Boosted objects@100TeV

(summary from 100TeV collider WS, May 2014, CERN)

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Boost 2014

University College London - August 21, 2014

Outline

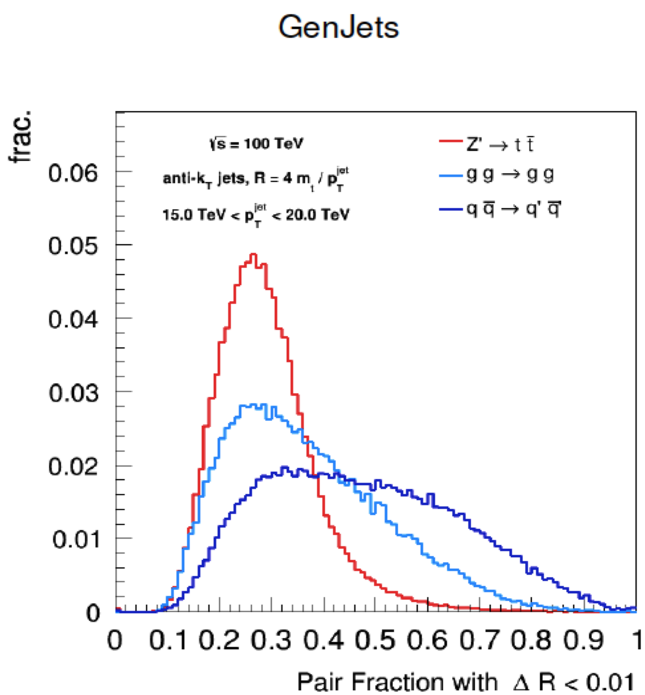
- Boosted objects at 100 TeV
- Boosted W/Z (H) – *M. Pierini*
- Boosted Tops - *A. Larskoski, F. Maltoni, MS*

100 TeV hadron collider

- Interest for a very high energy p-p collider is increasing
- Would potentially be able to look for undiscovered particles up to 40 TeV masses
- These heavy resonances will decay to highly boosted top quarks, W/Z bosons, H ...
- Several techniques for identifying jet sub-structure exist, and are widely used in ATLAS and CMS

Do currently used techniques work at the Terascale?
Can we think of some observables that can help?
Can we set constraints on future detectors?

Boosted jets



- cone size R ~ 1 / boost
- min. distance to resolve two partons:

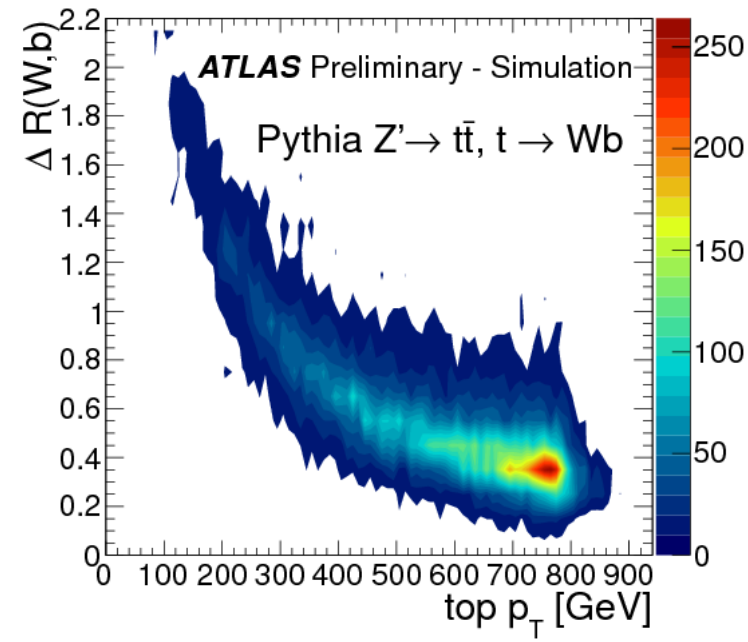
$$\Delta R \approx 2\, m / p_T$$

ex for top:

p_T = 200 GeV → R ~ 2

p_T = 1 TeV → R ~ 0.4

p_T = 10 TeV → R ~ 0.05



Detector considerations

Jet substructure success (e.g N-subjettiness) relies on:

- **good angular resolution**
- good energy/momentum resolution

.

ex for CMS:

Tracking	→	$\Delta R \sim 0.002$	$\Delta p/p \sim$ 5-10%	@1TeV
ECAL	→	$\Delta R \sim 0.02$	$\Delta E/E \sim 1\%$	@1TeV
HCAL	→	$\Delta R \sim 0.1$	$\Delta E/E \sim 5\%$	@1TeV

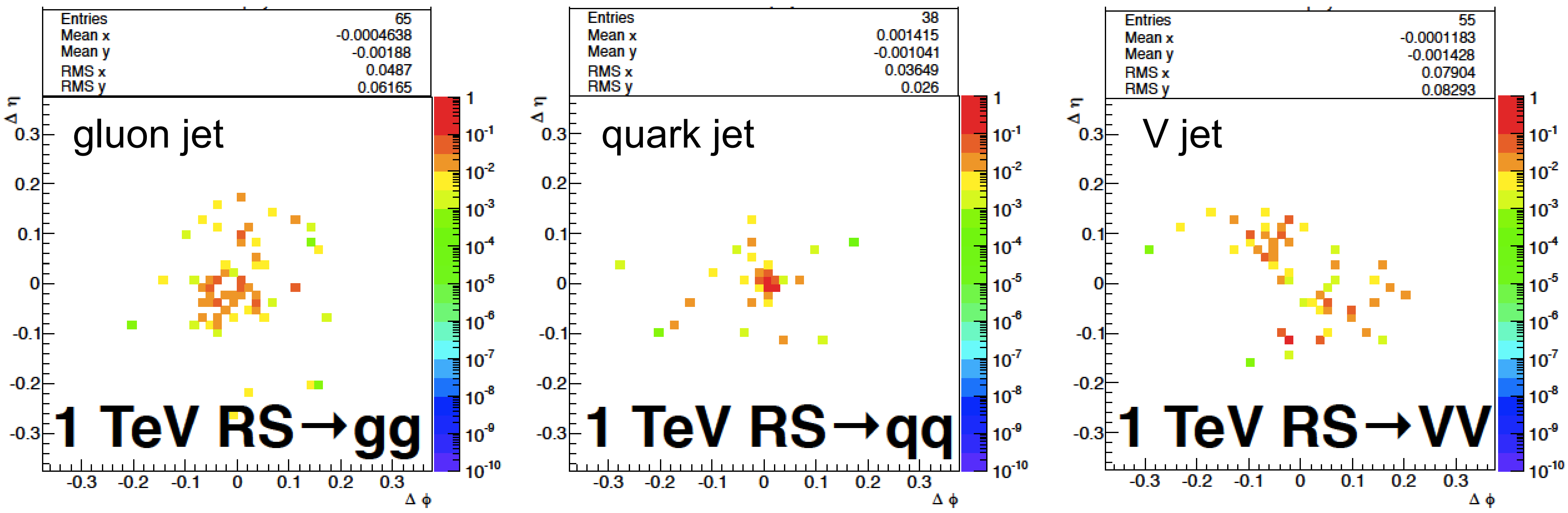
Charged Tracks will play a major role jet structure ID in highly boosted regimes

Hyper-boosted Heavy Bosons

(Maurizio Pierini)

M. Pierini

Jet Shapes



- **moderate** boost: pT ~ 0.5 TeV , DR(jj) ~ 0.35
- similar Picture for quark and gluons (gluons radiate more)
- Jet dipole structure in V-jet is visible

