Search for SUSY in events with e, μ and τ leptons at CMS

~~13/10/12 Kyoto, Japan, HCP 2012~~

21/01/13 DESY, Hamburg

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OVERVIEW

τ-leptons:

τ-leptons using the razor variables — CMS PAS SUS-11-029 — NEW!

Single-lepton:

Single lepton+b jets — CMS PAS SUS-11-028 arXiv:1211.3143

SS leptons:

SS leptons+b jets — CMS PAS SUS-12-029 — NEW!

More at:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Searches of SUSY with τ leptons

SUSY phenomenology

- **Third generation squarks and sleptons** play a special role in LHC phenomenology since they tend to be the lightest sfermions.

- **stau-neutralino coannihilation** region consistent with the amount of DM observed by the WMAP
  → expect **low p_T τ leptons [1]**

$$\tilde{\tau}_1 \to \tau \tilde{\chi}_1^0 \; (M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} \sim 10 \text{ GeV})$$

In GMSB:

- The stau is the next-to-lightest supersymmetric particle.

[1] Determining the Dark Matter Relic Density in Minimal Supergravity stau-neutralino Coannihilation Region at the LHC
http://dx.doi.org/10.1103/PhysRevLett.100.231802

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τ-leptons

- **Hadronically decaying** tau leptons are considered.

Reconstructed with the **Hadron Plus Strips (HPS) algorithm**:

- Strips of clustered EM energy to reconstruct neutral pions.
- Combined with charged hadrons within jets to reconstruct the main tau decay modes.

- Jet rejection within a cone of R=0.3

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τ leptons with razor variables

NEW!

τ leptons with razor variables

τ leptons :

- ≥1 τ lepton with p_T>15 GeV

Light lepton selection:

- 1 e || 1 μ with pT>14 GeV

Jets:

- Reconstructed with the anti-k_T algorithm with R=0.5
- Jets with p_T>40 GeV and |η| < 3 are grouped into two **megajets**.

Razor variables

Based on the generic process of pair production of two heavy particles.

The 2-megajet combination which yields the **lowest sum** of masses squared is chosen.

The **M_R** variable is constructed from the megajets

$$M_R \equiv \sqrt{(p_{j1} + p_{j2})^2 - (p_z^{j1} + p_z^{j2})^2}$$

Characterizes the presence of a heavy particle mass scale

The **M_R^T** variable is defined as:

$$M_T^R = \frac{\sqrt{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}}{2}$$

From which the razor dimensionless ratio is obtained:

$$R \equiv \frac{M_T^R}{M_R}$$

Analysis strategy:

Several regions (boxes) are defined

MU-TAU box (≥1 μ && ≥ 1 τ && 0 e)

MU box (≥1 μ && 0 τ && 0 e)

ELE-TAU box (≥1 e && ≥ 1 τ && 0 μ)

ELE box (≥ 1 e && 0 τ && μ)

M_R>300 GeV and R^2 >0.11 is imposed.

Avoid trigger inefficiencies

The R^2-M_R plane is separated into two regions, the fit region and the signal region.

Unbinned, extended, ML fit to extract SM shape parameters.

Six signal regions are defined where to quantify the data/MC agreement.

Analysis strategy:

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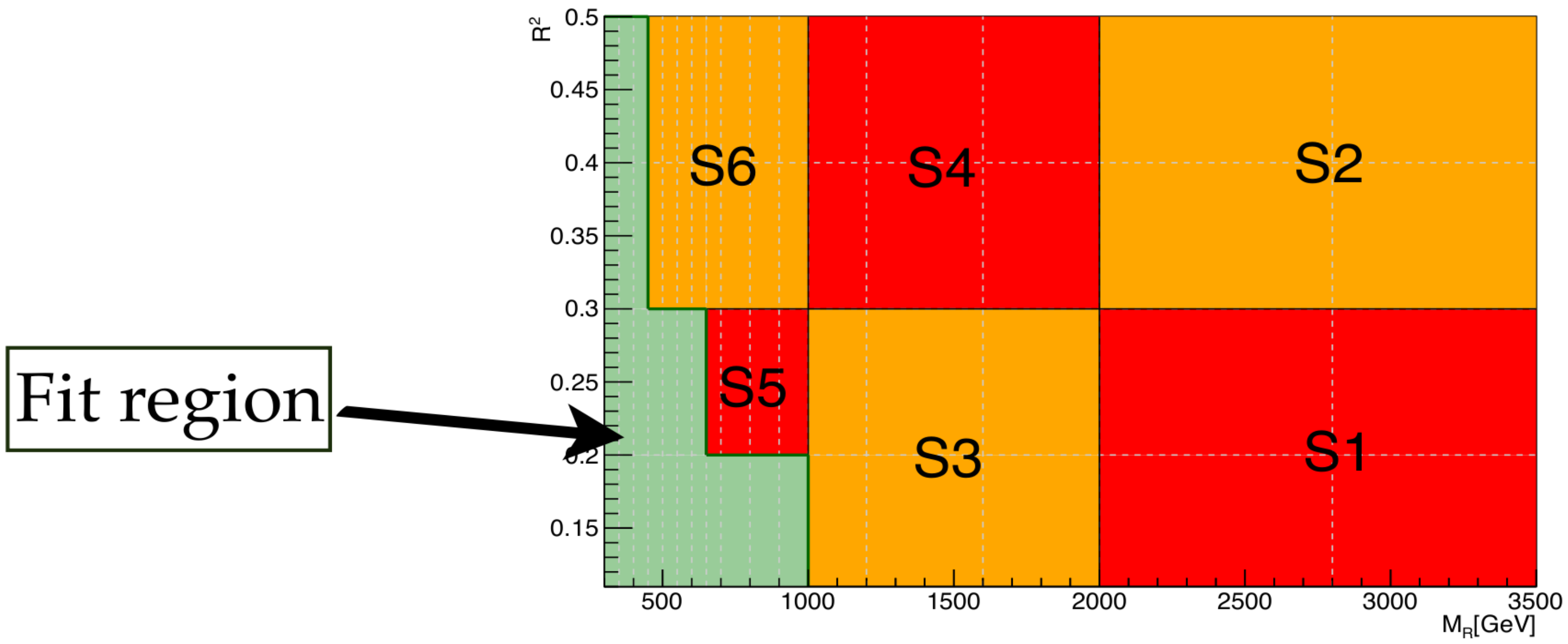


The R^2-M_R plane is separated into two regions:
- fit region
- signal regions

Unbinned, extended, ML fit to extract SM shape parameters.

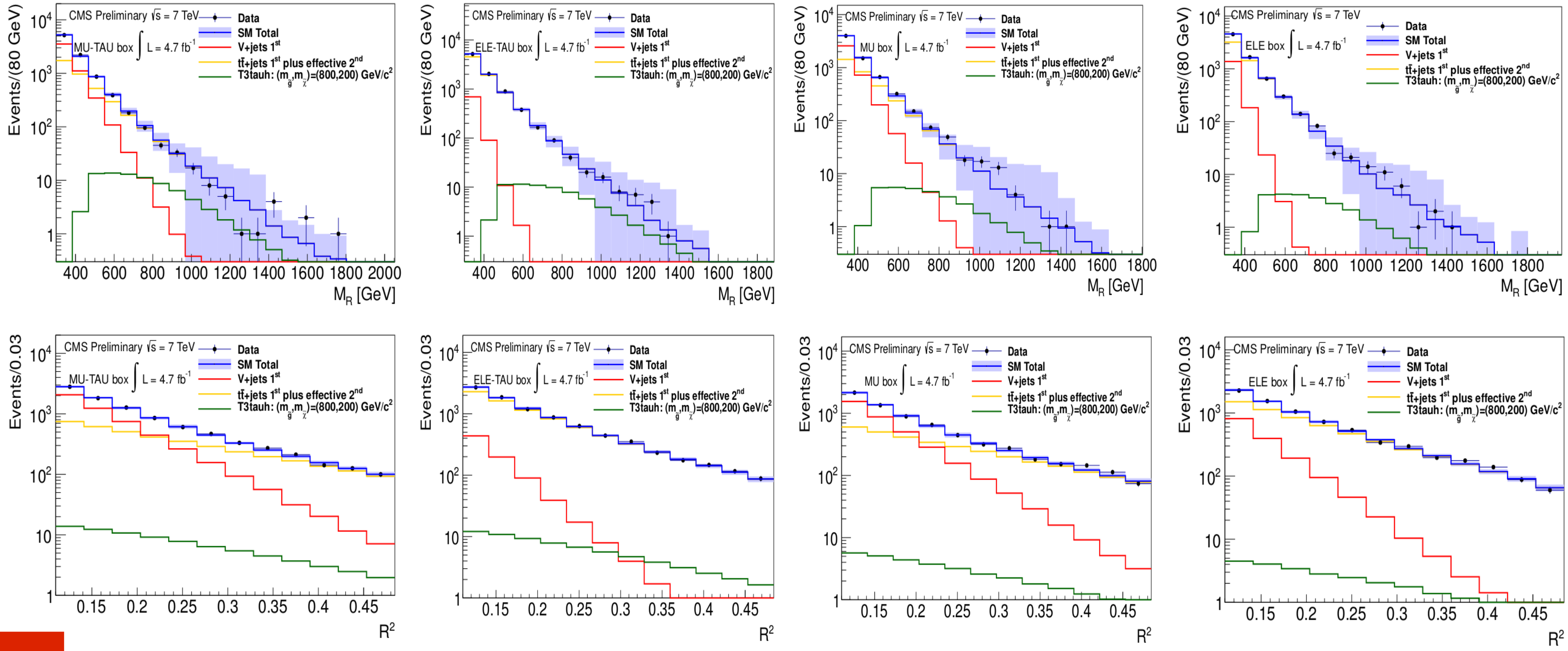
Six signal regions are defined where to quantify the data/expected background agreement.

Fit results:

MU-TAU box | ELE-TAU box | MU box | ELE box

M_R

R^2



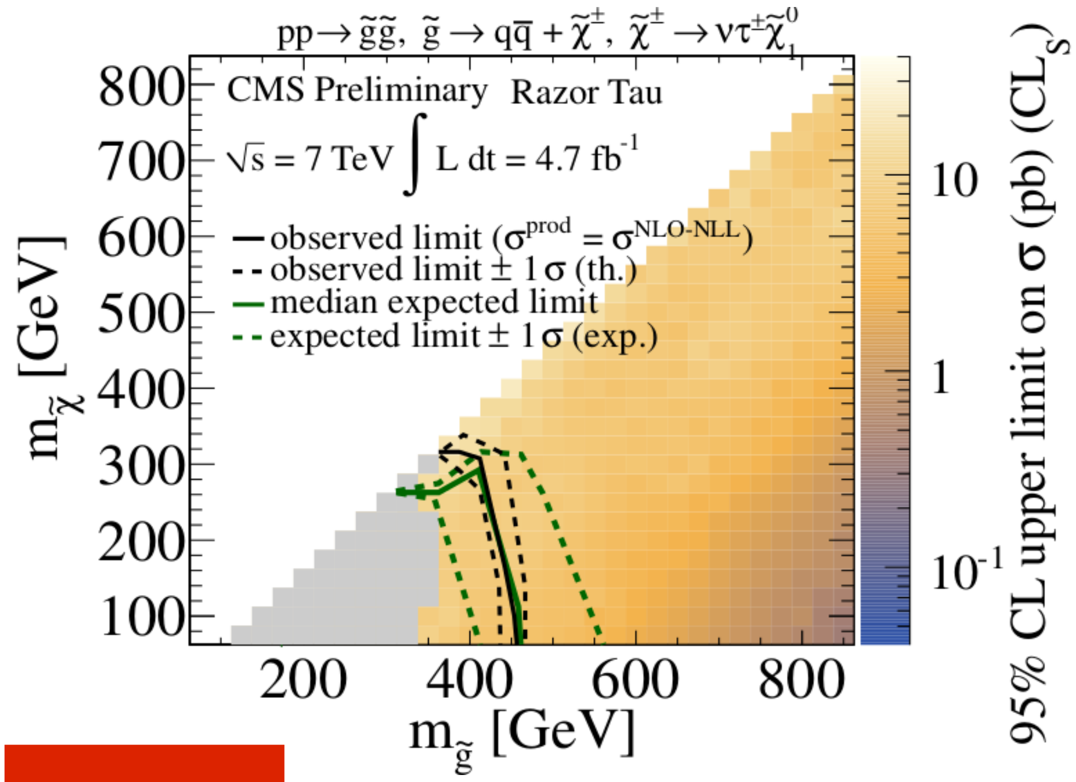
Agreement between data and SM

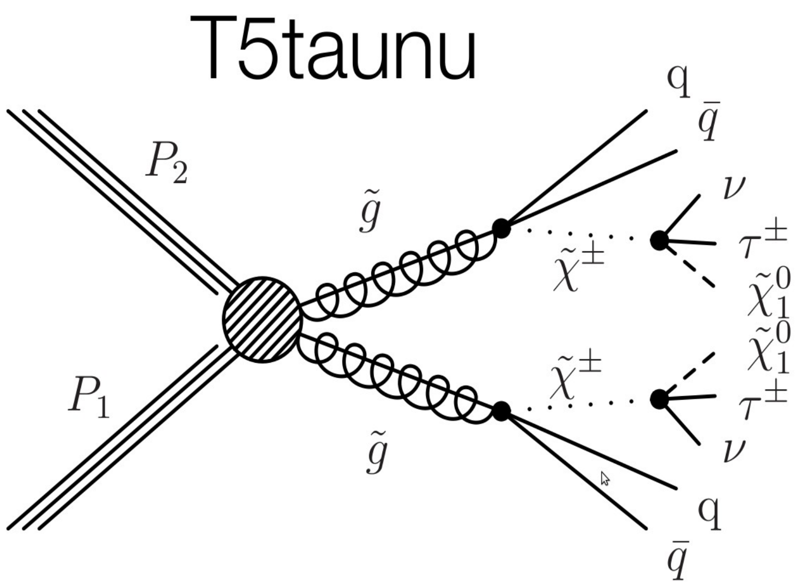
Interpretation of results: SMS T5taunu

Test background hypothesis against signal+bkg hypothesis in the signal region

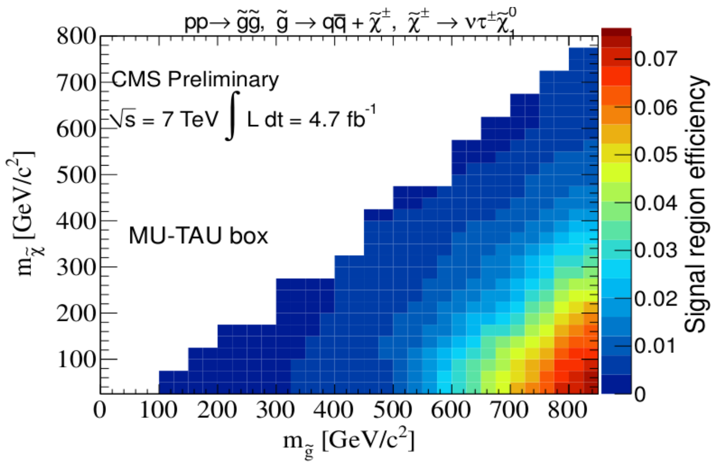
<u>All four boxes are combined</u>

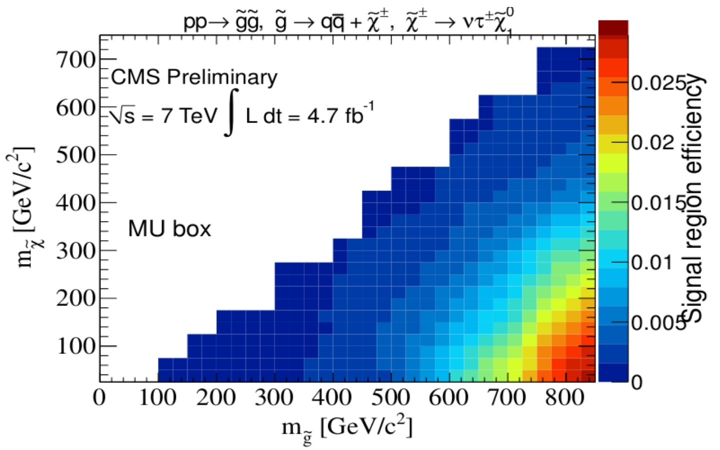
Grey area → large ISR corrections



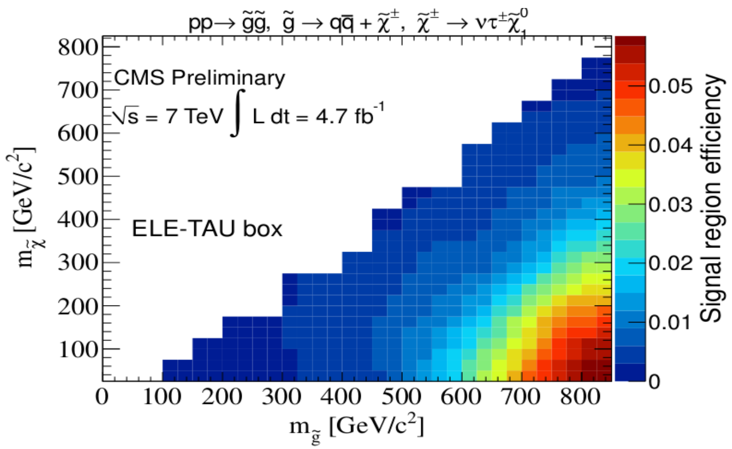


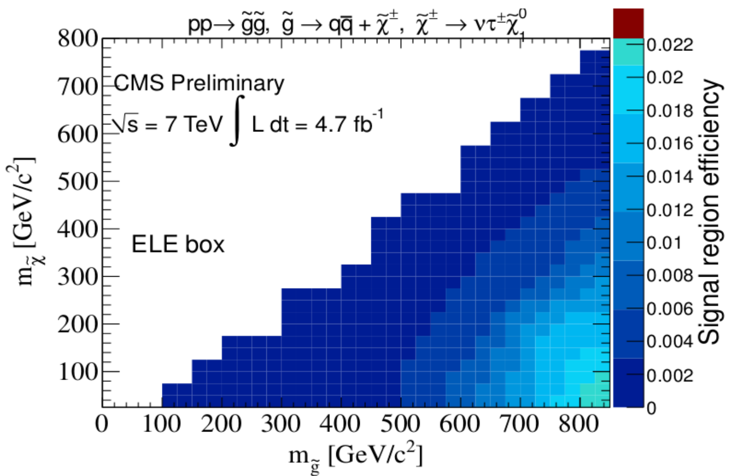
$m_{\chi 0}$





$m_{\hat{G}}$





Interpretation of results: SMS T3tauh

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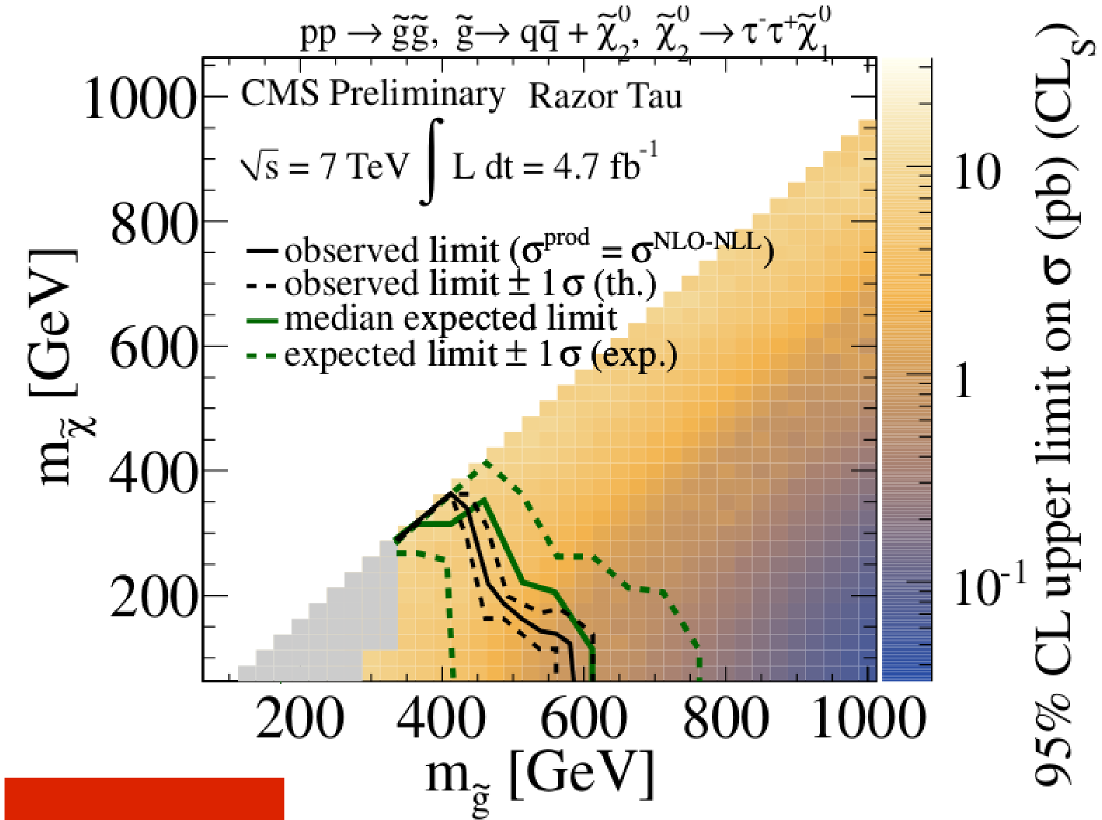
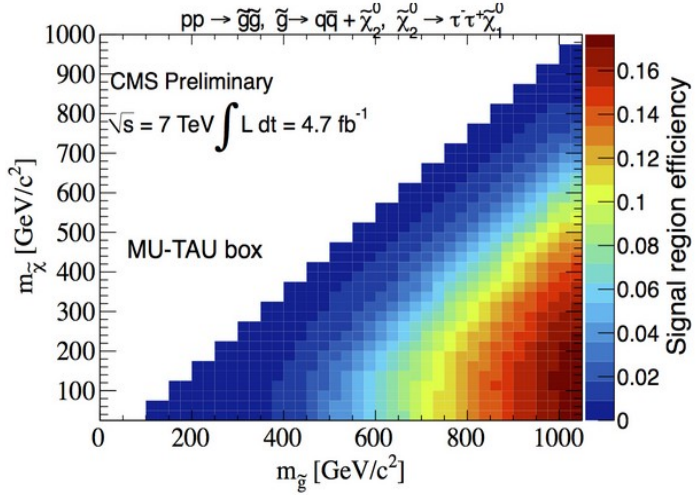
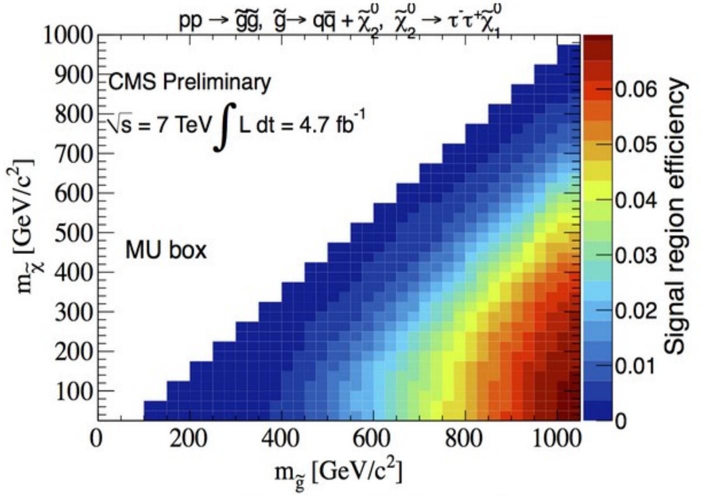


m_{χ^0}





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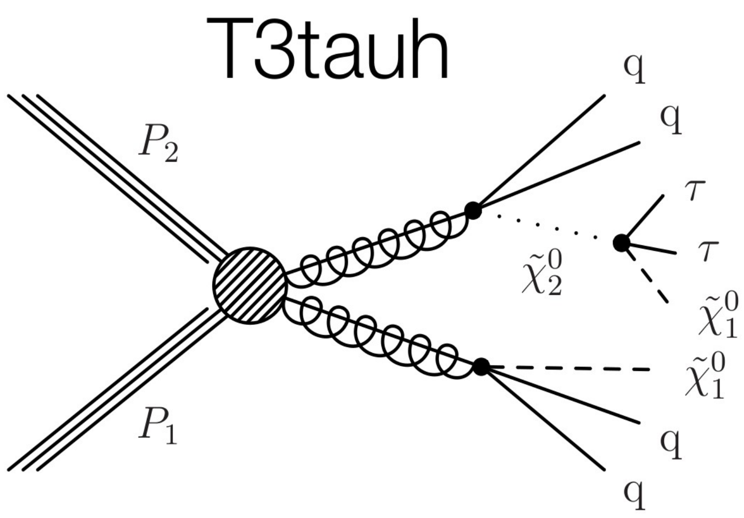
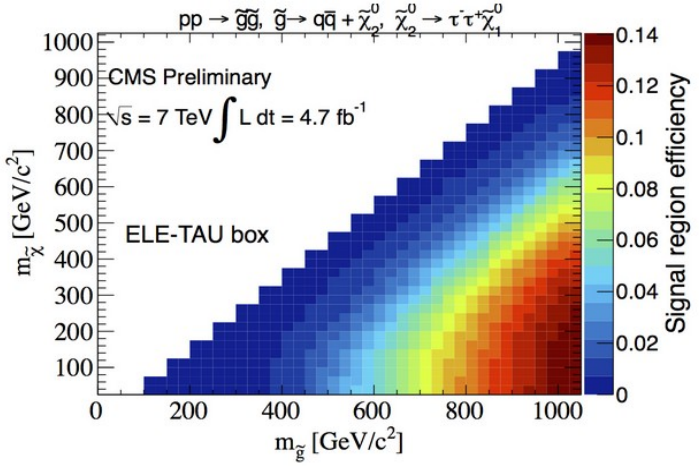
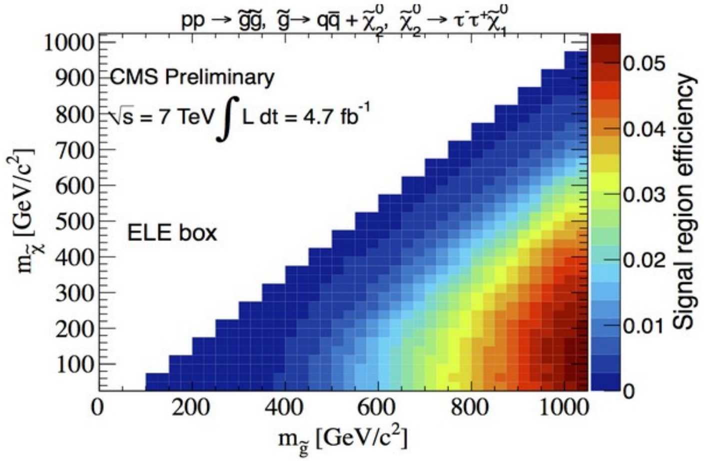






Single lepton, b-jets and MET

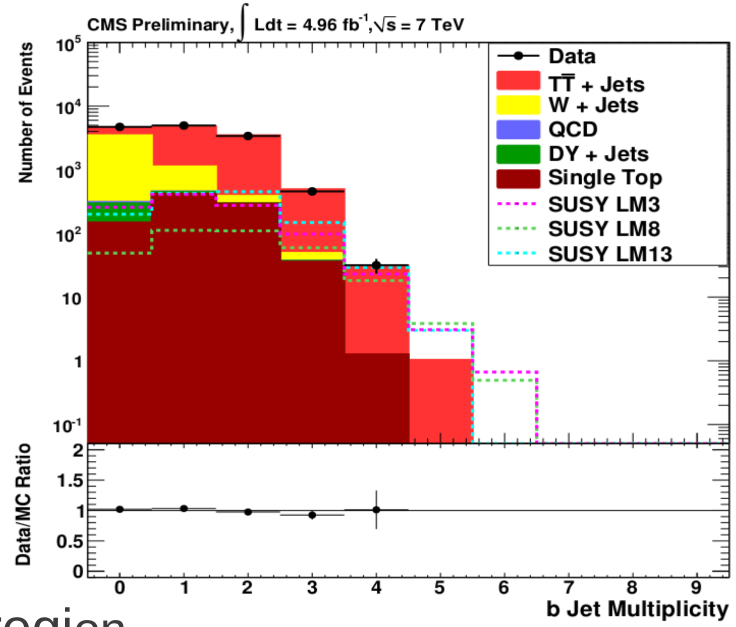
Single lepton, b-jets and MET

4.98 fb^{-1} at 7 TeV

- Search for light 3rd generation squarks and light gluinos
- sbottom and stops can be produced copiously the LHC, yielding final states with b-jets, leptons and MET

$$\tilde{g} \rightarrow t\tilde{t}^{*} \rightarrow t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Y_{MET} = MET/sqrt(HT)

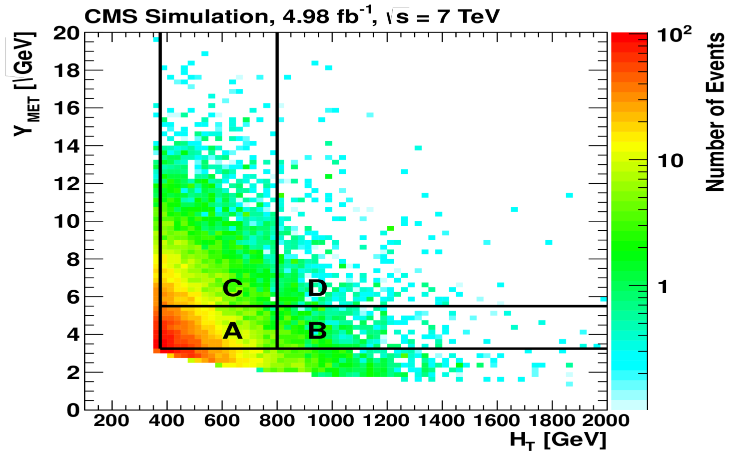


- Look for excess in H_T-Y_{MET} signal region
- Performed in 1, 2 and >=3 b tags

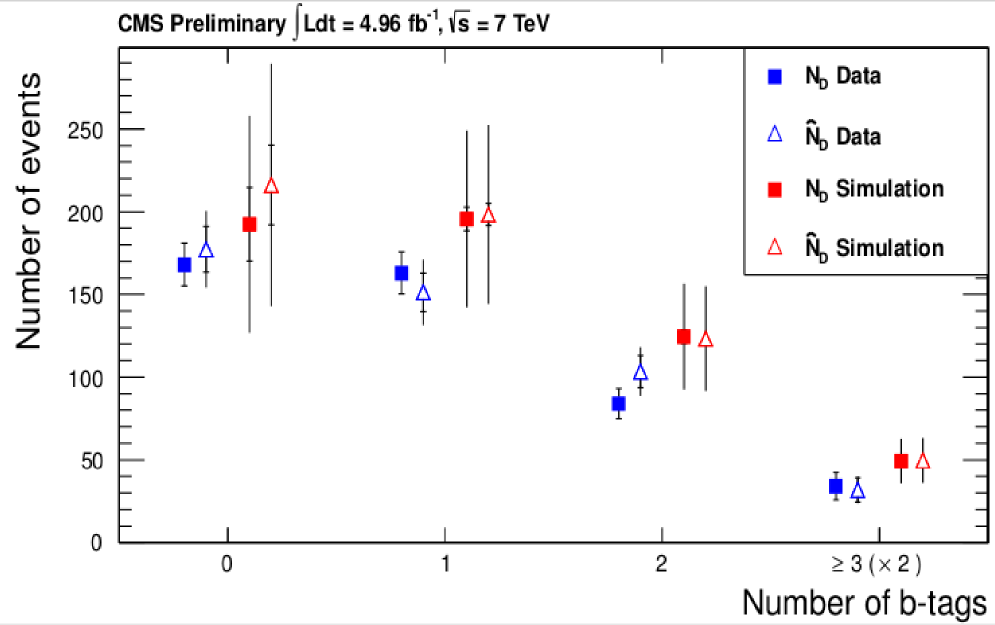
Background estimation: ABCD

- Y_{MET} and HT ~ small correlation
- Events in SR **D** are obtained from **A**,**B** and **C**.
- Corrections for small correlations are taken into account.

$$N_D = N_B \frac{N_C}{N_A}$$



RESULTS

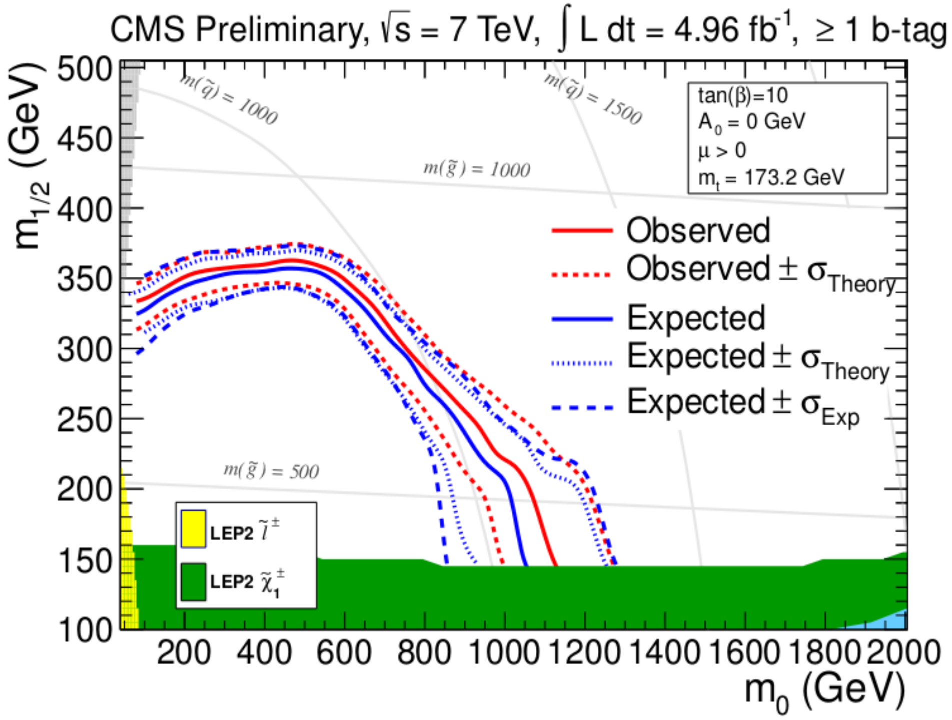


- Number of b tags in the SR D and predicted number of SM events in that region from data and simulation.
- Good agreement between data and estimation

