

# Theoretical status of EEC studies in heavy-ions

Alba Soto-Ontoso

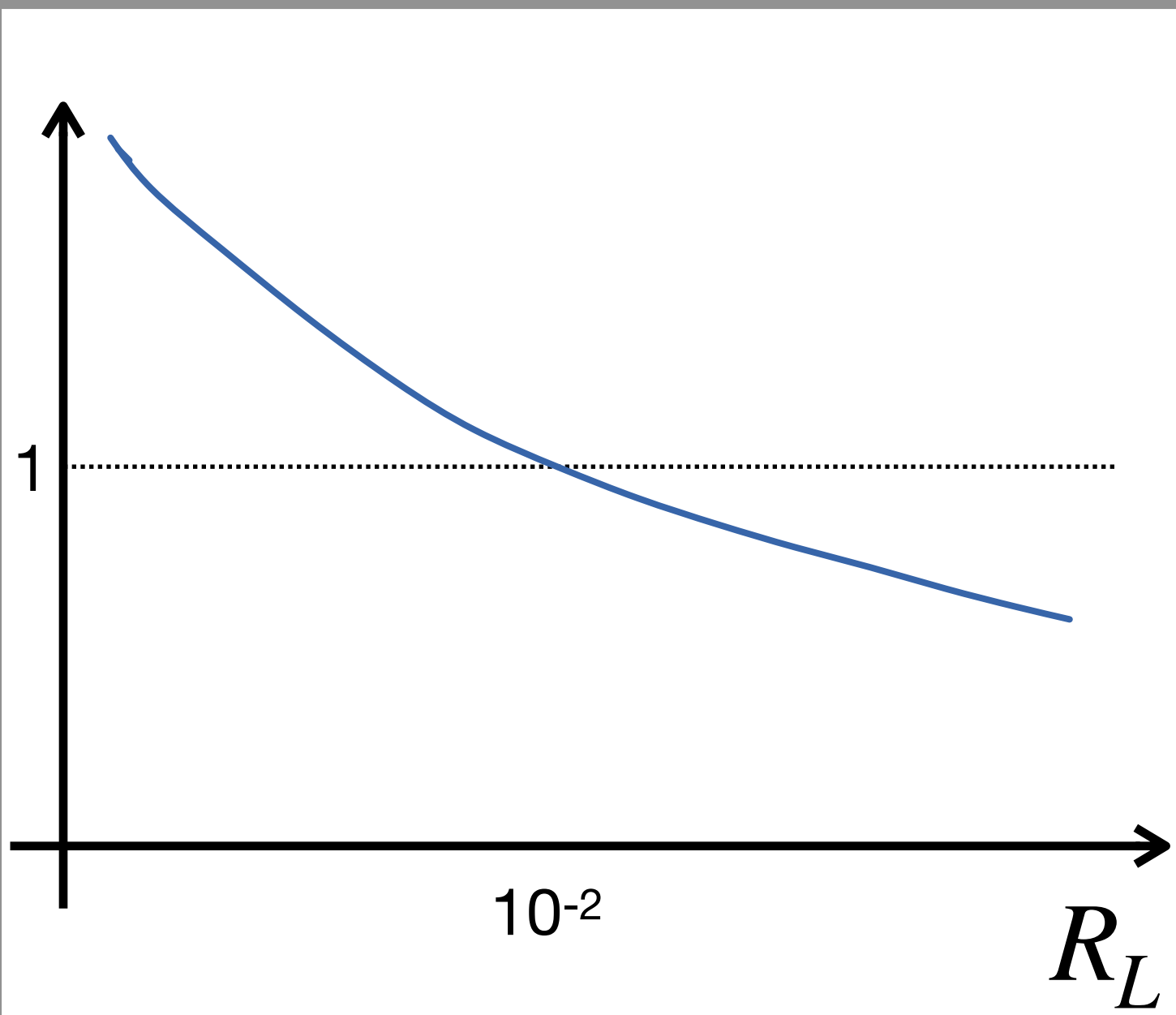
12th Hard Probes

Nagasaki, 23th September, 2024



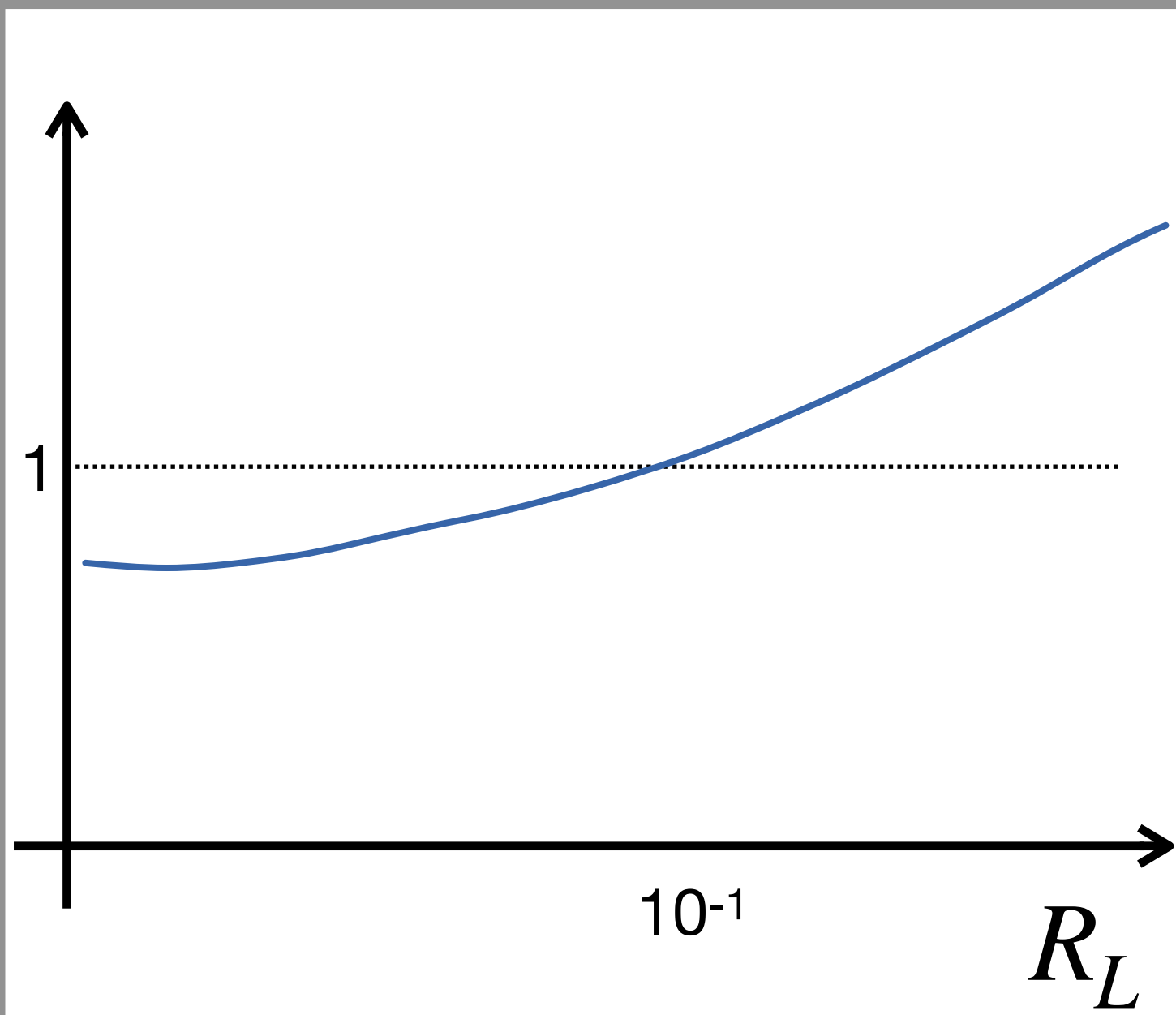
# Gauging my oracle skills: ECT\* workshop 13/02/2024

