Jet substructure variables in quark and gluon jets

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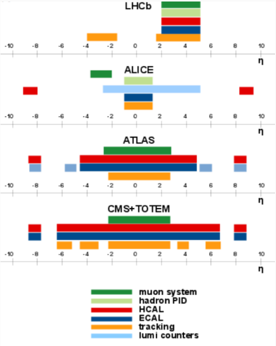
on behalf of the LHC collaborations

Motivation

- jet structure and evolution – open problem
- heavily boosted decays produce overlapping jets
  - New Physics particles are typically quite heavy...
  - ...and searched for via boosted final states
  - important to separate all jets!
- signal-background discrimination
  - jet characteristics reflect its origin
  - heavy particles (e.g. top) produce sub-jets
  - light quark and gluon jets lack distinguishable structure
- probe of perturbative and non-perturbative effects
  - effective QCD
  - resummation methods
  - parton showering

LHC experiments

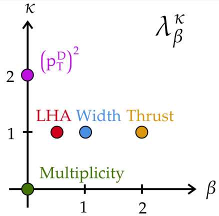
- different detectors give access to different jet aspects
- LHCb
  - overlap of boosted jets
  - mostly quark-initiated jets
- ATLAS and CMS
  - mostly central, gluon-initiated jets



Distinguishing between jet types

- J. High Energ. Phys. 2022, 188 (2022) (CMS)
- gluon-initiated di-jets and, for the first time, quark-initiated jets from Z+jets events
- a set of distinguishing variables proposed

$$\lambda_\beta^\kappa = \sum_{i \in jet} z_i^\kappa \left(\frac{\Delta R_i}{R} \right)^\beta$$



  - z_i – fractional transverse momenta
  - $\Delta R_i = \sqrt{(\Delta\phi_i)^2 + (\Delta y_i)^2}$
- influence of jet grooming tested
  - soft and wide angle radiation removed

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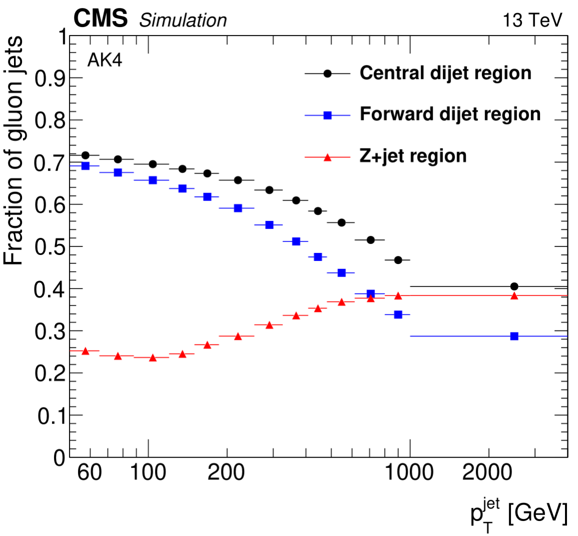
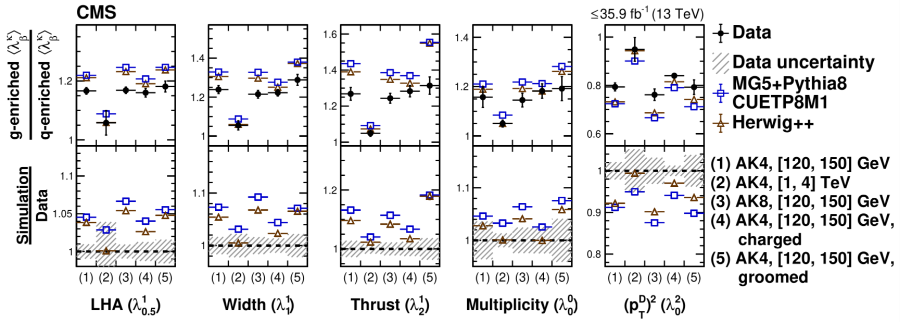
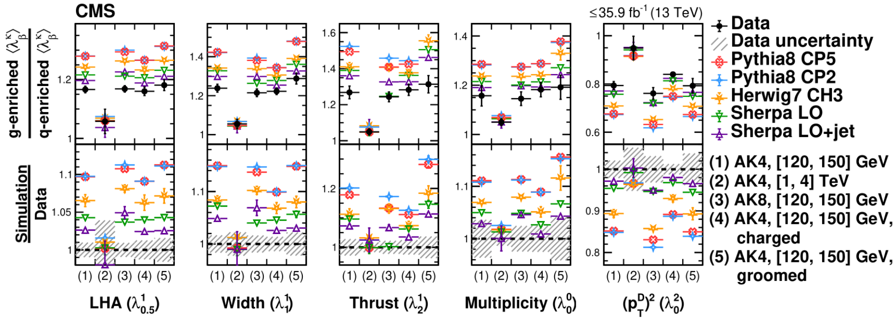


- high p_T jets have similar gluon and quark content



- on average, gluon jets produce higher values except for $(p_T^D)^2$
  - at low jet-p_T this difference is significant – good separation power
  - at high jet-p_T the gluon content is close to 50%
- the agreement with data is much better at high jet-p_T
- no significant improvement with grooming



- overall, Sherpa achieves the best agreement with data
  - improvements still needed!
- small differences between Pythia8's CP2 and CP5
  - low dependence on the choice of $\alpha_s(m_z)$
  - high on the fragmentation model
- extra jet improves Sherpa predictions
  - additional partons affect fraction of gluon jets in the signal region
  - measurement of ratio is sensitive to gluon content

