Jet substructure as a tool to study double parton scatterings in V + jets processes at the LHC

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Double Parton Scattering (DPS)

DPS: Two <u>hard</u> parton-parton interactions in a single proton-proton collision.

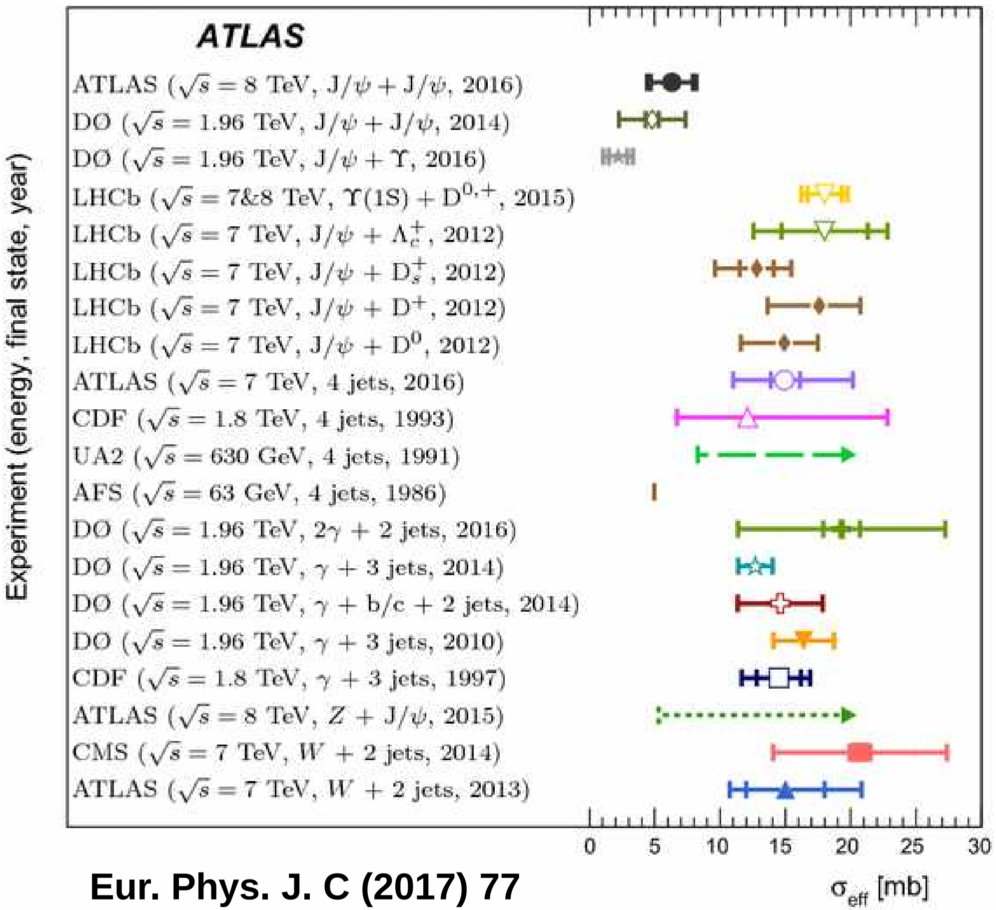
Several available DPS measurements with:

(pre-LHC & LHC)

- Different collsion energies
- Different final states
- Effective cross-section
- Using observables sensitive to DPS

Conclusion on energy (or process) (in)dependence???

