Charged Lepton Flavour Violation/Lepton Number Violation searches with the ATLAS experiment

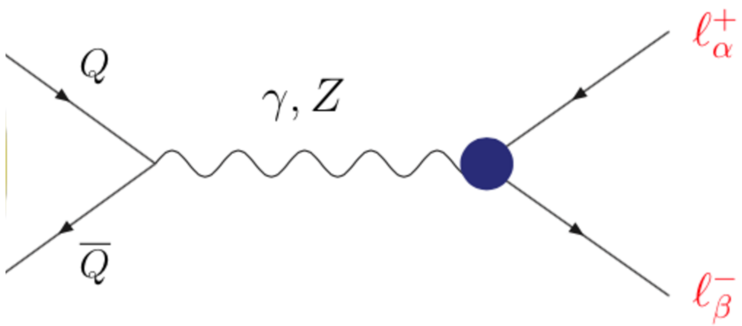
Stefania Xella
Niels Bohr Institute, Copenhagen University

on behalf of the ATLAS collaboration

Challenging the accidental symmetries of the Standard Model

- Lepton flavour (LF) number conservation is an accidental symmetry of the Standard Model (SM), so is the total Lepton Number (LN)

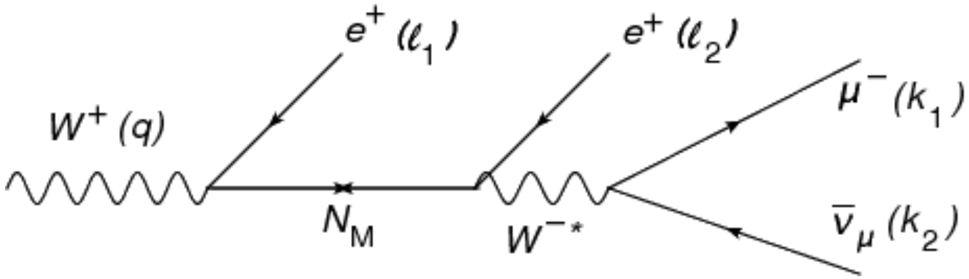
- Neutrino processes violate LF number (LFV). Charged leptons perhaps too (CLFV)?



CLFV

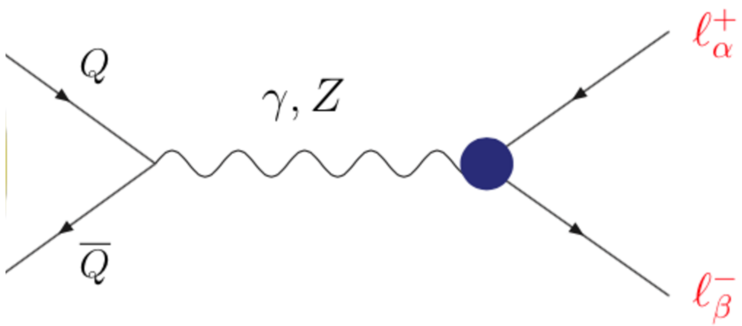
Challenging the accidental symmetries of the Standard Model

- Lepton flavour (LF) number conservation is an accidental symmetry of the Standard Model (SM), so is the total Lepton Number (LN)



LNV

- Neutrino processes violate LF number (LFV). Charged leptons perhaps too (CLFV)?

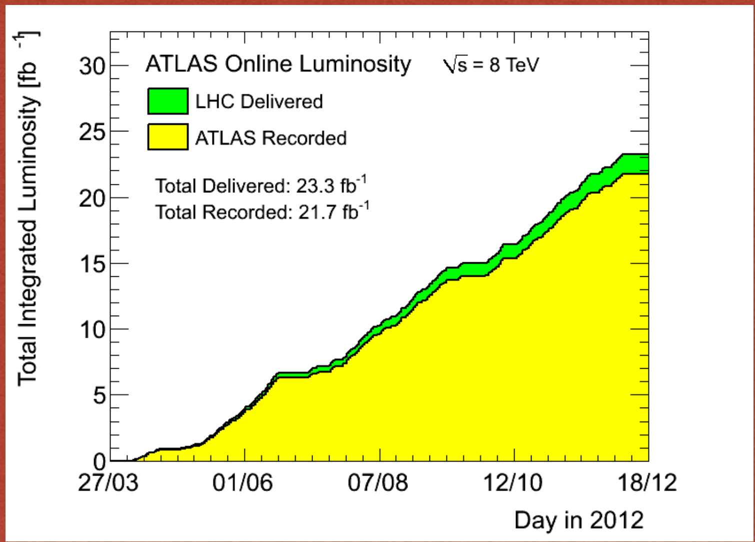


CLFV

- To explain neutrino masses, Majorana neutrinos are added to the SM and allow See-Saw mechanism

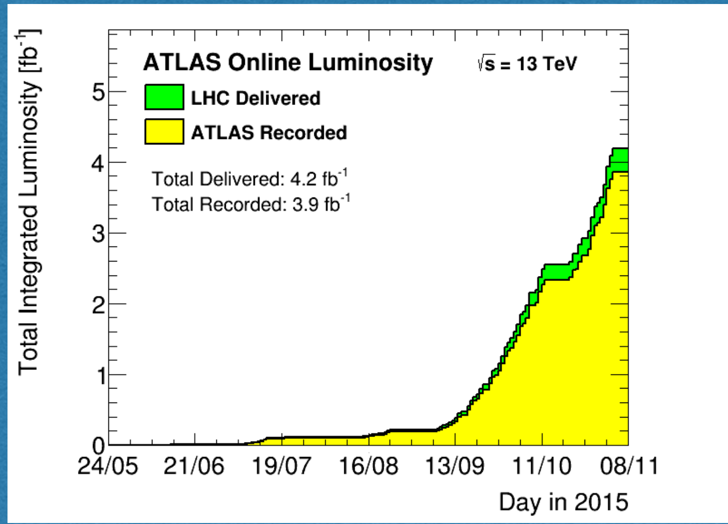
- processes with Majorana neutrinos represent an example of processes violating total lepton number (LNV)

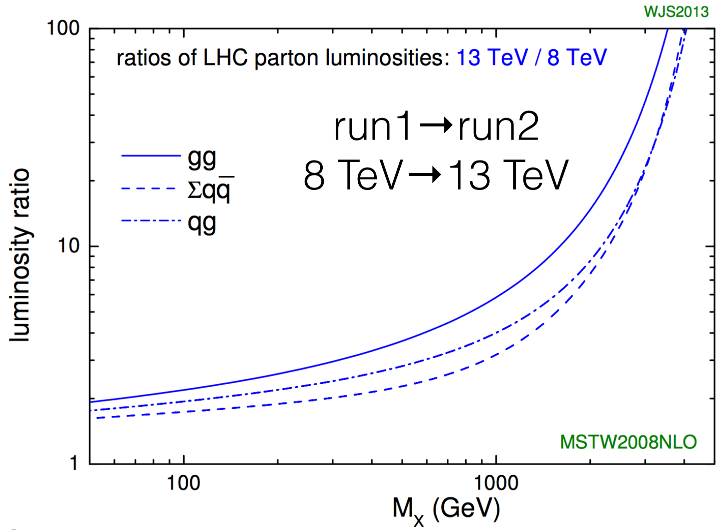
LHC Run1 & Run2

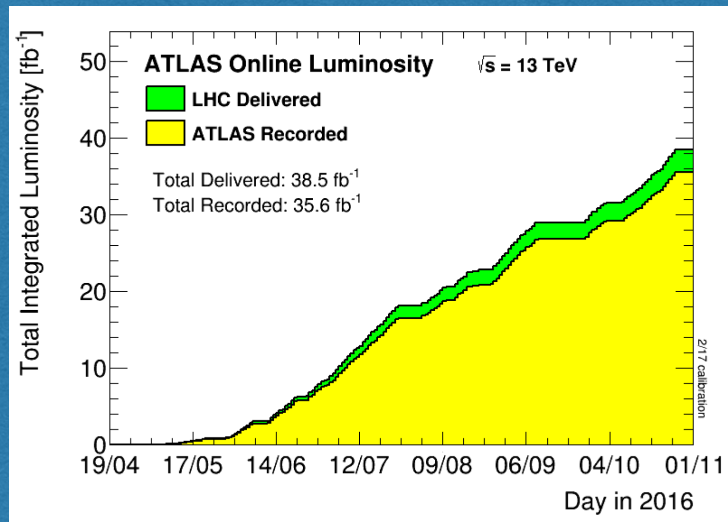


Run 1

Run 2



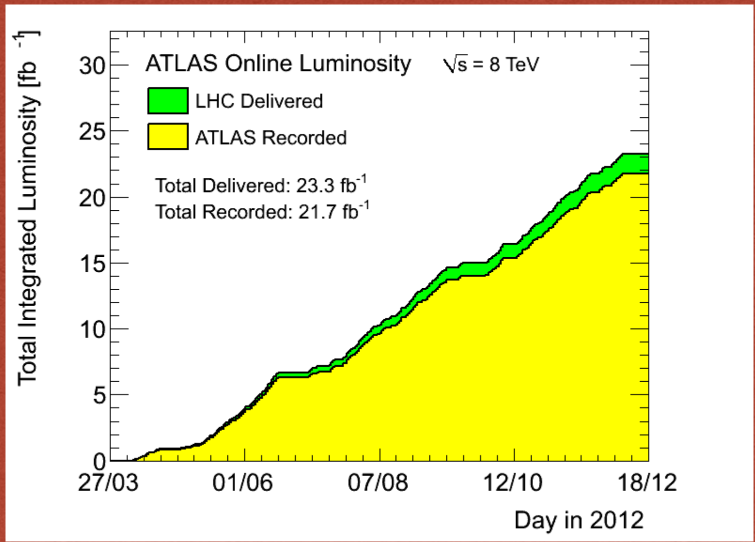




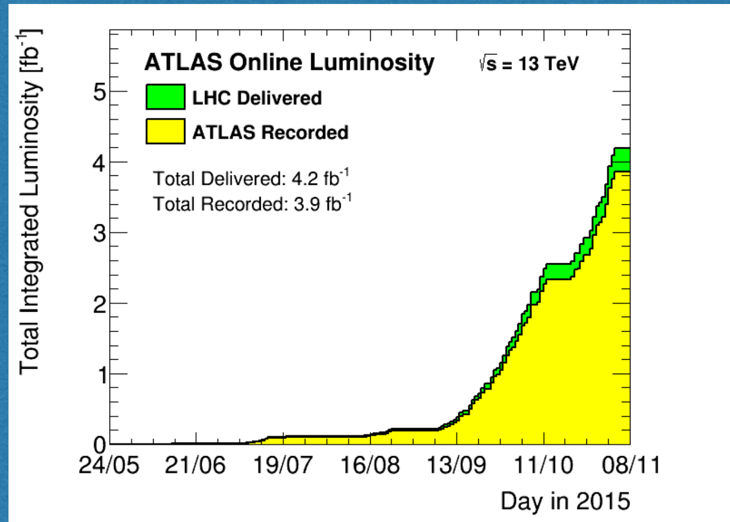
LHC provides huge dataset, hence a great chance to test CLFV and LNV processes.

