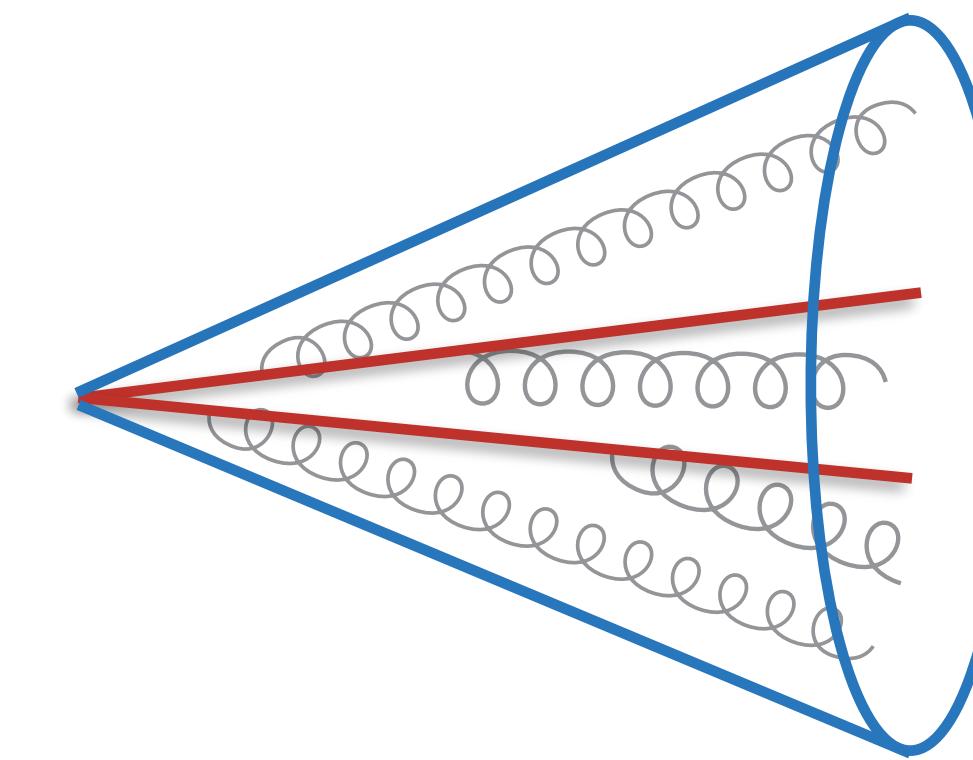


# JET SUBSTRUCTURE VIA DYNAMICAL GROOMING



Alba Soto-Ontoso

+ Yacine Mehtar-Tani and Konrad Tywoniuk

Hard Probes 2020

Remote, 3rd June, 2020



# Roadmap of this talk

---

1

## Motivation and state-of-the-art: SoftDrop

2

## Dynamical grooming: technique and substructure observables

### QCD jets

- Analytical framework
- Impact of underlying event and hadronization effects

[PRD 101 (2020) 3, 034004]

### W/top tagging

- n-Prong DyG extension
- Impact of pileup at HL-LHC conditions

[arXiv: 2005.07584]

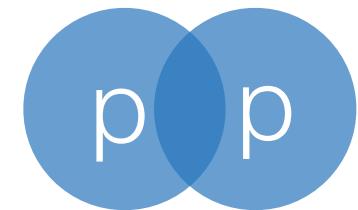
### Heavy-ions

- Sensitivity to QGP effects
- Impact of thermal background  
[Mulligan, Ploskon arXiv:2006.01812]

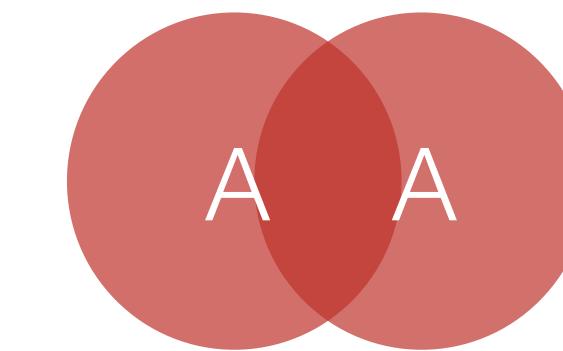


# Why grooming?

Remove soft, wide-angle radiation from the reconstructed jet



- Mitigate impact of:
  - Hadronization
  - Multi-parton interactions
  - Pileup
- Physics goals:
  - Enhance sensitivity to BSM searches
  - Constrain Monte Carlo generators



- Minimize sensitivity to:
  - Non-perturbative p+p effects
  - Thermal background
- Physics goals:
  - QGP effect on splitting function
  - Identify QGP angular resolution
  - Pin-down medium response

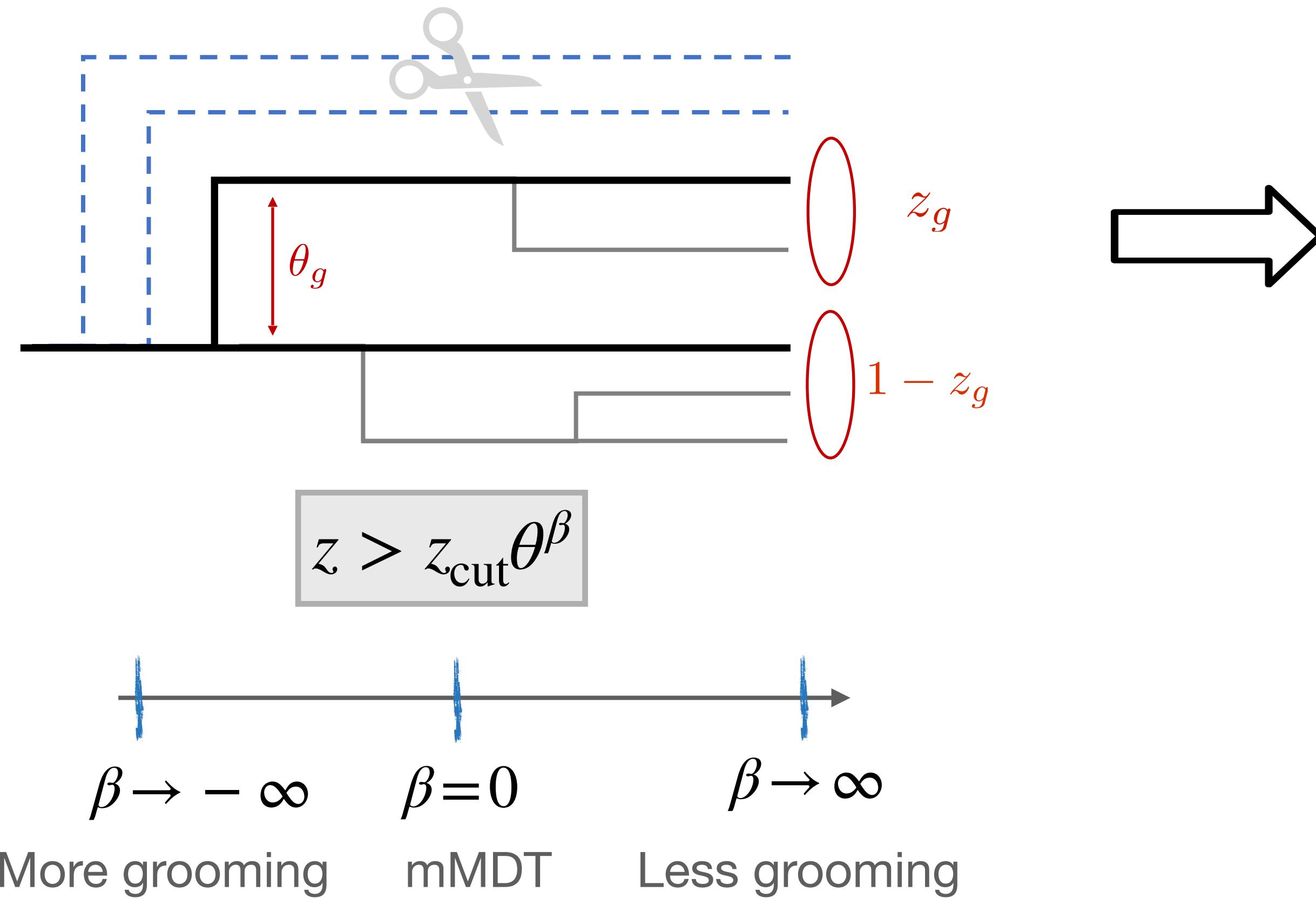
Enable theory-to-data comparisons without the need of a Monte Carlo

# State-of-the-art grooming techniques

Given a C/A reclustered jet, i.e. angular ordered tree:

## SoftDrop (SD)

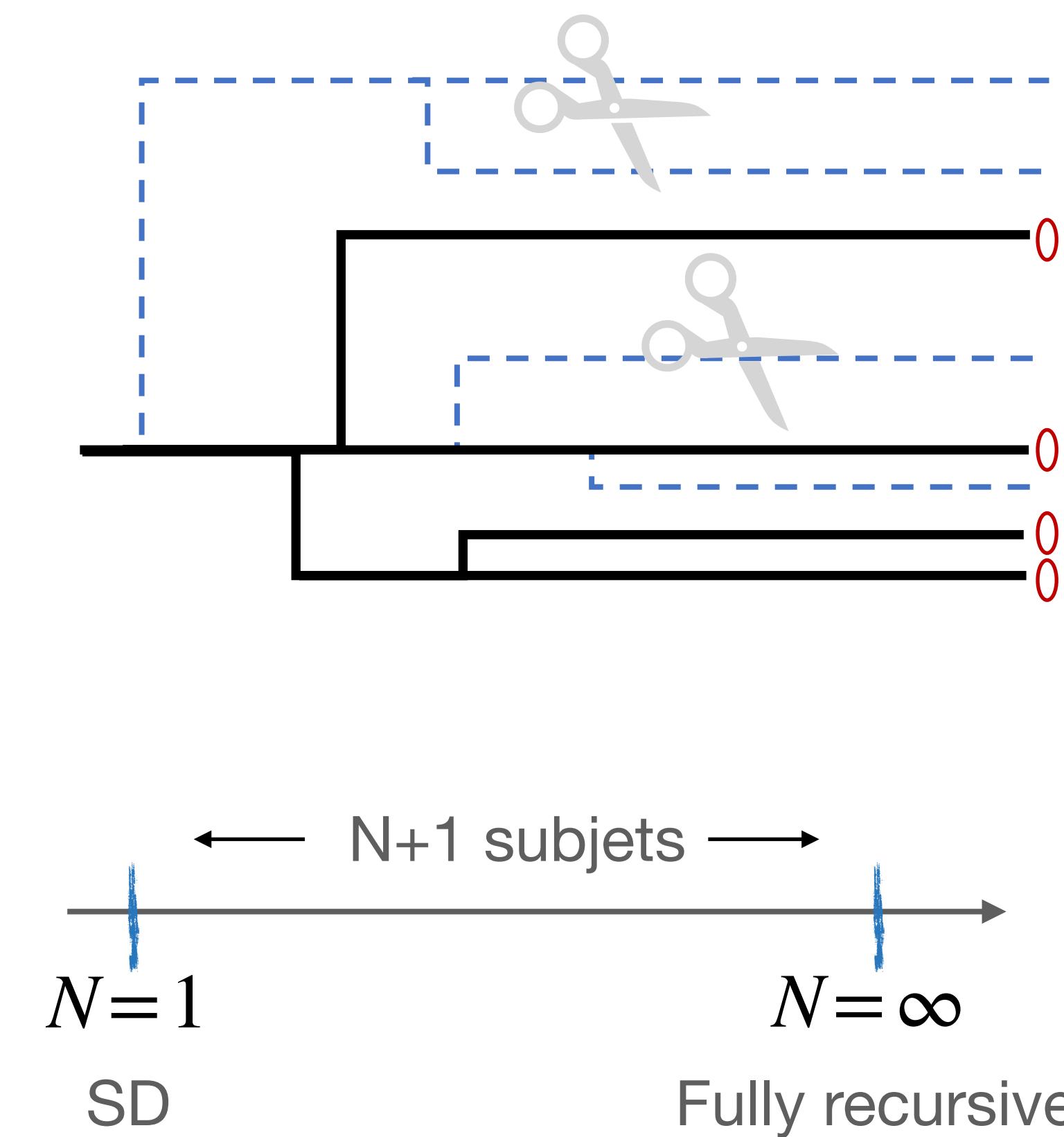
[Larkorski et al. JHEP'14]



[Butterworth et al.PRL'08]

