Searches for Supersymmetry with the CMS detector at the LHC

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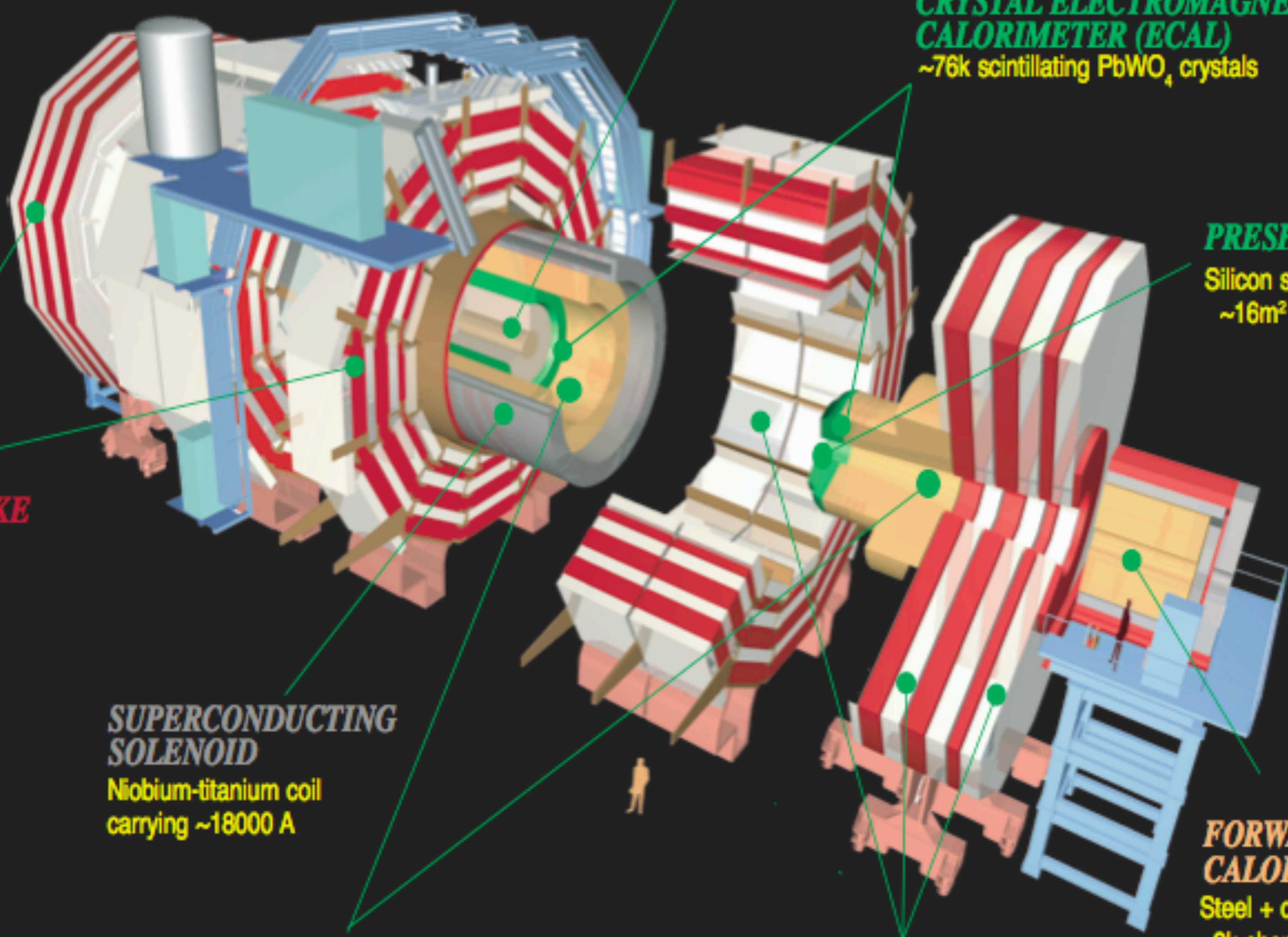
Outline

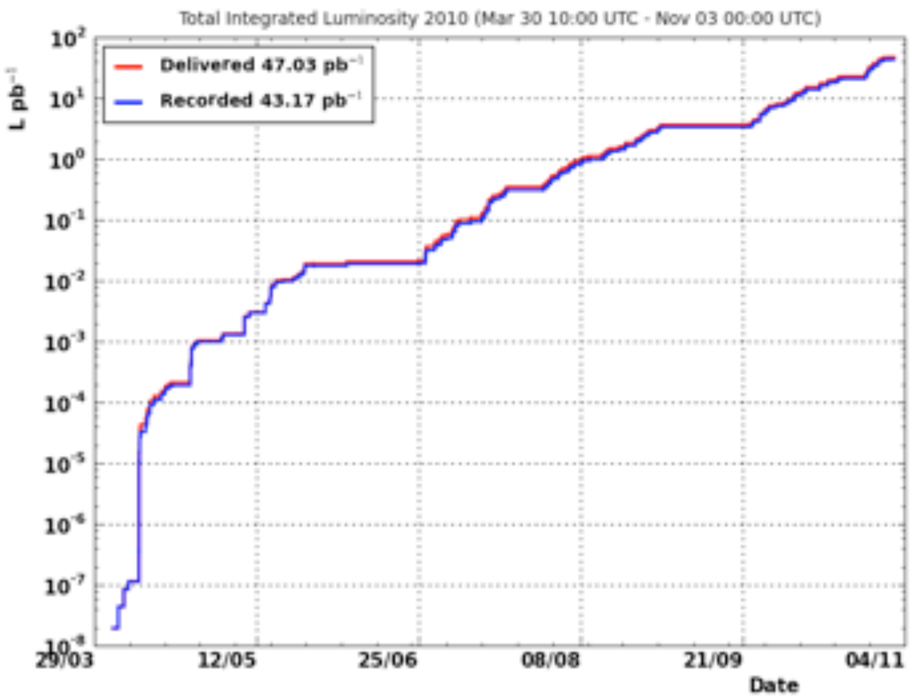
- The CMS detector
- CMS Data and SUSY searches
- 0-Lepton searches
  - n-Jets and MET
  - Jets and MHT
  - B-tagged jets and MET
  - Inclusive searches for squarks and gluinos
- Single Lepton, Jets, and MET
- Double lepton searches
  - Same-sign di-lepton, Jets and MET
  - Opposite-sign di-lepton, Jets and MET
- Multi-lepton searches
- Two Isolated Photons, Jets and MET
- Lepton, Photon, and MET
- Summary

CMS Detector



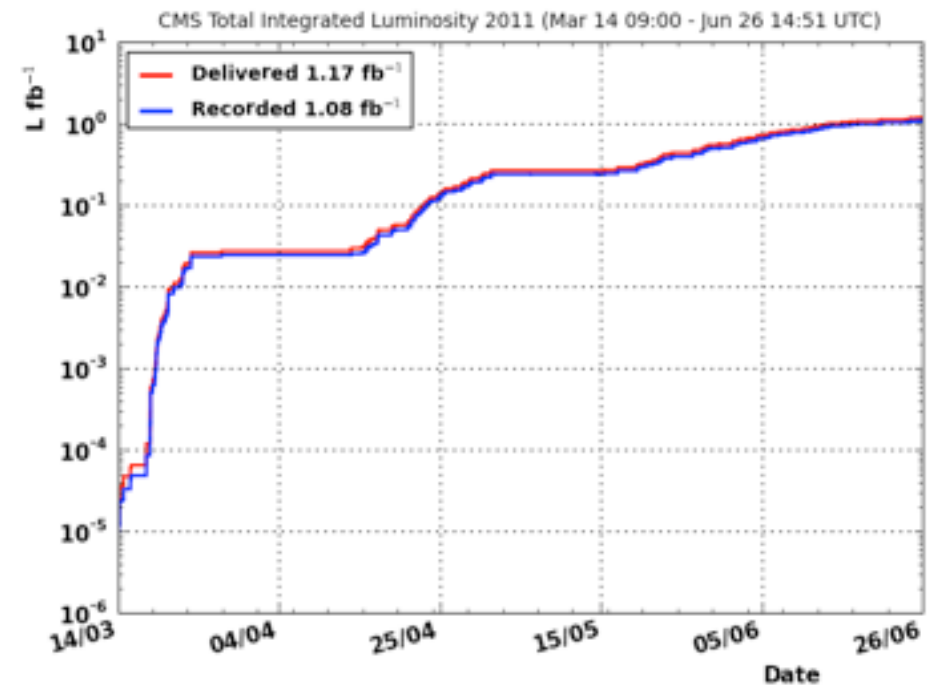
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

SUSY searches



Total Integrated Luminosity vs. Time during the 2010 proton-proton run, all the results presented here were obtained with these data

Total Integrated Luminosity vs. Time during the 2011 proton-proton run (so far), good potential for the analyses this year.



0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

n-Jets and Missing Transverse Energy

- This kind of analysis searches for R-Parity conserving SUSY
- Several energetic jets are characteristic of the decay of heavy squarks and gluinos.
- This analysis uses an H_T trigger to select the events
- Events with at least one jet that does not fulfil the identification criteria are vetoed
- Events with isolated photons are vetoed
- Events with isolated leptons (electron and muons) are vetoed
  - These vetoes reject approximately 5 % of the events after the selection
- To separate the QCD background from the signal like events the α_T variable was used
  - The n > 2 case is obtained by clustering the jets in to two final pseudo-jets, the combination that minimise the difference in H_T between both pseudo-jets is used to calculate α_T
- An α_T cut of 0.55 effectively separates QCD events from electroweak processes and top anti-top quark production
- Events in which the ratio between MHT and MET is bigger than 1.25 are rejected

$$H_T = \sum_{i=1}^{N_{jet}} E_T^{j_i}$$

$$\alpha_T = E_T^{j_2} / M_T \qquad \alpha_T = \frac{1}{2} \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}}$$

$$M_T = \sqrt{\left(\sum_{i=1}^{n} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{n} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{n} p_y^{j_i}\right)^2}$$

$$\not{H}_T = \left| -\sum_{\text{jets}} \vec{p}_{T\,\text{jets}} \right|$$

$$R_{\text{miss}} = \not{H}_T / \not{E}_T > 1.25$$

Selection cut	Data	SM	$QCD_{Pythia6\ Z2}$	$Z \to \nu\bar{\nu}$	W + jets	$t\bar{t}$
$H_T > 250$ GeV	4.68M	5.81M	5.81M	285.3±5.3	(2.0±0.0)k	(2.5±0.0)k
$j_2 : E_T > 100$ GeV	2.89M	3.40M	3.40M	160.5±4.0	610.3±8.2	832.4 ±1.9
$H_T > 350$ GeV	908k	1.11M	1.11M	79.1±2.8	281.6±5.5	650.1±1.7
$\alpha_T > 0.55$	37	30.5±4.7	19.5±4.6	4.2±0.6	3.9±0.7	2.8±0.1
$\Delta R_{ECAL} > 0.3 \vee \Delta\phi^* > 0.5$	32	24.5±4.2	14.3±4.1	4.2±0.6	3.6±0.6	2.4±0.1
$R_{miss} < 1.25$	13	9.26±0.9	0.03±0.02	4.1±0.6	3.3±0.6	1.8±0.1

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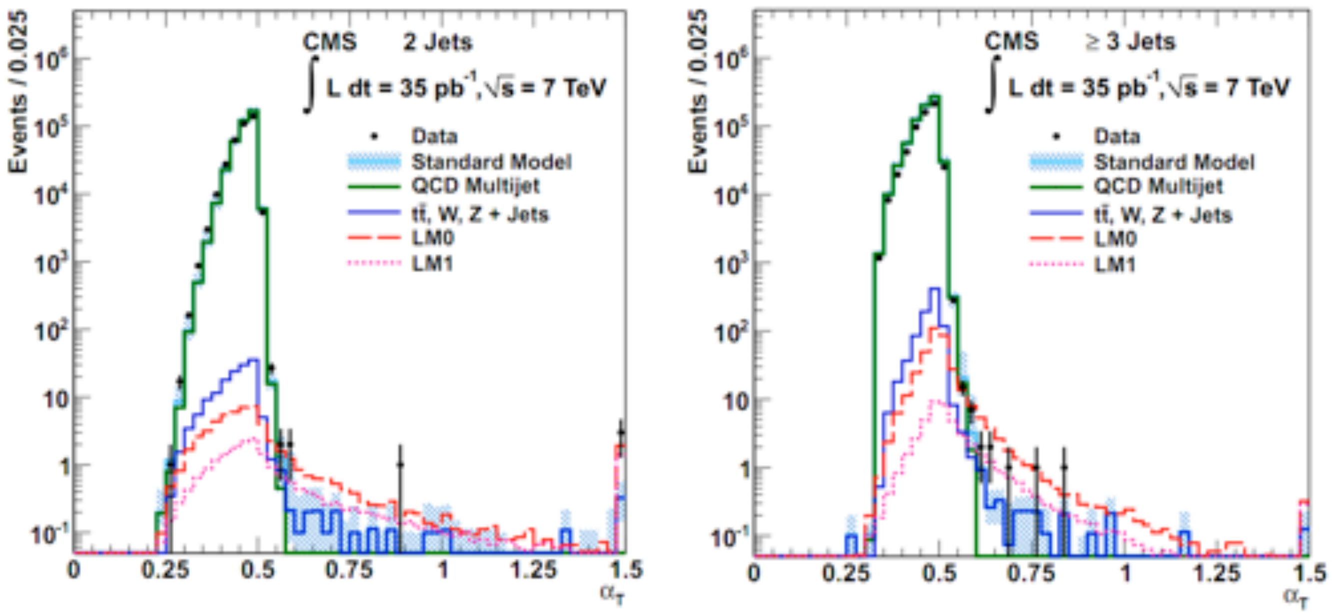
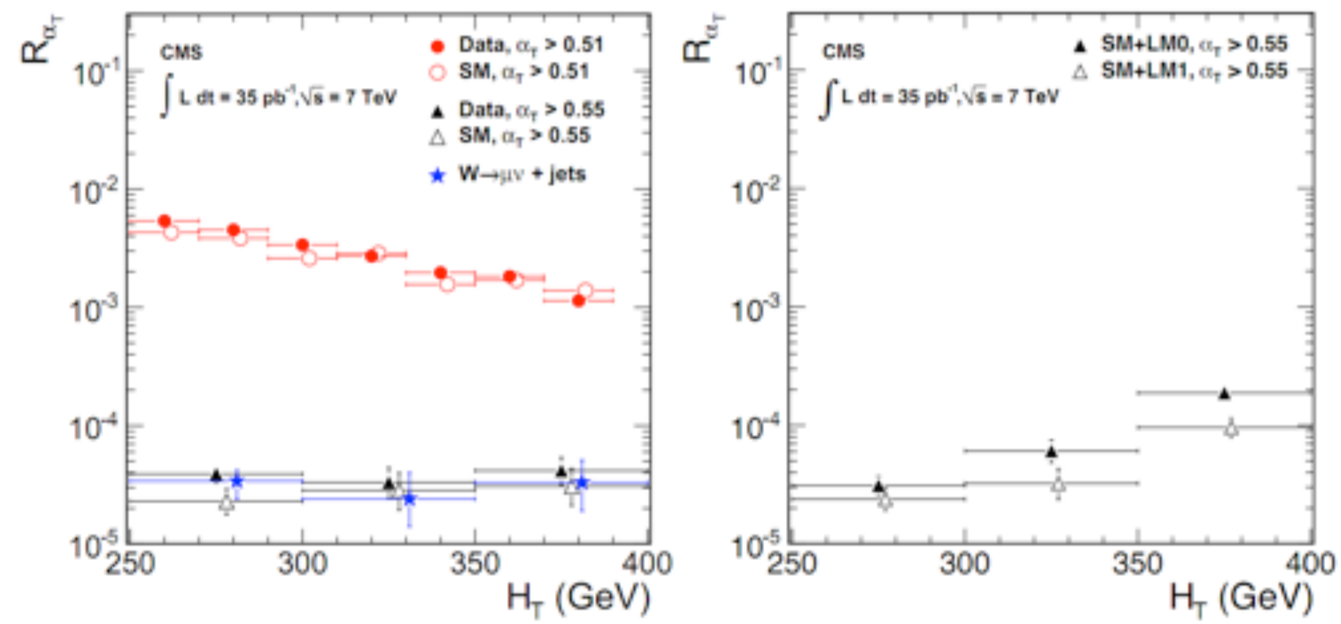


Distributions of α_T for dijets events (left) and > 2 jets (right), requiring H_T > 350 GeV. Events with α_T > 1.5 are shown in the right-most bin.



