Searches for SUSY in All-Hadronic Events and Studies of MET

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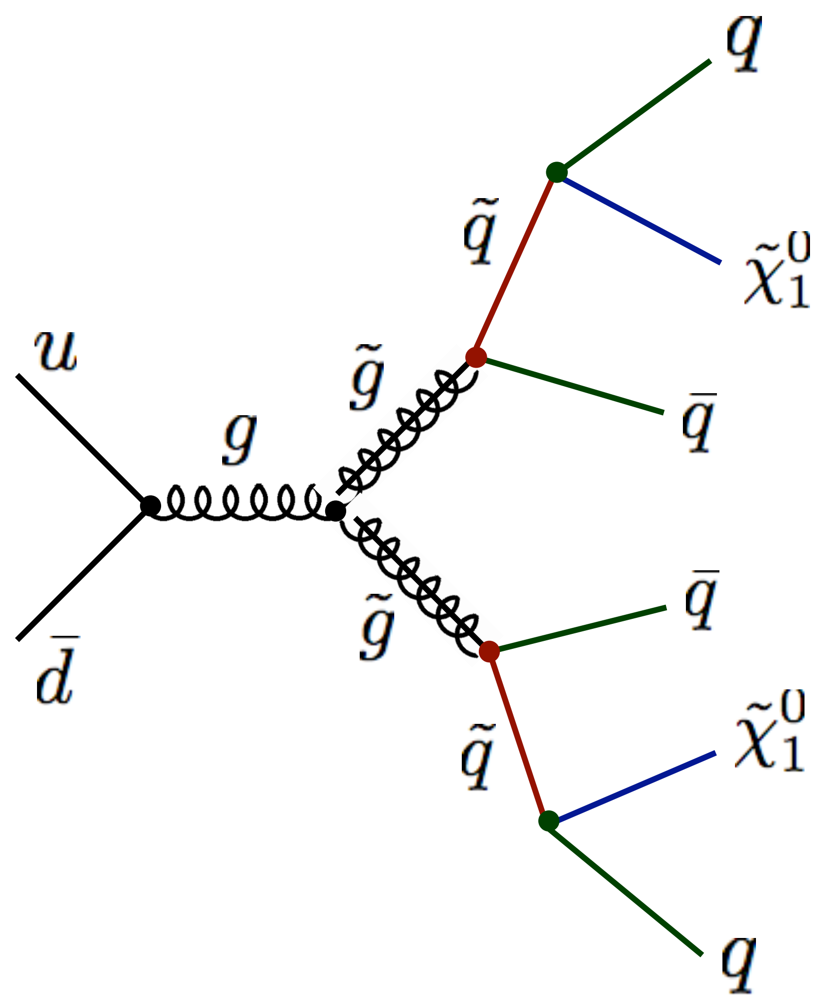
SUSY in All-Hadronic + MET Final State

Consider R-parity Conserving SUSY:

- ◆ Strongly interacting sparticles (squarks, gluinos) dominate production
- ◆ If Heavier than sleptons, gauginos etc. ⇒ cascade decays to LSP
- ◆ Long decay chains and large mass differences between SUSY states ⇒ Many high p_T objects observed (leptons, jets)
- ◆ R-parity conservation ⇒ LSP stable (DM candidate) and sparticles pair-produced



MET + jets + X final state

SUSY in All-Hadronic + MET Final State

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MET + jets + X final state

The Search:

- Require high p_T jets
  - At least three jets with p_T > 50 GeV/c
- Veto isolated leptons
  - Rejects $W(\ell\nu) + X$ backgrounds with real MET while maintaining efficiency for non-isolated leptons from SUSY decays
- Require azimuthal angle of MET to point away from jets
  - Reduces QCD background with MET resulting from jets mis-measurements
- Require high H_T and MET

SUSY in All-Hadronic + MET Final State

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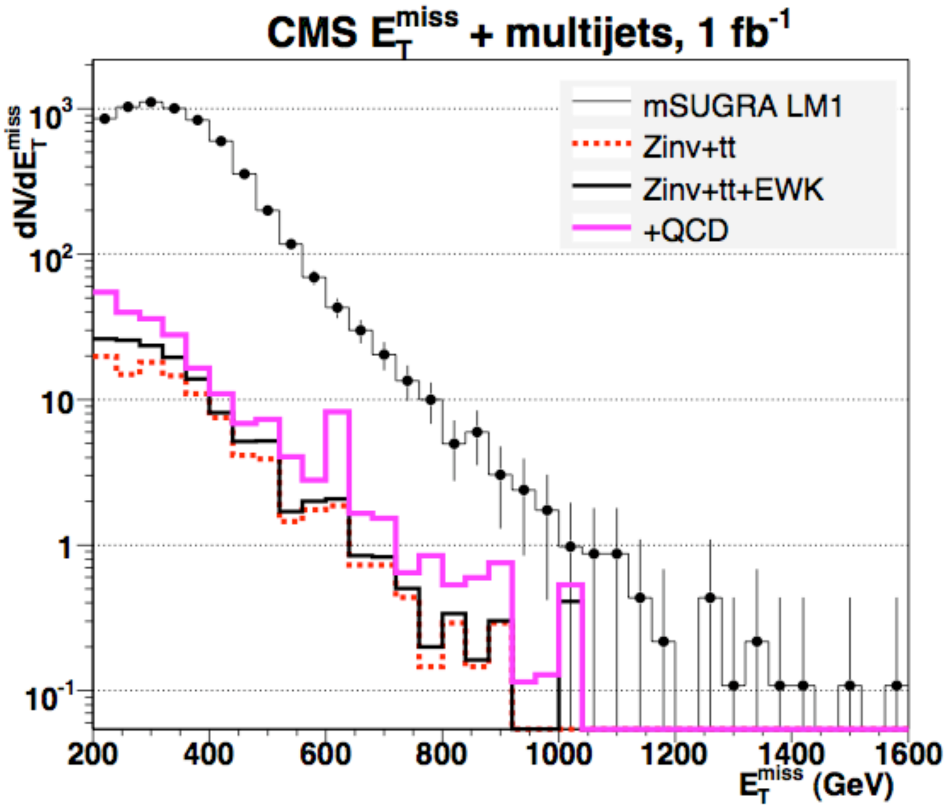

$\sqrt{s} = 14$ TeV MC
CERN-LHCC-2006-021

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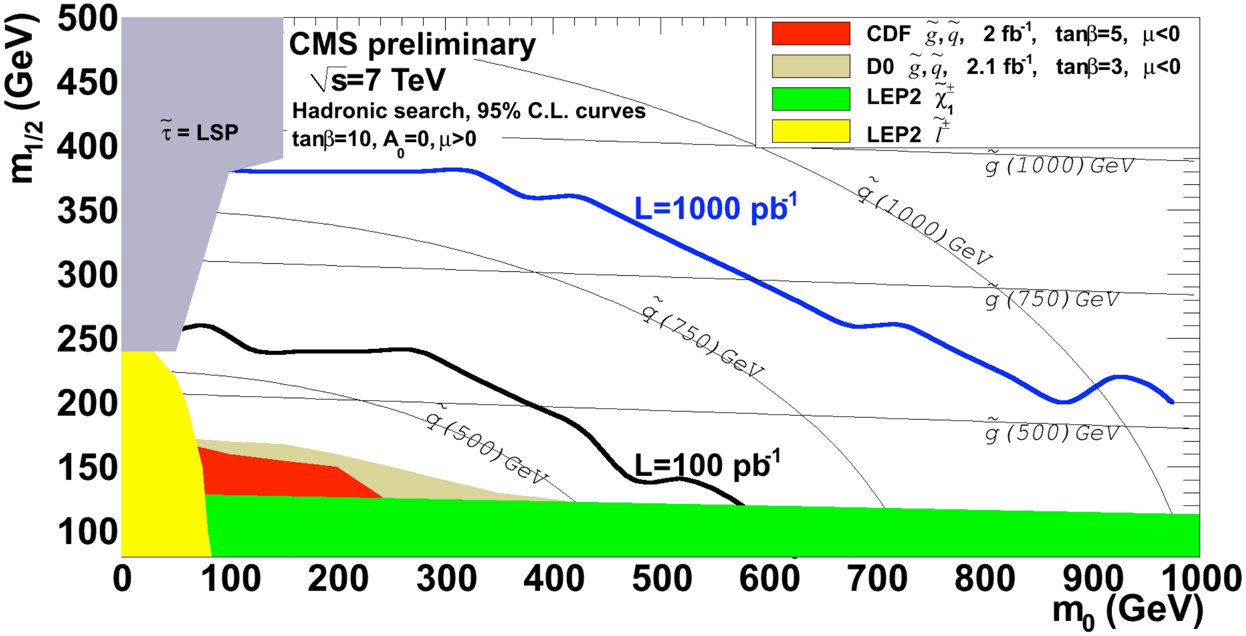
Discovery Potential

CMS NOTE-2010-008



With this strategy, 7 TeV data ≤100 pb^{-1} should provide sensitivity to SUSY parameter space beyond current TEVATRON limits

Achieving this sensitivity depends on:

- **Measuring/predicting SM backgrounds**
  - $Z(\nu\nu)+\text{jets}, W(\ell\nu)+X\ (\text{including}\ top+X), \text{QCD}, \cdots$
- **Understanding lepton, jets and MET reconstruction**
  - Angular resolution of jets/MET reconstruction in context of QCD rejection
  - Controlling/predicting MET tail in presence of instrumental backgrounds, noise, calorimeter non-compensation

Jets and MET in CMS

Calorimeter Jets:

Jets clustered from ECAL and HCAL combined cells (CaloTowers)

Calo MET:

Calculated from vectorial sum of CaloTowers

Track Jets:

Jets clustered from tracks of charged particles, independent of calorimetric measurement

Missing transverse momentum (MPT):

Calculated from charged particle tracks

JME-10-006

Default Jet Clustering Algorithm: Anti-K_T with R = 0.5

Jet-Plus-Track Jets (JPT):

