N-Subjettiness for boosted jets

Davide Napoletano QCD@LHC '19 (Buffalo)

Intro

[DN, G. Soyez JHEP12(2018)031]

- Jet-Substructure techniques for boosted jets for signal/bkg disc
- Particularly important for hadronically decaying colourless particles
- Here focus on two-pronged decays, like a W

N-Subjettiness: $$\tau_N^{(\beta)} = \frac{1}{p_\perp R^\beta} \sum_{i \in \text{jet}} p_{\perp_i} \min\left(\theta_{i a_1}, \ldots, \theta_{i a_N}\right)$$

N-subjettiness

$$d\mathcal{P}_W = dR_W(x) = \lambda^2 \, dz d\theta^2 P_W$$

- Uniform and flat in energy and angle

$$d\mathcal{P}_{\text{QCD}} = dR = \frac{\alpha_s C_i}{2\pi} d\log z d\log\theta^2 P_W$$

- more soft and collinear

$$\tau_2 = \sum_{i \in jet} \min\left(z_i \theta_{i1}^2, z_i \theta_{i2}^2\right)$$

$$\rightarrow \tau_2^W \sim \tau_2^{QCD}$$

However!

$$\tau_1 = \sum_{i \in jet} \min\left(z_i \theta_{i1}^2\right)$$

$$\rightarrow \tau_1^W > \tau_1^{QCD}$$

N-subjettiness

$$\mathrm{d}\mathcal{P}_W = \mathrm{d}R_W(x) = \lambda^2\,\mathrm{d}z\,\mathrm{d}\theta^2 P_W$$

- Uniform and flat in energy and angle

$$\mathrm{d}\mathcal{P}_{\mathrm{QCD}} = \mathrm{d}R = \frac{\alpha_s C_i}{2\pi}\,\mathrm{d}\log z\,\mathrm{d}\log\theta^2 P_W$$

- more soft and collinear

One then expects $\tau_{21} = \frac{\tau_2}{\tau_1}$ to be a good discriminant

N-Subjettines cut

- First efforts resumming double logs in the small tau region

$$\alpha_s^n \log^{2n} \rho \,, \quad \alpha_s^n \log^{2n} \tau \,, \quad \alpha_s^n \log^n \rho \log^n \tau$$

N-Subjettines cut

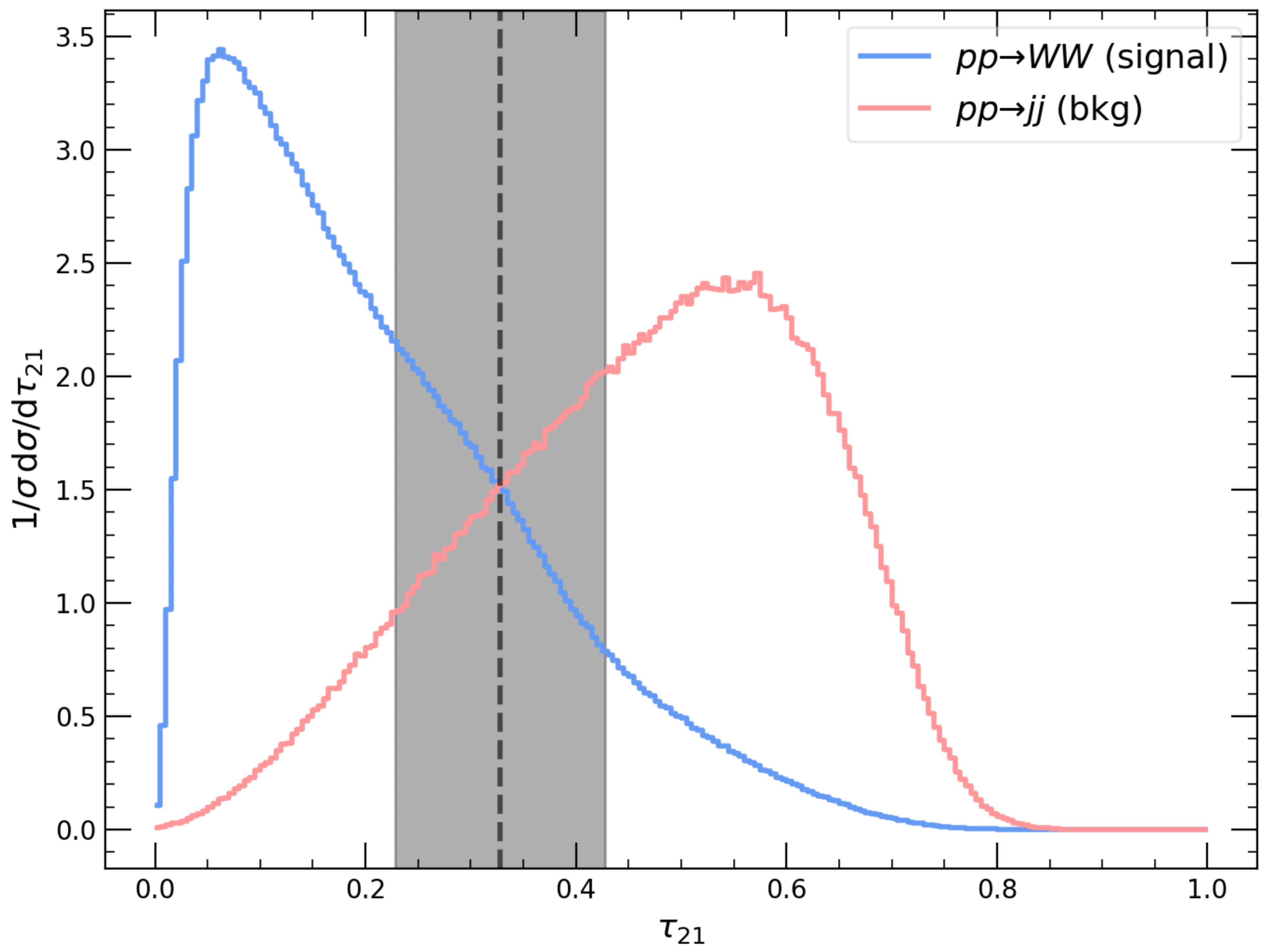
- First efforts resumming double logs in the small tau region

