PRUNING AND MASS-DROP WITH ANALYTICAL METHODS

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with
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Pruning

1. From an initial jet define pruning radius $R_{prune} \sim m / p_t$
2. Re-cluster the jet, vetoing recombination for which

$$z = \frac{\min(p_{ti}, p_{tj})}{|\vec{p}_{ti} + \vec{p}_{tj}|} < z_{\rm cut}$$

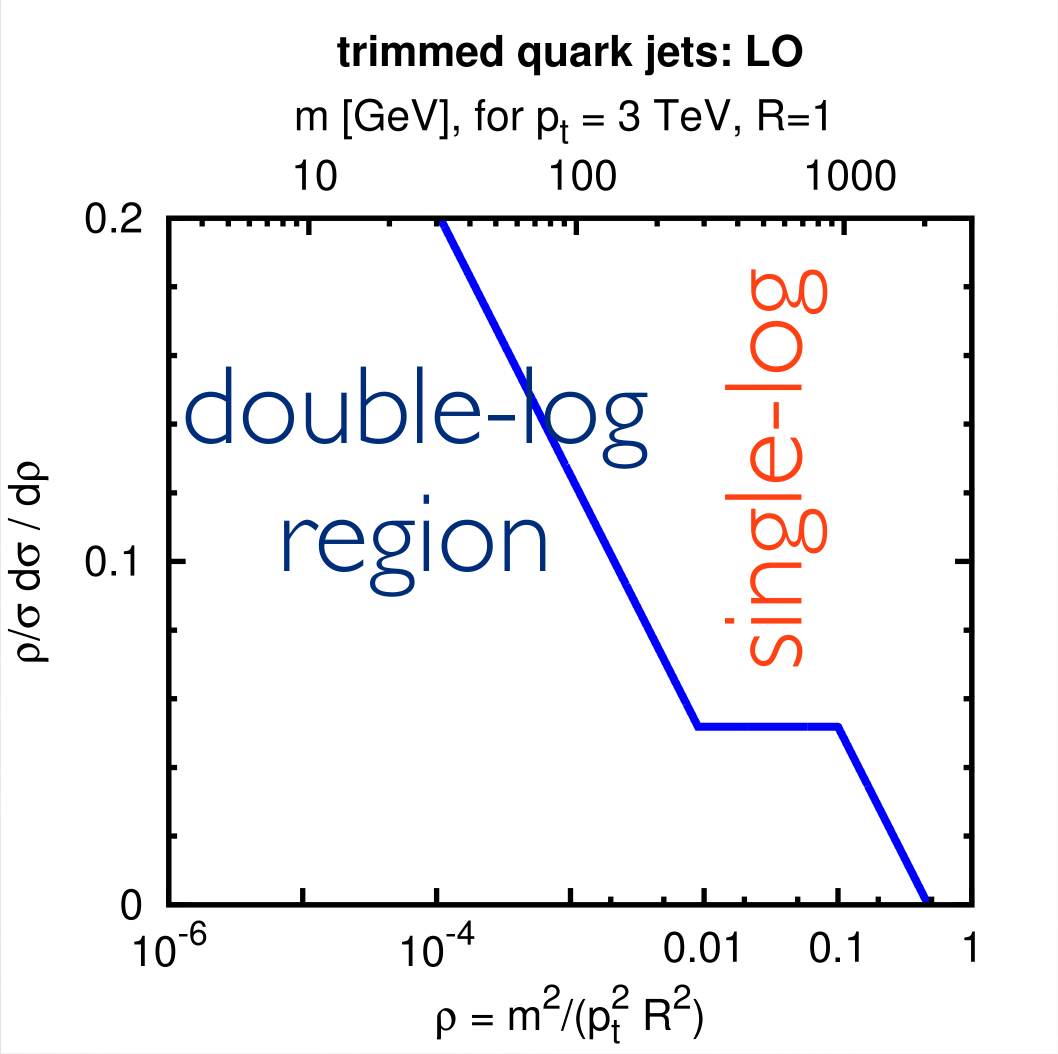
$$d_{ij} > R_{\rm prune}$$

i.e. soft and wide angle

Ellis, Vermillion and Walsh (2009)

