# Missing $E_T$ and jets, trigger and reconstruction efficiency in CMS

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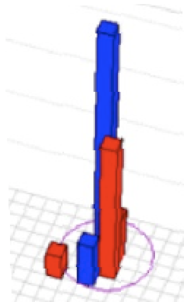
# Introduction

- Missing $E_T$ (MET) and jets play an important role in charged Higgs searches for both
  - in the charged Higgs decay signatures
  - in the backgrounds
- It is therefore crucial to have a good understanding in the reconstruction of MET and jets
- Understanding various triggers is equally crucial
  - Jet, MET, muon and electron/photon triggers are used for signal and/or background studies
- This talk covers
  - Jet and MET reconstruction in CMS
  - Jet and MET performance in 7 TeV collision data
  - Trigger performance in 7 TeV collision data

# Jet and MET reconstruction in CMS

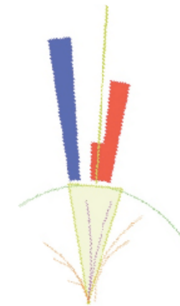
## Calorimeter Jets

Jets clustered from ECAL and HCAL deposits (Calo Towers)
Correspondingly **Calo MET**



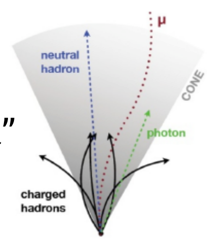
## Jet-Plus-Track Jets (JPT)

Subtract average calorimeter response from CaloJet and replace it with the track measurement
Correspondingly **Tc MET**



## Particle Flow Jets

Cluster Particle Flow objects:
Unique list of calibrated particles “à la Generater Level”
Correspondingly **PF MET**




## Track Jets

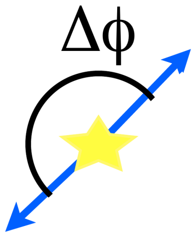
Reconstructed from tracks of charged particles
Independent from calorimetric jet measurements

Default jet clustering algorithm: Anti-$k_T$ with R=0.5

# Jet performance in $\sqrt{s} = 7$ TeV data

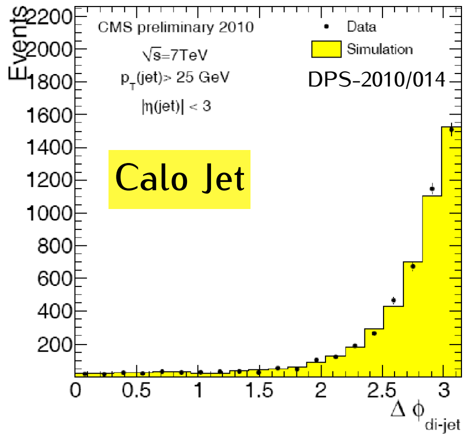
Jet energy scale and $p_T$ resolution

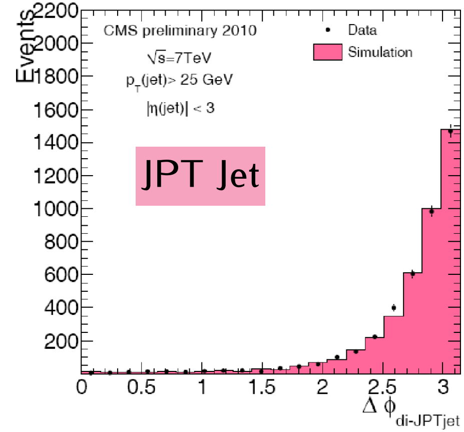
# Example: dijet $\Delta\phi$

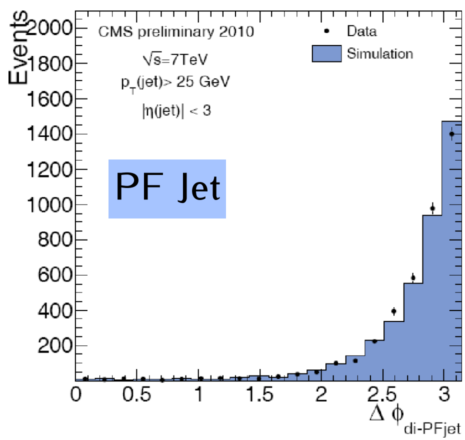


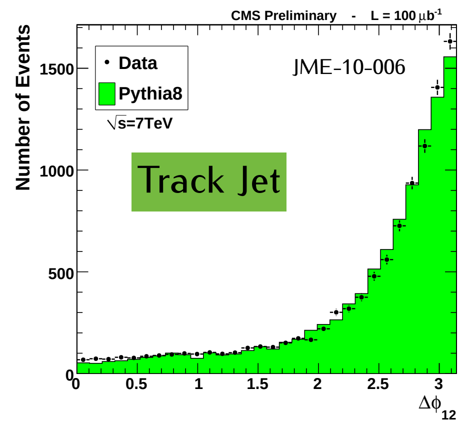

Important variable to select a clean dijet sample

Good agreement for all jet types between data and MC



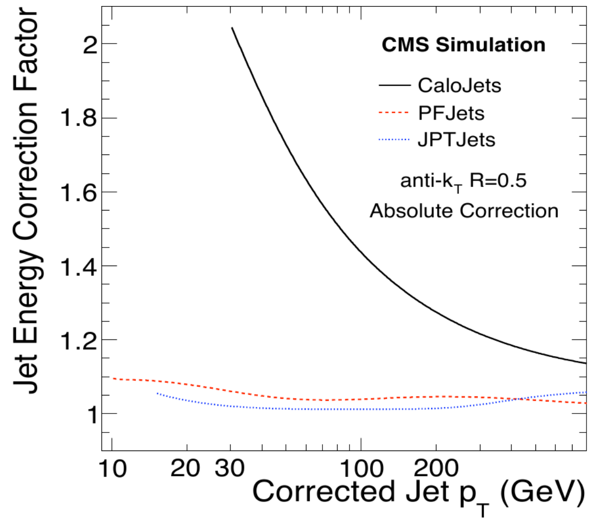



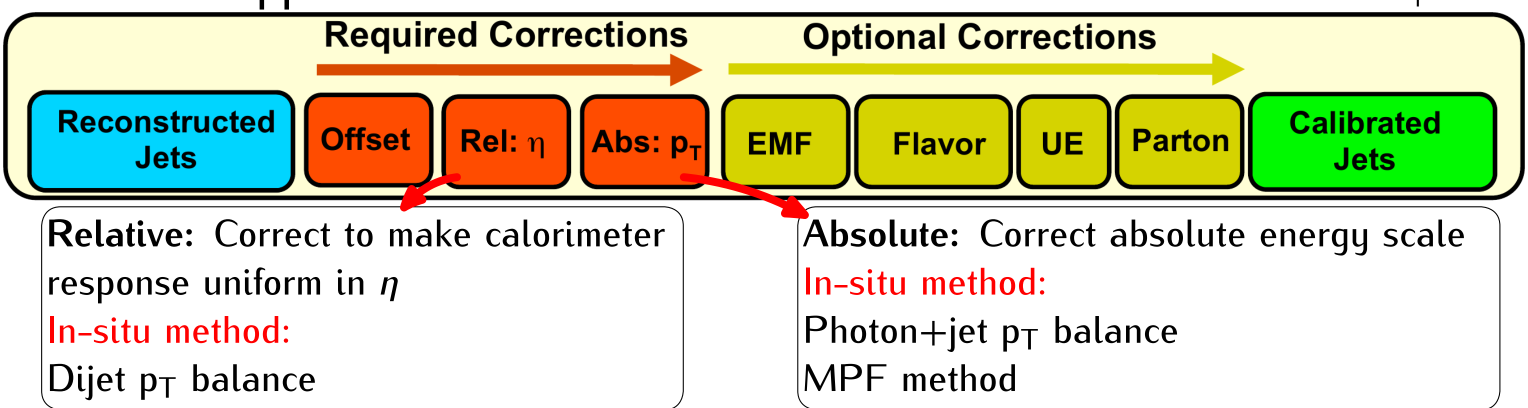



# Jet Energy corrections (JEC)

- MC-truth JEC
  - Used by majority of CMS physics analyses
  - MC corrections derived from PYTHIA QCD dijet MC events
- In-situ JEC sub-corrections will replace MC-truth corrections when available

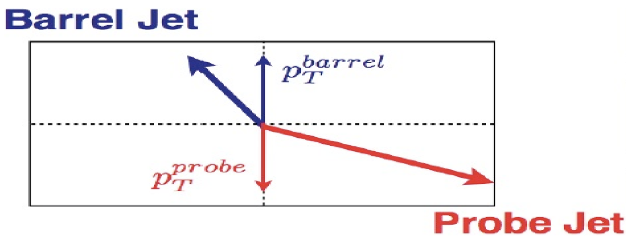



Factorized approach



# Relative JEC (dijet $p_T$ balance)

Relative JEC removes jet response variation in $\eta$
A priori estimate of uncertainty: $\pm 2\% \times |\eta|$