$$\alpha_s^n \log^{2n} \rho \,, \quad \alpha_s^n \log^{2n} \tau \,, \quad \alpha_s^n \log^n \rho \log^n \tau$$

- The interesting region's clearly at much larger tau!

- Structure now more complicated, as finite terms have to be included to have correct accuracy in rho

$$\alpha_s^n \log^{2n} \rho \,, \quad \alpha_s^n \log^{2n} \tau \,, \quad \alpha_s^n \log^n \rho \, f_n(\tau)$$



This is (in essence) the contribution we compute

N-Subjettiness cut

Small tau

$$\rho_1 \gg \rho_2 \gg \cdots \gg \rho_n$$
$$\theta_1 \ll \theta_2 \ll \cdots \ll \theta_n$$

Mass is set by first emission

$$\rho \sim \rho_1$$
$$\tau_{21} \sim \frac{\rho_2}{\rho_1}$$

N-Subjettiness cut

Small tau

$$\rho_1 \gg \rho_2 \gg \cdots \gg \rho_n$$
$$\theta_1 \ll \theta_2 \ll \cdots \ll \theta_n$$

Mass is set by first emission

$$\rho \sim \rho_1$$
$$\tau_{21} \sim \frac{\rho_2}{\rho_1}$$

Finite tau

$$\rho_1 \sim \rho_2 \sim \cdots \sim \rho_n$$
$$\theta_1 \ll \theta_2 \ll \cdots \ll \theta_n$$

All emissions contribute

$$\rho = \sum_{i=1}^{n} \rho_i$$
$$\tau_{21} = 1 - \frac{\max_i \rho_i}{\rho}$$

N-Subjettiness cut

Small tau

$$\rho_1 \gg \rho_2 \gg \cdots \gg \rho_n$$
$$\theta_1 \ll \theta_2 \ll \cdots \ll \theta_n$$

Mass is set by first emission

$$\frac{\rho}{\sigma}\frac{d\sigma}{d\rho}\Big|_{<\tau} \sim R'(\rho)\, e^{-R(\rho)-R_\tau(\rho)}$$

First emission

Sudakov mass supp.

No extra emissions

Finite tau

$$\rho_1 \sim \rho_2 \sim \cdots \sim \rho_n$$
$$\theta_1 \ll \theta_2 \ll \cdots \ll \theta_n$$

All emissions contribute

Next slides!!!

