Searches for gaugino production with the ATLAS detector

SEARCH 2012 – University of Maryland, USA

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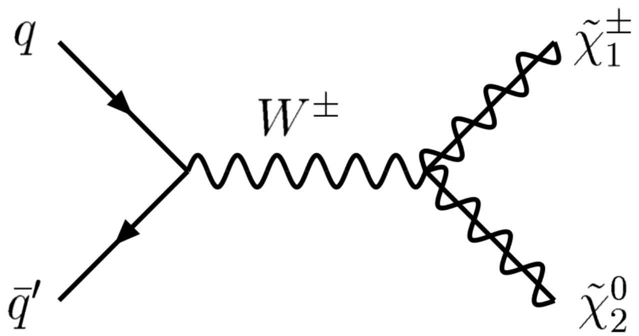
on behalf of the ATLAS Collaboration

Gaugino Production Signals In this Talk

Signal Region	#lept.	Eg. of possible gaugino signals
2 photon + E_T^{miss}	N/A	$\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
2-lepton OS and SS	=2	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow (l^\pm v \tilde{\chi}_1^0) + (l^\mp v \tilde{\chi}_1^0)$ $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow (l^+ l^- \tilde{\chi}_1^0) + (l^\pm v \tilde{\chi}_1^0)$ with one non-reconstructed lepton
3-lepton	=3	$\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow (l^+ l^- \tilde{\chi}_1^0) + (l^\pm v \tilde{\chi}_1^0)$
4 -lepton	≥4	$\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow (l^\pm l^\mp \tilde{\chi}_1^0) + (l^\pm l^\mp \tilde{\chi}_1^0)$



$\Rightarrow$ R-parity conserving scenarios

$\Rightarrow$ Two, Three and Four lepton analyses.

Gaugino decays can proceed via:
virtual or on-shell sleptons, Z*, W*

$\Rightarrow$ Signal regions with and w/o Z-veto

2 Photon + E_T^{miss} Analysis L=1 fb^{-1}

Accepted PLB
arXiv:1111.4116

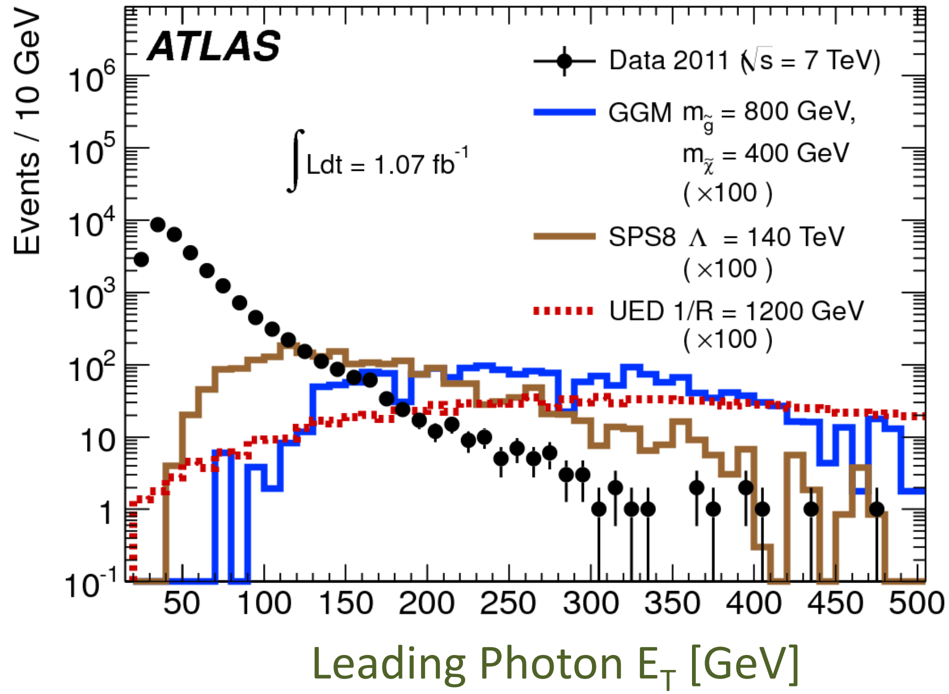
GMSB inspired models the **LSP** is gravitino $\tilde{G}$

If the **NLSP** $\tilde{\chi}_1^0$ is Bino-like giving $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$

- **Generalised model of gauge mediated** SUSY (GGM) with gluino production

- **Minimal model of GMSB** (SPS8)
  Squark-gluinos are very heavy

  Direct $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ production.



Models with one extra universal extra dimension (UED)

Production of the KK excitations of squarks and gluinos

Cascade decay chains until the Lighest KK Particle is produced: γ^*
If N additional dimensions accessible only to gravity and (4+N)-D Planck scale ~1TeV

$\Rightarrow$ The LKP is unstable $\gamma^* \rightarrow \gamma + G$

2 Photon + E_T^{miss} Selections

Loose photons

Limit on energy in the hadronic layers

Shower *width* in the 2nd ECAL layer

TIght photons

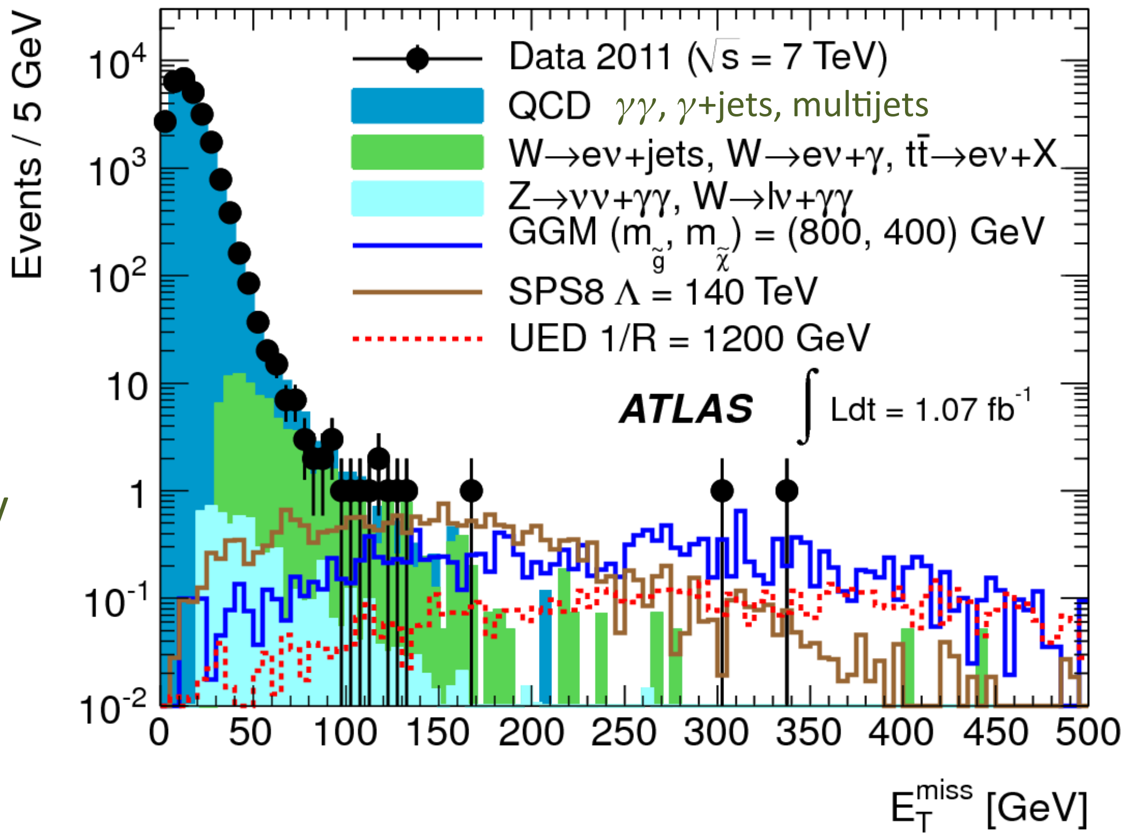
Detailed shower shape, use fine granularity of 1st ECAL layer.

Loose di-photon trigger with E_T>20 GeV

2 tight photons with E_T>25 GeV

Isolated clusters (E_T<5GeV)

Signal Region: E_T^{miss}>125 GeV



Backgrounds

$\gamma\gamma$, γ+jets, multijets

E_T^{miss} template from $\gamma\gamma$ sample with at ≥1 non tight γ or from Z->ee, normalised in E_T^{miss} <20 GeV.

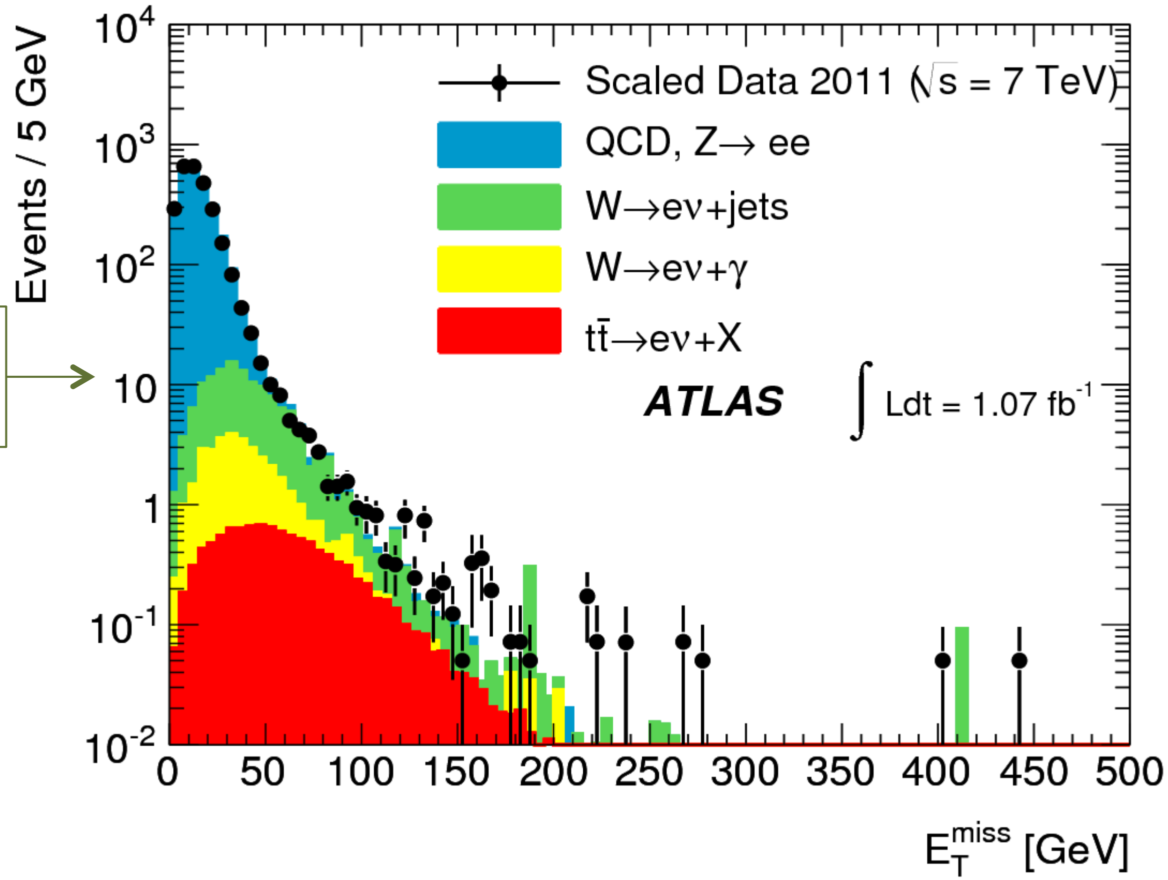
W+X and tt backgrounds

2 Photon + E_T^{miss} Backgrounds

W+X and tt backgrounds

E_T^{miss} template from 1 tight γ + 1 electron
in E_T^{miss} >20 GeV- scale by *Probability for electron to be mis-identified as tight electron*. (5-17% in η bins)

