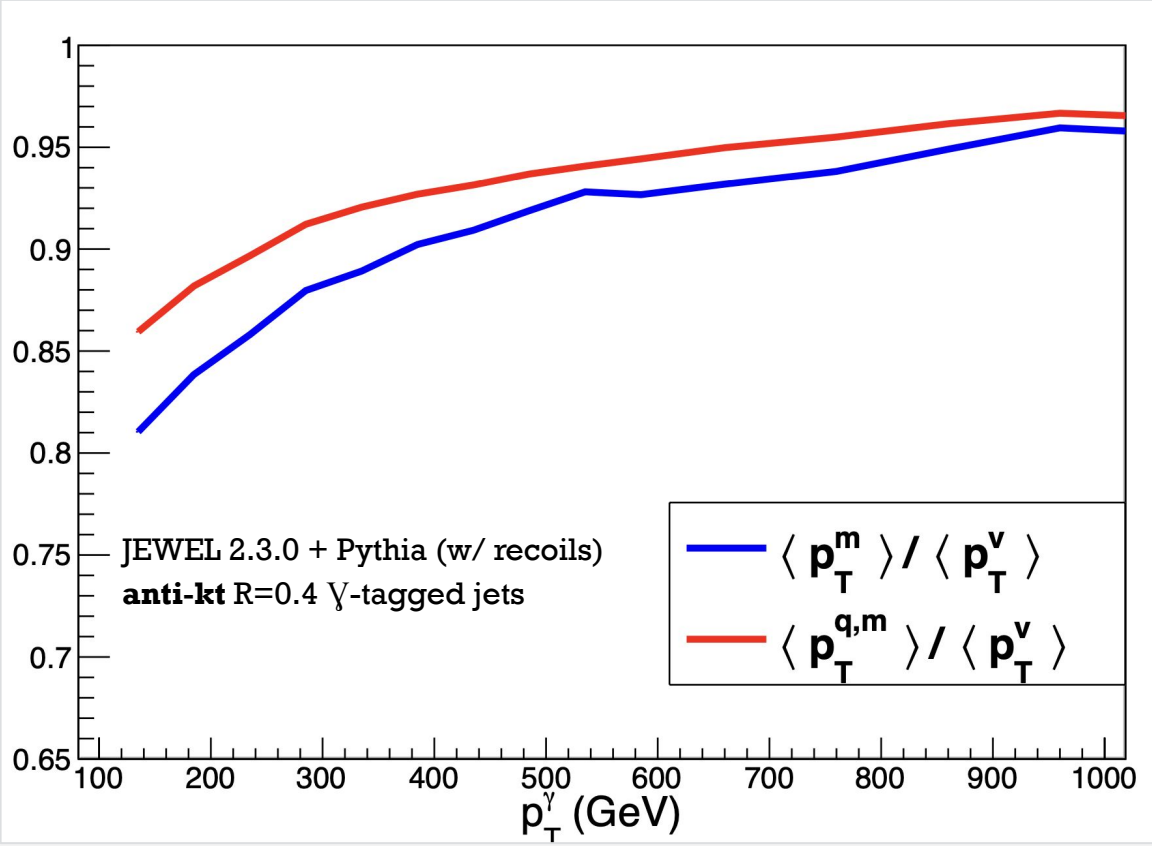
QAA validation

Average jet p_T for a given photon p_T

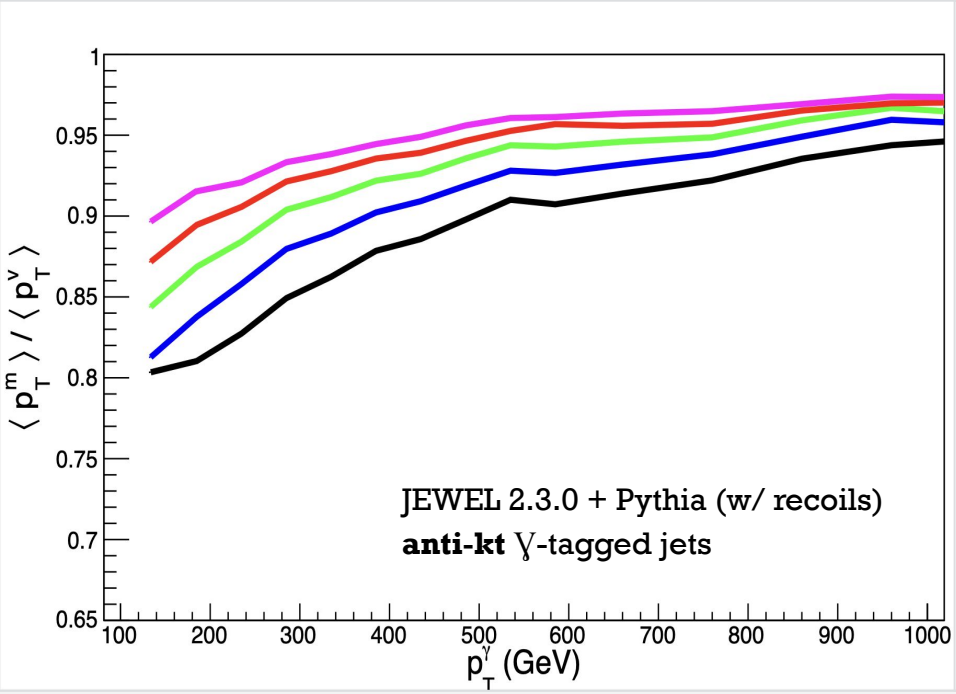
$$\langle p_T^{v/m} \rangle = \int dp_T \; \frac{dN^{v/m}}{dp_T}[p_T^{\gamma}] \; p_T$$