The evolution of $R\alpha_T$ as a function of H_T

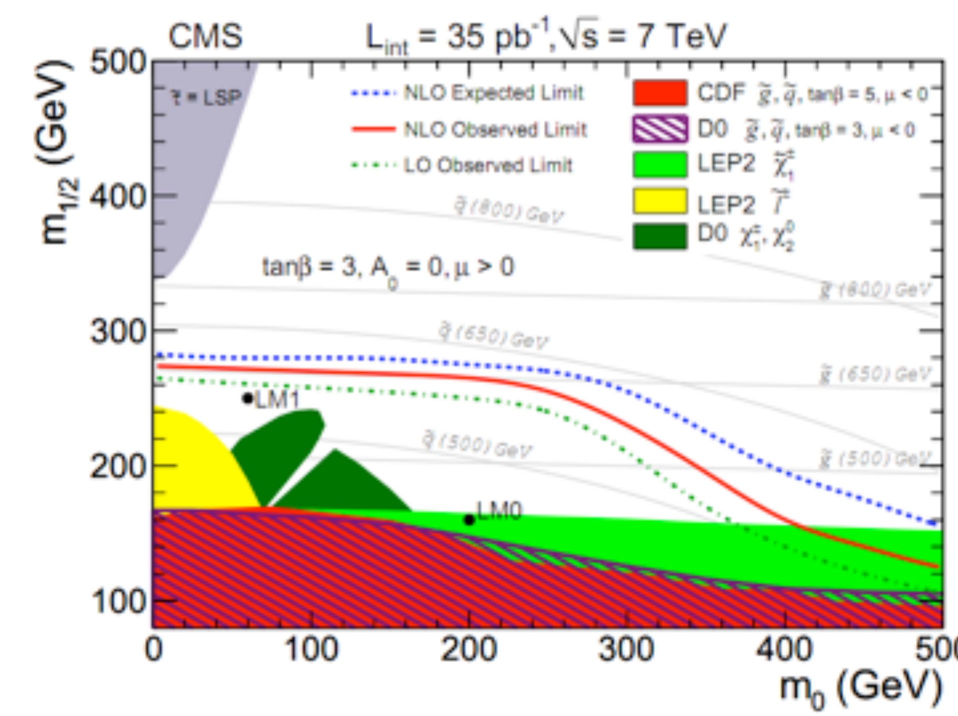
$$R_R = \frac{R_{\alpha_T}(\mathrm{HT300})}{R_{\alpha_T}(\mathrm{HT250})} = \frac{R_{\alpha_T}(\mathrm{HT350})}{R_{\alpha_T}(\mathrm{HT300})} \simeq 1.$$

- Two control regions were used at low HT: HT250 (250 to 300 GeV) , and HT300 (300 to 350 GeV), these regions are expected to be dominated by SM processes.
- If one defines $R\alpha_T$ as the ratio between the number of events that passes the entire selection over the number of events that fail
    - When $R\alpha_T$ is calculated for a α_T > 0.51, the numerator is dominated by the background with MET produced by mis-measurements in jets, this explains the negative slope
    - When $R\alpha_T$ is calculated for a α_T > 0.55, the ratio becomes a constant
        - Because $R\alpha_T$ becomes constant for α_T > 0.55, one can estimate the number of expected events coming from SM process in the signal region HT350
        - The total number of events in the HT350 region is then estimated to be

$$9.4^{+4.8}_{-4.0}\ (\mathrm{stat}) \pm 1.0\ (\mathrm{syst})$$

- To calculate the W + Jets background:

$$N^{\mathrm{W;\,had}}_{\mathrm{data}} = N^{\mathrm{W;}\,\mu}_{\mathrm{data}} \times N^{\mathrm{W;\,had}}_{\mathrm{MC}} / N^{\mathrm{W;}\,\mu}_{\mathrm{MC}} \approx 0.86 \times N^{\mathrm{W;}\,\mu}_{\mathrm{data}} \qquad 6.1^{+2.8}_{-1.9}\ (\mathrm{stat}) \pm 1.8\ (\mathrm{syst})$$



Measured (red line) and expected (blue dashed) 95 % CL exclusion contour at NLO in the CMSSM plane. The LO (green dashed) exclusion is also shown

- To calculate the Z to νν background:
    - From the data one selects all the events with one photon and jets, this number is re-scaled by the ratio of the cross sections for γ + jets and Z to νν + jets.

$$4.4^{+2.3}_{-1.6}\ (\mathrm{stat}) \pm 1.5\ (\mathrm{syst})$$

W+jets, + Z to νν → $10.5^{+3.6}_{-2.5}$

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Jets and Missing Momentum

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

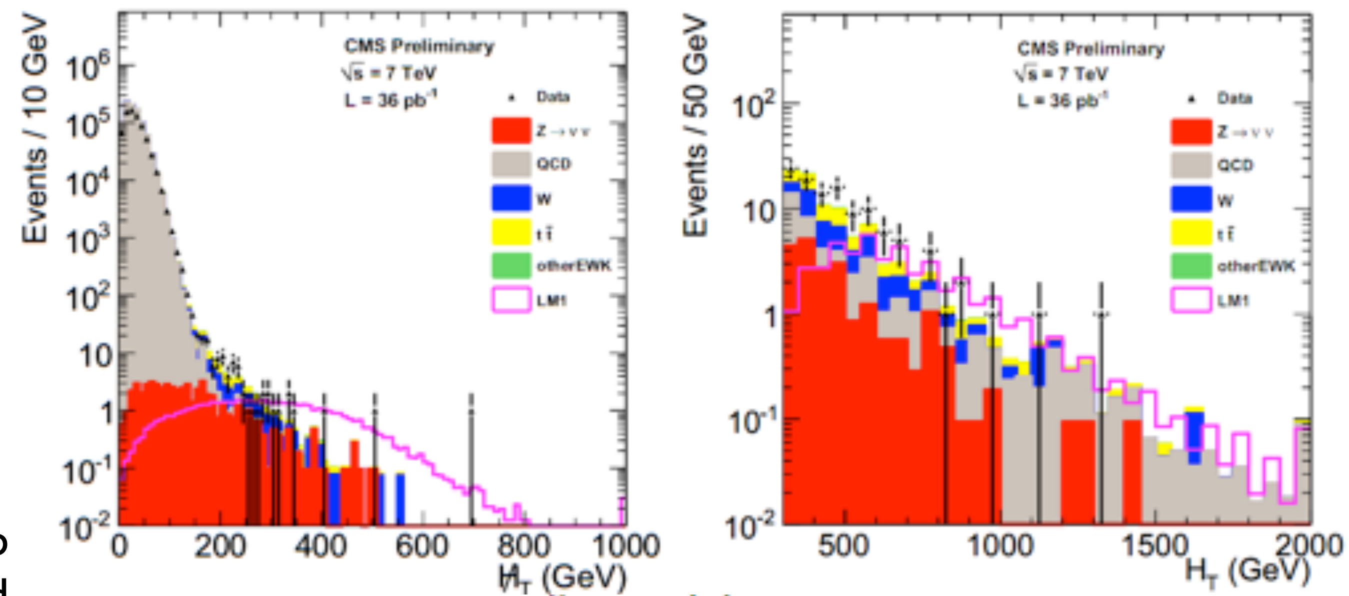
Events were selected with an H_T trigger

- The baseline selection consist in:
  - 3 or more jets
  - HT > 300 GeV
  - MHT > 150 GeV
  - Lepton veto
- The backgrounds are:
  - Z → νν + jets
  - W + jets and top anti-top processes with non identified leptons or hadronic taus
  - QCD with MET coming from mis-measurements

Z + Jets background

- Two methods were used
  - Count the number of Z going to leptons (electrons, muons), and re-scale it to the Z → νν + jets cross-section
  - Count the number of γ + jets events and re-scale to estimate the number of events coming from Z → νν

$$R(Z \to \nu\bar{\nu}/Z \to \ell\ell) = 5.95$$



	Baseline no Δφ cuts no e/μ veto	Baseline no e/μ veto	Baseline selection	High-$\not{H}_T$ selection	High-H_T selection
Data	482	180	111	15	40
Sum SM MC	406	149	93	14	29
QCD (PYTHIA6)	222.0	27.0	24.6	0.2	9.9
$Z \to \nu\bar{\nu}$ (MG, $\sigma = 5769$ pb)	26.7	21.1	21.1	6.3	5.7
W (MG, $\sigma = 5760$ pb)	93.9	57.8	23.5	4.7	7.6
$t\bar{t}$ (MG, $\sigma = 165$ pb)	57.5	40.1	21.9	2.6	5.7
WW+WZ+ZZ+tW +Wγ+Zγ+Z/γ*	6.1	3.4	2.1	0.2	0.2
LM1 (PYTHIA6, $\sigma = 4.9$ pb)	71.2	60.4	45.0	31.3	33.8

W + Jets background

- The method counts the number of events with one perfectly isolated muon in the signal region
  - This number is weighted using the isolation and identification efficiency to estimate the number of events with no identified and non isolated leptons

$$!ID^{e,\mu} = CS \cdot \frac{1}{\epsilon^{\mu}_{ISO}} \cdot \frac{1-\epsilon^{e,\mu}_{ID}}{\epsilon^{\mu}_{ID}}$$

$$!ISO^{e,\mu} = CS \cdot \frac{1-\epsilon^{e,\mu}_{ISO}}{\epsilon^{\mu}_{ISO}}$$

Hadronic Tau Background

- The muon + jets sample was used
- The muon was replaced by a hadronic tau jet, and the momentum corrected for the change
- The selections cuts are then applied