- Large systematic uncertainities
- Little sensitivity towards DPS



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From ATLAS paper

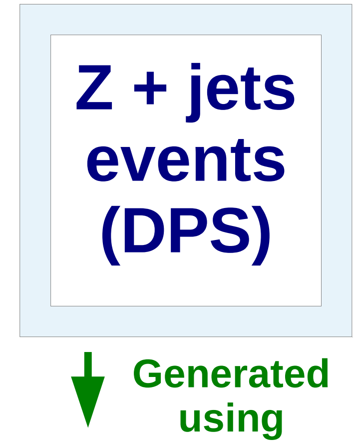
Motivation

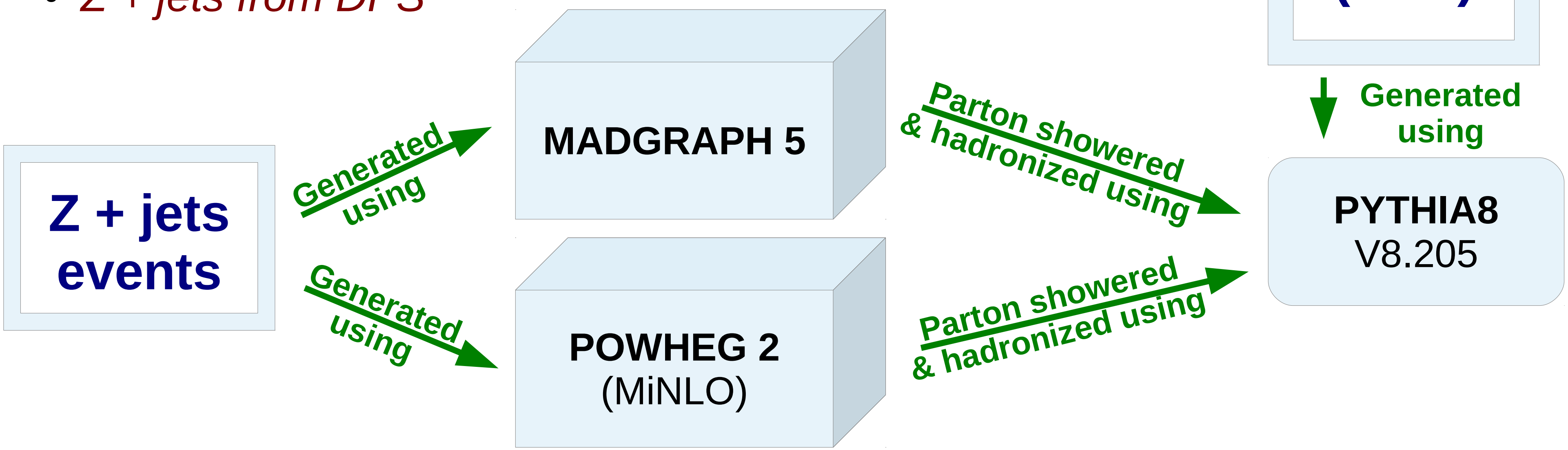
- The experimental measurements of DPS are dominated by production from SPS [DPS fraction <10%]
- Requirement to increase DPS sensitivity by controlling SPS with least effect on DPS.
- **Jet fragmentation properties: a possible solution?**
  (for DPS measurements involving jets in the final state)
- Study with Z + jets: a clean final state with large production cross-section.

MC Samples used

From 13 TeV pp collisions *(Simulations):*

- *Z + jets (inclusive: SPS+DPS)*
- *Z + jets from DPS*





- **POWHEG** and **MADGRAPH** describes LHC data well for W/Z +jets events.

JHEP08(2013)005; JHEP10(2012)155, JHEP03(2014)032

- **PYTHIA8** provides an accurate MPI model.

JHEP05(2006)026, Comput. Phys Comm.178(2008) 852

- **ATLAS A14** tune with PDF set **NNPDF 2.3LO**.

ATL-PHYS-PUB-2014-021

Event Selection Criteria

Two opposite sign Muons

p_T (μ) > 20 GeV/c

|η| (μ) < 2.5

Anti-k_T jets (ΔR=0.5)

p_T (jet) > 20 GeV/c

|η| (jet) < 2.5

$60 < M^{inv}(\mu\mu) < 120$ GeV/c^2

Partons:

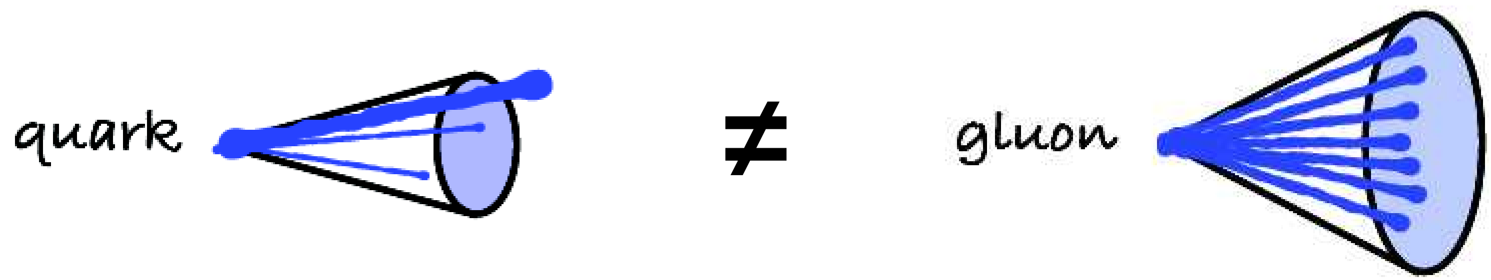
p_T (jet) > 15 GeV/c

|η| (jet) < 3.0

Two cases: Z-boost

1. **No cut on p_T (Z)**
2. **p_T (Z) < 10.0 GeV/c**

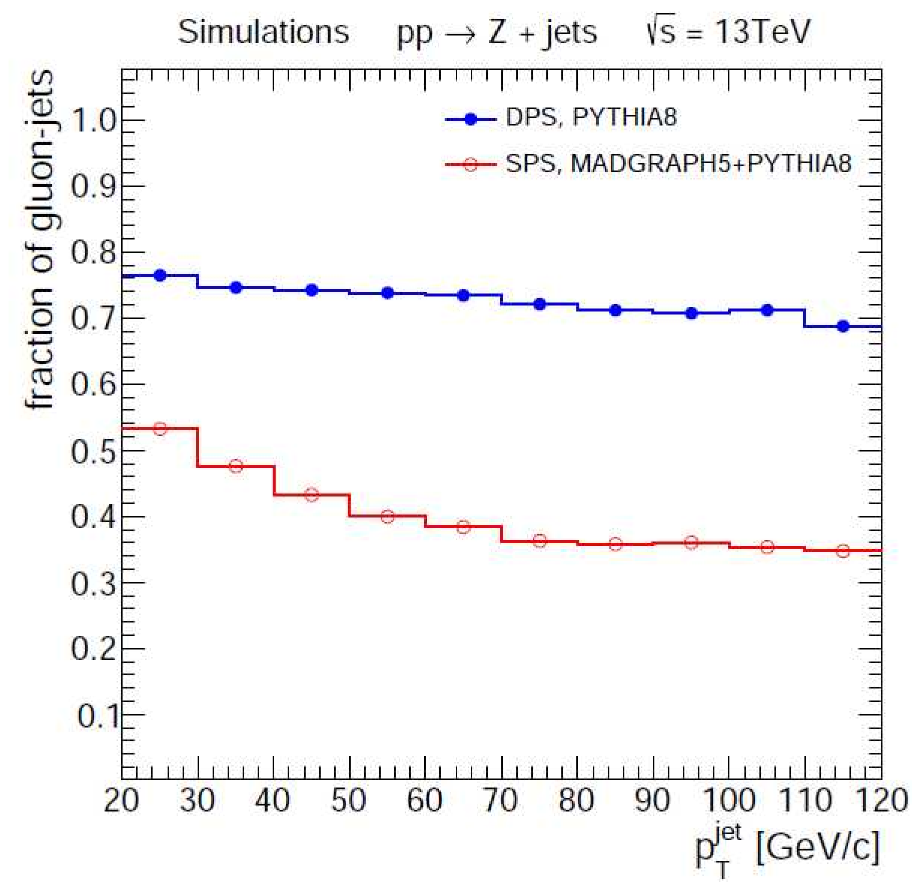
Methodology



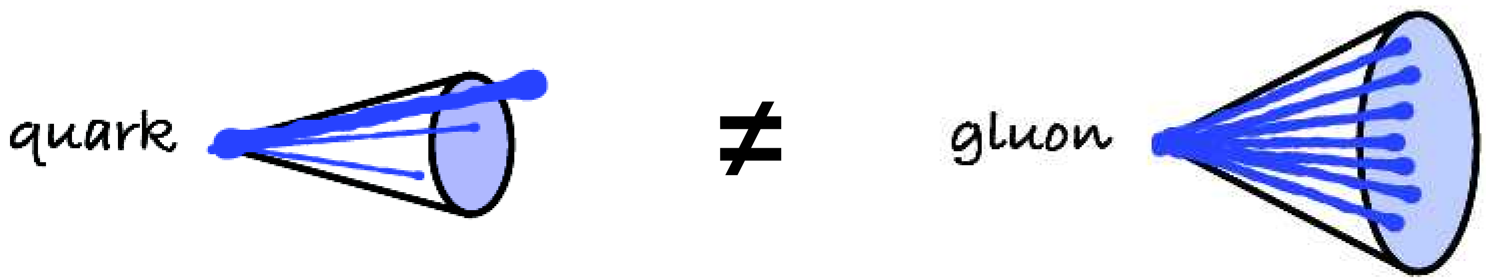
- A jet is tagged as gluon (or quark)-initiated after matching with partons in (η x φ) space with ΔR < 0.3.

$$\Delta R = \sqrt{(\eta_{\text{jet}} - \eta_{\text{parton}})^2 + (\phi_{\text{jet}} - \phi_{\text{parton}})^2}$$

- In Z+jets from SPS, jets originating from the quarks dominate over the ones from gluons, whereas DPS events are dominated by gluon-initiated jets.



