12th MPI at LHC

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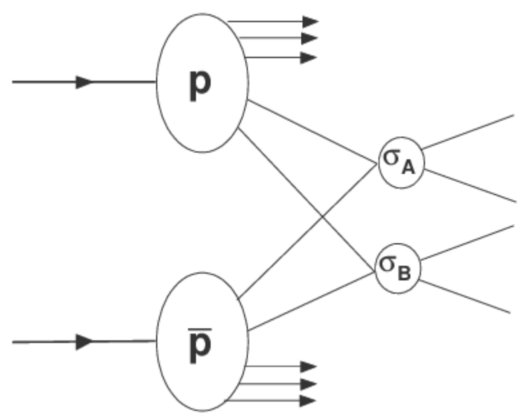
Importance of Jet Fragmentation Properties to Study Double Parton Scattering



Ramandeep Kumar[1], Monika Bansal[2], Sunil Bansal[3]

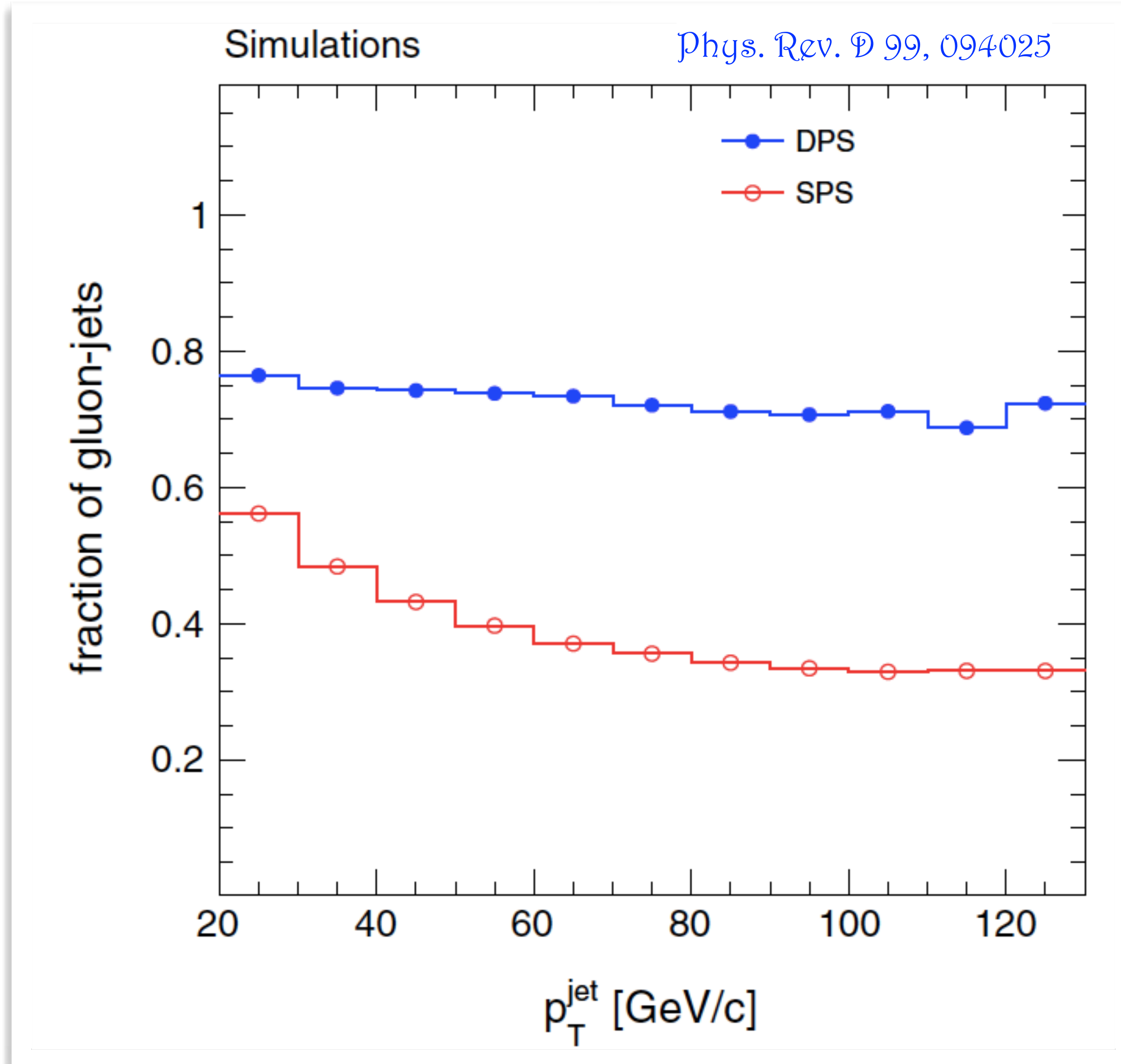
[1] Akal University, Talwandi Sabo, IN
[2] DAV College, Sector 10, Chandigarh, IN
[3] Panjab University, Chandigarh, IN

