Quantum Chromodynamics and Jets at the LHC

Herbstschule HEP

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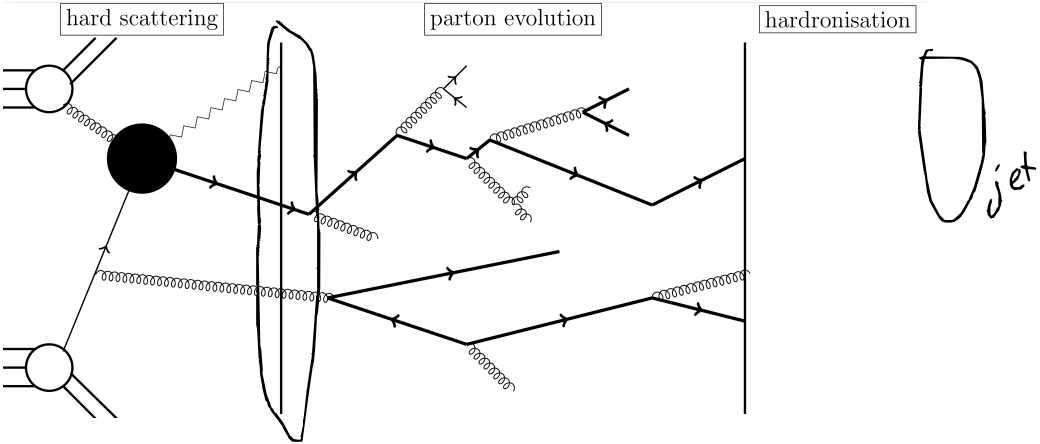
Jet evolution



Jet definition

Toward a Standardization of Jet Definitions

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December 1990

a good jet definition
- simple implement (theory & experiment)
- defined @ any order in pQCD
- finite @ - " -
- "reflective" insensitive to non-pQCD

=> undo "shower",
define the hard scattering

-> generation of cone based algorithm
-> infrared unsafe

-> two classes : cone
-> SISCone (seedless)

sequential
-> k_t - family (k_T^2)
-> Jade (e^+e^-)
-> Durham

Sequential algorithm

1) compute a distance d_{ij} among all particles
2) recombine the smallest pair (pseudojet)
3) repeat until stopping condition

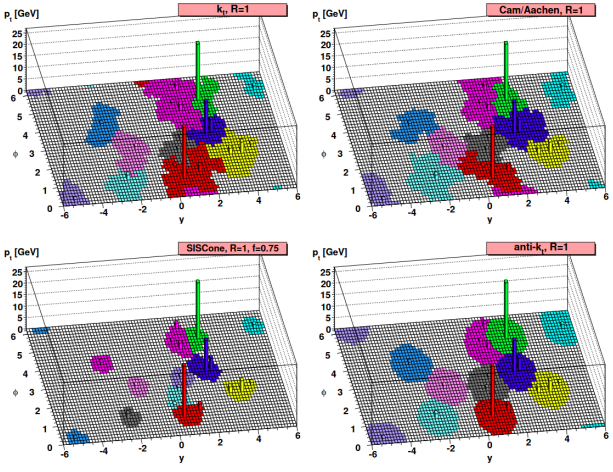
For example k_t : $d_{ij} = \min\left(k_{Ti}^{2p}, k_{Tj}^{2p}\right) \frac{\Delta R_{ij}}{R}$

$d_{iB} = k_{Ti}^{2p}$

if d_{iB} is the smallest ; remove pseudojet i

Stopp when no jet remain.

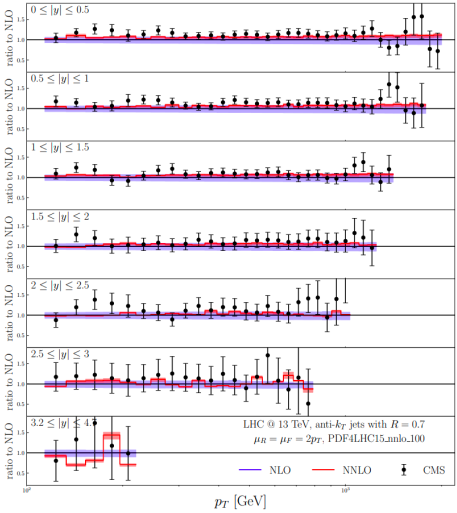
Jet shapes for different jet algorithms



[0906.1833]

