Jet ID in CMS

Philip Harris (CERN)
CMS collaboration

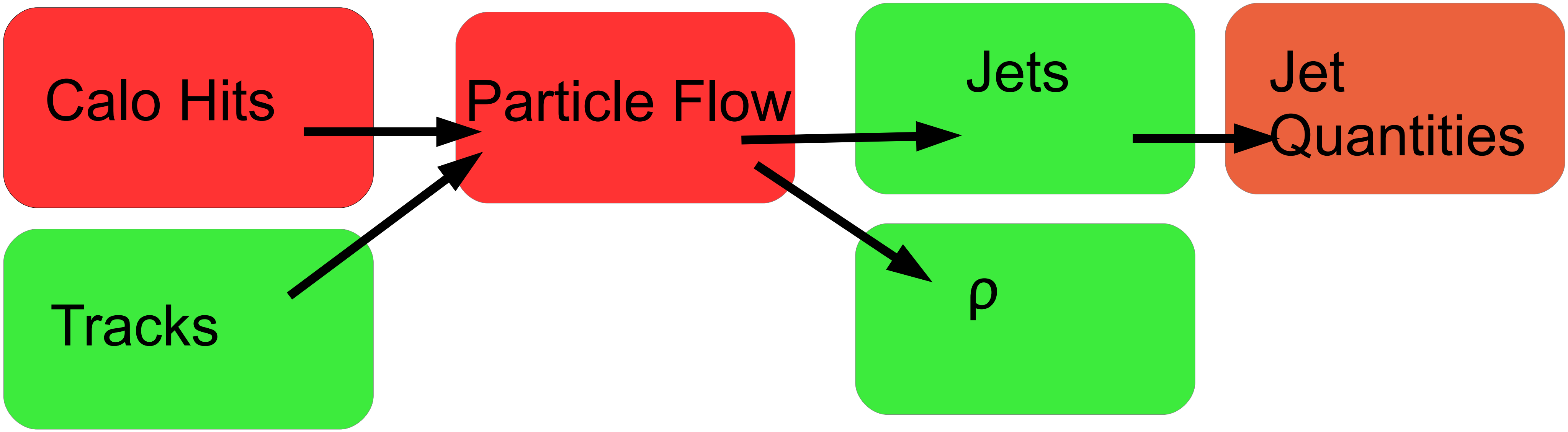
WAT is the Event?

- The event is composed of many jets
  - Correcting jets not necessarily correcting the event

Origins of PU Jet Id in CMS:
Approach to remove PU to the whole event

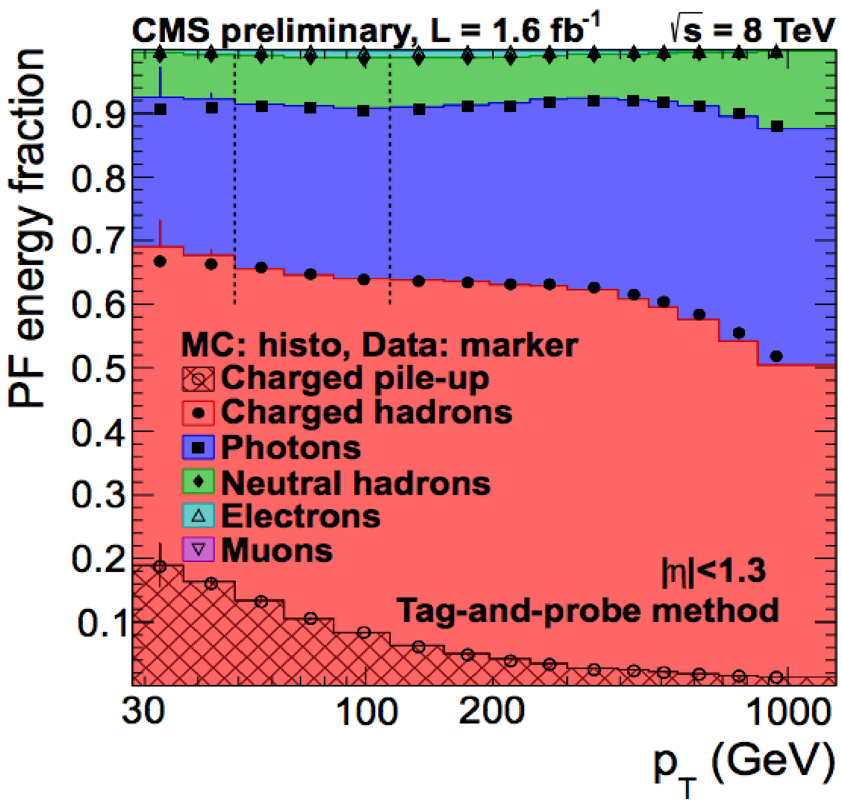
Both *MET* and Jets

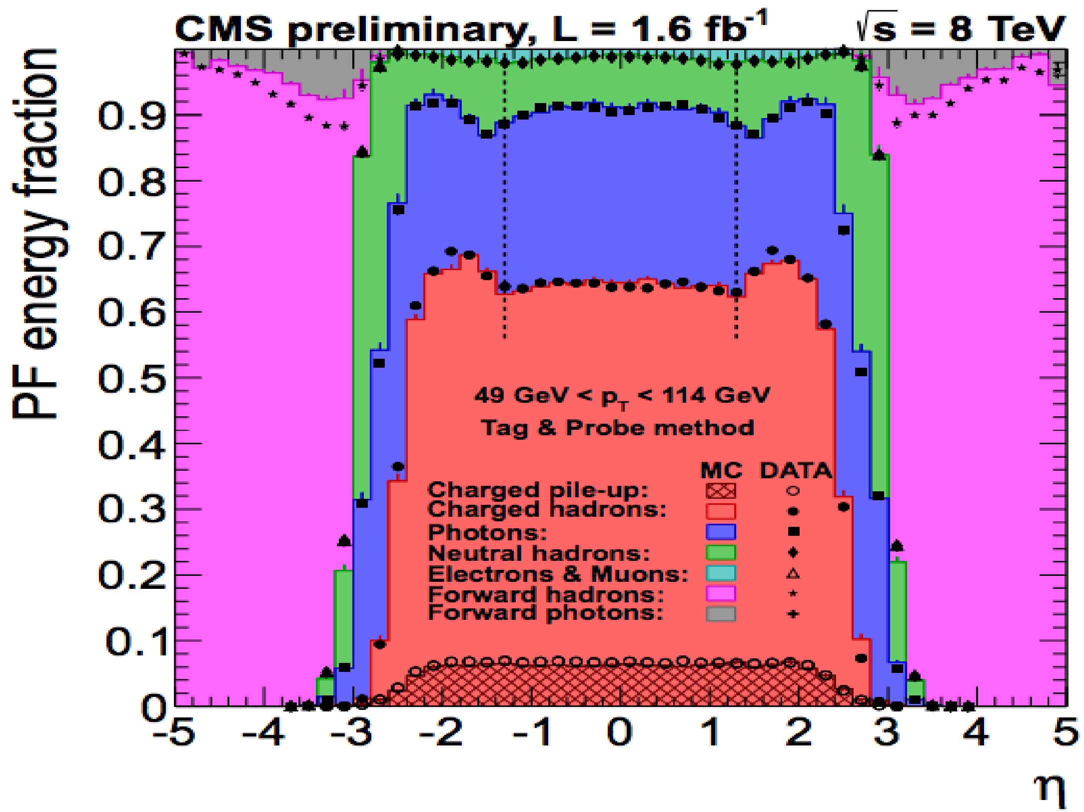
Stages of Jet ID



- At the lowest level perform basic noise cleaning
  - Each of the red boxes use noise cleaning
- Calo Hits : Basic cleaning
- PF : Cleaning on track quality + matching
- Jets : See next slide

Basic Jet ID : Cleaning Noise





Fraction	Loose	Medium	Tight
Neut. Had	< 0.99	< 0.95	<0.9
Neut. EM	< 0.99	< 0.95	<0.9
#constitsX	> 0	> 0	> 0
Chrgd. H	> 0	> 0	> 0
Neut. EM	< 0.99	< 0.95	0.9
#constitsX	> 0	> 0	> 0

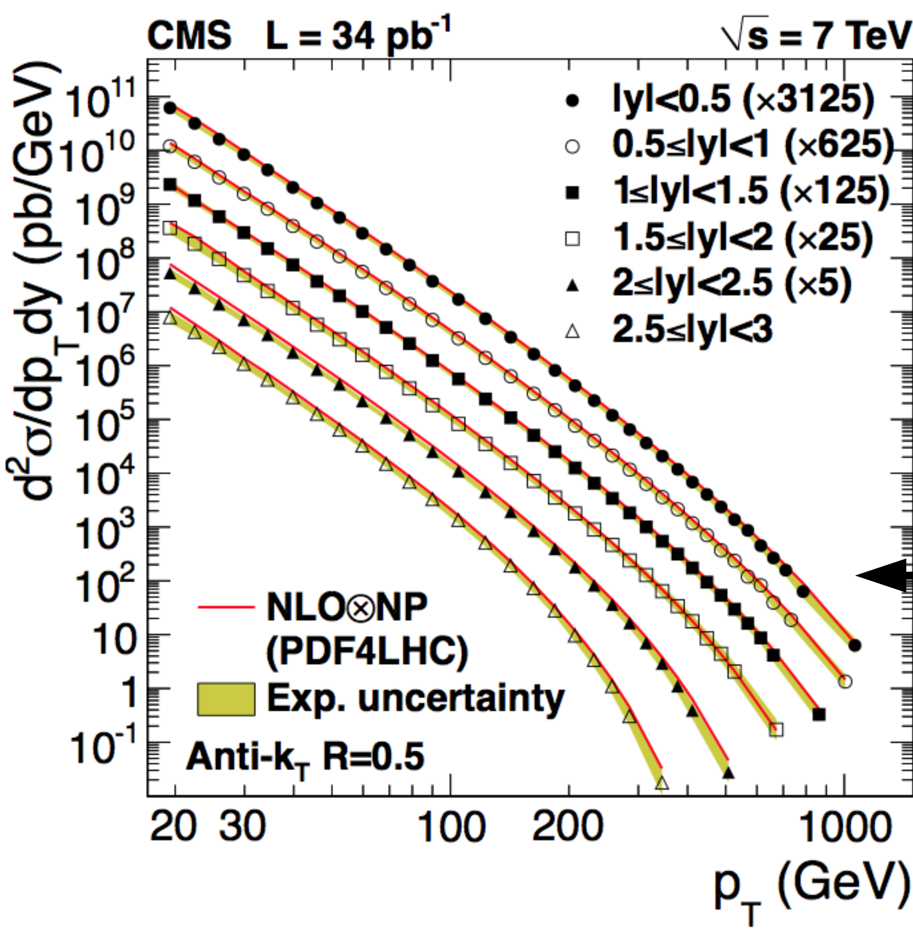
All Jets in CMS start with these cuts

Red : inside tracker

What is Pileup?

