

Reinforced jet grooming

ACAT 2019, Saas-Fee, 12 March 2019

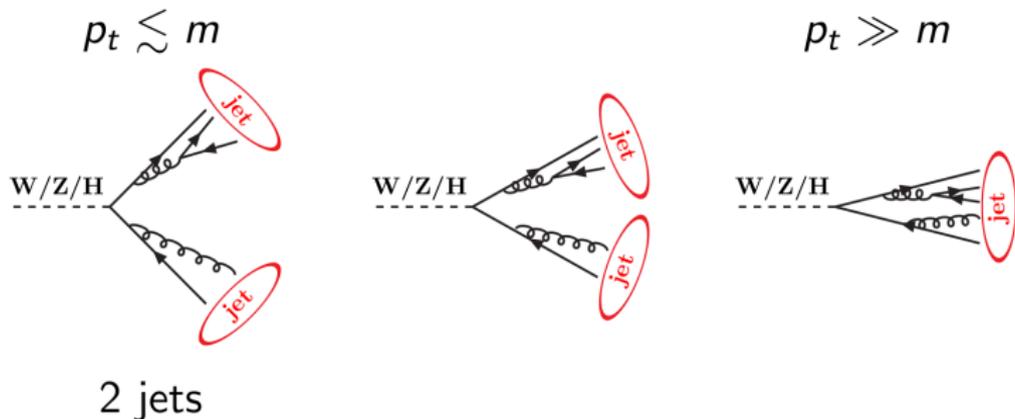
Frédéric Dreyer



work in progress with Stefano Carrazza

Boosted objects at the LHC

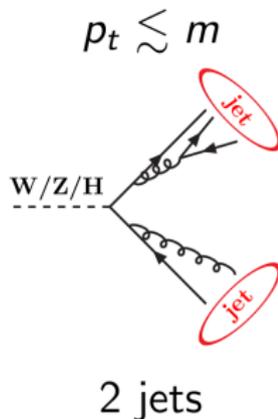
- ▶ At LHC energies, EW-scale particles (W/Z/t...) are often produced with $p_t \gg m$, leading to **collimated decays**.
- ▶ Hadronic decay products are thus often **reconstructed into single jets**.



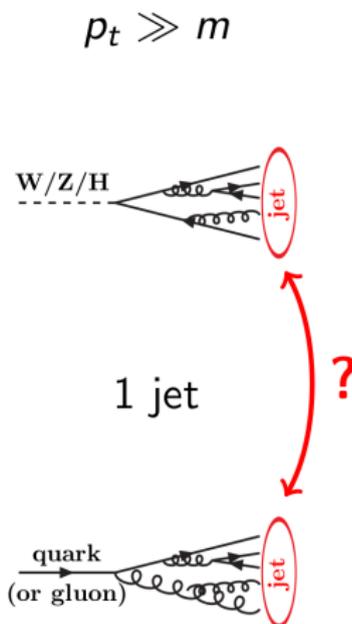
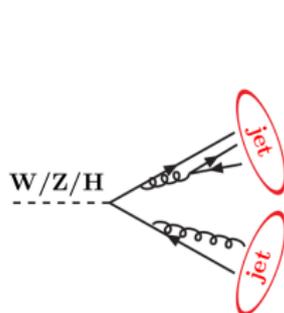
[Figure by G. Soyez]

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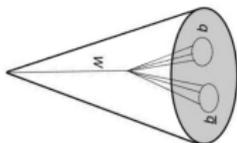
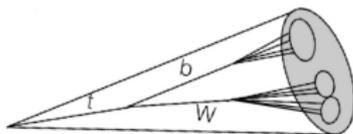


[Figure by G. Soyez]



