SoftDrop

Grooming and tagging boosted jets with analytc control

Grégory Soyez
with Andrew Larkoski, Simone Marzani and Jesse thaler, arXiv:1402.2657

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Everything will be boosted

The near and distant futures looks like

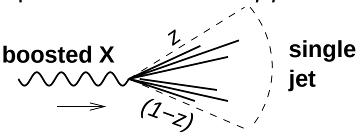
- Higher energy
- Higher luminosity
- Larger bounds/scales for new physics searches/studies

$\Rightarrow$ particles at larger scales (p_t), *i.e.* boosted

This requires new approaches to final-state analyses
Especially for the hadronic final-state

What is special about boosted objects?

Example: boosted $X \to q\bar{q}$



$$\Delta R_{q\bar{q}} \approx \frac{m}{\sqrt{z(1-z)}p_t} \sim \frac{2m}{p_t}$$

$\Rightarrow$ single jet for $p_t \gg m$

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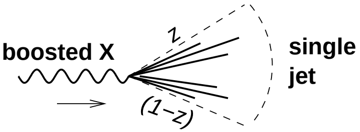

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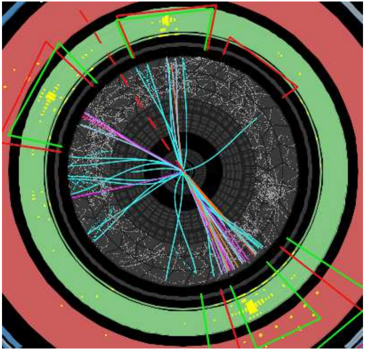

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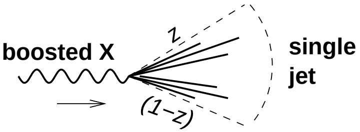

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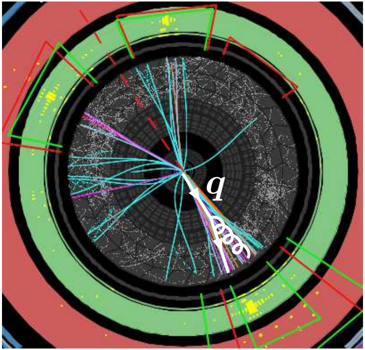
- a quark?



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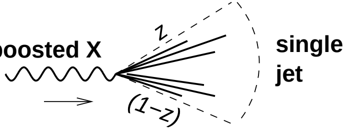

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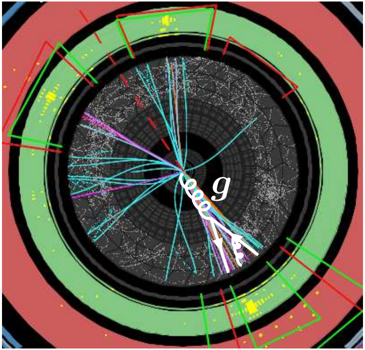
What jet do we have here?

- a quark?
- a gluon?



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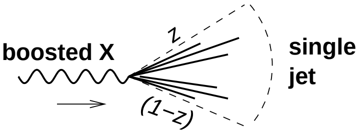

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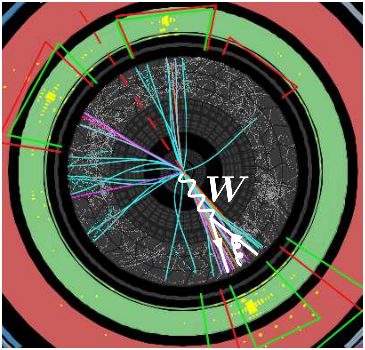
- a W/Z (or a Higgs)?



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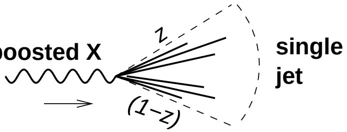

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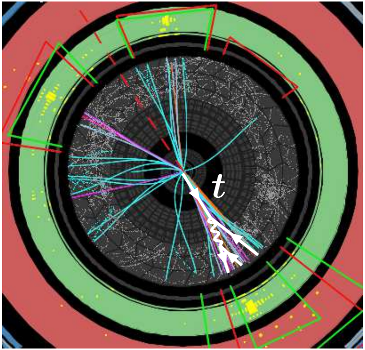
What jet do we have here?

- a quark?
- a gluon?
- a W/Z (or a Higgs)?
- a top quark?



Paradigm and frequent tools

- one typically work with fat jets, *i.e.* jet with large radius
- grooming: removing soft radiation
  Idea: QCD collimated $\Rightarrow$ get rid of soft and large-angle radiation
  Examples: trimming, pruning, ...
- tagging: disentangling signal (*e.g.* W) from backgrounds (QCD jets)
  Idea: signal (resp. QCD) generates multi-core (resp. single-core) jets
  Examples: MassDropTagger, John Hopking tagger, N-subjettiness, ...

