JETS

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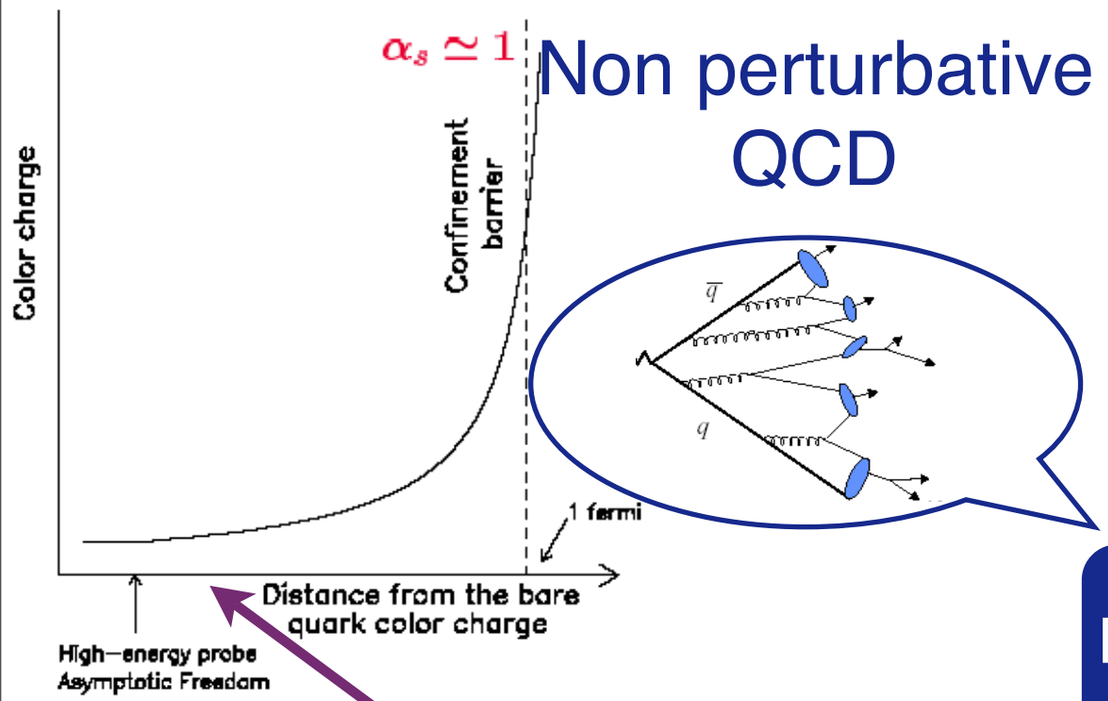
USCMS JTERM III

Outline

- Concepts
  - What is a Jet?
  - Jet Algorithms
  - Jet Types & Flavors
  - Jet Calibration
- Jet Groups @ CMS
- Practical Instructions for Beginners
- Performance
  - Jet Reconstruction Efficiency
  - Jet Resolution
  - Jet ID
- Links to Advanced Topics

What is a Jet?



Non perturbative QCD

Detector

Jet

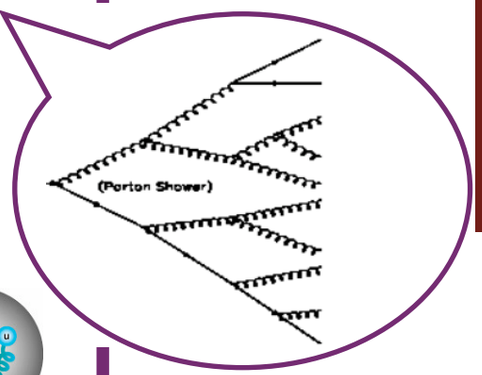
$\pi, K,$

Hadronization

Perturbative QCD

Parton showering

$q, \bar{q}, g$



Hard parton scattering (determined by matrix QCD element and proton PDF)

The Jets are the signature of partons, materialized as sprays of highly collimated hadrons.

Jet Algorithms

A Jet algorithm is a set of mathematical rules that reconstruct unambiguously the properties of a jet.

Basic Jet Algorithm Requirements

1. Simple to use in experimental analyses and theoretical calculations.
2. Collinear safe.
   The output of the jet algorithm remains the same if the energy of a particle is distributed among two collinear particles.
3. Infrared safe.
   The output of the jet algorithm is stable against addition of soft particles.
4. Works in the presence of pile-up and underlying event contamination.

Jet Algorithm Types

1. Fixed Cone Algorithms.
   The jet is defined as a cone (with fixed radius in η-ϕ) in the direction of the dominant energy flow.
2. Successive Recombination Algorithms (KT).
   The construction of the jet is based on the angular coherence of its constituents.

The two types of jet algorithms are complementary sensitive to different classes of non perturbative effects.

Jet Flavors

Official Jet Algorithms @ CMS

1. Seedless Cone (SISCone)

Fixed size cone of radius R=0.5, 0.7.
Infrared and collinear safe. $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

2. KT

Successive recombination with resolution parameter D=0.4, 0.6. Infrared and collinear safe. $D = \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$

3. Iterative Cone (ICone)

Fixed size cone with radius R=0.5.
NOT Infrared and collinear safe but fast!!! Used by HLT.

The jet algorithms take as input a set of 4-vectors:

1. GenJets

Stable simulated particles (after hadronization and before interaction with the detector)