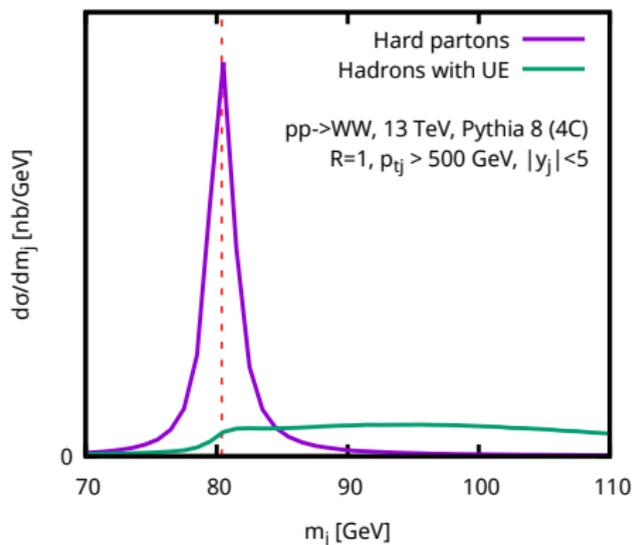
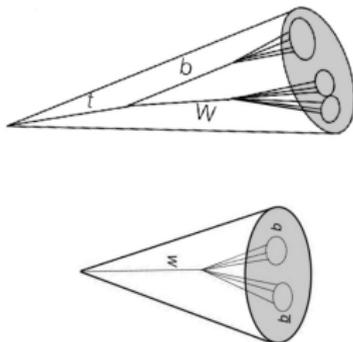
Boosted objects at the LHC

- ▶ Many techniques developed to identify **hard structure** of a jet based on radiation patterns.
- ▶ In principle, simplest way to identify these boosted objects is by looking at the **mass of the jet**.



Boosted objects at the LHC

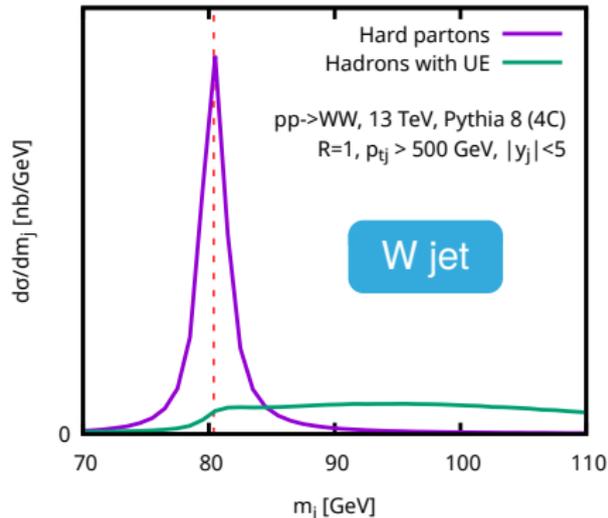
- ▶ Many techniques developed to identify **hard structure** of a jet based on radiation patterns.
- ▶ In principle, simplest way to identify these boosted objects is by looking at the **mass of the jet**.
- ▶ But jet mass distribution is highly distorted by QCD radiation and pileup.



Jet grooming: (Recursive) Soft Drop / mMDT

- ▶ Mass peak can be partly reconstructed by removing **unassociated soft wide-angle radiation** (grooming).
- ▶ Recurse through clustering tree and remove soft branch if

$$\frac{\min(p_{t,1}, p_{t,2})}{p_{t,1} + p_{t,2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0} \right)^\beta$$

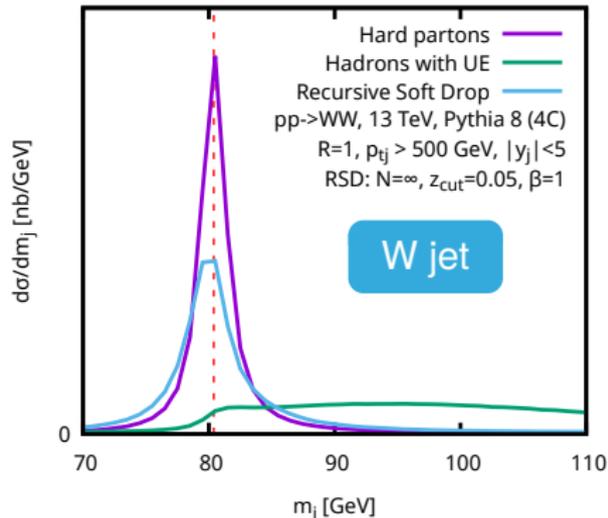


[Dasgupta, Fregoso, Marzani, Salam *JHEP* 1309 (2013) 029]
[Larkoski, Marzani, Soyez, Thaler *JHEP* 1405 (2014) 146]
[FD, Necib, Soyez, Thaler *JHEP* 1806 (2018) 093]

