Search for the standard model Higgs boson in the decay channel $H \rightarrow ZZ^{(*)} \rightarrow 4l$ with the ATLAS experiment and performance of the Liquid Argon calorimeter

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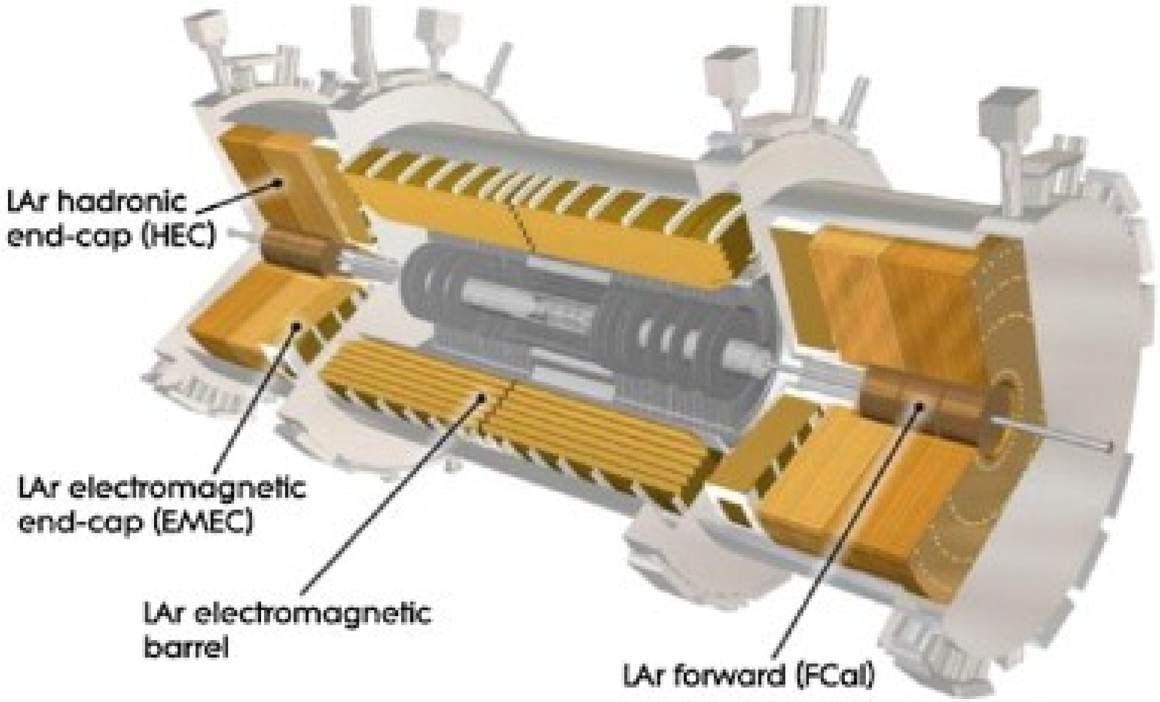
Introduction

- On July 4th, the ATLAS and CMS experiments announced the observation of a new particle consistent with the Higgs boson
- 1964: first possible explanation of how particles acquire their mass by the introduction of a scalar field → half a century ago!
- Such discovery depends on:
  - Data tacking: recorded lumi w.r.t delivered lumi by the LHC
  - Quality of the data: data used for the analysis
  - Trigger: selection of interesting events among huge amount of events
  - Grid computing
  - Reconstruction and identification of objects (e, μ, γ...)
  - Physics analysis

My contributions

Data quality- Liquid argon calorimeter (LAr)

- The good quality of the ATLAS data relies on each sub-detector
- My contribution was focused on the reduction of inefficiencies due to the LAr
- LAr:

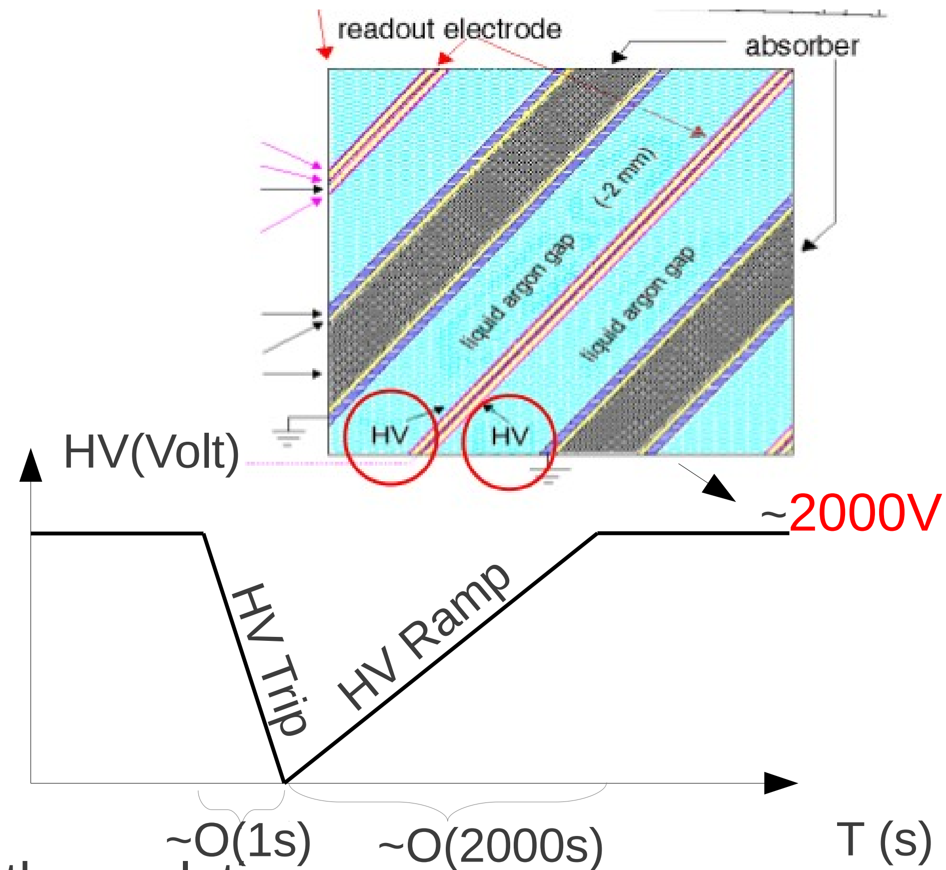


- Sampling calorimeter with accordion shape → 2π coverage in φ
- Measure the energy and identify the electromagnetic objects like the photons, electrons...

- All the recorded data can not be used directly because of detector problems which could have an impact on the reconstructed objects or the physics

Data quality- Liquid argon calorimeter

- Before my study the liquid argon calorimeter inefficiencies had different main sources called:
  - HV Trip → 4%
  - Data corruption → 2%
  - Noise burst → 6%



- Sometimes a resistivity of few µohms created by instabilities in the **Lar gap** (dusts, contact...) → ask for a big amount of intensity to keep HV stable. When I > threshold → HV line ramp down

- We know how to correct the energy knowing the evolution of the HV
  - Data during HV Trip are unusable for the data analysis
  - I contributed to show that the data during the ramping of the HV was usable for physics, checking that no fake objects (jets, photon) was created during this period

