# Jets and threshold summation in Deductor

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Workshop on Jets and Heavy Flavor
UCLA, January 2019

# Prequel

- Sometimes parton shower event generators can sum large logarithms.

- Zoltan Nagy (DESY) and I have a parton shower event generator, DEDUCTOR.

- It is based on the renormalization group.

- Splitting functions reflect soft and collinear limits of QCD.

- This is a dipole shower, so it includes quantum interference.

- It is based on the quantum color density matrix.

- Results today are in "LC+" approximation.

- DEDUCTOR now includes:
  - Summation of threshold logarithms.
  - $\Lambda$ ordering (virtuality based) and $k_\mathrm{T}$ ordering.
  - User code for checking effect of non-perturbative physics on an infrared safe observbable (with the help of PYTHIA).

# Gaps between jets

# The measurement

- $\sqrt{s} = 7$ TeV.
- Measure jets with the anti-$k_\mathrm{T}$ algorithm with $R = 0.6$.
- Jets must have $P_\mathrm{T} > p_\mathrm{T}^\mathrm{cut} = 20$ GeV, $|y| < 4.4$.
- Pick the two highest $P_\mathrm{T}$ jets, labeled so that $y_1 > y_2$.
- Define $\bar{p}_\mathrm{T} = (P_{\mathrm{T},1} + P_{\mathrm{T},2})/2$, $\Delta y = y_1 - y_2$.
- "Gap": no jets with $p_\mathrm{T} > p_\mathrm{T}^\mathrm{cut}$ and $y_2 < y < y_1$.
- $f(\bar{p}_\mathrm{T}, \Delta y)$ is the fraction of events with a gap.

# Motivation

- This is a problem of considerable theoretical interest.
- There are large logarithms: $\log(\bar{p}_{\rm T}/p_{\rm T}^{\rm cut})$ and $\Delta y$.
- There is data from Atlas at 7 TeV.
- For the most accurate prediction, one should combine NLO with a parton shower. (Höche and Schönherr.)
- Here we check what perturbation theory can do by itself
- and we see what Deductor can do by itself
- and we see if the ordering variable matters.

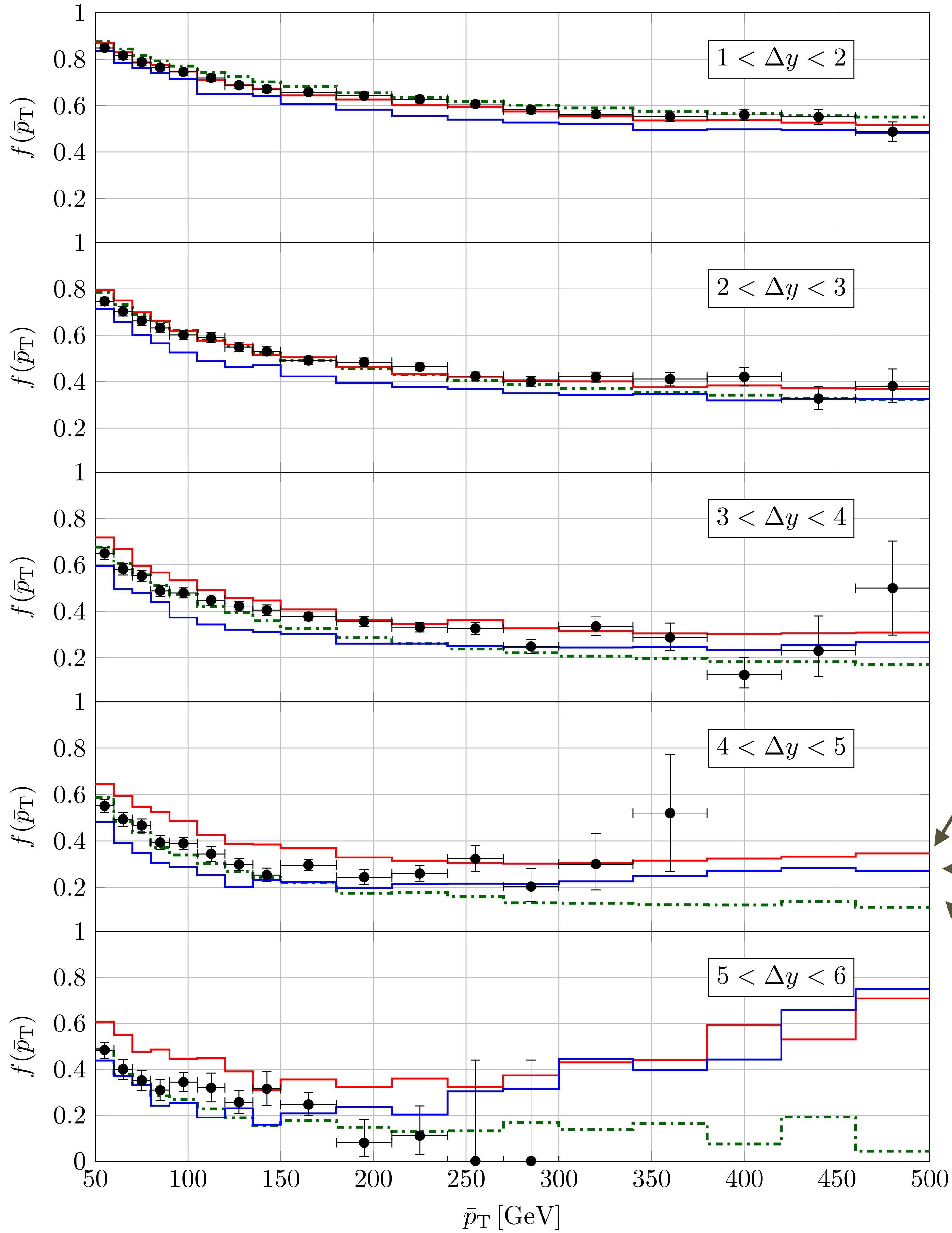
# Calculations

- Use Deductor with either $\Lambda$ or $k_\mathrm{T}$ ordering.
- Perturbative calculation (with NLOjet++).

$$f(\bar{p}_\mathrm{T}, \Delta y) = 1 - \frac{d\sigma_3/[d\bar{p}_\mathrm{T}\, d\Delta y]}{d\sigma_2/[d\bar{p}_\mathrm{T}\, d\Delta y]}$$

- $d\sigma_2/[d\bar{p}_\mathrm{T}\, d\Delta y]$ is the inclusive 2-jet cross section at NLO.
- $d\sigma_3/[d\bar{p}_\mathrm{T}\, d\Delta y]$ is the inclusive 3-jet cross section for the third jet with $p_\mathrm{T} > p_\mathrm{T}^\mathrm{cut}$, at NLO.