2. CaloJets

Calorimeter energy depositions

3. PFJets

Particle Flow objects

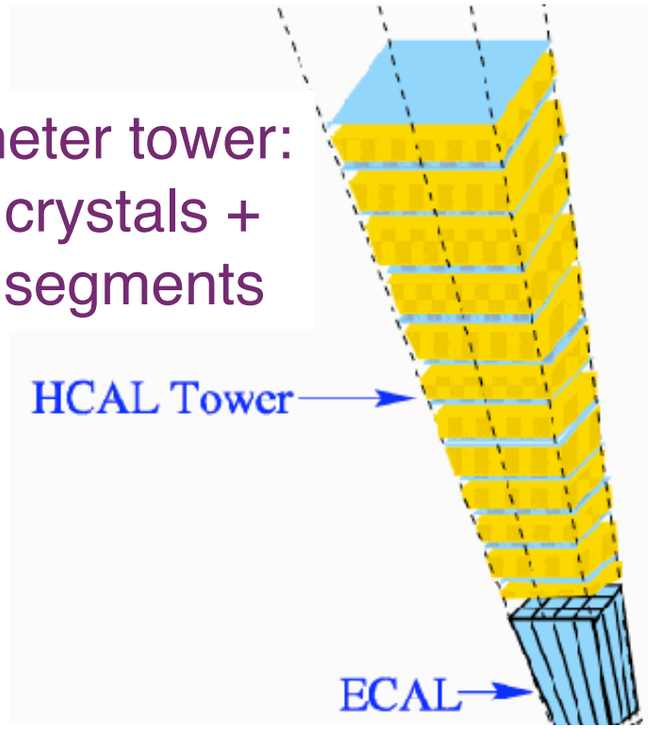
4. TrackJets

Tracks

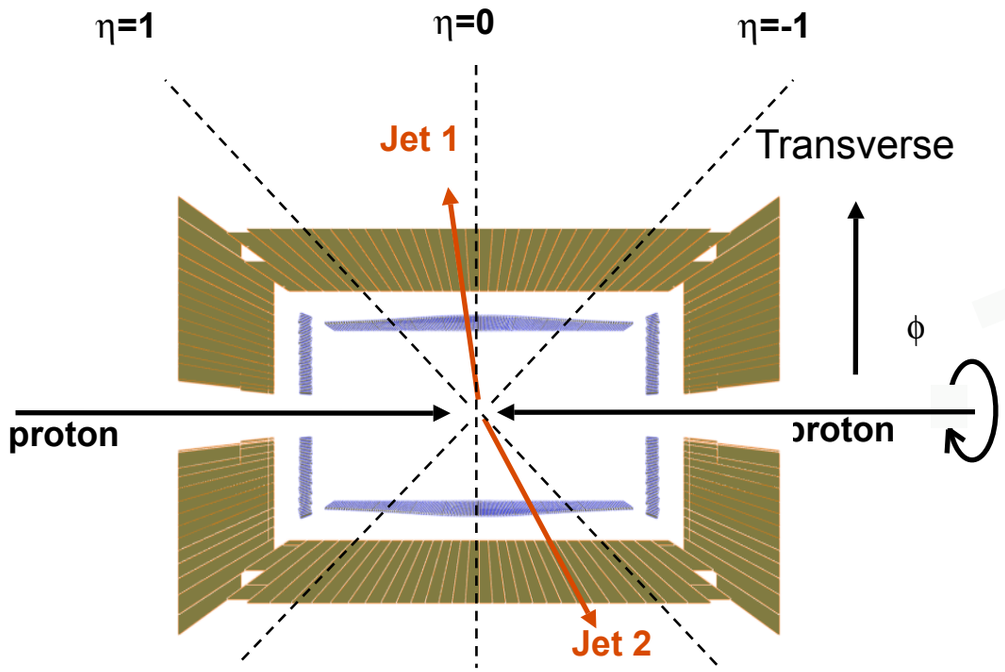
Particles, CaloTowers, PF, Tracks → **Jet Algorithm** → GenJets, CaloJets, PFJets, TrackJets