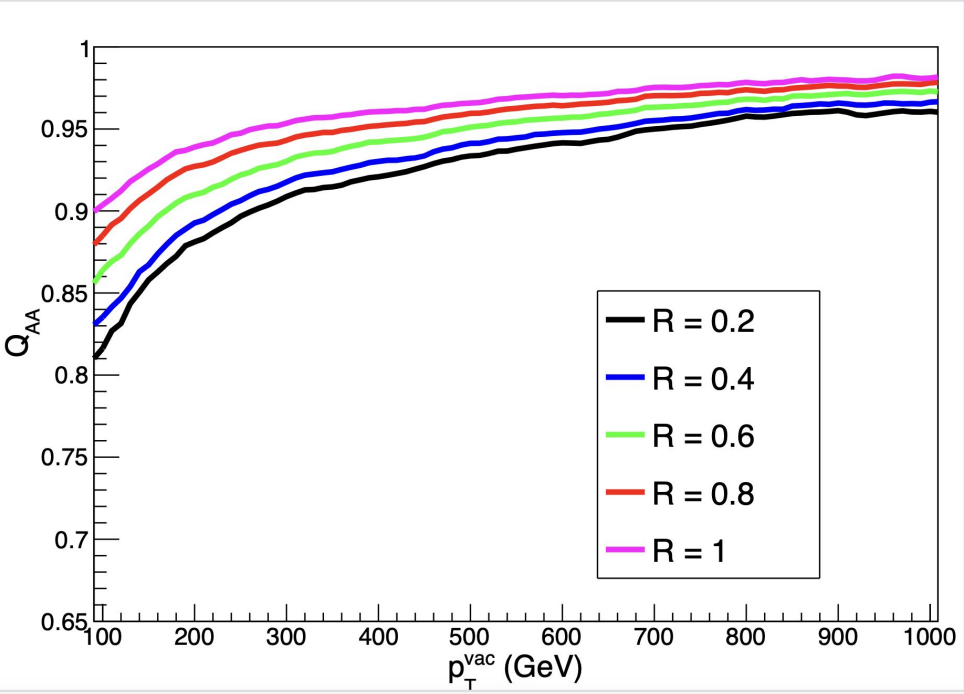
Average quantile p_T for a given photon p_T

$$\langle p_T^{q,m} \rangle = \int dp_T \; \frac{dN^{v}}{dp_T}[p_T^{\gamma}] \; p_T^{q,m}(p_T)$$



