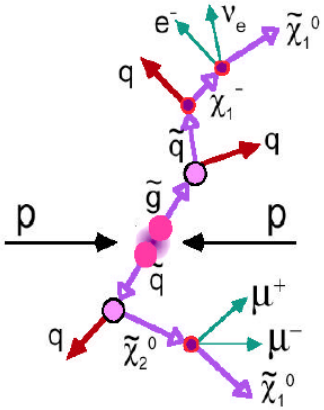
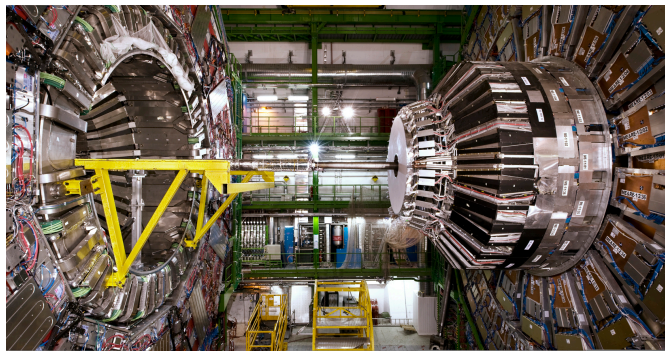
UniZH seminar

ETH Institute for Particle Physics

SUSY searches in leptonic final states With ATLAS and CMS

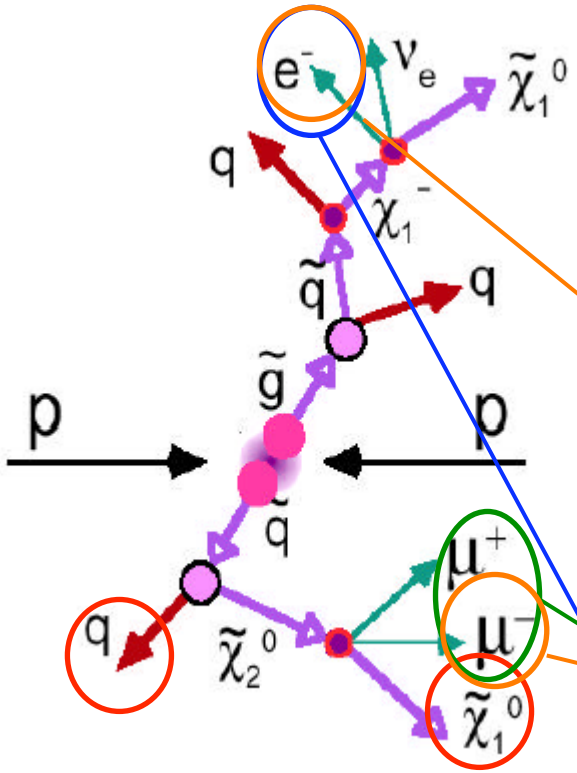
Filip Moortgat (ETH Zurich)





Implications of LHC results for TeV physics @ CERN, Aug 30, 2011

SUSY searches @ ATLAS/CMS



- All searches require jets and MET
- Further categorized by number of leptons
- Different searches have different dominant backgrounds

- Will focus on new results (Summer '11)

1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton

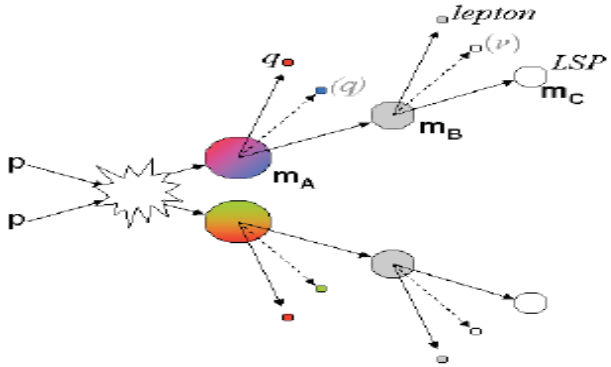
Single lepton search

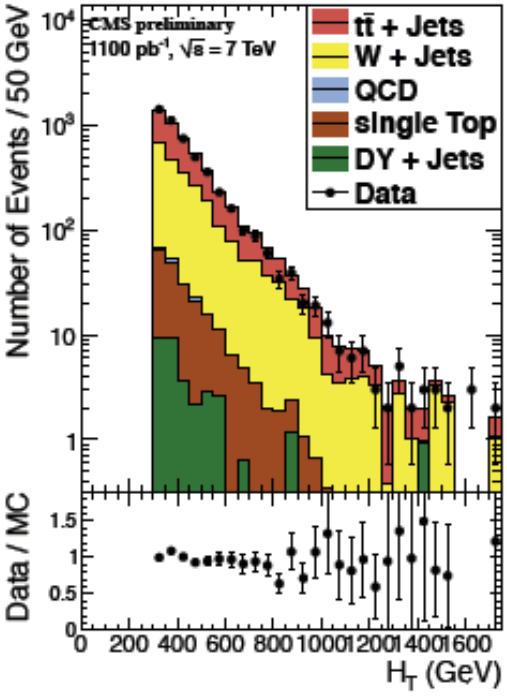
1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton

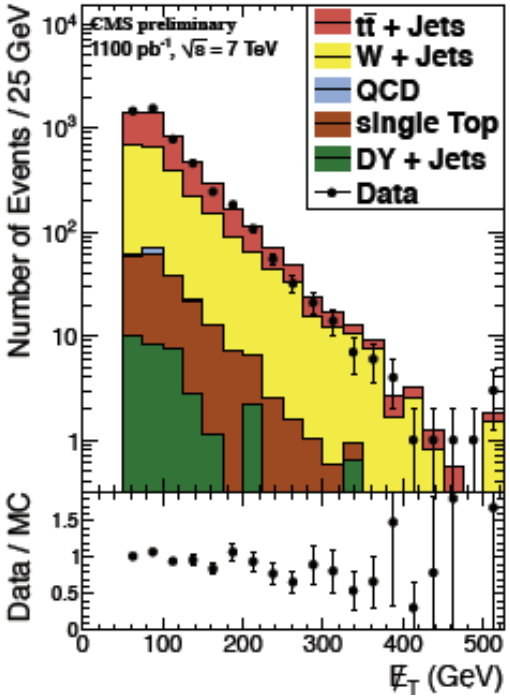
- Isolated lepton requirement reduces backgrounds considerably
- Mainly W+jets and top backgrounds left

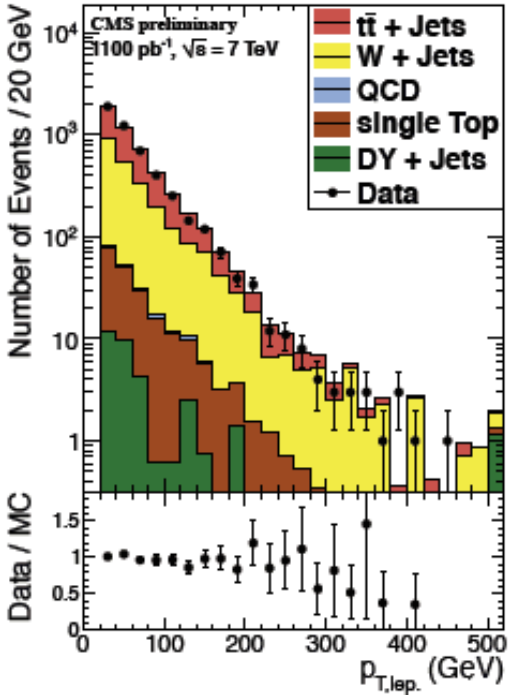
CMS 1 lepton: selection

- Baseline selection:
  - Exacly 1 isolated lepton:
    - pT > 20 GeV, |η|<2.4
    - Relative isolation
      < 0.1 (mu), < 0.3 (e)
  - 3 jets:
    - pT > 40 GeV, |η|<2.4









CMS 1 lepton: Method 1

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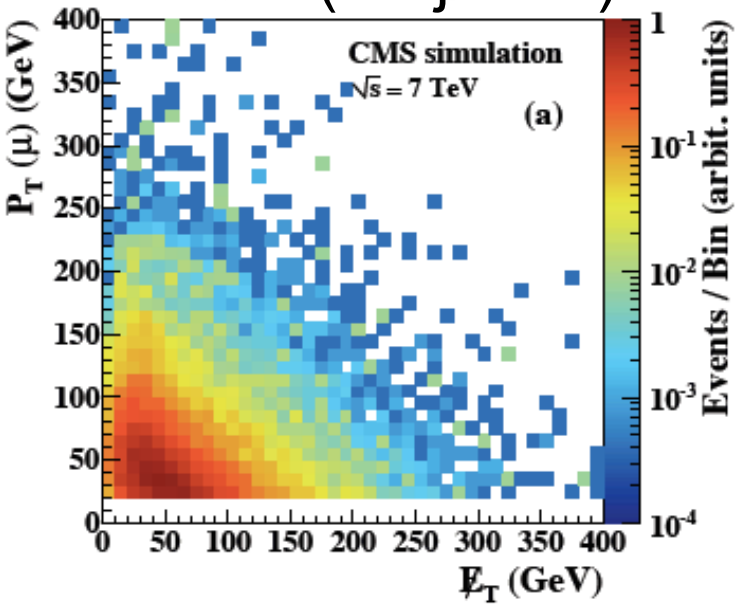
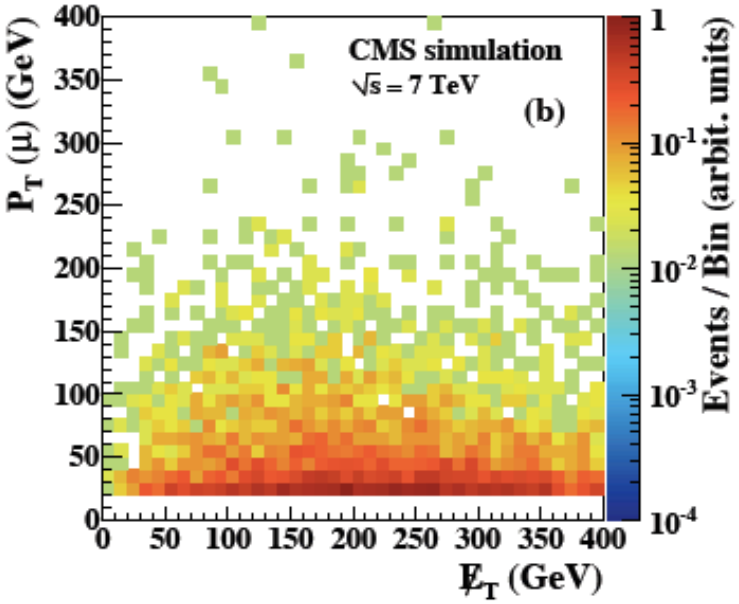
- Method 1: Lepton spectrum
  - Idea: in W decay, charged lepton and neutrino P_T spectra are on average approximately the same:
    - Take muon P_T spectrum & correct for acceptance, efficiency and polarization
    - MET resolution worse than lepton P_T resolution → smear using QCD templates

SM (W+j/ttbar)