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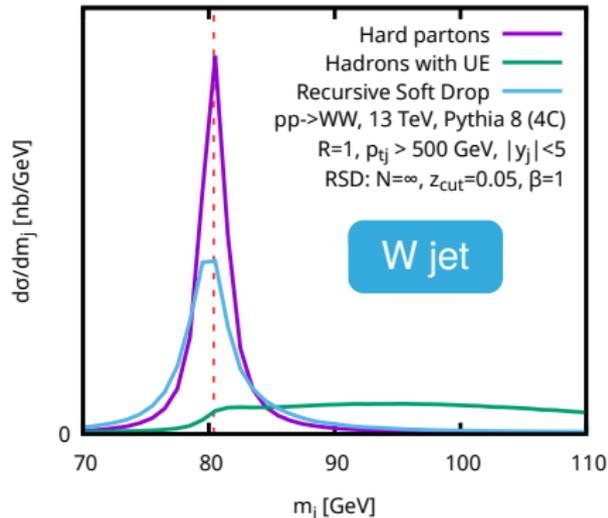


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Aim of this talk: Introduce a framework based on reinforcement learning to approach the problem of jet grooming.

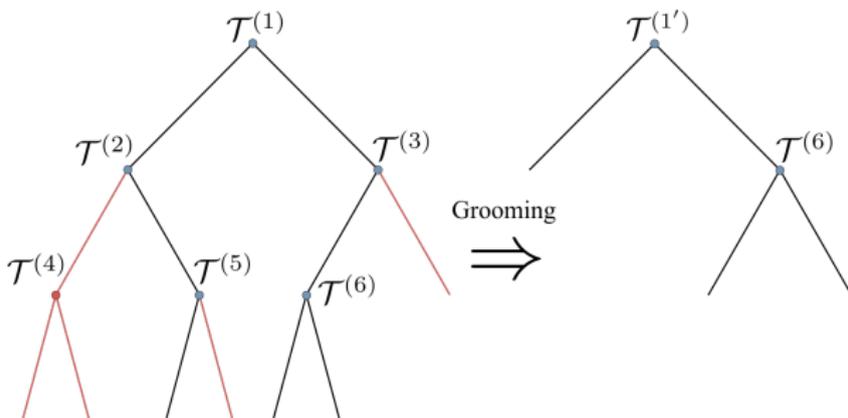
Grooming a jet tree

- ▶ Cast jet as clustering tree where state of each node $\mathcal{T}^{(i)}$ is a tuple with kinematic information on splitting

$$s_t = \{z, \Delta_{ab}, \psi, m, k_t\}$$

- ▶ Grooming algorithm defined as a function π_g observing a state and returning an action $\{0, 1\}$ on the removal of the softer branch, e.g.

$$\pi_{\text{RSD}}(s_t) = \begin{cases} 0 & \text{if } z > z_{\text{cut}} \left(\frac{\Delta_{ab}}{R_0}\right)^\beta \\ 1 & \text{else} \end{cases}$$

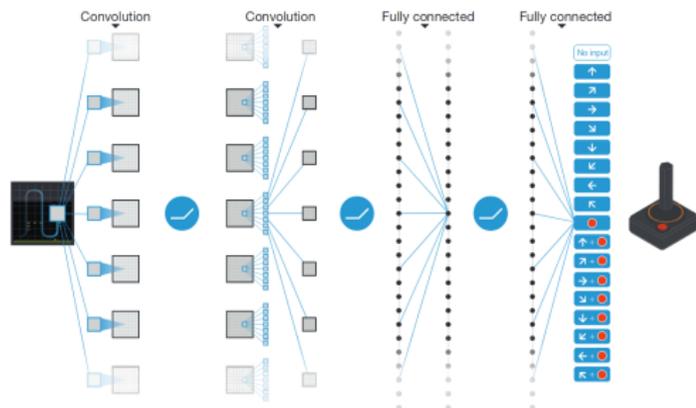


Reinforcement learning with Deep-Q-Networks

Reinforcement learning are usually built from two elements:

- ▶ an agent deciding which actions to take in order to maximize reward
- ▶ an environment, observed by the agent and affected by the action

Deep Q-Network is a RL algorithm which uses a table of Q -values $Q(s, a)$, determining the next action as the one that maximizes Q .