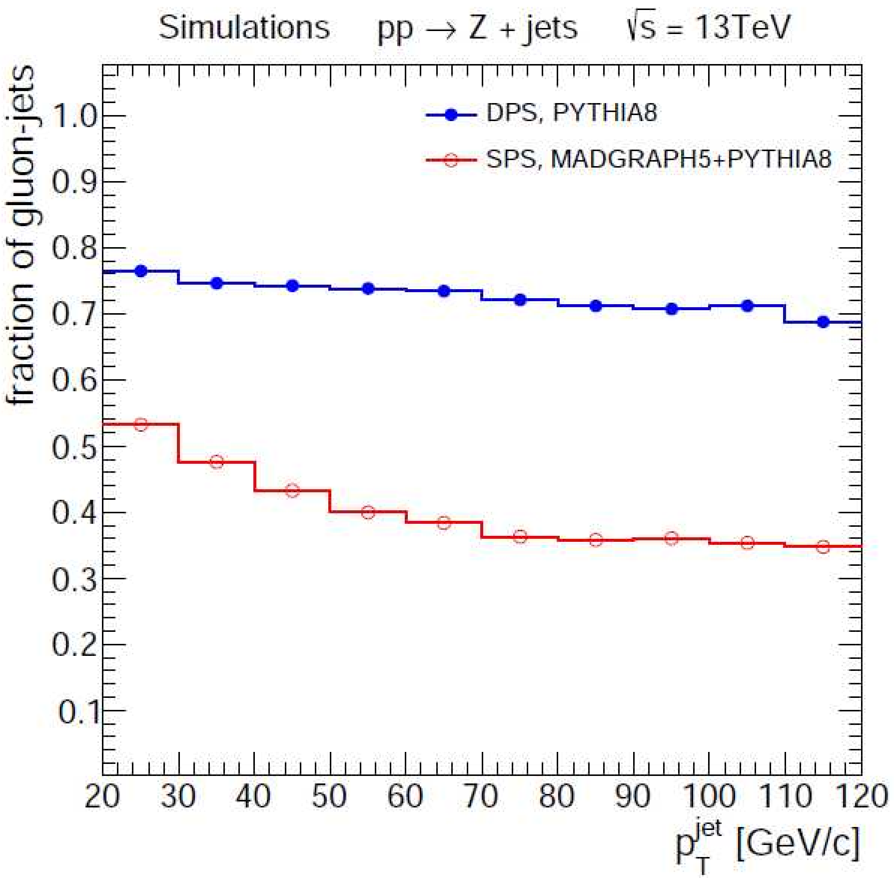
Methodology



To increase contribution of DPS:

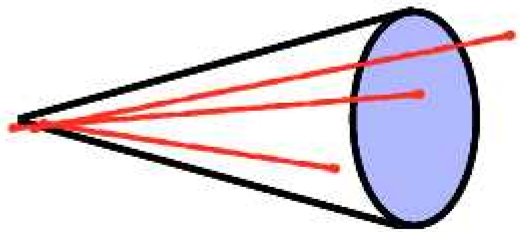
- identify the flavour of a jet (How?)
- choose the data sample with gluon-initiated jets only.

Different **fragmentation properties** of quarks and gluons helps to construct observables for identification of originating flavour of the jet.



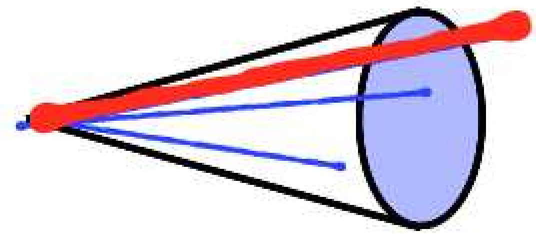
Discriminating Variables

Jet constituents multiplicity



Particle multiplicity is higher in case of gluon jets as compared to quark jets

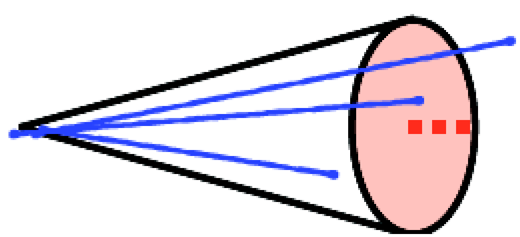
Fragmentation Function



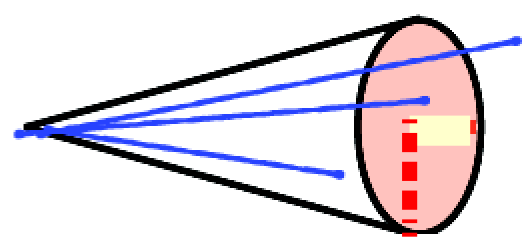
Fragmentation function of gluon jets is softer as compared to that of quarks.

$$p_{\mathrm{T}}^{\mathrm{jet}} D = \frac{\sqrt{\sum_i p_{\mathrm{T,i}}^2}}{\sum_i p_{\mathrm{T,i}}}$$