E_T^{miss} template for W+X background with E_T^{miss} from Monte Carlo



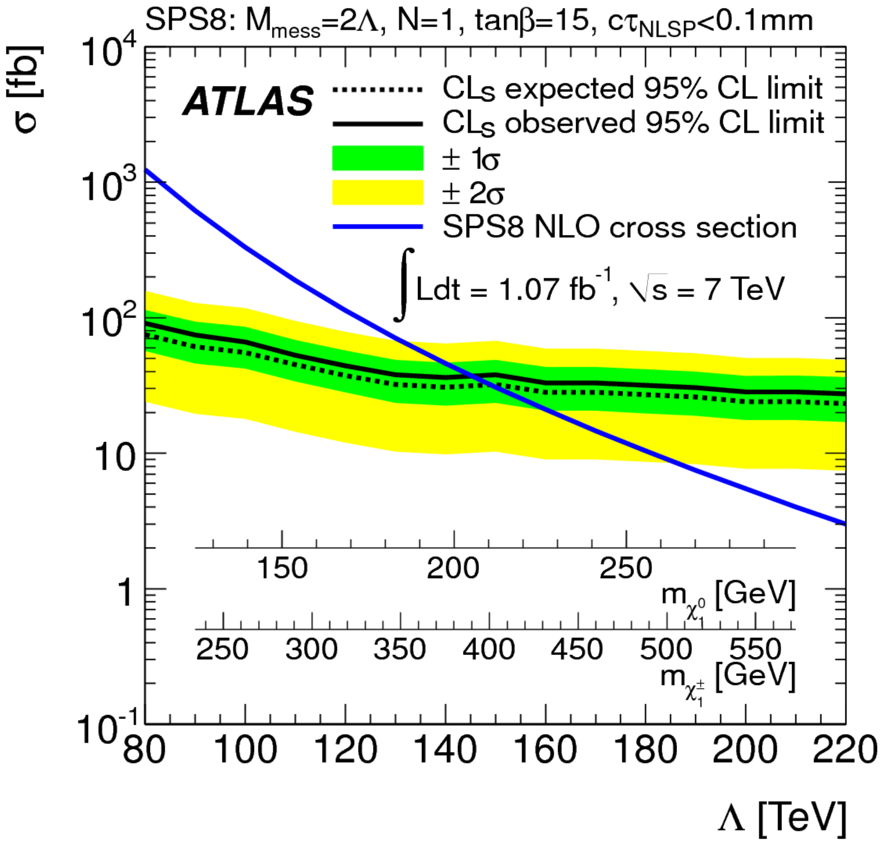
2 Photon + E_T^{miss} Results

5 events observed in signal region

4.1±0.6(stat)±1.6(syst) predicted SM events

uncertainties on the signal prediction

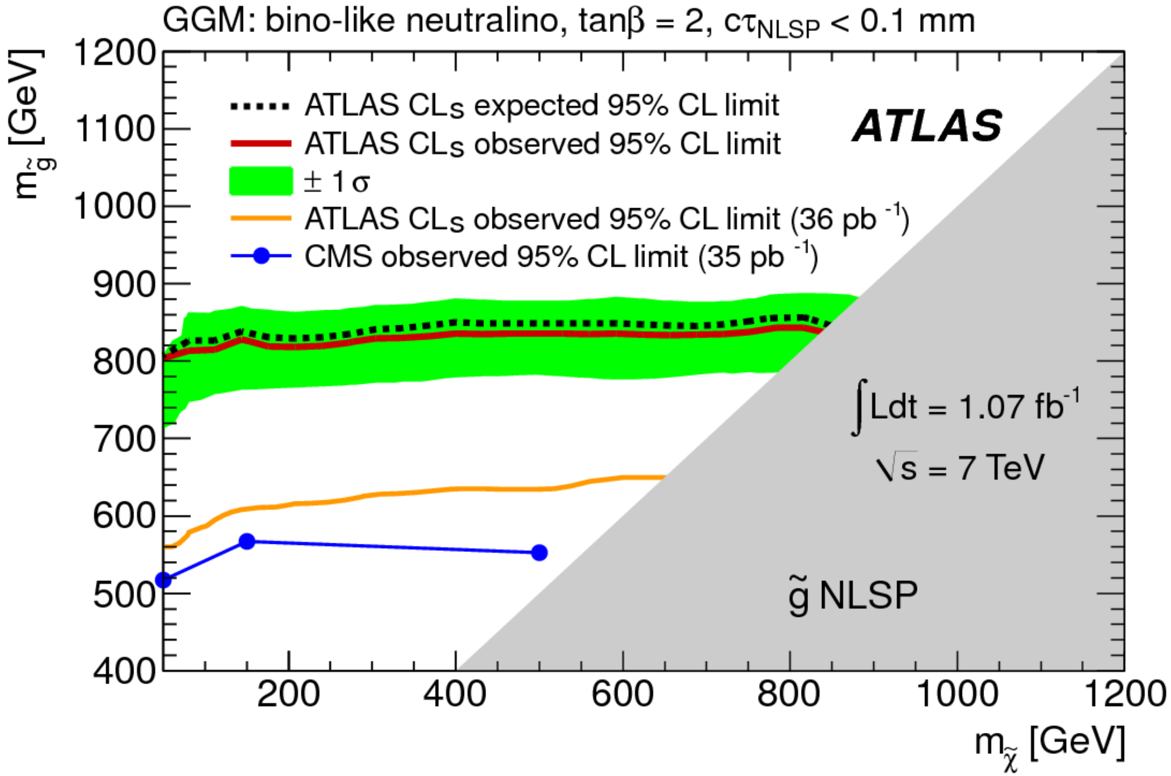
Source of uncertainty	Uncertainty		
	GGM	SPS8	UED
Integrated luminosity	3.7%	3.7%	3.7%
Trigger	0.6%	0.6%	0.6%
Photon identification	3.9%	3.9%	3.7%
Photon isolation	0.6%	0.6%	0.5%
Pile-up	1.3%	1.3%	1.6%
E_T^{miss} reconstruction and scale	1.7%	5.6%	0.7%
LAr readout	1.0%	0.7%	0.4%
Signal MC statistics	2.9%	2.3%	1.8%
Total signal uncertainty	6.6%	8.3%	6.0%
PDF and scale	31%	5.5%	10%*
Total	32%	10%	6.0%



SPS8 limits σ <(27-91) fb for Λ in 220-80 TeV

* calculated with LO PDF (NLO not available for UED)

2 Photon + E_T^{miss} GGM Results



other SUSY sparticles at 1.5 TeV

GGM model limits σ <(22-129) fb

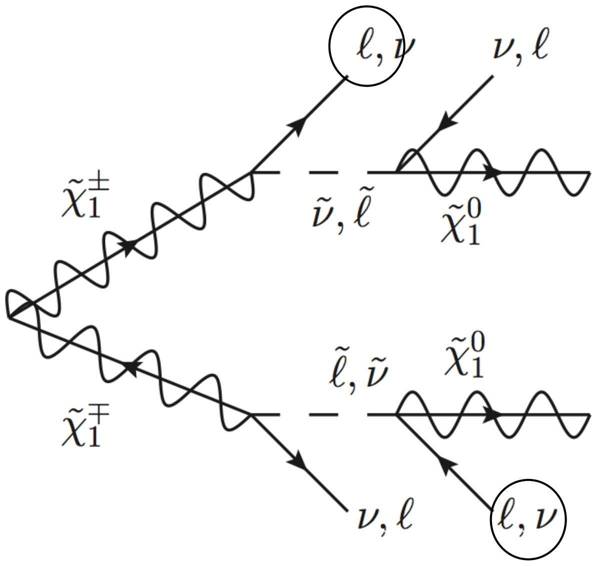
Larger value corresponds to $m_{\tilde{g}}, m_{\tilde{\chi}_1^0} = (400{,}50) GeV$

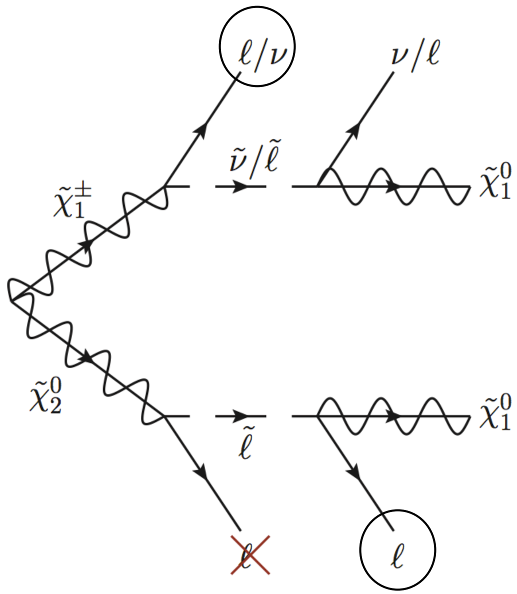
Lower value corresponds to heavy neutralino masses

=2 Lepton Analysis L=1 fb^{-1}

Phys. Lett. B 709 (2012) 137
arXiv:1110.6189v2

possible direct gaugino
2 lepton signals





Potentially OS and SS pairs and same of different flavour
ee, eμ, μμ pairs EXACTLY 2 leptons
M_{ll}>20 GeV

Single electron or muon triggers : **common to all analyses presented in this talk.**
Leading electron p_T>25 GeV, leading muon or 2nd lepton p_T>20 GeV (compability with trigger)

2-Lepton Analysis : Event Selections

In the paper, try to cover as many SUSY models as possible vary

The number of jets

The E_T^{miss} Selection

Flavour subtraction analysis, for SUSY with ee or μμ

Opposite Sign

Same Sign

Signal Region	OS-inc	OS-3j	OS-4j	SS-inc	SS-2j	FS-no Z	FS-2j	FS-inc
E_T^{miss} [GeV]	250	220	100	100	80	80	80	250
Leading jet p_T [GeV]	-	80	100	-	50	-	-	-
Second jet p_T [GeV]	-	40	70	-	50	-	-	-
Third jet p_T [GeV]	-	40	70	-	-	-	-	-
Fourth jet p_T [GeV]	-	-	70	-	-	-	-	-
Number of jets	-	≥ 3	≥ 4	-	≥ 2	-	≥ 2	-
m_{ll} veto [GeV]	-	-	-	-	-	80-100	-	-

OS / SS leptons pairs => Chains with leptons from the same/(or not) side of the event

Jets => Strong SUSY production

No jet selection => Sensitive to gaugino production.