LO calculation

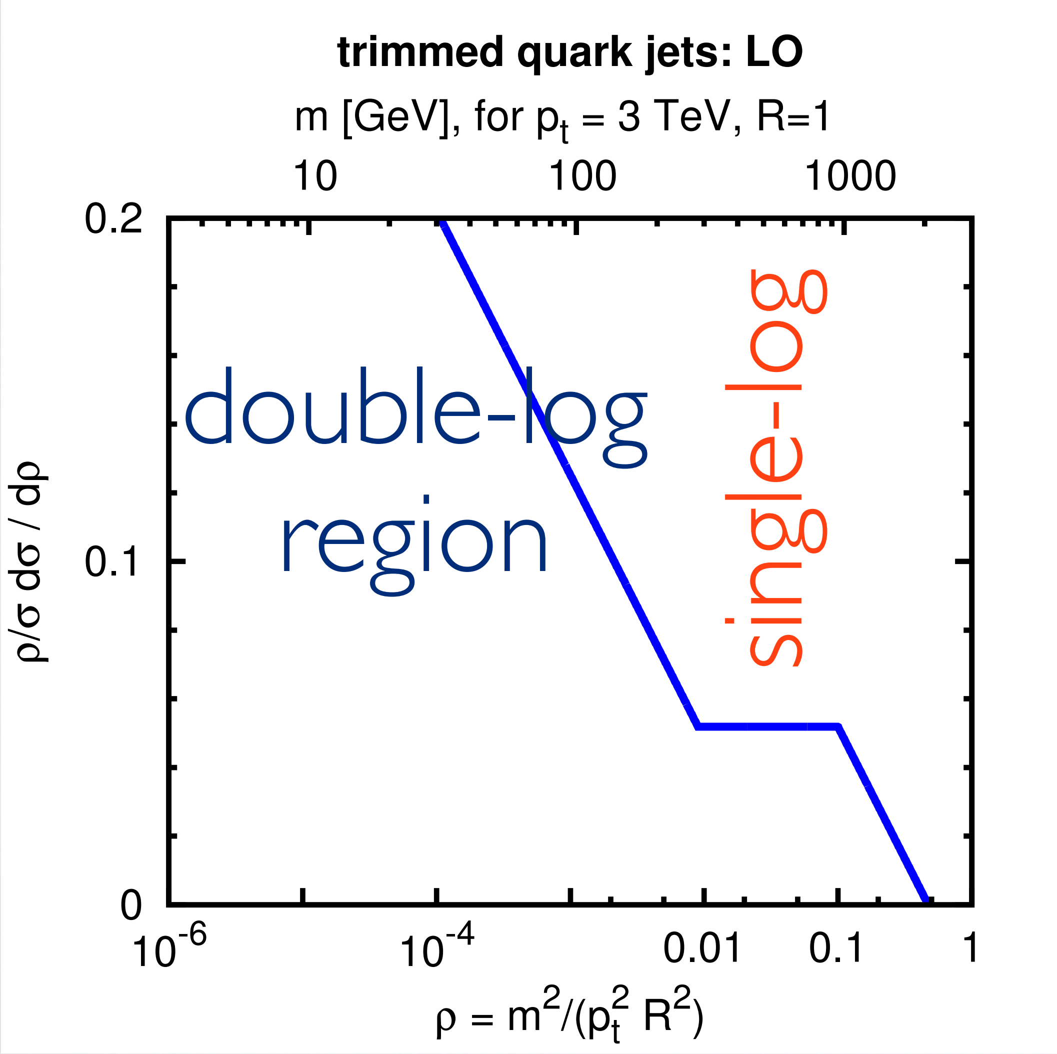
- LO calculation similar to trimming

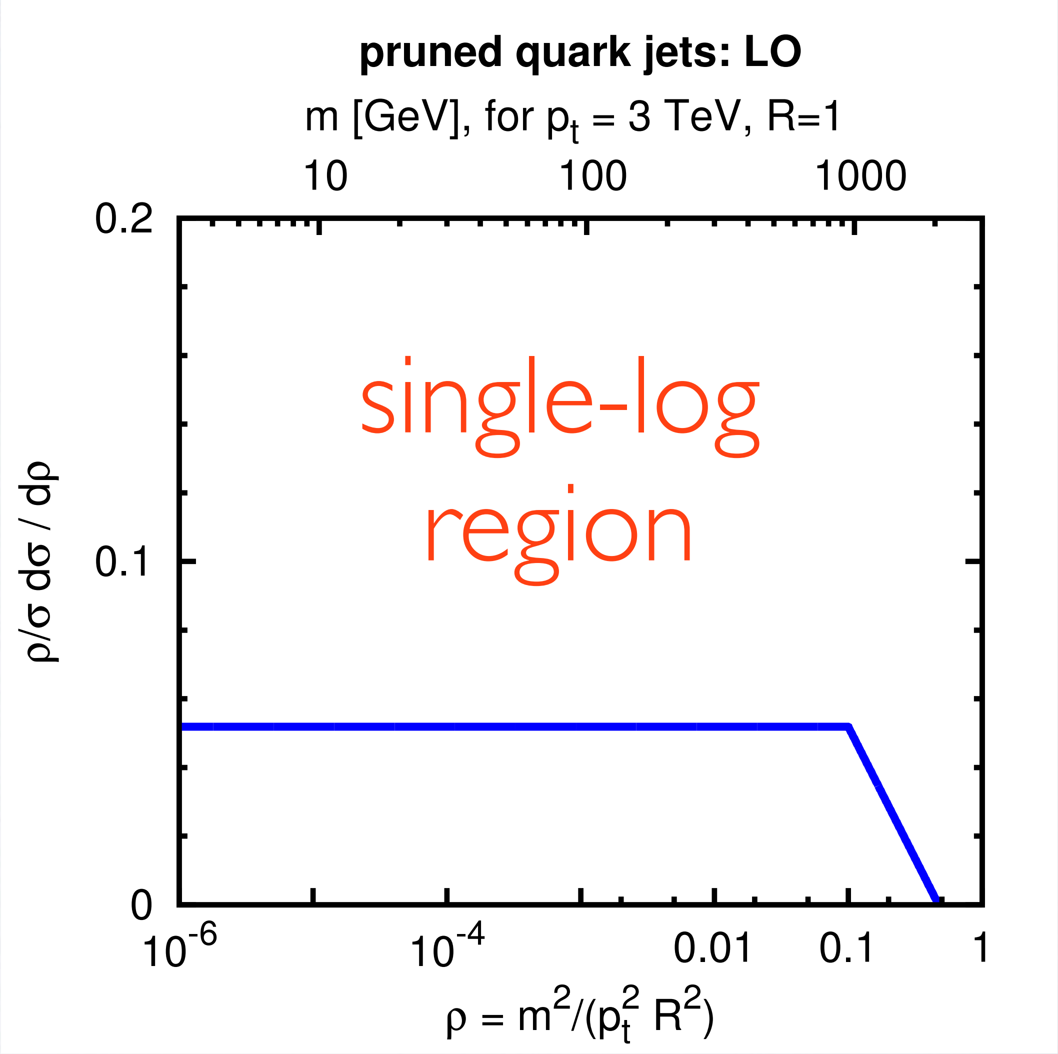


log-counting for cumulant distribution Σ

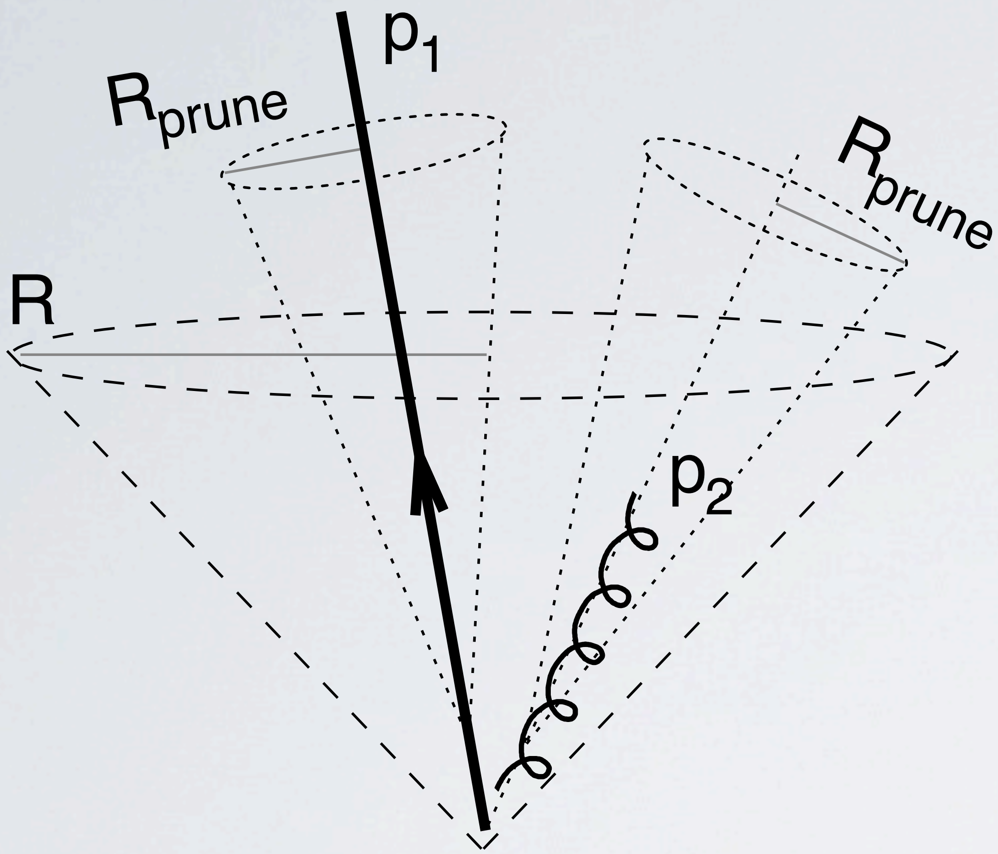
LO calculation

- LO calculation similar to trimming
- The pruning radius is set dynamically: $R_{prune} < d_{ij}$
- The 2 prongs are always tested for z_{cut}: single logs





Beyond LO

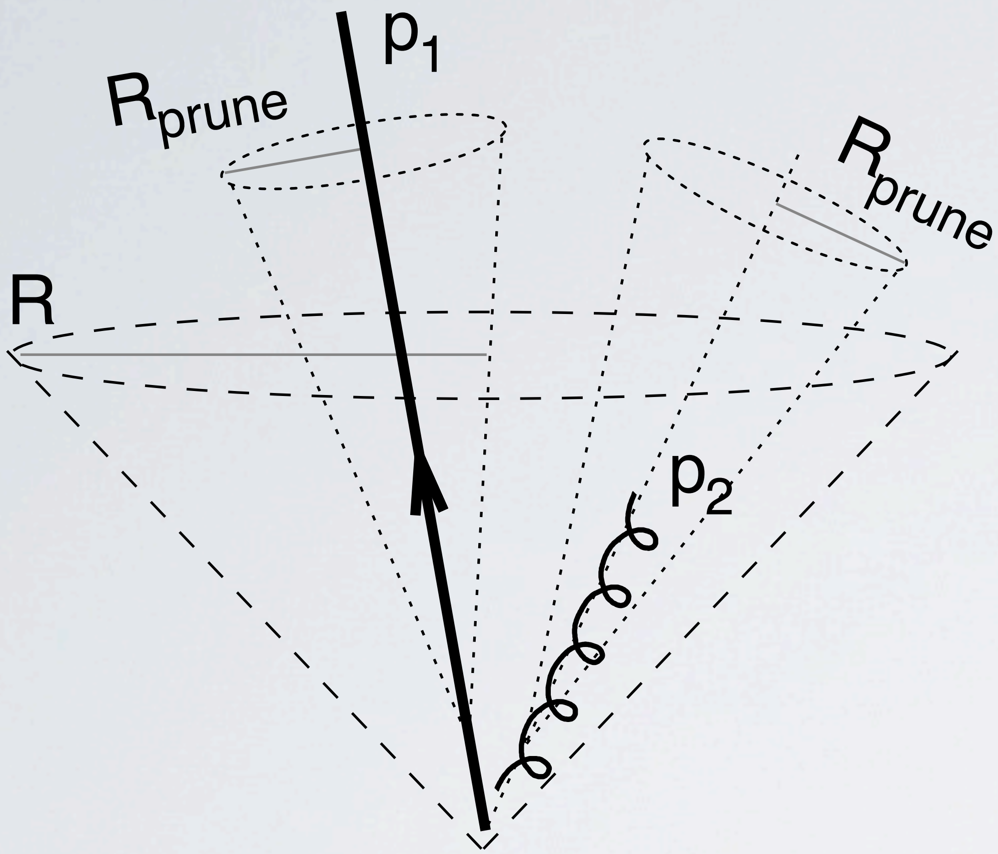


<u>What pruning is meant to do</u>

Choose an R_{prune} such that different hard prongs (p_1, p_2) end up in different hard subjets.

Discard any softer radiation.

Beyond LO



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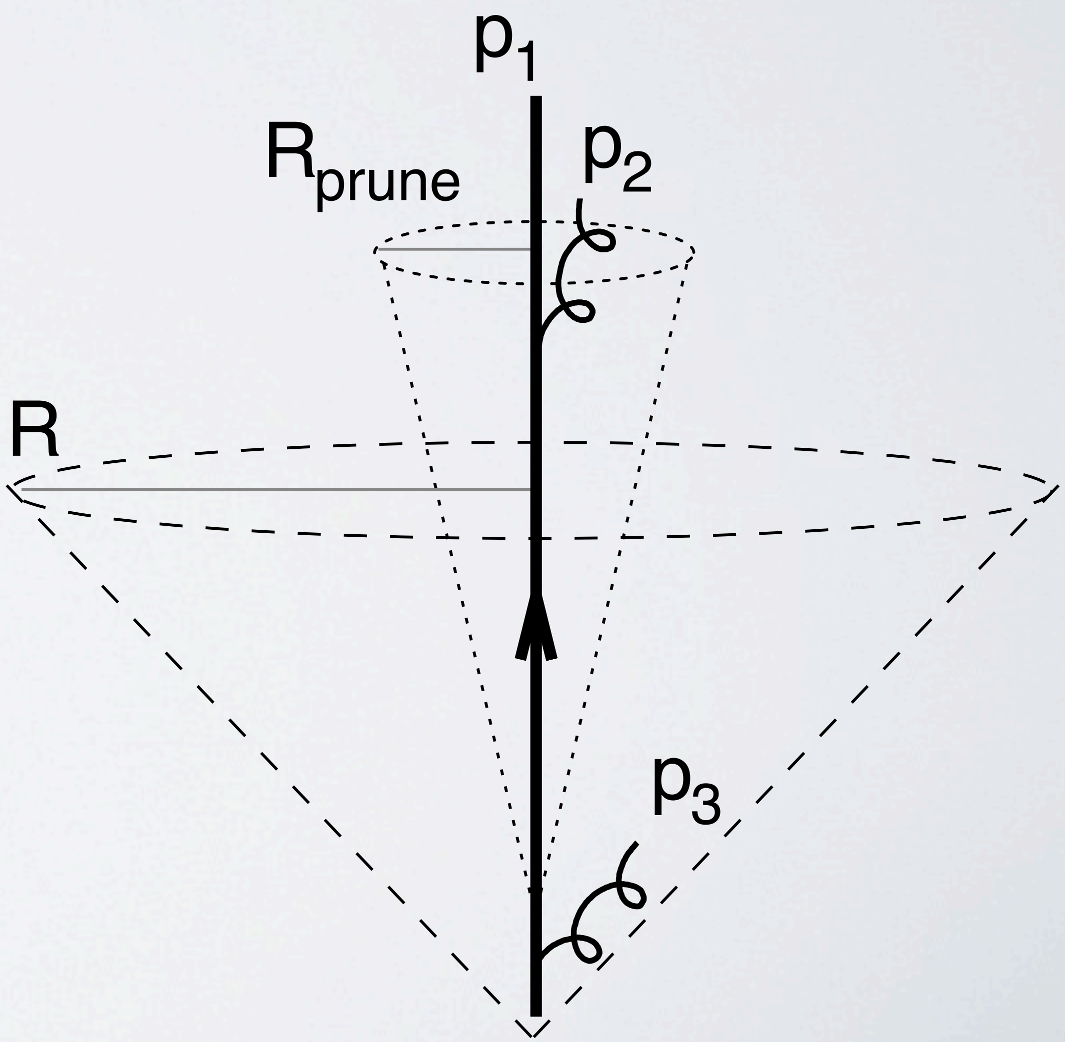

What pruning sometimes does

Chooses R_{prune} based on a soft p_3 (dominates total jet mass), and leads to a single narrow subjet whose mass is also dominated by a soft emission (p_2, within R_{prune} of p_1, so not pruned away).

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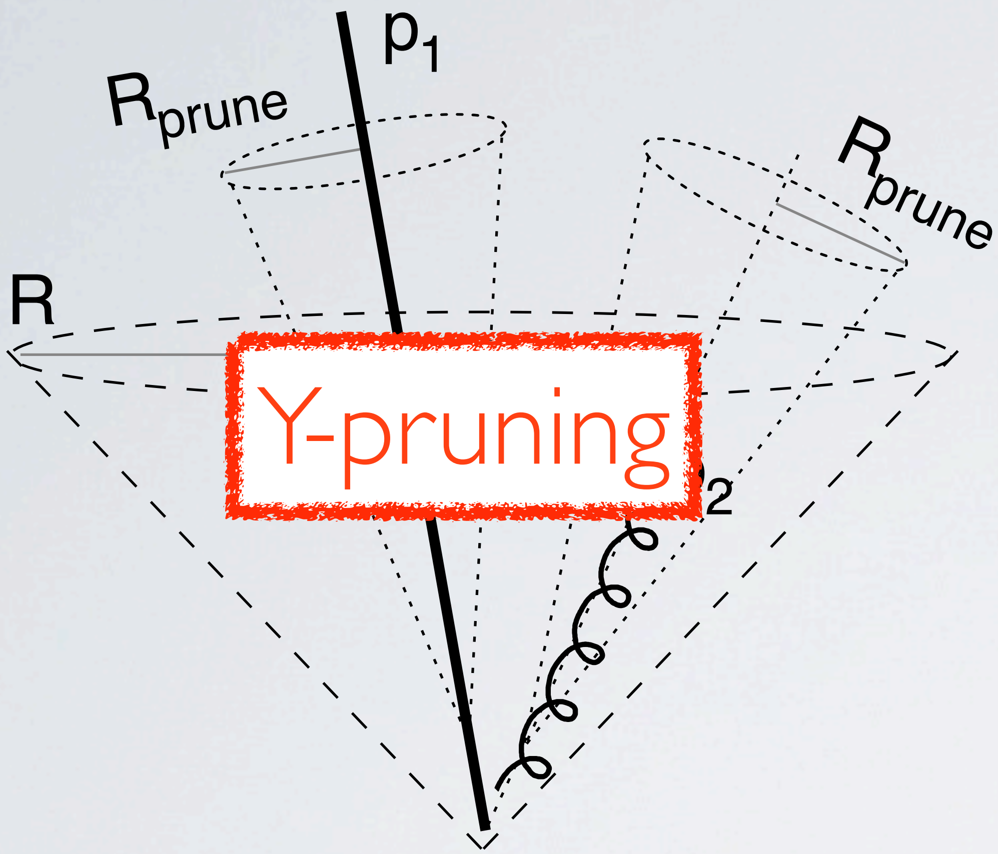

