

Nuclear modification factors for jet fragmentation

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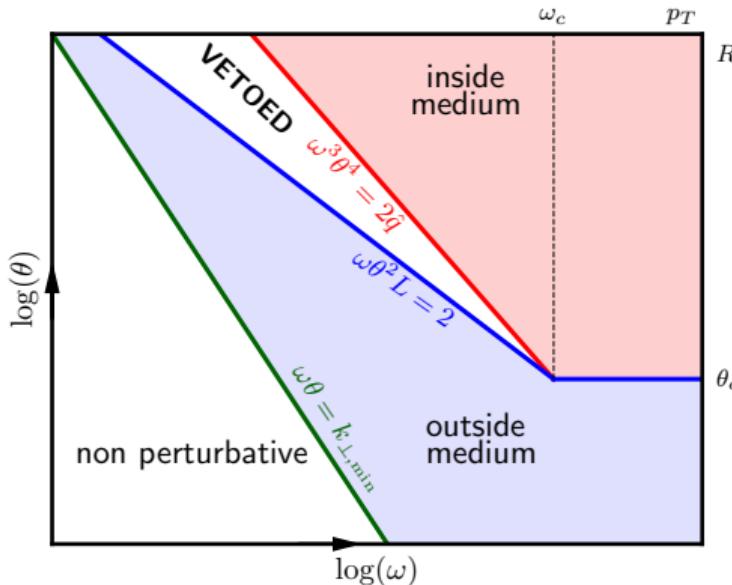
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Talk based on arXiv:2005.05852



A pQCD picture for jet evolution in the QGP

PC, Iancu, Mueller, Soyez, 2018



- Parton showers from pQCD: **factorization** between vacuum-like emissions (bremsstrahlung) and medium-induced ones (BDMPS-Z).
- Vetoed region** for VLEs inside the medium.
- VLEs \Rightarrow sources for energy loss via MIEs.
- Angular ordering** violation for the 1st emission outside the medium.

This talk:

First Monte-Carlo results based on this factorized picture (including **coherence effects**) for the **fragmentation function**.

Fragmentation function (FF): definition

- Energy (\simeq transverse momentum) distribution of particles within jets.

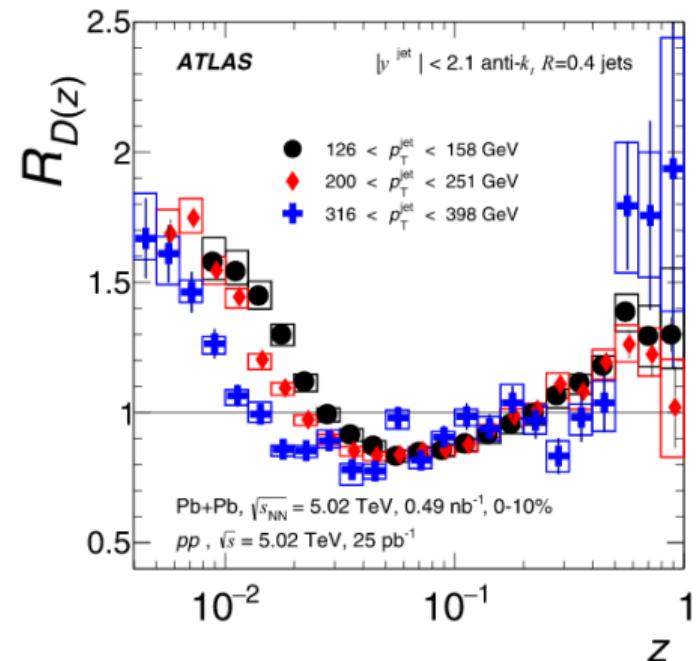
$$\mathcal{D}(x) = \frac{1}{N_{\text{jets}}} \frac{dN}{dx}$$

with $x = p_T \cos(\Delta R)/p_{T,\text{jet}} \sim p_T/p_{T,\text{jet}}$

N.B. x often denoted as z in experimental plots \Rightarrow

- Nuclear modification of the jet fragmentation function:

$$\mathcal{R}(x) = \frac{\mathcal{D}_{\text{PbPb}}(x)}{\mathcal{D}_{\text{pp}}(x)}$$

