Jet evolution & substructure modification within the QGP

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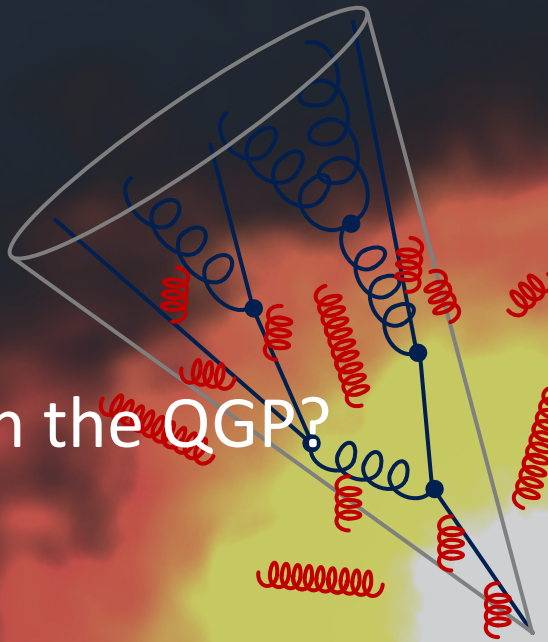
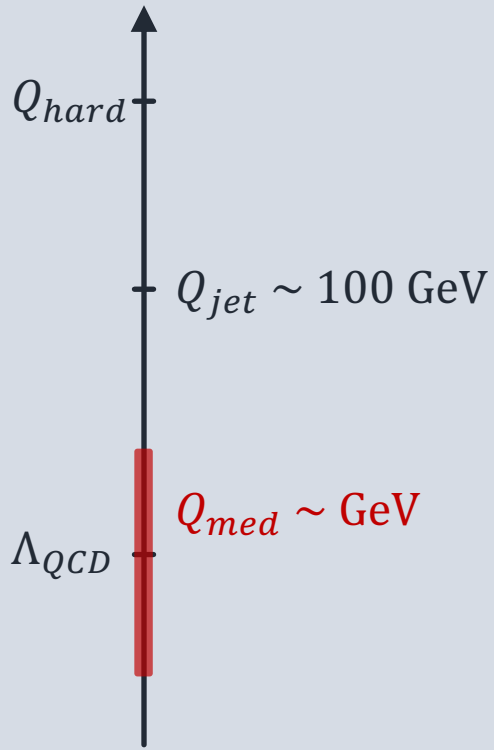
Large Hadron Collider Physics Conference, 3-8 Jun. 2024, Boston, US

What is jet modification in the QGP?



Introduction



- pQCD and factorization:

$$Q_{hard} \gg Q_{jet} \gg \Lambda_{QCD}$$

- Jet-medium interaction:

$$Q_{jet} \gg Q_{med}$$ ⇐ This talk!

- Weakly or strongly coupled medium?

$$Q_{med} \overset{?}{\gg} \Lambda_{QCD}$$ ⇐ Talk by Go, Almaalol, Li

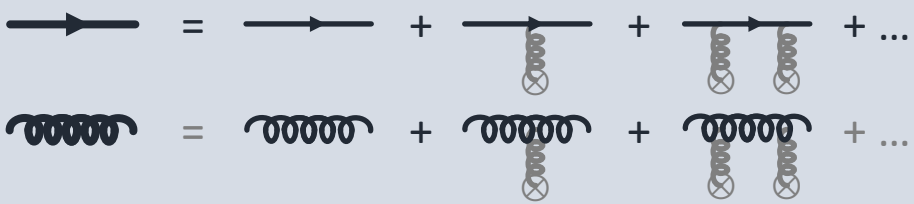
*There can be several medium scales and they can depend on the observable.

