Calibration of the ATLAS Electromagnetic Calorimeter, Measurement of W boson properties and Higgs physics in the Standard Model

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Chung-Yao Chao Fellowship Interview

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Introduction: Resume

- **Hicham ATMANI (26 years old), graduated in December 2020**.
- **2012 - 2017**: **Bachelor** and **Master** degrees at the University of Cadi Ayyad, Marrakesh, Morocco.
- **2017**: **M2 internship** at the **IJCLab** laboratory, Orsay, France: **Precision measurement of the W boson mass with the ATLAS detector at the LHC**.
- **2017-2020**: **PhD** at the **IJCLab** laboratory, Orsay, France: **Calibration of the ATLAS Electromagnetic Calorimeter and Measurement of W Boson Properties**.
- **2021-2023**: Postdoctoral Researcher at CERN, Shandong University: **Measurement of the Higgs boson production cross sections via ggF, using Run 2 data with the ATLAS detector**.

Outline

Previous work and achievements:

- Qualification task:
  - Calibration of the electromagnetic calorimeter of the ATLAS detector.
  - Development of a new method to calibrate the ATLAS electromagnetic calorimeter for low pileup runs, used for the electroweak measurements.
- physics analysis: measurement of W boson properties
  - Measurement of the W-boson transverse momentum distribution using low pileup runs data.
  - Measurement of the W-boson production cross sections.
  - Measurement of the differential and double differential cross sections using the unfolding technique.

Work status at SDU:

- Higgs physics: Measurement of the Higgs boson production and differential cross sections via ggF in the $H \to WW^{\star} \to \ell\nu\ell\nu$.

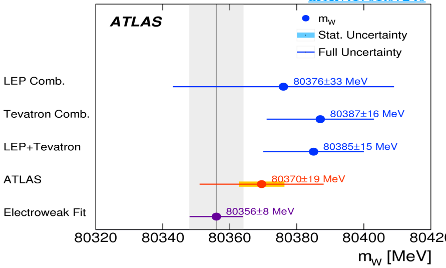
Previous work and achievements: Qualification task

Motivation

- Electrons and photons are heavily used in precision measurements due to the high precision reachable by the electromagnetic (EM) calorimeter.

Measuring the mass of the W boson with an uncertainty less than 19 MeV

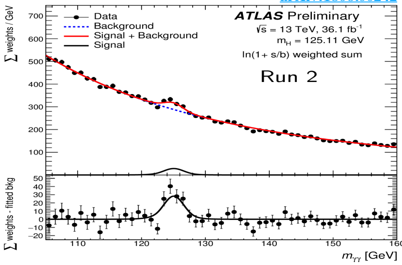
arXiv:1701.07240



$$m_W = 80370 \pm 7\ \text{(stat.)} \pm 11\ \text{(exp. syst.)} \pm 14\ \text{(mod. syst.)}\ \text{MeV}$$
$$= 80370 \pm 19\ \text{MeV},$$

The measurement of the properties of the Higgs boson ($H \to \gamma\gamma$ and $H \to 4l$)

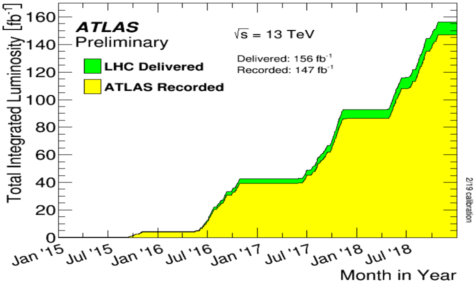
arXiv:1806.00242

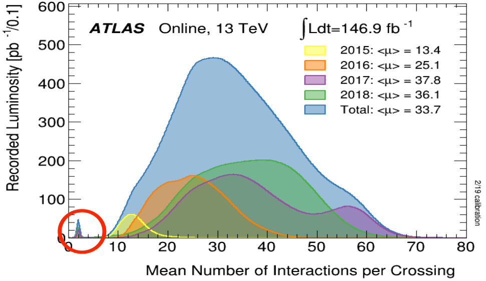


Channel	Mass measurement [GeV]
$H \to \gamma\gamma$	$125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{syst}) = 125.98 \pm 0.50$
$H \to ZZ^* \to 4\ell$	$124.51 \pm 0.52(\text{stat}) \pm 0.06(\text{syst}) = 124.51 \pm 0.52$
Combined	$125.36 \pm 0.37(\text{stat}) \pm 0.18(\text{syst}) = 125.36 \pm 0.41$

To reach a high precision in property measurements, a precise calibration of the energy of electrons and photons is required.

