Search for New Physics in Multijet Events with Large Missing Energy

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For the CMS Collaboration

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Outline

Motivation

Analysis Strategy

Backgrounds

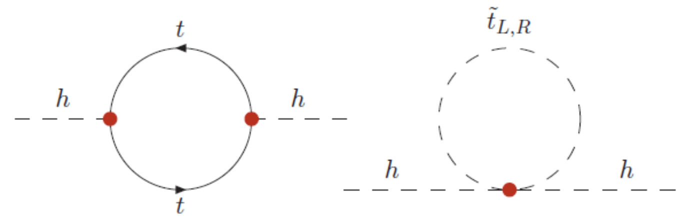
Results & Limits Setting

Summary

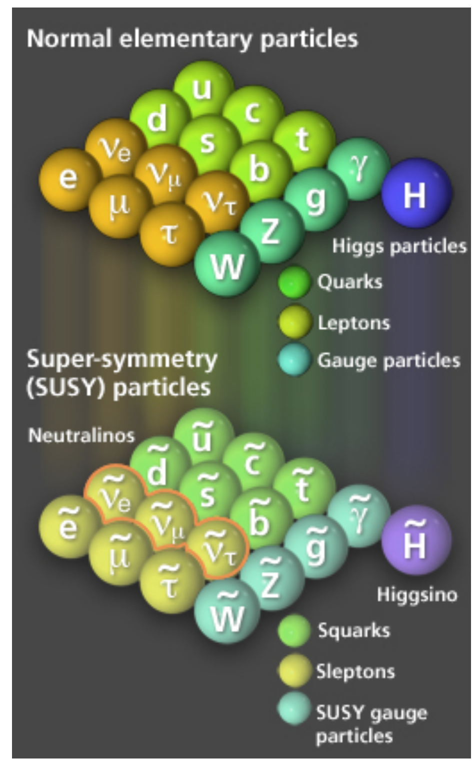
Motivation

Supersymmetry (SUSY)

- SUSY is a fundamental global symmetry between fermions and bosons.
  - Each fermion has a boson superpartner, and vice versa
  - Higgs mass stabilizes against loop correction (fine tuning problem)
  - Modifies running of SM gauge couplings just enough to give “Grand Unification” at single scale
  - SUSY is broken (sparticles are not seen)

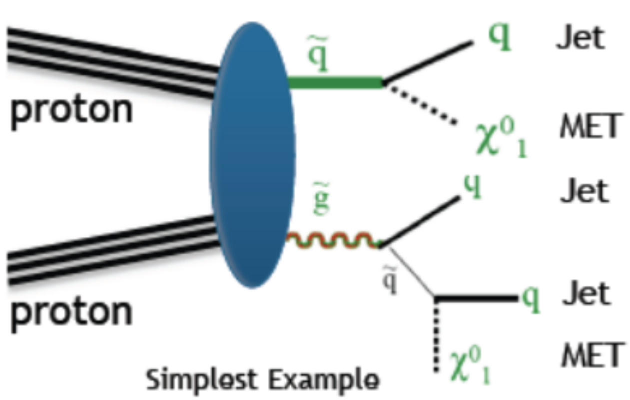


- MSSM: Simple SUSY model consistent w/ SM
  - R-parity conservation
    - $R=(-1)^{2S+3B+L}$
    - Sparticles produced in pairs, decay to an odd number of Lightest Supersymmetry Particle (LSP)
    - LSP is a dark matter candidate
  - SUSY breaking
    - mSUGRA, GMSB, …



Jets + MHT: Introduction

- A generic search for large missing transverse momentum in events containing multijets is "motivated" by R-parity conserving SUSY



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

Characterize visible energy of the event

$$\not{H}_T = \left| -\sum_i^{jets} \vec{p}_{T,i} \right|$$

Characterize energy carried by undetected particle

<u>SM Backgrounds</u>

- W/tt+jets with W(e/μ/τ ν)
- Z(νν)+jets
- QCD multijet

- The key is that we understand SM backgrounds including the MHT arising from detector effects and reconstruction failure

Analysis Strategy

Analysis Strategy

- Analysis strategy
  - An inclusive analysis based on HT and MHT

- Sample selection
  - HT - scalar sum of all jets with p_T > 50 & |η|<2.5
  - MHT - magnitude of vector sum of all jets with p_T>30 GeV & |η|<5
  - At least 3 jets with p_T>50 GeV & |η|<2.5 (central production)
  - Veto events with isolated e & μ (reduce W/top background)
    - p_T>10 GeV, |η|<2.5, isolation<0.2
  - $\Delta\Phi(\text{MHT}, \text{Jets}_{123})$ > (0.5, 0.5, 0.3) (reduce QCD background)

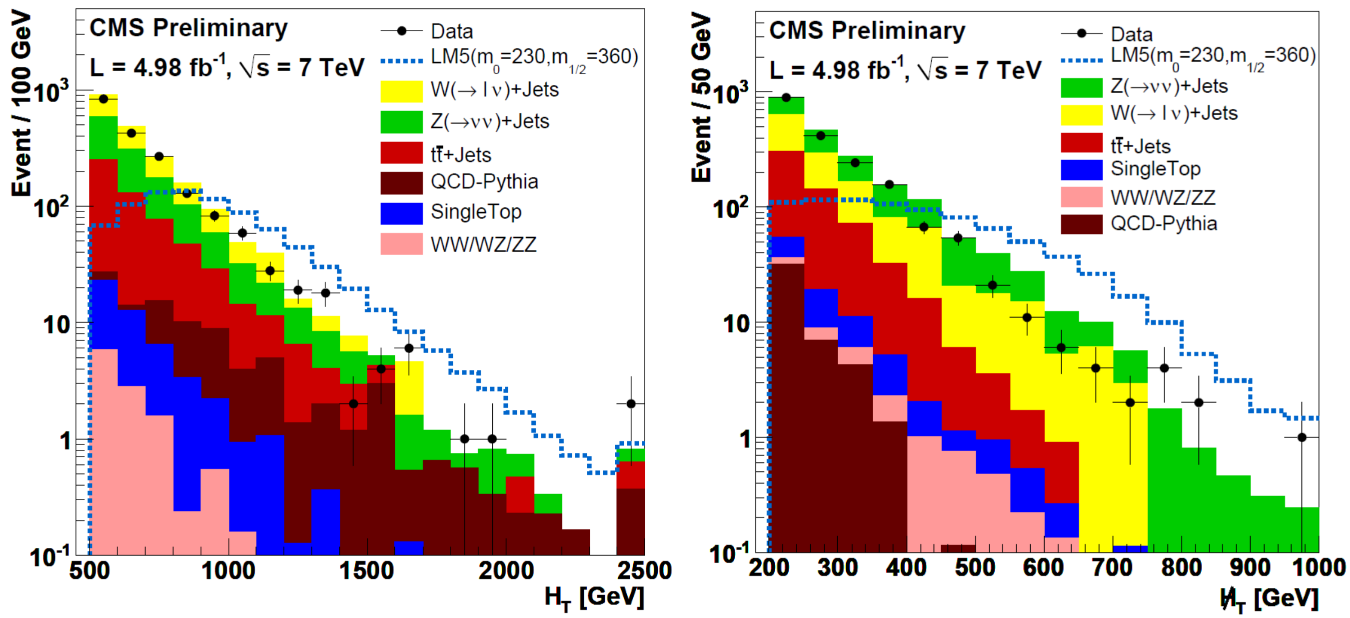
- Search regions in HT & MHT
  - Baseline
    (HT>500 & MHT >200 GeV)
    - loose event selection used for validation
  - 14 exclusive bins in HT & MHT

MHT→ HT↓	200-350	350-500	500-600	>600
500-800	bin 1	bin 2	bin 3	bin 4
800-1000	bin 5	bin 6	bin 7	bin 8
1000-1200	bin 9	bin 10	bin 11	
1200-1400	bin 12	bin 13		
>1400	bin 14			

Data vs Standard Model MC

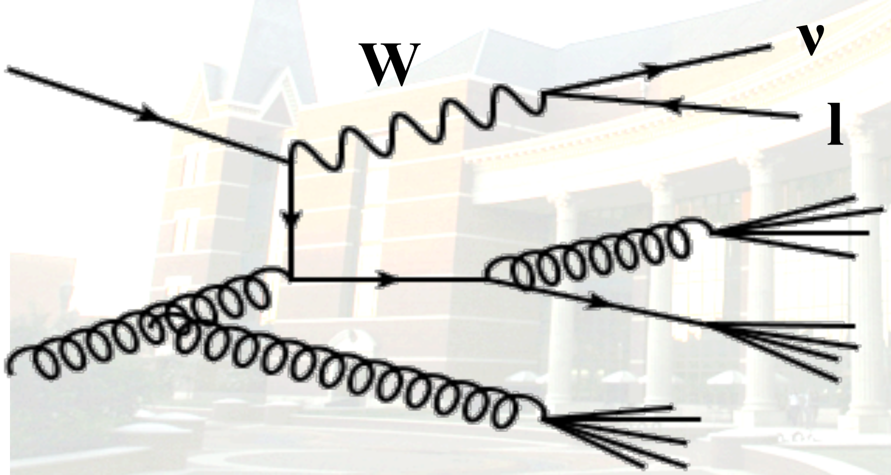
An out-of-box comparison of Data vs MC for search variables

HT and MHT for baseline



- The HT & MHT distributions are well described by CMS simulation
  - Evaluating systematics for both the generator-level information and detector simulation accurately is not trivial.
- We estimate the backgrounds from collision data.

