SUSY searches in γ+MET/b+MET at CMS

Joshua Thompson, Cornell University
On behalf of the CMS Collaboration

17 March 2012

SEARCH workshop, U of Maryland

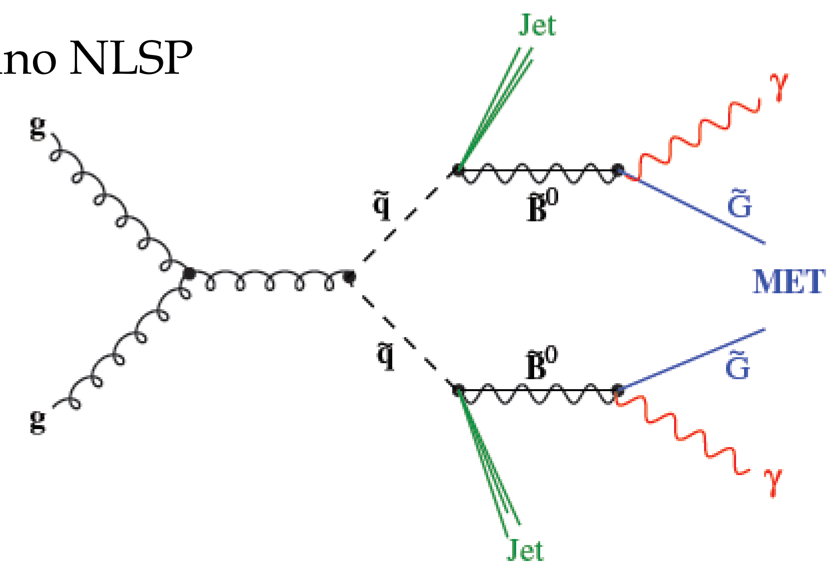
Analyses

- SUSY in γ+MET
  - Results with 4.7 fb^{-1}
    - γ+jets+MET, γγ+jet(s)+MET (SUS-12-001)
- SUSY in b+MET
  - Results with 1.1 fb^{-1}
    - b+jets+MT2 (SUS-11-005)
    - b+jets+MET (SUS-11-006)

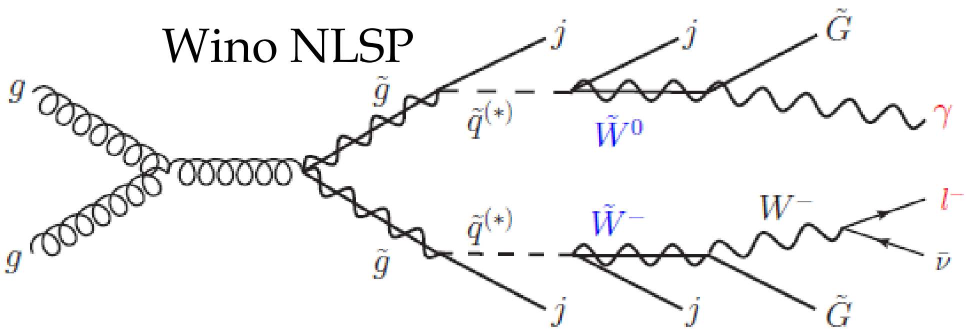
γ+MET: example diagrams

- General Gauge Mediation SUSY scenario
  - Lightest SUSY particle is the gravitino G~
  - Phenomenology depends on the NLSP type

Bino NLSP



Wino NLSP



[Ruderman & Shih: arXiv:1103.6083]

γ+MET: Signatures and backgrounds

NLSP type	γ + 2 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	$\gamma\gamma$ + jet + $E_{\mathrm{T}}^{\mathrm{miss}}$
Bino	$\mathrm{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \mathrm{jets} + \gamma + Z + \tilde{G}\tilde{G}$	$\mathrm{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \mathrm{jets} + \gamma\gamma + \tilde{G}\tilde{G}$
Wino	$\mathrm{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \mathrm{jets} + \gamma + Z + \tilde{G}\tilde{G}$ $\mathrm{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^\pm \to \mathrm{jets} + \gamma + W^\pm + \tilde{G}\tilde{G}$	$\mathrm{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \mathrm{jets} + \gamma\gamma + \tilde{G}\tilde{G}$

- Signatures
  - ≥2 photons, ≥1 jet, MET
  - ≥1 photon, ≥2 jets, MET
- Backgrounds
  - QCD: mutltijet production with or without real photons
    - MET from mismeasurement of jets
  - Electroweak: W→eν with fake photons
  - ≥1 photon analysis only: W, Z, ttbar with real FSR, ISR photons

γ+MET: Event selection

- Photon thresholds defined by the trigger
  - 2γ: diphoton trigger (36, 22 GeV online)
    - → analysis selection of $E_{\gamma 1}$ > 40 GeV, $E_{\gamma 2}$ > 25 GeV
  - 1γ: photon (70 GeV online)+H_T trigger
    - → analysis selection of E_{γ} > 80 GeV
- Jets
  - Particle flow reconstruction, pileup correction applied
  - p_T > 30 GeV, $|\eta|$<2.6, pass quality requirements
    - 2γ: ≥1 jet
    - 1γ: ≥2 jets, H_T>450 GeV
- MET (particle flow)
  - 2γ: MET>50 GeV
  - 1γ: MET>100 GeV
- Leptons
  - No veto or requirements on leptons in the event
    - Want to avoid vetoing signal with W/Z decays to leptons!

γ+MET: details on photon selection

- $|\eta|<1.4$ (barrel ECAL)
- Isolation
  - Total energy in tracker and calorimeters within $\Delta R=0.3$ must be <6 GeV after correcting for pileup
- Quality
  - Cluster shape and HCAL energy requirements
    - Isolated photon candidates failing quality criteria are called "fakes"
      - Mostly jets with EM fluctuation
      - Used in forming control samples
- Pixel match
  - Isolation and quality criteria select both electrons and photons
    - Match to pixel detector → electron candidate
    - No match to pixel detector → photon candidate

γ+MET: QCD background estimation

- Fake MET arises from mismeasurement of hadronic objects (jets) recoiling off of the EM objects (photons or fake photons)
  - 2γ analysis:
    - Use ff control sample
      - Data-driven reweighting of events to compensate for different p_T spectrum of the EM objects between control (ff) and signal ($\gamma\gamma$) samples
      - MET shape taken from reweighted ff sample
      - Normalization taken from $\gamma\gamma$ sample at MET<20 GeV
    - Similar technique applied to Z→ee sample
      - Difference from ff result taken as a systematic
  - 1γ analysis:
    - Control sample with looser photon ID
      - Similar reweighting

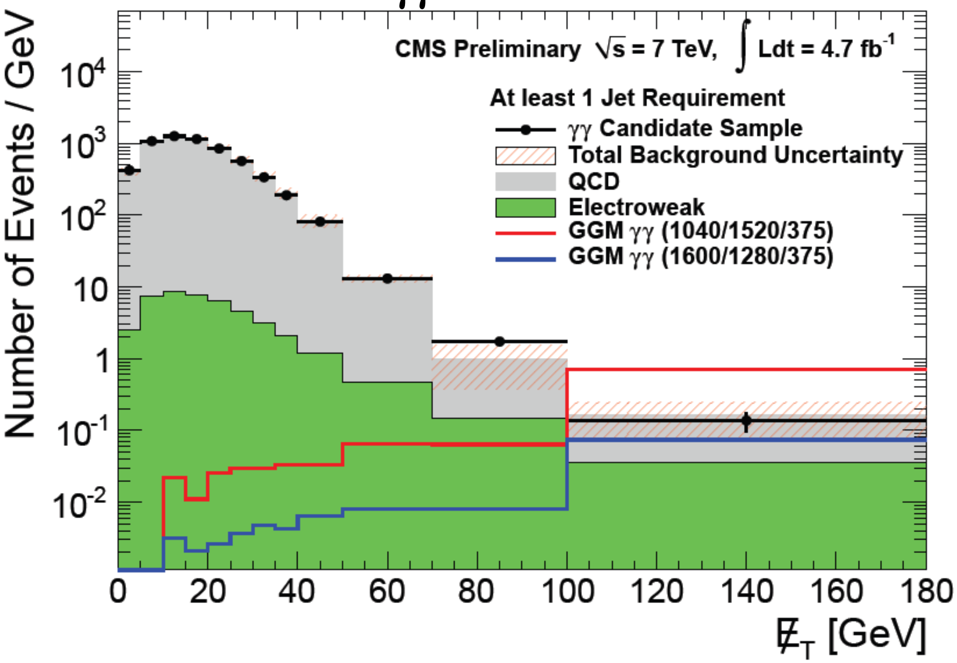
γ+MET: Electroweak backgrounds

- 2γ analysis
  - Main background: $W \rightarrow e\nu$ + radiated γ
    - Real MET from neutrino in W decay
    - e fakes γ
  - Measure fake rate $f(e \rightarrow \gamma)$ by comparing the number of $Z \rightarrow ee$ events in ee and $e\gamma$ samples, in bins of p_T
    - Weight a sample of $e\gamma$ events using the fake rate to get the number of fake 2γ events
- 1γ analysis
  - ttbar, W, Z all contribute
    - Portions with $e \rightarrow \gamma$ fakes estimated from data as above
    - Remaining contributions (ISR/FSR) from MC

