

# Multilepton Searches at ATLAS

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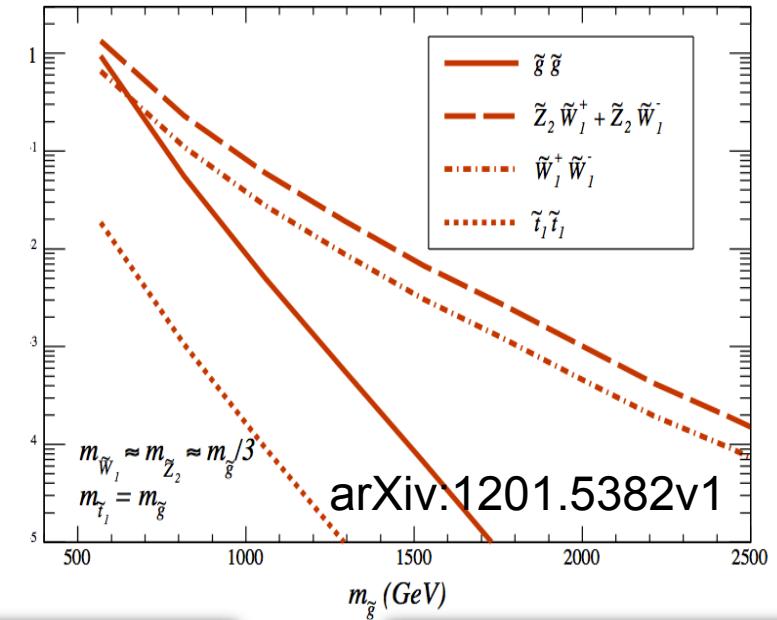
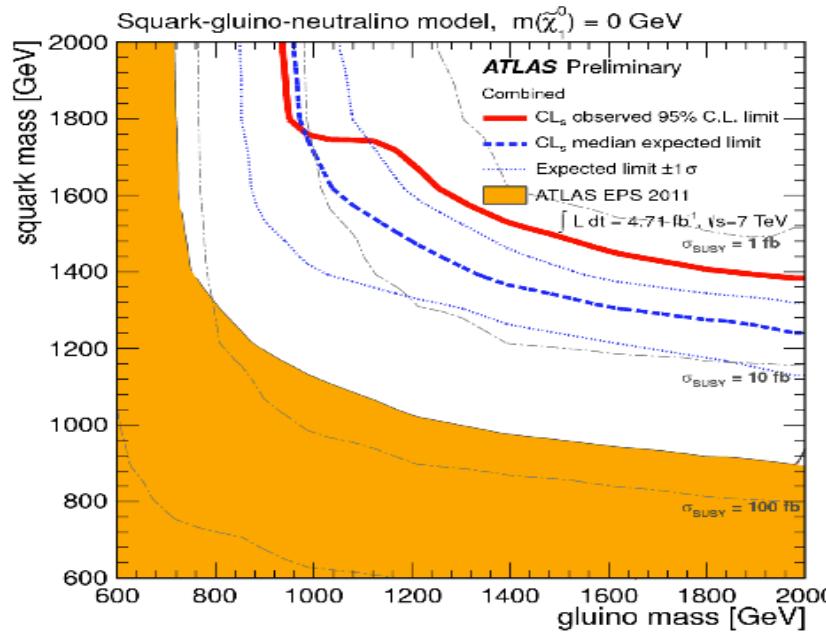
CHICAGO 2012 WORKSHOP ON THE LHC PHYSICS

# Outline

	SIGNATURE	NEW PHYSICS MODEL
Non Resonant	3L + MET	Weak Gauginos RPC
	4L + MET	Weak Gauginos RPV
Resonant	3L, 4L	$H^{++}$
	3L	$W'$ , $\rho_T$
	4L	Graviton

# Why Weak Gauginos ?

- No strongly produced SUSY observed by current searches
  - squarks and gluinos may be too heavy to be directly produced at high rate
- Weak gauginos mass could be in the ~100 GeV range
  - based on naturalness arguments
  - favored in decoupling scenarios
- Cross sections higher than for strongly interacting sparticles at 7 TeV!



# RPC Frameworks

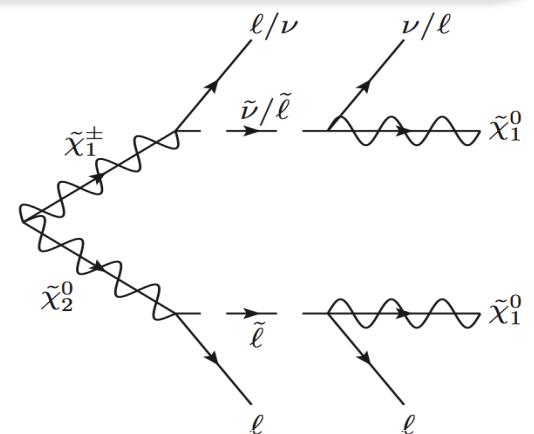
## pMSSM

- MSSM with 19 parameters
  - CP conservation, minimal flavor violation, negligible trilinear couplings for 1<sup>st</sup> and 2<sup>nd</sup> generation, degenerate 1<sup>st</sup> and 2<sup>nd</sup> generation sfermion masses
  - Heavy squarks, gluinos and LH sleptons,  $\tan\beta=6$ ,  $m_A=500$  GeV
  - RH slepton masses in between N1 and C1
  - **M1, M2,  $\mu$  free parameters**

**Production of C1N2 dominant, contributions from C<sub>i</sub>N<sub>j</sub>**

## Simplified Models

- Model defined by a TeV scale effective lagrangian describing particle and interactions
- Mass degenerate C1 and N2 (wino like)
- N1 (bino like)
- BR into LH sleptons /sneutrinos set to 50%
- LH slepton midpoint between N1 and C1 mass
- **C1=N2 and N1, free parameters**



## Production of C1N2

# Overview of the 3L Search

Weak Gauginos' leptonic decay lead to 3L+MET final states  
Heavy neutralinos decay via sleptons and Zs

## OBJECT SELECTION

- Lepton (electrons, muon)  $p_T > 10 \text{ GeV}$ 
  - At least 1 trigger electron (muon) with  $p_T > 25 (20) \text{ GeV}$

## EVENT PRE-SELECTION

- 3 Isolated leptons
- 1 SFOS pair  $m_{\parallel} > 20 \text{ GeV}$

## Z-depleted Signal Region (SR1)

- Z veto (10 GeV window)
- no b-jet candidate
- MET  $> 50 \text{ GeV}$

## Z-enriched Signal Region (SR2)

- Z request (10 GeV window)
- MET  $> 50 \text{ GeV}$

- **Dominant Background in the SRs:**
  - WZ/ $\gamma^*$  and tt
- Negligible contributions due to:
  - ZZ, ttV, V/tt+heavy photon, Z
- **Z-validation region (VR1)**
  - 3L; MET in [30:50] GeV
- **tt-validation region (VR2)**
  - 3L; MET  $> 50 \text{ GeV}$ ; no SFOS pair

# Background Estimation

**Real leptons:** W, Z decay; **Fake leptons:** HF decay, conversions, mis-id LF

- **Irreducible background** (3 real) estimated from MC
- **Reducible background** (at least 1 fake) estimated with data driven ‘Matrix Method’ depending on real efficiencies ( $\epsilon$ ) and fake rates ( $f$ )
  - Bkg. from heavy photons estimated with data driven ‘Weighting Method’
  - 2L events scaled by the probability that a heavy photon is emitted and decays asymmetrically into one identified muon