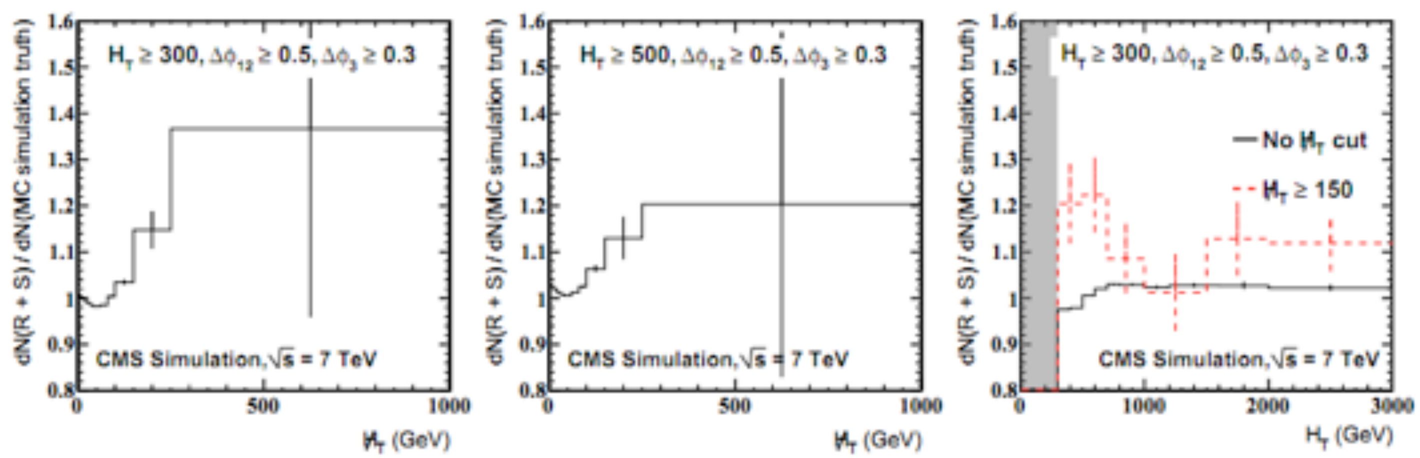
PAS SUS-10-005

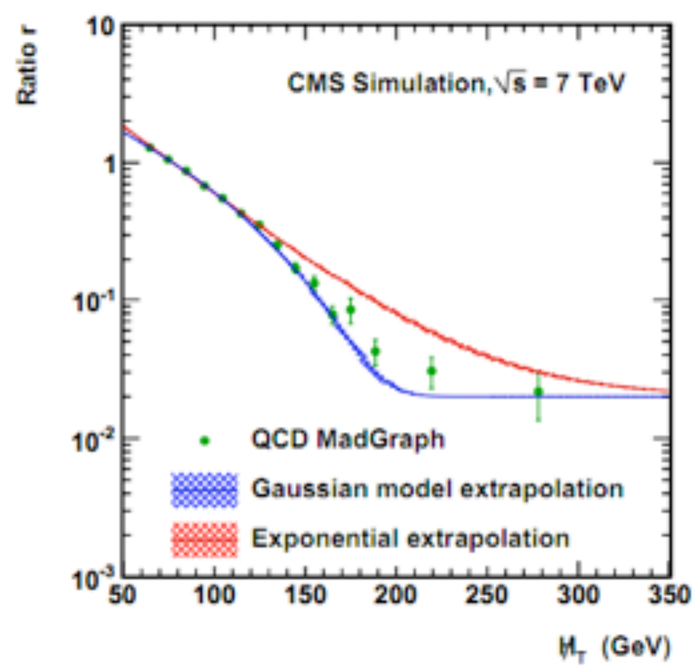
QCD background

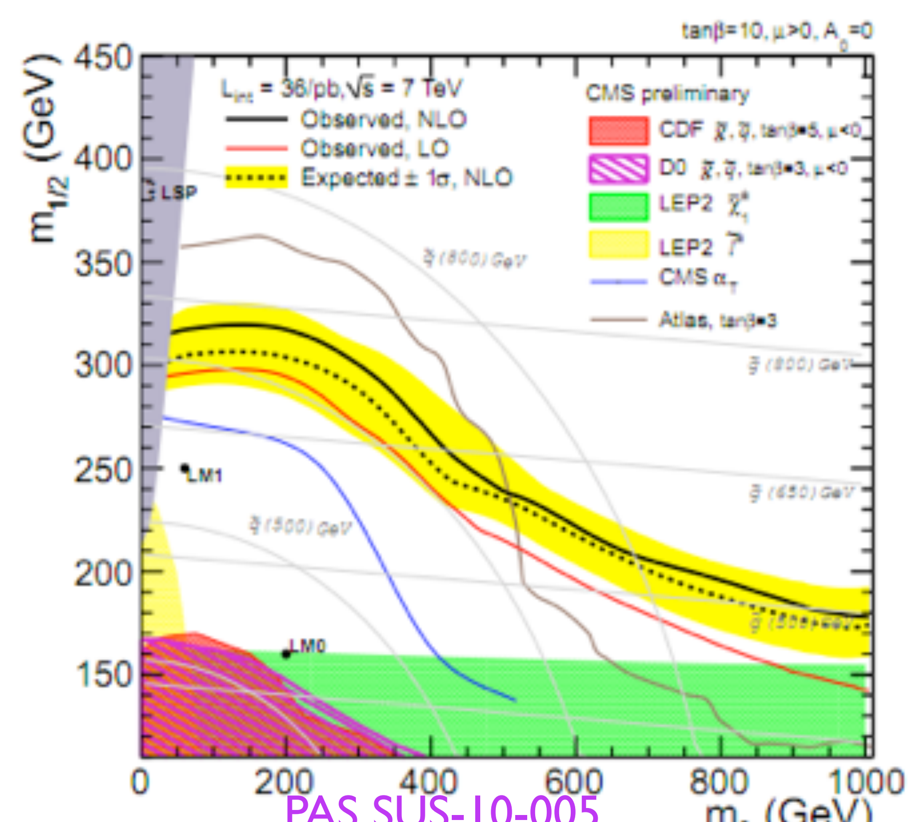
- Rebalance + Smear Method
  - Is a simplified simulation where jet response is modelled by a parametrized resolution function
  - From a multi-jet data sample one takes seeds events and "rebalance" them to make them QCD like.
  - In the "Smear" step the momentum of each seed is scaled to by a factor drawn from the jet resolution distribution
  - The search cuts are applied to the smeared events to have an estimation of the QCD background
  - To measure the jet resolution, γ + jet, and di-jet events were used
- Factorisation Method
  - Method similar to ABCD for two uncorrelated variables
  - However it uses MH_T and minimum angle between a jet and the MH_T which are correlated
  - Therefore this bias is corrected by measuring the ratio of event before and after a predefined angle.

$$N_{\text{bg in signal region}} = \sum_{i=\text{high } \not{H}_T,\, \text{low } \Delta\phi_{\min}} r(\not{H}_{T,i})$$

Method	Baseline selection		High-$\not{H}_T$ selection		High-H_T selection	
$Z \to \nu\bar{\nu}$ from γ+jets	26.3	±4.8	7.1	±2.2	8.4	±2.3
$t\bar{t}/W \to e, \mu$+X lost-lepton method	33.0	±8.1	4.8	±1.9	10.9	±3.4
$t\bar{t}/W \to \tau_{hadr}$+X method	22.3	±4.6	6.7	±2.1	8.5	±2.5
QCD Rebalance+Smear method	29.7	±15.2	0.16	±0.10	16.0	±7.9
QCD factorization method	25.2	±13.4	0.4	±0.3	17.3	±9.4
Total data-driven background	111.3	±18.5	18.8	±3.5	43.8	±9.2
Observed in 36 pb^{-1} of data	111		15		40	
95% C.L. limit on signal events	40.4		9.6		19.6	







B-Jets and MET

H_T trigger

$$\alpha_T = \frac{E_T^{j2}}{M_T^{j1,j2}} \qquad \alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}}$$

Veto on isolated leptons and photons

Photon $E_T > 25$ GeV and $|\eta| < 2.5$

Electron $E_T > 10$ GeV and $|\eta| < 2.5$

Muon $p_T > 10$ GeV and $|\eta| < 2.5$

Events are rejected if leptons or photons are not in a cone of radius R close to a jet

$$\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$$

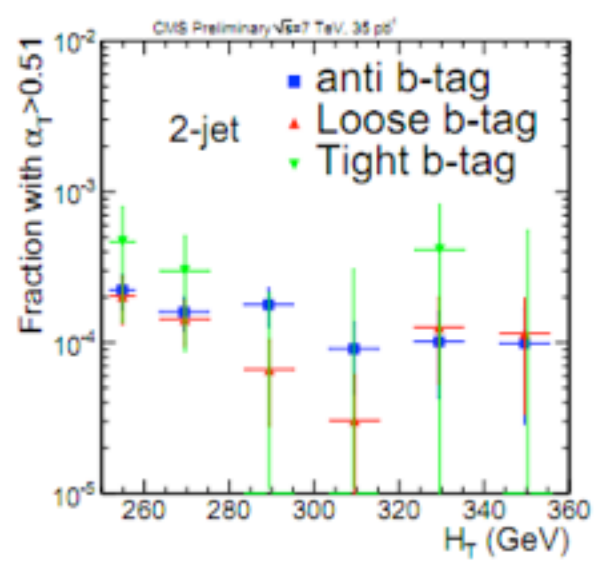
Events are required to fulfil $\not{H}_T / \not{E}_T < 1.25$

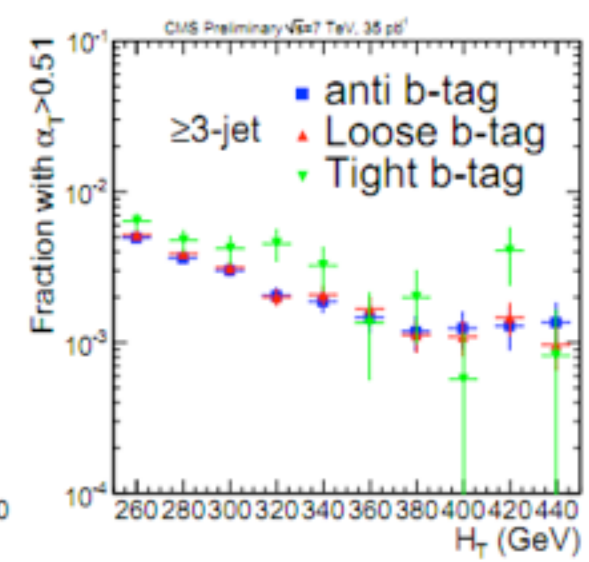
An additional requirement is two jets wit ET > 100 GeV $|\eta| < 2.5$

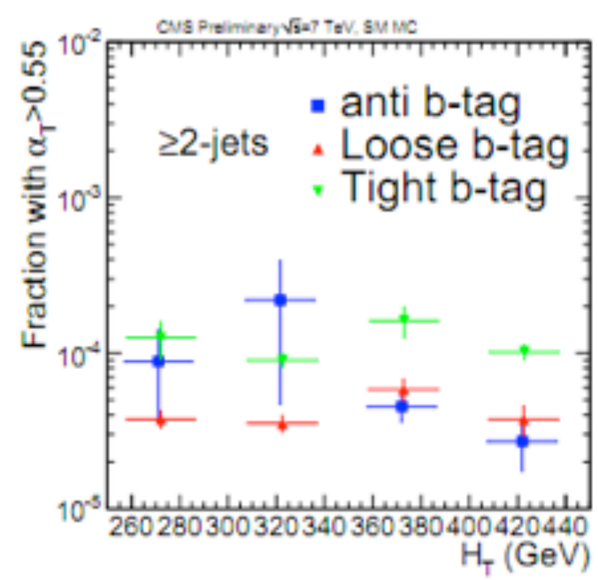
$\alpha_T > 0.55$

HT > 350 GeV, at least one jet tagged as coming from a b quark.

Background estimation







N-jets	QCD	$t\bar{t}$	W	$Z \to \nu\bar{\nu}$	$Z \to l^+l^-$	total
2	0 ± 0.11	0.01 ± 0.01	0 ± 0.1	0 ± 0.09	0 ± 0.09	0.01 ± 0.21
≥ 3	0.05 ± 0.05	1.08 ± 0.07	0.10 ± 0.10	0.38 ± 0.18	0 ± 0.09	1.61 ± 0.26

N-jets	MC	Background Prediction	Data	LM0
≥ 2	1.61 ± 0.26	$0.33^{+0.43}_{-0.33}$ (stat) ± 0.13 (syst)	1	14.2 ± 0.3

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Inclusive search for Squarks and gluinos

Two mega-jets are constructed for each event, in the approximation in which:
- The squarks are produced at threshold
- Their visible decay products are massless
- The CM frame looks like

$$p_{j1} = \frac{M_\Delta}{2}(1, \hat{u}_1)\,, \quad p_{j2} = \frac{M_\Delta}{2}(1, \hat{u}_2)\,,$$
$$p_{\chi_1} = \frac{M_\Delta}{2}(\frac{2M_{\tilde{q}}}{M_\Delta} - 1, -\hat{u}_1)\,, \quad p_{\chi_2} = \frac{M_\Delta}{2}(\frac{2M_{\tilde{q}}}{M_\Delta} - 1, -\hat{u}_2)\,,$$

$$M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}\,.$$

R-Frame is a longitudinal boosted frame that equalises the mega-jet 3-momentum

$$\beta_R \equiv \frac{E^{j1} - E^{j2}}{p_z^{j1} - p_z^{j2}}$$

In this frame the scalar sum of the transverse momentum, and the MET are equal to M_Δ

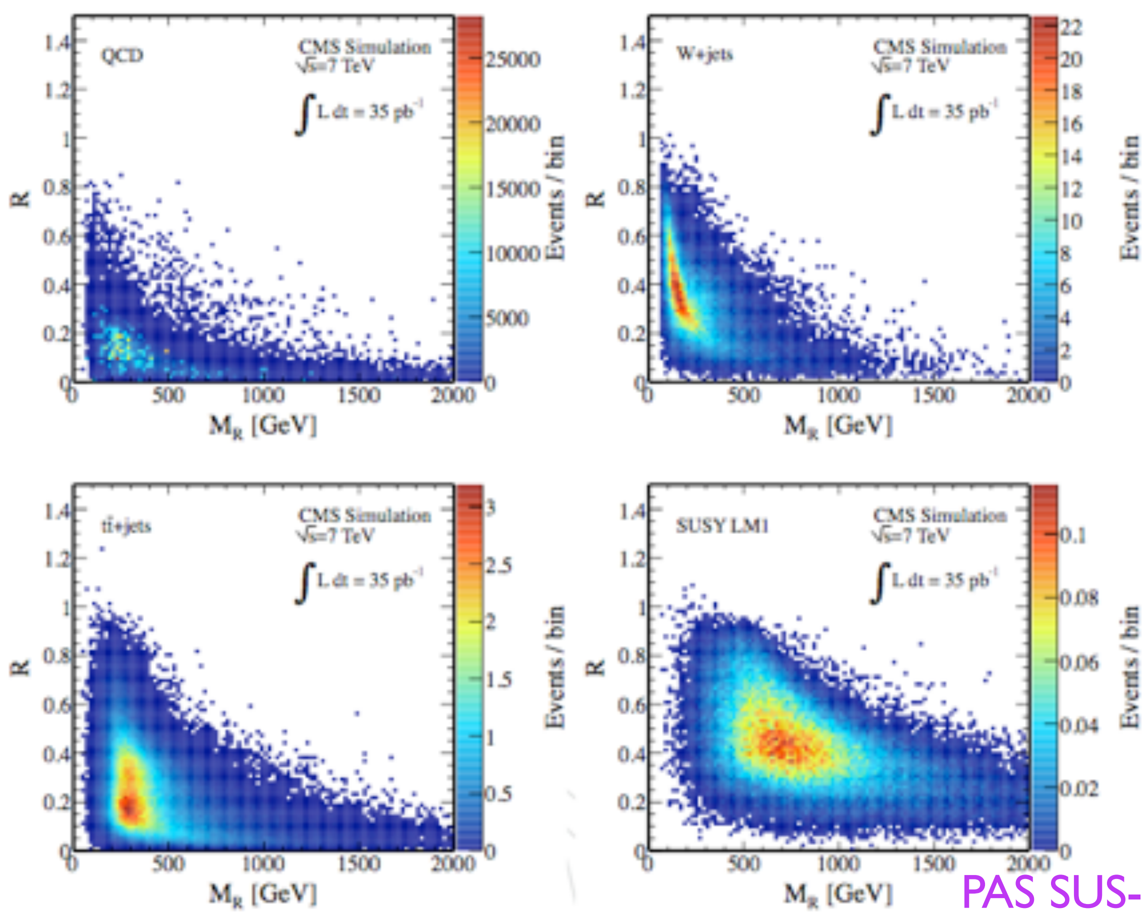
$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

An estimator of M_Δ

$$M_R \equiv 2|\vec{p}_{j1}^{\,R}| = 2|\vec{p}_{j2}^{\,R}|$$

To extract a peak behaviour and discriminate signal from background the Razor variable is introduced

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



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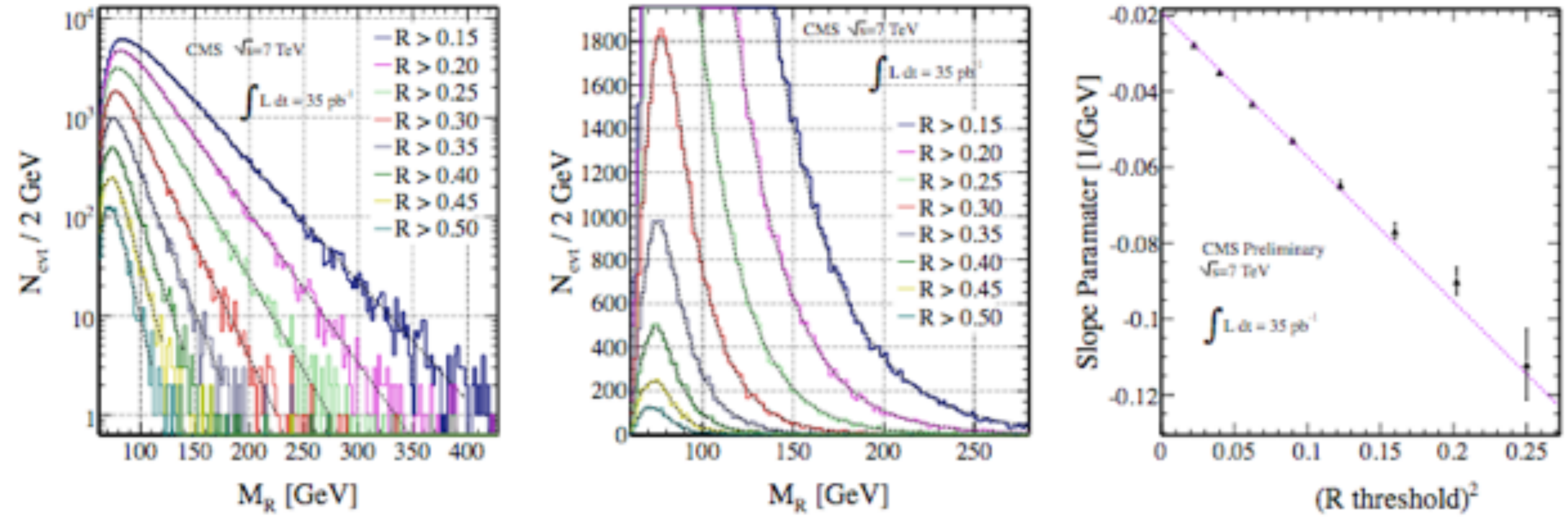
- Events are triggered by a lepton or a hadronic trigger
- The events are selected to go into disjoint boxes, electron, muon, or hadronic box
- Two mega-jets are created and the relevant variables calculated
- In the lepton boxes two kinematic regions are identified, in the R,MR plane one dominated by W+Jets, and one dominated by non QCD backgrounds
- In the hadronic box, the non-QCD background is estimated using the lepton boxes.
- The QCD normalisation and shape in the lepton boxes is estimated by requiring the anti-isolation cuts
- The QCD in the hadronic box is estimated using QCD samples collected with pre-scaled triggers
- High R and MR regions are the signal region, the background is extracted by extrapolating from low R and MR regions.