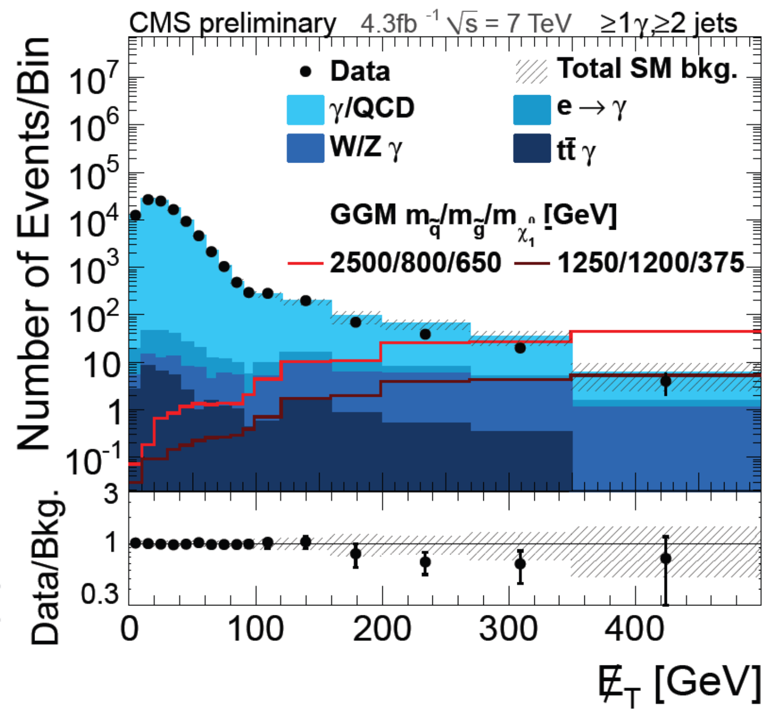
γ+MET: MET distributions

- Observed data in agreement with background predictions

γγ channel



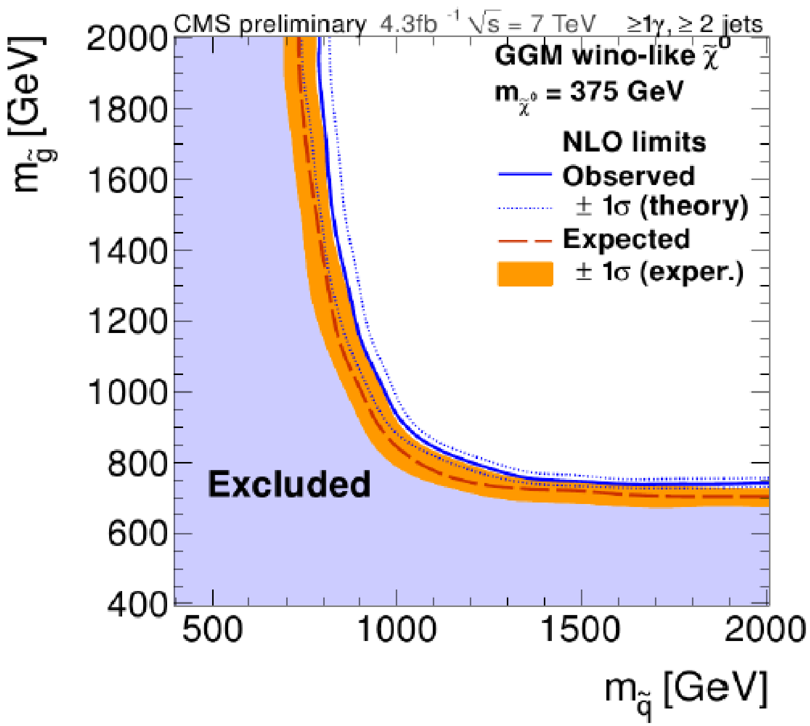
γ channel



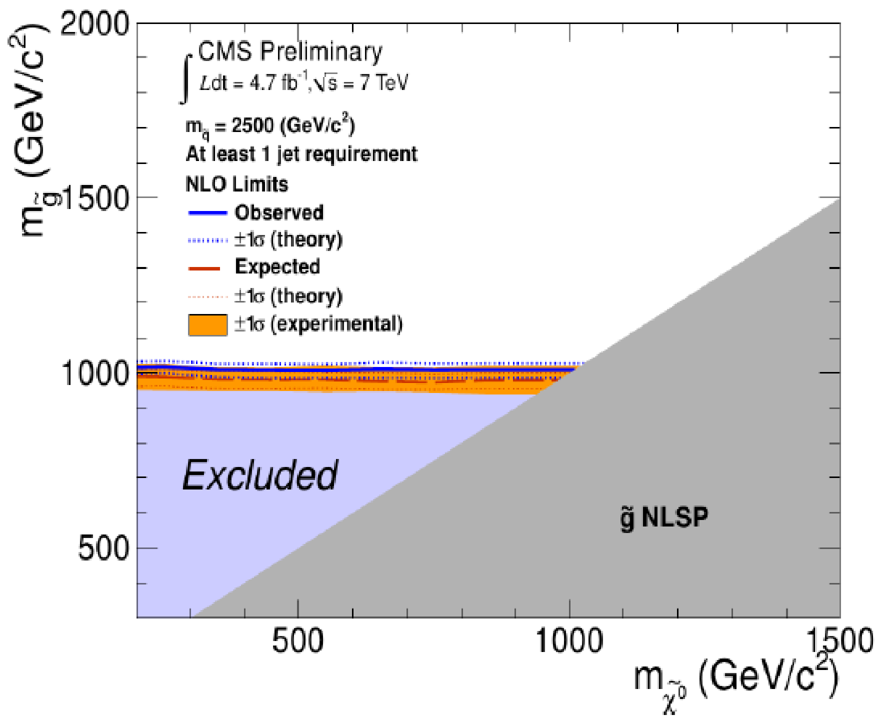
Limits calculated by combining exclusive bins of MET
1γ: 6 bins starting at MET of 100 GeV
2γ: 6 bins starting at MET of 50 GeV

Interpretation in simplified models

- Interpretations given for bino, wino-like NLSP
- γ, γγ channels set similar limits



1γ search, wino-like NLSP
NLSP mass fixed to 375 GeV



2γ search, bino-like NLSP
Squark mass fixed to 2500 GeV

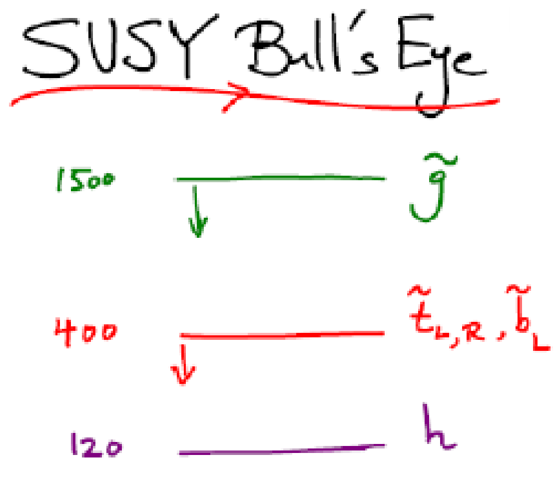
Complete results in backup slides

γ+MET summary

- Searches done with full 2011 dataset in 1γ, 2γ + MET channels
  - Main backgrounds predicted using data-driven methods
  - Observed data analyzed in bins of MET and found consistent with background
- Interpretation in terms of SUSY models with bino, wino-like NLSP for varying squark, gluino, and NLSP masses
  - Also interpreted in terms of Universal Extra Dimensions

b+MET: Introduction

- Many SUSY scenarios predict a light 3rd generation (naturalness) with light q~ heavier
- Add b-tag to inclusive searches
  - Cut background while keeping b~, t~ signal
  - This talk: hadronic searches with ≥3 jets (1.1 fb^{-1})
    - Particularly sensitive to g~ → bbX_0~
  - Tomorrow: same-sign dileptons + b tag (4.7 fb^{-1}) [Slava Krutelyov]
    - Better performance on t~



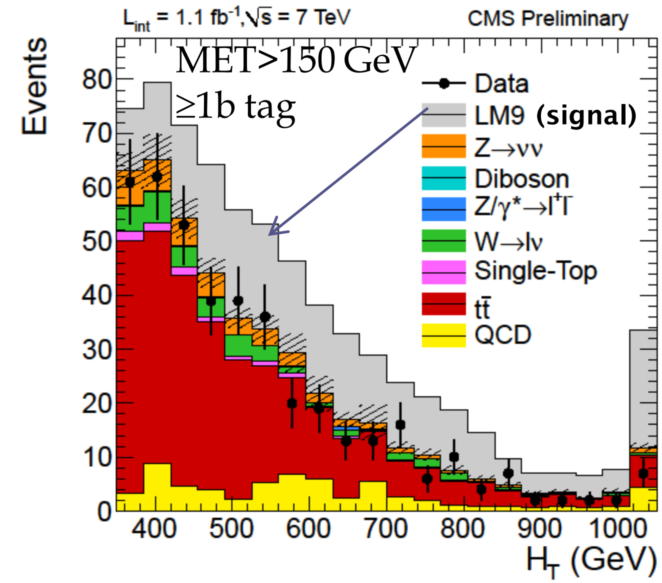
N. Arkani-Hamed
https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=157244

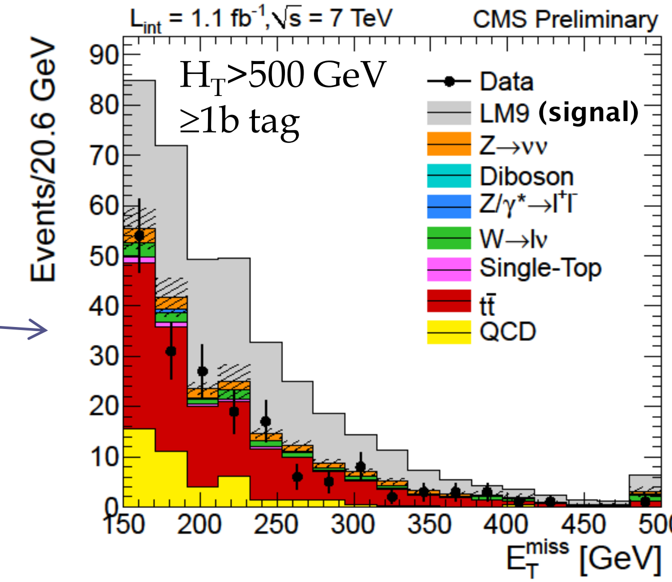
b+MET: Signature and Backgrounds

- Signature: jets + b-tag + MET
- Backgrounds:
  - ttbar → bW bW → bqq′ blν
    - real MET from ν
  - Smaller (suppressed by b-tag):
    - Z+jets with Z→νν
      - Real MET, so irreducible
    - W+jets, single top
    - QCD (fake MET)

b+MET: event selection

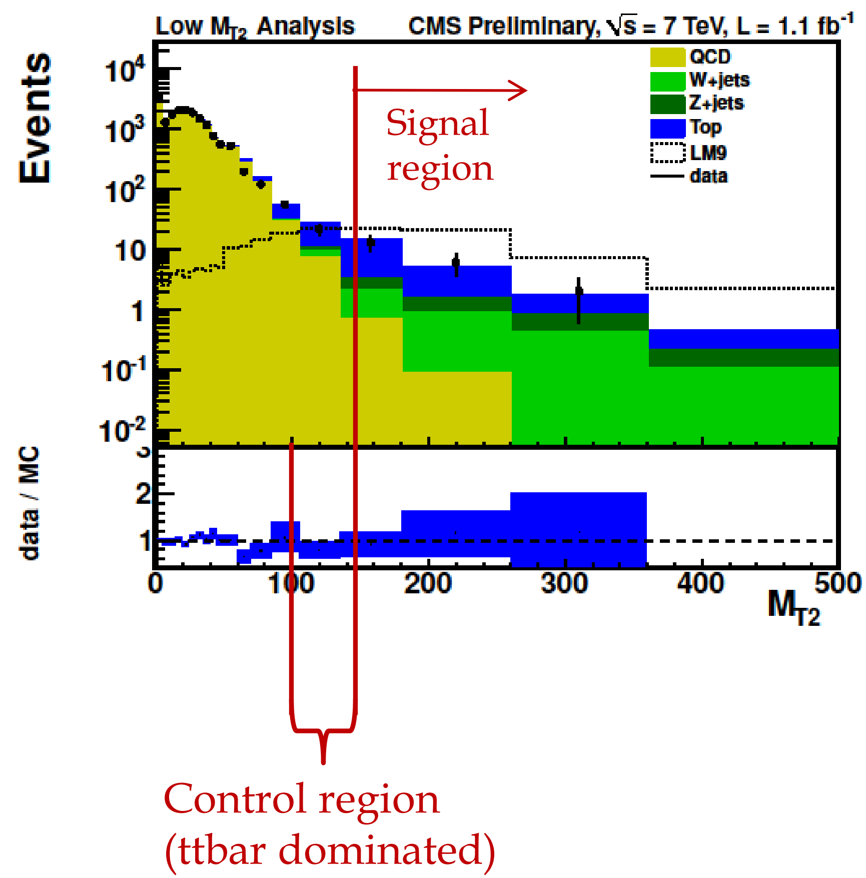
- Large hadronic activity
  - Multiple hard jets
    - ≥4 for MT2 analysis
    - ≥3 for MET analysis
  - Large $H_T = \Sigma_{jets} |p_T|$
    - MT2 analysis: $H_T > 650$ GeV
      - (driven by trigger)
    - MET analysis: $H_T > 350$ (500) GeV for Loose (Tight) branch
- Veto isolated leptons (e,μ)
  - Cut down on ttbar, W
- Veto events with small Δϕ(jet, MET)
  - Reject QCD with fake MET
- Large missing energy
  - Either directly as MET or recast as MT2
    - MT2 analysis: MT2>150 GeV
    - MET analysis: MET>200 (300) GeV for Loose (Tight)





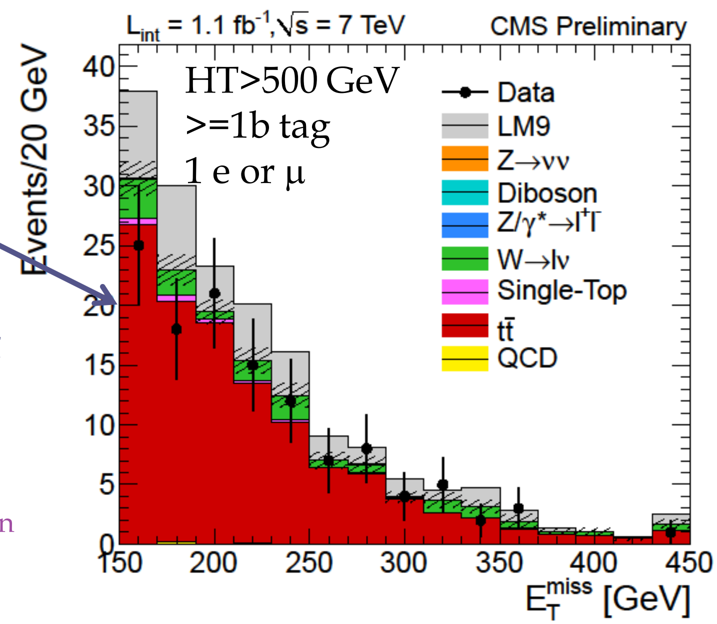
MT2 plus b-tag

- b-tagging allows for looser MT2 selection
  - MT2>150 GeV (400 GeV in inclusive analysis)
    - Looser cut enhances sensitivity to some models
      - e.g. CMSSM test point LM9 has relatively soft missing energy distribution
- ttbar background estimate:
  - Use ttbar-dominated sample with 1 electron or 1 muon
    - Use MC efficiency numbers to move from 1 lepton → 0 lepton sample
      - Perform this method in control region 100<MT2<150 GeV
        - Compare prediction for 0 lepton sample to MC for 0 lepton sample; level of agreement quantified in the uncertainty
    - Scale from control region to signal region using MC, propagating uncertainties
- Result
  - Background = 10.6 ± 1.9 ± 4.8 events
  - Observed = 19 events
  - (LM9 signal = 42.9 events)



MET+b tag: background methods

- ttbar+W+t
  - Find MET shape in 1 lepton control sample
  - Normalize to ttbar-dominated region at medium MET (150<MET<200 GeV)
    - $(N_{\text{high MET}})^{0\text{ lepton}} = (N_{\text{medium MET}})^{0\text{ lepton}} (N_{\text{high MET}}/N_{\text{medium MET}})^{1\text{ lepton}}$
  - Cross-check with independent method



