The Lund Jet Plane for boosted top quarks

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Graz, 04.07.2024

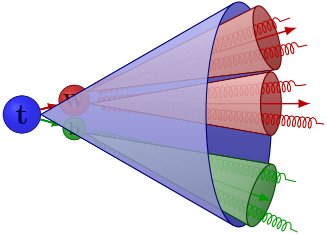
Overview

- Motivation
- Understanding the top quark lund jet plane
- W boson and b quark lund jet planes
- Boundary effects

Introduction

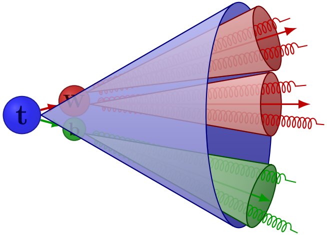
Why boosted top quarks and lund jet planes?

- The PS and hadronisation of heavy quarks has not been studied in great detail, but this results in large uncertainties
- PS has never been experimentally studied in detail in cases where a heavy W/Z was involved (resonance aware PS)
- Understand the substructure of hadronic top decay for preciser top mass measurements



Boosted top quarks

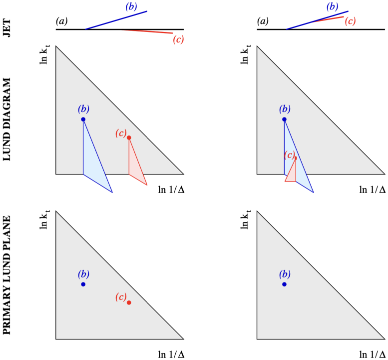
- All the decay products of the top quark confined in a large radius jet
- Clear substructure:
  - Two light quark jets from the W boson decay
  - One b quark jet
  - No colour connection
- Contribution of underlying event/multi parton interactions small
- Overall a clean environment to study the top quark, final state showers and hadronisation

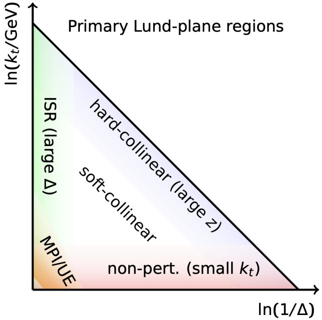


Lund jet plane

Slide based on [F. A. Dreyer, G. P. Salam, G. Soyez, 2018]

> Representation of the phase space within the jet mapped to a triangle

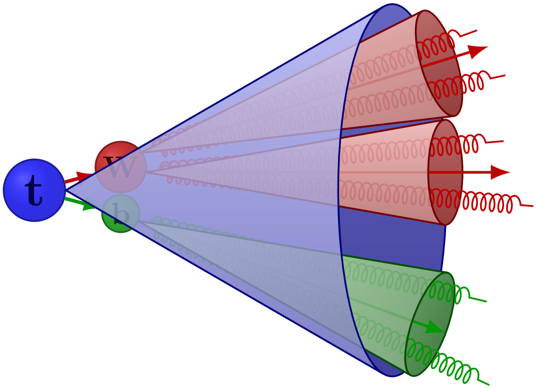


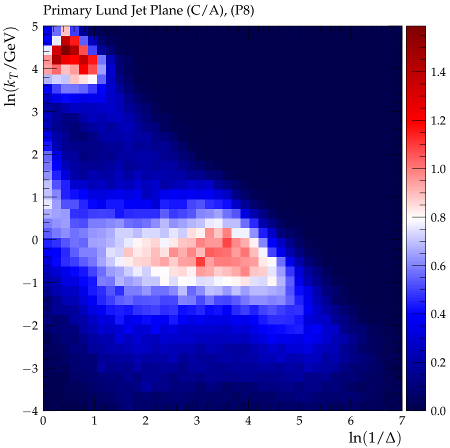


$$\Delta = \Delta_{ab} \qquad k_T = p_{T,b}\Delta \qquad m^2 = (p_a^2 + p_b^2)$$

$$z = \frac{p_{T,b}}{p_{T,b} + p_{T,a}} \qquad \kappa = z\Delta$$

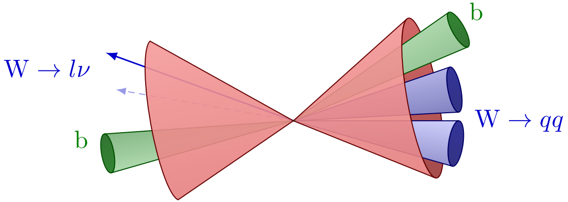
The Lund jet plane and boosted Top quarks