Introduction

- **Jet substructure** plays a significant role in:
  - probing the Standard Model (SM) physics
  - Improving the sensitivity to new physics searches
- The quark jets are different in substructure from gluon jets and different observables have been investigated to distinguish quarks jets and gluon jets:
  - Casimir colour factor of quarks (4/3) is different from that of gluons (3) & it leads to a higher probability to radiate a soft gluon
  - The gluon jets are expected to contain (on average) more constituents, with a wider geometric spread in the detector

Introduction

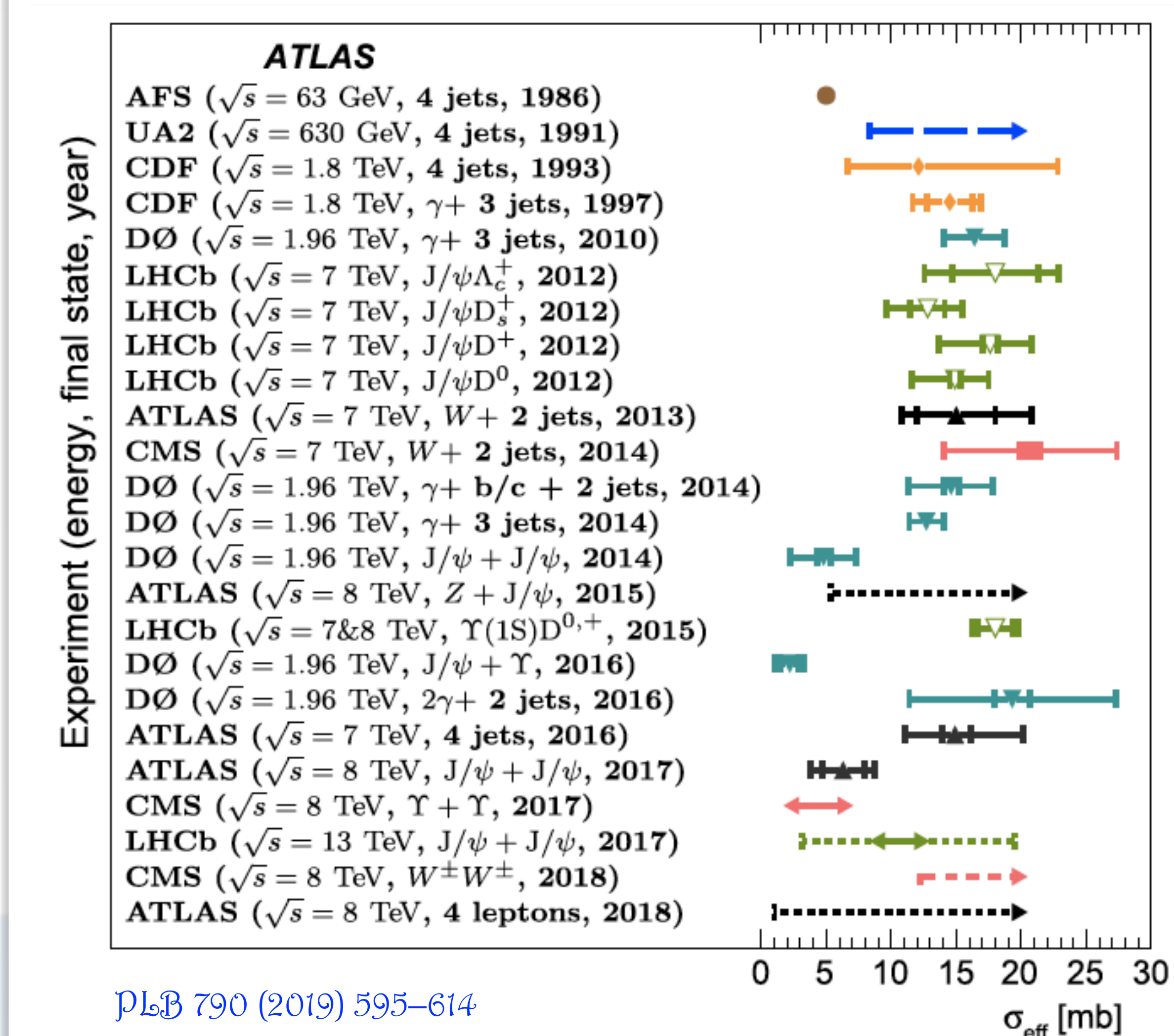
- Jet fragmentation studies are expected to play an important role in the study of double parton scattering (DPS)
- The gluon jets dominates the quark jets in the events produced by DPS, & events from single parton scattering (SPS) are dominated by quark jets



