Understanding MET at CMS in view of SUSY

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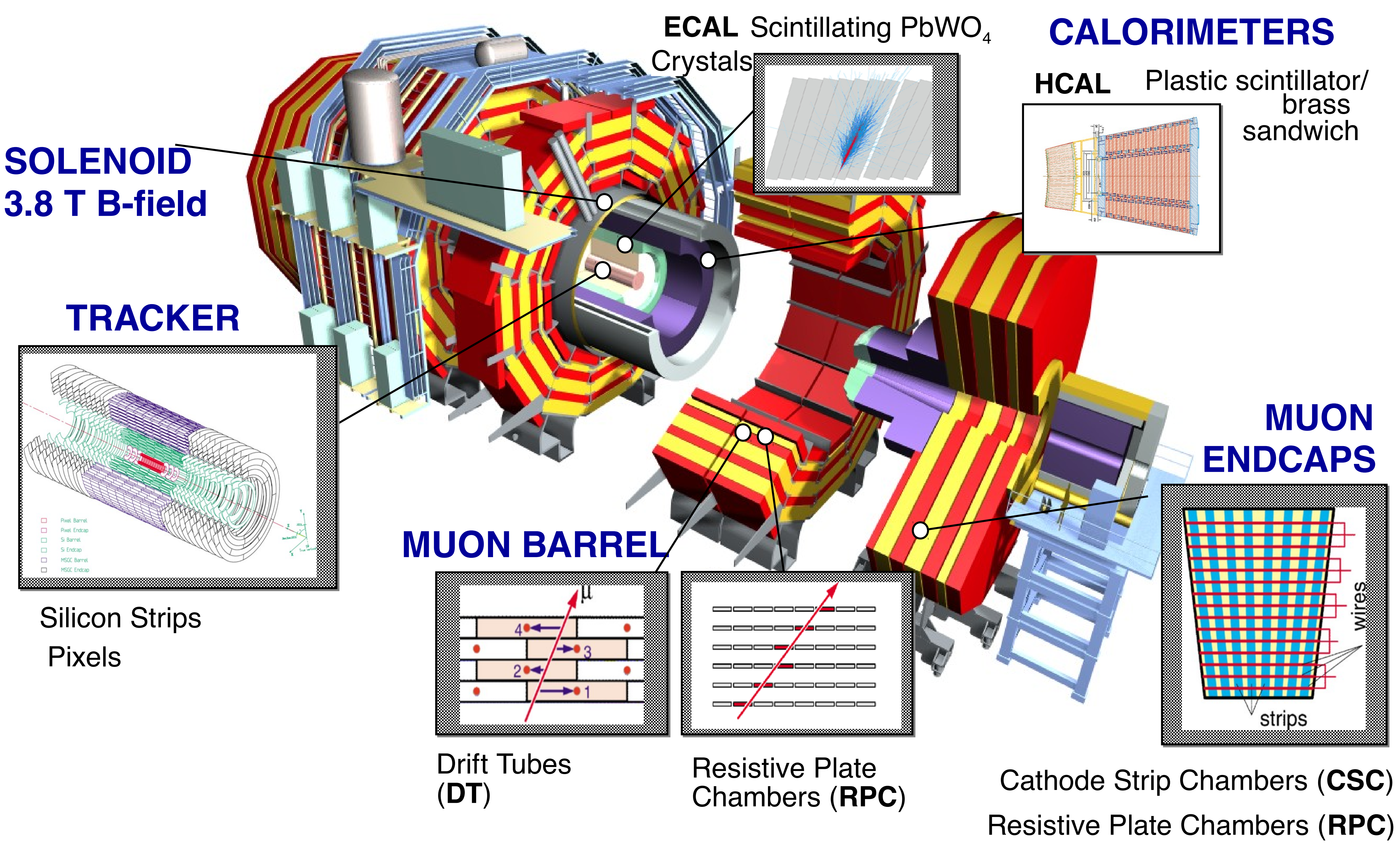
Introduction

- MET measures the energy imbalance in the plane transverse to the beam axis
    - consequence of the law of energy conservation
- Sources
    - particles escaping detection (SM and beyond)
    - detector resolution ⇒ energy mismeasurement
    - detector malfunction, beam halo, cosmic rays
- *Useful quantity to commission the detector*
- *Provides a great discriminant in the search for new physics*

CMS detector



Azimuthal angle: ϕ

Polar angle: θ

Pseudorapitidy: $\eta = -\ln \tan(\theta/2)$

MET algorithms in CMS

Generic definition ⇒ $$\vec{\not\!\!E}_T = - \sum_{\text{particles}} (p_x\hat{\mathbf{i}} + p_y\hat{\mathbf{j}})$$

Depending on what is used as "particles" we have:

- *CaloMET* = based on calorimeter towers
    - traditional definition
- *tcMET* = tracks replace matched calorimeter towers
    - take advantage of the better tracker momentum resolution
- *pfMET* = based on Particle Flow reconstruction
    - improved resolution due to particle identification
- *MHT* = based on reconstructed jets
    - more robust against detector noise and pile-up effects