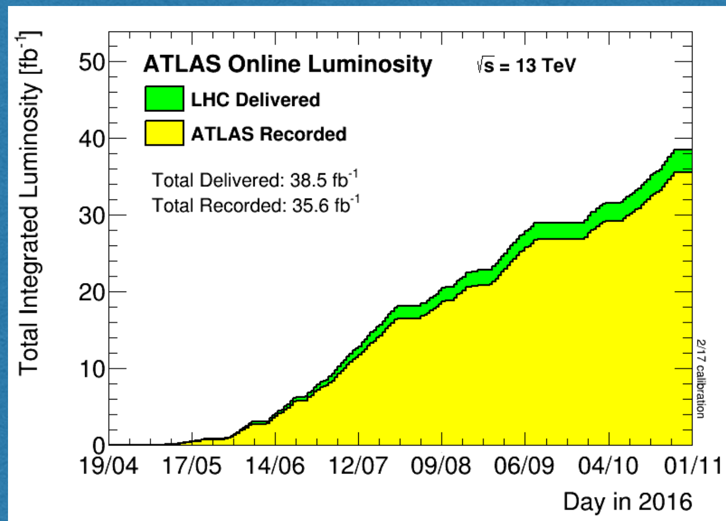
LHC Run1 & Run2

Run 1



Run 2

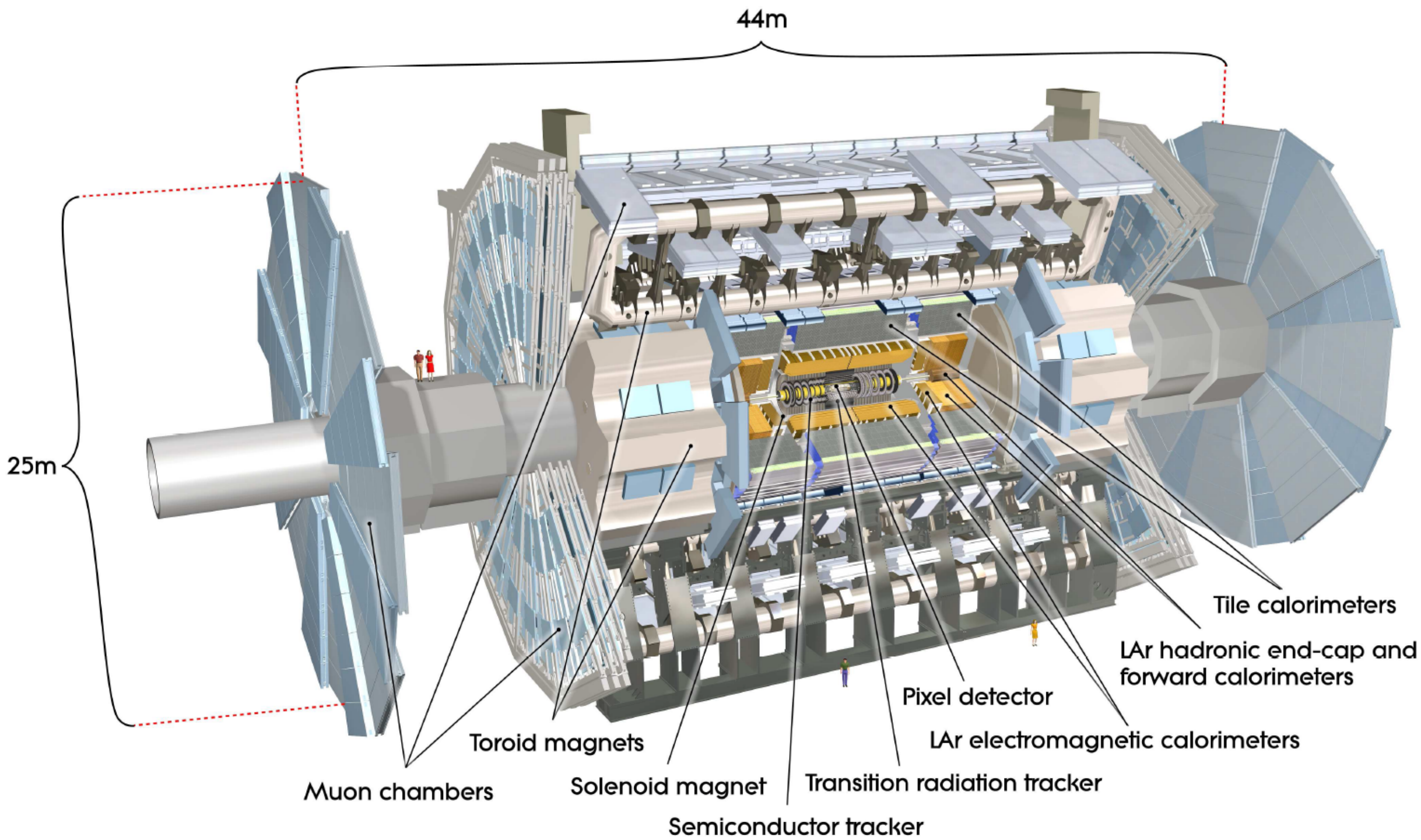




when available,
Run 2 results will be
shown, even if from a partial
dataset, since more
powerfull than full Run1

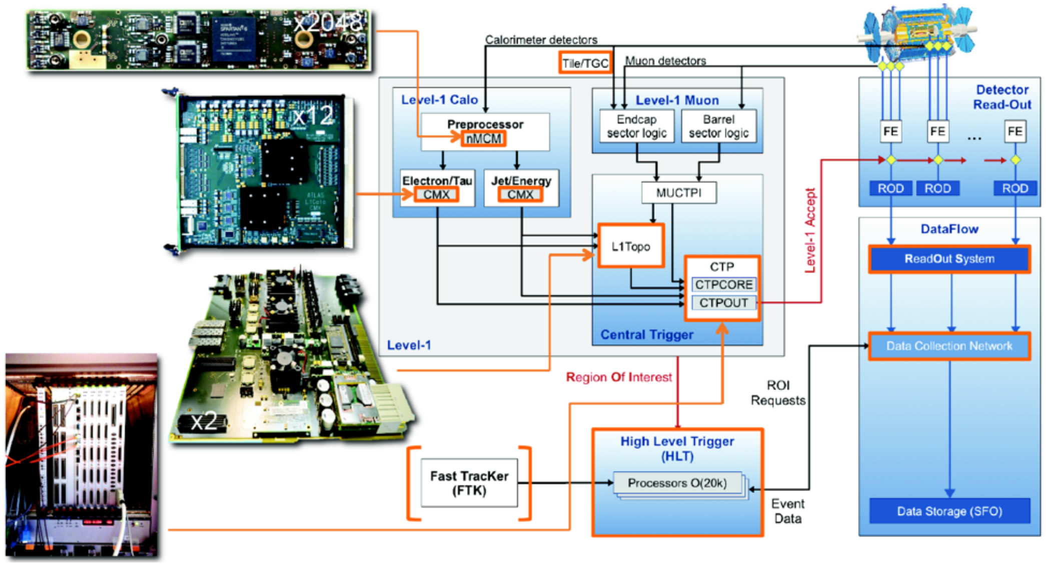
LHC provides huge dataset, hence a great chance to test CLFV and LNV processes.

ATLAS experiment



No major changes between Run 1 and 2 in detector components. BUT: one pixel layer added , it increase track reconstruction and secondary vertex reconstruction quality significantly, and b-tagging performance improves significantly as a consequence

ATLAS trigger

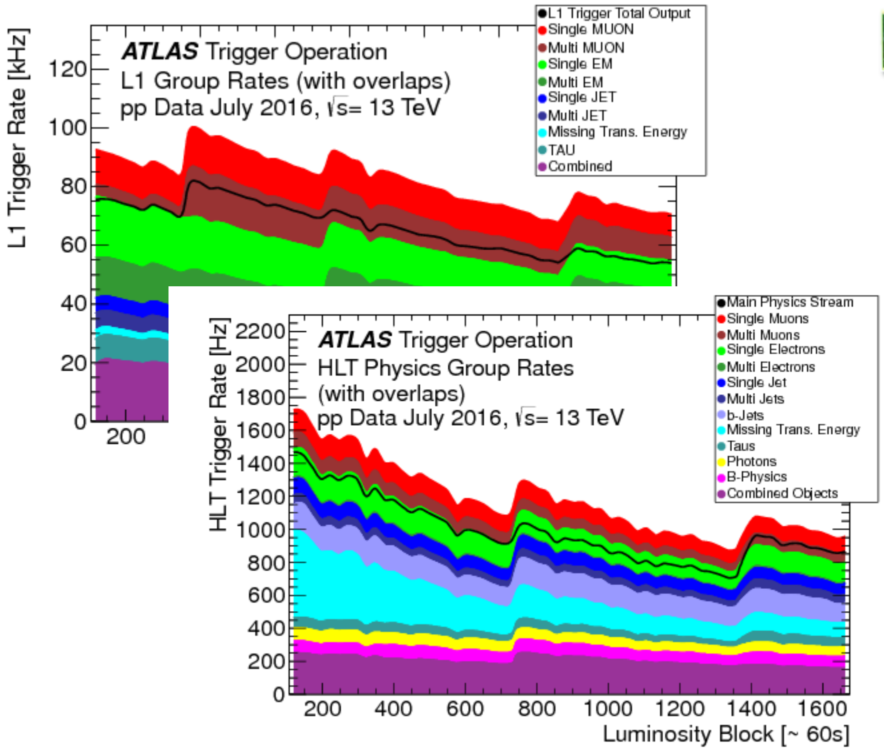


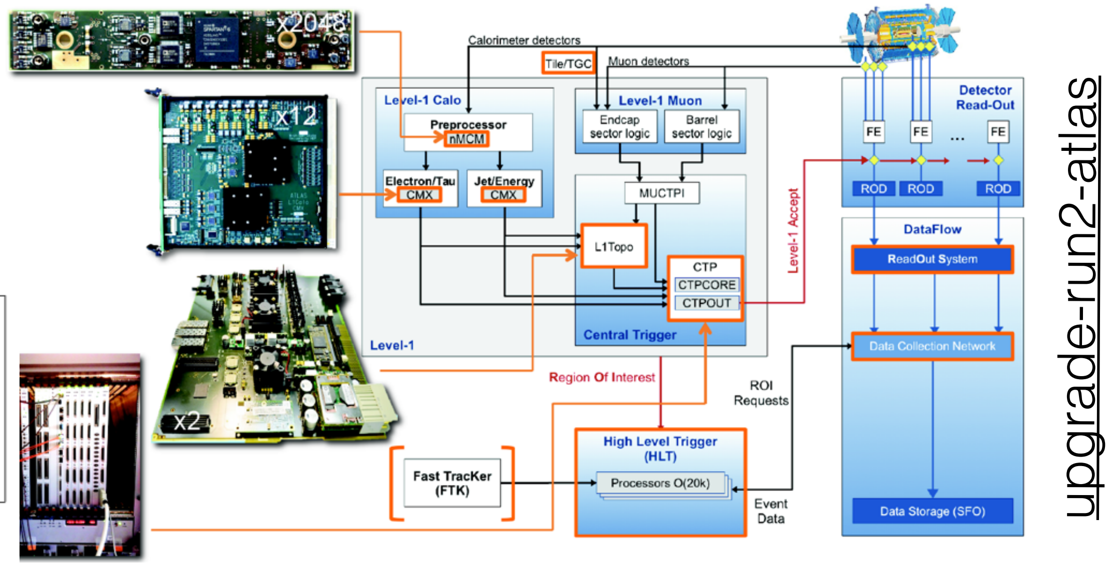
upgrade-run2-atlas

orange : upgraded components between run1 and run2

- trigger = key factor in sensitivity of all analyses
- upgrade during Run1-2 shutdown: increase inputs and flexibility, add robustness to pile-up, increase efficiency at L1 by using topology, increase number of processors, …

ATLAS trigger





orange : upgraded components between run1 and run2

- trigger = key factor in sensitivity of all analyses
- upgrade during Run1-2 shutdown: increase inputs and flexibility, add robustness to pile-up, increase efficiency at L1 by using topology, increase number of processors, …
- Output rate doubled at HLT in Run 2
- Wide set of triggers, to achieve high efficiency for many possible final states
- Overall great efficiency for searches of rare phenomena