Dataset





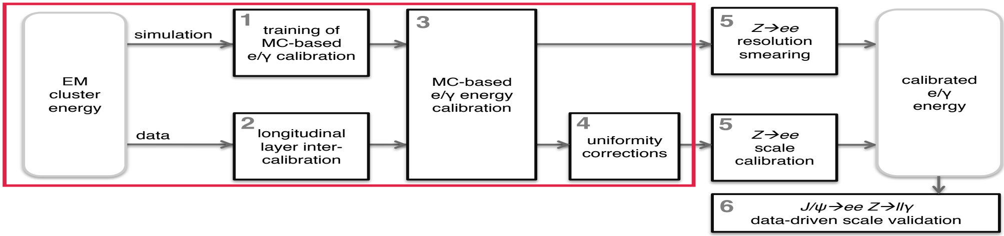
- Run 1: 2010 $\rightarrow$ 2012, (7 and 8 TeV)
- Run 2: 2015 $\rightarrow$ 2018, (13 TeV)
- The integrated luminosity:

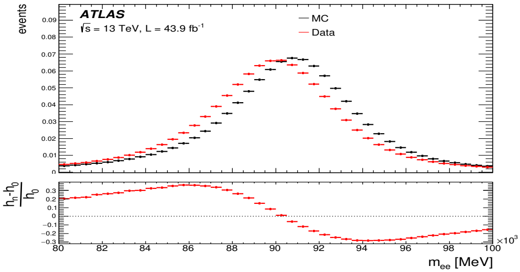
$$L_{\text{int}} = \frac{N_{\text{process}}}{\sigma_{\text{process}}},$$

- total integrated luminosity at Run 2 correspond to 147 fb^{-1} ($\times$ 7 Run 1).

- Recorded luminosity as a function of the number of interactions per crossing.
- Special runs are collected at ($\mu \approx 2$), correspond to 599 pb^{-1} at 5 and 13 TeV.
- Low pile-up runs are used for precision measurements.

Calibration procedure: Overview





Step 4: An important difference between data & MC:

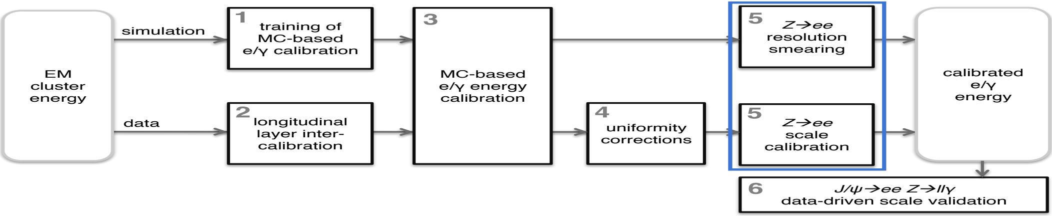
- Di-electron invariant mass m_{ee} at the step 4 of the calibration procedure:

$$m_{ee} = \sqrt{2 \cdot E_1 \cdot E_2 \cdot (1 - cos(\theta_{12}))} \qquad (1)$$

- The difference between data and simulation is corrected in step 5.

Calibration procedure: Method

Step 5: Two correction factors are extracted and applied to data and simulation.;



- The energy scale factor α:

$$E_i^{\mathrm{corr}} = \frac{E_i^{\mathrm{data}}}{1+\alpha_i}$$

- Applied to the data in order to match the energy response of the simulation.

- The additional constant term c':

$$\left(\frac{\sigma(E)}{E}\right)_i^{\mathrm{corr}} = \left(\frac{\sigma(E)}{E}\right)_i^{\mathrm{MC}} \oplus c'_i$$

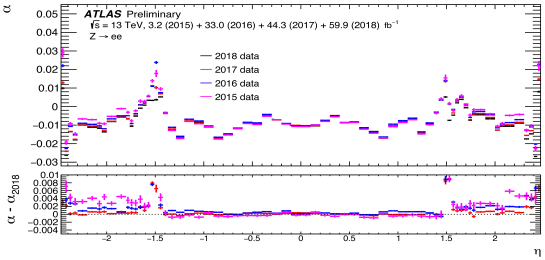
- Applied to the simulation to be in agreement with the energy resolution of the data.

Both correction factors are extracted using the templates method.

Calibration procedure: Results

JINST 14 (2019) P12006

Energy scale correction α



- The difference observed in the end-cap region is related to the difference of instantaneous luminosity.
- The difference of instantaneous luminosity affects the HV drop and temperature.

