Observation of the electroweak production of two same-sign W bosons in proton-proton collisions with the ATLAS detector

Chilufya Mwewa

Brookhaven National Laboratory

African School of Physics Seminar Series

16 February 2021

My origin

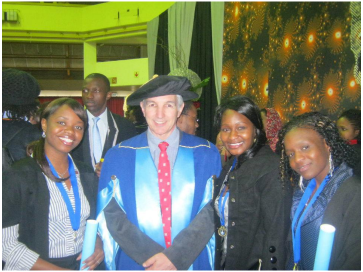
- I was born and bred in Zambia.

Photo credit: emmausrdministries.org

1st year at the University of Zambia

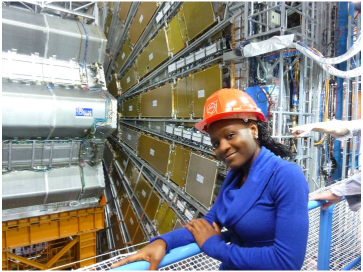
ASP 2010

My career path



- July 2020 - October 2020: Postdoc at UCT; November 2020 to date: Postdoc at BNL.

Opportunities



What is particle physics?

- The study of the fundamental building blocks of the universe and their interactions.

Photo credit: BBC-Earth

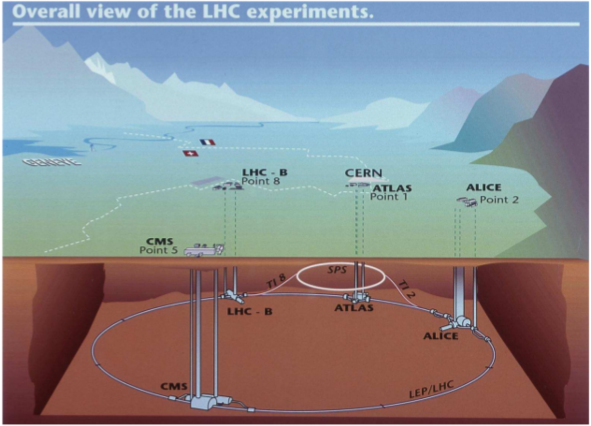
Experimentalists: Particle smashers!

- Seek to prove/disprove theoretical predictions or discover something totally new.
- Get a part of the universe and smash it until we get to the smallest unbreakable piece.

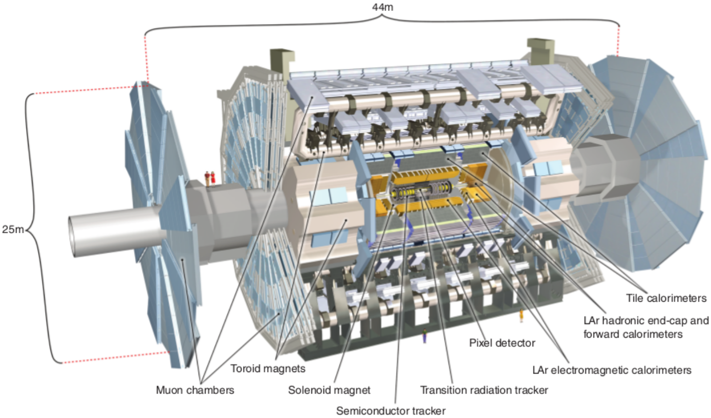
Photo credit: news.toyark.com

The Large Hadron Collider

- The largest particle accelerator ever built.