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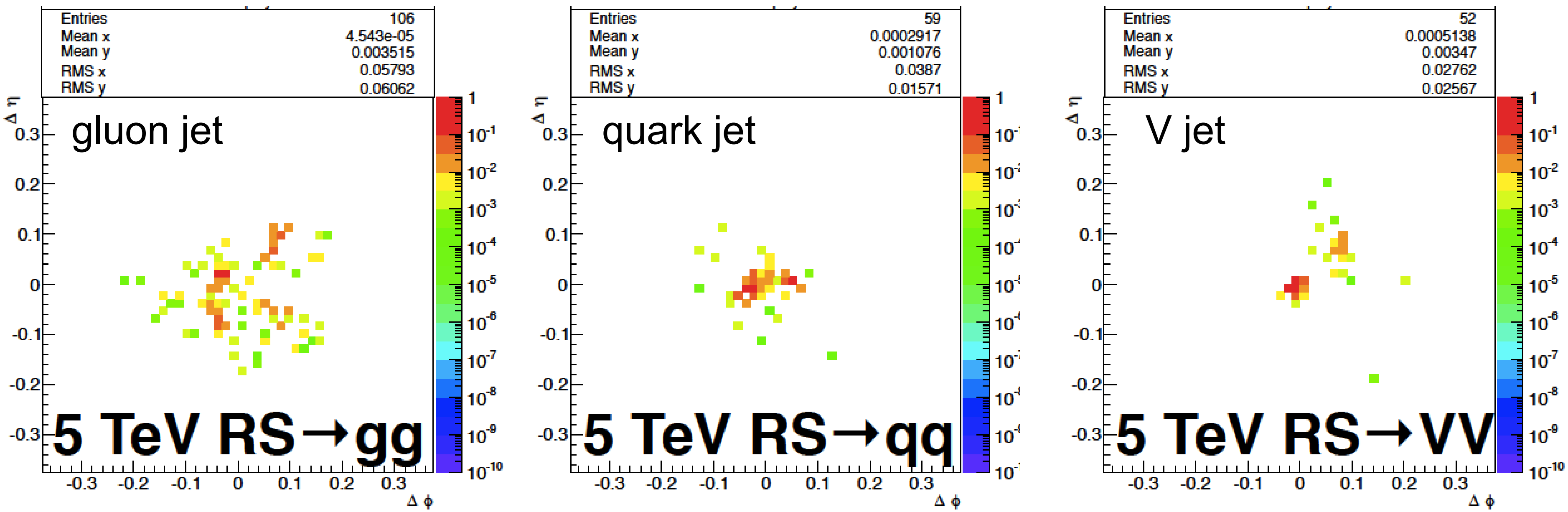
Jet Shapes



- **large** boost: pT ~ 2.5 TeV , DR(jj) ~ 0.07
- similar picture for quark and gluons (gluons radiate more)
- Jet dipole structure in V-jet is more visible, less overall radiation, subjets more collimated

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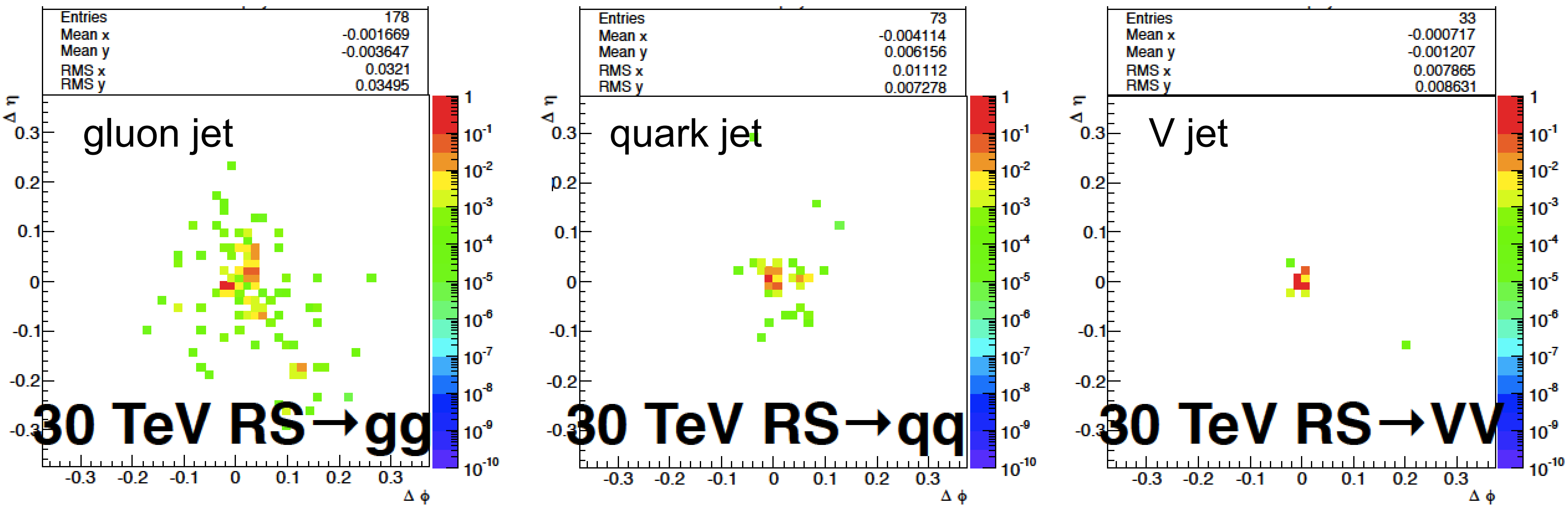
Jet Shapes



- **very large** boost: pT ~ 15 TeV , DR(jj) ~ 0.01
- two subjets merge into one **extremely collimated jet**
- jet dipole structure is lost, but the energy flow distribution in V vs. q/g is different

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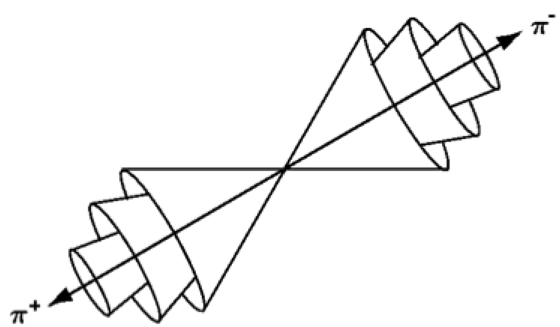
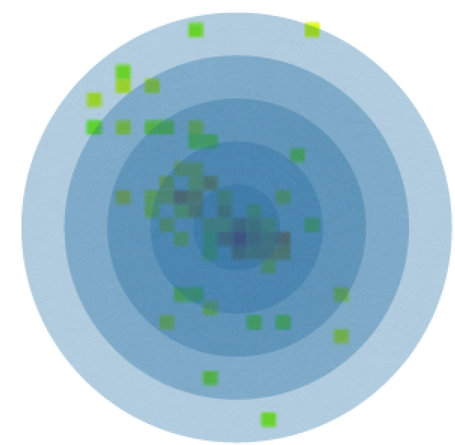
Strategy

- V boson is color neutral, does not radiate (QCD-wise)
- Discrimination based on the jet p_T spread



$$p_T^i(flow) = \frac{\sum\limits_{p \epsilon C_i} p_T^p}{p_T^{jet}}$$



- For highly boosted V's , external crowns contain small momentum flow, while the internal ones contain almost all the energy

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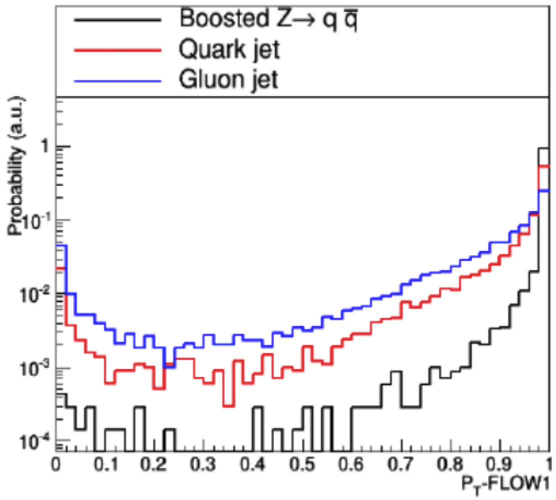
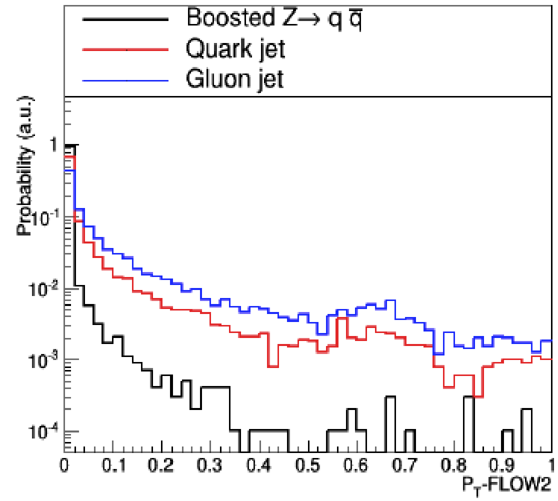
pT-flow distributions



