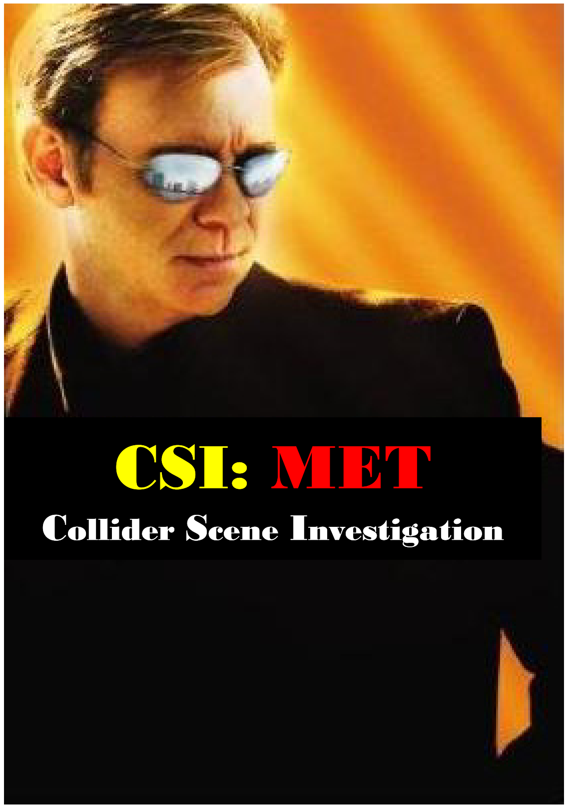
MISSING TRANSVERSE ENERGY

TERUKI KAMON

(TAMU/ Fermilab / Kyungpook National Univ.)



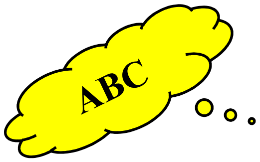
OUTLINE

1) "Why MET? - very exciting physics opportunities"

2) Concept of missing transverse energy (missing E_T or MET) to infer the escaping particles - neutrinos, weakly interacting non-SM particles (*e.g.*, SUSY dark matter particle), particles in very forward region ($|\eta| > 5$)

3) Three different techniques to calculate MET in CMS

4) Summary



… if you see this, it is a CMS or HEP jargon. Not in a physics textbook.

DISCOVERIES WITH “MET”

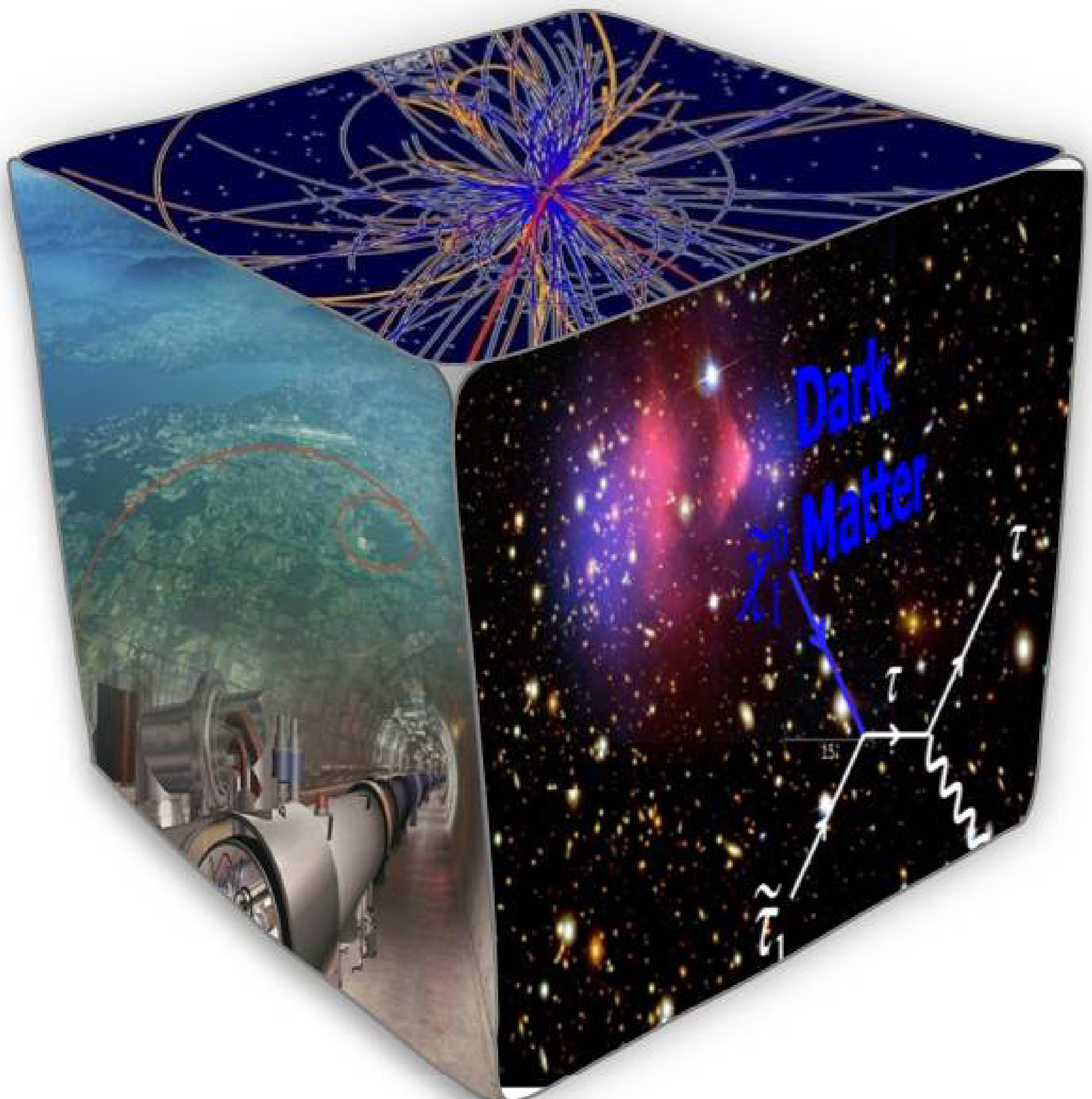
Standard Model’s CV	
1973	**B.S. – Neutral current**
	@ CERN SPS (400 GeV *p*)
1983	**M.S. – “*W*/*Z* discovery”**
	@ CERN Sp$\bar{p}$S (540 GeV $p\bar{p}$)
1995	**Ph.D. – “Top discovery”**
	@ Fermilab Tevatron (1.8 TeV $p\bar{p}$)
20??	**???**

$W \to e\nu$

$t \to W b$

MET - inferring neutrinos

MET(& JETS) AT THE LHC

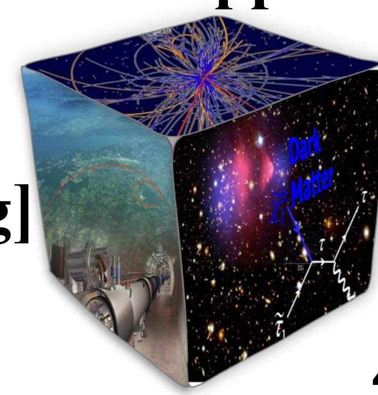


MET - inferring new physics (e.g., Dark Matter)

