Search for SuperSymmetry with one lepton in the final state

(in CMS experiment at LHC centre of mass energy of 7 TeV)

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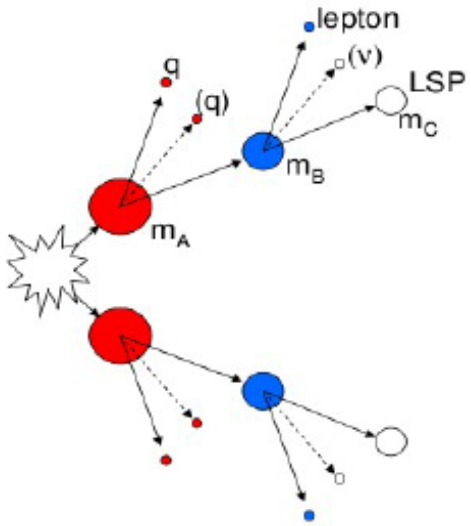
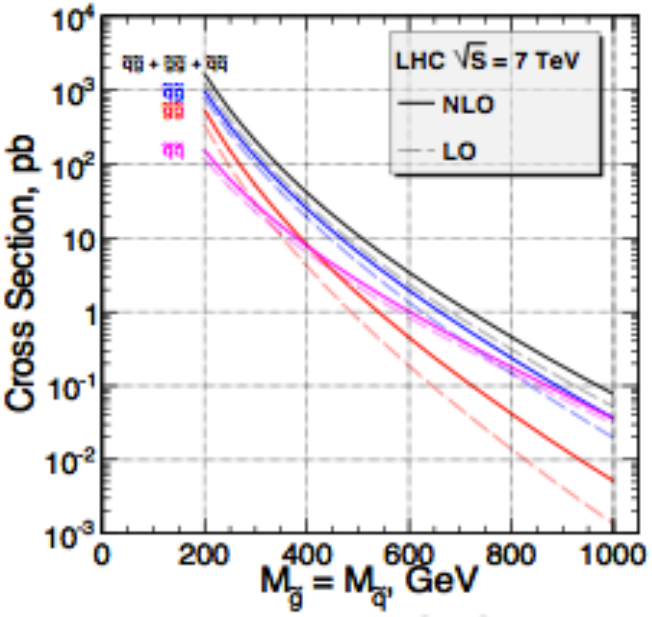
On behalf of CMS collaboration, CERN

SUSY parellel session, ICHEP, Melbourne, July 5, 2012

Production of SUSY particles at LHC



- m_A ➔ cross-section
- Δm_{AB} ➔ Σ jet energies
- Δm_{BC} ➔ lepton's momentum
- Δm_{AC} ➔ missing energy



No resonance production ➔ SUSY events characterized by excess in the tails of kinematical distributions of Standard Model (SM) processes.
➔ measuring background is the key.

• Benchmark points chosen in constrained MSSM (cMSSM):
➔ To cover a range of topologies and large volumes of phase space.
➔Topology-based searches performed with robust and simple signatures which are common to a wide variety of models and to avoid problems of small branching fractions.

Search Strategy

Some of the benchmark points of cMSSM

Name	m_0 (GeV/c^2)	$m_{1/2}$ (GeV/c^2)	A_0	$tan\beta$	sign(μ)	σ_{LO}	$\frac{\sigma_{NLO}}{\sigma_{LO}}$
LM0	200	160	-400	10	+	38.93	1.41
LM3	330	240	0	20	+	3.438	1.40
LM6	85	400	0	10	+	0.3104	1.30

- Generic search utilizes selections categorized by number of leptons and jets.
  - Choose multijet events with large energy, define $H_T = \sum_i p_T^{j_i}$
    + Large missing transverse energy $\not{E}_T$ $\not{E}_T = |\vec{\not{E}}_T|$ $\vec{\not{E}}_T = -\sum \vec{p}_T$
  - Requiring a lepton (e/μ) in the final state

→ QCD multijets events do not contribute much in the selected sample.

- In the characteristic distributions

→Define *control* region dominated by SM background.

→Estimate contribution of SM in *signal* region by extrapolation.

→ Data driven estimates of main background processes.

Single-lepton search

A) 1 lepton + ≥ 3jets + $\not{E}_T$

Several analyses with complementary methods for background estimation

→ lepton projection, lepton spectrum, neural network

CMS PAS- SUS-12-010, CMS PAS-SUS-11-026

B) 1 lepton + ≥ 3jets + ≥ 1- b-jet + $\not{E}_T$ ⟶ Talk by A.Cakir

Backgrounds due to SM processes with real $\not{E}_T$ → essentially leptonic decays of W.

→ W+jets (σ =28000 pb @ 7 TeV)

→ $t\bar{t}$ (σ =157.5 pb @ 7 TeV)

→ Z+jets, single top, QCD multijet processes are less severe

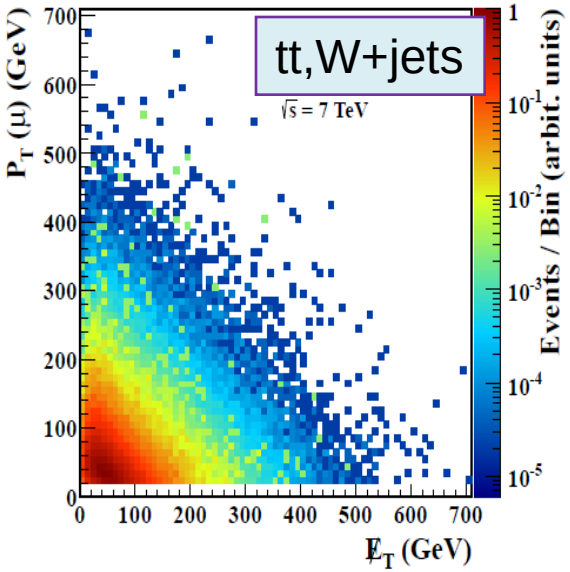
Selections:

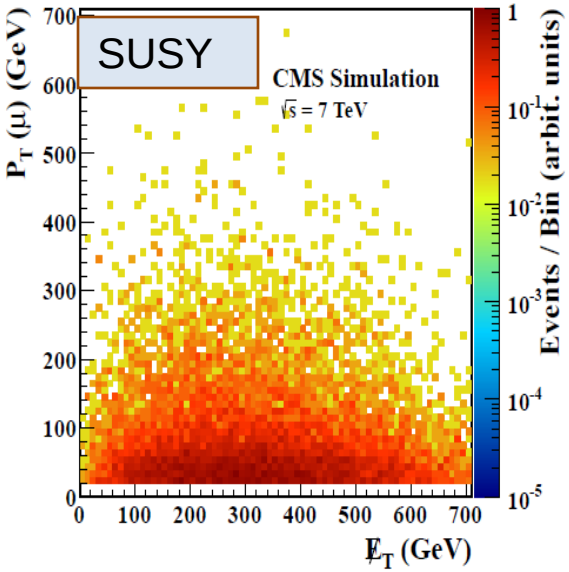
- Isolated e OR μ above 20 GeV/c, in central region
- Jets above 40 GeV in central region
- Lepton-jet separation > 0.3

