

Searches for new physics in multileptons or like-sign leptons with the ATLAS detector

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On behalf of the ATLAS collaboration

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Multileptons & Like-sign dileptons

- Excesses predicted by many models, and relatively little Standard model background
- **ATLAS Inclusive searches**
 - Inclusive searches for like-sign and multileptons resulting in fiducial cross section limits
- **ATLAS Dedicated searches**
 - For instance: Left-right symmetric models ,
supersymmetry,
heavy neutrinos,
doubly charged higgs models,
excited ν_e ,
 $X \rightarrow$ dibosons,
TeV scale gravity,
same-sign tops, etc ...

Analyses mentioned in this talk:

- ATLAS Inclusive searches
 - **Inclusive searches for like-sign** and **multileptons** resulting in fiducial cross section limits
- ATLAS Dedicated searches
 - For instance: **Left-right symmetric models** ,
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heavy neutrinos,
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 $X \rightarrow$ dibosons,
TeV scale gravity,
same-sign tops, etc ...

Inclusive search for like-sign same-flavor dileptons

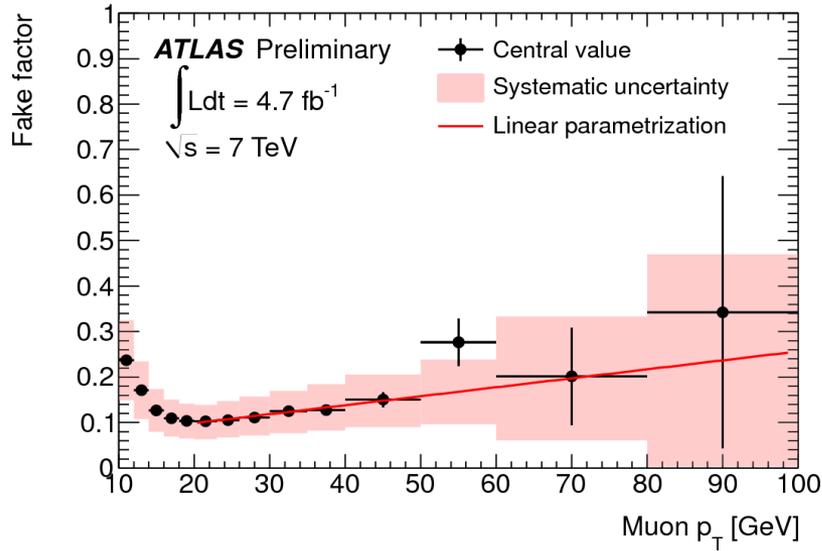


NEW!

ATLAS-CONF-2012-069

- **Analysis designed to catch broad range of new physics models**
 - **tight lepton identification to reduce SM background**
- Simple selection of high pt, prompt, isolated, like-sign with $m(\ell\ell) > 15 \text{ GeV}$ (Like-sign Z peak excluded from ee channel)
- Fiducial limit on $e^\pm e^\pm$ and $\mu^\pm \mu^\pm$ production using 4.7 fb^{-1} @ 7 TeV
- Main backgrounds:
 - WZ, ZZ: Sherpa MC normalized to MCFM
 - Charge misid: negligible for muons, important for electrons (hard brem + conversion). MC + data-driven corrections
 - Non-prompt leptons and jets faking leptons (bb, W+jets). Data-driven estimate.

Like-sign incl: Background estimation



Non-prompt leptons:

fake factor = $N(\text{selected})/N(\text{anti-selected})$

Function of p_T, η

Correct for prompt contamination using MC and for double-fakes

Uncertainties range 10-100% , from trigger bias to sample/composition dependence

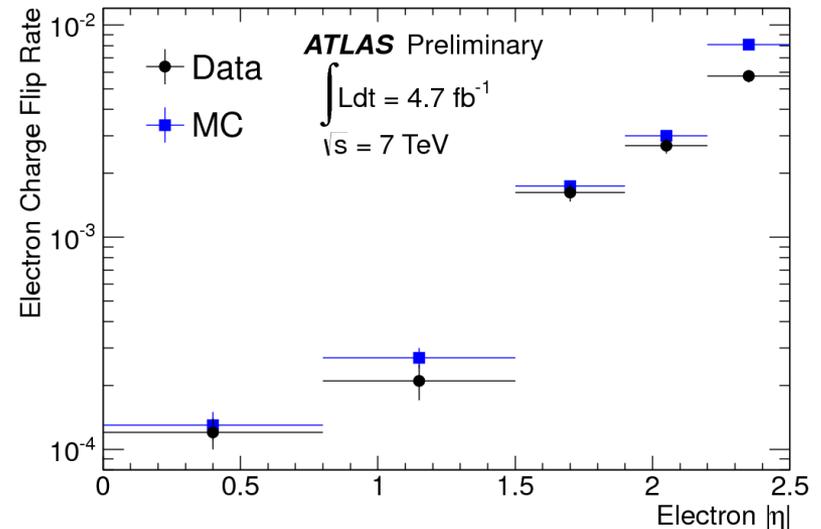
Electron charge flips:

Like-sign Z peak used to measure rate

Over predicted in MC (~15%)

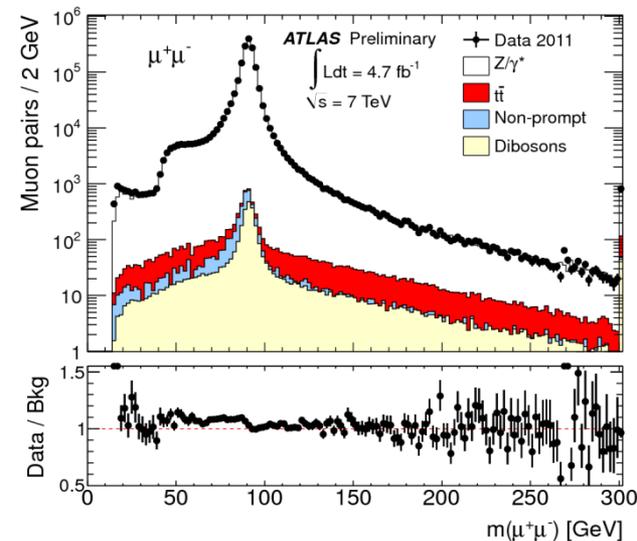
Apply η -dependent scale factor :

Syst. uncertainty (10-20%) from comparing different methods



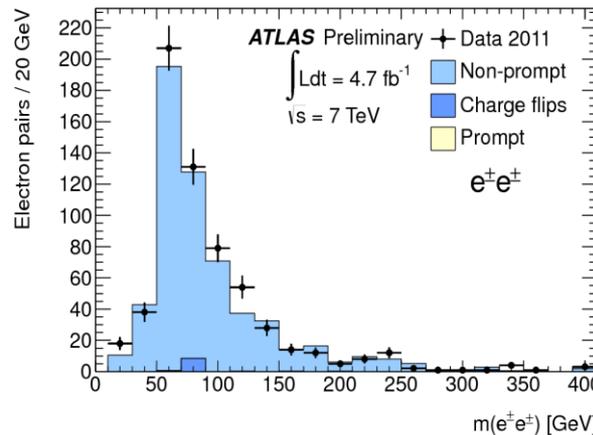
Like-sign incl: Validation of background estimation

Several control regions investigated to validate background estimates before looking at potential signal. Some examples are:



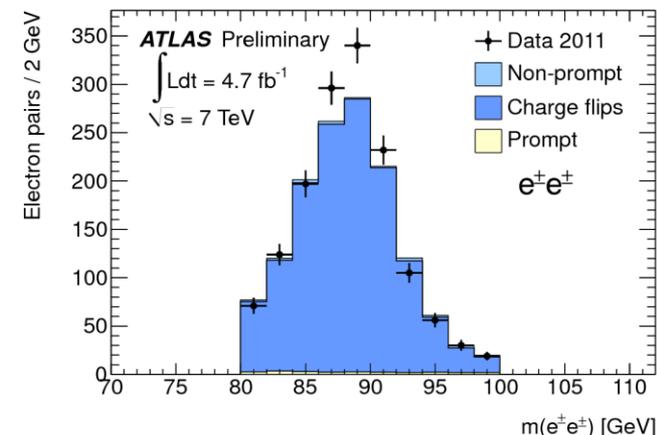
Opposite-sign leptons:

Check overall normalization (luminosity, scale factors etc)



Intermediate isolation:

Looser electron cuts:
 Check prediction of fakes/
 non-prompt backgrounds



Like-sign ee Z peak:

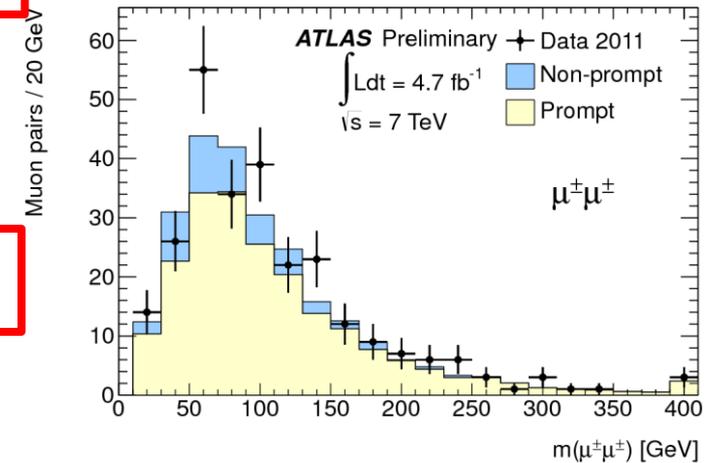
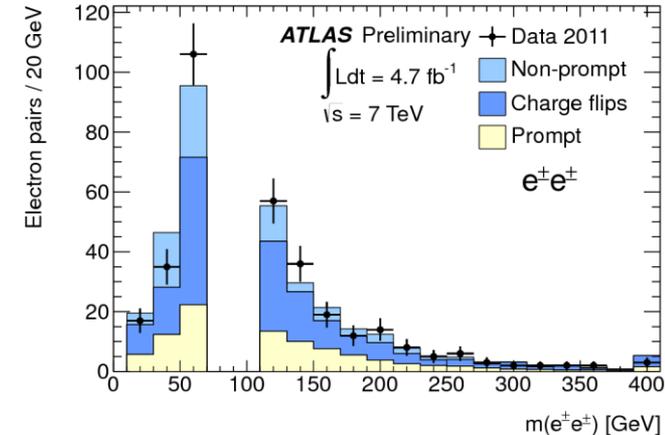
Check modeling of
 charge misID rate

Like-sign incl: Results

In bins of like-sign mass, using 4.7 fb^{-1} :

Sample	Number of electron pairs with $m(e^+e^\pm)$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
Prompt	93.6 ± 9.4	52.9 ± 5.7	13.6 ± 1.6	4.0 ± 0.6	1.3 ± 0.2
Non-prompt	75 ± 29	29 ± 12	6.0 ± 2.8	$0.6^{+1.0}_{-0.6}$	$0.0^{+0.2}_{-0.0}$
Charge flips and conversions	161 ± 25	86 ± 13	21.0 ± 3.5	7.9 ± 1.4	3.5 ± 0.8
Sum of backgrounds	330 ± 39	169 ± 19	40.6 ± 4.7	$12.4^{+1.8}_{-1.7}$	$4.8^{+0.9}_{-0.8}$
Data	329	171	38	10	3

Sample	Number of muon pairs with $m(\mu^\pm\mu^\pm)$				
	> 15 GeV	> 100 GeV	> 200 GeV	> 300 GeV	> 400 GeV
Prompt	205 ± 26	90 ± 11	21.8 ± 2.8	5.8 ± 0.9	2.2 ± 0.4
Non-prompt	42 ± 14	12.1 ± 4.6	1.0 ± 0.6	$0.0^{+0.3}_{-0.0}$	$0.0^{+0.3}_{-0.0}$
Charge flips	$0.0^{+4.9}_{-0.0}$	$0.0^{+2.5}_{-0.0}$	$0.0^{+1.8}_{-0.0}$	$0.0^{+1.7}_{-0.0}$	$0.0^{+1.7}_{-0.0}$
Sum of backgrounds	247^{+30}_{-29}	102 ± 12	$22.8^{+3.4}_{-2.9}$	$5.8^{+1.9}_{-0.9}$	$2.2^{+1.7}_{-0.4}$
Data	265	111	29	6	2



All mass bins consistent with SM only hypothesis

Like-sign incl.: fiducial efficiencies

Goal: \approx model-independent limits for easy interpretation

Define fiducial signal region as events passing generator level cuts on mass and:

	Electron requirement	Muon requirement
Leading lepton p_T	$p_T > 25 \text{ GeV}$	$p_T > 20 \text{ GeV}$
Sub-leading lepton p_T	$p_T > 20 \text{ GeV}$	$p_T > 20 \text{ GeV}$
Lepton η	$ \eta < 1.37$ or $1.52 < \eta < 2.47$	$ \eta < 2.5$
Isolation	$p_T^{\text{cone}0.3} / p_T < 0.1$	$p_T^{\text{cone}0.4} / p_T < 0.06$ and $p_T^{\text{cone}0.4} < 4 \text{ GeV} + 0.02 \times p_T$

(Where $p_T^{\text{cone}R}$ = sum of charged, stable particles with $pt > 1 \text{ GeV}$ in cone of radius R)

Fiducial efficiency = fraction of these that pass experimental full selection.

Tested with several new physics models; 4th generation quarks, $H^{++/--}$, like-sign tops, W_R

Lowest efficiency obtained is used : 43.4% for ee and 60.6% for $\mu\mu$

Resulting fiducial limits

Limit on charge inclusive
selection

1.7 to 45.7 fb

dependent on mass cut

Most interesting bin

($m > 100$ GeV $\mu^-\mu^-$)