Introduction

- Separate hard and background fields ($q = q_h + q_0, A = A_h + A_0$)

$$\mathcal{L}_{QCD}(q, A) = \mathcal{L}(q_h, A_h) + \mathcal{L}(q_0, A_0) + \mathcal{L}_{int}(q_h, A_h, q_0, A_0)$$
$$\approx \mathcal{L}(q_h, A_h) + g\bar{q}_h\langle J\rangle q_h + gA_h\langle J\rangle A_h$$

- Dressed propagators:



- Models for the background $\langle J(x^\mu)\rangle$:
  - High-temperature plasma ($T \gg \Lambda_{QCD}$)
  - Random color-fields
  - Non-perturbative “function”

Introduction

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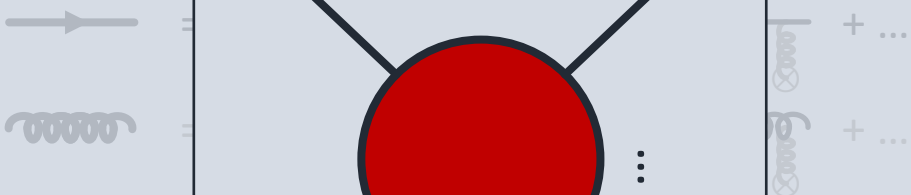

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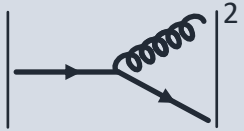
*This talk focuses on $i \to 1,\ldots,n$.

Jet modification: medium-induced emissions

Vacuum

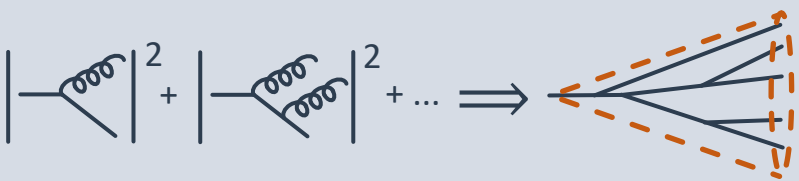
- Emission:



$$\Longrightarrow \quad \frac{dI_i^{vac}}{dzd\vartheta} \approx \frac{\alpha_s}{\pi}\frac{2C_i}{z}\frac{1}{\vartheta}$$

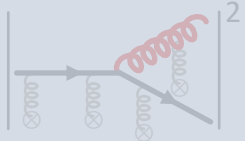
soft & collinear poles!

- Resumming emissions: collinear jet



Medium

- Vacuum + medium-induced emissions:



$$\Longrightarrow \quad \frac{dI_i^{med}}{dz} \approx \frac{\alpha_s}{\pi}\sqrt{\frac{Q_{med}}{E}}\frac{C_i}{\sqrt{z^3}}$$

soft pole!

$m \ll Q_{med}$

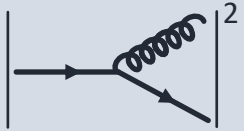
$z \ll Q_{med}/E$

- Wide-angle medium-induced cascade:

Jet modification: medium-induced emissions

Vacuum

- Emission:



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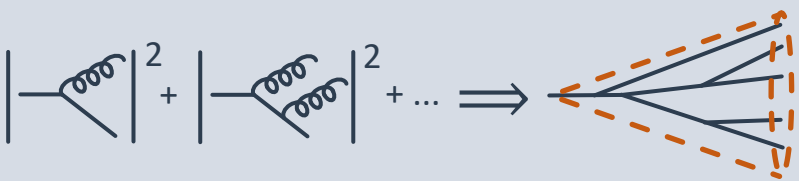

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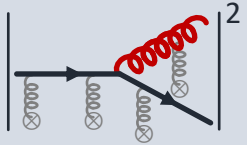

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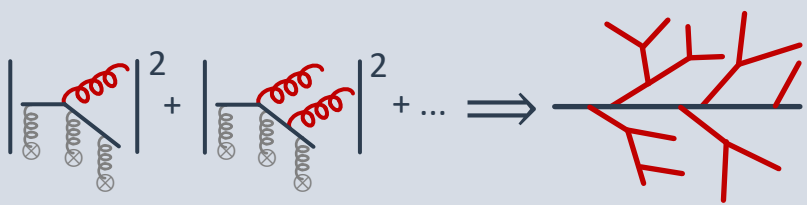
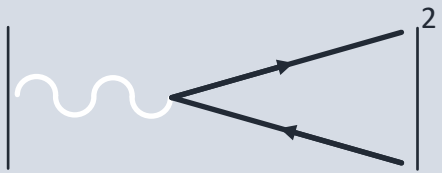