- Any object from another collision
  - Some resulting QCD from UE/jet production
  - Consider instance where objects are clustered

What is the rate of overlapping pileup?



Phys.Rev.Lett.107:132001,2011

Two jets w/Sum $pT = pT_1 + pT_2$

Consider a simplified model

$$P(\text{overlap}|pT) \approx N^2_{pu}\, a^2_{jet} \int A$$

$$\int A = \int d pT \frac{d\sigma_1}{dpT} \frac{d\sigma_2}{dpT} \delta(pT - pT_1 + pT_2)$$

$$\frac{d\sigma}{dpT} = pT^{-5} \text{ (NLO/measurement)}$$

$$\int A = C\, pT^{-6.2} \text{ (C a constant)}$$

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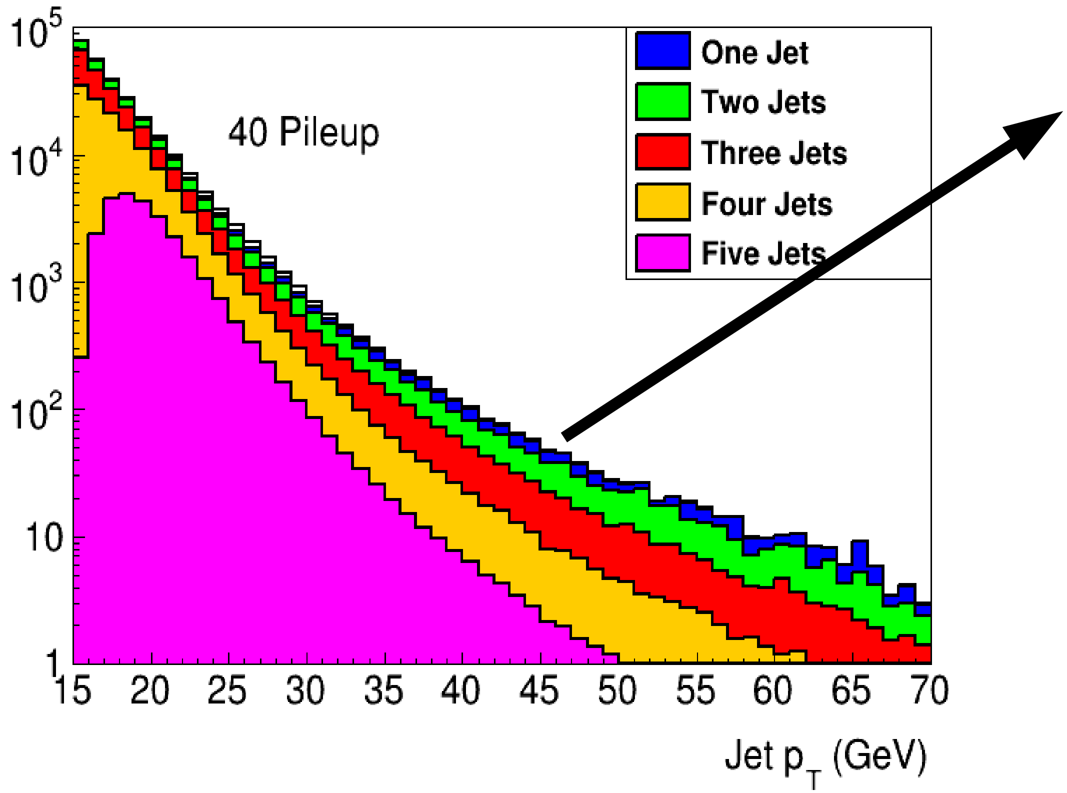


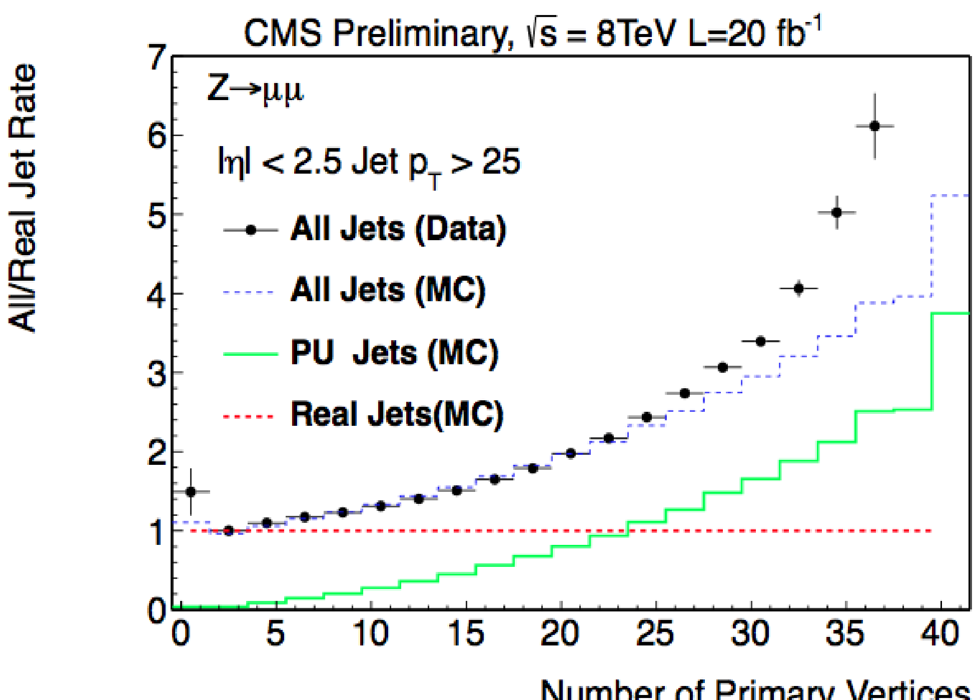
Contribution of overlapping jets To pileup jet spectrum

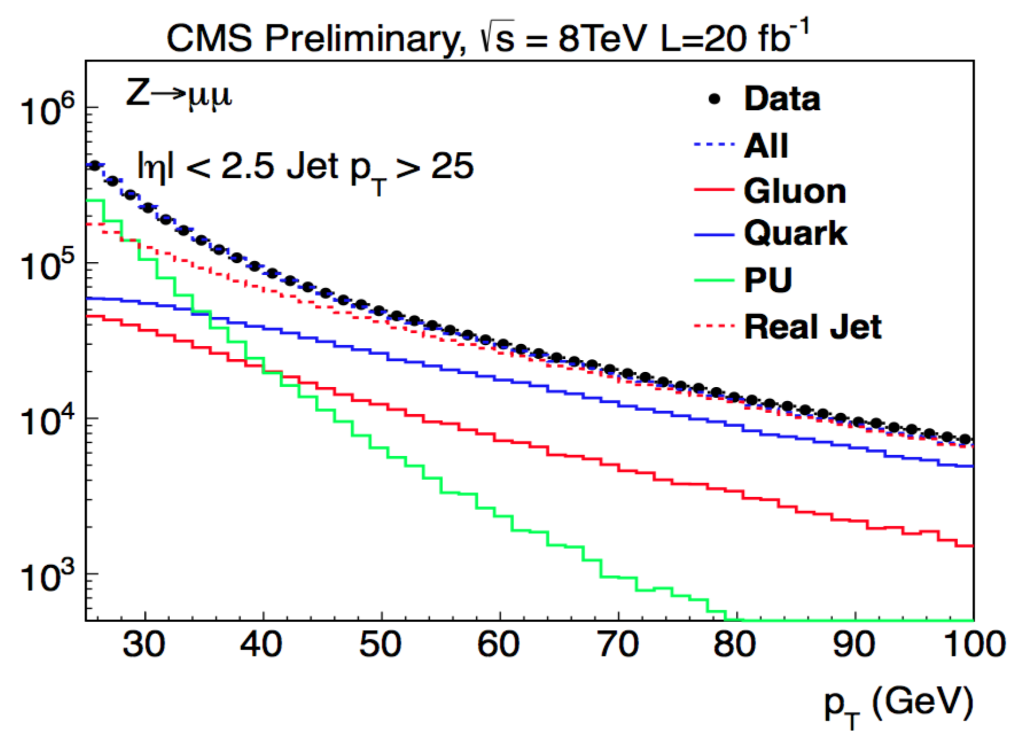
Two jets are dominant contribution

What does it look like in Data?

$$P(\text{overlap}|pT) \approx C\, N^2_{pu}\, a^2_{jet}\, pT^{-6.2}$$

- Expect pileup to grow quadratically
- Expect pileup jets to fall off more rapidly
  - Pileup jets remain a few% level problem up to 70 GeV





