$\not{E}_T$ in CMS

Greg Landsberg

BROWN UNIVERSITY

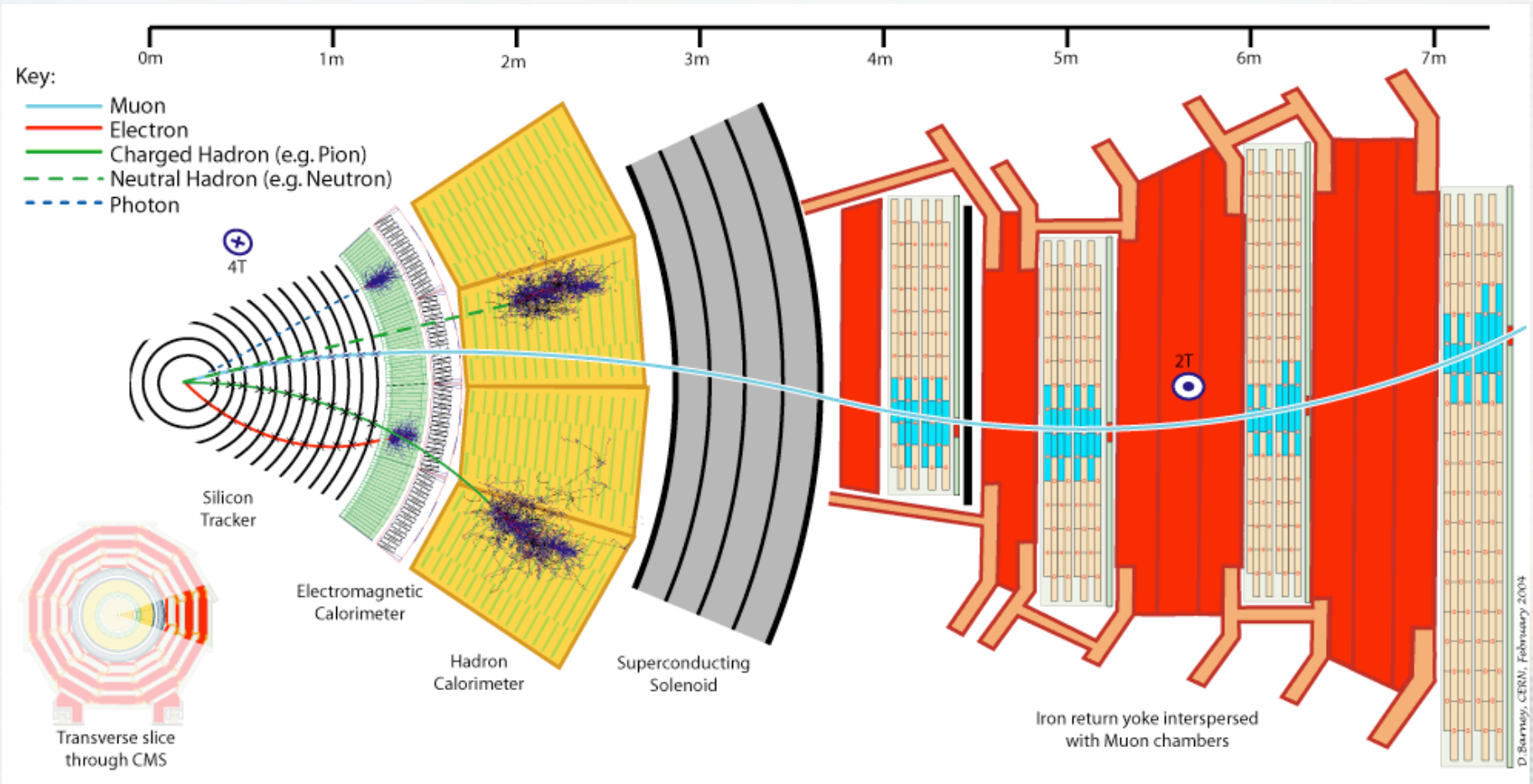
Missing Energy Signals at LHC

HEFTI Workshop, UC Davis

April 1, 2009

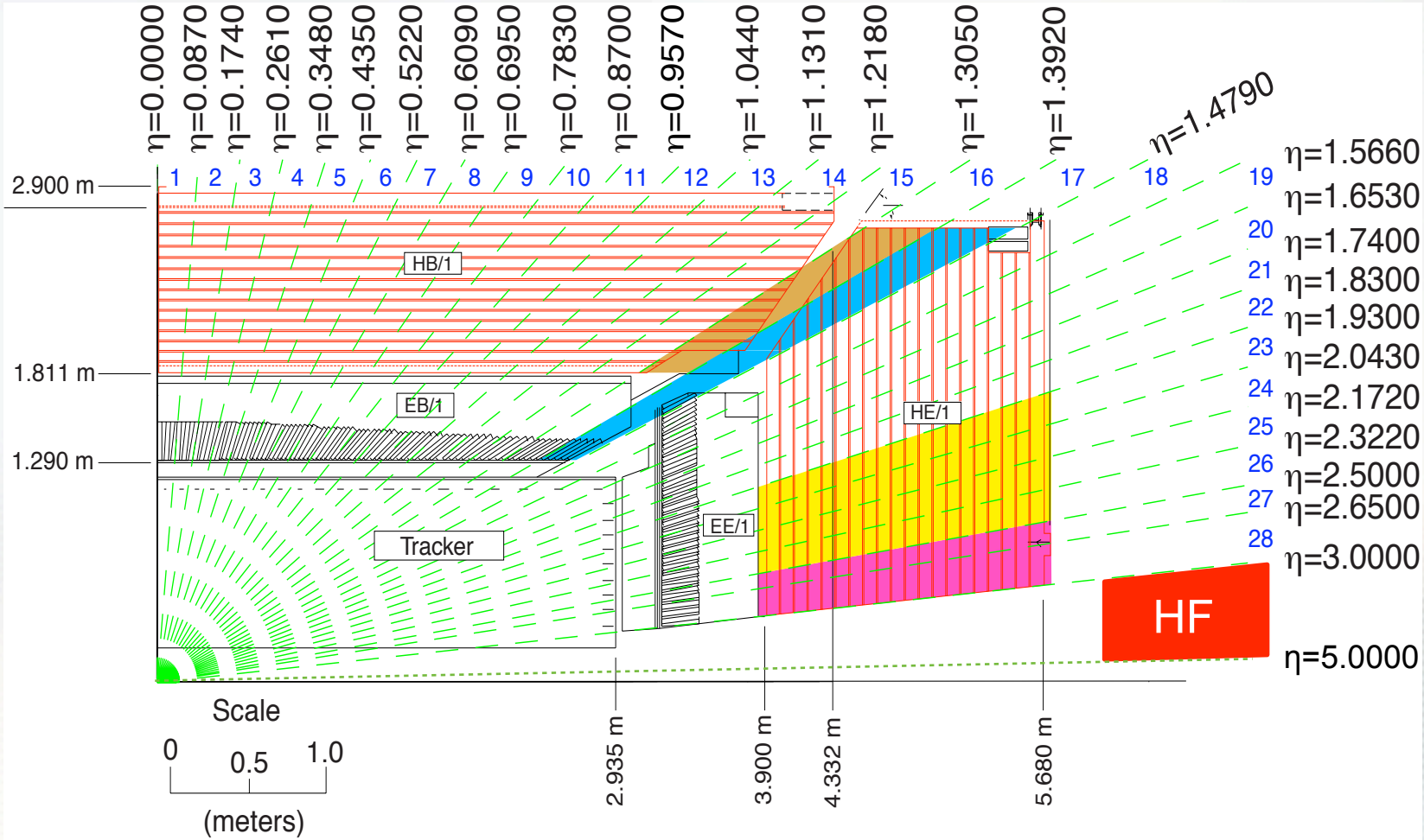
Collider Detector Concept

- Nearly 4π, hermetic, redundant, Russian-doll design



CMS Hermeticity

- CMS calorimeter coverage:
  - Central region: |η| < 3.0
  - Forward region (HF): 3.0 <|η| < 5.0



Monojets: Tainted History

EXPERIMENTAL OBSERVATION OF EVENTS WITH LARGE MISSING TRANSVERSE ENERGY ACCOMPANIED BY A JET OR A PHOTON(S) IN $p\bar{p}$ COLLISIONS AT $\sqrt{s}$ = 540 GeV

[PL, **139B**, 115 (1984)]

UA1 Collaboration, CERN, Geneva, Switzerland

Abstract

We report the observation of five events in which a missing transverse energy larger than 40 GeV is associated with a narrow hadronic jet and of two similar events with a neutral electromagnetic cluster (either one or more closely spaced photons). We cannot find an explanation for such events in terms of backgrounds or within the expectations of the Standard Model.

