Fermilab
UIC University of Illinois at Chicago

"Improving Jets and MET in CMS"

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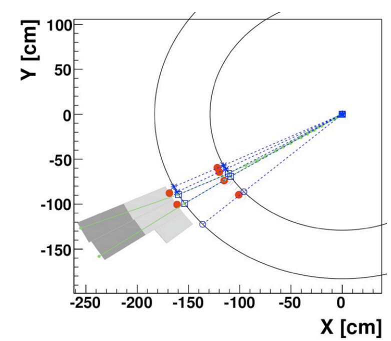
& University of Illinois at Chicago

CMS

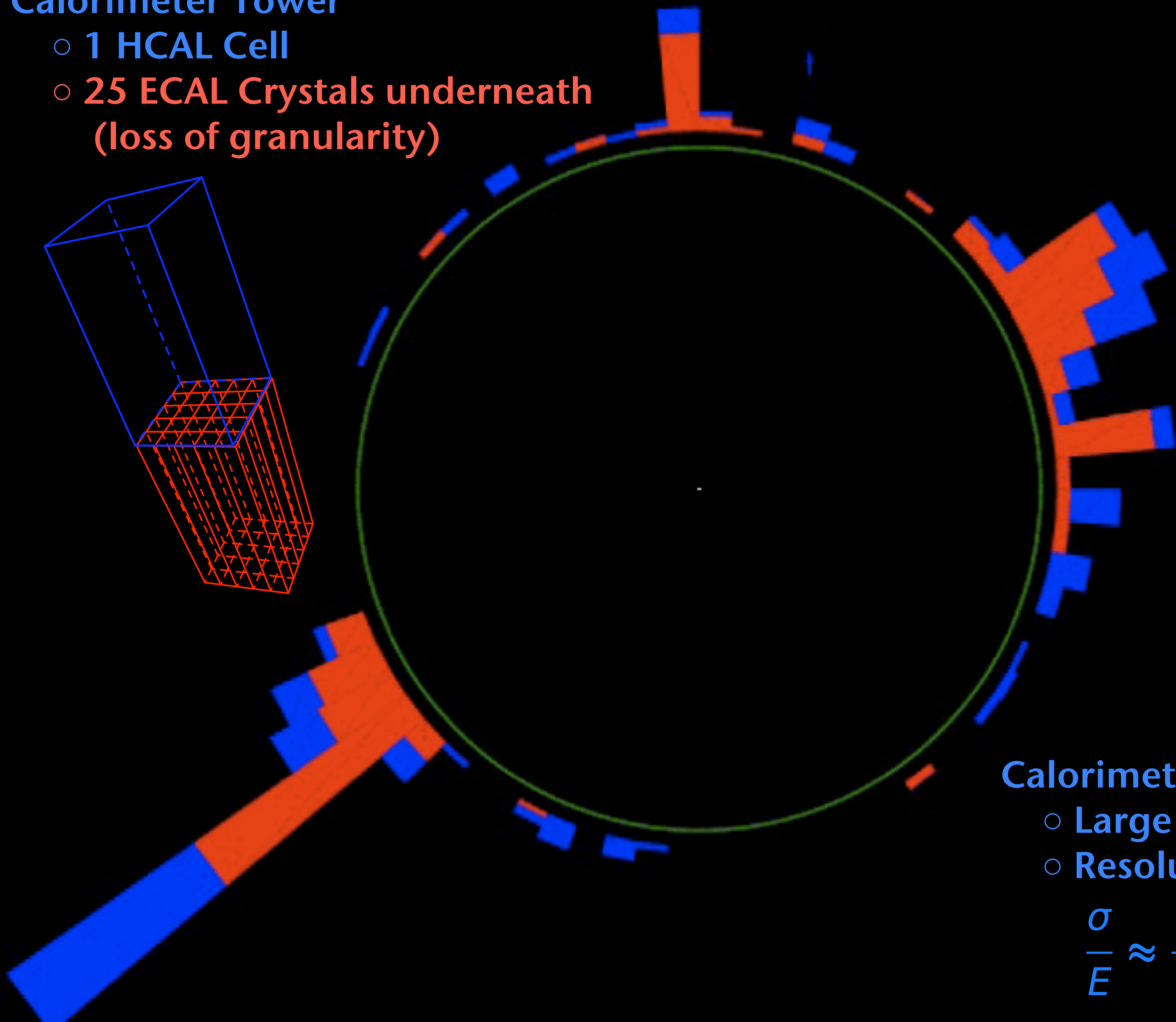


J-Term IV, CERN
3 August, 2009

- **Why? How?**
- ***A priori*** **use of tracks and calorimeter "Particle Flow"**
- ***A posteriori*** **corrections to calorimeter using tracks "JPT" & "tcMET"**

Calorimeter Tower

- 1 HCAL Cell
- 25 ECAL Crystals underneath (loss of granularity)



Calorimeter Jets

- Large Jet E Corr.
- Resolution HCAL

$$\frac{\sigma}{E} \approx \frac{100\%}{\sqrt{E}}$$

Calorimeter Tower

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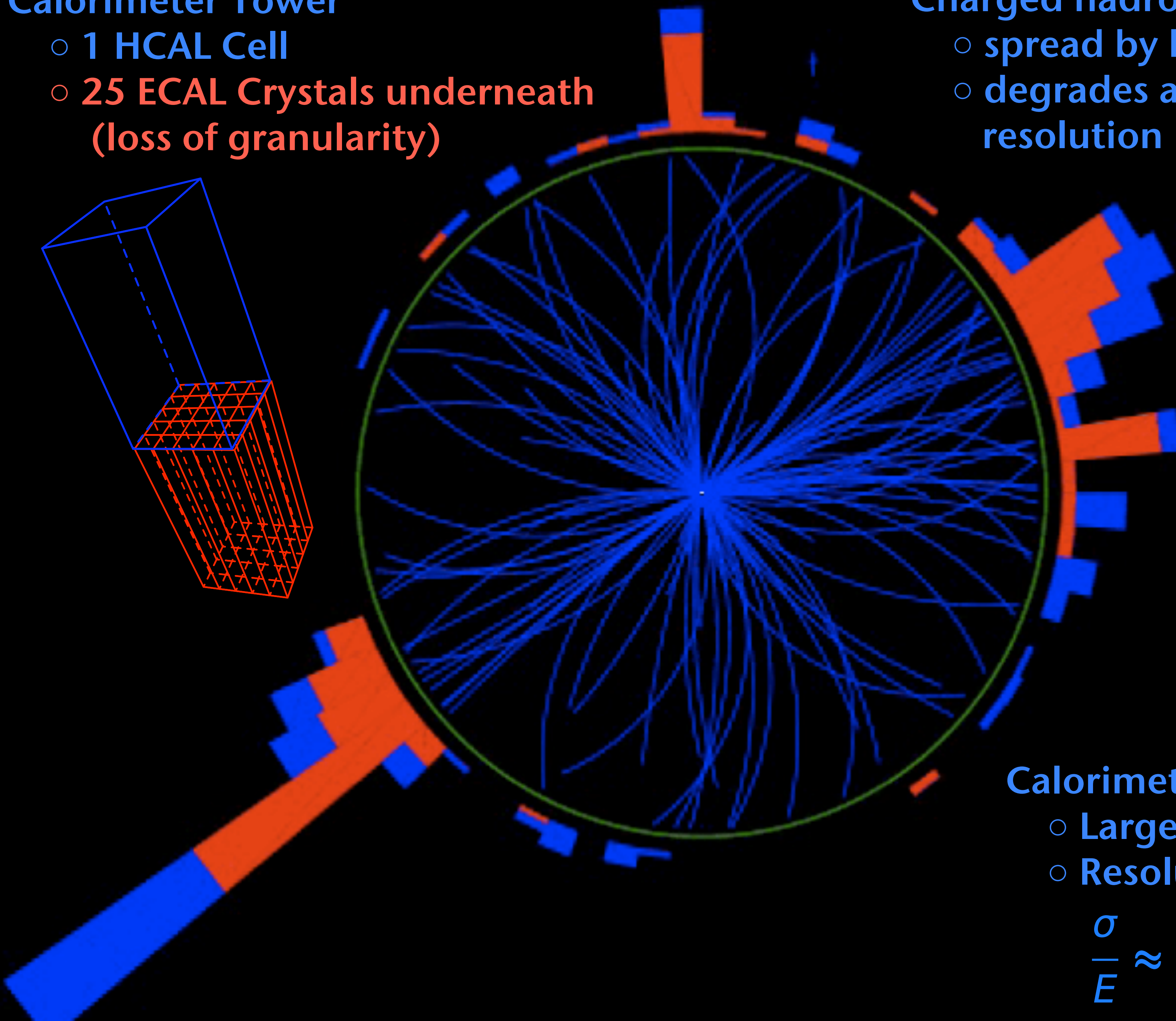
- 25 ECAL Crystals underneath (loss of granularity)



Charged hadrons

- spread by high B-field
- degrades angular resolution

Calorimeter Jets

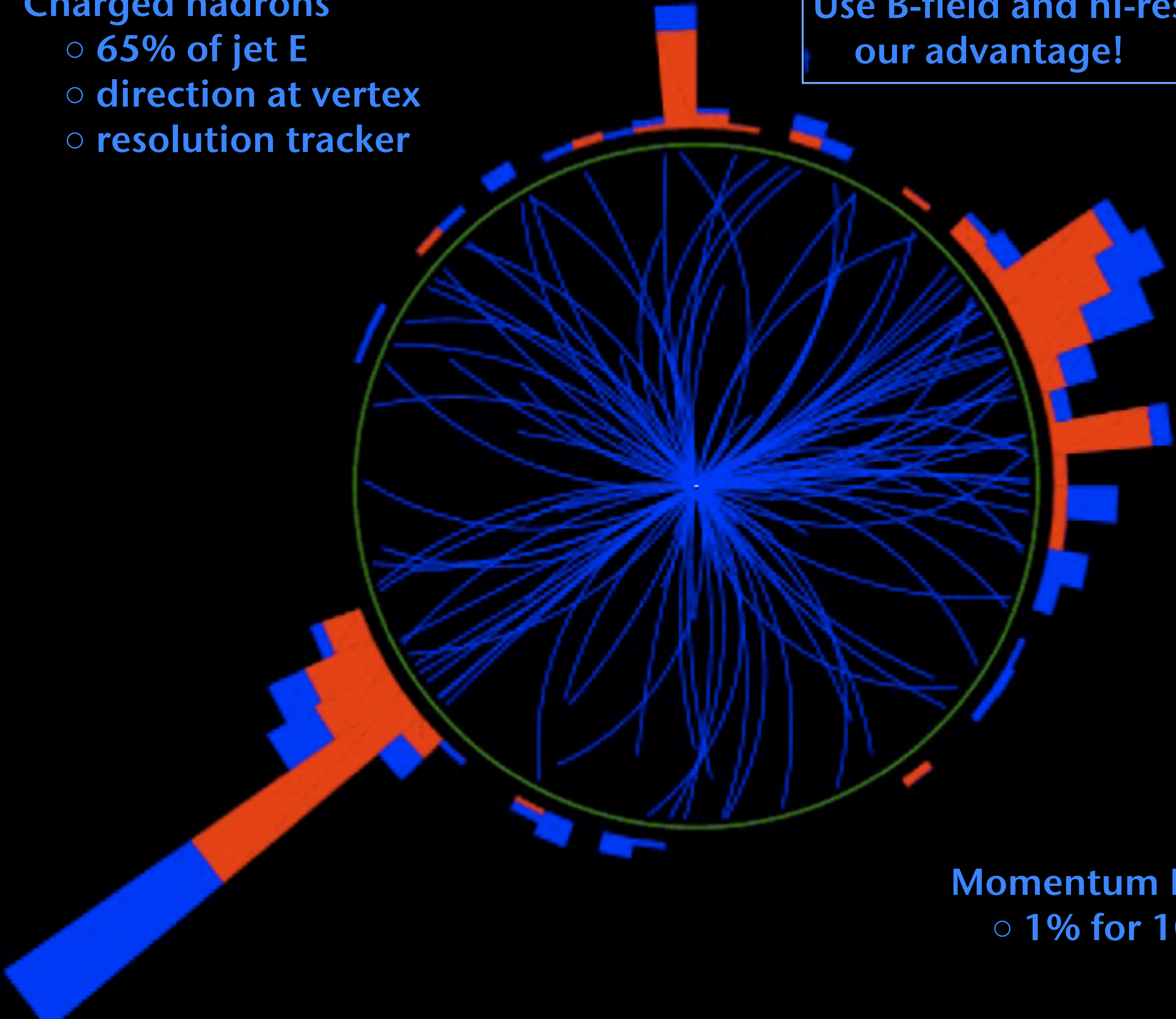
- Large Jet E Corr.
- Resolution HCAL

$$\frac{\sigma}{E} \approx \frac{100\%}{\sqrt{E}}$$

Charged hadrons

- 65% of jet E
- direction at vertex
- resolution tracker

Use B-field and hi-res tracker to our advantage!



