A Search for New Physics in Events with Jets and Missing Transverse Energy at CMS

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(On behalf of CMS Collaboration)

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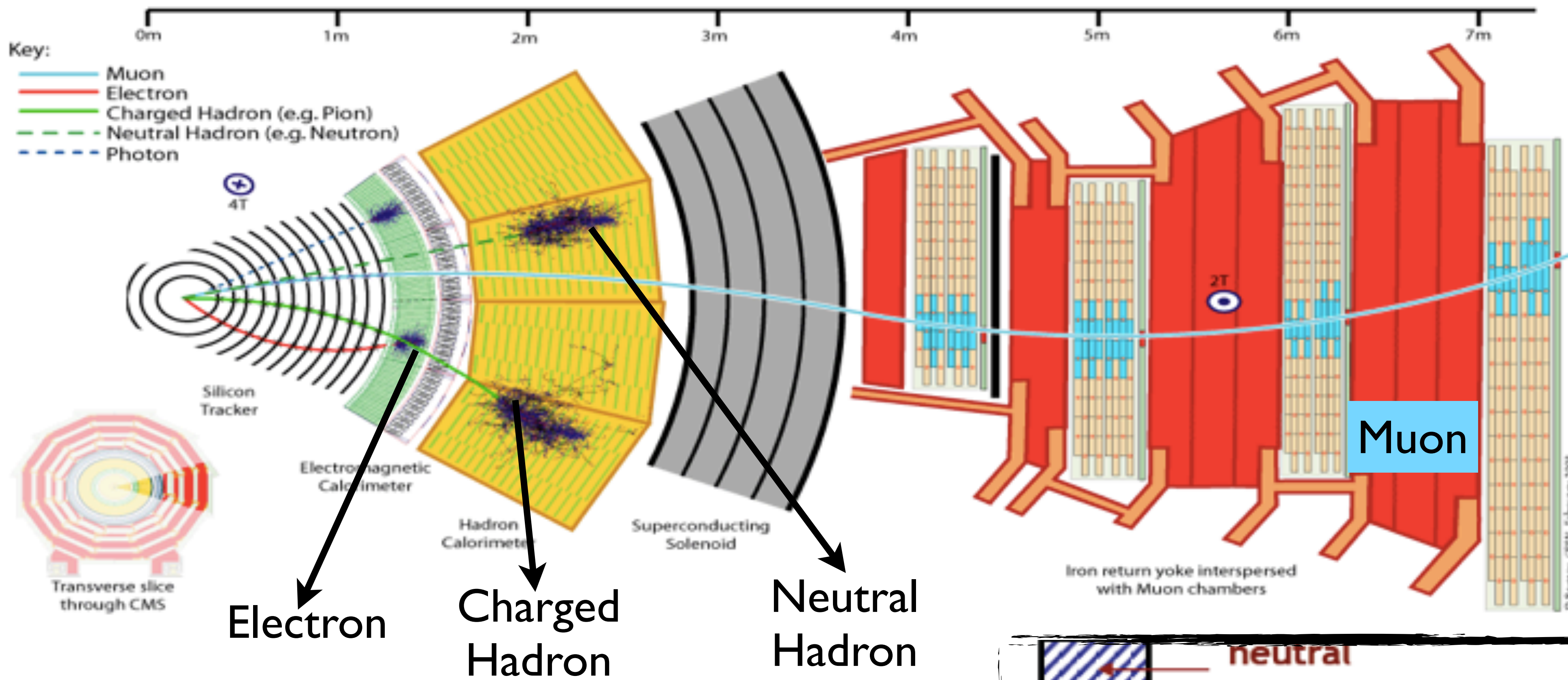
Outline

- Introduction to the analysis
- Measuring backgrounds from data
- Results & interpretation

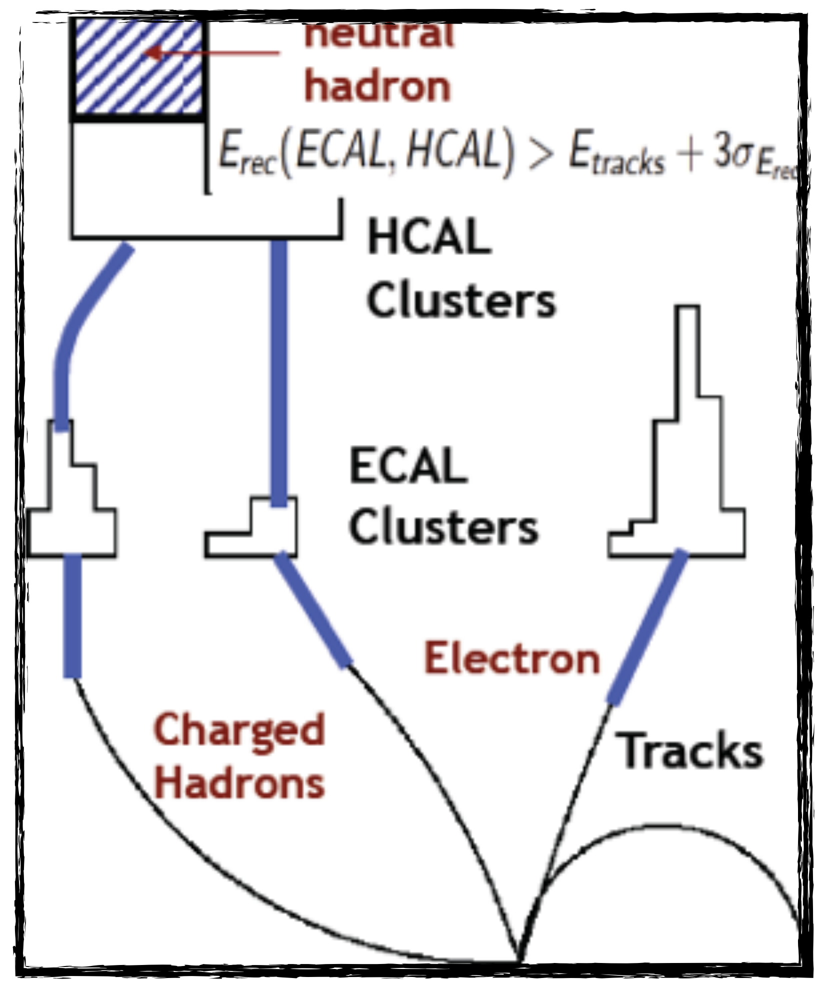
Analysis presented here is based on 1.1 fb^{-1} data collected by CMS detector from March-July 2011.

CMS Detector & Event Reconstruction



Events are reconstructed using Particle Flow algorithm which combines information from the tracker, EM calorimeter, Hadron Calorimeter and Muon detectors in an optimized way to get the best estimate of energy, direction and identity of particles.

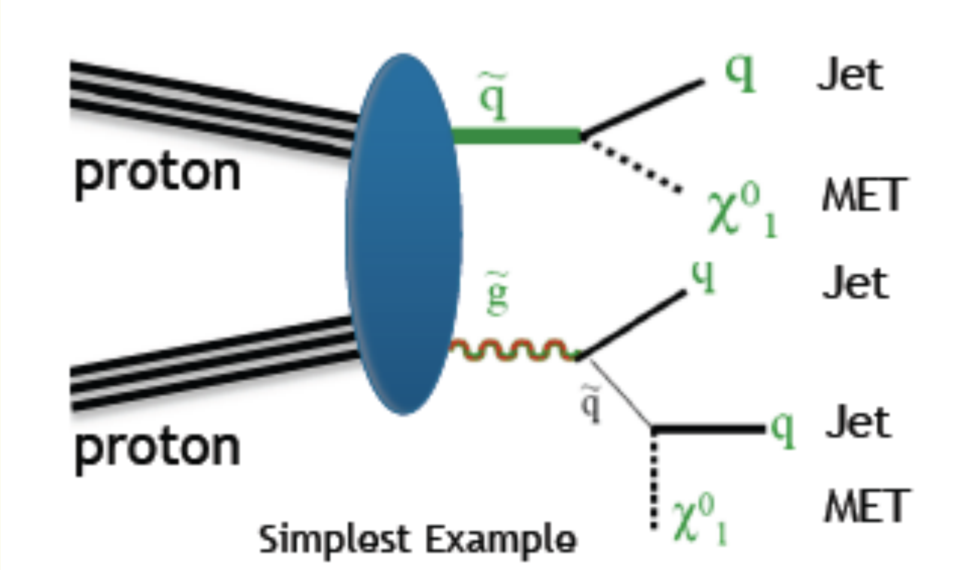
The various physics objects used in this analysis are jets (antiKT 0.5), photons, electrons & muons.



Introduction : Jets+Missing Transverse Momentum

- A generic search for large missing transverse momentum in events containing multijets is motivated by R-parity conserving SUSY
  - strong production of pairs of $\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$
  - largest cross-section, most sensitive channel
  - key point is to understand the backgrounds

SUSY particles eventually decay to **L**ightest **S**upersymmetric **P**article (stable, neutral, massive) which results in missing transverse momentum ($\chi^0{}_1$ in this example)



Experimental signature:
Jets + Missing Transverse Momentum

The standards model processes which can give similar signature are Z(ν ν) +Jets, W/tt+Jets with W(e/μ/τ ν), QCD (mis-measured jets)

Sensitive variables used in this analysis

HT : Transverse Hadronic Energy

$$H_T = \sum_i^{jets} \left| \vec{p}_T, i \right|$$

MHT : Missing Transverse Hadronic Energy

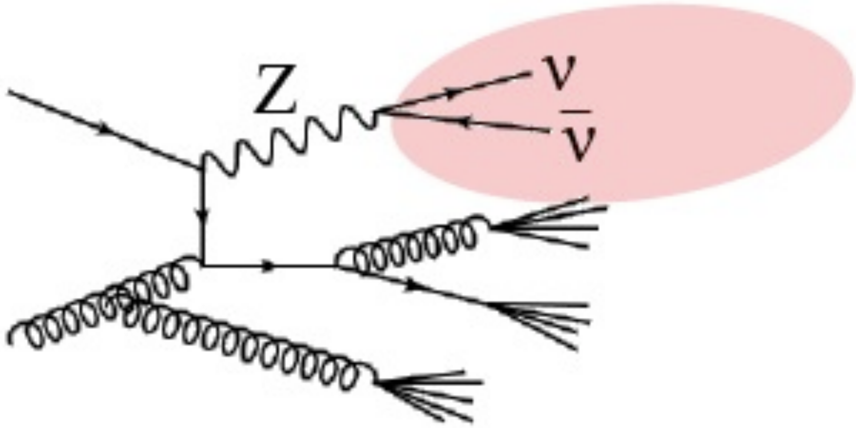
$$\cancel{H}_T = \left| -\sum_i^{jets} \vec{p}_T, i \right|$$

Analysis Strategy & Sample Selection

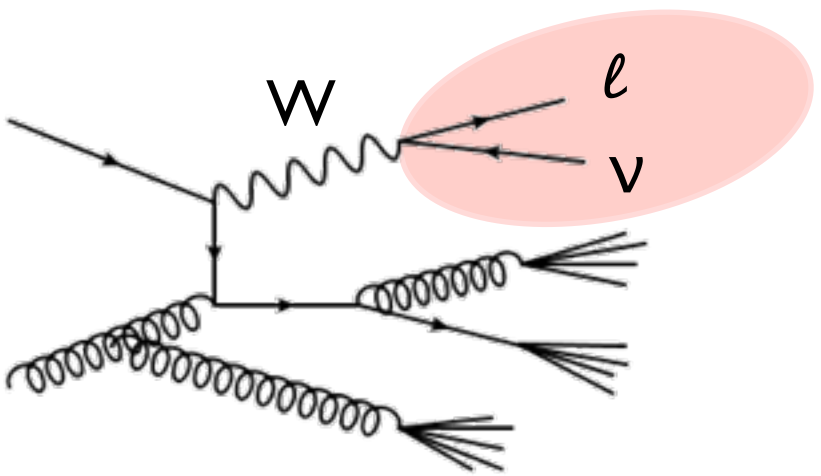
- Analysis strategy
  - Aim for an inclusive analysis based on HT and MHT
- Sample selection
  - Based on data acquired with online selection on HT and MHT
  - At least 3 jets with pT>50 GeV & $|\eta|<2.5$ (central production)
  - Veto events with isolated electrons & muons (suppress W & top backgrounds)
  - $\Delta\Phi$(MHT, Jets123) > (0.5, 0.5, 0.3) (reduce QCD background)
  - HT - scalar sum of all jets with pT > 50 & $|\eta|<2.5$
  - MHT - magnitude of negative vector sum of all jets with pT>30 GeV & |eta|<5
- Search regions in HT & MHT
  - Baseline (HT>350 & MHT > 200) - loose event selection used for validation
  - Medium (HT>500 & MHT > 350) - generic high multiplicity and missing momentum search
  - High HT (HT>800 & MHT > 200) - long cascades, high particle multiplicity
  - High MHT (HT>800 & MHT > 500) - generic search for weakly interacting neutral particle, good background rejection