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1 \epsilon_2 & \epsilon_1 f_2 & f_1 \epsilon_2 & f_1 f_2 \\ \epsilon_1 (1 - \epsilon_2) & \epsilon_1 (1 - f_2) & f_1 (1 - \epsilon_2) & f_1 (1 - f_2) \\ (1 - \epsilon_1) \epsilon_2 & (1 - \epsilon_1) f_2 & (1 - f_1) \epsilon_2 & (1 - f_1) f_2 \\ (1 - \epsilon_1) (1 - \epsilon_2) & (1 - \epsilon_1) (1 - f_2) & (1 - f_1) (1 - \epsilon_2) & (1 - f_1) (1 - f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

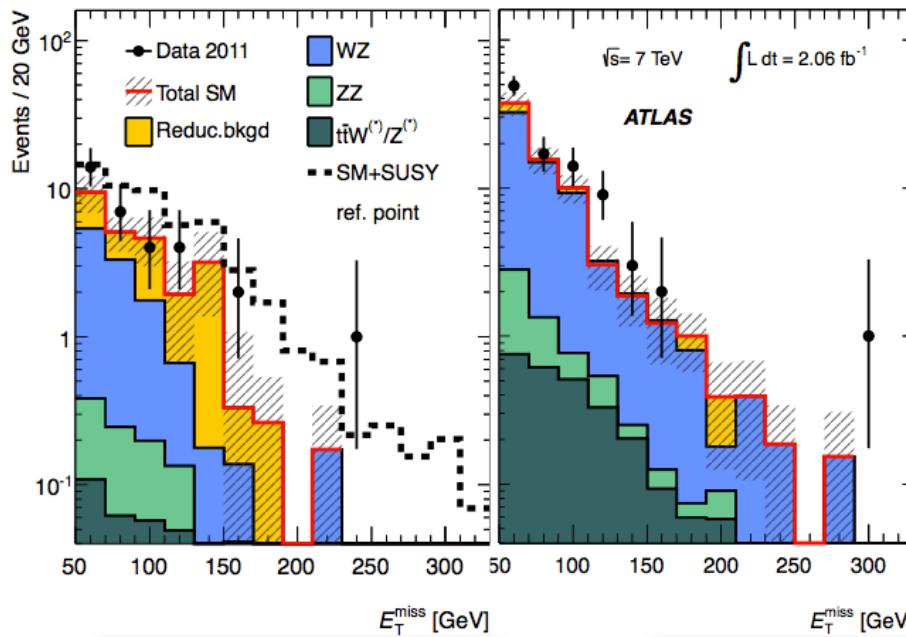
$$f_{XR}^\ell = \sum_{i,j} (s f^i \times R_{XR}^{ij} \times f^{ij})$$

Fake rate determined as weighted average on type and process

- i : type of fake (HF, conversion)
- j : type of process (tt or V)
- $s f^i$  : scale factor of fake type i
- $R_{XR}^{ij}$  : MC derived fraction of fake type i process j region XR
- $f^{ij}$  : fake rate of fake type I process j

# Results for 2/fb

Selection	VR1	VR2	SR1	SR2
$t\bar{t} W^*/Z^*$	$1.4 \pm 1.1$	$0.7 \pm 0.6$	$0.4 \pm 0.3$	$2.7 \pm 2.1$
$ZZ^*$	$6.7 \pm 1.5$	$0.03 \pm 0.04$	$0.7 \pm 0.2$	$3.4 \pm 0.8$
$WZ^*$	$61 \pm 11$	$0.4 \pm 0.2$	$11 \pm 2$	$58 \pm 11$
Reducible Bkg.	$56 \pm 35$	$14 \pm 9$	$14 \pm 4$	$7.5 \pm 3.9$
Total Bkg.	$125 \pm 37$	$15 \pm 9$	$26 \pm 5$	$72 \pm 12$
Data	122	12	32	95



## Dominant systematical uncertainty

- PDF uncertainty on the acceptance for the irreducible background
- Statistical uncertainty on the fake rate estimation for the reducible background

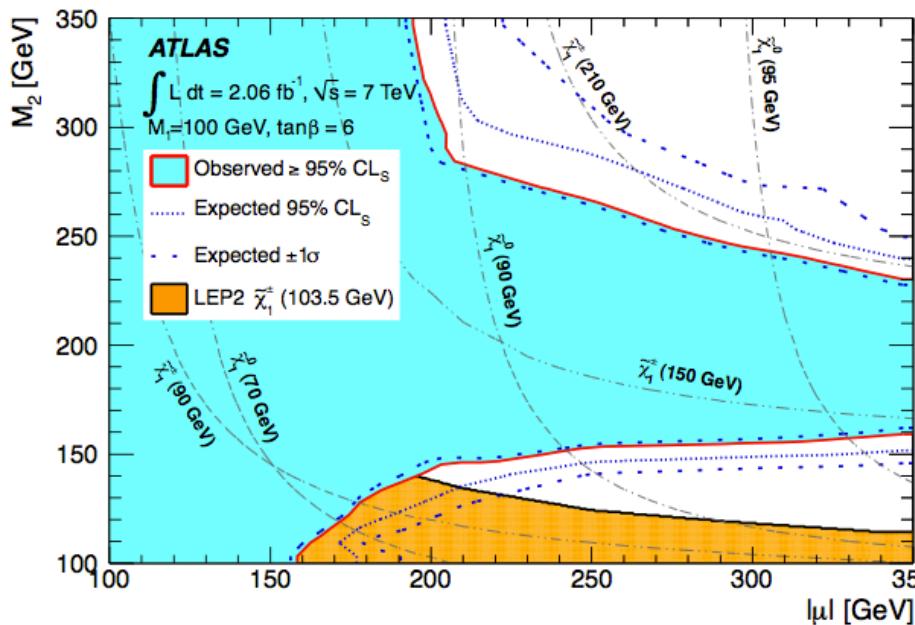
Signal Region	p-value
SR1	19%
SR2	6%

# Interpretation of the 3L Results

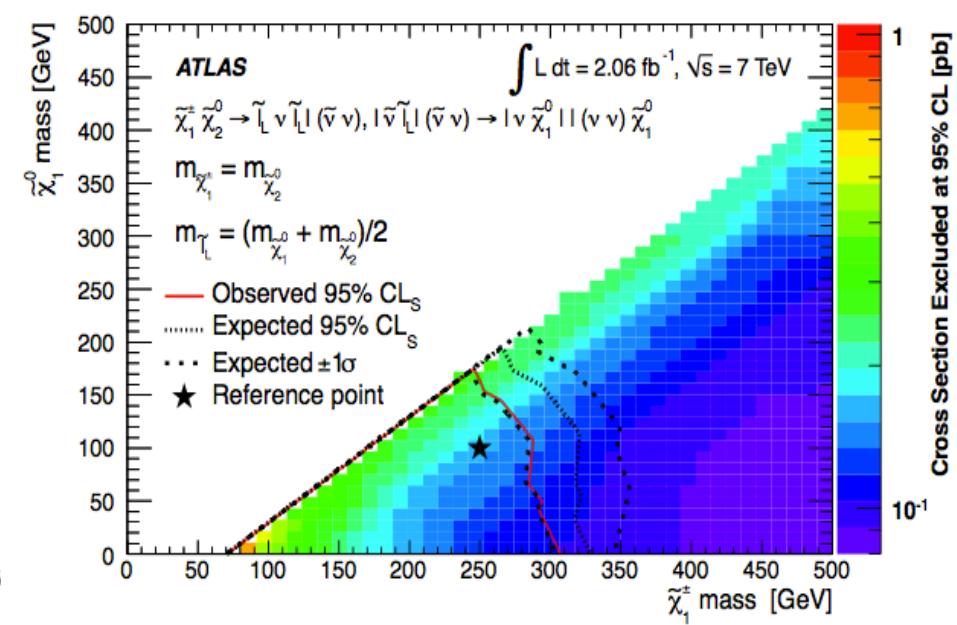
Model-independent  $A \cdot \epsilon \cdot \sigma$  95% C.L. upper limits