$1 - \text{CL}_b \cong 0.075$

Mass range	95% C.L. upper limit [fb]			
	$e^\pm e^\pm$		$\mu^\pm \mu^\pm$	
	expected	observed	expected	observed
$M > 15$ GeV	$45.0^{+17.3}_{-12.0}$	45.7	$23.4^{+8.6}_{-5.8}$	29.1
$M > 100$ GeV	$24.3^{+9.1}_{-7.0}$	25.6	$11.9^{+4.4}_{-2.9}$	14.6
$M > 200$ GeV	$8.8^{+3.2}_{-2.9}$	8.1	$4.2^{+1.8}_{-1.1}$	6.6
$M > 300$ GeV	$4.5^{+1.6}_{-1.3}$	3.9	$2.3^{+0.8}_{-0.7}$	2.5
$M > 400$ GeV	$2.9^{+1.1}_{-0.9}$	2.3	$1.6^{+0.6}_{-0.5}$	1.7
	$e^+ e^+$		$\mu^+ \mu^+$	
$M > 15$ GeV	$27.3^{+10.0}_{-7.9}$	23.8	$14.7^{+6.0}_{-3.2}$	14.9
$M > 100$ GeV	$16.2^{+6.0}_{-4.8}$	12.4	$8.2^{+3.2}_{-2.4}$	7.7
$M > 200$ GeV	$6.6^{+2.8}_{-1.5}$	6.5	$3.4^{+1.5}_{-0.7}$	4.2
$M > 300$ GeV	$3.5^{+1.6}_{-0.8}$	2.9	$2.0^{+0.8}_{-0.5}$	2.0
$M > 400$ GeV	$2.4^{+1.1}_{-0.6}$	1.7	$1.5^{+0.6}_{-0.3}$	1.7
	$e^- e^-$		$\mu^- \mu^-$	
$M > 15$ GeV	$24.6^{+8.5}_{-6.8}$	29.1	$11.9^{+4.4}_{-3.4}$	18.0
$M > 100$ GeV	$12.7^{+4.6}_{-3.9}$	19.9	$5.8^{+2.2}_{-1.9}$	9.8
$M > 200$ GeV	$4.7^{+1.9}_{-1.3}$	4.4	$2.7^{+1.1}_{-0.7}$	4.3
$M > 300$ GeV	$2.8^{+1.1}_{-0.8}$	2.7	$1.4^{+0.7}_{-0.3}$	1.7
$M > 400$ GeV	$1.8^{+1.0}_{-0.4}$	2.2	$1.2^{+0.4}_{-0.0}$	1.1

To set limits on other models: derive acceptance within fiducial region

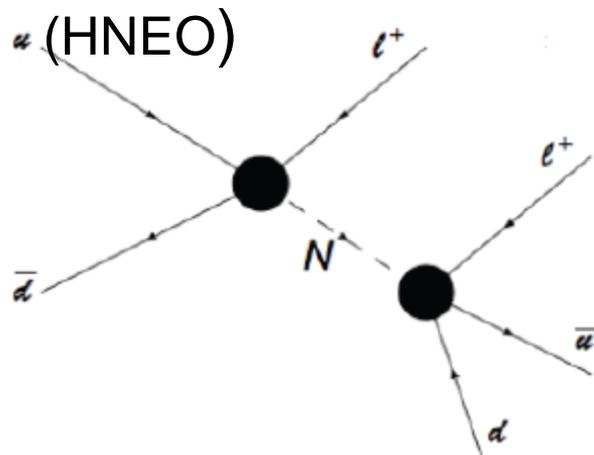
W_R /Heavy neutrinos

[arXiv:1203.5420](https://arxiv.org/abs/1203.5420)

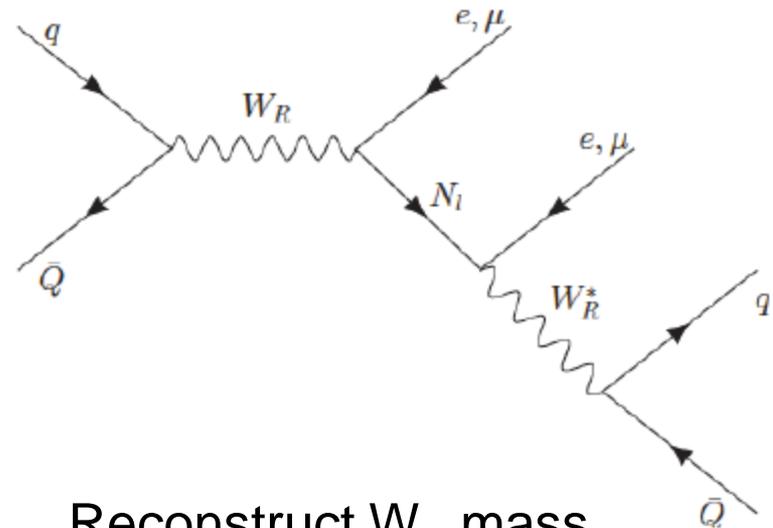
- Non-zero neutrino mass could be explained by for instance Seesaw mechanism
 - predicts light ν and heavy neutrino N .
- If Majorana particles: like-sign leptons in final state
Analysis: SS (Majorana only) or OS (Dirac, Majorana)

Two models:

Langrangian of effective operators



Left-right symmetric model (LRSM)



W_R /Heavy Neutrino Results

Main SS backgrounds:

Fake leptons (W+jets, tt) ← Data-driven

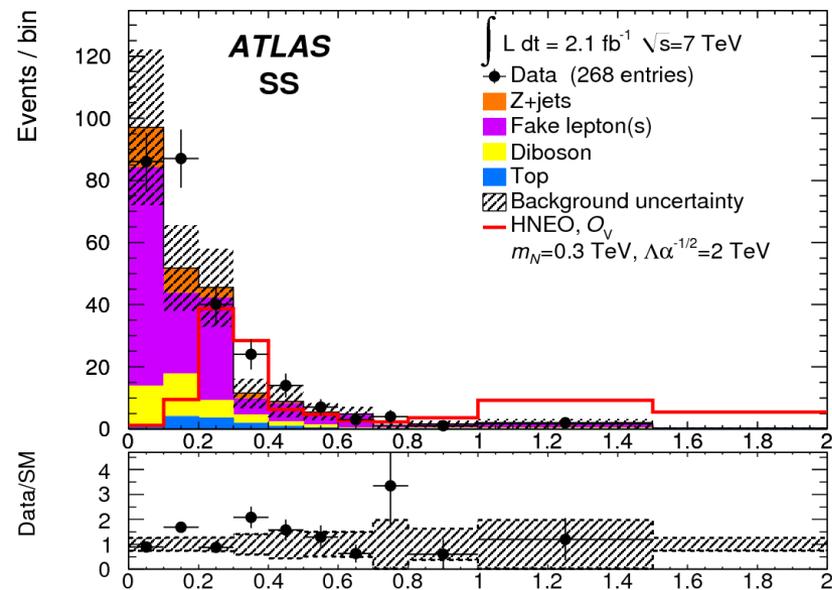
Dibosons ← MC

Charge misid (hard brem) ← OS MC with data-driven corrections

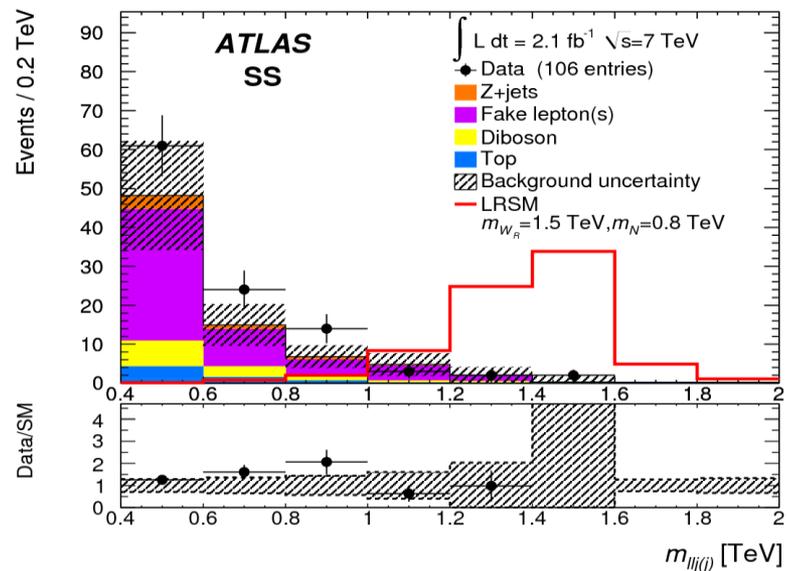
← Data-driven

← MC

← OS MC with data-driven corrections



Reconstructed N mass
 $m(lj) > 110 \text{ GeV}$

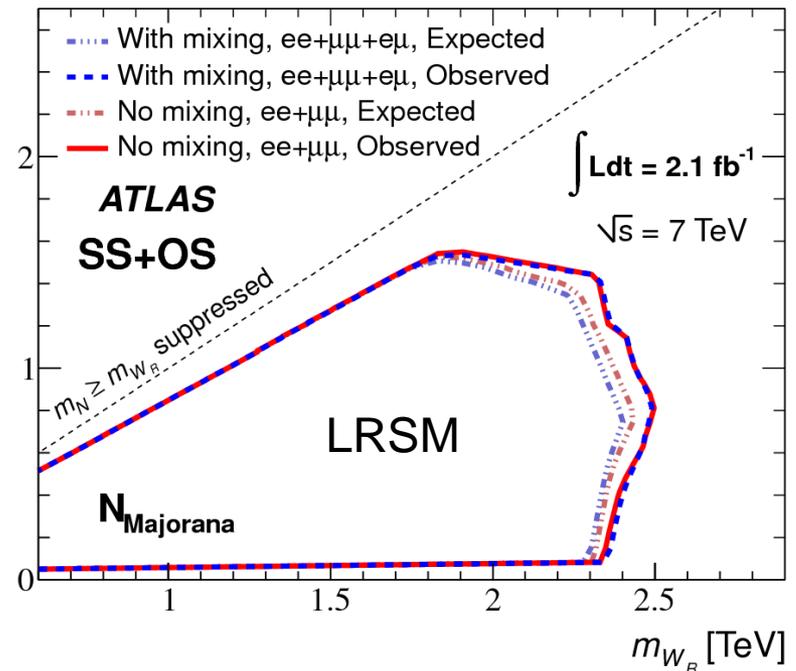
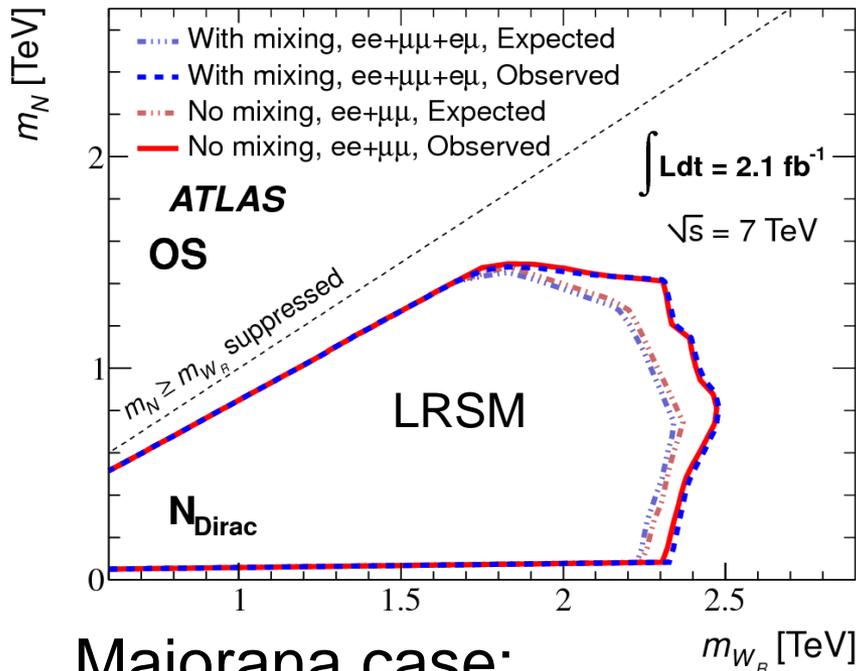


Reconstructed W_R mass
 $m(lj) > 110 \text{ GeV}$ and $m(lj(j)) \geq 400 \text{ GeV}$

No significant excess observed

W_R / Heavy neutrino Limits

Using ee , $e\mu$, and $\mu\mu$: 95% CL limits on both left-right symmetric model (LRSM) and the effective lagrangian approach, both Dirac and Majorana N



Majorana case:

$$M(W_R) > 1.8 \text{ (2.3) TeV for } \Delta M(W_R, N) > 0.3 \text{ (0.9) TeV}$$

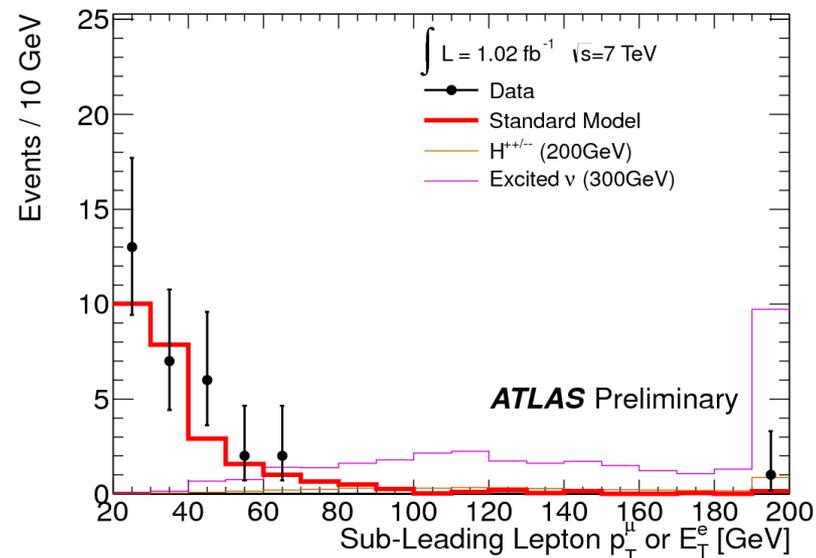
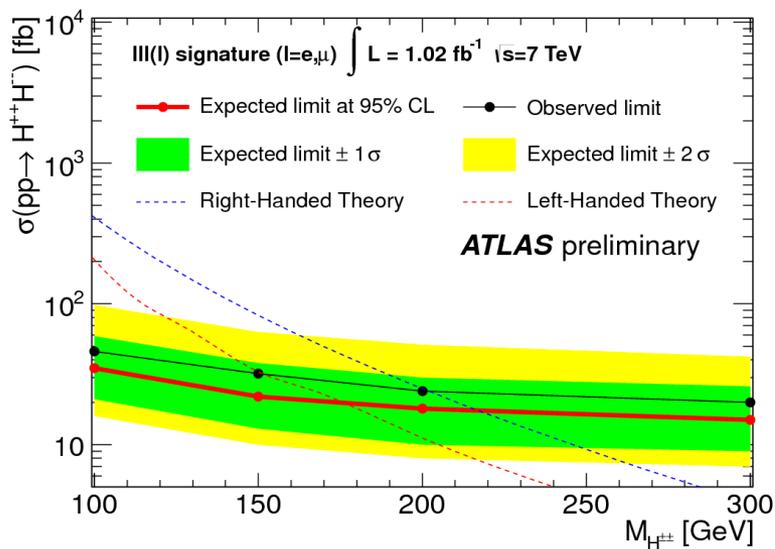
Multi-leptons