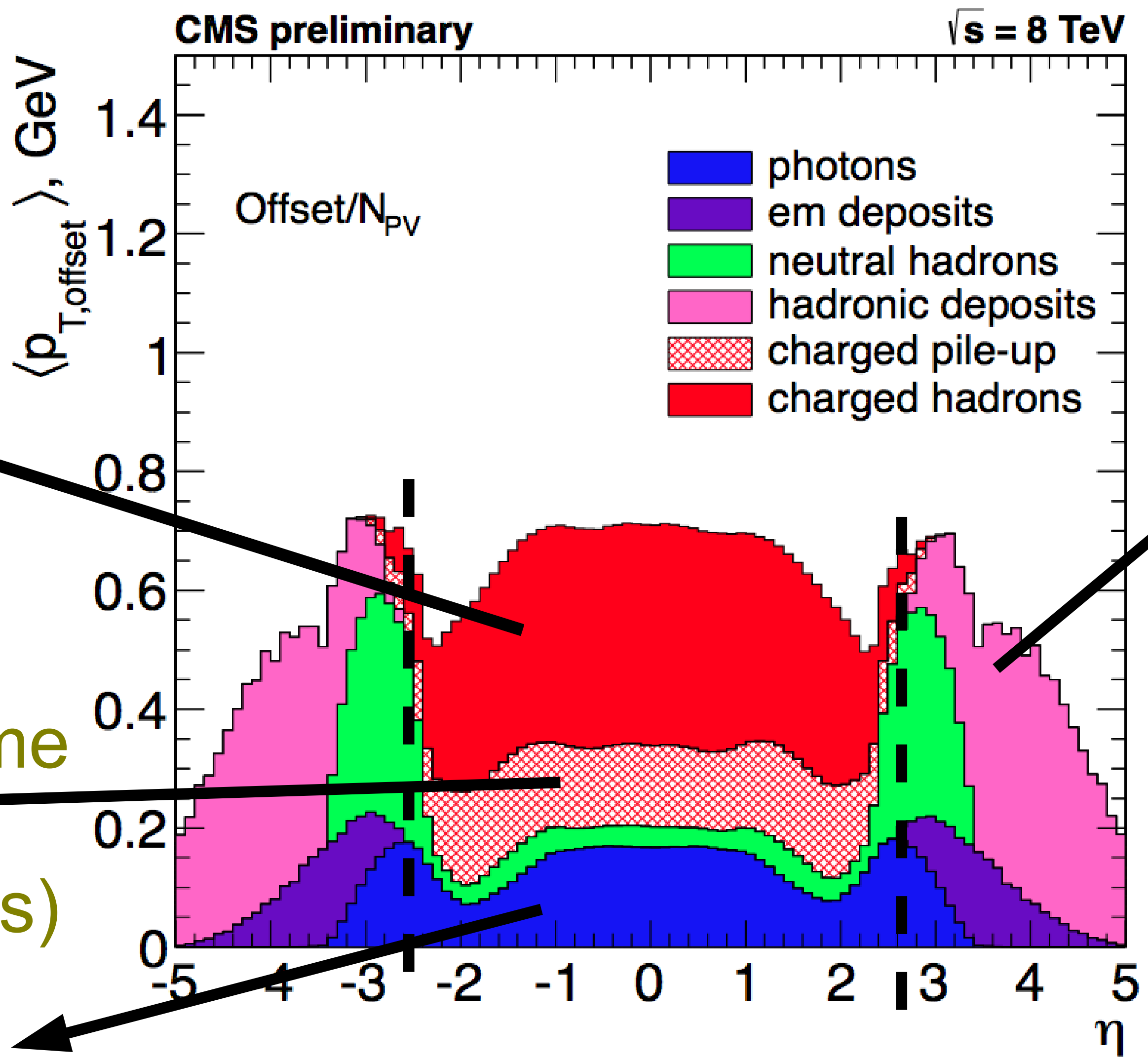
Number of PV = 0.7 x N_{pu}

Pileup Composition in CMS

Flag with Vertexing

Flag with some uncertainty (vtx + shapes)

Guilty by Association (rely on clustering)



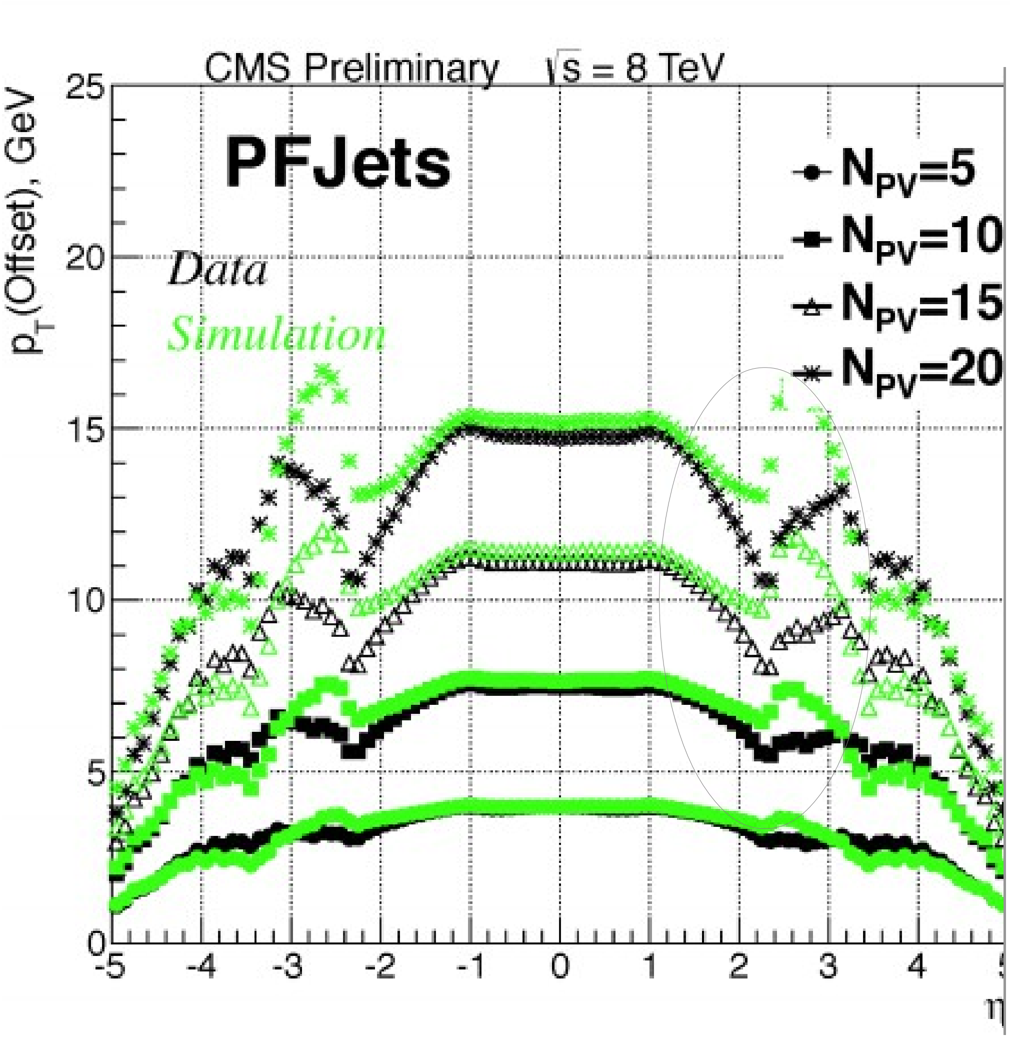
No tracker Must rely on shapes to identify

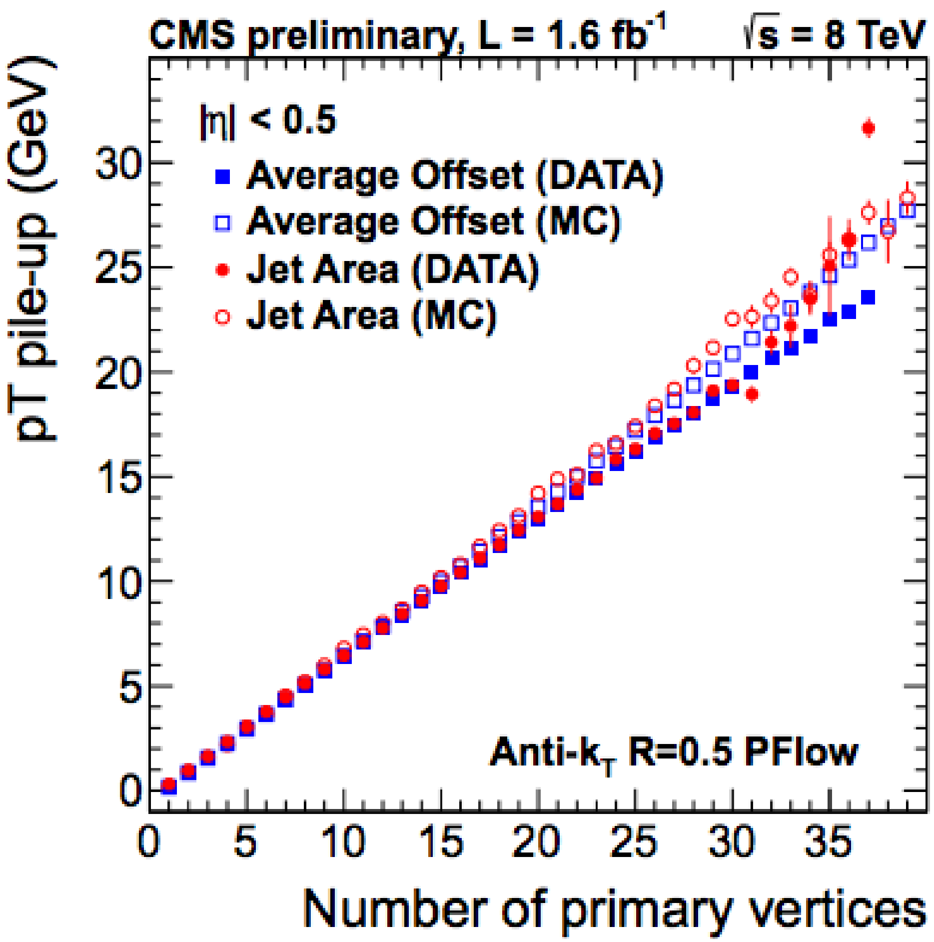
Charge Hadron Subtraction:
Flag from another vertex and remove it

Cleaning up the Pielup

- Pileup Subtraction

  Pileup measured in zero bias events : effectively is 1 2D Plot





Pileup Removal in CMS

- PF Jet reconstruction
  - Take all particle flow (PF) candidates
  - Cluster
  - Apply ρ correction
- Charged Hadron Subtraction(CHS) Jet reconstruction
  - Remove PF candidates assigned to another vertex
  - Cluster
  - Apply modified ρ correction (modified in TK volume)
  - Baseline for substructure and shape variables