MET(& JETS) AT THE LHC

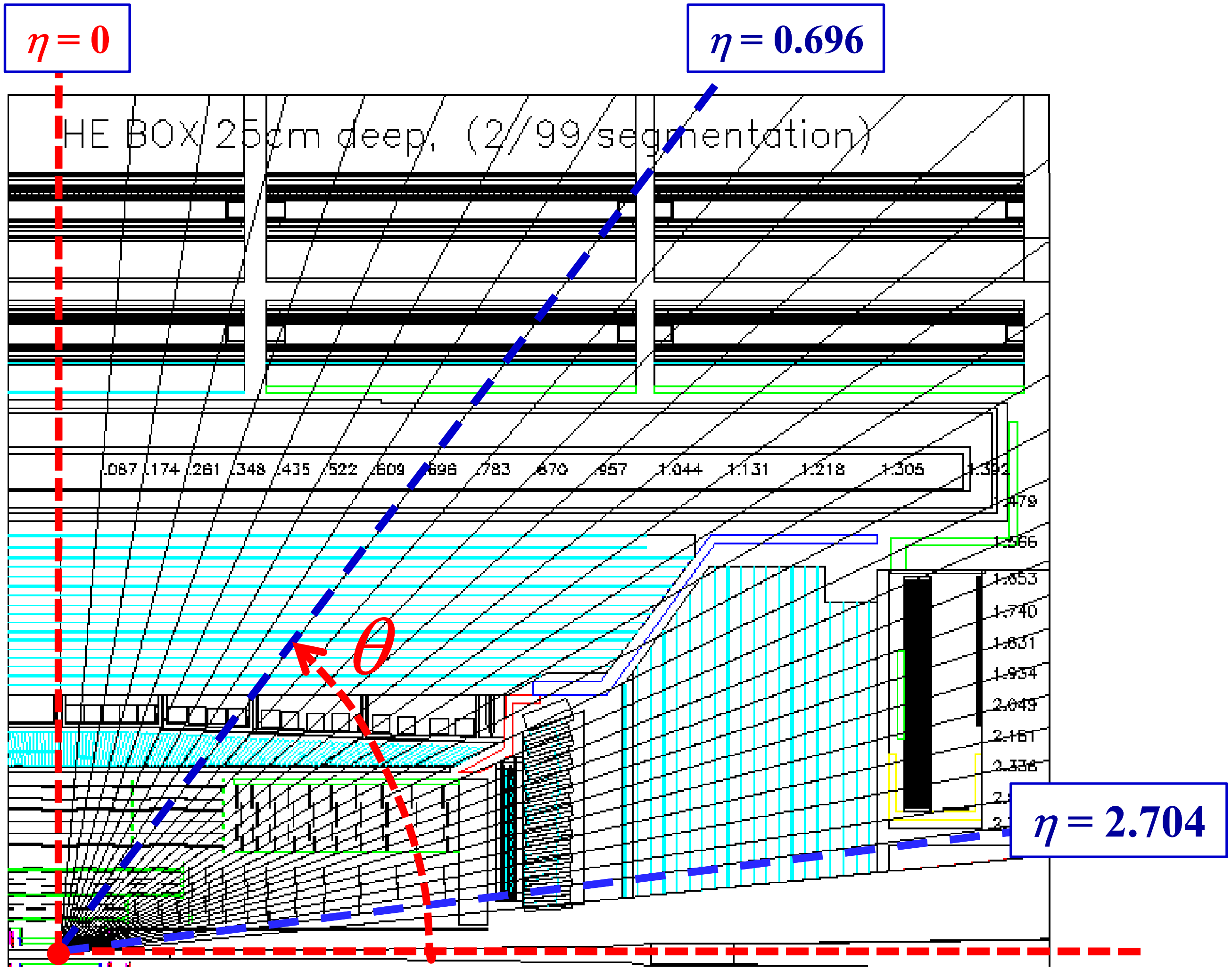
Example: SUSY with R-parity Conservation

- $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, or $\tilde{q}\tilde{q}$ production will be dominant, followed by their decays (e.g., $\tilde{q} \rightarrow q\tilde{\chi}_2^0$). → **Jets**
- R parity conservation
  - Stable lightest supersymmetric particle (LSP)
  - If LSP is the lightest neutralino ($\tilde{\chi}_1^0$),
    - it will escape the detector → **MET** ($\not{E}_T$)
    - $\tilde{\chi}_1^0$ = Cold Dark Matter candidate → **Cosmology**
  - Thus, the evidence of SUSY-like new physics will appear in the Jets+MET final states.
- **Cosmology** + **LHC**
  = [Exciting Motivation]+ [Right Place&Timing]

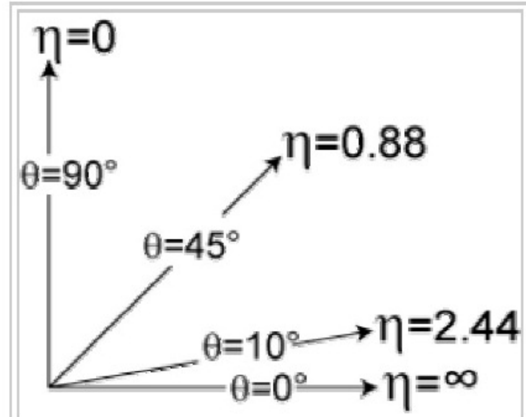


STARTING WITH "TOWER" GEOMETRY

A design to measure the direction of energy flow



$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



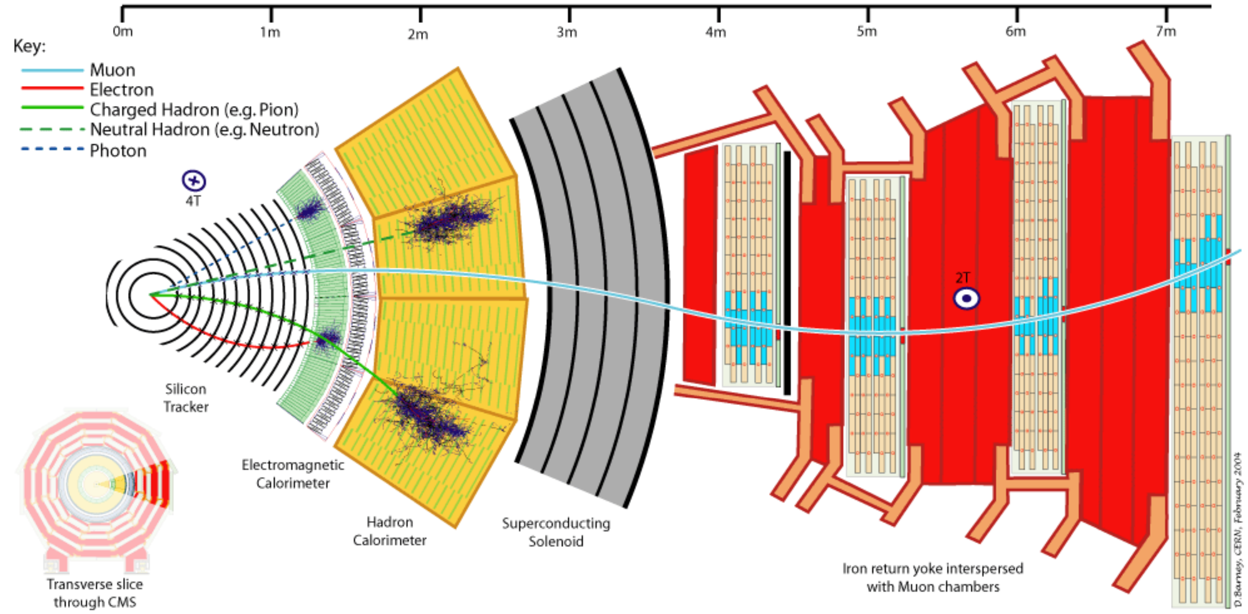
As angle increases from zero, pseudorapidity decreases from infinity. In particle physics, an angle of zero is usually along the beam axis.