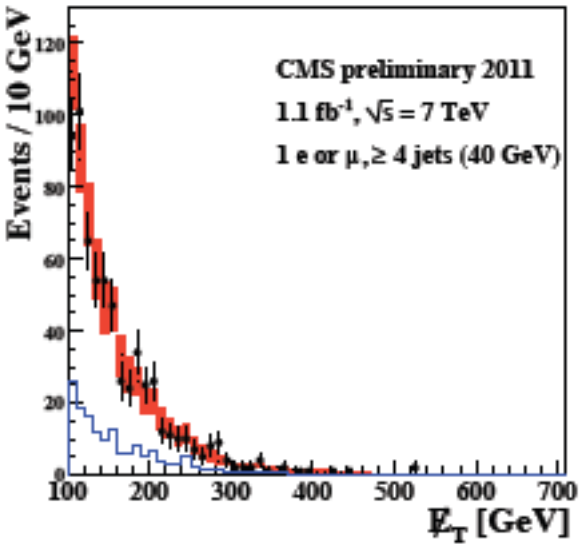


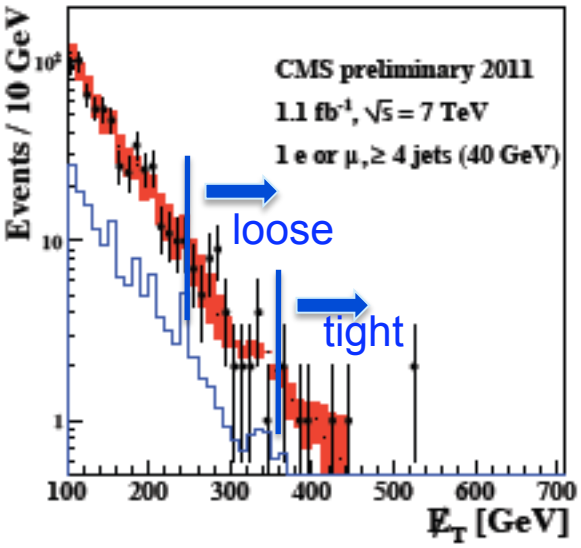
SUSY



CMS 1 lepton: Method 1

- Final selection:
  - MET > 250 GeV (loose), >350 GeV (tight)
  - HT > 500 GeV





Sample	Loose Selection (e+μ)	Tight Selection (e+μ)
Predicted SM 1 ℓ	$34.6 \pm 7.7 \pm 10.8$	$8.8 \pm 3.7 \pm 3.4$
Predicted SM dilepton	$4.0 \pm 3.9 \pm 0.8$	$0.9 \pm 1.9 \pm 0.9$
Predicted single τ	$10.5 \pm 1.2 \pm 0.2$	$2.3 \pm 0.5 \pm 0.2$
Predicted QCD background	$0.0 \pm 1.2 \pm 0.3$	$0.0 \pm 1.0 \pm 0.3$
Single top (MC), Z+jets (MC)	$0.7 \pm 0.2 \pm 0.2$	$0.1 \pm 0.1 \pm 0.1$
Total predicted SM	$49.8 \pm 8.8 \pm 10.8$	$12.1 \pm 4.3 \pm 3.6$
Data	52	8

CMS 1 lepton: Method 2

- Method 2: lepton projection
  - Idea: exploit difference in correlation between lepton and MET

in SM (W+jets and ttbar) and SUSY processes

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

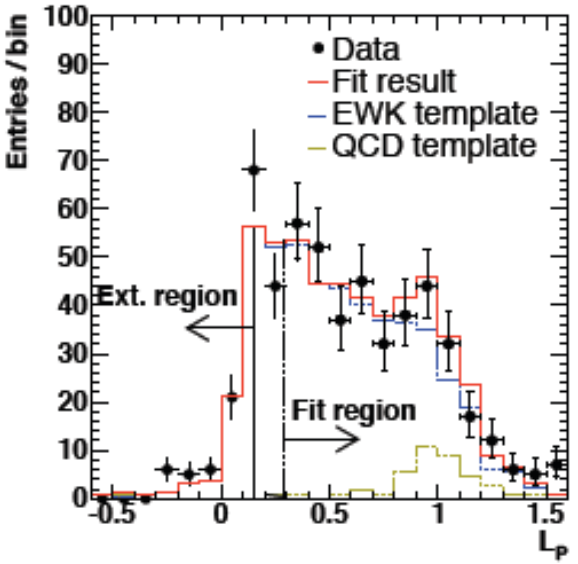
Define a signal and control region:

$$N_{SMpred}(L_P < 0.15) = R_{CS} N_{data}(L_P > 0.30)$$

signal region norm. region

With the ratio R determined from simulation:

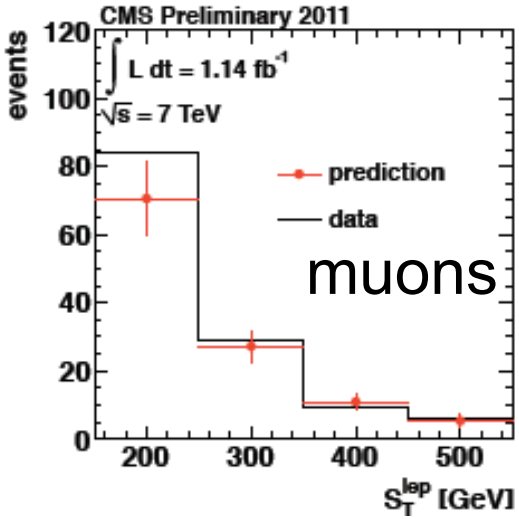
$$R_{CS} = \frac{N_{MC}(L_P < 0.15)}{N_{MC}(L_P > 0.30)}$$

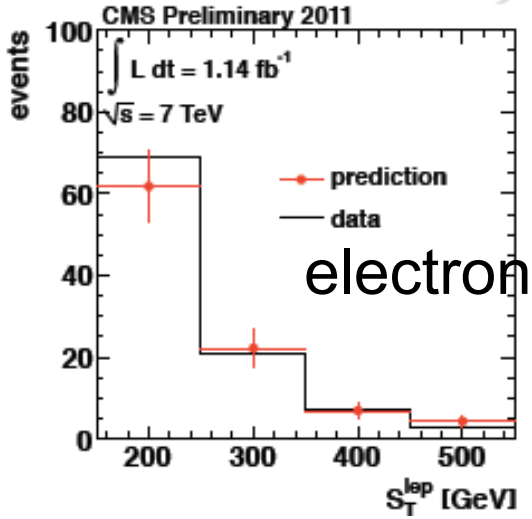


CMS 1 lepton: Method 2

- Multiple bins in ST:

$$S_T^{lep} = p_T(\ell) + \not{E}_T$$





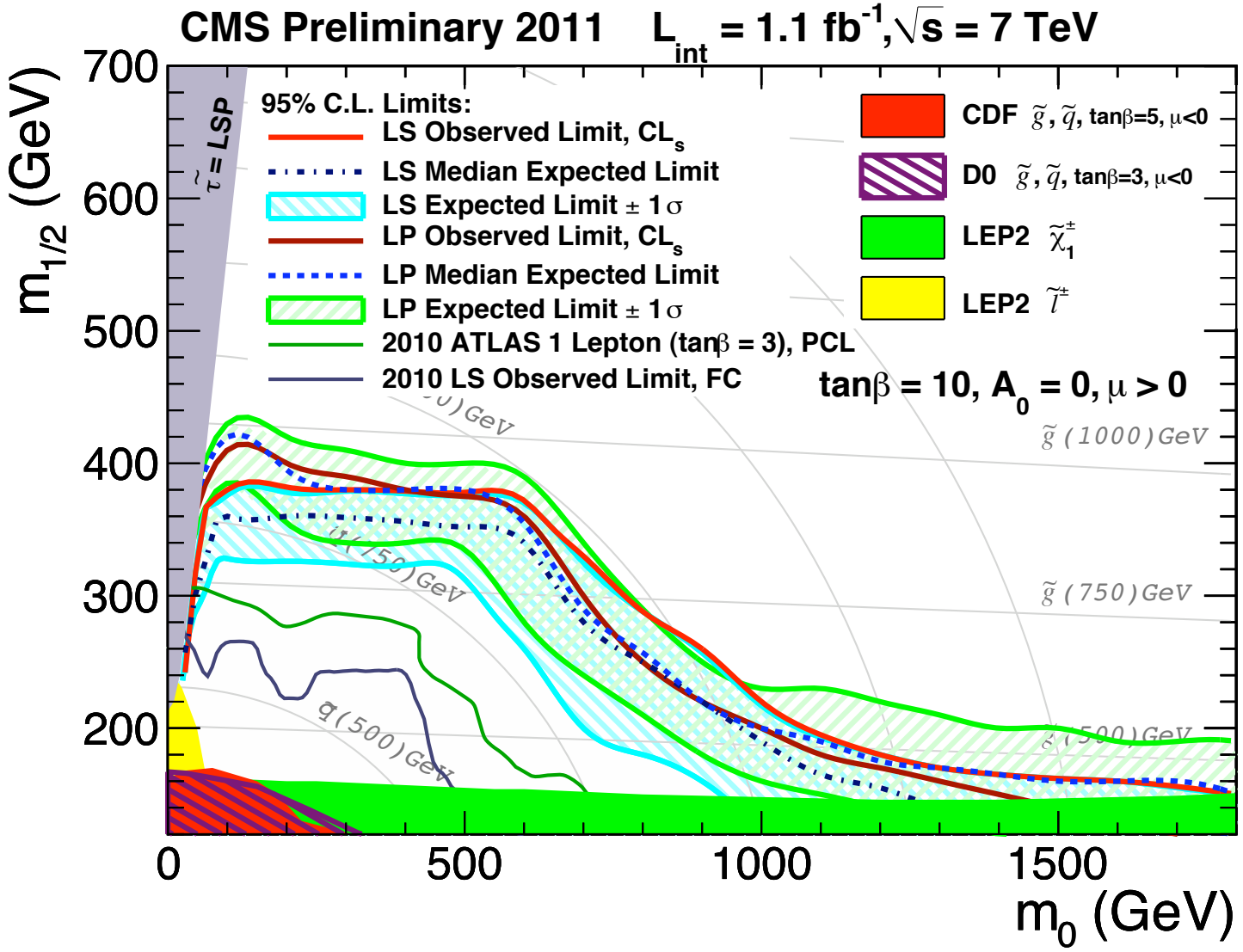
muons

	Control Region (L_P >0.3)		Signal Region (L_P <0.15)		
S_T^{lep} Range (GeV)	Total MC	DATA	Total MC	SM estimate	DATA
[150-250]	385±7	368	73.9±3.0	70.6±11	84
[250-350]	116±2	112	28.1±1.1	27.2±4.6	29
[350-450]	43.4±2.	41	11.5±0.7	10.9± 2.3	9
> 450	18.4±0.8	15	6.5±0.4	5.3± 1.8	6

electrons

	Control Region (L_P >0.3)			Signal Region (L_P <0.15)			
S_T^{lep} Range (GeV)	QCD	EWK	DATA	QCD	EWK	SM estimate	DATA
[150-250]	39.5±15.5	350±24	390	1.0±0.3	60.8±4.1	61.8±8.7	69
[250-350]	5.0±5.2	117±12	122	0	22.2±2.2	22.2±4.4	21
[350-450]	7.1±3.9	28.9±6.2	36	0	6.9±1.5	6.9±1.7	7
> 450	6.5±5.7	12.5±3.8	19	0	4.3±1.3	4.3±1.5	3

CMS 1 lepton: Results



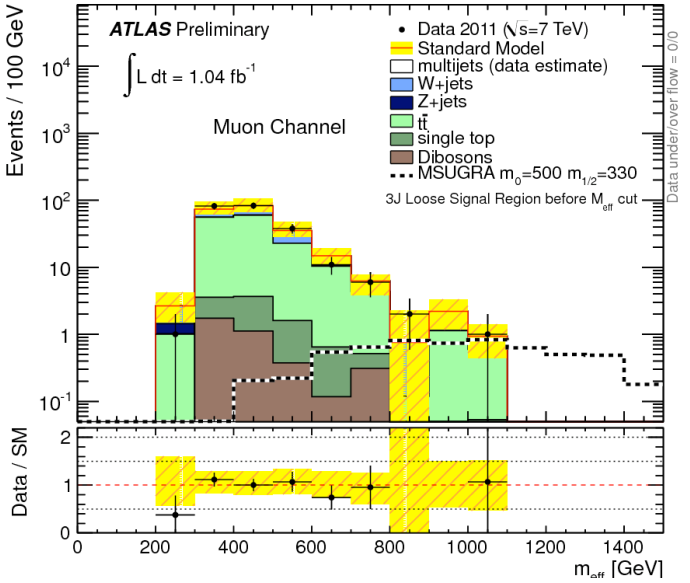
ATLAS: 1 lepton

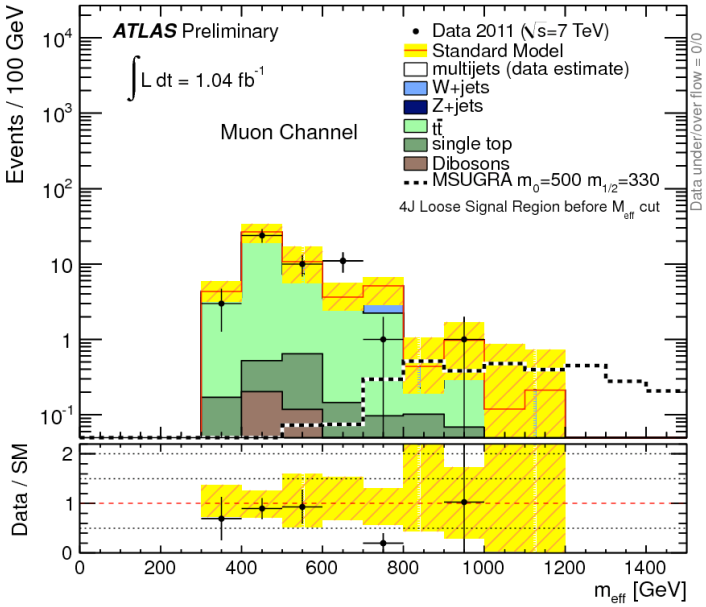
- ATLAS: updated search with 1 fb-1
  - Pt e (mu) > 25 (20) GeV
  - 4 signal regions:
    - > 3 or 4 jets
    - Various MT, MET and Meff cuts