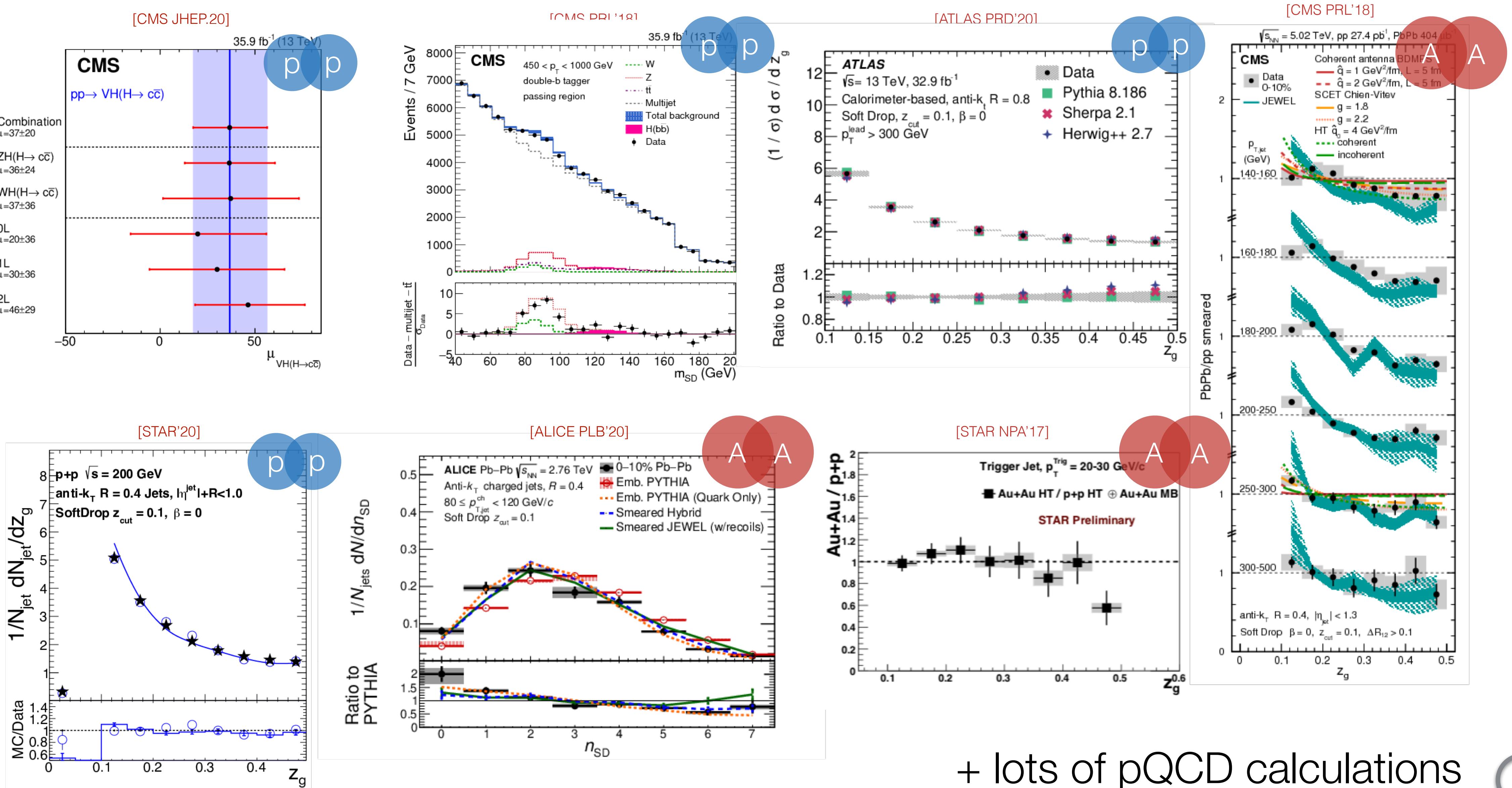
## Recursive SoftDrop (RSD<sub>N</sub>)

[Dreyer et al. JHEP'18]



# SoftDrop at work: from RHIC to LHC

[See HP talks by Mulligan, Kucera, Nemes, Sickles, Mooney...]



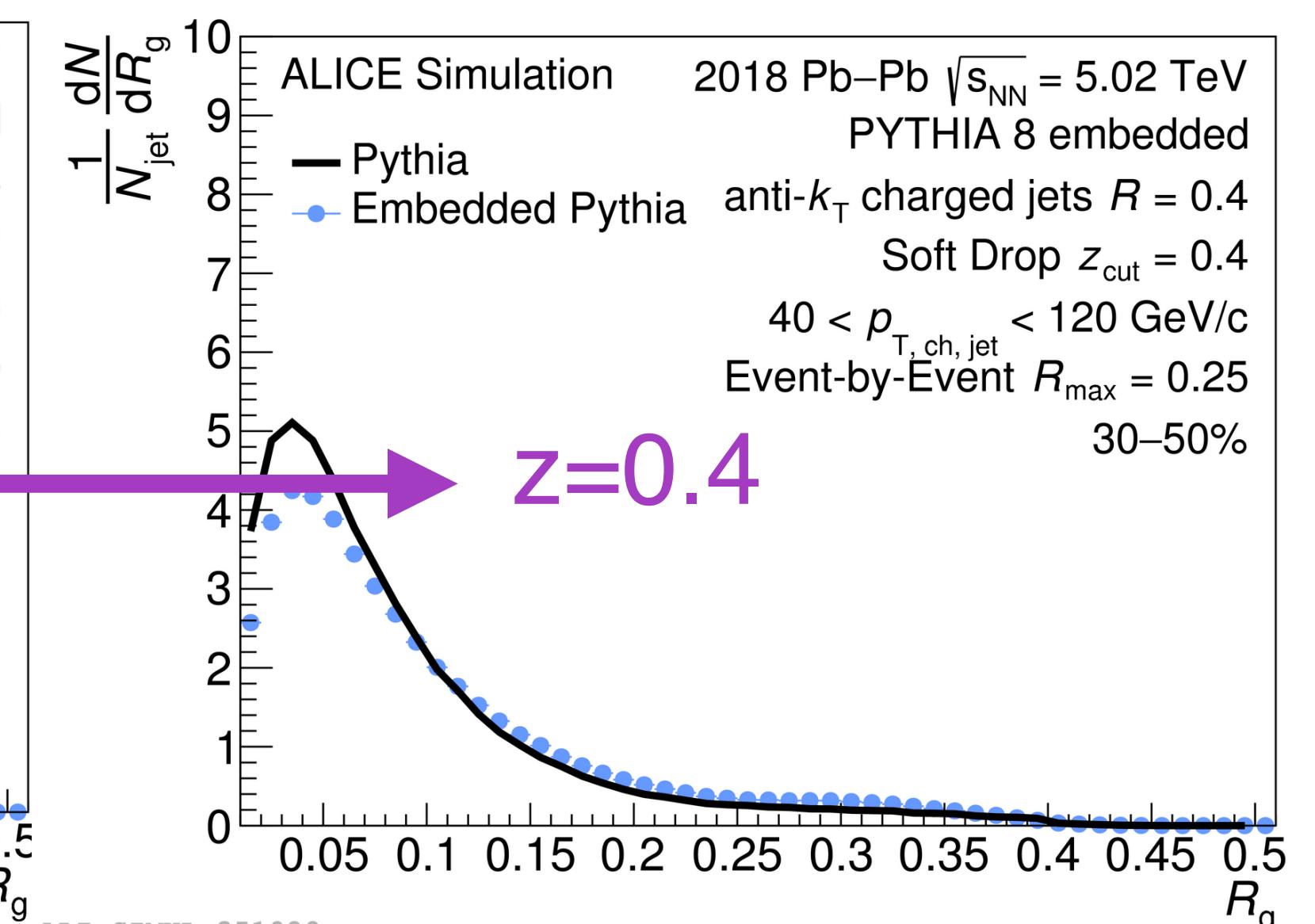
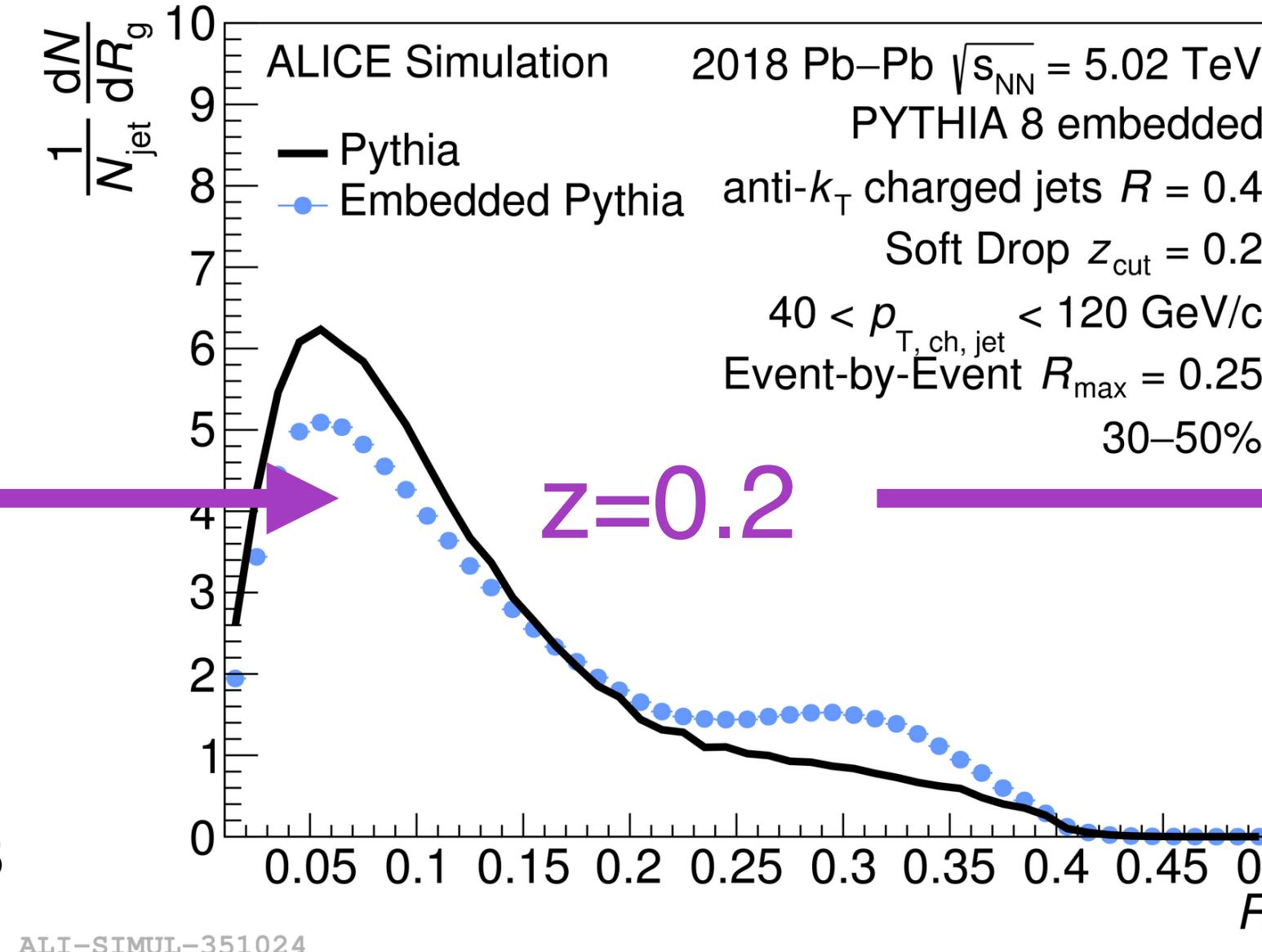
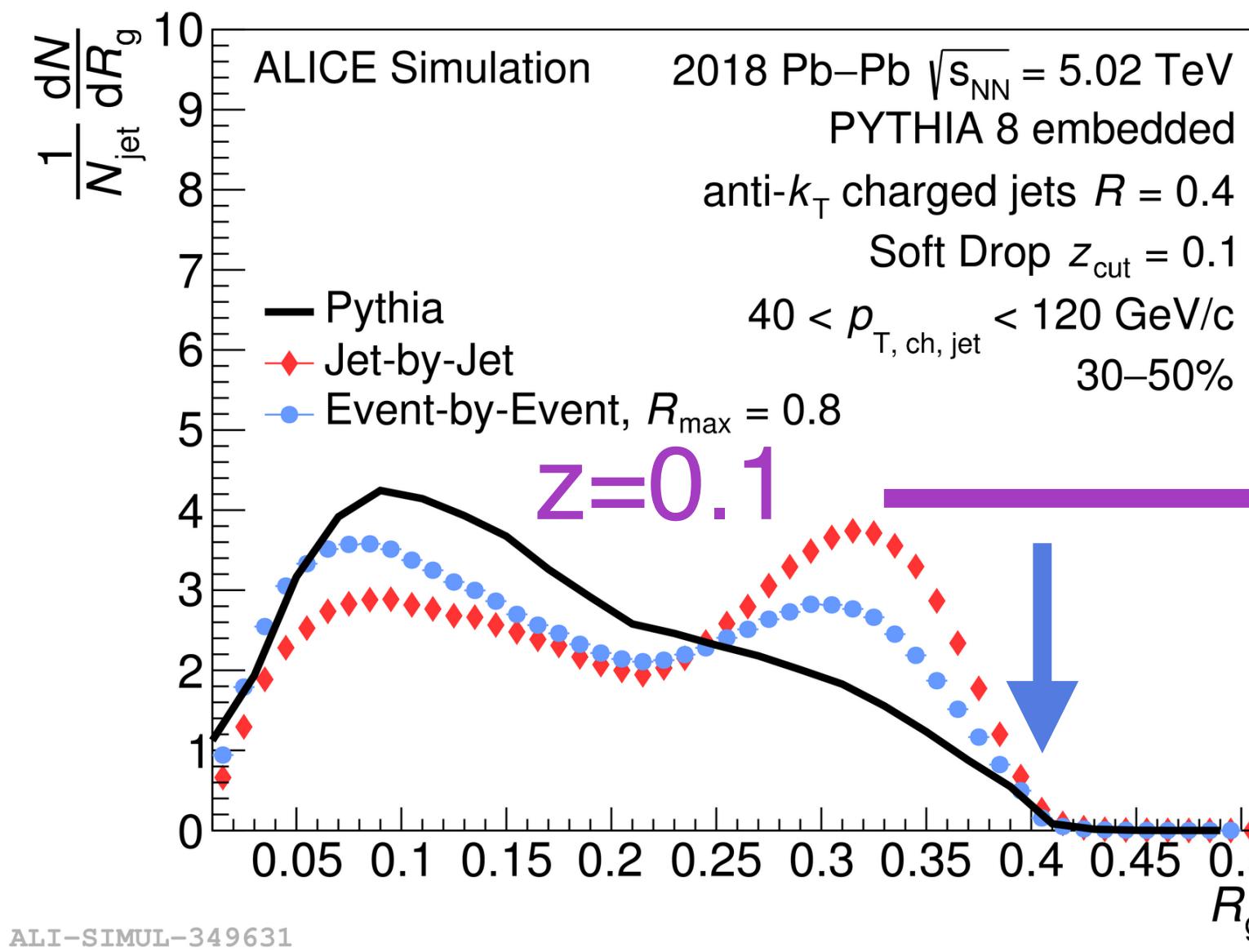
# SoftDrop condition: free parameters

$$z > z_{\text{cut}} \theta^{\beta}$$

Theoretically: flexibility to select splittings from different kinematic regions

Experimentally: no optimal  $(z_{\text{cut}}, \beta, N)$ -values a priori. Tuned on an observable basis with Monte-Carlo, e.g. :

[Laura Havener talk at LHCP'20]

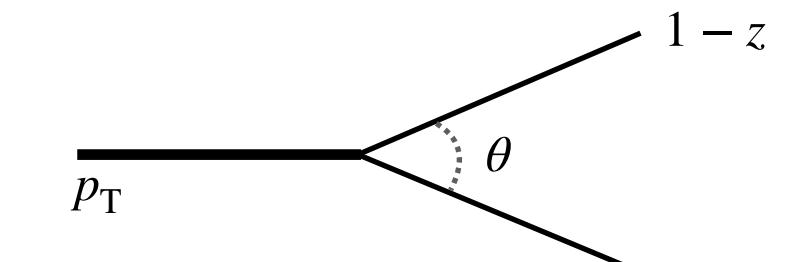


# Dynamical grooming

Code: [github/aontoso/JetToyHI](https://github/aontoso/JetToyHI)

1) Find hardest branch in the C/A sequence, i.e.