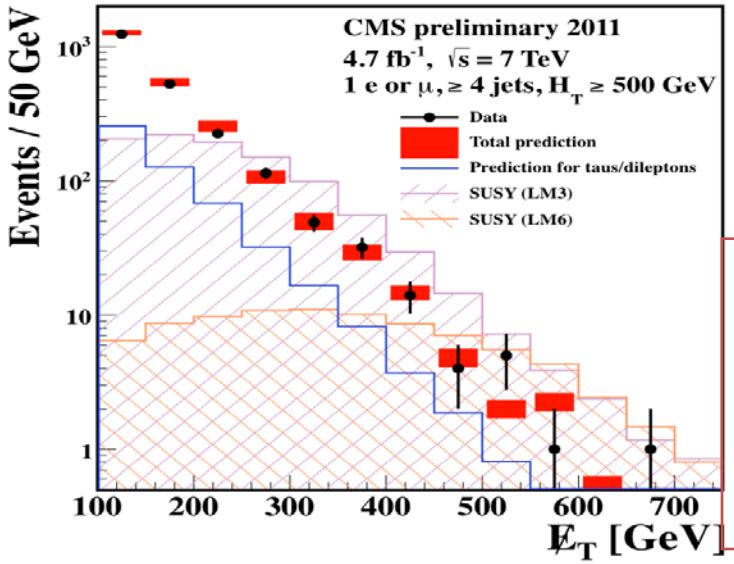
Lepton spectrum method

In SUSY, $\not\!\!E_T$ is independent of lepton and also much harder.
➔ NOT the case in SM.

Use observed lepton p_T to predict $\not\!\!E_T$ from SM at high end.







Events categorized in HT and $\not\!\!E_T$ bins

Event yields in 4.7 /fb for HT> 500 GeV

$\not\!\!E_T$ (GeV)	predicted	observed (e,μ)
(250 - 350)	159 ± 13.8 ± 17.8	163 (84, 79)
(350 - 450)	44.0 ± 7.7 ± 6.0	46 (21,25)
(450 - 550)	6.6 ± 3.0 ± 1.8	9 (8,1)
>550	4.3 ± 2.6 ± 1.6	2 (1,1)

Data consistent with background

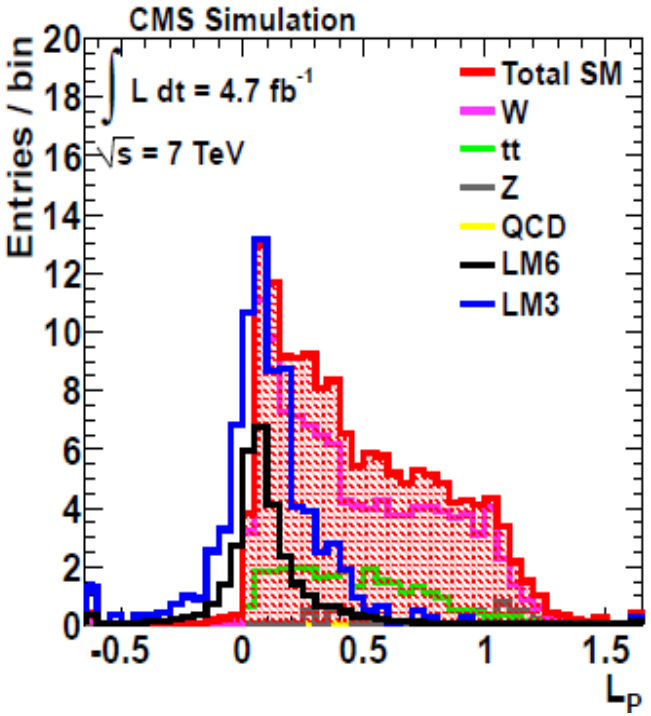
CMS-PAS-SUS-12-010

Lepton Projection method

CMS-PAS-SUS-12-010

Angular distribution of the lepton in W rest frame differentiates SM from signal.
Total W momentum unknown ➔ use only the transverse components to define lepton projection variable

$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$



- Lp peaks near zero for SUSY due to large $\not{E}_T$ relative to the lepton momentum.
- SM processes have broad Lp distributions.

Signal region : Lp <0.15
Control region: Lp>0.3

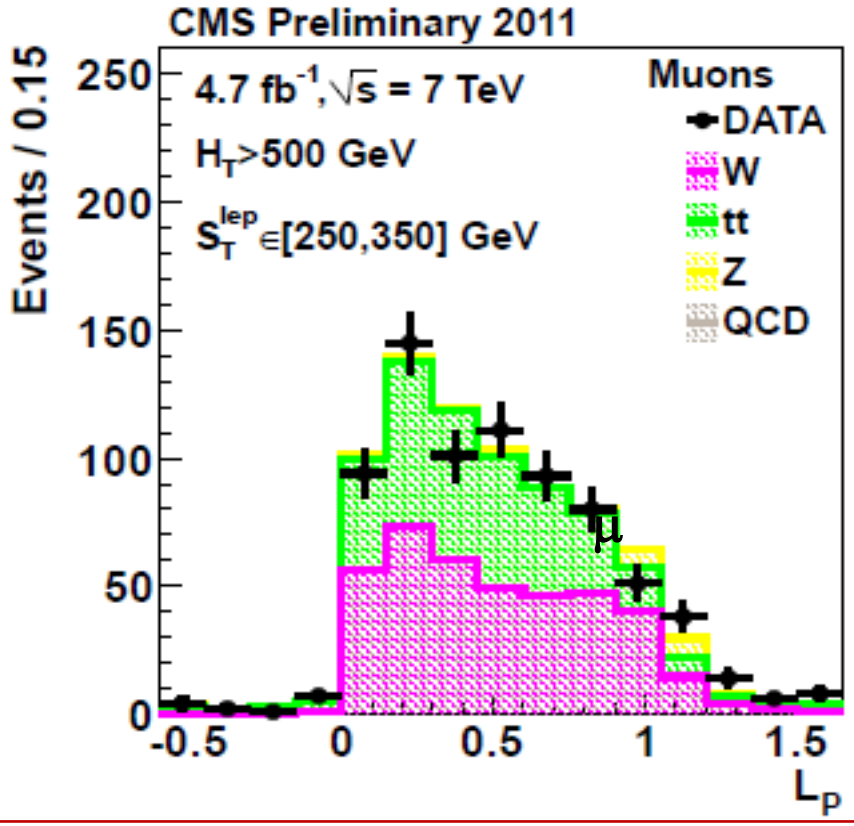
$$N_{SM}^{pred}(L_P < 0.15) = R_{CS} N_{data}(L_P > 0.3)$$