Forward Calorimeter, *not* shown

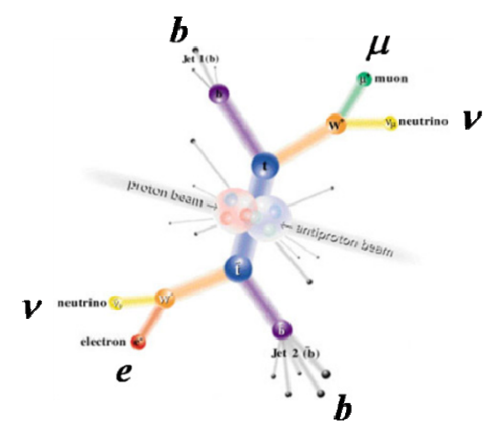
$$\vec{E}_{\text{tower}} = \left(E_{\text{tower}} \sin\theta \cos\phi\right)\hat{i} + \left(E_{\text{tower}} \sin\theta \sin\phi\right)\hat{j} + \left(E_{\text{tower}} \cos\theta\right)\hat{k}$$

PARTICLE IDENTIFICATION (ID)

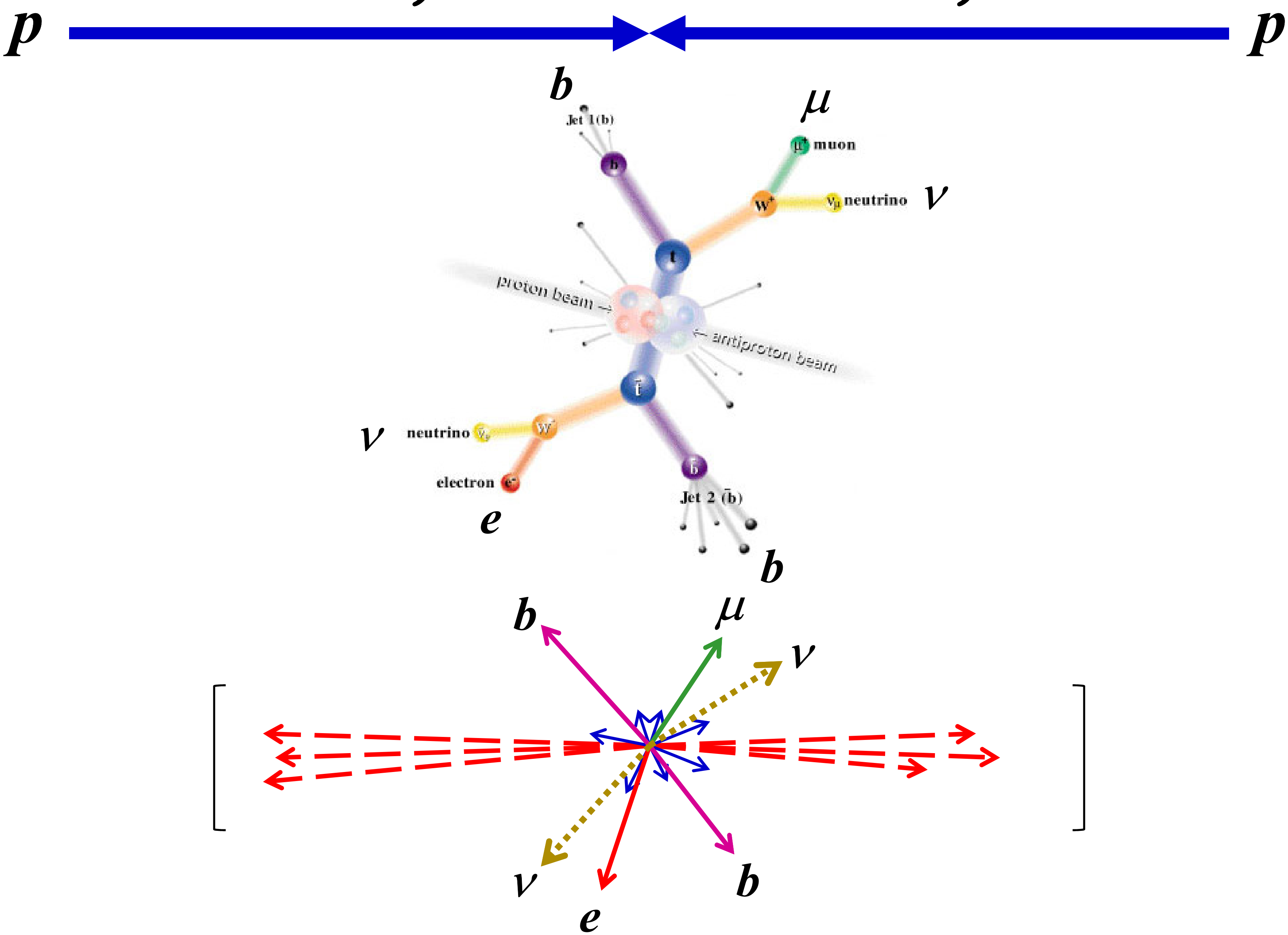
Identify all particles and measure their 4-vectors



Global μ

Object Reconstruction	Particle ID	Physics Objects
Global muon reconstruction	Muons	
HCAL clusters w/ tracks	Charged hadrons	
ECAL clusters w/ tracks	Electrons	
HCAL clusters w/o tracks	Neutral hadrons	
ECAL clusters w/o tracks	Photons	
HCAL, ECAL w/ tracks	Quarks, gluons	

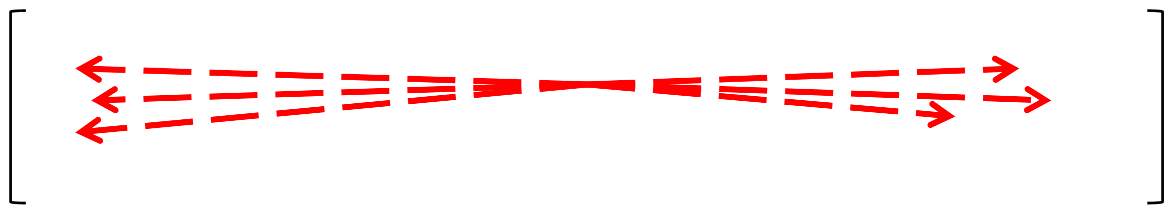
COLLISION, PRODUCTION, DECAYS



MOMENTUM IMBALANCE

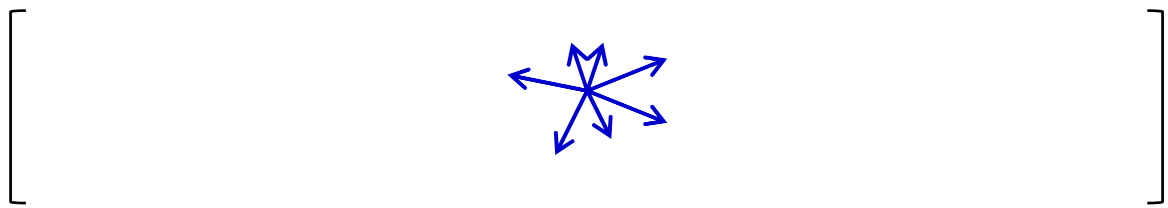
$$\sum_{\nu} \vec{p} + \sum_{visible} \vec{p} = \vec{0} \quad \Rightarrow \quad \sum_{\nu} \vec{p} = - \sum_{visible} \vec{p} \equiv \underbrace{\not{p}}_{p \text{ slash}}$$

