Missing Transverse Energy Performance with CMS

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ArXiv:1106.5048
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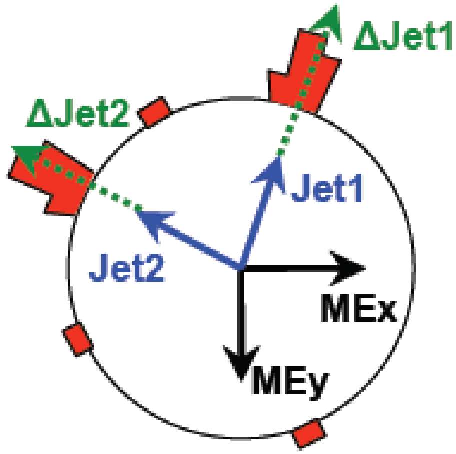
The Missing Transverse Energy

- A very important variable for various analyses:
  - indirect detection of invisible particles
  - one of the most promising signatures of new physics
  - Allow to reduce QCD and other low MET backgrounds
- A challenging variable:
  - Easy to obtain fake MET
    - For example, jets tend to fluctuate
      - Large shower fluctuation
      - Fluctuations in the e/h energy ratio
      - Non-linear calorimeter response
      - Non-compensation
    - Instrumental effects
      - Dead or « hot » calorimeter cells
      - Instrumental noise
      - Poorly instrumented area of the detector
      - Accelerator-induced MET

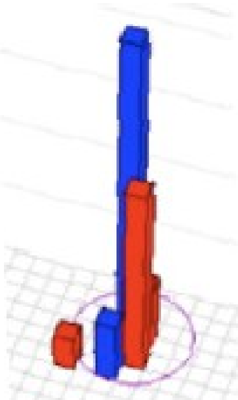


- **tails** are important to understand for searches
- the **resolution** is vital for precision measurements (top mass, W mass etc)

MET reconstruction algorithms in CMS

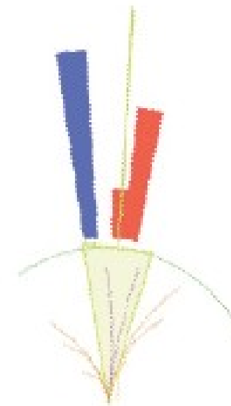
Calorimeter MET

- Computed from ECAL and HCAL energy deposits (caloTowers)
- Corrected a posteriori for energy scale, muons, unclustered energy



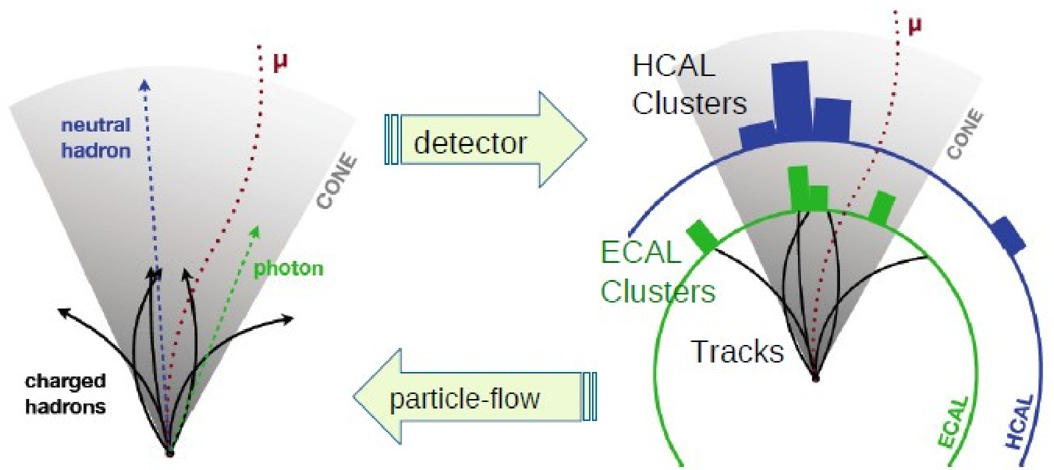
Track-corrected MET

- Computed from caloMET
- The average expected calorimeter response for charged particles is subtracted and replaced by the tracks measurement.

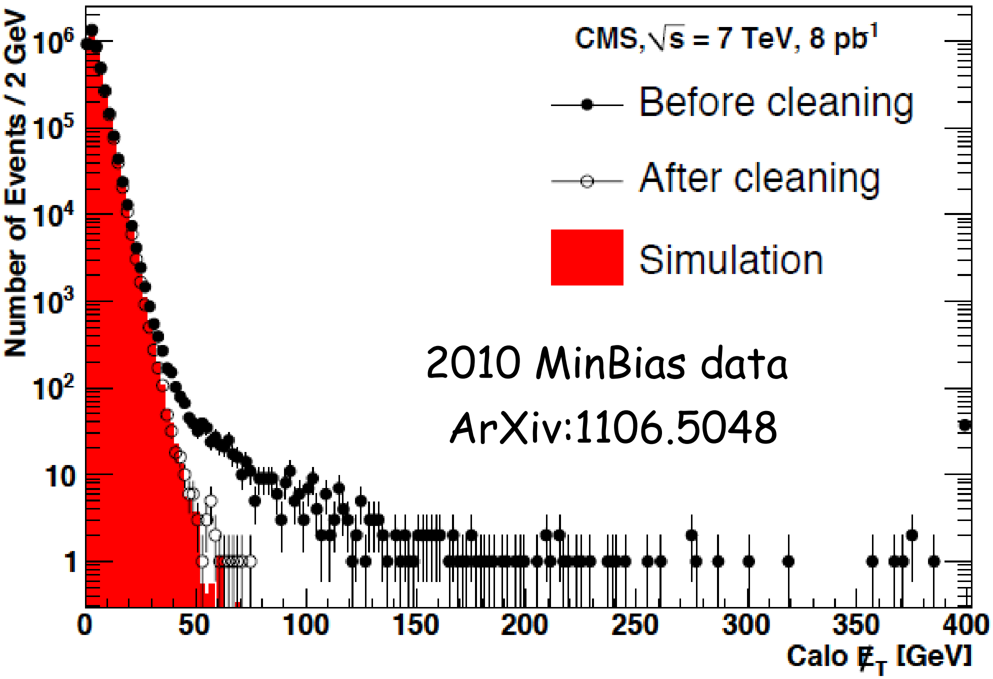


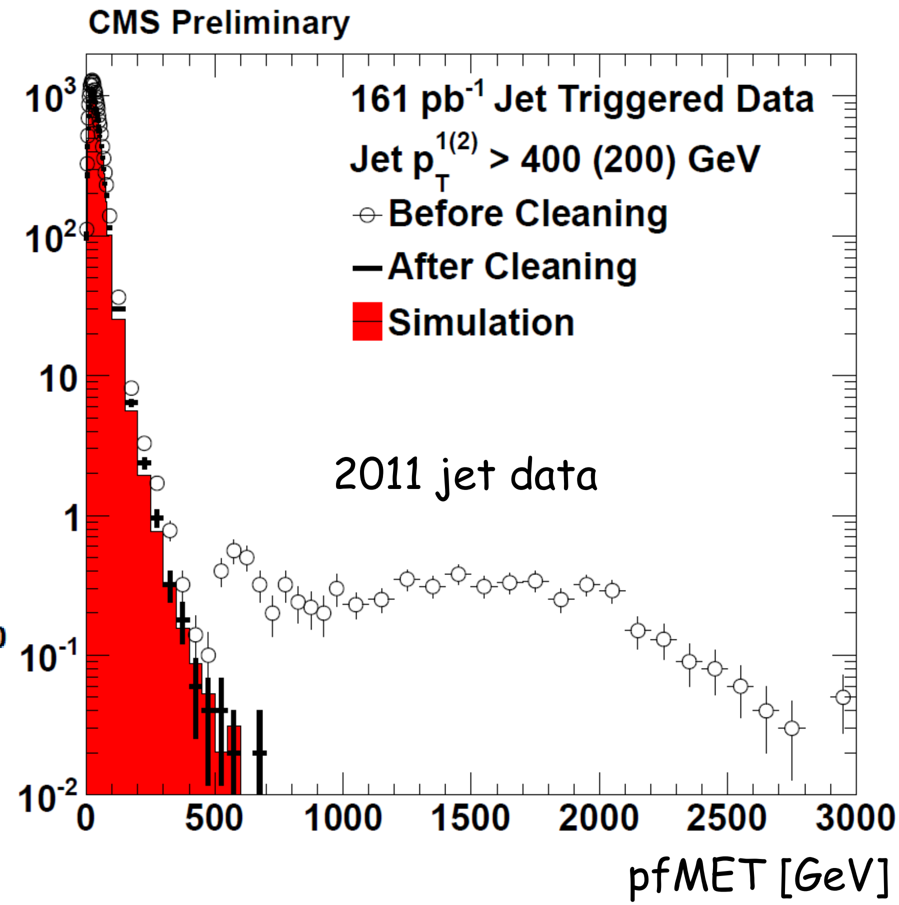
Particle flow MET

- A unique list of particles is determined in each event (neutral and charged hadrons, photons, leptons)



Large MET due to misreconstruction

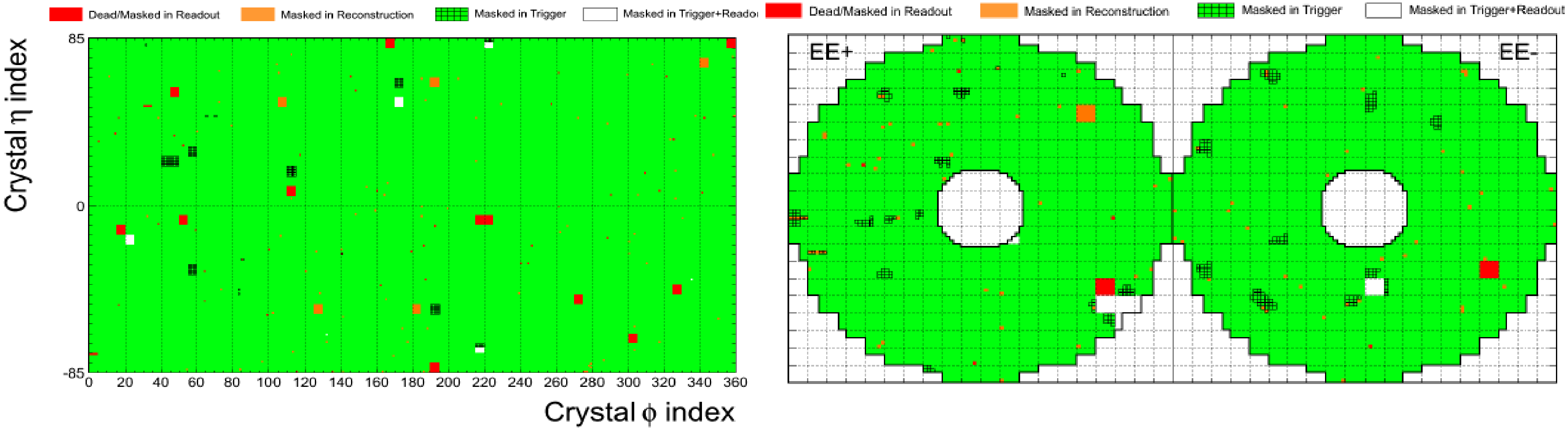




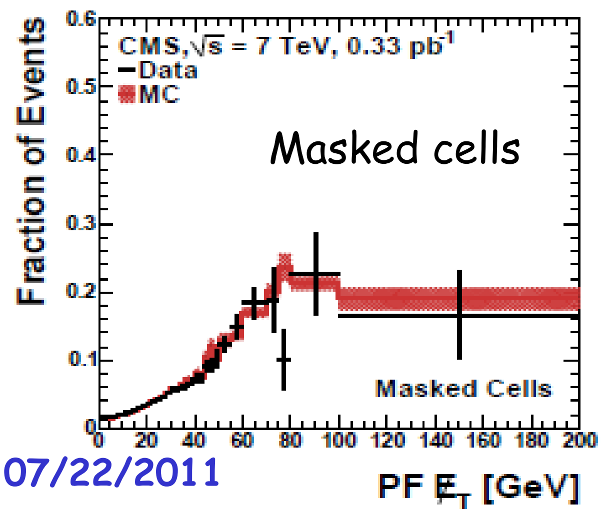
- Anomalous signals come mainly from:
- Particles hitting the transducers
- Random discharges of readout detectors
- Cleaning algorithms are based on timing, pulse shape or unphysical charge sharing between neighboring channels.

Contributions of non-functioning detector regions

- ~1% of ECAL crystal are not operational or have a high electronic noise



- Fraction of dijet events with at least 1 jet aligned to the MET and pointing towards masked ECAL channels.



- 20% of the event with MET>80 GeV have contributions to the measured MET from mismeasurement due to masked ECAL channel.
- Good agreement between data and simulation results.