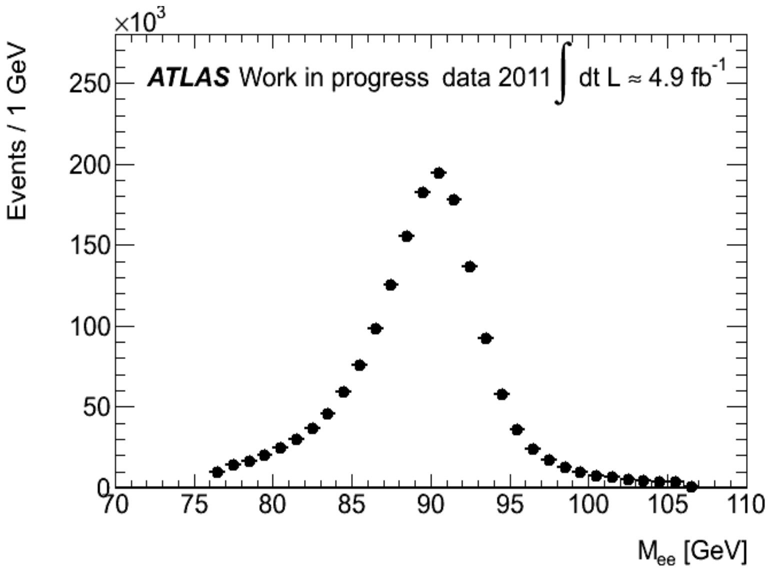
Gain of 2% of the data

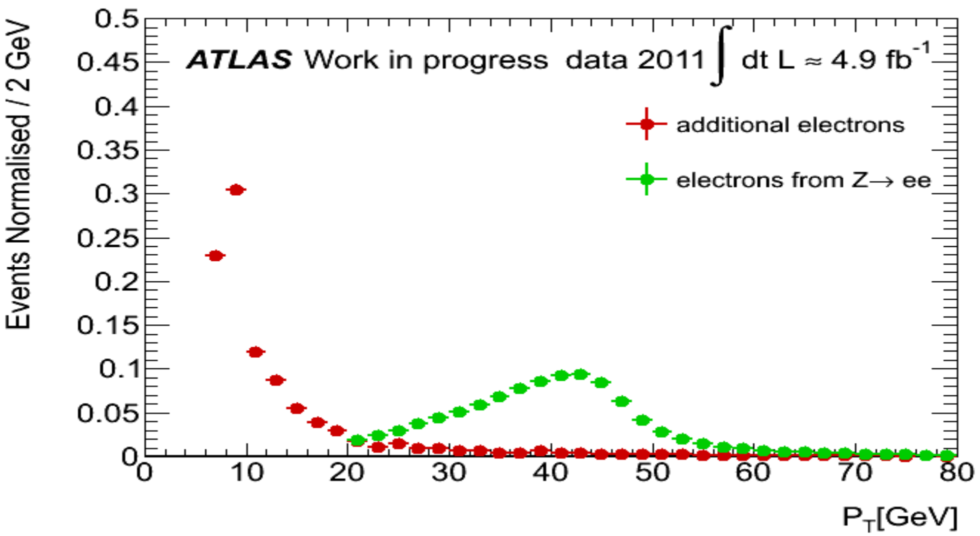
Performance - Reconstruction of electrons

- Between 2011 and 2012 many improvements of the algorithm which reconstruct the electron were made.
- Electron reconstruction in ATLAS:
  - Electromagnetic clusters are first reconstructed in LAr calorimeter
  - Tracks are reconstructed in the Inner Detector
  - If the cluster matches to a track of the ID → the EM cluster belong to an electron, else to a photon
- I measured the electron reconstruction efficiencies in 2012 data and Monte Carlo following the work done by Julien Maurer in 2011
- $Eff_{reco,electron}$: probability that a electromagnetic cluster is reconstructed and match to a reconstructed track → using *Tag and Probe* method

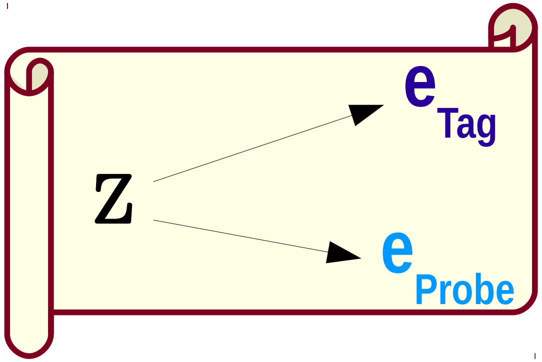
Performance – Tag and probe method

- Tagging a clean sample of events allow to measure the efficiency of a cut on an electron candidate called “probe”
- Resonance Z $\rightarrow$ ee allow to select clean hight E_T electrons



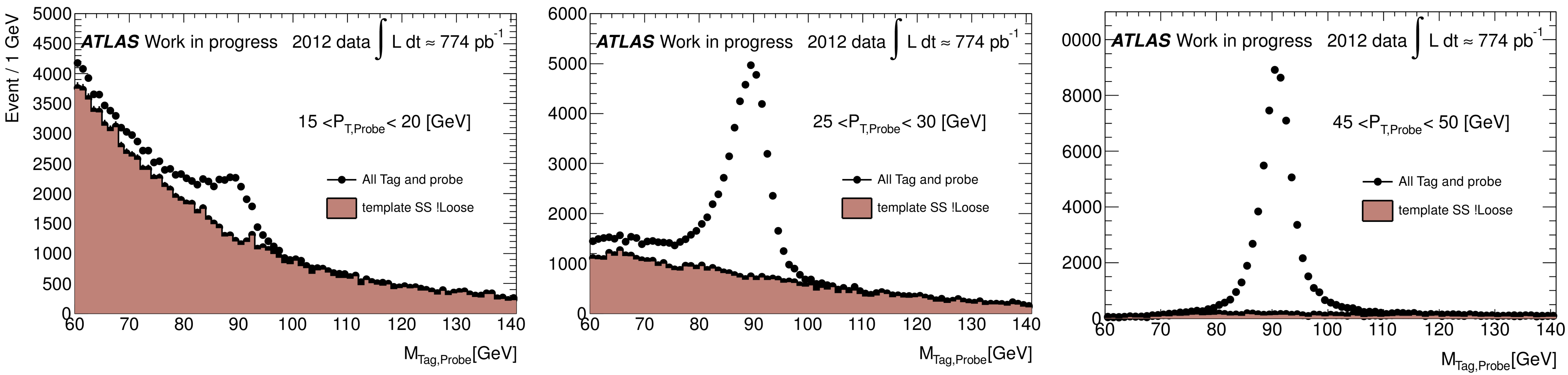


- Tag one electrons with tight criteria and measure the efficiency on the other object which form a pair with a reconstructed mass close to the Z one.
- Cut efficiency:
  - $$\mathrm{Eff}_{reco,electron} = \frac{N\text{probes passing the cuts}}{N\text{probes}}$$



