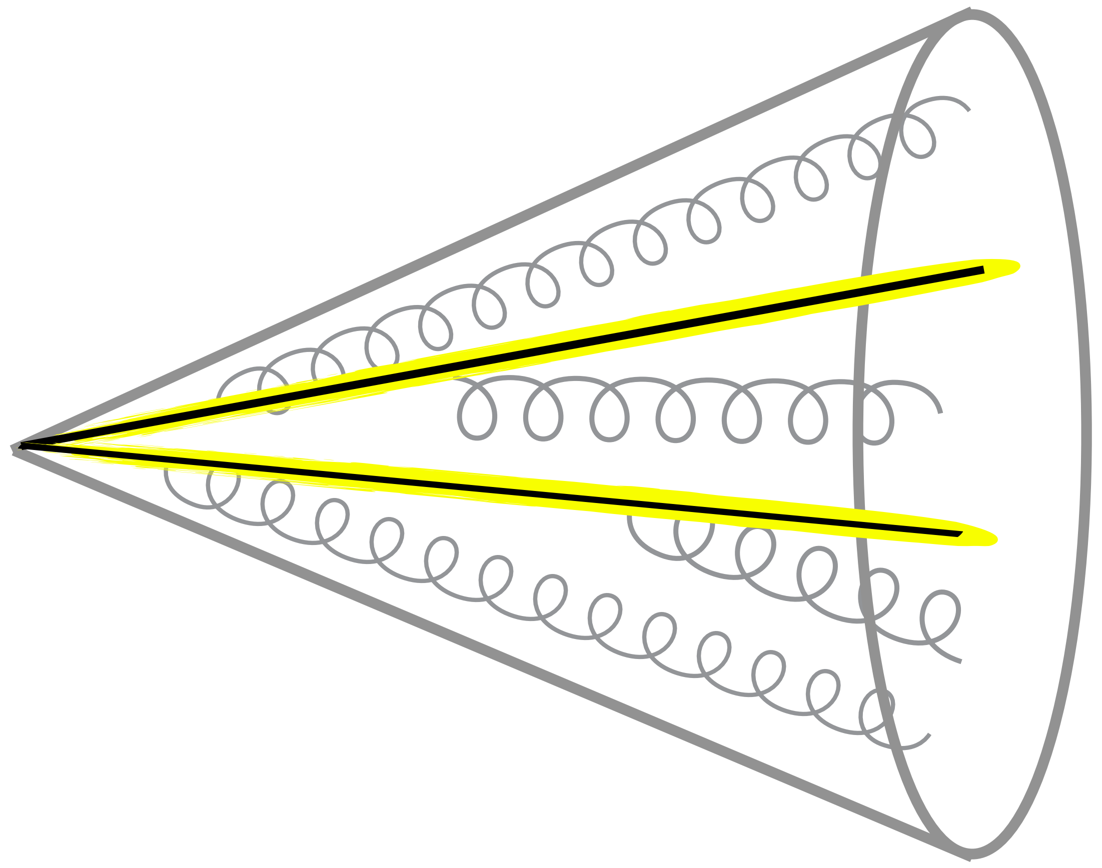
Lessons from jet substructure measurements at RHIC and LHC



Alba Soto-Ontoso

+ Paul Caucal, Yacine Mehtar-Tani, Adam Takacs and Konrad Tywoniuk

2021 RHIC/AGS Annual Users' Meeting

Remote, 9th June, 2021

Engineering jet substructure observables

Minimal checklist to keep in mind for potential jet substructure observables

- Theoretically calculable: IRC (or at least Sudakov) safety

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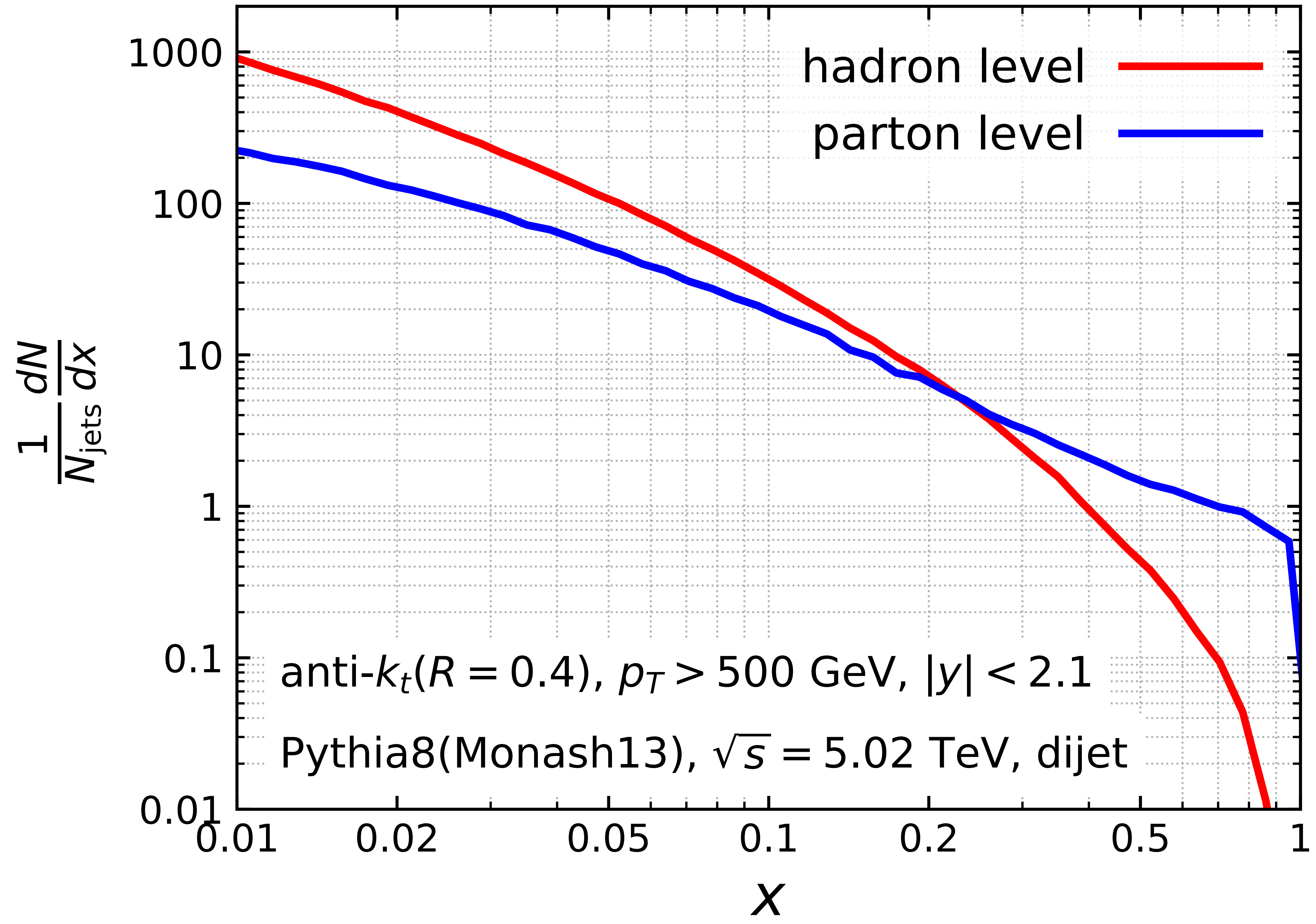
e.g. fragmentation function $D(x) = \frac{1}{N_{\text{jets}}}\frac{\mathrm{d}N}{\mathrm{d}x}$ with $x = \frac{p_t \cos\theta}{p_{t,\text{jet}}}$

$$xD_{\text{LL}}(x) = 2\frac{\alpha_s C_R}{\pi}\int_0^R \frac{\mathrm{d}\theta}{\theta} f(1/x, 1/\theta)$$

$$\Downarrow$$

$$xD_{\text{LL}}(x) = 2\frac{\alpha_s C_R}{\pi}\int_{k_{\perp,\min}/(xp_t)}^R \frac{\mathrm{d}\theta}{\theta} f(1/x, 1/\theta)$$

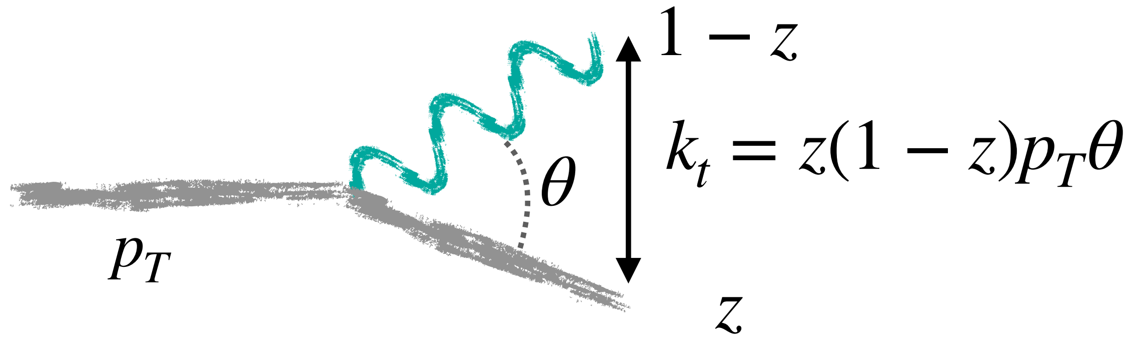


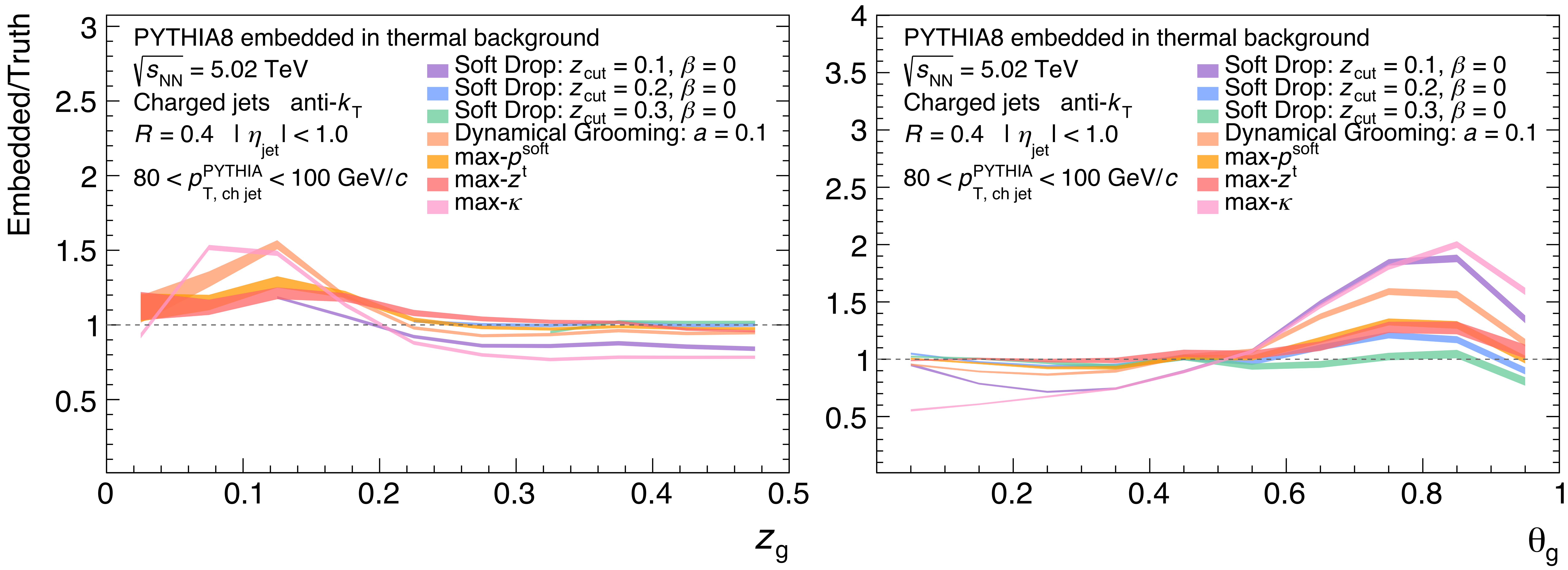
[Caucal et al JHEP10(2020)204]

Engineering jet substructure observables

Minimal checklist to keep in mind for potential jet substructure observables

- Theoretically calculable: IRC (or at least Sudakov) safety
- Experimentally measurable, e.g. thermal background impact on





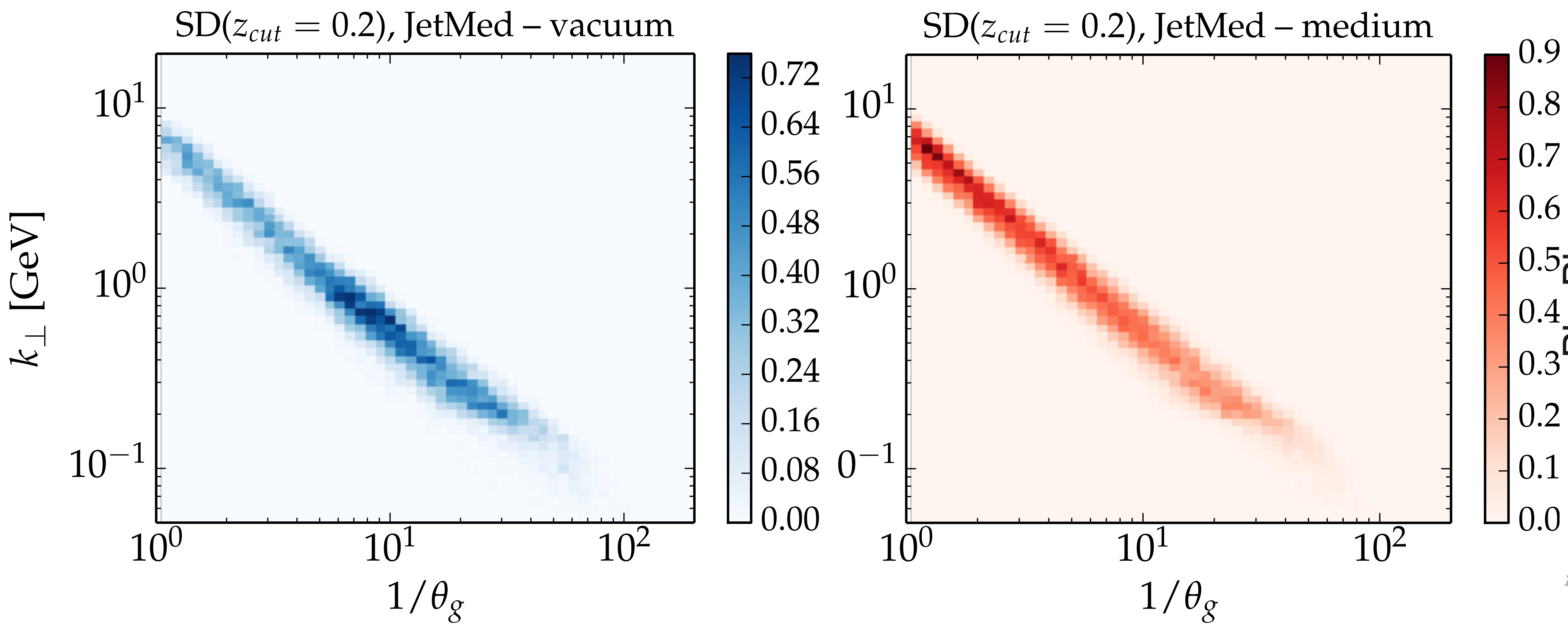
[Mulligan, Ploskon PRC 102(2020) 4]

Engineering jet substructure observables

Minimal checklist to keep in mind for potential jet substructure observables

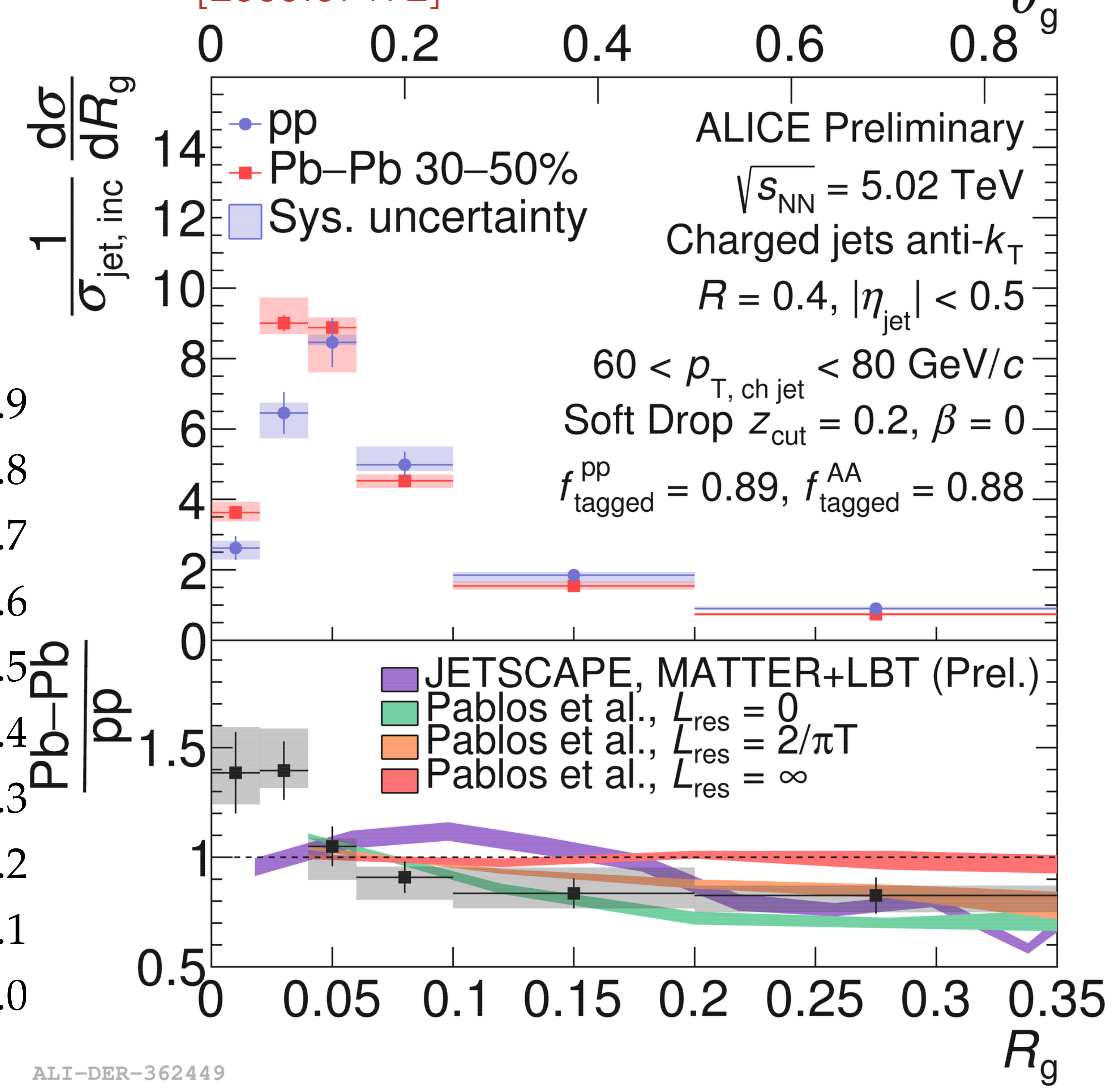
- Theoretically calculable: IRC (or at least Sudakov) safety
- Experimentally measurable
- Designed to probe a particular physics mechanism