# Results



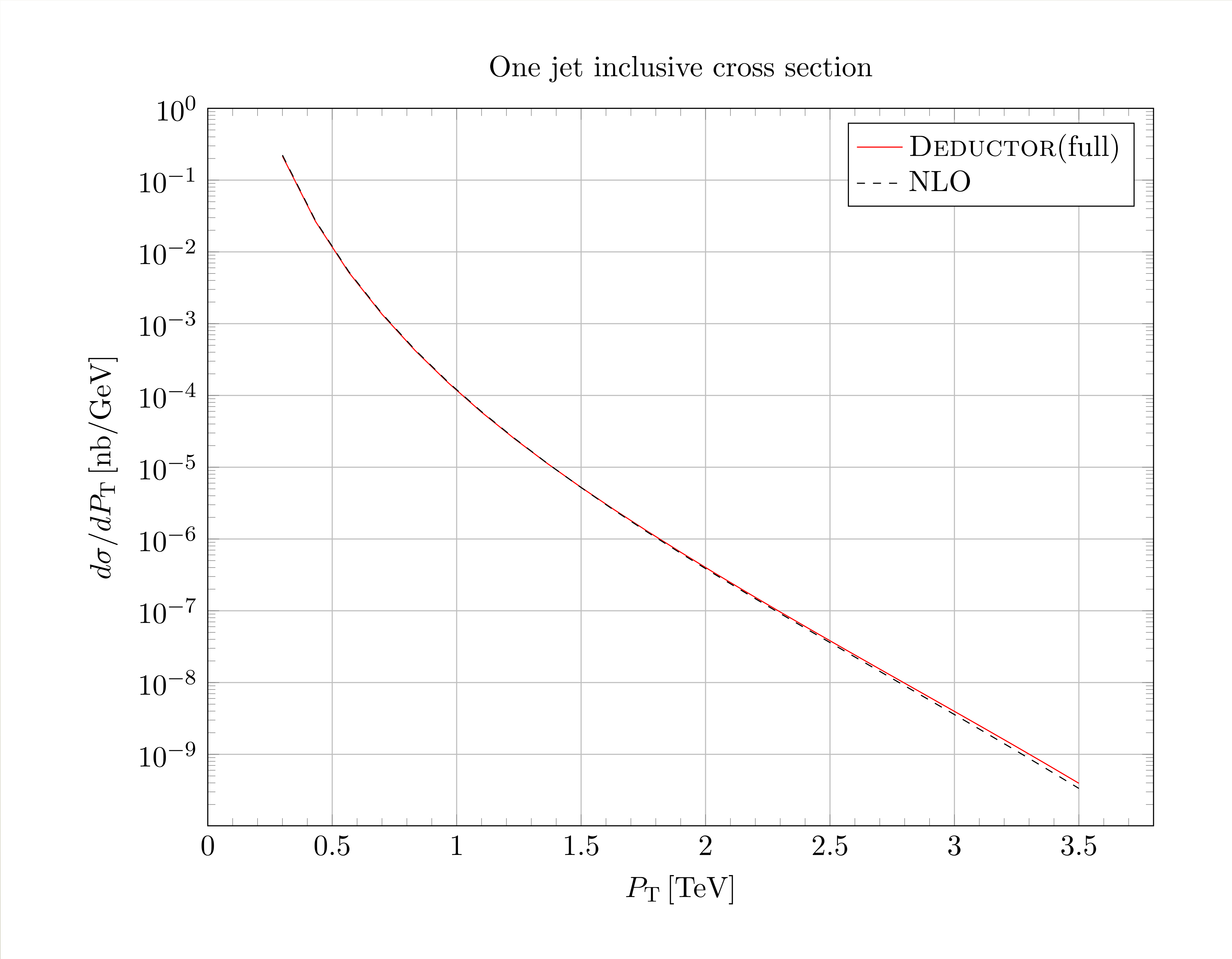

Data from Atlas

DEDUCTOR-$\Lambda$

DEDUCTOR-$k_T$

perturbative

# One jet inclusive cross section


One jet inclusive cross section
Deductor(full)
NLO
$d\sigma/dP_T$ [nb/GeV]
$P_T$ [TeV]
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
0
0.5
1
1.5
2
2.5
3
3.5

# Effect of jet finding

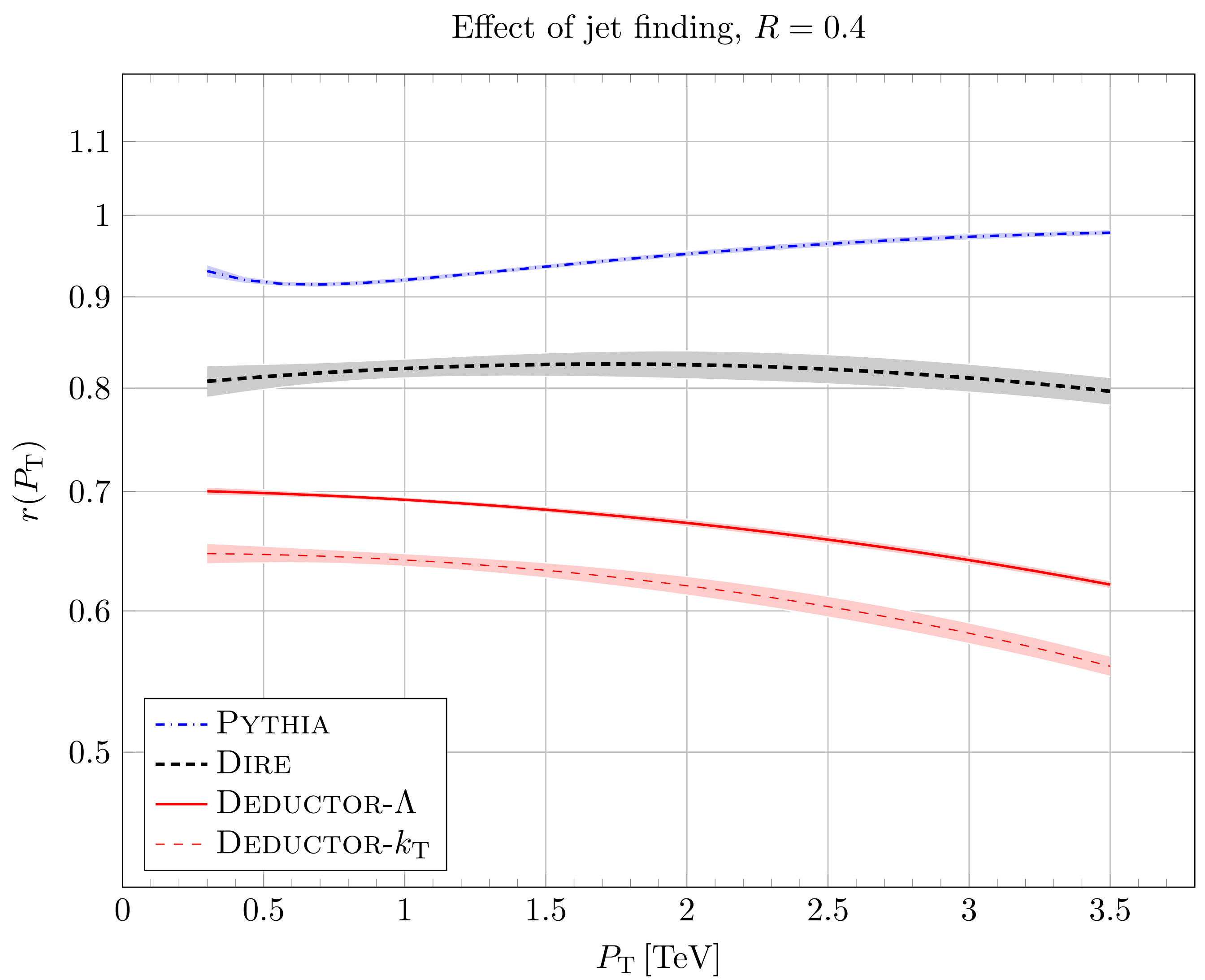
- A parton is not the same as a jet.

- Use the anti-$k_\mathrm{T}$ jet algorithm with $R = 0.4$.
- Examine

$$r(P_\mathrm{T}) = \frac{d\sigma(\mathrm{std.})/dP_\mathrm{T}}{d\sigma(\mathrm{LO})/dP_\mathrm{T}}$$

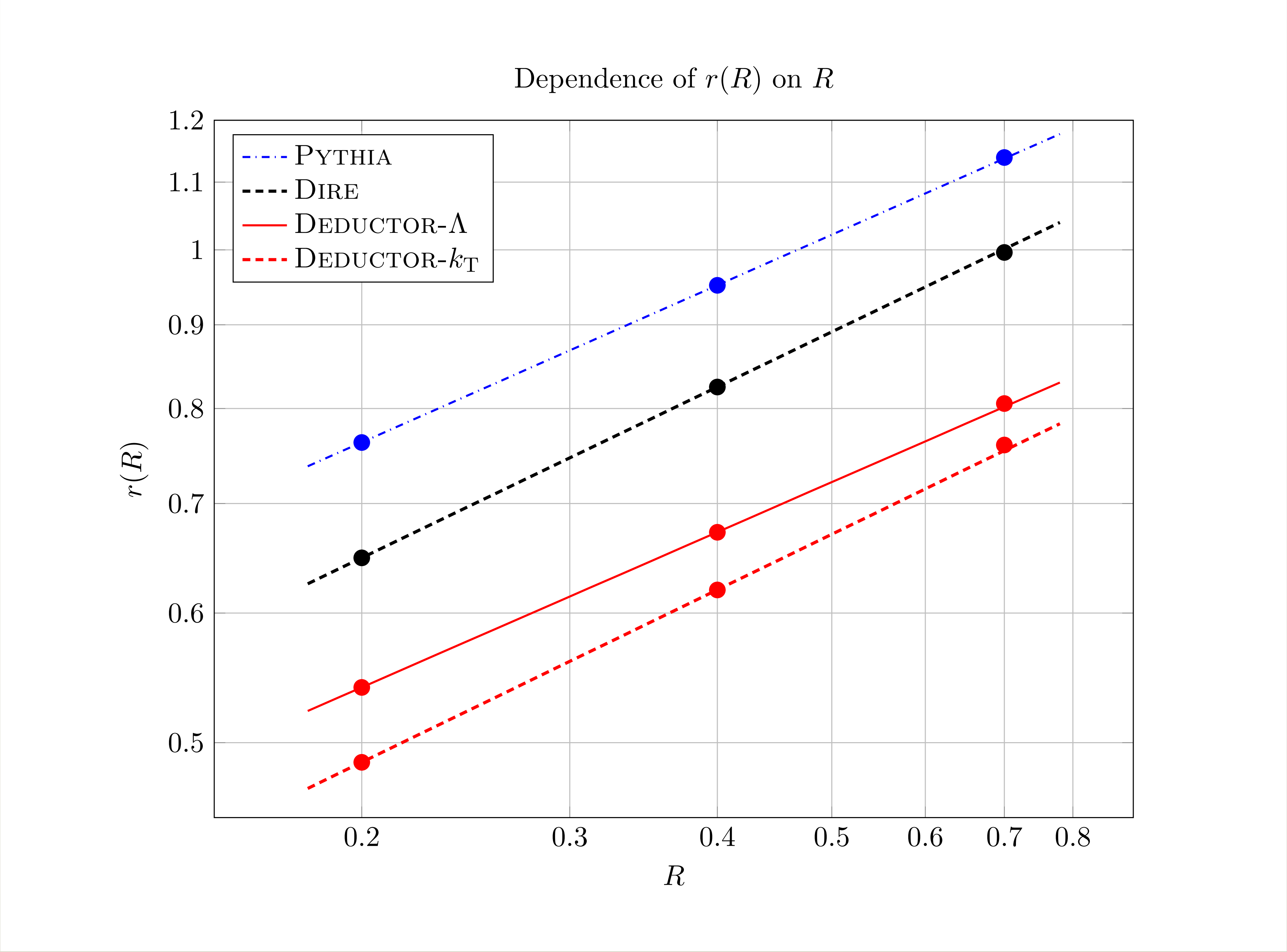
- $d\sigma(\mathrm{std.})/dP_\mathrm{T}$ from Deductor
  with no summation of threshold logs.