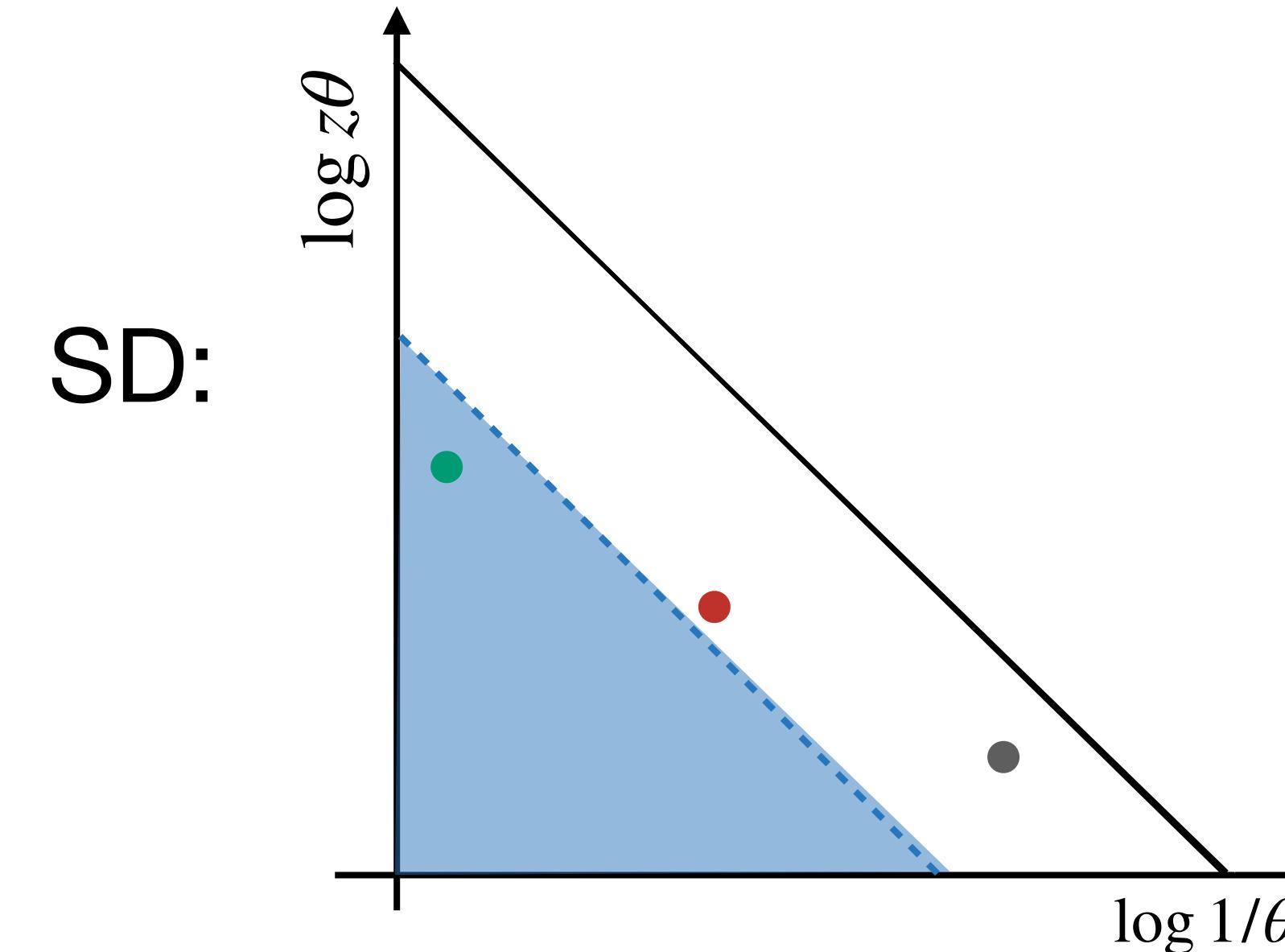
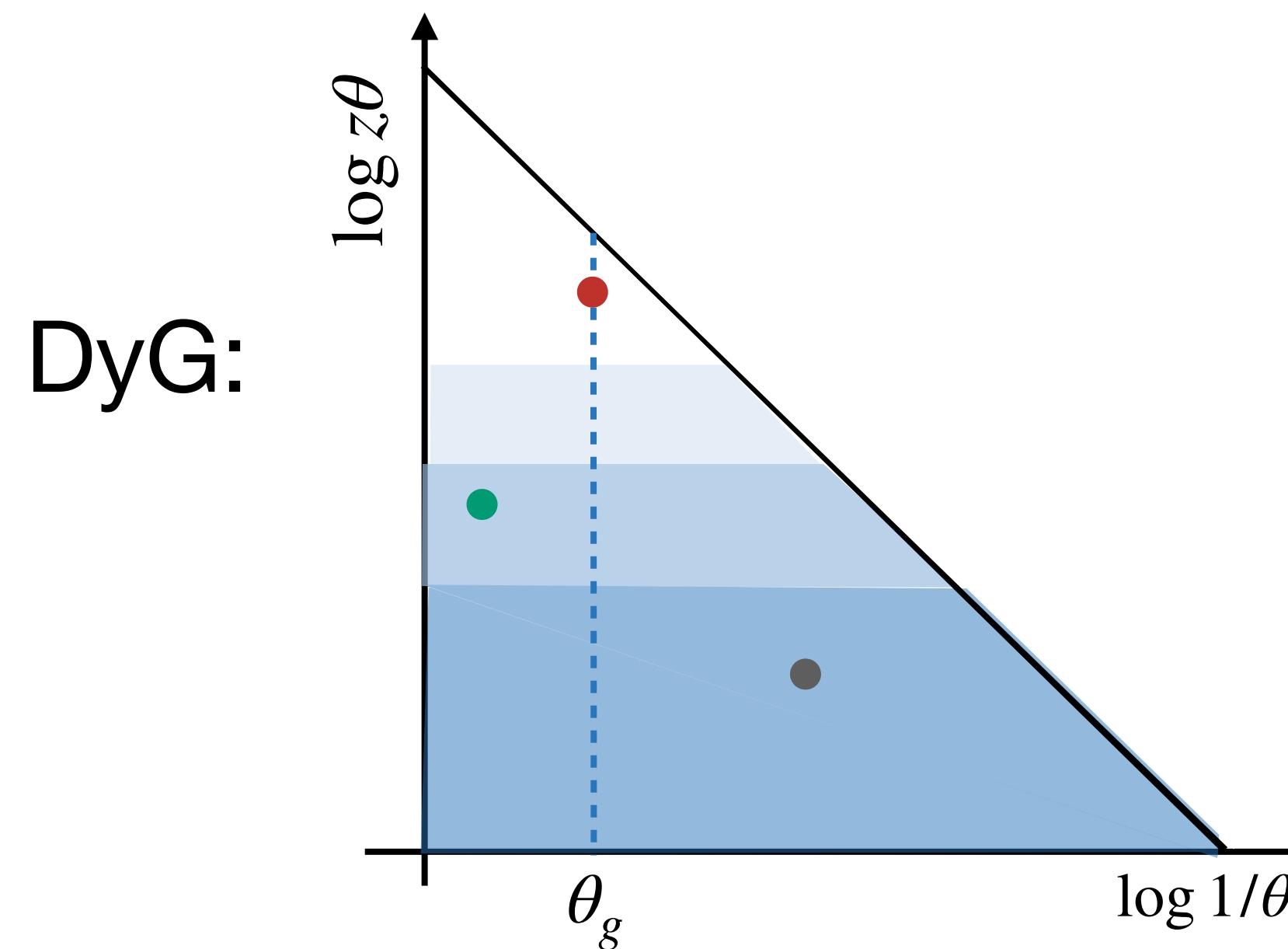
$$\kappa^{(a)} = \frac{1}{p_T} \max_{i \in \text{C/A}} z_i(1 - z_i)p_{T,i}(\theta_i/R)^a$$



Physical interpretation:

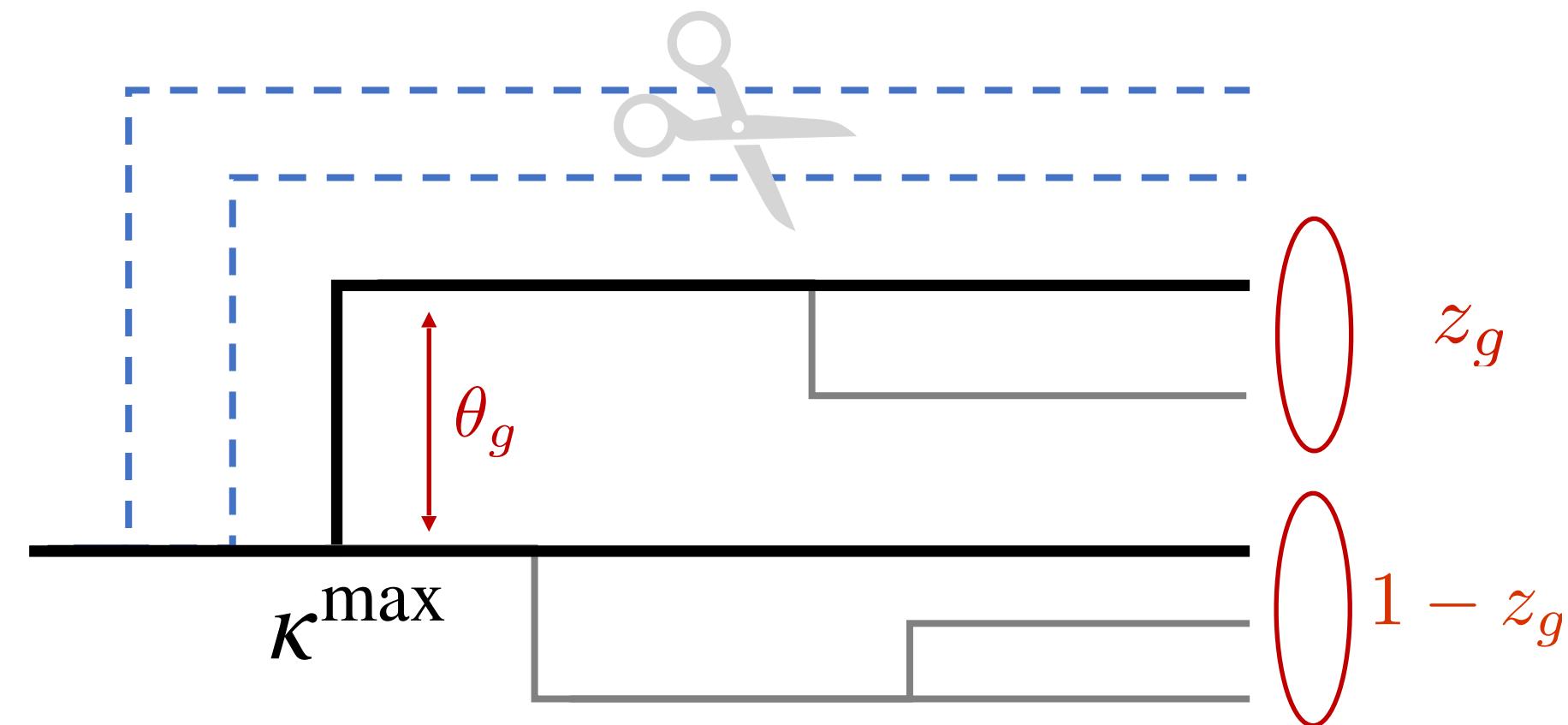
- $a=2$ : TimeDrop
- $a=1$ :  $k_T$ Drop
- $a \sim 0$ :  $z$ Drop

2) Drop all branches at larger angles, i.e.  $\theta_i > \theta_g$



# Remarks and physical interpretation of DyG

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



- Removing soft radiation sensitive to the total color charge of the jet
- Grooming condition auto-generated on a jet-by-jet basis
- More aggressive grooming with decreasing  $a$  (similar to  $\beta$  in SD)



