Jet MET 2013

Philip Harris (CERN)
and the JetMET group

Overview

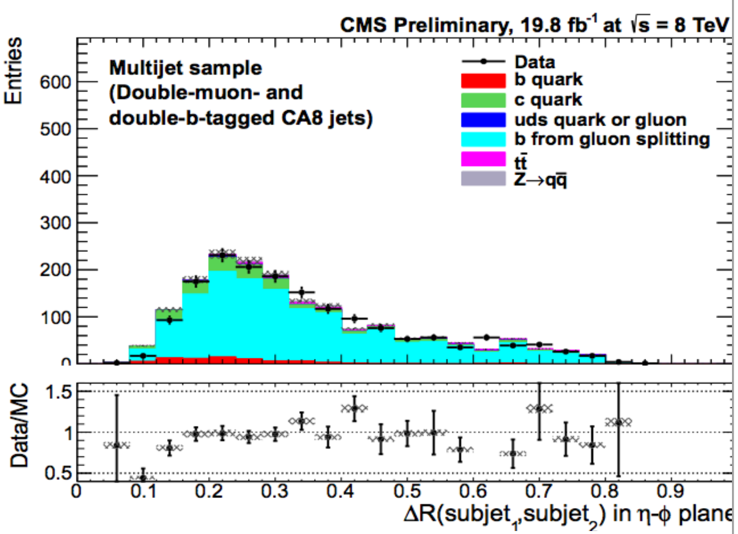
- Analysis slowly finished over 2013 running
  - Along with that: JetMET results on data finished
- Perspective of JetMET over 2013 :
  - Put the finishing touches on data/MC agreement
  - Reviewed tools that are necessary for the future
- This year we restart the cycle
  - Start low level reconstruction and build from there
- This talk: we review 2013 to start seeing where we go

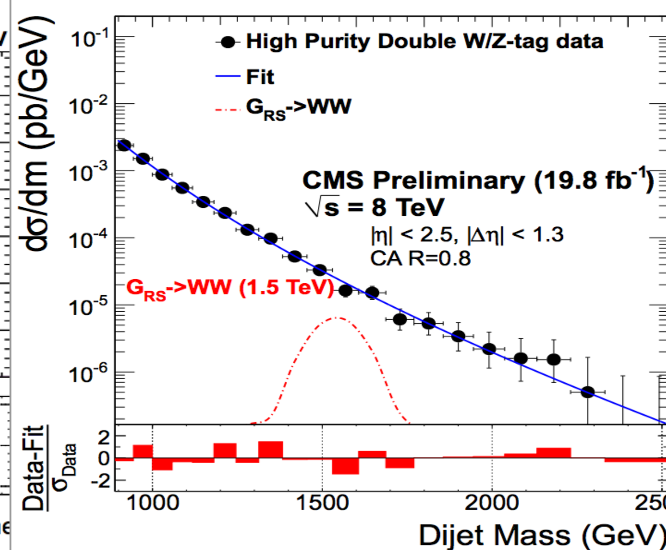
Public Results from CMS in 2013

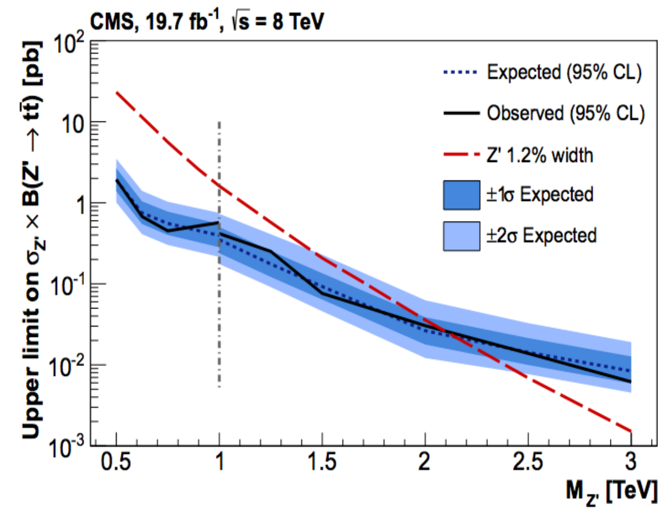
- DP Notes :
  - W Tagging shapes
  - UE event subtraction in HI events
  - JEC I &II
- PASs :
  - JME-12-002 MET Performance
  - JME-13-002 Q/G discrimination
  - JME-13-005 PU Jet Id
  - JME-13-006 W Tagging
  - JME-13-007 Top Tagging

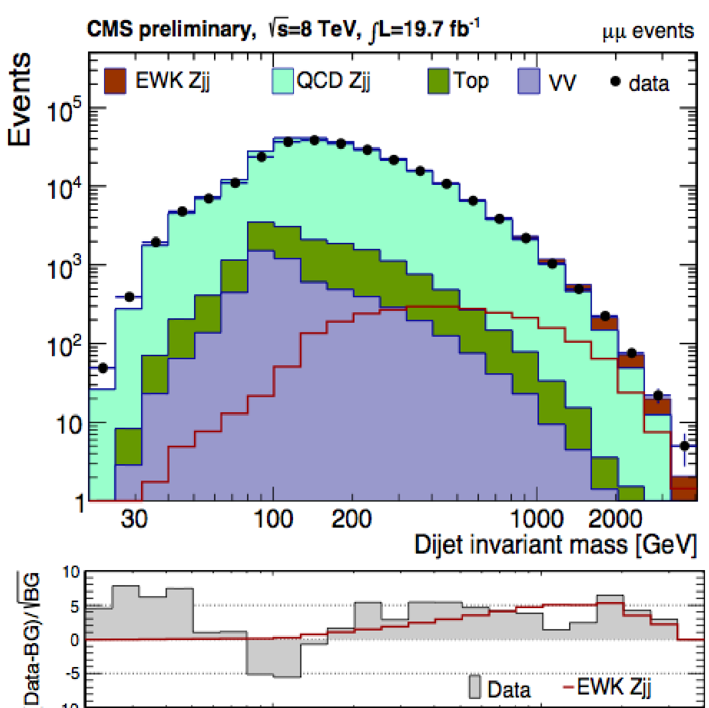
Physics Results

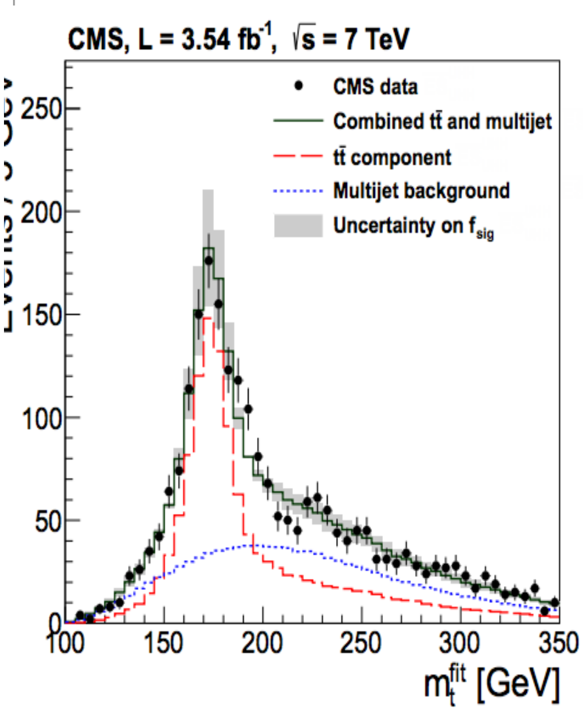
- Jet MET studies go hand and hand w/physics

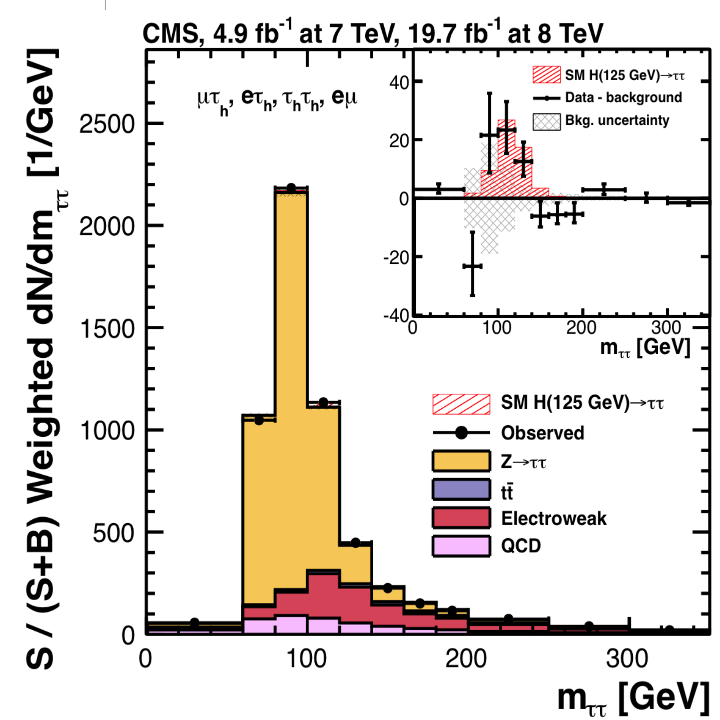




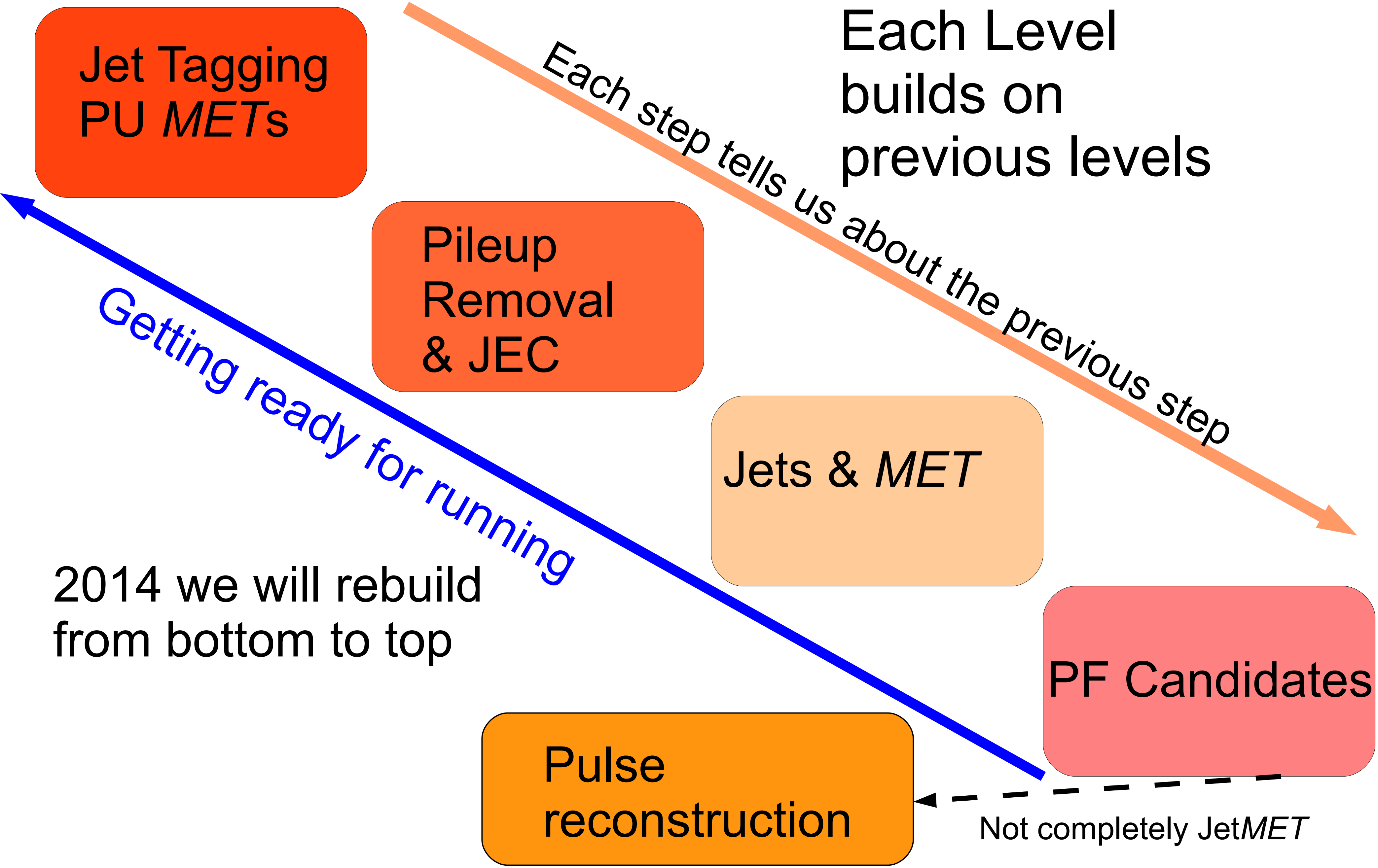




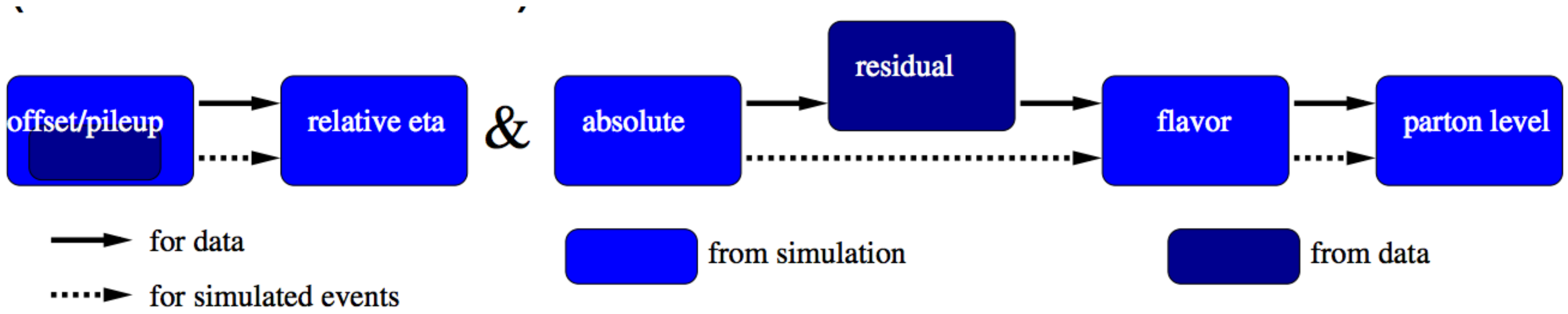




Deconstructing JetMet



JEC : Overview

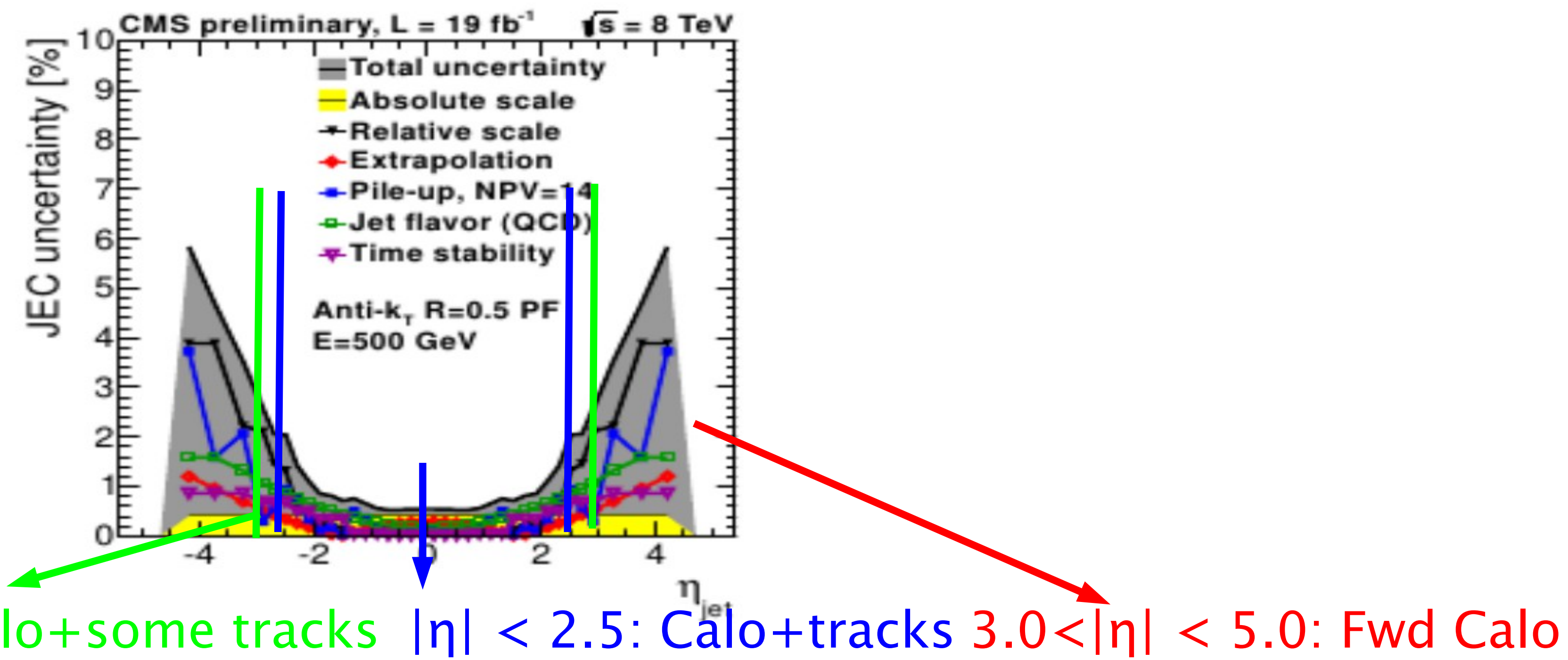


- Step 1 : Pileup correction
- Step 2 : Relative eta
- Step 3 : Absolute scale vs. pT
- Step 4 : Data/MC corrections
- Step 5 : Flavor

We use AK5 and AK7 for corrections

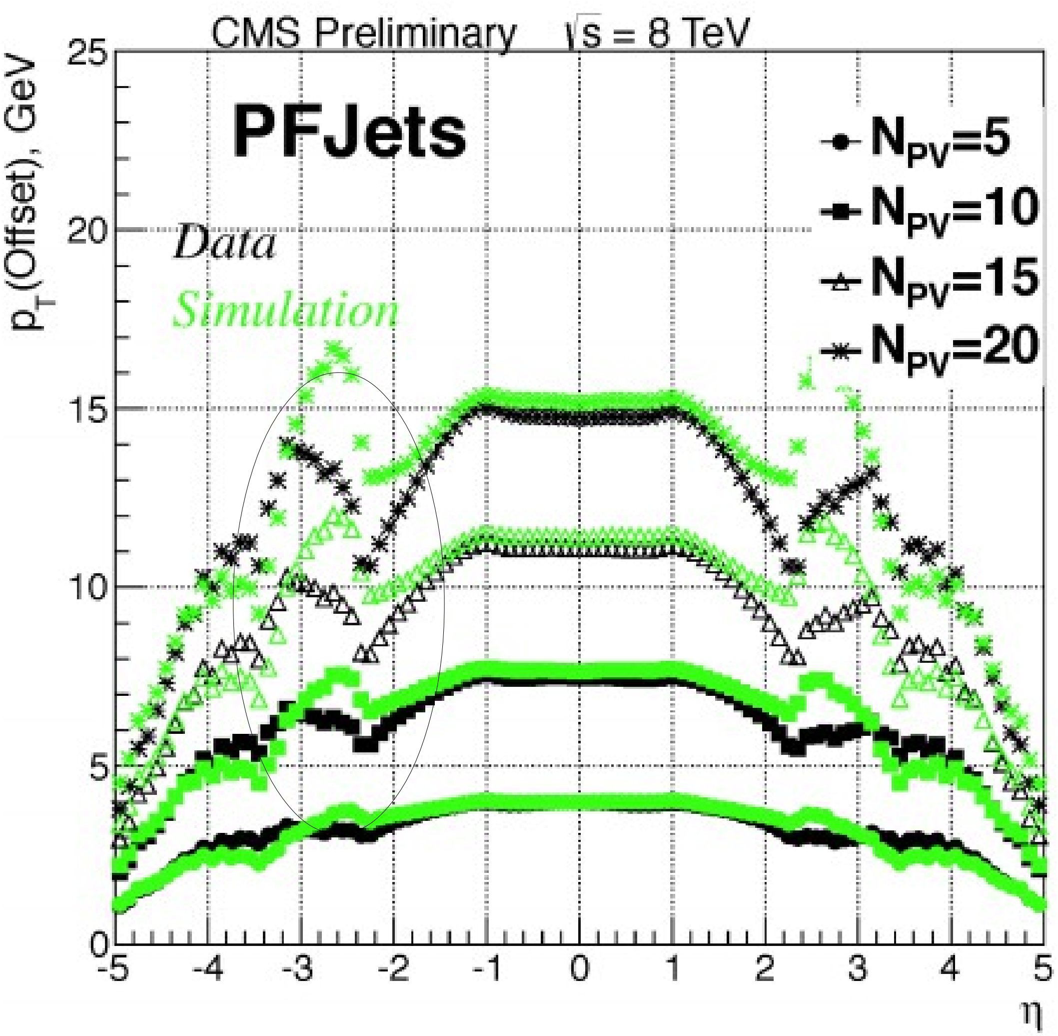
JERC

- 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



8TeV Precision

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



How do we deal with the systemaitcs?

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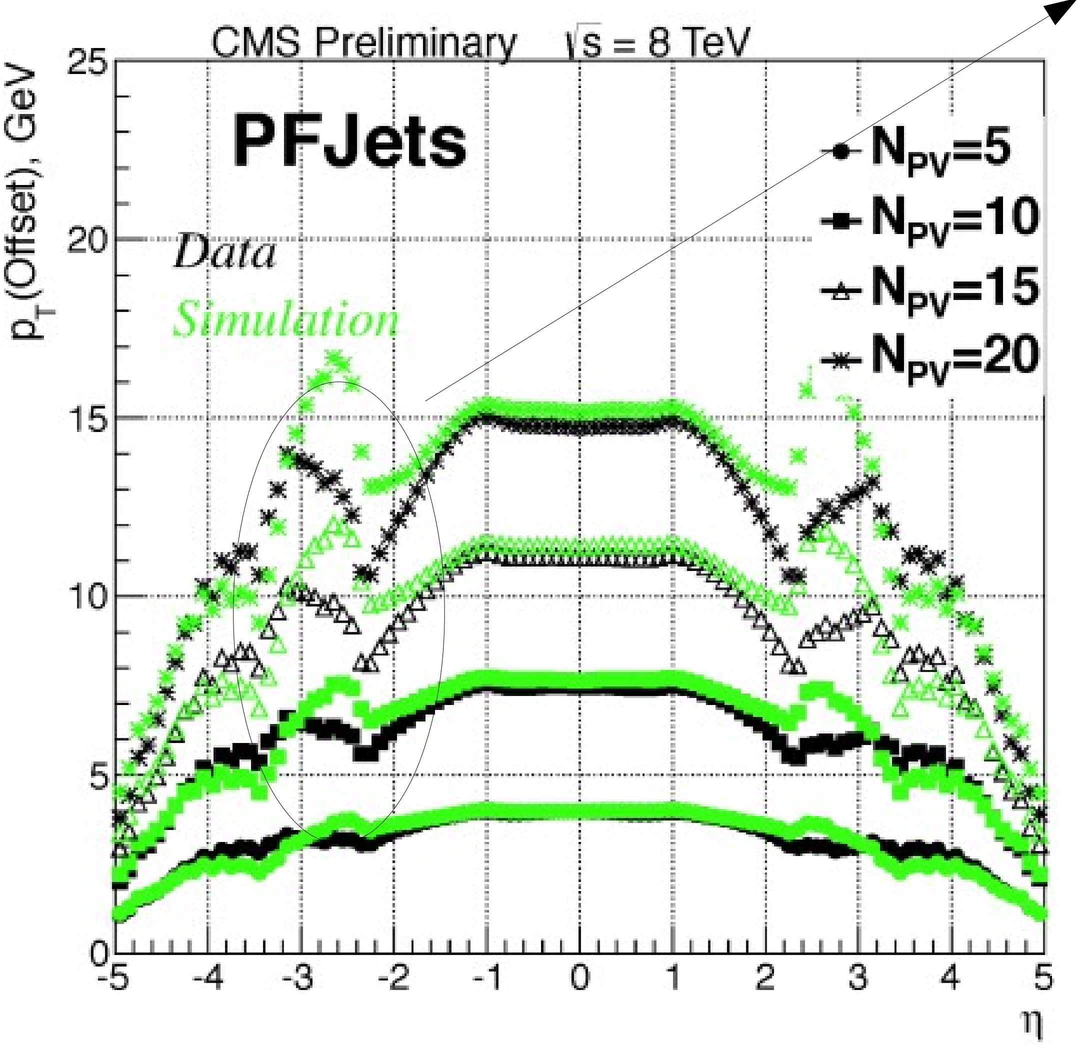

Originally had systematic unc. Based on full data/MC difference

How do we deal with the systemaitcs?

8TeV Precision

- Pileup Subtraction
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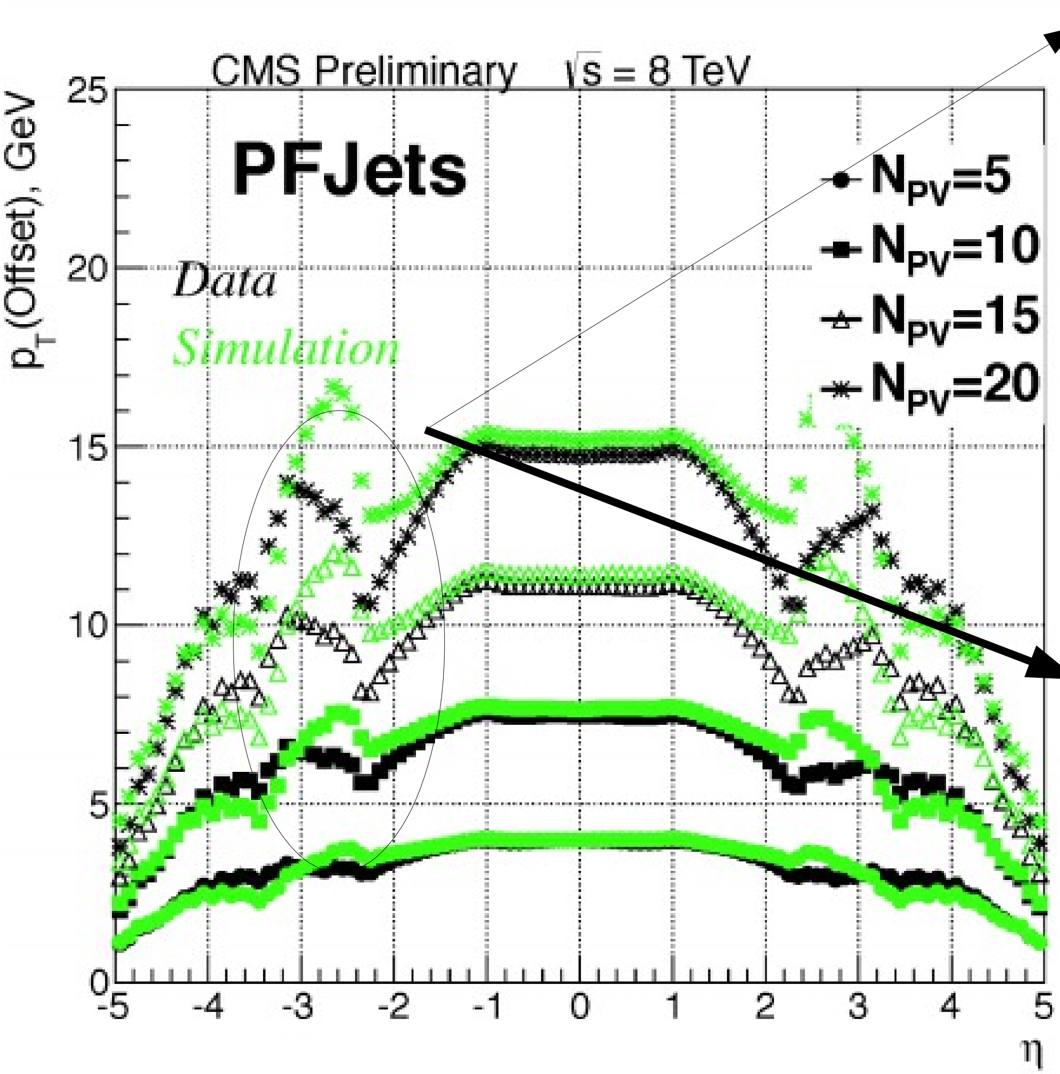
How do we deal with the systemaitcs?