ATLAS-CONF-2011-158

Inclusive search for ≥ 3 high pt leptons, Z veto

Background dominated
by jets faking leptons
Data-driven estimate

Incl + tighter signal region



Fiducial obs (exp) limits:

$\sigma < 38$ (28) fb , $pt > 20$ GeV

$\sigma < 14$ (11) fb , $pt > 30$ GeV

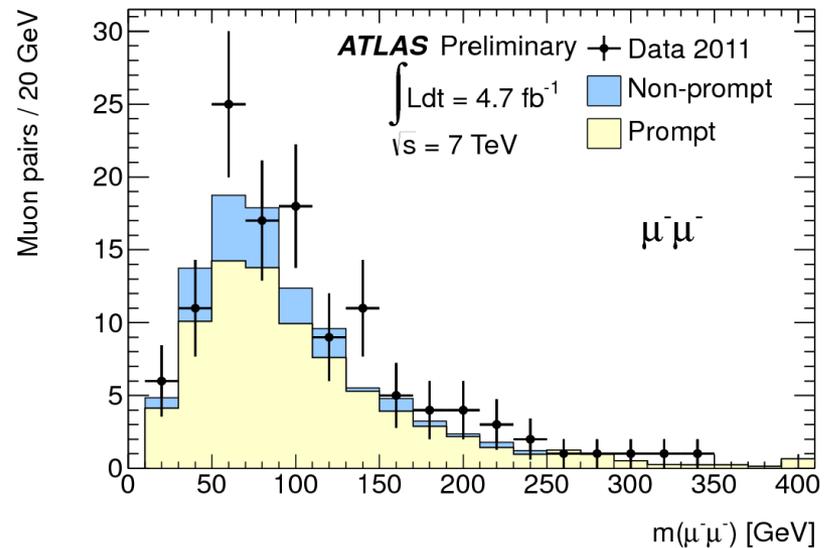
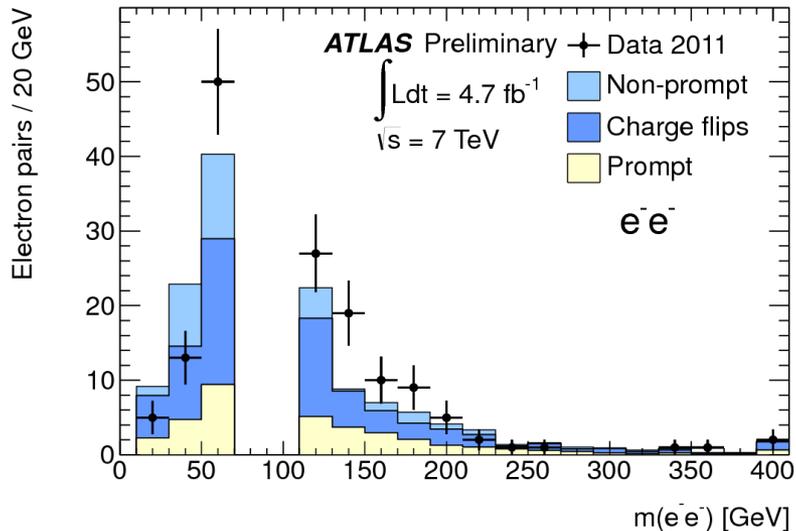
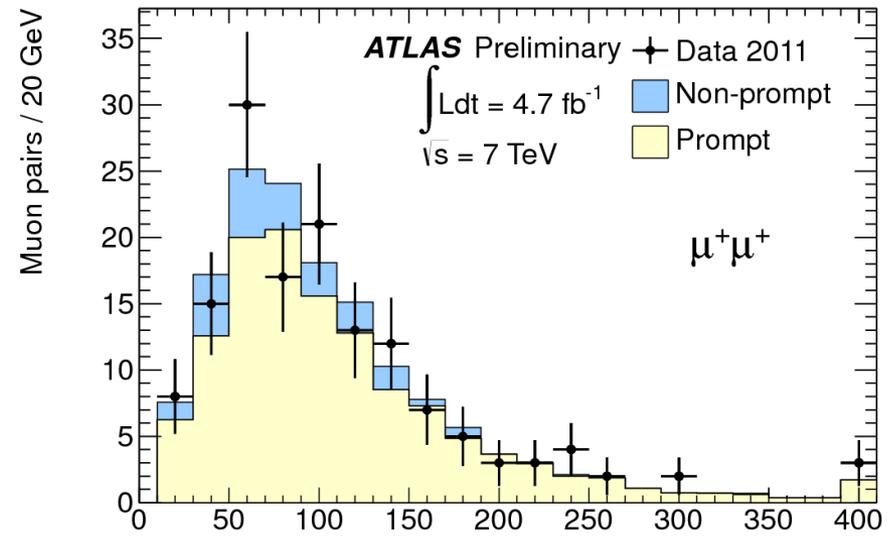
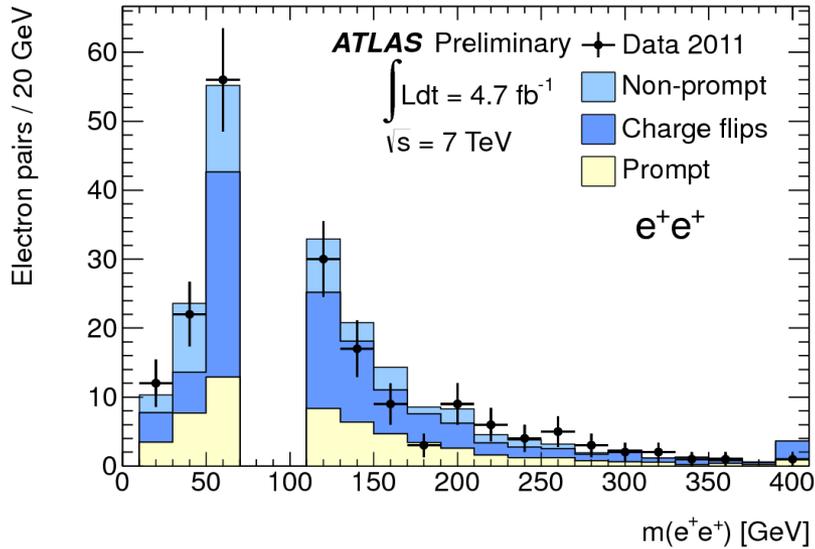
Excited ν_e : $\sigma < 41$ (34) fb for
 $m(\nu^*)=200$ (300) GeV