A

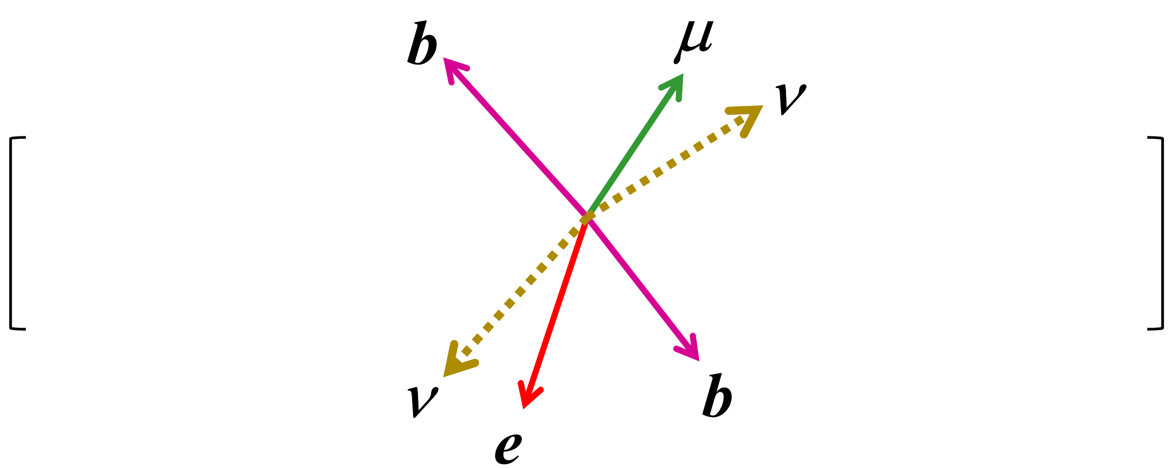


Escaping from CMS
$|\eta| > 5$

B



C

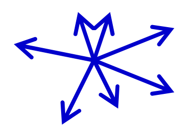


"MET" CREATION

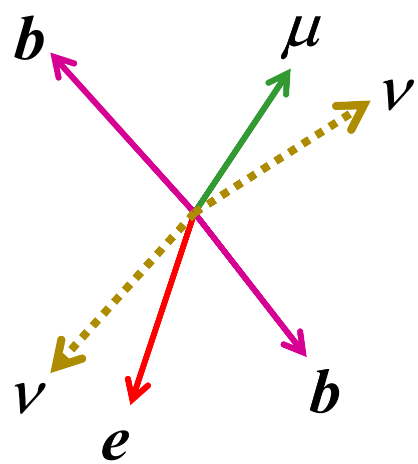
$$\not{p}_T \approx \begin{cases} \vec{\not{E}}_T^{\text{calo}} = -\sum \vec{E}_{T(\text{tower})} \\ \not{H}_T = -\sum\limits_{p_T > p_T^{\text{th}}} \vec{p}_T^{\text{calo jet}} \\ \vec{\not{E}}_T^{\text{PF}} = -\sum \vec{p}_T^{\text{PF object}} \end{cases}$$

Calo MET
Missing HT
PF MET

B



C



"MET" CORRECTIONS

MET corrections are necessary to bring to the true value.

1) Muon Correction

- Replace muon calorimeter response with muon track momentum

2) Jet Energy Scale (JES) Correction

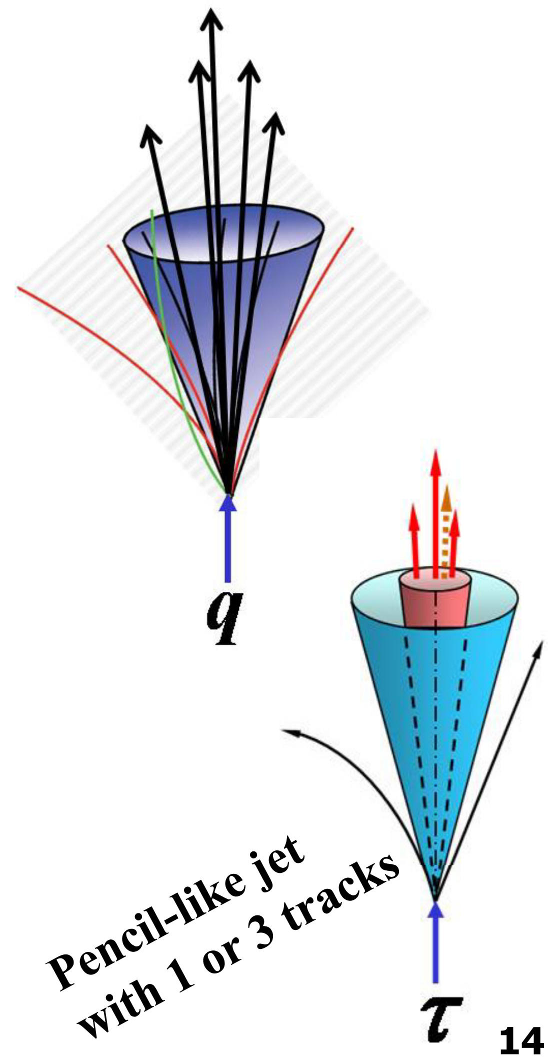
- Calibrate calorimeter towers (or cells) within jets as a function of η, p_T, and EM fraction

3) Unclustered Energy and Pile-up Correction

- Account for response variations due to unclustered particles, soft particles, and double counting in JES from (i) underlying event (UE) and (ii) pile-up (PU).

