# On heavy-flavour jets with Soft Drop

Andrea Ghira

Heavy Flavours at High $p_T$, Edinburgh, 30th November

In collaboration with S.Caletti and S.Marzani

# Introduction

We analyze heavy-flavour initiated jets groomed with the Soft-Drop (SD) procedure (A. Larkoski, S. Marzani, G. Soyez, J. Thaler).

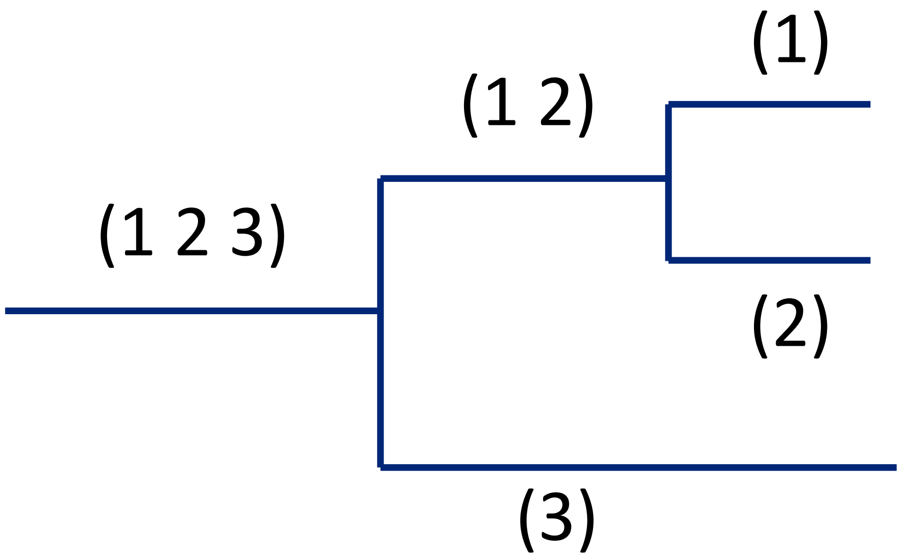
$\theta_g$: angular opening of the groomed jet (access to the dead-cone)

$z_g$: allows us to probe the heavy quark splitting function

Recent measurement by ALICE of the SD observables on c-jets.

# The Soft Drop Procedure

The SD algorithm removes consistently soft emission at large angle




$$\frac{\min\left(p_{t(12)}, p_{t(3)}\right)}{p_{t(12)} + p_{t(3)}} > z_{\text{cut}} \left(\frac{\Delta_{(12)(3)}}{R_0}\right)^{\beta},$$

$$\Delta_{(12)(3)} = \sqrt{(y_{(12)} - y_{(3)})^2 + (\phi_{(12)} - \phi_{(3)})^2}.$$

After the declustering procedure, the jet constituents are re-clustered according to C/A.

# Definition of the observables

The first branching that passes the soft-drop procedure defines the groomed jet radius $\theta_g$ and the groomed fraction of momentum $z_g$

$$\theta_g = \frac{\Delta_{(12)(3)}}{R_0}, \qquad z_g = \frac{\min\left(p_{t(12)}, p_{t(3)}\right)}{p_{t(12)} + p_{t(3)}}.$$

- The $\theta_g$ distribution is IRC safe both for massive and massless particles.
- The $z_g$ distribution is IRC safe for massless particles only for $\beta < 0$. Conversely, it is always IRC safe for massive particles.

# $\theta_g$ distribution

The all-order cumulative distribution can be computed from the exponentiation of the fixed-order result.