MET scale and resolution: hadronic recoil

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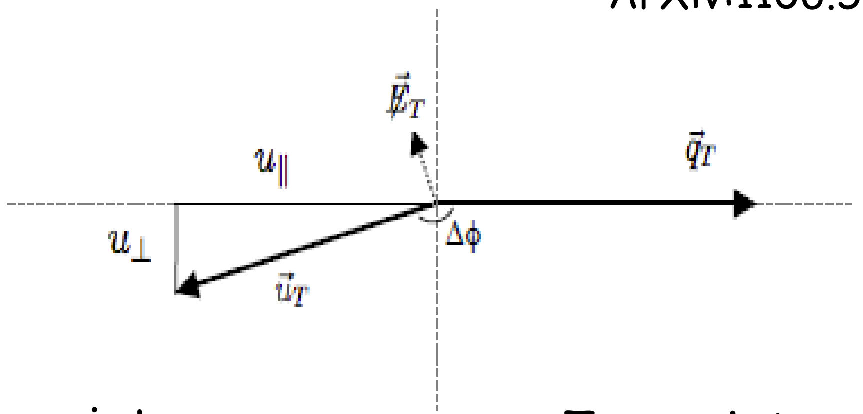
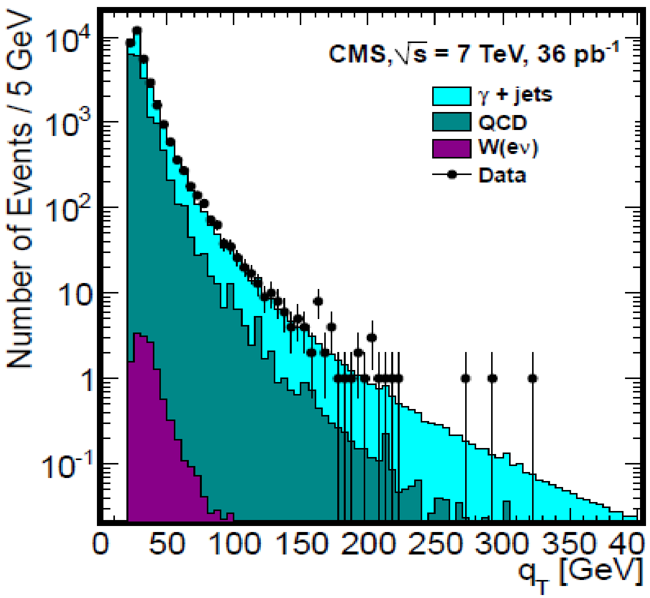
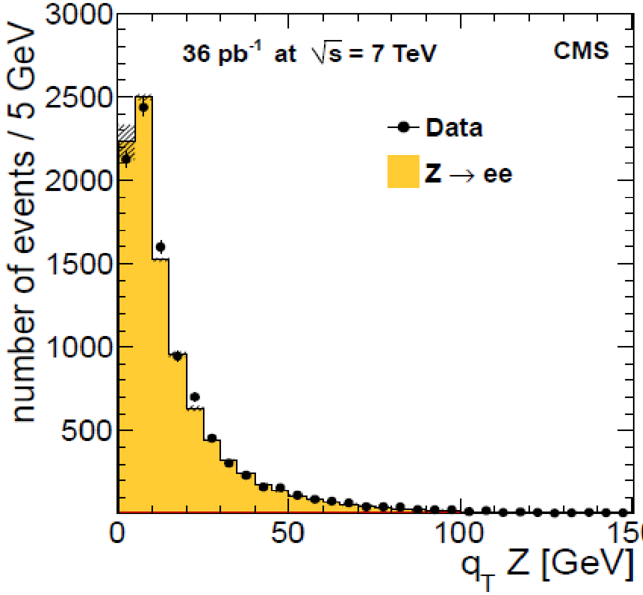
- MET scale and resolution is measured in photon+jets and Z+jets events.
- The hadronic recoil is compared with the well measured Z or photon.



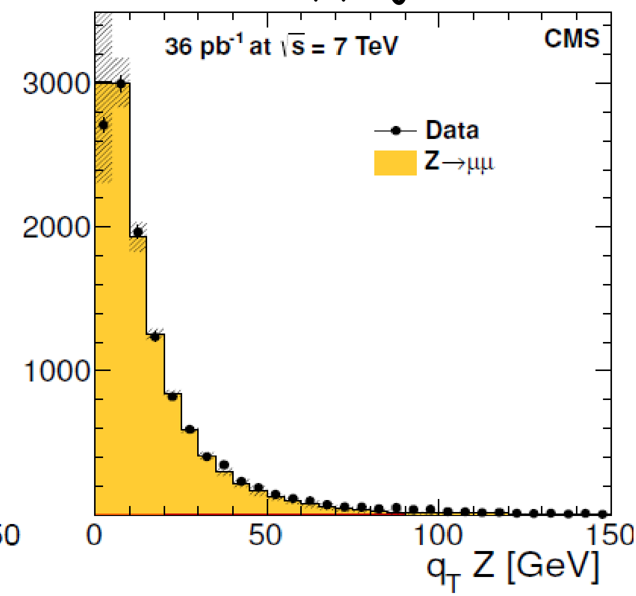
photon+jets



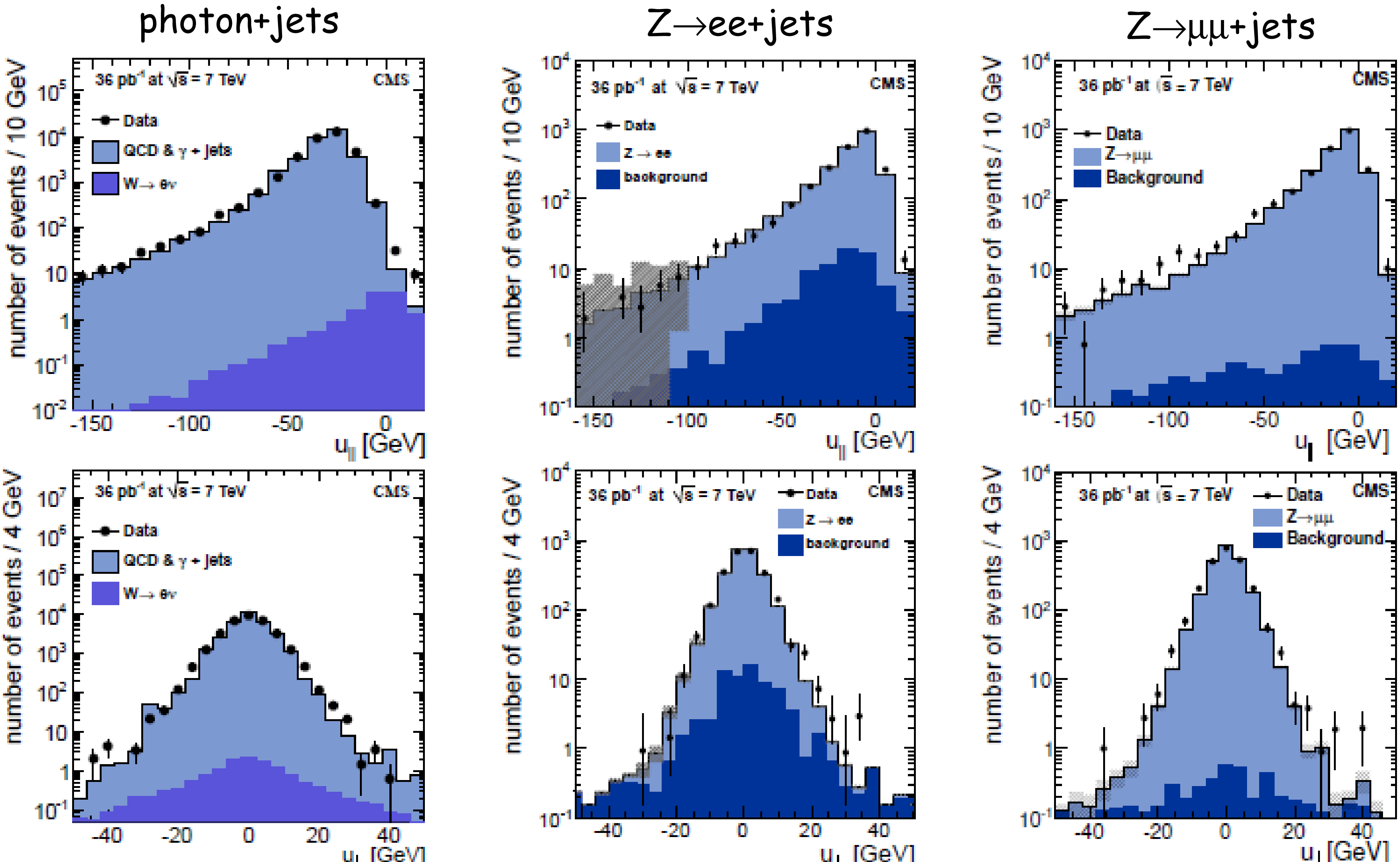
Z→ee+jets



Z→μμ+jets



$u_{||}$ and $u_{\perp}$ in 1 PV events



- Distributions are corrected for the residual contamination from events with >1PV

MET scale in 1 PV events

- MET response: $\langle u_{||} \rangle / q_T$

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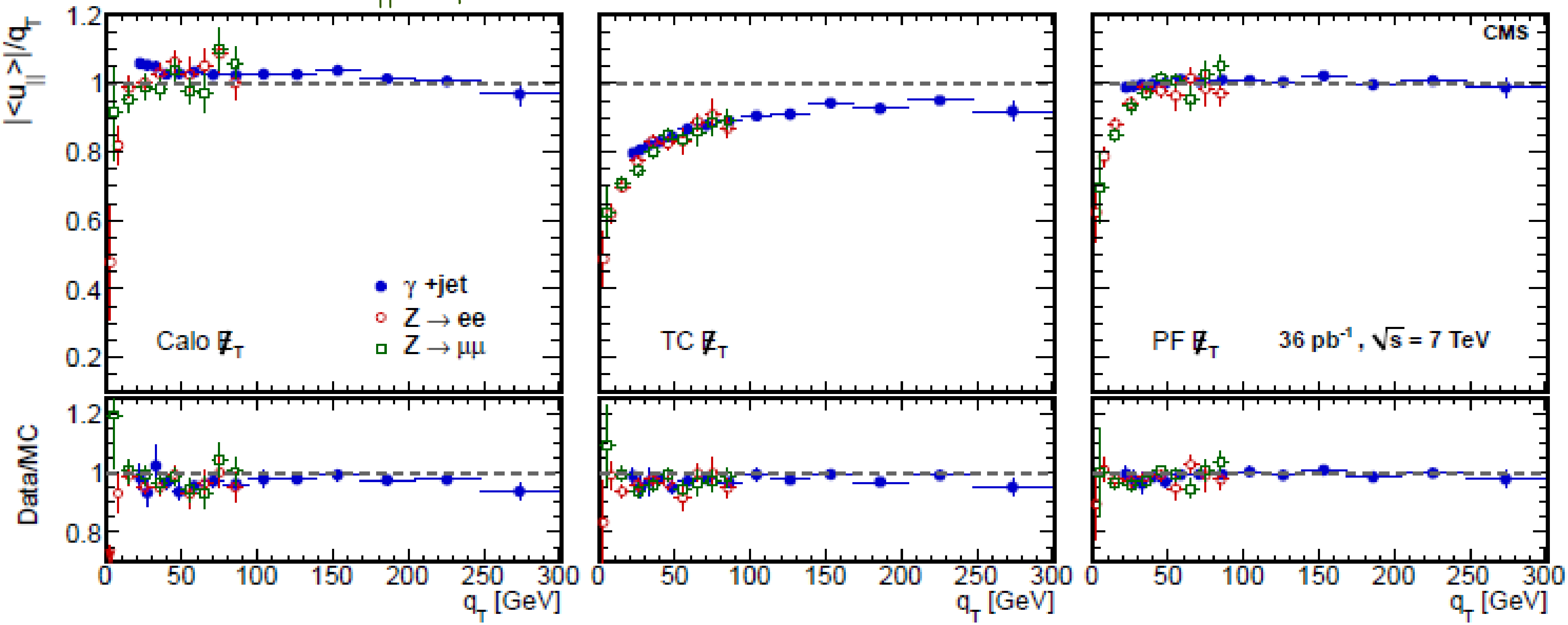

- CaloMET response is slightly larger than 1 because the type JES corrections is from a sample with a mixture of quark and gluons, while for these samples the leading jet is primarily a quark jet
- tcMET response is lower than 1, because no JES corrections are applied
- No unclustered energy correction is applied to pfMET

MET resolution

- MET resolution in photon + jets events

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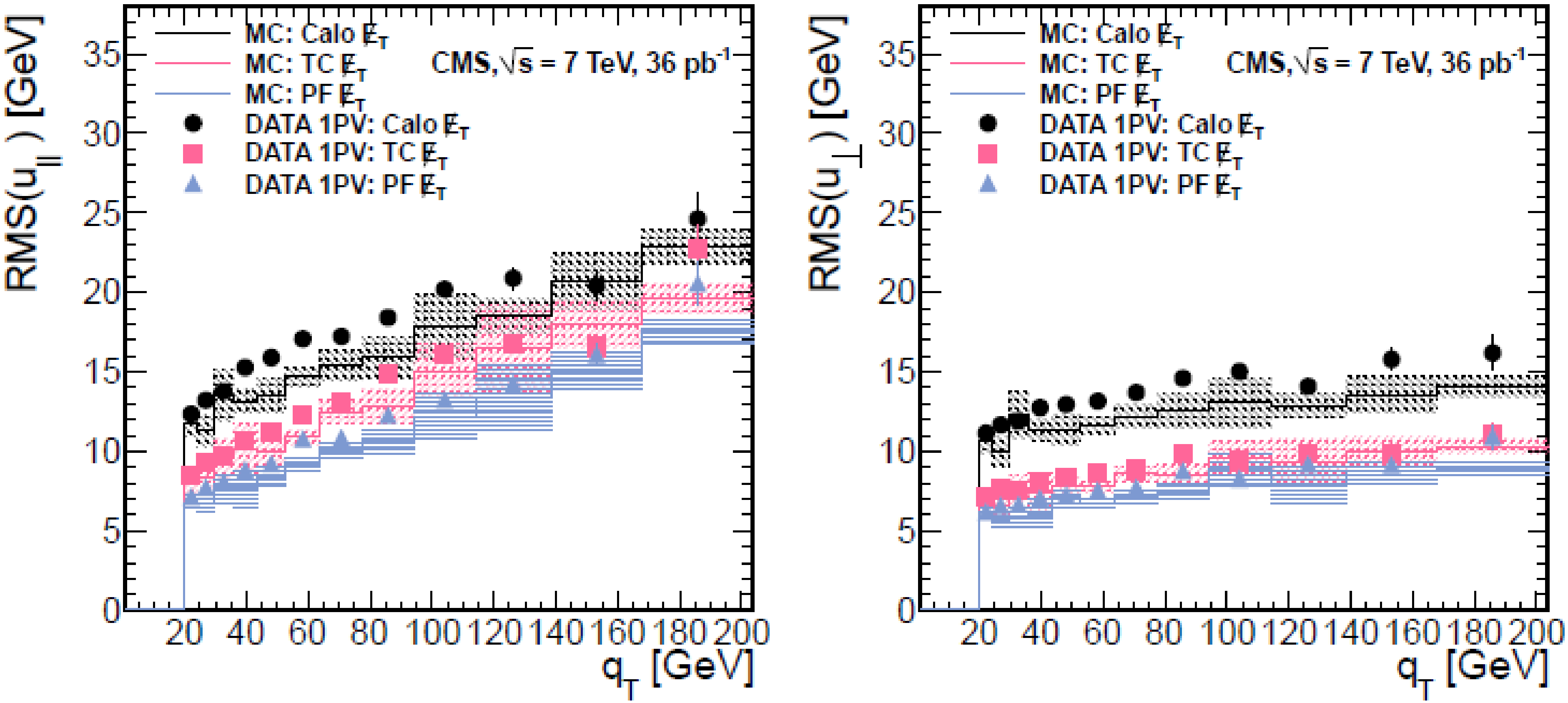