Conclusion and outlook

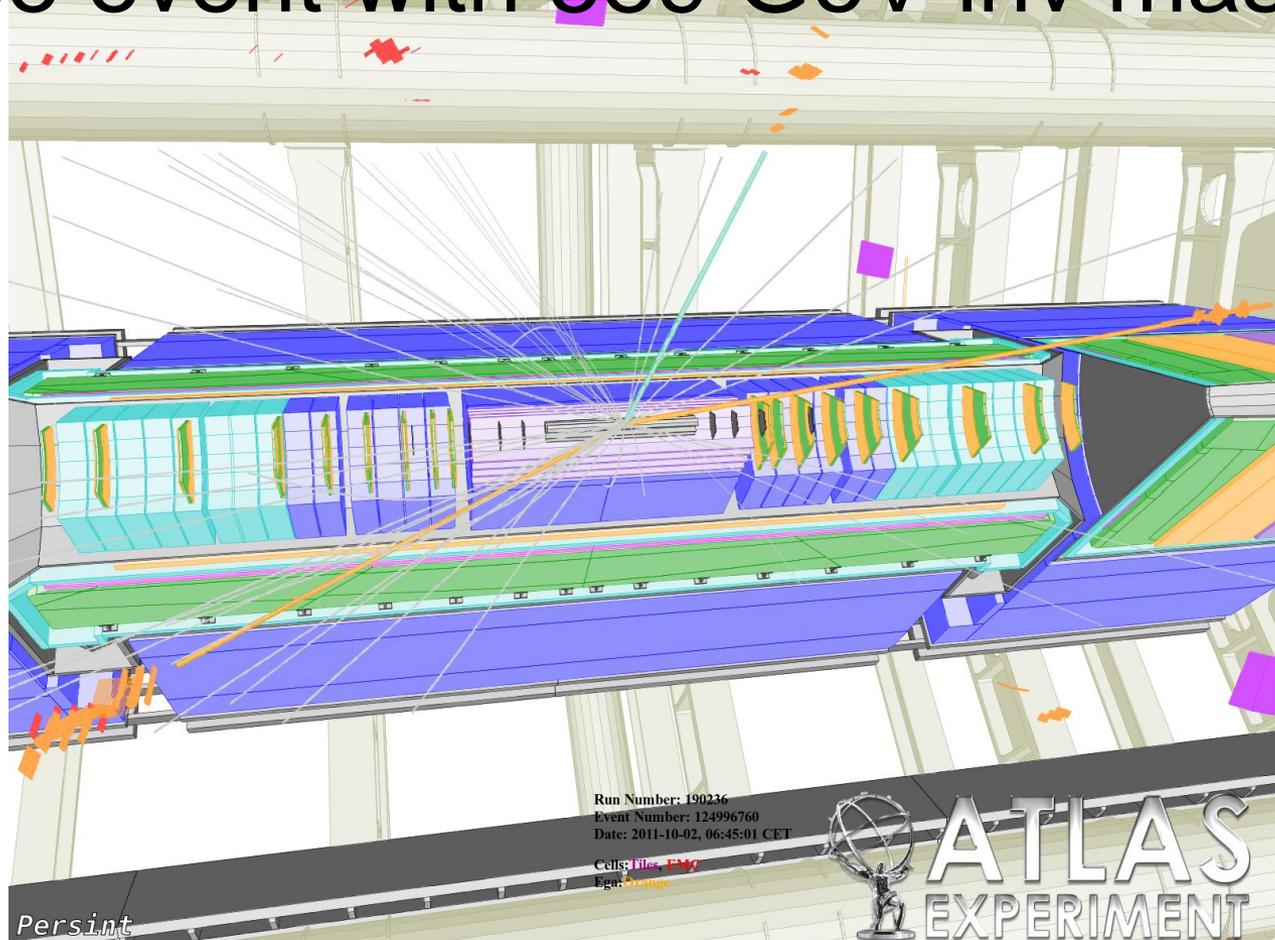
- ATLAS has searched for evidence of new physics in several multi / like-sign channels in 7 TeV:
- Like-sign dileptons:
 - Preliminary ee and $\mu\mu$ fiducial limits in bins of mass
 - Limits on $M(W_R)$ vs $M(N)$ for LRSM
- Multileptons
 - Fiducial limits on ≥ 3 leptons
 - Limits on $H^{++}H^-$ production
 - Limits on ν^* production for specific masses
- Unfortunately no claims for new physics so far.
- Fortunately updates + many more results in the pipeline!

Extras

Like-sign charge separated



LS ee event with 589 GeV inv mass



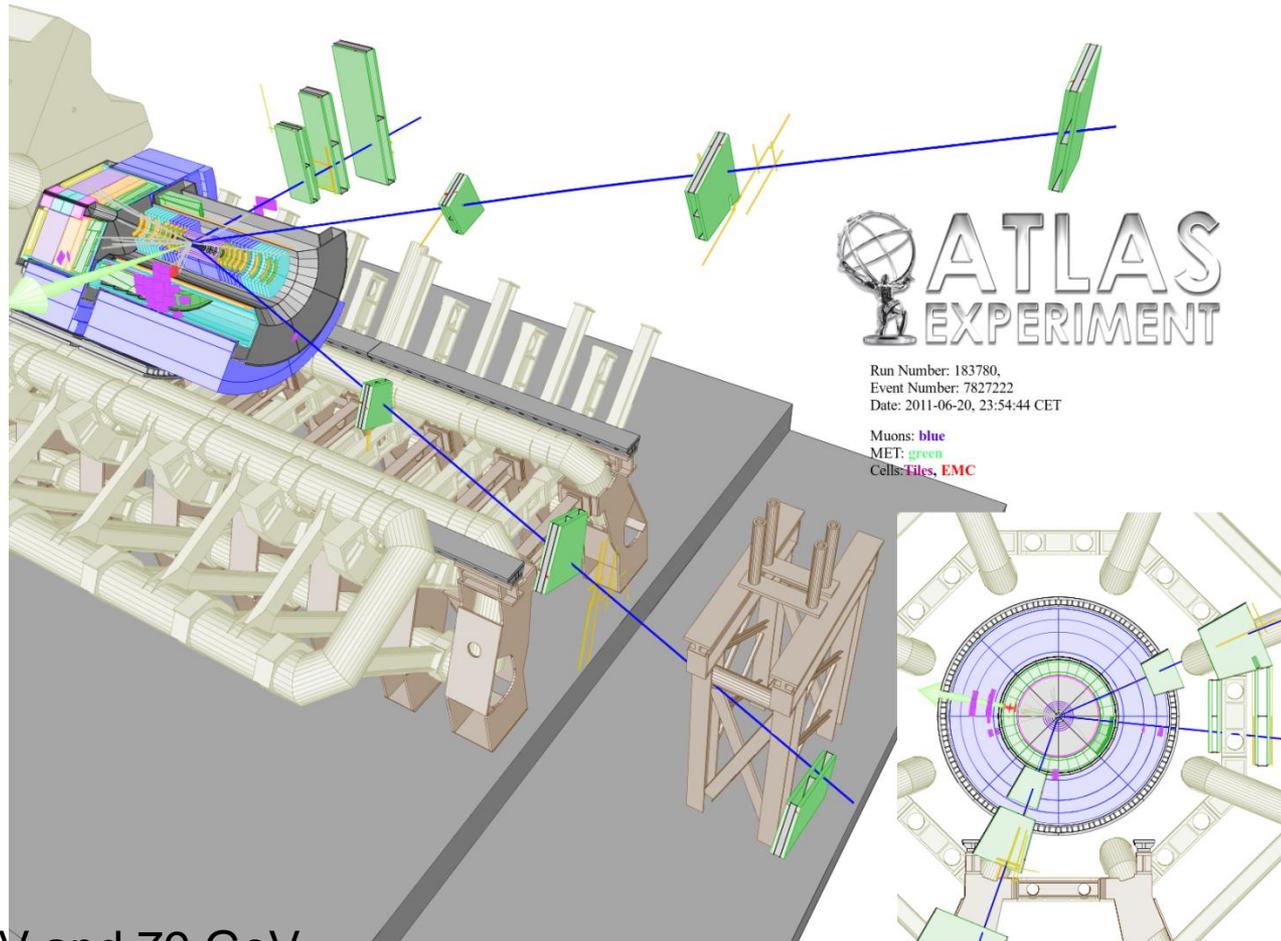
Electron ET : 196 GeV, and 50 GeV.