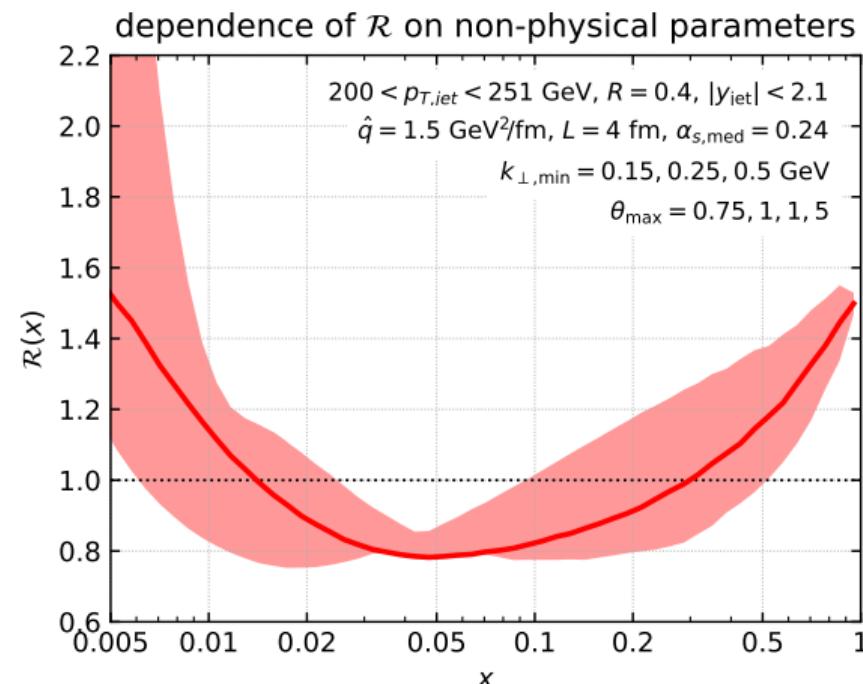


ATLAS Collaboration, Phys. Rev. C98, 2018

FF is not infrared and collinear safe

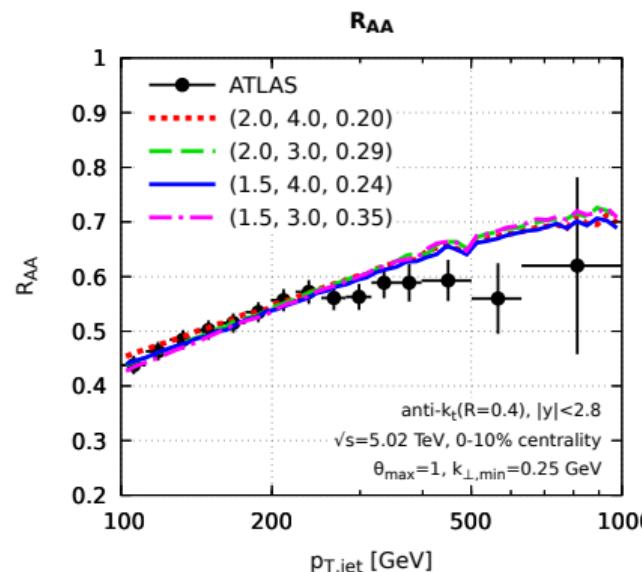
$$x\mathcal{D}_{\text{pp}}(x) \stackrel{\text{DLA}}{=} 2\bar{\alpha}_s \int_{k_{\perp,\min}/(xp_T)}^R \frac{d\theta}{\theta} I_0\left(2\bar{\alpha}_s \sqrt{2\log(1/x)\log(R/\theta)}\right)$$

- \Rightarrow **strong** dependence upon $k_{\perp,\min}$.
- Two ways out:
 - focus on the ratio $\mathcal{R}(x)$,
 - replace FF with better behaved (IRC-safe) observables.

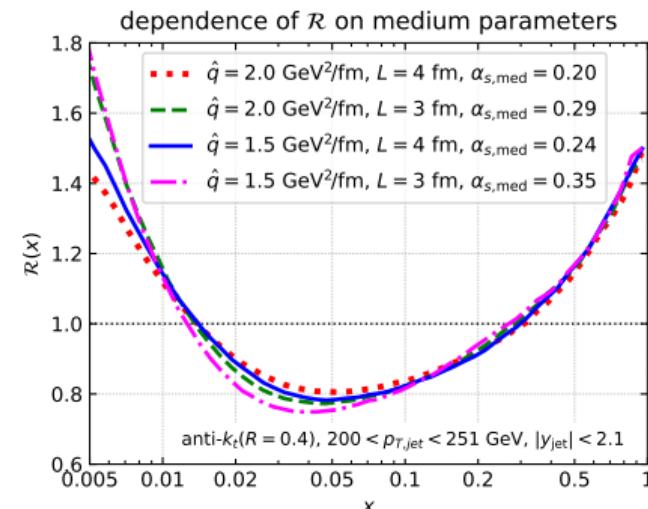


Our Monte-Carlo calculations

Sets of parameters describing R_{AA}
(R_{AA} controlled by $\alpha_{s,\text{med}}^2 \hat{q} L^2$)