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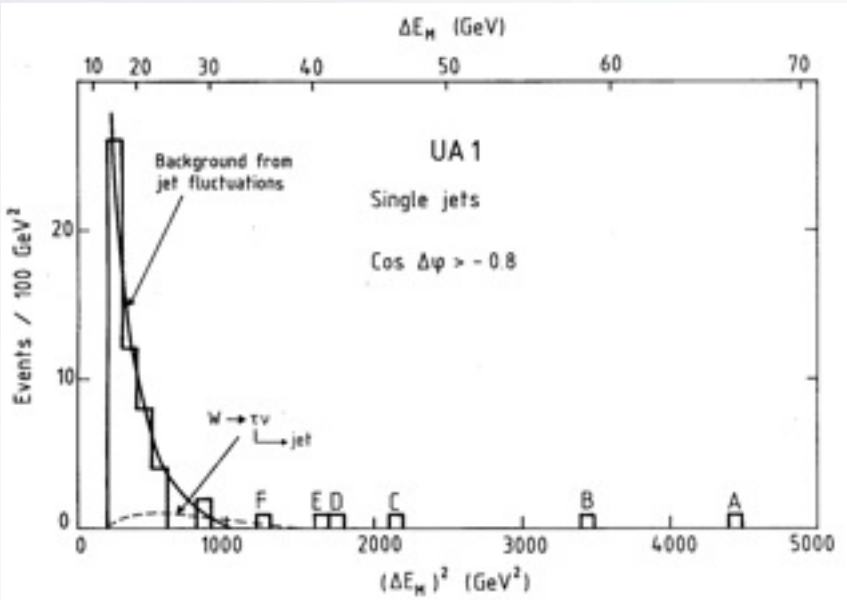
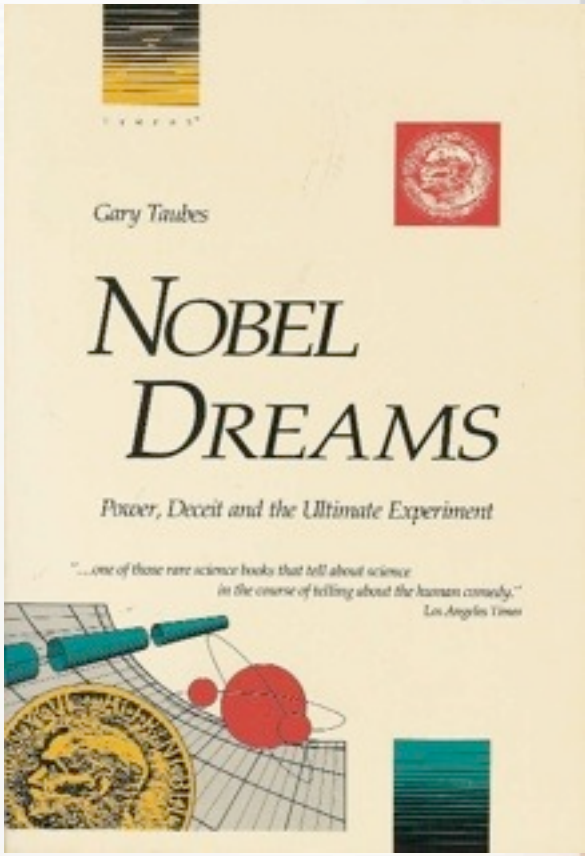
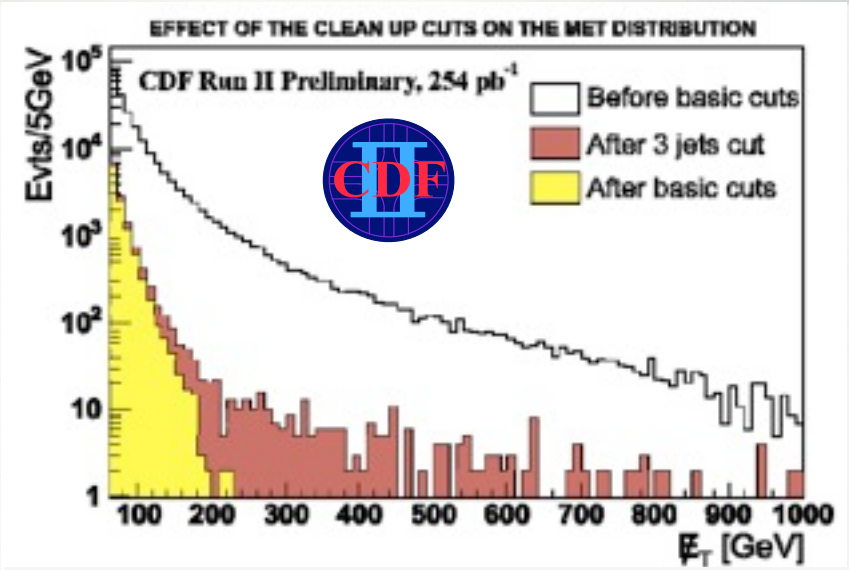