Selection	Signal Regions 3JL	3JT	4JL	4JT	Control Regions 3J	4J
Number of Leptons	= 1					
Lepton p_T (GeV)	> 25(20) for electrons (muons)					
Veto lepton p_T (GeV)	> 20(10) for electrons (muons)					
Number of jets	≥ 3		≥ 4		≥ 3	≥ 4
Leading jet p_T (GeV)	60	80	60	60	60	60
Subsequent jets p_T (GeV)	25	25	25	40	25	25
$\Delta\phi(\vec{\text{jet}}_i, \vec{E}_T^{\text{miss}})$	[> 0.2 (mod.π)] for all 3 (4) jets					
m_T (GeV)	> 100				40 < m_T < 80	
E_T^{miss} (GeV)	> 125	> 240	> 140	> 200	30 < E_T^{miss} < 80	
$E_T^{\text{miss}}/m_{\text{eff}}$	> 0.25	> 0.15	> 0.30	> 0.15	–	–
m_{eff} (GeV)	> 500	> 600	> 300	> 500	> 500	> 300

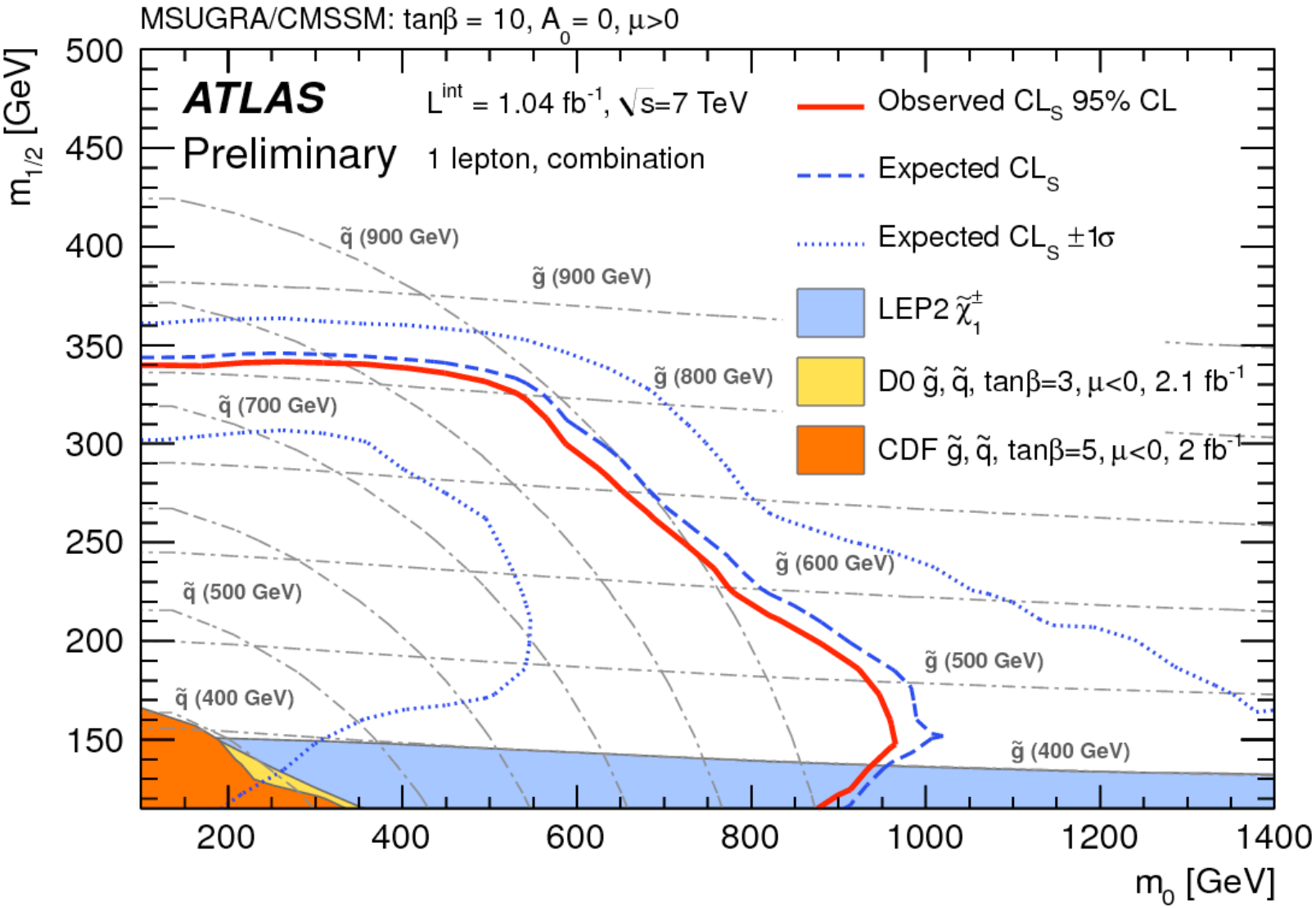
Transfer factors:

- **Control region → Signal region**
- **$N_{SR}^{est.} = N_{SR}^{MC}/N_{CR}^{MC} \times (N_{CR}^{obs}-N_{CR}^{bkg})$**





ATLAS 1l: results

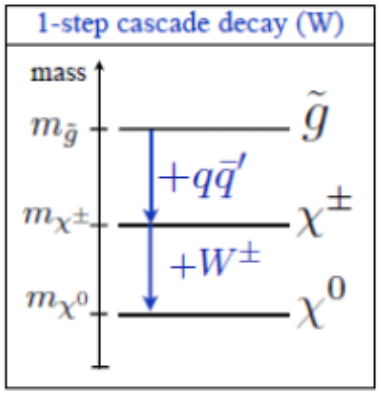


ATLAS: simplified models

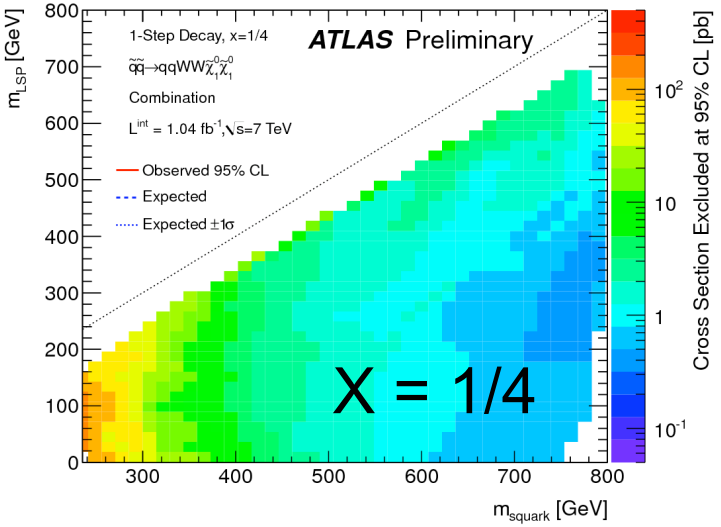
- Presented in simplified models:

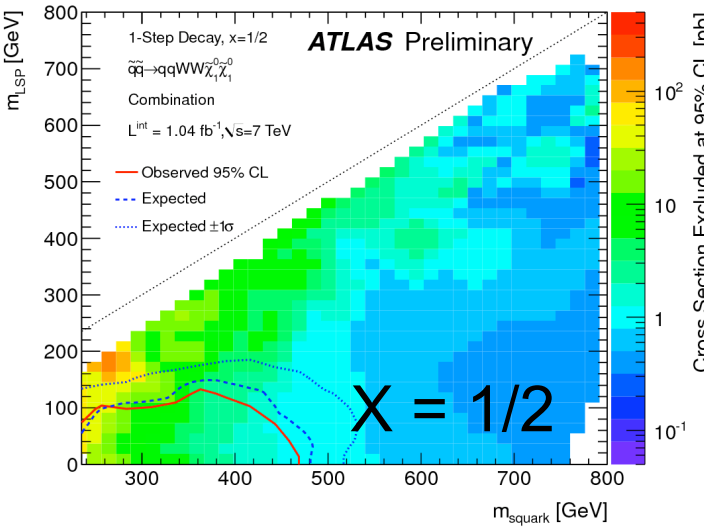
e.g. $\tilde{q} \to q' \tilde{\chi}_1^{\pm} \to q' W \tilde{\chi}_1^0$,

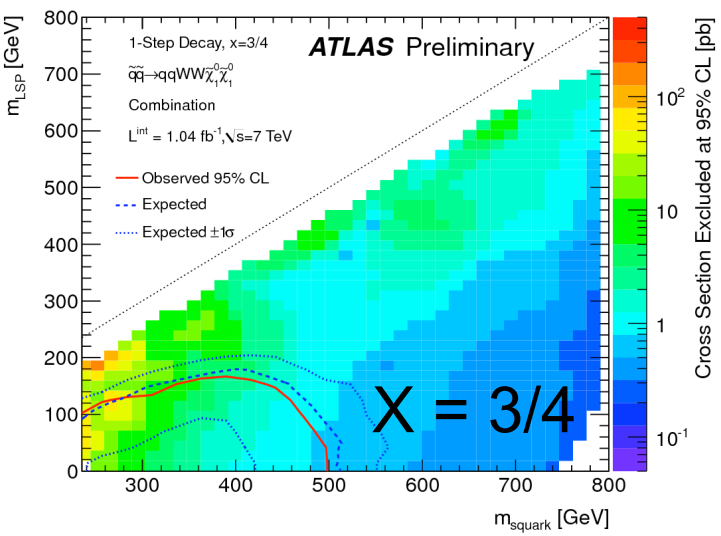
$x = (m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0)) / (m(\tilde{q}) - m(\tilde{\chi}_1^0))$



Note: no exclusion in x=1/4 model!