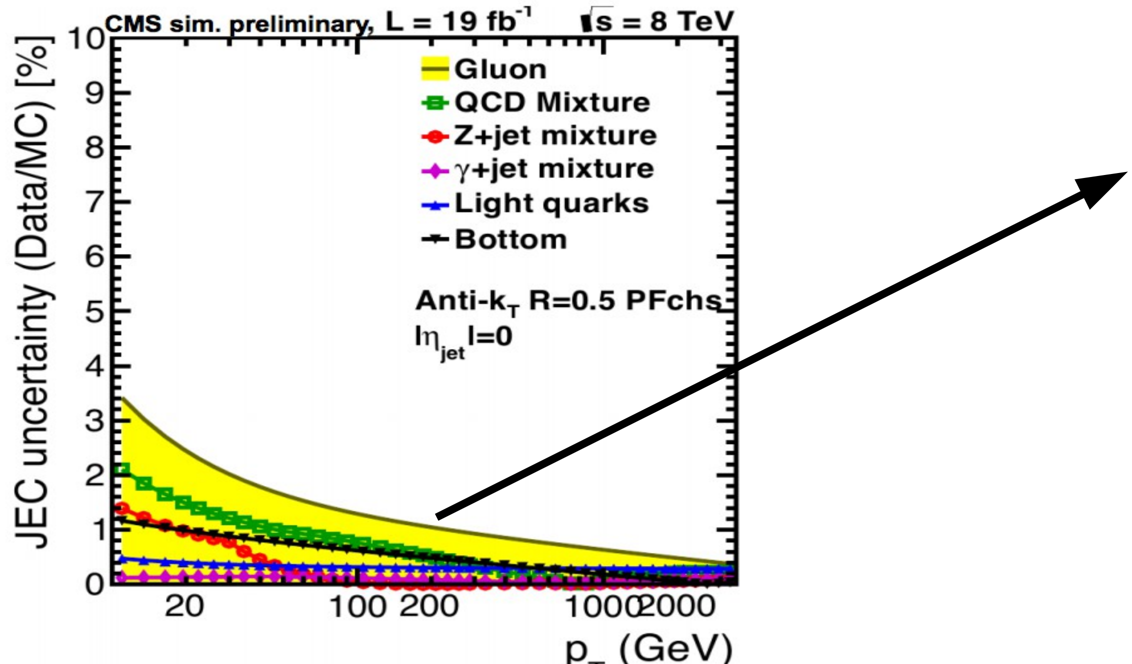


Migrated to residual bias Using same jets w/o pileup

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

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

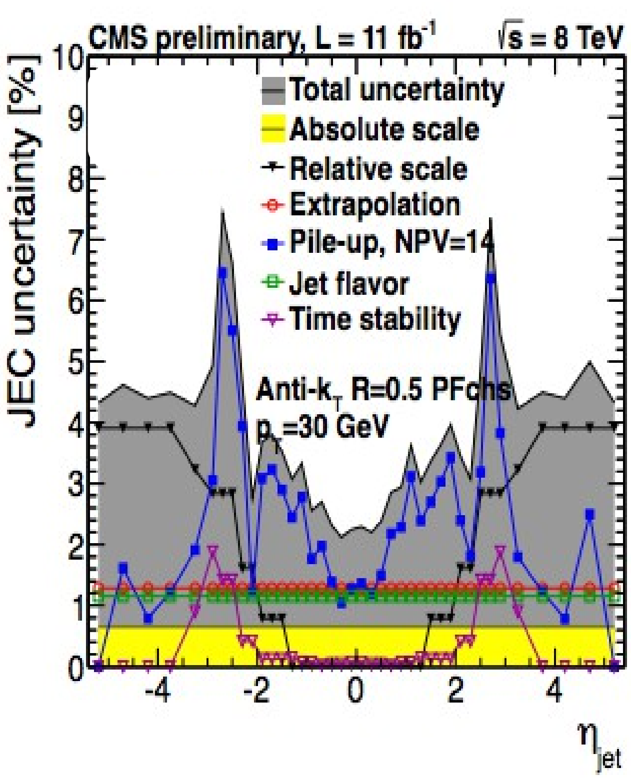


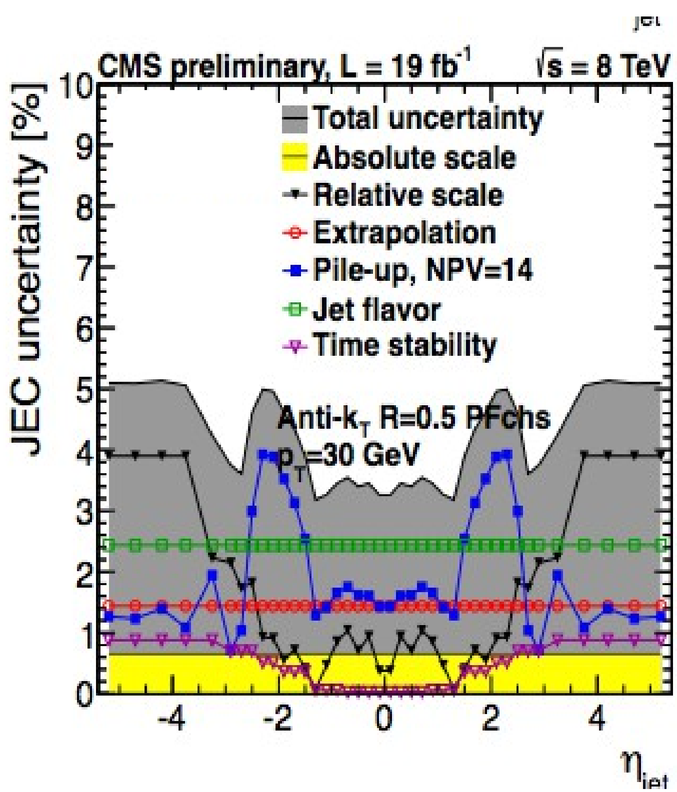
Different unc.
For different
componsition

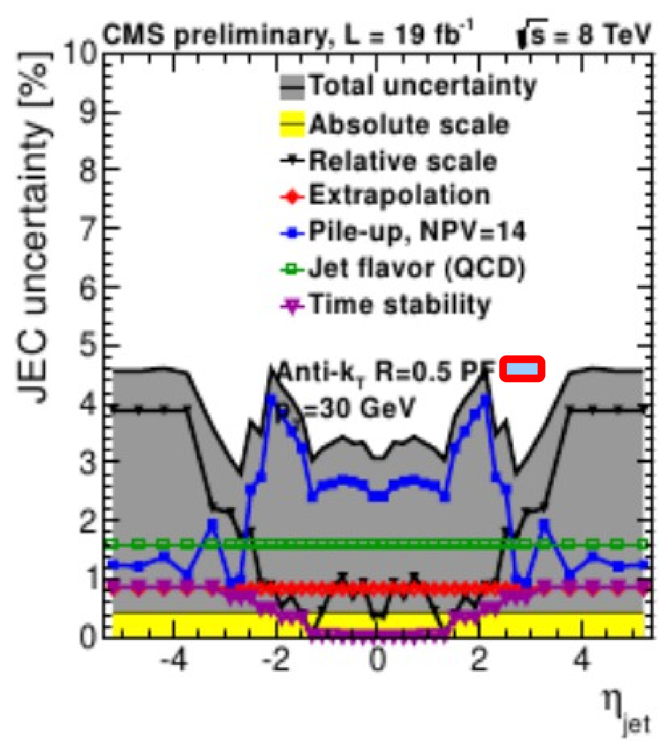
Evolution

- 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





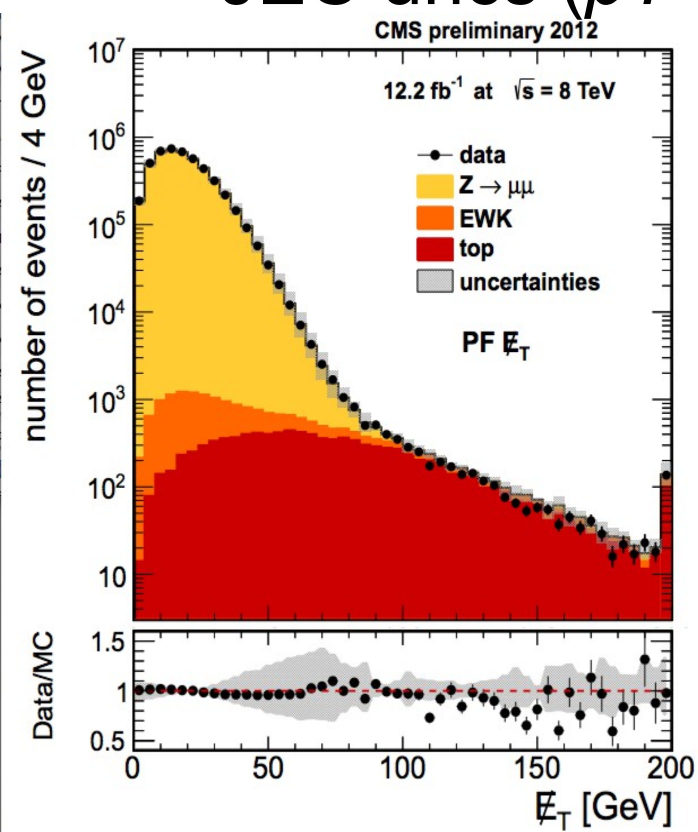


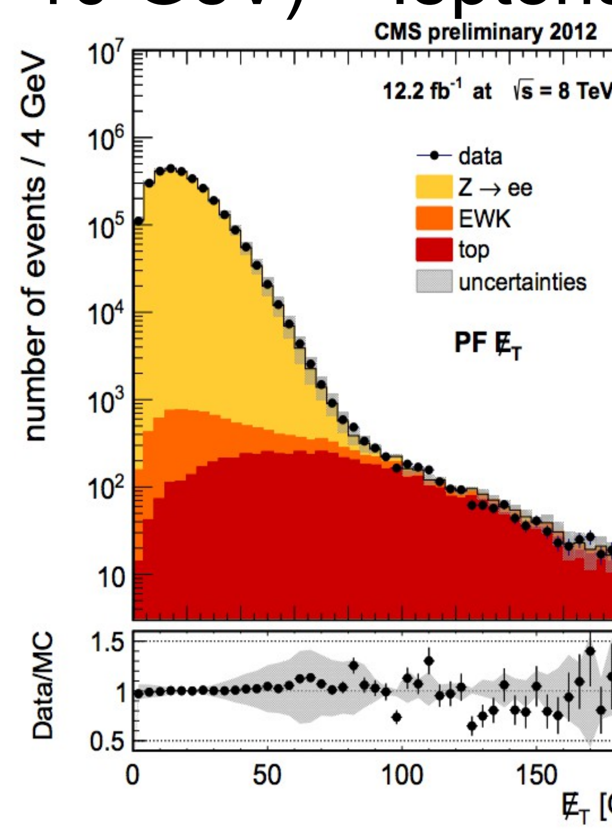
JEC equivalent for *MET*

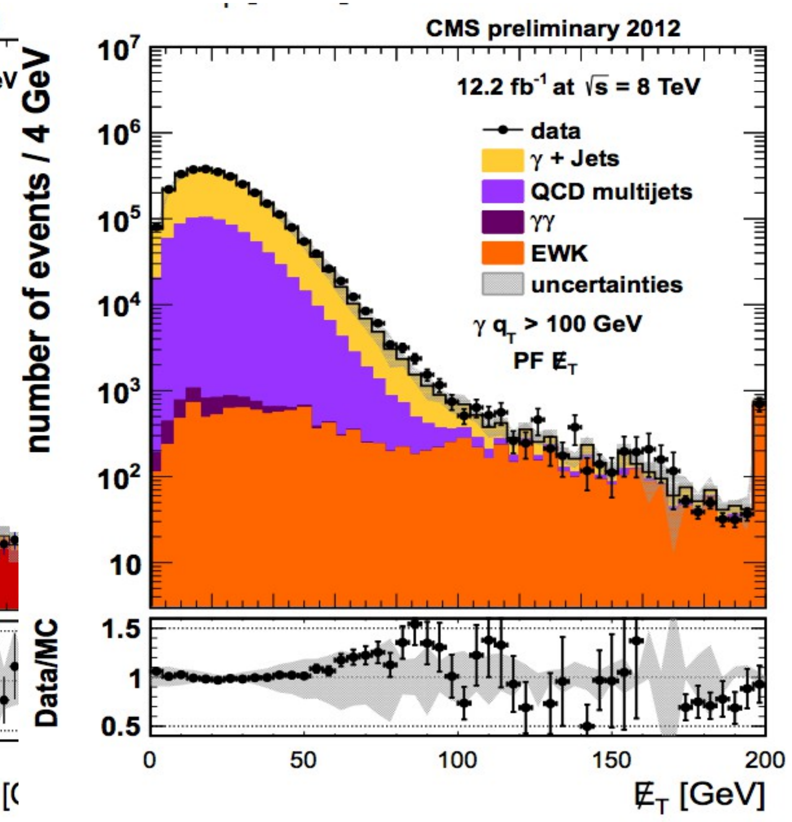
- Step 0 :
  - Take negative vector sum of pf components
- Step 1 (Type 1 *MET*) :
  - Apply jet energy + res corrections (excluding PU corr)
- Step 2 (φ corrections):
  - Measure mean MET_x and mean MET_y
- Step 3 (Type 0 *MET*)
  - Add (tracks not from PV) x (constant~3/2)
- Step A (PU reduction) : (done between 1 and 2)
  - MVA/No PU Algorithms

MET Precision

- *MET* is a measure of the low energy jets in event
  - Excellent agreement across many orders of magnitude
  - Evidence Low energy PF Candidates well calibrated
- Generic Unc prescription gives good coverage
  - JEC uncs (*pT* > 10 GeV) + leptons unc + 10% the rest



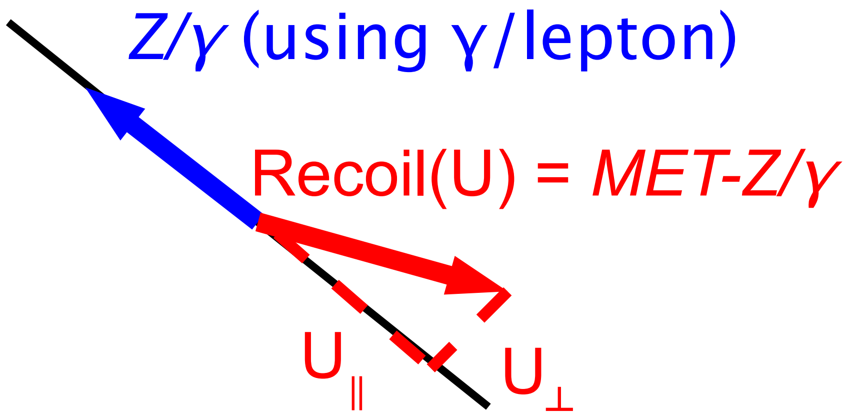




Understanding *MET* Precision

- Biggest Issue
  - Scale factor of response at low pT drops down
  - Effect is understood :
    - Same effect as the pileup

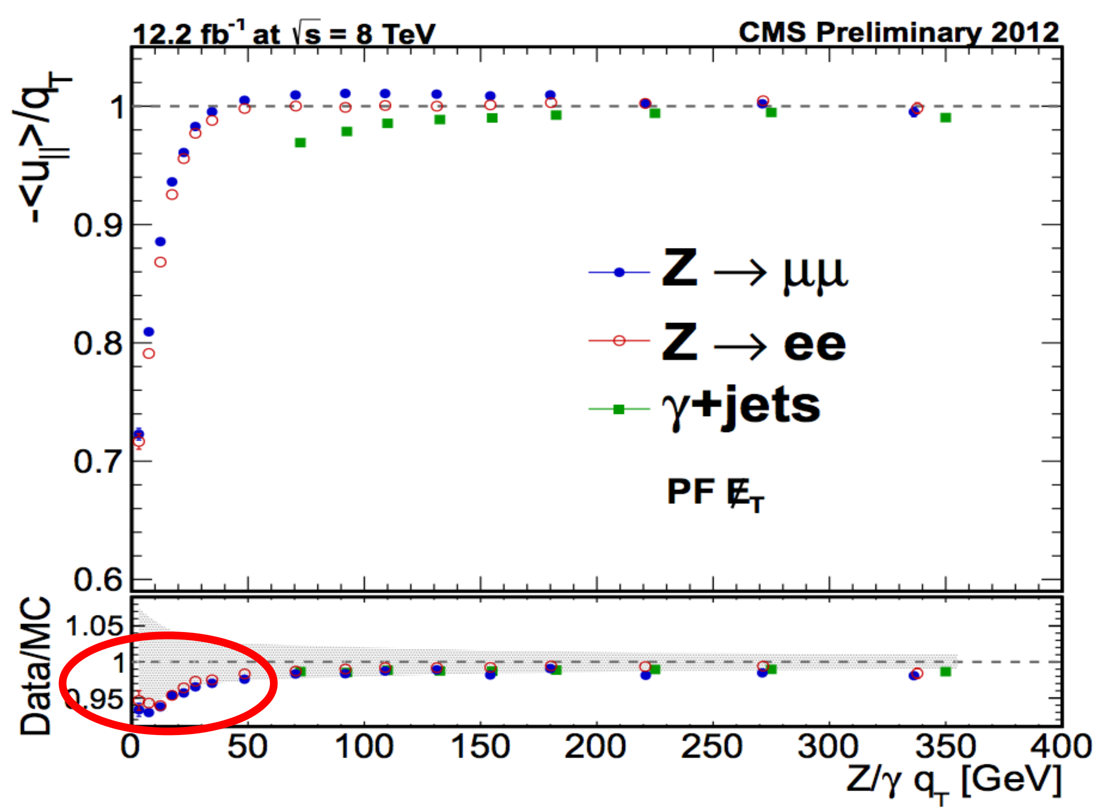
MET variable definitions



Measures :

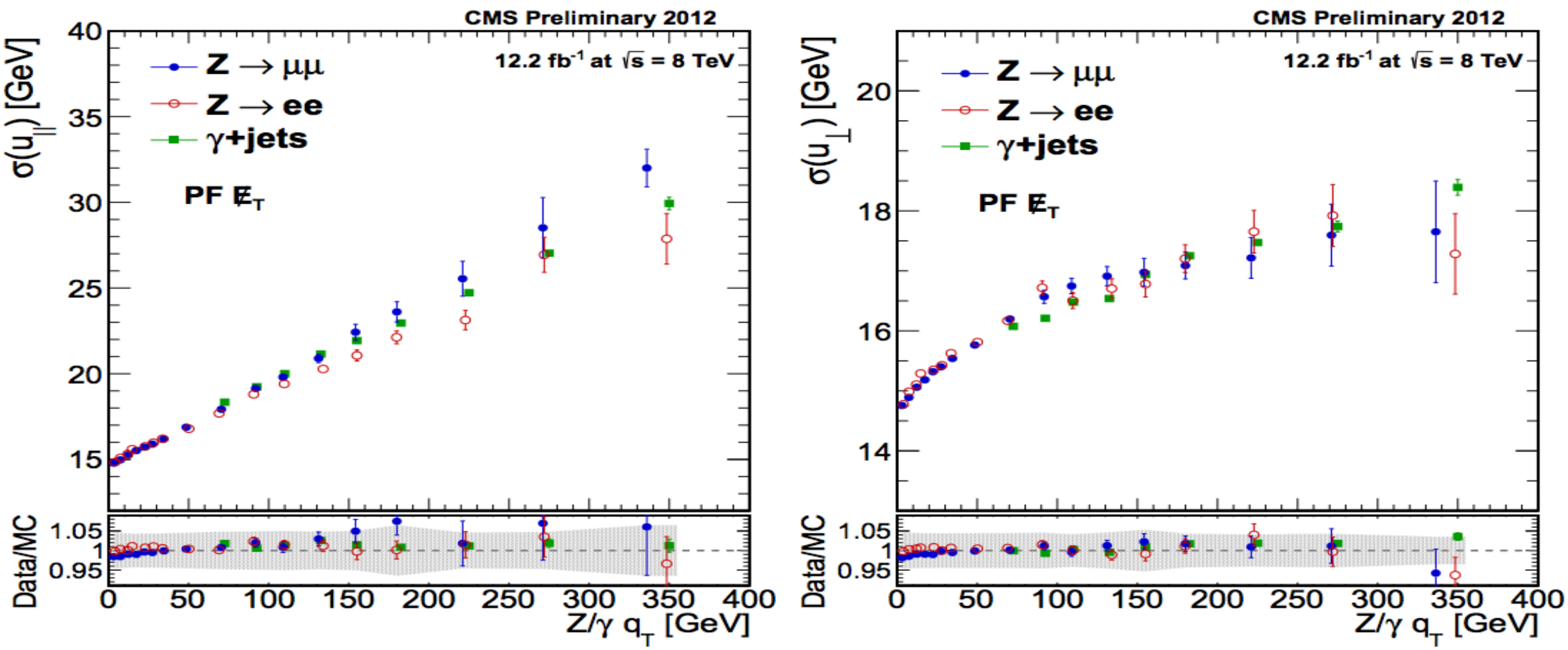
Response : $U_{\parallel}/pT$

Resolution : $U_{\perp}, U_{\parallel}$



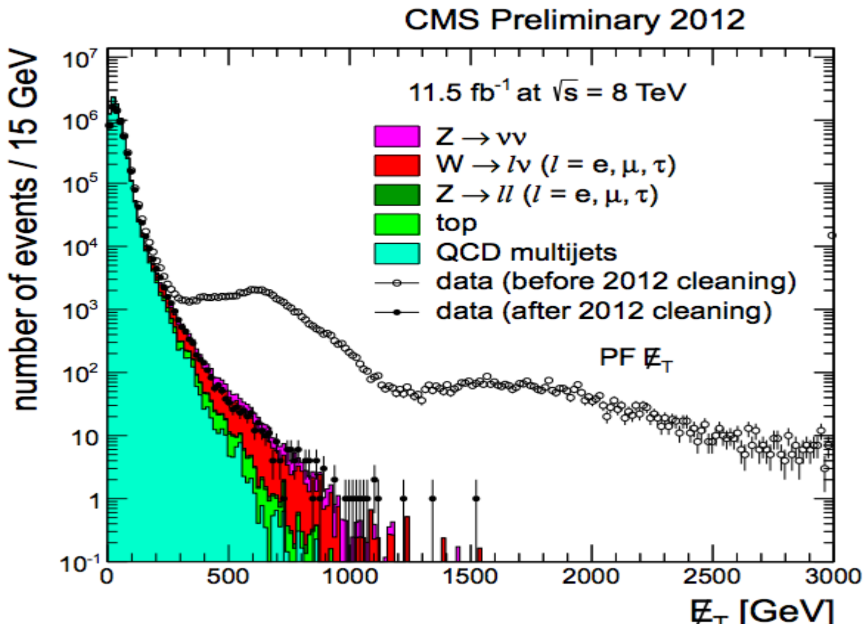
Understanding *MET* Precision

- Resolution is well understood :
  - Resolution obtained by applying data/MC JER scale
    - Scale factor is roughly 10% (same since 2010)
  - Correcting for φ helps bring resolution effect
- Problem is we have a chicken/egg issue
  - Can we fix the intrinsic issue of smearing?



Taking it to the Tails

- We have a well established set of filters:
  - HB/HE filters
  - JetID
  - Tracking....
  - What will be new?



- A number of analysis techniques developed for tails
  - Min met => Min(Track *MET*,PF *MET*)
  - *MET* significance
  - Likelihood minimization
- How can we incorporate these generically?