Jet modification: subsequent emissions

Vacuum

- Color conservation:



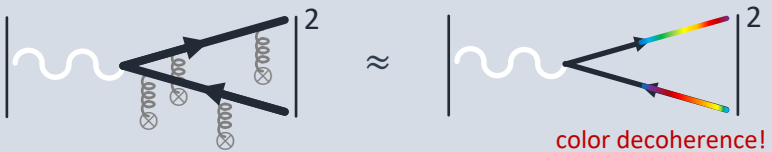
- Two gluon emission:

$$\left| \quad + \quad \right|^2 \approx \frac{dI_q^{vac}}{dz_1 d\vartheta_1} \frac{dI_g^{vac}}{dz_2 d\vartheta_2} \times \Theta(\vartheta_1 > \vartheta_2)$$

angular-ordering!

Medium

- Color decoherence:



- Two gluon emission:
  - (anti-)Angular ordering:
    [Mehtar-Tani, Tywoniuk, Salgado]
    [Caucal, Iancu, Mueller, Soyez]
  - Medium resolution:
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  - Medium ordering:
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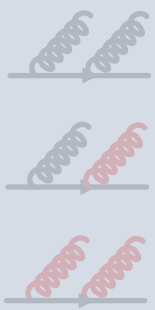
    [Arnold 2015-]



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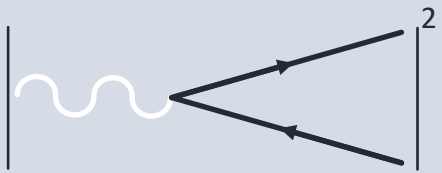

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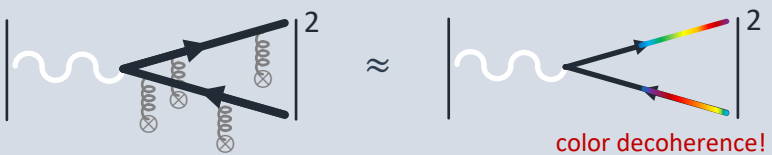

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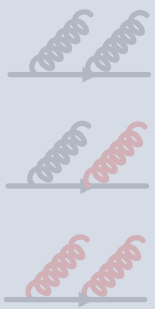

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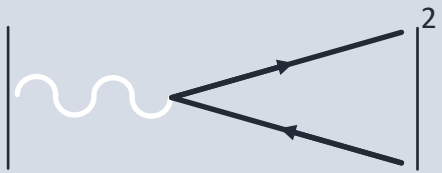

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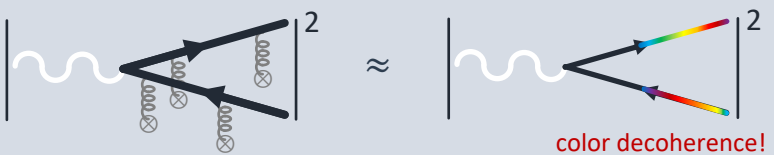

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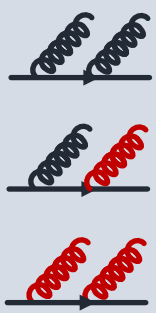

Jet evolution: factorized picture

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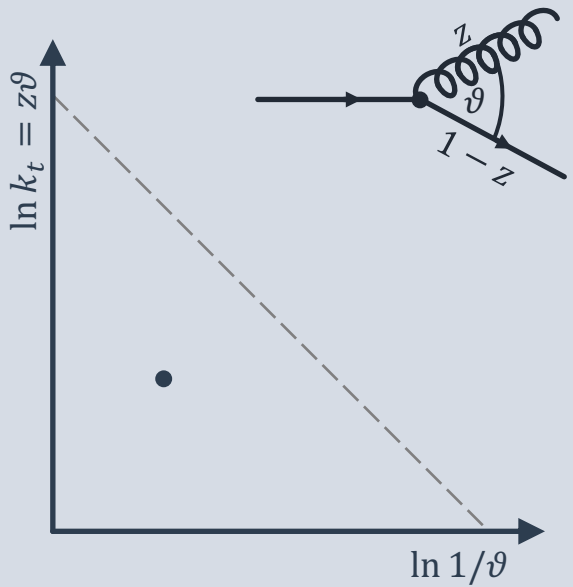