Physics Backgrounds

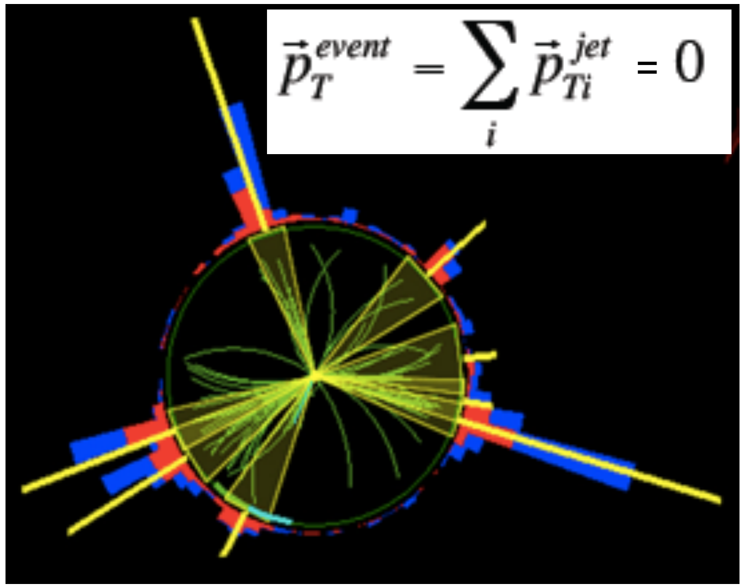
- Z + Jets
  - with Z decaying to neutrinos
  - These events with real jets and real missing momentum due to neutrinos have the same signature as SUSY events

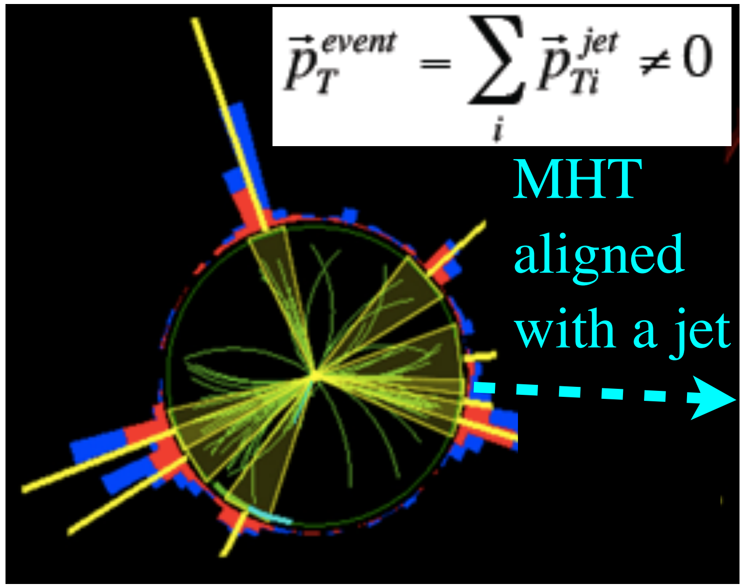


- W/top + Jets
  - t → W (→ lost lepton + ν) + Jets :
    - if W decays leptonically and e/μ is not detected or reconstructed
  - Top/W (→ hadronic τ + ν)+ Jets :
    - if W decays to τ+ν and τ decays hadronically



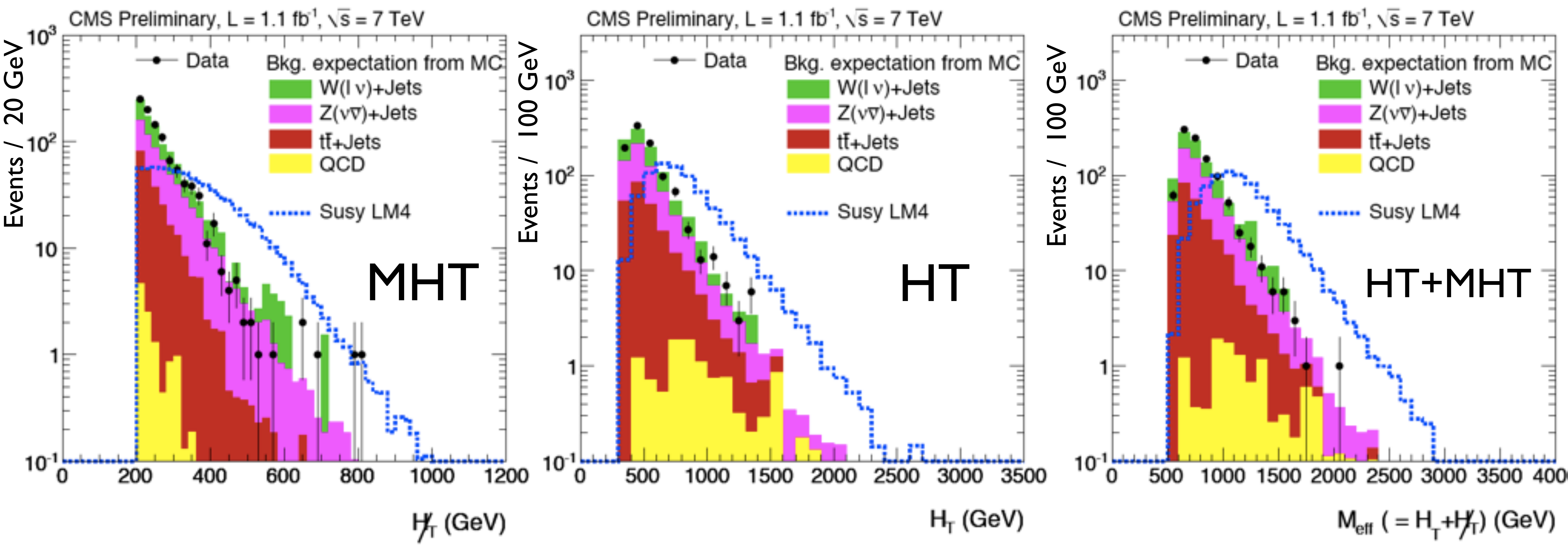
- QCD MultiJets
  - jet mis-measurements resulting in imbalance
  - semi leptonically decaying b or c quarks





Data vs MC Comparison

- Distributions of HT, MHT and HT+MHT from data are compared with the expected distributions from Monte Carlo CMS simulation of major backgrounds



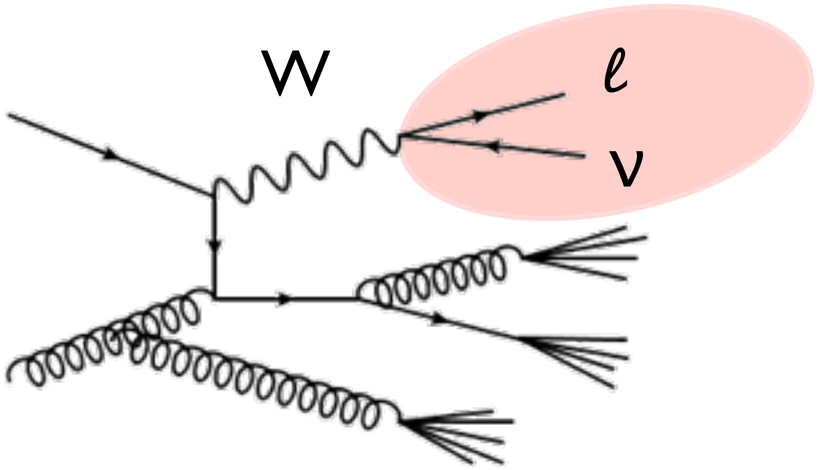
- The HT, MHT and HT+MHT distributions are well described by CMS simulation.
- The low mass SUSY benchmark point LM4 is used only for illustration
  - $m_0 = 210$ GeV, $m_{1/2} = 285$ GeV, $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$
  - cross section 2.5 pb (Prospino NLO)
- In the analysis the backgrounds are estimated from the collision data.

Background Prediction using Data Events

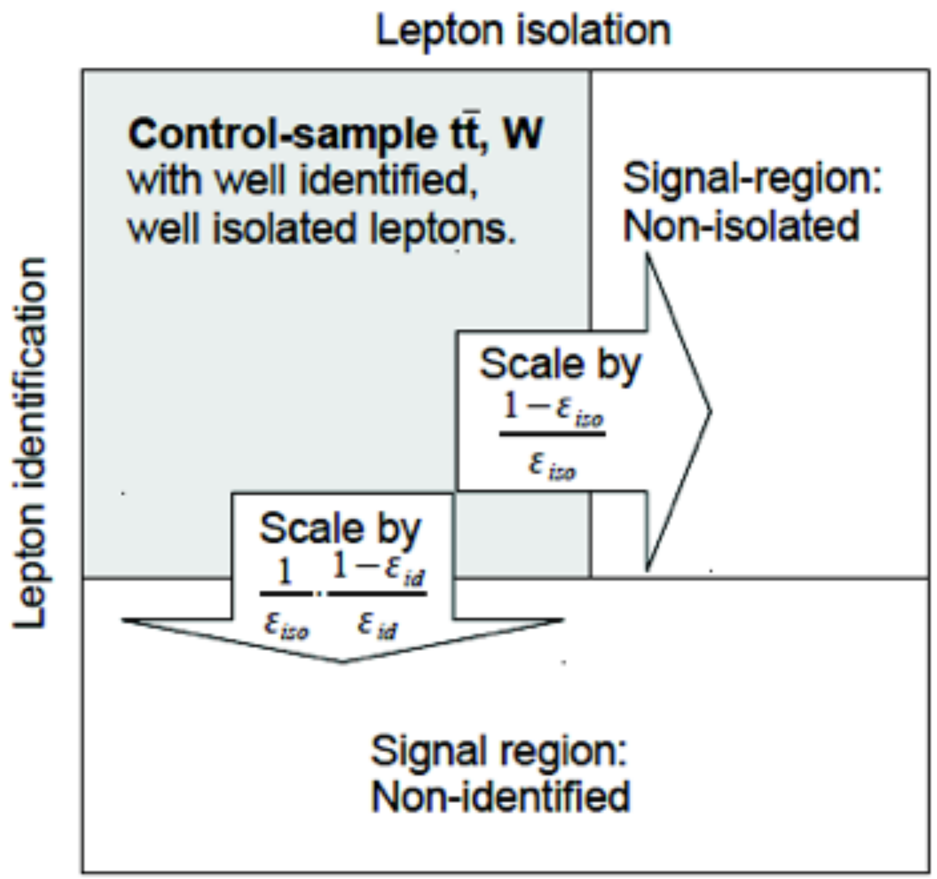
- Data driven methods are used for the background prediction from the collision data for this analysis
- A control data sample is a set of events which is signal depleted
  - This sample can be used to infer the backgrounds in the signal enriched phase space using event properties, physics laws, our theoretical knowledge of various physics processes ...
- A search region is the area of phase space where the signal is enhanced (good signal to background distinction)