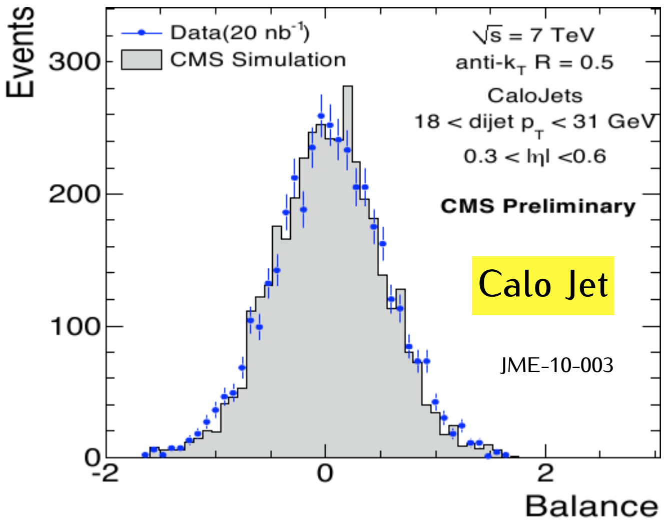

- Require at least 2 jets, one jet in the barrel region ($|\eta| < 1.3$)
- Azimuthal separation ($\Delta\phi > 2.7$ rad)
- Third jet veto $p_T^{3rd}/p_T^{dijet} < 0.2$

Measure distributions of balance variable B in representative ($p_T^{dijet}, |\eta|$) bins for all jet types.

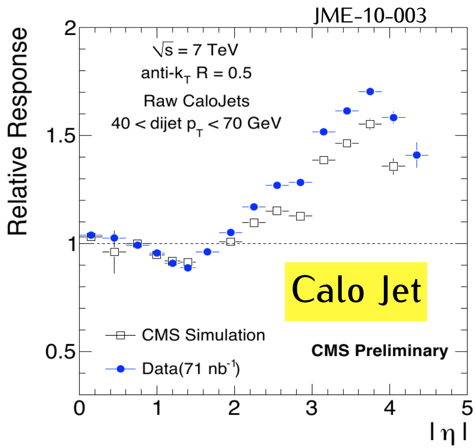
$$p_T^{dijet} = \frac{p_T^{probe} + p_T^{barrel}}{2}$$

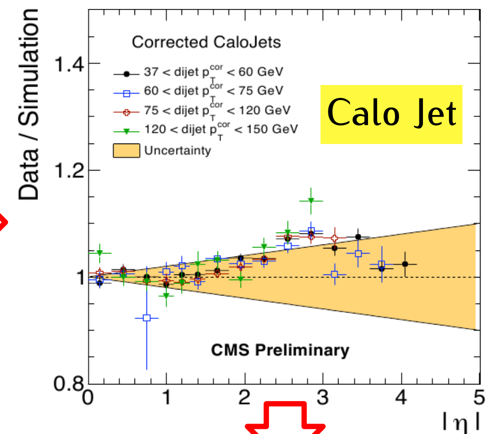
$$B = \frac{p_T^{probe} - p_T^{barrel}}{p_T^{dijet}}$$

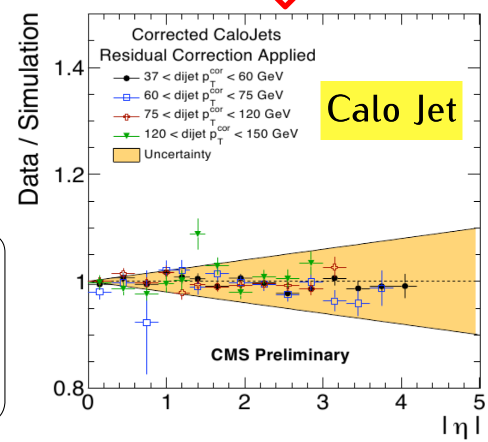
$$r = \frac{2 + \langle B \rangle}{2 - \langle B \rangle}$$



# Relative JEC (data vs. MC)



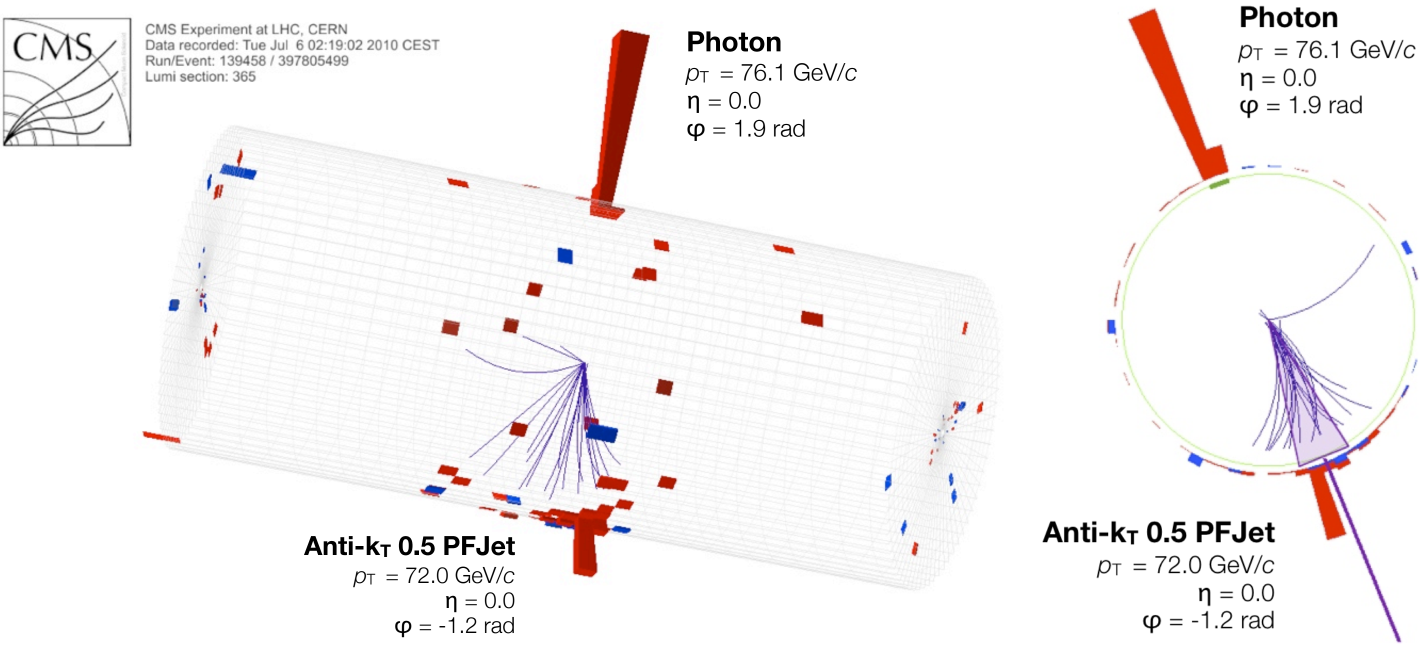




- Good agreement up to $|\eta| = 2$
- Relative response in data ∼10 % higher compared to simulation for $|\eta| > 2$

- Data/MC close to unity after the residual correction
- Data/MC deviations are covered by a conservatice $\eta$-dependent systematic unvertainty of $\pm 2\% \times |\eta|$

# Absolute JEC (photon+jet balance)

Correct absolute energy scale
A priori estimate of uncertainty in barrel: 10 % for CaloJets, 5 % for tracking based jets (JPTJets, PFJets, TrackJets)