- Compare to Pythia and Dire.




- Differences among parton shower algorithms can yield different results.
  - splitting functions away from soft and collinear limits.
  - ordering variable.
  - global vs. local momentum mapping.

- Look at dependence on $R$ for $P_{\mathrm{T}} = 2$ TeV.



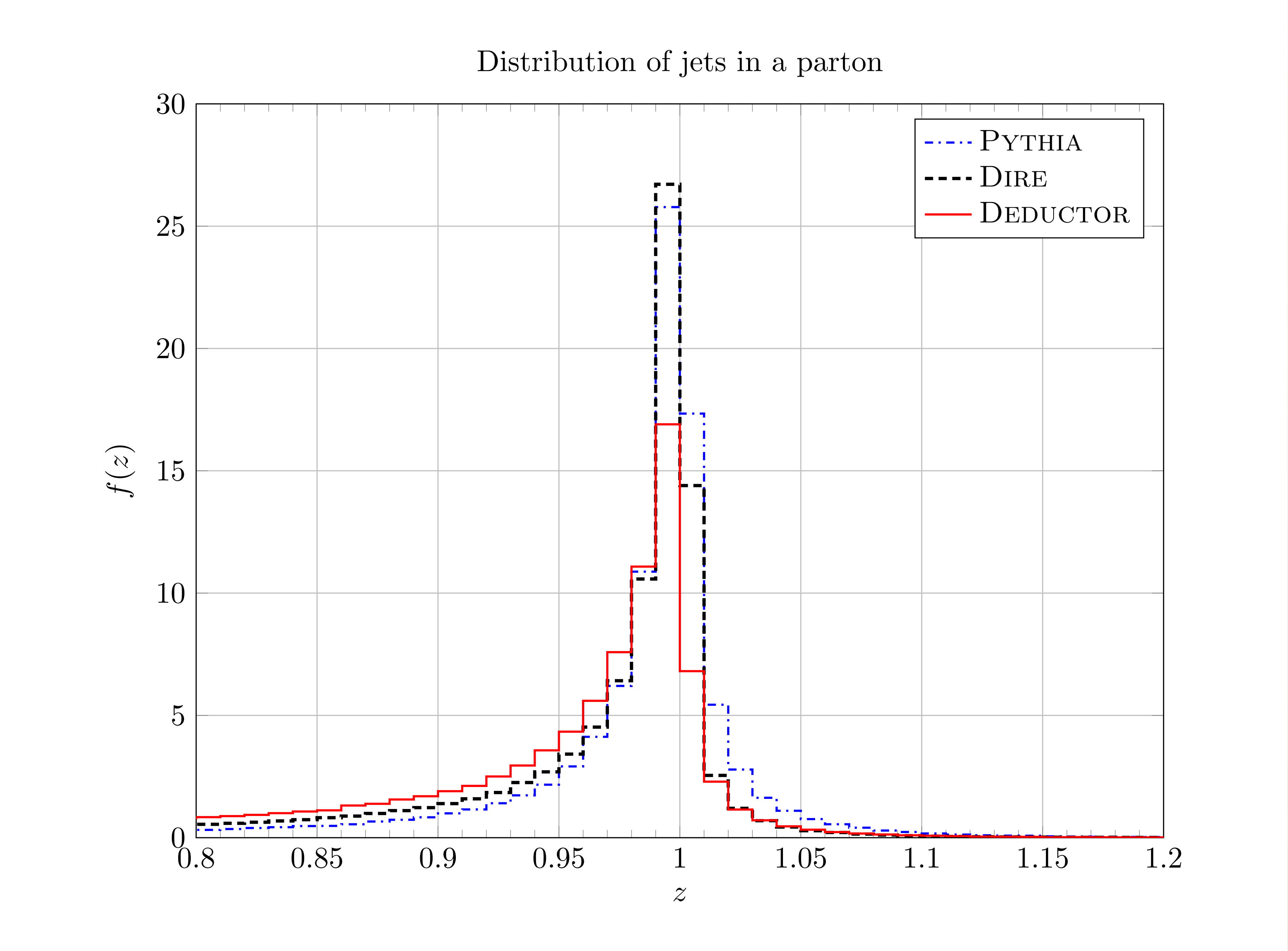

- The slopes agree pretty well.
- The values of $r(0.4)$ do not agree.

- Examine the distribution $f(z)$ of jets in a parton.

- Choose events with $P_{\rm T}^{\rm Born} \approx 3$ TeV, $|y_i| < 2$.

- Let $f(z)$ be the distribution of jets as a function of $z$,

$$z = \frac{P_{\rm T}^{\rm jet}}{P_{\rm T}^{\rm Born}}$$




- The distributions are pretty similar.
- A Deductor shower is more likely to radiate some $p_\mathrm{T}$ outside of the jet.

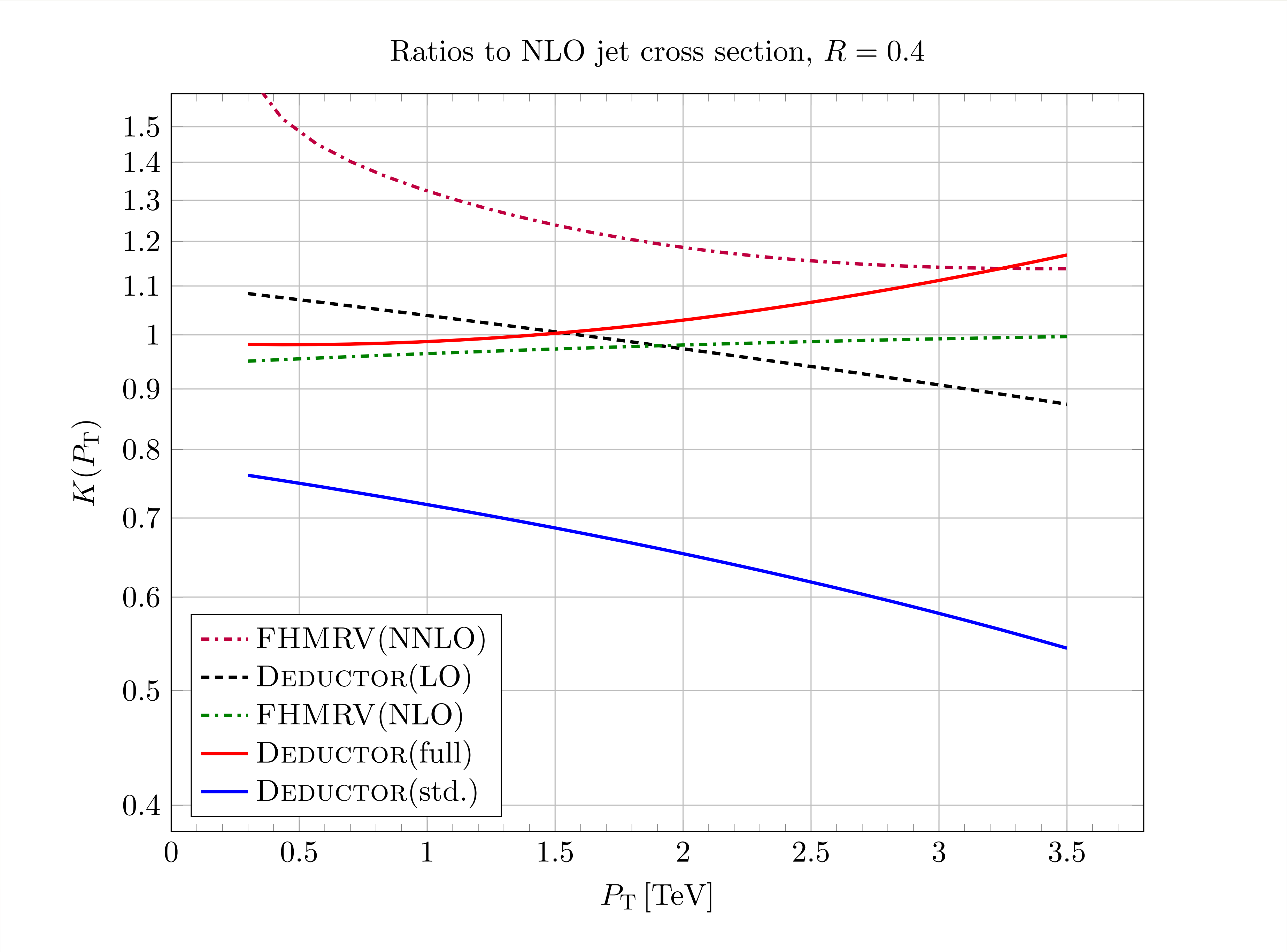
# Effect of threshold logarithms

- DEDUCTOR contains a summation of threshold logarithms.
- These are important for high $P_{\rm T}$.
- Define ratios to NLO