Single lepton, b-jets and MET

4.98 fb^{-1} at 7 TeV

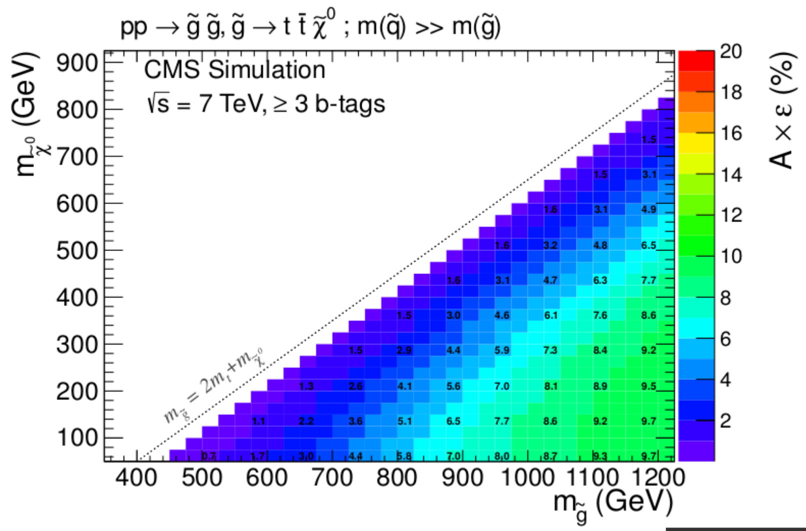
Interpretation in the CMSSM



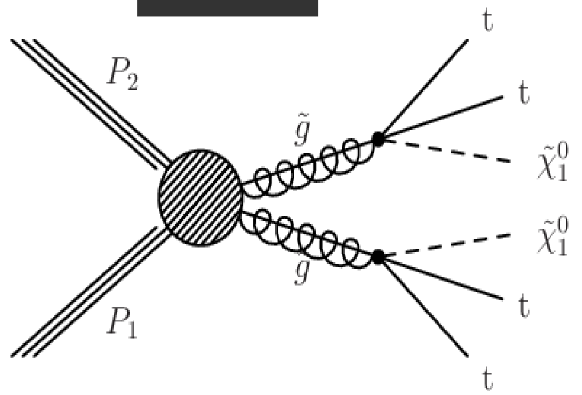
tan β = 10 | A_0=0 GeV | μ>0

Simplified models

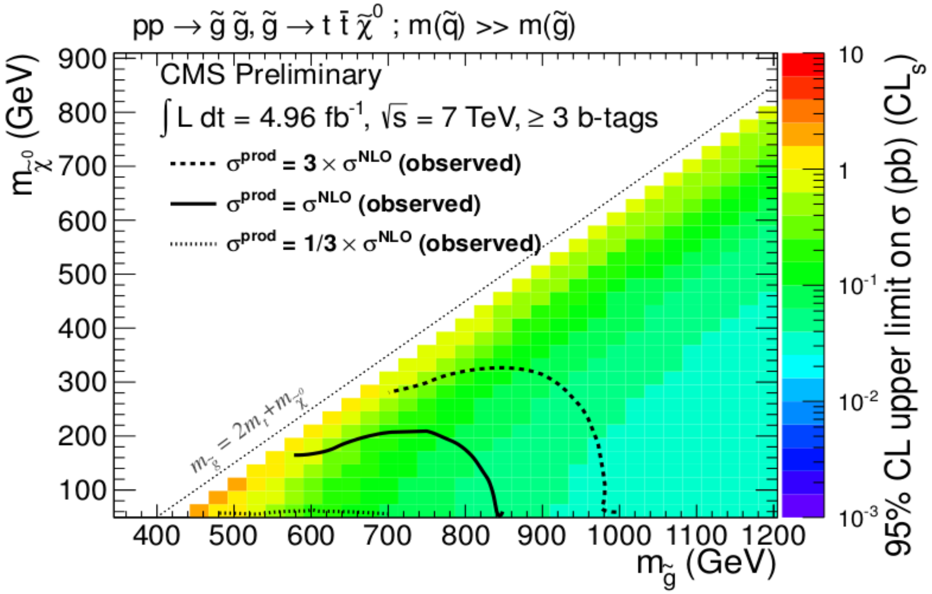
N Btags >=3



T1tttt



Accept. x efficiency for T1tttt



Area below solid line is excluded at 95% in CL_s.

Same-Sign leptons and b-jets

Same-Sign leptons and b-jets

$10.5\ fb^{-1}$ at 8 TeV

Motivation :

-Rare topology in SM but arises naturally in many SUSY scenarios

Leptons :

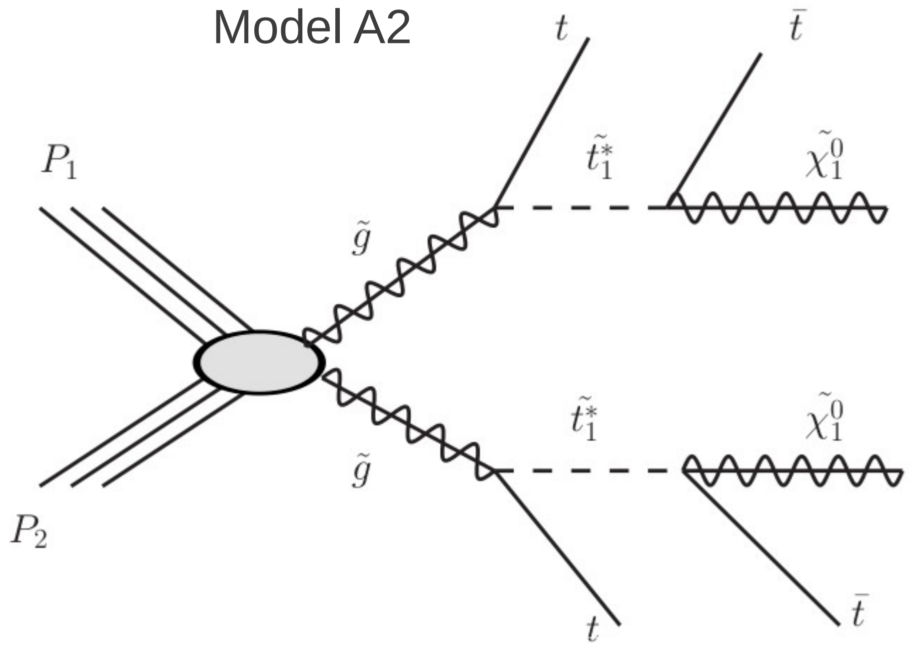
-Two same-sign isolated leptons (ee, eμ, μμ)

Jets:

-Reconstructed with the anti-kt algorithm with R=0.5

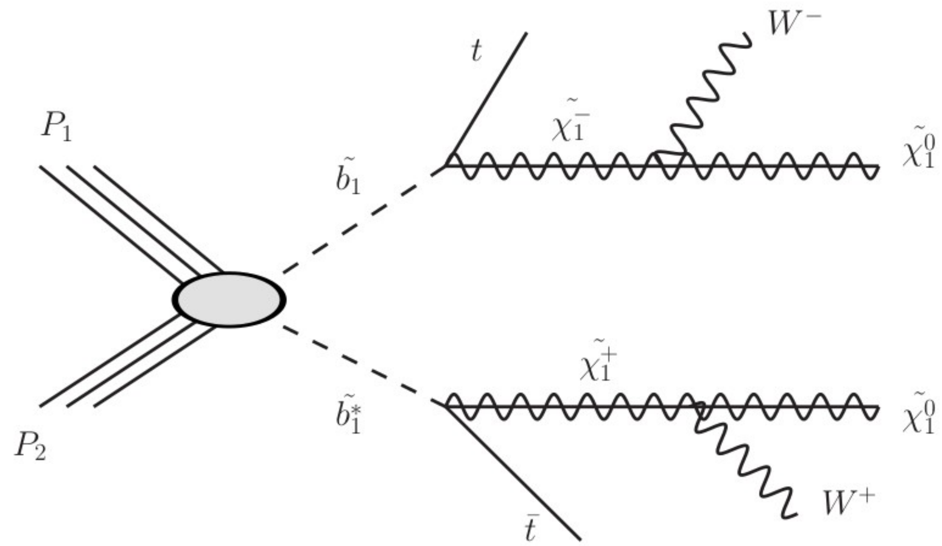
-At least **2 b-tagged jets.**

Model A2



gluino-mediated stop production

Model B1



direct sbottom production

Same-Sign leptons and b-jets

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Search regions

- Preselection region SR0 has:

-two SS leptons with p_T>20 GeV.
-At least two b-tagged jets

- Nine more search regions are defined by varying the number of jets, b-tagged jets, HT and MET.

Region	# btags	# jets	H_T (GeV)	$\not{E}_T$ (GeV)	comment
SR0	≥ 2	≥ 2	80	0	
SR1	≥ 2	≥ 2	80	30	
SR2	≥ 2	≥ 2	80	30	++ only
SR3	≥ 2	≥ 4	200	120	
SR4	≥ 2	≥ 4	200	50	
SR5	≥ 2	≥ 4	320	50	
SR6	≥ 2	≥ 4	320	120	
SR7	≥ 3	≥ 3	300	50	
SR8	≥ 2	≥ 4	320	0	

Same-Sign leptons and b-jets

10.5 fb^{-1} at 8 TeV

Backgrounds :

- One or two **"fake"** leptons: non-prompt leptons and jets mimicking leptons.

Data-driven estimation.

-**Tight-to-loose ratio**: Ratio is measured in a CR and extrapolated to the signal region.

- Two SS promp leptons.

Estimated from simulation: dominant contribution from **ttbarW/ttbarZ**

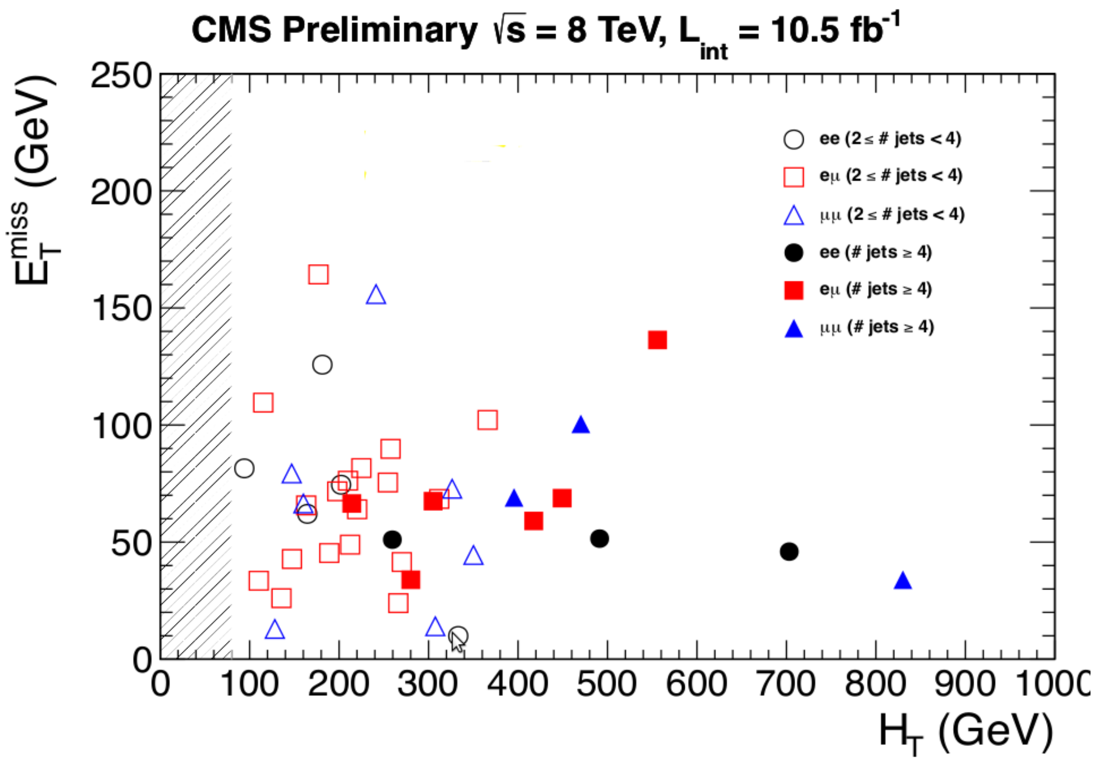
- Two OS prompt leptons with a charge mismeasurement

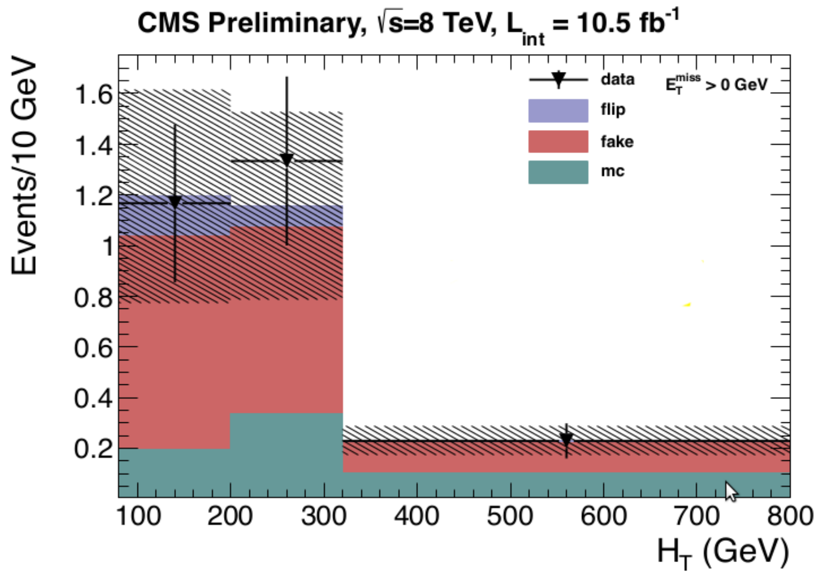
Only relevant for electrons
Estimated from simulation and validated with data

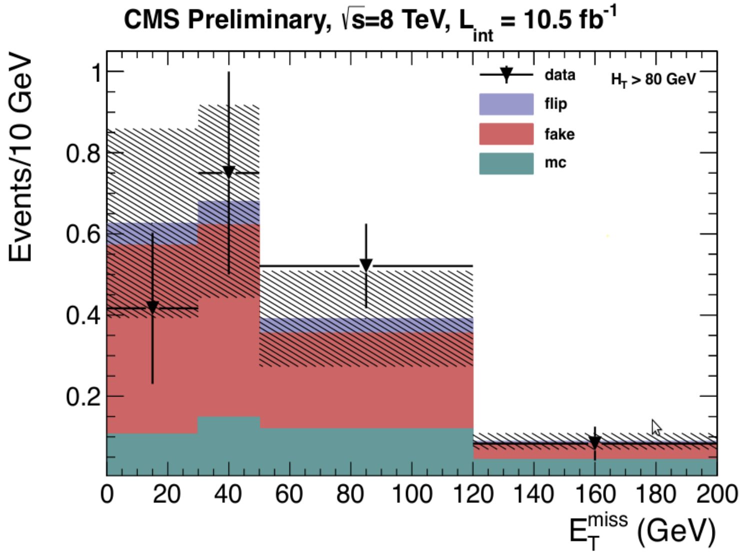
Same-Sign leptons and b-jets

10.5 fb^{-1} at 8 TeV

Distribution of observed events







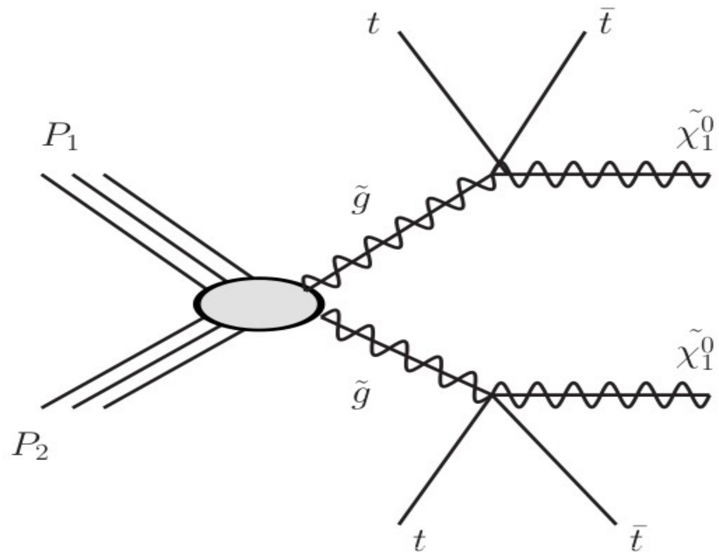
Event yields in each search region

No. of jets	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4	≥ 4	≥ 4	≥ 3	≥ 4
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Charge-flip BG	3.35 ± 0.67	2.70 ± 0.54	1.35 ± 0.27	0.04 ± 0.01	0.21 ± 0.05	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.21 ± 0.05
Fake BG	24.77 ± 12.62	19.18 ± 9.83	9.59 ± 5.02	0.99 ± 0.69	4.51 ± 2.85	2.88 ± 1.69	0.67 ± 0.48	0.71 ± 0.47	4.39 ± 2.64
Rare SM BG	11.75 ± 5.89	10.46 ± 5.25	6.73 ± 3.39	1.18 ± 0.67	3.35 ± 1.84	2.66 ± 1.47	1.02 ± 0.60	0.44 ± 0.39	3.50 ± 1.92
Total BG	39.87 ± 13.94	32.34 ± 11.16	17.67 ± 6.06	2.22 ± 0.96	8.07 ± 3.39	5.67 ± 2.24	1.73 ± 0.77	1.18 ± 0.61	8.11 ± 3.26
Event yield	43	38	14	1	10	7	1	1	9
N_{UL} (13% unc.)	27.2	26.0	9.9	3.6	10.8	8.6	3.6	3.7	9.6
N_{UL} (20% unc.)	28.2	27.2	10.2	3.6	11.2	8.9	3.7	3.8	9.9
N_{UL} (30% unc.)	30.4	29.6	10.7	3.8	12.0	9.6	3.9	4.0	10.5