Review : Jet Taggers

- Four Jet tagging PASs
  - Pileup Jets
  - Quark/Gluon discrimination
  - W Tagging
  - Top Tagging

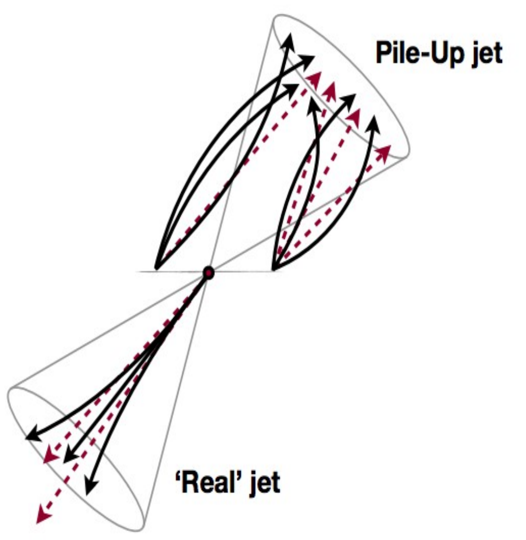
Rely on CA algorithm
+Pruning/Filtering
+larger cones

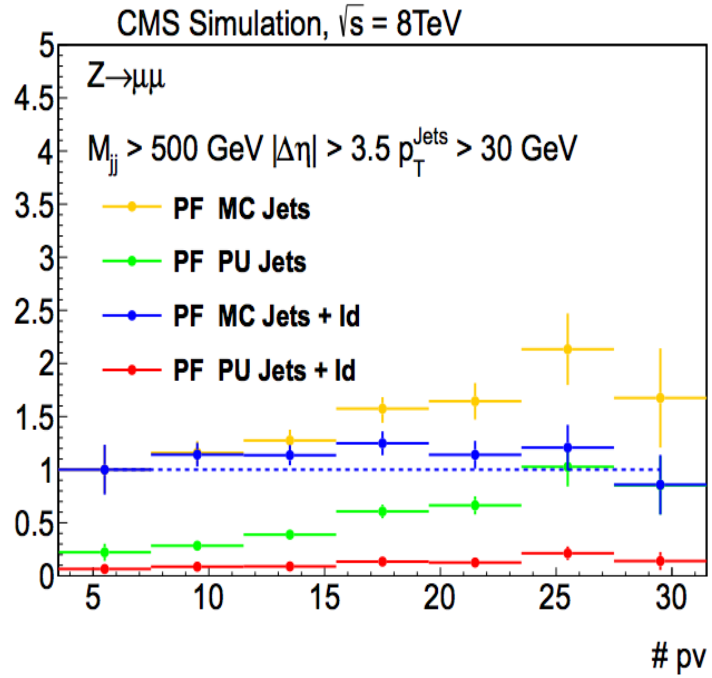
Jet *pT*

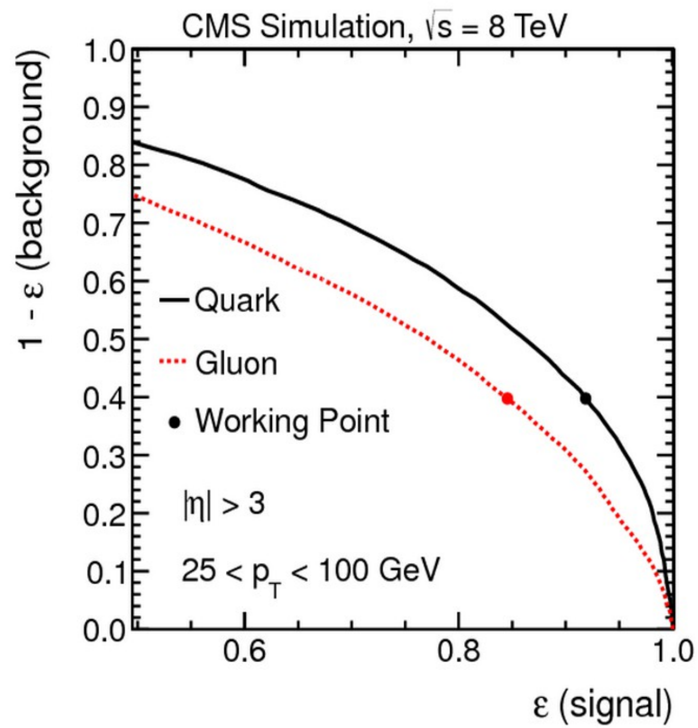
- Core of all taggers rely on Jet sub-structure
  - Jet shapes and sub-parameters used in all
- Jet taggers force additional review over all pTs
  - Allows us to drive development in 2014

Pileup Jet ID

- Goal : Identify Pileup by clustering jets
  - Use shapes and vertexing combined in a BDT
  - Extends performance of jet to lower jet pT
  - Data/MC based tag and probe
- Uncs. : Quark/Gluon differences+PU modelling
  - Application : AK5 Jets

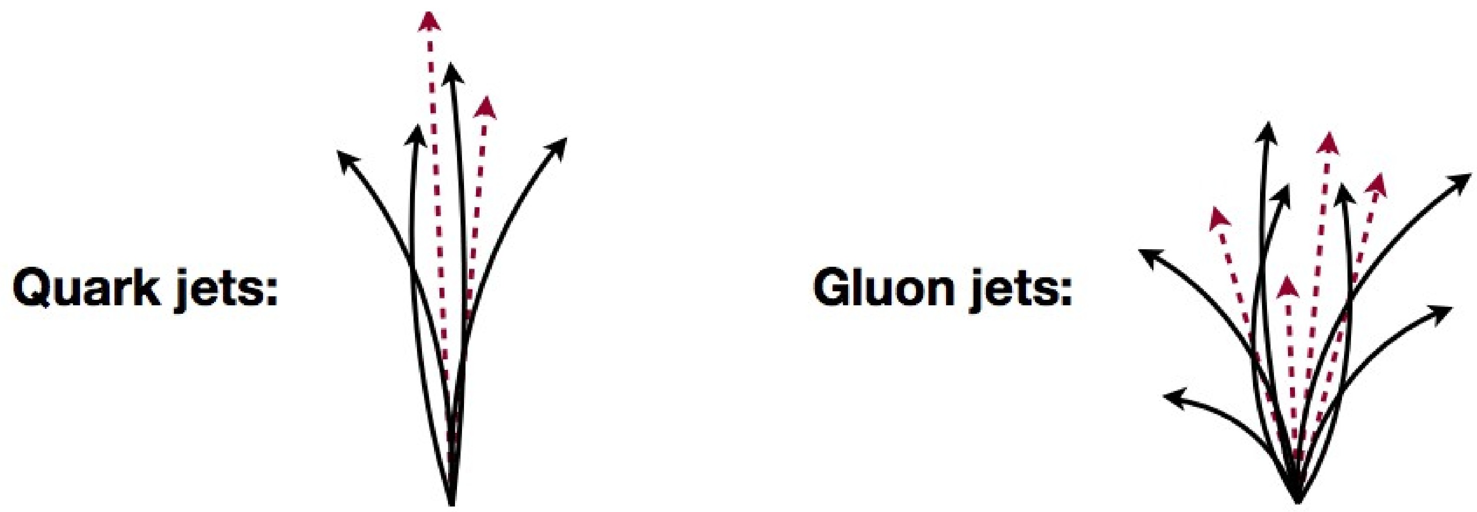






Quark Gluon Discrimination

- Goal : Separate quarks and gluons
  - Likelihood discriminant of 3 variables ptD,σ_2,#particles
    - Established set of most discriminating variables
  - New technique for modeling of discriminant in data
  - Application : AK5 Jets



Unc : MC modeling (paraticularly that of gluons)

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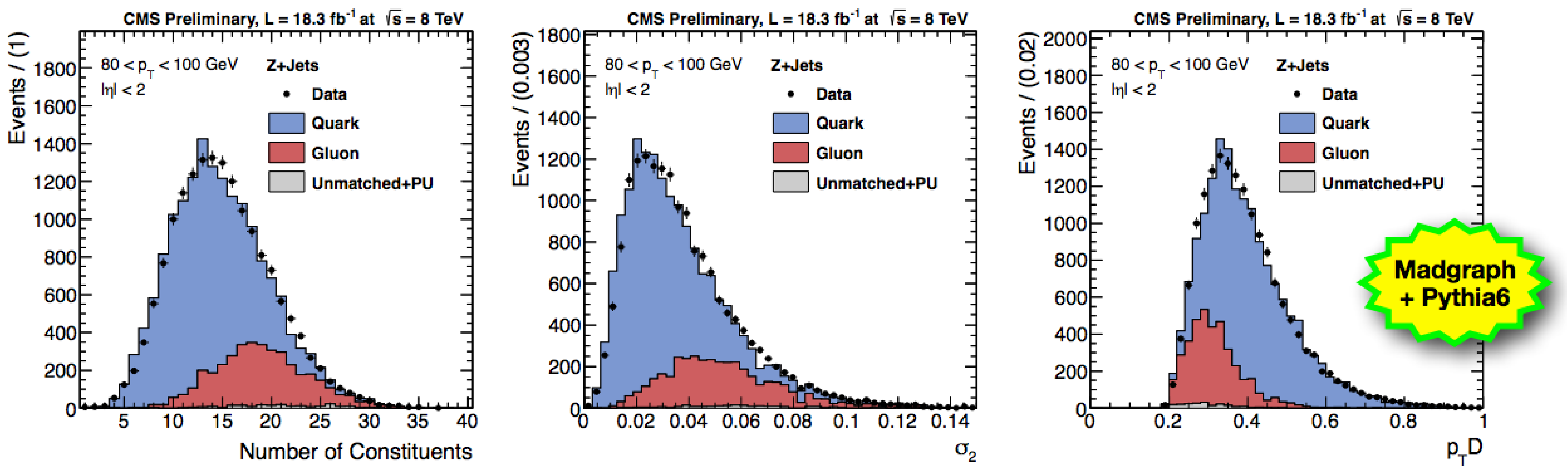

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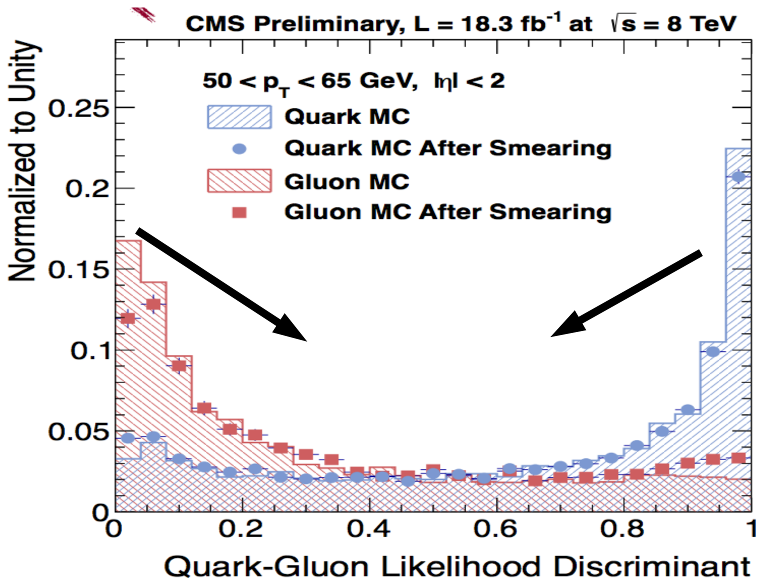
Q/G Data/MC agreement

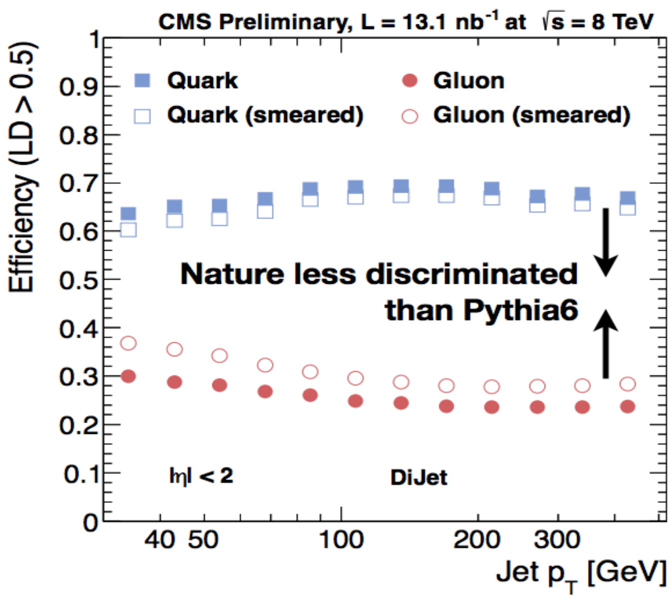


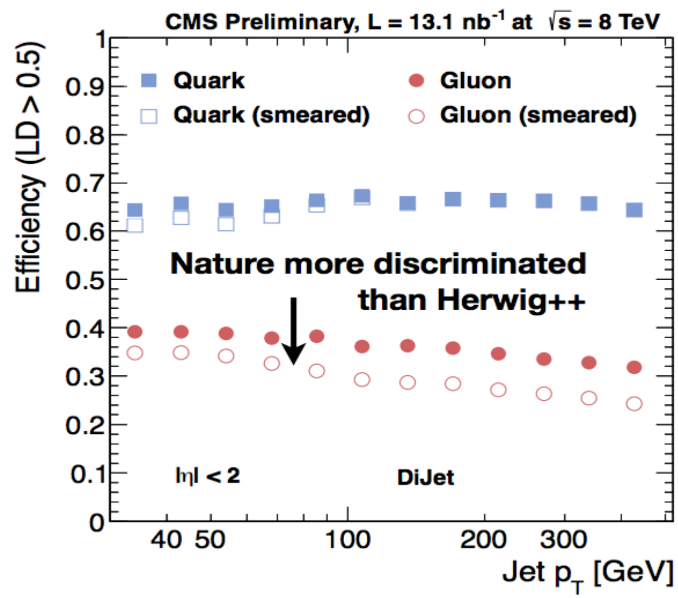
Smearing approach :

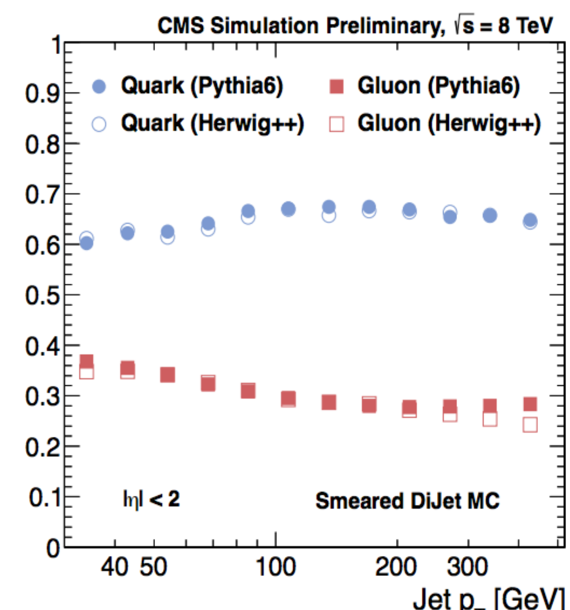
Take MC discriminant and fit to data

Use : $g(x,a,b) = \tanh\left(a \operatorname{arctanh}(2x-1) + b\right)/2 + \frac{1}{2}$

Fit Z data and apply to di-jet MC





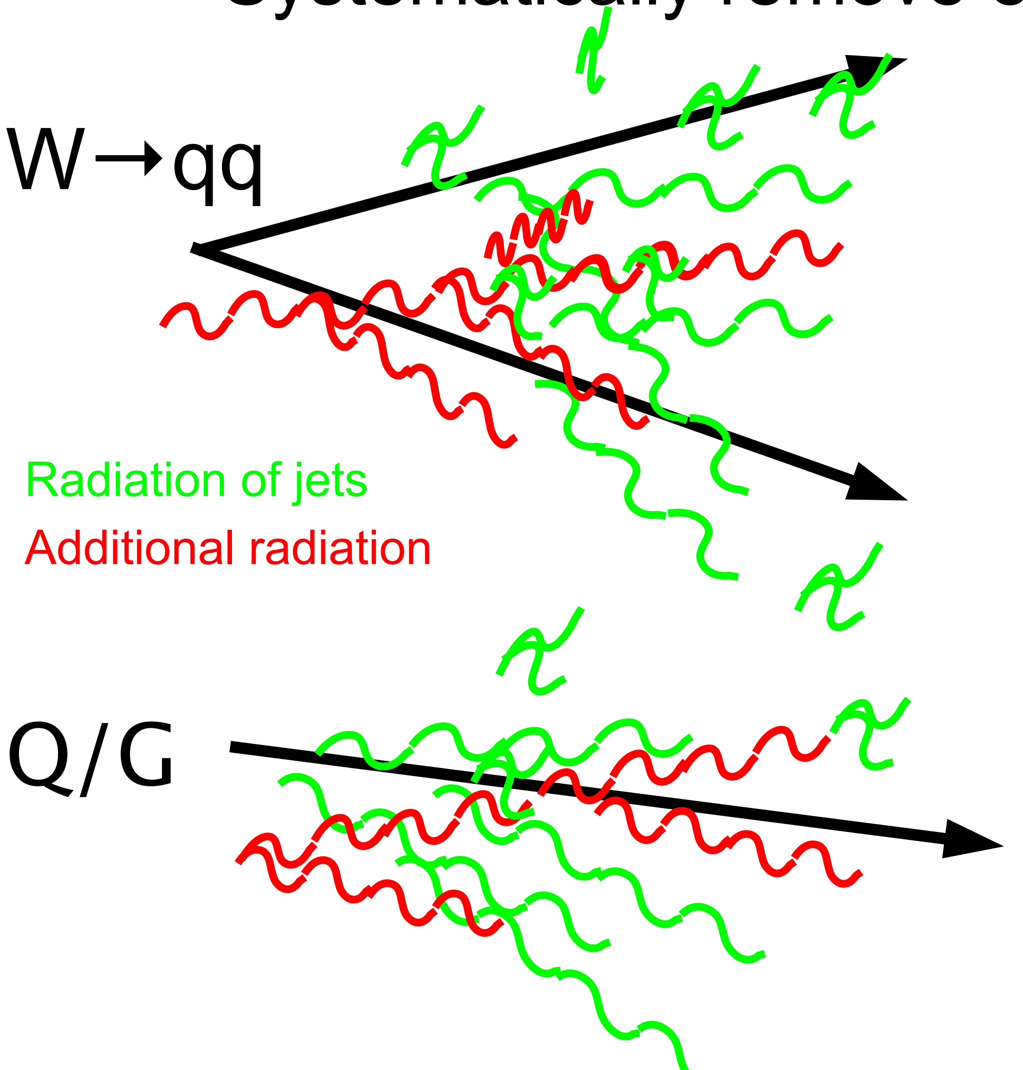


Unc : MC modeling (particularly that of gluons)

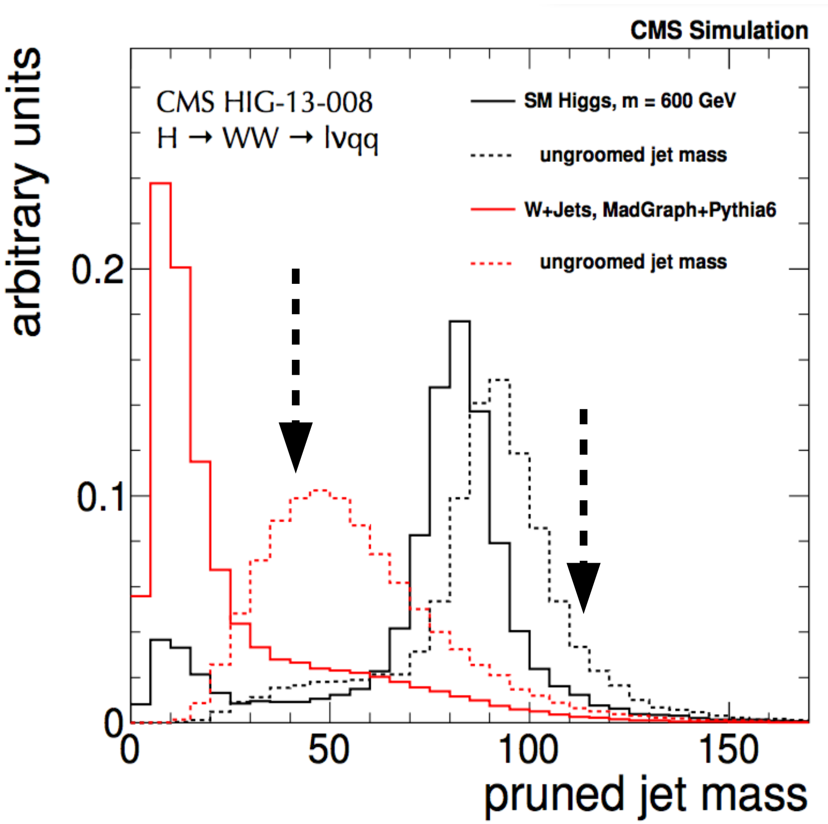
These same disagreements are affecting JERC

Boosted Objects in 1 Slide

- How do I resolve boosted hadronic objects?
  - Look at the properties of the jet
  - Systematically remove extraneous radiation



Before



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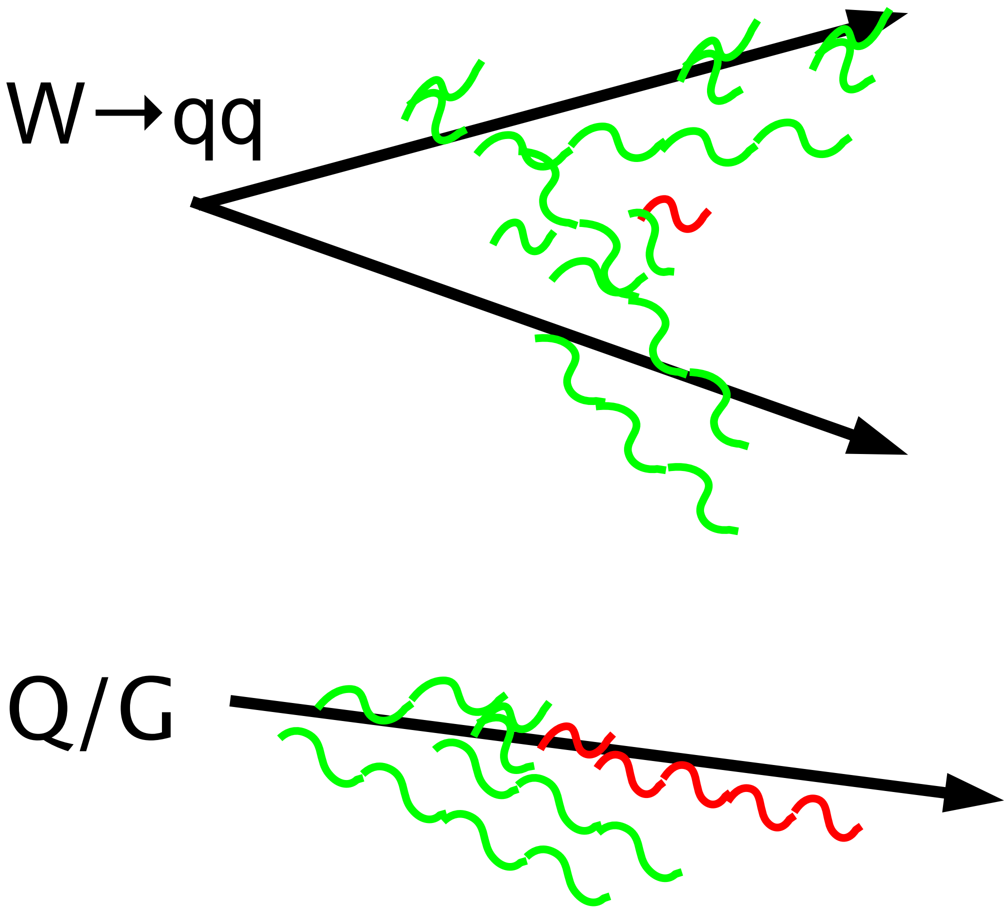
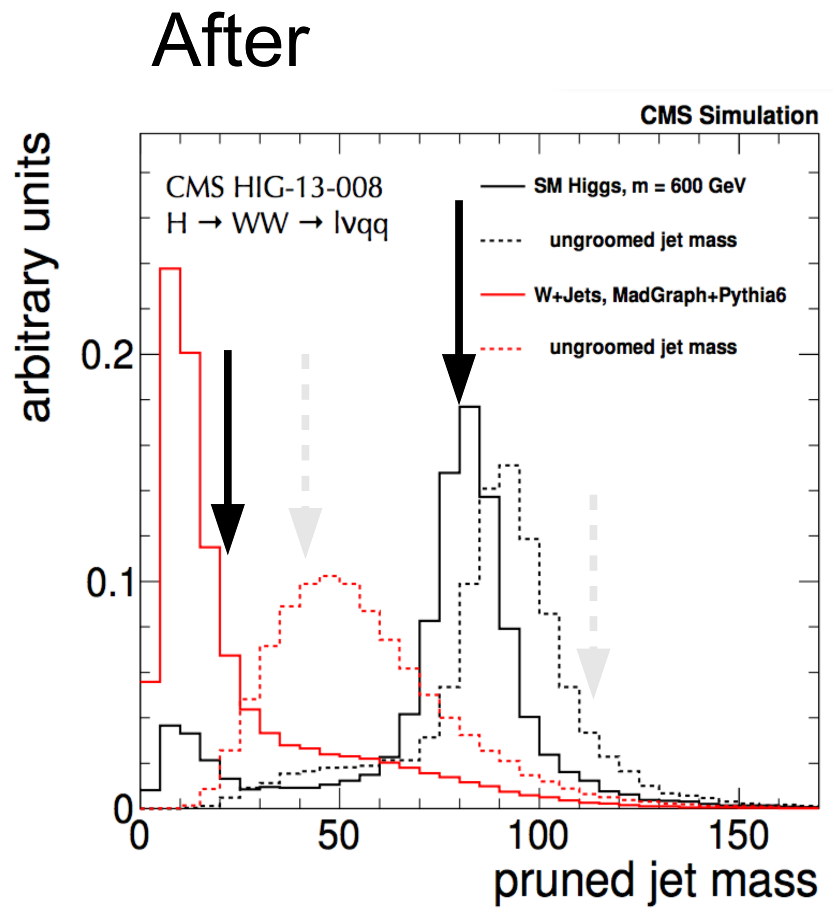
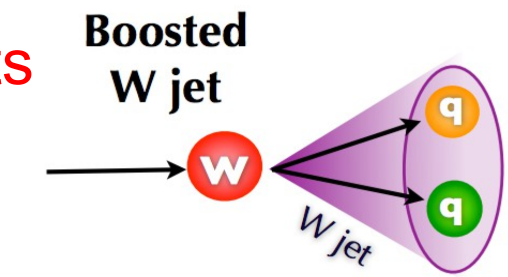




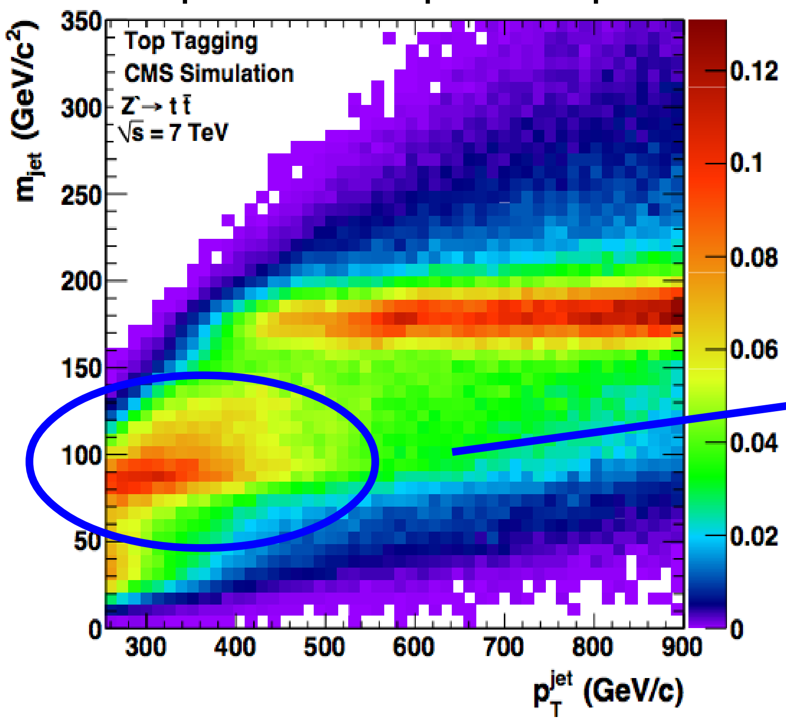
Along with this we can look at the jet shapes like Q/G or PU