Newspaper A



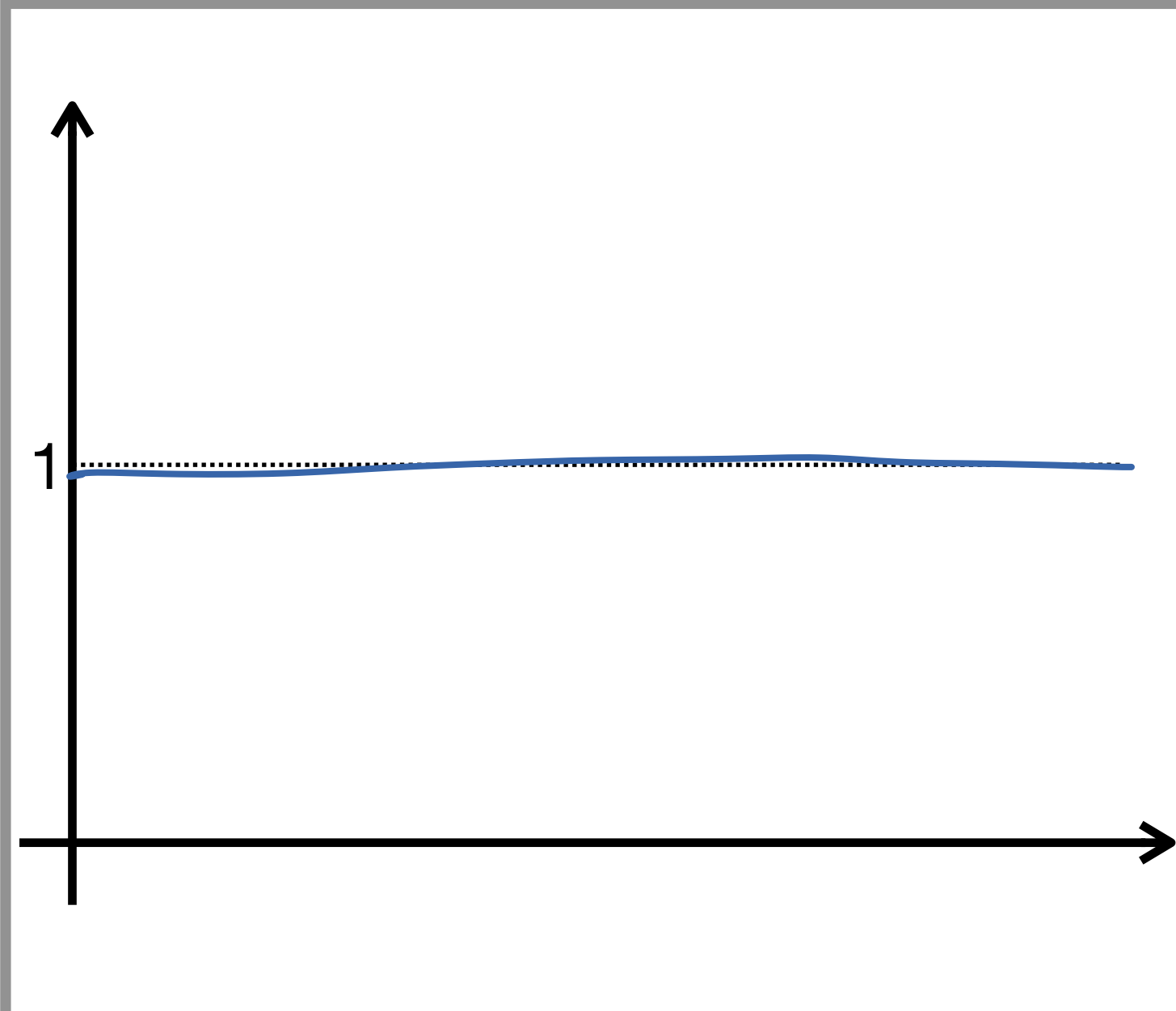
Survivor bias dominates EECs  
Color coherence or q/g frac?  
New proposal: measure in boson-tagged jets

Newspaper B



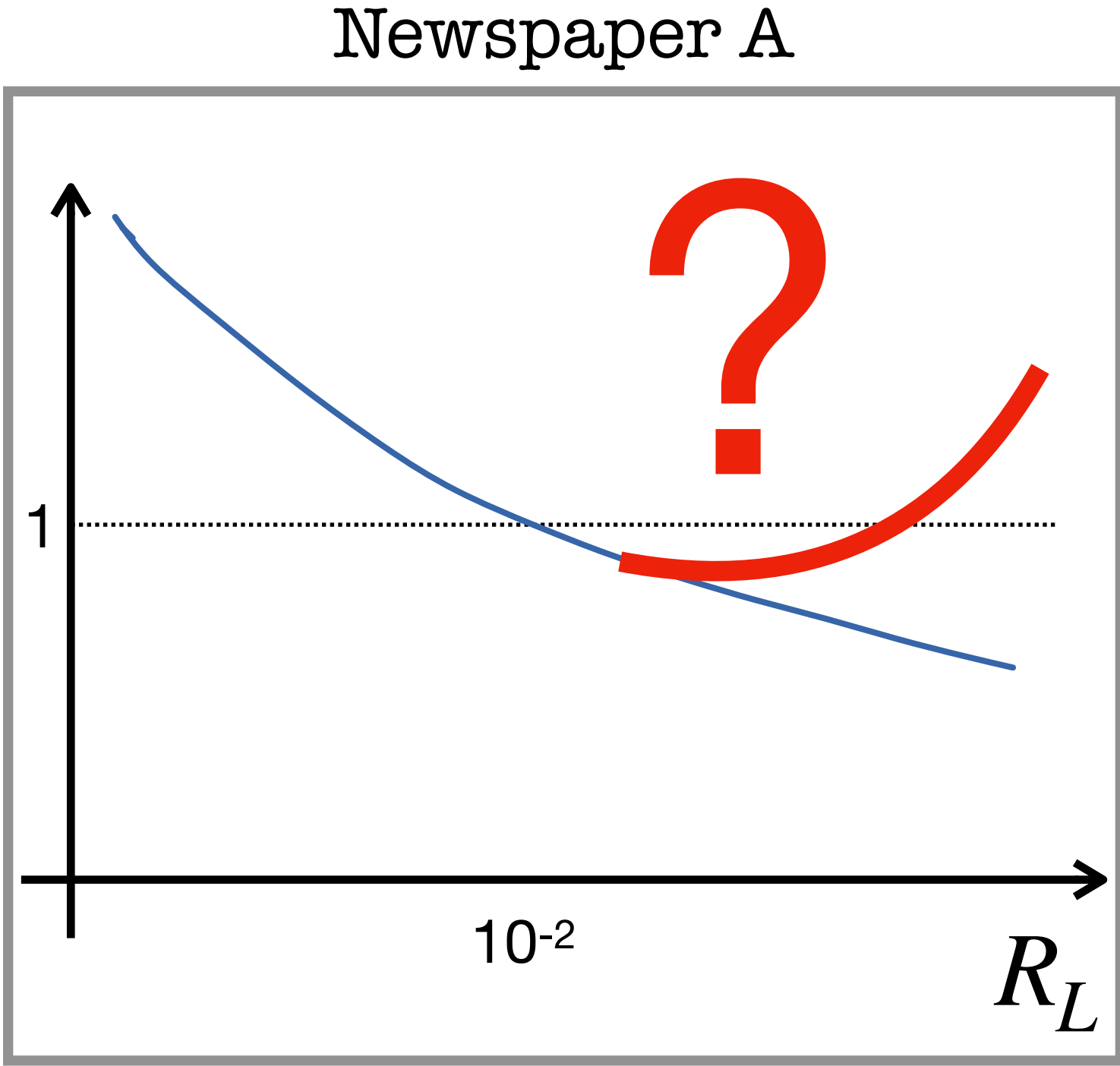
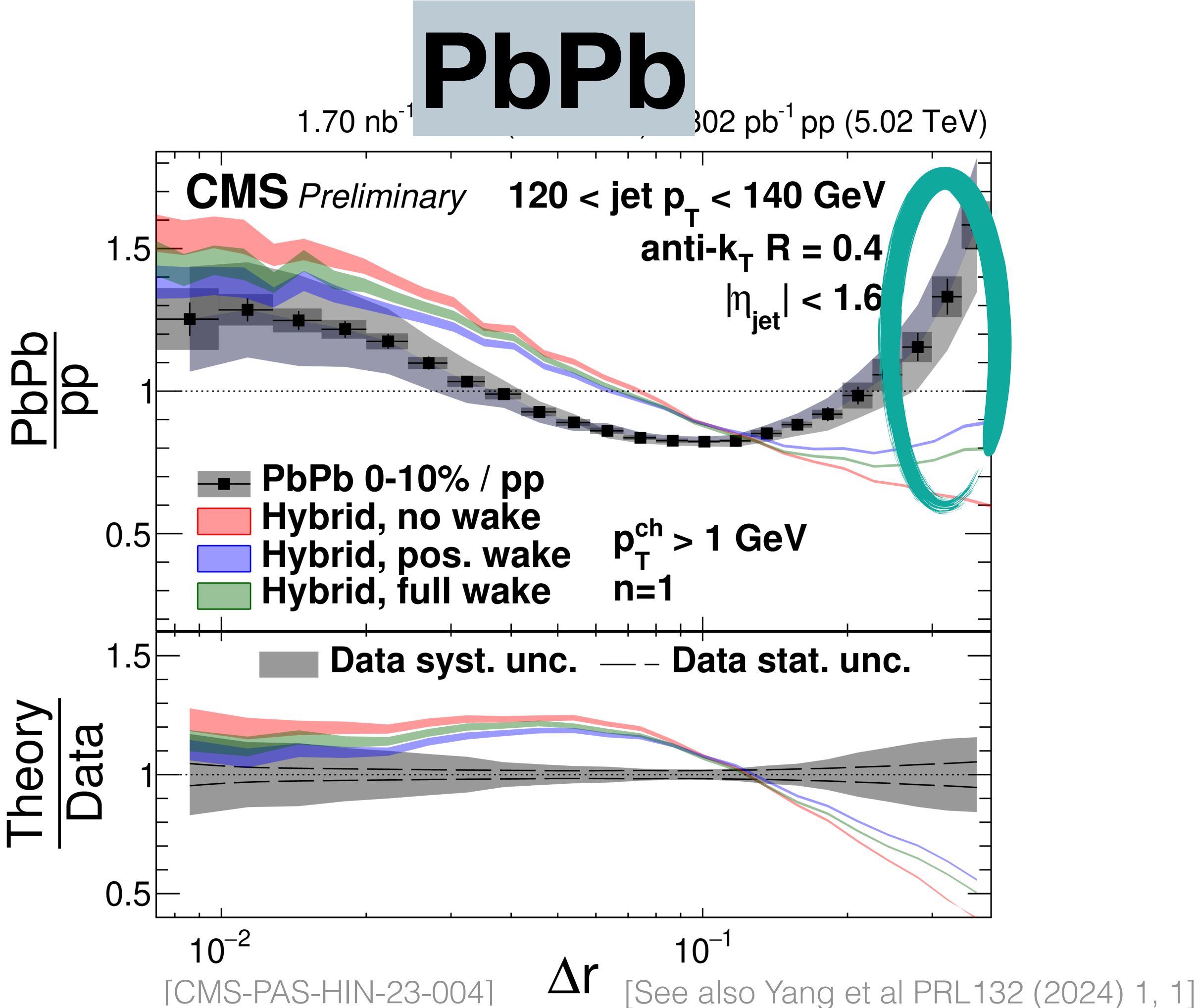
Wake first observed with EECs  
or  
Medium induced emissions captured by EECs  
New proposal: measure in boson-tagged jets