Jet cone minor axis



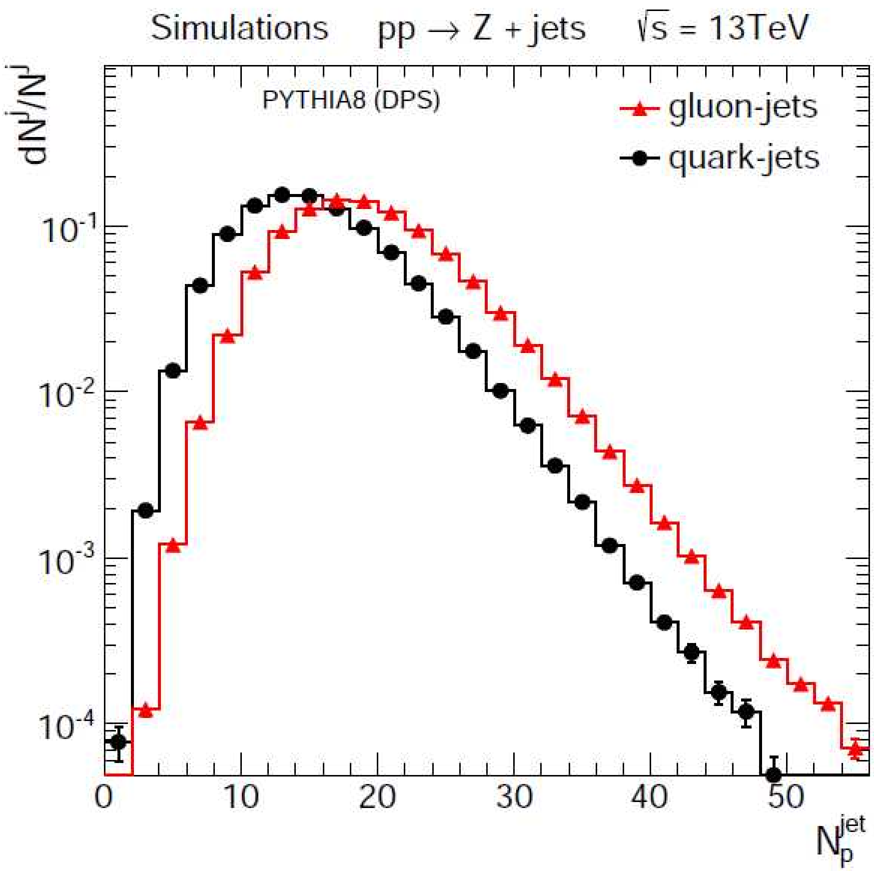
Jet cone major axis



(Gluon jets are less collimated as compared to quark jets)
=> length of major/minor axes of jet cone size for gluon jets is larger as compared to that of quark jets

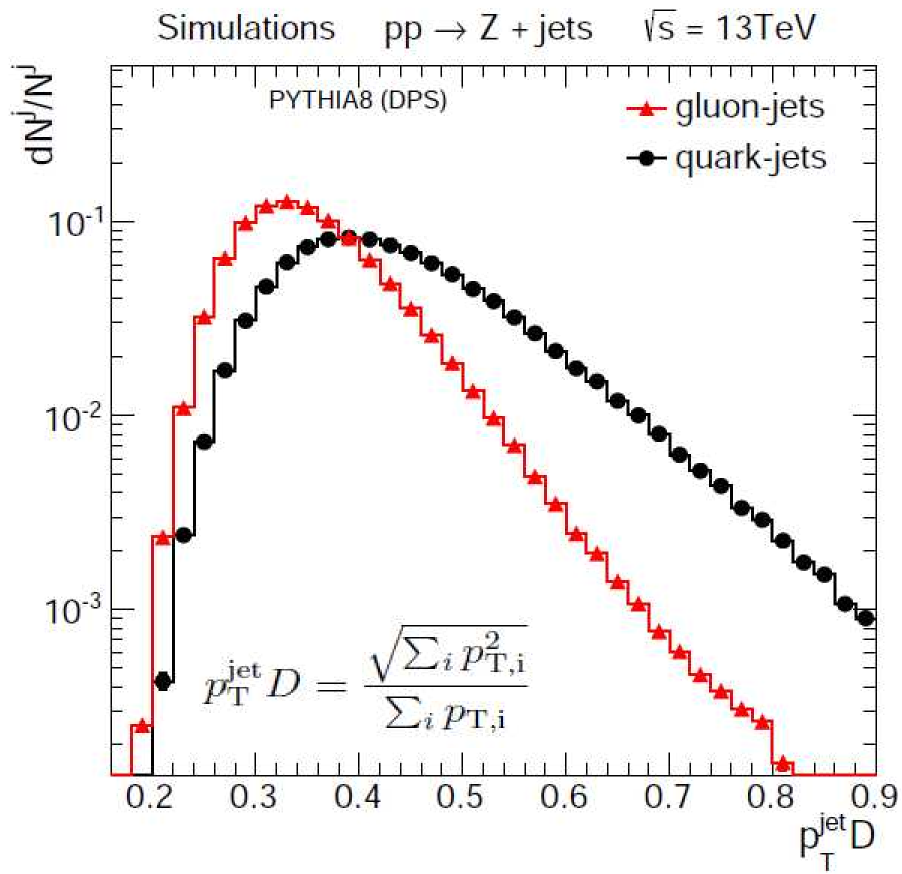
Discriminating Variables

Jet constituents multiplicity



- Gluon-initiated jets have large number of particles as constituents.