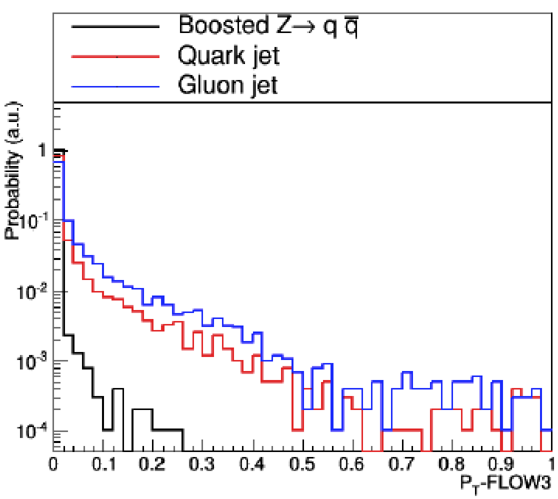


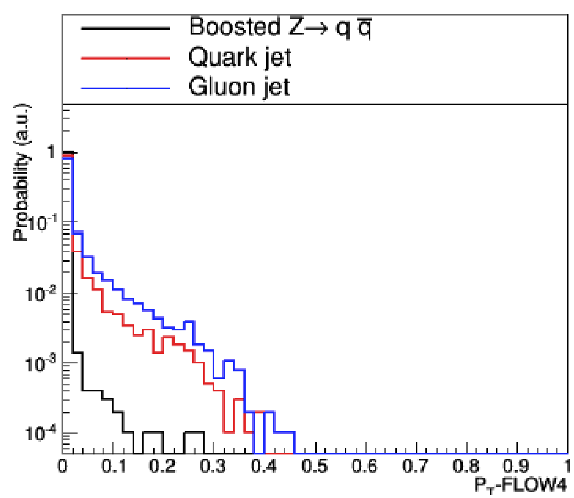
30 TeV G → Z Z

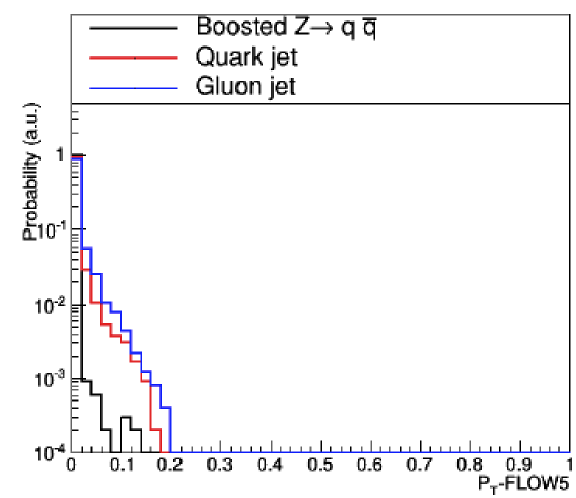
Anti kT GenJets

Jet Cone size R = 0.25

5 crowns







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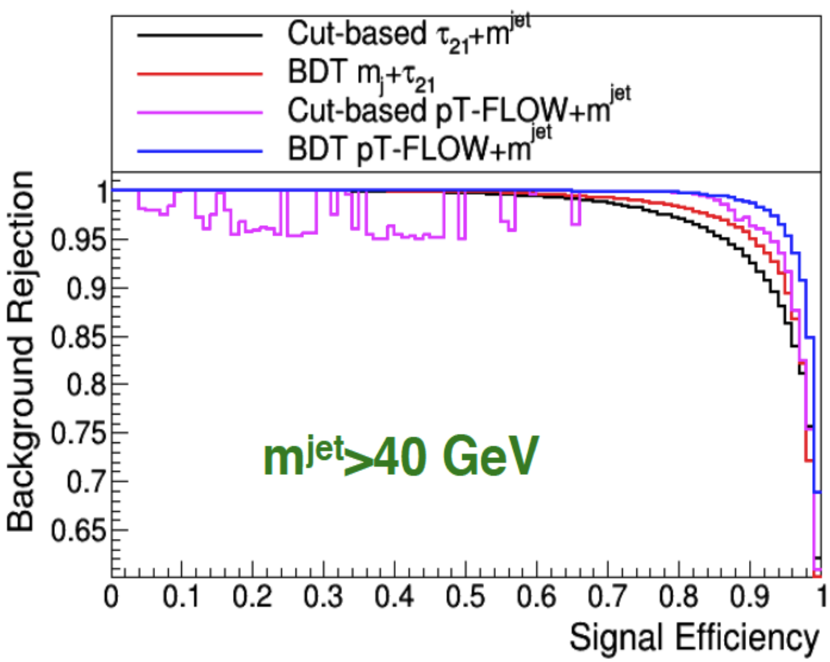
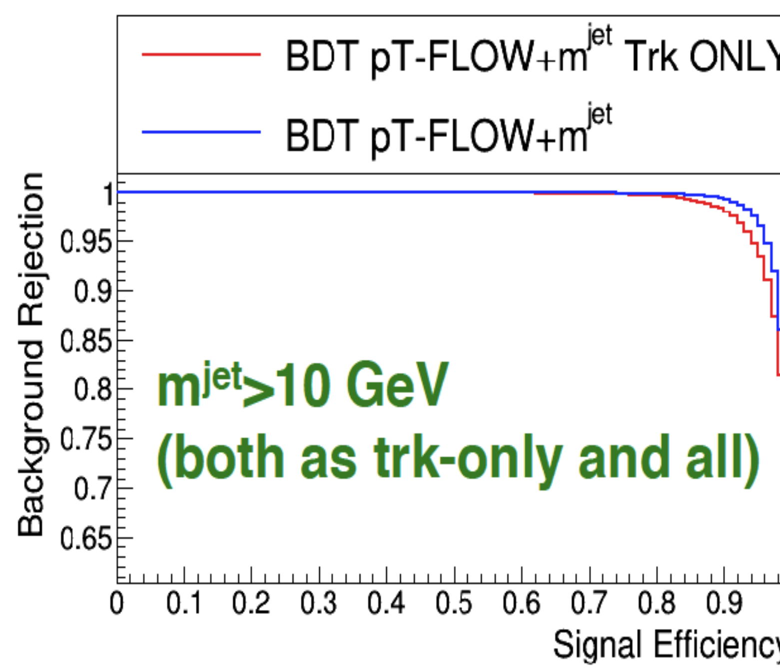
MVA-based tagger

- Five variables as input to MVA
- Background is a 50% mix of qq/gg





→ Best discrimination is obtained with **pT-FLOW**

→ Using **tracks only** provides good discrimination

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General Remarks

- pure gen. level jets and hadronic decay were considered here.
- simple but effective approach:

  → V bosons do not radiate
  → "dipole" structure for W/Z decays is lost at high boost/poor angular resolution, result is highly collimated jets

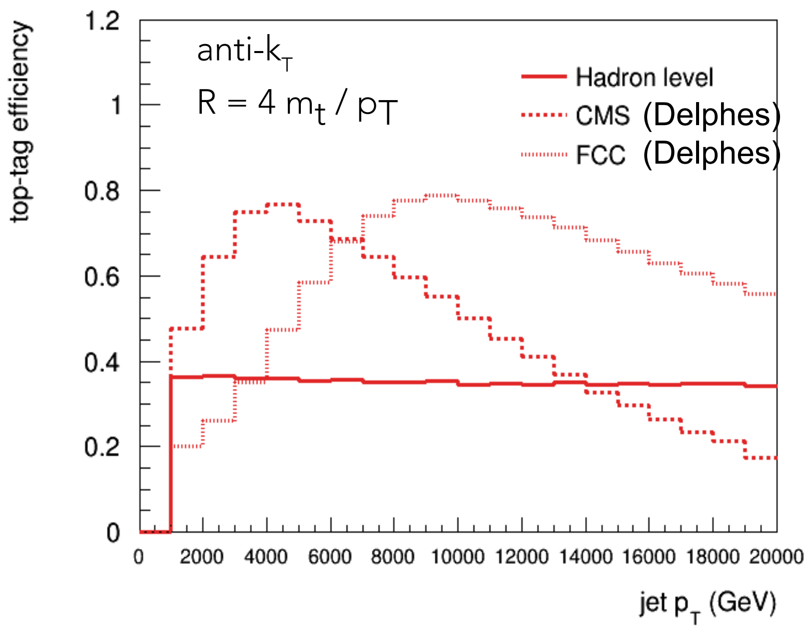
- PT-Flow observable can be used to disentangle different radiation pattern in QCD vs. Color neutral