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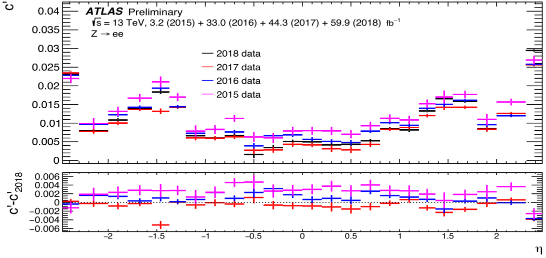
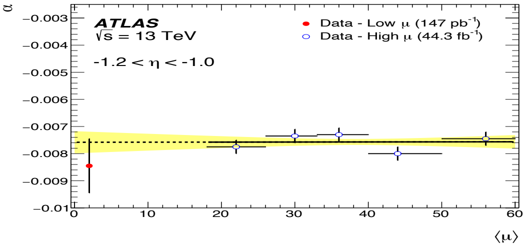
Resolution correction c'

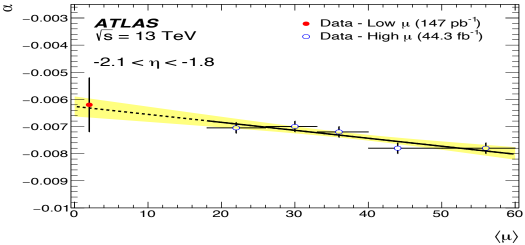


- The derived effective constant terms depend on the year i.e on the pileup (lower values for 2017 than 2016).
- This effect is explained by an overestimation of the pileup noise in the simulation.

Calibration of low pileup runs: Extrapolation approach (New method)

- **Motivation**: Calibrate the ATLAS electromagnetic calorimeter for low pileup runs used in the electroweak measurements.
- **Analysis Idea**: Because of low stats of low pileup runs, an alternative approach is used for the calibration: Extrapolate the results from standard to low pileup runs.
  1. The blue circles show the energy scale α for the high pileup dataset as a function of $\langle \mu \rangle$.
  2. The black lines show the extrapolation to $\langle \mu \rangle \approx 2$ using a linear function and five intervals of $\langle \mu \rangle$.
  3. The extrapolation results are compared with the energy scale factors extracted from the low pileup dataset, represented by the red point. **JINST 14 (2019) P03017**





Previous Work and Achievements: physics analysis

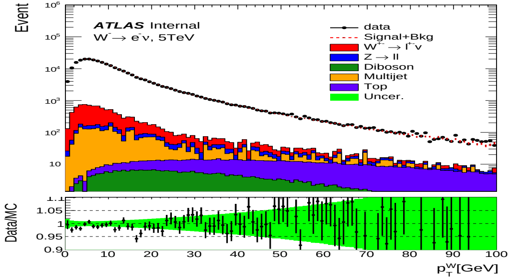
Goal: Increase the precision of W boson mass: from 19 MeV (Run 1) to less than 10 MeV (Run 2)

Combined categories	Value MeV	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
m_{T}^{W} , p_{T}^{ℓ}	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5

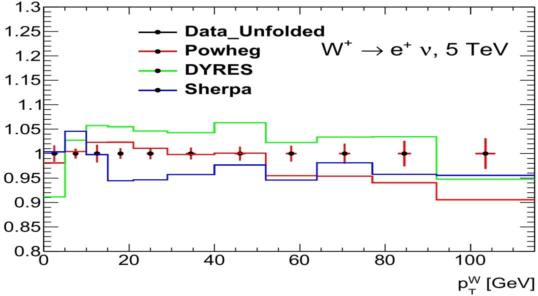
- **Measurement of p_T^W**: A precise measurement of p_T^W reduces the QCD modelling uncertainty in the measurement of M_W by a factor of two (8.3 $\rightarrow$ 4 MeV).
- **Measurement of the W boson differential Xs**: The rapidity dependence of the W boson production provides constraints on the parton distribution functions (PDFs), also the PDF uncertainty on the M_W measurement.

- **Analysis Idea:** The measurement of p_T^W is based on the unfolding procedure. The goal of the unfolding is to correct data detector resolution effects, and compare our distributions with the theoretical predictions.