(PLB 709 (2012) 137 has also a GMSB interpretation, cf. ATLAS-CONF-2011-156

https://cdsweb.cern.ch/record/139824)

2 lepton backgrounds

Irreducible (=2 real isolated leptons)

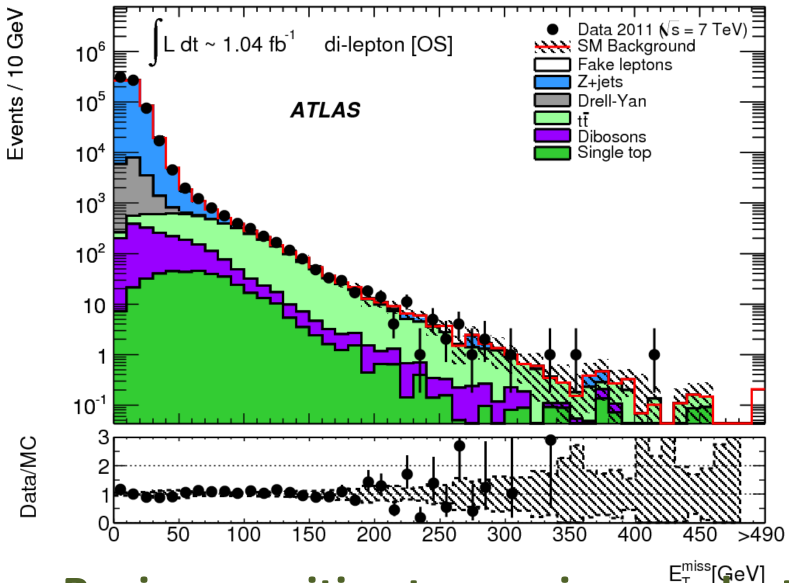
double top	Data driven, **leading background** in OS sample
WW, WZ, ZZ	Monte Carlo derivation NLO cross section
single top	MC NLO cross section
Z/*-> ll + jets	

Reducible backgrounds

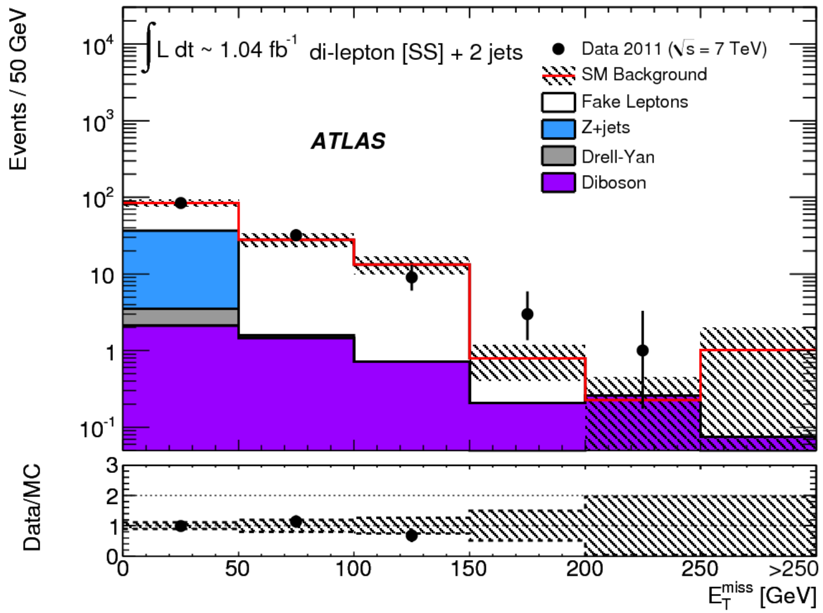
1 or 2 fake leptons from heavy flavor, prompt photons, photon conversions

charge flip in the same sign region,

Opposite Sign No Jet Requirements



Same Sign after Jet Requirements

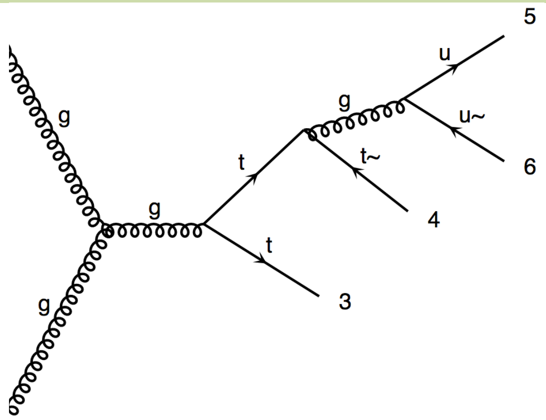


Region sensitive to gaugino production

Data Driven Top Background

Signal region requires E_T^{miss}> 150 GeV (up to 250 GeV) and up to 4 jets

In practice a small fraction of top only passes these extreme cuts.



This is a less well known part of top pair production where

ttbar + 1,2,3,… partons dominates.

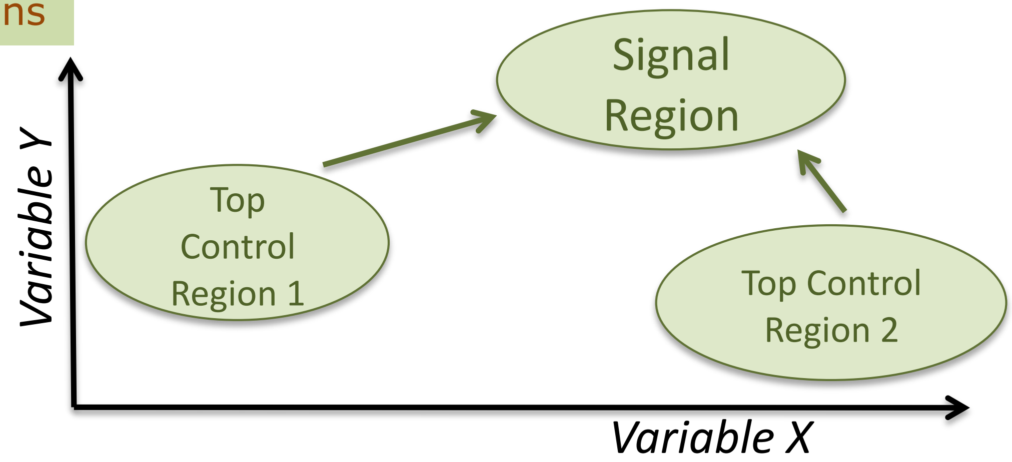
Cannot rely on Monte Carlo until this phase space of top production has been measured.

⇒ Build one or several Control Regions to as close as possible to the signal region

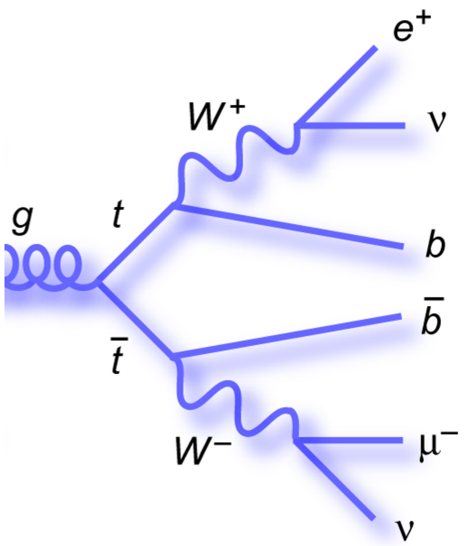
⇒ Extrapolate to the signal region.

⇒ Compare consistency between control regions

$$N^{top}_{prediction} = N^{top}_{CR} \times \left(\frac{N^{top}_{SR}}{N^{top}_{CR}} \right)_{MC}$$



Selecting Control Regions with a Top-Tagger



Top Tagger: M_{CT} Tagger

$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [\mathbf{p}_T(v_1) - \mathbf{p}_T(v_2)]^2$$

where v1, v2 are leptons, jets, and jet-lepton combinations

Possess *kinematic end-points* characteristic of top pairs.

Top-tag =
3 M_{CT} variables+ lepton-jet mass are compatible with top

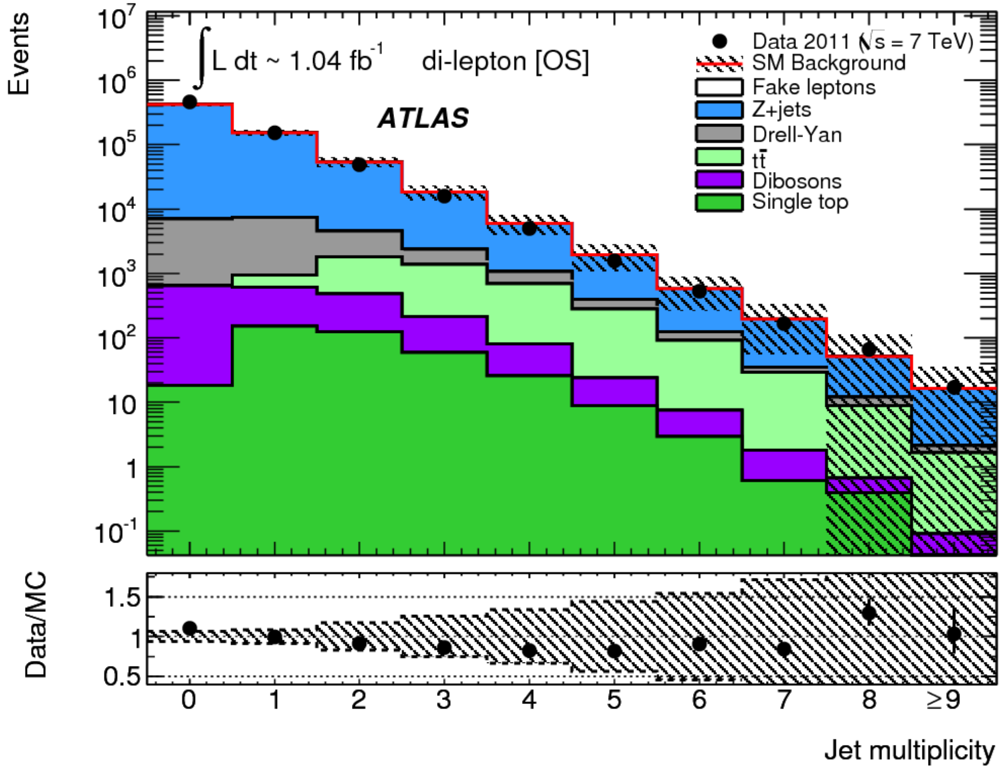
Dominating systematics

from the extrapolation CR->SR.

Optimize the control regions to minimise the expected systematic error.

Same regions give same performance, methods are comparable.

Opposite Sign Dilepton Region



Excellent agreement between the data and the Standard Model prediction.