Understanding the top quark lund jet plane

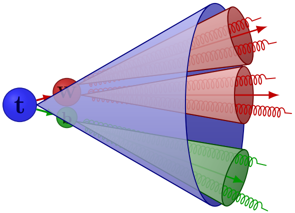
Event selection: $t\bar{t}$ events

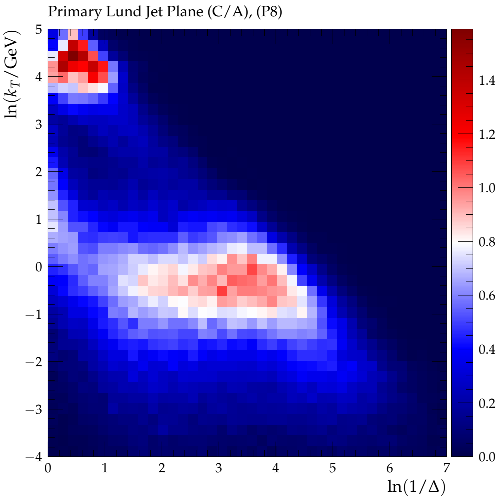


- At least one lepton with $p_T > 60$ GeV
- Two large-R jets (R=1.2)
  - $|\eta| < 2.5$
  - Closest (furthest) jet to the lepton, j_{lep} (j_{had})
  - $p_{T,j_{had}} > 400$ GeV
  - $m_{j_{had}} > m_{j_{lep}}$

Contributions to the Lund jet plane

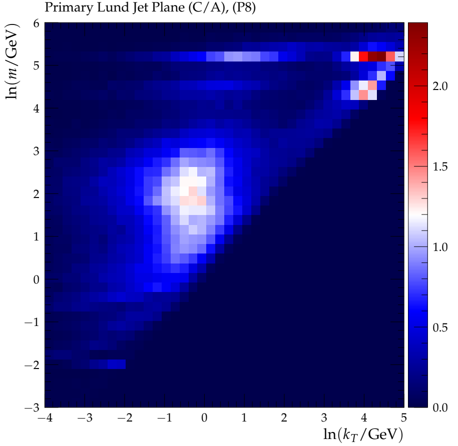
1. Top quark decay
2. W boson decay / b quark, which one do we follow?
3. Multi-parton interactions
4. Hadronisation

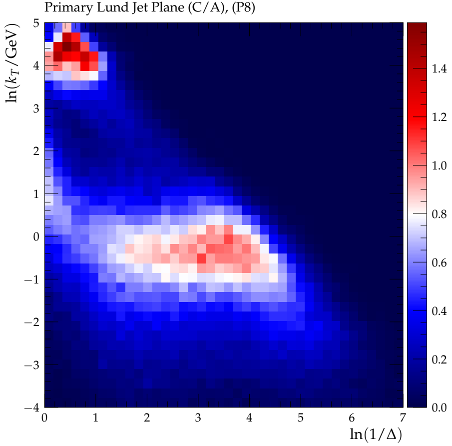




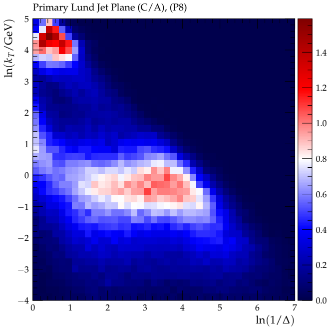
Top quark and W boson decays

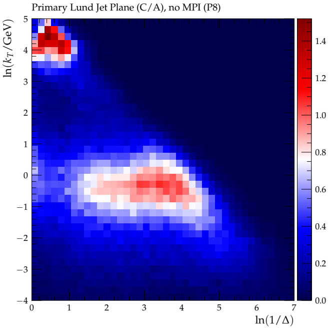
Challenging to disentangle both contributions $\rightarrow$Mass of the splitting: $m^2 = (p_a^2 + p_b^2)$