W and Top Background



Missing ET / MHT

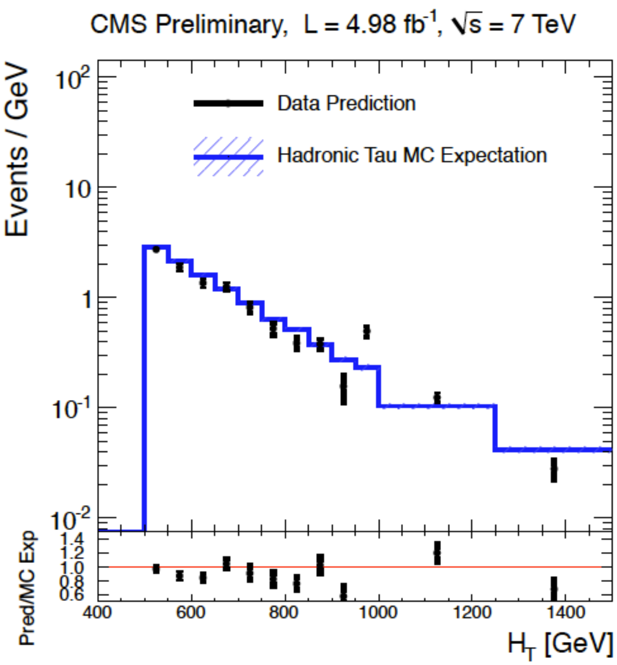
Hadronically-decaying τ constitute BG - hadronic tau

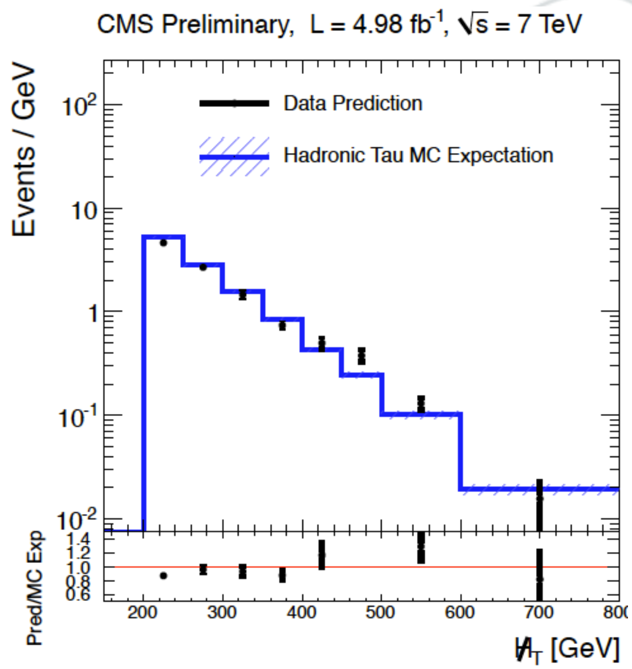
Veto leptons (e,μ) to suppress BGs, still occasionally fail to find and veto leptons - lost leptons

Top / W + hadronic tau + ν + Jets

- Start with a μ+jets sample
- Replace the μ by τ response template derived from MC
- Recalculate HT and MHT including this expected energy from τ
- Correct for muon acceptance, trigger, reco, & iso efficiency BR(W →τ →hadrons)/BR(W →μ)
- Use events with $M_T(W)$ < 100 GeV to reduce signal contamination

$$m_T = \sqrt{2P_T(\mu)E_T^{miss}(1-\cos(\Delta\Phi))}$$



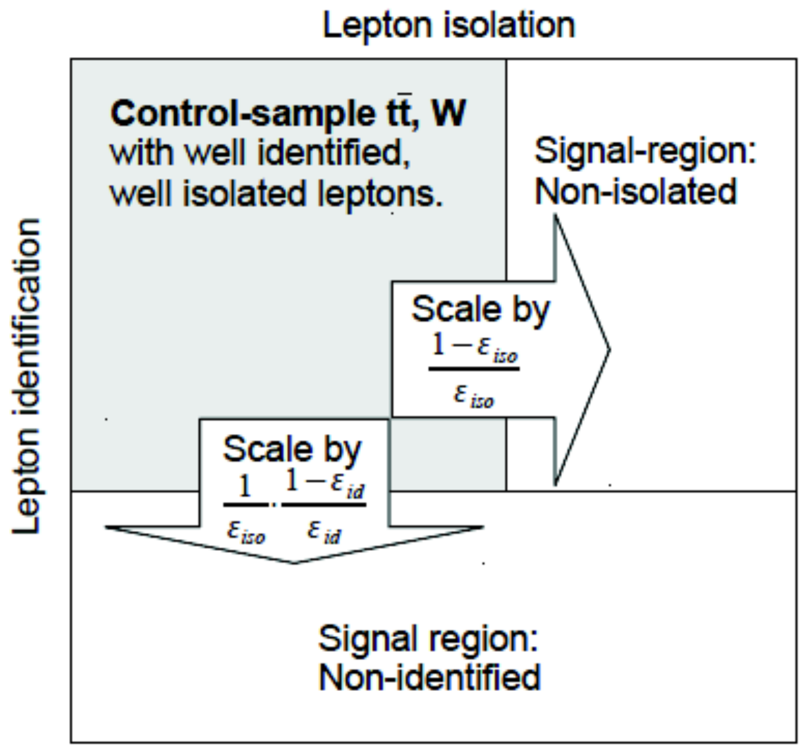


Method validated using MC simulation.

Data-driven estimate consistent with MC expectation

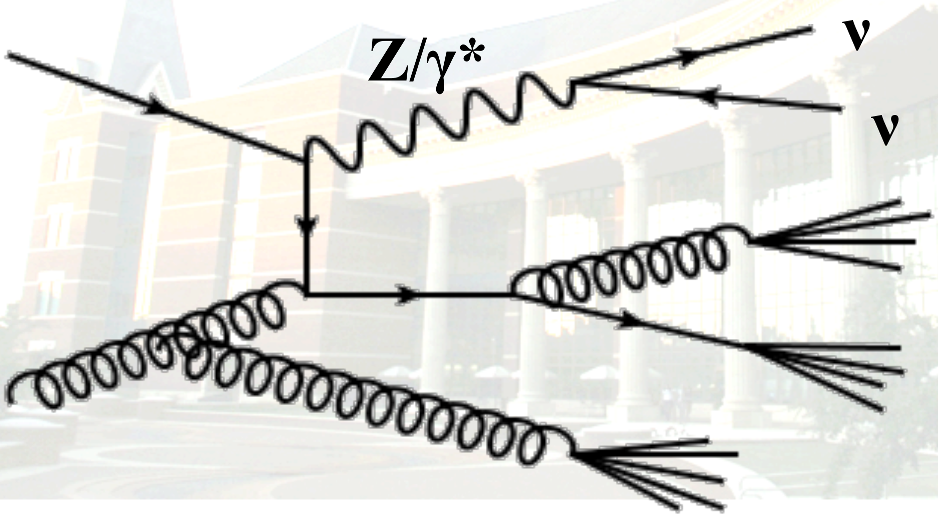
Lost Leptons

- Leptons failing the lepton veto contribute to background
- There can be 3 reasons to lose leptons
  - the lepton is not isolated
  - not reconstructed
  - out of acceptance ➔ estimated from MC
- Start with a control sample of events with exactly one muon (no electron)
- Measure the identification and isolation (in)efficiencies with the "Tag & Probe" method
- Scale the control sample according to the measured (in)efficiencies



For electrons, use muon control sample by assuming lepton universality.