Tracks matched with Calo jets ⇒ expected calorimeter responses subtracted ⇒ replaced with track measurement

Track corrected (Tc) MET:

Calo MET appended with tracks' momentum, minus expected calo depositions

JME-09-002 JME-09-010

Particle Flow (PF) Jets:

Geometric linking between tracks and calorimeter depositions ⇒ "particle candidates" ⇒ calibrations applied depending on "particle" hypothesis ⇒ jets clustered from particles

PF MET:

MET calculated from "particle" list

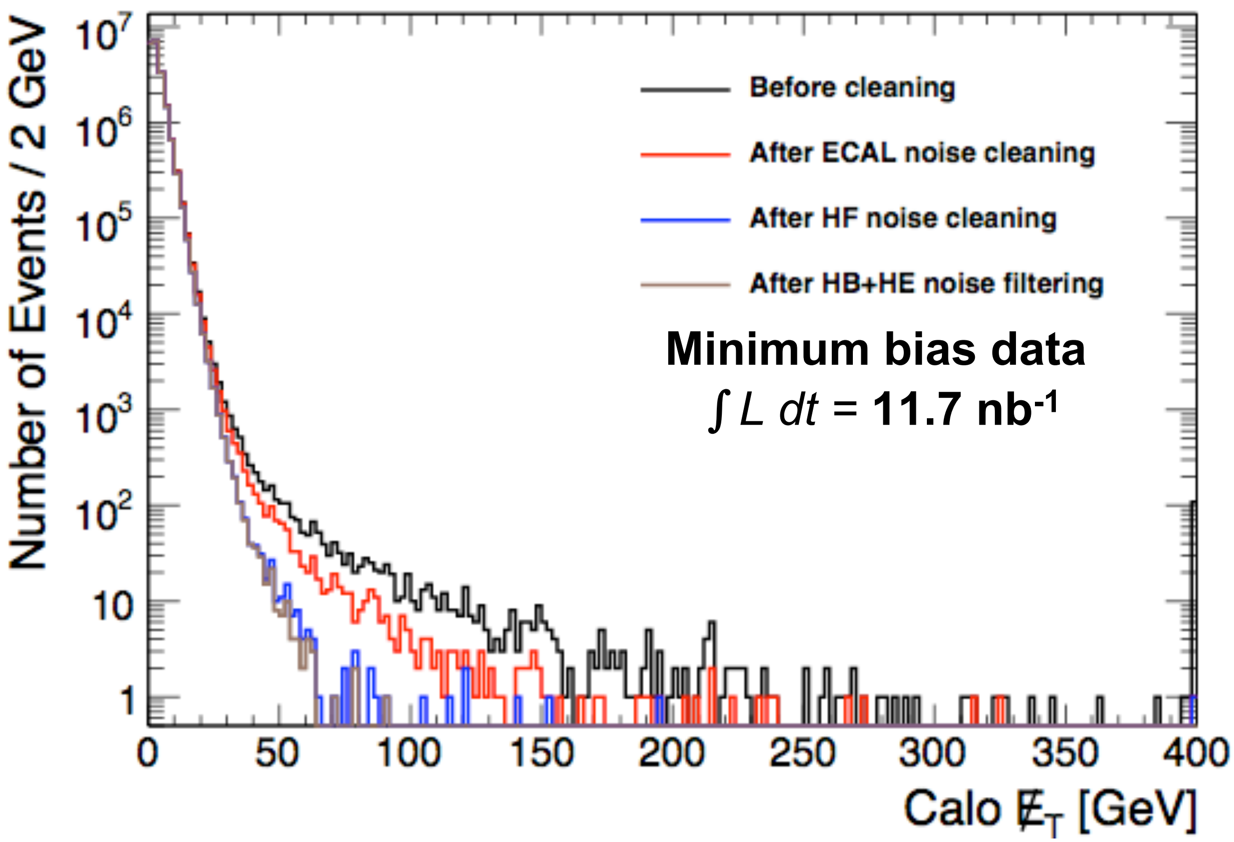
PFT-10-002

Orthogonal sub-detector measurements used to cross-check results and combined to improve reconstruction performance

MET Event Cleaning

Basic event cleaning strategy identifies anomalous signals based on (see back-up slide):