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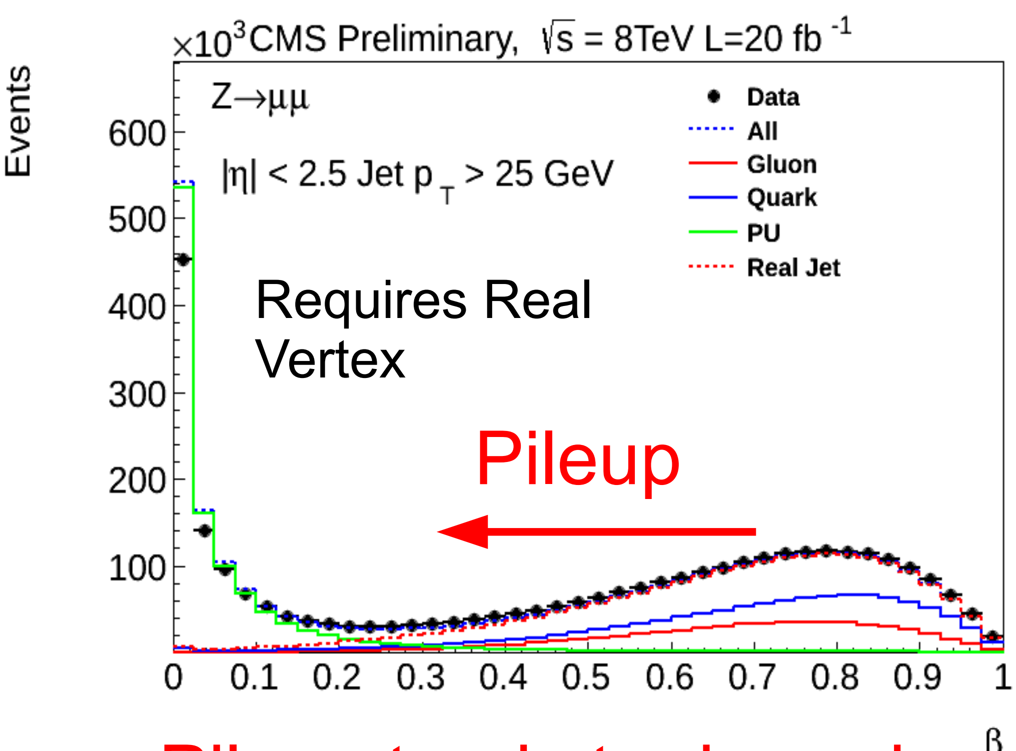
Apply Pileup jet Id on either (separate for each algo)

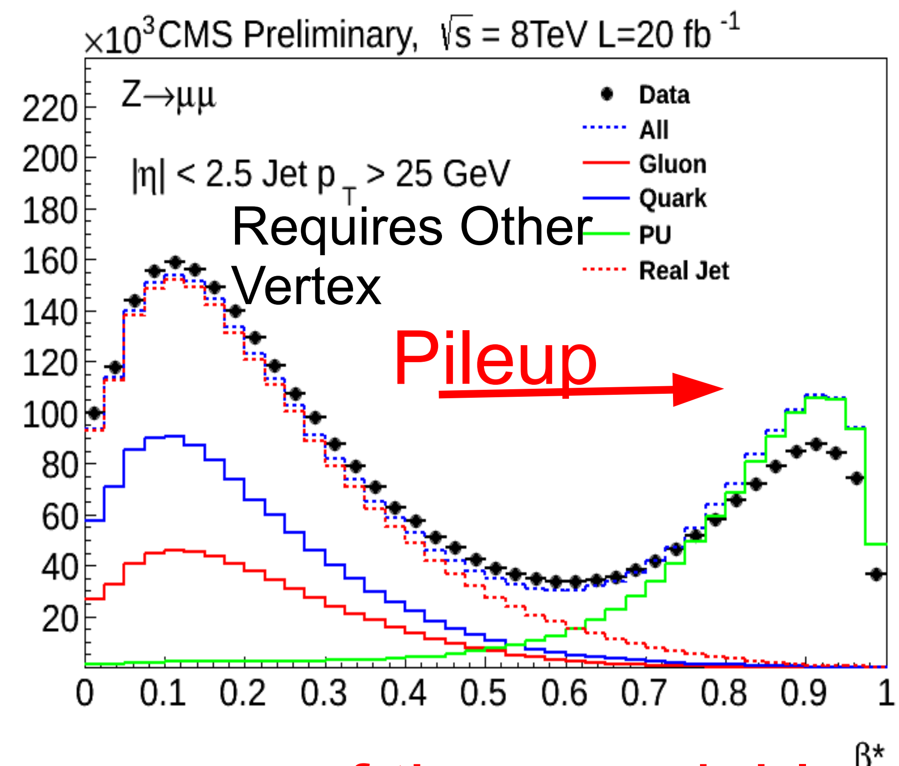
Pileup Jet Id Algorithm:Tracking

- 13 variables for the full discrimination
  - 4 Vertexing related variables (2 most impt shown):

#vertices, dZ of leading track in jet +

$$\beta = \frac{\sum_{i \in PV} p_{Ti}}{\sum_i p_{Ti}} \qquad \beta^* = \frac{\sum_{i \in otherPV} p_{Ti}}{\sum_i p_{Ti}}$$

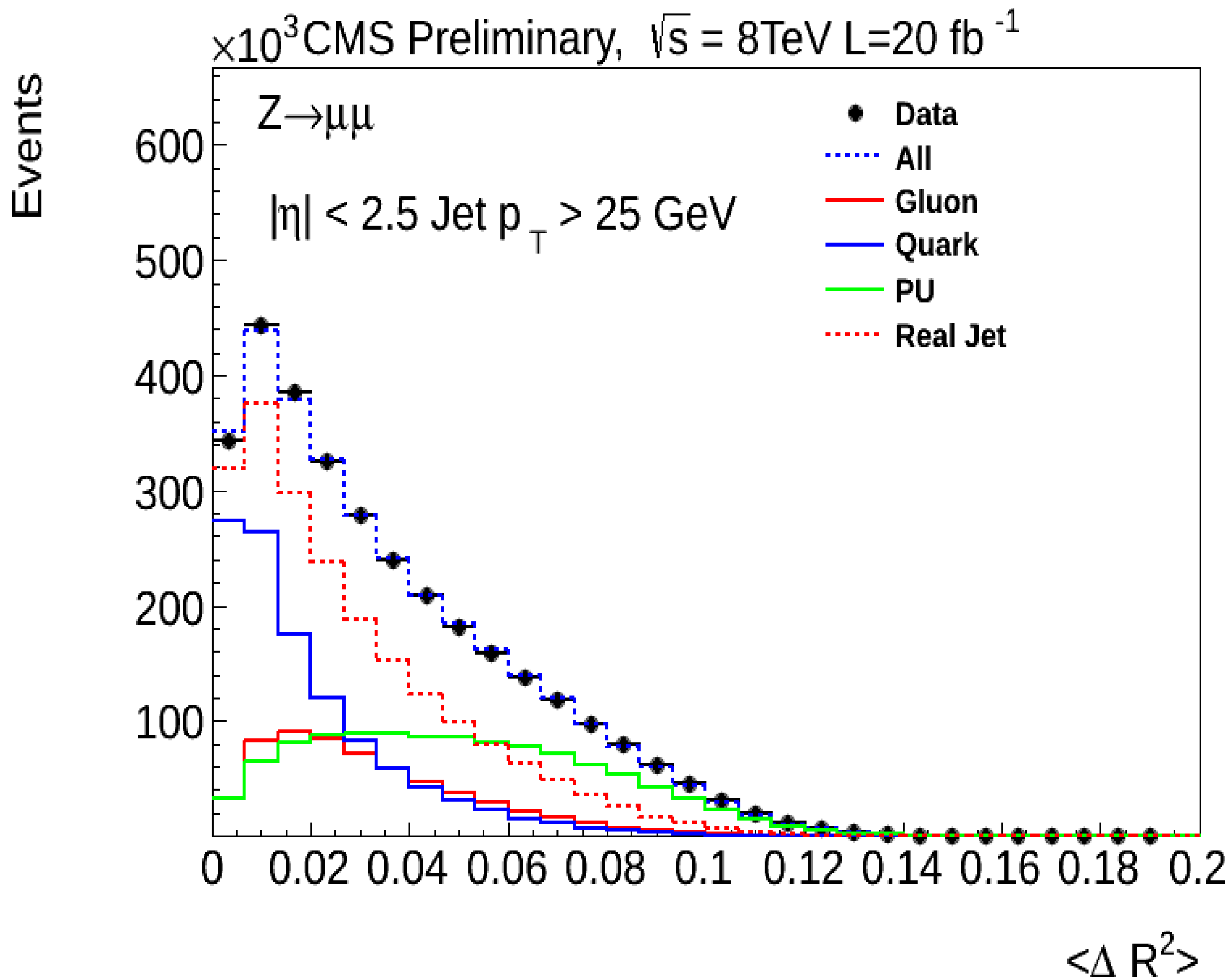




Pileup tends to degrade performance of these variables

Pileup Jet Id Algorithm:Shapes

- 13 variables for the full discrimination
  - QG disc: *pTD*,#Charged particles,#Neutral particles
  - 6 Shape variables

