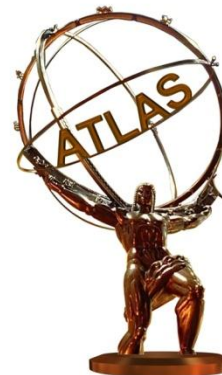
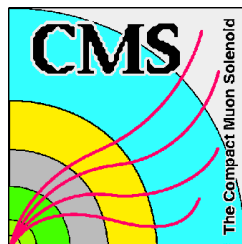


Non-SUSY searches involving MET with ATLAS and CMS

G. Bruno

CP3, Université catholique de Louvain (UCL)

Implications of LHC results for TeV-scale physics
1 September 2011



Outline

- MET measurement and performance
- Survey of analyses
 - Large number of results. Priority to recent 2011 ones
 - Analyses presented in terms of final state: from simpler to more exclusive ones
 - Emphasis on model-independent results when available

MET

CMS MET

- Definitions

- Calorimeter-based MET (calo)

- from ECAL and HCAL deposits. Muon corrected

- Track-corrected MET (tc)

- Subtract from Calo-MET the calorimeter expected response to charged hadrons measured in inner tracker ($2 < p_T < 100$ GeV). Replace with measured p_T

- Particle-flow MET (pf)

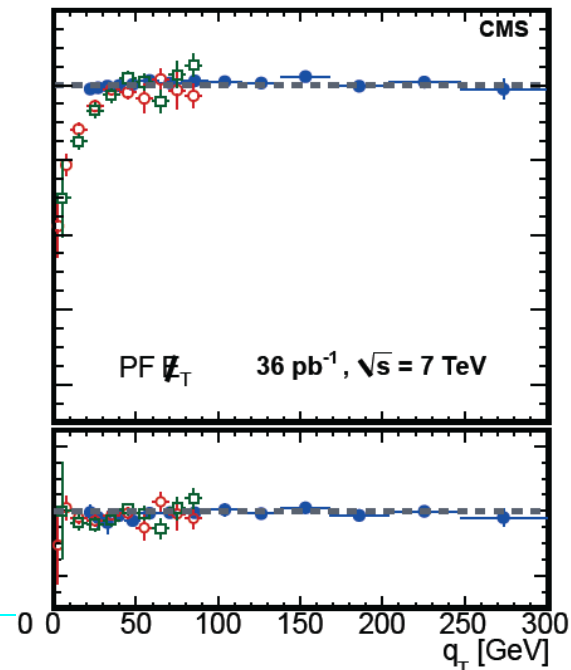
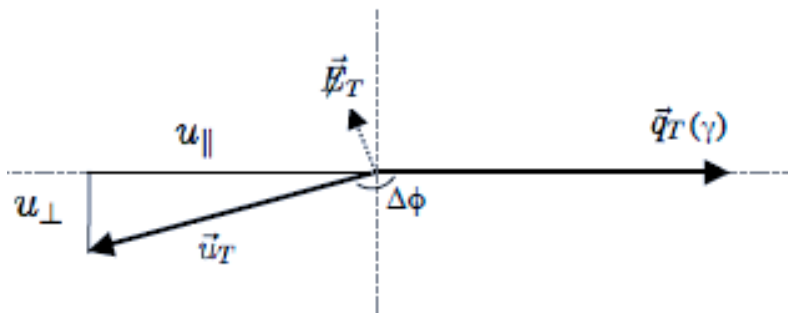
- From a full list of identified particles in each event (neutral and charged hadrons, photons and leptons)

- MET scale corrections

- Individual jet energy scale corrections propagated to MET

- Jets with $p_T \geq 10$ (20) GeV for pf (calo)

- Unclustered energy

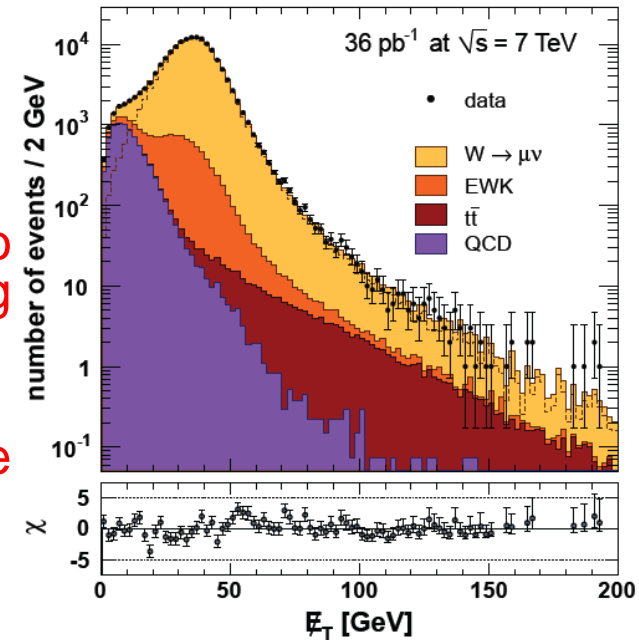


CMS MET (II)

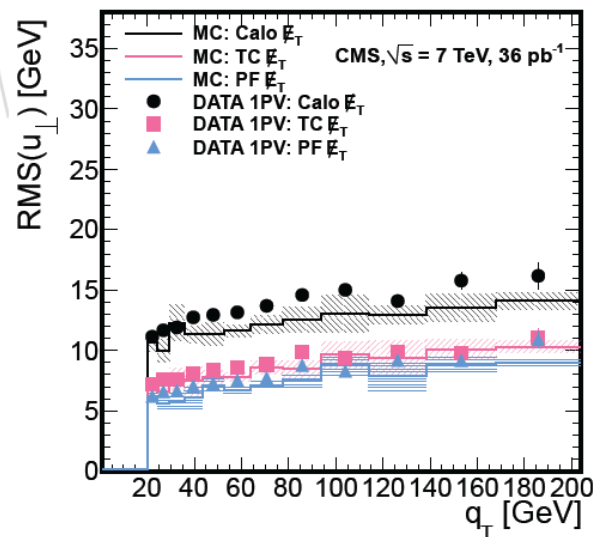
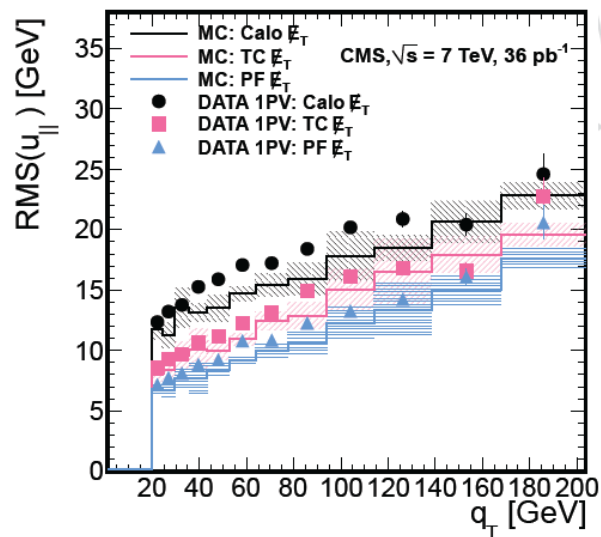
- Best performance from pf MET
 - ▣ Used by majority of analyses
- Systematic uncertainties
 - ▣ Vary scale and smear energy according to specific uncertainties of all contributing objects
- Pile-up
 - ▣ Very small effect on scale; non negligible on resolution

CMS-PAS-EWK-10-005

CMS

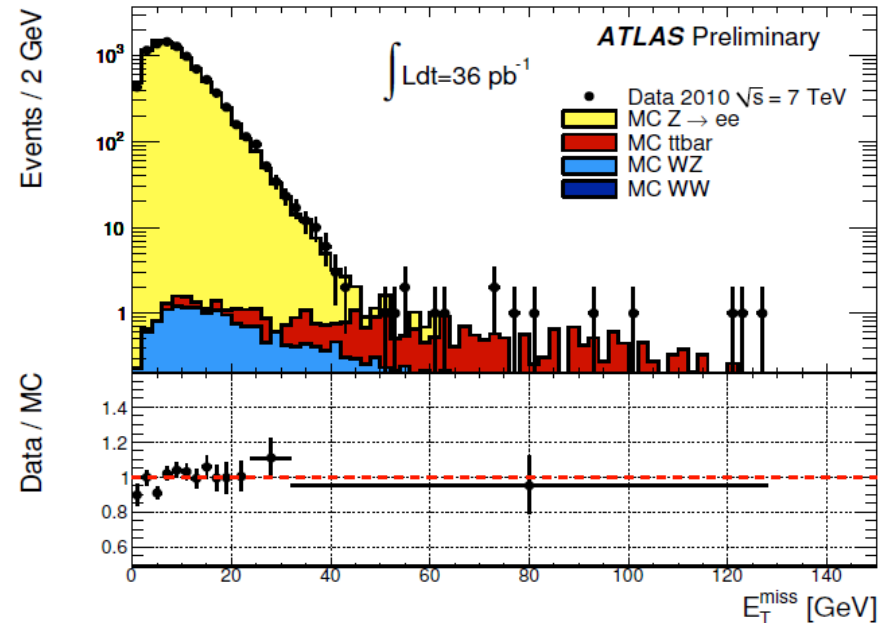
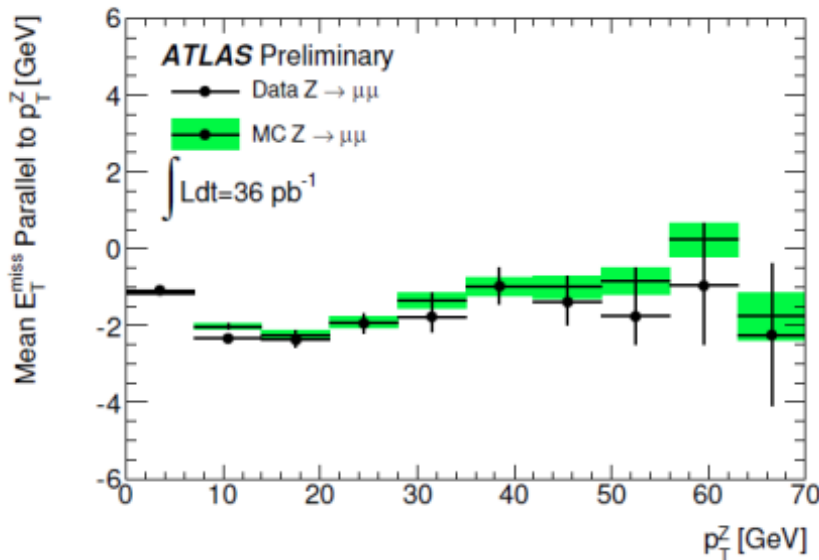