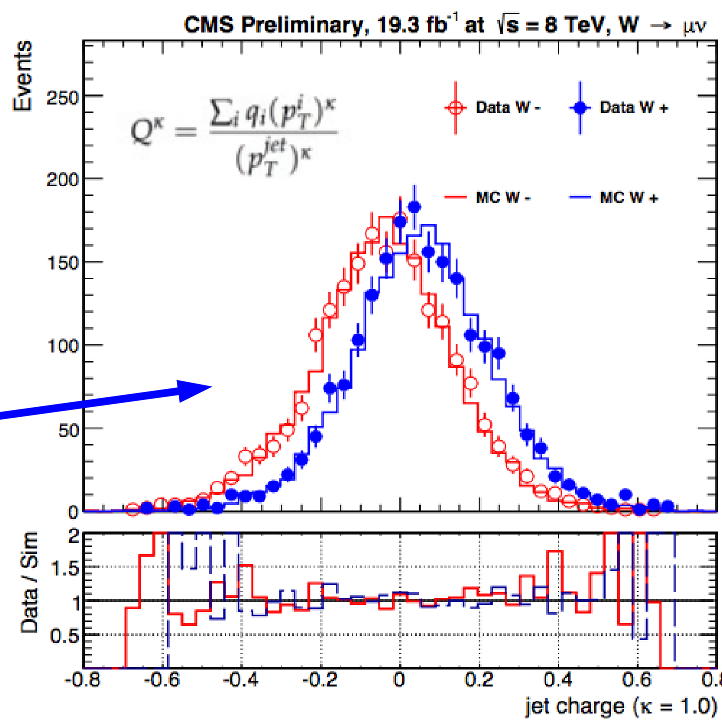
W Tagging

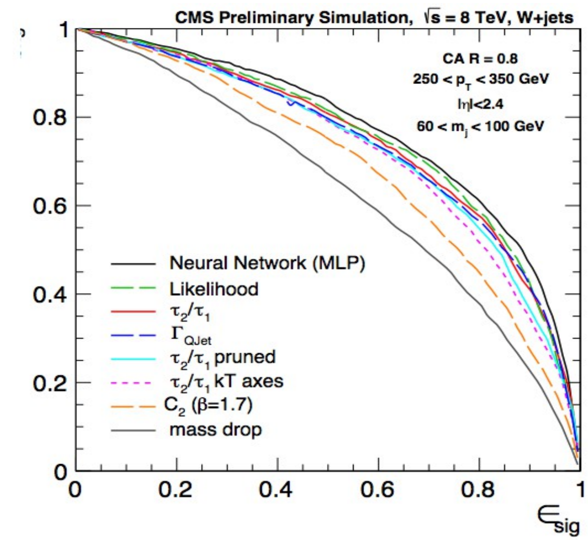
- Goal : Establish boosted hadronic W tags
  - Set of most discriminating variables
  - Variation over large pT range/tunes/Polarization
  - Validation of data/MC of all shapes for W
    - Signal sample: Tops Bkg Sample : di-jet/W+jets
  - Application : CA8 Pruned jets



Top selection phase space

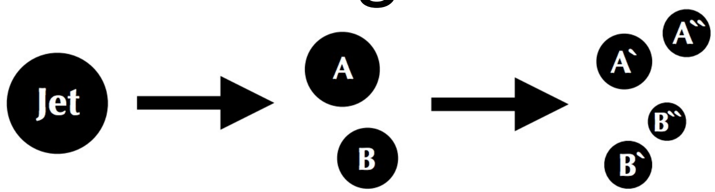






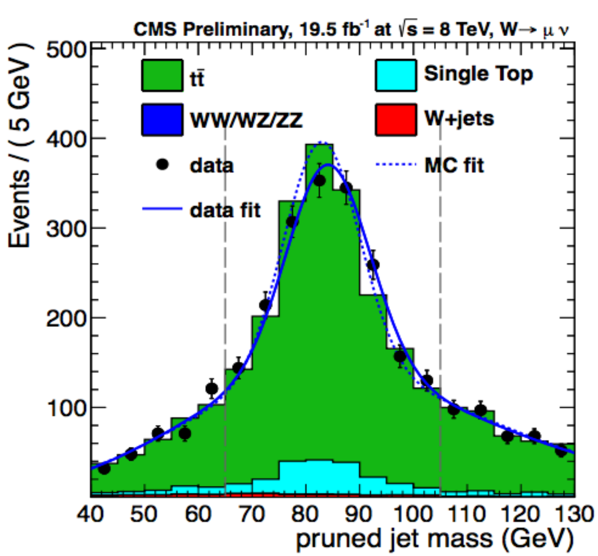
Jet Grooming and JERC

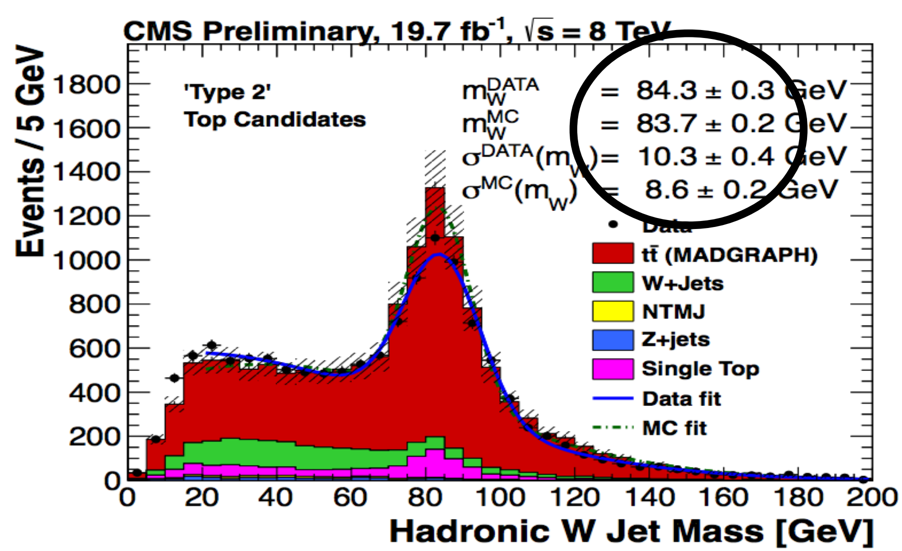
- Jet Grooming used for heavy boson taggers



Grooming removes parts of jets to isolate subjets

- Question:How do we validate JERC w/substructure?
  - Current approach : apply AK7 corrections and fit W peak
    - Fitting W peak just used for validation
    - For current studies precise jet energy corrections not needed
  - Not clear what will be needed in the future

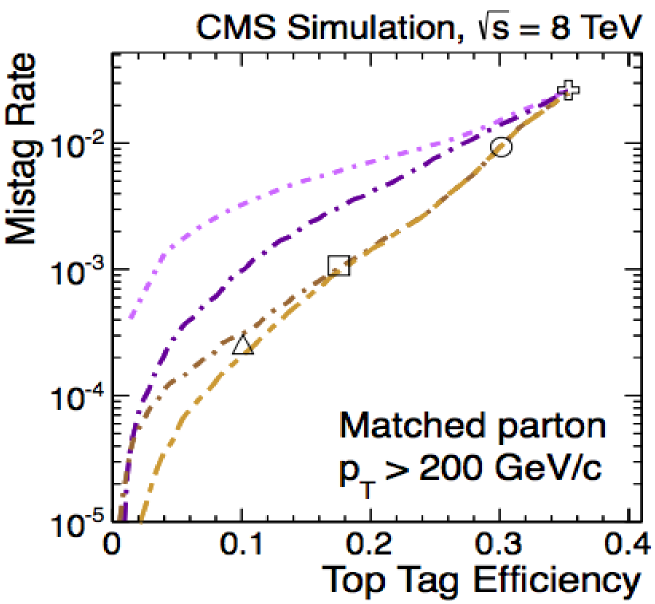


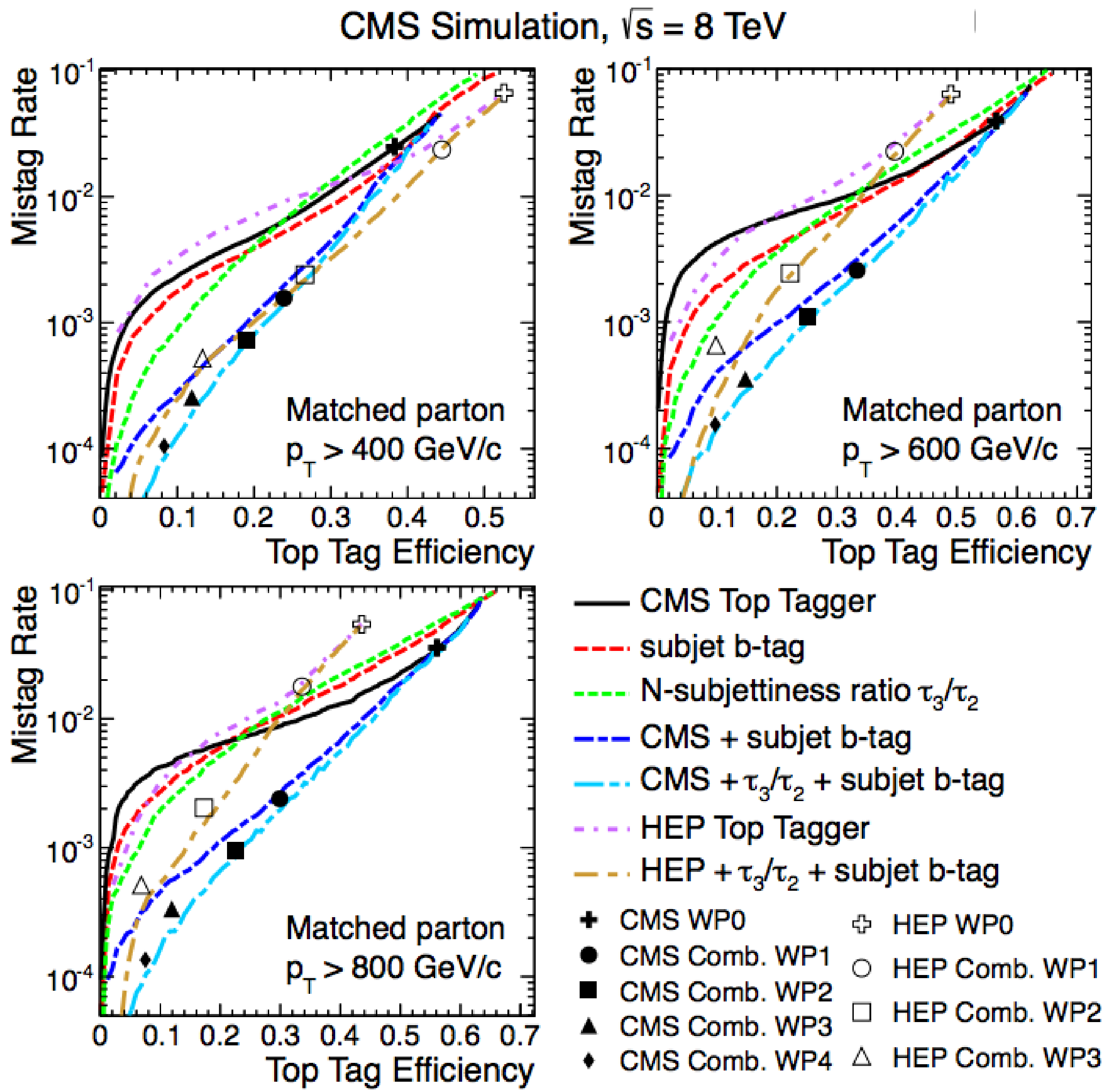


jet smearing is off by ~10% Consistent w/JER

Fresh Out of the Gate : Top Tagging

- Top Tagging PAS : JME-13-007





Supermarket Sweep of all Taggers on the market

Application
CMS Top Tagger : CA8 modified
HEP Top Tagger : CA15 Filtered

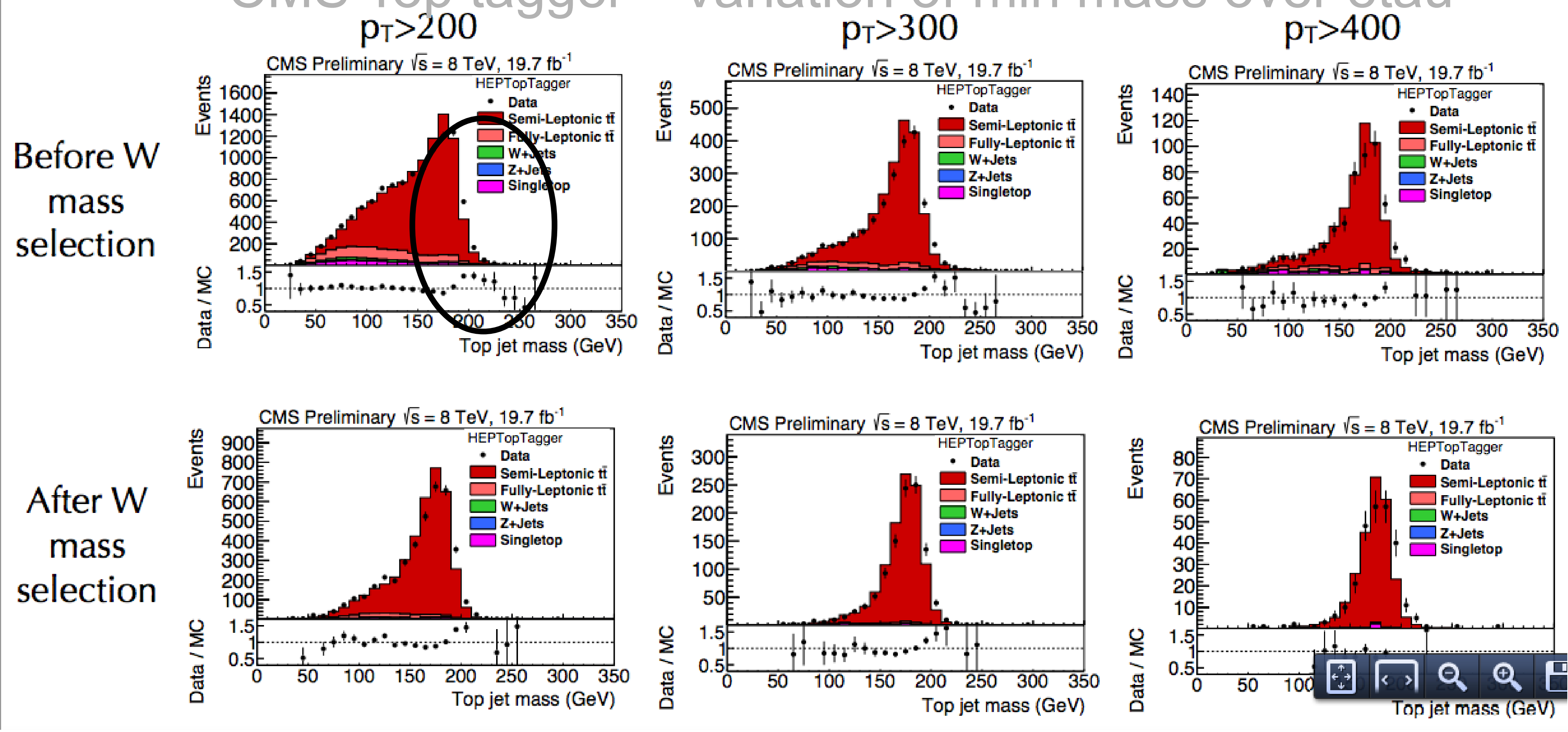
Top Tagging PAS (cont'd)

- Validation of data/MC modeling : T &P

Two issues of further investigation

HEP Top tagger → Top mass shape

CMS Top tagger→Variation of min mass over etau



Top Tagging PAS (cont'd)

- Validation of data/MC modeling : T &P

Two issues of further investigation

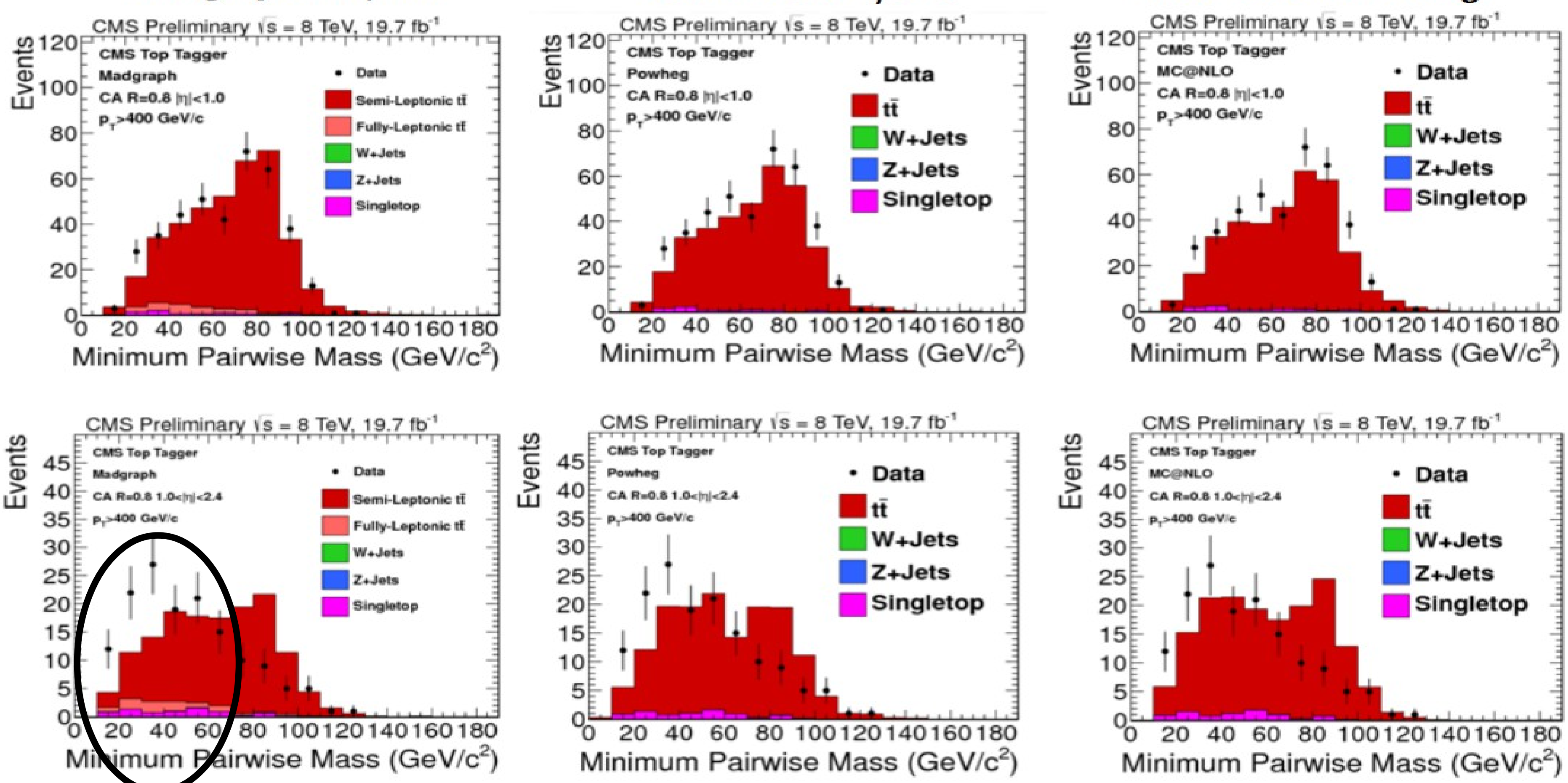
HEP Top tagger → Top mass shape

CMS Top tagger→Variation of min mass over η

Madgraph + Pythia | POWHEG + Pythia | MC@NLO + Herwig

Central η

High η



Modeling of Shapes

- Three regions of shapes :

Detector

Pileup/ Simulation	Detector resolution effects	Merging of PFCandidates

Jet pT

Sensitive to underlying event	Sensitive to hadronization effects	Sensitive to Radiative effects

MC

Modeling of Shapes

- Three regions of shapes :

Detector

Pileup/ Simulation

Detector resolution effects

Merging of PFCandidate

Jet *pT*

Pileup Jets

Quark Gluon

W/Z Tags

Top Tags

Sensitive to underlying event

Sensitive to hadronization effects

Sensitive to Radiative effects

MC

Low pT: Jet Issues

- Key issue : resolving UE tuning from simulation

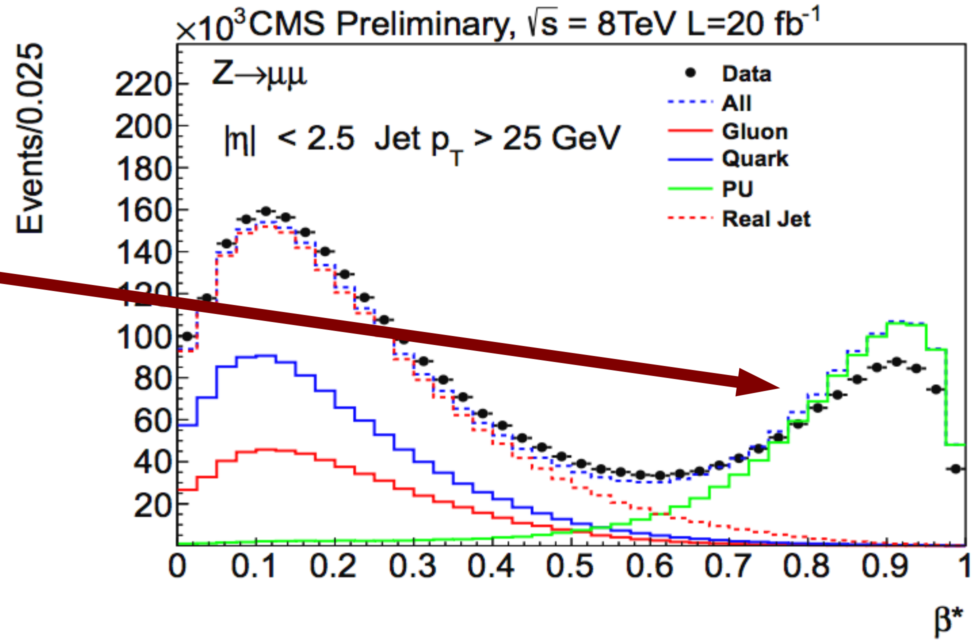
Detector

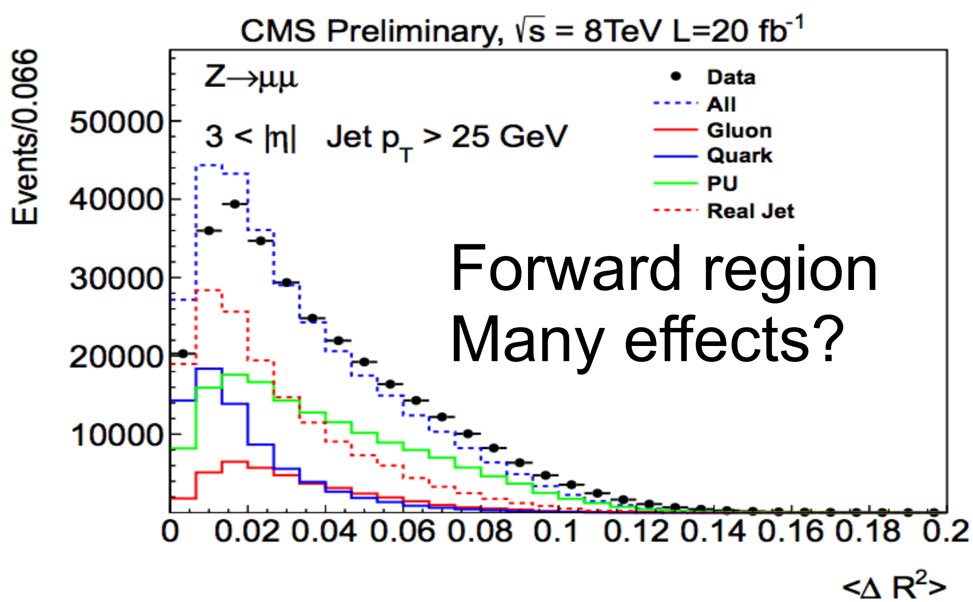
Pileup/
Simulation

Pileup
Jets

Sensitive to underlying event

MC

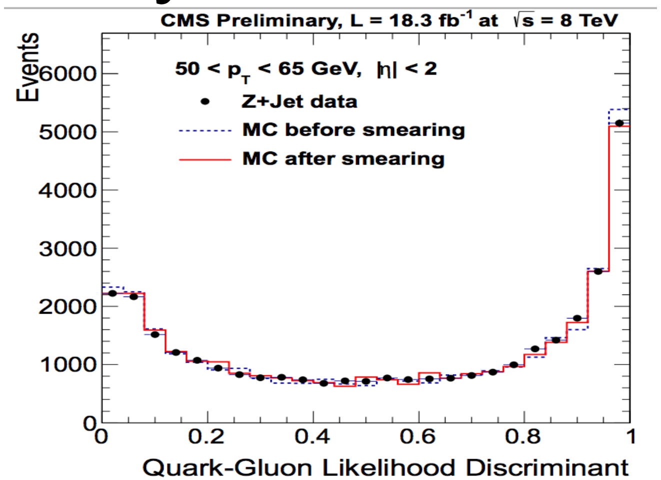


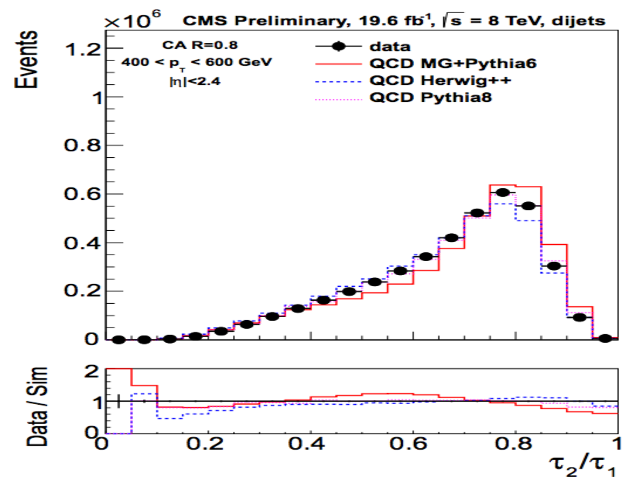


Forward region
Many effects?

Medium pT : Jet Issues

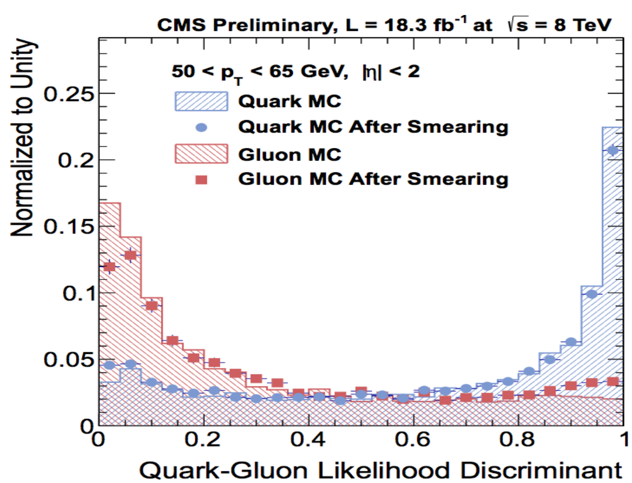
- Key Issue : what hadronization model is best?

