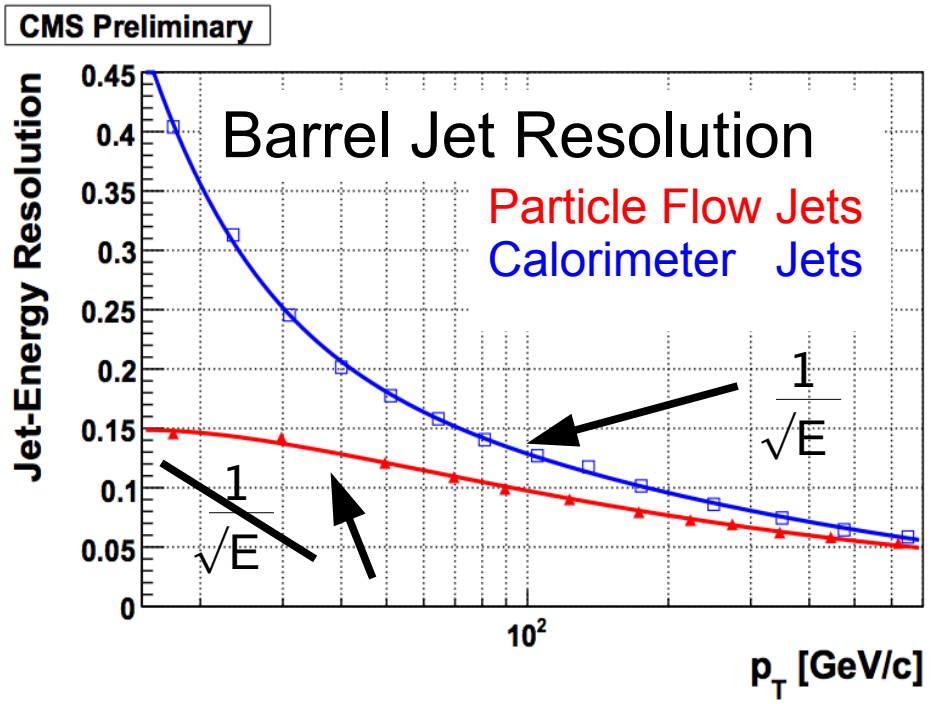
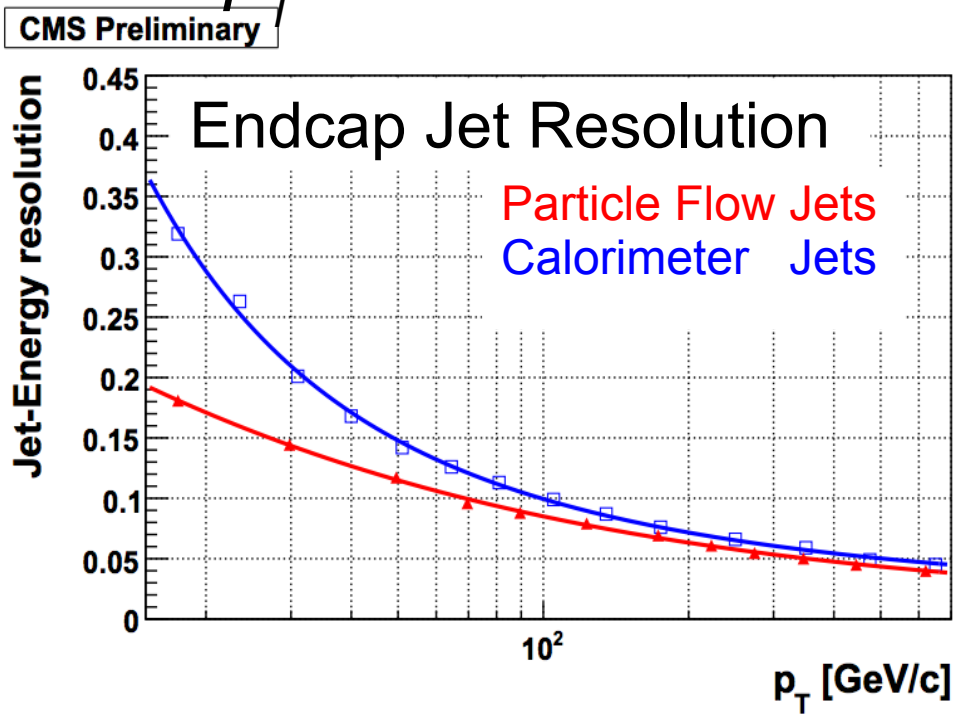
Particle Flow Techniques

Philip Harris (CERN)
CMS collaboration

Advanced Techniques w/Particle Flow

- The general feel of the particle flow
  - Minimize the information loss at every step
    - Best subcomponents possible
    - Allows for standard objects to be pushed to new regimes
  - Simple example : Jets at low p_T

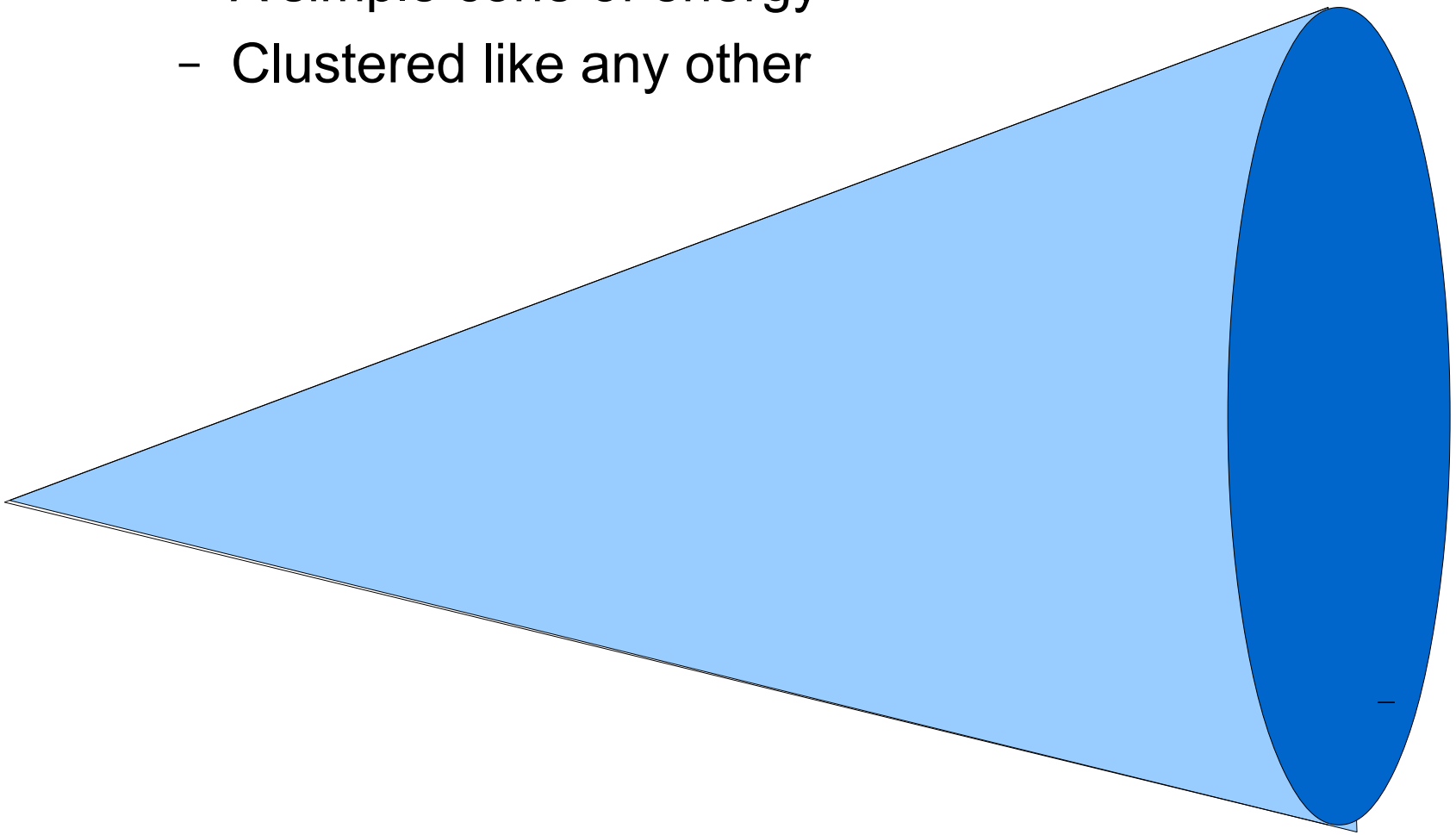




- This talk expands on this concept

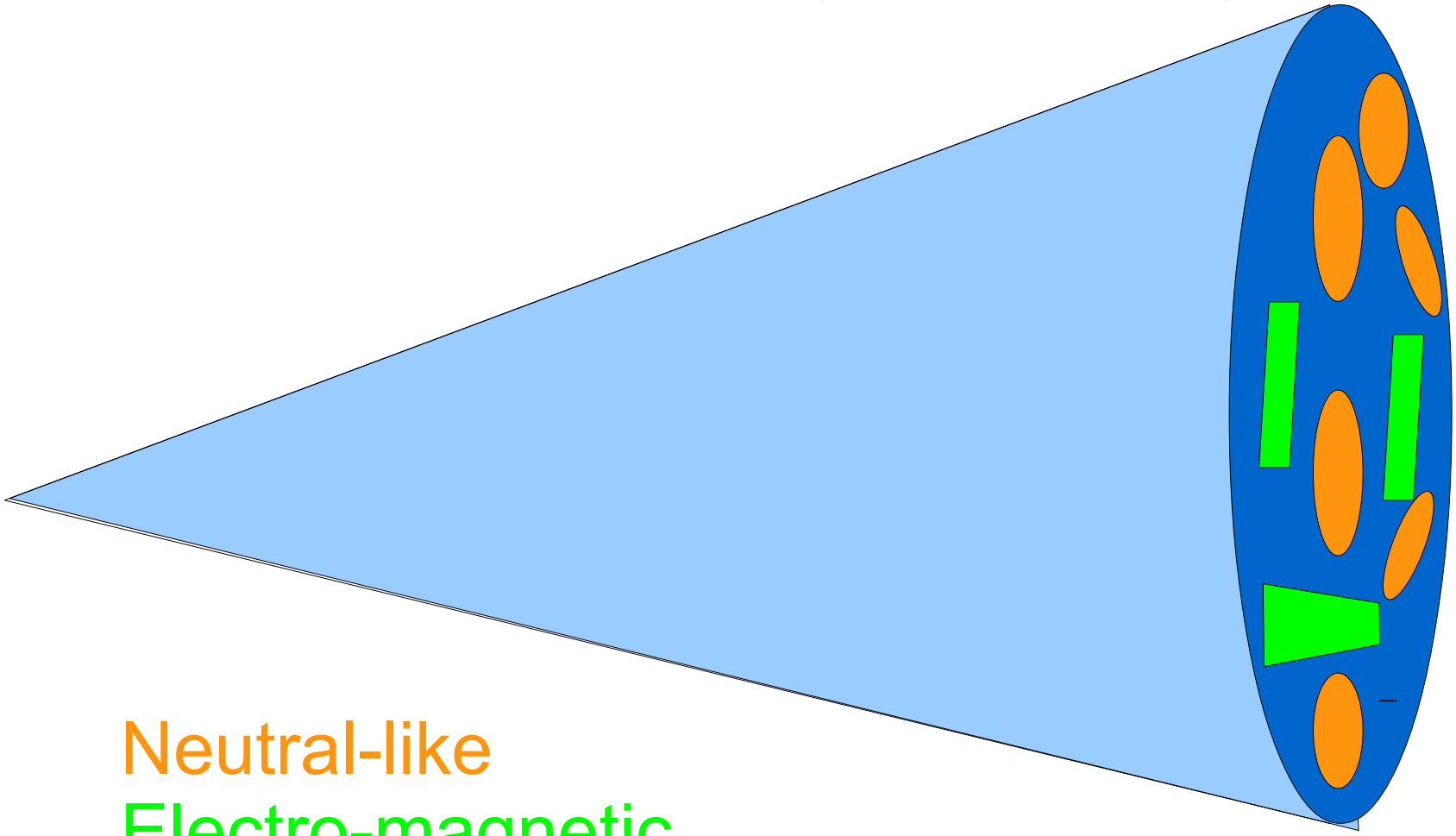
What can we do with particle flow?

- Consider tau reconstruction
  - Tau reconstruction starts with a jet
    - A simple cone of energy
    - Clustered like any other



Basic Jet Information

- Tau reconstruction : 1st step
  - Look at the composition of the jet
    - This is where non PF algorithms basically stop