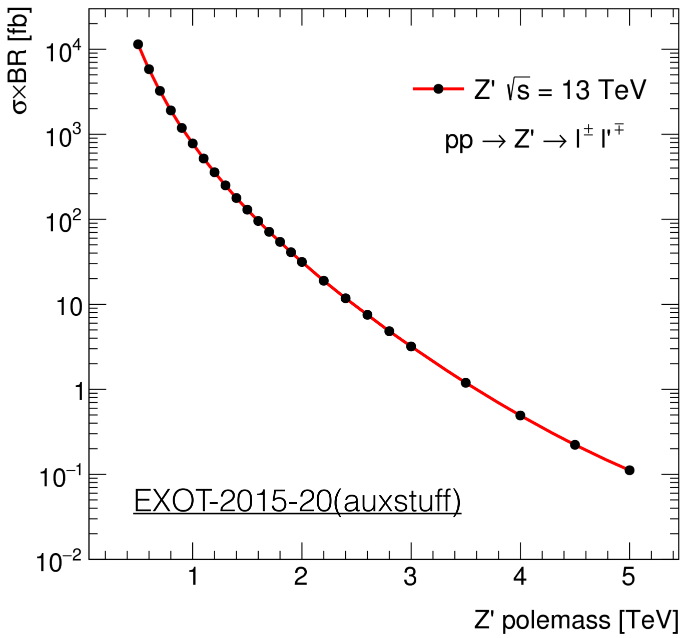
Outline

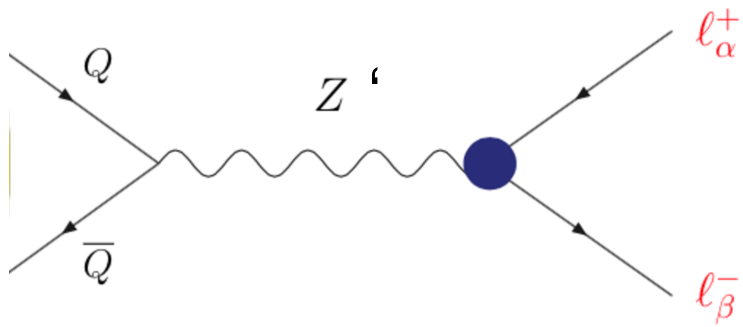
- CLFV in Z’ decays (Run 2, partial dataset)
- CLFV in Z, H boson decays (Run 1, full dataset)
- CLFV in Double Charged Higgs decays (Run 2, partial dataset)
- CLFV $\tau \rightarrow \mu\mu\mu$ decay (Run 1, full dataset)
- LNV Heavy Neutral Leptons processes (Run 1, full dataset)

CLFV Z' decays

3.2 fb^{-1} 2015

Eur. Phys. J. C76 (2016) 541



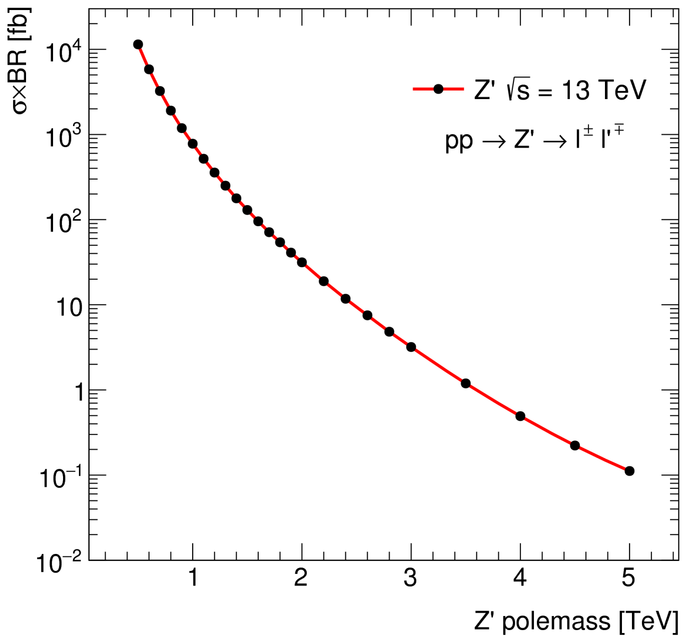


basic selection very simple
two leptons of different flavour, opposite charge

CLFV Z' decays

3.2 fb^{-1} 2015

Eur. Phys. J. C76 (2016) 541



basic selection very simple
two leptons of different flavour, opposite charge

region : validation signal

Process	$m_{e\mu} < 600$ GeV	$m_{e\mu} > 600$ GeV
Top quark	1190 ± 140	22 ± 5
Diboson	159 ± 17	4.9 ± 0.9
Multi-jet and W+jets	55 ± 11	2.7 ± 1.7
$Z/\gamma^* \to \ell\ell$	14.5 ± 2.0	0.18 ± 0.04
Total SM background	1410 ± 150	30 ± 7
SM+Z' ($M_{Z'}$ = 2 TeV)	-	75 ± 13
SM+$\tilde{\nu}_\tau$ ($M_{\tilde{\nu}_\tau}$ = 2 TeV) **RPV SUSY**	-	40 ± 8
SM+QBH RS n = 1 (M_{th} = 2 TeV)	-	44 ± 9
Data	1463	25

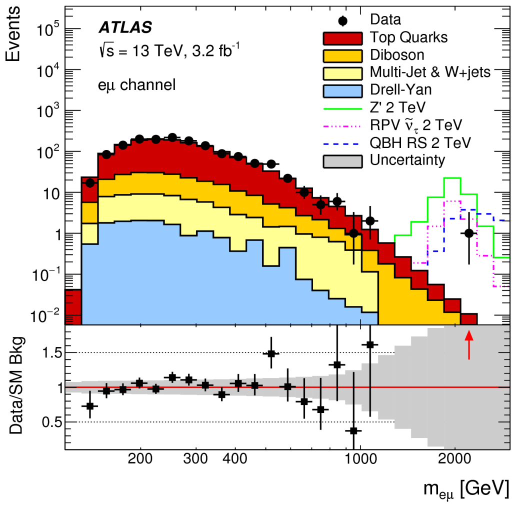
(a) $e\mu$ channel

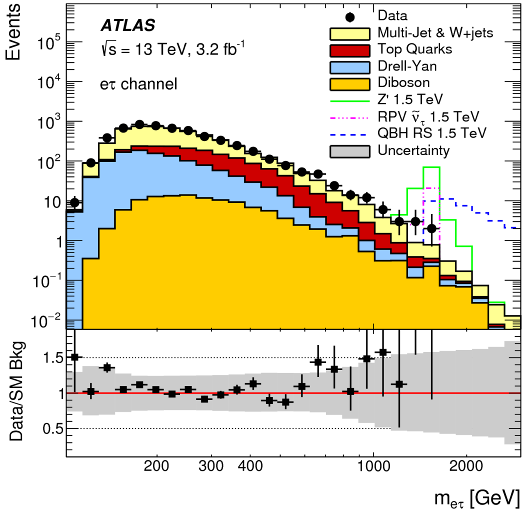
Process	$m_{e\tau} < 600$ GeV	$m_{e\tau} > 600$ GeV
Top quark	790 ± 190	25 ± 9
Diboson	109 ± 26	6.2 ± 1.9
Multi-jet and W+jets	3200 ± 800	45 ± 14
$Z/\gamma^* \to \ell\ell$	1030 ± 240	5.2 ± 1.4
Total SM background	5200 ± 1300	81 ± 25
SM+Z' ($M_{Z'}$ = 1.5 TeV)	-	185 ± 34
SM+$\tilde{\nu}_\tau$ ($M_{\tilde{\nu}_\tau}$ = 1.5 TeV) **RPV SUSY**	-	105 ± 27
SM+QBH RS n = 1 (M_{th} = 1.5 TeV)	-	122 ± 28
Data	5416	111

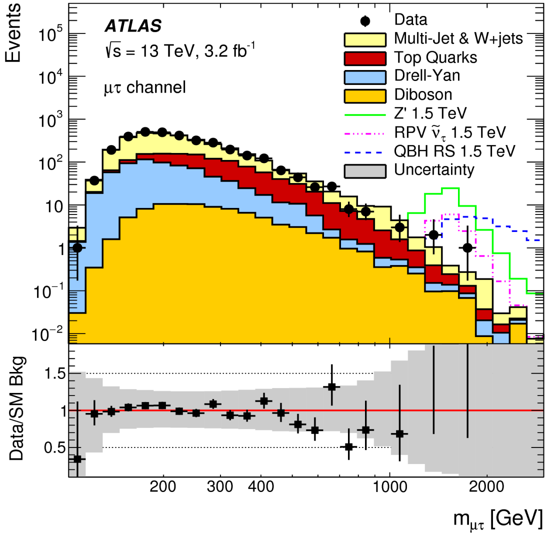
(b) $e\tau$ channel

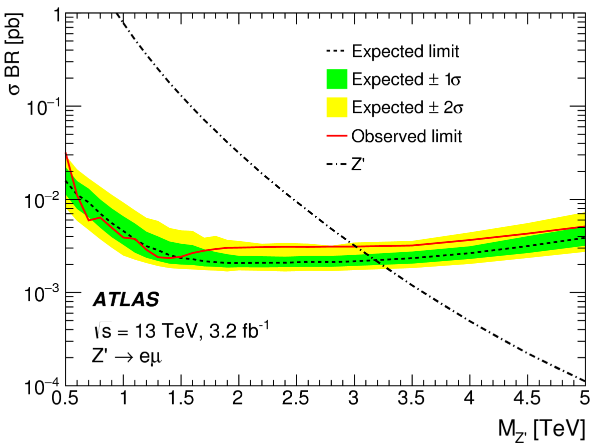
includes systematic and statistical error
(largest contributions >10%: fake lepton background when using hadronic taus; theoretical uncertainties(PDF))