Newspaper C (highly unlikely)



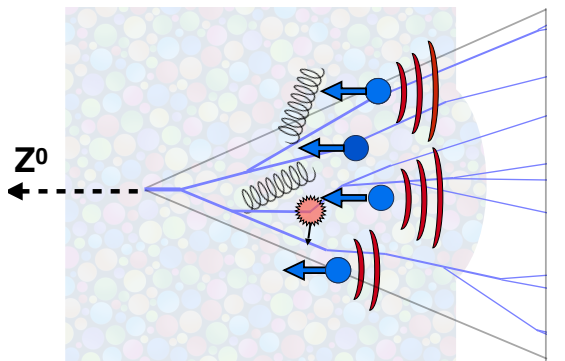
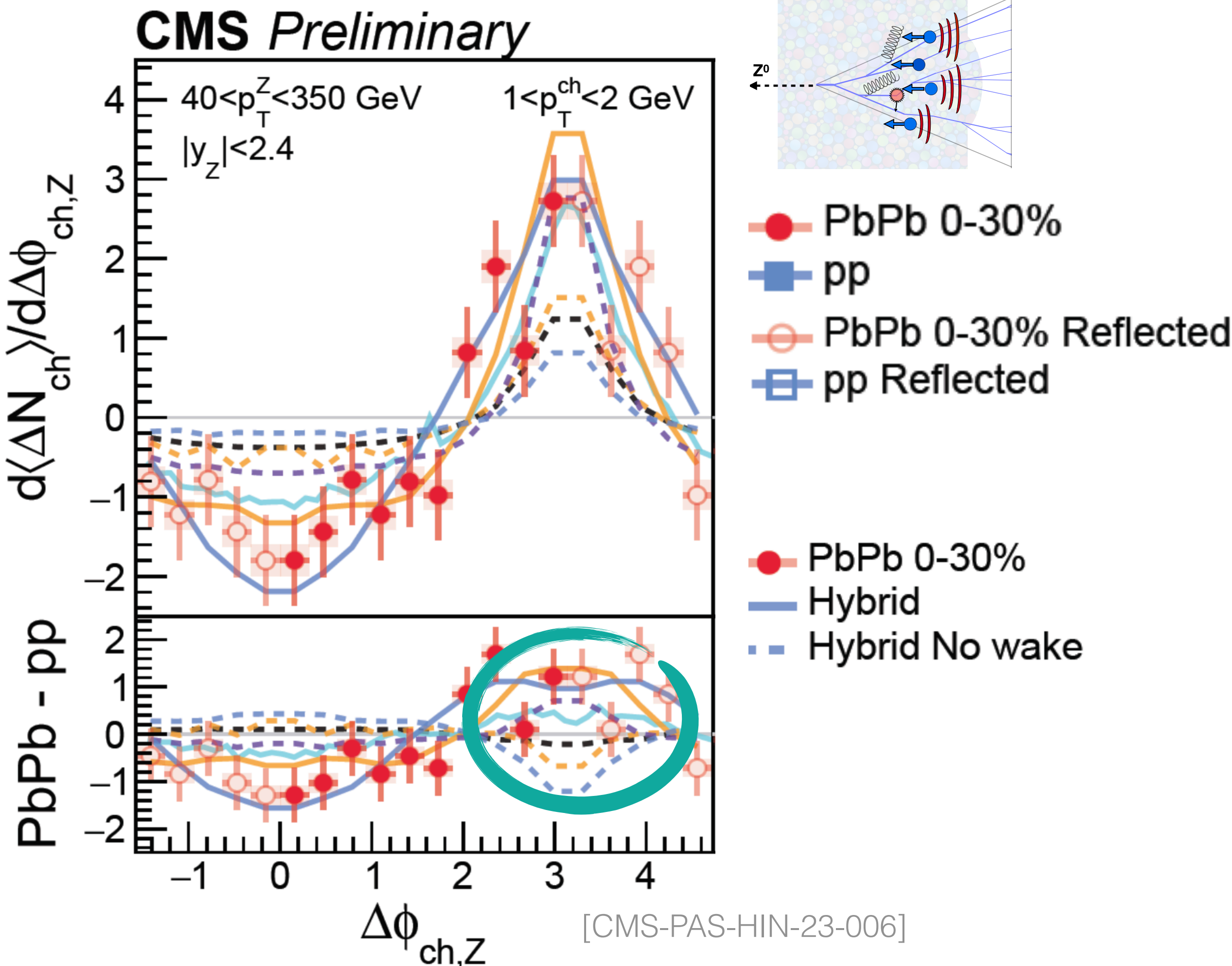
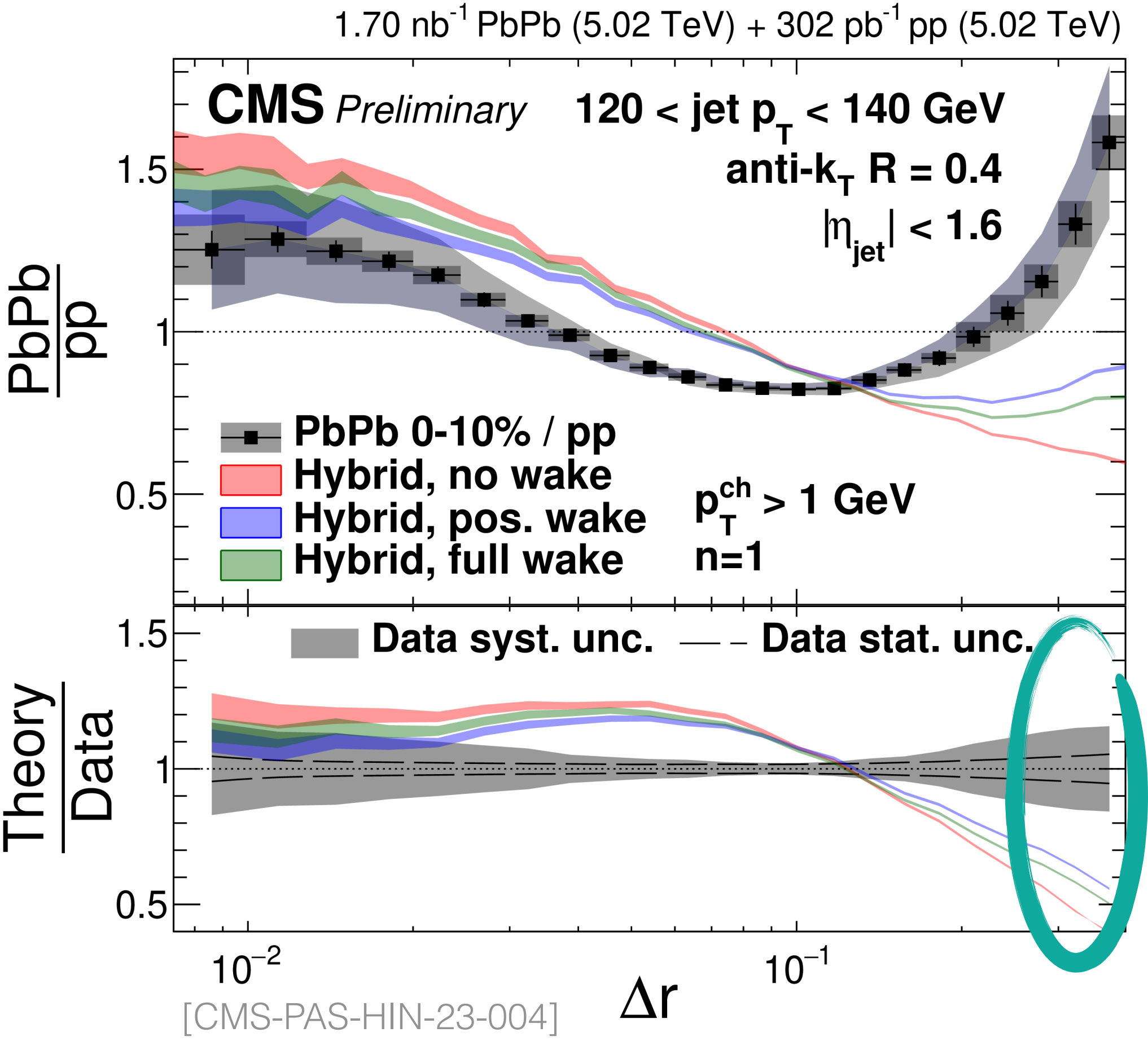
Breaking news: the QGP does not modify the energy flow pattern within a jet  
  