  e.g. θ_g and color coherence

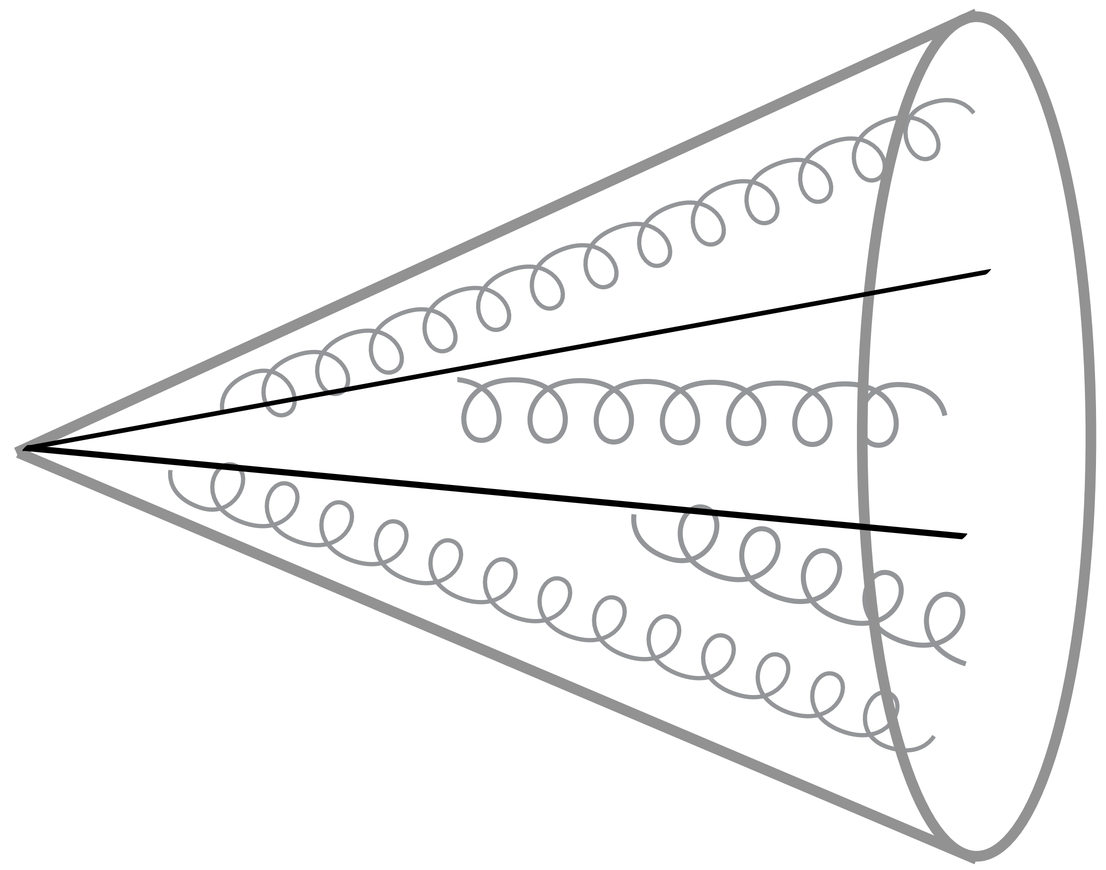


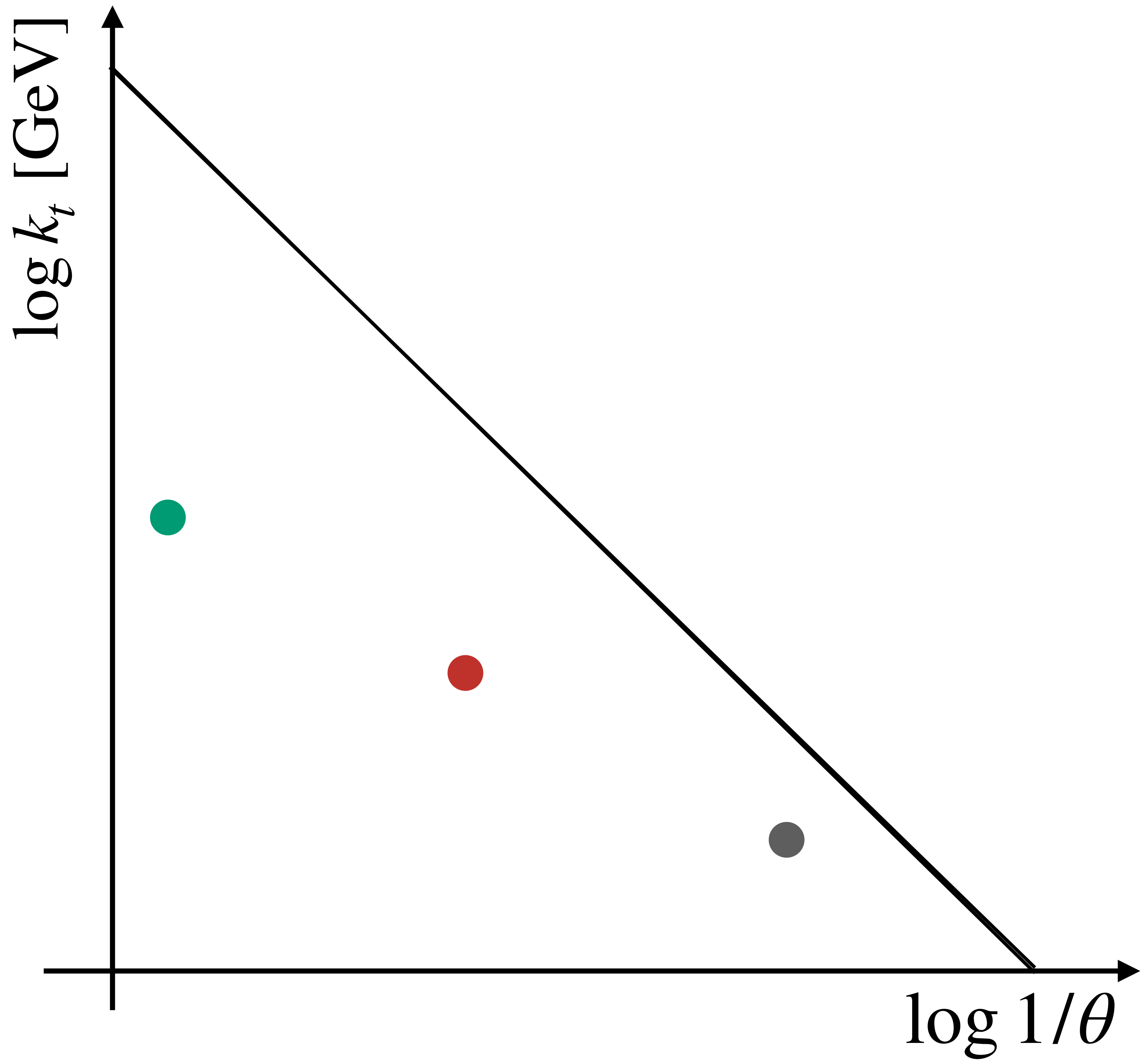
[Caucal, ASO, Takacs in preparation]

[2009.07172]



The Lund Jet plane: concept [Andersson, Gustafson, Lönnblad, Pettersson '89]

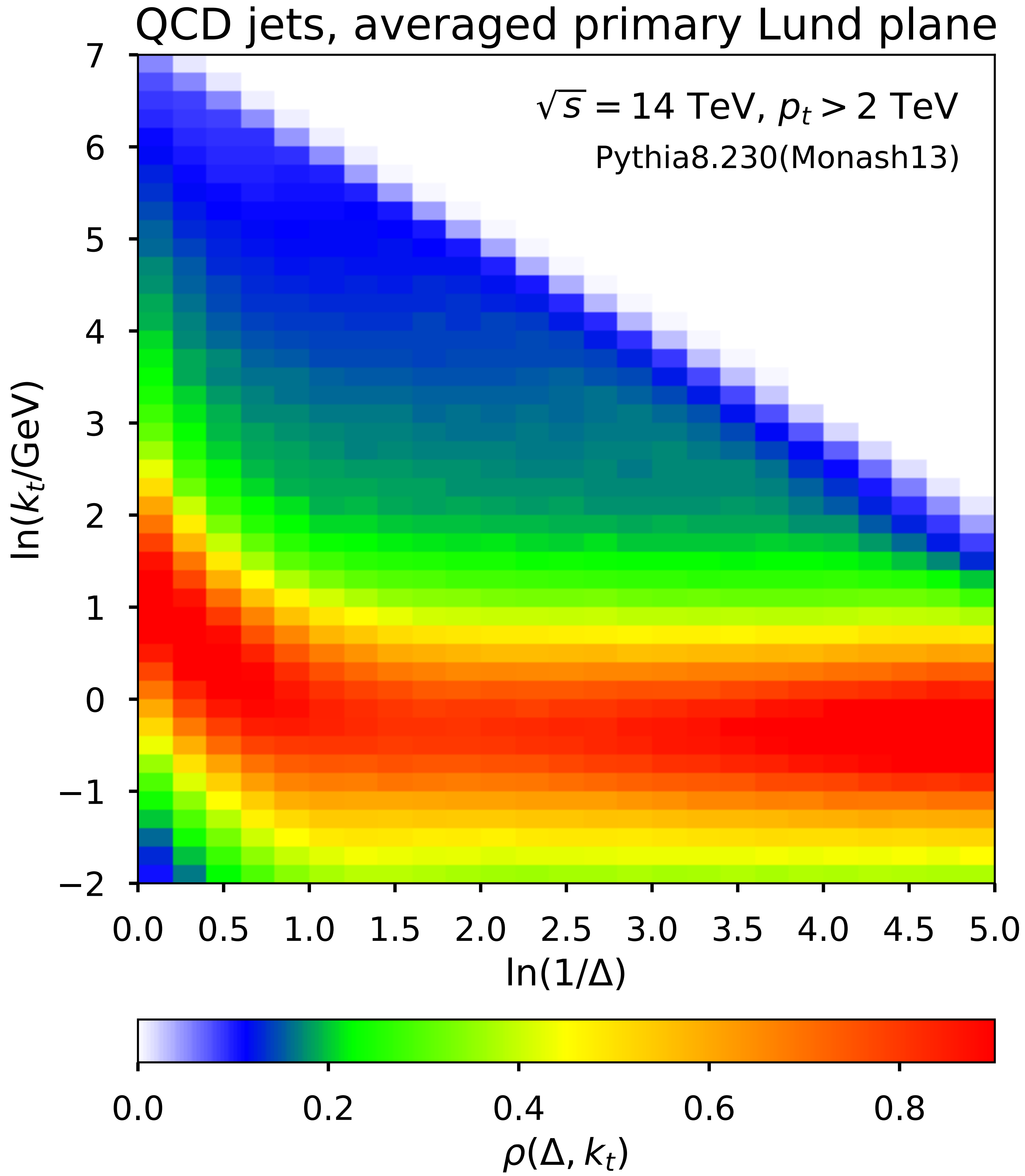




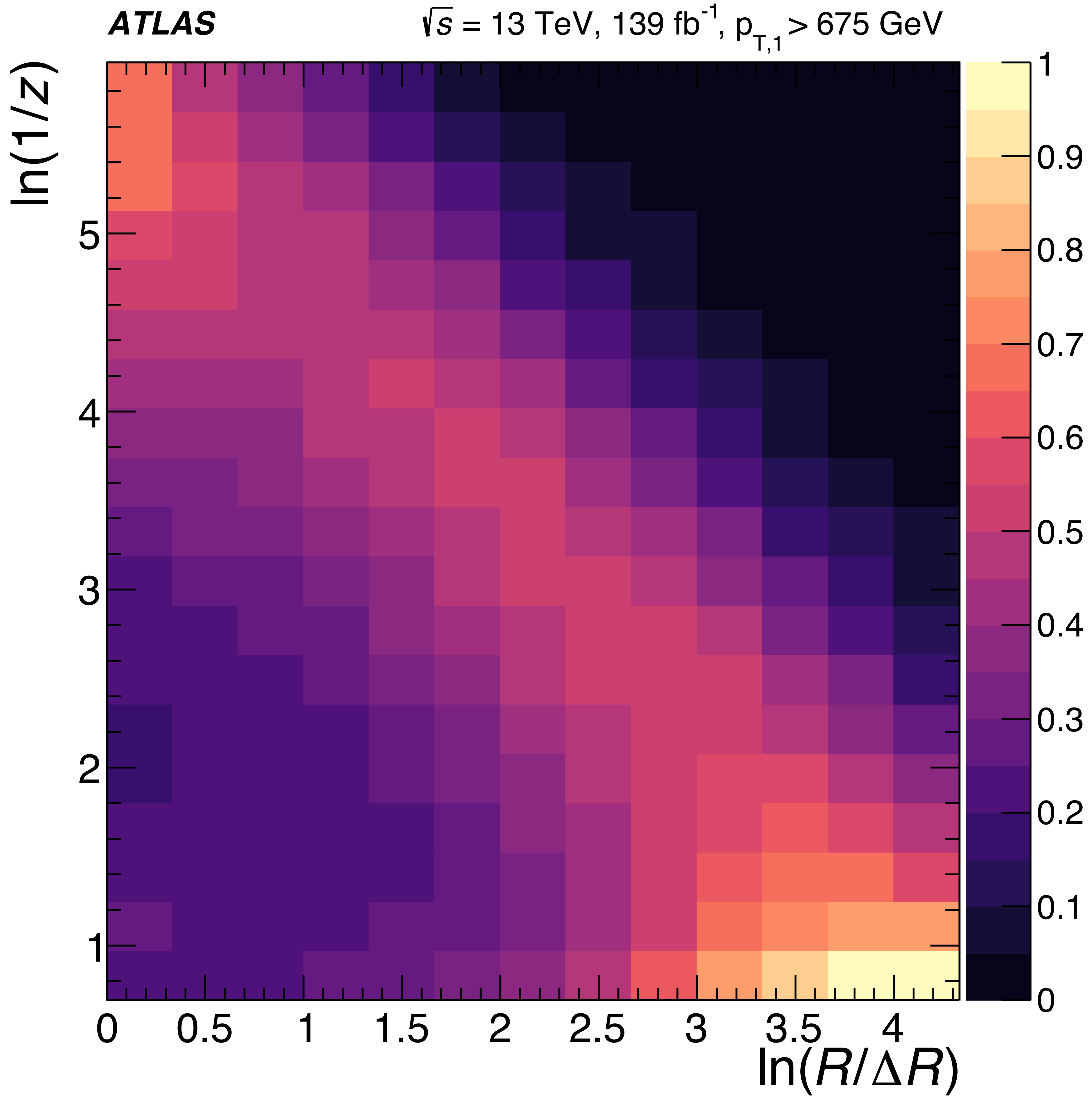
Primary Lund Jet plane density: all splittings along the hardest branch

The Lund Jet plane: Monte Carlo and data

[Dreyer, Salam, Soyez 1807.04758]



[2004.03540]

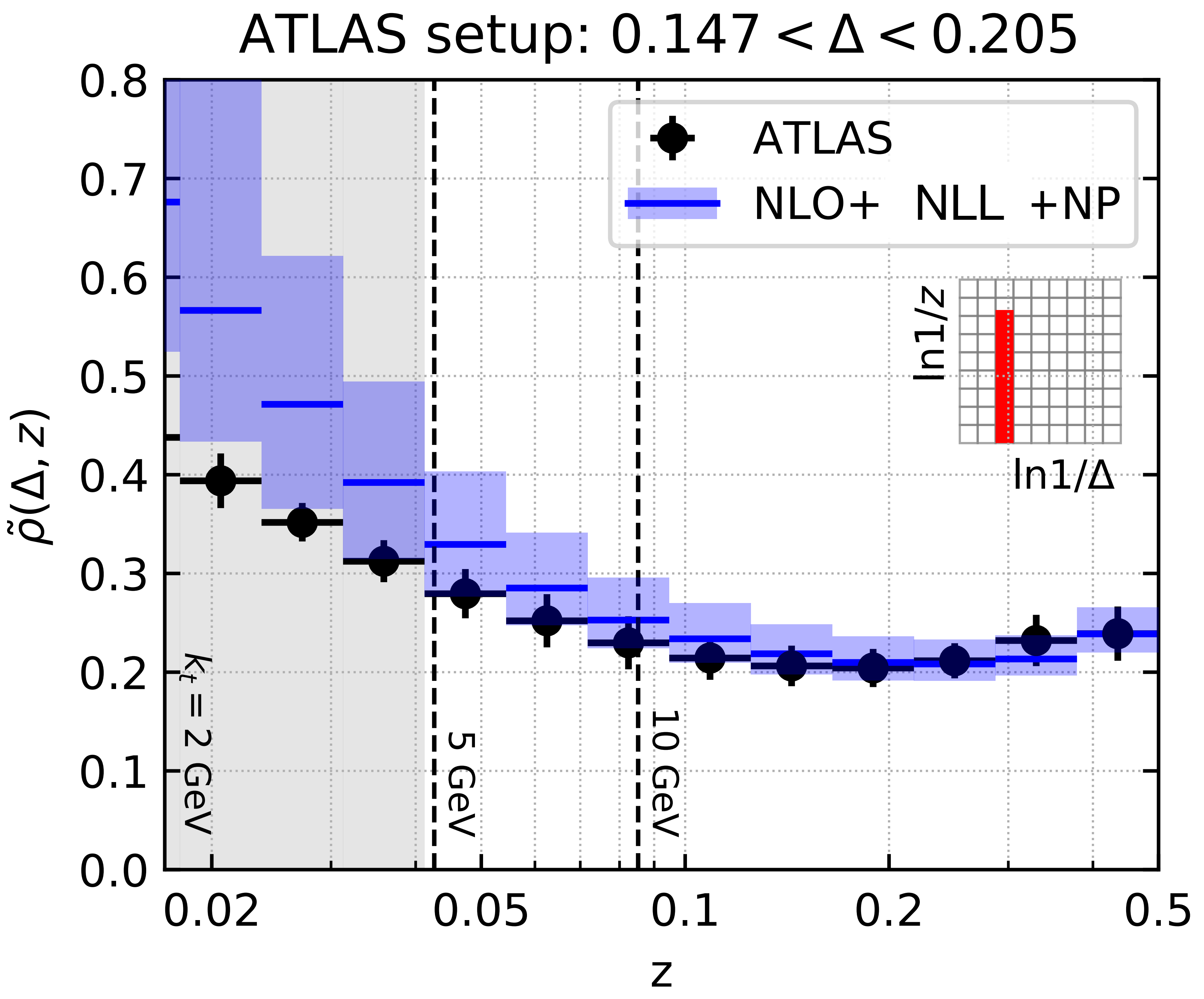


Excellent synergy between theory and experiment

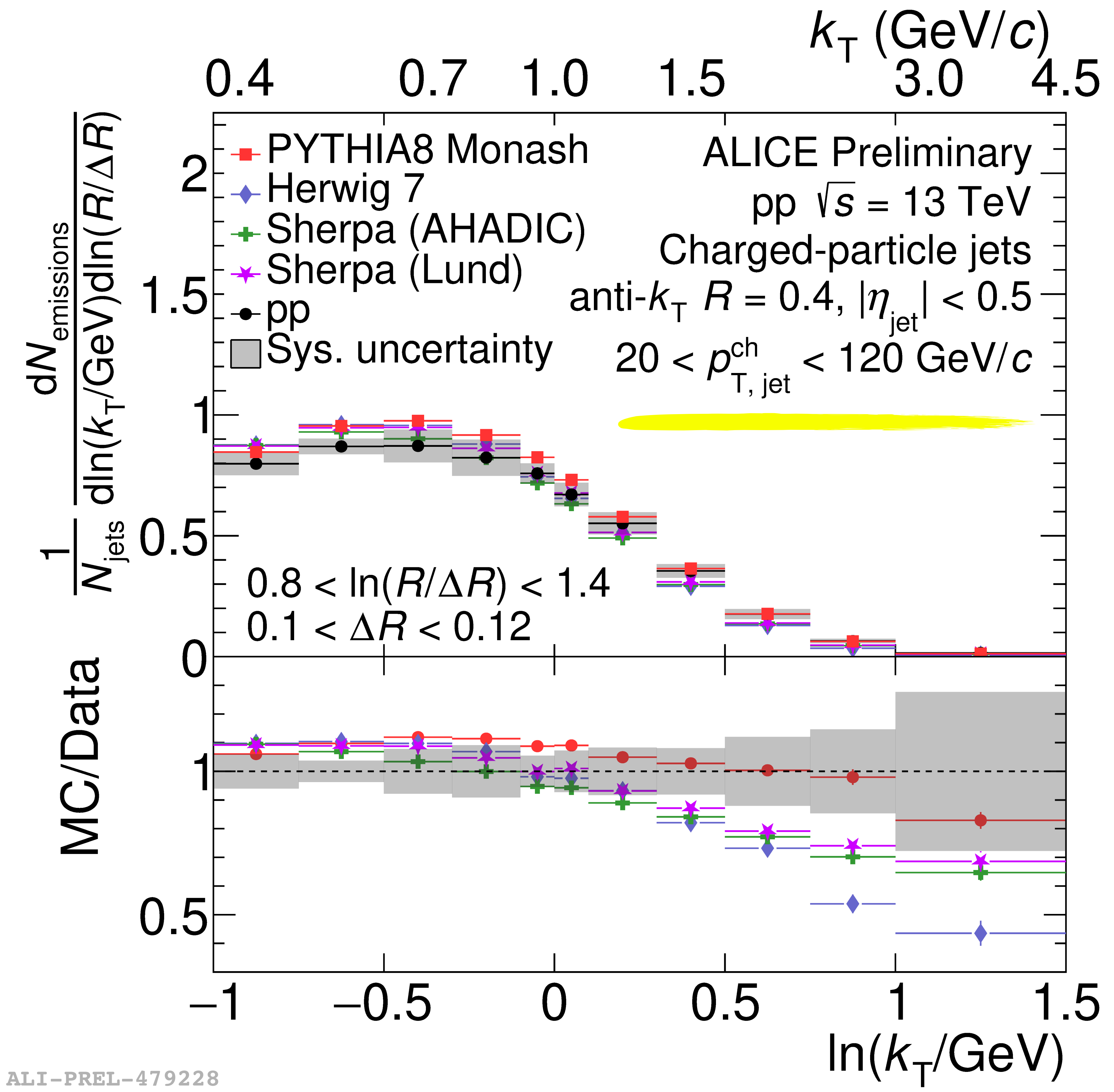
The Lund Jet plane: constraints on theory