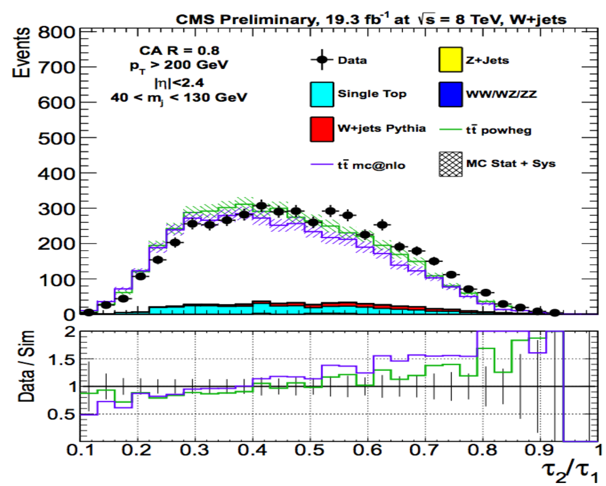




Quark/Gluon

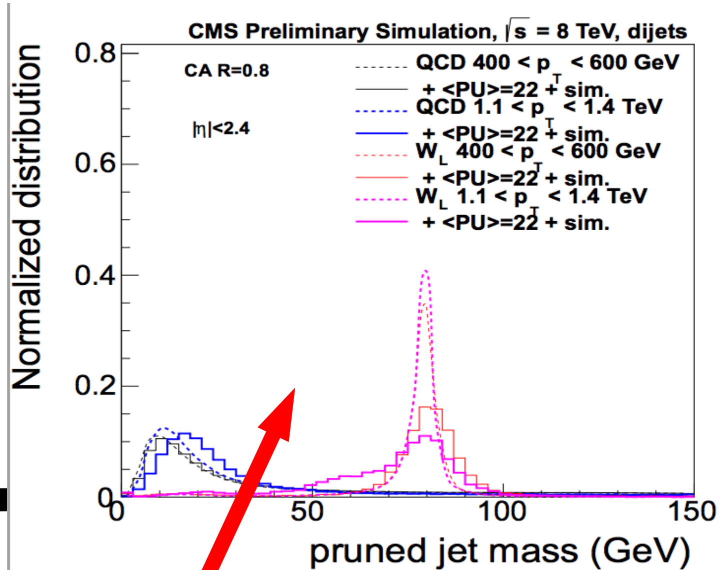
W/Z Tags

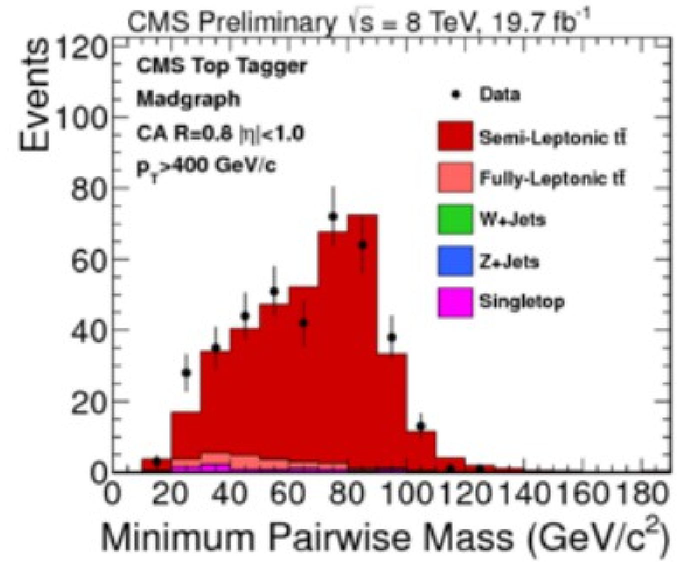




High pT : Jet Issues

- Key Issue : What breaks down at high pT?

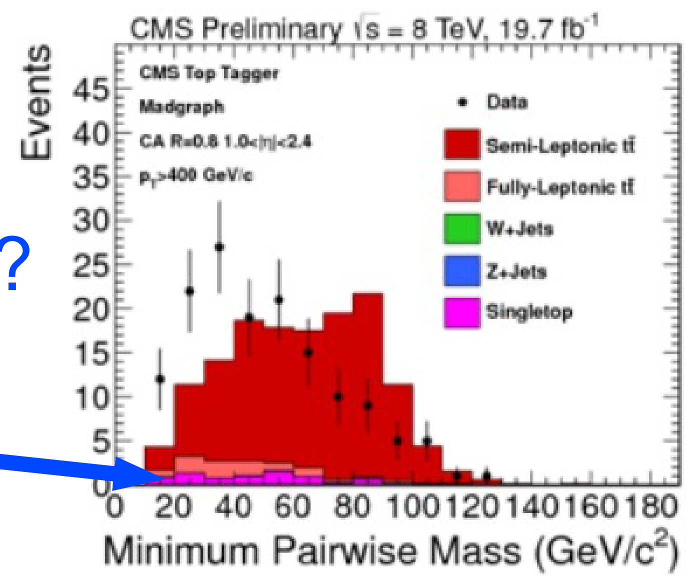




Sign of reconstruction breakdown

Sign of additional radiation?

More investigation

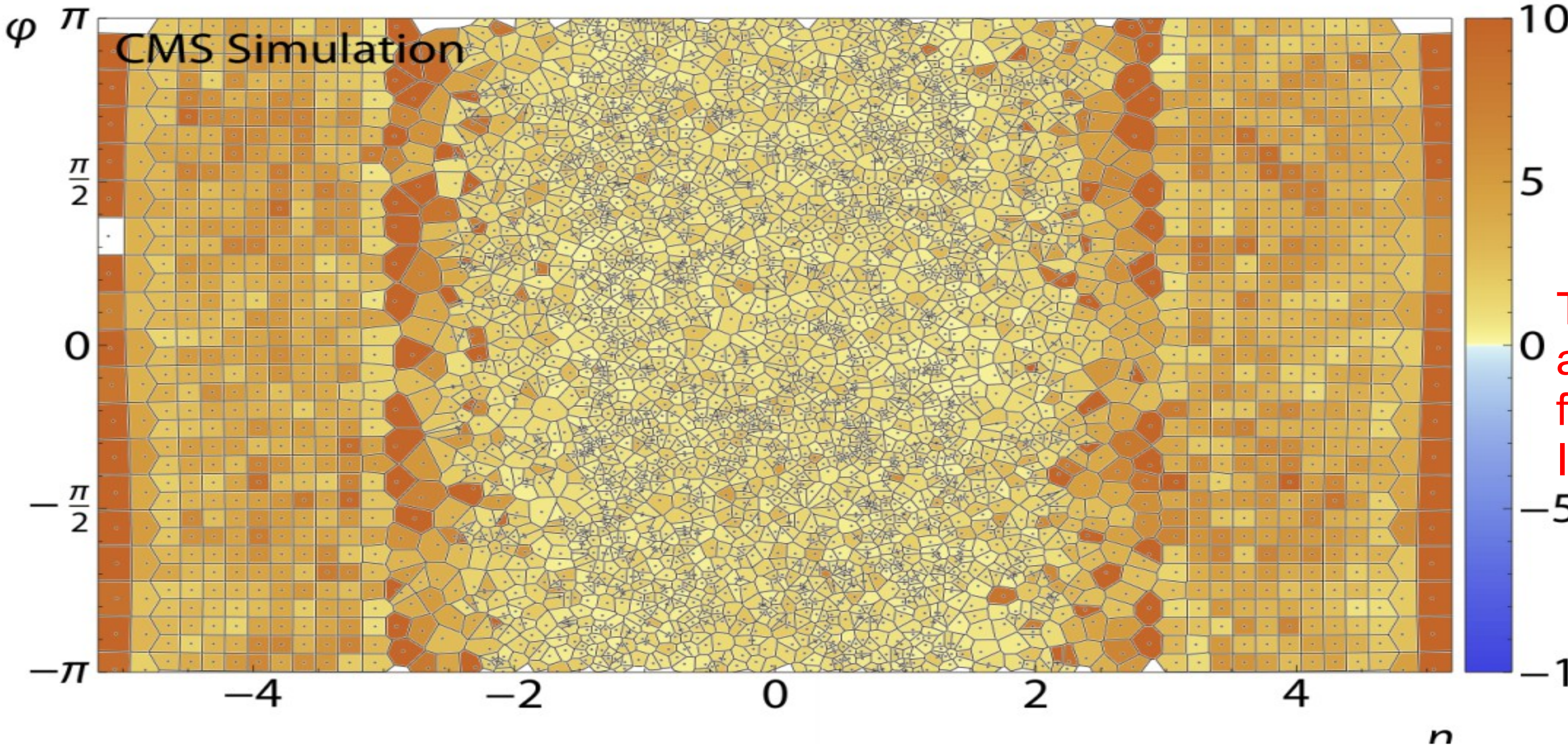


Putting it together

- Jet tagging studies pointing to a few key issues
  - Simulation of PU could use more more work
    - Particularly forward η region
  - Tuning of the hadronization needs jet tagging
    - Active work is ongoing (see tomorrow)
    - Do theorists have a new approach to tuning?
  - Detector effects are a major issue at high *pT*
    - Can we re-tun the particle flow algorithm?
  - What is going on with high η top jets?
- Talk avoids discussion tagging variables work
  - Suffices to say that such work is constantly ongoing
  - Success w/above will allow for more flexibility

Breaking It down even more

- Pileup/UE subtraction can go two approaches
  - Current approach subtract: pT' = pT – ρ(η)a
    - Only works on pT (no way to correct mass/...)
    - Try to subtract dVar/ρ and correct Var' = Var- ρ(η)dVar/dρ
  - Alternative subtract PU/UE from each PF candidate



This is the approach for Heavy Ions

Step 1 : Draw voronoi diagram around each pf candidate

Breaking It down even more

- Pileup/UE subtraction can go two approaches
  - Current approach subtract: pT' = pT – ρ(η)a
    - Only works on pT (no way to correct mass/...)
    - Try to subtract dVar/ρ and correct Var' = Var- ρ(η)dVar/dρ
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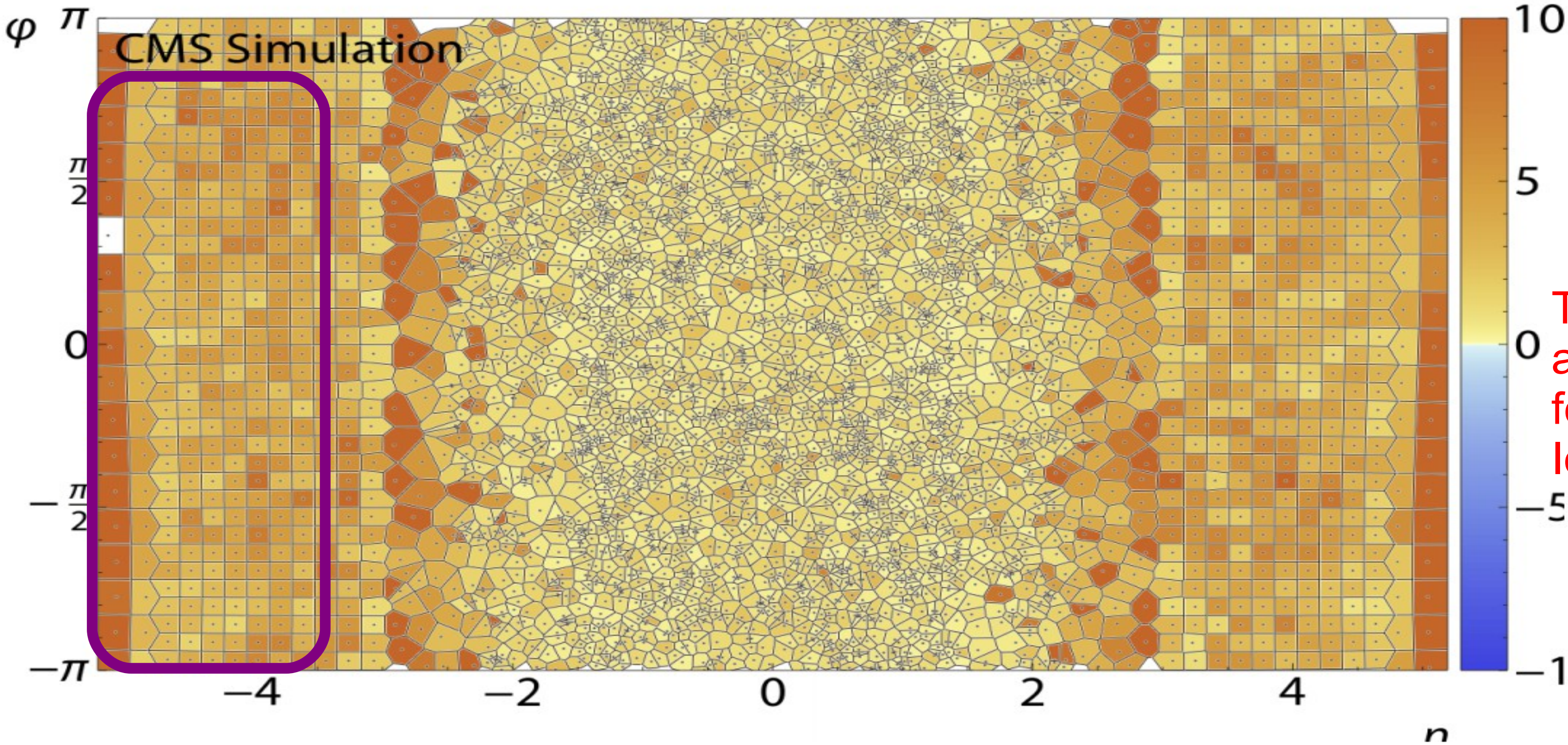
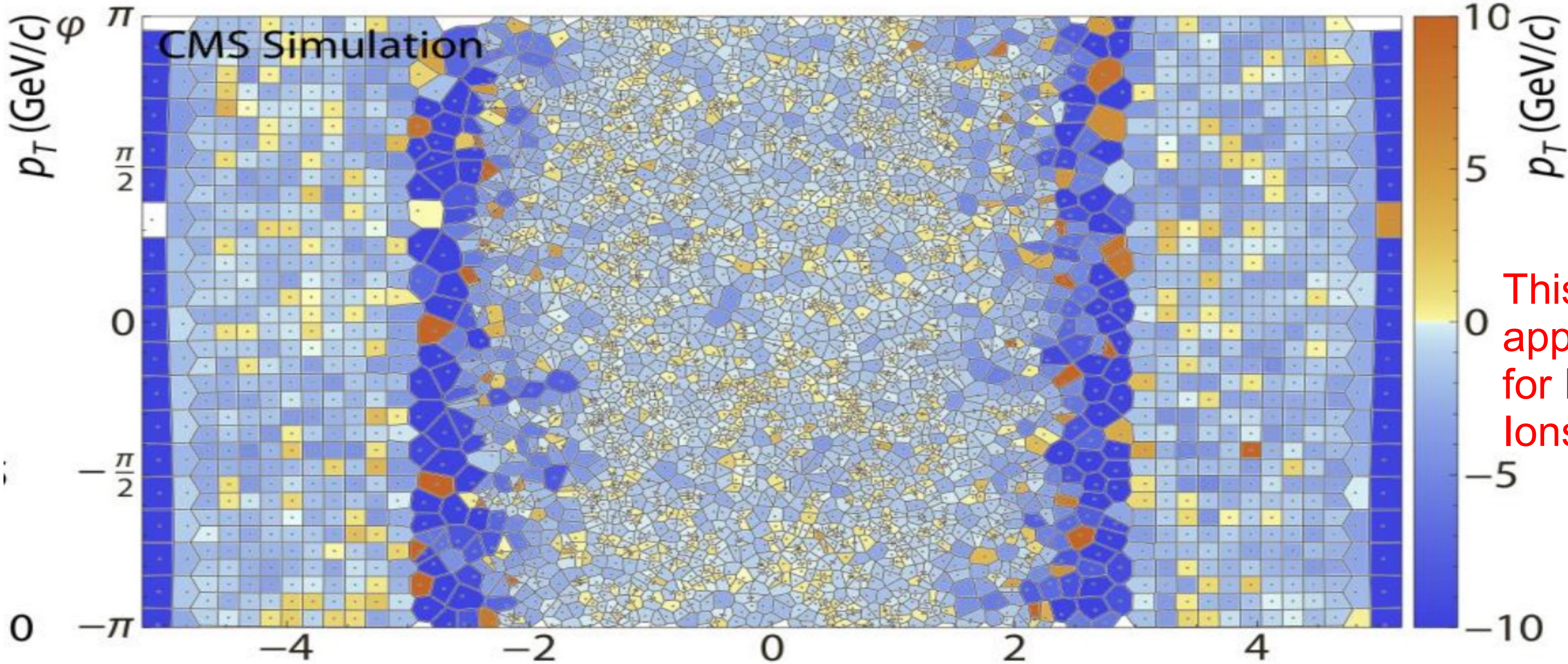


This is the approach for Heavy Ions

Step 2 : Estimate the energy from the forward region

Breaking It down even more

- Pileup/UE subtraction can go two approaches
  - Current approach subtract: pT' = pT – ρ(η)a
    - Only works on pT (no way to correct mass/...)
    - Try to subtract dVar/ρ and correct Var' = Var- ρ(η)dVar/dρ
  - Alternative subtract PU/UE from each PF candidate

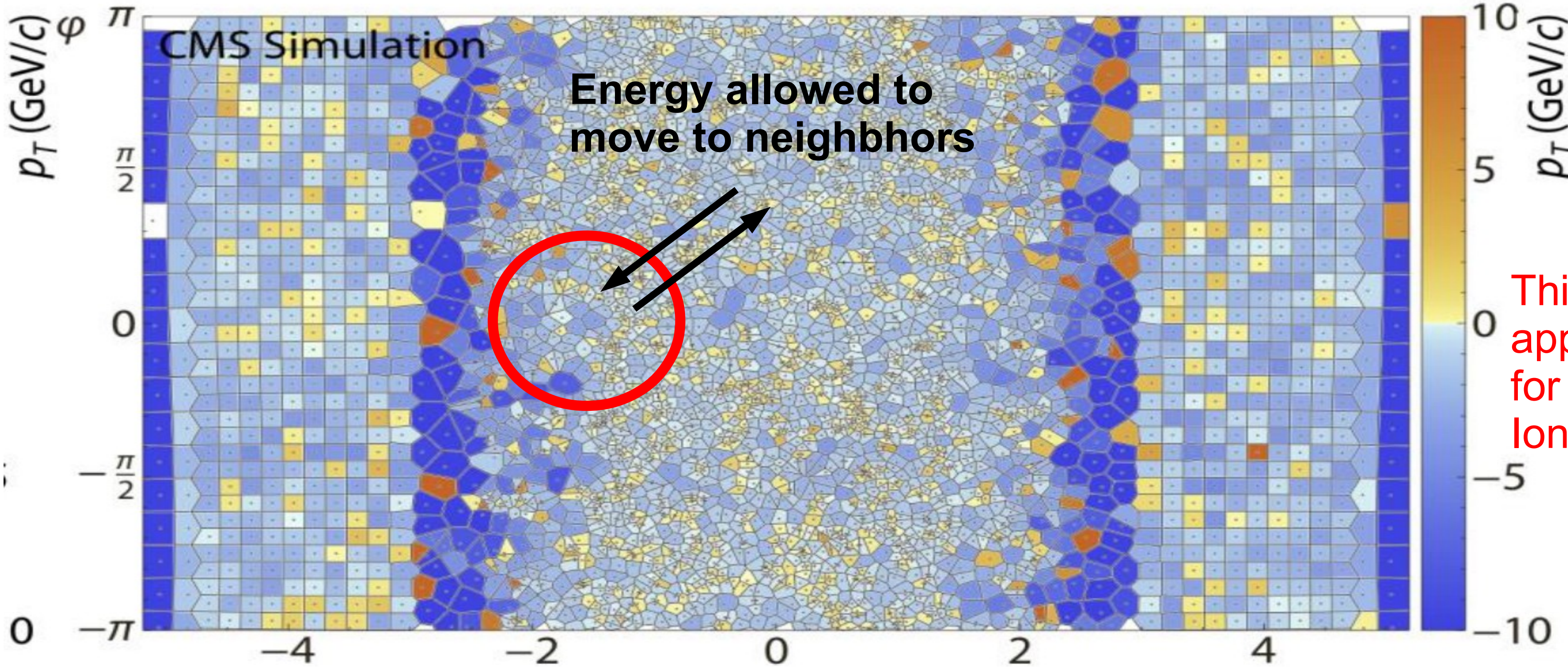


This is the approach for Heavy Ions

Step 3 : Subtract first 3 fourier modes from the UE event

Breaking It down even more

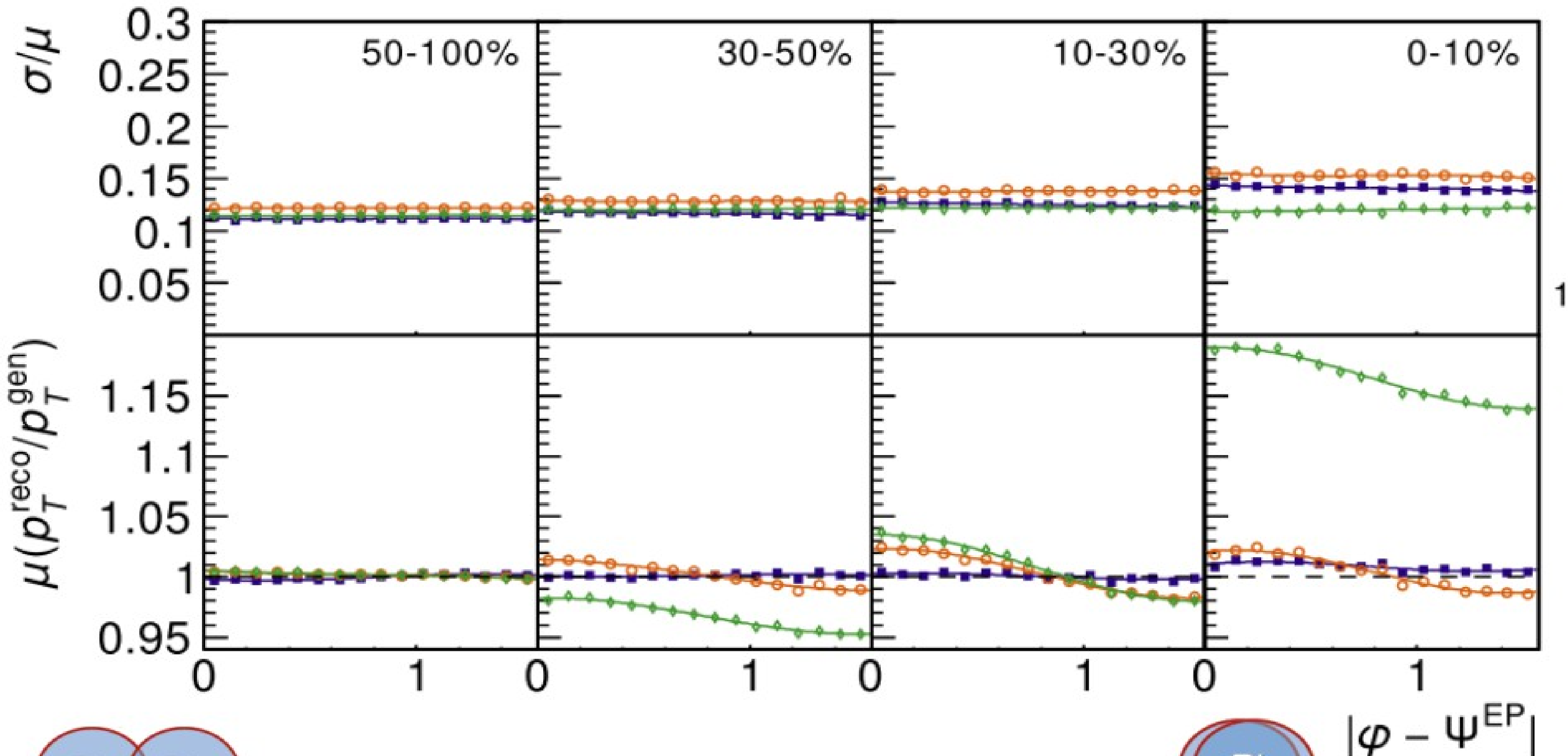
- Pileup/UE subtraction can go two approaches
  - Current approach subtract: pT' = pT – ρ(η)a
    - Only works on pT (no way to correct mass/...)
    - Try to subtract dVar/ρ and correct Var' = Var- ρ(η)dVar/dρ
  - Alternative subtract PU/UE from each PF candidate

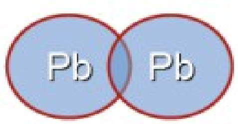


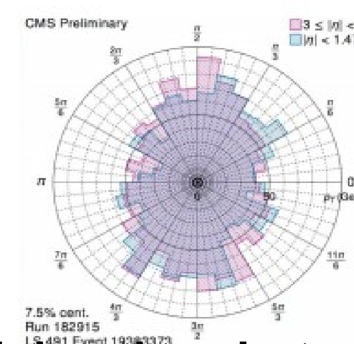
This is the approach for Heavy Ions

Step 4 : Iterative balance the negative energy flcutuations

Affect of PU Subtraction

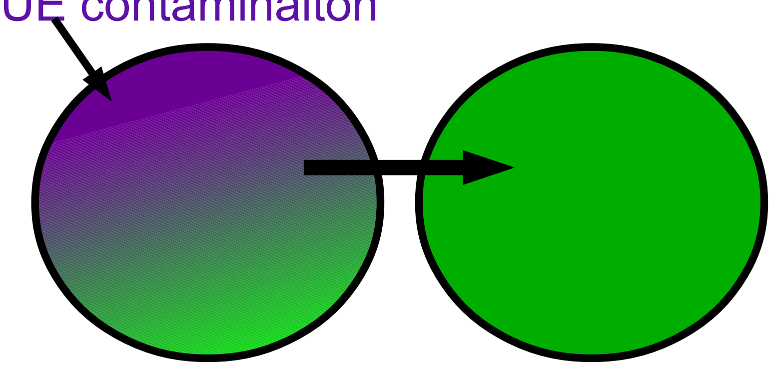






Typical Jet

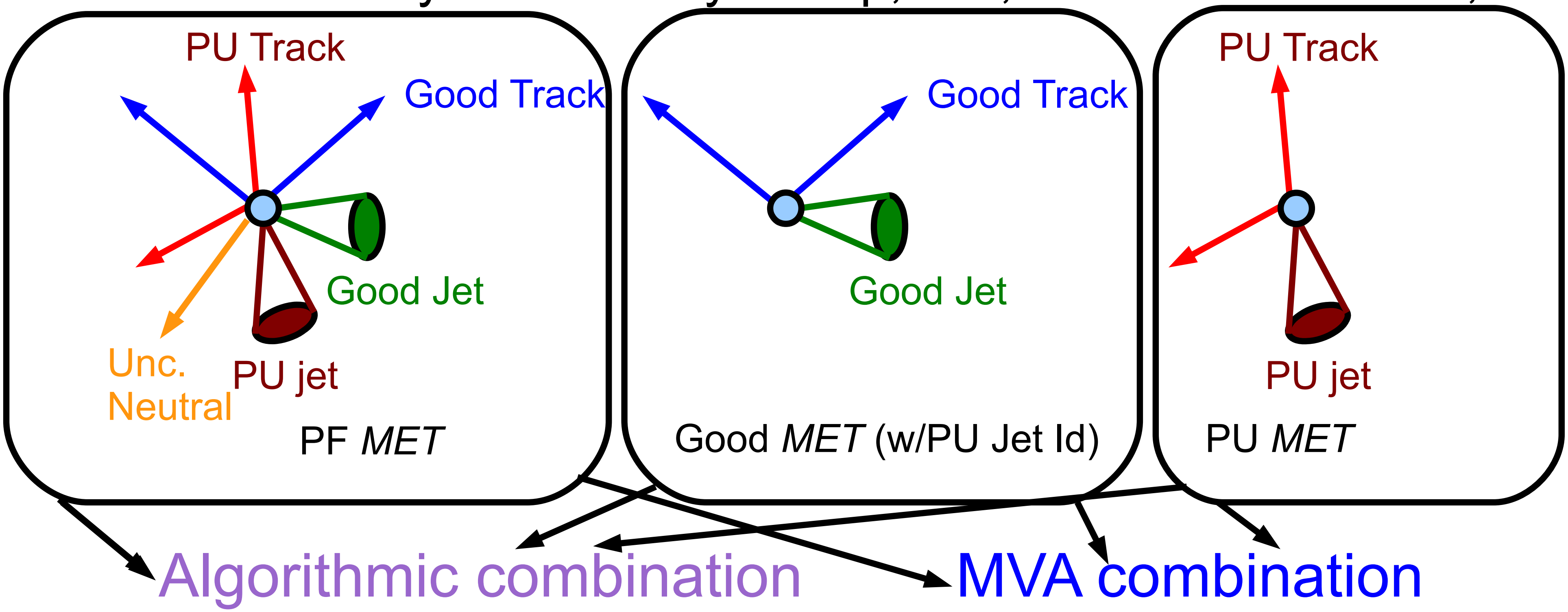
UE contaminaiton



Resolve UE fluctuations inside the jet
Allows for better UE/Pileup subtraction
Works for all jet shapes