Distributions at the reconstructed level:



Distributions at the unfolded level:

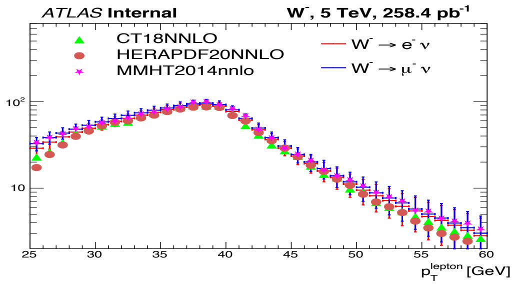


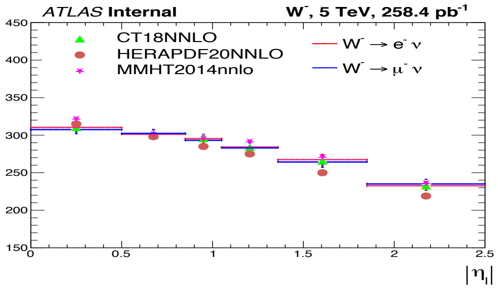
- The Bayesian method is used for the unfolding.
- All the sources of uncertainties are propagated to the unfolded level.
- The results for the unfolded p_T^W distributions compared to the different predictions.
- Paper of p_T^W measurement is in the review.

W boson differential cross sections

- **Motivation**: The measurement of differential cross sections in this process provides stringent tests of the QCD theory, also provides constraints on the parton distribution functions (PDFs).
- **Methodology**: The measurement of the differential cross sections is based on the unfolded distributions of our observable of interest $(\eta_\ell,\ p_\ell^T)$.

$$\frac{d\sigma_i}{dx^i} = \frac{N^i_{\mathrm{Unf}}}{\Delta x^i \mathcal{L}} \cdot \frac{1}{A_c} = \frac{1}{\Delta x^i \mathcal{L}} \cdot \Sigma_j M_{ij}^{-1} \left(N^j_{\mathrm{reco}} - N^j_{\mathrm{reco,bkg}} \right) \cdot \frac{1}{A_c}, \tag{2}$$





- Results are compared with theoretical predictions using DYTURBO.

Previous work and achievements: Conclusion and Publications

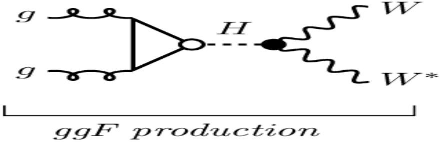
Previous work and achievements:

- Qualification task:
  1. I worked on the extraction of two scale factors (α, c') used for the calibration of ATLAS electromagnetic calorimeter.
  2. The results presented today are used by the ATLAS collaboration for Run 2 analyses.
  3. This work is published in **JINST 14 (2019) P12006** and **JINST 14 (2019) P03017**.
- Analyses work:
  1. I worked on the measurement of W boson properties: Measurement of p_T^W, Fiducial and differential cross sections.
  2. The paper for the measurement of p_T^W will be published before the end of 2021, together with the measurement of W boson fiducial cross sections (**in collaboration review**).
  3. We will have another paper covering the differential cross sections of W and Z bosons.

Work status at SDU:

Work status at SDU

- After 4 years in electroweak precision measurements, I started working on the Higgs physics.
- I joined the effort for the measurement of differential and fiducial cross sections of Higgs boson, via ggF in the $H \to WW^* \to \ell v \ell v$, with the Run 2 datasets.
  - Goal: Measure the fiducial cross sections, Inclusive as well as Differential, Associated with 2 Jets.
  - HWW: the dominant Higgs boson production mechanism, Large branching ratio, Clean signal in leptonic decay mode.
  - Strategy: Based on ggF couplings analysis (the object & event selections for signal region and control regions are same as in the couplings analysis).
  - Target: We are working hard to get a first version of the paper by the end of this year.

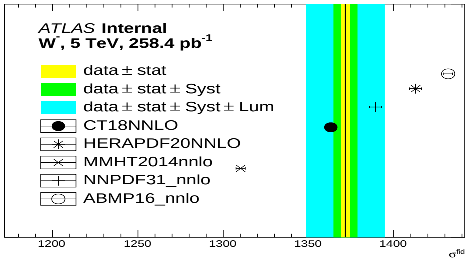


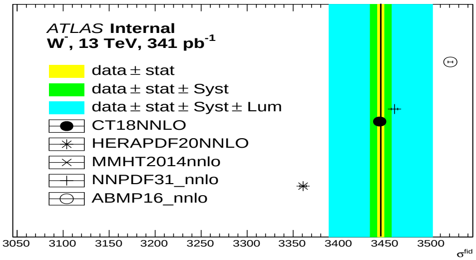
Backup

W boson production cross sections:

- **Analysis Idea**: The measurement of W boson production cross sections is based on the unfolded distributions of p_T^W:

$$\sigma_{fid} = \frac{N^{Unfolded}}{\mathcal{L}} \cdot A_{unf} \quad (3)$$





- Theoretical predictions are calculated for the fiducial cross-sections σ_{fid} using DYTURBO at NNLO QCD, with different PDF sets.
- W boson production cross sections using Run 2 ATLAS datasets, will be published with the p_T^W paper.