⇒ Set model independent upper limits on the visible SUSY cross section (Acceptance x efficiency x Branching)

⇒Set model dependent limits in simplified model grids.

Model Independent Limit σ_{eff} with $L=1fb^{-1}$

	Background	Obs.	95% CL
OS-inc	15.5 ± 4.0	13	9.9 fb
OS-3j	13.0 ± 4.0	17	14.4 fb
OS-4j	5.7 ± 3.6	2	6.4 fb
SS-inc	32.6 ± 7.9	25	14.8 fb
SS-2j	24.9 ± 5.9	28	17.7 fb

systematics uncertainties on tt in OS

Signal Region	OS-inc	OS-3j	OS-4j
MC & CR statistics	7%	10%	21%
JES	11%	6%	6%
JER	1%	11%	15%
Generator	16%	13%	58%
ISR/FSR	20%	16%	26%
Total	27%	25%	68%

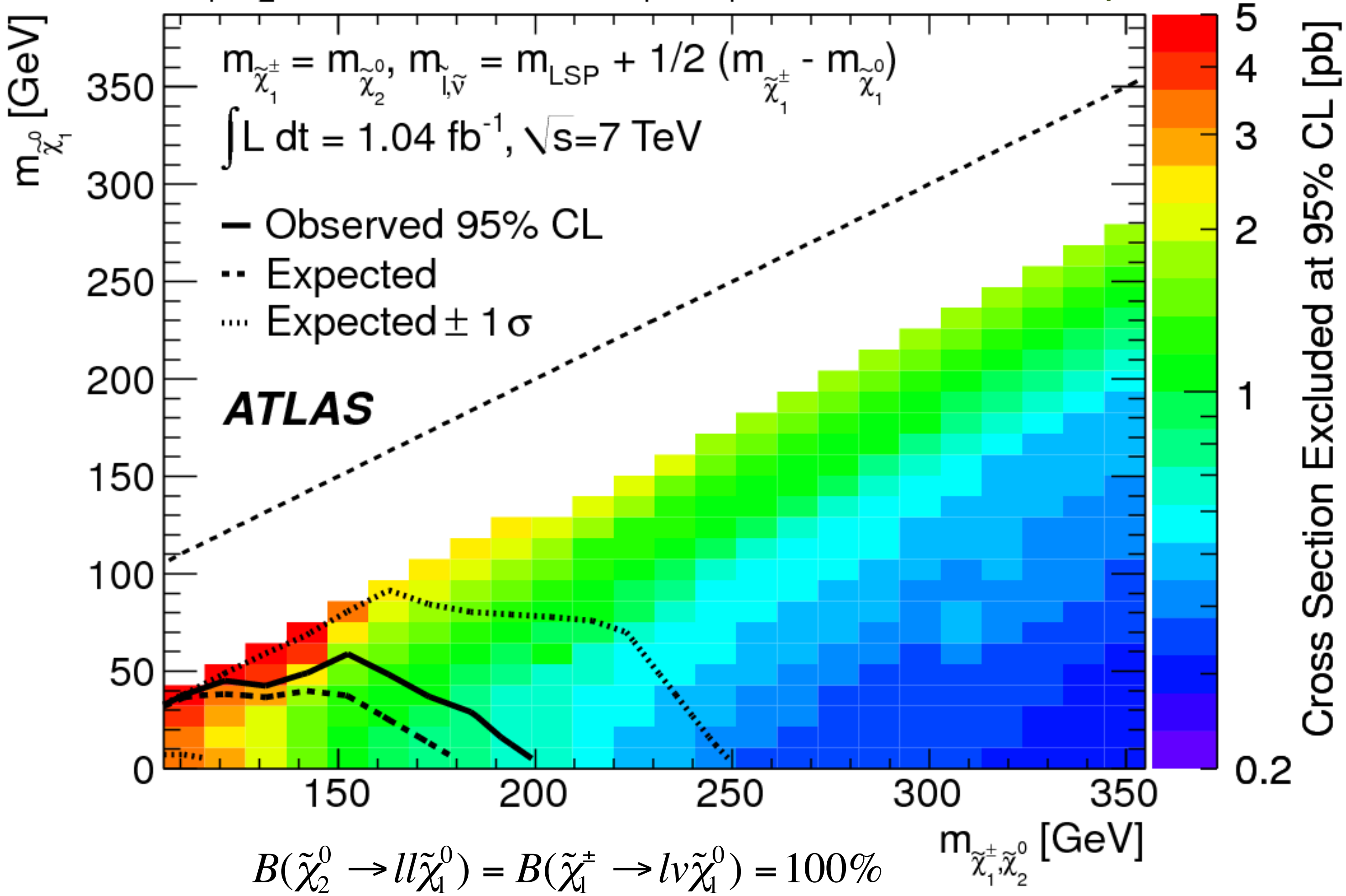
OS: leading systematics JES, JER

SS: leading systematics is lepton fake rate

Simplified Model Interpretation Pure Wino ($L=1fb^{-1}$)

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow \tilde{l}\nu\,\tilde{l}l,\ l\tilde{\nu}\,\tilde{l}l \rightarrow l\nu\,\tilde{\chi}_1^0\,ll\,\tilde{\chi}_1^0$

Same Sign E_T^{miss}>100 GeV

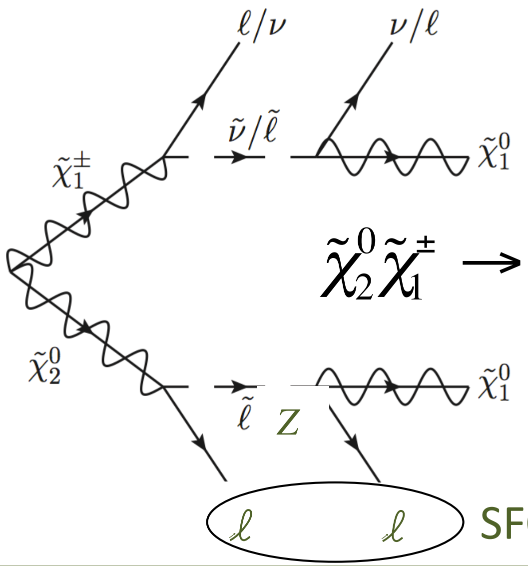


$$B(\tilde{\chi}_2^0 \rightarrow ll\tilde{\chi}_1^0) = B(\tilde{\chi}_1^{\pm} \rightarrow l\nu\tilde{\chi}_1^0) = 100\%$$

Limit on σ_{eff} / A x ε
Color gives limit for the given masses

=3 Lepton Analysis L=2 fb^{-1}

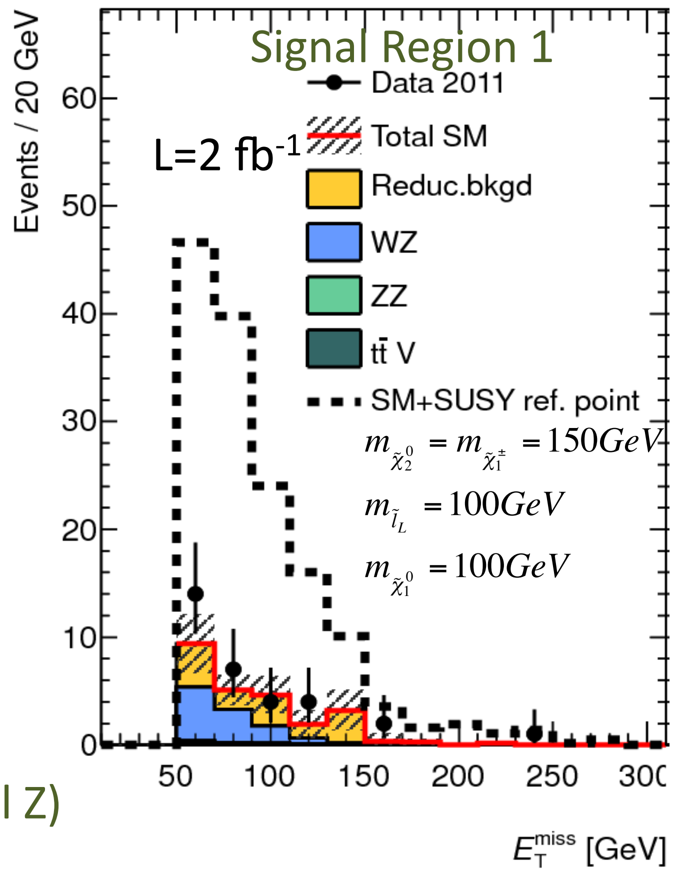
ATLAS-CONF-2012-023
https://cdsweb.cern.ch/record/1430732



$$\tilde{\chi}_2^0\tilde{\chi}_1^{\pm} \rightarrow (l^+l^-\tilde{\chi}_1^0) + (l^{\pm}\nu\tilde{\chi}_1^0)$$

SFOS pair, M_{ll}>20 GeV

Exactly 3 leptons are required



Two signal regions

⇒ ***Z depleted "SR1"*** (sensitive to virtual sleptons, off-shell Z)

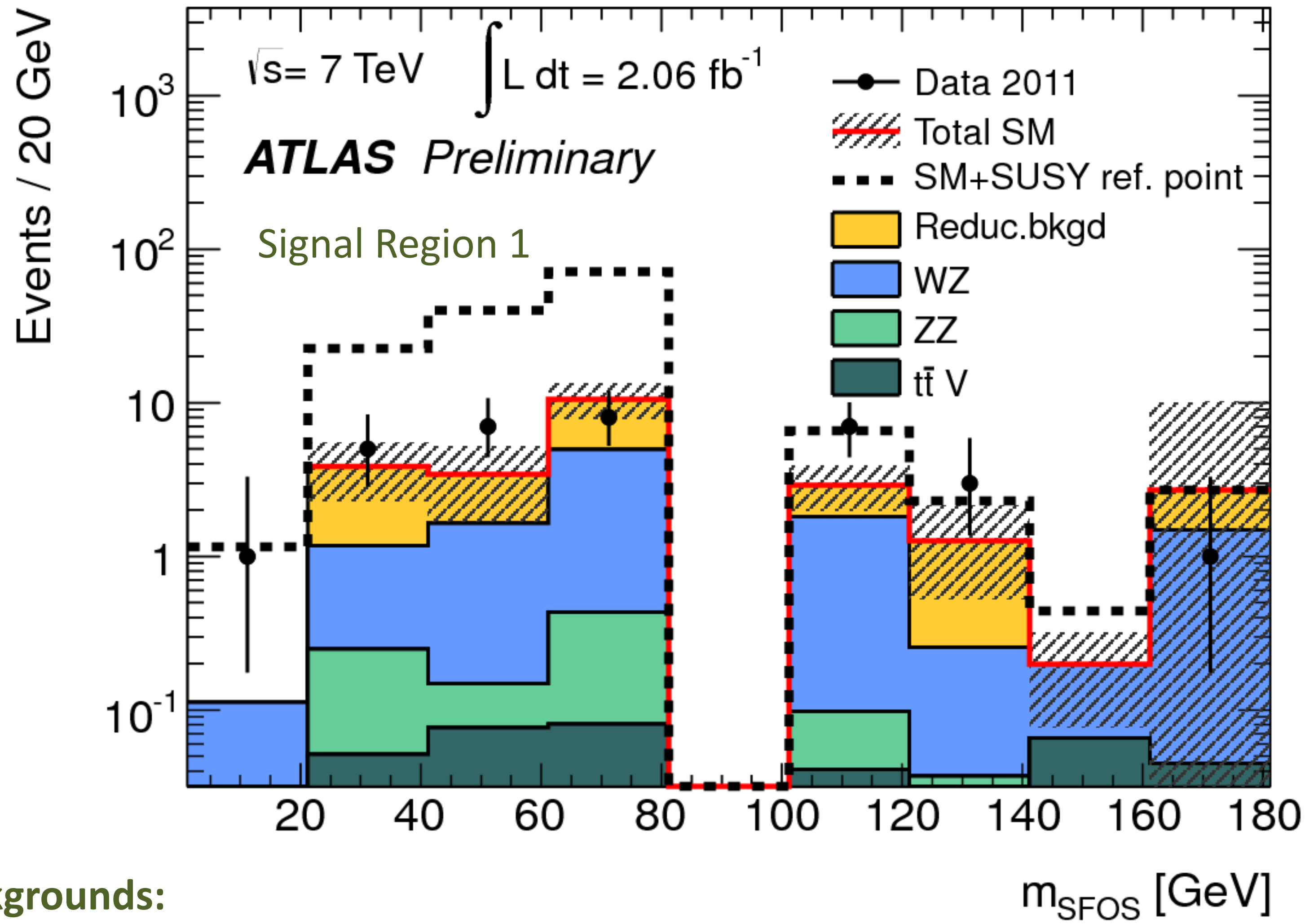
⇒ ***Z enriched "SR2"*** (sentitive to on-shell Z)