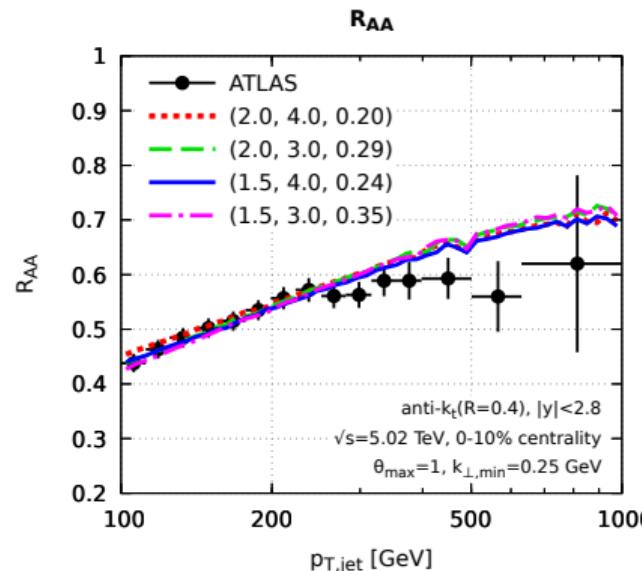
Fragmentation function ratio



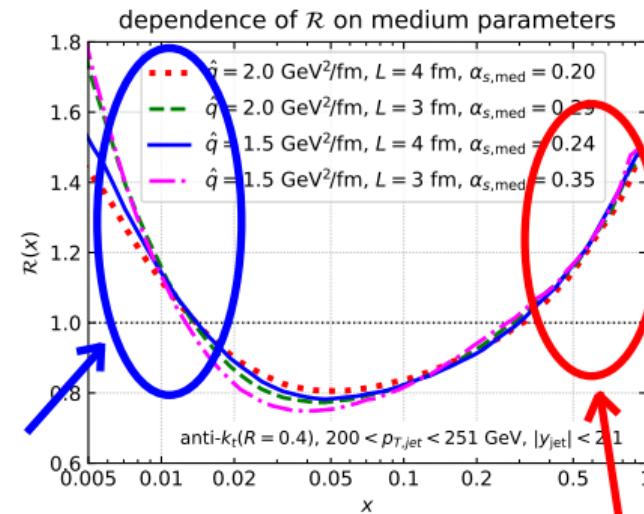
3 medium parameters: \hat{q} , L , and $\alpha_{s,\text{med}}$ (vertex for MIEs).

Our Monte-Carlo calculations

Sets of parameters describing R_{AA}
(R_{AA} controlled by $\alpha_{s,\text{med}}^2 \hat{q} L^2$)



Fragmentation function ratio



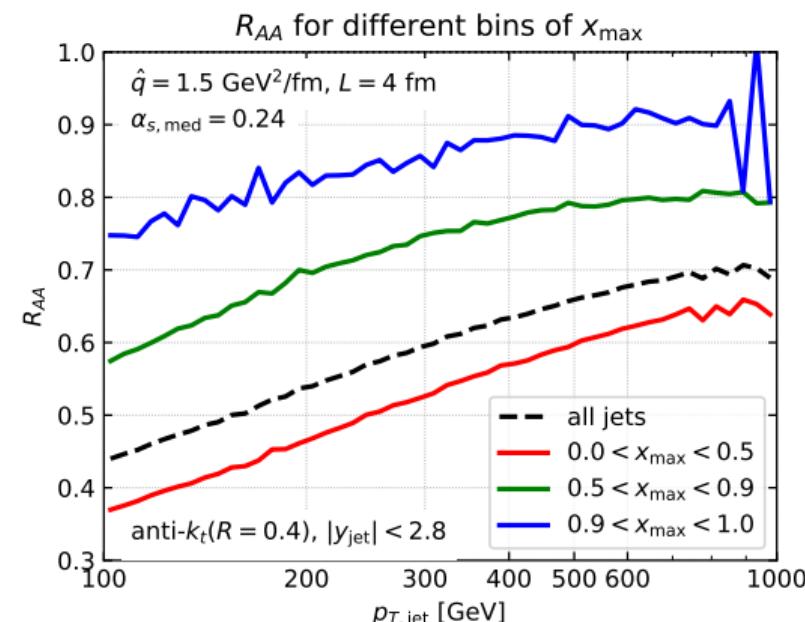
Two regimes

Nuclear enhancement at large x and low x : same behaviour seen in the data.