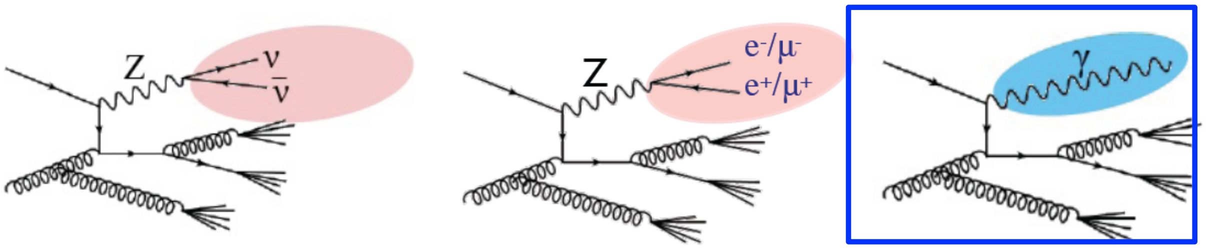
Invisible Z Background

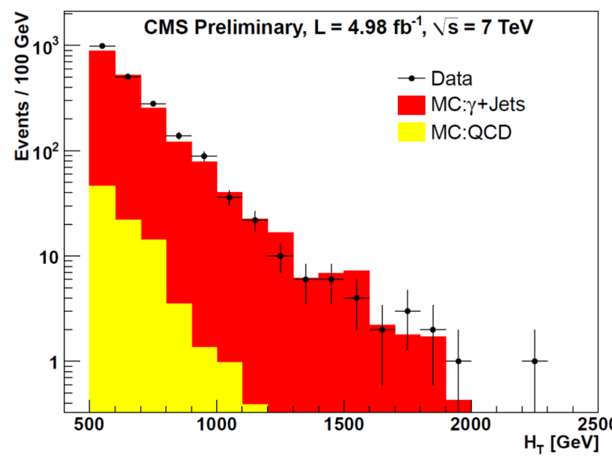


Missing ET / MHT

Z(νν)+Jets from γ+Jets

- A straightforward method is to use Z(ll) +Jets events
  - suffers from lack of statistics in tighter search regions and is used only to cross-check the background prediction using γ + Jets

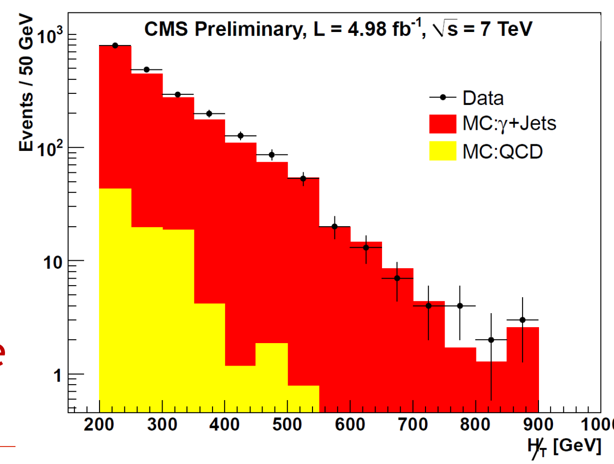




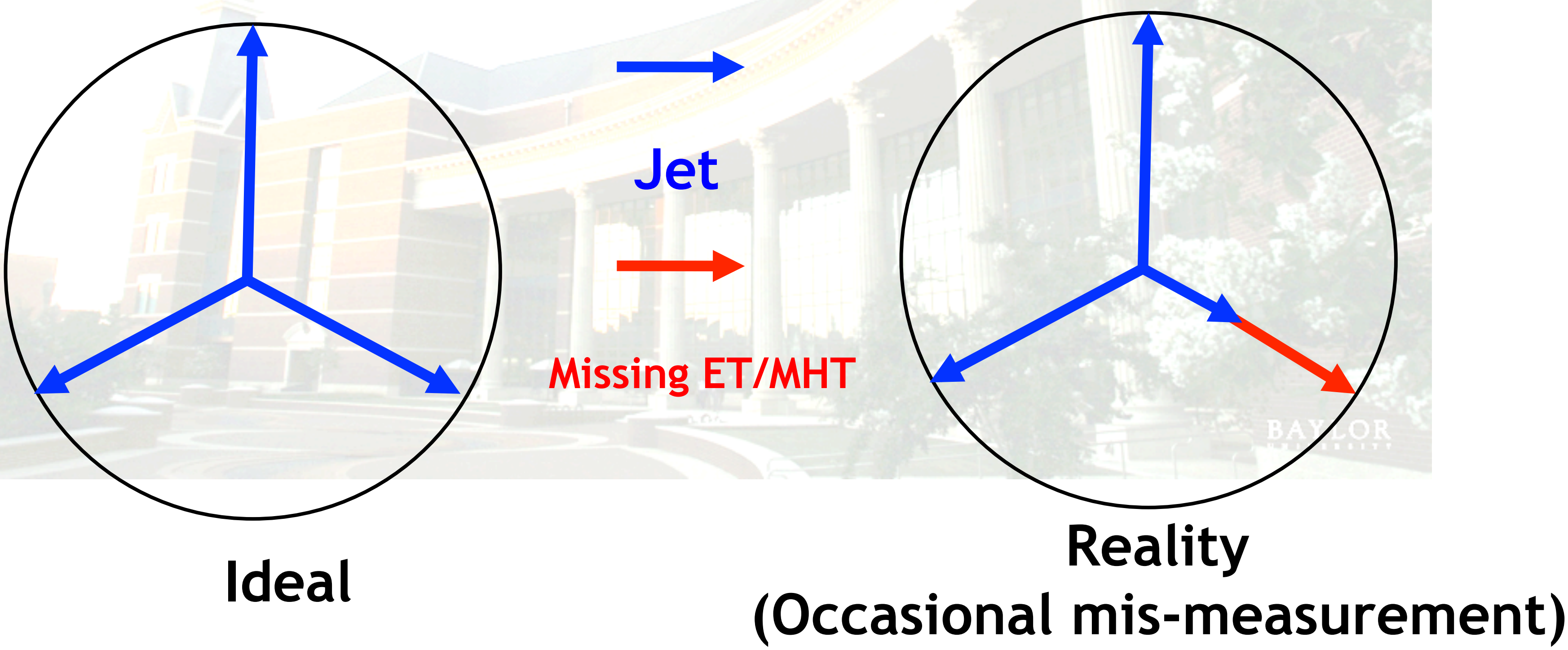
- Start with a γ+jets control sample: $p_T(\gamma)$>100 GeV.

$$N^{Z(\nu\nu)+jets}(\mathbf{data}) = \frac{Z+\mathbf{jets}}{\gamma+\mathbf{jets}} \cdot \mathbf{Purity} \cdot N^{\gamma+\mathbf{jets}}(\mathbf{data})$$

- Scale with Z(νν)+jets/γ+jets production ratio
- Subtract contributions from secondary photons: purity=98-99% as measured from data using isolation
- Correct for photon reco & isolation efficiencies measured from data using tag-and-probe method on Z (ee)+jets
- Predictions of Z(νν)+jets using μ+μ- +jets are compatible with those from γ+jets within uncertainties



QCD


Jet
Missing ET/MHT
Ideal
Reality
(Occasional mis-measurement)

QCD: Rebalance + Smear

Detector effects: Jet resolution, dead ECAL cells, Punch through ...

Physics: Leptonic heavy flavor decays

→ **mismeasured jets (→ large MHT)**

Full jet response (incl. tails) measured from data

↓

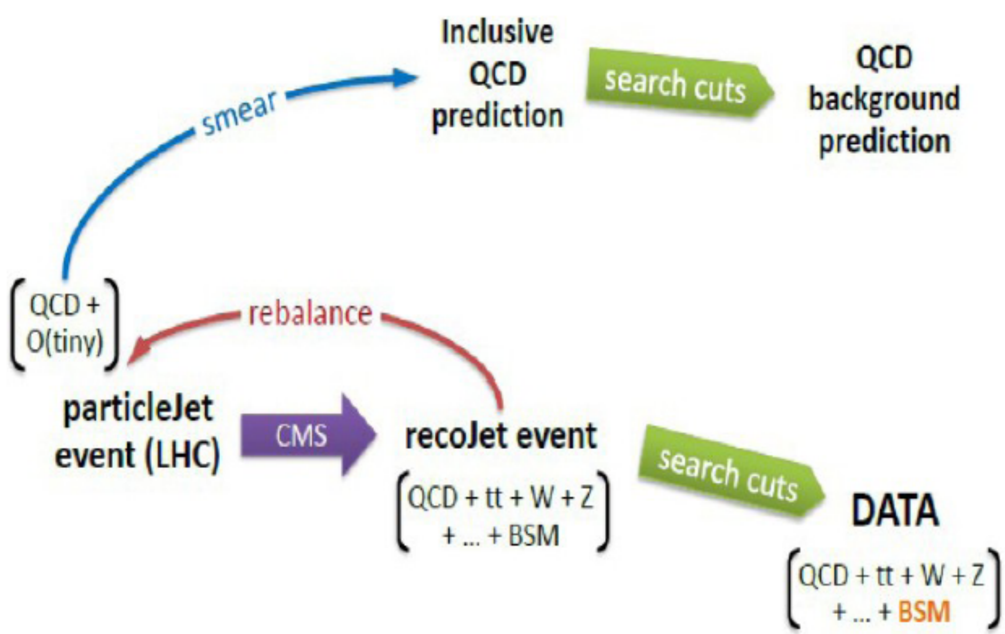
Select or mimic particle jets (rebalance seed events):