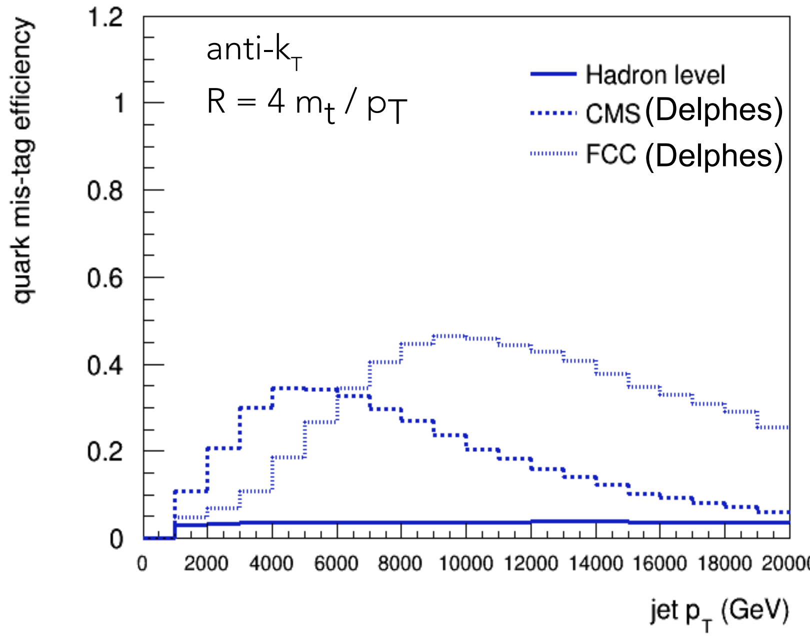
- Preliminary MVA tagger has been developped

Hyper-boosted Tops

(A. Larkoski, F. Maltoni, M. Selvaggi)

HepTopTagger at high p_T





- at moderate p_T efficiency and mistag rate increase
  $\longrightarrow$ fake hard prongs due to cell merging
- at very high p_T, calo cell merging results in inefficiencies

Approach

- Neutral hadrons will be measured poorly in such a dense environment
- Most methods will suffer a decrease in performance at high p_T

  → increased QCD radiation can spoil their effectiveness (tops radiate!)

  → angular separation provided by calorimeters is limited

- Use *shrinking jet radius*
- Make maximal use of measured information on *charged particles* (for better angular resolution, more robust against pile-up)

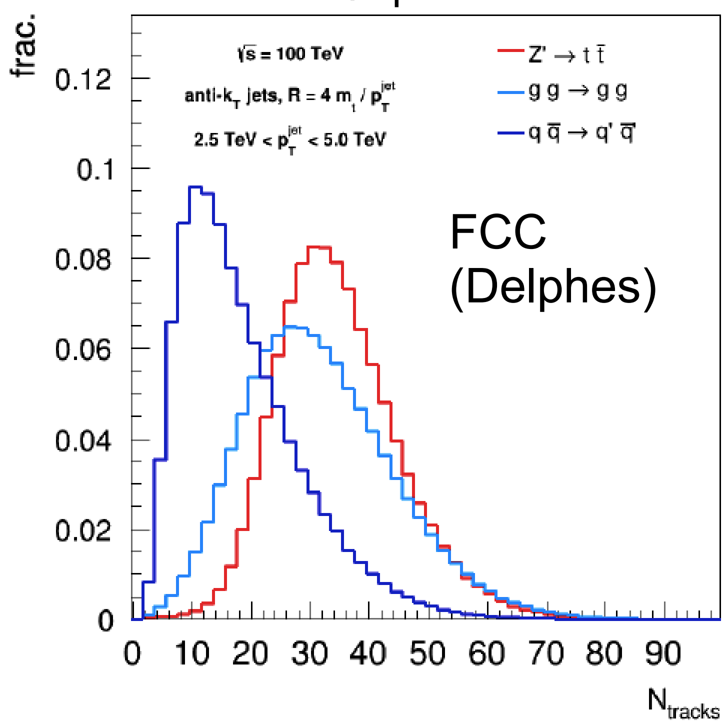
- Look at observables built on tracking (or Particle-Flow) information that can help discriminating between top and background jets

Setup

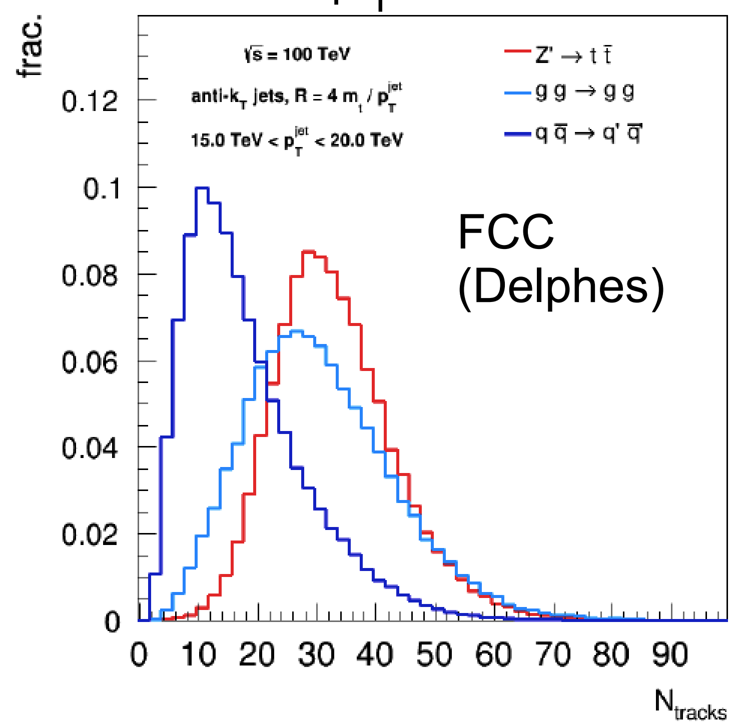
- Samples @100TeV (MadGraph5+Pythia6)
  - $p\,p \to Z' \to t\,t$ (signal)
  - $q\,q \to q\,q$ (bkg)
  - $g\,g \to g\,g$ (bkg)
- looking at hadronic W decays only
- jets clustered with anti-k_T algorithm with shrinking cone $R = 4\,m_t / p_T$
- Scenarios: gen level / CMS / FCC (Delphes3)
- Review of some simple observables that can help in discriminating QCD vs. Top jets at high boosts

Charged Multiplicity

$2.5 < p_T < 5$ TeV



$15 < p_T < 20$ TeV

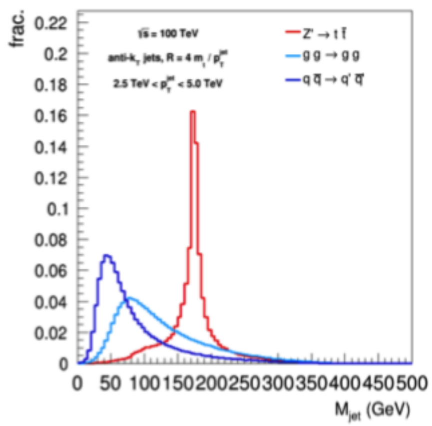


- provides good discrimination vs. quarks
- mostly stable vs. p_T (due to soft radiation removal via shrinking cone)

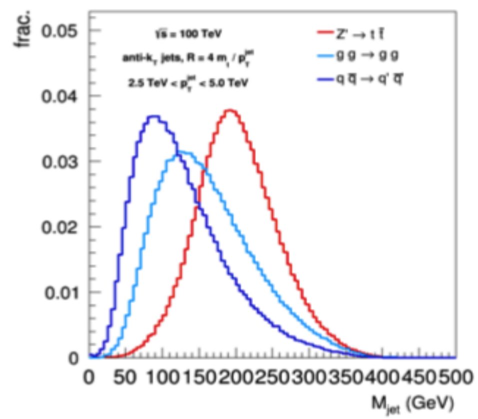
Needs validation via full simulation

Jet Mass (I)

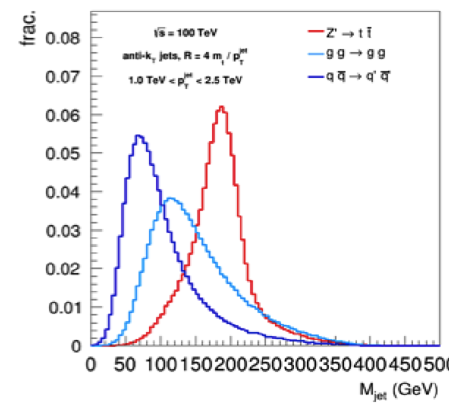
GenJets



CaloJets (CMS)



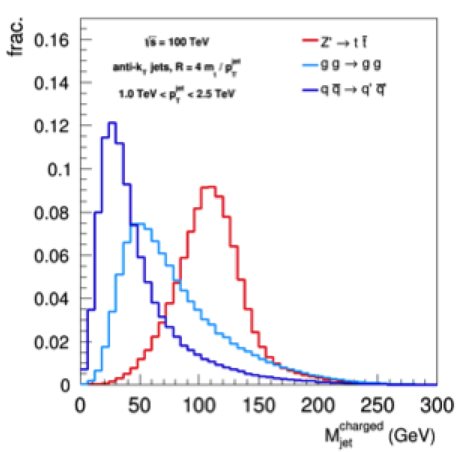
CaloJets (FCC)