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



Effective cleaning procedure removes anomalous signals in MET distribution tail

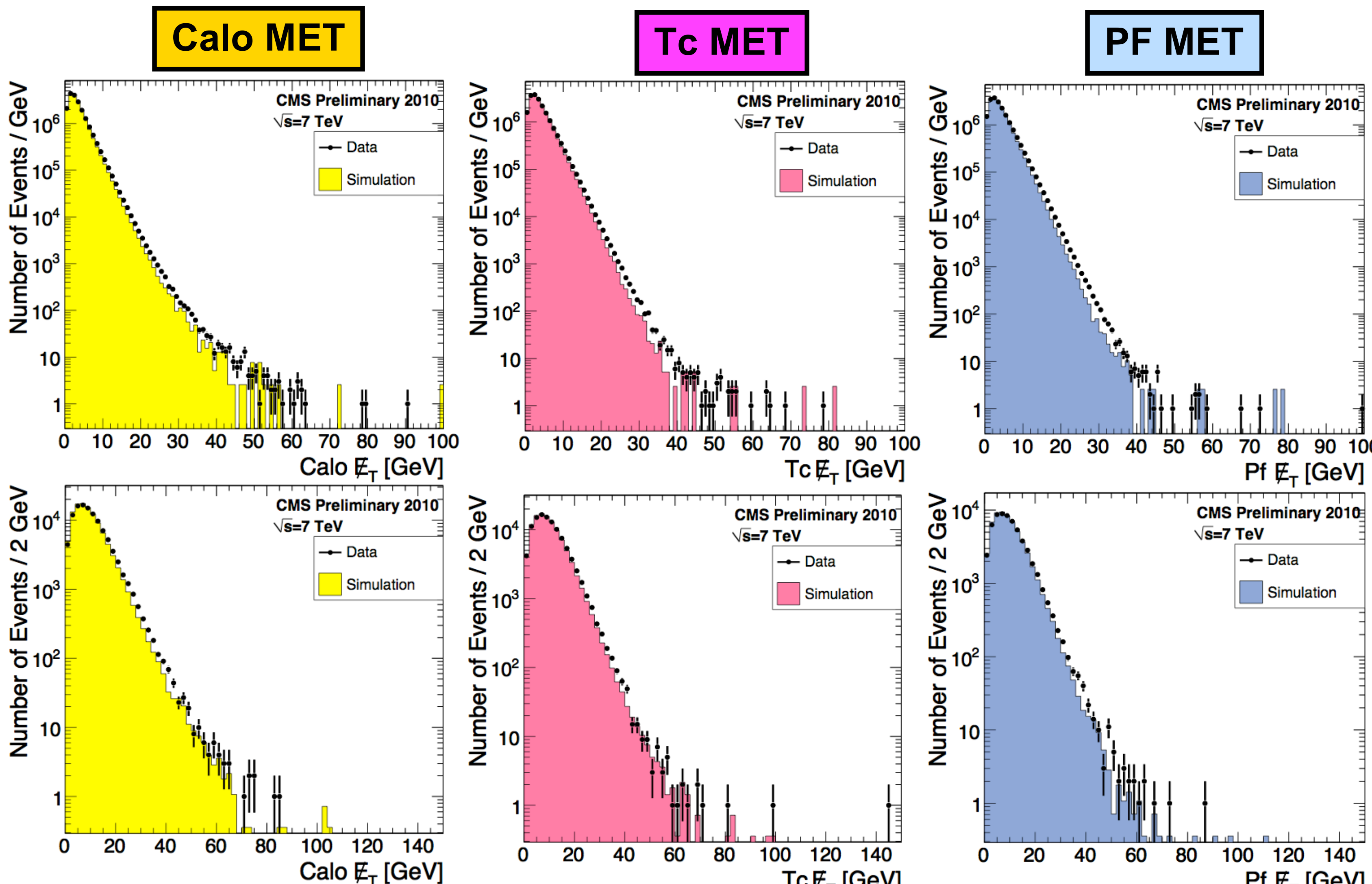
JME-10-004

$\int L\,dt$ = 11.7 nb^{-1}

MET in Data and Monte Carlo

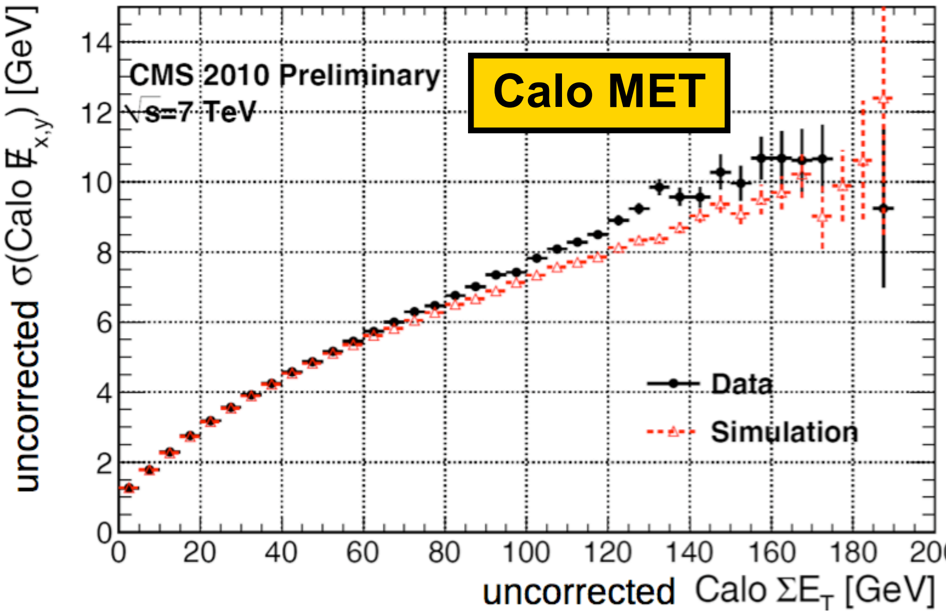
Minimum Bias

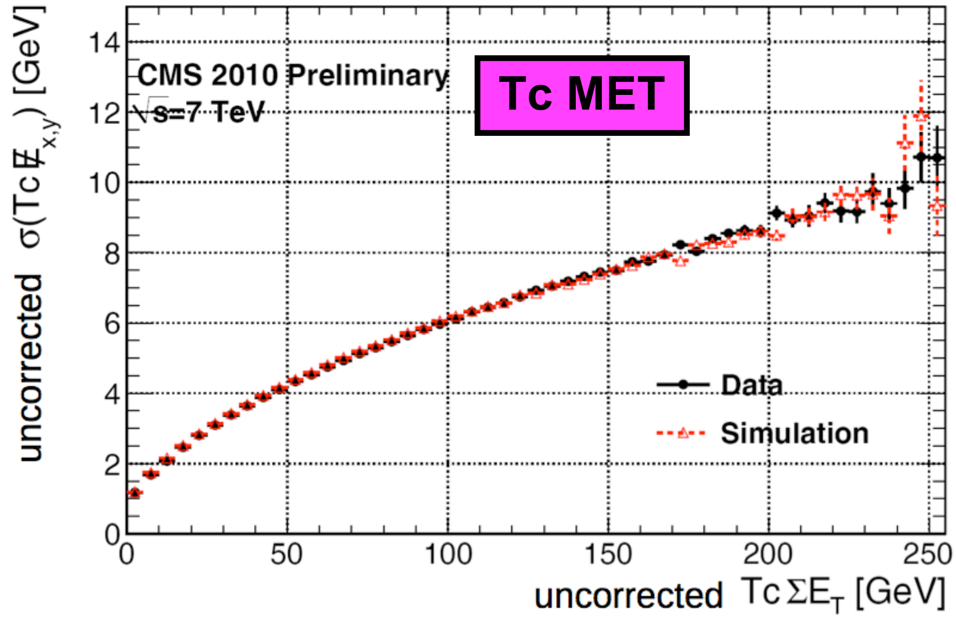
Di-jet events ($p_T^{1,2} > 25$ GeV/c, $|\eta_{1,2}| < 3$)

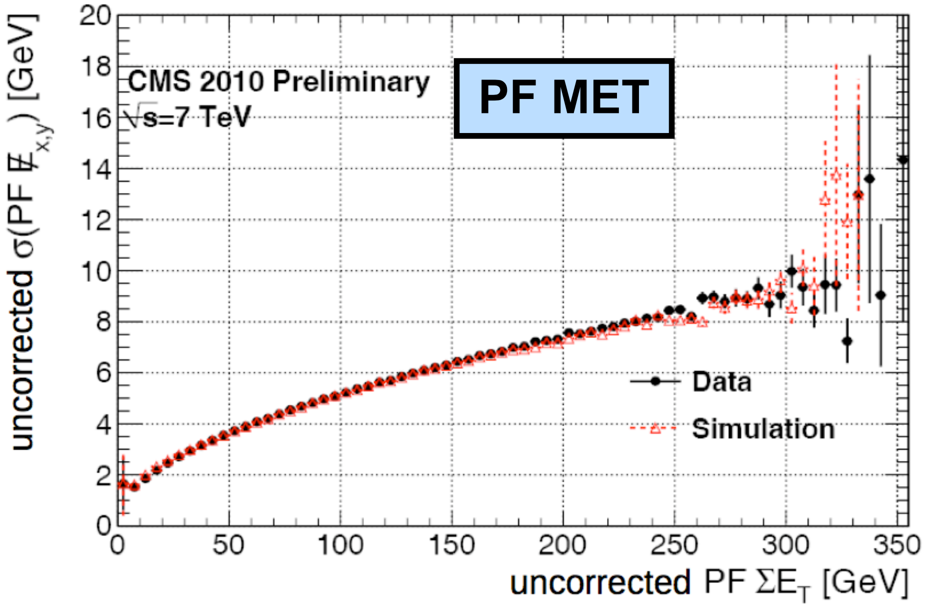


General Data/MC agreement in minimum bias and di-jet events

MET Resolution







MET resolution calculated through fit of MET x/y components (CMS reference frame) with Gaussian function, as a function of SumE$_T$

Good agreement between data and simulation observed in each MET type

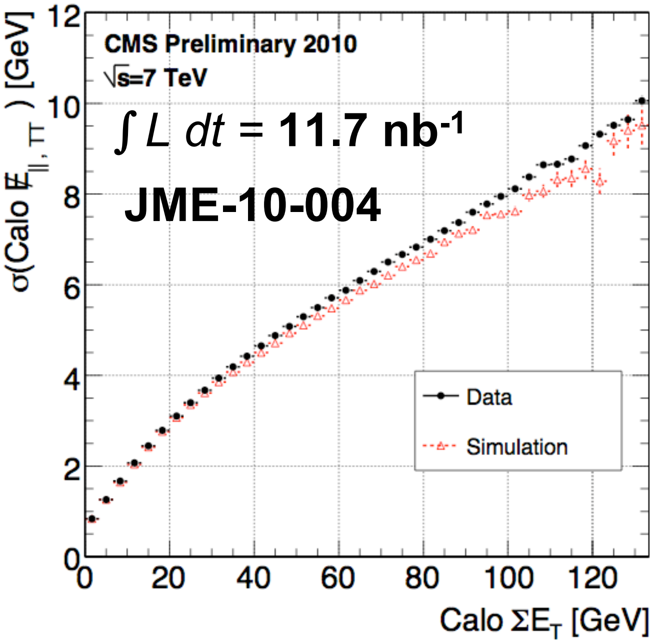
Event transverse thrust axis calculated using reconstructed tracks in event

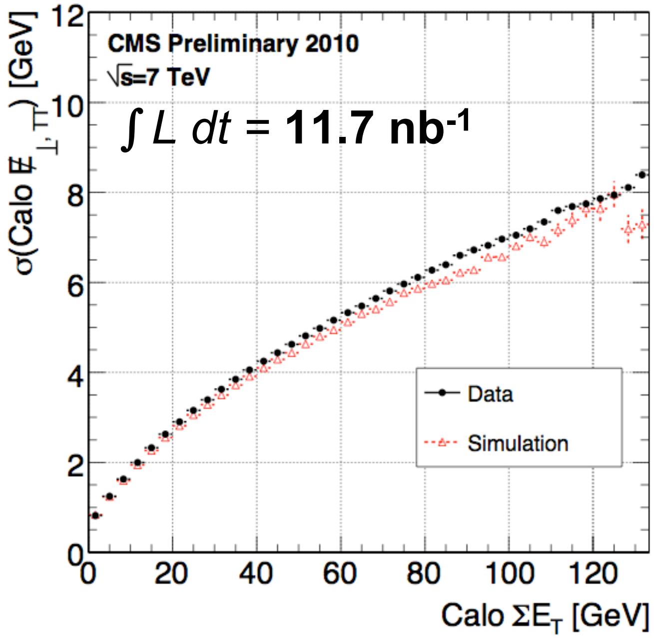
$$\mathrm{TT} = \max_{\phi_{\mathrm{TT}}} \frac{\sum_i p_T^i \cos(\phi_{\mathrm{TT}} - \phi_i)}{\sum_i p_T^i}$$

MET components parallel and perpendicular to TT axis probe different contributions to MET resolution:

- Perpendicular component more sensitive to calorimetric noise
- Parallel component more sensitive to detector response to particles

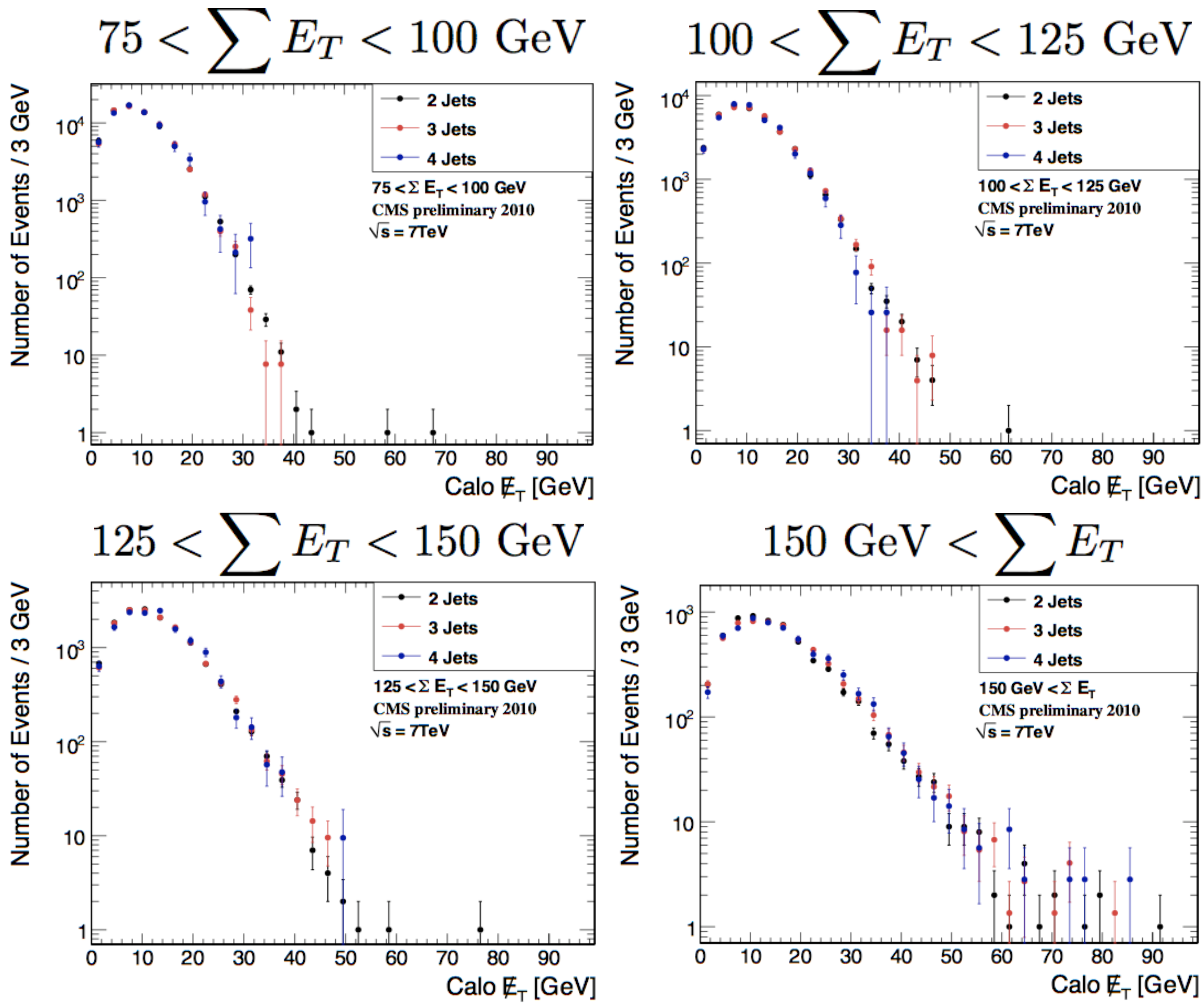
MET resolution parallel and perpendicular to TT axis