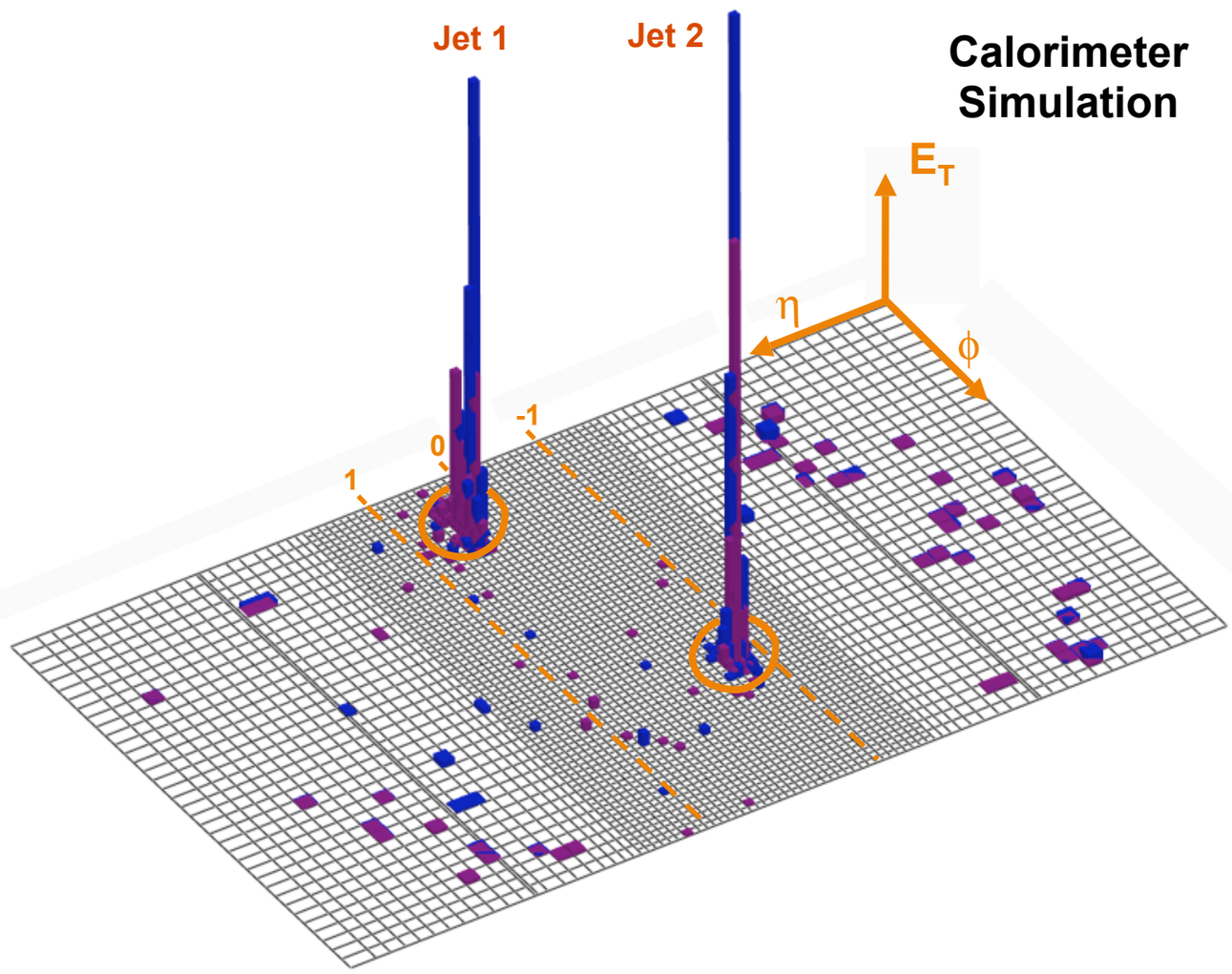
Calorimeter Jets

Calorimeter tower:
ECAL crystals +
HCAL segments

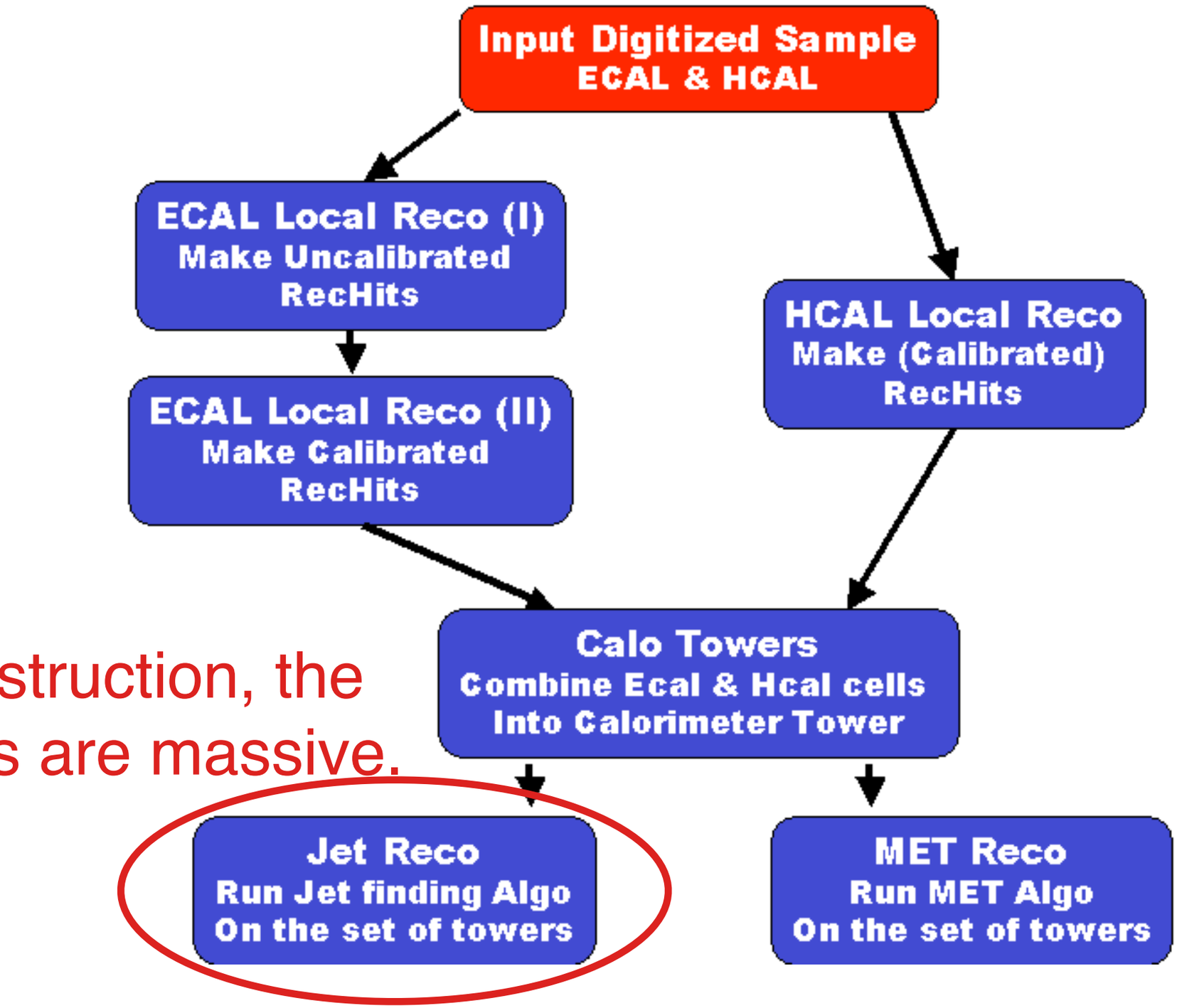


A calorimeter jet is the output of the jet finding algorithm when applied to the CaloTowers.





Jet Reco Workflow



By construction, the CMS jets are massive.

Accessing Jets in CMSSW

https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#JetAna

Example code: RecoJets/JetAnalyzers/src/JetValidation.cc

```
#include "DataFormats/JetReco/interface/CaloJetCollection.h"
#include "DataFormats/JetReco/interface/CaloJet.h"
.....
calAlgo = cfg.getParameter<string> ("calAlgo");
.....
Handle<CaloJetCollection> caljets;
event.getByLabel(calAlgo,caljets);
CaloJetCollection::const_iterator i_jet;
for(i_jet = caljets->begin(); i_jet != caljets->end(); ++i_jet)
 {
  e = i_jet->energy();
  pt = i_jet->pt();
  phi = i_jet->phi();
  eta = i_jet->eta();
  .....
  emEB = i_jet->emEnergyInEB();
  hadHB = i_jet->hadEnergyInHB();
  .....
 }
```

Configurable jet collection name

Handle the jet collection

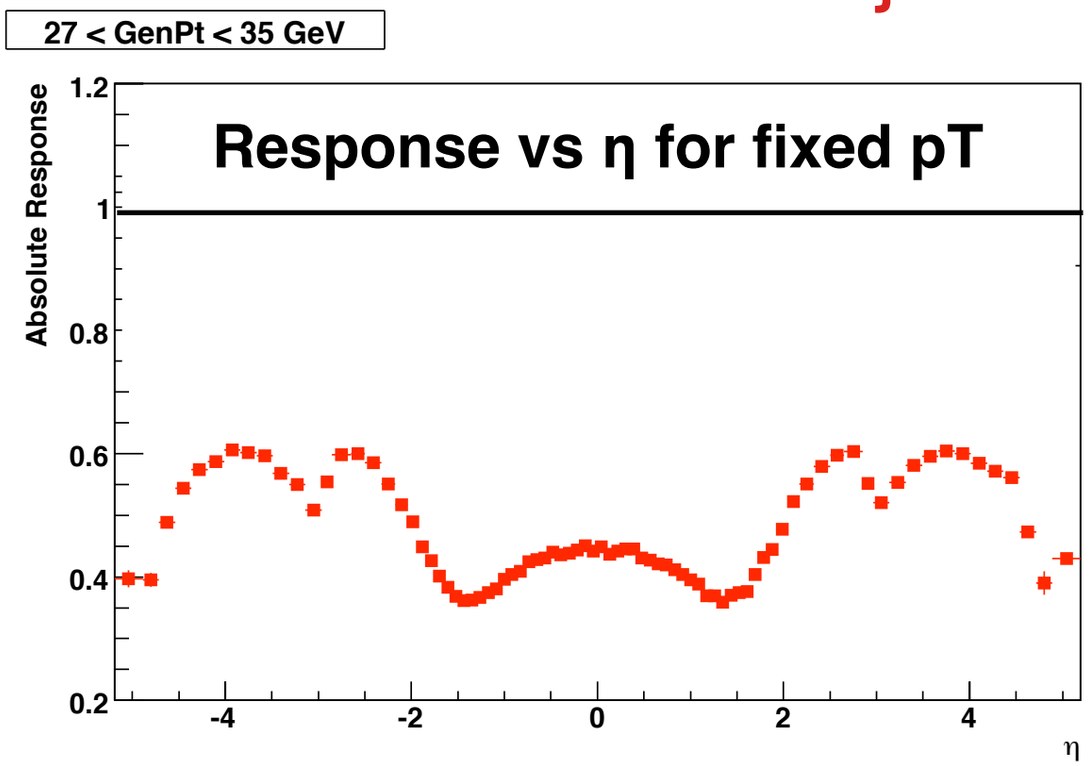
Define an iterator for the jet collection

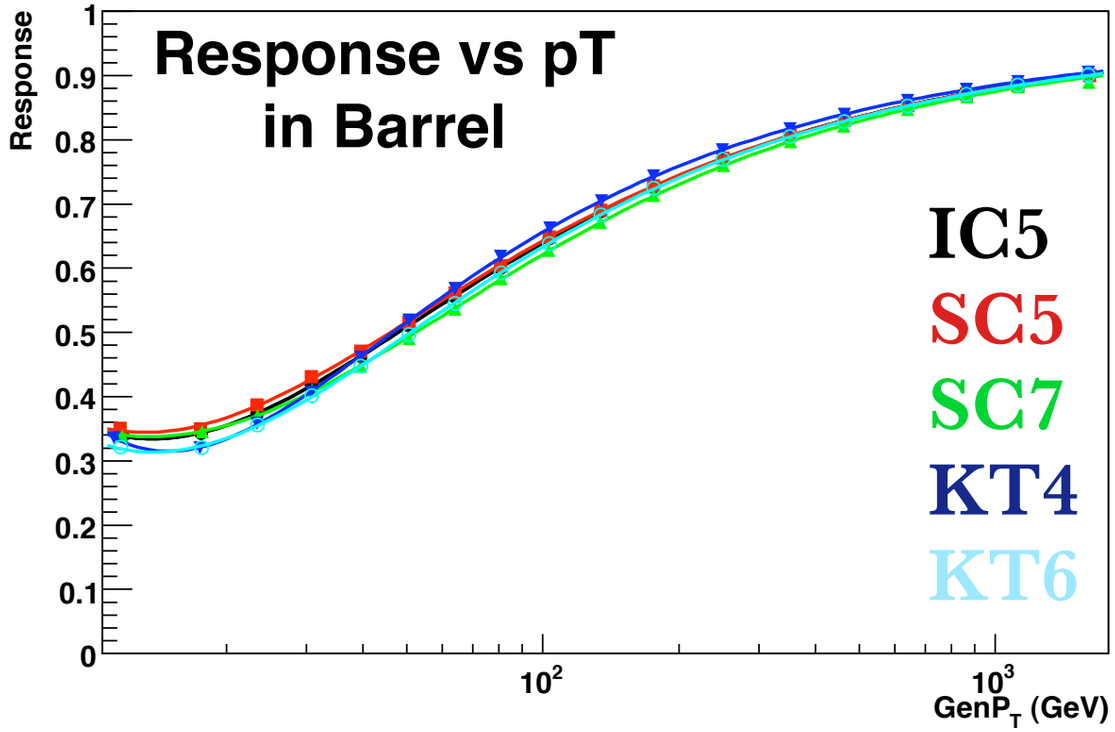
BasicJet quantities

CaloJet specific quantities

Jet Energy Response

The CMS calorimeter is not linear and non uniform.
The measured jet energy needs to be corrected.





The response shape vs η is the convolution of the energy dependence of calorimetry, the differences in construction of the calorimeter elements and the material budget in front of them.