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This talk: Soft Drop

a new tool: both a tagger and a groomer with analytic control

Soft Drop

[A.Larkoski, S.Marzani, GS, J.Thaler, arXiv:1402.2657]

- Start with a given jet
- Re-cluster it with the Cambridge/Aachen algorithm ($d_{ij} = \Delta R_{ij}^2$)
- Recursively undo the last step of the clustering $j \to j_1 + j_2$
- if the splitting is symmetric enough stop (j is the result)

$$\frac{\min(p_{t1}, p_{t2})}{p_{t1} + p_{t2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

- otherwise, repeat with the hardest of j_1 and j_2

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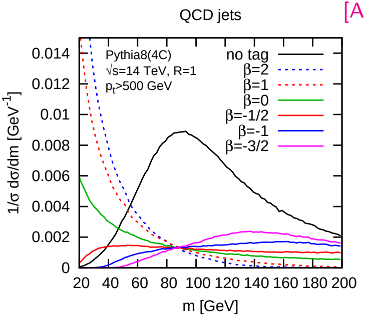
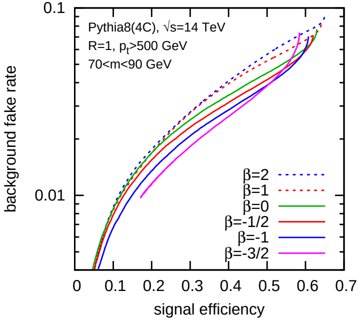
Notes

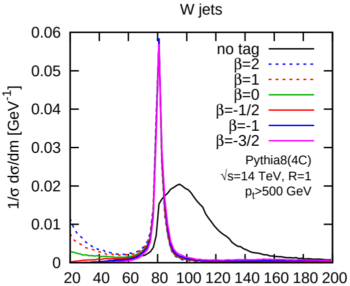
- β and z_{cut} are the two adjustable parameters
- $\beta = 0$ first introduced as the "modified Mass-Drop Tagger (mMDT)" by M. Dasgupta, A. Fregoso, S. Marzani and G. Salam

Performance as a tagger

[A.Larkoski, S.Marzani, GS, J.Thaler, arXiv:1402.2657]





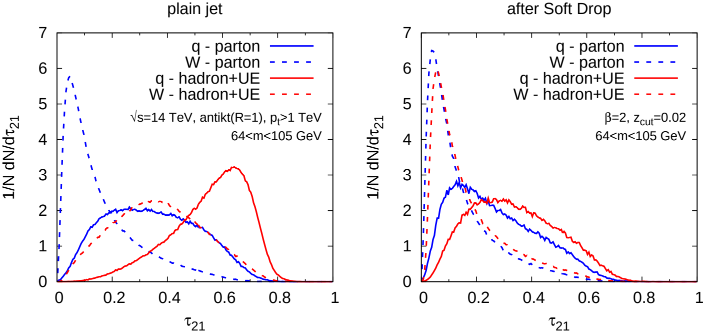


- W peak nicely reconstructed
- QCD background killed
- $\beta \leq 0$ works best

Performance as a groomer

[M.Dasgupta, GS, G.Salam, arXiv:1402.2657]

Example: N-subjettiness distribution ($\tau_{21} \equiv$ tendency to have 2 prongs)



- discriminate between W (dashed) and QCD (solid)
- strongly affected by non-peturbative physics

- discriminate between W (dashed) and QCD (solid)
- non-perturbative effects largely reduced

Analytic properties

Crucial to understand the physics beyond Monte-Carlo simulations

Analytic properties

For a generic jet observable v (*e.g.* the jet mass)

$$P(< v) \equiv \Sigma(v) = \exp[-g_1(\alpha_s L)L - g_2(\alpha_s L) - ...]$$

- $L = \log(1/v)$: log-enhanced terms need be resummed at all orders

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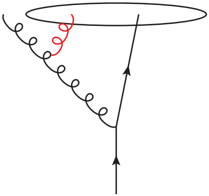
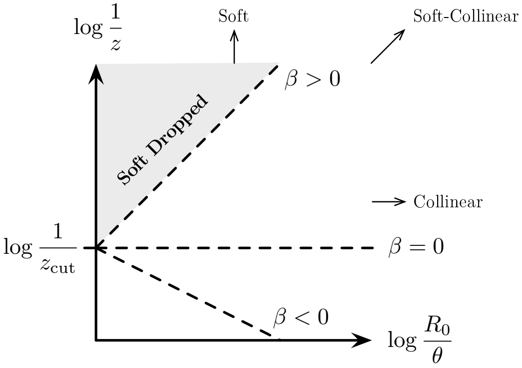
- Leading-log (LL): $g_1 = \alpha_s L^2 + ...$
  Typically a double logarithm (one collinear, one soft)
- Next-to-leading log (NLL): $g_2 = \alpha_s L + ...$
  - contributions from hard collinear splittings ($\alpha_s L + ...$)
  - contributions from multiple emissions ($\alpha_s^2 L^2 + ...$)
  - running-coupling corrections
  - potential non-global logarithms (nasty!)