Both components well-modeled for calorimetric MET in simulation

MET in Multi-jet Events



JME-10-004

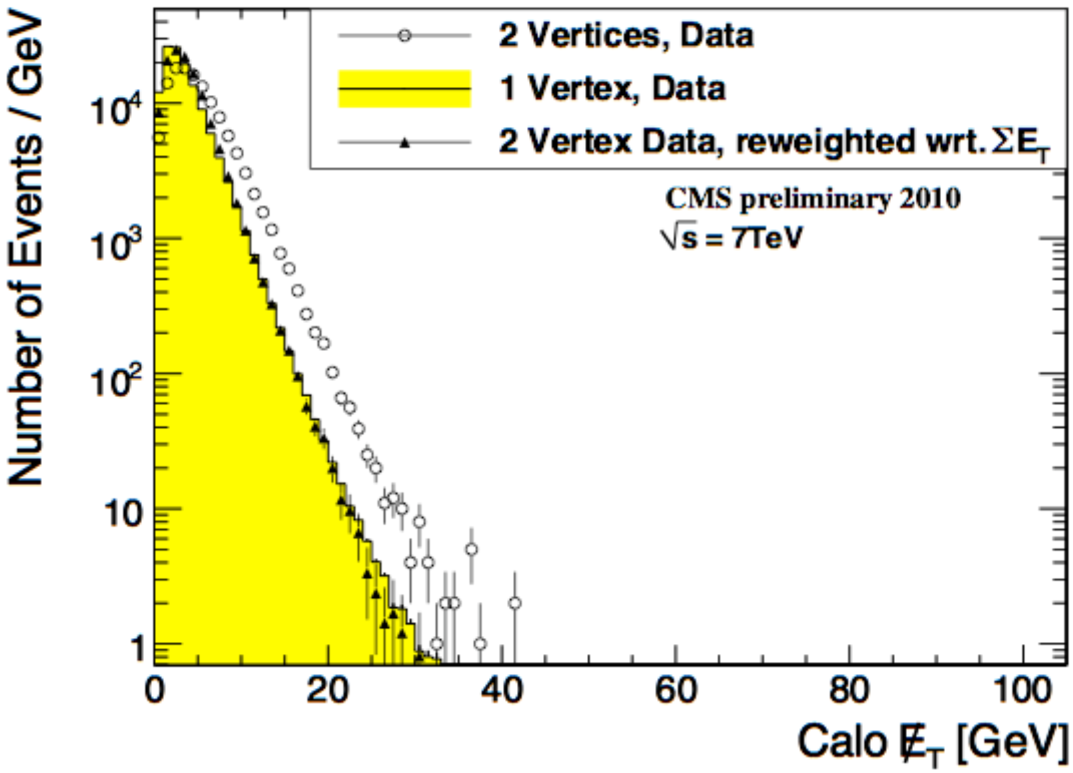
$\int L\,dt$ = **11.7 nb^{-1}**

Jet counting with p_T > 20 GeV/c, |η| < 3

MET distribution shows strong dependence on $SumE_T$, not on number of reconstructed jets

MET in Events with Pile-up

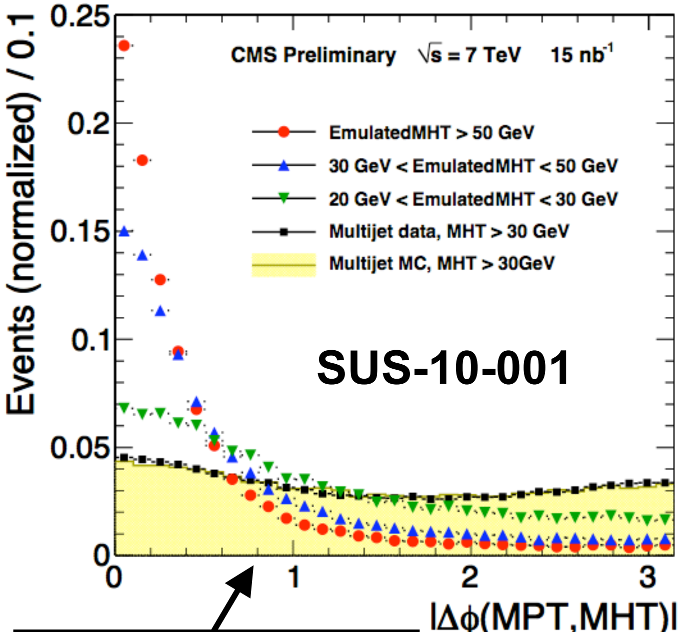
MET in 1- and 2- vertex minimum bias events

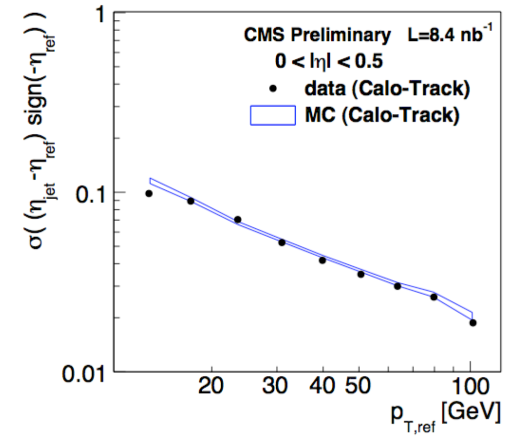


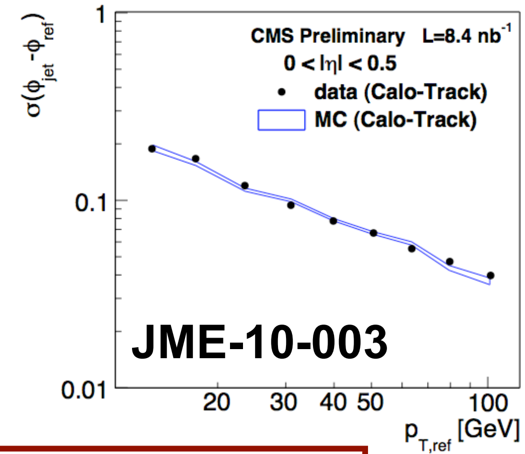
- MET distribution wider in events with 2 primary vertices (pile-up)
- Re-weight 2-vertex events events such that the $SumE_T$ distribution matches that of 1-vertex events
- After re-weighting, MET distribution agrees between 1-vertex and 2-vertex events

MET distribution's dependence on $SumE_T$ consistent between 1-vertex and 2-vertex events

Jets/MET Angular Resolution and Correlations







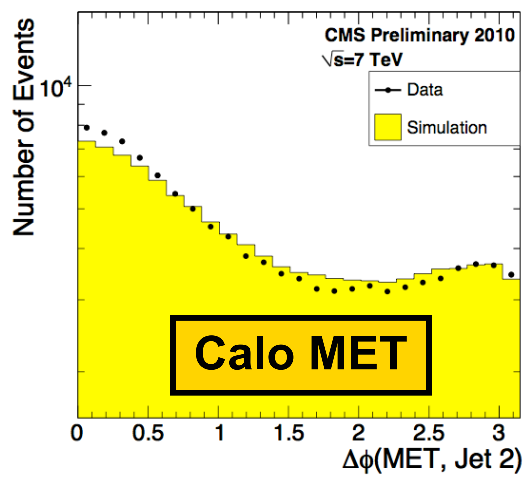
Azimuthal angular correlations between jets/MET/MHT agree well with expectations, as do angular resolutions

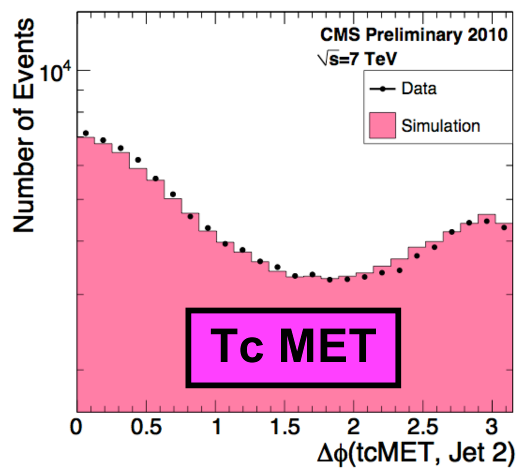
$$\vec{MHT} \equiv -\sum_{i}^{\text{jets}} \vec{p}_T^{\,i}$$

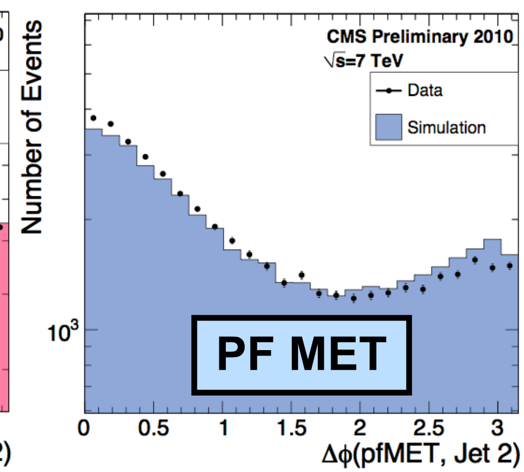
$$\vec{MPT} \equiv -\sum_{i}^{\text{tracks}} \vec{p}_T^{\,i}$$

