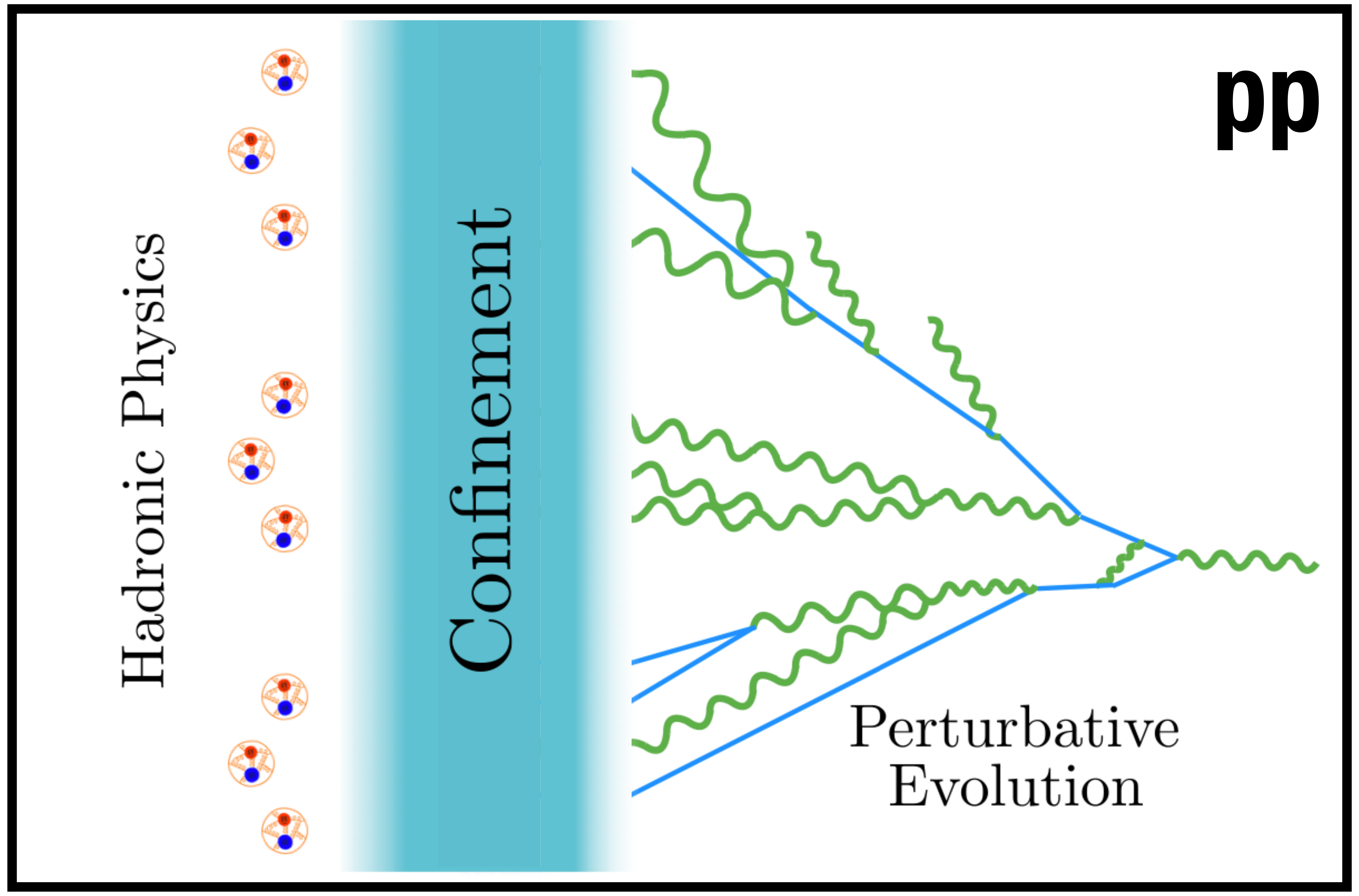
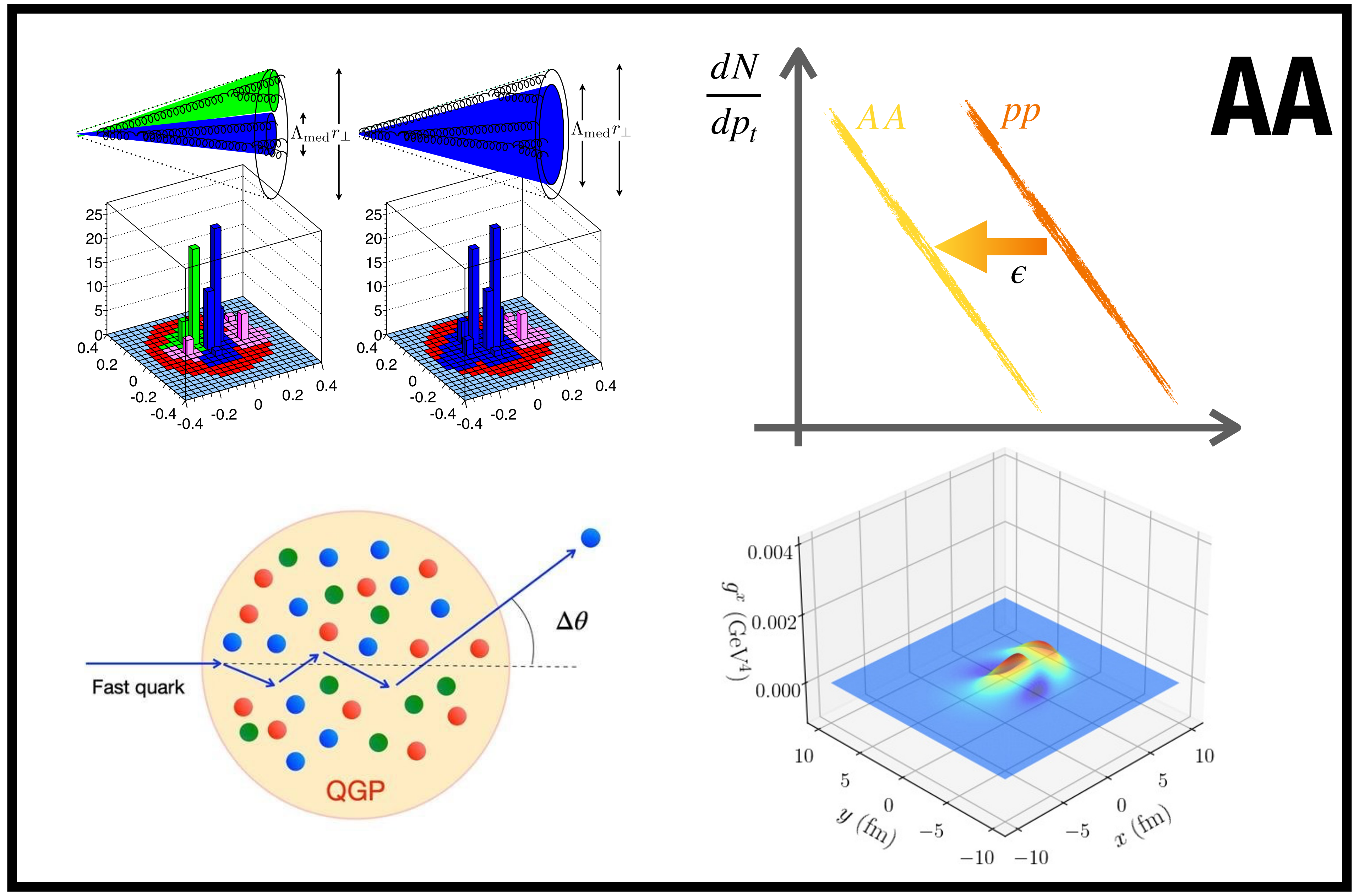
On the theory interpretation of upcoming EECs measurements



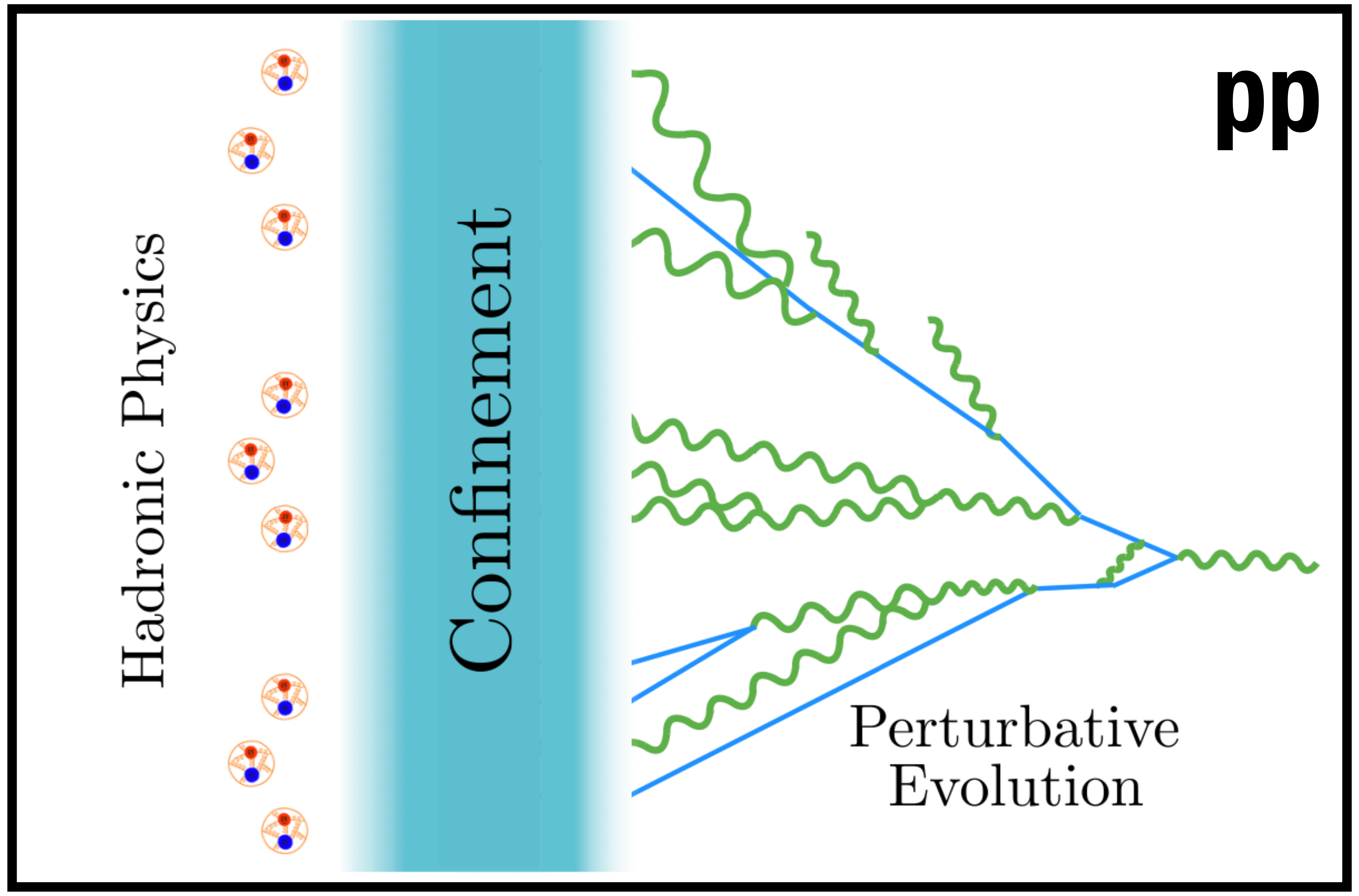


Alba Soto-Ontoso

New jet quenching tools to explore equilibrium and non equilibrium dynamics in heavy-ion collisions

ECT*, 13th February, 2024

On the theory interpretation of upcoming EECs measurements



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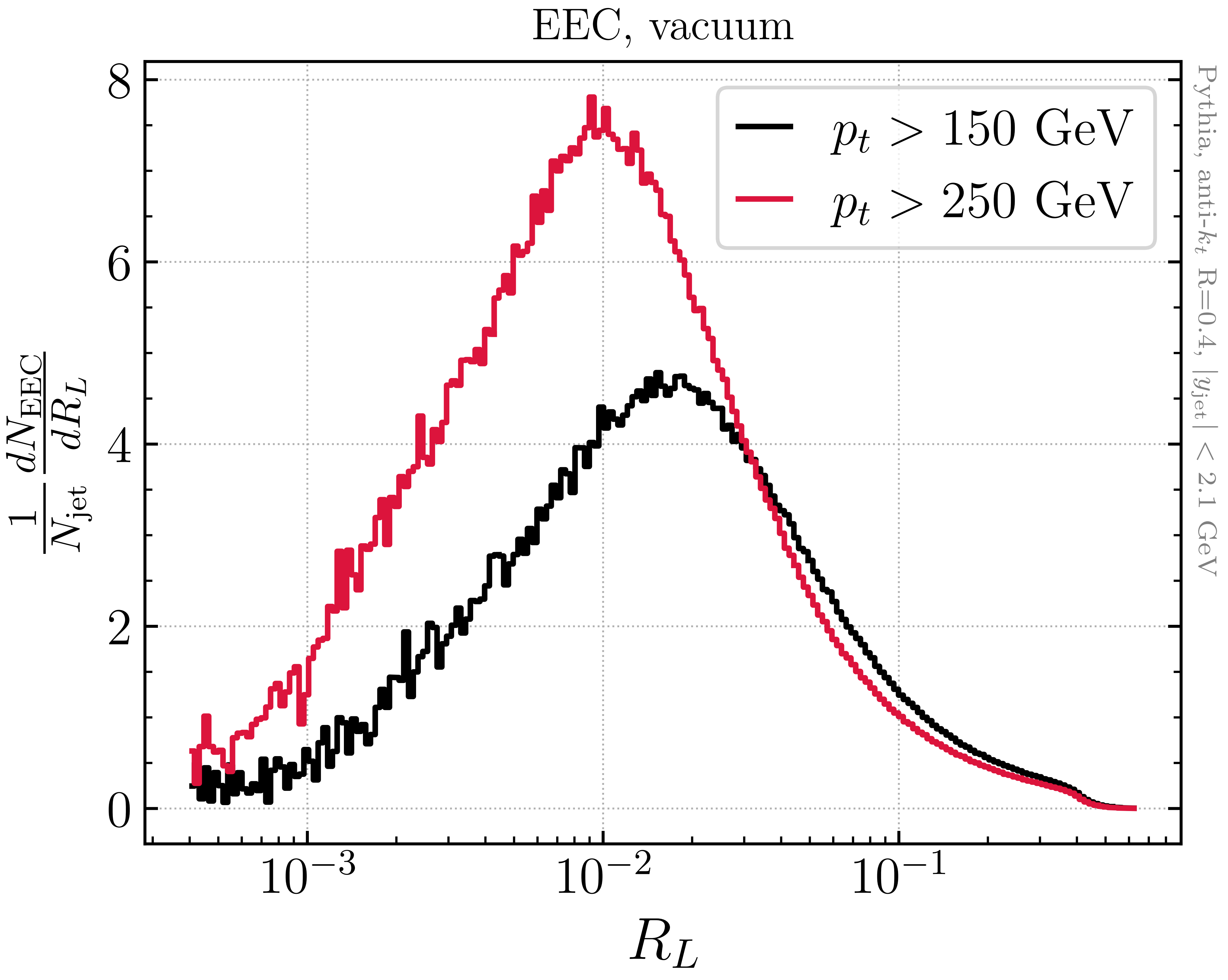
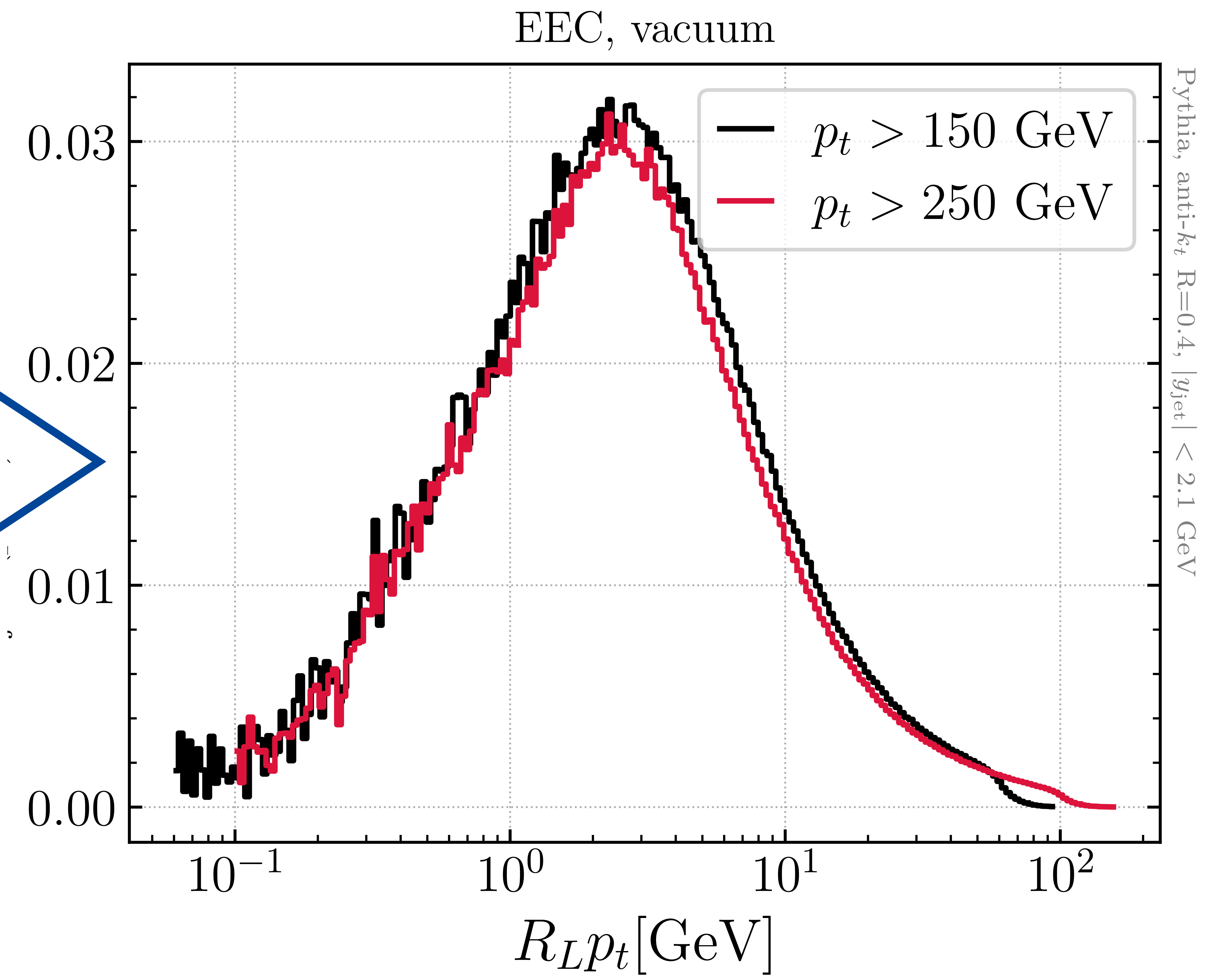
Scaling argument for EECs: PYTHIA simulation