- Production of Z + jets events at 13 TeV
- Jets: $p_T > 20$ GeV; $|\eta| < 2.5$

Double Parton Scattering (DPS)

- **DPS**: Two hard parton-parton interactions in a single proton-proton collision
- Several measurements with:
  - Different collision energies (pre-LHC & LHC)
  - Different final states
  - Using observables sensitive to DPS



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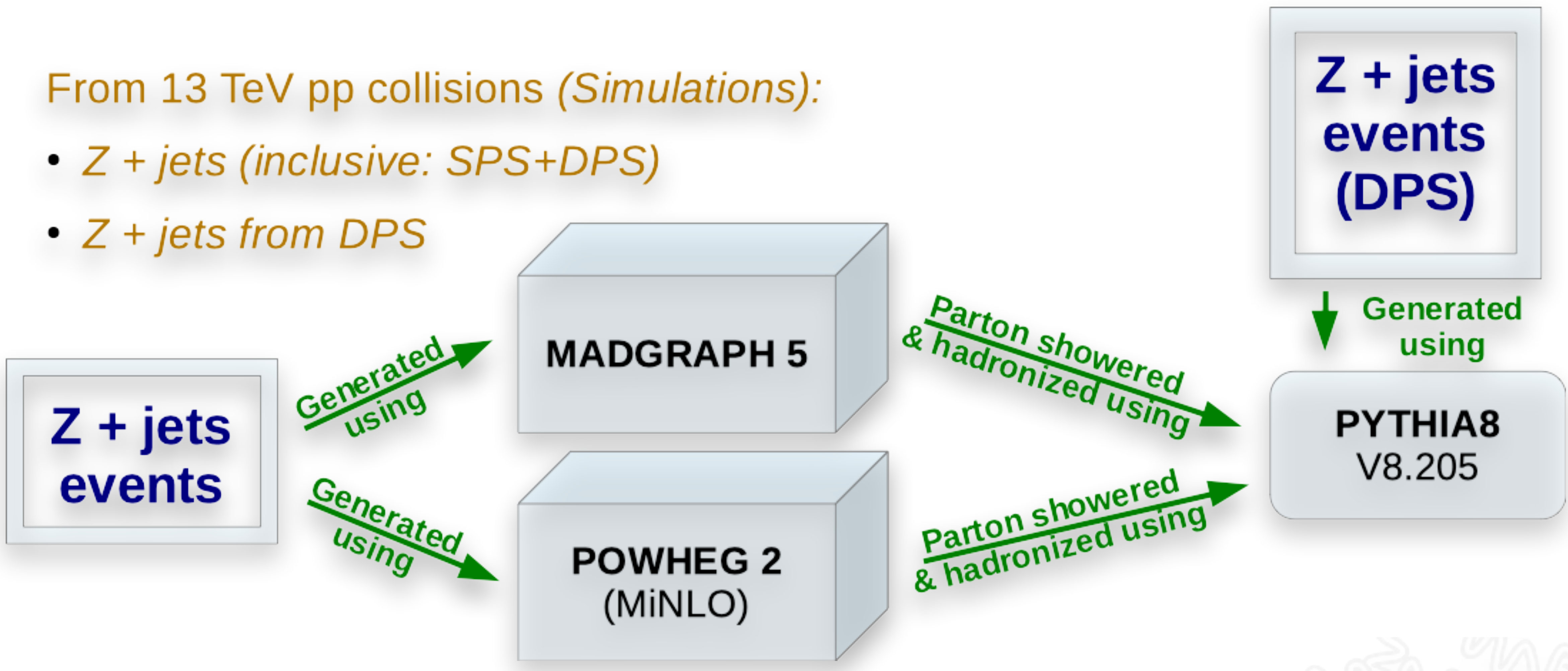
- Large systematic uncertainties
- Little sensitivity towards DPS