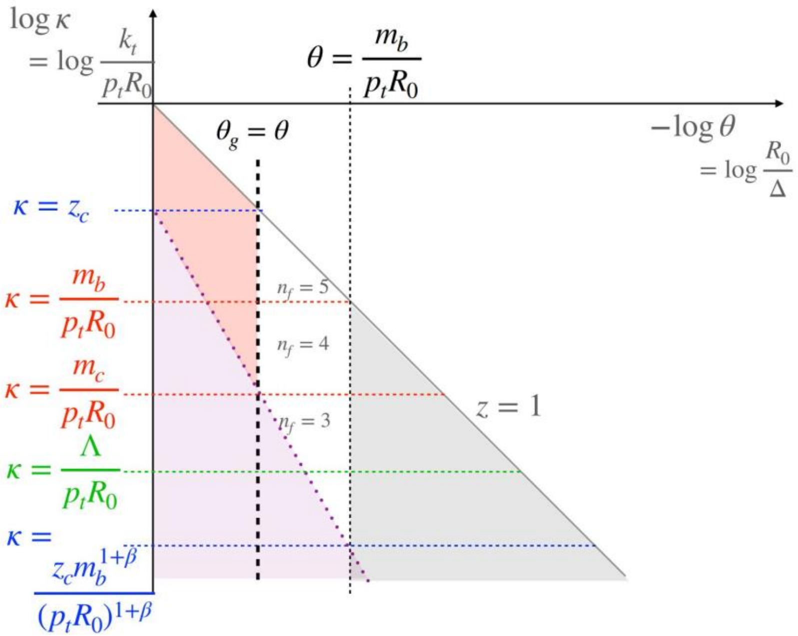
$$R(\vartheta^2_{g,i}) = \int_0^1 \frac{\mathrm{d}\theta^2}{\theta^2+\theta_i^2} \int_0^1 \mathrm{d}z \mathcal{P}_{gi}(z,\theta^2) \frac{\alpha_s^{\mathrm{CMW}}(k_t^2)}{2\pi} \Theta\left(z - z_{\mathrm{cut}}\theta^\beta\right) \Theta\left(\theta^2 - \theta_g^2\right)$$

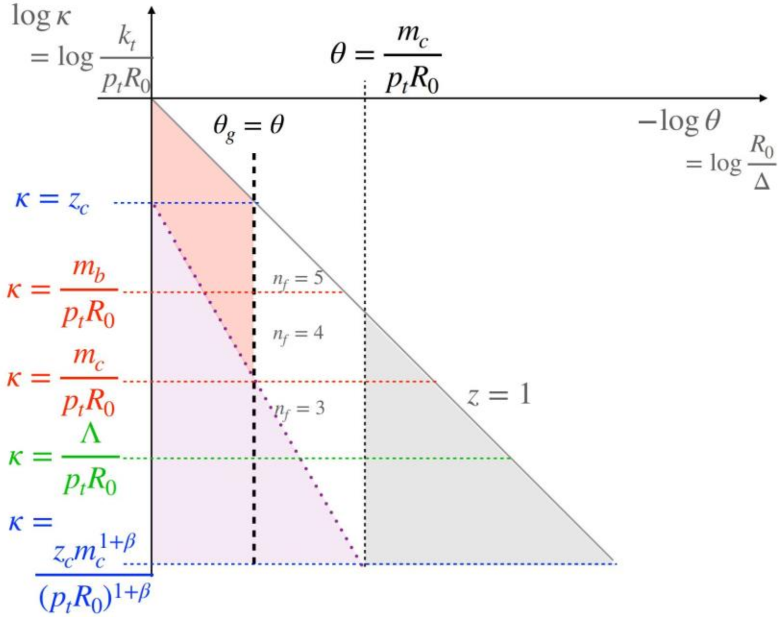
$$\sigma(\theta_g, \theta_i) = S(\theta_g, \theta_i) e^{-R(\vartheta^2_{g,i})}, \quad i = b, c$$

- The Sudakov exponent is a function of $\vartheta^2_{g,i} = \theta_g^2 + \theta_i^2$, $\theta_i^2 = \frac{m_i^2}{p_T^2 R^2}$.
- We have smooth interpolation between the different flavor regions
- The $S$ factor is generated by non-global logs

# Lund Plane geography

In order to perform the calculation of the Sudakov form factor, we exploited the Lund diagrams (A. G., S. Marzani, G. Ridolfi).