Signal Region	Exp.	Obs.
SR1	7.1 fb	9.9 fb
SR2	14.1 fb	23.8 fb

pMSSM



Simplified Model



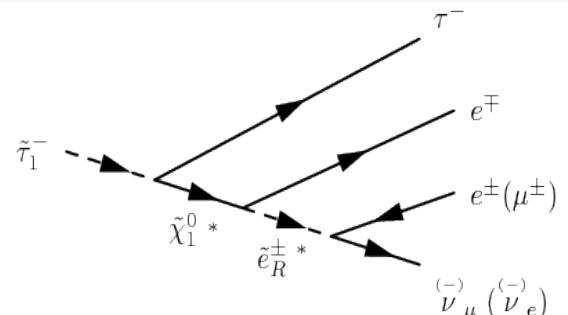
<http://arxiv.org/abs/1204.5638>

# Overview of the 4L Search

Relatively small RPV coupling lead to LSP decay =>  
final state with 4 or more leptons

Final state sensitive to the production and leptonic  
decay of N2N2 as well

**BC1 Scenario**  
RPV within mSUGRA/CMSSM  
Stau LSP decays promptly



## OBJECT SELECTION

- Lepton (electrons, muon)  $p_T > 10$  GeV
  - At least 1 trigger electron (muon) with  $p_T > 25$  (20) GeV

## EVENT PRE-SELECTION

- 4 Isolated leptons
- 1 SFOS pair  $m_{\parallel} > 20$  GeV

## Z-enhanced Signal Region (SR1)

- Z request (10 GeV window)
- MET  $> 50$  GeV

## Z-depleted Signal Region (SR2)

- Z veto (10 GeV window)
- MET  $> 50$  GeV

# Background Estimation

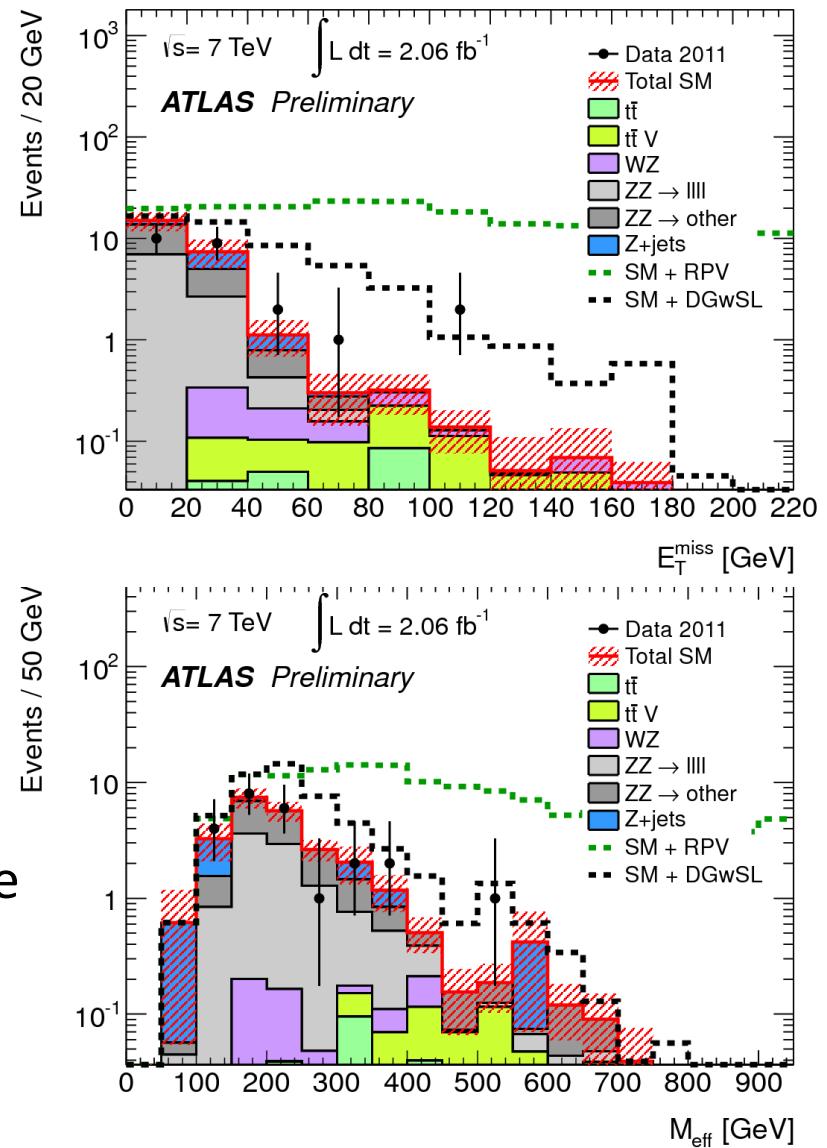
- **Very small background!**
  - Dominant contributions due to  $t\bar{t}V$ , ZZ, Z, WZ,  $t\bar{t}$
- **Estimated from MC**
  - Except for negligible contribution from Z+heavy photon
  - 2L sample scaled by the probability that any of leptons emits a heavy photon decaying into a pair of leptons
- **ZZ- Validation region VR1**
  - 4L, MET < 50 GeV
- **tt-Validation region VR2**
  - 2L, 2 anti-isolated leptons
  - 1 OFOS pair, 1 b candidate
  - MET > 50 GeV