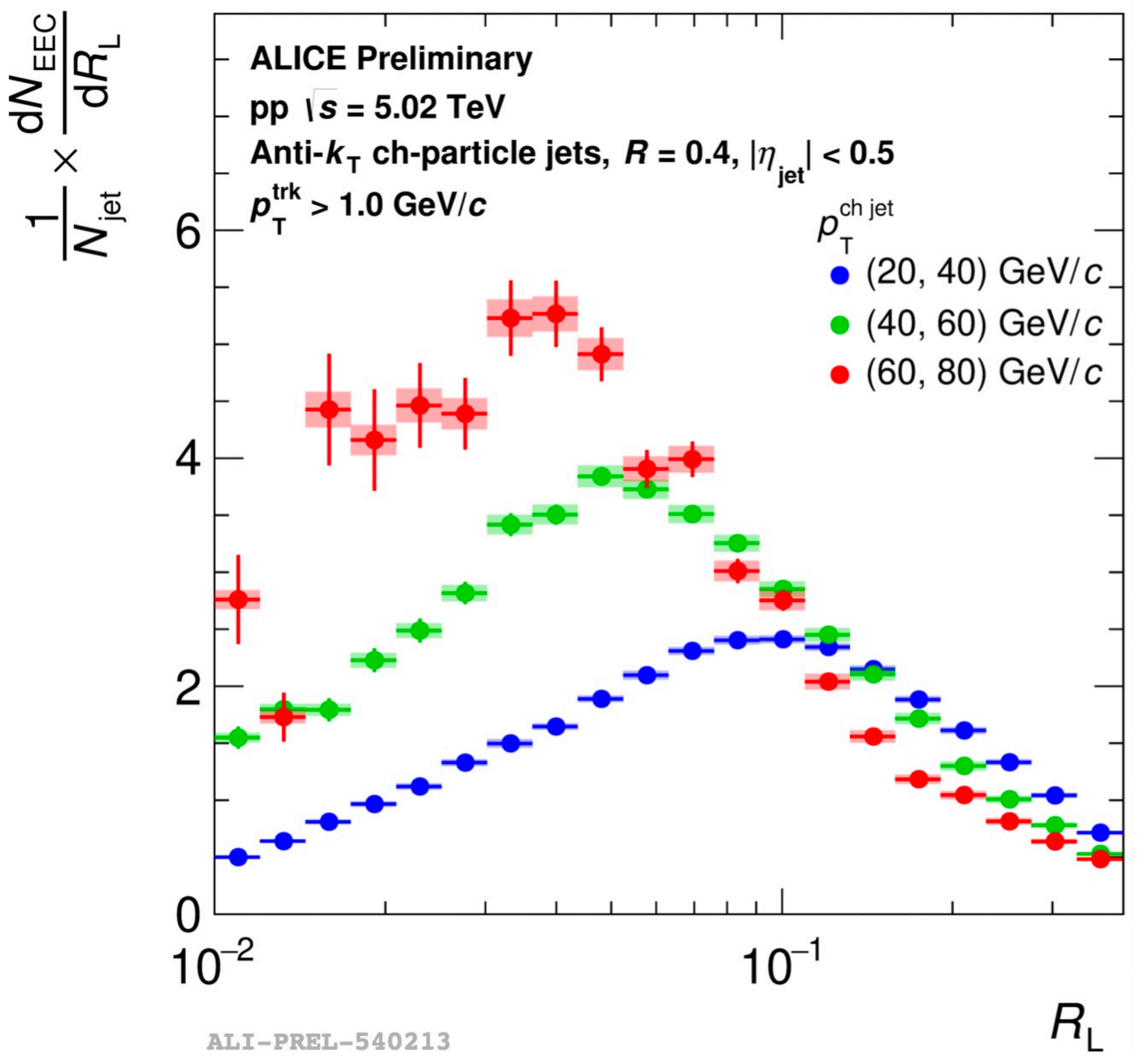
Rescale by p_t



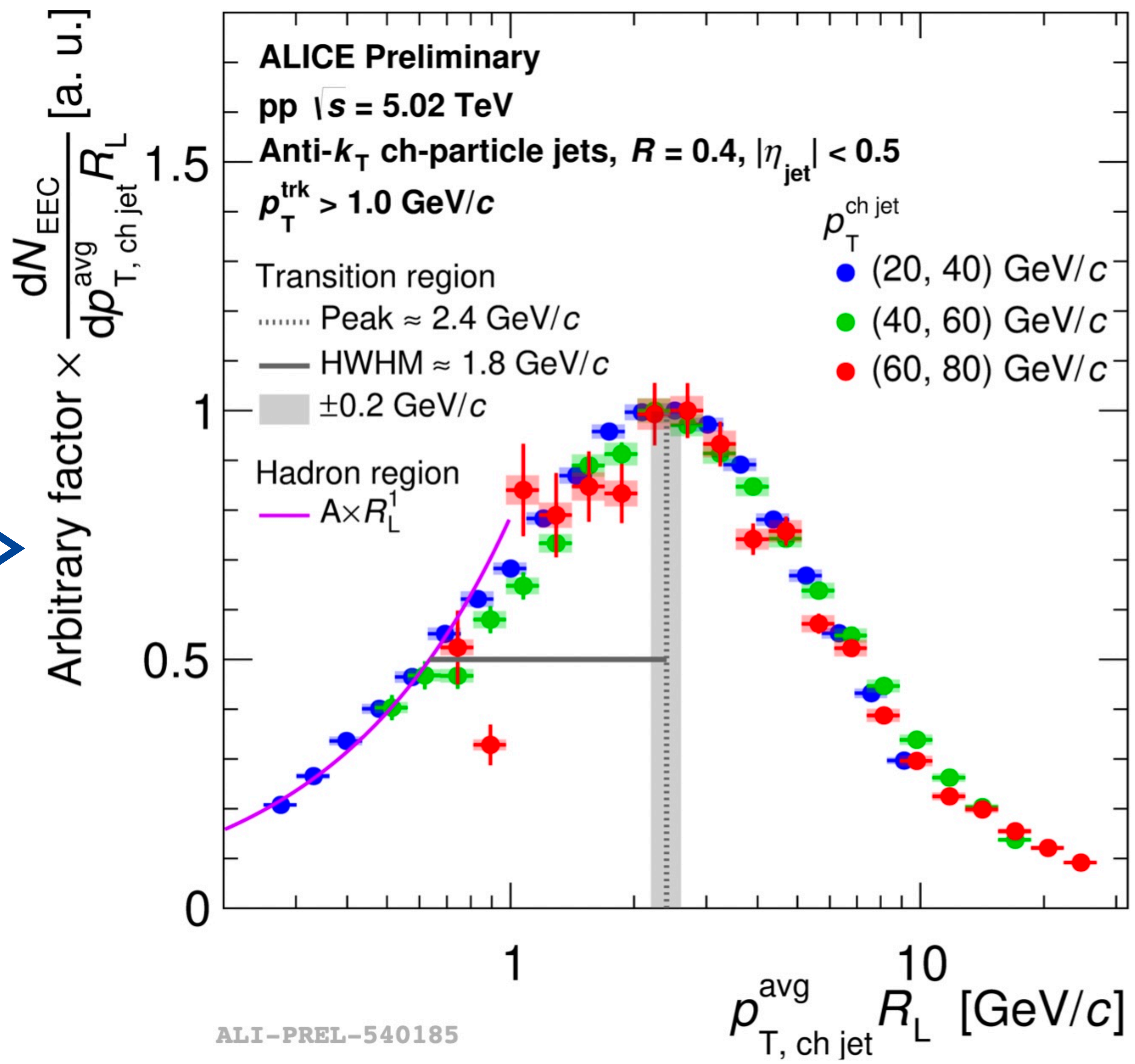
Minimum angle accessed perturbatively ~$\lambda_{\rm QCD}/p_{t,\rm jet}$

Scaling argument for EECs: preliminary ALICE data

[Talks by R. Cruz-Torres and A. Tamis at HP23]