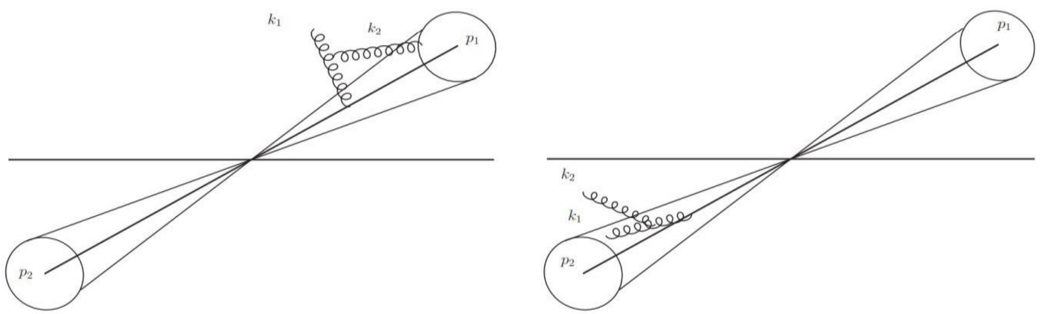



- We fixed $z_{cut} = 0.1$ and $R_0 = 0.4$.
- The non perturbative scale is set at 1 GeV.

# Non global Logs

- Non global logs represent correlated gluon emissions (M. Dasgupta, G. Salam and A. Banfi, M. Dasgupta, K. Khelifa-Kerfa, S. Marzani)




- Their contribution is reduced with the inclusion of clustering effects

(Z. Kang, K. Lee, X. Liu, D. Neill, F. Ringer)

$$S_0(\theta_g) = 1 + \left(\frac{\alpha_s}{\pi}\right)^2 \frac{\pi^2}{108} \left(C_F^2 - 4C_F C_A\right) \log\left(z_{\text{cut}}\theta_g^\beta\right)^2 + \mathcal{O}(\alpha_s^3)$$

# Mass effects on NGLs

The inclusion of the masses in the computation further reduce the effect of the NGLs.

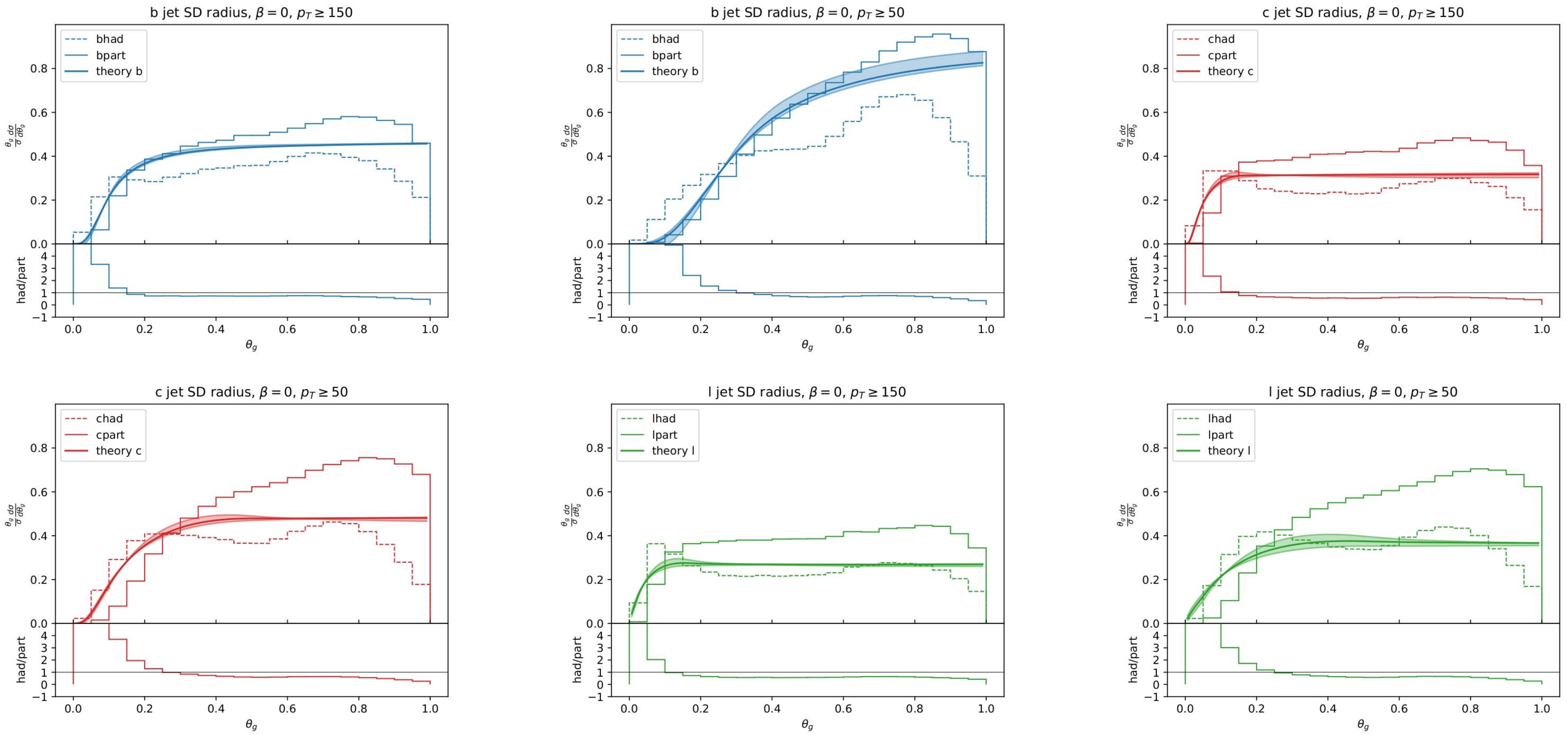
$$S(\theta_g, \theta_i) = 1 + \left(\frac{\alpha_s}{\pi}\right)^2 \left(C_F^2 \mathcal{F}_1\left(\theta_g, \theta_i\right) + C_F C_A \mathcal{F}_2\left(\theta_g, \theta_i\right)\right) \log\left(z_{\mathrm{cut}} \theta_g^\beta\right)^2 + \mathcal{O}(\alpha_s^3)$$