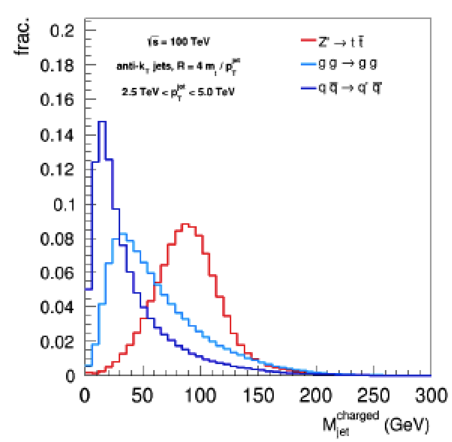
full mass
calo-based

$2.5 < p_T < 5$ TeV

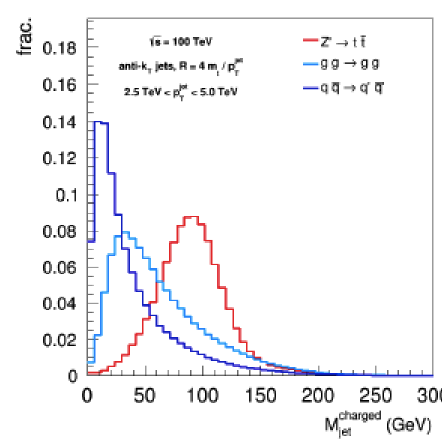
GenJets



PFJets (CMS)

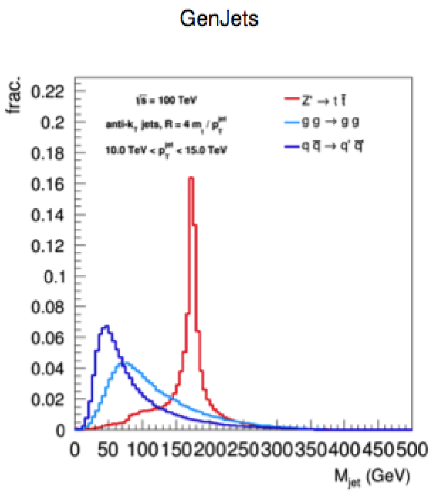


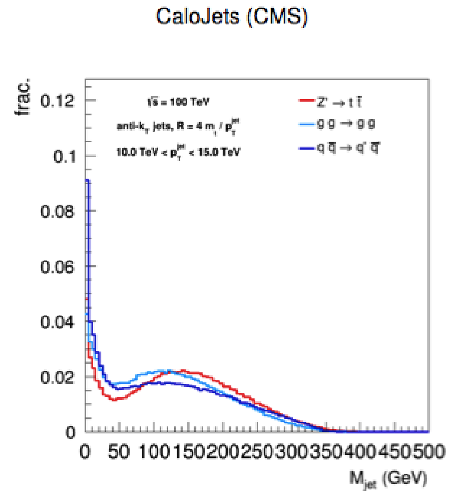
PFJets (FCC)

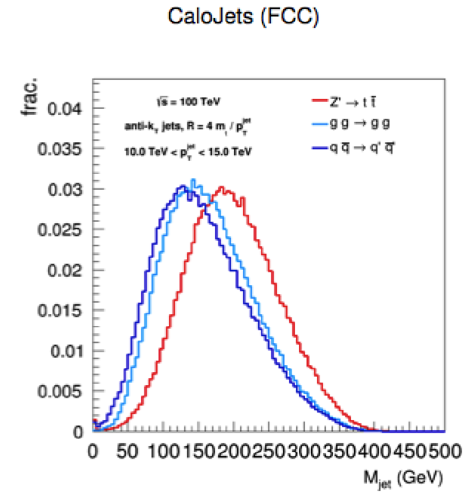


charged mass
trk-based

Jet Mass (II)

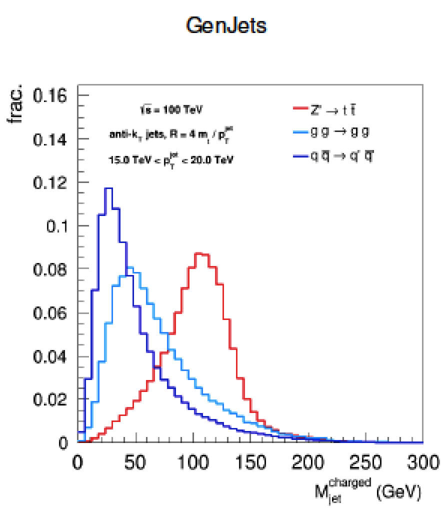


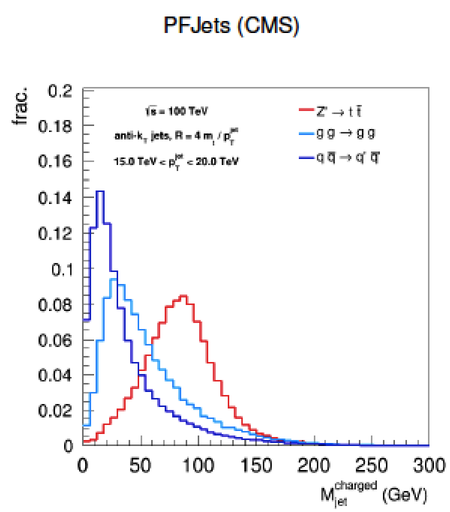


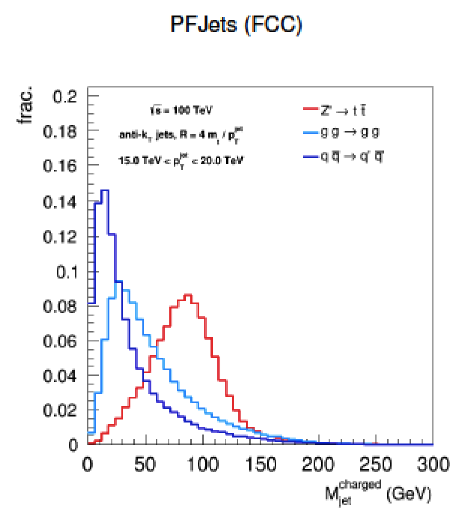


full mass
calo-based

10 < p_T < 15 TeV

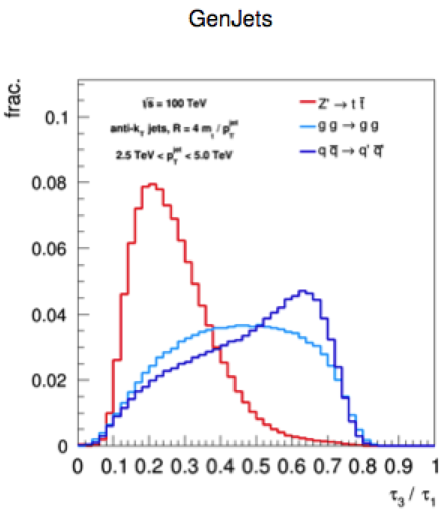


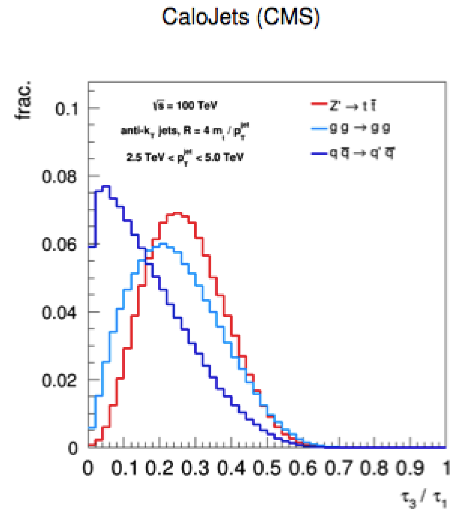


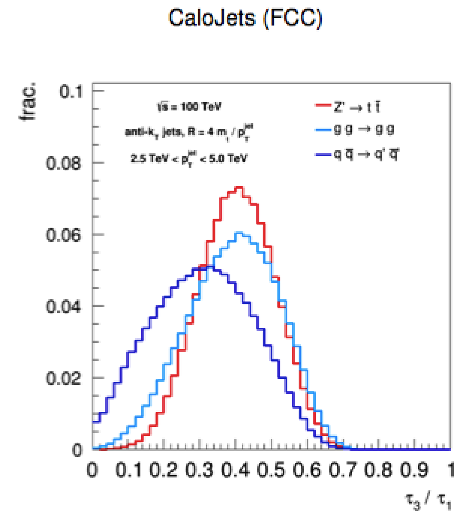


charged mass
trk-based

N-subjettiness ratio (I)