4) Tau Correction

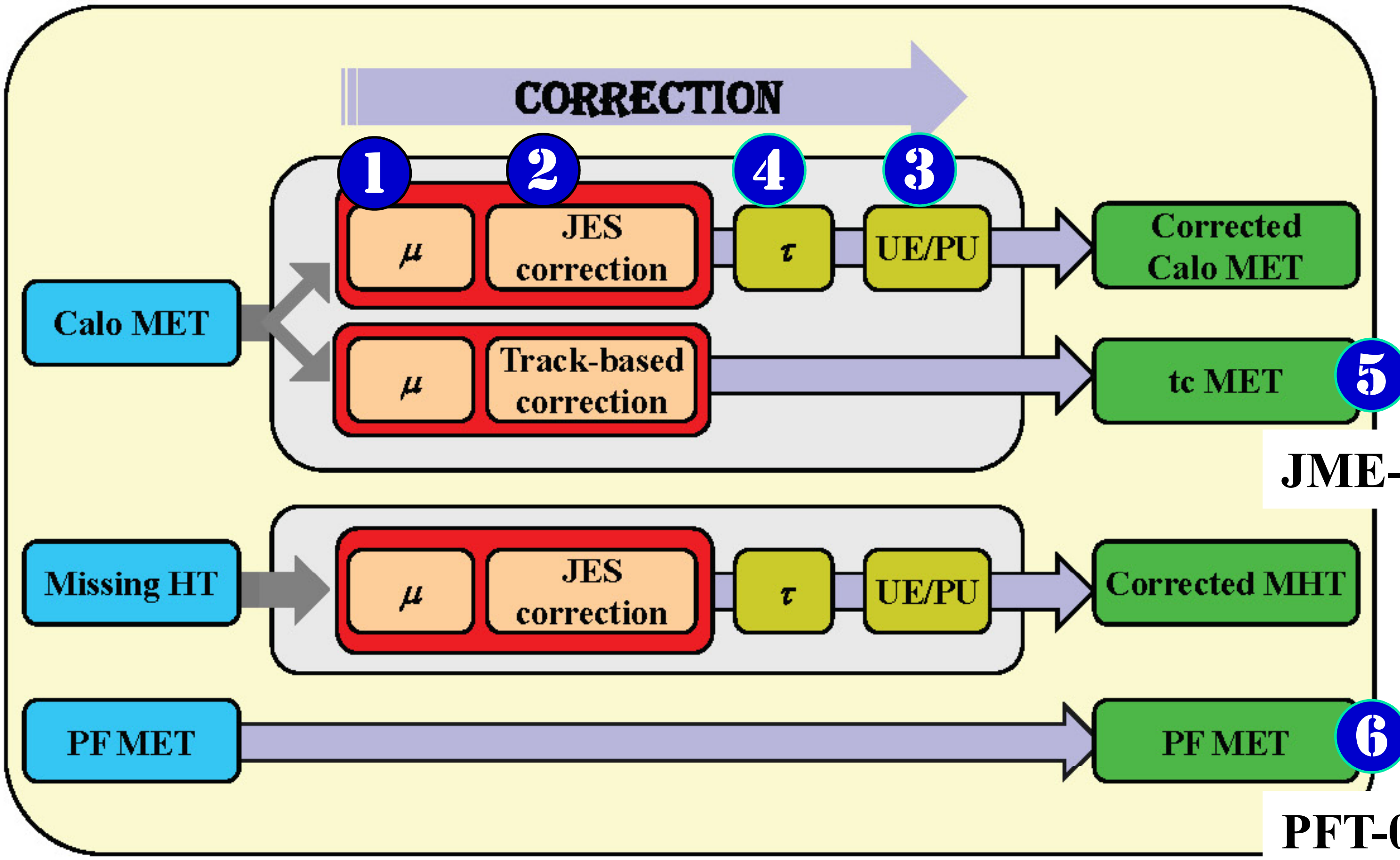
- Account for difference in its energy scale between hadronically-decaying taus and light-flavor jets



SEQUENCE OF MET CORRECTIONS

MET corrections are necessary to bring to the true value:

$$\vec{E}_T^{\,\text{corr}} = -\vec{E}_T^{\,\text{calo}} + \vec{\Delta}_\mu + \vec{\Delta}_{\text{JES}} + \vec{\Delta}_{\text{UE\&PU}} + \vec{\Delta}_\tau + \ldots$$