"EmulatedMHT" from ignoring random jet and matching tracks

JME-10-004 $\int L\,dt = 11.7\ \text{nb}^{-1}$







Jet p_T Resolution

Di-jet Asymmetry Method

- Select QCD di-jet events and calculate "Di-jet asymmetry", *A*, as a function of p_T^{ave}:

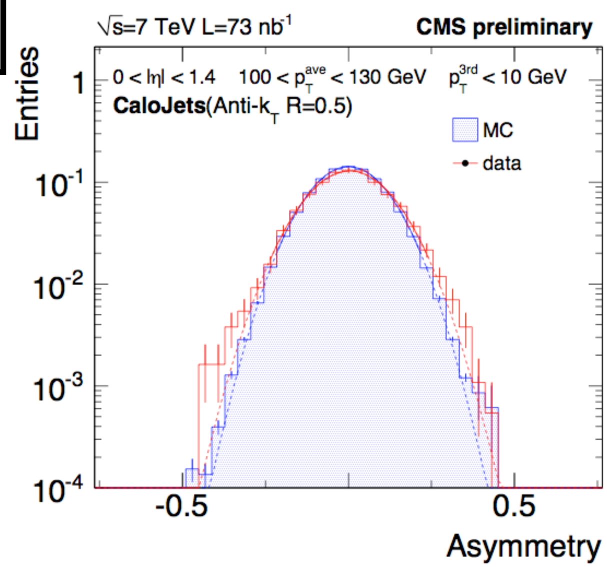
$$A = \frac{p_T^{\text{jet1}} - p_T^{\text{jet2}}}{p_T^{\text{jet1}} + p_T^{\text{jet2}}}$$

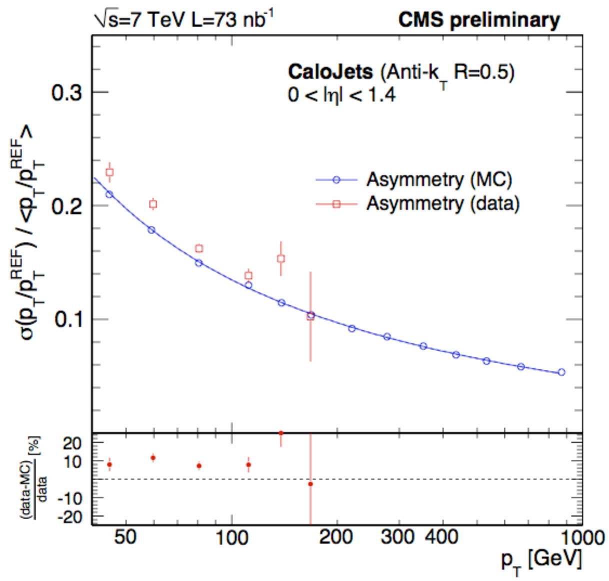
$$p_T^{\text{ave}} \equiv (p_T^{\text{jet1}} + p_T^{\text{jet2}})/2$$

- *A* distribution can be used to infer p_T resolution

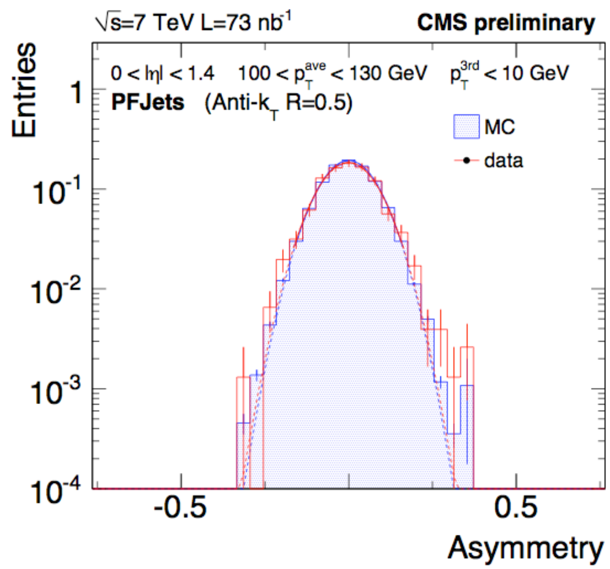
$$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$

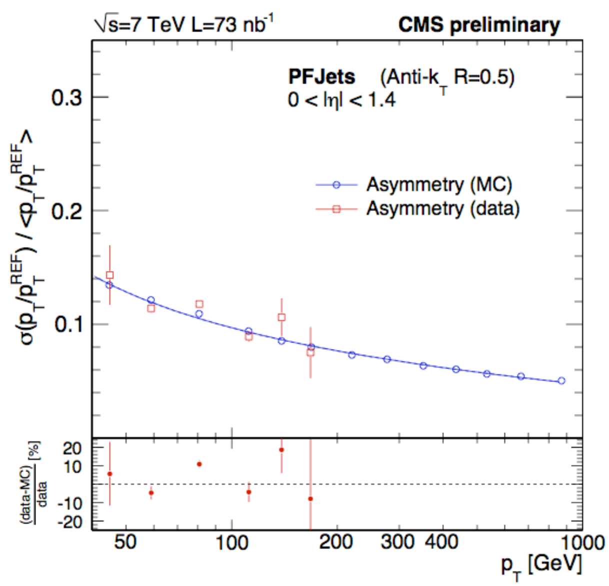
- QCD background in MET tail can be estimated by using measured jet resolution function to smear events and then re-calculating MET





Calo Jets





PF Jets

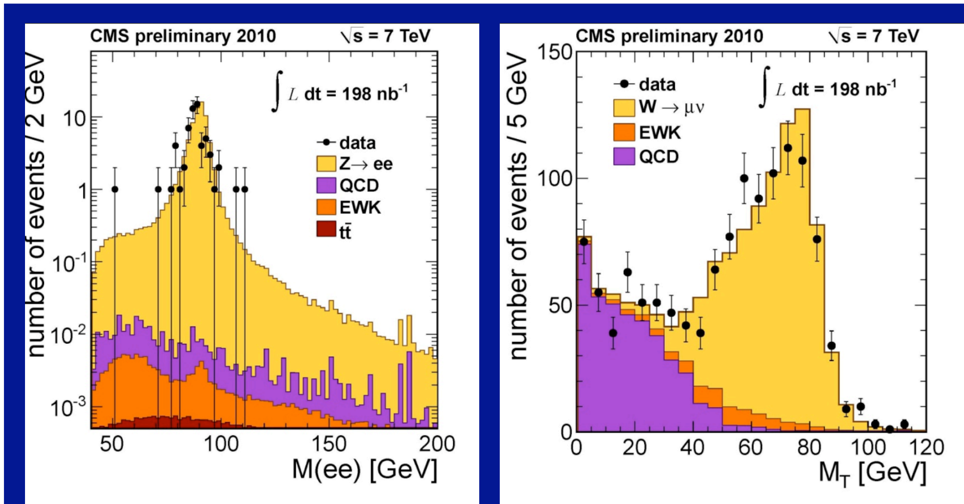
EW Backgrounds - W/Z+jets Candles and Handles

Masses

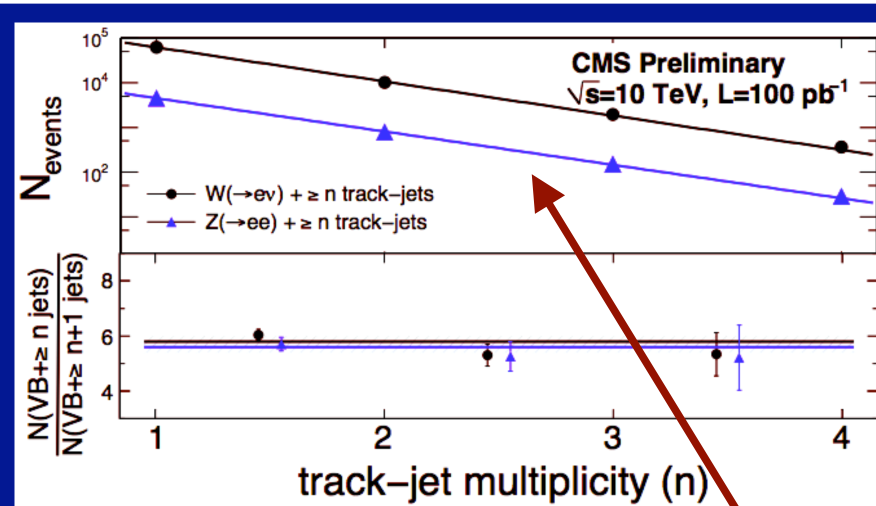
$$(m(\ell\ell), m_T(\ell\nu))$$

Scaling/Ratios

aka "Berends-Giele" (BG) scaling



EWK-10-002



EWK-09-006

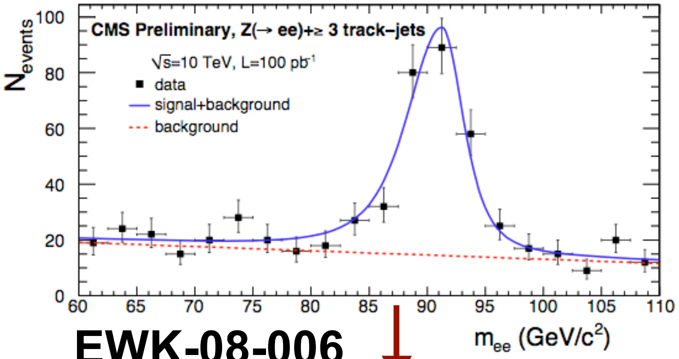
CONSTANT SLOPE

Fully DATA-DRIVEN methods for studying W/Z+jets production, using candles/handles to:

- **Study detector reconstruction performance**
- **Estimate backgrounds to BSM searches**
- **Probe pQCD**

EW Backgrounds - W/Z+jets Candles and Handles (MC and Data)

$\sqrt{s} = 10$ TeV MC



EWK-08-006

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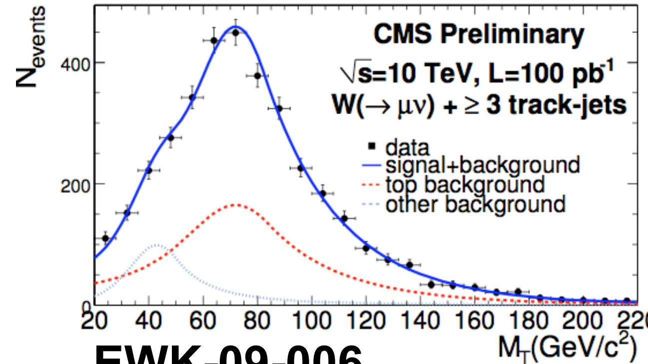
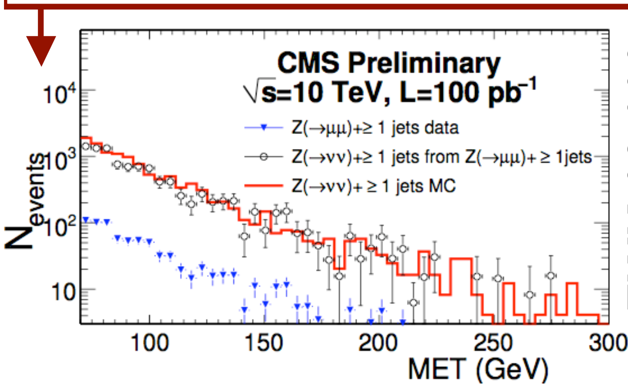


EWK-09-006

- **ML Fit used to extract W/Z+jets yields as a function of jet multiplicity**

$$C_W/C_Z = \frac{W + n \text{ jets}/W + (n+1) \text{ jets}}{Z + n \text{ jets}/Z + (n+1) \text{ jets}}$$

- **Statistical background subtraction (sPlots) yields "candle" data-set**



EWK-08-006 $\sqrt{s} = 10$ TeV MC

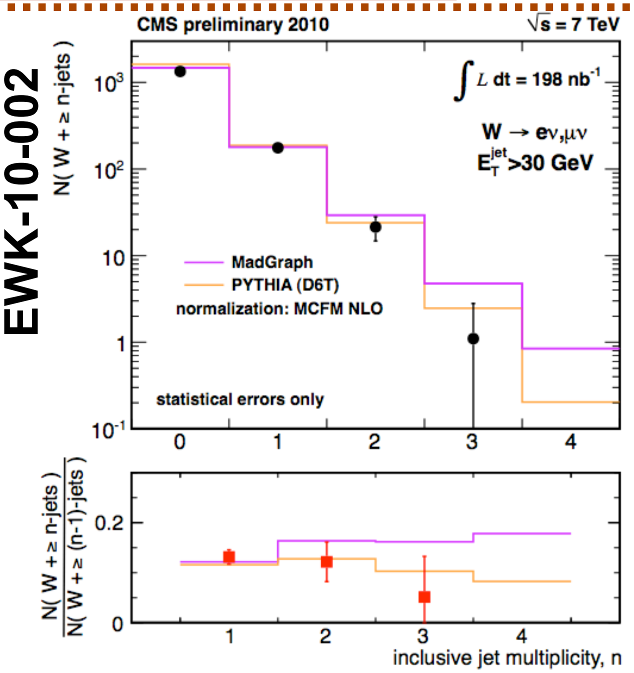
$Z(\nu\nu) + \text{jets normalization}$

Can also use (SUS-08-002):

$W + \text{jets}$ $\gamma + \text{jets}$

- **BG Scaling + C_W/C_Z ratio + low jet mult. yields ⇒ exp. high mult. yields**
- **W ML fit gives handles on leptonic top+X (see back-up slide)**

EWK-10-002



Outlook

- CMS expects to have sensitivity to SUSY in the MET+jets+X final state surpassing that of TEVATRON quite soon

- Data-driven approaches for measuring/predicting SM backgrounds in place and already being executed with 7 TeV data

- Performance of jet and MET reconstruction under active study, with preliminary results showing excellent agreement with expectations

- STAY TUNED: already > 10x more data than presented here recorded - potentially exciting times are approaching rapidly…

References

- CMS NOTE-2010-008 -- The CMS physics reach for searches at 7 TeV
- CERN-LHCC-2006-021 -- CMS Physics TDR: Volume II, Physics Performance
- CMS DP-2010-014 -- Jet and MET Commissioning Results from 7 TeV Collision Data
- JME-10-003 -- CMS Jet Performance in pp Collisions at 7 TeV
- JME-10-004 -- Missing Transverse Energy Performance in Minimum-Bias and Jet Events from Proton-Proton Collisions at 7TeV
- JME-10-006 -- Commissioning of Track Jets in pp Collisions at 7 TeV
- JME-09-002 -- The Jet Plus Tracks Algorithm
- JME-09-010 -- Performance of Track Corrected Missing ET in CMS
- SUS-10-001 -- Performance of Methods for Data-Driven Background Estimation in SUSY Searches
- SUS-08-002 -- Data-Driven Estimation of te Invisible Z Background to the SUSY MET Plus Jets Search
- EWK-10-002 -- Measurements of Inclusive W and Z Cross Sections in pp Collisions
- EWK-09-006 -- W+Njets/Z+Njets ratio
- EWK-08-006 -- Measurement of the production of Z bosons in association with jets in pp Collisions at 10 TeV
- PFT-10-002 -- Commissioning of the Particle-flow Event Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV

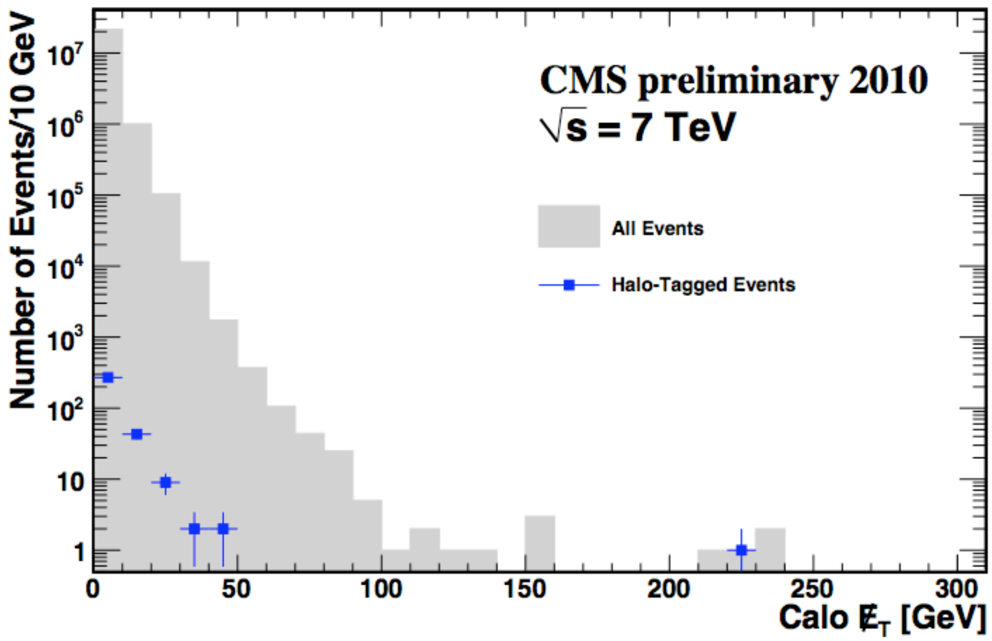
http://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

BACK-UP SLIDES

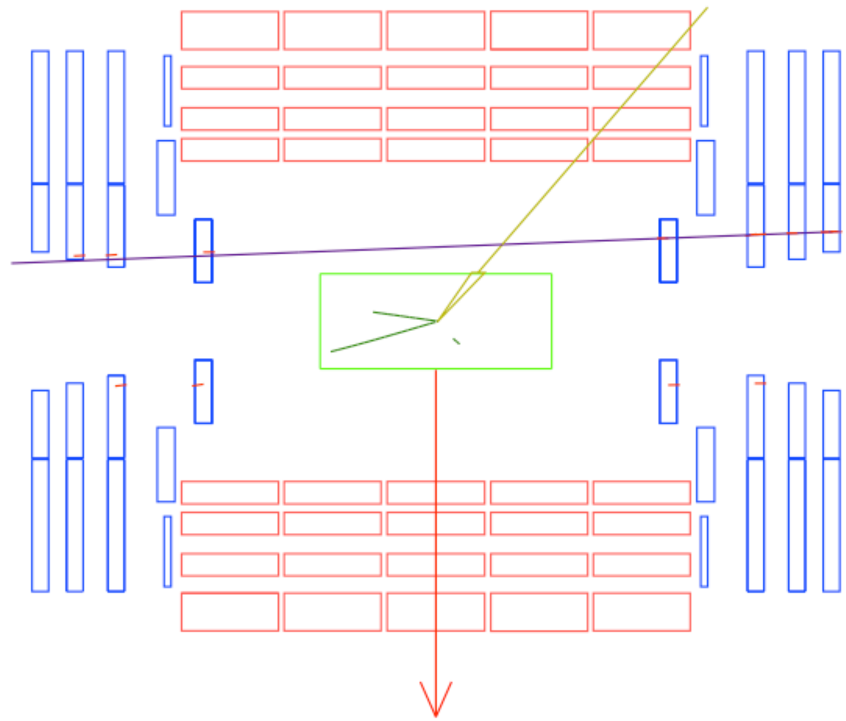
Anomalous Signal Cleaning

- **ECAL spikes**
  - Remove rechits with ET > 5 GeV and "1-E4/E1 < 0.95"
  - Remove out-of-time rechits ($t \in [-4, +2]$ ns)
- **HF anomalous signals**
  - Cut on (L-S)/(L+S) for short fibers
  - Topological isolation cut for long fibers based on S9/S1
  - Remove rechits with "faulty" pulse-shape
- **HBHE noise in RBX/HPD**
  - Rejects events with high energy/high hit multiplicity anomalous noise