Large- x behaviour: bias towards “hard-branching” jets

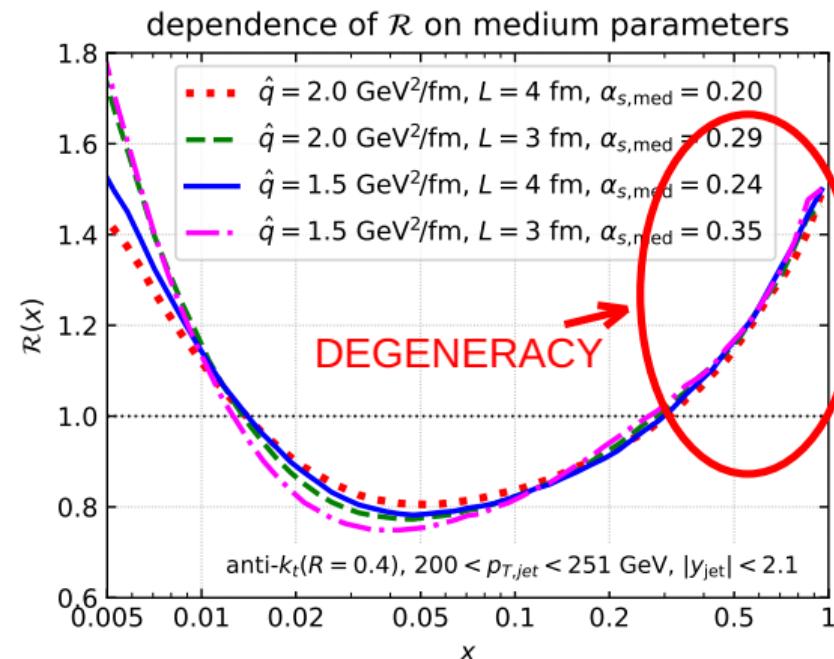
- Not a nuclear change in the fragmentation pattern, but in the statistics of hard-fragmenting jets.
- Hard-fragmenting jets have less structure, hence they lose less energy.
- Additionally: bias towards quark-initiated jets.

see also Casalderrey-Solana et al.(1808.07386) 2019, Spousta and Cole, (1504.05169) 2016



Large- x behaviour: bias towards “hard-branching” jets

- Strong correlation between R_{AA} and **large x** fragmentation function ratio.
- Mild effect coming from the medium fragmentation pattern itself [PC, Mueller, Iancu, Soyez, 2020](#)

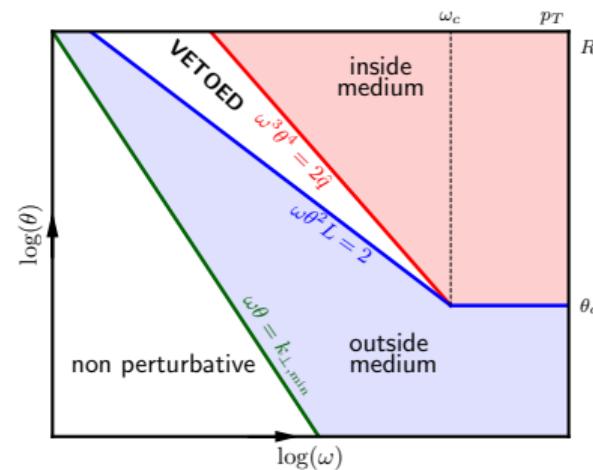
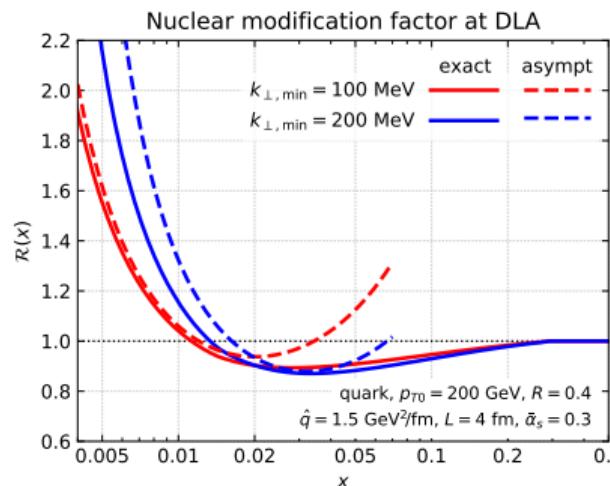


Enhancement at low x : colour decoherence and MIEs

Colour decoherence

- ⇒ **no angular ordering** for the first emission outside the medium,
- ⇒ **factorisation** between parton cascades inside & outside the medium. PC, Iancu, Mueller, Soyez, 2020