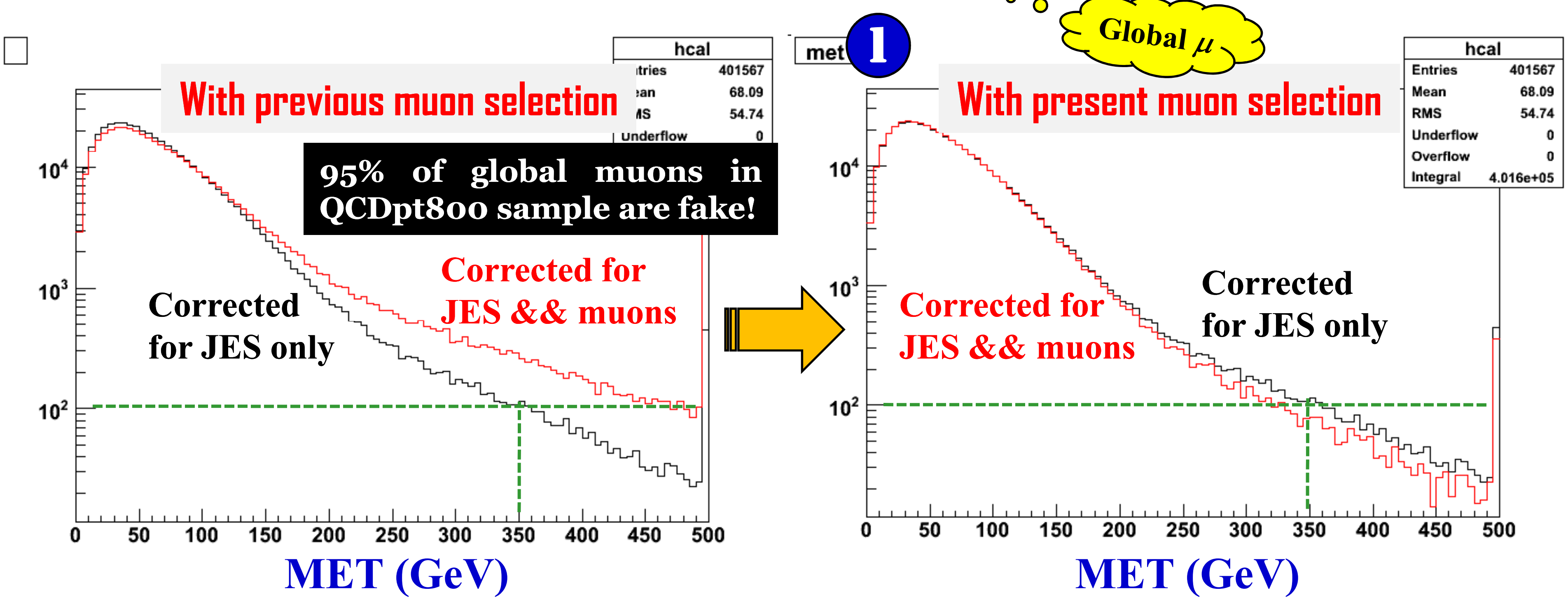


JME-09-010

PFT-09-001

MUON SELECTION FOR MET

QCD P_T > 800 GeV with at least one global muon P_T > 10 GeV



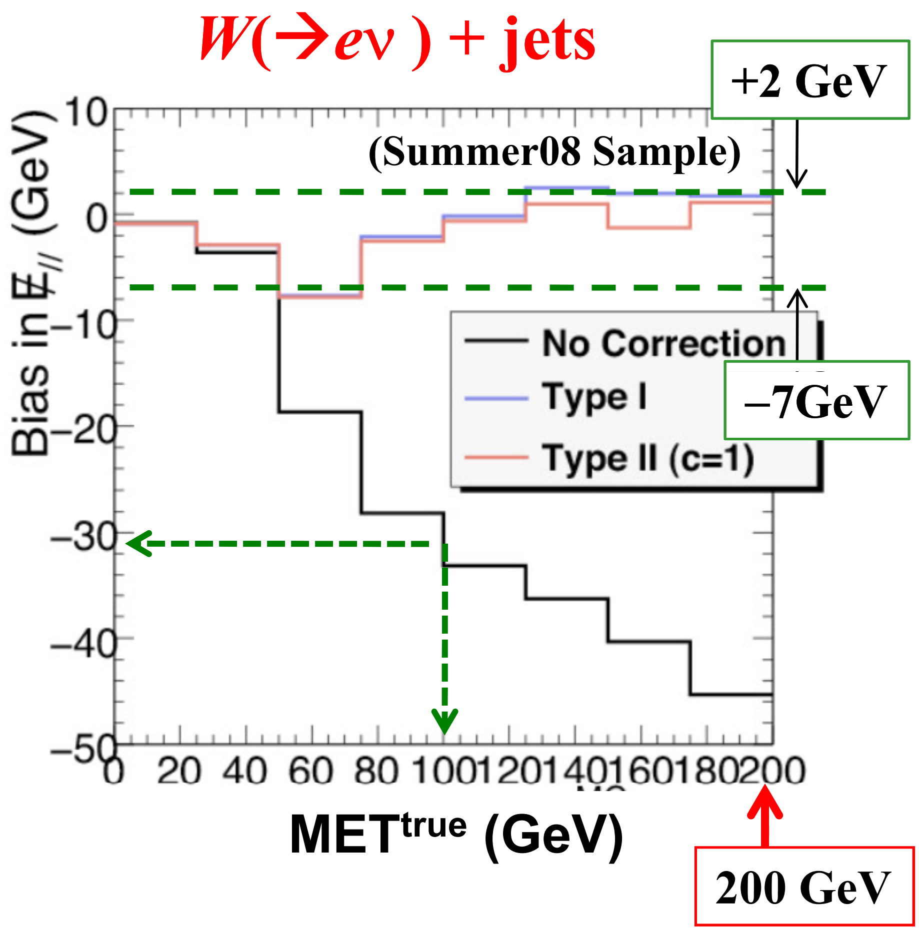
	"good" muons	"fake" muons
Global muons, no cuts	**100%**	**100%**
d_0 < 2 mm, number of hits > 10	**96%**	**76%**
Must be a tracker muon	**95%**	**27%**
χ^2 cut (< 10)	**93%**	**9.7%**

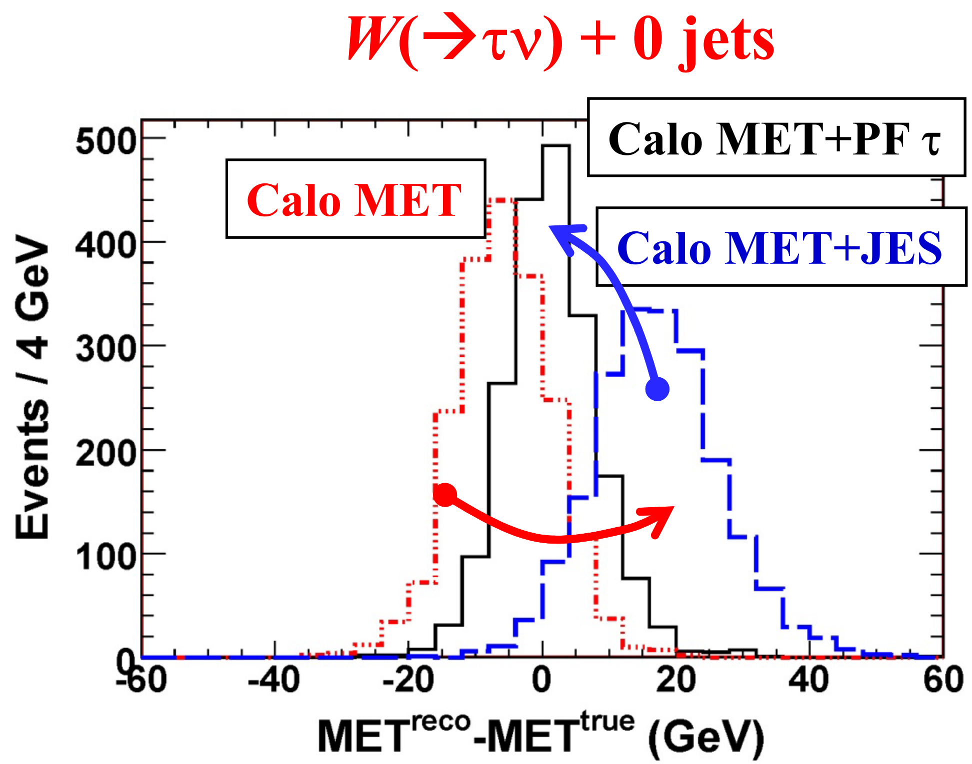
tracker μ

MUON, JETS, AND TAU CORRECTIONS

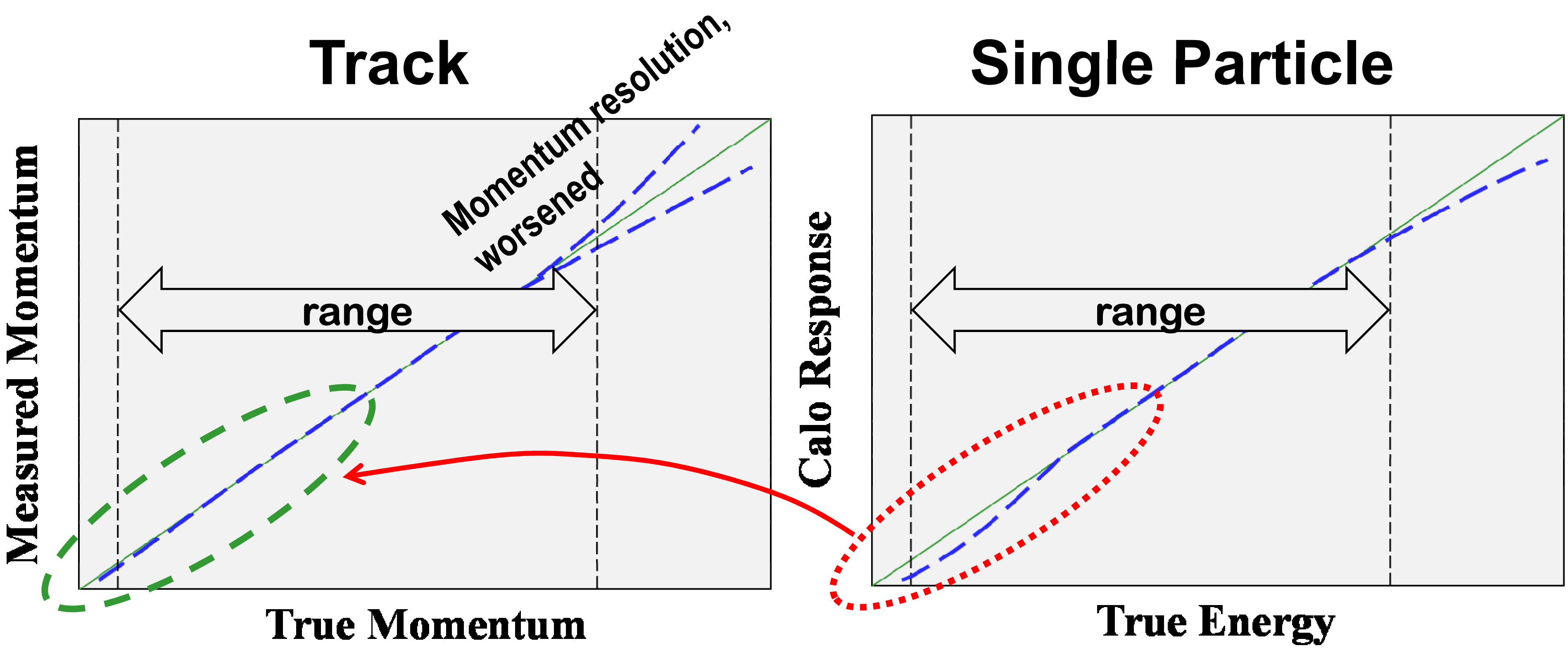
❶❷ "Type I" = μ + JES
❸ "Type II" = UE + PU