Finite tau

- Single out the emission with the largest rho: ρ_a

$$\frac{\rho}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\rho}\bigg|_{<\tau} = \int_0^1 \frac{d\rho_a}{\rho_a} R'(\rho_a) \lim_{\epsilon\to 0} e^{-\int_\epsilon^1 \frac{d\rho_v}{\rho_v} R'(\rho_v)}$$

$$\sum_{p=1}^{\infty} \frac{1}{p!} \int_\epsilon^{\rho_a} \prod_{i=1}^{p} \frac{d\rho_i}{\rho_i} R'(\rho_i)\, \rho\delta\left(\rho - \rho_a - \sum_{i=1}^{p} \rho_i\right) \Theta\left(\frac{\rho_a}{\rho} > 1 - \tau\right)$$

- Identify two regions $\tau \lesseqgtr \frac{1}{2}$ and expand around $\frac{\tau}{1-\tau}$

$$R(\rho - \rho_a) \approx R\left(\rho\frac{\tau}{1-\tau}\right) + R'\left(\rho\frac{\tau}{1-\tau}\right)\log\left(\frac{\rho\tau}{(1-\tau)(\rho-\rho_a)}\right)$$

$$R'(\rho - \rho_a) \approx R'\left(\rho\frac{\tau}{1-\tau}\right).$$

Finite tau

$$\frac{\rho}{\sigma}\frac{d\sigma}{d\rho}\bigg|_{<\tau} = \begin{cases} R'(\rho)\,\mathcal{R}\left(\frac{\rho\,\tau}{1-\tau}\right)(1-\tau)^{R'}\,{}_2F_1 & \tau < \frac{1}{2} \\ R'(\rho)\,\mathcal{R}\left(\rho\right)\left[2^{-R'(\rho)}\,{}_2F_1 + R'(\rho)\mathcal{I}_{\mathrm{ME}}\right] & \tau > \frac{1}{2} \end{cases}$$

$$\mathcal{R}(x) = \frac{e^{-R(x)-\gamma_E\,R'(x)}}{\Gamma(1+R'(x))}$$

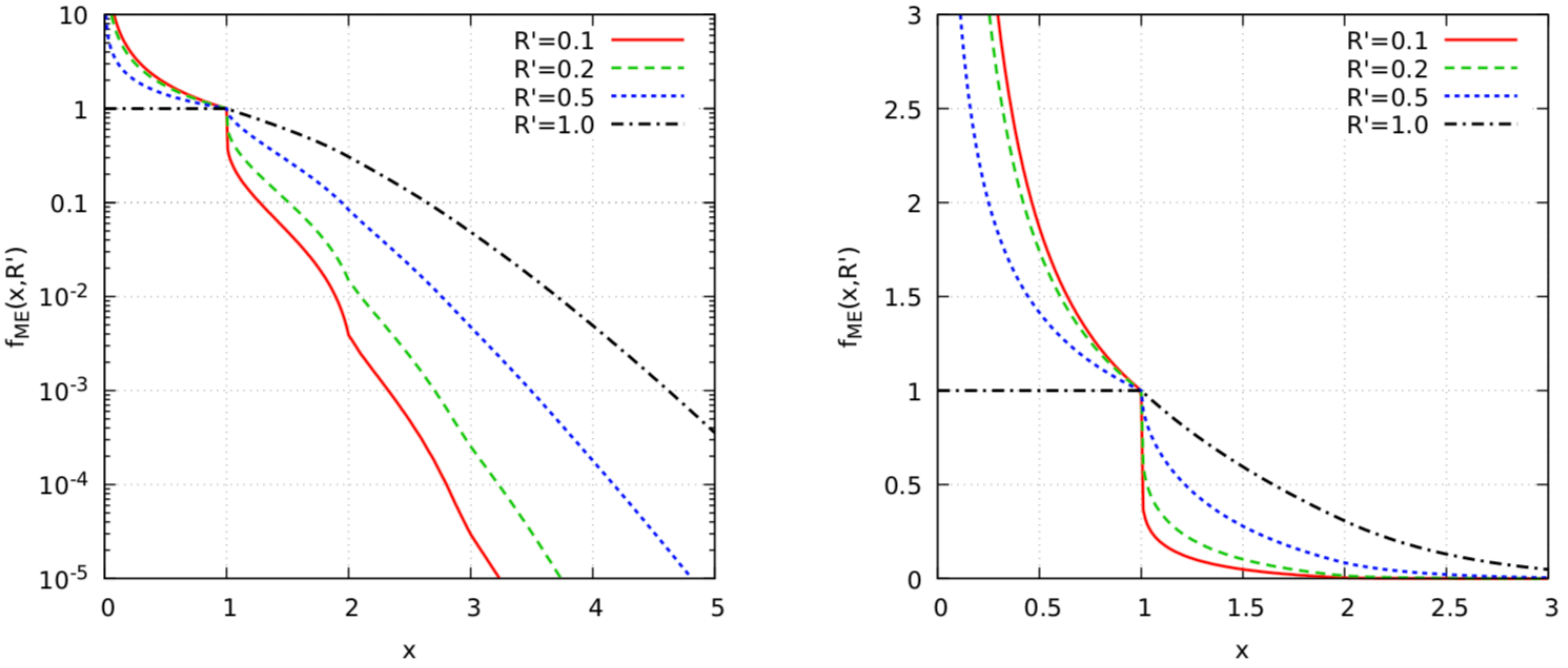
- Structure of the result is remarkably simple: scale depends on value of tau