W/top (lost lepton + ν) + Jets

- Lepton (e/μ) failing veto criteria contribute to background
- There can be three reasons a lepton is lost
  - if it is not reconstructed
  - not isolated
  - out of detector acceptance



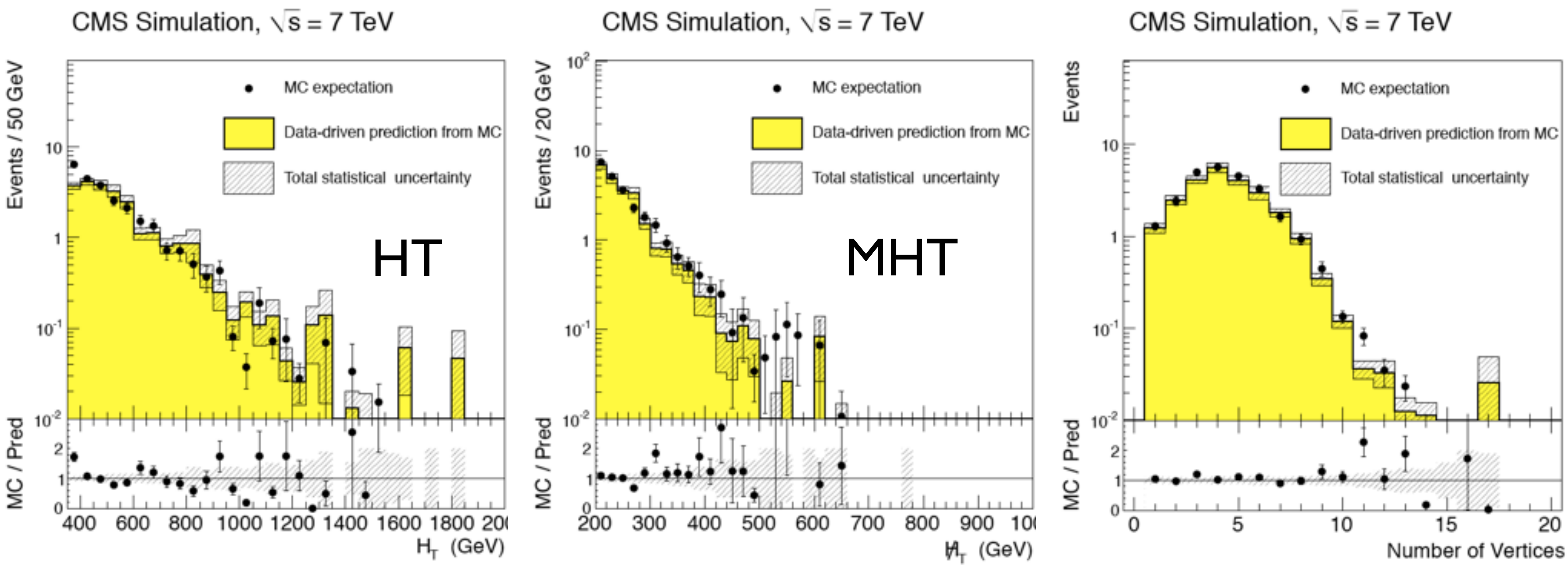
- Start with a control sample of μ+jets events (invert the lepton veto)
- Measure the muon reconstruction and isolation (in)efficiencies from data
  - scale the control sample with measured (in)efficiencies from data
  - Correct for detector acceptance



W/top (lost lepton + ν) + Jets

Performance of the Method in MC

- using Monte Carlo CMS simulation W(ℓ ν)+Jets samples
  - apply data driven technique to a MC sample and predict the full kinematics in signal region.
  - the reproducibility of various distributions from the MC expectations defines the level of closure of the method.

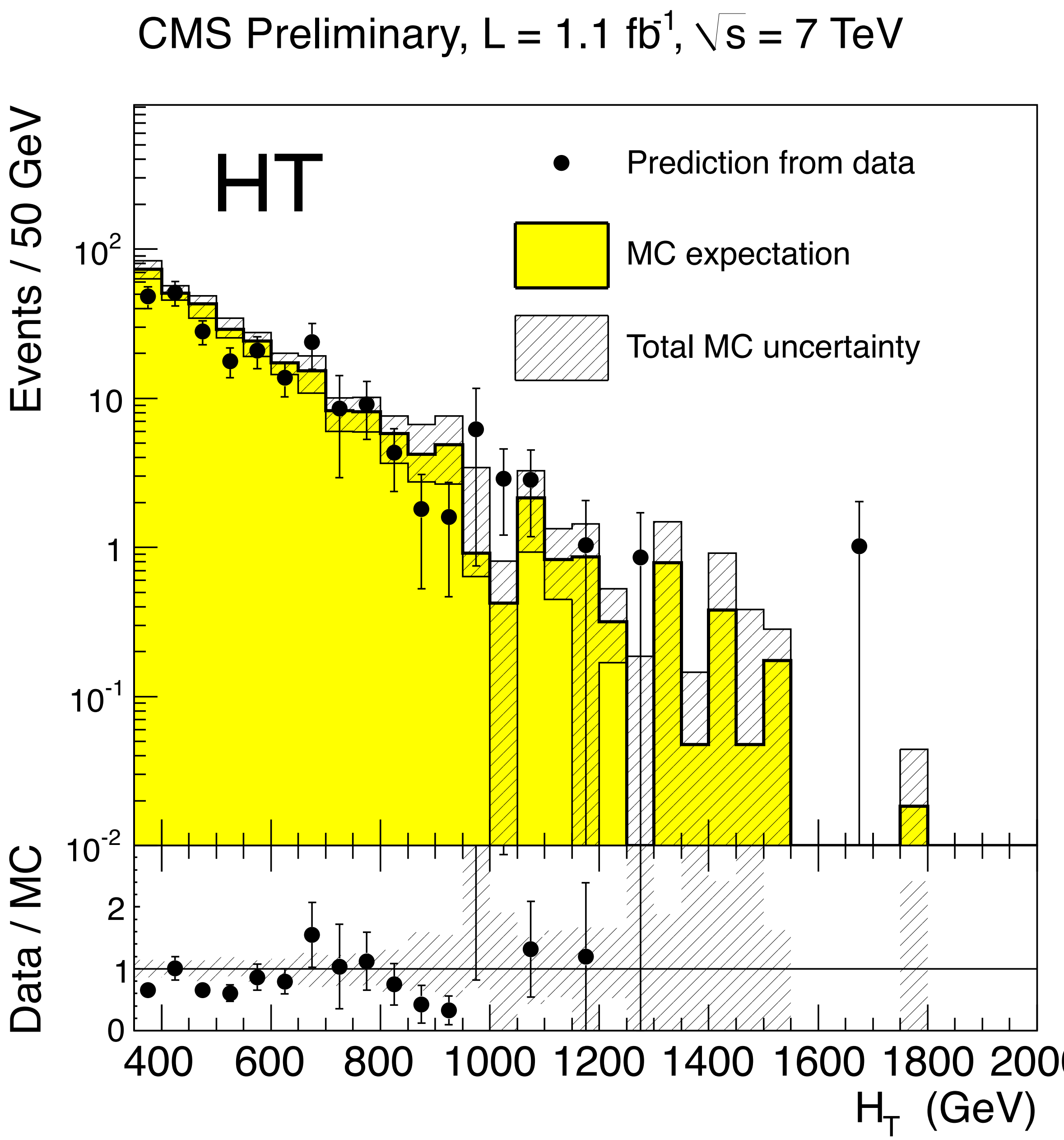


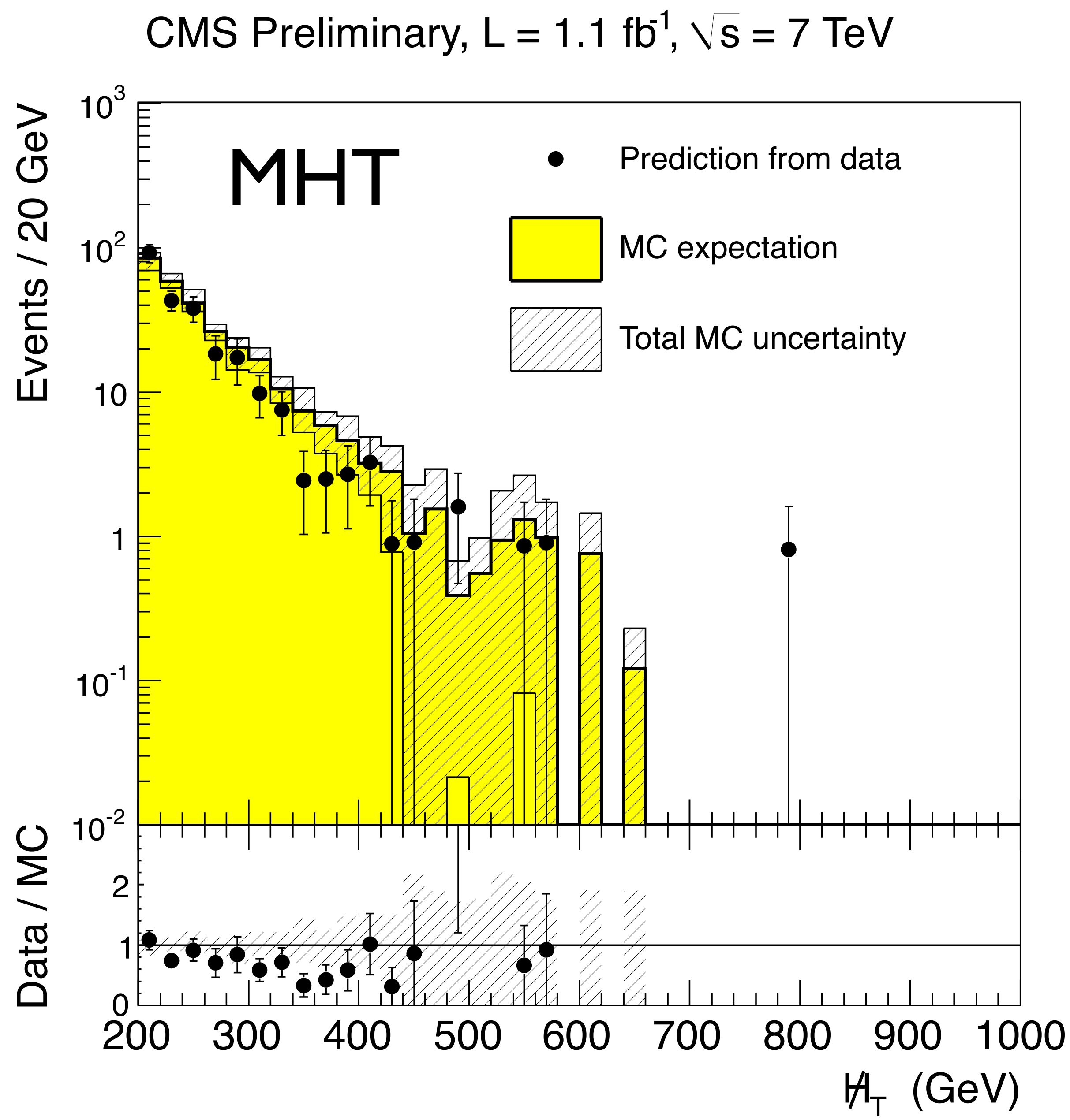
The method of lost lepton using μ+jets control samples closes well in MC