High-p_t jets

[Lifson, Soyez, Salam 2007.06578]



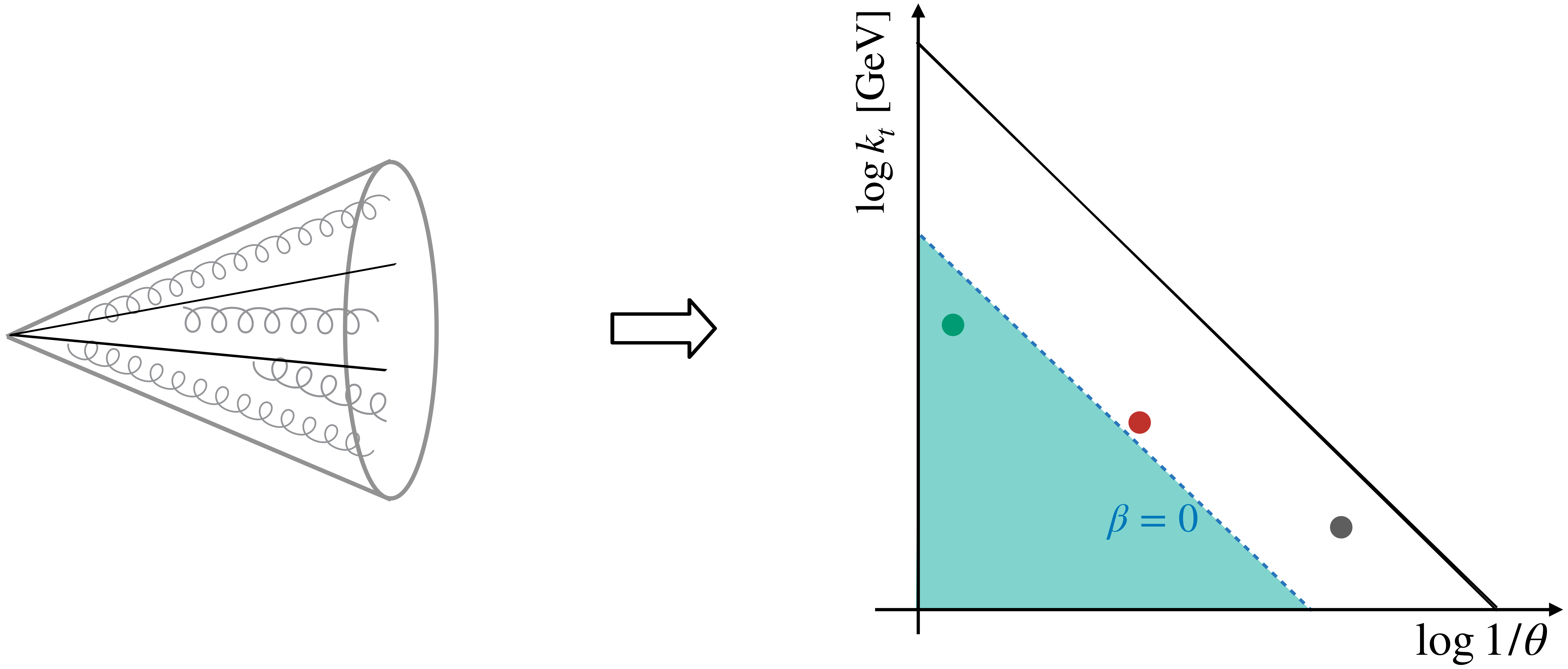
Low-p_t jets



Challenging measurement for theory. Ideal for tuning MC tuning

SoftDrop observables

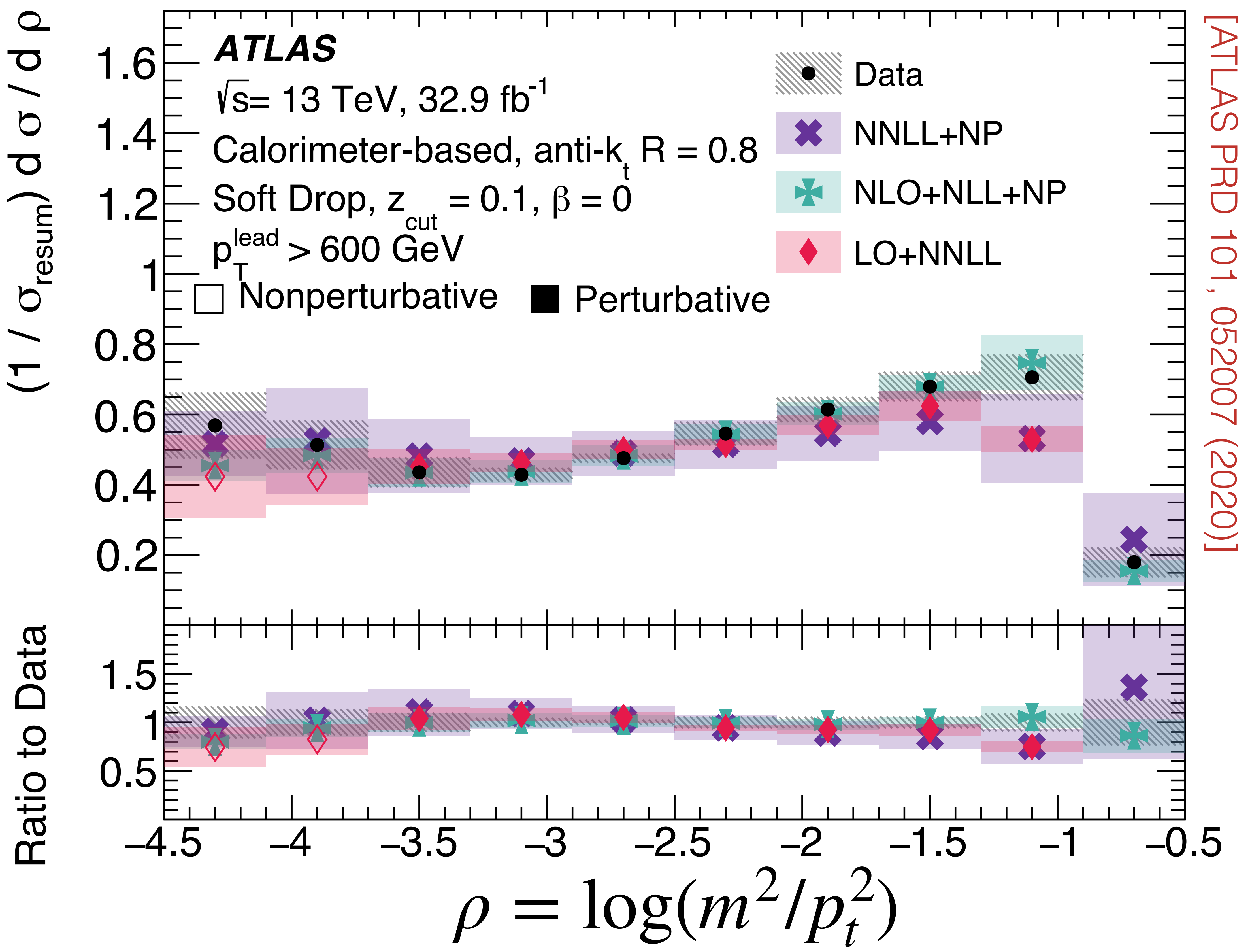
[Larkorski, Marzani, Soyez, Thaler 1402.2657]
[Dasgupta, Fregoso, Marzani, Salam 1307.0007] [Dreyer, Necib, Soyez, Thaler 1804.03657]



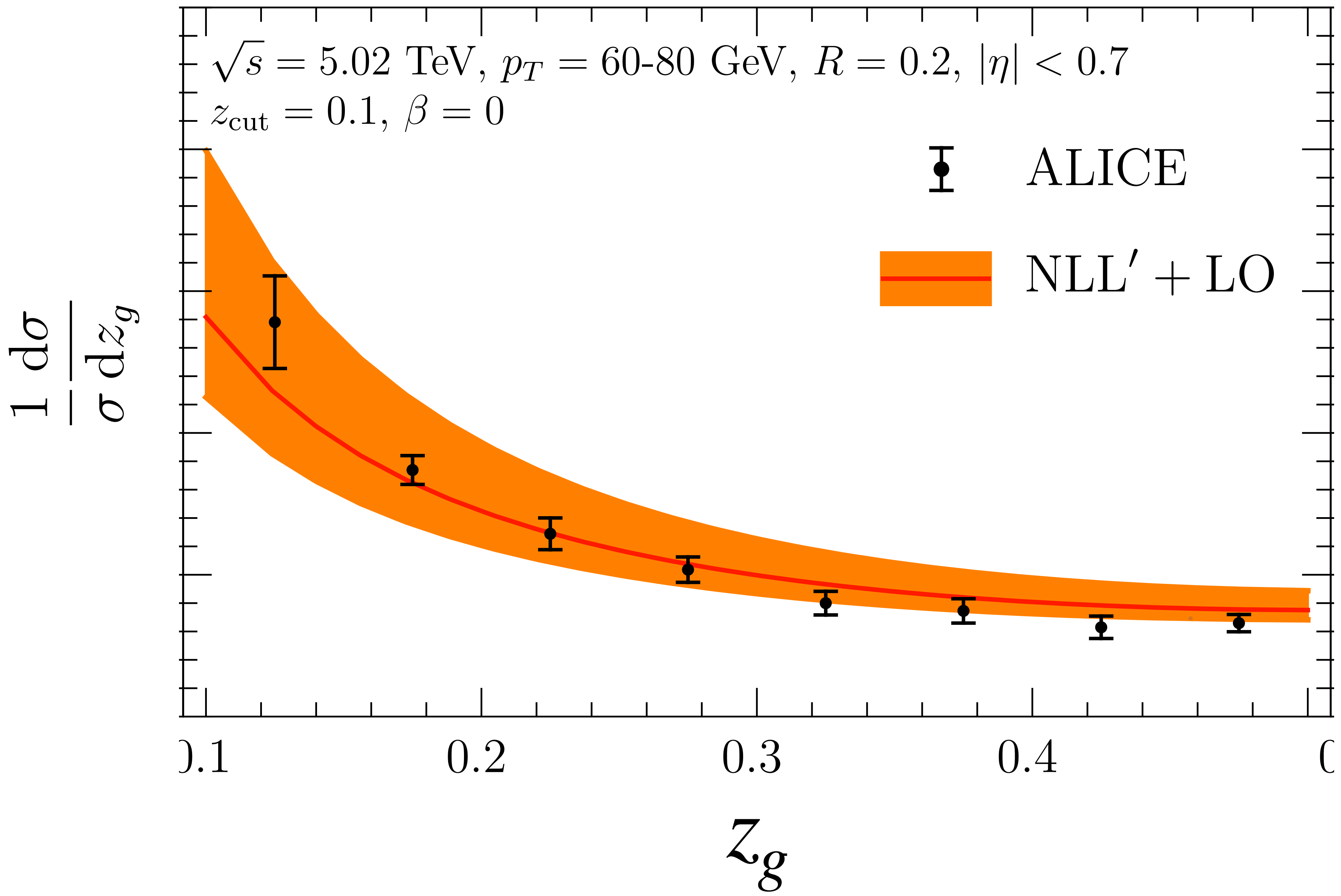
SoftDrop: Splittings that satisfy $z > z_{\text{cut}}\theta^{\beta}$

SoftDrop at LHC: pp

High-pt jets



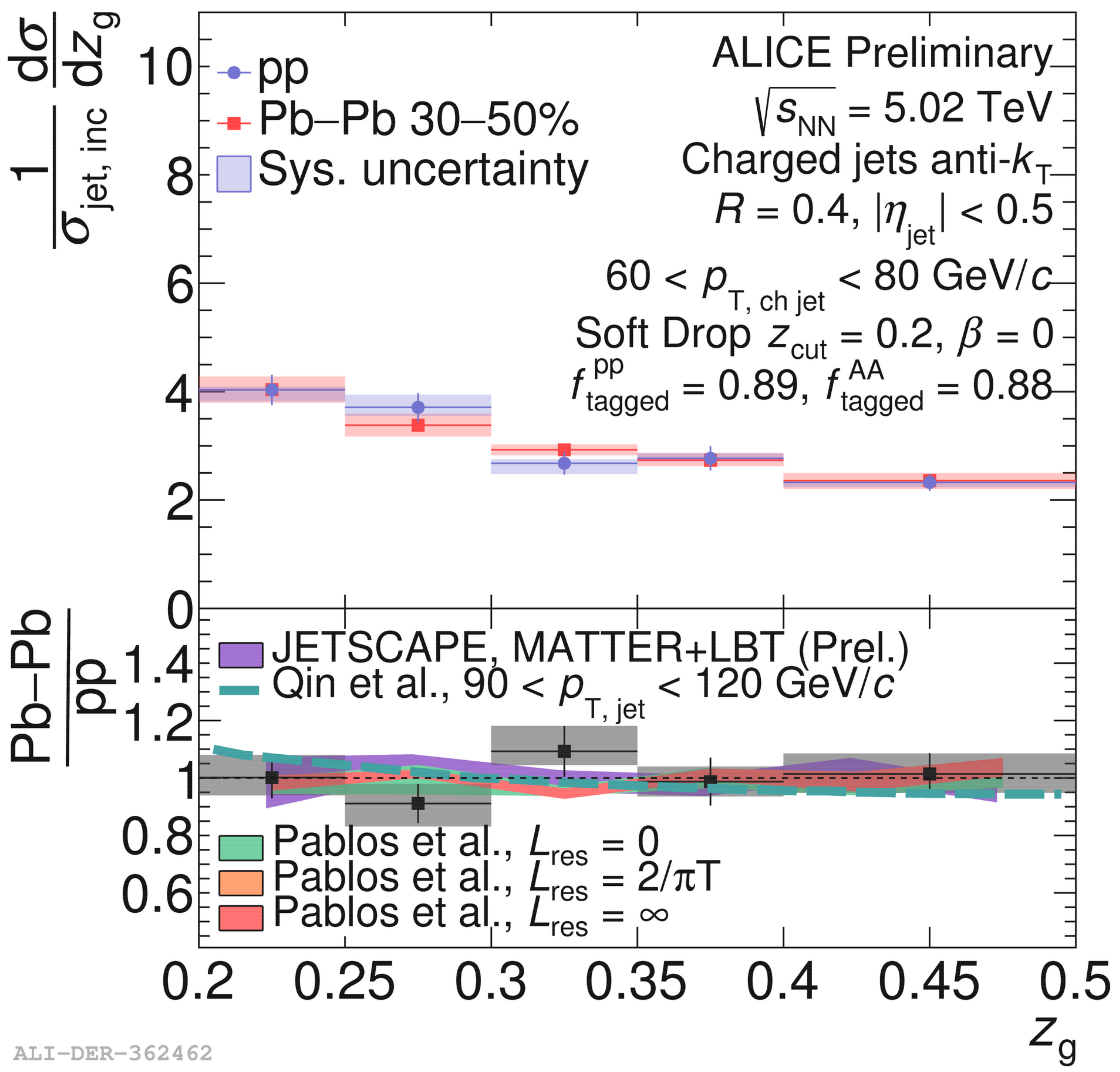
Low-pt jets

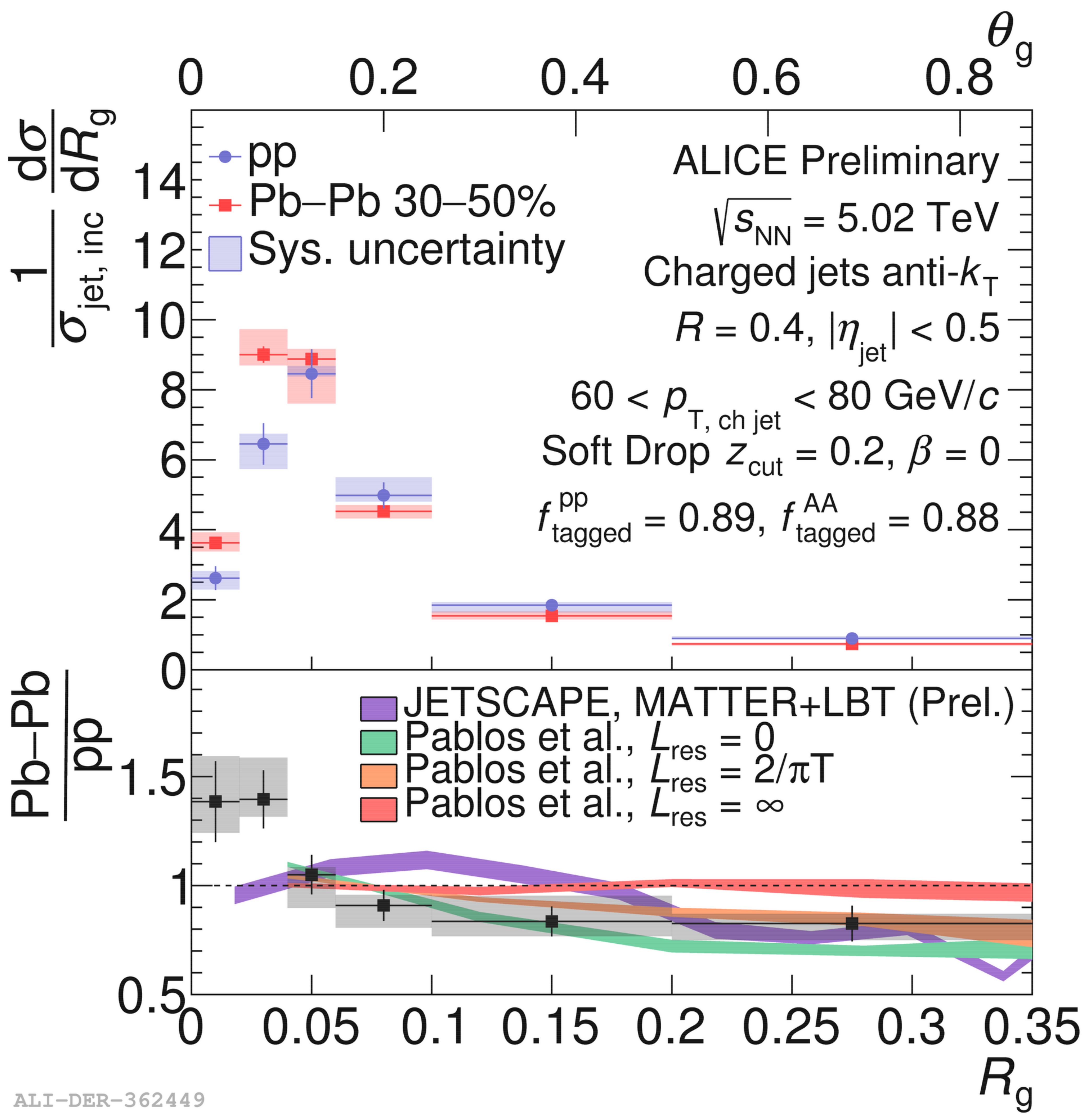


[P.Cal talk at 'Jets and their substructure from LHC data']