...yet another reason not to build future colliders

# Gauging my oracle skills: PbPb reality



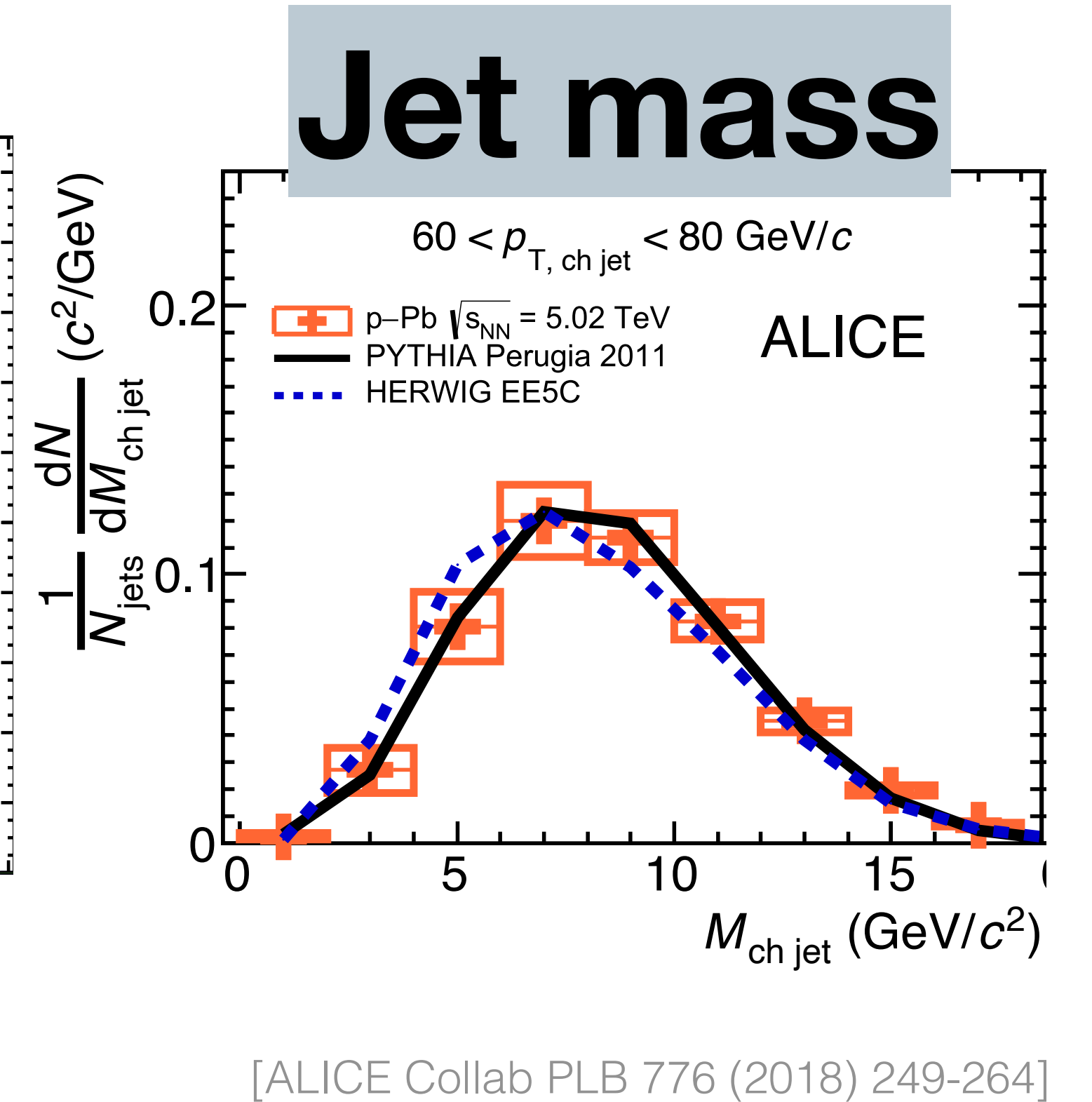
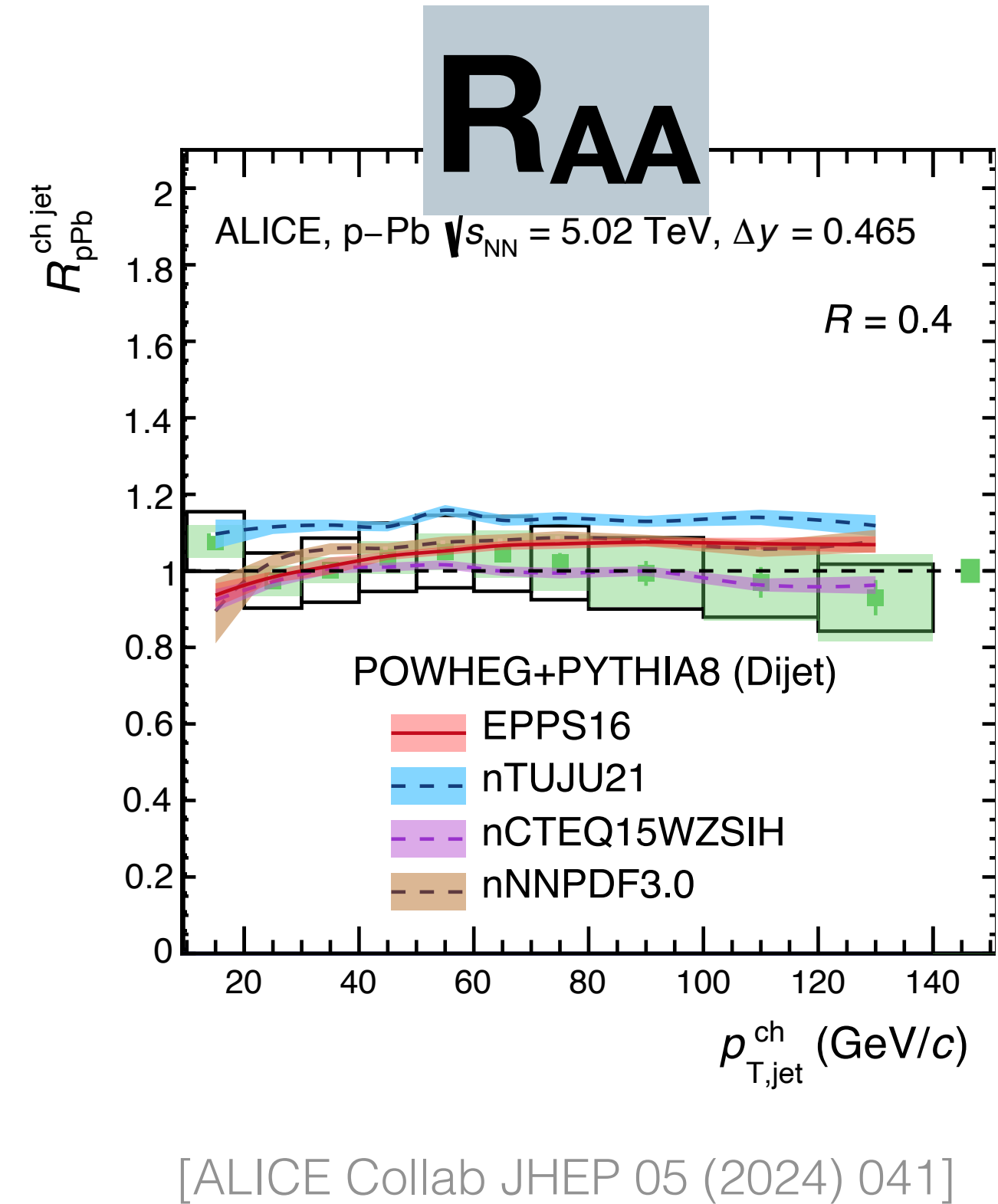
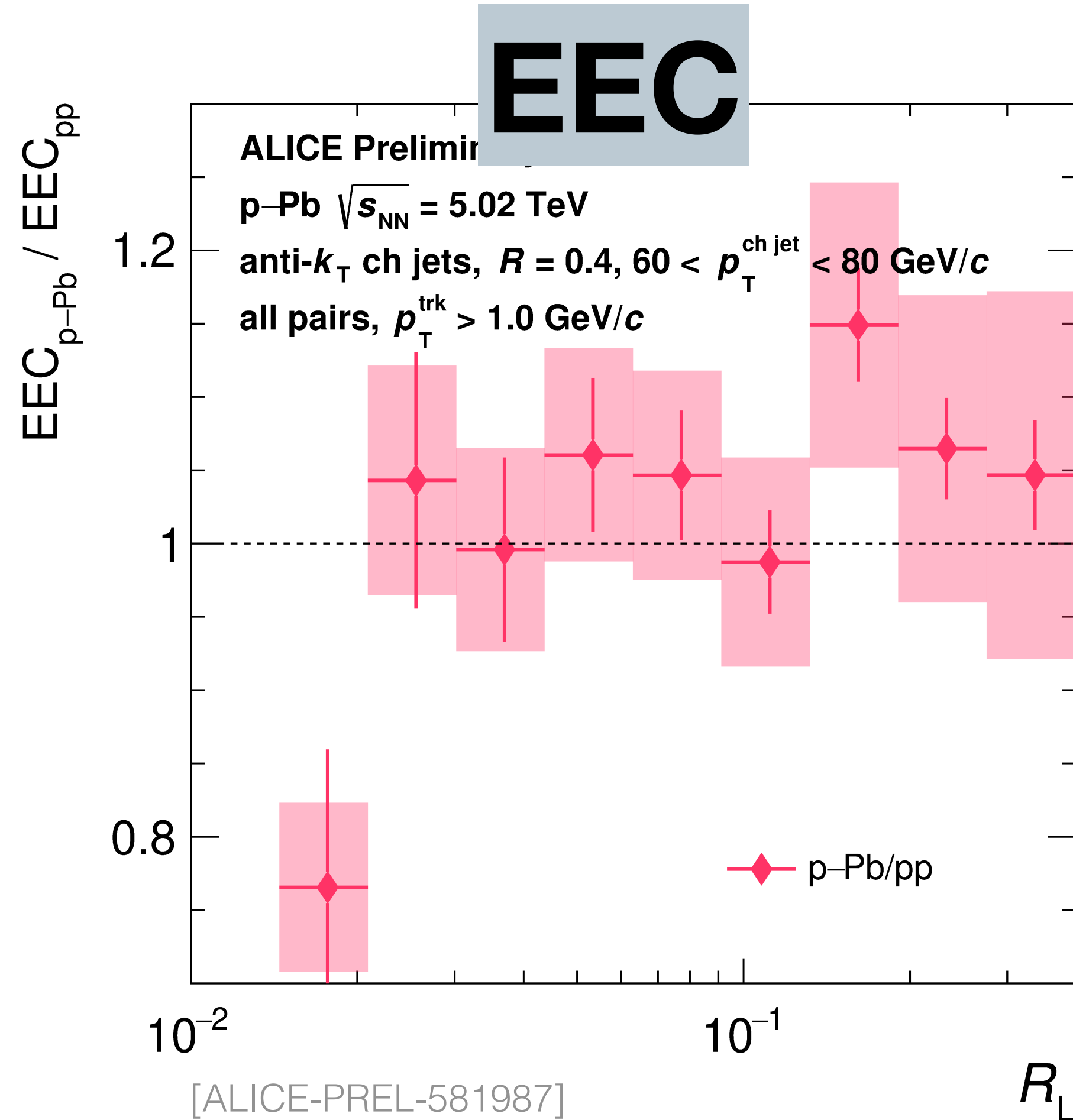
What's causing the large angle enhancement?

# Gauging my oracle skills: PbPb reality



Is it possible to get a consistent picture across observables?

# Another puzzle: pPb reality



Is it possible to get a consistent picture across observables?

# Let's take a step back: analytic understanding of jet substructure

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$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$

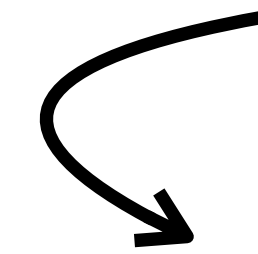
Single-emission matrix element



# Let's take a step back: analytic understanding of jet substructure

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$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$



*multiple emission function*

# Let's take a step back: analytic understanding of jet substructure

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$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$

