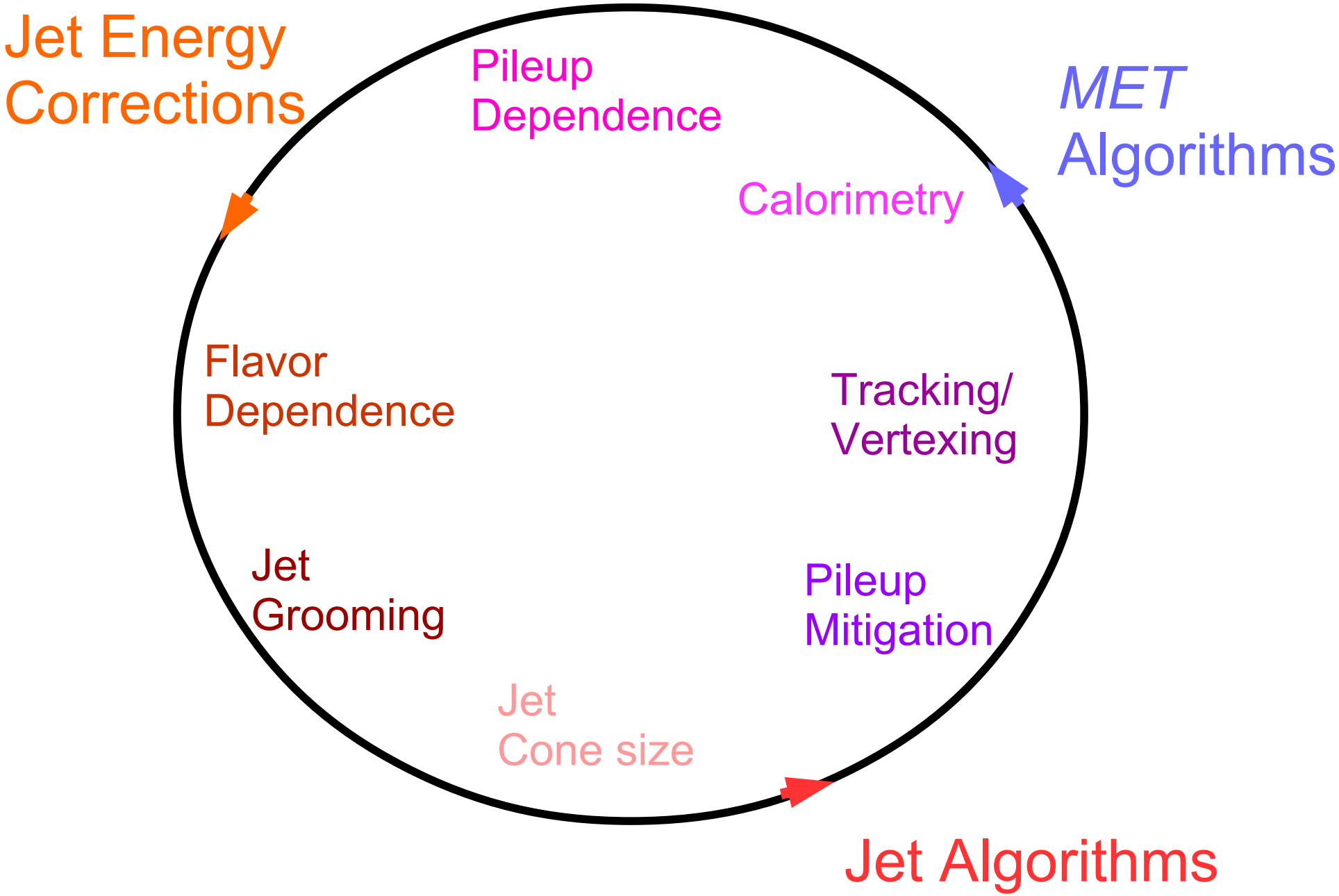
Tops and Jet/MET

Philip Harris (CERN)
CMS collaboration

Cycle of Development



Documenting Run I

JEC

- JME-13-001 : b-jet energy scale
- JME-13-004 : Run I JEC Performance
- JME-14-003 : ATLAS/CMS JEC Combo

MET

- JME-13-003 : Run I *MET* Performance

Jet Algorithms

- JME-13-002 : Quark/Gluon Discrimination
- JME-13-005 : Pileup Jet Id
- JME-13-006 : Boosted W-tagging performance
- JME-13-007 : Top Tagging performance
- JME-14-001 : Pileup subtraction in jets
- JME-14-002 : V-tagging Observables and correlations

JME-14-005 : JPT performance

JME-DP-14/037 : Jet Cones

JME-DP-13/018 : HI UE sub.

Almost public

JME-DP-14/038 : Top Tagging

Top Mass Measurement

Numbers Are the rankings of nuisances

7 out of 10 are Jet/MET related

	Correlations ρ_{year}	Correlations ρ_{chan}	Combined uncertainty
Experimental uncertainties			
In-situ JSF factor	0	0	0.10
Inter-calibration JES component	1	1	0.01
MPF *in-situ* JES component	1	1	0.05
Uncorrelated JES component	0	1	0.14
Other JES uncertainties	0	0	0.00
Lepton energy scale	1	1	0.02
E_T^{miss} scale	1	1	0.06
Jet energy resolution	1	1	0.17
b-tagging	1	1	0.03
Trigger	0	0	0.04
MHI(Pileup)	0	1	0.20
Background Data	0	0	0.05
Background MC	1	1	0.07
Fit calibration	0	0	0.05
Modeling of hadronization			
Flavor JES component	1	1	0.05
Flavor-dependent hadronization uncertainty	1	1	0.36
b fragmentation and B branching fractions	1	1	0.14
Modeling of the hard scattering process and radiation			
Parton distribution functions	1	1	0.06
Renormalization and factorization scales	1	1	0.17
ME-PS matching threshold	1	1	0.16
ME generator	1	1	0.13
Top quark p_T	1	1	0.12
Modeling of non-perturbative QCD			
Underlying event	1	1	0.16
Color reconnection	1	1	0.18
Statistical uncertainty			0.10
Total systematic uncertainty			0.65
Total uncertainty			0.65

8

4

2

1/9

5

7

10

3/6

TOP-14-015

	Correlations ρ_{year}	ρ_{chan}	Combined uncertainty
Experimental uncertainties			
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Total systematic uncertainty			0.65
Total uncertainty			0.65

Jet energy corrections 8

Hadronic Resolution 4

2

Flavor Dependence 1/9

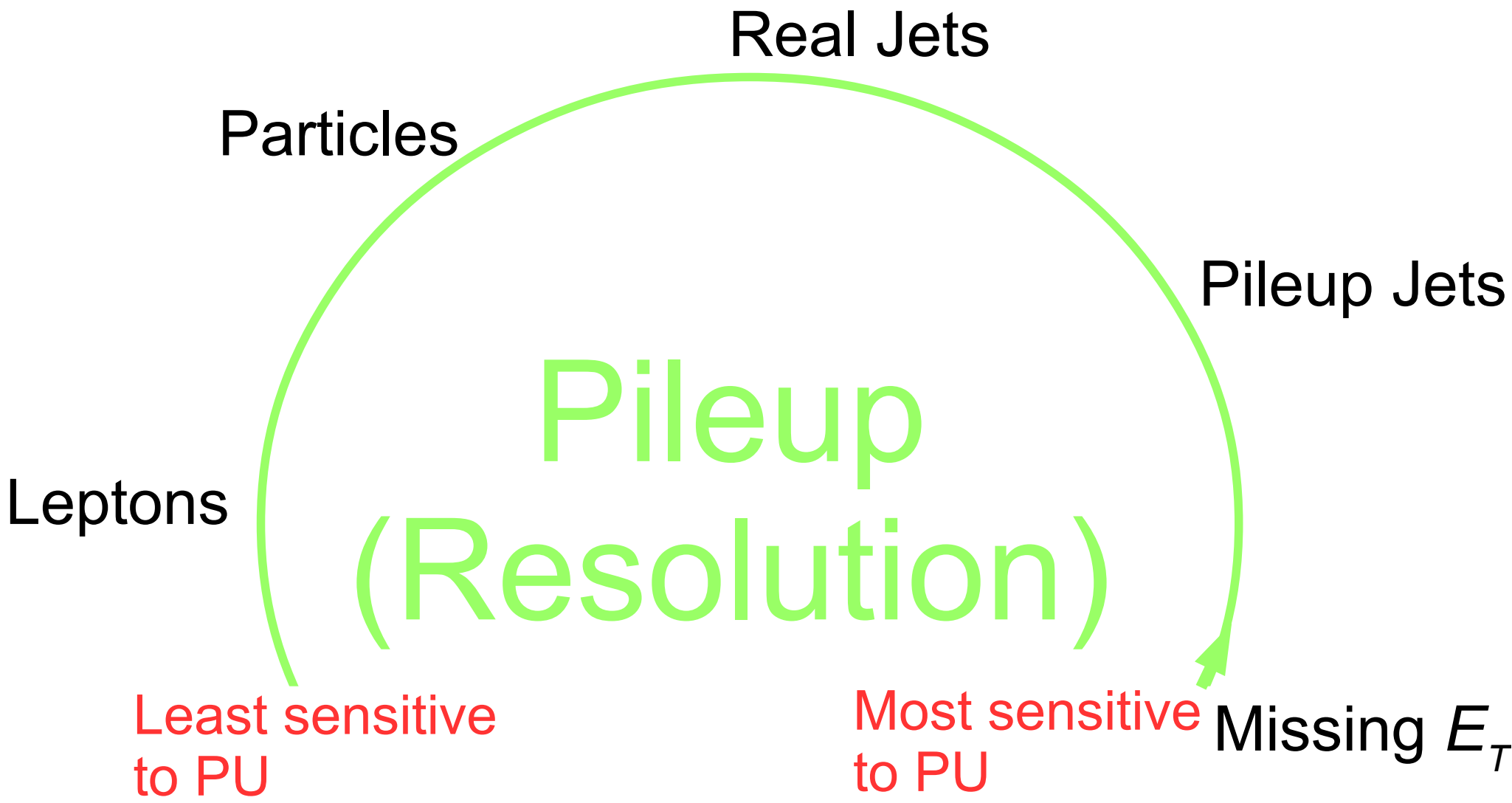
5

7

10

Color Flow 3/6

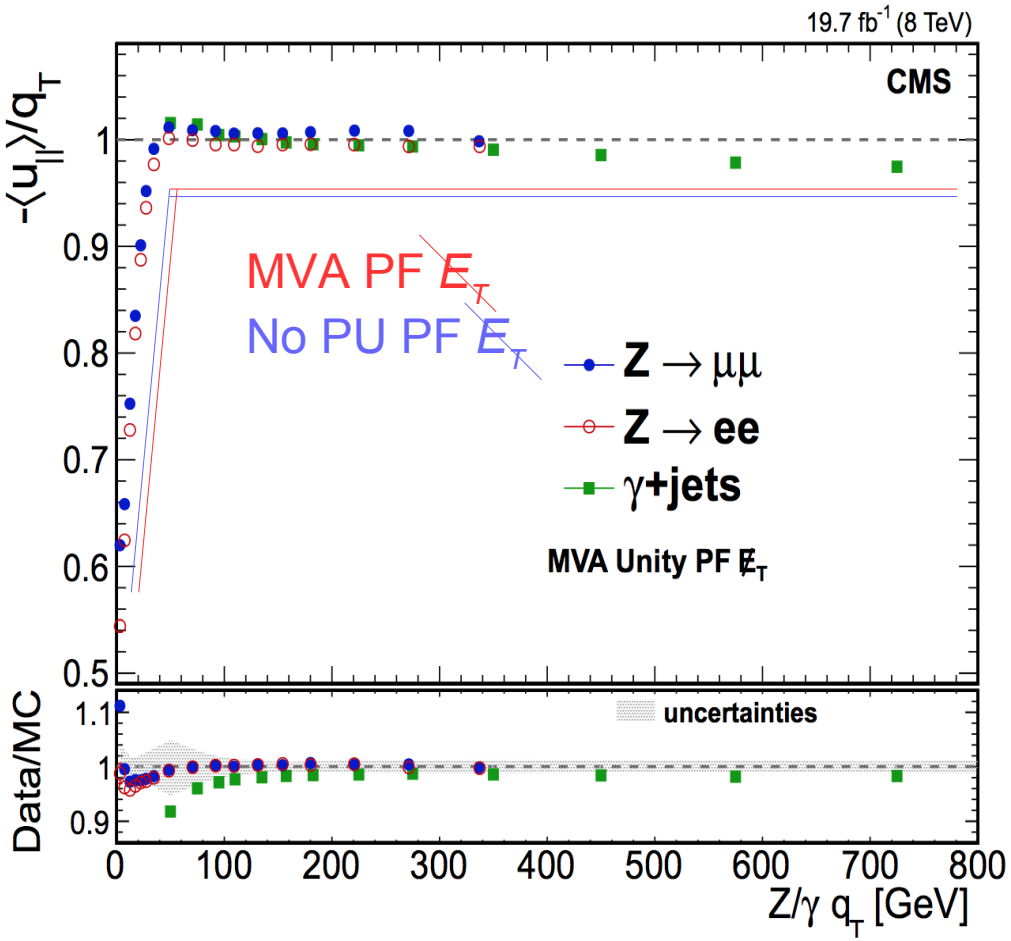
TOP-14-015

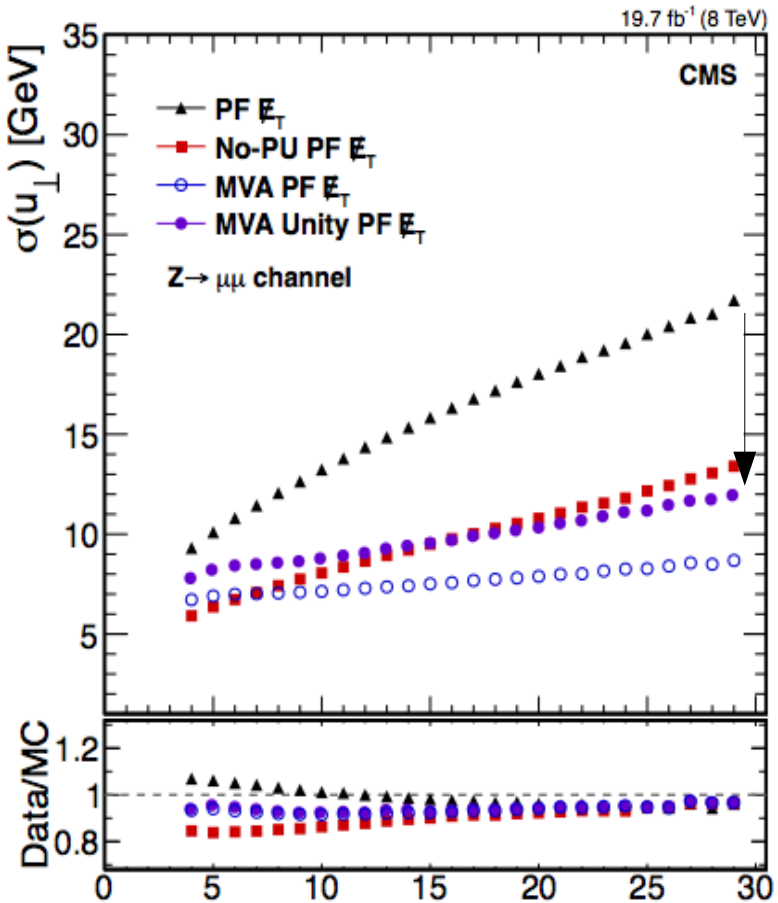

Real Jets
Particles
Pileup Jets
Pileup
(Resolution)
Leptons
Least sensitive
to PU
Most sensitive
to PU
Missing E_T

Impact of Pileup on *MET*

- *MET* has a large effect on pileup

We can reduce with advanced techniques (MVA *MET*)

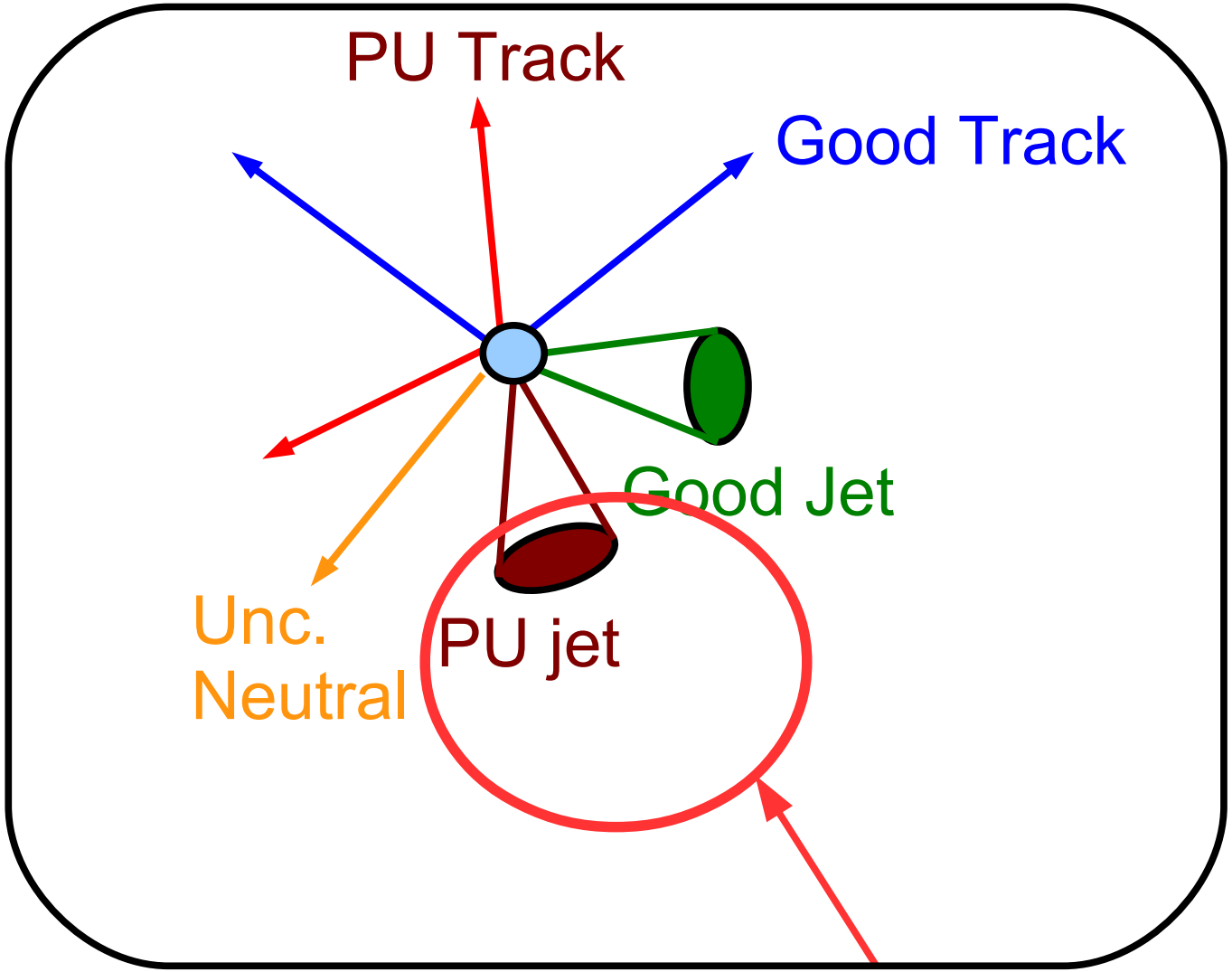




Final *MET* (MVA Unity) keeps response at unity

JME-13-003

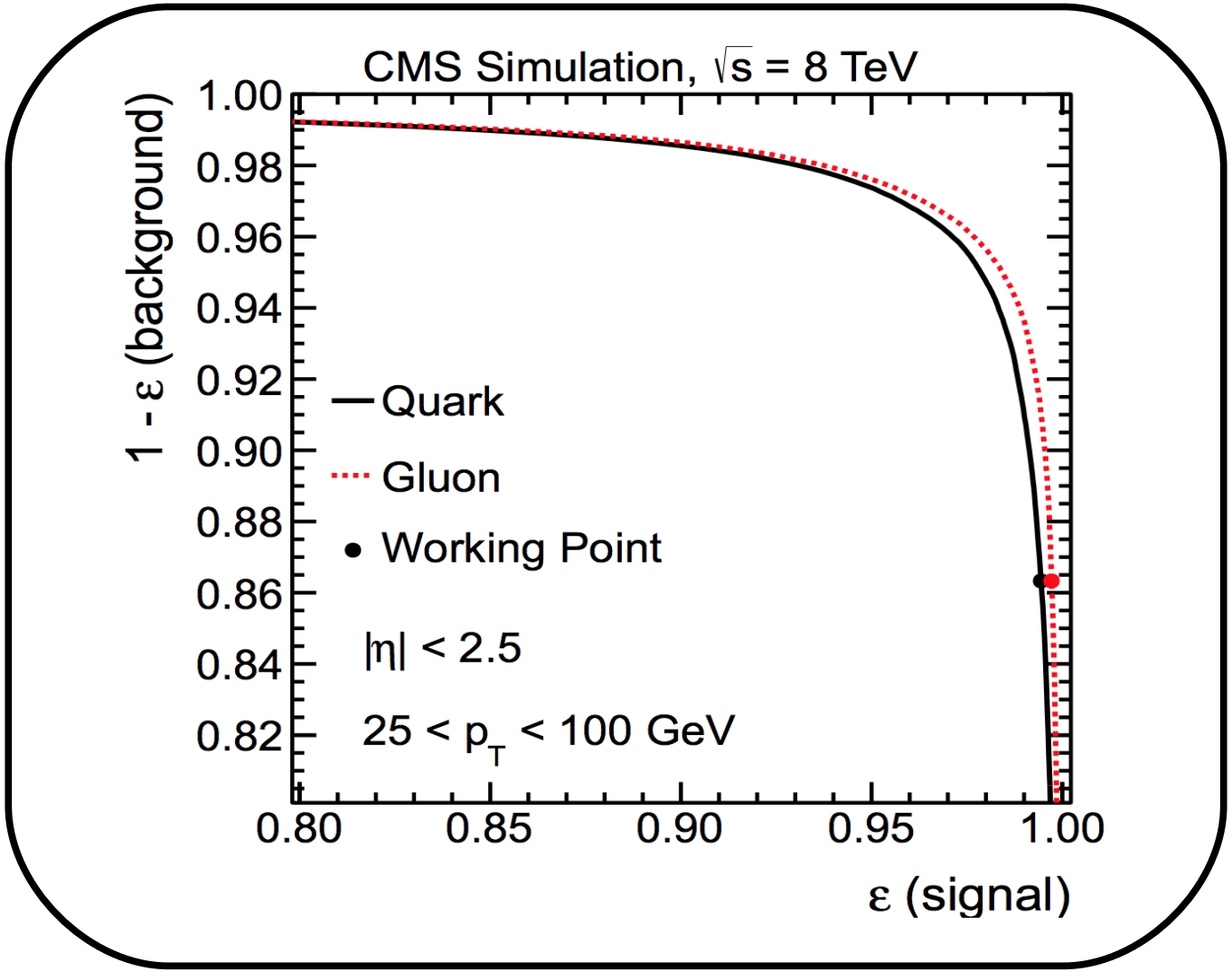
Whats causing the PU dependence?



Dominant component of *MET* are PU Jets

JME-13-005

Whats causing the PU dependence?