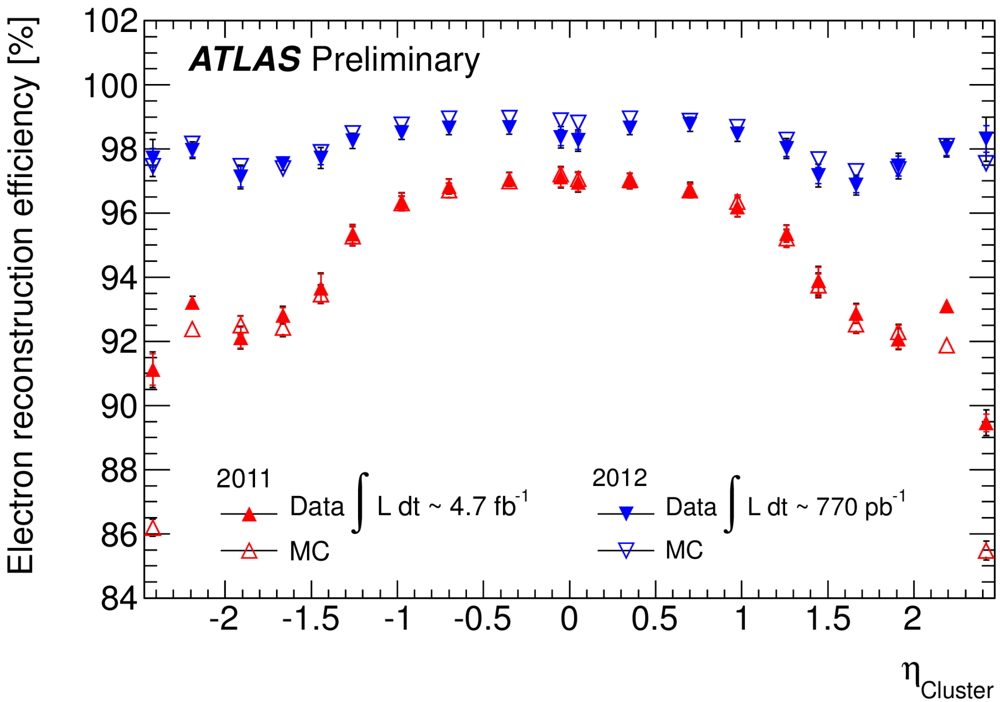
Performance – Tag and probe method

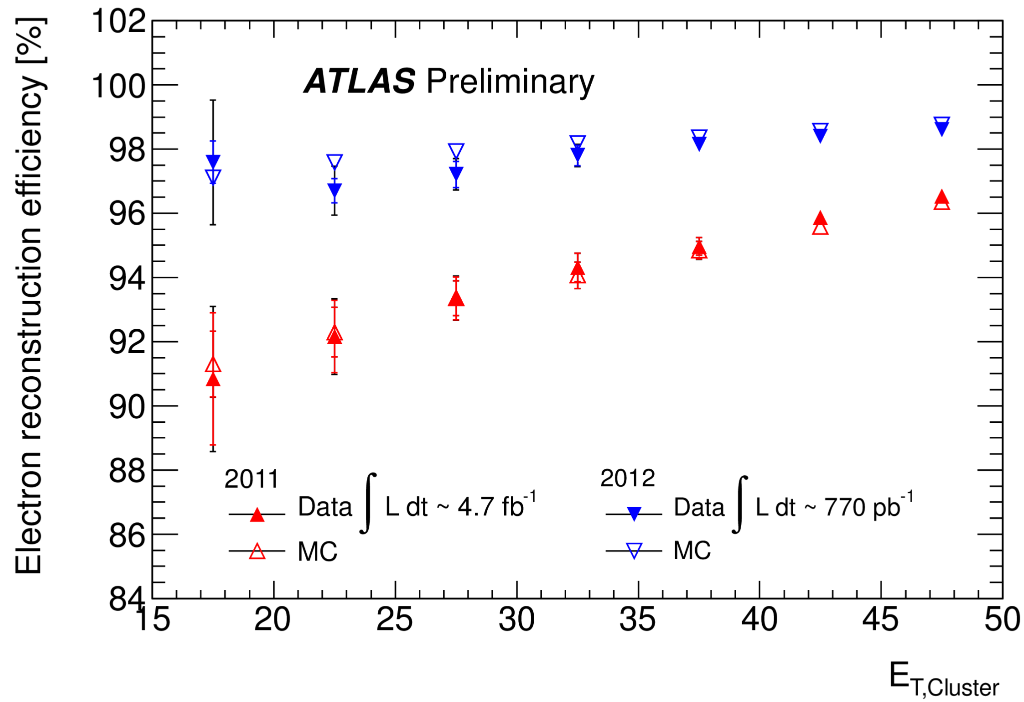
- The measurement of the efficiency have to be performed using pure sample of electron → Background subtraction using **template method**