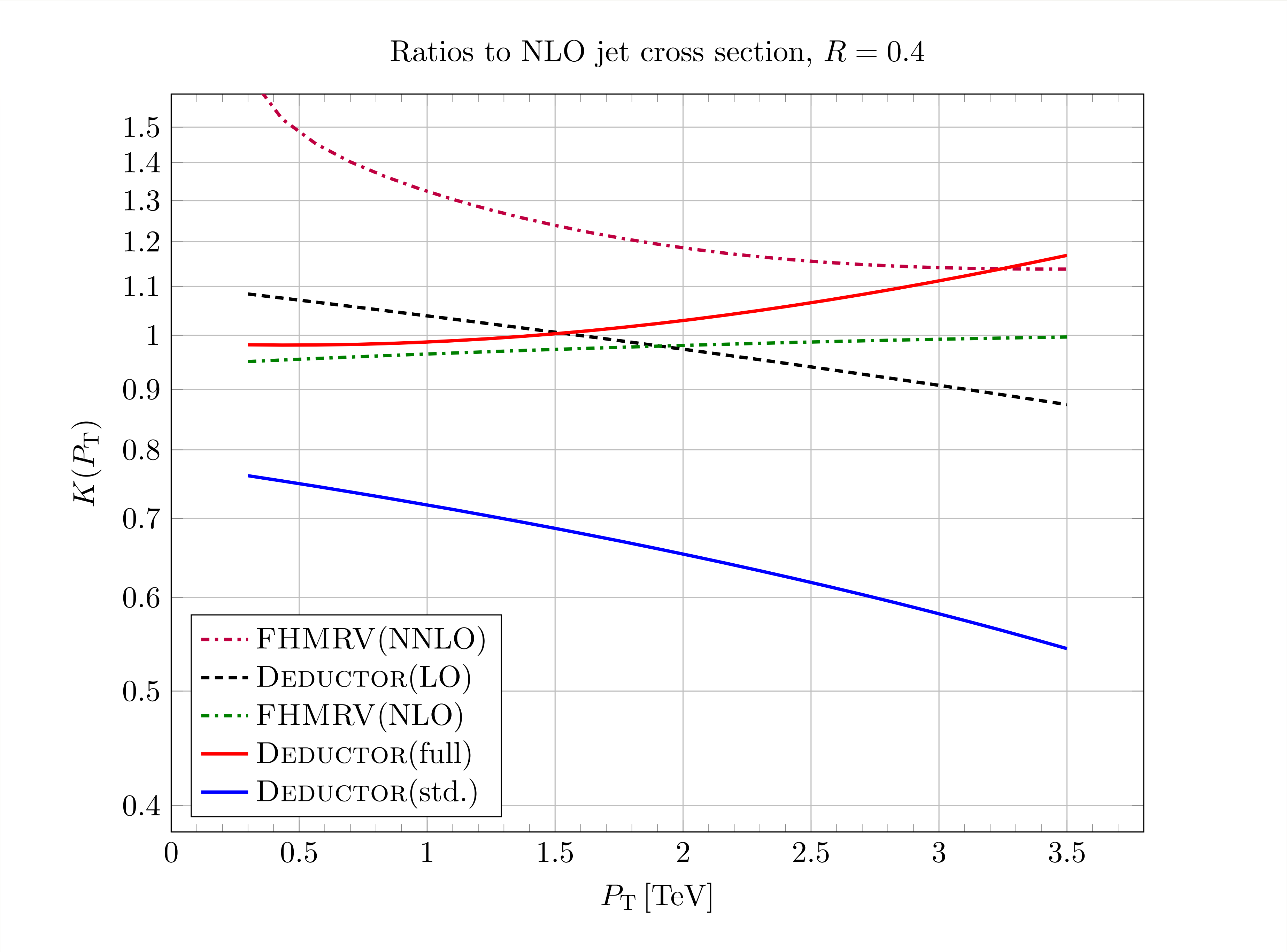
$$K(\text{“A”}) = \frac{d\sigma(\text{“A”})/dP_{\rm T}}{d\sigma(\text{NLO})/dP_{\rm T}}$$

- This includes analytical summations by FHMRV:

de Florian, Hinderer, Mukherjee, Ringer and Vogelsang.




- LO is close to NLO by choice of scales.
- DEDUCTOR(std.) is smaller, as we have seen.



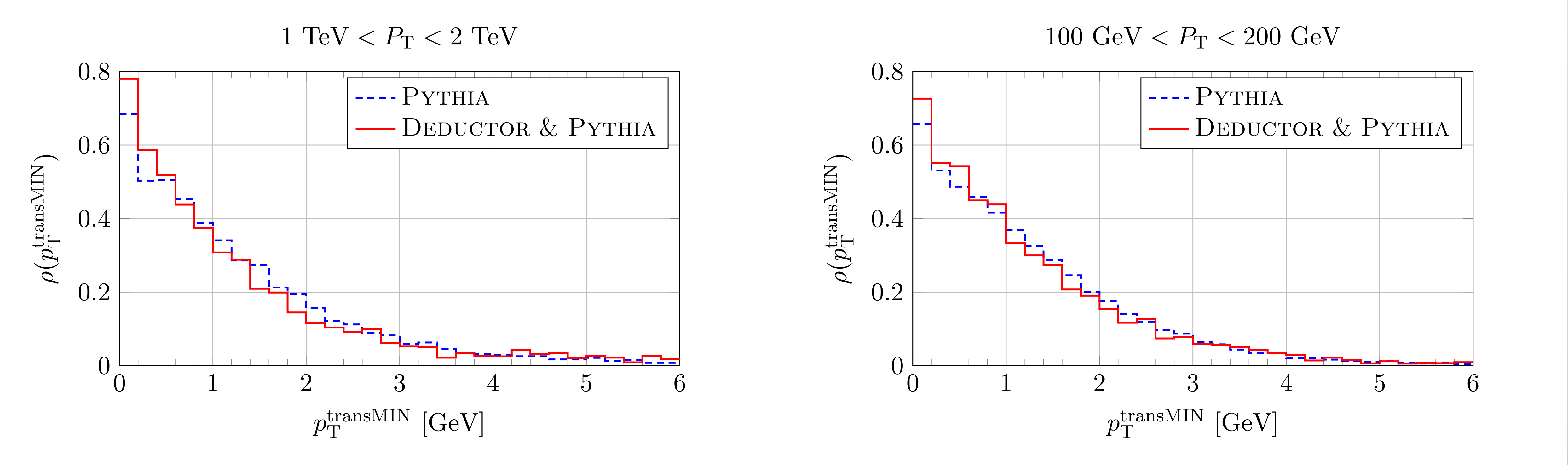

- DEDUCTOR(full)/ DEDUCTOR(std.) is quite large.
- FHMRV(NLO) is close to DEDUCTOR(full).
- New Liu, Moch, Ringer summation is similar to FHMRV(NLO).

# Conclusion on the jet cross section

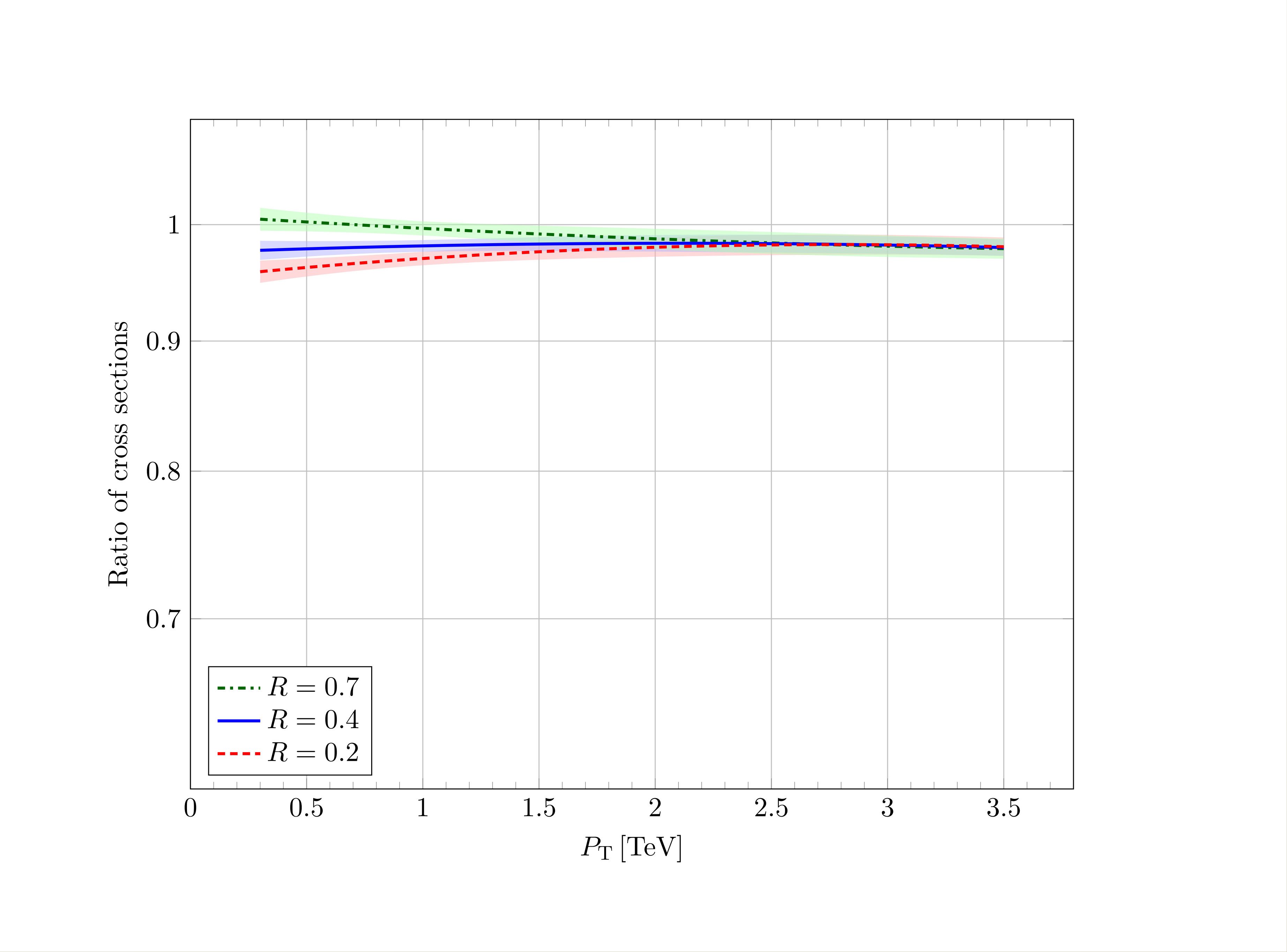
- Differences among parton shower algorithms can yield different results.
- The threshold summation factor is important at large $P_{\mathrm{T}}$.
- The one jet inclusive cross section contains factors that are substantially different from 1 and largely cancel.