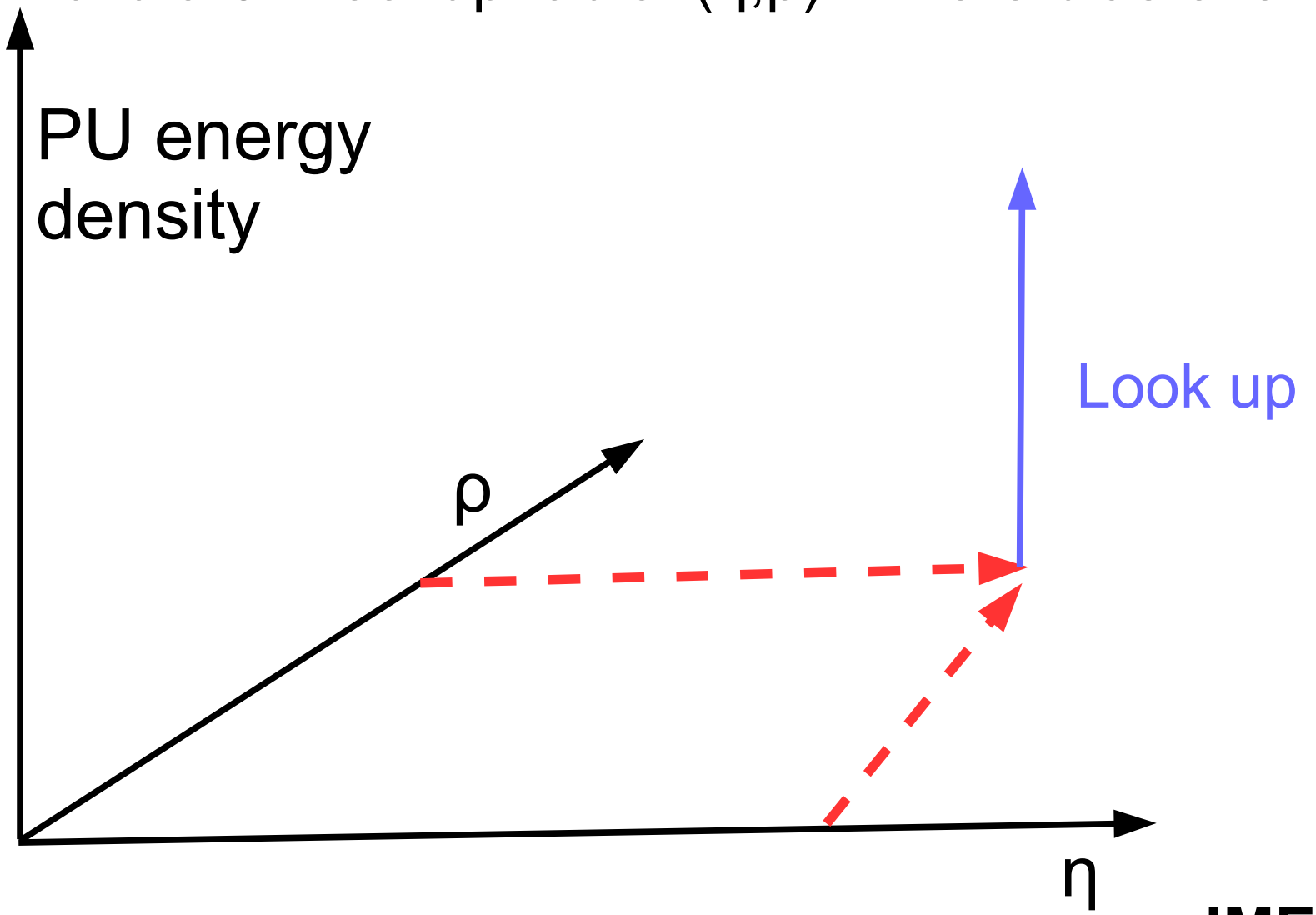


Well established PU rejection
From Run I

JME-13-005

Pileup Subtraction

- Strategy:
  - Build a 3D lookup table f(η,ρ) in Zero bias events



JME-13-004

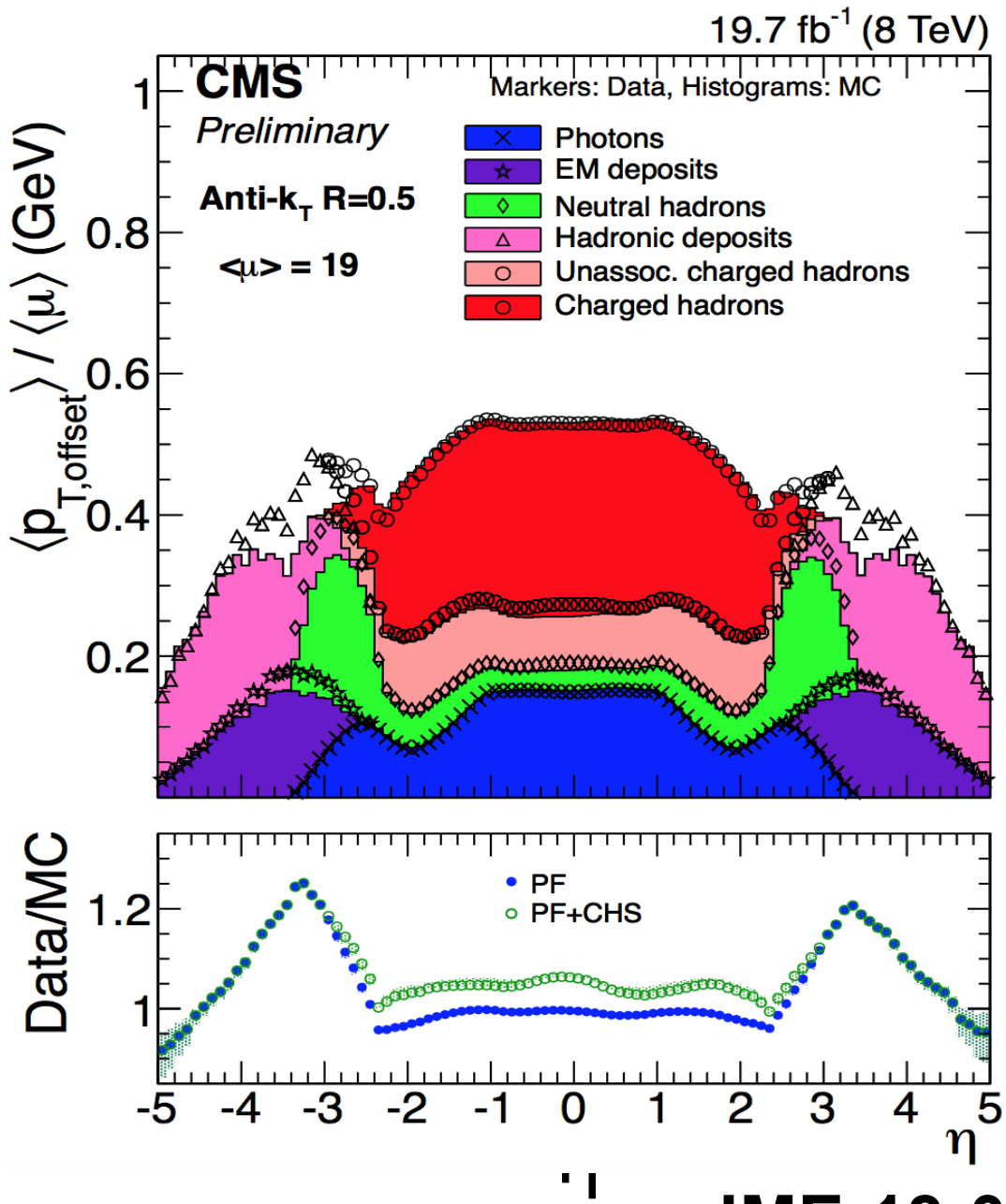
Pileup Subtraction

- Strategy

Lookup techique
Is very robust

Can use it for any algo

Whats New?
Can start to shrink
y-axis



JME-13-004

Pileup Subtraction

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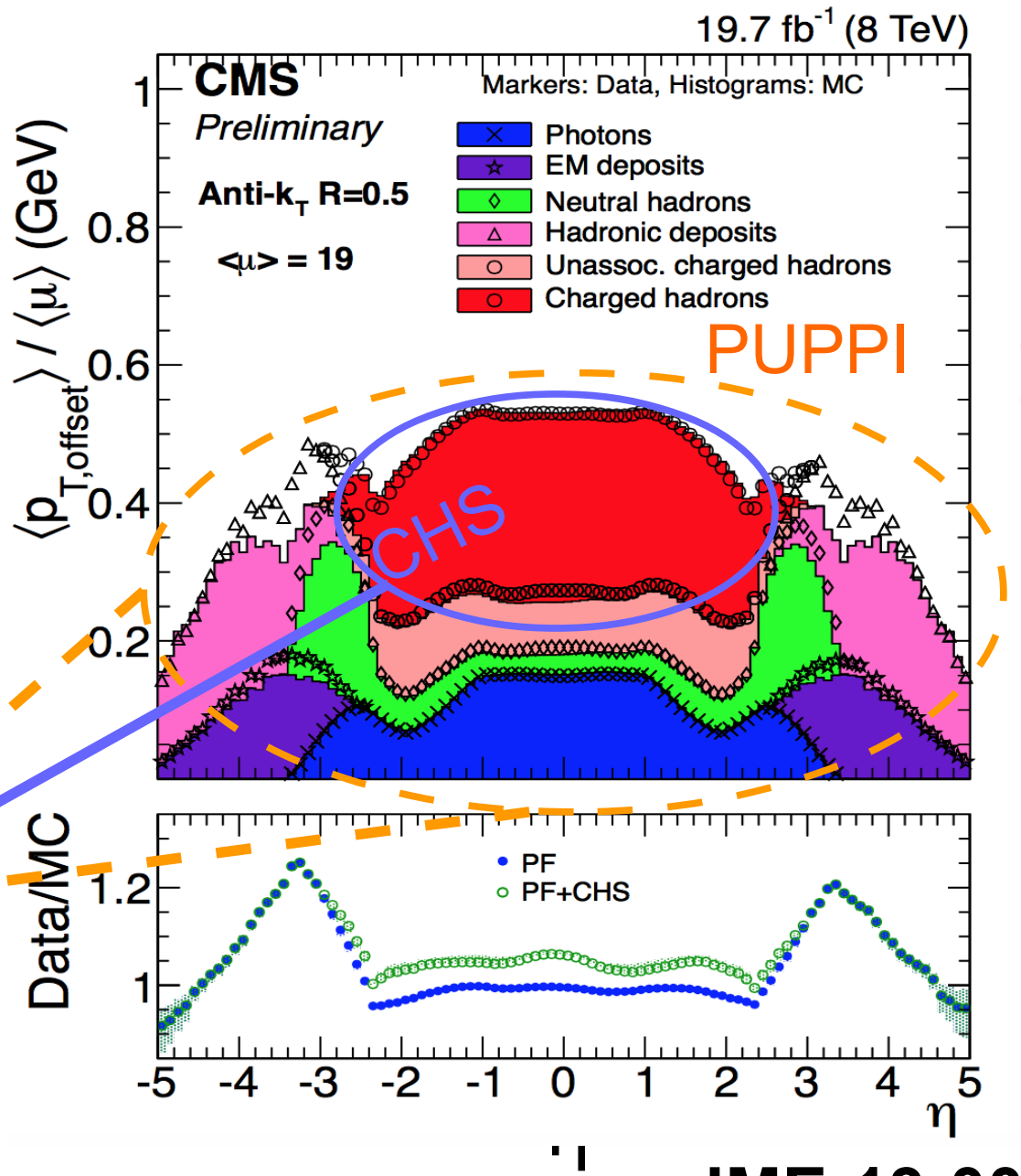
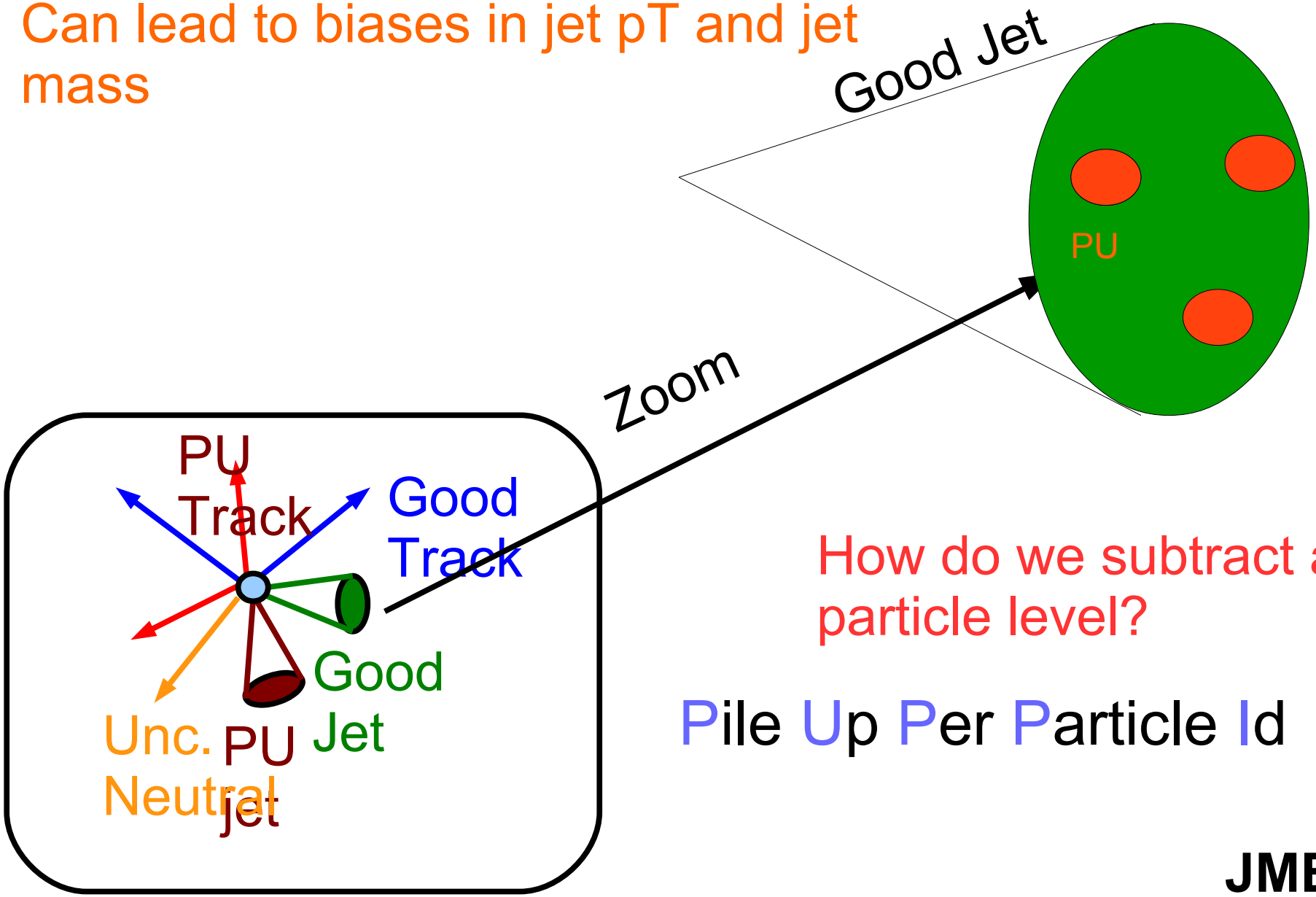


JME-13-004

Evolution of PU Subtraction

Pileup effects jets at the particle level
Can lead to biases in jet pT and jet mass



How do we subtract at the particle level?

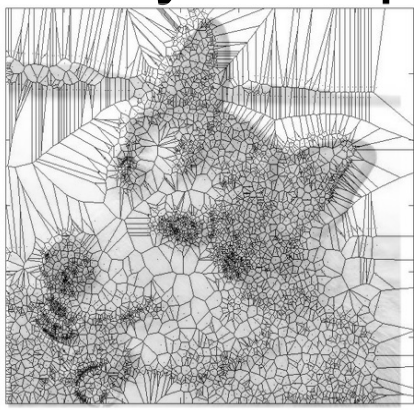
Pile Up Per Particle Id

JME-14-001

Evolution of PU Subtraction

Aim is to remove pileup at particle level

Heavy Ion approach



HF Voronoi
Per-particle subtraction
Using voronoi cells

PUPPI
PU Jet id @particle level

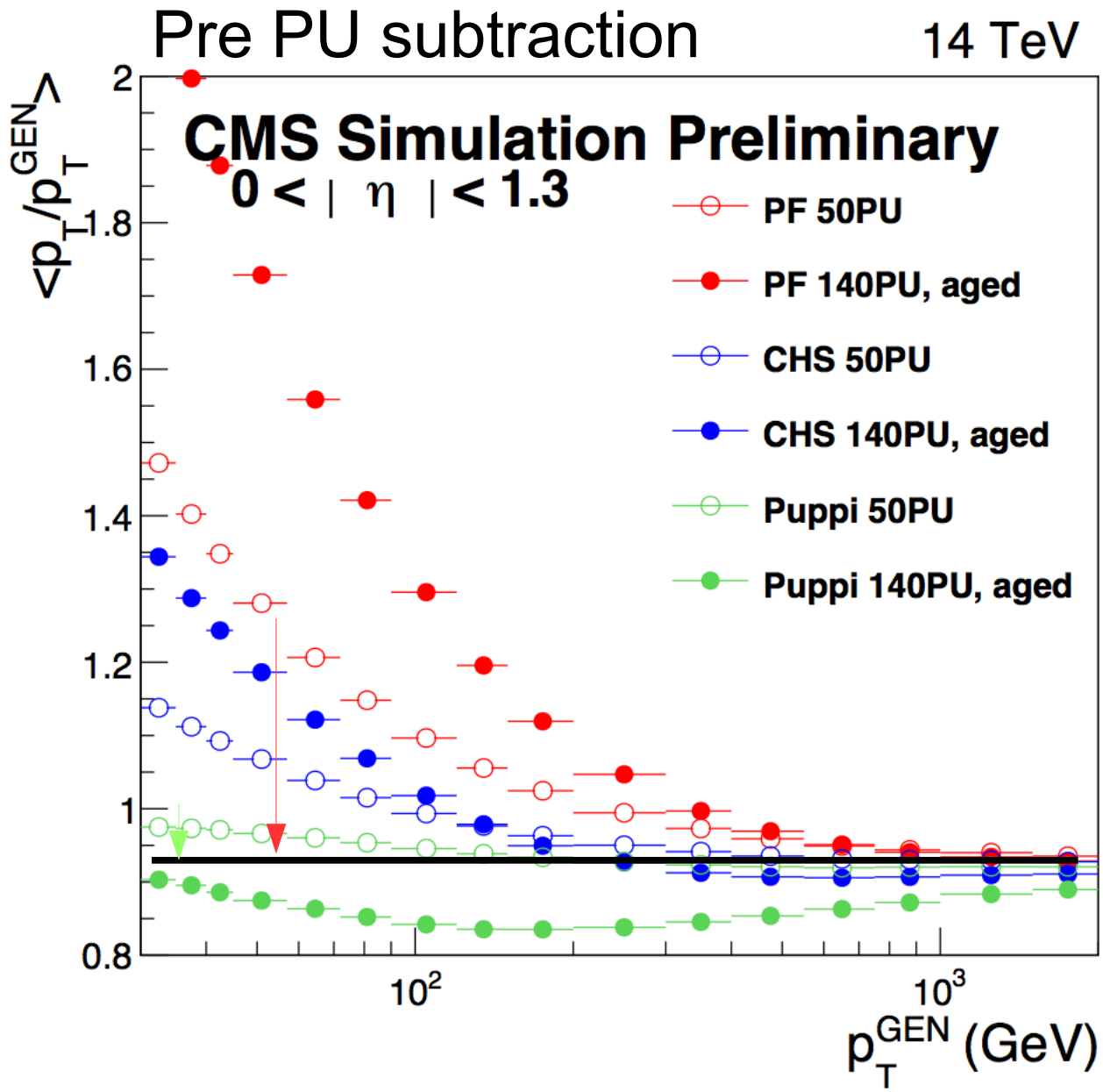
Constituent Subtraction
ρA correction per particle

Soft Killer
Median ρ removal
Per particle

JME-DP-13-018
JME-14-001

Evolution of PU Subtraction

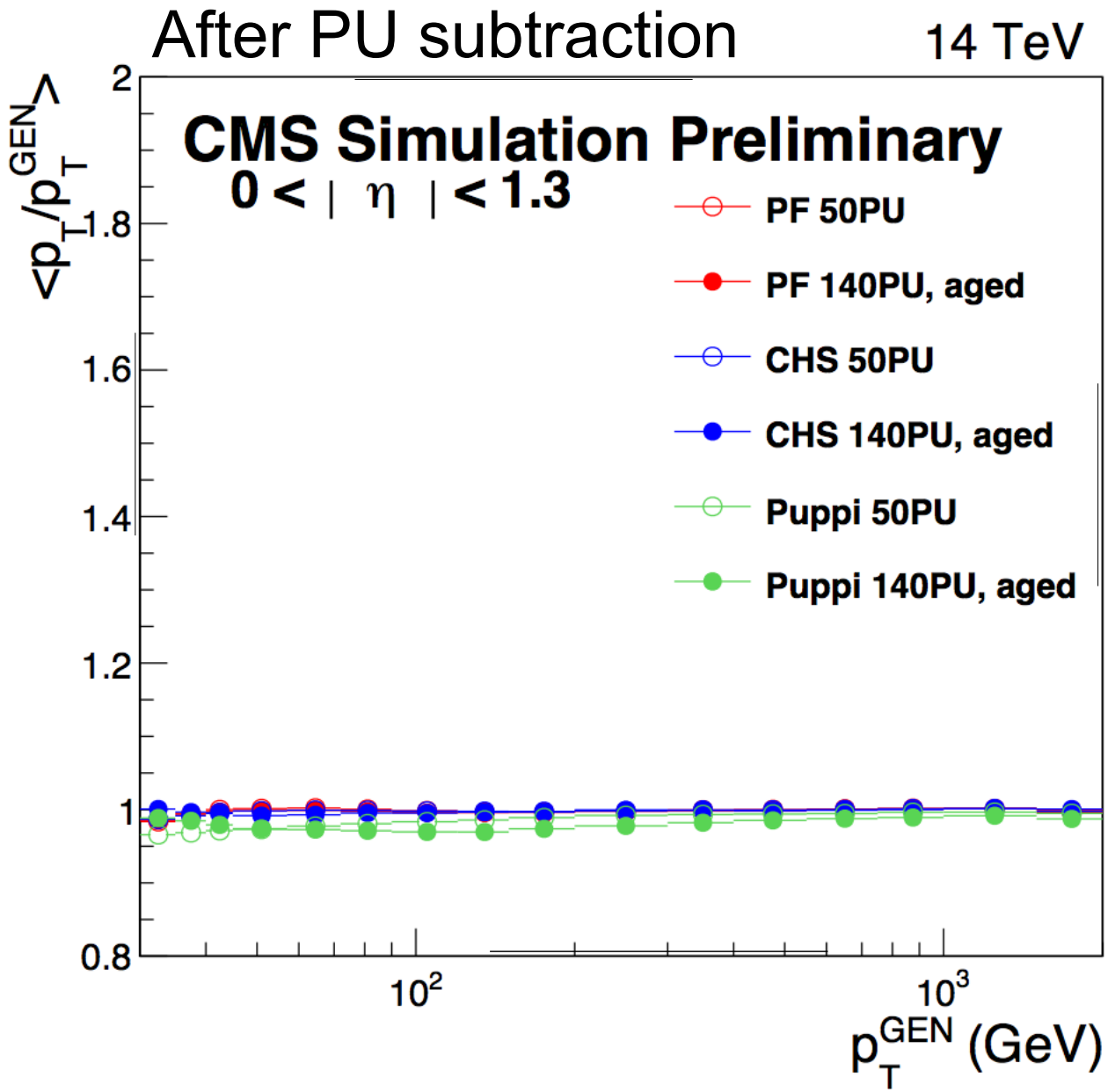
Aim is to remove pileup at particle level



FTR-ECFA

Evolution of PU Subtraction

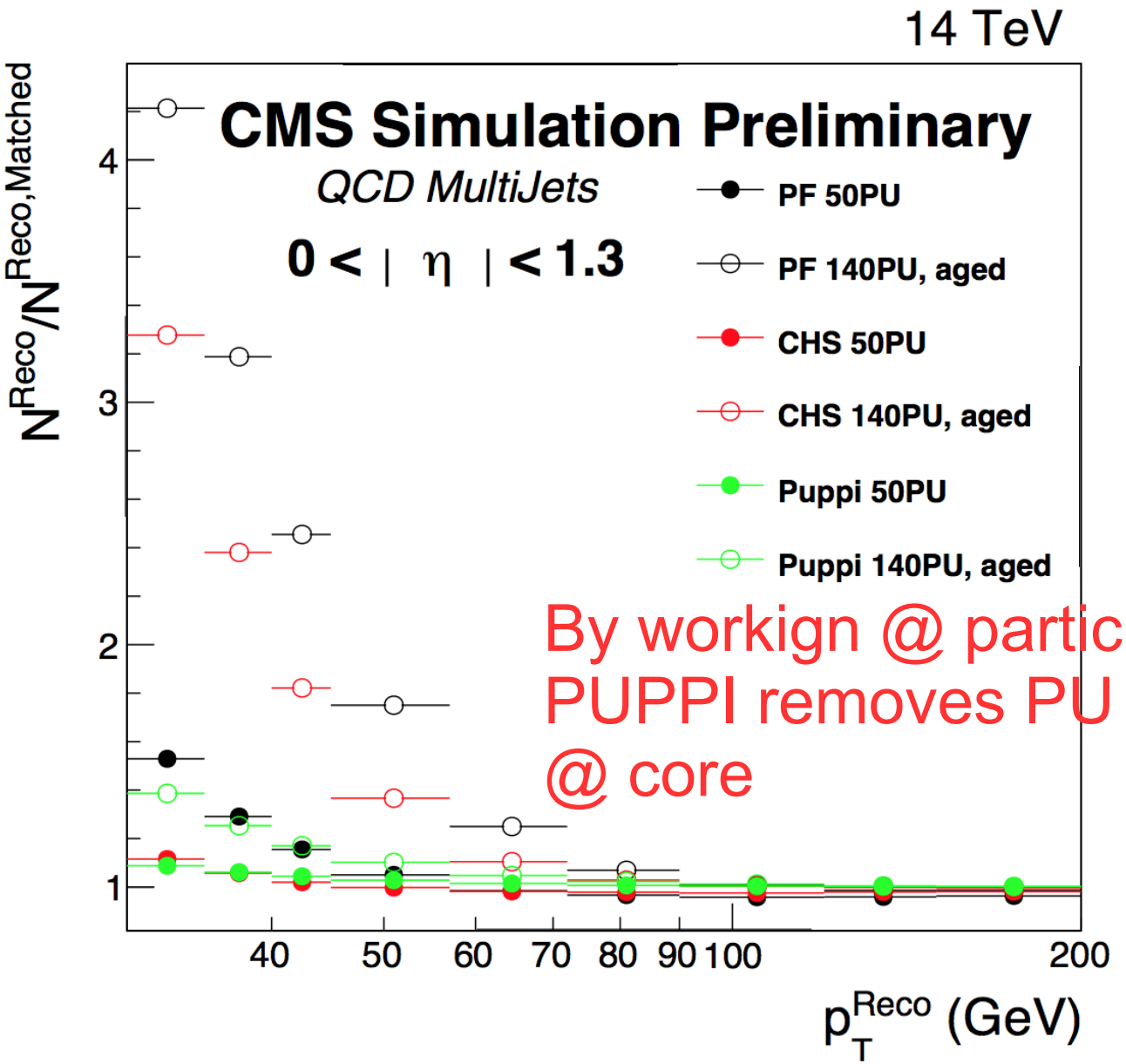
Aim is to remove pileup at particle level



FTR-ECFA

Evolution of PU Subtraction

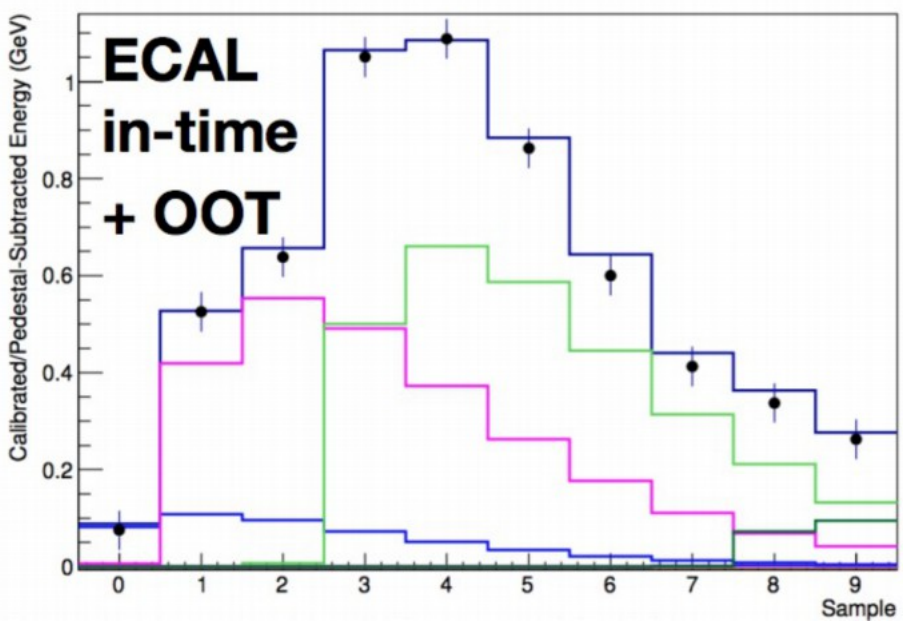
Aim is to remove pileup at particle level

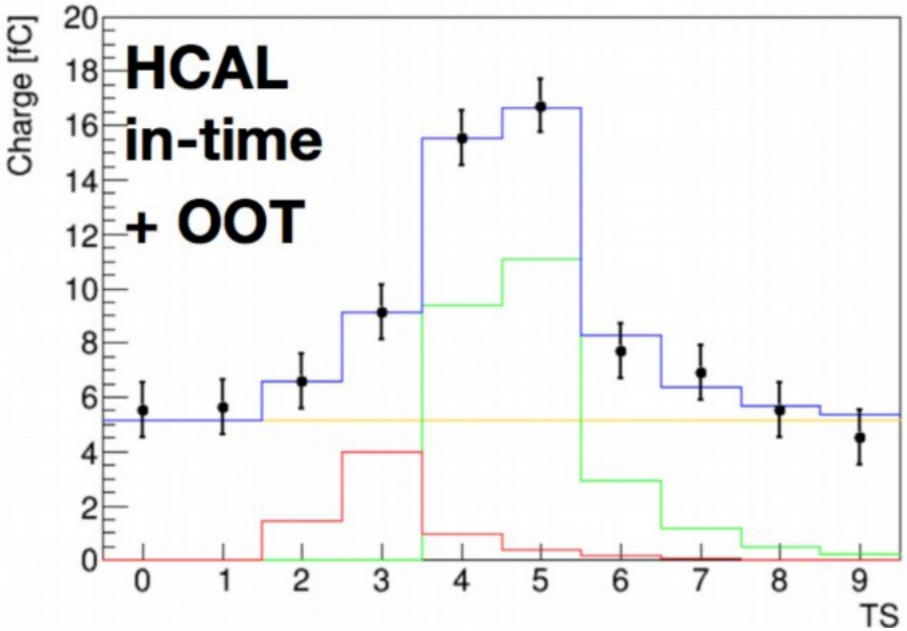


By workign @ particle level PUPPI removes PU Jets @ core

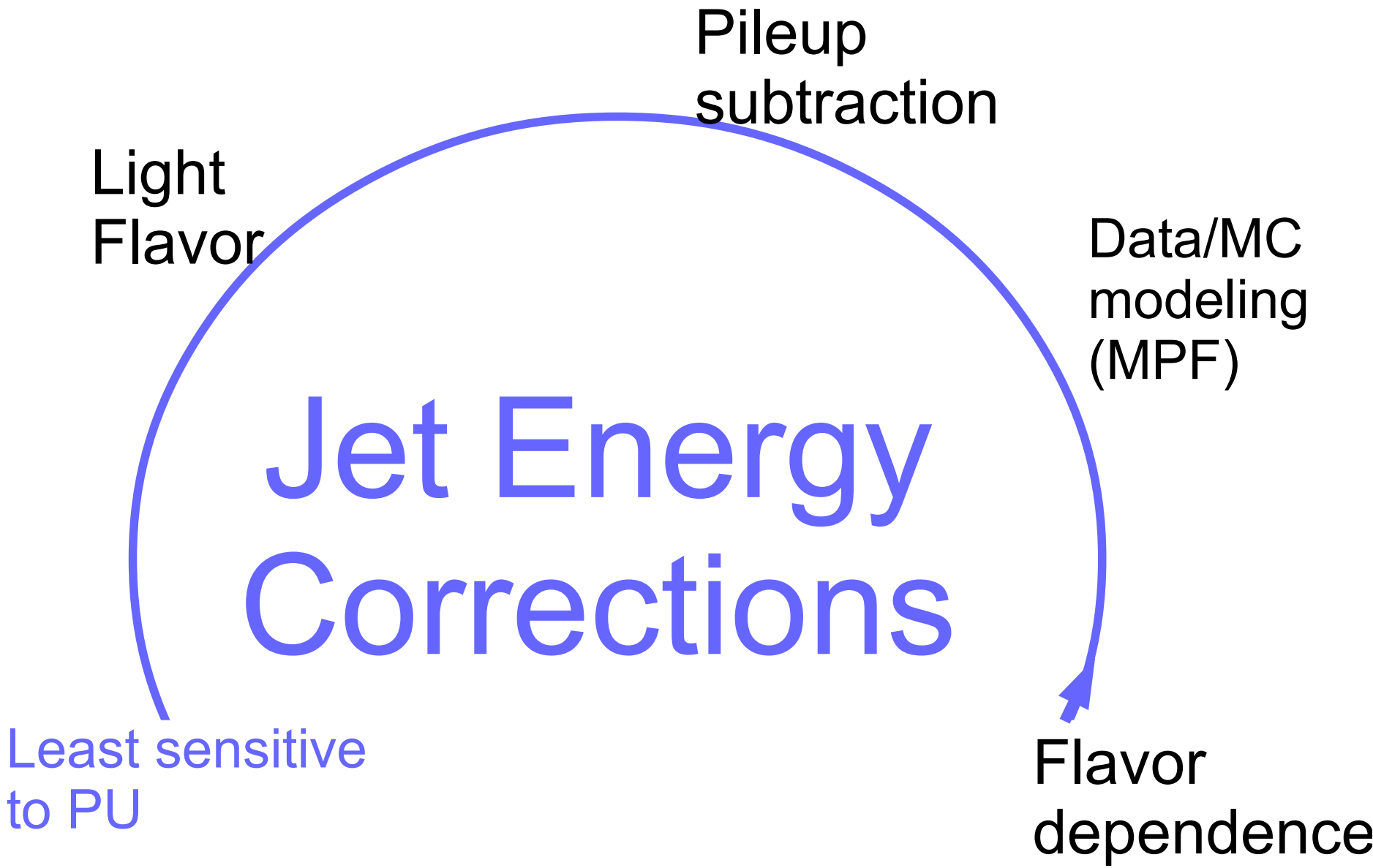
25ns or Bust!

- Solved the issue of 25ns reconstruction



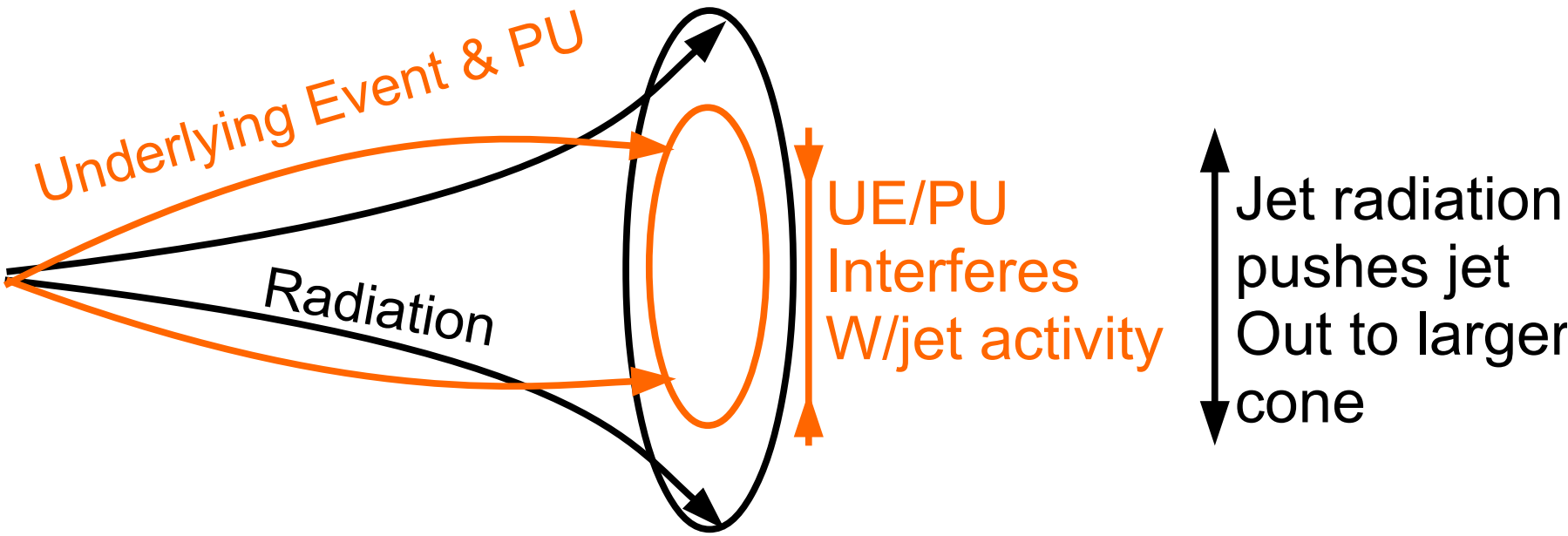


- Analysis strategy is in place for calorimeters
- Expect small degradation from 25ns running
  - Out of time pileup will be a small issue


Pileup subtraction
Light Flavor
Data/MC modeling (MPF)
Jet Energy Corrections
Least sensitive to PU
Flavor dependence

Jet Energy Correction

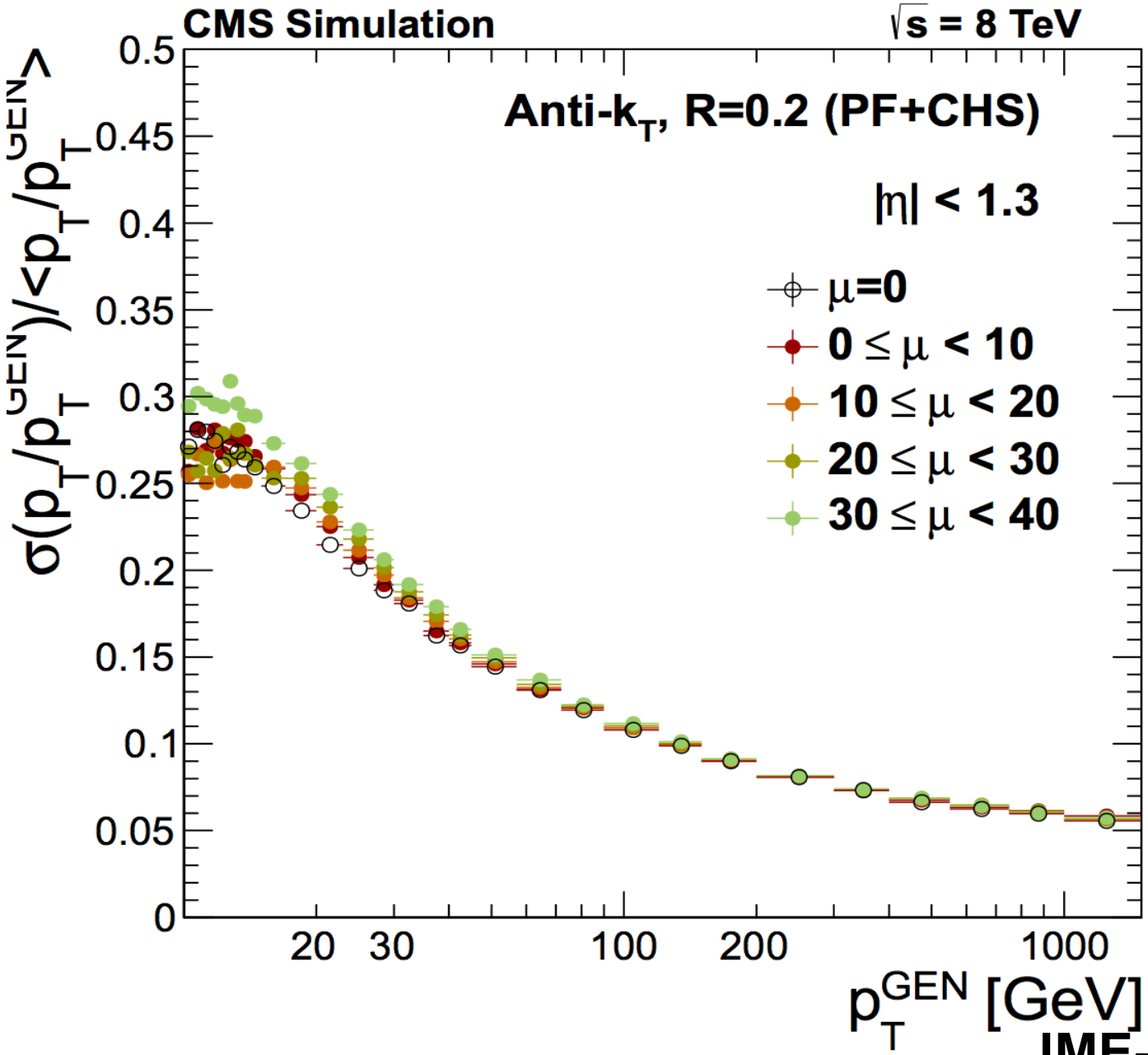
- Correcting to truth



Why did CMS switch to AK4?