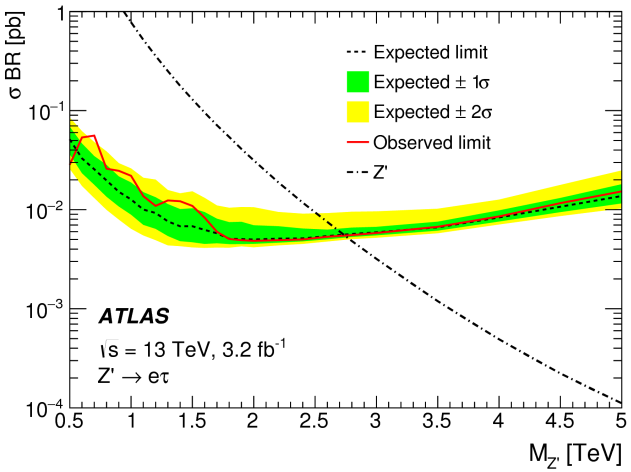
CLFV Z' decays - Results

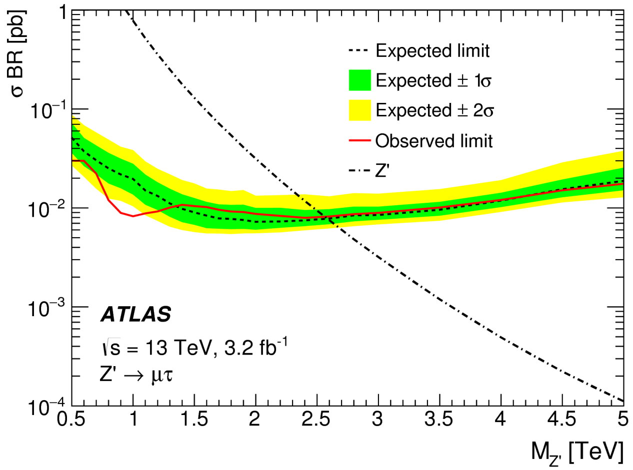




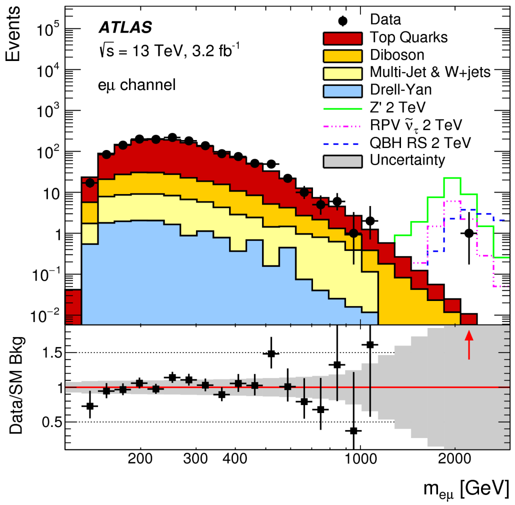


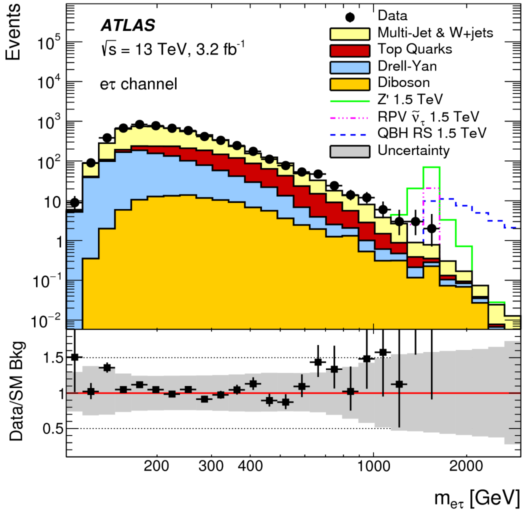


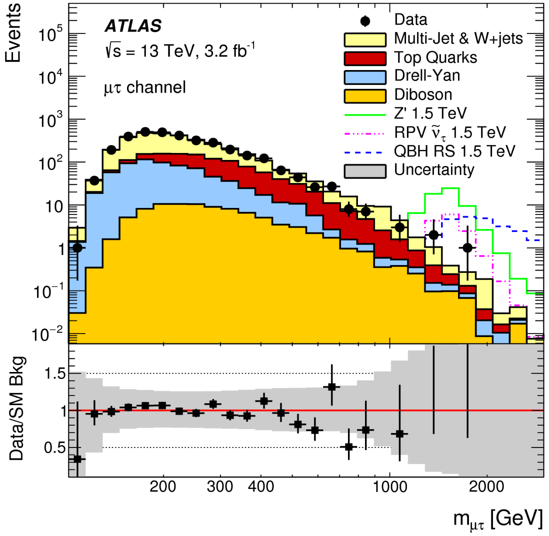


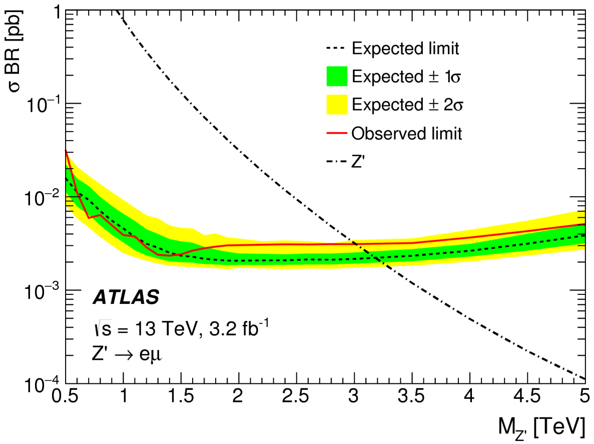


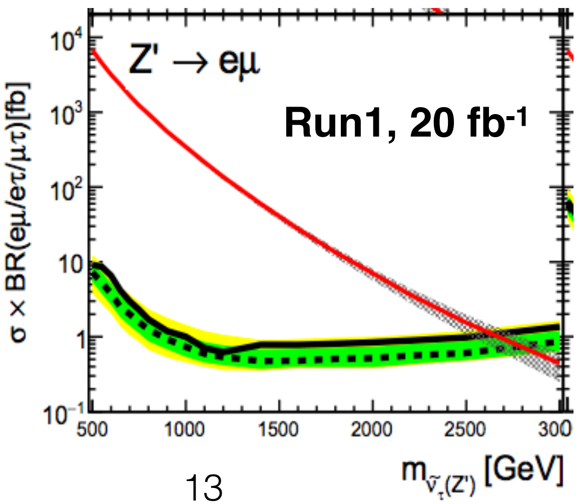
CLFV Z' decays : Results











already superseeded with just 3 fb^{-1} Run2

shows how powerfull the full Run2 dataset will be

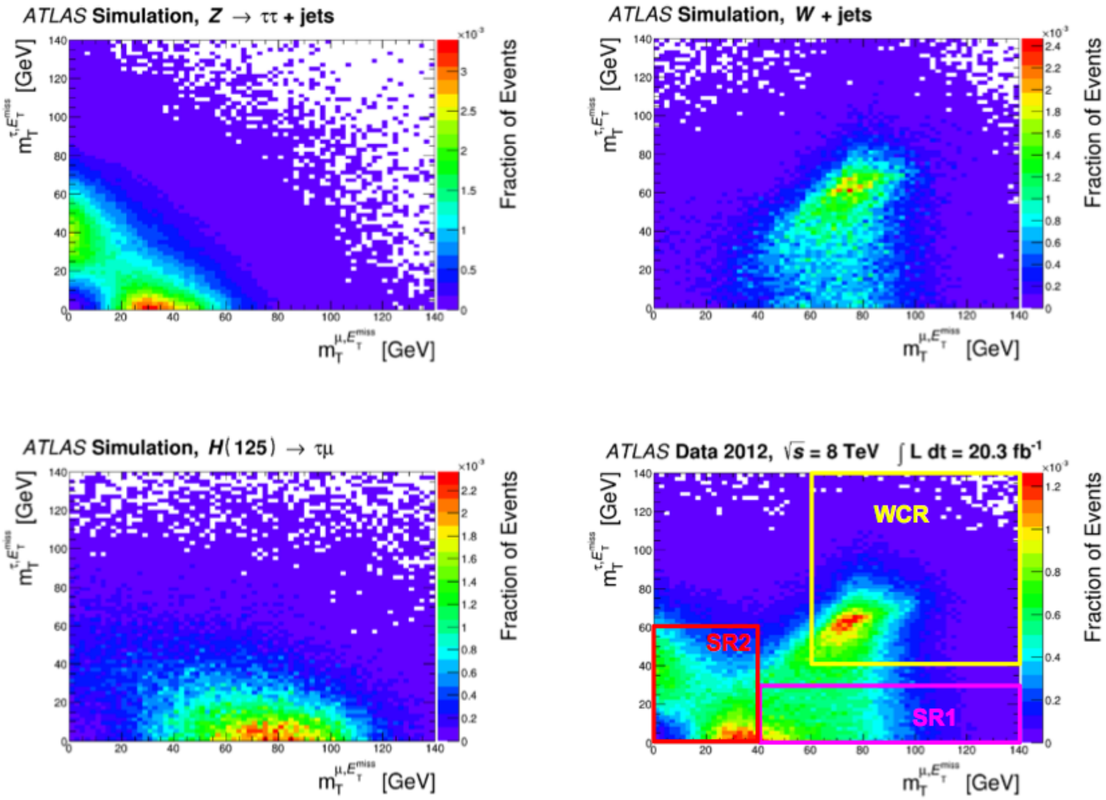
CLFV Higgs decays

20.3 fb^{-1}, 2012

JHEP 11 (2015) 211

Eur. Phys. J. C (2017) 77:70

H→eτ, μτ



$$m_T = \sqrt{2 p_T^{\ell} E_T^{\text{miss}} (1 - \cos \Delta\phi)},$$

signal regions SR1, SR2 defined in transverse mass 2-D region

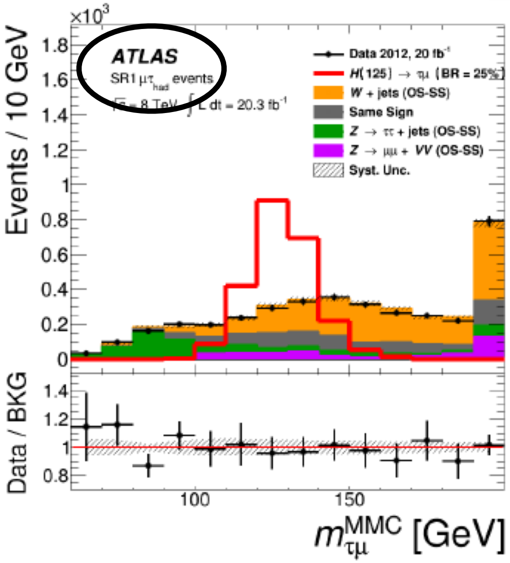
CLFV Higgs decays

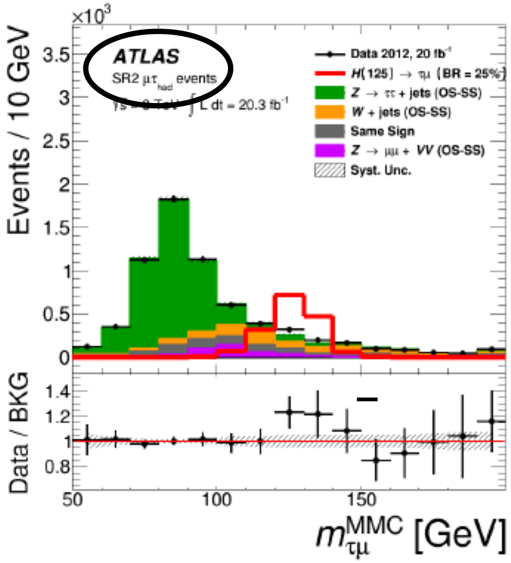
20.3 fb^{-1}, 2012

H→μτ

[JHEP 11 (2015) 211](#)

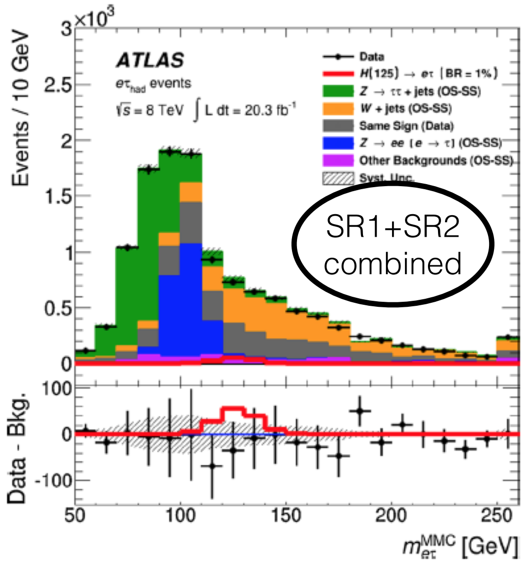
[Eur. Phys. J. C (2017) 77:70](#)