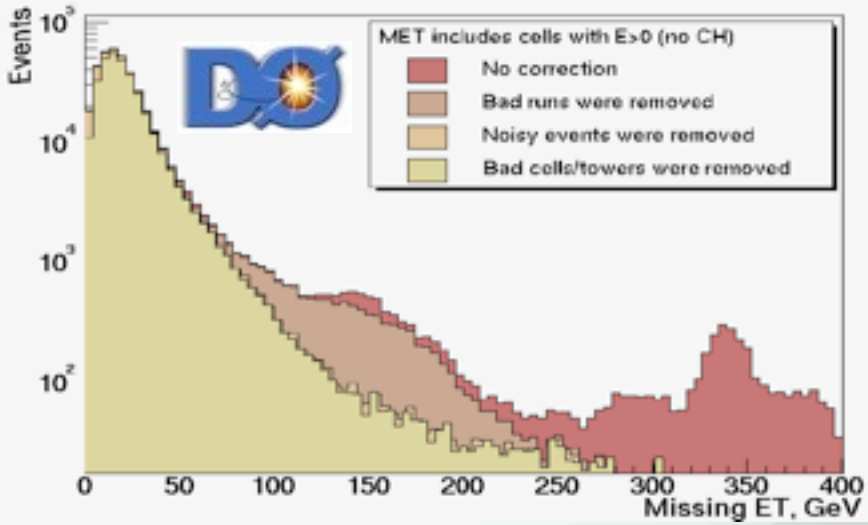


- These monojets turned out to be due to unaccounted background
- The signature was deemed doomed and nearly forgotten
- It took many years for successful monojet analyses at a hadron collider to be completed (CDF/DØ)

Why ME_T is Tough?

- Fake ME_T appears naturally in multijet events, which have enormous rate at the LHC
- Jets tend to fluctuate wildly:
  - Large shower fluctuation
  - Fluctuations in the e/h energy ratio
  - Non-linear calorimeter response
  - Non-compensation (i.e., e/h ≠ 1)
- Instrumental effects:
  - Dead or "hot" calorimeter cells
  - Cosmic ray bremsstrahlung
  - Poorly instrumented area of the detector
- Consequently, it will be a challenge to use in early LHC running
- Nevertheless, ME_T is one of the most prominent signatures for new physics and thus must be pursued





- Raw ME_T spectrum at the Tevatron and that after thorough clean-up

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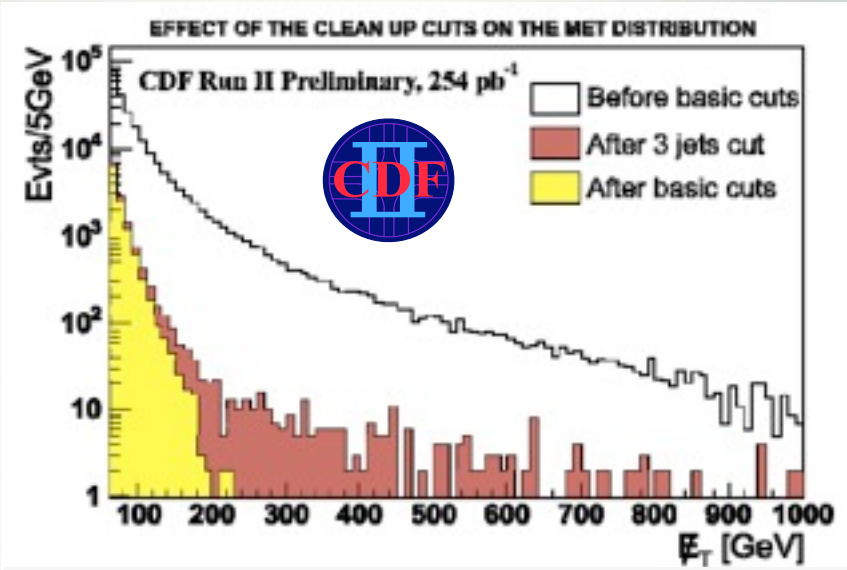