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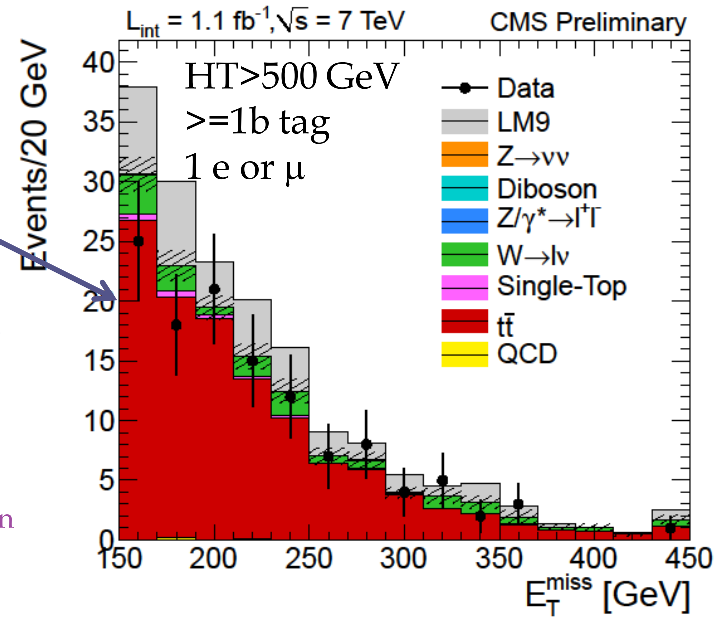
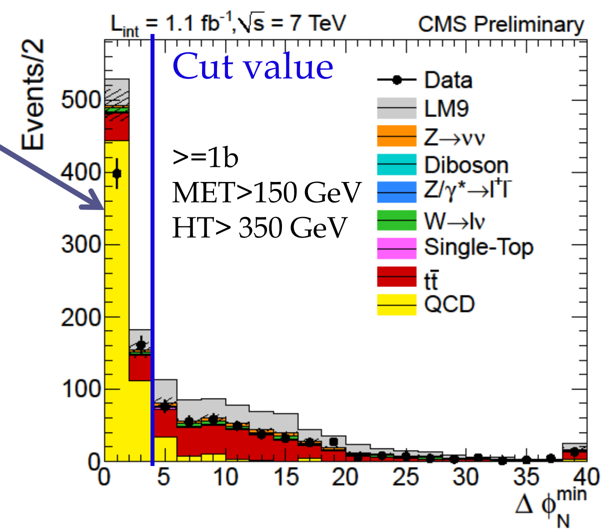
  - Cross-check with independent method
- QCD
  - Novel resolution-normalized Δϕ(j,MET) variable and MET are uncorrelated
    $(N_{\text{pass}})^{\text{high MET}} = (N_{\text{fail}})^{\text{high MET}} (N_{\text{pass}}/N_{\text{fail}})^{\text{low MET}}$





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  - Cross-check with independent method
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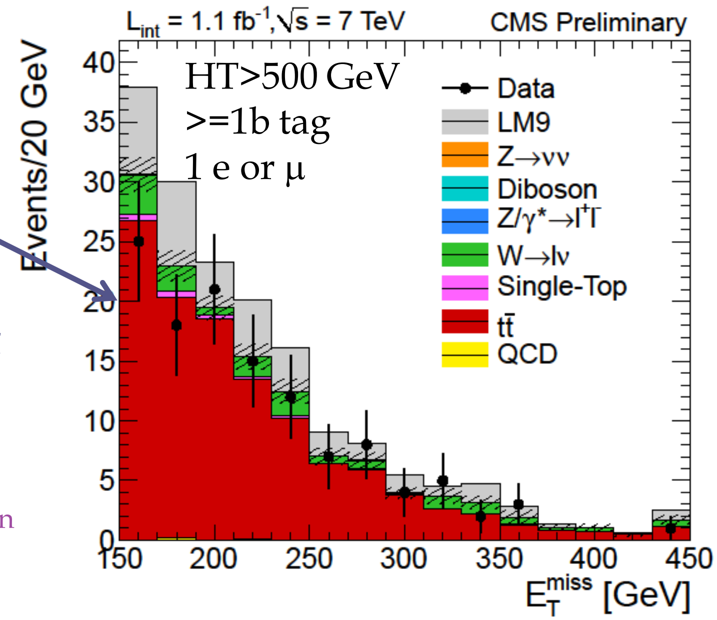
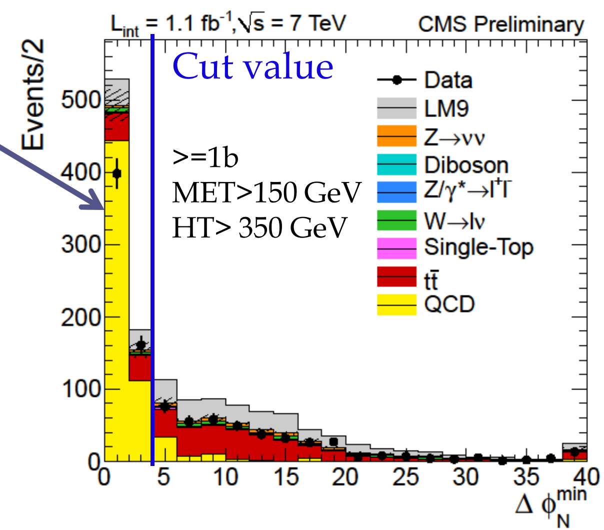
$$(N_{\text{pass}})^{\text{high MET}} = (N_{\text{fail}})^{\text{high MET}} (N_{\text{pass}}/N_{\text{fail}})^{\text{low MET}}$$

- Z→νν
  - Data-driven translation of Z→ll control samples





MET+b: results

- Background predictions agree with data

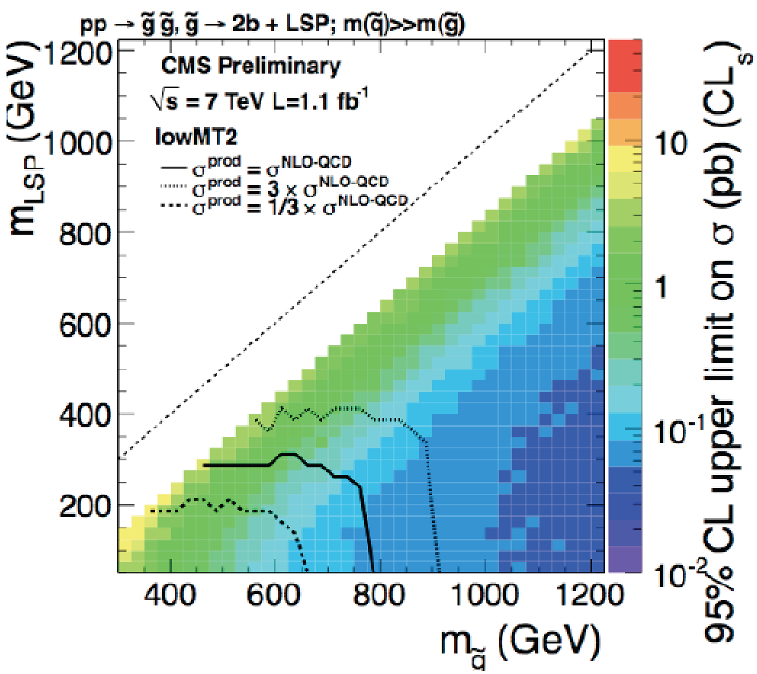
	">=2b Loose" HT>350 GeV MET>200 GeV	">=1b Tight" HT>500 GeV MET>300 GeV
	≥ 2 b	≥ 1 b
QCD	$0.0 \pm 0.4^{+5.8}_{-0.0}$	$0.2 \pm 0.2^{+0.5}_{-0.2}$
top and W+jets	$24 \pm 7 \pm 5$	$13 \pm 5 \pm 4$
top and W+jets cross-check	—	$17.0 \pm 5.7 \pm 2.1$
$Z \to \nu\overline{\nu}$	$2.6 \pm 2.9 \pm 2.0$	$5.0 \pm 1.6 \pm 2.0$
Total SM	$25.8 \pm 7.4^{+7.8}_{-5.2}$	$18.2 \pm 5.3 \pm 4.5$
Data	30	20
SM MC prediction	35.7 ±1.3	25.1 ± 1.6
LM9 (CMSSM) signal	60.0 ±2.5	27.7 ± 2.2

Not shown here: results of ">=1b Loose" and ">=2b Tight" selections.
→Also good agreement between SM prediction and data.

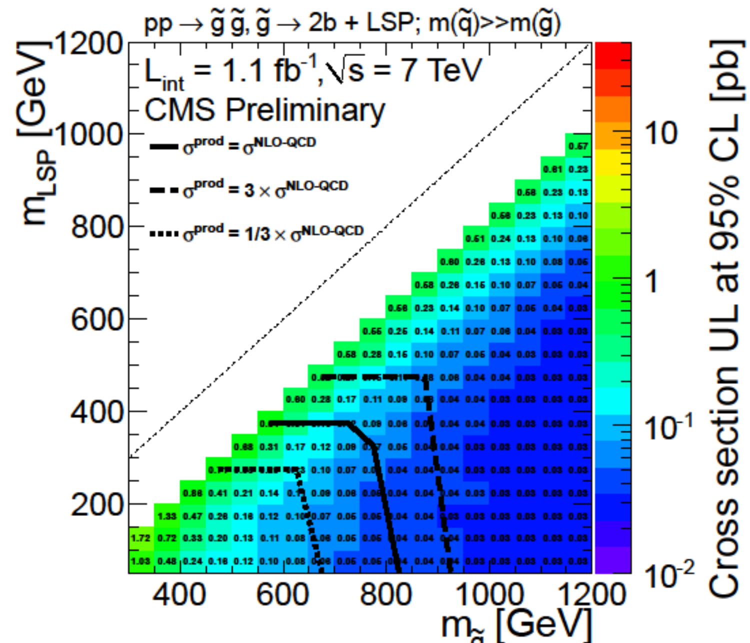
Interpretation in Simplified Models

- Simple topological model
  - g~g~ → bbX~ bbX~
    - Exclusive production and decay
  - Set an upper limit on the cross section as function of $m_{g\sim}$, $m_{X\sim}$
    - (Also get excluded region based on NLO cross section)

MT2+b



MET+b

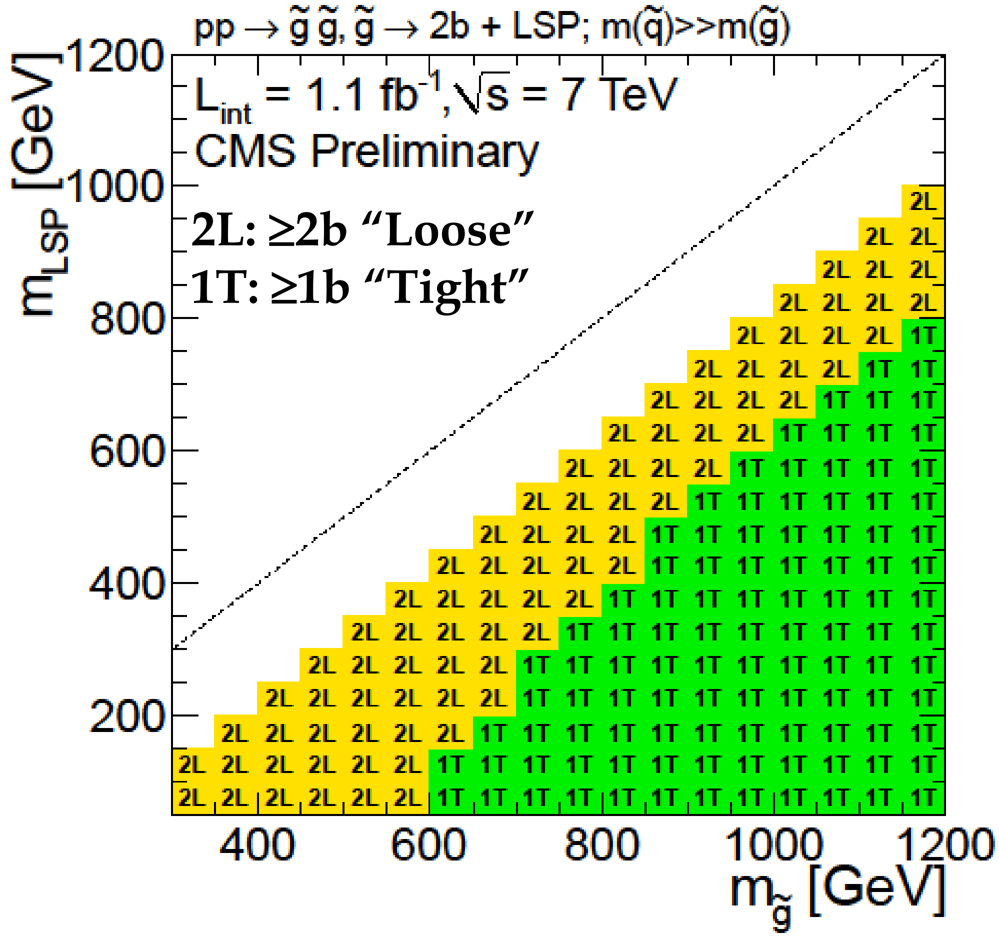


→**Similar sensitivity**; MET+b does better in regions closer to the diagonal

Note on kinematics and selections

- Simplified models have widely varying kinematics by construction
  - Heavy gluino, light LSP gives high p_T daughters → hard jets and lots of MET
  - Nearly degenerate gluino, LSP → soft jets and little MET
    - Challenging! Favors looser selections
- In MET+b, show the limit at each point as determined by the best **expected** limit
  - "expected" limit is derived from data-driven background estimates, but without using the observed data counts in the signal region
  - The limit you would expect if your observed data exactly matched your background estimate