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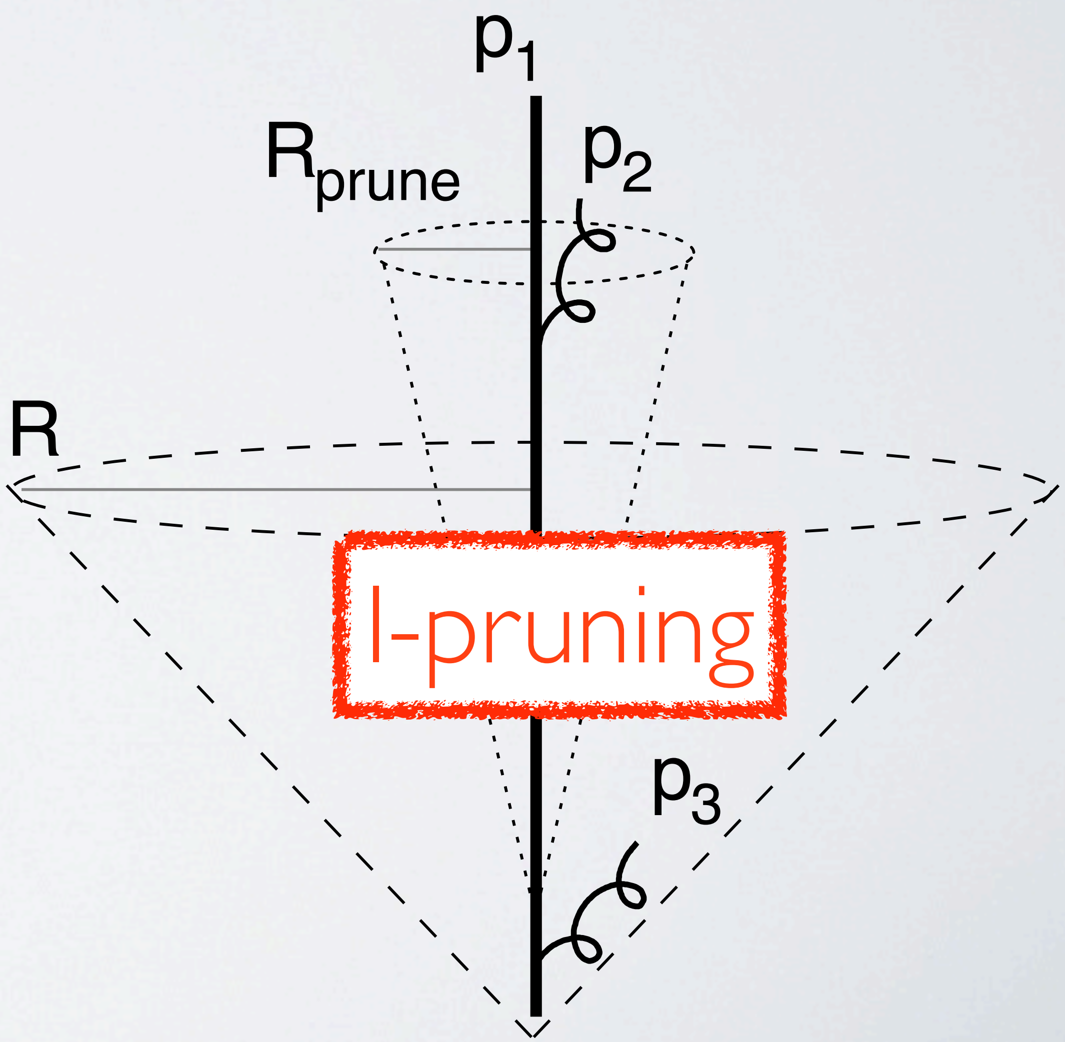

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Structure beyond LO

- Pruning @ NLO ~α_s^2 L^4 (like plain jet mass)
- Explicit calculation shows that I-pruning is active for $\rho < z_{cut}^2$
- A simple modification: require at least one successful merging with $\Delta R > R_{prune}$ and $z > z_{cut}$ (Y-pruning)

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- It is convenient to resum the two components separately
- Y-pruning: essentially Sudakov suppression of LO ~ $\alpha_s^n L^{2n-1}$
- I-pruning: convolution between the pruned and the original mass ~ $\alpha_s^n L^{2n}$

All-order results

- Full Pruning: single-log region for $z_{cut}^2 < \rho < z_{cut}$
- We control $\alpha_s^n L^{2n}$ and $\alpha_s^n L^{2n-1}$ in the expansion
- NG logs present but deferred to NNLO

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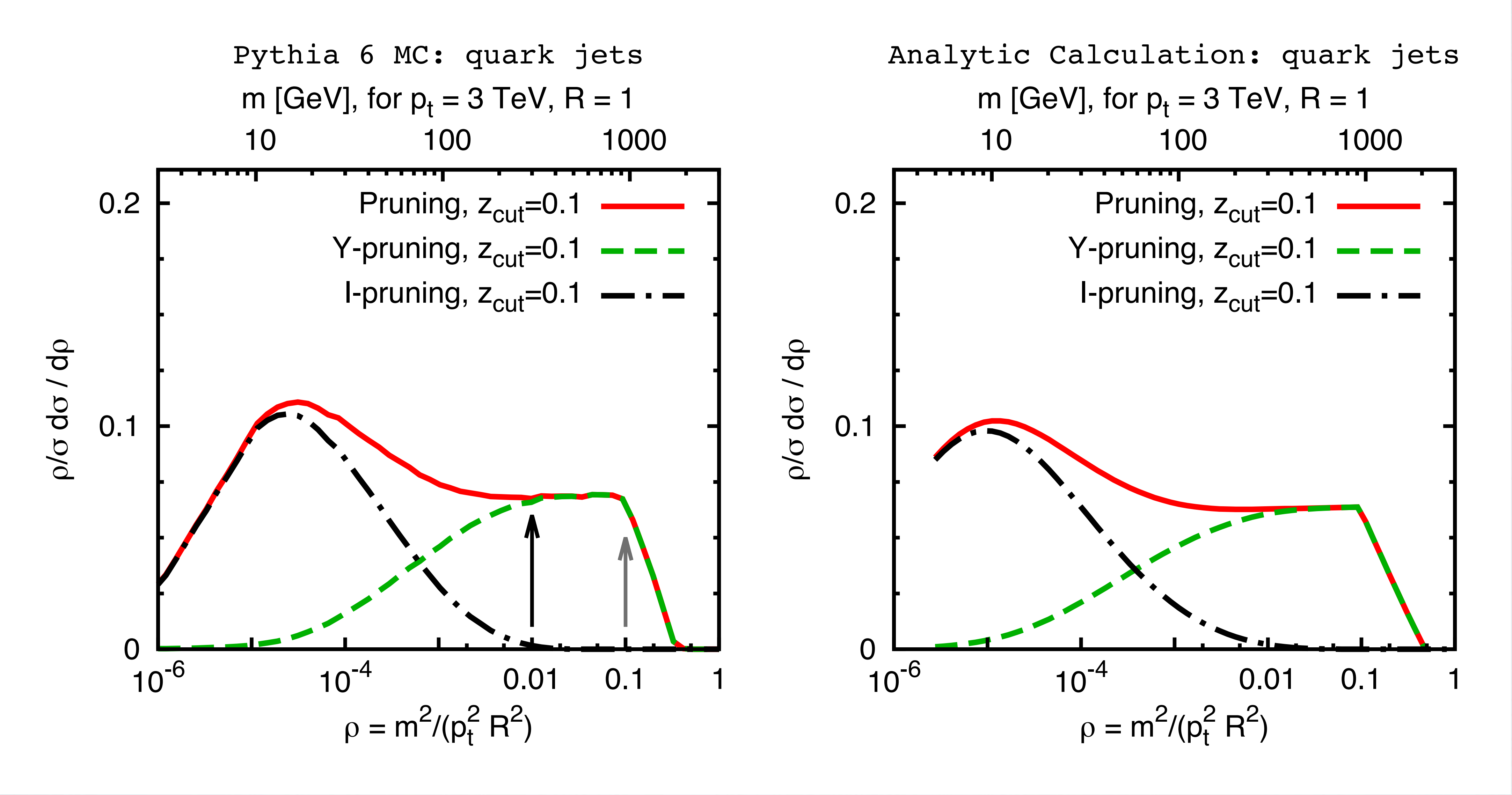

All-order calculation done in the small-z_{cut} limit

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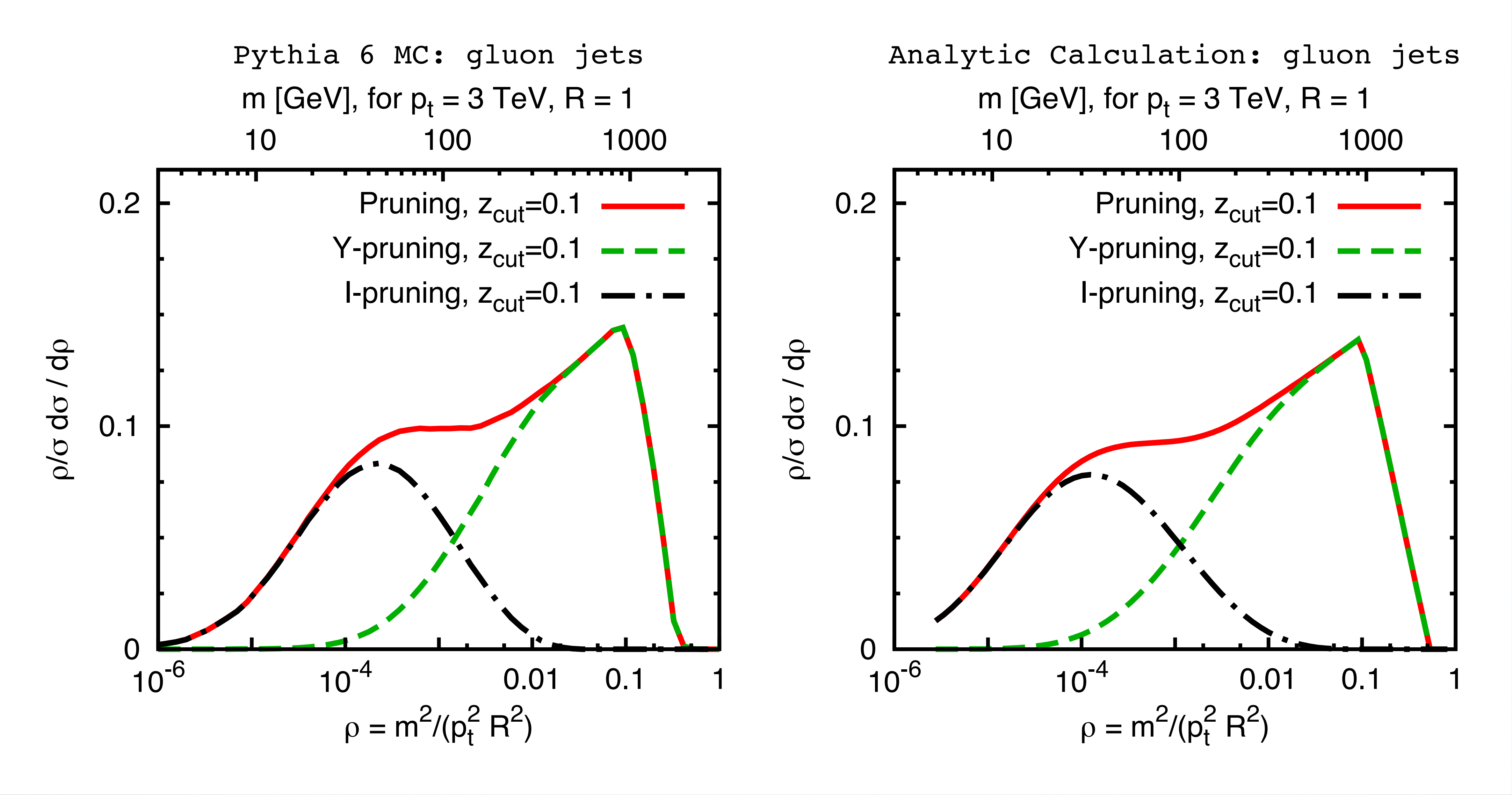