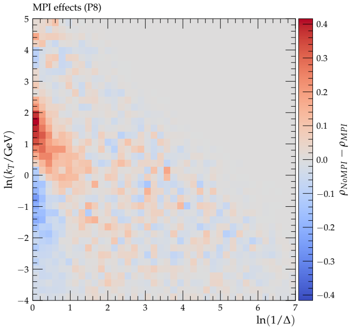




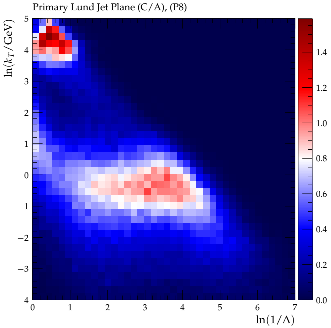
Multi-parton interactions (MPI)

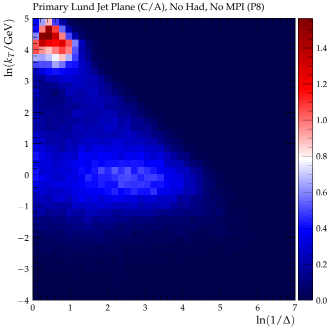


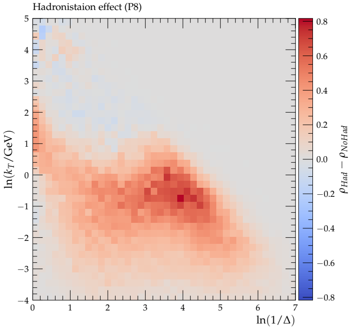




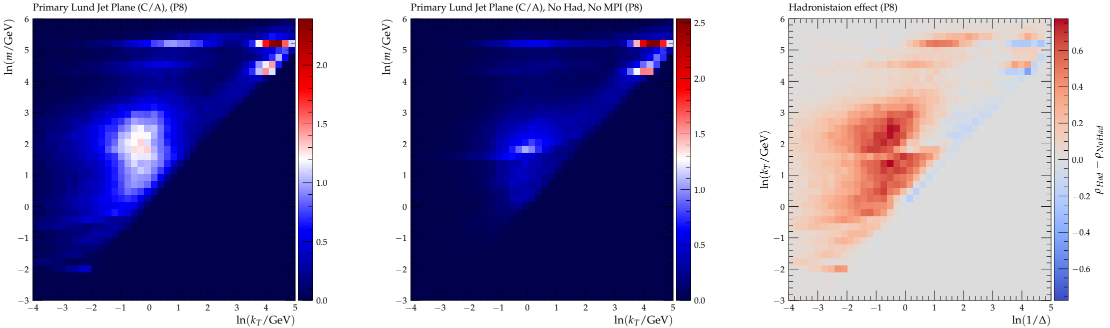
Hadronisation



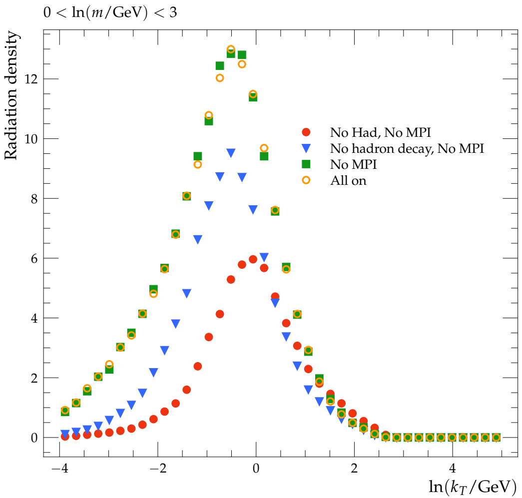




Hadronisation: mass of splitting

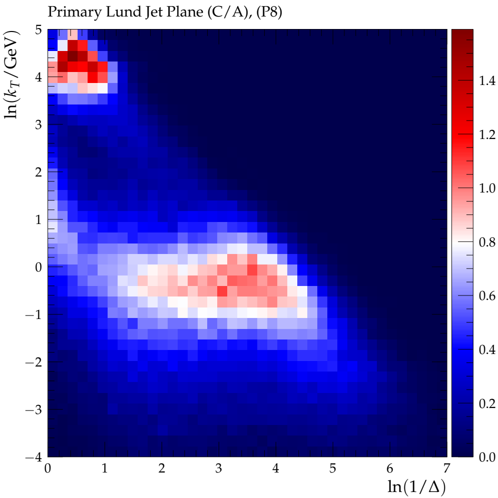


Hadronisation: $0 < \ln(m/\mathbf{GeV}) < 3$



Small recap

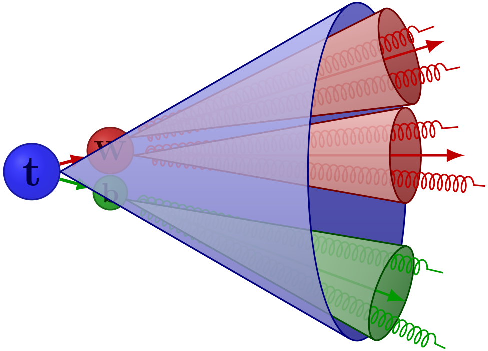
1. Top quark and W boson decays
2. Multi-parton interactions
3. Hadronisation