Current trigger thresholds:
 MET: 120 GeV
 MET_jet: 100_80 GeV



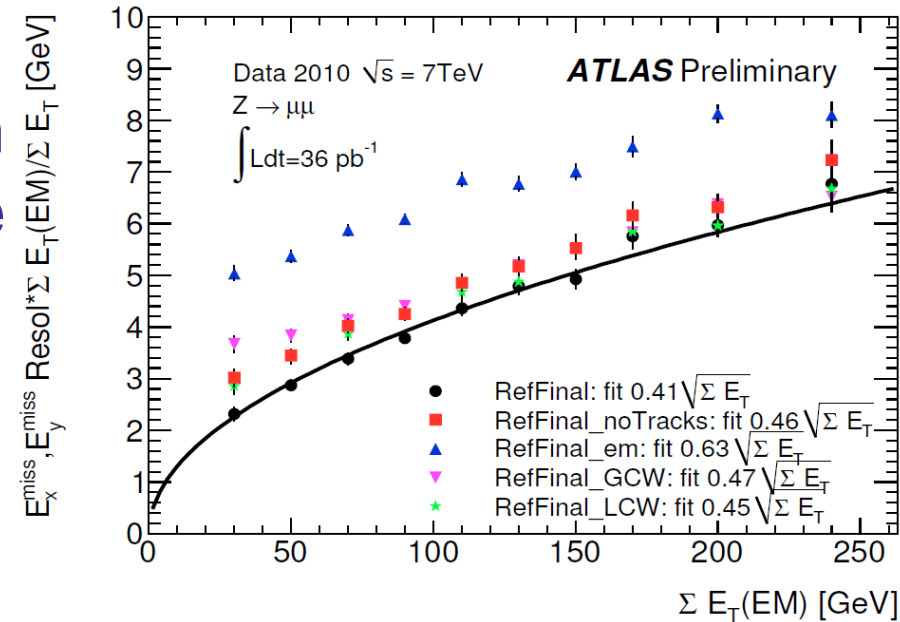
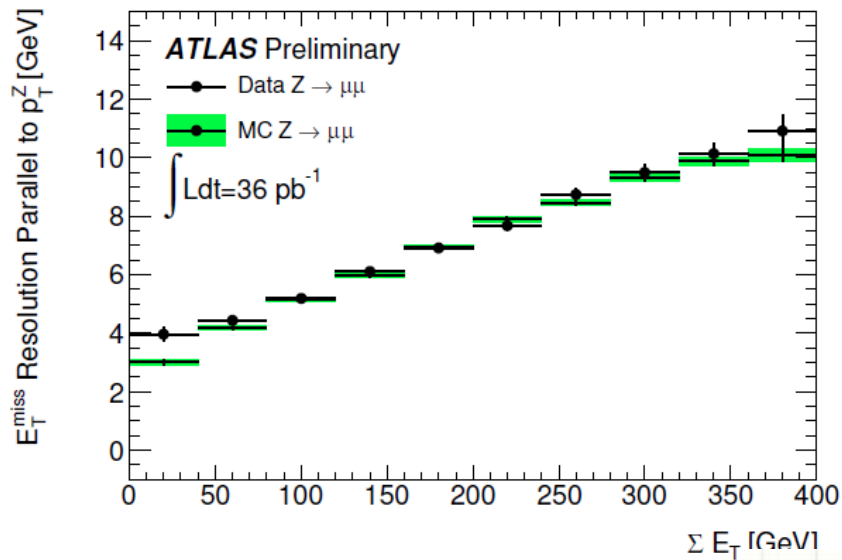
ATLAS MET

- MET from energy in calorimeter cells and muons
- Individual cells calibrated event by event according to associated physics object
 - Include individual jet energy scale corrections
 - Jets with $p_T \geq 7$ GeV
 - Accounts for unidentified and unclustered cells



ATLAS MET (II)

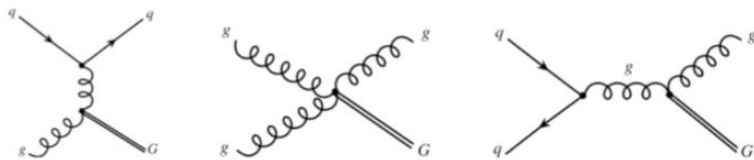
- Very good resolution
- Little difference between standard and more refined calibrations



- Fe-scint+Cu-Ar, $>11 \lambda_0$, $\sigma_E/E \sim 50\%/ \sqrt{E[\text{GeV}]}$ +/- 3%
- CMS- Brass-scint., $>7 \lambda_0$, $\sigma_E/E \sim 100\%/ \sqrt{E[\text{GeV}]}$ +/- 3%

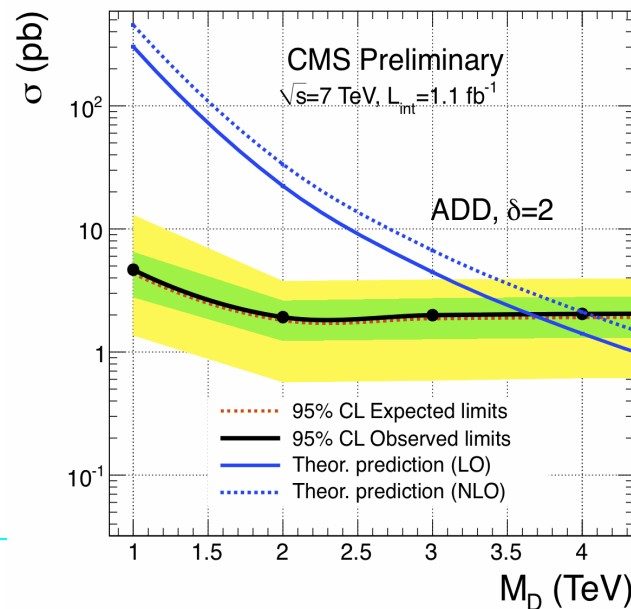
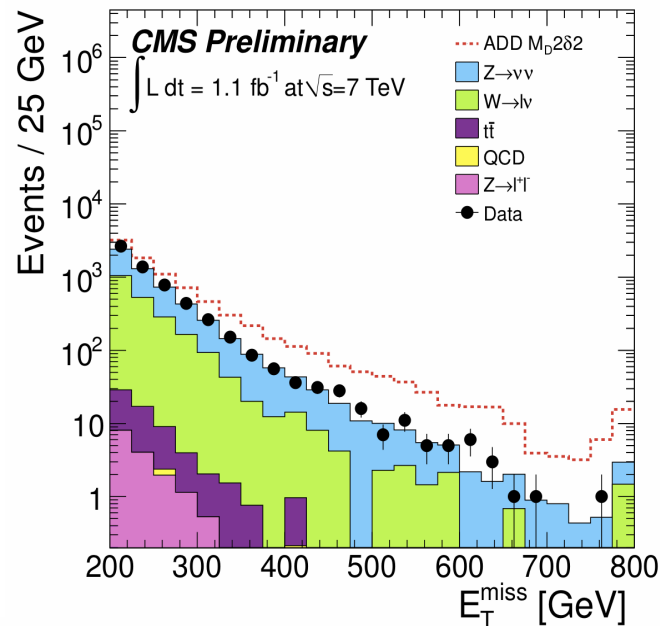
Simple final state analyses