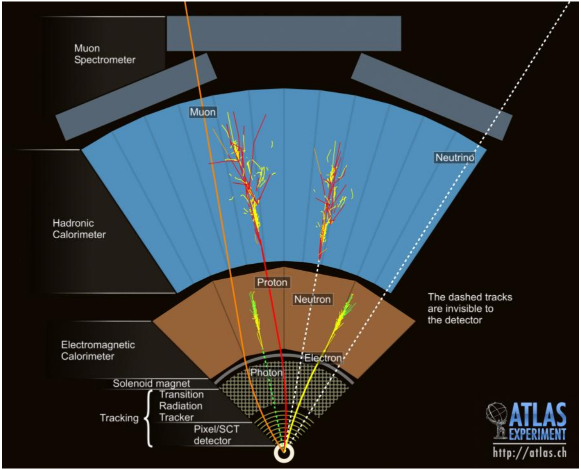


The ATLAS detector



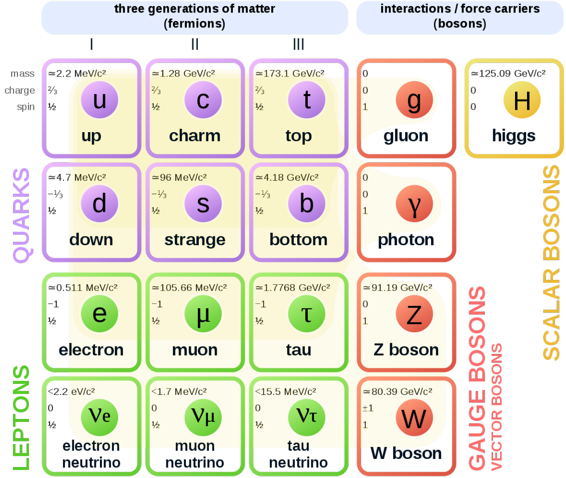
Particle identification

- Each particle emerging from the $p - p$ collision leaves a distinct signature in the detector.

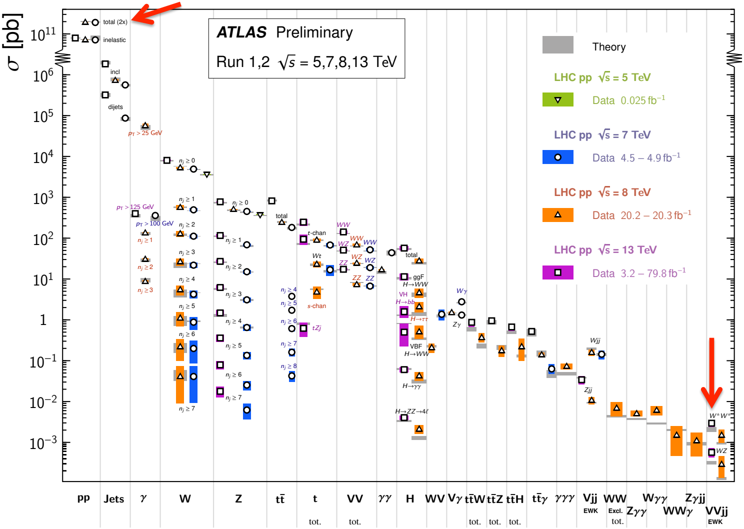


The Standard Model (SM)

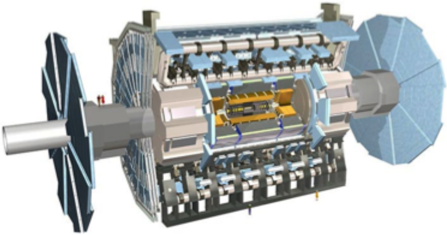
- Fundamental building blocks of the universe.

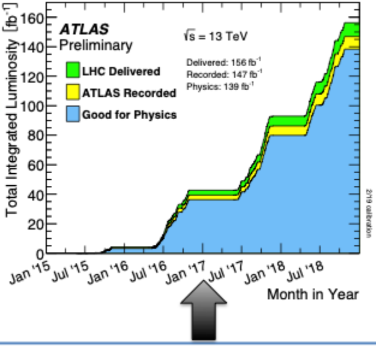


Overview of SM measurements in ATLAS



ATLAS data



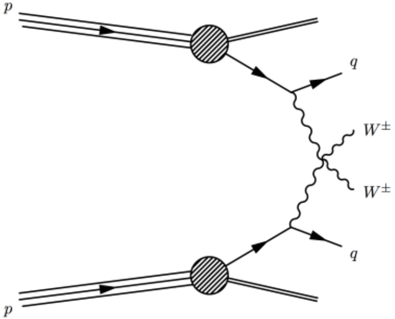


The total integrated luminosity recorded by ATLAS in 2015 and 2016 amounted to 36.1 fb^{-1}