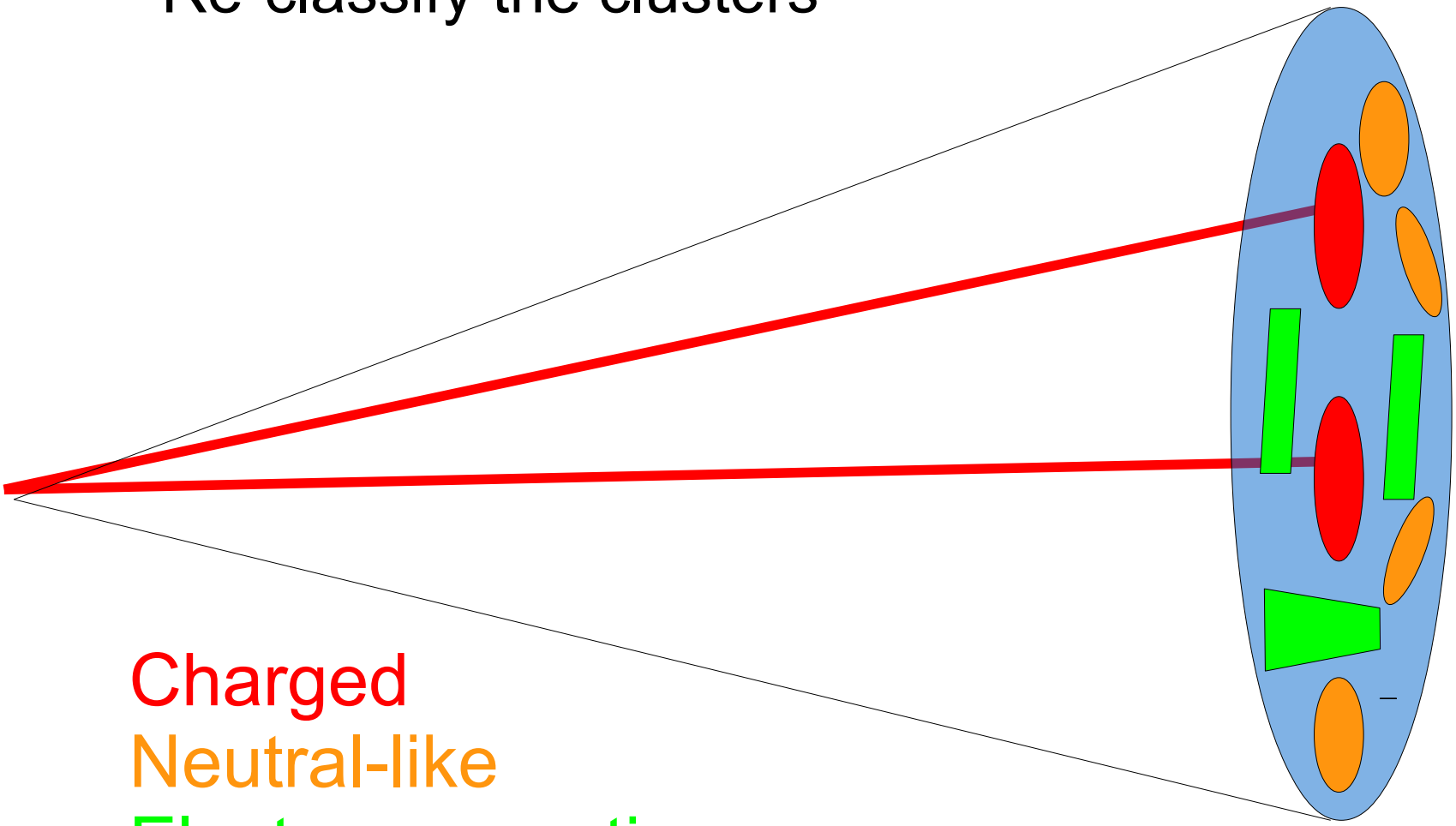


Neutral-like

Electro-magnetic

Simple view of Particle Flow

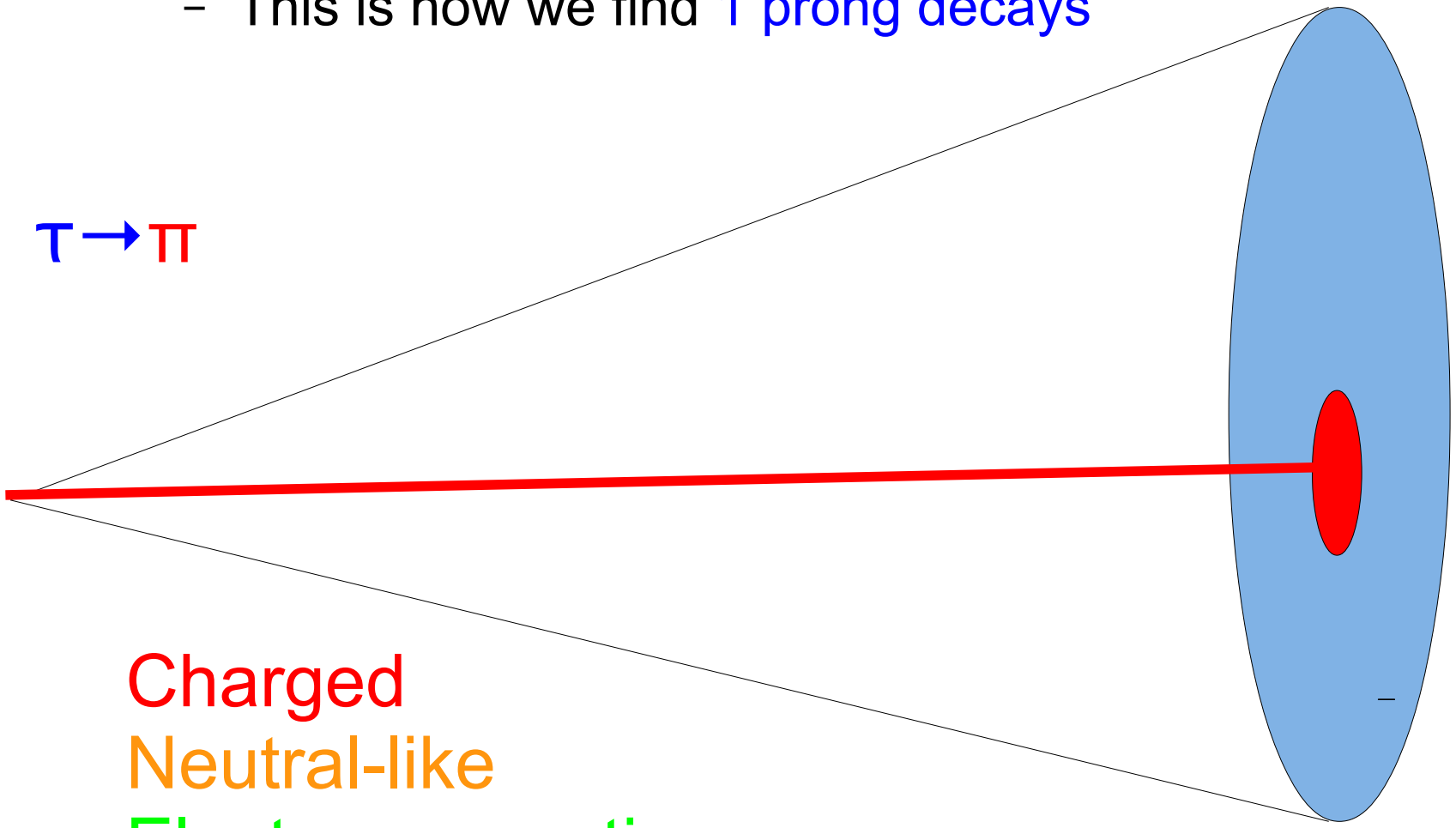
- Tau reconstruction : 2nd Step
  - Pull out the charged components of the jet
  - Re-classify the clusters



Charged
Neutral-like
Electro-magnetic

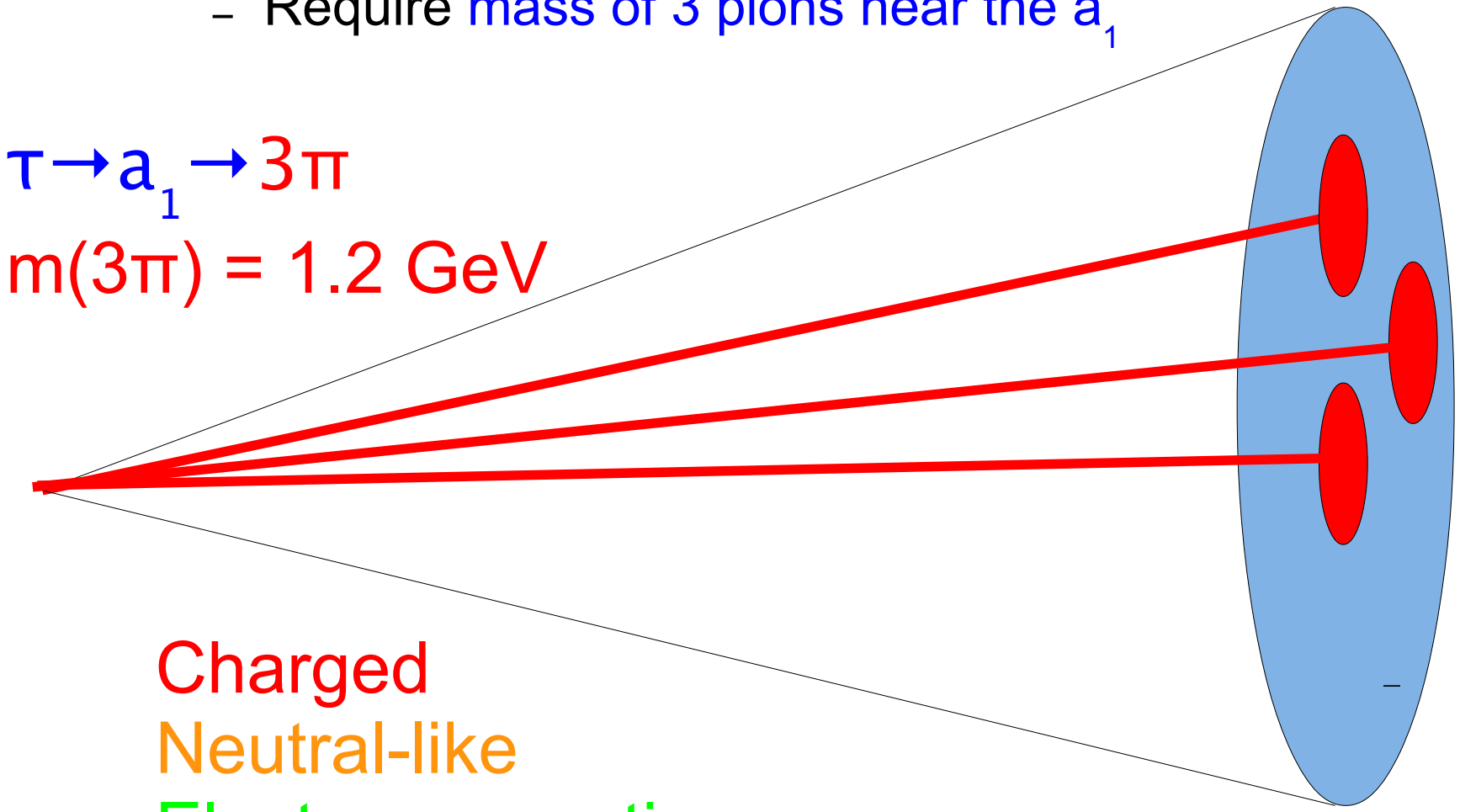
Identifying Tau decay: 1 prong

- Tau reconstruction : 3rd Step
  - With classified particles look for high p_T pion
    - This is how we find 1 prong decays



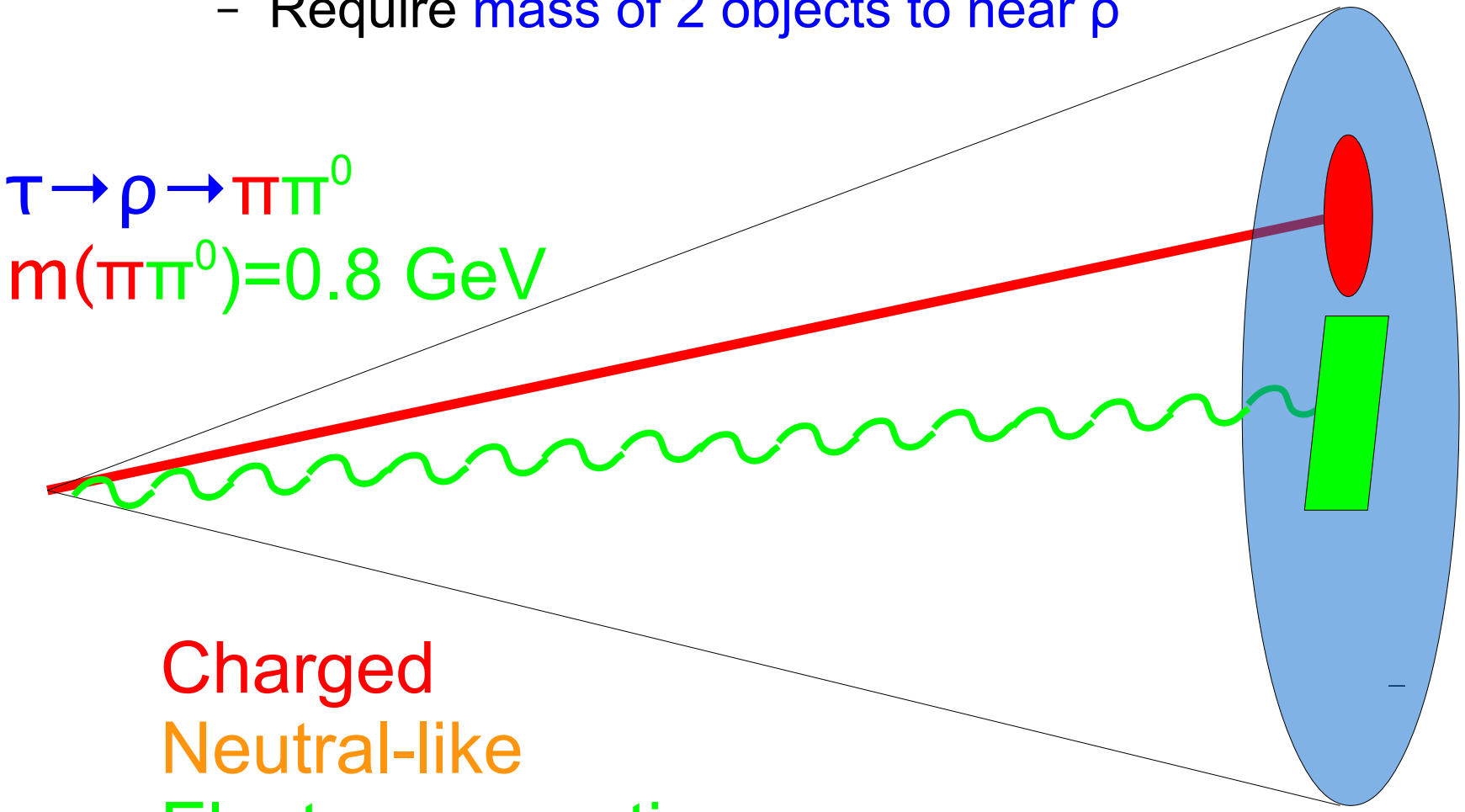
Identifying Tau decay: 3 prong

- Tau reconstruction : 3rd Step
  - With classified particles look for 3 high p_T pions
    - Require mass of 3 pions near the a_1



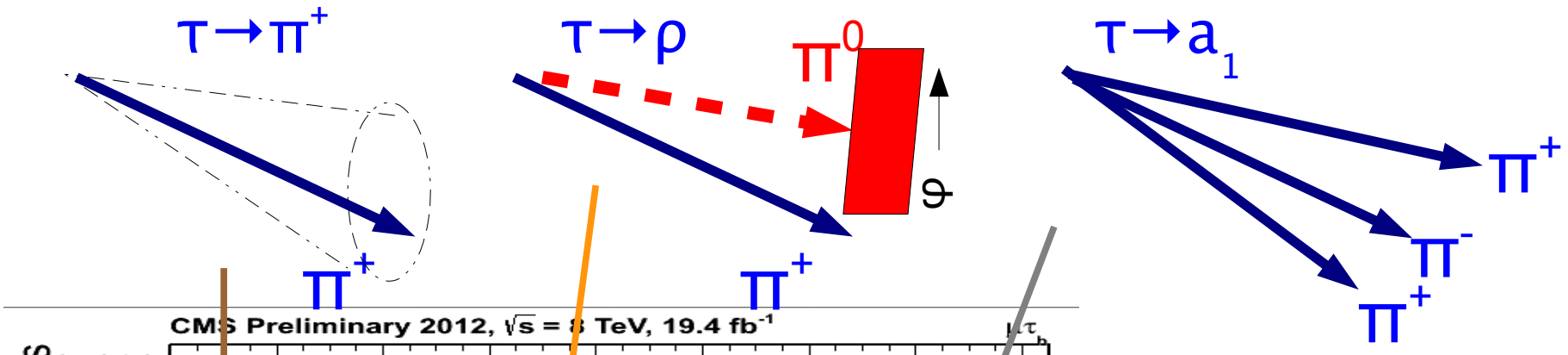
Identifying Tau decay:1prong +π^0

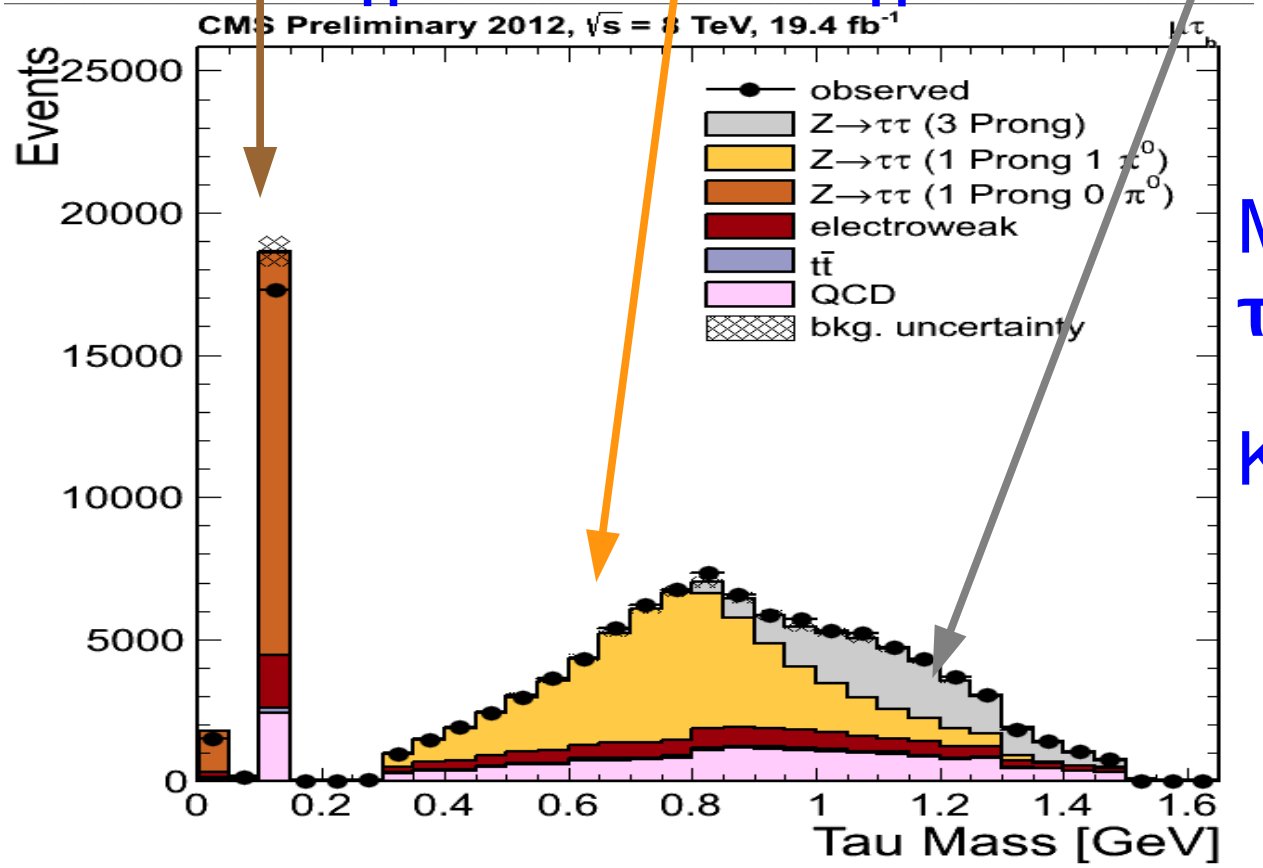
- Tau reconstruction : 3rd Step
  - Look for 1 high p_T pion + em object (π^0)
    - Require mass of 2 objects to near ρ