- The more the probe is energetic the less there is background to subtract
- Finally $Eff_{reco,electron} = \dfrac{N_{\text{probes passing the cut}} - N_{\text{background passing the cut}}}{N_{\text{probes}} - N_{\text{background}}}$
- With:
  - probes : EM cluster (electrons, photons),
  - probes passing the cut (reconstructed as electrons) : EM cluster of electron + track Q

Performance – Results



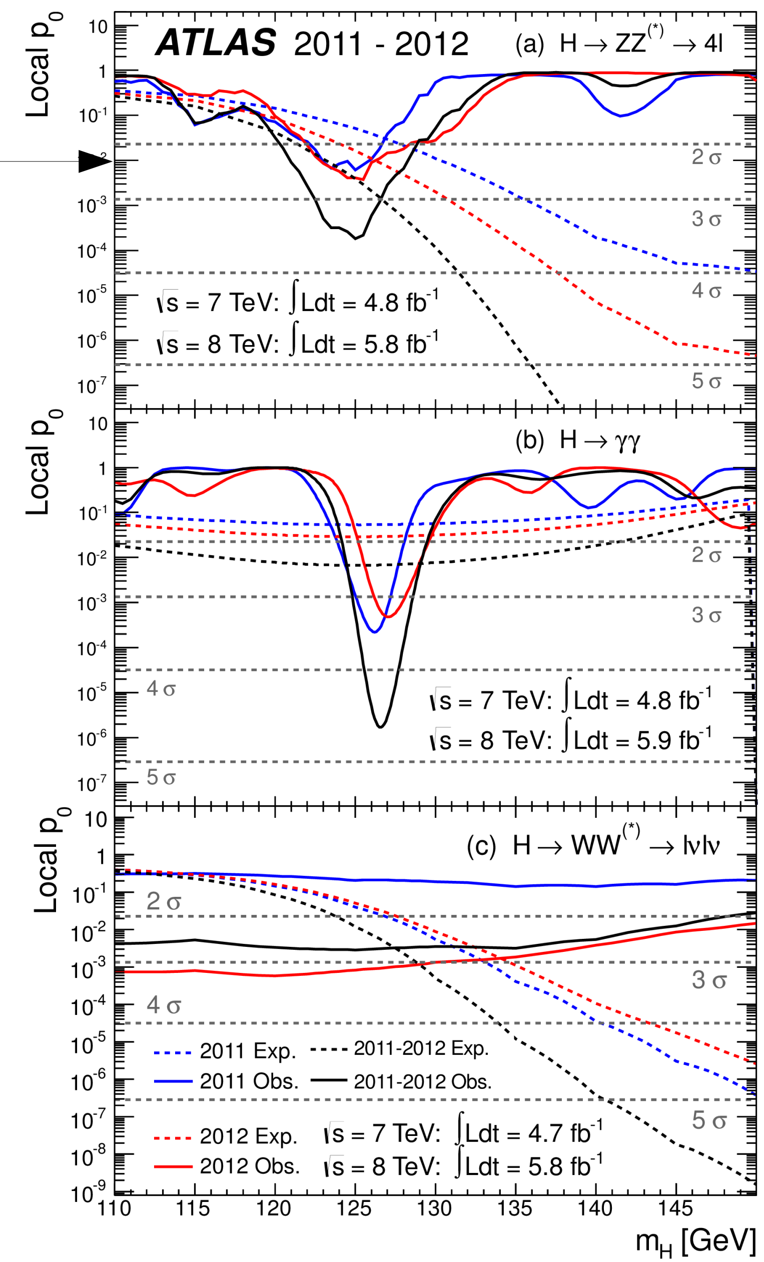


- Gain in 2012 compared to 2011 : 96% → 98% in the barrel, 92%-98% in the end cap, 97% → 99% at high P_T, 91% → 97 at low P_T
- Distribution flat within 2% in 2012
- Good agreement between data and MC within the error bars
- Global gain of 30% of sensitivity for the Higgs →ZZ → 4e – results used in the Higgs discovery analyses

Physics analysis – Higgs → ZZ → 4l

- The observed local p0[1] as a function of the hypothesized Higgs boson mass in H → ZZ(*) → 4l (top), H → γγ (middle), H → WW (*) → lνlν (bottom) channels

- For M_{higgs} = 126 GeV, σ x BR ~ 2.5 fb
- S/B ~ 1 (compared to 0.03 fo the γγ channel) → High
- But suffer of low statistic, for instance in the low mass region we observed 39 events and expected 34 ± 3 of background
- Really important to estimate well the background