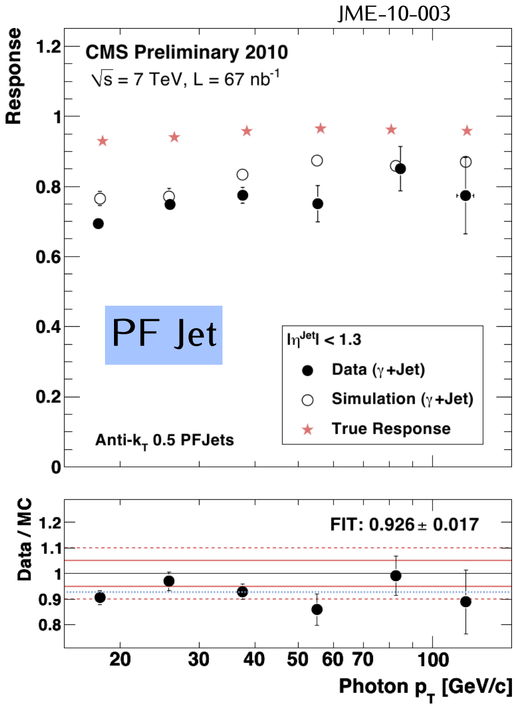


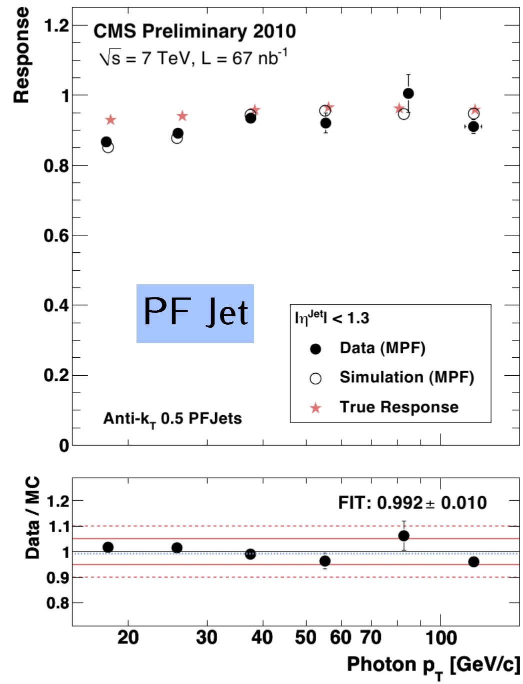

- Method employs $p_T$ balance in back-to-back photon+jet events (well measured photon as a reference object)
- Use photon trigger and isolated photons $p_T > 15$ GeV and $|\eta| < 1.3$

# Absolute JEC (photon+jet balance)

Photon+jet balance: Bias due to soft veto on second jet

Missing $E_T$ projection fraction method (MPF, from D0) uses MET to measure the balance and is less sensitive to QCD radiation

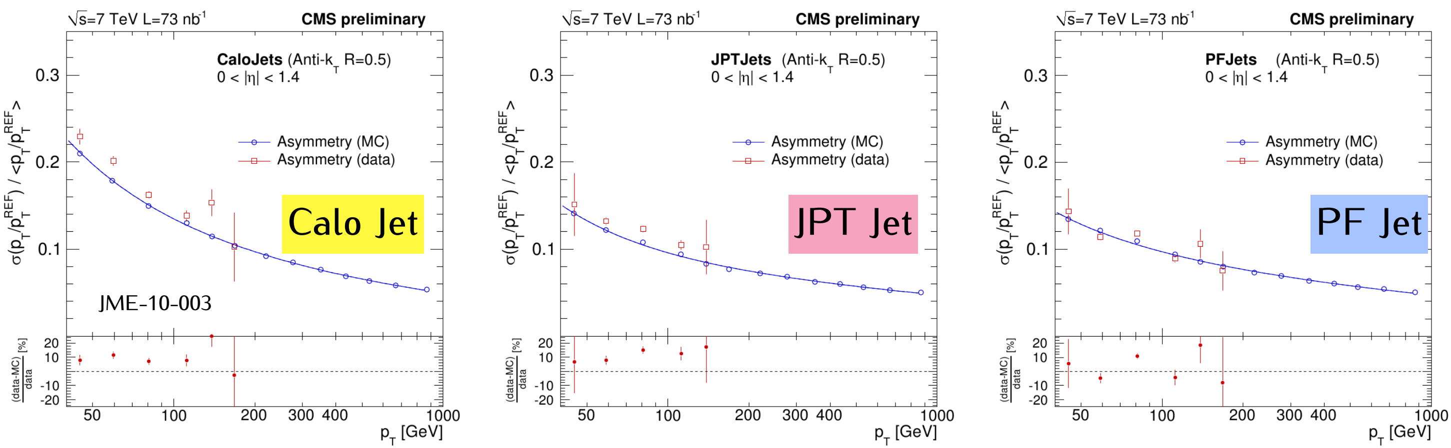



- Mostly good agreement when same method applied to MC and data
- Direct evidence from MPF supports 5 %/10 % JEC uncertainty as conservatice

# Jet $p_T$ resolutions

- Extracted from Pythia QCD sample (MC) and Dijet Asymmetry method In situ
- Define $p_T$ asymmetry of the two leading jets in back-to-back diject events $A = \frac{p_T^{jet1} - p_T^{jet2}}{p_T^{jet1} + p_T^{jet2}}$
- For approximately equal value of the jets $p_T$'s $\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$




Full chain of Dijet Asymmetry method applied to data and MC to extract jet $p_T$ resolution

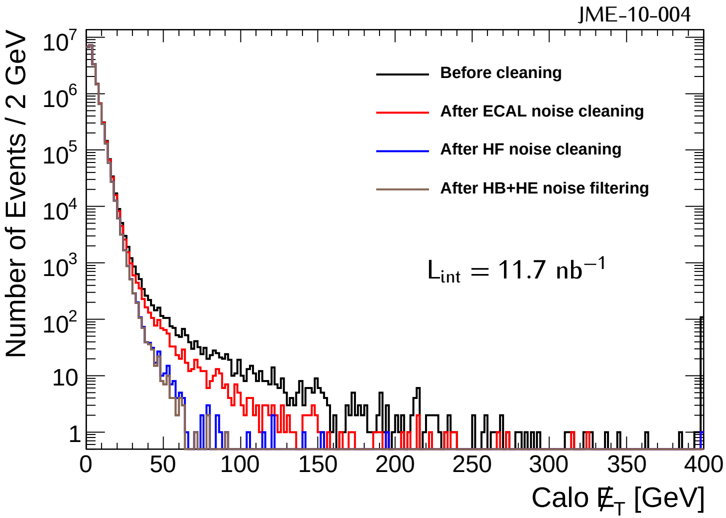
Observed data/MC agreement within a priori ~10 % uncertainty

# Missing $E_T$ performance in $\sqrt{s} = 7$ TeV data

MET tails, resolution and scale

# Cleaning of MET tails

No large MET expected for Minimum-bias or QCD jet events



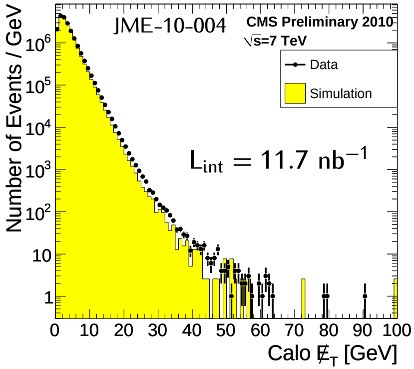

Basic cleaning strategy is to identify anomalous signals based on

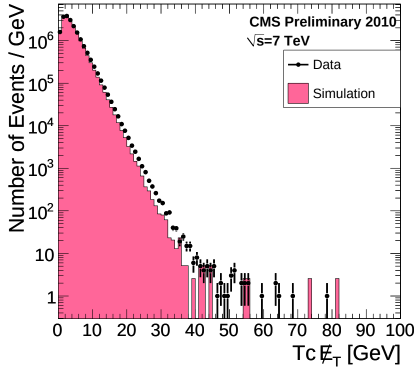
- Unphysical charge sharing of neighboring channels
- Timing/pulse shape information

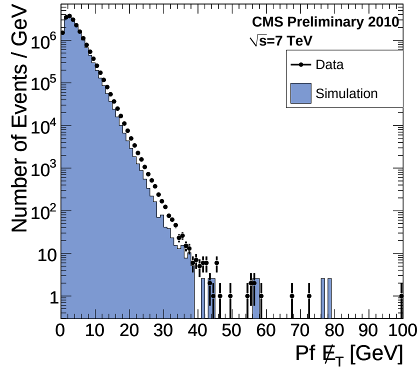
- Cleaning is very effective
- After cleaning, MET tail is no longer dominated by anomalous signals