Control Region	Exp.	Obs.
ZZ	$23 \pm 5$	20
$t\bar{t}$	$8.4 \pm 0.8$	8

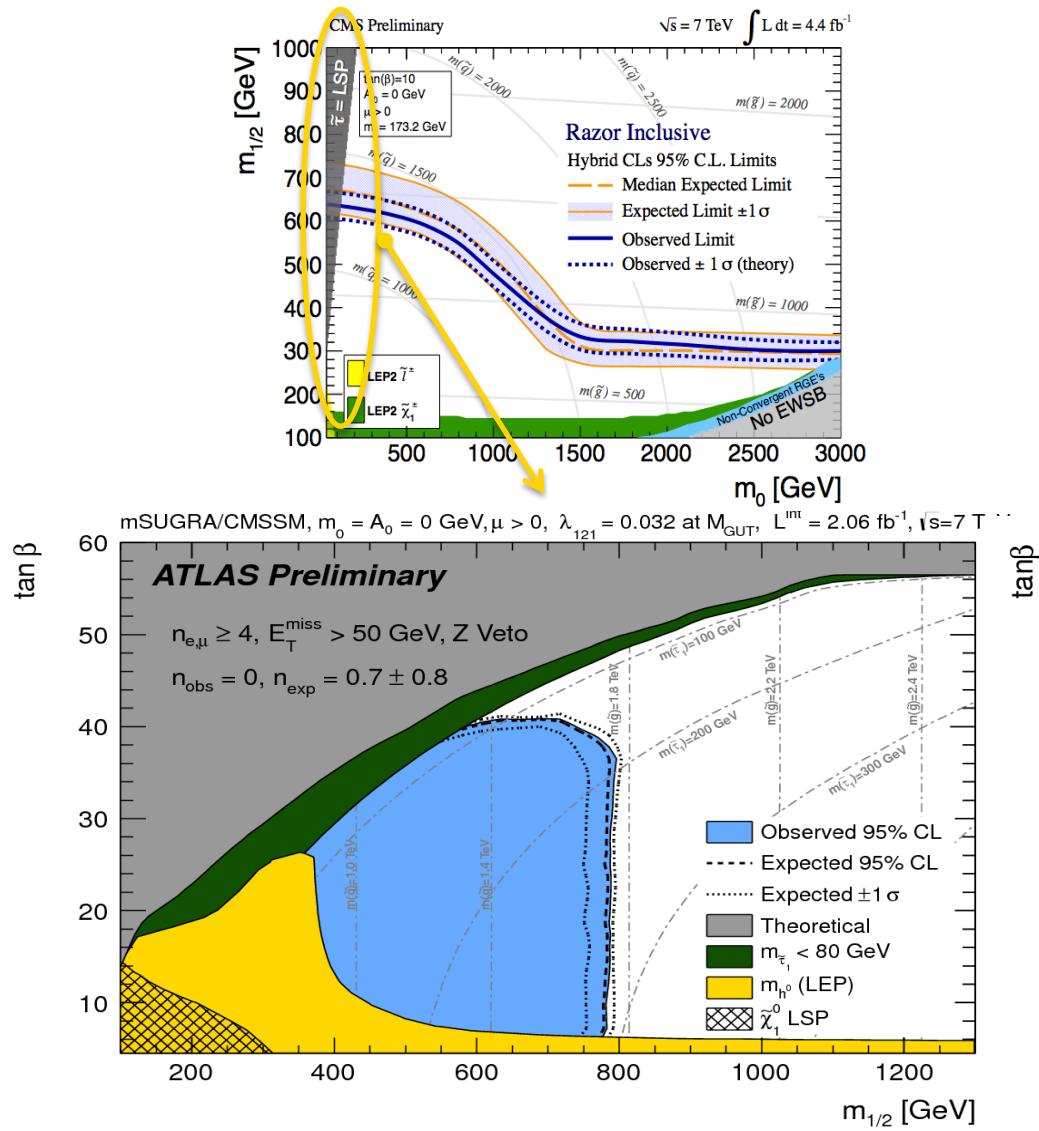
# Results for 2/fb

SR1	All	SR2	All
$t\bar{t}$	$0.17 \pm 0.14$	$t\bar{t}$	$0.13 \pm 0.11$
Single $t$	$0 \pm 0.04$	Single $t$	$0 \pm 0.04$
$t\bar{t}V$	$0.48 \pm 0.21$	$t\bar{t}V$	$0.07 \pm 0.04$
$ZZ$	$0.44 \pm 0.19$	$ZZ$	$0.019 \pm 0.020$
$WZ$	$0.25 \pm 0.10$	$WZ$	$0.09 \pm 0.05$
$WW$	$0 \pm 0.015$	$WW$	$0 \pm 0.015$
$Z\gamma$	$0 \pm 0.5$	$Z\gamma$	$0 \pm 0.5$
$Z+(u, d, s \text{ jets})$	$0.33 \pm 0.67$	$Z+(u, d, s \text{ jets})$	$0.33 \pm 0.67$
$Z+(c, b \text{ jets})$	$0.024 \pm 0.035$	$Z+(c, b \text{ jets})$	$0.024 \pm 0.035$
Drell-Yan	$0 \pm 0.05$	Drell-Yan	$0 \pm 0.05$
$\Sigma \text{ SM}$	$1.7 \pm 0.9$	$\Sigma \text{ SM}$	$0.7 \pm 0.8$
Data	4	Data	0

- Dominant systematical uncertainties due to electron/jet scale and
- SR1: p-value 10%
- SR2: p-value > 0.5

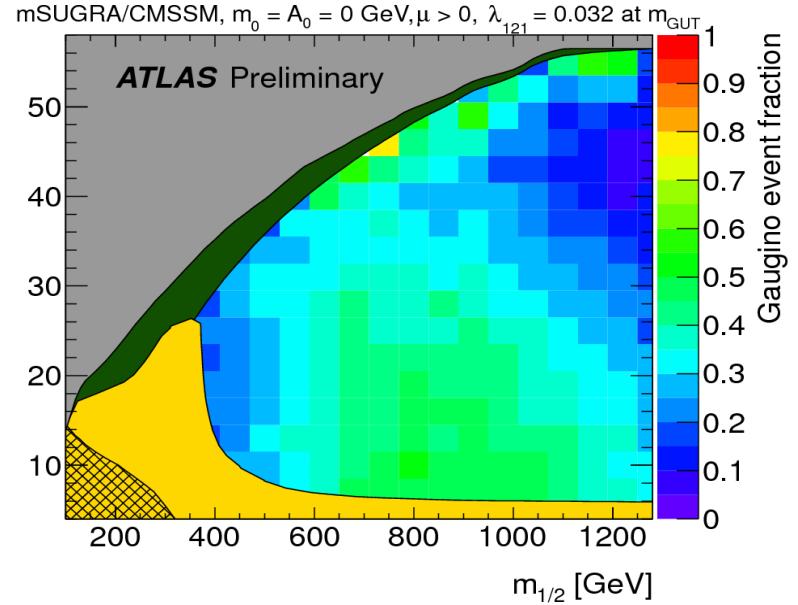


# Interpretation of the 4L results



Model-independent  
 $A \cdot \varepsilon \cdot \sigma$  95% C.L. upper limits

Signal Region	Exp.	Obs.
SR1	2.1 fb	3.5 fb
SR2	1.5 fb	1.5 fb



[ATLAS-CONF-2012-001](#), [ATLAS-CONF-2012-035](#)

# Overview of the Exotics 3L Search

Several models for New Physics produce to a 3-lepton signature

## OBJECT SELECTION

- Leptons (electron, muon)  $p_T > 20 \text{ GeV}$ 
  - At least 1 trigger lepton with  $p_T > 25 \text{ GeV}$

## EVENT PRE-SELECTION

- 3 Isolated leptons
- no SFOS pair  $m_{\parallel} < 20 \text{ GeV}$

## Nominal Signal Region

- Z veto (10 GeV window)

## Tighter Signal Region

- Z veto (10 GeV window)
- lepton  $p_T > 30 \text{ GeV}$

- Dominant Background
  - tt, Z
- Smaller contributions
  - W, diboson

## Samples for background determination

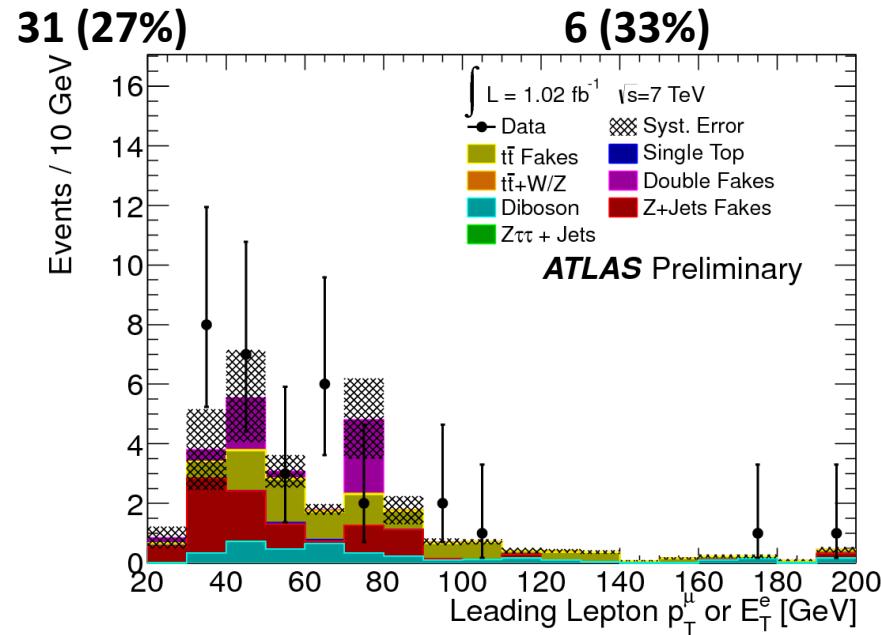
- **Z-dominated sample (1 fake)**
  - Z request (10 GeV window)
  - 2L+1 loosely isolated lepton
  - MET  $< 50 \text{ GeV}$
- **tt-dominated sample (1 fake)**
  - e $\mu$ +1 anti-isolated lepton, MET  $> 20 \text{ GeV}$
- **W-dominated sample (2 fakes)**
  - 2L+1 anti-isolated leptons