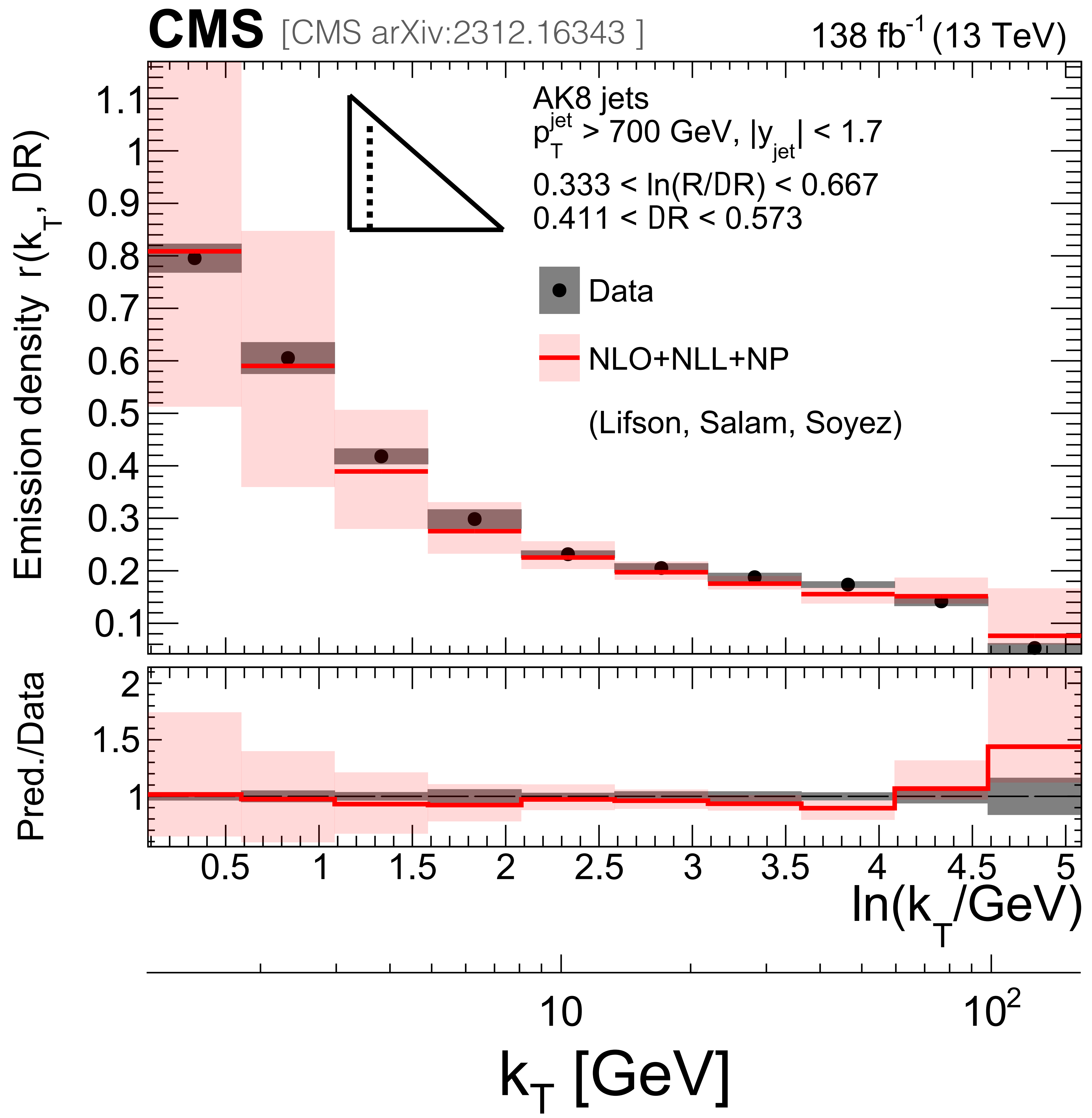


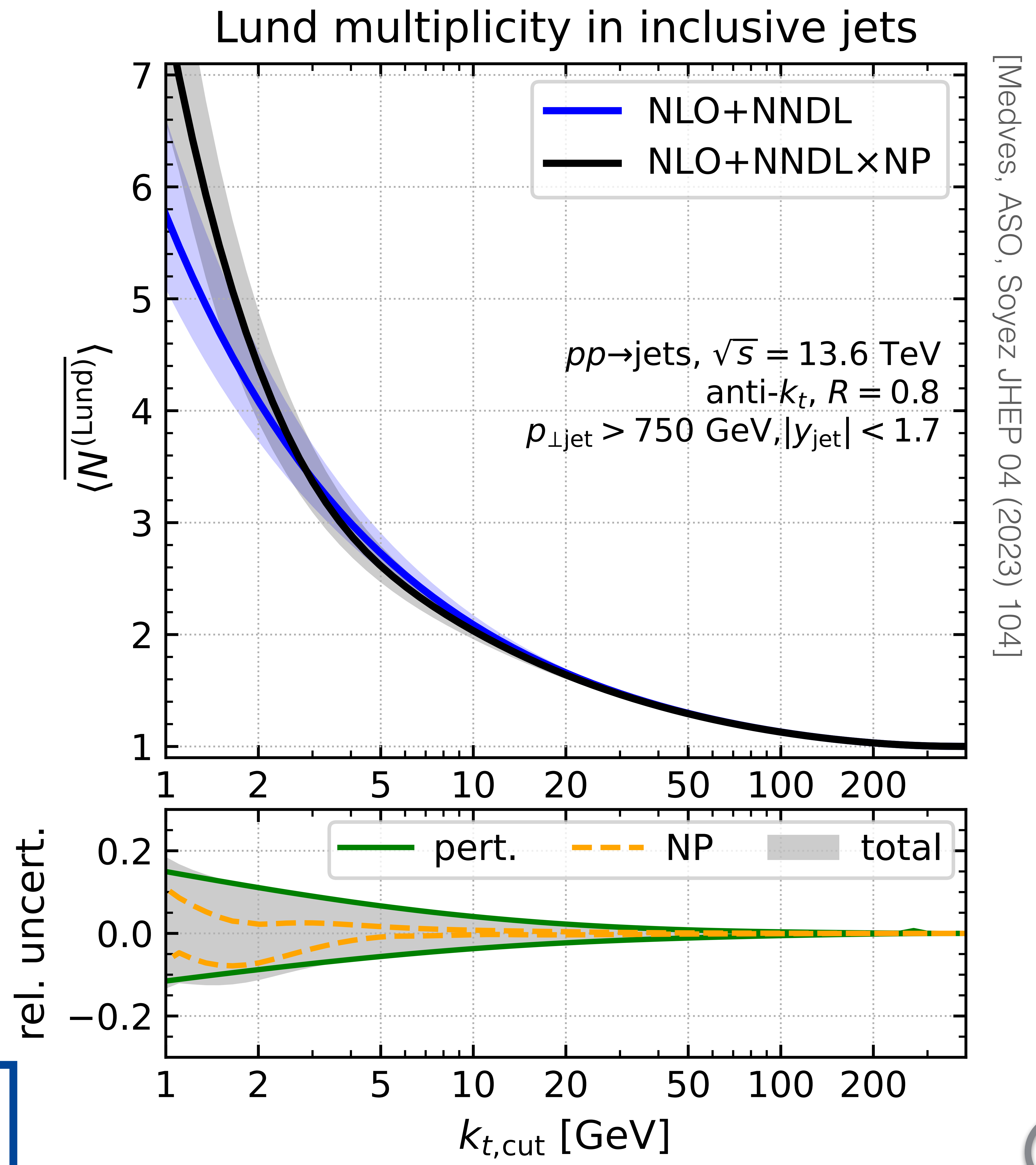
Rescale by p_t



Non-perturbative, universal scale extracted from peak position ~ 2 to 3 GeV

Scale of non-perturbative physics in other jet observables



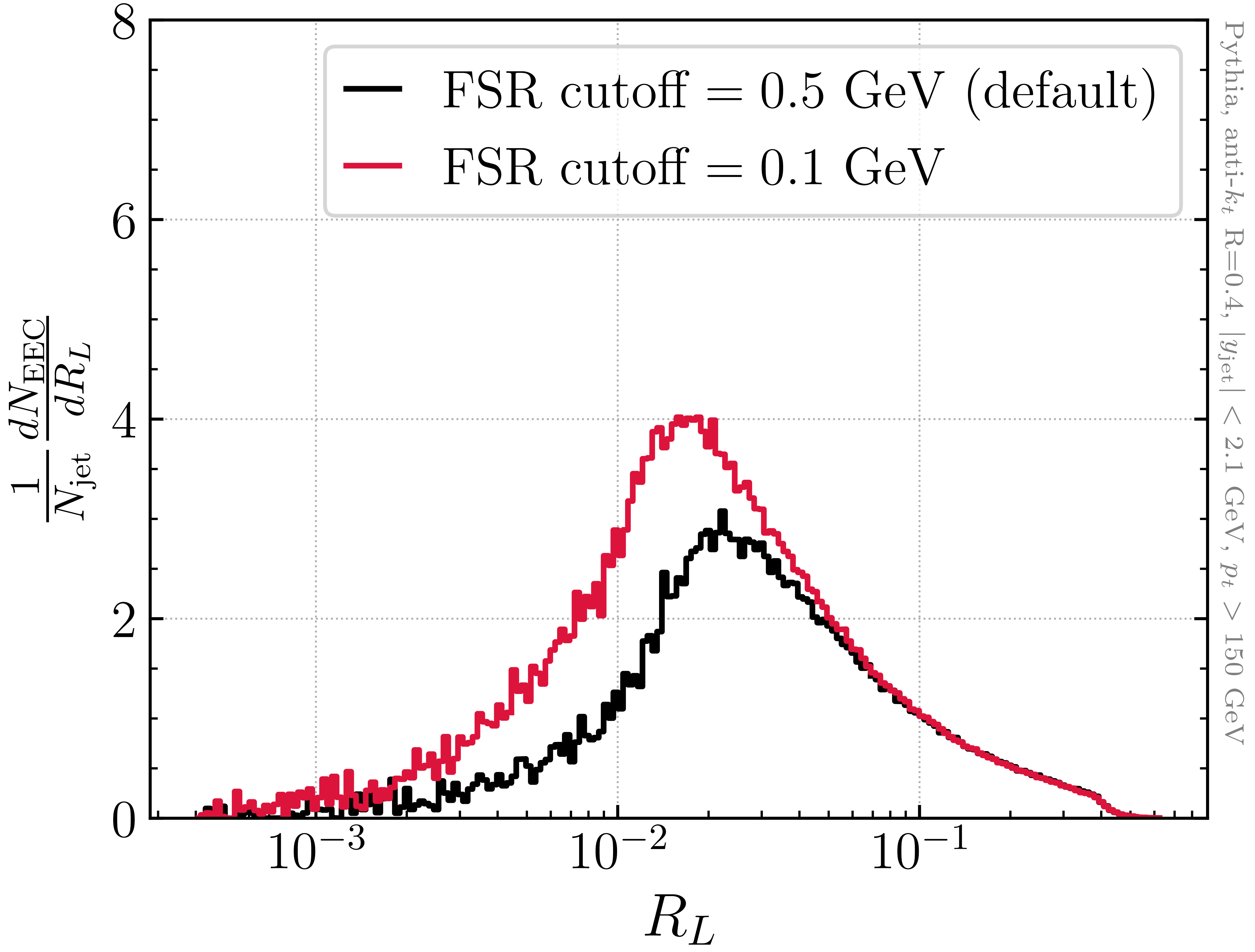


Similar infrared scale in other observables

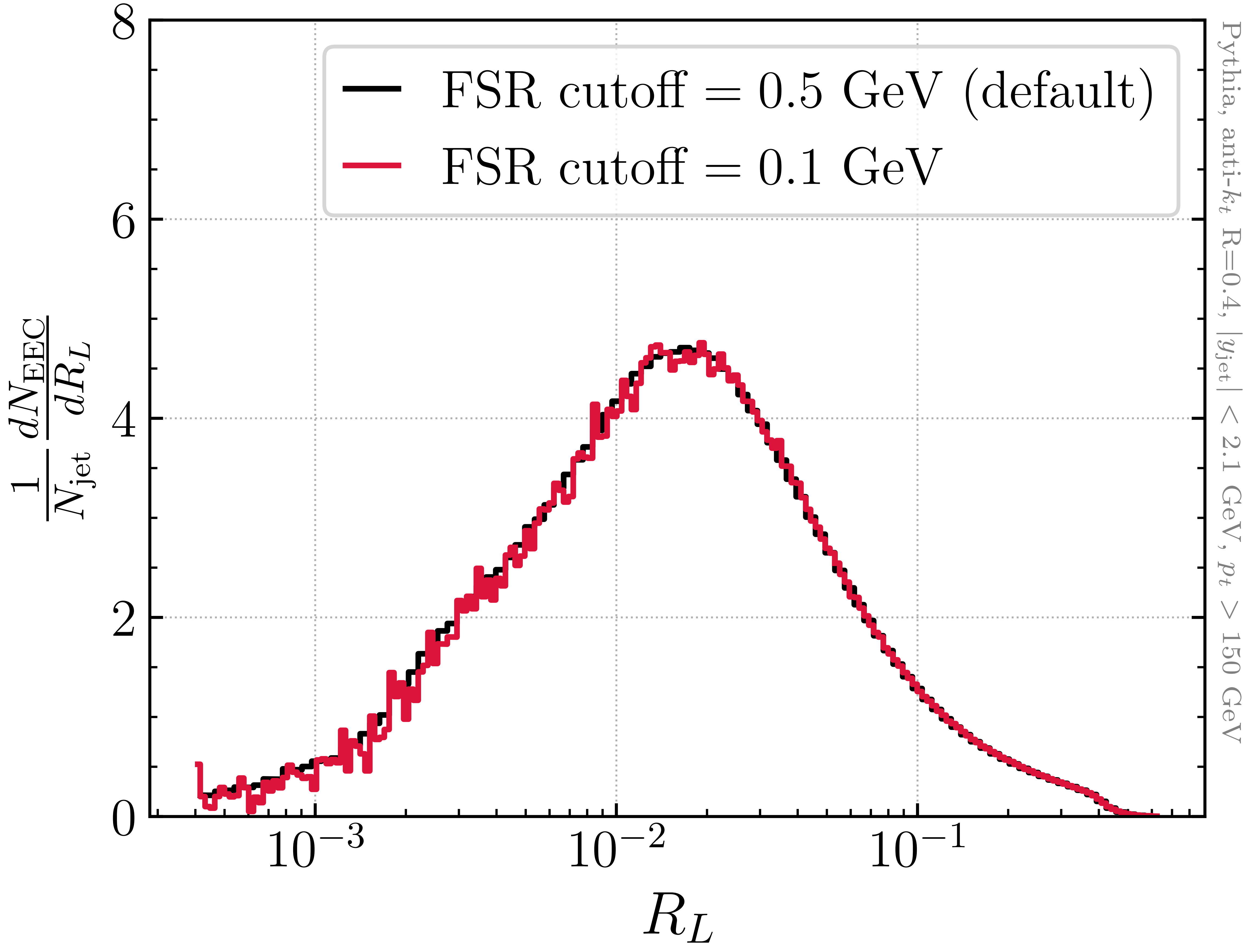
Connection between EEC's peak and infrared scales in MC

[M. Leitão, G. Milhano and ASO, in preparation]

Parton level



Hadron level

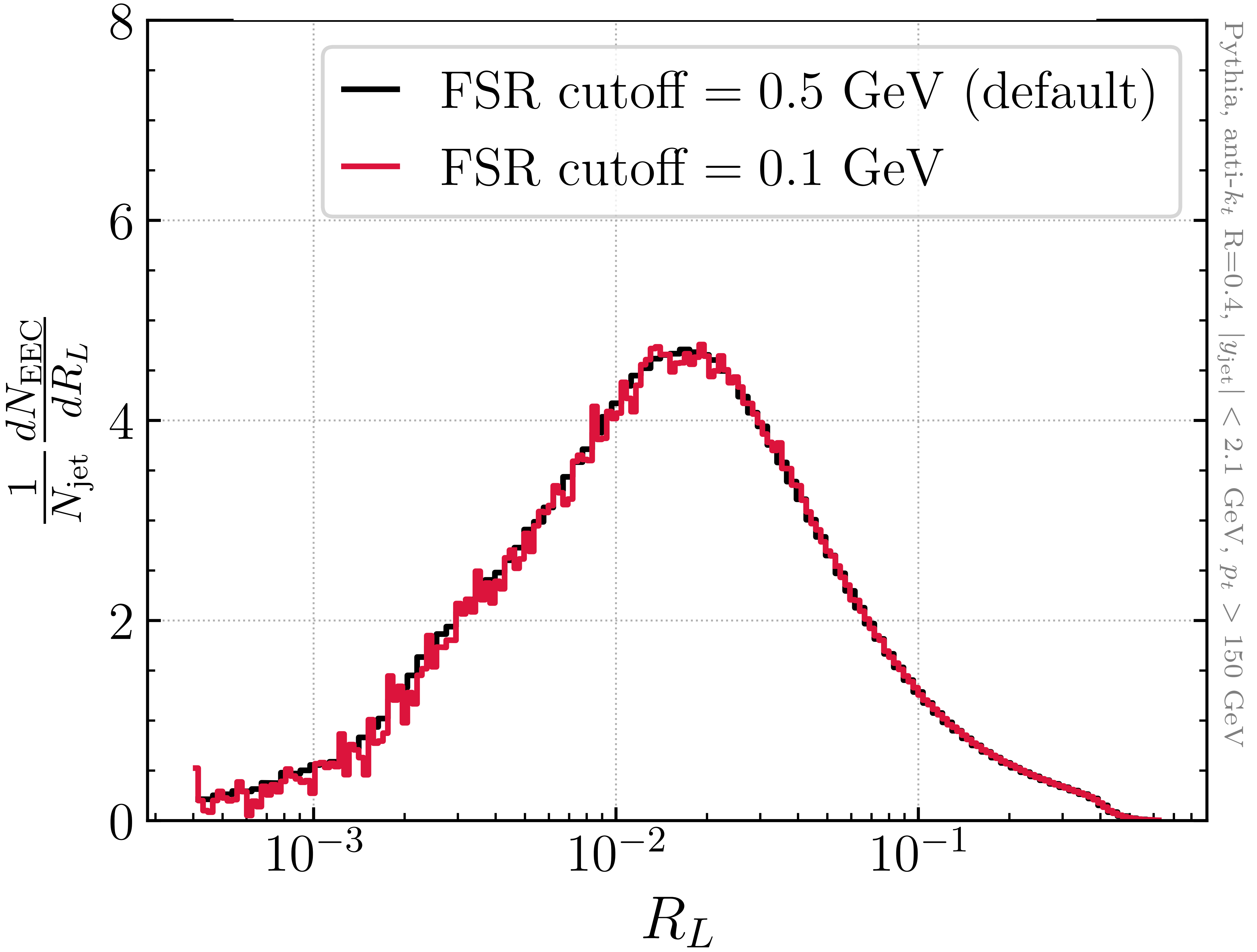


Comment on Barbara's talk: peak-position at parton level ≠ hadron one

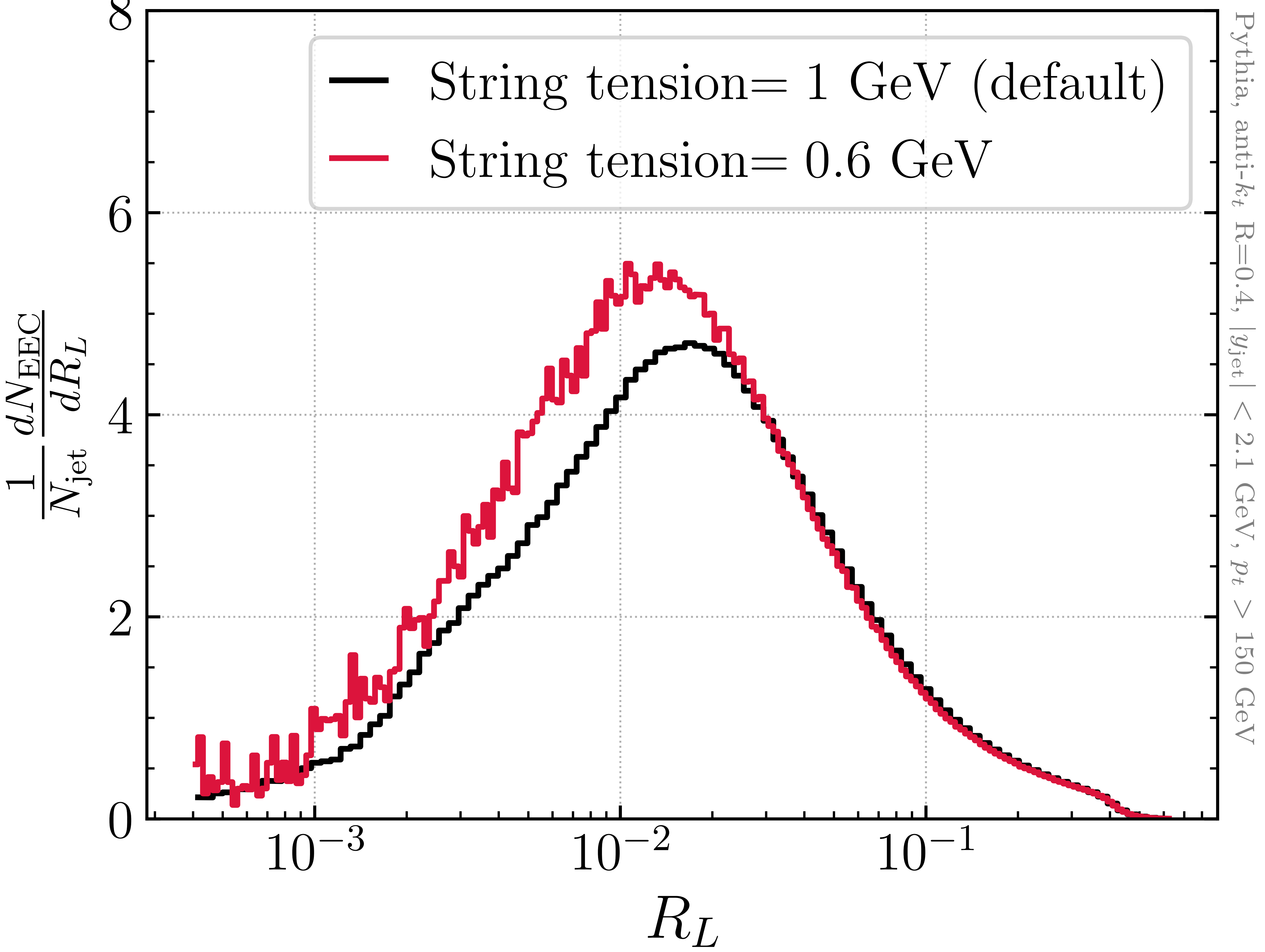
Connection between EEC's peak and infrared scales in MC