Single inclusive jet rates

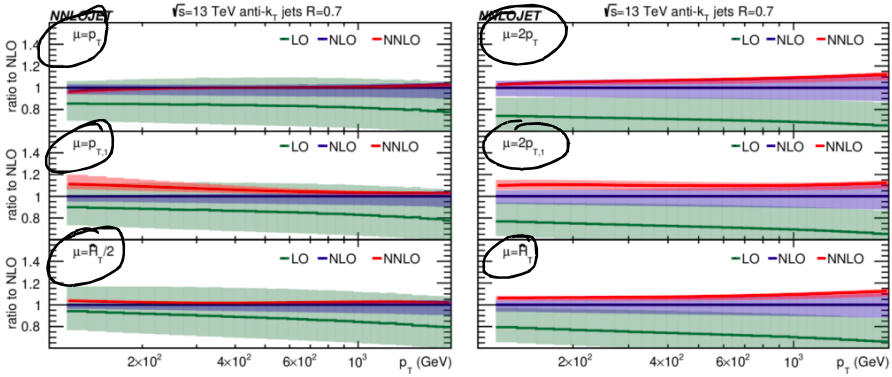
$d\sigma_{pp\to jet+X}$



← |y| slice

[1907.1291]

Single inclusive jet rates - infrared sensitivity



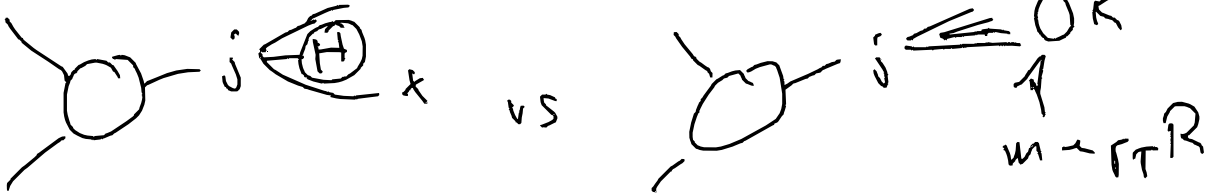
[1807.03692]

think NLO: $\underbrace{d\sigma^B + d\sigma^V}_{\text{independent of } R} + \underbrace{d\sigma^R}_{\text{depends on } R}$

$\rightarrow \ln(R)$

$\rightarrow$ for small R resummation needed

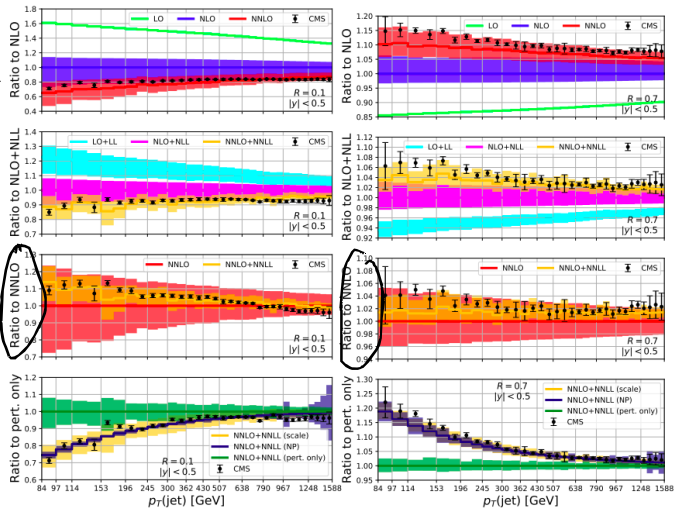
- $\rightarrow$ parton-shower
- $\rightarrow$ analytic in a fragmentation approach



$$d\sigma_{jet+x} = f_a \otimes f_b \otimes d\hat{\sigma}(z, \mu_F) \otimes \alpha \Big] \left(\frac{2p_T \cdot R}{\mu_F}\right)$$