SR1= ≥1 SFOS pair (M_{ll}>20 GeV) + E_T^{miss} > 50 GeV + $|M_{ll}-M_Z|$>10 GeV + b-jet veto

SR2= ≥1 SFOS pair (M_{ll}>20 GeV) + E_T^{miss} > 50 GeV + $|M_{ll}-M_Z|$<10 GeV

Leptons are e (p_T>25GeV) or μ (p_T>20 GeV) and are required to be isolated from other activity

Background Composition



Dominated by backgrounds:

- 3 real leptons WW, ZZ, tt+V
- Non negligible component of reducible backgrounds

3 lepton backgrounds

<u>Irreducible (≥3 real isolated leptons)</u>

WZ, ZZ, tt + W, tt + Z

Derived from simulation with cross sections at NLO

<u>Reducible backgrounds (leptons from heavy flavor and isolated photons)</u>

tt (dominant, heavy flavor)

single top, WW

V + jets (<1% of the backgrounds)

In 99% of the reducible background the leading lepton is real and isolated

$\Rightarrow$ Multijet QCD is negligible

Determined by using the data itself (matrix method)

<u>Reducible backgrounds (ℓ->ℓ γ^*->$\ell\mu$)</u>

A virtual photon converts into an asymmetric $\mu\mu$ pair, only one μ *is found*.

Derived from data

<u>Background Validation Regions 1,2</u>

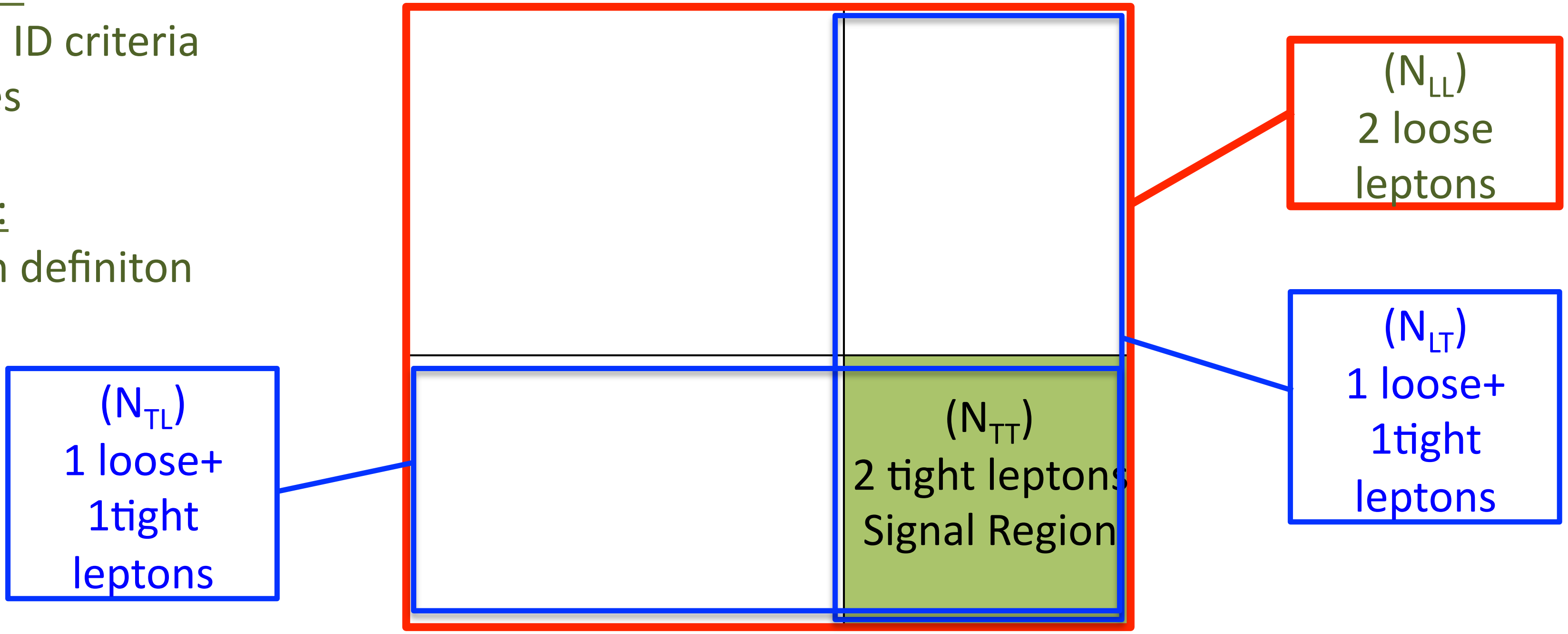
Z dominated: 3 leptons with 30 <E_T^{miss}<50 GeV **VR1**

tt dominated: 3 leptons with SFOS veto, E_T^{miss} > 50 GeV **VR2**

Fake Lepton Estimates: Matrix Method

<u>Loose lepton:</u>
loose lepton ID criteria
⇒more fakes

<u>Tight lepton:</u>
signal lepton definiton
⇒ less fakes



N_{LL}, N_{LT}, N_{TL}, N_{TT} are <u>event counts</u> in the data

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)r_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

f and ε are **probabilities** P(lepton is tight | lepton is loose) for the *fake* and the *real* leptons

- Derive f and ε from data
- Computed for different types of fakes: heavy flavor, conversions

Contribution from $\ell\ell\text{->}\ell\ell\mu$

<u>Reducible backgrounds (ℓ->ℓ γ*->$\ell\mu$)</u>

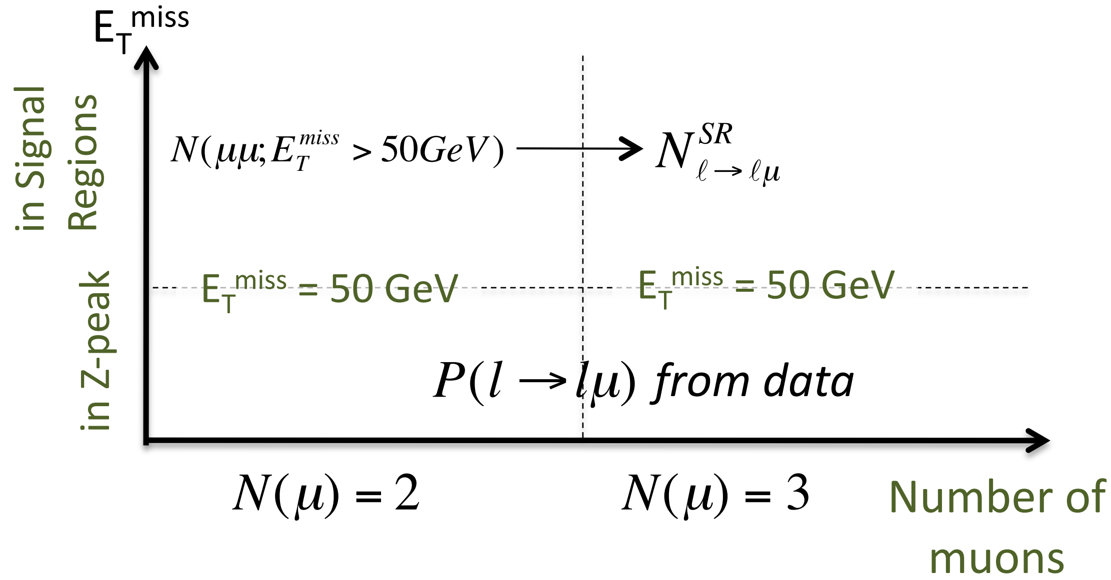
A virtual photon converts into an asymmetric $\mu\mu$ pair, only one μ *is found*.
Probability for this process derived from data and normalised with data

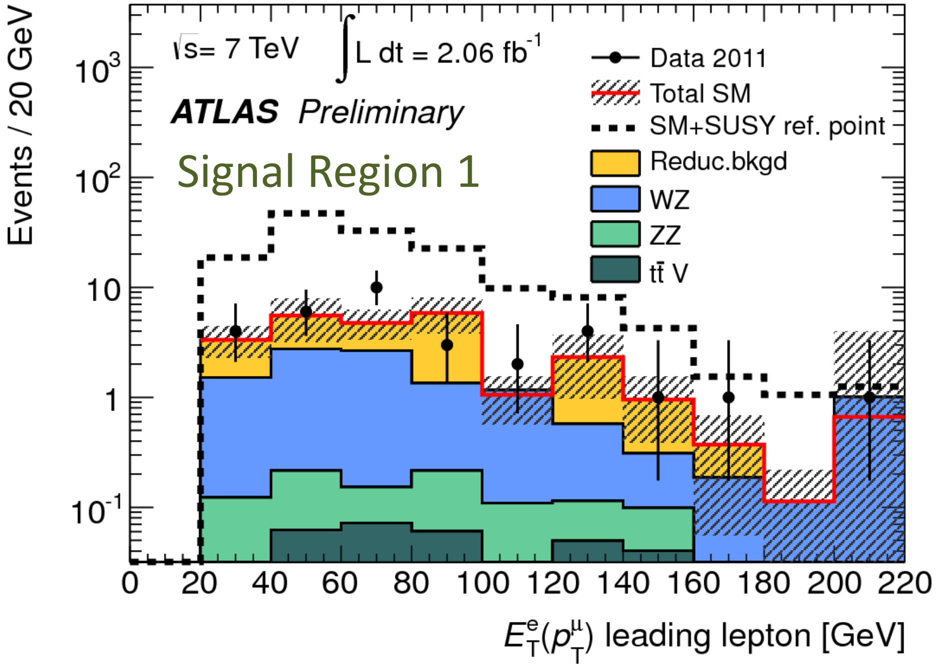
Step 1) In E_T^{miss}< 50 GeV derive:

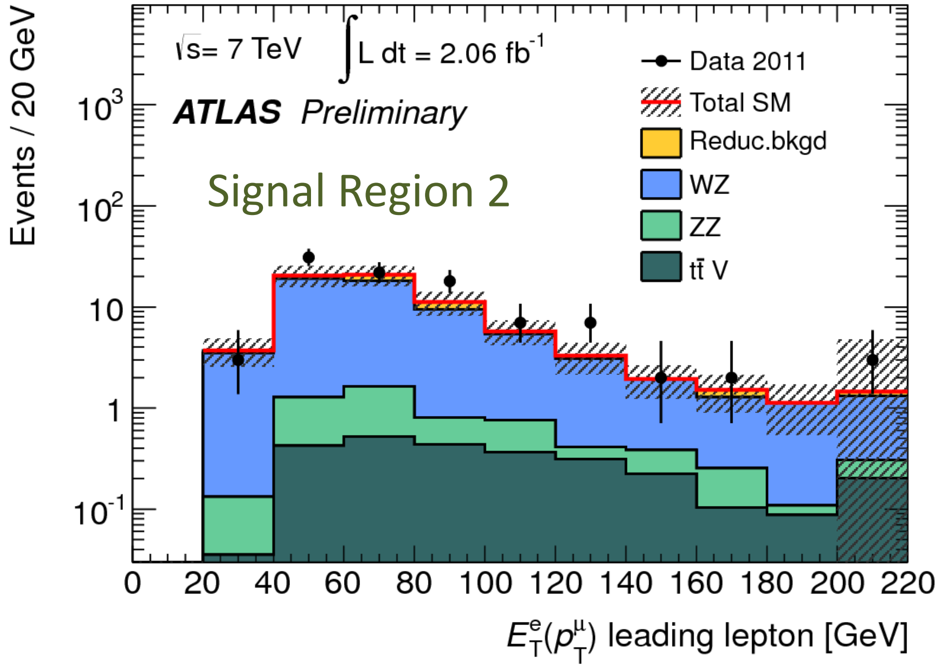
$$P(l \to l\mu) = \frac{N(\mu\mu\mu \,|\, m_{\mu\mu\mu} \sim m_Z)}{N(\mu\mu \,|\, m_{\mu\mu} \sim m_Z)}$$

Step 2) Apply probability in E_T^{miss}>50 GeV:

$$N^{SR}_{\ell \to \ell\mu} = P(l \to l\mu) \times N(\mu\mu; E_T^{miss} > 50 GeV)$$



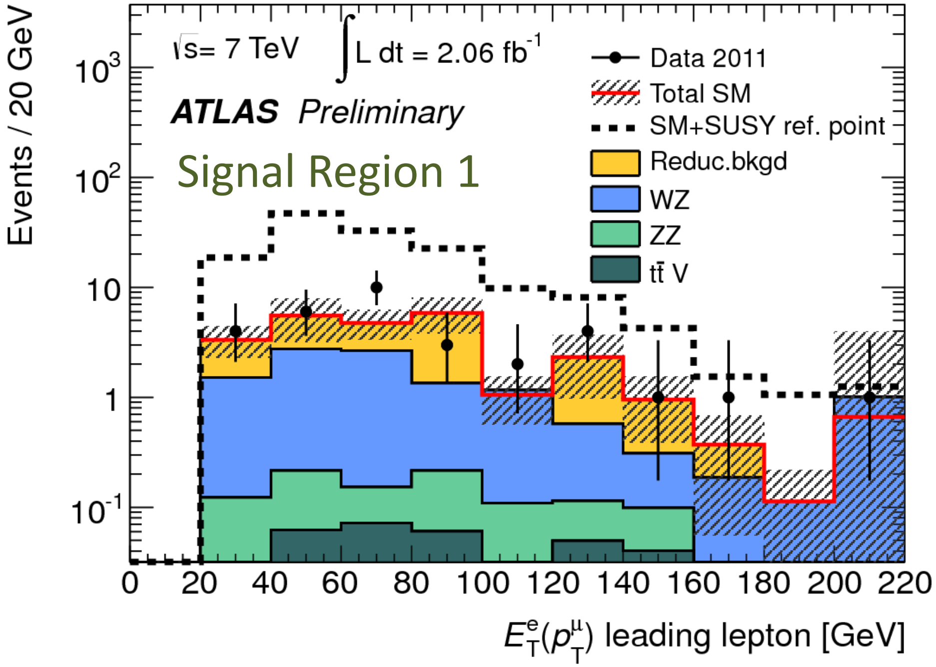


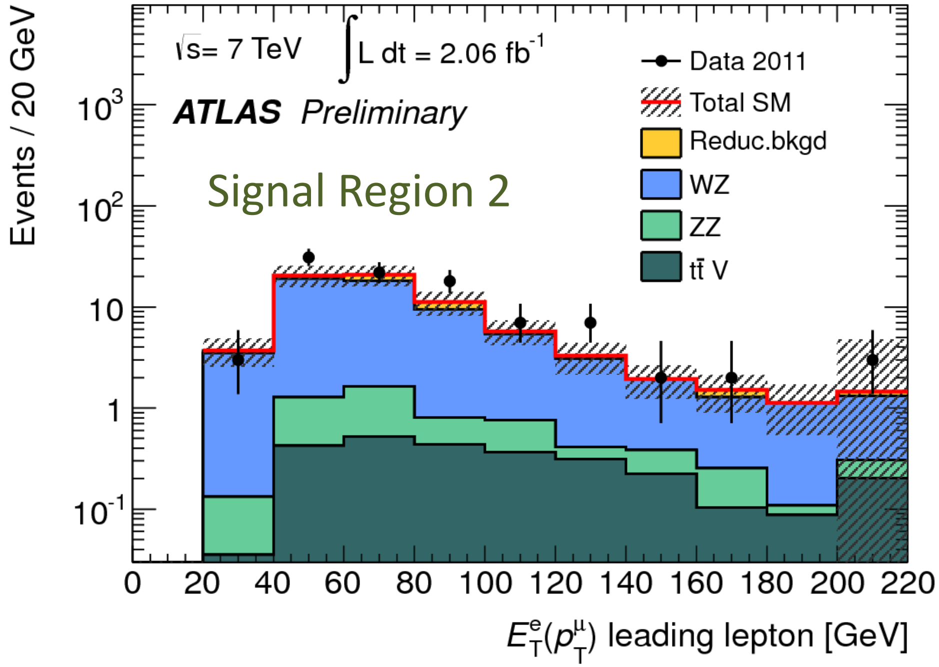


$L=2fb^{-1}$

Selection	VR1	VR2
$t\bar{t}V$	1.4±0.6	0.7±0.6
ZZ	6.7±1.8	0.03±0.04
WZ	61±15	0.4±0.2
Reducible Bkg.	56±35	14±9
Total Bkg.	125±38	15±9
Data	122	12

Good agreement in validation regions





$L=2fb^{-1}$

Selection	VR1	VR2	SR1	SR2
$t\bar{t}V$	1.4±0.6	0.7±0.6	0.4±0.3	2.7±2.1
ZZ	6.7±1.8	0.03±0.04	0.7±0.2	3.4±0.9
WZ	61±15	0.4±0.2	11±3	58±14
Reducible Bkg.	56±35	14±9	14±4	7.5±3.9
Total Bkg.	125±38	15±9	26±5	72±15
Data	122	12	32	95

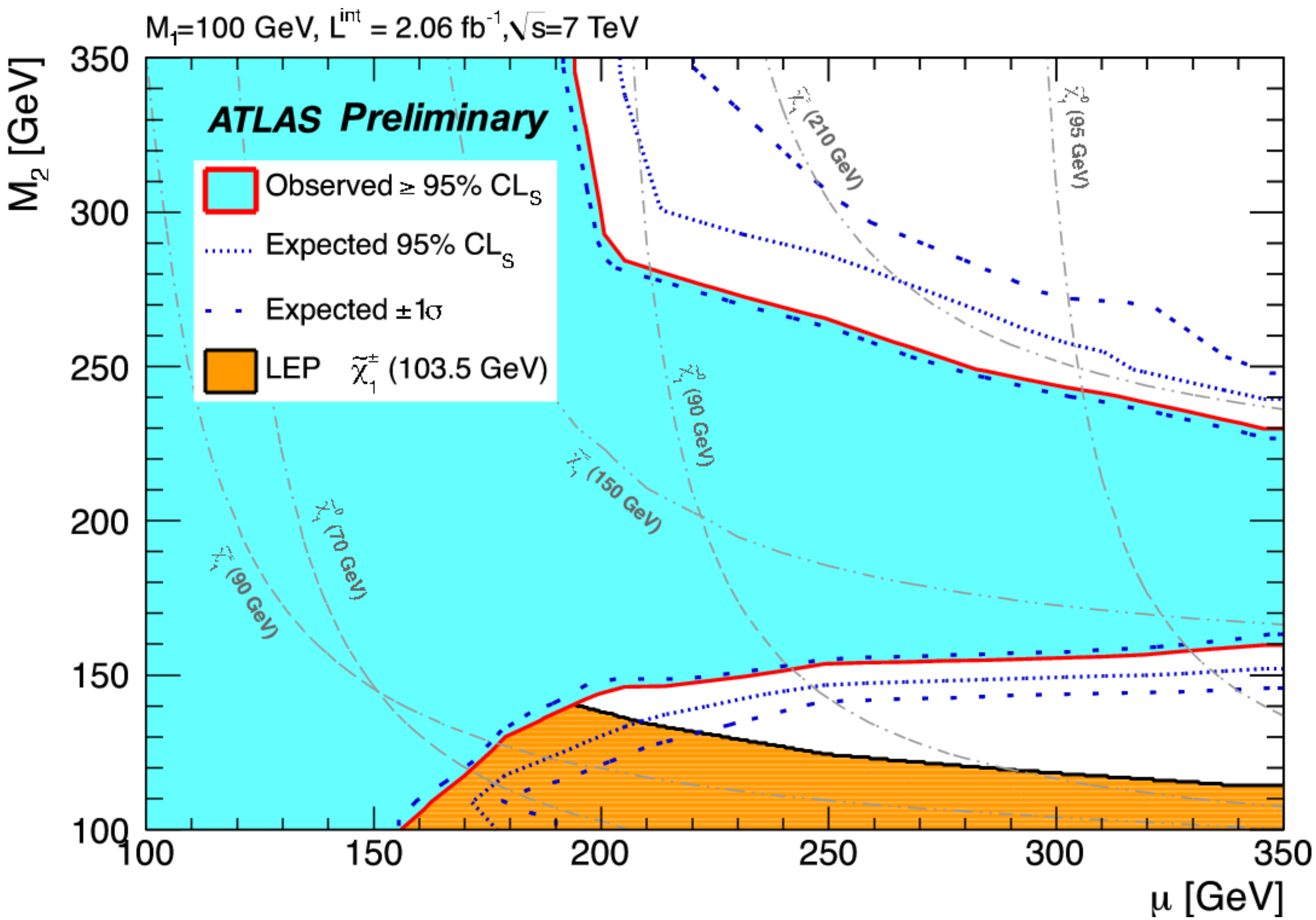
Good agreement in validation regions

No discrepancy between the prediction and the **signal regions**
⇒ Set upper limits on the SUSY production