MET+b: which selection is best



b+MET: Future directions

- Expect many more SUSY searches to add a b-tag requirement in the future
  - As advertised, the first of these is being presented tomorrow by Slava Krutelyov
  - The analyses shown here, plus others, are being updated on the full 2011 dataset
    - Key new developments:
      - Higher jet and/or b-tag multiplicity
      - More sophisticated analysis (multiple exclusive bins)
    - Challenges:
      - Dealing with higher trigger thresholds and pileup at the end of the 2011 run
        - Pileup even worse in 2012 – a number of strategies are being pursued (particle flow and PU corrections in trigger)

Extra slides

γ+MET: p_T spectrum reweighting

- Details on diphoton QCD estimate
  - QCD topology is EM objects (photons or electrons or photon fakes) with recoiling jets
    - Find PF jets associated with EM objects
    - Make a vector sum of the momenta of those PF jets
    - p_T is the transverse part of that vector sum
  - Plot that p_T spectrum for ff, $\gamma\gamma$ samples
    - Reweight ff sample to match the $\gamma\gamma$ p_T spectrum
  - Notes:
    - Using PF jets associated with EM objects found to do a better job than using the EM objects themselves (to get the right hadronic energy content)
    - Fake MET is dominated by the recoiling jets
      - This is true for both the signal ($\gamma\gamma$) events and events with fake photons
- 1γ analysis:
  - Similar procedure, except no need for vector sum

γ+MET: background summary

Table 2: The number of events with $E_T^{miss} \geq 100$ GeV from $\gamma\gamma$, ff, and $Z \to ee$ as well as the total number of background events with $E_T^{miss} \geq 100$ GeV using the ff data. We also show the contributions to the errors due to the re-weighting technique and normalization.

Type	Events	scal. error	norm. error
$\gamma\gamma$ candidates	11		
ff QCD background	10.1 ± 4.2	± 0.3	± 0.03
ee QCD background	14.7 ± 3.1	± 0.1	± 0.03
EWK background	2.9 ± 1.0	± 0.0	± 0.9
Total background (ff)	13.0 ± 4.3		

Table 3: Resulting event yields for the $\geq$1 photon + $\geq$2 jet selection for three different signal regions ($E_T^{miss} > 100/200/350$ GeV). The FSR/ISR statistical errors are due to limited MC statistics.

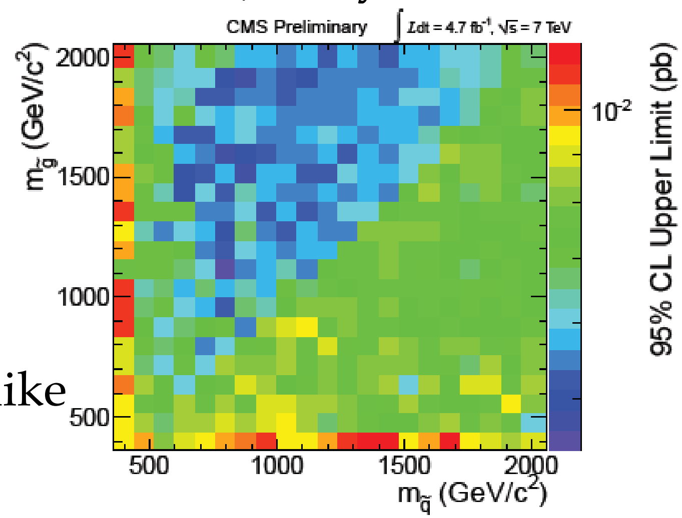
	$E_T^{miss} \geq 100$ GeV			$E_T^{miss} \geq 200$ GeV			$E_T^{miss} \geq 350$ GeV		
$\geq 1\gamma$, ≥ 2 jets		(stat.)	(syst.)		(stat.)	(syst.)		(stat.)	(syst.)
QCD (from data)	607.7	±46.7	±54.0	90.7	±16.4	±9.9	6.8	±4.1	±0.8
$e \to \gamma$ (from data)	17.2	±0.3	±7.2	3.5	±0.2	±1.5	0.4	±0.01	±0.2
FSR/ISR(W,Z)	27.6	±3.2	±27.6	10.4	±2.0	±10.4	1.6	±0.8	±1.6
FSR/ISR($t\bar{t}$)	3.8	±0.9	±3.8	0.8	±0.4	±0.8	< 0.01	< 0.01	< 0.01
total SM estimate	656.4	±46.9	±92.7	105.5	±16.5	±22.6	8.7	±4.2	±2.5
Data	615			63			4		

γ+MET: Interpretation in simplified models

- NLSP fixed to 375 GeV

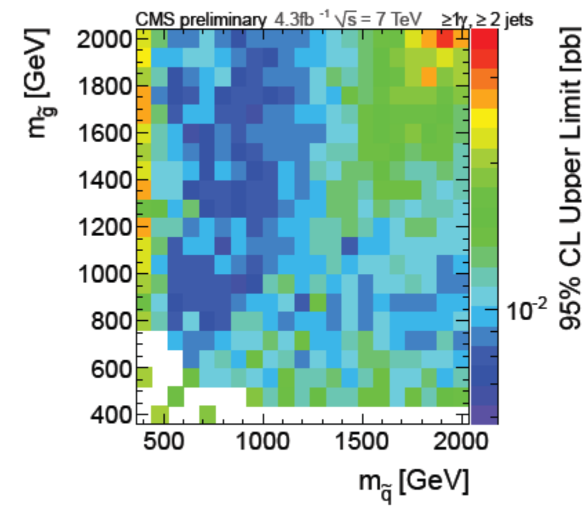
95% CL upper limits on the signal cross-section

2γ analysis

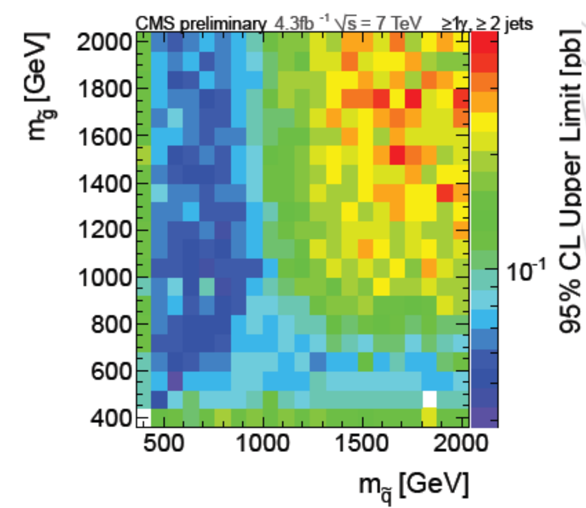


Bino-like

1γ analysis



Wino-like



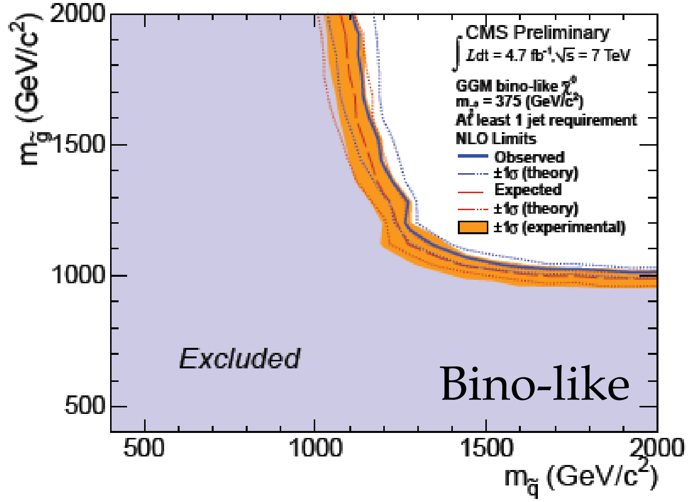
J. Thompson, Cornell 17 March 2012

γ+MET: Interpretation in simplified models

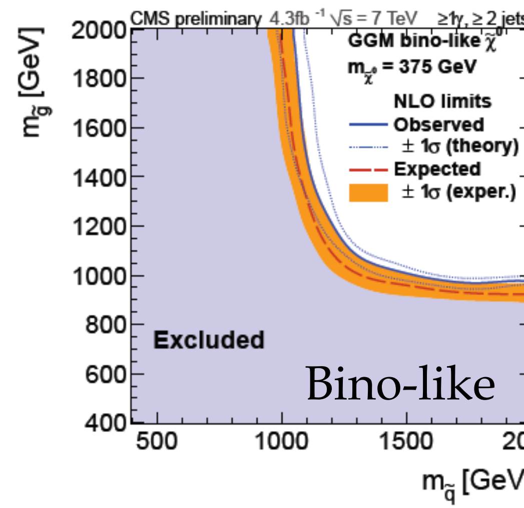
- NLSP fixed to 375 GeV

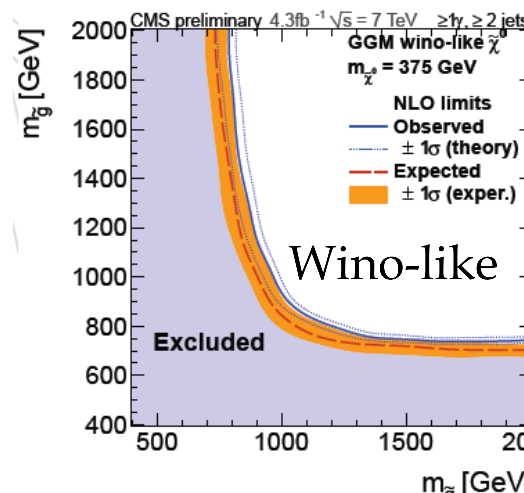
Exclusion contours based on UL values on previous slide

2γ analysis



1γ analysis

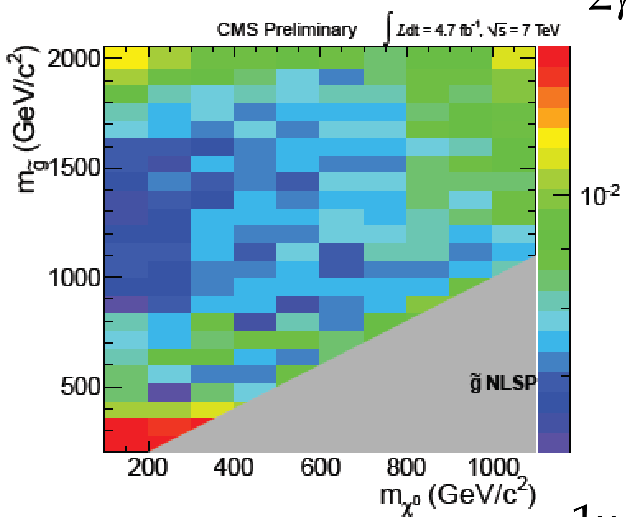


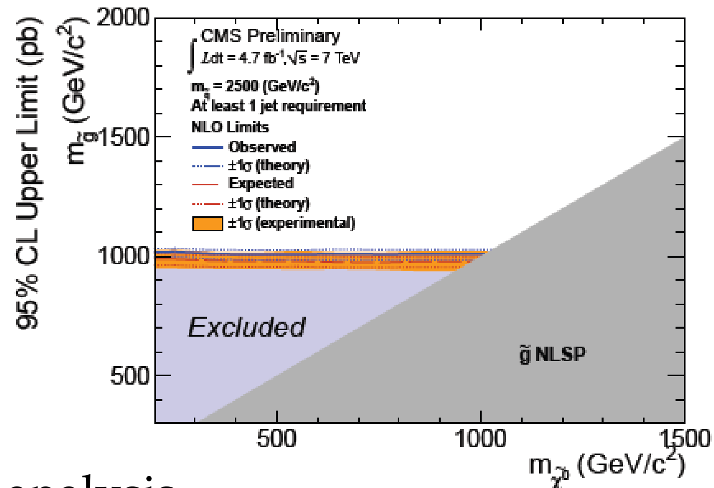


γ+MET: bino-like NLSP

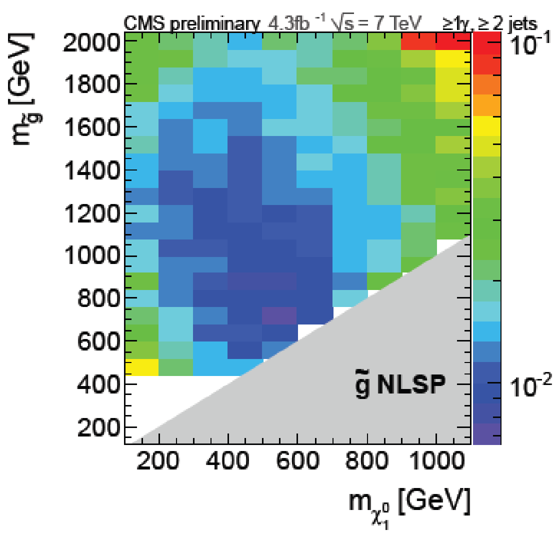
Heavy squarks ($m_{\tilde{q}}$=2500 GeV)