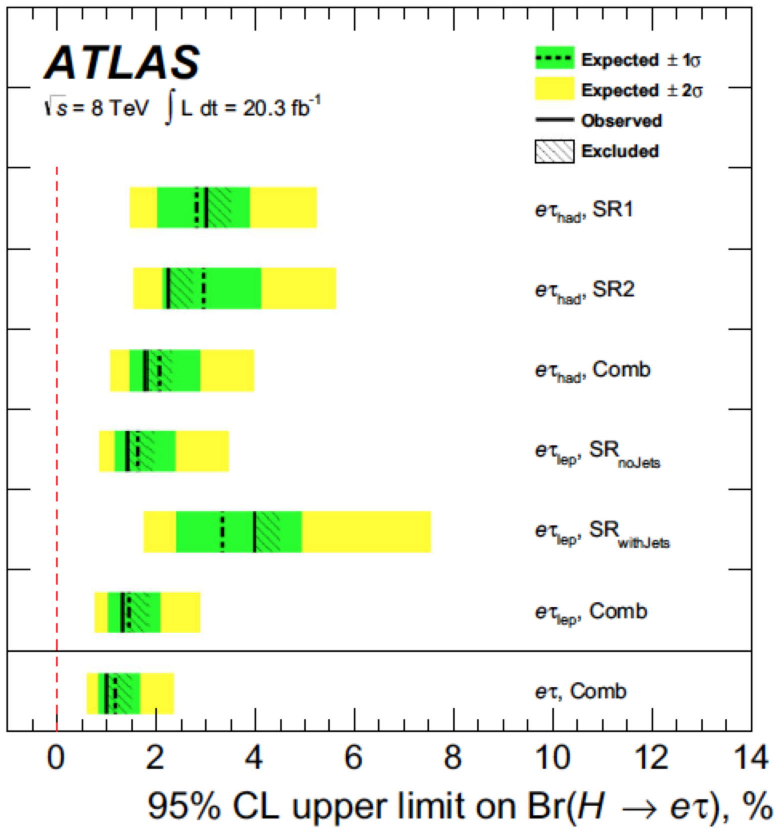
use tau kinematic and missing transverse energy vector to correct invariant mass calculation for the missing neutrino (MMC algorithm)

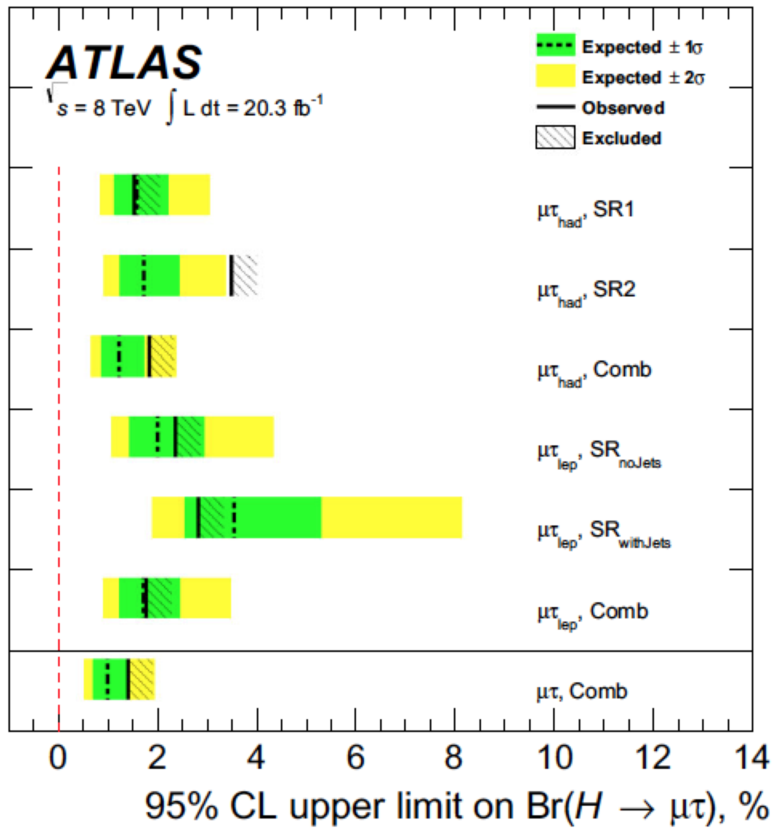
H→eτ



Main systematics (>10%):
normalization and shape W+jets
OS/SS multi-jet component scaling
normaliation and modelling of Z+jets

CLFV Higgs decays



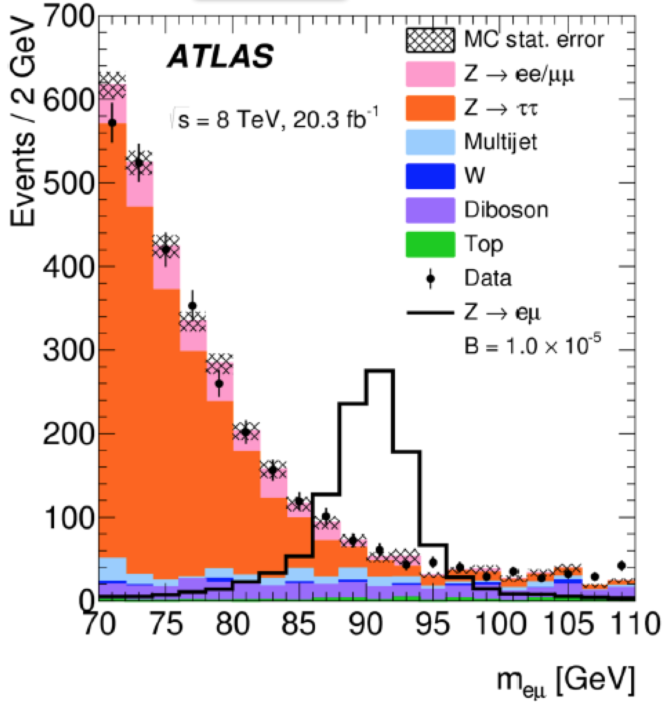


theory : BR < 10% from $\tau \to \mu\gamma$ and g-2 (e,μ)

CLFV Z decays

PRD90 072010 (2014)

Z→eμ



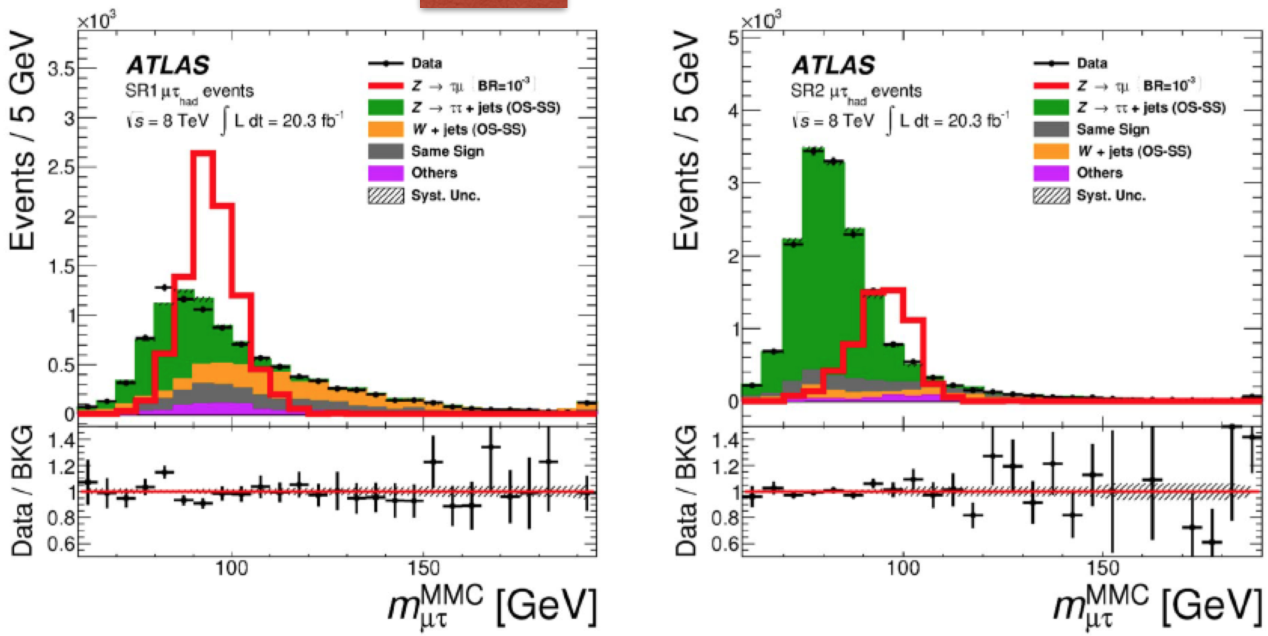
2 leptons , different flavor
opposite charge

BR(Z→eμ)<7.5 10^{-7} @95%CL
(LEP results <1.7 10^{-6} @95%CL)

20.3 fb^{-1}, 2012

Eur. Phys. J. C (2017) 77:70

Z→μτ



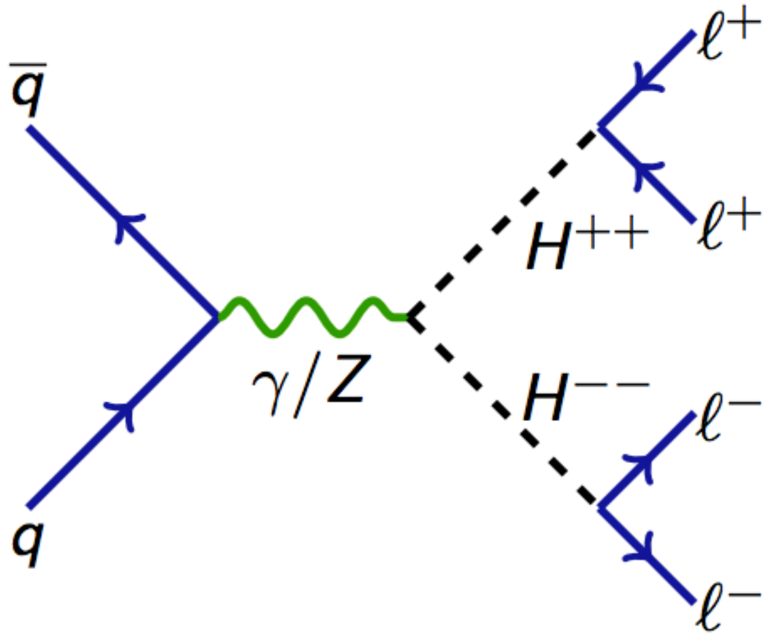
similar analysis and selection as in H→τμ

BR(Z→τμ)<1.7 10^{-5} @95%CL
(LEP results <1.2 10^{-5} @95%CL)

CLFV Double charged Higgs decays

3.2 fb^{-1} 2015 + 10.7 fb^{-1} 2016

ATLAS-CONF-2016-051



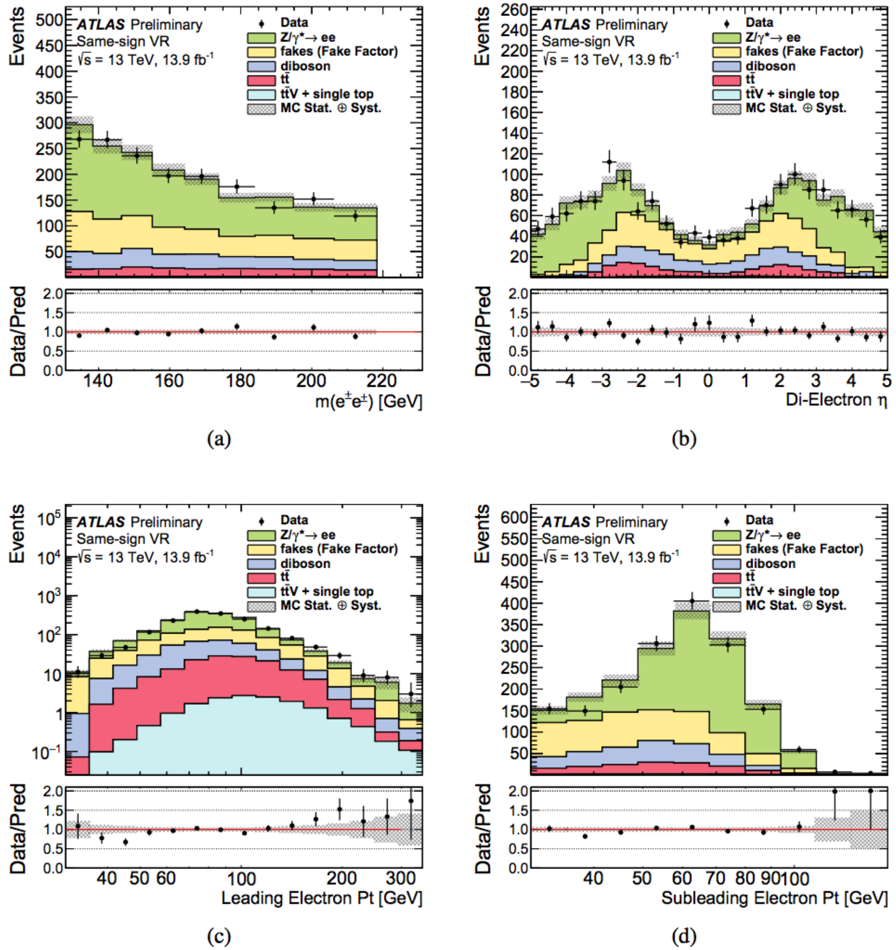
predicted in
SeeSaw Type II ,
Left Right Symmetric Models (LRSM),
Higgs triplet models, ..