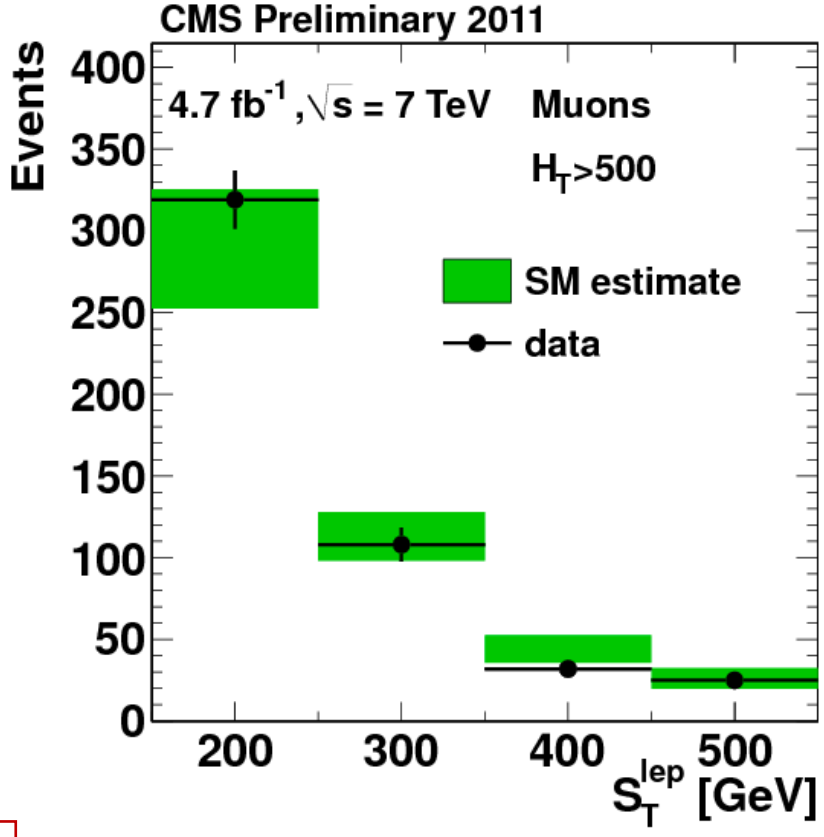
$$R_{CS} = \frac{N_{MC}(L_P < 0.15)}{N_{MC}(L_P > 0.3)}$$

Lepton projection in different ST bins

- Categorize events in terms of event's mass scale ⟶ $S_T^{lep} = p_T(\ell) + \not{E}_T$
  (expect large S_T for SUSY)
- For each S_T bin, fit background in control region to estimate rate in signal region.