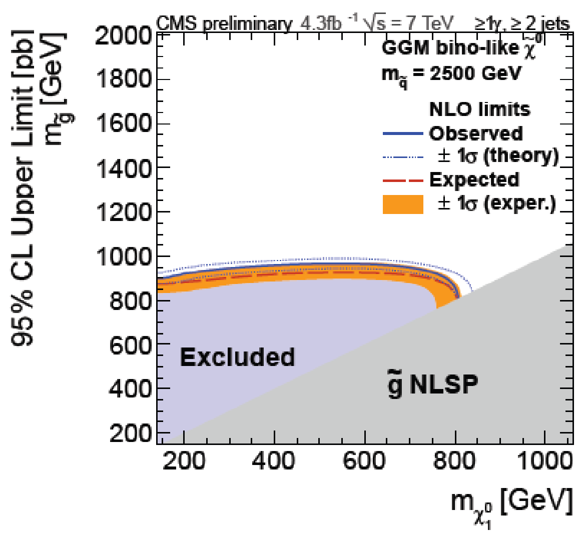
2γ analysis





1γ analysis





γ+MET: Universal Extra Dimensions

- Lightest Kaluza-Klein particle (KK photon) decays to photon+gravitino
  - 2γ + MET final state

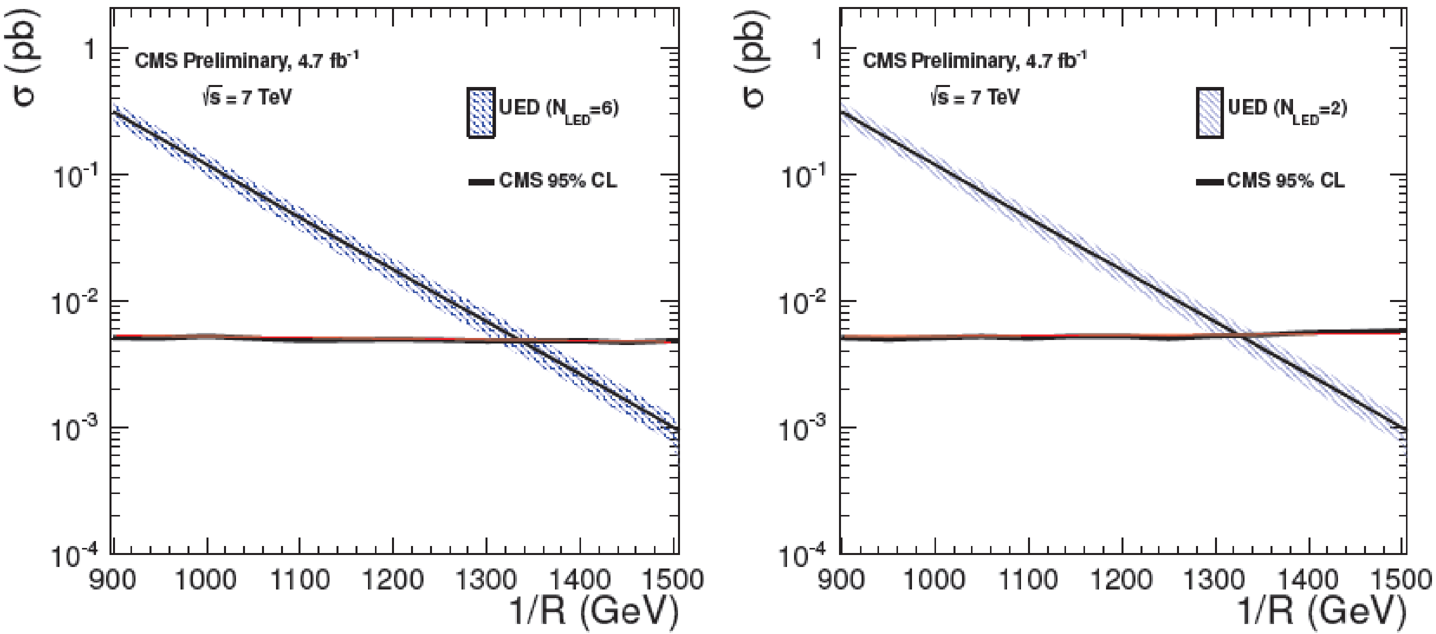
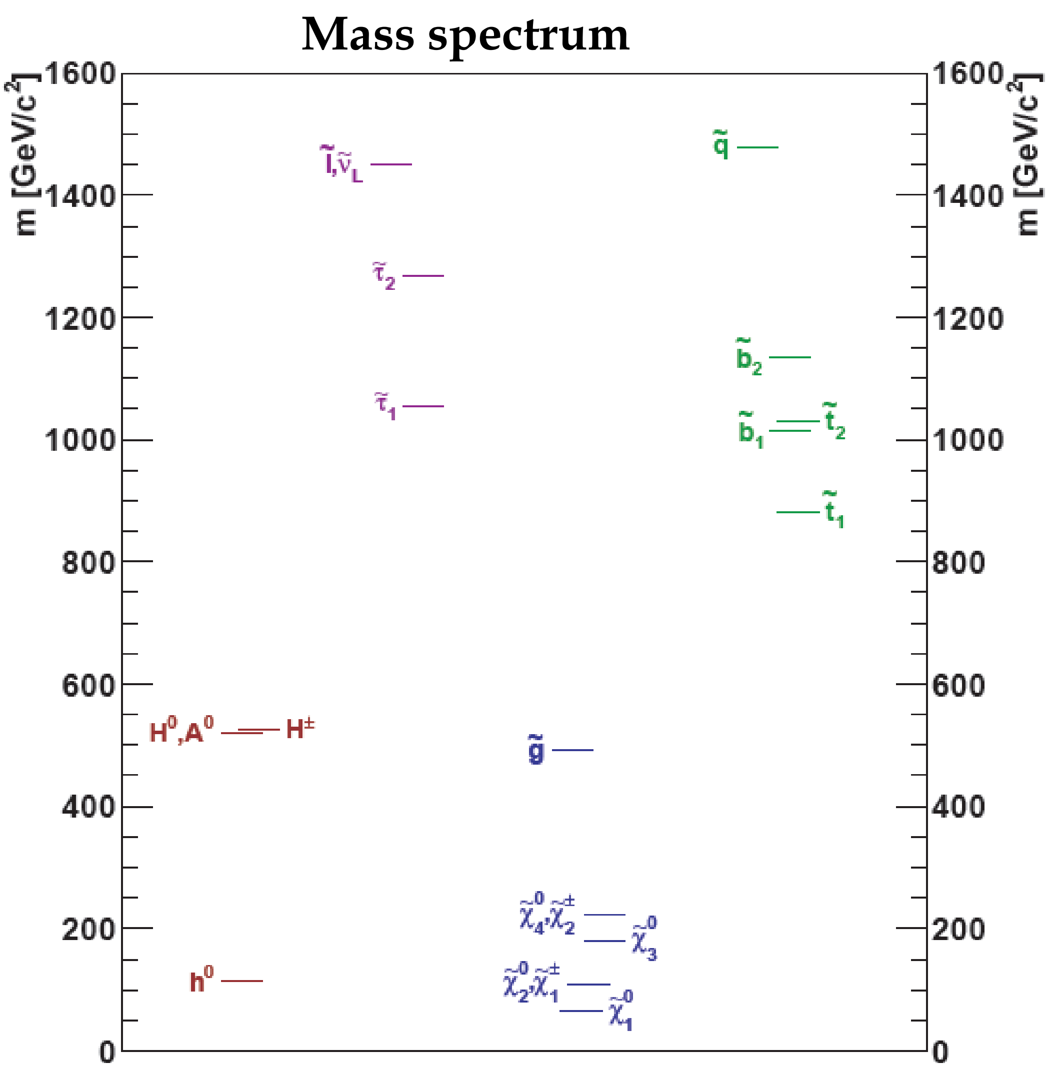


Figure 7: The UED cross section upper limit for 6 (left), and 2 (right) LEDs at the 95% C.L. is compared with UED LO production cross sections. Intersection of the central cross section value implies exclusion of all values of $1/R < 1335$ (1323) GeV for 6 (2) LEDs. The shaded region shows uncertainty due to PDFs and renormalization scale.

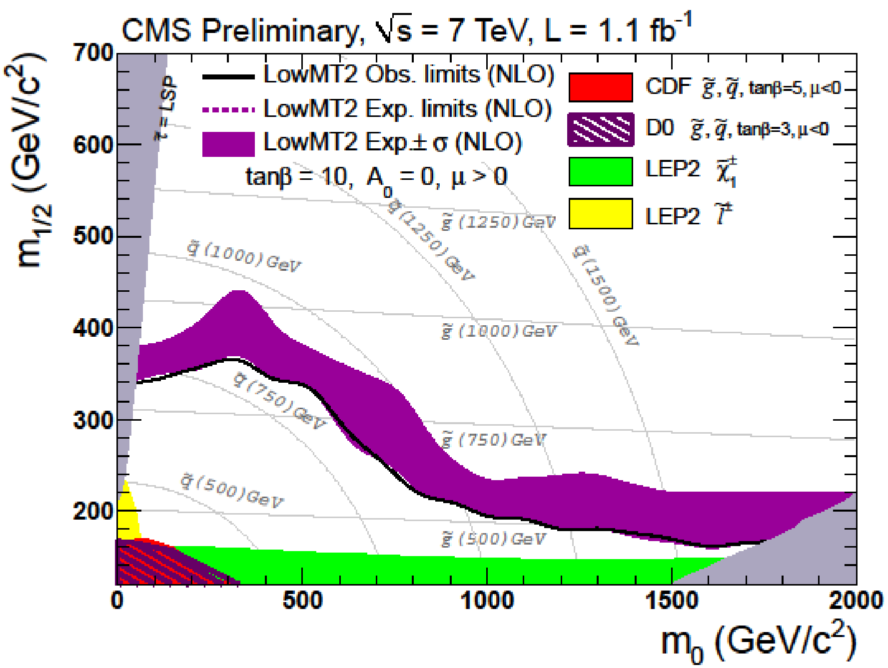
Details of signal point "LM9"

- High m_0, low $m_{1/2}$, high tan β
  - m_0=1450 GeV
  - $m_{1/2}$=175 GeV
  - A_0=0 GeV
  - tan β=50
  - μ>0
- Light gluino, heavy squarks
  - 3rd generation SM from decays of gluinos

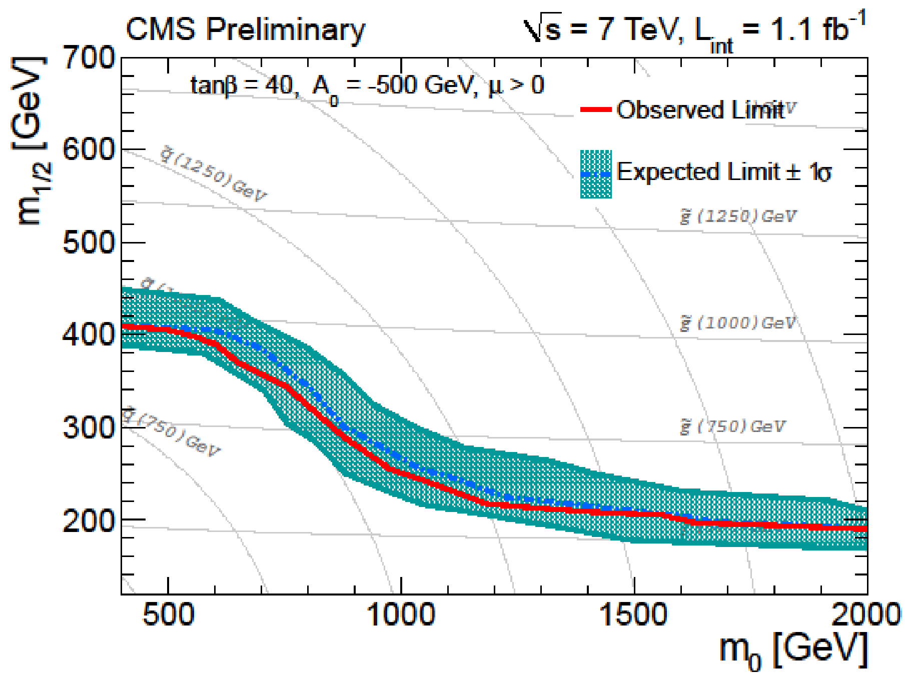


b+MET: Comparison of results in the CMSSM

MT2+b



MET+b



Note: >=1b "Tight" selection gives best *expected* limit everywhere in CMSSM, so we focus on that result