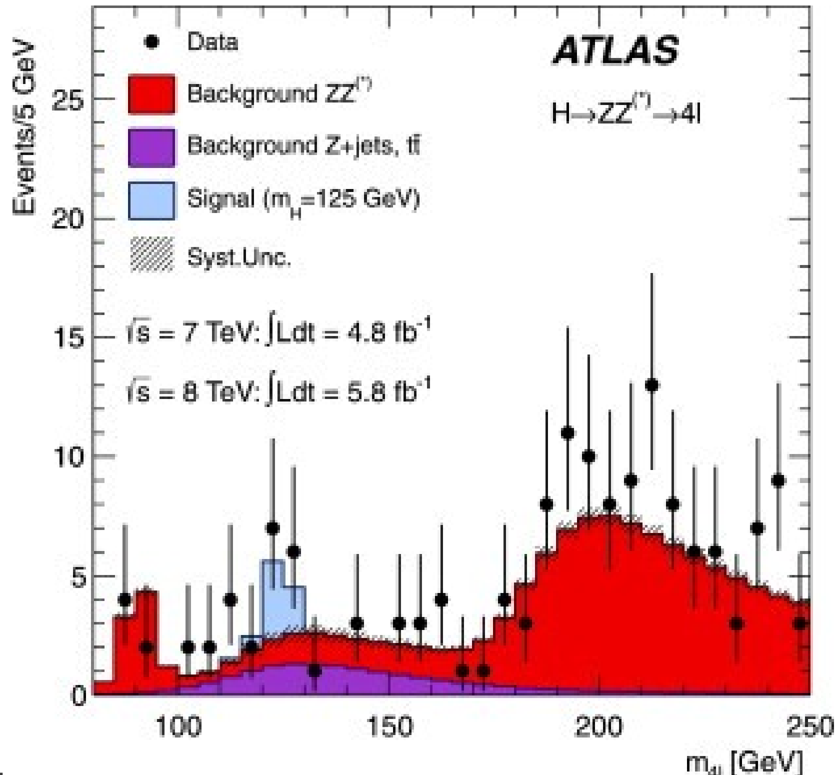
[1]P0 value: probability of background only hypothesis to reproduce the data

Physics analysis – Higgs → ZZ → 4l

Event Pre-selection	
Electrons	
"MultiLepton" quality GSF electrons with $E_T > 7$ GeV and $\|\eta\| < 2.47$	
Muons	
combined or segment-tagged muons with $p_T > 6$ GeV and $\|\eta\| < 2.7$	
calo-tagged muons with $p_T > 15$ GeV and $\|\eta\| < 0.1$	
standalone muons with $p_T > 6$ GeV, $2.5 < \|\eta\| < 2.7$ and $\Delta R > 0.2$ from closest segment-tagged	
Event Selection	
Kinematic Selection	Require at least one quadruplet of leptons consisting of two pairs of same-flavour opposite-charge leptons fulfilling the following requirements: p_T thresholds for three leading leptons in the quadruplet 20, 15 and 10 GeV Leading di-lepton mass requirement 50 GeV $< m_{12} <$ 106 GeV Sub-leading di-lepton mass requirement $m_{threshold} < m_{34} <$ 115 GeV Remove quadruplet if alternative same-flavour opposite-charge di-lepton gives $m_{\ell\ell} < 5$ GeV $\Delta R(\ell, \ell') > 0.10(0.20)$ for all same (different) flavour leptons in the quadruplet.
Isolation	Lepton track isolation ($\Delta R = 0.20$): $\Sigma p_T / p_T < 0.15$ Electron calorimeter isolation ($\Delta R = 0.20$) : $\Sigma E_T / E_T < 0.20$ Muon calorimeter isolation ($\Delta R = 0.20$) : $\Sigma E_T / E_T < 0.30$ Stand-Alone muons calorimeter isolation ($\Delta R = 0.20$) : $\Sigma E_T / E_T < 0.15$
Impact Parameter Significance	Apply impact parameter significance cut to all leptons of the quadruplet. For electrons : $d_0/\sigma_{d_0} < 6.5$ For muons : $d_0/\sigma_{d_0} < 3.5$

Physics analysis – Higgs → $ZZ^{(*)}$ → 4l

- Two kind of background:
  - Irreducible: standard model $ZZ^{(*)}$
  - Reducible: Z + jets, Zbb, $t\bar{t}$
- Reducible background estimation
  - ZZ + μμ background
    - Zbb, tt MC Monte Carlo
    - Zbb + Z + jets Monte Carlo
  - Z + ee background
    - Using categories in Z + XX control region



- We would like to use only one full data driven method for both ZZ + μμ and Z + ee background
  - If more simple we understand better the error systematics
  - No more based on MC because with more data we will be dominated by the statistical error in the MC