monoJet + MET - CMS



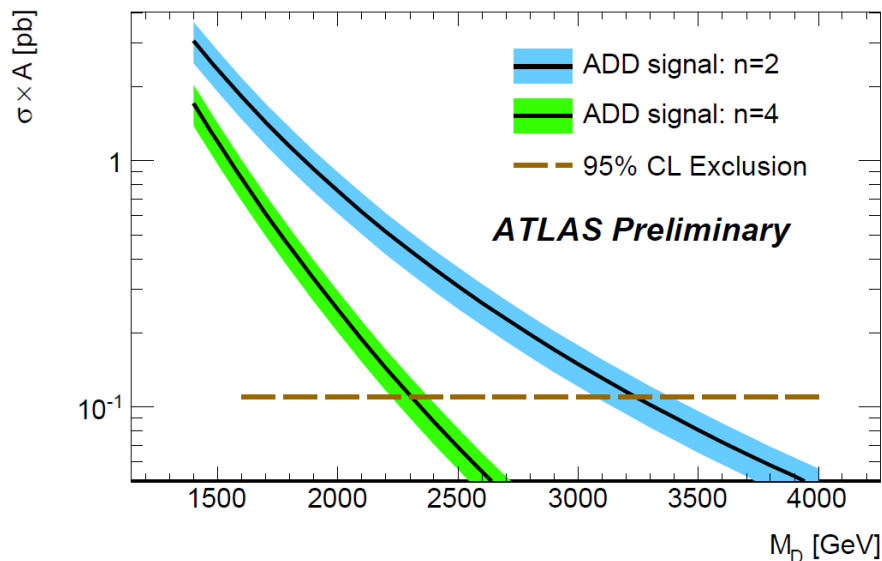
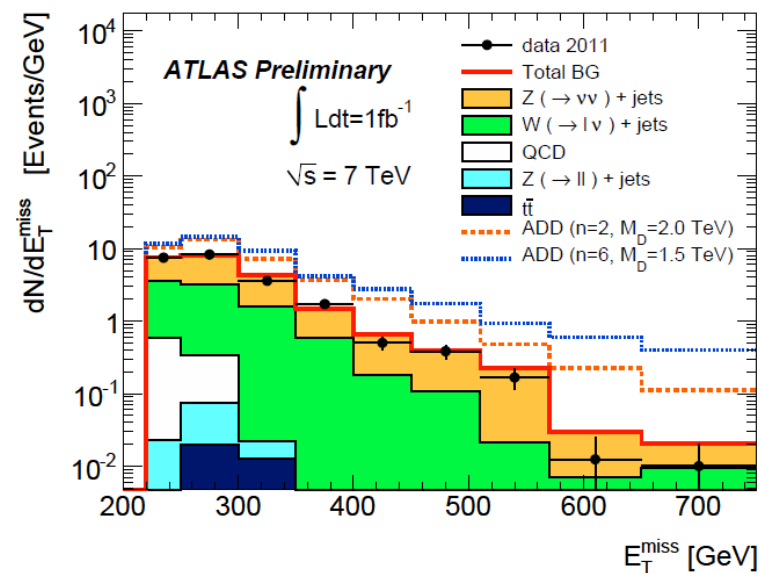
- Motivation: ADD Extra Dimensions
- Search: counting experiment
- Selection
 - MET > 350 GeV; # of jets = 1 or 2 (pT > 30 GeV)
 - Leading Jet: PT > 110 GeV and |η| < 2.4
 - Δφ (jet1, jet2) < 2.5; isolated lepton/track veto
- Background: Z(invisible)+jets , W+jets
 - From data-driven methods
- Results
 - MET cut optimized to set limits on ADD ED
 - Best limits to date on ADD ED

δ	K factor	M _D [TeV/c ²]	
		LO	NLO
2	1.5	3.67	4.03
3	1.5	2.96	3.21
4	1.4	2.66	2.80
5	1.4	2.41	2.55
6	1.4	2.25	2.36



monoJet + MET - ATLAS

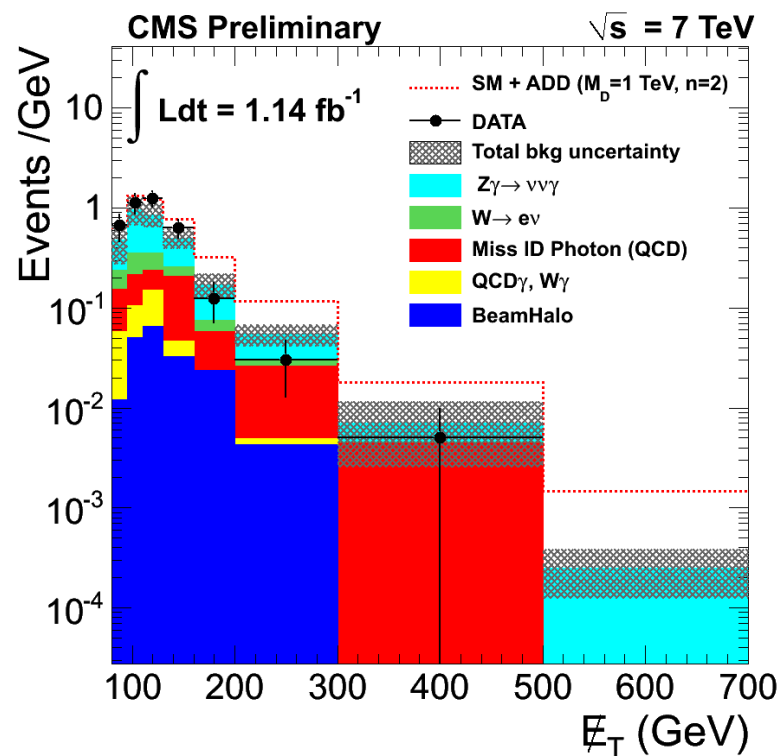
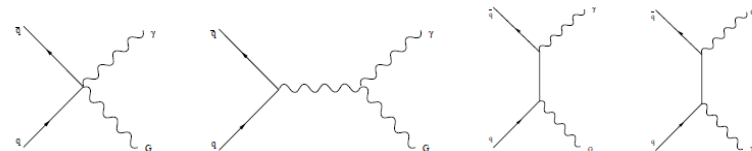
- Differences in Selection
 - Higher leading Jet PT cut (250 GeV in $|\eta| < 2$)
 - no 2nd leading jet with $p_T > 60$ GeV;
 - MET > 220 GeV
 - $\Delta\phi(\text{jet2}, \text{MET}) > 0.5$
- Model independent limit
- No k factors for ADD limits


 95% CL limits on M_D for the ADD model ($\hat{s} < M_D^2$)

n	observed [TeV]
2	3.16
3	2.50
4	2.15
5	1.89
6	1.68

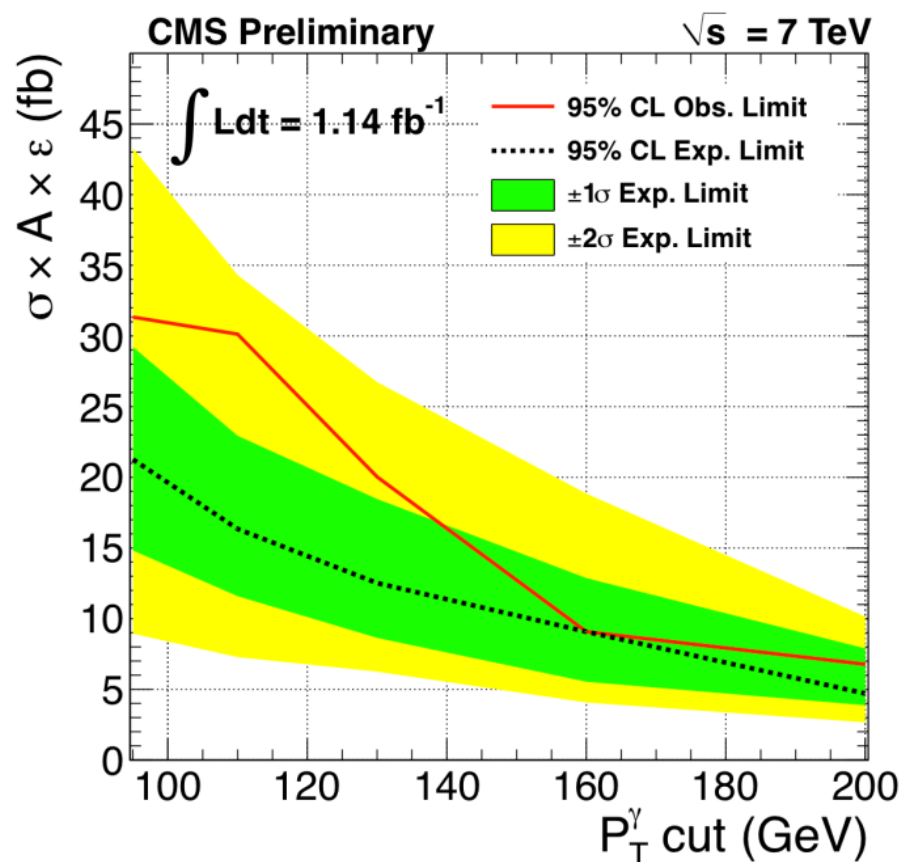
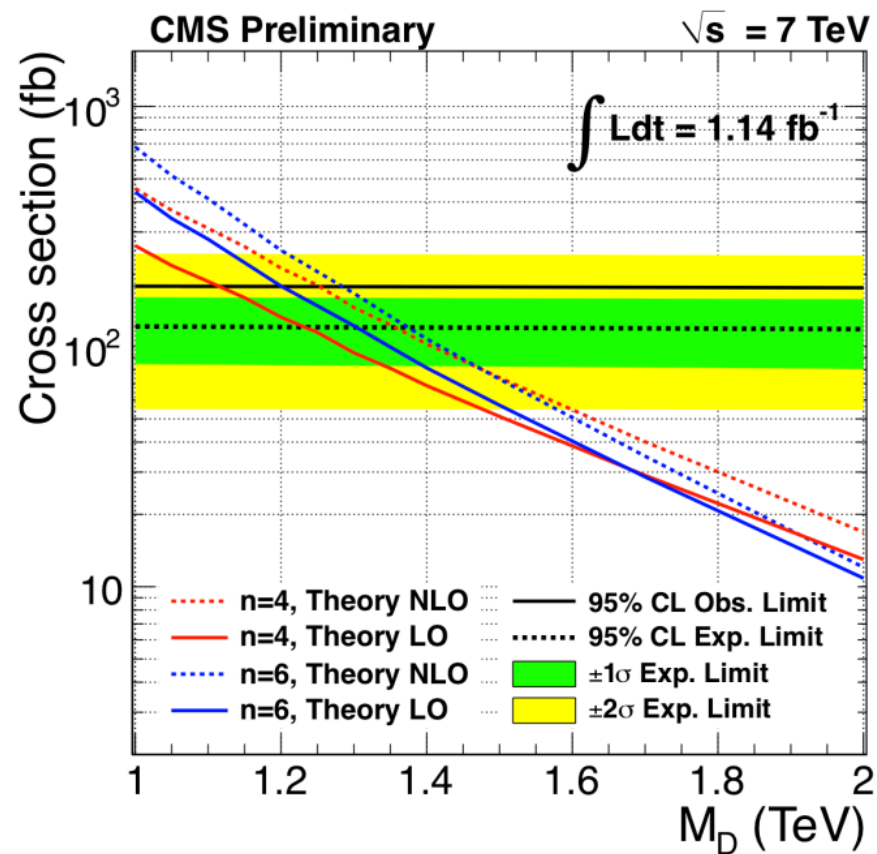
mono Photon + MET