Beam Halo MET



CaloMET for events before the beam-halo filter is applied and for beam-halo tagged events in MinBias or Jet15 trigger events



Beam halo tagged event with highest CaloMET (224 GeV)

<u>**CSC beam halo filter:**</u>

Efficiency 65% for MET > 15 GeV (beam halo MC)

Mis-tag efficiency 1.5 x 10^{-7} (minimum bias MC)

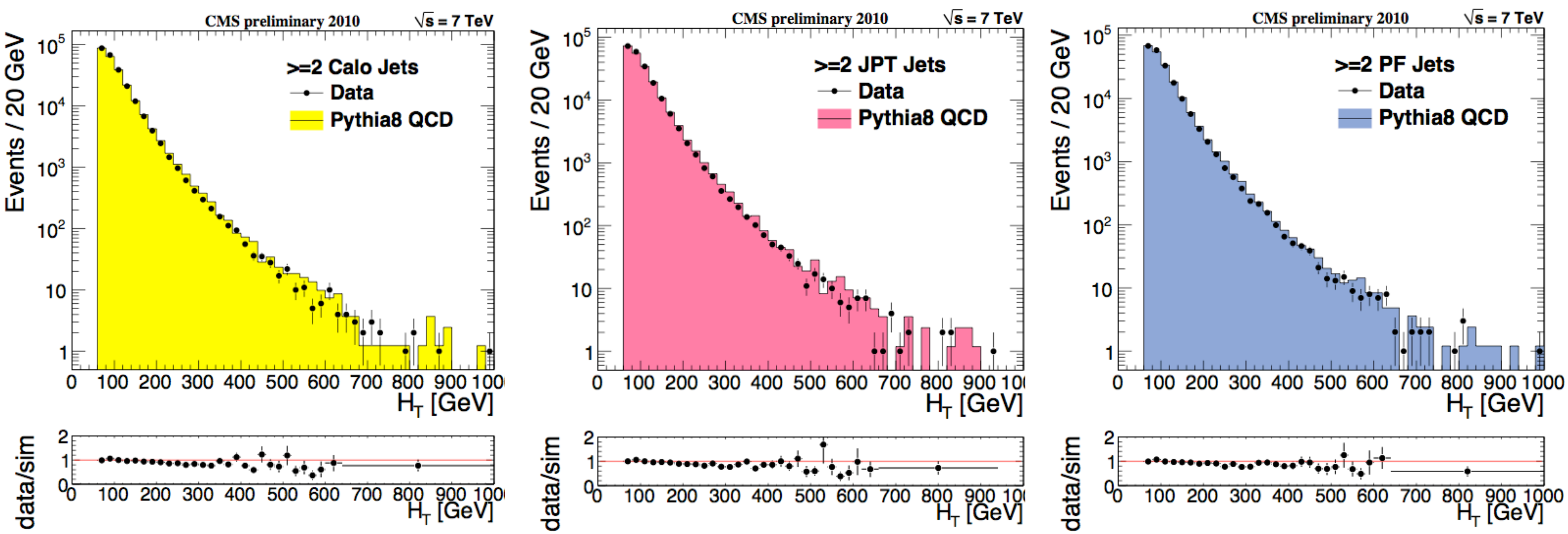
H_T and MH_T

$\int L\,dt$ = **11.7 nb^{-1}**

$$H_T = \sum p_T^{jets} \text{ and } MH_T = |\vec{MH}_T| \ (\vec{MH}_T = -\sum \vec{p}_T^{jets})$$

H_T and MH_T calculation depends only on clustered energy/momentum ⇒ less sensitivity to pile-up/unclustered noise

Selection: Leading jet with p_T > 40 GeV/c, other jets w/ p_T > 20 GeV/c, |η| < 5



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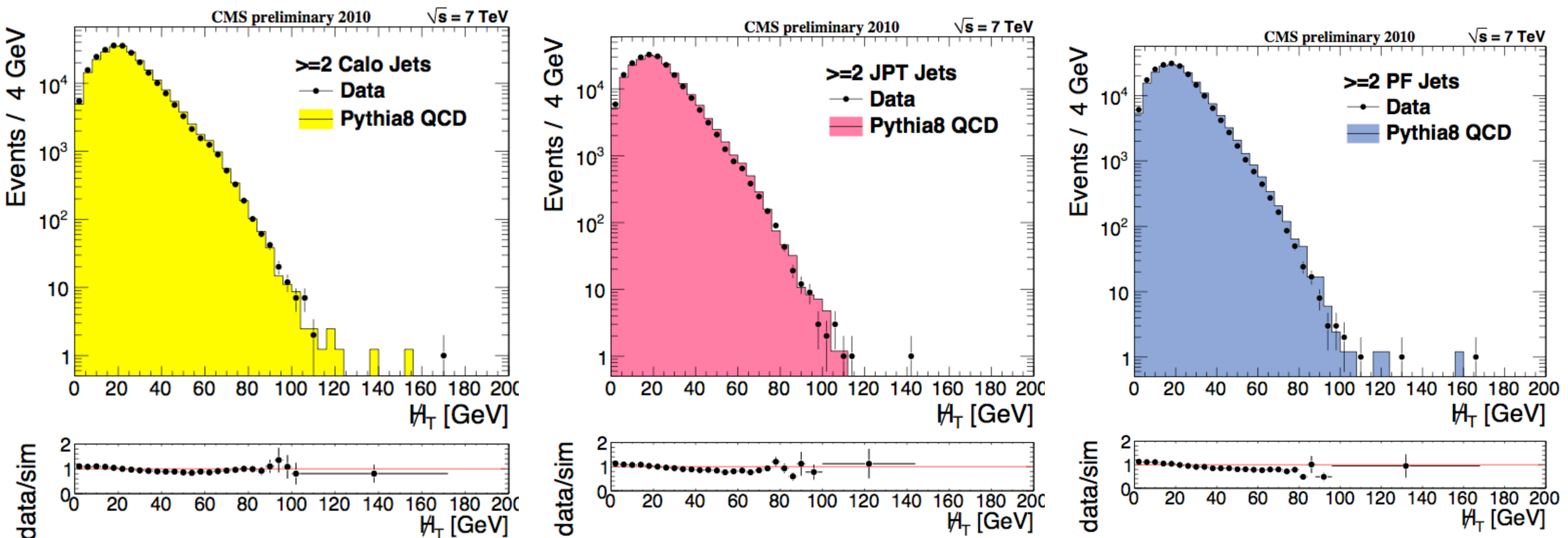
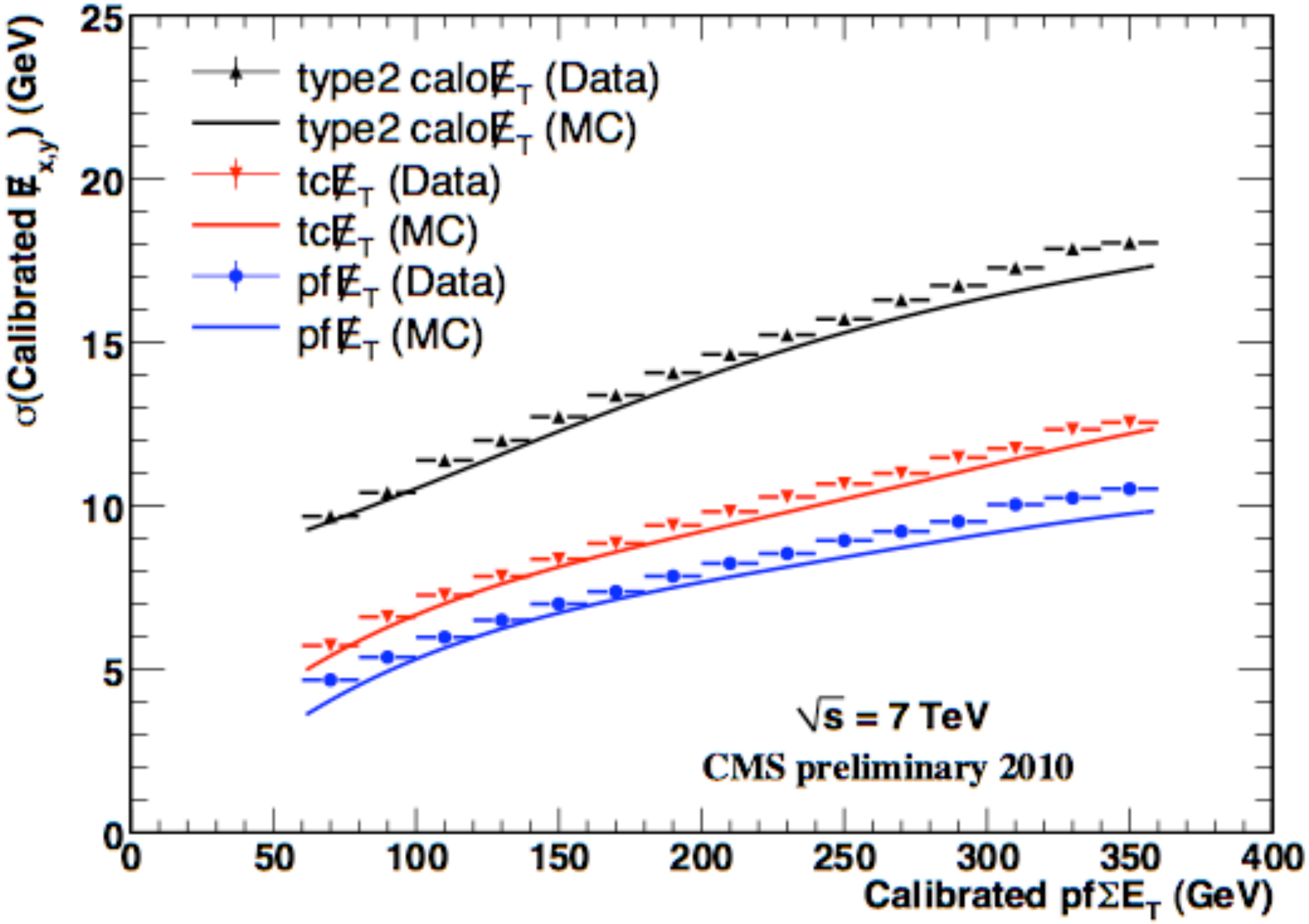


