NEWS FROM JET SUBSTRUCTURE: SOFT DROP

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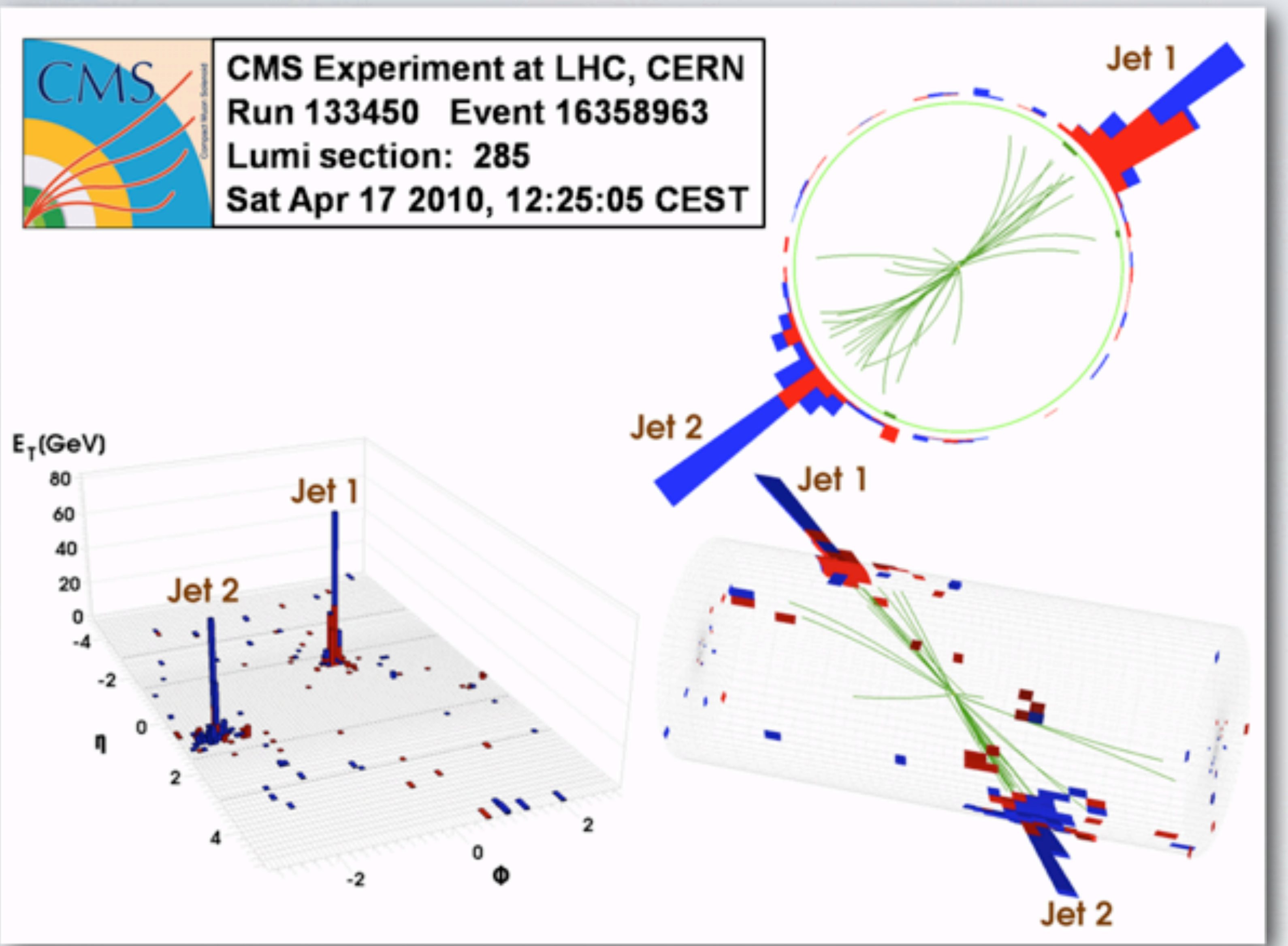
based on Dasgupta, Fregoso, SM and Salam JHEP 1309 028
Dasgupta, Fregoso, SM and Powling EPJ C 73 11
Larkoski, SM, Soyez and Thaler JHEP 1405 146

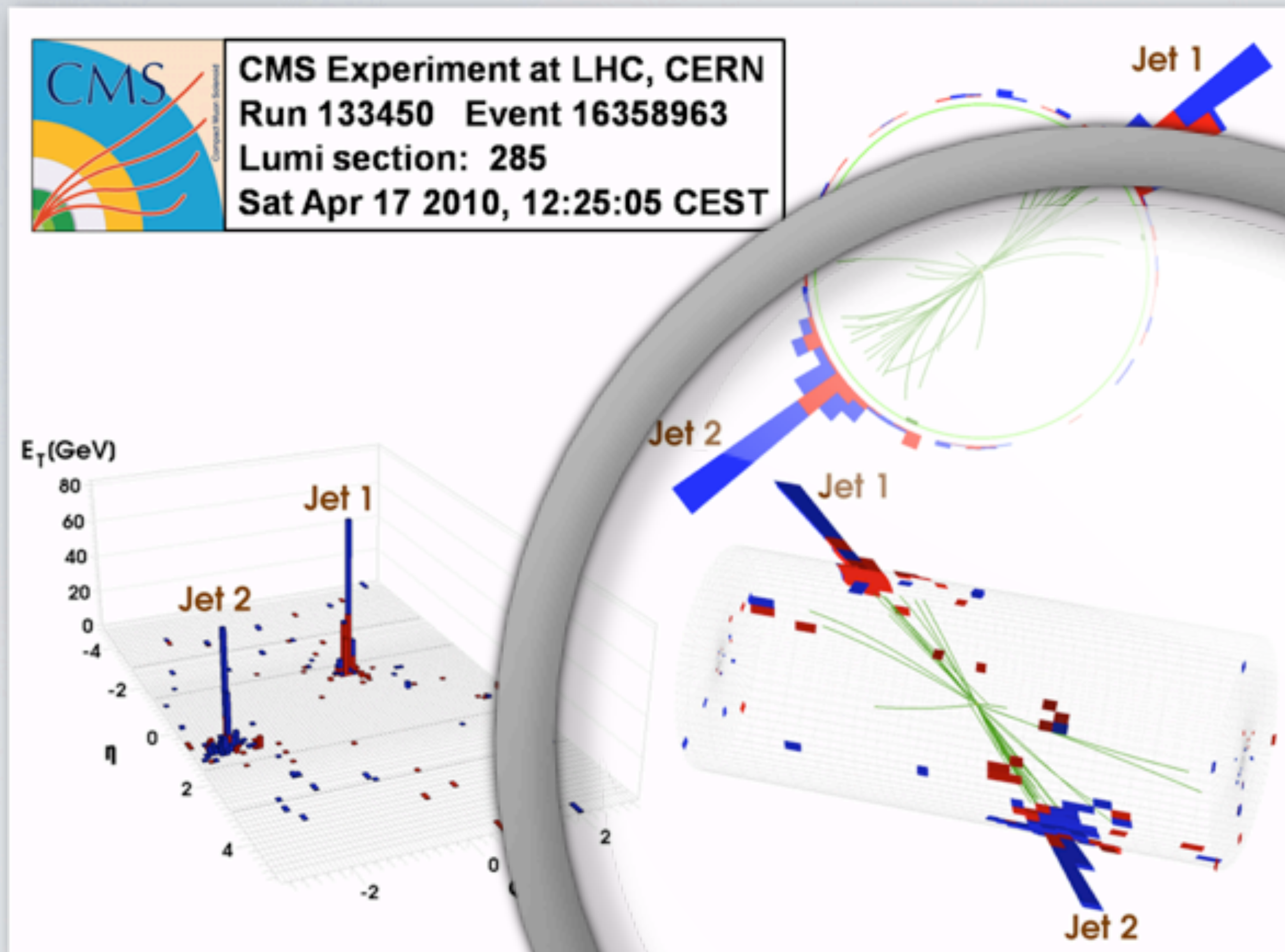
Jets and their properties



- collimated, energetic sprays of particles
- are ubiquitous in collider phenomenology
- boundary between theory and experiments

- LHC energy (10^4 GeV) $\gg$ electro-weak scale (10^2 GeV)
- EW-scale particles (new physics, Z/W/H/top) are abundantly produced with a large boost
- their decay-products are then collimated and can be reconstructed in a single jet