All-order calculation done in the small-z_{cut} limit

Mass Drop Tagger at LO

1. Undo the last stage of the C/A clustering. Label the two subjets j_1 and j_2 ($m_1 > m_2$)
2. If $m_1 < \mu m$ (mass drop) and the splitting was not too asymmetric ($y_{ij} > y_{cut}$), tag the jet.
3. Otherwise redefine $j = j_1$ and iterate.

Butterworth, Davison, Rubin and Salam (2008)

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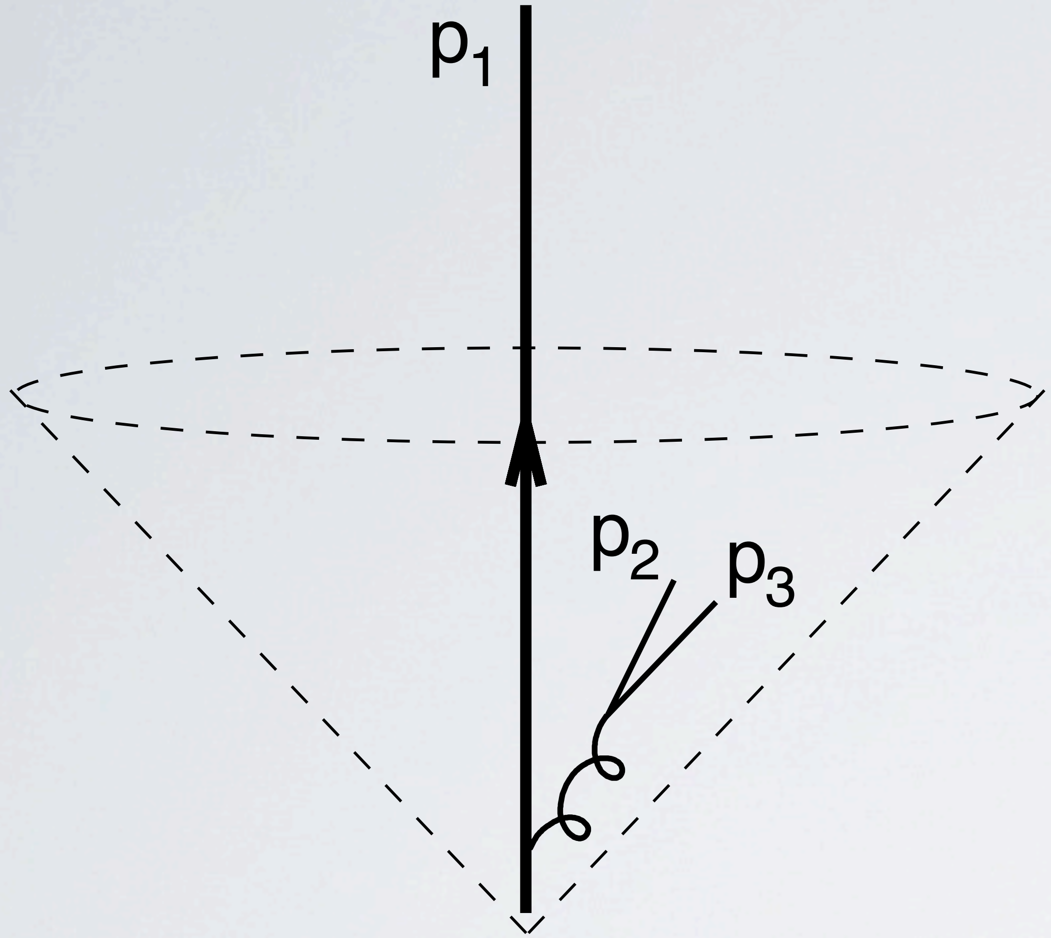
In the small-y_{cut} limit the result is identical to LO pruning: single-log distribution

Problems beyond LO



What MDT does wrong:

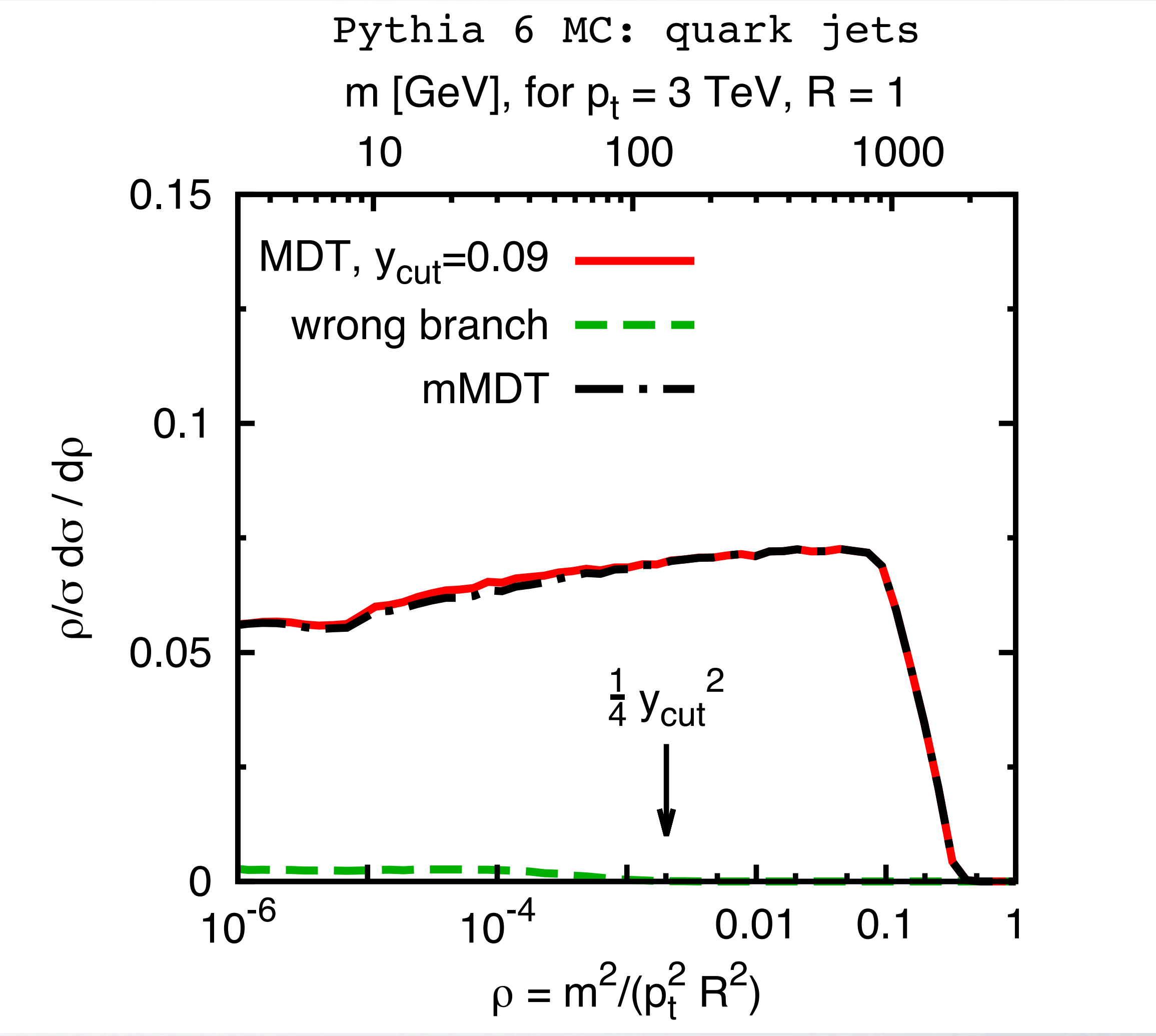
If the y_{ij} condition fails, MDT iterates on the more massive subjet. It can follow a soft branch ($p_2+p_3 < y_{cut}\, p_{tjet}$), when the "right" answer was that the (massless) hard branch had no substructure

- This can be considered a flaw of the tagger
- It worsens the logarithmic structure: $\alpha_s^2 L^3$
- It makes all-order treatment difficult
- It calls for a modification

Modified Mass Drop Tagger

1. Undo the last stage of the C/A clustering. Label the two subjets j_1 and j_2 ($m_1 > m_2$)
2. If $m_1 < \mu m$ (mass drop) and the splitting was not too asymmetric ($y_{ij} > y_{cut}$), tag the jet.
3. Otherwise redefine j **to be the subjet with highest transverse mass** and iterate.