Grooming enables theory-to-data comparisons without the need of MCs

SoftDrop at LHC: heavy-ions [2009.07172]

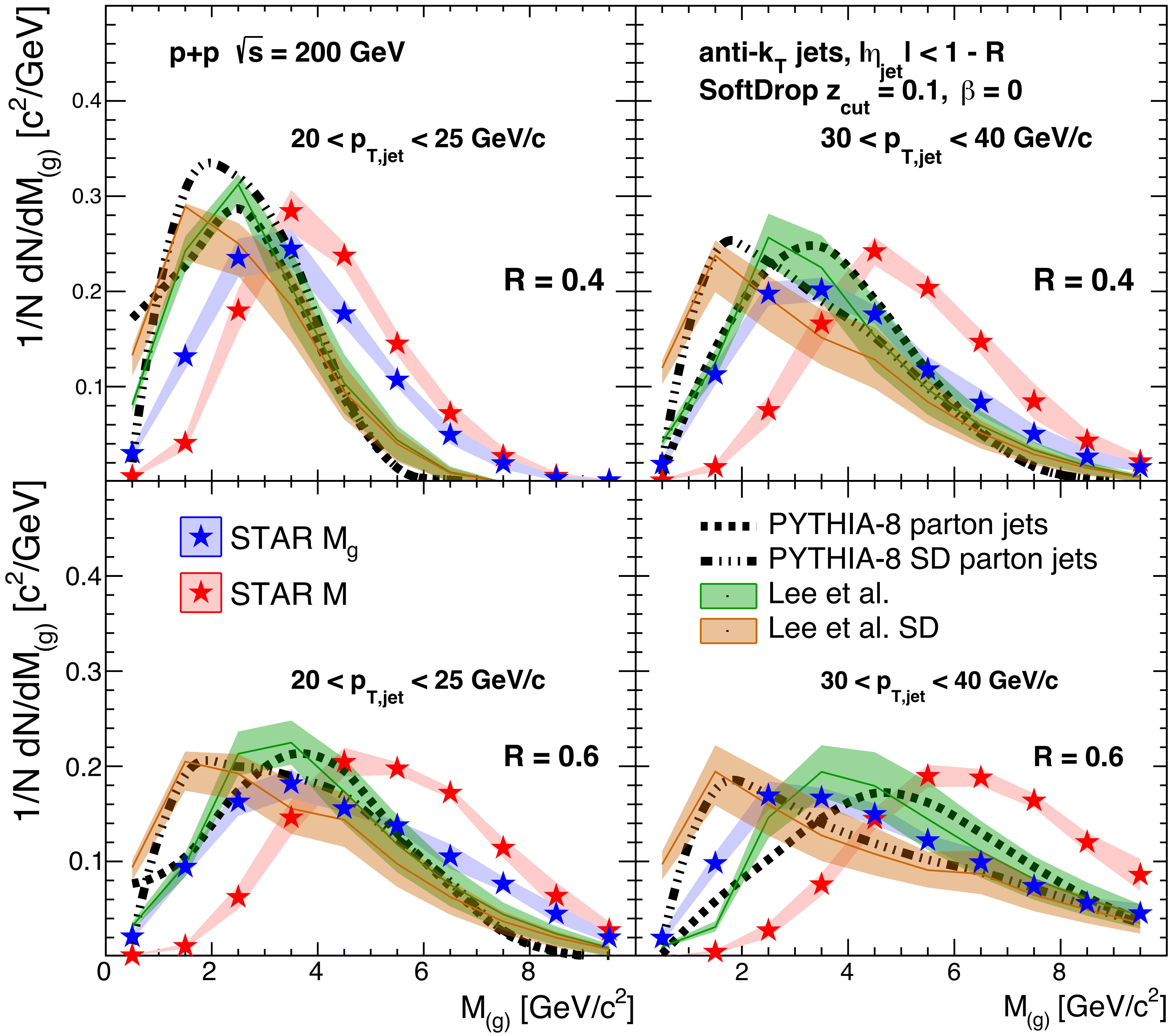


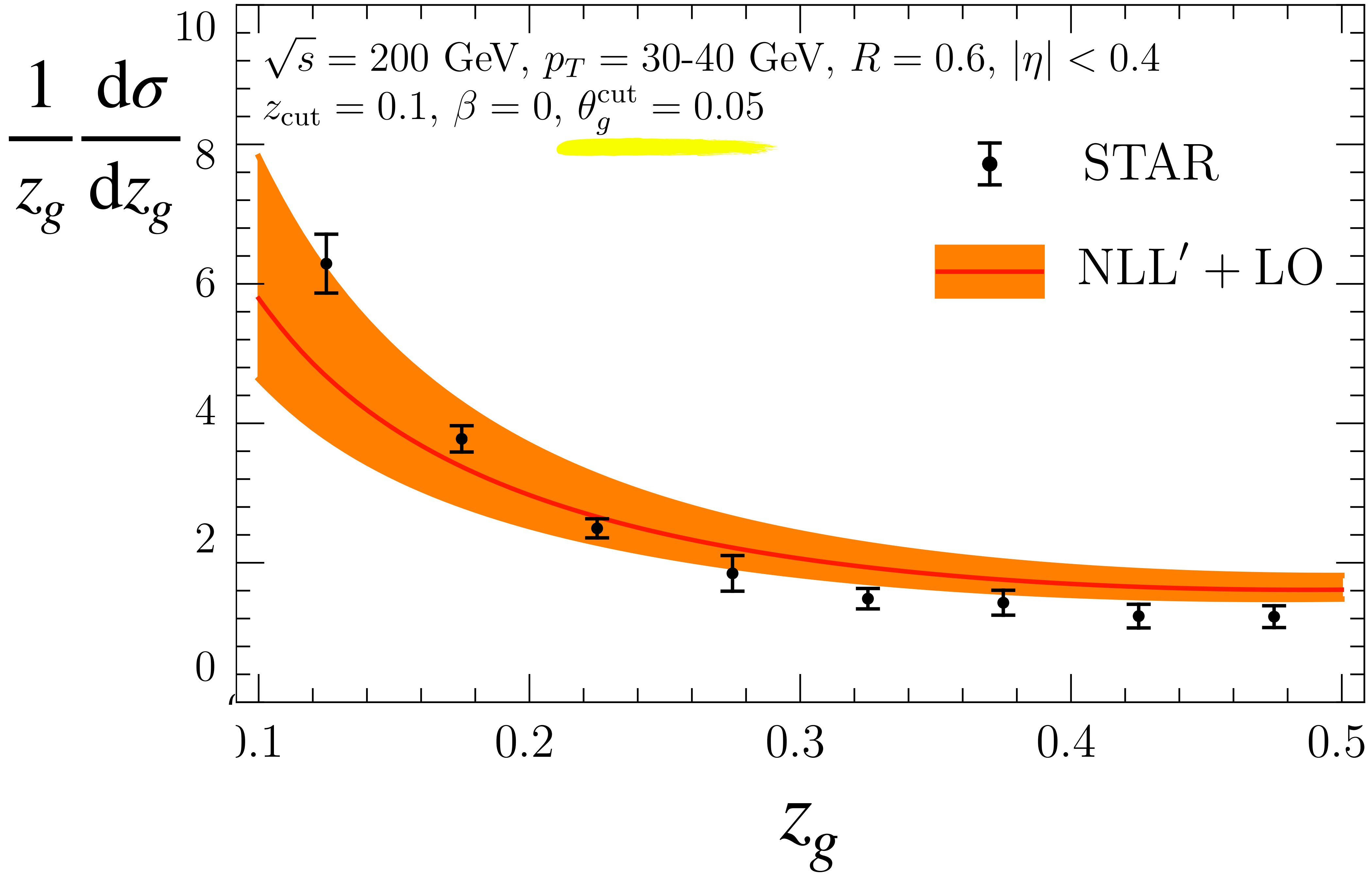


Data does not have enough discriminatory power

SoftDrop at RHIC energies

[2103.13286]

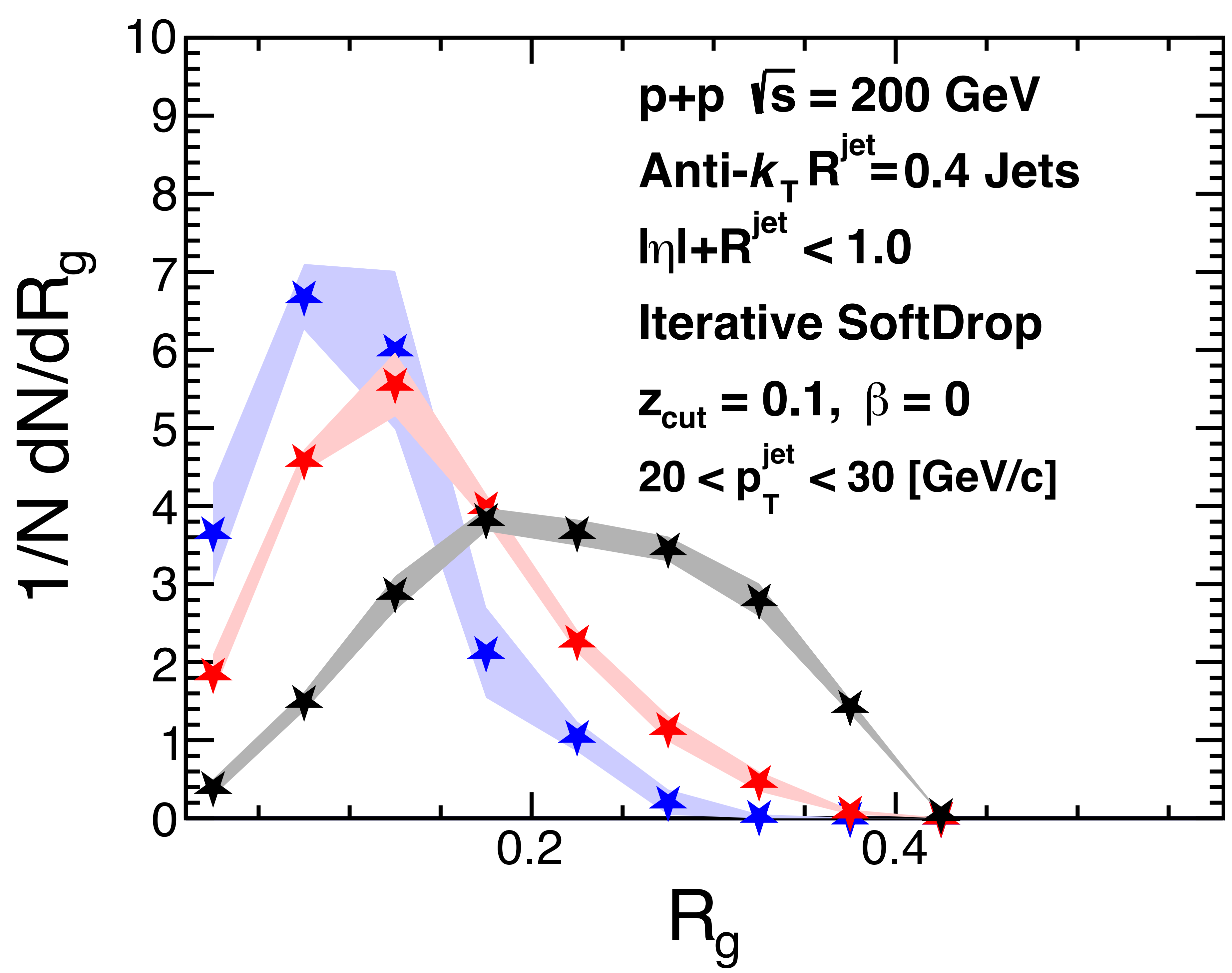




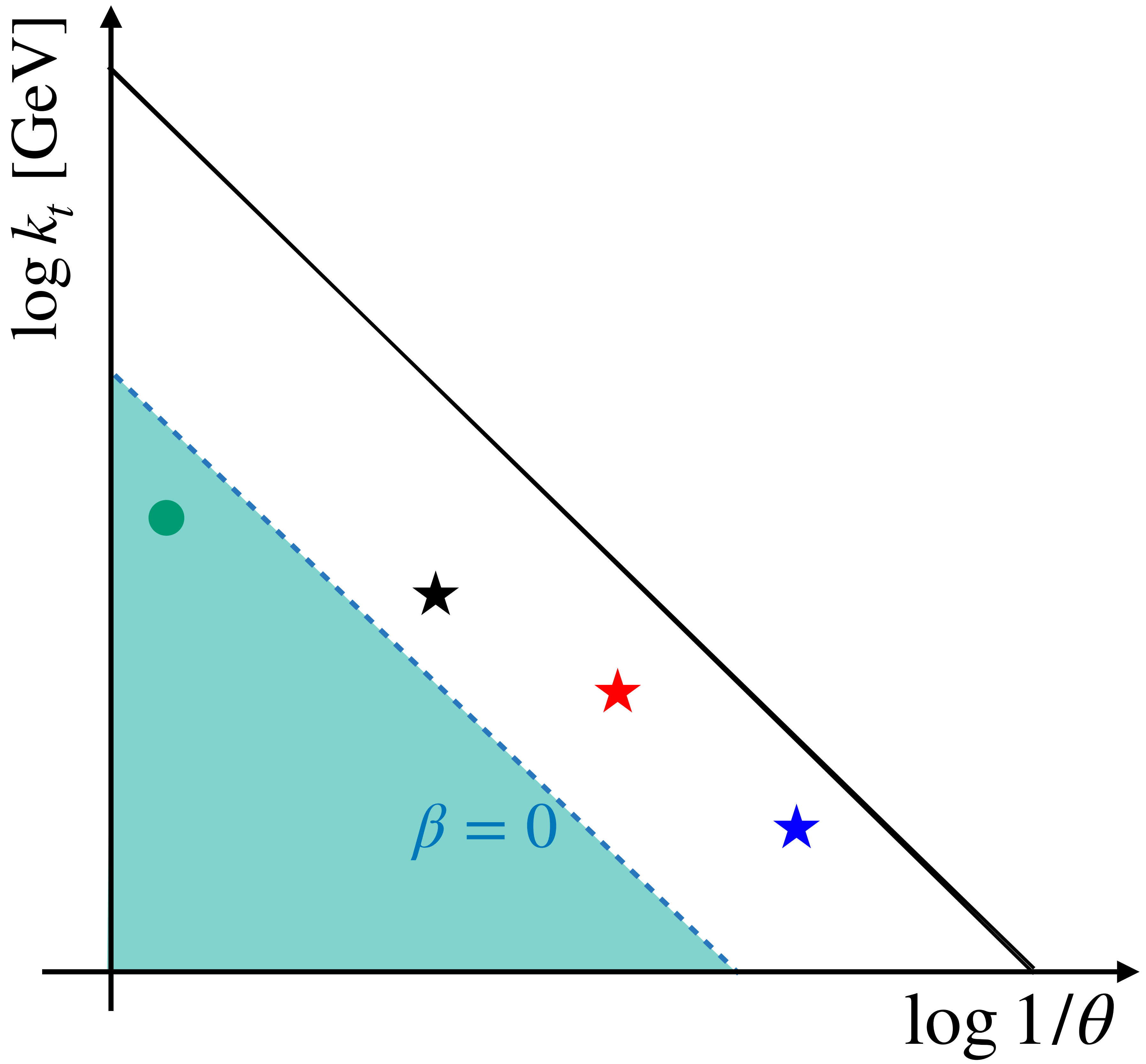
[P.Cal talk at 'Jets and their substructure from LHC data']