Opposite-sign di-lepton

1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton

- Requiring 2 isolated leptons strongly reduces QCD and W+jet background. Top becomes the dominant background.
- Analyses inside and outside of the Z peak
- Channel very suitable for sparticle mass reconstruction

CMS: OS 2l: selection

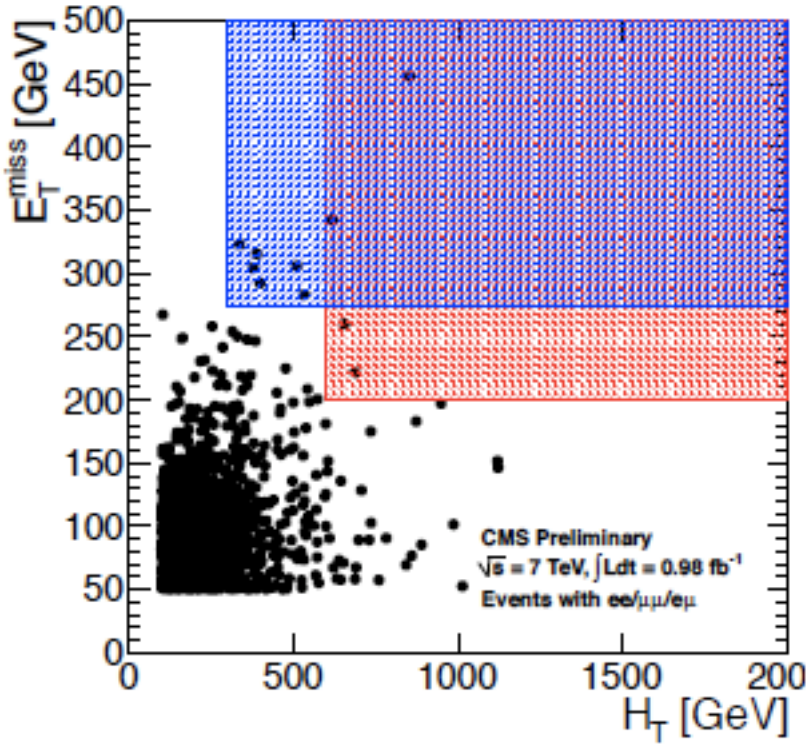
- Baseline selection:
  - 2 opposite-sign isolated leptons:
    - pT > 20 (first), 10 (second) GeV, |η|<2.4
    - Relative isolation < 0.15
  - At least 2 jets:

    pT > 30 GeV, |η|<3
  - HT>100 GeV, MET > 50 GeV

- Final selection:
  - Two signal regions:

    HT > 300 and MET > 275 GeV

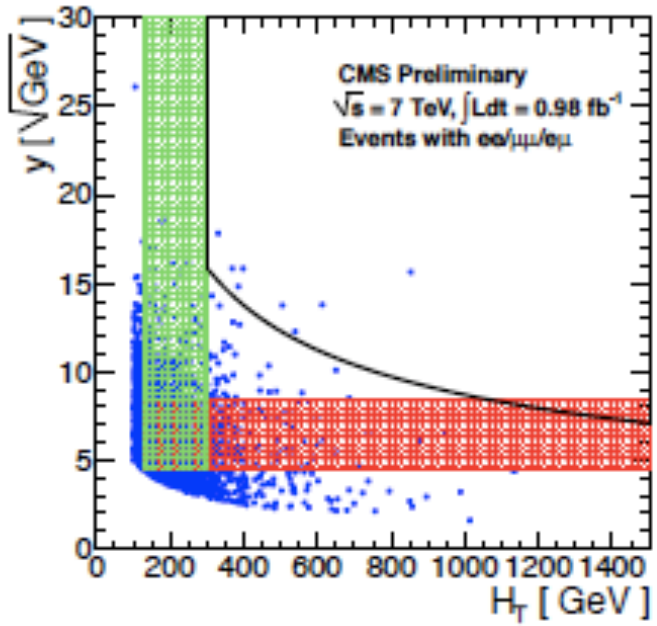
    HT > 600 and MET > 200 Gev



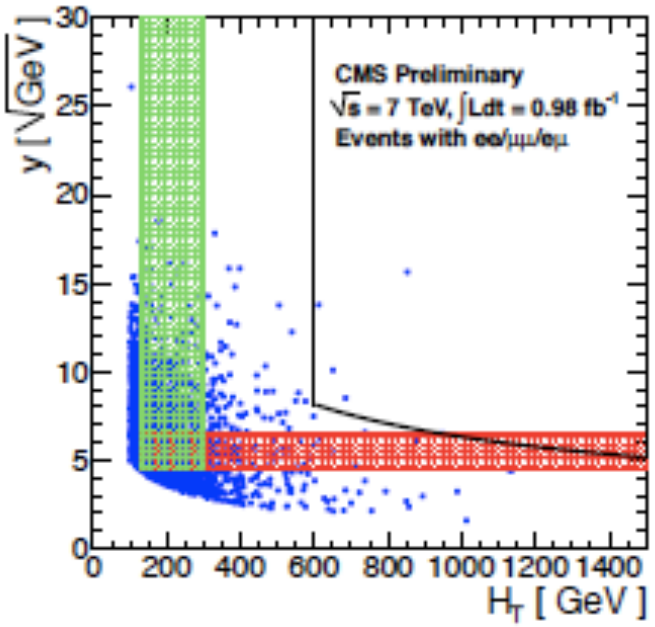
CMS OS 2l: backgrounds

- Again 2 methods
  - Method 1: matrix method based on HT and y=MET/sqrt(HT):

$E_T^{miss} > 275$ GeV, $H_T > 300$ GeV

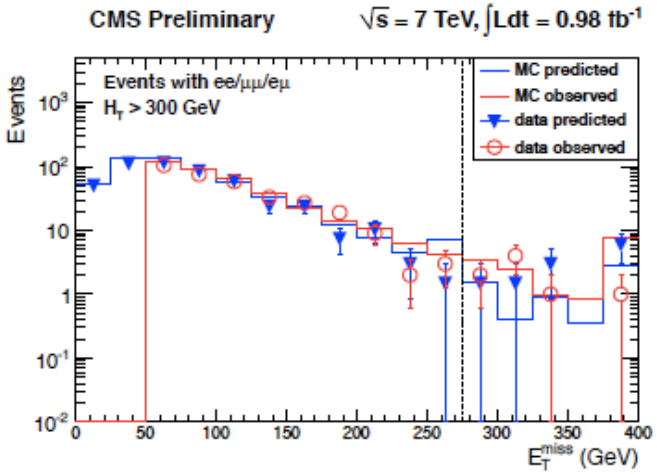


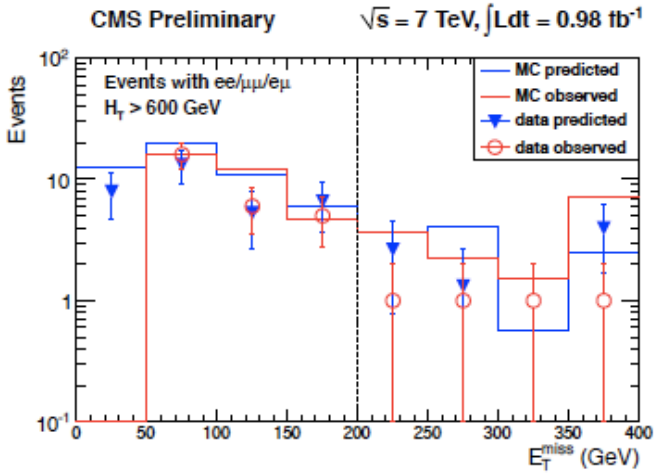
$E_T^{miss} > 200$ GeV, $H_T > 600$ GeV



CMS OS 2l: backgrounds (2)

- Method 2: Lepton spectrum method (same as for 1-lepton search)

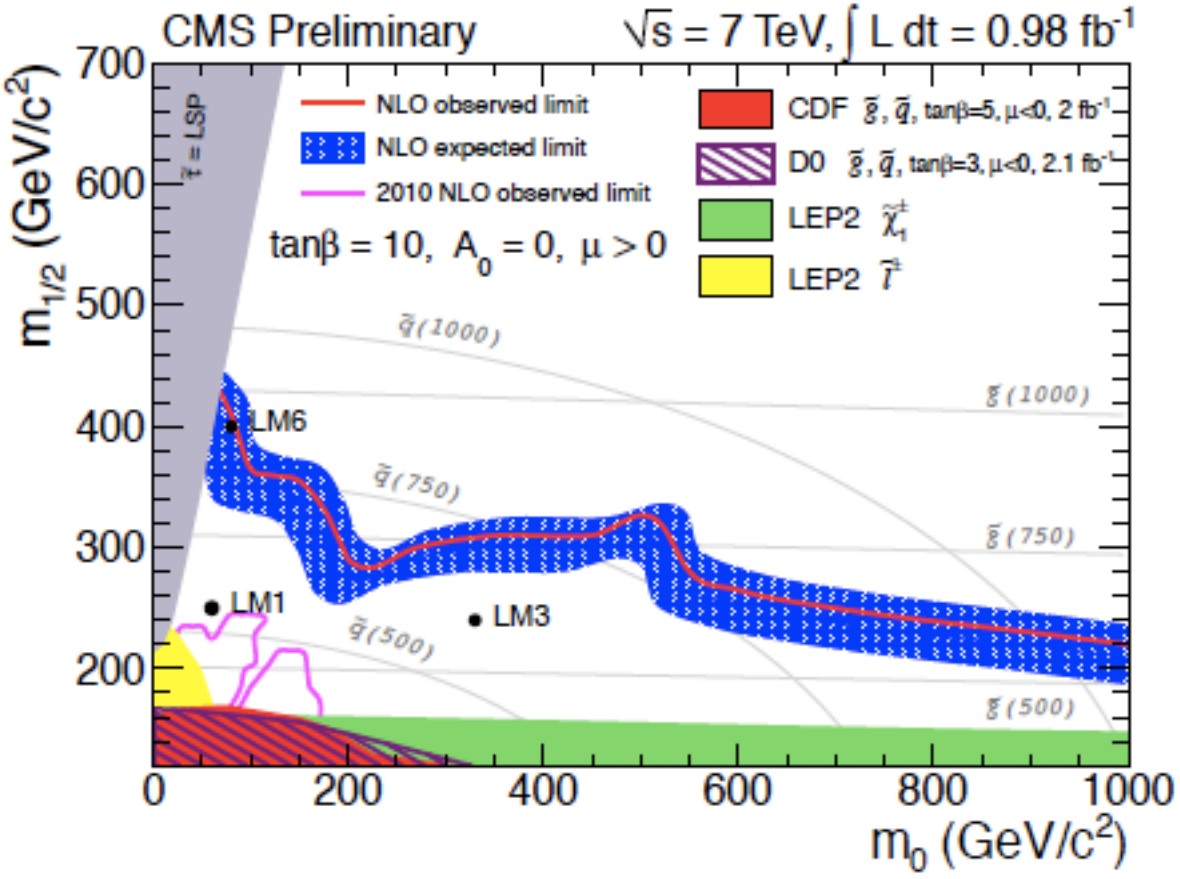




- Results:

	high E_T^{miss} signal region	high H_T signal region
observed yield	8	4
MC prediction	7.3 ± 2.2	7.1 ± 2.2
ABCD′ prediction	4.0 ± 1.0 (stat) ± 0.8 (syst)	4.5 ± 1.6 (stat) ± 0.9 (syst)
$p_T(\ell\ell)$ prediction	14.3 ± 6.3 (stat) ± 5.3 (syst)	10.1 ± 4.2 (stat) ± 3.5 (syst)
N_{bkg}	4.2 ± 1.3	5.1 ± 1.7
non-SM yield UL	10	5.3