$R\,(0.45)\,/\,M_R\,(500)$	Predicted	Observed
ELE box	0.63 ± 0.23	0
MU box	0.51 ± 0.20	3

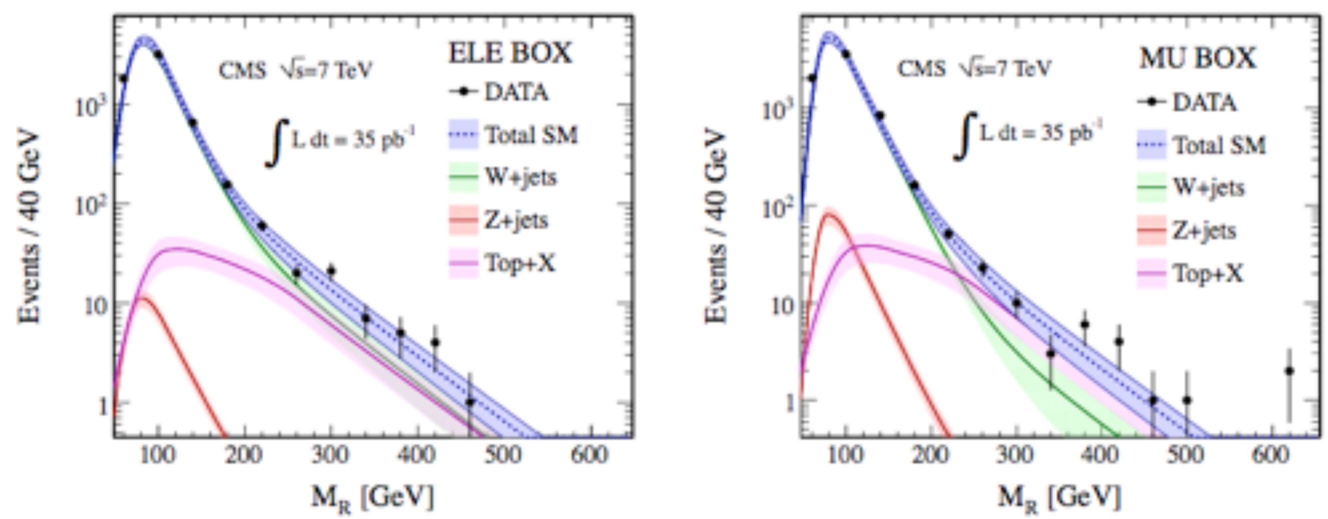
R > 0.5

M_R	Predicted	Observed
$M_R > 500$ GeV	5.5 ± 1.4	7

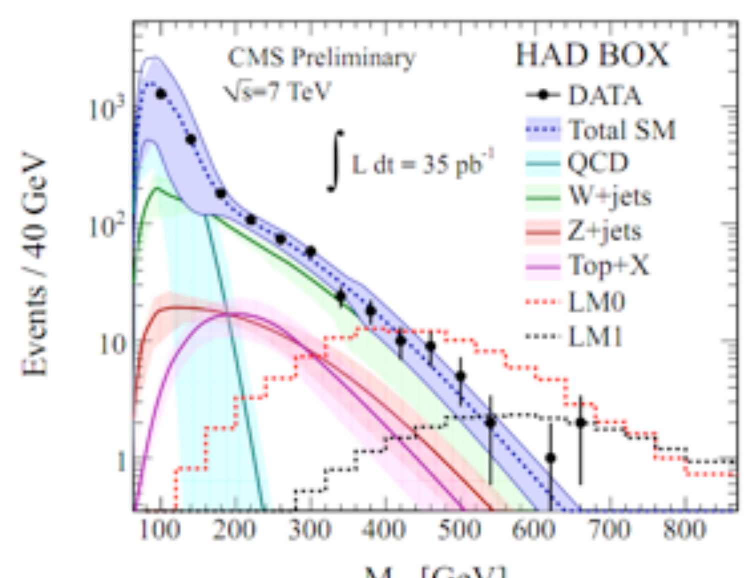
QCD

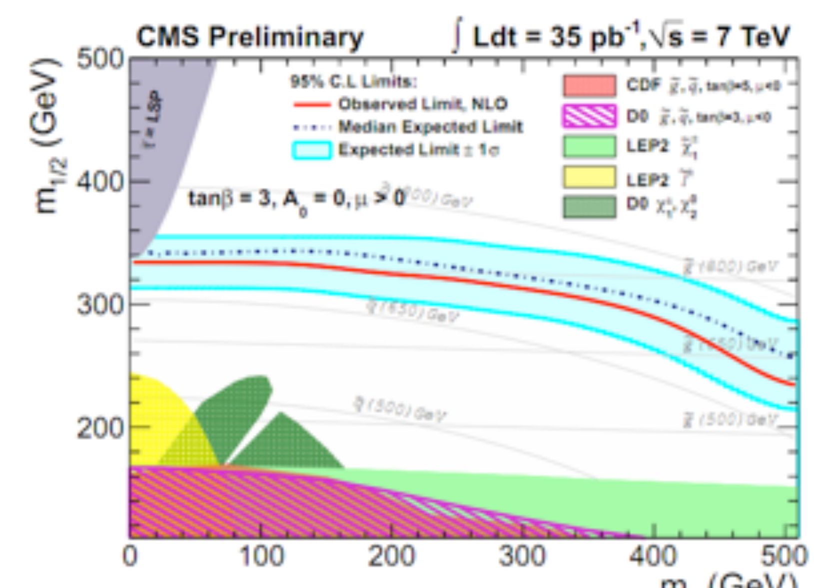


Lepton boxes



Hadron Box





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Single lepton, Jets and MET

- Requiring 4 jets suppresses most of W background
- Isolation cut discriminates between QCD and Signal

Triggers

Muon Pt > 11 GeV
Muon Pt > 5 GeV and HT > 70 GeV
Electron Pt > 17 GeV

Events were selected with at least one primary vertex, four jets, and an isolated electron or muon.

Jets

$p_T > 30$ GeV and $|\eta| \leq 2.4$

Muons

$P_T > 15$ GeV $|\eta| < 2.1$

$\Delta R > 0.3$ with respect to the closest jet

$I = \Sigma_{\Delta R<0.3}(E_T + p_T)$, $I/p_T(\mu) < 0.1$

Electrons

$P_T > 20$ GeV $|\eta| < 2.4$ excluding the overlap region

$1.44 < |\eta| < 1.57$.

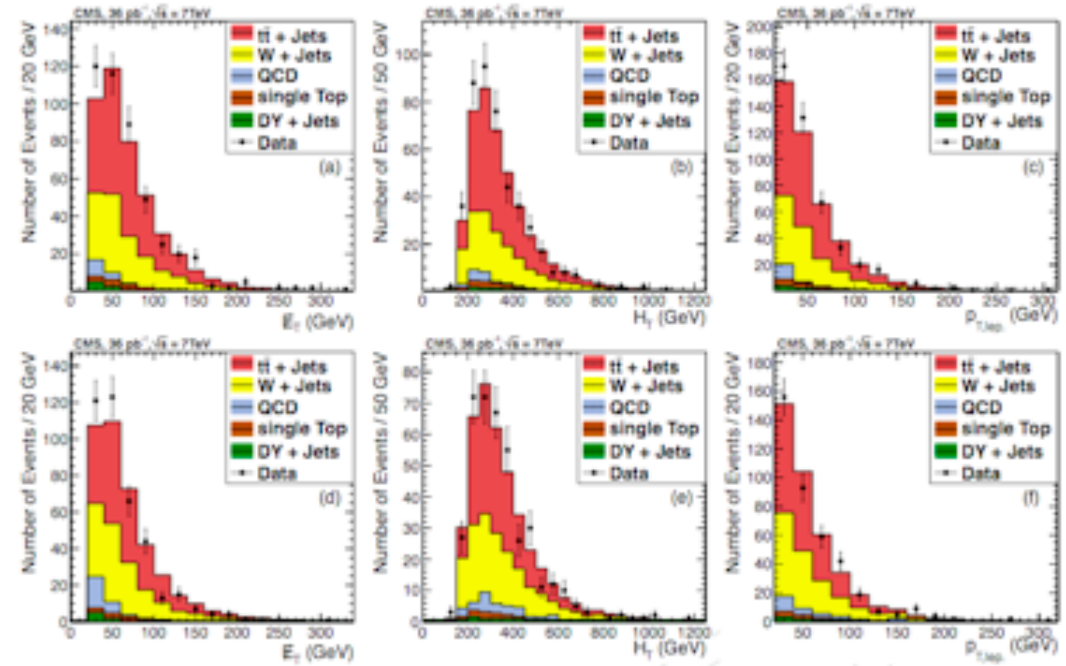
$I/p_T(e) < 0.07$ In the barrel

$I/p_T(e) < 0.06$

an more identification and cleaning cuts

Muon

Electron



$\not{E}_T > 25$ GeV.

Background

The ABCD method was used to estimate the background

$$Y_{MET} \equiv \not{E}_T/\sqrt{H_T},$$

$$N(D) = [N(C)/N(A)]N(B)$$

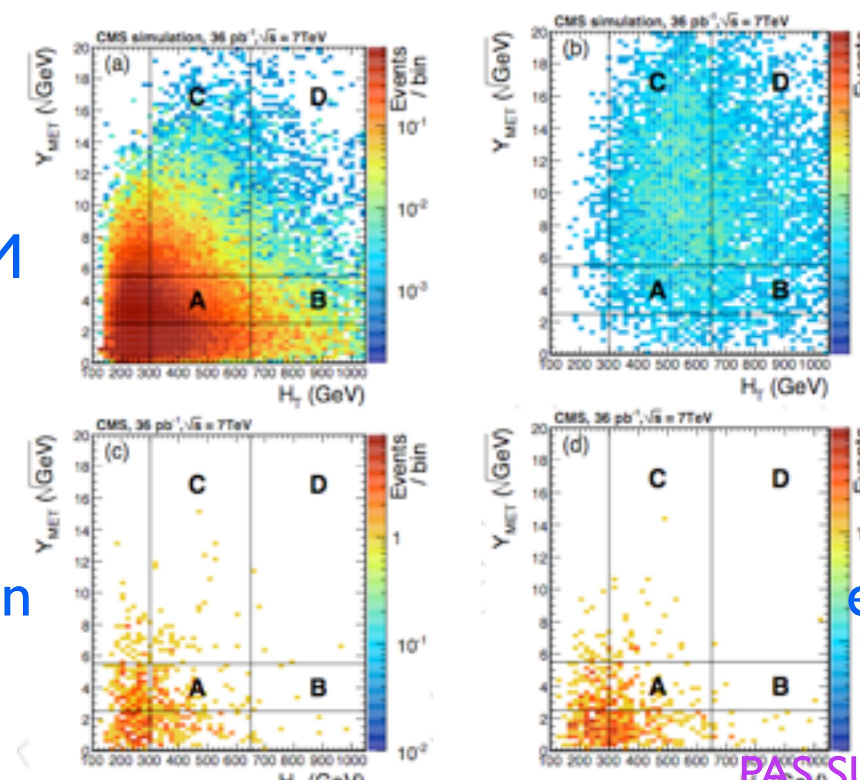
Region	Loose selection H_T (GeV)	Loose selection Y_{MET} ($\sqrt{\text{GeV}}$)	Tight selection H_T (GeV)	Tight selection Y_{MET} ($\sqrt{\text{GeV}}$)
A	$300 < H_T < 350$	$2.5 < Y_{MET} < 4.5$	$300 < H_T < 650$	$2.5 < Y_{MET} < 5.5$
B	$H_T > 400$	$2.5 < Y_{MET} < 4.5$	$H_T > 650$	$2.5 < Y_{MET} < 5.5$
C	$300 < H_T < 350$	$Y_{MET} > 4.5$	$300 < H_T < 650$	$Y_{MET} > 5.5$
D	$H_T > 400$	$Y_{MET} > 4.5$	$H_T > 650$	$Y_{MET} > 5.5$