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)
- **<u>Study with Z + jets</u>**: a clean final state with large production cross-section

Details of MC Samples



- 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

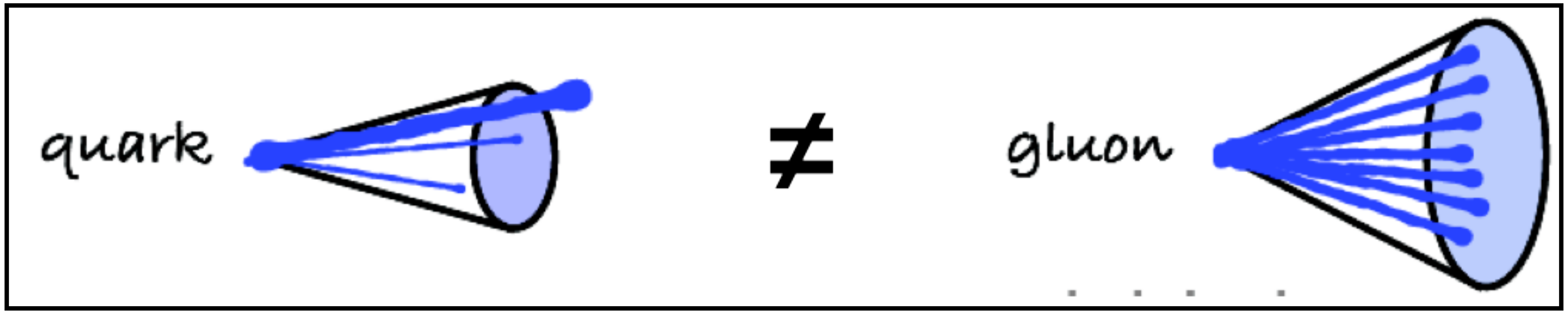
Two opposite sign Muons	Anti-k_T jets ($\Delta R=0.5$)
$p_T\,(\mu) > 20$ GeV/c	p_T (jet) > 20 GeV/c
$\lvert\eta\rvert\,(\mu) < 2.5$	$\lvert\eta\rvert$ (jet) < 2.5

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

Partons:	Two cases: Z-boost
p_T (jet) > 15 GeV/c	1. No cut on p_T (Z)
$\lvert\eta\rvert$ (jet) < 3.0	2. p_T (Z) < 10.0 GeV/c

- The jets are clustered using **FastJet** software package

Methodology



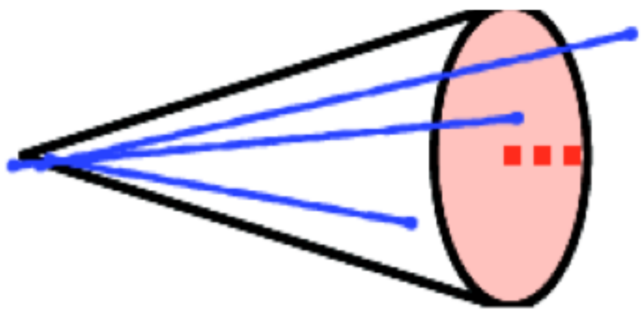
- A jet is tagged as gluon (or quark)-initiated after matching with partons in $(\eta \times \phi)$ space with $\Delta R < 0.3$

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

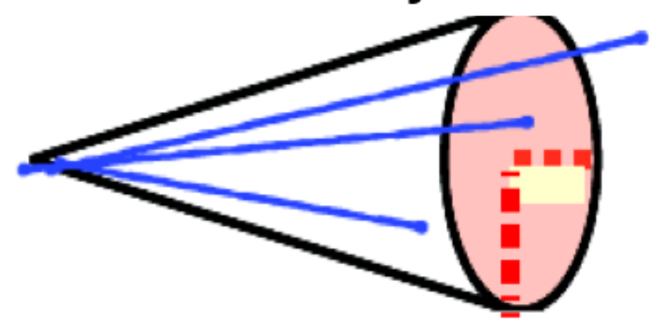
- The gluon jets dominate over the quarks jets in the events produced by DPS, & events from single parton scattering (SPS) are dominated by quark jets
- To increase contribution of DPS:
  - identify the flavour of a jet
  - choose the data sample with gluon jets only