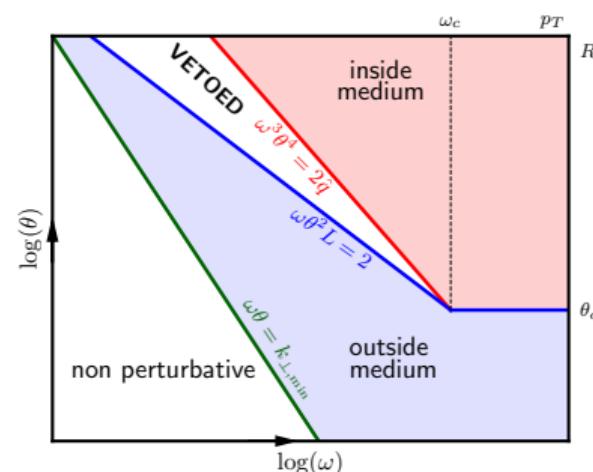
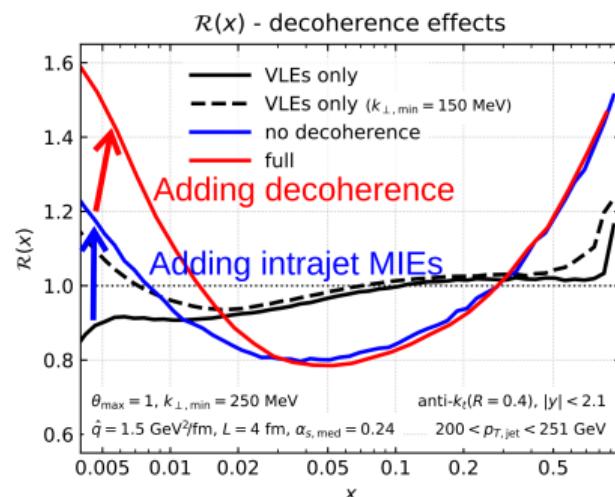
$$x\mathcal{D}_{\text{PbPb}}(x) \simeq \frac{\sqrt{\bar{\alpha}_s}}{4} \times \overbrace{\mathcal{N}_{\text{med}}}^{\text{number of "in" sources}} \times \overbrace{\exp(\bar{\alpha}_s \log(2xp_T/\Lambda^2 L))}^{\text{outside DL cascade}}$$



Enhancement at low x : colour decoherence and MIEs

Monte Carlo tests of various mechanisms

- VLEs only: medium effect = vetoed region + colour decoherence,
- VLEs and MIEs: vetoed region, energy loss, but no colour decoherence,
- Full MC: no angular ordering for the first emission outside the medium.

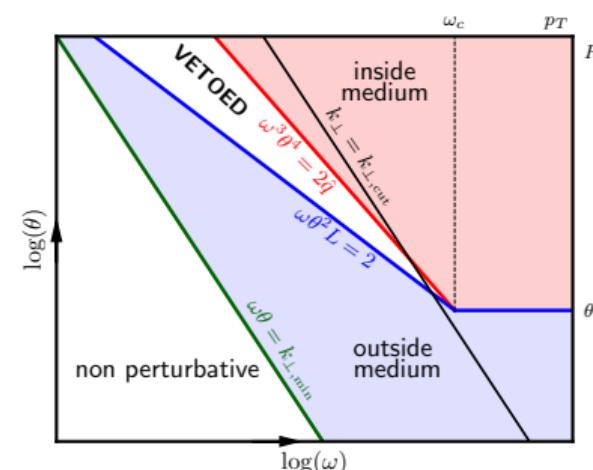
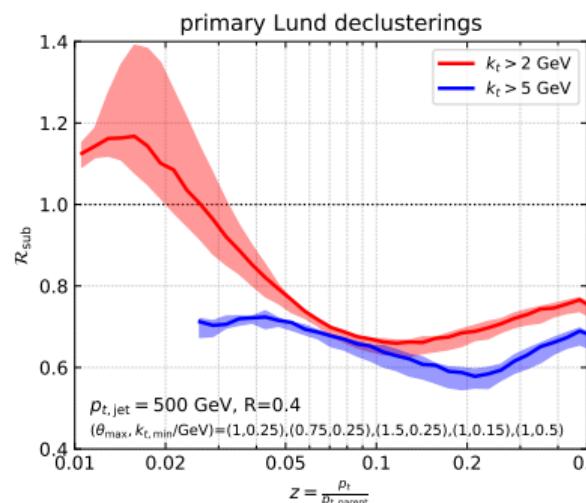


IRC safe fragmentation function: FF from subjets

Definition

$$\mathcal{D}_{\text{sub}}(z) = \frac{1}{N_{\text{jets}}} \frac{dN_{\text{sub}}}{dz}$$