CMS-PAS-SUS-12-010

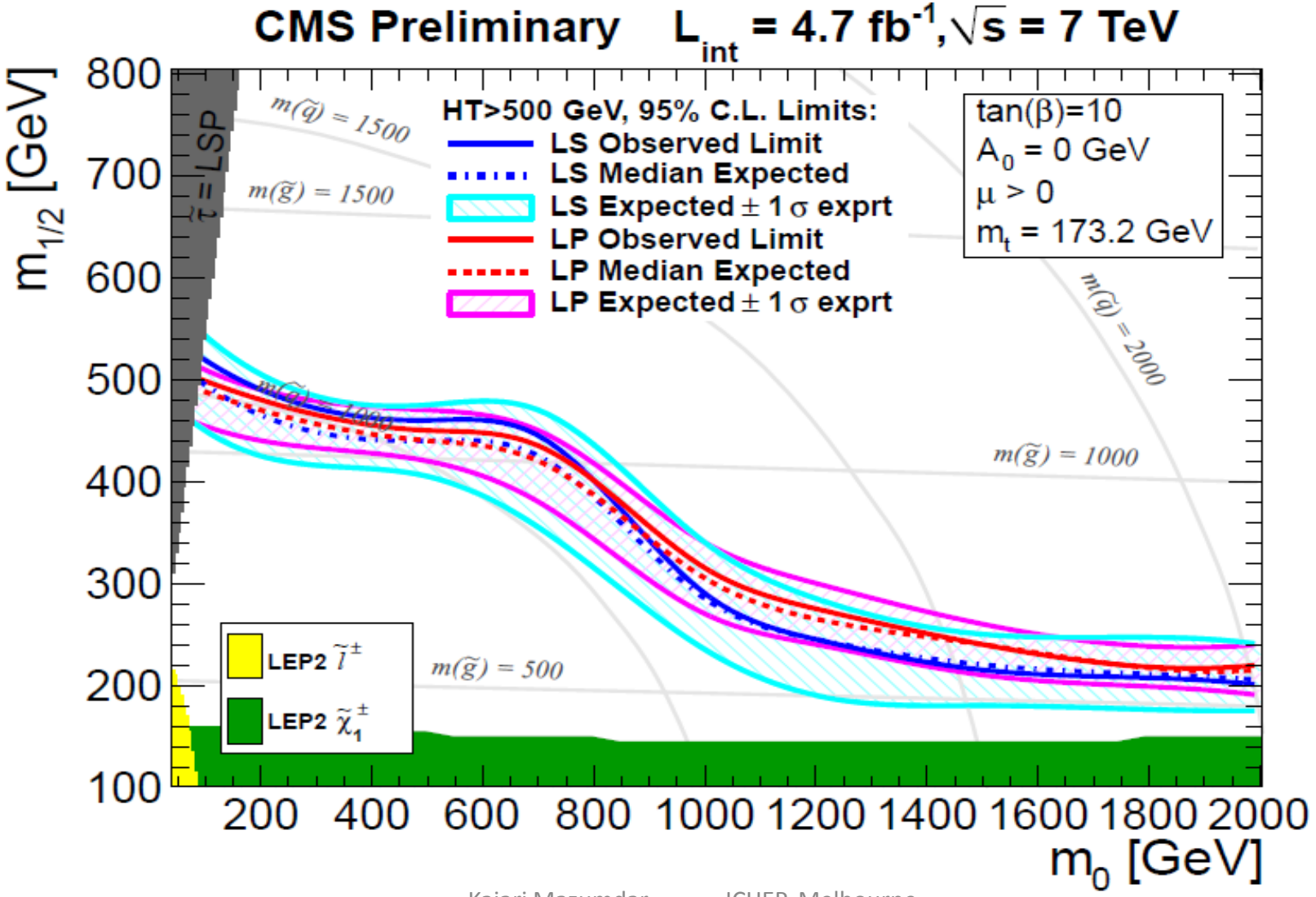




No excess in data over SM backgrounds

Exclusion in cMSSM parameter space in 1lepton+jets + $\not{E}_T$ channel

CMS-PAS-SUS-12-010



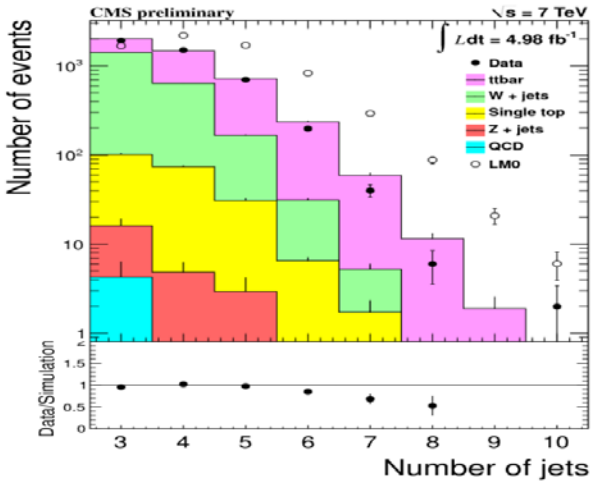
Use of Artifical Neural Network

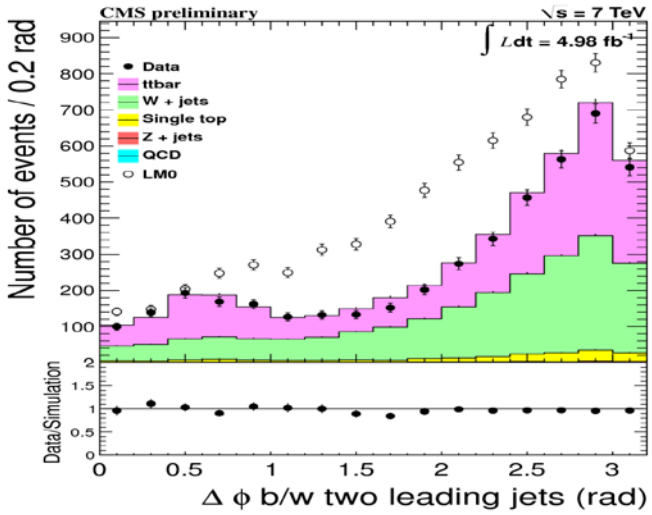
CMS-PAS-SUS-11-026

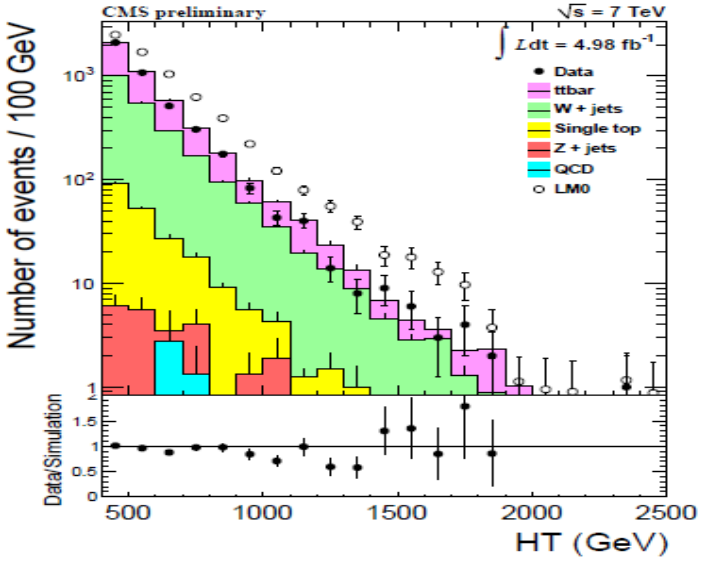
Allows less stringent requirement on total energy in the event.

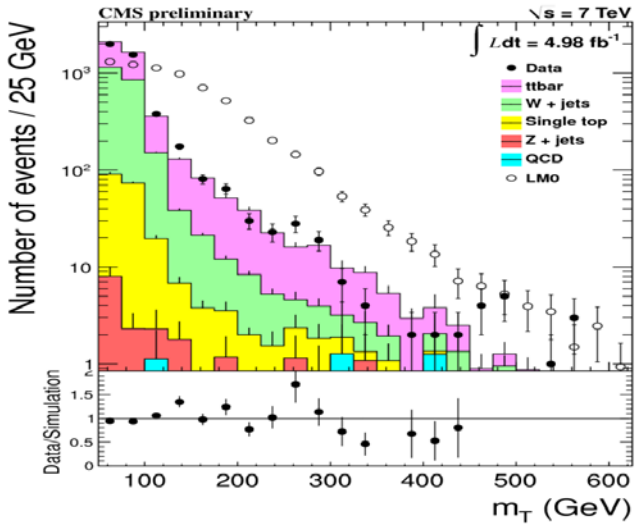
ANN based on # jets, H_T, $\Delta\phi$, m_T

$$m_T = \sqrt{(E_{T,lepton} + \not{E}_T)^2 - |\overrightarrow{p}_{T,lepton} + \overrightarrow{\not{E}}_T|^2}$$