Jet Response = <CaloJet pT/GenJet pT>

Jet Calibration (I)

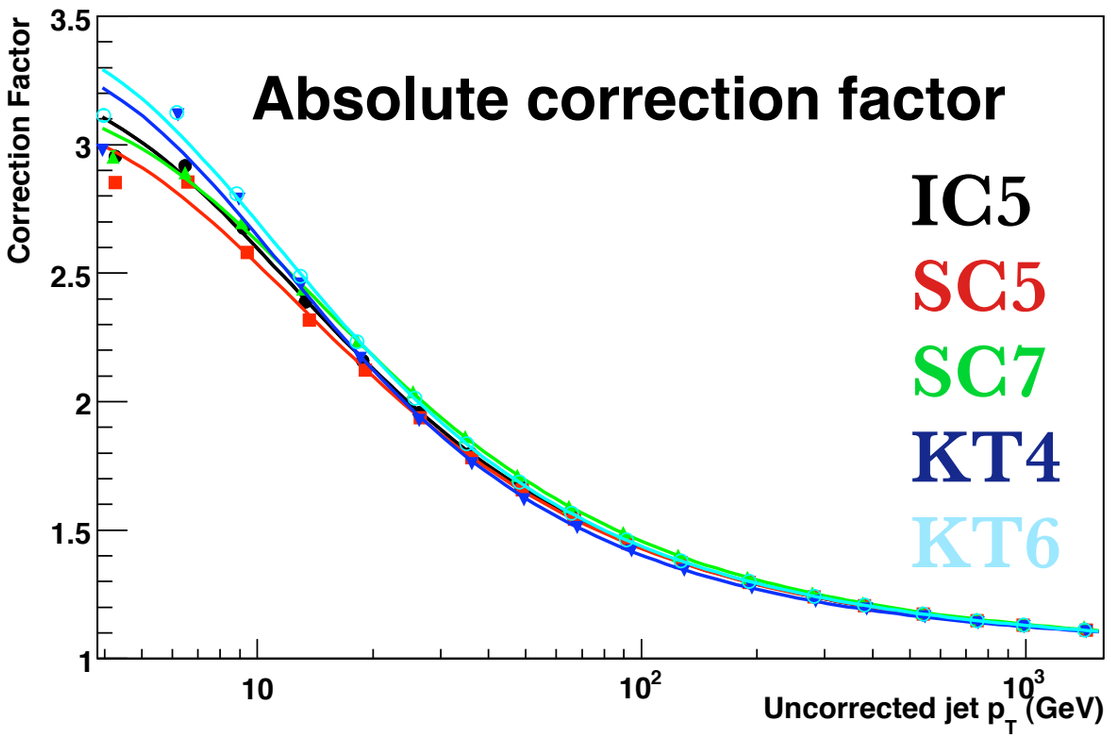
Required → Optional

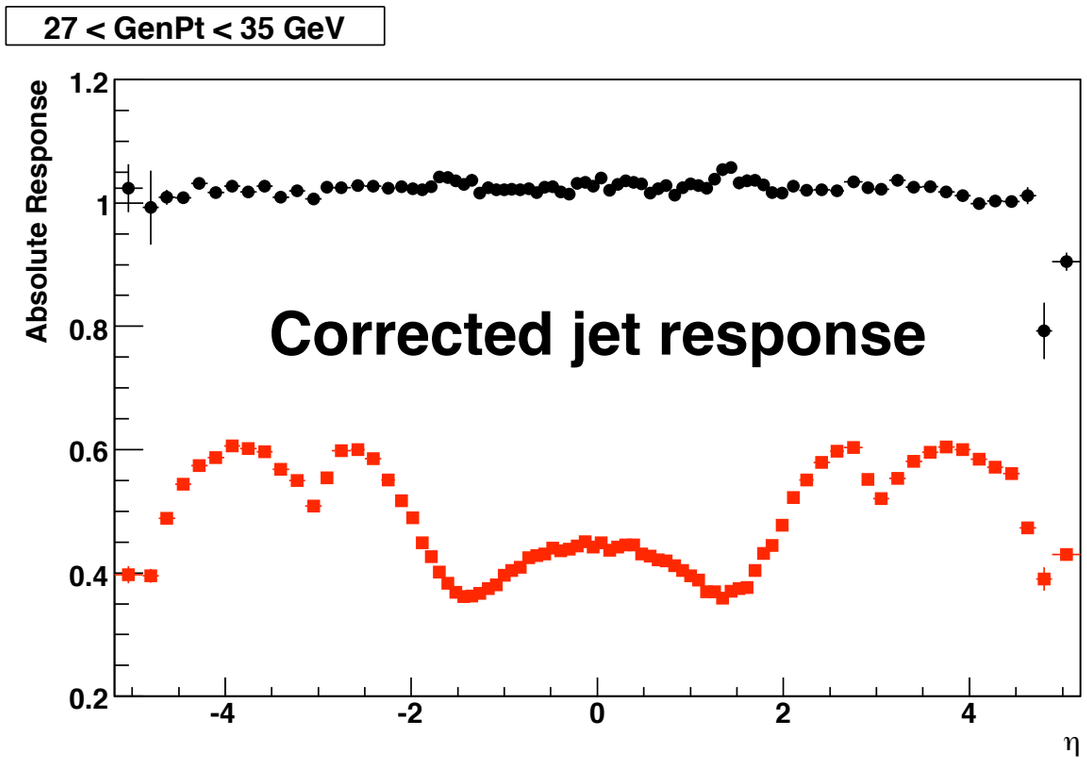
Reconstructed Jet	L1 Offset	L2 Rel: η	L3 Abs: pt	L4 EMF	L5 Flavor	L6 UE	L7 Parton	Calibrated Jet

The jet calibration is done in a multilevel approach with fixed order.

(better understanding of systematics, employment of data driven techniques, etc)

The L1 offset correction is currently part of the L3 correction.





Jet Calibration (II)

1. The jet correction is a scalar factor, depending on the measured jet quantities, that scales the raw jet 4-vector.
2. The "jet correction service" is the software that delivers the correction factor.
3. The "correction module" delivers the corrected, re-ordered, jet collection.
4. The currently available jet corrections are derived from MC truth.

Example configuration: RecoJets/JetAnalyzers/test/runL2L3JetCorrectionExample_cfg.py

```
.....
process.load("JetMETCorrections.Configuration.L2L3Corrections_Summer08_cff")
process.prefer("L2L3JetCorrectorIC5Calo")
required by CMSSW but IRRELEVANT to the actual corrections applied. ANY
correction service defined in L2L3Corrections_Summer08_cff can be used.
.....
process.corrected = cms.EDAnalyzer("CaloJetPlotsExample",
    JetAlgorithm  = cms.string('L2L3CorJetIC5Calo'),
    HistoFileName = cms.string('CorJetHisto.root'),
    NJets         = cms.int32(2)
)
process.p = cms.Path(process.L2L3CorJetIC5Calo * process.corrected)
```

Step 1: Include the file defining the default jet correction services and modules

Step 2: Use the corrected jet collection in your EDAnalyzer

Step 3: Include the correction module in the path BEFORE your EDAnalyzer

Jet Calibration (III)

How can I learn more about jet energy corrections?

https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#JetCorrections

In the above TWiki you can find examples for applying the optional corrections on top of the default L2+L3.

Where can I find details on the derivation of jet corrections?