LHC Run II: 2015-2018

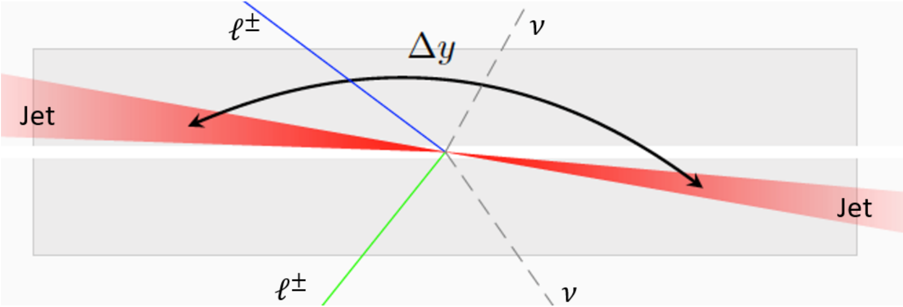
$W^{\pm}W^{\pm}jj$: Motivation

1. A rare process in the Standard Model (SM).
2. Vector Boson Scattering (VBS): unitarity is violated at high $\sqrt{s}$ in the absence of the Higgs.
   - Unitarity: Probabilities of all diagrams (processes) contributing to this should add up to one.
   - Provides a unique test of the SM ElectroWeak (EW) sector.

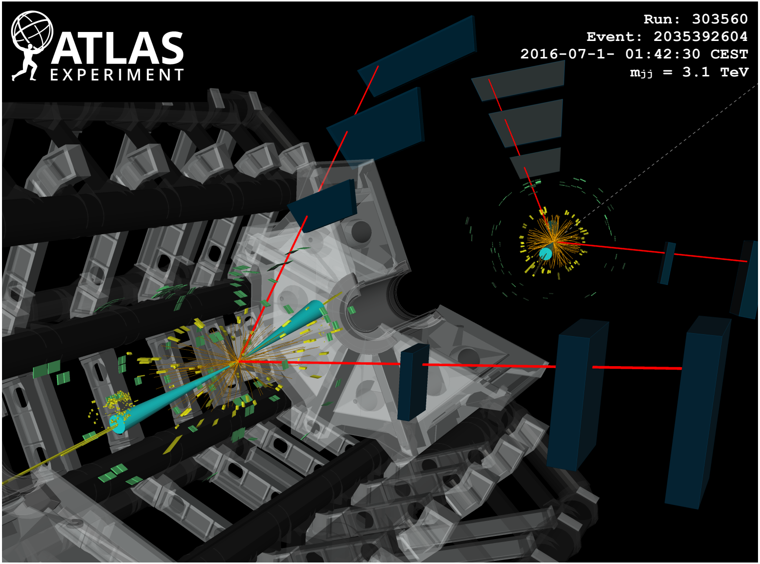


Event selection

- Two same-charge leptons with high transverse momentum (p_T).
- Large Missing Transverse Energy (E_T^{miss}).
- Two forward jets with large dijet invariant mass (M_{jj}) and a large rapidity separation (Δy_{jj})



Event display



Background estimation

Non-prompt

- $t\bar{t}$, W+jets, single top
- $t \rightarrow W + b$-jet
- one lepton from the W
- another lepton from the b-jet
- estimated from data

e/γ conversions

- $W^{\pm}W^{\mp}$, $V\gamma$
- one lepton is assigned a wrong charge
- γ is mis-identified as e
- estimated from data and simulation

Prompt

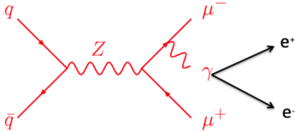
- WZ, ZZ, VVV
- two same-charge leptons are picked up
- estimated from data and simulation

QCD $W^{\pm}W^{\pm}$

- estimated from simulation

Background due to γ conversions in $V\gamma$

- We used a region dominated by $Z\gamma$ events with $Z \to \mu^+\mu^-$ and $\gamma \to e^-e^+$.



Event selection

- $\mu^+\mu^- + e^\pm$
- $E_T^{miss} < 30$ GeV
- $75 < M_{\mu\mu e} < 100$ GeV

- Obtained a Scale Factor (SF) by comparing data to $Z\gamma$ events.

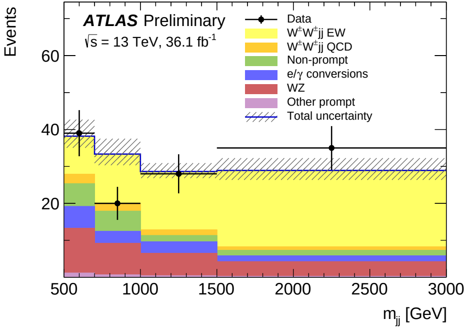
$$SF = \frac{Data - OtherProcesses}{Z\gamma}$$

- $V\gamma$ events in the signal region were scaled by SF.
- Uncertainty on SF was added as a systematic uncertainty.

