Heavy flavour jet substructure

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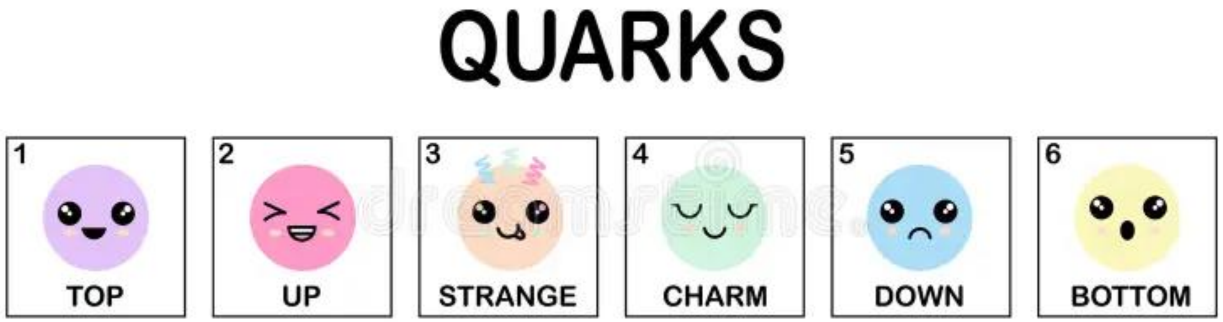
Definition of heavy flavors

Gluons couple to quarks irrespectively of their flavors.

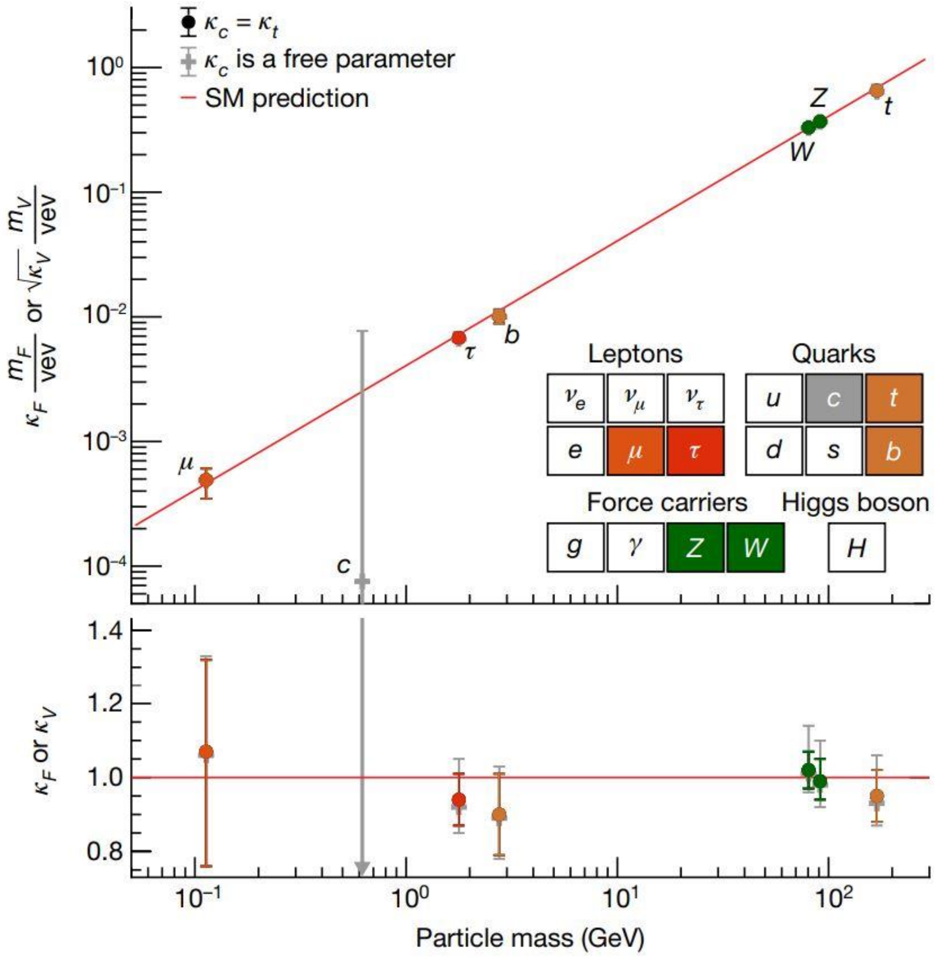
Thus, flavors are distinguished only by their mass.