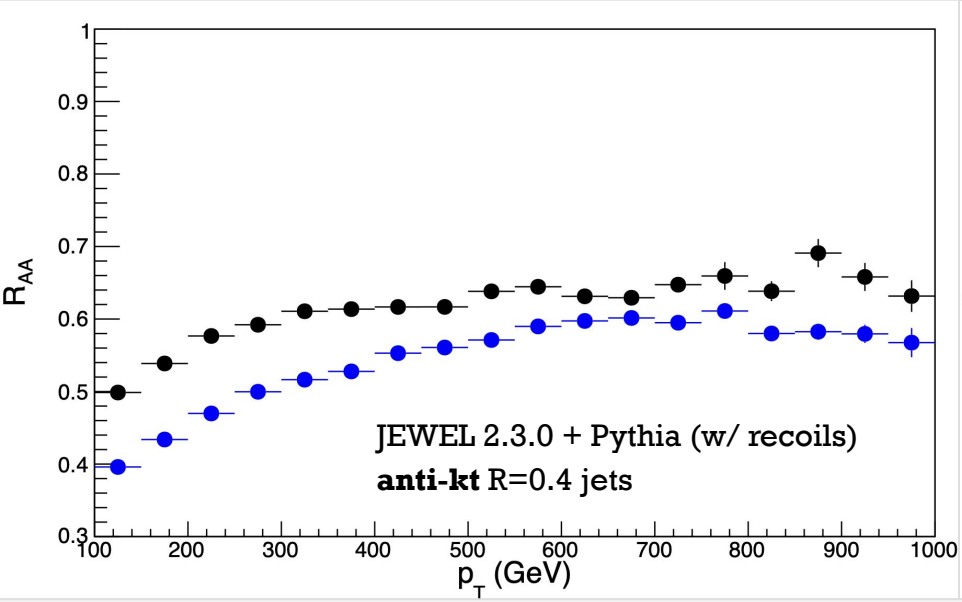
Energy loss as a function of jet radius

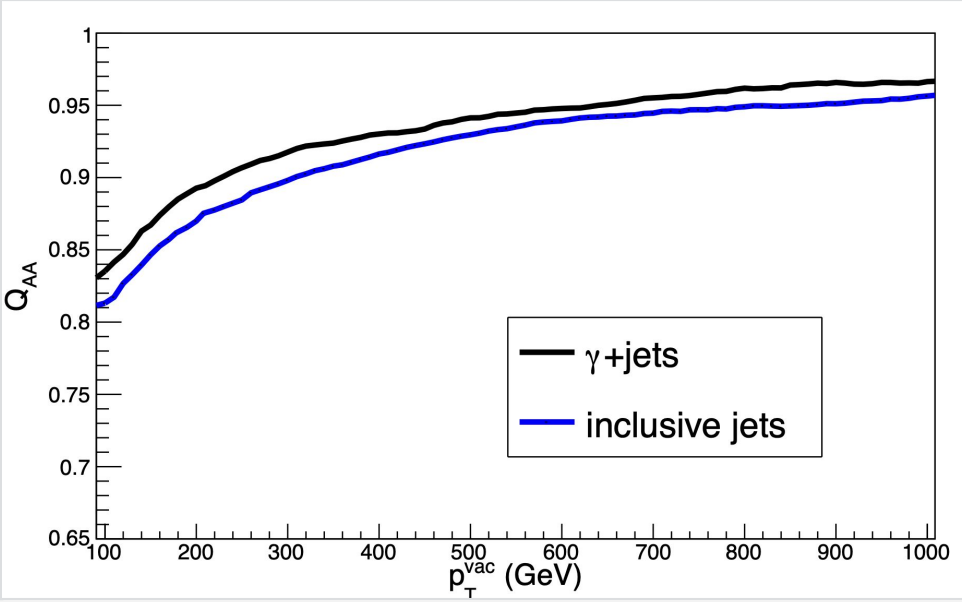




Larger jets lose less energy

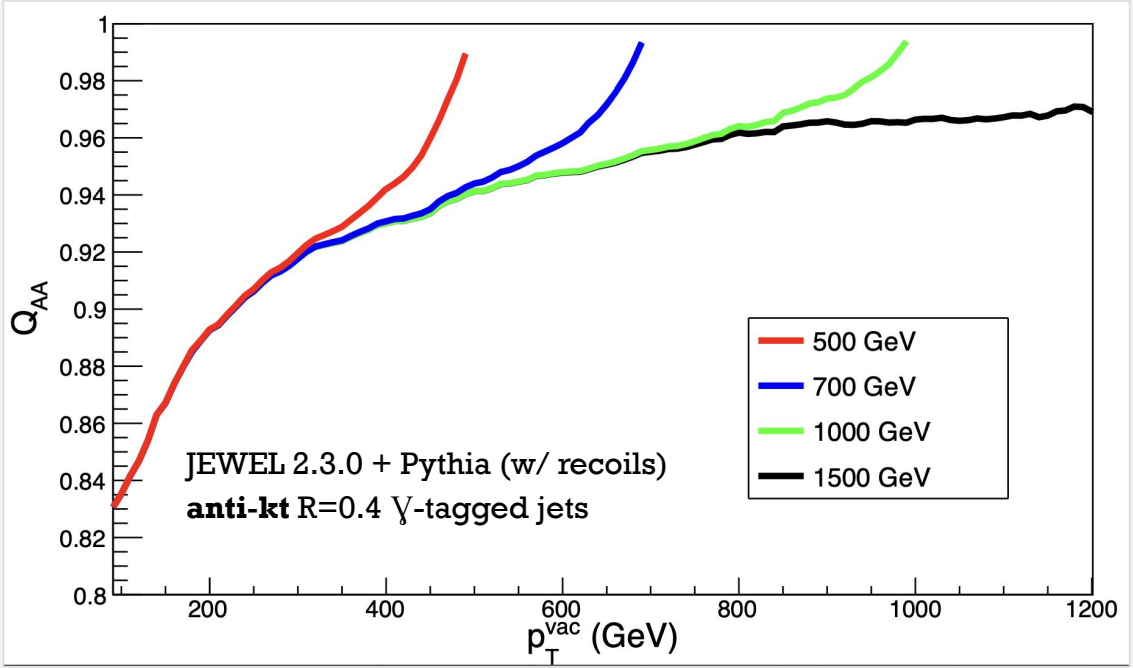
QAA dependence on color charge





Color charge dependence of jet energy loss is not as strong as suggested by the R_{AA}

Spectrum cutoff effect



$$p_T^{q,m} - \overline{p}_T^{q,m} \sim \langle \epsilon \rangle \left(\frac{p_T^{q,m}}{p_T^c} \right)^n$$