Finite tau

- Multiple emission function, keeps track of transition points at $\tau = \frac{n-1}{n}$

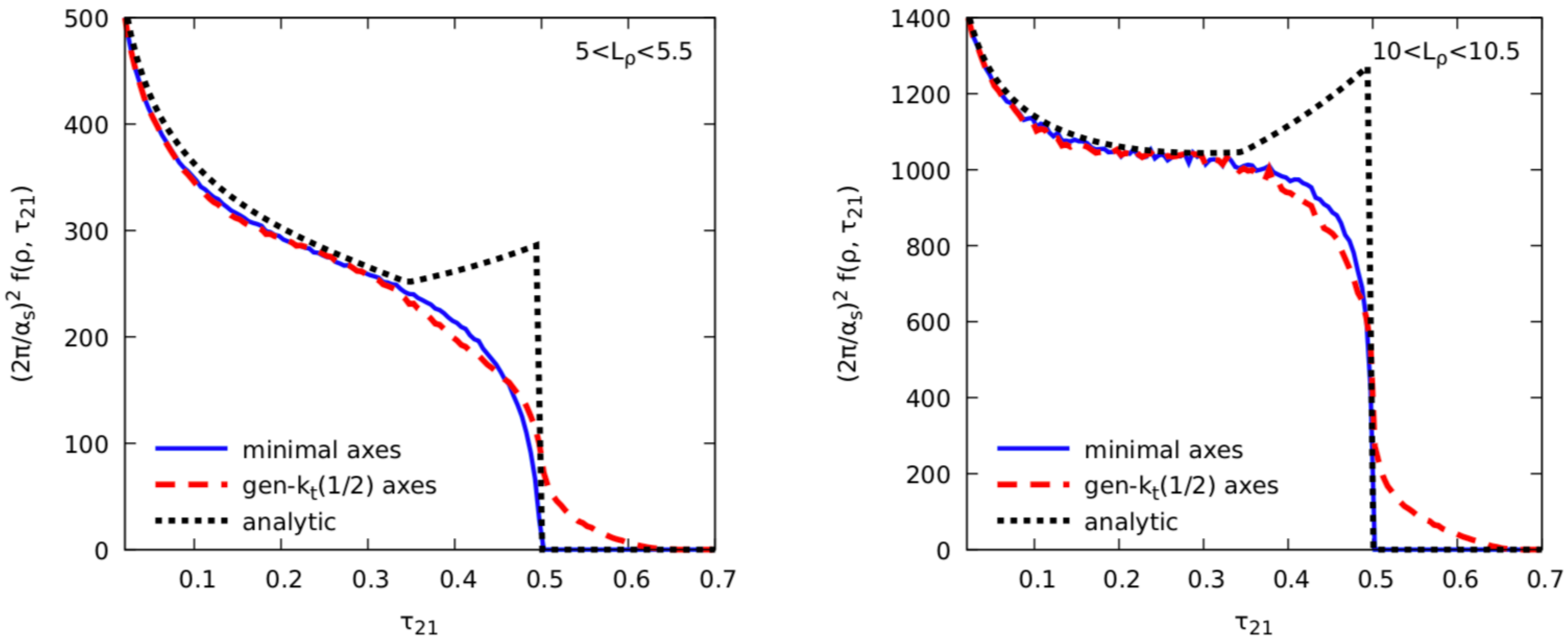
$f_{\mathrm{ME}}(x, R')$

$$\mathcal{I}_{\mathrm{ME}} = \int_1^x \frac{\mathrm{d}u}{(1+u)^{R'}} \Gamma(R') \oint \frac{\mathrm{d}\nu}{2\imath\pi} e^{\nu