# Analytical framework of DyG

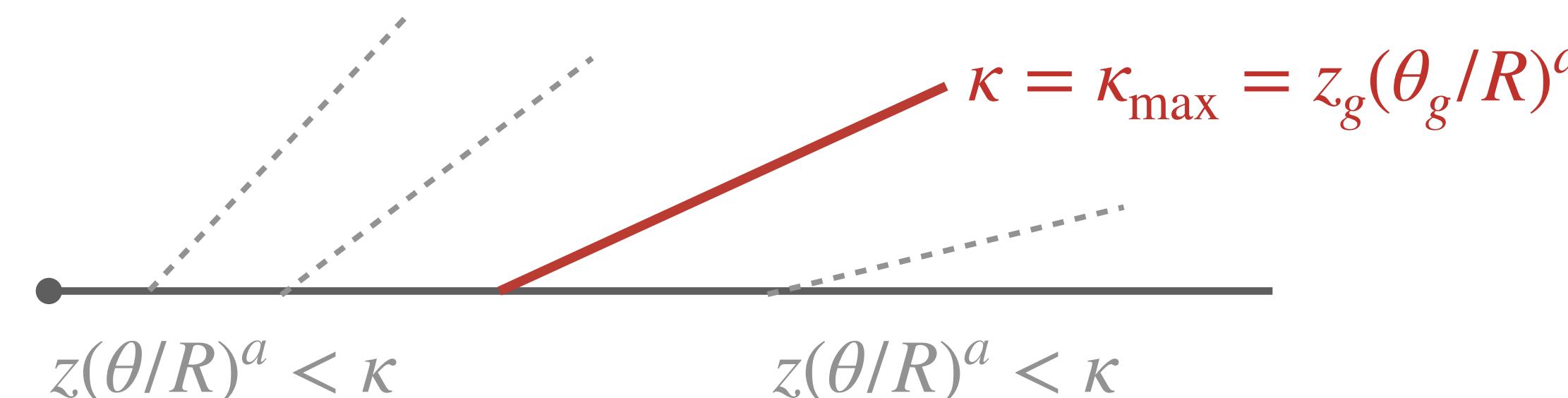
Building block: 2D phase space probability for the tagged DyG splitting

$$\mathcal{P}(z, \theta) = \frac{\alpha_s(k_t^2)}{\pi} P(z) \Delta(\kappa | a)$$

- **Splitting function:** probability to split given that all other splittings are softer
- **Sudakov form factor:** probability for no emission with  $z(\theta/R)^a > \kappa$

$$\Delta(\kappa | a) = \exp \left[ - \int_0^R \frac{d\theta}{\theta} \int_0^1 dz P(z) \times \Theta(z(1-z)(\theta/R)^a > \kappa) \right] \quad \text{IRC safe for } a > 0$$

Vetoed showers  
[Nason JHEP'04]

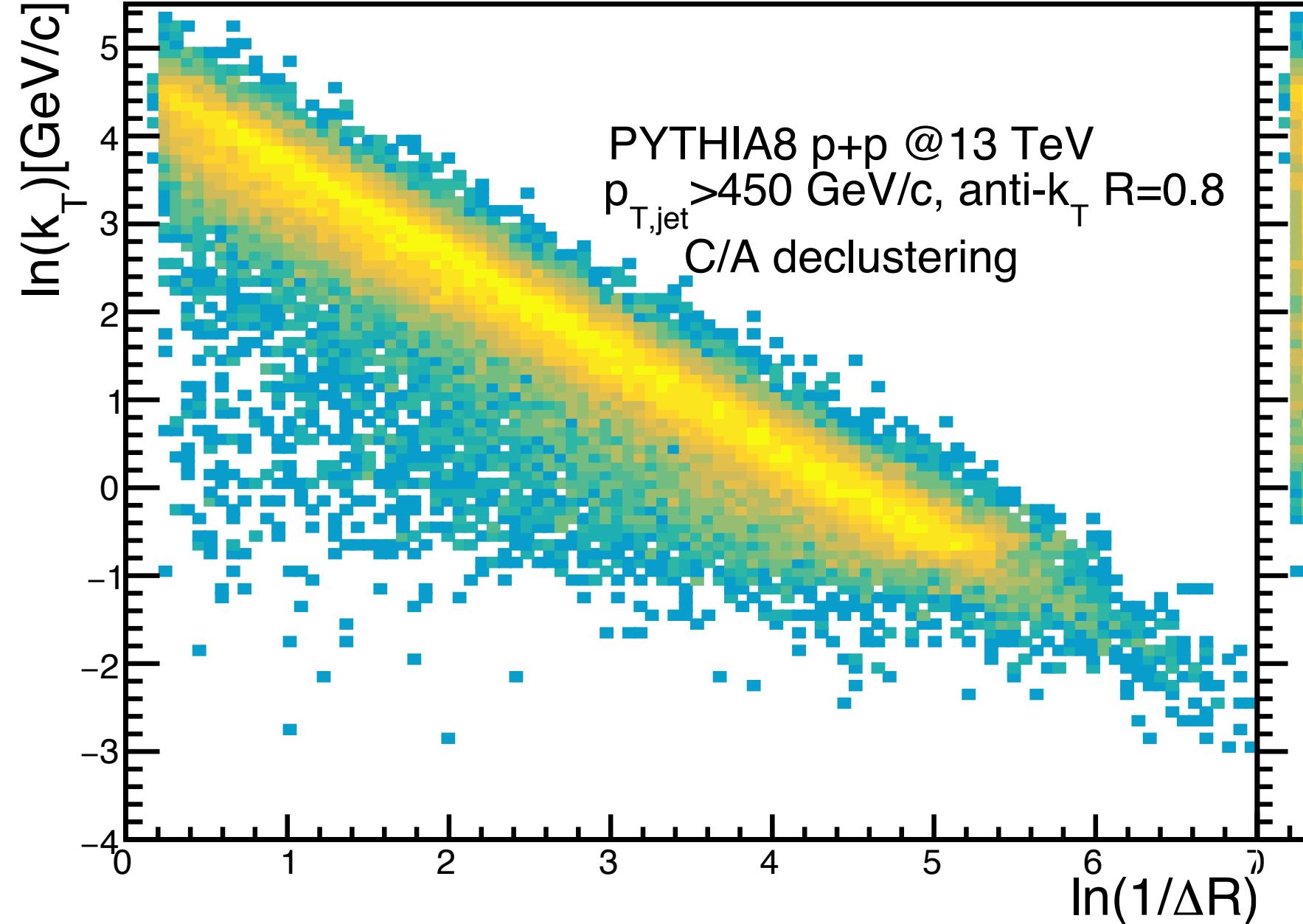


# Lund planes for dynamically groomed QCD jets

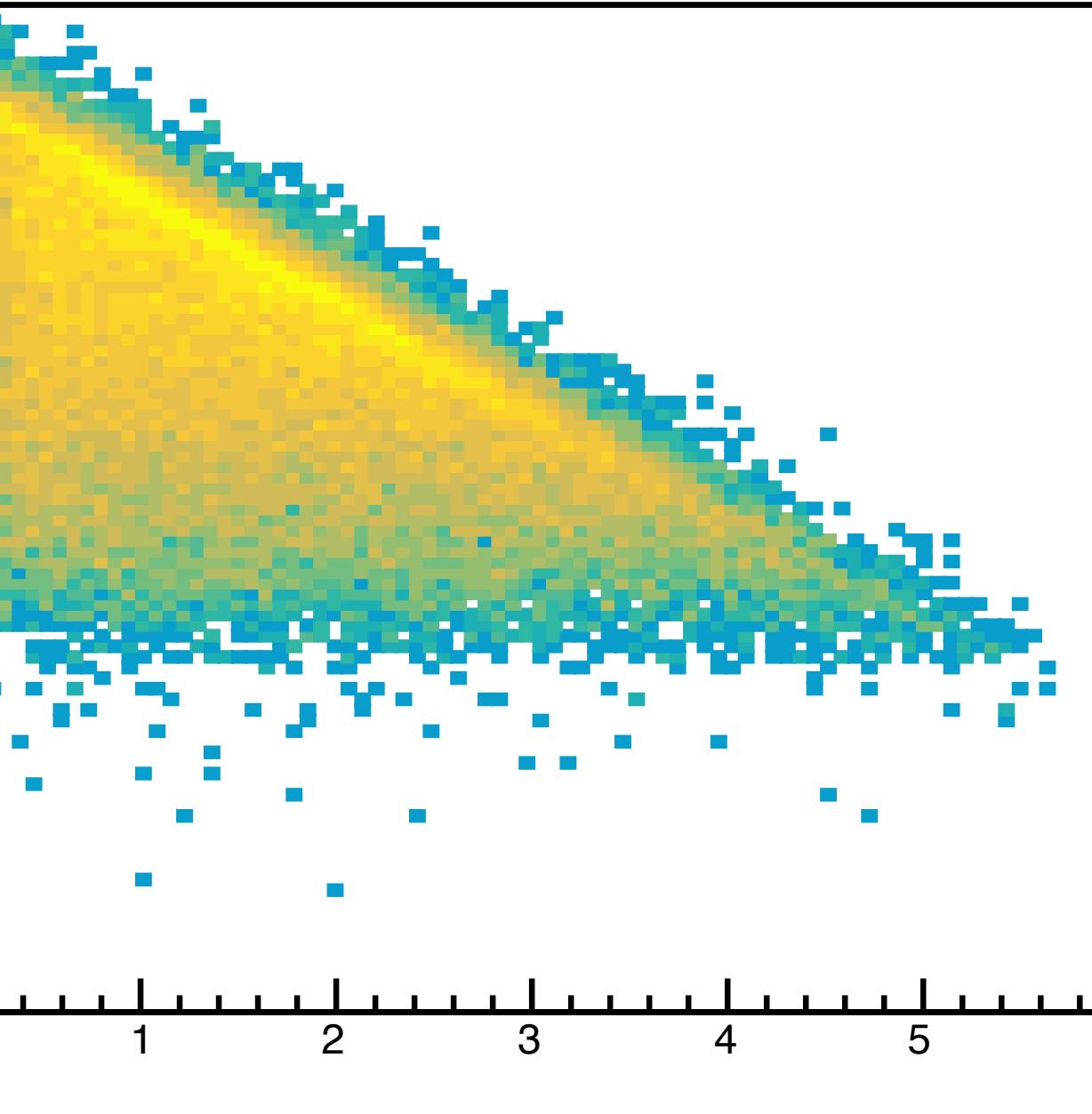
PYTHIA 8, pp $\rightarrow$ dijet@13 TeV  
HAD, UE::off

$$\mathcal{P}(z, \theta) = \frac{\alpha_s(k_t^2)}{\pi} P(z) \Delta(\kappa | a)$$

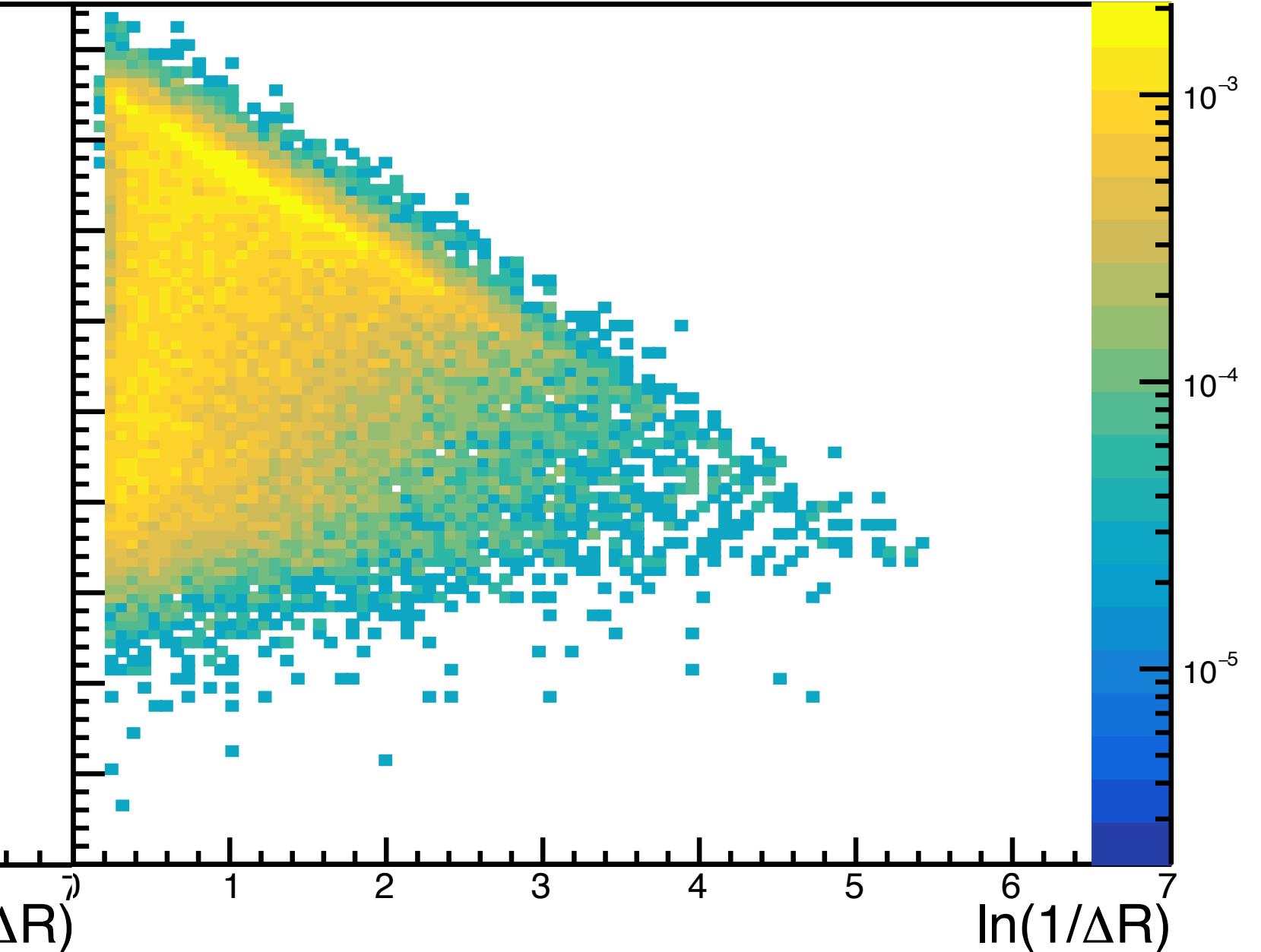
zDrop



$k_T$ Drop



TimeDrop



Dynamical cut when  $\log^2(\kappa)^{\text{DLA}} \sim \log^2(z\theta^a) > a/\alpha_s$

# $z_g$ -distribution in DyG QCD jets

$$\frac{1}{\sigma} \frac{d\sigma}{dz} = \int_0^R \frac{d\theta}{\theta} \mathcal{P}(z, \theta)$$