Same-Sign leptons and b-jets

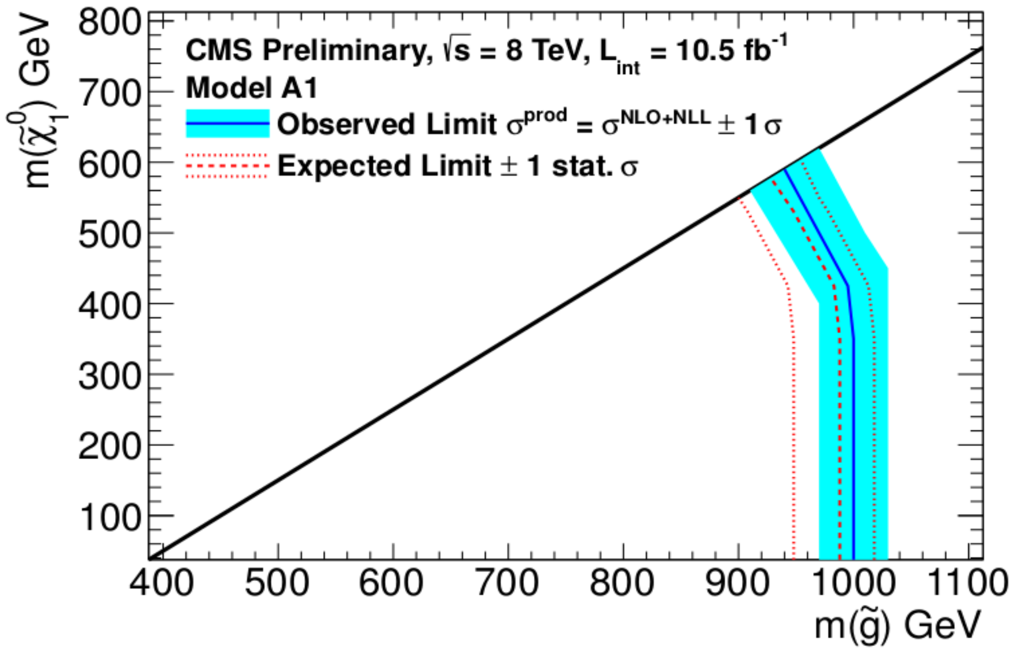
10.5 fb^{-1} at 8 TeV

Models with 4-top quarks ad two LSP from gluino pair production

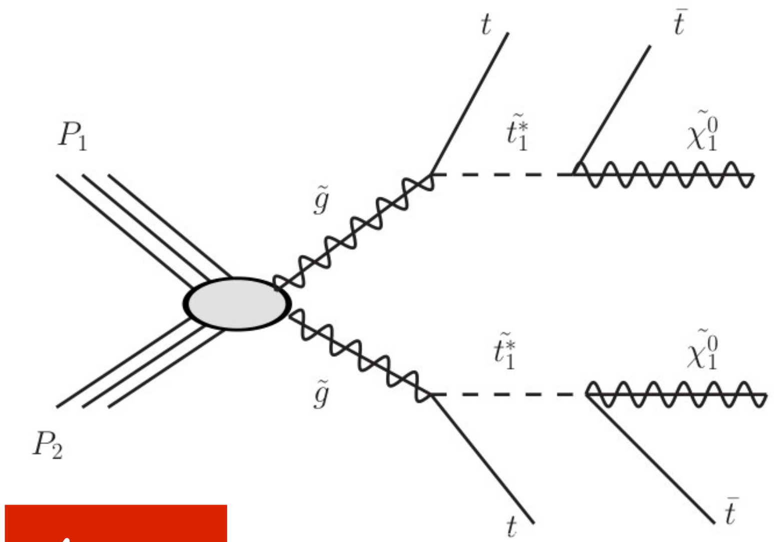


Model A1

Decay via real top squarks

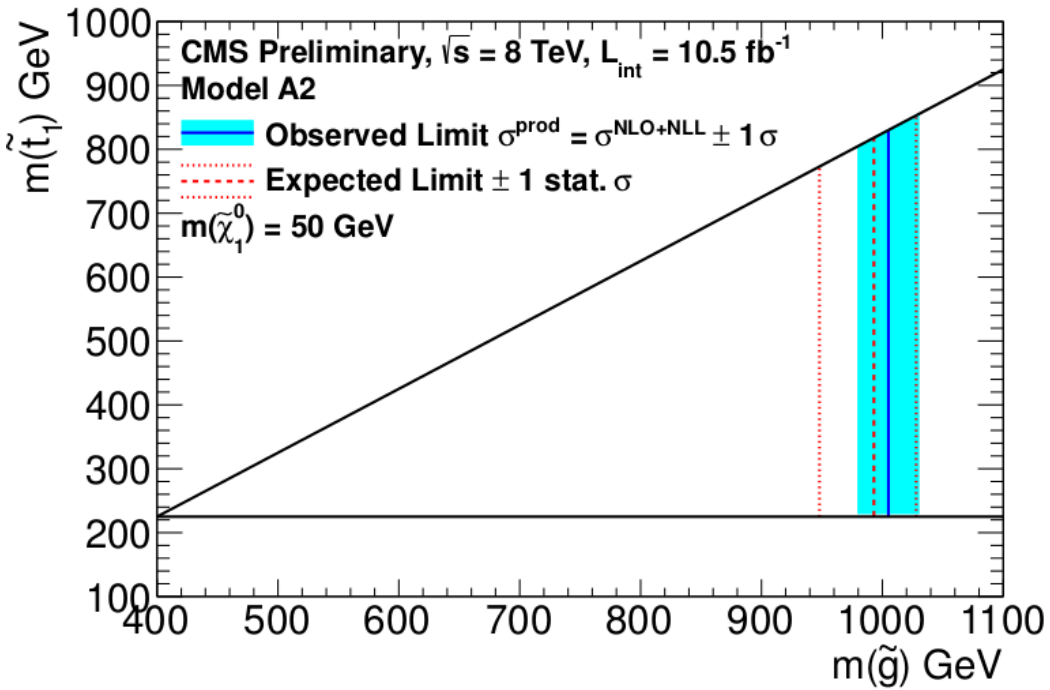


$m(\tilde{g})>970$ GeV



Model A2

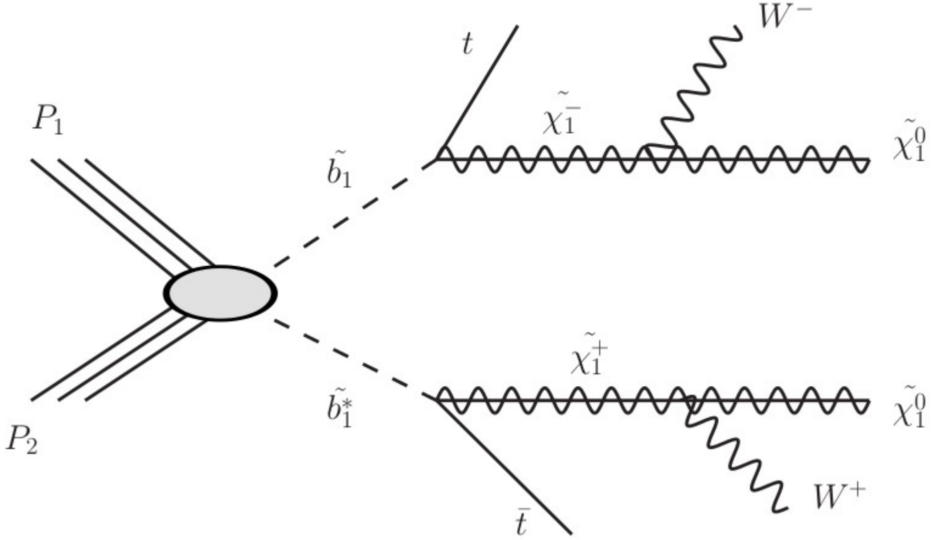
Decay via virtual top squarks



Same-Sign leptons and b-jets

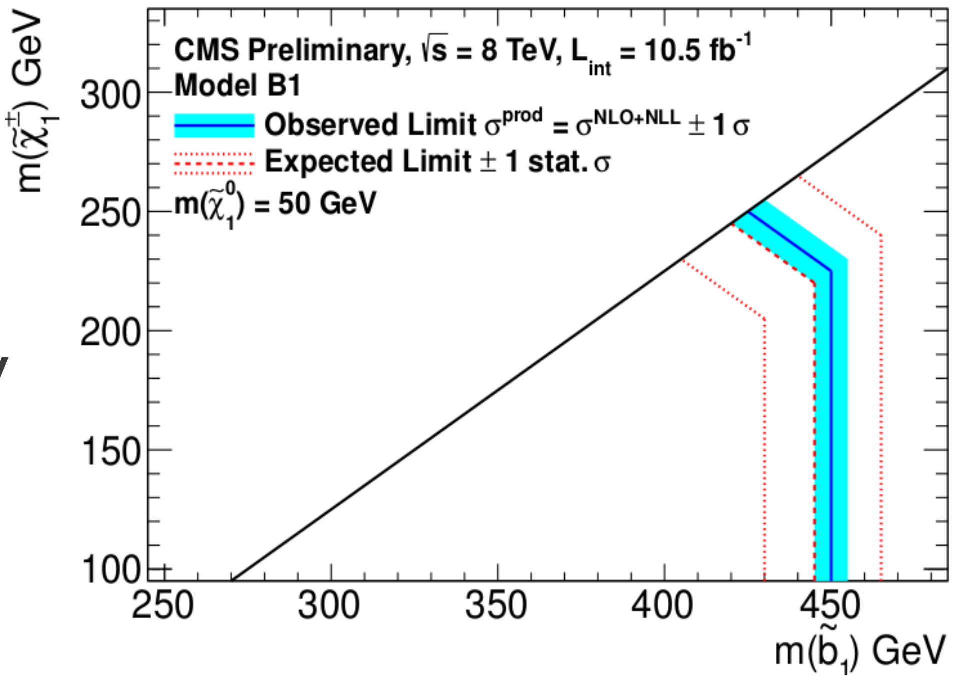
$10.5\ fb^{-1}$ at 8 TeV

Models with multiple top quarks and W-bosons

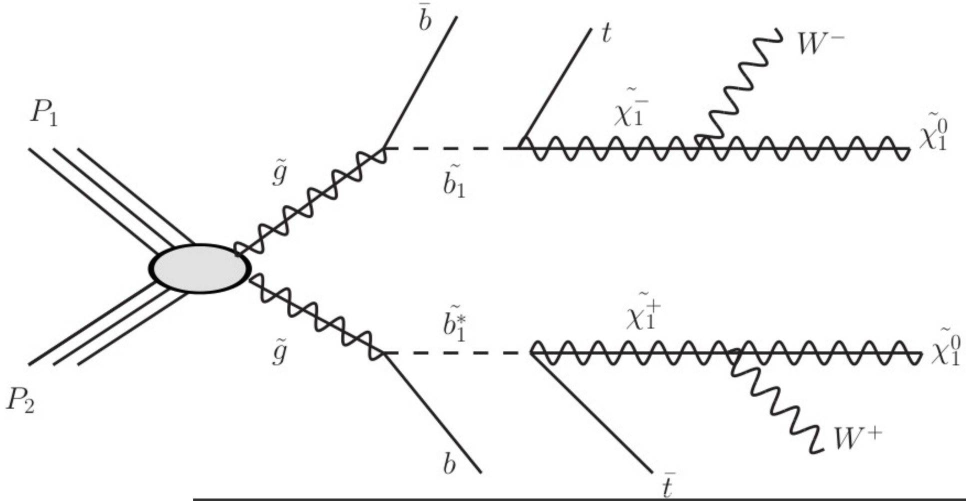


Model B1

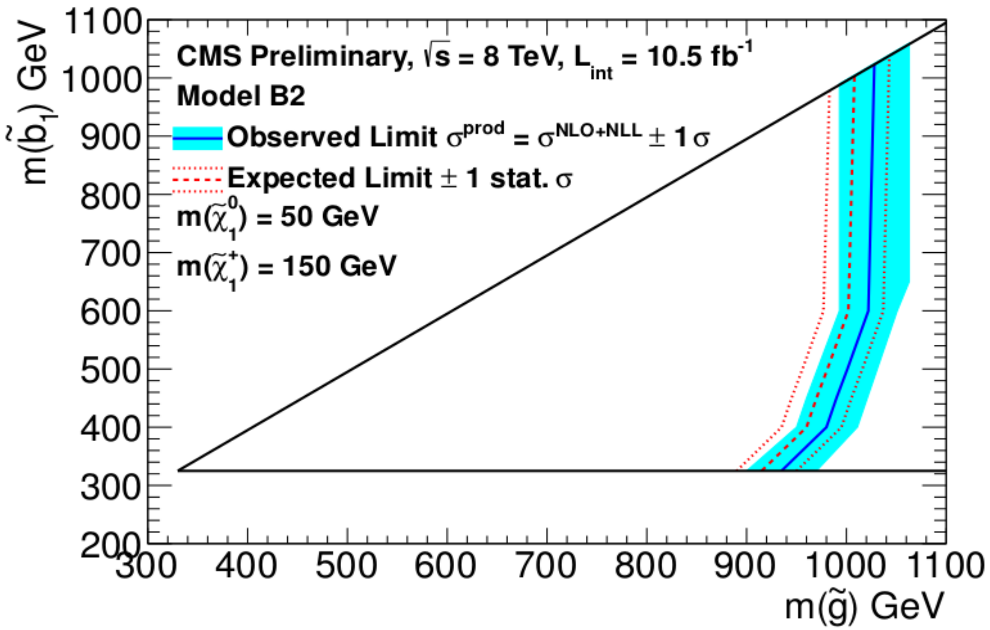
$m(\tilde{b})$>450 GeV



Decay via real bottom squarks



Model B2



Decay via virtual bottom squarks

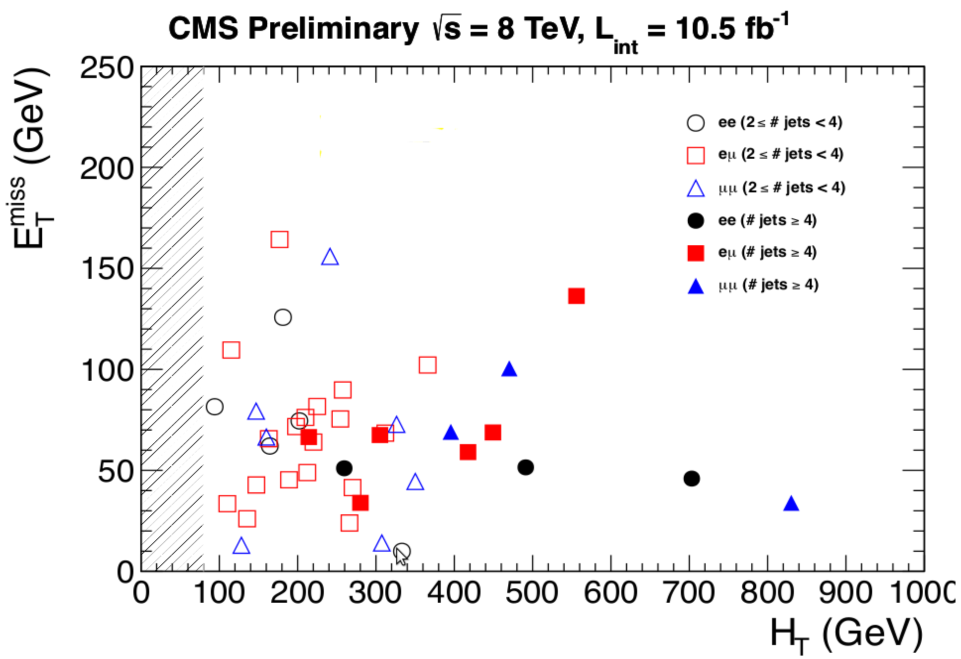
SUMMARY and OUTLOOK

- Rich variety of SUSY searches with one or two leptons

- Plethora of variables and estimation methods to maximize the sensitivity of CMS to the presence of new physics