CMS OS 2l: results

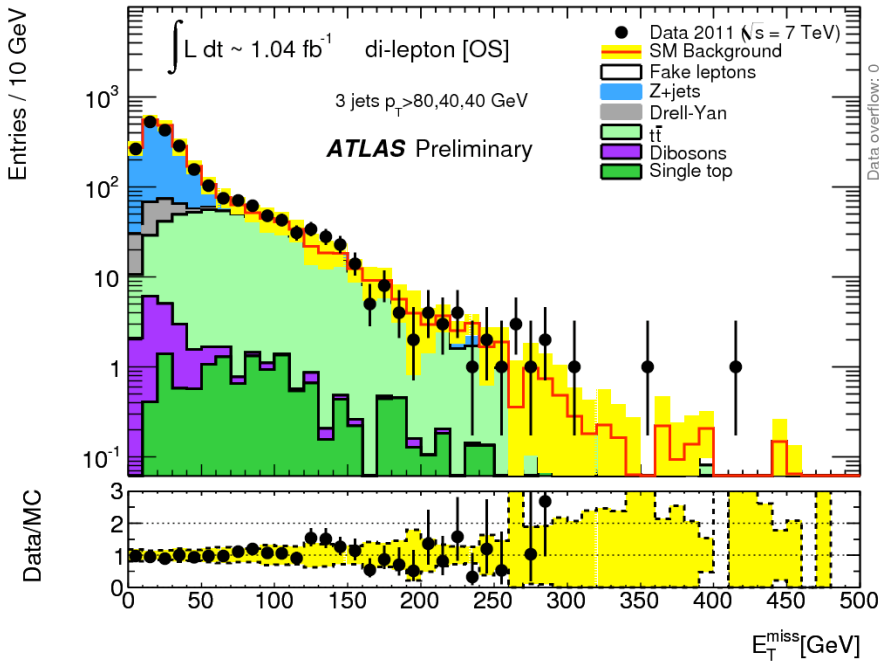


ATLAS: 2l OS

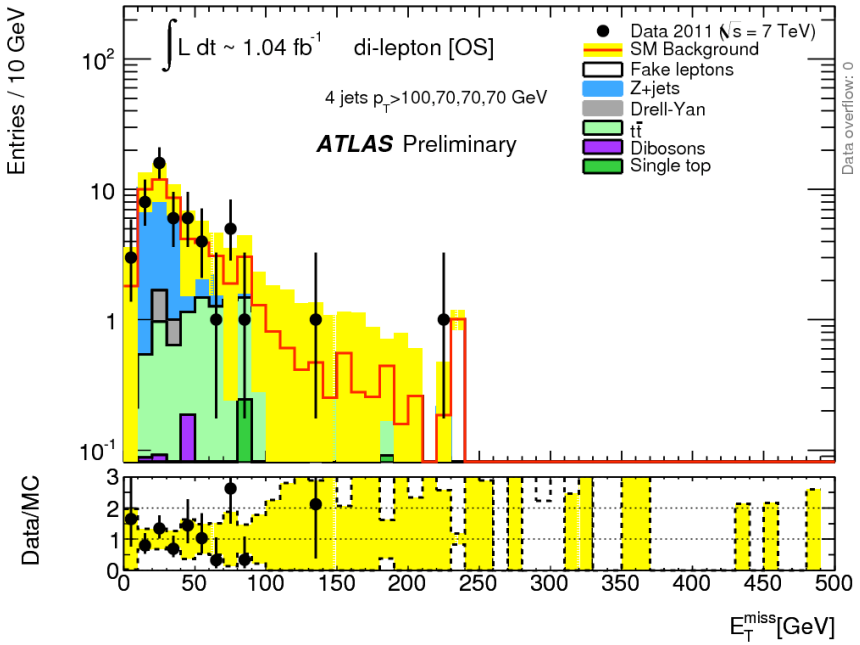
Signal Region	OS-SR1	OS-SR2	OS-SR3
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	250	220	100
Leading jet p_{T} [GeV]	-	80	100
Second jet p_{T} [GeV]	-	40	70
Third jet p_{T} [GeV]	-	40	70
Fourth jet p_{T} [GeV]	-	-	70
Number of jets	-	-	-
m_{ll} veto [GeV]	-	-	-

	Background	Obs.	95% C.L.
OS-SR1	$15.5 \pm 1.2 \pm 4.4$	13	9.5 fb
OS-SR2	$13.0 \pm 1.8 \pm 4.1$	17	15.2 fb
OS-SR3	$5.7 \pm 1.1 \pm 3.5$	2	5.0 fb

3 jet



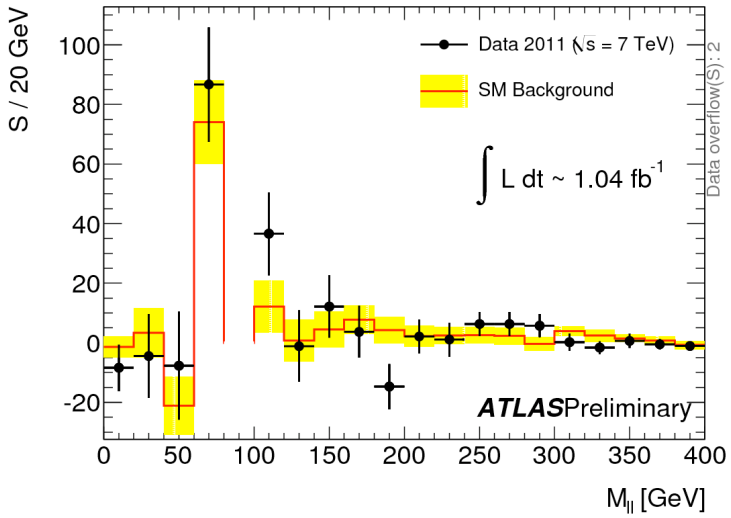
4 jet



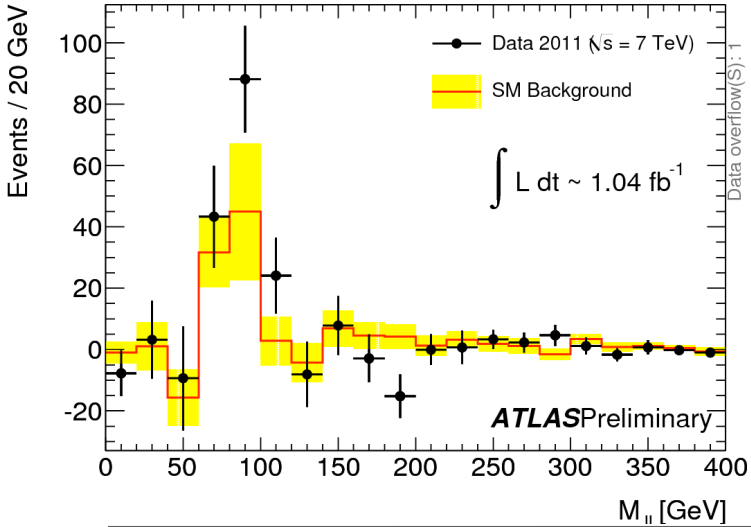
ATLAS: DF subtraction

- Other approach:
  - Search for an excess in Same Flavour di-leptons
    - E.g. from chi_20 decay
  - subtract Different Flavour (DF) pairs from Same-Flavour pairs (SF)

MET > 80 GeV + Z-veto



MET > 80 GeV + >= 2 jets

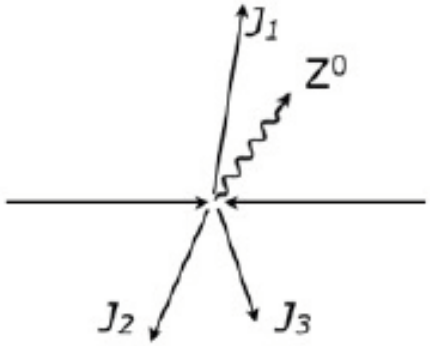


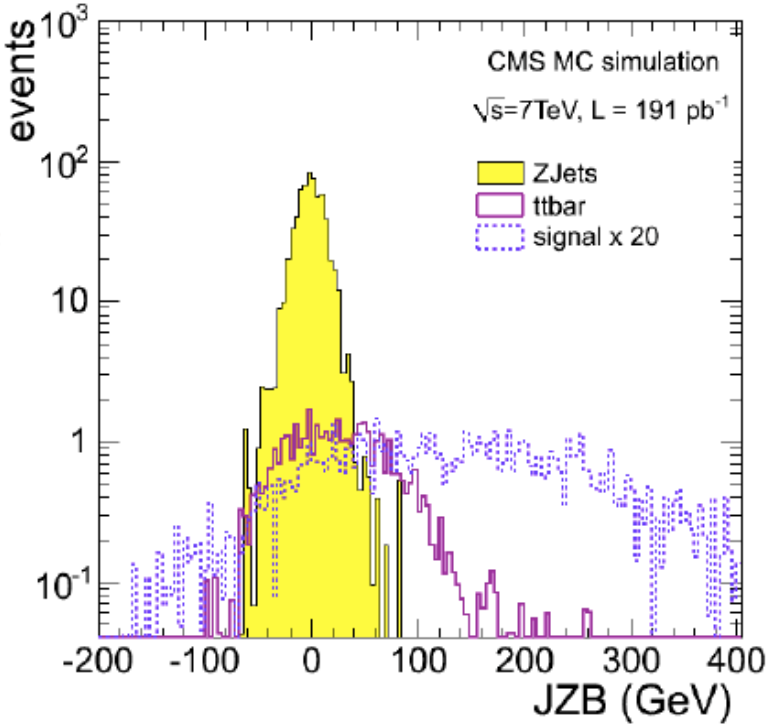
	$\mathcal{S}_{obs}$	$\bar{\mathcal{S}}_b$	RMS	$\mathcal{S} > \mathcal{S}_{obs}$ (%)	Limit $\bar{\mathcal{S}}_s$ (95% C.L.)
FS-SR1	131.6±0.6(sys)	126.5±23.5±17.2	49.9	46	88
FS-SR2	142.2±0.6(sys)	70.0±23.2±16.8	49.1	7	156
FS-SR3	-3.1±0.0(03)(sys)	0.4±1.2±1.2	4.6	77	4.9

Z+jet+MET final states

- CMS: final states containing $Z \rightarrow l^+l^-$ + jets + MET
- SM Background:
  - Instrumental: Z+jets with artificial MET
    - Use MET templates from photon + jet sample
    - Reject using JZB (Jet-Z balance) variable:

$$JZB = \left| \sum_{jets} \vec{p}_T \right| - \left| \vec{p}^{\,Z} \right|$$

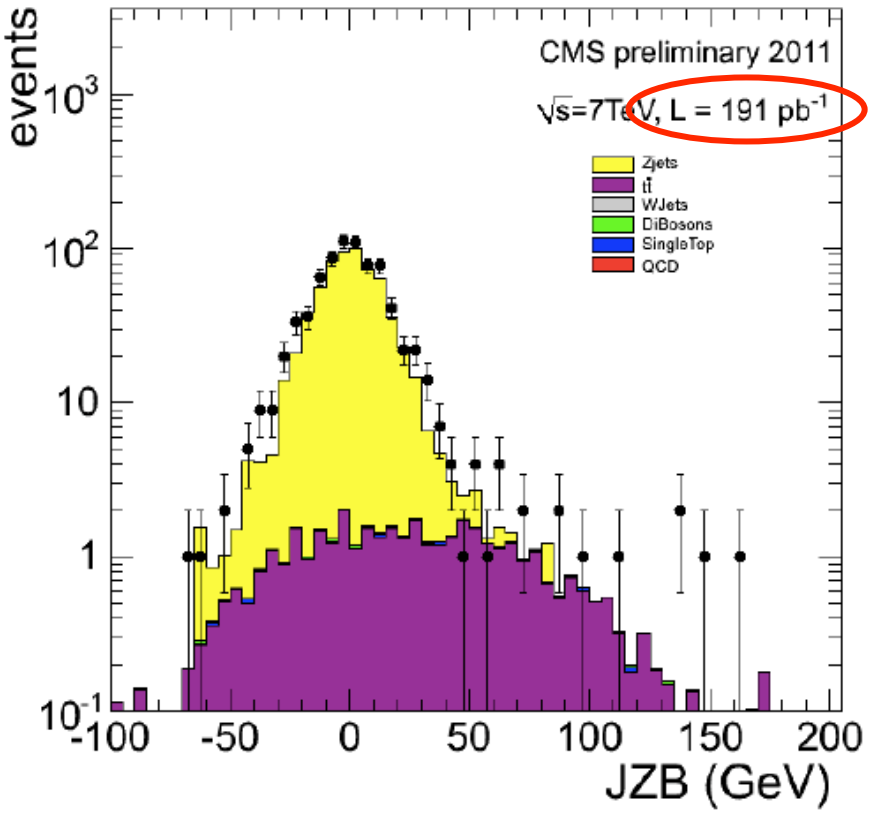


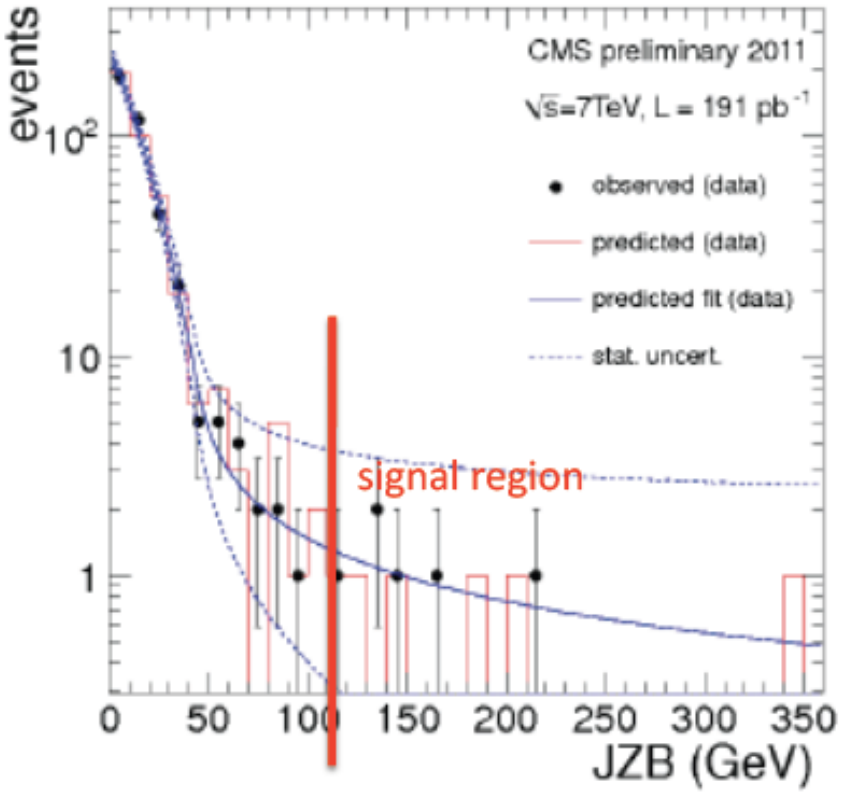


  - True OSSF di-leptons (mainly from tt) with accidental m_{ll} in Z mass window
    - Reject using OSOF subtraction