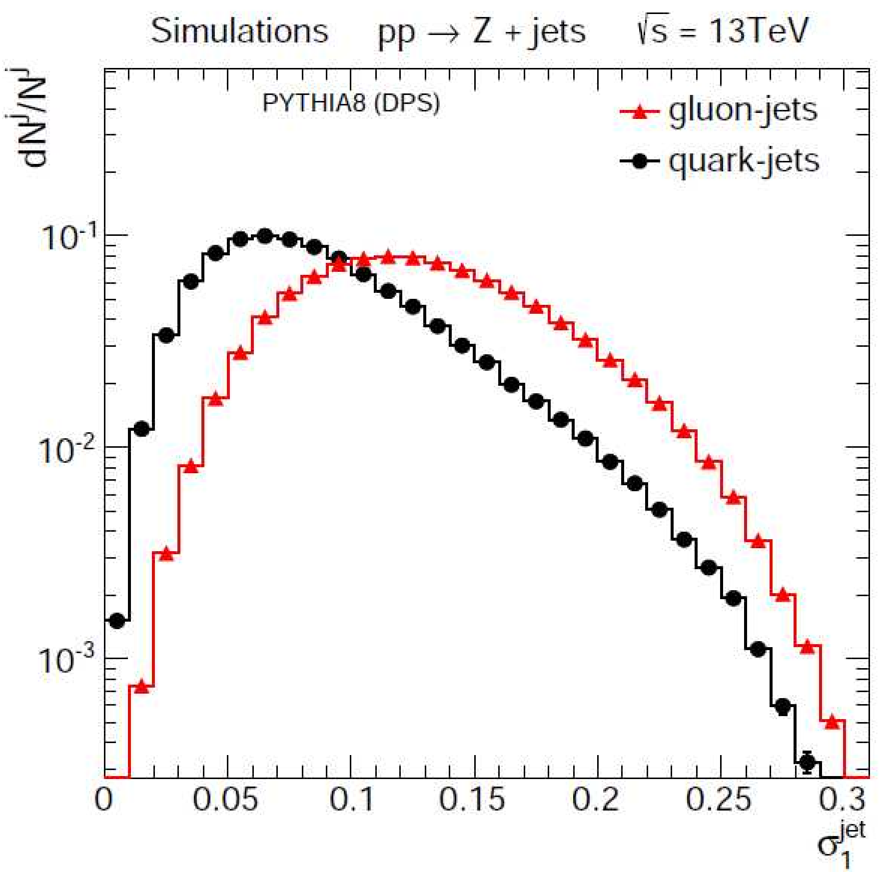
Jet fragmentation function



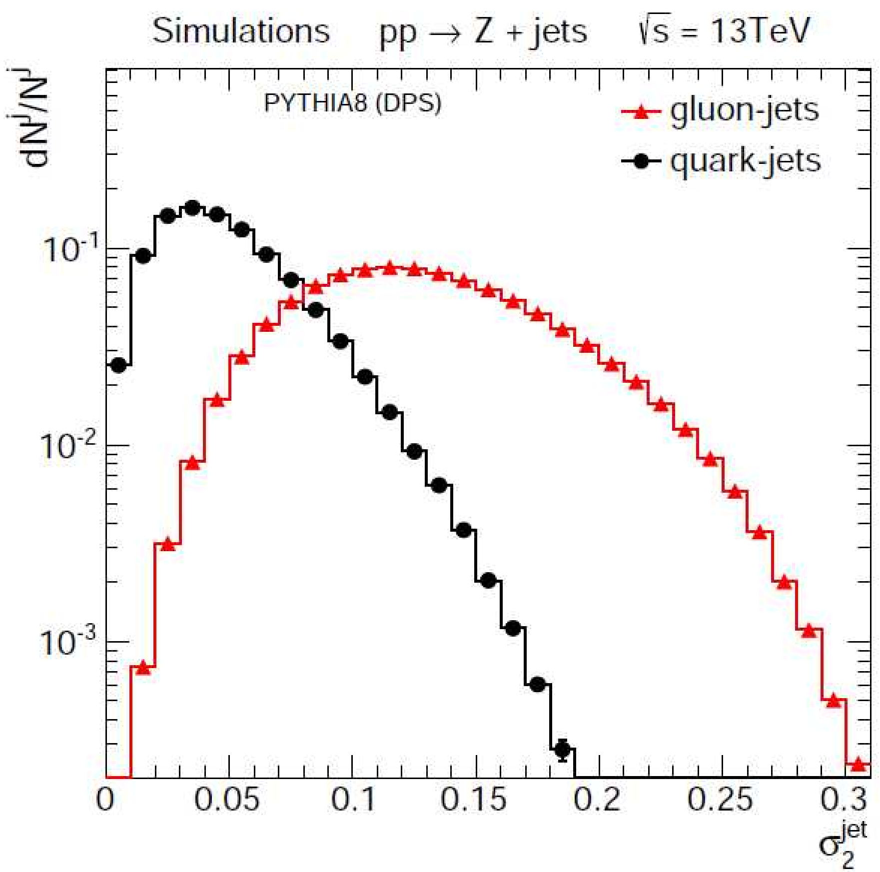
- Constituents of quark-initiated jets are hard as compred to gluon-ones.