SM

SUSY

muon

electron



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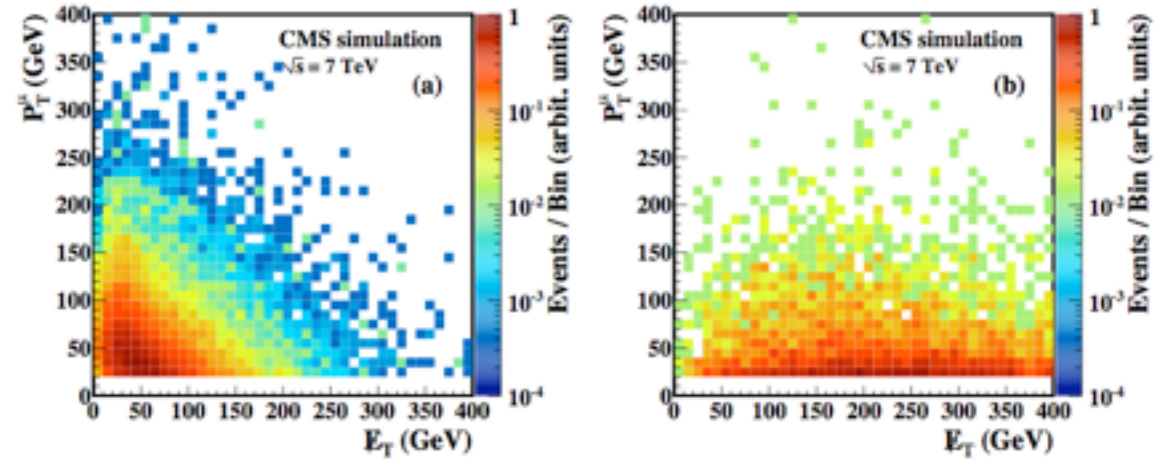
sample	$N(A)$	$N(B)$	$N(C)$	$N(D)$	$N(D)_{pred}$
Loose selection					
μ channel: total SM MC	25.1 ± 0.6	37.1 ± 0.7	19.3 ± 0.5	30.6 ± 0.6	28.5 ± 1.1
μ channel: data	30	35	25	30	29.2 ± 9.3
e channel: total SM MC	20.0 ± 0.5	31.5 ± 0.9	14.6 ± 0.5	23.6 ± 0.5	22.9 ± 1.2
e channel: data	19	33	19	17	33.0 ± 12.2
Tight selection					
μ channel: total SM MC	93.1 ± 1.1	8.7 ± 0.4	37.6 ± 0.7	3.4 ± 0.2	3.5 ± 0.2
μ channel: data	98	4	41	5	1.7 ± 0.9
e channel: total SM MC	76.8 ± 1.5	6.5 ± 0.3	29.5 ± 0.7	2.9 ± 0.2	2.5 ± 0.1
e channel: data	80	4	30	2	1.5 ± 0.8

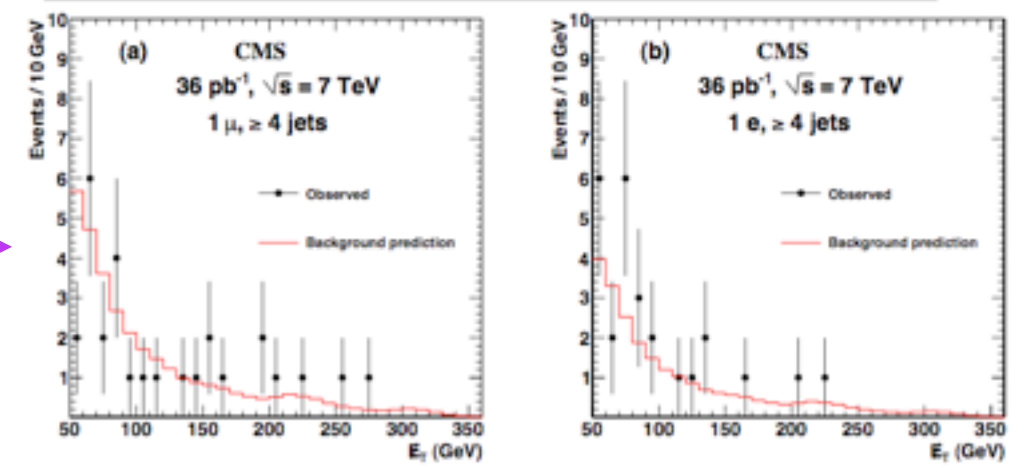


Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0

Background with MET and Lepton Pt distributions

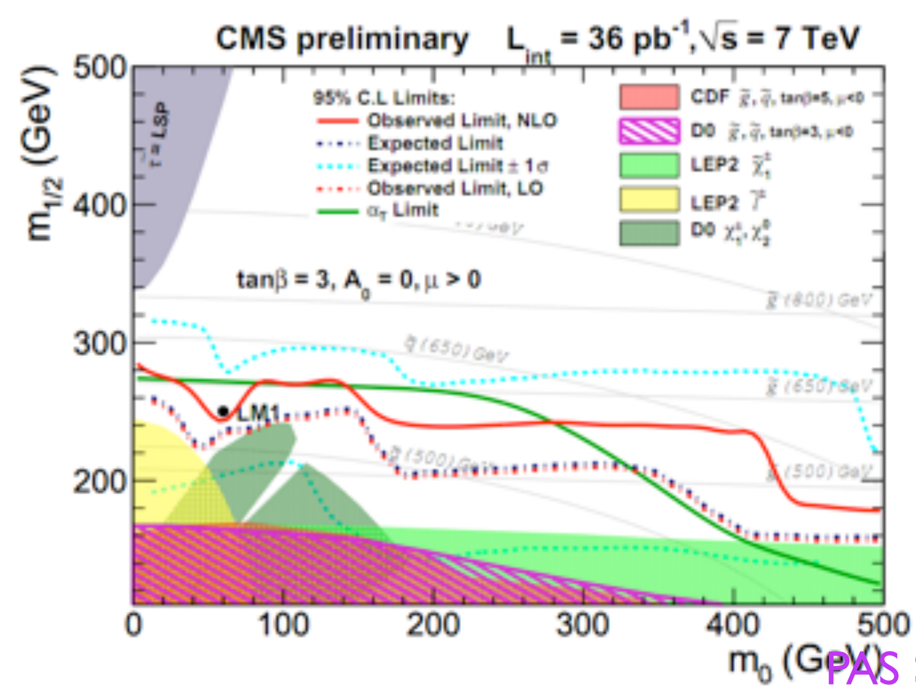
Two regions, (loose) with leptons Pt > 20 GeV and MET > 150 GeV. (Tight) with leptons Pt > 20 GeV , MET > 150 GeV, and HT > 500 GeV

In top anti-top and W + jets processes, the MET and the lepton Pt are anti-correlated, but have very similar distributions, therefore the spectrum of the leptons can be used to predict the MET spectrum, however corrections must be applied for:
Effect of W polarisation
The applied lepton Pt threshold
The difference in experimental resolution for both variables.



QCD background estimation

- Uses the MET vs Isolation distribution
- Calculates the ratio between isolated events and events in an isolation sideband
- Scale the number of events in the sideband that pass the MET cut to obtain the number of events in the signal region



PAS SUS-10-006

Opposite sign di-leptons, jets and MET

Event selection

First lepton Pt > 20 GeV
Second lepton Pt > 10 GeV
electron (muon) $|\eta| < 2.5$ ($|\eta| < 2.4$)

$(e^+e^-, e^\pm\mu^\mp, \text{or } \mu^+\mu^-)$

In case more than 3 leptons are present , the two with the higher Pt are consider
A Z veto is implemented, as well as a veto in low invariant mass to suppress lepton resonances
Single or a double lepton trigger
Leptons are required to be isolated
At least two jets are required separated from the leptons

$p_T > 30\,\text{GeV}/c$ $\quad |\eta| < 2.5$

$\Delta R > 0.4$

The events are required to pass

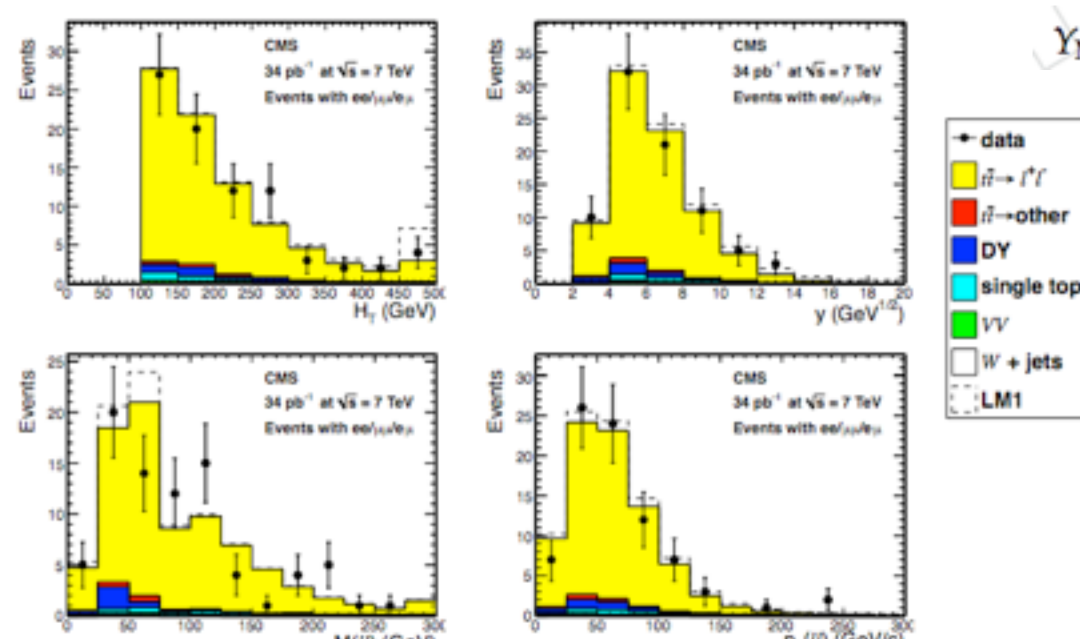
$H_T > 100\,\text{GeV}$

and MET > 50 GeV

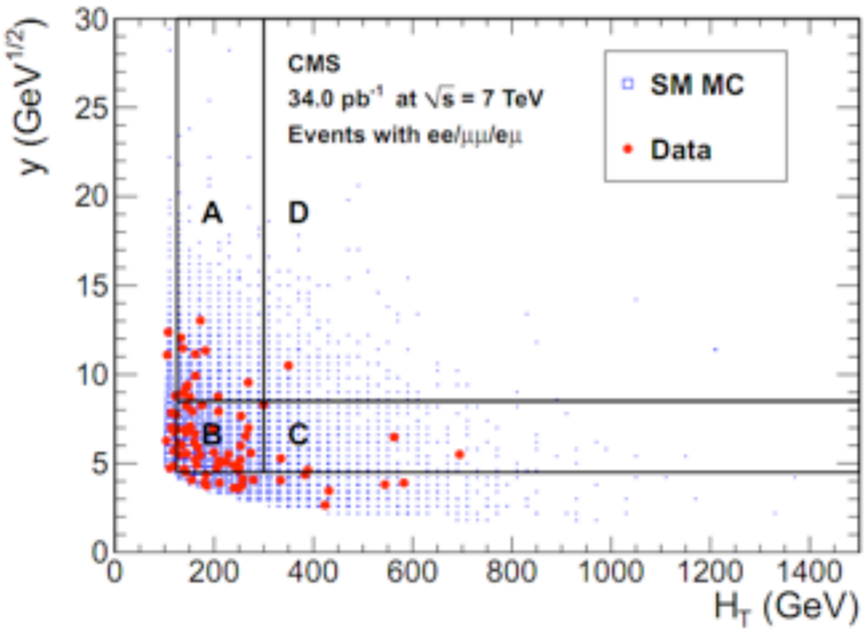
Sample	σ (pb)	ee	$\mu\mu$	$e\mu$	tot
$t\bar{t} \to \ell^+\ell^-$	16.9	14.50 ± 0.24	17.52 ± 0.26	41.34 ± 0.40	73.36 ± 0.53
$t\bar{t} \to$ other	140.6	0.49 ± 0.04	0.21 ± 0.03	1.02 ± 0.06	1.72 ± 0.08
Drell Yan	18417	1.02 ± 0.21	1.16 ± 0.22	1.20 ± 0.22	3.38 ± 0.37
$W^\pm$ + jets	28049	0.19 ± 0.13	0.00 ± 0.00	0.09 ± 0.09	0.28 ± 0.16
W^+W^-	2.9	0.15 ± 0.01	0.16 ± 0.01	0.37 ± 0.02	0.68 ± 0.03
$W^\pm Z$	0.3	0.02 ± 0.00	0.02 ± 0.00	0.04 ± 0.00	0.09 ± 0.00
ZZ	4.3	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.05 ± 0.00
single top	33.0	0.46 ± 0.02	0.55 ± 0.02	1.24 ± 0.03	2.25 ± 0.04
total SM MC		16.85 ± 0.34	19.63 ± 0.34	45.33 ± 0.47	81.81 ± 0.67
data		15	22	45	82
LM0	52.9	10.67 ± 0.31	12.63 ± 0.34	17.81 ± 0.41	41.11 ± 0.62
LM1	6.7	2.35 ± 0.05	2.83 ± 0.06	1.51 ± 0.04	6.69 ± 0.09

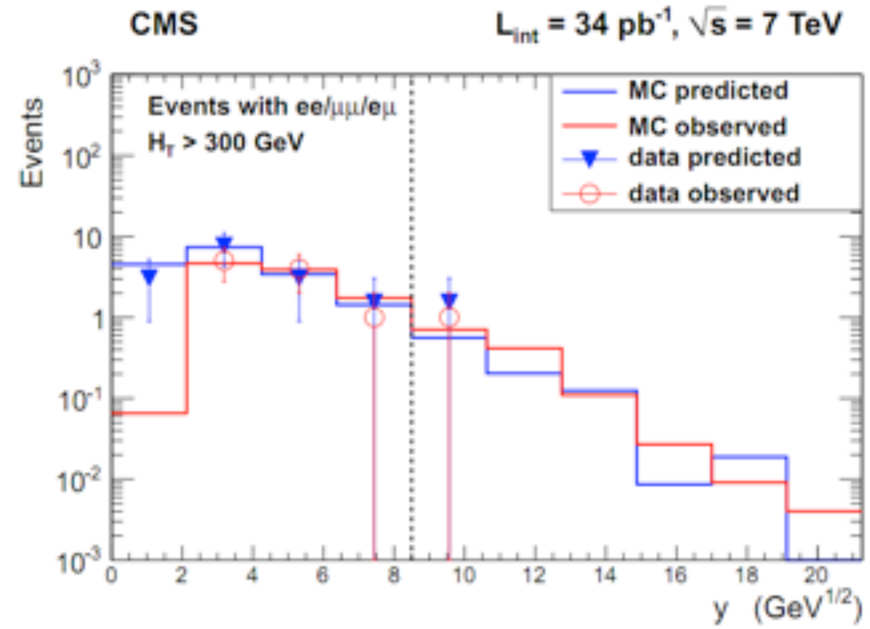
To look for possible BSM contributions $H_T > 300\,\text{GeV}$ and $y > 8.5\,\text{GeV}^{1/2}$