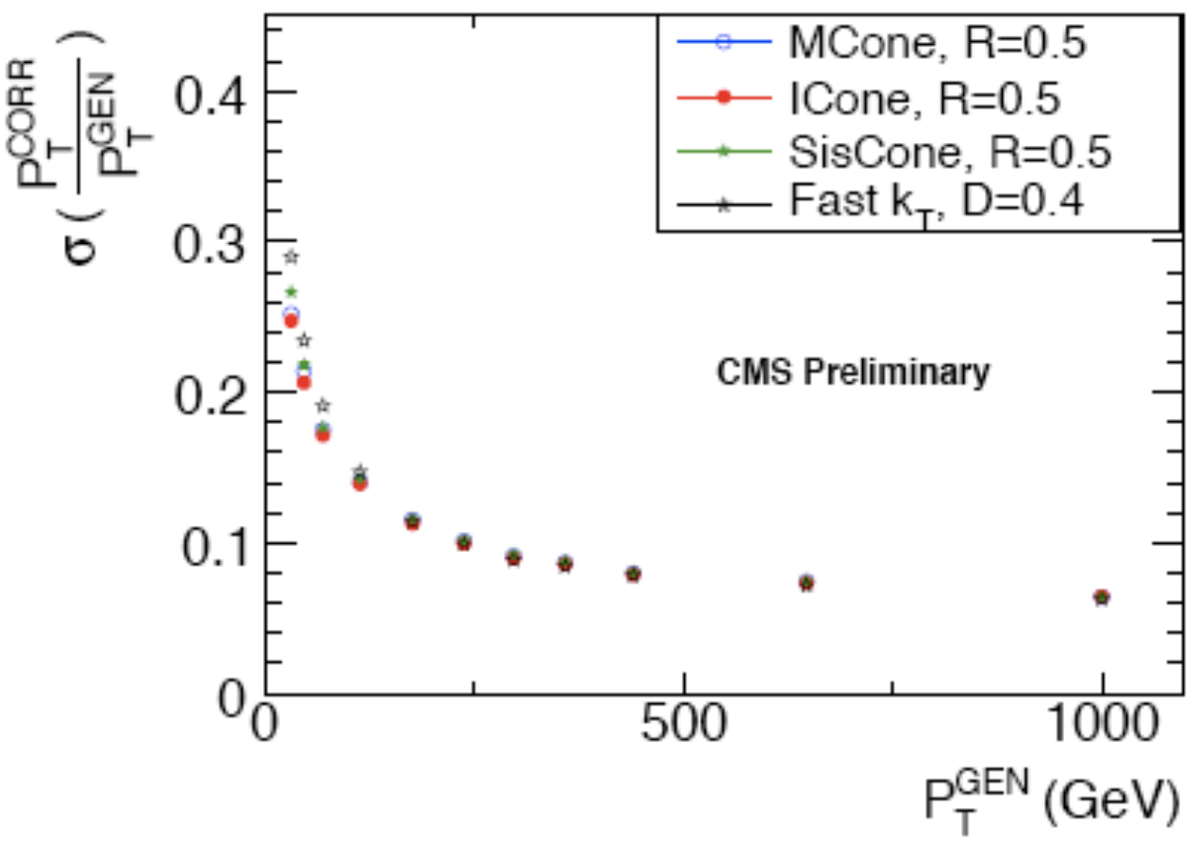
- CMS AN-2007/055 (“Plans for Jet Energy Corrections at CMS”)
- CMS AN-2008/003 (“MC Truth L2 & L3 Factorized Jet Corrections at CMS”)
- CMS AN-2008/031 (“Determination of the Relative Jet Energy Scale at CMS from Dijet Balance”)
- CMS AN-2008/115 (“Data-driven calibration of the absolute jet energy scale with Z->mu(+)mu(-) jet events at CMS”)
- CMS AN-2008/084 (“Parton Jet Correction”)

IMPORTANT: Don’t hesitate to ask the experts!!!!!

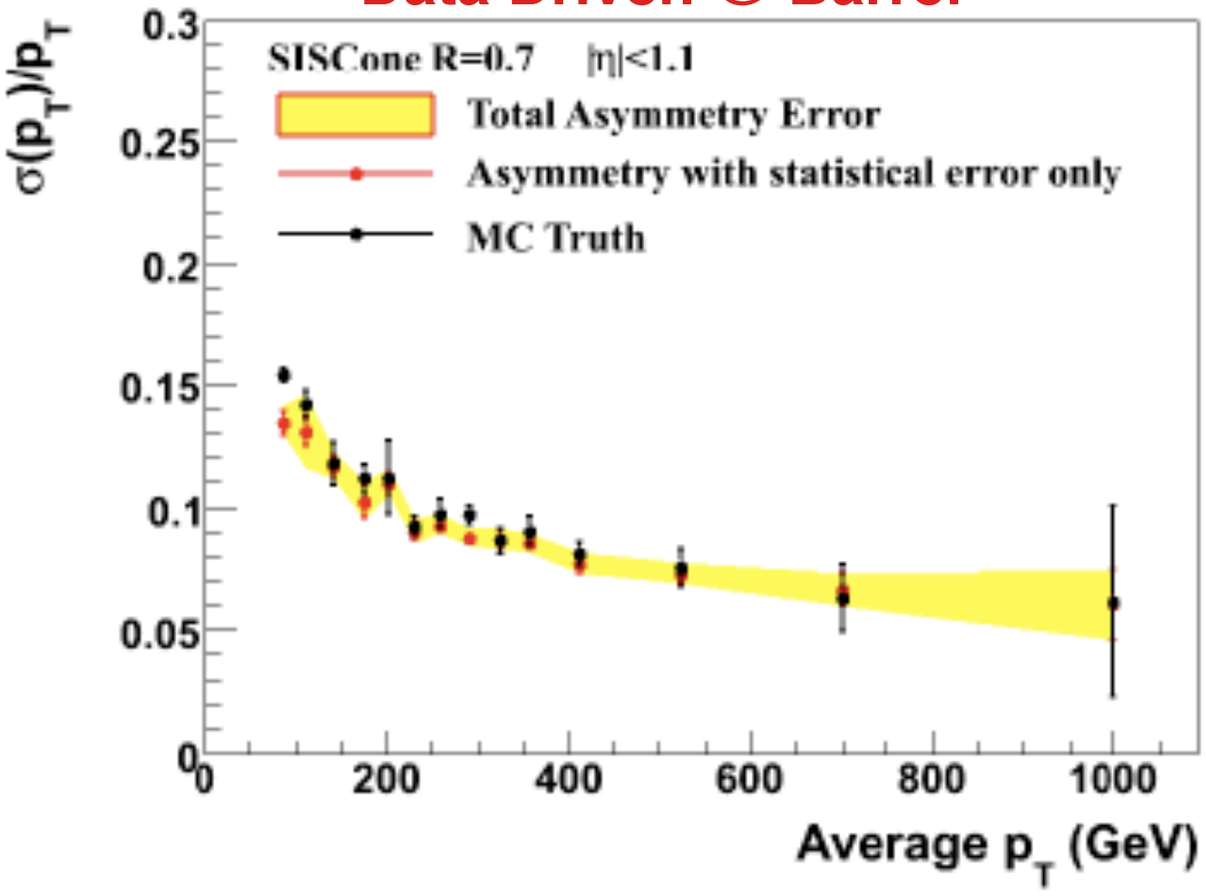
Jet Energy Resolution

CMS AN-2008/001 ("Performance of Jet Algorithms in CMS")