Note: MT2+b is tanβ=10 while MET+b is tanβ=40

→ignoring this difference, limits are similar

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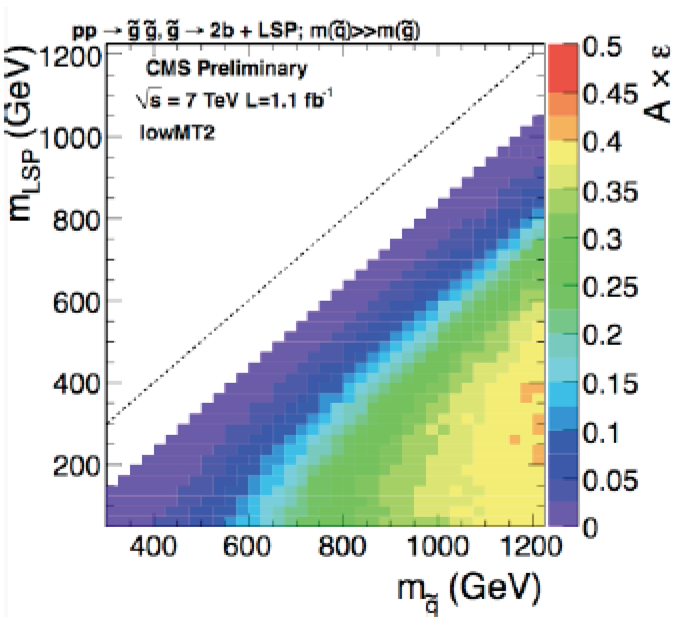
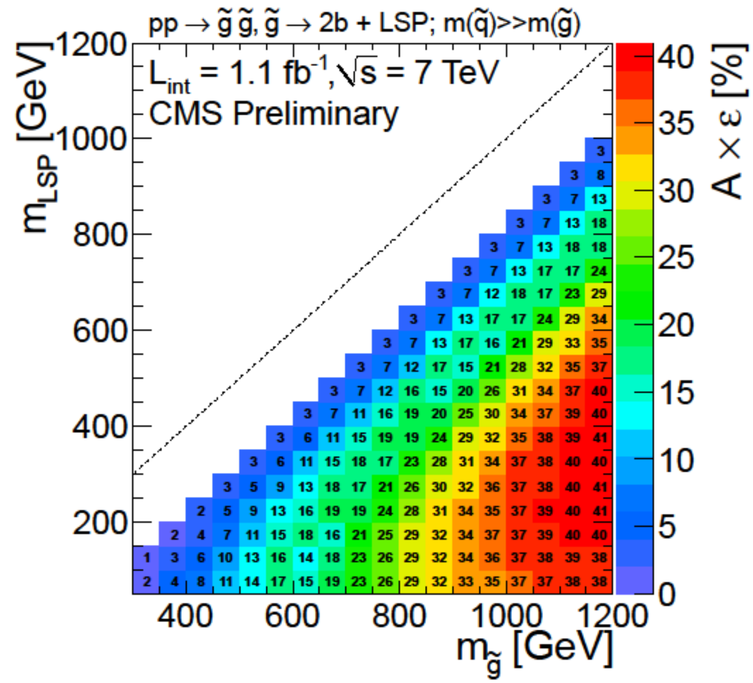
b+MET: Signal efficiency in 4b model

MT2+b



MET+b



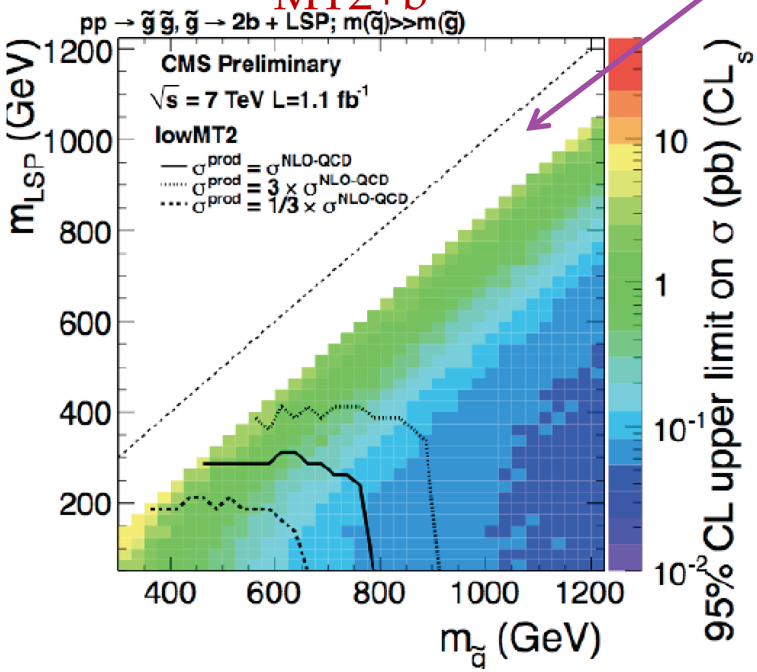
Shows efficiency of the selection used to make UL plot (best expected limit)

b+MET: Treatment of ISR

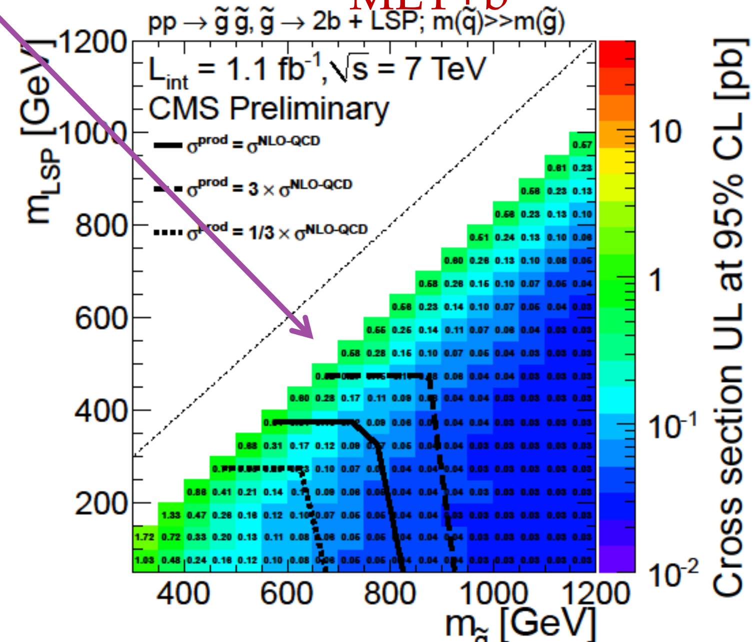
Note: Region very near the diagonal is very sensitive to ISR.

At the moment we do not consider a systematic uncertainty due to ISR in these analyses, so we do not show results in this region.

MT2+b



MET+b



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b+MET: MC background expectations

MT2+b

Table 4: Expected background event yields and observed number of events in data for all relaxed cuts after preselection for events with at least one b-tagged jet.

Process	QCD	W+jets	Z+jets	Top	Other	Total Bkg.	data
After full selection	16857.5	27.8	14.8	445.3	24.6	17370	17370
MT2 > 80 GeV	58.8	7.5	5.5	61.4	0.0	133.3	131
MT2 > 100 GeV	10.1	5.2	4.6	36.9	0.0	56.9	49
MT2 > 120 GeV	3.0	3.6	3.9	23.3	0.0	33.8	26
MT2 > 135 GeV	0.8	2.7	2.6	15.8	0.0	21.9	21
MT2 > 150 GeV	0.2	2.2	1.8	10.8	0.0	15.0	19

Table 1: Number of data events and corresponding MC predictions for the loose ($H_T > 350$ GeV, $E_T^{miss} > 200$ GeV) and tight ($H_T > 500$ GeV, $E_T^{miss} > 300$ GeV) signal selections. MC results for the CMSSM test point LM9 are also shown. The MC uncertainties are statistical. The normalization is to 1143 pb^{-1}.

MET+b

	$(H_T, E_T^{miss}) > (350, 200)$ GeV		$(H_T, E_T^{miss}) > (500, 300)$ GeV	
	≥ 1 b-jets	≥ 2 b-jets	≥ 1 b-jets	≥ 2 b-jets
Data	155	30	20	5
Total SM	183 ± 5	35.7 ± 1.3	25.1 ± 1.6	4.54 ± 0.37
$t\bar{t}$	122 ± 2	28.9 ± 0.7	14.7 ± 0.8	3.49 ± 0.24
Single top	4.54 ± 0.38	0.77 ± 0.09	0.59 ± 0.15	0.12 ± 0.04
W+Jets	17.0 ± 2.1	1.21 ± 0.45	4.20 ± 1.28	0.42 ± 0.28
$Z \to \nu\bar{\nu}$	22.5 ± 0.5	2.23 ± 0.10	4.25 ± 0.20	0.43 ± 0.04
$Z/\gamma^* \to \ell^+\ell^-$	0.17 ± 0.17	0.01 ± 0.01	0	0
Diboson	0.69 ± 0.07	0.10 ± 0.02	0.10 ± 0.02	0.006 ± 0.002
QCD	16.4 ± 3.9	2.5 ± 0.9	1.28 ± 0.40	0.08 ± 0.01
SUSY LM9	147 ± 5	60.0 ± 2.5	27.7 ± 2.2	10.1 ± 1.0

b+MET: Signal efficiency systematics

Table 17: Systematic uncertainties, in percent, on the efficiency of the LM9 signal. The "Other" category includes the trigger efficiency, the lepton veto, and the anomalous E_T^{miss} terms.

	Loose search region		Tight search region	
Source	≥ 1 b	≥ 2 b	≥ 1 b	≥ 2 b
Jet energy scale	7.7	8.6	12.1	13.7
Jet energy resolution	0.1	0.3	3.0	4.2
Unclustered energy	2.0	1.6	5.7	7.5
Pileup	3.4	3.1	4.3	4.2
b-tagging efficiency	6.5	15.8	7.1	17.2
Parton distribution functions	11.1	11.2	11.8	12.1
Other	3.5	3.5	3.5	3.5
Luminosity	4.5	4.5	4.5	4.5
Total uncertainty	16.5	22.2	20.7	27.5

→JES, unclustered energy, b-tag eff, PDF are evaluated point-by-point across the CMSSM and simplified model planes

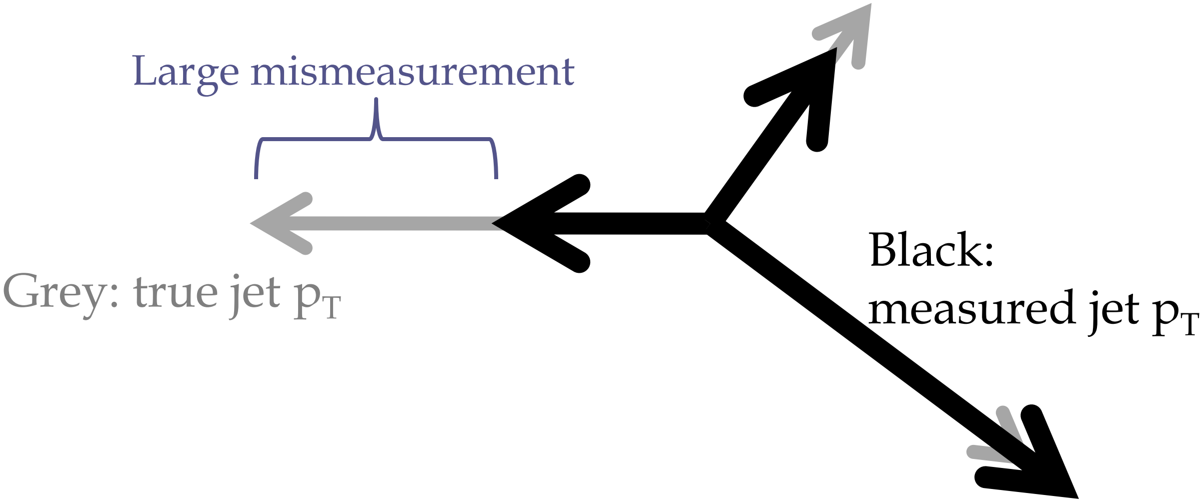
→Other uncertainties are fixed to LM9 values.