Jet substructure as a window into non-perturbative dynamics

Iterative SoftDrop at RHIC energies

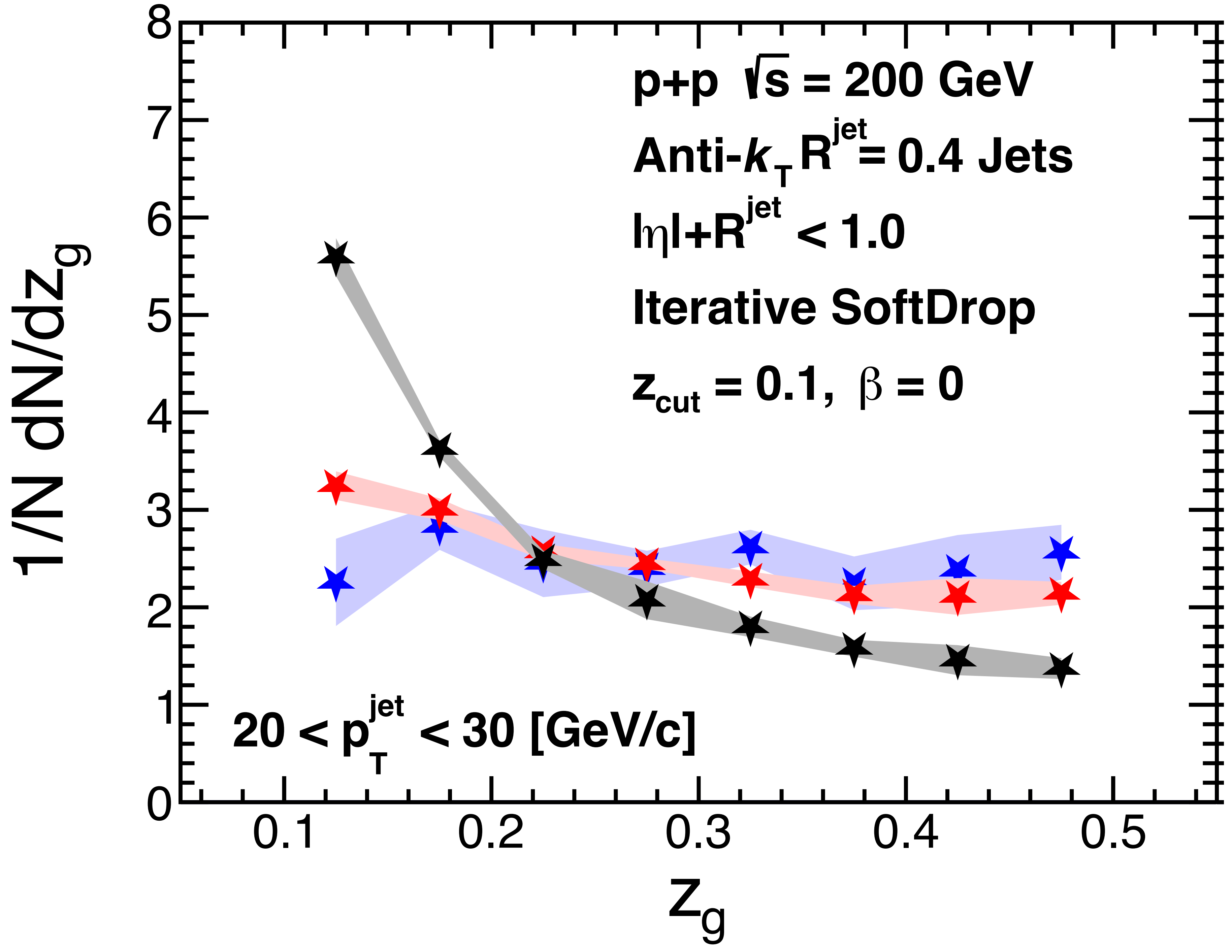


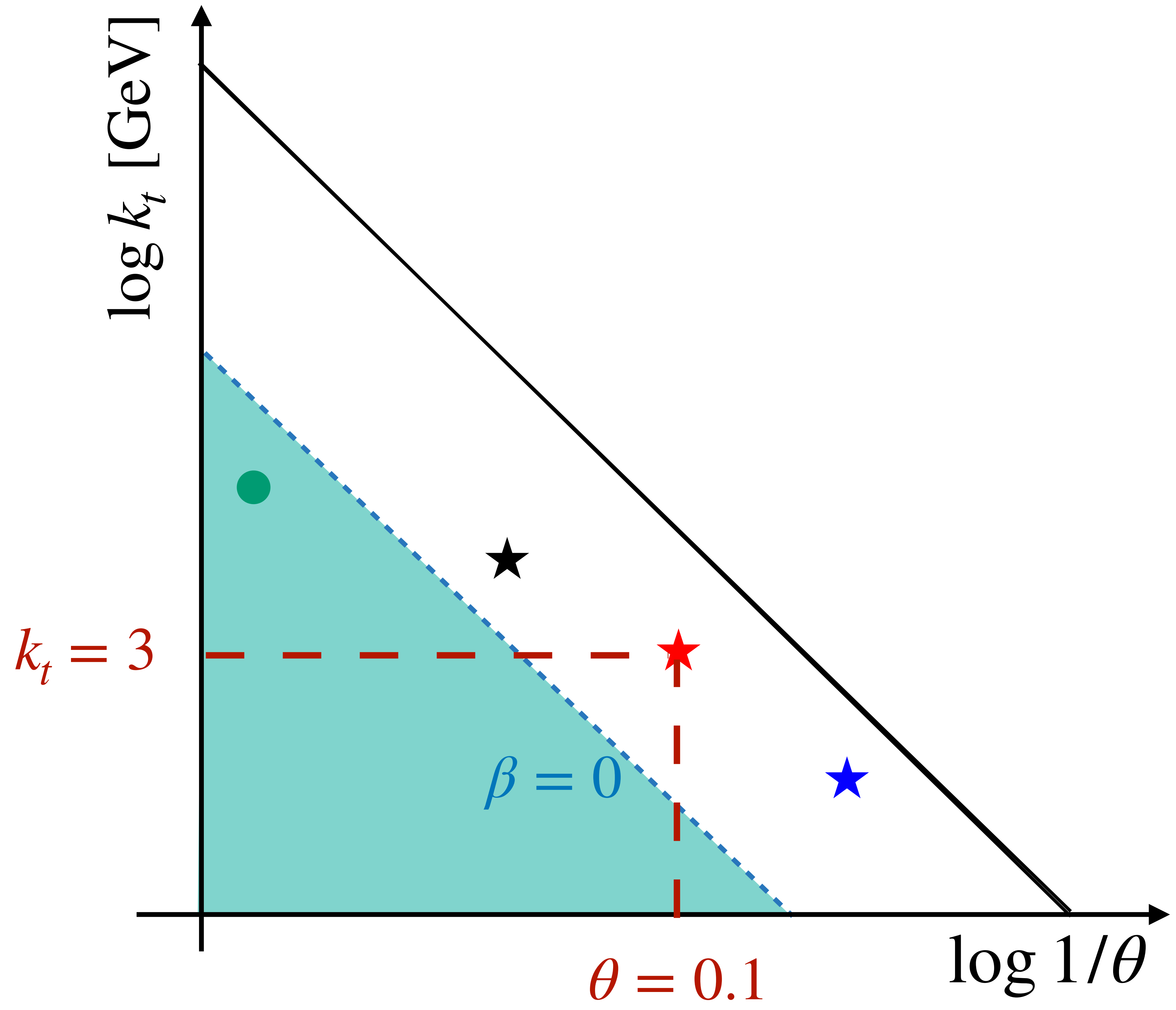
[R.Kunnawalkam Elayavalli and M. Robotkova Talks at 'DIS 2021']



Expected narrowing as due to the Cambridge/Aachen algo

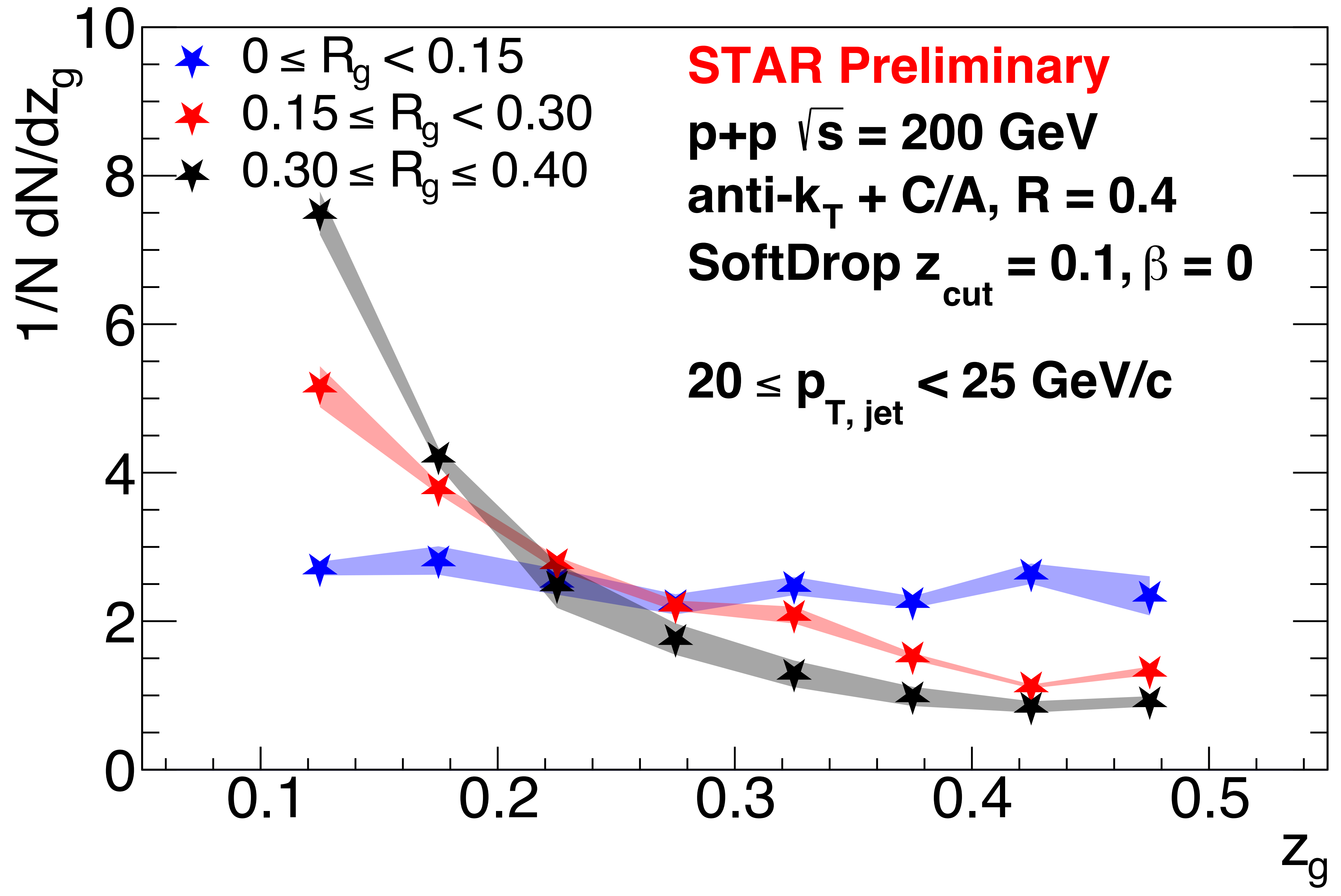
Iterative SoftDrop at RHIC energies

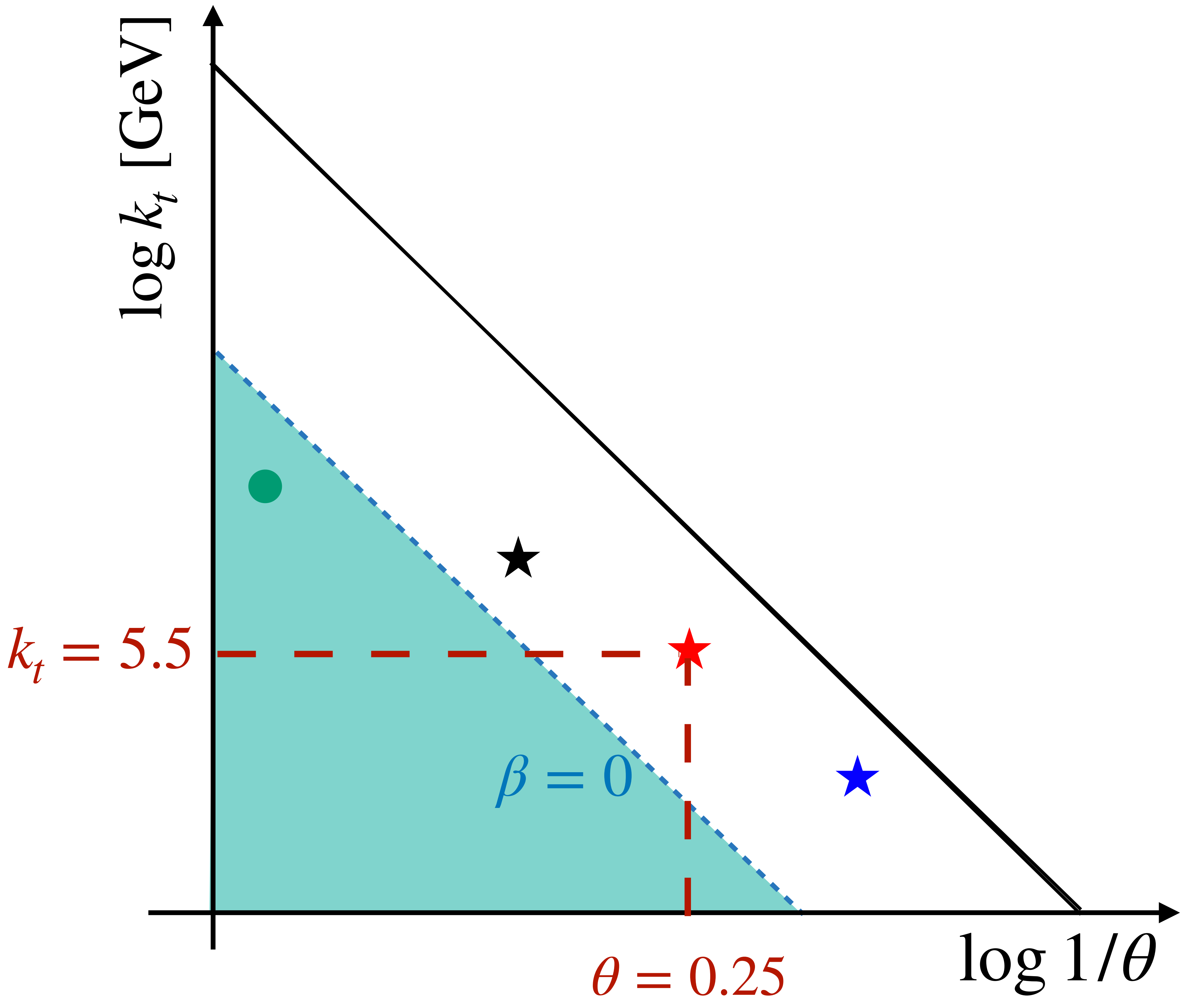




Observable dominated by non-perturbative dynamics

Iterative SoftDrop at RHIC energies





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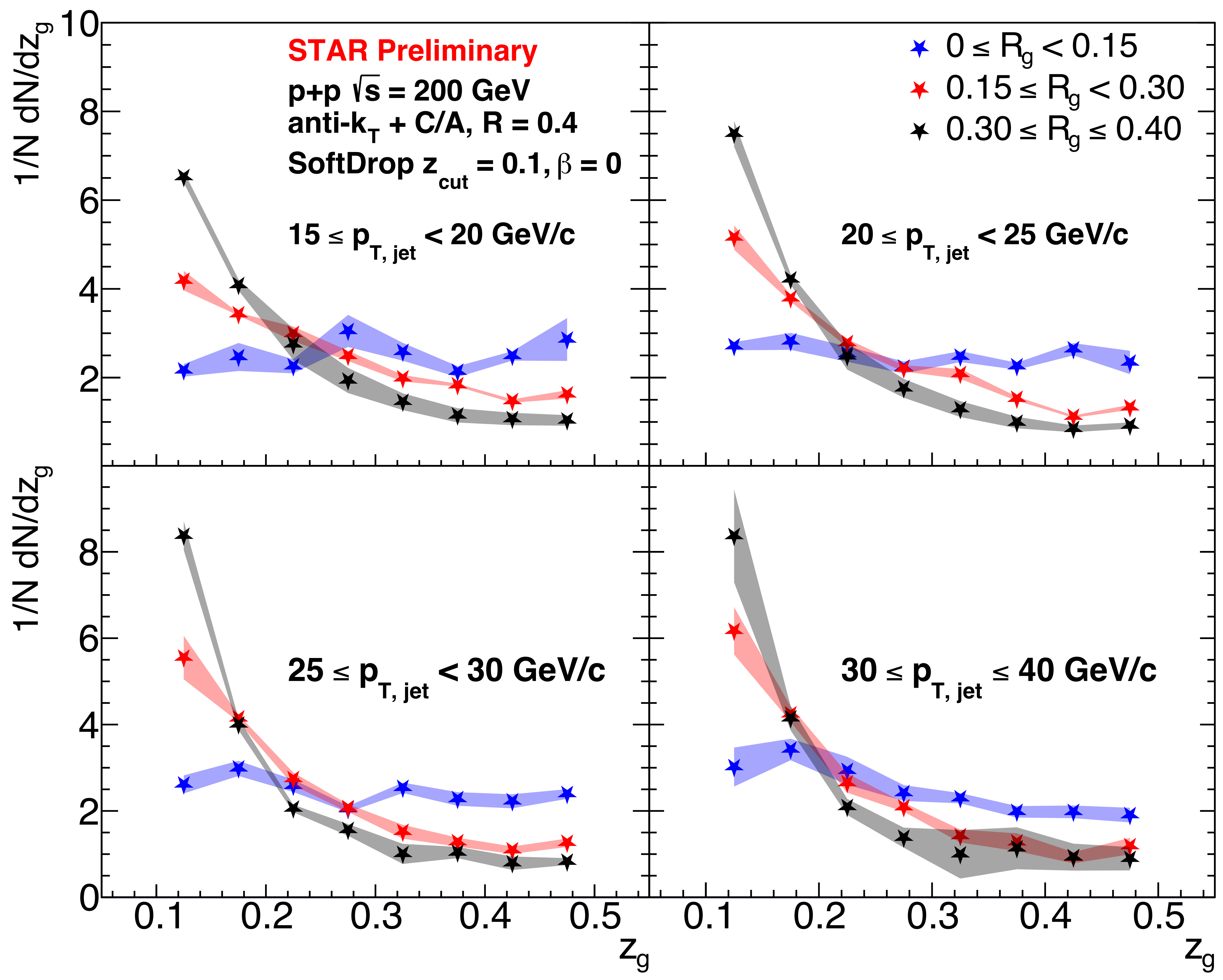
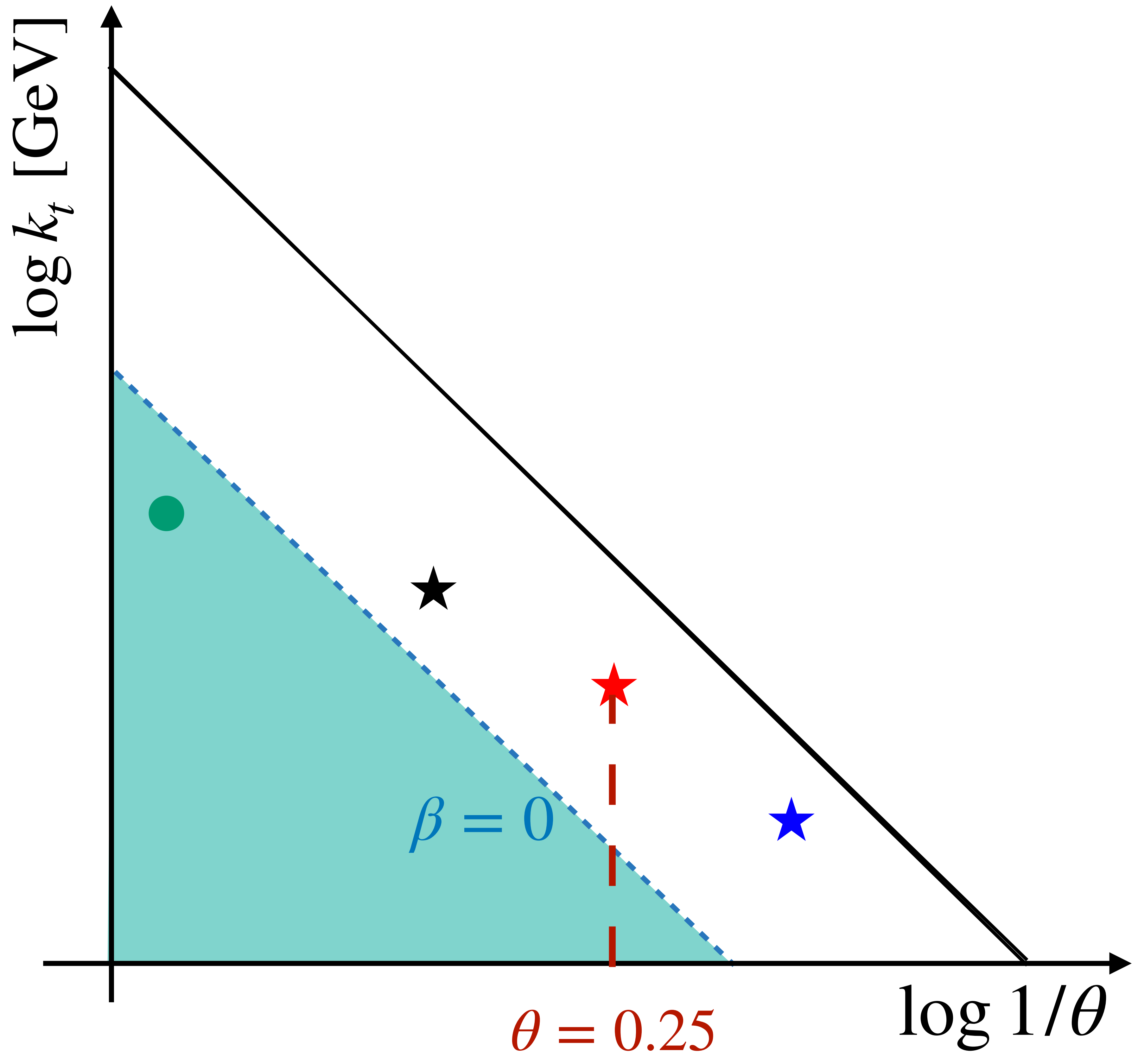
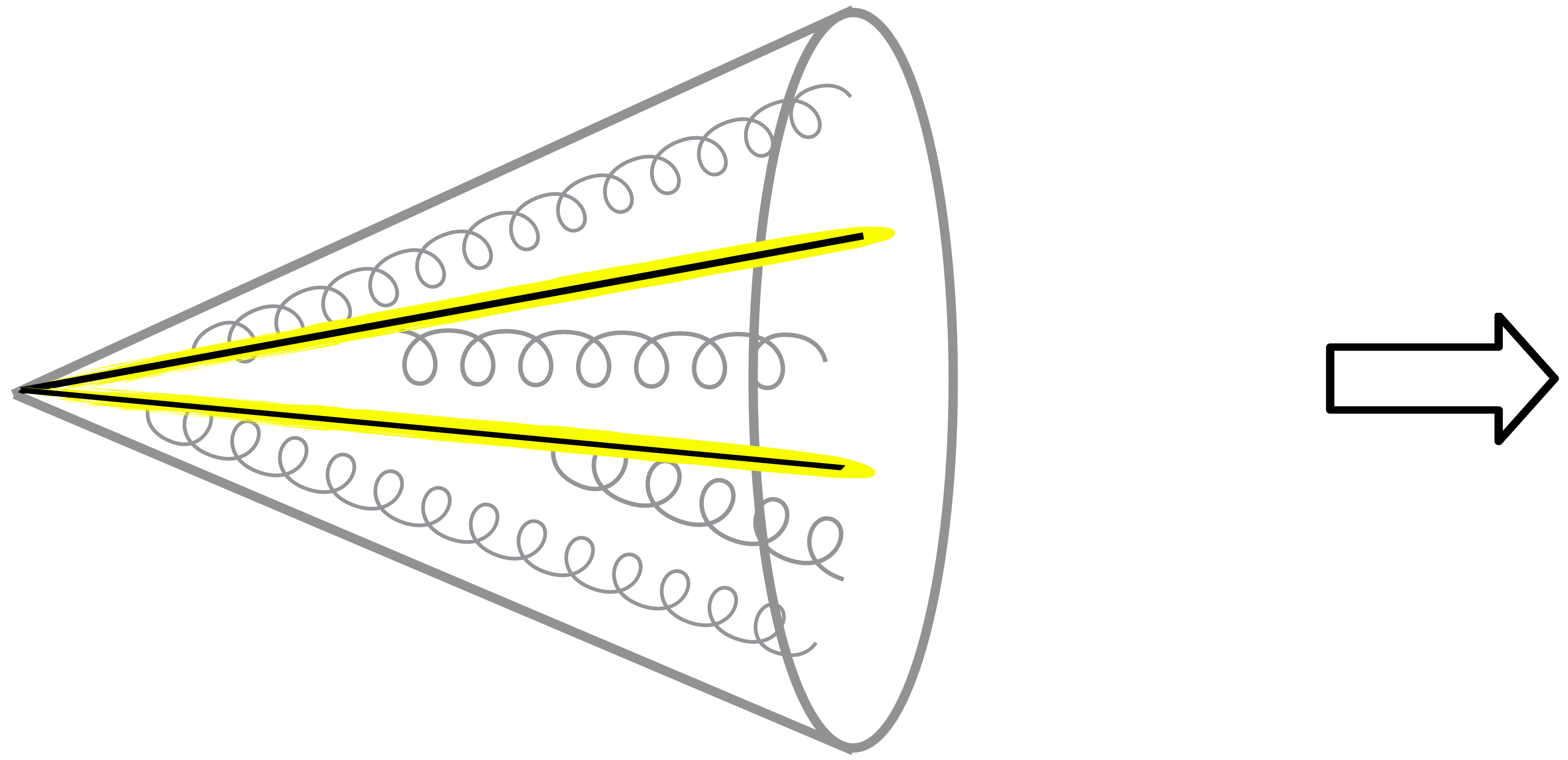
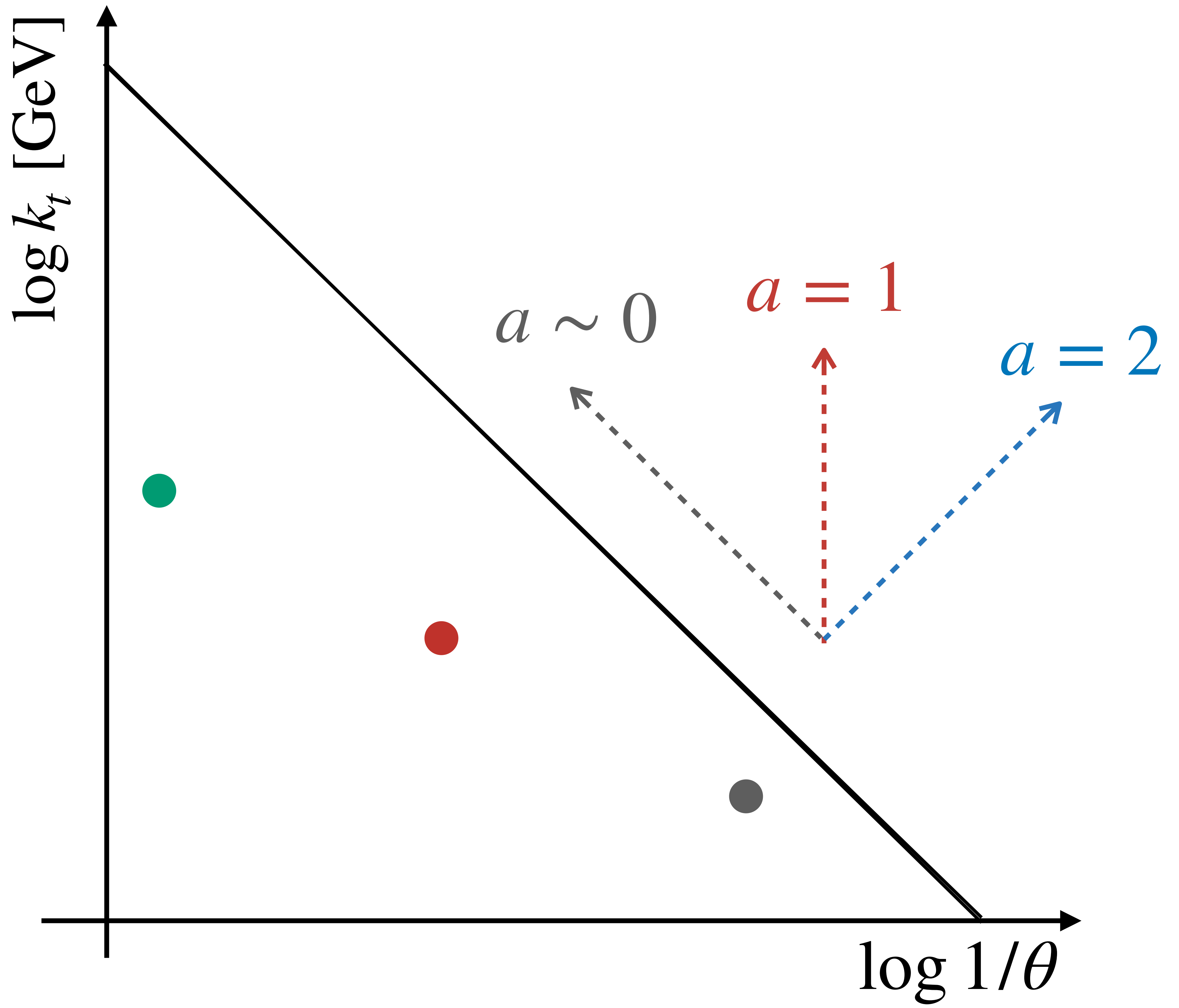