Jets and their properties



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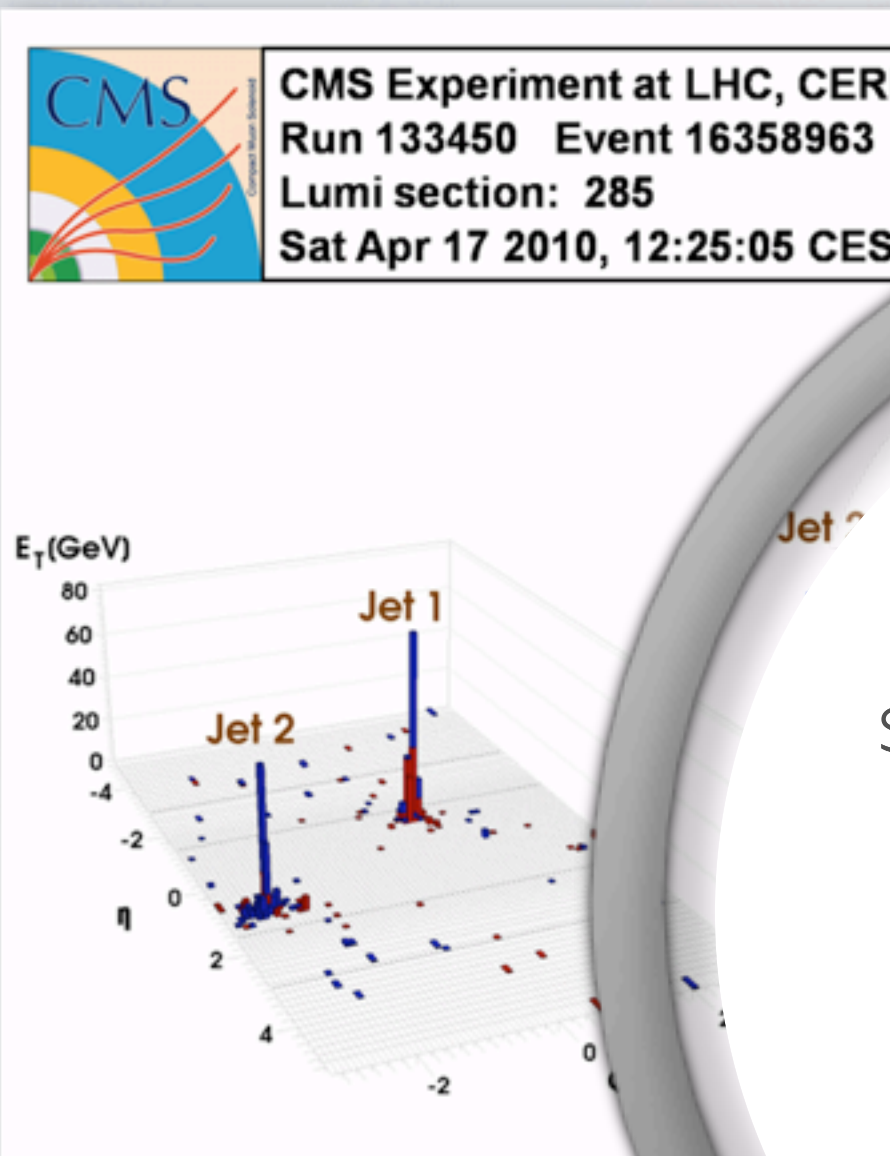

collimated, energetic
sp ys of particles
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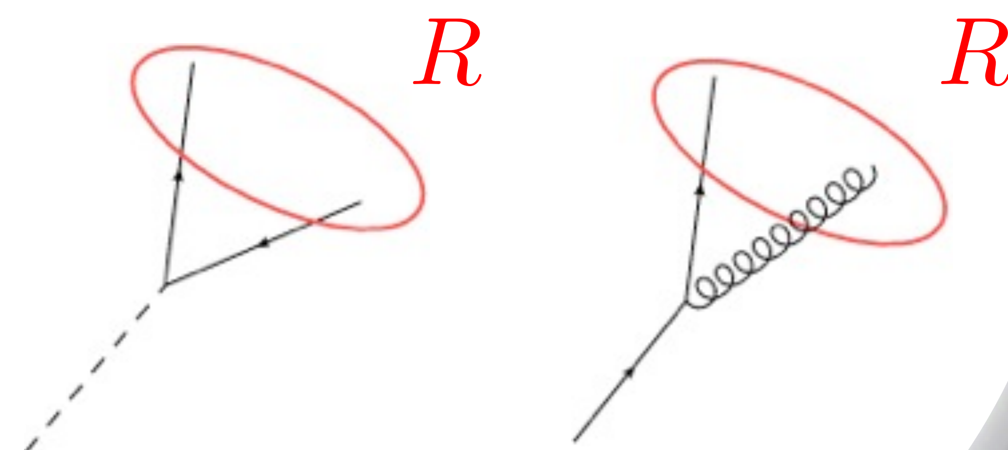
exploit jets' properties

to distinguish

signal jets from bkgd jets



$$p_t > 2m/R$$

- LHC energy (1 4 e (10² GeV)
- EW-scale particle (n op) re abundantly produced with a larg boost
- their decay-products are t ted and reconstructed in a single jet

Jet mass

- It's the simplest variable describing the structure of a jet
- How well can we compute it ?
- Jet mass distributions are affected by *double* (soft & collinear) logarithms

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}m_J^2} = \frac{1}{m_J^2}\left[\alpha_s A_1 \ln\frac{m_J^2}{p_T^2} + \alpha_s^2 A_2 \ln^3\frac{m_J^2}{p_T^2} + \ldots\right]$$

- Reliable estimates of jet shapes should include:
  - fixed-order calculations at NLO (OK with public codes)
  - resummed (N)NLL predictions

Jet mass: all-order calculations

NLL calculation of the jet mass in p-p collision

Banfi, Dasgupta, Khelifa-Kerfa and S.M. (2010)
Dasgupta, Khelifa-Kerfa, S.M. and Spannowsky (2012)

Calculations also in SCET

Chien, Kelley, Schwartz and Zhu (2012)
Jouttenus, Stewart, Tackmann and Waalewijn (2013)

For an isolated jet (small-R limit) the NLL cumulative distribution is

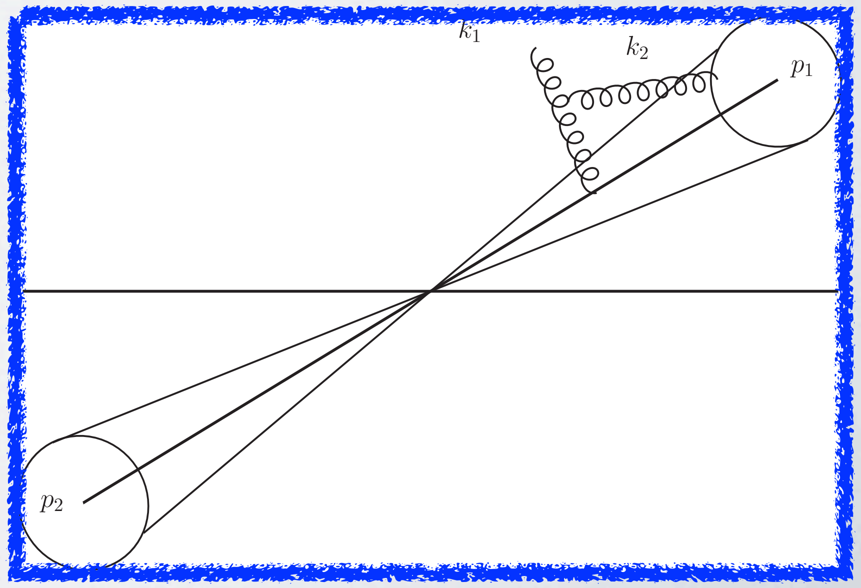
independent emissions — multiple emissions

$$\Sigma(\rho) \equiv \frac{1}{\sigma}\int^{\rho} d\,\rho' \frac{d\sigma}{d\rho'} = e^{-D(\rho)} \cdot \frac{e^{-\gamma_E D'(\rho)}}{\Gamma(1+D'(\rho))} \cdot \mathcal{N}(\rho)$$

correlated emissions

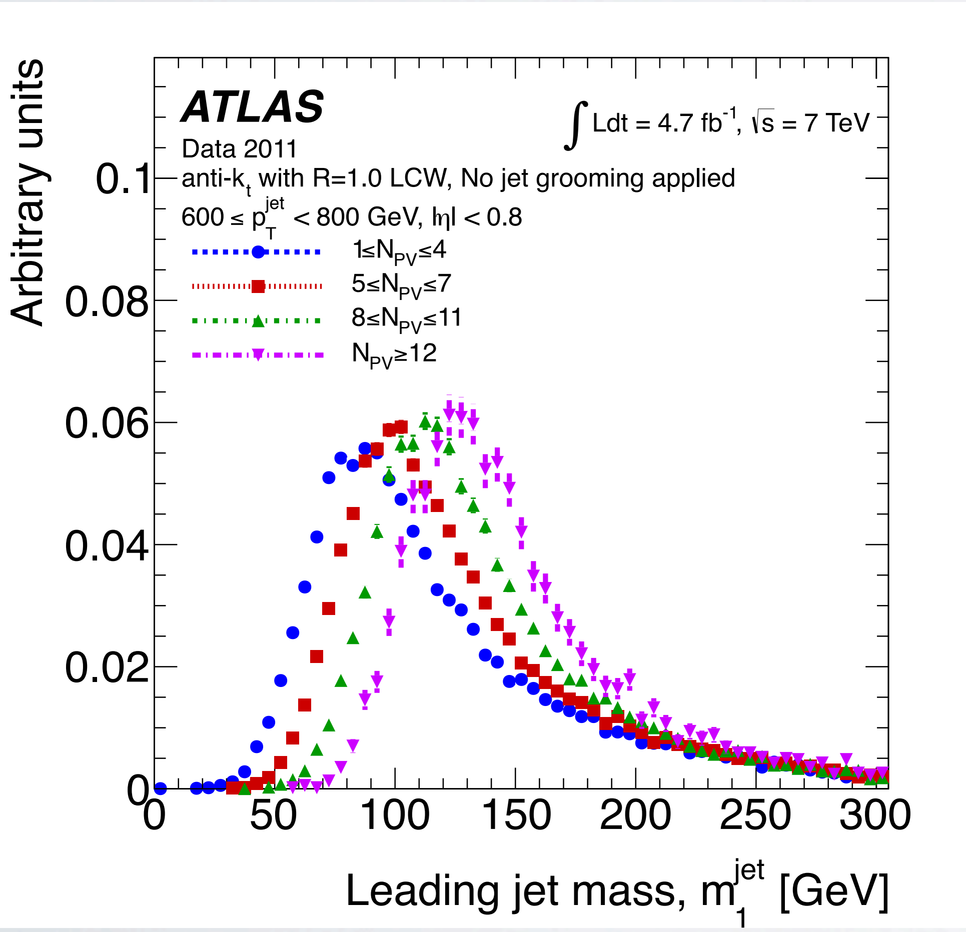
$$\rho = \frac{m_j^2}{p_t^2 R^2}$$

non-global logs: difficult to resum
dependence on the jet algorithm



Beyond the mass: substructure

- Multiple interactions (UE and pile-up) shift background peak to the EW region
- Need to go beyond the mass and exploit jet substructure
- Grooming and Tagging:
  1. clean the jets up by removing soft junk
  2. identify the features of hard decays and cut on them