# MET in data / MC

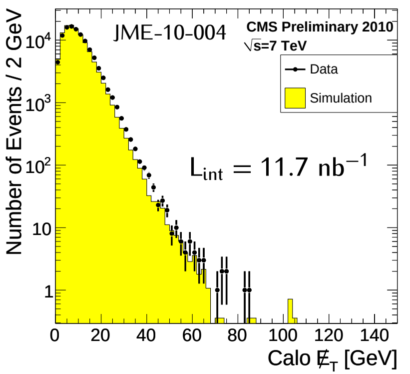
Minimum bias Calo MET | Tc MET | PF MET

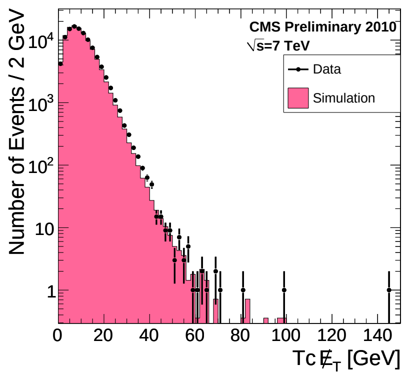


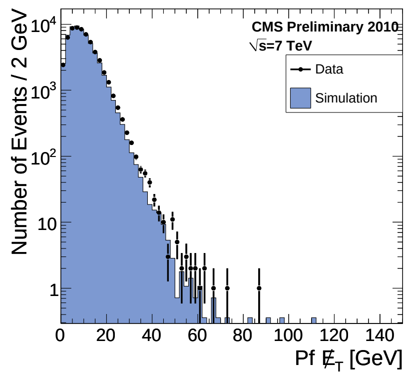




Dijet events with corr. $p_T^{1,2} > 25$ GeV, $|\eta_{1,2}| < 3$



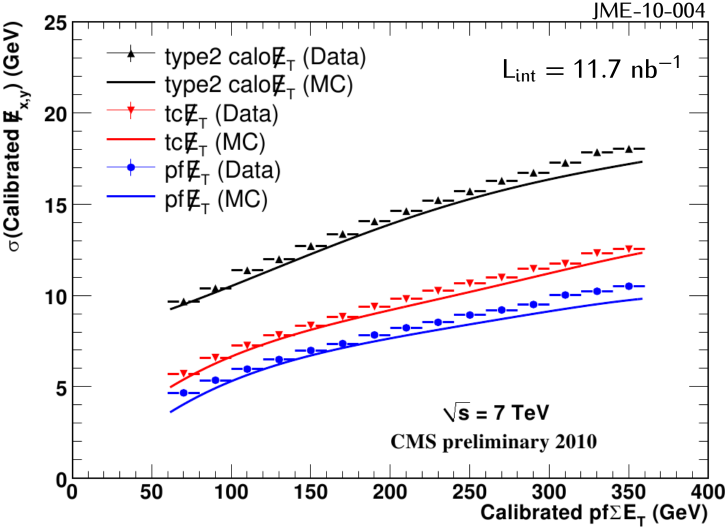



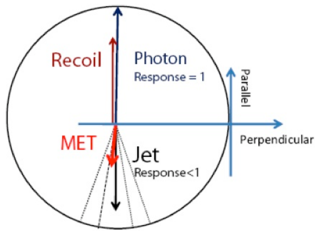

General agreement between data and MC

# MET resolution vs. $\text{SumE}_T$

Compare the resolution of different MET types at the same PF $\text{SumE}_T$ (closest to real $\text{SumE}_T$)



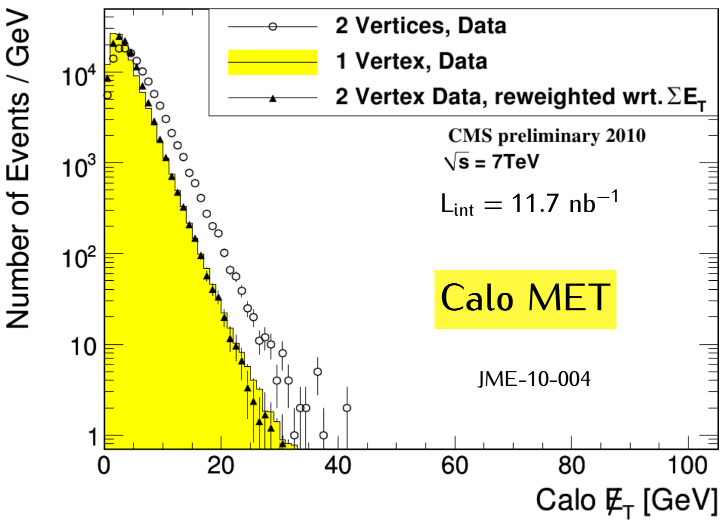

- PF $\text{SumE}_T$ is calibrated to the generator level $\text{SumE}_T$
- Observed MET $\sigma$ is calibrated using photon+jets MC events




- PF MET has the best resolution
- Tc MET also shows a significant improvement w.r.t Calo MET

# MET in pile-up events

Study of MET distributions in 1- and 2-vertex MinimumBias events

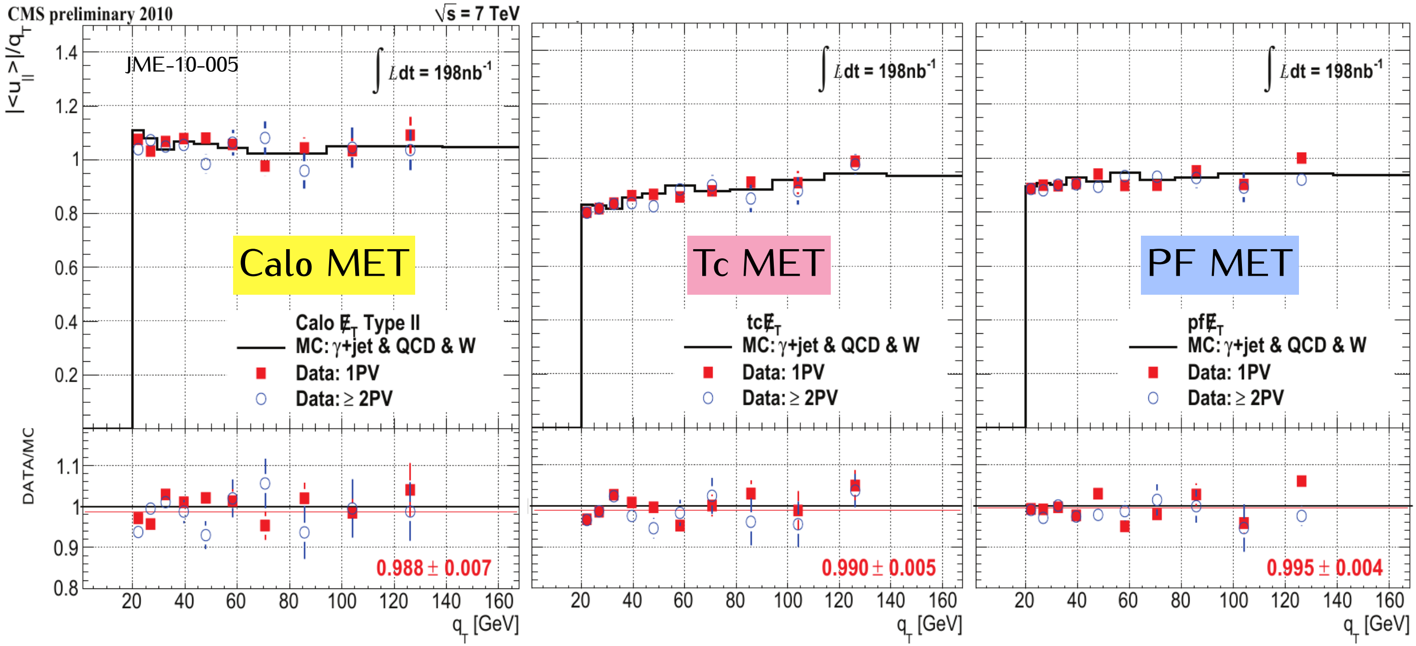



- MET distributions wider in 2-vertex events
- Reweight events such that the $SumE_T$ distribution matches to that of 1-vertex events
- After reweighting, MET distribution agrees between 1-vertex and 2-vertex events

Widening of MET distribution in 2-vertex events due to transverse energy increase