# Additional plots

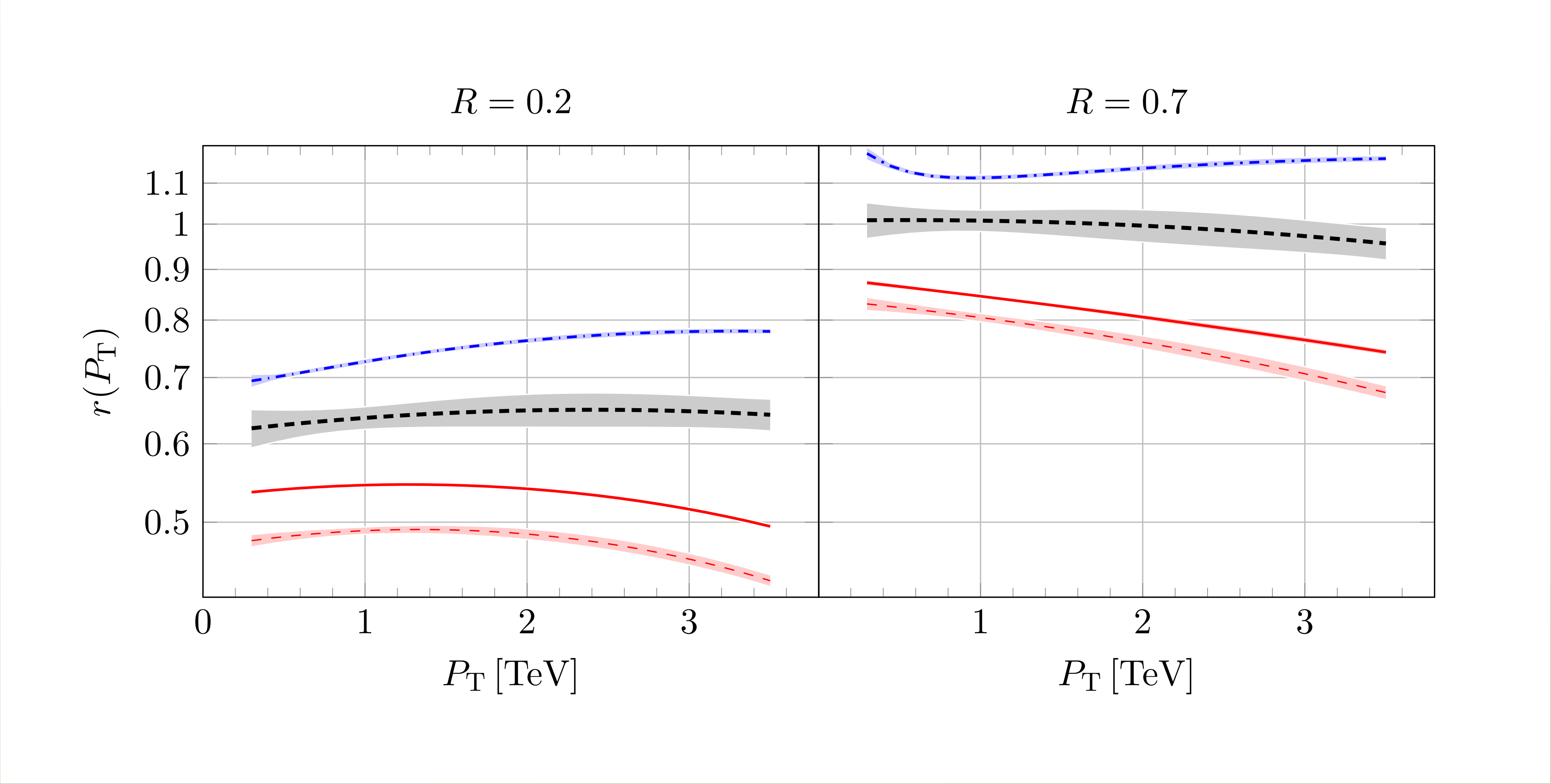
- Distribution of $p_{\mathrm{T}}^{\mathrm{transMIN}}$ after underlying event and Pythia hadronization.



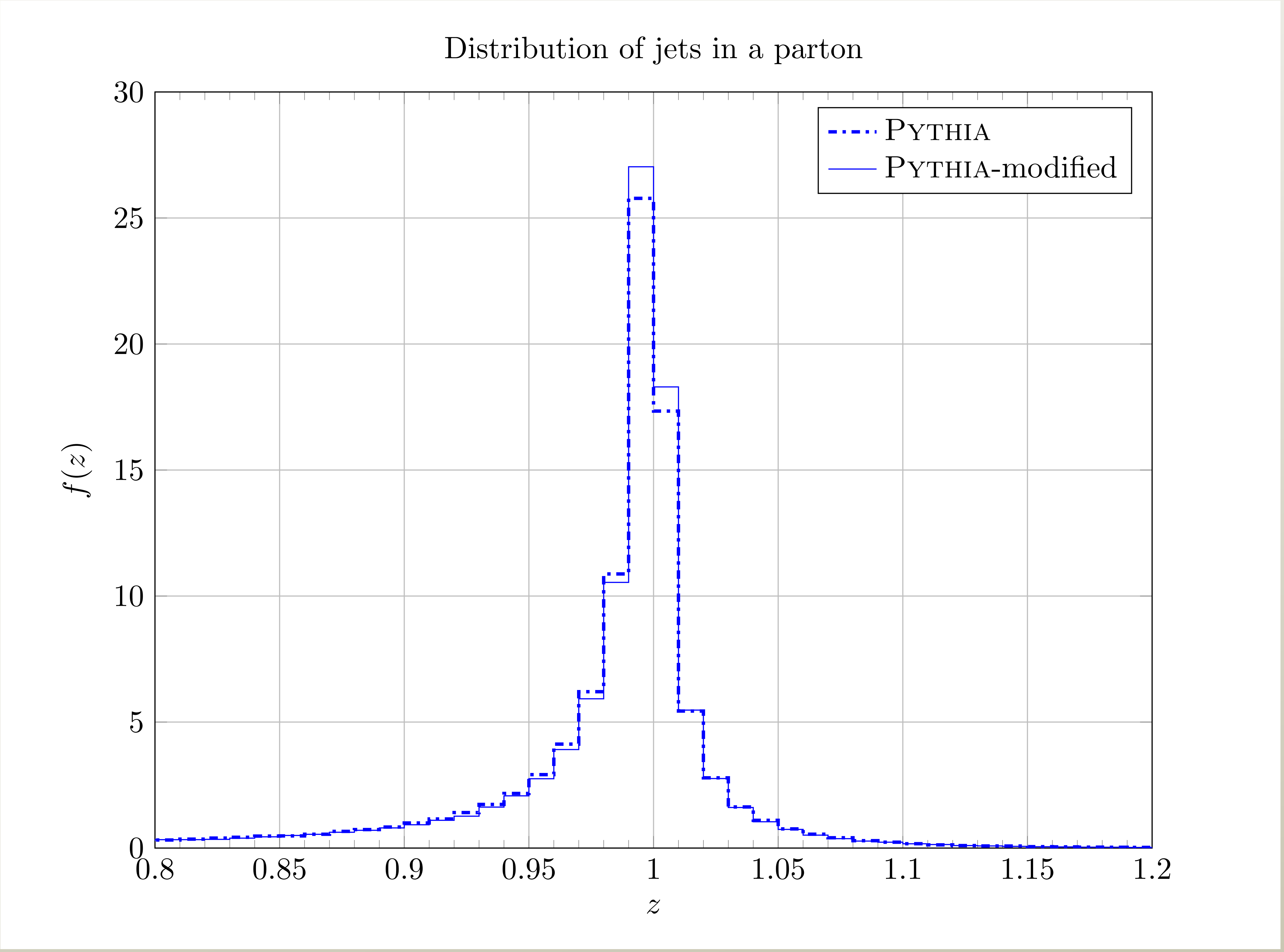
- Nonperturbative effects on the one jet inclusive cross section.