CMS: JZB selection

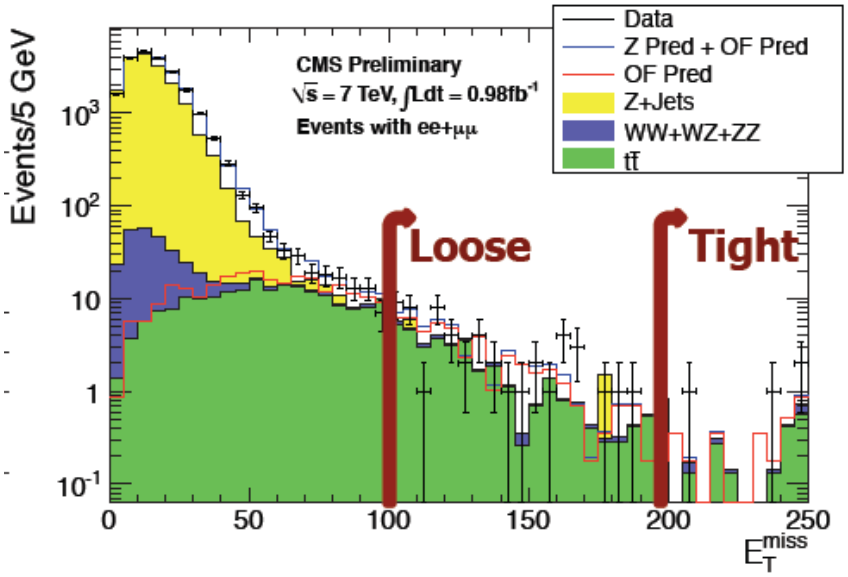
- Signal selection
  - Two OSSF di-leptons (p_T > 20 GeV, |η|< 2.4) with invariant mass in the Z mass window (91 ± 20 GeV)
  - At least 3 jets (p_T > 30 GeV, |η|< 3.0)





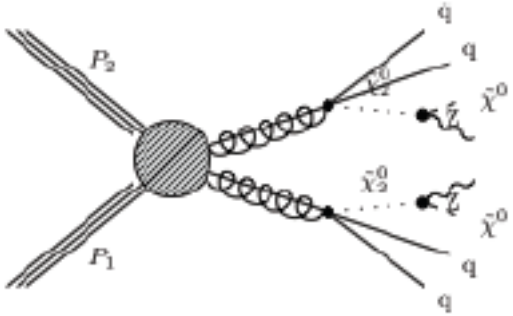
CMS: OS 2l in Z window

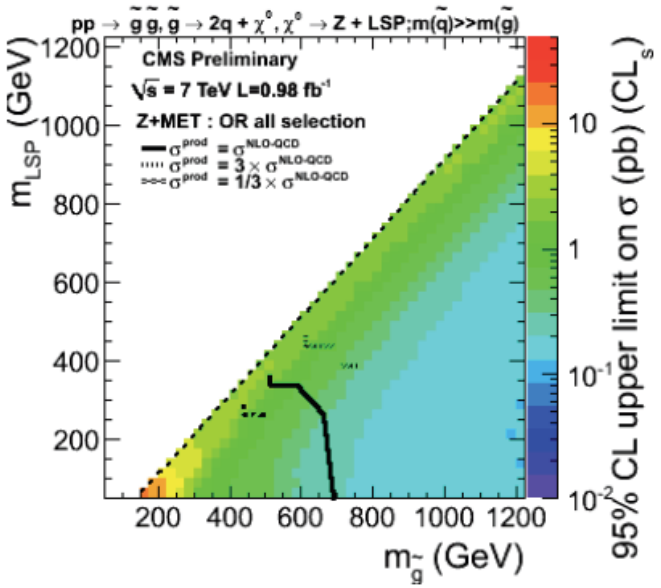
- Alternative: use MET templates from photon + jet samples



	Loose	Tight
	$E_T^{miss} > 100$ GeV	$E_T^{miss} > 200$ GeV
Z Pred	$5.1 \pm 1.0 \pm 0.8$	$0.09 \pm 0.04 \pm 0.01$
$t\bar{t}$ Pred	$50.6 \pm 2.8 \pm 4.6$	$3.2 \pm 0.7 \pm 0.3$
Prediction	$55.7 \pm 3.0 \pm 4.6$	$3.3 \pm 0.7 \pm 0.3$
Data	57 (25,32)	4 (1,3)
UL	20	5.9
LM4	20.1 ± 1.7	12.3 ± 1.7
LM8	8.7 ± 0.8	5.0 ± 0.7

Interpretation:





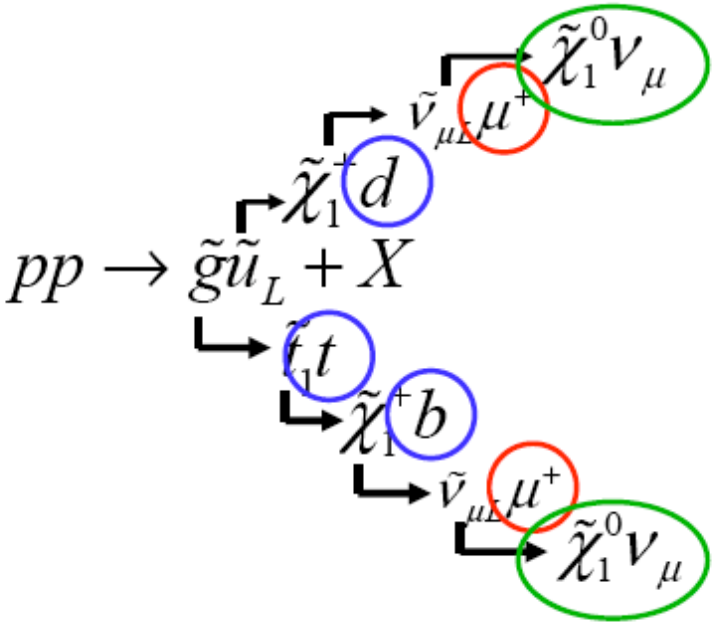
Same-sign di-leptons

1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton

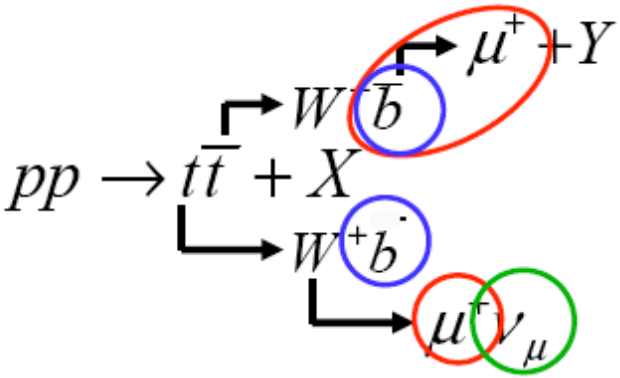
- Almost SM background free (apart from fakes)
- In SUSY, expect significant production through charginos in gluino cascades

Same-sign dileptons

Signal:



Background:

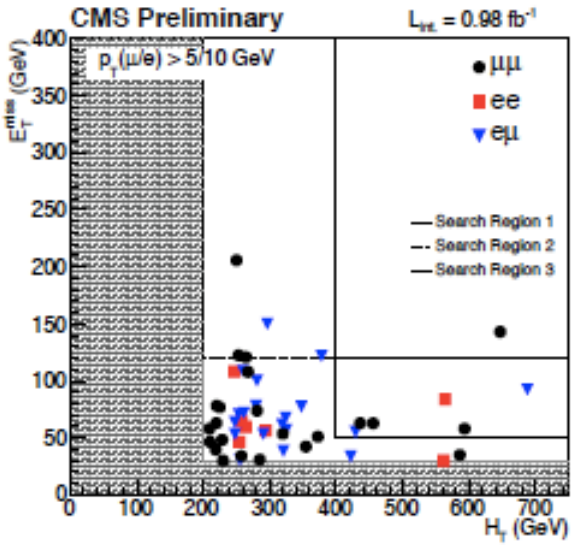


→ require well-isolated leptons

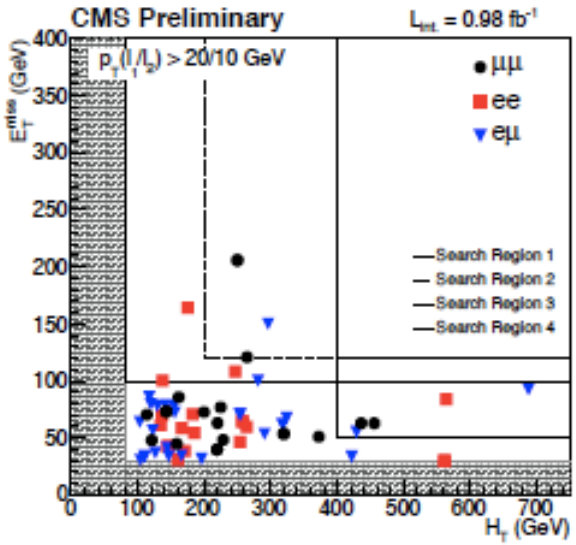
CMS: Same-sign selection

- Require 2 well-isolated same-sign leptons
- search in various HT/MET search regions:

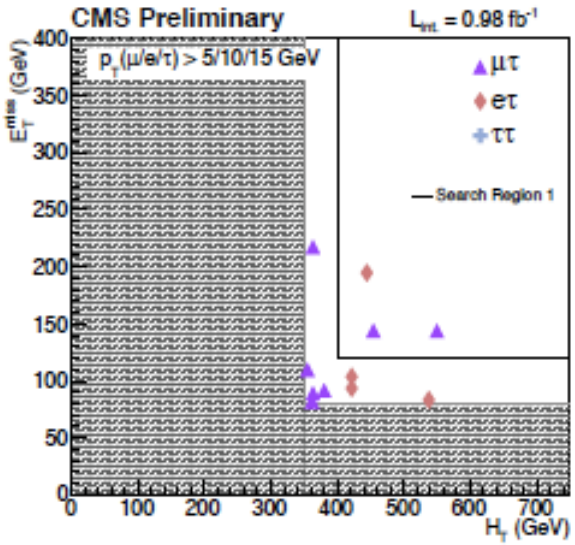
Inclusive dileptons



High Pt dileptons



Tau dileptons



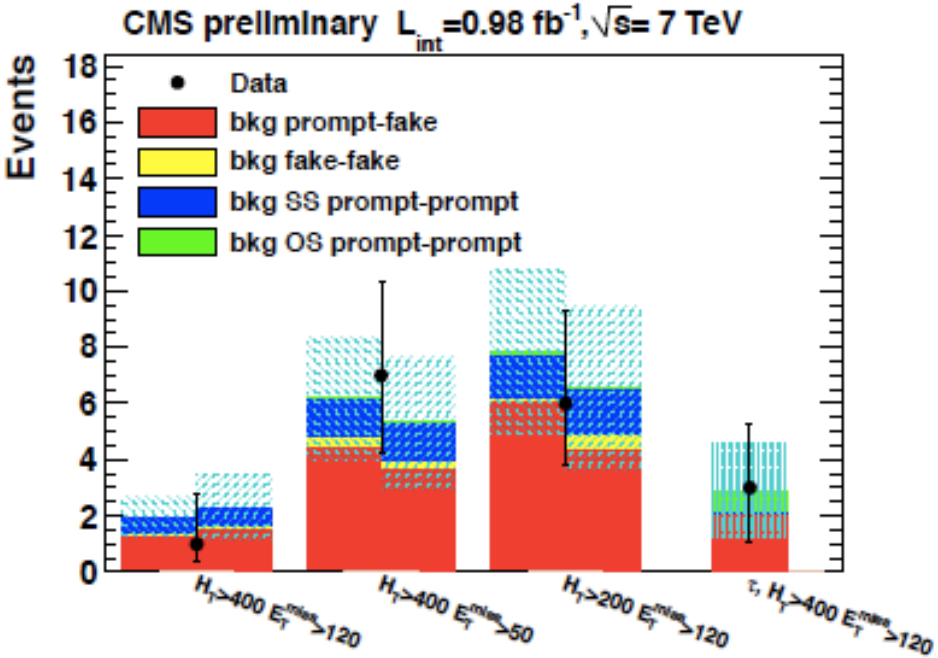
→ Main background = fakes → use data-driven methods:

- various tight-to-loose lepton probability methods
- b-tag and probe for ttbar / factorization for QCD

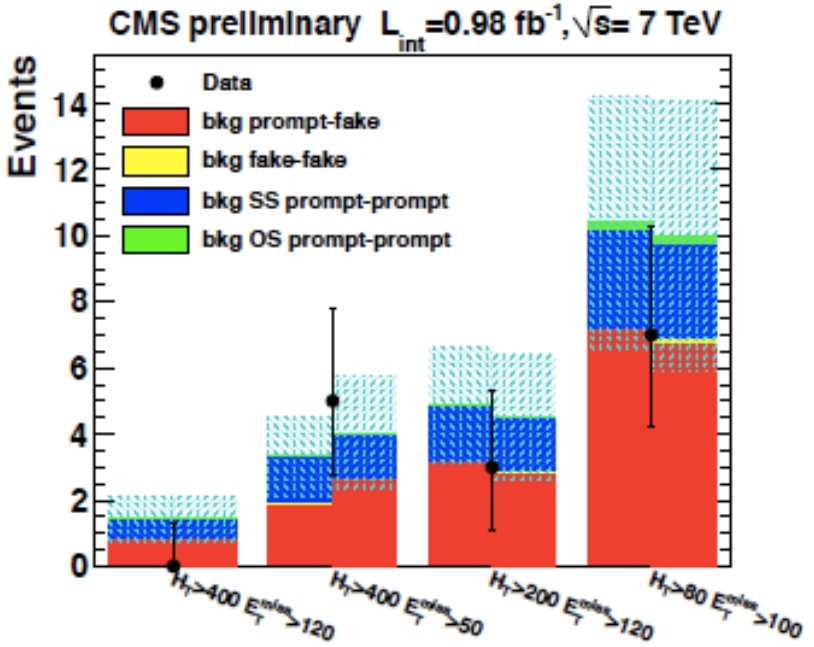
Same-sign results

Counting experiment in the various search regions:

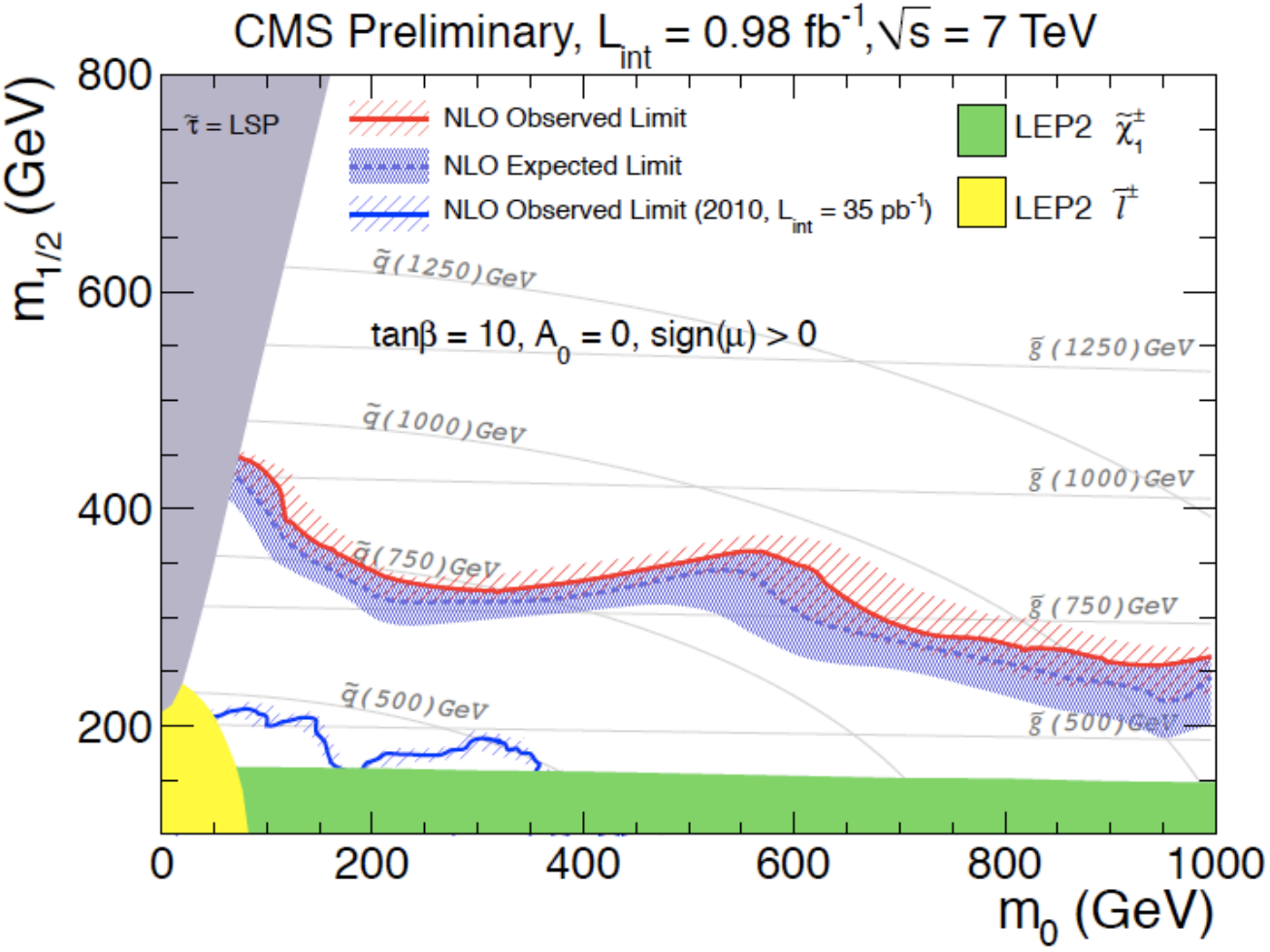
Inclusive and tau dileptons



High Pt dileptons

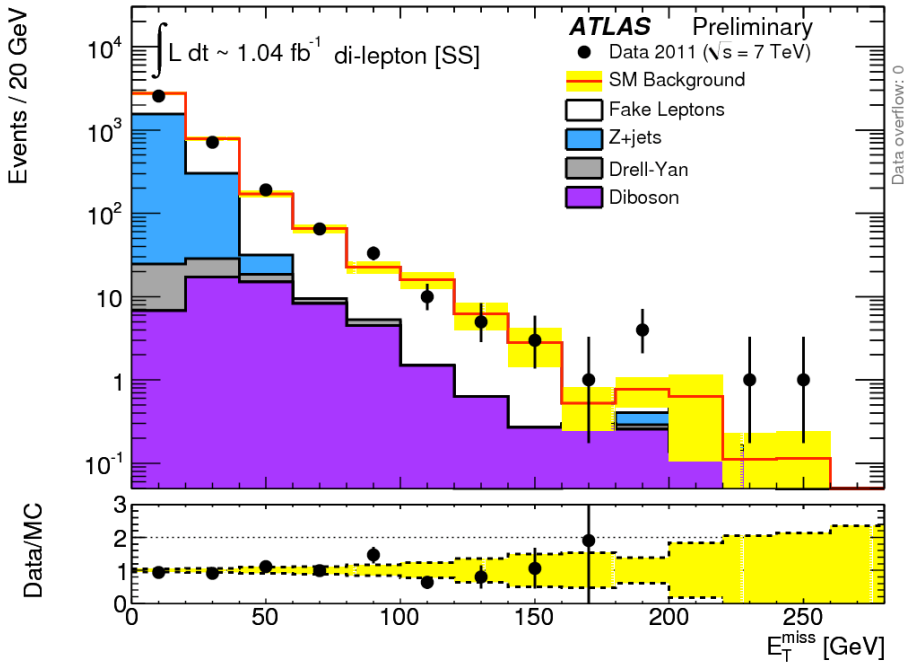


CMS SS 2l : results

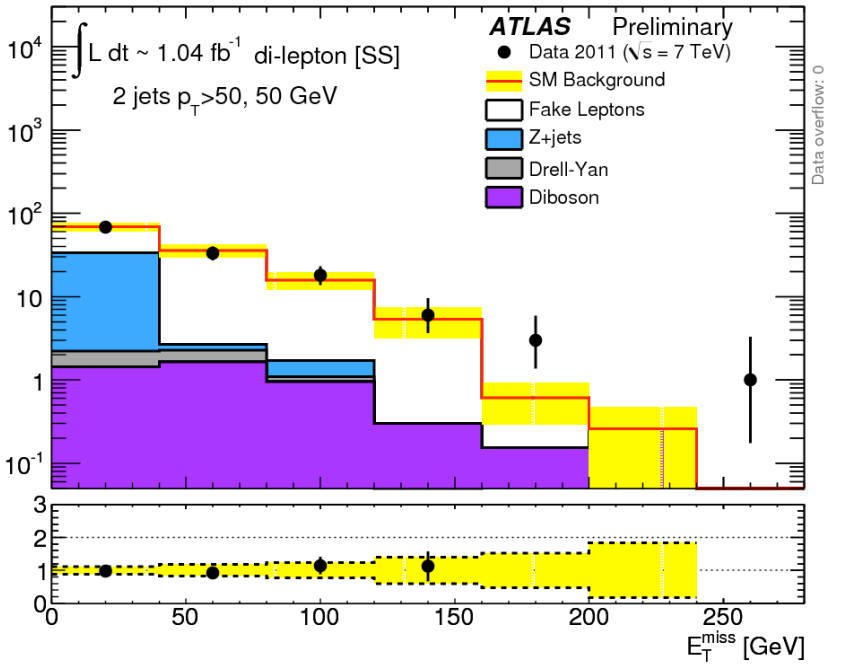


ATLAS: SS results

MET > 100 GeV



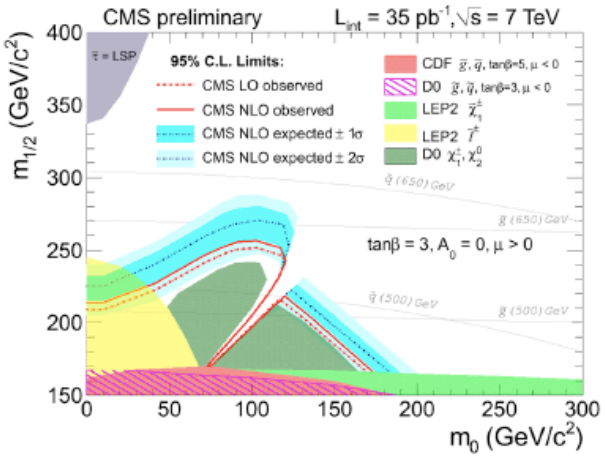
MET > 80 GeV, 2j > 50 GeV

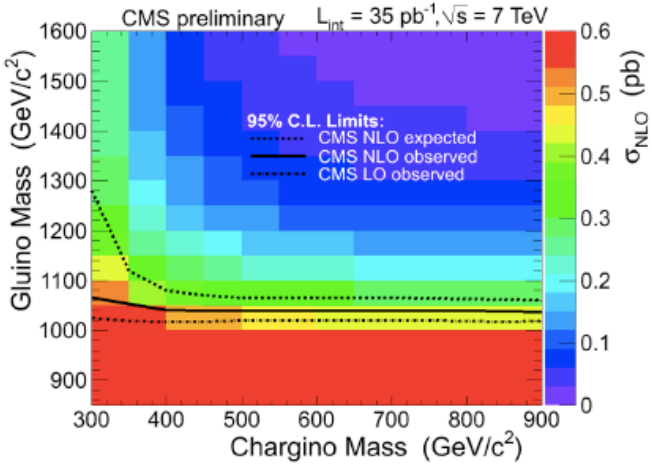


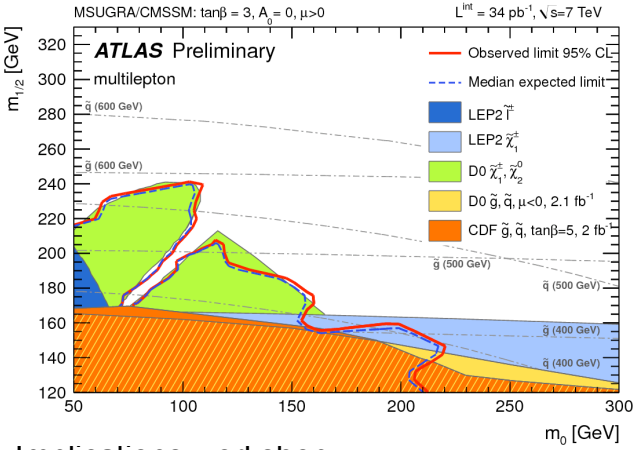
	Background	Obs.	95% C.L.
SS-SR1	$32.6 \pm 4.4 \pm 4.4$	25	10.2 fb
SS-SR2	$24.9 \pm 4.1 \pm 6.6$	28	20.3 fb