- Nature is being (so far) mean to us
  → on the bright side, many exclusion plots

- These and more studies ongoing for searches at 8 TeV



summary

BACK-UP

τ-leptons, jets and MET

τ-leptons, jets and MET

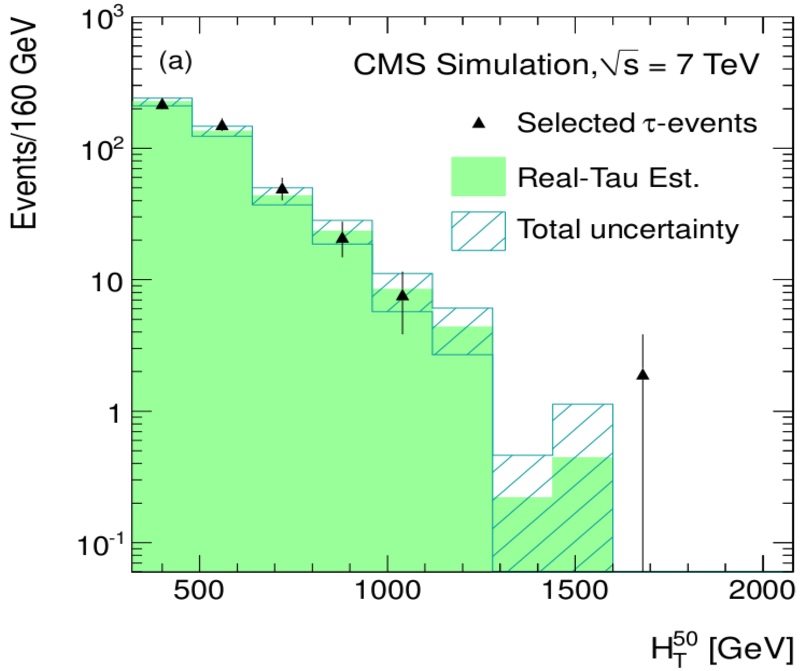
4.98 fb^{-1} at 7 TeV

Single τ_H final state

- Exactly one τ_H in the final state
- Veto on light leptons

H_T^{50}>600 GeV   MHT>400 GeV

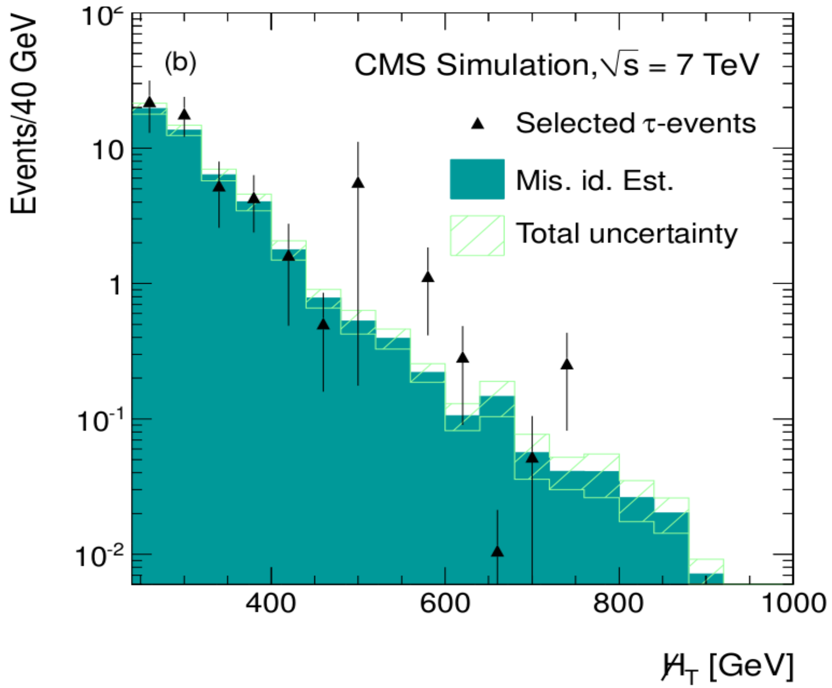
$$H_T^{50} = \sum_{jet_i, P_T^{jet_i} > 50GeV} P_T^{jet_i} \qquad \not{H}_T = \left| -\sum \vec{p}_T^{\,jet} \right|$$



Closure test with MC

BG from W+jets with a real τ_H

- Estimated from W-> μν (lepton universality)



Closure test with MC

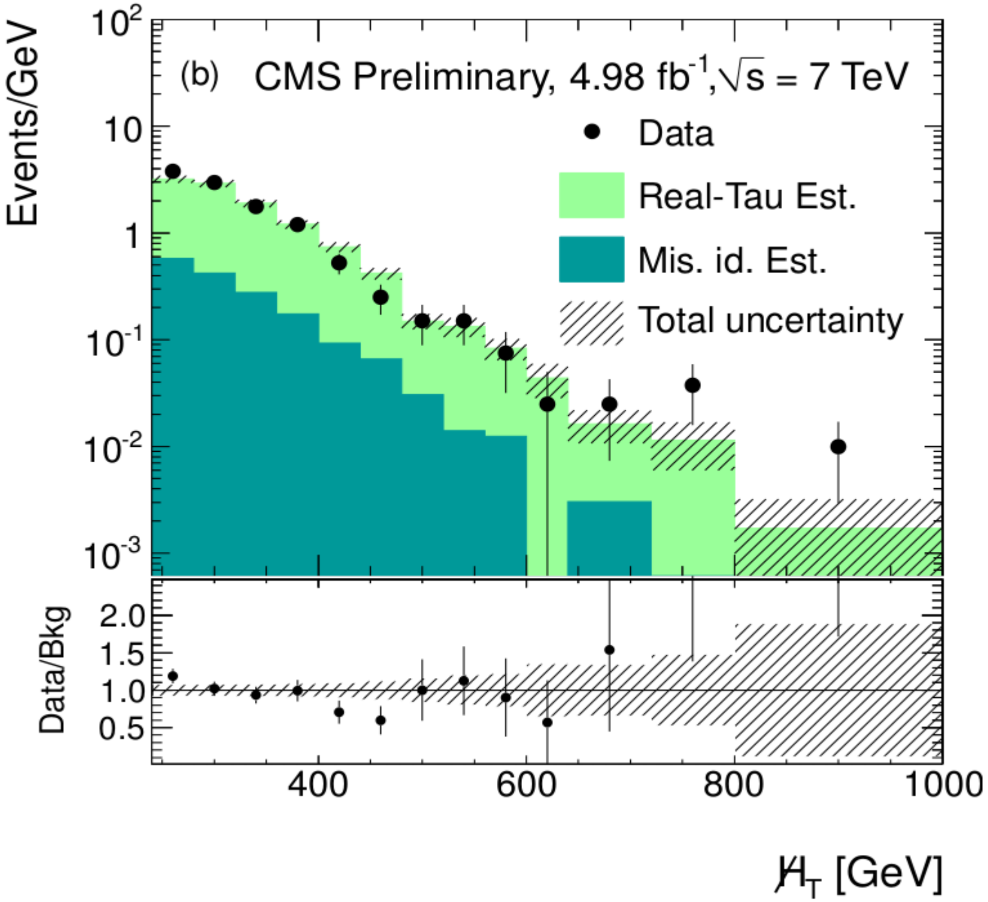
BG from jets faking τ_H

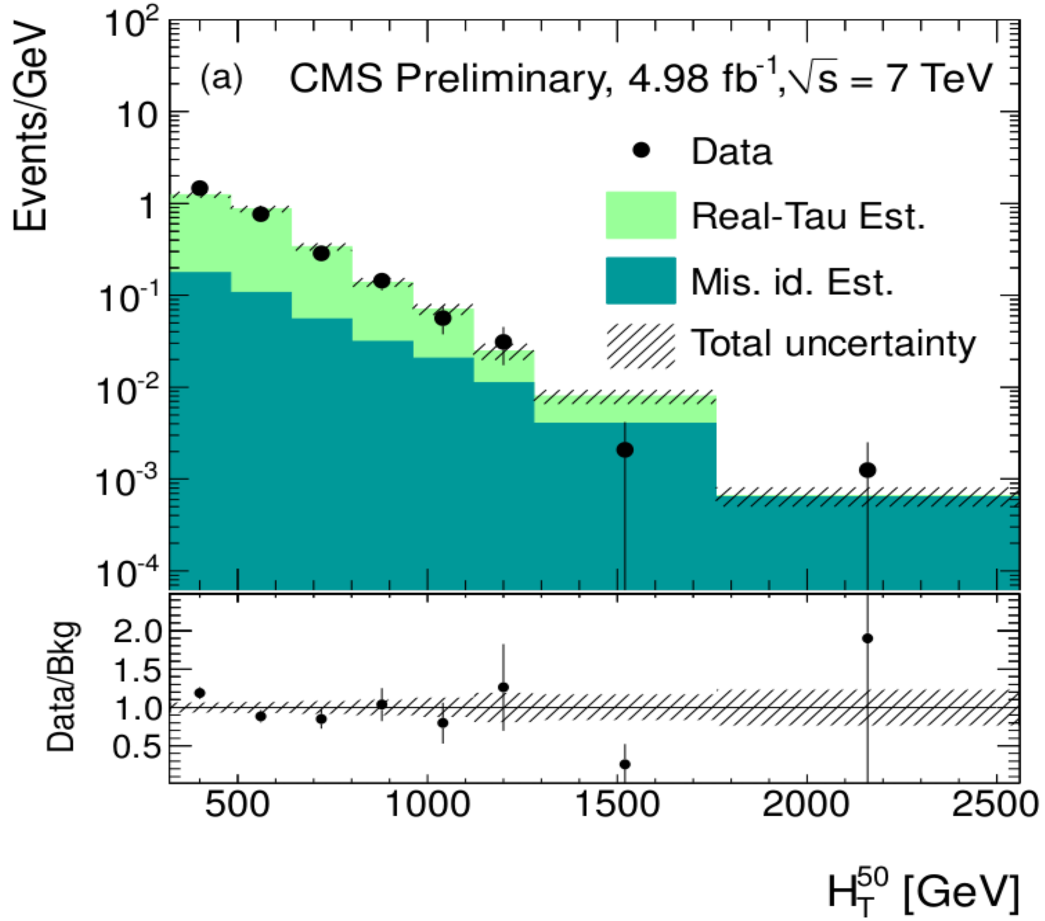
- Estimated from jet-dominated control sample, by application of the jet → tau misidentification rate.

τ-leptons, jets and MET

$4.98\ fb^{-1}$ at 7 TeV

Single τ_H final state





Process	Baseline	Signal Region
Fake$-\tau_h$	$67 \pm 2_{stat} \pm 19_{syst}$	$3.4 \pm 0.4_{stat} \pm 1.0_{syst}$
Real$-\tau_h$	$367 \pm 10_{stat} \pm 27_{syst}$	$25.9 \pm 2.5_{stat} \pm 2.3_{syst}$
Estimated $\sum SM$	$434 \pm 10_{stat} \pm 33_{syst}$	$29.3 \pm 2.6_{stat} \pm 2.5_{syst}$
Observed *Data*	444	28

No excess is observed

τ-leptons, jets and MET

4.98 fb^{-1} at 7 TeV

di-τ_H final state

- $\geq 2\ \tau_H$

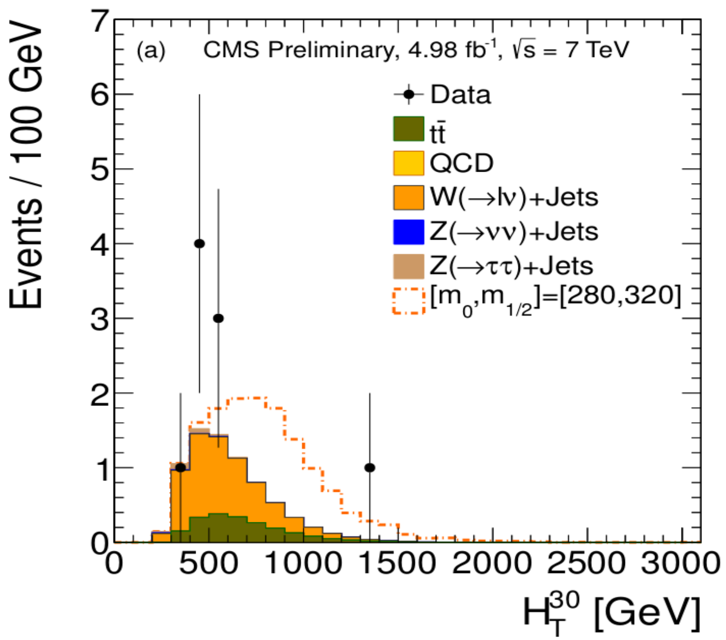
2 jets $p_T > 100$ GeV MHT > 250GeV

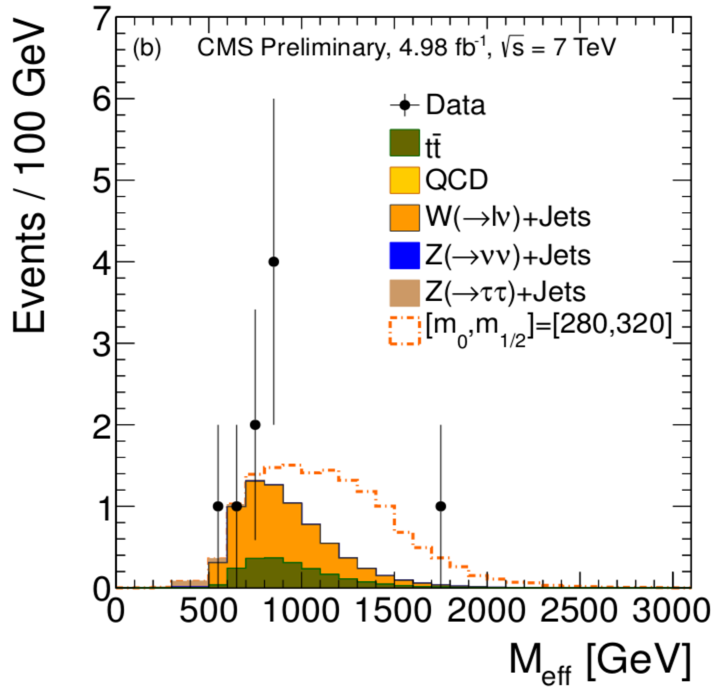
$H_T^{50} > 600$ (250) GeV MHT > 400 (250) GeV

Main background: W+jets, ttbar

- Estimated from control samples

Process	Signal Region
multijet events	$0.02 \pm 0.02_{stat} \pm 0.17_{syst}$
W+jets	$5.20 \pm 0.63_{stat} \pm 0.62_{syst}$
$t\bar{t}$	$2.03 \pm 0.36_{stat} \pm 0.34_{syst}$
$Z \rightarrow \tau\bar{\tau}+$ jets	$0.21 \pm 0.13_{stat} \pm 0.17_{syst}$
$Z \rightarrow \nu\bar{\nu}+$ jets	$0.03 \pm 0.02_{stat} \pm 0.50_{syst}$
Estimated $\sum SM$	$7.49 \pm 0.74_{stat} \pm 0.90_{syst}$
Observed *Data*	9
$[m_0, m_{1/2}] = [280, 320]$	$7.1 \pm 1.2_{stat}$