Phase-space for emissions (Leading-log ⇒ ordered emissions) :

SoftDrop cuts
soft-and-large-angle emissions

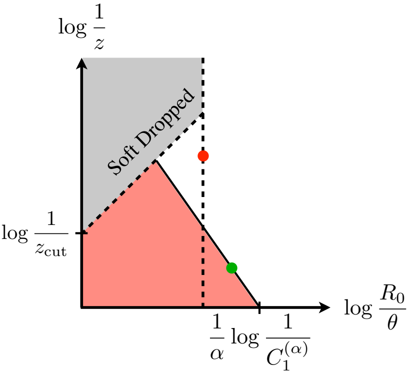


Analytic properties

Phase-space for emissions (Leading-log $\Rightarrow$ ordered emissions) :

Sudakov: $(\rho = m^2/(p_t R)^2 < z_{\rm cut}))$

$$\Sigma(m) = \exp\left[-\frac{\alpha_s C_F}{2\pi}\left(\frac{\beta}{2+\beta}\log^2(1/\rho) + \frac{4}{2+\beta}\log(1/\rho)\log(1/z_{\rm cut}) - \frac{2}{2+\beta}\log^2(1/z_{\rm cut})\right)\right]$$



- double log in $\rho = m^2/(p_t R)^2$
- single-log for $\beta = 0$ (mMDT)

Analytic properties

- With running coupling, hard-collinear splittings and multiple emissions

$$\Sigma(m) = \frac{e^{-R(\rho)-\gamma_E R'(\rho)}}{\Gamma(1+R'(\rho))}$$

$$R(\rho) = \frac{C_i}{2\pi\alpha_s\beta_0^2}\Bigg[-\frac{\mathrm{W}(1-\lambda_c)}{1+\beta} - \frac{\alpha\mathrm{W}(1-\frac{1}{\alpha}\lambda)}{\alpha-1} - 2\alpha_s\beta_0 B_i \log(1-\frac{1}{\alpha}\lambda)$$
$$+ \frac{\alpha+\beta}{(\alpha-1)(1+\beta)}\mathrm{W}\left(1-\frac{1+\beta}{\alpha+\beta}\lambda - \frac{\alpha-1}{\alpha+\beta}\lambda_c\right)\Bigg]$$

$$R'(\rho) = -\partial_{\log(\rho)} R(\rho) \qquad W(x) = x\log(x) \qquad \lambda_X = 2\alpha_s\beta_0 \log(1/X)$$

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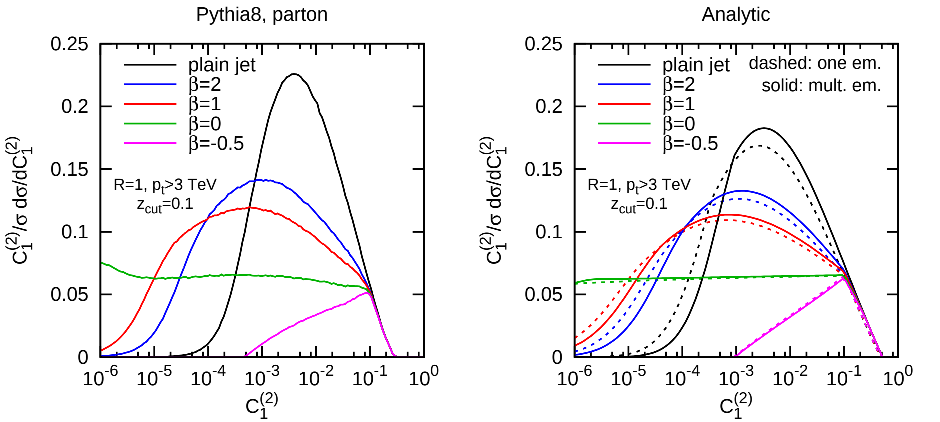
- Non-global logs are power-suppressed and absent for mMDT ($\beta = 0$)