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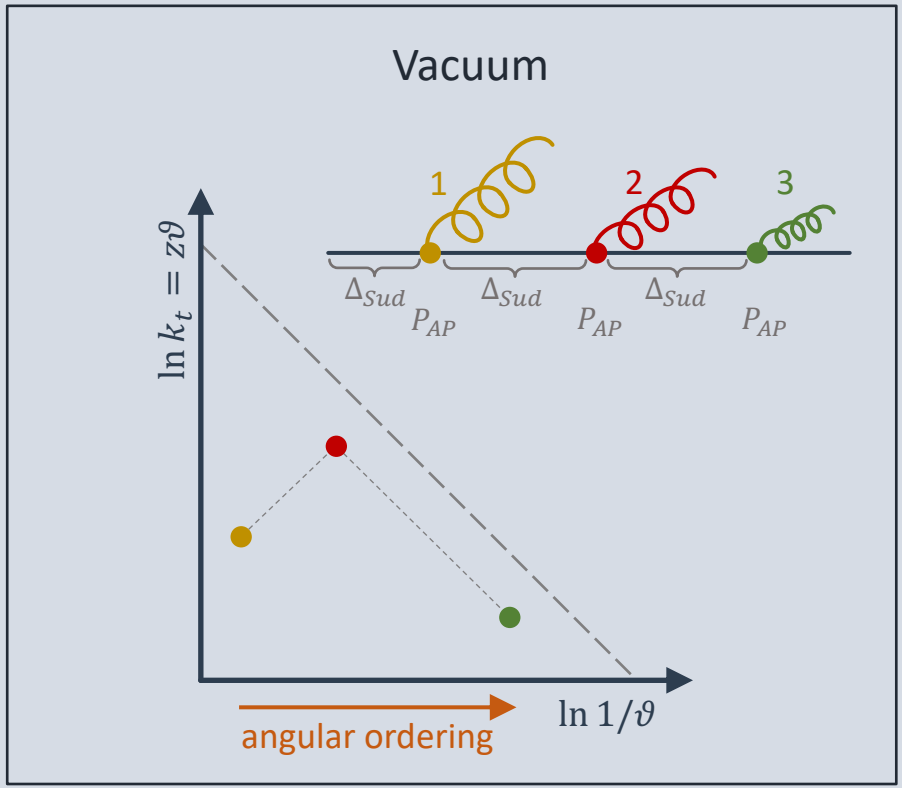