Significance extraction (I)

- Maximum likelihood fit: 4 bins of M_{jj}
- Inputs: Signal and background yields + systematics
- Expected number of events per m_{jj} bin:

$$N_i^{exp}(\theta) = \mu \cdot N_i^{sig}(\theta) + N_i^{bkg}(\theta)$$



- Probability of observing a particular number of data events per m_{jj} bin is given by a likelihood function:

$$L(\mu|\theta) = \prod_i Poisson(N_i^{obs}|N_i^{exp})$$

Significance extraction (II)

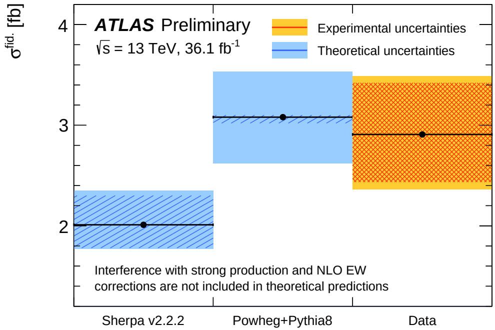
- Profile likelihood ratio is used as the test statistic.

$$q_\mu = -2ln\frac{L(\mu = 0, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\theta})}$$

- p-value is used to quantify the compatibility between observed and expected data.
- p-value: Probability of observing a result as extreme as the test statistic, given that the background-only hypothesis is true.
- p-value $\leq 2.7 \times 10^{-7} \rightarrow$ significance $\geq 5\sigma$

For this study, we had a 6.9σ observed significance

Cross section measurement

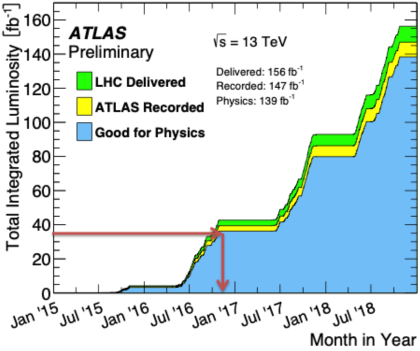


$$N = \sigma \times \mathcal{L}$$

$$\sigma_{obs} = 2.91^{+0.51}_{-0.47}\textbf{(stat)} \pm 0.23\textbf{(sys) fb}$$

Summary

- My journey as an experimental particle physicist started at ASP2010.
- My PhD work: VBS EW production of $W^{\pm}W^{\pm}$ was observed by ATLAS at a significance of 6.9σ and a cross-section of 2.91 fb.

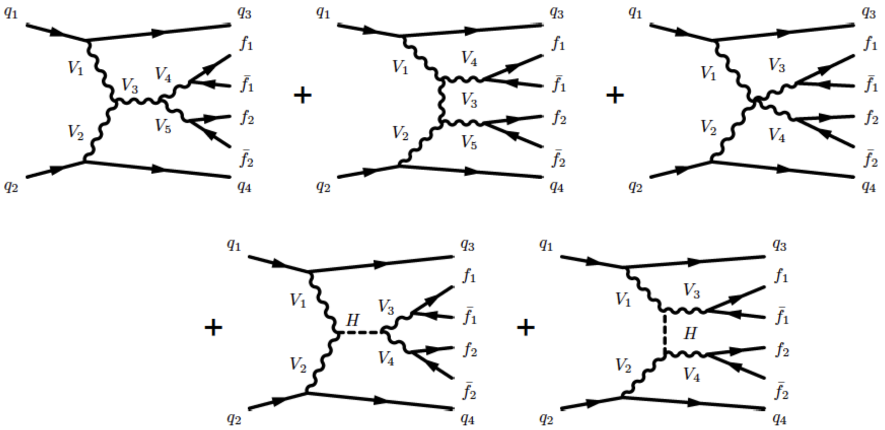


- Only 36.1 fb^{-1} of ATLAS Run II data was utilized for this measurement.
- This analysis is being repeated on the full RunII data set.
- More statistics $\Rightarrow$ higher precision!!