- Resolution is corrected for the scale.
- Tracking gives considerable improvement
- pfMET gives the best resolution.

pfMET resolution

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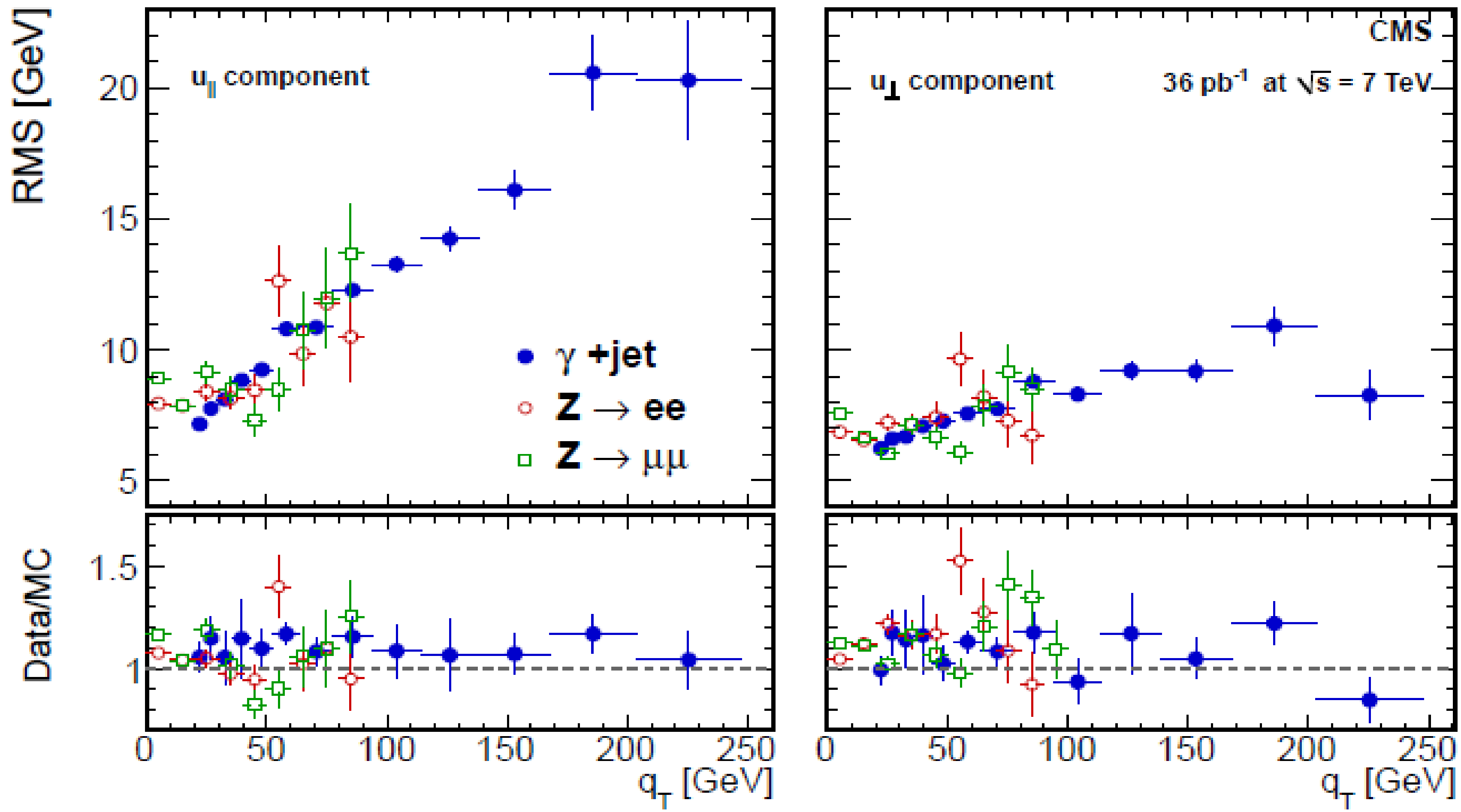

- Consistency between different channels
- Slightly better resolution in MC than in data

PU effect

- pfMET distribution in jets data (ht>200 GeV):

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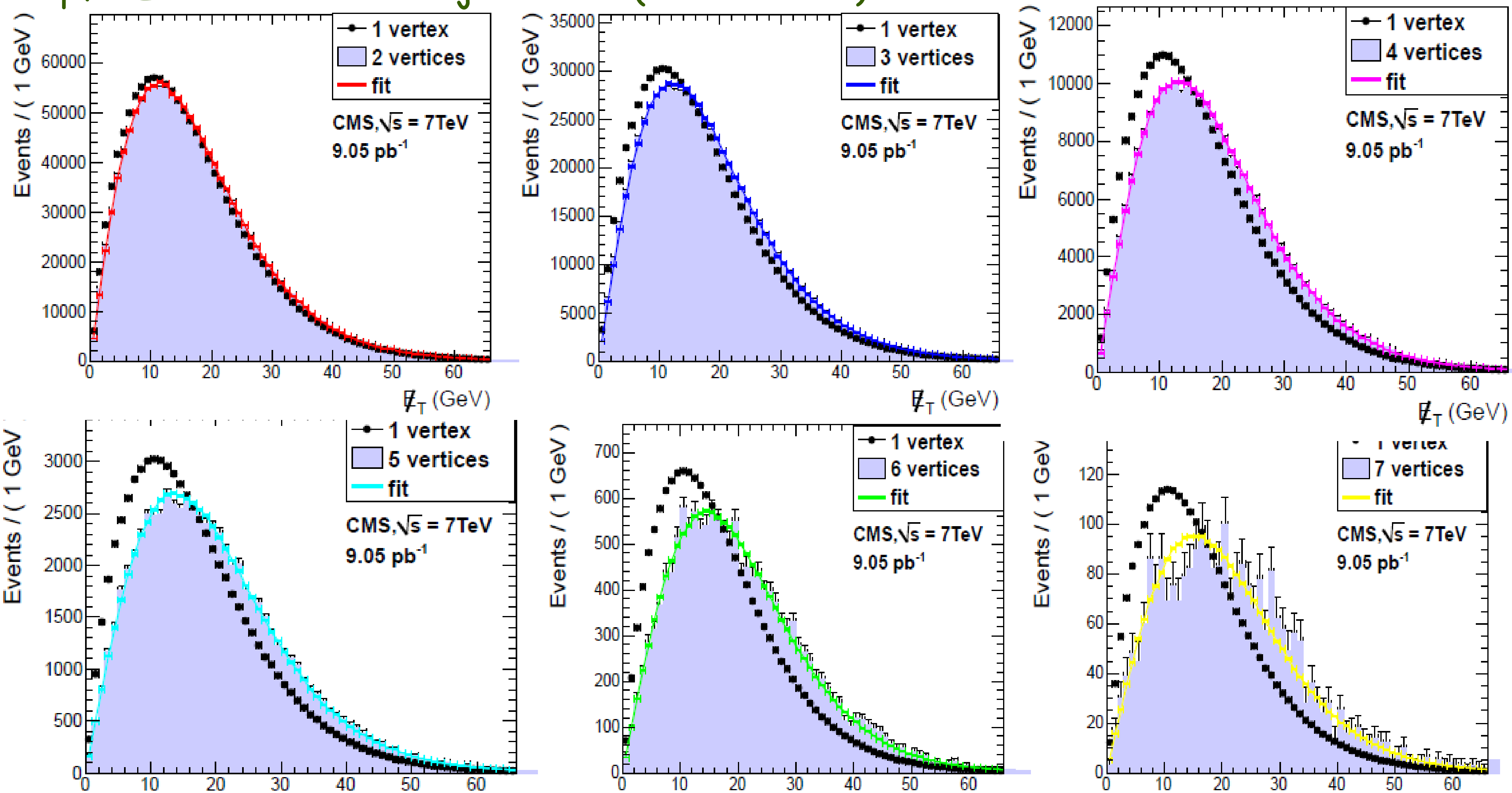
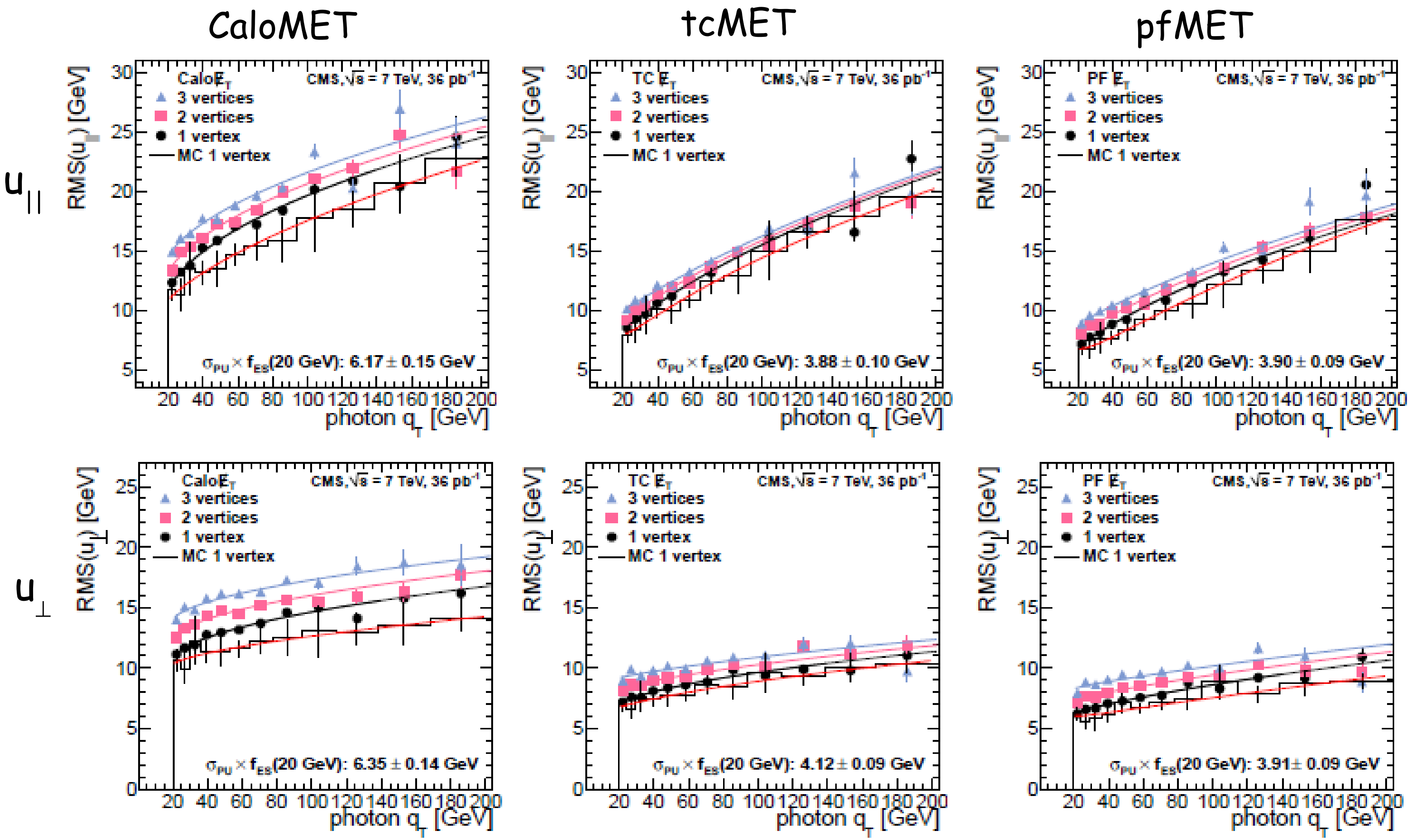


$$\not{E}_{T,n} = \sqrt{(\not{E}_{x1} \otimes G[(n-1)\cdot\Delta\mu_x, \sqrt{n-1}\cdot\Delta\sigma_x])^2 + (\not{E}_{y1} \otimes G[(n-1)\cdot\Delta\mu_y, \sqrt{n-1}\cdot\Delta\sigma_y])^2}$$