W/top (lost lepton + ν) + Jets

Results from 1.1 fb^{-1} Data

Using μ+jets events (control sample) from collision data



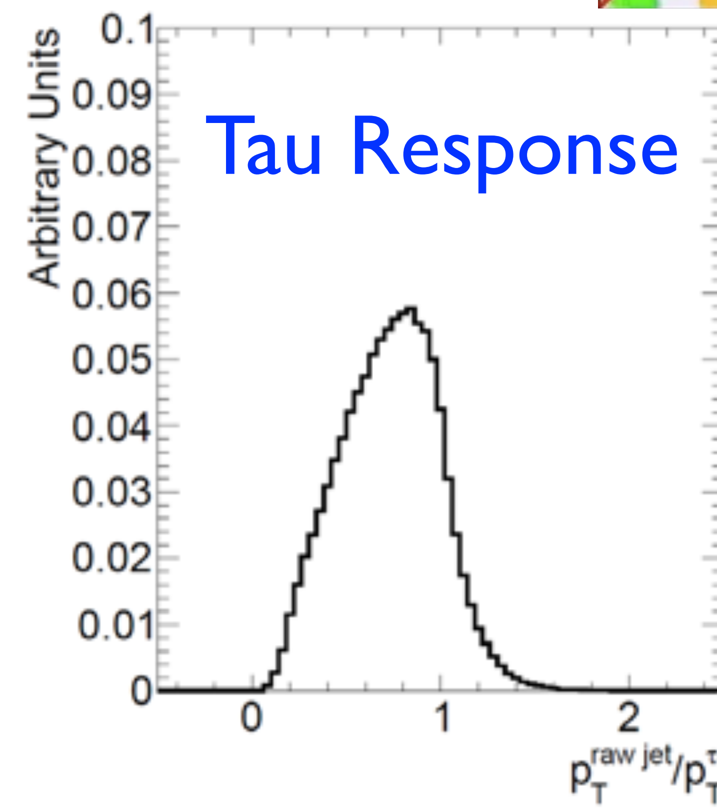


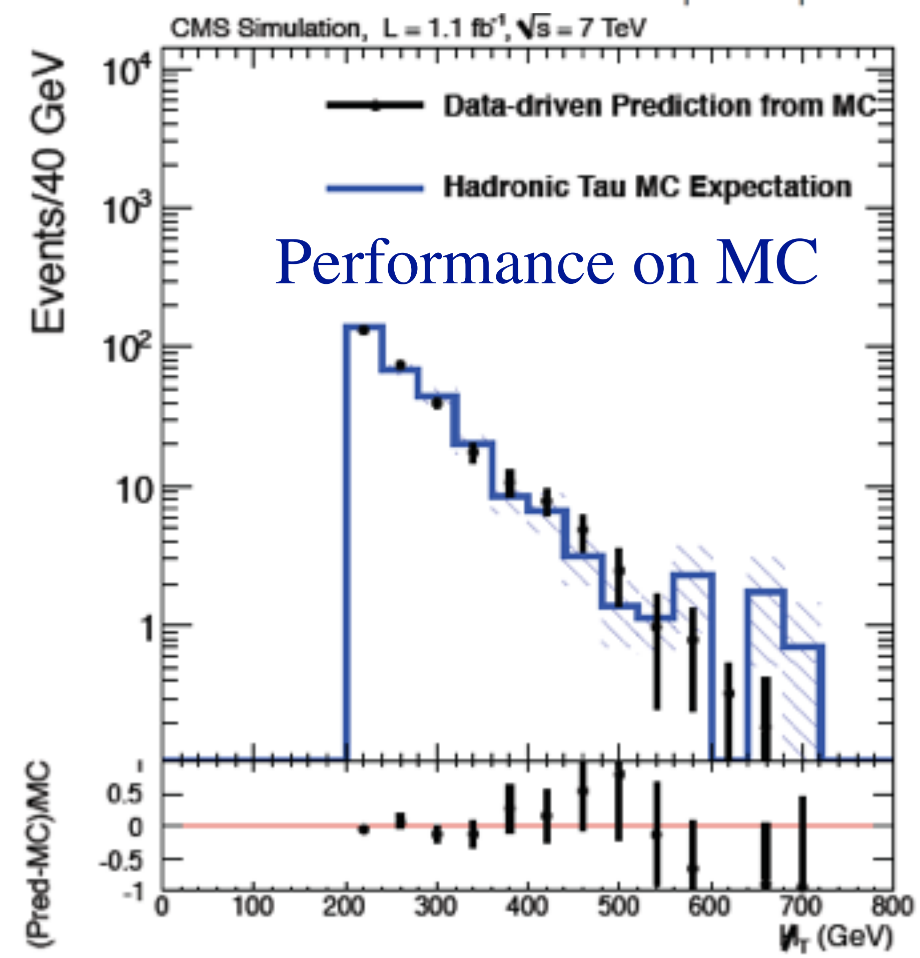
	Baseline			Medium			High H_T			high $\not{H}_T$		
Prediction	244	±20	$^{+30}_{-31}$	12.7	±3.3	±1.5	22.5	±6.7	$^{+3.0}_{-3.1}$	0.8	±0.8	±0.1

Top/W (hadronic τ + ν) + Jets

- Start with a μ + (≥2) jets control sample
- Replace the μ with a τ jet using a τ jet response template (MC)
  - response = (reconstructed pT of τ jet)/(pT of generated τ)
- Recalculate HT and MHT including the τ jet (which replace the μ)
- Corrections : Trigger efficiency, reconstruction efficiency, detector acceptance, branching ratio of W boson decaying to a hadronic τ.
- Systematic uncertainties : tau energy scale, acceptance, background subtraction, muon identification and isolation efficiencies, trigger efficiency.

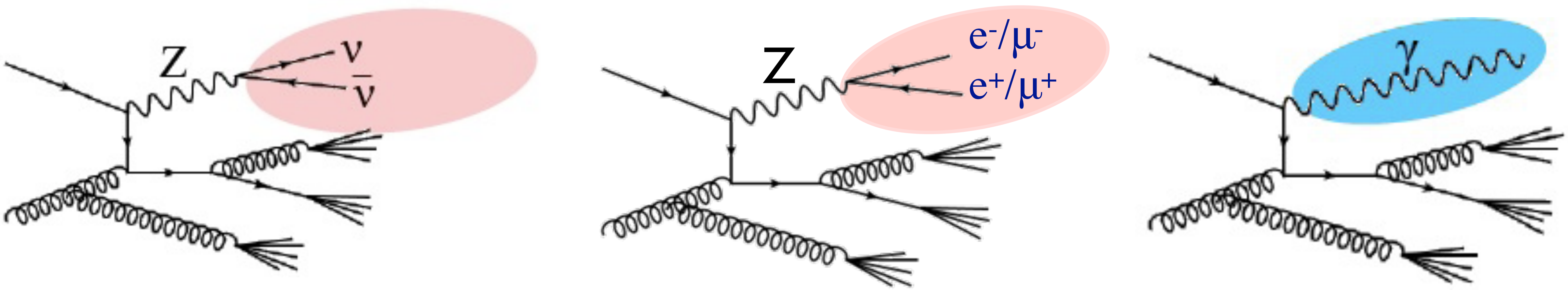
Results : Prediction from **Data** ($1.1\ fb^{-1}$)	
Baseline (HT>350, MHT>200)	263 ± 8 ± 7
Medium (HT>500, MHT>350)	17 ± 2 ± 0.7
High HT (HT>800, MHT>200)	18 ± 2 ± 0.5
High MHT (HT>800, MHT>500)	0.73 ± 0.73 ± 0.04





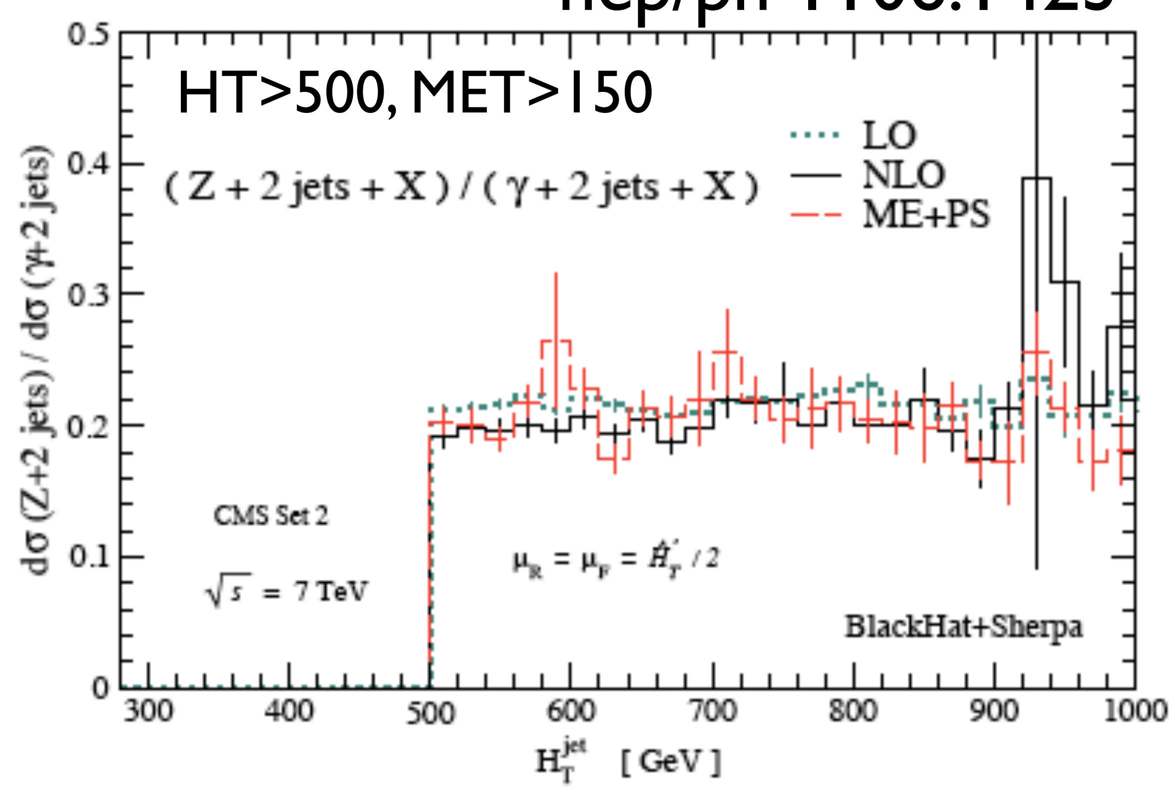
Z (ν ν) + Jets

- Z(→ ν ν) +Jets : real jets and real missing transverse momentum
- A straightforward method is to use Z (→ e^+e^- or $\mu^+\mu^-$) +Jets events as the topology of events is identical if one ignores leptons in the event
  - suffers from lack of statistics in tighter search regions and is used only to cross-check the background prediction using γ + Jets



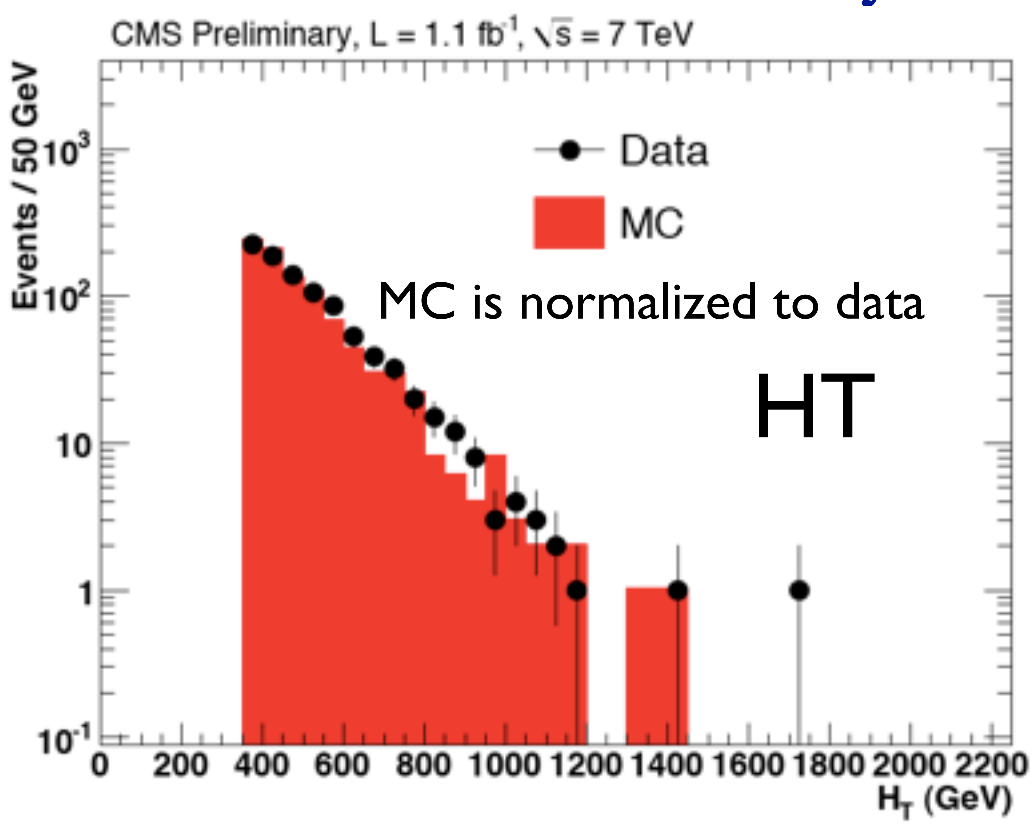
- At sufficiently high pT, the ratio of Z+jets to γ +jets production cross-section depends mainly on the electroweak characteristics of the event.
- Hadronic part of the event is independent of whether boson is Z or γ (figure on right)
- Theoretical uncertainty is assumed to be 20%.