m(300 GeV) σ ~ 10 fb
m(1300 GeV) σ ~ 1 ab

$H^{++/--}$ decay : CLFV process.
Possibly also LNV.
Though preliminary analysis uses electrons/positrons only

CLFV H++: Selection & Validation

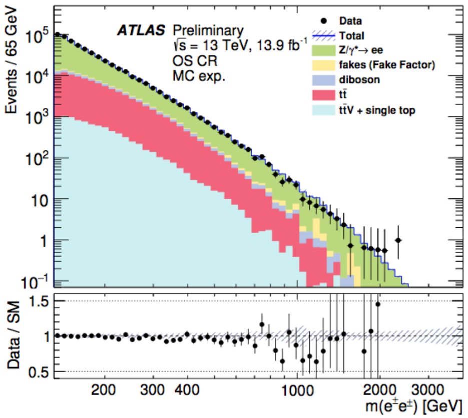
Region name	Region type	Brief Selection
signal region (SR)	signal region	at least 1 SS pair ($m_{ee} > 300$ GeV)
opposite-sign control region (OSCR)	control region	1 OS pair, 0 SS pairs
diboson control region (DBCR)	control region	1 OS pair (Z) + SS pairs ($m_{ee} < 200$ GeV)
same-sign validation region (SSVR)	validation region	at least 1 SS pair ($m_{ee} < 200$ GeV)

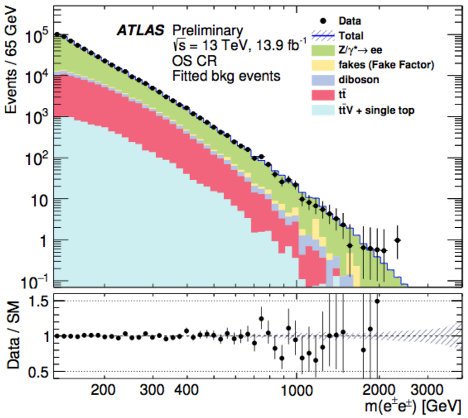


high signal efficiency ~ 90%

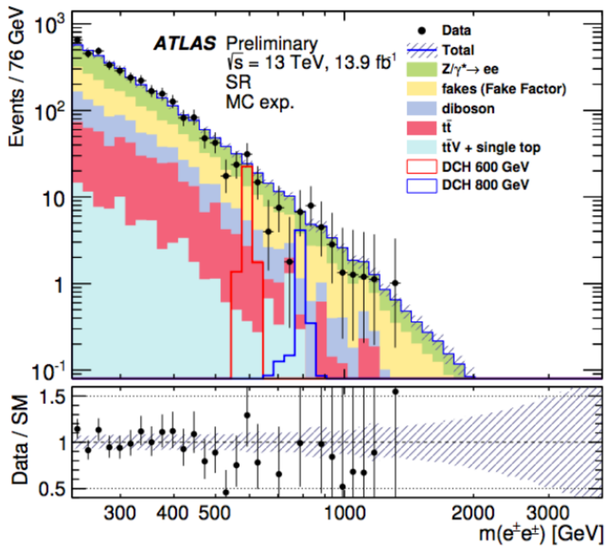
trigger : single e p_T 120 GeV

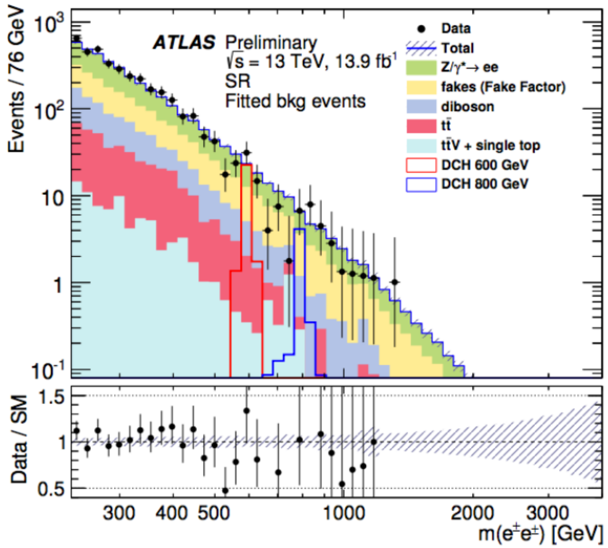
OR double e p_T 17 GeV

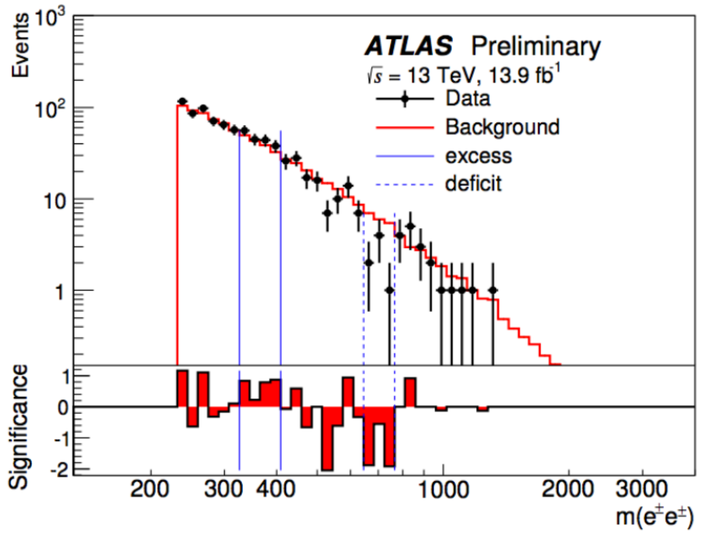




CLFV H++ : Results

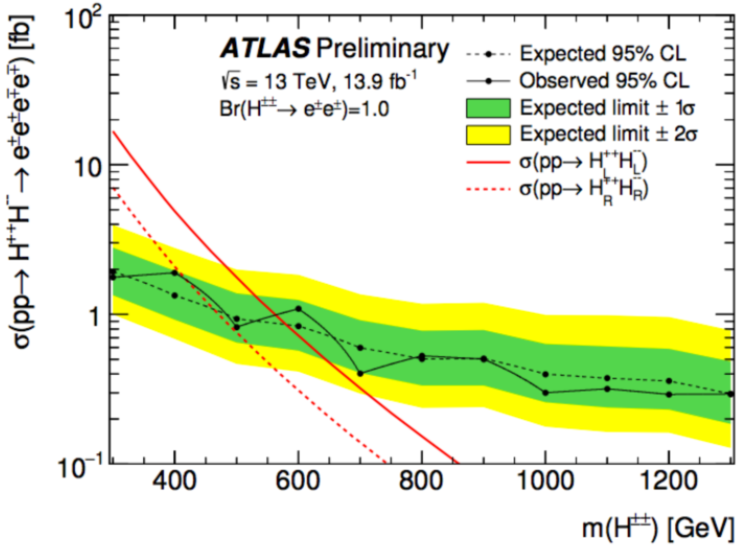






$m(e^{\pm}e^{\pm})$ [GeV]	≥ 345	≥ 410	≥ 485	≥ 575	≥ 680	≥ 810	≥ 1020
Observed events	278	151	80	47	24	15	5
Fitted bkg events	290 ± 17	175 ± 11	103 ± 7.3	59 ± 4.5	32.9 ± 3.1	17.5 ± 2.1	9.5 ± 1.5

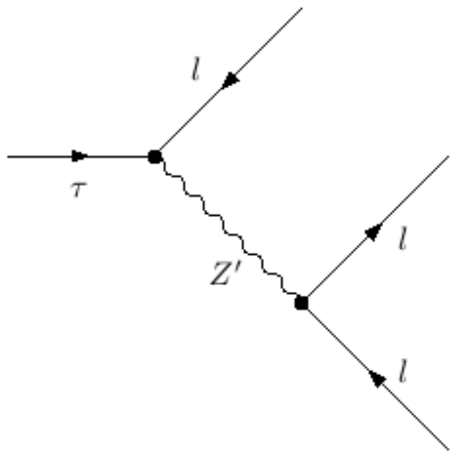
expected SM background, shows systematic uncertainties.
biggest systematic (>10%): fakes estimation