Jet Energy Correction

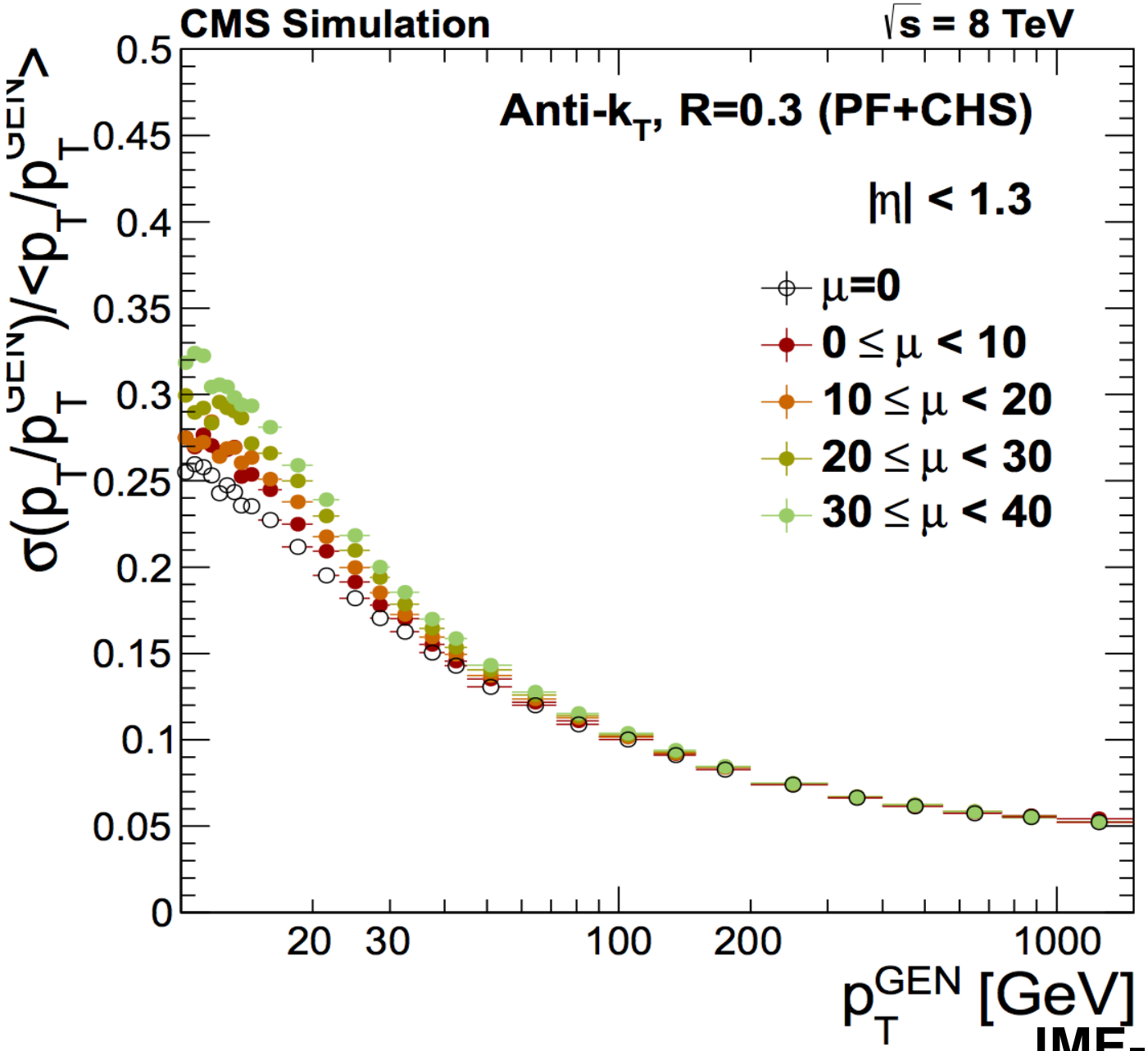
- AK2



JME-DP-14/037

Jet Energy Correction

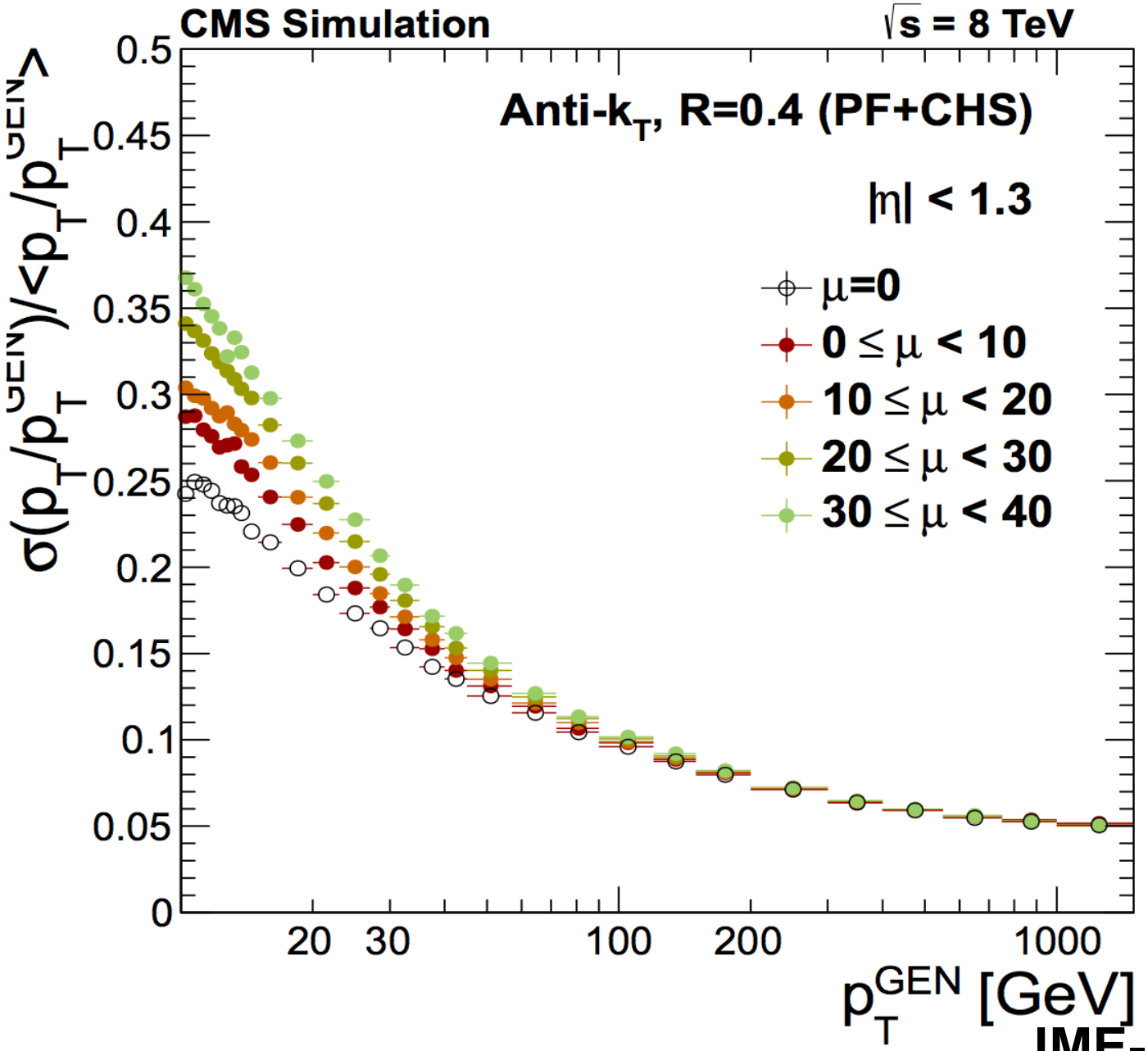
- AK3



JME-DP-14/037

Jet Energy Correction

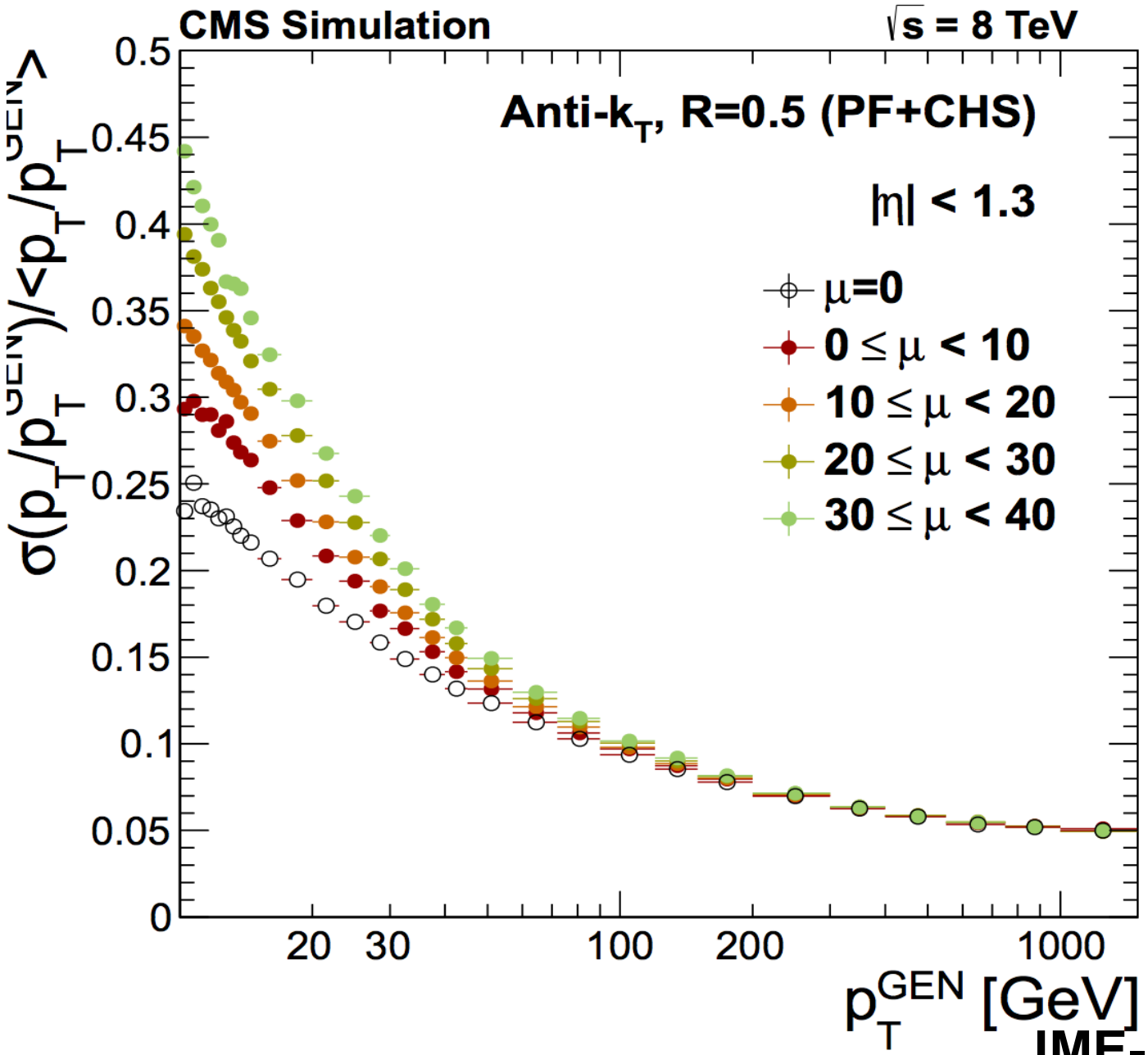
- AK4



JME-DP-14/037

Jet Energy Correction

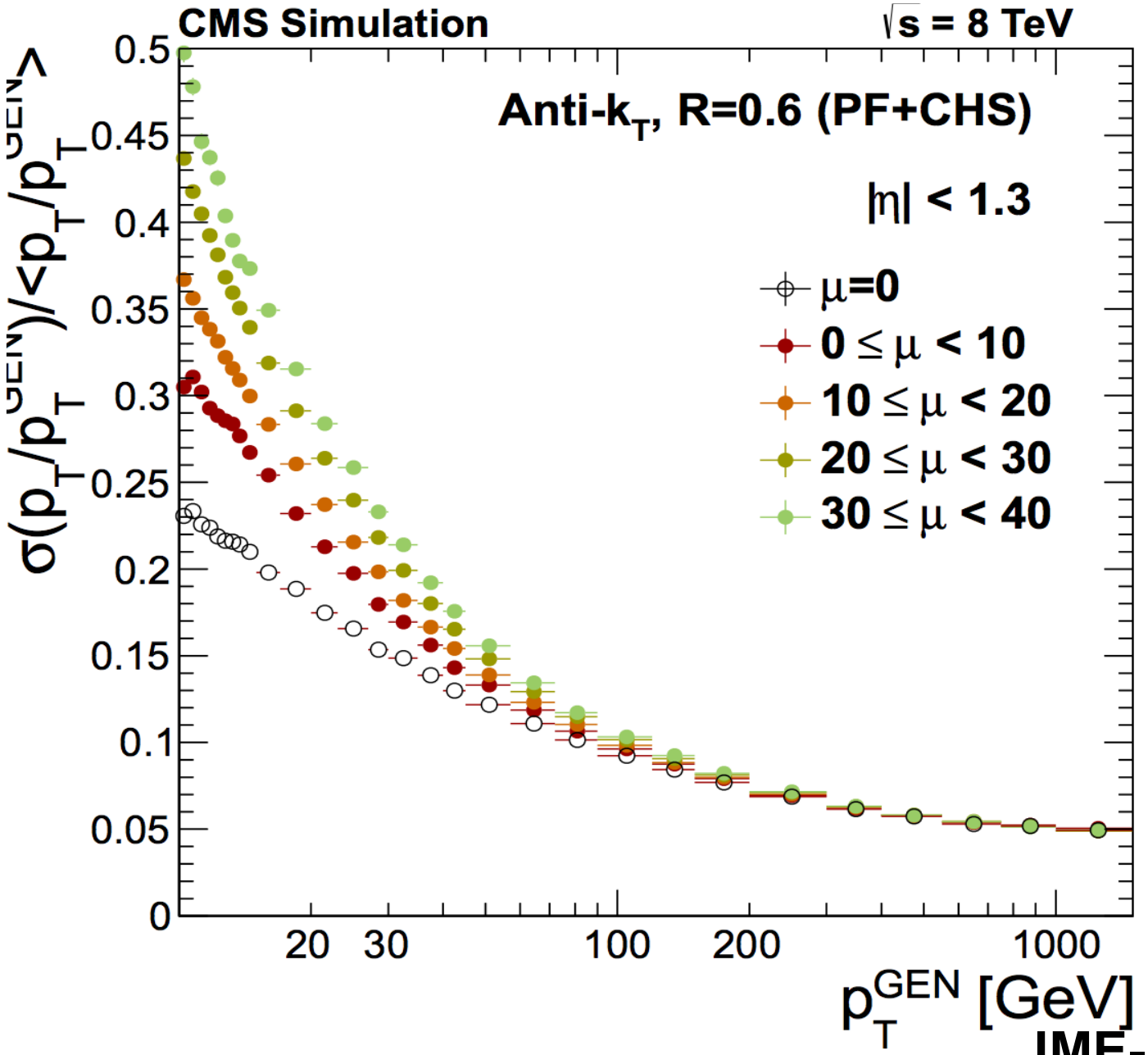
- AK5



JME-DP-14/037

Jet Energy Correction

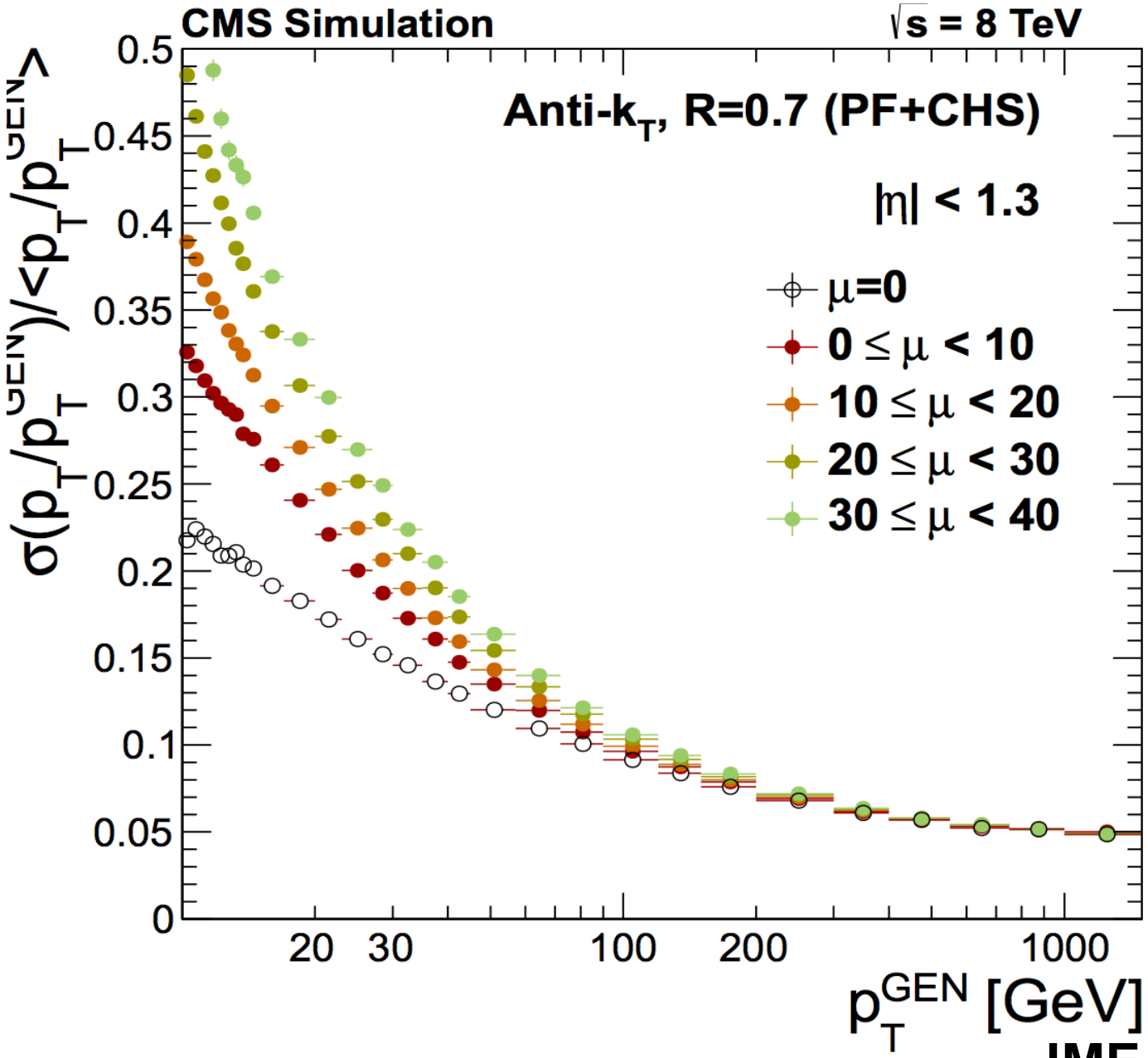
- AK6



JME-DP-14/037

Jet Energy Correction

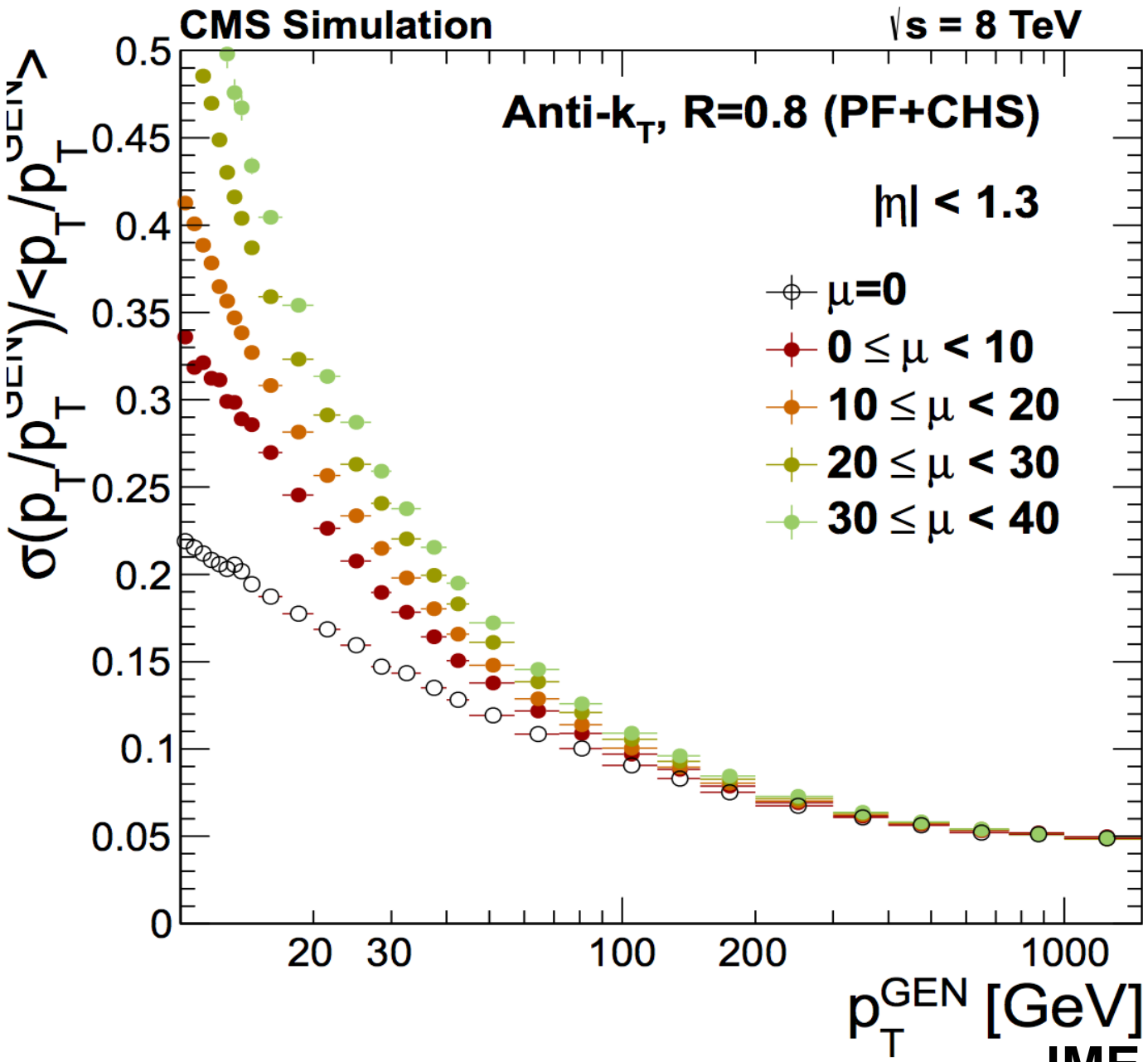
- AK7



JME-DP-14/037

Jet Energy Correction

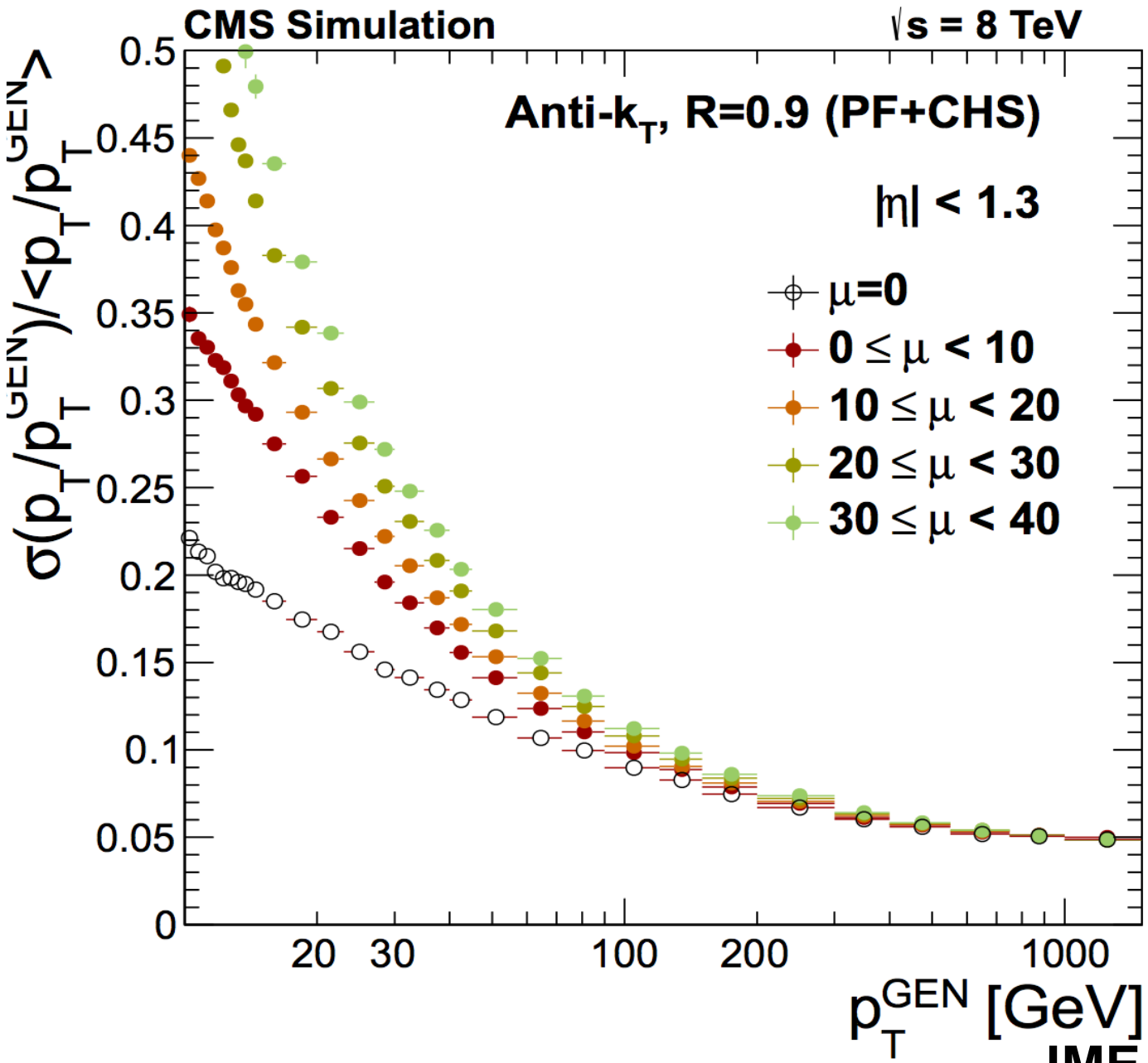
- AK8



JME-DP-14/037

Jet Energy Correction

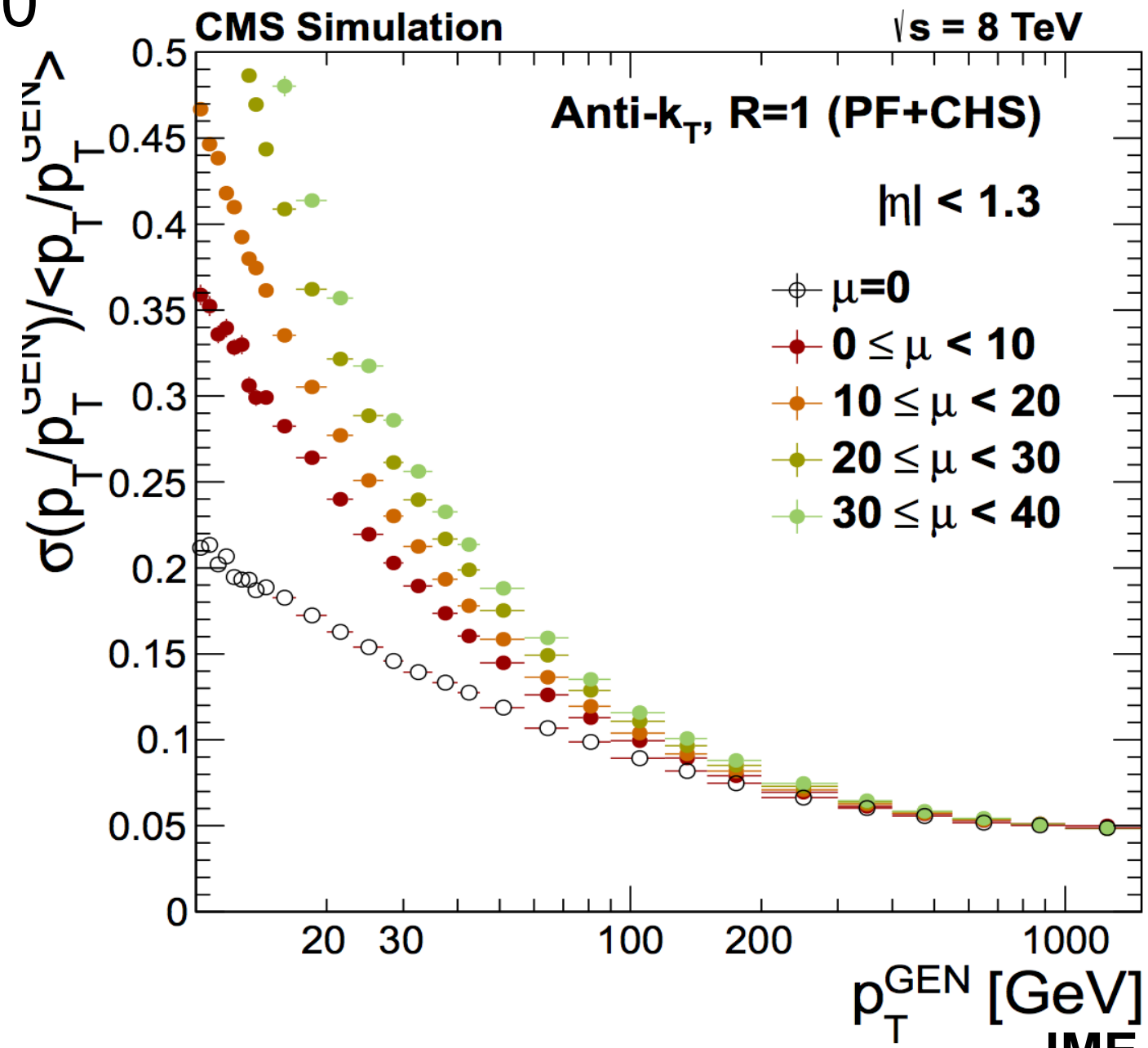
- AK9



JME-DP-14/037

Jet Energy Correction

- AK1.0



JME-DP-14/037

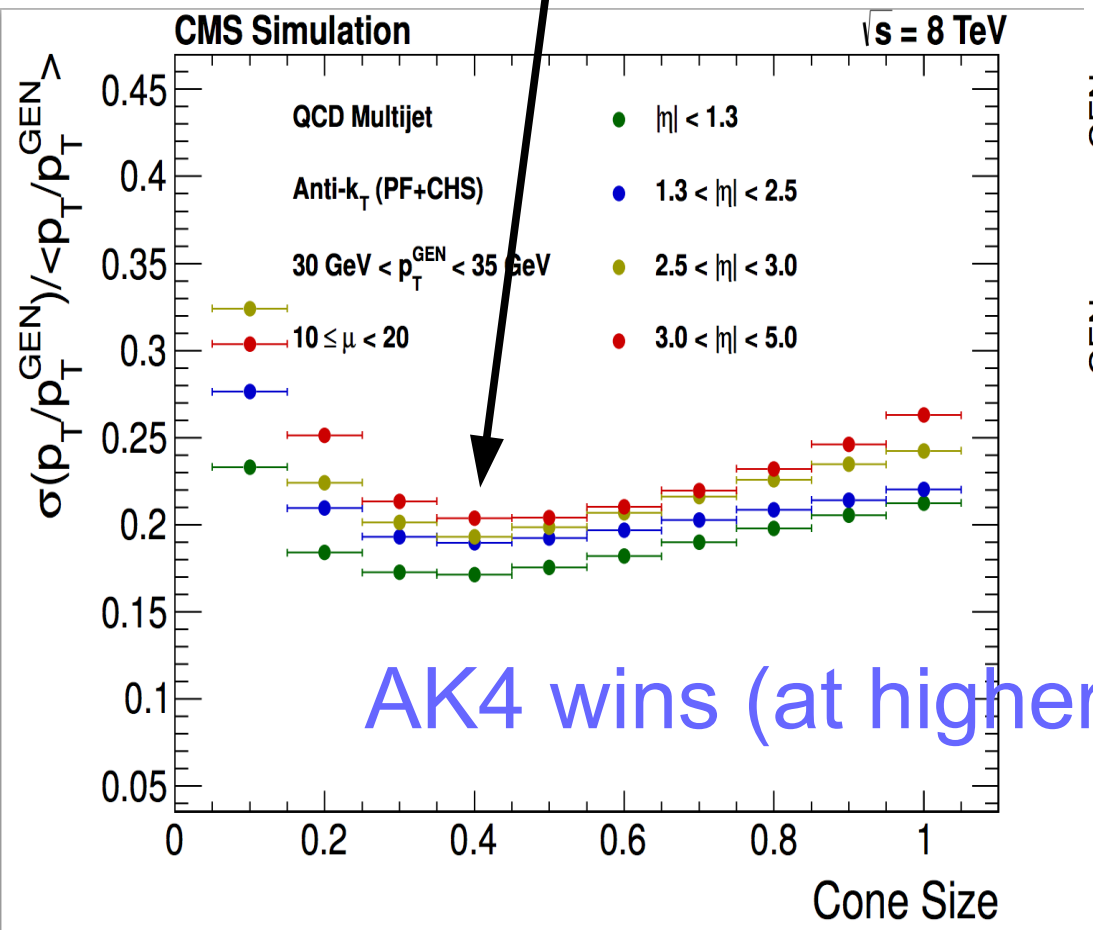
Jet Energy Correction

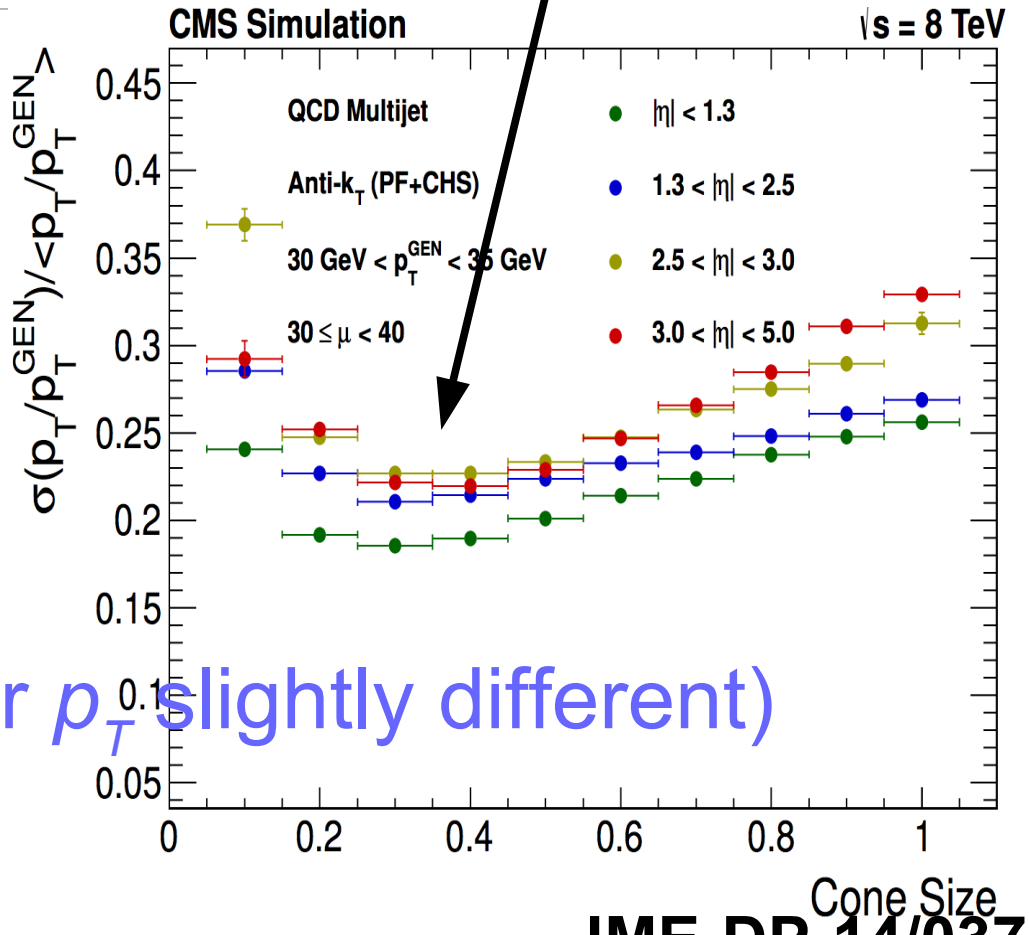
- Executive Summary :

We switch to AK4

Run I PU

Run II PU





AK4 wins (at higher p_T slightly different)

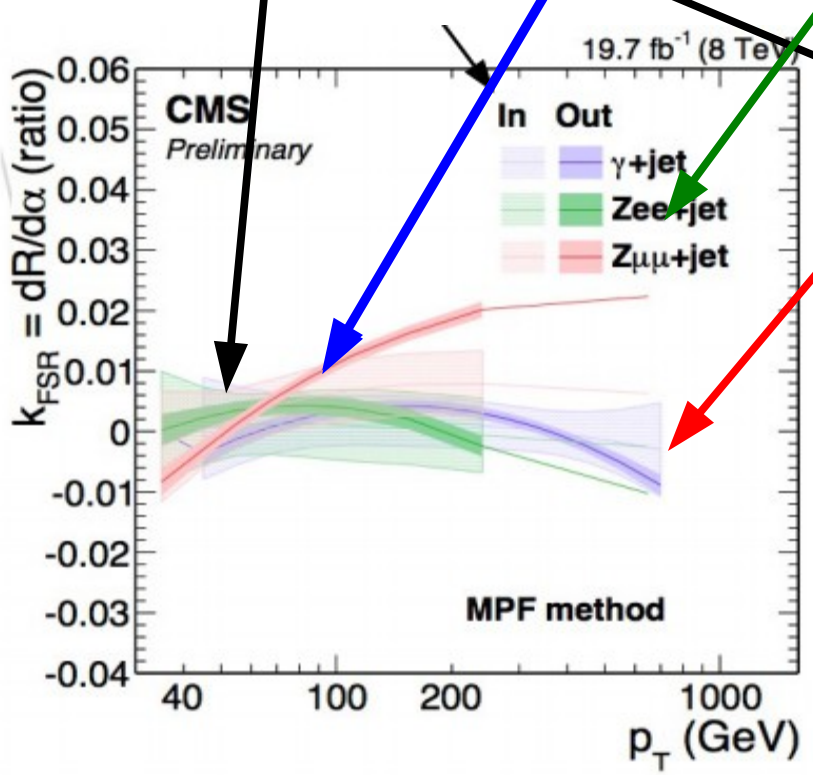
JME-DP-14/037

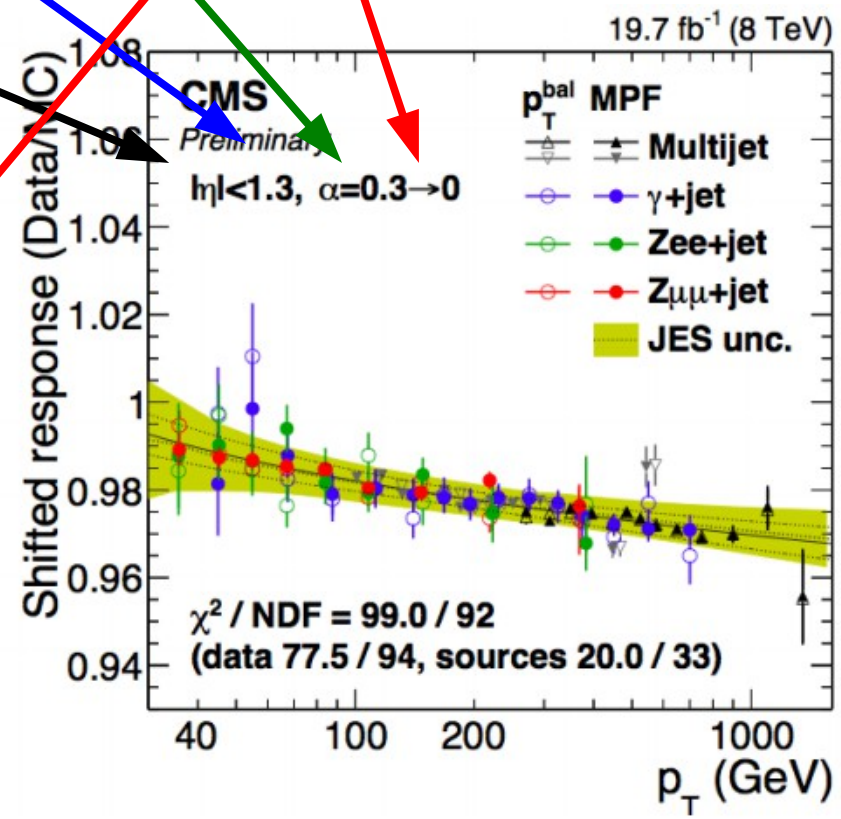
Global Fit