$$\lim_{\theta_g \to 0} \mathcal{F}_1(\theta_g, \theta_i) = \lim_{\theta_g \to 0} \mathcal{F}_2(\theta_g, \theta_i) = 0$$

- This result is related to the requirement that one of the two gluons is within the jet radius. Performing the small $\theta_g$ limit of such configuration $S \to 1$.

- The resumed expression is obtained exponentiating the two-loop result with RC corrections (M. Dasgupta, G. Salam )

# Comparison with Monte Carlo: $\boldsymbol{\beta = 0}$



# $z_g$ distribution: Sudakov Safety

In the massless case $z_g$ is not an IRC safe observable

➡ Sudakov Safety (A. Larkoski, S. Marzani, J. Thaler) .

$$\frac{1}{\sigma_0}\frac{\mathrm{d}\sigma}{\mathrm{d}z_g} = \int_0^1 \mathrm{d}\theta_g \left[\frac{p(z_g,\theta_g)}{p(\theta_g)}\right]^{\mathrm{F.O}} p(\theta_g)^{\mathrm{RES}}, \quad p(\theta_g) = \frac{1}{\sigma_0}\frac{\mathrm{d}\sigma}{\mathrm{d}\theta_g}$$

- In the massless case , this mechanism allows to obtain a finite expression of the differential cross section.
- The full resummation of the logs of $z_g$ and $z_{cut}$ is not implemented (P. Cal, K. Lee, F. Ringer, W. Waalewijn).