- Also motivated by ADD ED
- Search: counting experiment
- Selection
 - MET > 80 GeV;
 - Photon: ET > 95 GeV and $|\eta| < 1.44$
 - jet veto ($p_T > 20$ GeV) and track veto ($p_T > 10$ GeV)
- Background:
 - From data driven estimates: non-collision, QCD, $W \rightarrow e\nu_e$
 - From MC : $W/Z + \gamma$, $\gamma\gamma$, $\gamma + \text{jet}$
- Results
 - Exp. bkg = 67.3 ± 8.4 ; Data = 80



mono Photon + MET - limits

- Also model-independent limit on $\sigma \times A$



Diphotons + MET

- Tested models: GGM SUSY and UED

- Selection

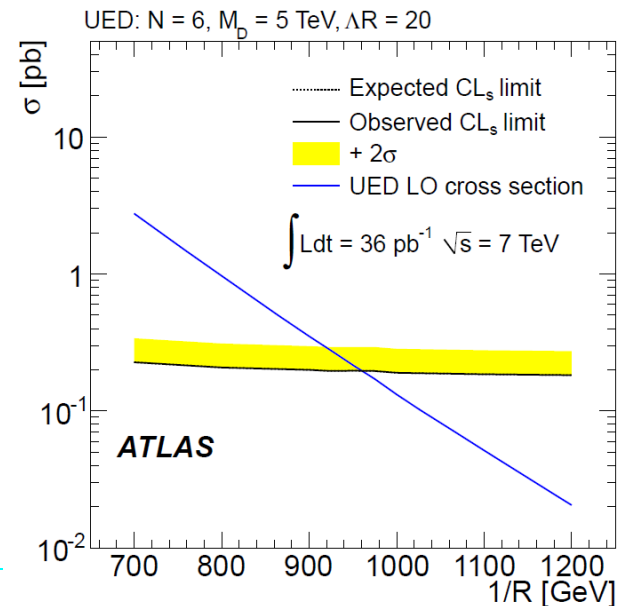
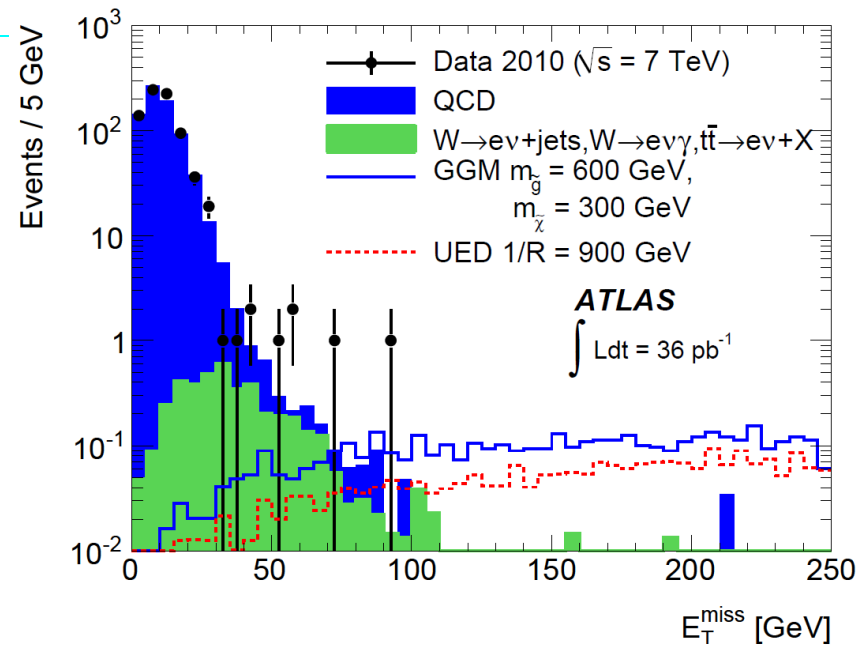
- ≥ 2 photons: $ET > 30$, 20 GeV in $|\eta| < 1.37$ or $1.52 < |\eta| < 1.81$
- $MET > 125$ GeV
- MET cut determined from maximising expected signal sensitivity

- Main background:

- QCD, $W\gamma$ and W +jet all estimated from data

- Results

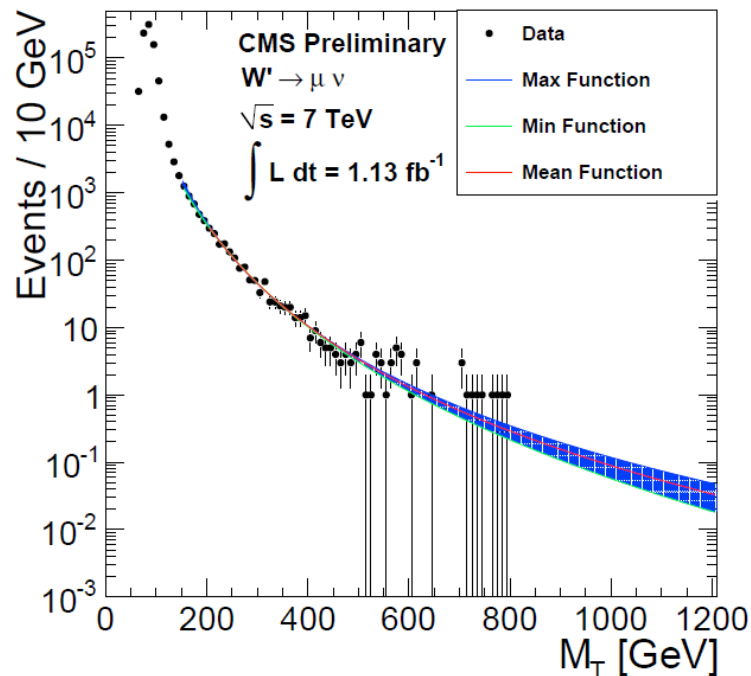
- Data=0
- Exp. Bgd = 0.10 ± 0.4 (stat) ± 0.5 (syst) ;
- Most stringent limits to date



Lepton + MET



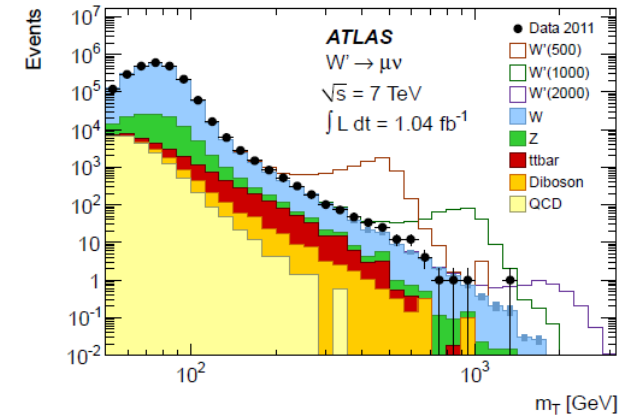
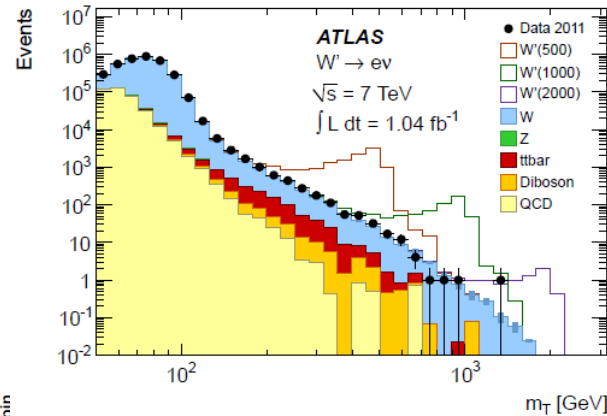
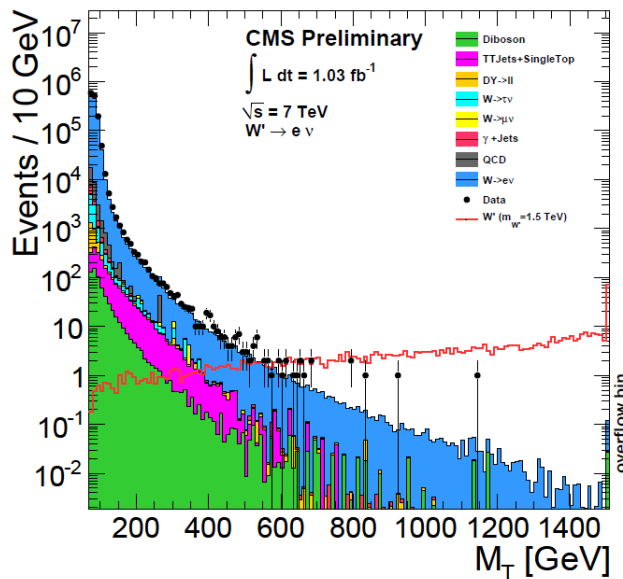
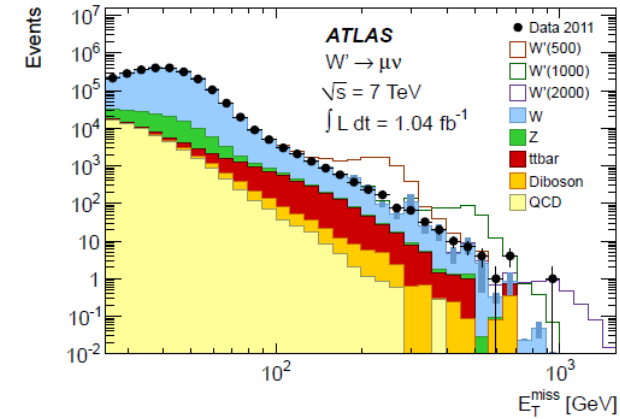
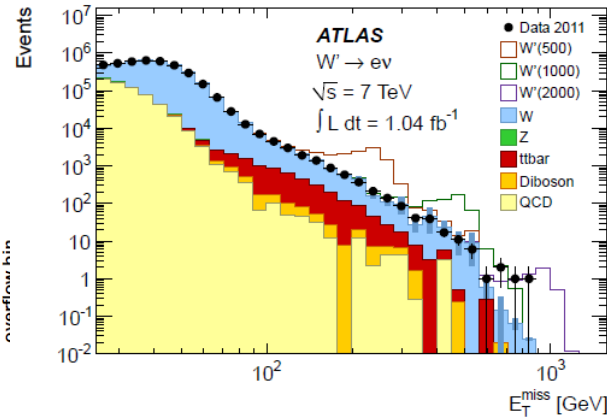
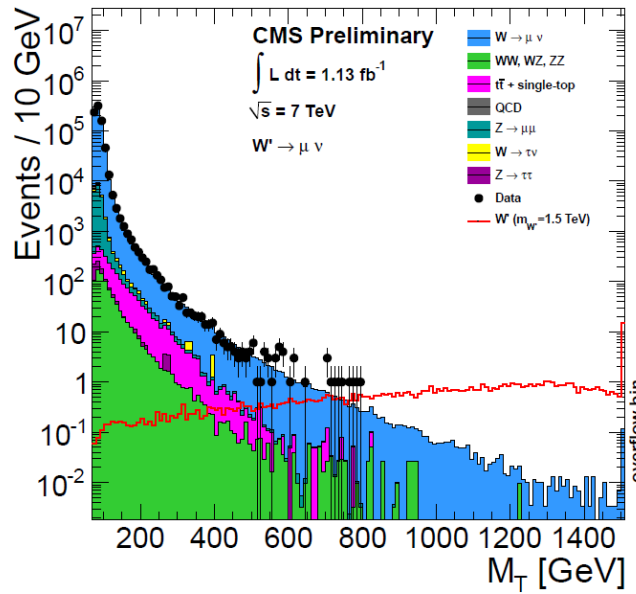
- Motivation: $l+\nu$ resonances
- Count in the tail of the M_T distribution
- Selection (CMS)
 - Muon $p_T > [25, 40]$ GeV
 - Electron $p_T > [25, 32]$.AND. $MET > 40$ GeV
 - $0.4 < PT/MET < 1.5$
 - $\Delta\phi(l, MET) > 2.5$;
- Selection (ATLAS)
 - Muon $p_T > 25$ GeV
 - Electron $p_T > 25$ GeV
 - $MET > 25$ GeV
 - $MET > 0.6 p_T$ (ele)
- Background
 - W (followed by tt)
 - CMS: extrapolate from data in control region to higher masses.
 - ATLAS: from MC normalized with NNLO cross sections