↓

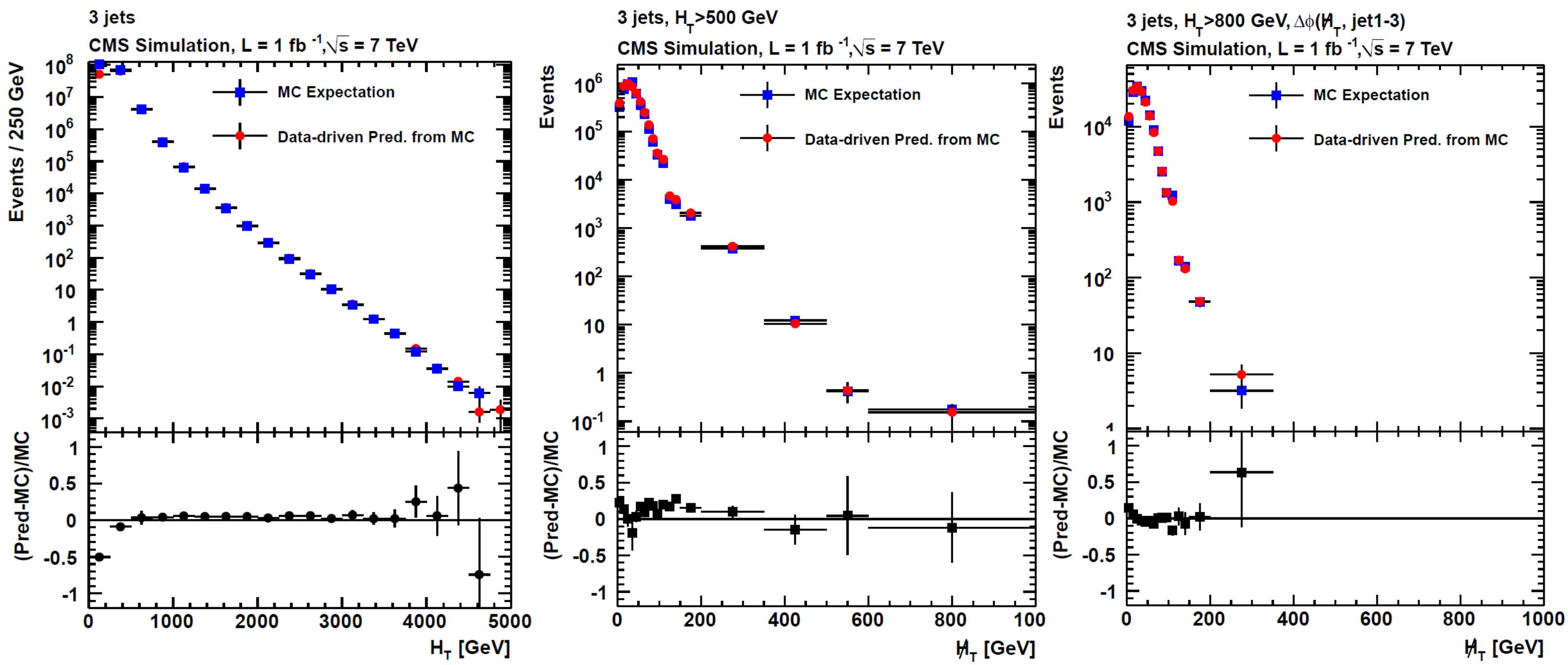
Smear seed events according to measured jet resolutions

↓

Obtain **"data driven fast MC simulation sample"**



QCD : Rebalance + Smear

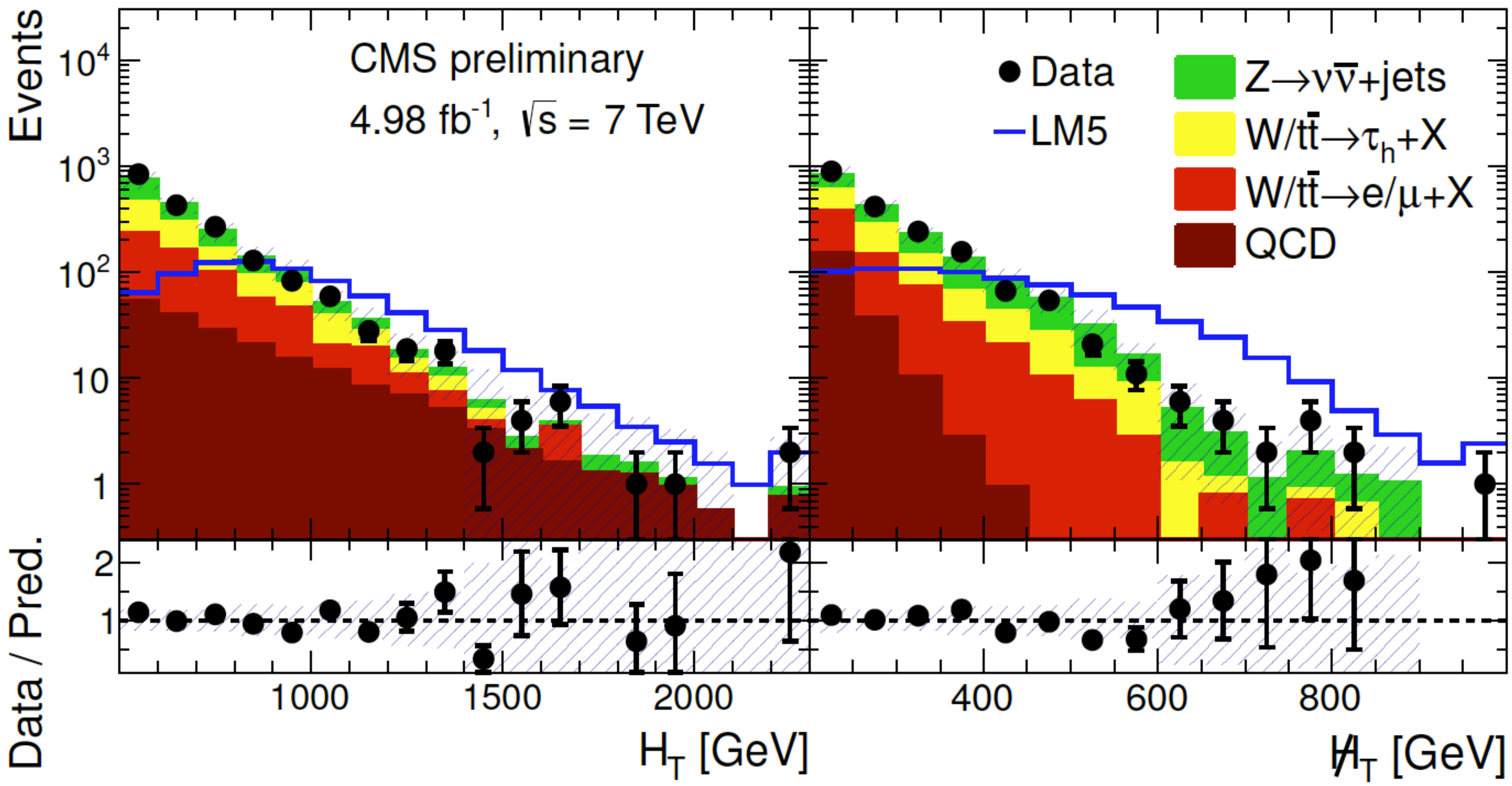


- Method validated using the MC Simulation
- Total systematic uncertainty 60-70%
  - Closure test, jet resolution measurements, pileup effects, heavy-flavor modeling