# $z_g$ distribution: massive case

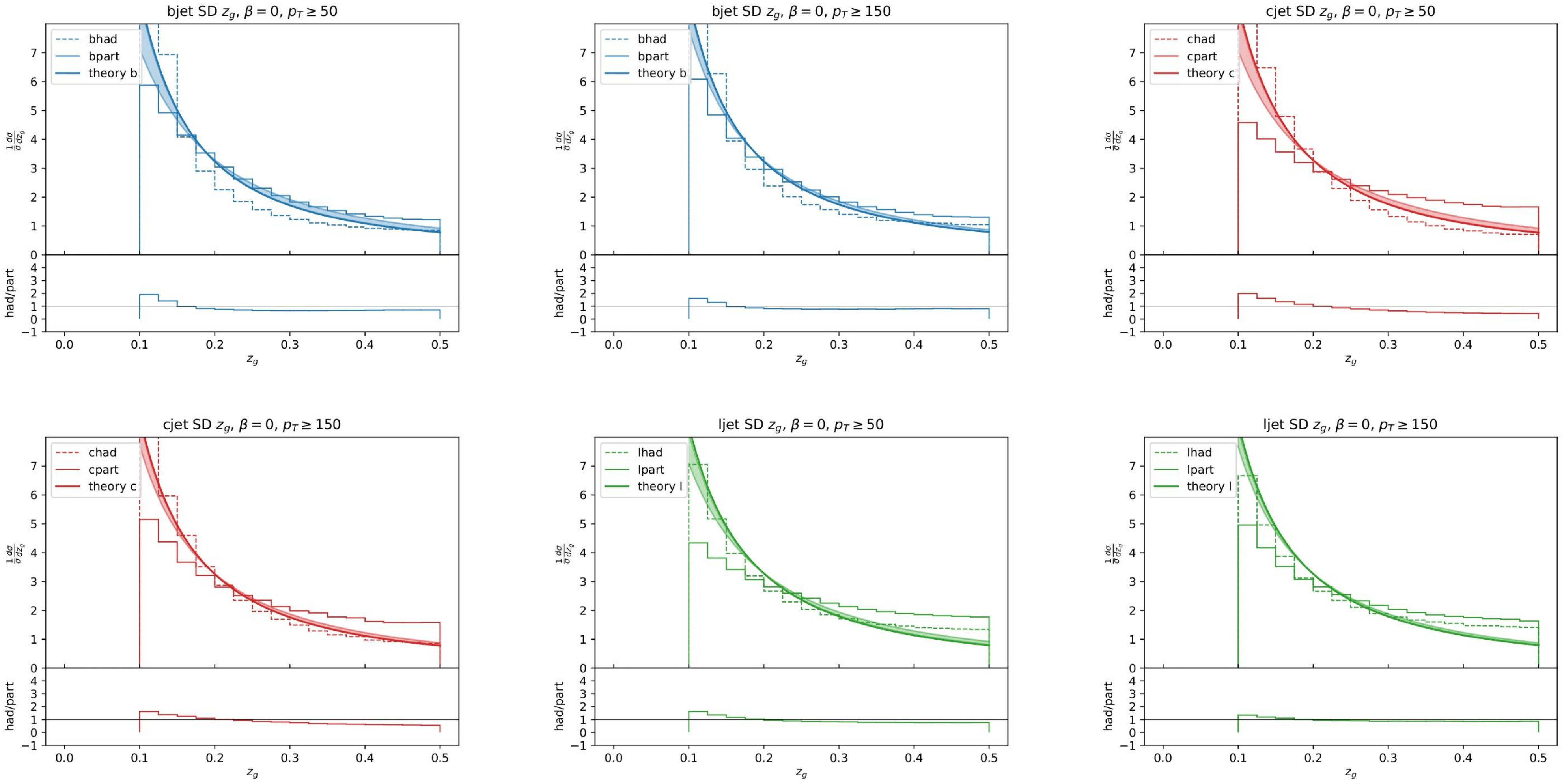
In the massive case the Sudakov safety is not necessary since the presence of the mass screens the collinear singularity.

At fixed order:

$$\frac{1}{\sigma_0}\frac{\mathrm{d}\sigma^{(\mathrm{f.o.})}}{\mathrm{d}z_g} = -\frac{\alpha_\mathrm{s} C_\mathrm{F}}{\pi}\frac{1}{z_g}\begin{cases}\log\theta_i^2 & z_g > z_c,\\ \frac{2}{\beta}\log\frac{z_c\theta_i^\beta}{z_g} & z_c\theta_i^\beta < z_g < z_c,\end{cases}$$

- We still employed SS in order to recover the massless calculation.
- At fixed order, we recover the differential distribution over the fragmentation variable $x = \frac{p_{Tb}}{p_T}$.