Upper limits on the visible SUSY cross section
10.0 fb (expected 7.3fb) in signal region 1 p-value 0.19
26.1 fb (expected 16.7fb) in signal region 2 p-value 0.10

3 Lepton Results with pMSSM

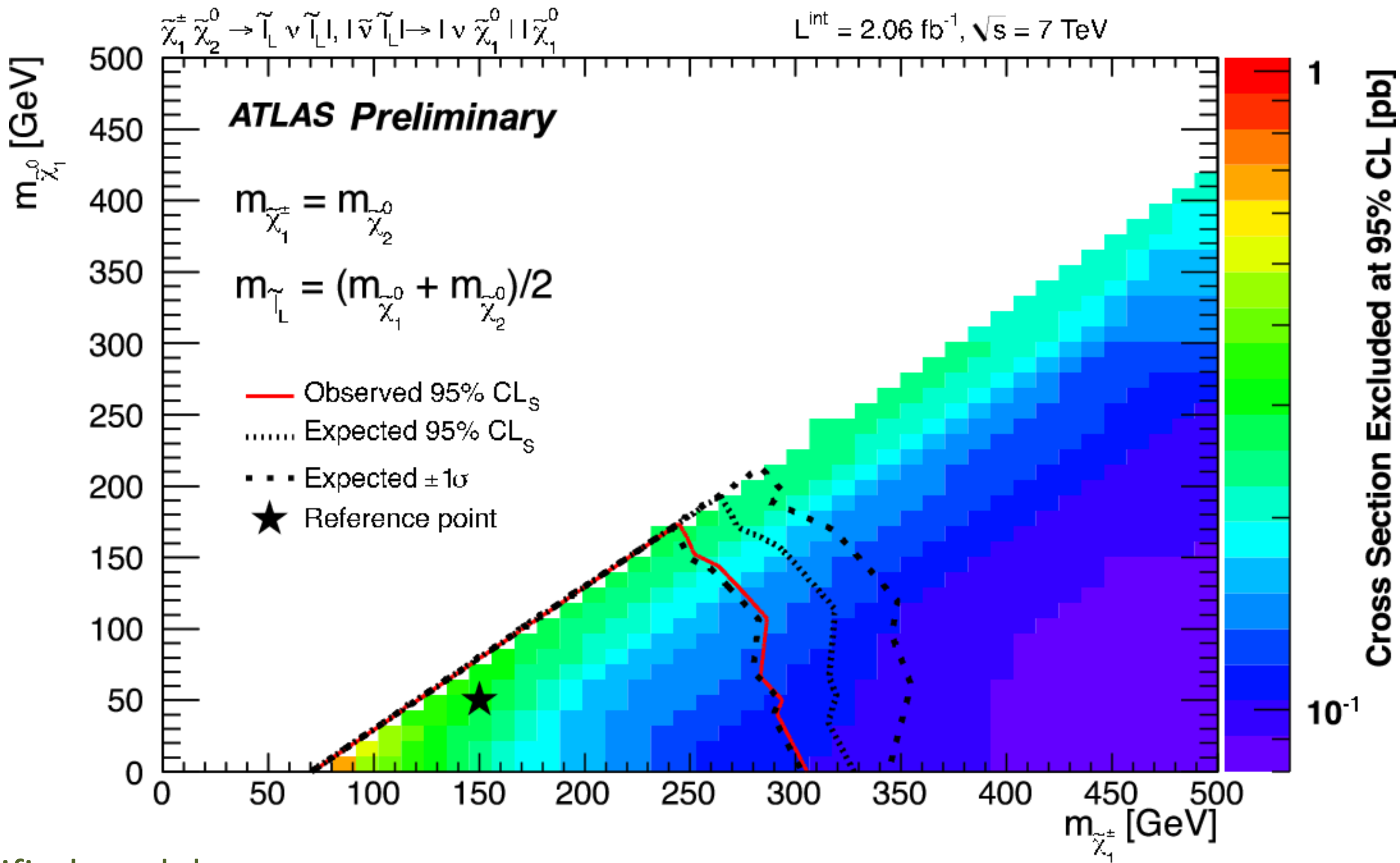
Based on SR1
(Z-veto)



Limits in pMSSM
tan (β)=6
heavy gluinos, squarks and heavy left handed sleptons
right handed sleptons half way between $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$

3 Lepton Results with Simplified Models

Based on SR1
(Z-veto)



Limits in simplified models

$$B(\tilde{\chi}_2^0 \to \tilde{l}\, l \to l l \tilde{\chi}_1^0) = B(\tilde{\chi}_2^0 \to \tilde{\nu}\nu \to \nu\nu\tilde{\chi}_1^0) = 50\%$$

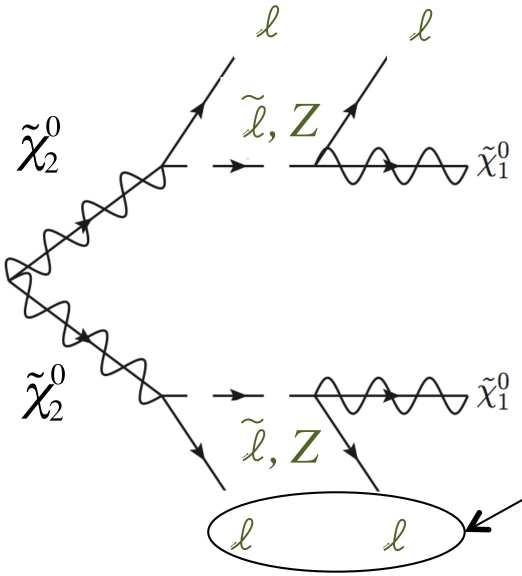
Wino like $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ and Bino like $\tilde{\chi}_1^0$

Limit on σ_{eff} / A x ε
Color gives limit for the given masses

4 Lepton Signal

ATLAS-CONF-2012-001
https://cdsweb.cern.ch/record/1418920

4-lepton



$$\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow (l^{\pm}l^{\mp}\tilde{\chi}_1^0) + (l^{\pm}l^{\mp}\tilde{\chi}_1^0)$$

SFOS pair, M_{ll}>20 GeV

With 4 leptons, acceptance and signal efficiency becomes an issue
⇒ Lower p_T thresholds compared to the 2 and 3 lepton analyses

4 isolated e or μ with p_T>10 GeV (15 GeV for crack region electrons)

Signal Region 1= E_T^{miss} >50 GeV
Signal Region 2= E_T^{miss} >50 GeV + veto on SFOS pairs with $|M_{ll}-M_Z|$<10 GeV

SR2 is sensitive to a range of signals, either sleptons or off-shell Z in the Neutralino 2 or completely different signals eg. RPV SUSY which will not contain Z bosons-

4 lepton backgrounds

Backgrounds with less than 2 real isolated leptons are negligible

Irreducible backgrounds

ZZ-> $\ell\ell\ell\ell$

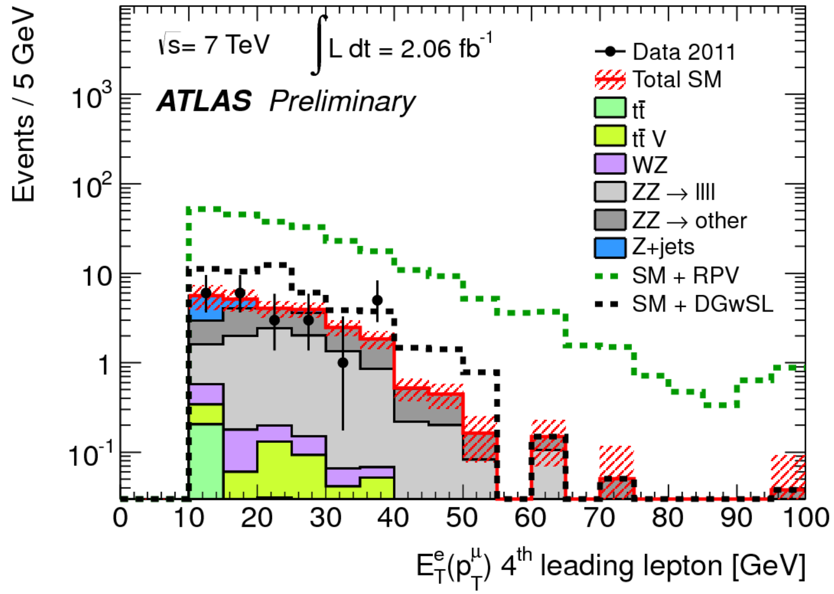
ttZ ->$\ell\nu b\ell\nu b\ell\ell$

<u>Internal conversions</u>

Z->$\ell\ell\gamma^*$ ->$\ell\ell\ell\ell$

Photon conversion probability measured in data

Contribution with the largest uncertainty in SR's



<u>Validation regions</u>

- tt-rich region $\ell\ell\ell\ell$ with one OS eμ pair + b-tag + one non-iso lepton + E_T^{miss}>50 GeV
- ZZ-rich region $\ell\ell\ell\ell$ and E_T^{miss}<50 GeV

Validation Region	Prediction	Observation
tt-rich	8.4±0.8	8
ZZ-rich	23±5	20

Contribution from Internal Conversions

Extract the following ratio from data with E_T^{miss}< 50 GeV

$$P_{conv} = \frac{N(\ell\ell\ell\ell \mid m_{\ell\ell\ell\ell} \sim m_Z)}{N(\ell\ell\gamma \mid m_{\ell\ell\gamma} \sim m_Z)}$$