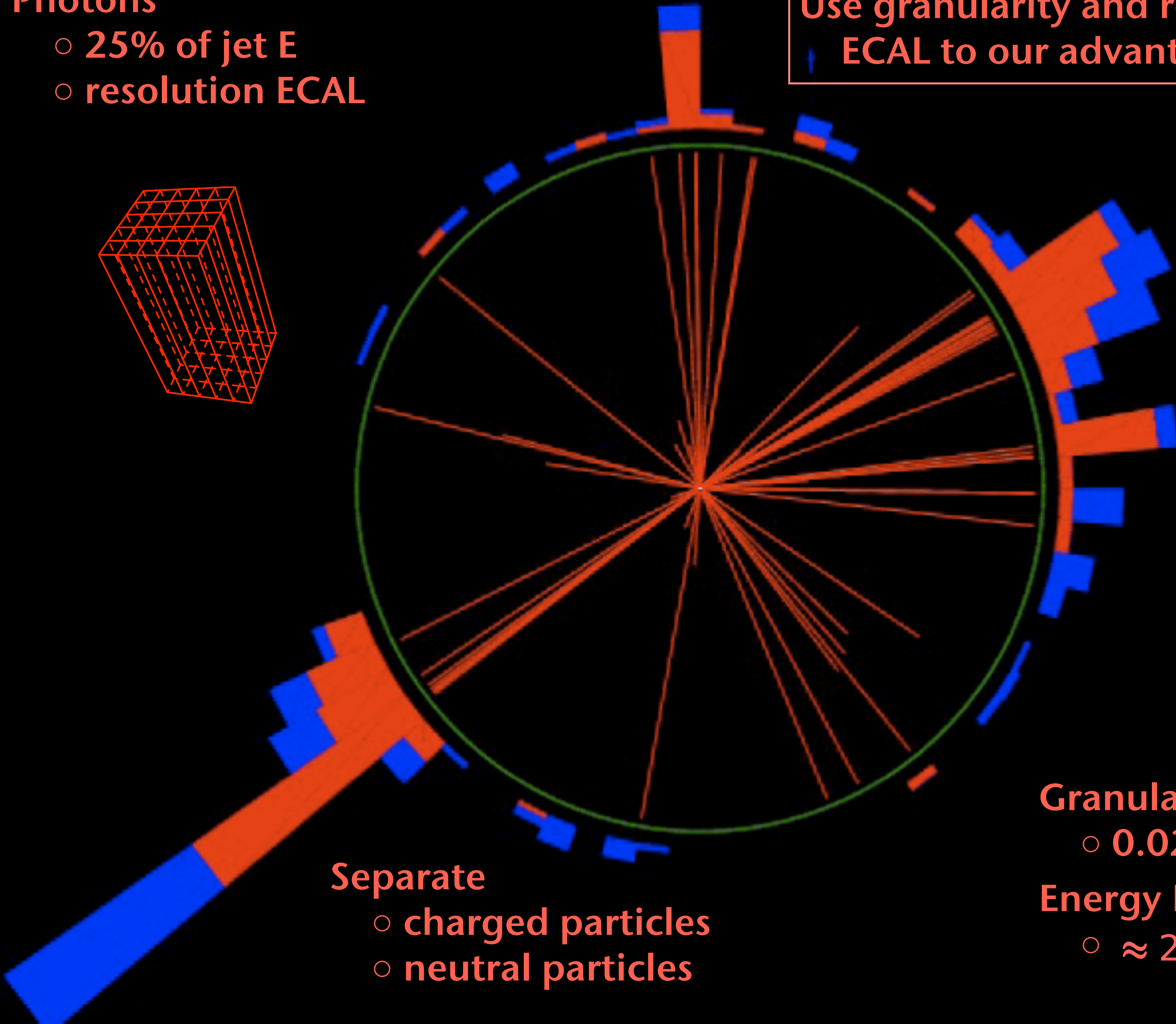
Momentum Resolution

- 1% for 100 GeV

Photons

- 25% of jet E
- resolution ECAL

Use granularity and resolution of ECAL to our advantage!



Separate

- charged particles
- neutral particles

Granularity

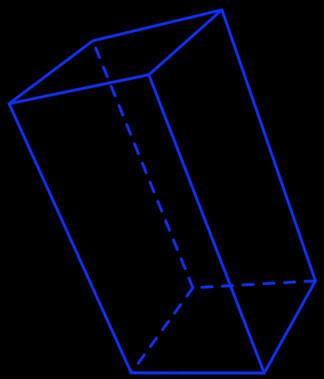
- 0.02 ($\Delta\eta \times \Delta\varphi$)

Energy Resolution

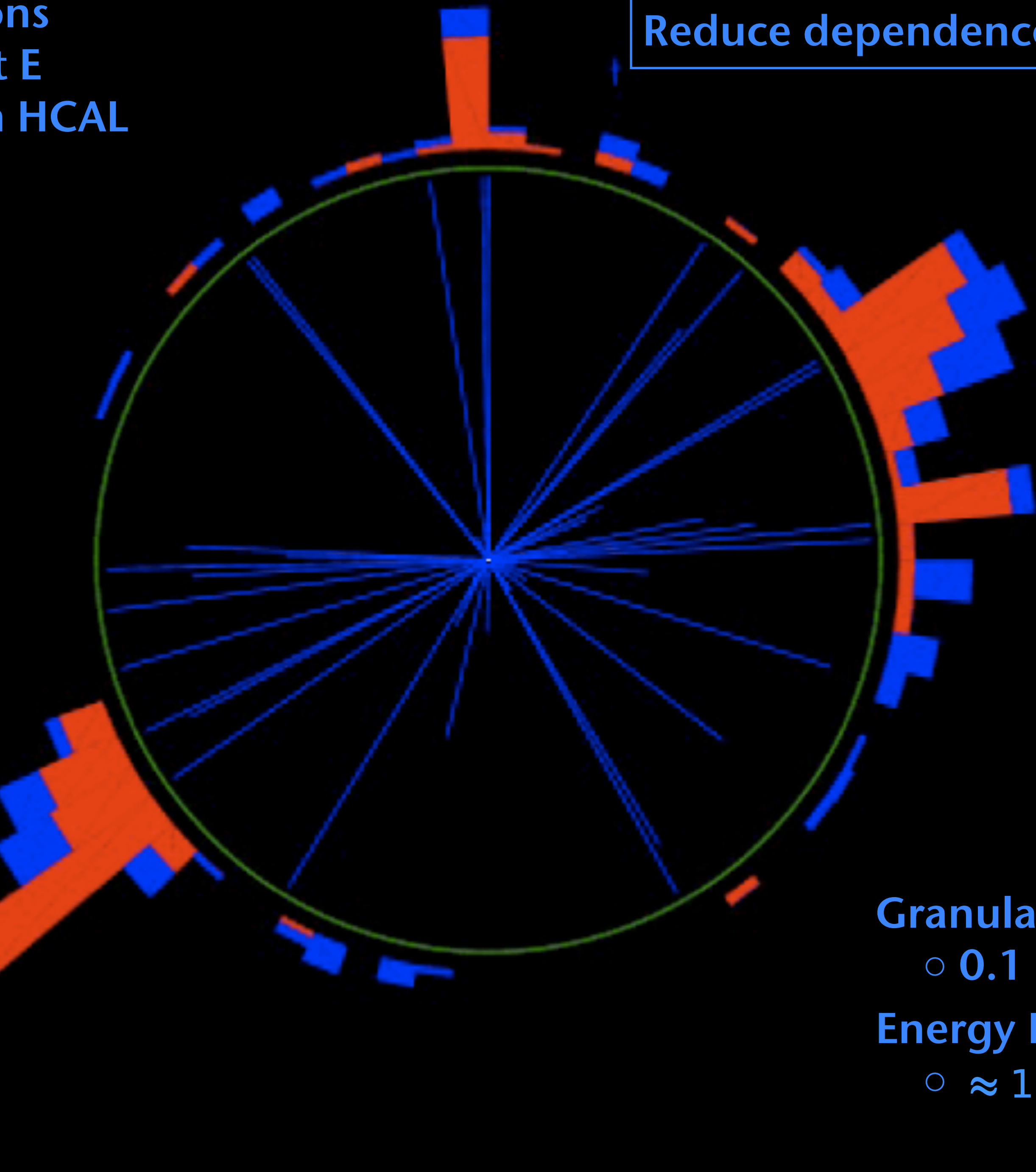
- $\approx 2\%/\sqrt{E}$

Neutral Hadrons

- 10% of jet E
- resolution HCAL



Reduce dependence on HCAL



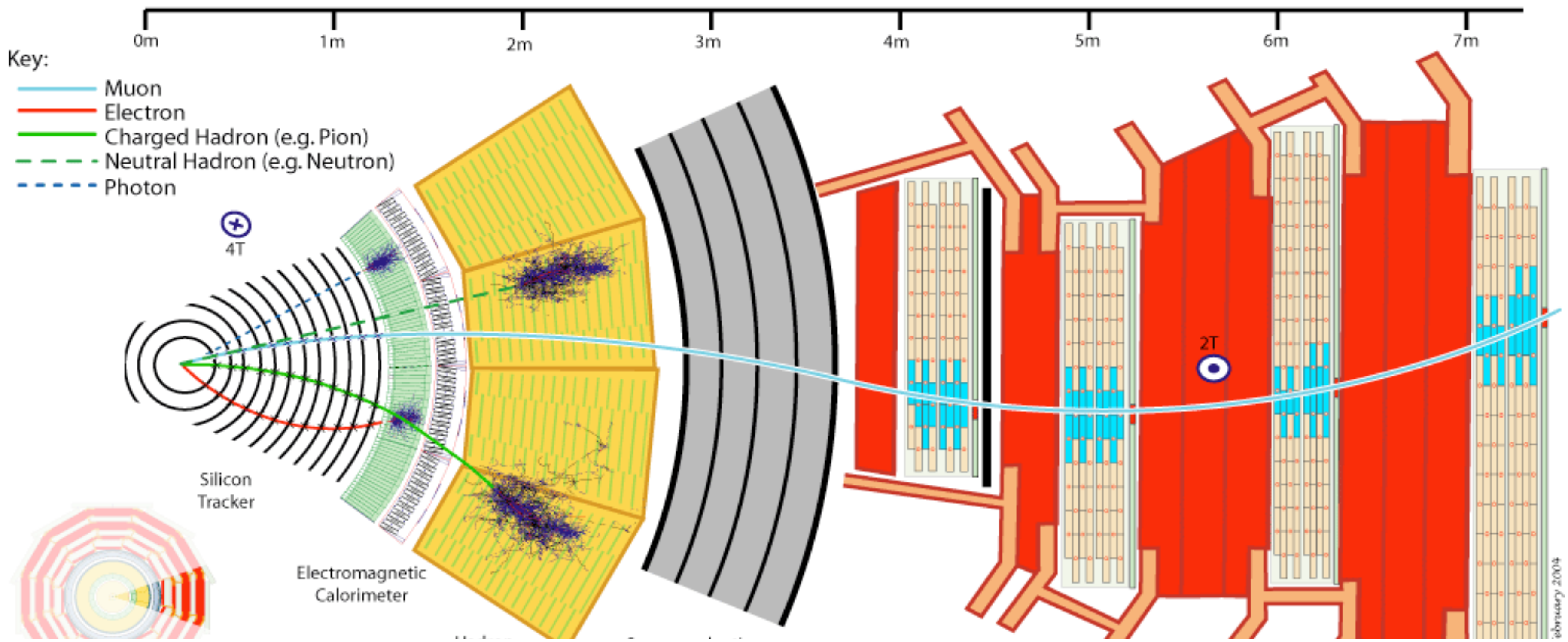
Granularity

- 0.1 ($\Delta\eta x \Delta\varphi$)