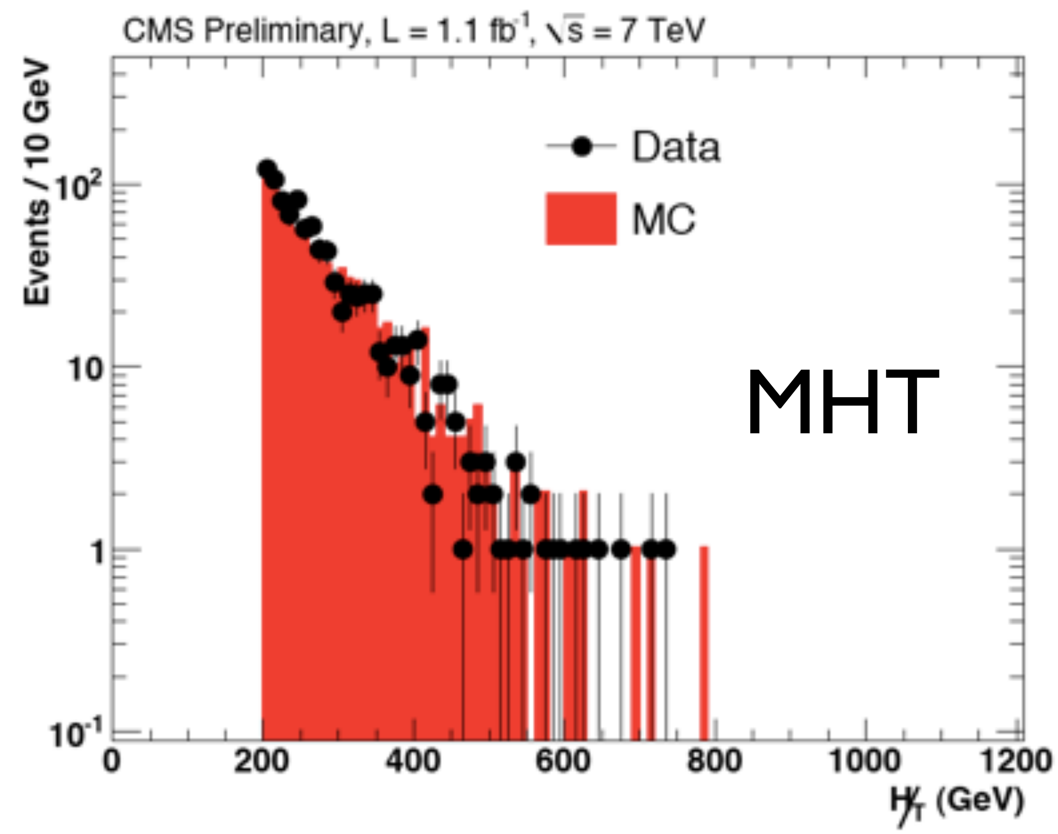
hep/ph 1106.1423



Z (ν ν) + Jets using γ+jets

Calculate HT and MHT using jets in the event (ignoring γ) and apply all the selections of the analysis.





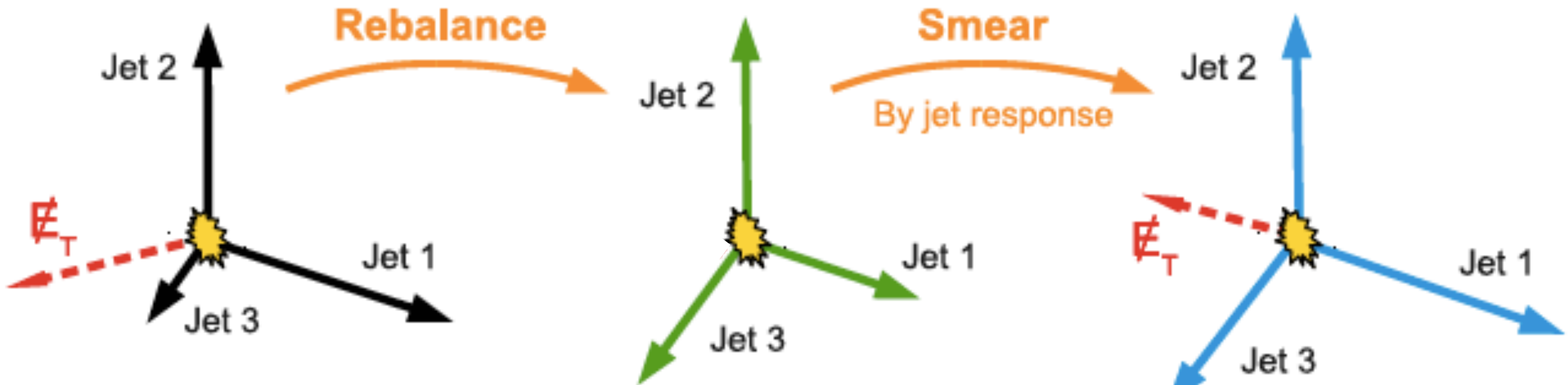
Prediction of Z(ν ν) +Jets

- Start with Photon+Jets data
- Subtract the contribution from secondary photons (measured from data) & photons radiated from final state partons.
- Correct for photon reconstruction & isolation efficiencies measured from data.
- Scale with Z(ν ν)+Jets/γ + Jets production ratio taken from theory.

Results : Prediction from Data (1.1 fb^{-1})	
Baseline (HT>350, MHT>200)	376 ± 12 ± 79
Medium (HT>500, MHT>350)	42.6 ± 4.4 ± 8.9
High HT (HT>800, MHT>200)	24.9 ± 3.5 ± 5.2
High MHT (HT>800, MHT>500)	2.4 ± 1.1 ± 0.5

QCD Multijet : Rebalance & Smear

- QCD multijet events are balanced at the parton level
- An imbalance is introduced by the mis-measurement of jets due to fluctuations in response of detector, non-functional detector channels or a small fraction of events with b or c quarks decaying semileptonically

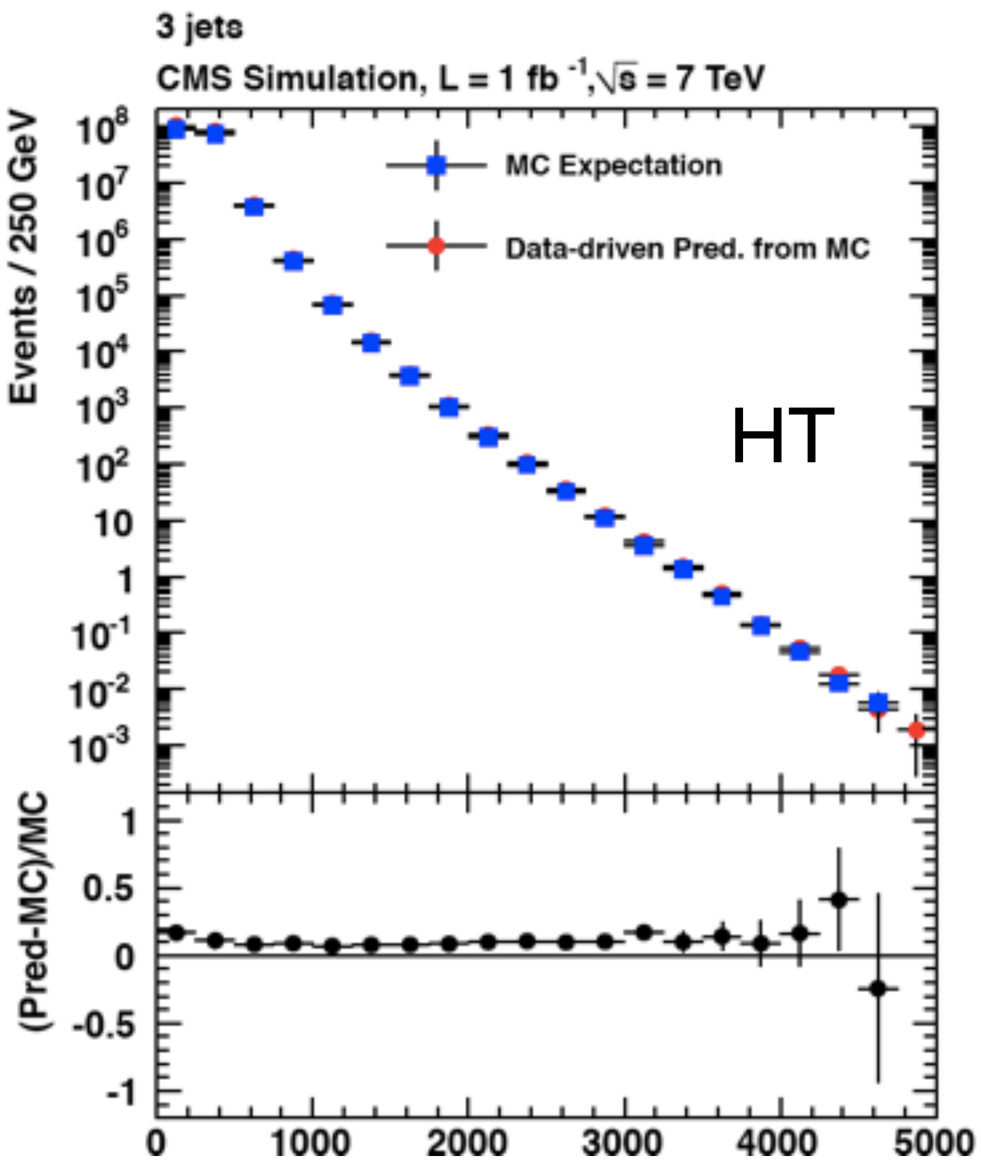


- Rebalance : Particle level jet pT is restored from detector level inclusive multijet data using a kinematic fit with jet response functions derived from data & subject to constraint MHT=0
- Smear : "Rebalanced" events are smeared using the measured jet response functions including the tails
- Obtain a data driven estimation of full kinematics of QCD multijet events
  - predict HT, MHT, angles between jets and MHT and apply kinematic selection of the analysis to predict the background from QCD multijet events from data