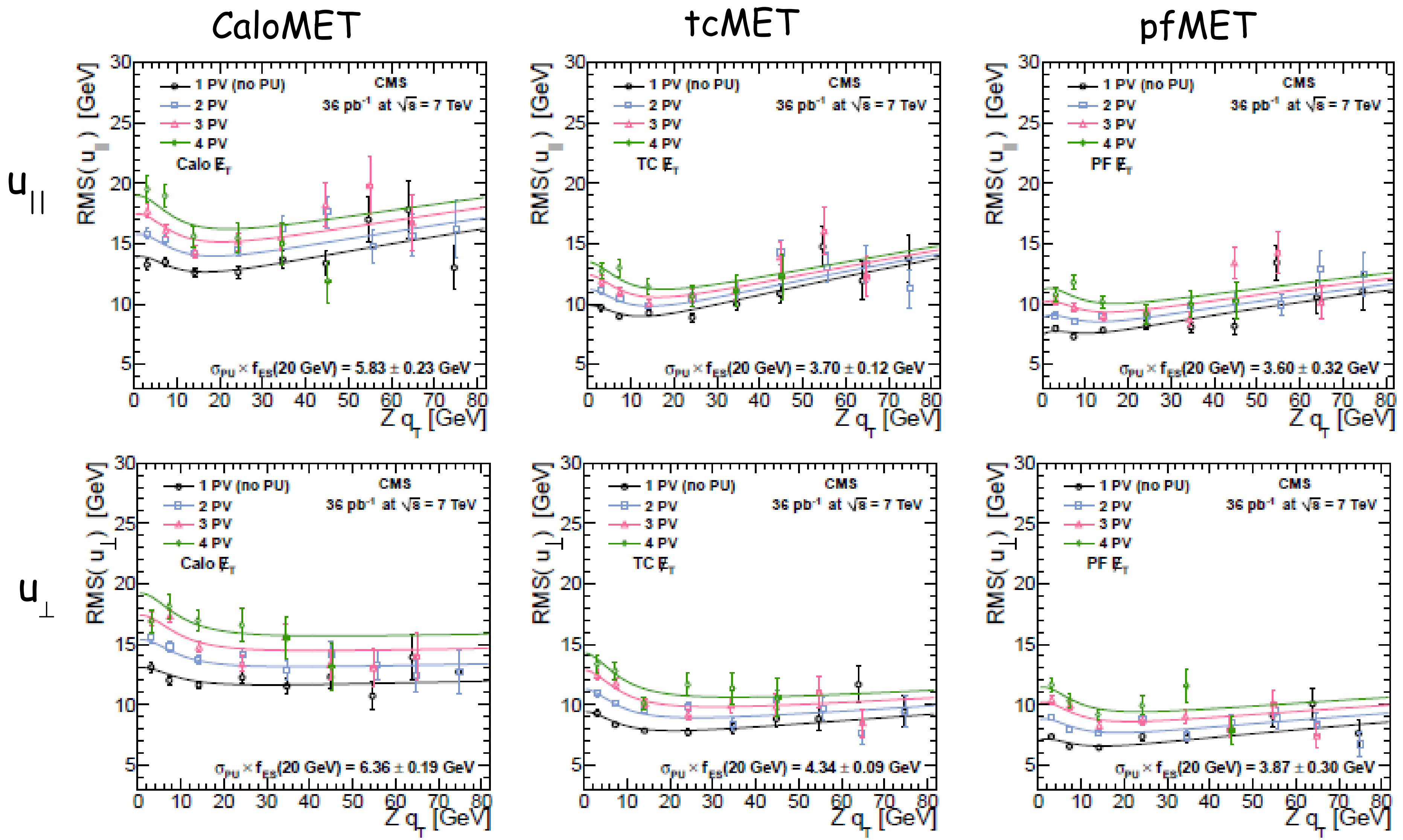
$$\Delta\sigma_x = \Delta\sigma_y = 3.7\ \text{GeV}, \quad \Delta\mu_x = 0.5\ \text{GeV}$$

PU effect on resolution



- Parametrization: $\sigma_{\text{total}}^2 = (a\sqrt{q_T} + b)^2 + (\sigma_{\text{noise}} f_{\text{ES}}(q_T))^2 + (N-1)\,(\sigma_{\text{PU}} f_{\text{ES}}(q_T))^2$

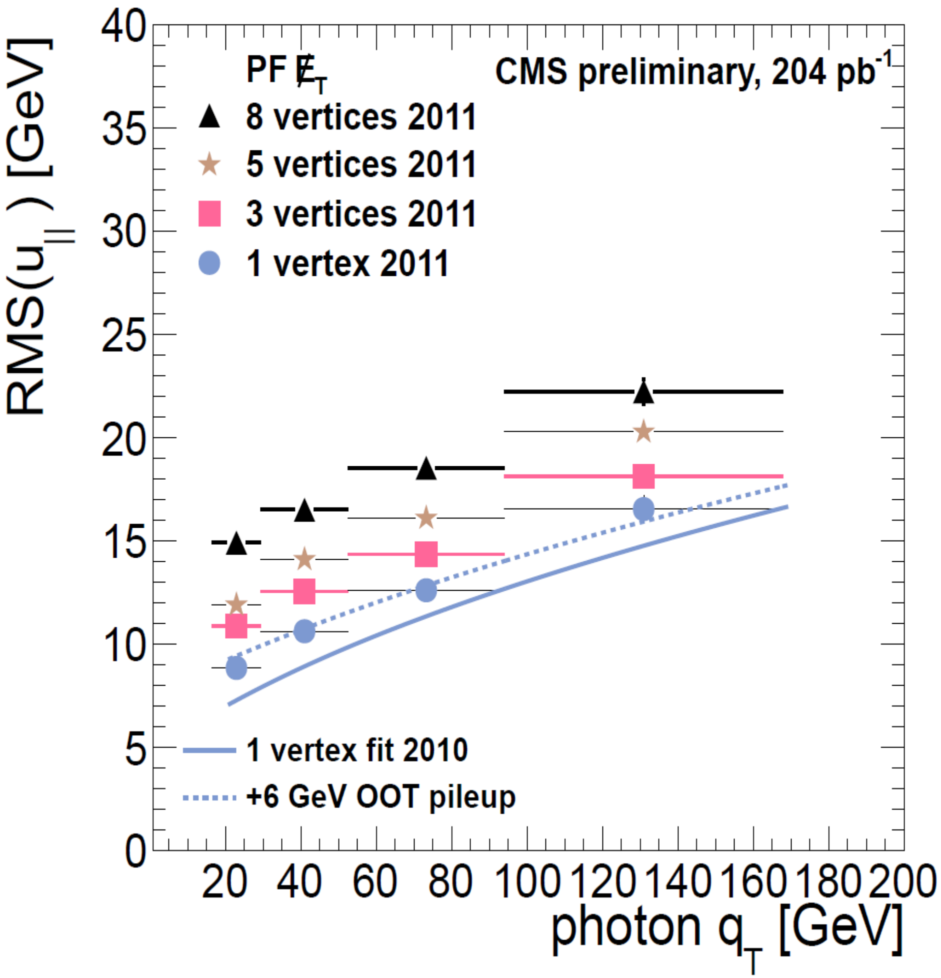
PU effect in Z+jets events

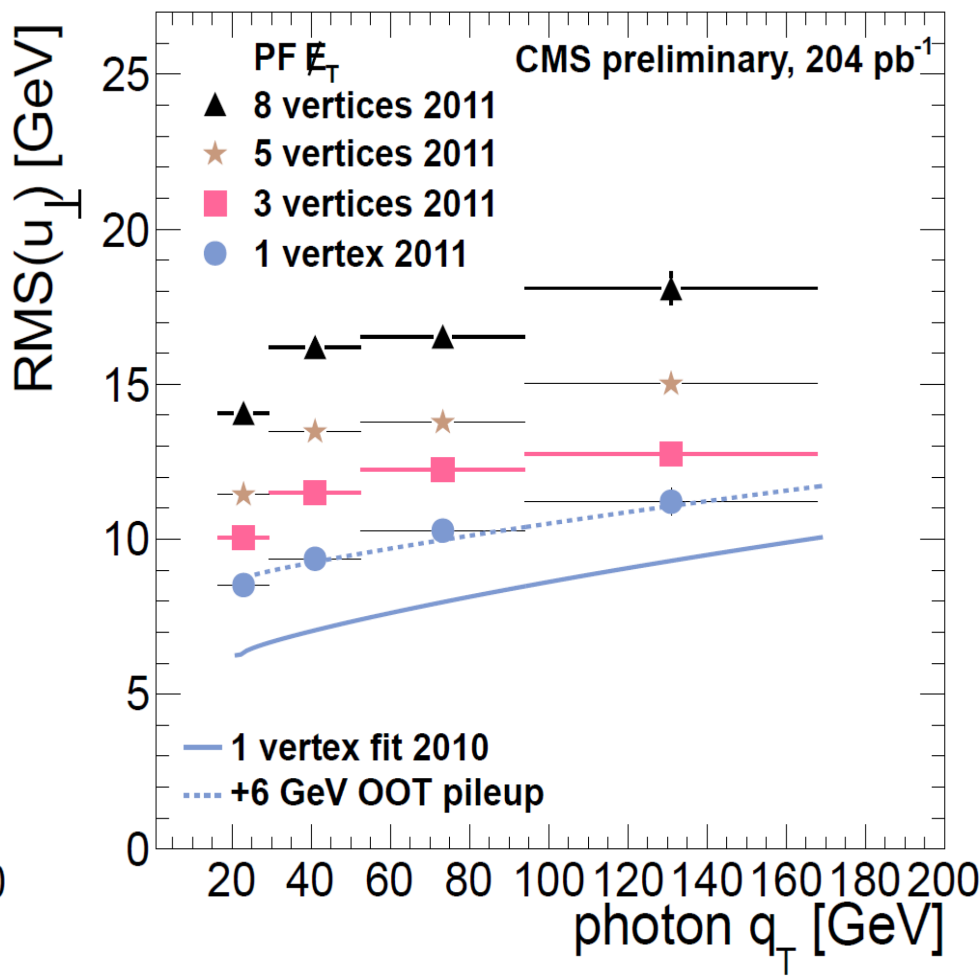


- Parametrization: $\sigma_{\mathrm{total}}^2 = (a\sqrt{q_T} + b)^2 + (\sigma_{\mathrm{noise}} f_{\mathrm{ES}}(q_T))^2 + (N-1)\,(\sigma_{\mathrm{PU}} f_{\mathrm{ES}}(q_T))^2$

PU effect up to 8 vertices with OOT PU

- MET resolution in 204 pb^{-1} of 2011 data:





- A 6 GeV degradation in the resolution is observed due to out of time pile up.

MET significance

- Determination of the significance requires evaluation of the uncertainty of the total MET sum. The uncertainty on the pt of each reconstructed object can be characterized by a likelihood function.
- The significance is defined as: $$\mathcal{S} \equiv 2\ln\left(\frac{\mathcal{L}(\vec{\varepsilon}=\sum\vec{\varepsilon}_i)}{\mathcal{L}(\vec{\varepsilon}=0)}\right)$$
- So, in the Gaussian likelihood case:

$$\mathcal{S} = \left(\sum_{i\in X}\vec{E}_{\mathrm{T_i}}\right)^T\left(\sum_{i\in X}R(\phi_i)\mathrm{U}_iR^{-1}(\phi_i)\right)^{-1}\left(\sum_{i\in X}\vec{E}_{\mathrm{T_i}}\right)$$