Background estimation using ANN

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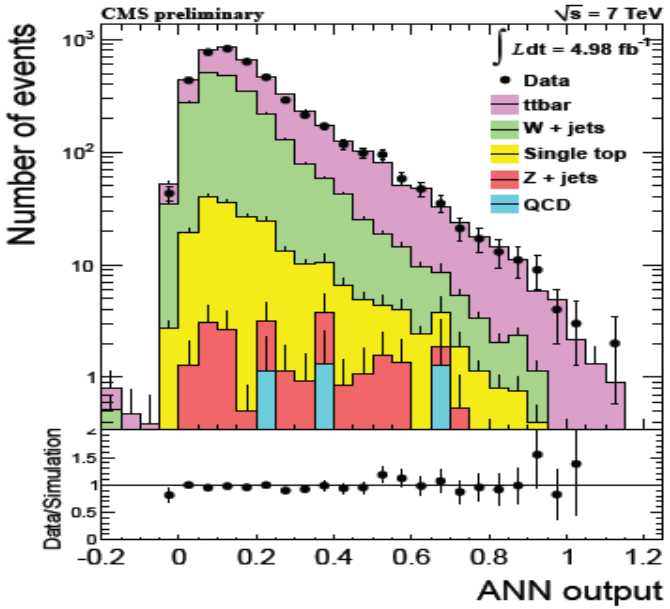
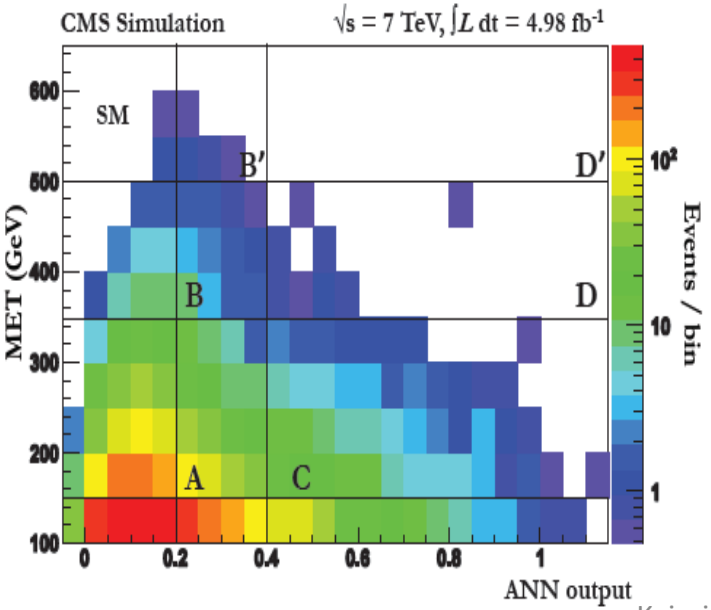
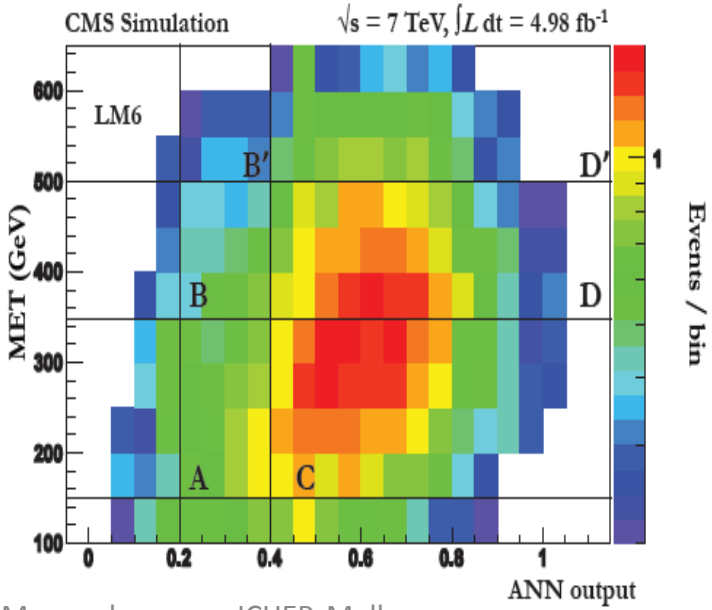
ANN trained with LM0 signal sample.
Performance comparable with other points.



SM concentrated near low ANN values
➔ 2 signal regions:
ANN>0.4, $\not{E}_T$ > 500 GeV
ANN>0.4, 350 < $\not{E}_T$ < 500 GeV

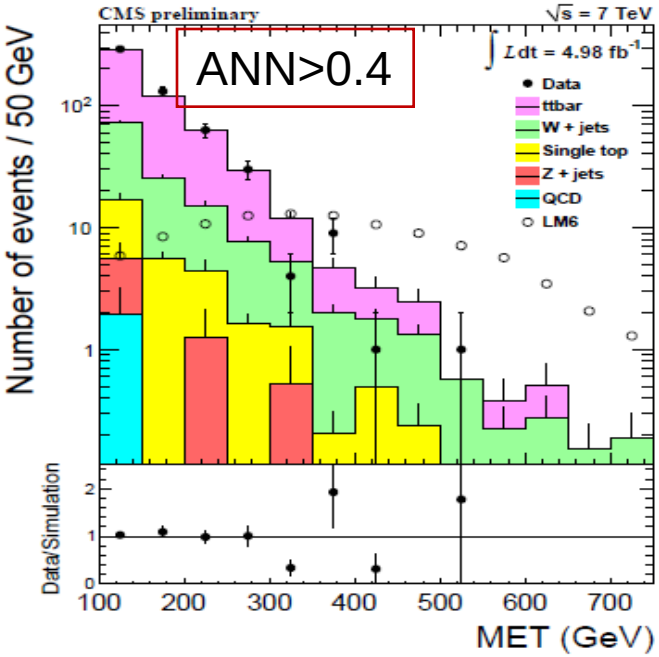
Template for low ANN used for high ANN region