[M. Leitão, G. Milhano and ASO, in preparation]

Shower cutoff



String tension

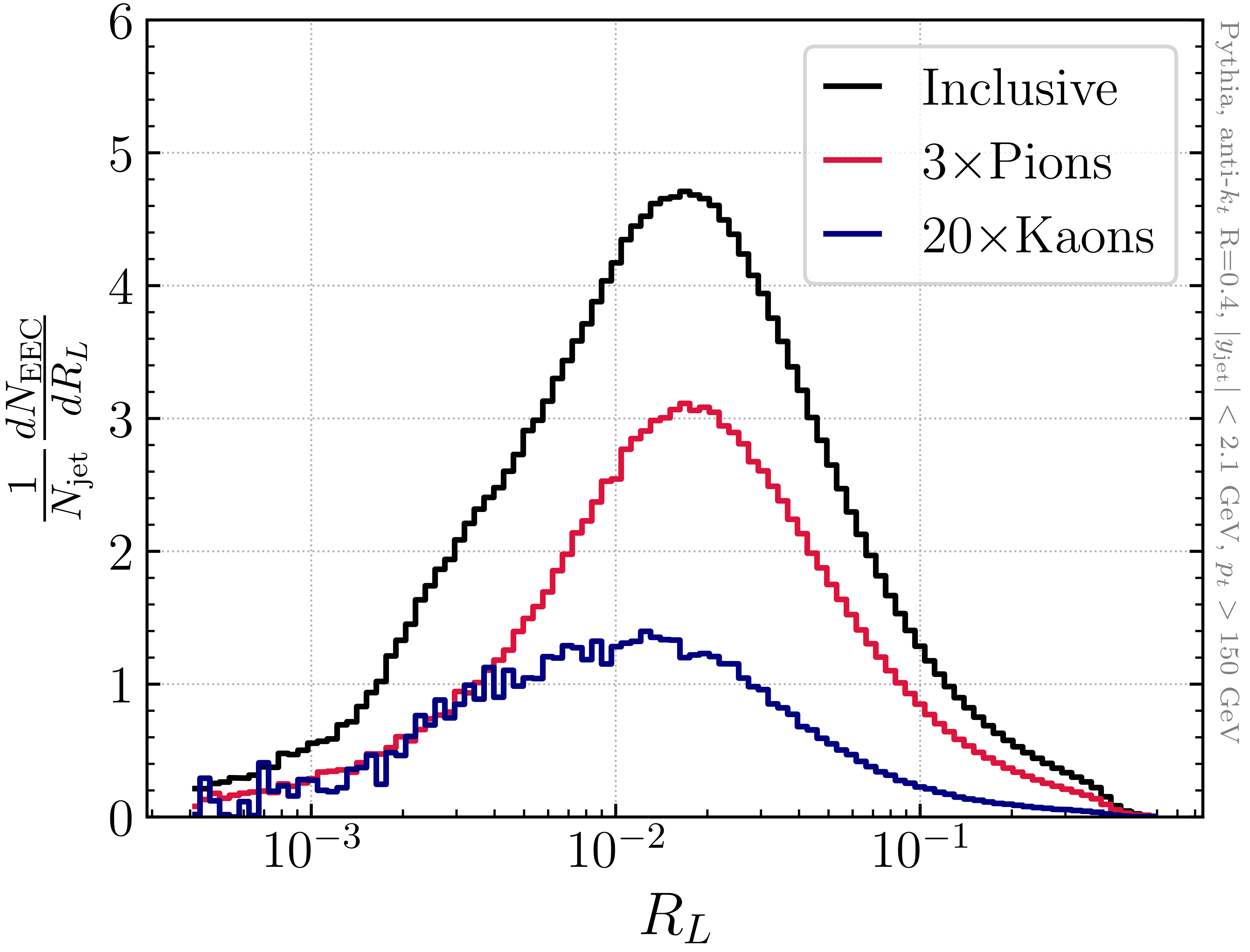


EEC peak independent of shower cutoff (as it should). It shifts when decreasing string tension ⇛ later hadronization

Flavour-dependence of hadronization *time*

[M. Leitão, G. Milhano and ASO, in preparation]

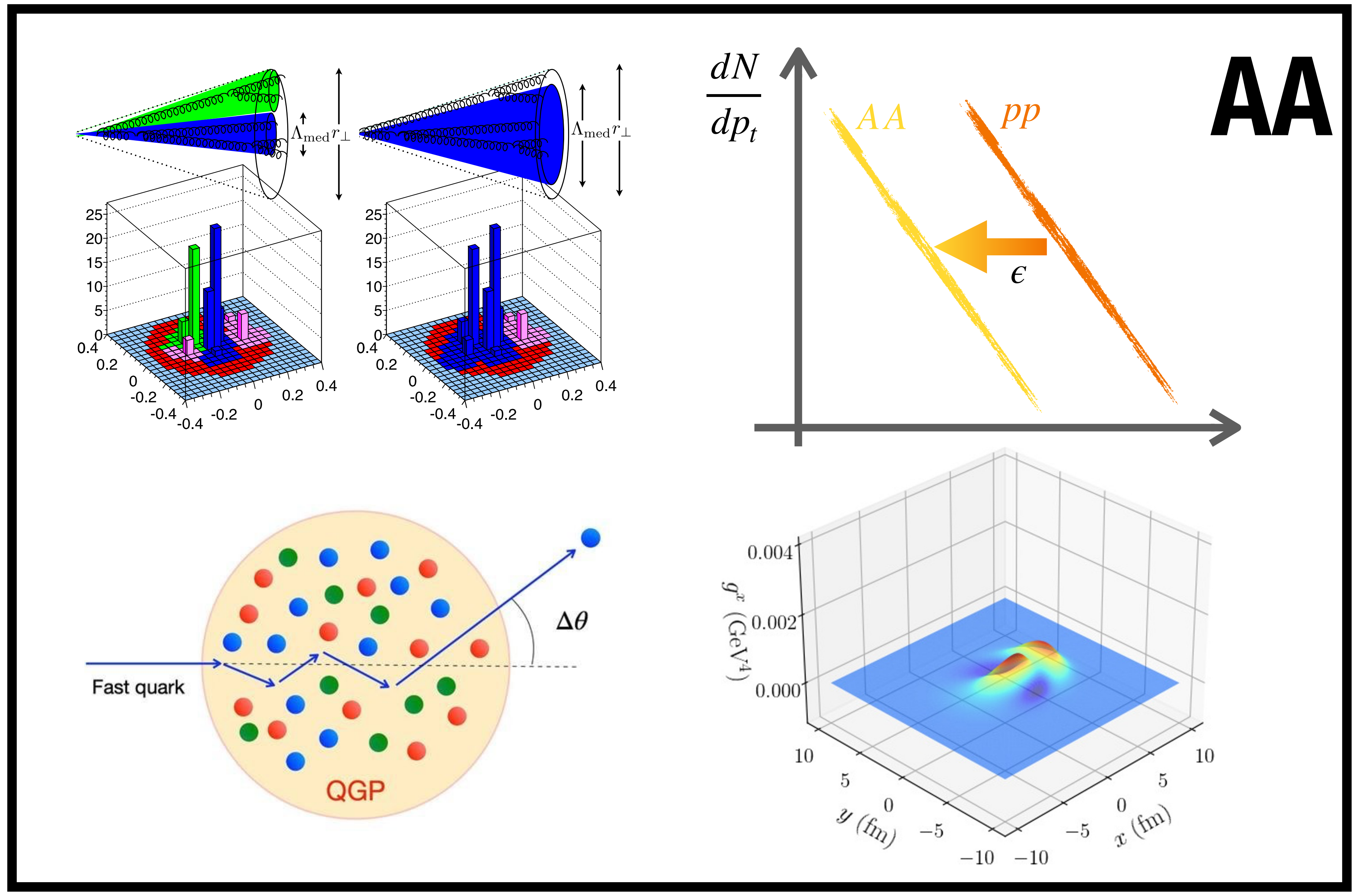
PID-EEC



Note: max p_t for PID not included

EEC peak seems to depend on hadron species. Origin of this effect, i.e. mass hierarchy of hadronisation scale to be determined

On the **theory interpretation** of upcoming EECs measurements



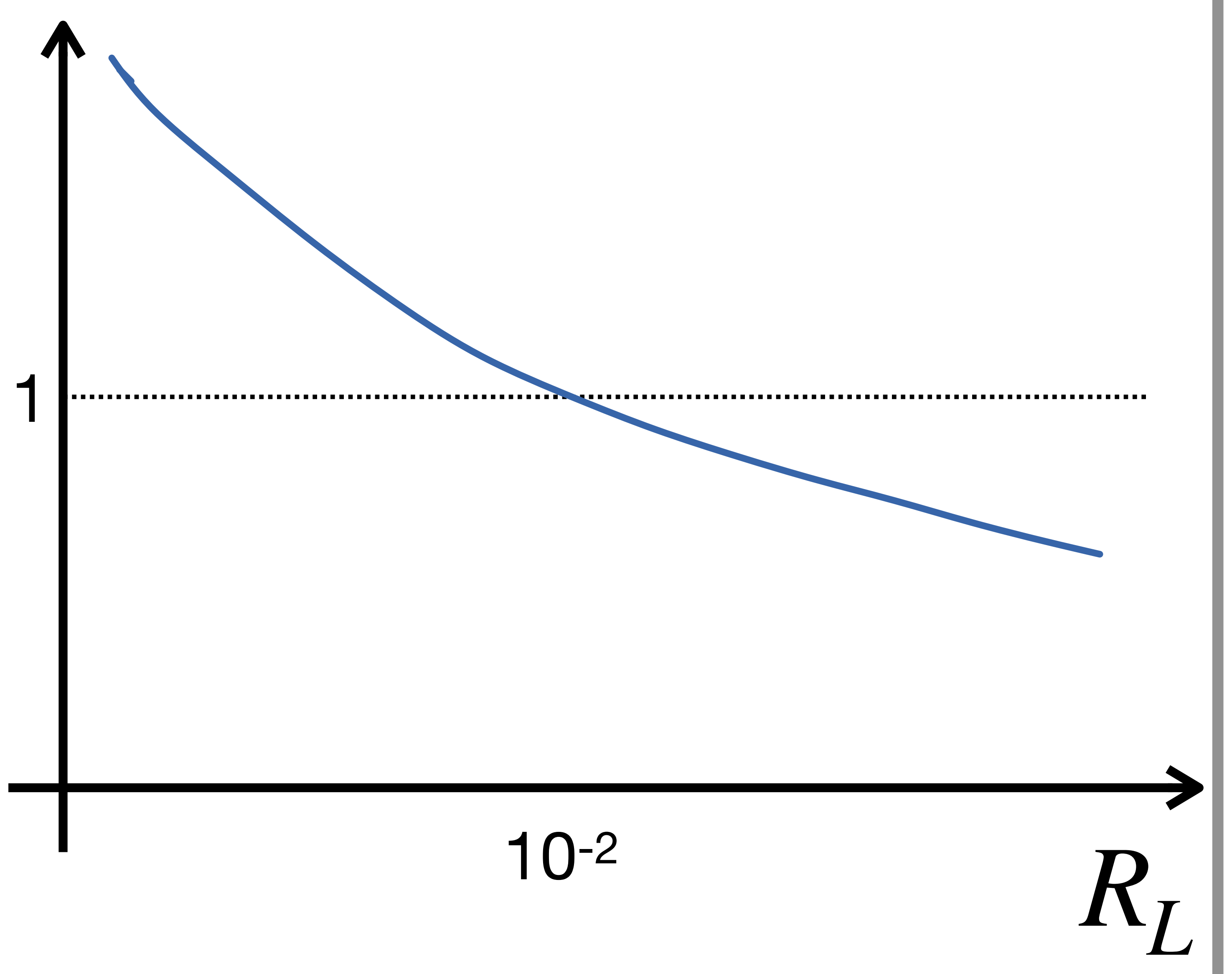
Alba Soto-Ontoso

New jet quenching tools to explore equilibrium and non equilibrium dynamics in heavy-ion collisions

ECT*, 13th February, 2024

Some (not serious) crystal-balling on EEC (AA) / EEC (pp)

Newspaper A



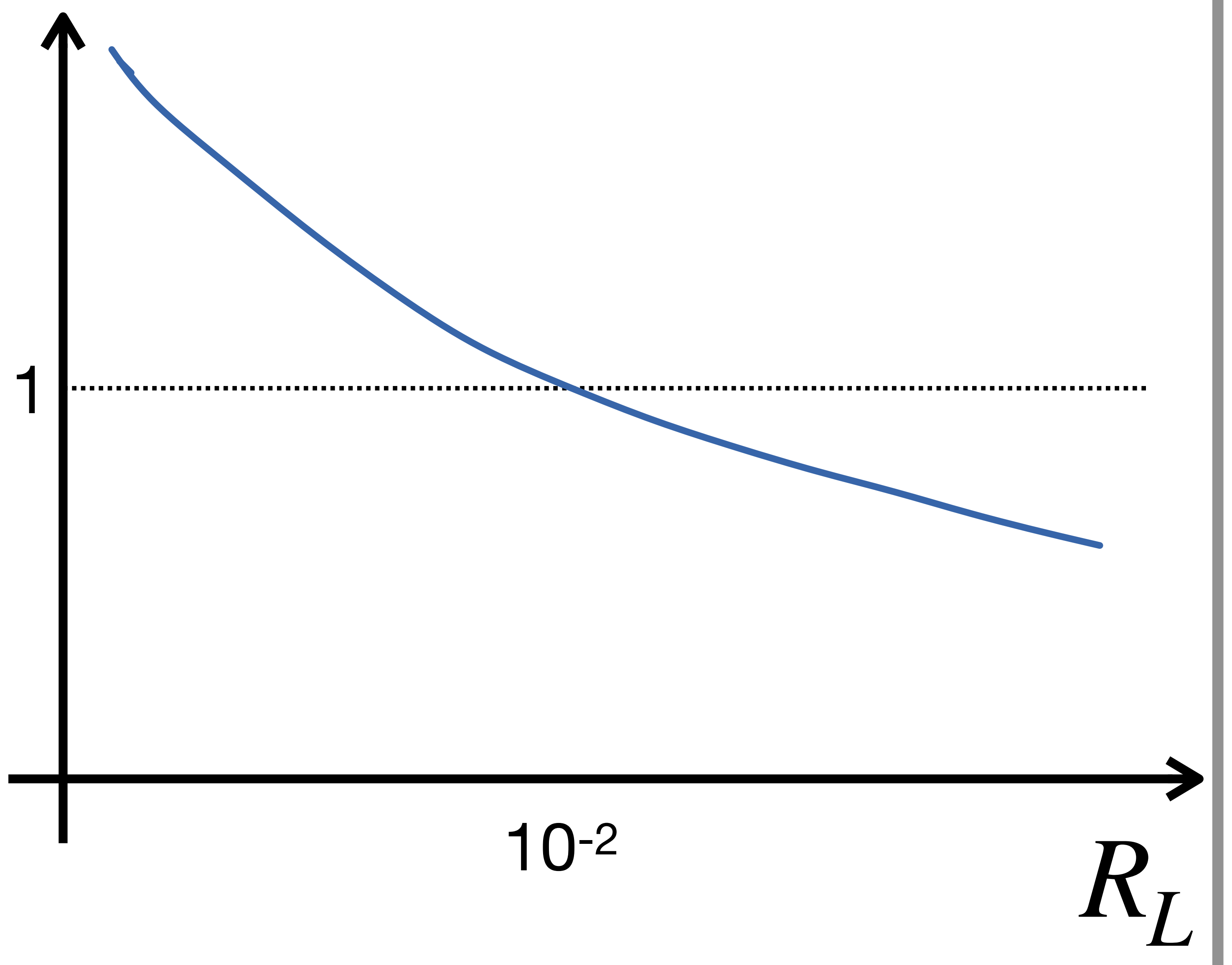
Survivor bias dominates EECs

Color coherence or q/g frac?