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*

- *MET* is effectively summing up all the trash
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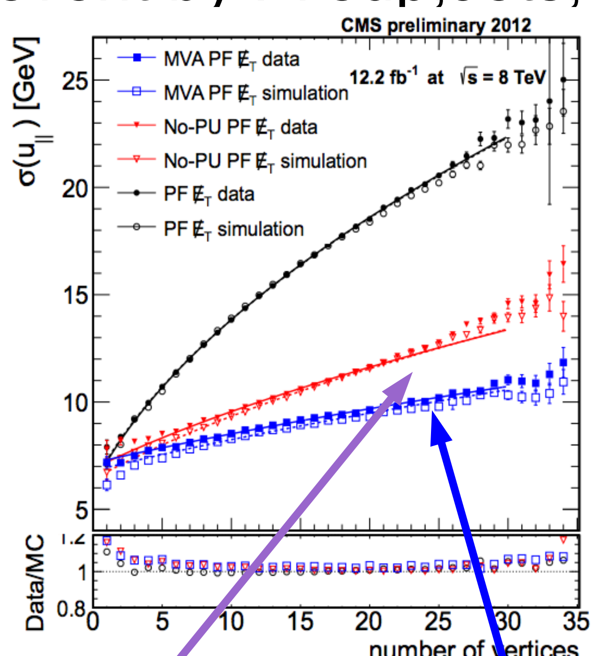


Algorithmic combination

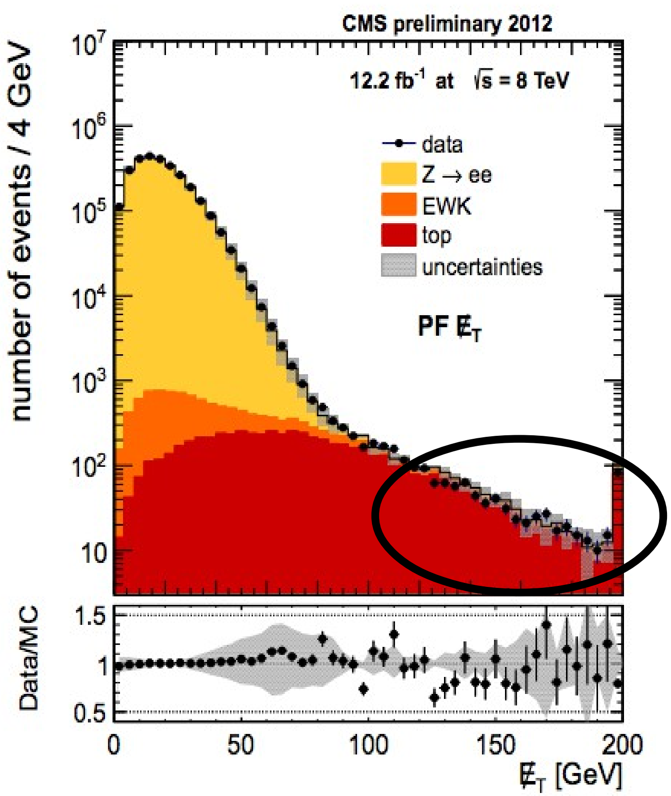
MVA combination

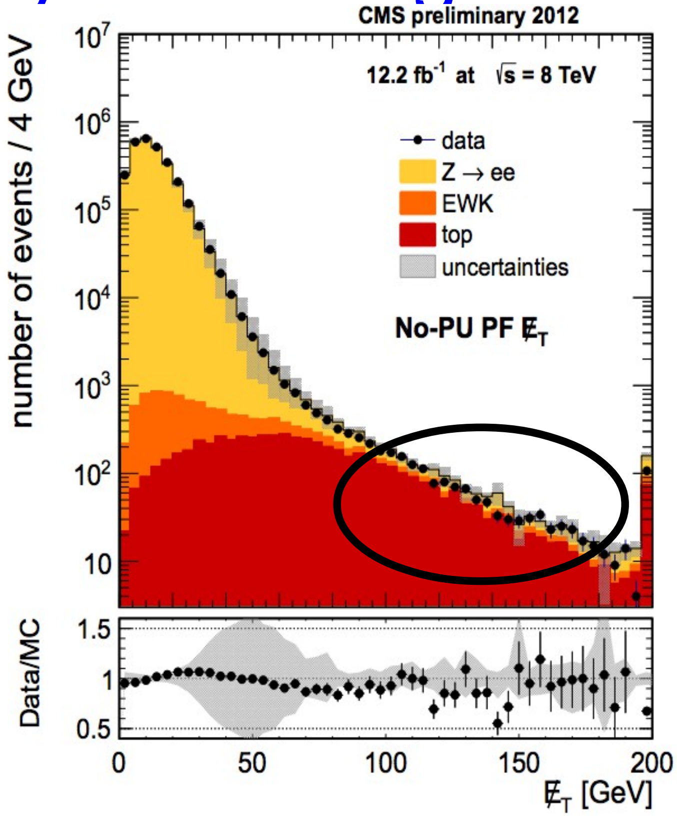
Combine all of the estimates into one best estimate

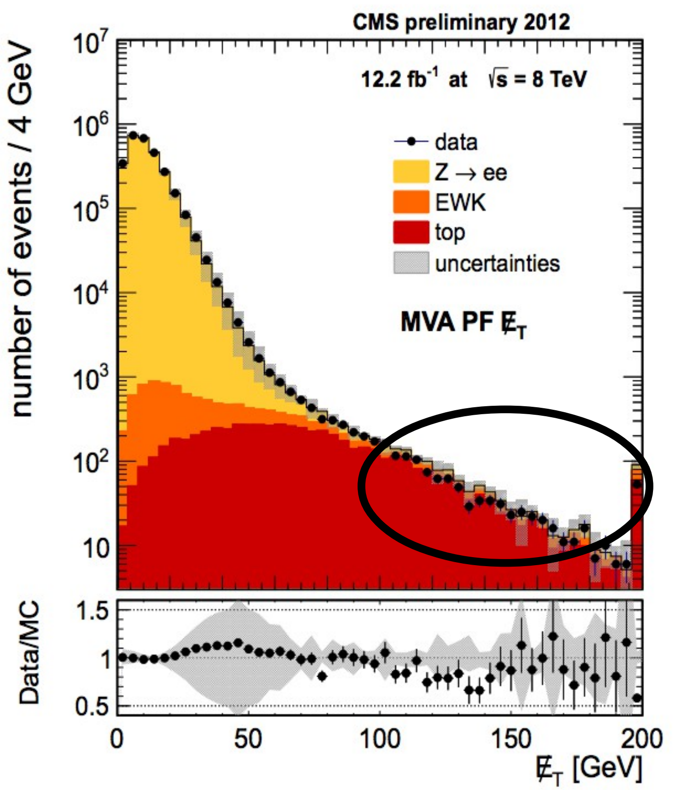
There is no perfect way to remove objects from the *MET*

PU Reduced *METs*

- A few kinks existed in first iteration of PU *METs*
  - Corrections to recoil necessary to the PU(now fixed)
  - Performance in far tails the same as PFMET or worse
    - MVA is better than No-PU; no perfect way at moment
- Usage is slowly becoming more prevalent

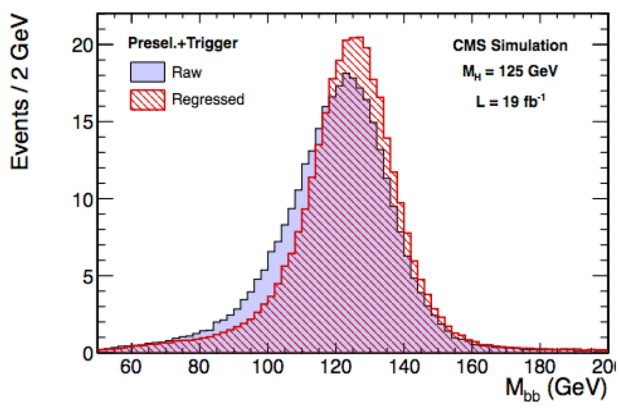


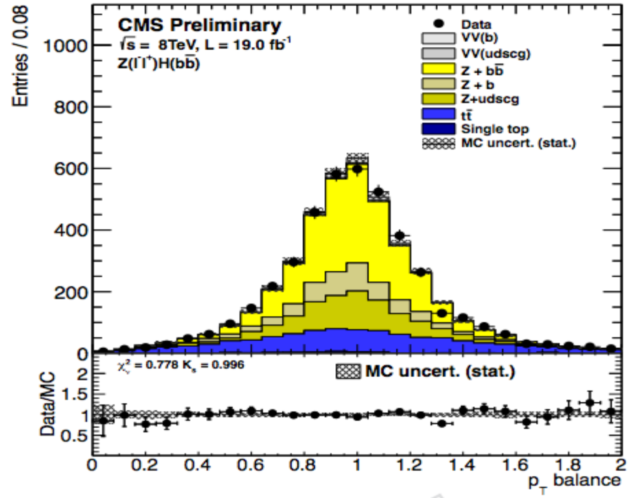




Aside on Regression Use

- Jet*MET* used BDT Regression on Jets & *MET*
- Regression is a great tool at the last step
  - Throw a large number of ideas/vars at a problem
  - Pushes the corrections/calibrations to the extreme
- Regression doesn't change development process
  - For every BDT we should also have an algorithm
  - Validation of regression requires standard candle





Conclusions

Jet Tagging
PU *METs*

Pileup
Removal
& JEC

Jets & *MET*

PF Candidates

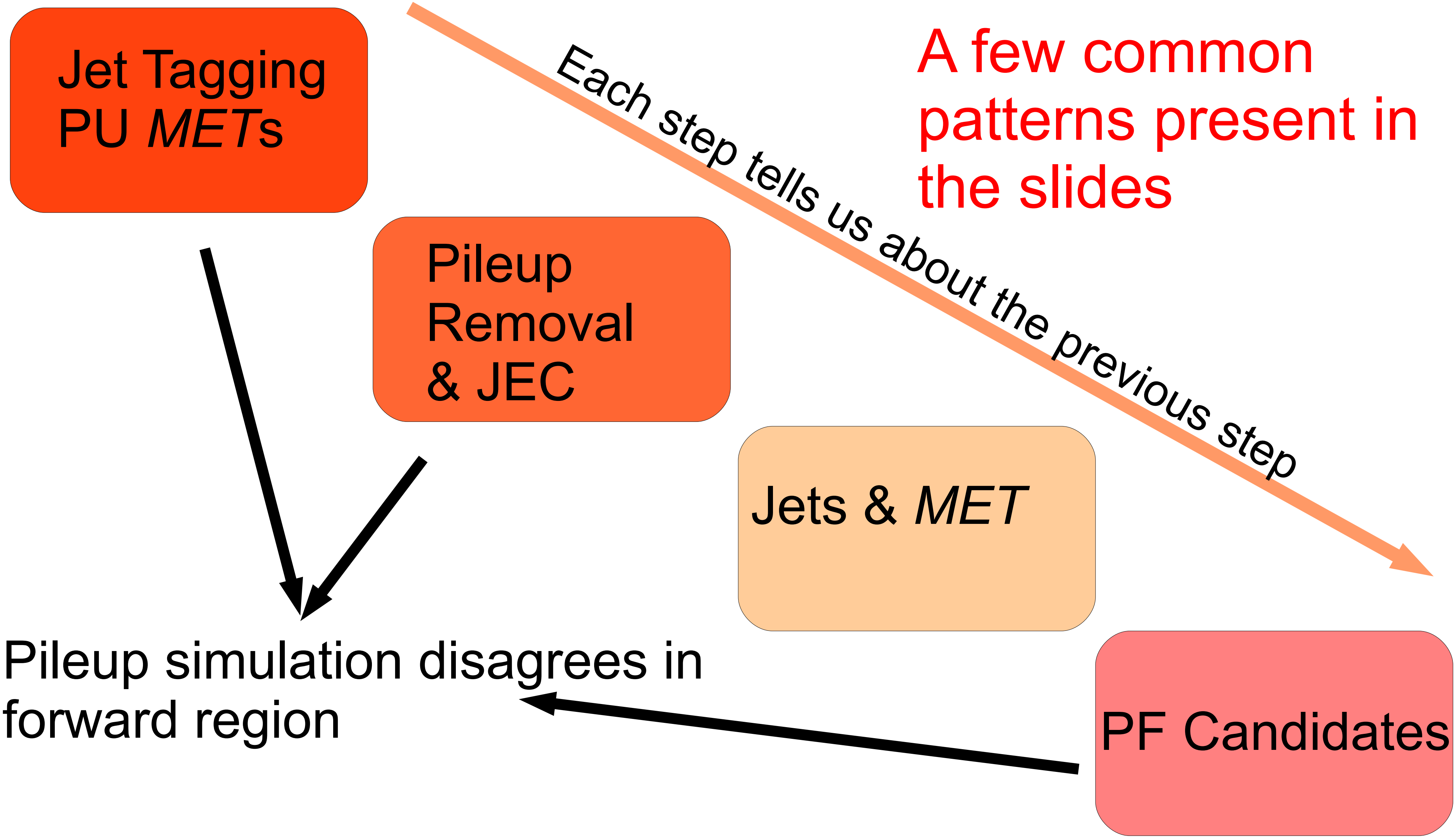
Each step tells us about the previous step

A few common patterns present in the slides

Herwig/Pythia differ on quark/gluon description and Pythia 8 is better

Is it possible to re-tune both?

Conclusions



Known effect will be fixed

Conclusions

A few common patterns present in the slides

Each step tells us about the previous step

Jet Tagging
PU *METs*

Pileup Removal & JEC

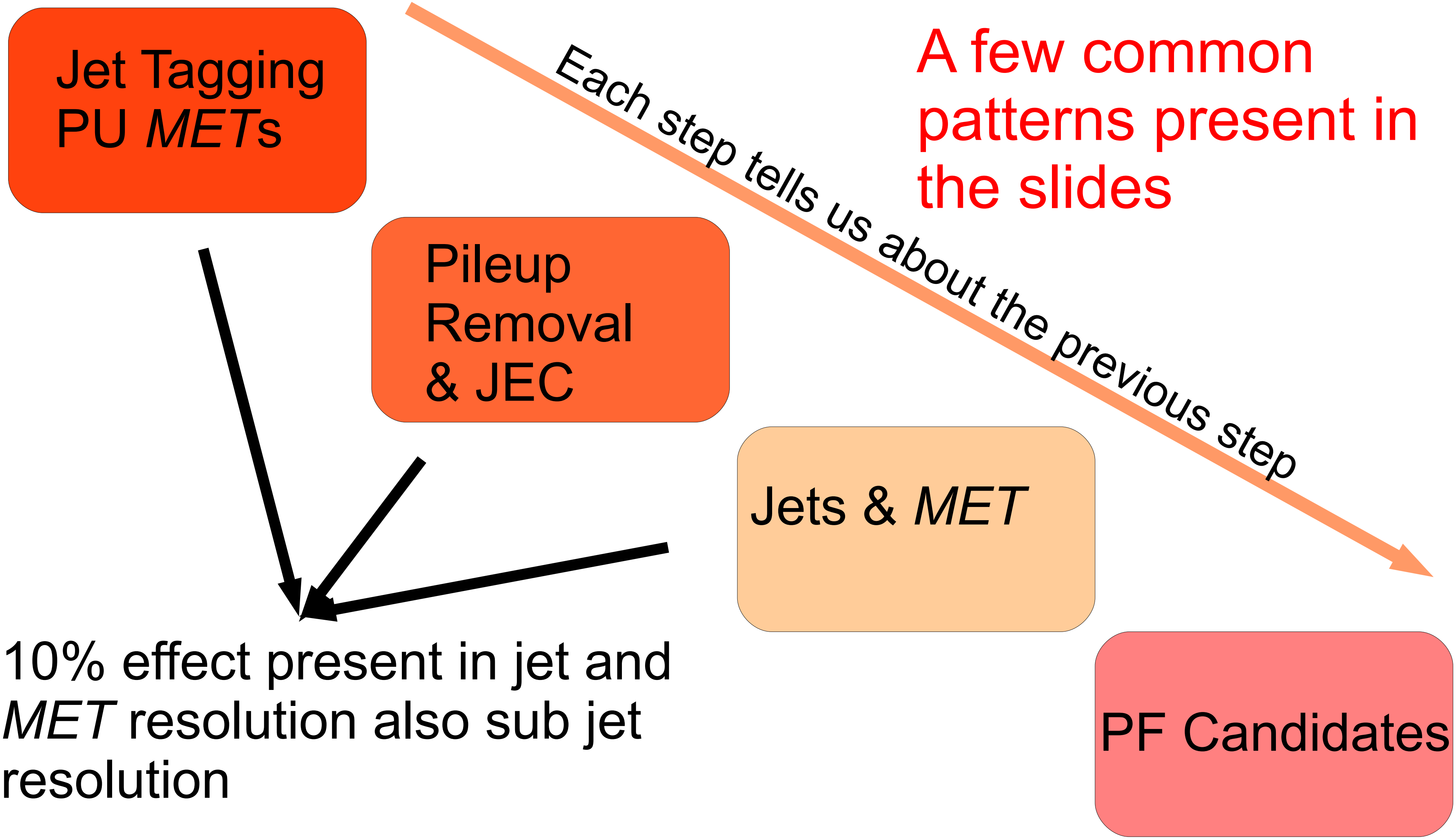
Jets & *MET*

PF Candidates

Pileup simulation disagrees in forward region

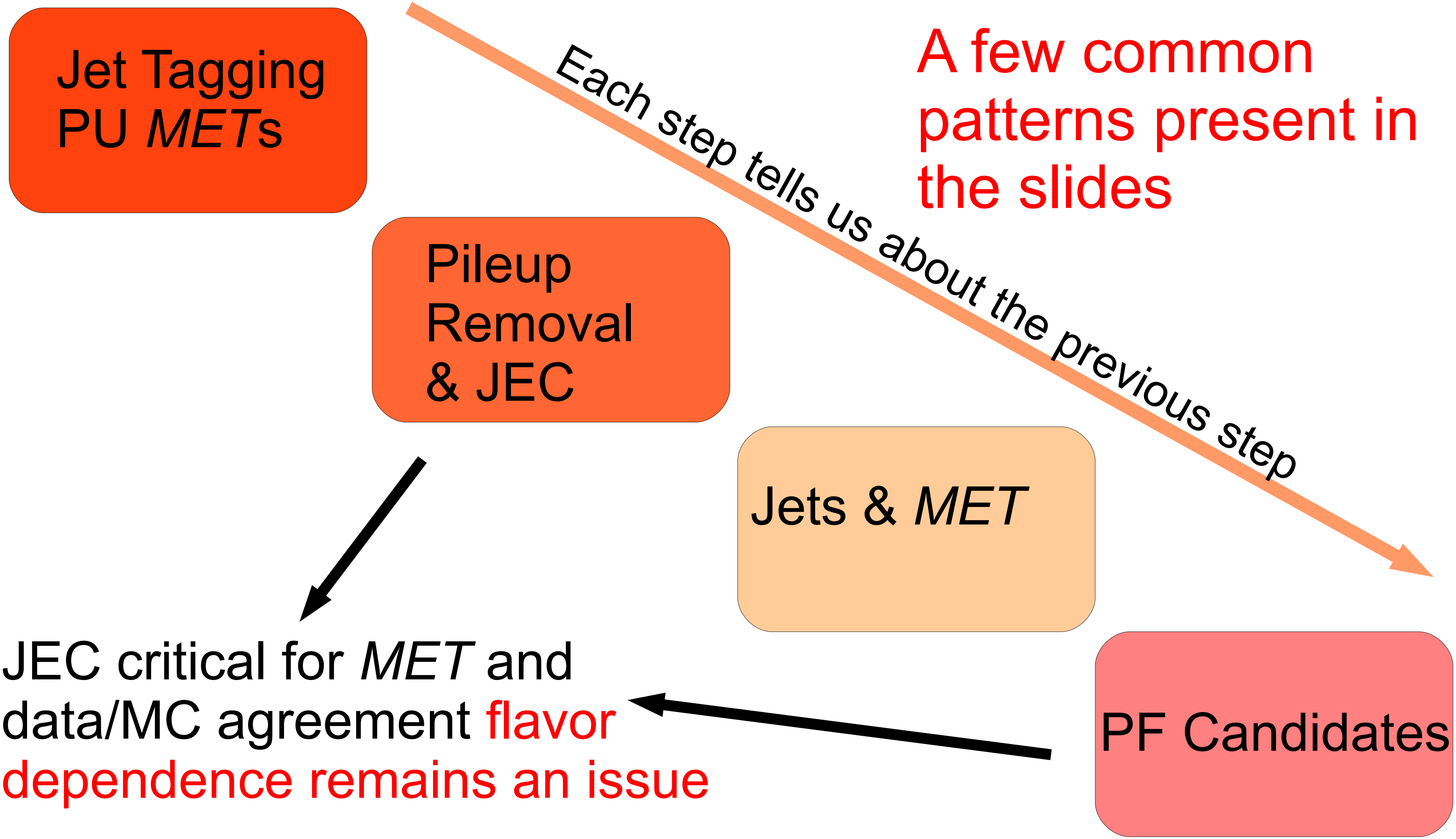
Known effect will be fixed

Conclusions



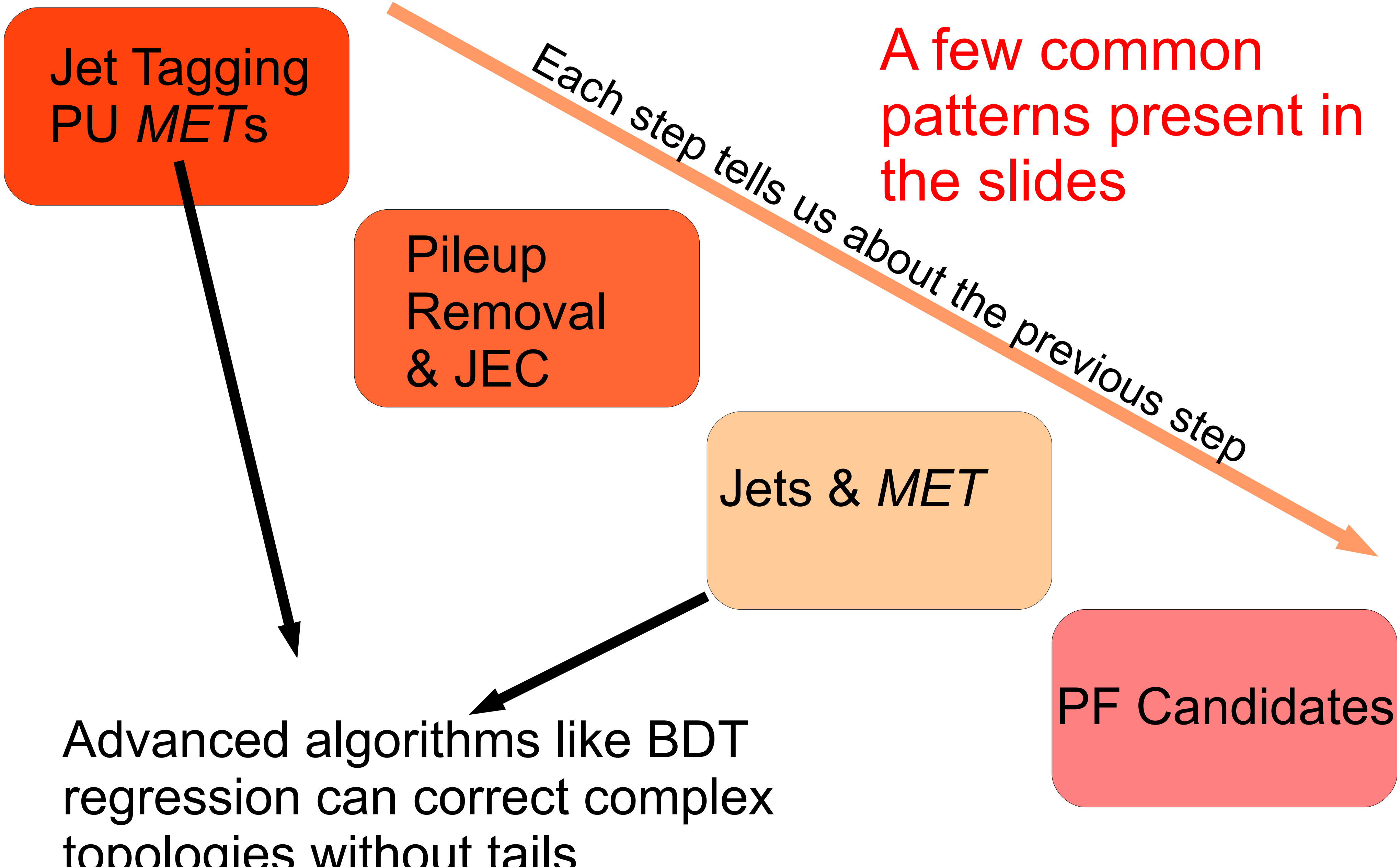
Can this be fixed at lower level?