Discriminating Observables

Jet cone minor axis

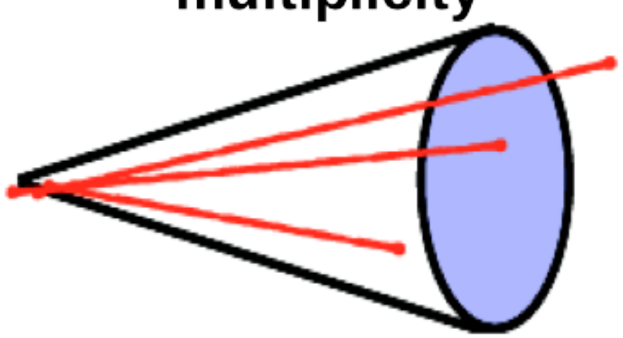


Jet cone major axis



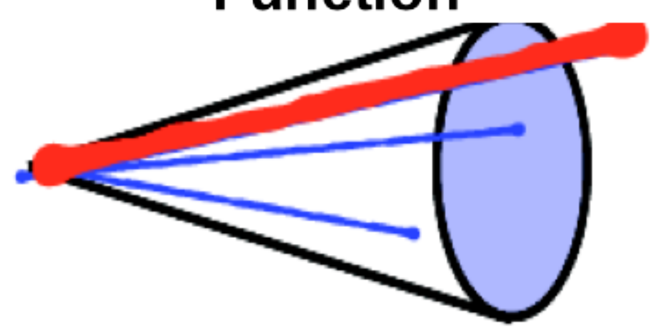
(Gluon jets are less collimated as compared to quark jets)
→ length of major/minor axes of jet cone size for gluon jets is larger as compared to that of quark jets