New proposal: measure in boson-tagged jets

Some (not serious) crystal-balling on EEC (AA) / EEC (pp)

Newspaper A

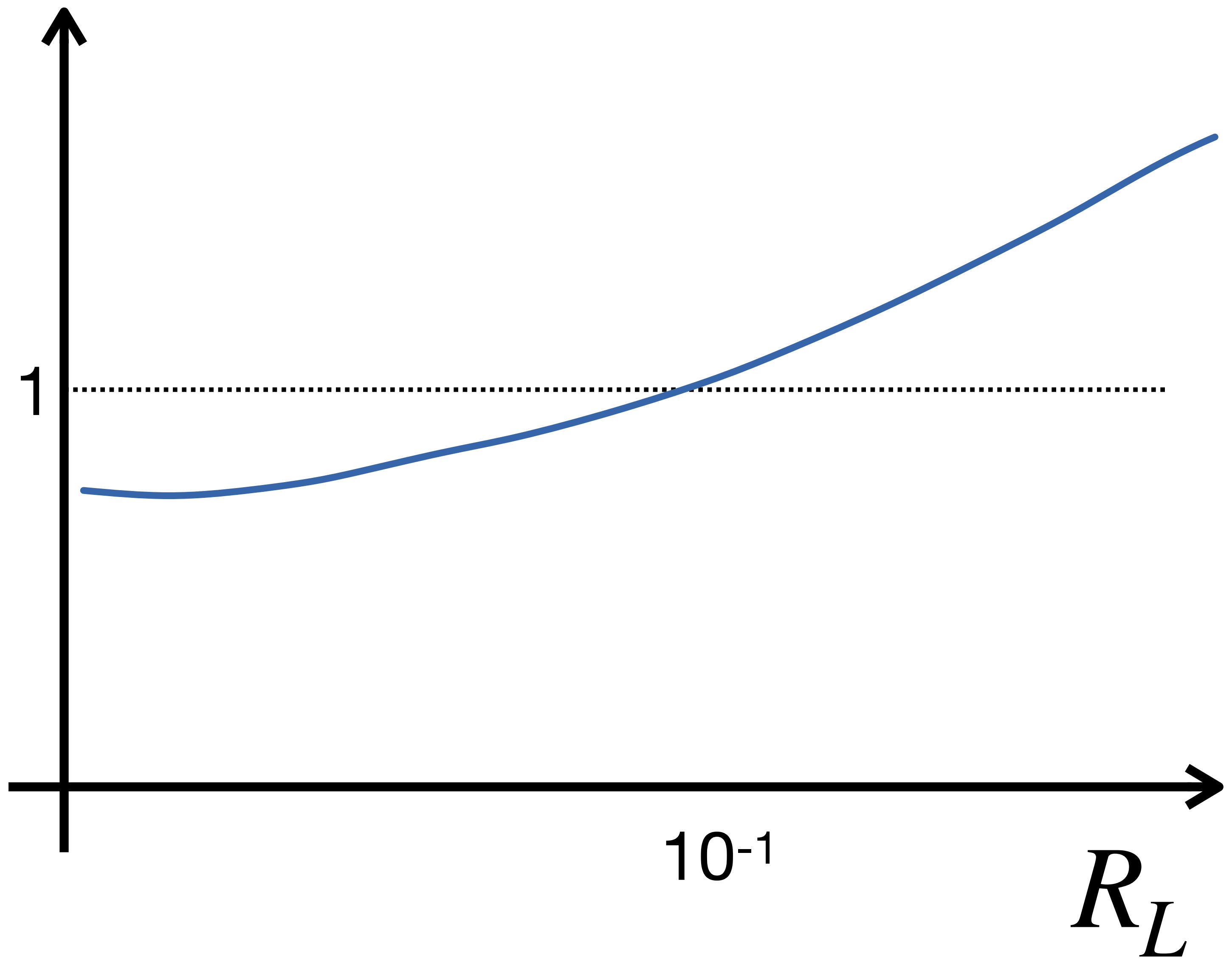


Survivor bias dominates EECs

Color coherence or q/g frac?

New proposal: measure in boson-tagged jets

Newspaper B



Wake first observed with EECs

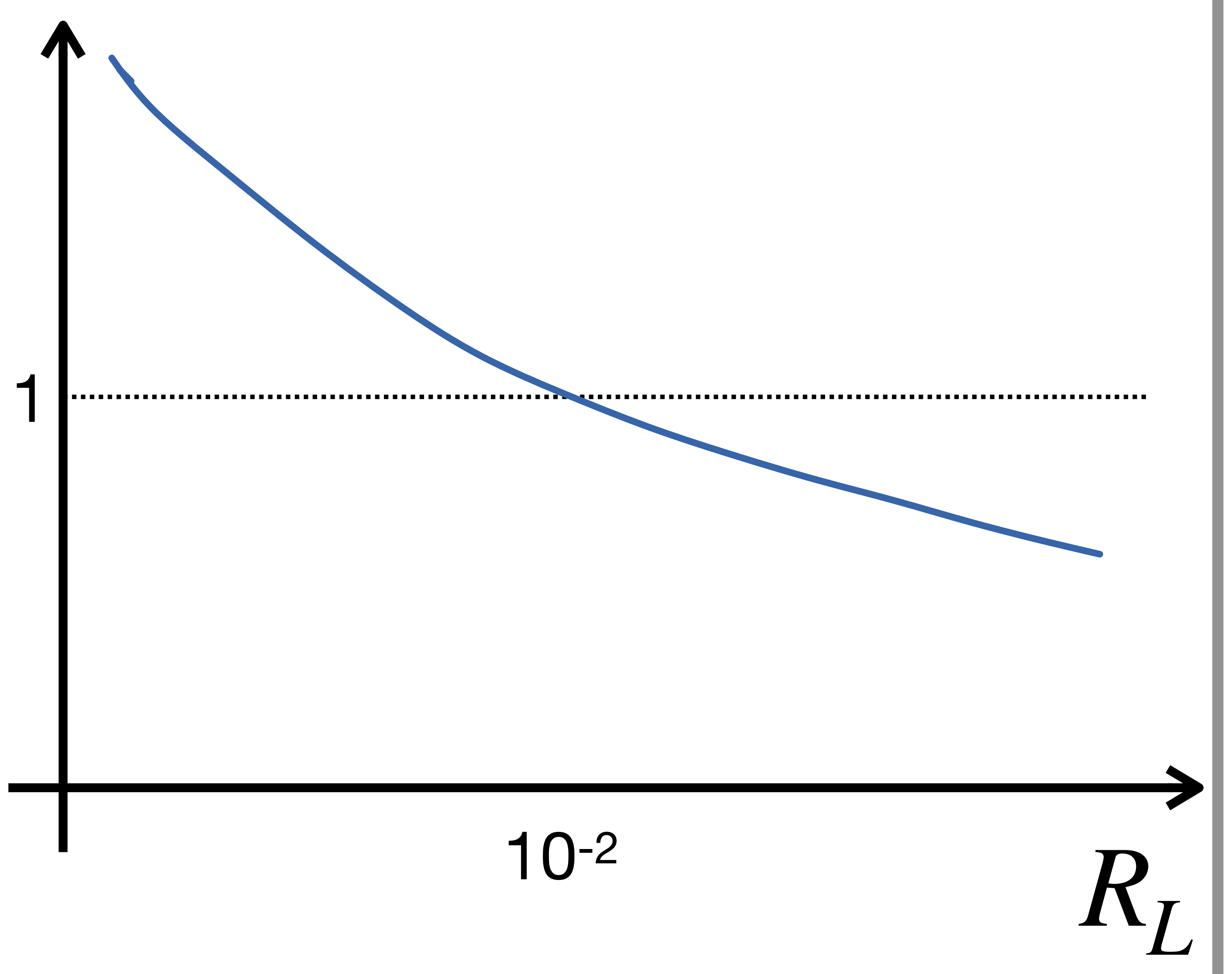
or

Medium induced emissions captured by EECs

New proposal: measure in boson-tagged jets

Some (not serious) crystal-balling on EEC (AA) / EEC (pp)

Newspaper A



Survivor bias dominates EECs

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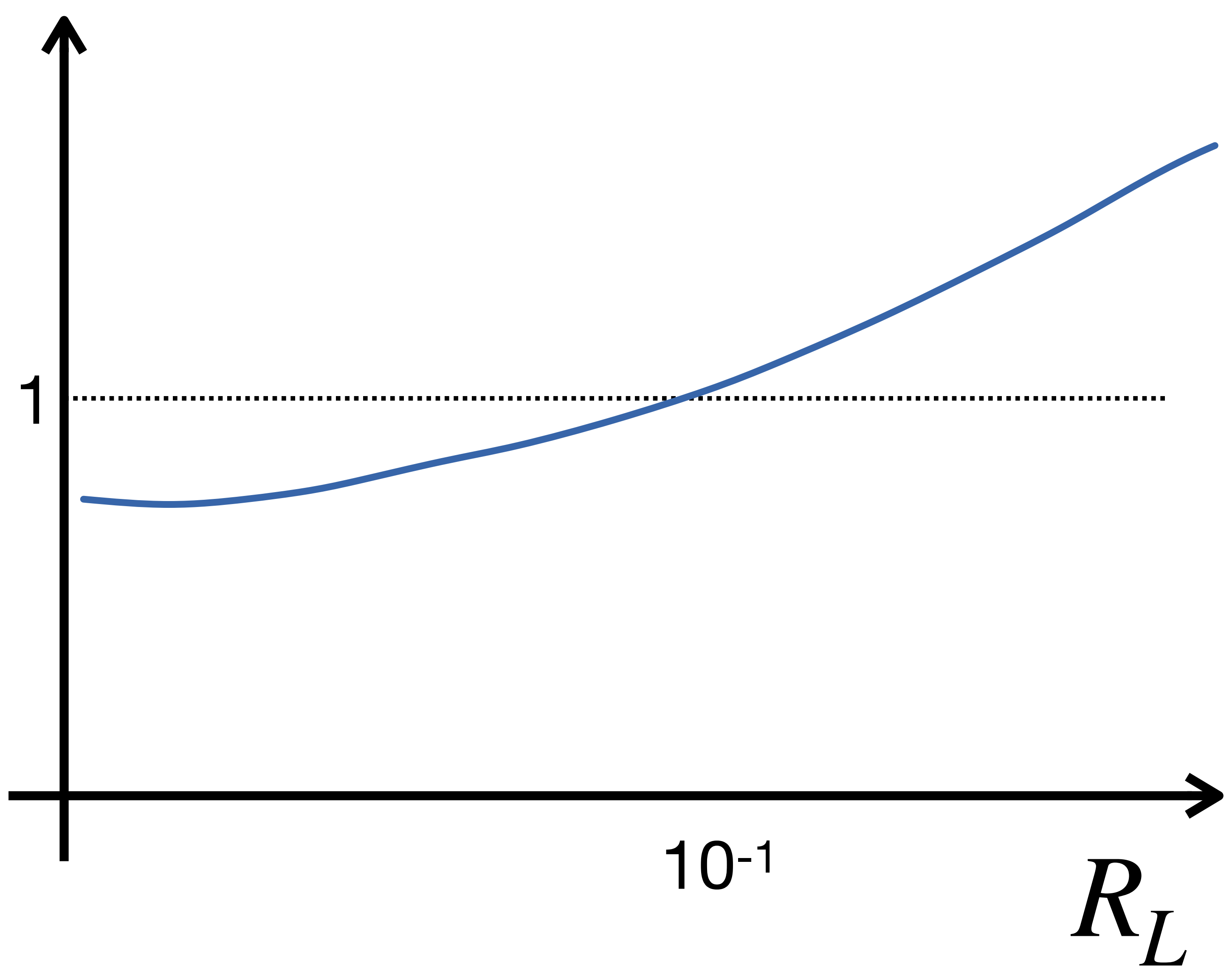
Newspaper B



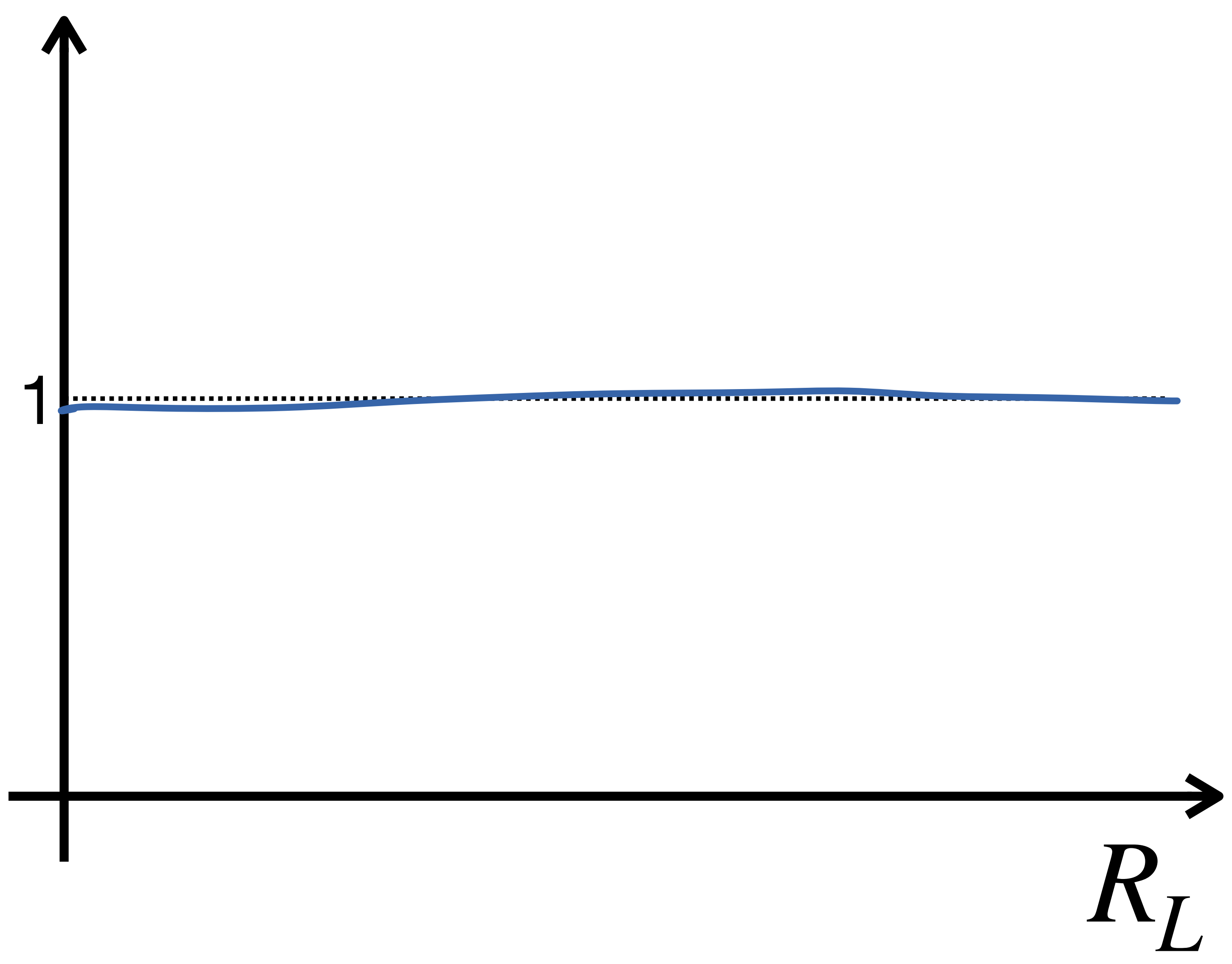
Wake first observed with EECs

or

Medium induced emissions captured by EECs

New proposal: measure in boson-tagged jets

Newspaper C (highly unlikely)