$\Rightarrow$ small R resummation

Single inclusive jet rates - small R resummation



[2503.21866]

Jet substructure

many interesting observables:

- jet mass: $m_{jet}^2 = \left(\sum_{i \in jet} E_i\right)^2 - \left(\sum_{i \in jet} \vec{p}_i\right)^2$

$\sim R \cdot p_{T\,jet}$

- N-subjettiness:

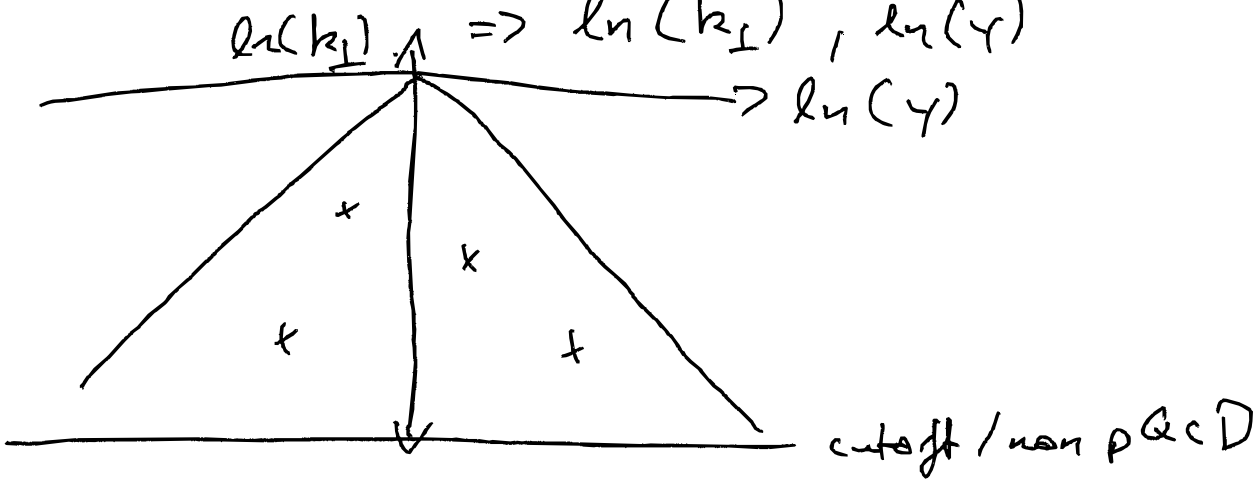
$$\tau_N = \frac{1}{d_0} \sum_{k=1} p_{T,k} \min_{\{n_1,\dots,n_N\}} (\Delta R_{n_1 k}, \dots \Delta_{n_N, k})$$

↳ Naxes are chosen in minimization

→ discriminate heavy particle decays

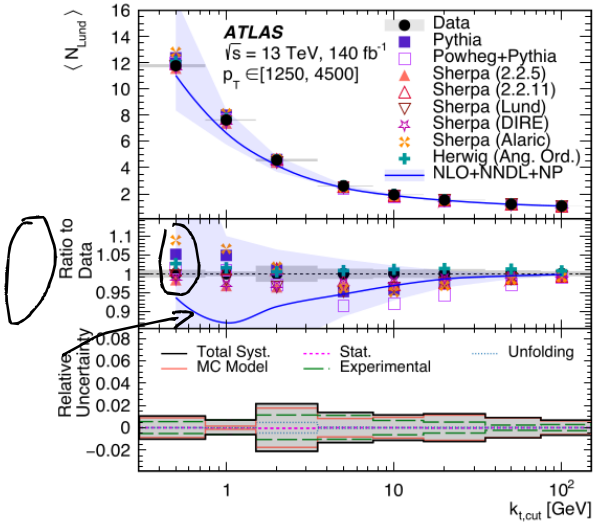
- jet angularity: $\lambda_\alpha^\kappa = \sum_{i \in jet} \left(\frac{p_{T,i}}{\sum_{j \in jet} p_{T,j}}\right)^\kappa \left(\frac{\Delta_i}{R}\right)^\alpha_{WTA}$