# Results for 1/fb

Process	Yield (nominal signal selection)	Yield (tighter signal selection)
Z+jets	$7.9 \pm 3.2 \pm 2.4$	$1.0 \pm 1.5$
$t\bar{t} + e$ Fake	$3.9 \pm 1.6 \pm 0.5$	$1.1 \pm 0.5 \pm 0.2$
$t\bar{t} + \mu$ Fake	$4.8 \pm 0.6 \pm 0.2$	$0.9 \pm 0.1 \pm 0.1$
Z $\rightarrow \tau\tau$ +jets	$0 \pm 0.6$	$0 \pm 0.6$
Double Fakes	$5.1 \pm 1.1^{+1.7}_{-1.4}$	$0.2 \pm 0.2 \pm 0.0$
Diboson	$3.6 \pm 0.4$	$1.5 \pm 0.2$
Single Top	$0.1 \pm 0.1$	$0.0 \pm 0.0$
$t\bar{t}+W/Z$	$0.5 \pm 0.0$	$0.3 \pm 0.0$
Total Background	$25.9 \pm 3.8 \pm 4.3$	$4.9 \pm 1.6 \pm 0.9$

## Data (p-value)

- Dominant systematical uncertainties due to mis-identification probability dependence on lepton  $p_T$ , number of jets, HF fraction

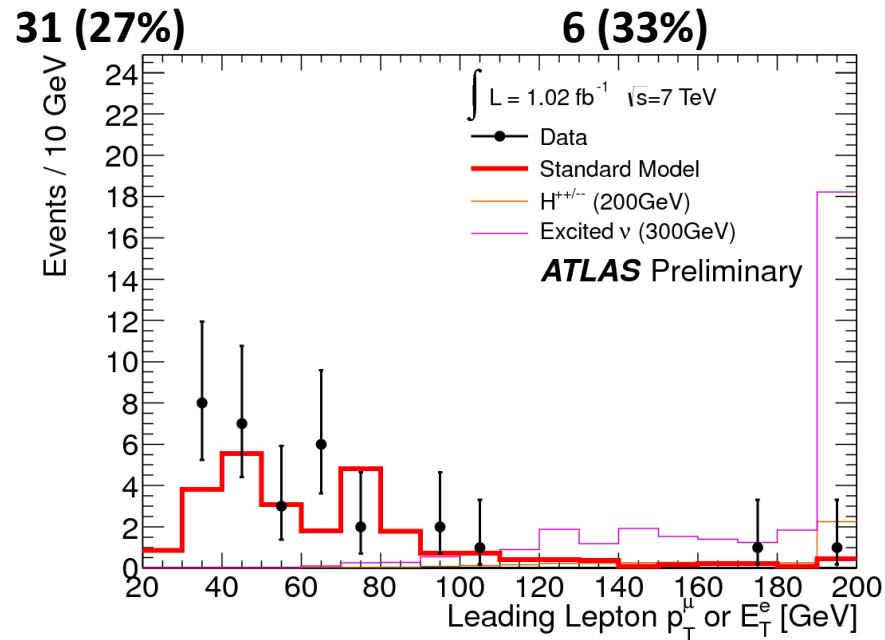


# Results for 1/fb

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$t\bar{t} + \mu$ Fake	$4.8 \pm 0.6 \pm 0.2$	$0.9 \pm 0.1 \pm 0.1$
Z $\rightarrow \tau\tau$ +jets	$0 \pm 0.6$	$0 \pm 0.6$
Double Fakes	$5.1 \pm 1.1^{+1.7}_{-1.4}$	$0.2 \pm 0.2 \pm 0.0$
Diboson	$3.6 \pm 0.4$	$1.5 \pm 0.2$
Single Top	$0.1 \pm 0.1$	$0.0 \pm 0.0$
$t\bar{t}+W/Z$	$0.5 \pm 0.0$	$0.3 \pm 0.0$
Total Background	$25.9 \pm 3.8 \pm 4.3$	$4.9 \pm 1.6 \pm 0.9$

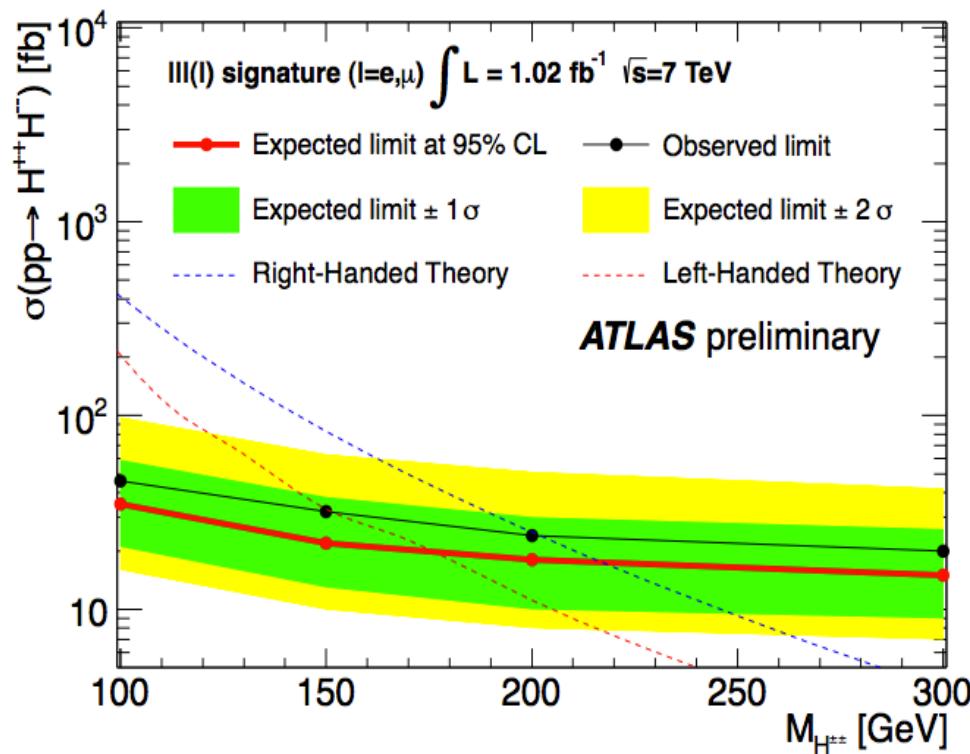
## Data (p-value)

- Dominant systematical uncertainties due to mis-identification probability dependence on lepton  $p_T$ , number of jets, HF fraction



# Interpretation for the 3L Results

Signal Region	Exp.	Obs.
Nominal	28 fb	38 fb
Tight	11 fb	14 fb



## DOUBLY CHARGED HIGGS

ATLAS Like-sign Dimuon search set 95% CL limit of 244 (209) for LH (RH) doubly charged Higgs

## EXCITED ELECTRON NEUTRINO

41 pb for 200 GeV mass

34 pb for 300 GeV mass

H1 excluded excited electron neutrino with mass < 196 GeV at 95% C.L.