Energy Resolution

- $\approx 100\%/\sqrt{E}$

Particle Flow in CMS

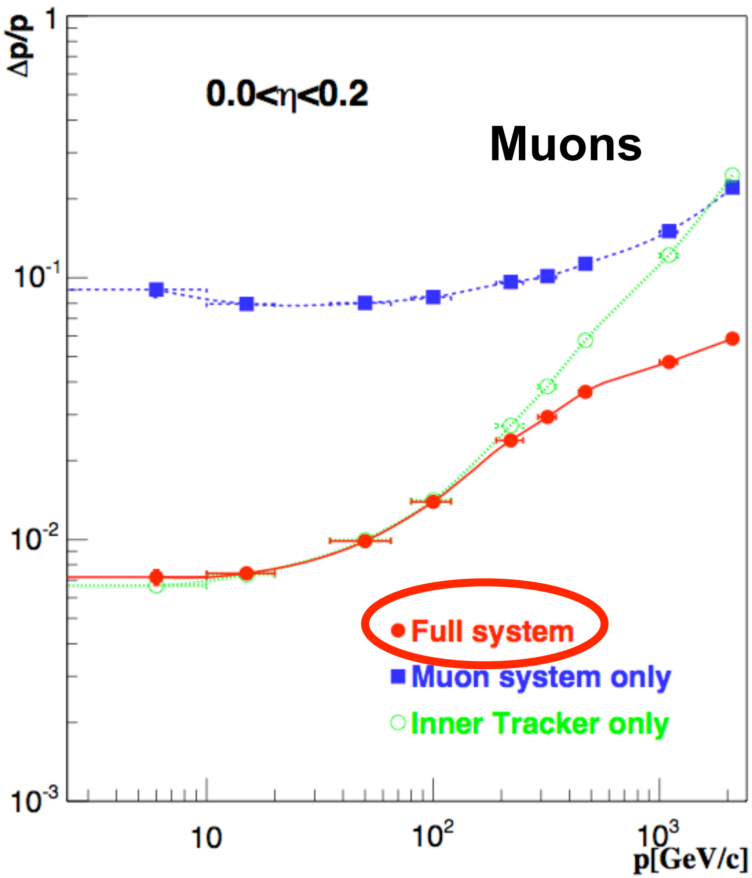


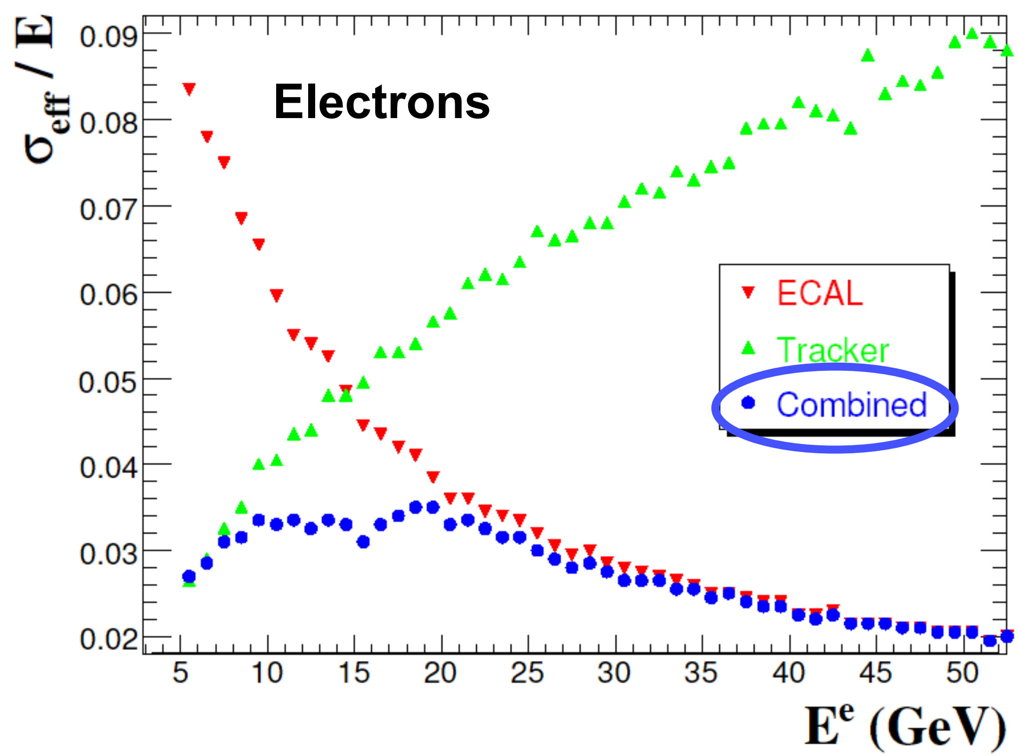
- CMS ideally suited to reconstruct and identify particles!
  - Very Large Tracker; High B-Field
  - Large Lever-arm for High PT Muons
  - Fine Granularity, High Resolution ECAL
  - Nearly full solid-angle coverage HCAL

Goal of Particle-Flow

- Reconstruct & identify *all* particles
  - γ, e, μ, charged hadrons, neutral hadrons, pileup particles, and even converted photons & nuclear interactions
  - Use the best combination of all CMS sub-detectors to get the best estimates of energy, direction, particle ID
- Provide consistent & complete list of ID'd & calibrated particles for
  - Tau reconstruction
  - Jet reconstruction
  - Missing Energy and total Visible Energy determination
- Use of Redundant Information: Calorimeter & Tracking
  - Tracking and Calorimetery fundamentally integrated
- Very different from "Traditional" Tau, Jet, MET Reconstruction…
  - Corrections performed after the fact

Using the *Detailed* Full Detector





Significant improvement achieved for leptons by using the Detailed Full Detector…

…why not also for all other particles: charged pions, neutral hadrons, etc?

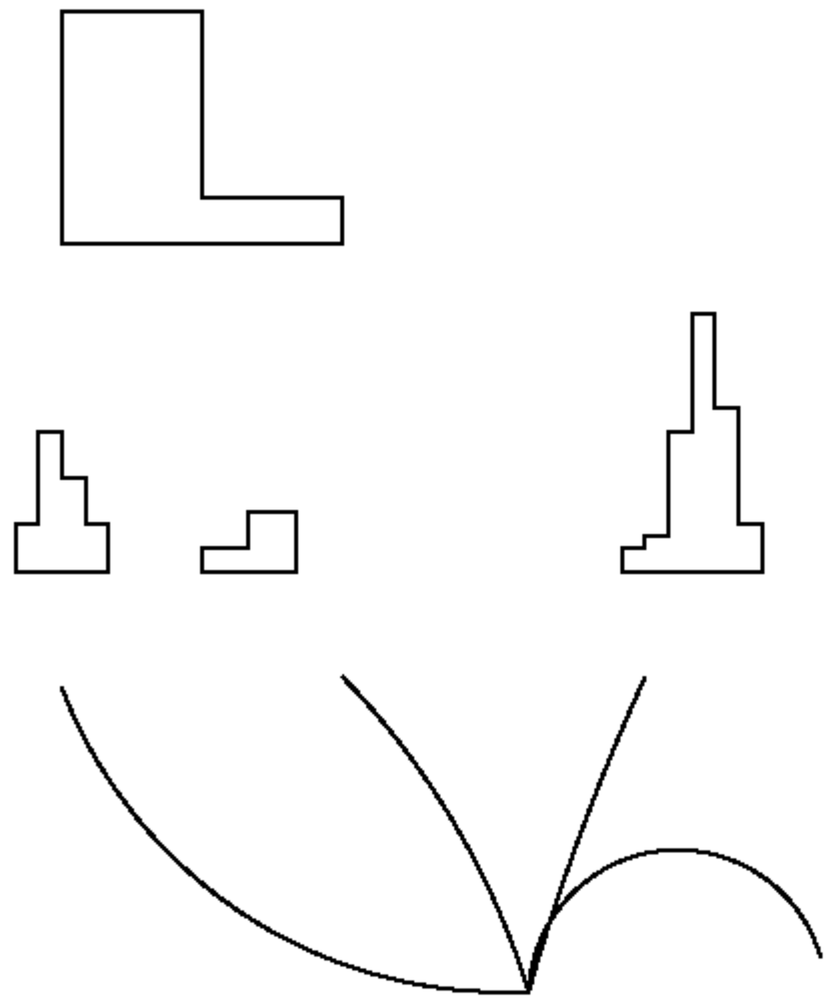
…and then use for Jets and MET?