Summary of Tau objects

- Start with a jet → look for τ decay inside



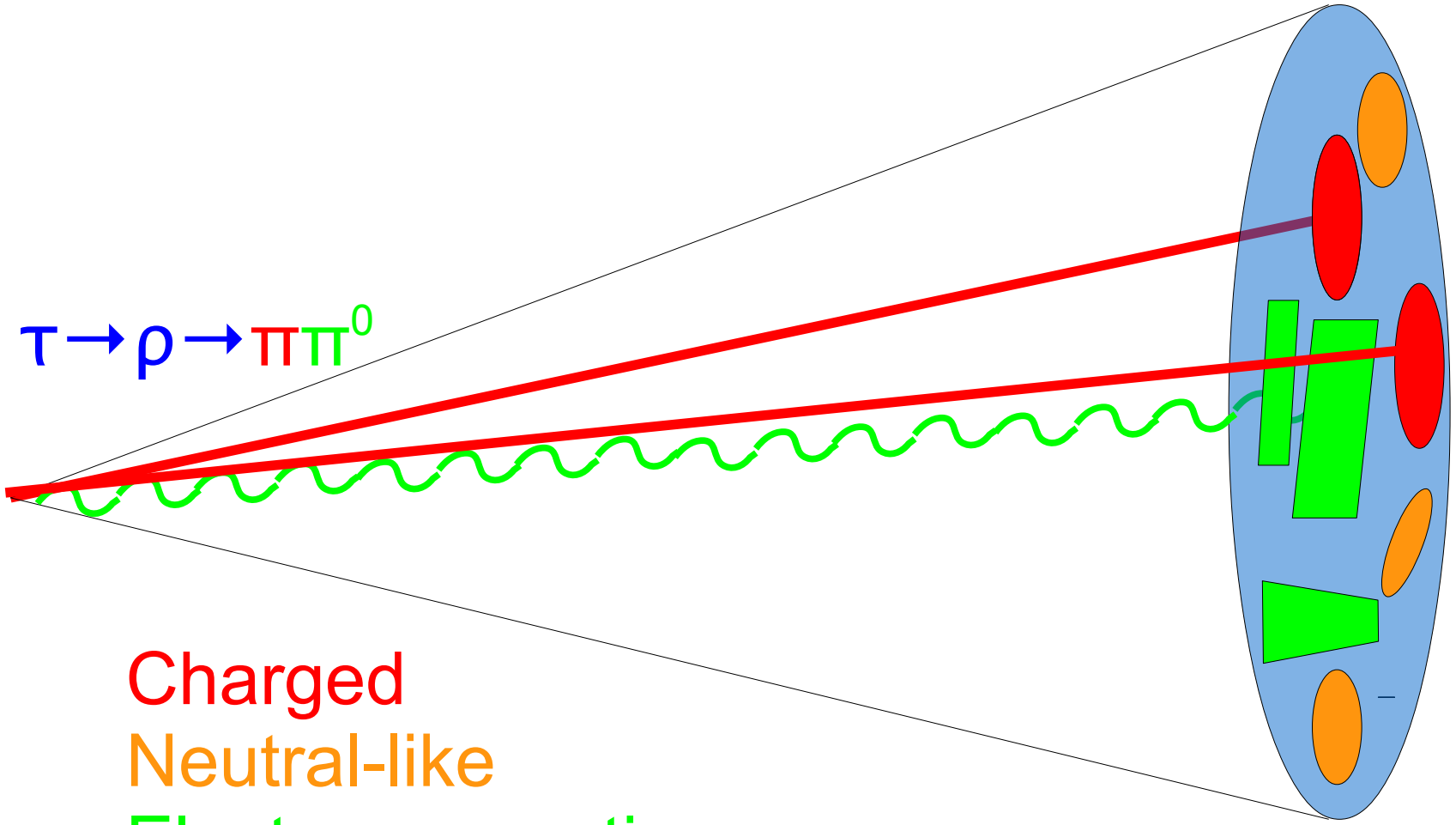


Mass used for
τ energy scale

Key to precision (1%)

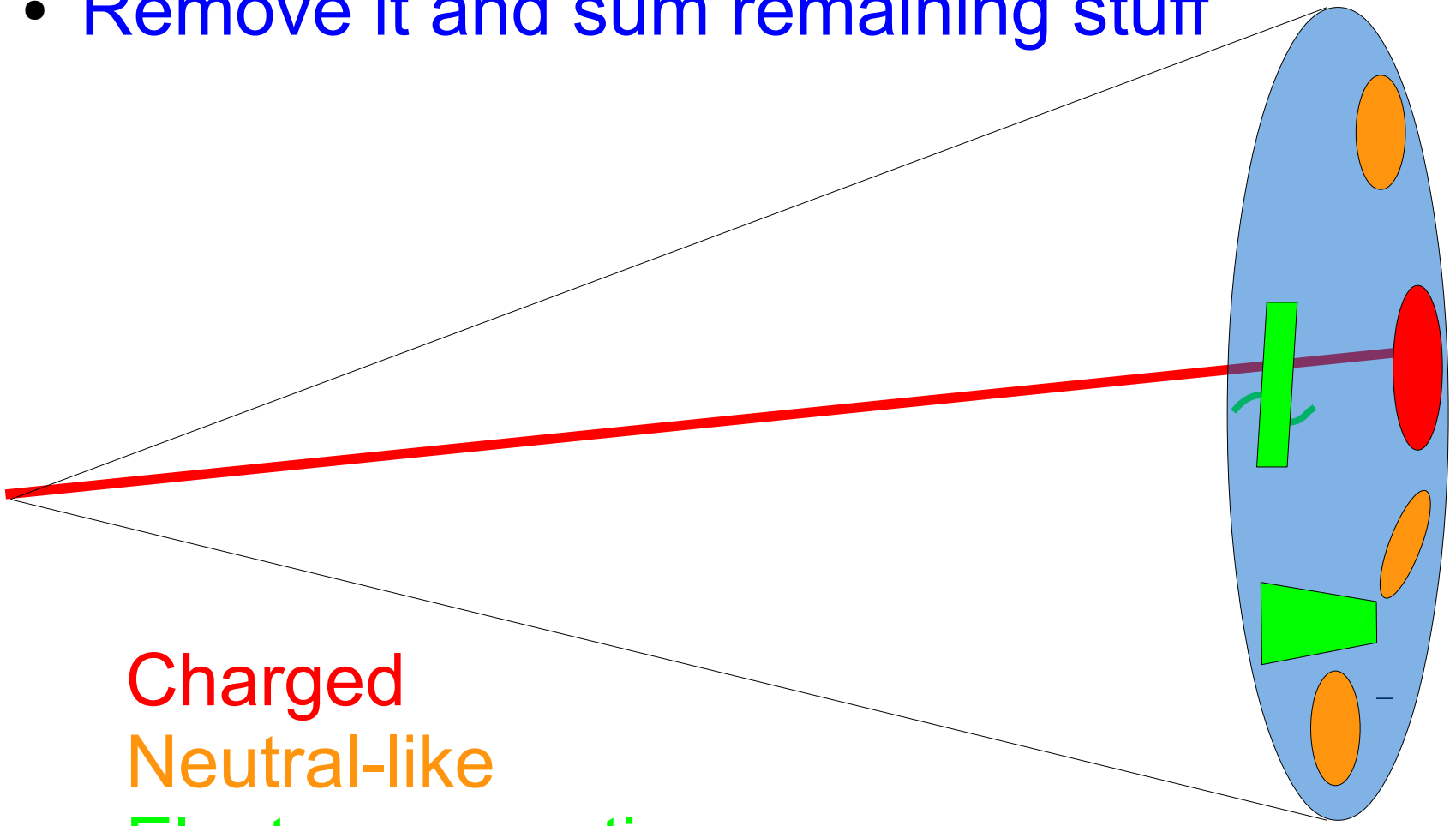
Second critical key to Tau Id

- Particle flow allows for isolation of the tau
- Concept : identify the tau



Second critical key to Tau Id

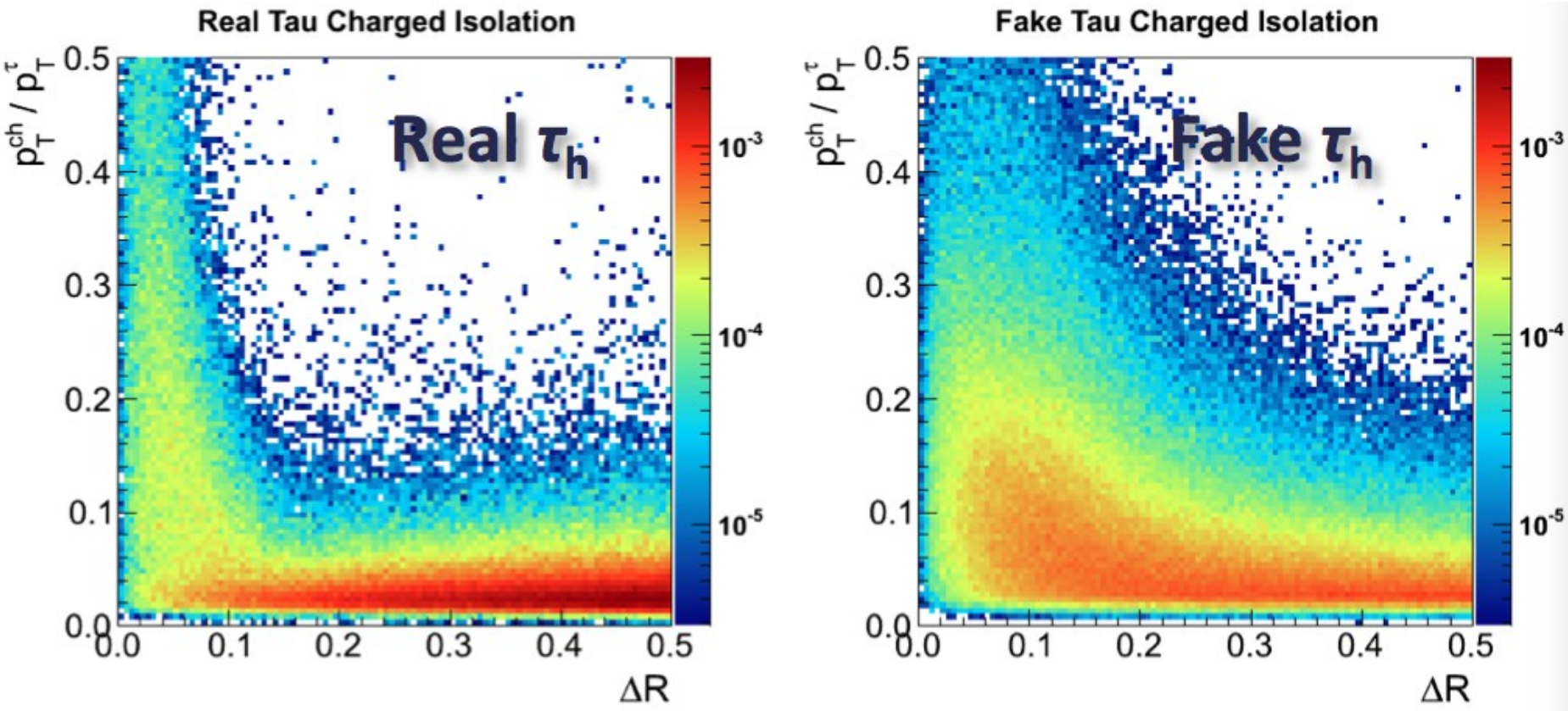
- Particle flow allows for isolation of the tau
- Concept : identify the tau
- Remove it and sum remaining stuff



Charged
Neutral-like
Electro-magnetic

Tau Isolation in Plots

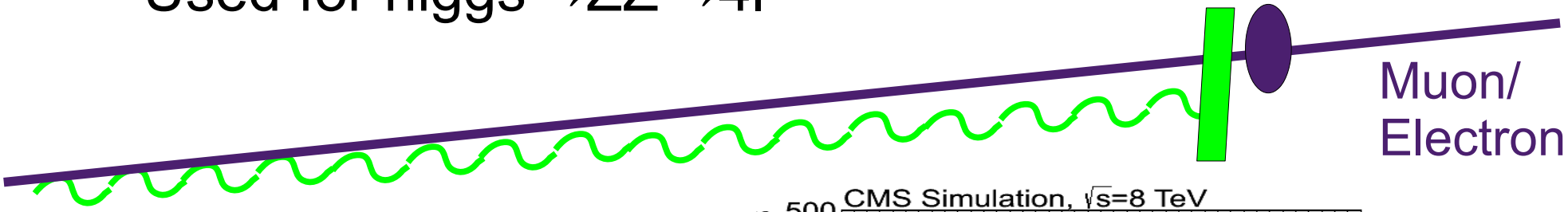
- Shape of isolation inside used to remove bkg
- Distribution/type of object identifies pileup
  - Isolation separated out into photonic/charged/neutral



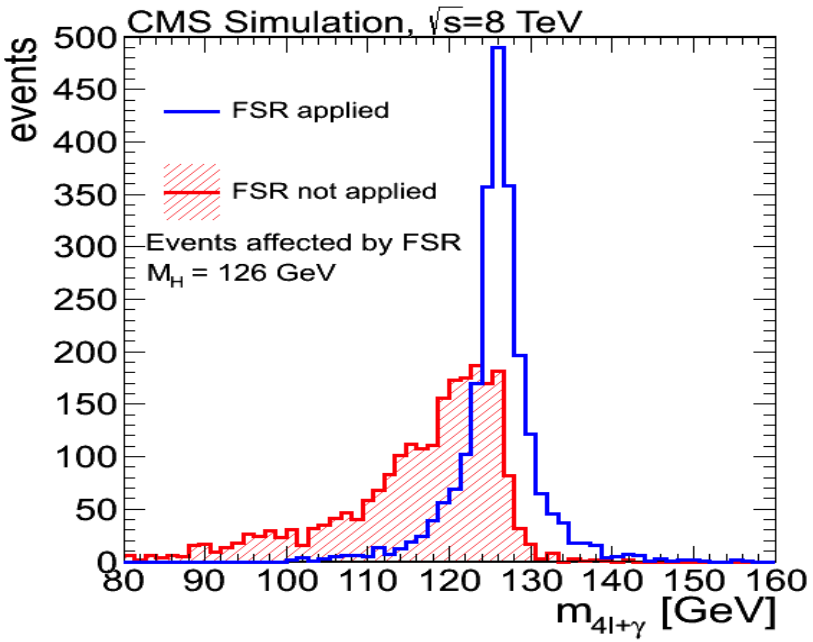
Distribution inside cone key to classifying a good isolation