Results & Limit Setting

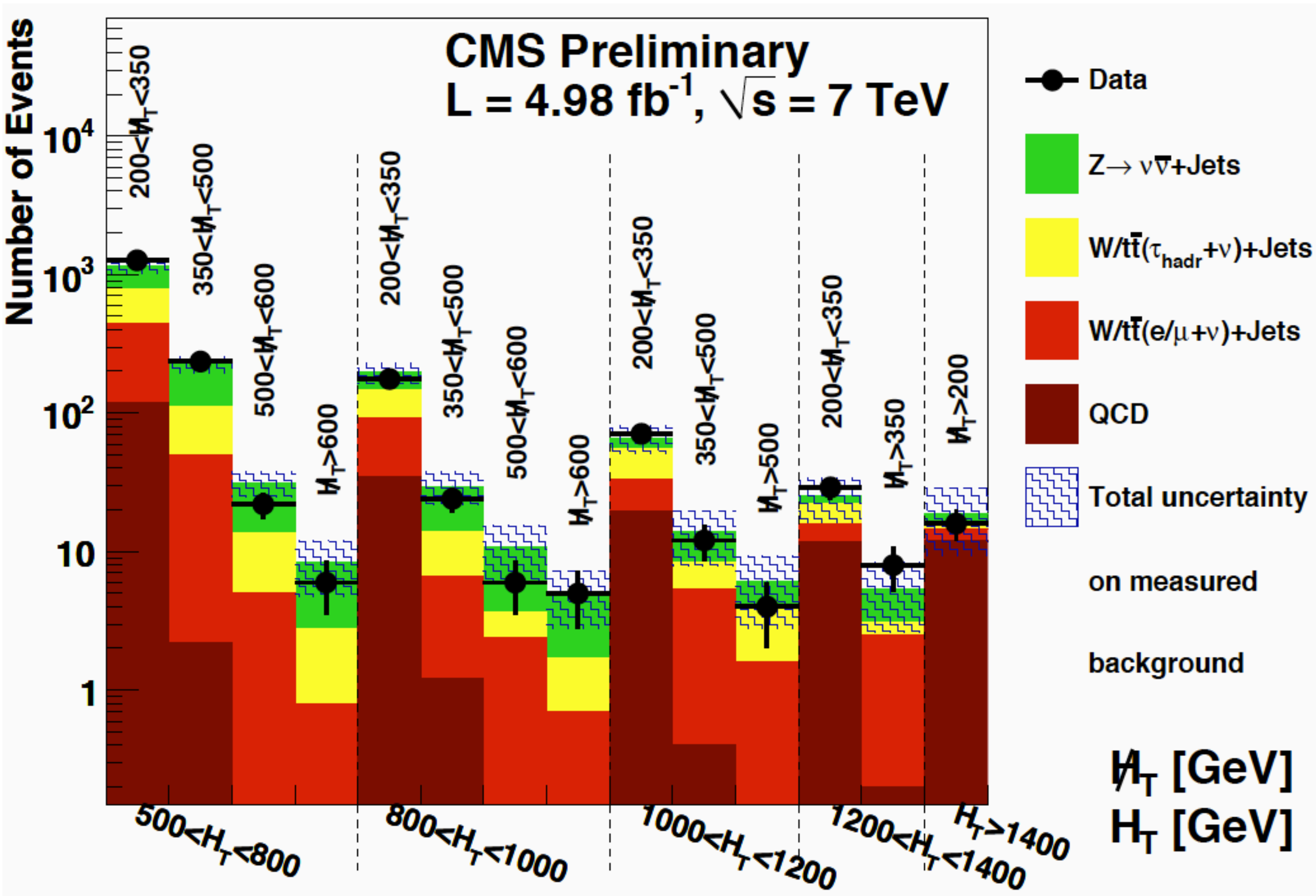
Results : Background Combination

Various backgrounds predicted from data are combined and compared with distributions observed in data for sensitive variables HT and MHT (for baseline event selection)



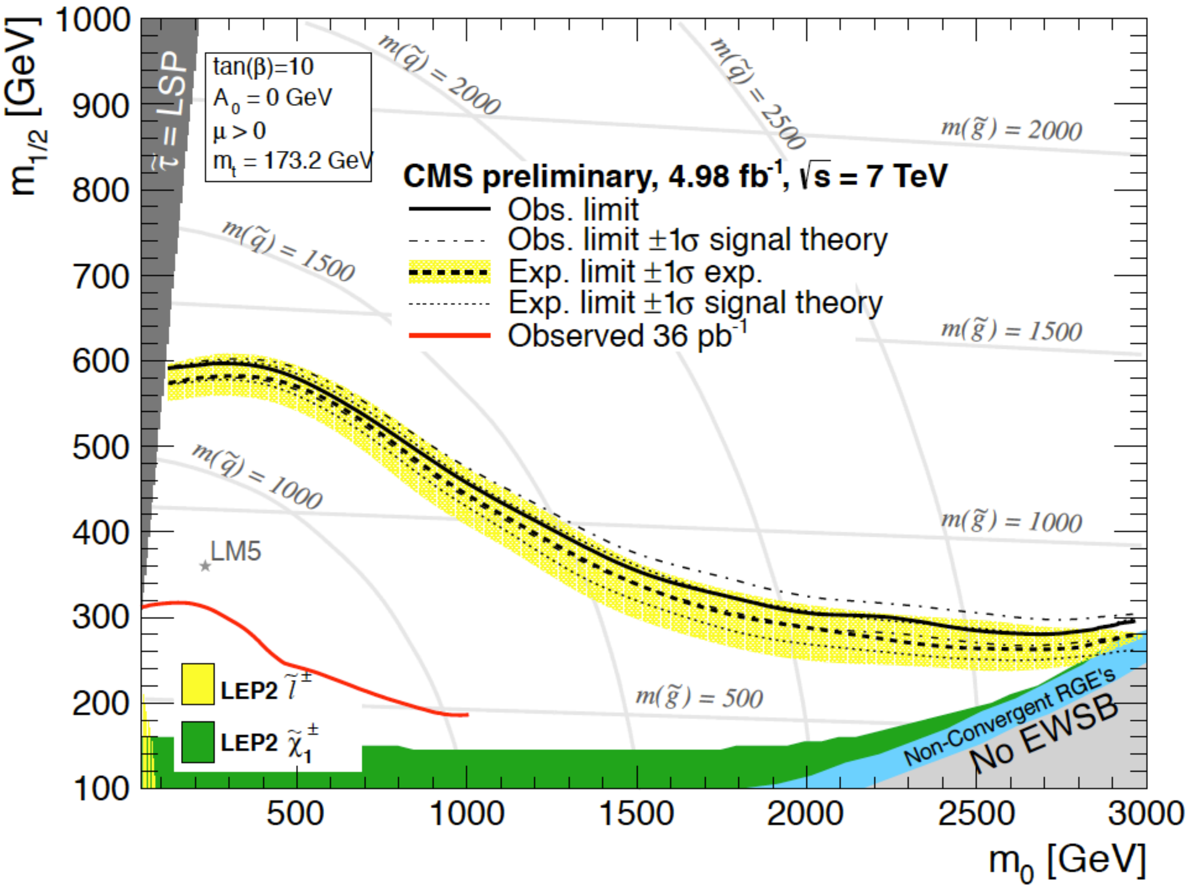
No excess of data above SM expectations is observed.

Results : Background Combination



- No excess of data above SM expectations is observed.
- mSUGRA and Simplified Models are considered to set the limits.

mSUGRA Exclusions



Uncertainties considered on signal

- Statistical Uncertainty
- Jet Energy Scale
- Jet Energy Resolution
- Theoretical uncertainties
- Signal contamination
- Luminosity
- Trigger inefficiency
- Event cleaning

- **$m_{1/2}$ of 600 GeV for low m_0 (200 GeV)**
- **$m_{1/2}$ of 350 GeV for high m_0 (1500 GeV)**

Simplified Topologies

- In a simplified model a very reduced set of hypothetical particles is introduced; the phenomenological masses and the decay ratios are free parameters of the model.

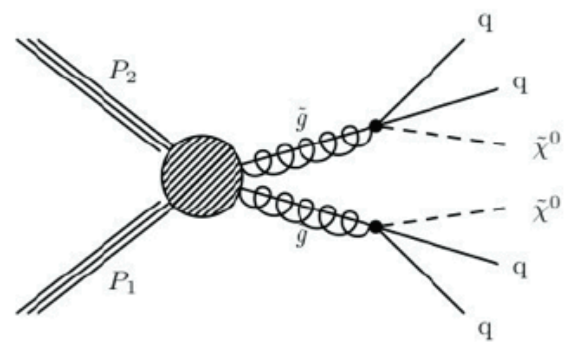
- Allows interpretation of an analysis results in terms of simple topologies exploring a wide range of mass splitting between mother (e.g., a colored particle) and daughter masses (e.g., a lightest SUSY particle).

- Language is SUSY, but not constrained to SUSY.

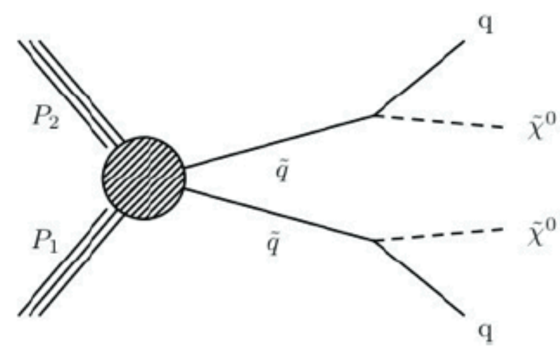
- Allow us to describe and compare results of CMS analyses in a fashion independent from full/constrained models.