Jet constituents multiplicity



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

Fragmentation Function

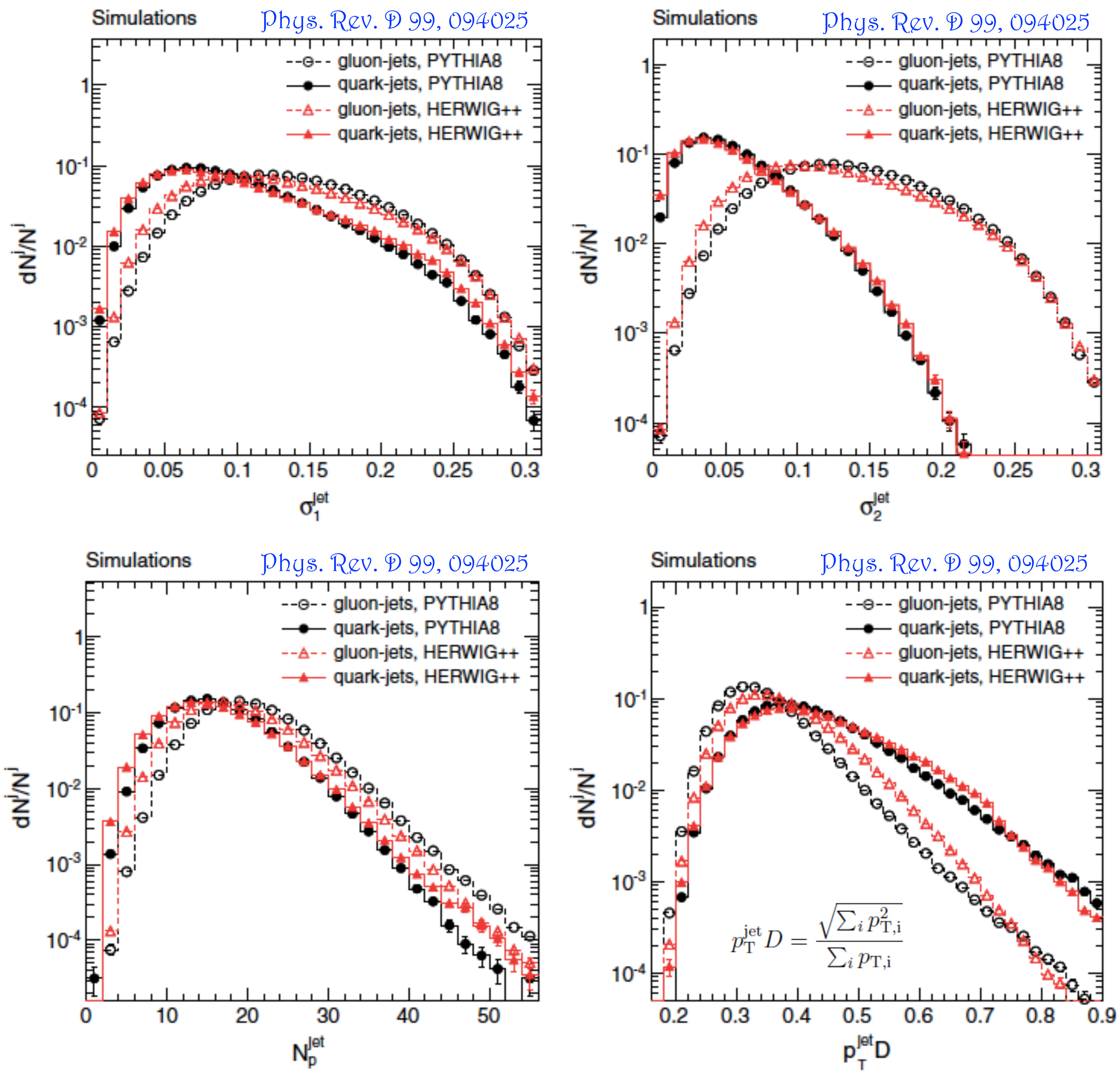


Fragmentation function of gluon jets is softer as compared to that of quarks.

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

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

Discriminating Observables



- **Gluon jets:**
  - Are broader as compared to quark-initiated ones
  - have large number of particles as constituents
  - have softer constituents
- Significant difference in the shape of input variables for different generators

Effectiveness of Variables

- A selected event is considered to be produced by DPS, if there are two MPI partons present within the acceptance, otherwise event is considered as SPS background.
- The fraction of DPS processes contributing in selected Z + 2-jets sample is about 7.5% (which is consistent with the previous studies)
- The effectiveness of the observables, sensitive to quark-gluon discrimination, is evaluated by calculating the gain in DPS fraction after requiring selected two jets to be gluon-initiated
- The effectiveness of these variables is tested using two approaches:
  - Cut-based approach
  - Multivariate analysis (BDT) approach

Cut-based Approach

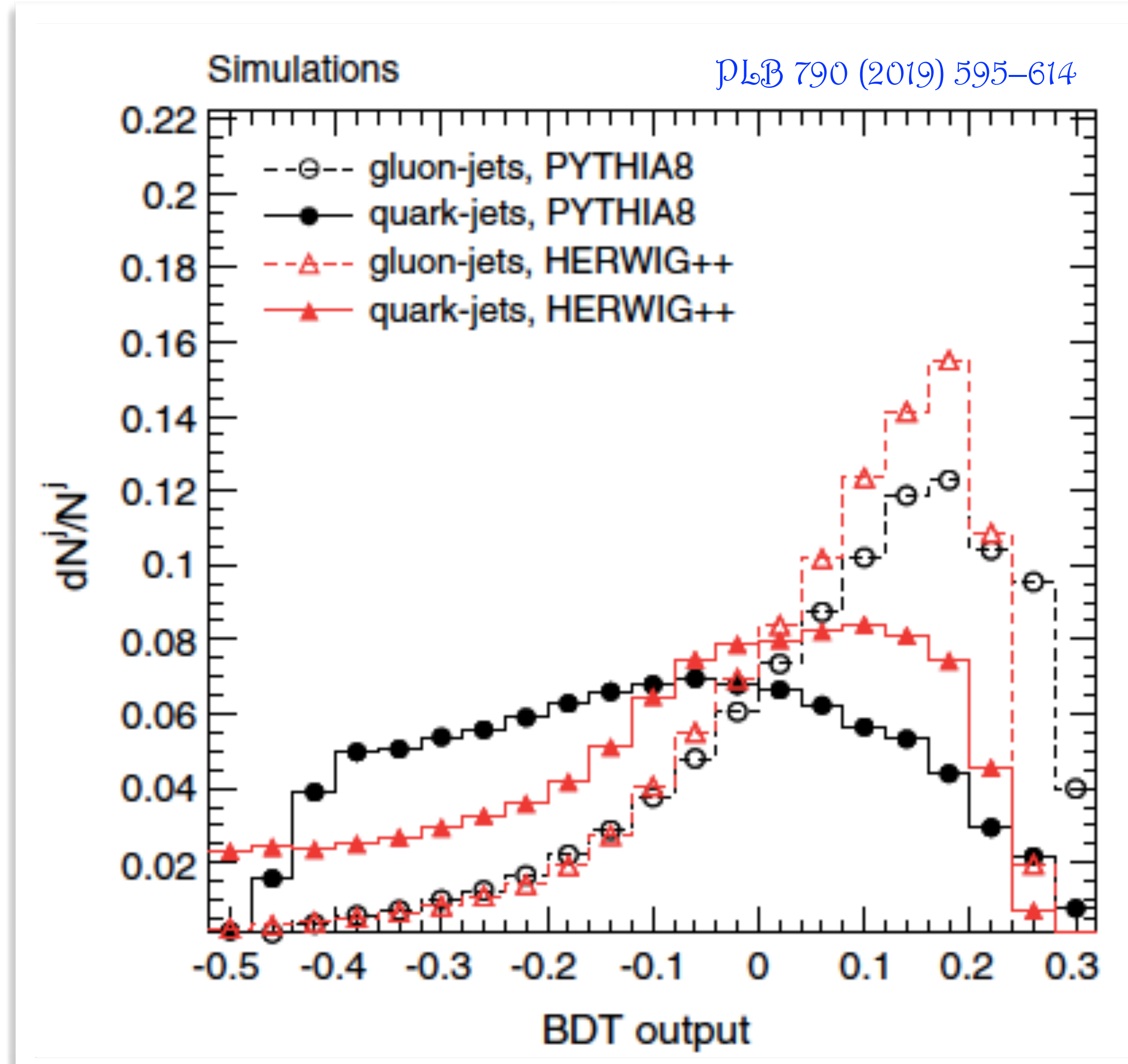
- The jets are considered to be gluon-initiated if two selected jets satisfy the conditions, optimised by maximising the figure of merit:

Observable	Condition
σ_1^{jet}	>0.04
σ_2^{jet}	>0.02
N_p^{jet}	>12.0
$p_{\text{T}}^{\text{jet}}D$	<0.49

- This selection criteria selects ≈82% of gluon-initiated jets with 54% rejection of quark-initiated jets.
- When both of the jets are required to be gluon initiated, DPS fraction reaches up to 10.6% with a gain of **41**%.

MVA Approach

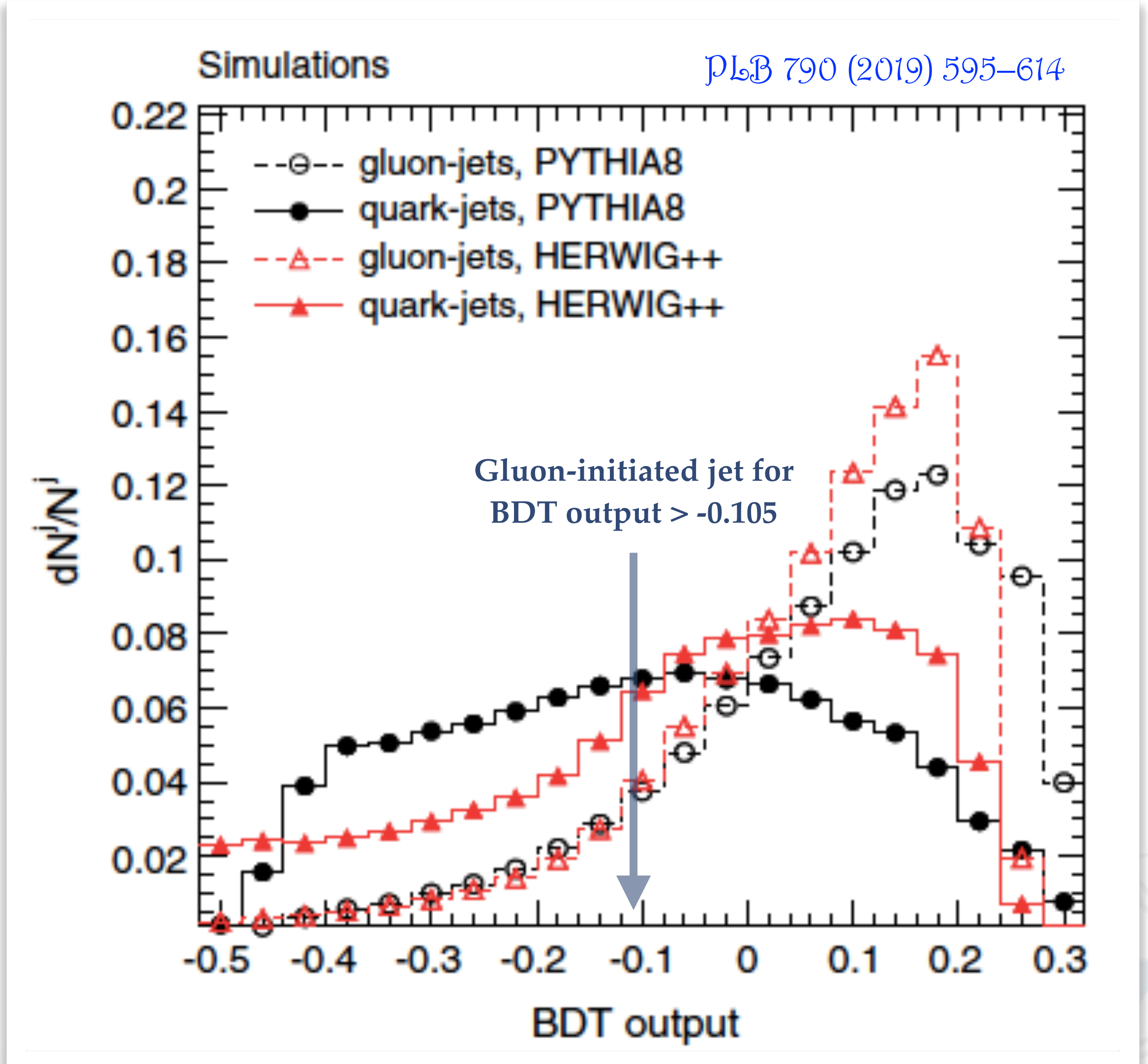
- To enhance the sensitivity and consider possible correlations b/w the observables, multivariate analysis (BDT) is performed
- **Input to BDT:**
  - Four discriminating observables along with pT and η of jets.
- A clear distinction is observed between two types of jets from BDT output.