$Y_{MET} \equiv \not{E}_T / \sqrt{H_T}$,



PAS SUS-10-007





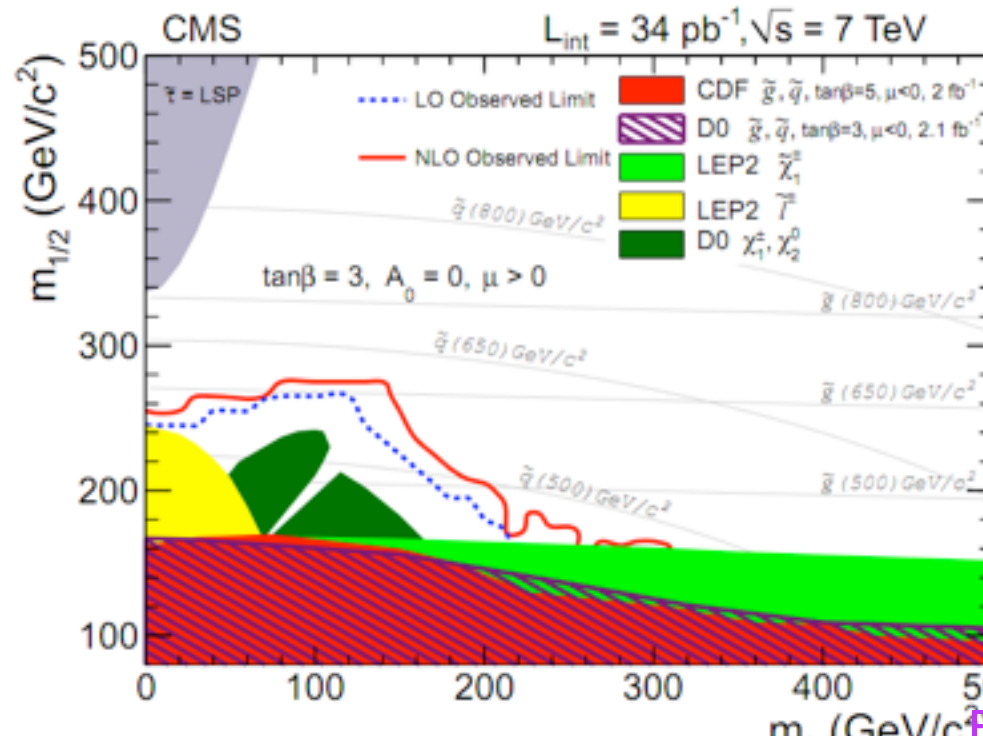
Background estimation

ABCD method, and similar method to the one used in single lepton searches using lepton pt MET distributions

sample	N_A	N_B	N_C	N_D	$N_A \times N_C/N_B$
$t\bar{t} \to \ell^+\ell^-$	8.44 ± 0.18	32.83 ± 0.35	4.78 ± 0.14	1.07 ± 0.06	1.23 ± 0.05
$t\bar{t} \to$ other	0.12 ± 0.02	0.78 ± 0.05	0.16 ± 0.02	0.02 ± 0.01	0.02 ± 0.01
Drell Yan	0.17 ± 0.08	1.18 ± 0.22	0.04 ± 0.04	0.12 ± 0.07	0.01 ± 0.01
$W^\pm$ + jets	0.00 ± 0.00	0.09 ± 0.09	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
W^+W^-	0.11 ± 0.01	0.29 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	0.01 ± 0.00
$W^\pm Z$	0.01 ± 0.00	0.04 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZ	0.01 ± 0.00	0.02 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
single top	0.29 ± 0.01	1.04 ± 0.03	0.04 ± 0.01	0.01 ± 0.00	0.01 ± 0.00
total SM MC	9.14 ± 0.20	36.26 ± 0.43	5.05 ± 0.14	1.27 ± 0.10	1.27 ± 0.05
data	12	37	4	1	1.30 ± 0.78
LM0	4.04 ± 0.19	4.45 ± 0.20	13.92 ± 0.36	8.63 ± 0.27	12.63 ± 0.88
LM1	0.52 ± 0.02	0.26 ± 0.02	1.64 ± 0.04	3.56 ± 0.06	3.33 ± 0.27

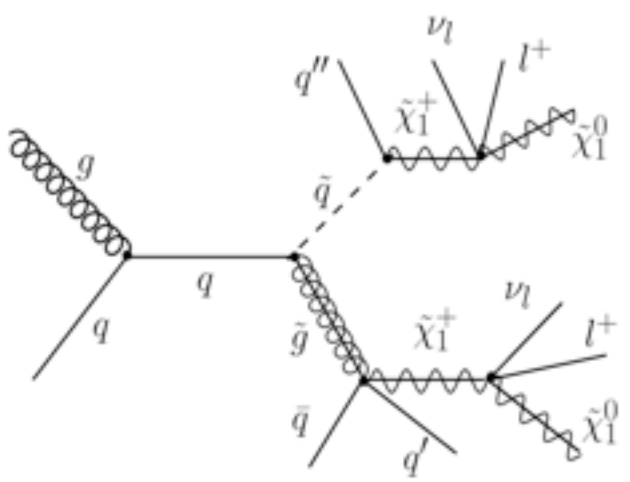
HT > 350 GeV and MET > 150 GeV

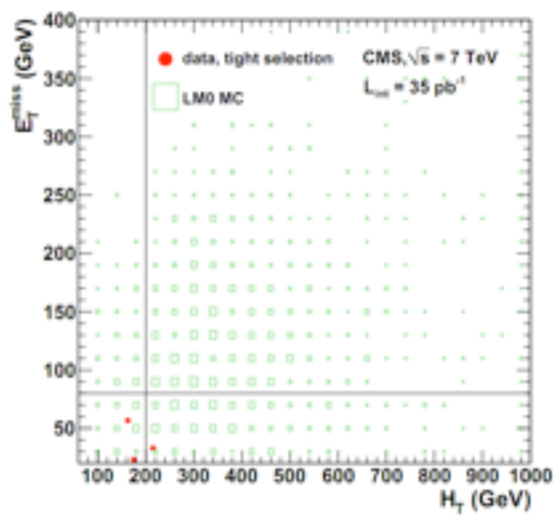
	Signal Region	
Process	ee	$\mu\mu$
$t\bar{t}$ from $e\mu$	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Non-W/Z	0	0
Total predicted	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Total observed	0	0
SM MC	0.38 ± 0.08	0.56 ± 0.07
LM0	3.4 ± 0.2	3.9 ± 0.2
LM1	1.6 ± 0.1	2.0 ± 0.1

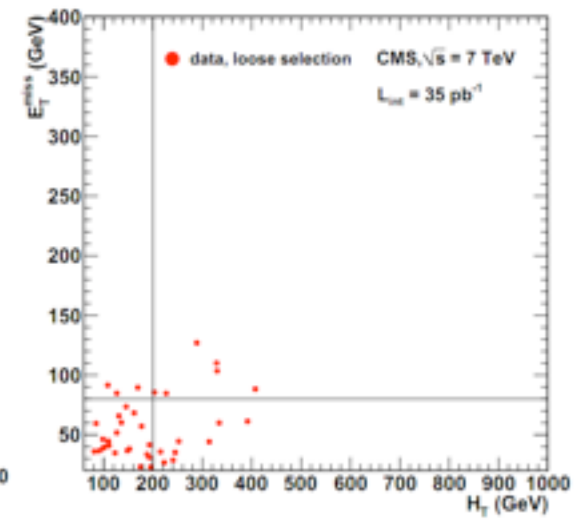


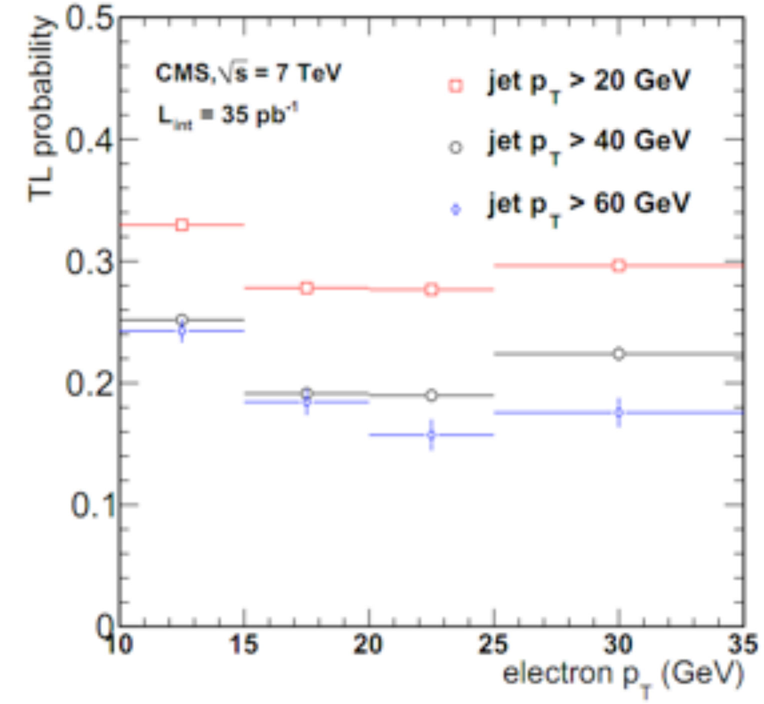
PAS SUS-10-007

Same-sign isolated leptons, jets, and MET

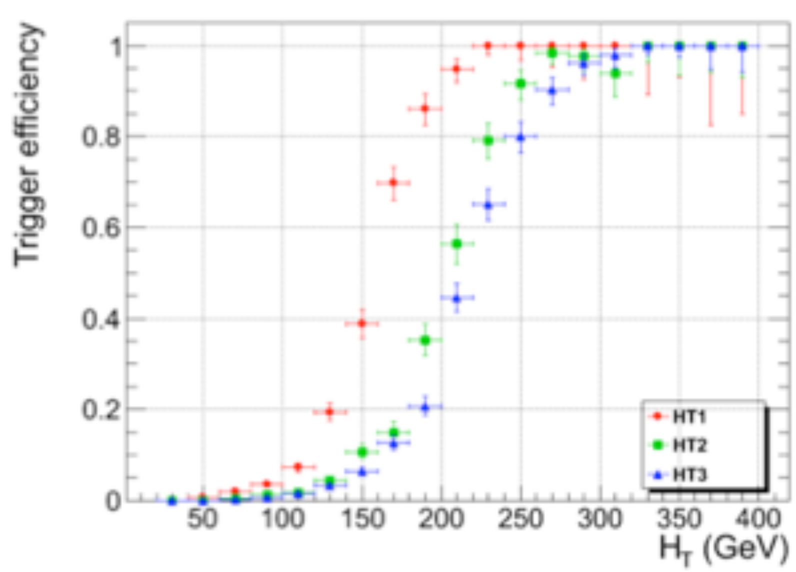


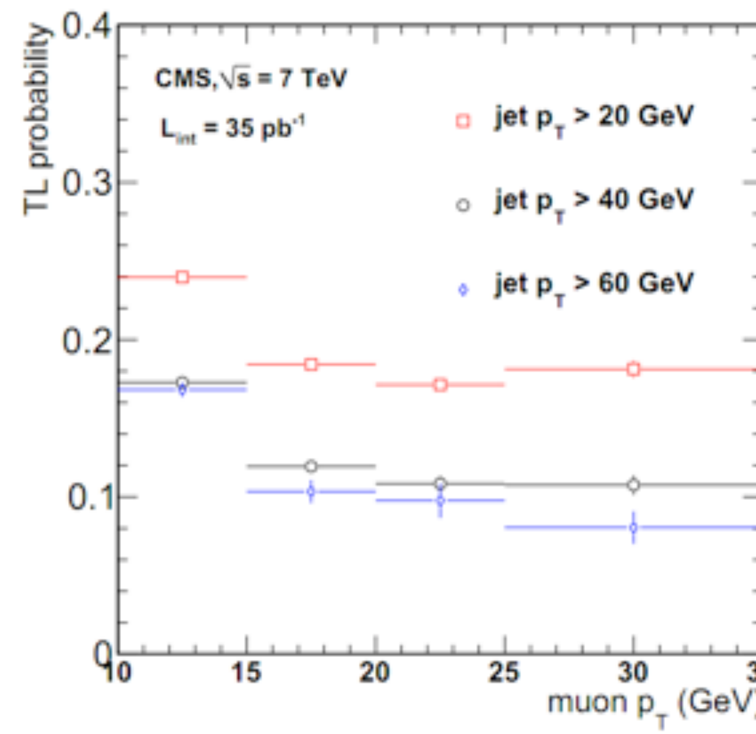






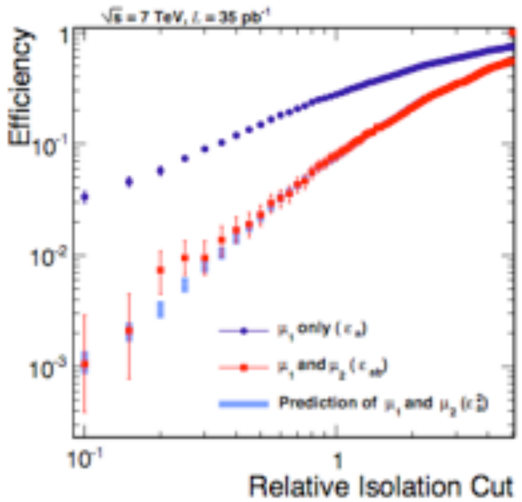
- Two trigger strategies, hadronic H_T trigger and leptonic trigger
- Preselection, Two Jets (> 30 GeV each), and MET (> 30 GeV) were required
- Lepton triggers
  - Two search regions were defined
    - MET > 80 and low H_T
    - H_T > 200 GeV and low MET
- Hadronic triggers
  - A single region H_T > 300 GeV
- Most of the background for these searches comes from fakes, SM processes have a very small contribution.
- Leptonic trigger background estimation
  - To estimate the background coming from fakes, the probability of a fake to be identified as a prompt lepton is measured
  - The background produced by fake leptons is estimated by counting and weighting the number of events with one or two fake leptons