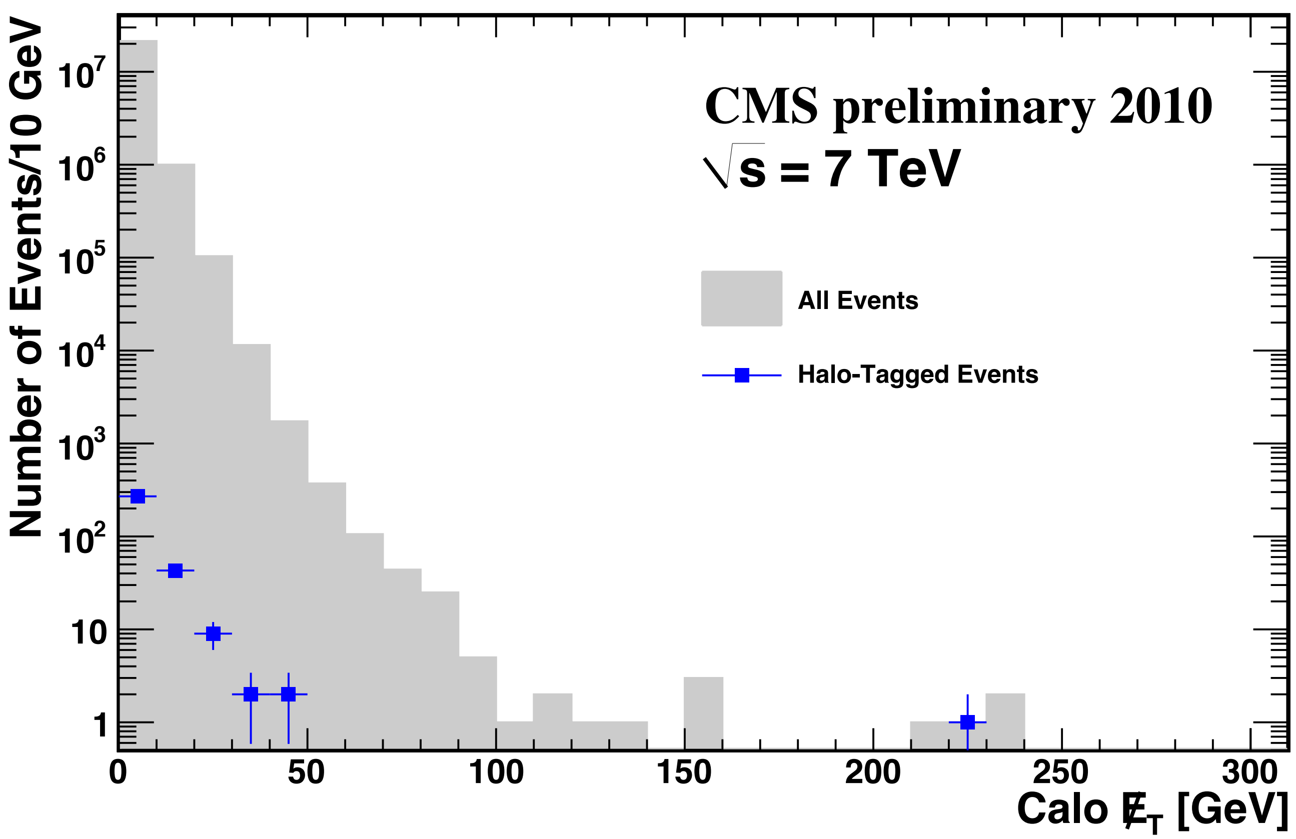
Cleaning-up the events

Select good collisions

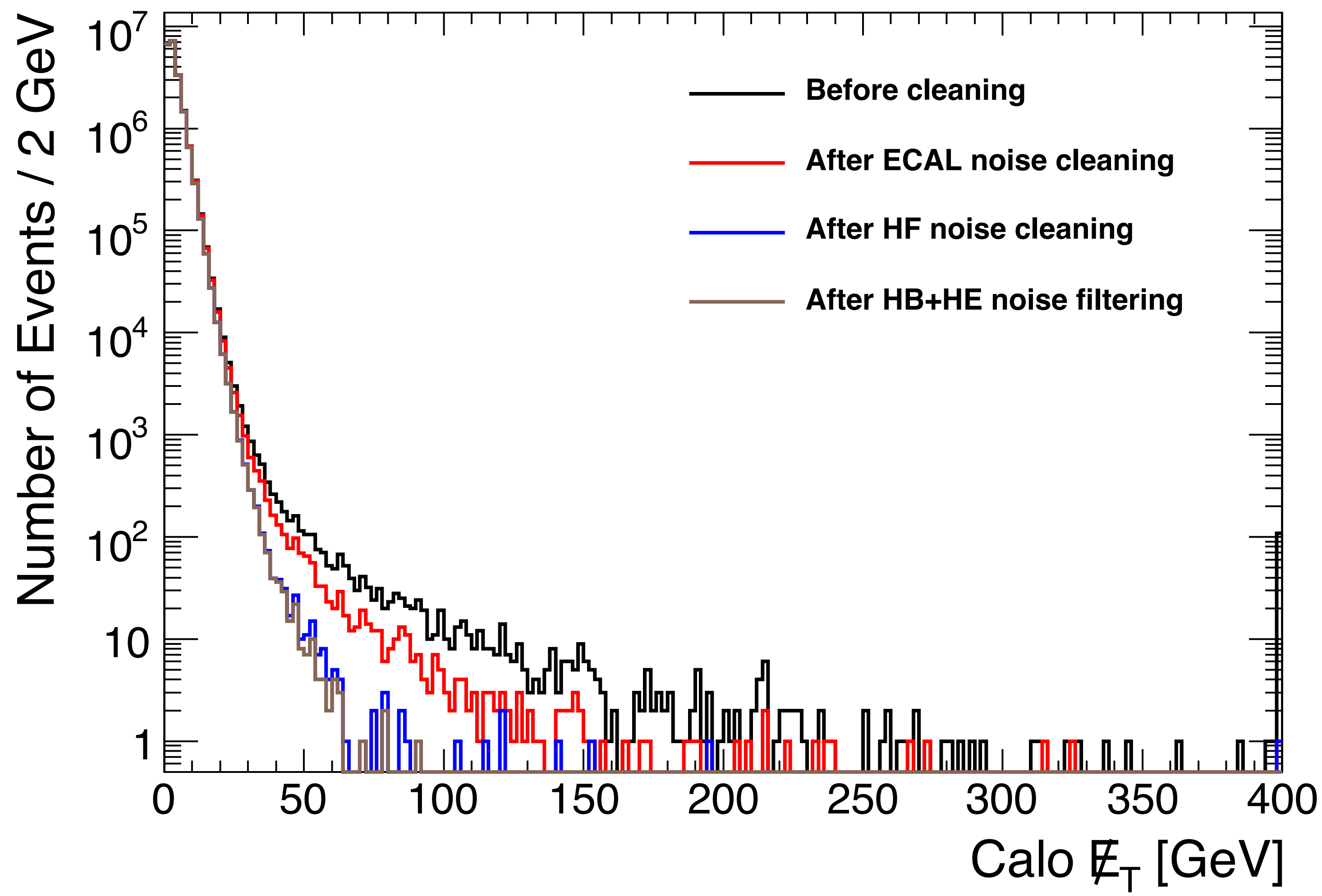
- ≥ 1 well identified primary vertex
- vertex z-position <15 cm away from center of detector
- >25% fraction of high-purity tracks if $N_{tracks} < 10$
    - removes events where bunches of particles cross detector longitudinally

Beam Halo removal

- identify muons going parallel to the beam
- use CSC muon detectors
- $1\text{-}2\times10^{-5}$ fraction removed
    - will increase with beam intensity