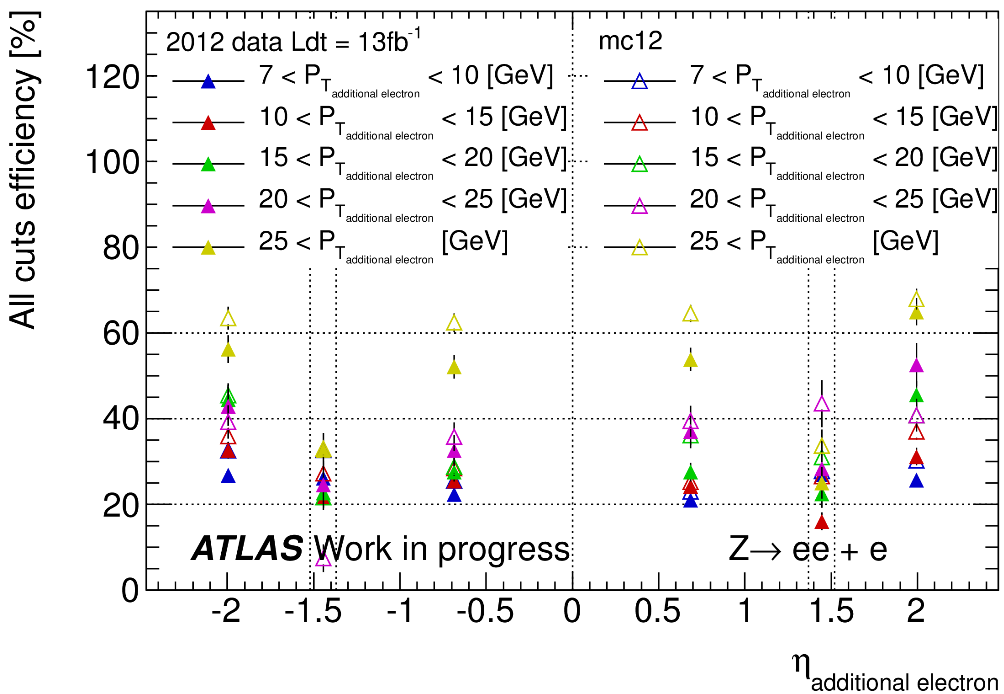
Physics analysis – Higgs → $ZZ^{(*)}$ → 4l

- I present here first preliminary results based on 13 fb^{-1} of 2012 data and on background Monte Carlo
- Estimation of Z + ee reducible background in three steps:
  - 1. Compute efficiencies of the three additional cuts (calorimeter isolation, track isolation and d0 significance) on background-like electrons → Fake factor
    - Control region Z + leptons
  - 2. Build a control region enriched in reducible background inverting at least one of the 3 additional cuts on the leptons of the sub leading Z
  - 3. Estimate the Z + ee background knowing the probability of an event of the control region to be found in the signal region

Physics analysis – Higgs → ZZ$^{(*)}$ → 4l

- **1. Fake factor measurement**
  - Select Z + exactly 1 additional e/μ events → Reject ZZ events
  - Reject event with E_T^{miss} > 25 GeV → Reject WZ events

Events	$Z(ee)+1e/Z(\mu\mu)+1e$
Data	16158 ± 127 / 16828 ± 130
MC total	16329 ± 169 / 18744 ± 181
Z+light jets	15237 ± 169 / 17560 ± 181
$Z+b\bar{b}$	947 ± 7.13/ 1037 ± 7.49
ZZ	42.5 ± 0.24/ 46.6 ± 0.34
WZ	78.7 ± 2.07/ 79.7 ± 2.08
$t\bar{t}$	22.8 ± 1.69/ 20.4 ± 1.60



- Combining the 3 additional cuts lead to a powerful discriminant against background-like electrons
- The best performance for high PT background like electrons in the crack region

Physics analysis – Higgs → ZZ(*) → 4l

- **2. Build enriched control region in reducible background**
  - Apply the higgs → 4l selection without the additional cuts on the electrons of the subleading Z (CR 0)
  - Idem + invert additional cut on subleading Z leptons (CR 4)

	Control region 0 $Z(ee) \mid Z(\mu\mu)+ee$	Control region 4 $Z(ee) \mid Z(\mu\mu)+ee$
Data	119±10.9|104±10.2	62±7.87|53±7.28
MC Total	106±9.46|114±9.73	58.1±8.93|64.1±9.5
Z + light jets	44.8±9.42|48.4±9.68	39.8±8.88|46.1±9.46
Z+bb	8.09±0.50|9.28±0.54	7.48±0.47|8.56±0.51
ZZ	46.4±0.25|51.1±0.38	4.52±0.08|4.28±0.11
WZ	1.76±0.31|1.91±0.32	1.19±0.25|1.36±0.27
$t\bar{t}$	5.26±0.70|3.63±0.51	5.09±0.69|3.75±0.53

- Monte carlo used only to have a rought estimate of the composition of the background
- Inverting cut reject significantly ZZ contribution

- **3. Extrapolation to the signal region**
  - The number in the CR N_{CRn} can be extrapolated to the signal region N_{SR} applying a transfer factor weight to each event in the CR