Improving Lepton Resolutions

- Understanding known effect: final state radiation
  - Recovering these photons enables higher resolution
- Improves sensitivity to resonant searches
  - Used for higgs→ZZ→4l

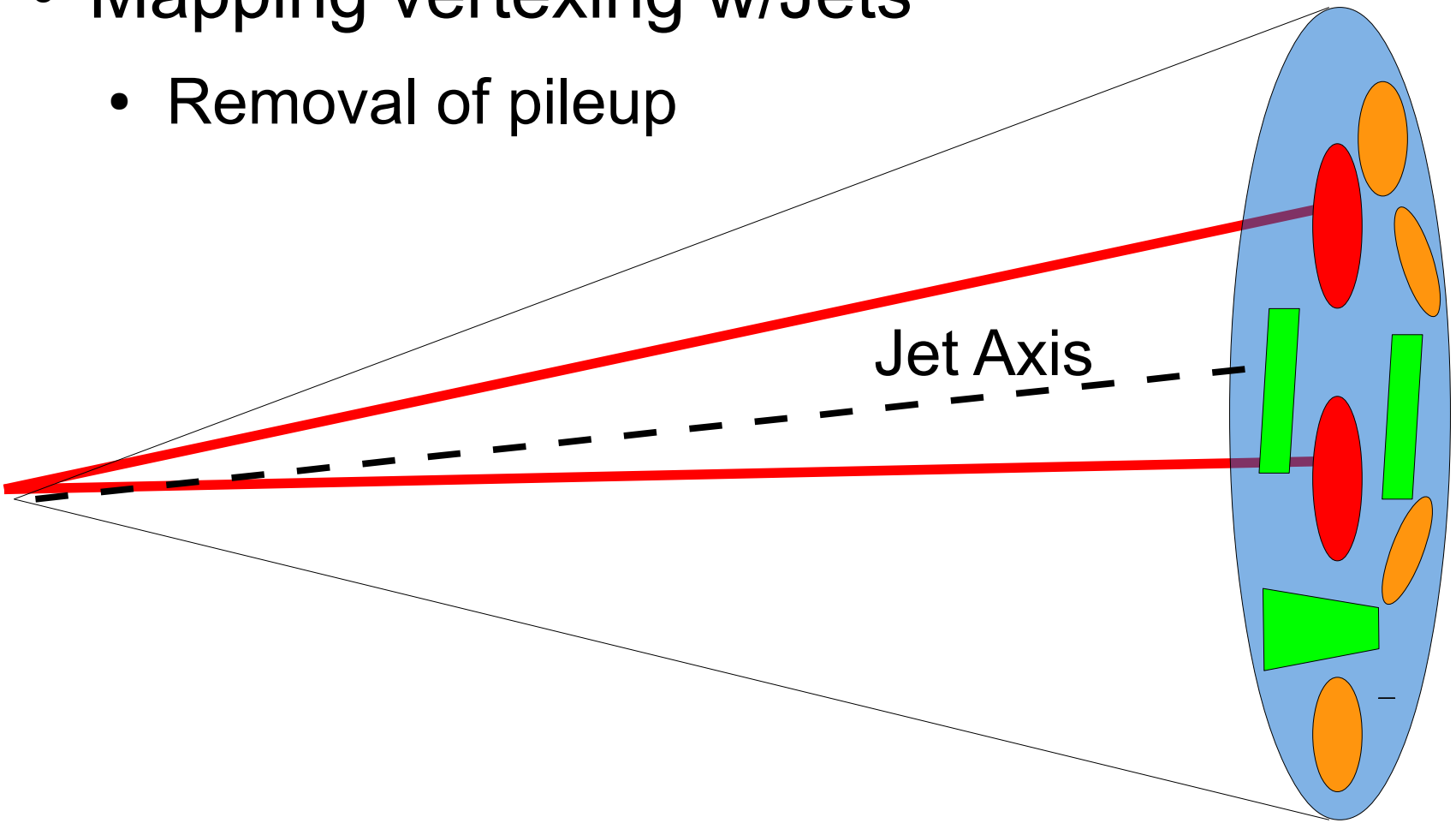


Photon efficiency 50%
5% recovery for Z→μμ
0.5% recovery for Z→ee



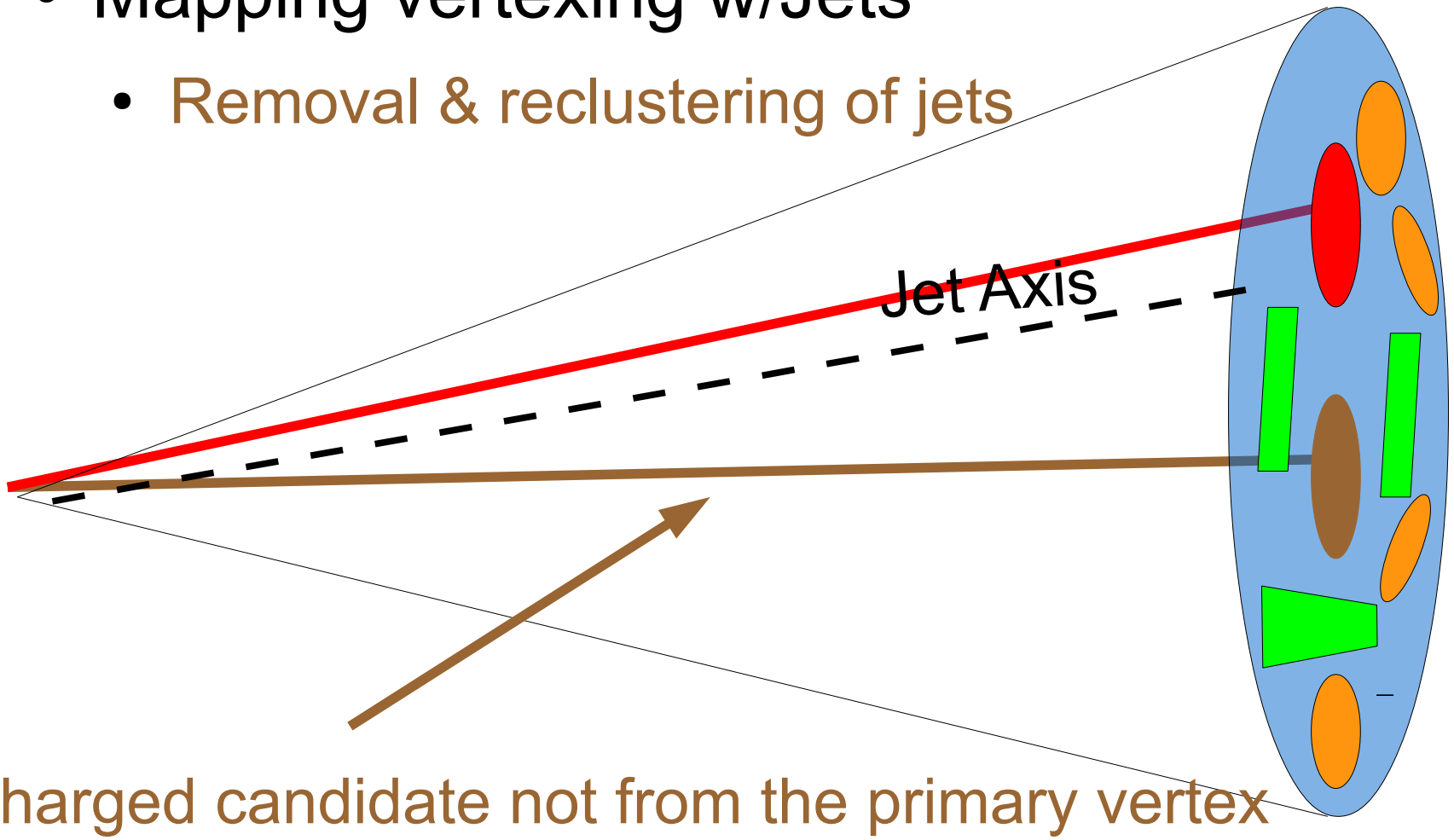
Understanding Jets

- The insides of jets have a lot of information
  - We can use these insides to isolate pileup
- Mapping vertexing w/Jets
  - Removal of pileup



Charged Hadron Subtraction

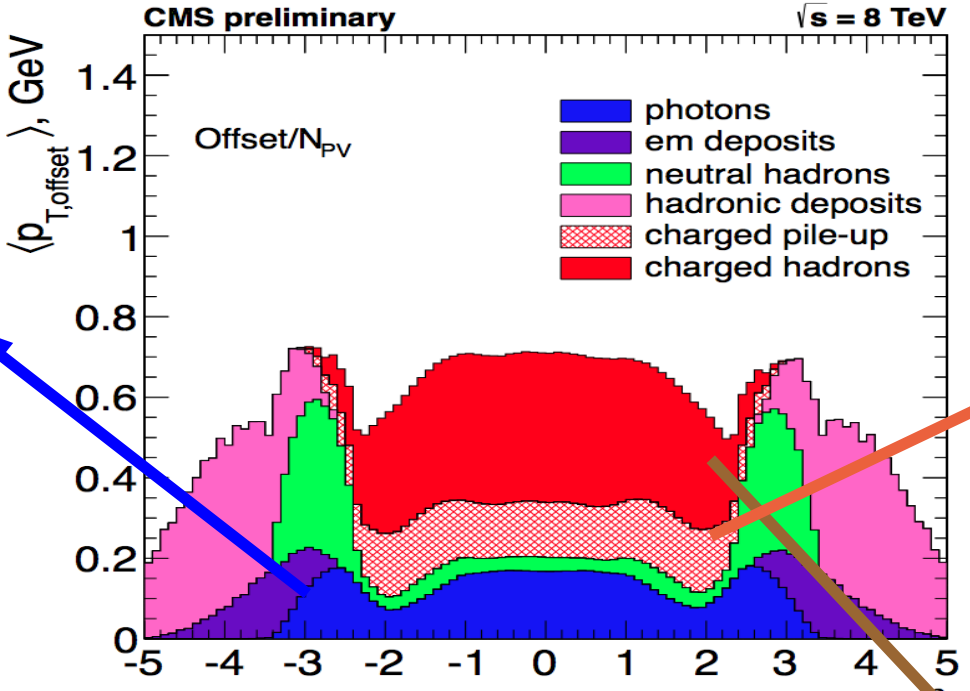
- The insides of jets have a lot of information
  - We can use these insides to isolate pileup
- Mapping vertexing w/Jets
  - Removal & reclustering of jets



Removing Pileup

- Charged hadron subtraction: 50% less pileup
  - Does not remove the neutral pileup
    - Observed by measuring looking randomly in detector

Pileup Contribution



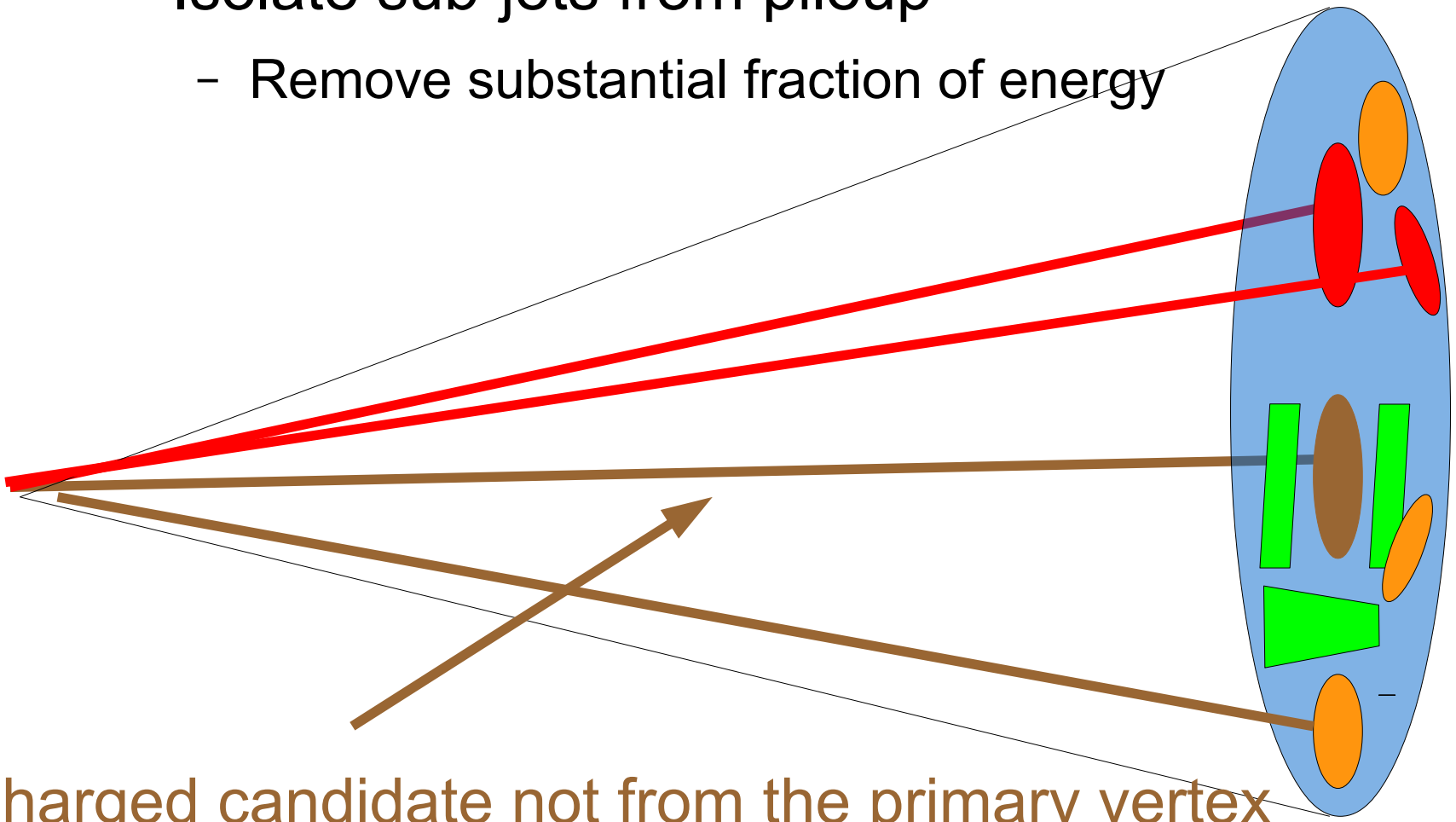
??