MC truth @ Barrel



Data Driven @ Barrel

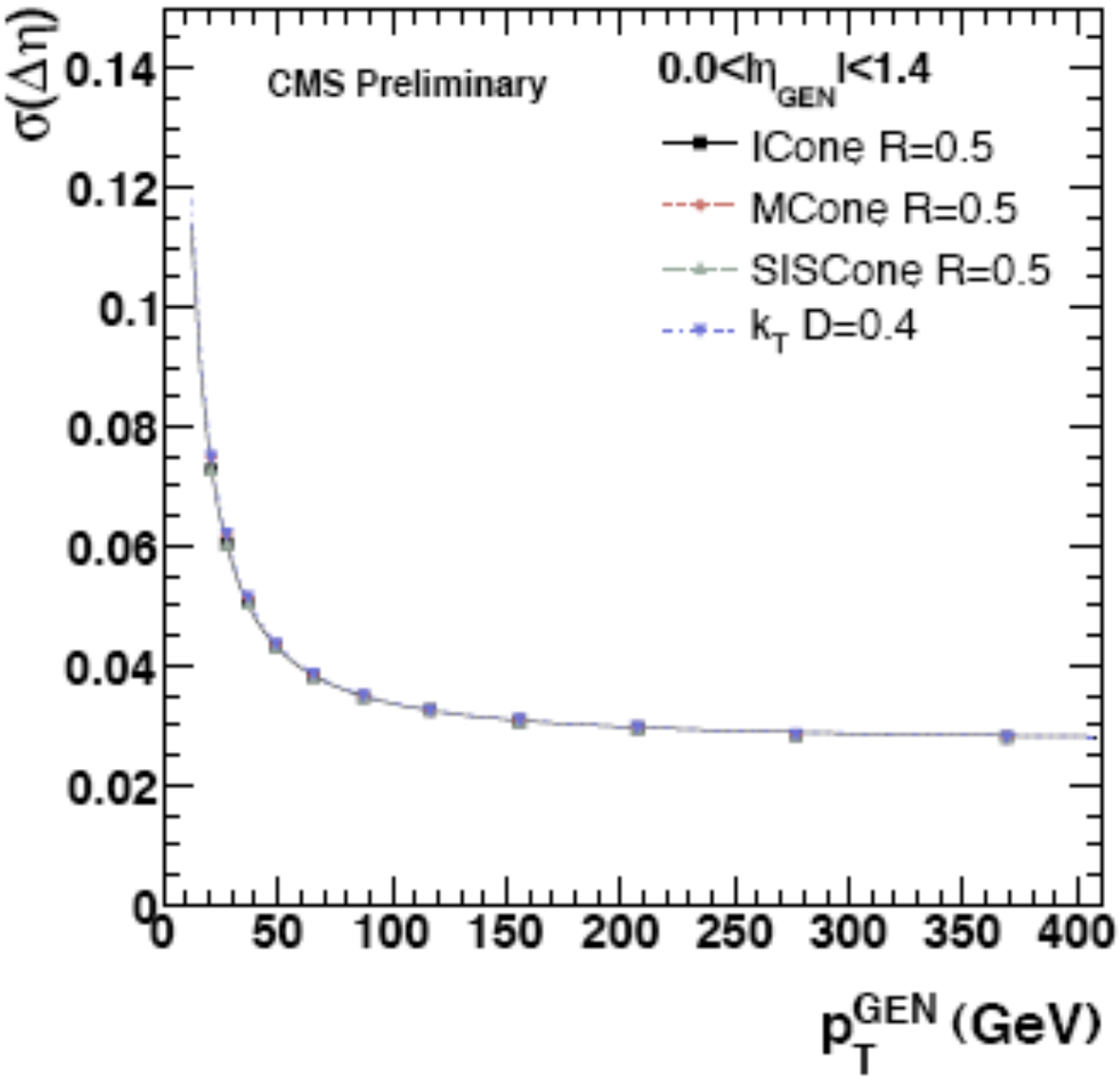


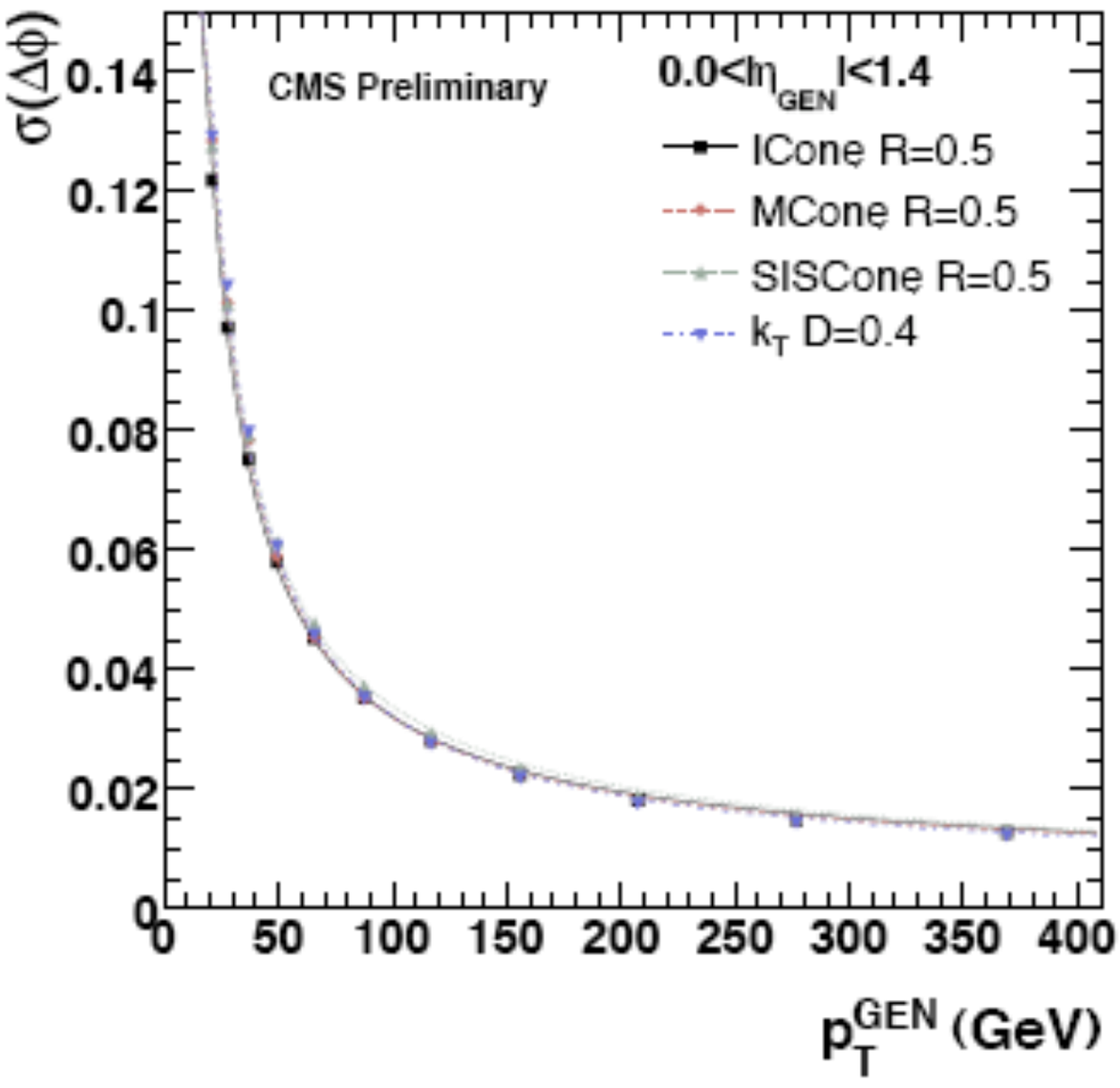
When data will be available, jet energy resolution will be derived utilizing the Asymmetry method.

A new AN NOTE is expected soon!!!