Conclusions

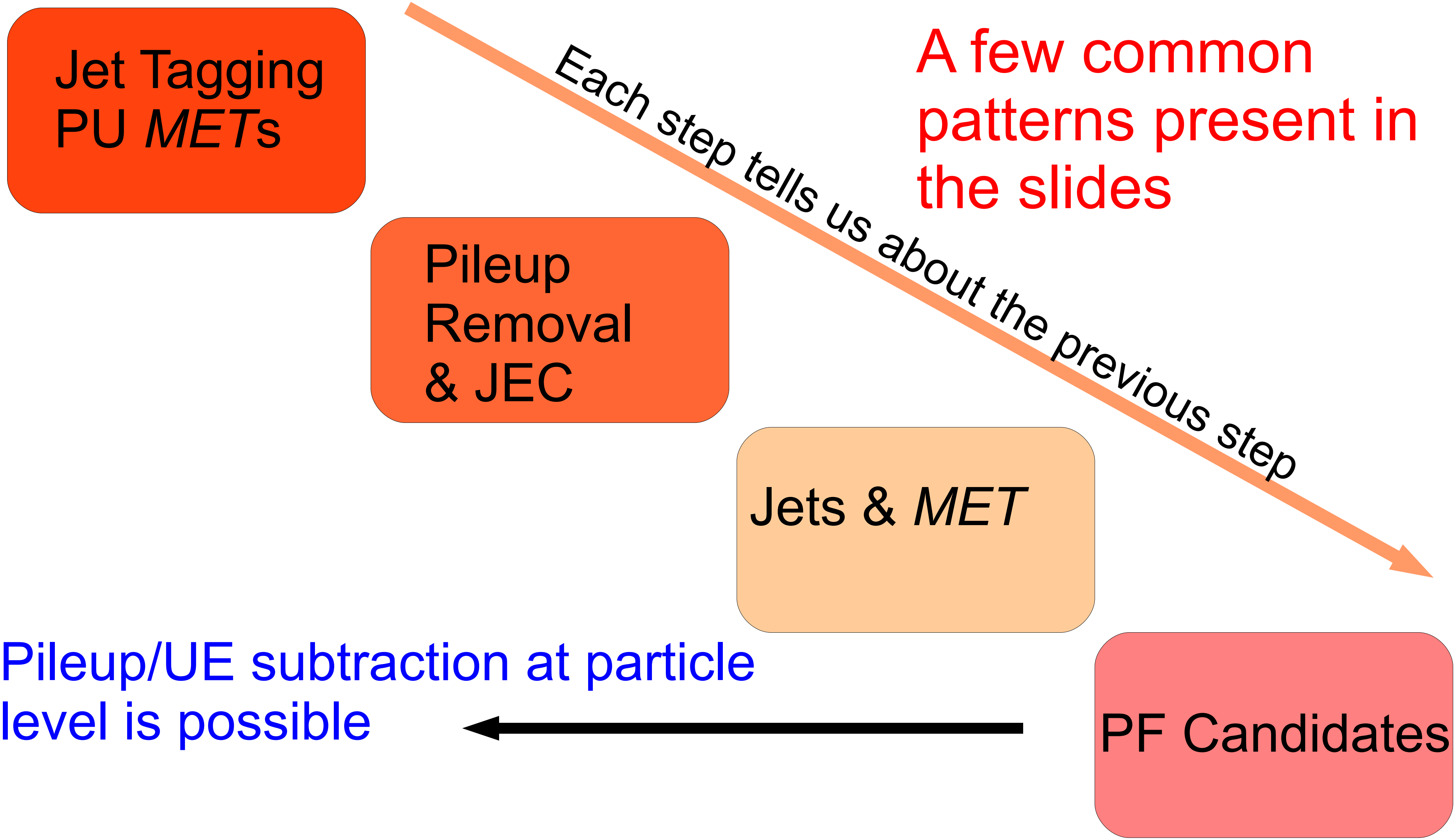


Is it possible to fix JEC at lower level?

Conclusions



Conclusions



Now is the time to rebuild the jets and *MET* in CMS

Conclusions

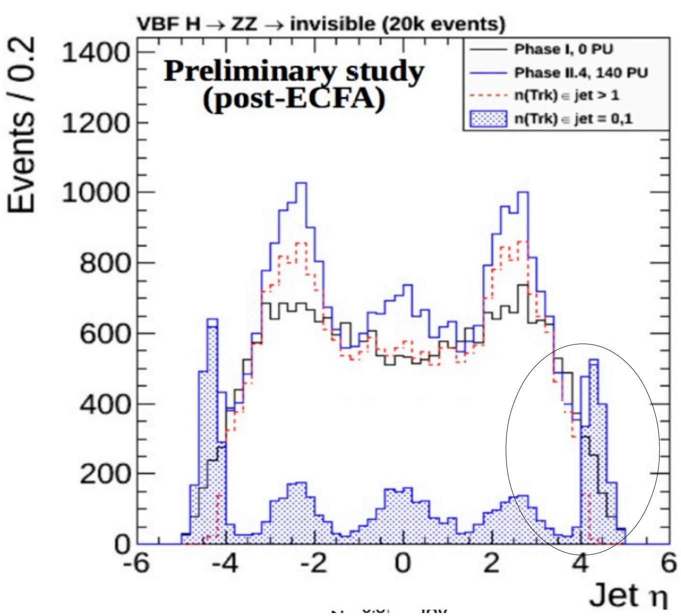
Jet Tagging
PU *METs*

Each step tells us about the previous step

A few common patterns present in the slides

Pileup Removal & JEC

Jets & *MET*



Fwd Tracking?

PF Candidates

How you can bring this work to the future detectors?

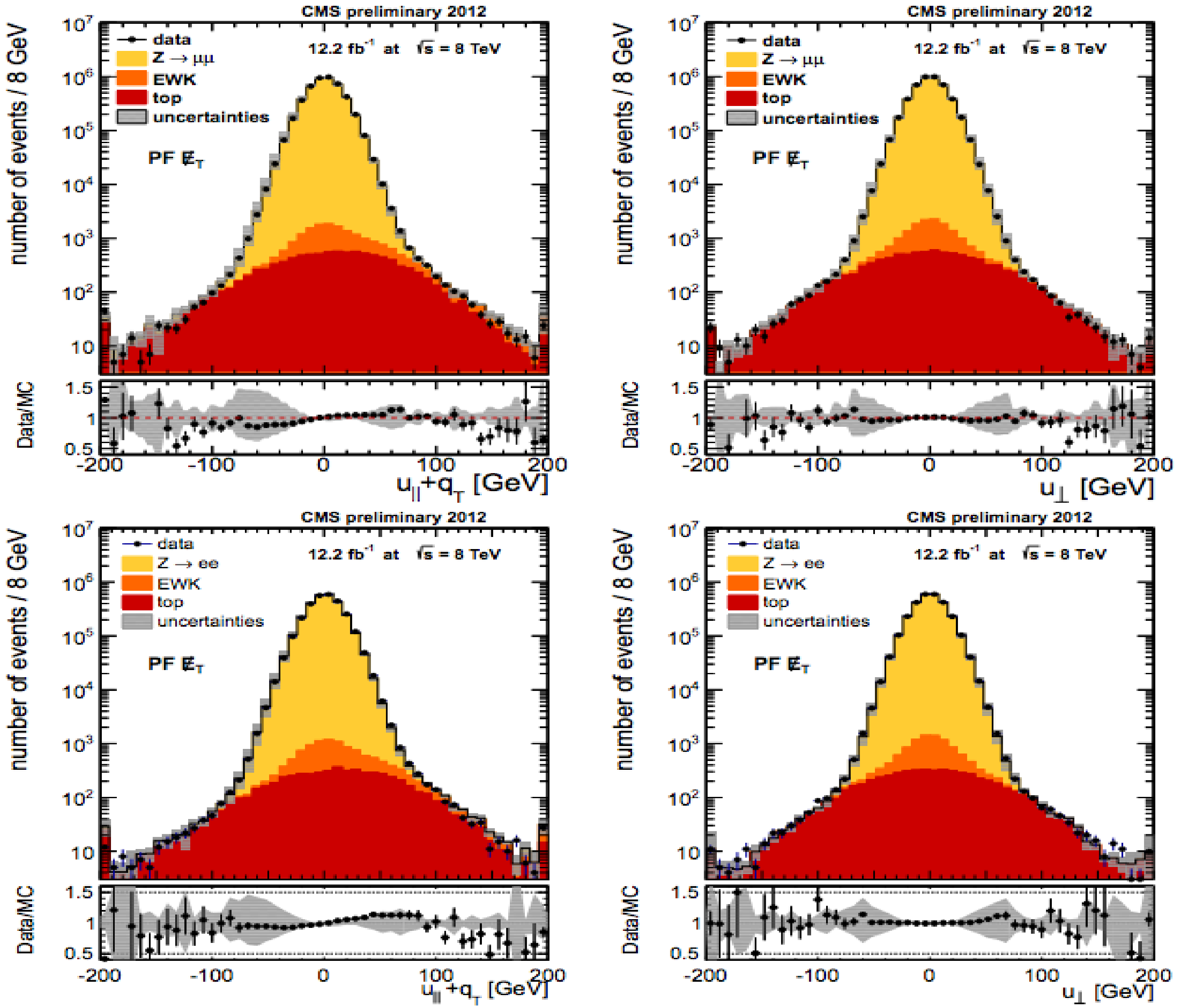
Thank You Filip!

- All of would not have been possible without Filip

- Stay close to the jetMET group
  - We need you!

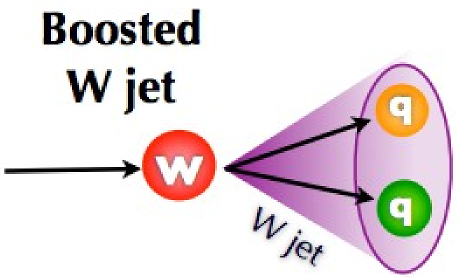
Backup

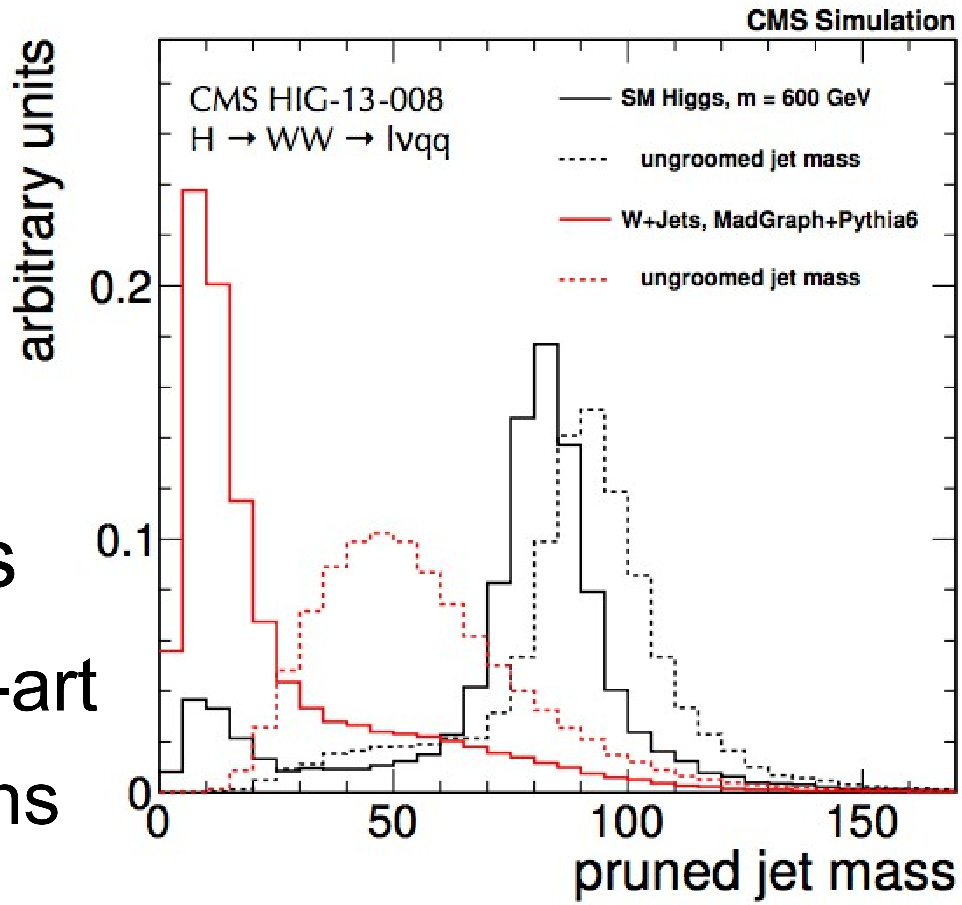
MET variables



W-Tagging

- W-Tagging Procedure :
  - Cluster jet with CA8
  - Apply jet pruning
  - Cut on pruned mass
  - Cut on selected var
    - Default is τ_2/τ_1

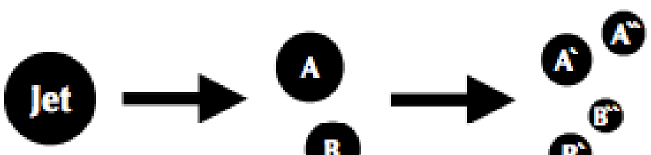




- Frequent additional vars
  - Must keep up w/state-of-art
  - Not clear best in 6 months

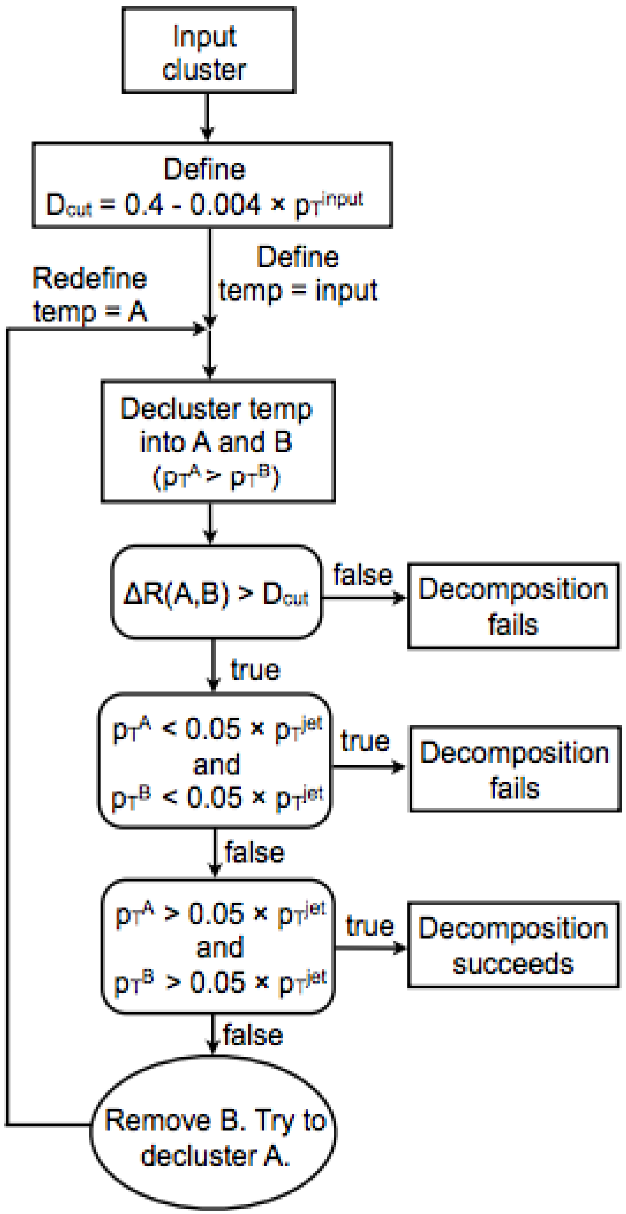
CMS Top Tagger

- Based on JHU Top Tagger (Kaplan et al., Phys.Rev.Lett. 101 (2008) 142001)
- Cluster a jet using a sequential recombination algorithm (CA R=0.8)
- Decluster in two stages in order to find up to 4 subjets

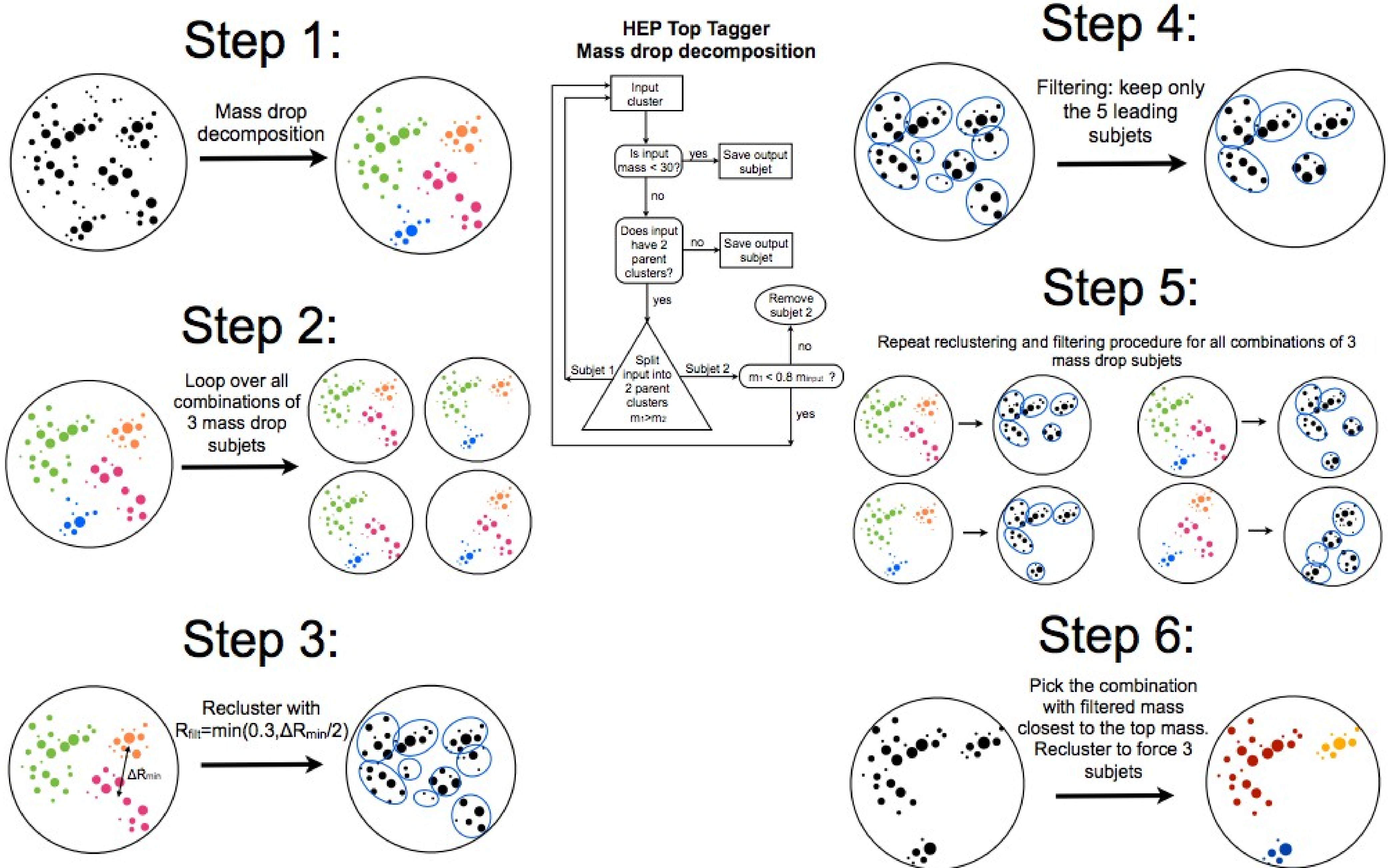


- Subjets must satisfy two requirements
  - Momentum fraction criterion: $p_T^{subjet} > 0.05 \times p_T^{jet}$
  - Adjacency criterion: $\Delta R(C_1, C_2) > 0.4 - 0.0004 \times pT(C)$
- Iterative process - throw out subjets that fail momentum fraction cut and try to decluster again
- Tag top jets with selections on the CA8 jet mass, number of subjets, and minimum pairwise subjet mass ($m_{min} = \min[m_{12}, m_{13}, m_{23}]$)

CMS Top Tagger decomposition



HEP Top Tagger



Top Tagging Optimization

$$R^2_{\rm min}(1+(\frac{m_{12}}{m_{13}})^2) < 1-(\frac{m_{23}}{m_{123}})^2 < R^2_{\rm max}(1+(\frac{m_{12}}{m_{13}})^2)$$

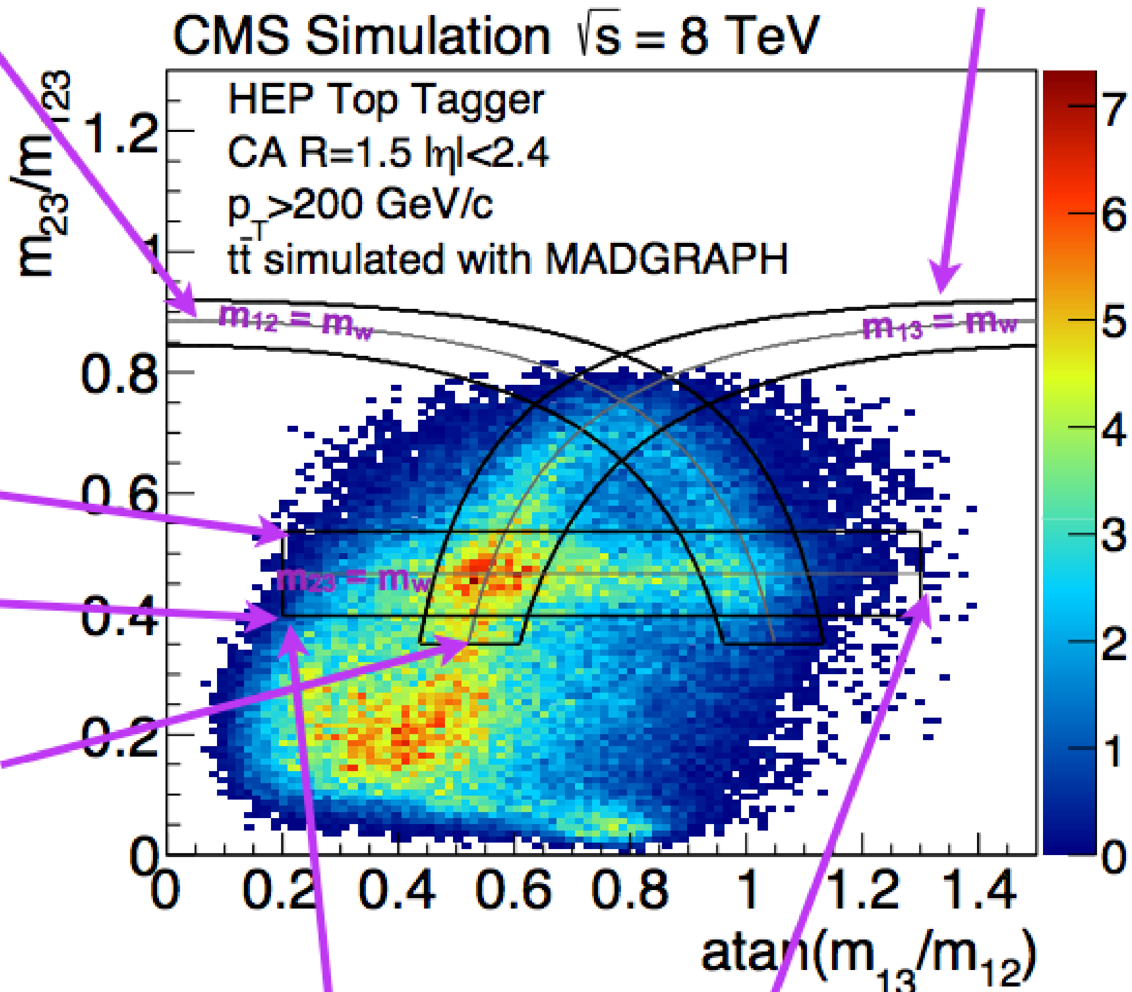
$$R^2_{\rm min}(1+(\frac{m_{13}}{m_{12}})^2) < 1-(\frac{m_{23}}{m_{123}})^2 < R^2_{\rm max}(1+(\frac{m_{13}}{m_{12}})^2)$$

$$R_{\rm min} < \frac{m_{23}}{m_{123}} < R_{\rm max}$$

$$R_{\rm max} = (1+f_W) \times m_W/m_t$$

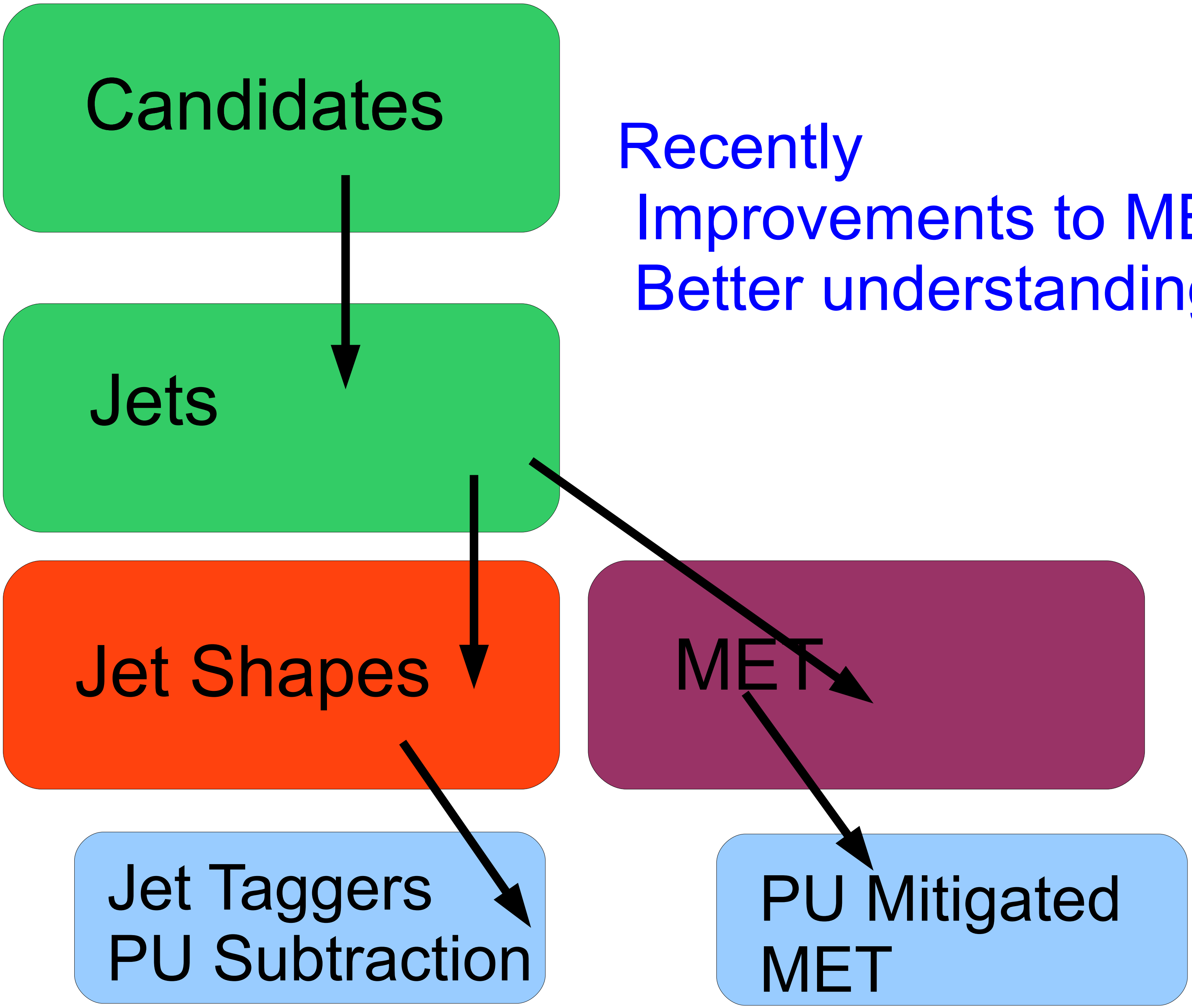
$$R_{\rm min} = (1-f_W) \times m_W/m_t$$