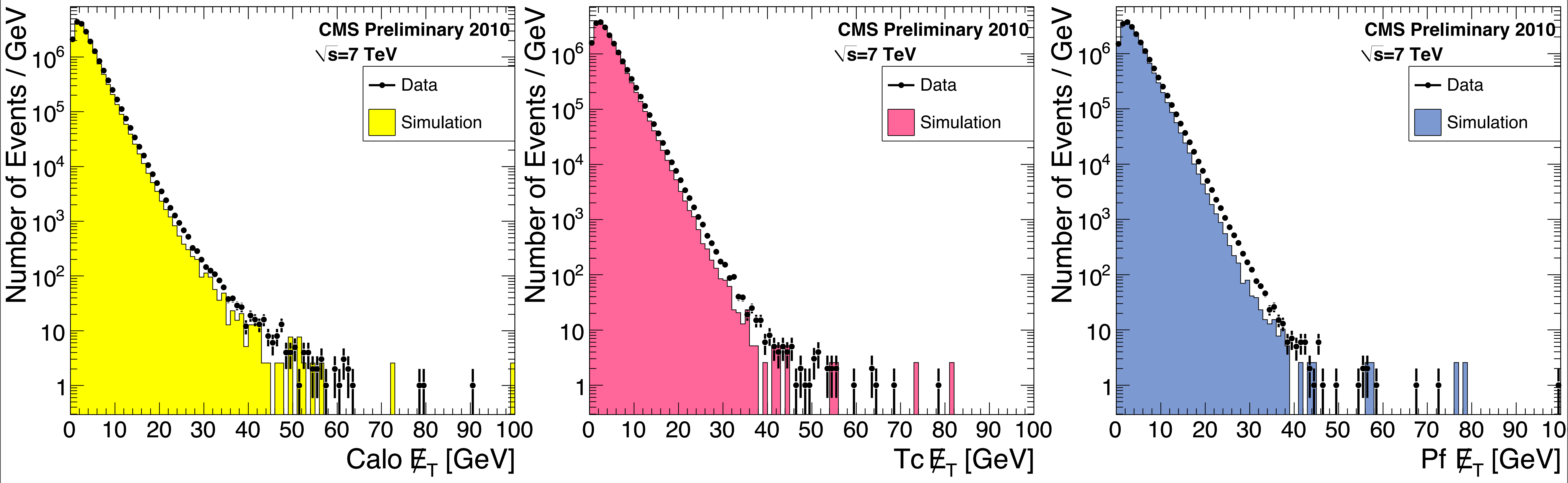


Calorimeter Noise removal



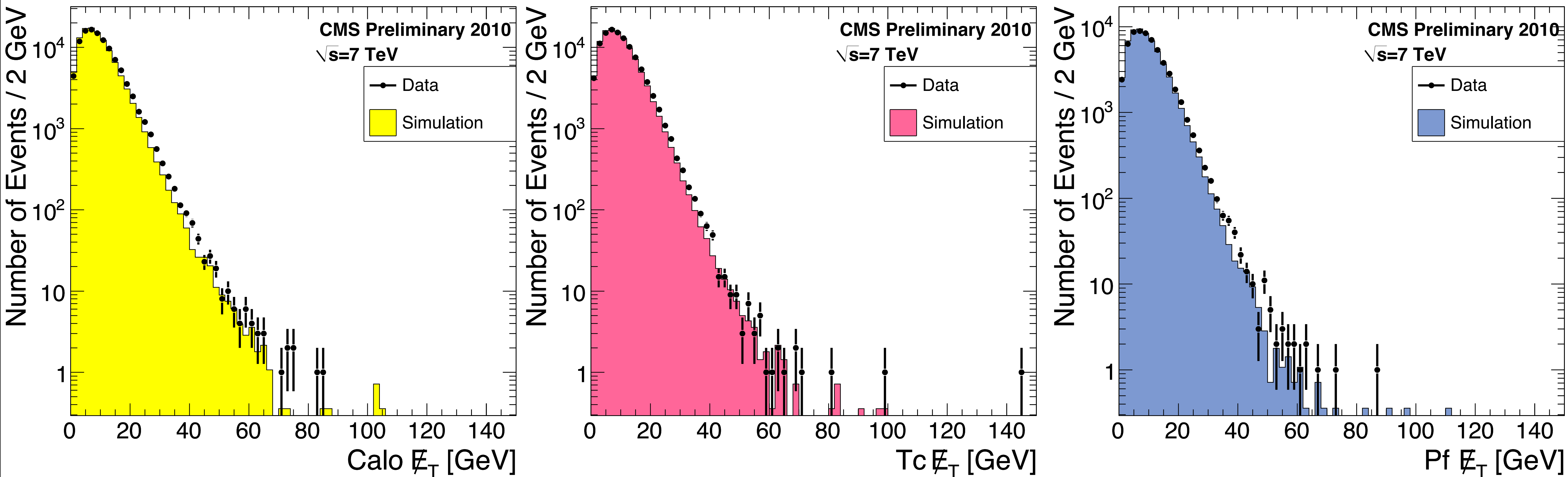
- Remove anomalous signals based on:
  - unphysical charge sharing between channels
  - timing and pulse shape information
- *This excludes 0.003% of all minimum bias events*

Data vs Simulation - minBias



- Good agreement with simulated minBias events using Pythia 8
  - Monte Carlo simulation normalized to data
- CaloMET(left), tcMET(middle), pfMET(right)
- Events with MET > 60 GeV studied in more detail
- *Cleaning procedures can and will be improved*

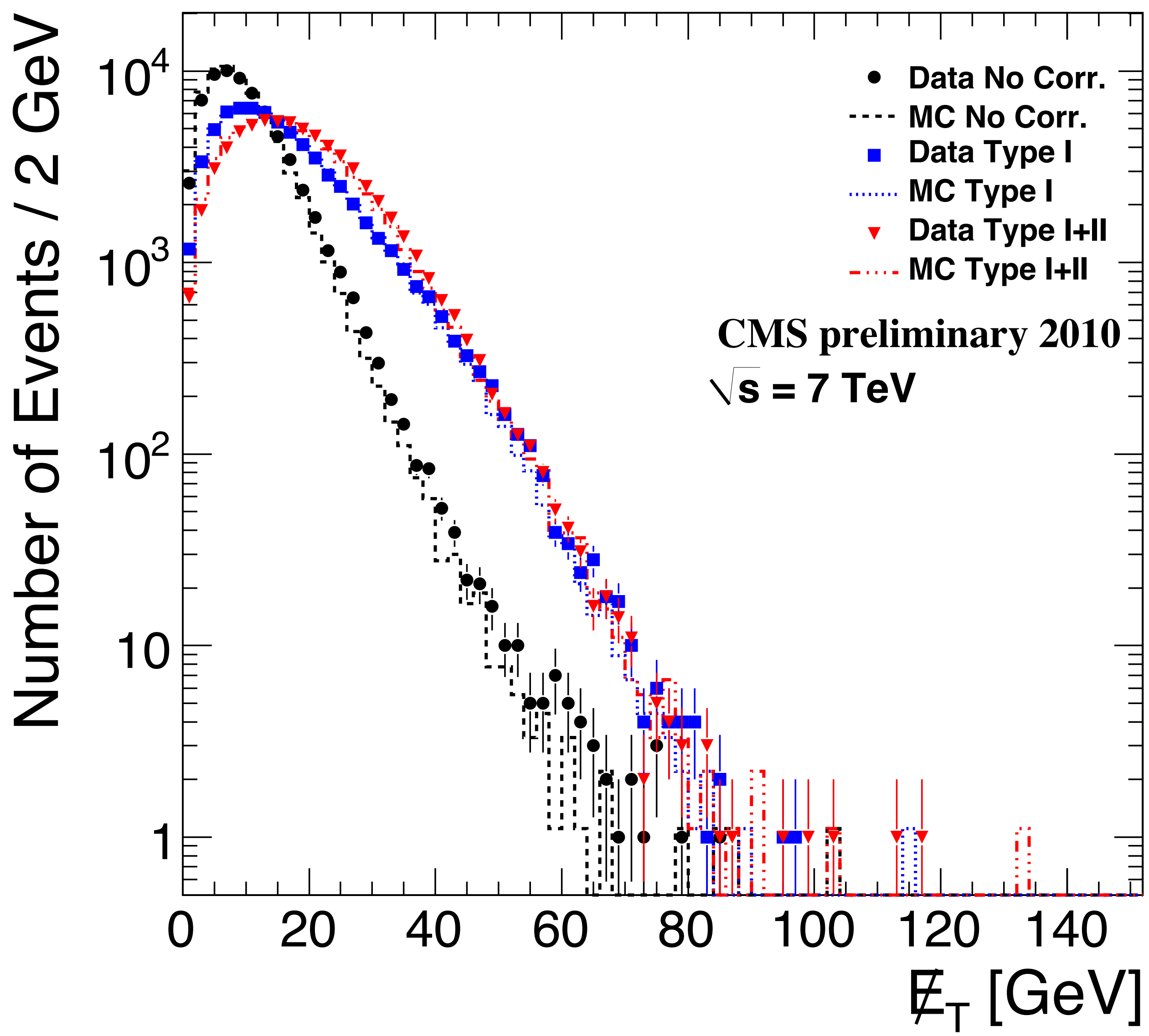
Data vs Simulation - DiJets



- Event topology closer to those used in searches
  - require two leading jets $P_T > 25$ GeV, $|\eta| < 3$
- Simulation is more reliable for this production
- *Good agreement between data and simulation in this sample as well*