A neural network is used to approximate the optimal action-value function

$$Q^*(s, a) = \max_{\pi} \mathbb{E}[r_t + \gamma r_{t+1} + \dots | s_t = s, a_t = a, \pi]$$

Defining a grooming environment

To find optimal grooming policy π_g , define an environment and a reward function so that problem can be solved with RL.

- ▶ Initialize list of all trees used for training.
- ▶ Each episode starts by randomly selecting a tree and adding its root to a priority queue (ordered in Δ_{ab}).
- ▶ Each step removes first node from priority queue, then takes action on removal of soft branch based on state s_t of node.
- ▶ After action, update kinematics of parent nodes, add current children to priority queue, and evaluate reward function.
- ▶ Episode terminates once priority queue is empty.

Scanning hyperparameters

To determine optimal choice of hyper-parameters of the model architecture and grooming agent, we use distributed asynchronous hyperparameter optimization library `hyperopt`.

- ▶ Performance of an agent is defined from loss function evaluated on validation sample of 50k signal (W) and background (QCD) jets.
- ▶ Derive groomed jet mass distribution from validation data and determine window (w_{\min}, w_{\max}) containing 60% of signal distribution, with w_{med} the median in that interval.
- ▶ Define f_{bkg} the fraction of groomed background sample contained in the same window
- ▶ Loss function is given by

$$\mathcal{L} = \frac{1}{5} |w_{\max} - w_{\min}| + |m_{\text{target}} - w_{\text{med}}| + 20 f_{\text{bkg}}$$

Defining the reward function

- ▶ Key ingredient for optimization of grooming policy is reward function used at each training step.
- ▶ We construct a reward with two components
 - ▶ First piece R_M evaluated on the full jet tree, comparing the jet mass to a target value.
 - ▶ Second component R_{SD} looks at kinematics of current node.
- ▶ Total reward is then given by

$$R(m, a_t, \Delta, z) = R_M(m) + \frac{1}{N_{SD}} R_{SD}(a_t, \Delta, z)$$

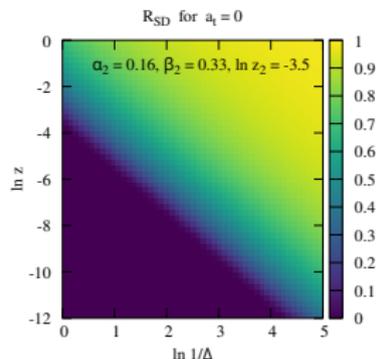
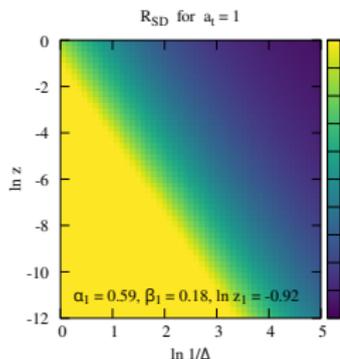
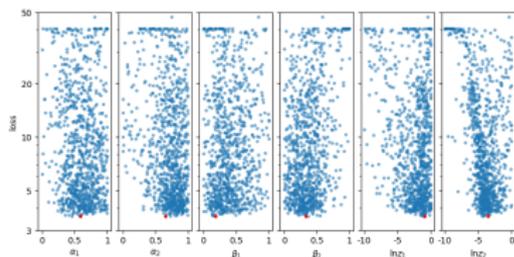
- ▶ where mass reward is defined using a Cauchy distribution

$$R_M(m) = \frac{\Gamma^2}{\pi(|m - m_{\text{target}}|^2 + \Gamma^2)}$$

Defining the reward function

- ▶ To provide baseline behaviour for the groomer, we include a “Soft-Drop” reward R_{SD} evaluated on the current node
- ▶ Calculated on the current node state, gives positive reward for removal of wide-angle soft radiation and for keeping hard-collinear emissions.