$$\frac{m_{23}}{m_{123}} > 0.35$$



$$0.2 < \arctan\frac{m_{13}}{m_{12}} < 1.3$$

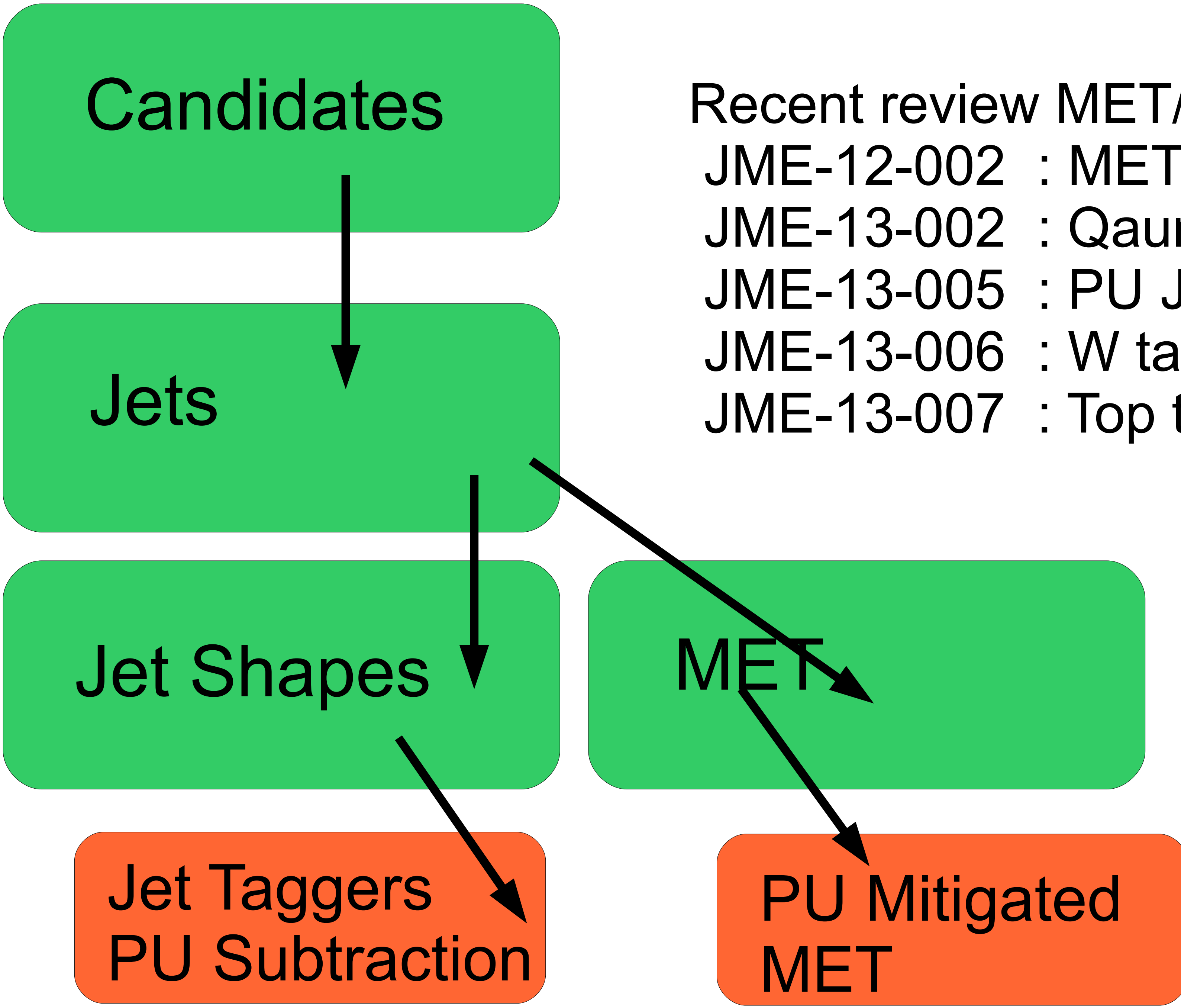
Direction of Work



Recently
Improvements to MET
Better understanding Jet

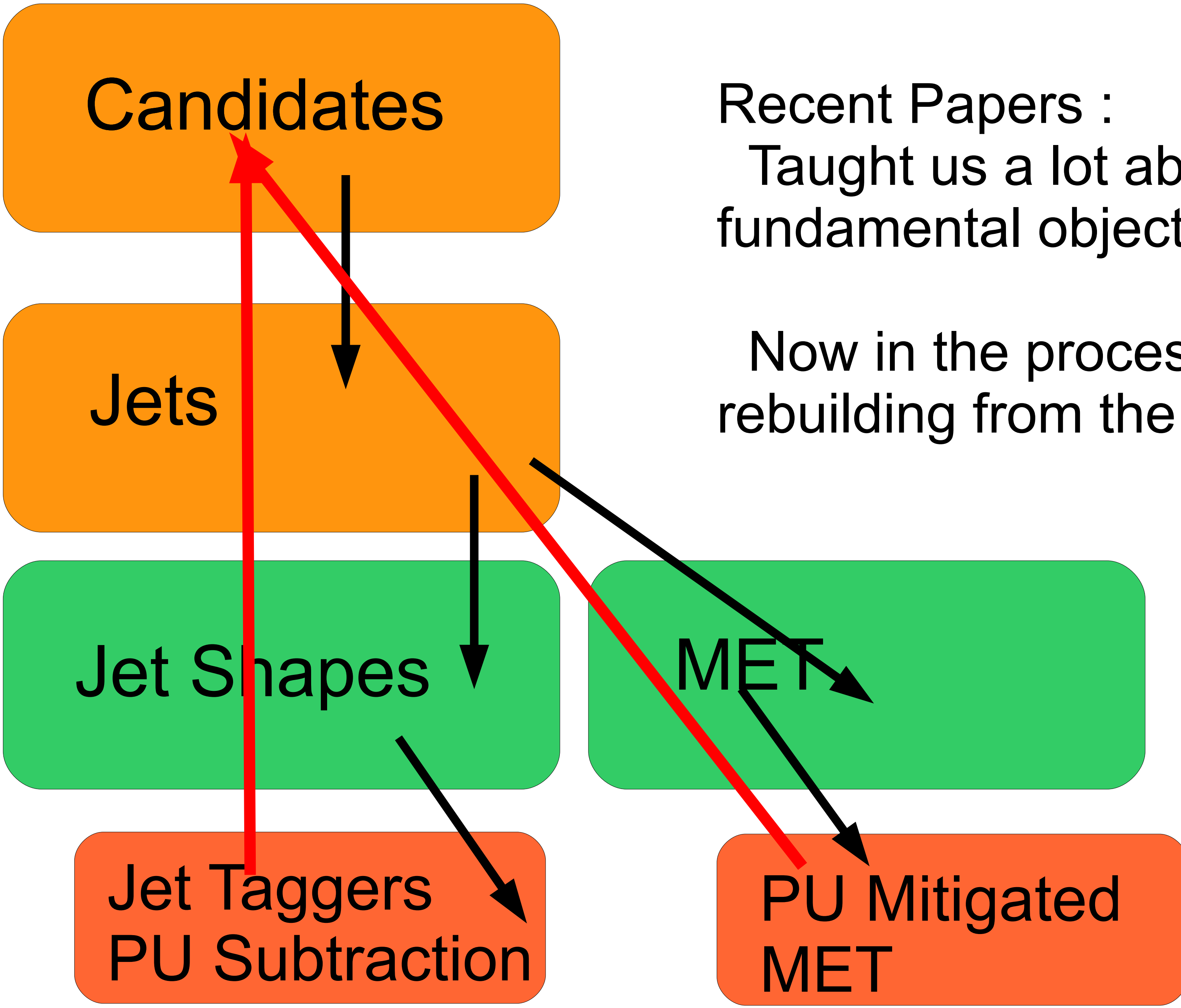
Deconstruct
everything

Direction of Work



Recent review MET/Jet Shapes :
- JME-12-002 : MET Performance
- JME-13-002 : Qaurk Gluon Id
- JME-13-005 : PU Jet Id
- JME-13-006 : W tagging
- JME-13-007 : Top tagging

Direction of Work

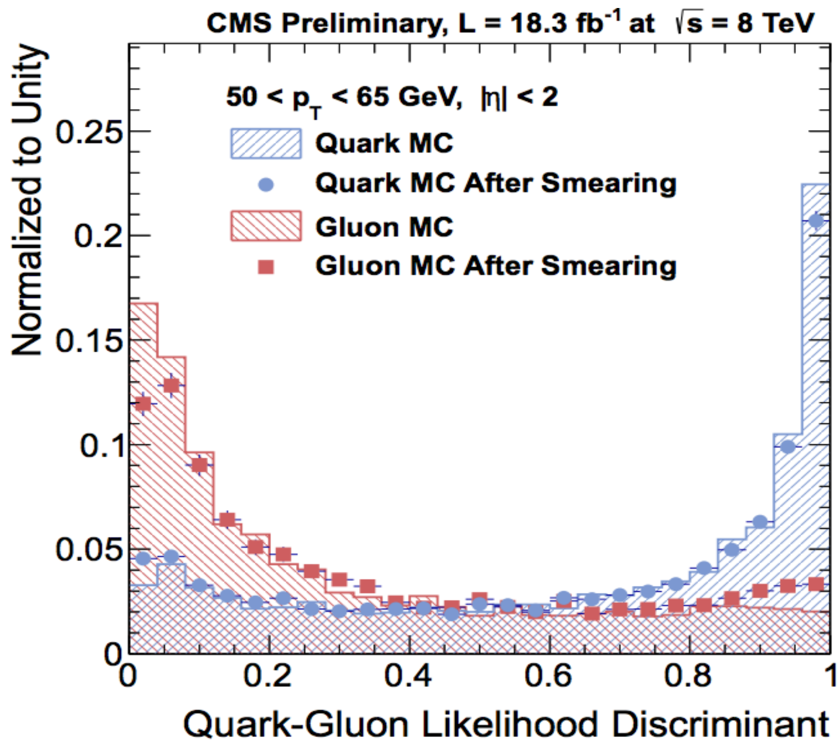


Recent Papers :
Taught us a lot about the fundamental objects

Now in the process of rebuilding from the ground up

Understanding Jet Shapes

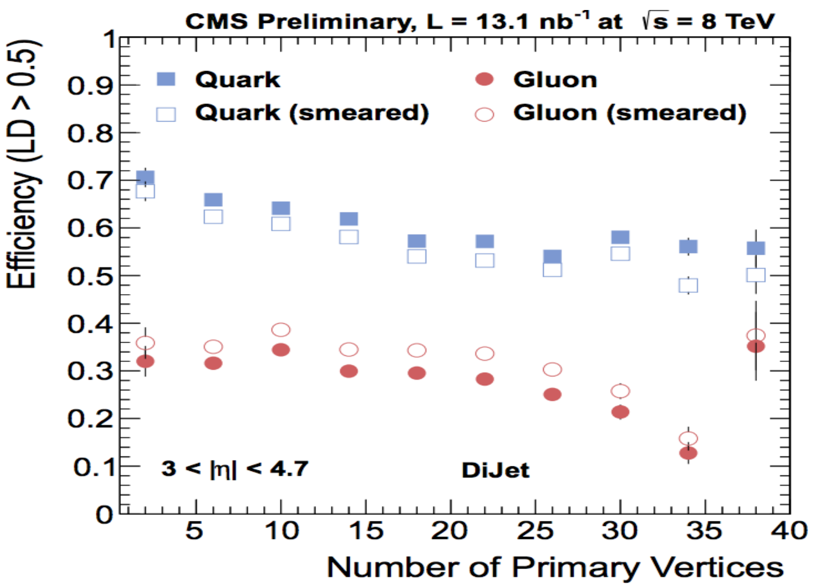
- To improve :
  - Corrections
  - Pileup modeling
  - Discrimination with background
- Key is to take advantage of the jet shapes

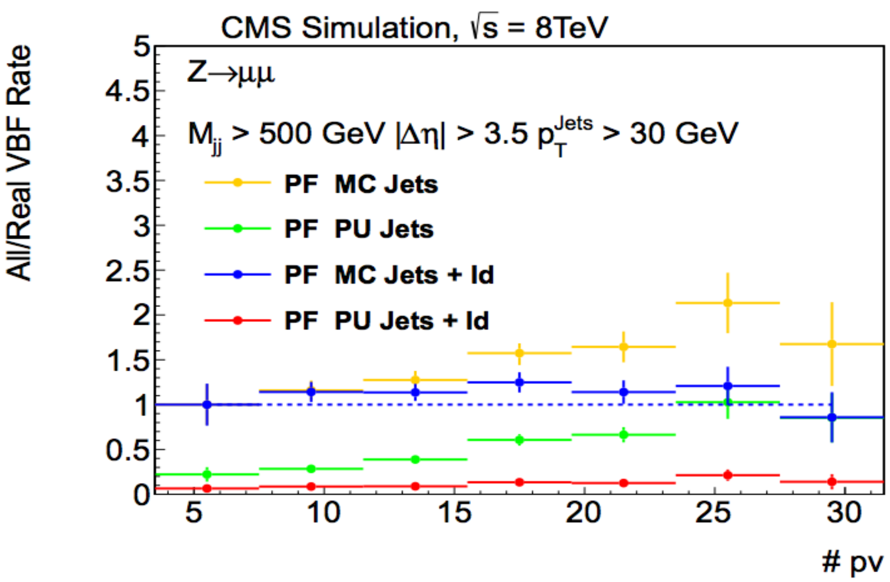


Now have a well commissioned Quark Gluon discriminator JME-13-002

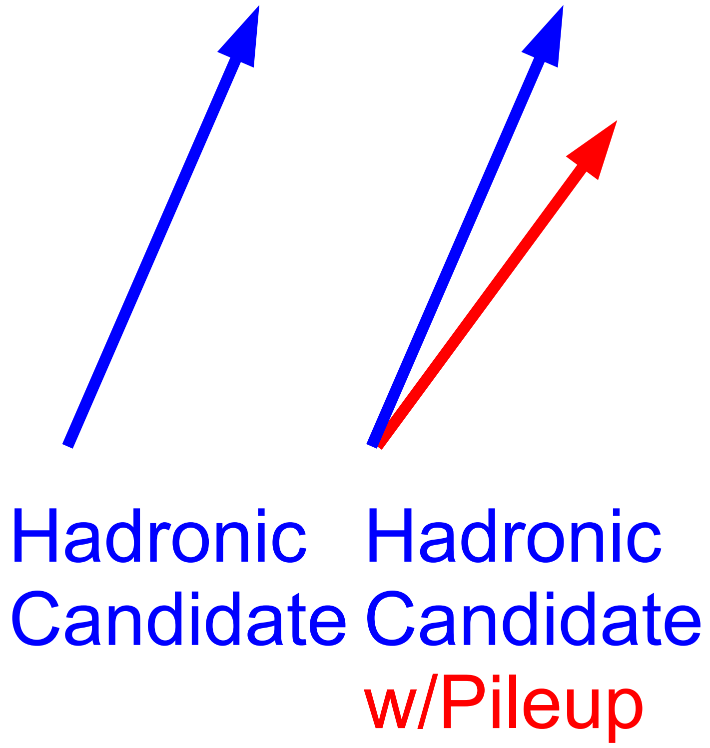
What we have learned from PASs?

- PASs were a very good way for consolidation
  - Jet ids are now well established
  - A number of small issues to work on at each step
  - Q/G discrimination :
    - Herwig vs Pythia yield differences in efficiencies
  - PU Jet Id : forward jet efficiency drops at high PU
    - Will requiring retuning at high pileup

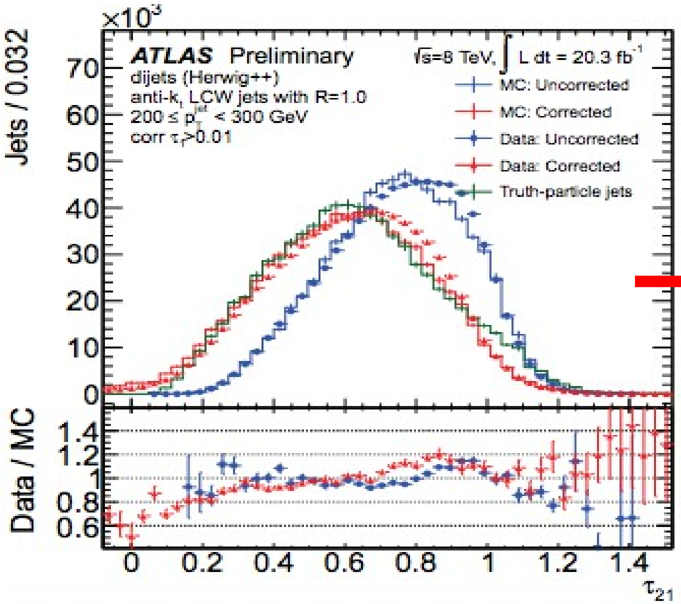




Candidate Level



Clustering Jets with Modified E

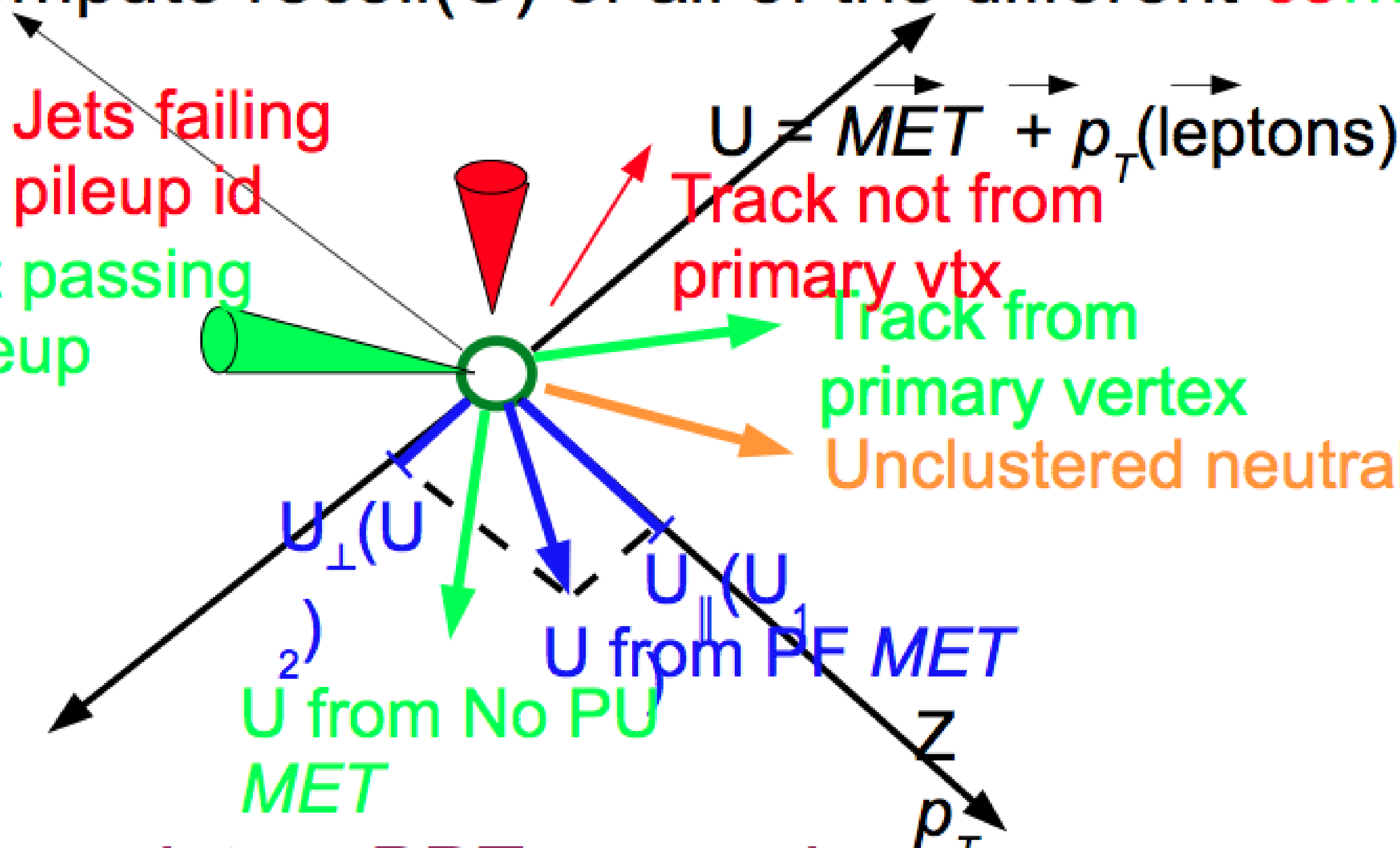


Shape subtraction:
Differential ρ correction
To correct specific Var
Compute dVar/dρ
Can correct only 1 Var

- Bringing the pileup energy to initial PF Candidates
  - Idea would be to cluster jets with this modified energy
  - Minimizes the need to do differential pileup corrections
  - Allows for a consistent picture of jets/jet shapes/MET
- We still have a lot of work to get this ready
  - Keep this concept in mind for the future

MVA *MET* Concept

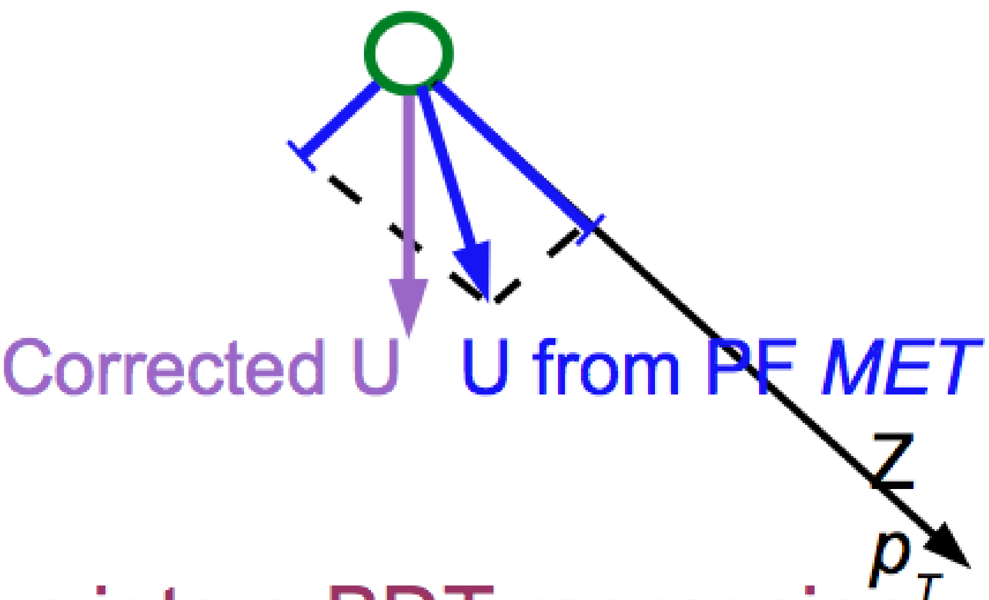
- Concept:
  - Compute recoil(U) of all of the different components



Feed them into a BDT regression :

MVA *MET* Concept

- Concept:
  - Recoil here => defined as *MET* – leptons

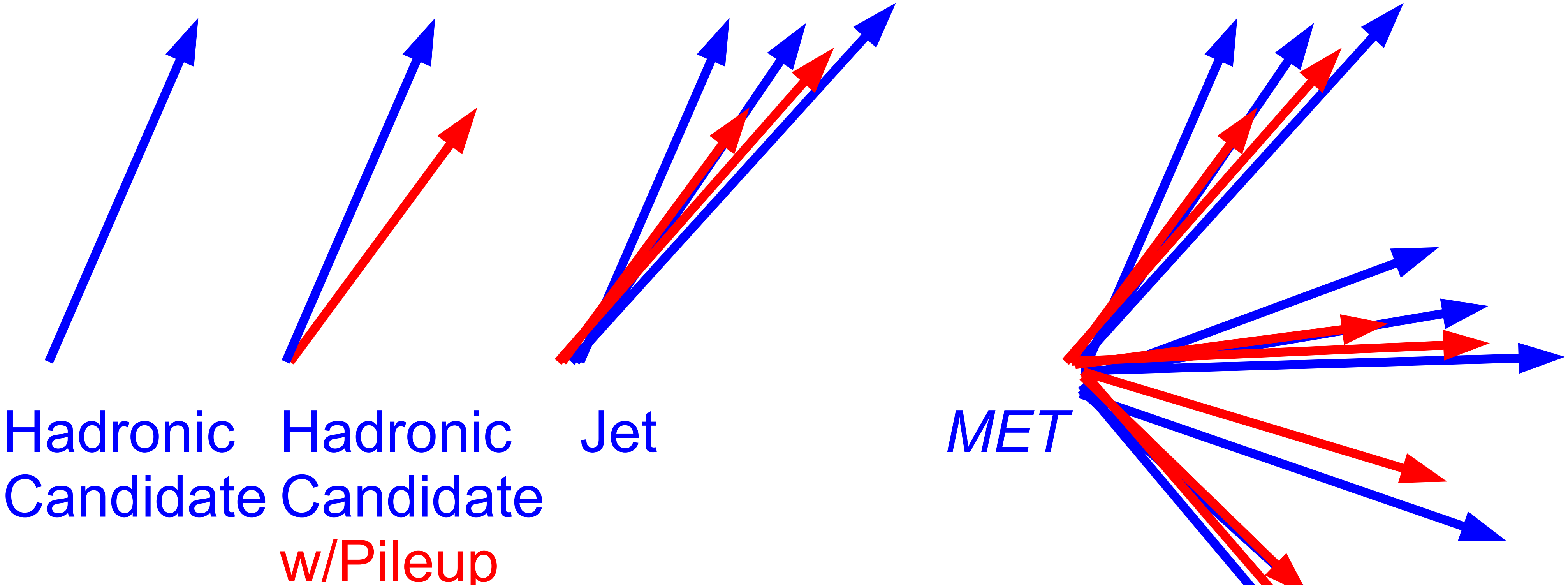


Feed them into a BDT regression : Correct Recoil

Conclusions

- Jet *MET* is actively preparing for the next run
    - https://twiki.cern.ch/twiki/bin/view/CMS/MissingETTaskForLS1
- How can we fix the data/MC agreement?
    - Full out of time simulation (+/- 300 ns)?
    - Showering: tune that is closer to the futrure?
        - Both for real and pileup simulation
    - MC will allow for more advanced studies/algos
- What do we do with 25ns + high pileup?
    - Application of Pileup jet id or CHS
    - Fixing tails of *MET*/jets involves more understanding
        - We saw this with the reduction of the jet Flavor uncertianty
- One possible solution
    - How can we understand the inside of a jet?

Spectrum of Jet*MET*



- Running is over
- It is time to re-think jet/*MET* reconstruction
    - Talk about the ongoing solutions