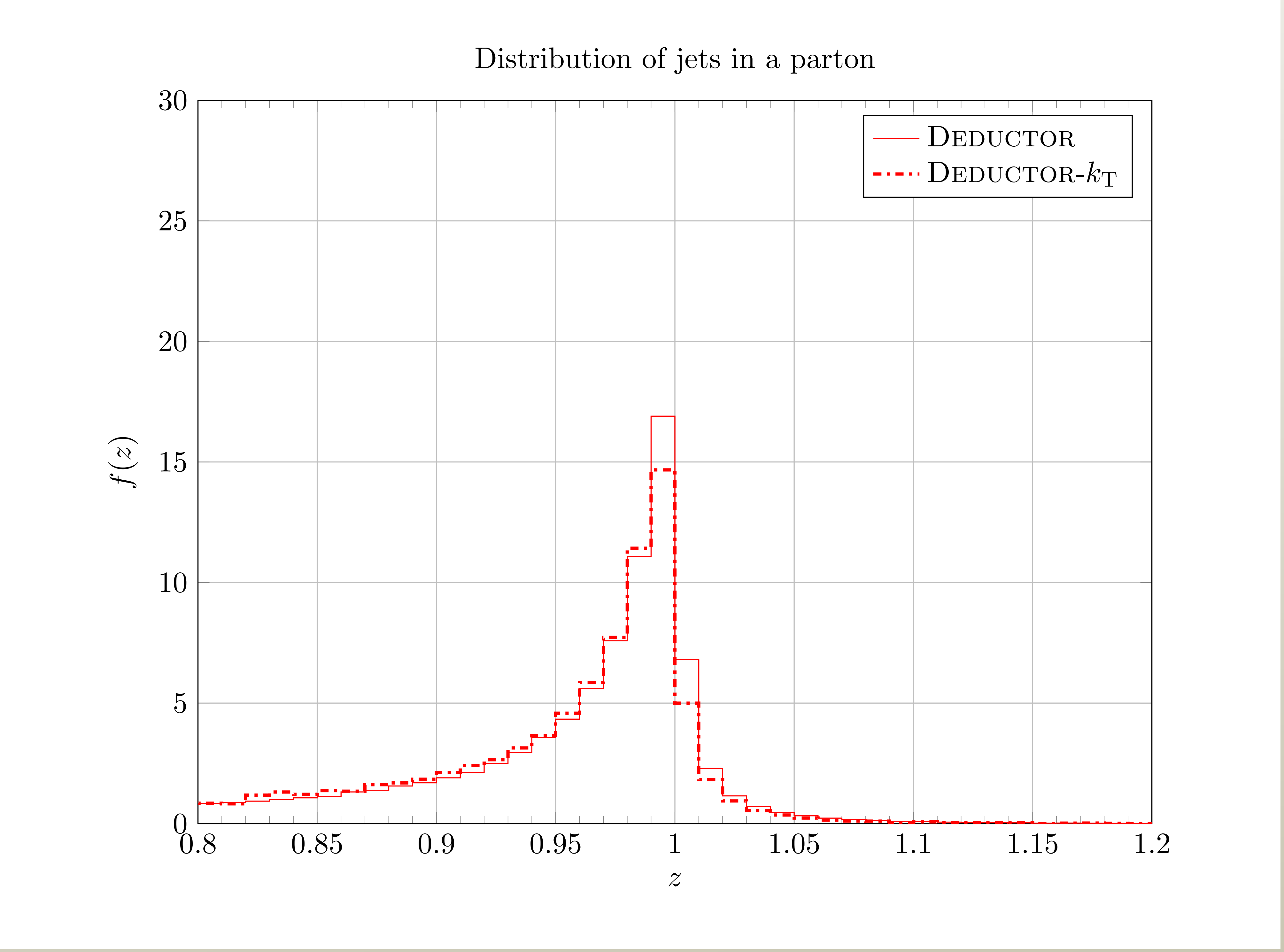
- Jet finding ratio $r(P_{\mathrm{T}})$ for $R = 0.2$ and $R = 0.7$.



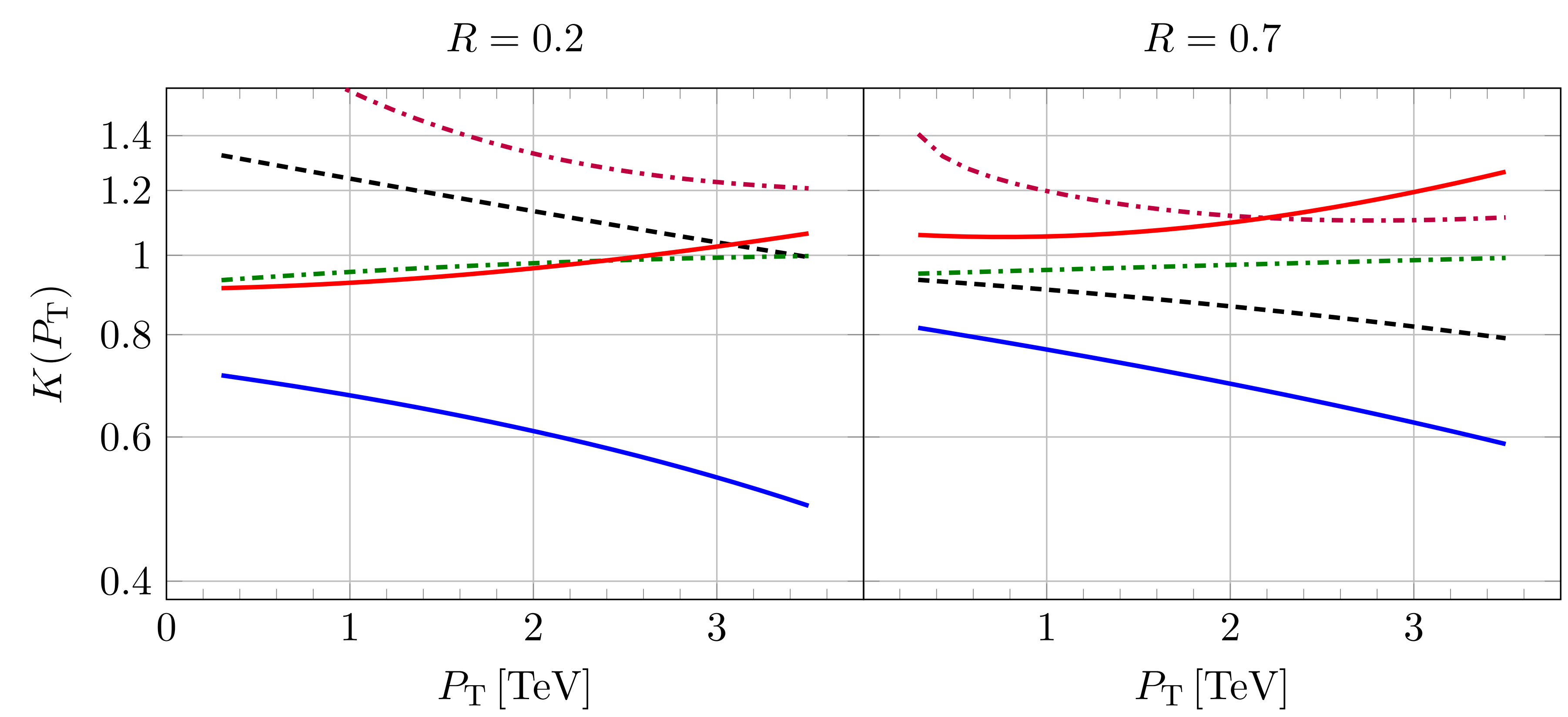
- Effect of PYTHIA conventions for $\alpha_s$ on distribution of jets in a parton $f(z)$.