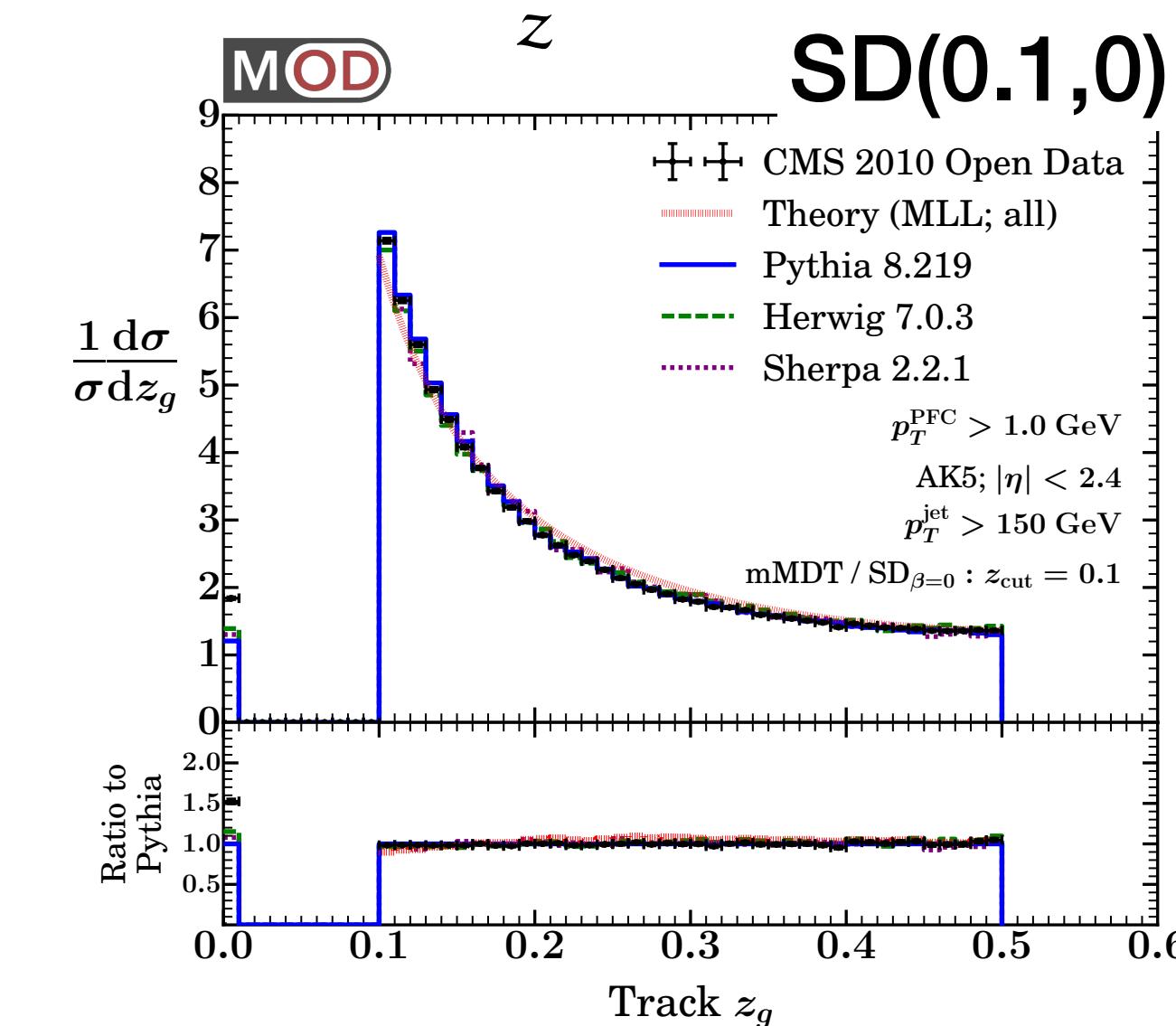
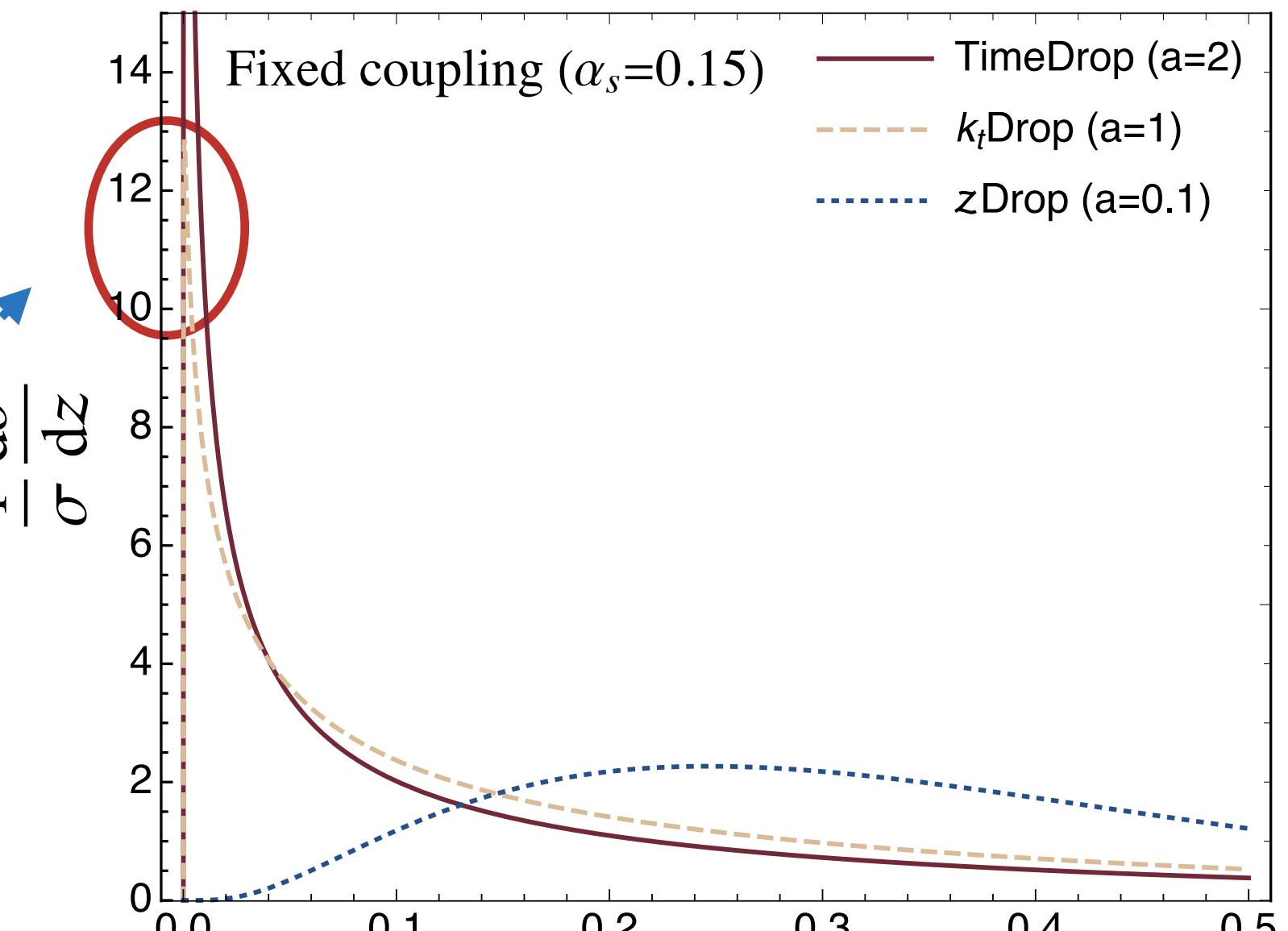
- Dynamical cut-off generated at

$$z_{\text{cut}}^{\text{DLA}} \approx e^{-\sqrt{a/\bar{a}}}$$

- For  $z_{\text{cut}} < z < 0.5$

$$\frac{1}{\sigma} \frac{d\sigma}{dz} \approx P(z) \times \sqrt{\bar{a}/a}$$

Possibility to measure  $P(z)$  down to lower  $z$



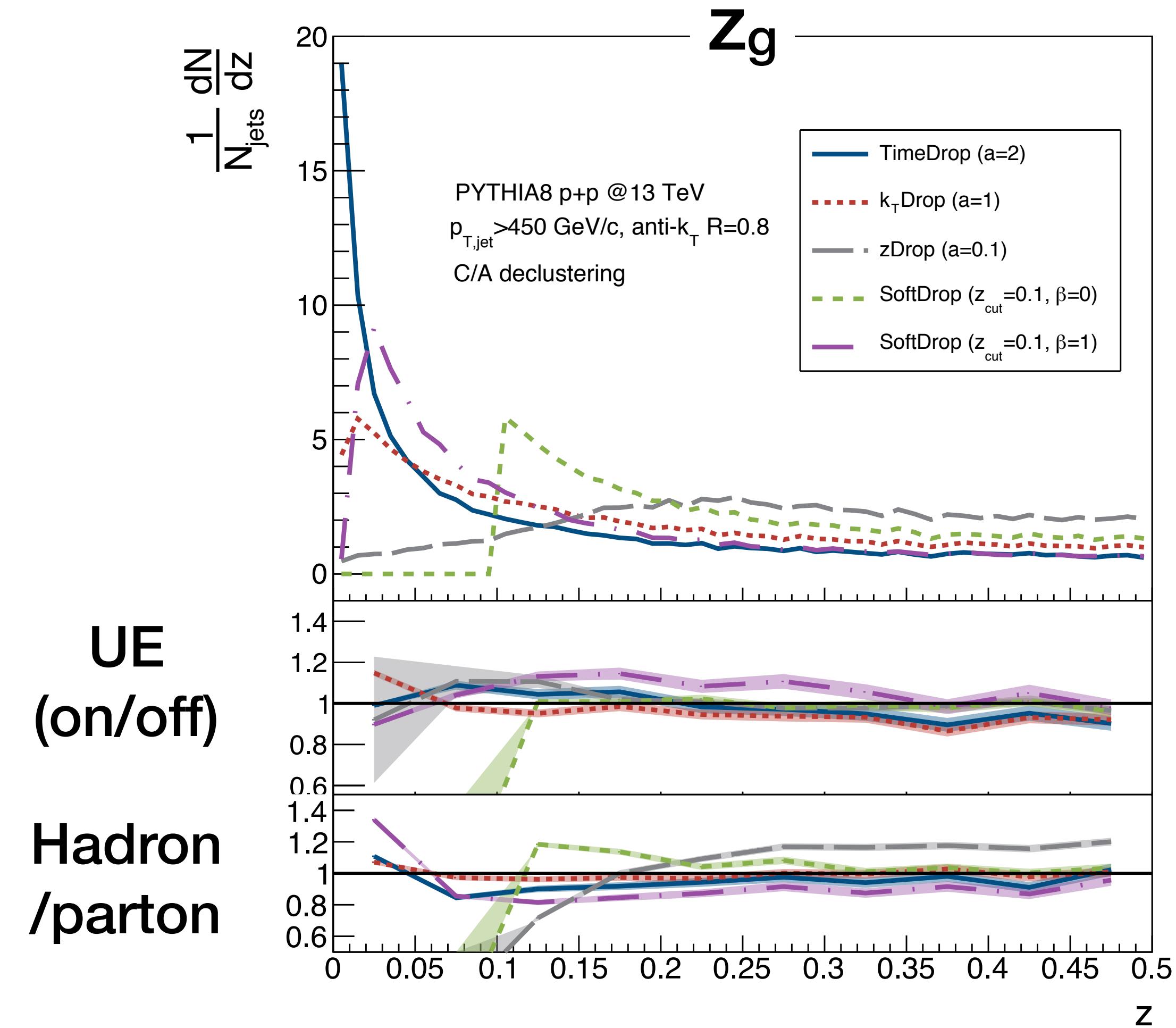
[Larkowski et al PRL'17)

# Impact of UE\* and hadronization in DyG-Z<sub>g</sub>

(\*UE==ISR and MPI)

Comparison among:

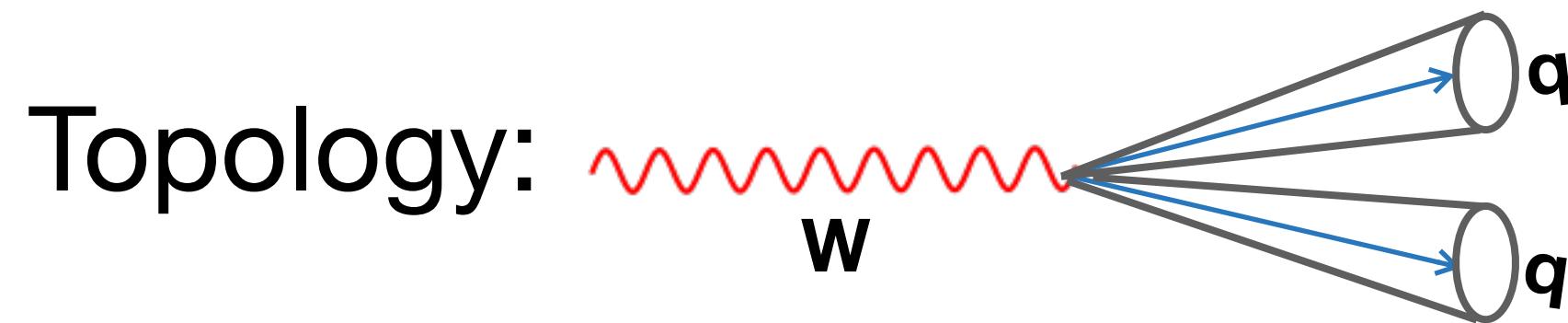
- TimeDrop
- k<sub>T</sub>Drop
- zDrop
- SD(0.1,0)
- SD(0.1,1)



Overall similar behavior to SD. k<sub>T</sub>Drop remarkably robust to hadronization