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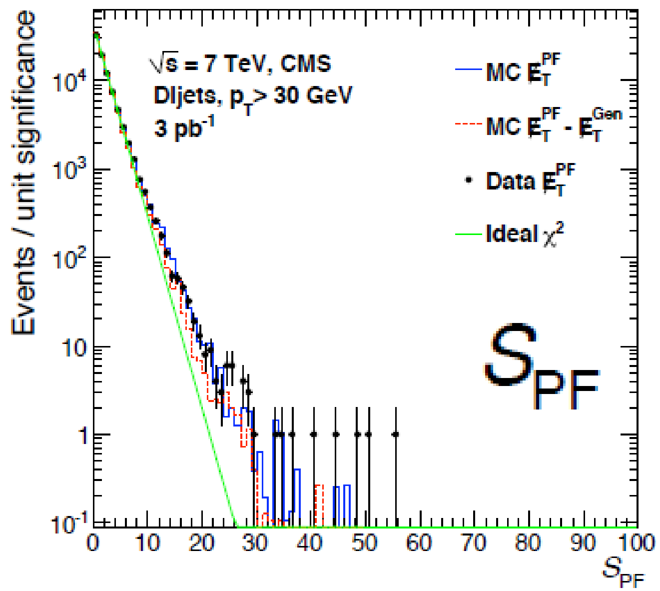
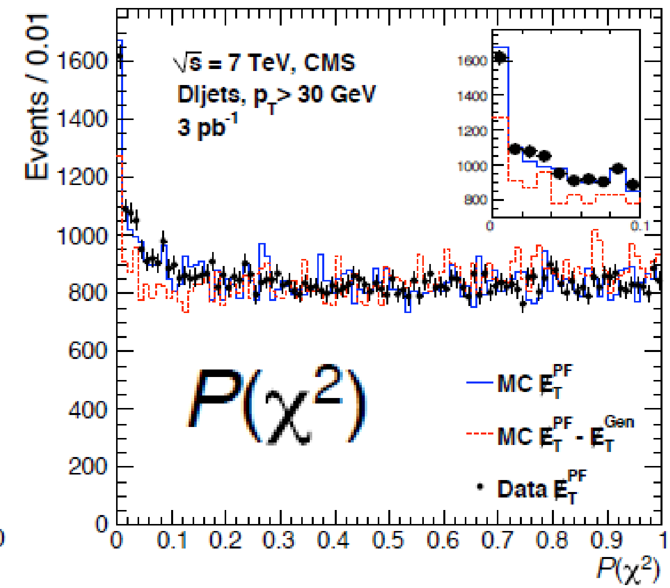
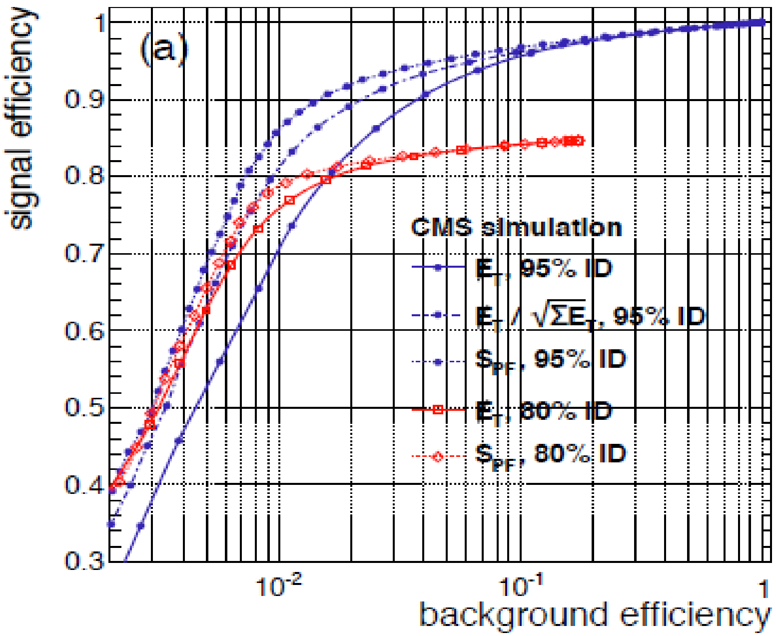
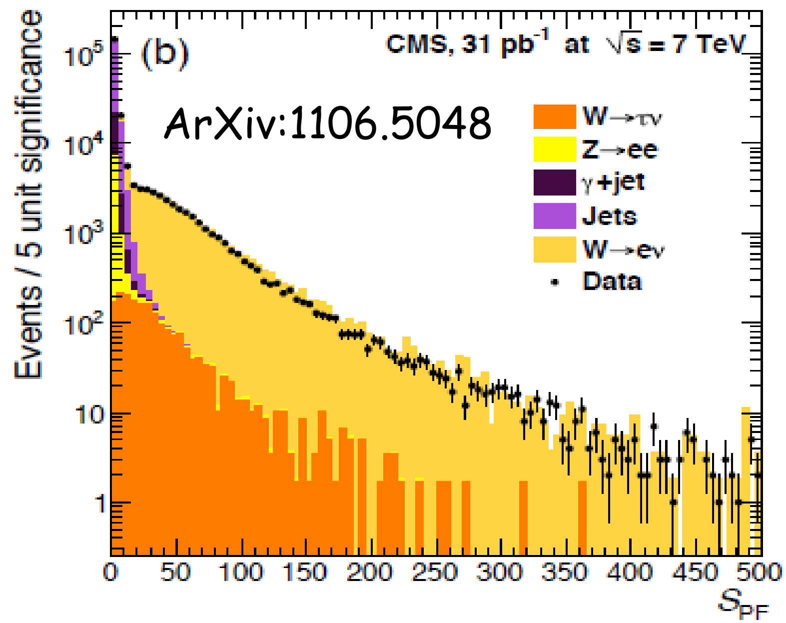
- Performances in dijet events: exponential S_{PF} behavior and flat $P(X^2)$ distribution as expected for no MET events.



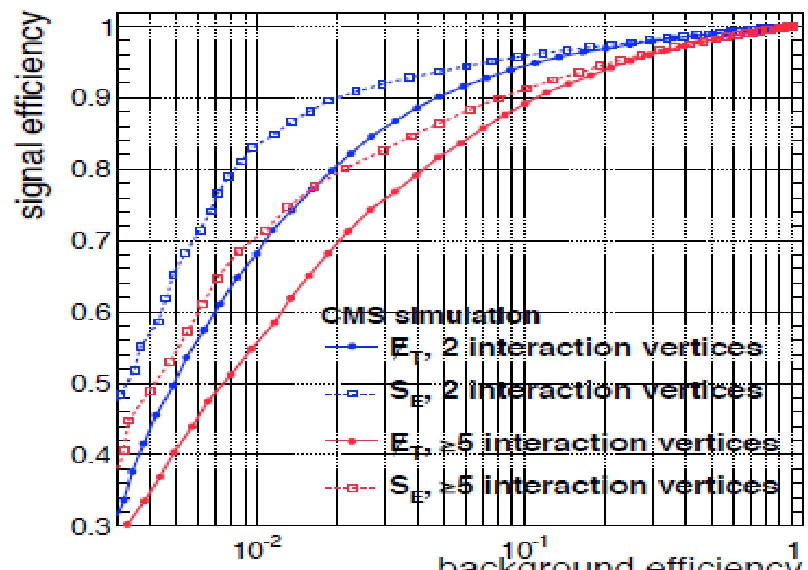


MET significance results on W+jets events





- Better efficiency/rejection than MET or MET/sqrt(sumEt), even with PU
- Good data/MC agreement



Conclusions

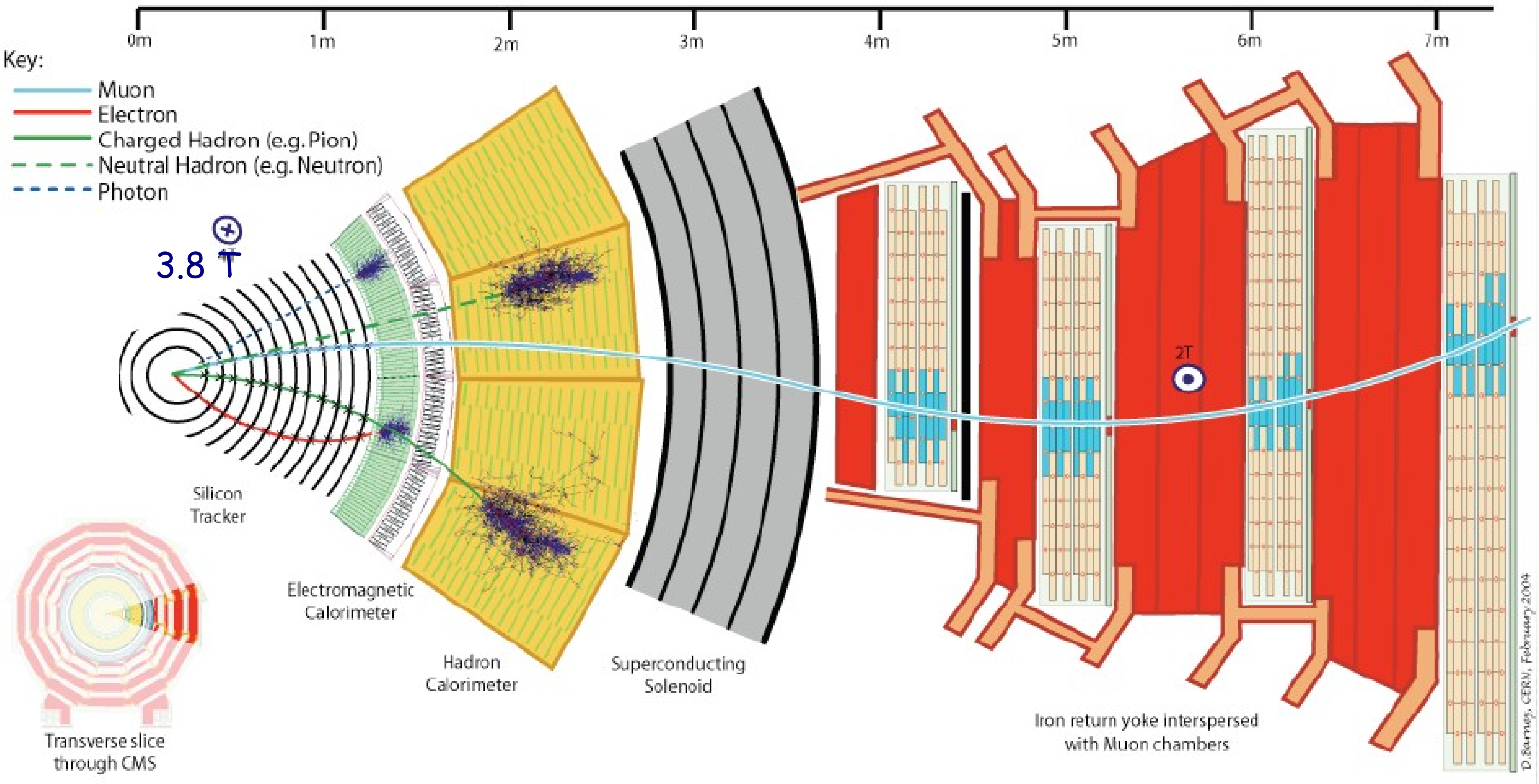
- The MET in CMS is well understood.
- Tails are under control, thanks to cleaning algorithms.
- MET scale and resolution have been determined in various samples.
- Pile up degradation has been parametrized.
- The MET significance algorithm is available for analysis.
- CMS is prepared for discovery!

BACK UP

SLIDES

The Compact Muon Solenoid detector

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



Beam halo muons

- Beam halo muons are identified using the Cathode Strip Chambers (CSCs) with an efficiency of 92% (65%) and a mistag probability of 10^{-5} (10^{-7}) for the loose (tight) filter.

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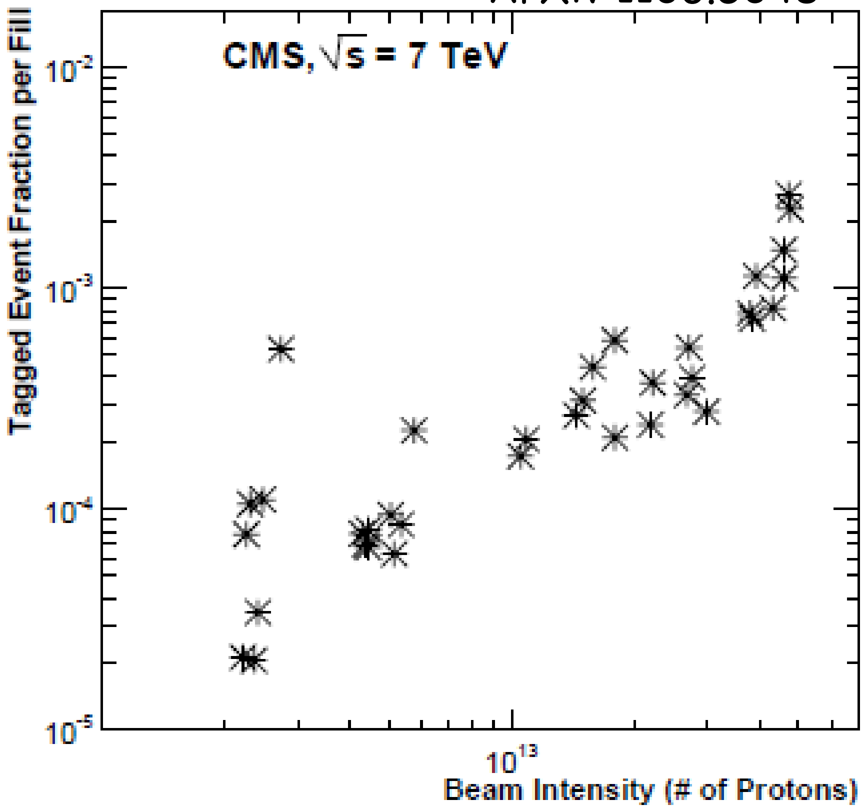