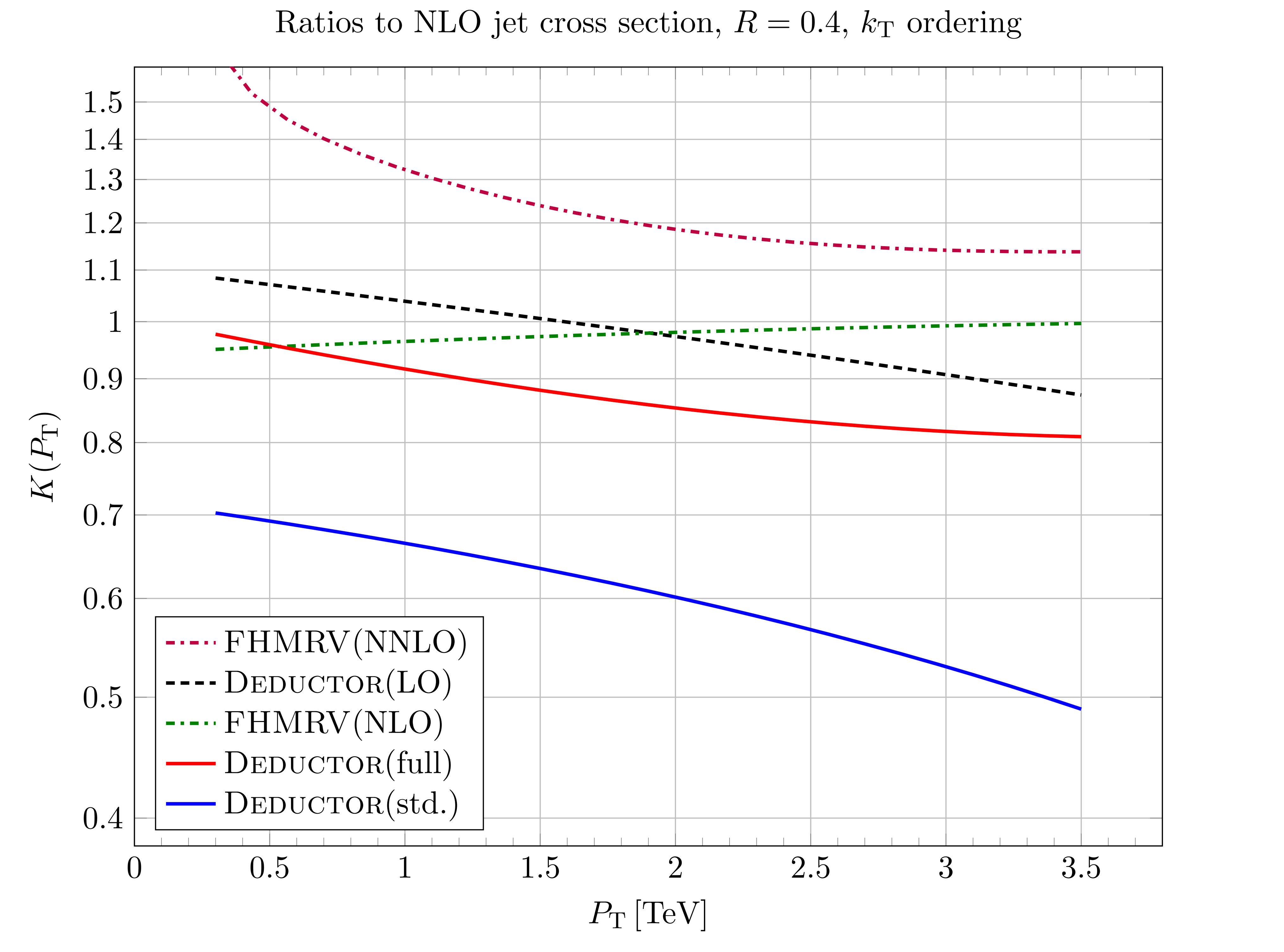
- Effect of DEDUCTOR ordering parameter choice on distribution of jets in a parton $f(z)$.



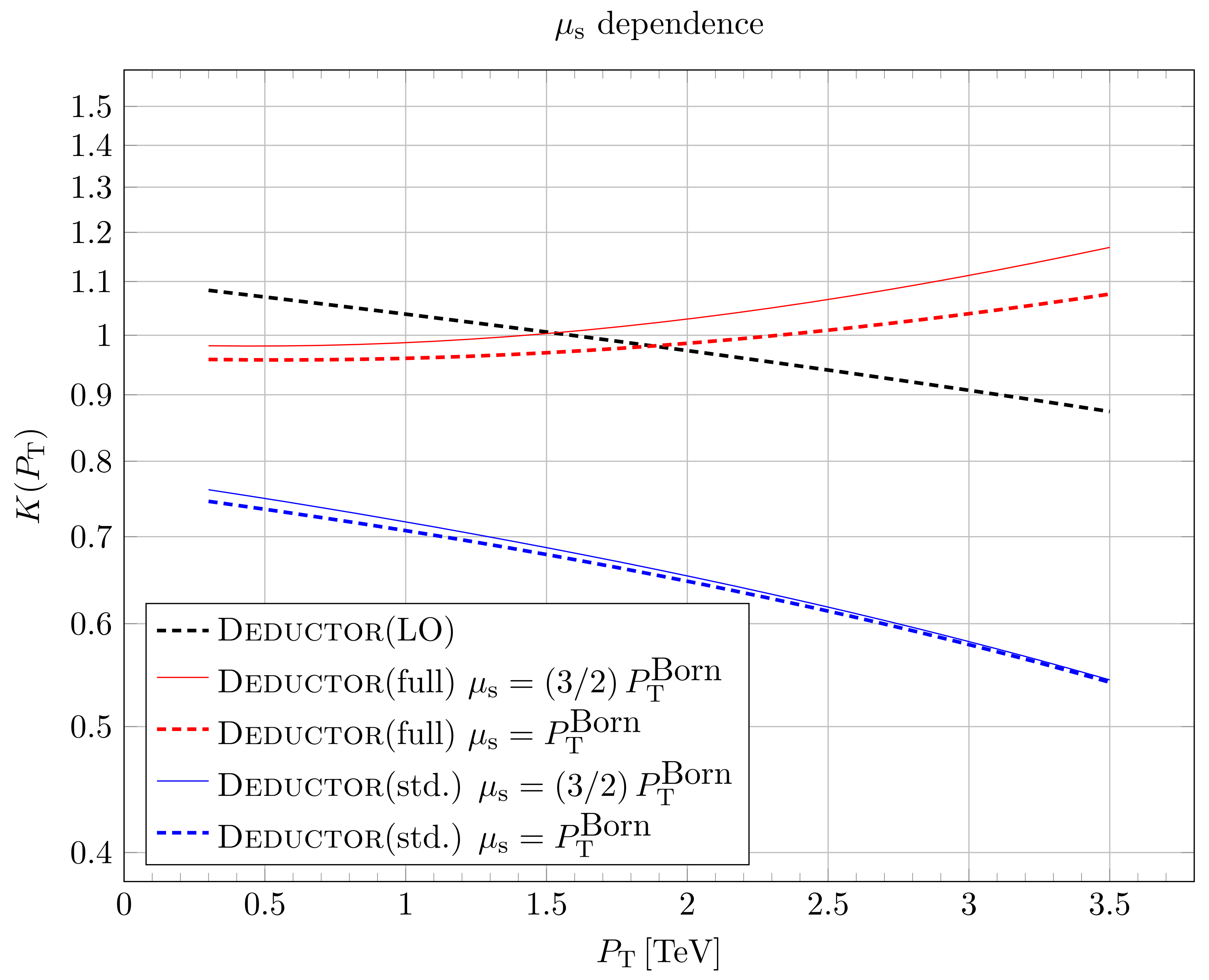
- Ratios $K(P_{\mathrm{T}})$ of the one jet inclusive cross section $d\sigma/dP_{\mathrm{T}}$ to the NLO cross section with $R = 0.2$ and $R = 0.7$.



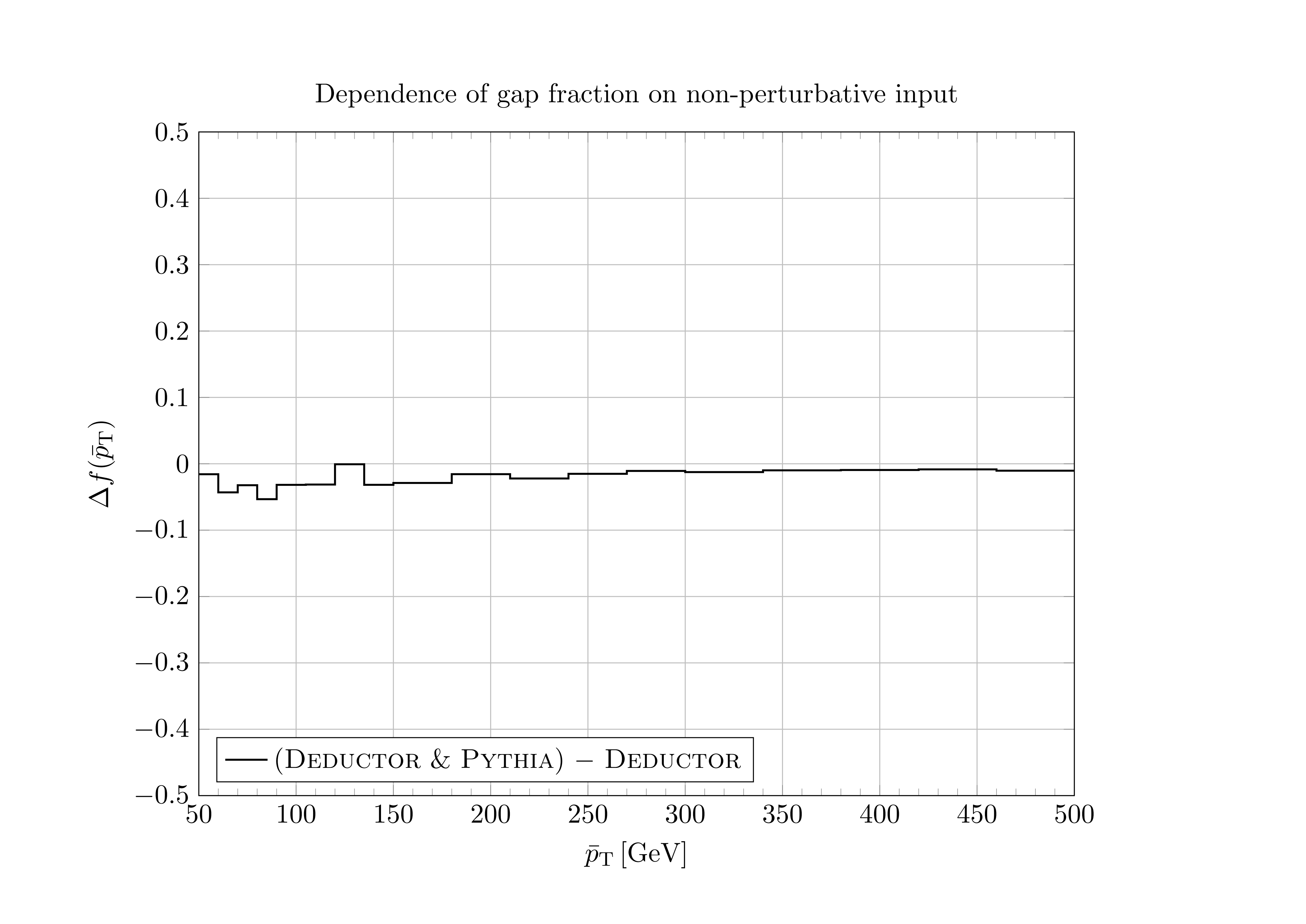
- Ratios $K(P_\mathrm{T})$ of the one jet inclusive cross section $d\sigma/dP_\mathrm{T}$ to the NLO cross section calculated using DEDUCTOR in different approximations with $k_\mathrm{T}$ ordering.