# Comparison with Monte Carlo: $\boldsymbol{\beta = 0}$



# Conclusions

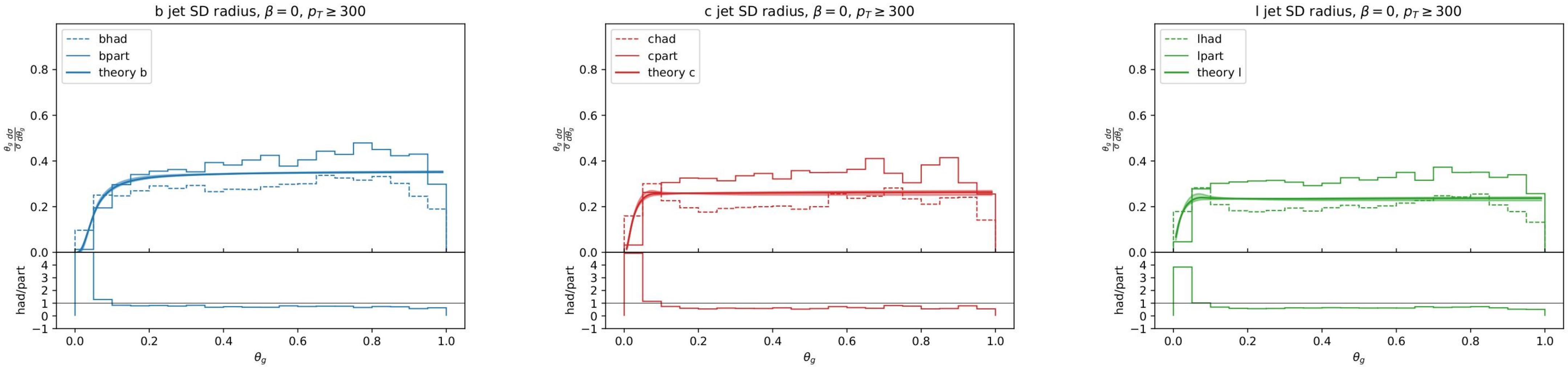
- $\theta_g$ : analytic results agree with the Monte Carlo distribution for $\beta = 0$, but there is a significant discrepancy for $\beta = 1$.

- $z_g$ : mass effect are negligible, light and heavy flavoured jet distribution have the same shape within our accuracy (different result obtained by ALICE)

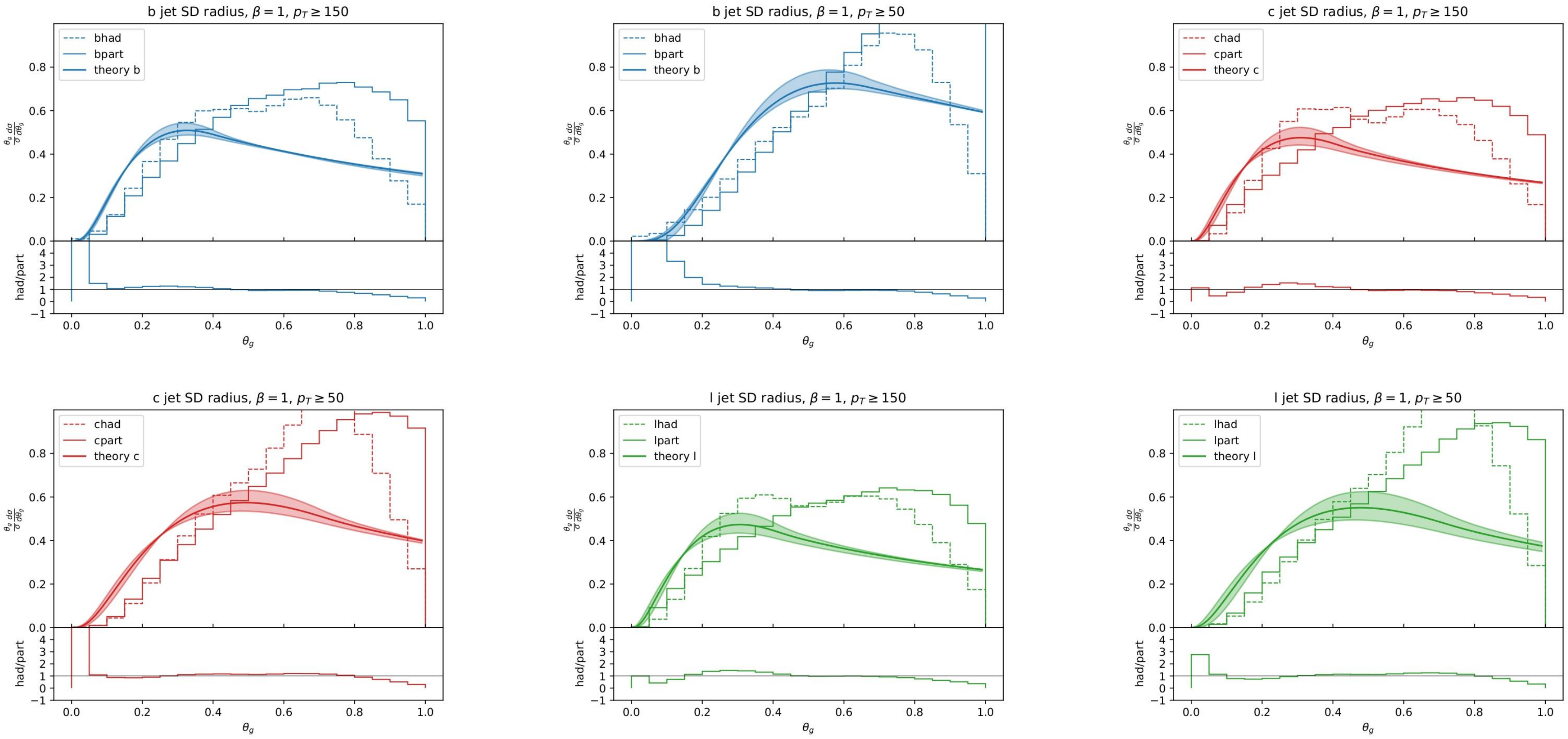
- Correlation with $1 - x$: only preliminary studies, fragmentation strongly affected by hadronization