$P(z_g) \sim 1/z_g$ recovered when raising the jet p_t

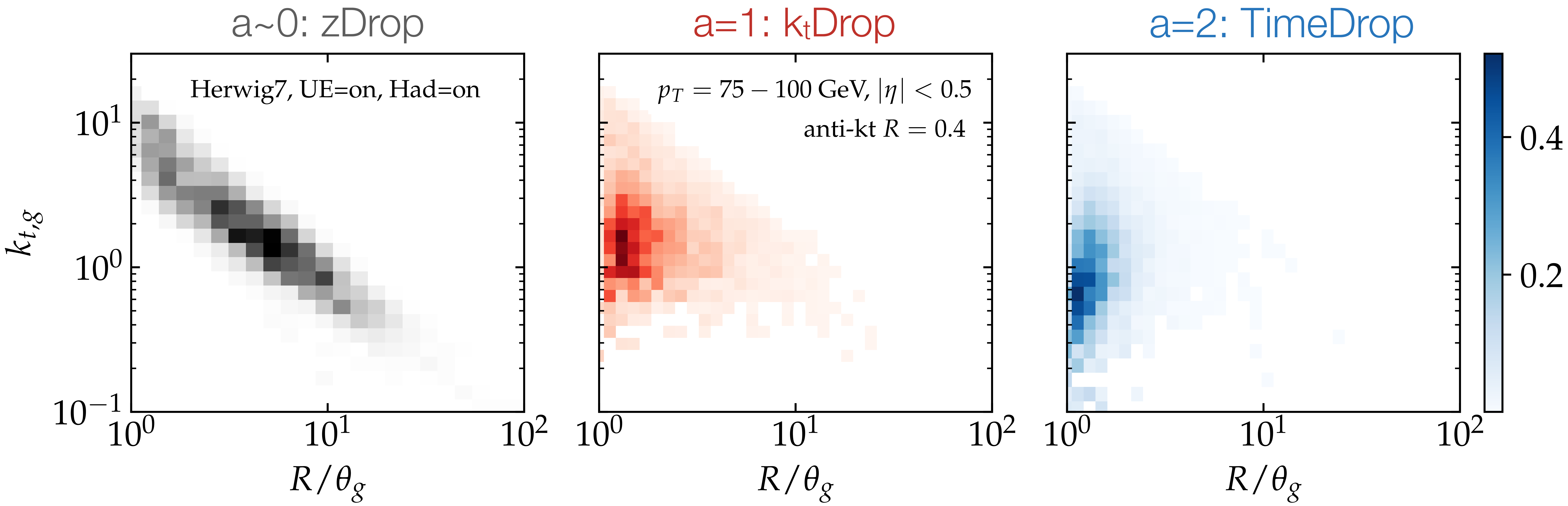
Dynamical grooming [Mehtar-Tani, ASO, Tywoniuk 1911.00375, 2005.07584]





Dynamical grooming: Hardest splitting $\kappa^{(a)} = \frac{1}{p_T} \max_{i \in \mathrm{C/A}} z_i(1 - z_i) p_{T,i} (\theta_i / R)^a$

Dynamical grooming: primary Lund Jet Plane



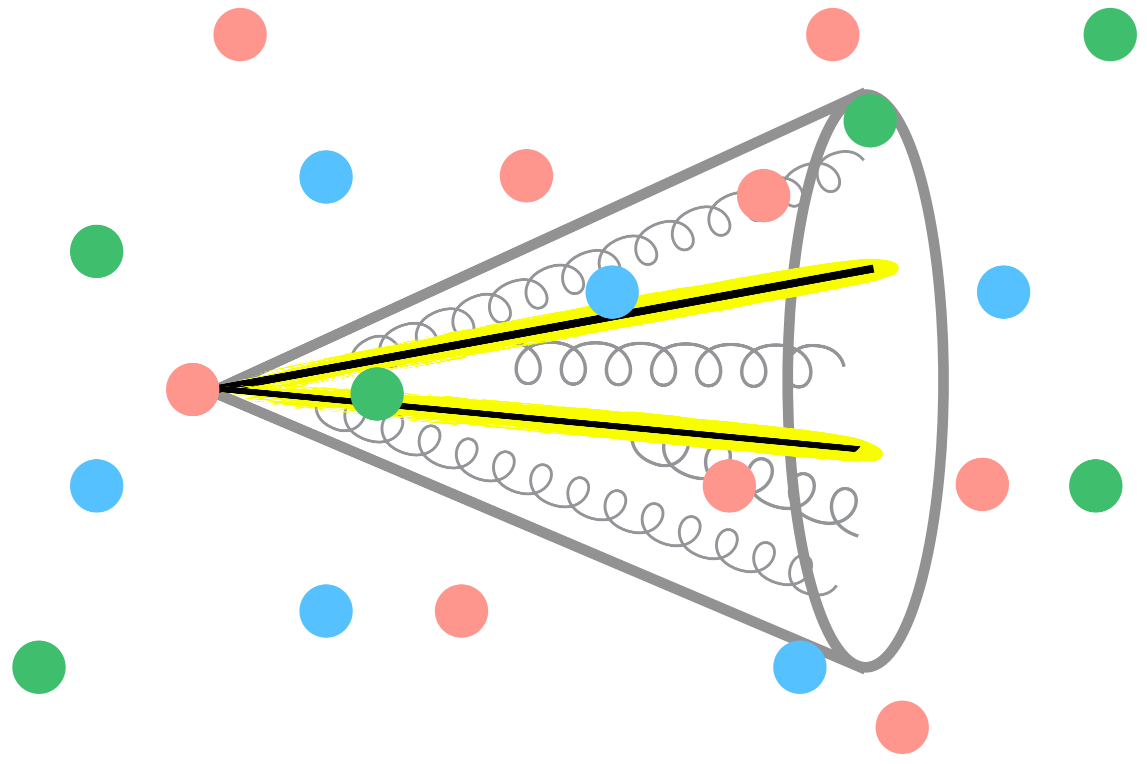
Grooming condition auto-generated on a jet-by-jet basis

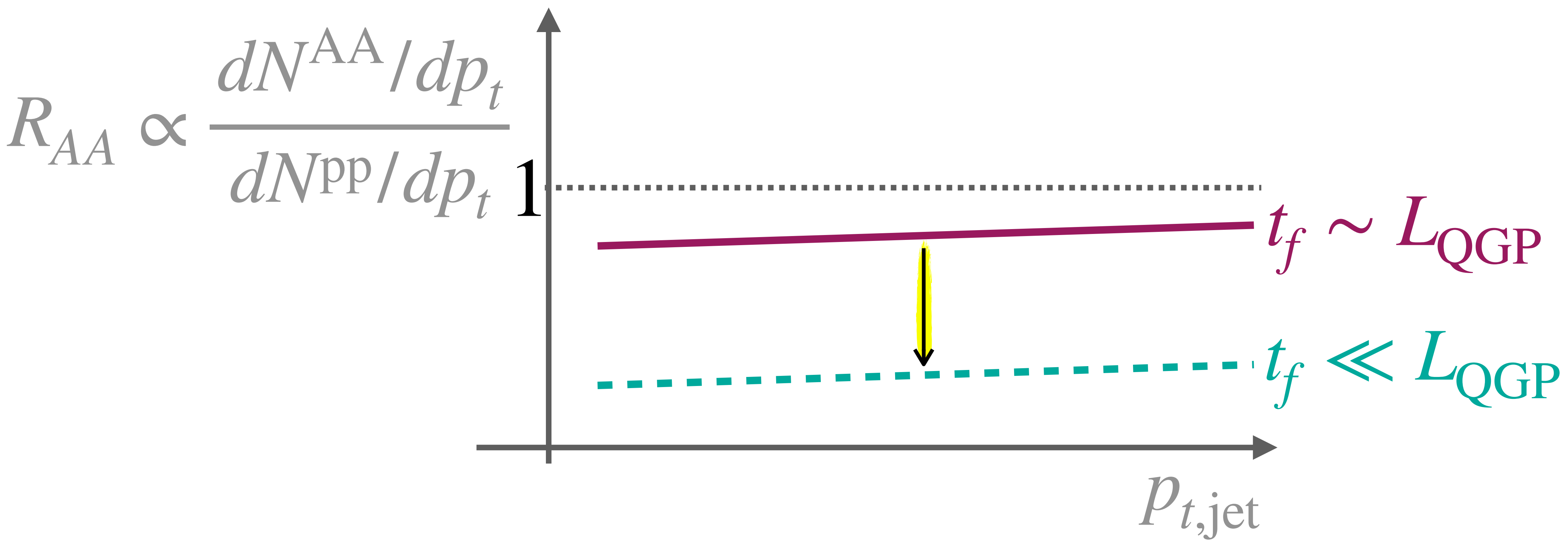
DyG: motivation from a heavy-ions perspective

Accessing the spatio-temporal evolution of the Quark Gluon plasma

a Early vs. late splittings with TimeDrop

[See also Apolinário et al. 2012.02199]





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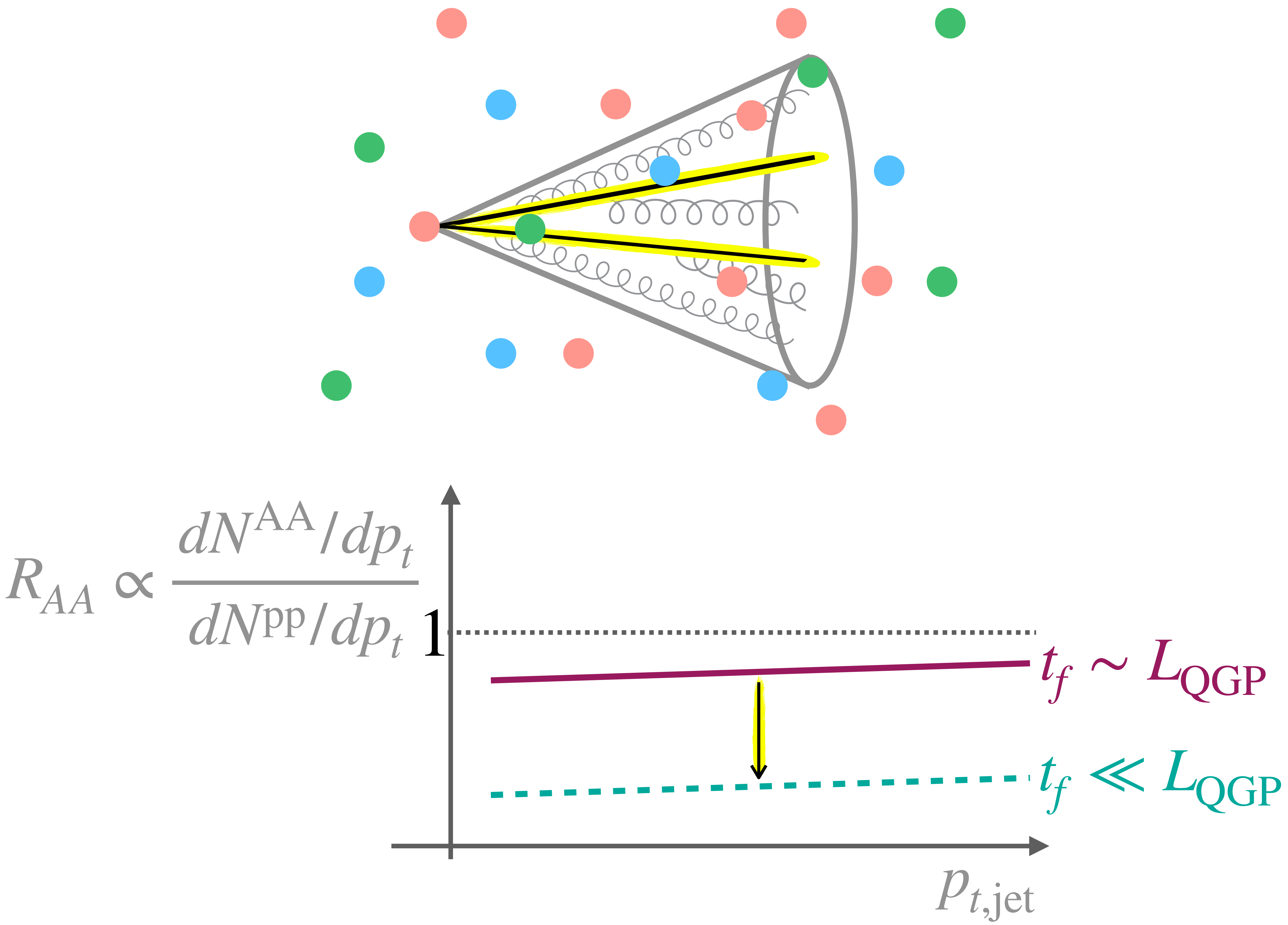
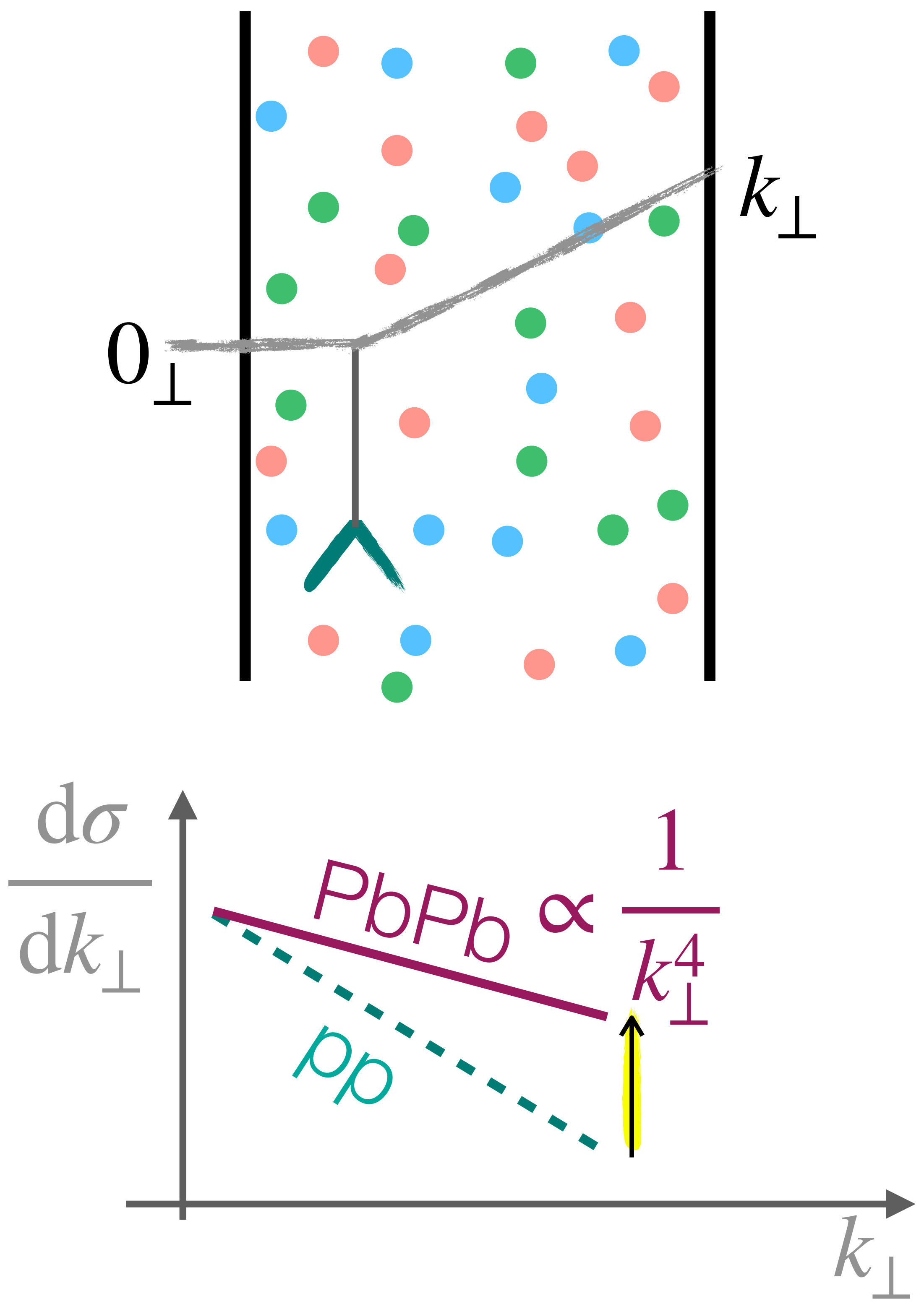