ATLAS, JHEP 1309 (2013) 076

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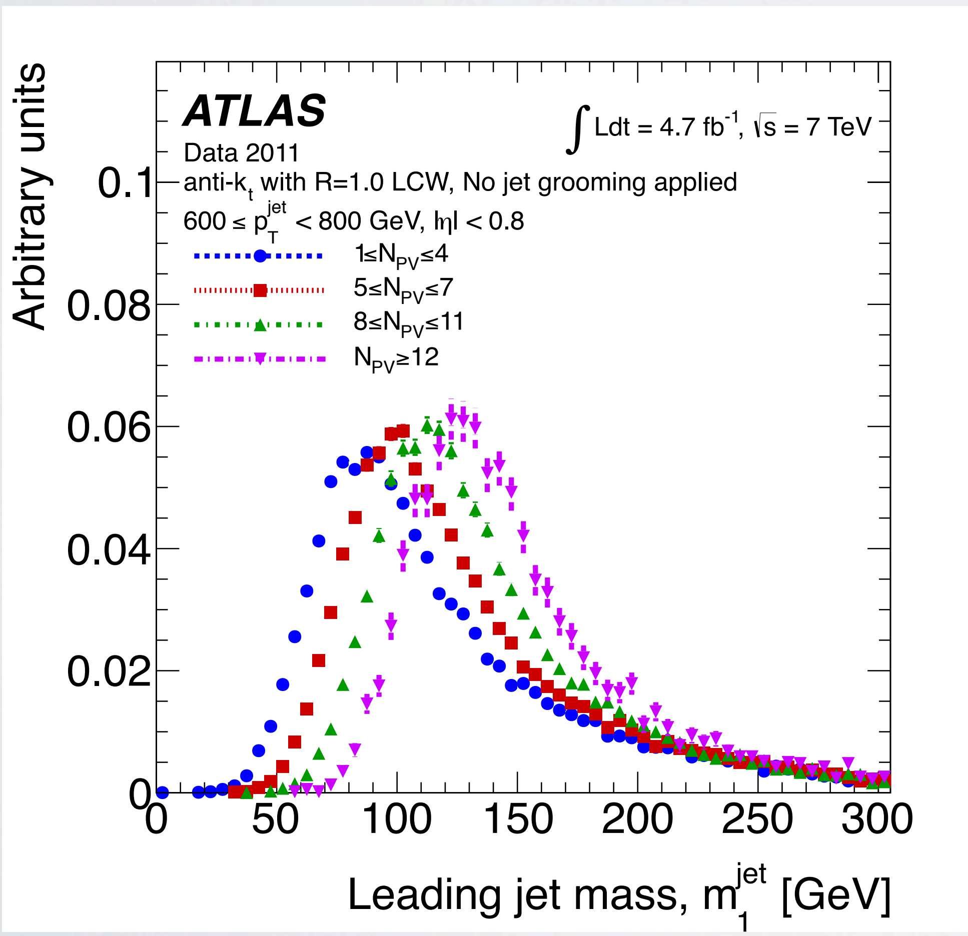

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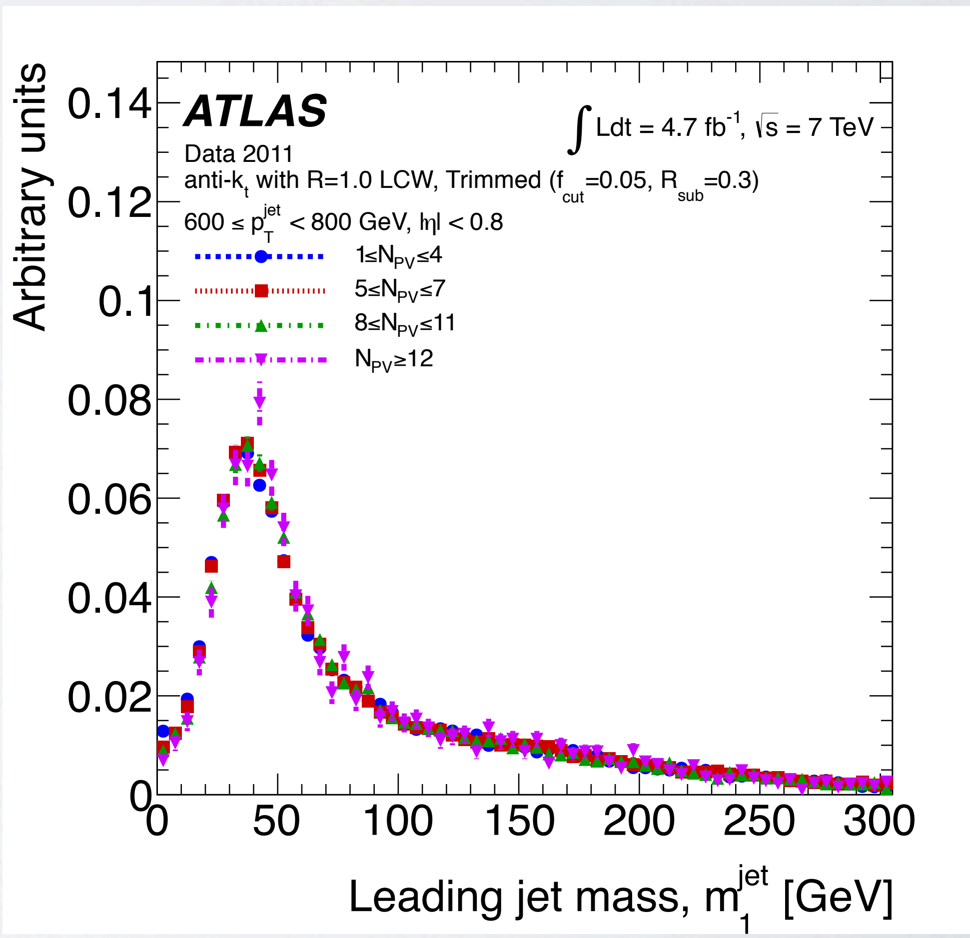
grooming



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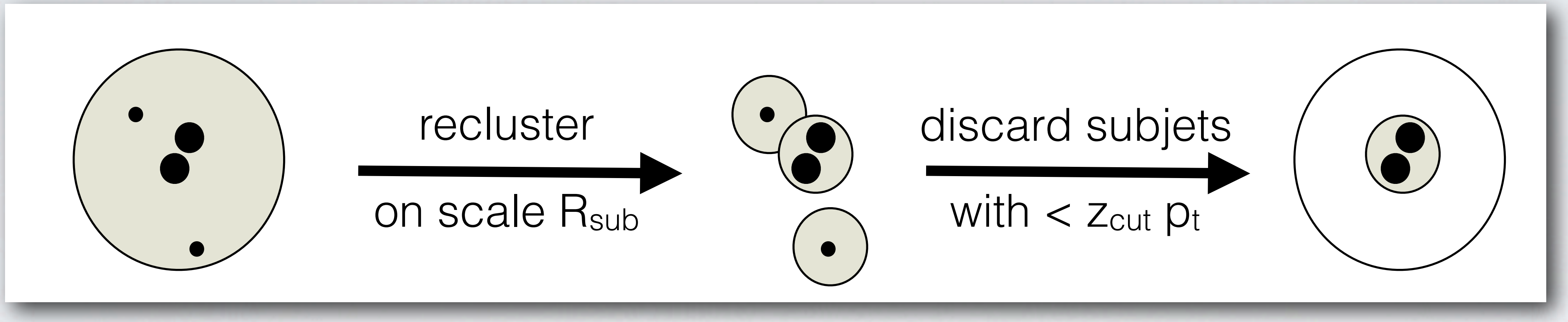
Trimming