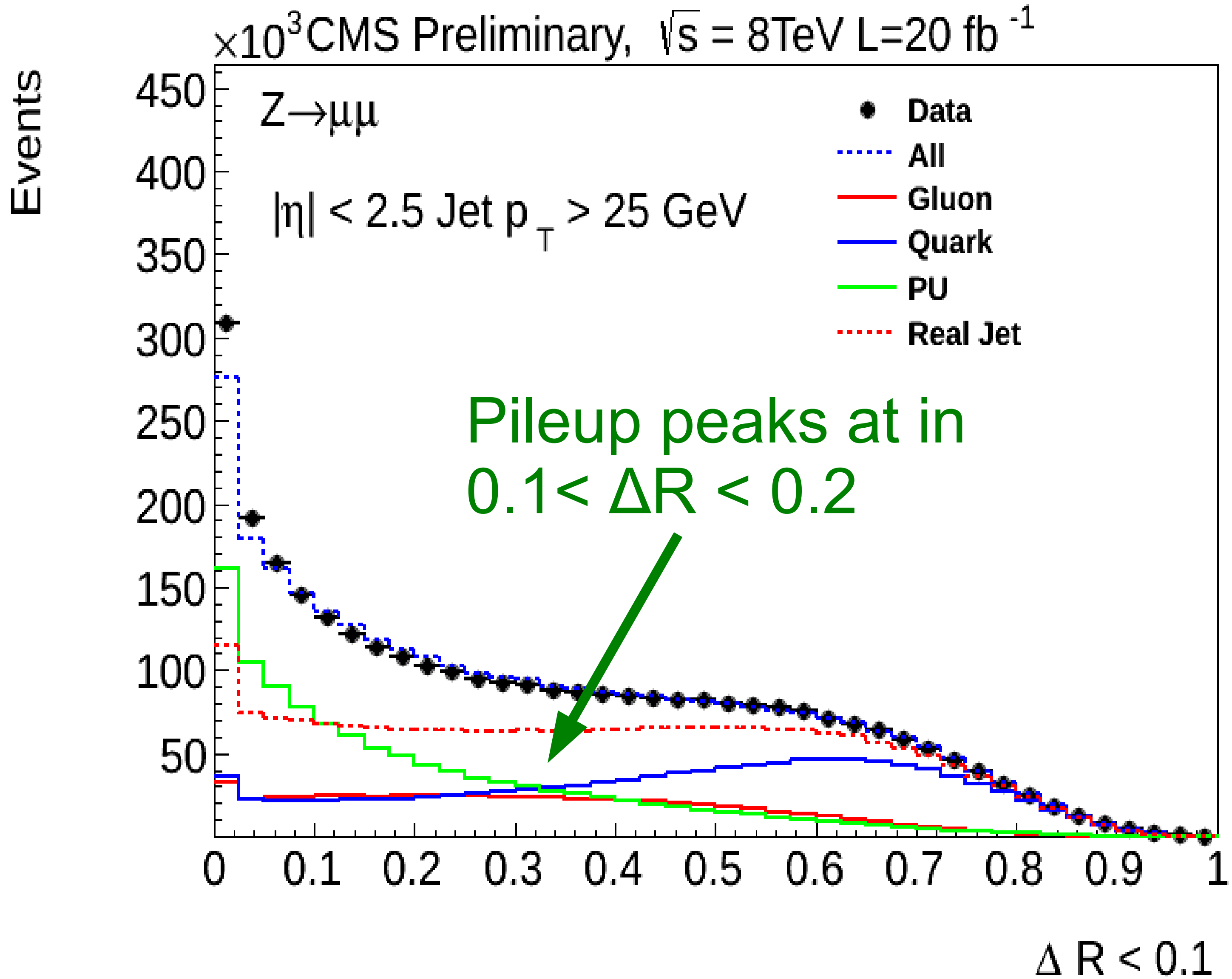


Most Effective
Jet shape variable

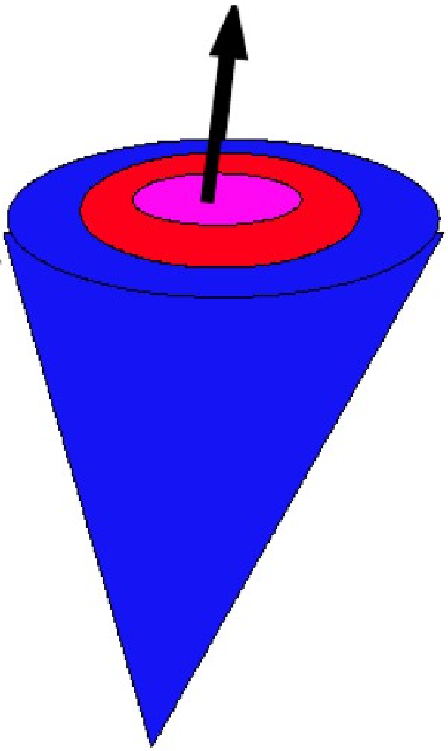
$$\langle \Delta R^2 \rangle = \frac{\sum_i \Delta R_i^2 p_{Ti}^2}{\sum_i p_{Ti}^2}$$

Pileup Jet Id Algorithm:Cones

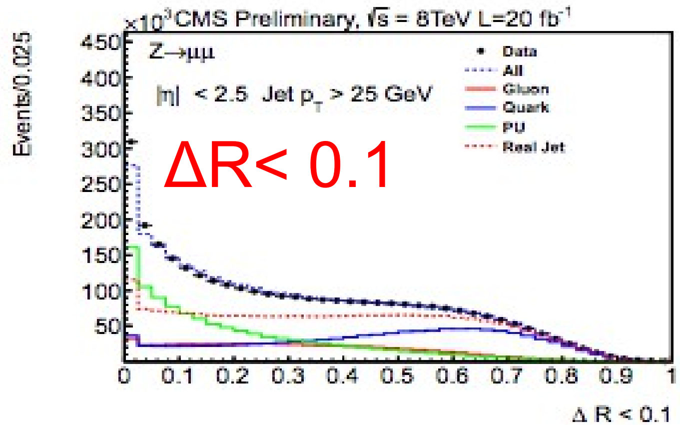
- Additional shape variables : ΔR annuli