Charged hadrons in Z-tagged and inclusive jets

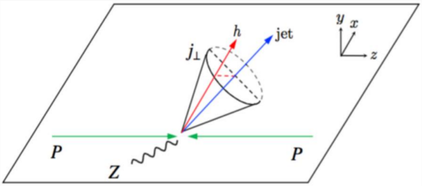
- PRL 123 (2019) 232001 (LHCb)
  - charged hadrons produced in jets recoiling of a Z boson
  - first measurement in the forward region and first with Z boson
  - relatively low background (Z+jets)
  - dominated by light-quark jets
- EPJ C71, 1795 (2011) (ATLAS)
  - jet fragmentation and transverse profile of inclusive jets
  - dominated by gluon-initiated jets
  - see also Phys. Rev. D 100 (2019) 052011 for 13 TeV follow-up

- spatial momentum distribution
  - longitudinal fraction

$$z \equiv \frac{\boldsymbol{p}_{jet} \cdot \boldsymbol{p}_{hadron}}{\left|\boldsymbol{p}_{jet}\right|^2}$$

  - transverse to jet axis

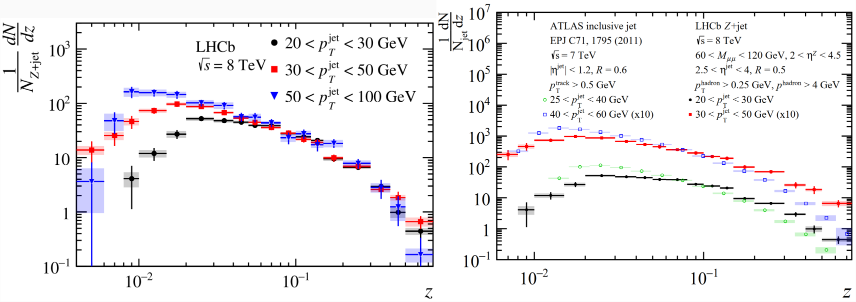
$$j_T \equiv \frac{\left|\boldsymbol{p}_{jet} \times \boldsymbol{p}_{hadron}\right|}{\left|\boldsymbol{p}_{jet}\right|}$$



- radial profile

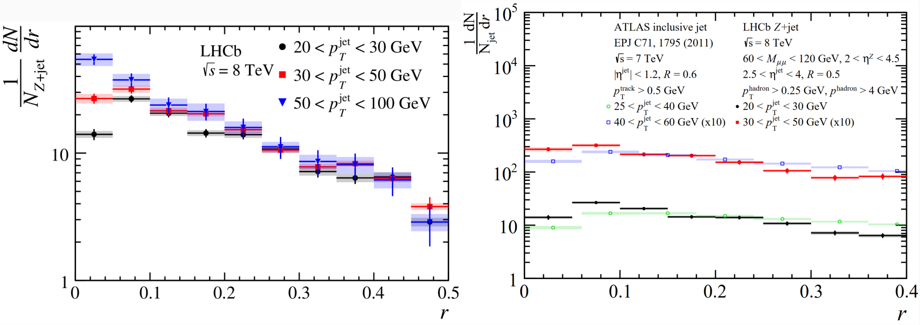
$$r \equiv \sqrt{(\phi_{jet} - \phi_{hadron})^2 + (y_{jet} - y_{hadron})^2}$$

PRL 123 (2019) 232001 (LHCb) and EPJ C71, 1795 (2011) (ATLAS)



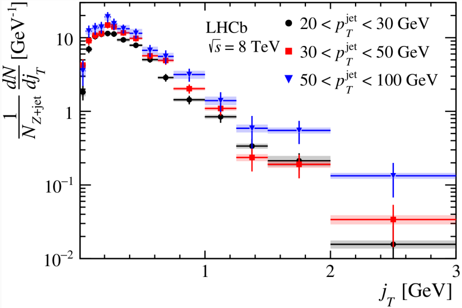
- low z difference due to $p_{track} > 4$ GeV requirement
  - higher p_T jets probe lower z
- jets from quarks (LHCb) narrower than gluon-initiated jets (ATLAS)
- quark-initiated jets produce more hadrons than gluon-initiated jets at higher longitudal momentum fractions

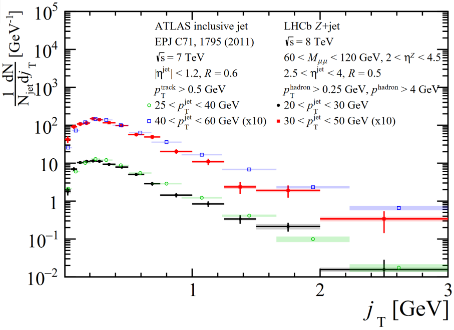
PRL 123 (2019) 232001 (LHCb) and EPJ C71, 1795 (2011) (ATLAS)



- number of hadrons produced at small r highly sensitive to jet p_T
- reduced p_T dependence at higher r may suggest small dependence in non-perturbative contributions
- more low-r hadrons in quark-initiated jets

PRL 123 (2019) 232001 (LHCb) and EPJ C71, 1795 (2011) (ATLAS)





- the shape of j_T distribution indicates a useful observable for transverse-momentum-dependent framework
- similar characteristics of quark- and gluon-initiated jets around the peak

Conclusions

- study of jet fragmentation provides valuable insights into their evolution and reconstruction algorithms
- gluon- and quark-initiated jets differ and they can be effectively distinguished
- flavor-dependence and jet parameters are a useful background discriminant
- many predictions are still inconsistent with the data