Simplified Topologies

- gluino-gluino with gluino->qq LSP
  ➔ 3 or more jets easily available



- squark-squark with squark->q LSP
  ➔ energetic jets, usually third jet from ISR

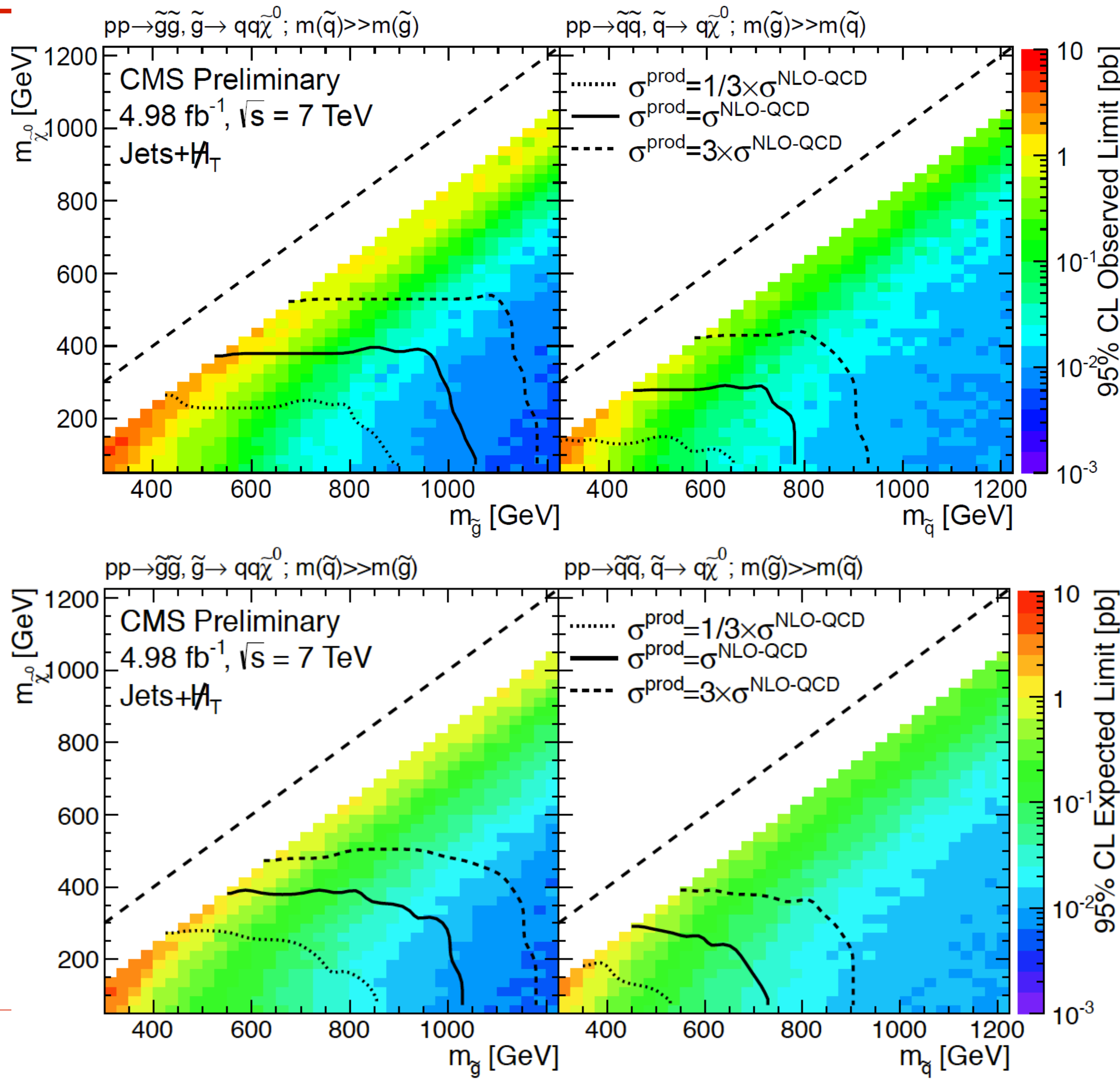


For gluino pair production, squark mass is set to be at infinitely high mass and vice versa.

Cross Section Limits on Simplified Topologies

Observed

Expected



Summary

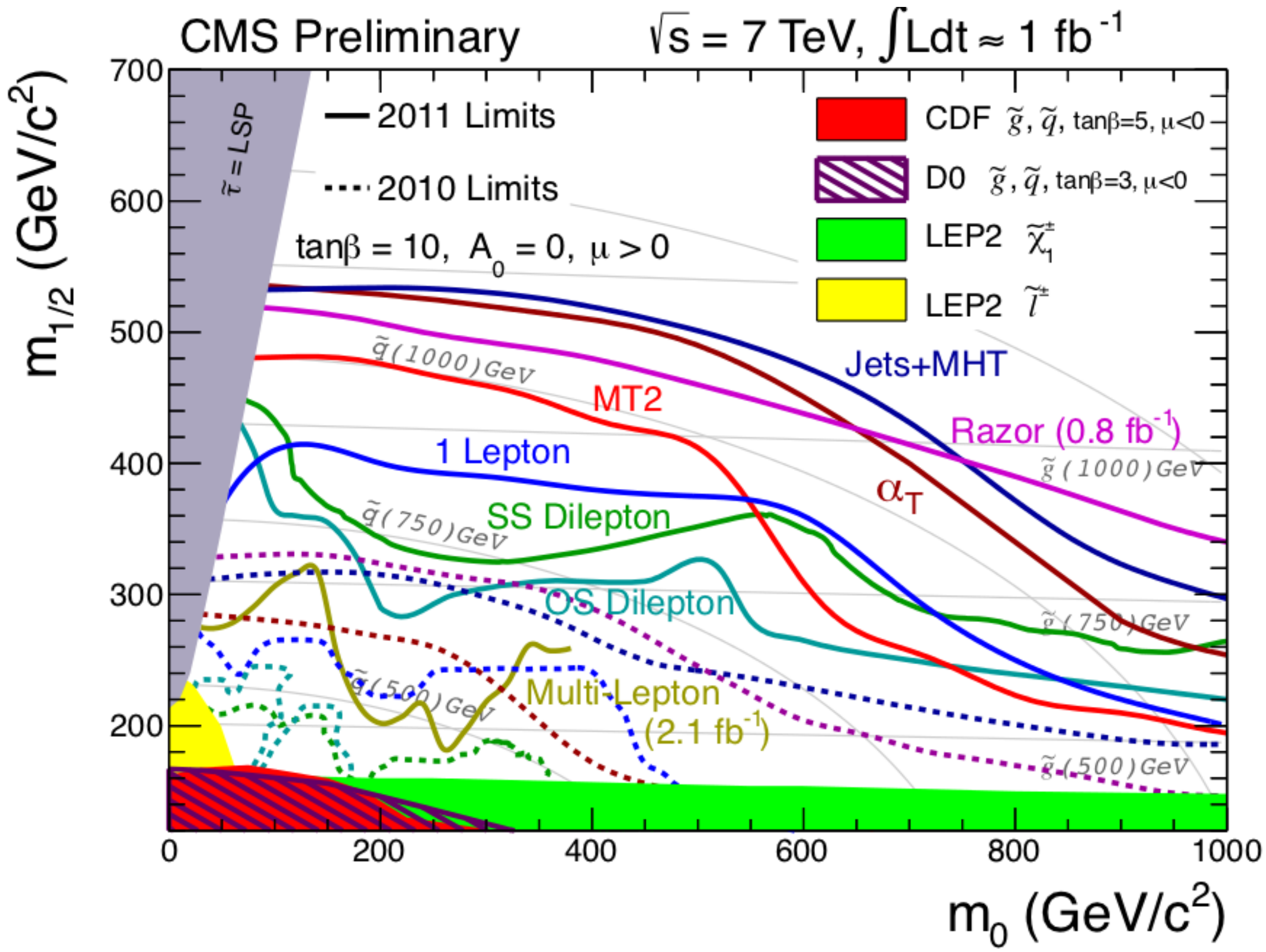
- CMS has performed an inclusive search for physics beyond the standard model in the multi-jets and missing transverse energy final state using the full 2011 data.
- Our constraints on the gluinos and 1st generation squarks are getting quite strong:
  - Gluino mass exclusion reaching ~1 TeV depending on the assumptions on other SUSY parameters.
  - The naïve picture with copiously-produced strongly-interacting gluinos and 1st generation quarks is getting disfavored, but we still need to keep looking.
- CMS searches have various ways to improve the search sensitivities for 2012 data analysis:
  - Specifically look at high jet multiplicities – sensitivities to long-cascade models. Reduce systematics for $Z(\rightarrow\nu\nu)$+jets BG estimation from γ+jets (close collaboration with theory groups), etc etc.