Energy scale corrections

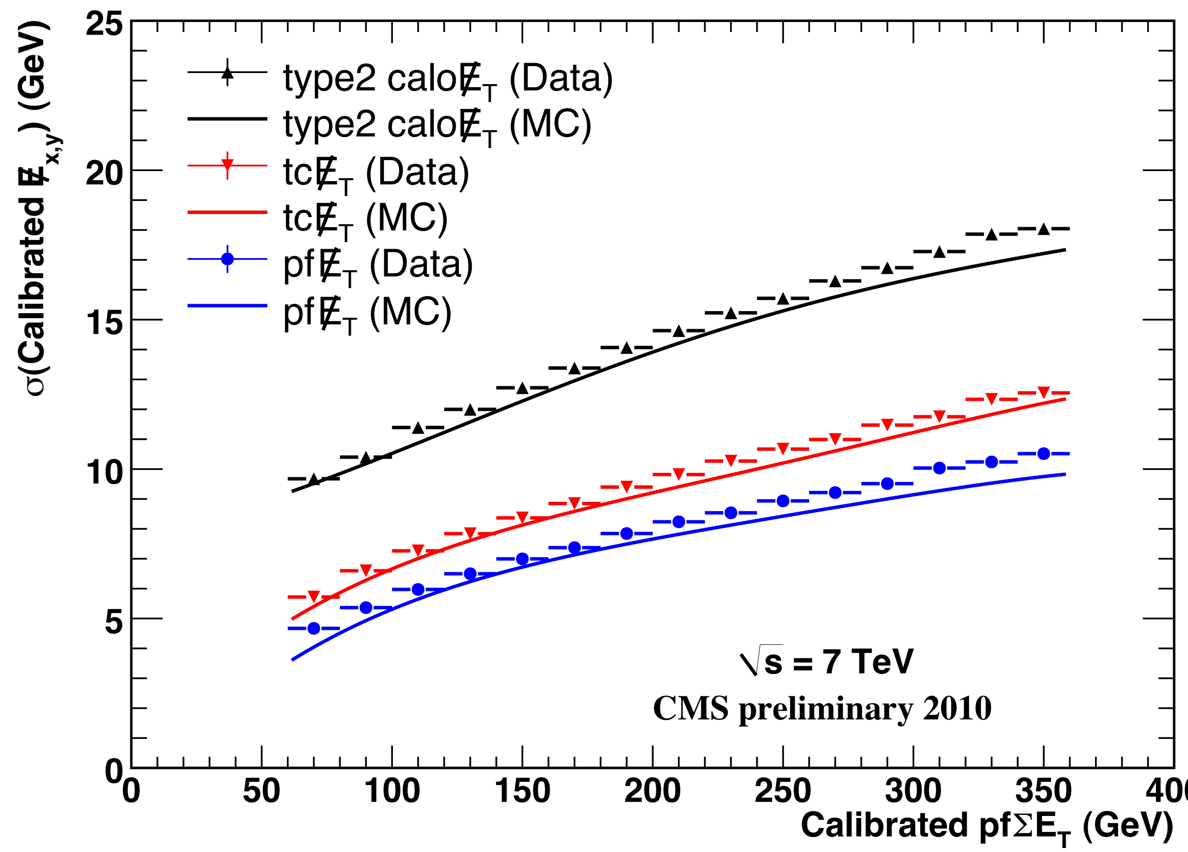
- *Non-compensating calorimeter leads to energy under-measurement* (CaloMET is affected the most)
  - type-I correction ⇒ vector sum of transverse momentum of jets
    - apply jet energy corrections using dijet (η dependence) and photon +jet (absolute scale) events
    - use jets with EM fraction < 0.9 and P_T > 20 GeV
  - type-II correction ⇒ soft jets unaccounted in type-I and unclustered energy
    - from simulated Z→ee events



MET resolution vs SumET

Compare the resolutions for CaloMET, tcMET and pfMET in data and simulation

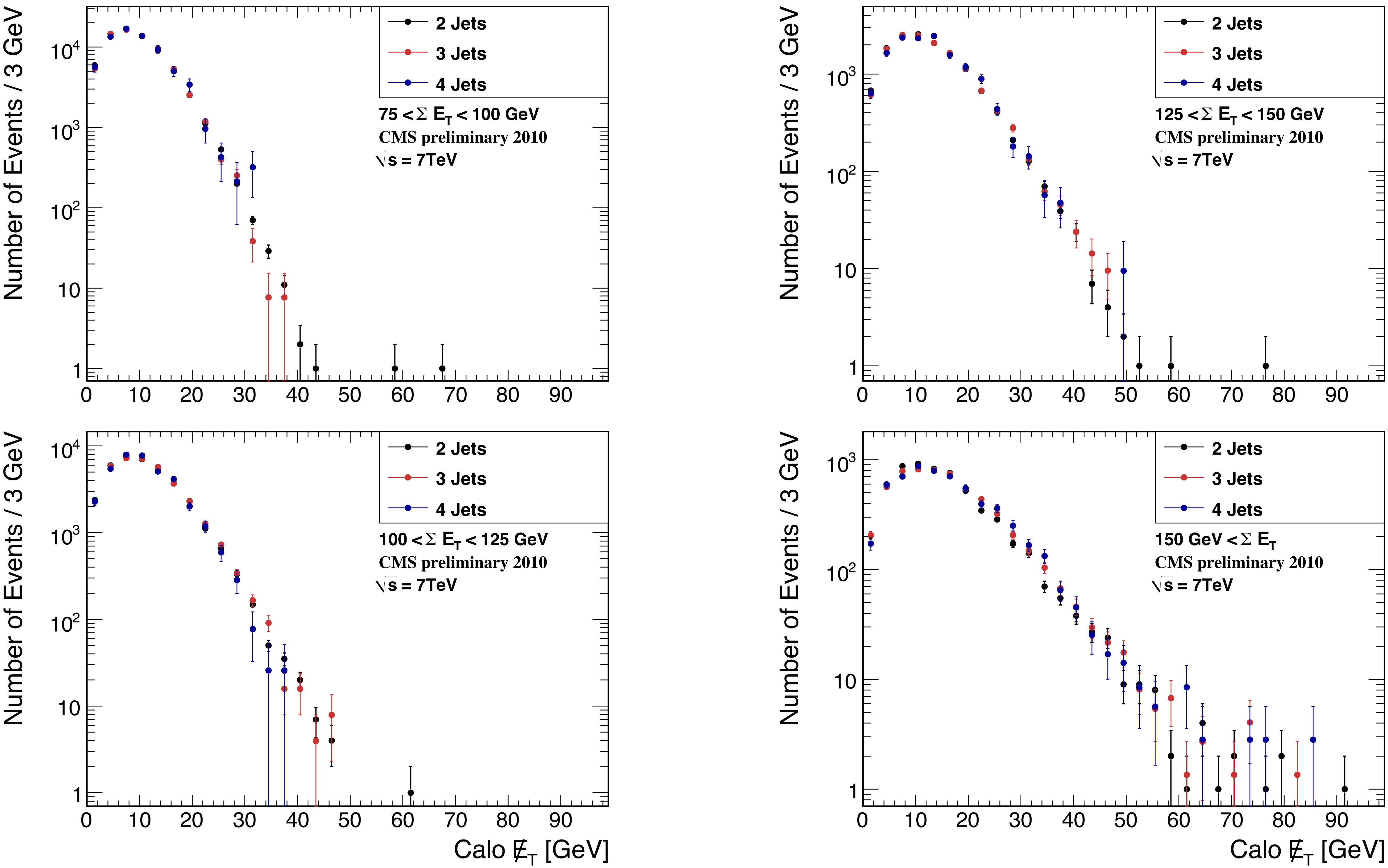
- require two leading jets $P_T > 25$ GeV, $|\eta| < 3$
- MET resolution = σ of Gaussian fit to calibrated $MET_{x,y}$
  - calibrate MET to photon ET in photon+jets events
- show dependence on SumET calculated with particle flow algorithm
  - pfSumET calibrated particle level using Pythia