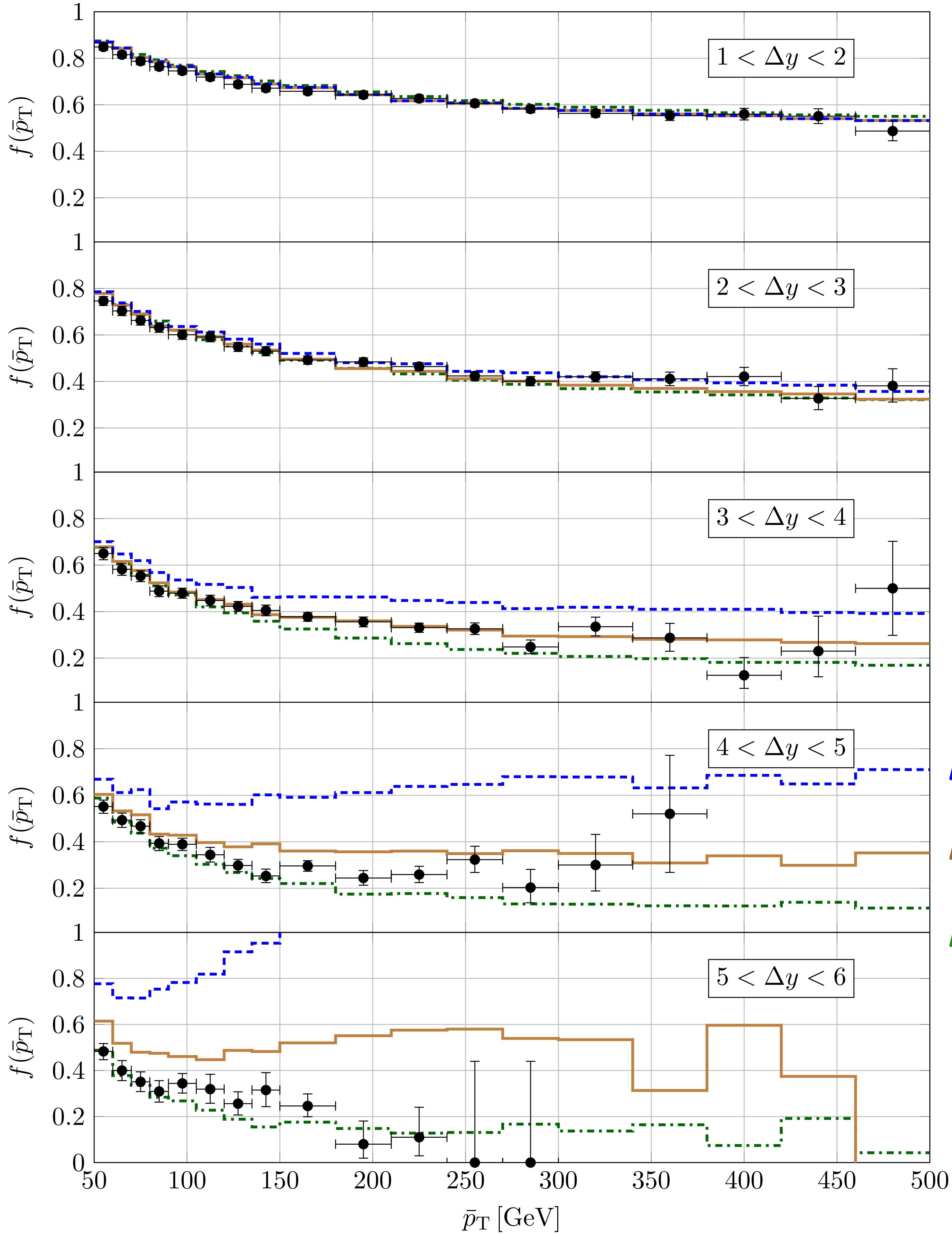
- Ratios $K(P_\mathrm{T})$ of the one jet inclusive cross section $d\sigma/dP_\mathrm{T}$ to the NLO cross section with the shower start scale set to $\mu_\mathrm{s} = P_\mathrm{T}^\mathrm{Born}$. These are compared to the results with our standard choice $\mu_\mathrm{s} = (3/2)\, P_\mathrm{T}^\mathrm{Born}$.



- Change $\Delta f$ in the gap fraction for $2 < \Delta y < 3$ when nonperturbative effects are added.



- Dependence of perturbative gap fraction result on $\mu_R$ and $\mu_F$.

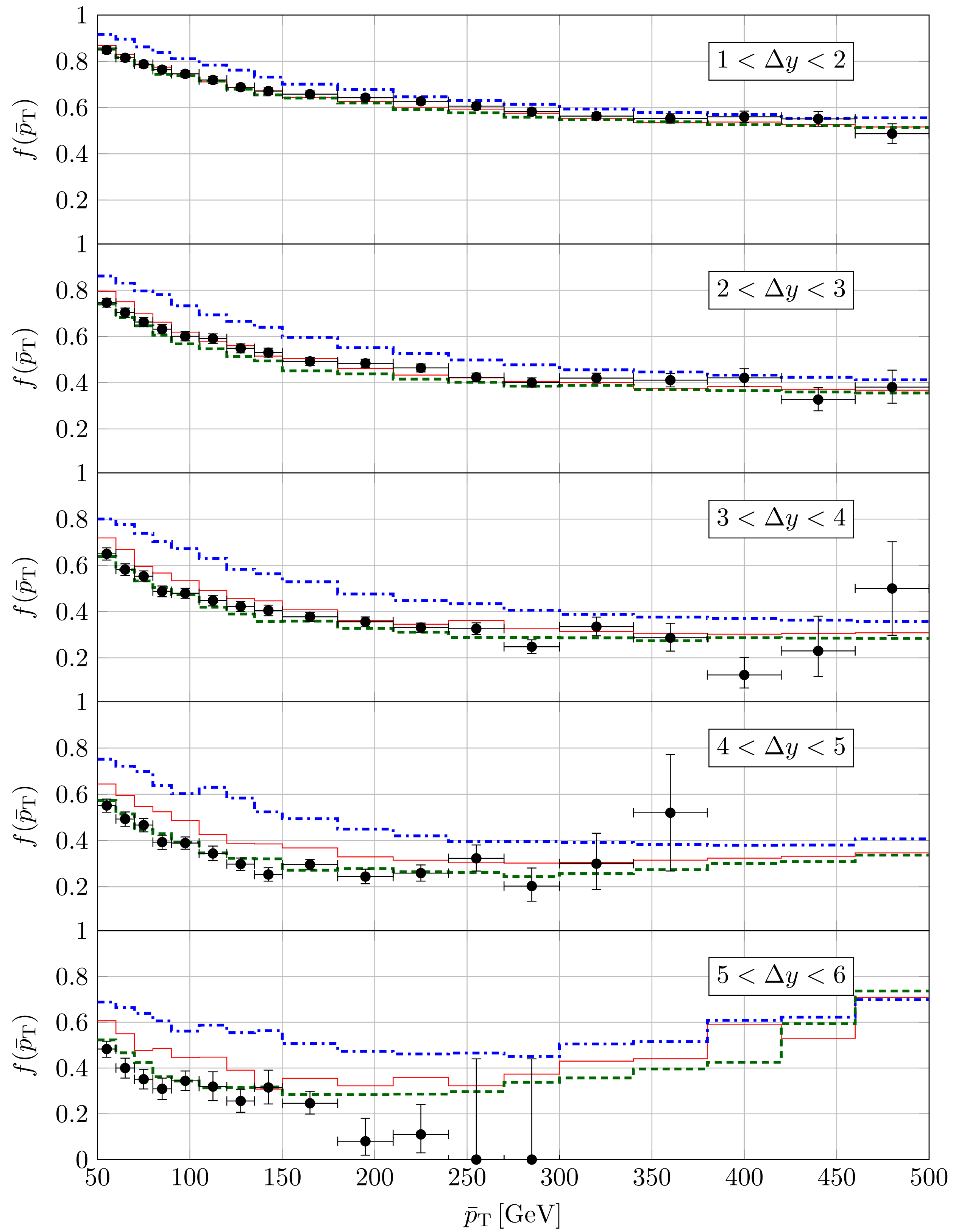



$\mu_R = \mu_F = \bar{p}_T/2$

$\mu_R = \mu_F = \bar{p}_T$

$\mu_R = \mu_F = 2\bar{p}_T$

- Dependence of DEDUCTOR gap fraction result on shower start scale $\mu_s$.




$\mu_s = P_T^{\rm Born}$

$\mu_s = (3/2)\, P_T^{\rm Born}$

$\mu_s = 2\, P_T^{\rm Born}$