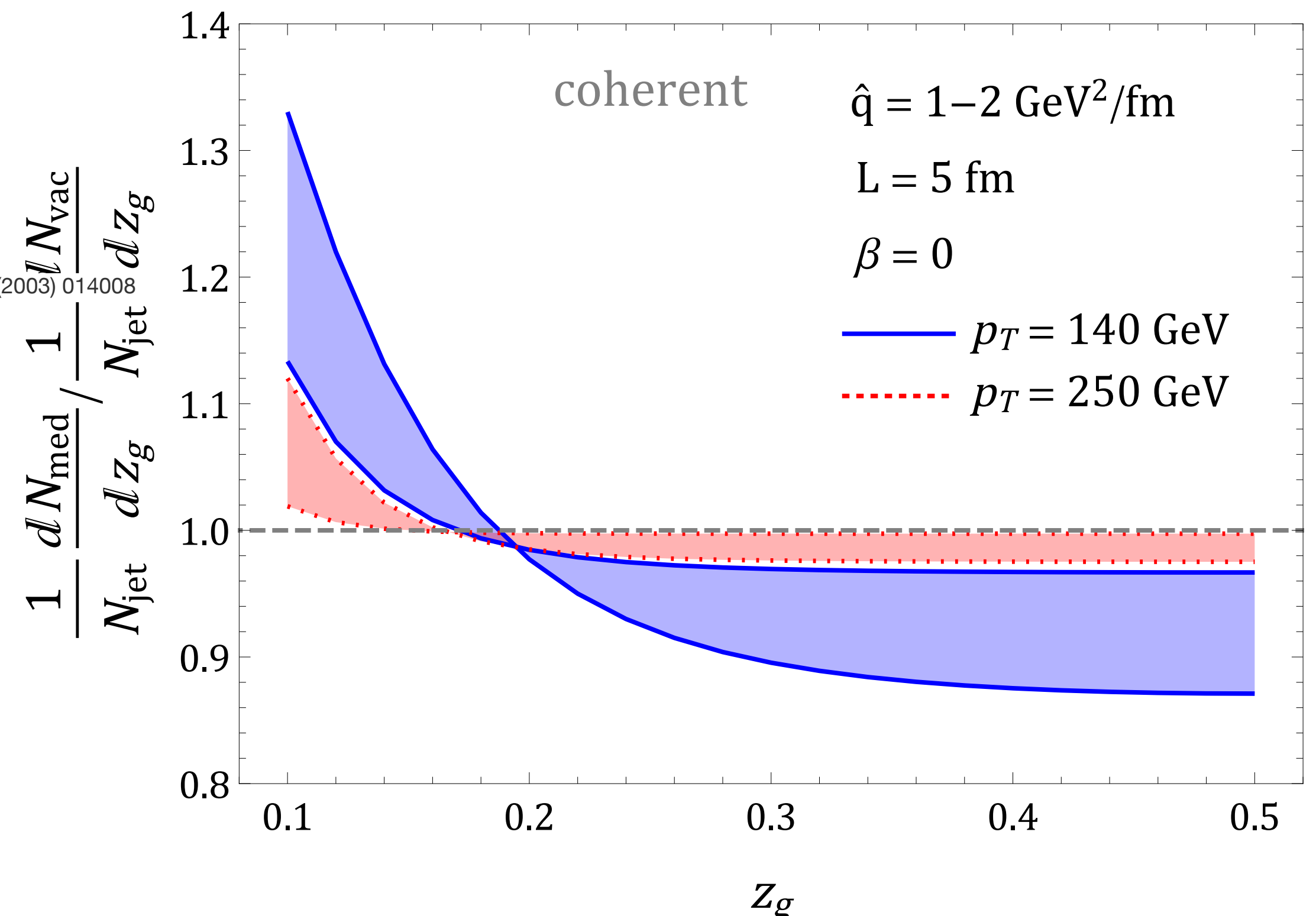
Energy loss



# Some jet substructure studies: $z_g$ in 2017 [Mehtar-Tani, Tywoniuk JHEP 04 (2017) 125]

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) \mathcal{Q}(z, \theta; \epsilon, p_t)$$

- $P(z, \theta)$  : vacuum+BDMPS-Z  
[Phys.Rev.D 68 (2003) 014008]
- $F(z, \theta)$  : vacuum LL resummation
- $\mathcal{Q}(\epsilon, p_t)$  : quenching weight  
[Salgado, Wiedemann PRD 68 (2003) 014008]  
[Baier et al JHEP 09 (2001) 033]

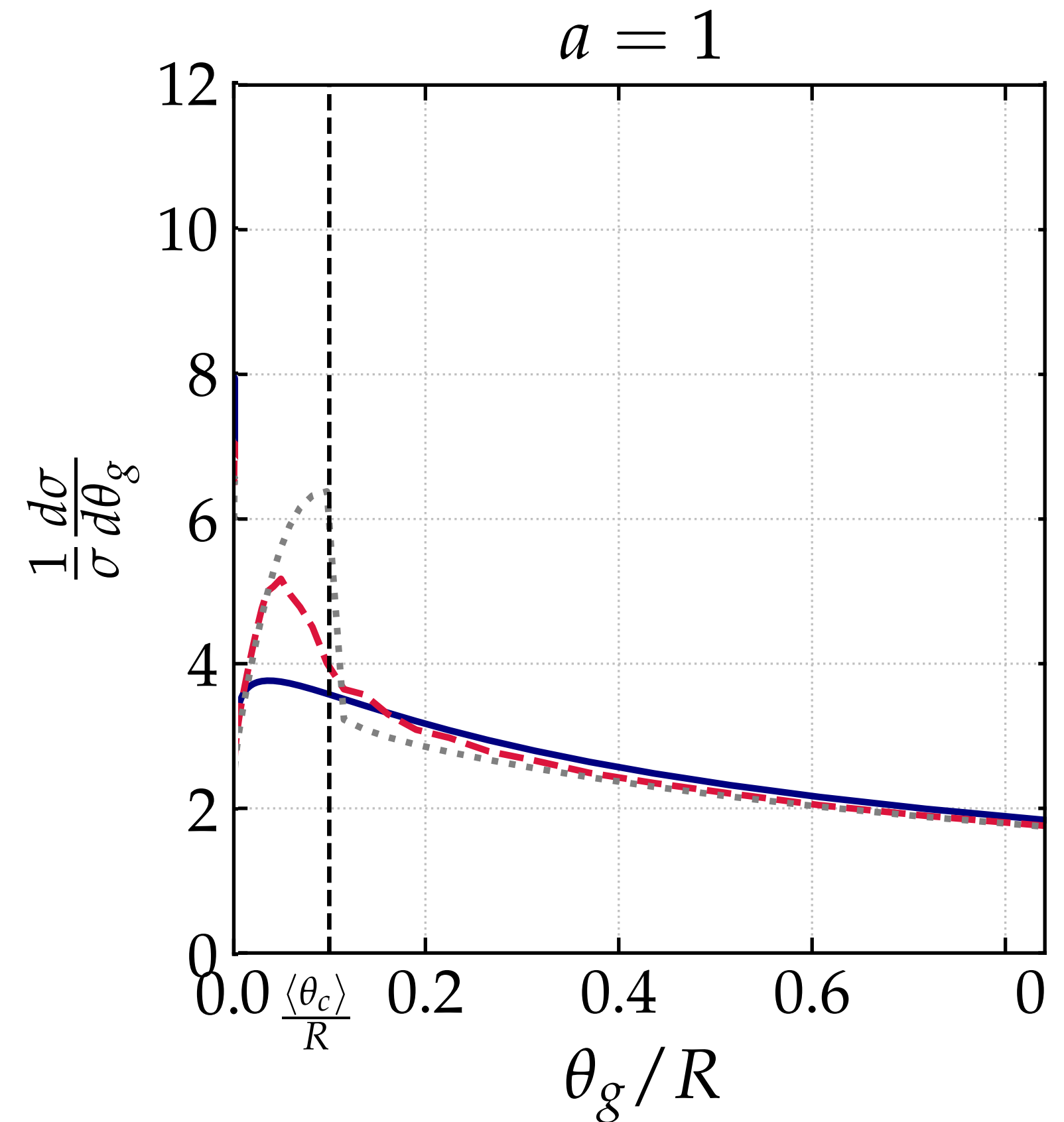


Enhancement of unbalanced splittings due to  $z^{3/2}$  slope of BDMPS-Z

# Some jet substructure studies: DyG in 2022 [Caucal, ASO, Takacs, PRD 105 (2022) 11, 114046]

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$

- $P(z, \theta)$ : vacuum  $\Theta_{\text{veto}}$ +BDMPS-Z  
[Caucal et al PRL 120 (2018) 232001]
- $F(z, \theta)$ : vacuum LL resummation
- $Q(\theta; \epsilon, p_t)$ : quenching weight ( $\theta_c$ )  
[Methar-Tani, Tywoniuk PRD 98 (2018) 5, 051501]
- Path length fluctuations