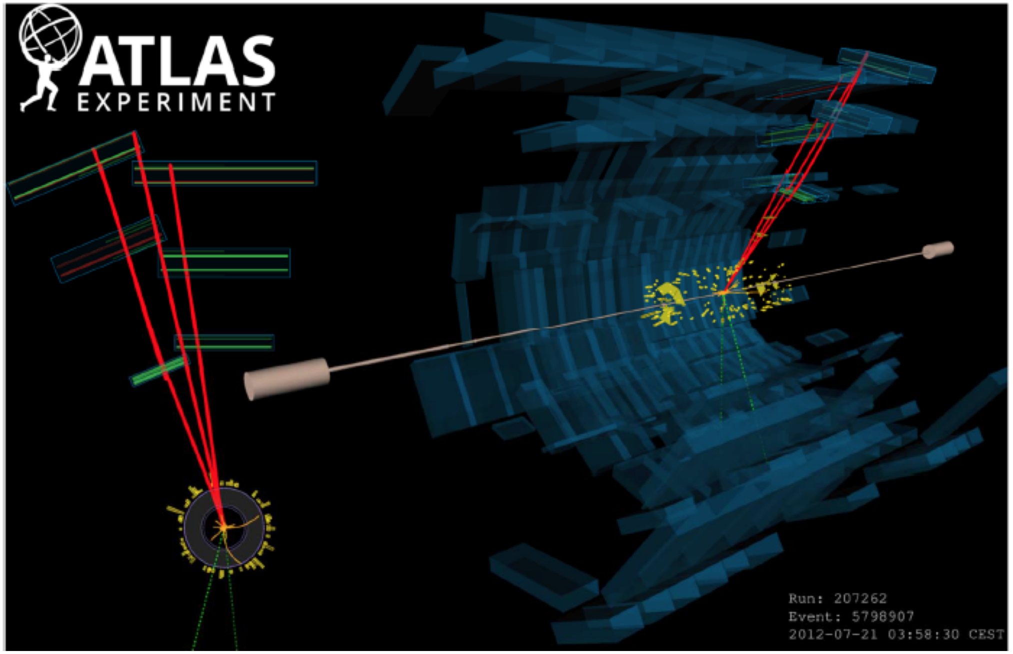


CLFV $\tau \to \mu\mu\mu$

EPJ C (2016) 76: 232

20.3 fb^{-1}, 2012



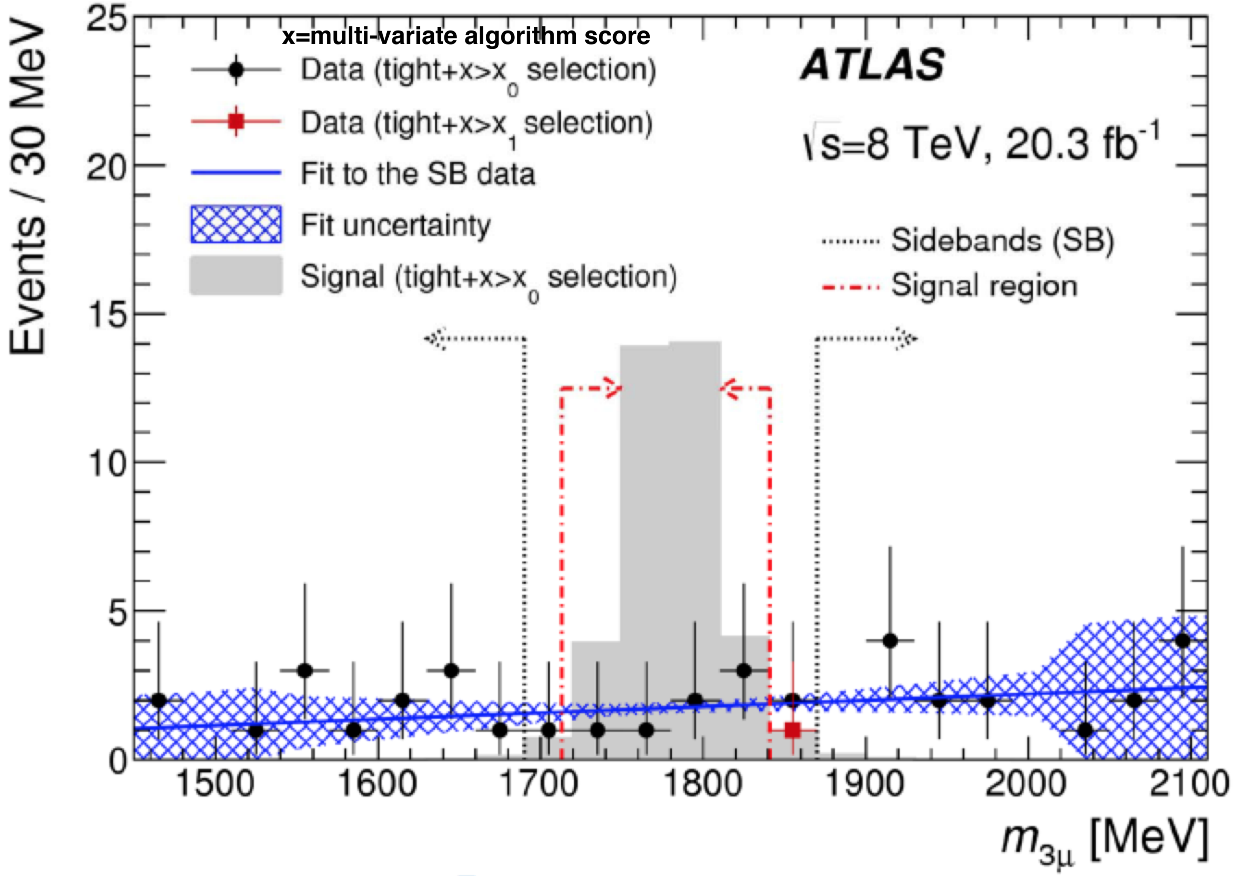


exploiting W production, W decaying into tau leptons (Run1 : 10^8 $W \to \tau\nu$ decays)

signal detection:

- 3 muons inv. mass compatible with mass of tau lepton, large missing energy mainly back-to-back to the 3 muon system
- multi-variate analysis using kinematics of W decay products and final products track and vertex quality and significance.

CLFV $\tau \to \mu\mu\mu$



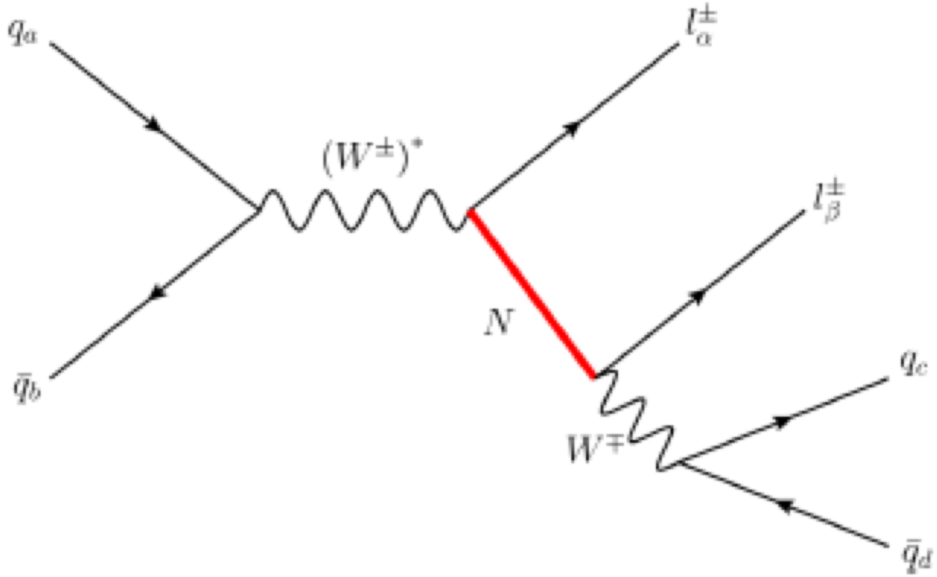
largest uncertainty: extrapolation of the background from the tight +x>x0 selection to the tight +x>x1 selection

BR($\tau \to \mu\mu\mu$)< 3.8 10^{-7} @ 95% CL
PDG : BR($\tau \to \mu\mu\mu$)< 2.1 10^{-8} @ 95% CL

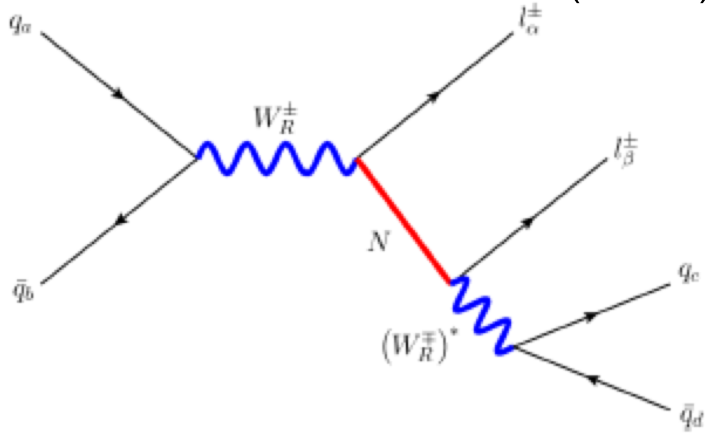
LNV, Majorana neutrinos

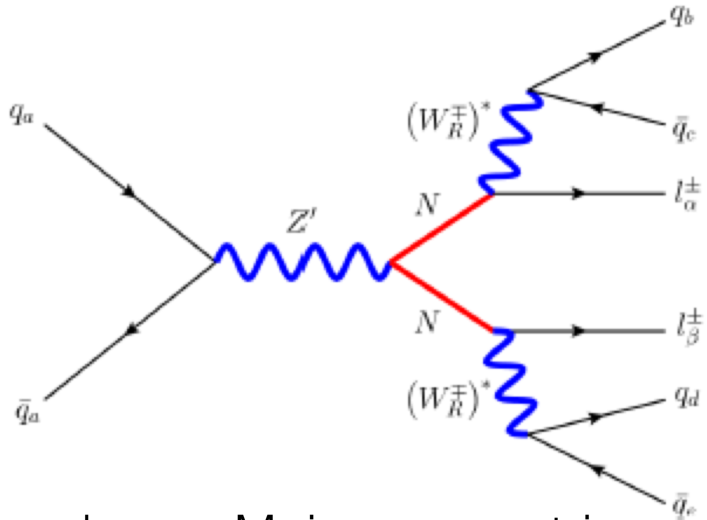
20.3 fb^{-1} 2012

JHEP (2015) 162



heavy Majorana neutrino
produced via off-shell W,
Type I See-saw



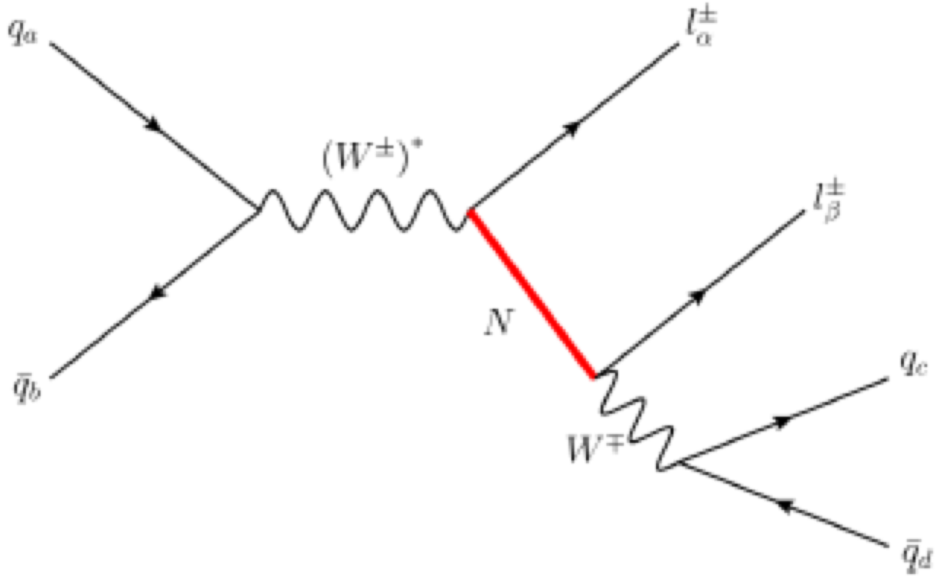


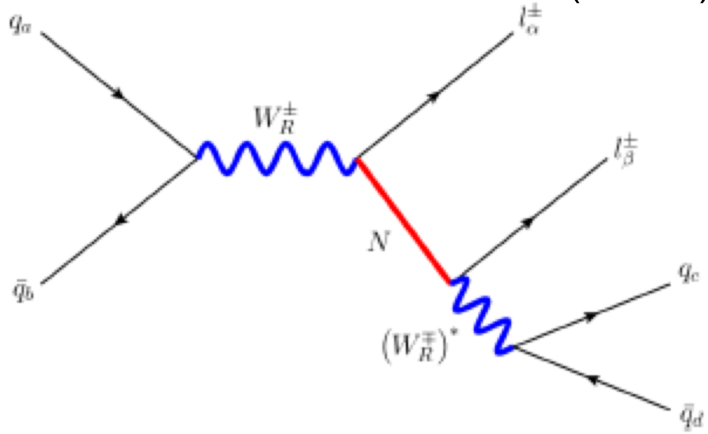
heavy Majorana neutrino
produced via new W_R, Z'/Z_R bosons
(LRSM)