Particle Flow Algorthm
First Associate Hits within Each Detector

HCAL Clusters

ECAL Clusters

Tracks

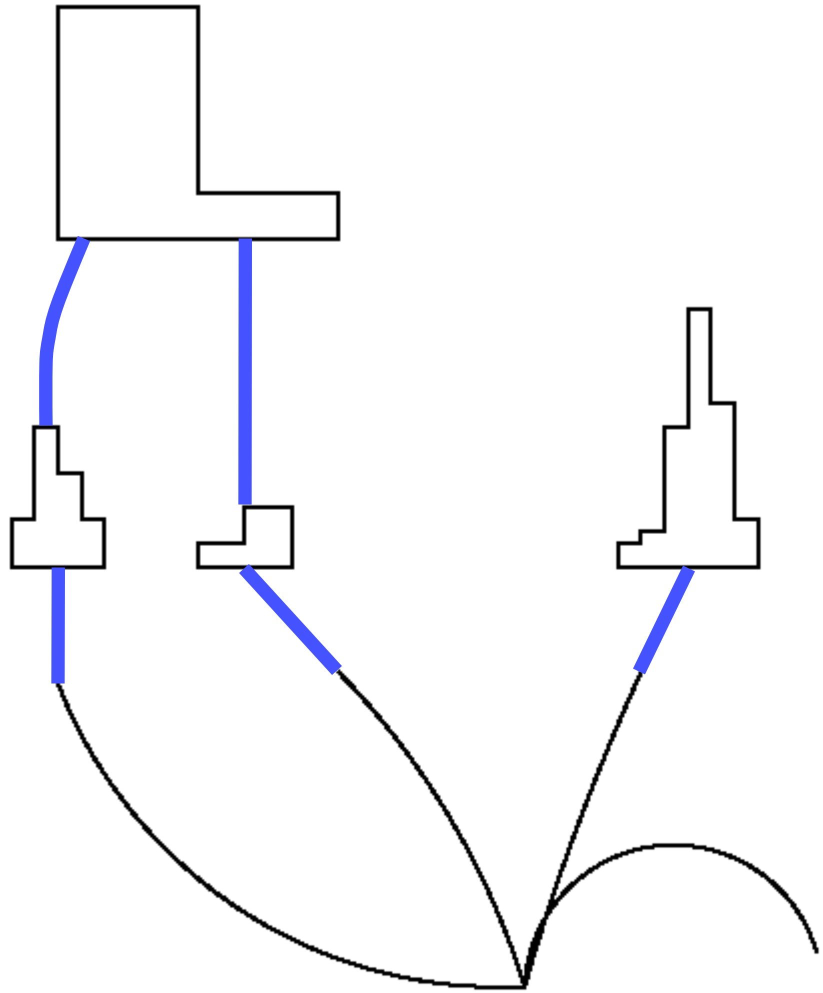


Particle Flow Algorthm
Linking Across Detectors

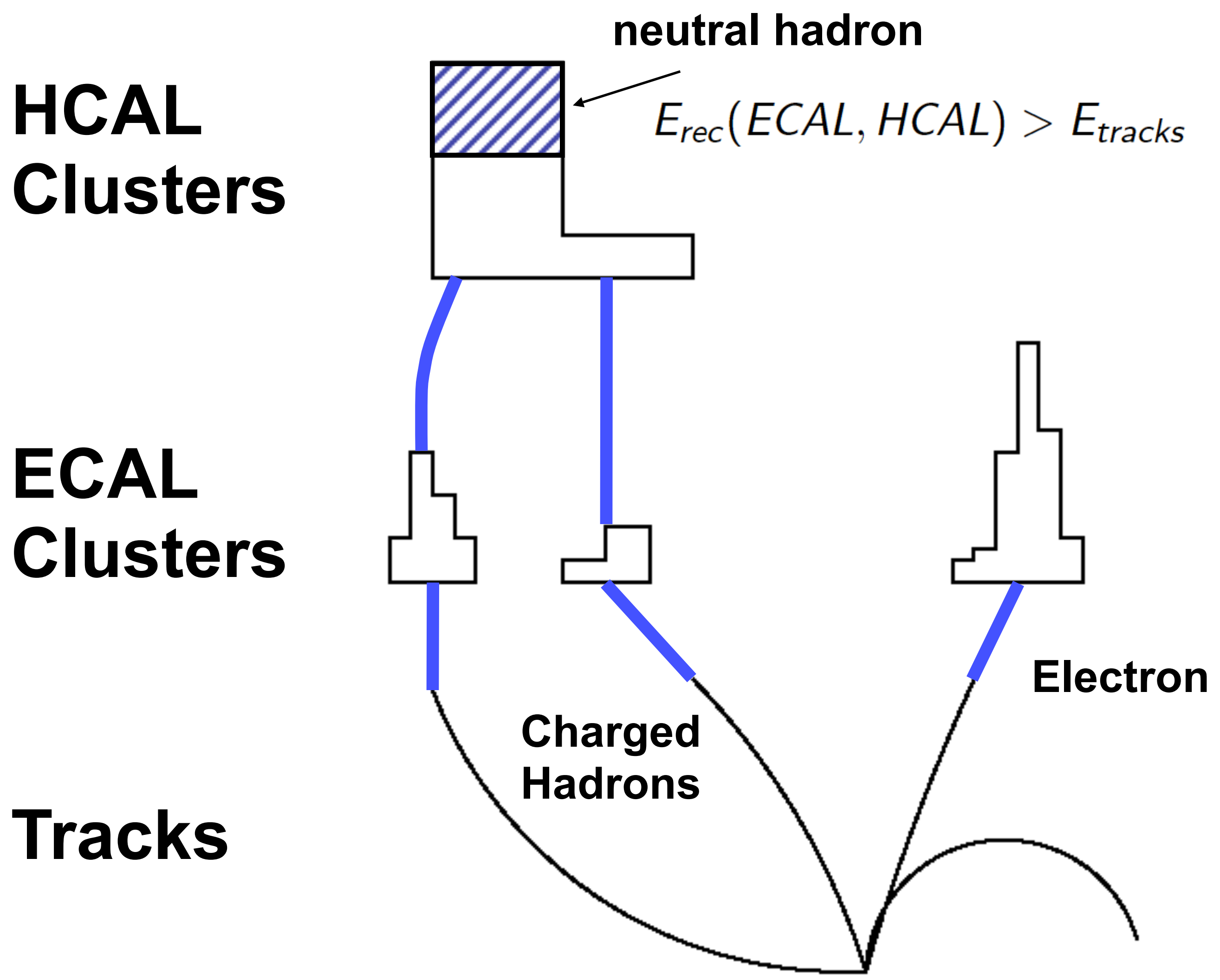
HCAL Clusters

ECAL Clusters

Tracks



Basic Idea of Particle Flow : Finally Apply Particle ID & Separation



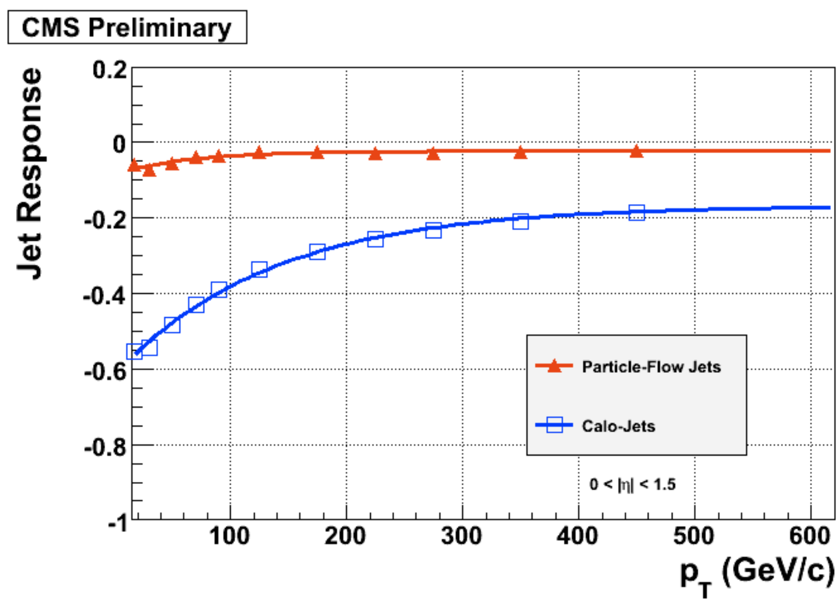
Very Basic View of Particle Flow

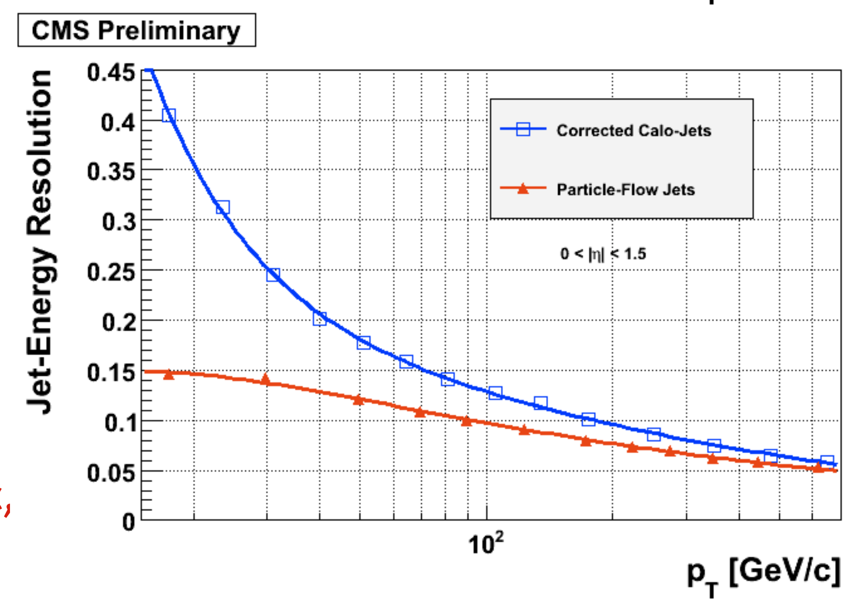
"Clean" the Event During Reconstruction!

- Find and "remove" muons (σ_{track})
- Find and "remove" electrons (min[σ_{track}, σ_{ECAL}])
- Find and "remove" converted photons (min[σ_{track}, σ_{ECAL}])
- Find and "remove" charged hadrons (σ_{track})
- Find and "remove" V0's (σ_{track})
- Find and "remove" photons (σ_{ECAL})
- Left with neutral hadrons (10%) (σ_{HCAL} + fake)
- ***Use above list of Reconstructed Particles to describe the entire event!***
- Jets & MET remain simple (no complicated corrections):
  - just use standard algorithms with "particles" instead of "towers"

Jet Reconstruction

- Approaching Self-calibration
  - much smaller residual corrections 5% compared with 65% at 100 GeV
  - Nearly independent of Jet Flavour
- Better Energy Resolution
  - Factor 3 at 15 GeV (tracker dominates)
  - Converges to Calorimeter at high pT
- Better Angular Resolution
  - Especially in azimuth (B-Field)
  - Especially at low pT, but also at high pT
- Enables Better Jet Definitions
  - Clustering Algorithms:
    - smaller cone sizes possible
    - lower pT thresholds possible
  - Reduces isolated e/γ faking a jet
    - can be excluded from jet clustering
  - Particle Multiplicity and Content:
    - neutral hadronic, charged hadronic, photonic, leptonic, etc





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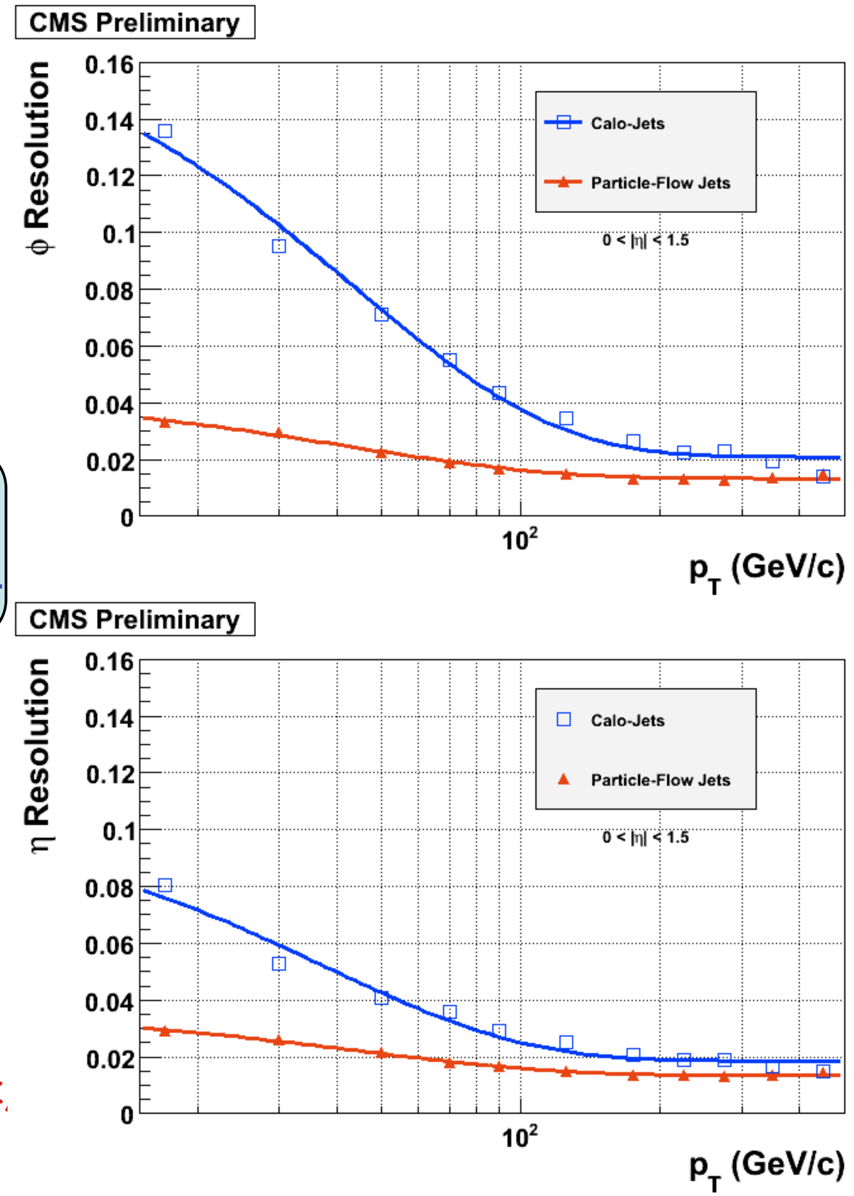
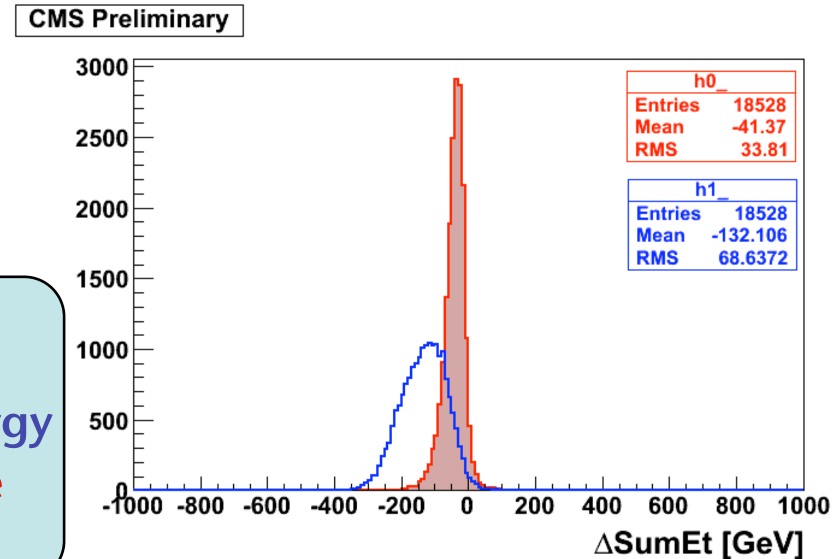
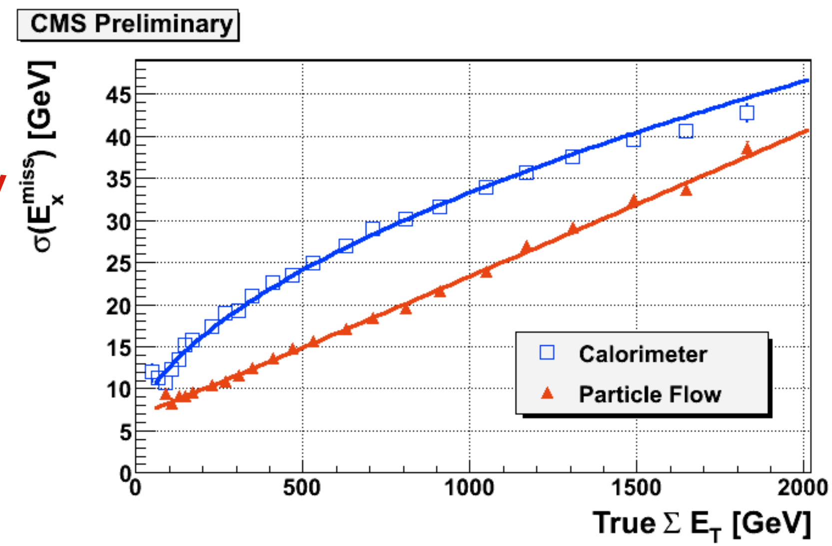


MET Performance

- MET is the very last step
  - Benefits from all progress in the jets!
  - Will continue to benefit from further progress!
- Better able to measure zero-MET (e.g as in QCD)
  - Improved estimate of event visible energy
    - better measure of “zero” imbalance
  - 60% better at 500 GeV of Sum ET
- Better able to measure real-MET (e.g. as in ttbar)
  - Improved Energy Response
    - Calibrated within 5% above 20 GeV
  - Improved Energy Resolution
    - About 60% better at 20 GeV
    - Factor 1.5 or 2 better in ttbar
- Better able to distinguish
  - real-MET from zero-MET





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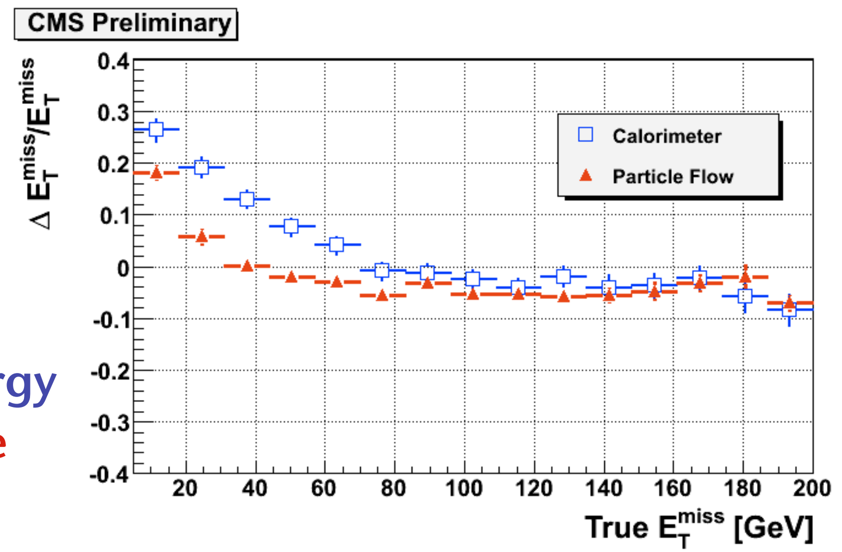