Expected bgd for $M_T > 891$ GeV (ATLAS)

	$e\nu$		$\mu\nu$	
$W \rightarrow l\nu$	1.59	± 0.13	1.36	± 0.13
$Z \rightarrow ll$	0.00010	± 0.00004	0.095	± 0.005
diboson	0.08	± 0.08	0.11	± 0.08
$t\bar{t}$	0.08	± 0.08	0	
QCD	0	$^{+0.17}_{-0}$	0.01	$^{+0.02}_{-0.01}$
Total	1.75	$^{+0.24}_{-0.18}$	1.57	± 0.15

Lepton+MET: spectra

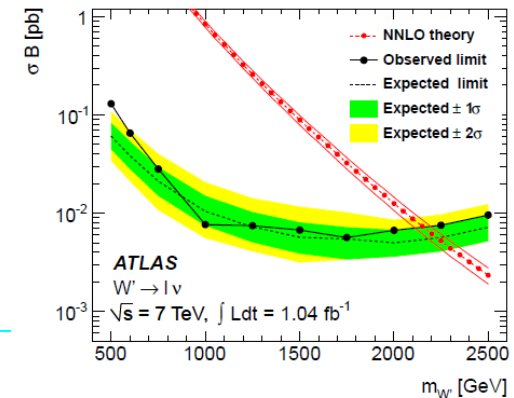
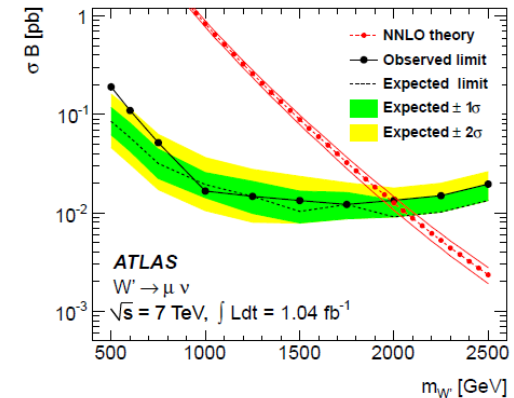
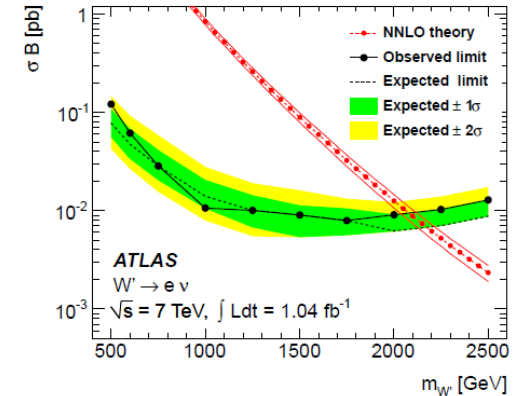
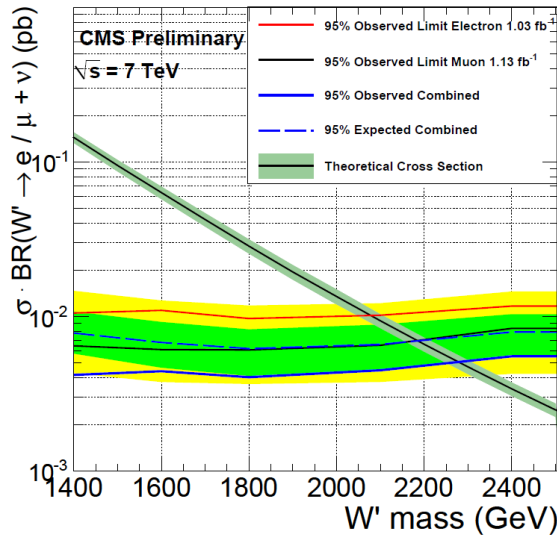


Lepton+MET: limits

Most stringent limits to date on SSM W'

systematic uncertainties (ATLAS)

Source	ϵ_{sig}		N_{bg}	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Efficiency	2.7%	3.9%	2.7%	3.8%
Energy/momentum resolution	0.3%	2.3%	2.9%	0.6%
Energy/momentum scale	0.5%	1.3%	5.2%	3.0%
QCD background	-	-	10.0%	1.3%
Monte Carlo statistics	2.5%	3.1%	9.4%	9.9%
Cross section (shape/level)	3.0%	3.0%	9.5%	9.5%
All	4.7%	6.3%	18%	15%



ST – black holes

- Motivated by BH search but very inclusive
- Signature: high $ST \equiv \sum p_T$ over $e, \mu, \gamma, \text{jets}$ and MET
- Search: counting experiment in the tail of the ST distribution

- Selection

- Object multiplicity (N):

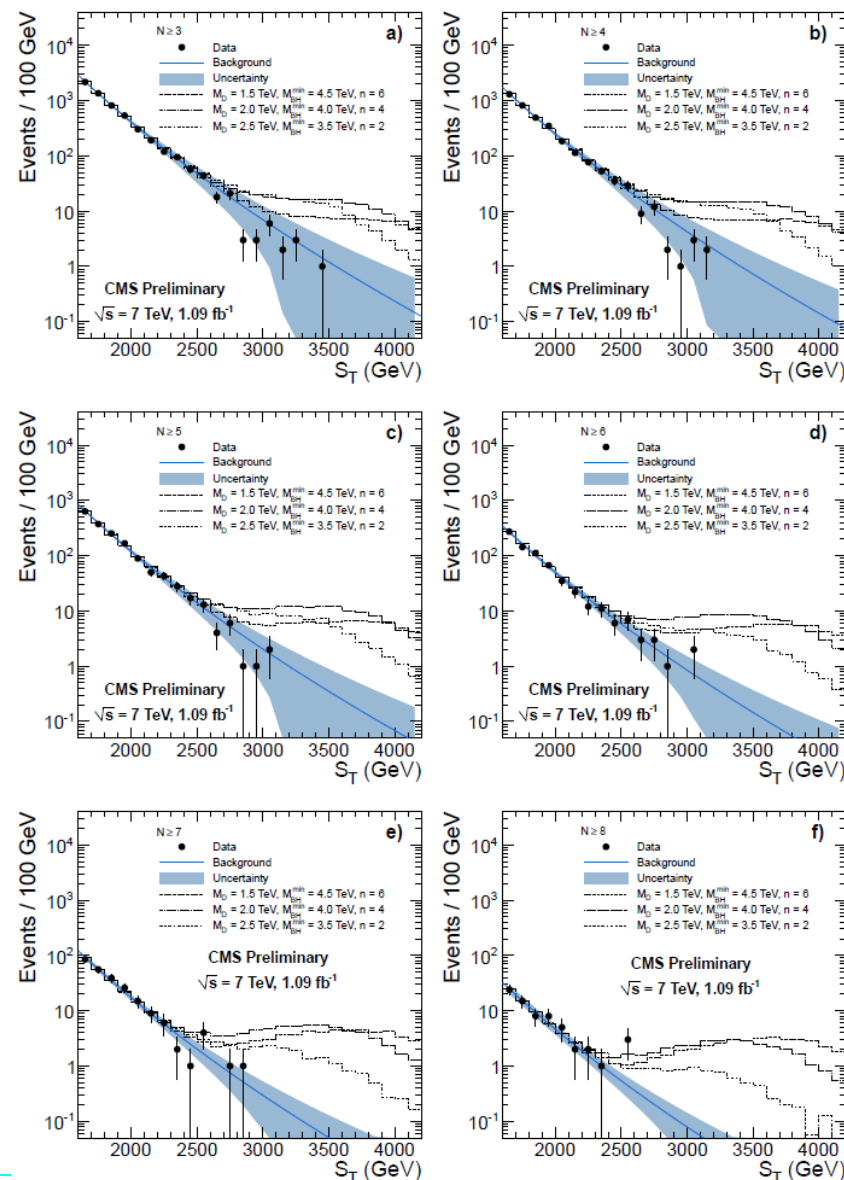
- Jets from calo: $p_T > 20$ GeV in $|\eta| < 2.6$
- Muons: isolated with $p_T > 20$ GeV and $|\eta| < 2.1$
- e, γ : isolated with $p_T > 20$ GeV and $|\eta| < 1.44$ or $|\eta| > 1.56$
- MET from calo
- Separated by at least $\Delta R = 0.5$