x} \exp\left\{\frac{R'}{2}\mathrm{Ei}(-\nu)\left[\log(-\nu) - \log\left(\frac{1}{\nu}\right)\right]\right\}$$



Results

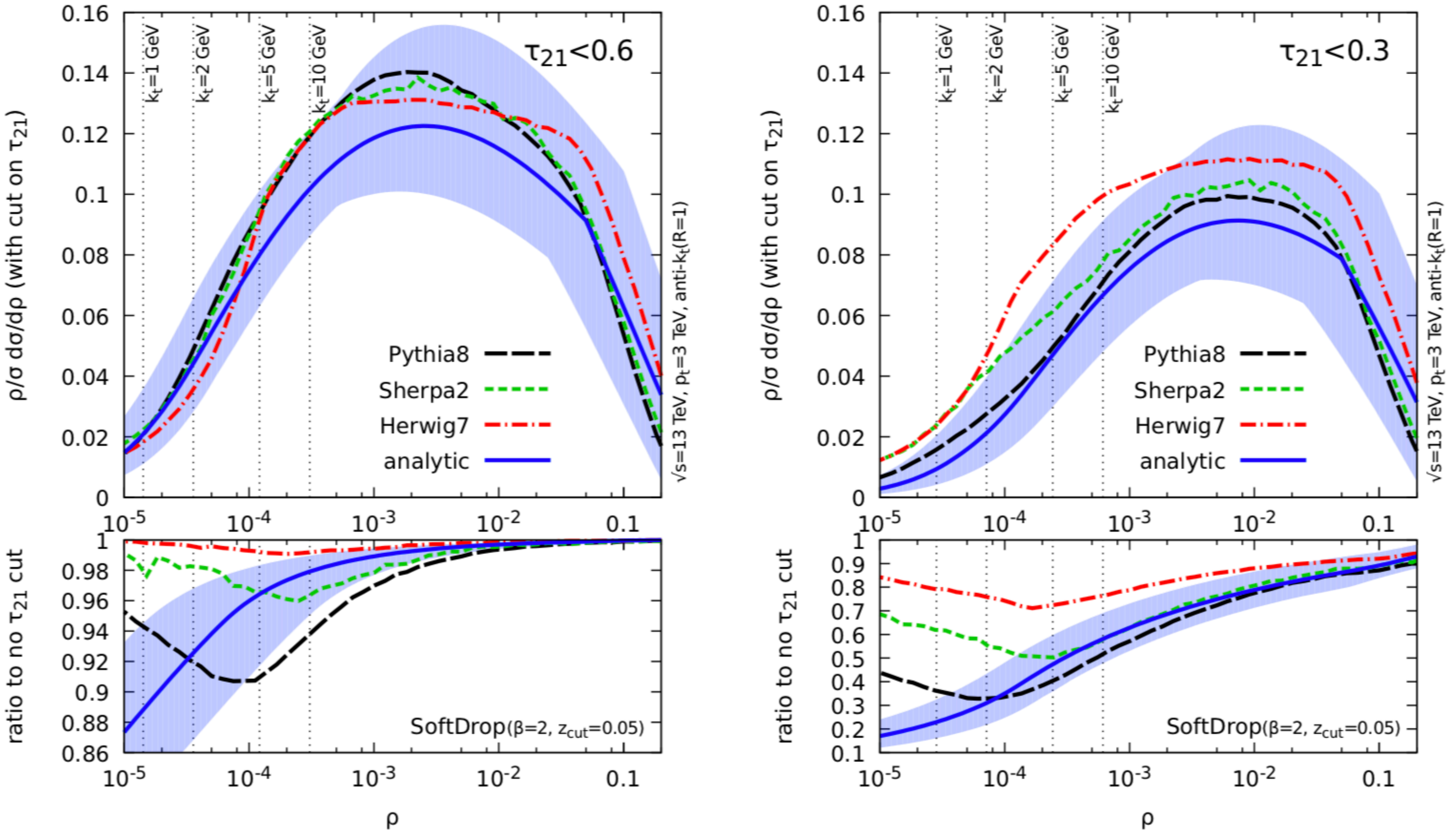
- Checks of the minimisation procedure
- minimal axes quite similar to kt
- Analytical vs exact: quite good at small/large tau
- **But**, it's integrated over, so beyond our accuracy (originates in neglecting large angle effects)