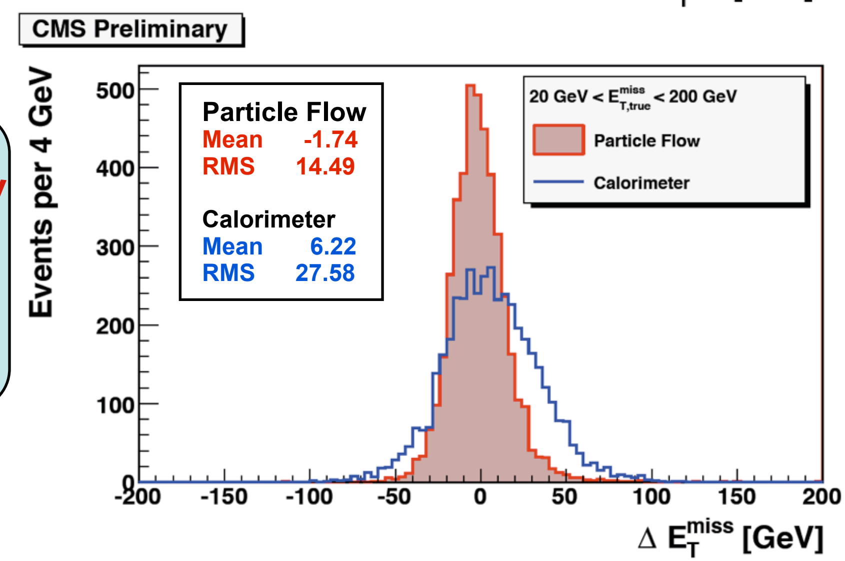

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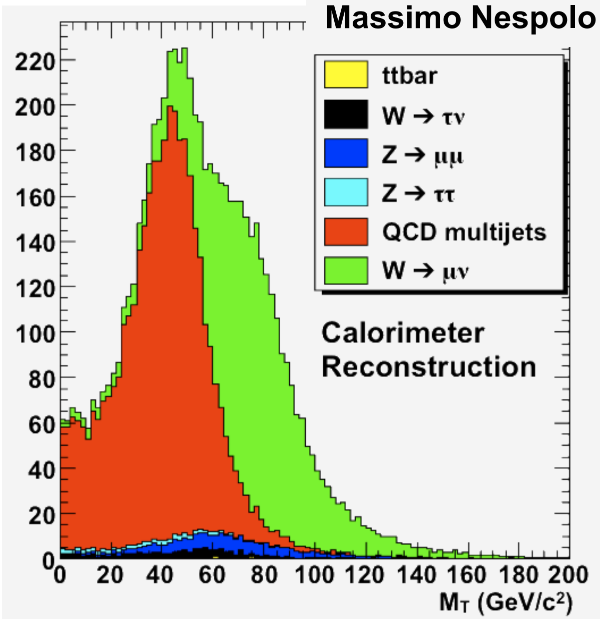
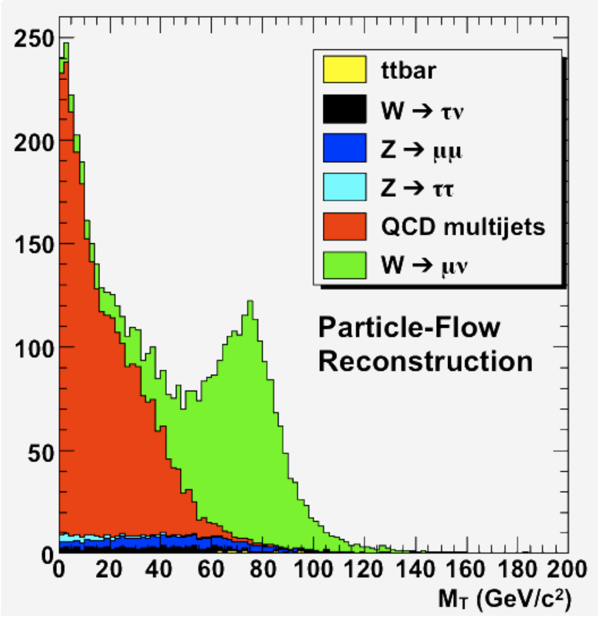
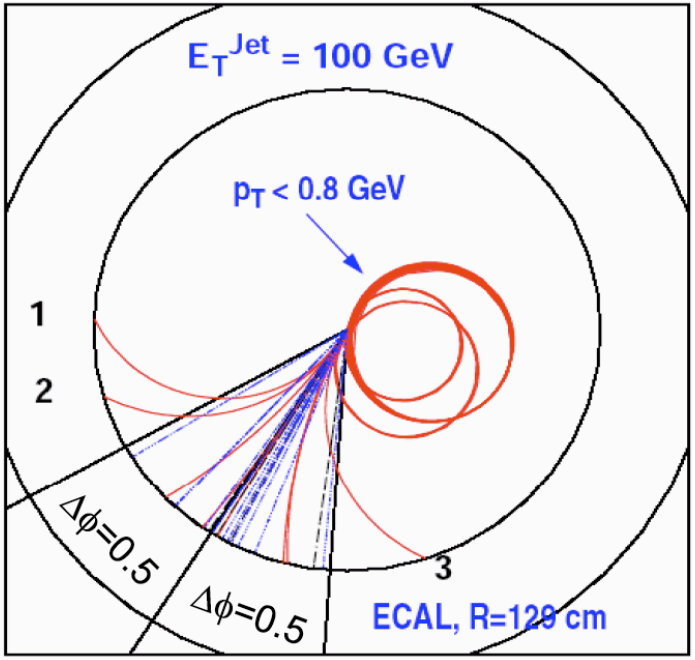
Massimo Nespolo





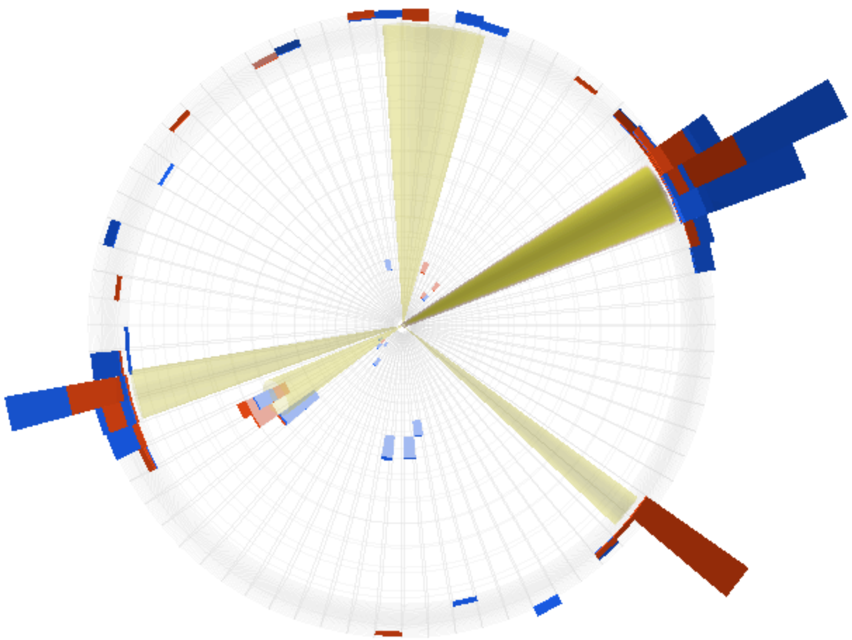
A posteriori Track Corrections to Jets & MET

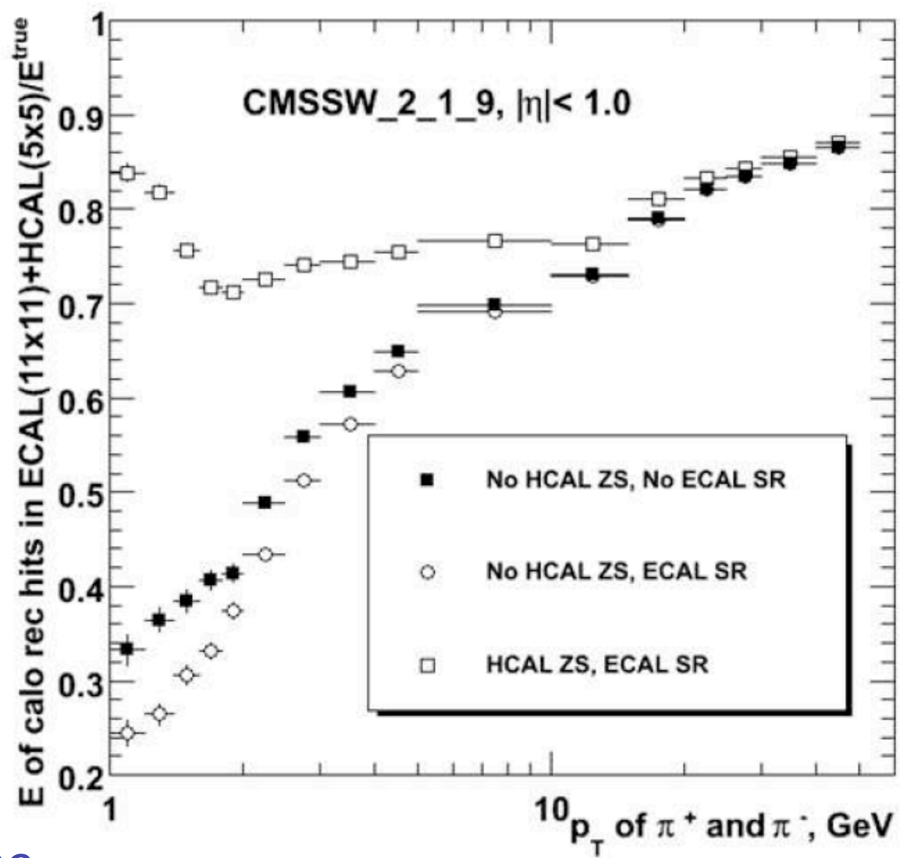
- **Track-corrected Calorimeter Jets**
  - "seeded" by calorimeter only
  - add track momenta inside jet-cone
  - subtract *average* single-particle response for each track



- **Very different from Particle-Flow**
  - conceptionally and systematically
  - track & calo. info. simultaneously used to reco. particles
  - jets "seeded" by reconstructed particles
- **Multiple (different) systematic approaches**
  - Good! Helps Understanding. Healthy competition :-)
  - Especially important during early running

Calorimeter Zero-Suppression



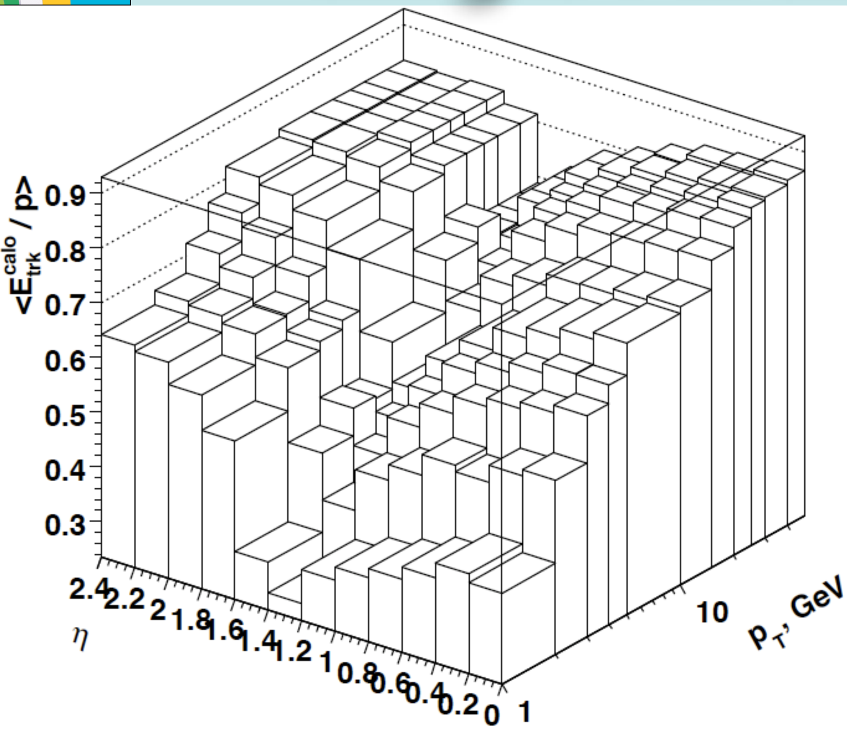


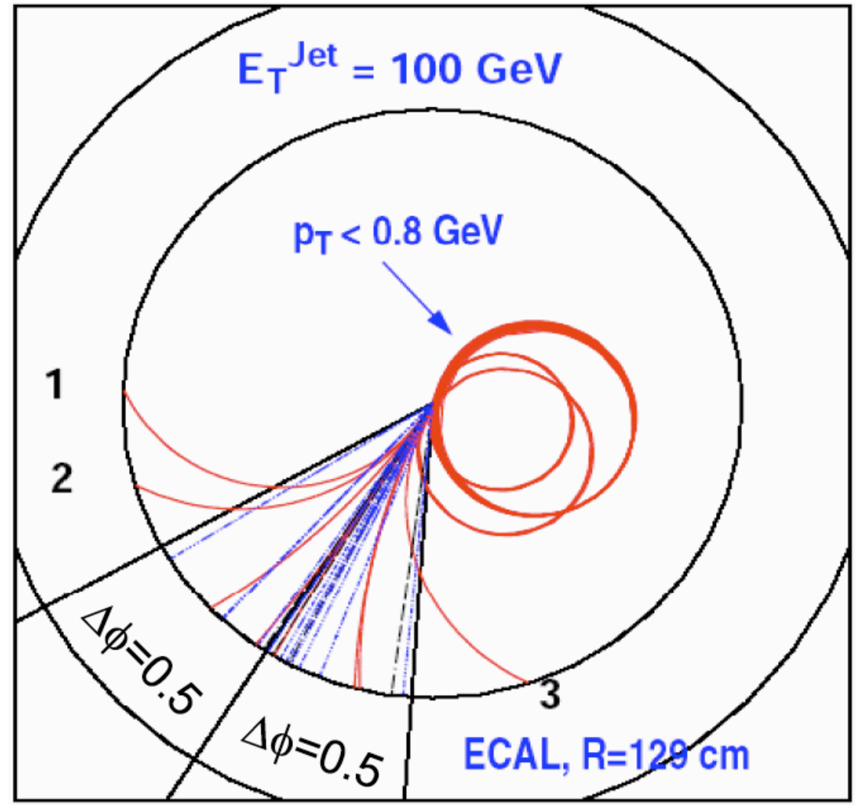
- Zero-Suppression of the calorimeter
  - Only positive values above the HCAL Pedestals are read out
  - ECAL Selectively read-out
  - Noise thresholds also applied