- Compute ST from objects with $ET > 50$ GeV

- $S/\sqrt{S+B}$ Optimization of final ST cut

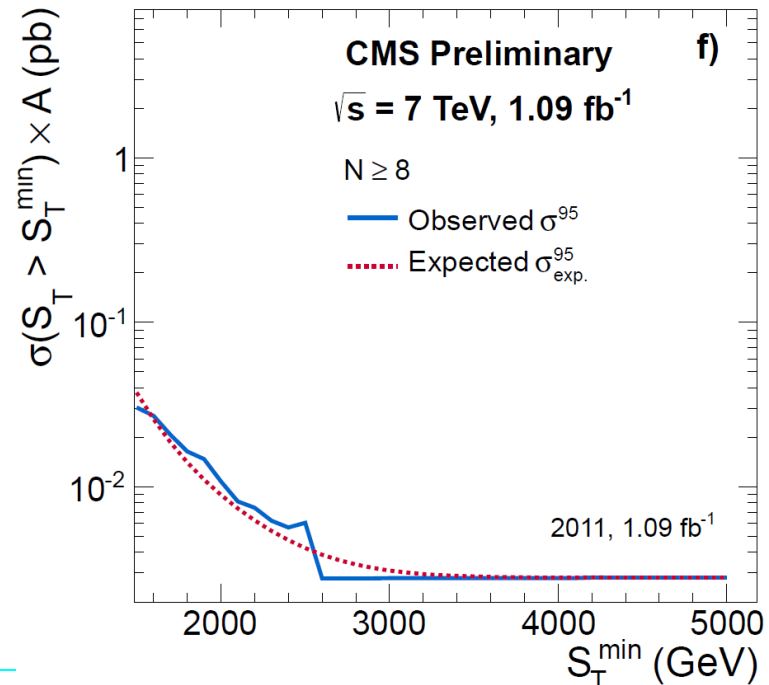
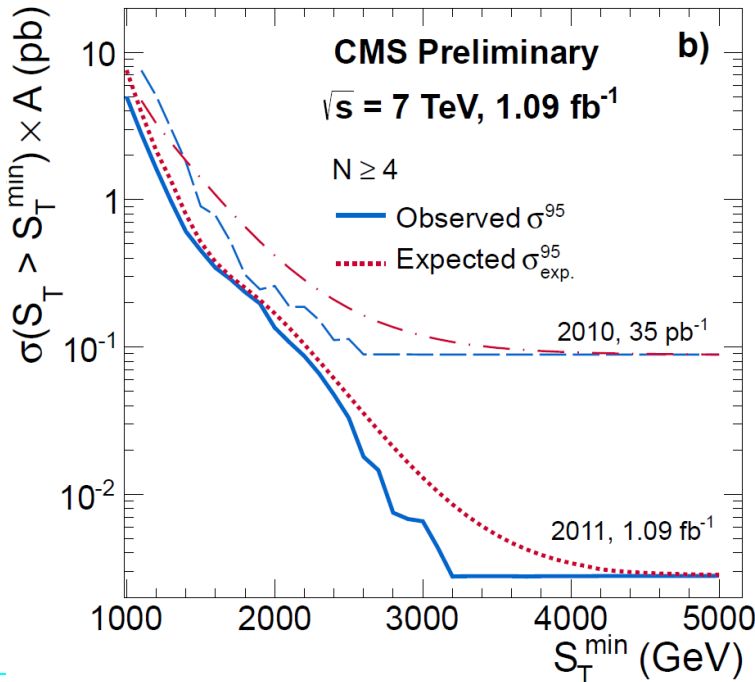
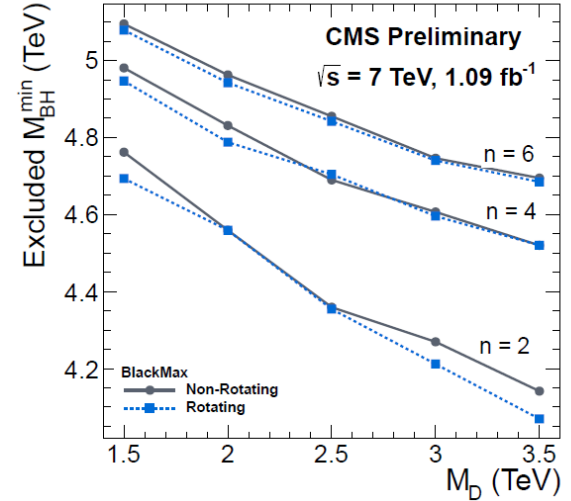
- Background:

- QCD dominant; estimated from data. Independence of ST shape for QCD from N



ST – black holes

- Model-independent limits on $\sigma \times A$ vs S_T cut and N
- Mass lower limits on BH and string balls



Final states with W and heavy quarks

ttbar + MET

Search

- $e\mu, \mu\mu, ee$ final states
- Inspect full $HT+MET=ST$ binned distribution

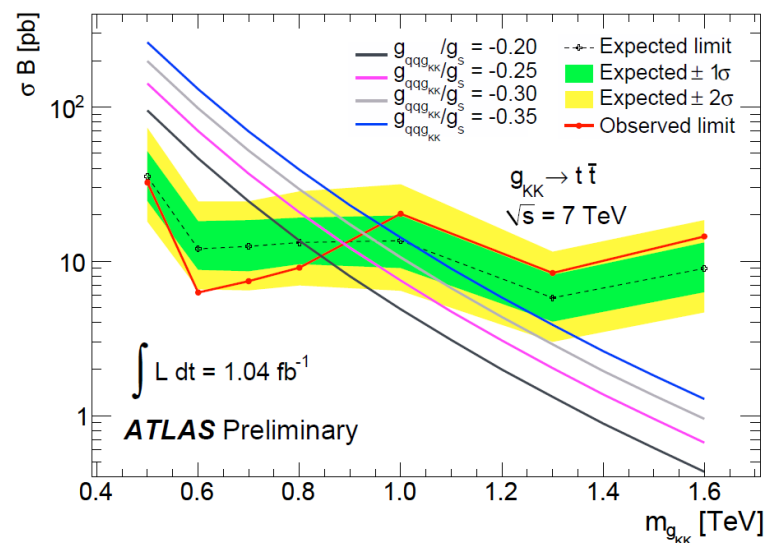
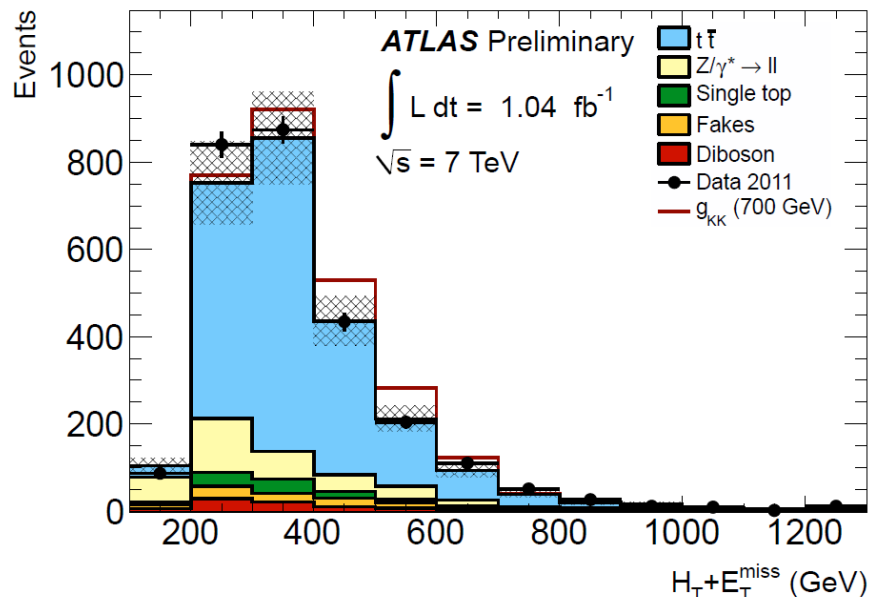
Trigger: single lepton

Selection

- Exactly 2 isolated leptons
 - e : $pT > 25$ GeV in $|\eta| < 2.5$
 - μ : $pT > 20$ in $|\eta| < 2.5$
- ≥ 2 jets: $pT > 25$ GeV in $|\eta| < 2.5$
- $MET > 40$ GeV
- $HT = pt(l) + \sum pT(\text{jets}) \geq 130$ GeV in $e\mu$ channel