Heavy flavors are those quarks whose mass is greater than the typical scale of hadron formation $\Lambda \simeq 1$ GeV ($m_c \simeq 1.5$ GeV, $m_b \simeq 5$ GeV, $m_t \simeq 175$ GeV)

Heavy flavours in the Standard Model

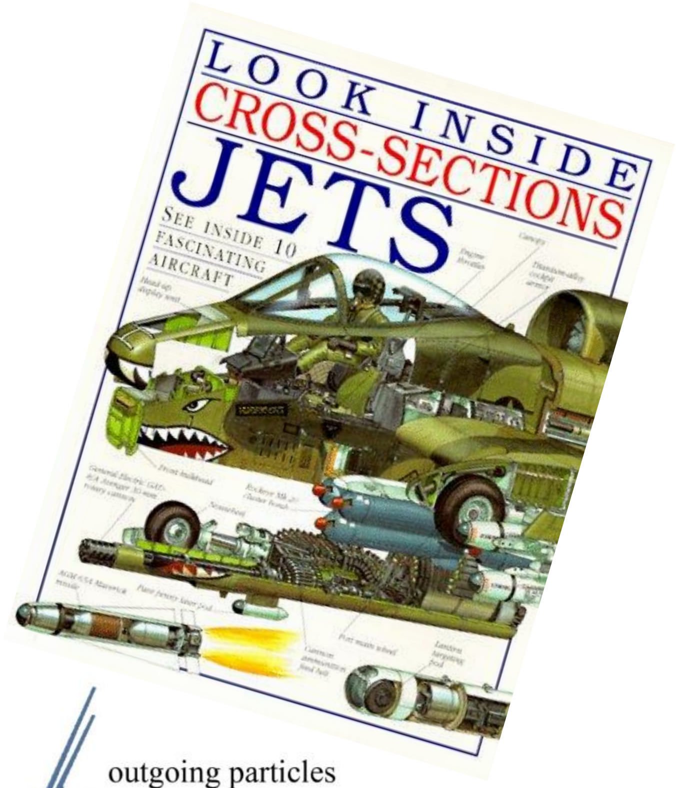
- All the fundamental particles acquire mass through the Higgs mechanism
- SM prediction: $Y_f \propto m_f$
- from theory viewpoint m_b and m_c set perturbative scales
- b and c quarks constitute a portal to non perturbative physics since they hadronize before decaying.



Jets @ LHC

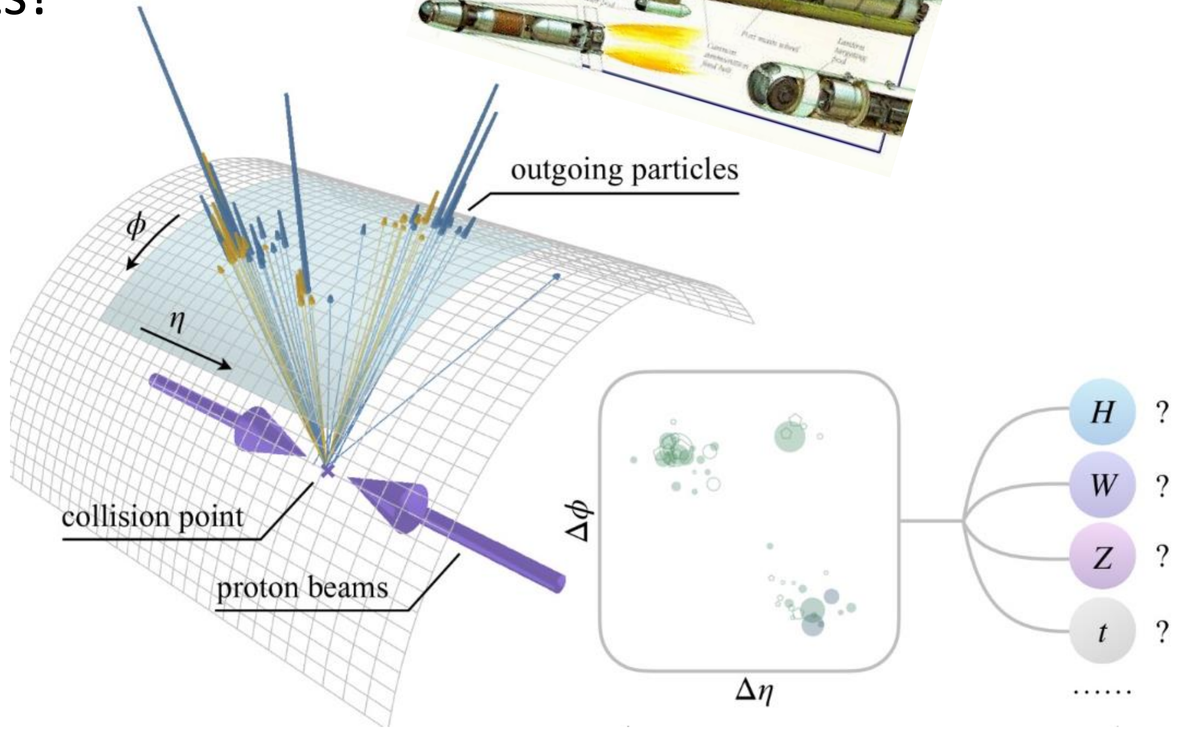
- High energy collisions @ LHC are mostly driven by QCD interaction.