Breaking news: the QGP does not modify the energy flow pattern within a jet

...yet another reason not to build future colliders

Some (more serious) considerations

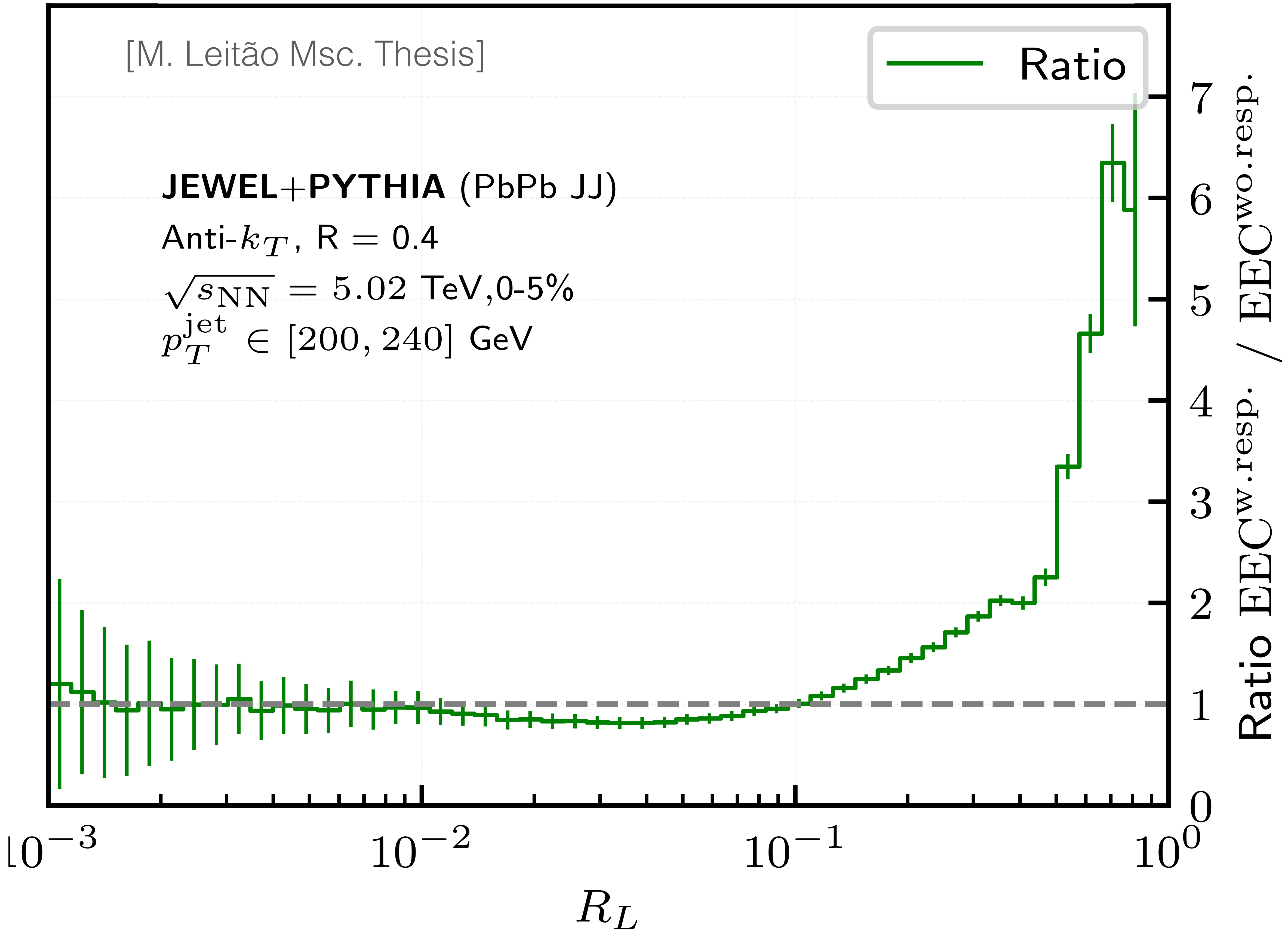
- Precise (à la pp) theoretical calculations of jet observables in heavy-ions are, unfortunately, out-of-the-scope.
- Recent proposals for new observables have been based on over-simplistic (mainly leading-order) predictions ⇒ disappointment once measurement is out.
- We (as a community) have a new opportunity to do things better with EECs.
- Keywords to avoid without a systematic study: #SmokingGun, #Unravel, #GoldenChannel, #PinDownCriticalAngle, #WakeDiscovery,…
- Rest of this talk: point out a few effects beyond the leading-order picture

[Barata, Caucal, ASO and Szafron arXiv:2312.12527]
[Barata, Caucal, Monni, ASO, Szafron work in progress]

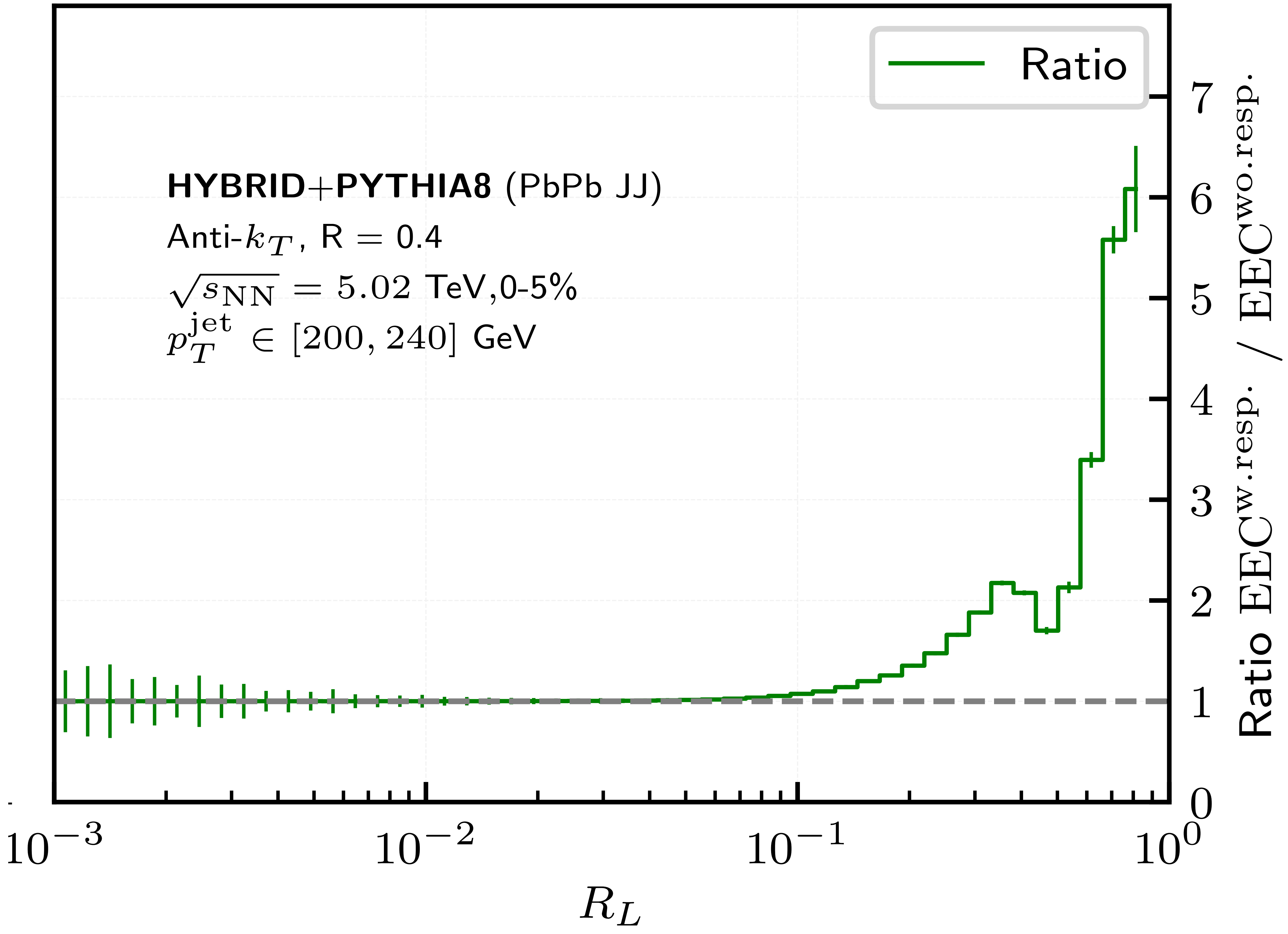
Before going into analytics…a word on the role of soft physics

[See Hannah's talk]

JEWEL medium response



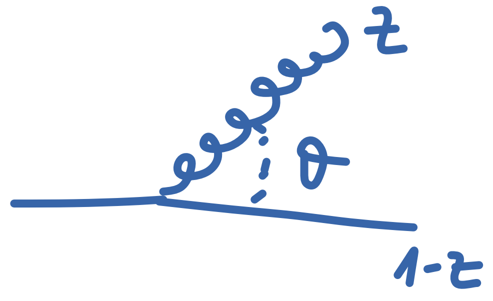
HYBRID medium response



Non-negligible impact of soft physics despite energy weight in the EEC

Leading-logarithmic calculation of the EEC in vacuum

The cumulative distribution for the abelian EEC in the collinear limit at $\mathcal{O}(\alpha_s)$ is



$$\Sigma^{\rm R}(\chi)\Big|_{\mathcal{O}(\alpha_s)} = \bar{\alpha}\int_0^1 \frac{d\theta}{\theta}\int_0^1 dz\, P_{gq}(z)\Big[z^2\Theta(\chi) + (1-z)^2\Theta(\chi) + 2z(1-z)\Theta(\chi-\theta)\Big]$$

$$\Sigma^{\rm V}(\chi)\Big|_{\mathcal{O}(\alpha_s)} = -\,\bar{\alpha}\int_0^1 \frac{d\theta}{\theta}\int_0^1 dz P_{gq}(z)\Theta(\chi)$$

Iterating this procedure one finds the all-orders result at leading-log accuracy

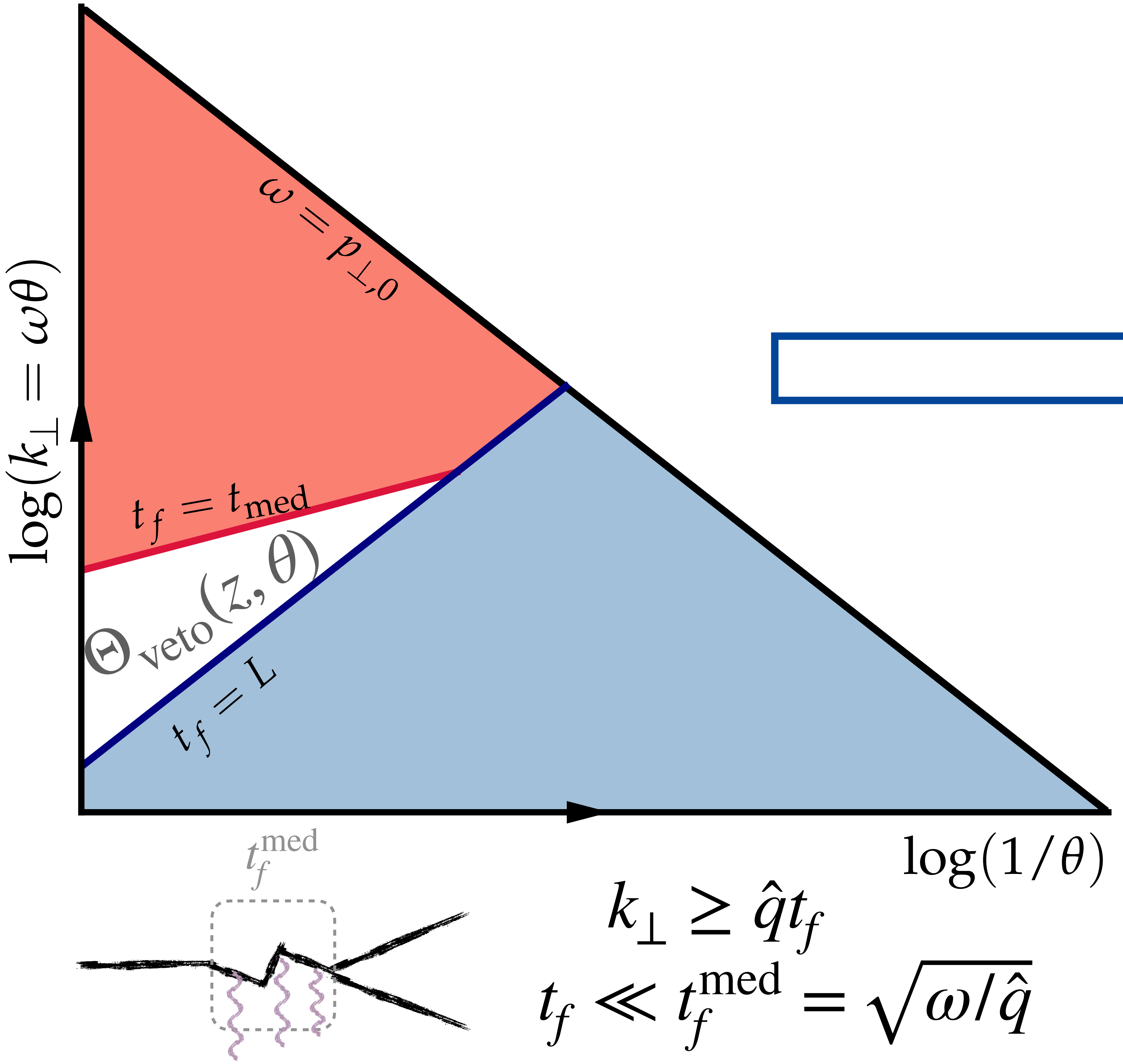
$$\Sigma(\chi) = \sum_{k=0}^{\infty}(-1)^{k+1}\frac{\bar{\alpha}^{k+1}}{(k+1)!}\ln^{k+1}\frac{1}{\chi}[\gamma_{qq}^{k+1}(3) + \gamma_{qq}^{k}(3)\gamma_{gq}(3)] = \left(-1 + \chi^{\bar{\alpha}\gamma_{qq}(3)}\right)\frac{\gamma_{gq}(3)+\gamma_{qq}(3)}{\gamma_{qq}(3)}$$

where $\gamma_{ik}(j) = -\int_0^1 dz\, z^{j-1}\hat{P}_{ik}(z)$ are the so-called anomalous dimensions

↳ regularized

Effect #1: impact of phase-space constraints on VLEs

The phase-space for vacuum-like emissions affects anomalous dimensions



$$k_\perp \geq \hat{q} t_f$$

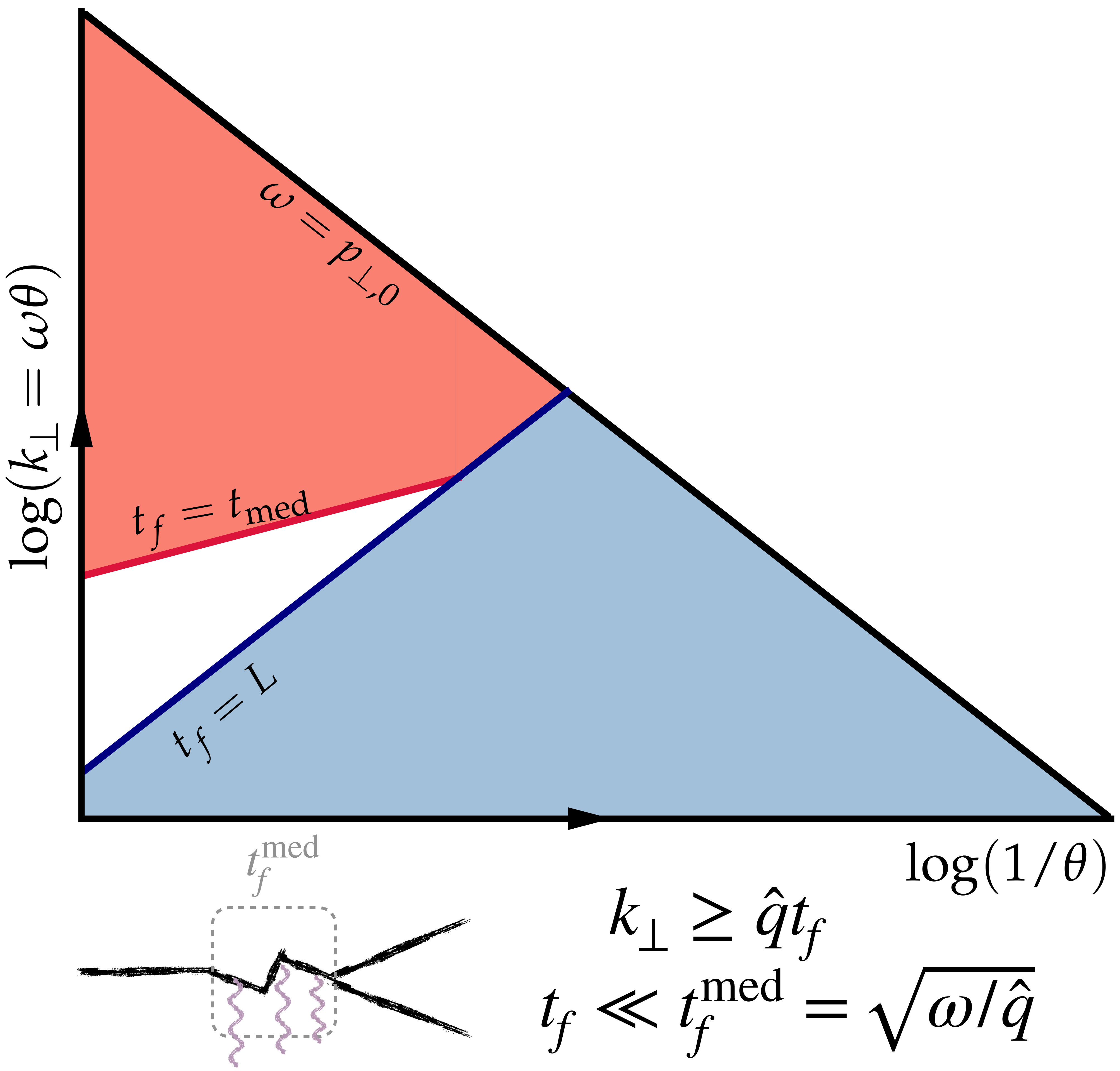
$$t_f \ll t_f^{med} = \sqrt{\omega/\hat{q}}$$

$$\gamma^{med}(j,\theta) = -\int_0^1 dz\, z^{j-1} \hat{P}(z)[1 - \Theta_{veto}(z,\theta)]$$