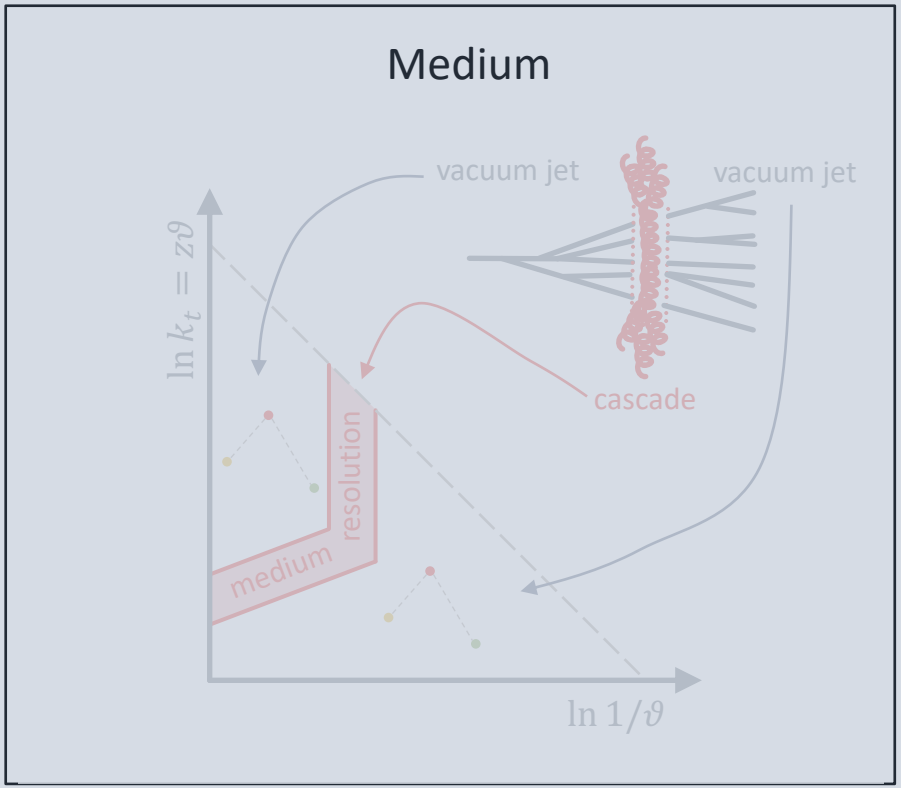

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