$$E_1 = E_{jet}^{raw\ calo} \times f_{ZSP}(E_{jet}^{raw\ calo}, \eta_{jet})$$

- Correct for ZSP ↔ single particle energy = track momentum

Single Particle Response





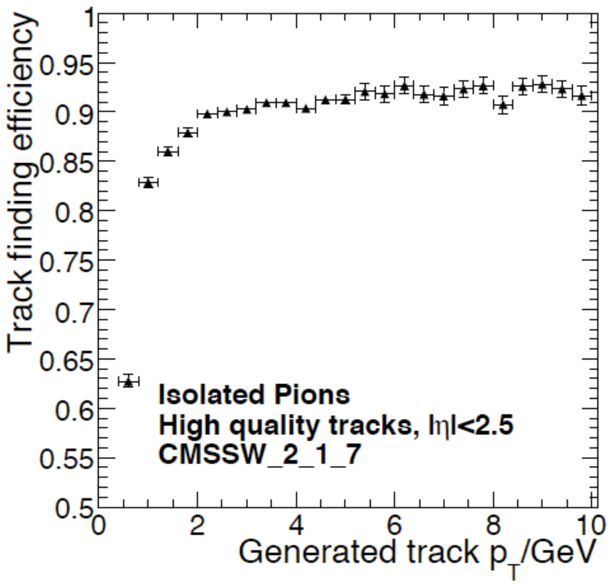
- Form single particle response map
  - η and p_T
- In cone:
  - add track momenta
  - subtract *average* single-particle response for each track
- out of cone
  - just add track momenta

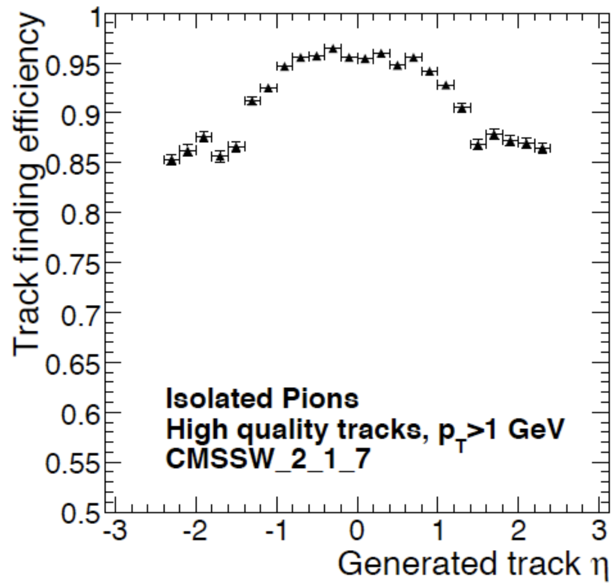
ZSP

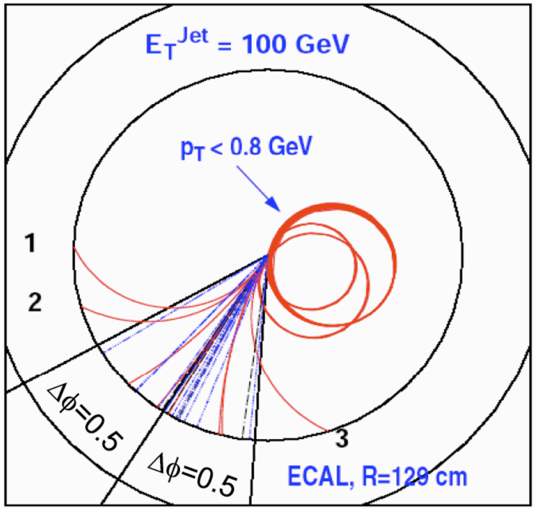
$$E_2 = E_1 + \sum_{in-cone\ trk} (p_{trk} - < E_{trk}^{calo} >)$$

$$E_3 = E_2 + \sum_{out-of-cone\ trk} p_{trk}$$

Track Finding Efficiency







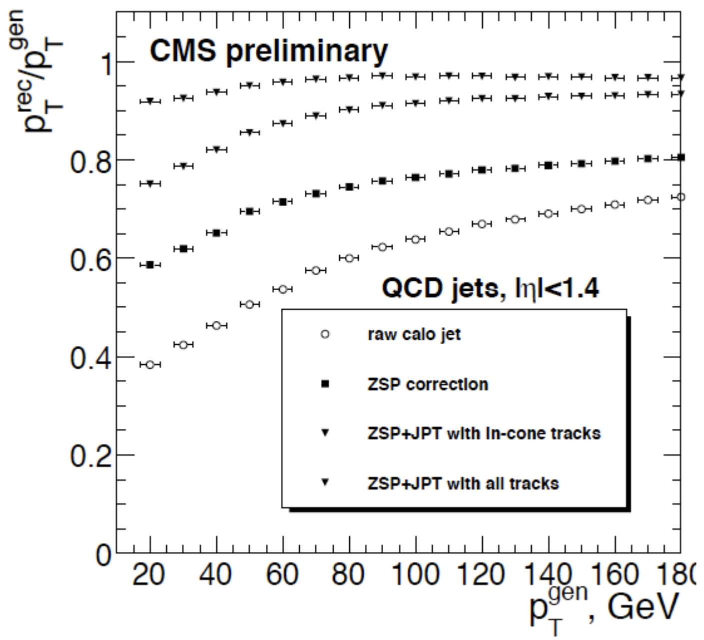
trk - < calo response >

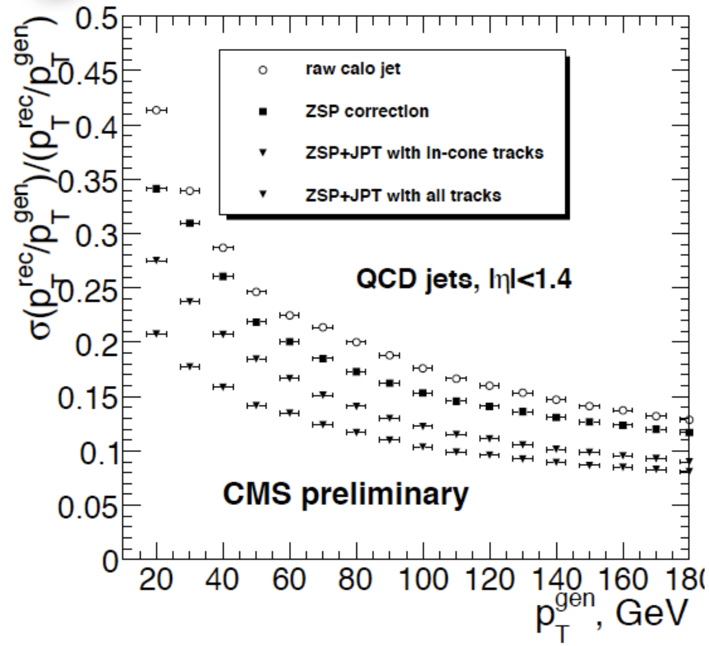
$$E_4 = E_3 + \Delta E^{in-cone} + \Delta E^{out-of-cone}$$

$$\Delta E^{in-cone} = \sum_{p_T}\sum_{\eta} n_{trk}^{in-cone}(p_T,\eta) \times \frac{1-\varepsilon_{trk}}{\varepsilon_{trk}} \times (< p_{trk} > - < E_{trk}^{calo} >)$$

$$\Delta E^{out-of-cone} = \sum_{p_T}\sum_{\eta} n_{trk}^{out-of-cone}(p_T,\eta) \times \frac{1-\varepsilon_{trk}}{\varepsilon_{trk}} \times < p_{trk} >$$

Putting it all together



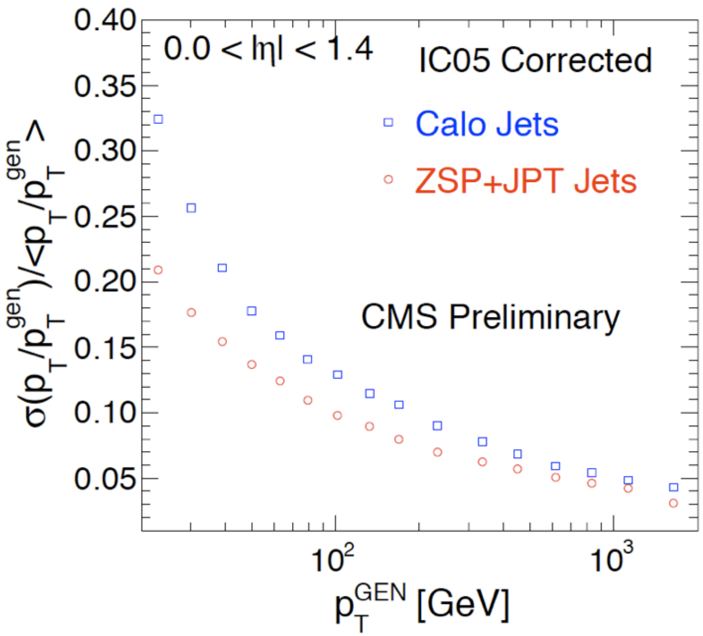


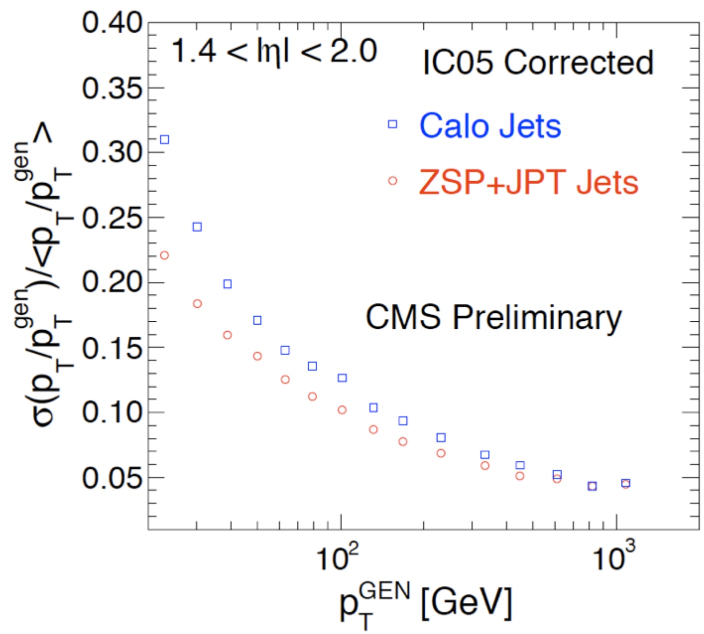
$$E_{JPT} = E_{jet}^{raw\ calo} \times f_{ZSP} + \sum_{in-cone\ trk} (p_{trk} - < E_{trk}^{calo} >) + \sum_{out-of-cone\ trk} p_{trk} + \Delta E_{trk.ineff}$$

$$+ \sum_{muons} (p_{\mu} - 2\,GeV),$$

- **Jet response improves close to unity**
- **Energy Resolution improves**
- **Angular Resolution stays consistent with calorimeter**
  - **Later versions will also use tracks to correct jet angle**

Performance of JPT





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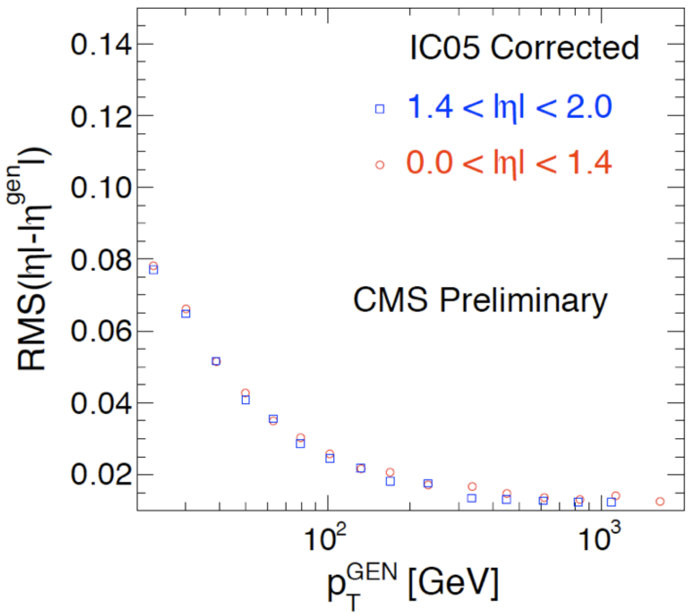