- The result of the interaction consists of collimated sprays of particles: jets!



Definition of jet:

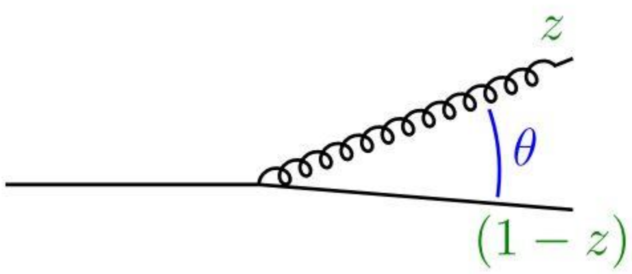
collection of hadrons clustered together according to a jet algorithm



Jet formation: a parton level explanation

At high energies we assume that:

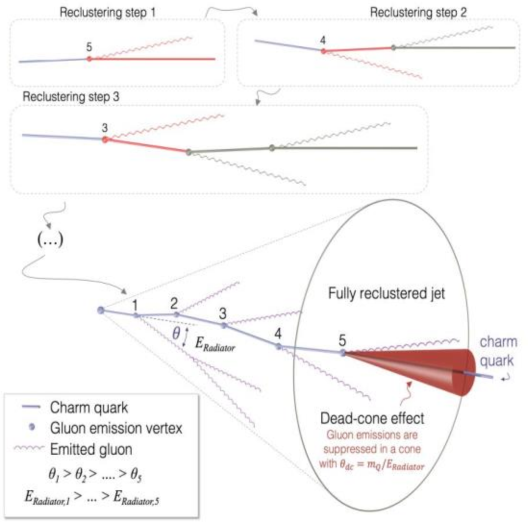
- The QCD coupling constant α_S is small, we can use perturbation theory.
- In a fully massless theory, there are no intrinsic scales and QCD is a scale invariant qft



$$P(z,\theta^2)\,\mathrm{d}z\,\mathrm{d}\theta^2 = \frac{\alpha_s C_F}{2\pi}\frac{\mathrm{d}z}{z}\frac{\mathrm{d}\theta^2}{\theta^2}, \quad z = \frac{E_g}{E_q + E_g}$$