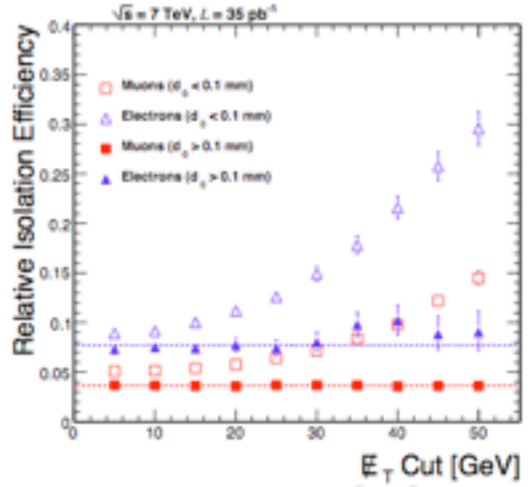


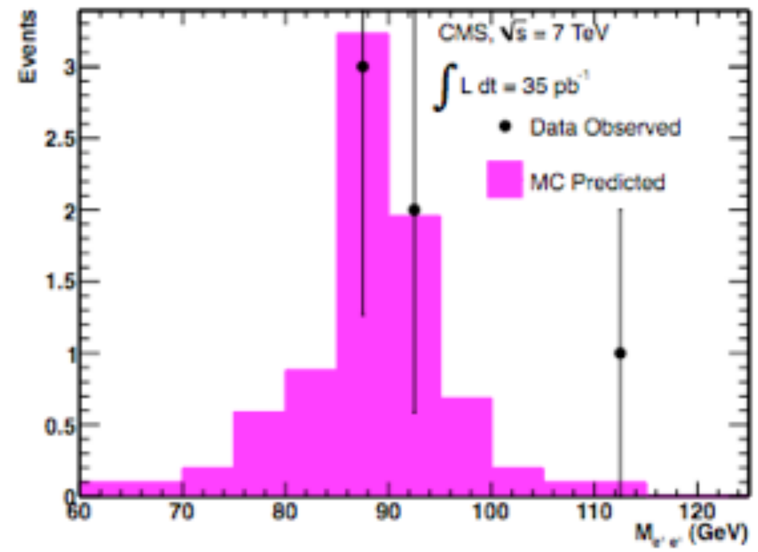


$$\epsilon_{T/L}/(1-\epsilon_{T/L})$$

PAS SUS-10-004

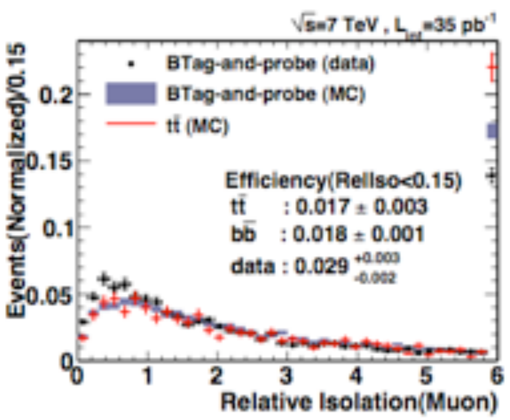


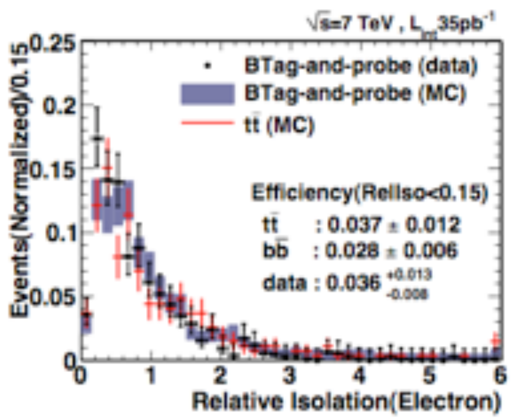




Electron Charge Flip

- In the two electrons case the invariant mass in the Z window was used to reconstructed for the same and the opposite sign cases.
- The number of Z's in the same-sign case divided by the number of Z's in the opposite-sign case, gives an estimation of the electron charge flip

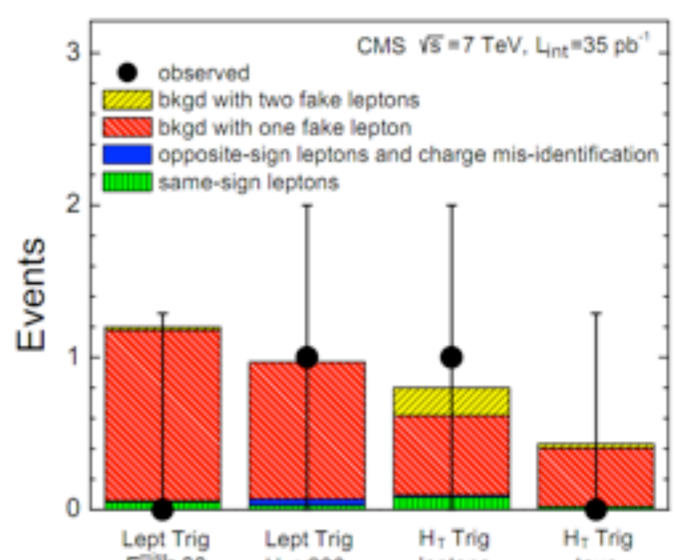


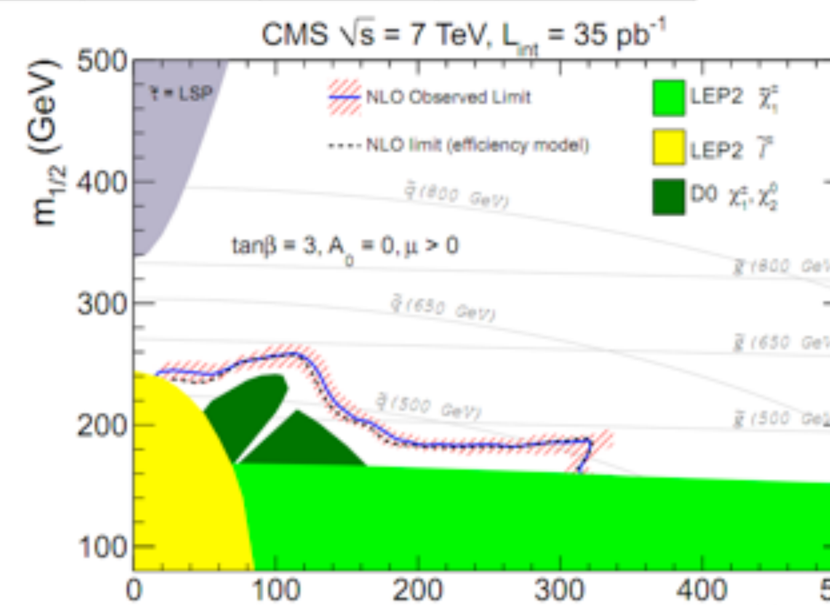


Search Region	ee	$\mu\mu$	$e\mu$	total	95% CL UL Yield
Lepton Trigger					
$E_T^{miss} > 80$ GeV					
MC	0.05	0.07	0.23	0.35	
predicted BG	$0.23^{+0.35}_{-0.23}$	$0.23^{+0.26}_{-0.23}$	0.74 ± 0.55	1.2 ± 0.8	
observed	0	0	0	0	3.1
$H_T > 200$ GeV					
MC	0.04	0.10	0.17	0.32	
predicted BG	0.71 ± 0.58	$0.01^{+0.24}_{-0.01}$	$0.25^{+0.27}_{-0.25}$	0.97 ± 0.74	
observed	0	0	1	1	4.3
H_T Trigger					
Low-p_T					
MC	0.05	0.16	0.21	0.41	
predicted BG	0.10 ± 0.07	0.30 ± 0.13	0.40 ± 0.18	0.80 ± 0.31	
observed	1	0	0	1	4.4
	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$	total	95% CL UL Yield
τ_h enriched					
MC	0.36	0.47	0.08	0.91	
predicted BG	0.10 ± 0.10	0.17 ± 0.14	0.02 ± 0.01	0.29 ± 0.17	
observed	0	0	0	0	3.4

Hadronic trigger background estimation

- It was proven that the Isolation efficiency and the MET efficiency can be factorized
- A preselected sample that applies all cuts but the lepton isolations and MET efficiency was used to estimate the 2 fake leptons background (multiplying the preselected events by the efficiencies)
- Another preselected sample that includes the MET and the isolation for one lepton was taken to estimate the background produced by events with one fake lepton
    - The contribution coming from two fakes in this new sample was subtracted
    - The resulting yield is expected to come from top anti-top production, therefore it was weighted by the isolation efficiency taken from b-tag leptons, re-scaled to match the top anti-top isolation efficiency (first bin only) $\epsilon_{iso}^{(b)}/(1-\epsilon_{iso}^{(b)})$





PAS SUS-10-004

Multi-lepton searches

Events were triggered with a single lepton trigger and a double lepton trigger

Pt > 8 GeV and $|\eta| < 2.1$ for electrons and muons

At least one muon with P_T > 15 GeV or one electron with P_T > 20 GeV must be present

Particle Flow Taus were also included to scan regions in the parameter space were tau production is enhanced

55 channels in this search

A Z veto is imposed to events with a pair of opposite sign same flavour leptons, and event with 3 leptons that have a same flavour pair (electrons, muons)

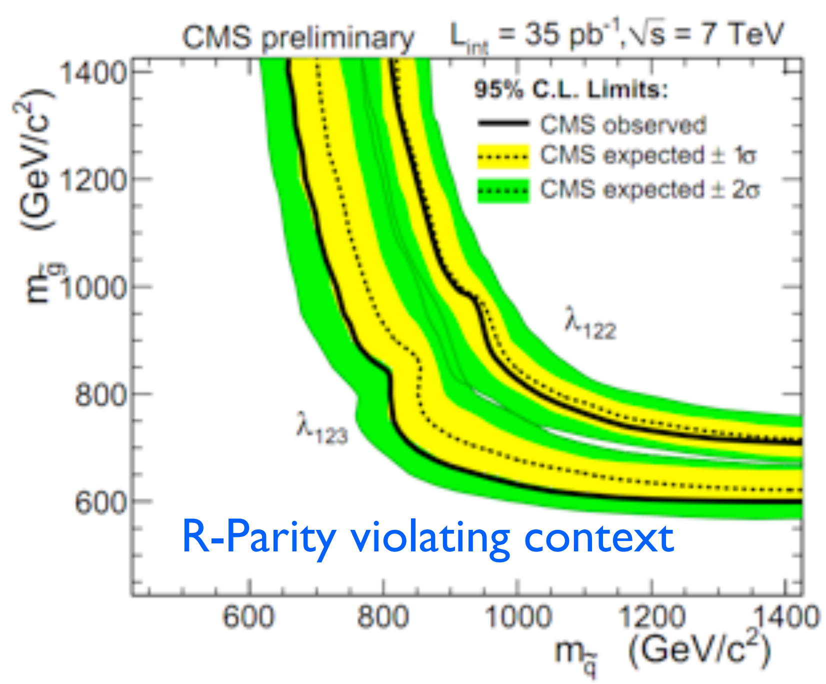
There are two selection

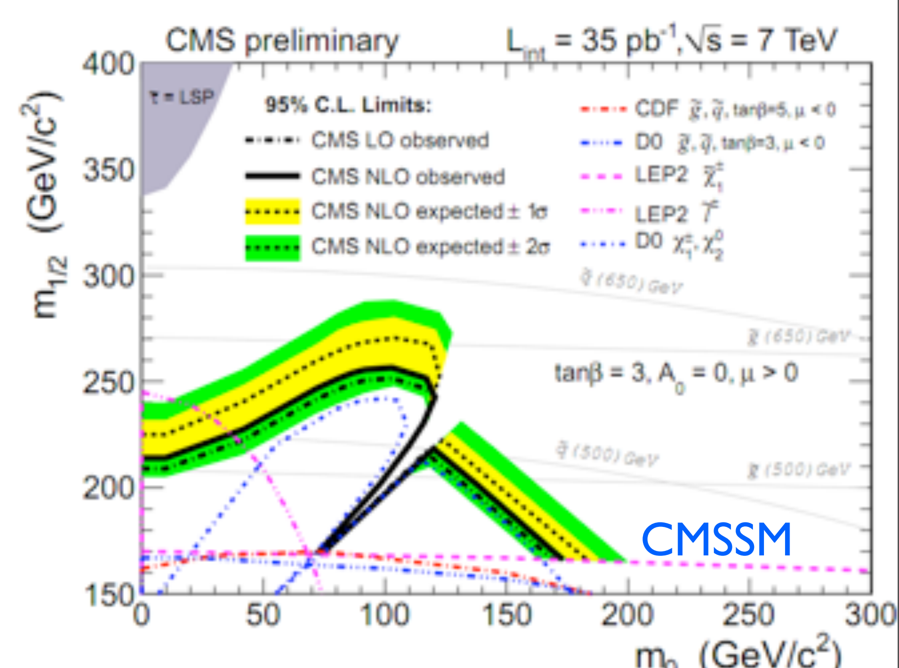
One in which events are required to have a MET > 50 GeV, and other in which H_T > 200 GeV.

Background

- Most of the backgrounds are eliminated by requiring at least three leptons
- The remanent background is Z + jets production that includes Drell-Yan Processes.
- This background can be produced when an isolated track is identified as a lepton.
- The probability for this to happen is measured from a di-lepton control sample
- This probability is used to weight all the events with two leptons an isolated tracks on them

	After Lepton ID Requirement					MET > 50 GeV		H_T > 200 GeV		ML01 Signals	
	Z +jets	$t\bar{t}$	V V +jets	ΣSM	Data	ΣSM	Data	ΣSM	Data	MET > 50	H_T > 200
Channel	3-lepton channels										
ll(OS)e	1.7	0.1	1.2	4.4 ± 1.5	6	0.1 ± 0.1	0	0.2 ± 0.1	1	121.4	141.5
ll(OS)μ	2.83	0.2	1.7	4.7 ± 0.5	6	0.10 ± 0.1	0	0.1 ± 0.1	0	123.6	120.8
ll(OS)T	121.5	0.5	0.7	123 ± 16	127	0.4 ± 0.1	0	–	–	80.5	–
ll(OS)τ	476	2.7	3.9	484 ± 77	442	–	–	0.6 ± 0.2	1	–	68
ll′T	0.72	0.5	0.2	1.7 ± 0.7	3	0.4 ± 0.2	2	–	–	18.6	–
ll′τ	4.7	2.9	0.6	11.2 ± 2.5	10	–	–	0.4 ± 0.1	1	–	12.3
ll(SS)l′	0.13	0.1	0.0	0.2 ± 0.1	0	0.2 ± 0.1	0	0	0	2.8	2.8
ll(SS)T	0.25	0.0	0.1	0.7 ± 0.4	3	0.1 ± 0.1	0	–	–	9.0	–
ll(SS)τ	1.4	0.0	0.1	3.0 ± 1.1	3	–	–	0.0 ± 0.1	0	–	6.9
Σ lll(T)	127.1	1.4	3.8	135 ± 16	145	1.3 ± 0.2	2	–	–	355.9	–
Σ lll(τ)	486.8	6.0	7.5	507 ± 77	467	–	–	1.3 ± 0.3	3	–	349.5
lTT	47.1	0.33	0.1	48 ± 9	30	0.4 ± 0.1	0	–	–	8.0	–
Channel	4-lepton channels										
llll	0	0	0.2	0.2 ± 0.1	2	0	0	0	0	163.9	149.2
lllT	0	0	0.1	0.1 ± 0.1	0	0	0	–	–	62.3	–
lllτ	0	0	0.1	0.1 ± 0.1	0	–	–	0	0	–	33.2
llTT	0	0	0	0.0 ± 0.1	0	0	0	–	–	20.6	–
llττ	3.1	0.1	0.1	3.2 ± 0.7	5	–	–	0	0	–	16.8
Σ llll(T)	0	0	0.3	0.3 ± 0.1	2	0	0	–	–	246.8	–
Σ llll(τ)	3.1	0.1	0.4	3.5 ± 0.7	5	–	–	0	0		199.2





To estimate the SM background an isolation sideband was used 0.2 < Iso < 1. To extrapolate the signal region Iso < 0.15