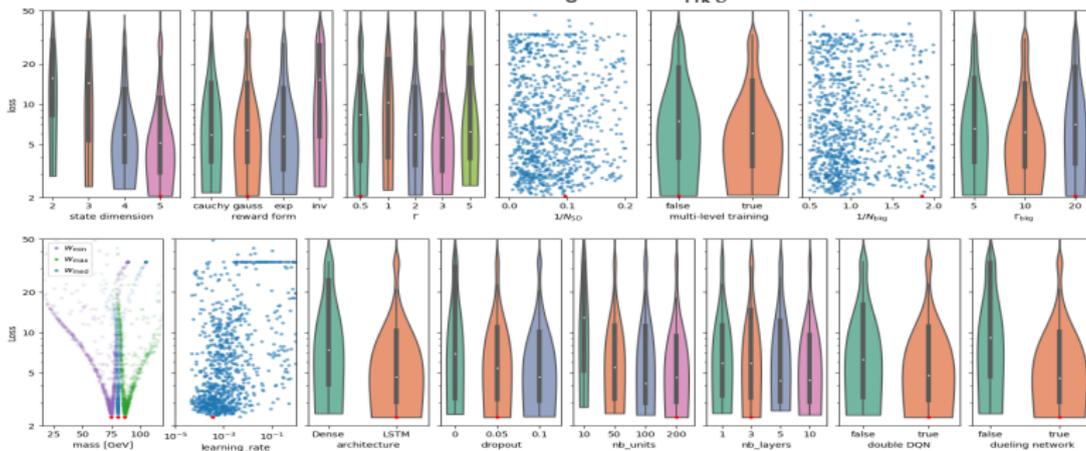
$$R_{SD}(a_t, \Delta, z) = a_t \min \left(1, e^{-\alpha_1 \ln(1/\Delta) + \beta_1 \ln(z_1/z)} \right) + (1 - a_t) \max \left(0, 1 - e^{-\alpha_2 \ln(1/\Delta) + \beta_2 \ln(z_2/z)} \right)$$



Implementation and multi-level training

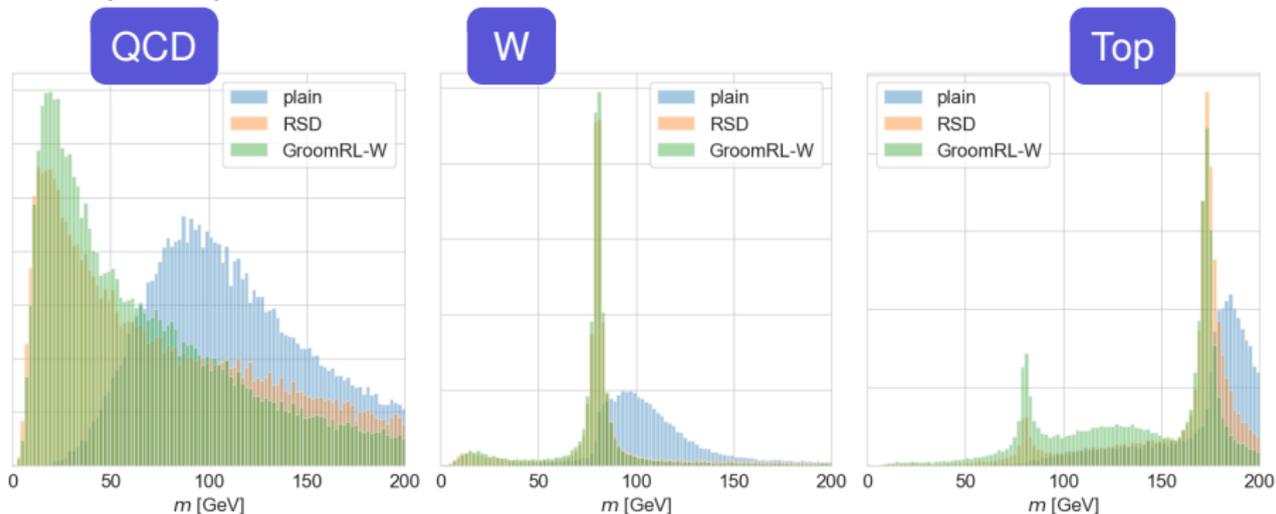
- ▶ Train RL agent with multi-level approach using both signal and bkg into account. Sample consists of 500k W/QCD Pythia 8 jets.
- ▶ At the beginning of each episode, randomly select a signal or background jet.
- ▶ In the background case, mass reward function is changed to