W boson and b quark Lund jet planes

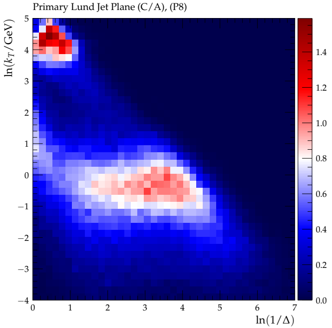
W boson and b quark lund jet planes

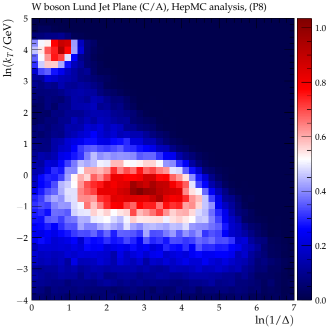
The Top quark Lund jet plane is a mixture between the W boson and the b quark lund jet planes:

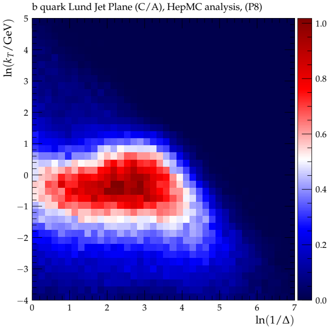


- In each declustering step the largest p_T subjet is chosen
- Can we disentangle the contribution from the W boson and the b quark?
- We build two large-R jets (R=1.2):
  - One jet with the descendants of the W
  - One jet with the descendants of the b
- We build a lund jet plane for each jet

W boson and b quark lund jet planes





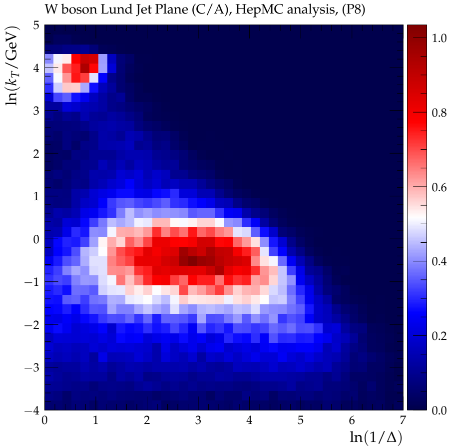


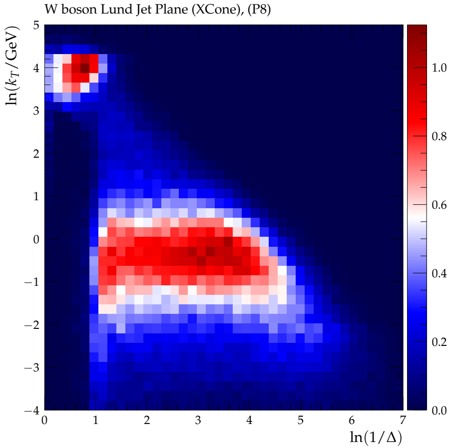
W boson and b quark lund jet planes with XCone jets

In experiment we do not have access to the descendant information. Goal: can we get a similar result using XCone jets:

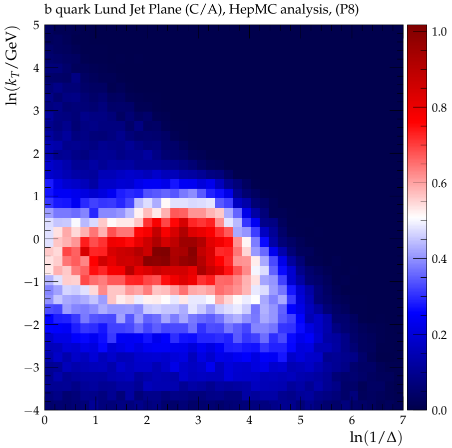
- From the ttbar event we reconstruct to fat jets using the XCone algorithm (R=1.2)
  - One jet for the leptonic decay
  - One jet for the hadronic decay
- With the constituents of the hadronic jet we reconstruct three small-R jets (R=0.4) with the XCone algorithm
- We combine two small-R jets into a jet of R=0.8:
  - The combination with the mass closest to the m_W we tag as the W
  - The remaining slim jet is tagged as b jet