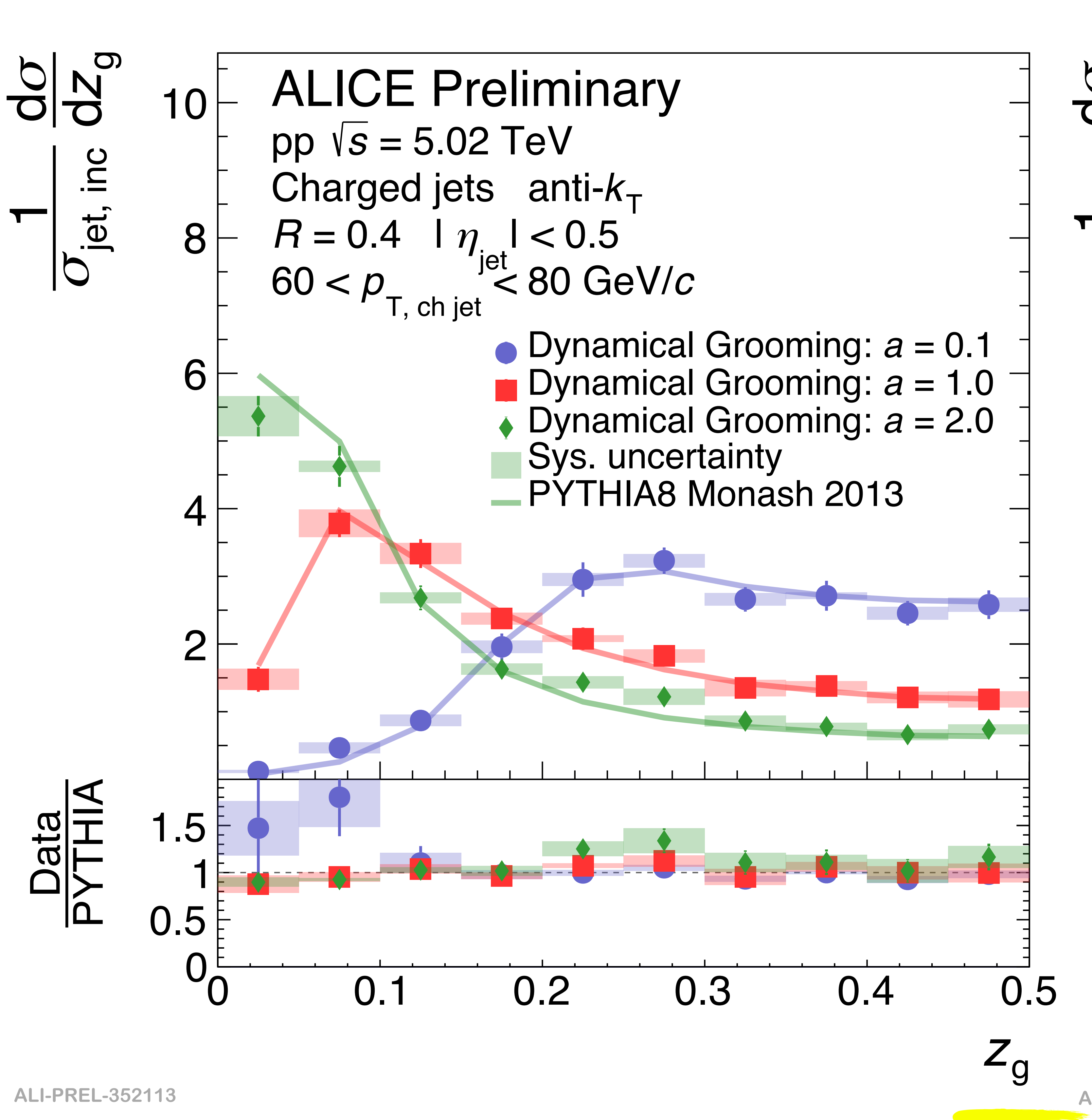
b Molière scattering with k_tDrop

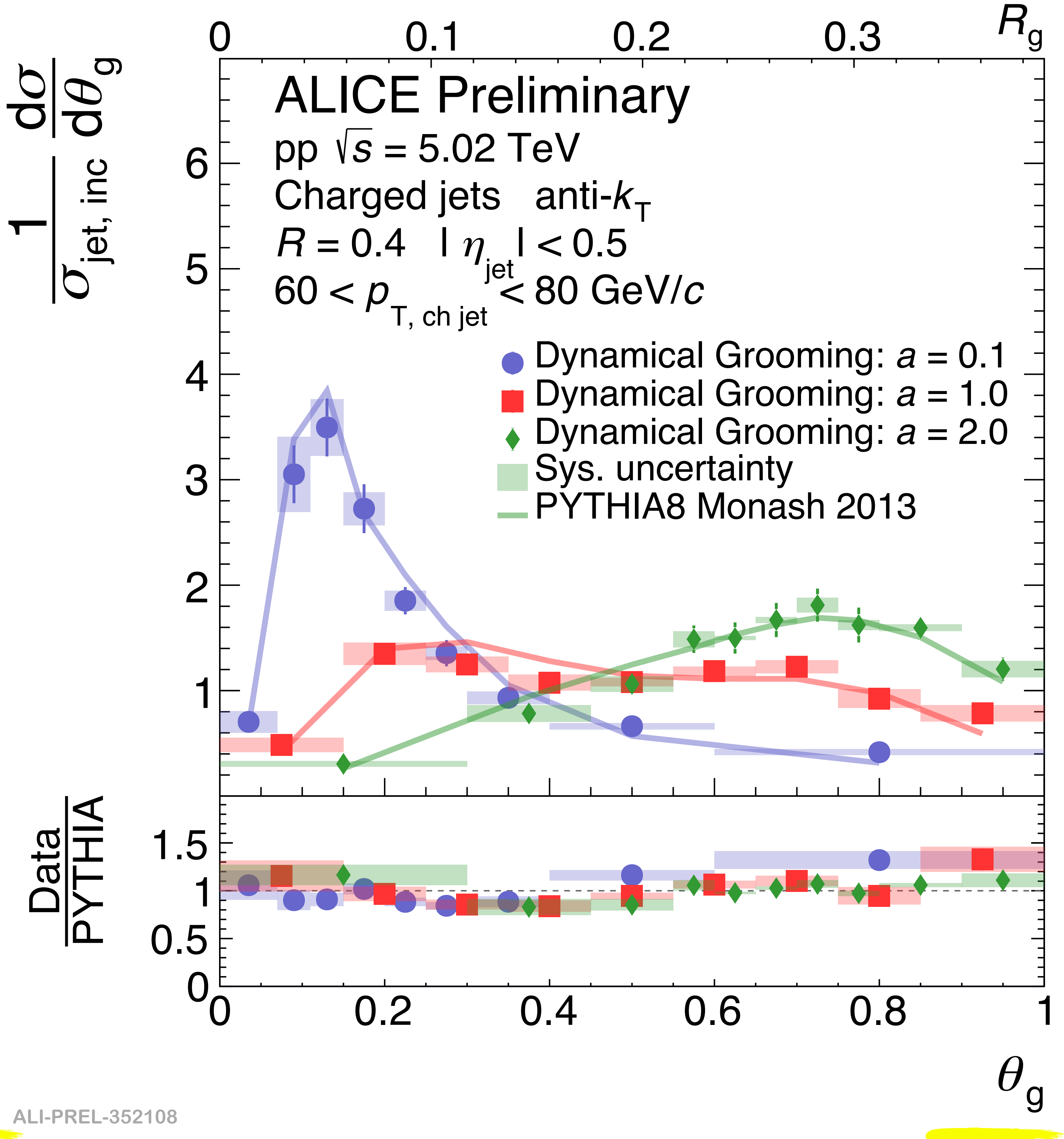
[See also d'Eramo et al.1211.1922]

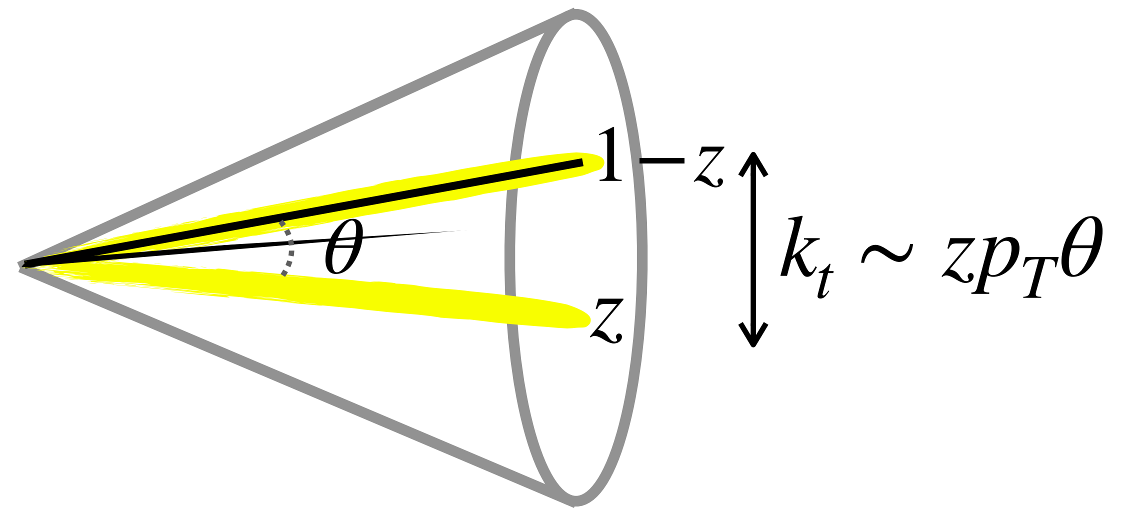


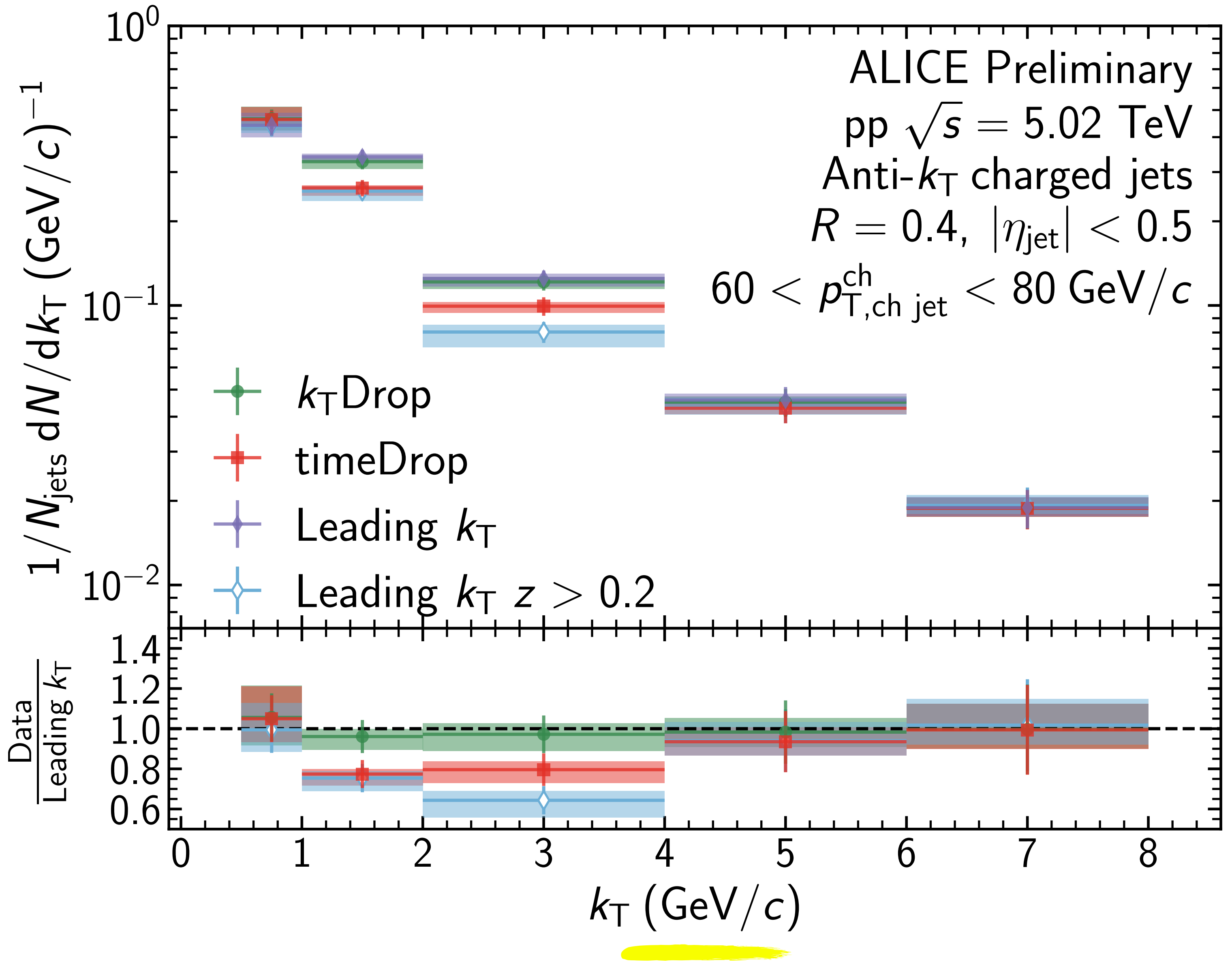
First measurements by the ALICE Collaboration

[2009.07172, 2009.12247]



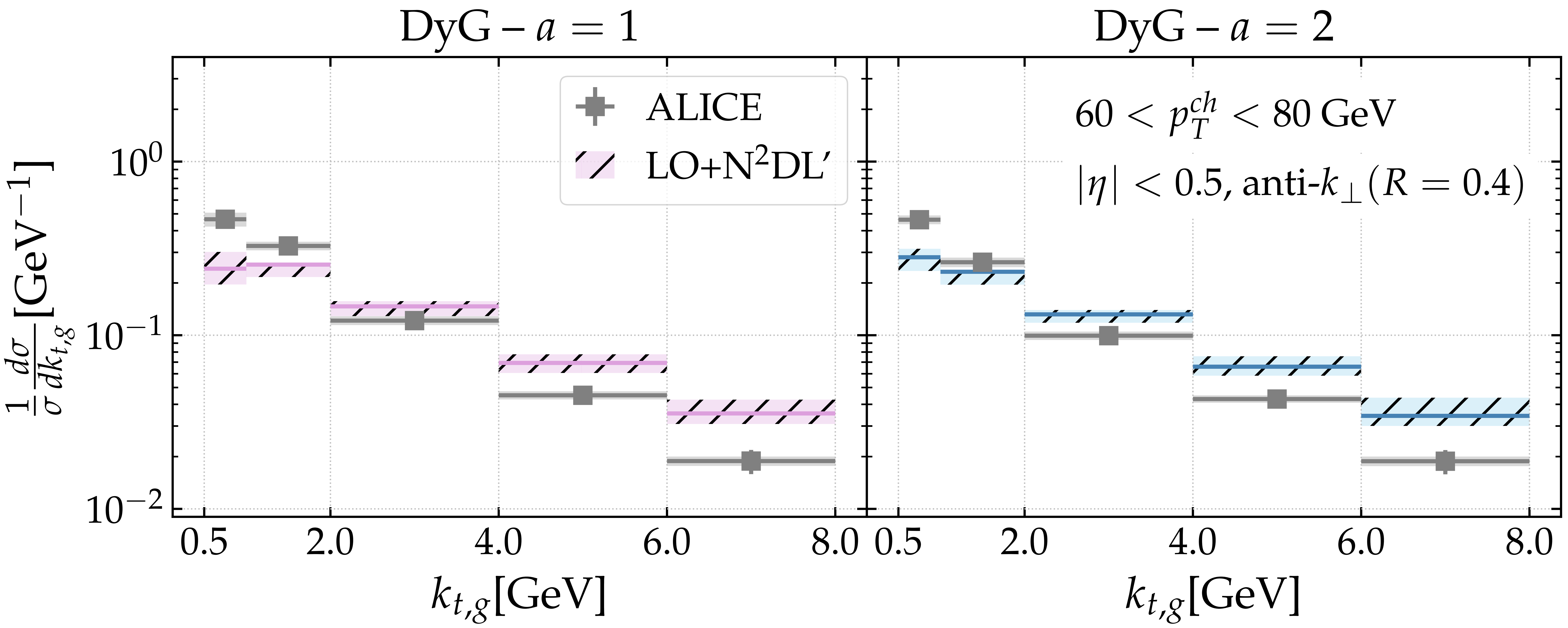






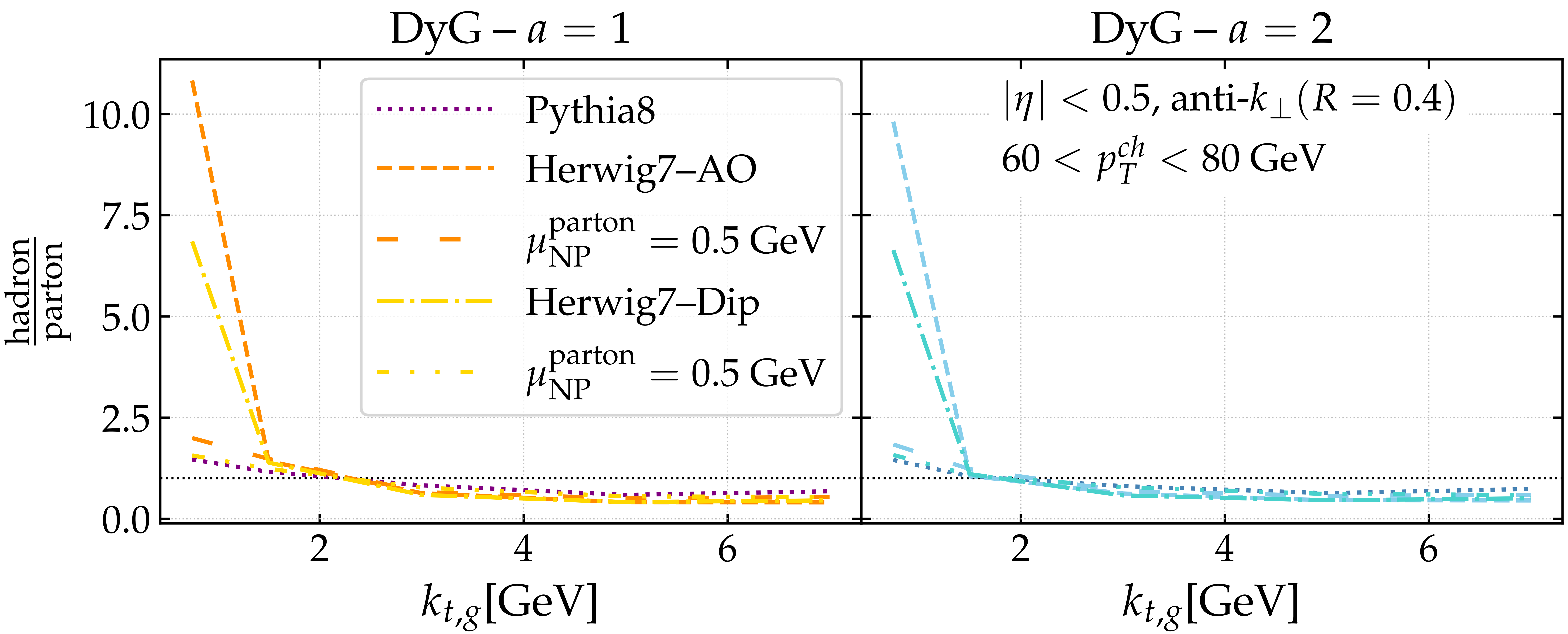
Goal: describe this data through pQCD techniques