BACKUP

Results : Background Combination

Selection H_T (GeV)	$\not{H}_T$ (GeV)	$Z \to \nu\bar{\nu}$ from γ+jets	$t\bar{t}/W \to e, \mu$+X	$t\bar{t}/W \to \tau_{hadr}$+X	QCD multijets	Total background	Data
500–800	200–350	359.2 ± 82.2	326.5 ± 47.0	348.5 ± 40.1	118.6 ± 76.9	1152.8 ± 128.4	1269
500–800	350–500	112.3 ± 27.4	47.8 ± 9.2	62.5 ± 8.7	2.2 ± 2.2	224.8 ± 30.3	236
500–800	500–600	17.6 ± 5.6	5.0 ± 2.2	8.7 ± 2.5	0.0 ± 0.1	31.3 ± 6.5	22
500–800	>600	5.5 ± 3.1	0.8 ± 0.8	2.0 ± 1.8	0.0 ± 0.0	8.3 ± 3.6	6
800–1000	200–350	48.4 ± 19.1	57.7 ± 15.3	56.3 ± 8.3	34.6 ± 24.0	197.0 ± 35.3	177
800–1000	350–500	16.0 ± 7.3	5.4 ± 2.3	7.2 ± 2.0	1.2 ± 1.3	29.8 ± 8.0	24
800–1000	500–600	7.1 ± 4.5	2.4 ± 1.5	1.3 ± 0.6	0.0 ± 0.2	10.8 ± 4.8	6
800–1000	>600	3.3 ± 2.0	0.7 ± 0.7	1.0 ± 0.3	0.0 ± 0.1	5.0 ± 2.2	5
1000–1200	200–350	10.9 ± 5.5	13.7 ± 3.8	21.9 ± 4.6	19.7 ± 13.3	66.2 ± 15.5	71
1000–1200	350–500	5.5 ± 3.5	5.0 ± 4.4	2.9 ± 1.3	0.4 ± 0.7	13.8 ± 5.8	12
1000–1200	>500	2.2 ± 2.9	1.6 ± 1.2	2.3 ± 1.0	0.0 ± 0.2	6.1 ± 3.3	4
1200–1400	200–350	3.1 ± 2.0	4.2 ± 2.1	6.2 ± 1.8	11.7 ± 8.3	25.2 ± 9.0	29
1200–1400	>350	2.3 ± 2.3	2.3 ± 1.4	0.6 ± 0.8	0.2 ± 0.6	5.4 ± 2.9	8
>1400	>200	3.2 ± 2.4	2.7 ± 1.6	1.1 ± 0.5	12.0 ± 9.1	19.0 ± 9.6	16

Summary of Summer2011 Results



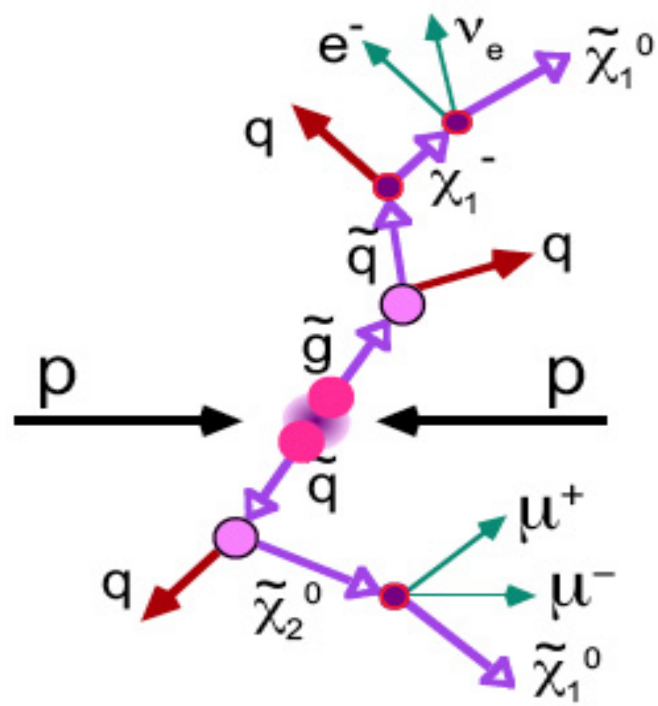
How much more did we learn since then?

Experimental Signature

- Signature: MultiJets + MET

- Squarks & Gluinos cascade decays: produce a number of quarks and gluons, leptons and possibly weakly interacting stable neutral particles (WIMP).

- In the detector WIMP/LSP appears as the momentum imbalance in the transverse plane (Missing ET).

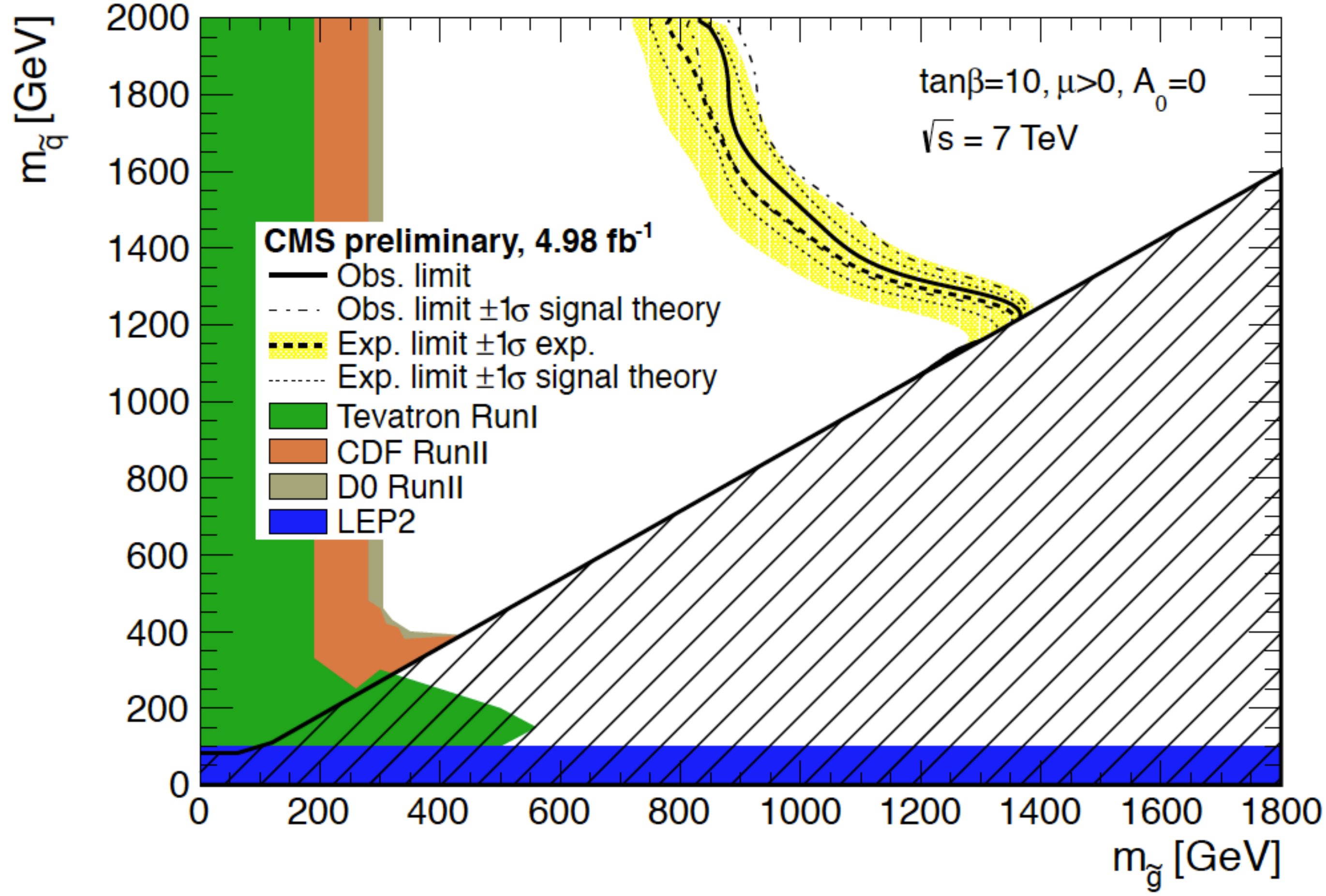


Interpretation : CMSSM

- Scan the SUSY parameter space in mSUGRA framework
- mSUGRA : parameter space can be explored in terms of 5 quantities defined at GUT scale :

  m0 – common scalar mass
  m1/2 – common gaugino mass
  A0 – common trilinear coupling
  tan(β) – ratio of Higgs vacuum expectation values
  sign(μ) = where μ is SUSY conserving Higgsino mass parameter

mSUGRA Exclusions



Top / W + hadronic tau + ν + Jets

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- Replace the μ by τ response template derived from MC
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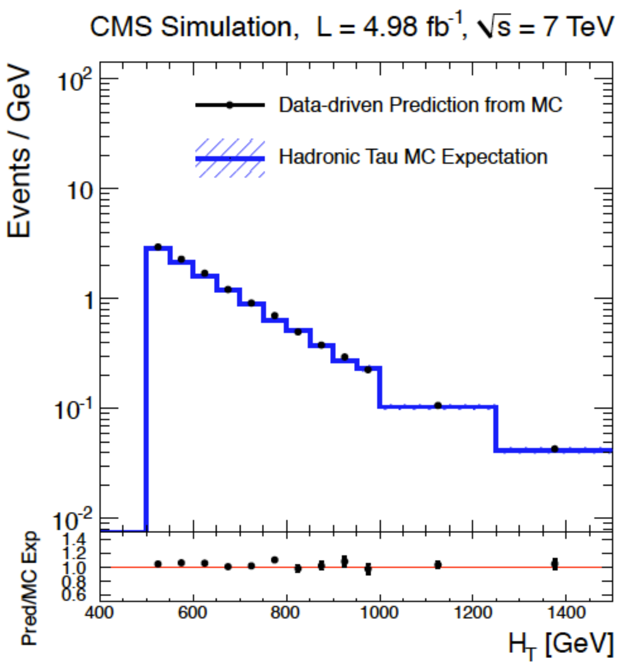
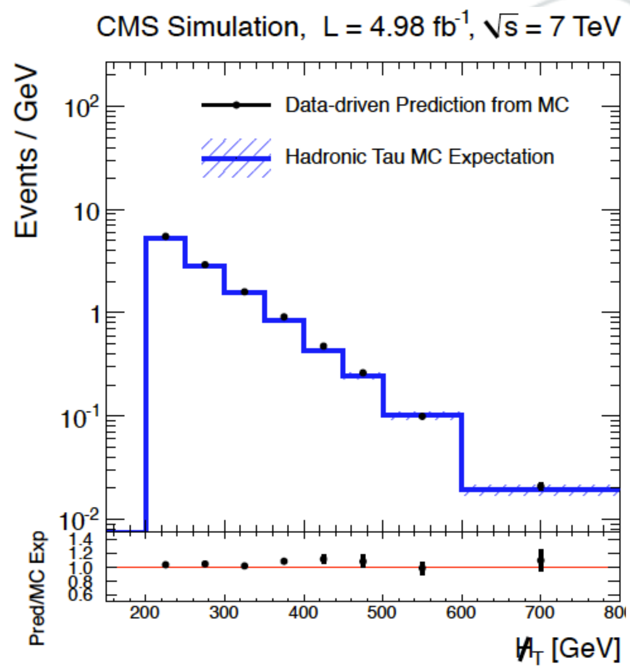
$$m_T = \sqrt{2P_T(\mu)E_T^{miss}(1-\cos(\Delta\Phi))}$$