[ATLAS-CONF-2011-158](#)

# Overview of the Exotics 4L Search

Doubly-charged Higgs, extra gauge bosons, seesaw mediators, lepto-quarks, Technicolor could have a 4-lepton signature

## OBJECT SELECTION

- Leptons (electron, muon)  $p_T > 15$  GeV
  - At least 1 trigger muon (electron) with  $p_T > 20(25)$  GeV

## EVENT PRE-SELECTION

- 4 Isolated leptons
- no SFOS pair  $m_{\parallel} < 20$  GeV

## Signal Region

- Z veto (66-116 GeV window)
- Events classified by dilepton pair class:
  - 2 SFOS
  - 1 SFOS
  - No SFOS
  - 4 SS

- **Irreducible background (4 real)**
  - ZZ
  - Estimated from MC
- **Reducible background (at least 1 fake)**
  - WZ, Z, tt
  - Data driven weighting method based on rescaling 3L+1 ‘lepton-like jet’ and 2L +2‘lepton-like jets’ samples by the lepton-like jet mis-identification probability

# Background Validation

- **Muon-like jet**, muon candidate failing isolation
- **Electron-like jet**, clusters in the EM calorimeter matched to an ID track failing either or both the ID and isolation requirements
- Probabilities for lepton-jet to be mis-identified measured in QCD data
  - Same method applied in MC and difference taken as system.
  - Systematical uncertainty of 30-100% cover for the flavor composition

Process	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$ $\mu^+\mu^-e^+e^-$
$ZZ$	$1.3 \pm 0.1 \pm 0.1$	$2.5 \pm 0.1 \pm 0.1$	$3.6 \pm 0.1 \pm 0.1$
Mis. lep.	$0.01^{+0.02}_{-0.01} {}^{+0.02}_{-0.01}$	$0.3^{+0.9}_{-0.3} \pm 0.2$	$0.0^{+1.0}_{-0.0} {}^{+0.8}_{-0.0}$
Total Bkg.	$1.3 \pm 0.1 \pm 0.1$	$2.7^{+0.9}_{-0.3} \pm 0.3$	$3.6^{+1.0}_{-0.1} {}^{+0.8}_{-0.1}$
Data	2	6	1

**ZZ Control sample**

2 SFOS pairs in Z  
and  $m_{zz} < 300$  GeV

Red. Bkg	Irr. Bkg	Obs.
$0+1.3+0.8$	$0.15\pm0.01\pm0.01$	0

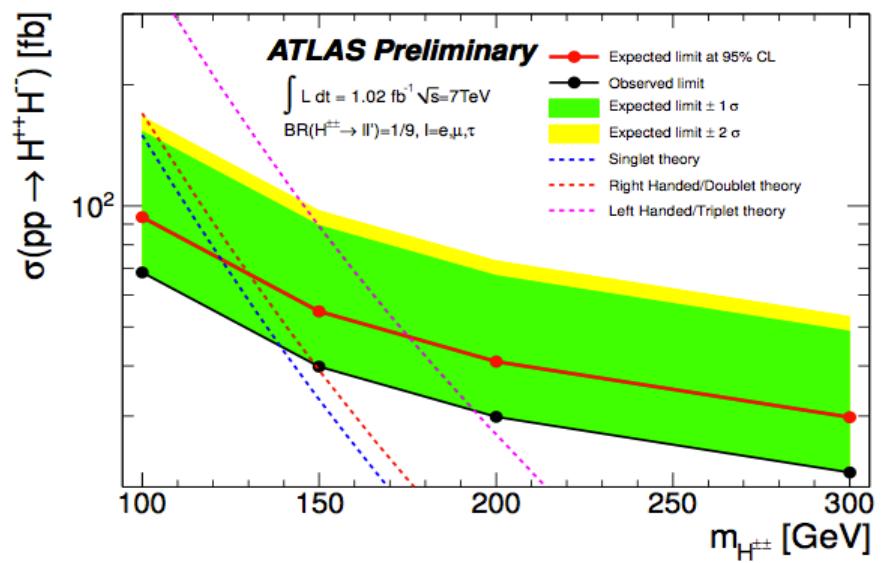
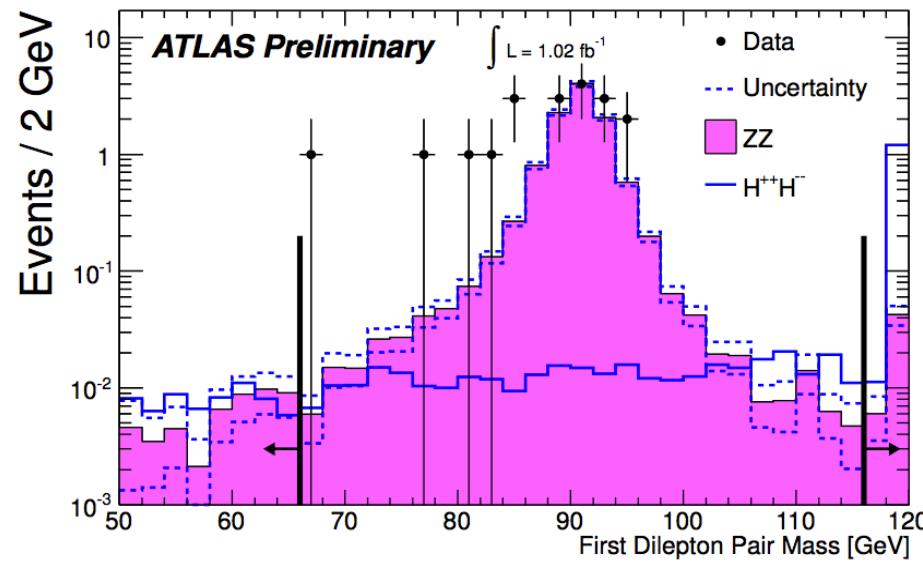
**Z+fakes Control sample**

No. SFOS pairs < 2  
SFOS pair in Z window

# Results and Interpretation for 1/fb

Process	Total	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\mu^+\mu^-e^+e^-$
ZZ	$0.10 \pm 0.01 \pm 0.01$	$0.02 \pm 0.00 \pm 0.00$	$0.03 \pm 0.01 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.01$
Fakes	$0.61^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$	$0.01 \pm 0.01 \pm 0.01$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+0.01}_{-0.00}{}^{+0.01}_{-0.00}$
Total Bkg.	$0.71^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$	$0.02 \pm 0.01 \pm 0.01$	$0.03^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.01 \pm 0.01 \pm 0.01$
$H_{200}^{\pm\pm}$	$1.27 \pm 0.04 \pm 0.03$	$0.05 \pm 0.01 \pm 0.01$	$0.09 \pm 0.01 \pm 0.01$	$0.13 \pm 0.01 \pm 0.01$	$0.16 \pm 0.01 \pm 0.01$
Data	0	0	0	0	0

Process	$e^+e^-\ell\ell$	$\mu^+\mu^-\ell\ell$	$e^+\mu^\mp\ell\ell$	4 same-sign
ZZ	$0.01 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00$	$0.00 \pm 0.00 \pm 0.00$	$0.01 \pm 0.01 \pm 0.00$
Fakes	$0.61^{+0.69}_{-0.61} \pm 0.51$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$
Total Bkg.	$0.61^{+0.69}_{-0.61} \pm 0.51$	$0.02^{+1.03}_{-0.02}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$
$H_{200}^{\pm\pm}$	$0.30 \pm 0.02 \pm 0.02$	$0.37 \pm 0.02 \pm 0.02$	$0.18 \pm 0.01 \pm 0.01$	$0.00 \pm 0.00 \pm 0.00$
Data	0	0	0	0