- Lund plane: $\theta, E \Leftrightarrow k_t, y$

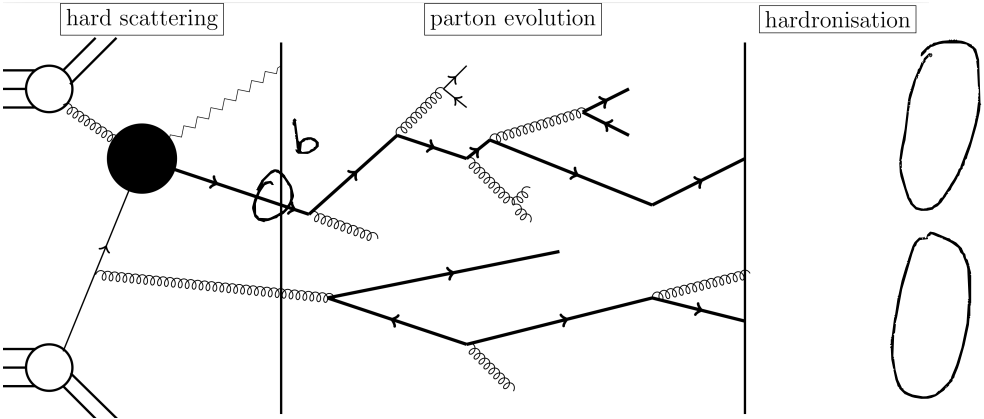


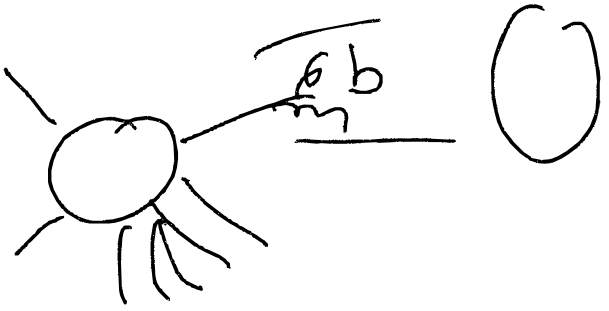
- flavored jets

Jet-substructure example

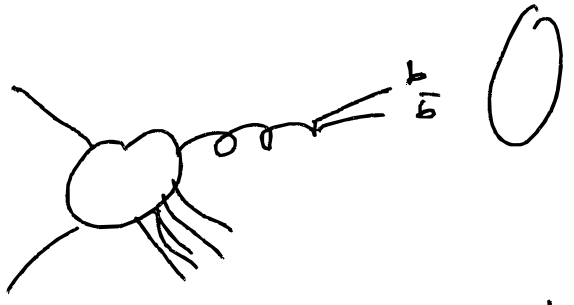


Flavoured jets





if there b-quark mit



is this a b-jet ?

for massless quarks

@ fixed-orde → ∞
@ PS → ln(Λ_QCD)

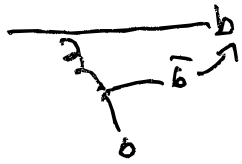
} IR unsafe

→ quark/gluon separation ????

for massive quarks: $\ln\left(\frac{m_q}{p_T}\right)$

⇒ flavour jet algorithms:

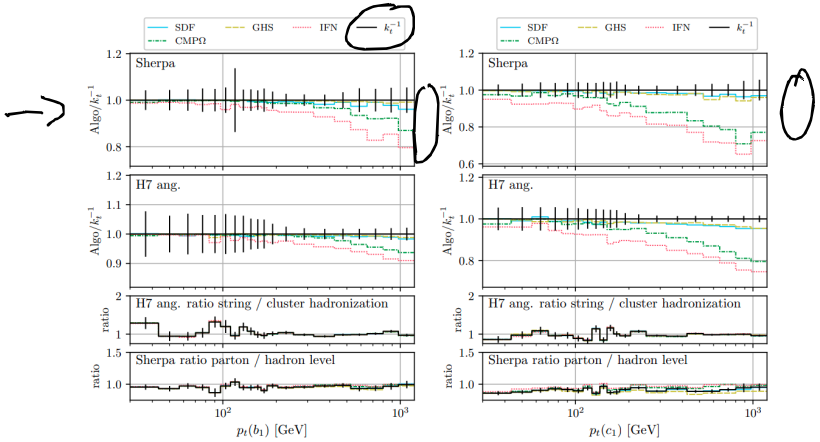
@NLO:  → gluon-jet

@NNLO:  → gluon-jet

different variants: Soft-Drop-flavour, mod. anti-k_t

Flavour-dressing, IFN (exp. inspired)