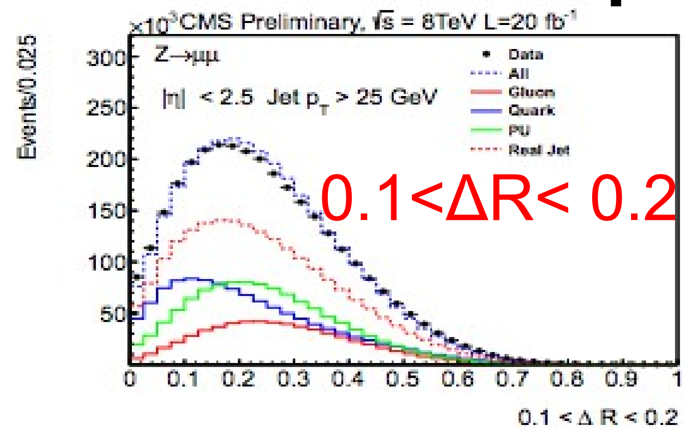


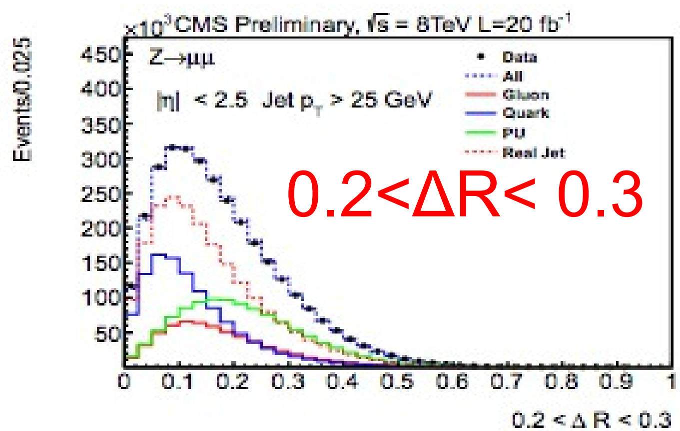
ΔR 0.1=>0.5

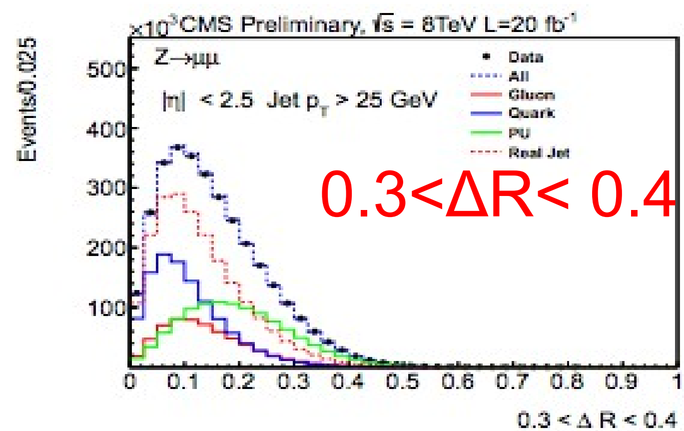


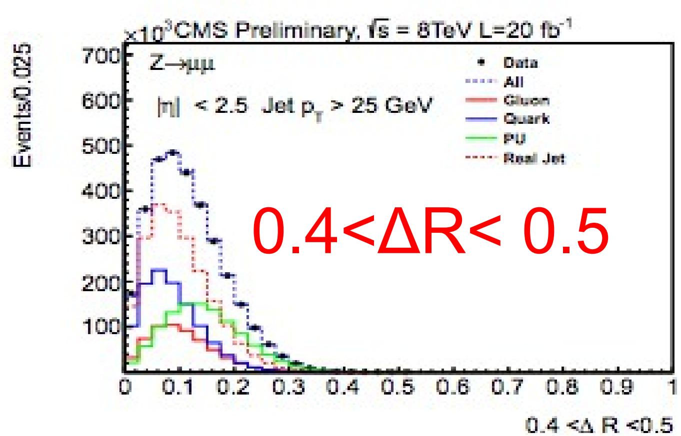
Evolution of the Jet Shape











Separation of PU clear when looking at the rings

Algorithm Construction

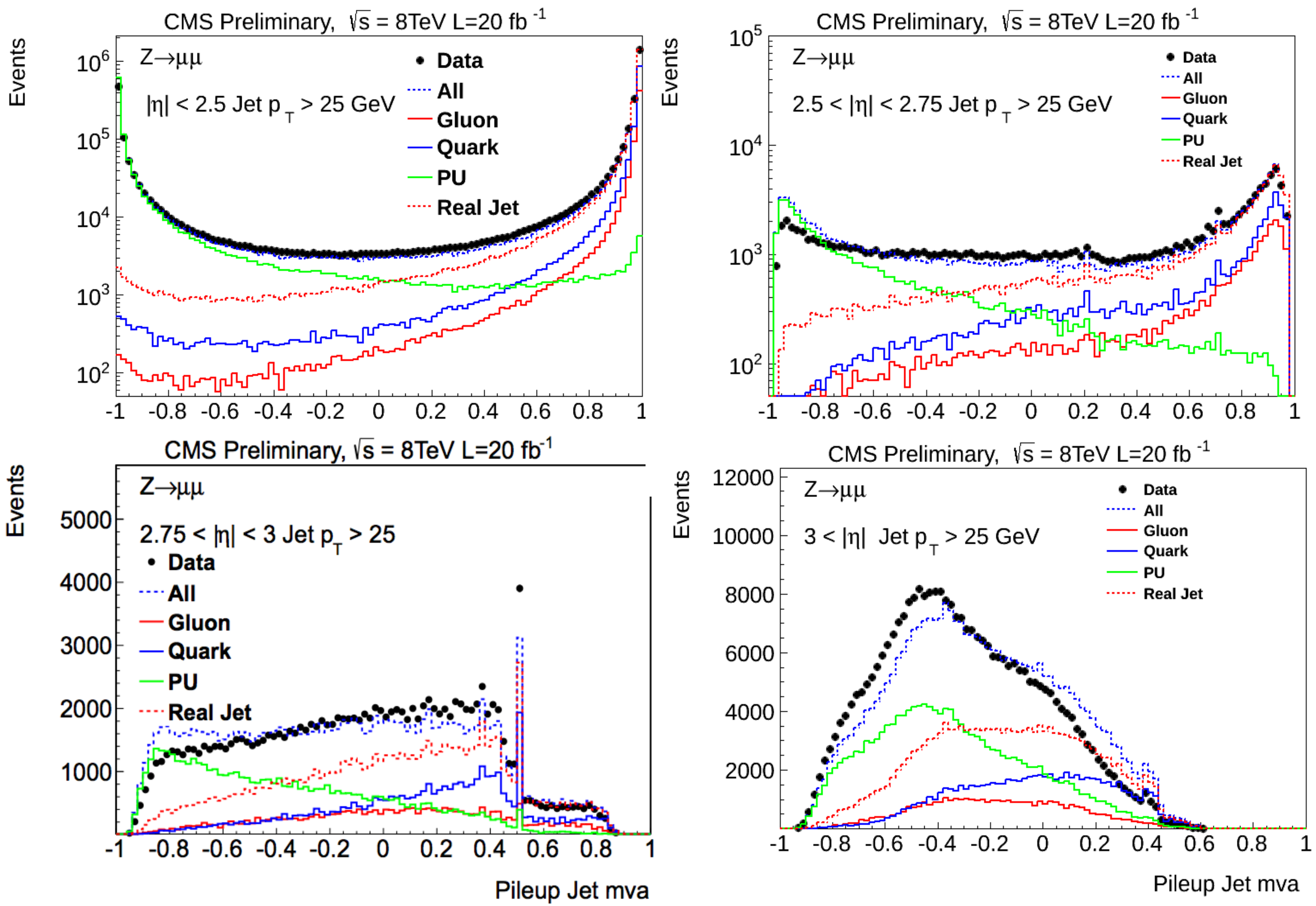
- Construct a Boosted decision tree real vs PU Jets
  - Train in four separate regions of η

$\|\eta\| < 2.5$ tracking Shape variables	$2.5 < \|\eta\| < 2.75$ Weak tracking (tracking ends at 2.5) Shape variables
$2.75 < \|\eta\| < 3.0$ Shape variables	$3.0 < \|\eta\| < 5.0$ Forward HCAL Shape variables

Construct a Boosted decision tree (trained on Z+jets for each)

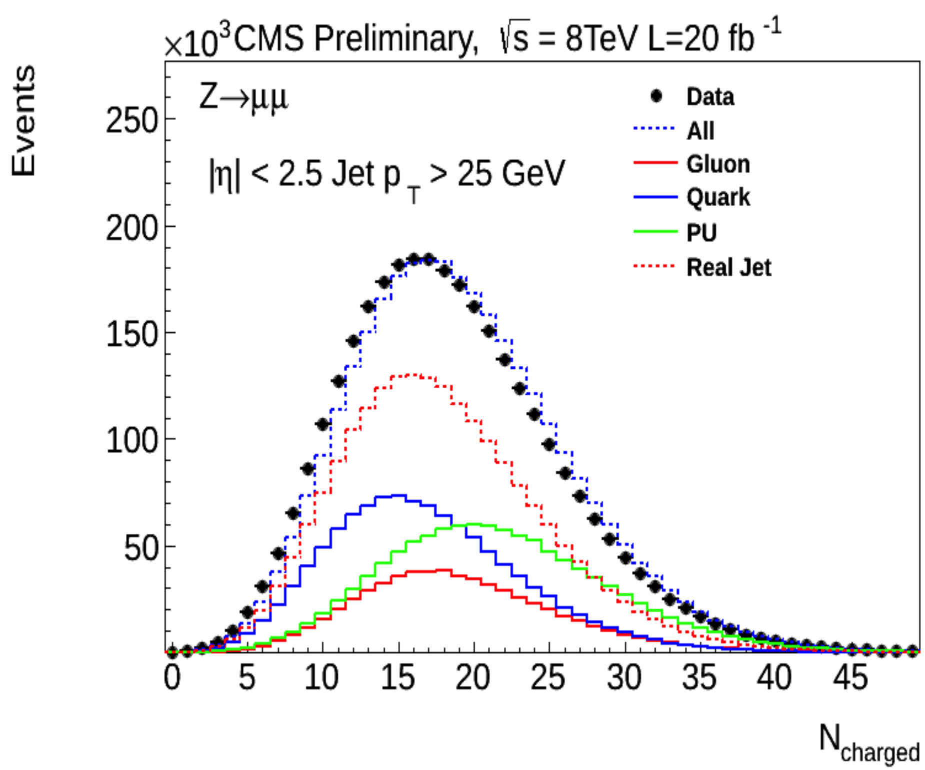
Pileup Jet Id in Data

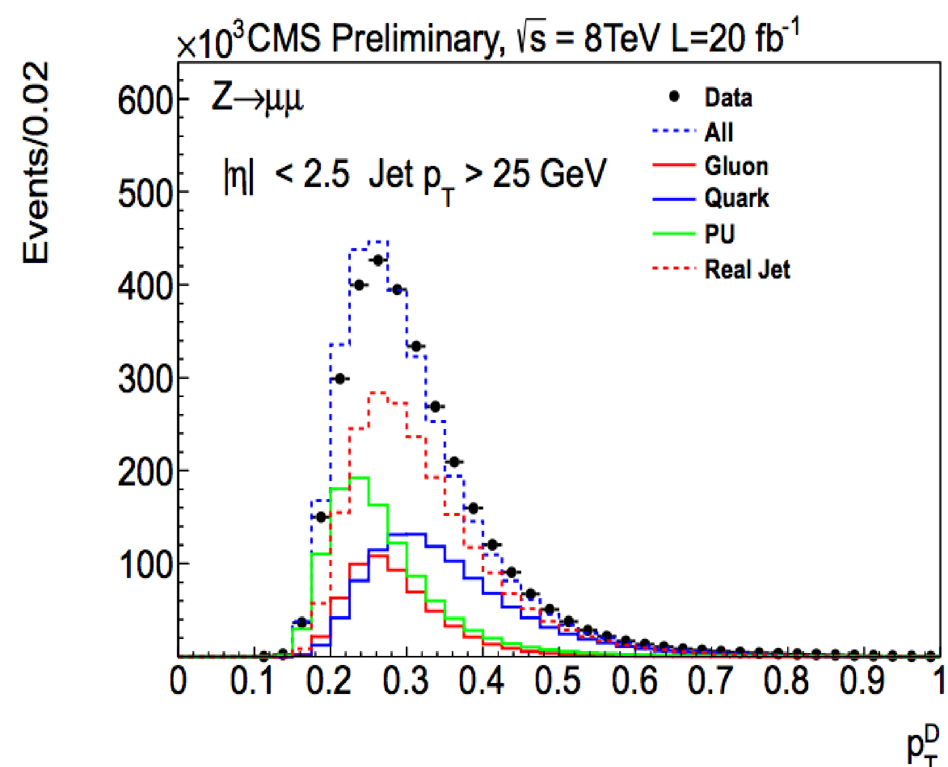
- Fraction of pileup grows with higher |η|



Quark/Gluon Discrimination in PU

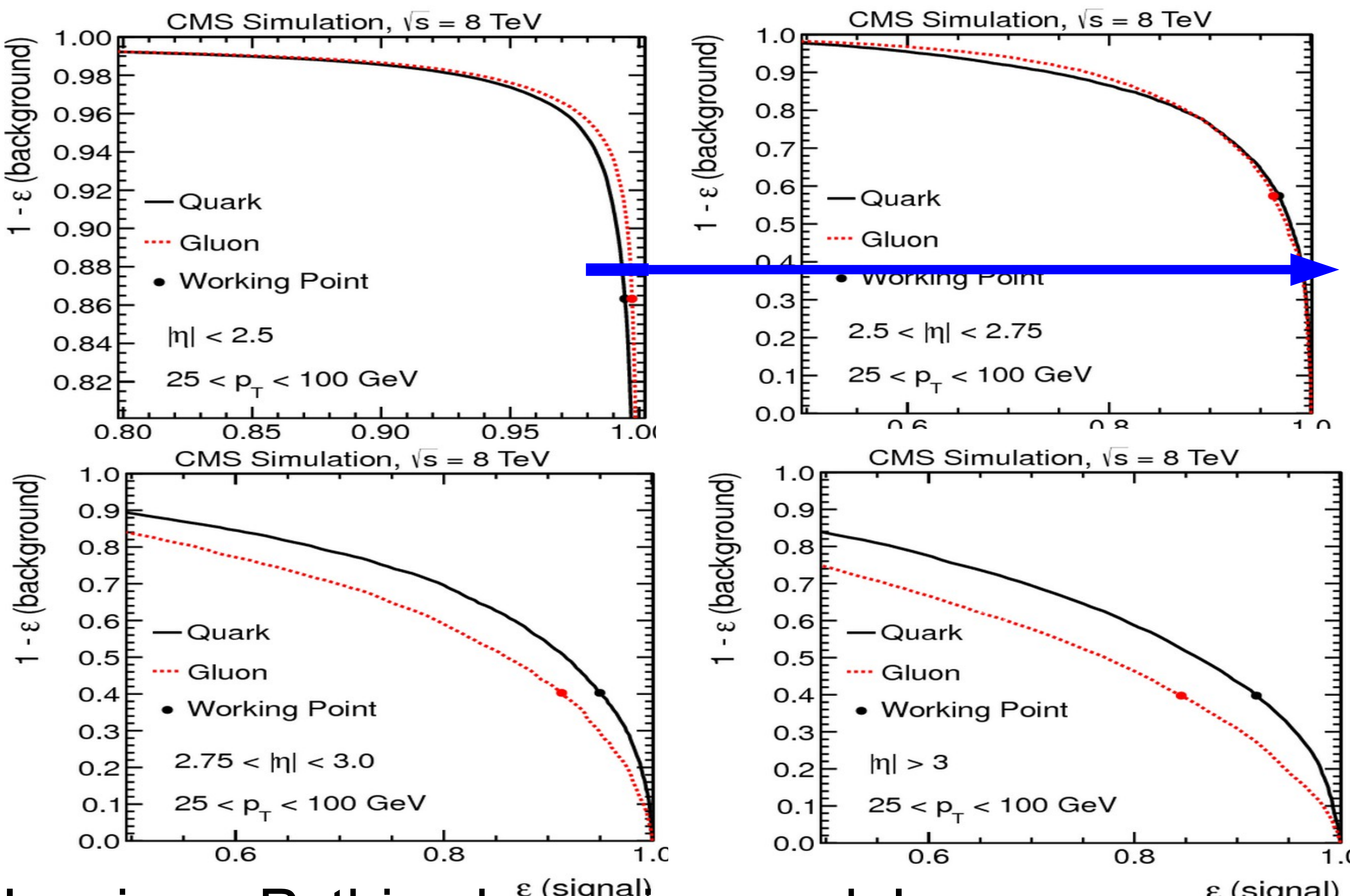
- Using jet shapes gives added advantage to PU
  - However: gives differences between Quarks/Gluons
- To improve Q vs PU and G vs PU
  - We add the quark gluon discrimination varaibles in