❹ jet $\neq \tau$





MET USING TRACKS



Track-corrected MET (tcMET)

$$\vec{E}_T^{\,\text{calo}+\mu+\text{track}} = -\vec{E}_T^{\,\text{calo}} + \Delta_\mu + \underbrace{\sum_{\text{B, C}} \left(RF(p,\eta) - \vec{p}_T \right)}_{\Delta_{tc}}$$

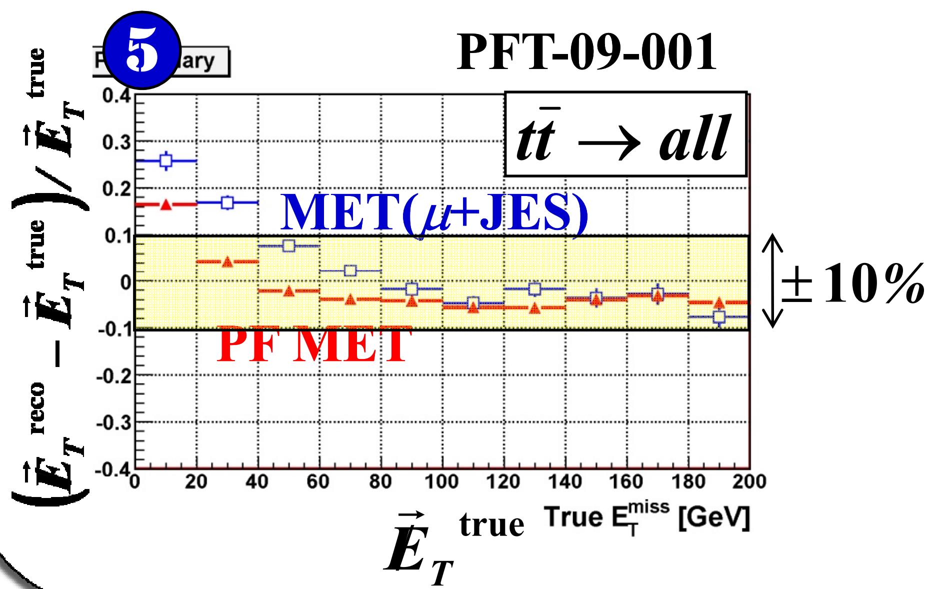
MET USING ALL SUB-DETECTORS

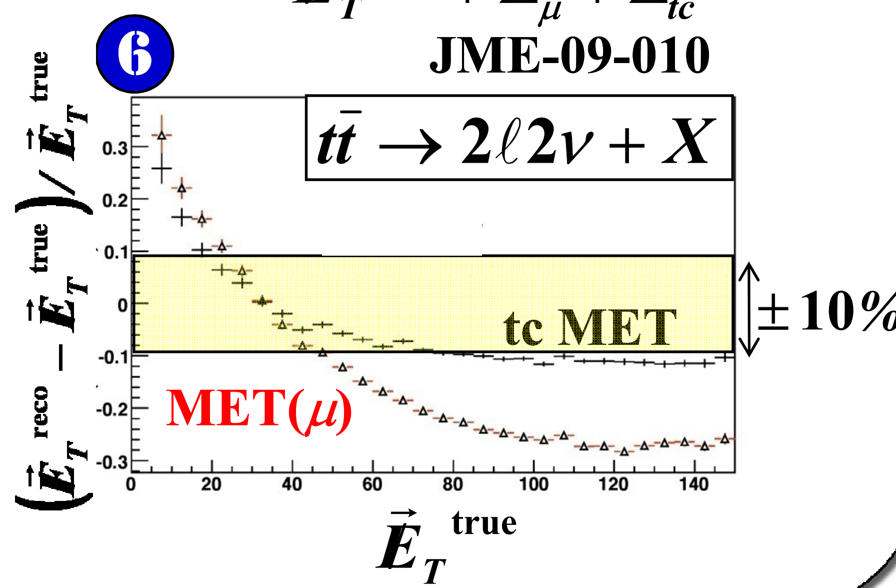
Particle Flow Algorithm: Individual particles (e, μ, τ, π, γ, N^0, V^0, PU, NI) are reconstructed and identified by thoroughly exploiting the characteristics of all sub-detectors simultaneously. This algorithm will maximize its efficiency, purity, and accuracy.

$$\left(\vec{E}_T^{\text{reco}} - \vec{E}_T^{\text{true}}\right) / \vec{E}_T^{\text{true}}$$

$$\vec{E}_T^{\text{PF}} = -\sum_{\text{B, C}} \vec{p}_T^{\text{PF object}}$$

$$\vec{E}_T^{\text{calo}+\mu+\text{track}} = -\vec{E}_T^{\text{calo}} + \Delta_\mu + \Delta_{tc}$$



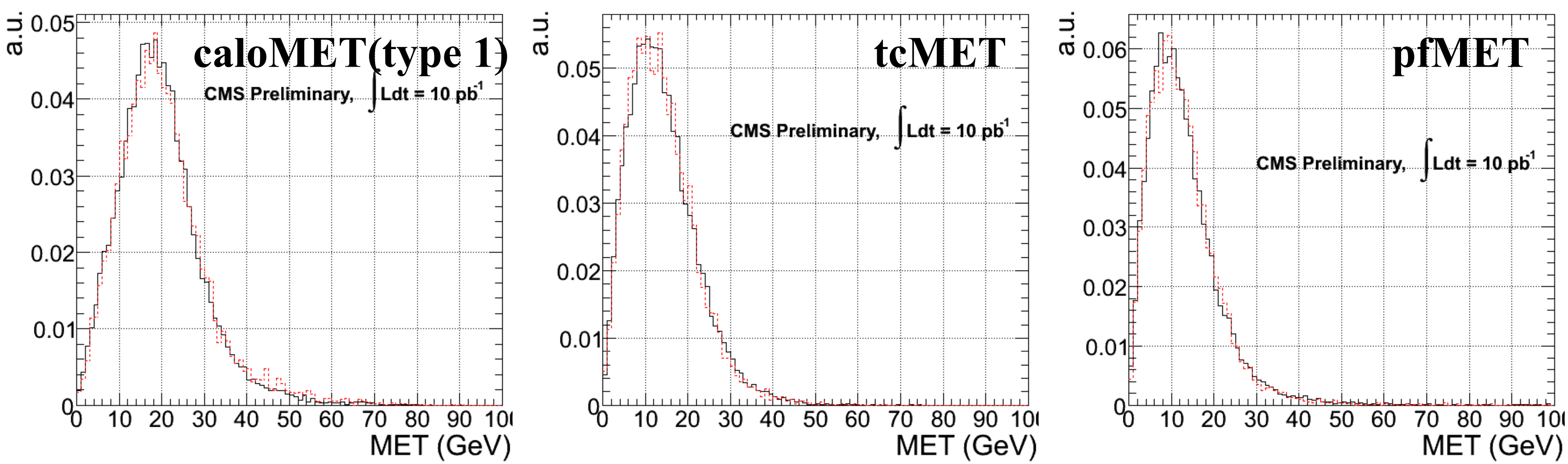


ROBUSTNESS

CaloMET, tcMET, and pfMET are conceptually different, but provide:

1) respective performances with largely independent systematic uncertainties and different failure modes;
2) rapid understanding and a robust determination of the missing transverse energy in CMS, especially for the first collision data at the LHC.