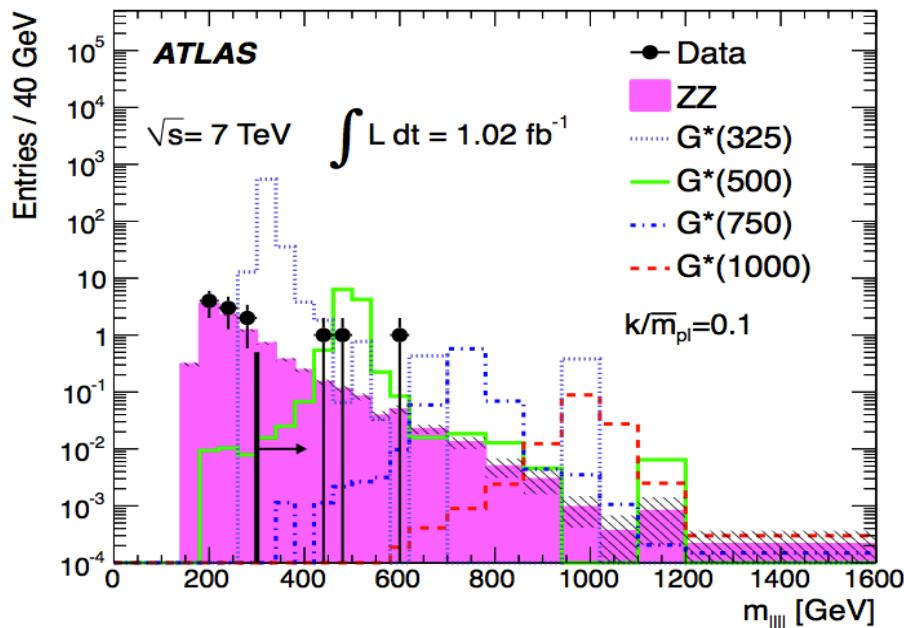


# 4L Search for ZZ Resonances

<http://arxiv.org/abs/1203.0718>

Models of warped ED predict the existence of  $G^*$  with enhanced coupling to ZZ

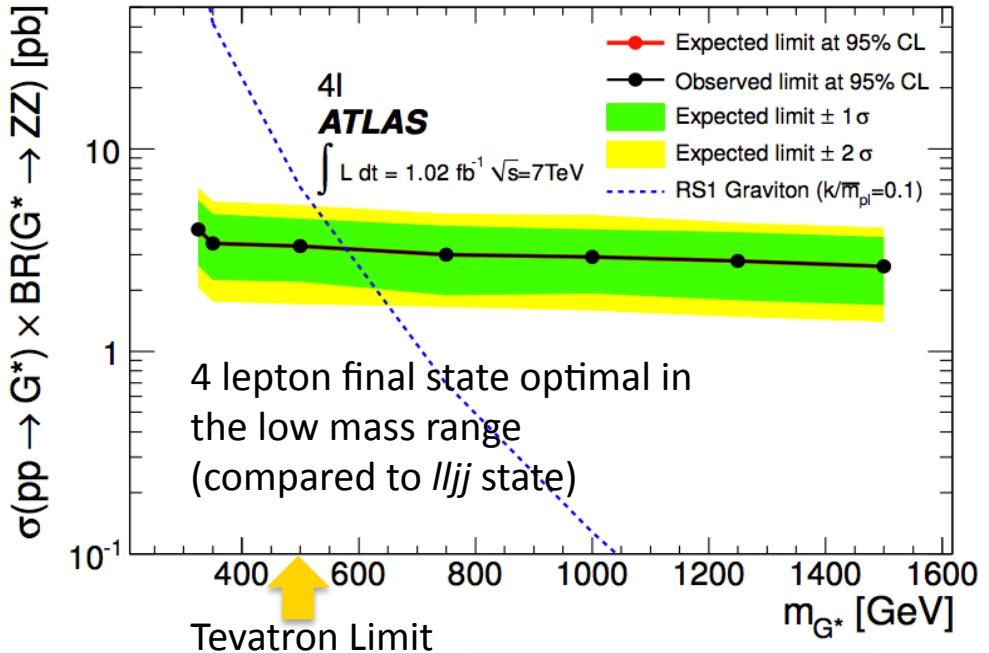
Process	Total
ZZ	$1.9 \pm 0.1 \pm 0.1$
Misident. leptons	$0.02^{+1.0}_{-0.01} {}^{+0.8}_{-0.02}$
Total Bkg.	$1.9^{+1.0}_{-0.1} {}^{+0.8}_{-0.1}$
Data	3



## SIGNAL REGION

- 4 Isolated leptons
- 2 Z candidate [66;116] with  $m_{ZZ} > 300 \text{ GeV}$

- Largest excess with p-value 7% ( $1.5\sigma$ )
- Single mass-independent counting experiment
  - 95% C.L upper limit on  $\sigma_{ZZ,\text{fid}} = 0.92 \text{ pb}$



# 3L Search for WZ Resonances

Search sensitive

<http://arxiv.org/abs/1203.0718>

to heavy particles predicted by Extended Gauge Models, Extra-Dimensions Technicolor

## OBJECT SELECTION

- Leptons (electron, muon)  $p_T > 25 \text{ GeV}$

## Signal Region

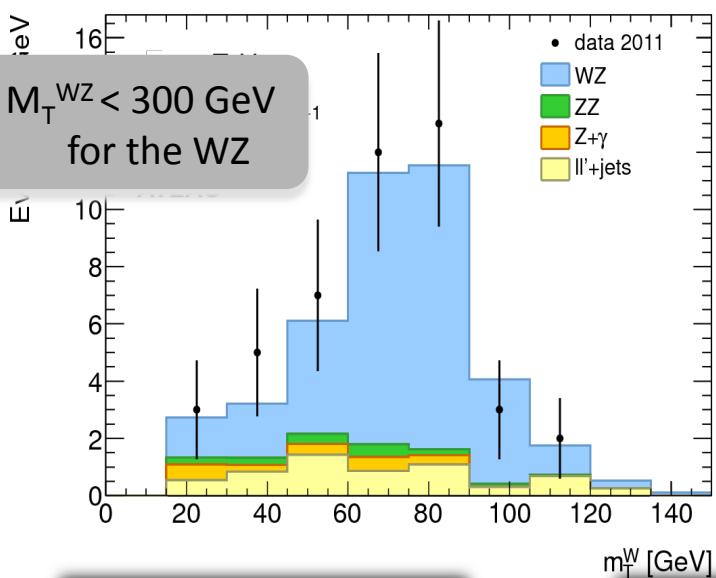
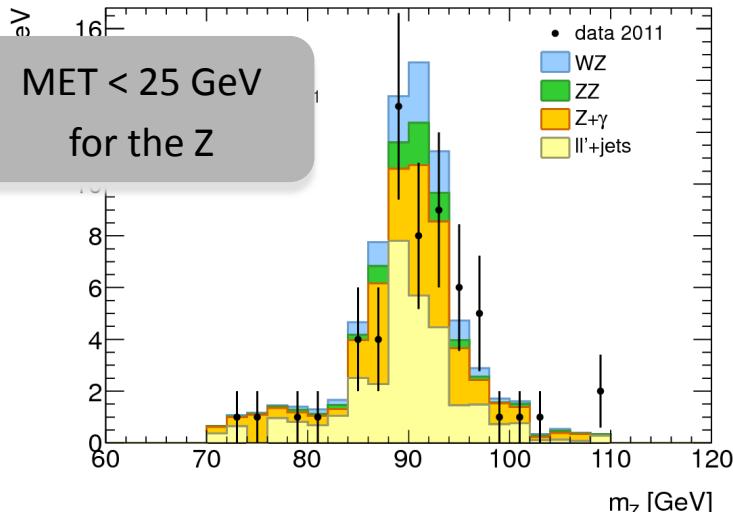
- Z request (20 GeV window)
- MET  $> 15 \text{ GeV}$
- $M_T > 25 \text{ GeV}$
- $M_T^{WZ} > 200 \text{ GeV}$

## EVENT PRE-SELECTION

- 3 Isolated leptons
- 4 flavor combinations analyzed separately and then combined
- Dominant background
  - WZ, tt, Z
- Smaller contributions
  - ZZ, ZY
- All background determined from MC except for the Z that is determined from data
  - 2 isolated leptons + 1 lepton failing quality requirement (ID: electron, isolation: muons)  
sample scaled by the mis-identification fraction