Discriminating Variables

Major axis of jet cone



Minor axis of jet cone



- Gluon-initiated jets are broader as compared to quark-initiated ones.

BDT output

- To enhance the sensitivity of the discriminating observables and consider the possible correlations b/w observables, multivariate analysis (BDT) is performed.

- **Input to BDT:**

  Four discriminating observables

  along with p_T and η of jets.

BDT output

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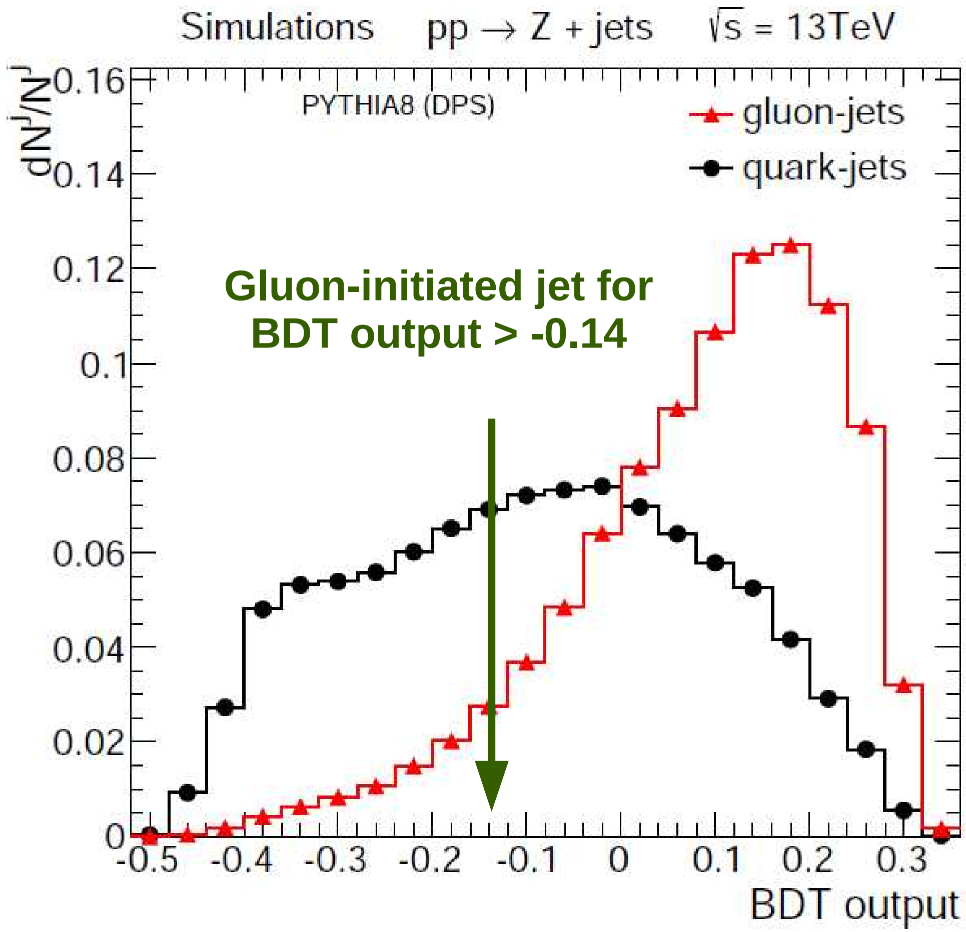
- **Input to BDT:**
  Four discriminating observables along with p_T and η of jets.