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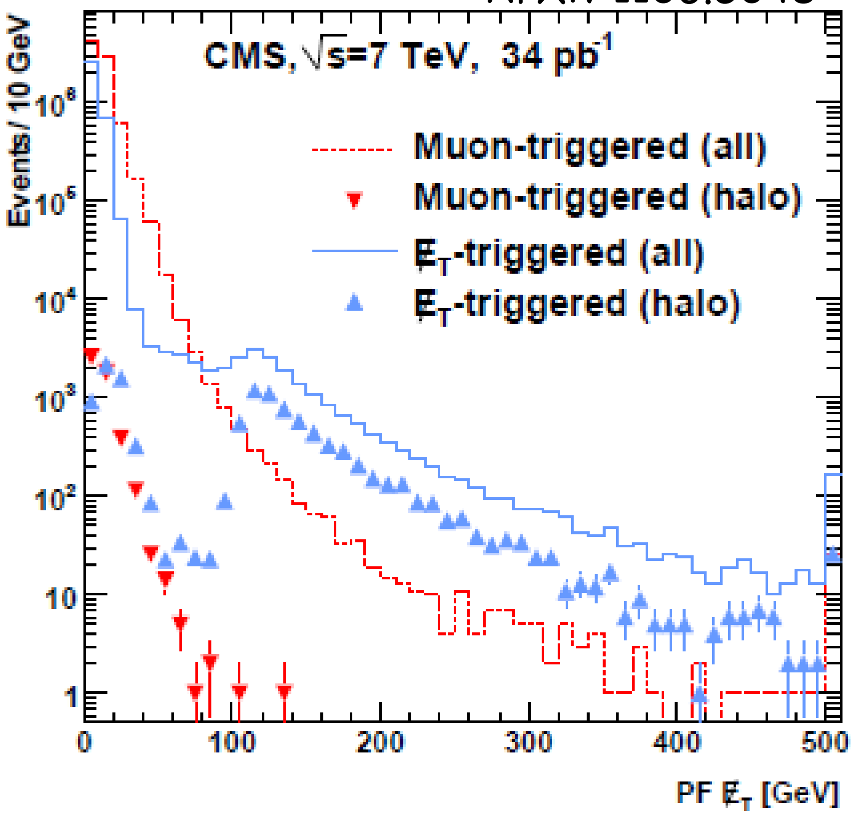
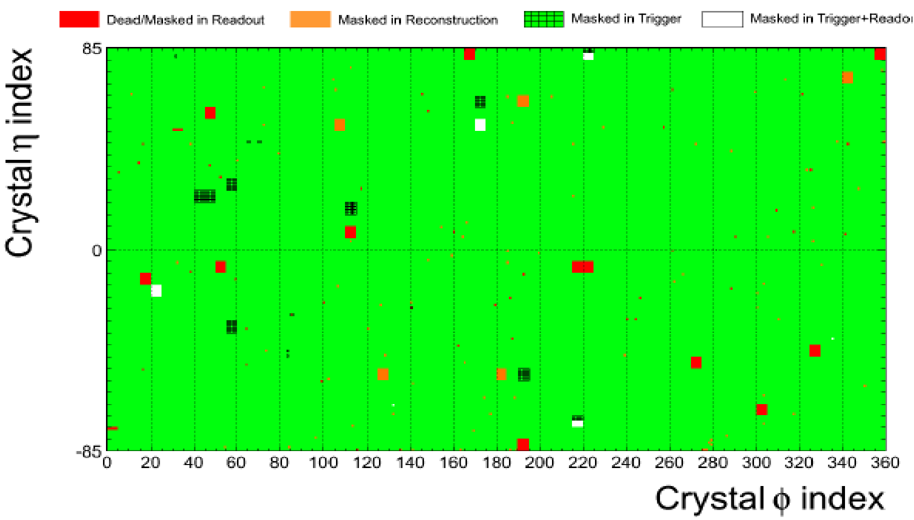
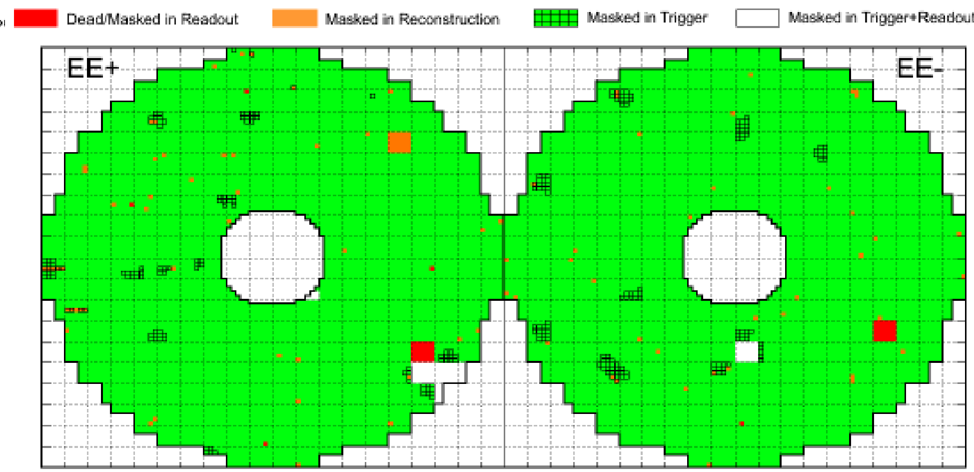


- The probability that a halo muon produces large MET in events taken from triggers that are uncorrelated with MET is small.

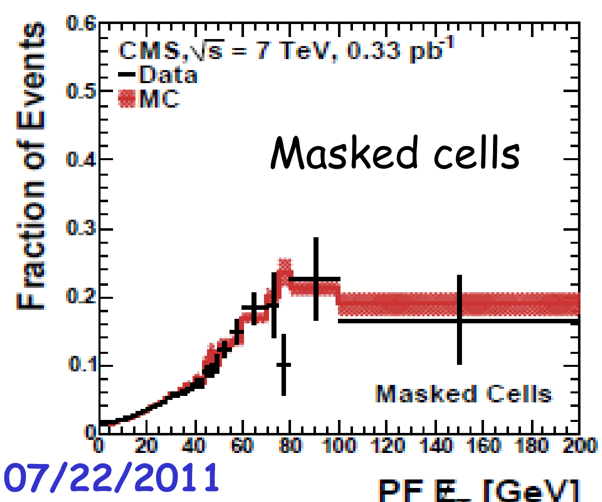
Contributions of non-functioning detector regions

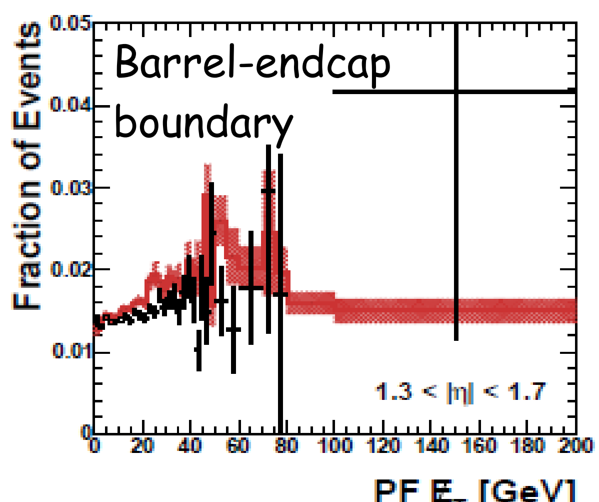
- ~1% of ECAL crystal are not operational or have a high electronic noise

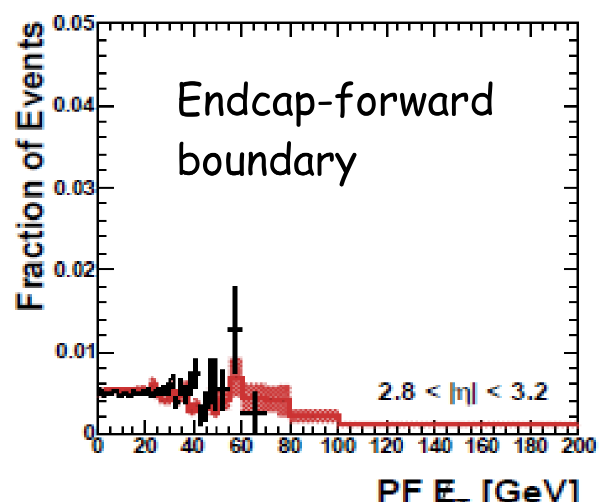




- Fraction of dijet events with at least 1 jet aligned to the MET and pointing towards masked ECAL channels, barrel-endcap or endcap-forward boundary.







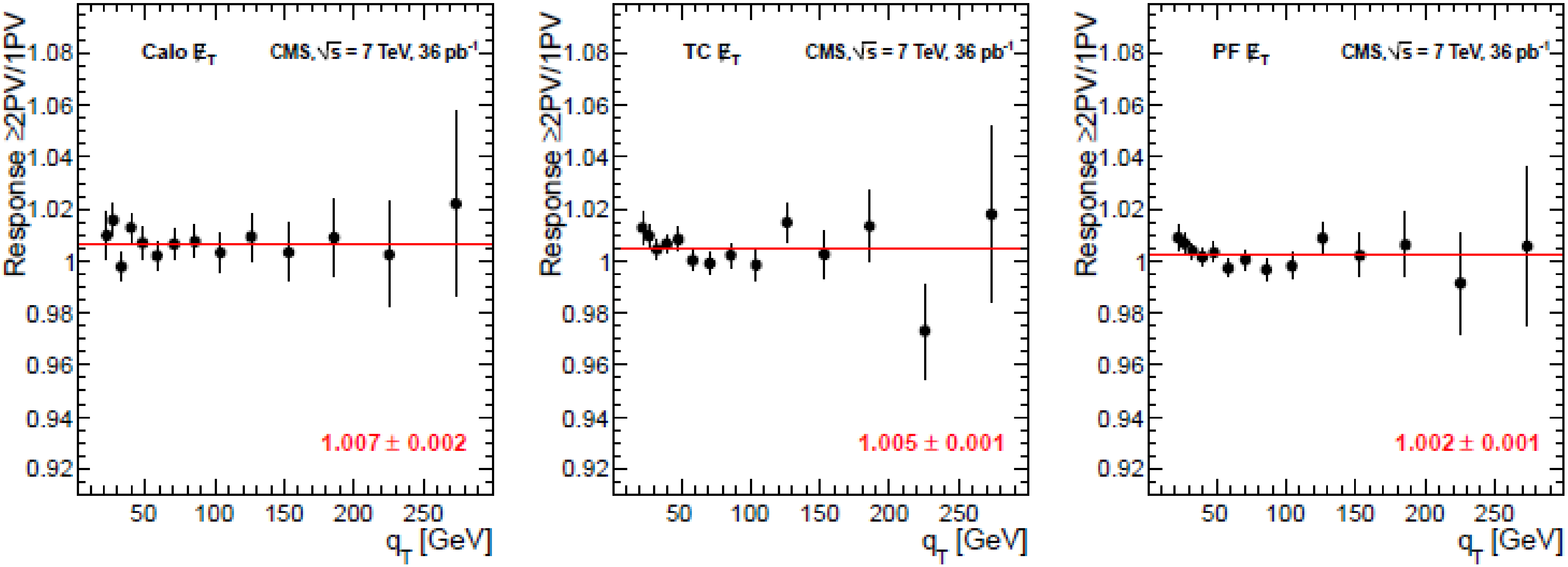


Figure 15: The ratio of the response for the component of the induced $\vec{\not\!\!E}_T$ along the boson direction, measured in γ events for events containing 1 PV and at least 2 PVs for (left) Calo $\not\!\!E_T$, (middle) TC $\not\!\!E_T$, and (right) PF $\not\!\!E_T$. Also given is the best fit value for the average ratio, which corresponds to the solid, red line.

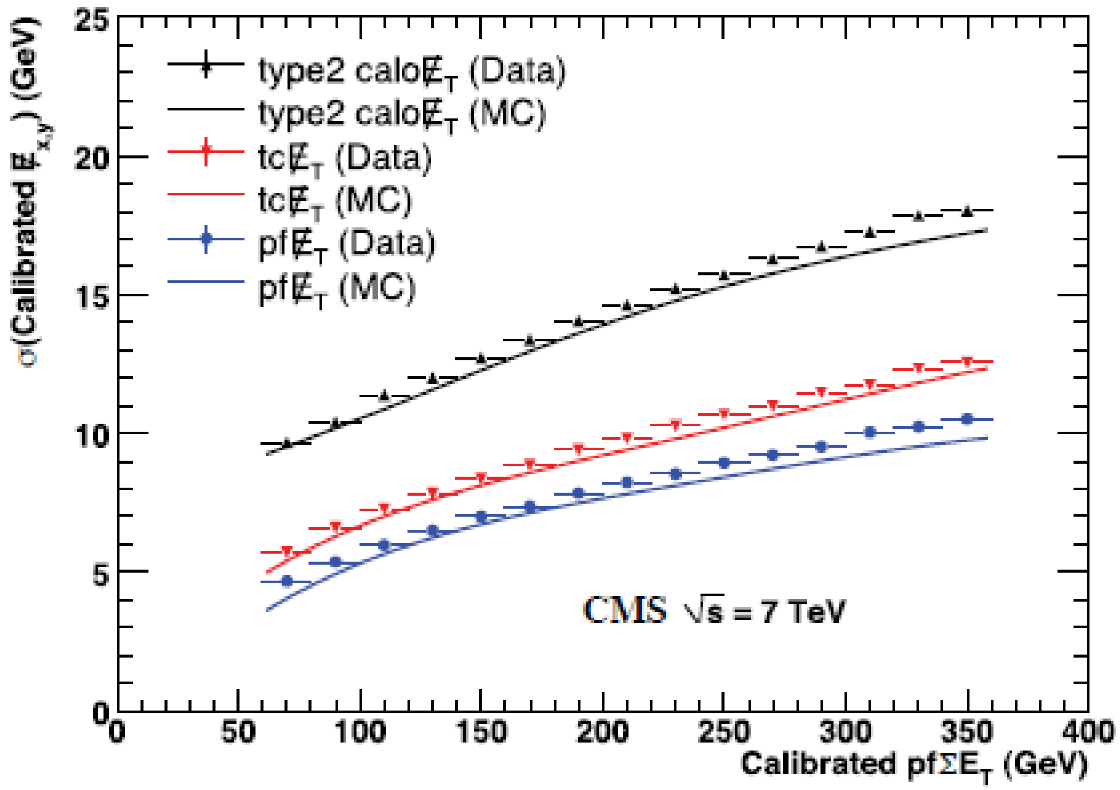
The parameterization of $\not{E}_T$ resolution used in Figs. 16 and 17 is given by :

$$\sigma_{\text{total}}^2 = (a\sqrt{q_T} + b)^2 + (\sigma_{\text{noise}} f_{\text{ES}}(q_T))^2 + (N-1)(\sigma_{\text{PU}} f_{\text{ES}}(q_T))^2 \quad (1)$$

where a and b characterize the hard process, σ_{noise} is the intrinsic noise resolution, N is the number of reconstructed vertices in the event, σ_{PU} is the intrinsic pile-up resolution, and $f_{\text{ES}}(q_T)$ is the energy scale correction applied on each event. At low q_T, the resolution is dominated by contributions from the underlying event and detector noise (σ_{noise}). Since these contributions can not be distinguished from those due to the particles from the recoil, and since the recoil measurement needs to be corrected for the detector response, these contributions are magnified and have a larger contribution at low boson q_T when energy scale corrections are applied. As expected, the resolution is degraded with increasing pile-up interactions. Results from the Z and γ channels are in agreement and are similar to the values obtained in Section 6.5.2 from jet data.