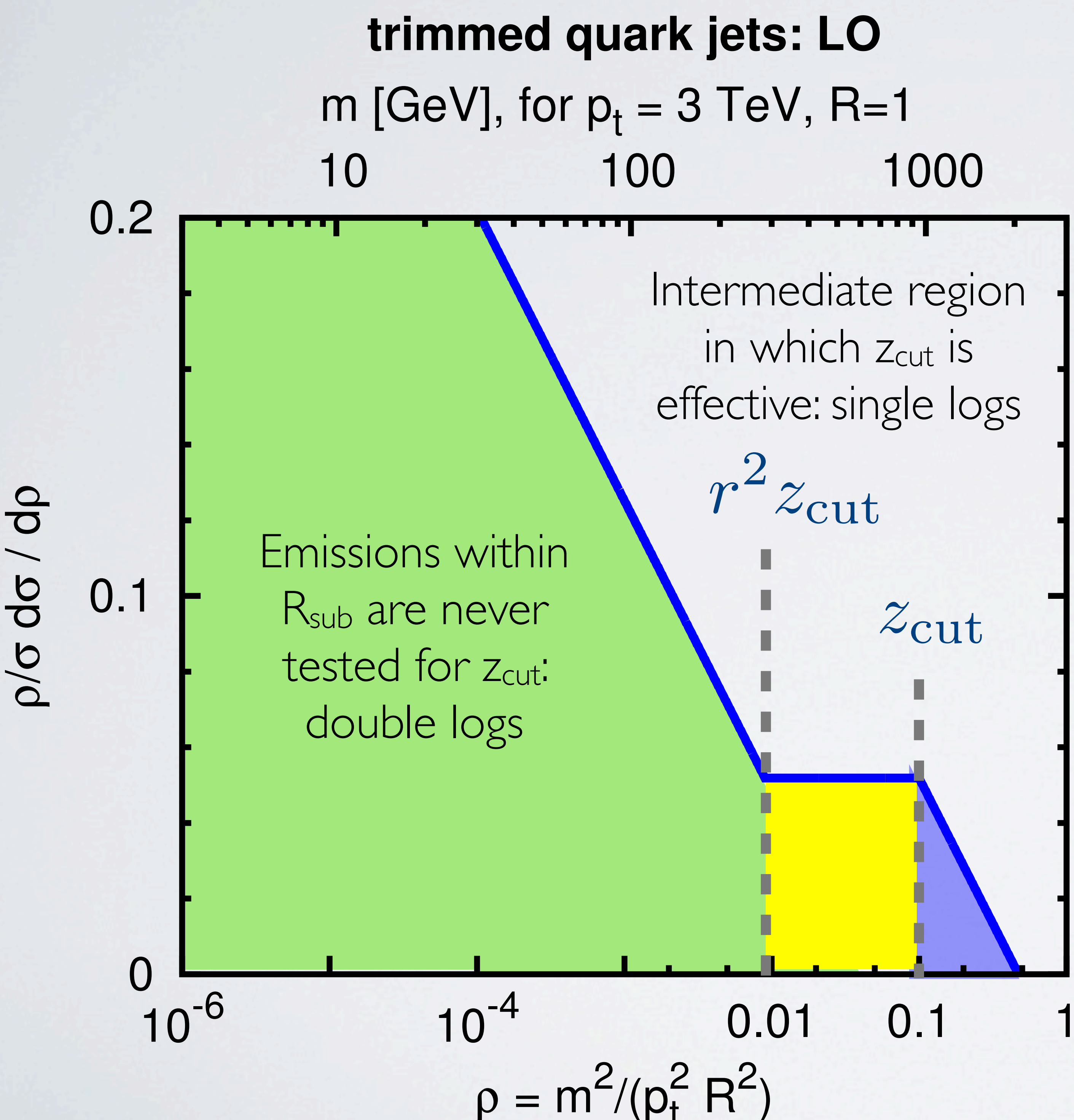
Krohn, Thaler and Wang (2010)

1. Take all particles in a jet and re-cluster them with a smaller jet radius $R_{sub} < R$
2. Keep all subjets for which $p_t^{subjet} > z_{cut}\, p_t$
3. Recombine the subjets to form the trimmed jet



- a theorist's worry: complicated algorithms with many parameters
- Q: Are we giving up on calculability / precision QCD ?

Trimming at LO



$$\frac{\rho}{\sigma}\frac{d\sigma^{(\rm trim,LO)}}{d\rho} =$$

$$\frac{\alpha_s C_F}{\pi}\left(\ln\frac{r^2}{\rho} - \frac{3}{4}\right)$$

$$\frac{\alpha_s C_F}{\pi}\left(\ln\frac{1}{z_{\rm cut}} - \frac{3}{4}\right)$$

$$\frac{\alpha_s C_F}{\pi}\left(\ln\frac{1}{\rho} - \frac{3}{4}\right)$$

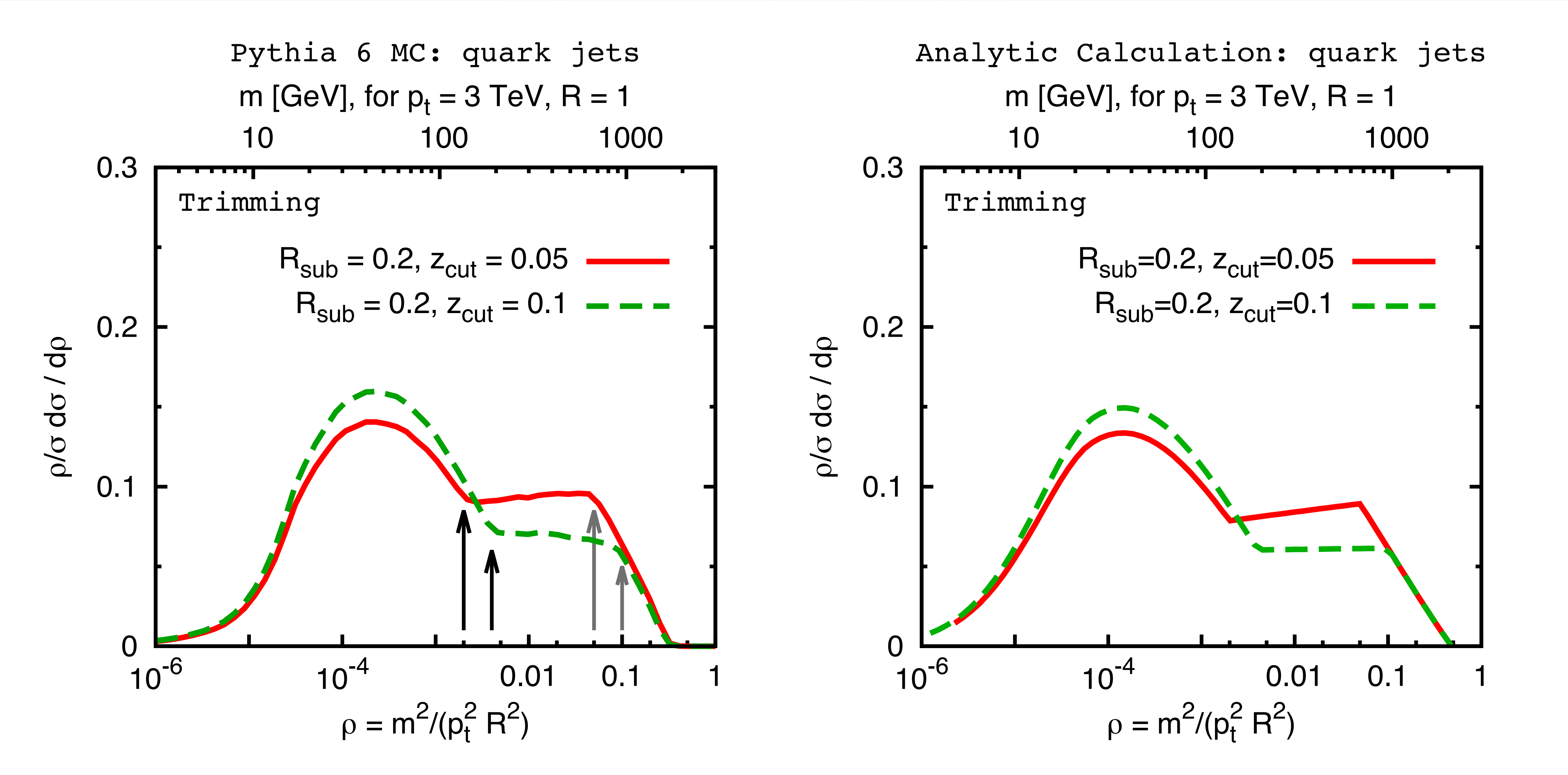
$$r = \frac{R_{\rm sub}}{R}$$

Dasgupta, Fregoso, SM and Salam (2013)
Dasgupta, Fregoso, SM and Powling (2013)

Trimming: all orders

One gets exponentiation of LO (+ running coupling)

$$\frac{d\sigma^{\text{trim,resum}}}{d\rho} = \frac{d\sigma^{\text{trim,LO}}}{d\rho} \exp\left[-\int_{\rho} d\rho' \frac{1}{\sigma}\frac{d\sigma^{\text{trim,LO}}}{d\rho'}\right]$$



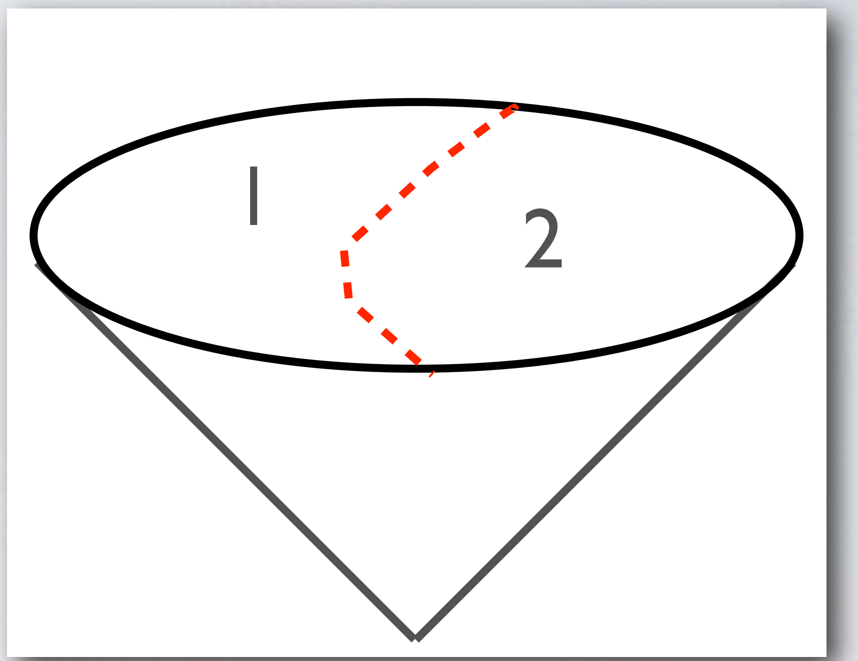
A: groomed-mass distributions understood with resummation