MVA Approach

- The selected jets are tagged as gluon-initiated jets with requirement of BDT value greater than −0.105, otherwise considered as initiated by quarks.
- This criteria selects ≈90% of gluon-initiated jets with 50% rejection of quark-initiated jets.
- DPS fraction in Z + 2-jets sample is now about 11.3% which is 20% larger as compared to the cut-based analysis.

A gain of ~50%, if no jet fragmentation properties are used



- The presented results are using the Z+jets events produced with MADGRAPH + PYTHIA8
- The dijet events generated using PYTHIA8 are used for BDT training

Results using HERWIG++

- Different hadronization models can also affect the discrimination based on fragmentation properties of a jet (tested with dijet events produced with HERWIG++ for BDT training)
- This difference in hadronization properties results in reduction of DPS fraction to 10.7%, but still there is a gain of 43% as compared to selection when fragmentation properties of the jets were not used

Generator for use of BDT Training	Gain in DPS Fraction
PYTHIA8	50%
HERWIG++	**43%**

Results using POWHEG

- Using events generated with POWHEG, hadronized and parton showered using PYTHIA8:
  - **A gain of 36% in the DPS fraction is observed**

Generator	Gain in DPS Fraction
MADGRAPH + PYTHIA8	50%
POWHEG + PYTHIA8	**36%**

- The difference in the SPS rejection for two generators is expected due to the differences in treatment of the LO and NLO effects which also change relative fraction of quark- and gluon-initiated jets

Results after constraining Z-boost

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

Case	DPS fraction (No use of fragmentation properties)	DPS fraction (with use of fragmentation properties)
No constraint on Z-boost	7.5%	11.3%
With an upper cut of 10 GeV on Z-boost	**32%**	**42%**

- With an upper constraint on Z-boost, most of remaining jets are produced by ISR/FSR, which leads to reduction in the gain.

Optimization of QG-discriminator

- The quark-gluon discriminator is required to be optimized according to the measurements in actual experimental conditions
- For example, use of additional infrared and collinear (IRC) safe observables (such as jet mass, jet shape and girth) lead to to a gain of 59% as compared to selection when fragmentation properties of the jets were not used
- Furthermore, the jets initiated by heavy quarks (in particular, b-quarks) show fragmentation properties similar to gluon-initiated jets
- These jets may be vetoed for effective separation between quark- and gluon-tagged jets by using available b-tagging algorithms

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 being explored 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 interesting to study in the actual experimental conditions

Thank you

kumardeepraman@gmail.com