- Data/MC understood by a global fit

QCD Mulitjet γ+jet Zee+jet Zμμ+jet

...

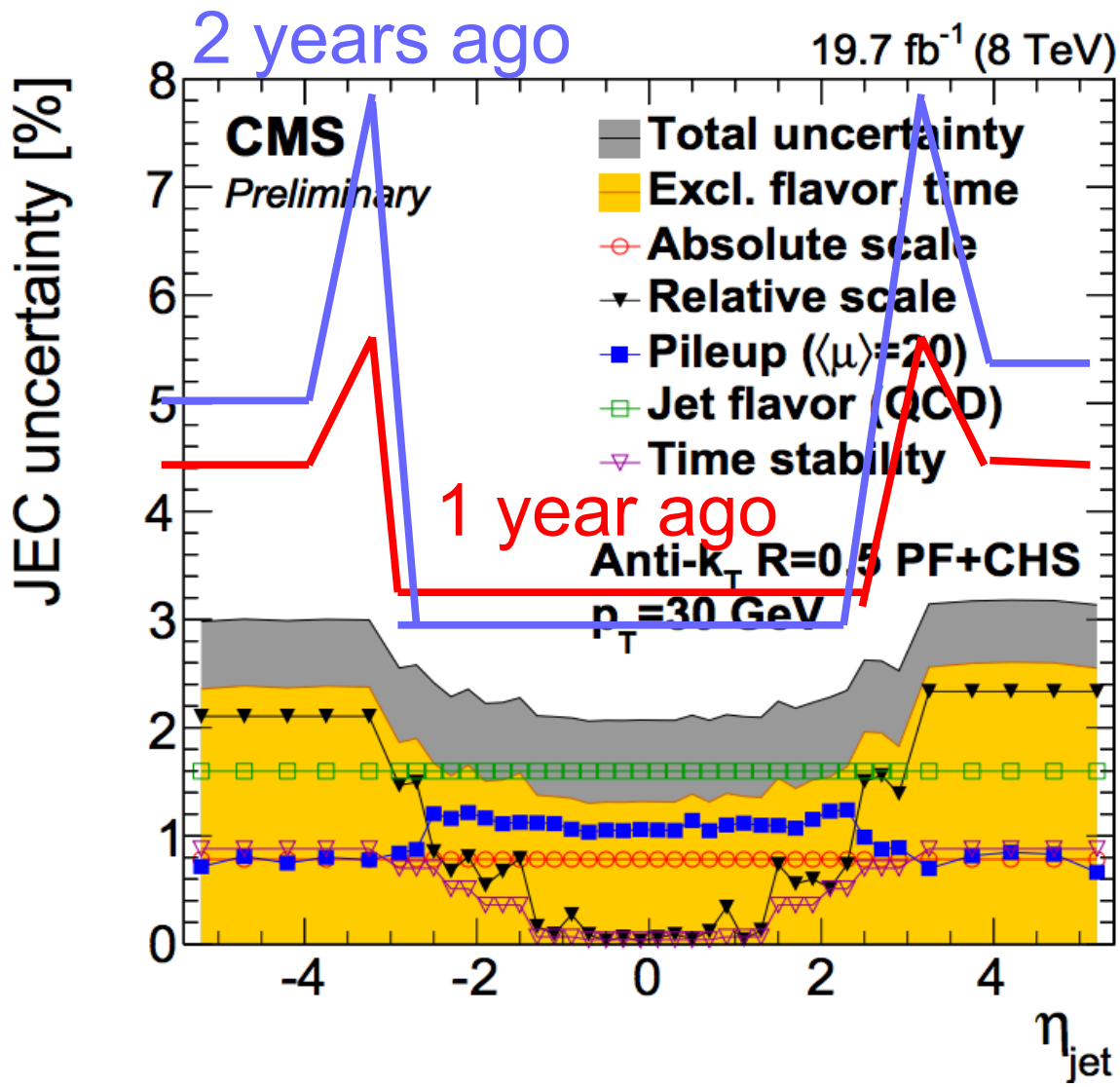




Profile all unc. : Lep. scale/Response/...

JME-13-004

Jet Energy Scale

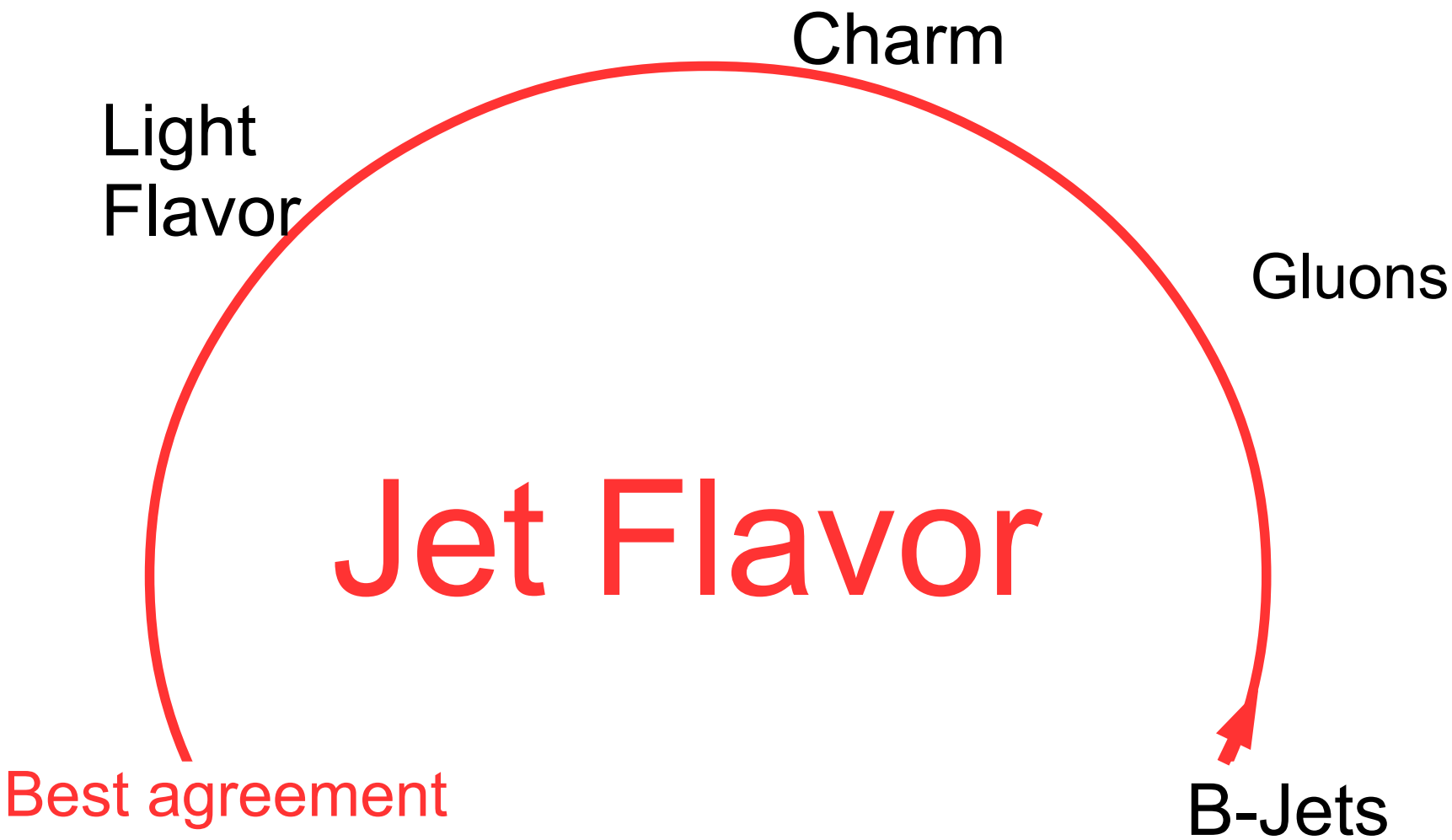


Understanding of JEC
Steadily improved

As we dealt with detector effects

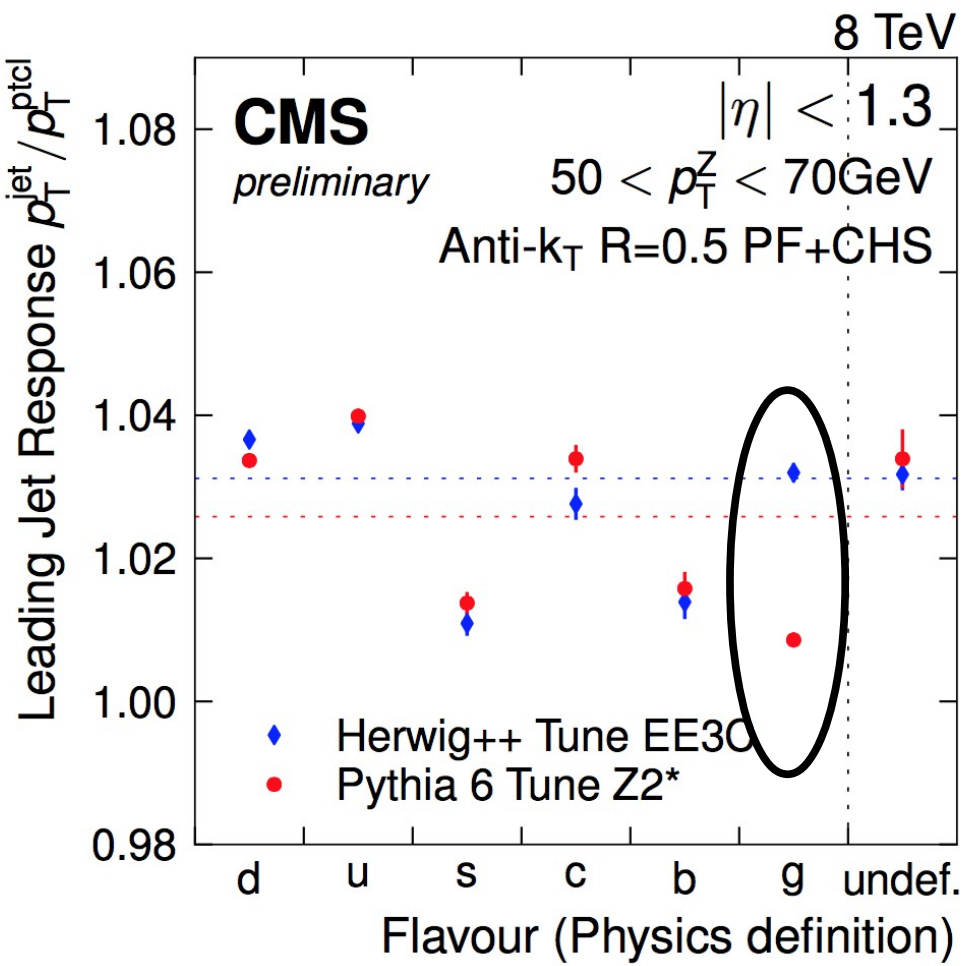
- Run II: expect same trend with a faster timescale
- We are now down to 3% uncertainty a 30 GeV!

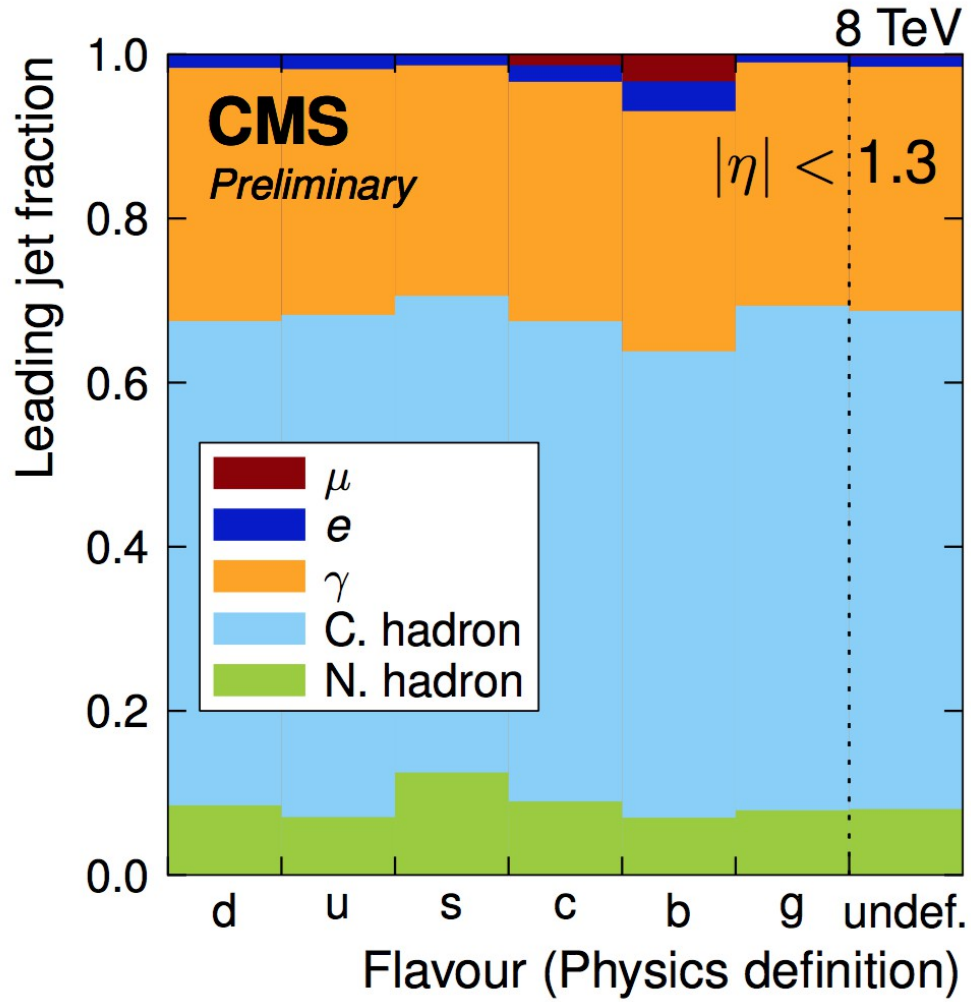
JME-13-004


Charm
Light
Flavor
Gluons
Jet Flavor
Best agreement
B-Jets

Splitting by Flavor

- Flavor is known to vary in response





Isolating flavor based jet variations are key to beating down jet scale

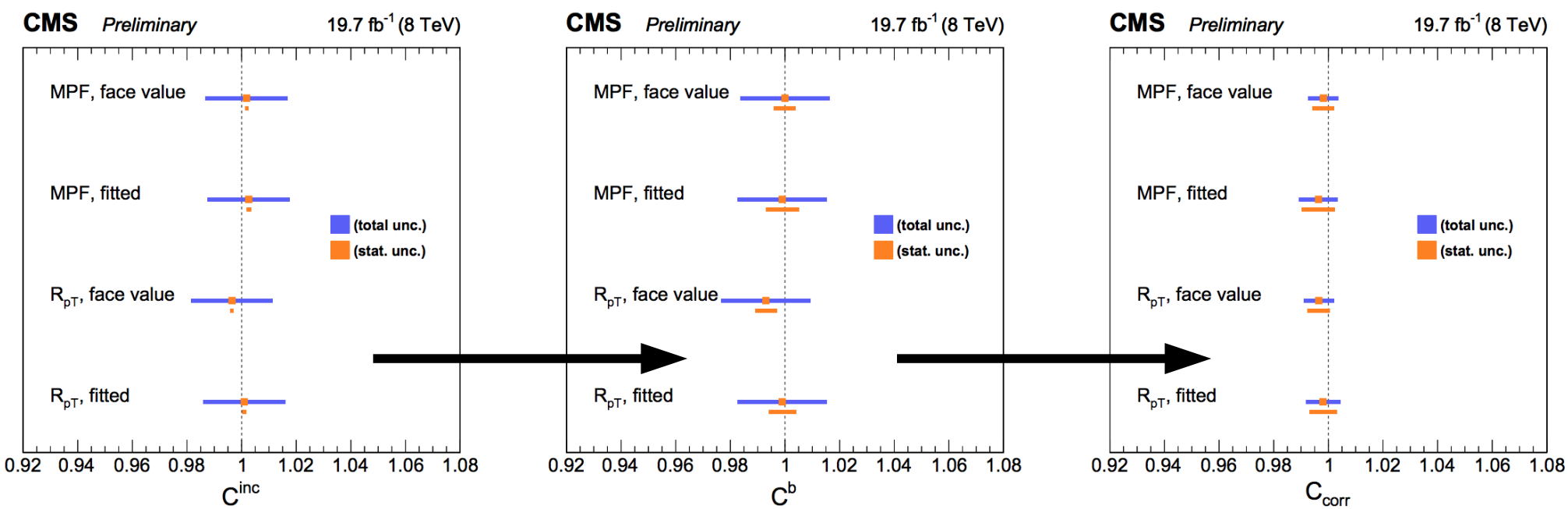
JME-13-004

Isolation of Quarks

Quark Jets

b(displaced) Jets

$$\frac{1}{\text{Quark Jets}} \times \text{b(displaced) Jets} = \text{Sub percentage precision}$$

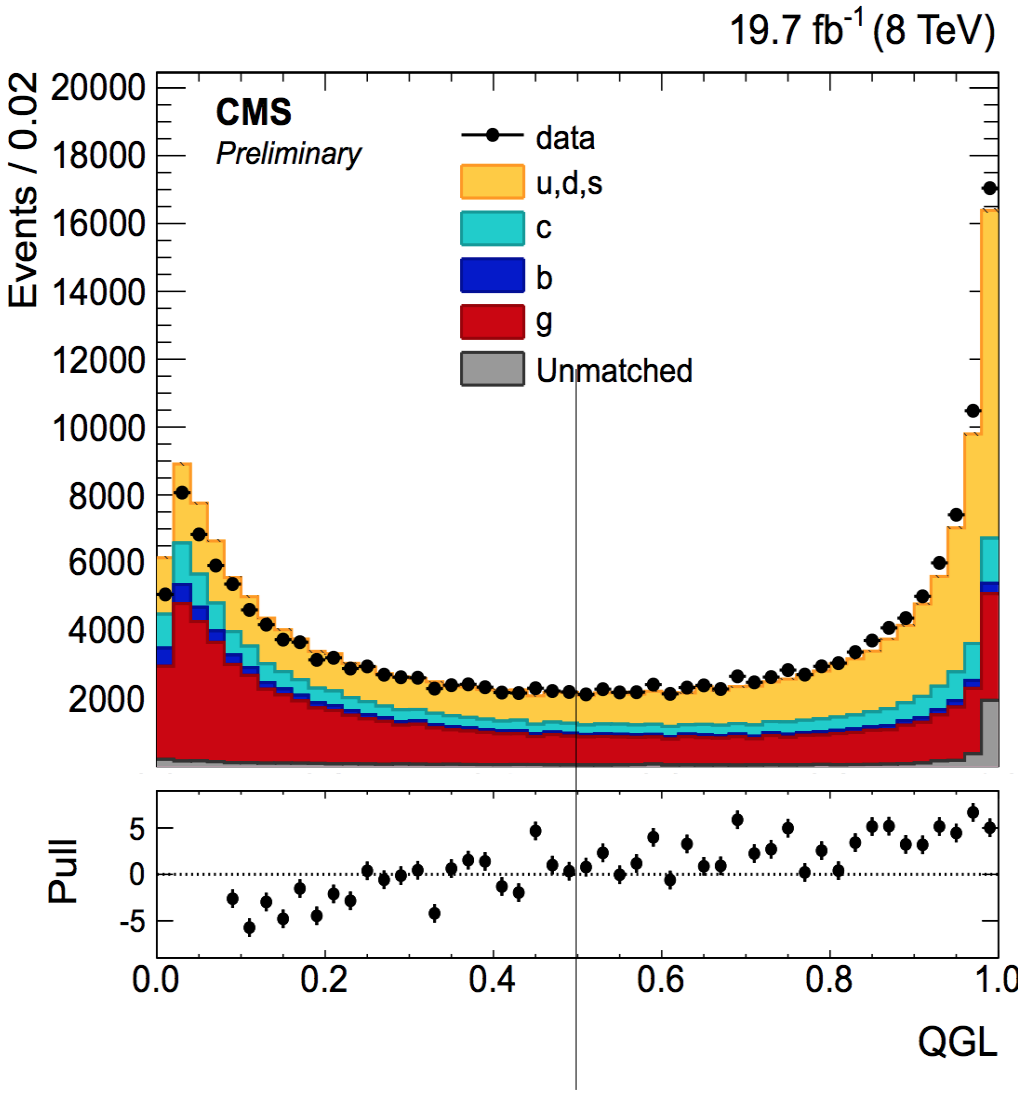


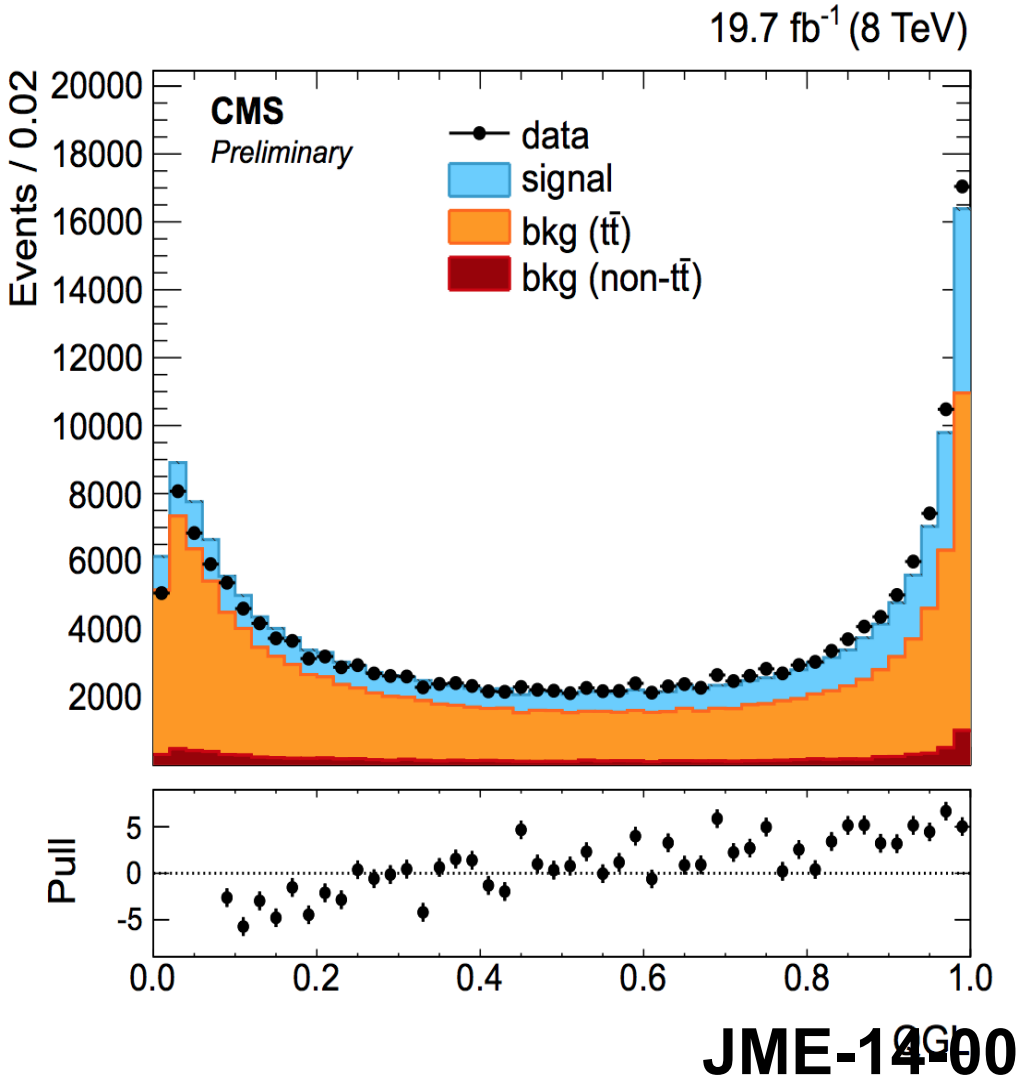
Correction confirms no significant deviation in b vs light flavor response