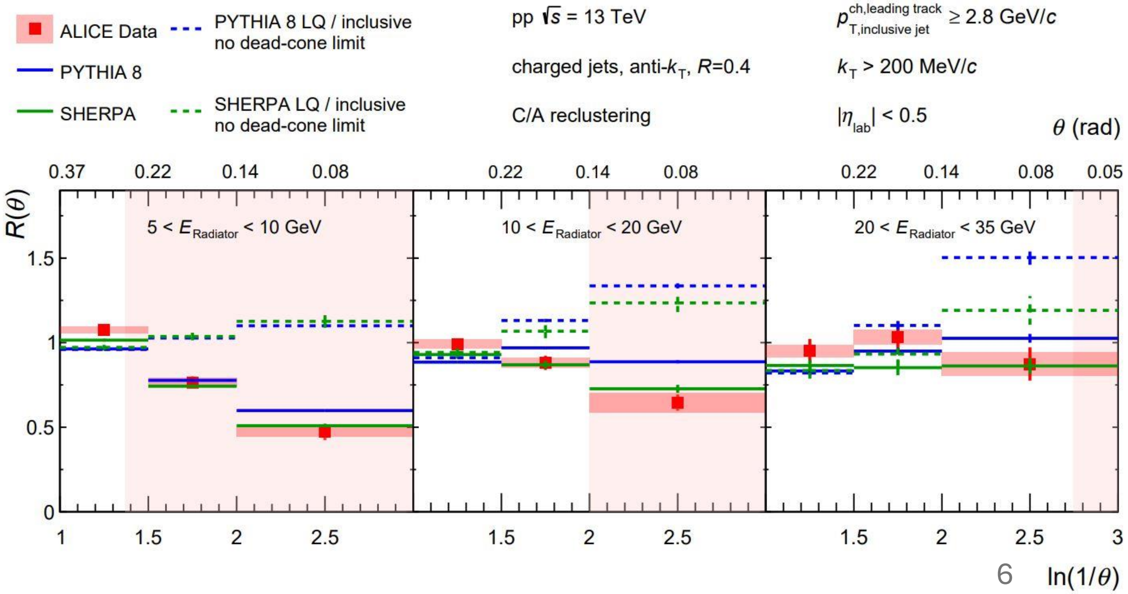
The probability of emitting a gluon off a quark is enhanced in the soft ($z \to 0$) and collinear ($\theta^2 \to 0$) limit

Jets with heavy flavours



When jets are initiated by a heavy flavour, the quark mass shields the collinear singularity

$$P(z,\theta^2)\,\mathrm{d}z\,\mathrm{d}\theta^2 = \frac{\alpha_s C_F}{2\pi}\frac{\mathrm{d}z}{z}\frac{\mathrm{d}\theta^2}{\theta^2+\frac{m^2}{E^2}}$$



Dead Cone effect

the radiation emitted off a heavy flavour is suppressed inside a cone of opening angle $\theta \sim m/E$ (ALICE)

Theoretical framework

- In the next slides we will examine different observables , i.e. functions of momenta of the final state particles that are sensitive to the dead-cone effect.

- We analyze jets initiated by b and c quarks, comparing our analytical results with Monte Carlo simulations.

- We will work in the high energy regime and in the soft/collinear limit. A fixed order calculation (i.e. computing scattering amplitudes order by order in α_S) is not sufficient to have a valuable description of data.

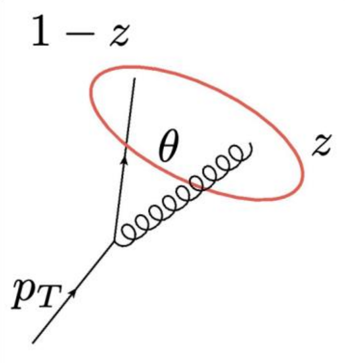
- Many measurements on HF jets over the past three years. The next step will be compare our calculations with actual data.

Jet angularities

We study jet angularities λ^{α} (see backup slides for energy-correlation functions (ECFs) e_2^{α})

In a massless theory, considering only one emission:

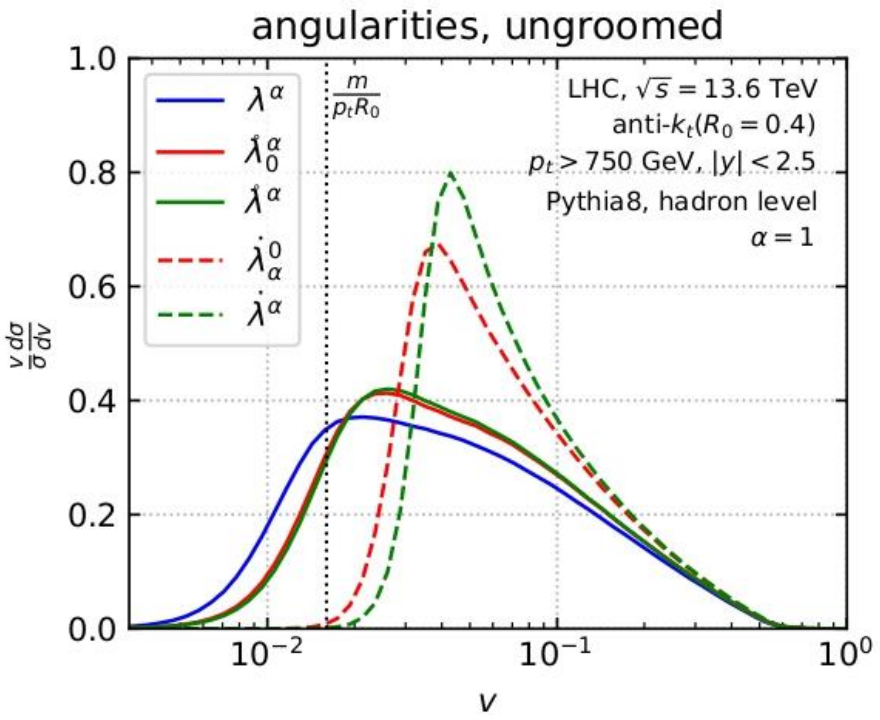
$$\lambda^{\alpha} \simeq z\theta^{\alpha}$$