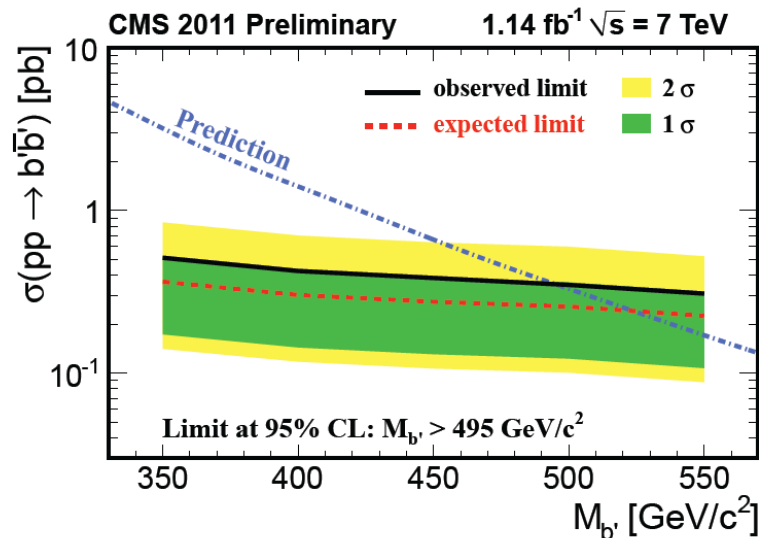
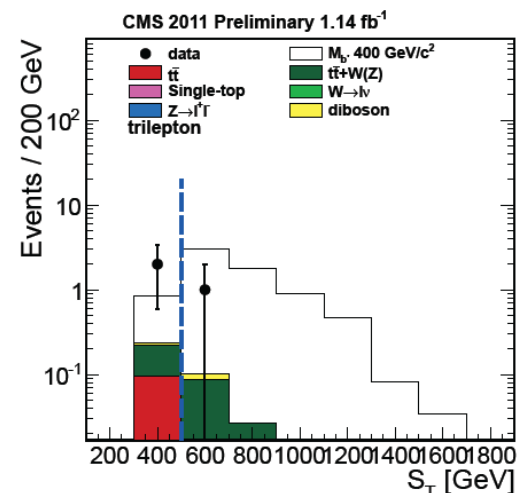
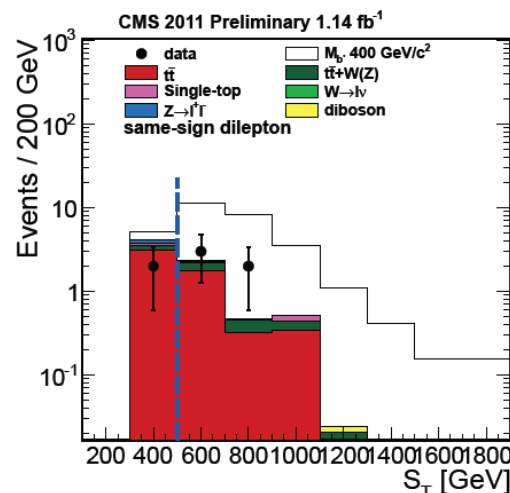
Background

- ttbar: from MC@NLO with x-section from Hather (NNLO)
- $Z/\gamma^* \rightarrow ll$ normalization computed from data and MC



$b'b' \rightarrow tWtW$

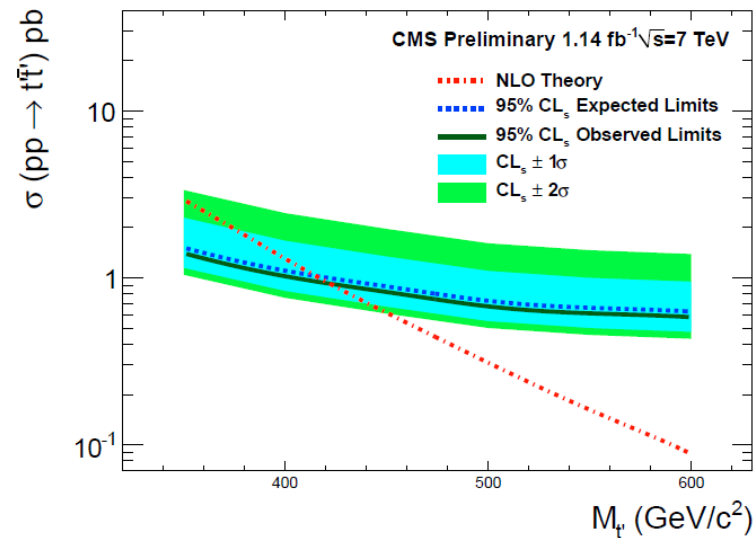
- **Signature:**
 - 2 ss leptons, ≥ 4 jets (≥ 1 b jet) and ST
 - 3 leptons, ≥ 2 jets (≥ 1 b-jet) and ST
- **Search:** counting experiment in ST tail
- **Thresholds**
 - Muon: $p_T > 20$ GeV and $|\eta| < 2.4$
 - Electrons: $p_T > 20$ GeV and $|\eta| < 2.4$
 - Jets(pf): $p_T > 25$ GeV in $|\eta| < 2.4$
 - $ST = \sum p_T(l) + \sum p_T(\text{jets}) + MET > 500$ GeV
- **Background:**
 - Main background from events with a fake lepton. Determined from data
 - Others estimated from MC with normalization to measured or high-order theoretical x-section
- **Results**
 - Dominant systematic uncertainty: b-tagging and lepton selection efficiency
 - supersedes CDF limit at 372 GeV



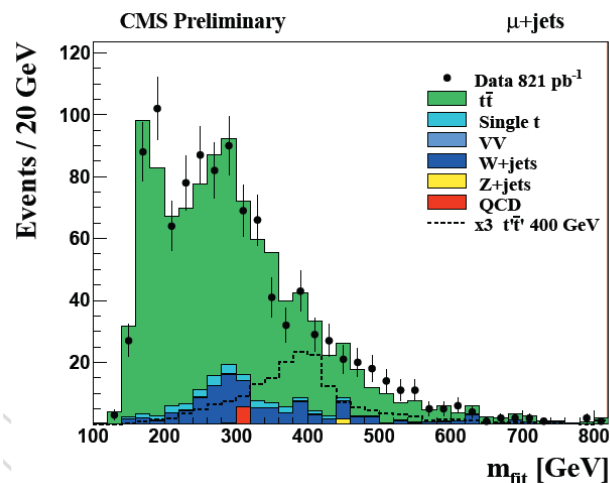
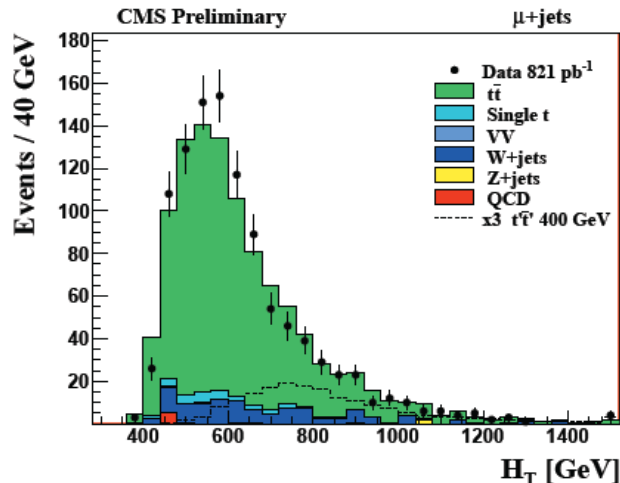
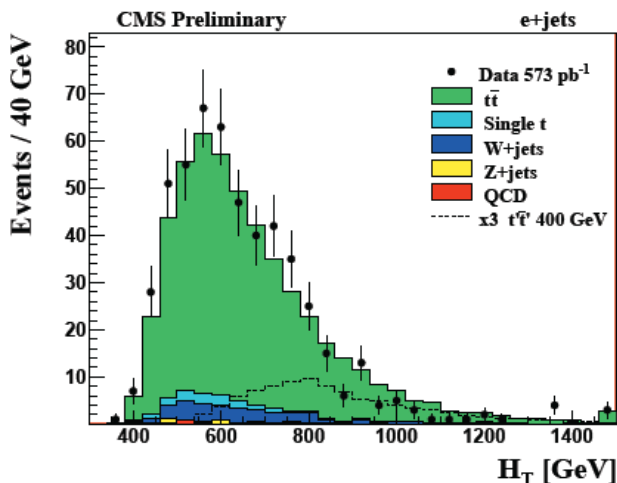
$t\bar{t} \rightarrow Wb Wb$ (di-leptonic)

- Search: count events
- Trigger: di-lepton
- Selection
 - ❑ 2 isolated os leptons: $p_T > 20$ GeV in $|\eta| < 2.4$ (μ)/ 2.5 (e)
 - ❑ ≥ 2 jets: $p_T > 30$ GeV in $|\eta| < 2.5$
 - ❑ ≥ 2 b-jets
 - ❑ MET > 30 GeV
 - ❑ $M(I1b1) > 170$ GeV AND $M(I2b2) > 170$ GeV
 - Paired by smallest distance
- Results
 - ❑ Syst. Uncert on acceptance: b-tagging (10%) and jet/MET scale (8%) sig.