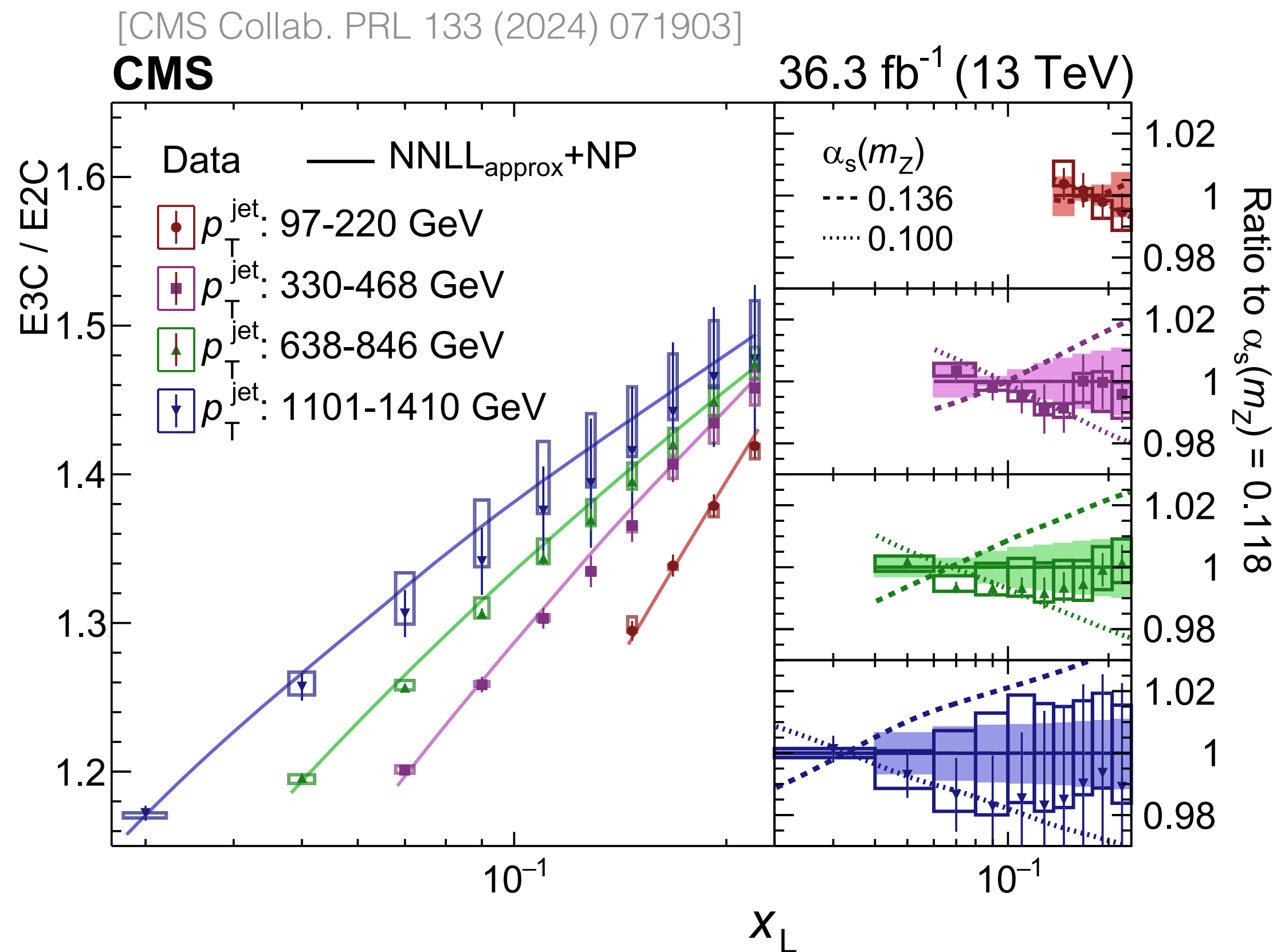


Drastic modification around the critical angle

# What about the EEC? Vacuum considerations

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$

only sensitive to collinear physics, i.e. easier to resum!



$$\alpha_s(M_Z) = 0.1229^{+0.0040}_{-0.0050}$$

# What about the EEC? Medium considerations

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$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) Q(z, \theta; \epsilon, p_t)$$

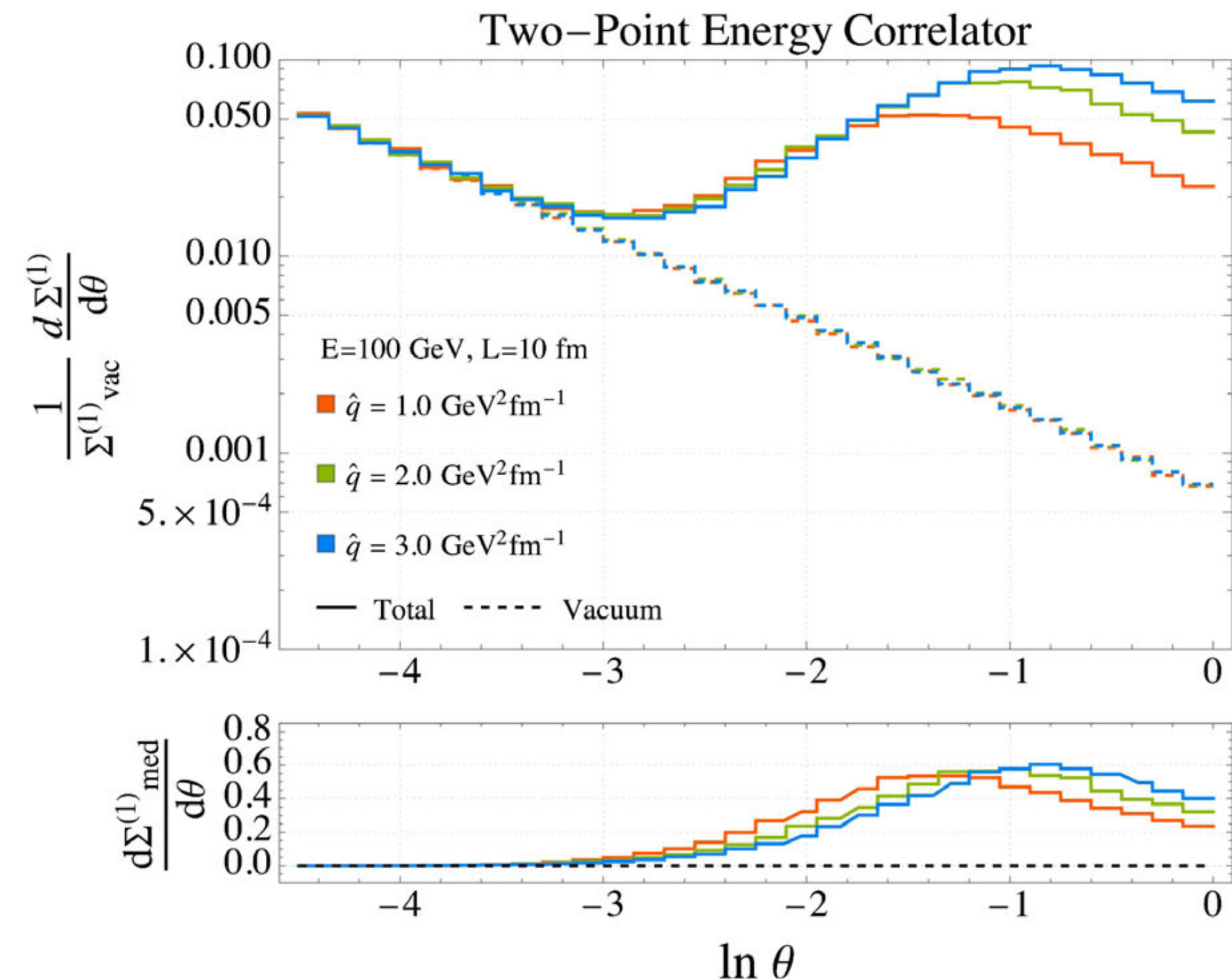
? ? ?

In-medium calculation of EEC is *as complicated* as other jet substructure observables, i.e. no apparent simplification due to its definition

# Some semi-analytic studies: EEC in summer 2023 [Andres et al PRL130, 262301 (2023)]

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) \mathcal{Q}(z, \theta; \epsilon, p_t)$$

- $P(z, \theta)$  : vacuum+semi-classical approx [Dominguez et al, EPJC 80 (2020) 1, 11]
- $F(z, \theta)$  : vacuum LL resummation
- $\mathcal{Q}(\epsilon, p_t)$  : no E-loss ( $\gamma$ -jet)