# Thanks for your attention!!

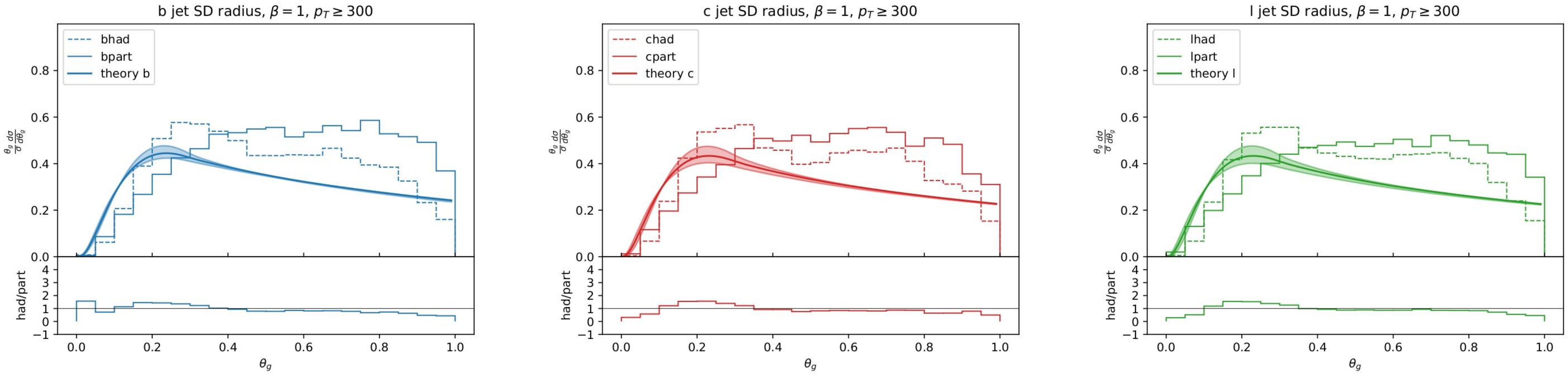
# Back Up: $\boldsymbol{\theta_g @ p_T = 300\ GeV, \beta = 0}$