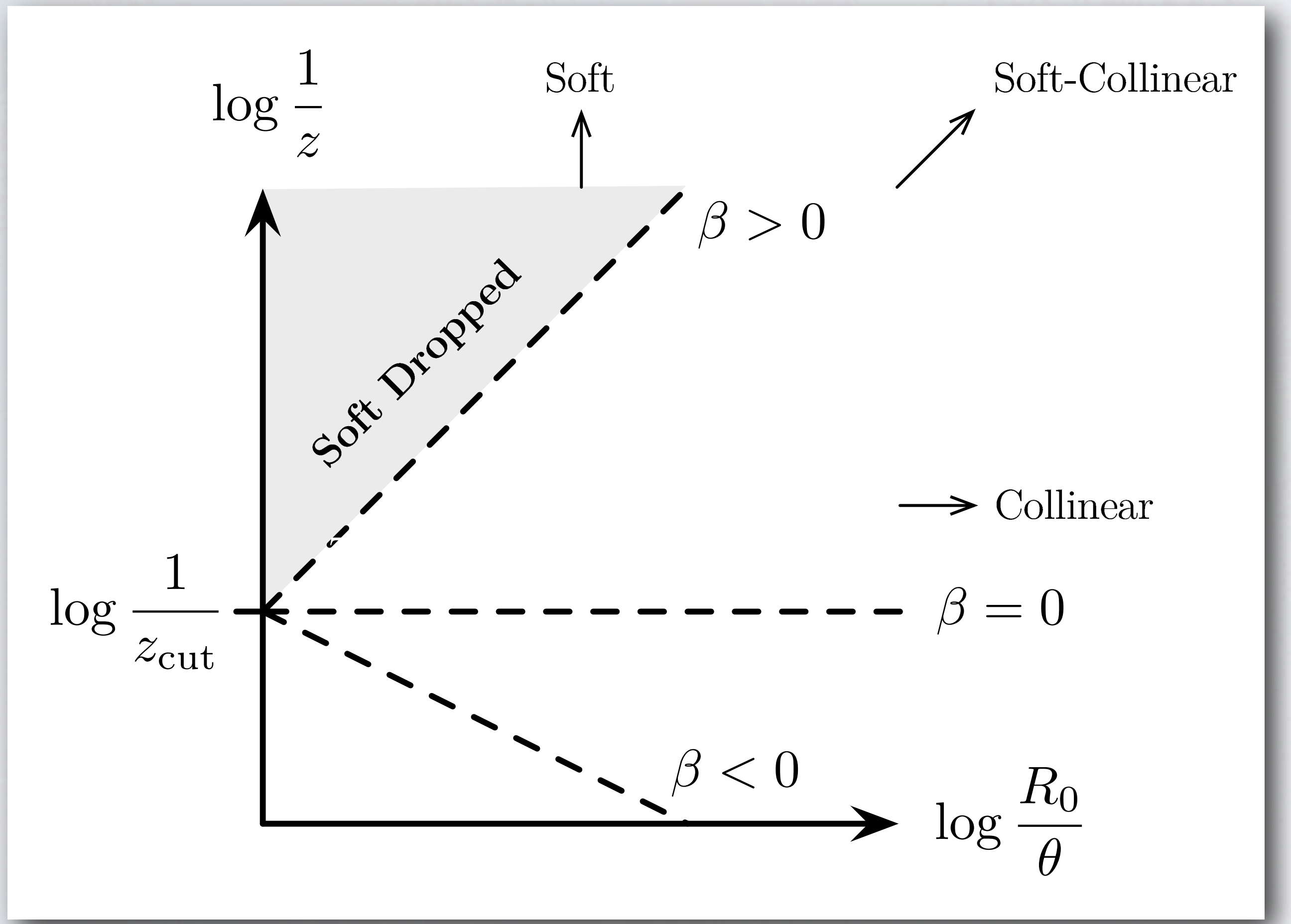
Dasgupta, Fregoso, SM and Salam (2013)

Soft drop

- Soft Drop: recursive de-clustering of a jet that checks

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$





$\beta > 0$ grooming mode (dynamical trimmer)

$\beta = 0$ mMDT BDRS (2008)

$\beta < 0$ tagging mode (cut on pure collinear)

Larkoski, SM, Soyez and Thaler (2014)

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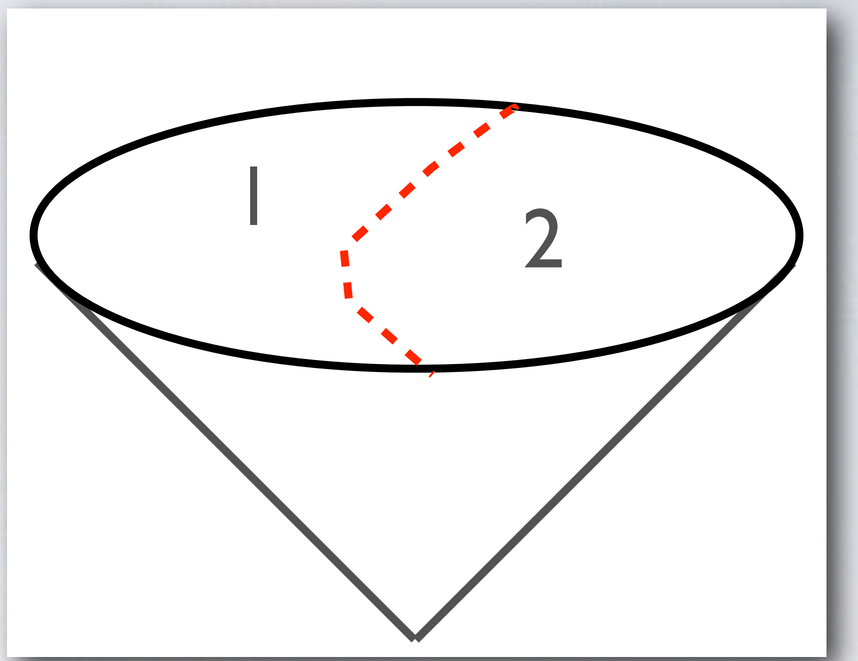