- In practice the soft-branch contribution is very small
- However, this modification makes the all-order structure particularly interesting



All-order structure of mMDT

- In the small y_{cut} limit, it is just the exponentiation of LO
- The mMDT has single logs to all orders (i.e. $\alpha_s^n L^n$)
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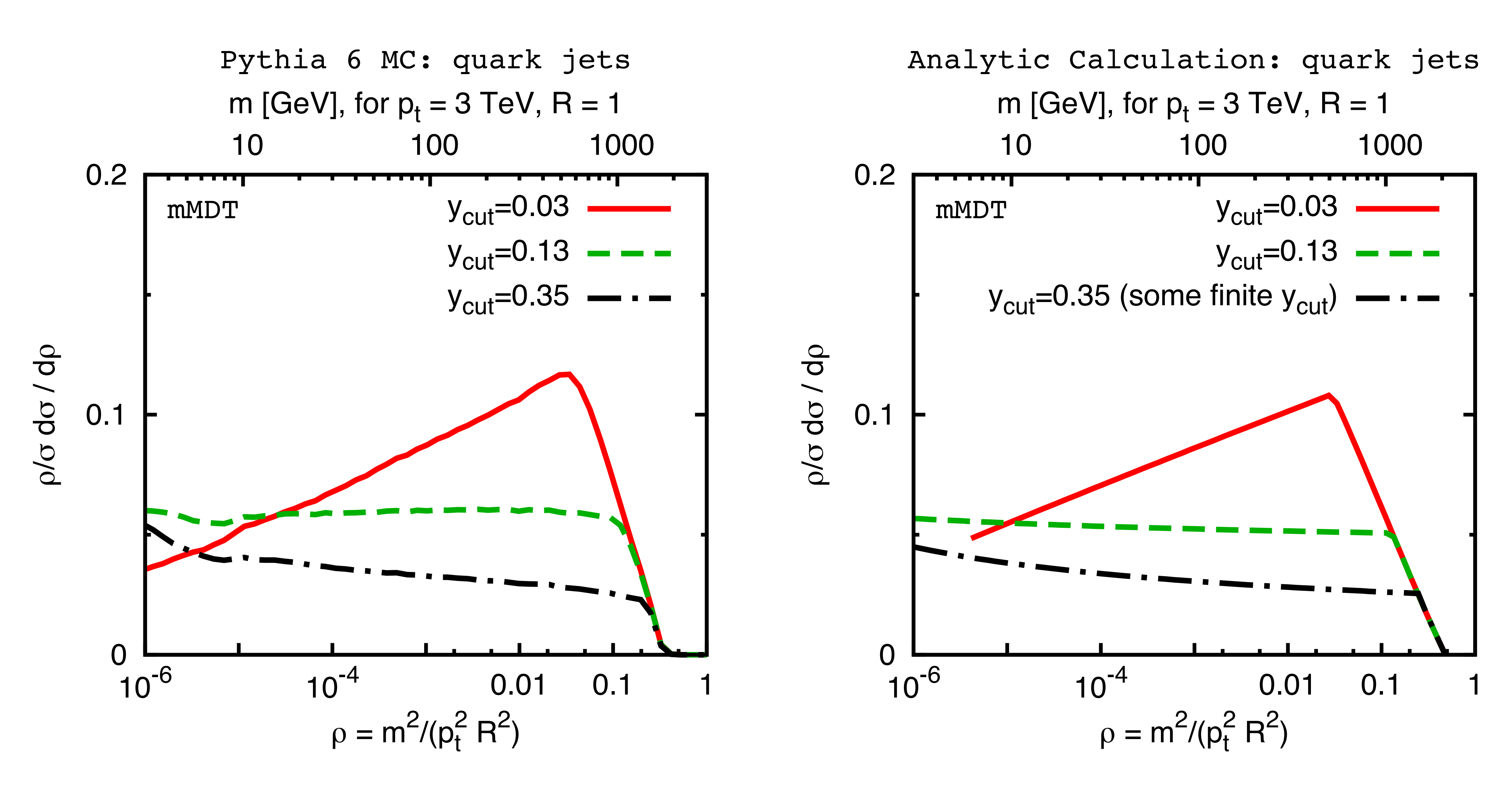
All-order structure of mMDT

- In the small y_{cut} limit, it is just the exponentiation of LO
- The mMDT has single logs to all orders (i.e. $\alpha_s^n L^n$)
- This potentially extends the validity of FO calculations

- These single logs are of collinear origin
- Remarkable consequence: mMDT is free of non-global logs!

Comparison to MC



Remarkable agreement !

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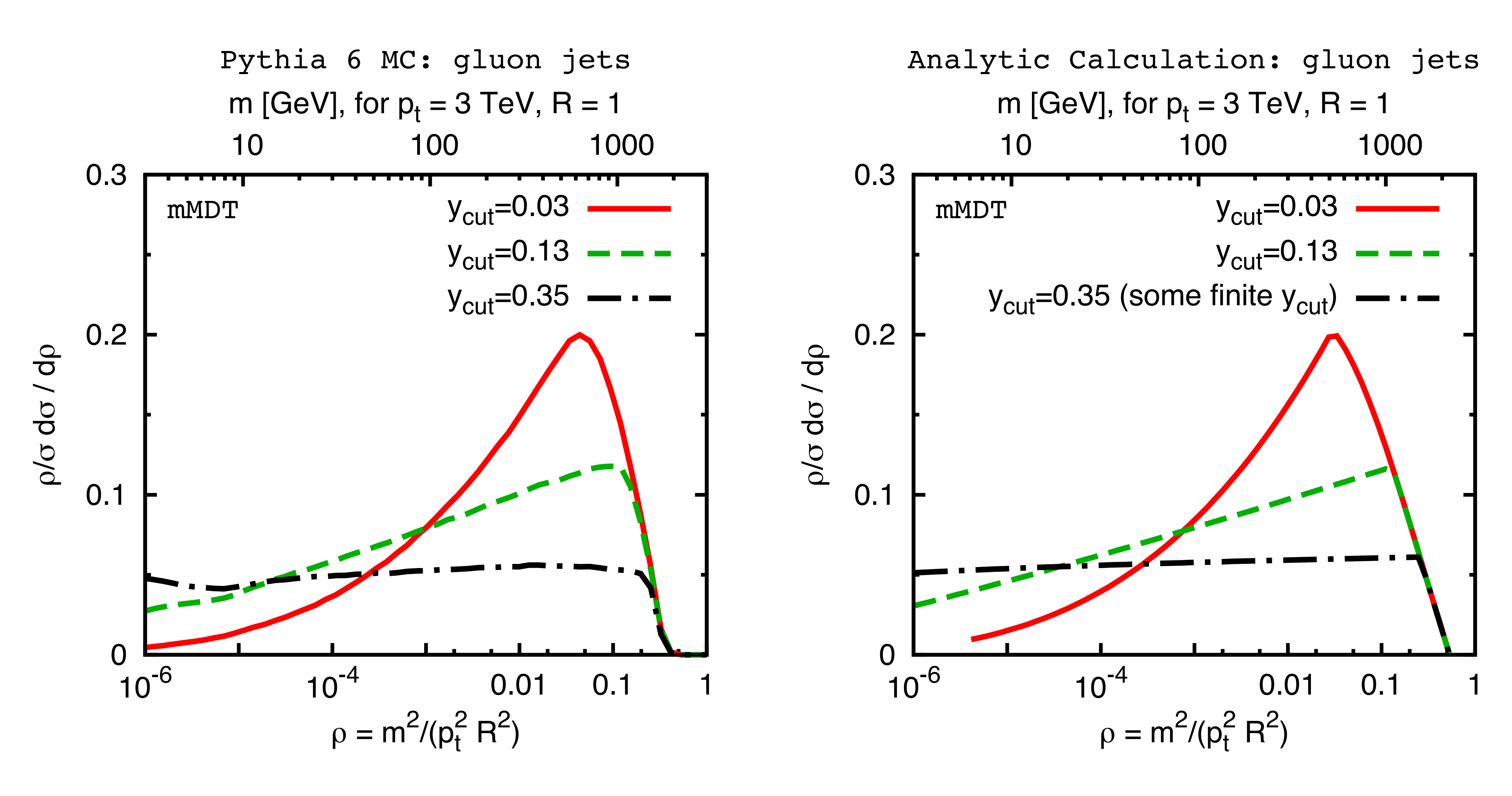
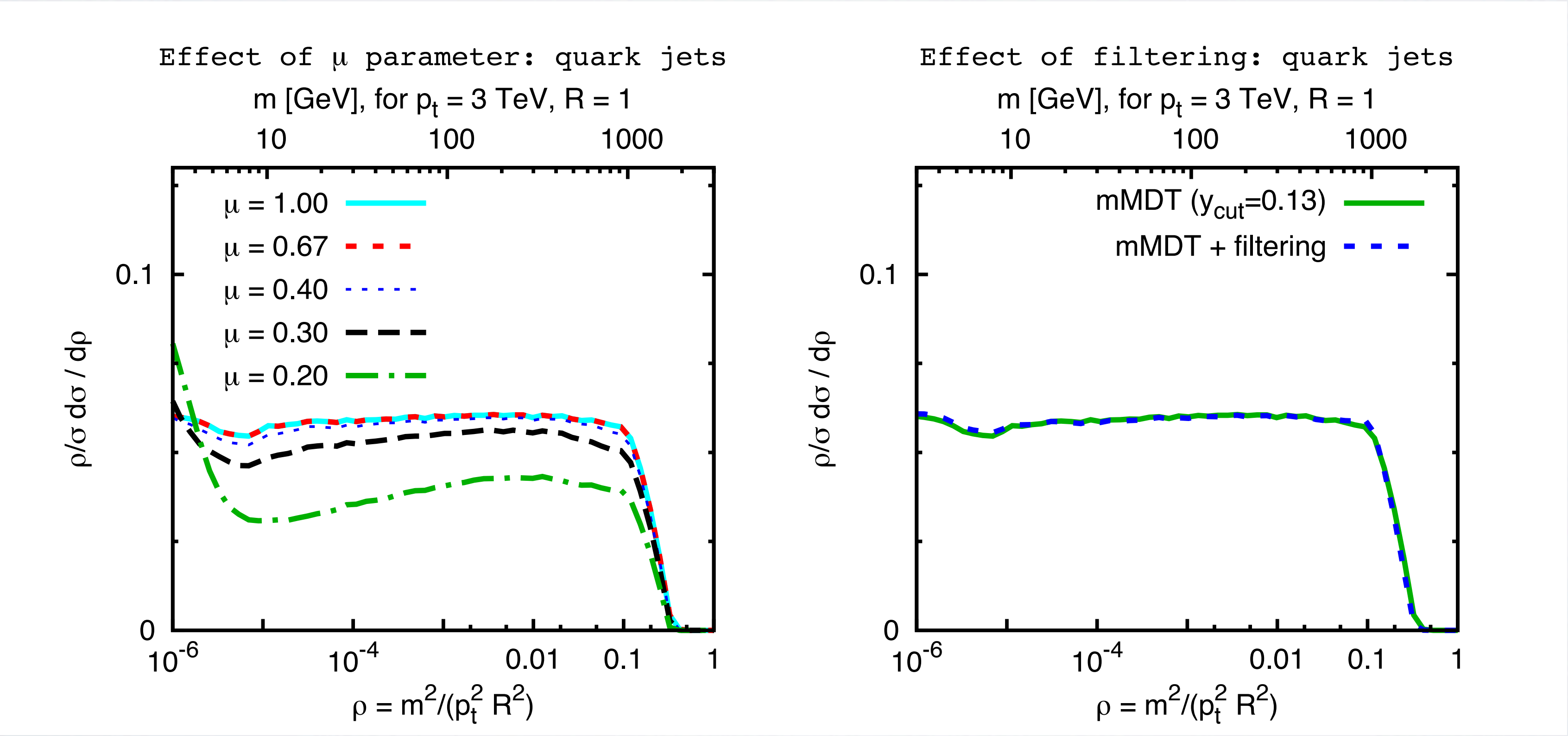