Flavoured jets - comparison of jet algorithms

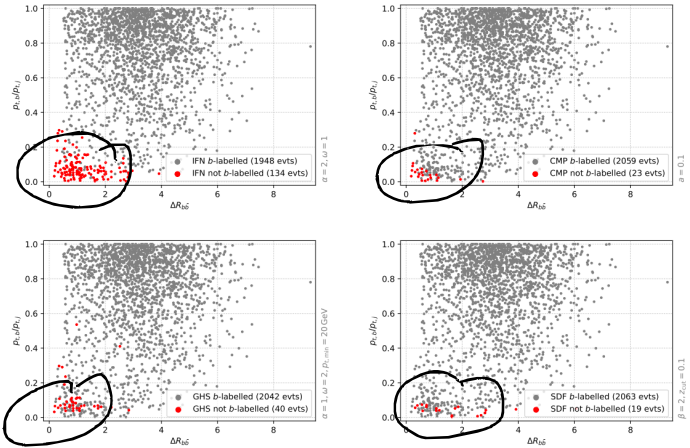


[2506.13449]

b-jet

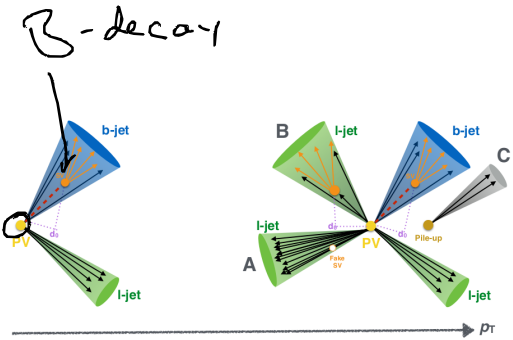
c-jets

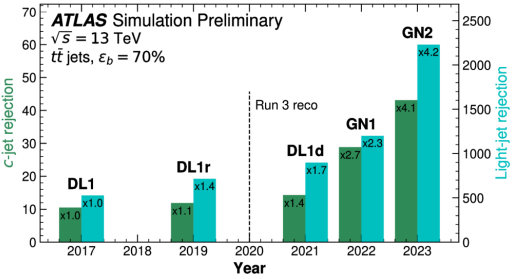
Flavoured jets - mislabelling in anti-kT



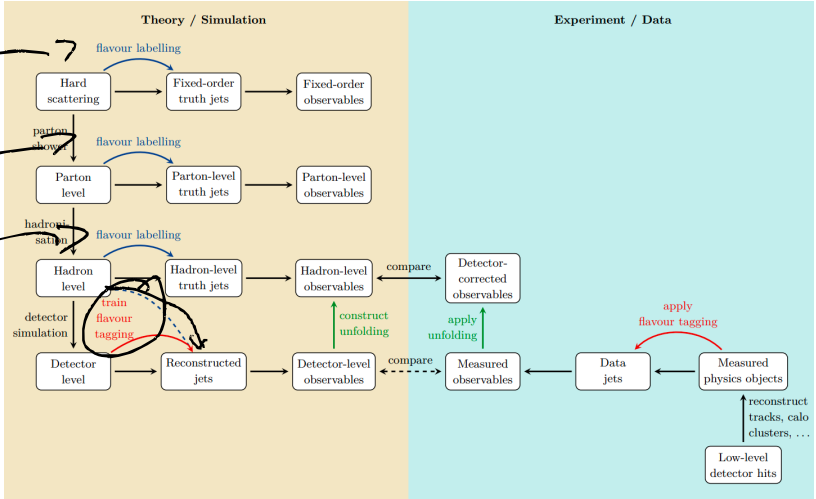
[2506.13449]

Flavoured jets - experiment





Flavoured jet algorithms in practise



[2506.13449]

End of Lecture