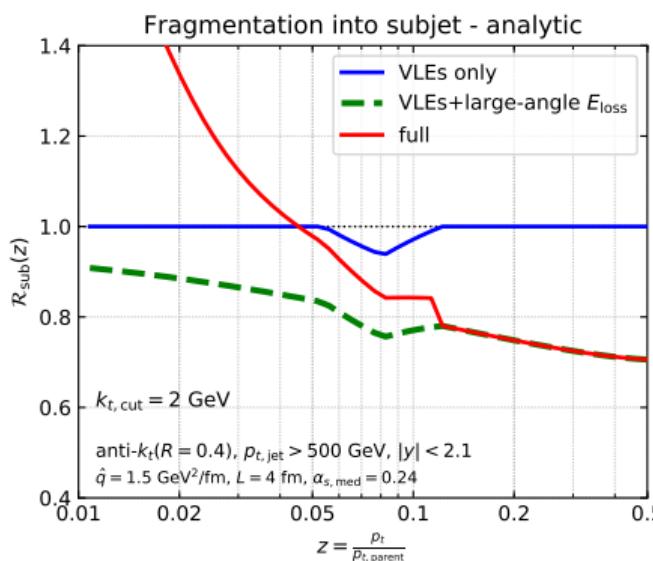
dN_{sub} number of **primary subjets** with $k_{\perp} > k_{\perp\text{cut}}$ found after an iterative C/A declustering.



FF from subjets: leading order analysis

DL result

$$\mathcal{D}_{\text{sub}}^{PbPb}(z) \simeq \left[\int_0^R \frac{d\theta}{\theta} \frac{2\alpha_s(z\theta p_T)}{\pi z} \Theta_{\text{cut}} \Theta_{\notin \text{veto}} \right] \times \sum_{i=q,g} \frac{C_i \sigma_i(p_T + \mathcal{E}_i(z))}{\sigma_q(p_T + \bar{\mathcal{E}}_q) + \sigma_g(p_T + \bar{\mathcal{E}}_g)}$$

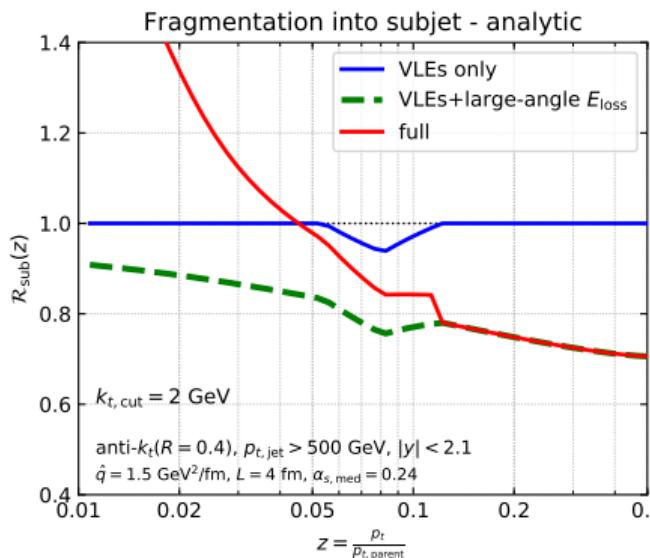


- Same physics at play as for the FF.
- Veto region $\Theta_{\text{cut}} \rightarrow \Theta_{\text{cut}} \Theta_{\notin \text{veto}}(z, \theta)$
- N_{jets} normalization effect:
energy loss \bar{E} of the average jets < energy loss $E_i(z)$ for 2 hard subjets