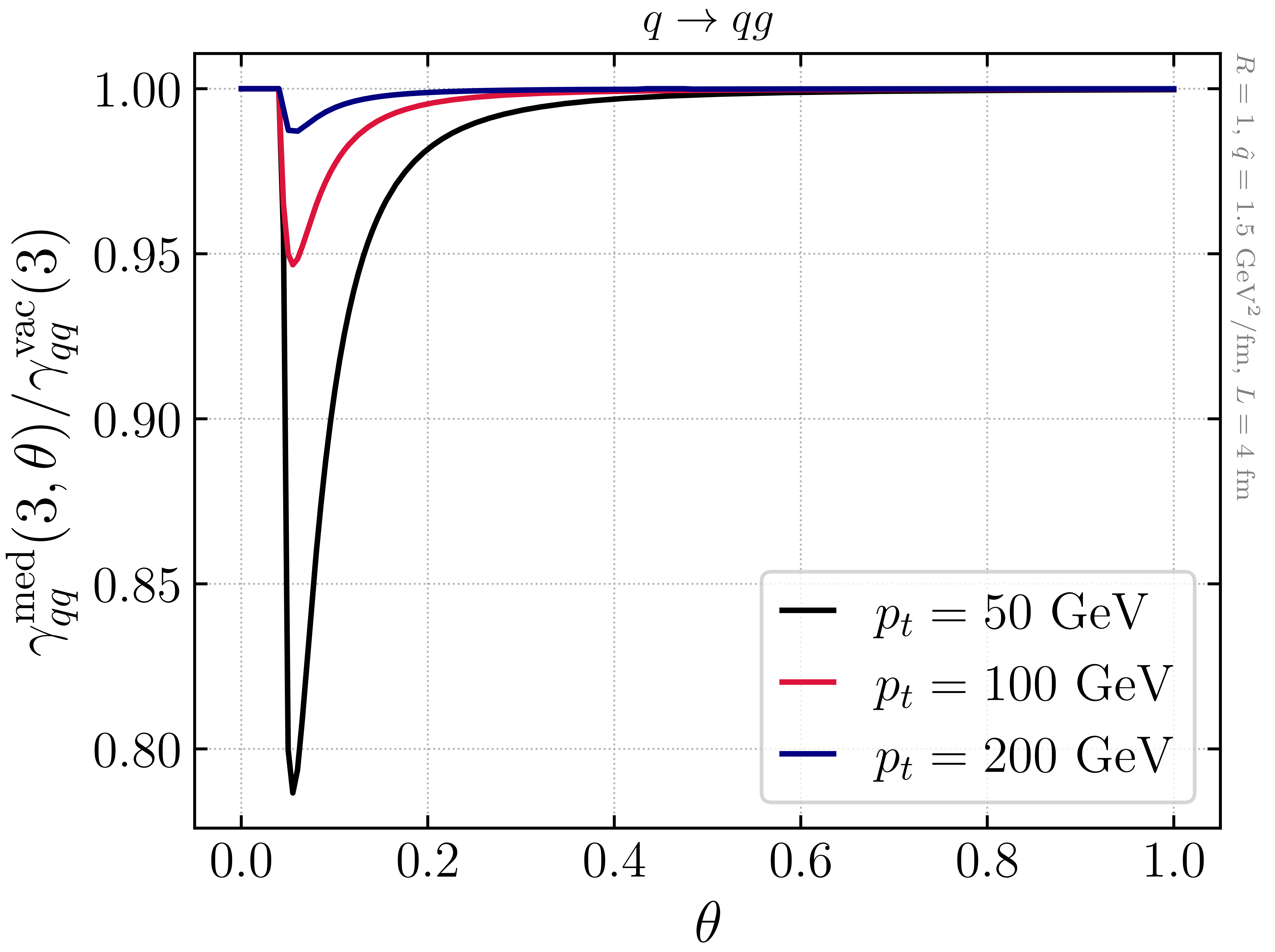
[Caucal et al. PRL 120 (2018) 232001]

Effect #1: impact of phase-space constraints on VLEs

The phase-space for vacuum-like emissions affects anomalous dimensions



$$k_\perp \geq \hat{q} t_f$$
$$t_f \ll t_f^{\text{med}} = \sqrt{\omega/\hat{q}}$$



[Caucal et al. PRL 120 (2018) 232001]

Effect #2: in-medium matrix element

The in-medium EEC at leading order ($\mathcal{O}(\alpha_s)$) can be expressed as:

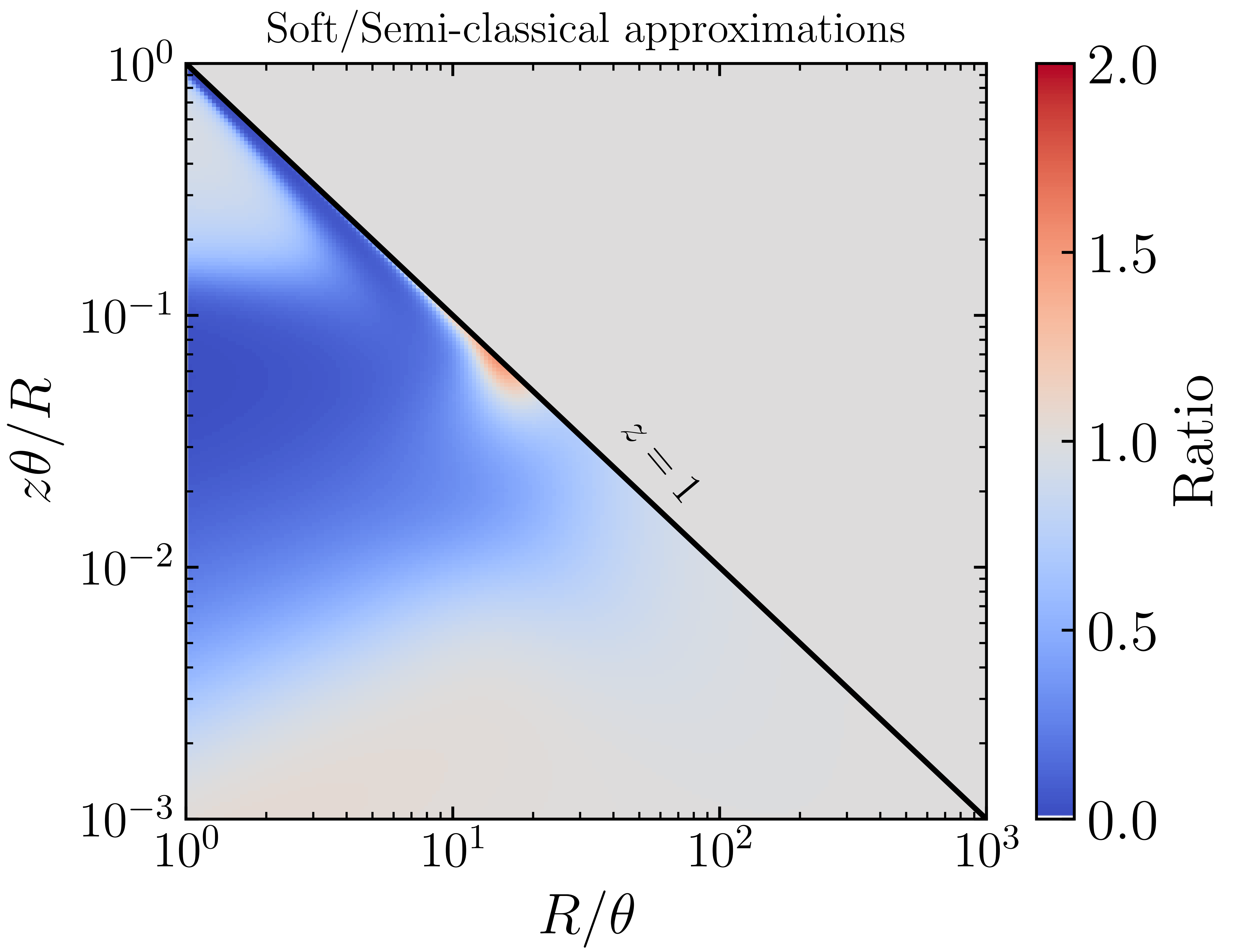
$$\frac{d\Sigma}{d\theta dp_t} = \sum_{\{i,j\}} \int_0^1 dz \left[z(1-z) \frac{dP_{ij}^{\text{vac}}}{d\theta dz} \left(1 + F_{\text{med}}^{ij}(\theta, z) \right) \right] \frac{d\sigma_j}{\sigma_j dp_t}$$

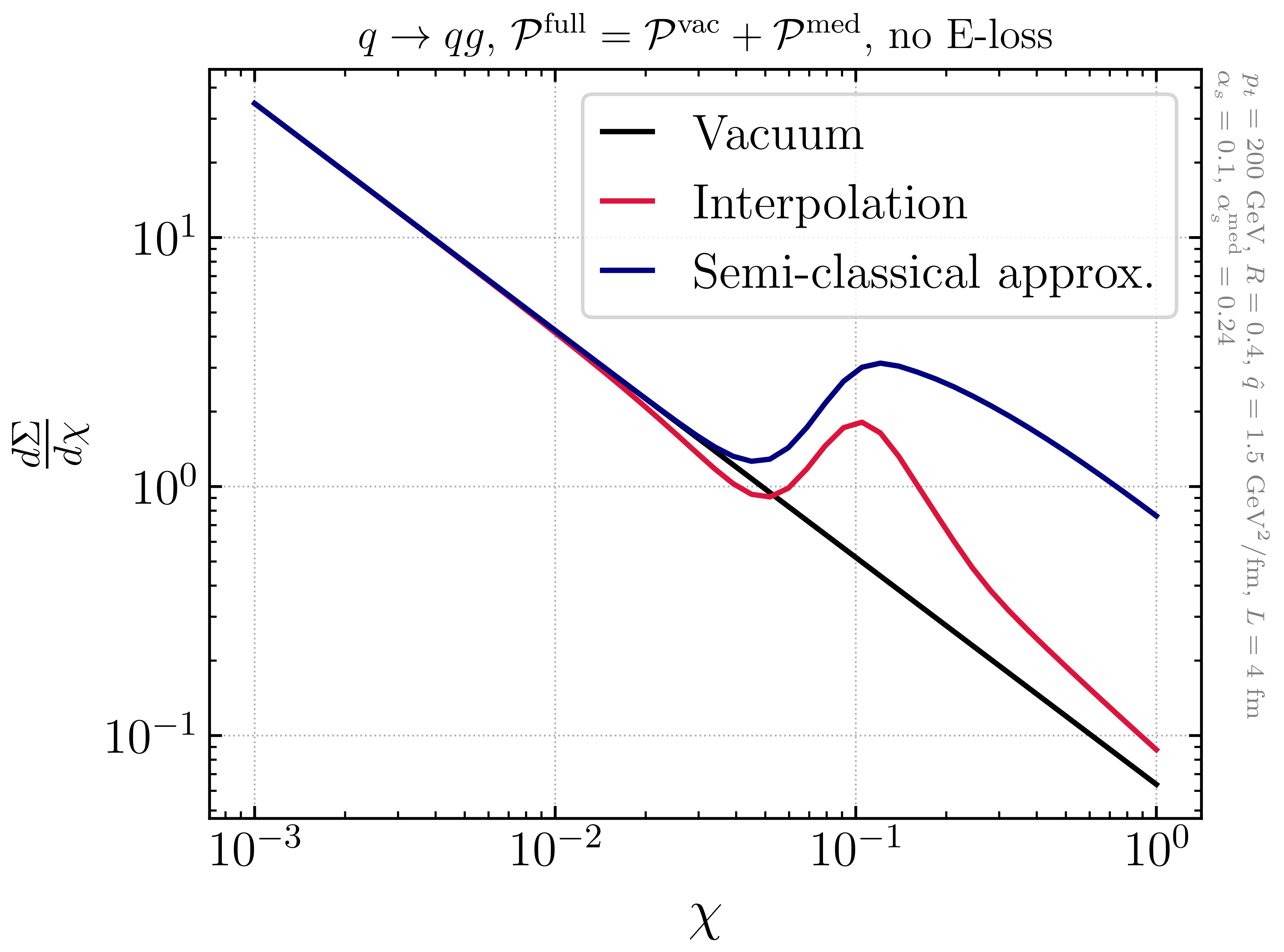
Available options for the $1 \to 2$ splitting function (F_{med}):

- Semi-classical approx: see Jack and Fabio's talks. Validity: $z \sim 1/2$
  [Dominguez, Milhano, Salgado, Vila EPJC 80 (2020) 1, 11]
- Soft approximation: BDMPS-Z spectrum. Validity: $z \to 0$
  [BDMPS, NPB 483 (1997) 291-320]
- *Exact (with all caveats that Fabio explained)*: only available for $\gamma \to q\bar{q}$
  [Isaksen, Tywoniuk JHEP 09 (2023) 049]

Simple question: Does the $z \to 0$ matter for the evaluation of the EEC?