Many possible choices in the case of massive particles within the jet
(C. Lee, P. Shrivastava, V. Vaidya)

Which one is more sensitive to the dead-cone effect?

Monte Carlo analysis (ungroomed case)



$$\lambda^\alpha = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{\Delta R_i}{R_0}\right)^\alpha$$

$$\mathring{\lambda}_0^\alpha \simeq \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{m_i^2}{p_{t_i}^2 R_0^2} + \frac{\Delta R_i^2}{R_0^2}\right)^{\frac{\alpha}{2}},$$

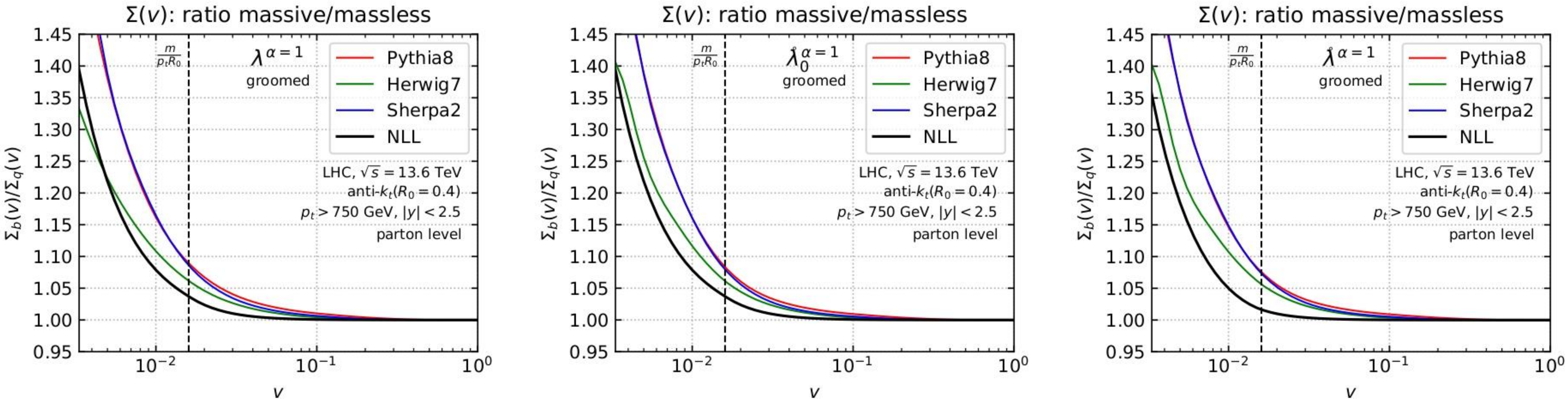
$$\mathring{\lambda}^\alpha \simeq \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{m_i^2}{p_{t_i}^2 R_0^2} + \frac{m_n^2}{p_t^2 R_0^2} + \frac{\Delta R_i^2}{R_0^2}\right)^{\frac{\alpha}{2}}$$

$$\dot{\lambda}_0^\alpha \simeq \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{m_i^2}{p_{t_i}^2 R_0^2} + \frac{\Delta R_i^2}{R_0^2}\right)^{\frac{\alpha}{2}} + \left(\frac{m_n^2}{p_t^2 R_0^2}\right)^{\frac{\alpha}{2}},$$

$$\dot{\lambda}^\alpha \simeq \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{m_i^2}{p_{t_i}^2 R_0^2} + \frac{m_n^2}{p_t^2 R_0^2} + \frac{\Delta R_i^2}{R_0^2}\right)^{\frac{\alpha}{2}} + \left(\frac{2m_n^2}{p_t^2 R_0^2}\right)^{\frac{\alpha}{2}}$$