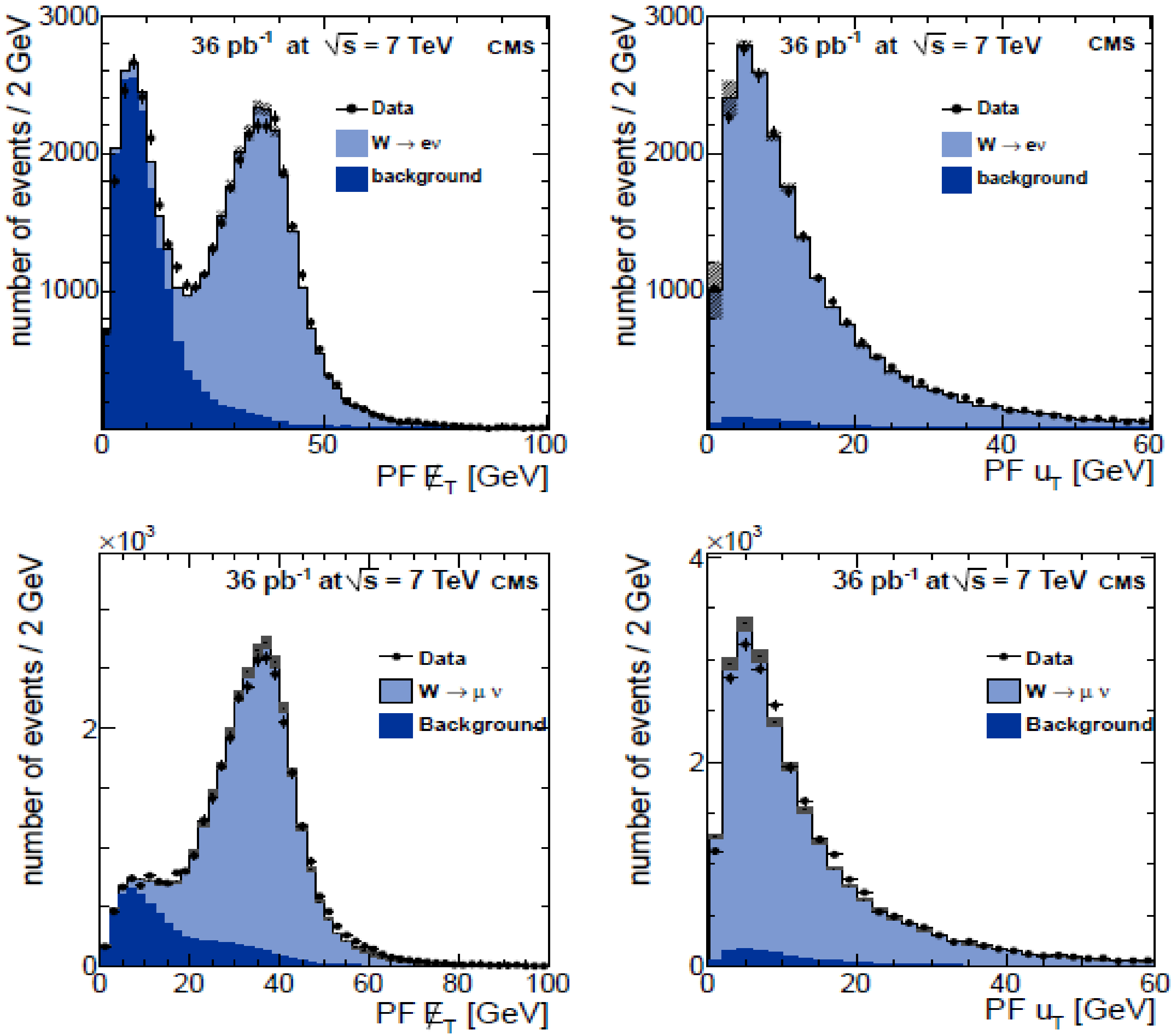
MET resolution in QCD events

- MET resolution as a function of SumEt in QCD dijet events

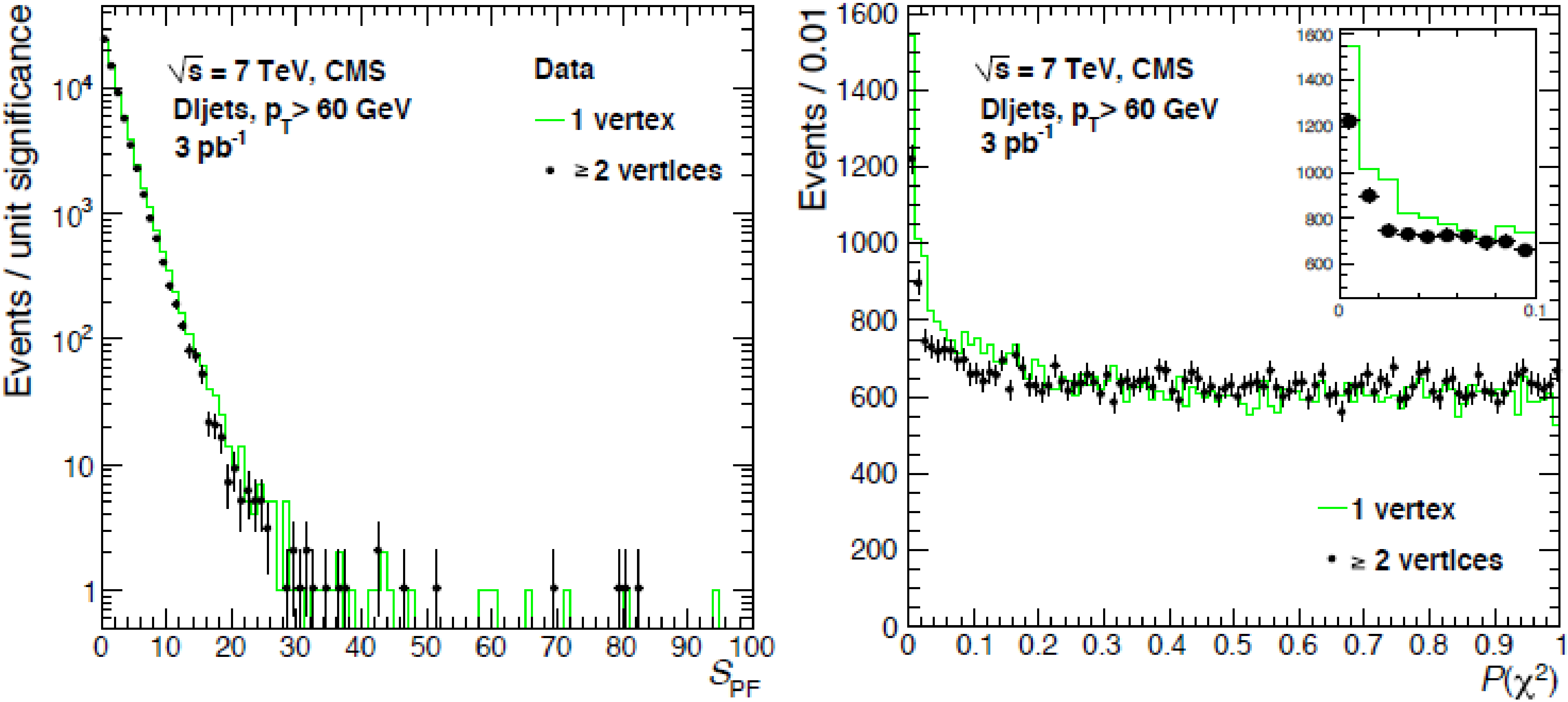


- Resolution is corrected for the scale.
- pfMET gives the best resolution.

W+jets events



PU effect on MET significance



track-corrected MET

- Basic idea: Use well measured tracks to correct the imperfect response of the calorimeter to charged hadrons (⇒lower tail, better resolution)
  - Add track momenta (Important to separate μ's from π's)
  - Substract average single-particle response for each track
- First step: Compute muon corrected caloMET

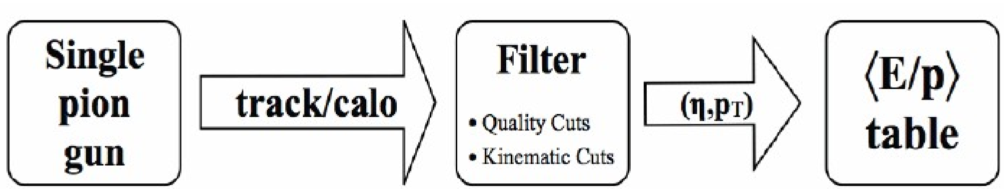
$$\not{E}_T^{\mu} = \not{E}_T^{\text{calo}} + \delta\not{E}_T^{\mu}, \\ = -\sum_{\text{towers}} \vec{E}_T - \sum_{\substack{\text{good}\\ \text{muons}}} \vec{p}_T + \sum_{\substack{\text{good}\\ \text{muons}}} \vec{E}_T^{\text{MIP}}$$

Tracker muon p_T | Calo E deposit (~2 GeV)

- Second step: Compute tcMET using hadron tracks

$$\not{E}_T^{\text{tc}} = \not{E}_T^{\mu} + \delta\not{E}_T^{\text{tc}}, \\ = \not{E}_T^{\mu} + \sum_{\substack{\text{good}\\ \text{tracks}}} \langle \vec{E}_T \rangle - \sum_{\substack{\text{good}\\ \text{tracks}}} \vec{p}_T$$

Expected energy deposited (RF) | Track momentum at vertex



Particle flow MET

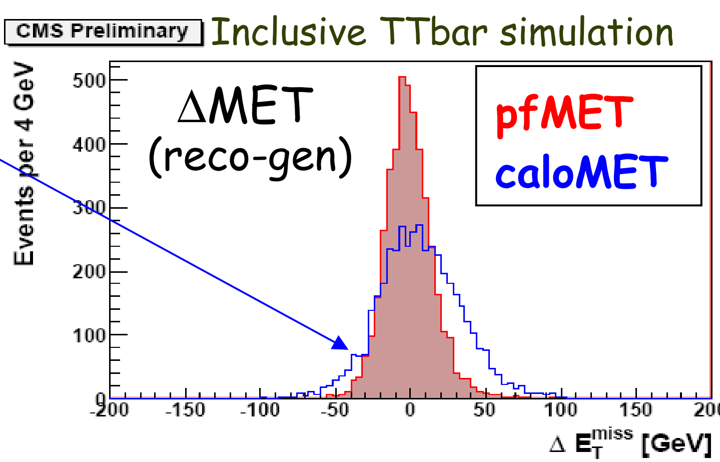
- The particle flow reconstruction aims at reconstructing all stable particles in the event:
  - $\mu^{\pm}$, $e^{\pm}$, γ, charged hadrons and neutral hadrons

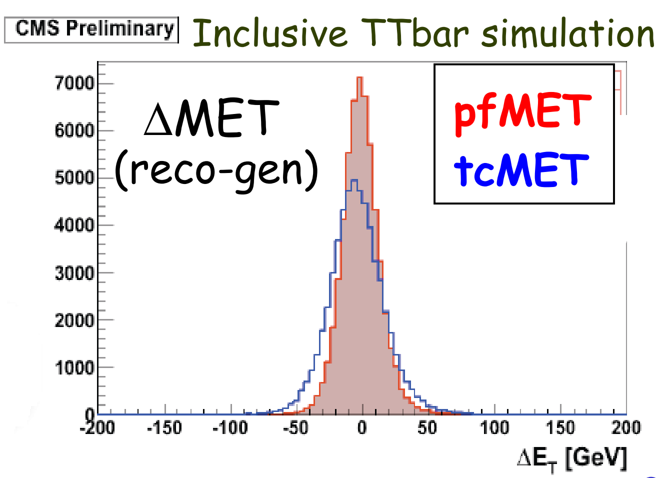
using full ensemble & redundancy of all CMS detectors:
  - Tracker, ECAL, HCAL, muon system

- PfMET is the transverse momentum vector sum over all reconstructed particles:

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

caloMET is corrected from muons and jet energy scale here, but in the following only raw quantities will be compared