JME-13-001

Isolating Gluons

- Quarks and gluons can be separated
  - One of our benchmark channels are tops

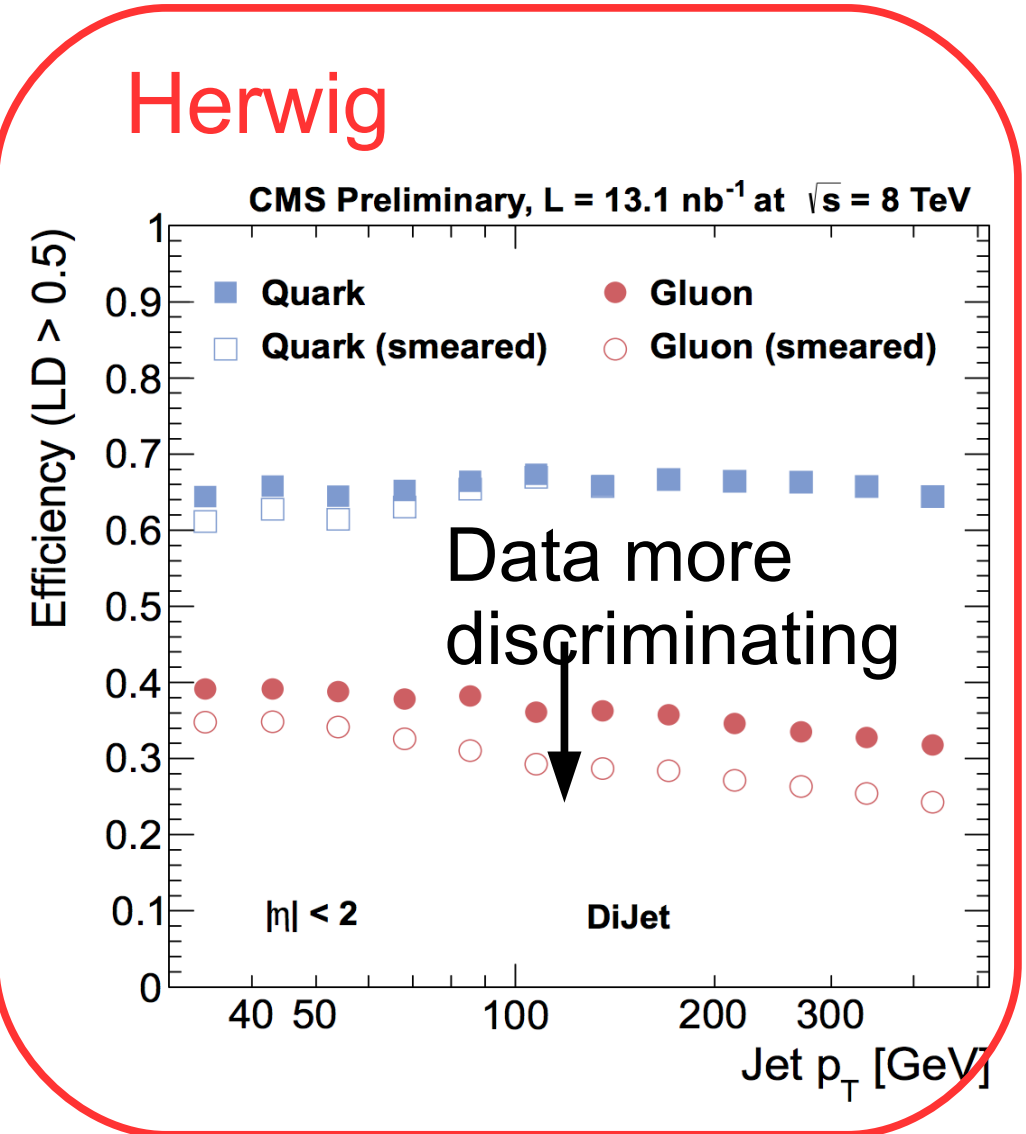


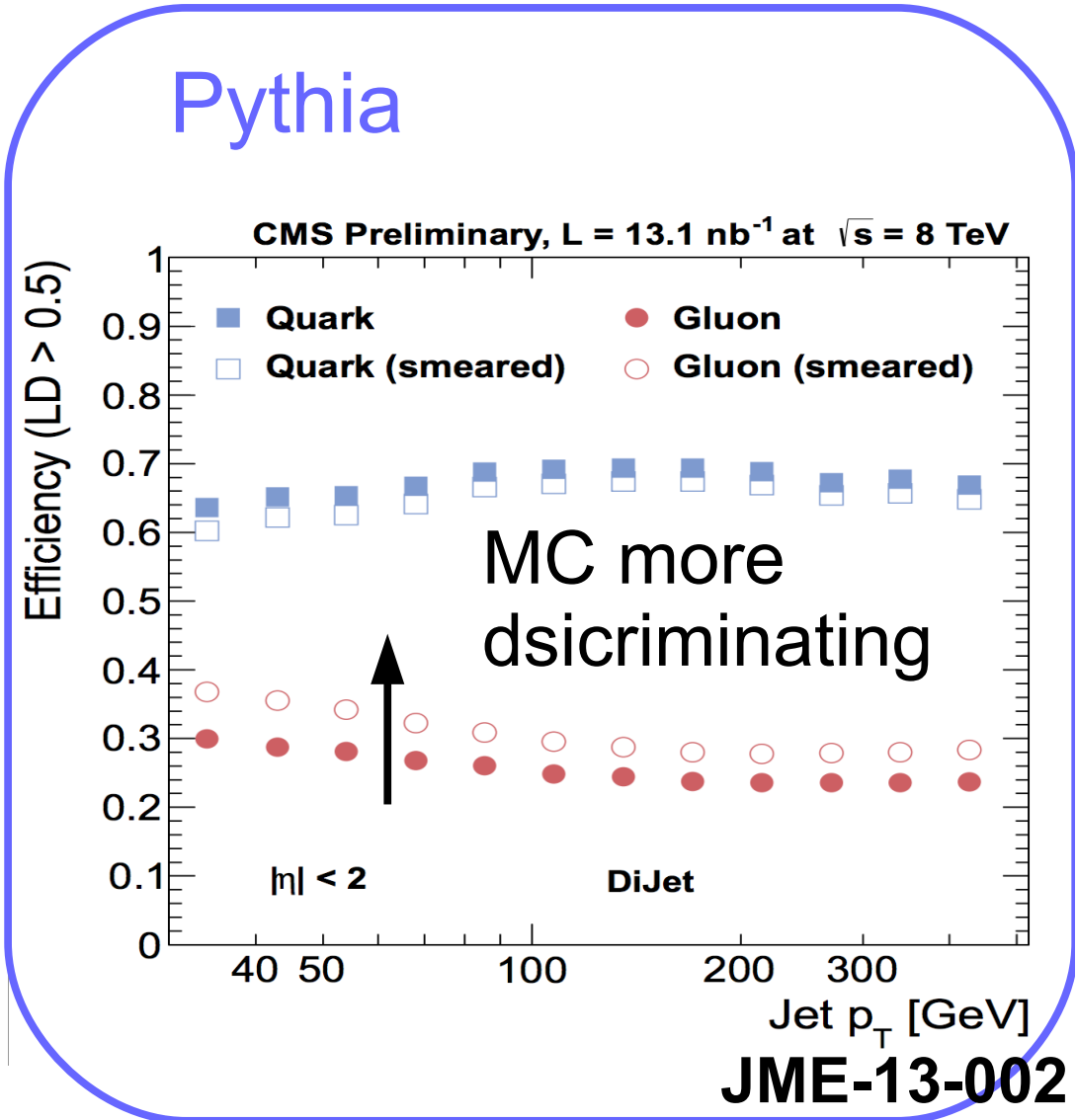


JME-14-002

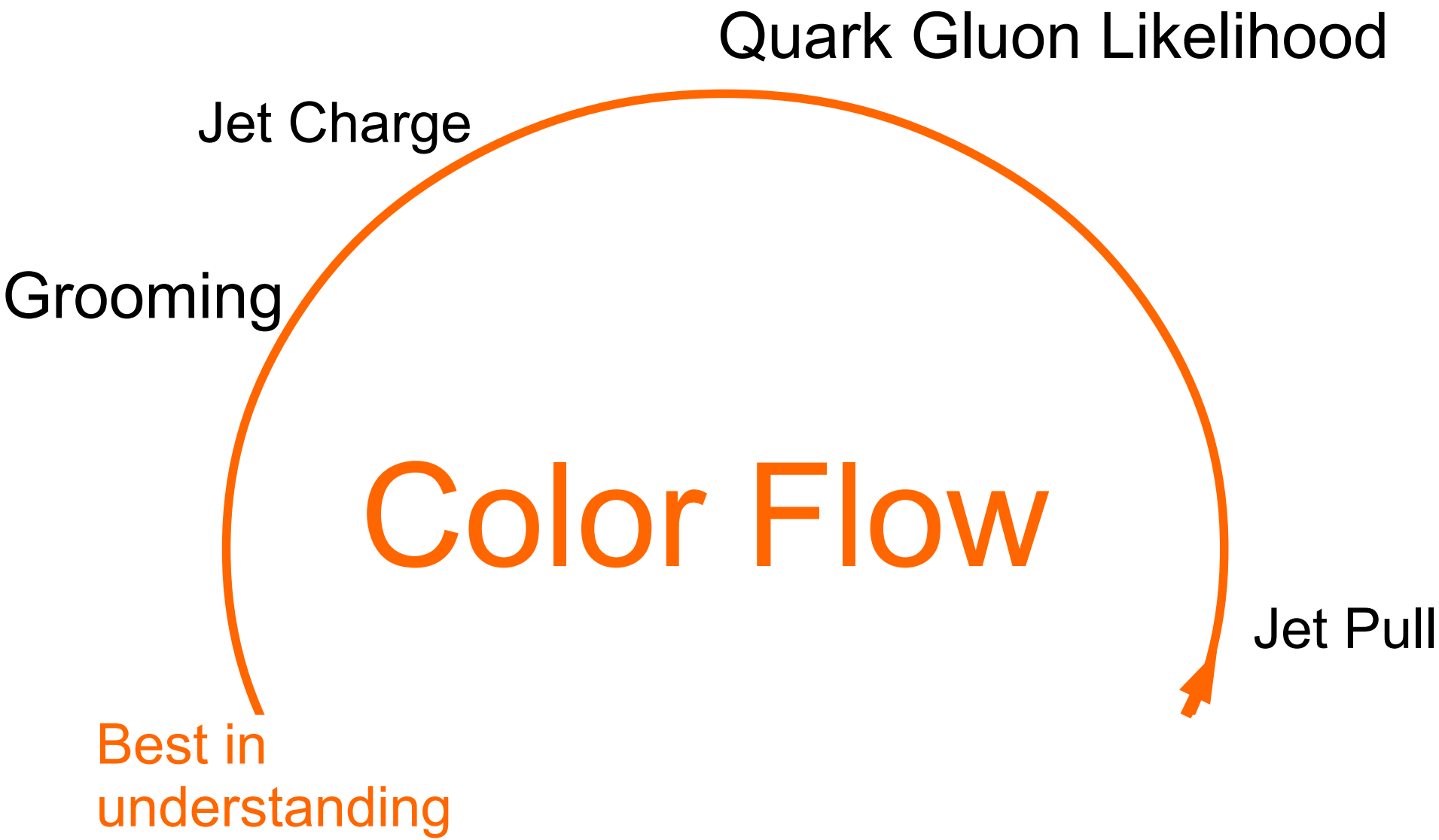
Isolating Gluons

- Differences between data,Pythia and Herwig
  - Can be understood with the help of QGL





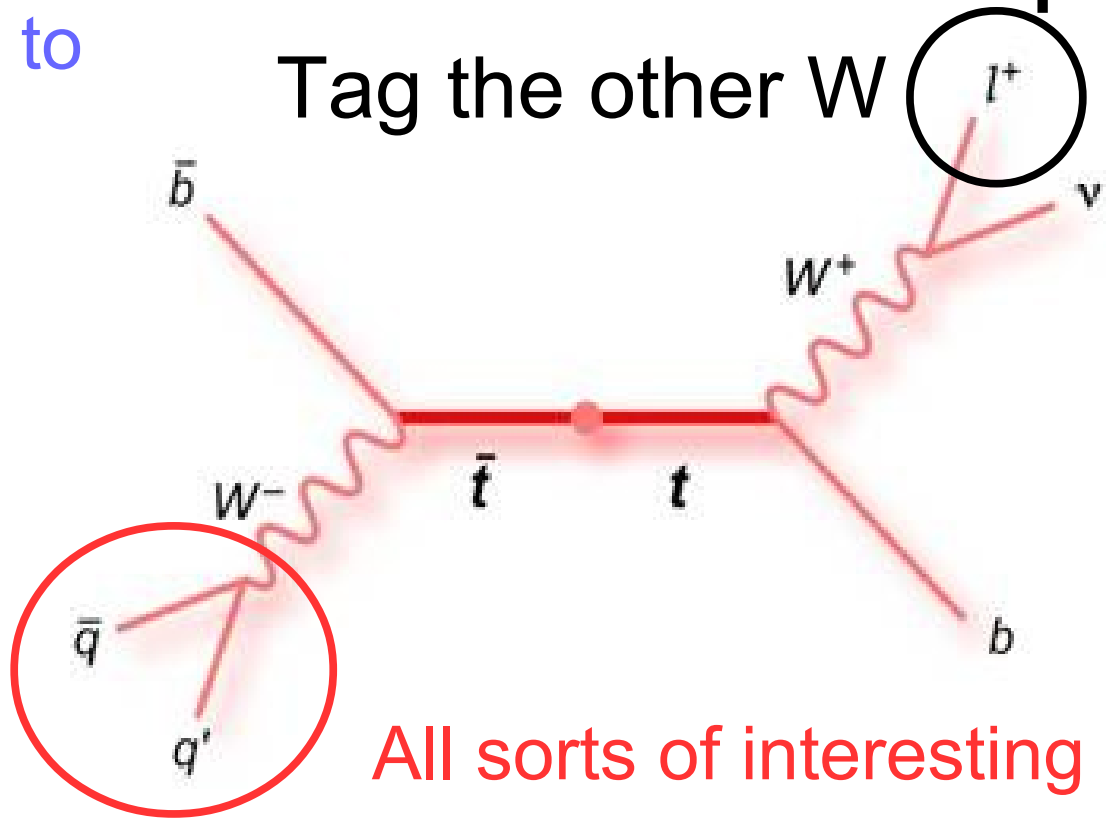
JME-13-002


Quark Gluon Likelihood
Jet Charge
Grooming
Color Flow
Jet Pull
Best in
understanding

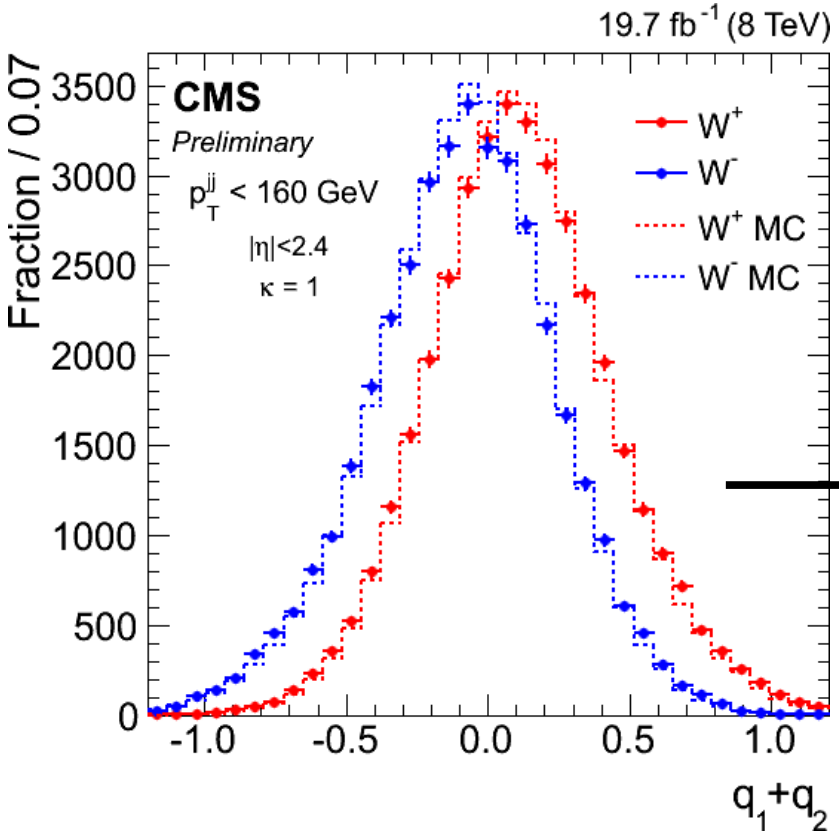
Fun with Tops

Tops have become a tool to understand the profound details of QCD

Tag the other W



All sorts of interesting stuff



Di-jet charge

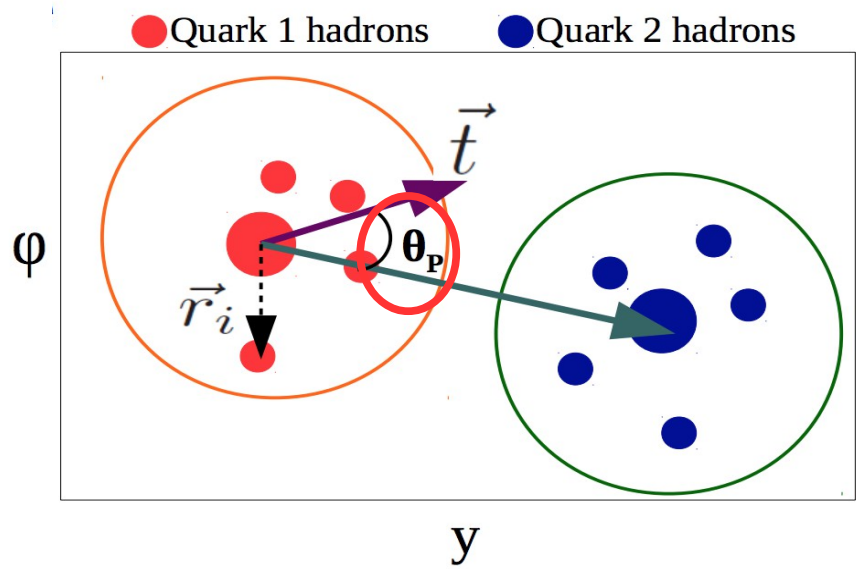
JME-13-006
JME-14-002

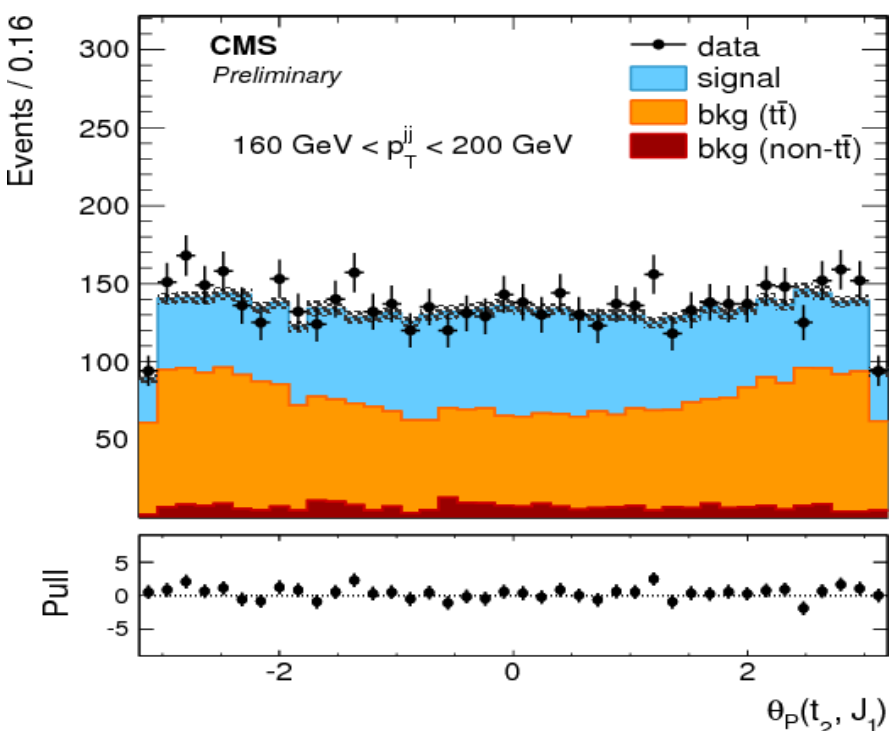
Color Flow in Tops

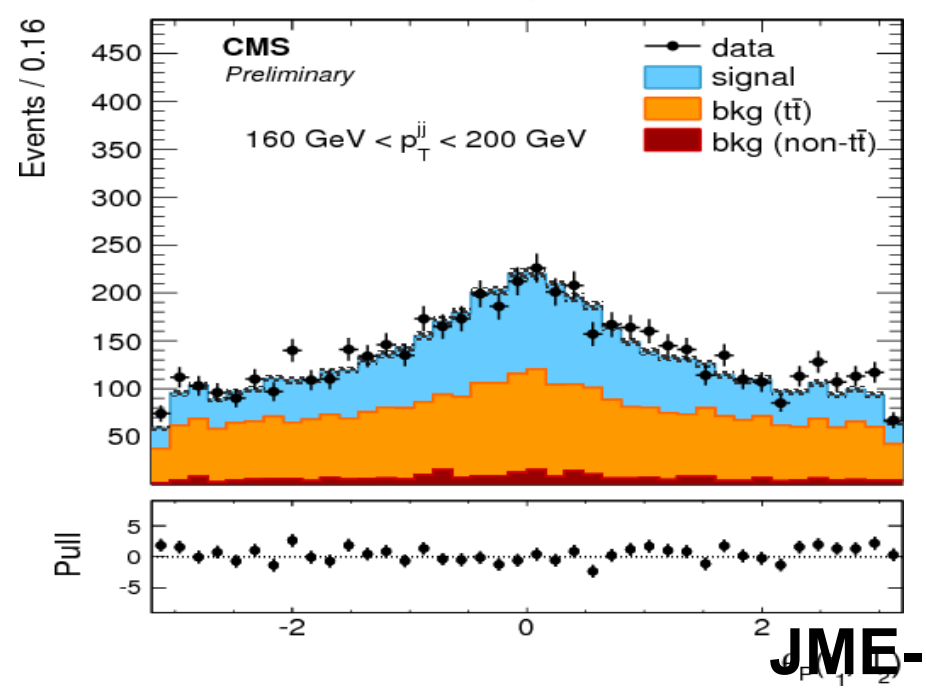
- Start to measure color flow between W bosons