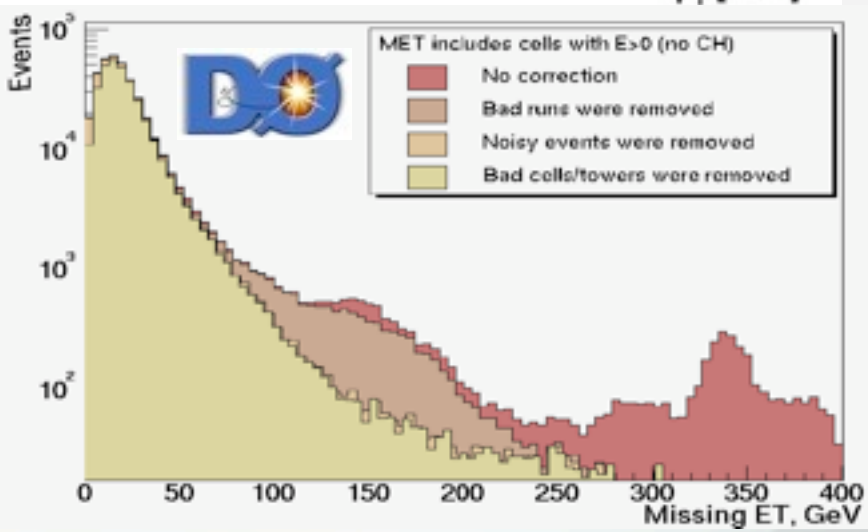

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ME_T Reconstruction and Performance

- Missing E_T is based on the calorimeter information and defined as a 2D-vector sum of transverse energy deposits in the calorimeter cells:

$$\vec{\not{E}}_T = -\sum_n (E_n \sin\theta_n \cos\phi_n \hat{\mathbf{i}} + E_n \sin\theta_n \sin\phi_n \hat{\mathbf{j}}) = -\not{E}_x \hat{\mathbf{i}} - \not{E}_y \hat{\mathbf{j}}$$

- In case of muons in the event, it receives an additional correction:

$$\vec{\not{E}}_T = -\sum_{i=1}^{\text{towers}} \vec{E}_T^{\,i} - \sum^{\text{muons}} \vec{p}_T^{\,\mu} + \sum_{i=1}^{\substack{\text{deposit}\\ \text{towers}}} \vec{E}_T^{\,i}.$$

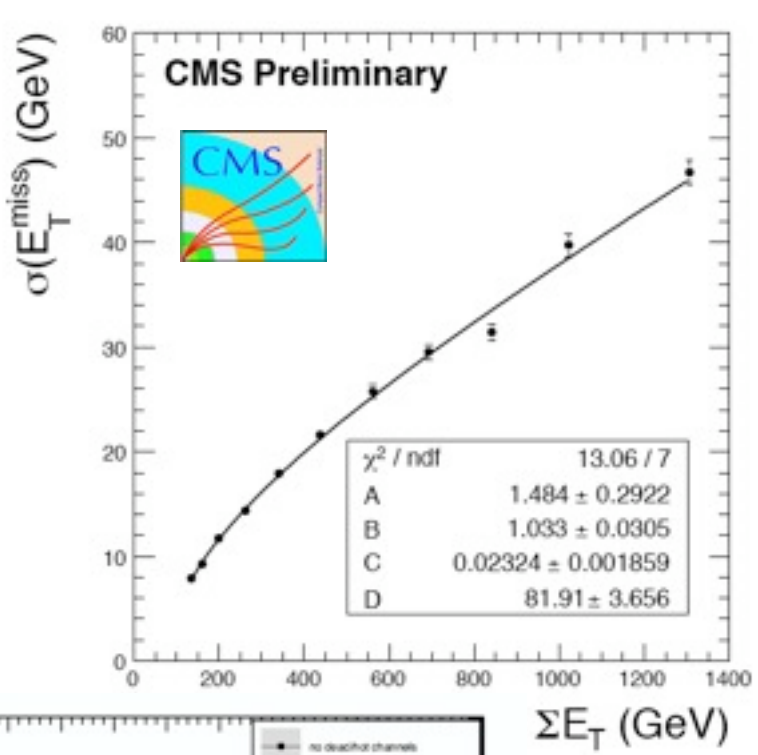
- ME_T resolution in QCD events depends on total transverse energy deposit in the calorimeter and is often parameterized as a function of scalar E_T sum over the calorimeter cells, or S_T:

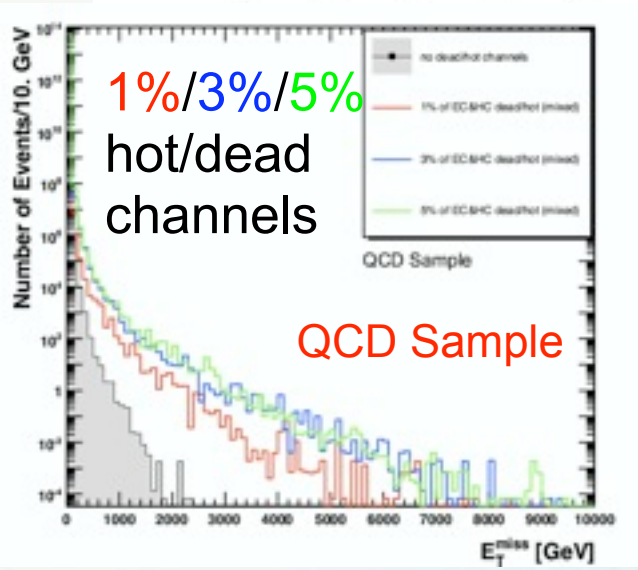
$$\sigma(\not{E}_T) = A \oplus B\sqrt{\Sigma E_T - D} \oplus C(\Sigma E_T - D)$$

Noise Stochastic Constant Offset

ME_T in CMS

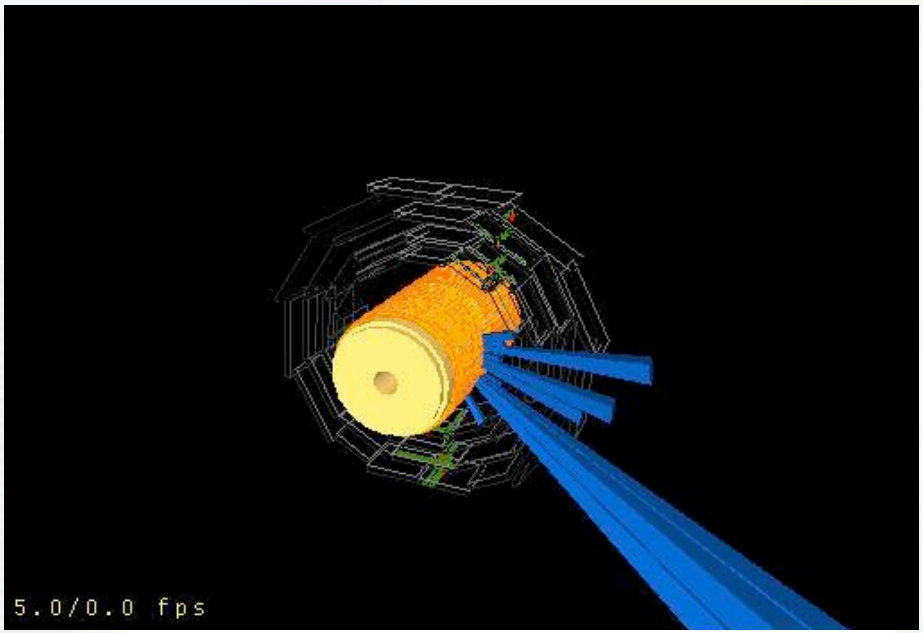
- Parameters:
  - A = 1.48 GeV
  - B = 1.03 $GeV^{1/2}$
  - C = 0.023 (dominates at large S_T)
  - D = 82 GeV
- Apart from the resolution an important characteristic is the non-Gaussian tails
- Very hard to simulate; will have to wait for real data to see how large the effect is
  - A few special cases have been looked at already, e.g. the effect of hot/dead channels