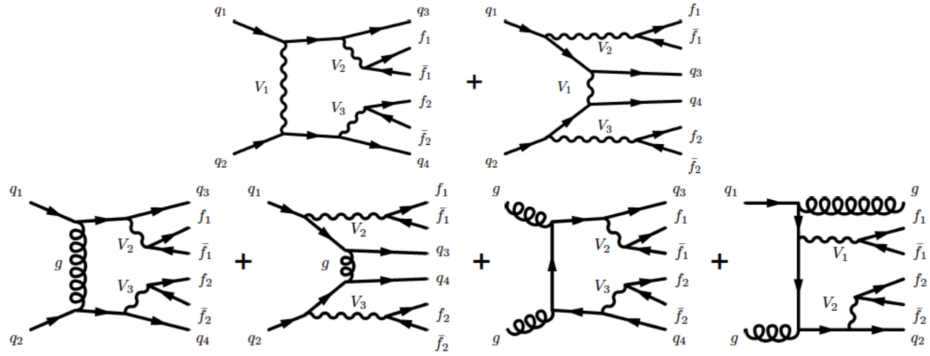
$\star$ Check this link for details on the results shown in this talk

Back up

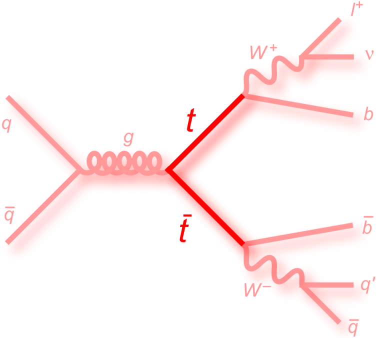
Same sign WW EW VBS production

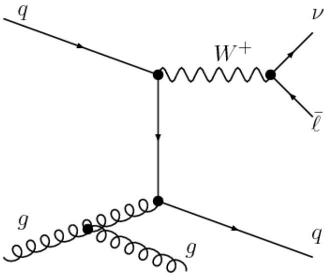


Same sign WW EW non-VBS and QCD production



$t\bar{t}$ and W+jets





Same sign WW analysis selections

event cleaning
exactly two signal leptons with $p_T > 27$ GeV and the same electrical charge with $\|\eta\| < 2.5$ for muons and with $\|\eta\| < 2.47$ excluding $1.37 \leq \|\eta\| \leq 1.52$ for electrons with $\|\eta\| < 1.37$ in the *ee* channel
$m_{\ell\ell'} \geq 20$ GeV
remove events with three or more preselected leptons
$\|m_{ee} - m_Z\| > 15$ GeV in the *ee*-channel
$E_{\mathrm{T}}^{\mathrm{miss}} \geq 30$ GeV
at least two jets leading and subleading jets satisfying $p_{\mathrm{T}} > 65$ GeV and $p_{\mathrm{T}} > 35$ GeV, respectively
$m_{jj} \geq 200$ GeV
b-jet veto using the MV2c10 tagger with the 85% efficiency working point
$\|\Delta y_{jj}\| > 2$

Pre-fit yields

	e^+e^+	e^-e^-	$e^+\mu^+$	$e^-\mu^-$	$\mu^+\mu^+$	$\mu^-\mu^-$	combined
WZ	1.7 ± 0.6	1.2 ± 0.4	13 ± 4	8.1 ± 2.5	5.0 ± 1.6	3.3 ± 1.1	32 ± 9
Non-prompt	4.1 ± 2.4	2.3 ± 1.8	9 ± 6	6 ± 4	0.57 ± 0.16	0.67 ± 0.26	23 ± 12
e/γ conversions	1.74 ± 0.31	1.8 ± 0.4	6.1 ± 2.4	3.7 ± 1.0	-	-	13.4 ± 3.5
Other prompt	0.17 ± 0.06	0.14 ± 0.05	0.90 ± 0.24	0.60 ± 0.25	0.36 ± 0.12	0.19 ± 0.07	2.4 ± 0.5
$W^\pm W^\pm$jj strong	0.38 ± 0.13	0.16 ± 0.06	3.0 ± 1.0	1.2 ± 0.4	1.8 ± 0.6	0.76 ± 0.26	7.3 ± 2.5
Expected background	8.1 ± 2.4	5.6 ± 1.9	32 ± 7	20 ± 5	7.7 ± 1.7	4.9 ± 1.1	78 ± 15
$W^\pm W^\pm$jj electroweak	3.80 ± 0.30	1.49 ± 0.13	16.5 ± 1.2	6.5 ± 0.5	9.1 ± 0.7	3.50 ± 0.29	40.9 ± 2.9
Data	10	4	44	28	25	11	122