pfMET has best resolution

Data & simulation agree well

CaloMET in MultiJet Data

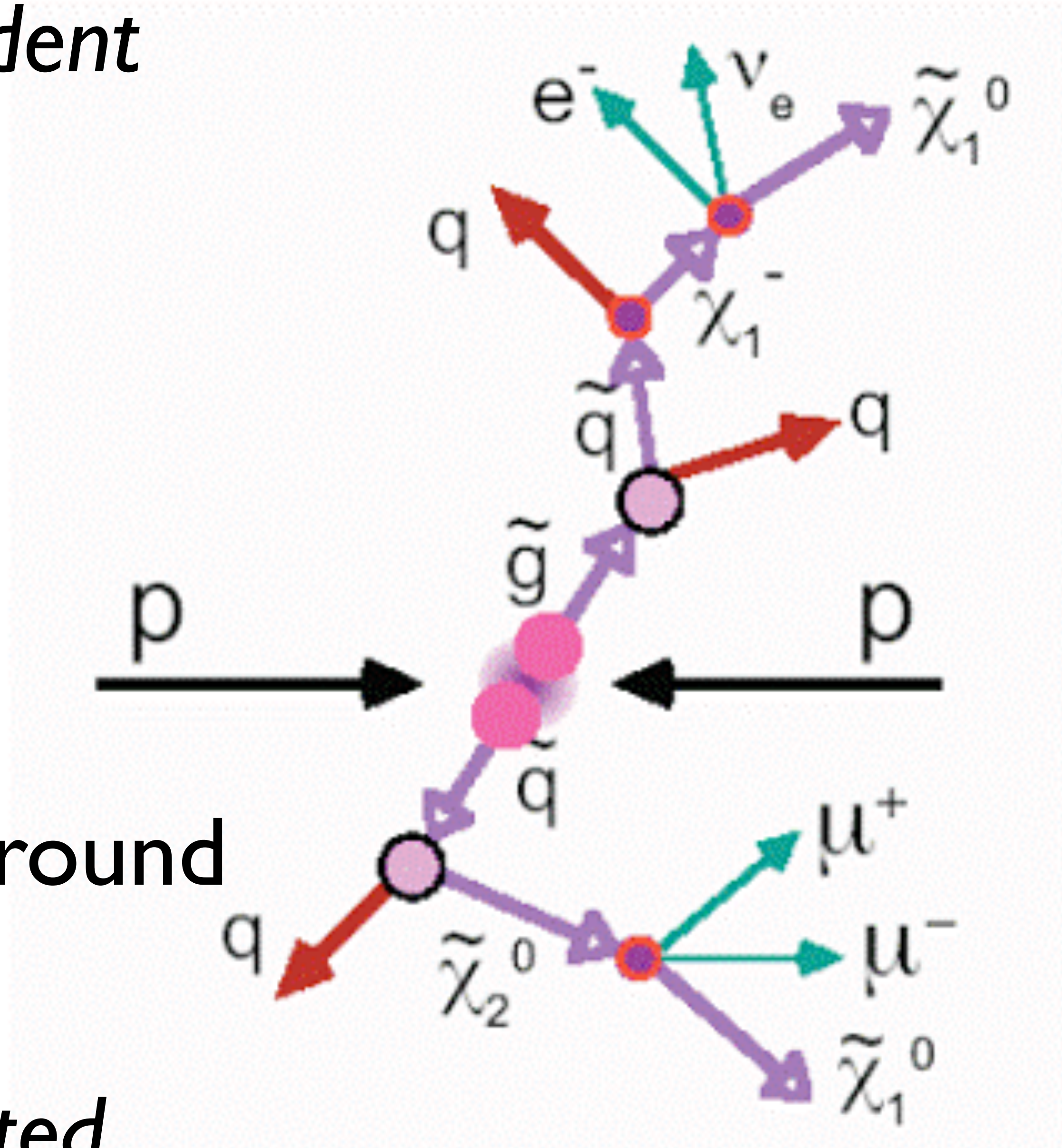


Many searches for new physics beyond SM use multijet samples

MET seems unaffected by jet multiplicity

SUSY searches at CMS

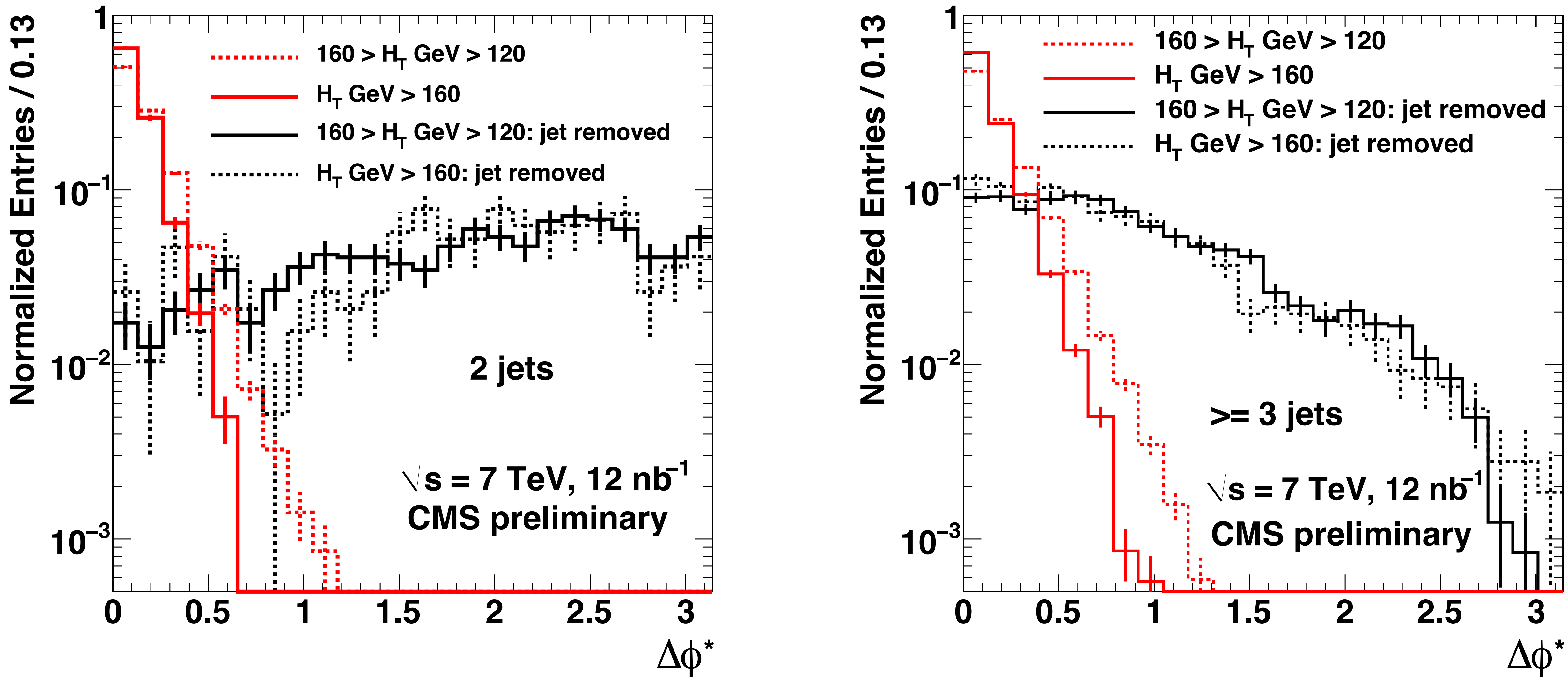
- Search channels are defined based on event content ⇒ *less model dependent*
  - fully hadronic = jets + MET
  - lepton + jets + MET
  - dilepton + MET
  - trilepton + MET
  - photons + MET