$$\vec{t} = \sum_i \frac{(p_T)_i \, |r_i|}{(p_T)_{jet}} \vec{r}_i$$

$$\vec{r}_i = (\Delta y_i, \Delta \phi_i)$$







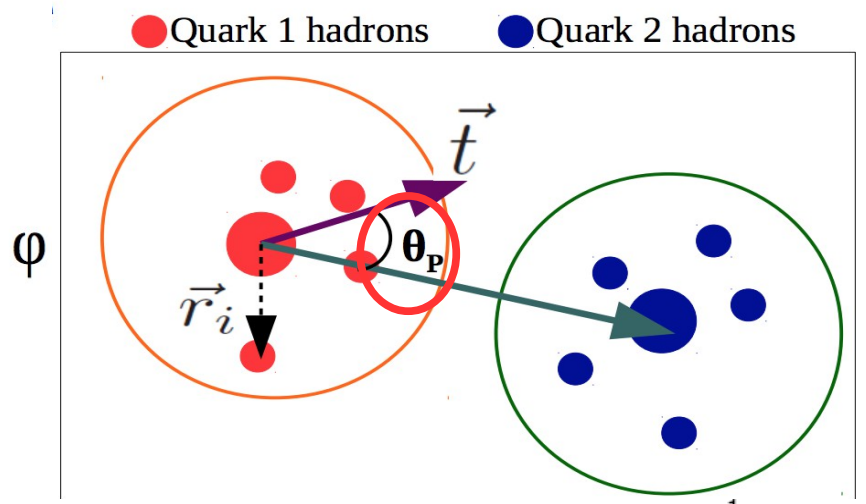
JME-14-002

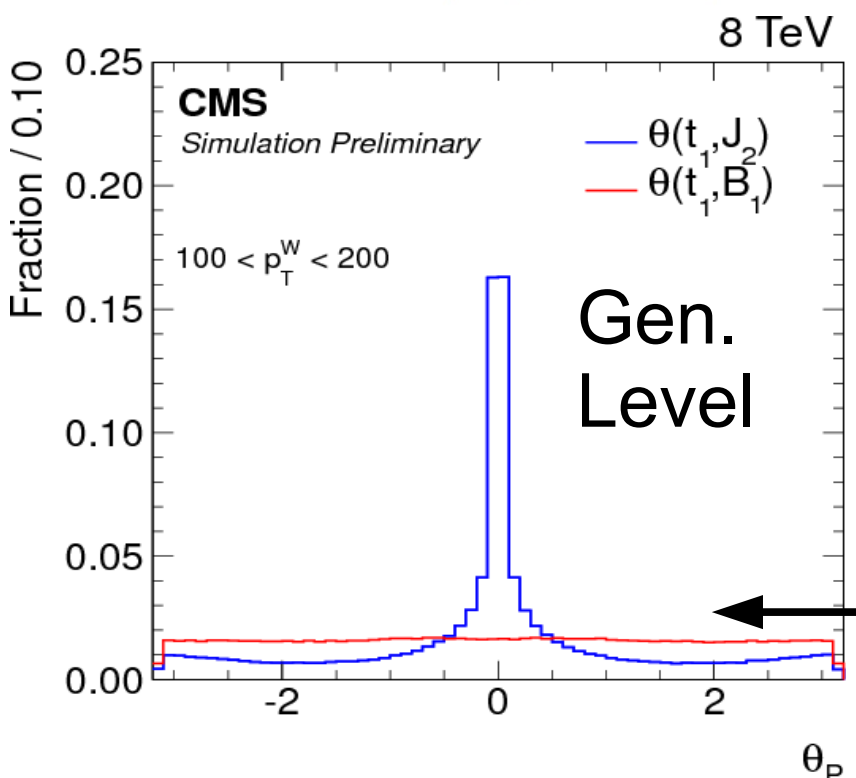
Color Flow in Tops

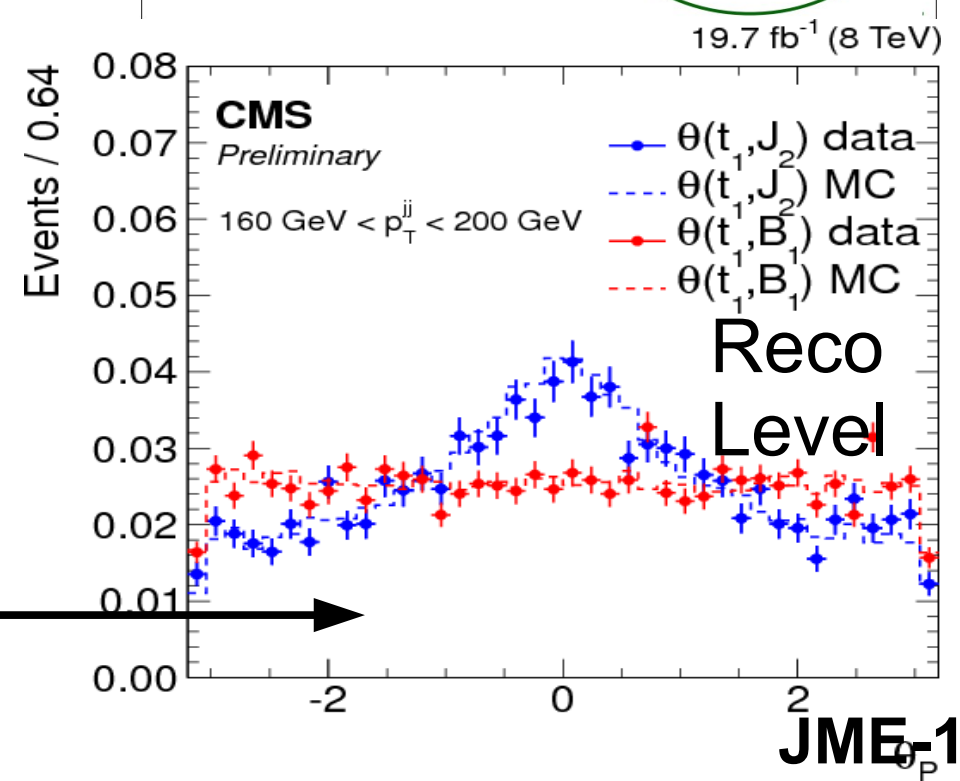
- Background subtracting

$$\vec{t} = \sum_i \frac{(p_T)_i \, |r_i|}{(p_T)_{jet}} \vec{r}_i$$

$$\vec{r}_i = (\Delta y_i, \Delta \phi_i)$$



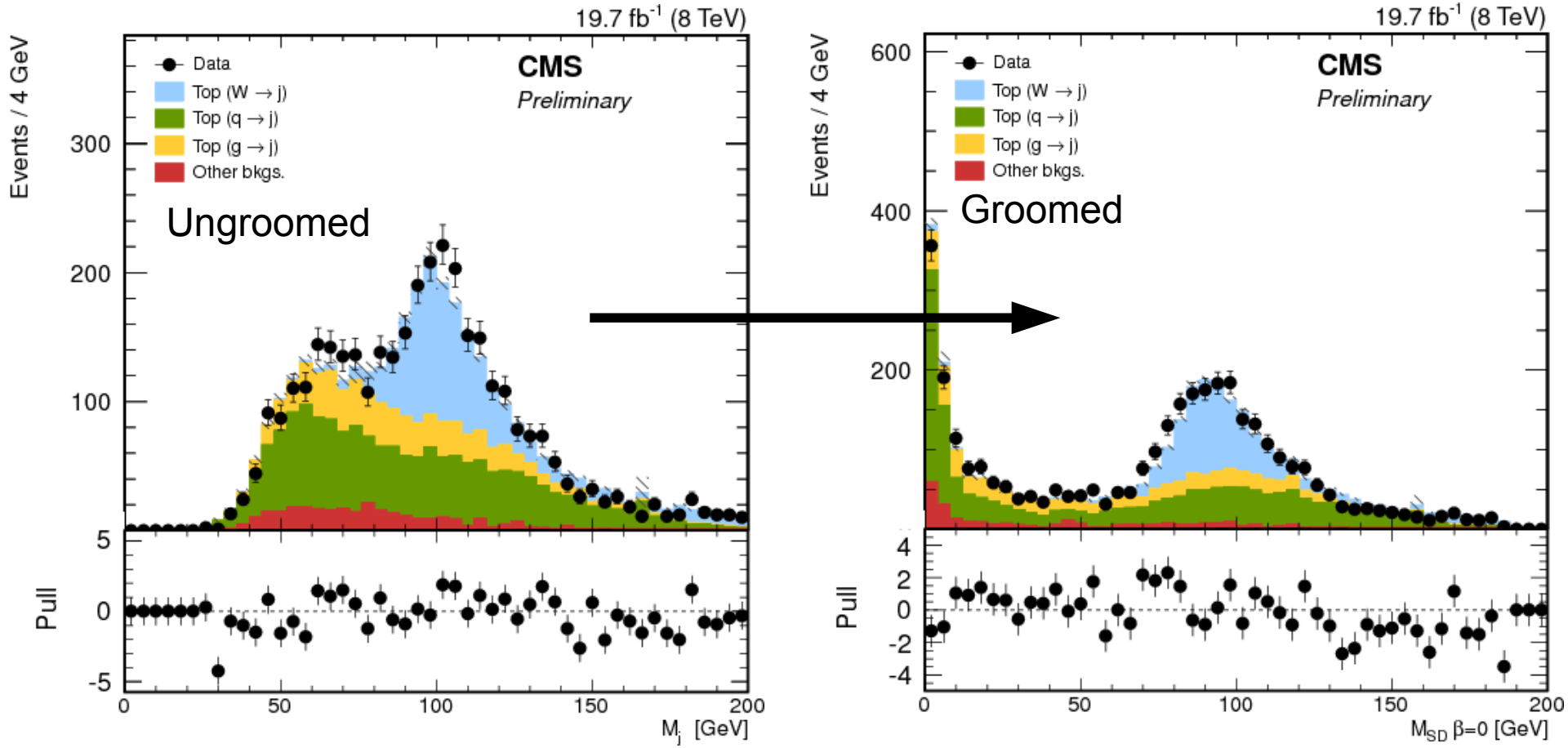




JME-14-002

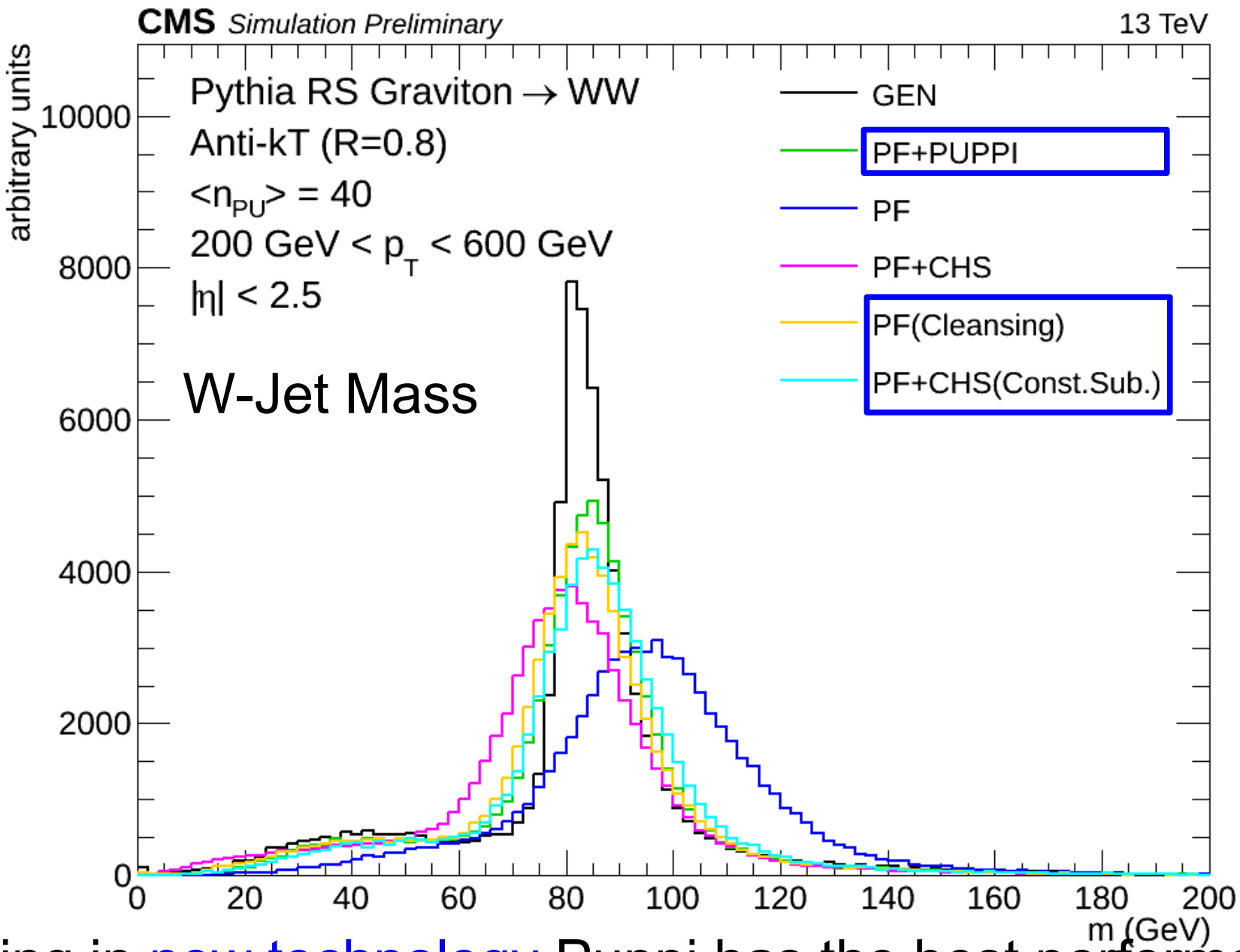
Going to High p_T

- Bringing tops to higher p_Ts
  - W bosons start to merge
  - Time for some jet grooming



JME-14-002

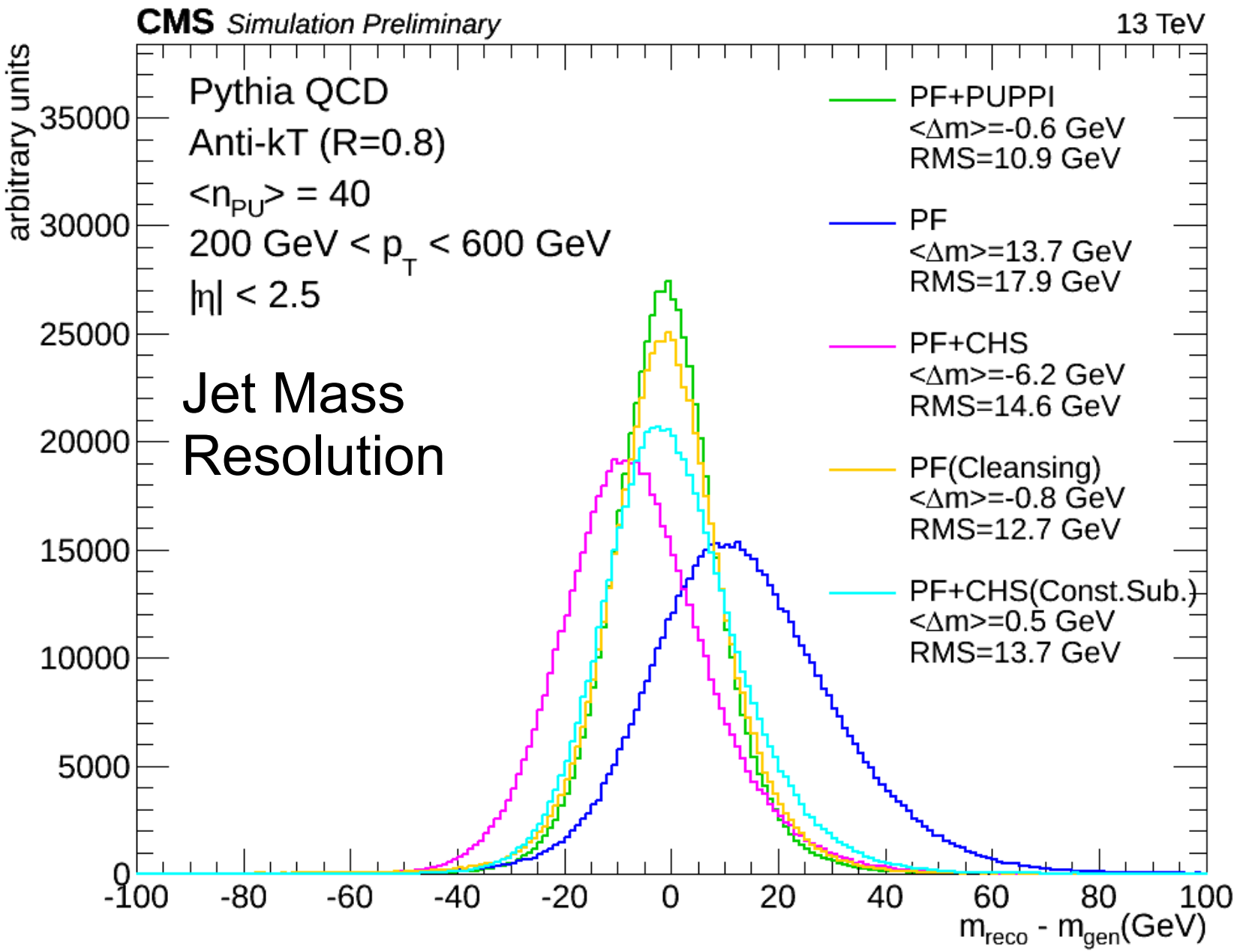
Puppi and W-tagging



Adding in new technology Puppi has the best performance

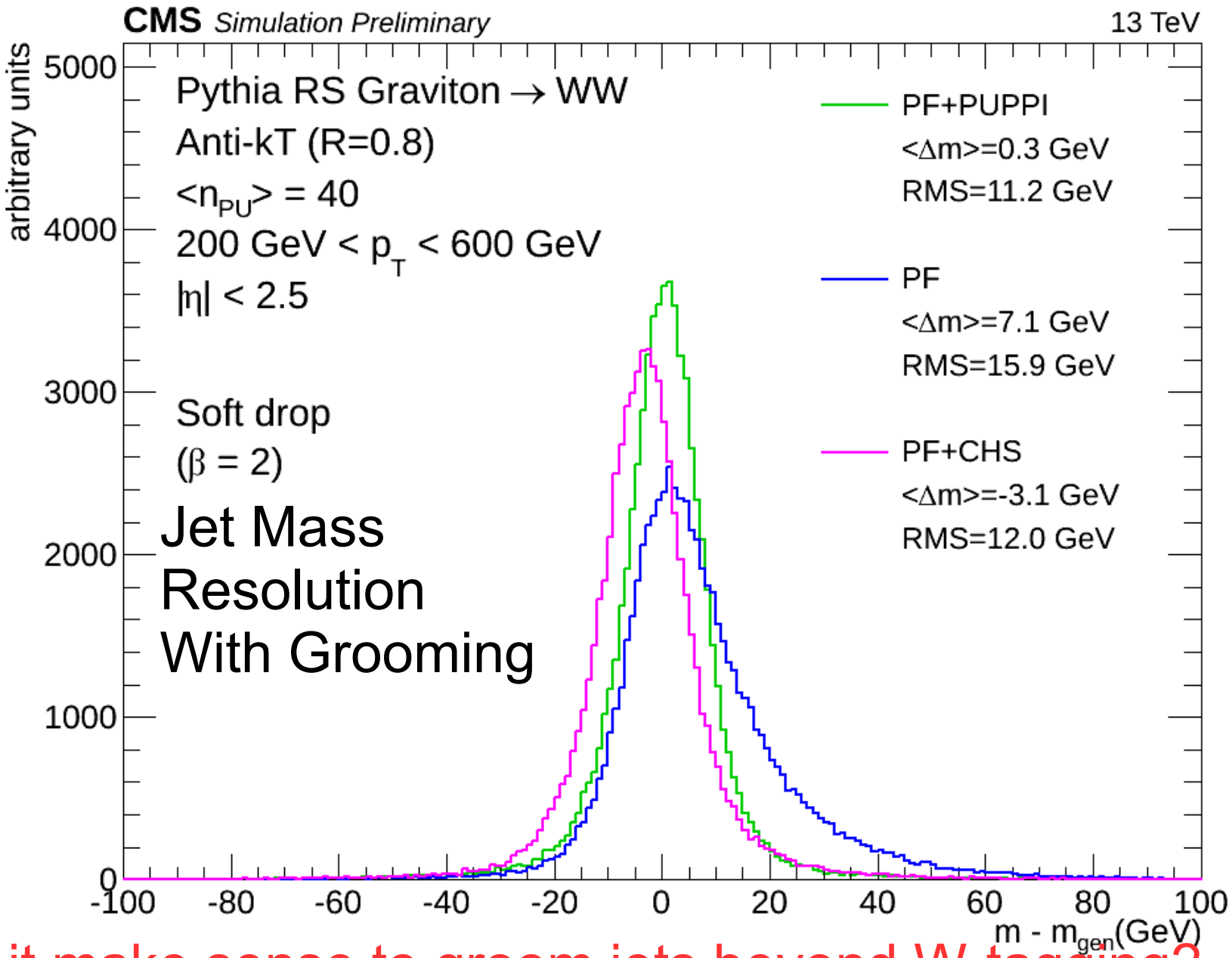
JME-14-001

Puppi and W-tagging



Mass resolution shows clear improvement (40 PU) **JME-14-001**

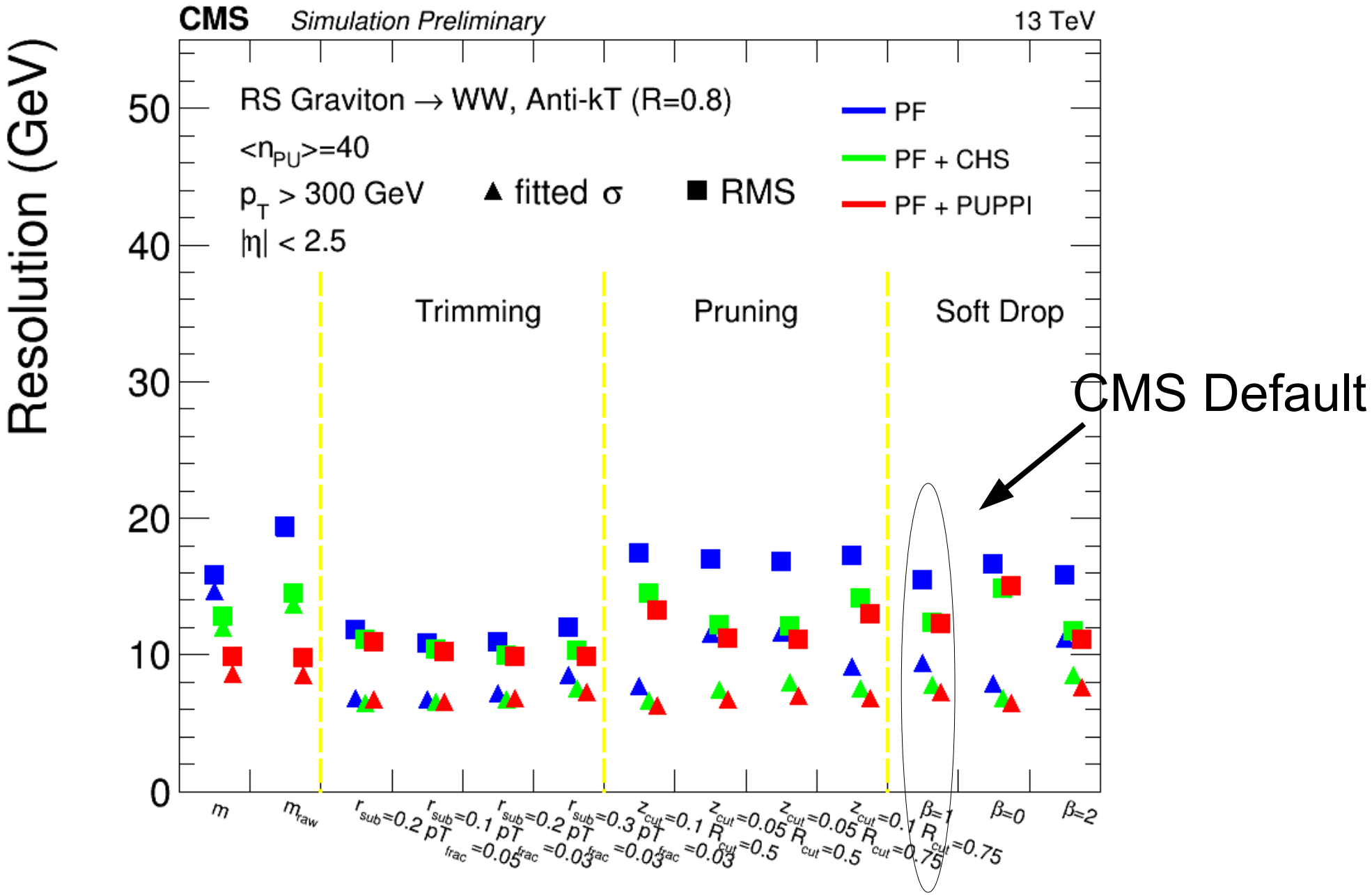
Beyond W-tagging?



Does it make sense to groom jets beyond W-tagging?