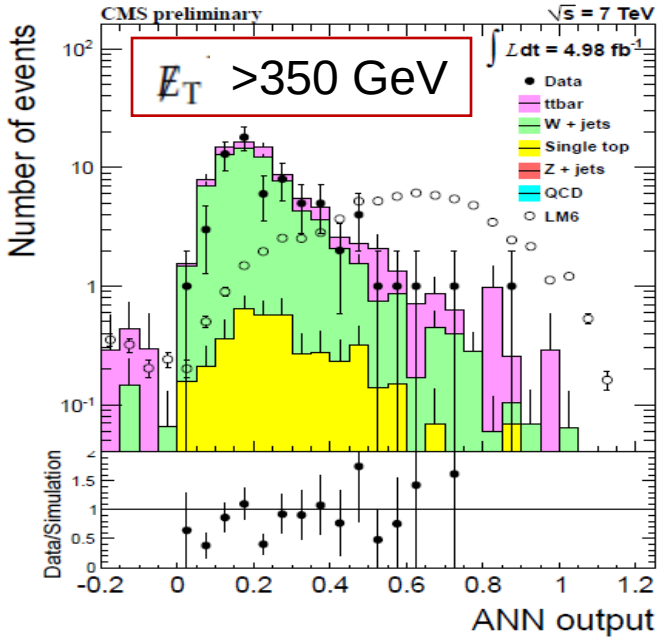




$$D_{pred} = \frac{B \times C}{A}$$

Exclusion in cMSSM space with neural network analysis

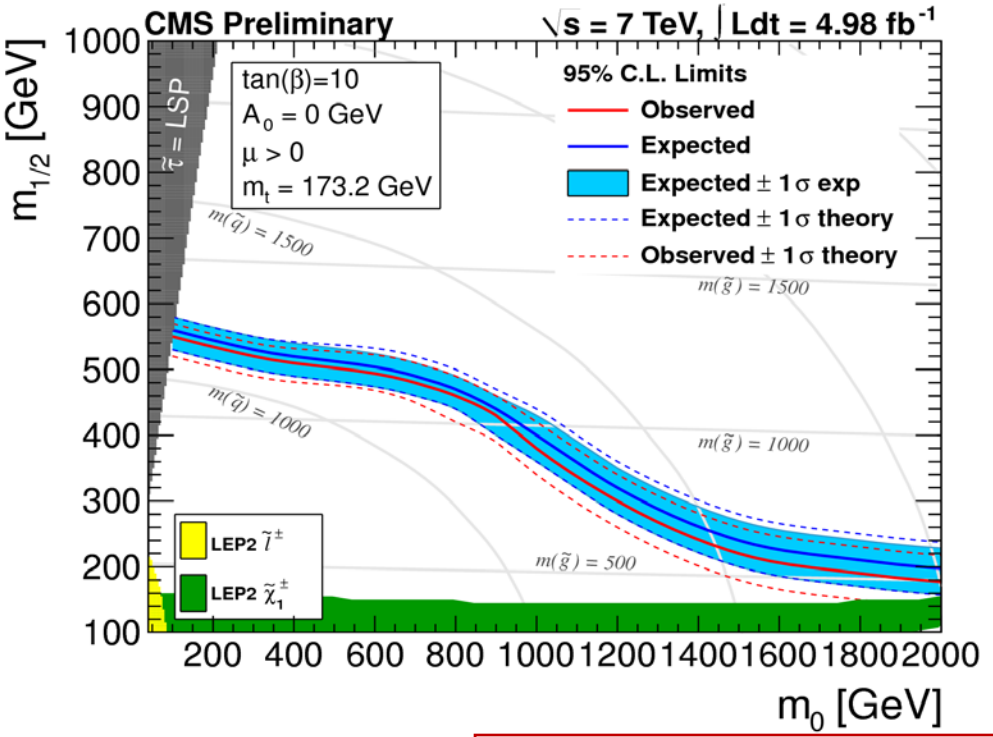




Event yield signal region

		actual	predicted
low	$\not\!\!E_T$:	10	9.5 ± 2.2
high	$\not\!\!E_T$:	1	0.7 ± 0.5

Data consistent with SM background



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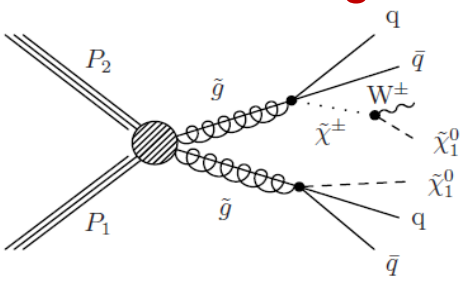
Interpretation

CMS-PAS-SUS-11-016

Resort to *Simplified Model Spectrum* for current searches to be meaningful.

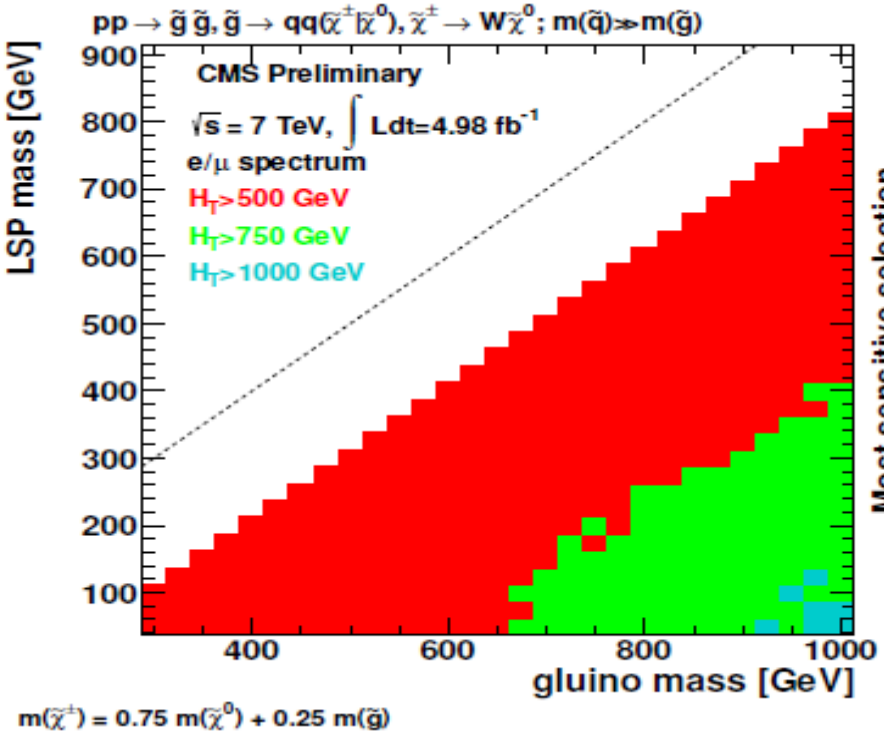


Assumptions:

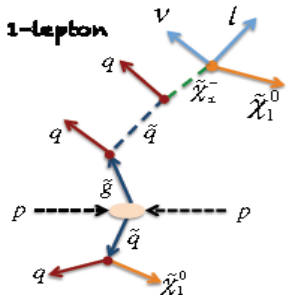
1. Sparticles are produced in pairs.
2. A sparticle decays
   (a) directly to a SM particles and LSP
   OR (b) to an on-shell sparticle which in turn decays to SM particles and LSP

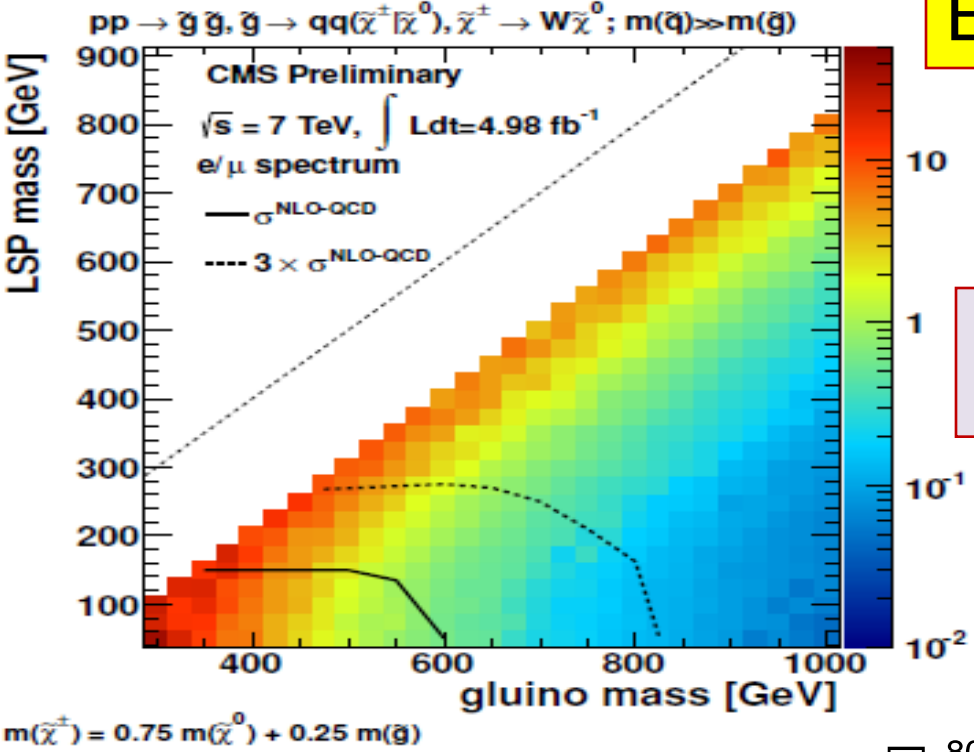
Gluino pair production
+ presence of one W in cascade decay of gluino
+ direct decay of other