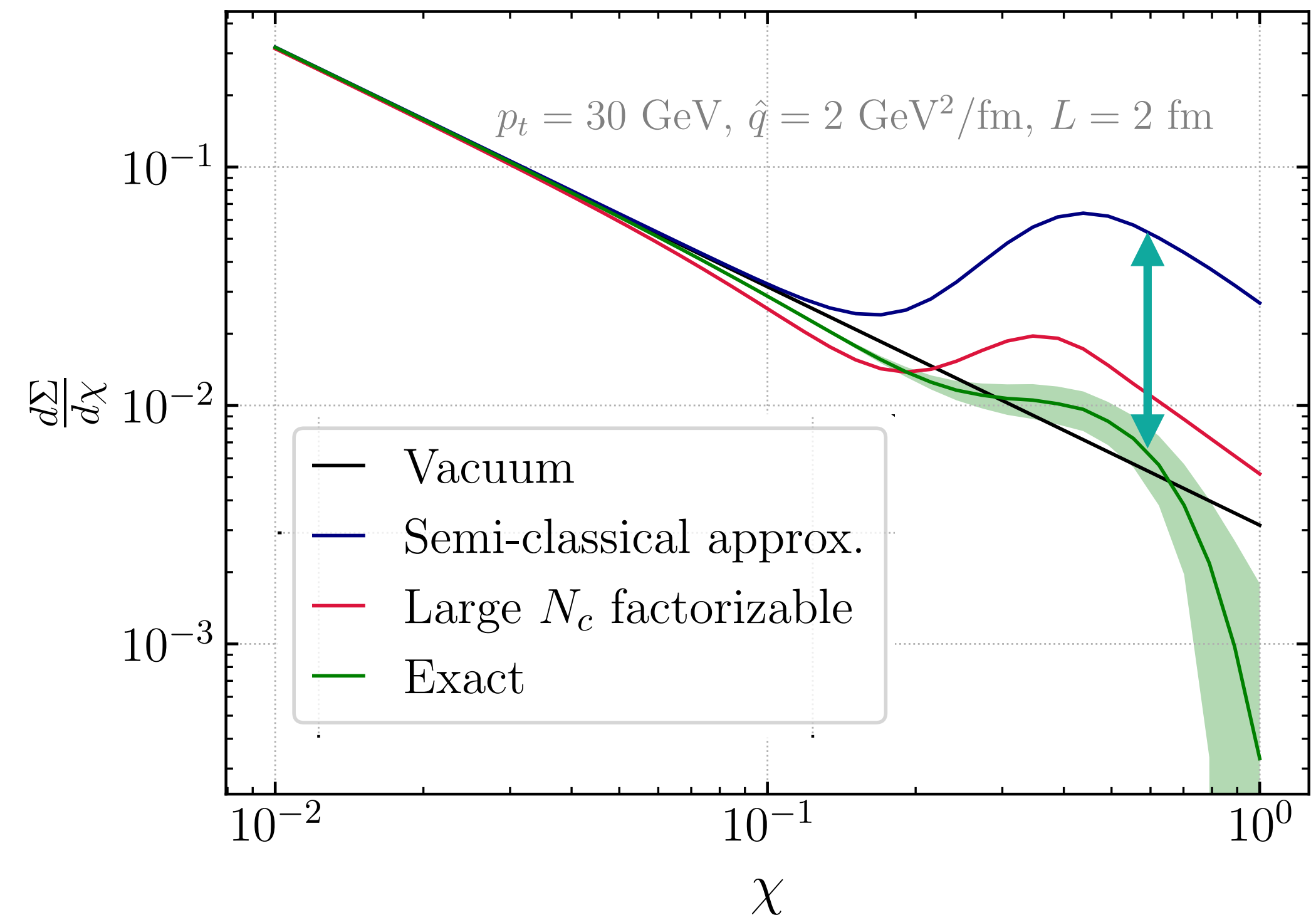


Enhancement of wide-angle splittings due to finite formation time effects

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) \mathcal{Q}(z, \theta; \epsilon, p_t)$$

$\gamma \rightarrow q\bar{q}$

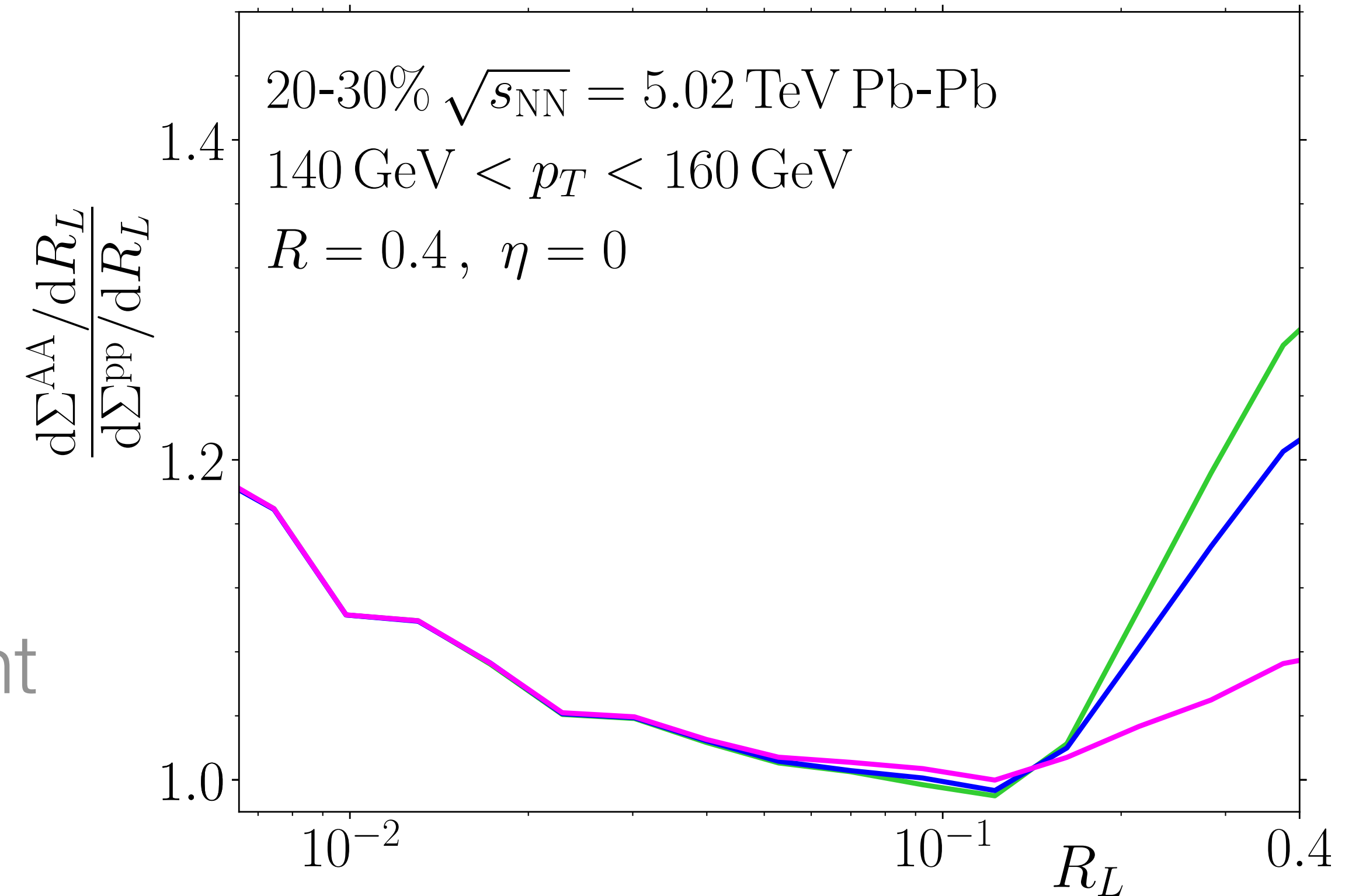
- $P(z, \theta)$ : vacuum  $\Theta_{\text{veto}}$  + state-of-the-art ME (for  $\gamma \rightarrow q\bar{q}$ )  
[Isaksen, Tywoniuk JHEP 09 (2023) 049]
- $F(z, \theta)$ : vacuum LL resummation
- $\mathcal{Q}(\theta; \epsilon, p_t)$ : quenching weight ( $\theta_c$ )



Significant reduction of wide-angle enhancement when improving the description of  $P(z, \theta)$ , i.e. leading order result not under control

$$\left. \frac{d\sigma}{d\mathcal{O}} \right|_{p_t} = P(z, \theta) \mathcal{F}(z, \theta) \mathcal{Q}(z, \theta; \epsilon, p_t)$$

- $P(z, \theta)$  :vacuum+semi-classical approx
- $F(z, \theta)$  :vacuum LL resummation
- $\mathcal{Q}(\epsilon, p_t)$  :coherent quenching weight
- Expanding media



Energy loss narrows the EEC as observed in [Barata, Mehtar-Tani PoS HardProbes2023 (2024) 145]  
[Barata, Caucal, ASO, Szafron 2312.12527]

# Some final considerations

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- Impressive on-going experimental program on energy-energy correlators
- Calculability of EEC is not obviously simpler than other observables
- Not many theoretical developments (also applies to MC) beside exploring different parametrizations of  $P(z, \theta) \rightarrow \mathcal{O}(1)$  effects
- As for other observables, analytic calculations not hitting precision frontier

In-medium EECs: quo vadis?