Remaining charged candidates after pileup subtraction

Charged candidate not from the primary vertex(removed)

Tagging Neutrals

- Can use the vertex info to link clustered deposit
  - Neutrals from pileup are often clustered w/charged
  - Isolate sub-jets from pileup
    - Remove substantial fraction of energy

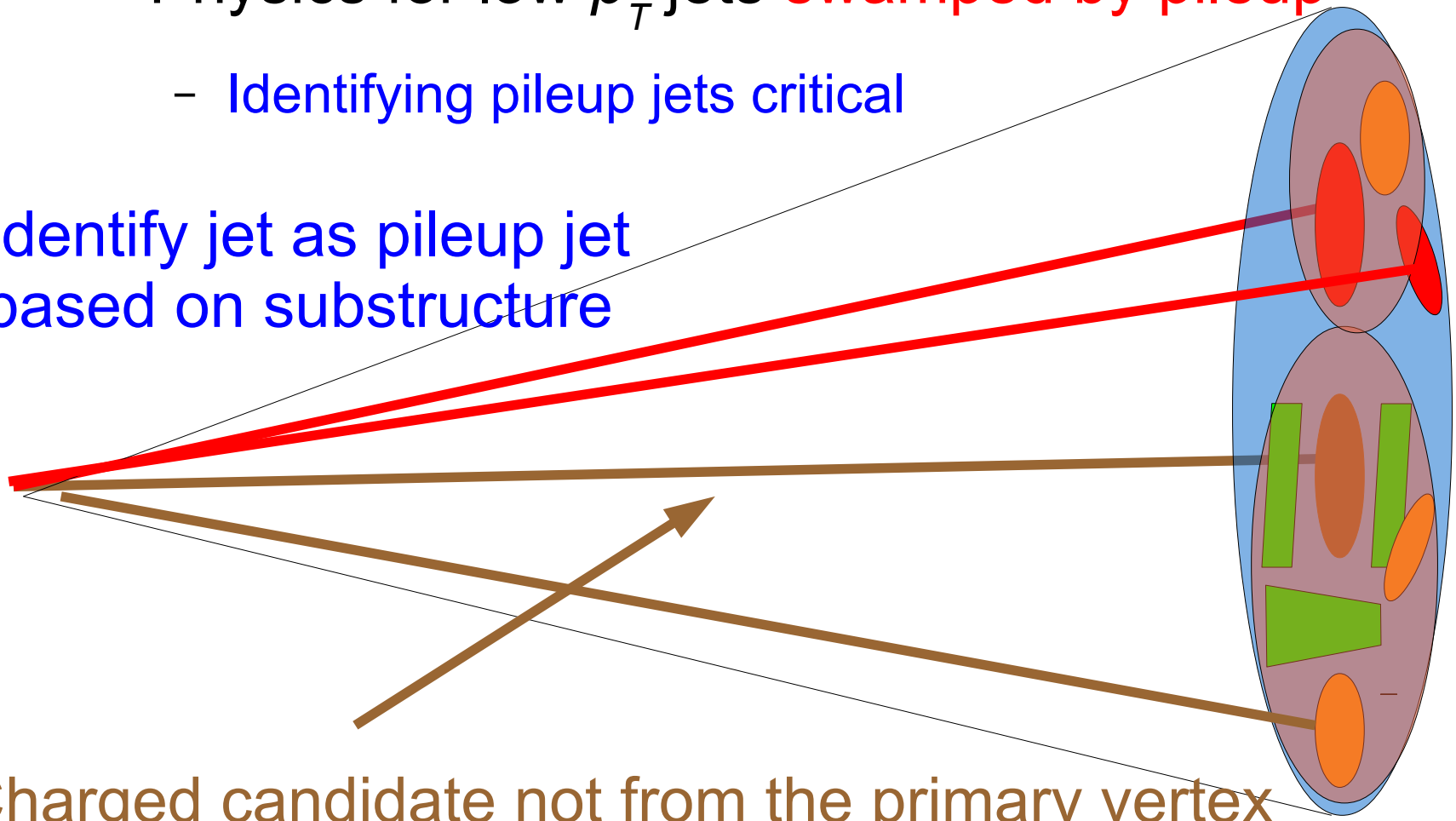


Charged candidate not from the primary vertex

Removing the Neutrals

- Pileup can be clustered into jets
  - Large incidence of two small pileup jets merging
  - Physics for low p_T jets swamped by pileup
    - Identifying pileup jets critical

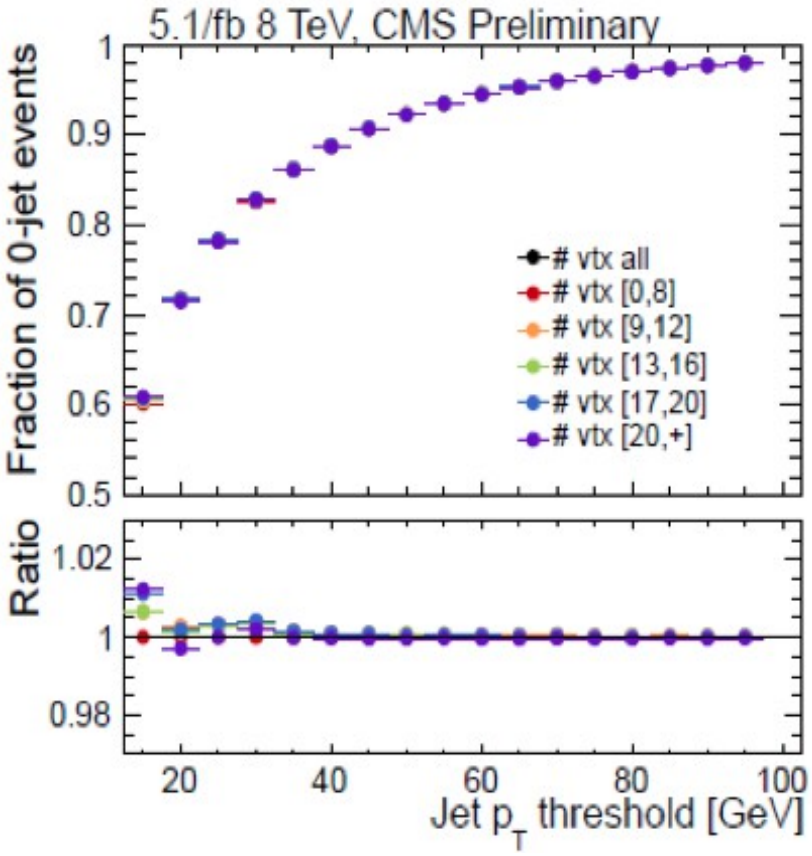
Identify jet as pileup jet
based on substructure



Charged candidate not from the primary vertex

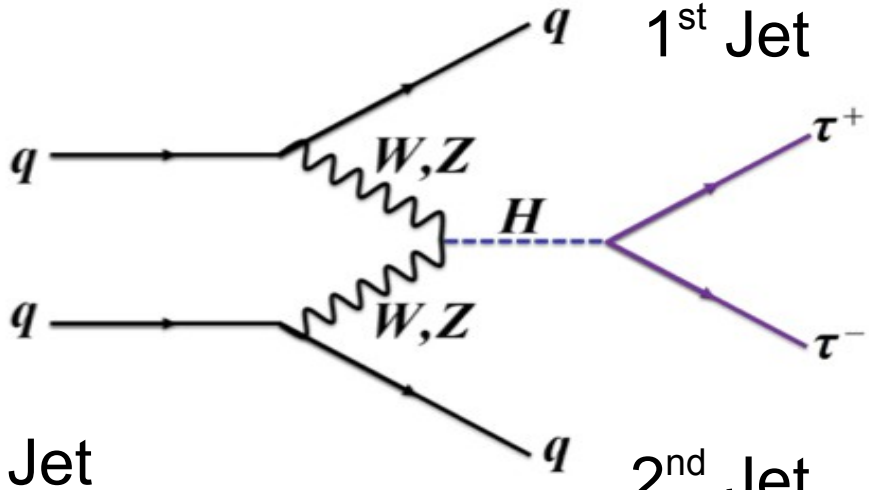
Pileup Jet Id Performance

- Identification allows for
  - Reduction of background (particularly forward jets)
  - Precise control of jet vetos
    - Minimized systematic uncertainties from pileup



14 TeV High Pileup VBF
25 ns spacing (+75 pileup)

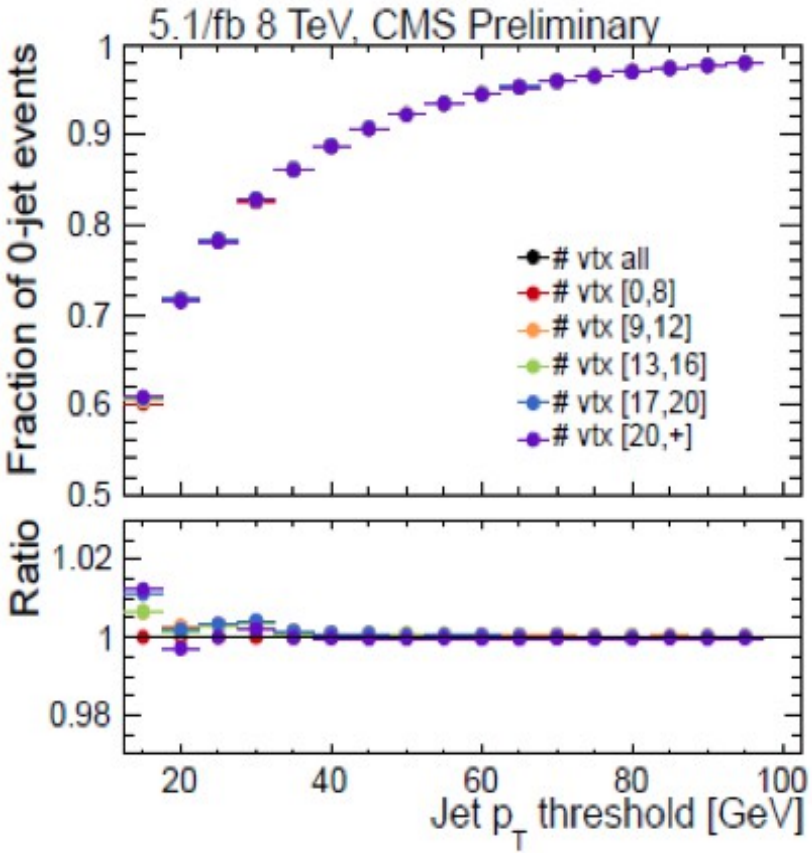
Look for production



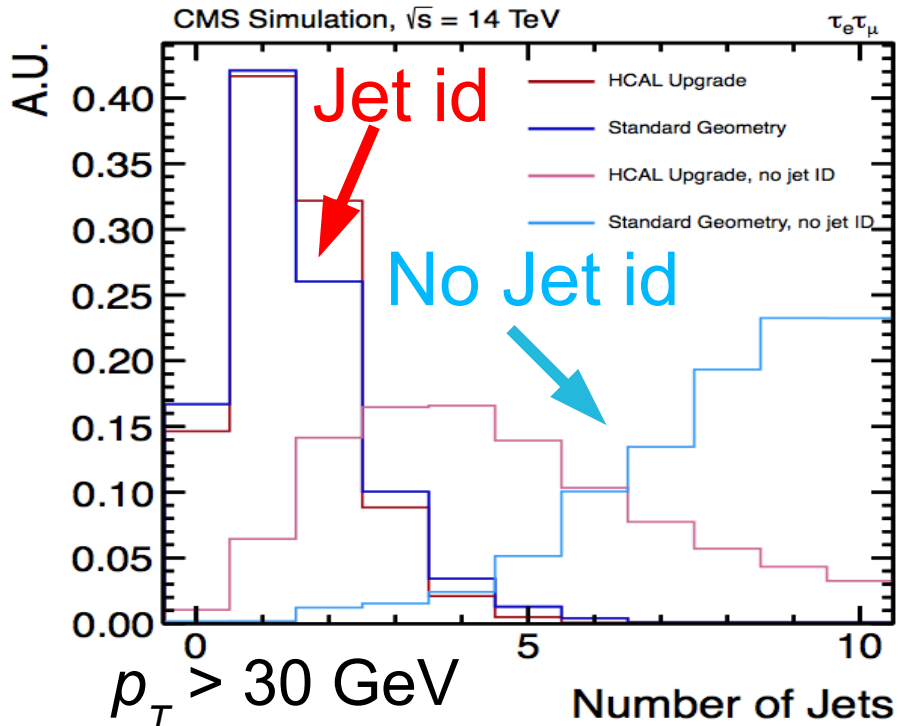
Jet
p_T > 30 GeV

Pileup Jet Id Performance

- Identification allows for
  - Reduction of background (particularly forward jets)
  - Precise control of jet vetos
    - Minimized systematic uncertainties from pileup