$M_{EFF}=MHT+H_T^{30}$

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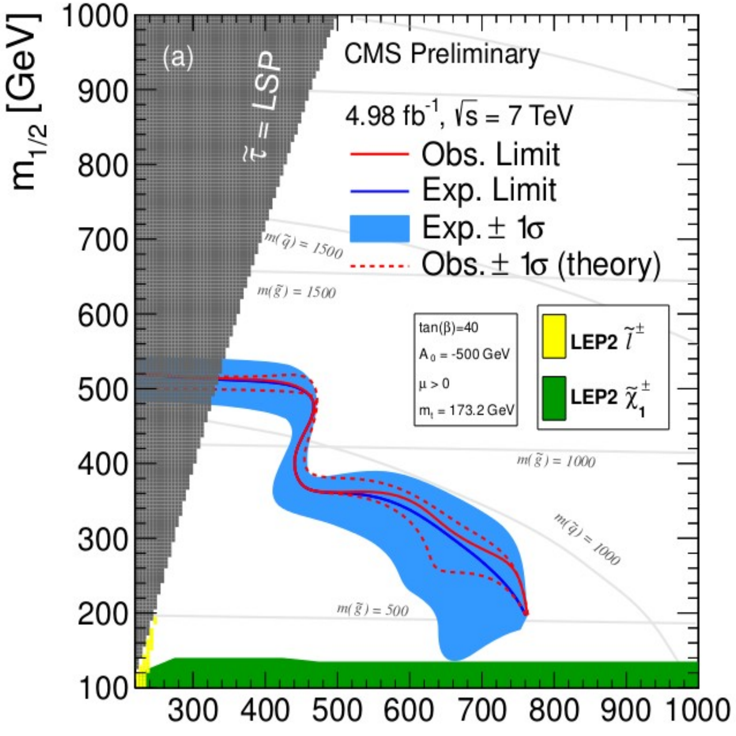
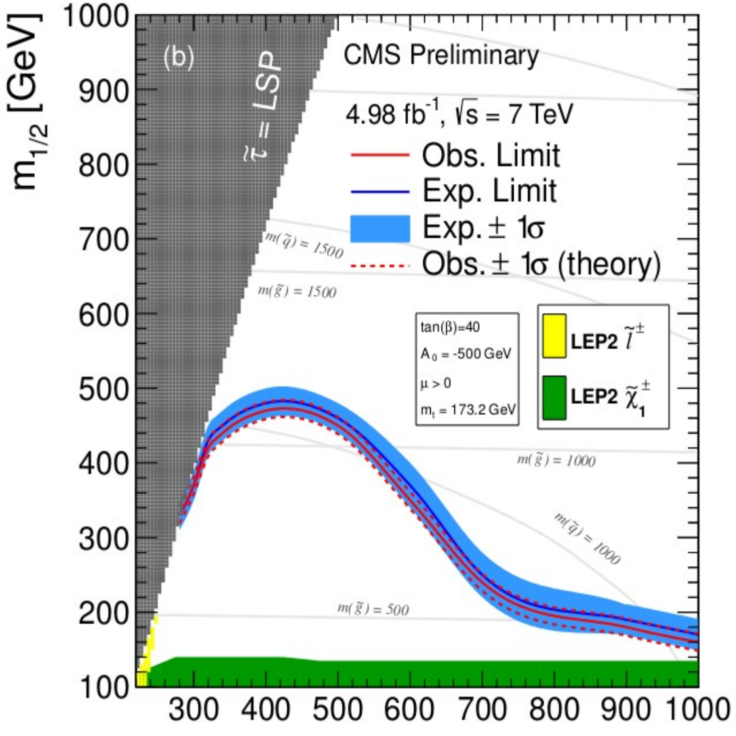
No excess is observed

τ-leptons, jets and MET

4.98 fb^{-1} at 7 TeV

CMSSM Interpretation





Single τ_H final state

m_0 [GeV]

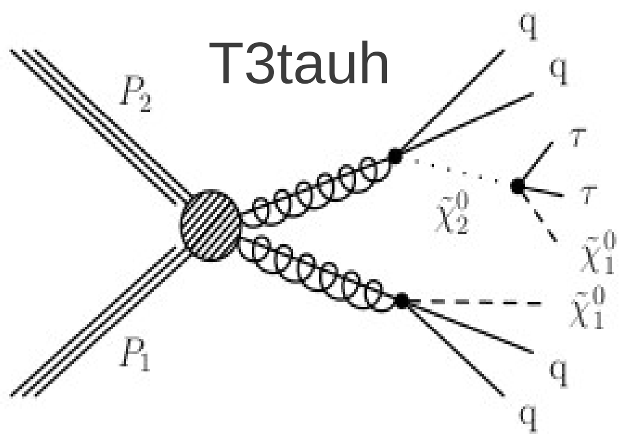
Two-or-more τ_H final state

m_0 [GeV]

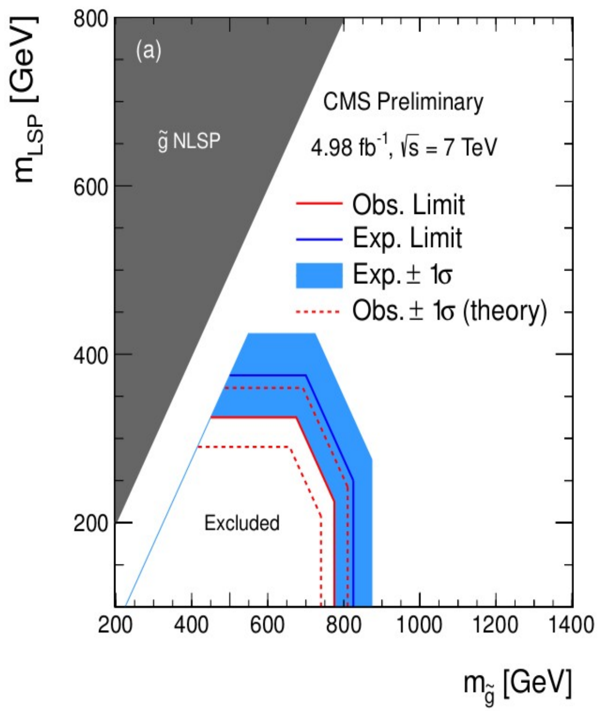
tan β = 40 | A_0=500 GeV | μ>0

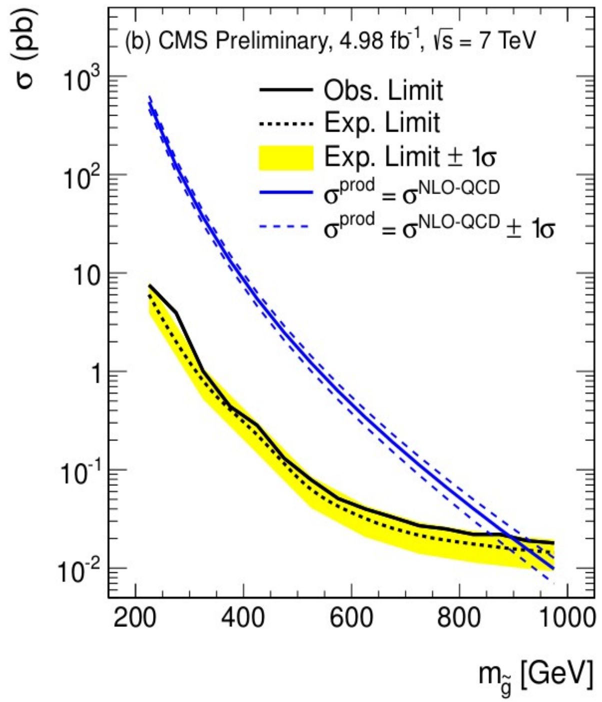
Simplified model

Two-or-more τ_H final state



GMSB has similar topology





Opposite-Sign leptons

Opposite-Sign leptons

4.98 fb^{-1} at 7 TeV

Opposite-sign leptons are commonly produced in SUSY models

$$\tilde{\chi}_2^0 \rightarrow \tilde{\ell}\ell \rightarrow \tilde{\chi}_1^0 \ \ell^+\ell^-$$

- Mass-edge in the di-lepton invariant mass
- Excess of events with OS leptons, MET and jets

Search strategies

- **Search for a kinematical edge**

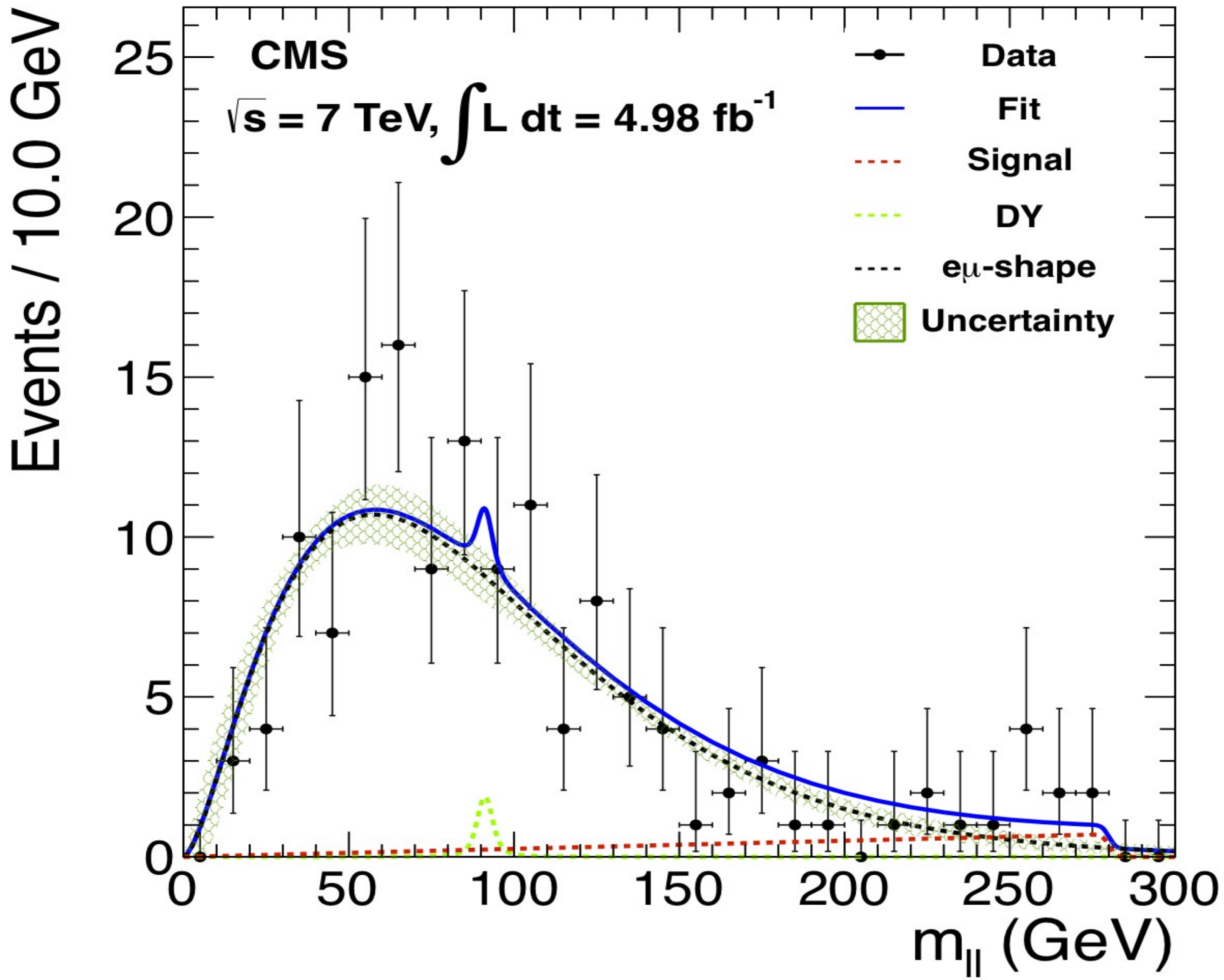
OS e and μ

Leptons in SUSY: same-flavour

ttbar: uncorrelated flavour

→ Obtain background with OF events

Kinematical edge shape + backgrounds shape are fitted



signal region HT>300 GeV and MET>150GeV

Local significance of 0.7 σ

No significant excess is observed

Opposite-Sign leptons

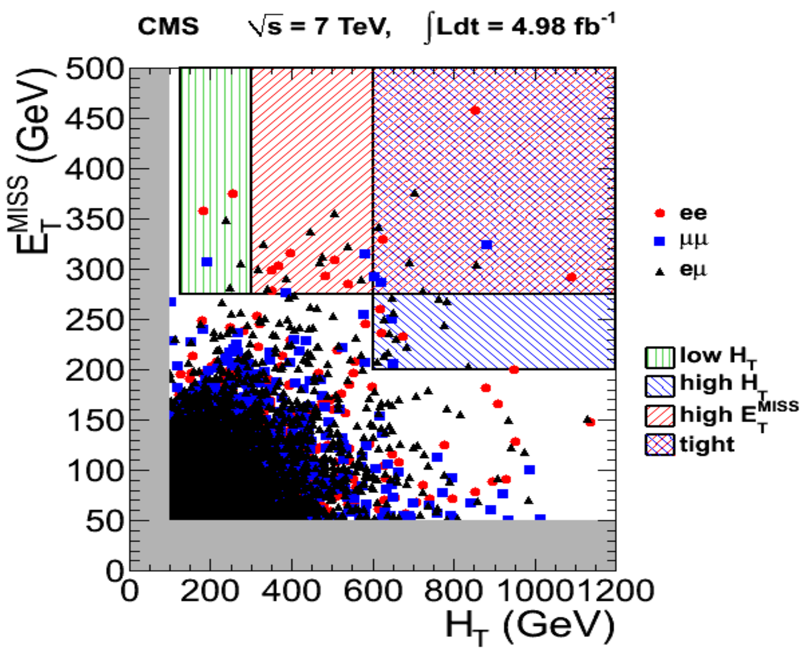
4.98 fb^{-1} at 7 TeV

Search strategies

- **Counting experiment**

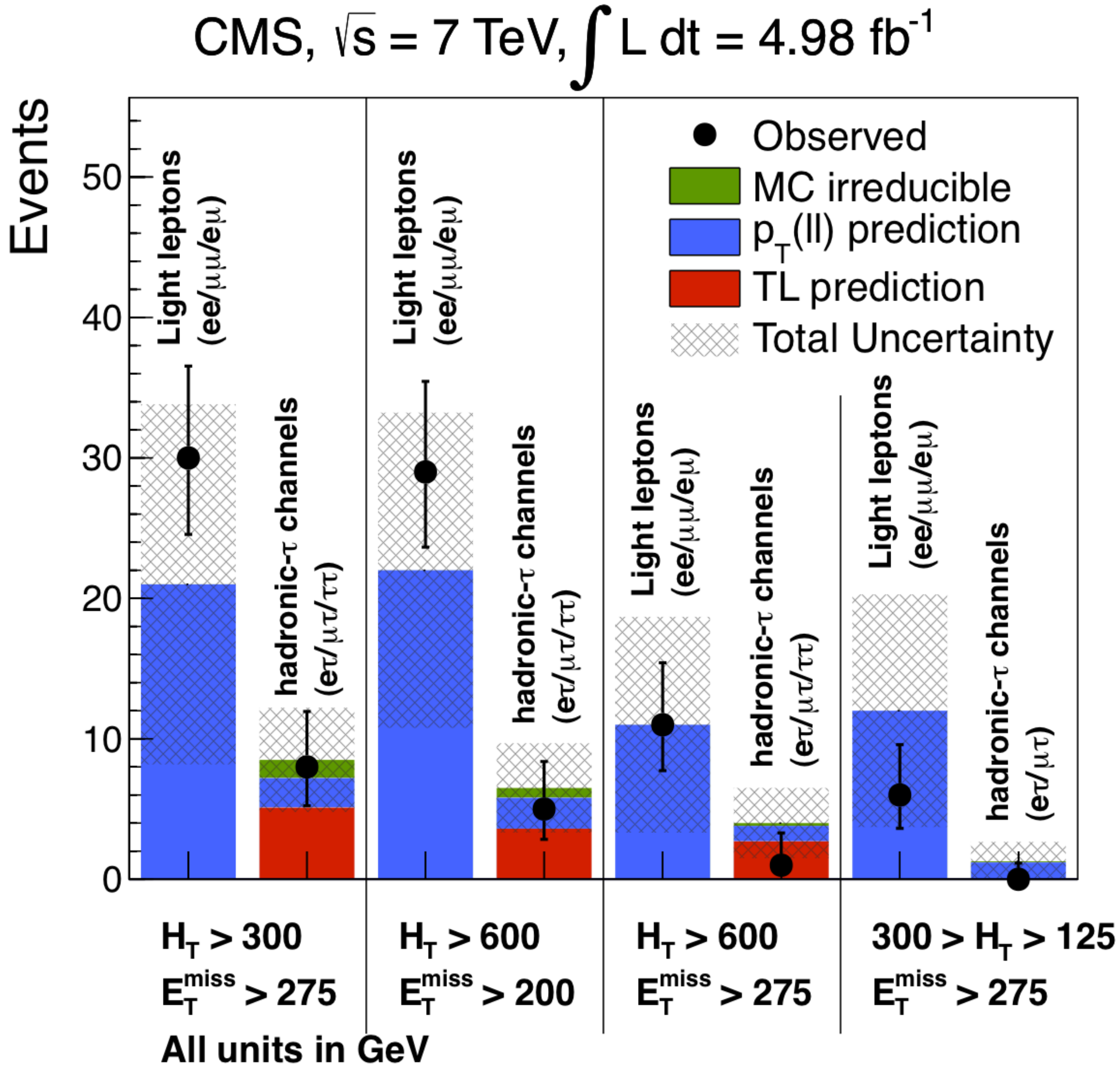
Events with lepton pairs with large MET and HT

Four different signal regions



Leptons and neutrinos in di-lepton ttbar have related p_T distributions ->p_T(ll) method.

Tight-to-loose method for misidentified jets as τ leptons.