LO+NNDL comparison to data [Caucal, ASO, Takacs 2103.06566]



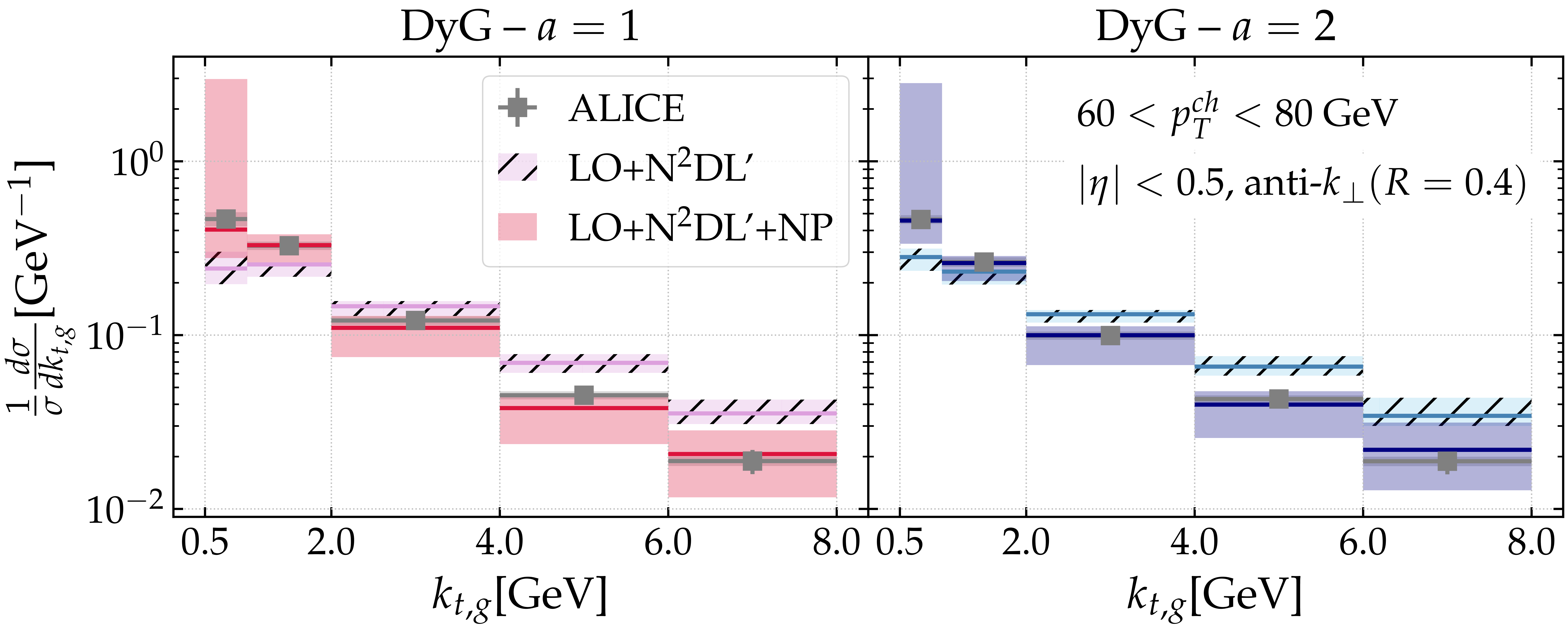
Not quite there yet…

Non-perturbative corrections



Strong sensitivity to the infra-red cutoff, i.e. $\alpha_s(\mu_{NP})=0$ of the parton shower

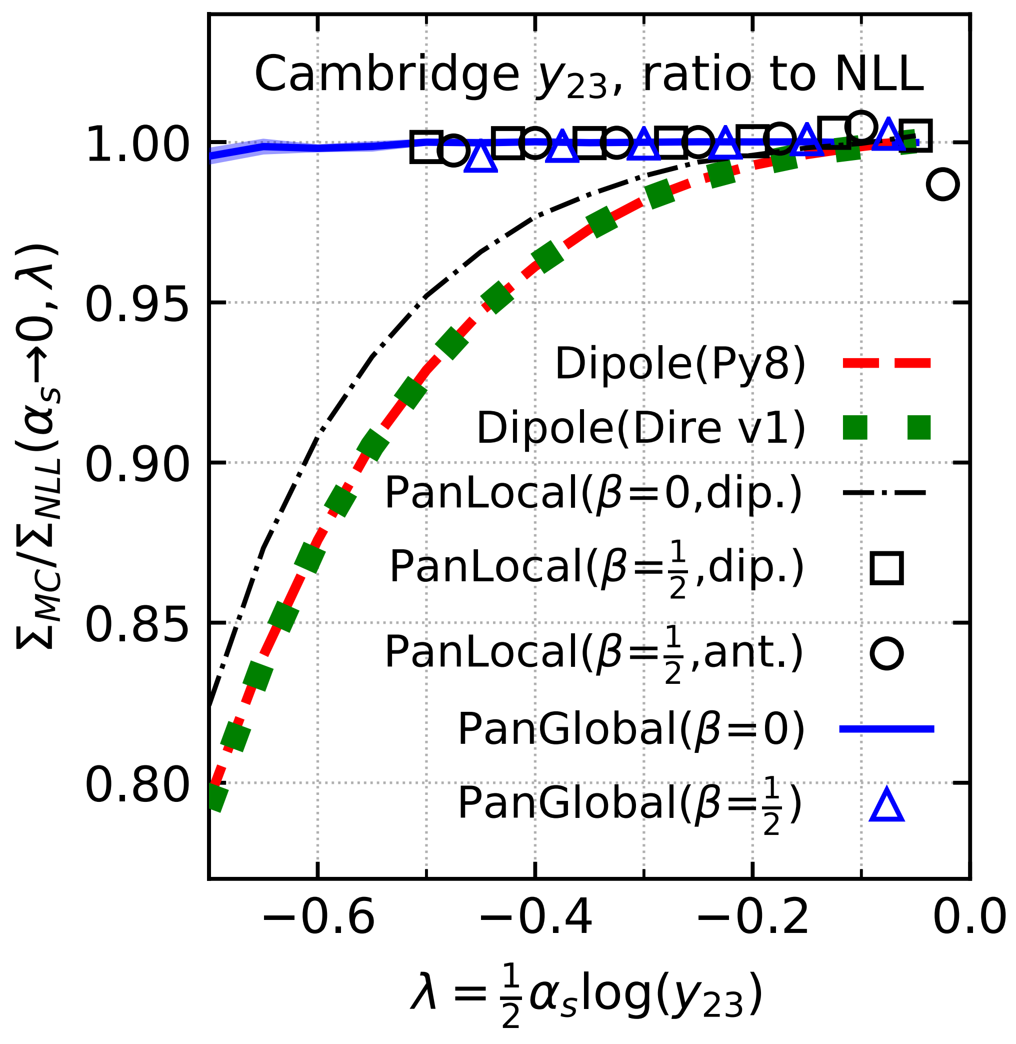
LO+NNDL+NP comparison to data

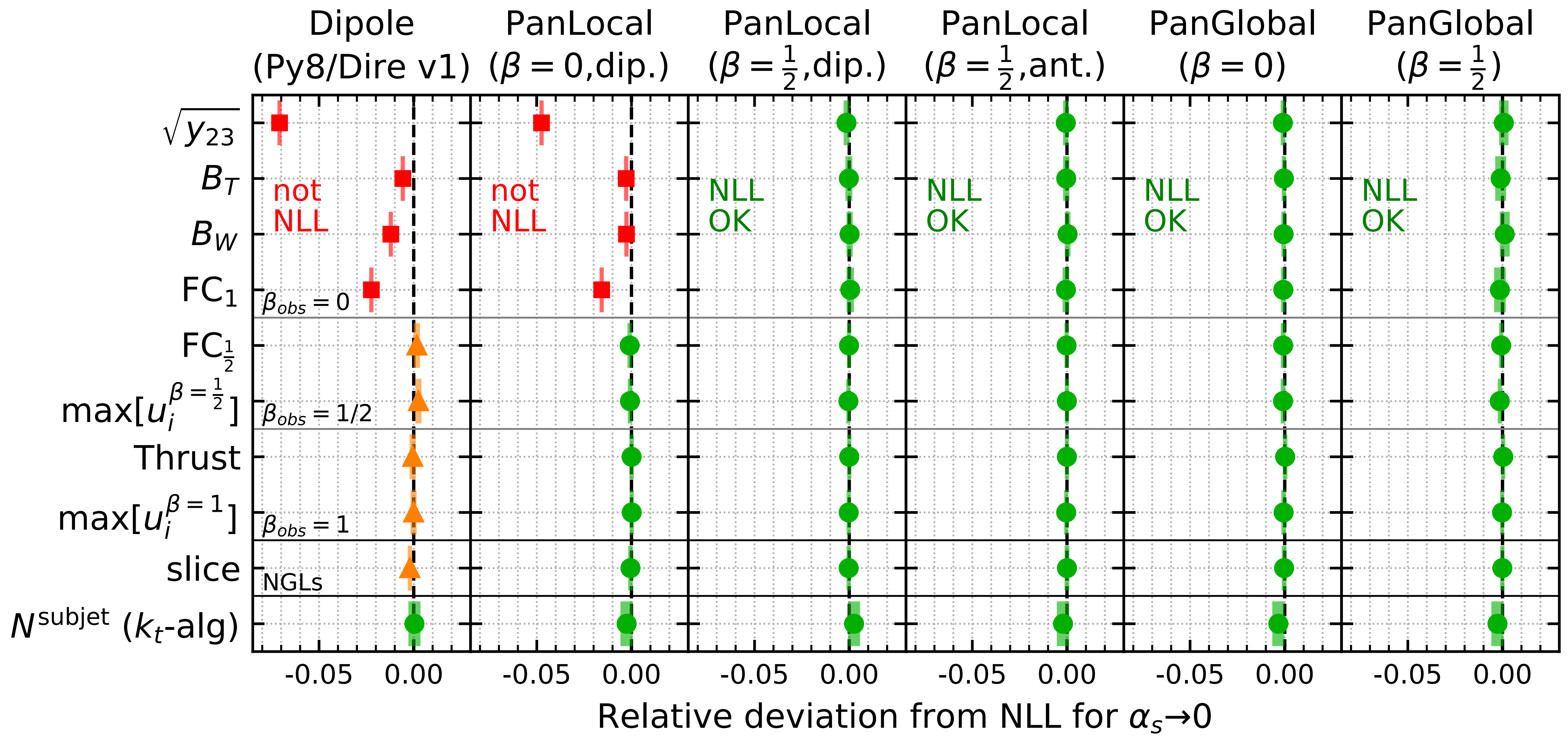


Very good agreement (< 5% deviations) when including NP effects

The road ahead

- In vacuum, jet substructure as tool to gauge the accuracy of parton showers





[Dasgupta et al. PRL 125 (2020)]

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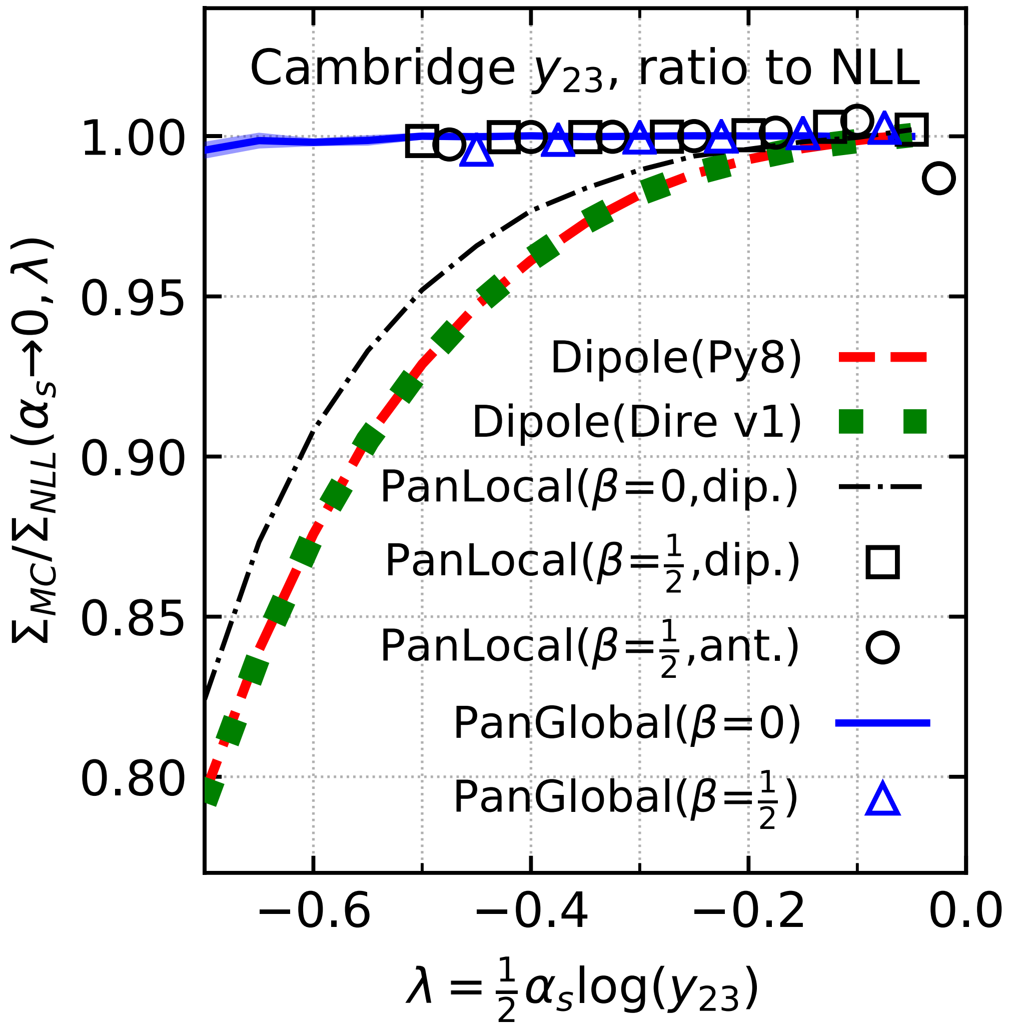

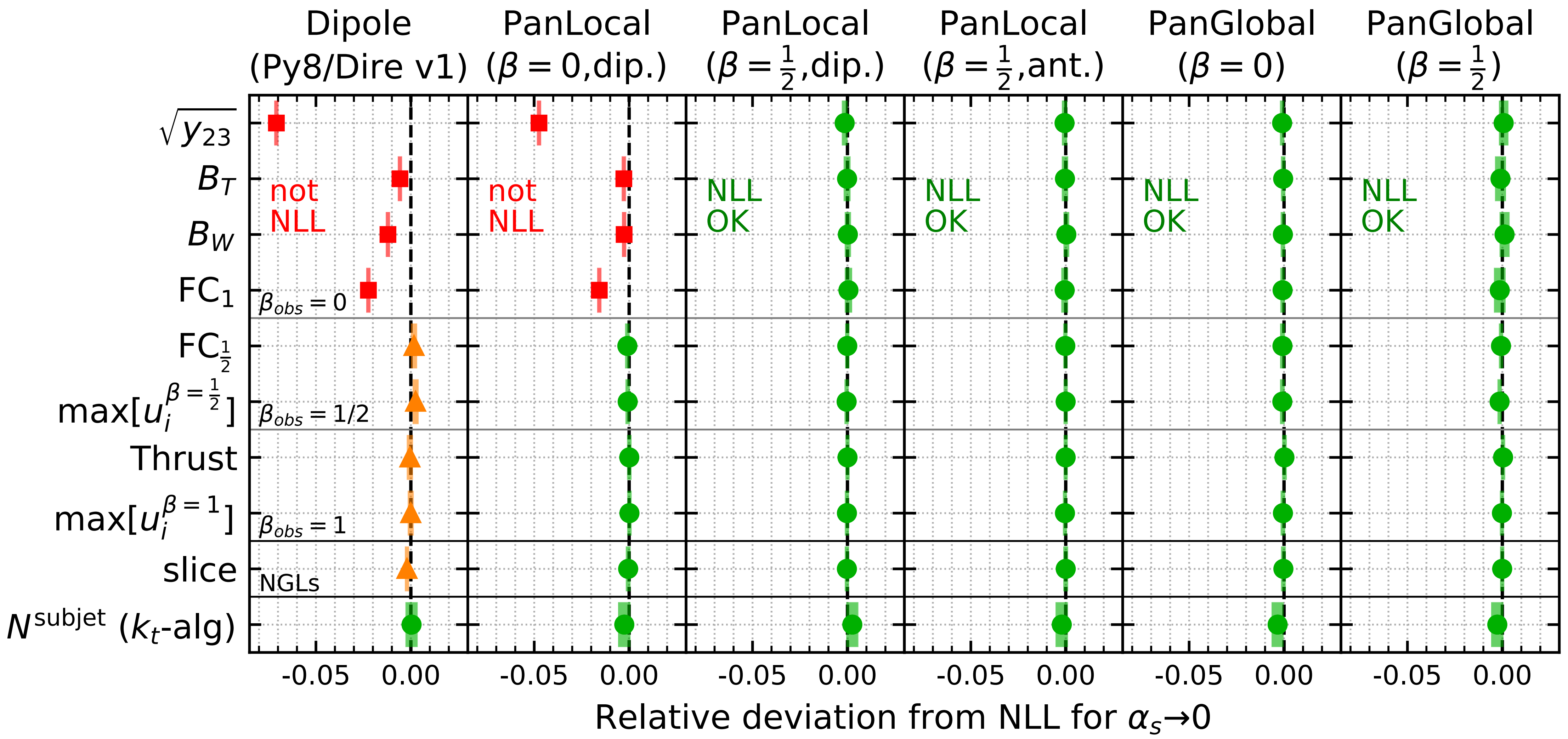

[Dasgupta et al. PRL 125 (2020)]

- Recent developments in jet quenching theory are paving the way to quantitative theory-to-data comparisons

[Caucal, ASO, Takacs to appear]

[Barata, Mehtar-Tani, ASO, Tywoniuk to appear]