Results

Parton Level

- Good excuse to do a generators comparison!
- Analytical scale var is quite large (it's only LL)
- Overall quite good agreement
  (Herwig was before color fix)



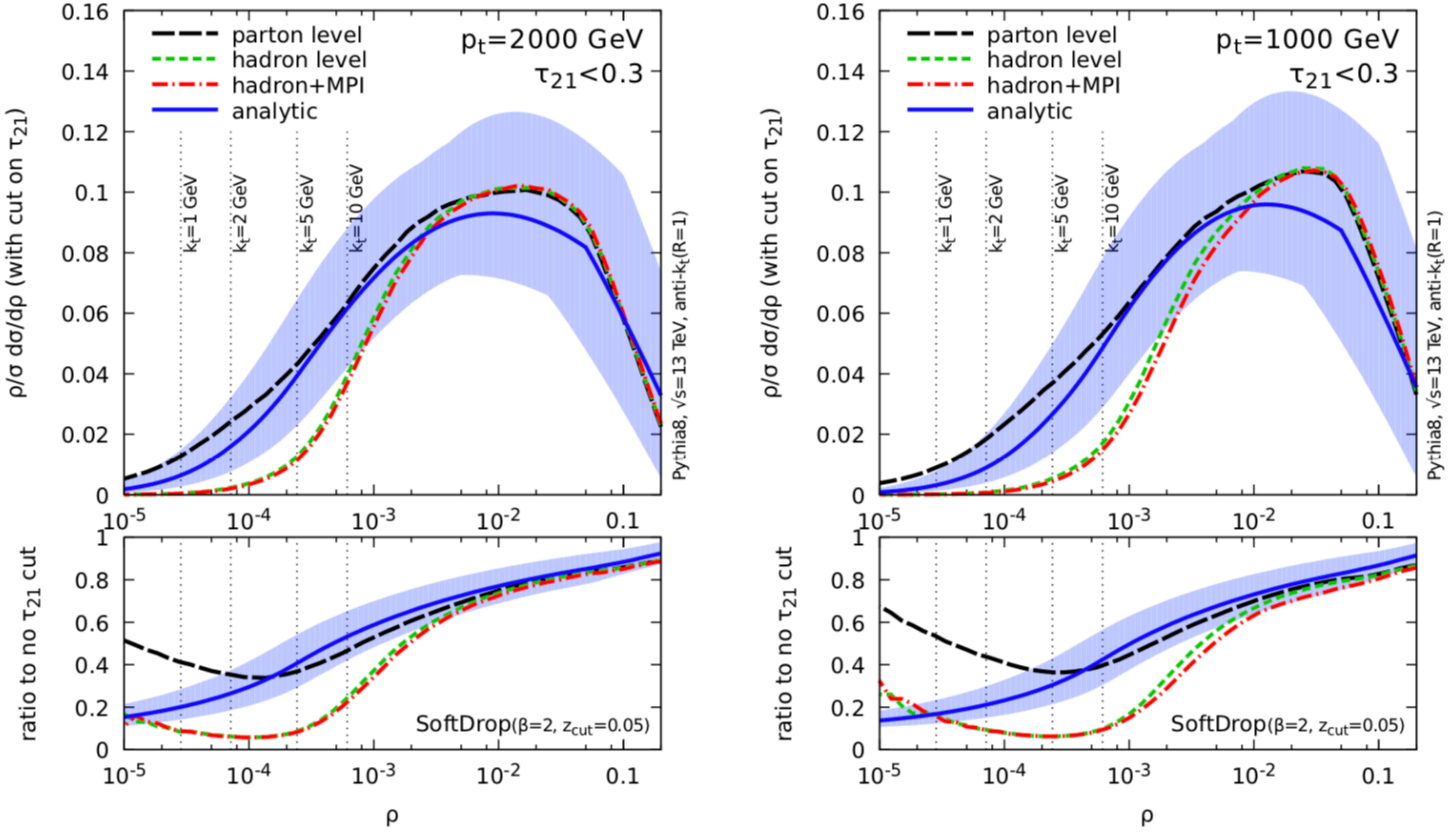
Results

- Clearly no control over NP-region

- still quite large effects in perturbative region

- rest is, over all, well under control

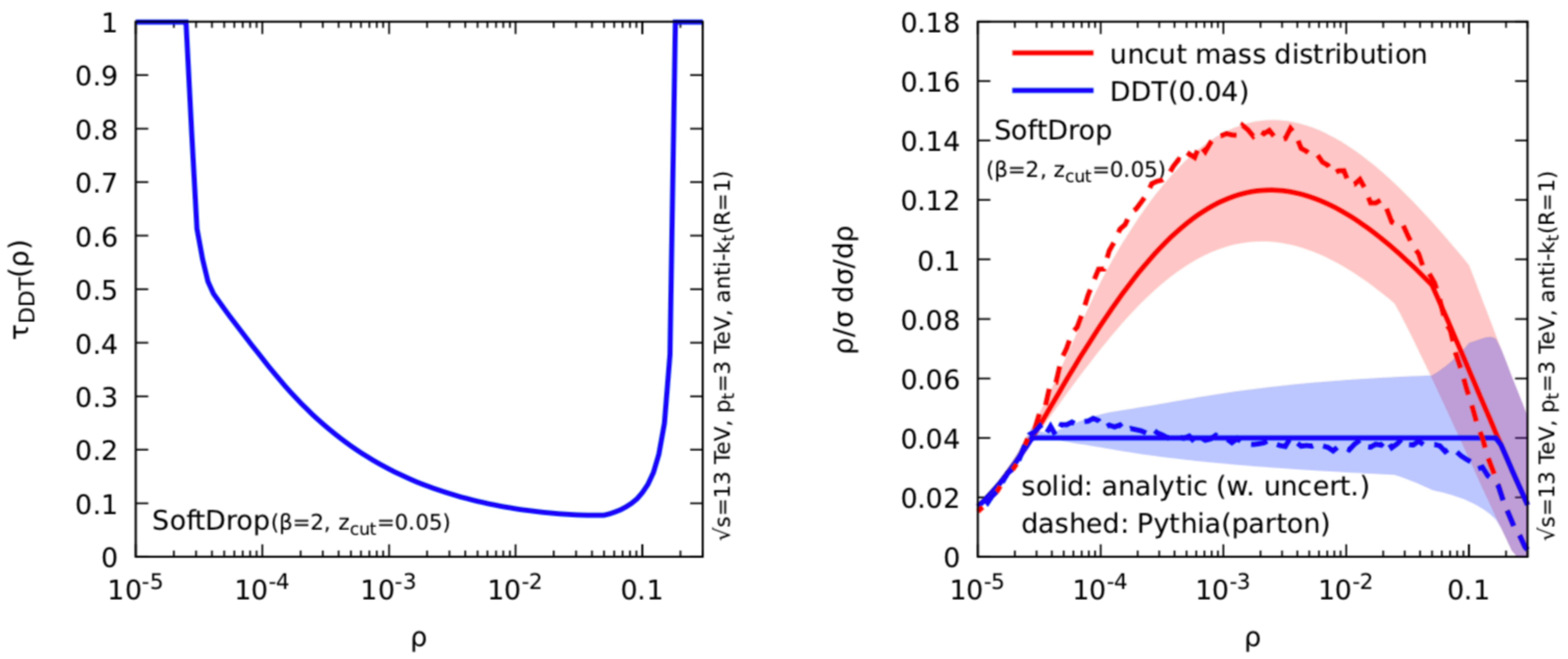
Hadron Level



Results

- Find the value of tau that makes distribution flat

Decorrelated taggers



- Not necessarily an easy task in general, quite easy having analytical control

- To show-off we do it and seems to be working pretty reliably

Conclusions

- Jet-substructure has been successfully used for discrimination problems
- Analytical calculations in this field have also helped introducing new observables
- However often oversimplifications to overcome difficulties
- This calculation addresses some of them, and we produce some results with it!
    - The important thing is that with an analytical calculation one is able to extract some physics information on the problem at hand