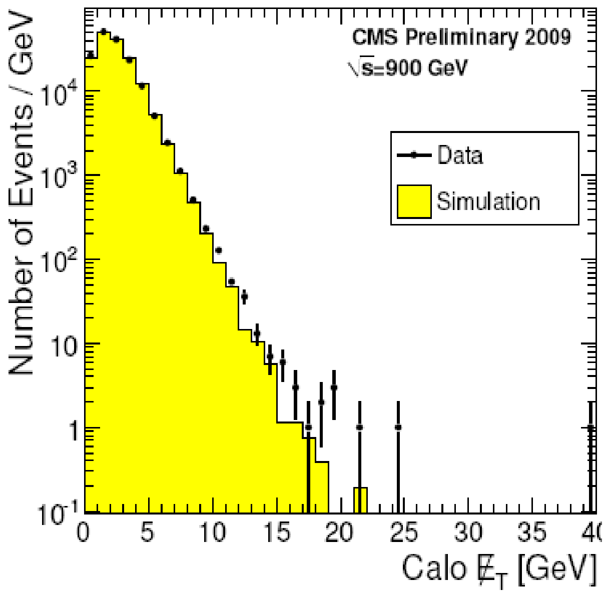




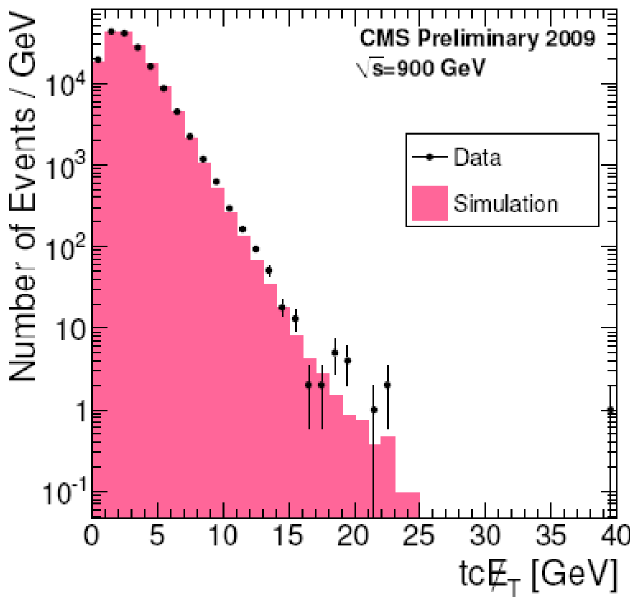
Factor ~2 improvement

MET: Comparison, after cleaning, with the simulation

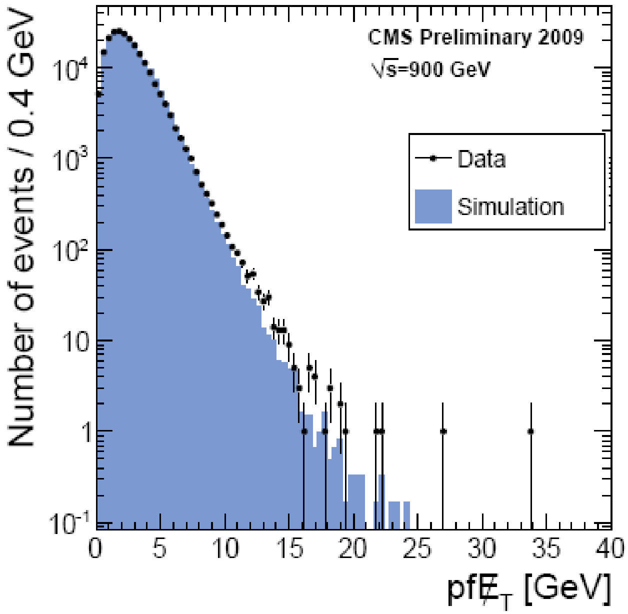
caloMET



tcMET

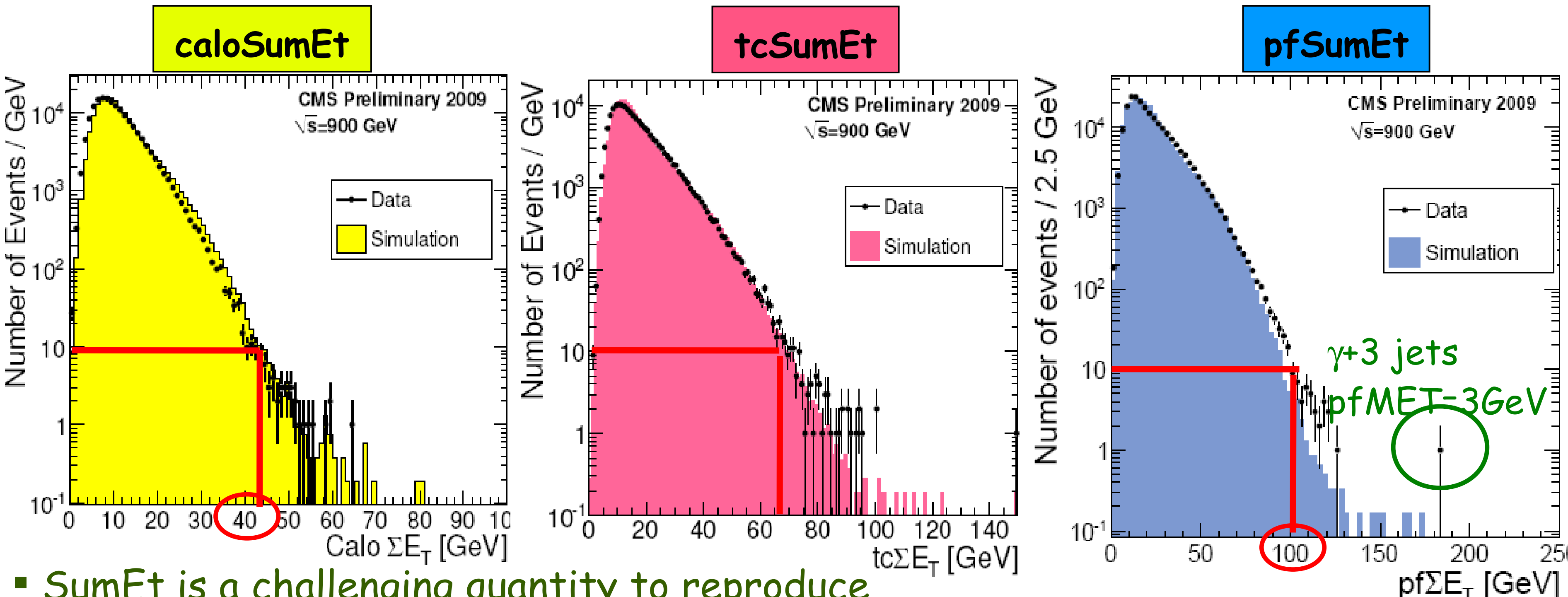


pfMET

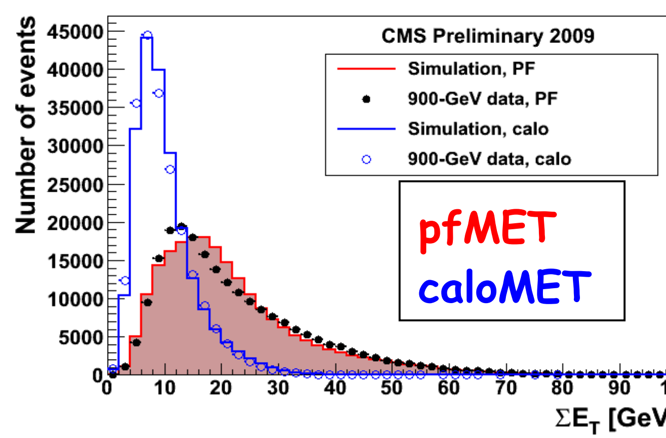


- 900 GeV data - No JES and muon corrections applied
- Good agreement between the data and the MinBias simulation

SumEt



- SumEt is a challenging quantity to reproduce
    - no cancellation (in contrast with the MET)
- The MinBias simulation gives a quite good agreement with the data
- Discrepancies are mainly due to charged hadron multiplicity. Small discrepancy also due to not perfect noise modeling in ECAL endcaps
- The particle flow reconstructs much more energy than the other algorithms.



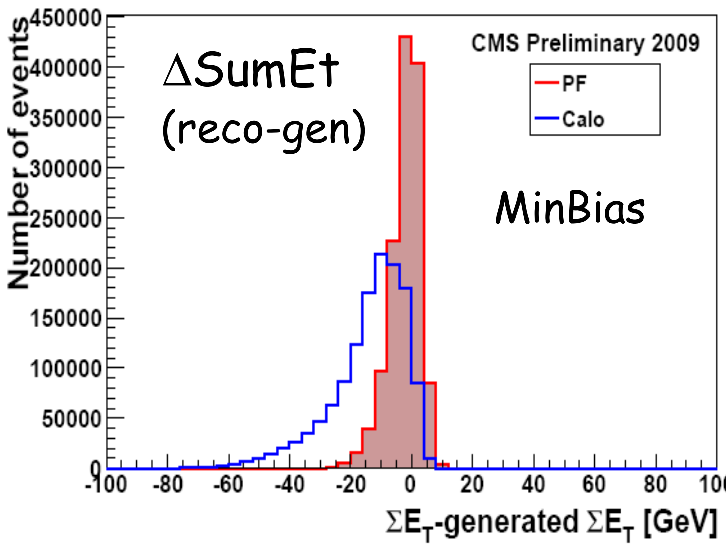
The particle-based SumEt is close to the true generated SumEt

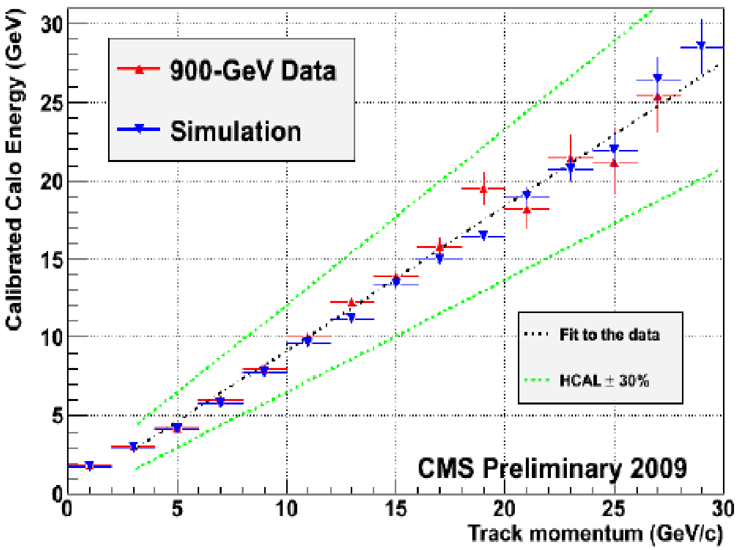
➢ Three reasons govern this observation:

▪ Charged hadrons (measured by the tracker) and photons (measured by the ECAL) are reconstructed at the correct energy scale and represent about 80% of the event energy.

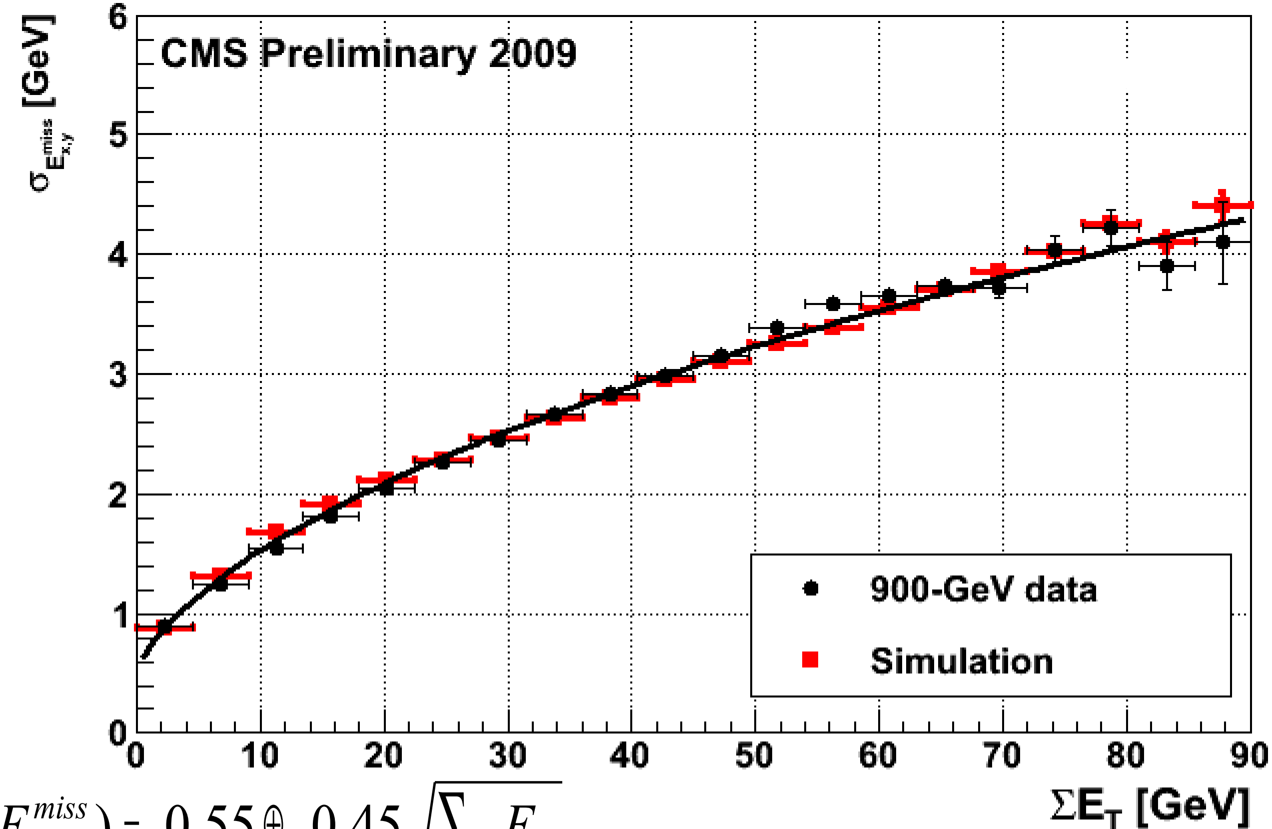
▪ The particle-flow algorithm is able to reconstruct very low-energy particles, down to a pT of 100 MeV/c for charged hadrons, and to an energy of 200 MeV for photons.

▪ The hadronic-cluster calibration brings the neutral hadron energy, which accounts for the remaining 20% of the event energy, to the proper scale as well.





$MET_{x,y}$ resolution: fit results



- $\sigma(E_{x,y}^{miss}) = 0.55 \oplus 0.45\sqrt{\sum E_T}$

~0.80 for caloMET

- Same results obtained with the 2.36 TeV events