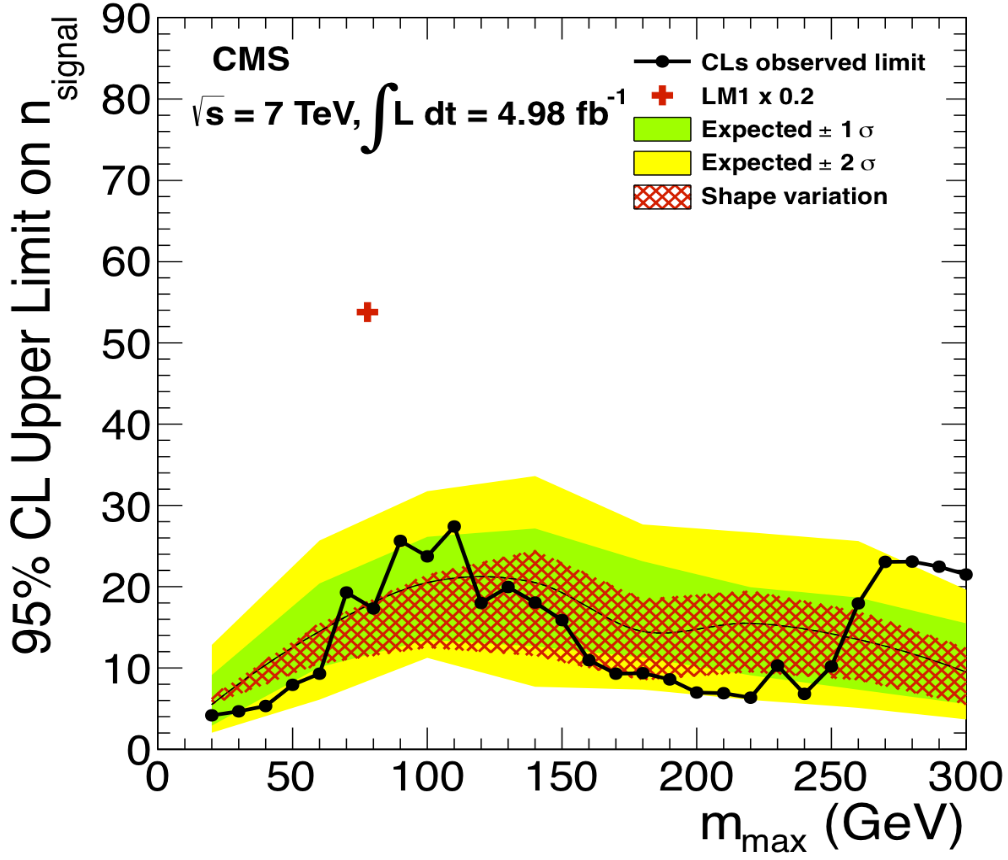


Opposite-Sign leptons

4.98 fb^{-1} at 7 TeV

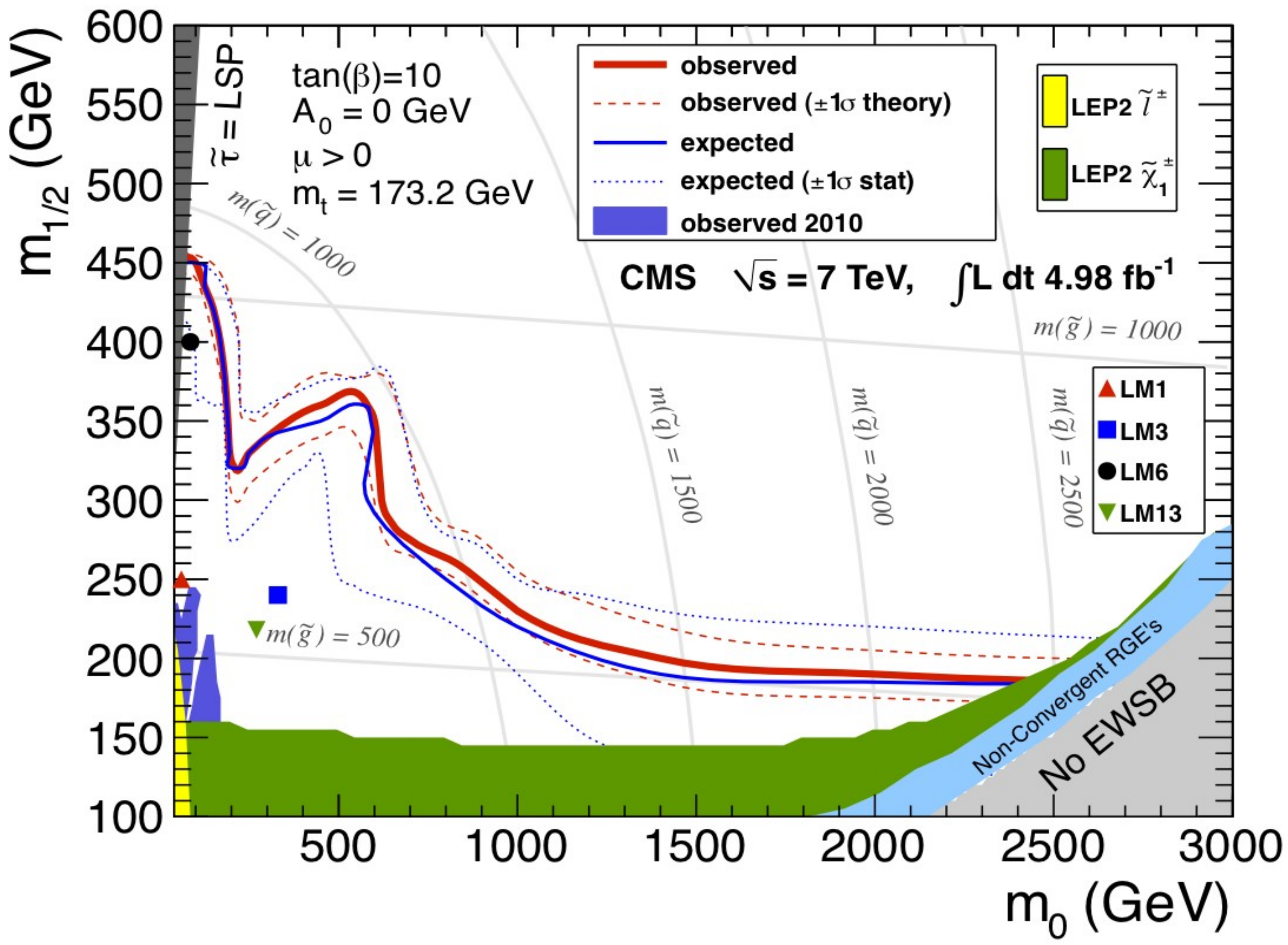
Interpretation

- Search for a kinematical edge



CLs 95% upper limit on the signal yield as a function of the endpoint in the invariant mass spectrum.

- Counting experiment



tan β = 10 | A_0=0 GeV | μ>0

Same-Sign leptons and b-jets

Single lepton, jets and MET

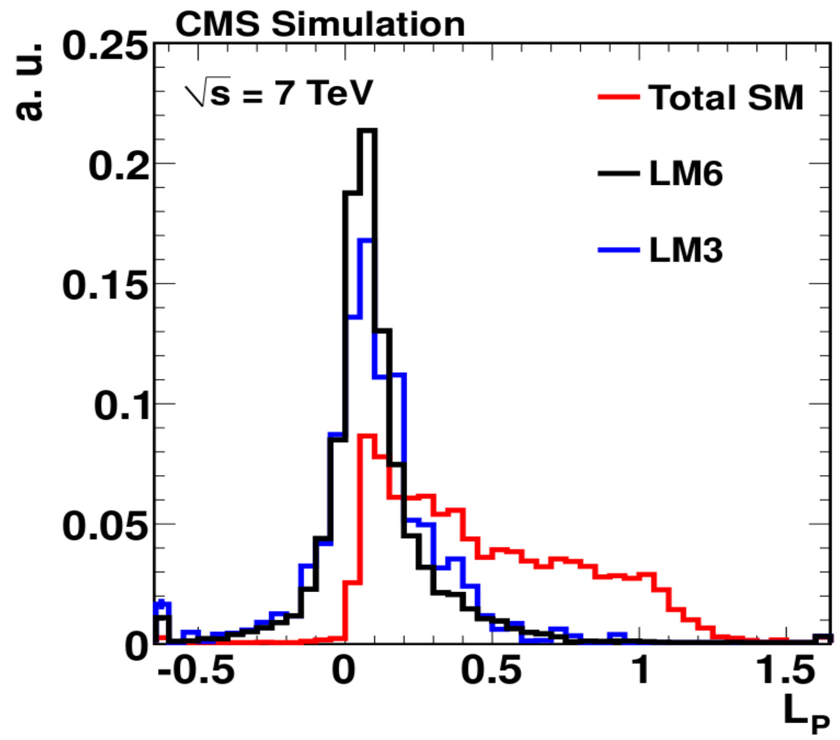
Single lepton, jets and MET

4.7 fb^{-1} at 7 TeV

Backgrounds obtained with two data-driven methods:

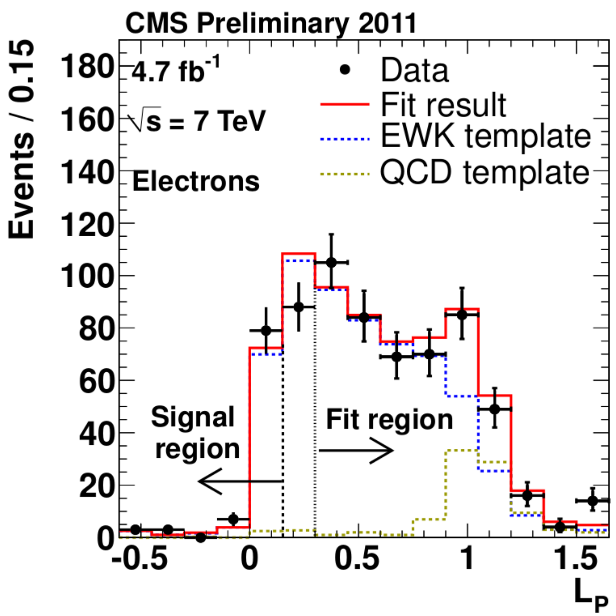
1)Lepton Spectrum method:

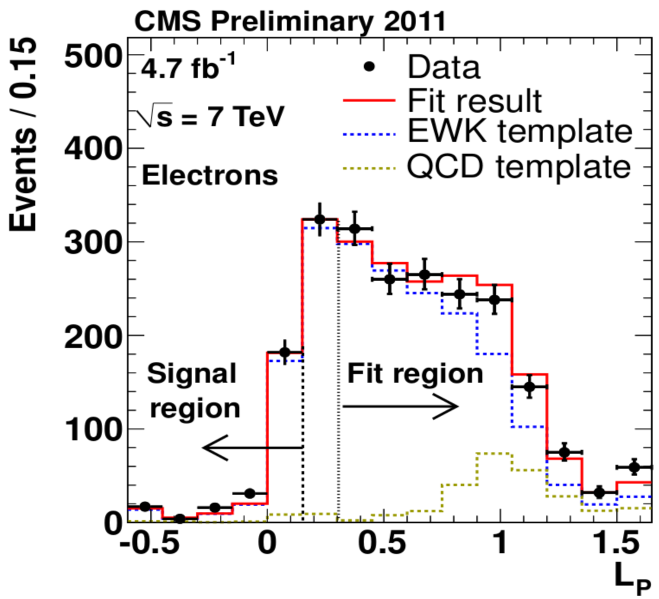
Exploits the correlation between the MET and lepton p_T in tt or in W+jets (main backgrounds), which should be absent in SUSY events.



2)Lepton Projection (L_P) variable method:

L_P correlated to the helicity angle of the lepton in the W-boson rest frame.





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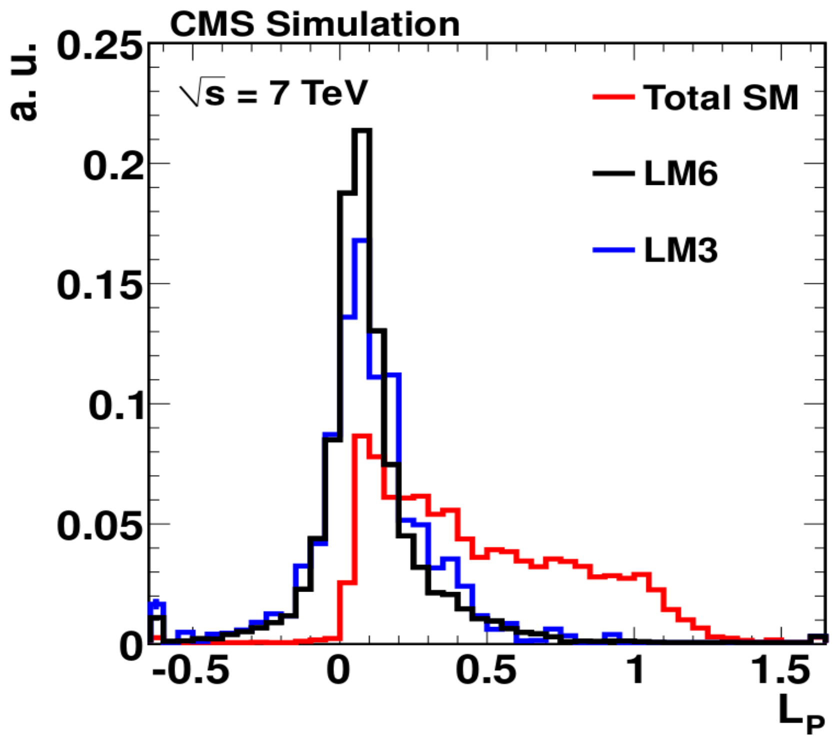

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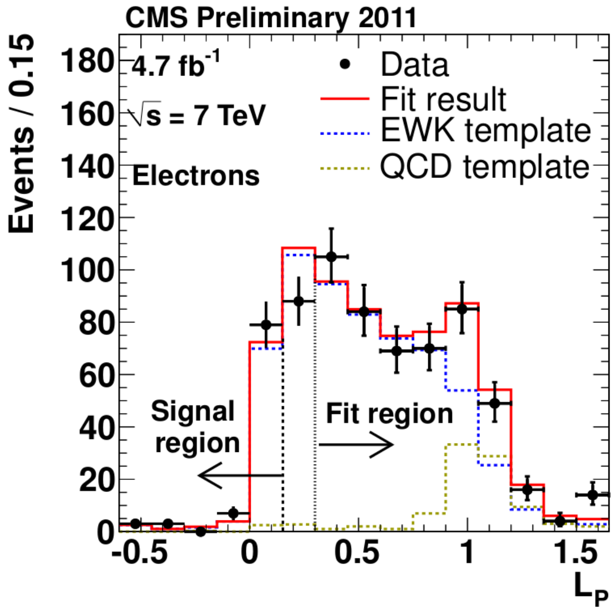
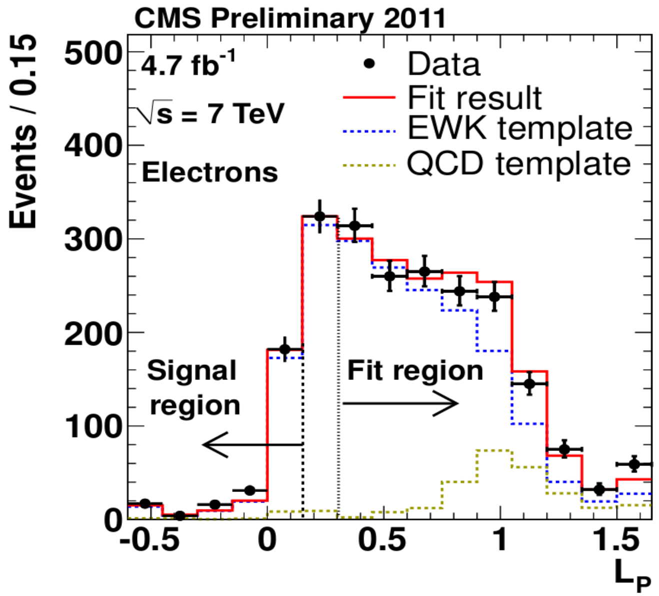