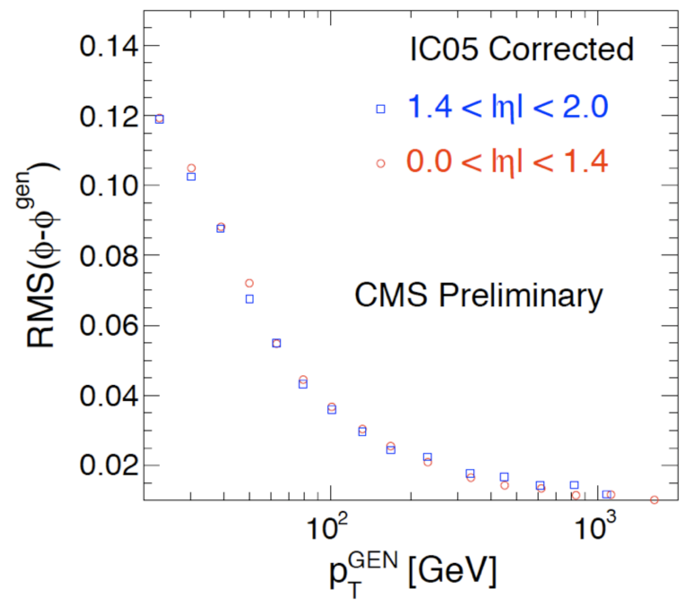

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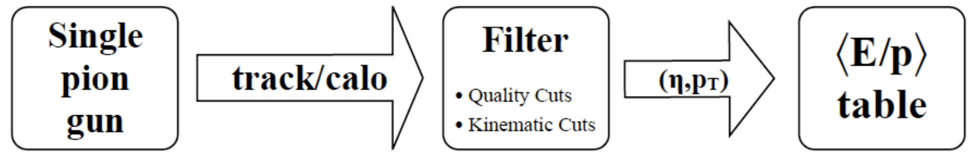
Track Corrected MET



- Track corrected MET
  - born out of desire to reduce MET tails in searches for new physics
    - well measured tracks used to remove badly measured calorimeter cells
- Basic Idea
  - add track momenta
  - subtract *average* single-particle response for each track
  - Similar to JPT algo, except
    - ZSP correction not applied
    - No out of cone tracks
    - Track eff. corr. not applied
  - Important to separate μ's from π's!
    - particular attention given to muon corrections
- Focus is on robustness (tails) & startup conditions
  - Response and Resolution also improved (added bonus!)

$$\begin{aligned} \not{E}_T^{\mu} &= \not{E}_T^{\text{calo}} + \delta \not{E}_T^{\mu}, \\ &= -\sum_{\text{towers}} \vec{E}_T - \sum_{\substack{\text{good}\\ \text{muons}}} \vec{p}_T + \sum_{\substack{\text{good}\\ \text{muons}}} \vec{E}_T^{\text{MIP}} \end{aligned}$$

$$\begin{aligned} \not{E}_T^{\text{tc}} &= \not{E}_T^{\mu} + \delta \not{E}_T^{\text{tc}}, \\ &= \not{E}_T^{\mu} + \sum_{\substack{\text{good}\\ \text{tracks}}} \langle \vec{E}_T \rangle - \sum_{\substack{\text{good}\\ \text{tracks}}} \vec{p}_T \end{aligned}$$

Attempt to Control Tails!

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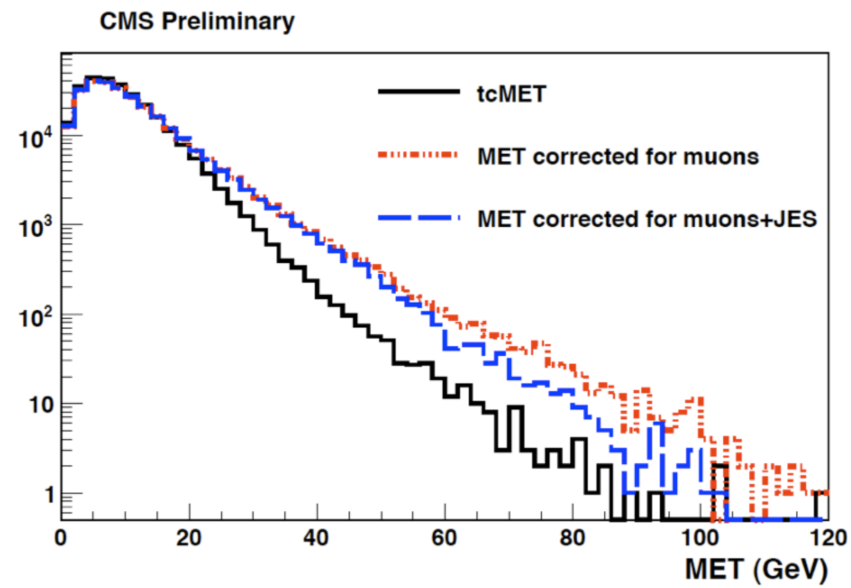

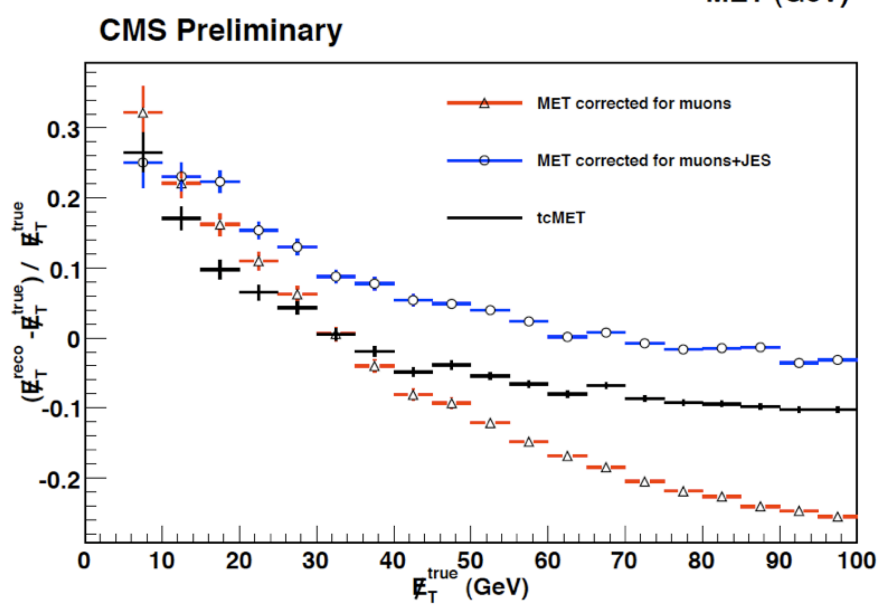

Resolution also Improves!

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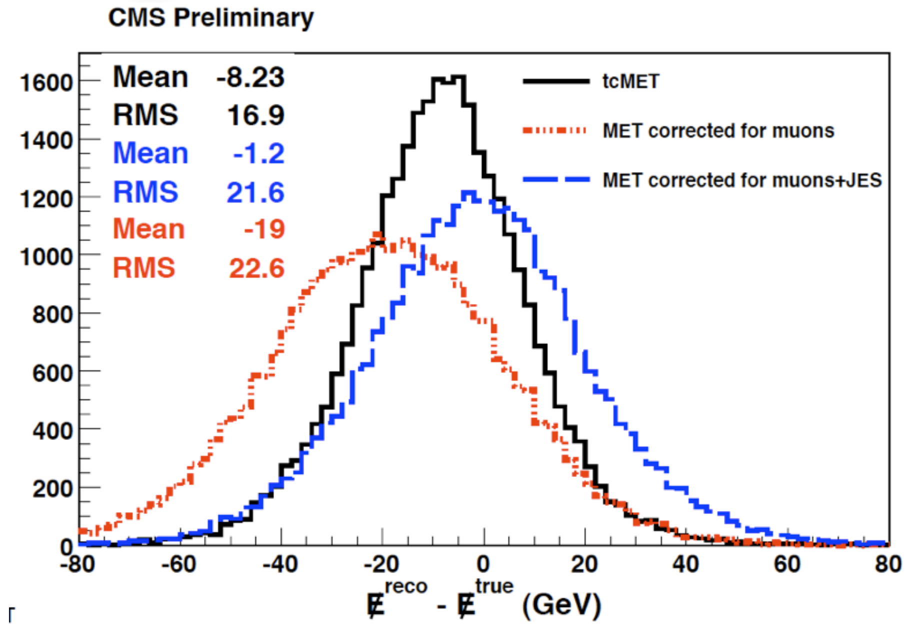

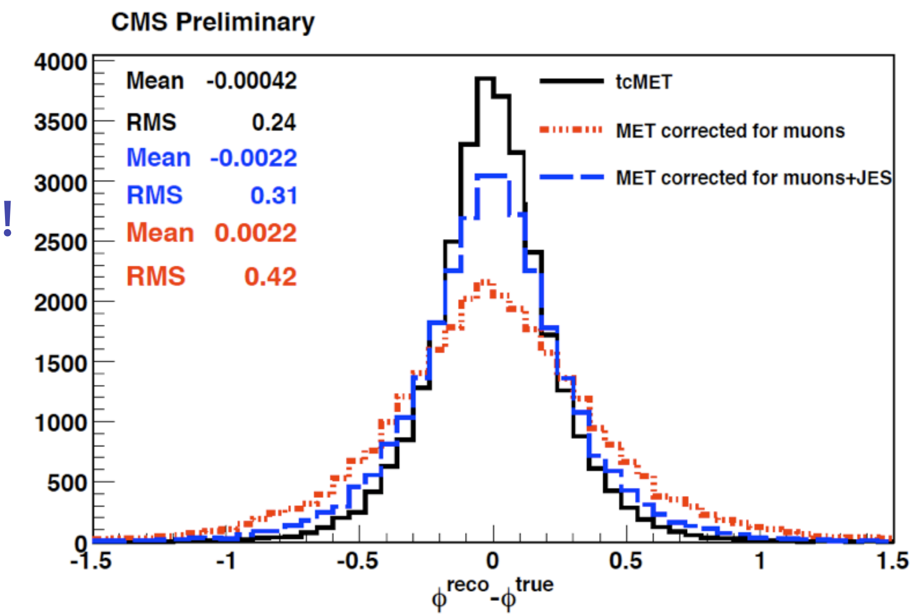

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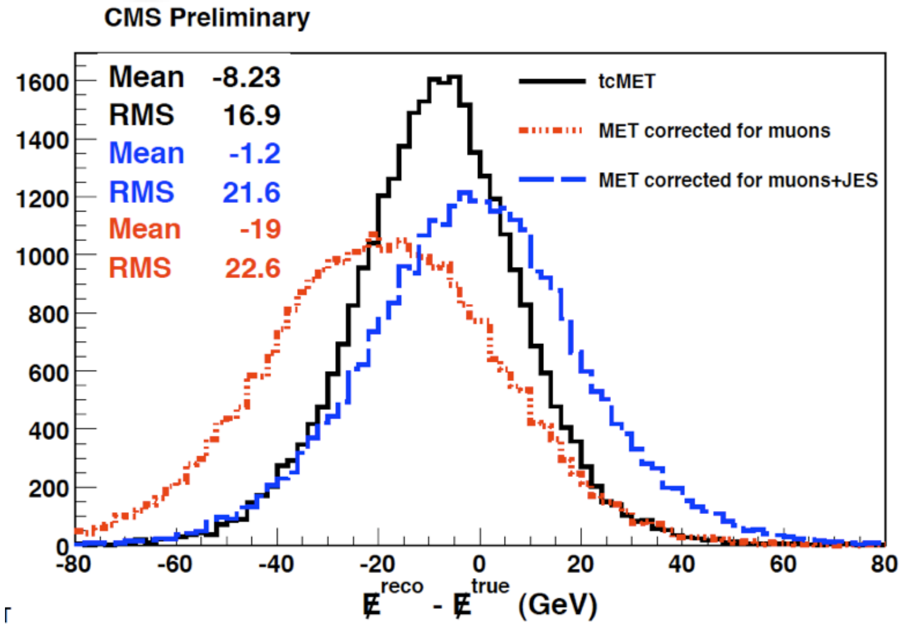
    - particular attention given to muon corrections
- Focus is on robustness (tails) & startup conditions
  - Response and Resolution also improved (added bonus!)