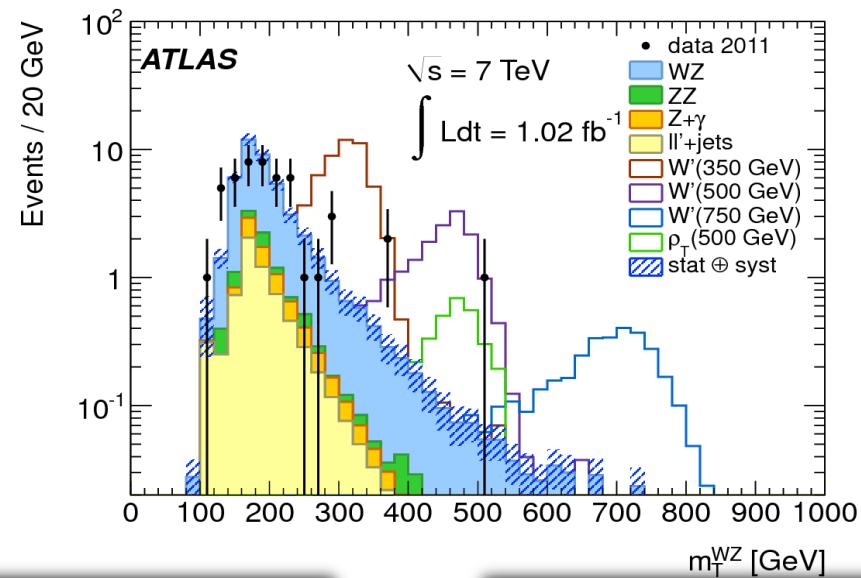
# Results for 1/fb

Samples for background validation



Signal region

	Combined
WZ	$34.6 \pm 3.1$
ZZ	$1.7 \pm 0.5$
Z $\gamma$	$2.3 \pm 1.1$
$\ell\ell' + \text{jets}$	$6.4 \pm 1.0 \pm 3.2$
Overall backgrounds	$45.0 \pm 1.0 \pm 4.6$
Data	48



# Interpretation for the 3L Results

## EGM

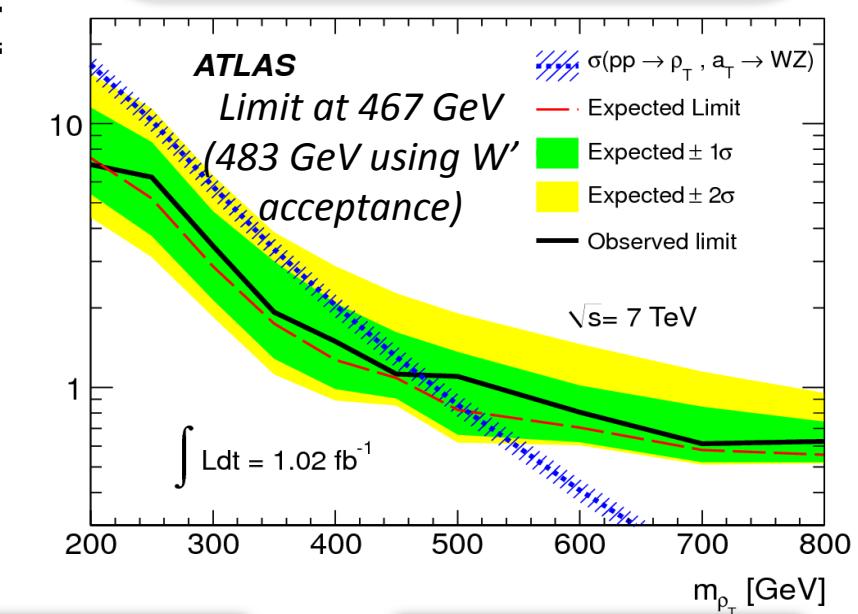
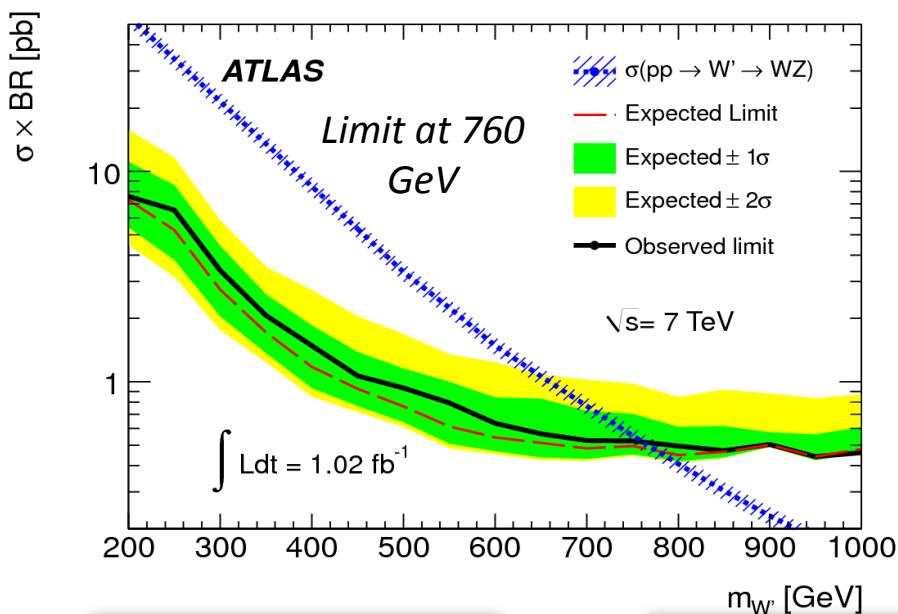
- Couplings of  $W'$  to SM particle as in SM except for

$$g_{W'WZ} = g_{WWZ} \cdot \frac{m_W m_Z}{m_{W'}^2}$$

- Tevatron 95% C.L. at 690 GeV

## Low Scale TechniColor

- Narrow resonances ( $\rho_T, a_T$ )
- Tevatron 95% C.L. at 408 GeV
- Assumptions
  - $m_{\rho_T} = m_W + m_{\pi_T}$
  - $m_{a_T} = 1.1 \times m_{\rho_T}$
  - Unpolarized W and Z decay



# Summary and Outlook

- Strong physics case for multilepton searches at the LHC
  - From theoretical point of view
    - SUSY, EGM, ED, Technicolor, excited neutrinos, etc
  - From experimental point of view
    - very sensitive probes for NP thanks to a low expected background
- ATLAS has developed a broad programme of searches in the 3L and 4L final states
  - Model dependent searches aiming at most likely discovery and Model independent searches aiming at largest coverage of parameter space
  - Searches for non resonant and for resonant NP
- No deviation with respect to the SM expectations observed
  - Most stringent limits up to date
  - 5/fb searches well underway
- Large dataset will be collected in 2012!

# Exotics 3L: Background Estimation

- **Irreducible background** (3 real) estimated from MC
- **Reducible background** (at least 1 fake)
  - Z: Z-control sample scaled to account for the MET,  $M_{\parallel}$  and the loosely isolated-lepton requirements
  - tt: measured in tt-dominated sample and scaled to SR using MC predictions
  - W: W-dominated sample scaled by the probability both leptons pass the isolation requirement

$$N_{Z,Est.}^{SR} = R_{iso} \cdot R_{MET} \cdot R_{m_{ll}} \cdot (N_{Obs.,Data}^{CR-Z} - N_{BG,MC}^{CR-Z})$$

$$R_{MET} = \frac{N_{Z,MC}^{SR}}{N_{Z,MC}^{SR,MET}}$$

$$R_{m_{ll}} = \frac{N_{Z,MC}^{SR}}{N_{Z,MC}^{SR,m_{ll}}}$$

**R<sub>iso</sub>** fractions function from QCD multi-jet data  
**R<sub>MET</sub>** and **R<sub>m<sub>ll</sub></sub>** fractions determined from MC