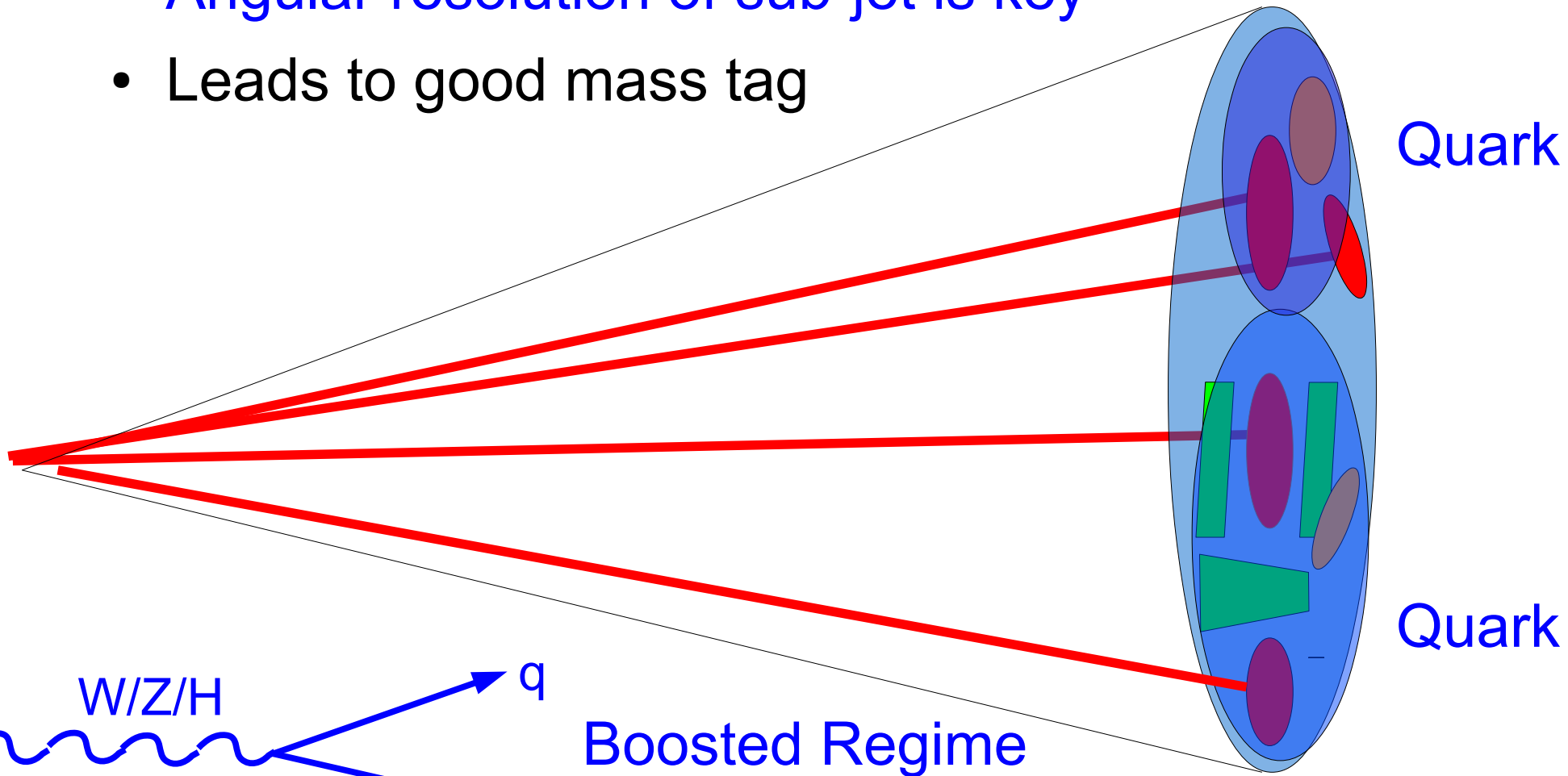


14 TeV High Pileup VBF
25 ns spacing (+75 pileup)



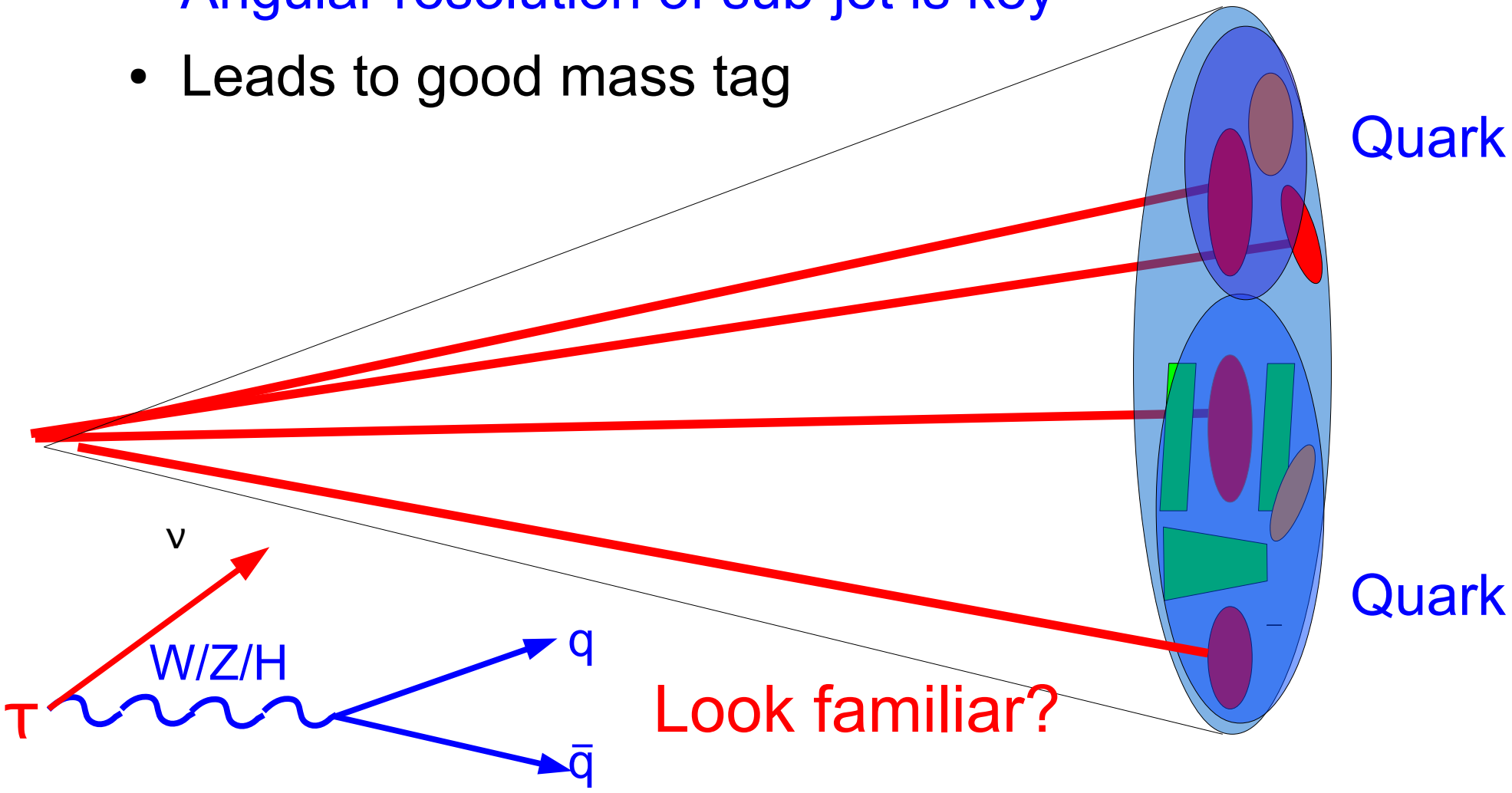
Expanding on this Concept

- Sub-clustering of jets allows for W/Z-tagged jets
  - Additionally Higgs and Top tagged jets
  - Angular resolution of sub-jet is key
  - Leads to good mass tag



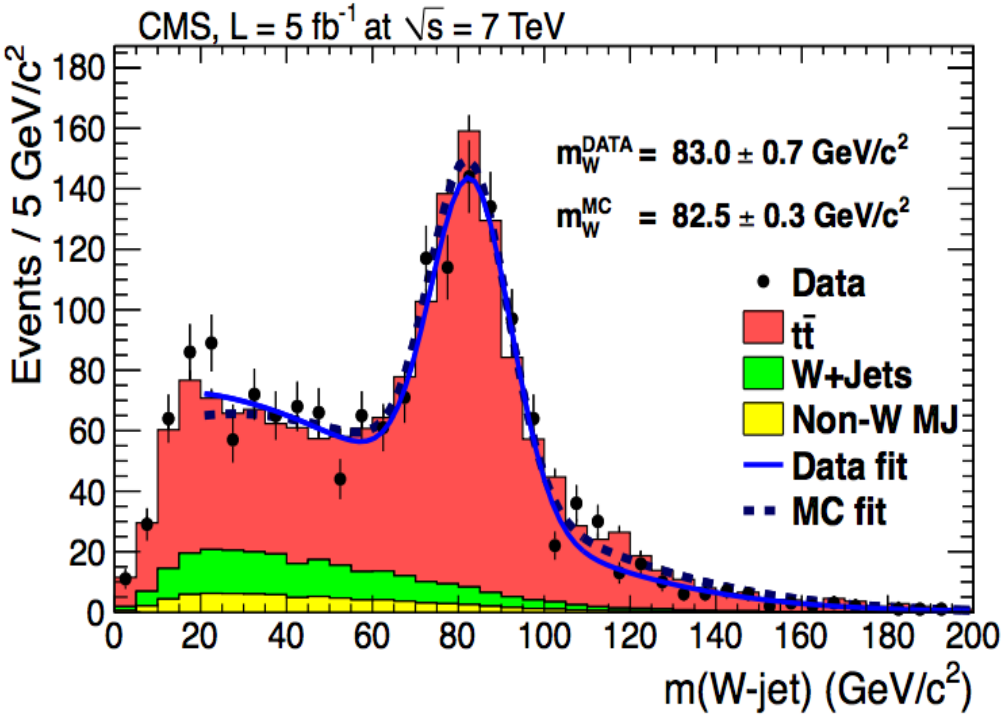
Expanding on this Concept

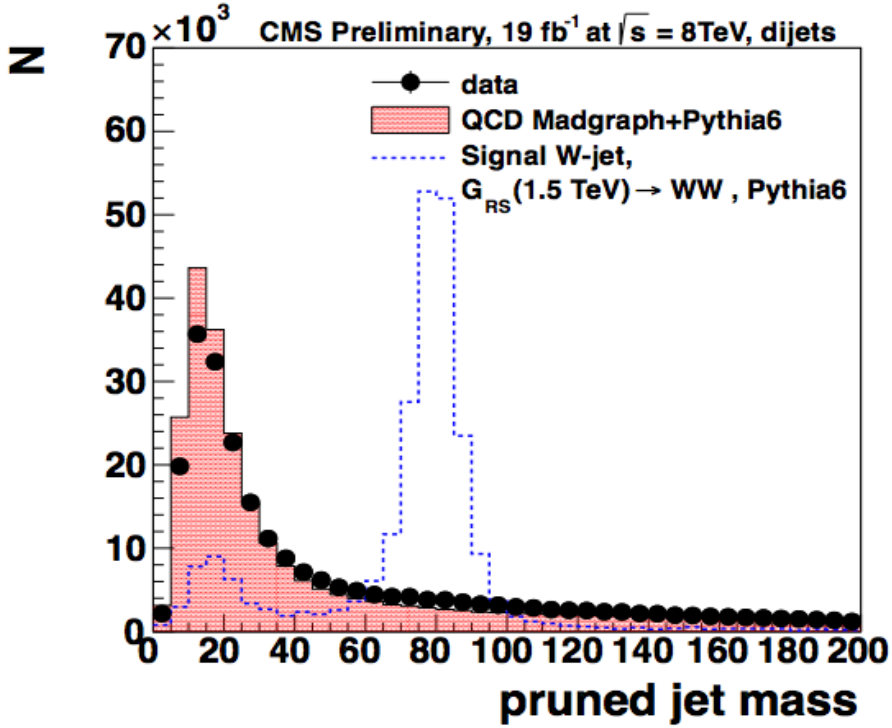
- Sub-clustering of jets allows for W/Z-tagged jets
  - Additionally Higgs and Top tagged jets
  - Angular resolution of sub-jet is key
  - Leads to good mass tag



W/Z/H tagged Jets

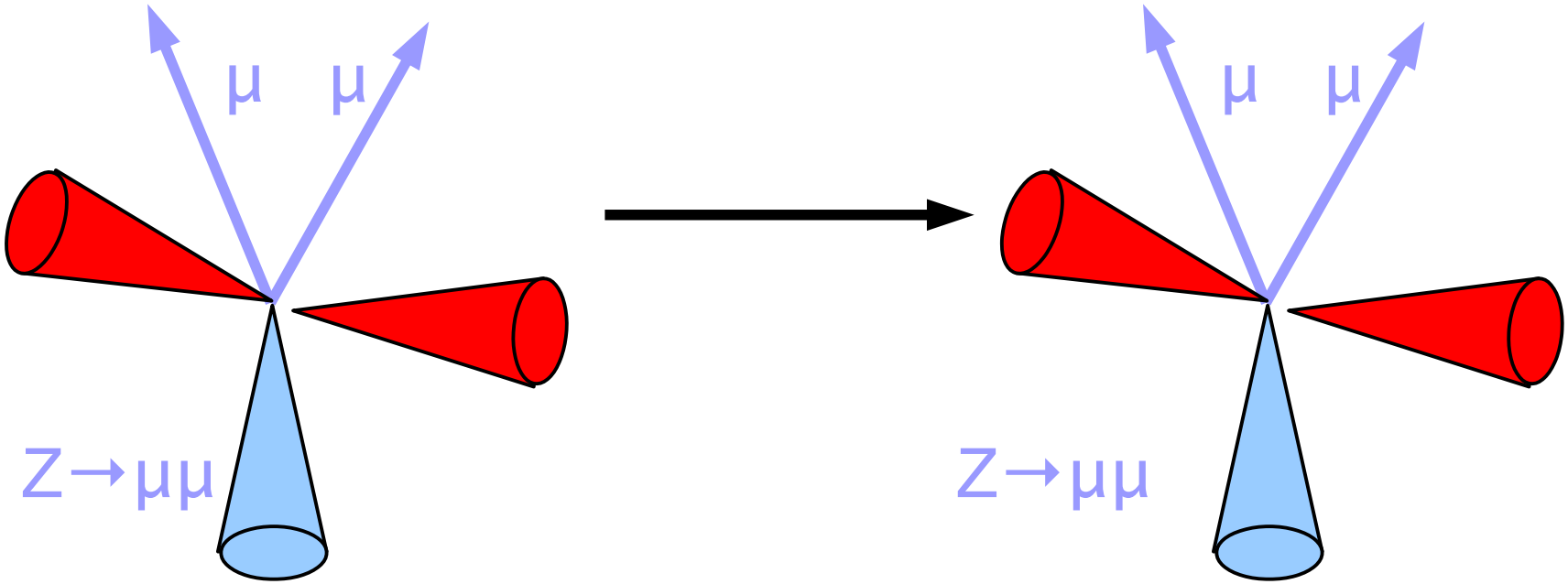
- W/Z/H-tagged jets will important in future LHC
  - Transition from higgs search to high mass searches
  - Substructure tagging probes high p_T electroweak
- Techniques further reduce the effects of pileup





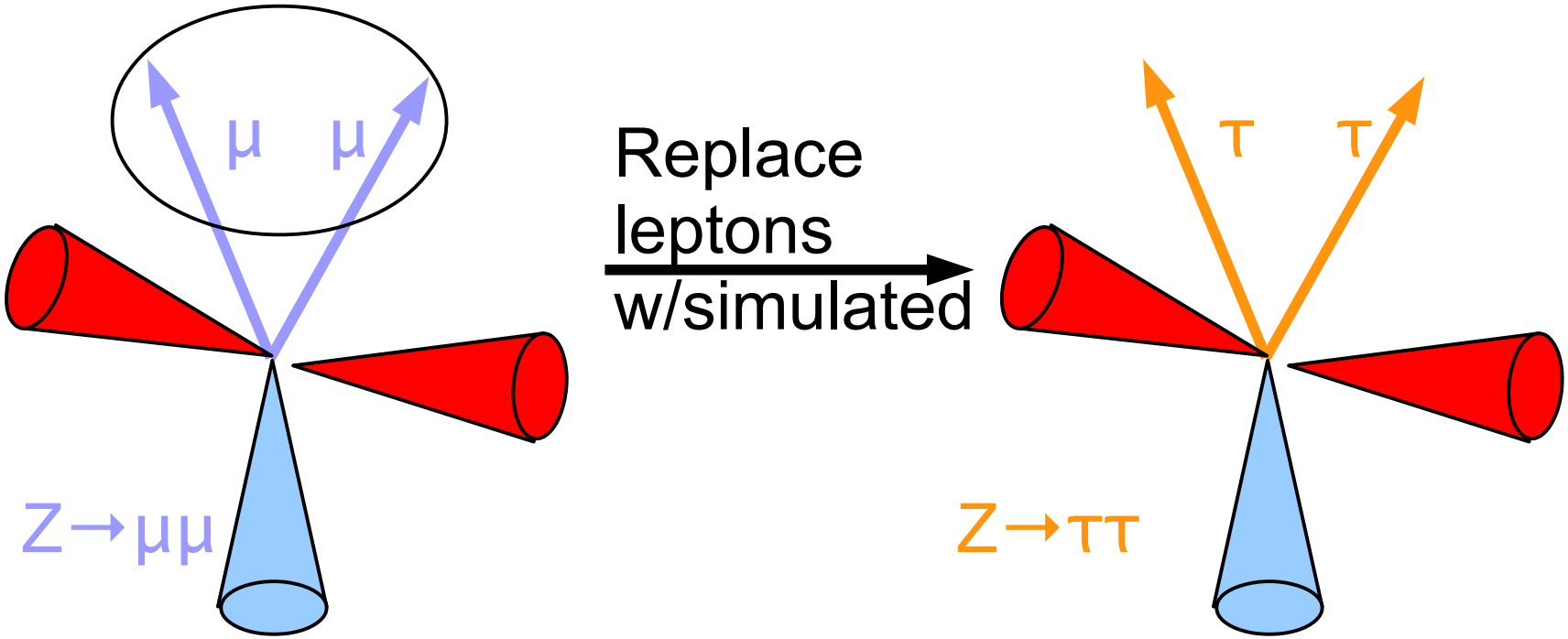
MET

- With particle flow : event can be dragged in easily
  - Allows embedding of data *MET* into MC event



Modelling *MET* in data

- With particle flow : event can be dragged in easily
  - Allows embedding of data *MET* into MC event