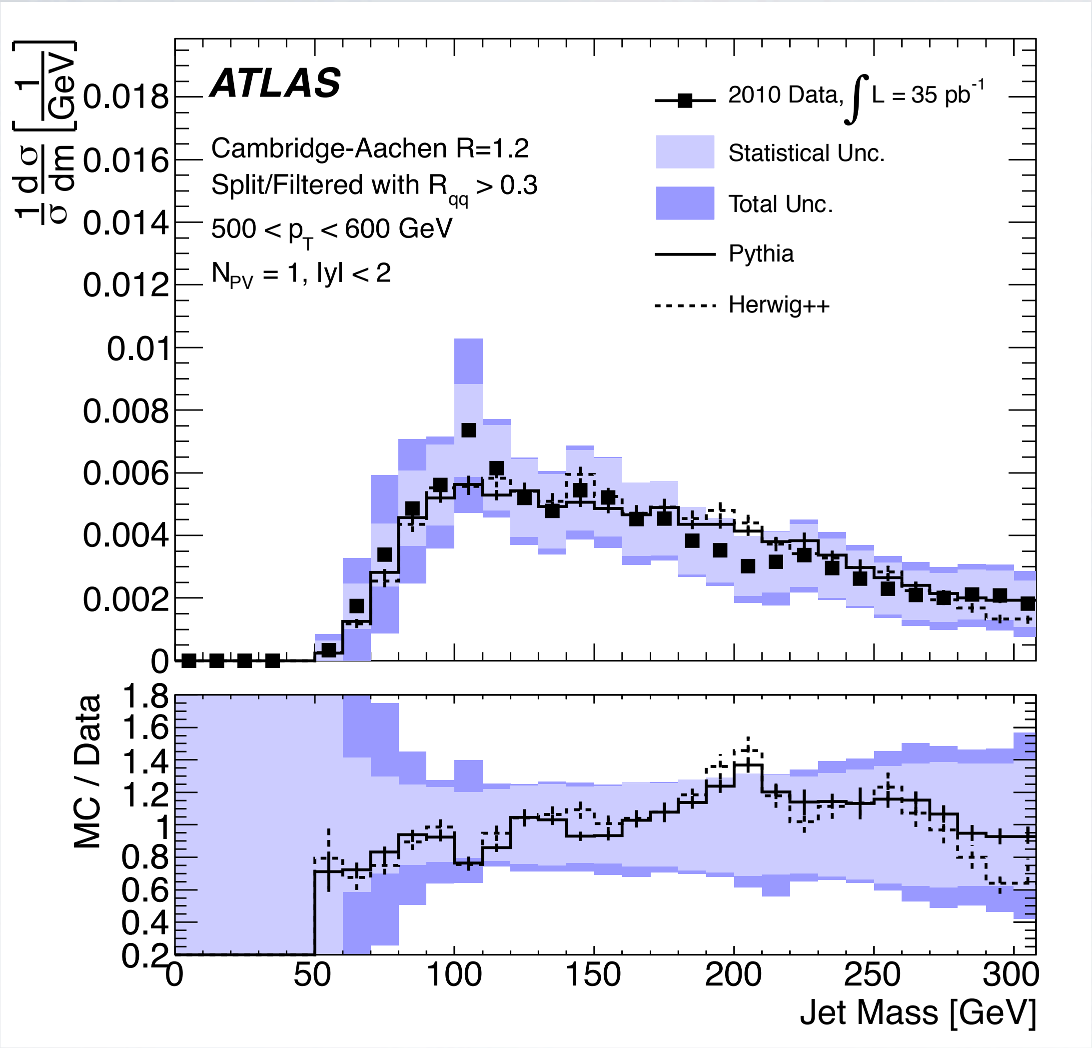
Remarkable agreement !

Other properties of mMDT

- Flatness of the background is a desirable property (data-driven analysis, side bands)
- y_{cut} can be adjusted to obtain it (analytic relation)
- Role of **μ**, not mentioned so far
- It contributes to subleading logs and has small impact if not too small (μ>0.4)
- Filtering only affects subleading ($N^{nfilt}LL$) terms



ATLAS MDT



- ATLAS measured the jet mass with MDT
- Different version of the tagger with R_{min}=0.3 between the prongs

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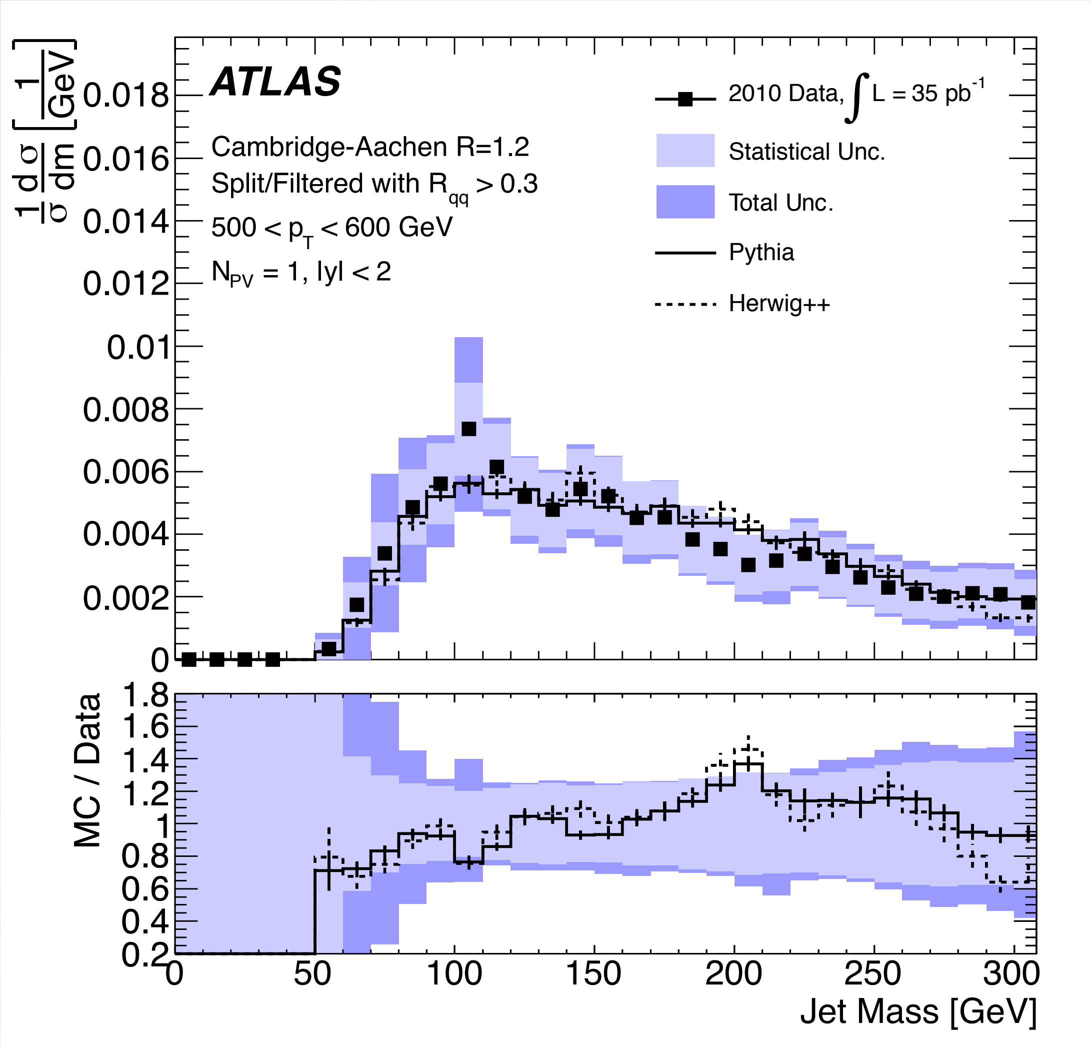

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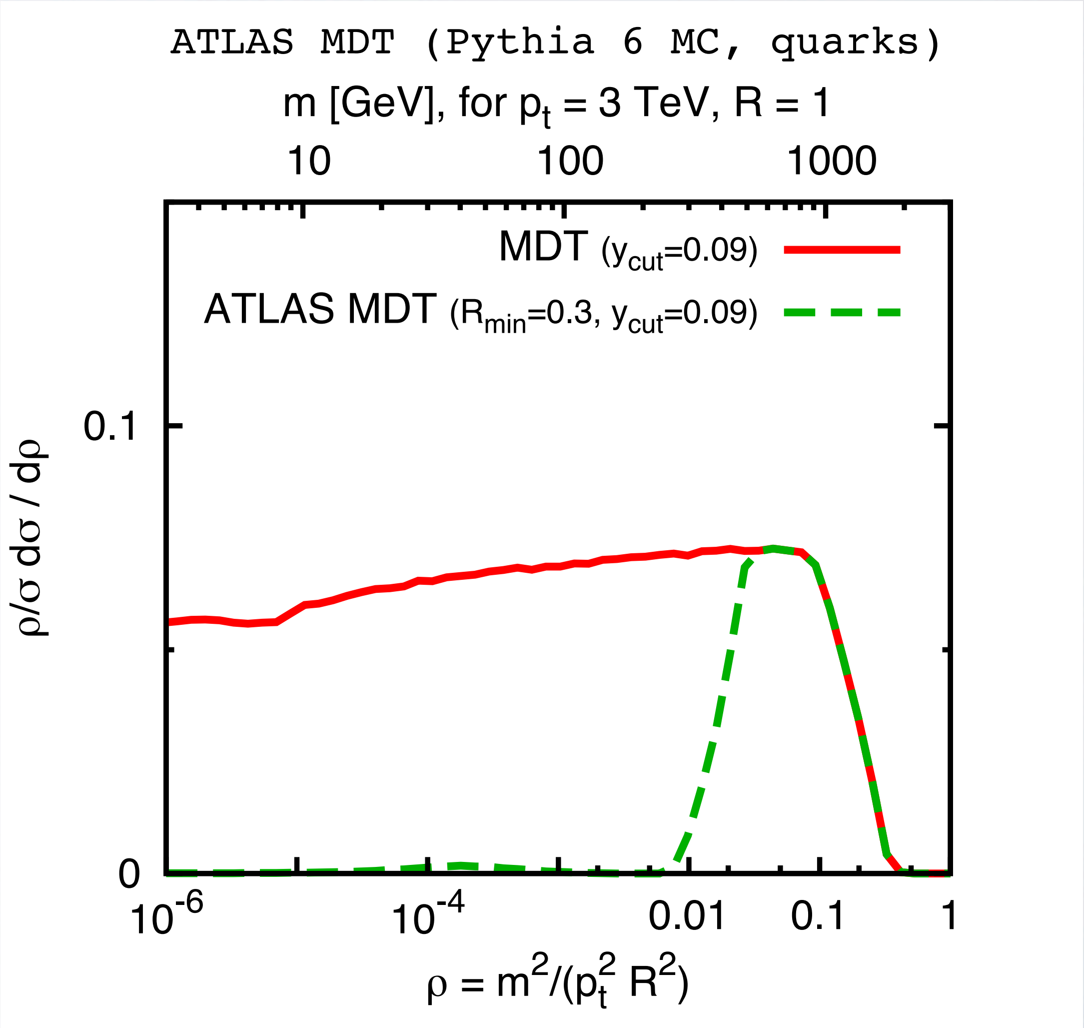
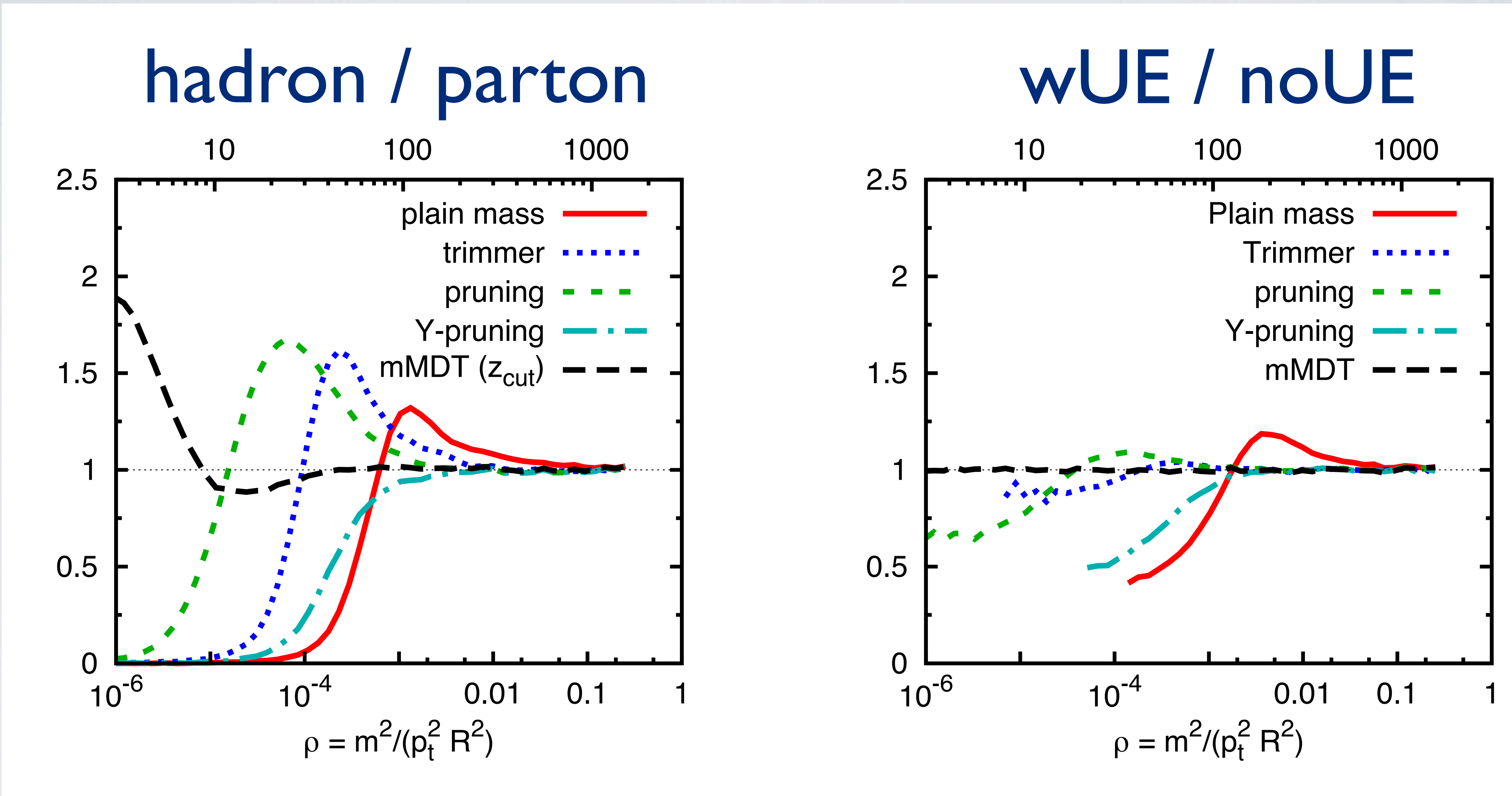