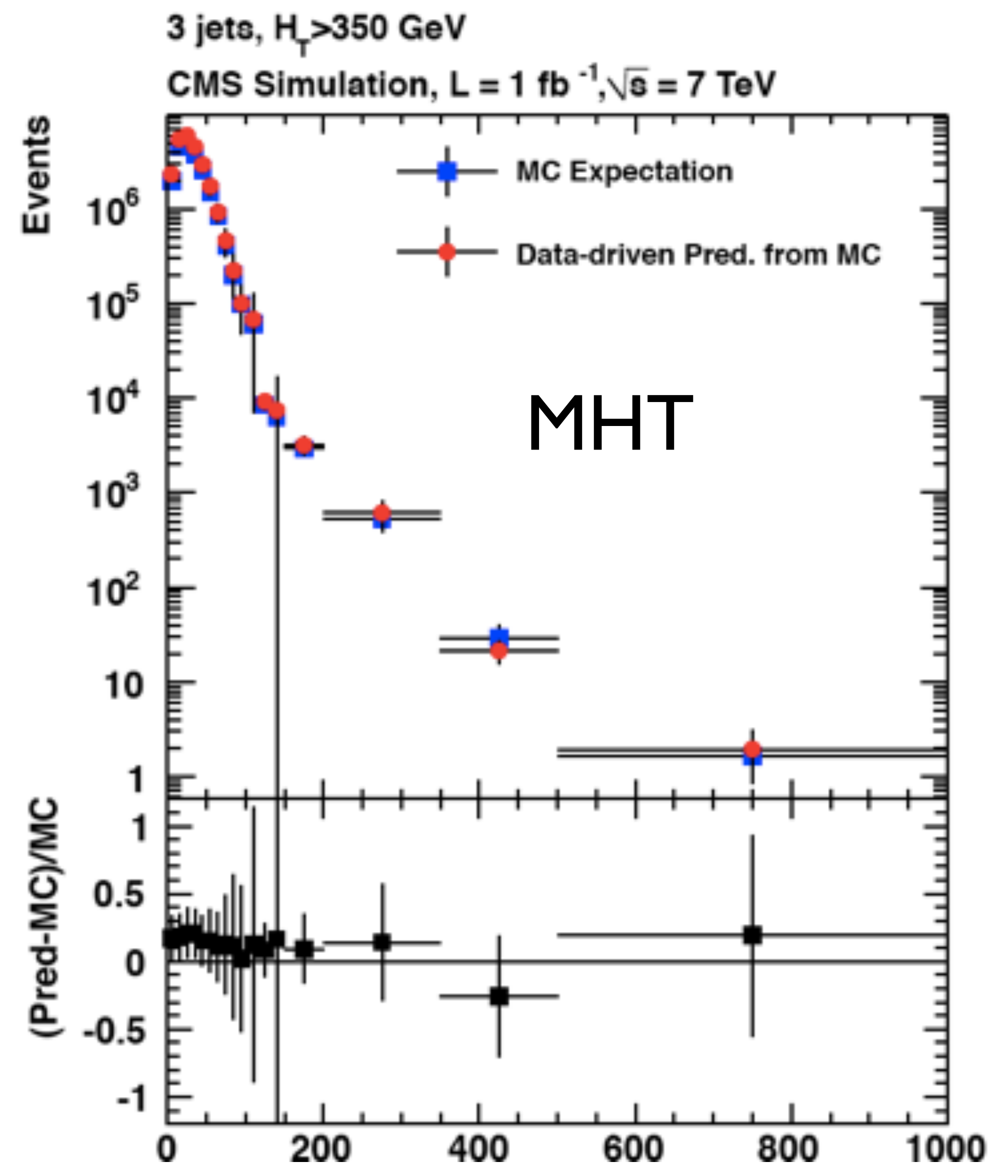
Performance of Rebalance & Smear

Compare the MC expectation with the data driven prediction applied on QCD sample.

Method reproduced HT/MHT distributions for various event selections



Selection : ≥3 Jets



Selection : ≥3 Jets, HT>350

QCD Multijet : Results from 1.1 fb^{-1} Data

- To predict the QCD background from **Data** using Rebalance & Smear method
  - The data events acquired with HT triggers are rebalanced using the jet response functions derived from data

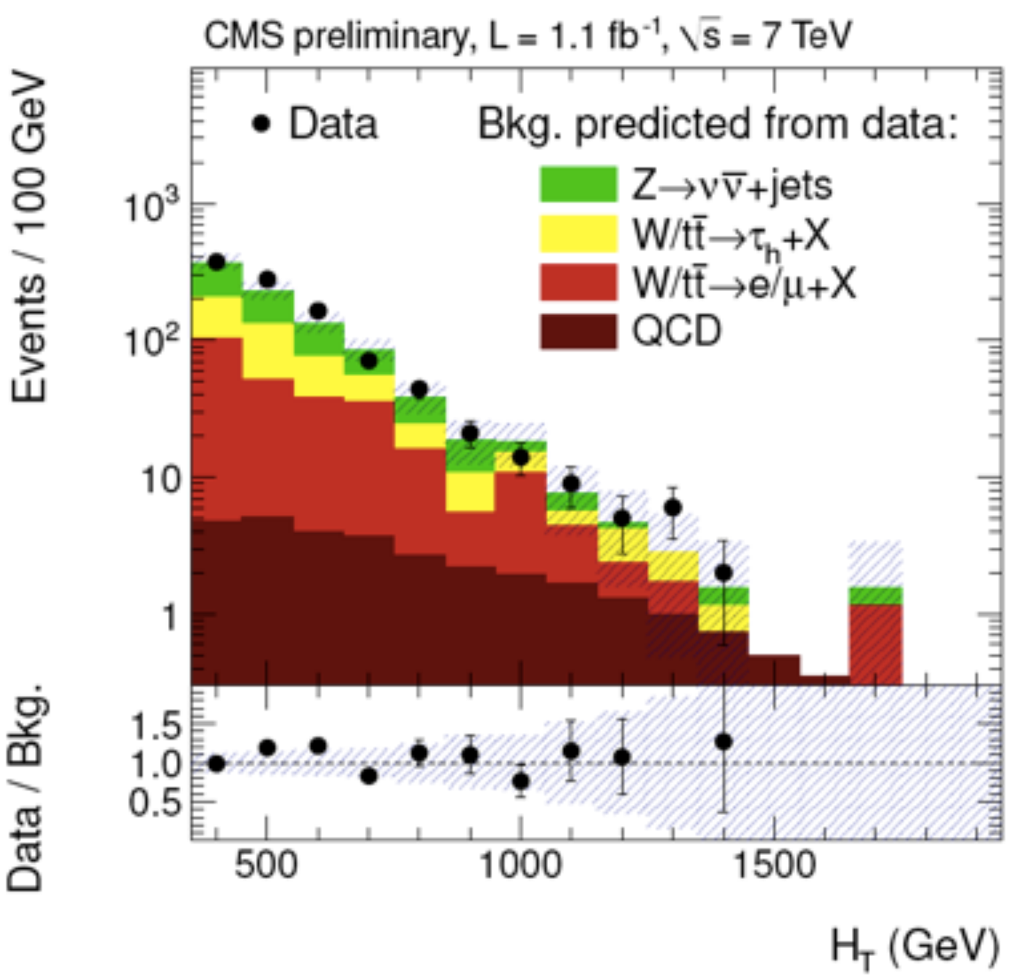
	Baseline	Medium	High H_T	High $\not{H}_T$
Bias-corrected prediction	31	1.3	13.5	0.09
Total uncertainty	$+125\%$ -116%	$+112\%$ -107%	$+62\%$ -44%	$+347\%$ -345%

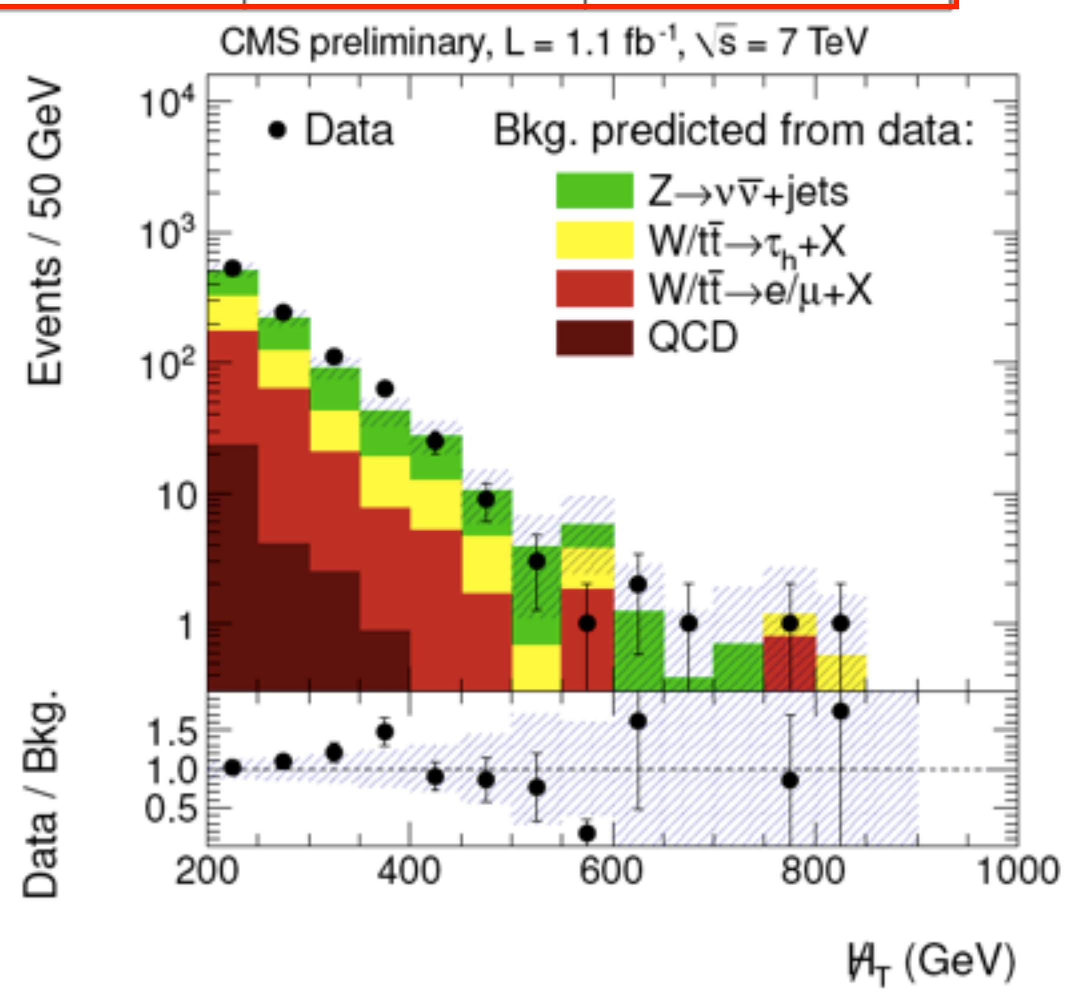
Systematics : statistics of data sample, gaussian and non-gaussian component of response functions, flavor, pileup effects, rebalance & smear closure

Results: Data vs SM Expectation

Backgrounds predicted from data are combined and compared with **distributions observed in data** for sensitive variables HT and MHT.