# (Absolute) MET scale

Measured from $\gamma$ + jet events, photon $p_T > 20$ GeV

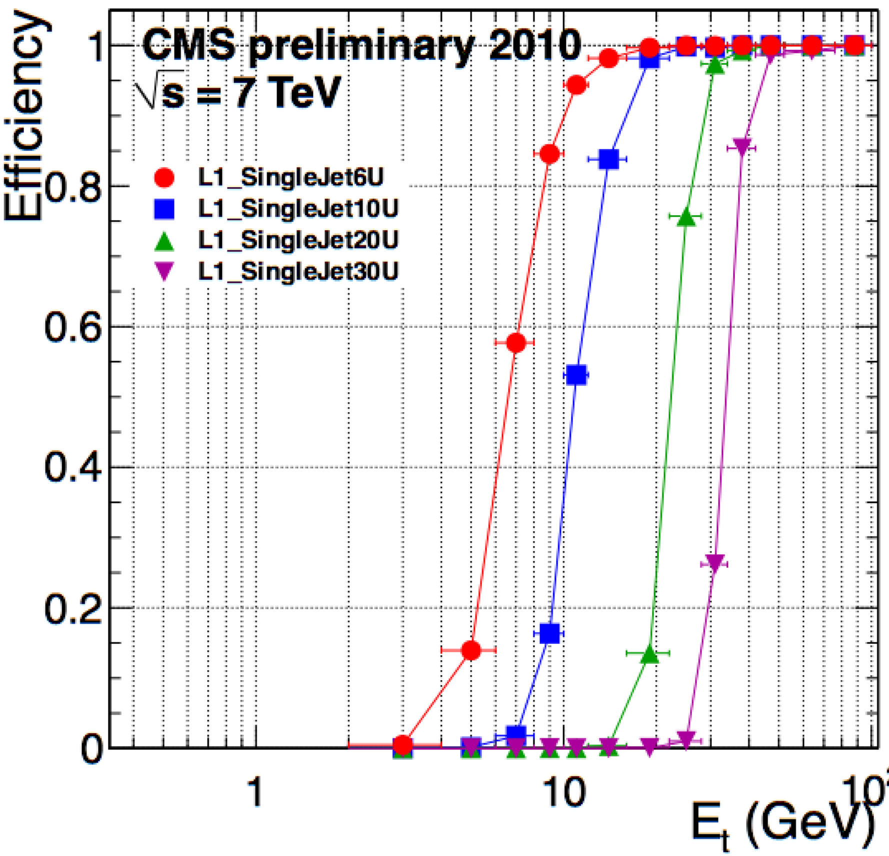



- $\vec{u}_T$ is the hadronic recoil ($\vec{q}_T + \vec{u}_T + \vec{\not{E}}_T = 0$), $u_{\parallel} = \vec{u}_T \cdot \hat{q}_T$
  - $|\langle u_{\parallel}\rangle|/q_T$ measures the scale factor correction
- Calo MET response overestimated, Tc MET and PF MET underestimated
- Good agreement between data and MC, response not sensitive to pile-up

# Trigger performance in $\sqrt{s} = 7$ TeV data

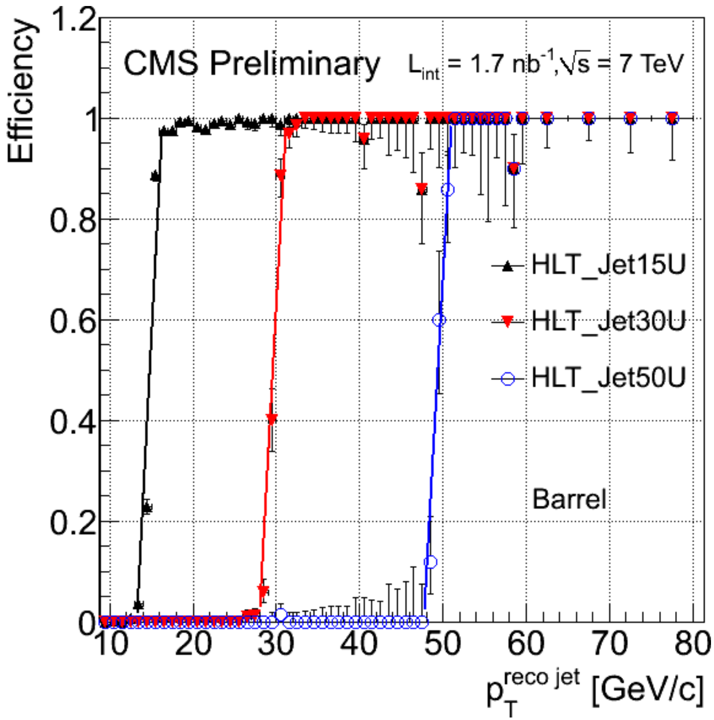
# Level 1 jet trigger

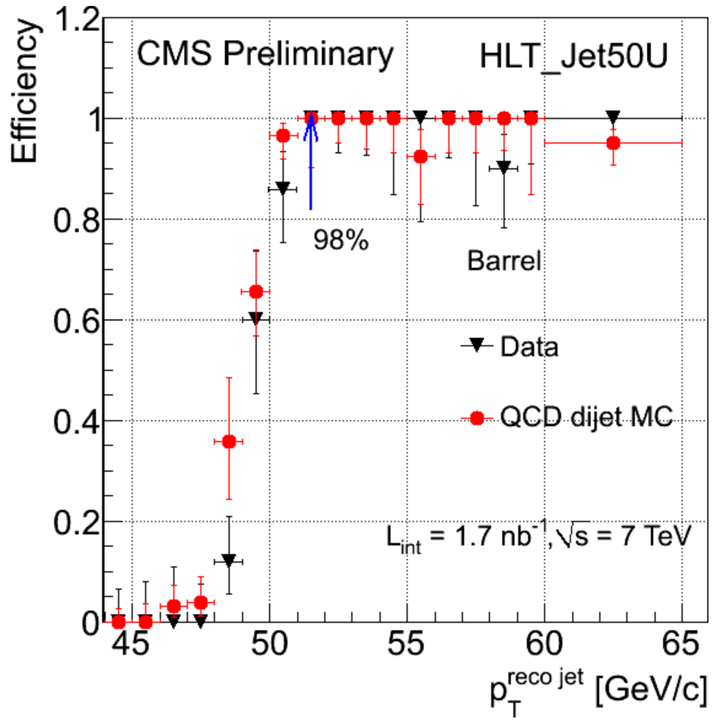
- Efficiency as a function of offline jet $E_T^{reco}$
- MinimumBias events
- Leading offline jet matched to a L1 jet ($\Delta R < 0.5$)
- $E_T^{reco} > 10$ GeV
- $|\eta^{reco}| < 2.6$