MET Reconstruction in CMS

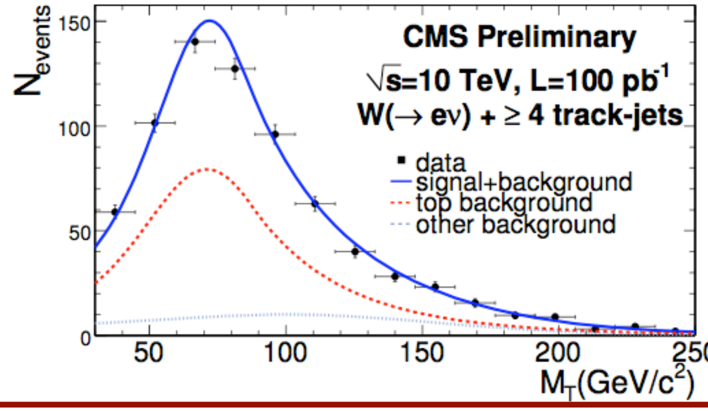


JME-10-004

$\int L\,dt$ = **11.7 nb^{-1}**

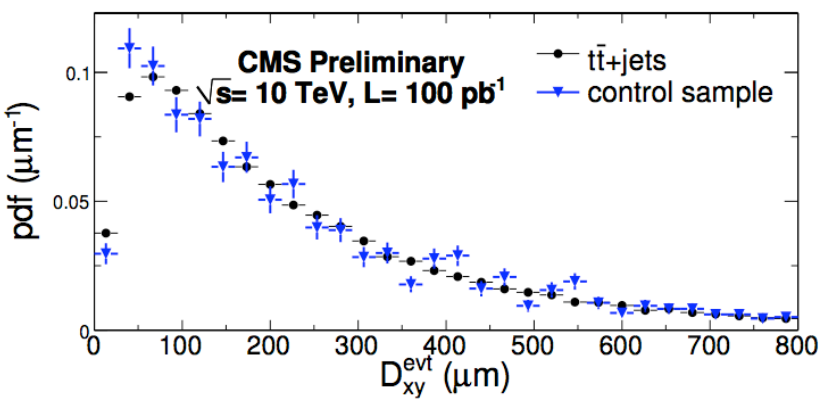
W+jets/top separation

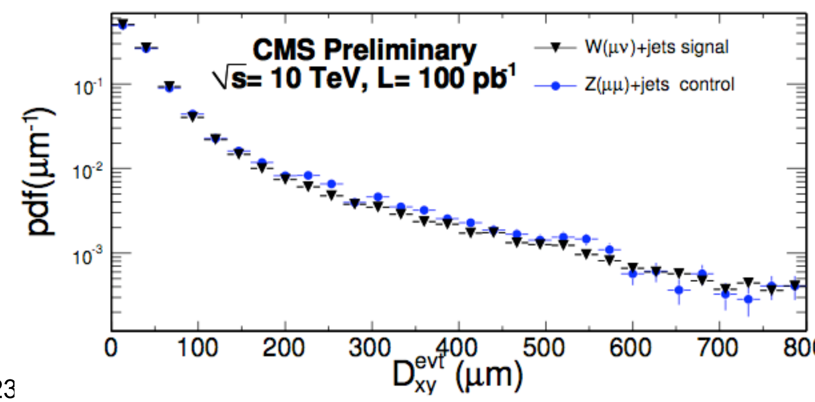
- In the W fit, **two different 'categories'** are defined: a 'heavy flavor' (hf) enriched ($\theta_{hf} = 1$) and depleted region ($\theta_{hf} = 0$), dominated by signal and single top + $t\bar{t}$, respectively.



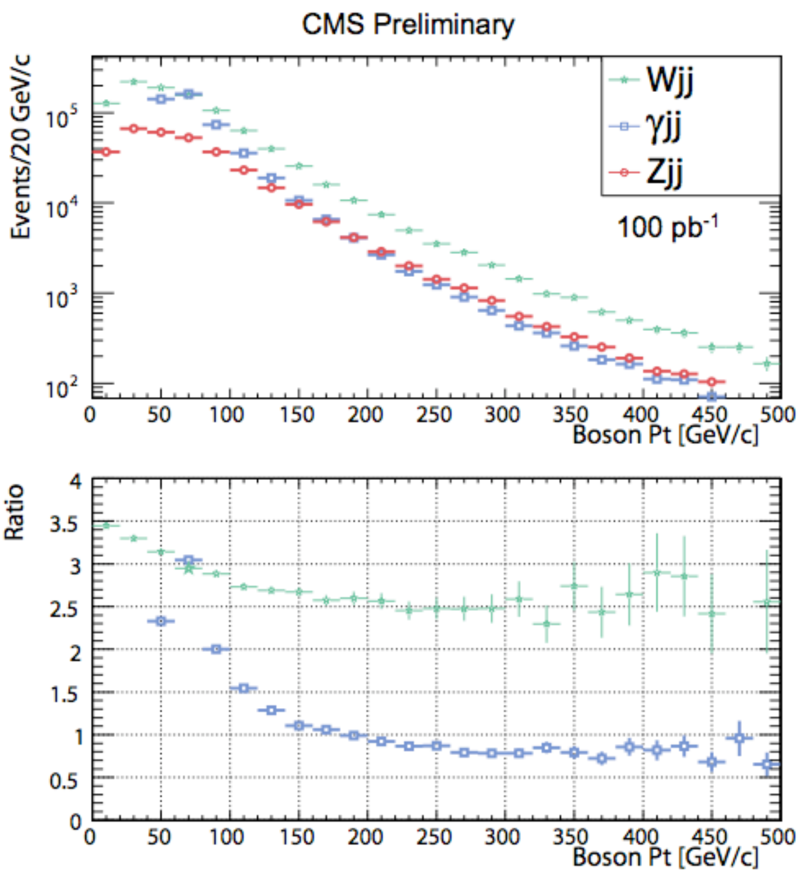
$$L_W = \frac{e^{-(N_S+N_B+N_t)}}{(N_S+N_B+N_t)!}\prod_i^{\mathrm{N_{evt}}}\{(1-\theta_{hf})[\epsilon_S\cdot N_S\cdot P_S(m^W_{T,i}) + \epsilon_B\cdot N_B\cdot P_B(m^W_{T,i}) + \epsilon_t\cdot N_t\cdot P_t(m^W_{T,i})] + \theta_{hf}[\epsilon_S\cdot N_S\cdot P_S(m^W_{T,i}) + \epsilon_B\cdot N_B\cdot P_B(m^W_{T,i}) + \epsilon_t\cdot N_t\cdot P_t(m^W_{T,i})]\}$$

- The hf enriched region is defined by a cut on variables related to the impact parameters of tracks matched to jets in the event, D_{xy}^{evt} and D_{sz}^{evt}. Control samples designed to measure these distributions



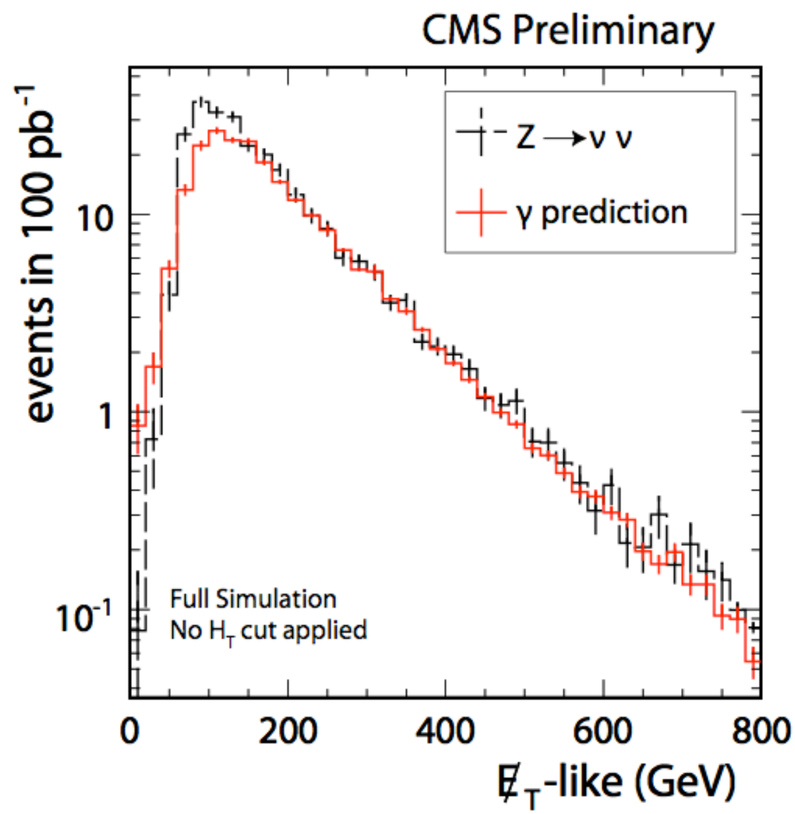


Z(νν)+jets Background Estimation



SUS-08-002

$$\sqrt{s} = 14\ \text{TeV MC}$$



Exploiting similarities in production, the MET background to an all hadronic SUSY search from Z(νν)+jets events can be estimated from:

$$Z(\ell\ell) + \text{jets}$$
$$W(\ell\nu) + \text{jets}$$
$$\gamma + \text{jets}$$

MET in Z(νν)+jets estimation from γ+jets events