Jet Angular Resolution

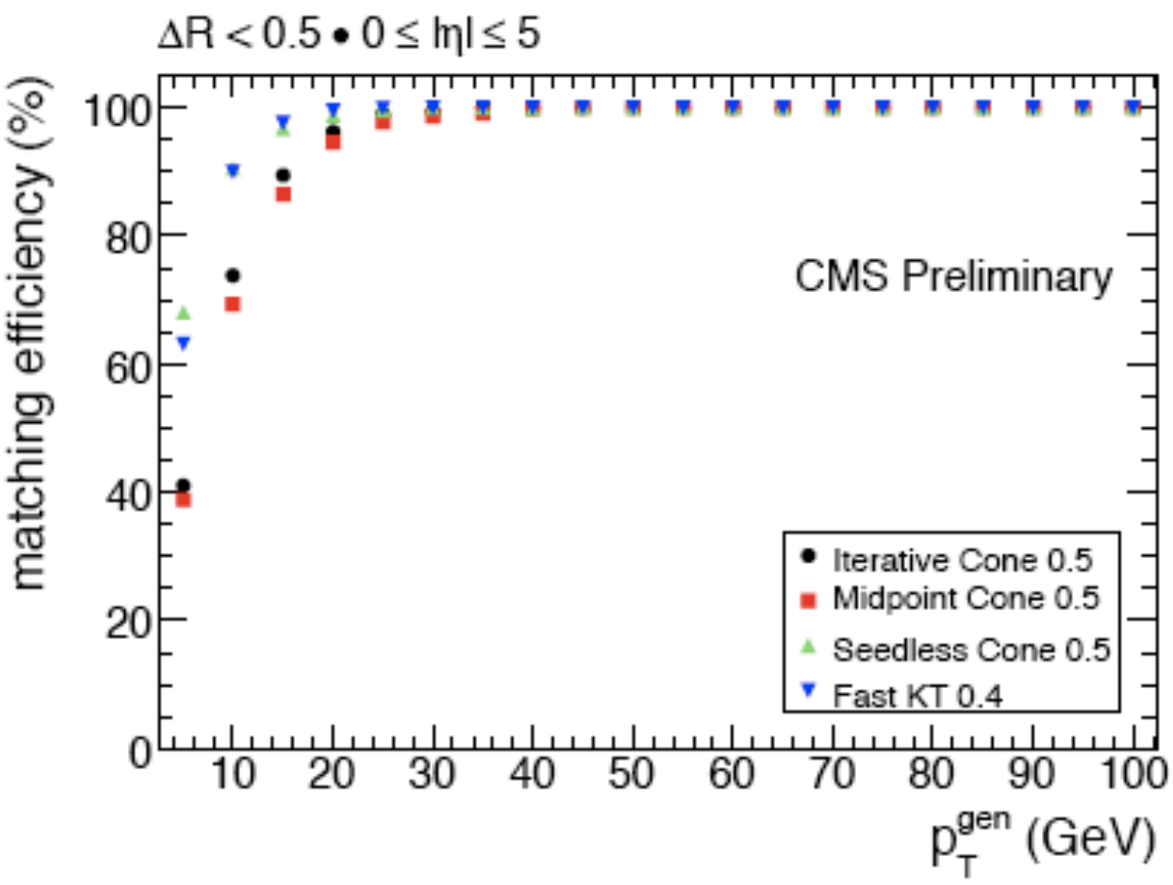
CMS AN-2008/001 ("Performance of Jet Algorithms in CMS")

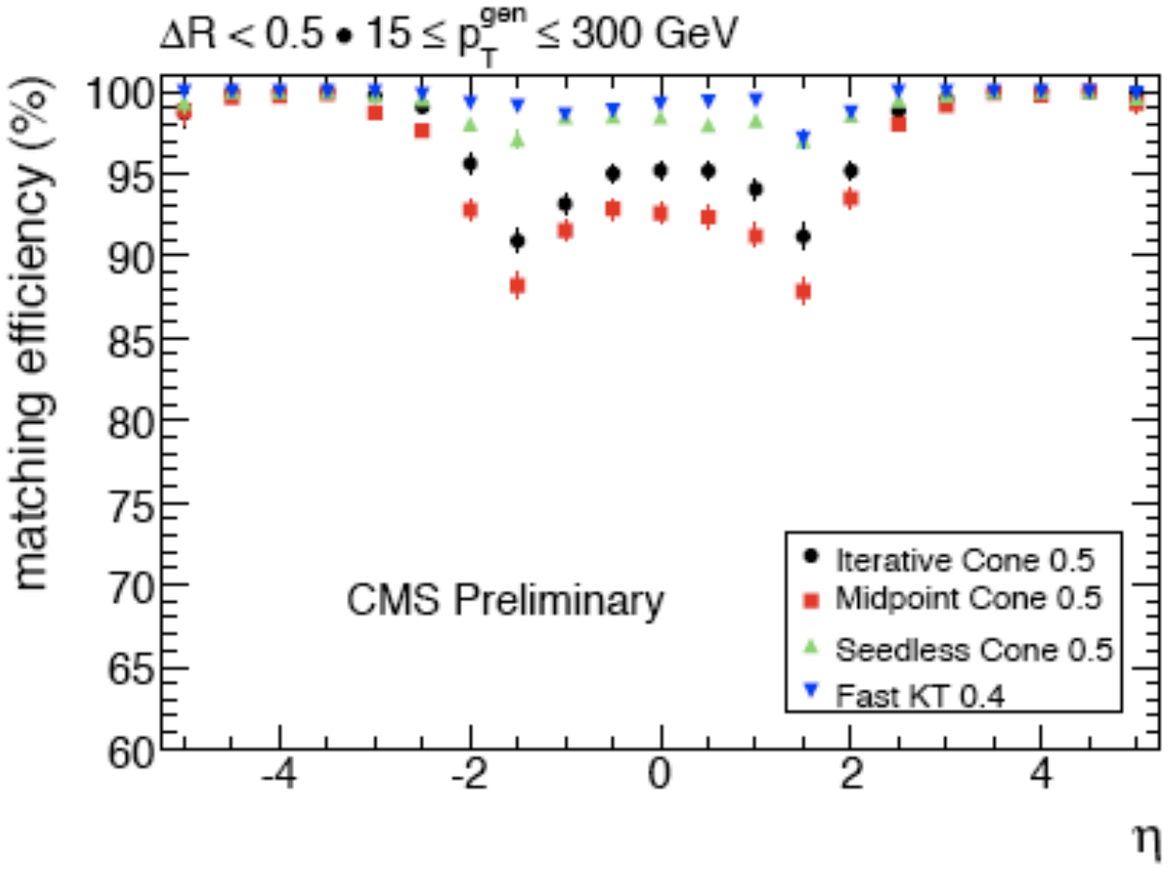




Jet Reco Efficiency

CMS AN-2008/001 ("Performance of Jet Algorithms in CMS")





A new AN NOTE is expected soon!!!

JetResponseAnalyzer

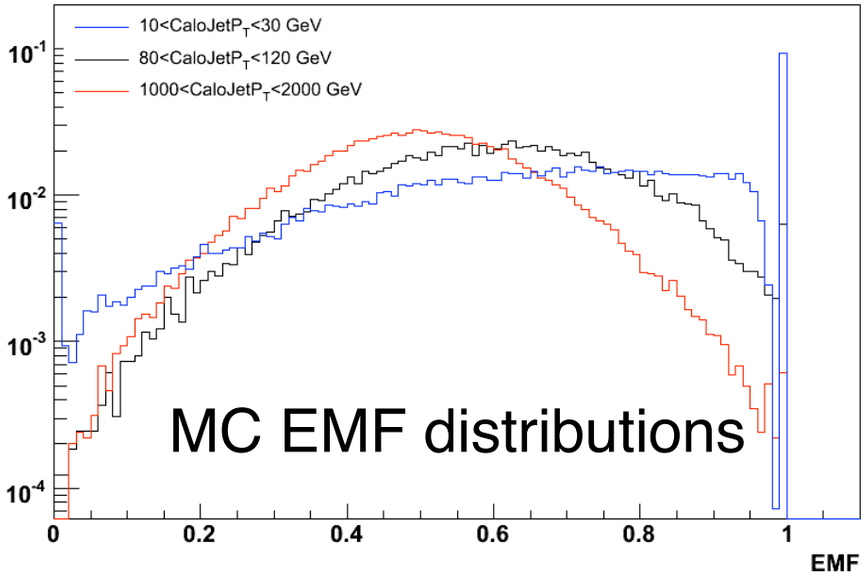
A multi-purpose tool

https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideJetResponseAnalyzer

1. CMSSW framework analyzer module,
2. records the necessary information to perform response and/or resolution measurements,
3. can be used for MC or real data analysis,
4. fully configurable,
5. “official” tool, debugged by the experts,
6. can handle all the possible jet definitions (O(100)).