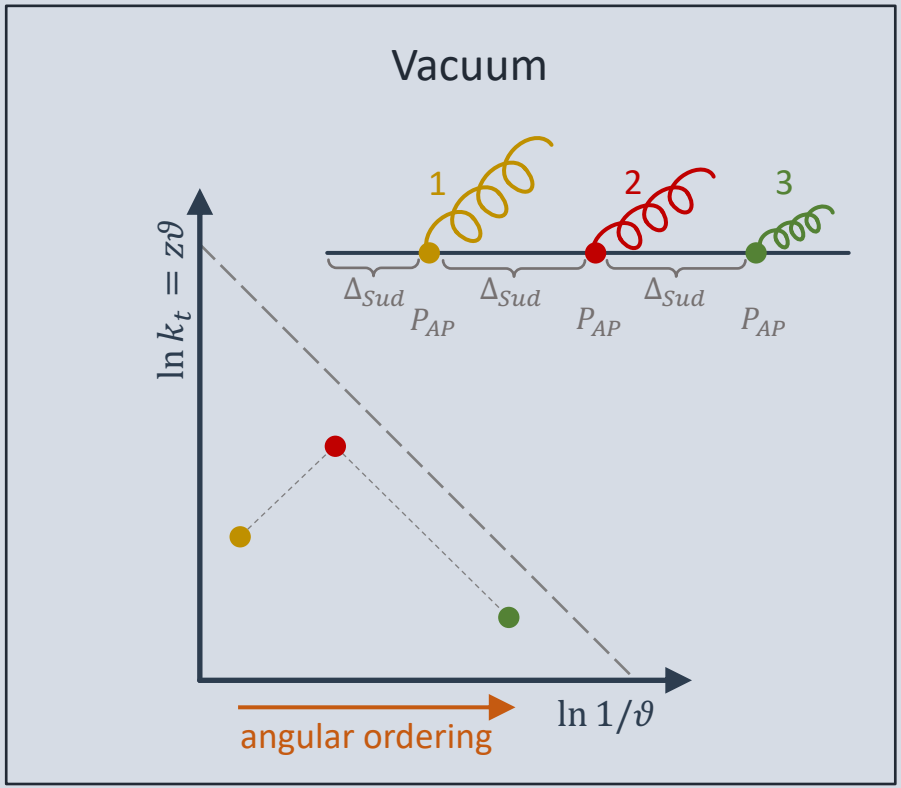
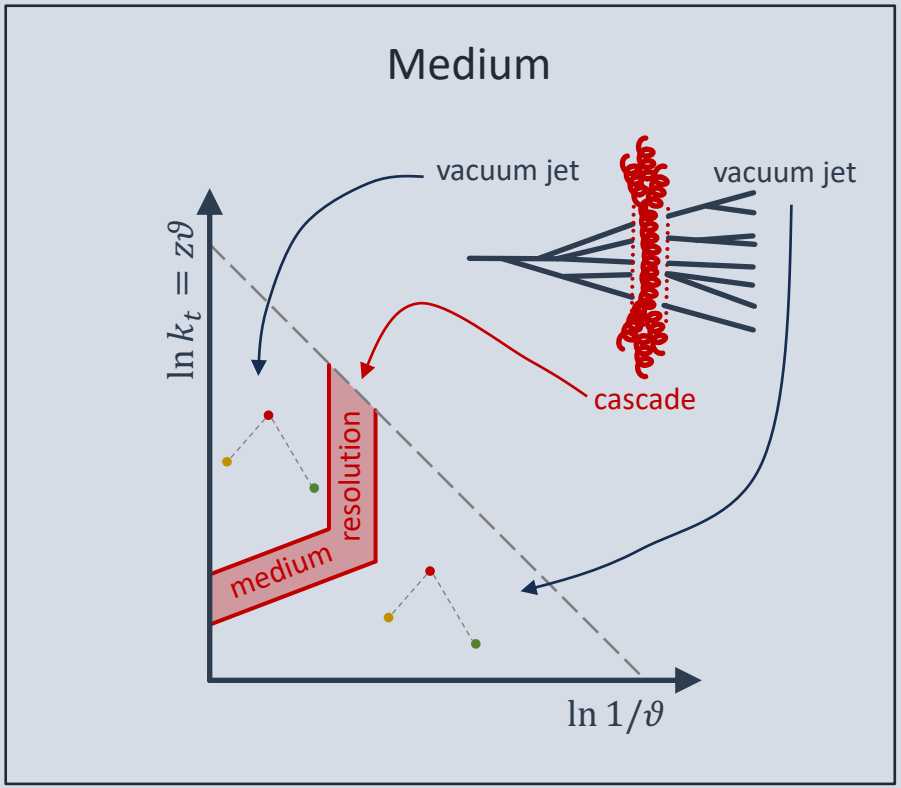
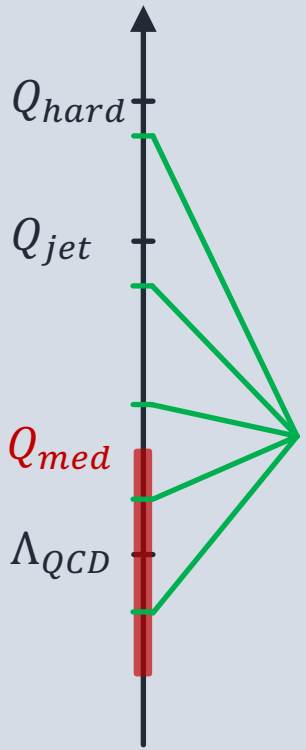