- Focus on estimating the SM background using *data-driven methods*
- *Results with first data in SM dominated regions*

MET is used for background modeling and for discrimination

QCD suppression

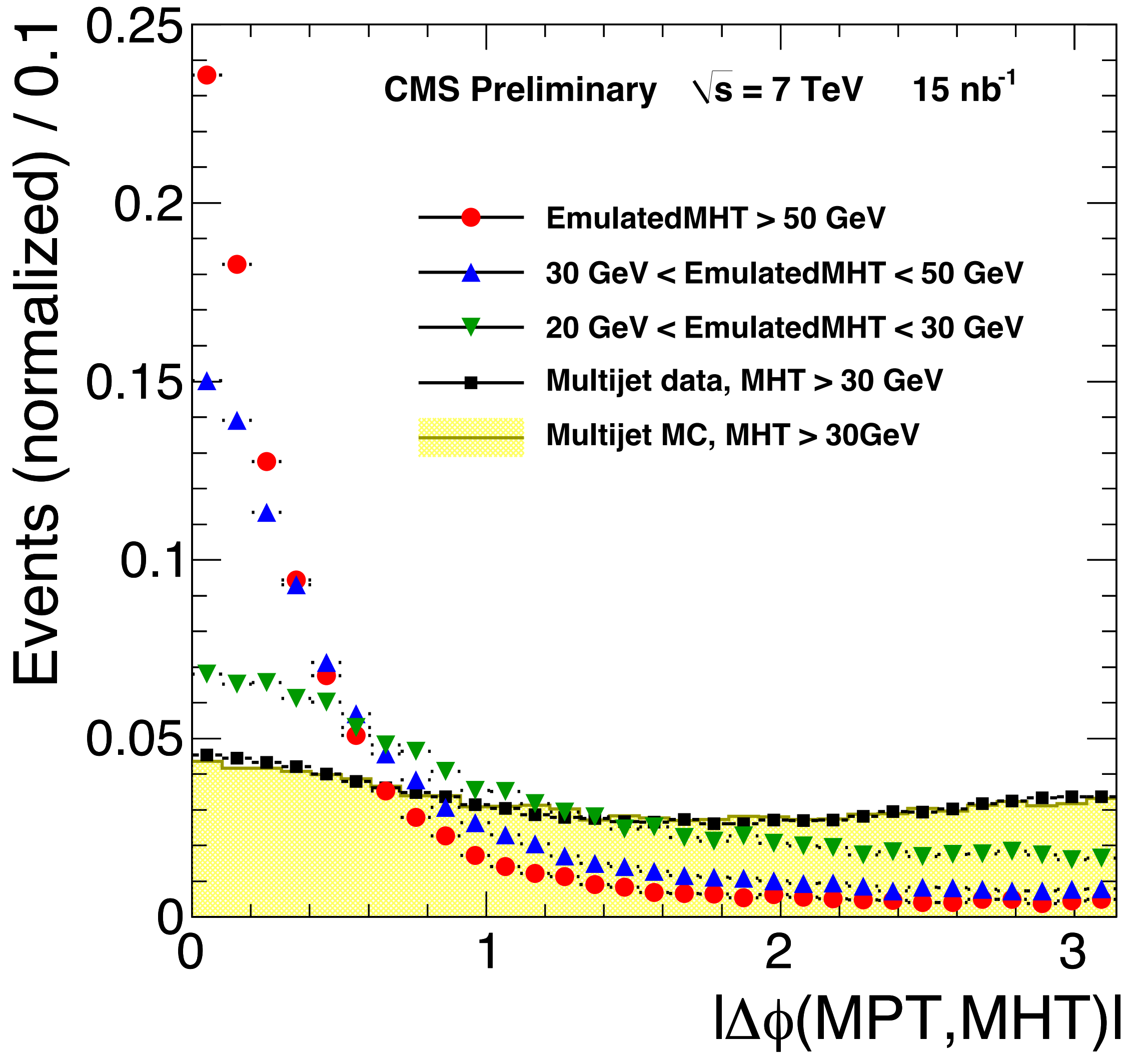


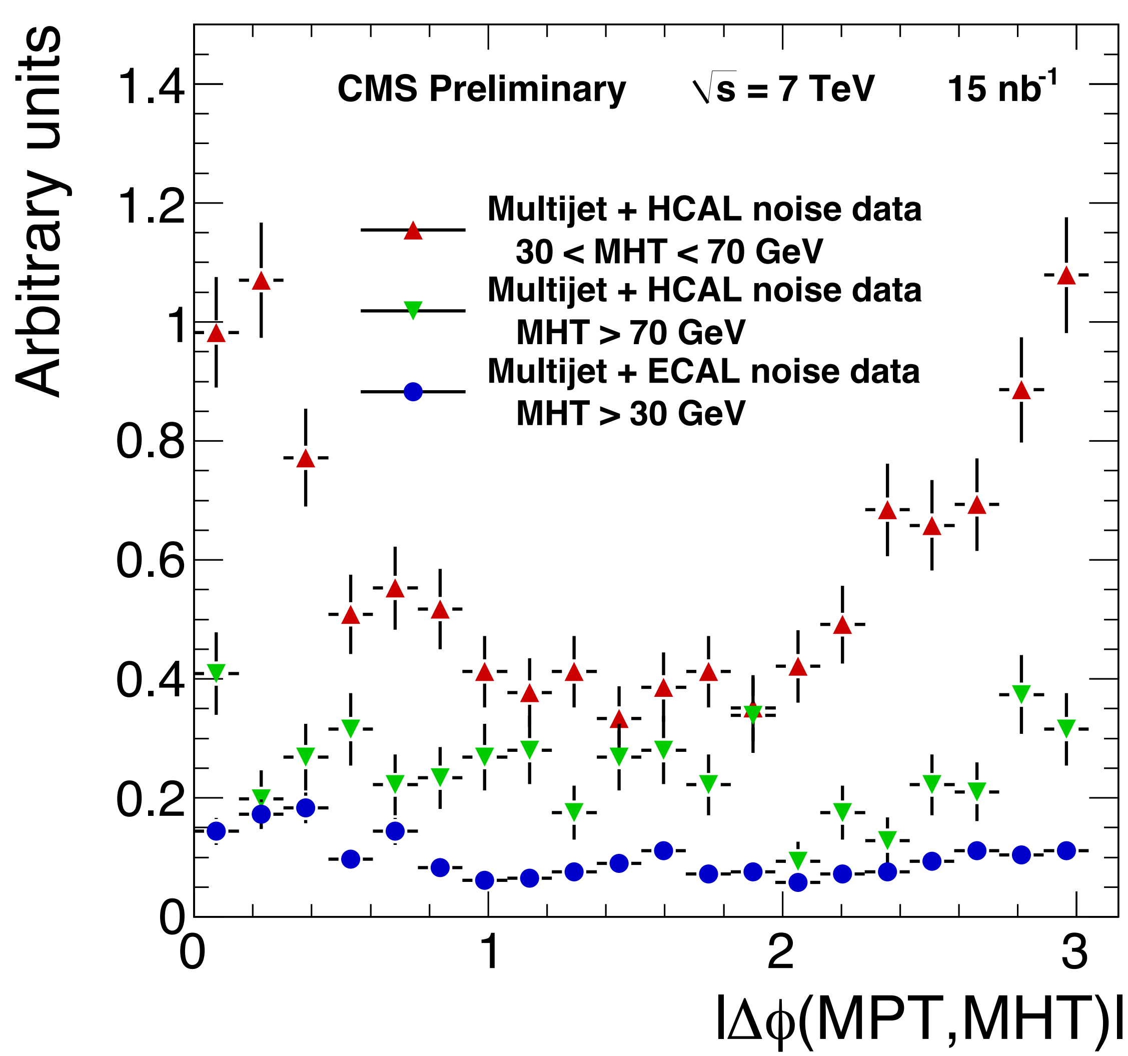
- *QCD background can play a major role in the hadronic searches*
  - small intrinsic MET, but high cross-section and resolution effects make up for it
- Use angle between MHT and jets to suppress it:
  - $\Delta\phi^*$ > 0.5 could efficiently reduce QCD