Pileup Jet Id Performance

- Largest systematic : from quark/gluon variation



CHS results consistent w/specific working point

Herwig vs Pythia showering models bounded by quark/gluon variation

Full Summary of Variables

$\langle \Delta R^2 \rangle$

$A < (\Delta R) < A + 0.1$

Shape

$$\longrightarrow \frac{1}{p_T^{jet}} \sum_{i \in A < \Delta R < A+0.1} p_{Ti}$$

$N_{charged}$

Q/G

$N_{neutrals}$

p_T^D

$$\longrightarrow p_T^D = \frac{\sqrt{\sum_i p_{Ti}^2}}{\sum_i p_{Ti}}$$

$$\beta = \frac{\sum_{i \in PV} p_{Ti}}{\sum_i p_{Ti}}$$

Tracking

We rely on tracks associate to vertices

$$\beta^* = \frac{\sum_{i \in other PV} p_{Ti}}{\sum_i p_{Ti}}$$

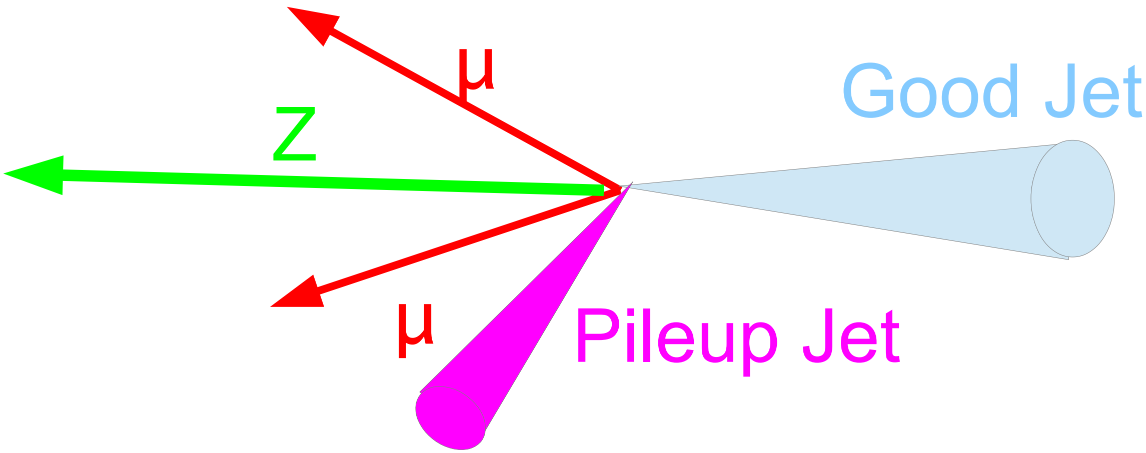
d_Z

$n_{vertices}$

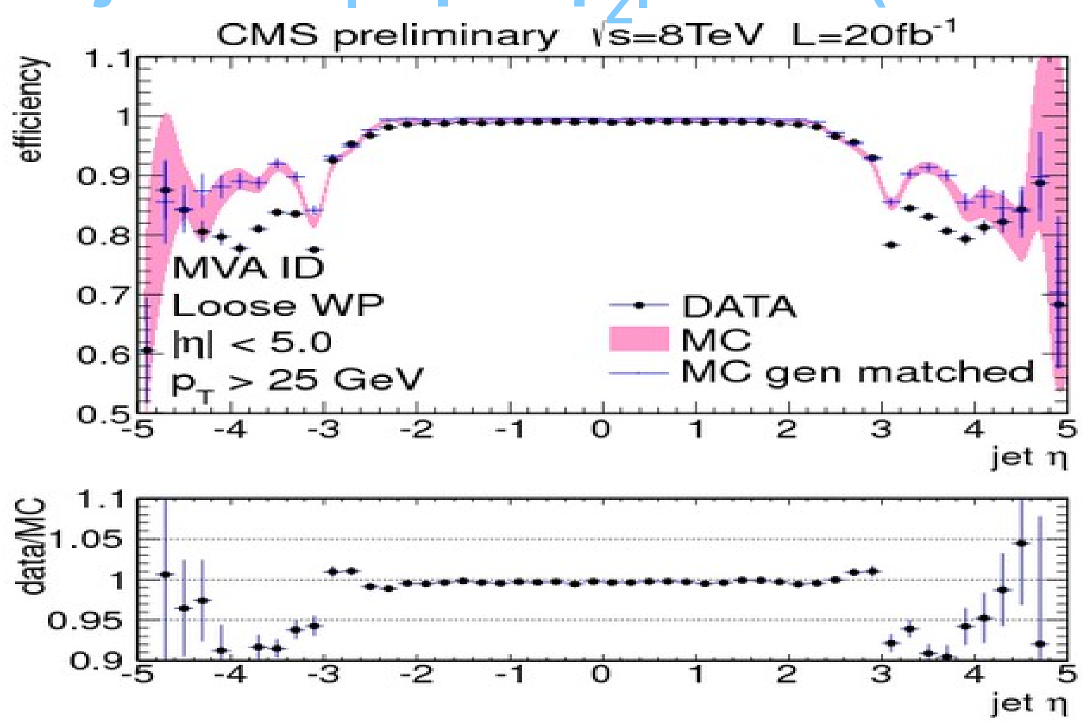
Event → Measure of the event scale

Pileup Jet Id: Efficiency in Data

- Use Z+Jet balance to measure efficiency in data



Good jet eff: |Δφ – φ_Z| > 3.0 (subtract scaled PU)



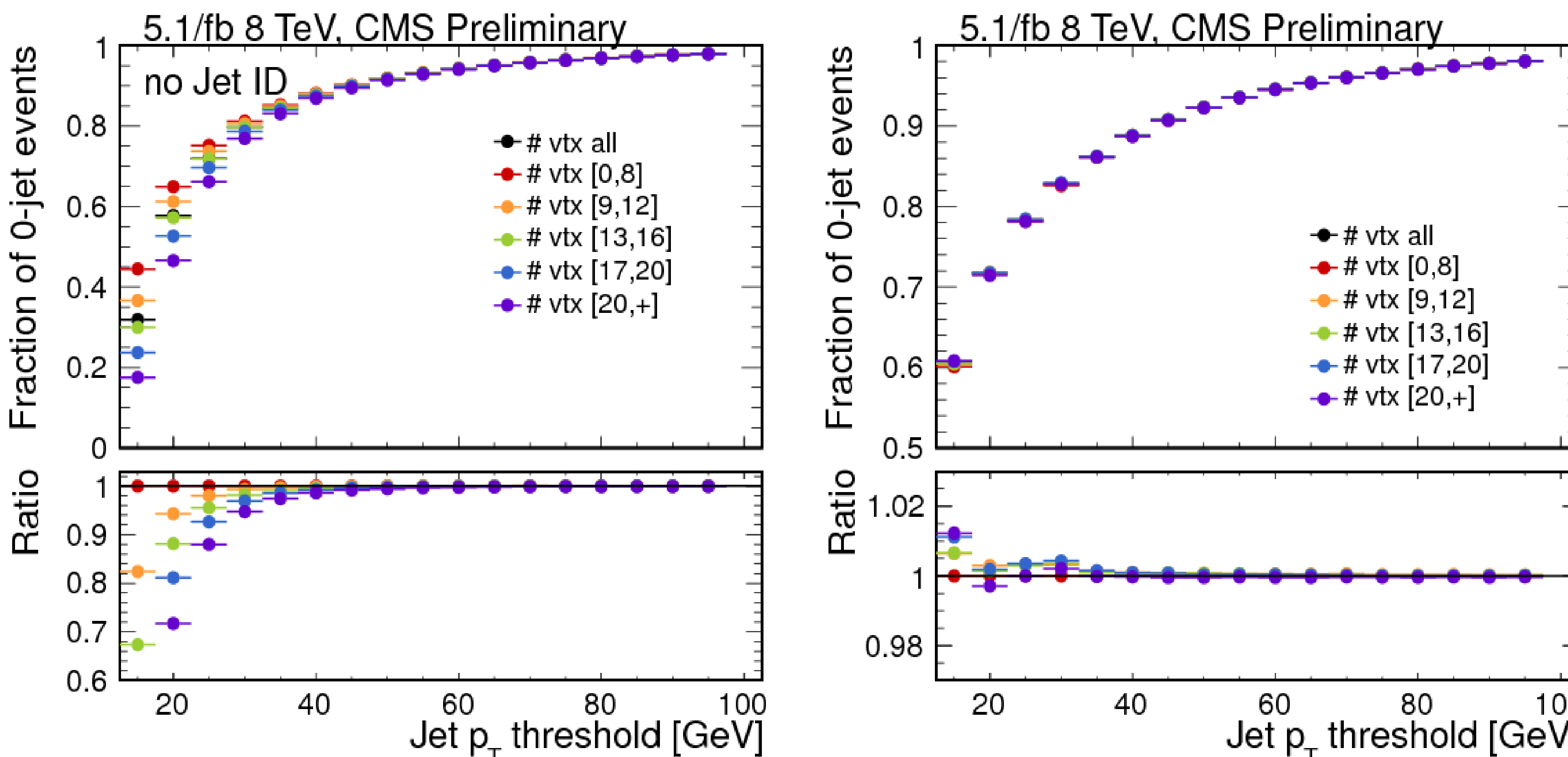
Example VBF:

VBF Eff: 90%

VBF Fake rate 15%

Usage Examples: Jet Vetos

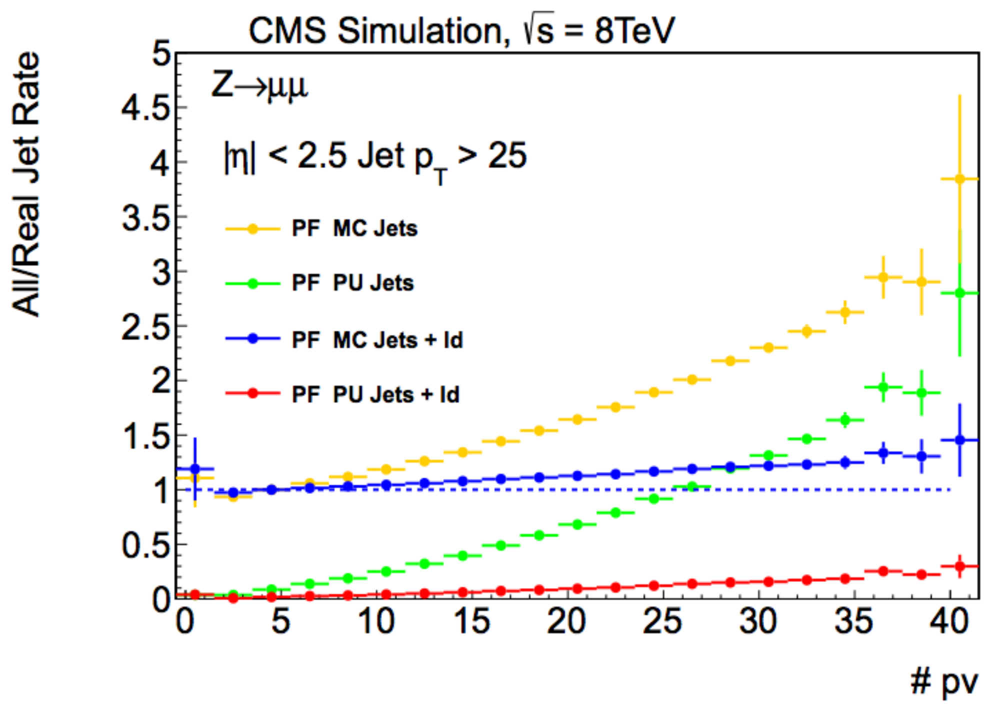
- Pileup jet id allows extension of jet vetos to low *pT*
  - Critical for b-tag veto (requires jets with *pT* > 10 GeV)

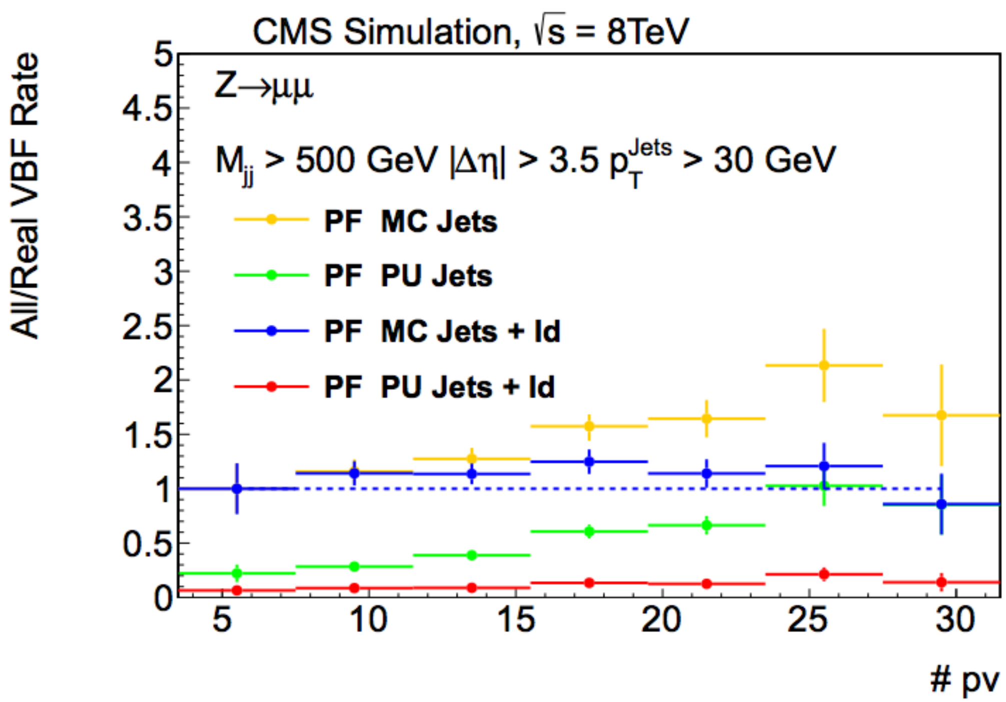


Vector boson fusion background reduced by a factor of 2 (90% good jet eff)

Reducing VBF backgrounds

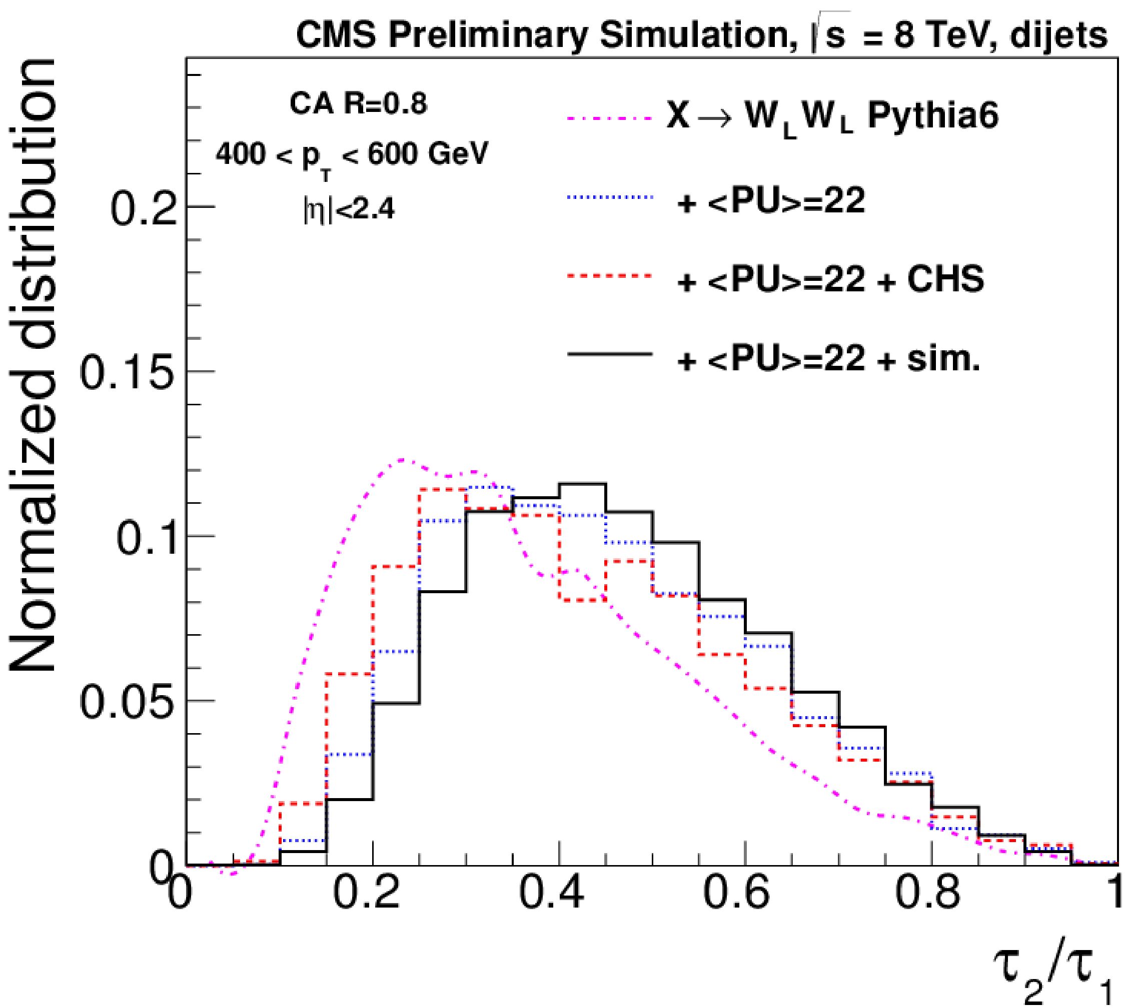
- Critical area for the PU Jet Id
  - Rely on both tracking and non-tracking pu rejection
  - PU Jet id was used in every VBF analysis
- Forward jets play an important role in *MET*
  - big advantage of using PU Jet Id over CHS





W Substructure : CHS

- Charge hadron subtraction clustering default
  - Jet shape effects minizmied with the CHS



Charged hadron subtraction reduces the Pileup effect by 2

Conclusions

- Pileup Jet Id has been a success
  - However it is just one approach to pileup rejection
  - Discrimination in both forward/central region
  - Critical element for reducing *MET* resolution
    - See Mathieu's talk on *MET* performance
- CHS has also worked well
  - A complementary approach to PU Jet Id
  - Pileup Jet Id can be run on CHS jets
  - Used in about 60% of jets in CMS
  - CHS gives an improvement in the jet shapes
- Look forward to extending with new approaches

Backup

Efficiency vs Kinematics