Experimental test of this picture

Experimental tests

Talks by: Barata, Rothman, Jacobs, Go, Ehlers, Andres



Observables:

- event shapes
- jet substructure
- energy correlators
- etc.

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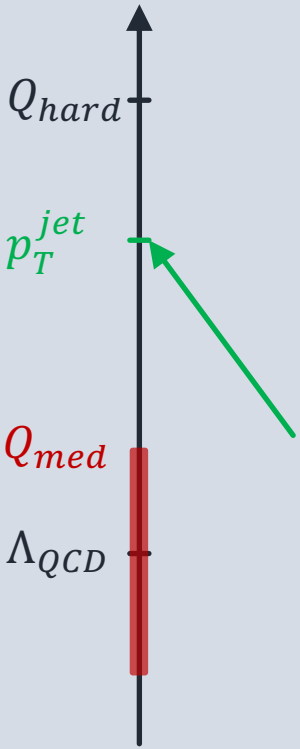

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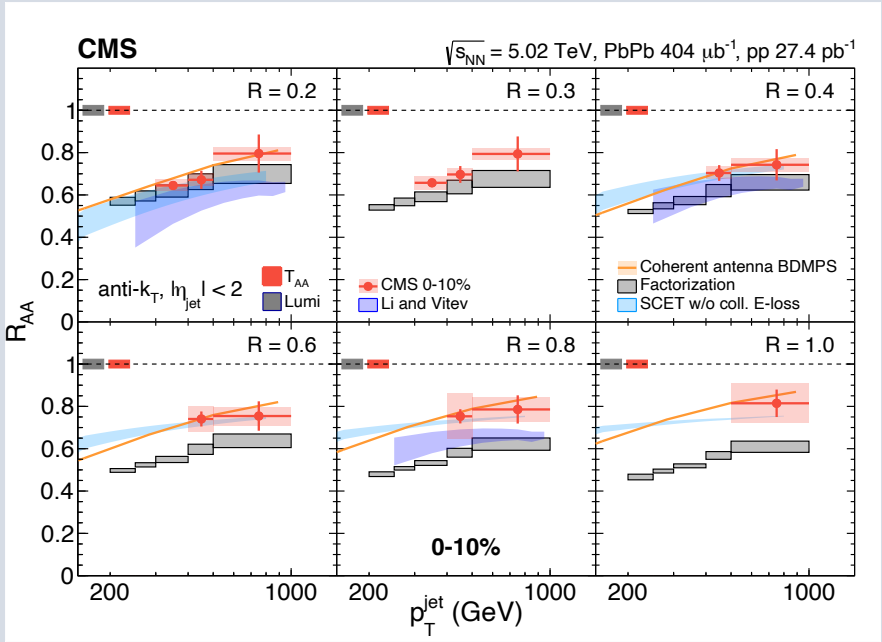

[CMS JHEP05(2021)]

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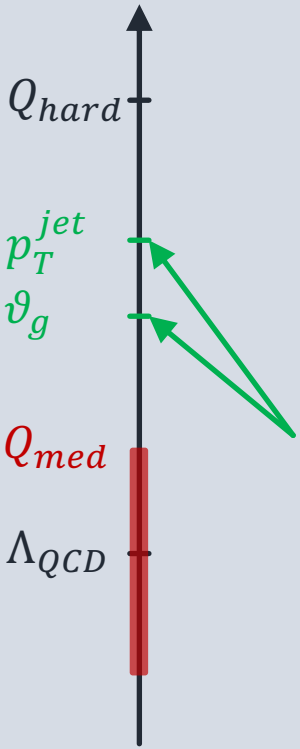

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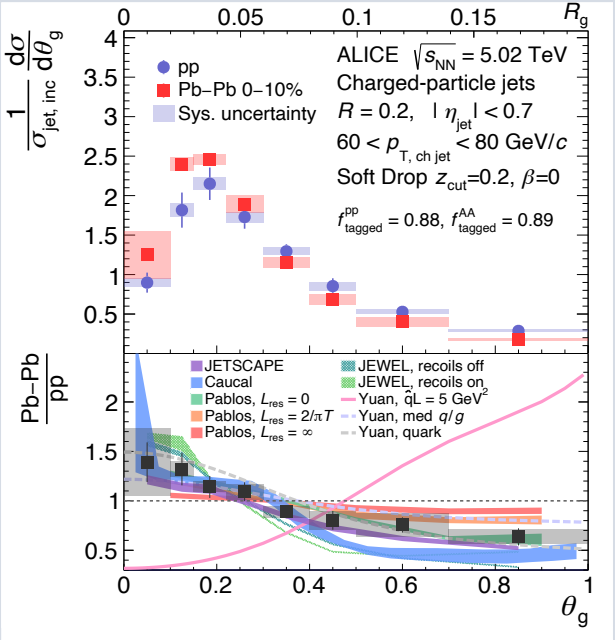

[ALICE PRL128(2022)]

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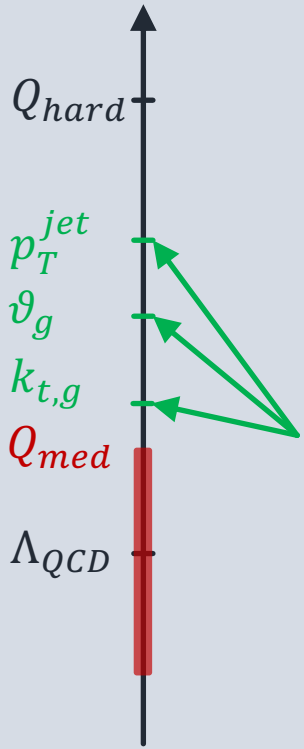