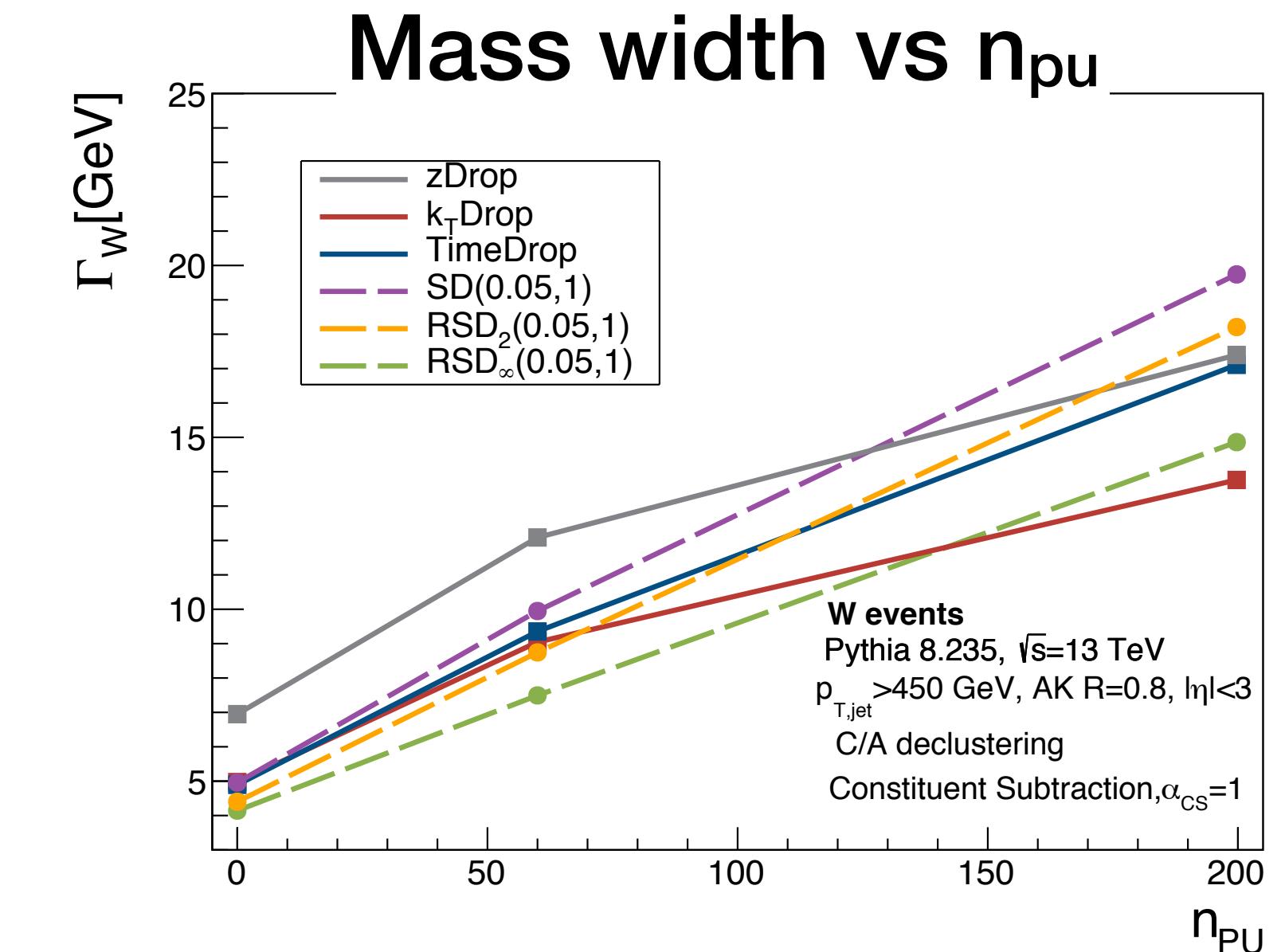
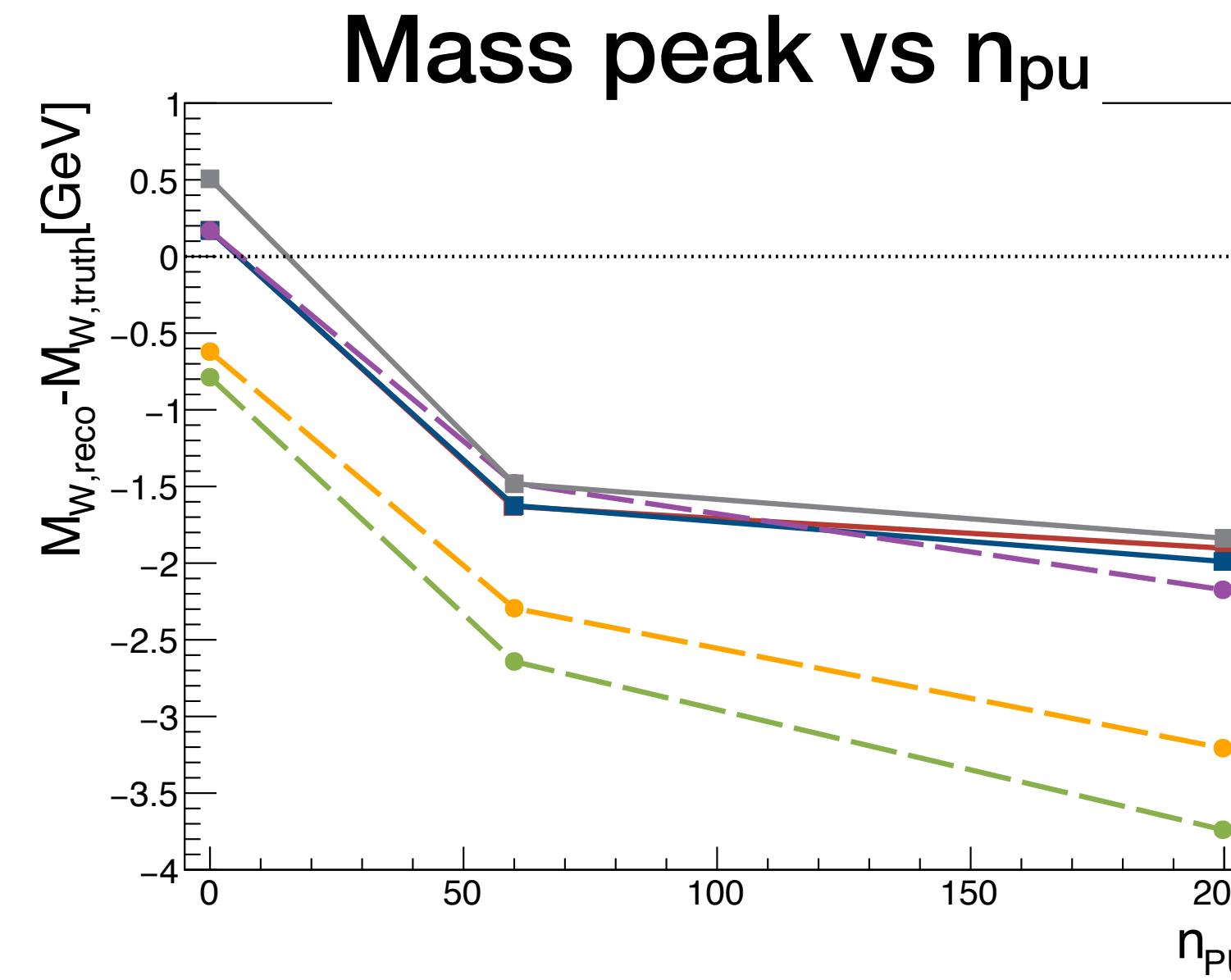
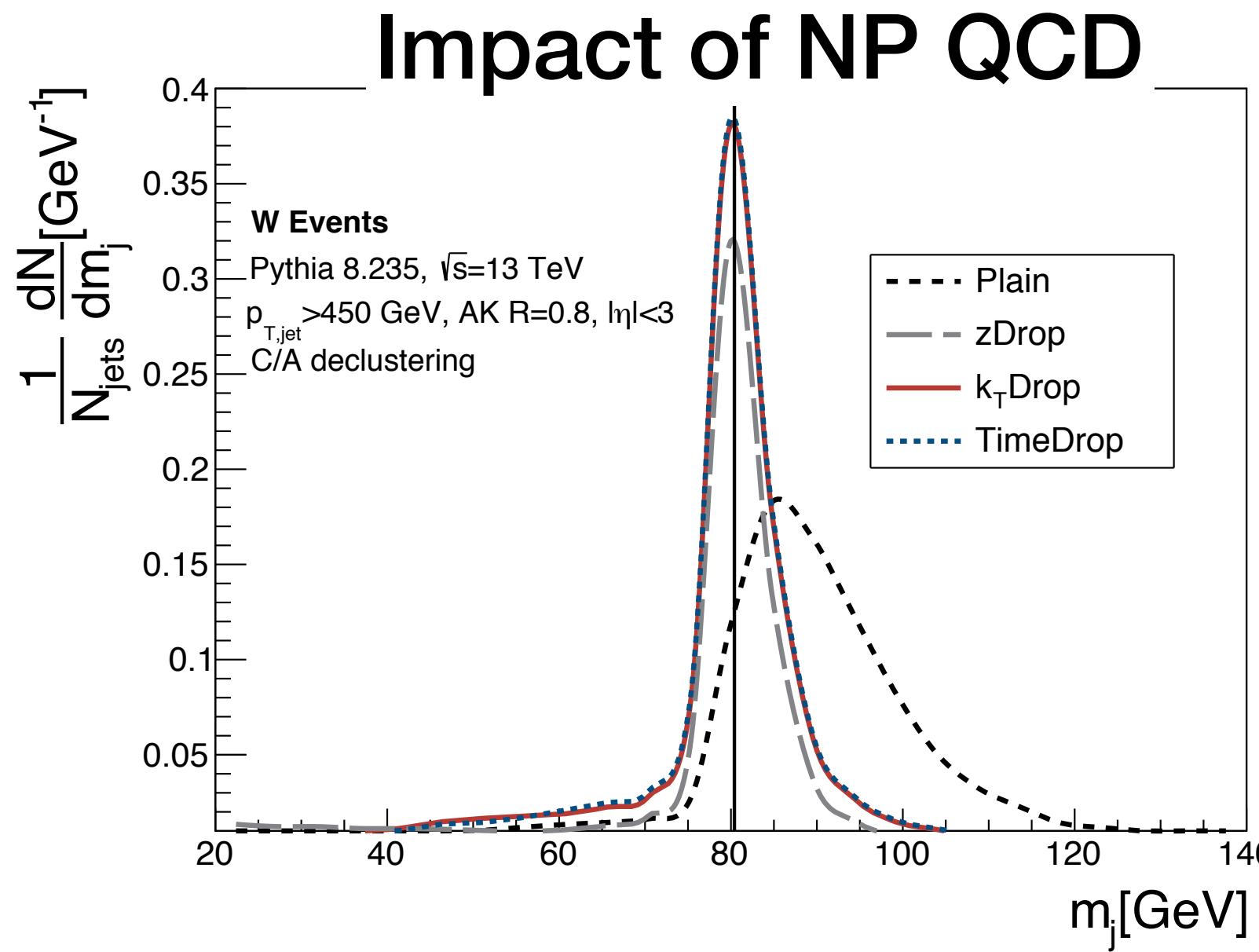
# W tagging in the boosted regime

PYTHIA 8,  $\text{pp} \rightarrow W; W \rightarrow q\bar{q}$  @ 13 TeV  
 +  $n_{\text{pu}}$  minimum bias events + Constituent Subtraction



- Comparison:
- TimeDrop
  - SD(0.05,1)
  - k<sub>T</sub>Drop
  - RSD<sub>2</sub>(0.05,1)
  - zDrop
  - RSD<sub>∞</sub>(0.05,1)
- tuned by

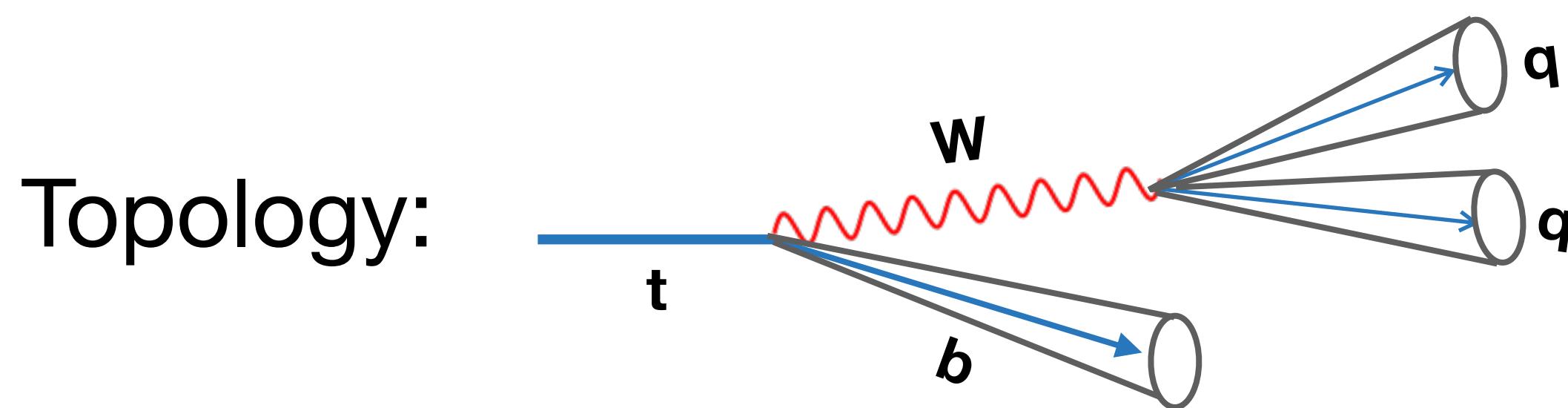
[Dreyer et al JHEP'20]