$$\Delta\phi^* \equiv \min_{\text{jets } k}\left(|\Delta\phi(\vec{p}_k, -\sum_{\text{jets } i\neq k}\vec{p}_i)|\right)$$

- Similar behavior between samples with 2 jets and ≥3 jets

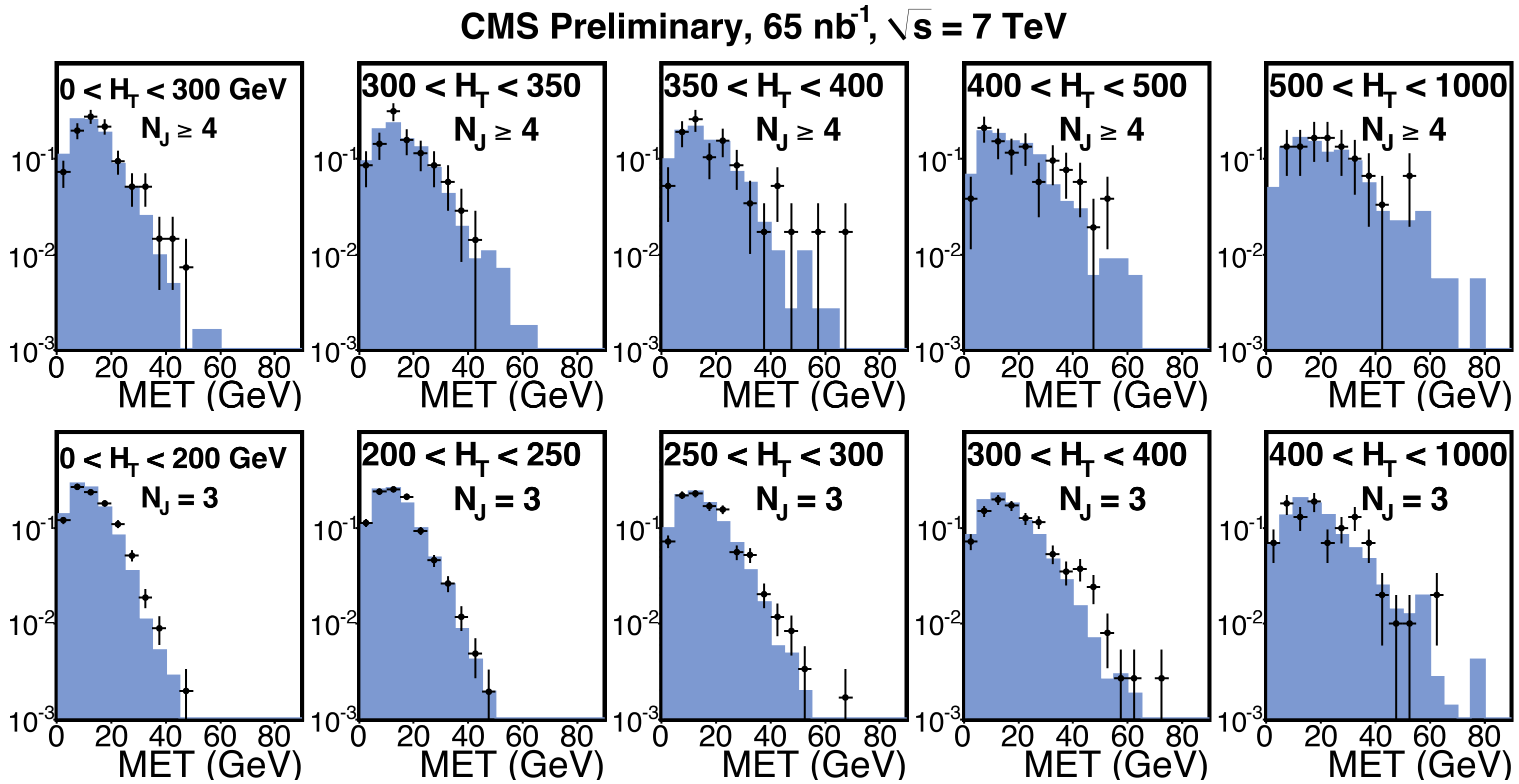
Control QCD and fake MET





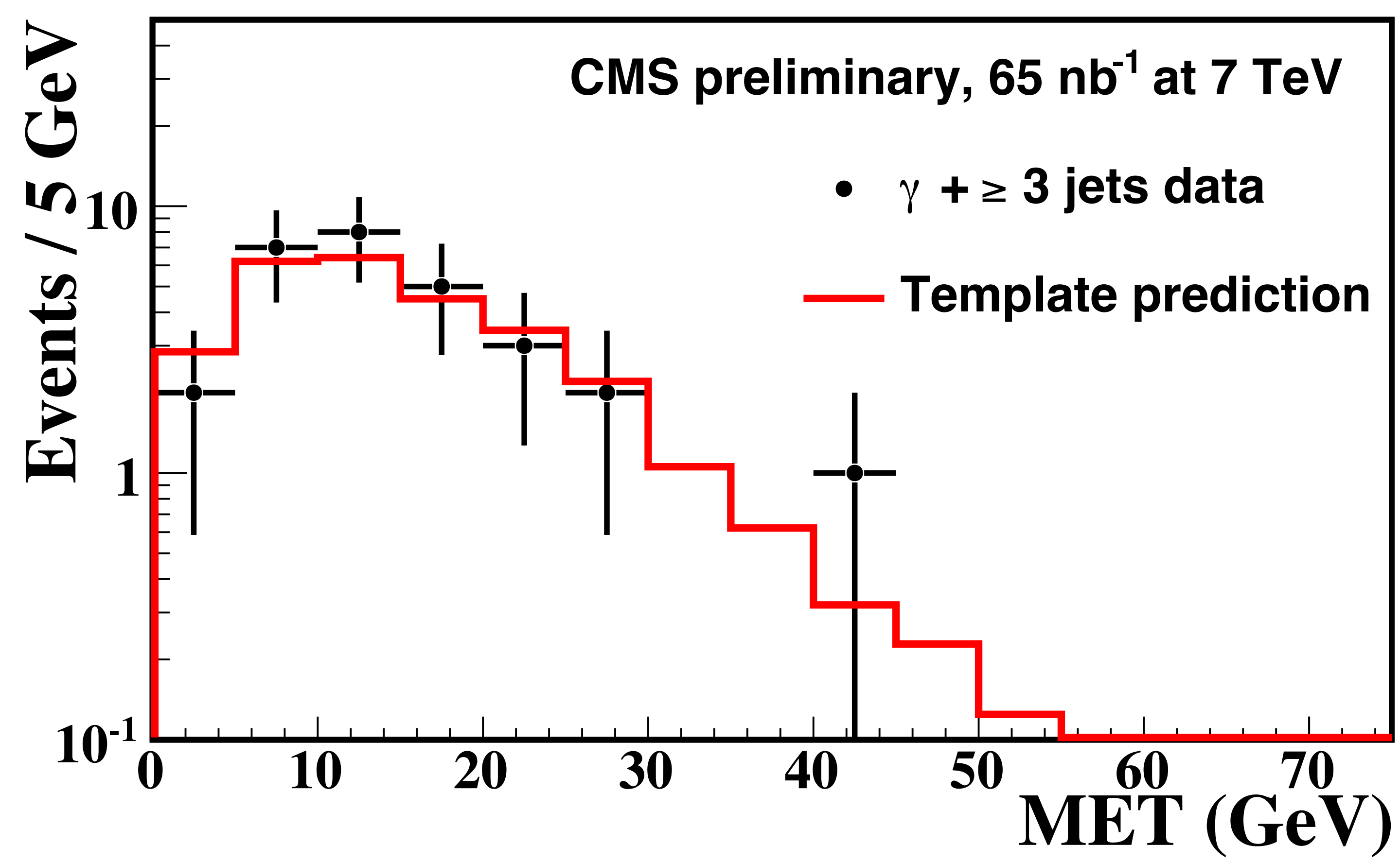
- *Look at the imbalance between tracks in the transverse plane = MPT*
  - neutrals are missing so the magnitude of MPT will be wrong, but the orientation is useful
- For QCD expect angle between MPT and MHT be flat, while peaking at 0 for real MET
- *Useful to suppress/predict QCD as well as to reduce the calorimeter noise*

Predicting QCD contribution



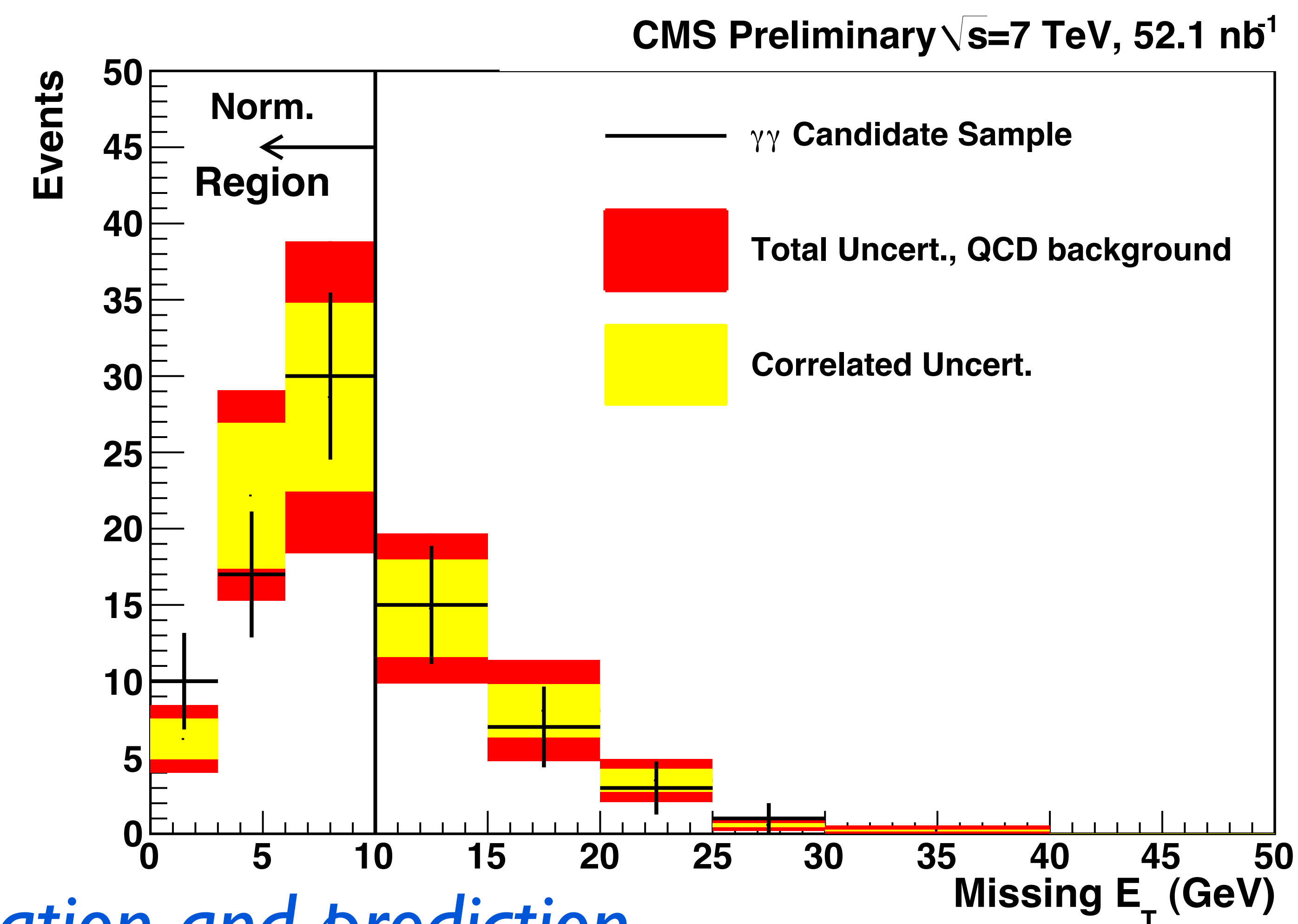
- *Build MET templates from multijet events*
- Bin in HT and N_{jets}

- *Test this in photon+jets events (P_T^{γ}>15 GeV)*
- Use PF reconstruction
- *Good agreement between observation and prediction*
  - N^{OBS}=11, N^{PRE}=12.5



QCD in diphoton+MET events

- Select a sample with 2 non-isolated photon candidates
- Weigh sample such that P_T of diphoton system matches that of the signal sample
- Normalize the MET distribution to the yield in the signal region with MET < 10 GeV



- *Good agreement between observation and prediction*
  - *N^{OBS} = 4 (MET > 20 GeV)*
  - *N^{PRE} = 4.2±1.5 (MET > 20 GeV)*

Conclusions

- *CMS has a good understanding of MET*
  - remarkable agreement between data and simulation
  - performant reconstructing algorithms
- *SUSY searches use a variety of tools to measure MET*
  - focus on data-driven approaches
  - alternative methods cross-checking each other
  - good description of SM contribution
- *More data on the way ⇒ expect improved results*