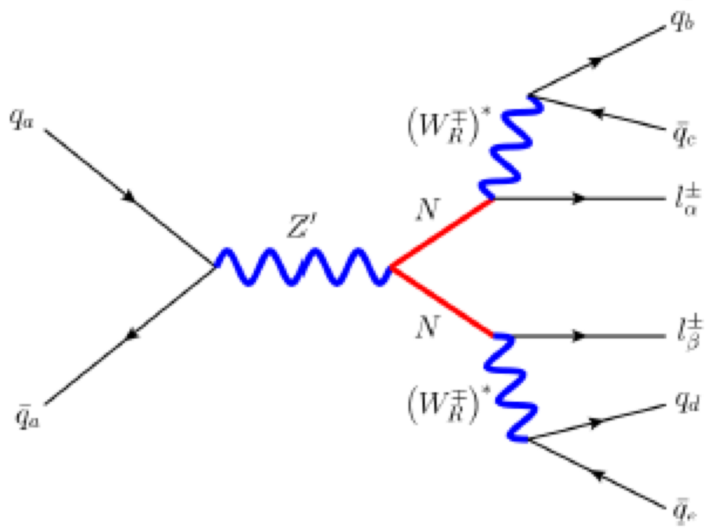
LNV, Majorana neutrinos

20.3 fb^{-1} 2012

JHEP (2015) 162

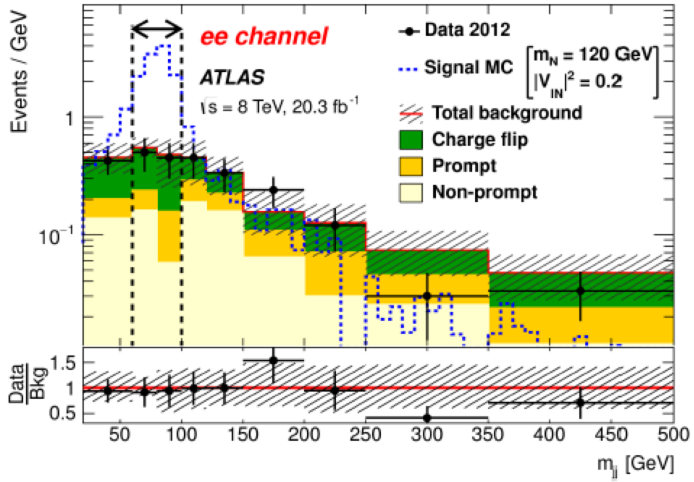


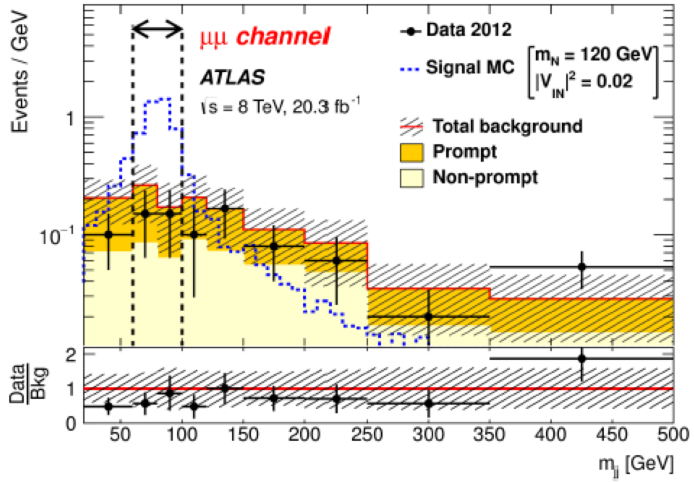


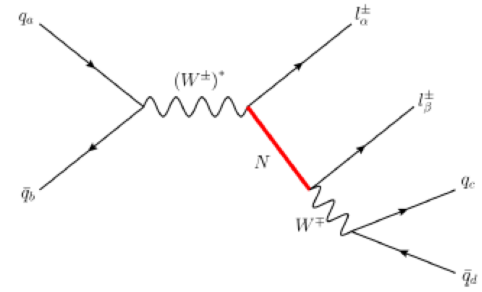


signature : 2 same sign leptons (e/μ) and high p_T jets

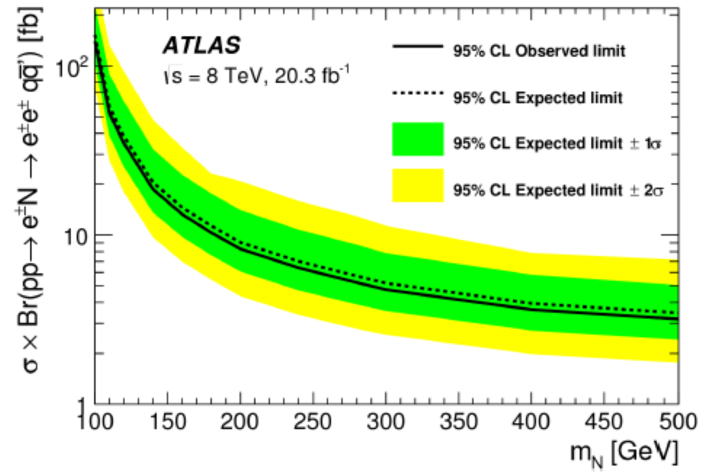
LNV, Majorana neutrinos : Results

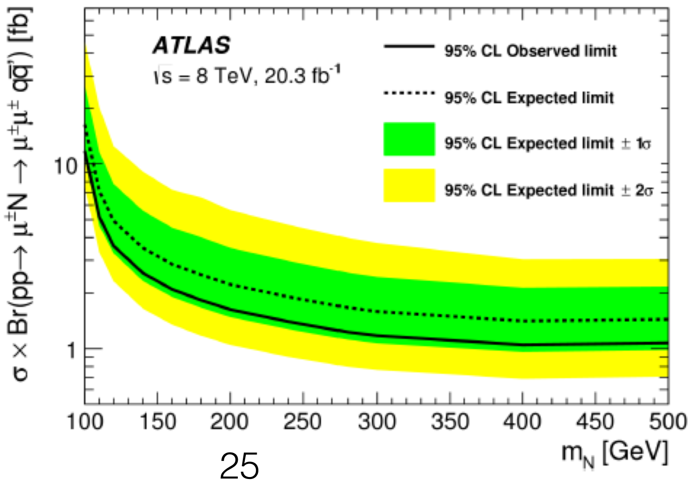






W from N decay on shell observable: m_{jj}



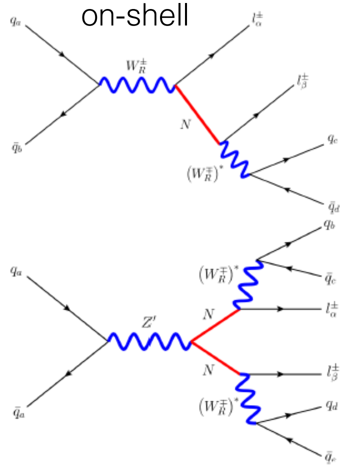


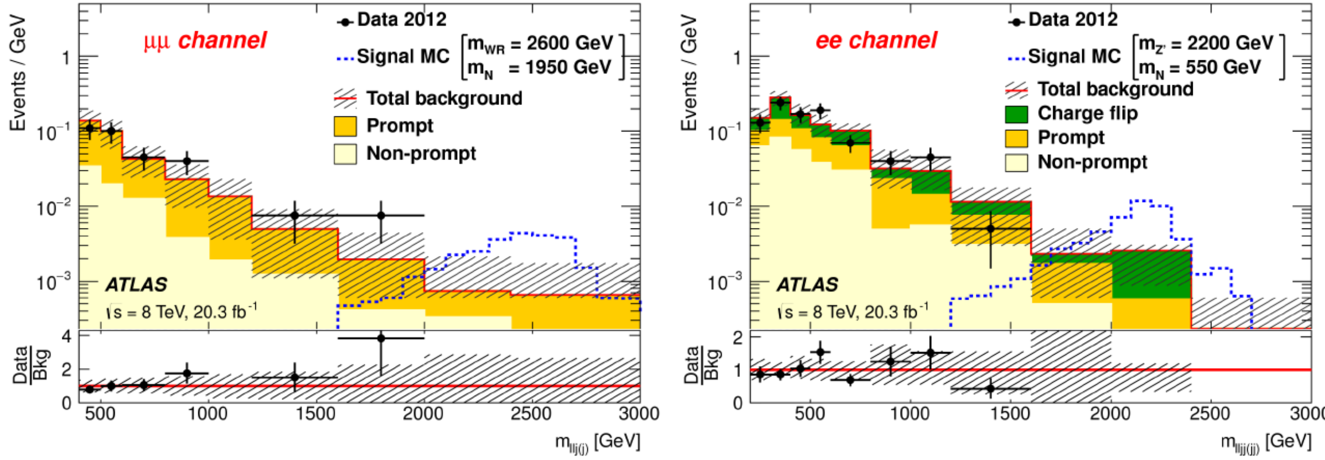
excluded mixing parameters with active neutrinos down to

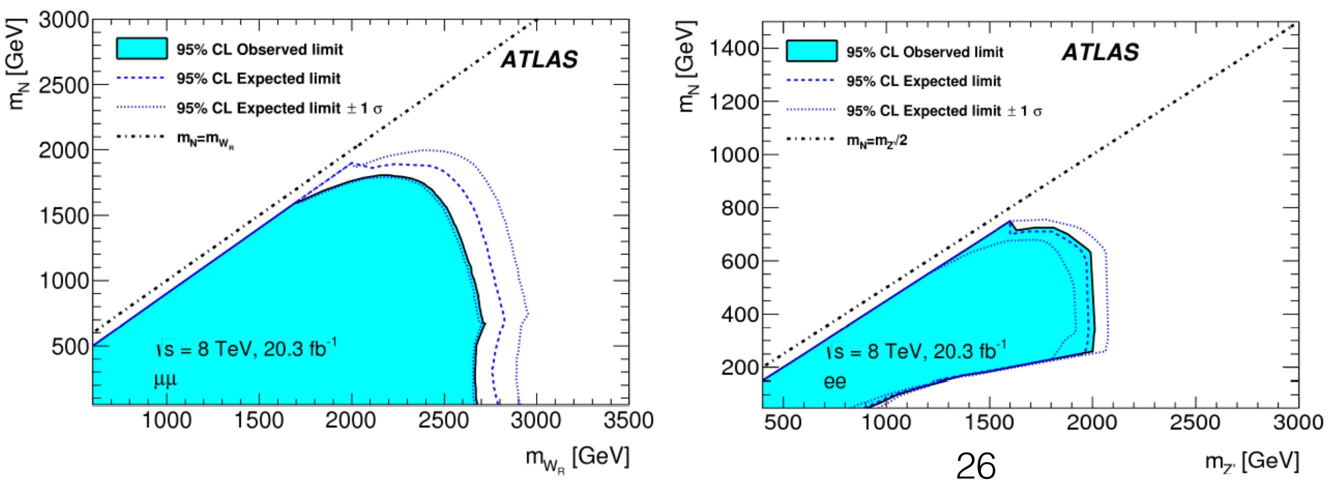
$|V_{\mu N}|^2 < 0.0028$

$|V_{eN}|^2 < 0.029$

LNV, Majorana neutrinos : Results







observable:
$m_{llj(j)}$ for W_R
$m_{lljj(jj)}$ for Z_R

main systematics (>10%):
jet energy scale
prompt and non-prompt background estimate

Conclusions

- ATLAS results on CLFV and LNV processes have been presented. Run1 full dataset or early Run2 dataset is used for these results.
- Limits set by ATLAS experiment are already or will soon be competitive with limits set by LEP and other past facilities such as Belle
- Run 2 full datasets, because three times larger than Run1 and taken at higher energy, will provide very strong insights on the possible mechanism for CLFV and LNV in nature

CLFV higgs

$$N_{\mathrm{OS}}^{\mathrm{bkg}} = r_{\mathrm{QCD}} \cdot N_{\mathrm{SS}}^{\mathrm{data}} + N_{\mathrm{OS-SS}}^{Z\to\tau\tau} + N_{\mathrm{OS-SS}}^{Z\to\mu\mu} + N_{\mathrm{OS-SS}}^{W+\mathrm{jets}} + N_{\mathrm{OS-SS}}^{\mathrm{top}} + N_{\mathrm{OS-SS}}^{VV} + N_{\mathrm{OS-SS}}^{H\to\tau\tau}, \quad (4.1)$$

$$r_{\mathrm{QCD}} = N_{\mathrm{OS}}^{\mathrm{multi-jet}} / N_{\mathrm{SS}}^{\mathrm{multi-jet}}$$