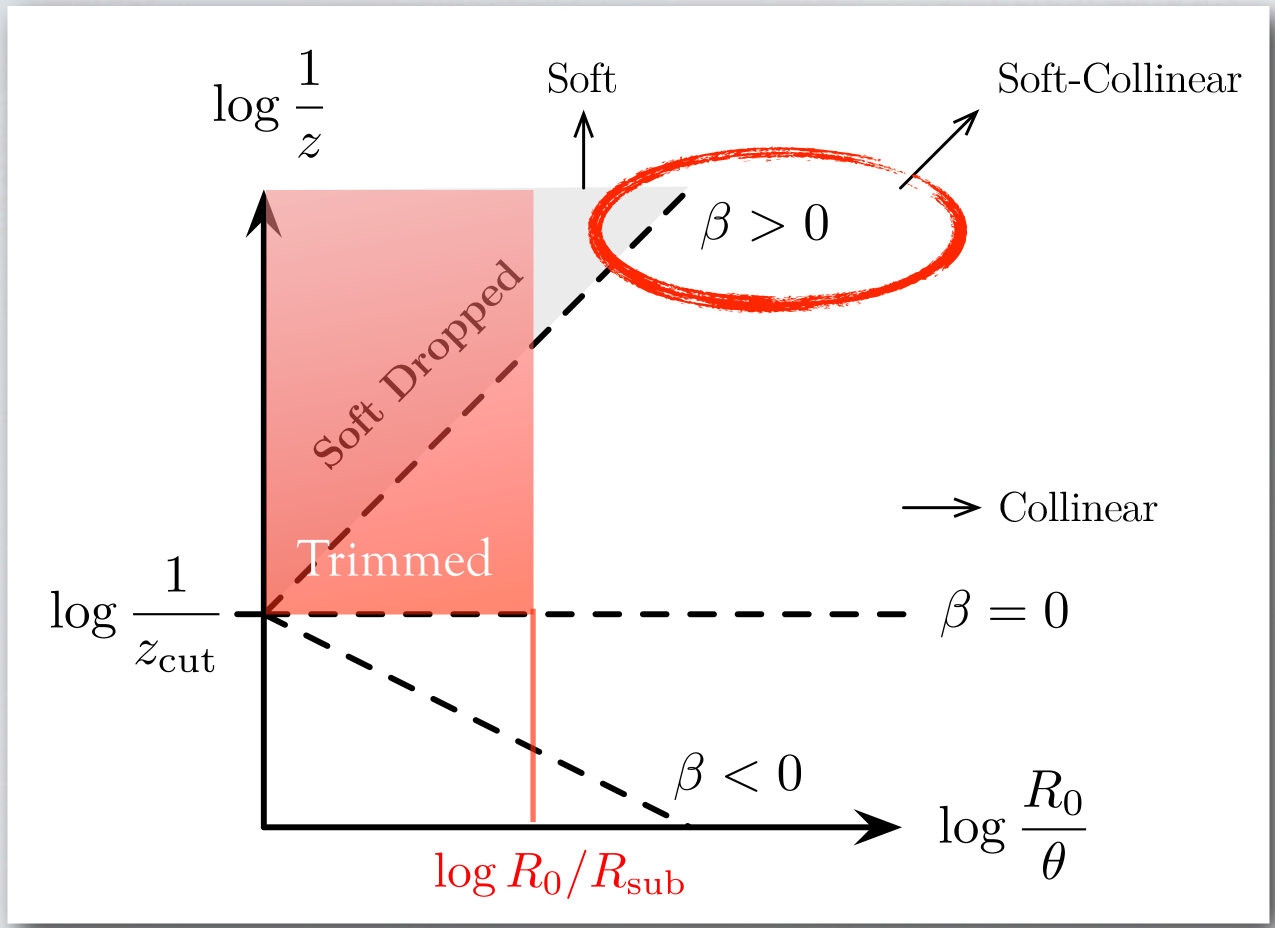

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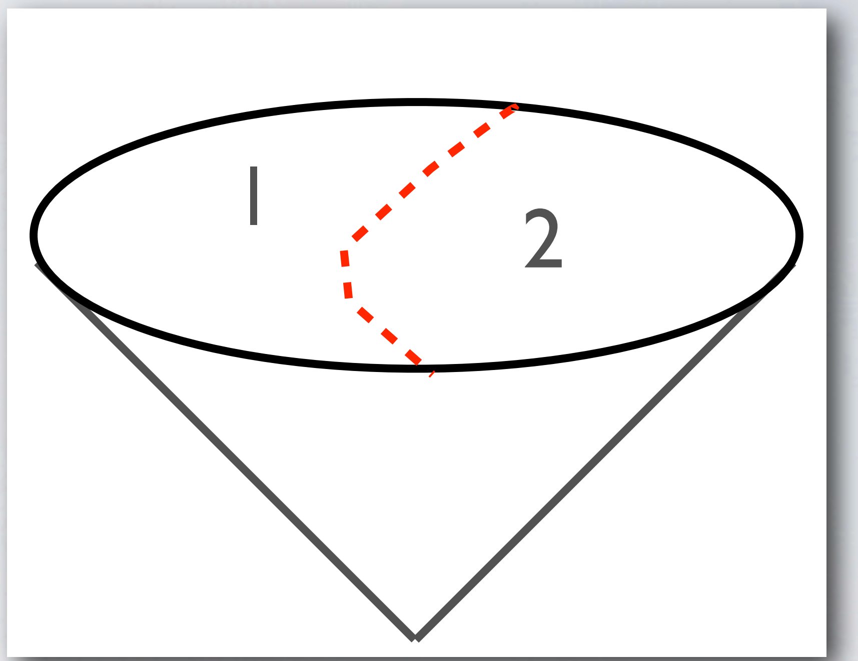

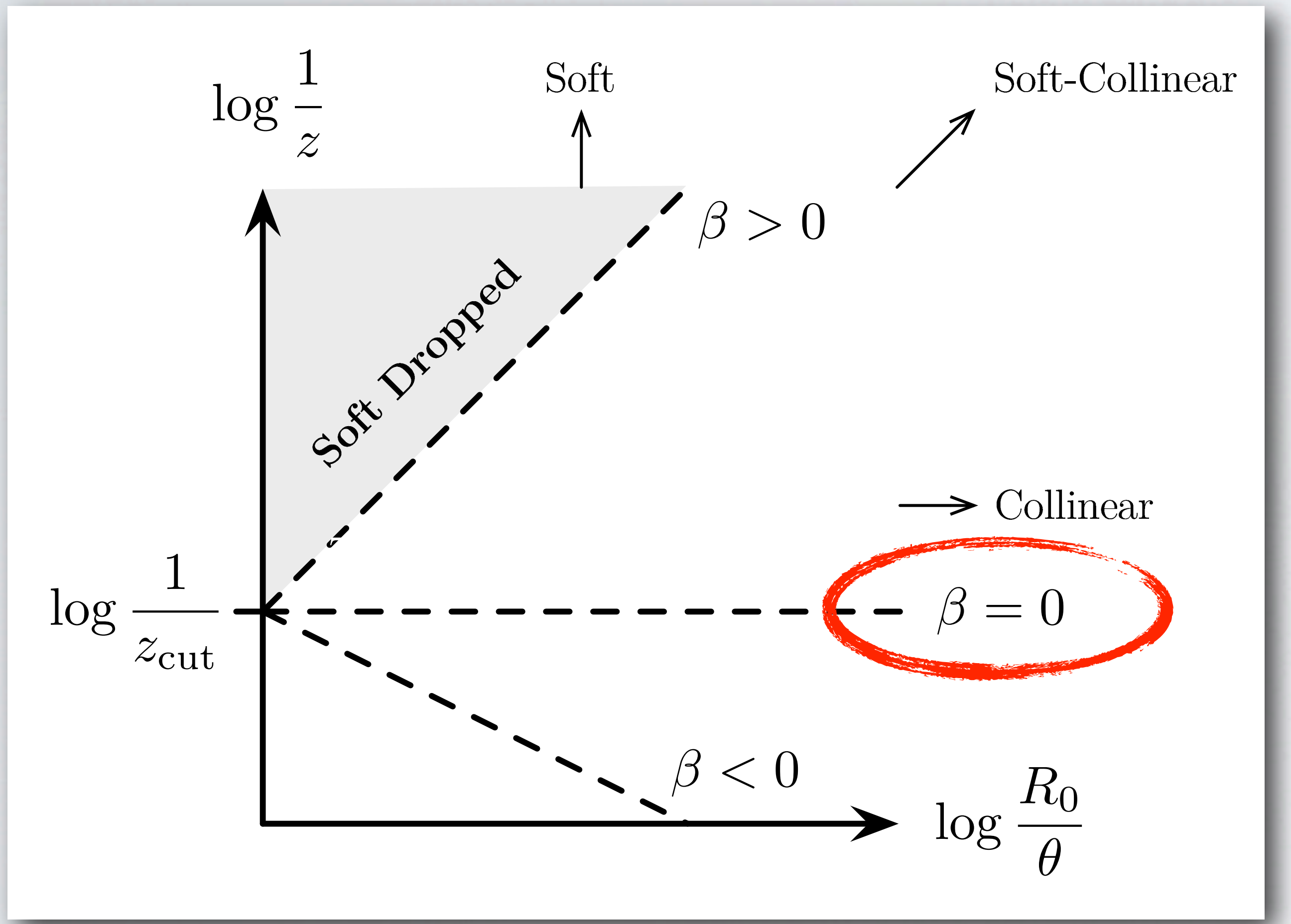

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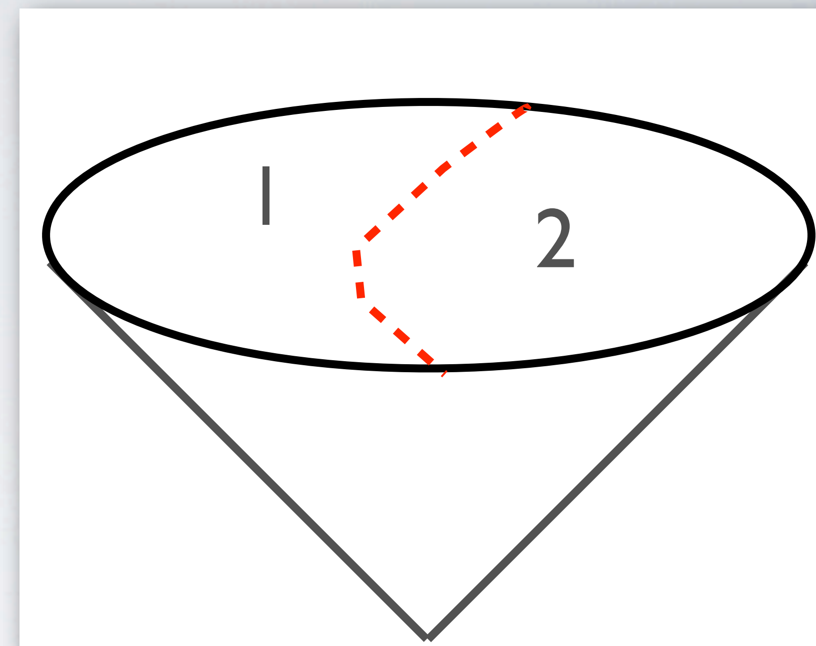