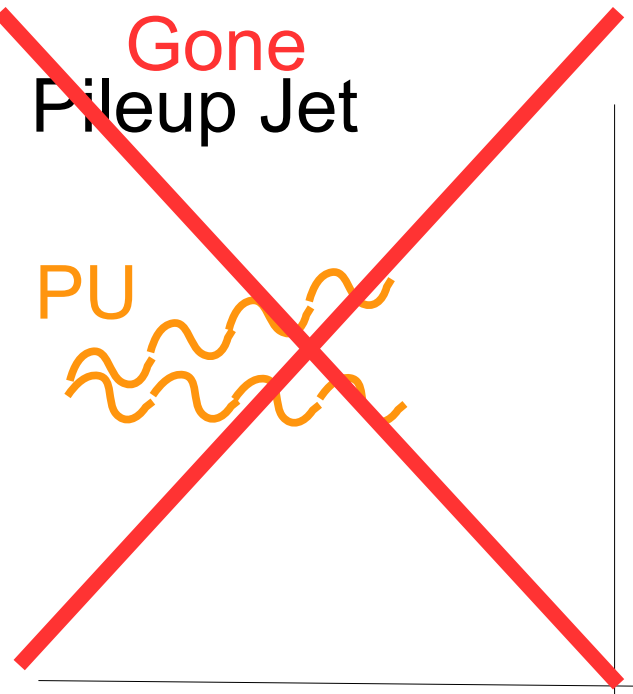
JME-14-001

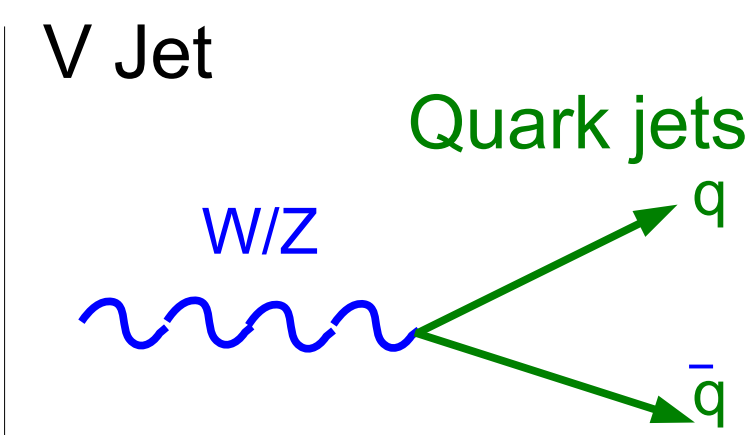
Survey of Grooming

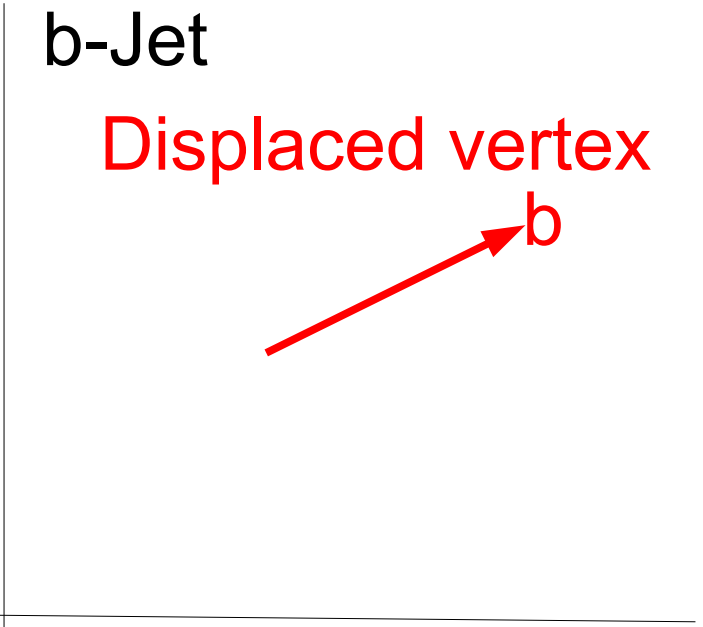


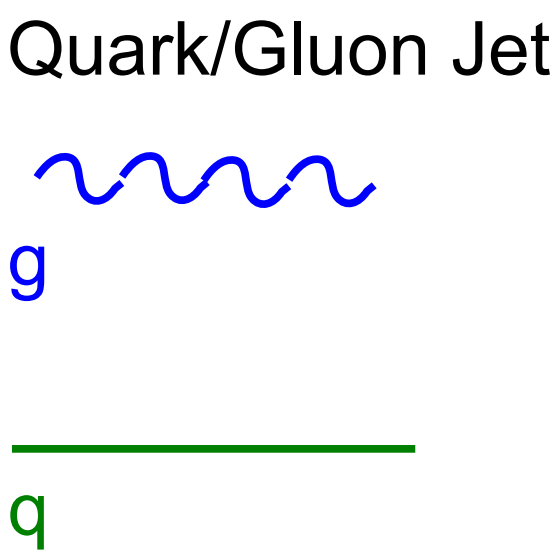
JME-14-001

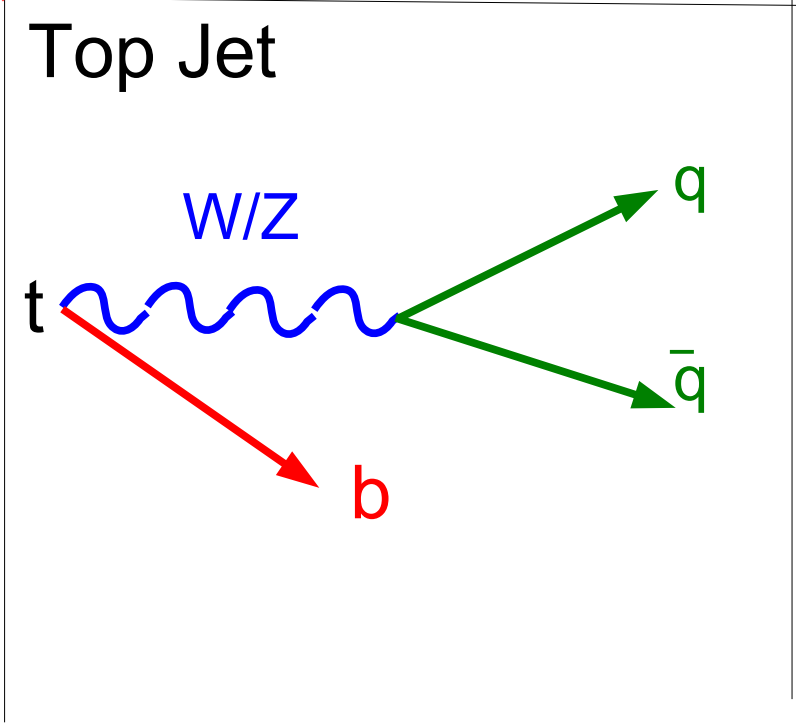
Many Phases of Jets

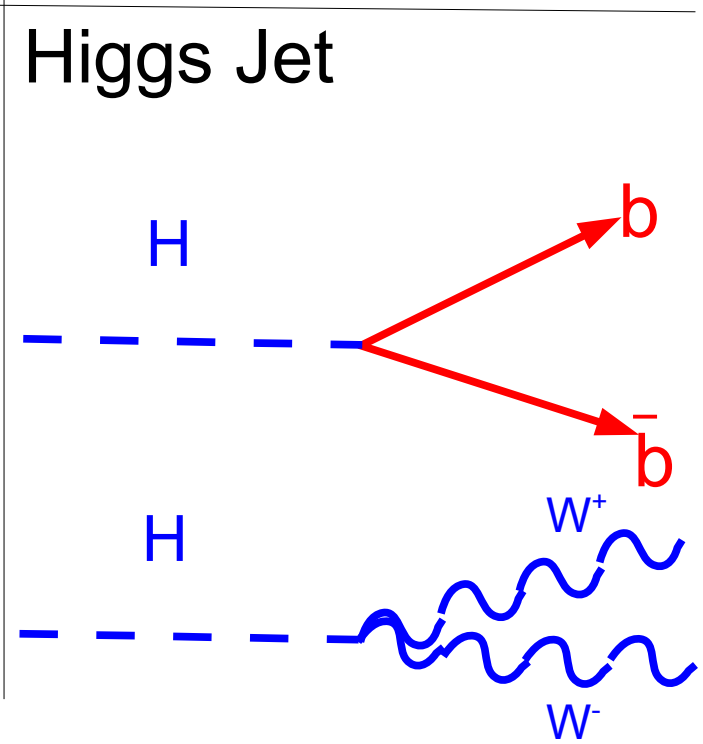




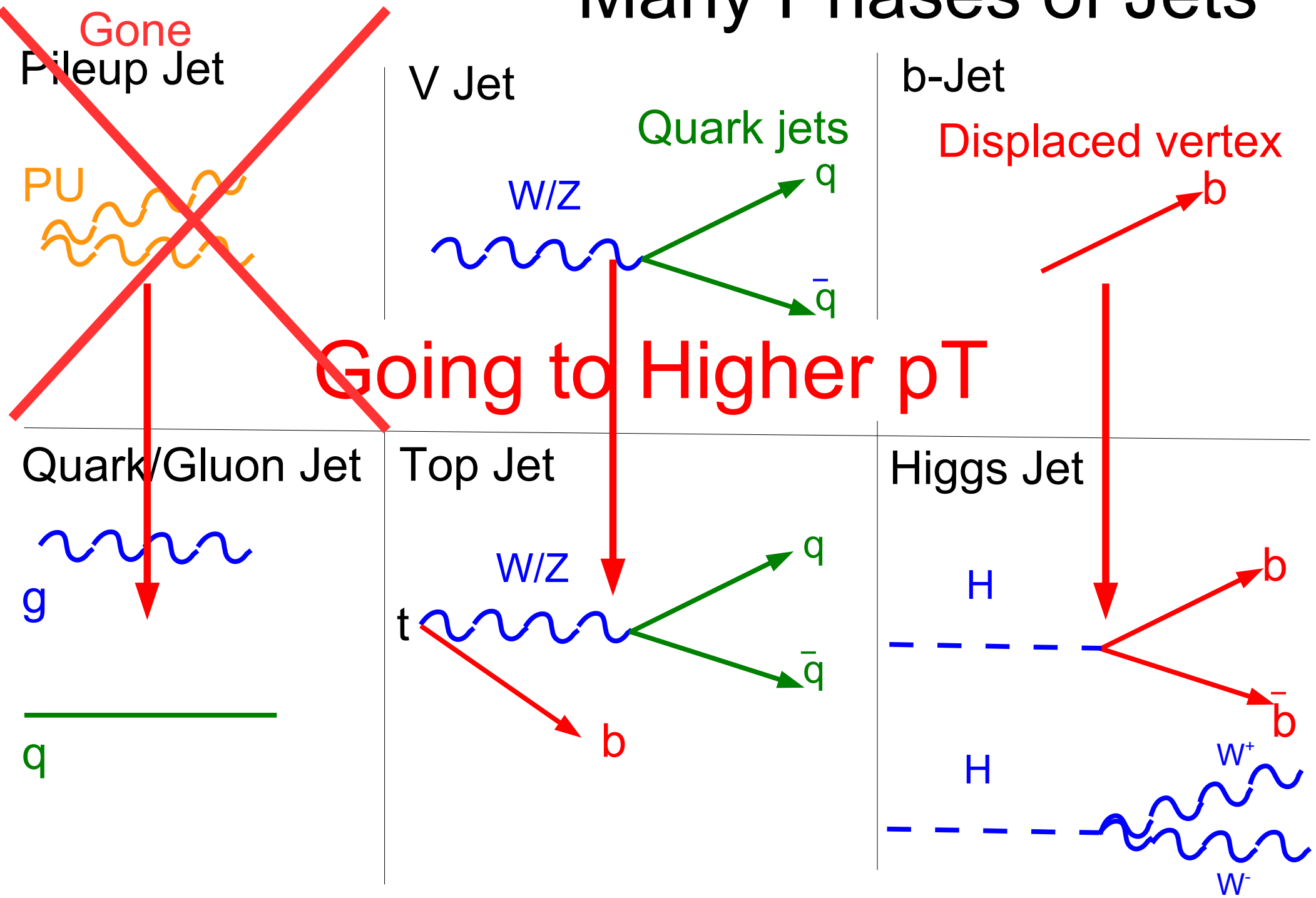




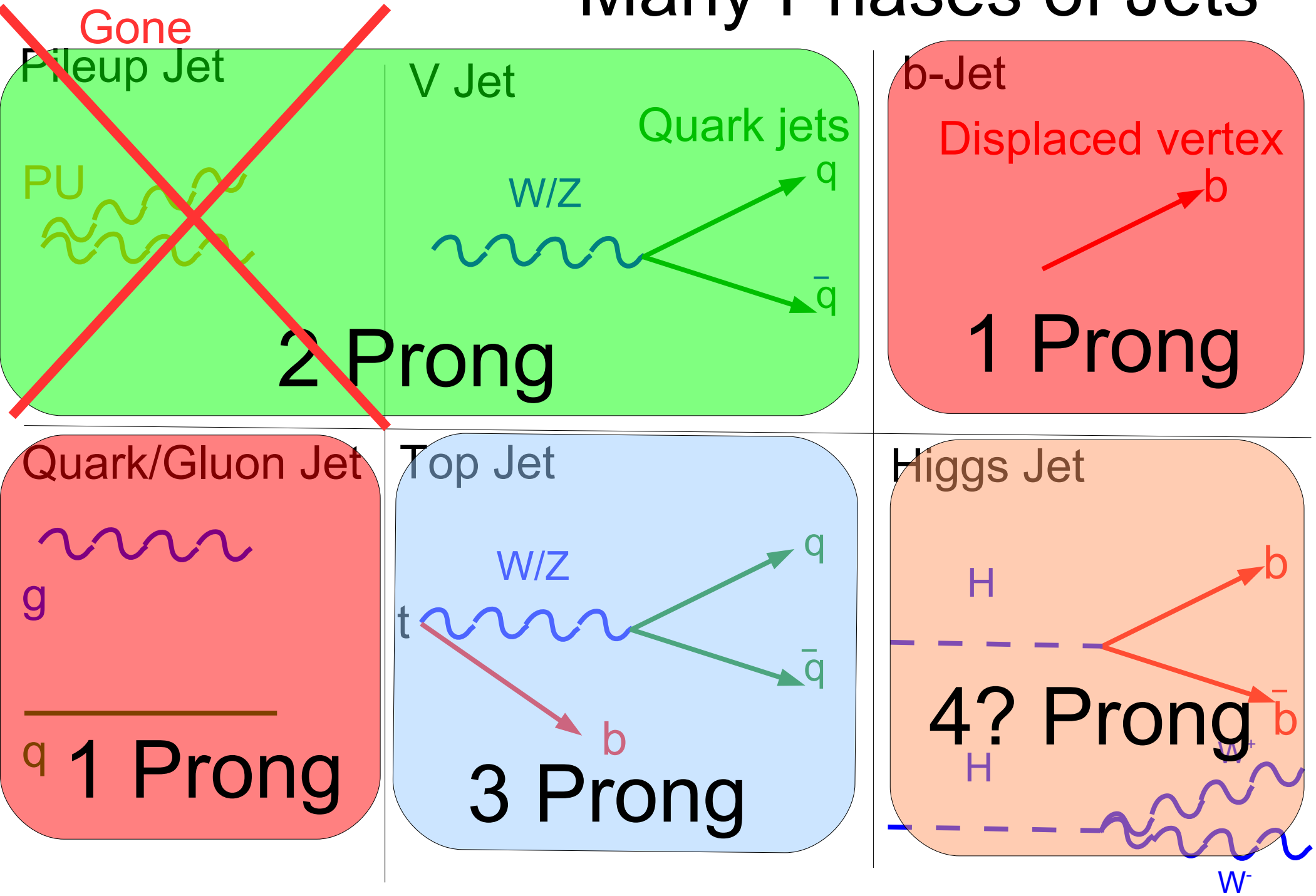




Many Phases of Jets

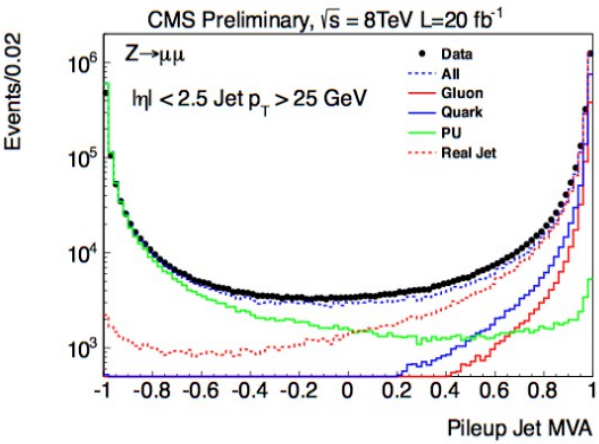


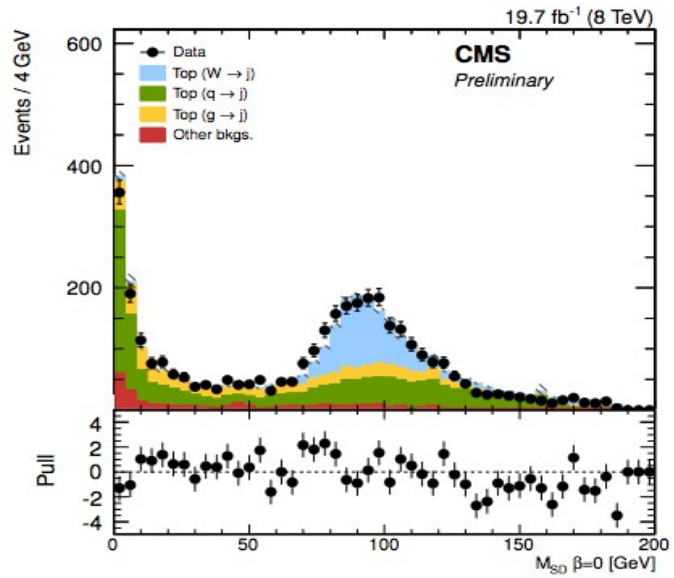
Many Phases of Jets

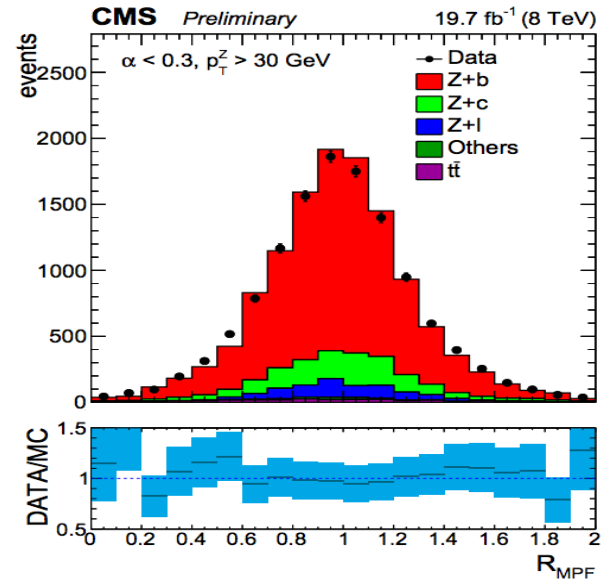


Understood in Data

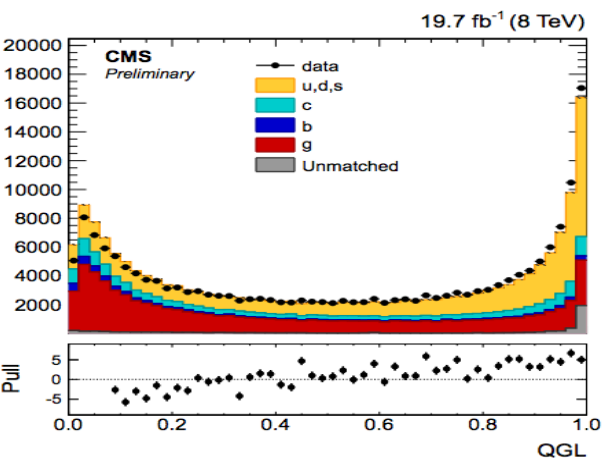
Pileup Jet



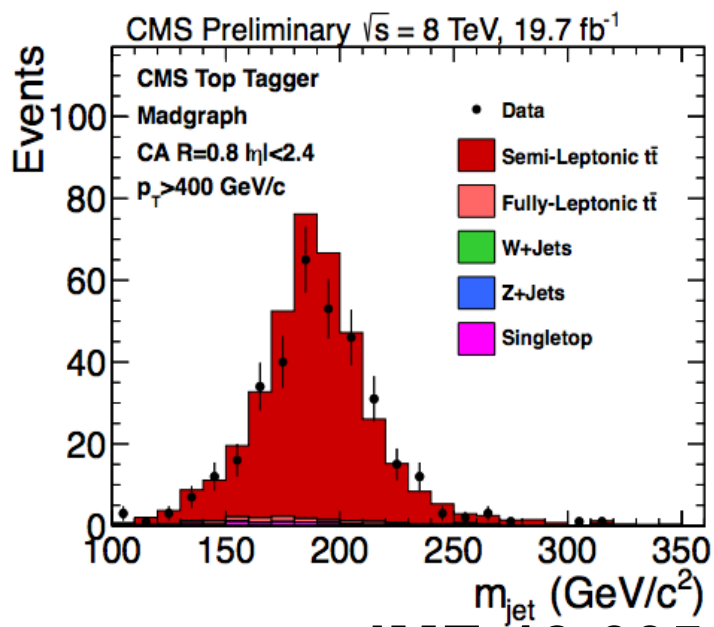




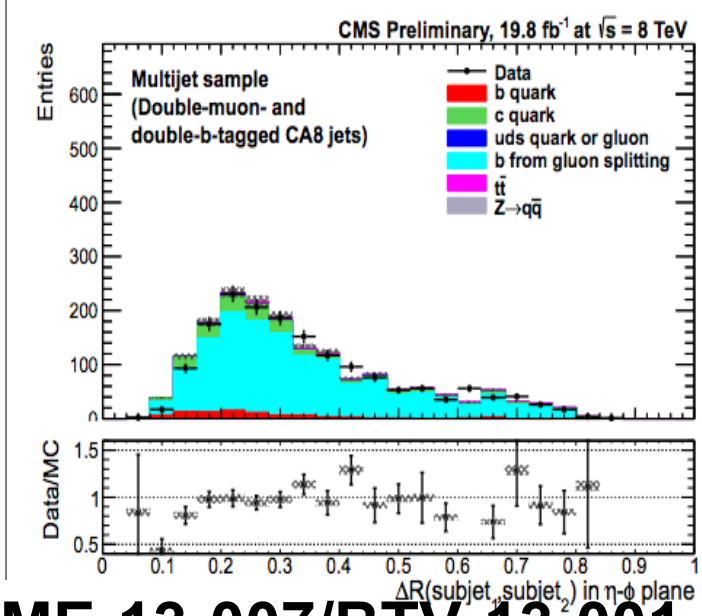
Quark/Gluon Jet



Top Jet

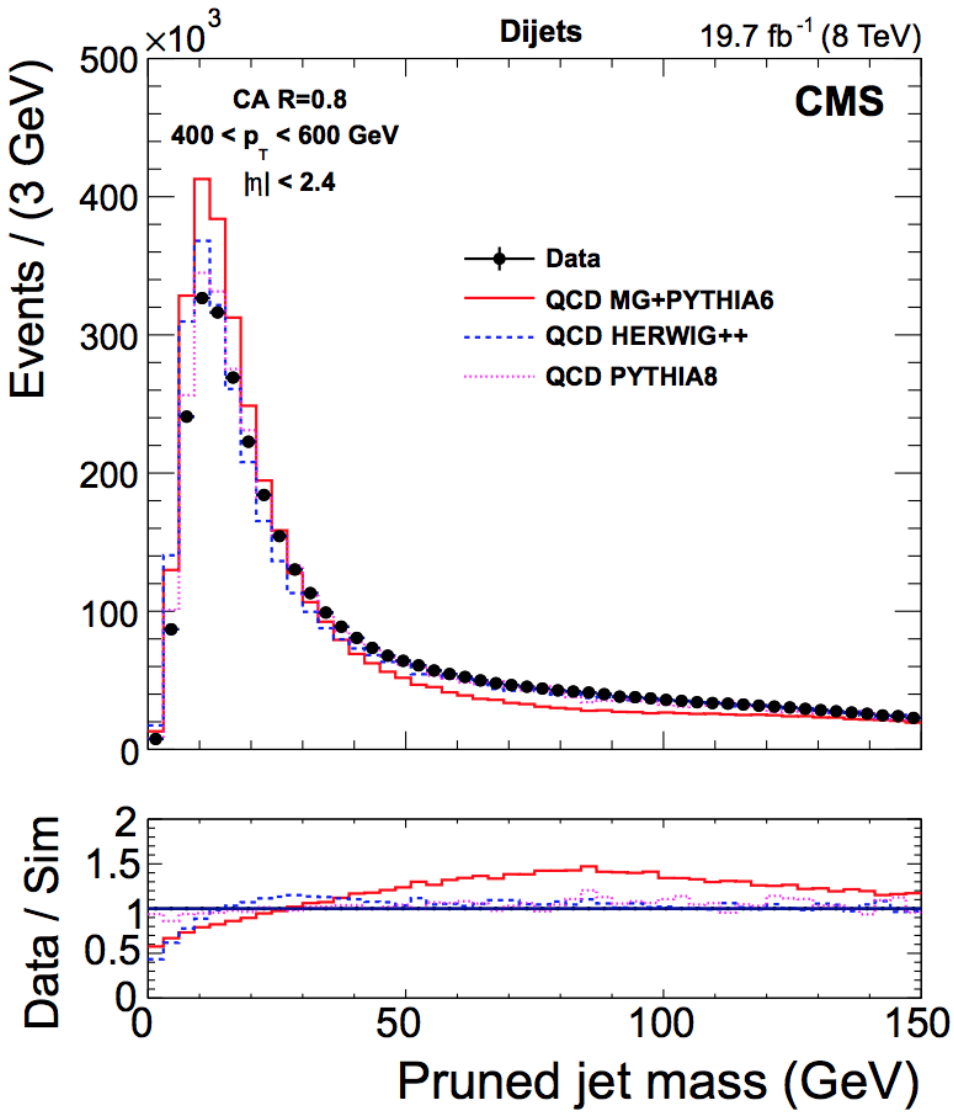


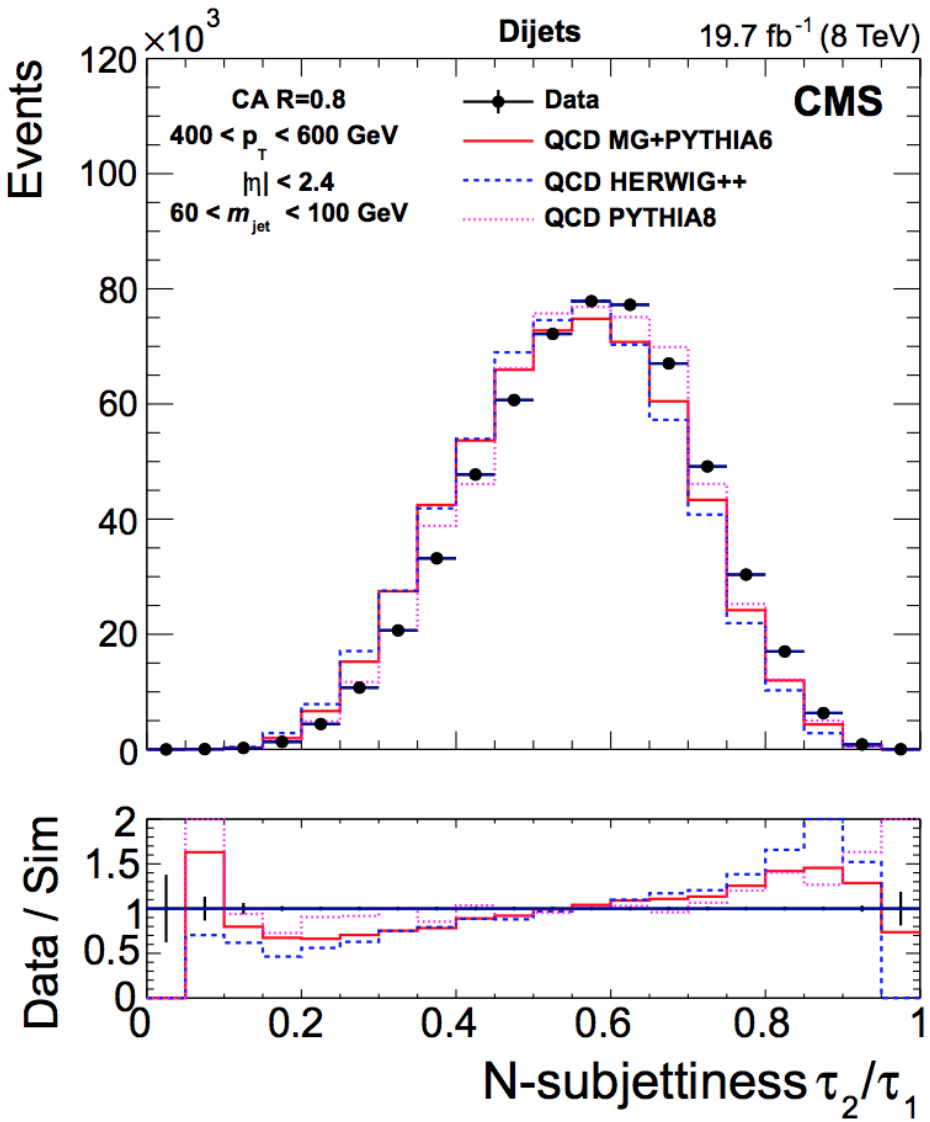
Higgs Jet



JME-13-005/JME-13-007/BTV-13-001

Tunes from W-tagging?



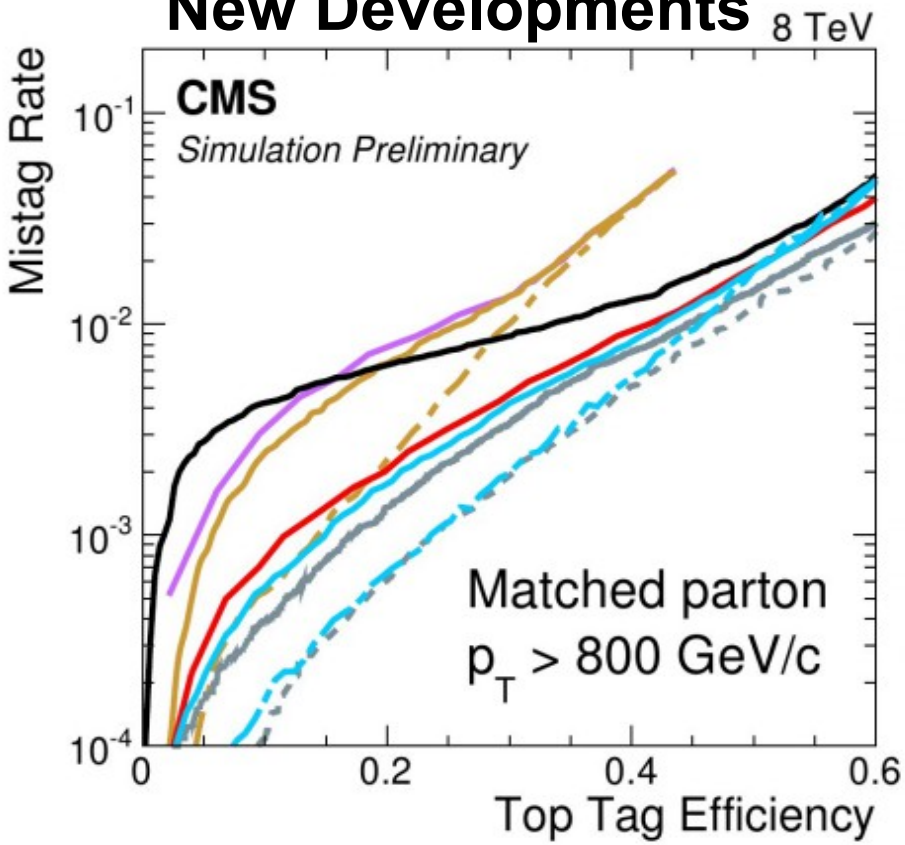


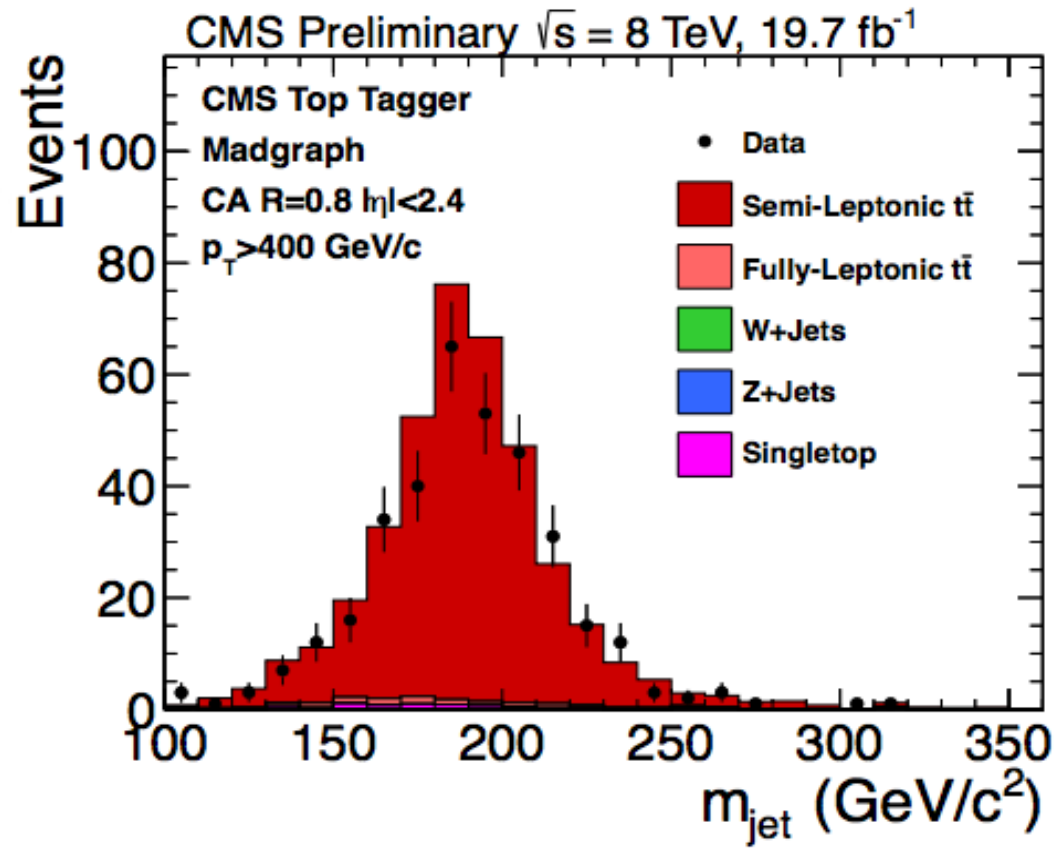
Powerful constraints from tunes are available in jet shape observables

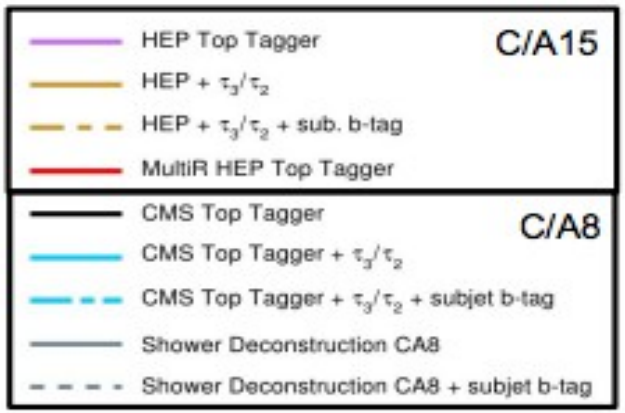
JME-13-006

Tagging Hadronic Tops

Top Tagging
New Developments







Plethora of techniques exist for boosted top tagging

Fake rates comparable to leptons

JME-13-007
JME-DP-14/038

Run II Executive Summary

- Pileup Effects :
  - MVA *MET*/Puppi
  - 25ns reconstruction
- Jet energy corrections :
  - Switch to AK4 for default
  - Global fit of all jet energy corrections
- Jet Flavor dependence :
  - Precise measurement of b-tag JSF
  - Quark/Gluon tagging
- Color Flow :
  - Jet Pull/charge/shapes
  - Jet Grooming/Jet Tagging

Stand by Our Charter

Jet energy scale uncertainty correlations between ATLAS and CMS

The ATLAS and CMS Collaborations

Abstract

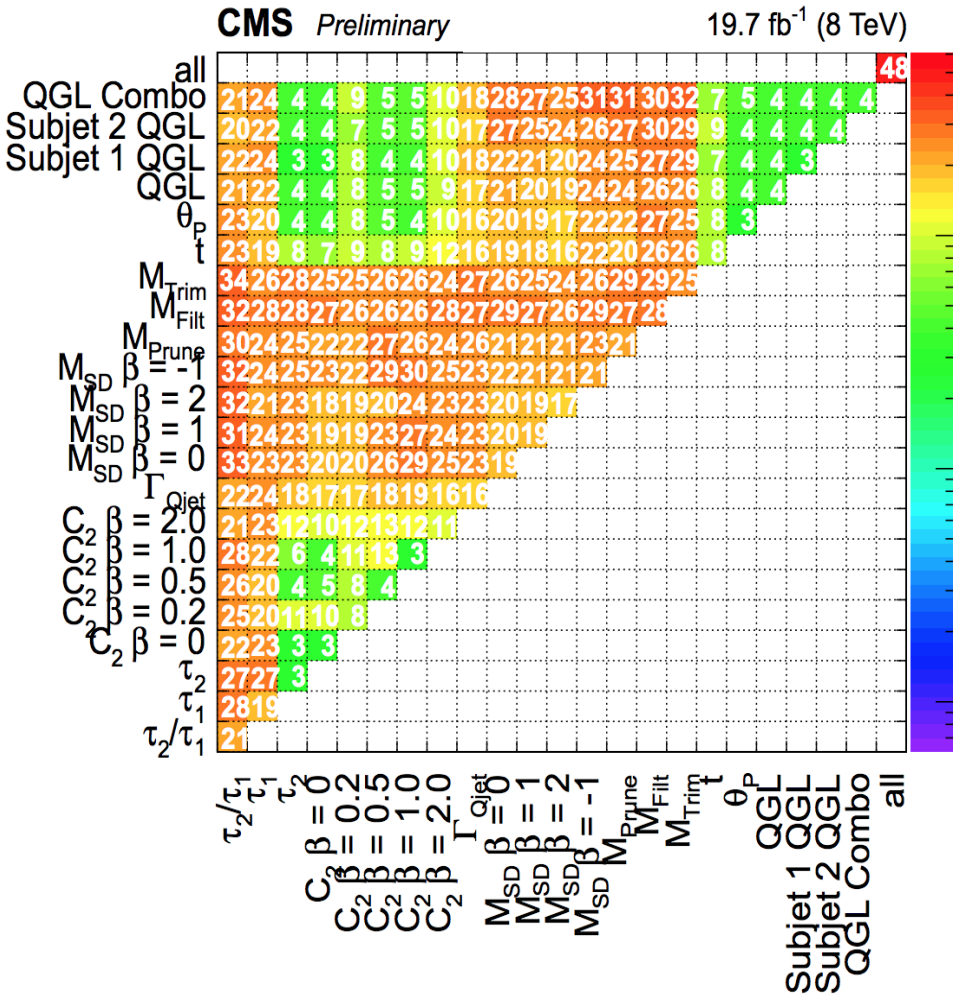
The correlation of the jet energy scale uncertainties between the ATLAS and CMS experiments are presented in this note. The uncertainty components for both experiments are grouped into categories. For each of these categories, the detailed comparison of the procedures to determine the jet calibration and its uncertainties allows to infer the range for the correlation coefficient between the two experiments. This information can be used for the combination of ATLAS and CMS precision measurements.

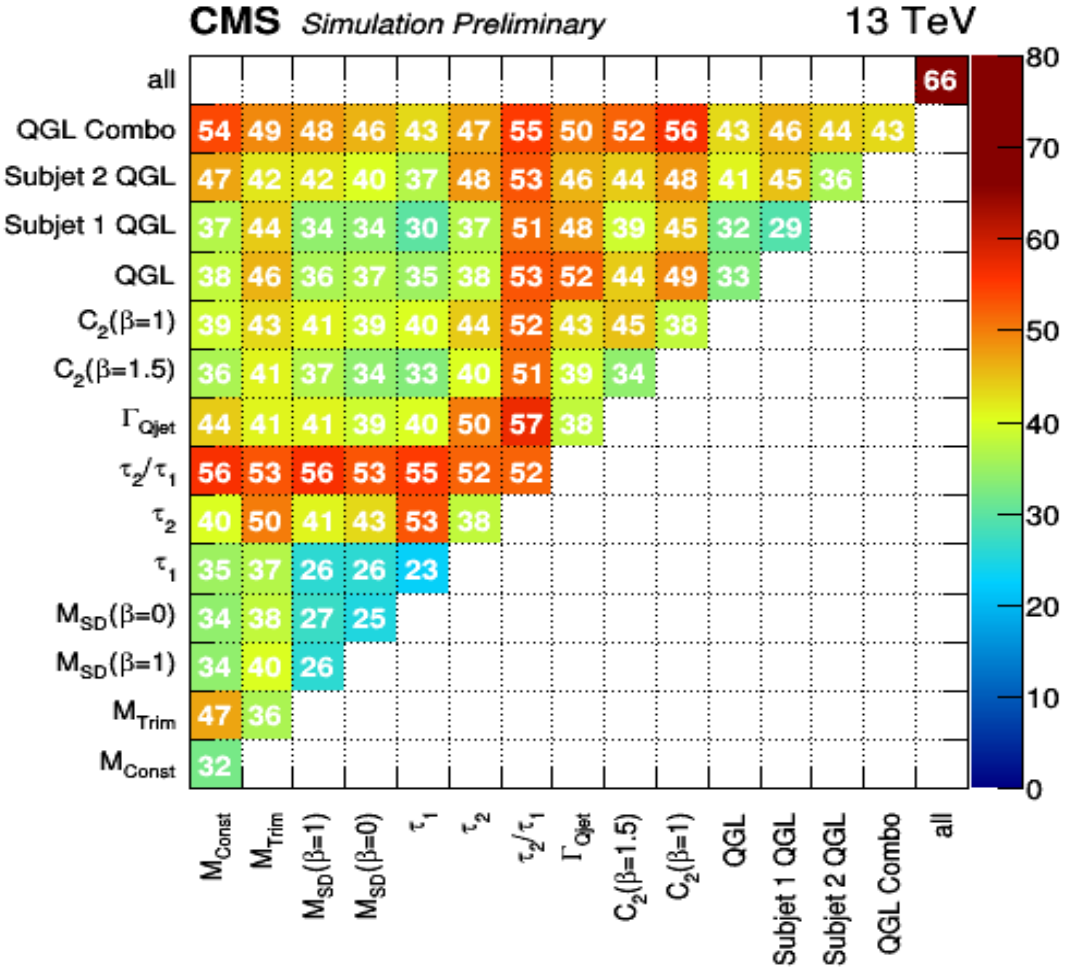
JME-14-003

Backup

Understanding Observables

- There are many more observables



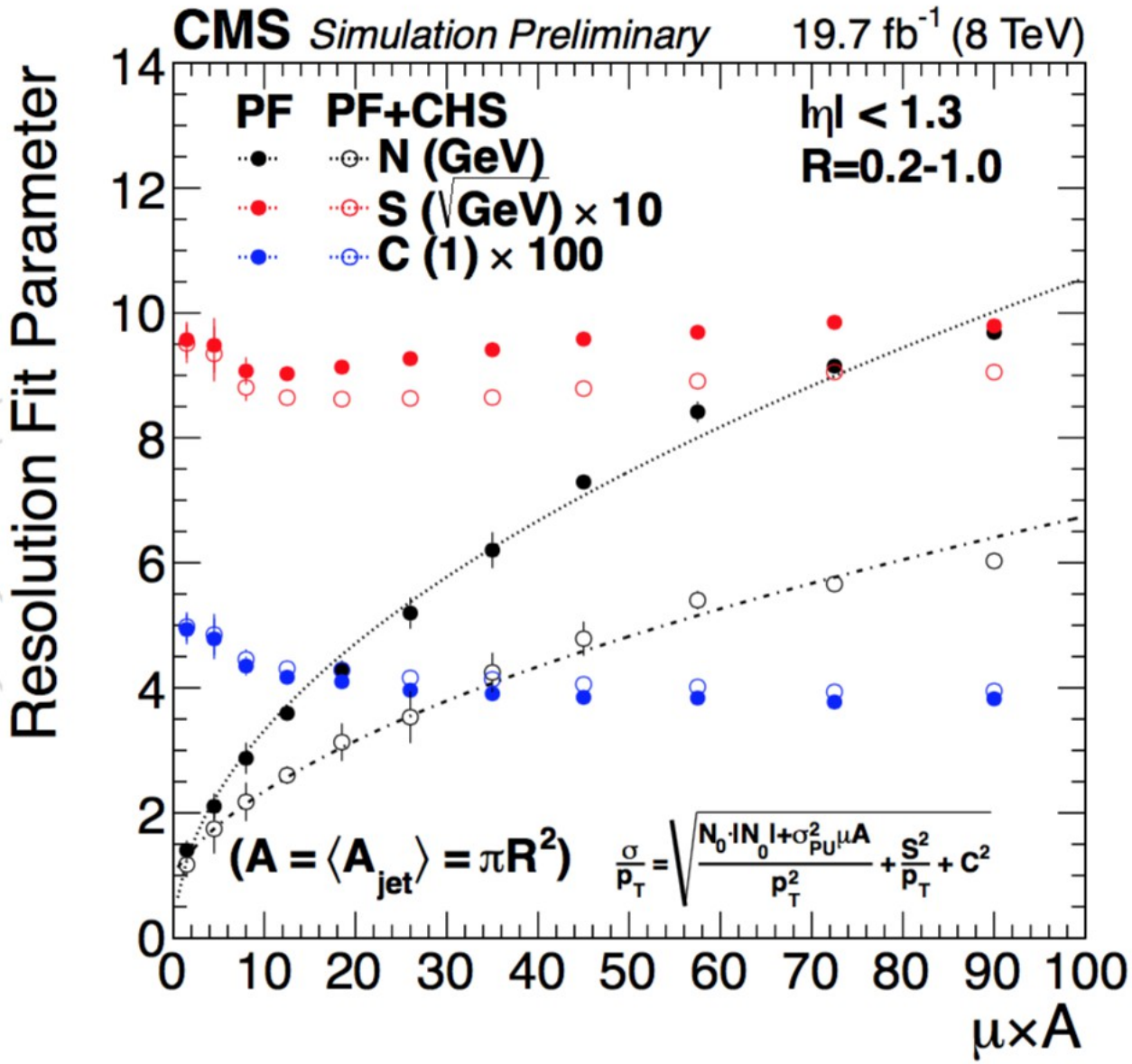


Doing our best to document them all

JME-14-002

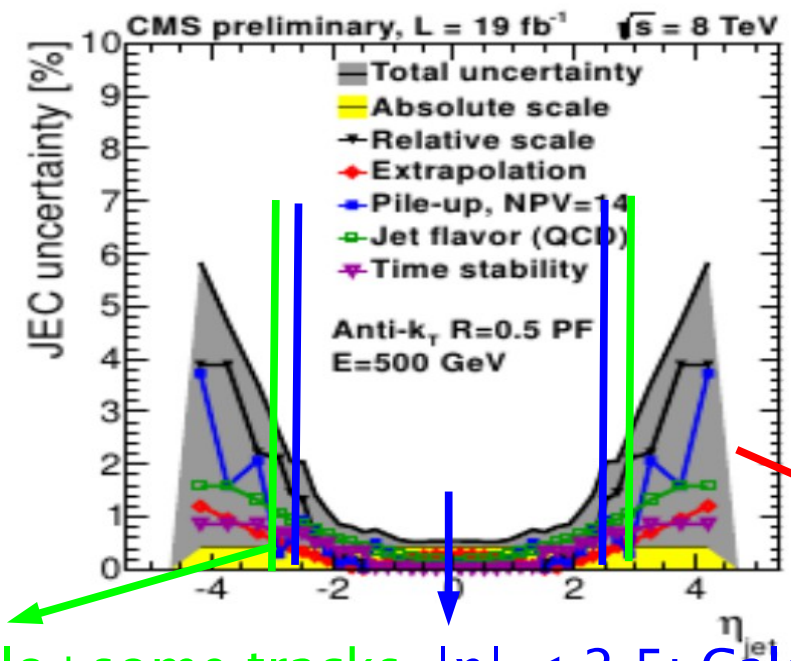
Stability of our detector

- Using all the jet cones allows plots like this:



JERC

- JERC : Jet Energy Resolutions and Corrections
  - Previous simple steps are quite involved
    - Corrections still peformed on Calo/J+Track/Partciel Flow Jets
  - Jets are different creatures at different η
  - Consistency with trigger (L1 and HLT): a necessity
    - Note that the L1 Trigger is not particle flow based

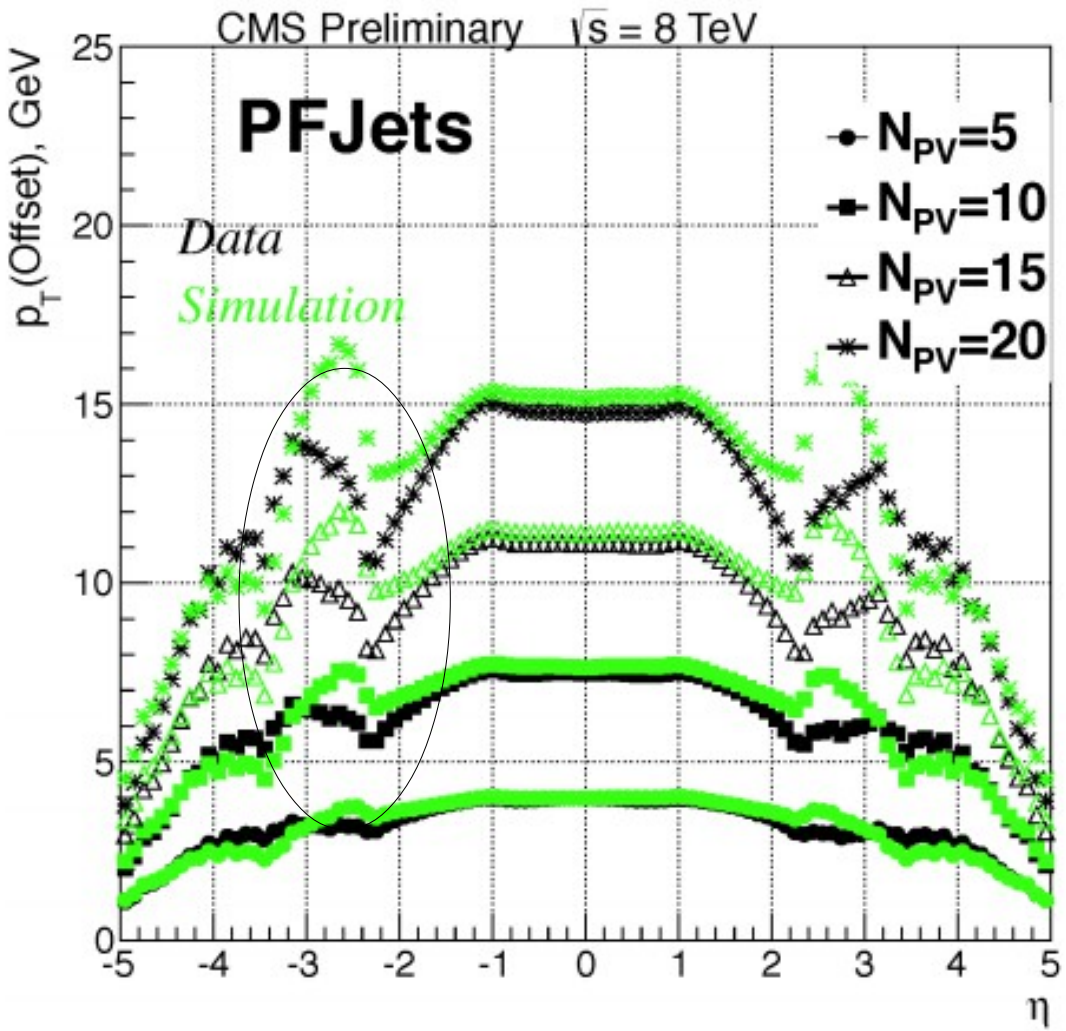


2.5<|η|< 3.0: Calo+some tracks |η| < 2.5: Calo+tracks 3.0<|η| < 5.0: Fwd Calo

8TeV Precision

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

How do we deal with the systemaitcs?



8TeV Precision

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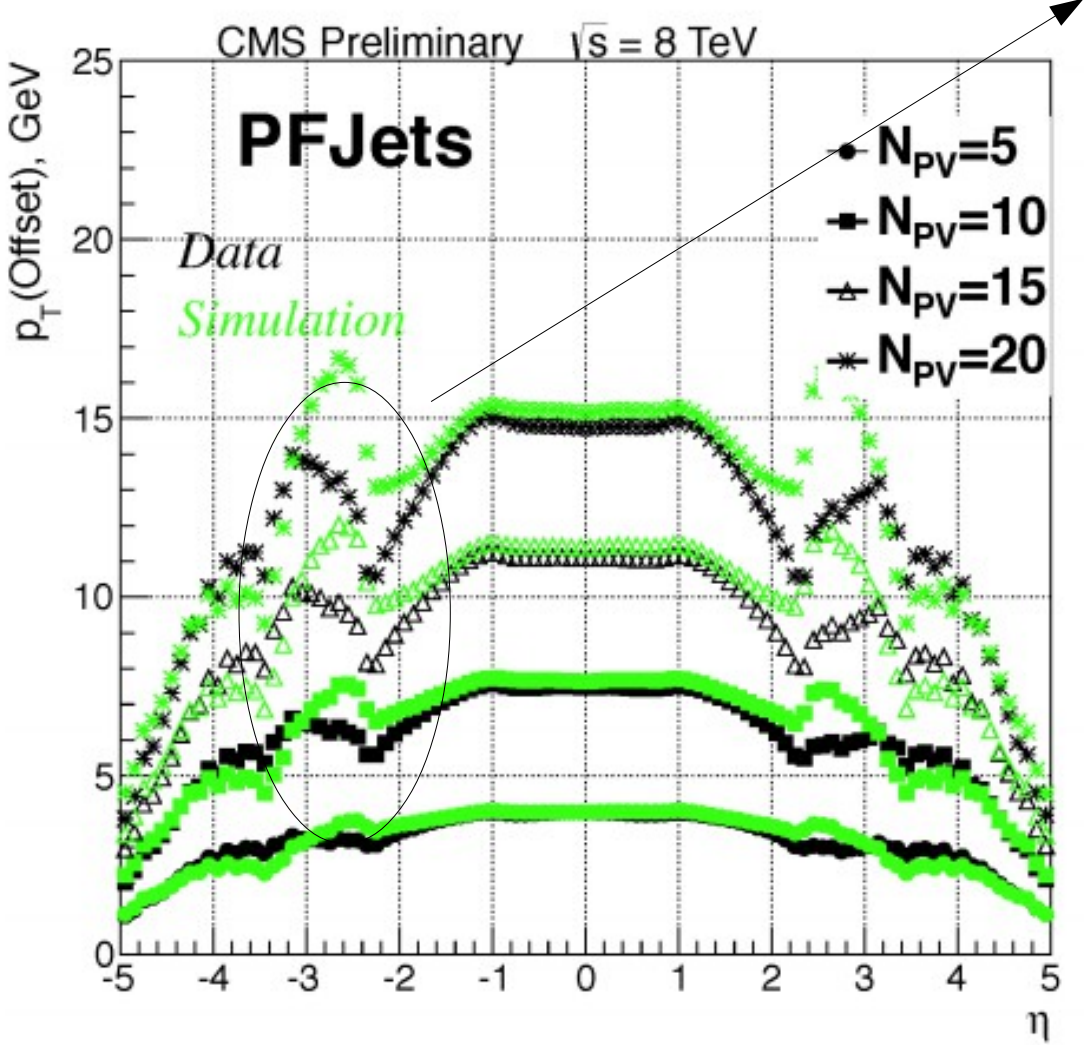
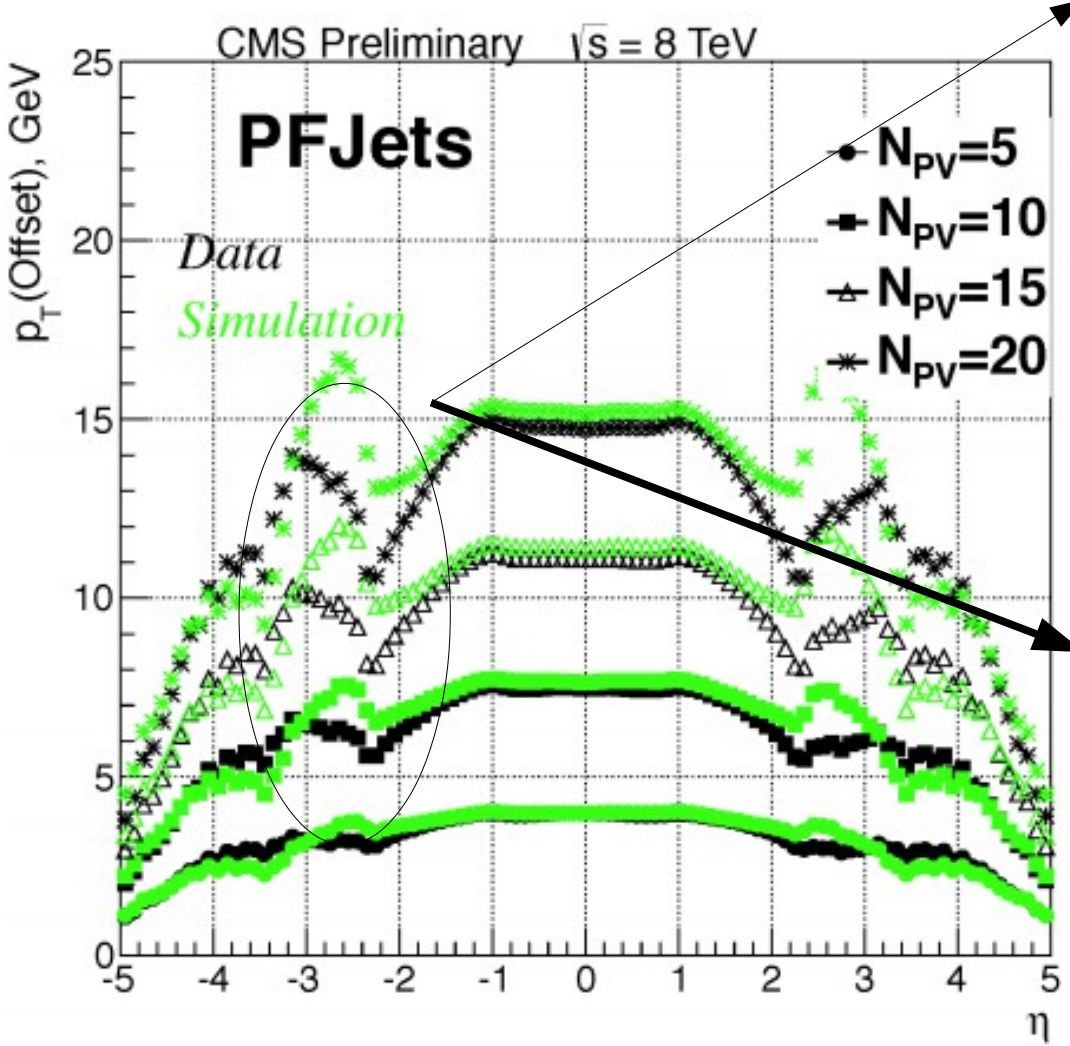


Originally had systematic unc. Based on full data/MC difference

How do we deal with the systemaitcs?

8TeV Precision

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



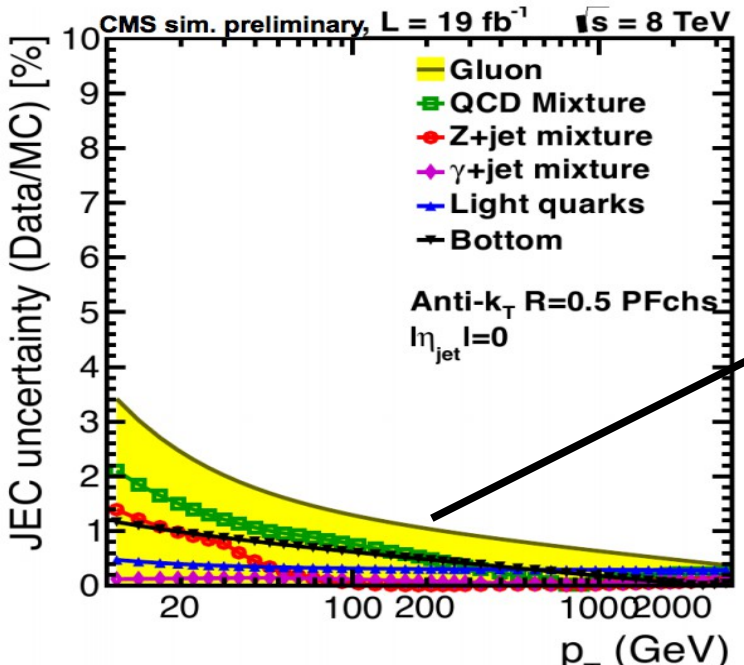
Migrated to residual bias Using same jets w/o pileup

Data/MC disagreement subsequently fixed (out of time PU)

How do we deal with the systemaitcs?

Flavor Dependence

- Understanding flavor dependence
  - A general theme in jet energy corrections 2013
  - New technology was exploited
- Old times : Physics can be pure gluons/quarks
- Update : All physics have both quark and gluons
  - Thus quote systematic by quark gluon composition

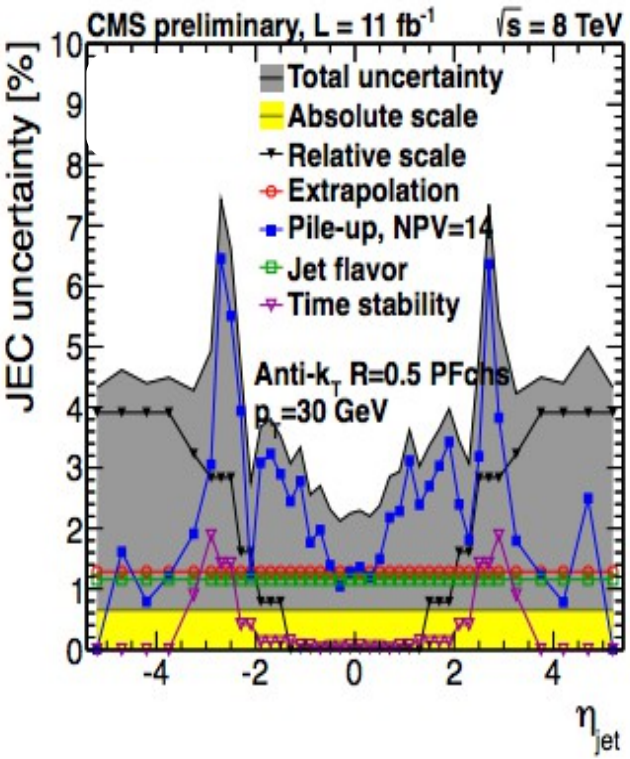


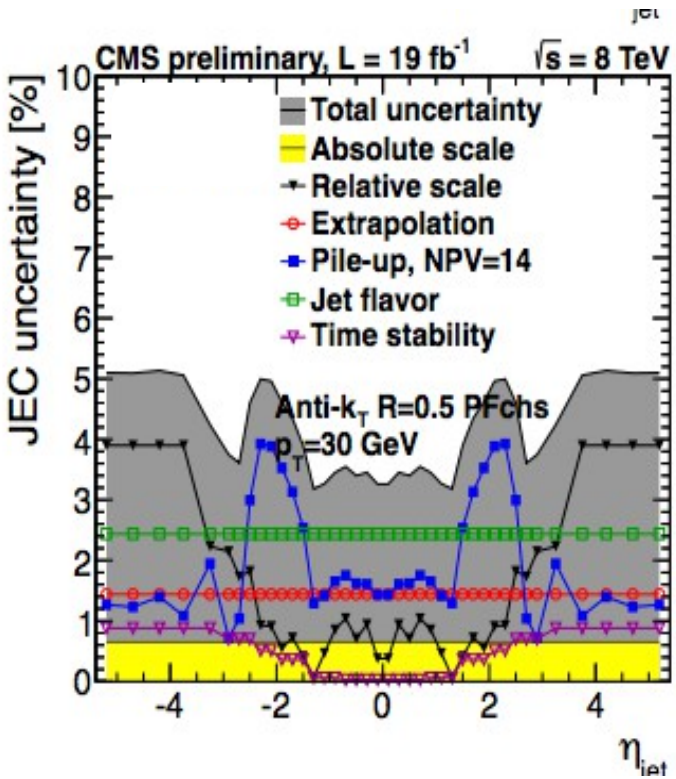
Different unc.
For different
componsition

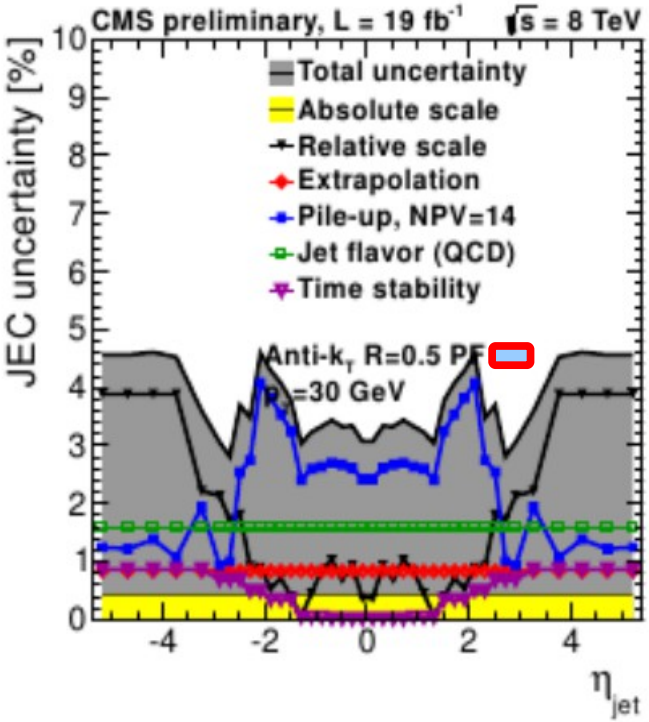
Evolution

- Where are we being limited :
  - Relative scale in the forward region
    - Result is the statiscal uncertainty of the method
  - Pileup (at low pT)

2012 → May 2013 → July 2013

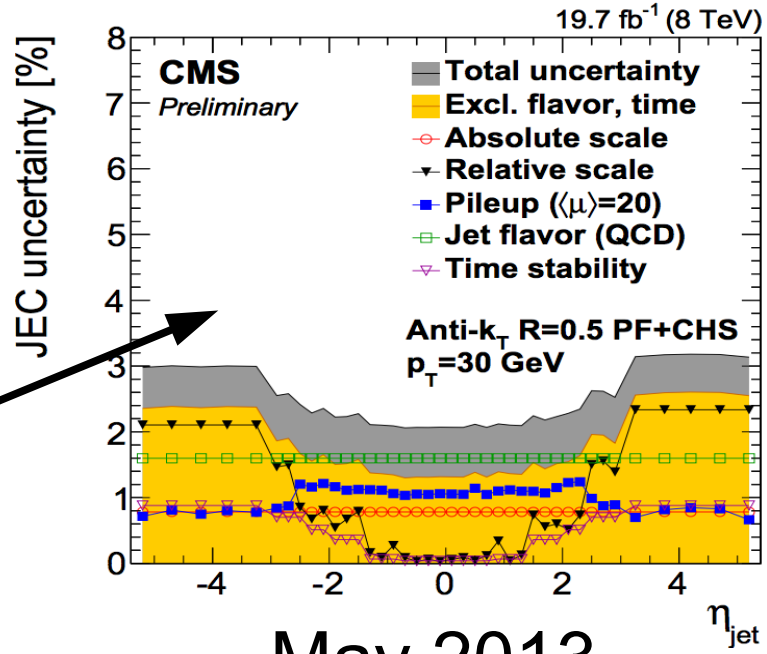




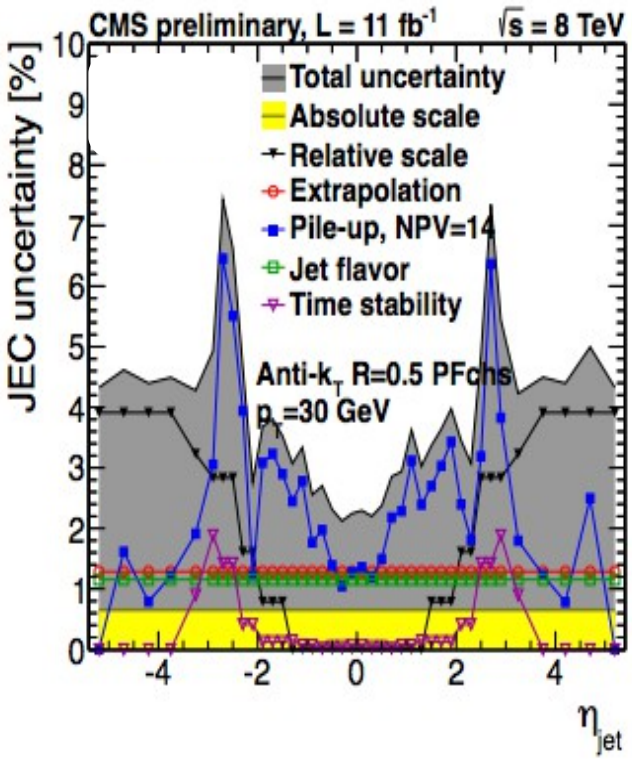


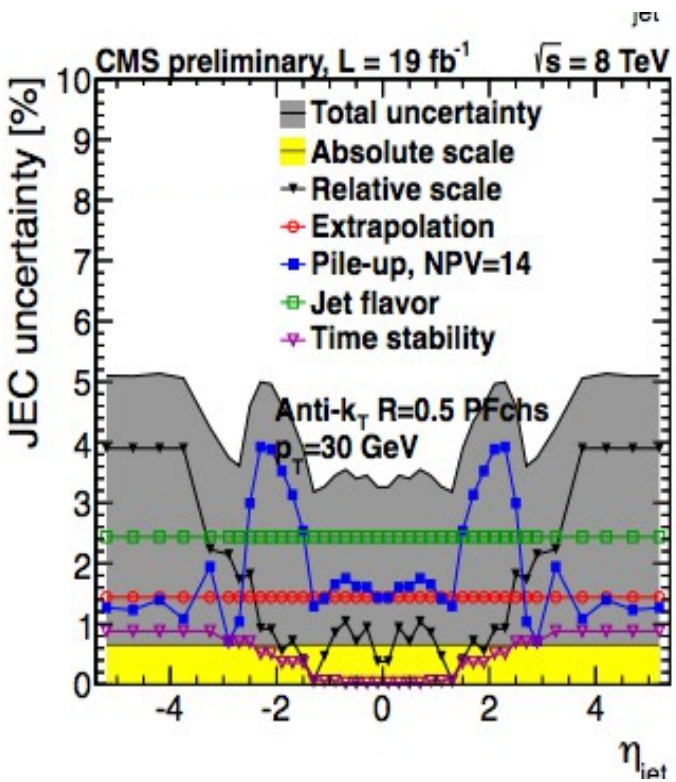
Evolution

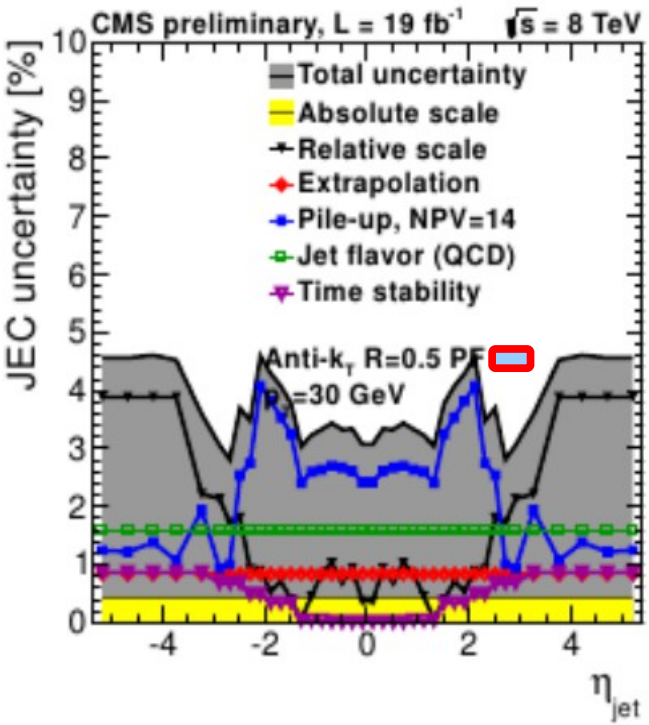
Now



2012 → May 2013 → July 2013

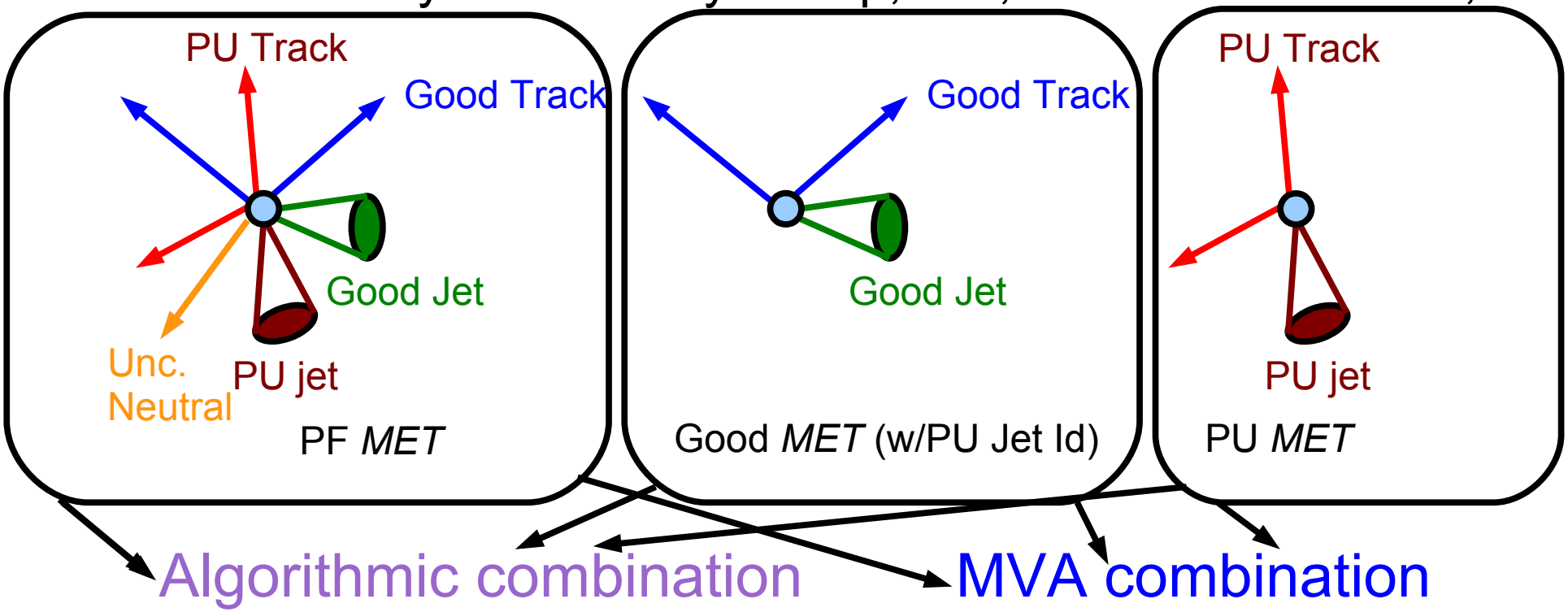






Garbage Collection: PU Reduced *METs*

- *MET* is effectively summing up all the trash
  - PU Reduced *METs* Equivalent to Recycling
    - Sorting your garbage by Metals/Plastics/Paper
    - Sort your event by Pileup,Jets,unclustered Neutral, tracks



Combine all of the estimates into one best estimate

There is no perfect way to remove objects from the *MET*

Garbage Collection: PU Reduced *METs*

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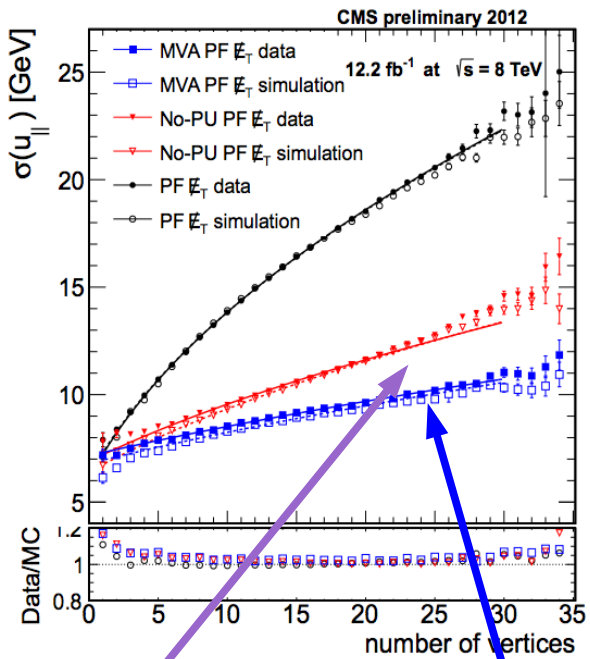

Algorithmic combination

MVA combination

Combine all of the estimates into one best estimate

There is no perfect way to remove objects from the *MET*