**k<sub>T</sub>Drop shows an enhanced resilience against background fluctuations**

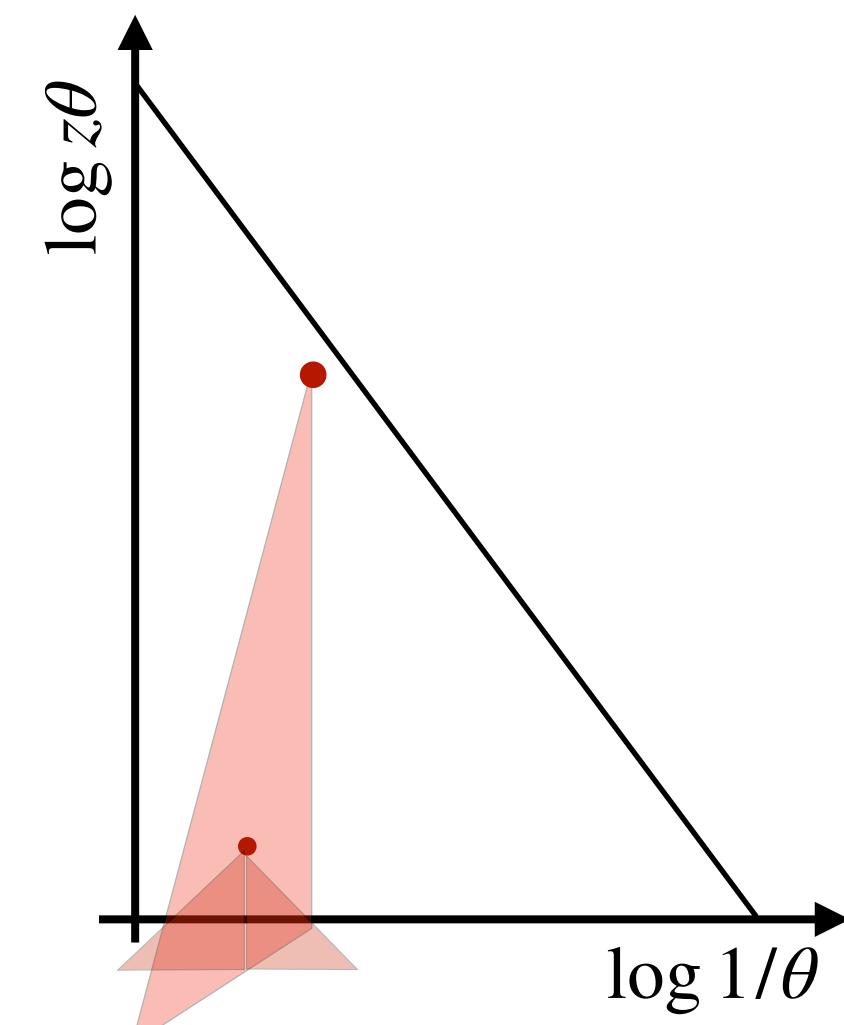
# Top tagging in the boosted regime

PYTHIA 8,  $\text{pp} \rightarrow \text{tt}$ ;  $\text{t} \rightarrow \text{Wb}$ ;  $\text{W} \rightarrow \text{qq}$  @13 TeV  
 $+n_{\text{pu}}$  minimum bias events +Constituent Subtraction



w/o angular ordering

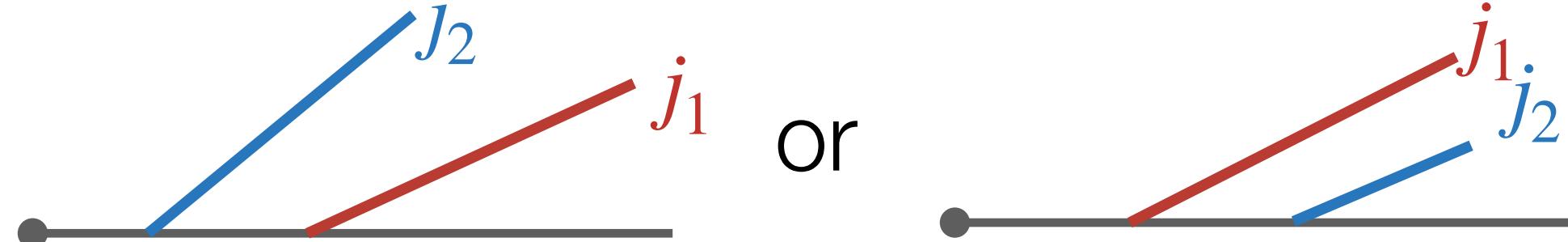
$$\theta_{qq} \not< \theta_{Wb}$$



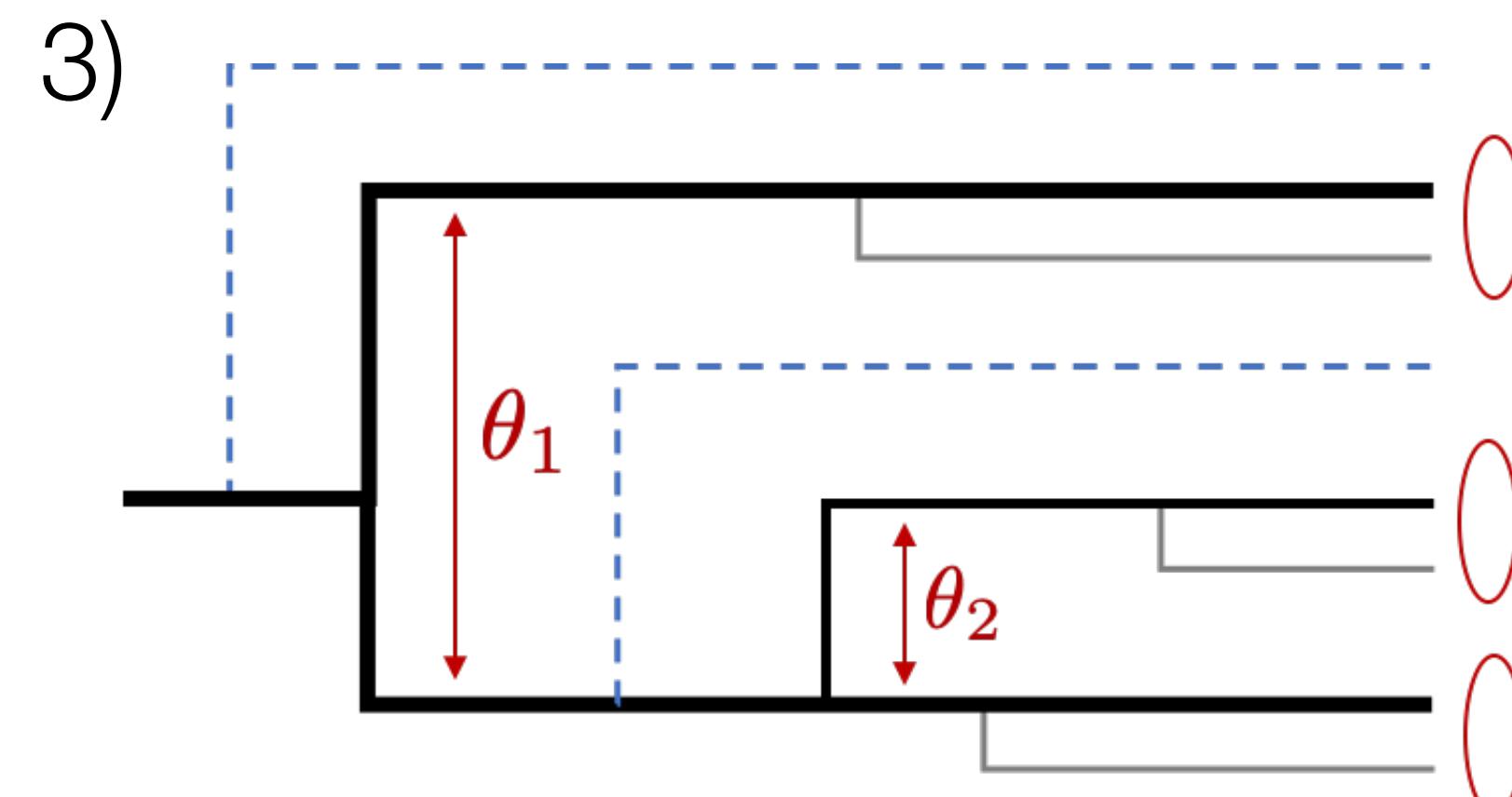
3-prong DyG: first step towards n-prong DyG

- 1) Find hardest branch:  $j_1, \theta_{\text{leading}}$
- 2) Look for the next-to-hardest:  $j_2, \theta_{\text{sub-leading}}$

a)  $j_2$  on primary Lund Plane of  $j_1$



b)  $j_2$  on secondary Lund Plane of  $j_1$



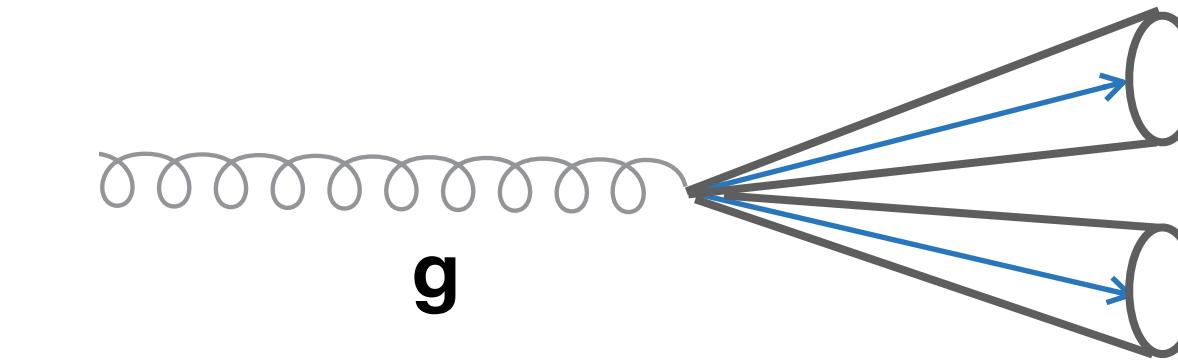
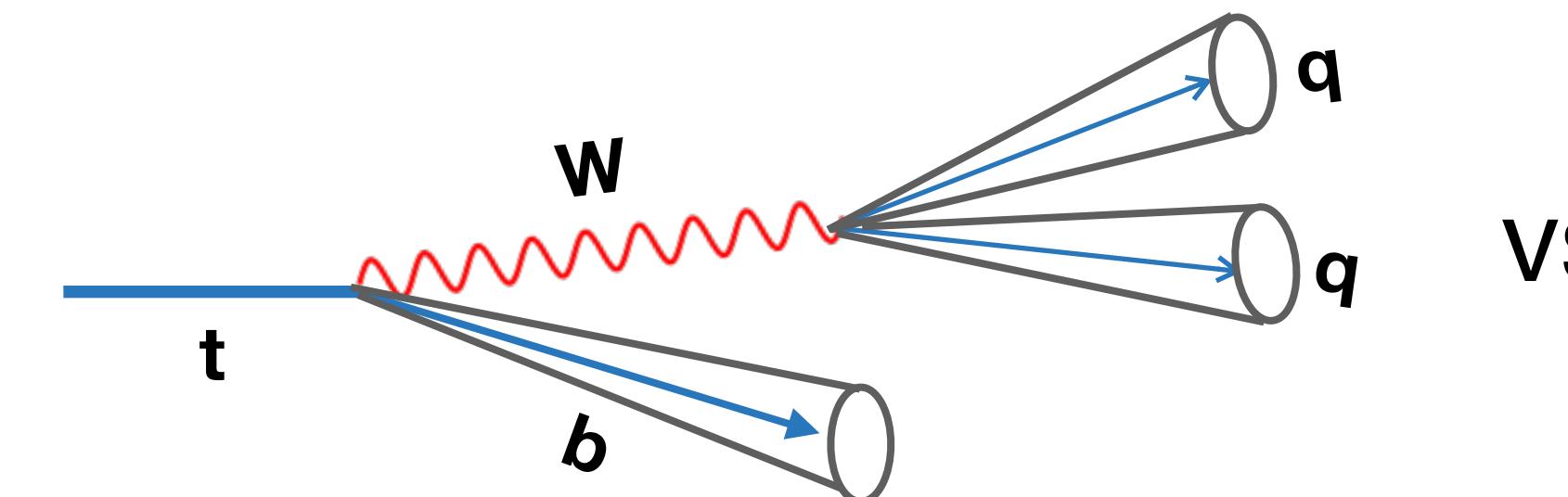
$$\theta_1 = \max(\theta_{\text{leading}}, \theta_{\text{sub-leading}})$$