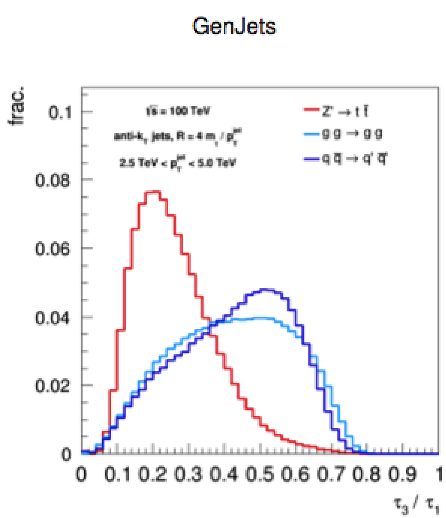


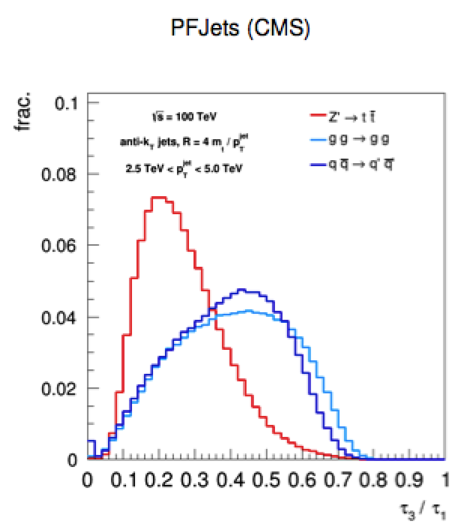


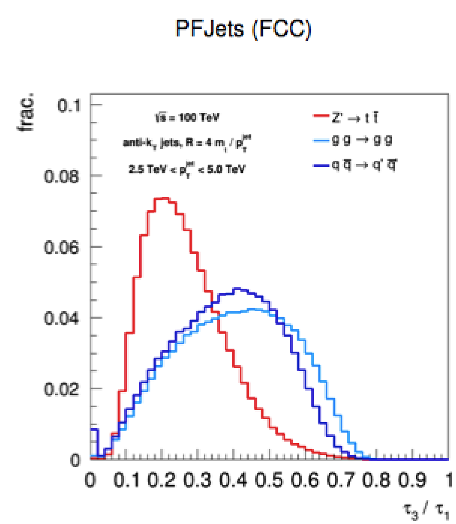
full τ_3/τ_1

calo-based

$2.5 < p_T < 5$ TeV



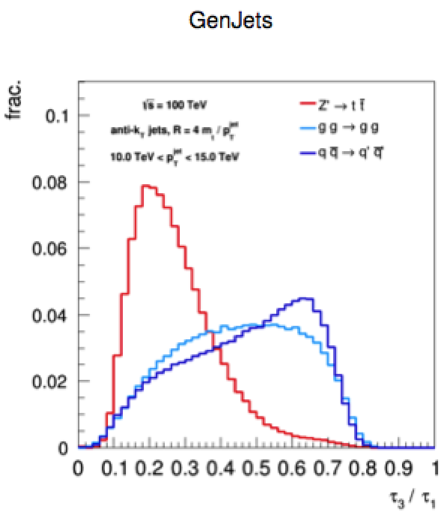


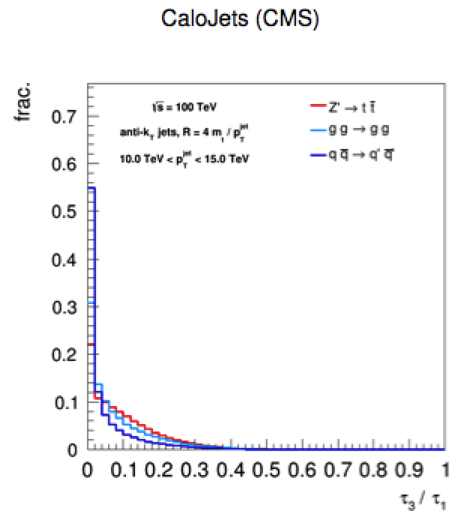


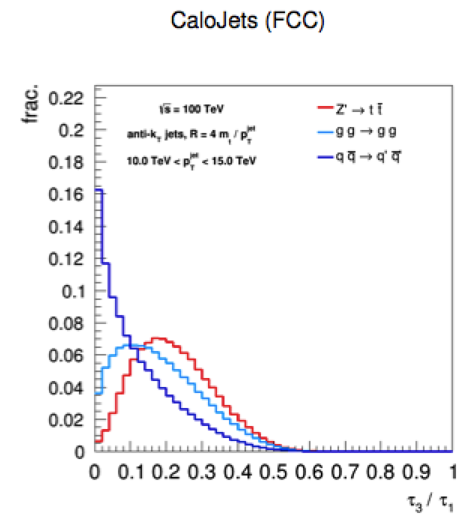
charged τ_3/τ_1

trk-based

N-subjettiness ratio (II)



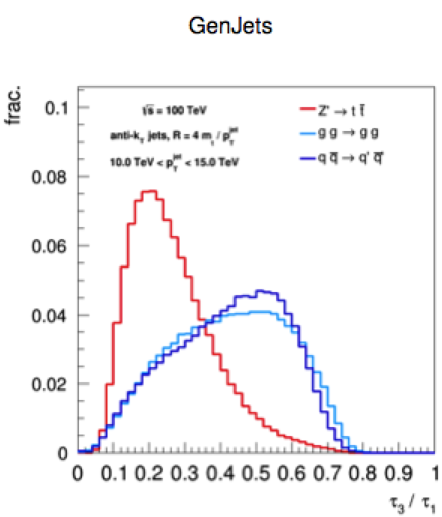


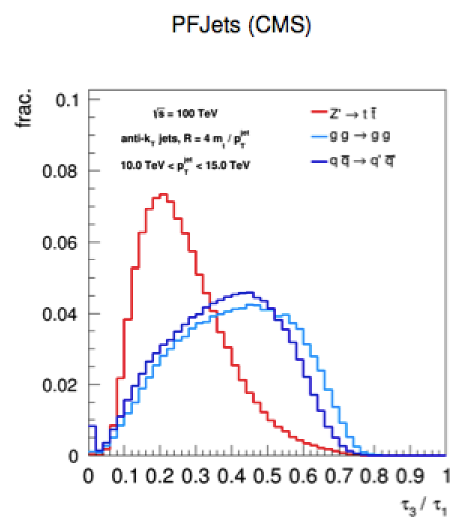


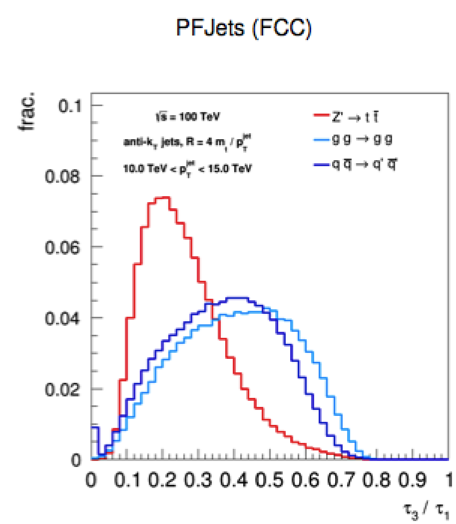
full τ_3/τ_1

calo-based

$10 < p_T < 15$ TeV







:harged τ_3/τ_1

rk-based

General Comments

- For very high boosts ($p_T > 5$ TeV), calorimeters granularity will simply not be able to resolve top decay substructure
- Tracking can achieve much better angular resolution, with good momentum resolution.
- Price to pay is sacrifice ~ 1/3 jet energy flow
- We have identified some simple track-based observables that can achieve good discrimination vs. QCD backgrounds:
  → charged jet multiplicity
  → charged jet mass
  → N-subjettiness built from charged jet components/ and ratios
- Included simple effects of detector simulation (but miss others, such as potential efficiency and resolution drop at high occupancy regimes, pileup) → full detector sim. needed

Summary/outlook

- We have shown some simple observables that can help in discriminating highly boosted heavy jets from QCD
- Everything proposed here will have to pass the test of full detector simulation, but things look good
- Need strong interplay between detector design and method building.
- Other existing techniques have to be explored and new ideas are needed