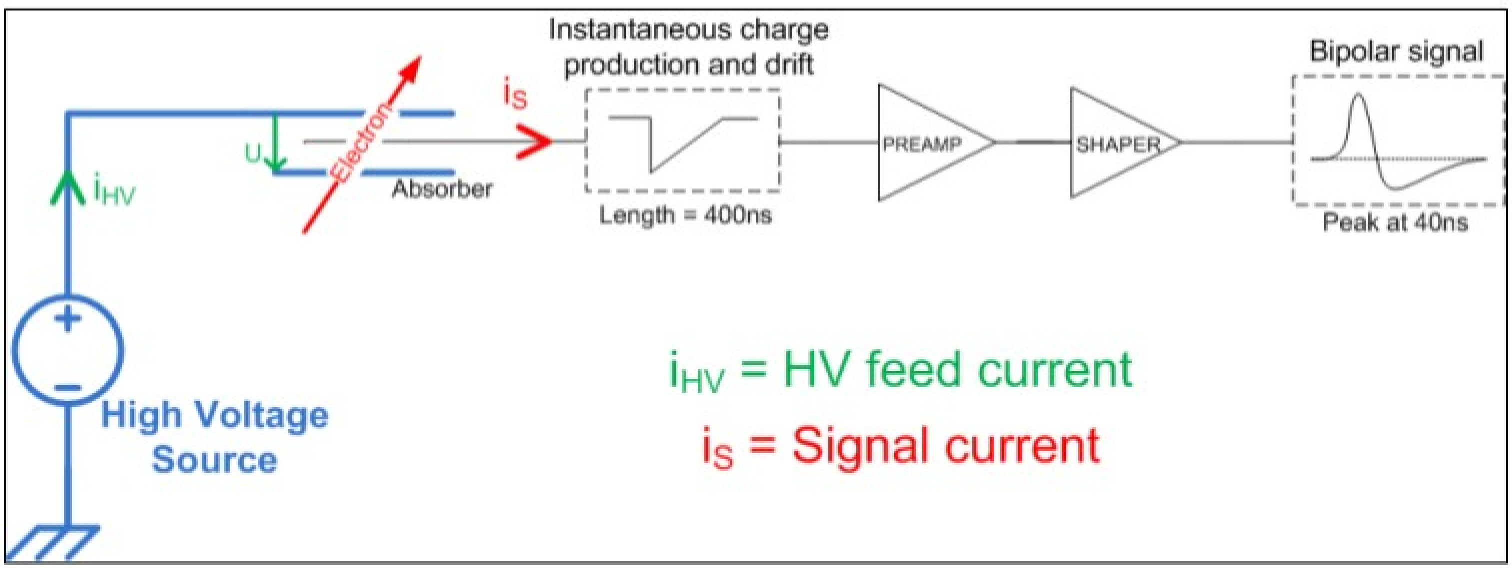
Conclusion/Outlook

- In the first part of this talk I presented my contribution in the data quality group of the LAr calorimeter which allow to gain 2% of the data in the analysis → this study + shifts at CERN qualified me as an author of ATLAS since July 2012
- Then I presented you my contributions to the performance group which consisted in the measurement of the reconstruction efficiency of the electrons
- Finally I presented first preliminary results on my contribution in the Higgs to 4 leptons group
  - Estimation of the Z + ee reducible background
  - This method will be probably used for the next official H->4l results

backup

Signal generation

- Charged particle traverses liquid argon gap
  - Liquid argon ionisation
  - Electrons produced drift due to electric field
  - Singal current i_s
    - produced by capacitive coupling in the LAr gap
    - proportional to energy deposited
  - To maintain electric field constant
    - HV system injects i_{HV} to compensate



DQ R16 vs R17

ATLAS 2011 p–p run													
Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.8	100	89.0	92.4	94.2	99.7	99.8	99.7	99.8	99.7	99.3	99.0

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and June 29th (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future. The magnets were not operational for a 3-day period at the start of the data taking.

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Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.8	100	96.3	98.6	98.9	99.7	99.8	99.8	99.8	99.7	99.3	99.0

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and June 29th (in %).

Presentation HV Ramp

- https://indico.cern.ch/conferenceDisplay.py?confId=194364
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Physics analysis – Higgs → ZZ$^{(*)}$ → 4l

- **3. Extrapolation to the signal region**
  - The number in the CR N_{CRn} can be extrapolated to the signal region N_{SR} applying a transfer factor weight to each event in the CR

$$N_{SR} = \sum_{i=1}^{N_{CR_n}} TF_i$$

$$TF_0 = \epsilon_{Allcuts}(\eta_3, p_{T3}) \times \epsilon_{Allcuts}(\eta_4, p_{T4})$$

$$TF_4 = \frac{\epsilon_{Allcuts}(\eta_3, p_{T3}) \times \epsilon_{Allcuts}(\eta_4, p_{T4})}{1 - \epsilon_{Allcuts}(\eta_3, p_{T3}) \times \epsilon_{Allcuts}(\eta_4, p_{T4})}$$