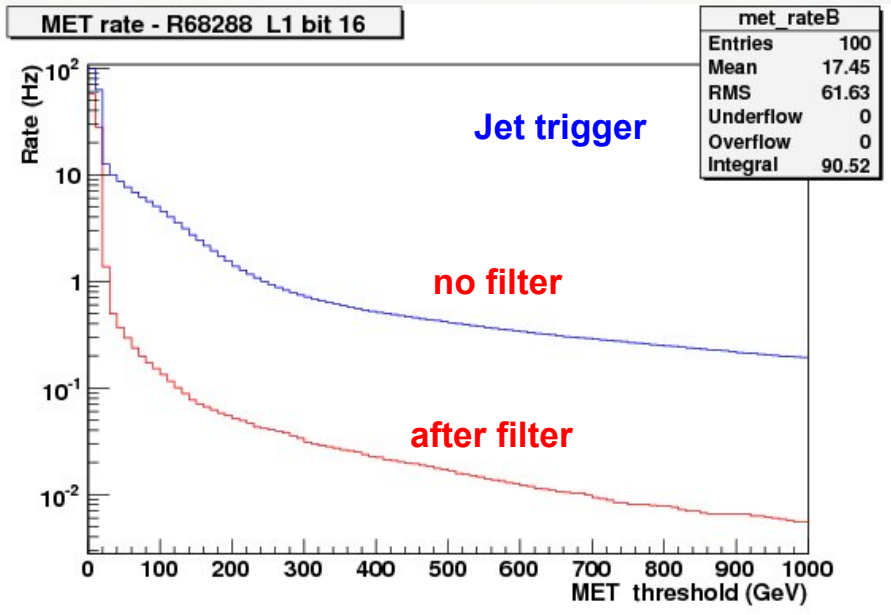




ME_T in Cosmic Ray Data

- Started commissioning of ME_T with cosmics data
- Focus on identifying calorimeter noise and developing filters to suppress it
- Not the final configuration of the detector; as a result of these tests the noisiest readout modules have been replaced
- Nevertheless the noise is under control for the trigger purposes and can be further reduced offline



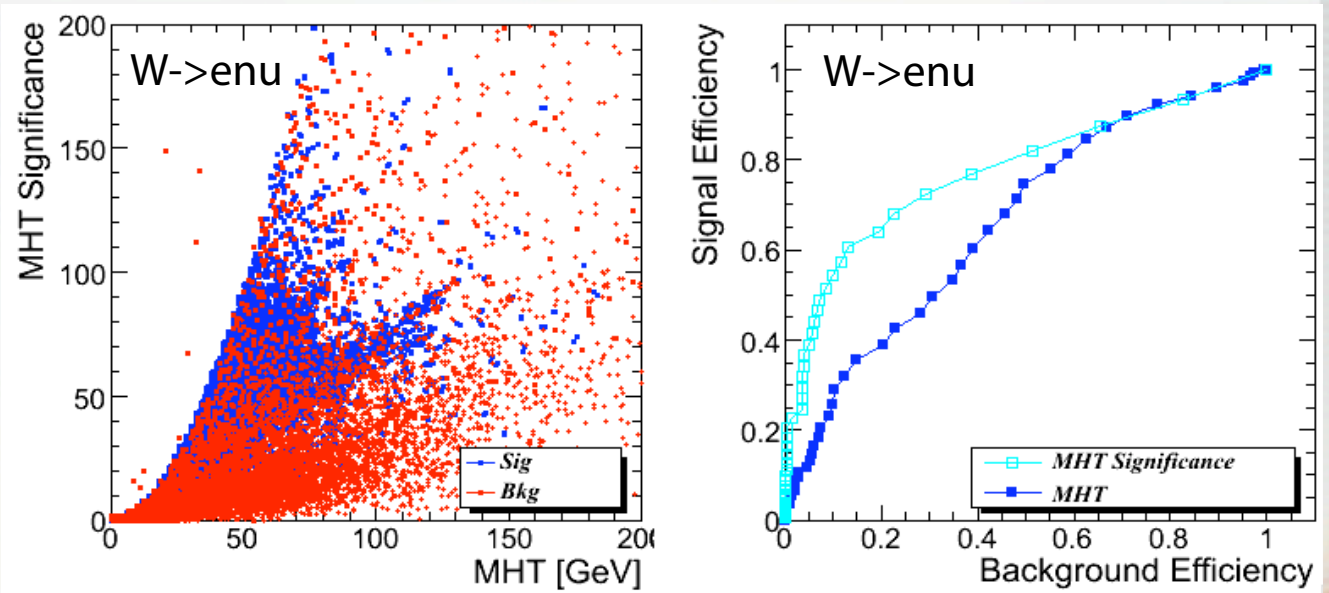


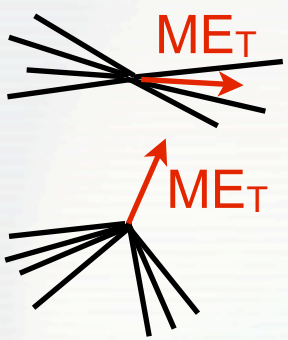
ME_T vs. MH_T

- ME_T is prone to instrumental effects
  - Hot/Dead calorimeter cells
  - Muon halo
- On the other hand, true ME_T is dominated by clustered energy (jets, EM clusters)
  - Unclustered energy is typically uniformly distributed
  - Consequently, the effect on ME_T goes as sqrt(ΣE_T) ("random walk") - equivalent to a slight increase in the stochastic term
- Most of instrumental effects won't be reconstructed as clustered energy (passing basic quality cuts)
- Thus, an alternative to ME_T is $MH_T = -\Sigma E^{(j)}_T$
  - Note that EM objects of sufficient energy are also reconstructed as jets
- CMS now uses MH_T at both trigger levels and offline!