Main parameter: mass splitting between gluino & LSP
➔ Large difference provides high H_T



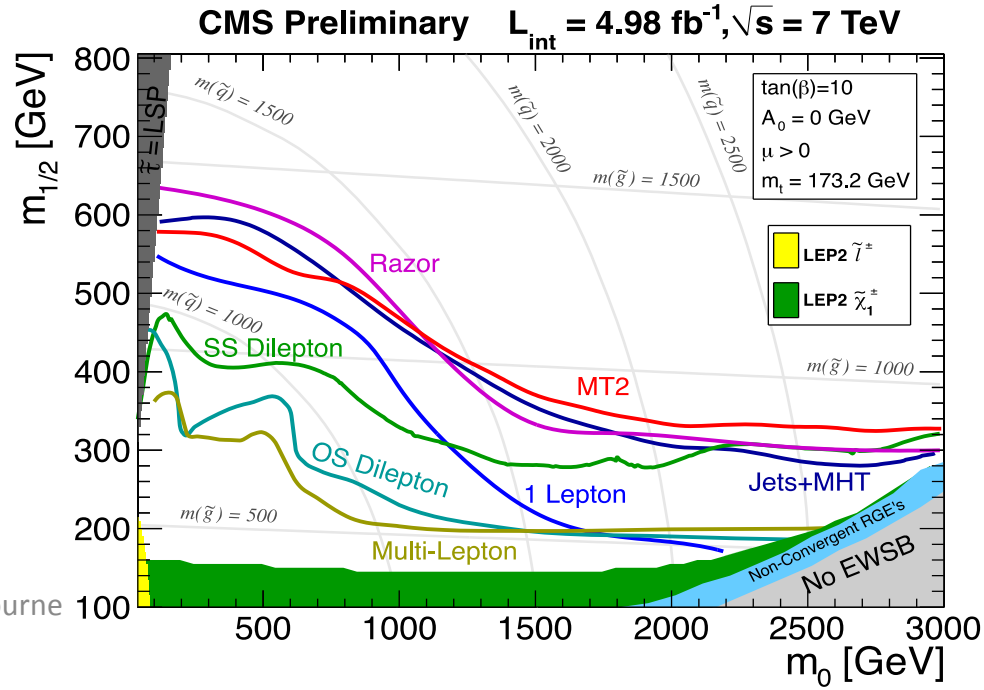
Exclusions





95% CL upper limit on the production cross-section [pb] in CLs method

CMS-PAS-SUS-11-016



Comparison with all-hadronic searches in m-SUGRA parameter space

Conclusion

- CMS has completed analyses p-p collison data at centre of mass energy of 7 TeV
- Searches with only 1 lepton in the final state is reported with the major background rates (W+jets, tt) determined from collision data.
- With data corresponding to an integrated luminosity of about 5 fb^{-1} --till now no sign of SUSY.
- Analyses with data at 8 TeV, collected in 2012 is on going.

→ stay tuned, exciting times ahead!

Details of work presented can be found at
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Backup

Event selection

Trigger:

- 1 lepton (p_T^{μ} >8 GeV/c OR p_T^{e} > 10 GeV/c) + HT (>200 GeV)
- Thresholds increased with instantaneous luminosity + $\not{E}_T$ >30 GeV]

Event preselection

$\not{E}_T$ > 100 GeV
HT > 500 GeV

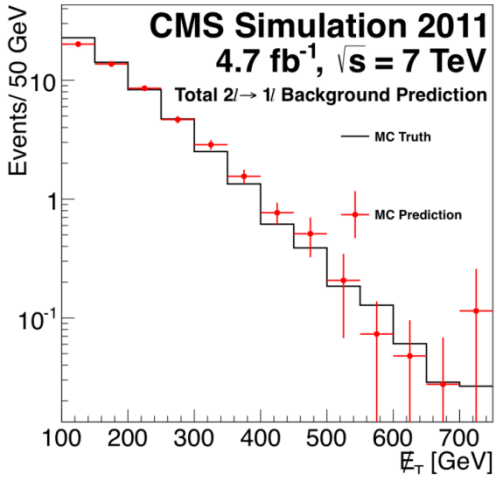
Lepton-jet Δr>0.3

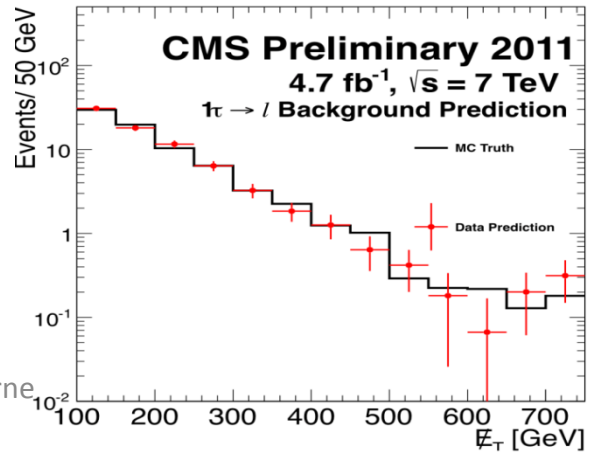
Quantity	Requirement
Primary vertex position	$\rho_{PV} < 2$ cm, $\lvert z_{PV} \rvert < 24$ cm
Jet p_T threshold	> 40 GeV
Jet η range	$\lvert \eta \rvert < 2.4$
Number of jets	≥ 3 (L_P Variable method),
	≥ 4 (Lepton Spectrum method)
Lepton p_T threshold	> 20 GeV
Muon η range	$\lvert \eta \rvert < 2.1$
Muon isolation (relative)	< 0.10
Electron η range	$\lvert \eta \rvert < 1.4$, $1.6 < \lvert \eta \rvert < 2.4$
Electron isolation (relative)	< 0.07 (barrel), < 0.06 (endcaps)
Lepton p_T threshold for veto	> 15 GeV

lepton isolation: $I_{\text{rel}}^{\text{comb}} = \sum_{\Delta R<0.3}(E_T + p_T)/p_T(\mu)$