Example [EWK-*e* group]: understanding the MET shape in dijet & γ+jet events for $\sigma(W \rightarrow e\nu)$



MET "EXERCISE" BOXES

All MET-related tasks are interconnected with DPG, POG and PAG.

MET Data Quality Monitoring

- Abnormal Cell Handling
- Noise Cleanup
- Cosmic Ray Muon Tag
  Beam Halo Muon Tag

- MET & MHT Triggers
- MET Trigger Monitoring
  MET > 100 Express Stream

ϕ / η Calibration

JES Correction

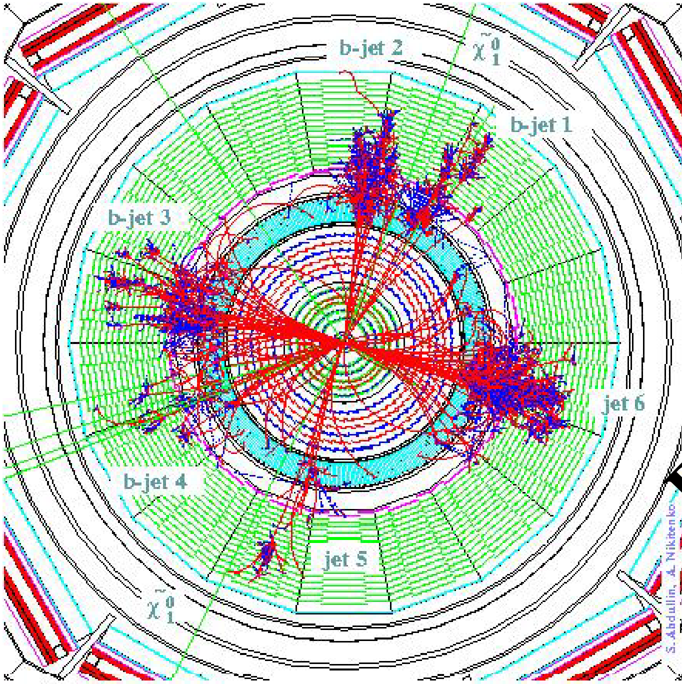
MET Creation/Correction

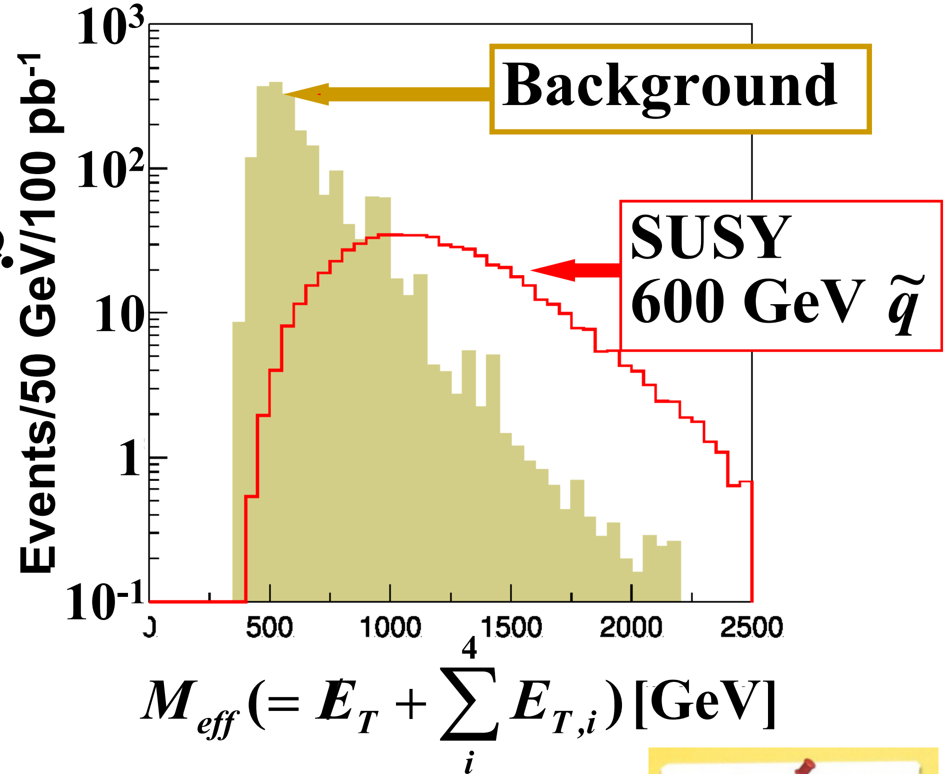
- CaloMET, Type I (JES, mu), tau , Type II
- MHT
- Track-corrected MET
- PF-MET
- MET & MHT significances
- Optimization of tower energy thresholds

MET Scale Validation with Data

- No real MET sample: $Z(\rightarrow ll)$ + jets
- Low MET sample: $W(\rightarrow l\nu)$ + jets
- Medium MET sample: $t\bar{t}$
- Explore new physics with high MET

AN EXCESS – NOT DISCOVERY





CMS MET Conveners

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US CMS Institutions

Brown, UC San Diego, UC Santa Barbara, UC Riverside, Cornell, Fermilab, Florida, U of Illinois at Chicago, Iowa, Maryland, Princeton, Rockefeller, Texas A&M, …

“SUPERSYMMETRISTS, BEWARE!”

SUMMARY

J. Ellis, SUSY07

Zoom To Fit

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-EP/84-42
29 March 1984

Experimental Observation of Events with Large Missing Transverse Energy Accompanied By a Jet or Photon(s) in ppbar Collisions at /s = 540 GeV

UA1 Collaboration, CERN, Geneva, Switzerland

Aachen[1]-Annecy(LAPP)[2]-Birmingham[3]-CERN[4]-Harvard[5]-Helsinki[6]-Kiel[7]
Queen Mary College, London[8]-NIKHEF, Amsterdam[9]-Paris(Coll.de France)[10]-Riverside[11]
Roma[12]-Rutherford Appleton Lab.[13]-Saclay(CEN)[14]
Vienna[15]-Wisconsin[16] Collaboration

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.

(submitted to Phys. Lett. B)

CERN-TH.3968/84

IS SUPERSYMMETRY FOUND?

John Ellis
CERN — Geneva

and

Marc Sher **)
University of California, Irvine

ABSTRACT

Monojet events seen recently by the UA1 collaboration at the CERN $p\bar{p}$ Collider may be due to squarks or gluinos with masses O(40) GeV. The thinness of the observed jets favours the squark interpretation. In this case, we predict that sleptons should have masses between 20 and 30 GeV and that the photino should have a mass between 5 and 10 GeV. Such masses are close to the experimental lower limits and sparticles could soon be detectable in $e^+e^- \to (\tilde{\gamma}\tilde{\gamma})\gamma$ experiments and $W^\pm$ and Z^0 decay. We demonstrate that such light sparticle masses are consistent with models whose weak gauge symmetry breaking is driven by a t quark weighing O(40) GeV as recently reported, and even with no-scale models in which the supersymmetry breaking scale is also determined dynamically.

CERN-TH.3968/84
July 1984