Summary

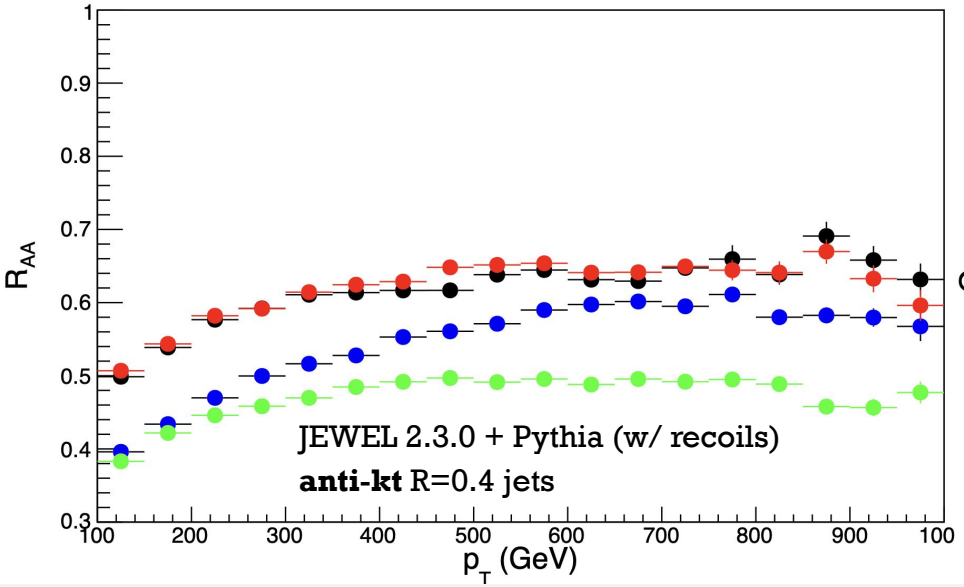
- ➔ The QAA provides **a proxy for jets that started out similarly** that can be used in inclusive jet events and possibly a model-independent way of quantifying jet energy loss;

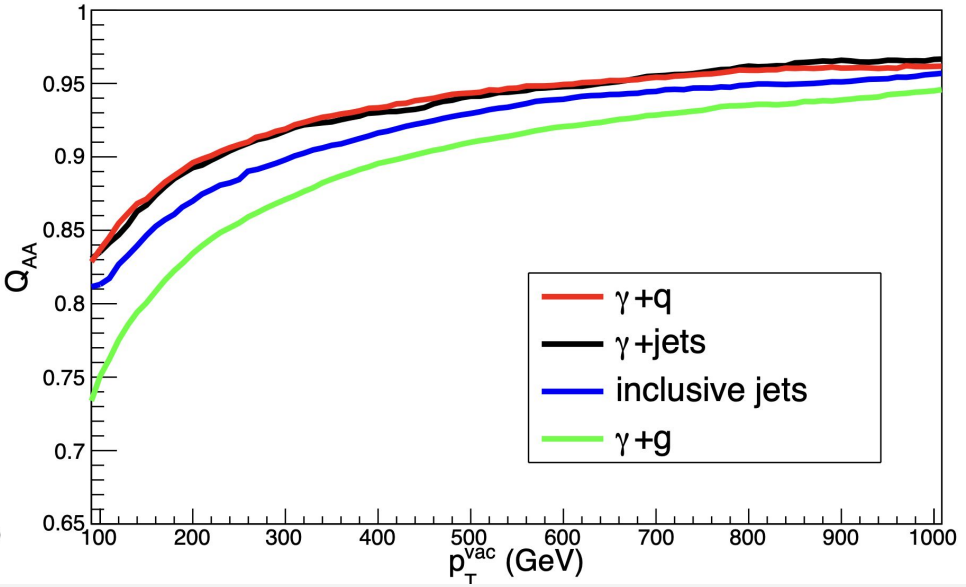
- ➔ The color charge of the initiating parton does not play as important a role in jet energy loss as one would have thought by looking into RAA - **the difference in spectrum steepness is quite impactful**;