	Baseline (H_T >350 GeV) ($\not{H}_T$ >200 GeV)	Medium (H_T >500 GeV) ($\not{H}_T$ >350 GeV)	High H_T (H_T >800 GeV) ($\not{H}_T$ >200 GeV)	High $\not{H}_T$ (H_T >800 GeV) ($\not{H}_T$ >500 GeV)
$Z \rightarrow \nu\bar{\nu}$ from γ+jets	$376 \pm 12 \pm 79$	$42.6 \pm 4.4 \pm 8.9$	$24.9 \pm 3.5 \pm 5.2$	$2.4 \pm 1.1 \pm 0.5$
$t\bar{t}/W \rightarrow e, \mu$+X	$244 \pm 20^{+30}_{-31}$	$12.7 \pm 3.3 \pm 1.5$	$22.5 \pm 6.7^{+3.0}_{-3.1}$	$0.8 \pm 0.8 \pm 0.1$
$t\bar{t}/W \rightarrow \tau_h$+X	$263 \pm 8 \pm 7$	$17 \pm 2 \pm 0.7$	$18 \pm 2 \pm 0.5$	$0.73 \pm 0.73 \pm 0.04$
QCD	$31 \pm 35^{+17}_{-6}$	$1.3 \pm 1.3^{+0.6}_{-0.4}$	$13.5 \pm 4.1^{+7.3}_{-4.3}$	$0.09 \pm 0.31^{+0.05}_{-0.04}$
Total background	928 ± 103	73.9 ± 11.9	79.4 ± 12.2	4.6 ± 1.5
Observed in data	986	78	70	3

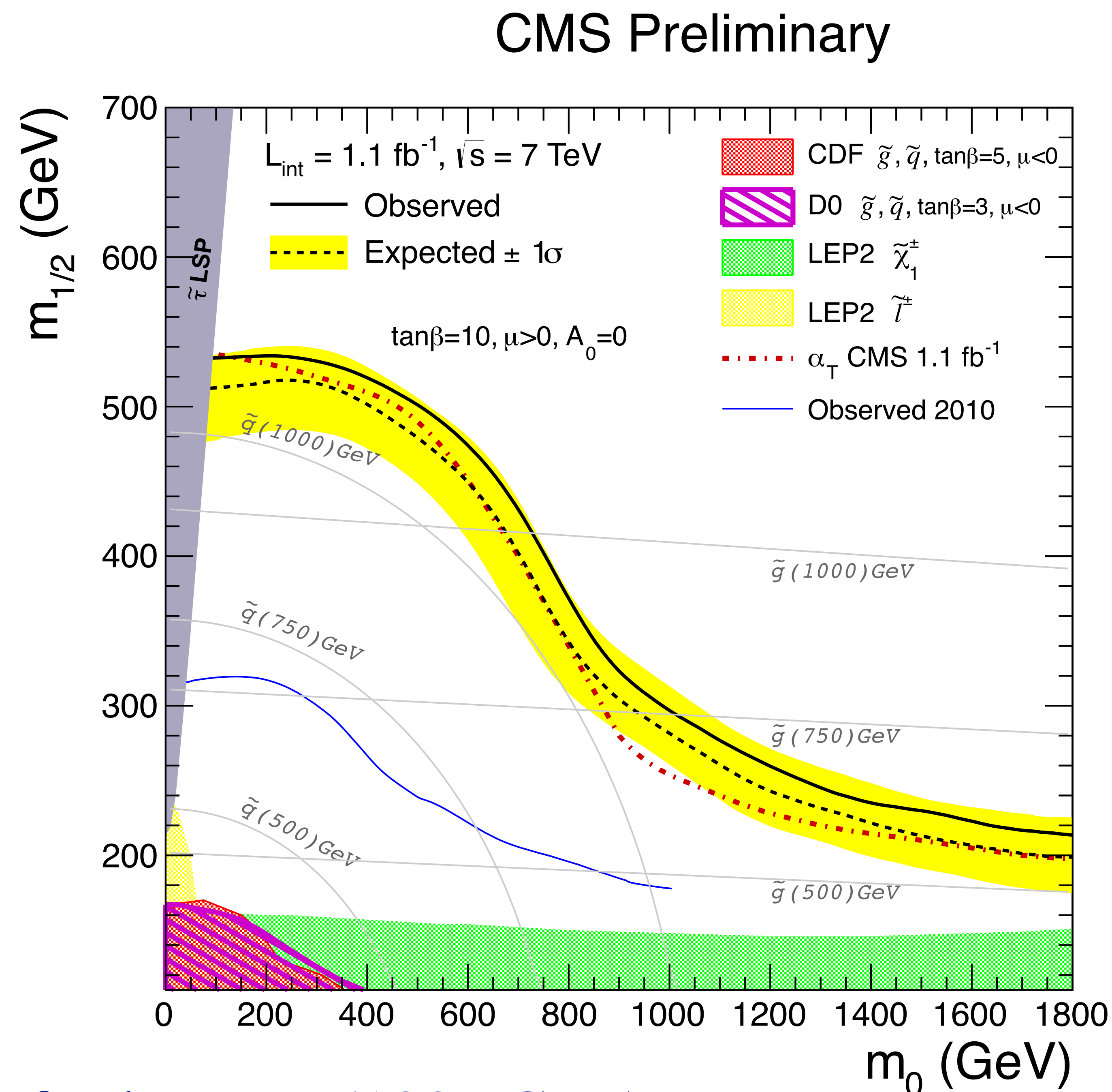




No excess of Data above SM expectations is observed

Interpretation : CMSSM Exclusion

- CMSSM : Constrained Minimal Supersymmetric Model
  - m_0, $m_{1/2}$, $\tan\beta$, Trilinear coupling A, sign (μ)
- The parameters m_0 and $m_{1/2}$ of the CMSSM are scanned in 10 GeV steps for $\tan\beta = 10$, $\mu>0$ and $A_0 = 0$



We exclude $m_{1/2}$ of 530 GeV for low m_0 (100 GeV) and $m_{1/2}$ of 230 GeV for high m_0 (1500 GeV)

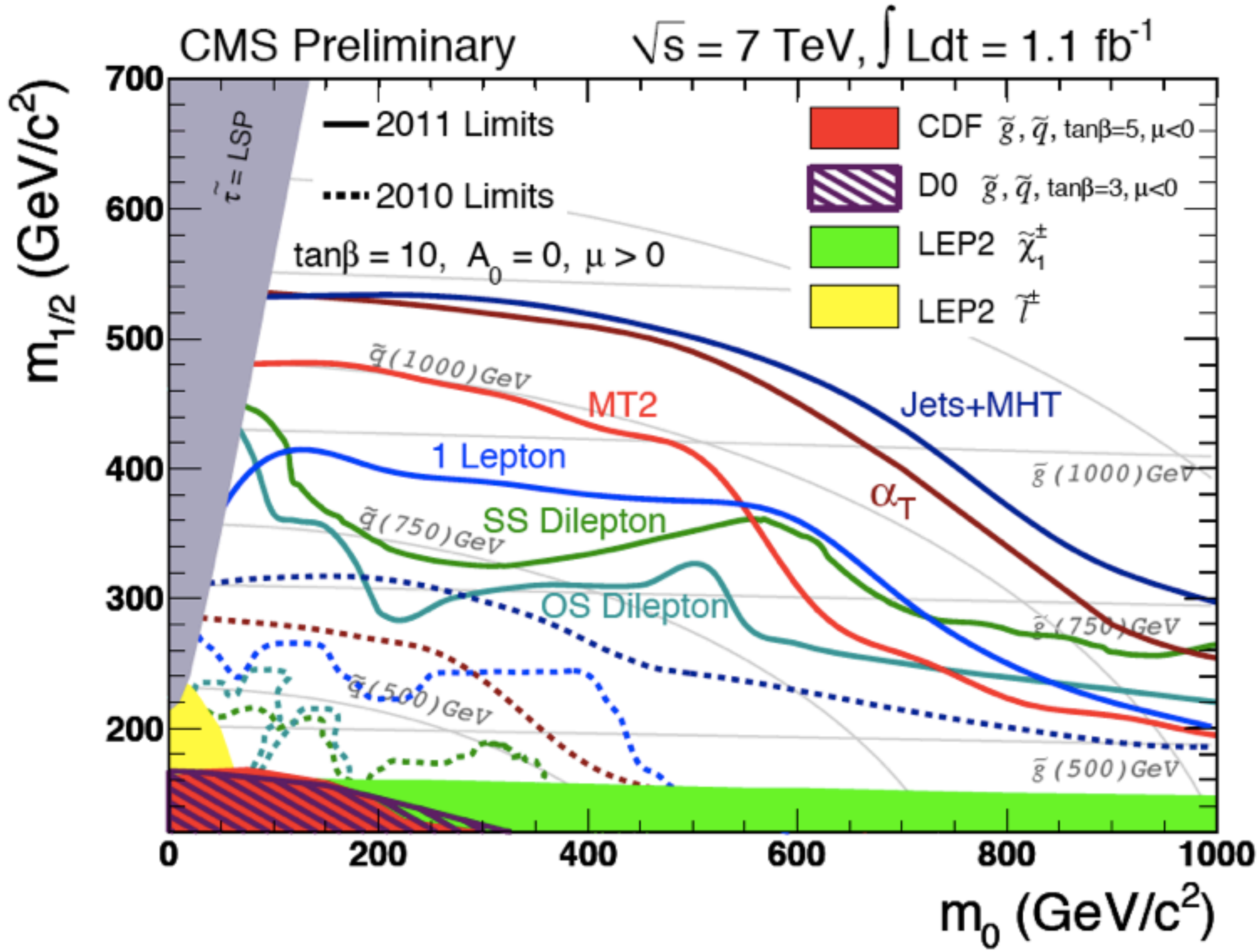
α_T CMS : PAS-SUS-11-003
See talk by E. Laird

Summary

- All hadronic (zero lepton) search is performed using Jets and Missing Transverse Momentum using 1.1 fb^{-1} data collected by CMS detector.
- The standard model backgrounds are measured from data directly using minimal information from monte carlo simulation.
- The Data are consistent with expectations from standard model and are used to further constraint the SUSY parameter space in the framework of CMSSM.
- The observed exclusion in the framework of CMSSM :
  - $m_{1/2}$ of 530 GeV for low m_0 (200 GeV),
  - $m_{1/2}$ of 230 GeV for high m_0 (1500 GeV)
- More than 2.5 fb^{-1} data on tape - more results on the way ...