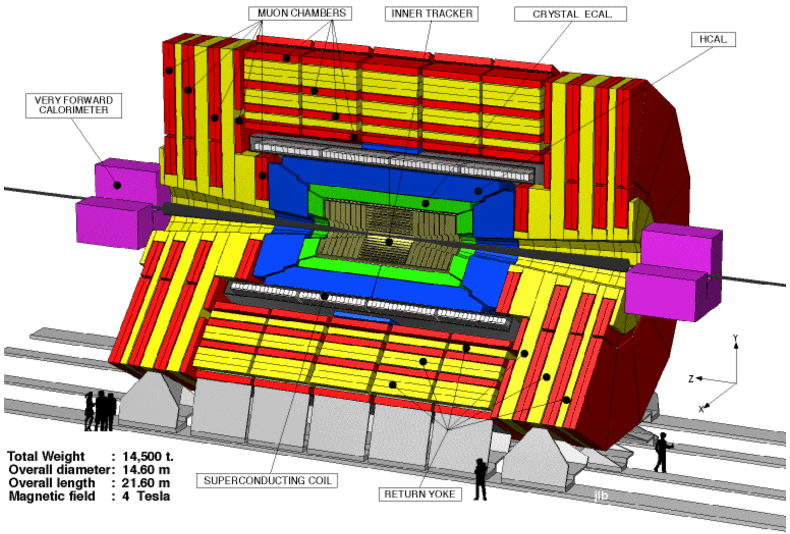


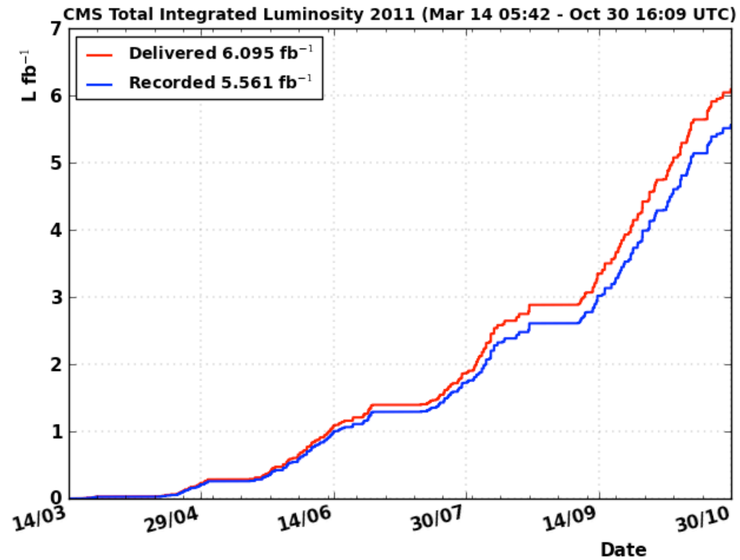
Method tested with MC. The shapes close well.

Correct for the 4.2% overall over-prediction

CMS Performance

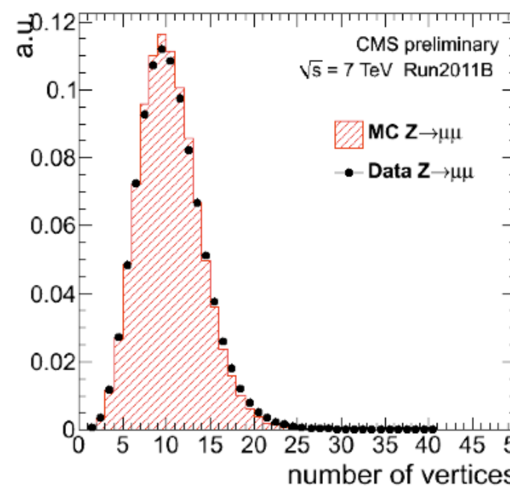
CMS in 2011





- More than 6 fb^{-1} collected @ 7 TeV
- Peak lumi 3.5×10^{33} $cm^{-2}s^{-1}$
- Data taking efficiency: 90%
- Mean pileup: ~10

And, in 2012 we already have ~1fb^{-1} of 8 TeV data with peak lumi 5.5×10^{33} $cm^{-2}s^{-1}$. Keep us happily busy!



Z(νν)+Jets from γ+Jets

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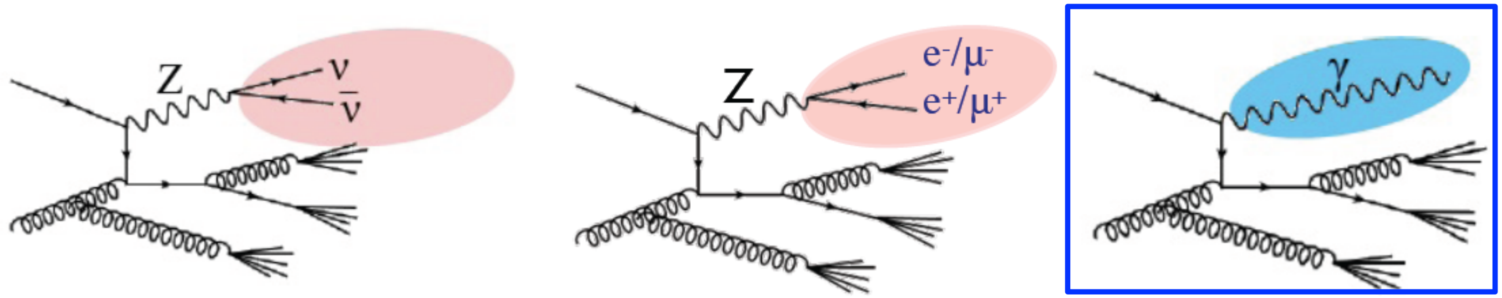
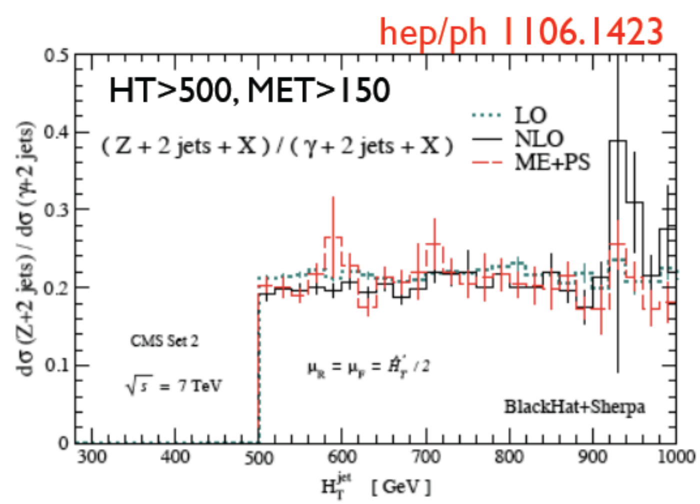


- At high p_T, the Z+jets/γ +jets ratio depends mainly on the EWK characteristics of the event
- Hadronic part of the event is independent of whether the boson is Z or γ
- Theoretical uncertainty (from BlackHat) :
  - EWK corr. at higher orders
  - large QCD logarithm terms



Sizable theory uncertainty: 21-42%. The reduction is critical for future searches.

Z(νν)+Jets from γ+Jets

- Start with a γ+jets control sample: $p_T(\gamma)$>100 GeV.

$$N^{Z(\nu\nu)+jets}(\mathbf{data}) = \frac{Z+\mathbf{jets}}{\gamma+\mathbf{jets}} \cdot \mathbf{Purity} \cdot N^{\gamma+\mathbf{jets}}(\mathbf{data})$$

- Subtract contributions from secondary photons: purity=98-99% as measured from data using isolation
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