Backup

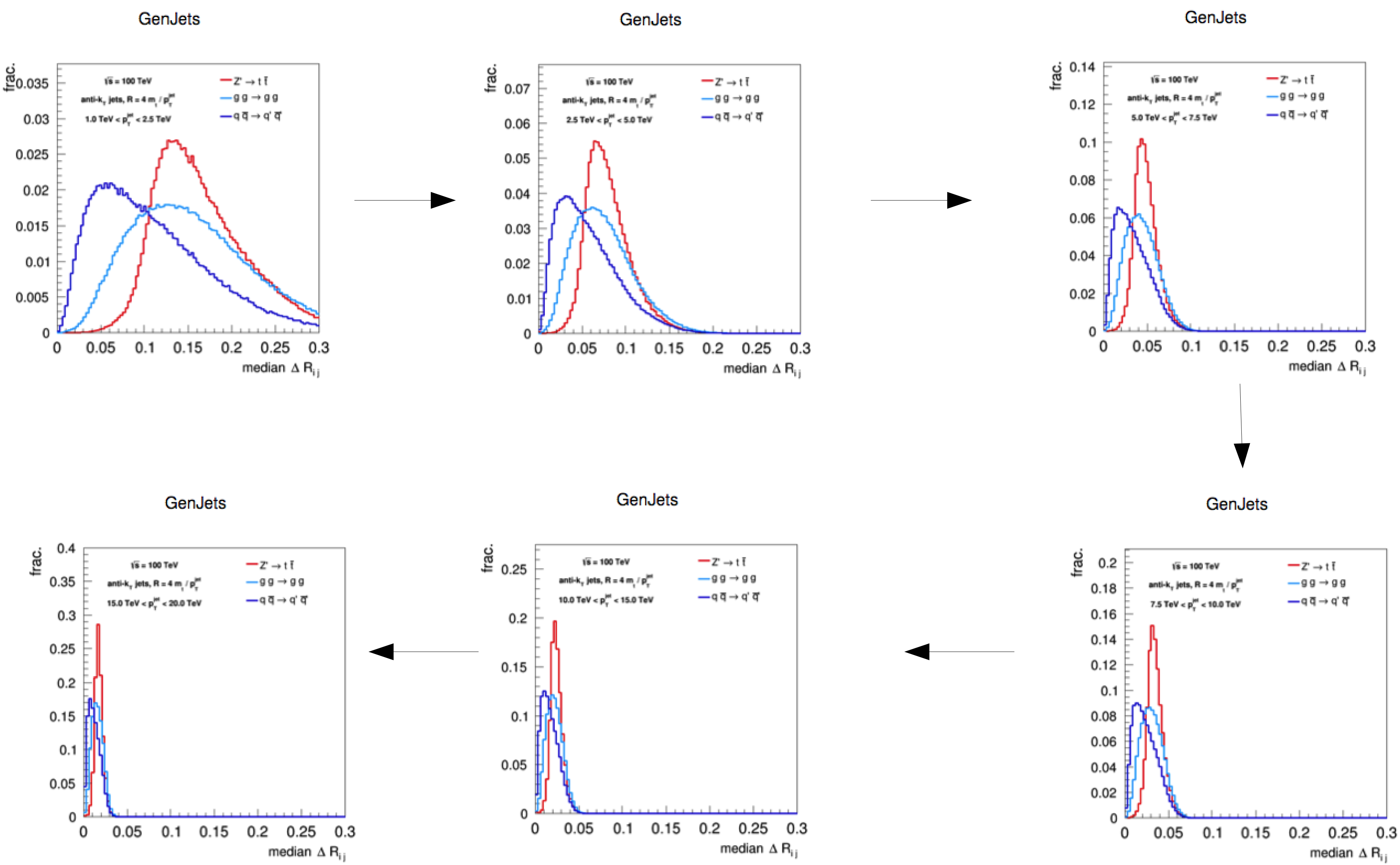
Detector simulation

- CMS
  - $\eta x \phi$ resolution :
    - tracks $\approx 2 \cdot 10^{-3}$
    - ECAL ≈ 0.02
    - HCAL ≈ 0.1
  - p_T, E resolution :
    - tracks : $\sigma / p_T \approx 2 \cdot 10^{-4} p_T + 0.01$
    - ECAL $\sigma / E \approx 0.35/E + 0.07/\sqrt{(E)} + 0.007$
    - HCAL $\sigma / E \approx 1.5/\sqrt{(E)} + 0.05$
- FCC
  - $\eta x \phi$ resolution :
    - tracks $\approx 5 \cdot 10^{-4}$
    - ECAL ≈ 0.01
    - HCAL $\approx 0.05.$
  - p_T, E resolution :
    - tracks : $\sigma / p_T \approx 2 \cdot 10^{-5} p_T + 0.01$
    - ECAL $\sigma / E \approx 0.125/E + 0.03/\sqrt{(E)} + 0.003$
    - HCAL $\sigma / E \approx 0.5/\sqrt{(E)} + 0.013$

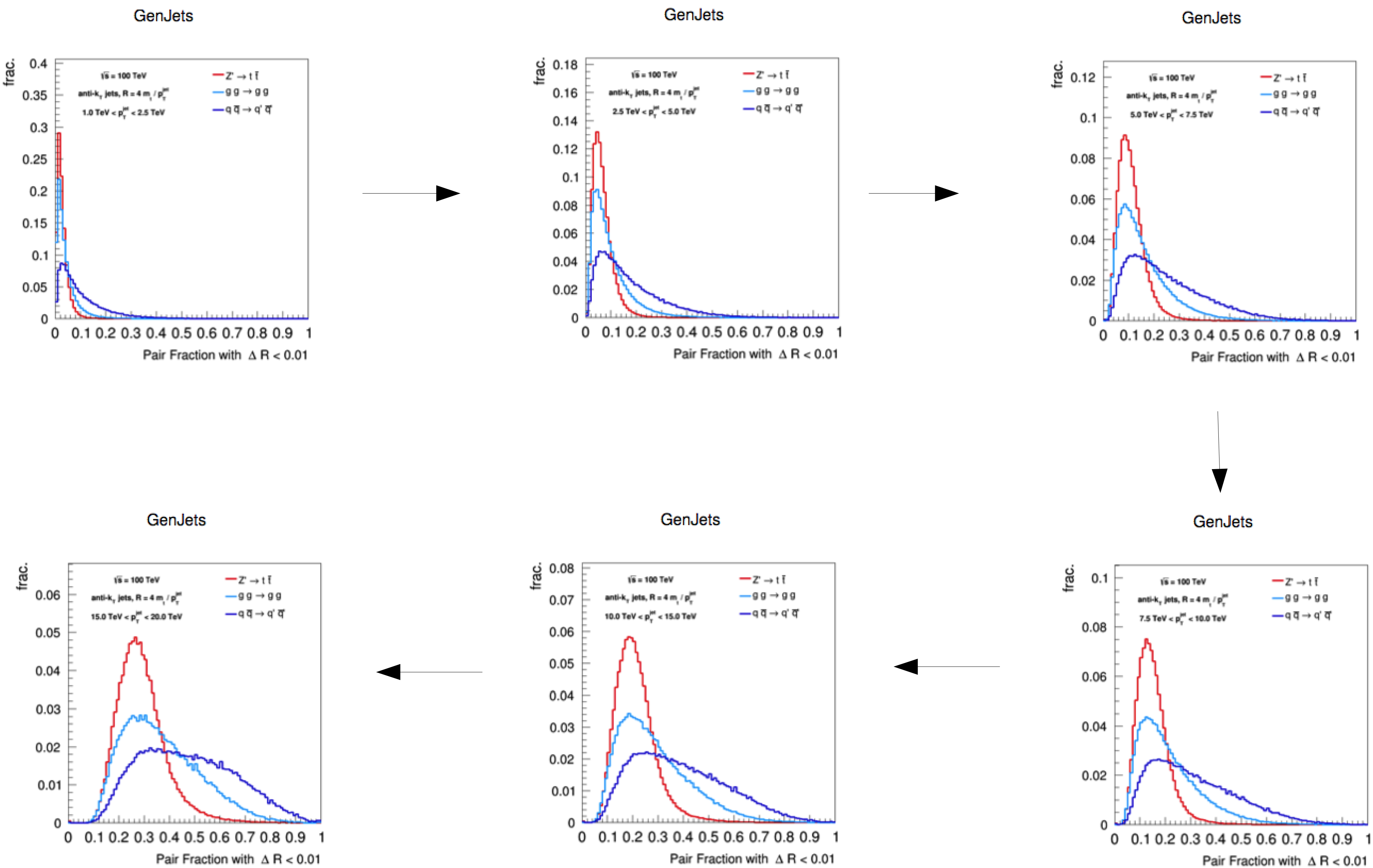
In addition assume some efficiency for reconstructing tracks in the core of the jet (flat in p_T):

eff = tanh(200*DR(track-jet))

Separation between const. (I)