Effect #2: in-medium matrix element ($q \to qg$)

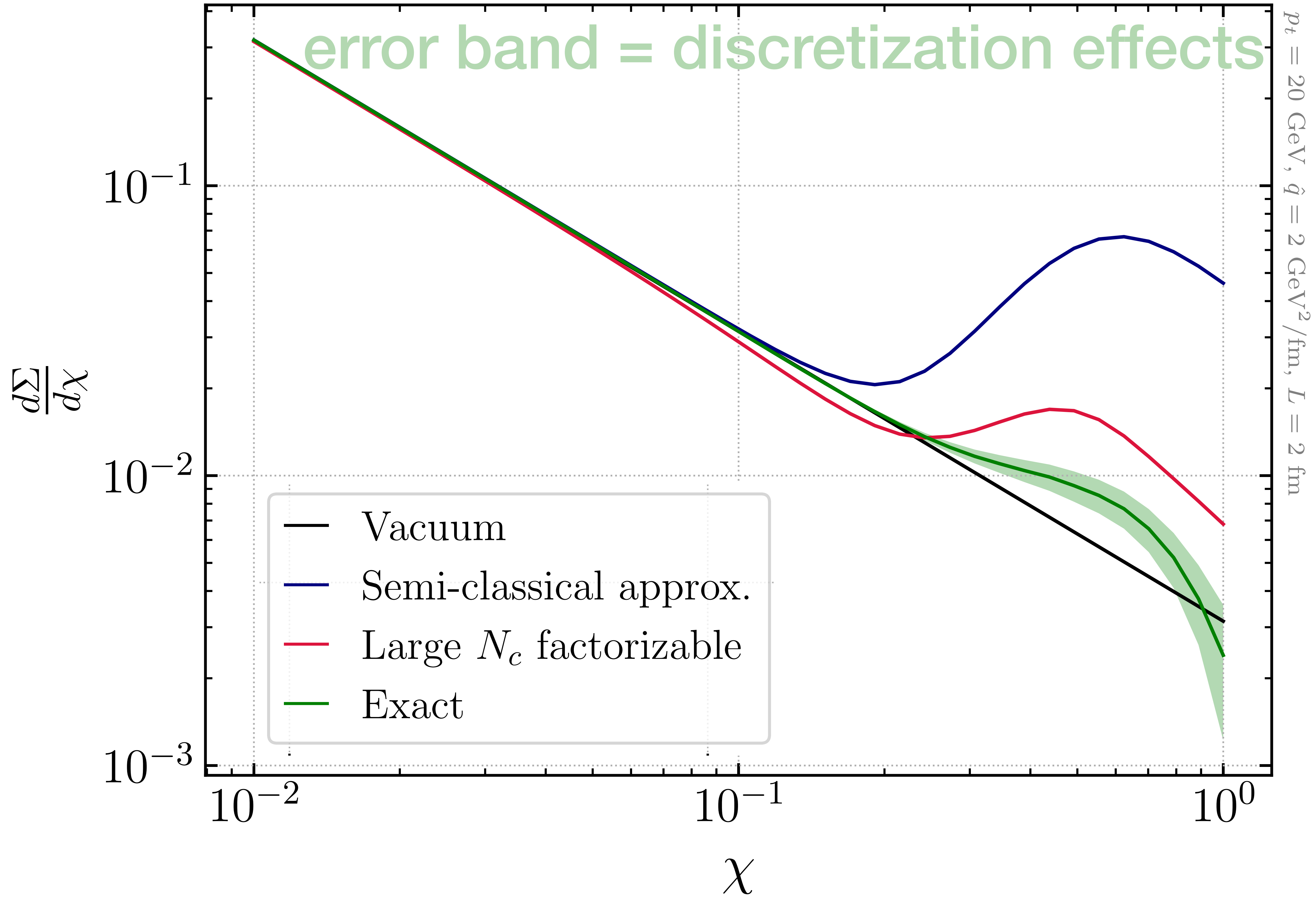




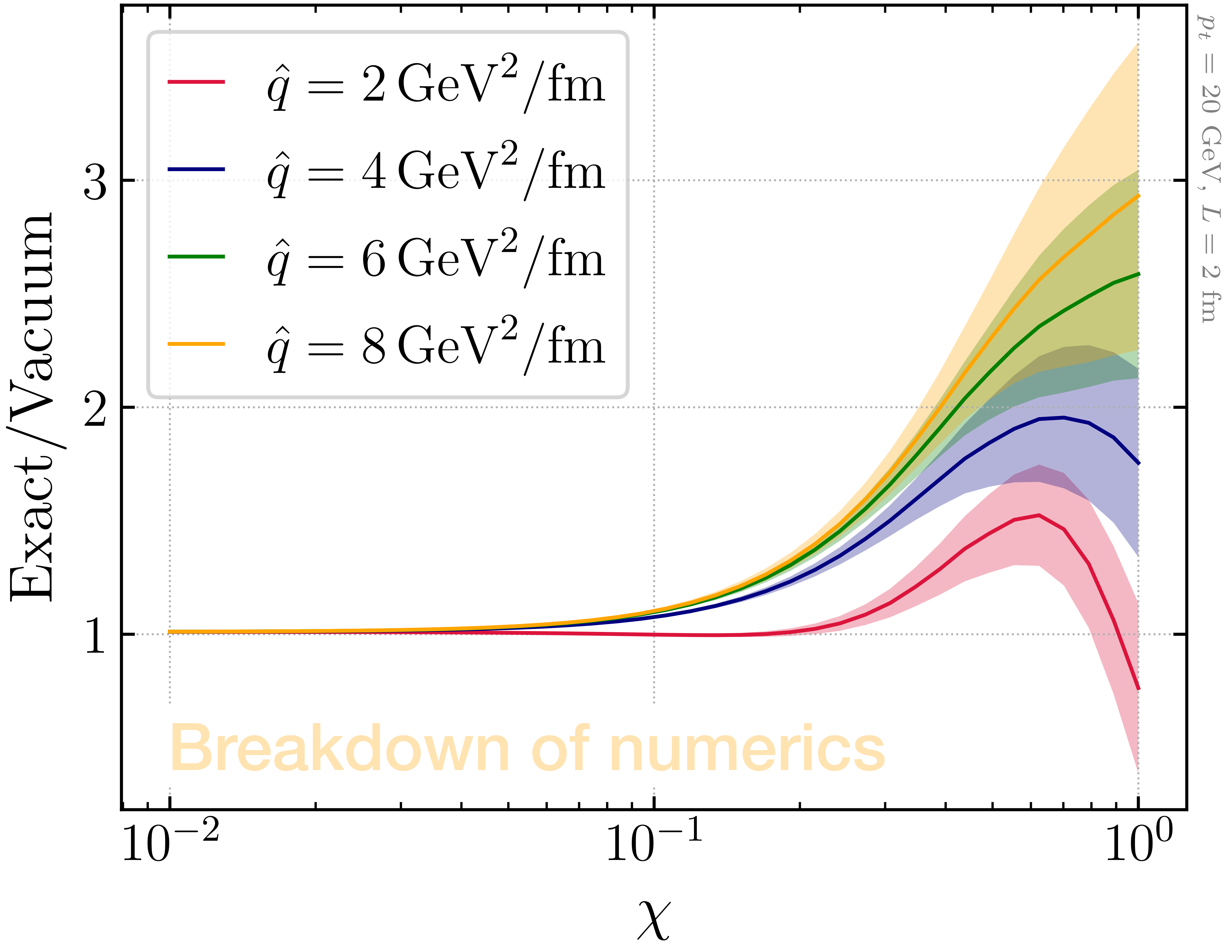
Simple answer: The $z \to 0$ does matter for the evaluation of the EEC

Effect #2: in-medium matrix element ($\gamma \to q\bar{q}$)

Different matrix-elements



Exact ME with varying $\hat{q}$



Wide-angle enhancement substantially reduced when using exact ME.
Another indication of the importance of describing full-z dependence.

Effect #3: better description of balanced splittings in JetMed

We modified the description of the **first** emission inside the medium

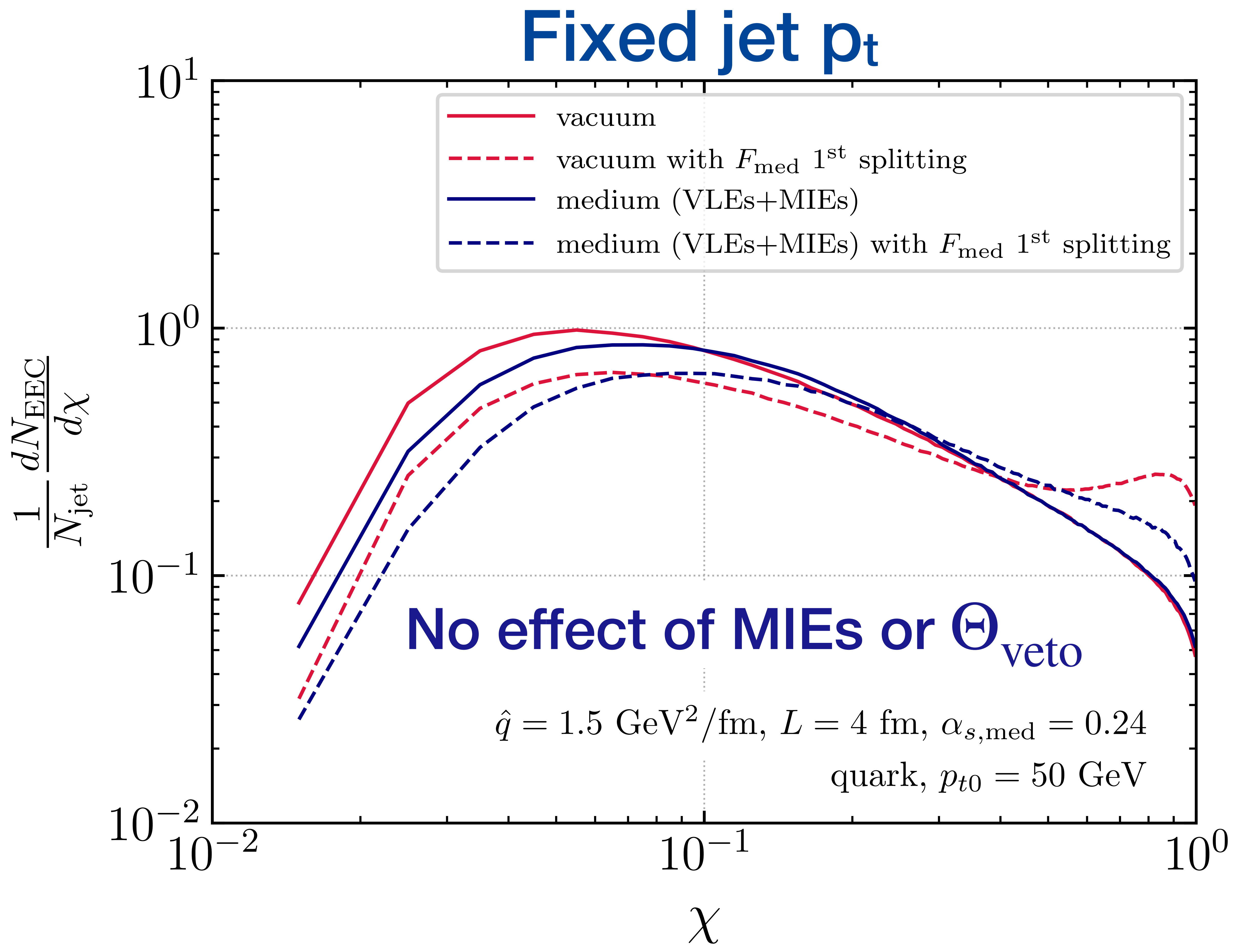
$$\frac{\alpha_s(k_\perp)}{\pi} P_{ij}(z) dz \frac{d\theta}{\theta} \left[1 + F_{\rm med}(z, \theta)\right]$$

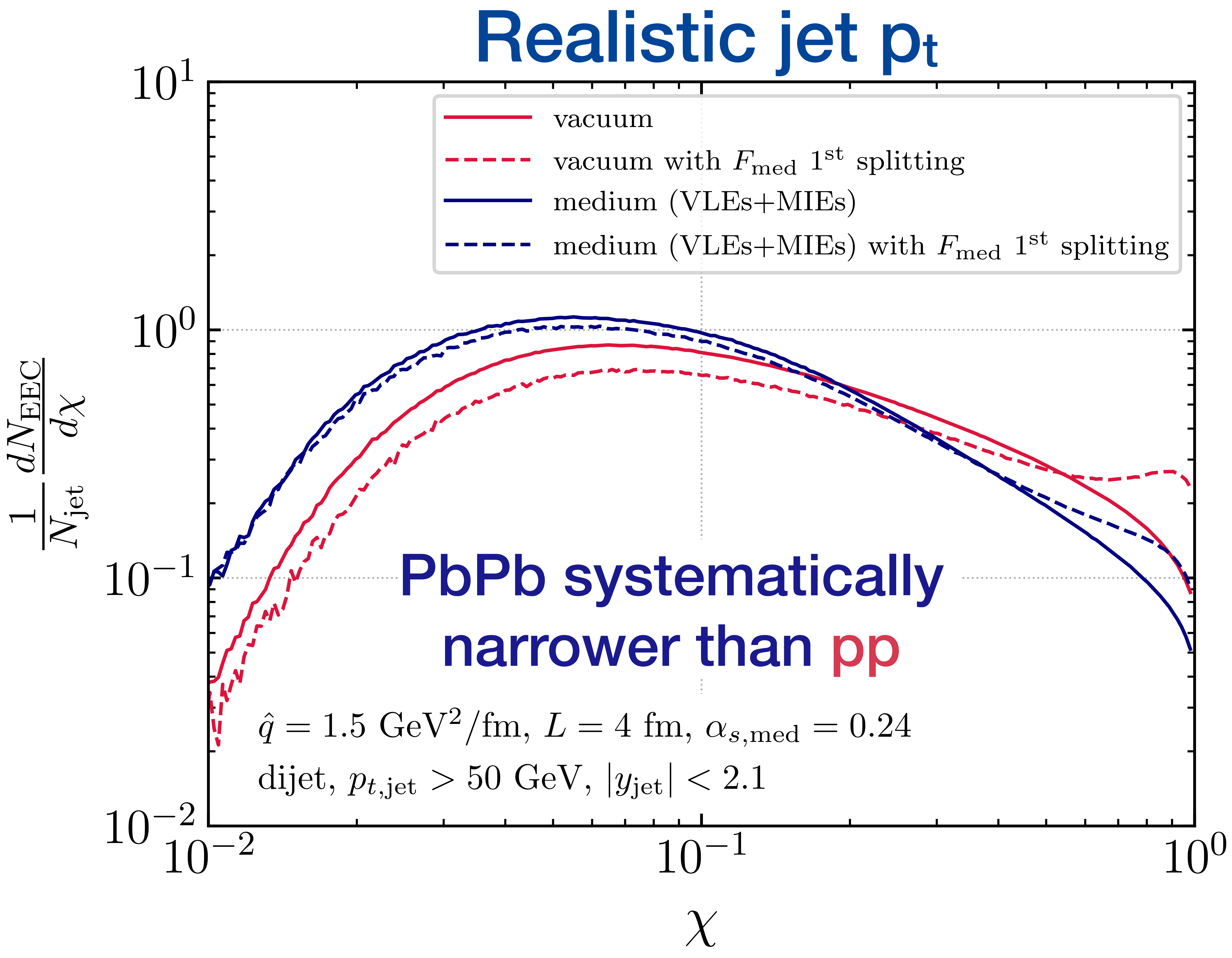
with $F_{\rm med}(z, \theta)$ an **overestimate** of the semi-classical matrix-element

+ Angular-ordered vacuum shower
+ Phase-space constraints for vacuum-like emissions
+ BDMPS-Z cascade of medium induced emissions
+ Gaussian transverse momentum broadening

[See Paul's talk]

Effect #3: better description of balanced splittings in JetMed





Energy-loss dominates over medium-induced emissions, i.e. narrowing

Instead of conclusions, a new observable! Lund-based EEC

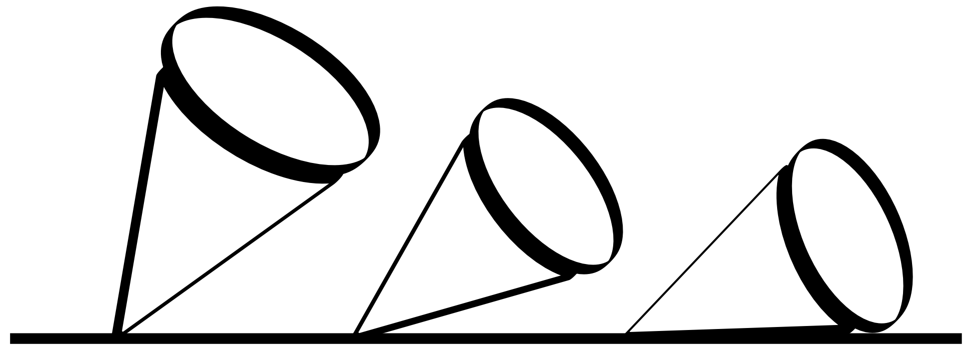
Several reasons to allow for different energy-weights on the EEC, e.g.

- Access higher moments of the splitting function
- Mitigate background contamination

Possible in the canonical EEC after introducing (non-perturbative) track functions

[Barata and Szafron arXiv:2401.04164]

Our approach: minimal modification without sacrificing calculability



primary declusterings as building blocks

$$\frac{d\Sigma^{(n)}}{d\chi} = \frac{1}{\sigma} \sum_{\{i,j\}\in \text{declust.}} \int_0^1 dz \frac{d\sigma}{d\theta_{ij} dz} \frac{E_i^n E_j^n}{Q^{2n}} \delta\left(\chi - \frac{\theta_{ij}}{R}\right)$$