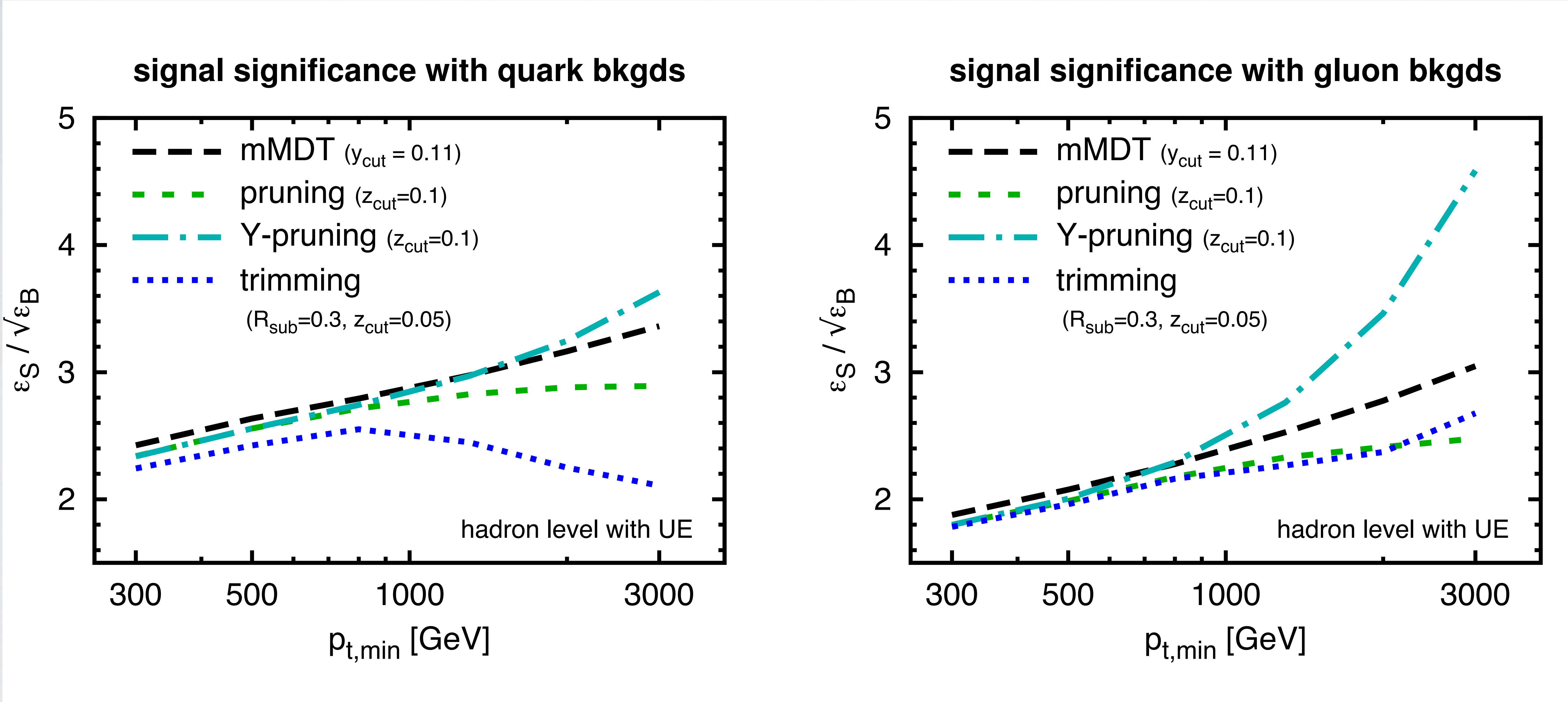
- This cut significantly changes the tagger's behaviour: mass minimum
- The single-log region is reduced (and can even disappear)
- We hope that future studies will be able to avoid this

Non-perturbative effects



- Most taggers have reduced sensitivity to NP physics
- mMDT particularly so (it's the most calculable)
- Y-pruning sensitive to UE because of the role played by the fat jet mass

Performances for finding signals (Ws)



Y-pruning gives a visible improvement

In summary ...

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- Particularly useful if MCs don't agree

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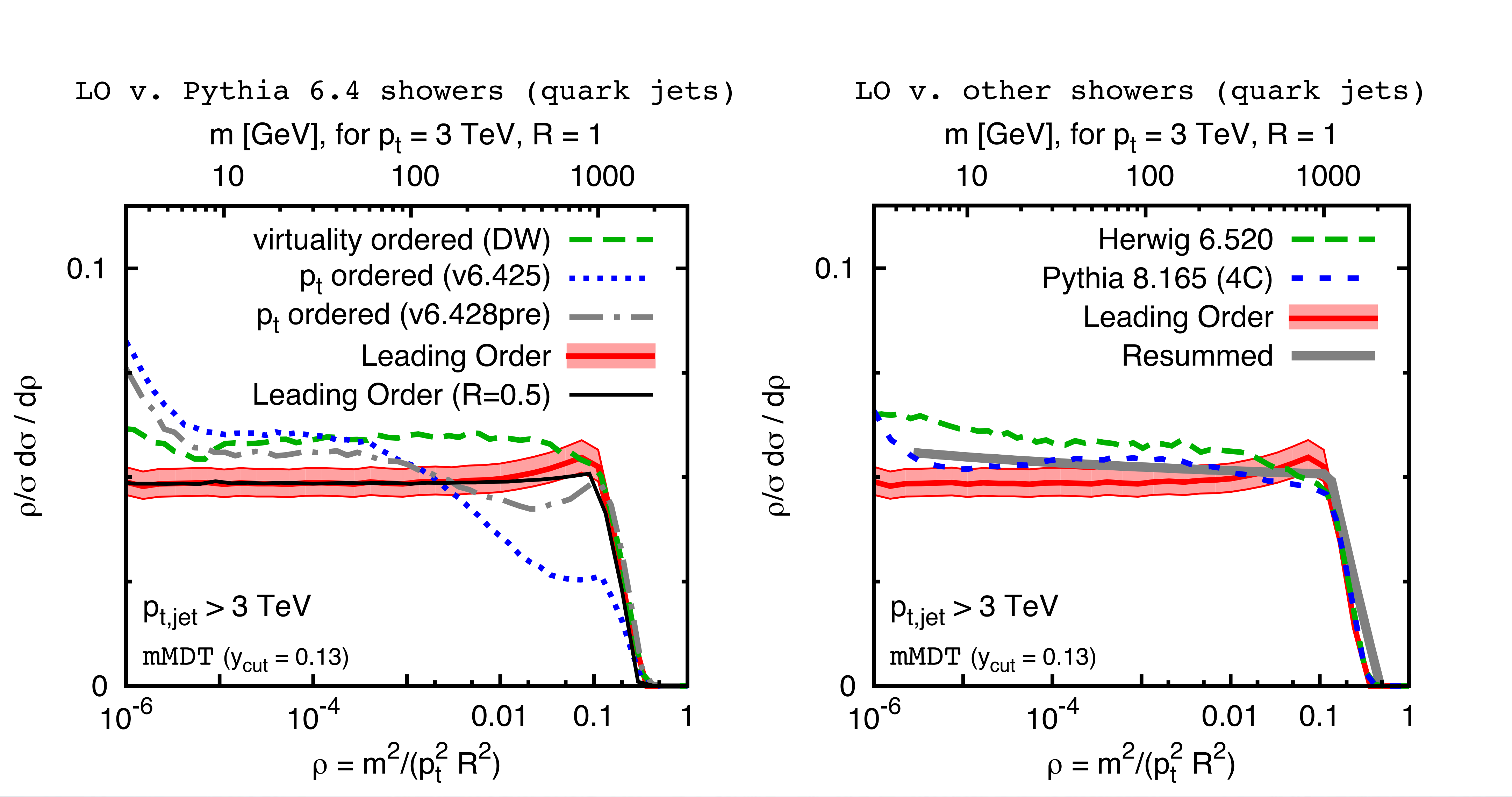


In summary ...