Lepton Spectrum method

$\not\!\!E_T$:	[250; 350)	[350; 450)	[450; 550)	$\geq$ 550 GeV
MC:				
1 l	137.0 ± 2.0	32.5 ± 1.0	7.9 ± 0.5	2.7 ± 0.3
Dilepton	18.6 ± 0.5	3.5 ± 0.2	0.7 ± 0.1	0.3 ± 0.1
1 τ	28.6 ± 0.9	7.4 ± 0.5	1.9 ± 0.2	0.8 ± 0.2
Z+jets	1.2 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total SM (MC)	185.4 ± 2.3(stat)	43.4 ± 1.1(stat)	10.5 ± 0.6(stat)	3.7 ± 0.4(stat)
SUSY LM3 (MC)	248.6 ± 3.5(stat)	85.0 ± 2.0(stat)	21.7 ± 1.0(stat)	9.2 ± 0.7(stat)
SUSY LM6 (MC)	21.9 ± 0.3(stat)	18.7 ± 0.3(stat)	12.5 ± 0.2(stat)	10.0 ± 0.2(stat)
Data-driven prediction:				
1 l	$109.1 \pm 13.4 \pm 17.5$	$32.1 \pm 7.5 \pm 5.8$	$3.9 \pm 2.6 \pm 1.3$	$3.1 \pm 2.3 \pm 1.0$
Dilepton	$15.8 \pm 1.9 \pm 1.8$	$3.0 \pm 0.9 \pm 0.5$	$0.5 \pm 0.3 \pm 0.2$	$0.1 \pm 0.2 \pm 0.2$
1 τ	$33.0 \pm 1.8 \pm 1.7$	$8.9 \pm 1.0 \pm 0.5$	$2.1 \pm 0.5 \pm 0.2$	$1.1 \pm 0.3 \pm 0.2$
QCD	$0.0 \pm 1.2 \pm 1.2$	$0.0 \pm 1.2 \pm 1.2$	$0.0 \pm 1.2 \pm 1.2$	$0.0 \pm 1.2 \pm 1.2$
Z+jets	$1.2 \pm 0.8 \pm 1.2$	$0.0 \pm 0.0 \pm 0.0$	$0.0 \pm 0.0 \pm 0.0$	$0.0 \pm 0.0 \pm 0.0$
Total (predicted):	$159.1 \pm 13.8 \pm 17.8$	$44.0 \pm 7.7 \pm 6.0$	$6.6 \pm 3.0 \pm 1.8$	$4.3 \pm 2.6 \pm 1.6$
Data (observed):	163 (84, 79)	46 (21, 25)	9 (8, 1)	2 (1, 1)





Lepton Projection Method

Event yield in muon channel

S_T^{lep} Range (GeV)	Total MC	DATA	Total MC	SM estimate	DATA
	Control Region (L_p >0.3)		Signal Region (L_p <0.15)		
500 < H_T < 750 GeV					
[150-250]	1383±10	1297	246±3.0	231±7±24	258
[250-350]	427±4.9	383	93.7±2.0	84.1±4.2±7.3	78
[350-450]	146±2.9	128	37.9±1.3	33.3±3.0±2.6	23
> 450	55.8±1.8	50	17.5±0.9	15.7±2.2±2.0	16
750 < H_T < 1000 GeV					
[150-250]	264.4±3.8	218	49.4±1.5	40.8±2.9±3.5	46
[250-350]	86.7±1.9	88	21.0±0.9	21.3±2.3± 2.2	22
[350-450]	32.6±1.3	25	9.8±0.6	7.5±1.5±1.0	8
> 450	25.2±1.3	18	8.3±0.6	5.9±1.4±0.7	7
1000 GeV < H_T					
[150-250]	87.1±2.3	76	19.3±0.9	16.9±1.9±1.7	15
[250-350]	31.0±1.2	31	8.2±0.7	8.2±1.5 ±1.0	8
[350-450]	10.3±0.6	7	4.3±0.4	2.9± 1.1 ± 0.6	1
> 450	11.2±0.7	12	4.3±0.4	4.6±1.4±0.7	2

Systematics in lepton projection

μ

S_T^{lep} Range (GeV)	[150 - 250]	[250 - 350]	[350 - 450]	> 450
Control Region Stat. (%)	3	4	8	11
MC stat. (%)	1	2	3	5
JES Uncertainty (%)	6	4	6	6
MET Resolution (%)	2	1	2	0
W Polarization (%)	2	2	3	3
$t\bar{t}$ Polarization (%)	0	1	1	1
Lepton pT Scale (%)	0	1	1	2
Lepton Efficiency (%)	5	4	2	1
W cross section (%)	1	0	0	0
$t\bar{t}$ cross section (%)	3	1	0	1
$t\bar{t}$ ($\ell\ell$) (%)	5	5	4	2
Total Syst. Uncertainty (%)	11	9	12	14

e

S_T^{lep} Range (GeV)	[150 - 250]	[250 - 350]	[350 - 450]	> 450
Control Region Stat. (%)	3	4	8	10
MC stat.	1	1	3	6
JES Uncertainty (%)	6	5	9	7
MET Resolution (%)	1	2	2	4
W Polarization (%)	3	2	2	2
$t\bar{t}$ Polarization (%)	1	1	2	2
Lepton Efficiency (%)	5	2	2	2
W cross section (%)	1	1	1	1
$t\bar{t}$ cross section(%)	1	1	1	1
$t\bar{t}$ ($\ell\ell$) (%)	5	5	4	2
Total Syst. Uncertainty (%)	11	9	14	15

Syst. Uncertainties in ANN method

Source	Low-$\not\!\!E_T$ signal reg.	High-$\not\!\!E_T$ signal reg.
SM simulation statistics	15%	23%
Jet and $\not\!\!E_T$ energy scales	3%	4%
Lepton and $\not\!\!E_T$ energy scales	3%	5%
W boson and $t\bar{t}$ cross sections	3%	2%
Other cross sections	1%	1%
Dilepton feed-down	1%	7%
Pile-up	0.5%	0.3%
W boson p_T spectrum	10%	2%
W boson polarization	1%	3%
Lepton trigger efficiency	0.3%	0.4%
Total	19%	26%