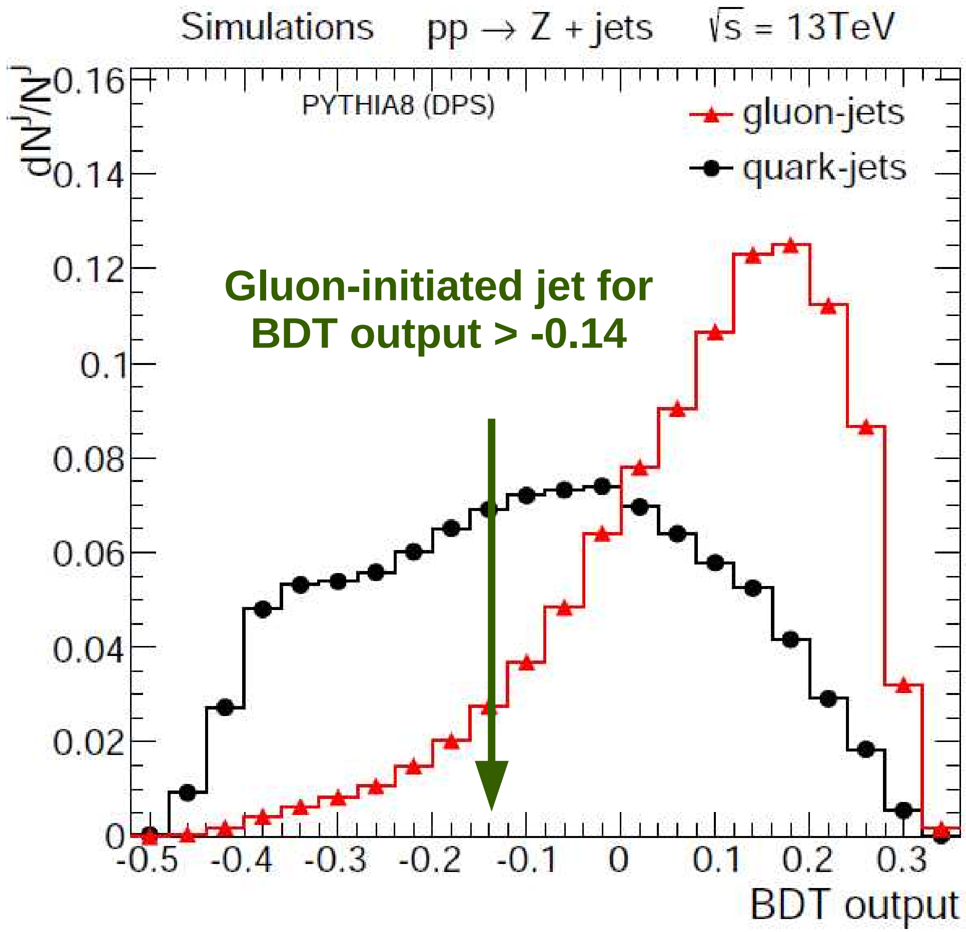
- A clear distinction is observed between two types of jets from BDT output.



BDT output

- If the value of BDT discriminant for a jet is greater than -0.14, it is considered as a gluon-initiated one. Otherwise, it is considered as quark-initiated one.

Jet Type	η (selection)
Gluon-initiated	91%
Quark-initiated	55%



Results

- A selected event is considered to be produced by DPS, if there are two MPI partons within the acceptance. Otherwise, it is considered as SPS background.

↓

DPS fraction = 7.5%

Consistant with experimental measurements

MADGRAPH + PYTHIA8

Results

- A selected event is considered to be produced by DPS, if there are two MPI partons within the acceptance. Otherwise, it is considered as SPS background.

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Consistant with experimental measurements

- An additional requirement is imposed on two selected jets to be initiated by gluons.

Reduction in SPS contribution by 48%

Reduction in DPS contribution by 30%

MADGRAPH + PYTHIA8

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Consistant with experimental measurements

MADGRAPH + PYTHIA8

- An additional requirement is imposed on two selected jets to be initiated by gluons.

Reduction in SPS contribution by 48%

Reduction in DPS contribution by 30%

DPS fraction = 11%

with gain of 45%

Results

- POWHEG produced the similar results with difference in percentage gain.

Sample	%age Gain in DPS fraction
MADGRAPH + PYTHIA8	45%
POWHEG + PYTHIA8	36%

- The differences arises due to differences in treatment of LO and NLO effects for two generators, which also change relative fractions of quark- and gluon-initiated jets.

Results

- The results are reproduced by constraing Z-boost with an upper cut of 10 GeV

Condition on Z-boost	%age Gain in DPS fraction
No condition	45%
Upper cut of 10 GeV	25%

- By constraing Z-boost, most of remaining jets are produced by ISR/FSR, which leads to reduction in the gain.

Summary

- Study of Z + jets events to explore the possibility to enhance the DPS sensitivity, using the jet fragmentation properties as a tool, is presented.
- Several observables are there to identify the origin of jets.
- A significant gain in the DPS fraction can be achieved by choosing data sample with gluon-dominating events.
- The impact of these studies will be intersting to check in the actual experimental conditions.

Any feedback or Comments?