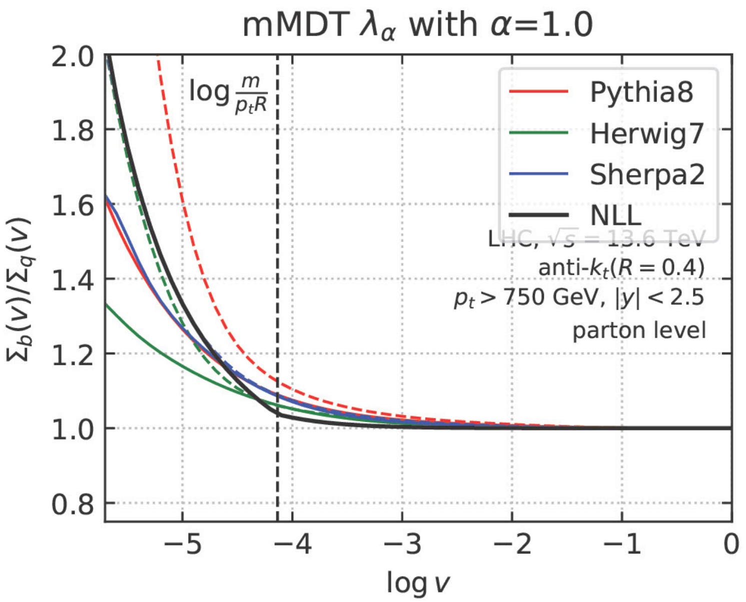
- Huge peak in the differential distribution associated to the dotted observables: they do not vanish at Born level
- The circled observables exhibits a larger peak than λ^α : "kinematical" effect.
- The mass contribution in on λ^α distribution is only "dynamical"

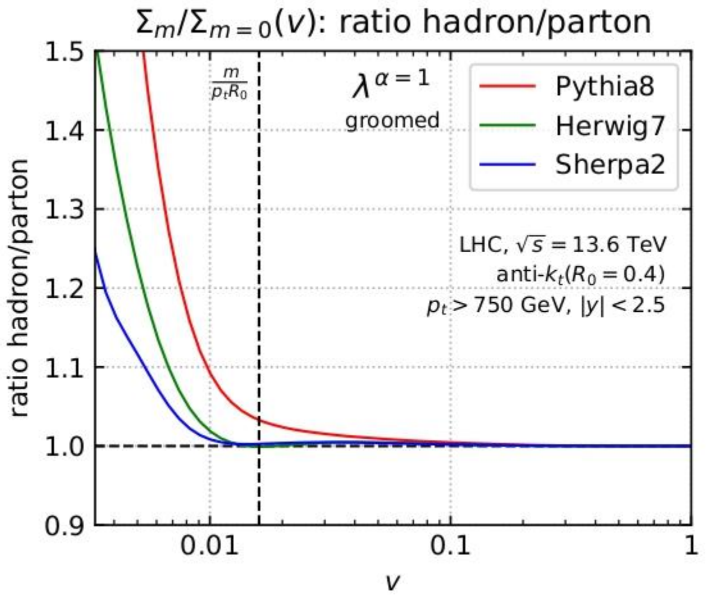
Comparison Analytics and Monte Carlo (groomed case)



- Plot of the ratio of the cumulative distribution massive/massless (NGL are absent in the groomed case)
- Closer to MC, soft radiation at large angle is removed by the soft drop algorithm

Non perturbative effects: groomed case





Ratio of the ratio: hadron level/ parton level

- The dashed line are the ratio $\frac{\Sigma_b^{hadron}}{\Sigma_q^{hadron}}$
- Non-pertubative corrections are reduced with grooming
- The scalar product observable are far more sensitive to non perturbative-corrections

Conclusions & outlook

- In this talk we focused on resummed calculation with heavy flavours: multiple scales involved, multiple resummations!

- The angularities defined with the scalar products are more sensitive to mass effects. Mass dependence both in the definition of the observable and at amplitude level.

- The distribution associated to λ^{α} depends on the mass only through the square matrix element, thus all the mass effects that we see are related to a dynamical suppression of the radiation: $\lambda^{\alpha=1}$ best way to probe the dead-cone

- Next step: phenomenological study (resummation plugin and matching to fixed order)

Thanks for your attention !!