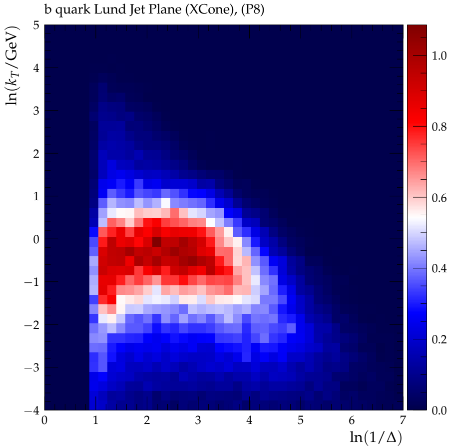
W boson lund jet plane





b quark lund jet plane





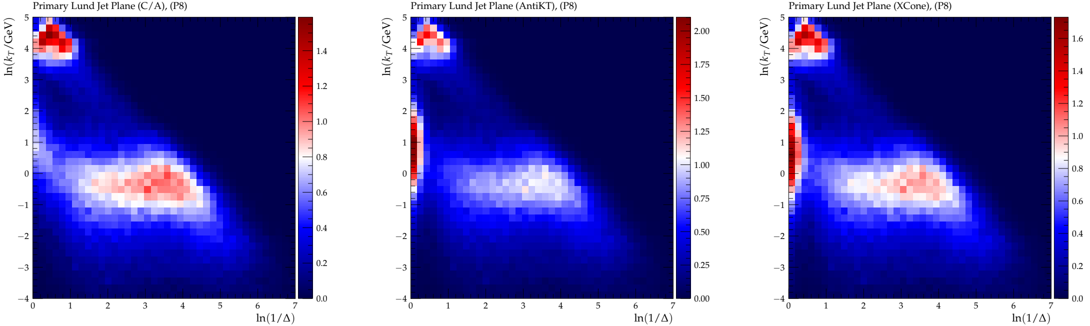
Boundary effects

Different jet clustering algorithms

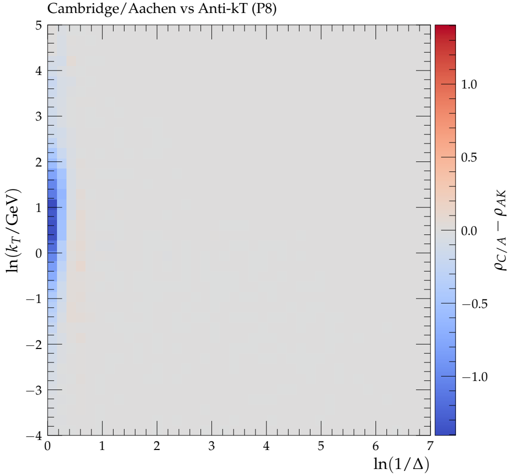
In experiments by default jets are clustered with the anti-kt (AK) algorithm [Cacciari, Salam, Soyez, 2018]):

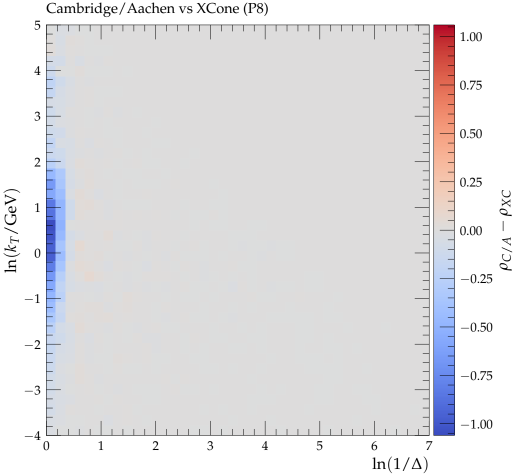
- The constituents of the AK jets are then reclustered with the C/A algorithm
- What effects can we observe?
- We compare a pure C/A approach to XCone [Stewart et al., 2015] and AK clustering algorithms