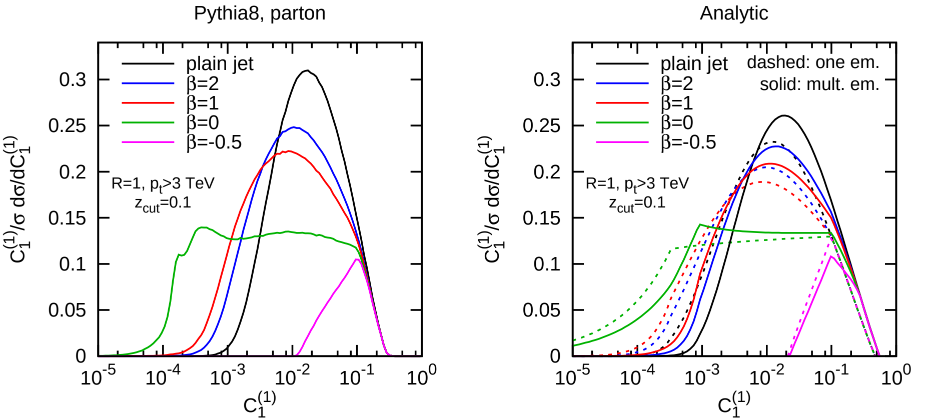
$$\lim_{\rho\to 0}\frac{\rho}{\sigma}\frac{d\sigma^{\mathrm{NG}}}{d\rho} = 4C_F C_A\left(\frac{\alpha_s}{2\pi}\right)^2\frac{\beta}{2+\beta}\left(\frac{\rho}{z_{\mathrm{cut}}}\right)^{\frac{2}{2+\beta}}\log(1/\rho)$$

Reproduces what is seen in Monte-Carlo simulations



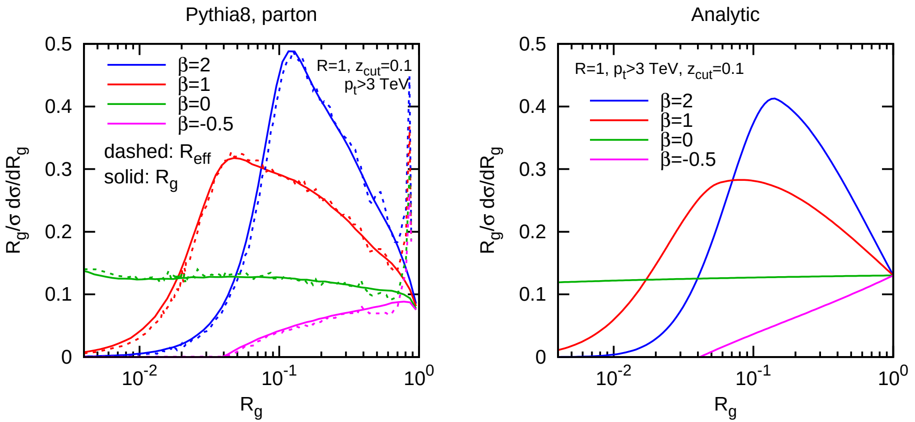
⇒ we understand the physics and can discuss theoretical uncertaintied

Also computable: angularities



Helpful *e.g.* for quark/gluon discrimination?

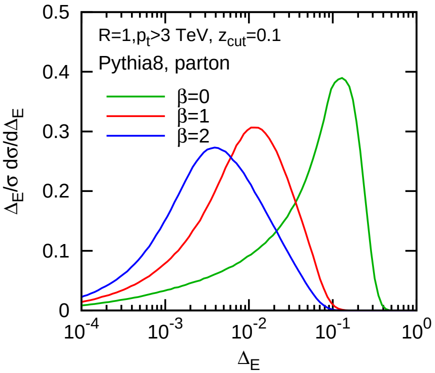
Also computable: angularities, grooming radius

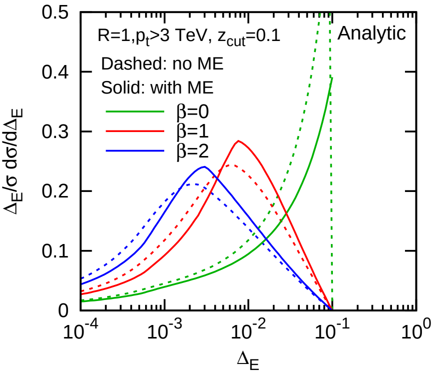


Helpful *e.g.* for pileup contamination studies?

Analytic properties

Also computable: angularities, grooming radius and jet energy loss





Shows interesting features for future theoretical studies/measurements

Conclusions

Take-home message

Soft Drop combines many great features for modern substructure studies

- good tagging efficiencies
- powerful groomer (reduce poorly-controlled non-perturbative effects)
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study the phenomenology of Soft-Dropped jets, for example

- predictions with uncertainties for the SoftDrop mass spectrum
- q/g discrimination with Soft-Drop+*e.g.* angularities
- W tagging with Soft-Drop+*e.g.* N-subjettiness

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thank you!