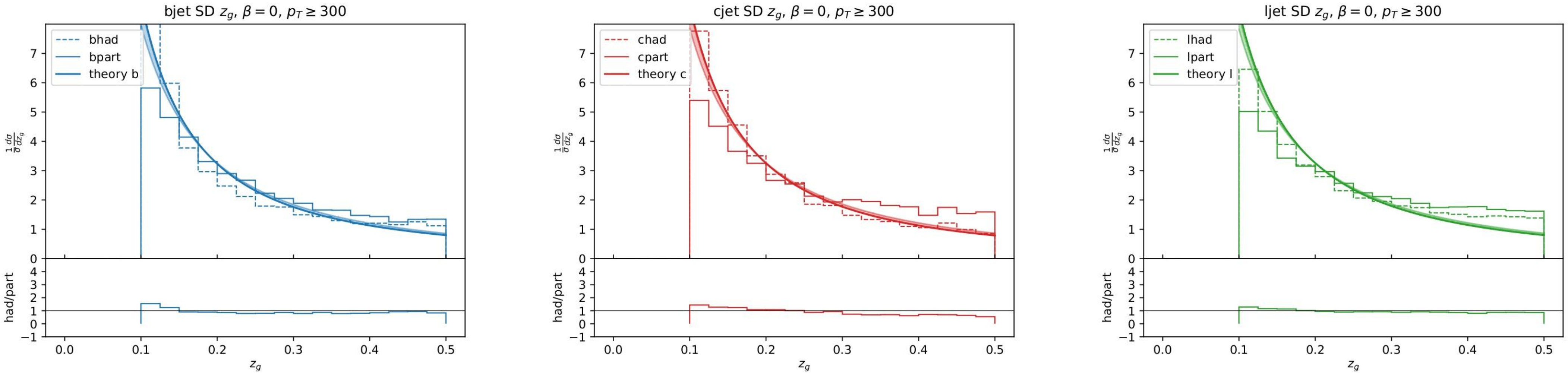
# Back up: Comparison with Monte Carlo: $\boldsymbol{\beta = 1}$



# Back Up: $\theta_g @ p_T = 300\ GeV, \beta = 1$



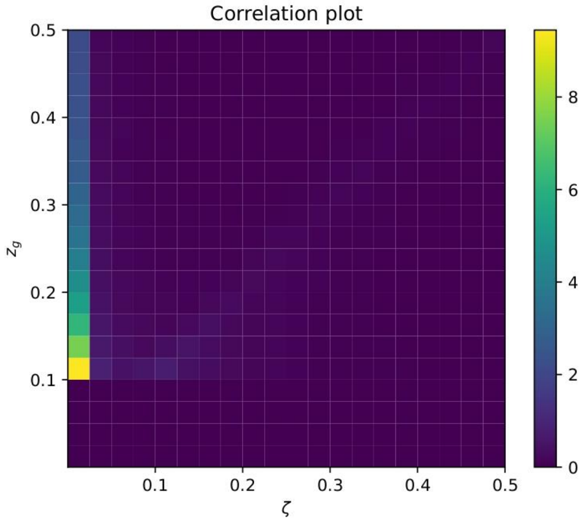
# Back Up: $z_g @ p_T = 300\ GeV, \beta = 0$



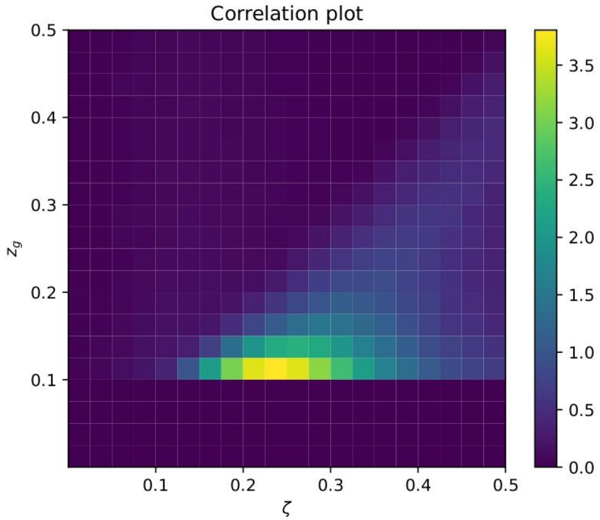
# Back up:Correlation between $z_g$ and $\zeta$

We analyzed the correlation between $z_g$ and $\zeta$ for $\beta = 0$

$\Rightarrow$ $z_g > z_{cut} \simeq 0.1$




**Parton Level**




**Hadron Level**

- B (and D) fragmentation strongly affected by hadronization, whereas $z_g$ distribution pretty stable.