$$\theta_2 = \min(\theta_{\text{leading}}, \theta_{\text{sub-leading}})$$

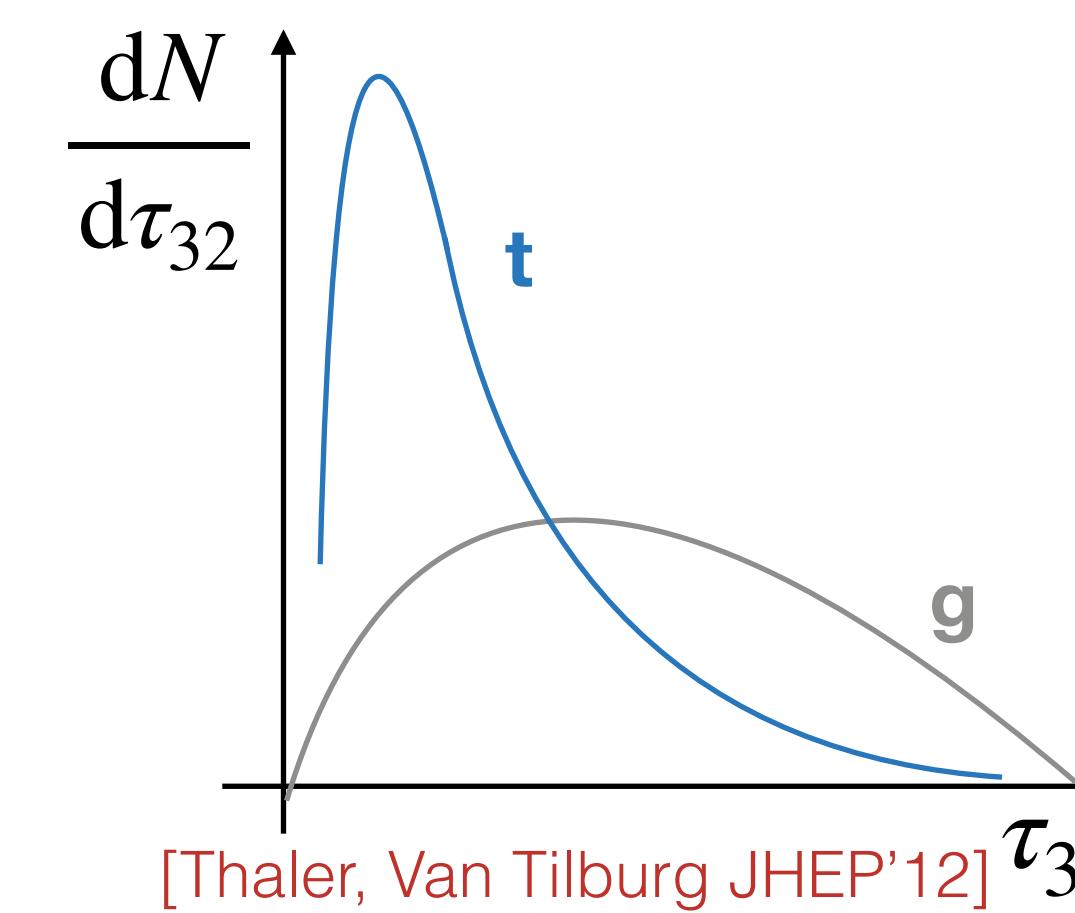
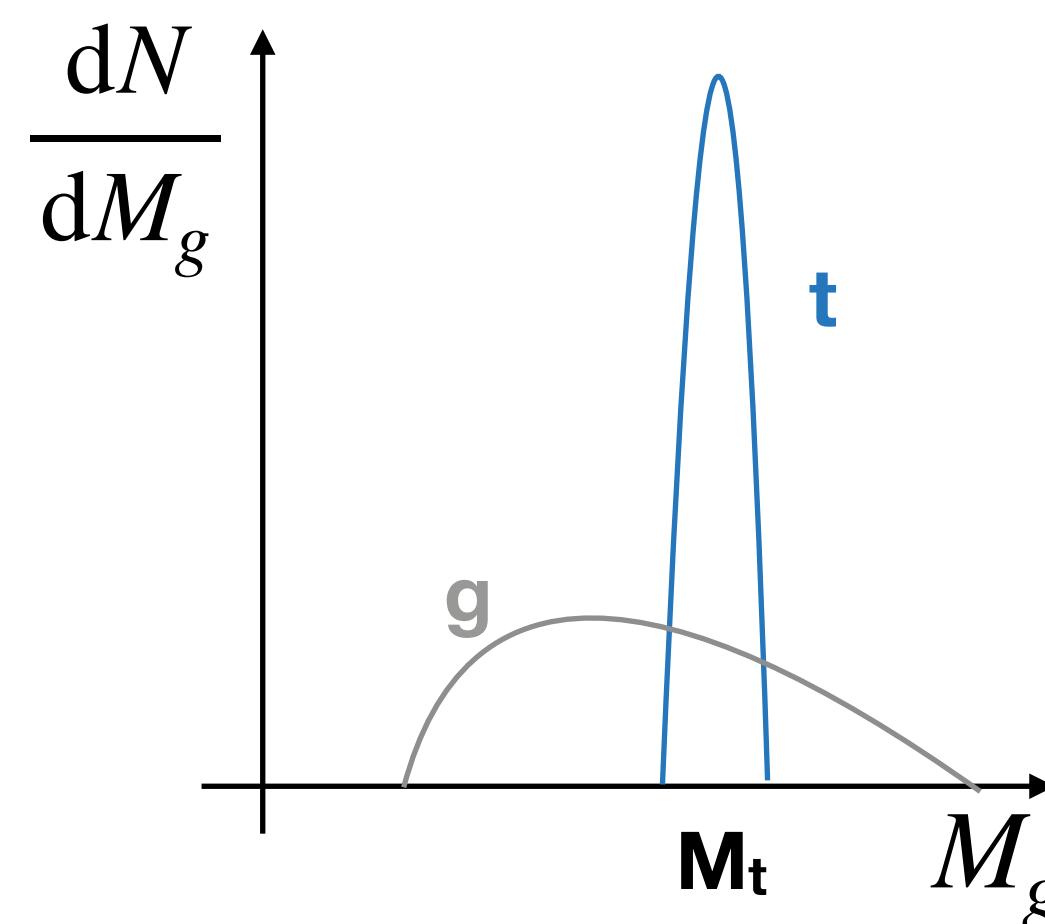
# Top tagging in the boosted regime

PYTHIA 8,  $pp \rightarrow tt$ ;  $t \rightarrow Wb$ ;  $W \rightarrow qq$  @13 TeV  
 $+n_{pu}$  minimum bias events +Constituent Subtraction

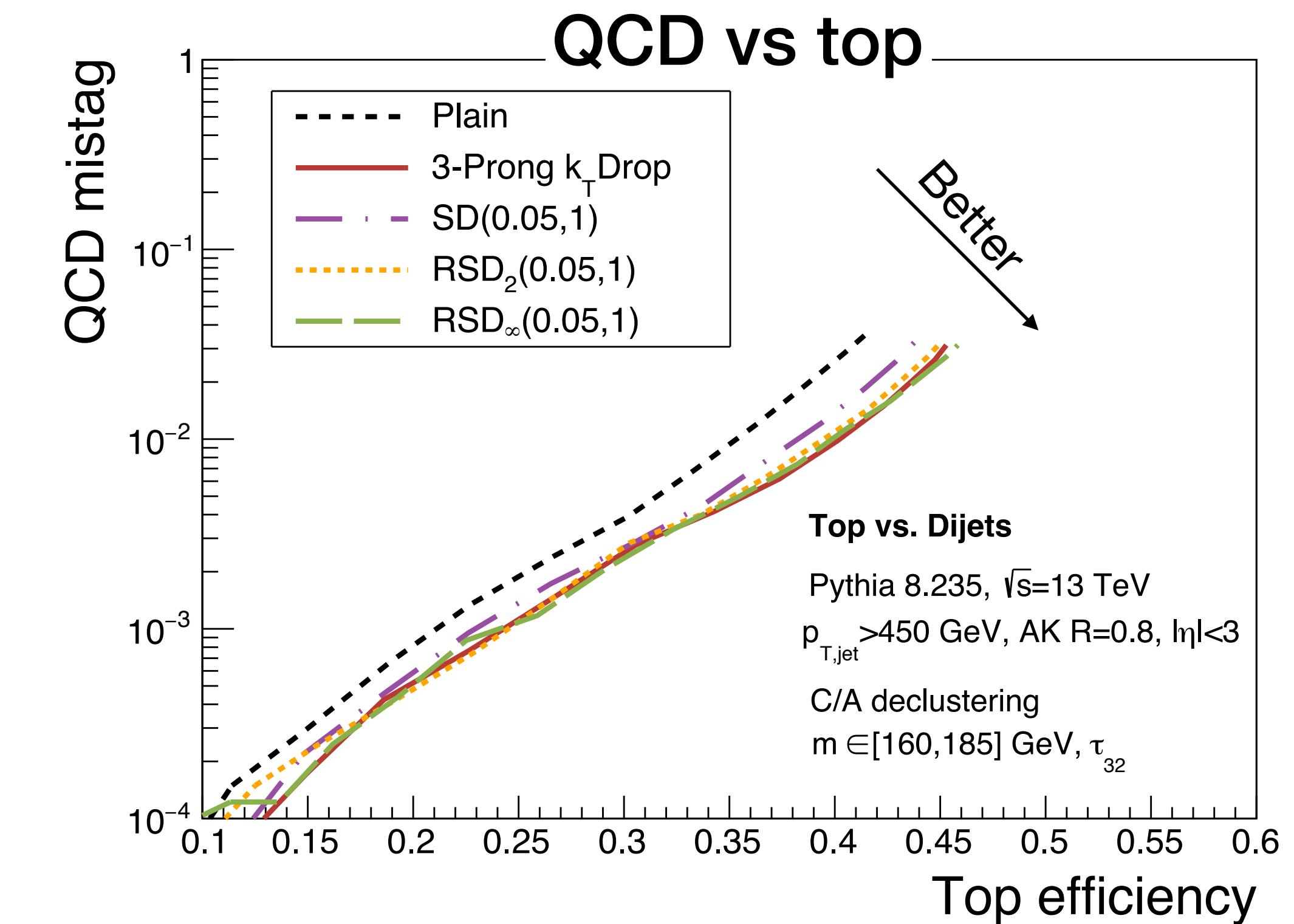
Tagging efficiency: how to distinguish a top jet from the abundant QCD background



Strategy: exploit differences on



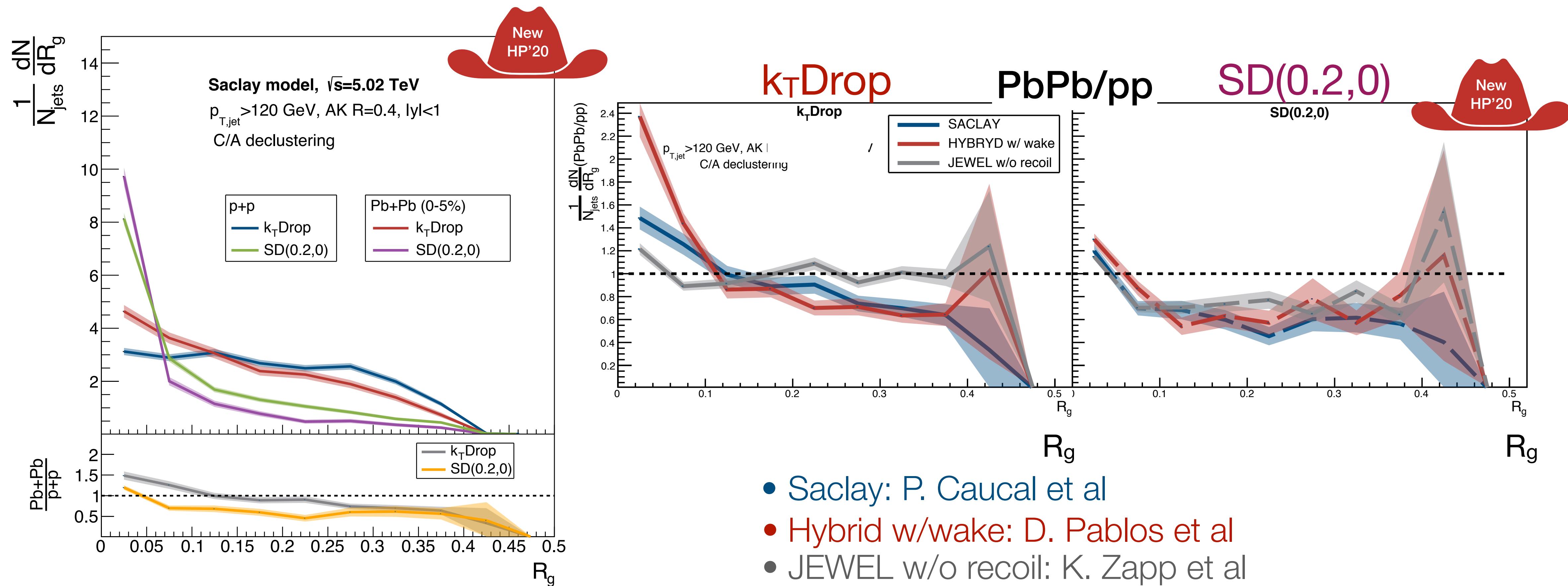
**3-Prong DyG neat improvement with respect to traditional SoftDrop**



# Sneak peek into heavy-ion collisions

ALICE-like set up  
Samples: JetTools GitHub

Goal: asses discriminating power of the  $k_T$ Drop  $R_g$ -distribution compared to SD



Beware: thermal background not included. See: [Mulligan, Ploskon arXiv:2006.01812]

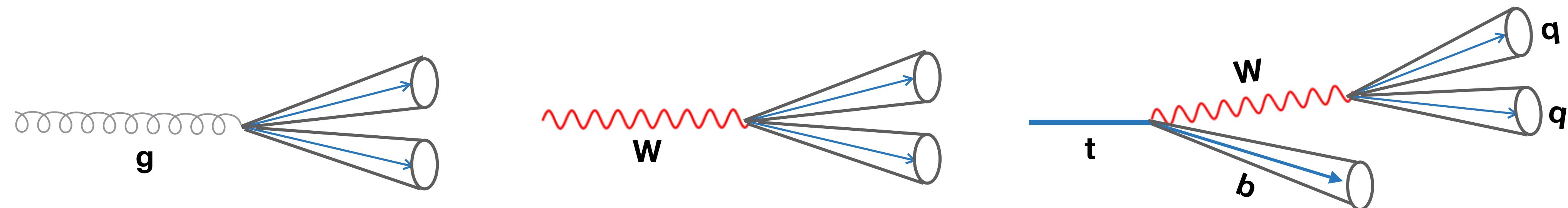
# Take-home messages

Introduced dynamical grooming based on identifying the hardest splitting jet-by-jet

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

Properties:

- **Calculable:** IRC (IR and Collinear) safe for  $a > 0$
- **Versatile:** successfully applied to different scenarios without fine-tuning



- **Resilient:** to underlying event, hadronization and pileup (thermal bkg in HIC?)

Ready to use: [Code: github/aontoso/JetToyHI](https://github/aontoso/JetToyHI)