- Steep rise
- Plateau near 100 %

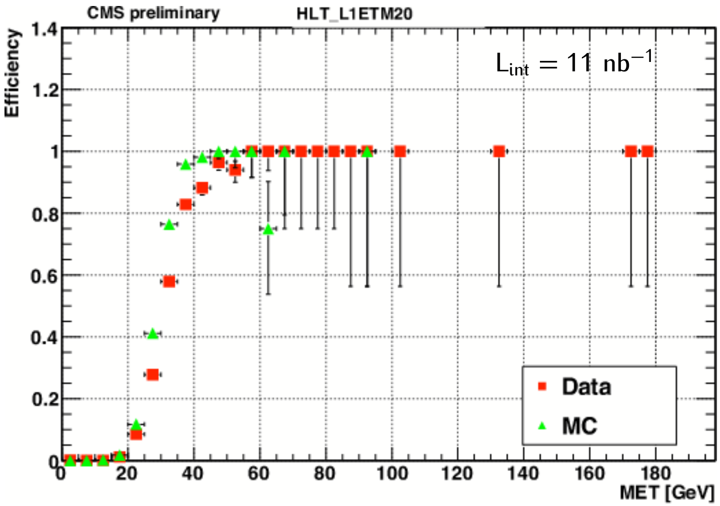
# HLT jet trigger



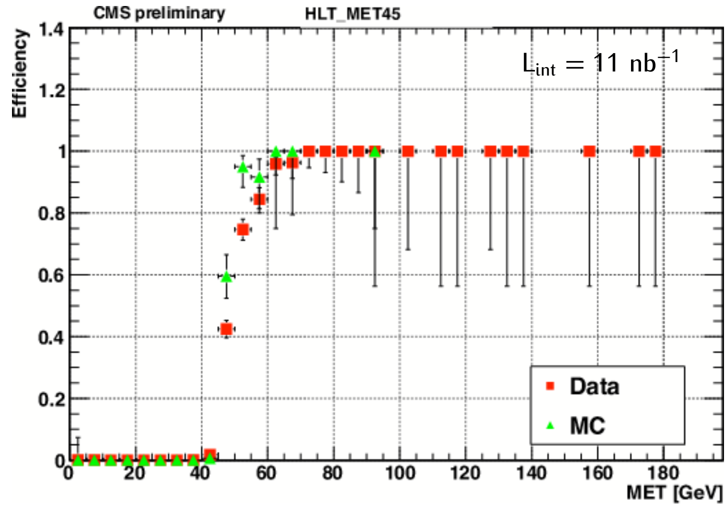




- Steep rise
- Plateau near 100 %

# MET trigger



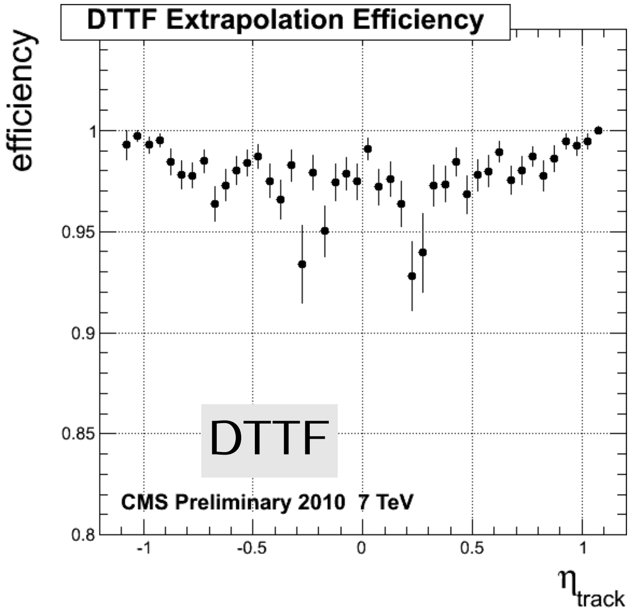

L1 MET 20

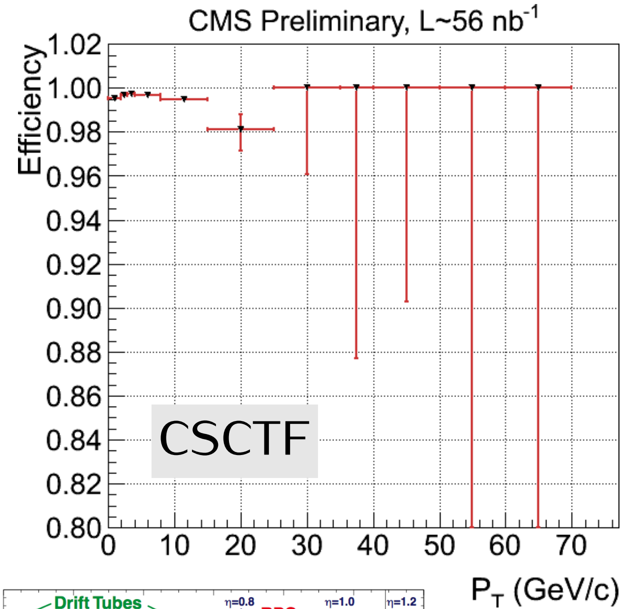


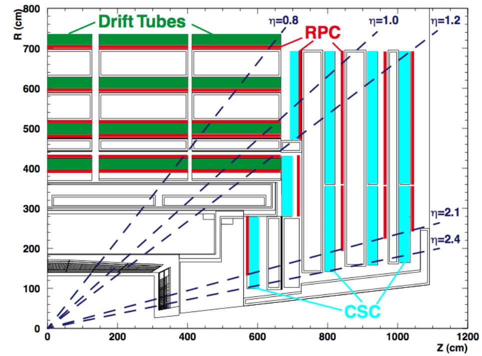

HLT MET 45

- Offline Calo MET
  - After cleaning of HCAL noise, ECAL spikes, HF bad hits
- Steep rise, plateau near 100 %
- Acceptable agreement between data and MC

# Level 1 muon trigger



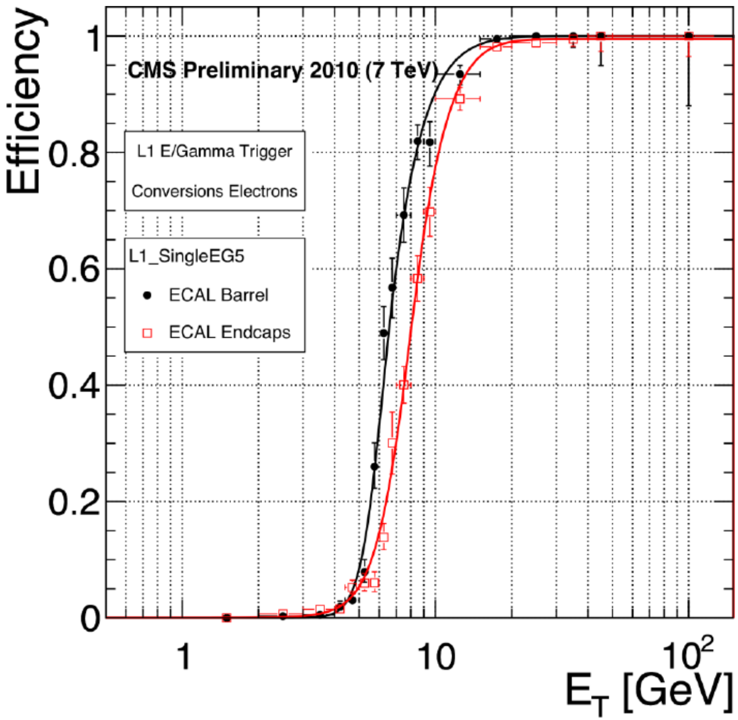



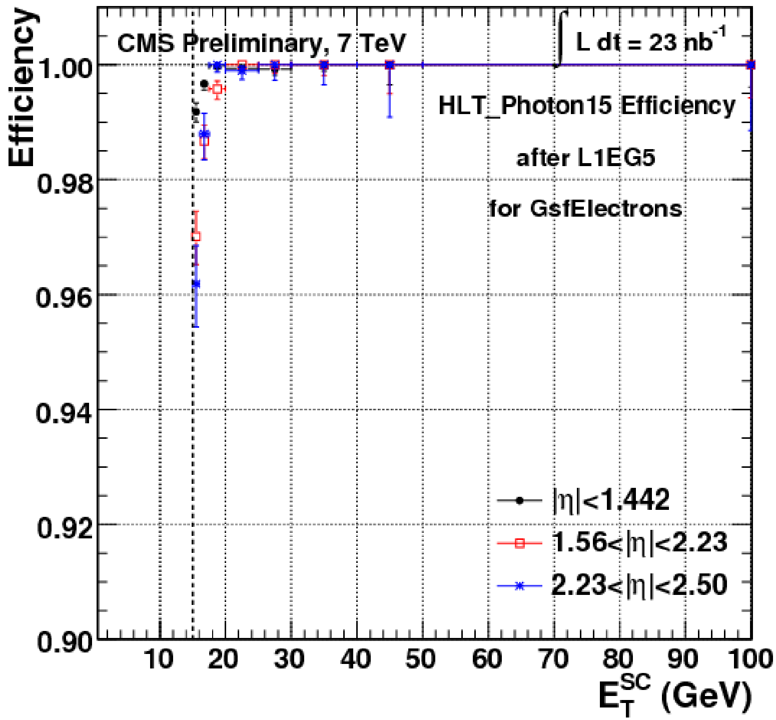

- Efficiency vs. triggerable event shown
- Good performance

# Electron and photon trigger

L1 trigger




HLT (after L1)




- Efficiency vs. electron supercluster $E_T$
- Good performance

# Summary

Results of the Jet and Missing $E_T$ performance on 7 TeV data were presented

- Jets
  - General data/MC agreement for jet response and $p_T$ resolution
  - Observations from the current data support a priori estimates:
    - ⋆ 10 % (5 %) JEC uncertainty for calorimeter jets (jets using tracking)
    - ⋆ Additional 2 % uncertainty per unit pseudorapidity
    - ⋆ 10 % $p_T$ resolution uncertainties for all three jet types
- Missing $E_T$
  - Acceptable data/MC agreement
  - Improved cleaning, tails under control
  - Tackling the challenge of MET commissioning with large pile-up
  - Tc MET and especially PF MET improve resolution significantly
- Triggers
  - Good performance in jet, MET, muon and electron & photon triggers