Analysis is documented in CMS PAS-SUS-11-004

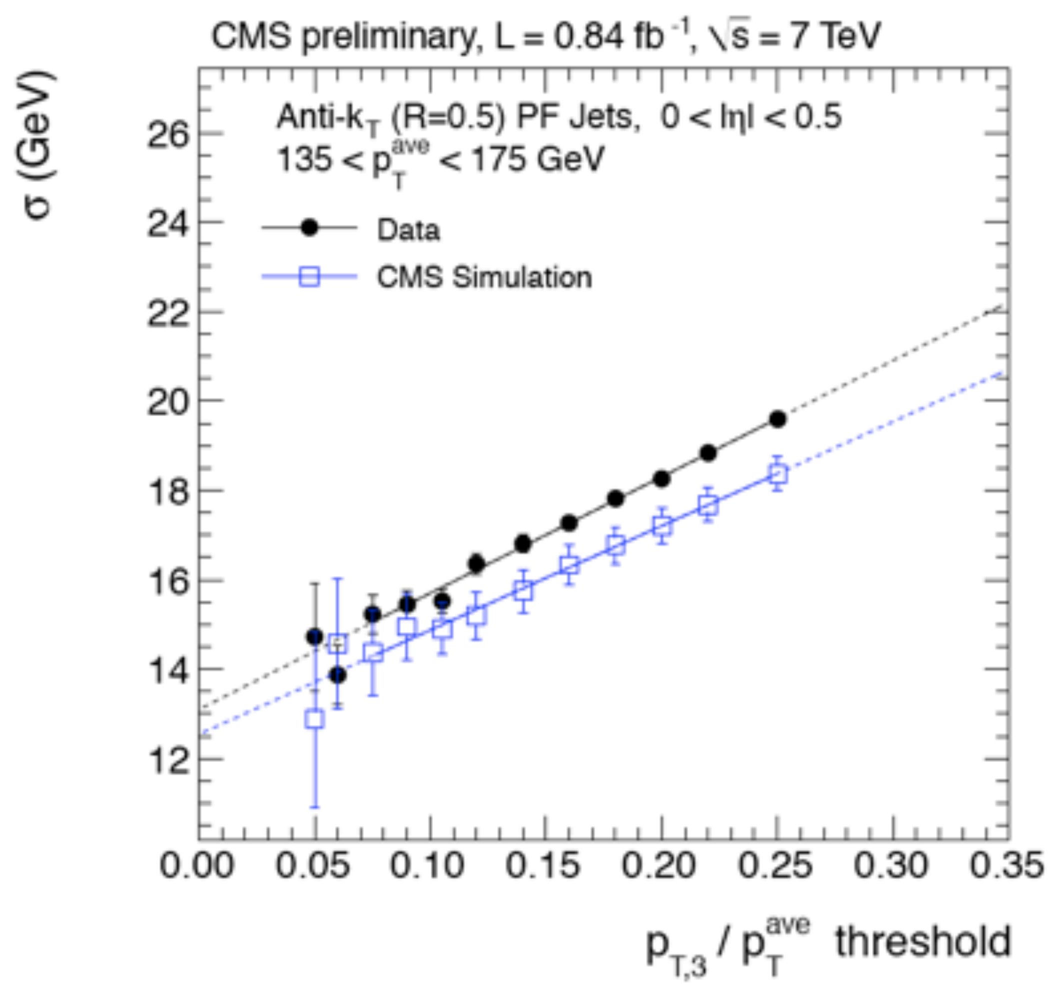
SUSY @ CMS from 1.1 fb^{-1}

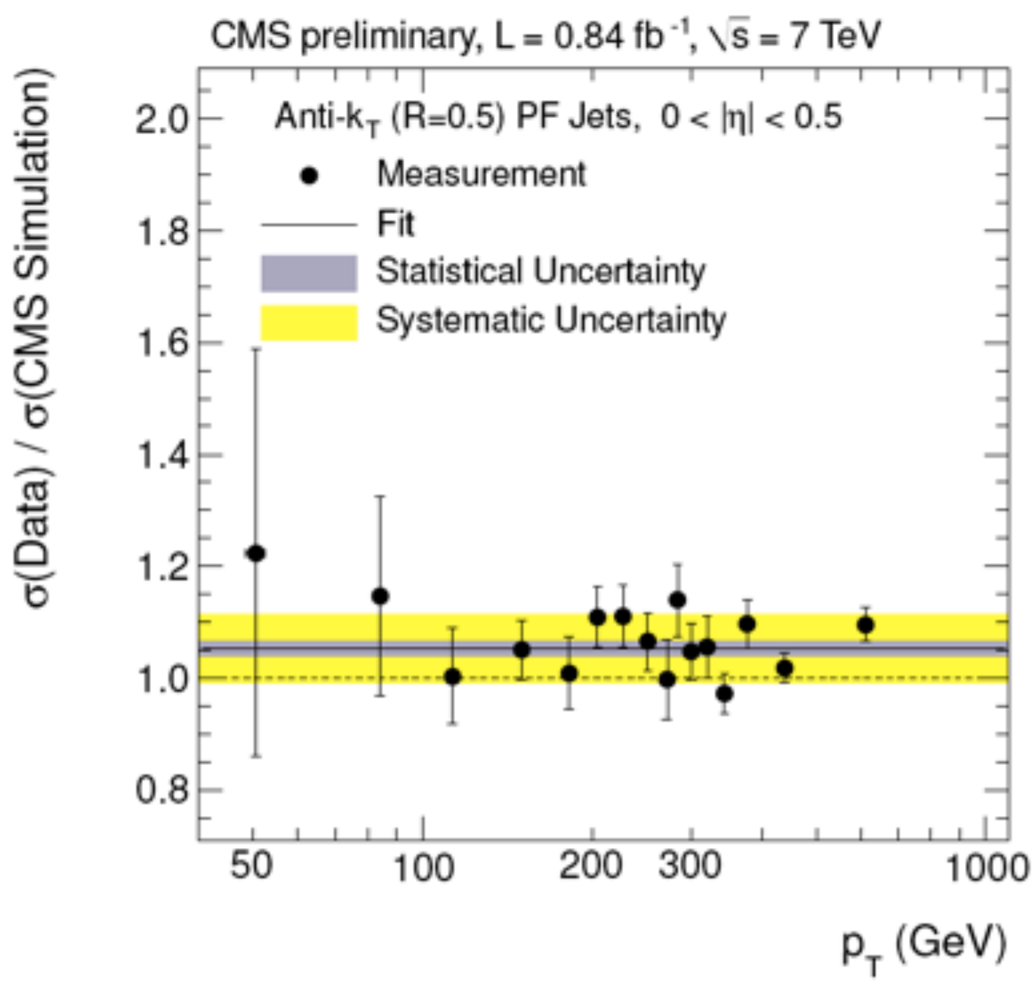


Additional Slides

Jet pT Response Function - Gaussian Core

- Measurement using maximum likelihood fit of measured pt imbalance in dijet events
- Strategy :
  - Extrapolate the measured resolution to zero 3rd jet pT
  - Measure the ratio σ(Data)/σ(MC)   (common biases cancel)
  - Correct MC truth response functions with the measured ratio

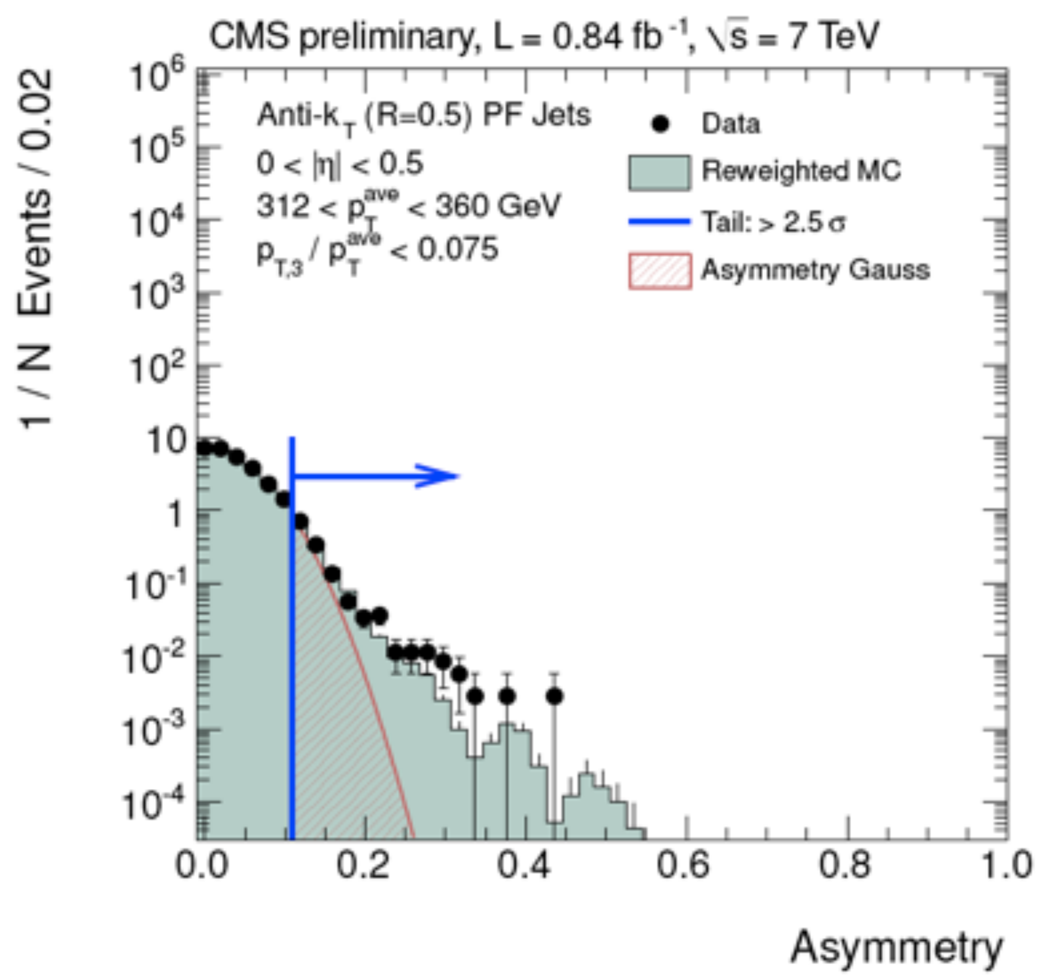


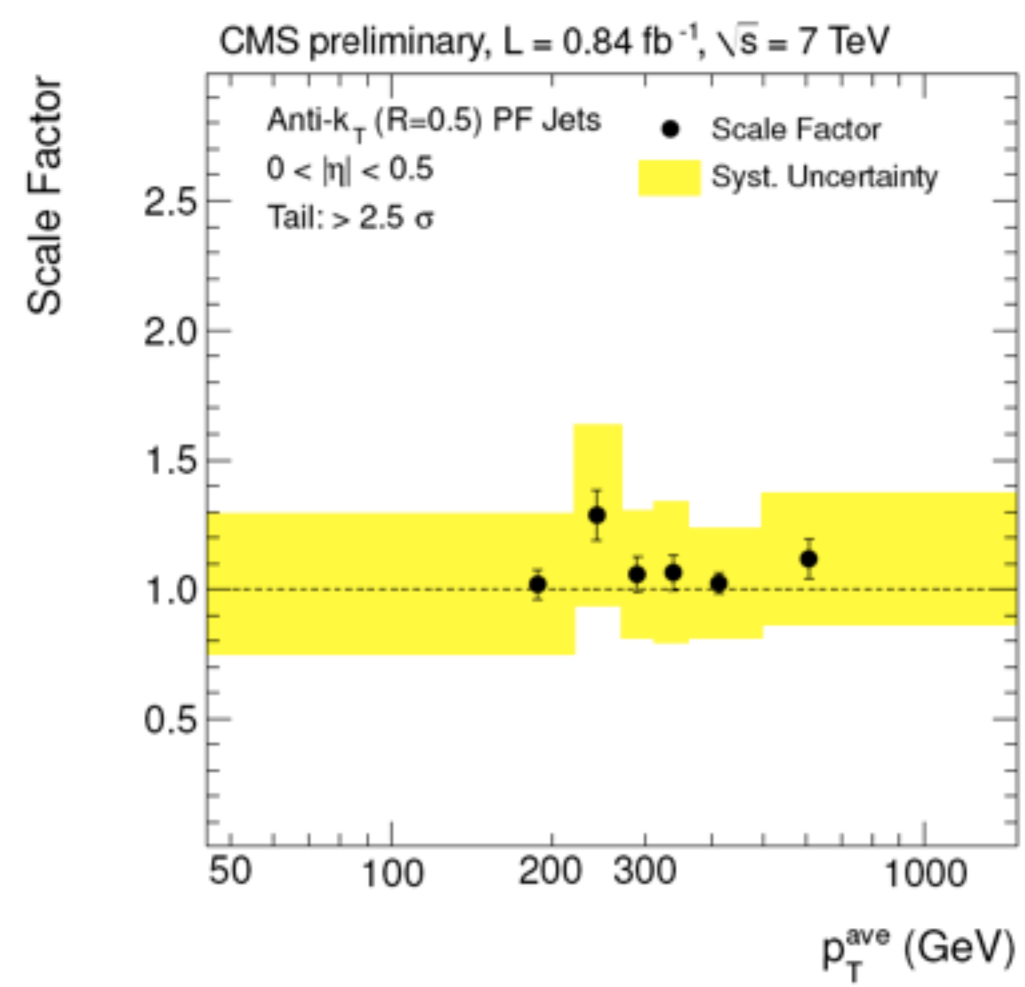


- Correction is ~5% in central regions and 25% in very forward region
- Dominant uncertainties : jet energy scale, extrapolation procedure (5-25%)

Jet pT Response Function : Non-Gaussian Tail

- Strategy : compare dijet asymmetry distributions in Data and MC
  - MC dijet asymmetry is corrected for larger core resolution in Data
  - Extrapolate the number of events in tail region to zero 3rd Jet pT
  - Scale the tails in MC truth response functions with Data/MC ratio





- Data/MC ratio of number of events in non-Gaussian component of response function is ~1 - simulation describes the data reasonably well.
- Dominant uncertainties : Core resolutions (others : pile-up, non-closure)

Large Hadron Collider

The LHC has already delivered more than 2.5 fb^{-1} of proton-proton collision data at centre of mass energy of 7 TeV.

Results presented here are based on 1.1 fb^{-1} data collected from March-July 2011.