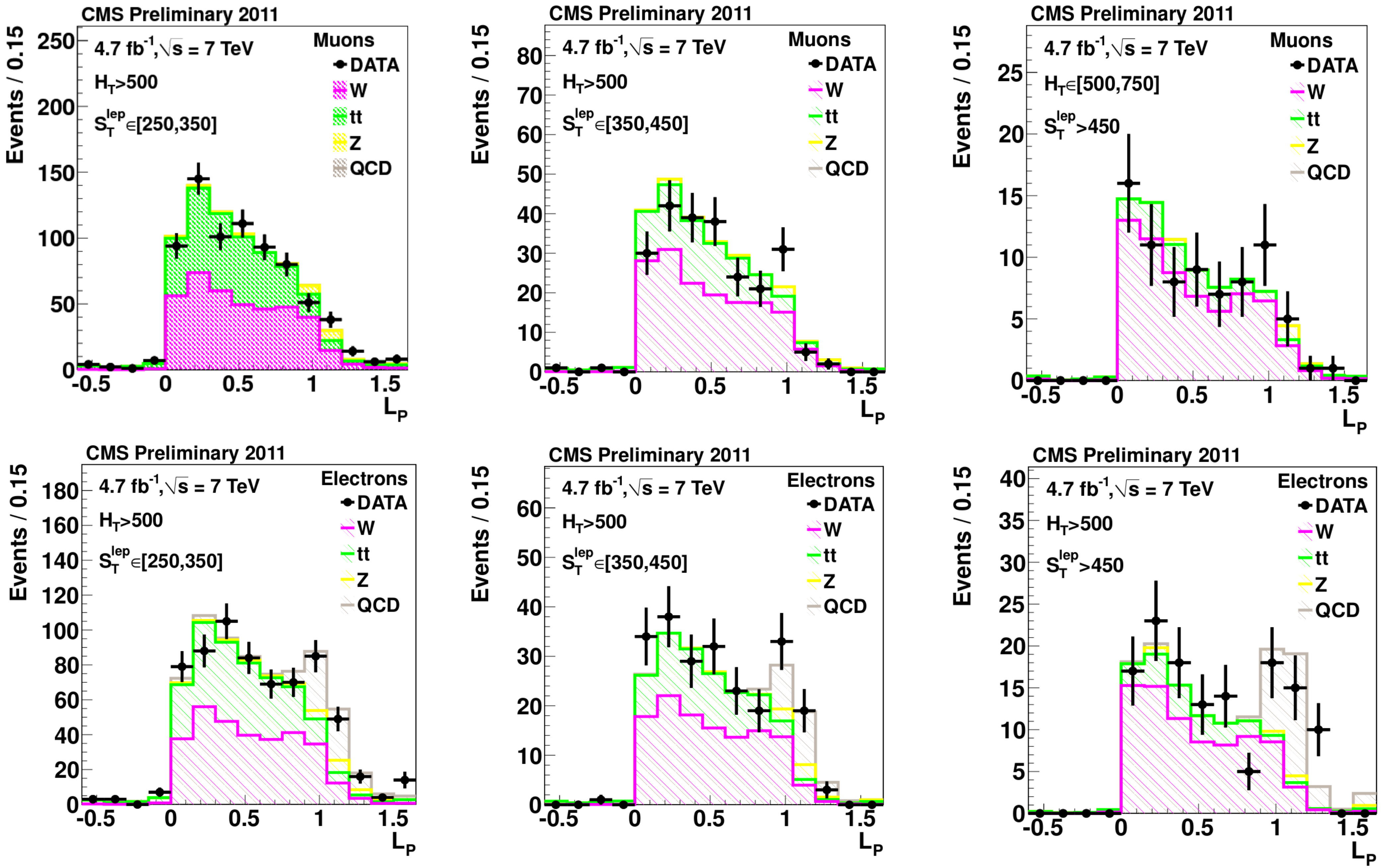
Single lepton, jets and MET

4.7 fb^{-1} at 7 TeV

2)Lepton Projection (L_P) variable method:

MUONS

ELECTRONS



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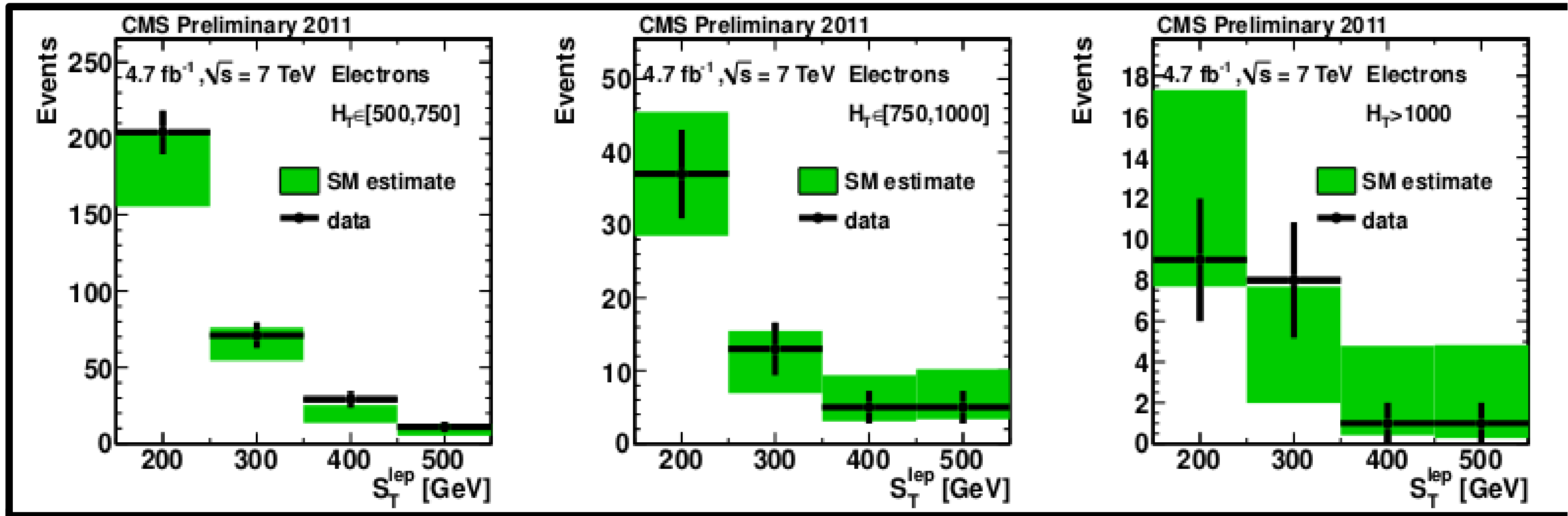
Single lepton, jets and MET

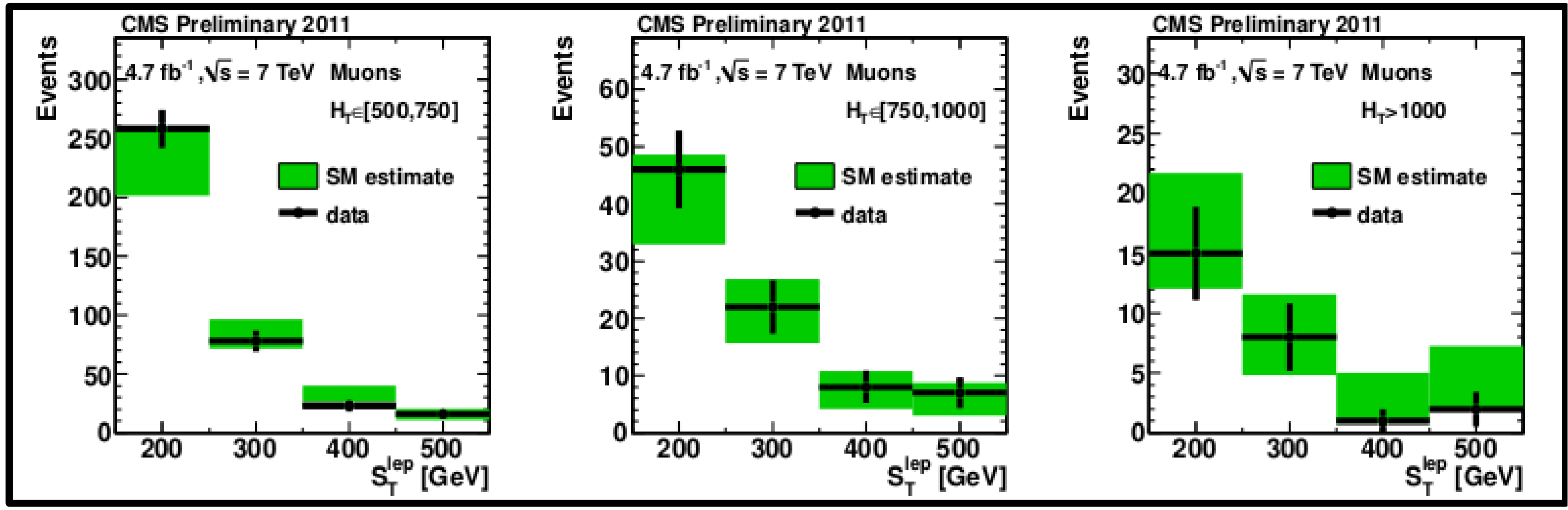
4.7 fb^{-1} at 7 TeV

SM prediction from the two methods considered



ELECTRONS: Number of data events compared with the the SM expectation, in different regions of H_T

No excess over the SM prediction is observed



MUONS: Number of data events compared with the the SM expectation, in different regions of H_T

1-lepton and jets with templates

4.98 fb^{-1} at 7 TeV

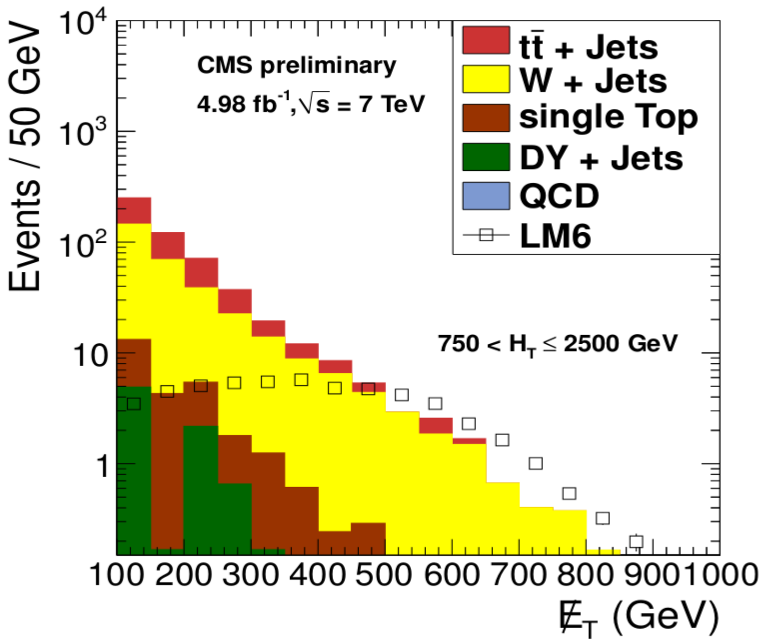
- 3 Jets with p_T > 40 GeV
- HT > 350 GeV
- MET > 100 GeV
- Veto on looser leptons

Main Backgrounds:

ttbar, W+Jets

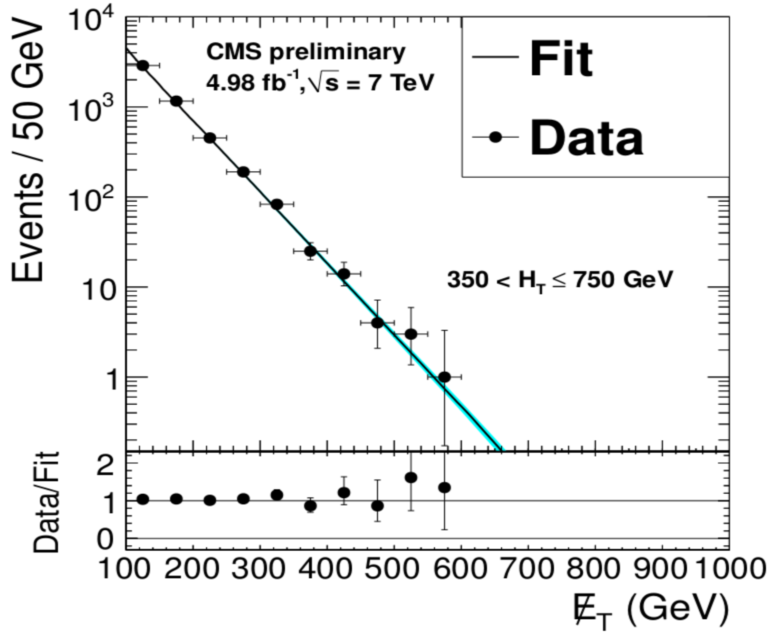
DY, Z+Jets, QCD

Estimated with a template for real MET, obtained in a control region at low HT.

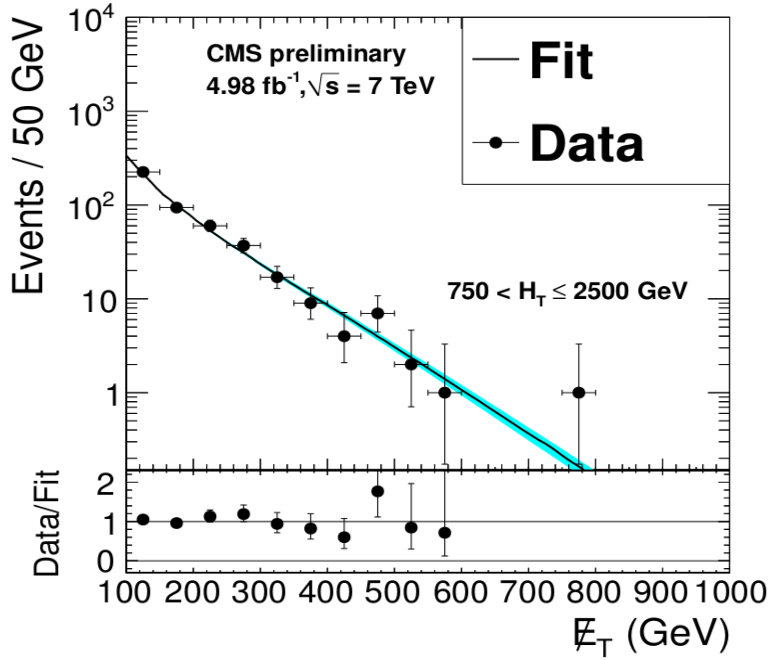


Distribution of MET in the μ channel

a



b

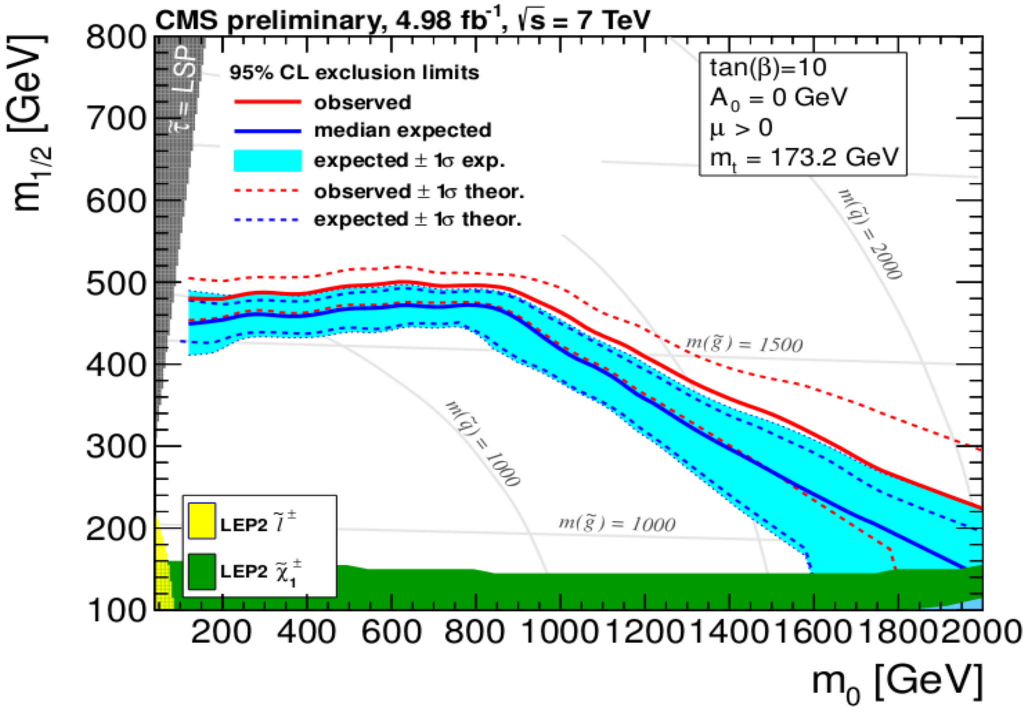


Distribution of MET in the μ channel for data and data-driven fit prediction for
a) 350<H_T<750 GeV
b) H_T>750 GeV

1-lepton and jets with templates

4.98 fb^{-1} at 7 TeV

Interpretation in the CMSSW



tan β = 10 A_0=0 μ>0

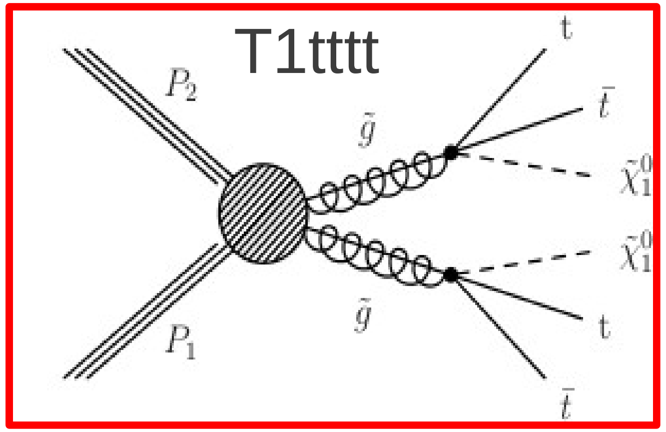
HT>1000 GeV and MET>250GeV

Simplified models

T1tttt model

4 b-quarks in the final state

40 % BR into single-lepton



HT>1000 GeV and MET>250GeV