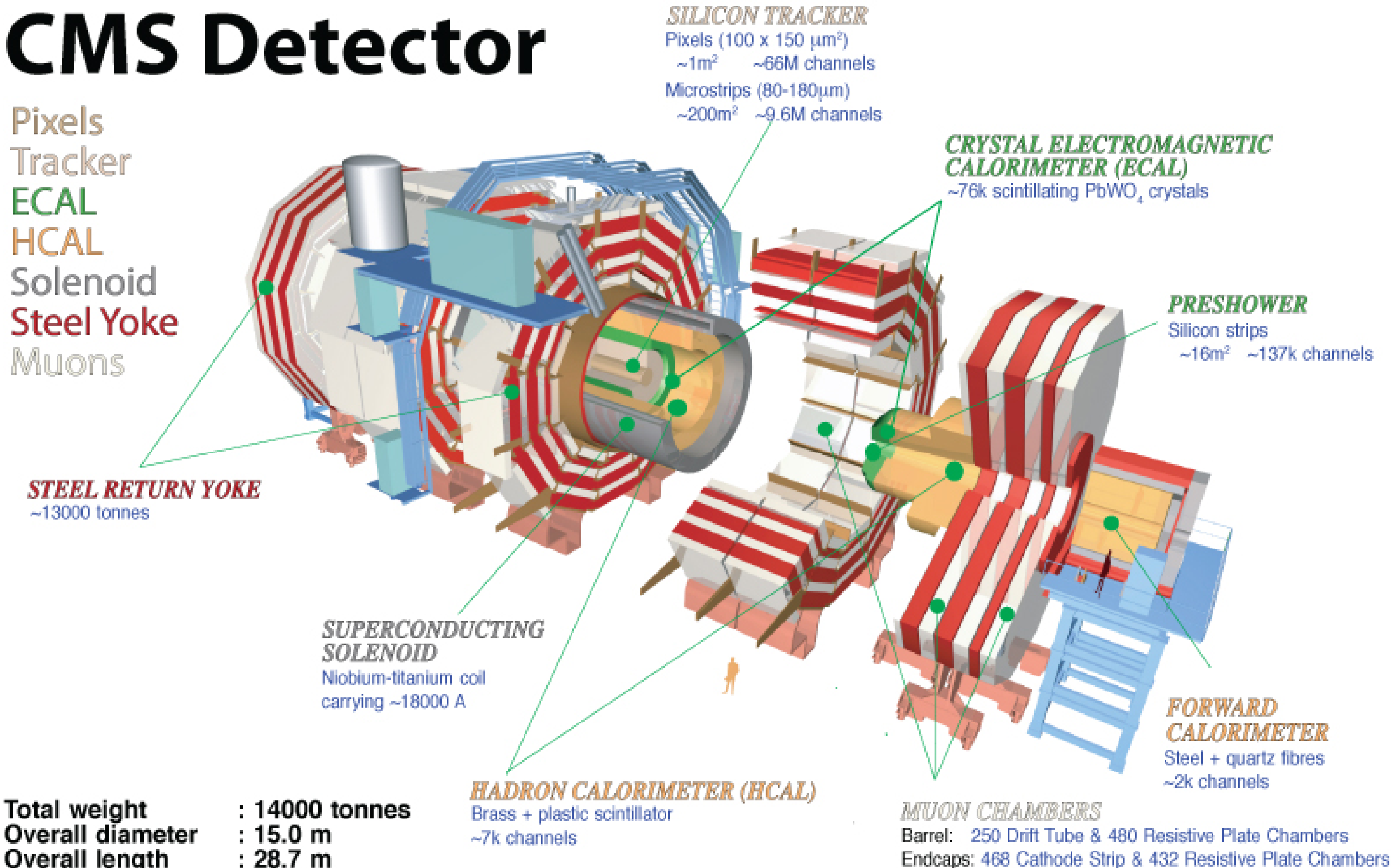
# References


- CMS **DPS-2010/014** *Jet and MET Commissioning Results from 7 TeV Collision Data*
- CMS PAS **JME-10-003** *CMS Jet Performance in pp collisions at* $\sqrt{s}$*=7 TeV*
- CMS PAS **JME-10-004** *Missing Transverse Energy Performance in Minimum-Bias and Jet Events from Proton-Proton Collisions at* $\sqrt{s}$*=7 TeV*
- CMS PAS **JME-10-005** *CMS MET Performance in Events Containing Electroweak Bosons from pp Collisions at* $\sqrt{s}$*=7 TeV*
- CMS PAS **JME-10-006** *Commissioning of TrackJets in pp Collisions at* $\sqrt{s}$*=7 TeV*
- CMS PAS **PFT-10-001** *Commissioning of the Particle-flow Event Reconstruction with the first LHC Collisions recorded in the CMS detector*
- CMS PAS **PFT-10-002** *Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp Collisions at* $\sqrt{s} = 7$ GeV