- Analytic studies of the taggers reveal their properties
- Particularly useful if MCs don't agree

- They also indicate how to develop better taggers

- Y-pruning:
- improved log behaviour wrt pruning ($\alpha_s^n L^{2n-1}$ vs $\alpha_s^n L^{2n}$)
- better rejection of QCD background

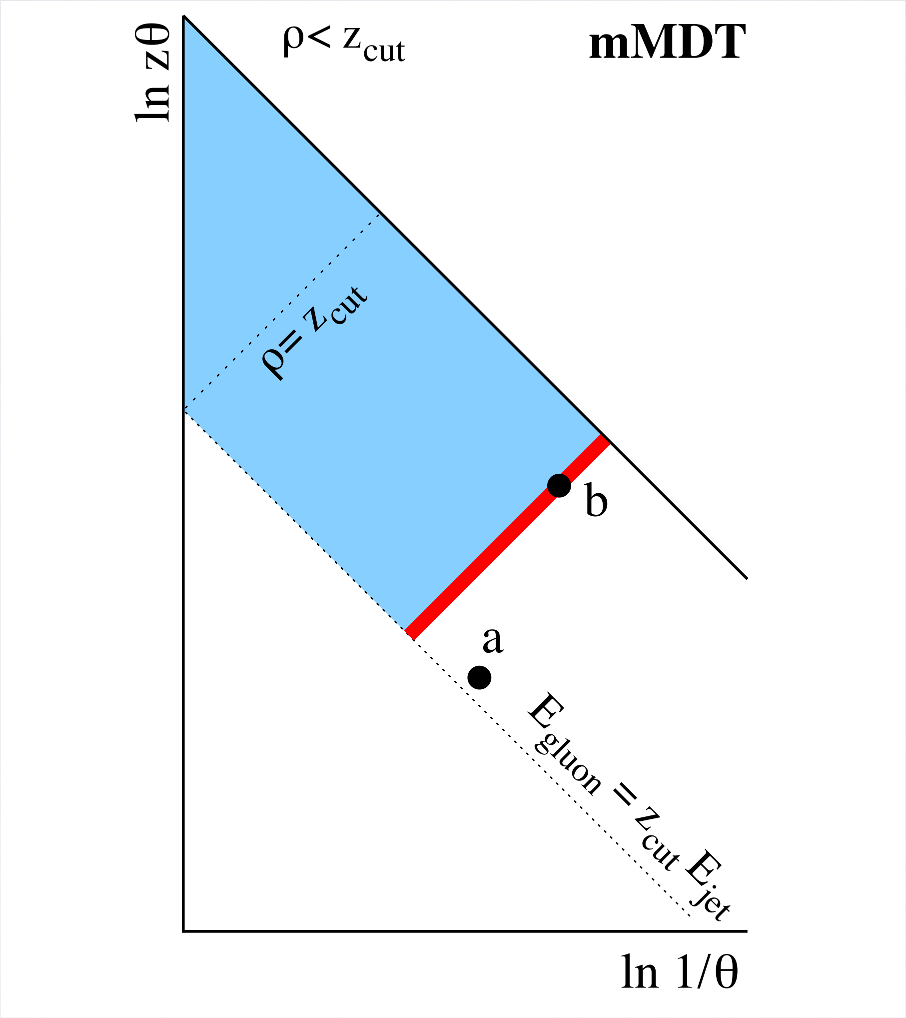
- mMDT:
- exceptionally simple structure (single logs, no non-global)
- reduced sensitivity to non-perturbative physics

BACKUP SLIDES

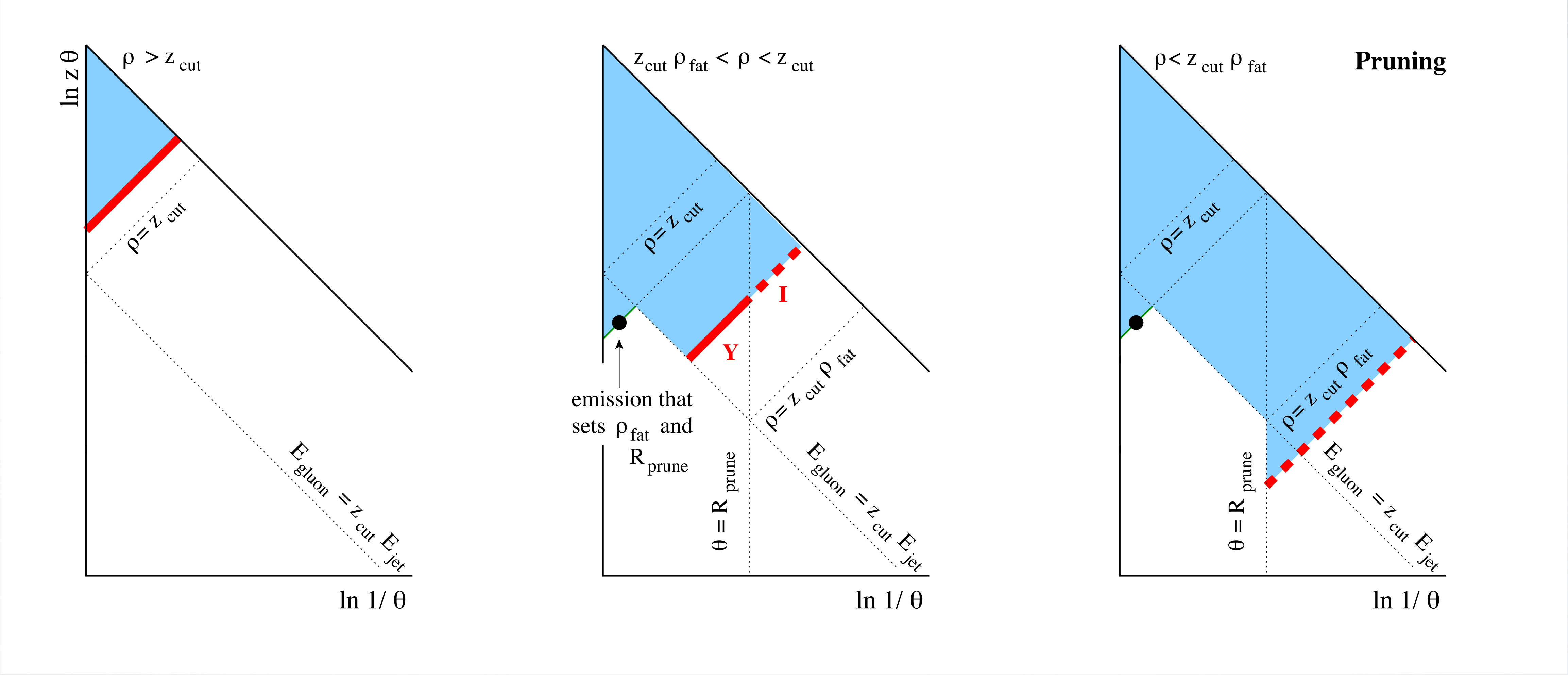
Summary table

	highest logs	transition(s)	Sudakov peak	NGLs	NP: $m^2 \lesssim$
plain mass	$\alpha_s^n L^{2n}$	—	$L \simeq 1/\sqrt{\bar{\alpha}_s}$	yes	$\mu_{\rm NP}\, p_t\, R$
trimming	$\alpha_s^n L^{2n}$	$z_{\rm cut},\ r^2 z_{\rm cut}$	$L \simeq 1/\sqrt{\bar{\alpha}_s} - 2\ln r$	yes	$\mu_{\rm NP}\, p_t\, R_{\rm sub}$
pruning	$\alpha_s^n L^{2n}$	$z_{\rm cut},\ z_{\rm cut}^2$	$L \simeq 2.3/\sqrt{\bar{\alpha}_s}$	yes	$\mu_{\rm NP}\, p_t\, R$
MDT	$\alpha_s^n L^{2n-1}$	$y_{\rm cut},\ \frac{1}{4} y_{\rm cut}^2,\ y_{\rm cut}^3$	—	yes	$\mu_{\rm NP}\, p_t\, R$
Y-pruning	$\alpha_s^n L^{2n-1}$	$z_{\rm cut}$	(Sudakov tail)	yes	$\mu_{\rm NP}\, p_t\, R$
mMDT	$\alpha_s^n L^n$	$y_{\rm cut}$	—	no	$\mu_{\rm NP}^2/y_{\rm cut}$

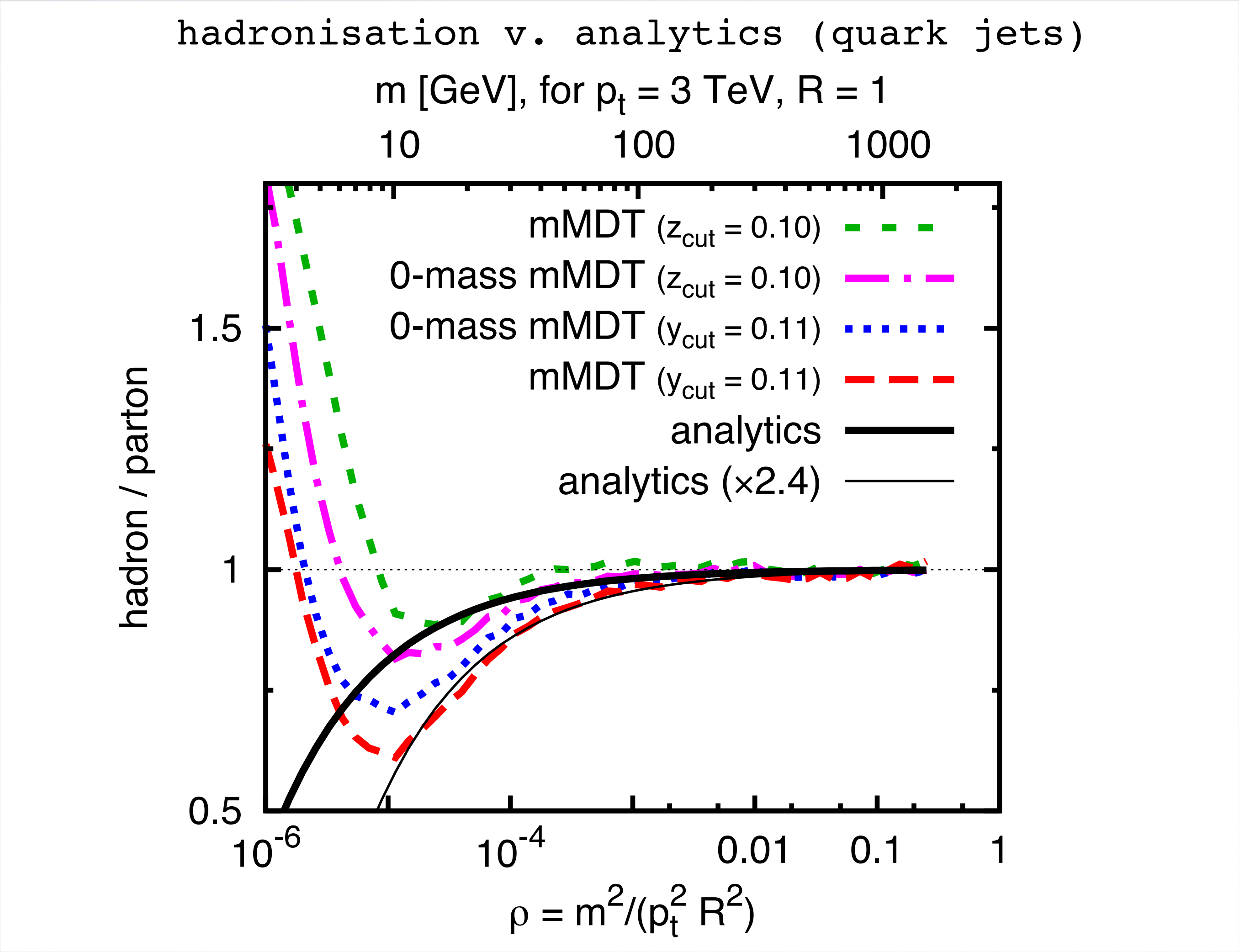
Lund diagrams for mMDT



Lund diagrams for pruning



Hadronisation effects for mMDT



Hadronisation produces:

1. a shift in the squared jet mass
2. a shift in the jet's (or prong's) momentum

Same power behaviour but with competing signs:

$$\frac{d\sigma^{\mathrm{NP}}}{dm} \simeq \frac{d\sigma^{\mathrm{PT}}}{dm}\left[1 + a\frac{\Lambda_{\mathrm{NP}}}{m}\right]$$

Examples of NLO checks