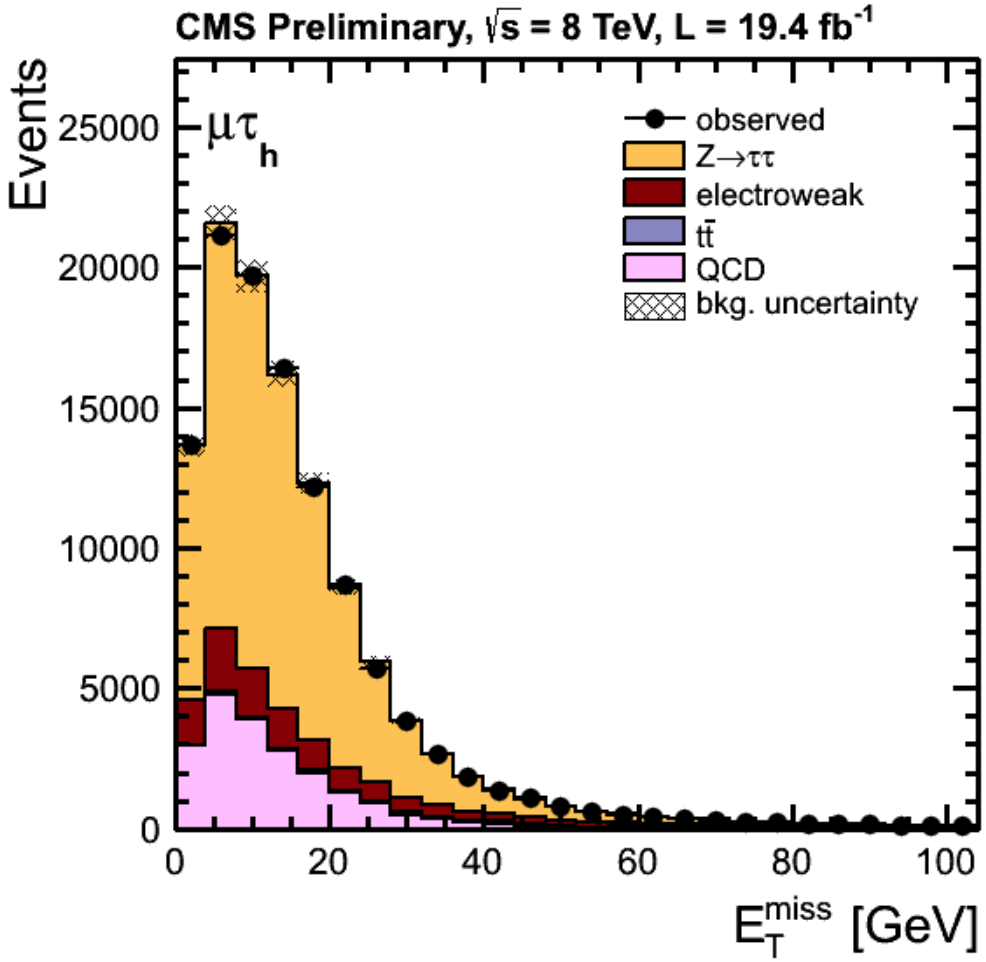


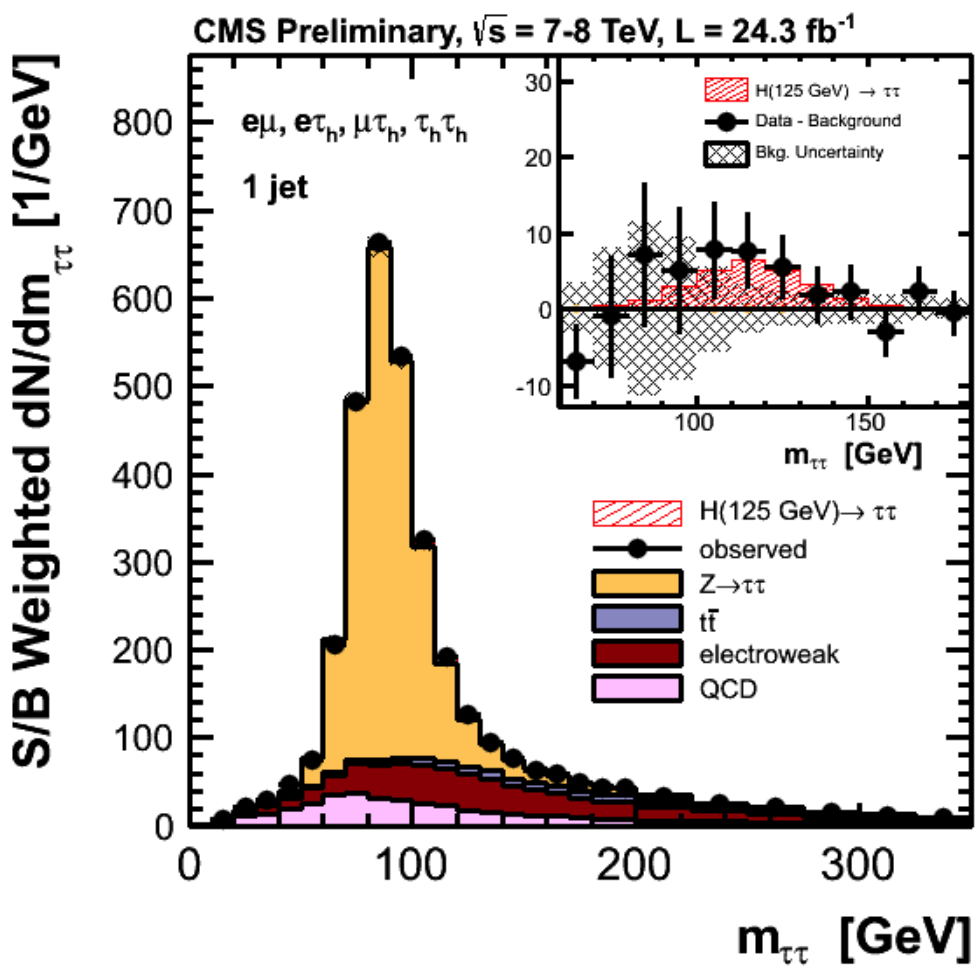
Particle level embedding avoids mis-alignment confusion between data/MC

Confusion persists at hit level

MET model performance

- Embedding of events preserves kinematics in data
  - Useful to model large yield backgrounds

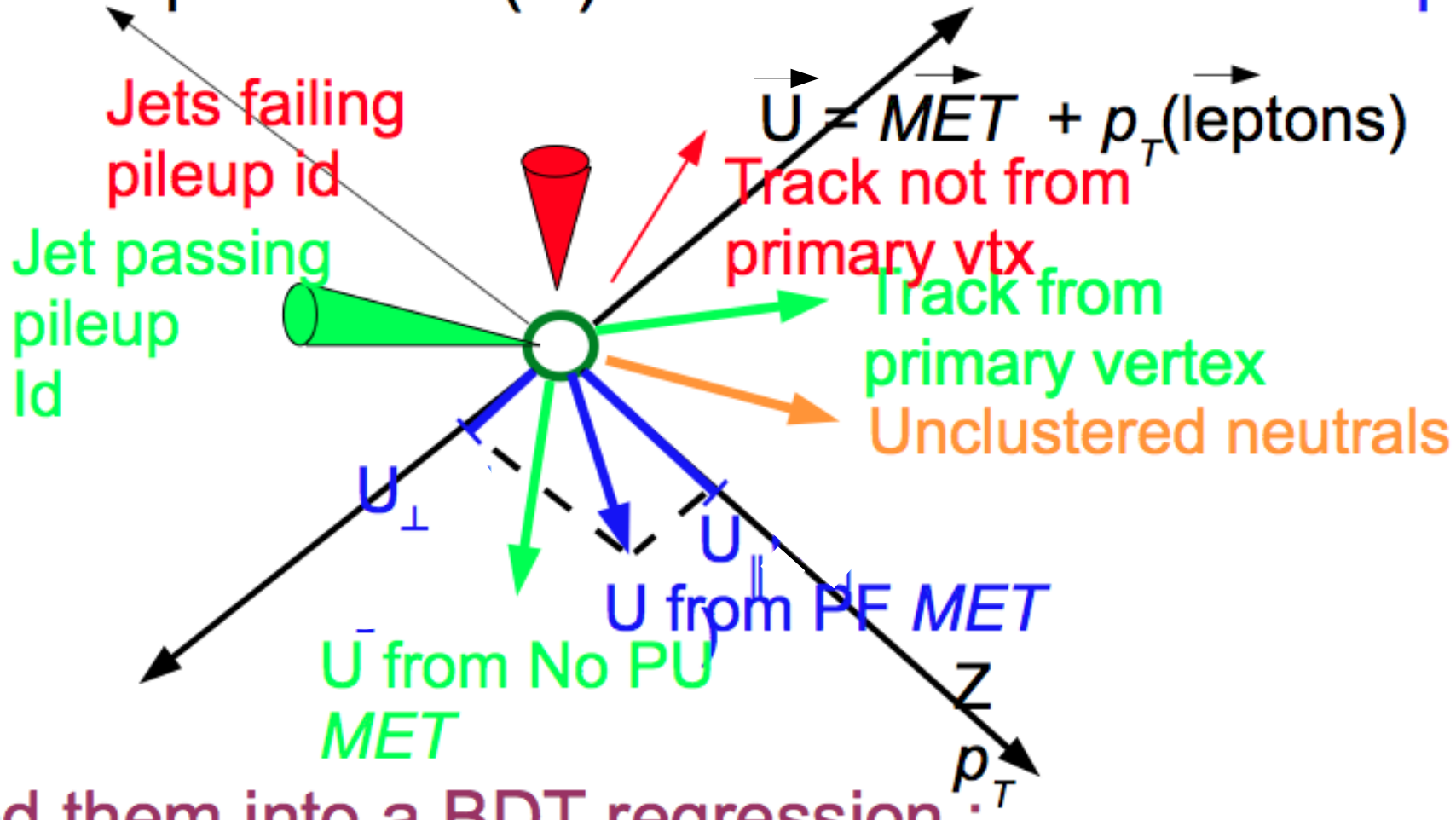




Embedding yields **extreme precision** in *MET* model of Drell-Yan

Combining Jets: *MET*

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

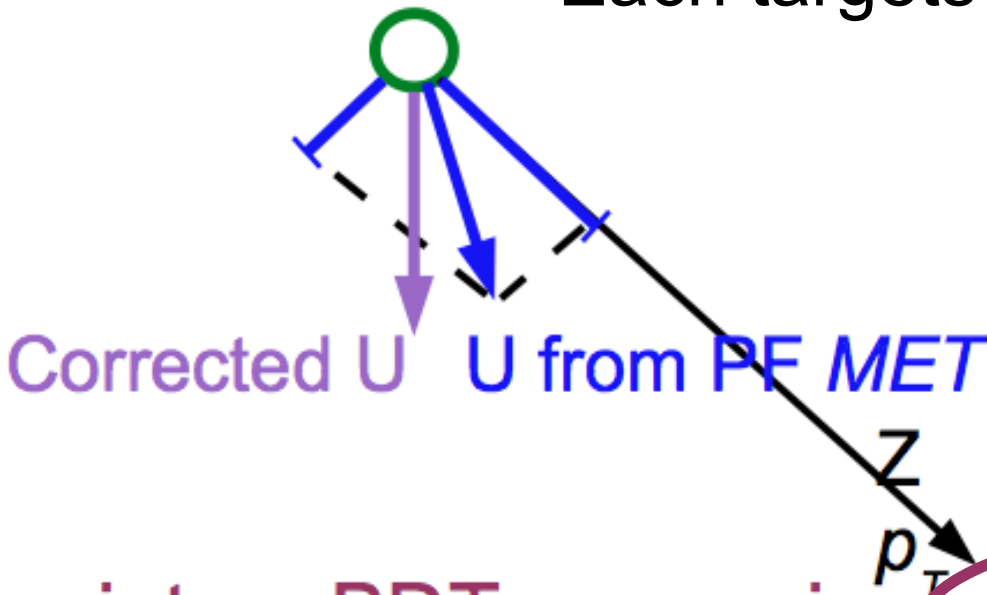


Feed them into a BDT regression :

MVA *MET*

- Concept:
  - Recoil here ➡ defined as *MET* – leptons

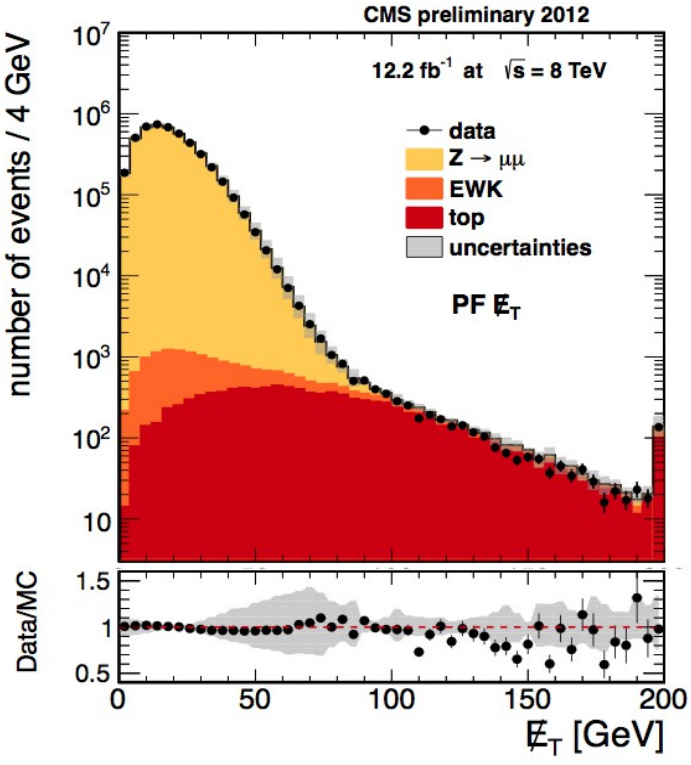
5 Separate recoils calculated
Each targets different component

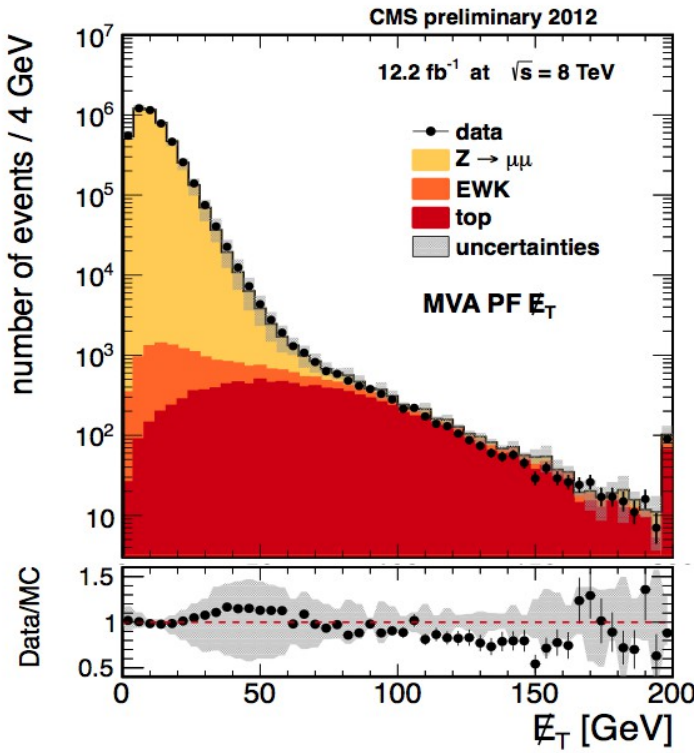


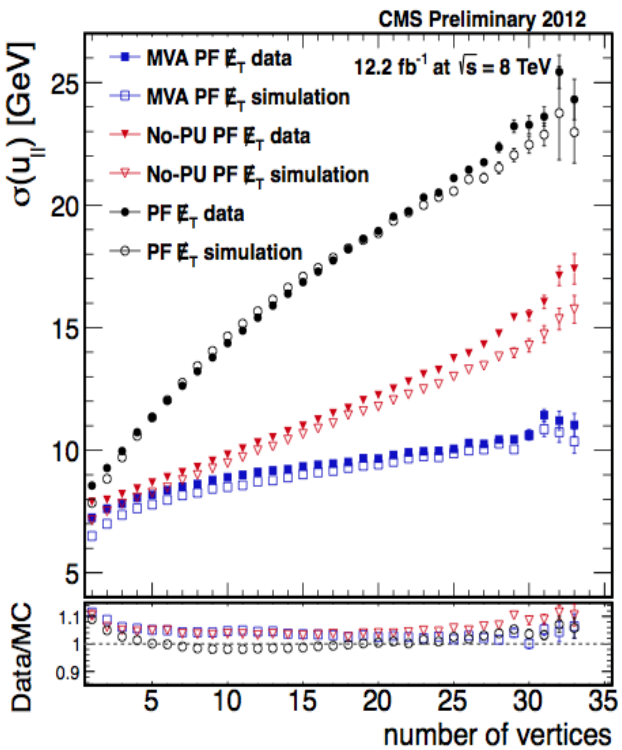
Feed them into a BDT regression: Correct Recoil

MVA *MET* Performance

- MVA *MET* reduces pileup contribution by 4
  - Maintains high response of other *MET*s
  - Small tails of *MET* are preserved
- Many ways to improve the peformance