# BACKUP SLIDES

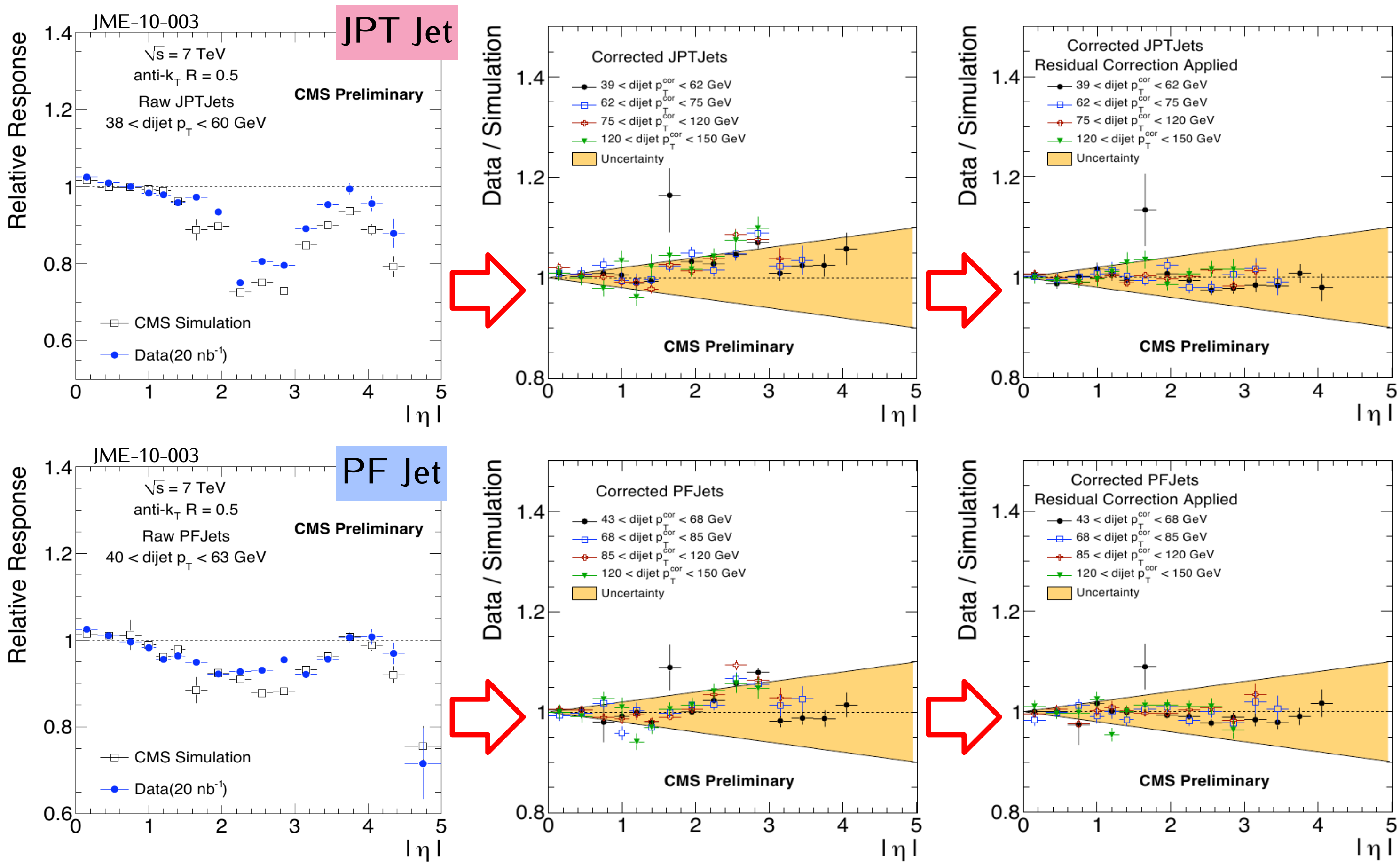
# Compact Muon Solenoid

## CMS Detector

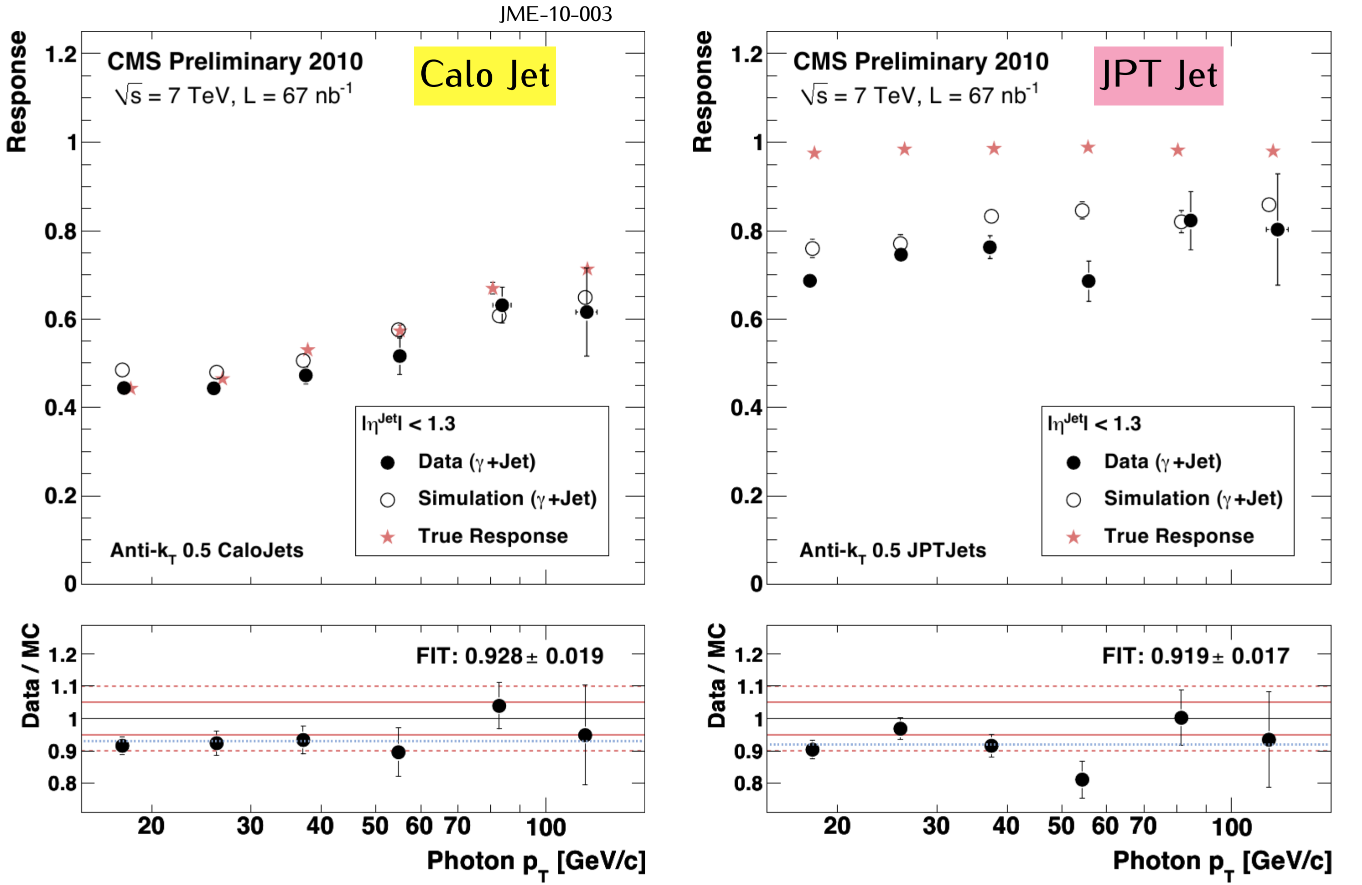



| | |
|---|---|
| **Total weight** | **: 14000 tonnes** |
| **Overall diameter** | **: 15.0 m** |
| **Overall length** | **: 28.7 m** |
| **Magnetic field** | **: 3.8 T** |

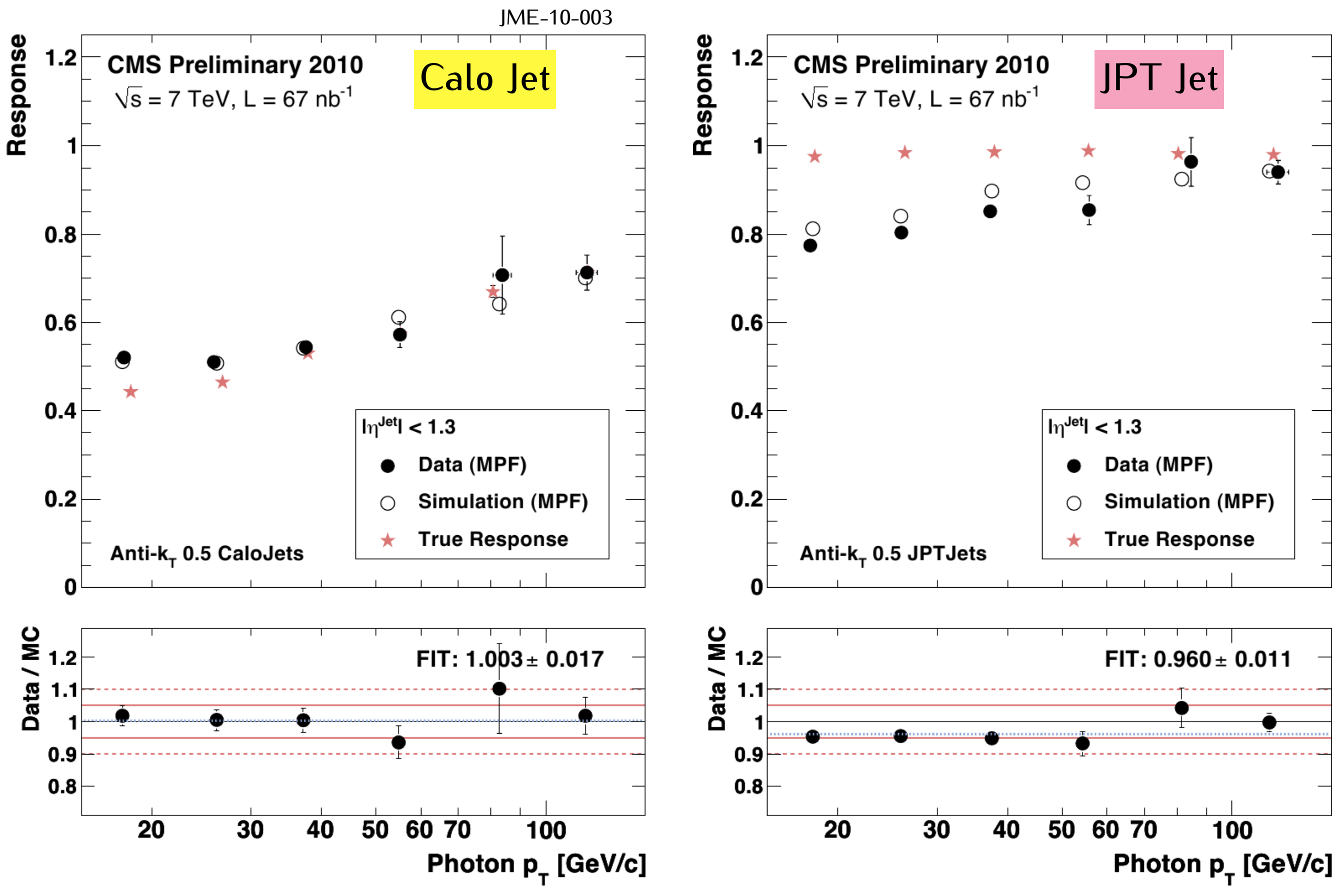
# Relative JEC (data vs. MC)



# Absolute JEC (photon+jet balance)

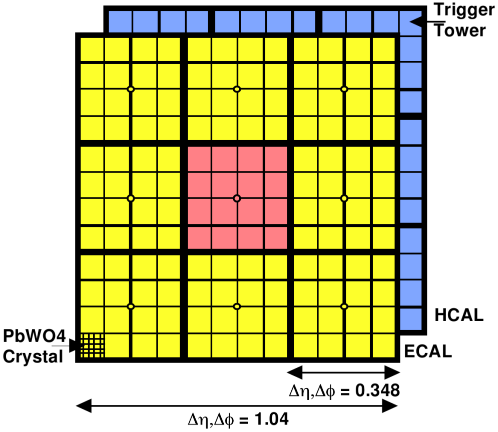


# Absolute JEC (MPF)



# Tau trigger algorithm

- Object definition
  - Characterized by $E_T$ in $3 \times 3$ calorimeter regions
  - Each region set $\tau$-veto ON, if more than 2 active ECAL or HCAL towers in the $4 \times 4$ region
  - $\tau$-like jet if all $\tau$-veto for all 9 regions is OFF
- L1: $E_T$ cut, isolation
- L2: calorimeter jet reconstruction (seeded by L1 $\tau$s), $E_T$ cut, isolation
- L2.5: seeded by L2 $\tau$s, leading track finding and cut on $p_T$
- L3: improved isolation




CMS Collaboration,
The TriDAS project:
TDR vol1: Level-1 trigger
http://cdsweb.cern.ch/record/706847
TDR vol2: DAQ and HLT
http://cdsweb.cern.ch/record/578006

# L1 muon trigger (CSCTF)