There is a third electron with an ET of 35 GeV, and charge -1.

There are two reconstructed jets with pT of 207 GeV and 30 GeV .

The missing transverse energy is 9 GeV with ϕ of -1.05.

LS $\mu+\mu+$ event with 522 GeV inv mass.



Muon p_T : 486 GeV and 79 GeV.

There is a third muon with p_T 32 GeV and charge -1.

There are two reconstructed jets of 394 GeV and 27 GeV.

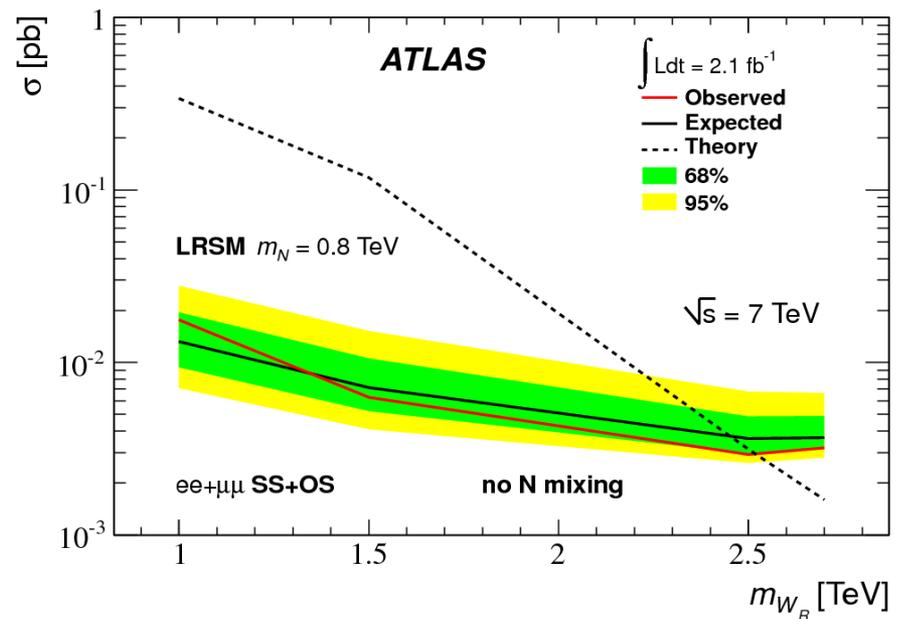
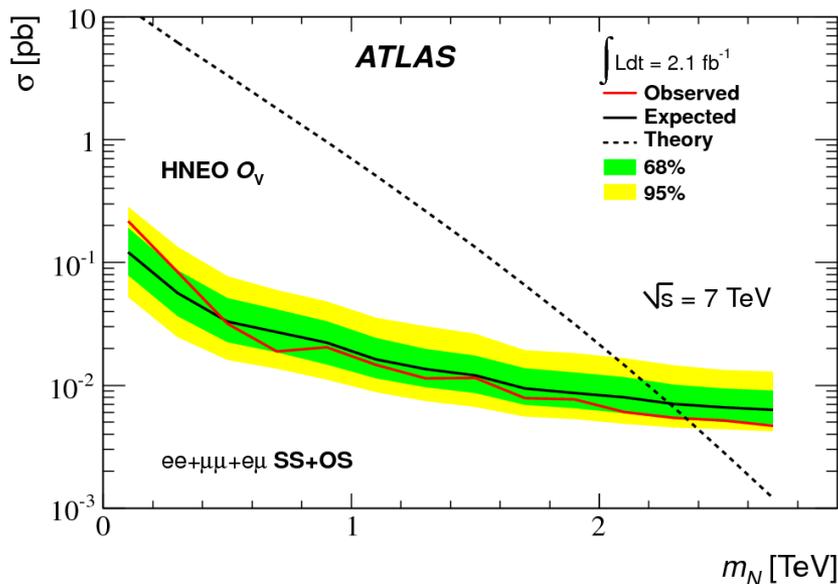
The missing transverse energy, shown as a green arrow, is 93 GeV with ϕ of 0.22.

W_R / heavy neutrino

1D limits on masses:

2350 GeV for HNEO model w $\Lambda/\sqrt{\alpha} = 1\text{TeV}$

2459 GeV for LRSM w $m(W_R) = 800\text{ GeV}$



W_R /heavy neutrino

Table 2 Summary of the expected background yields and observed numbers of events for the SS dilepton channels. The top part of the table shows the numbers obtained for events with two leptons, ≥ 1 jet and $m_{\ell\ell} > 110$ GeV. The bottom part of the table shows the numbers for the final LRSM selection, where an additional requirement $m_{\ell\ell(j)} \geq 400$ GeV is imposed. The quoted uncertainties include statistical and systematic components, excluding the luminosity uncertainty of $\pm 3.7\%$. The latter is relevant for all backgrounds except for the fake lepton(s) background, which is measured using data.

Physics Processes	$e^\pm e^\pm$		$\mu^\pm \mu^\pm$			$e^\pm \mu^\pm$			Total	
$Z/\gamma^* + \text{jets}$	26.1	± 5.6	0.0	± 1.6	0	1.2	± 0.7	27	± 6	
Diboson	12.7	± 2.3	7.2	± 1.7		18.8	± 3.0	39	± 6	
Top	5.8	± 1.3	0.7	± 0.3		6.8	± 1.6	13	± 3	
Fake lepton(s)	93.6	± 35.7	3.1	± 1.6		53.8	± 20.3	151	± 50	
Total Background	138.3	± 36.5	11.0	± 2.9	2.5	80.7	± 20.8	230	± 52	
Observed events	155		14			99		268		
	$m_{\ell\ell(j)} \geq 400$ GeV									
Total Background	48.4	± 16.1	4.4	± 2.1	1.3	24.6	± 7.6	77	± 21	
Observed events	59		8			39		106		

Multileptons

Table 3: The estimated Standard Model background and NP yields in the nominal and tighter signal regions, together with the observed event counts in data. Where two uncertainties are given, the first is from data statistics, and the second is from systematic uncertainties.