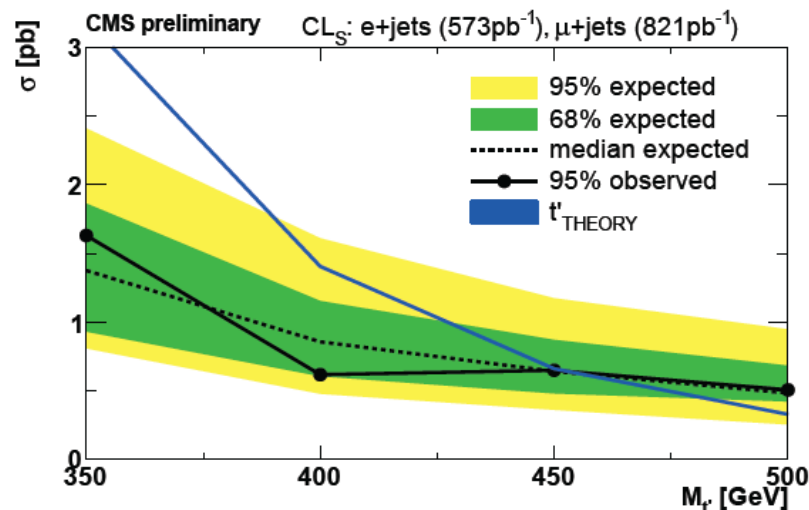
Sample	Yield	Prediction source
$t\bar{t} \rightarrow \ell^+ \ell^-$	1.35 ± 0.67	Data
Fake leptons	$0.0^{+0.4}_{-0.0}$	Data
$DY \rightarrow e^+ e^-$ or $\mu^+ \mu^-$	$0.07^{+0.13}_{-0.07}$	Data
$DY \rightarrow \tau^+ \tau^-$	0.11 ± 0.11	Simulation
Di-boson	0.02 ± 0.02	Simulation
Single top	0.07 ± 0.04	Simulation
Total prediction	$1.62^{+0.80}_{-0.70}$	
Data	1	



$t't' \rightarrow Wb Wb$ (semi-leptonic)

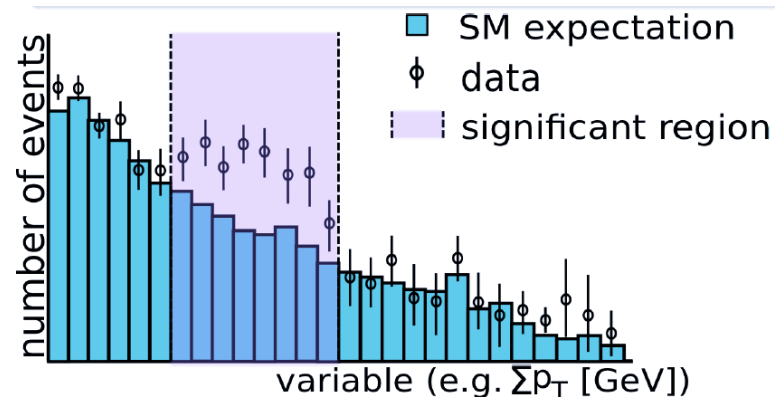
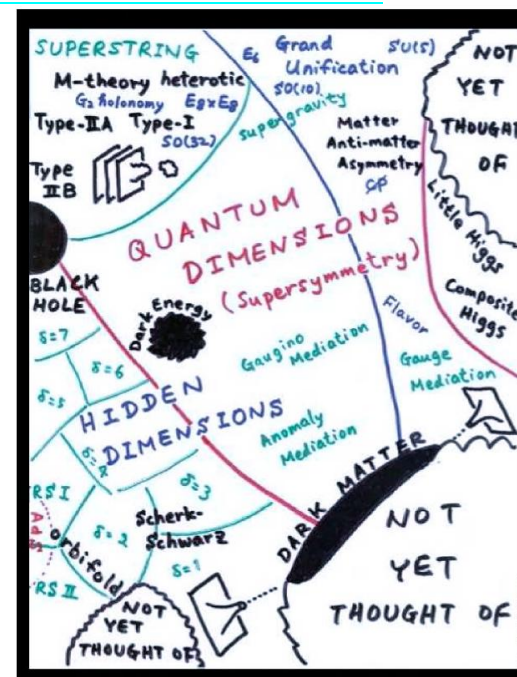


- Search: likelihood of H_T vs M_{fit} distribution
 - $H_T = p_T(l) + \sum p_T(jets) + MET$
- Trigger: single-lepton
- Selection
 - Optimized for max S/\sqrt{B} for $t'(400 \text{ GeV})$
 - 1 isolated lepton: $p_T > [30, 45](e) / 35(\mu) \text{ GeV}$ in $|\eta| < 2.1 (\mu) / 2.5(e)$
 - ≥ 4 jets(pf): $p_T > 120, 90, 35, 35 \text{ GeV}$ in $|\eta| < 2.4$
 - ≥ 1 b-jets
 - $MET > 20 \text{ GeV}$
 - Mass from Kinematic fit
- Background
 - All from MC
 - tt normalization from measured x-section
 - Normalization of the others free parameter of the fit

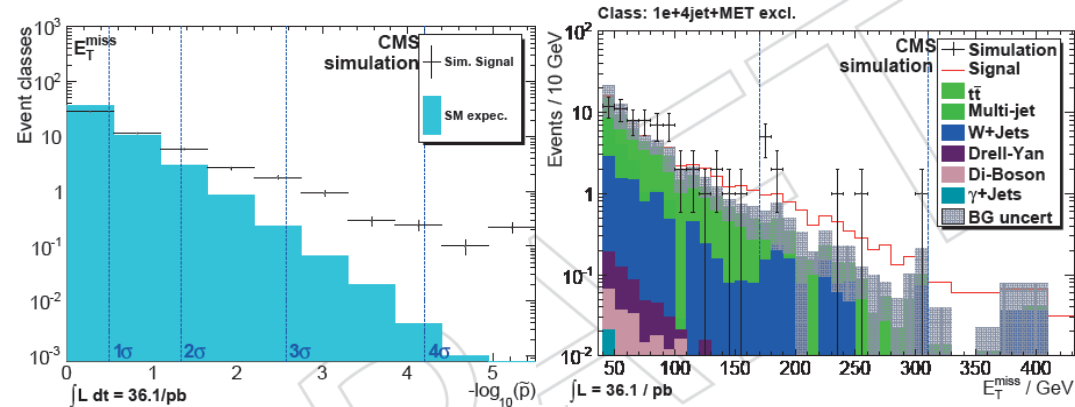
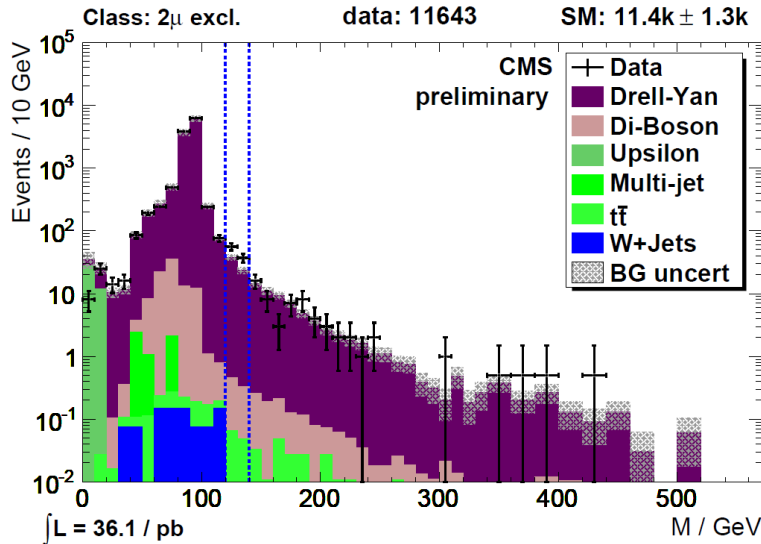


Have we left out something ?

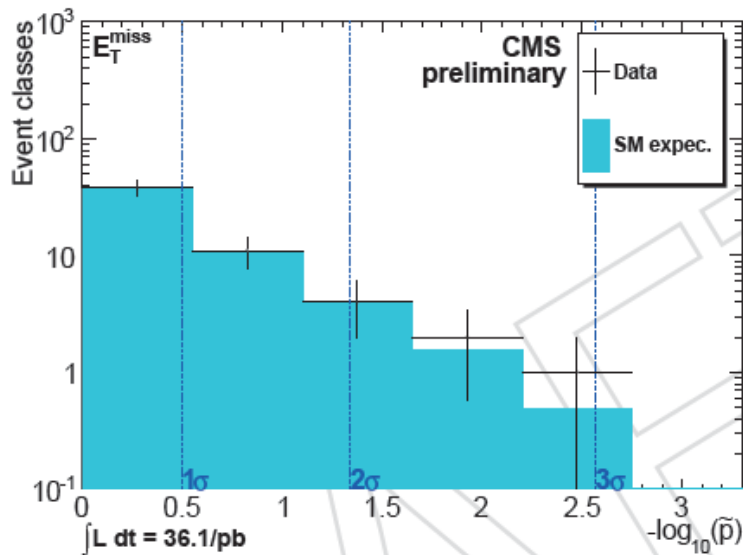
- Model Unspecific Search In CMS (MUSIC)
- Algorithm
 - ❑ Classify events according to content: $e, \mu, \gamma, \text{jets}, \text{MET}$
 - ❑ Produce $\Sigma p_T, M_{\text{inv}}^{(T)}, \text{MET}$ distributions
 - ❑ Select region with lowest p-value
 - account for prediction uncertainties, correlations and LEE
- Results on 2010 dataset (36 pb⁻¹)
 - ❑ Require at least one single μ (>25 GeV) or e (>30 GeV)
 - ❑ μ : $p_T > 18$ GeV isolated
 - ❑ e : $p_T > 25$ GeV isolated
 - ❑ γ : $p_T > 25$ GeV, $|\eta| < 1.44$, isolated
 - ❑ pf Jets: $p_T > 50$ GeV
 - ❑ MET > 30 GeV
 - ❑ Overlapping object cleaning



MUSIC results (2010 data)



Sensitivity cross-check: LM0 signal added to data



- 287 distributions
- p-value distributions consistent with SM expectations

-
- No time to cover the following 2011 recent final states with MET explored in non-SUSY and non-Higgs searches
 - **jjW (ATLAS-CONF-2011-097)**
 - **WZ (CMS-PAS-11-041)**
 - Full list of exotic searches (including 2010):
 - **ATLAS:**
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults>
 - **CMS:**
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>

Concluding remarks

- Enormous effort from the collaborations to try to cover all possible BSM manifestations
 - This talk focused on final states with MET
- Model independent limits presented in some cases
 - Help filling the gap between exp and th communities
 - Can certainly do more