Jet ID

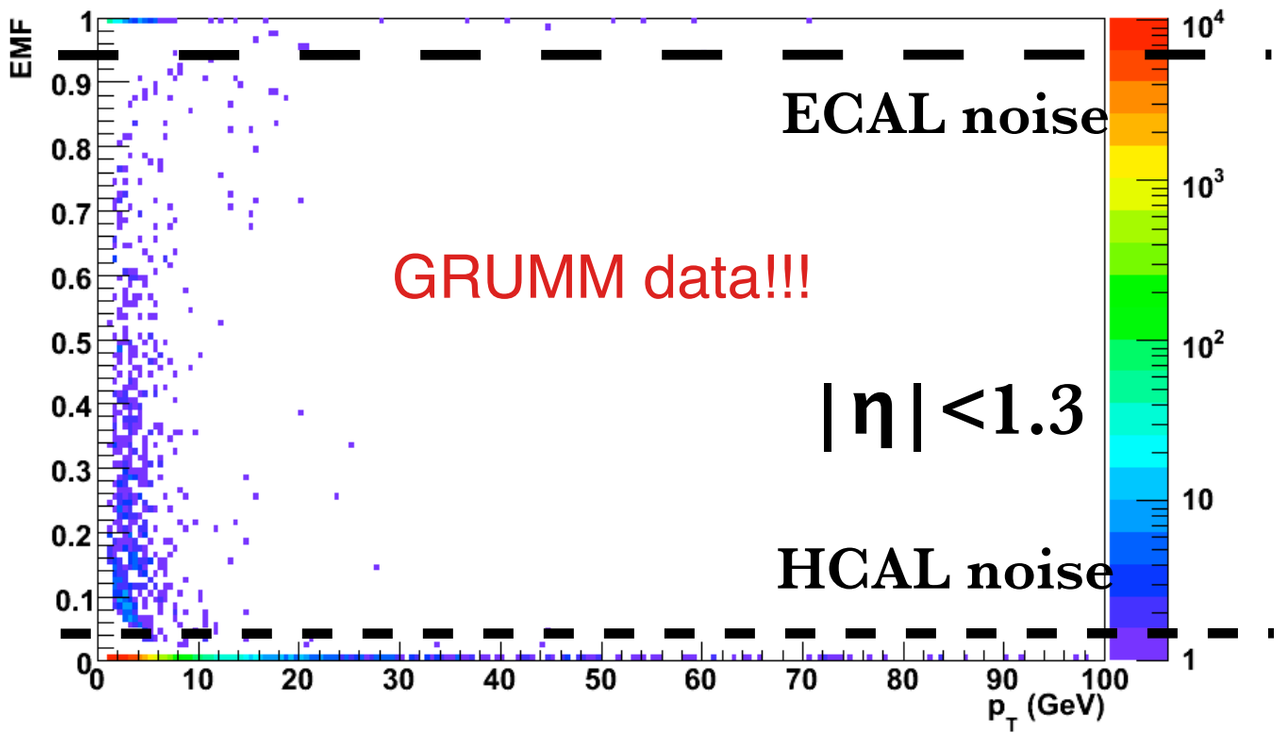
Normalized EMF distribution

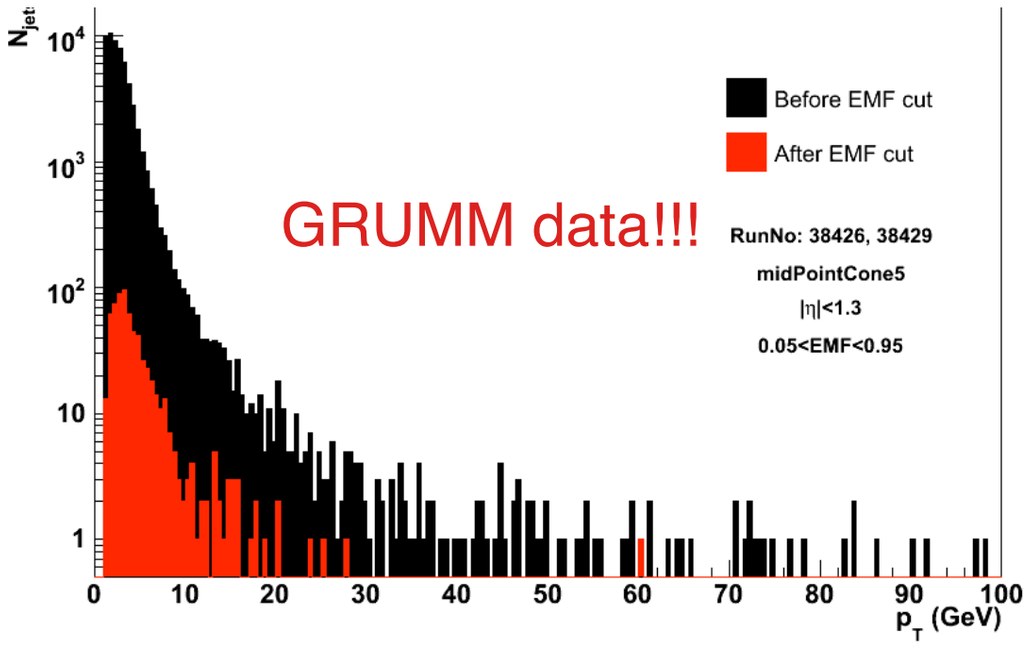


1. EMF is a key jet property for jet ID. The exact cut values are being studied.
2. Other jet ID quantity could be the number of good tracks associated to a jet.
3. The study is currently repeated using the CRAFT data.
4. Data driven techniques for the measurement of the jet ID efficiency are under investigation.

Example EMF cut for noise suppression: 0.05 < EMF < 0.95. These values are not necessarily optimal for jet ID.

EMF vs p_T





Links to advanced topics

Not enough time to be covered here!!!!

1. Jet Reconstruction
https://twiki.cern.ch/twiki/bin/view/CMSWorkBook210JetAnalysis#JetReco
2. Jet Energy Corrections “on the fly”
https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#CorrOnTheFly
3. Optional Jet Energy Corrections
https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#L4EMFCorr
https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#L5FlavorCorr
https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#L7PartonCorr
4. Jet Energy Corrections using the Jet+Track algorithm
https://twiki.cern.ch/twiki/bin/view/CMS/WorkBook210JetAnalysis#JetPlusTrack

Jet groups @ CMS

People in
RED: **USCMS**

JetMET POG

V.D.Elvira, P.Schleper

Meets on alternate Mon
(16:30-18:30 GVA)

JetAlgorithms

M.Zielinski
P.Schieferdecker

Meets on alternate Thu
(17:30-18:30 GVA)

JetEnergyCorrections

R.Harris
I.Iashvili

Meets on alternate Fri
(17:30-18:30 GVA)

JetPlusTracks

F.Chlebana
A.Nikitenko

Meets on alternate Thu
(16:30-17:30 GVA)

Experts

- S.Rappoccio: jet software, PAT
- A.Oehler: jet software
- A.Anastassov: jet software
- L.Apanasevich: jet triggers
- S.Sharma: jet plus tracks
- K.Kousouris: jet energy corrections

Summary

✓ Jets will be the most frequent objects at CMS!!! We need to understand their performance as early as possible.

✓ The baseline jet object at CMS is the calorimeter jet (CaloJet). Other types of jets are also investigated, either to improve the reconstruction efficiency (TrackJets) or the jet energy response and resolution (PFJets).

✓ The default jet calibration is applied in multiple, fixed order steps and corrects the measured jet energy to the particle level. The “jet plus track” algorithm is an alternative way to calibrate jets which improves the jet energy resolution.

✓ There exist advanced documentation on jets and a full set of examples.

✓ Despite the advanced understanding of jets at CMS, help is needed in EVERY corner of the “jet phase space”!!!! Contact the group leaders to point you at them!!!

LPC is full of highly responsive jet experts!!!!
Take the time to speak to them!!!!