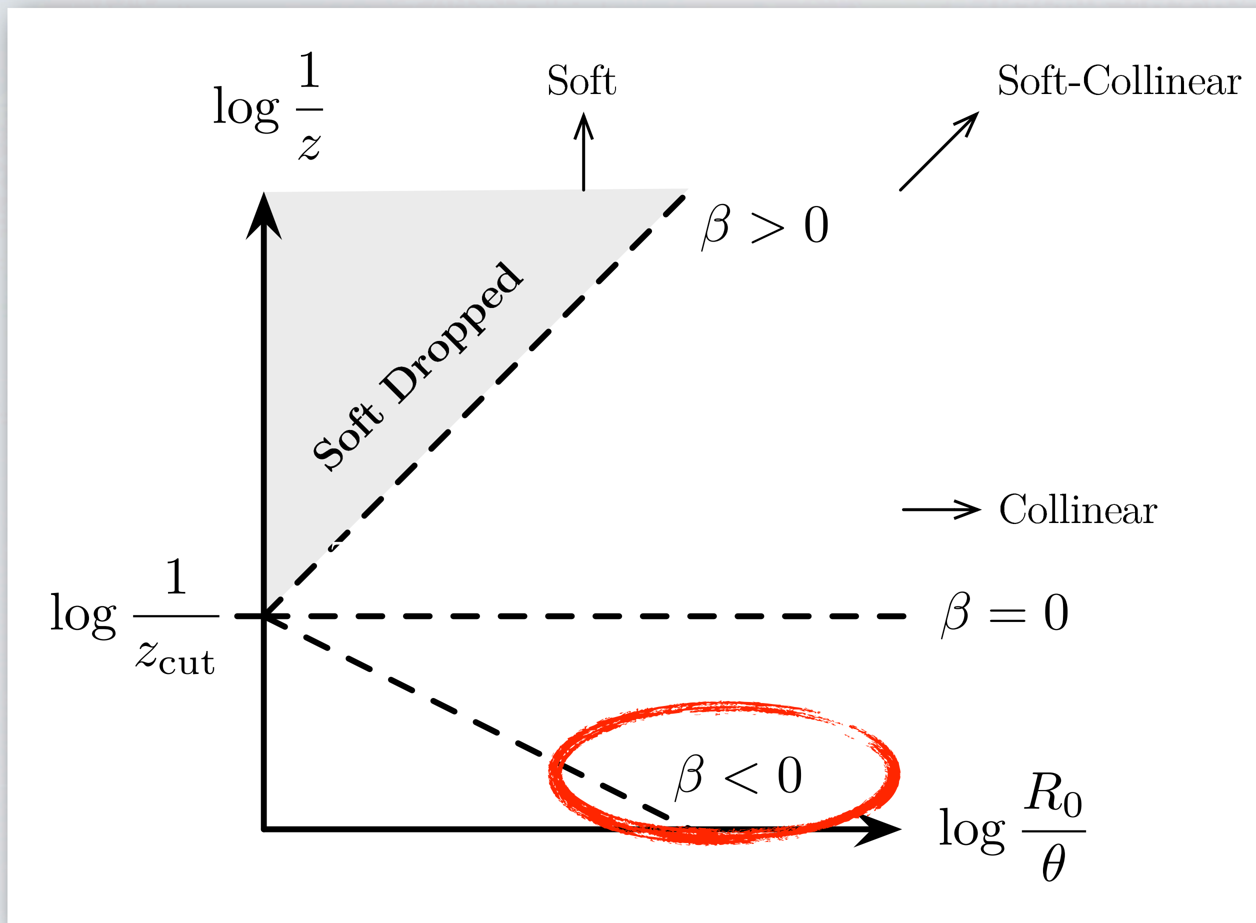

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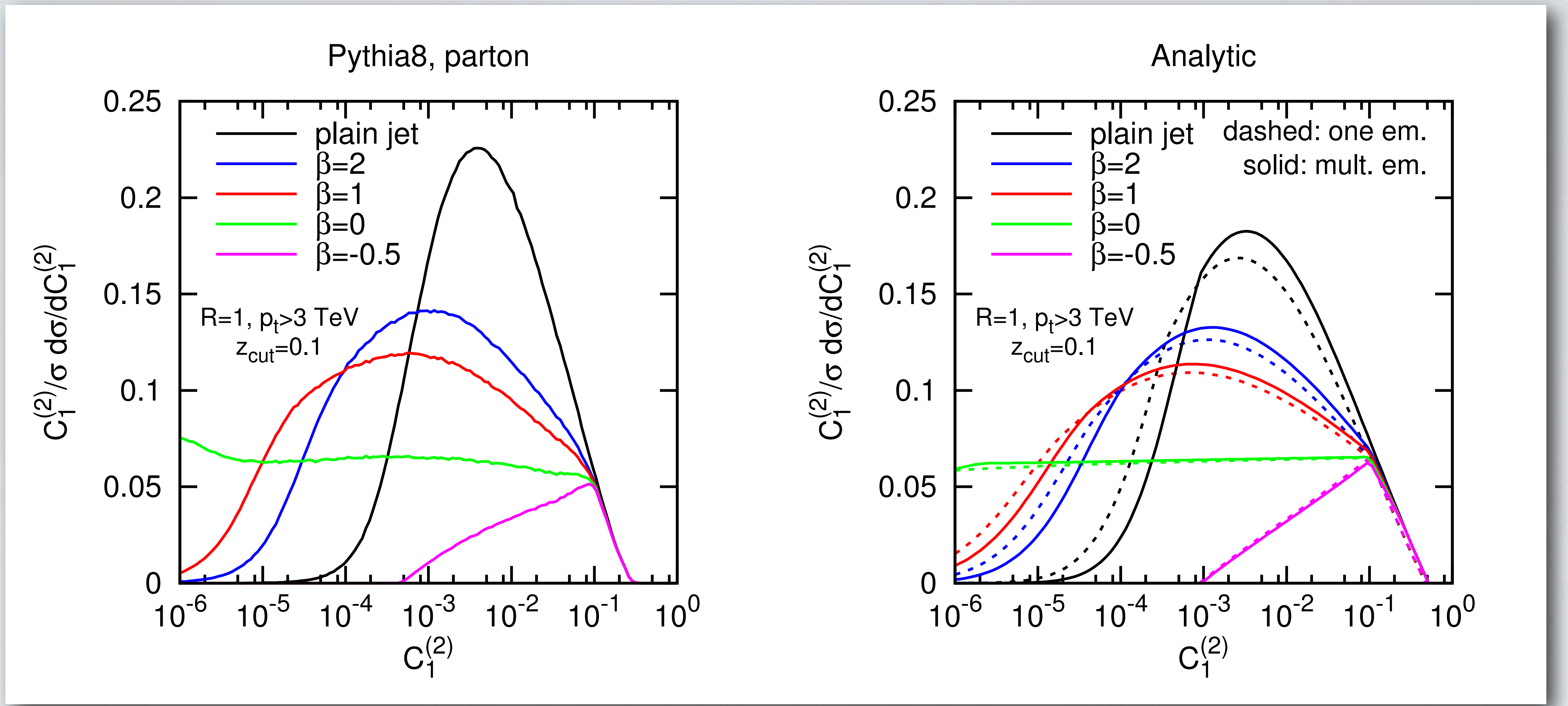
Soft-dropped 2-point correlations

$$\mathrm{ECF}\,(2,\alpha) = \sum_{i<j\,\in \mathrm{jet}} p_{Ti}\, p_{Tj} \left(\frac{\Delta R_{ij}}{R_0}\right)^{\alpha} \qquad C_1^{(\alpha)} = \frac{\mathrm{ECF}\,(2,\alpha)\,\mathrm{ECF}\,(0,\alpha)}{\mathrm{ECF}\,(1,\alpha)^2}$$

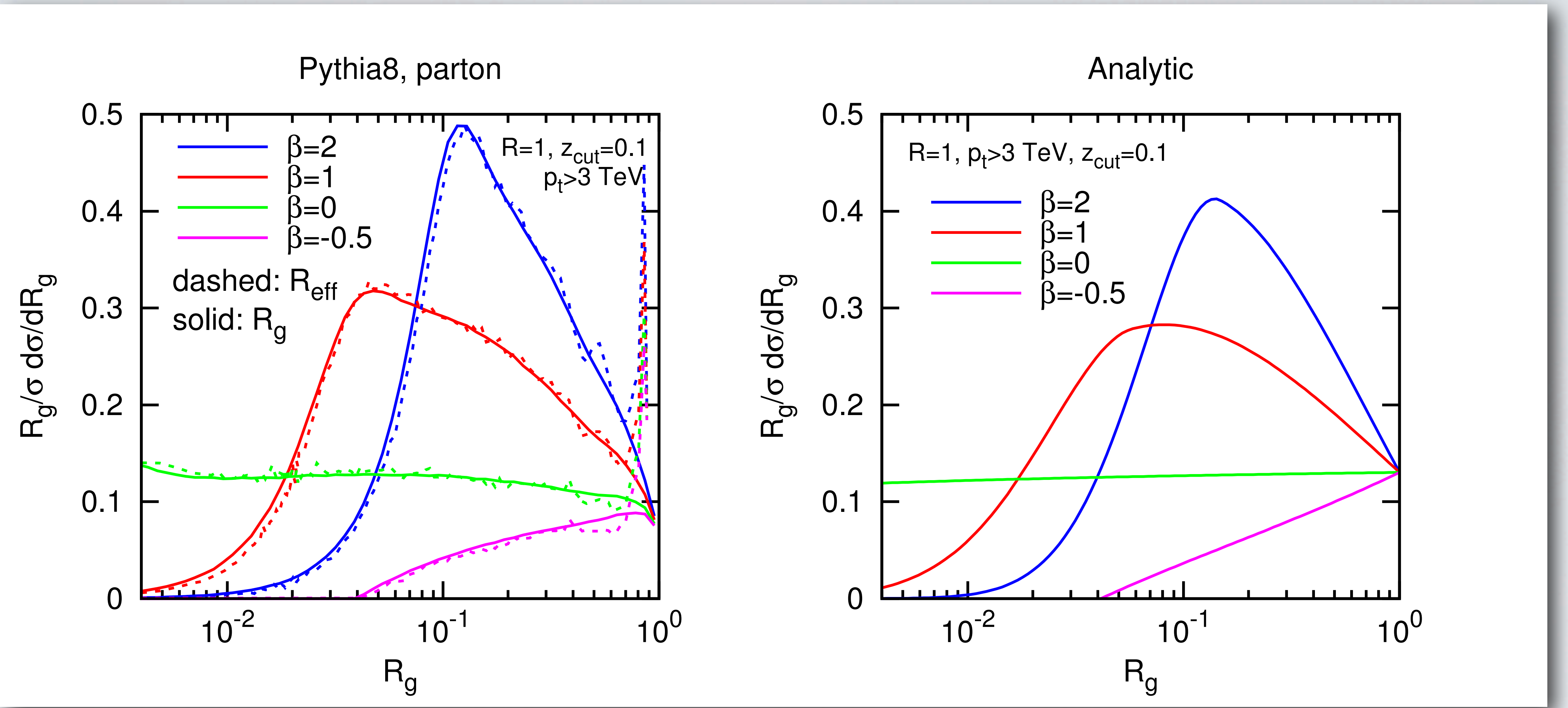
Larkoski, Salam and Thaler (2013)