FF from subjets: leading order analysis

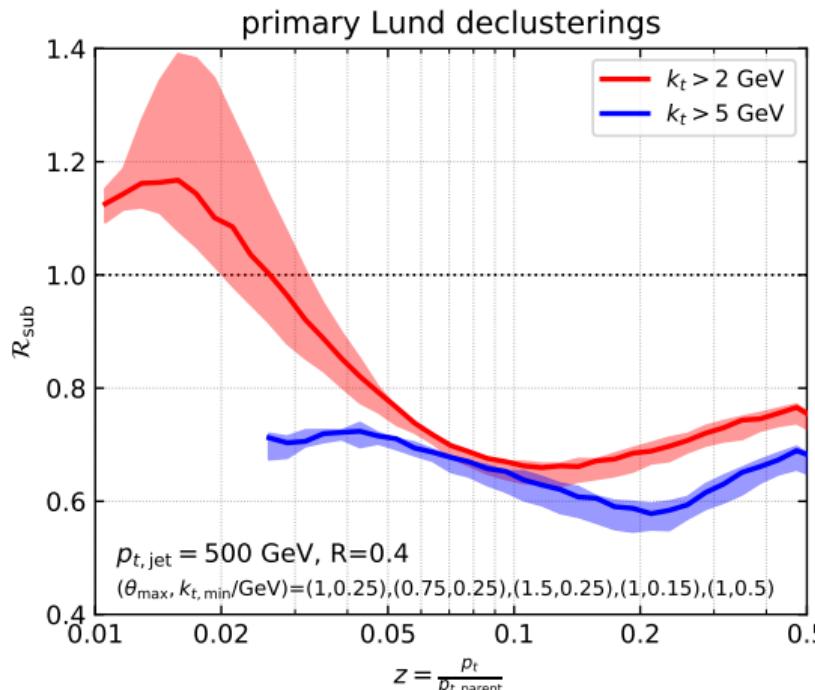
DL result

$$\mathcal{D}_{\text{sub}}^{PbPb}(z) \simeq \int_0^R d\theta \left[\frac{1}{\theta} \frac{2\alpha_s(z\theta p_T)}{\pi z} \Theta_{\notin \text{veto}} + \frac{d^2 N_{\text{mie}}}{dz d\theta} \right] \Theta_{\text{cut}} \times \sum_{i=q,g} \frac{C_i \sigma_i(p_T + \mathcal{E}_i(z))}{\sigma_q(p_T + \bar{\mathcal{E}}_q) + \sigma_g(p_T + \bar{\mathcal{E}}_g)}$$



- Same physics at play as for the FF.
- Veto region $\Theta_{\text{cut}} \rightarrow \Theta_{\text{cut}} \Theta_{\notin \text{veto}}(z, \theta)$
- N_{jets} normalization effect:
energy loss \bar{E} of the average jets < energy loss $E_i(z)$ for 2 hard subjets
- Intrajet hard MIEs.