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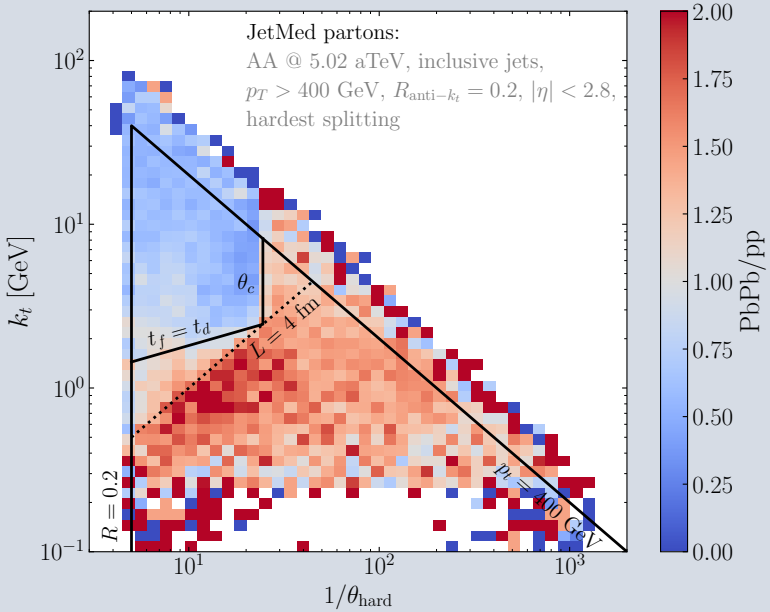
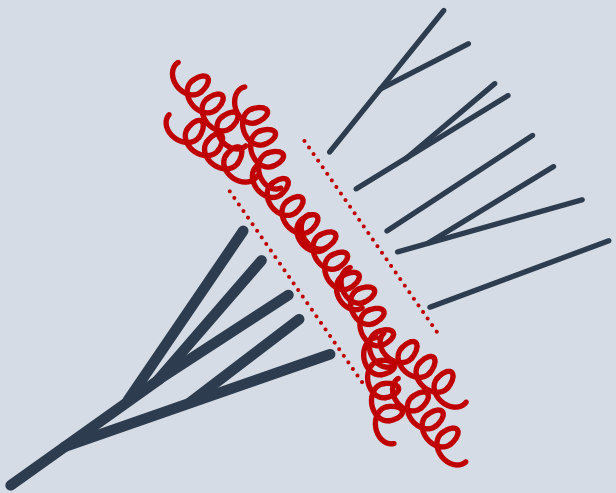


[Cunqueiro, Pablos, Soto-Ontoso, Spousta, Takacs, Verweij 2023]

How to improve this picture?

Improvements

Factorized picture:



Ingredients:

- vacuum evolution: Talks by Caletti, Roloff, Chahrour, Hoppe
  - jet creation (LO→NLO), jet evolution (DLA→NLL)
- cascade evolution:
  - beyond soft&collinear limit (NLO_{med}, NLL_{med})
  - finite sized medium [Ghigliery, Teaney] [Caron-Huot, Gale] [Isaksen, Takacs, Tywoniuk]
- medium scales:
  - resolution, coherence, orderings [Arnold 2023]

+1 medium modeling:

- homogeneous/static → dynamical medium [Sadofyev et al]
- medium response / jet thermalization Talks by Go, Almaalol, Li

Summary:

- Jets modify in the QGP ⇾ extract QGP features ($T, n, \varepsilon, \ldots$)
- (semi-) perturbative treatment
  - scattering amplitudes ⇿ jet observable
- State of the art picture of jet modification:
  - good agreement with data!
  - improvements in the doorstep!

Thank you for your attention!