$$R_M^{\text{bkg}}(m) = \frac{|m - m_{\text{target}}|^2 \Gamma_{\text{bkg}}^2}{\pi(|m - m_{\text{target}}|^2 + \Gamma_{\text{bkg}\sigma}^2)} \Theta(m_{\text{target}} - m)$$



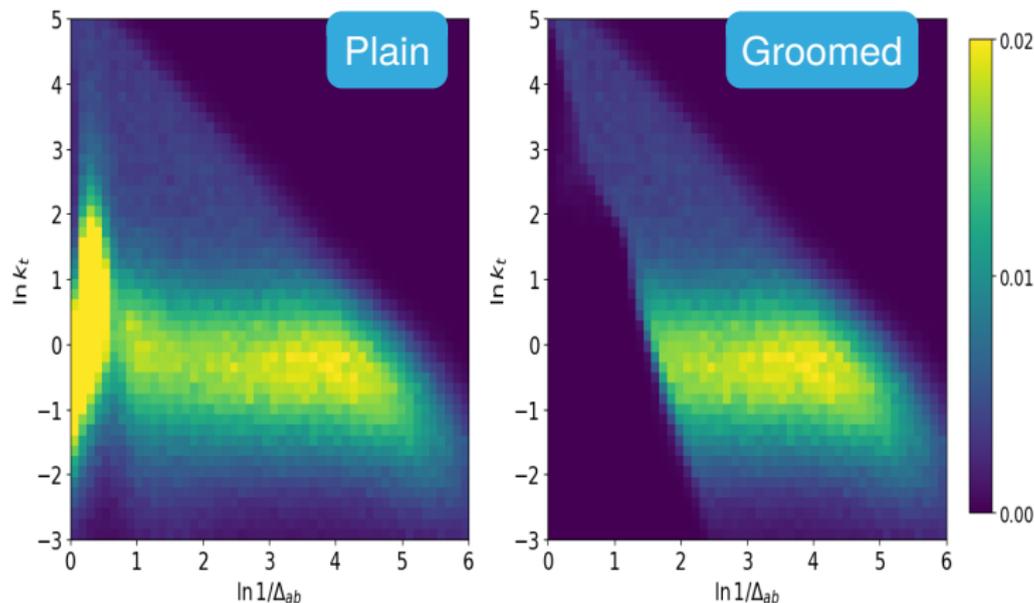
Groomed jet mass spectrum

- ▶ To test the grooming algorithm derived from the DQN agent, we apply our groomer to three test samples: QCD, W and Top jets.
- ▶ Small improvement in jet mass resolution compared to RSD.
- ▶ Algorithm performs well on data beyond its training range such as the top sample.



Lund jet plane density

- ▶ Visualize radiation patterns after grooming with Lund jet plane, defined as $(\ln 1/\Delta_{ab}, \ln k_t)$ of “primary” declustering sequence.
- ▶ Soft and wide-angle radiation is removed by the groomer.



- ▶ Promising application of RL to the issue of jet grooming.
- ▶ Carefully designed reward function can be used to construct a groomer from NN trained with DQN agent.
- ▶ Groomer can be applied with good performance to wide range of data.
- ▶ Due to its simplicity, the algorithm should retain some of the calculability of existings methods such as Soft Drop.
- ▶ Framework is generic and can easily be extended to higher-dimensional inputs or to other problems.