- large-angle soft is removed; soft-collinear ~**β**
- non-global logs are power-suppressed
- mMDT (**β**=0) is remarkable: only single (collinear) logs
- better agreement between MC and analytics

Groomed jet radius

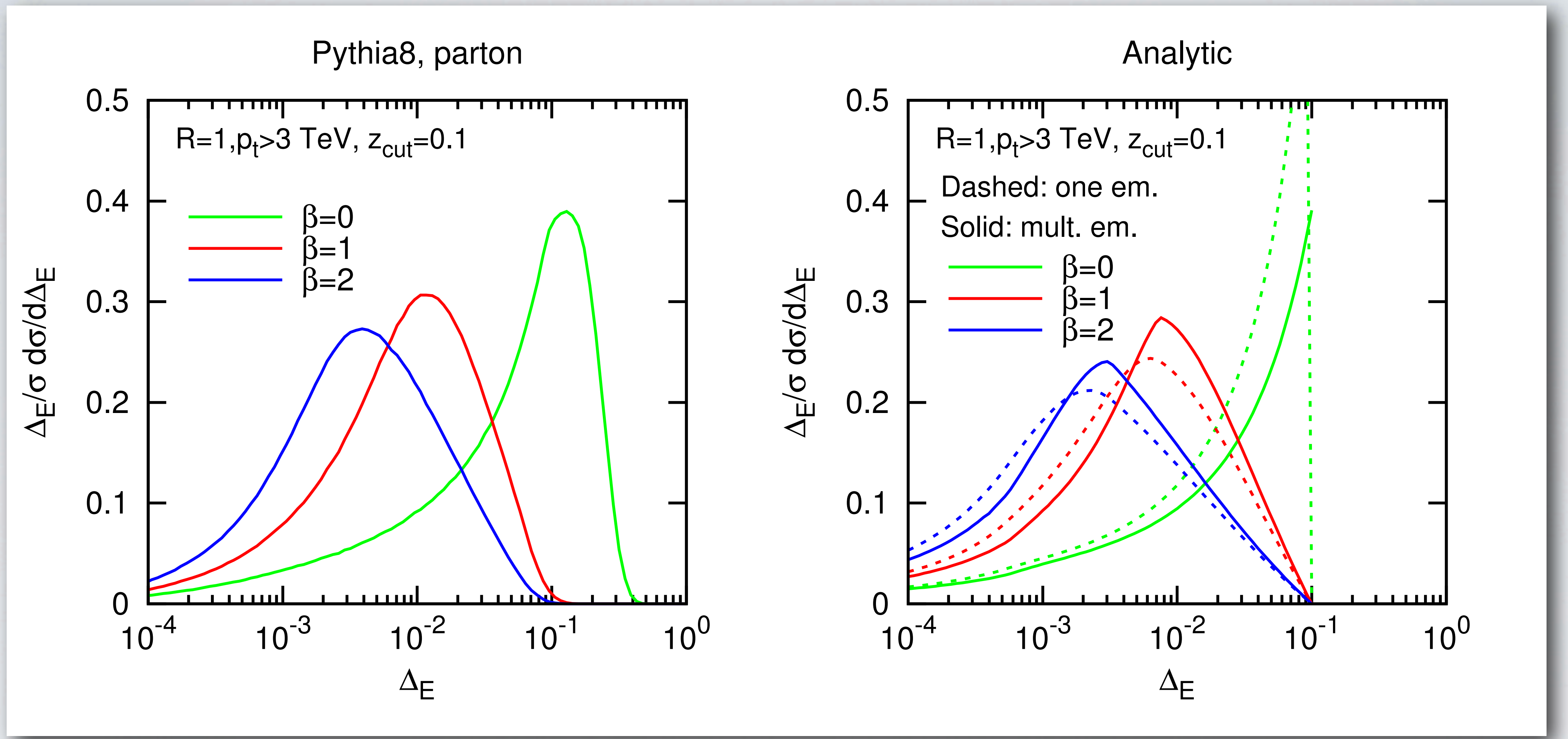
- Analytic control opens up the possibility of understanding different properties of groomed jets



- Good agreement between analytics, MC and jet-area methods

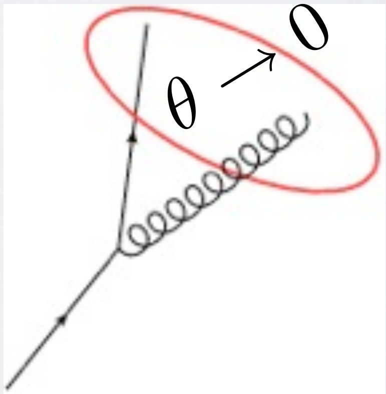
Jet Energy Drop

- What is the amount of energy which has been groomed away ?



- Not collinear safe for **β**=0 (mMDT)

$$\Sigma^{\text{energy-drop}}(\Delta_E) = 1 - \frac{\alpha_s}{\pi}\frac{C_i}{\beta}\log^2\frac{z_{\text{cut}}}{\Delta_E} + \mathcal{O}\left(\left(\frac{\alpha_s}{\beta}\right)^2\right)$$



always contributes if

$z < z_{\text{cut}}$

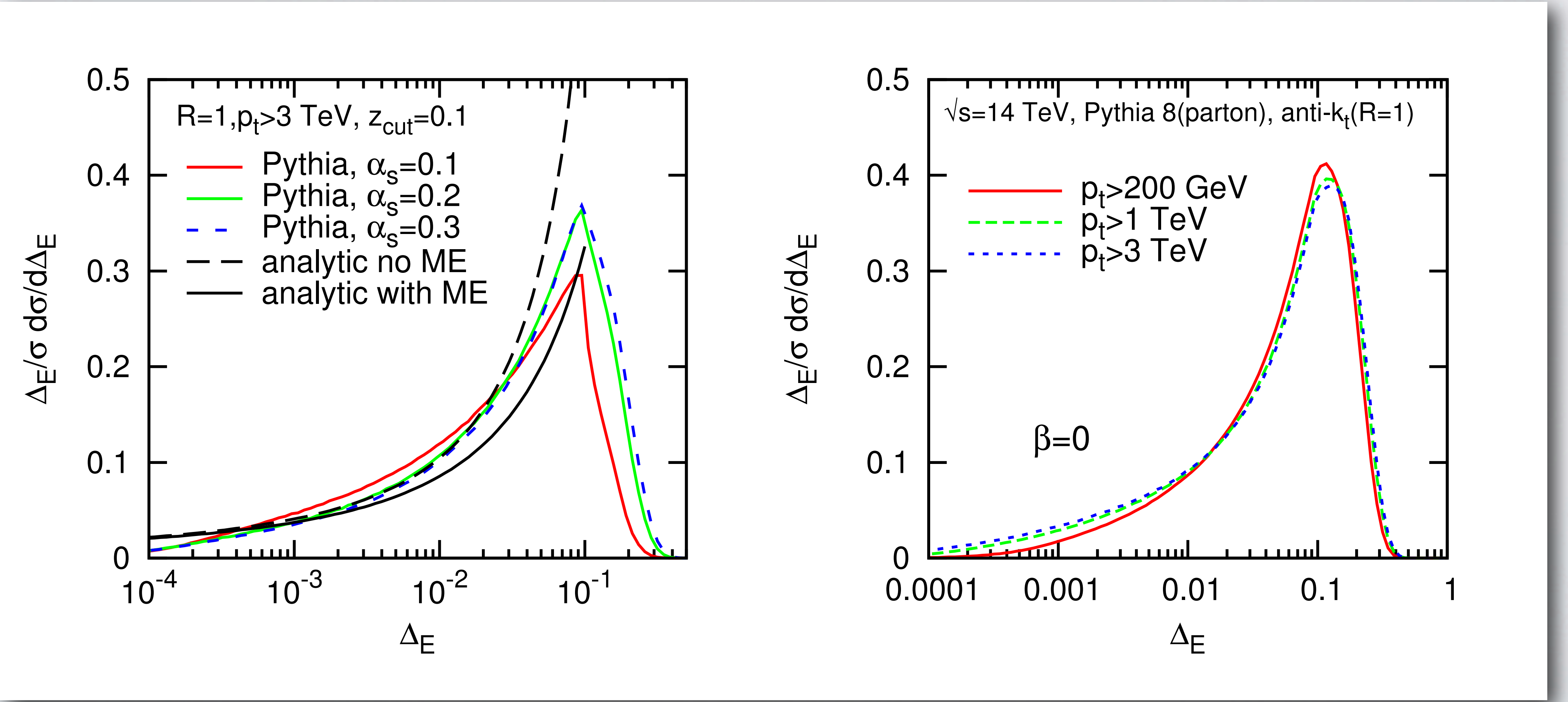
Sudakov Safety

Larkoski and Thaler (2013)

- Compute to all orders and then take **β**=0

$$\Sigma^{\text{energy-drop}}(\Delta_E)_{\beta=0} = \frac{\log z_{\text{cut}} - B_i}{\log \Delta_E - B_i}$$

- finite result which does not depend on **α_s** (at fixed coupling)



Conclusions

- Jet substructure is playing an important role in LHC phenomenology (searches and measurements)
- The use of these techniques will further increase with Run II
- In the last two years we've begun to reach a deeper (analytic) understanding of groomers and taggers
- Soft drop is an example of this knowledge put at work

Thank you !