Boundary effects



Boundary effects





The Soft drop algorithm to remove boundary effects

[A. J. Larkoski, S. Marzani, G. Soyez, J. Thaler, 2014]

Removal of soft wide angle radiation:

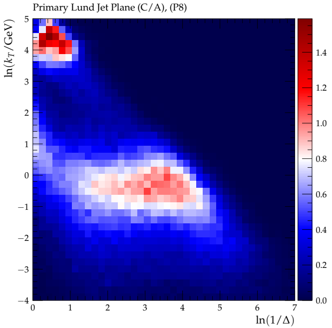
- Initial state radiation
- Multi parton interactions

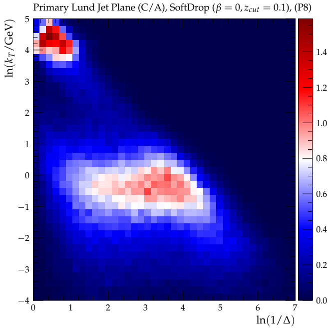
The Soft drop condition:

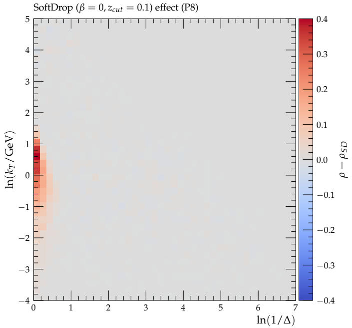
$$\frac{\min\left(p_{T,j_1}, p_{T,j_2}\right)}{p_{T,j_1} + p_{T,j_2}} > z_{cut}\left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

Jets are reclustered using C/A, removing constituents/subjets that do not comply with the Soft drop condition

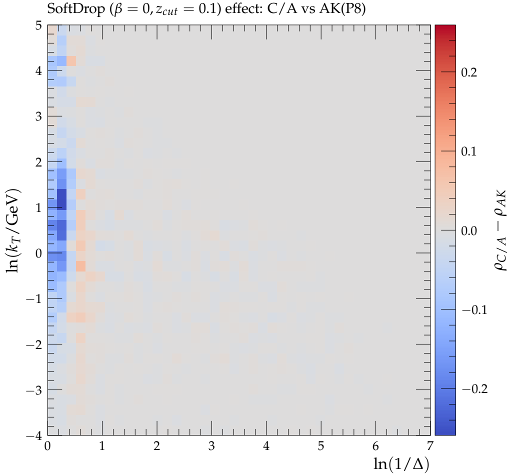
Soft drop: $\beta = 0, z_{cut} = 0.1$

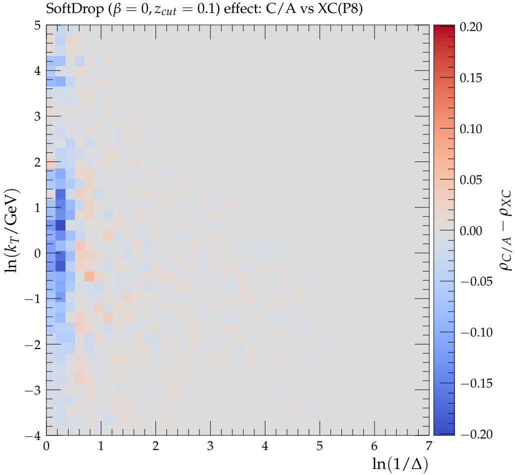






Boundary conditions after Soft Drop ($\beta = 0, z_{cut} = 0.1$)





Recap from boundary conditions

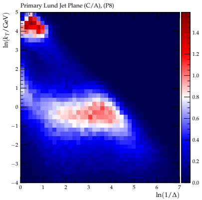
- The main difference between the different algorithms arise in the jet boundary
- Where the MPI has the largest contribution
- By using a SoftDrop approach these boundary effects are reduced:

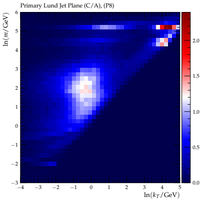
$$\Delta\rho \sim 1.0 \rightarrow \Delta\rho \sim 0.2$$

Conclusions and outlook

We have tried to understand the Lund jet plane of the top quark:

- Every effect is confined in a different region of the phase space
  - Top quark and W decay
  - MPI
  - Hadronisation





- Disentangle W from b quark contribution
- Find an observable to disentangle Hadronisation from the parton shower
- Comparison of results to Herwig available

Thank you!

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