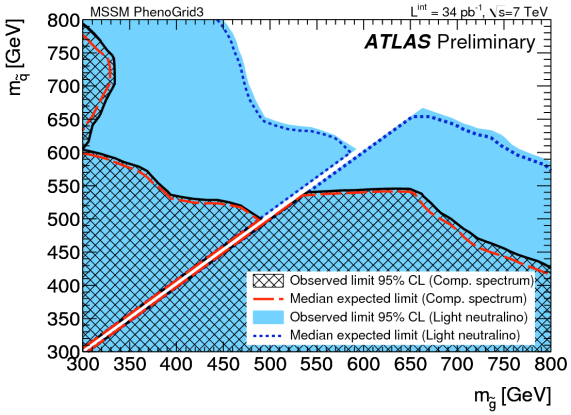
Other leptonic analyses

Multi-lepton (3 and more) analyses in CMS and ALTAS currently being updated to 1 fb^{-1}

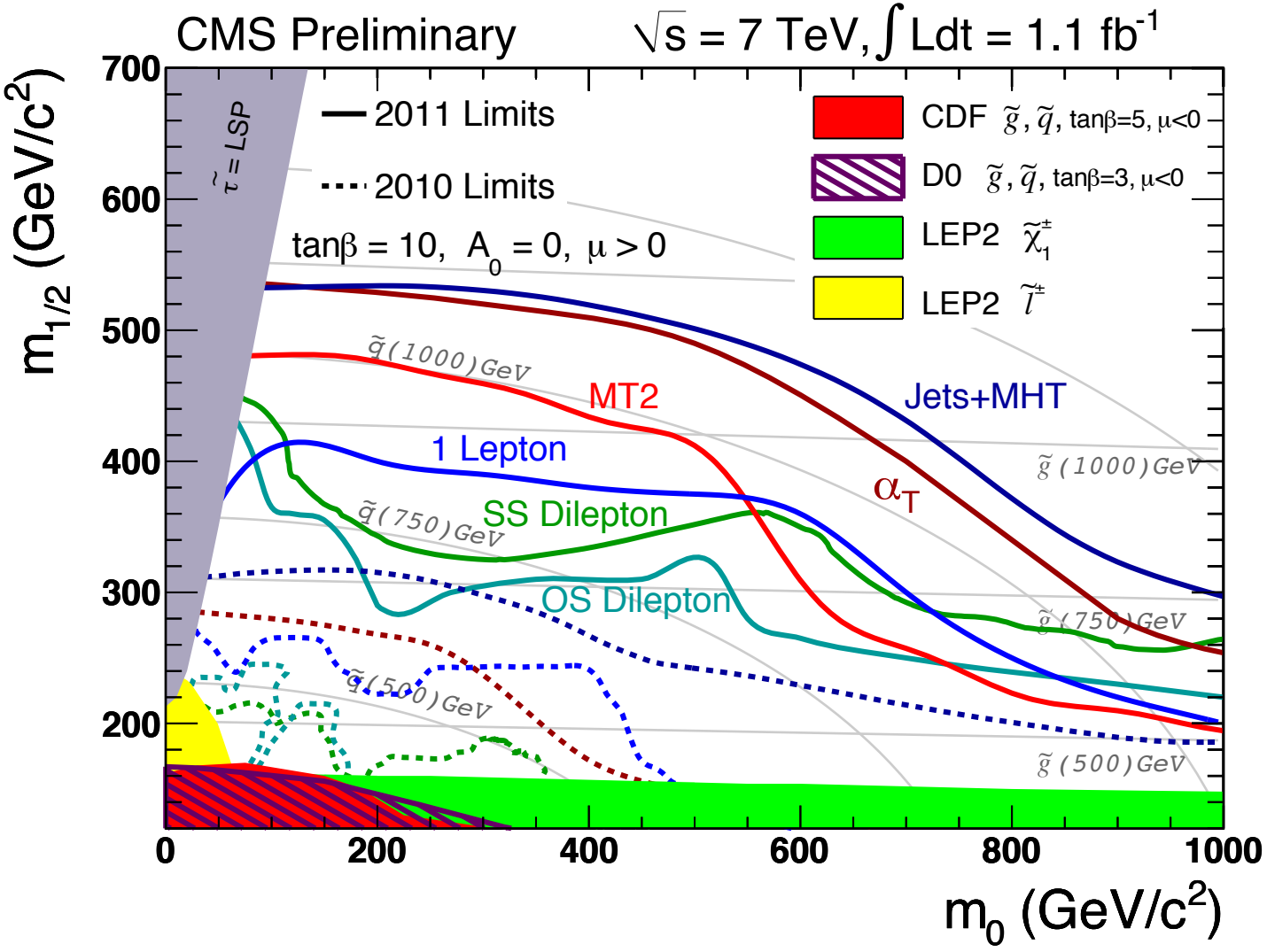






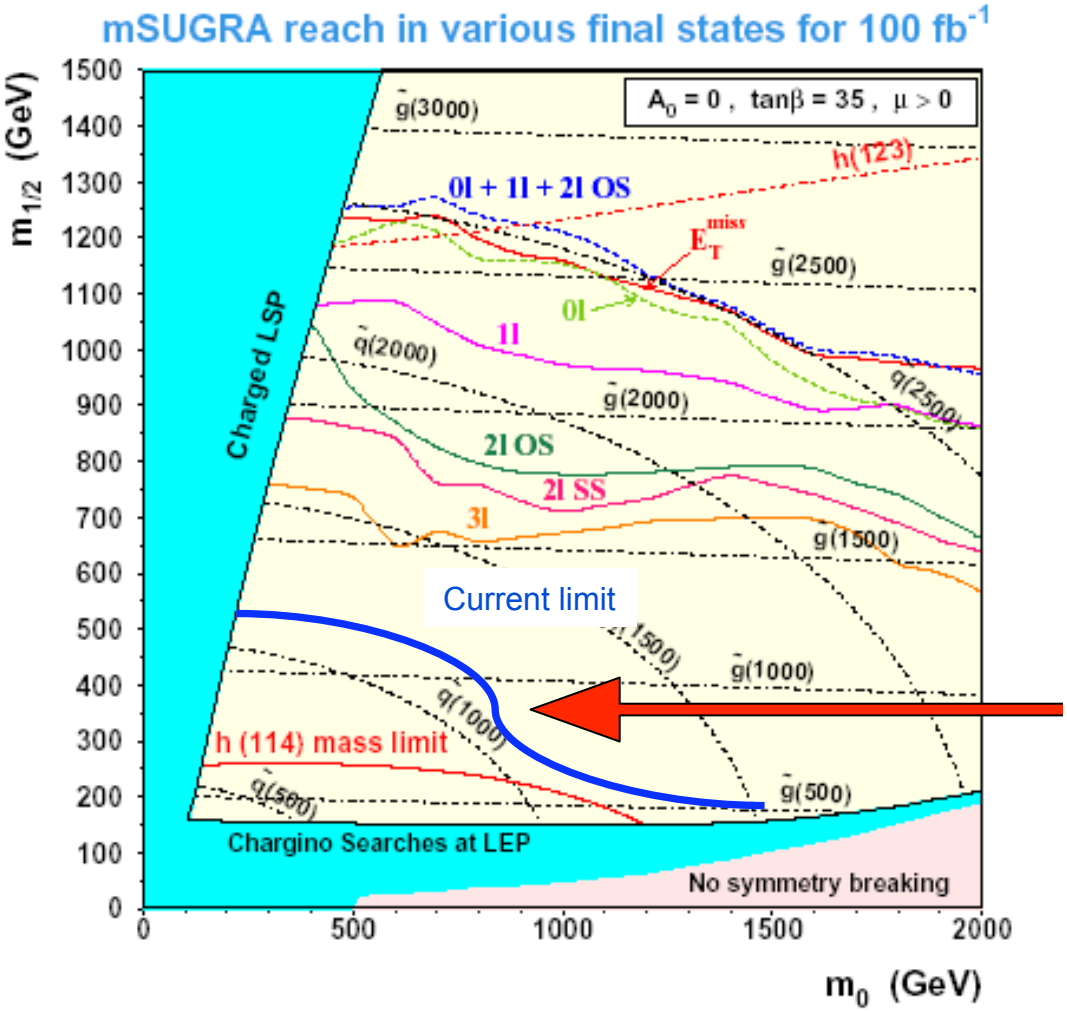


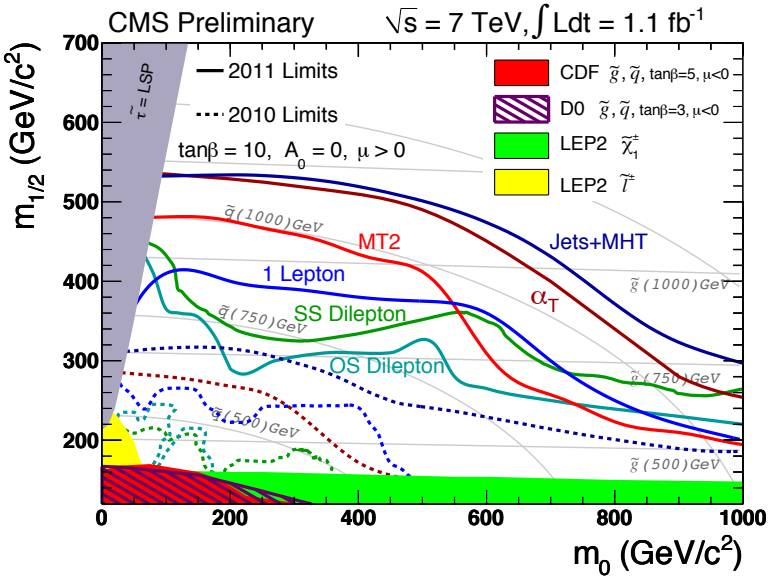
CMSSM summary in CMS



Outlook

Where we need to go: LHC @ 14 TeV





Conclusion

- LHC, ATLAS and CMS performed beautifully in 2011
- Many new 1 fb^{-1} results in leptonic SUSY
  - No evidence for new physics found so far
  - Exclusion limits have been set – in CMSSM and in Simplified Models
  - Often also cut flow + efficiency model
  - Several analyses (and interpretation plots) still in the pipeline
- Much more data already collected in 2011
  - If all goes well, expect 5 fb^{-1} or more by end of the year
- Don't believe the BBC ;-)
  - Rather: keep searching for new physics in a model-independent way (i.e. based on topologies)

Backup

mSUGRA and LM test points

ETH Institute for Particle Physics

Intermezzo:

mSUGRA / cMSSM

reduces MSSM parameter space by assuming at GUT scale:

- universal scalar masses
- universal gaugino masses
- universal tri-linear couplings

resulting in 5 free parameters :

m_0 , $m_{1/2}$, A_0 , $\tan\beta$, sign(μ)