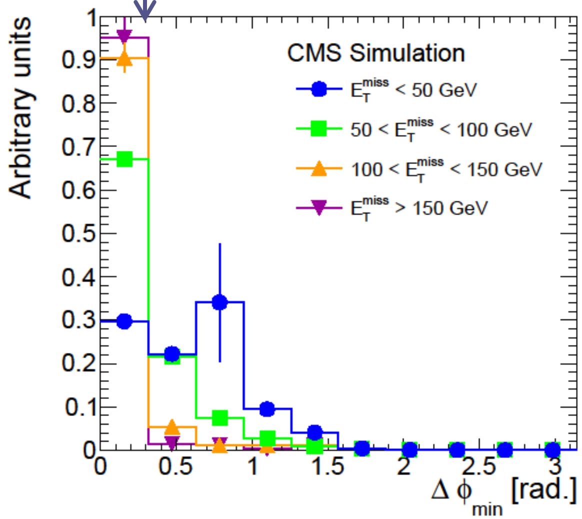
b+MET: Event selection details

- Jets: in both cases, particle flow R=0.5 anti-kT jets
  - MT2+b:
    - p_T>20 GeV, $|\eta|$<2.4, passing quality criteria
    - Note that HT is calculated with calorimeter-only jets while all other quantities use particle flow
    - p_T cuts on lead jets
  - MET+b:
    - p_T>50 GeV, $|\eta|$<2.4, passing quality criteria
    - HT is calculated using all jets passing the above requirements
    - For b jets, use p_T>30 GeV
- Leptons (particle flow):
  - p_T>10 GeV
  - $|\eta|$<2.4 (plus veto of barrel/endcap transition for electrons)
  - Various quality and isolation requirements
- $\Delta\phi_{(N)}^{min}$(jet, MET)
  - MT2+b: $\Delta\phi^{min}$>0.3 for all jets pT>20 GeV, $|\eta|$<5
  - MET+b: $\Delta\phi_N^{min}$>4 for lead 3 jets passing criteria given above

b+MET: Event selection: Δϕ(jet, MET)

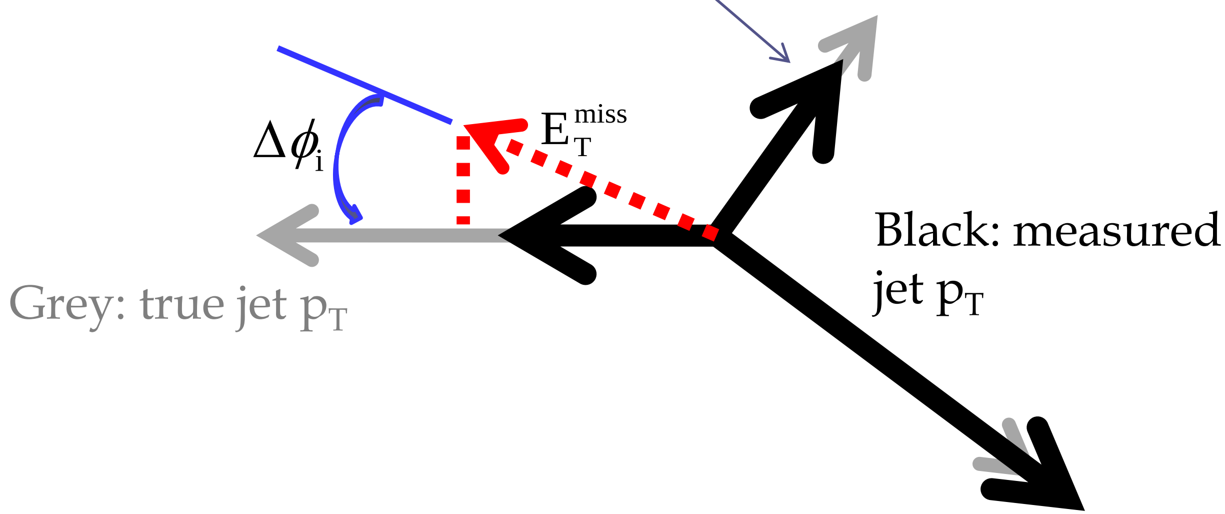
- QCD events can sneak into high MET region when a jet is severely mismeasured
  - Creates fake MET aligned with the jet
- Reject this background with angle Δϕ(jet, MET)
  - In MT2+b, require $\Delta\phi_{min}$(all jets, MET) > 0.3
  - In MET+b, use a slightly different variable
    - (more on the following slides)





Motivation for $\Delta\phi_N$(jet, MET)

- The standard Δϕ(jet, MET) variable is great for rejecting QCD at high MET
  - But it is also highly correlated with MET (and MT2)
- For an event with a very badly measured jet, why is the angle Δϕ(jet, MET) non-zero?
  - The MET direction is smeared by the small mismeasurements of the p_T of the other jets in the event



- This smearing becomes less important as the big mismeasurement (hence MET) increases
→MET and Δϕ(jet,MET) are correlated
- we try to model this and construct an uncorrelated variable

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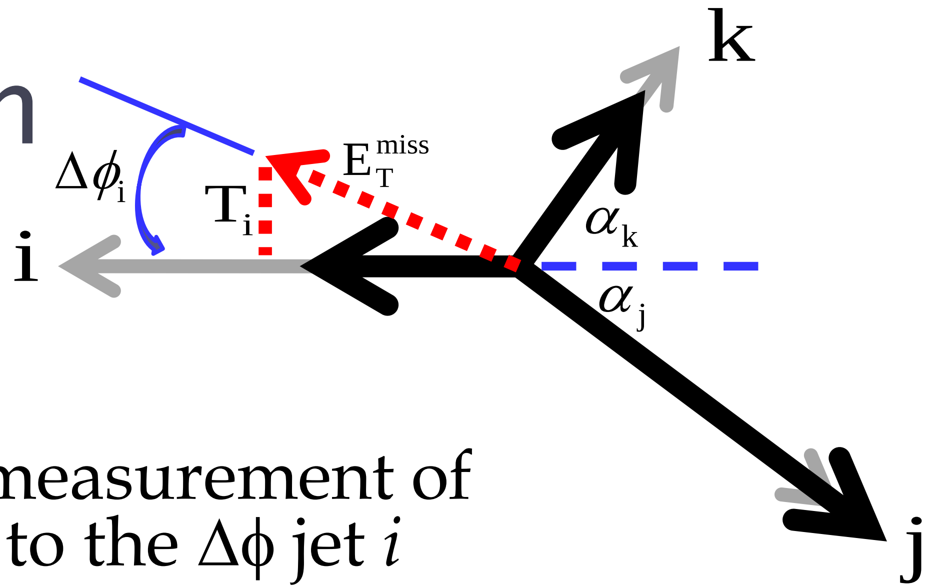
MET+b analysis

$\Delta\phi_N$ construction



- T_i is the component of mismeasurement of other jets that is transverse to the $\Delta\phi$ jet *i*

$$T_i^2 \approx \sum_n \left(\sigma_{pT,n} \sin\alpha_n\right)^2$$

- Use 10% for jet p_T resolution $\sigma_{pT,n}$
  - Cross-checks done to show we are not sensitive to this choice
- $\Delta\phi_{N,i} = \Delta\phi_i / \tan^{-1}(T_i / MET)$
- This new variable is $\Delta\phi_i$ normalized by its resolution

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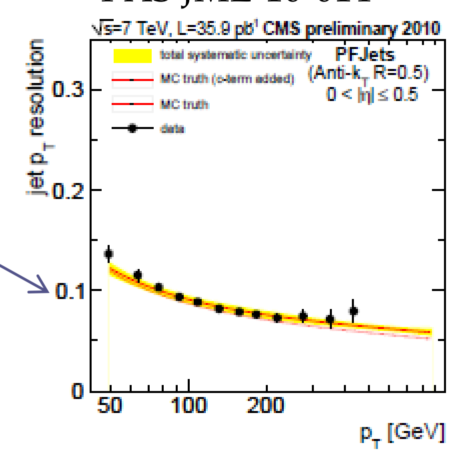
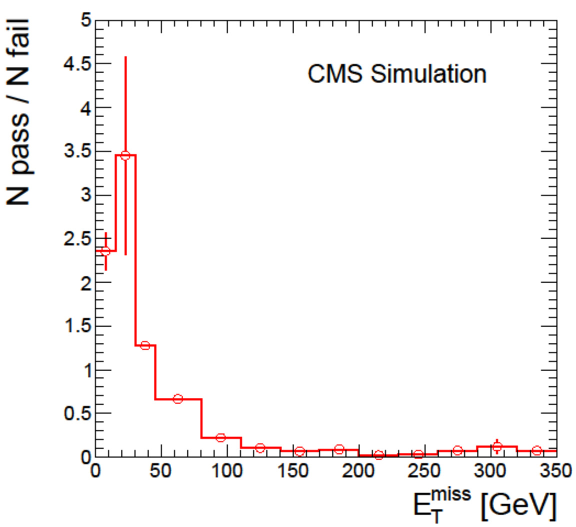


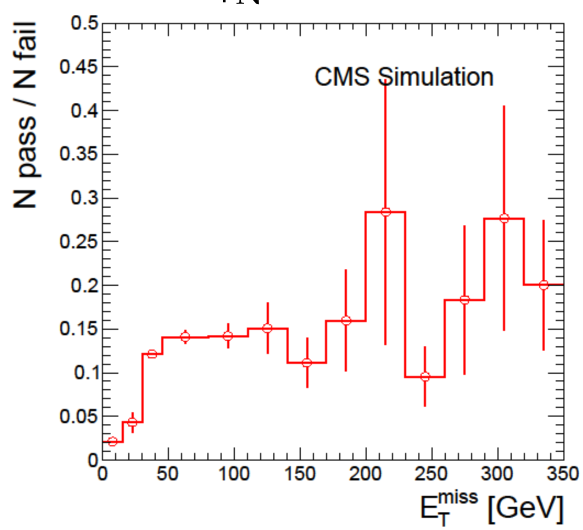
$\Delta\phi$ versus $\Delta\phi_N$

- Plot the ratio of events passing the $\Delta\phi$ cut to the ratio failing it, as a function of MET
  - This is a good way to judge the correlation
    - (flat means uncorrelated)

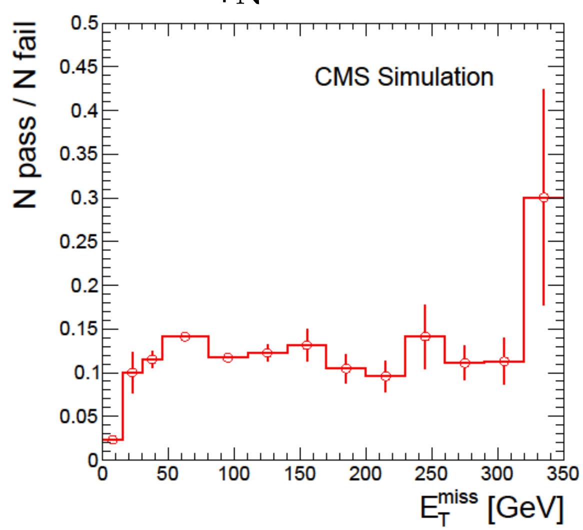
$\Delta\phi^{min}$, >=1b



$\Delta\phi_N{}^{min}$, >=1b



$\Delta\phi_N{}^{min}$, =0b

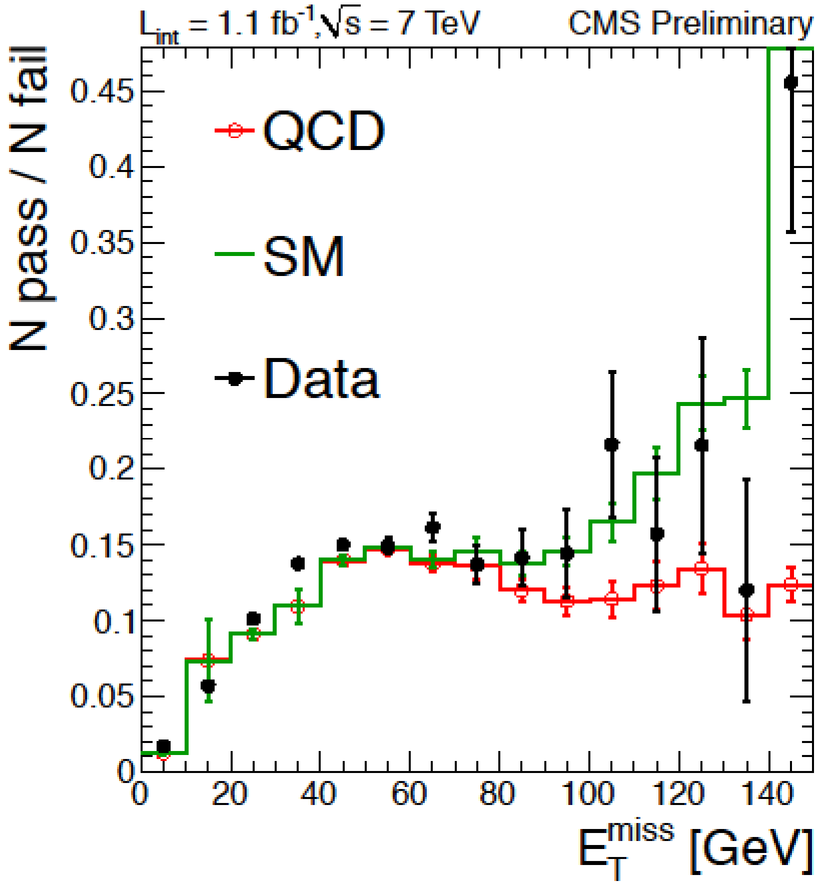


→pass/fail ratio for $\Delta\phi_N{}^{min}$ is ~constant for MET>~30GeV and independent of b tagging.