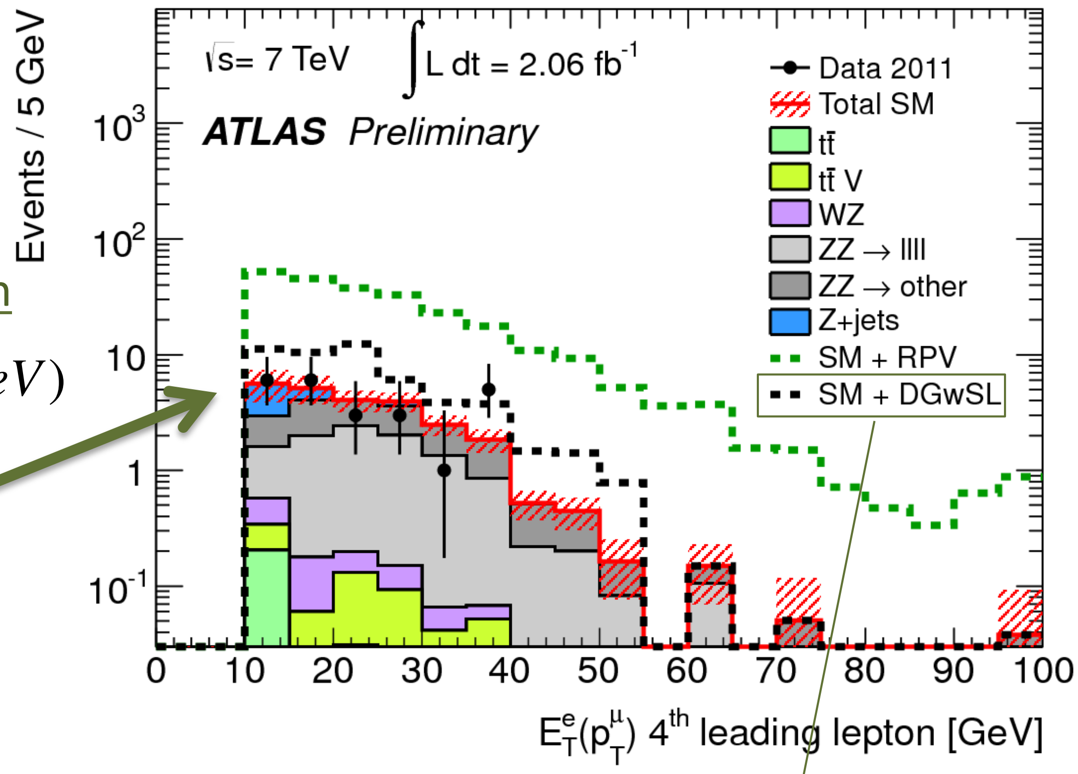
Internal conversions in the signal region

$$N^{SR}_{\text{int}-conv} = P_{conv} \times N(\ell\ell\gamma \mid E_T^{miss} > 50GeV)$$

Good agreement in control plots

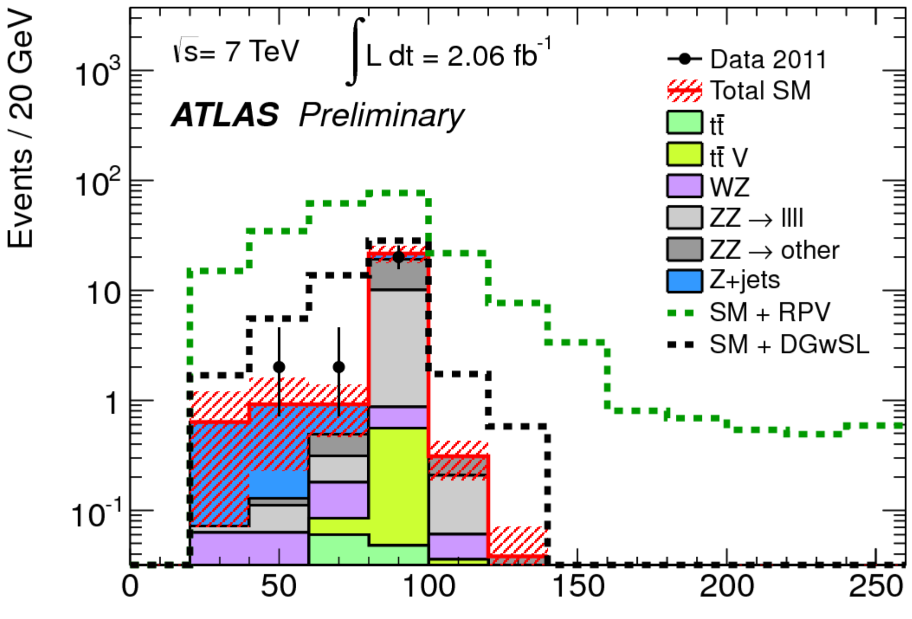
Low p_T region for 3rd and 4th leptons

Before E_T^{miss} selection

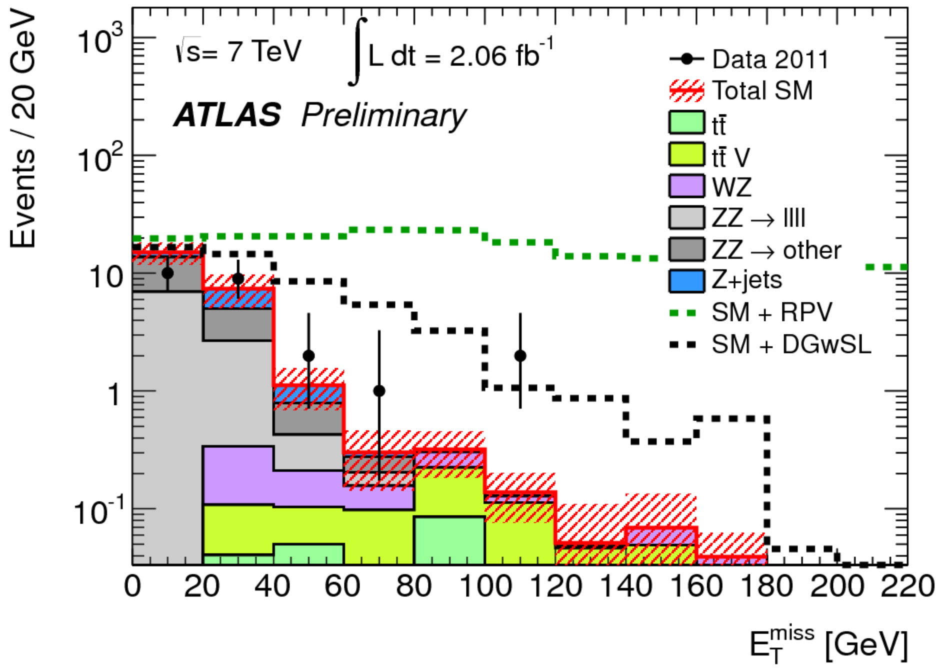


Direct gaugino production with intermediate slepton

4 Lepton Sample Before E_T^{miss} cut



Mass of the SFOS lepton pair



Good agreement b/w data and Monte Carlo in a range of variables

4 Lepton Yields **Before E_T^{miss} cut**

L=2fb^{-1}

4ℓ events	All	$eeee$	$eee\mu$	$ee\mu\mu$	$e\mu\mu\mu$	$\mu\mu\mu\mu$
$t\bar{t}$	0.22±0.15	0.012±0.042	0.06±0.06	0.10±0.07	0.05±0.07	0±0.018
Single t	0±0.04	0±0.04	0±0.04	0±0.04	0±0.04	0±0.04
$t\bar{t}V$	0.59±0.26	0.086±0.043	0.14±0.07	0.17±0.08	0.13±0.06	0.07±0.04
ZZ	19±5	3.8±1.0	0.16±0.08	10.0±2.5	0.17±0.07	4.9±1.2
WZ	0.54±0.17	0.06±0.03	0.07±0.04	0.17±0.07	0.24±0.09	0±0.011
WW	0±0.015	0±0.015	0±0.015	0±0.015	0±0.015	0±0.015
$Z\gamma$	0±0.5	0±0.5	0±0.5	0±0.5	0±0.5	0±0.5
Z+(u, d, s jets)	3.8±1.6	1.8±0.9	0±0.29	1.5±1.1	0.6±0.6	0±0.29
Z+(c, b jets)	0.26±0.28	0.022±0.037	0.06±0.07	0.13±0.14	0.05±0.06	0.0021±0.0034
Drell-Yan	0±0.29	0±0.14	0±0.018	0±0.14	0±0.06	0±0.014
Σ SM	25±5	5.8±1.4	0.5±0.6	12.0±2.8	1.2±0.7	5.0±1.4
Data	24	8	2	8	0	6

Good agreement b/w data and Monte Carlo yields

Final Yields In 4 Lepton Signal Regions

$L=2fb^{-1}$

19 ZZ events before E_T^{miss} cut

Signal Region 1
E_T^{miss} >50 GeV

SR1	All
$t\bar{t}$	0.17±0.14
Single t	0±0.04
$t\bar{t}V$	0.48±0.21
ZZ	0.44±0.19
WZ	0.25±0.10
WW	0±0.015
$Z\gamma$	0±0.5
Z+(u, d, s jets)	0.33±0.67
Z+(c, b jets)	0.024±0.035
Drell-Yan	0±0.05
Σ SM	1.7±0.9
Data	4

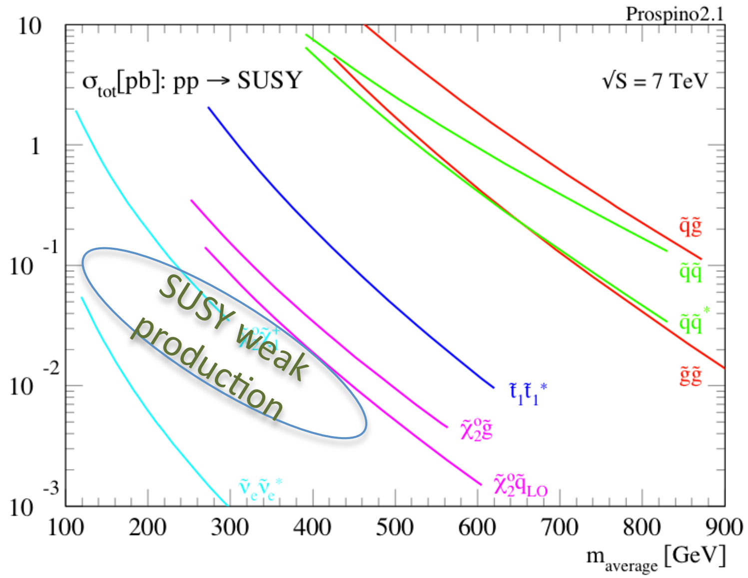
Expectation : 1.7±0.9
Observation : 4 events
p-value : 0.1

Signal Region 2
E_T^{miss} >50 GeV and Z-veto

SR2	All
$t\bar{t}$	0.13±0.11
Single t	0±0.04
$t\bar{t}V$	0.07±0.04
ZZ	0.019±0.020
WZ	0.09±0.05
WW	0±0.015
$Z\gamma$	0±0.5
Z+(u, d, s jets)	0.33±0.67
Z+(c, b jets)	0.024±0.035
Drell-Yan	0±0.05
Σ SM	0.7±0.8
Data	0

Expectation : 0.7±0.8
Observation : 0 events
p-value : >0.5

Conclusions



- ATLAS has searched for gaugino production in 1-2 fb^{-1}
- Examined final states with 2photons and
  =2, =3 and ≥4 leptons,
  sensitive to gaugino production and decays via
  on- and off-shell *Z* or *sleptons*
- No deviation from the Standard Model prediction
- A lot more can be done: tau decays, higgsino scenarios, additional gaugino decays.
- Additional results with the full 2011 data sets should appear soon.
- Search for electroweak SUSY production is an important element in the systematic search for SUSY at the electroweak scale.
- Due to the low cross section for these processes, gaugino search will benefit tremendously from the expected large integrated luminosity in 2012.
- Stay tuned!