Process	Yield (nominal signal selection)	Yield (tighter signal selection)
Z +jets	$7.9 \pm 3.2 \pm 2.4$	1.0 ± 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 ± 0.6	0 ± 0.6
Double Fakes	$5.1 \pm 1.1^{+1.7}_{-1.4}$	$0.2 \pm 0.2 \pm 0.0$
Diboson	3.6 ± 0.4	1.5 ± 0.2
Single Top	0.1 ± 0.1	0.0 ± 0.0
$t\bar{t} + W/Z$	0.5 ± 0.0	0.3 ± 0.0
Total Background	$25.9 \pm 3.8 \pm 4.3$	$4.9 \pm 1.6 \pm 0.9$
$H^{++/--}$ (LH $m_H=200$ GeV)	4.5 ± 0.2	4.2 ± 0.2
Data	31	6

Other results with like-sign dimuons

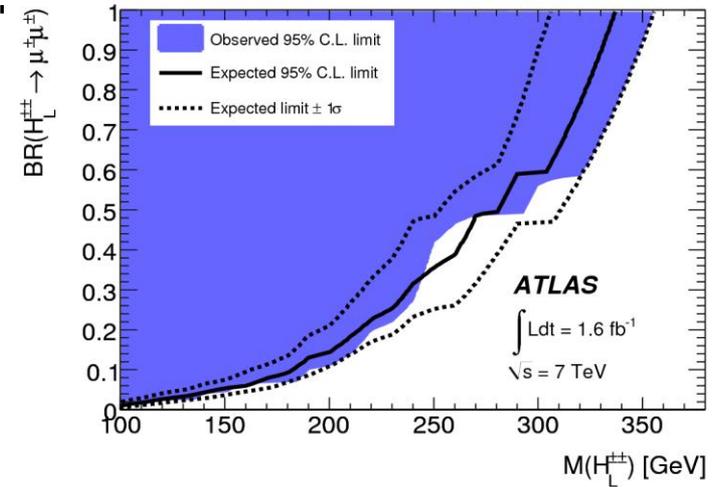
- Limits on $H^{++}H^{--}$ production:

Assuming 100% BR to $\mu\mu$

$M(H_R) > 375$ GeV

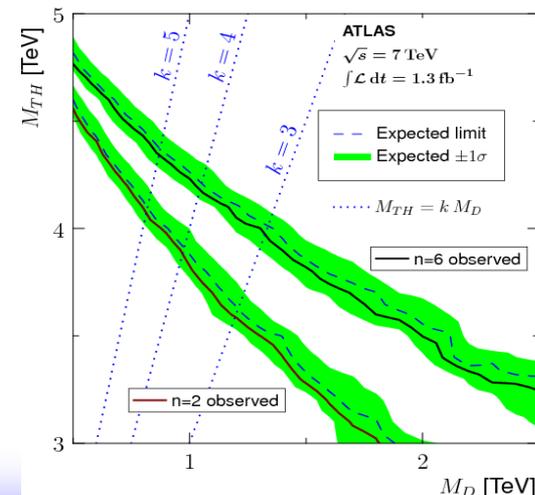
$M(H_L) > 295$ GeV @ 95% CL

[*Phys. Rev. D 85, 032004 \(2012\)*](#)



- Limits on black hole production: model-independent limit of 0.018 pb

[*Phys.Lett. B709 \(2012\) 322-340*](#)



Leptons in ATLAS

▶ Inner Tracking Detector (ID)

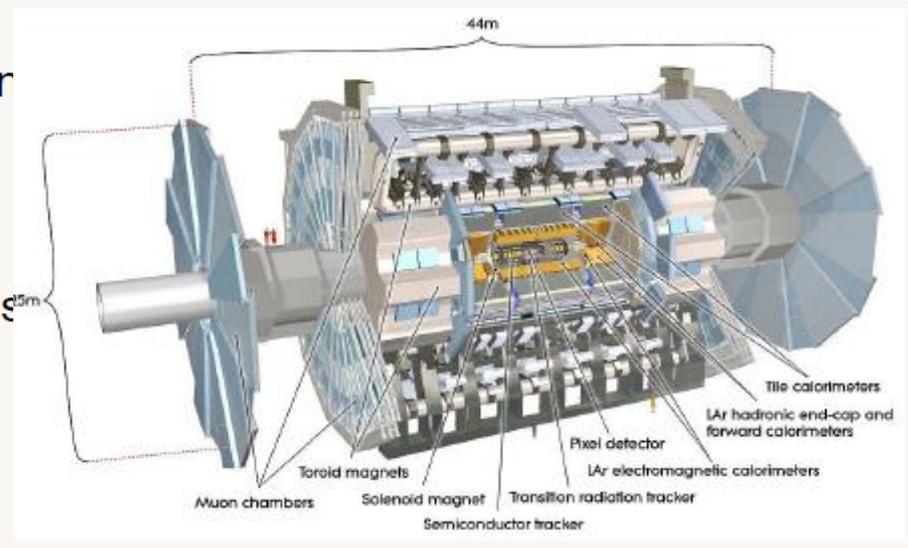
- ▶ Silicon pixels, silicon strips, and transition radiation detectors, covering $|\eta| < 2.5$
- ▶ Immersed in a homogeneous solenoidal magnetic field
- ▶ Reconstructs charged tracks and vertices

▶ Calorimeter

- ▶ Liquid argon-lead sampling for electromagnetic part
- ▶ Scintillating tiles-iron sampling (central), Liquid argon-copper/tungsten ($|\eta| > 1.7$)
- ▶ Reconstructs $3d$ particle showers

▶ Muon Spectrometer (MS)

- ▶ Immersed in a toroidal magnetic field
- ▶ Resistive-plate and thin-gap trigger chambers, and three sets of drift tubes and cathode strip chambers
- ▶ Reconstructs high precision muon tracks



Electrons:

EM clusters associated with tracks
Shower shape + track quality cuts

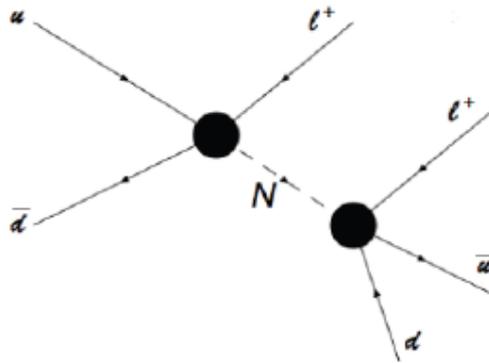
Muons:

Combined tracks from independent ID and MS tracks
Track quality cuts

W_R /Heavy neutrinos

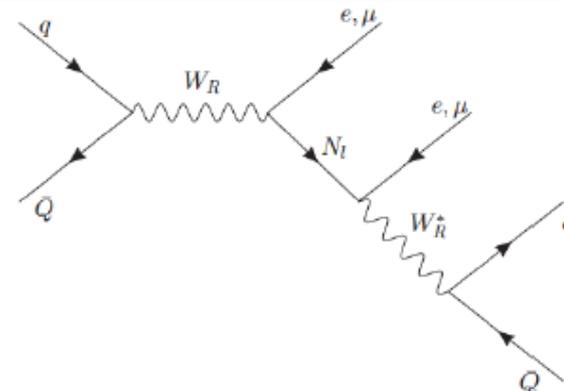
[arXiv:1203.5420](https://arxiv.org/abs/1203.5420)

- Non-zero neutrino mass could be explained by for instance Seesaw mechanism
 - predicts light ν and heavy neutrino N .
- If Majorana particles: like-sign leptons in final state
Analysis: SS (Majorana only) or OS (Dirac, Majorana)
high pt dileptons and ≥ 1 jet



Lagrangian of Effective Operator (HNEO)

- ▶ Based on effective operators
 - Vector (V), Scalar (S1, S2 and S3)
- ▶ Sensitivity varies with $\alpha^{-1/2}\Lambda$ vs N mass
 - α = heavy N - lepton coupling
 - Λ = new physics scale



Left-Right Symmetric Model (LRSM)

- ▶ Extend SM EW gauge group
 - new force carriers : W_R, Z'
- ▶ Heavy N produced in decay of W_R
- ▶ mixing and no-mixing scenarios
 - only electron and muon considered