ME_T Significance

- Consider event topology as well as resolution of individual objects,e.g. jets vs. EM objects
- Smear each object with its resolution and find the effect on ME_T
- Express the result in terms of significance (S) of ME_T not be consistent with zero





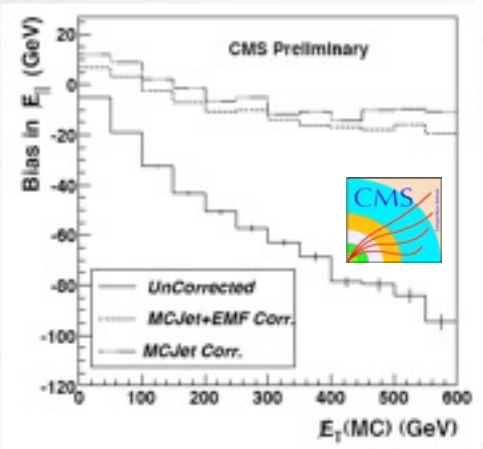
ME_T is easy to fake, $S \approx 0$

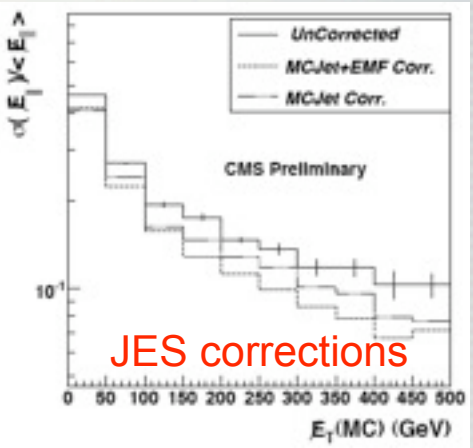
ME_T is hard to fake, $S \neq 0$

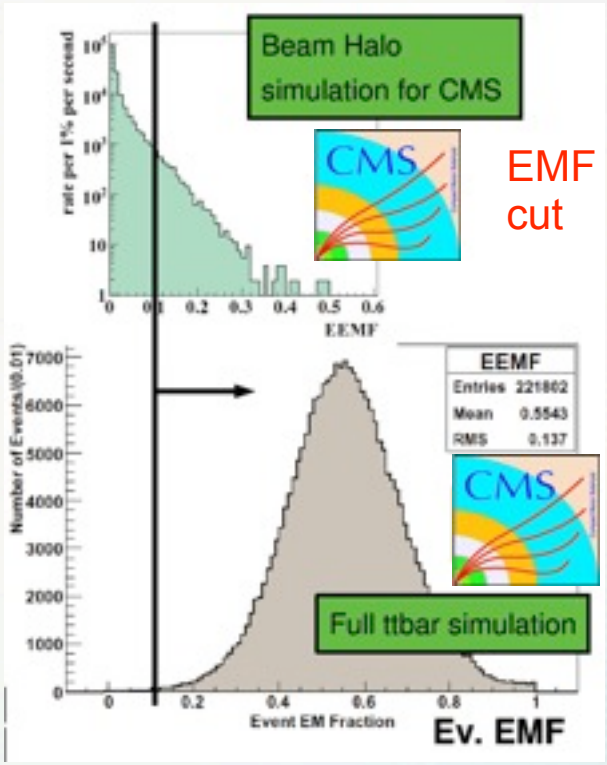
Significant improvement in signal vs. background separation for intermediate ME_T values

ME_T Corrections and Clean-Up

- To improve the resolution and remove possible bias for events with true ME_T, we correct ME_T for
  - Jet energy scale
  - Hadronic tau's
  - Muons
- The non-Gaussian tails are reduced by jet quality cuts, e.g. p_T/E_T or EMF
- Philosophy: make ME_T look as good as possible







Conclusions

- Robust ME_T is crucial for many early searches at the LHC (cf. Meenakshi Narain's talk)
- Yet, ME_T is one of the hardest objects to understand because of numerous instrumental effects
- At CMS, we have developed a number of handles for robust ME_T determination and a number of corrections to optimize ME_T performance
- ME_T triggering can be made robust using the MH_T variable
- First ME_T validation results using cosmics look quite promising: ME_T trigger rate is under control
- ME_T clean-up tools based on cosmic data experience are being commissioned
- Number of tools exist to monitor ME_T performance online and offline
- Eagerly anticipate collision data to validate ME_T performance