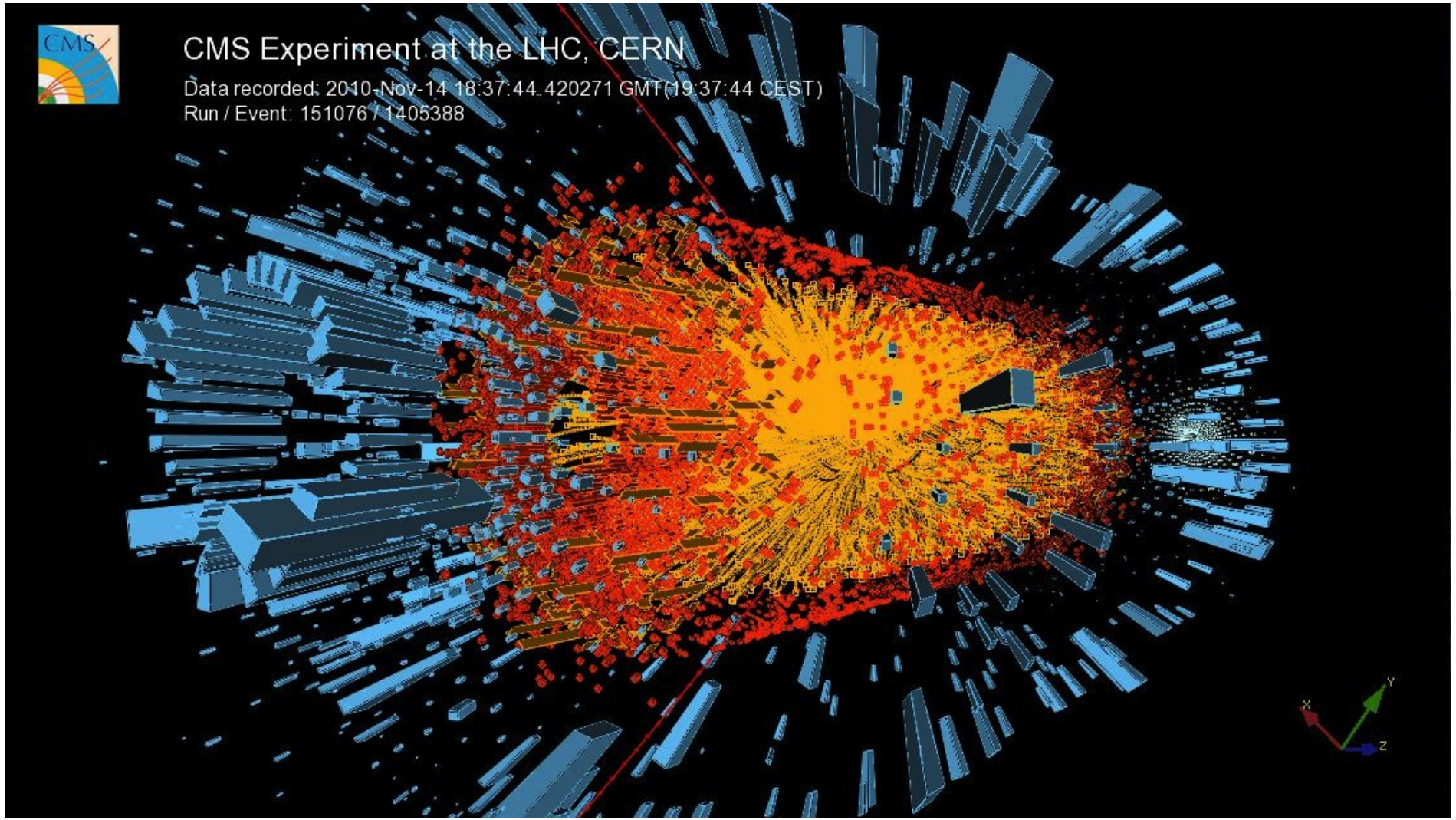






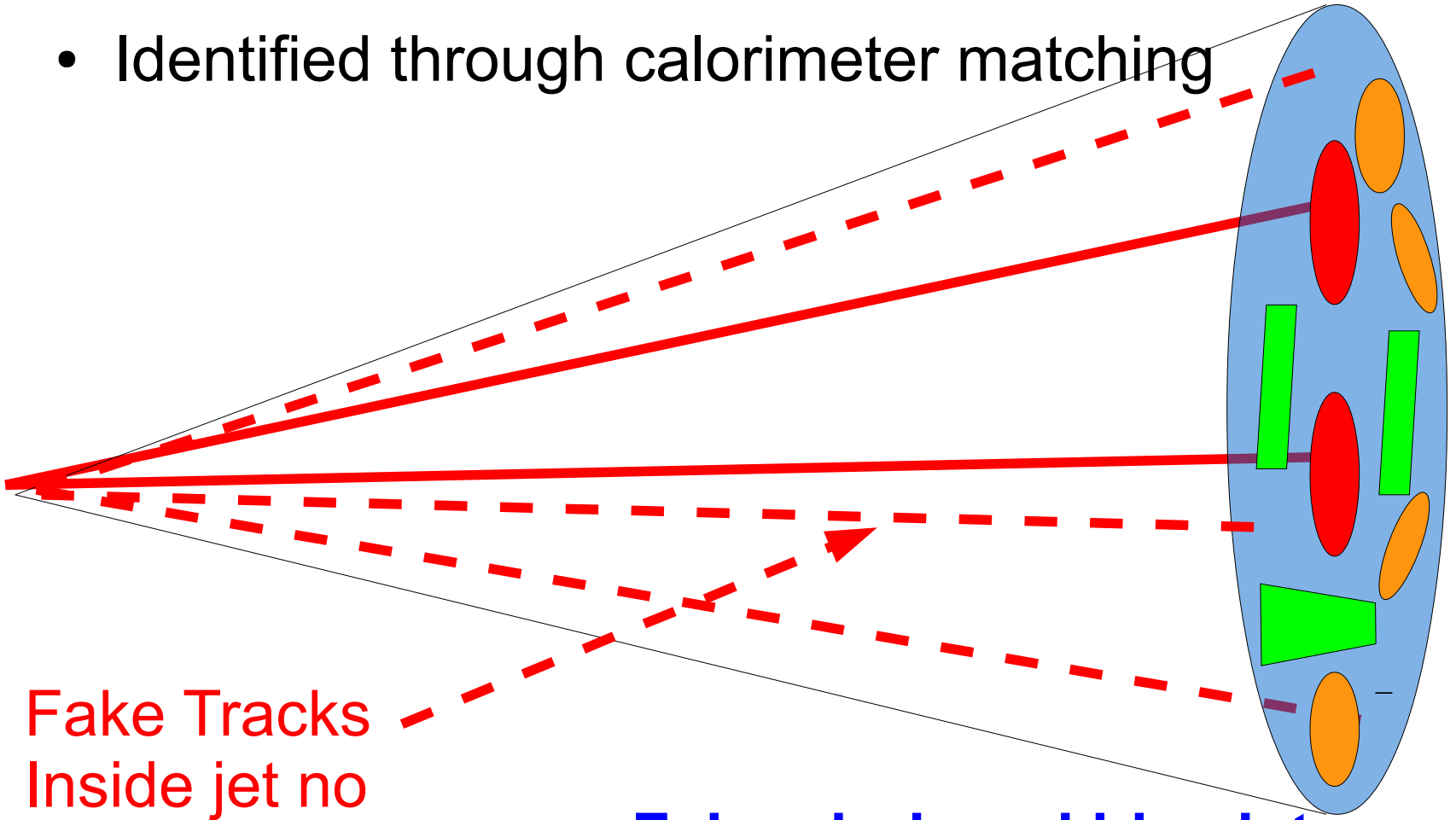
Going to the Extremes

- LHC already has a lot of data with heavy ion running
  - Particle Flow is successfully used in this environment



Advantage of Particle Flow

- Matching with calorimeters removes “fake” tracks
  - Fake tracks result from high number of silicon hits
    - Confusion track reconstruction leads to “fake” tracks
  - Identified through calorimeter matching

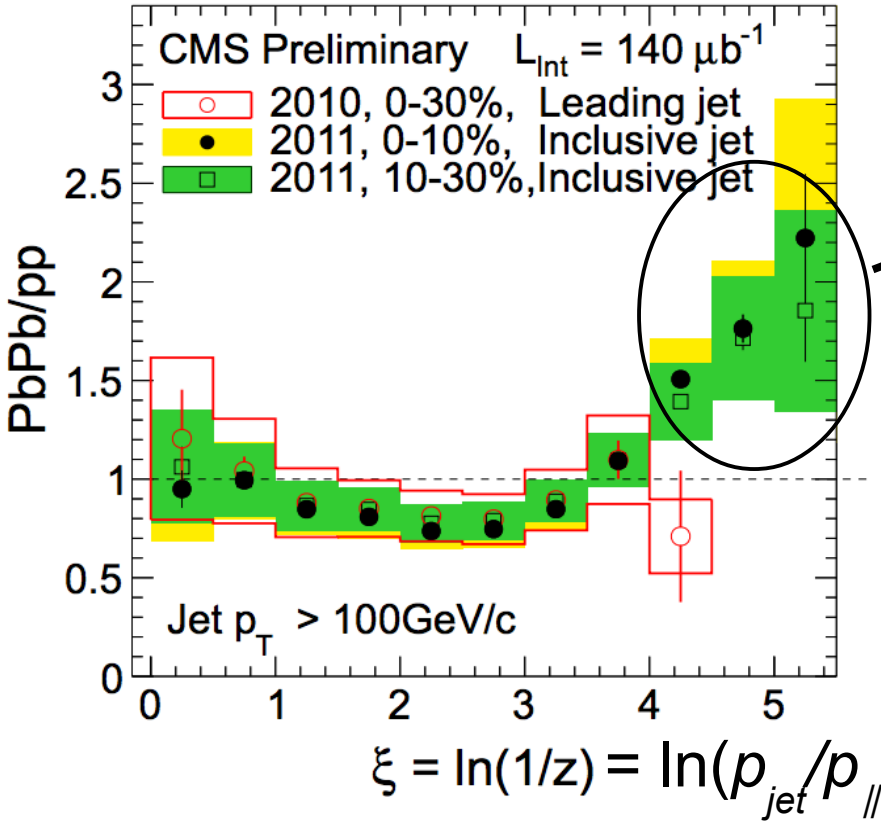


Fake Tracks Inside jet no calo deposit

Fakes induced bias jet p_T spectra

Precision in Heavy Ions

- Particle flow removes fragmentation bias in jets
  - Lack of PF(links) tracking gives dearth of low p_T deposits
  - PF minimizes jet shape biases (particularly at high p_T)
    - Enabling the low p_T charged hadrons to be clustered



Observed deviation in low p_T tracks

Results from quark gluon plasma

Conclusions

- Particle Flow enables advanced techniques
  - Impetus for a plethora of techniques
  - Allows for re-thinking of basic problems
- Algorithm performant at the frontier of LHC running
  - Used in identification of fundamental particles
  - Techniques involving extreme precision
  - Effective at mitigating effects of high pileup
  - Tested in the extreme heavy ion environment
- Essential tool for the future of LHC

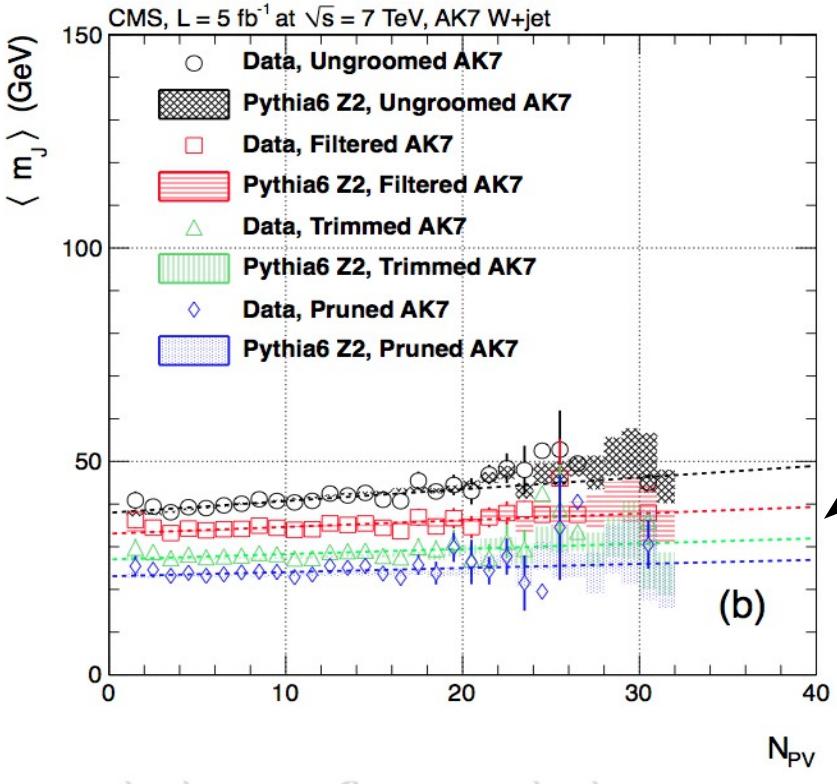
CHIEF

At the LHC Intensity will be crucial

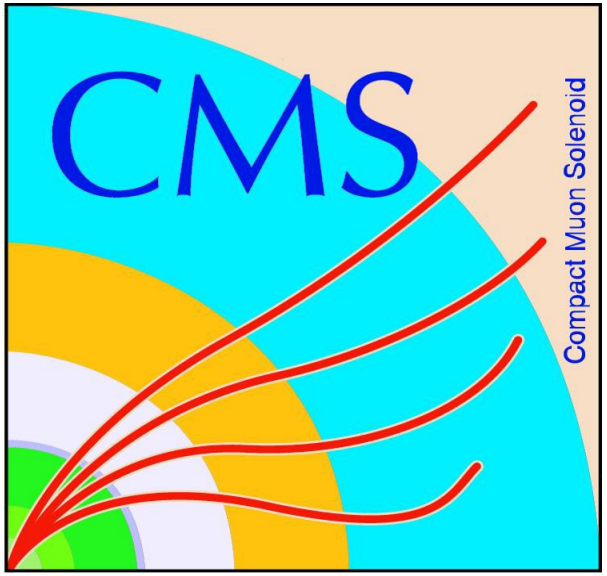
Particle Flow based algorithms have proven effective at the high intensity & Energy Fontier

Targeted Sub-Clustering

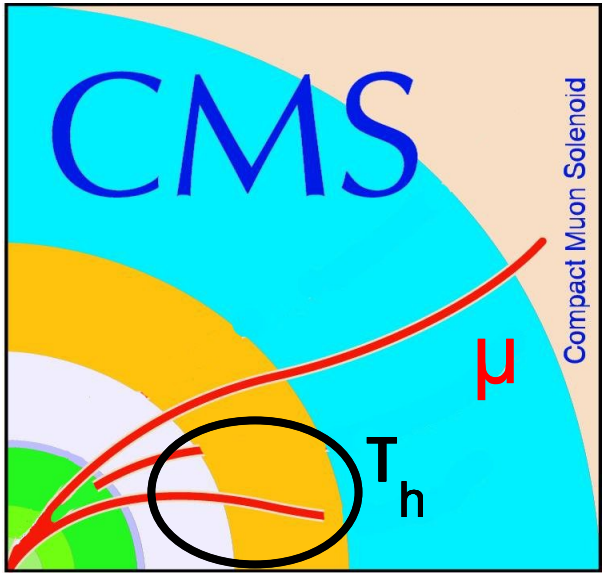
- Sub-clustering partially isolates the pileup
  - Sub-clusters from pileup are removed
    - Newest sub-clustering simple QCD splitting-likelihood
    - Algorithms known as jet grooming
  - Effectiveness on pileup is being understood



At each stage of grooming reduced slope vs pileup



Original CMS logo
(H→ZZ→4μ)



Logo on the Slide 1
(H→ττ→μτ)