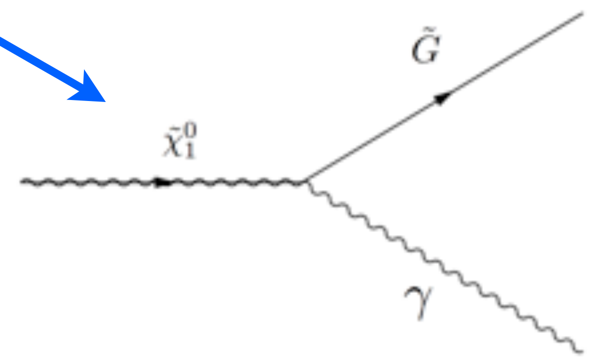
PAS SUS-10-008

Two Isolated Photons, at least one jet, and Large Missing Energy

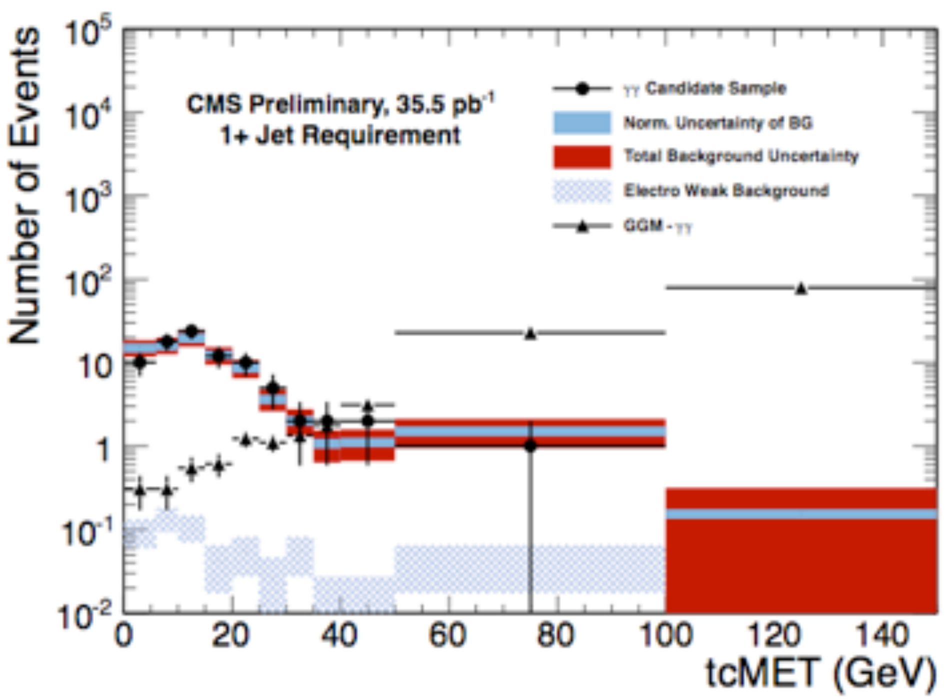
• Motivated by General Gauge Mediated Supersymmetry Breaking (GGB) with the lightest neutralino as the NLSP and Gravitino as the LSP

• Compare the MET distributions in events with two photons and at least one hadronic jet, with the expected SM distribution.

• Irreducible backgrounds from SM processes such as Z(→ νν)γγ and W(→ lν) γγ are negligible. The main background arise from SM processes with misidentified photons and/or mis-measured MET.



Single Photon trigger was used for the baseline selection



QCD Background

• To estimate the dominant backgrounds one uses control samples kinematically similar to the candidate sample but with no MET present.

- Two samples were used (ff) (QCD multijets with two fake photons), and a Z to ee + jets sample.
- Events in the control samples are re-weighted to reproduce the di-photon transverse energy distribution in the data.
- The re-weighted MET distributions are identical (within the uncertainties) and are used to estimate the magnitude of the background.

Electroweak Background

• The Second background comes from events with real MET

• It is dominated by a real or a fake photon and a W that decays to a neutrino and an electron, with the electron mis-identified as a photon.

• To estimate this background a weight is assigned to every electron in the eγ sample.

$$f_{e\to\gamma}/(1-f_{e\to\gamma})$$

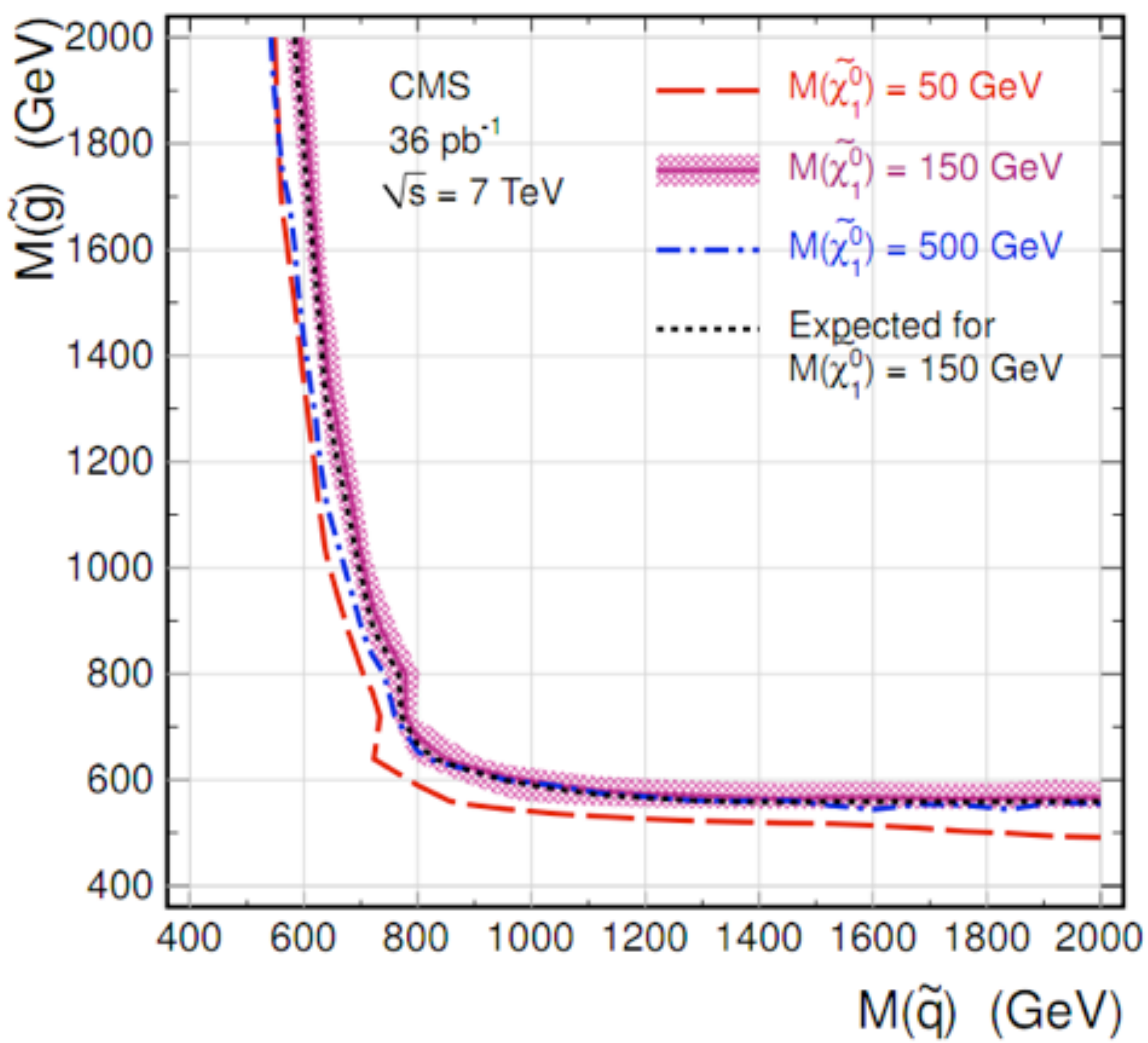
By determining the number of Z → ee events present in the ee and in the eγ sample we measured

$$f_{e\to\gamma} \longrightarrow 1.4\pm0.4\%$$

PAS SUS-10-002

Type	Observed Events	stat error	reweight error	normalization error
$\gamma\gamma$ events	1.0			
fake-fake QCD background est.	0.49 ± 0.40	± 0.36	± 0.06	± 0.07
$Z \rightarrow ee$ QCD background est.	1.67 ± 0.64	± 0.46	± 0.38	± 0.23
background from $e\gamma$	0.04 ± 0.15	± 0.15	± 0.0	± 0.01
Total Background $\geq$ 50 GeV (using ff)	0.53 ± 0.40			
Total Background $\geq$ 50 GeV (using ee)	1.71 ± 0.68			

- In 35.5 pb-1 of data one event was observed with MET > 50 GeV.
- 1.2 +/- 0.8 events were expected from QCD and EW backgrounds.
- From this measurement upper limits were obtained for GGM SUSY cross-sections between 0.3 and 1.1 pb at the 95 % CL depending on the squark, gluino, and neutralino mass region.
- 95 % CL exclusion limits for GGM production as a function of squarks and gluino masses for 50, 150, and 500 GeV/c^2 neutralino masses. The areas below the lines are excluded.



PAS SUS-10-002

Lepton, photon and MET

A single lepton trigger is required

Electrons and Muons

$$p_T > 20\ \text{GeV}/c,\ |\eta| < 2.1$$

plus identification and isolation cuts

Photons

$$p_T > 30\ \text{GeV}/c,\ |\eta| < 1.45$$

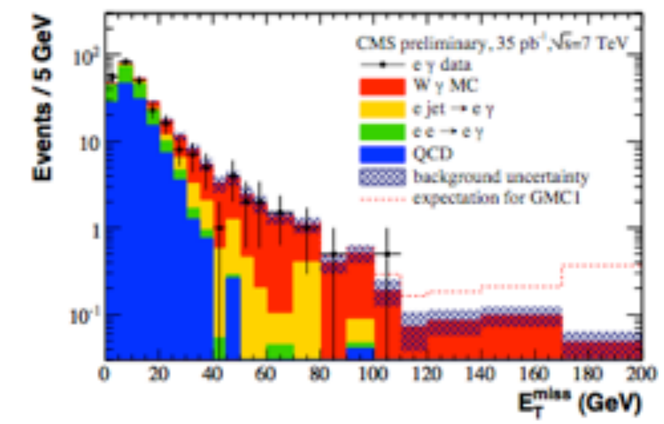
specially separated from the lepton

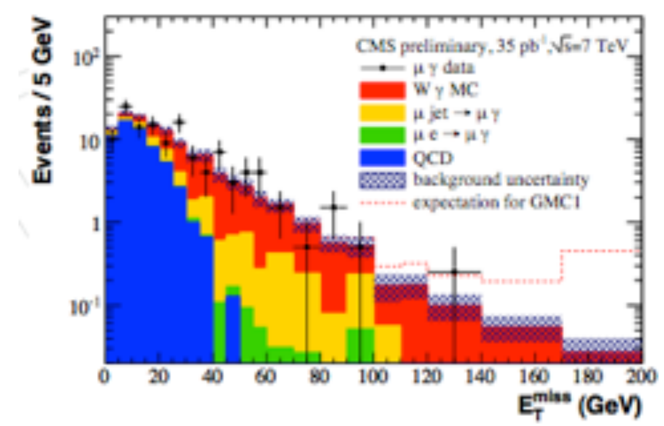
$$\Delta R(\ell,\gamma) = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 0.4.$$

Events are required to have MET > 100 GeV

Backgrounds

- Dominant background is the W+γ, It is estimated by simulated samples
- The background produced by the mis-identification of a jet as a photon is calculates by using the probability of a jet to be identified as a photon
- The background produced by the mis-identification of an electron is calculated using the probability of electron to be identified as a photon
- QCD background is estimated using Z to ee sample re-scaled to match a control region data



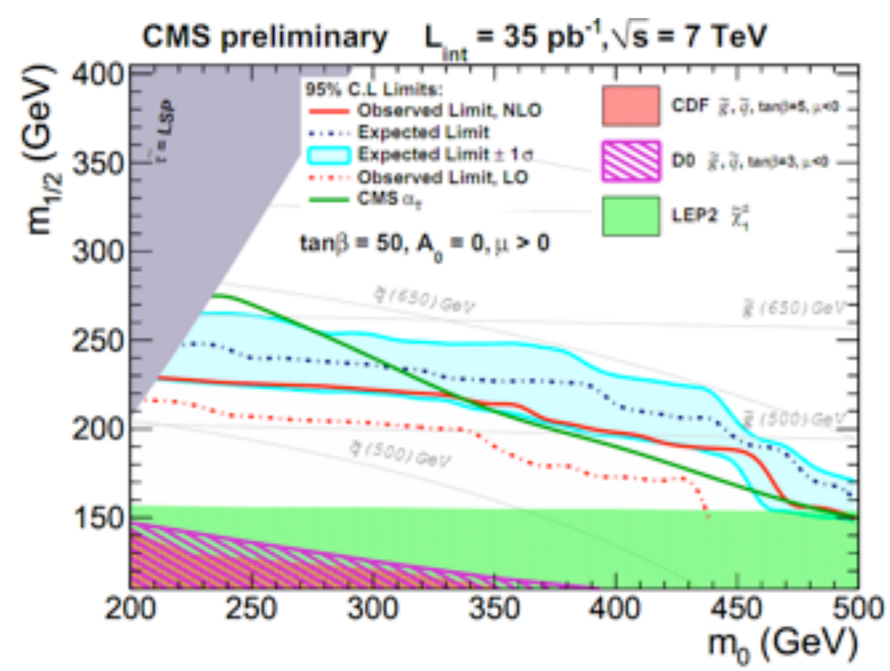


Electrons

	Candidate sample	$E_T^{miss} > 40$ GeV	$E_T^{miss} > 100$ GeV
$W\gamma$	44.5	16.1 ± 3.4	1.68 ± 0.42
jet$\to\gamma$	20.3	3.1 ± 0.9	0.02 ± 0.02
$e\to\gamma$	70.5	0.3 ± 0.1	0.04 ± 0.03
QCD	133.9	0.4 ± 0.2	0.00 ± 0.00
Total bck.	269.3	19.9 ± 3.7	1.74 ± 0.43
data	264	16	1
SUSY GMC1 prediction	4.32 ± 0.86	4.16 ± 0.83	3.38 ± 0.68

Muons

	Candidate sample	$E_T^{miss} > 40$ GeV	$E_T^{miss} > 100$ GeV
$W\gamma$	44.8	15.9 ± 3.4	1.40 ± 0.37
jet$\to\gamma$	18.0	3.7 ± 1.1	0.10 ± 0.09
$e\to\gamma$	1.2	0.6 ± 0.2	0.09 ± 0.04
QCD	58.3	0.2 ± 0.1	0.00 ± 0.00
Total bck.	122.3	20.4 ± 3.7	1.59 ± 0.39
data	126	27	1
SUSY GMC1 prediction	5.73 ± 1.15	5.46 ± 1.1	4.41 ± 0.88



PAS SUS-11-002

Summary

- CMS performed a variety of SUSY searches with the 35 pb-1 collected during the 2010
- Multiple methods have been developed to estimate the backgrounds directly from data, this results have been in agreement with simulation estimations
- We have not seen significant evidence for physics beyond the SM
- But this may change with the data taken during the entire 2011.
- All analysis have pushed the previously known limits further using the LHC 2010 data.
- The outstanding performance of the LHC let us believe that new physics may be very close...