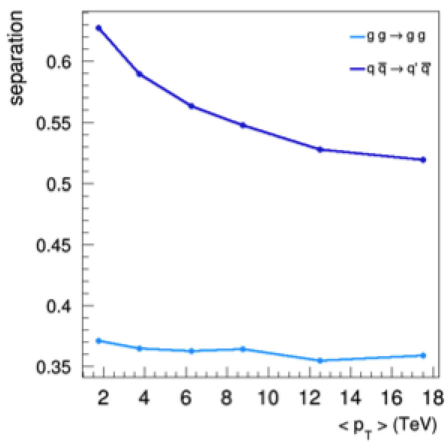


Separation between const. (II)

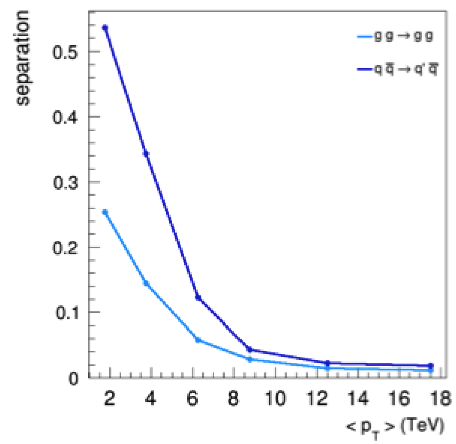


Separation: Mass

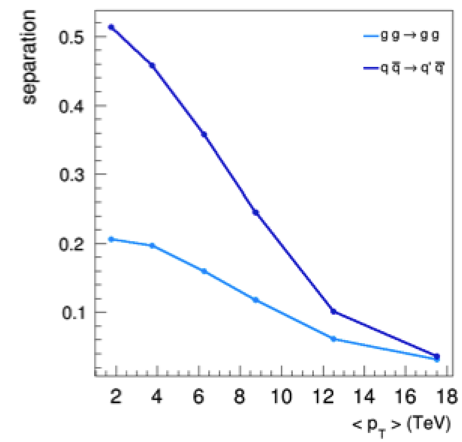
GenJets



CaloJets (CMS)

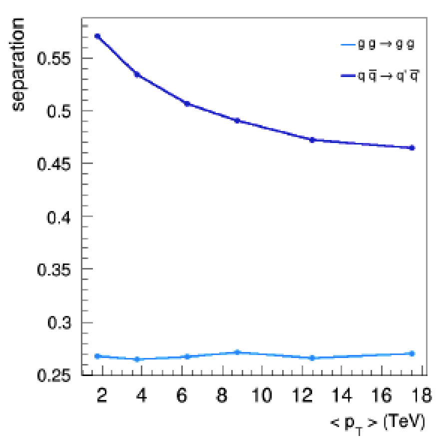


CaloJets (FCC)

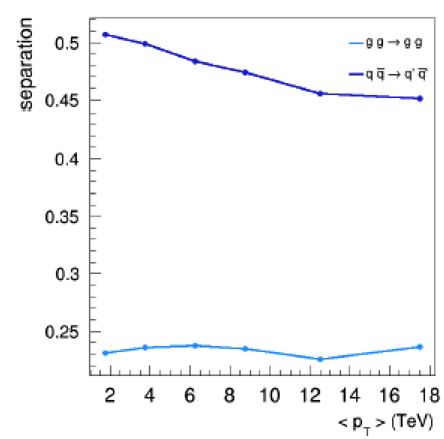


full mass
calo-based

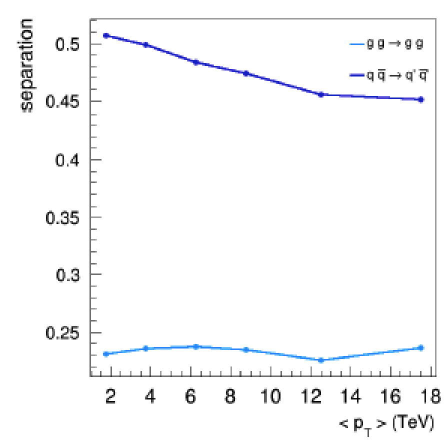
GenJets



PFJets (CMS)

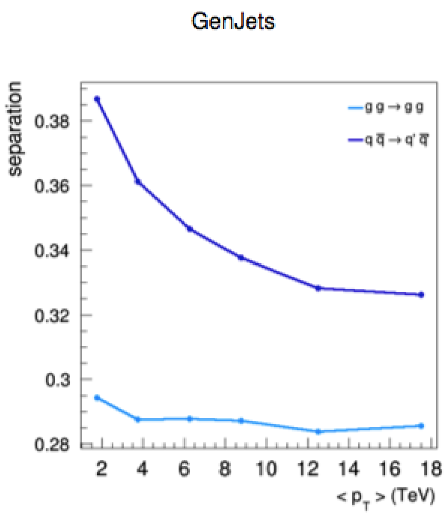


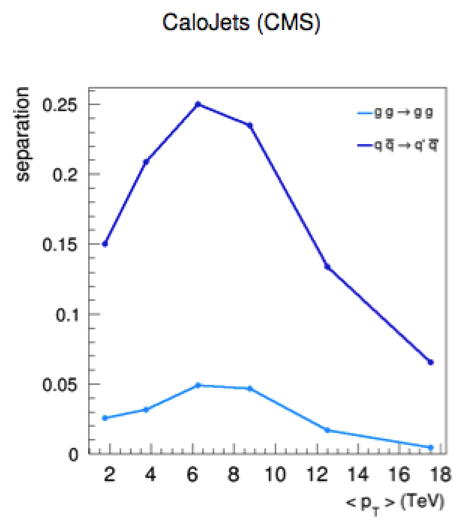
PFJets (FCC)

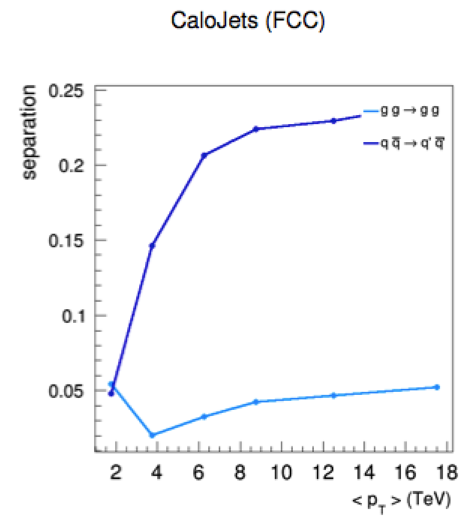


charged mass
trk-based

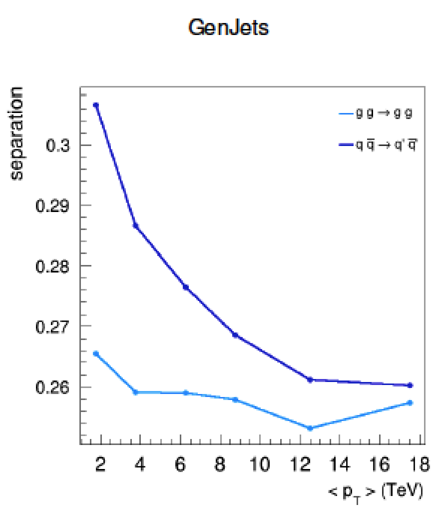
Separation: tau3/tau1

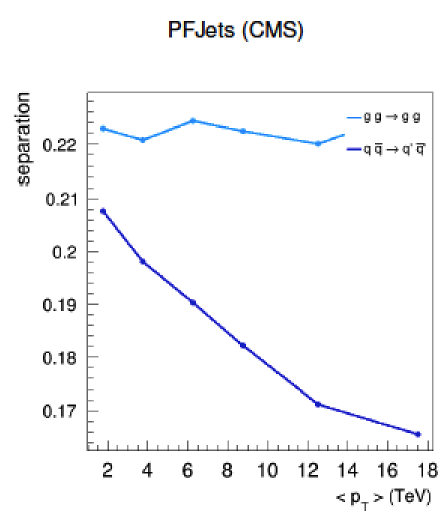


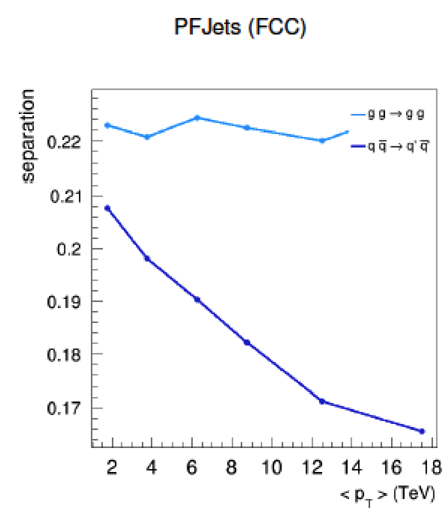




full τ_3/τ_1
calo-based







charged τ_3/τ_1
trk-based