Take-home messages

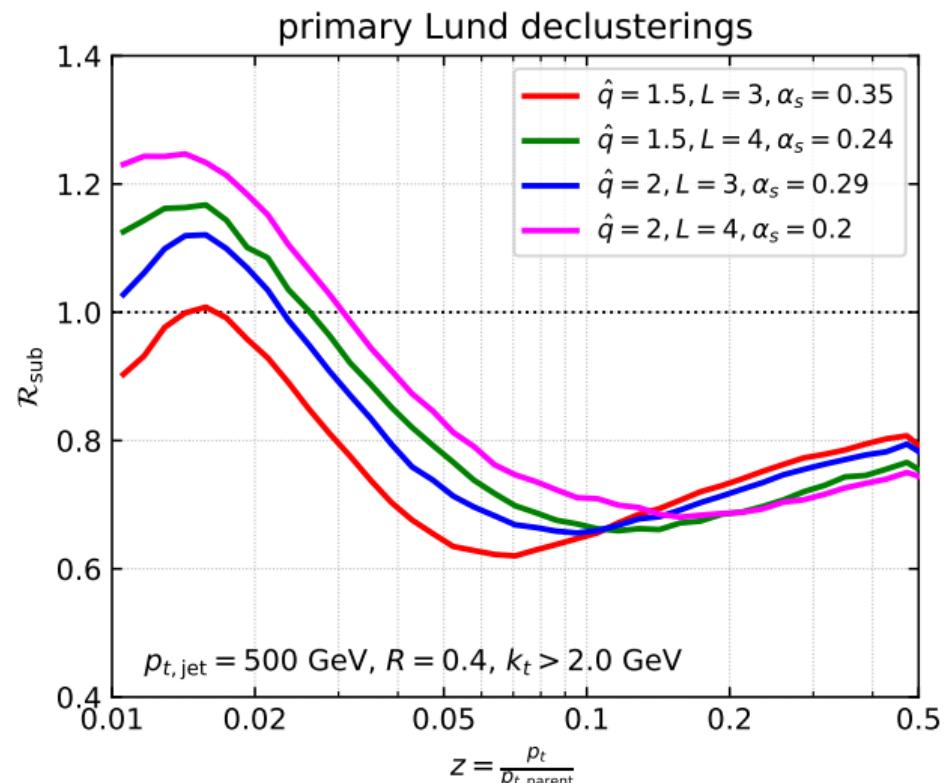


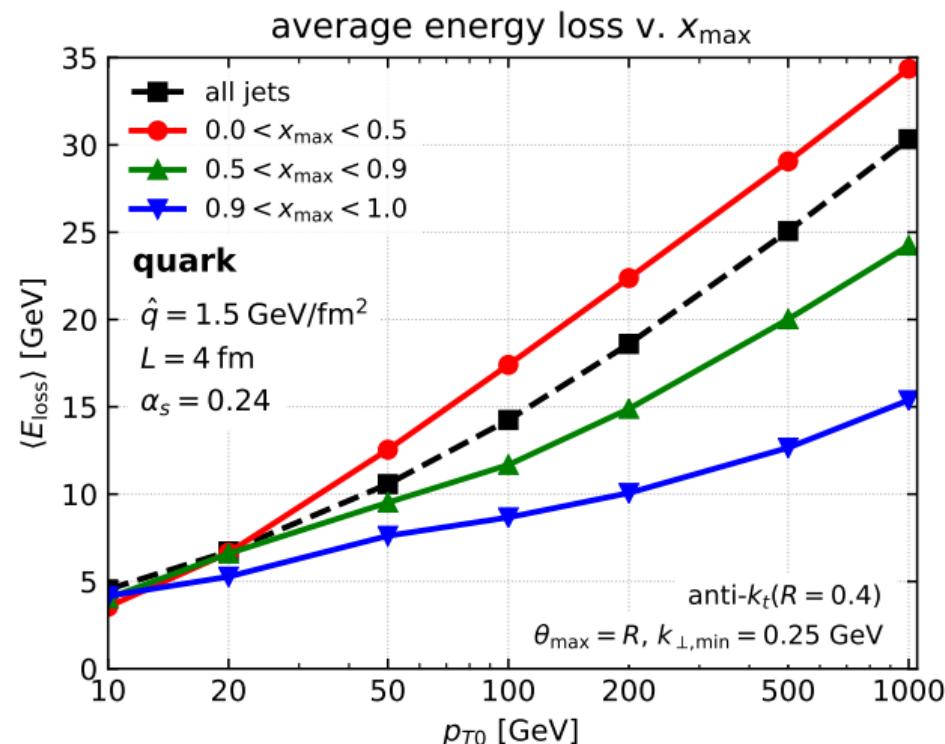
- IRC safe is ... safer !
- Standard FF (IRC unsafe):
 - large \times enhancement correlated with RAA,
 - small \times enhancement due to intrajet MIEs + decoherence,
 - large error bars (sensitivity to $k_{\perp \min}$).
- FF from subjets (IRC safe): better control for the nuclear effects.

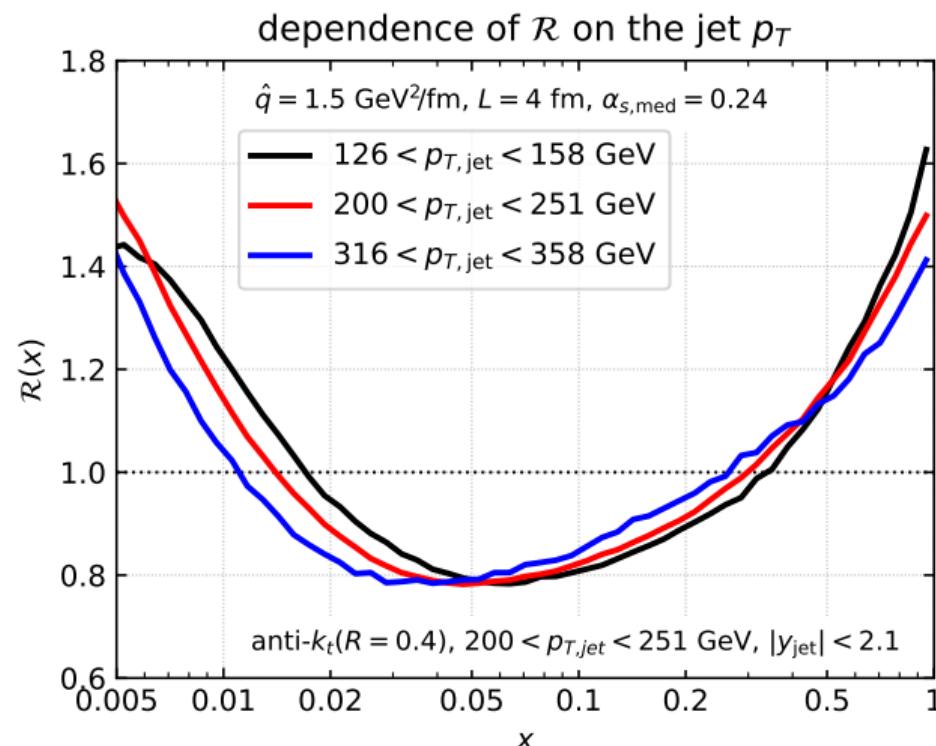
THANK YOU !

BACK-UP

FF from subjets: dependence on medium parameters



Jet energy loss as function of x_{\max} 

FF: dependence on jet p_T 

FF: disentangling statistical bias vs. in-medium fragmentation