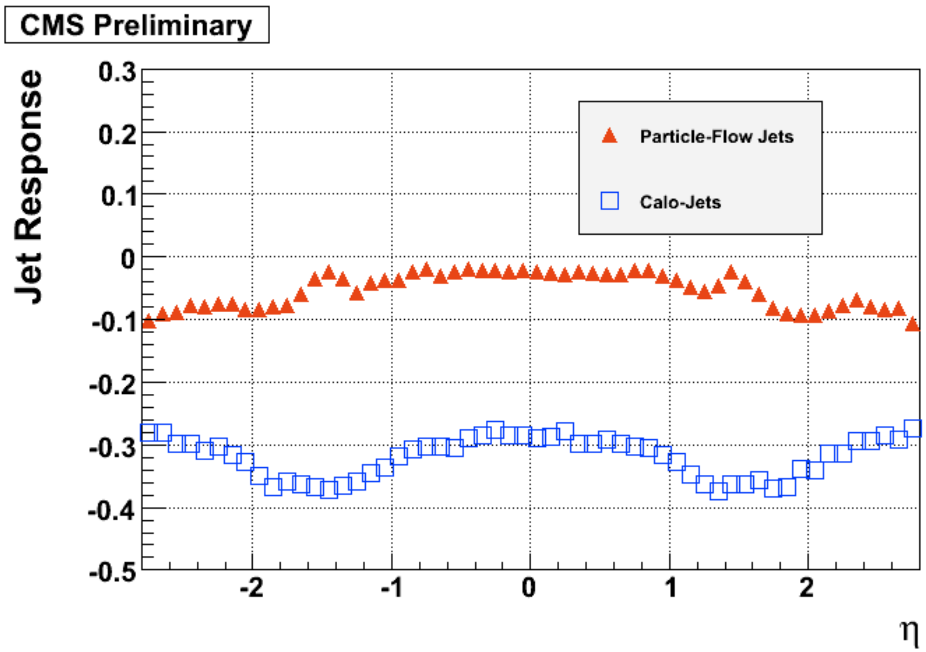
Drell-Yan background rejection

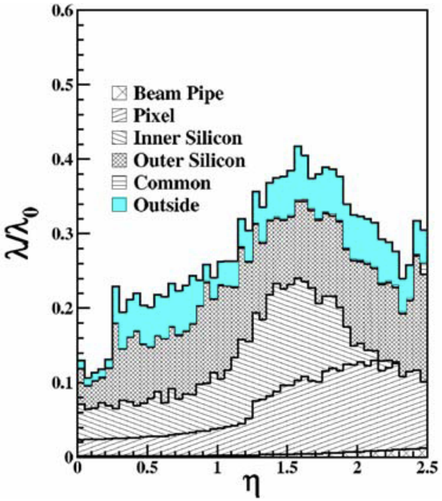
Case	0 jets	1 jet	2 jets	3+ jets
baseline	915/201863 0.5%	4860/53607 9%	852/2978 22%	2044/5201 39%
tcMET	435/201863 0.2%	1085/53607 2%	852/2978 6%	797/2044 15%
factor of improvement	2.1	4.5	3.5	2.6

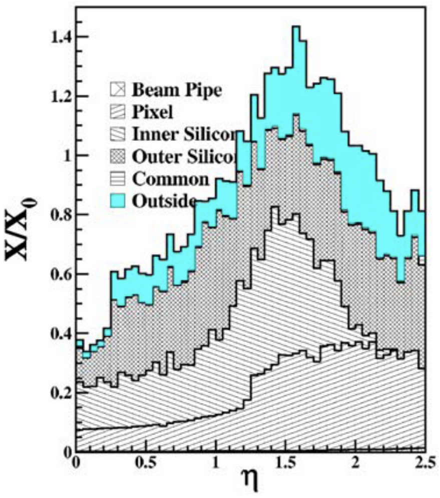
Summary

- Particle Flow is a fully generic description of the global event
  - exploits tracker resolution & full ECAL granularity
  - not tuned to taus, Jets, or MET; improves performance of each
- A posteriori track corrected Jets and MET
  - exploits tracker resolution & knowledge of calorimeter performance
  - specifically tuned to Jets or MET; also improves performance of each
- Both approaches are highly valuable to systematically understand data!
- All of these algorithms were developed in the context of MC simulations
  - Nevertheless, I personally expect all of these tools to be available and ready to use with very early CMS data
    - i.e. on same timeline (perhaps earlier!) as calor-only Jets & MET
- CMS is a "ready" experiment! Gone are the days:
    - "Whoa…the tracker is complex, what if it doesn't work?"
    - "Yikes…the ECAL is difficult to calibrate, what if it doesn't work?"
    - "The HCAL is simple! I just want simple things to start with!"
  - In a good position to maximize the use of our detector's redundancy!
- Try all of these tools out for yourselves!
  - Your analysis on Real Data will improve!
    - I guarantee it!

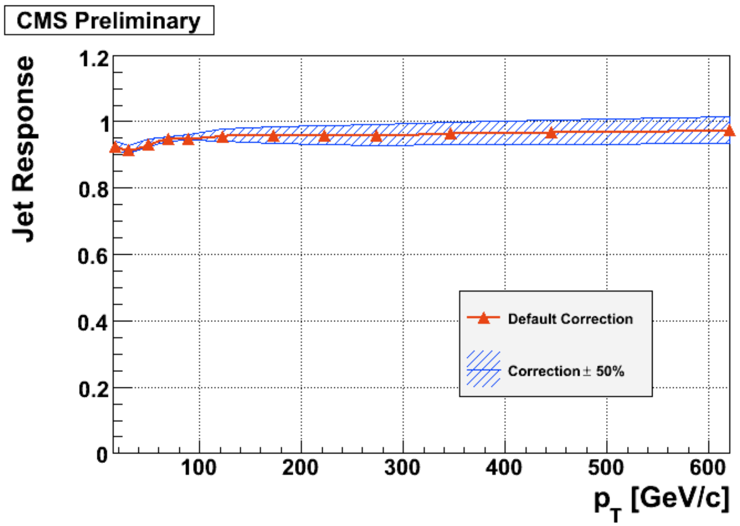
Backups - Systematic Checks

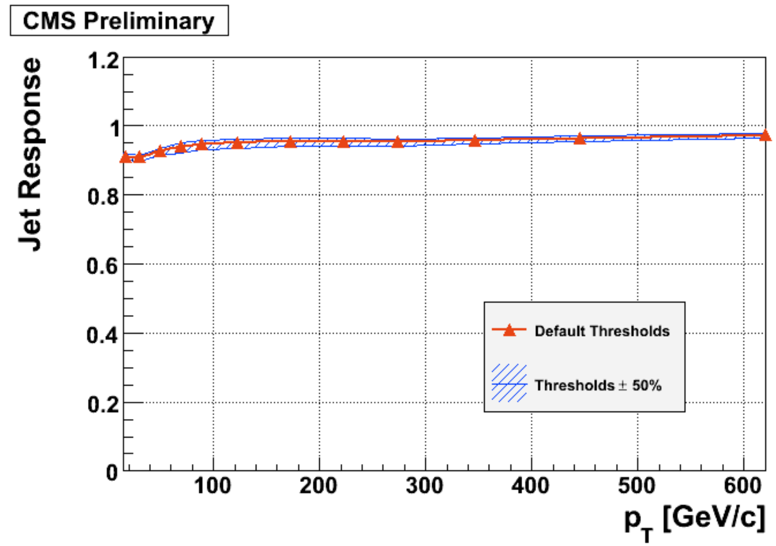


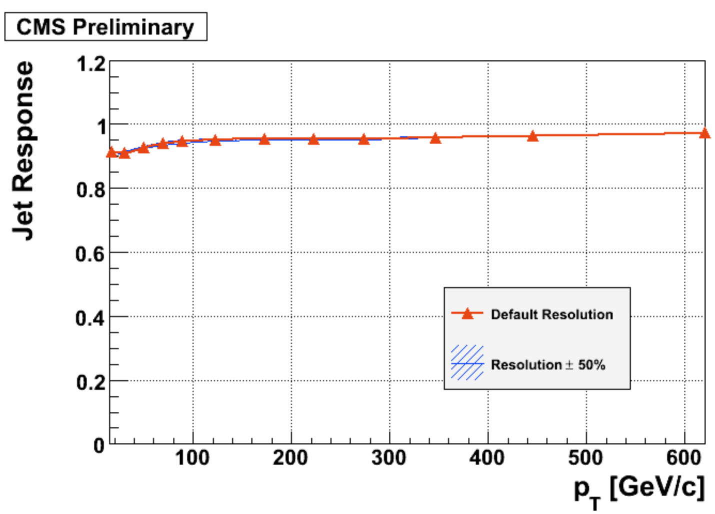


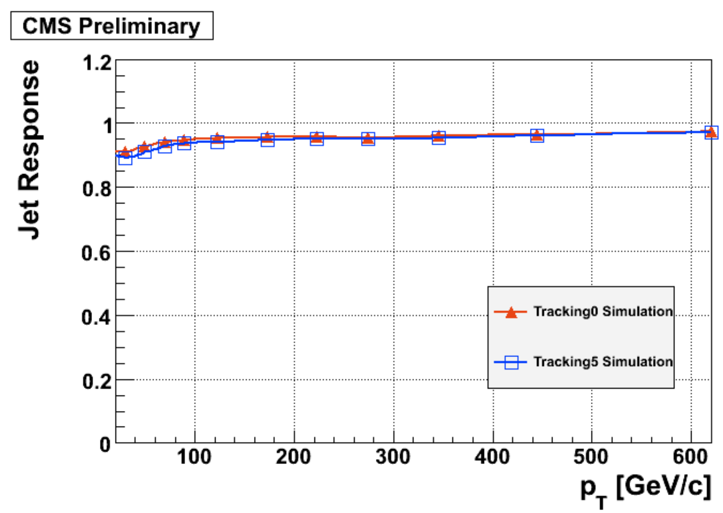


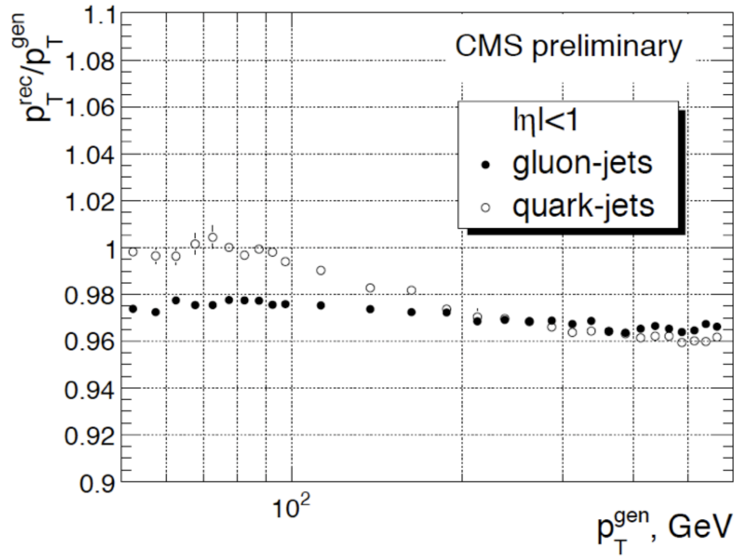
Backups - Systematic Checks

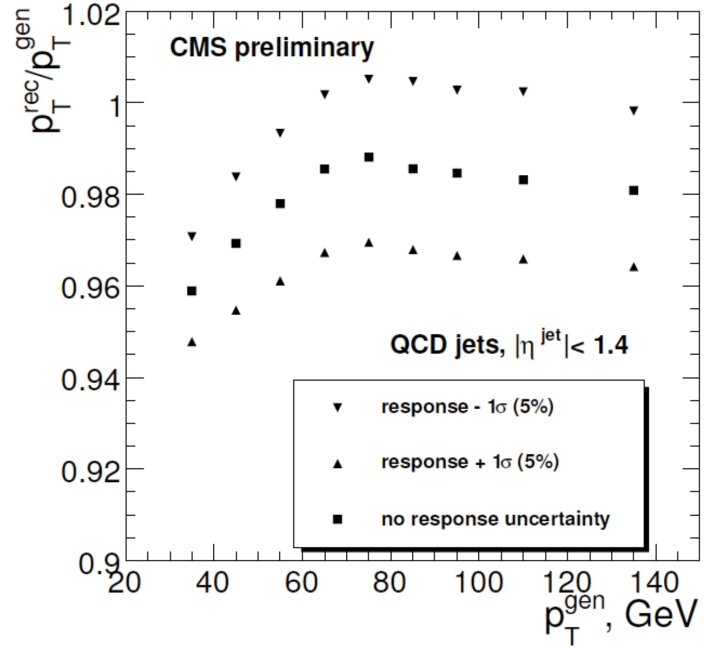


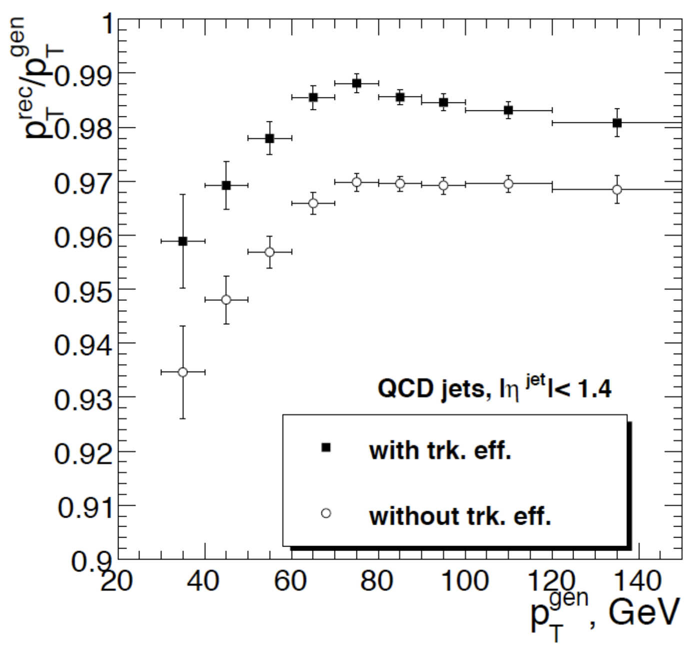







CMS preliminary
|η|<1
gluon-jets
quark-jets
p_T^{rec}/p_T^{gen}
p_T^{gen}, GeV
10^2


CMS preliminary
QCD jets, $|\eta^{jet}|< 1.4$
response - 1σ (5%)
response + 1σ (5%)
no response uncertainty
p_T^{rec}/p_T^{gen}
p_T^{gen}, GeV


QCD jets, $|\eta^{jet}|< 1.4$
with trk. eff.
without trk. eff.
p_T^{rec}/p_T^{gen}
p_T^{gen}, GeV