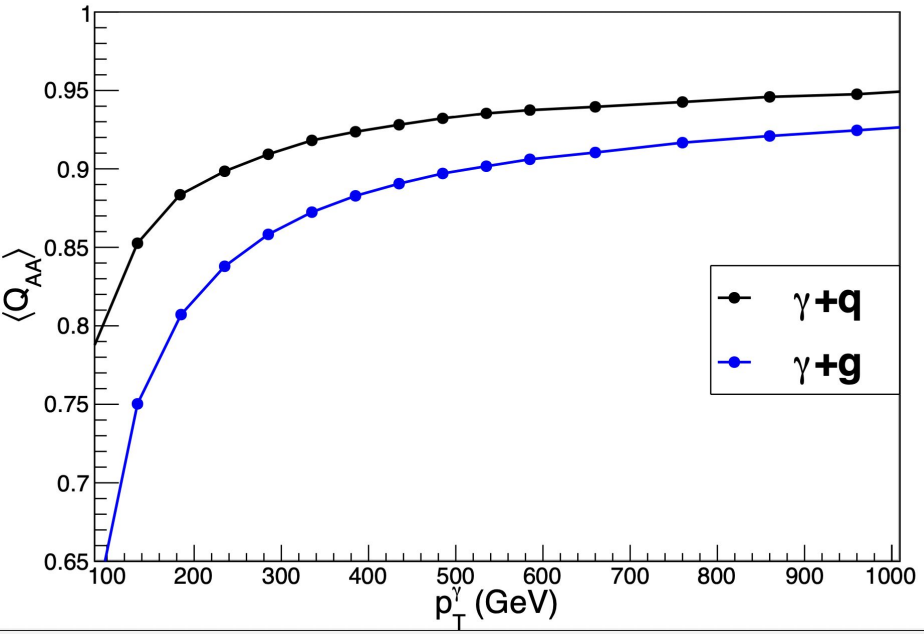
- ➔ Experimental challenges to the measurement of the QAA, e.g. cutting the integral at some **momentum cutoff**.

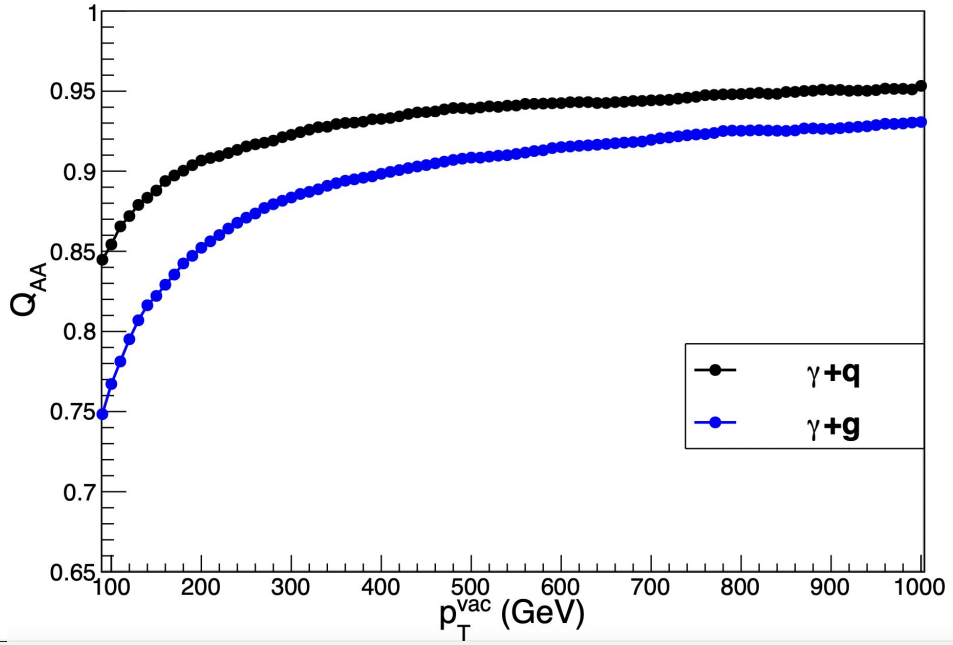
Thank you!

Back-up slides


R_{AA}
p_T (GeV)
JEWEL 2.3.0 + Pythia (w/ recoils)
anti-kt R=0.4 jets


Q_{AA}
p_T^{vac} (GeV)
γ+q
γ+jets
inclusive jets
γ+g


1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
⟨Q_AA⟩
100
200
300
400
500
600
700
800
900
1000
p_T^γ (GeV)
γ+q
γ+g


1
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