Lends itself to a simple background estimate (discussed later)

b+MET: QCD method in data

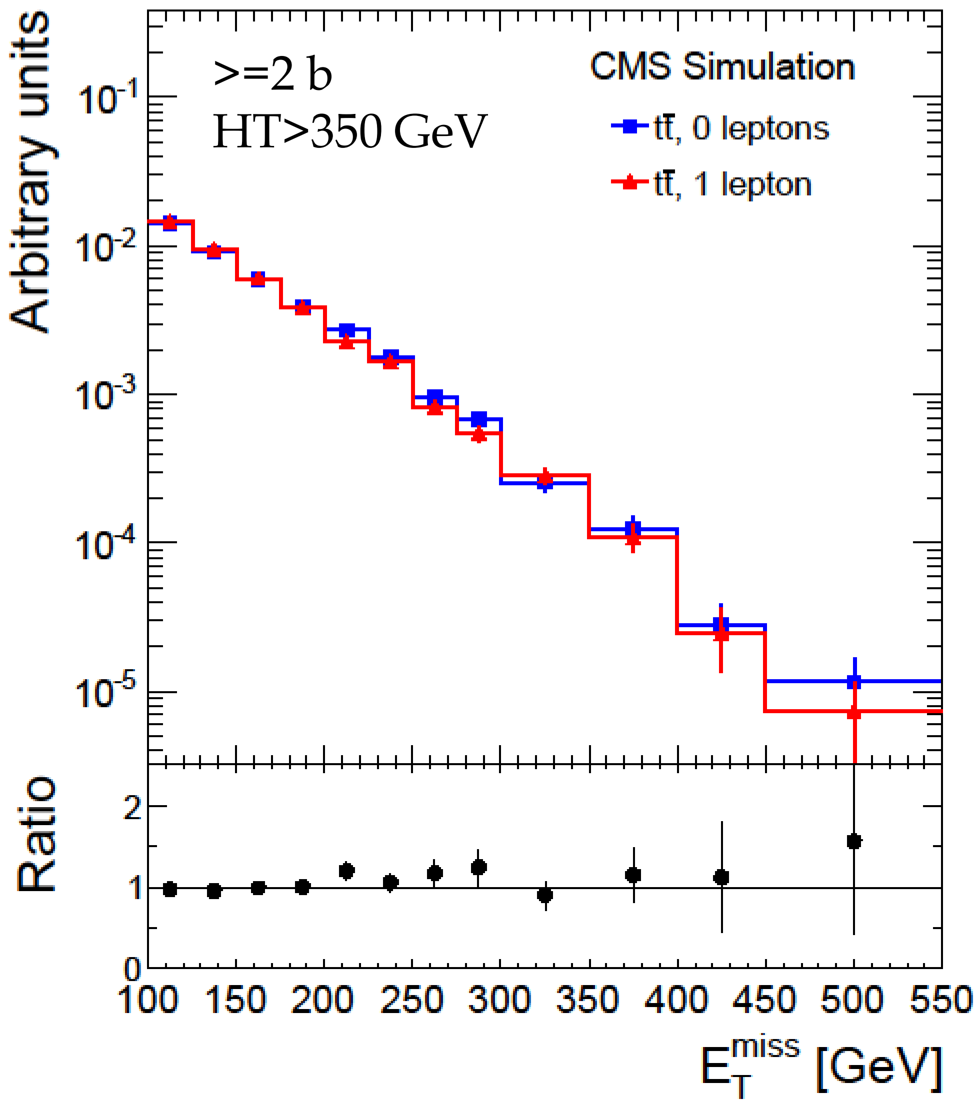
- Pass/fail ratio for $\Delta\phi_N^{min}$
  - Data compared to MC
    - Data collected with a prescaled HT-only trigger
  - 50-100 GeV region used for data-driven estimate



MET+b analysis

b+MET: tt/W/t background method details

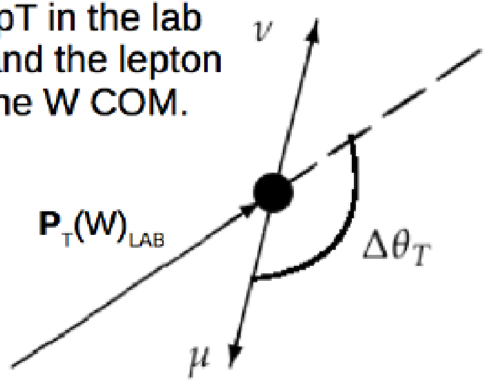
- Method depends on MET spectrum being the same in 1 lepton and 0 lepton samples
  - Checked in MC – works well
    - Have checked many effects that could be different in data and MC and find method should still work well in the data
    - Violation of this assumption is quantified and taken as a systematic error



Cross-check of ttbar+W+t with $\Delta\theta_T$

- For W→e,μ,τ (τ→e,μ) decays
  - Angular distribution of lepton w.r.t. W, $\Delta\theta_T$, depends on W polarization, which is well understood
    - $\Delta\theta_T$ low → lepton is boosted forward, neutrino goes backward→lower MET
    - $\Delta\theta_T$ high→lepton softer and neutrino boosted forward→higher MET
- For W→τ (τ→had) decays
  - Single muon control sample from μ+H_T trigger
  - Transform muon into a τ jet using a response template taken from MC
- For dileptonic decays
  - Dilepton control sample, scaled by an efficiency ratio taken from MC

The angle between the W pT in the lab frame, and the lepton pT in the W COM.



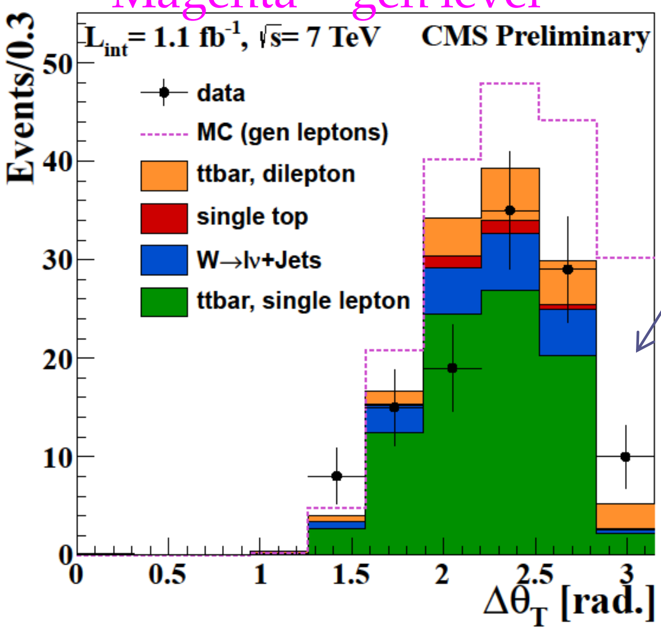
ttbar+W+t cross-check:

Method for decays with e or μ

- Start with single lepton control sample
- Rescale the MET distributions of the SL sample in bins of $\Delta\theta_T$ using scale factors from MC
- Predicts both the shape and normalization of signal sample MET distribution

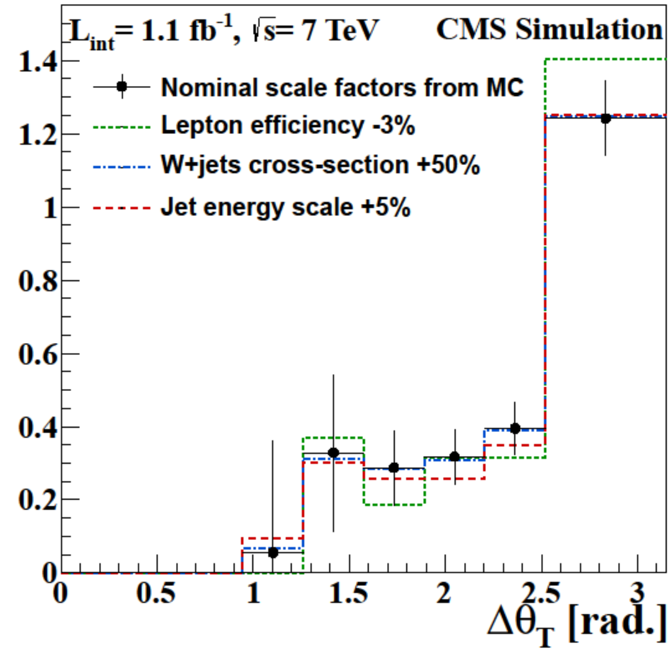
$$SF(\Delta\theta_T) = \frac{\text{N MC gen tt/W/t with 1 lost lepton}}{\text{N SM MC with 1 reco lepton}}$$

Magenta = gen level



Lost leptons

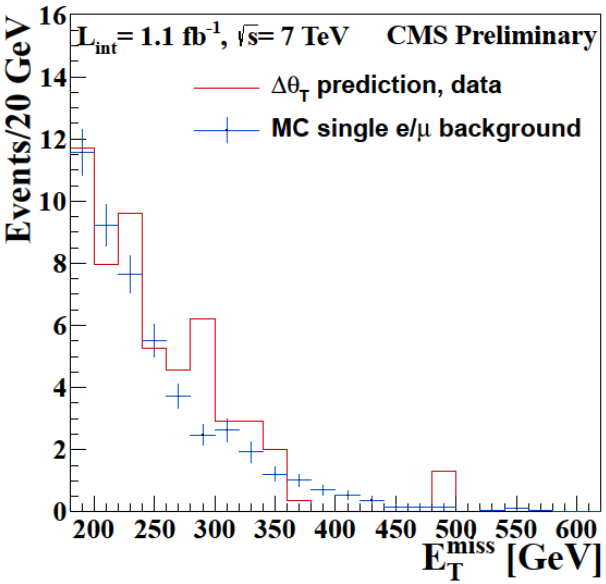
>=1b, MET>150 GeV



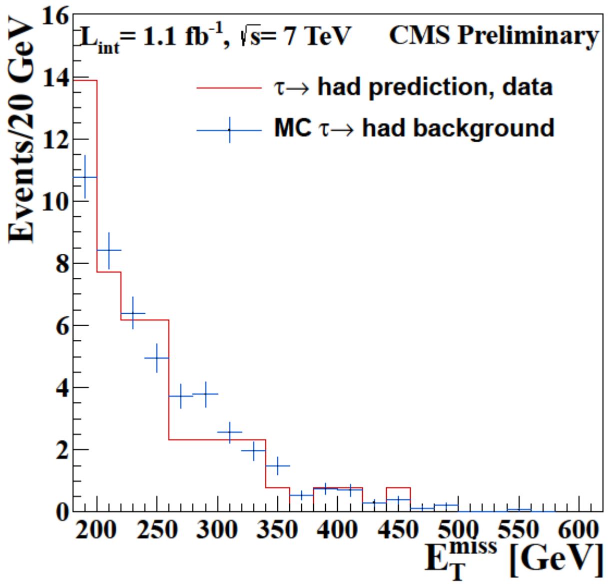
ttbar+W+t cross-check:

MET spectrum predictions

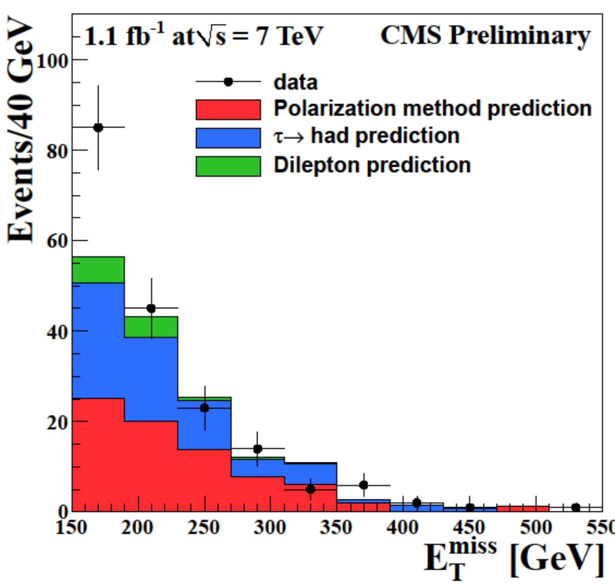
>=1b, Tight (HT>500 GeV) selection



$\Delta\theta_T$ prediction compared to MC shape



$\tau \rightarrow$had prediction compared to MC shape



Overall prediction compared to data

NB: sizable QCD contribution in lowest bin

Note: cross-check done only for Tight selection because trigger requirements preclude doing Loose selection

b+MET: Z→νν method notes

- Z→ll, l=e,μ is simple (efficiency factors mostly straightforward to extract from data) but statistics-limited
  - In loosest selection (>1b, Loose), can directly apply signal region cuts to Z→ll samples
  - In other cases, need to loosen kinematic selections and then scale final estimate using MC
    - This MC scaling has been checked in several ways, including a data-driven method where the nominal MET, HT cuts are used but the b-tagging is loosened, and the (nominal b tagger)/(loose b tagger) factor is taken from a data control sample