# Status report of the LAL-SDU/USTC project on ATLAS

Kunlin Han on behalf of

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April 25, 2019

# Outline

Brief summary of the project of last year(s):

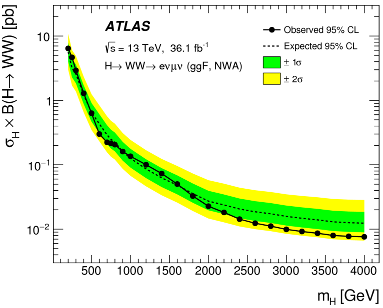
- High mass resonance search in $WW$

Focus on on-going projects:

- Precision measurement of electroweak (EW) parameters
- A generic search with inclusive $Z$ boson events at large $p_{\mathrm{T}}$

# High mass resonance search in *WW* [Eur. Phys. J. C78 (2018) 24]

- A search for neutral heavy resonances performed in the WW$\rightarrow e\nu\mu\nu$ decay channel using 2015+2016 data (36.1 $\mathrm{fb}^{-1}$)
- Analysis team: LAL, SDU, USTC.
- No evidence of such heavy resonances was found.
- Upper limits at 95% CL obtained over large mass range from 0.2 up to 5 TeV
- Seven scenarios/models studied:




Spin-0: Higgs-like scalars with 2 different widths;
Two-Higgs-doublet model;
Georgi–Machacek model

Spin-1: Heavy vector triplet

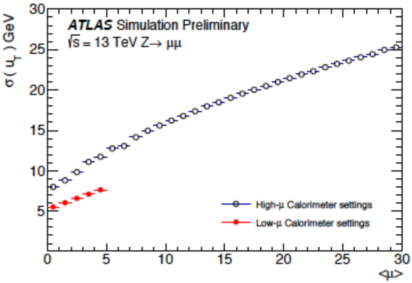
Spin-2: Kaluza–Klein graviton excitation in Randall–Sundrum model;
A tenser resonance in effective Lagrangian model

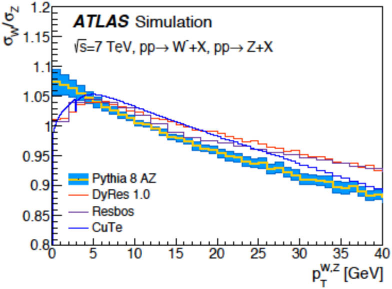
# Precision measurement of EW parameters

- ATLAS realized a precise $m_W$ measurement with 4.6 $\text{fb}^{-1}$ at 7 TeV [Eur. Phys. J. C78 (2018) 110], we aim for a factor of 2 improvement in next years
- We convinced the ATLAS Collaboration to take dedicated low pile-up data
- Energy scale calibration of electromagnetic calorimeter
- Implementation of hadronic recoil calculation in ATLAS
- Developed a statistical tool aiming for an improved $m_W$ measurement
- Measurement of $p_{\mathrm{T}}^{W,Z}$ being performed using unfolding technique

# Motivation for dedicated low pile-up data taking

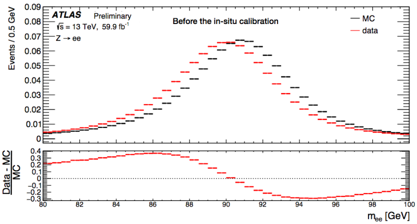
- Hadronic recoil resolution is strongly pile-up dependent
- There is a significant discrepancy in $p_{\mathrm{T}}$ distributions among different predictions
- This was one of the dominant uncertainties for the $m_W$ measurement
- The dedicated low pile-up data would allow to pin down the uncertainty



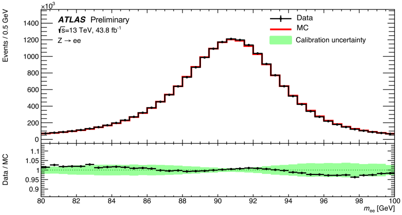



# Energy scale calibration of electromagnetic calorimeter

- A precise calibration of the electron and photon energy is indispensable for any precision measurement
- Corrections for the energy scale in data and resolution in simulation are derived using $Z \to ee$ events in the final step of the ATLAS calibration chain



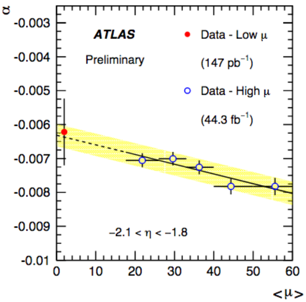

Before

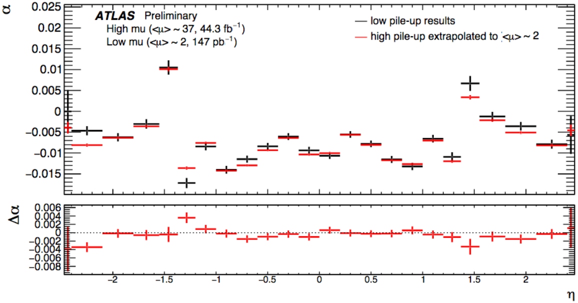



After

# Energy scale calibration for low pile-up data

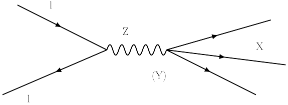
- Calibration performed for both low pile-up and nominal data samples
- The precision limited for the low pile-up data due to its low statistics
- The extrapolation from the pile-up dependence of the nominal data sample is more precise and both are in good agreement



# A generic search with inclusive $Z$ boson events at large $p_T$

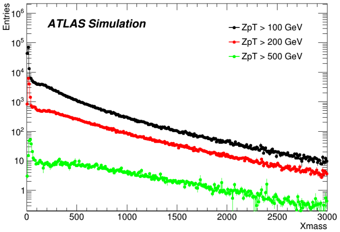
- Model independent search for new resonances in high $P_T$ $Z$ events
- Leptonic $Z$ decays provide a clean tag and fully triggered sample

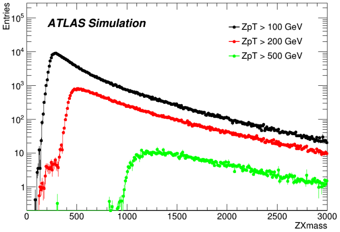


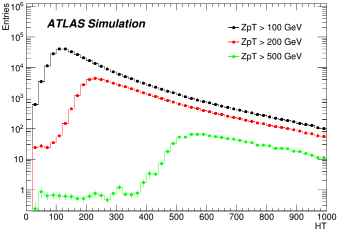

- Signal process: $pp \rightarrow (Y) \rightarrow ZX$, the resonances could be $X$ or $Y$
- A generic search in the sense that $X$ can have all possible final states
- Relevant variables: $m_X$, $m_{ZX}$ or $H_T$ (scalar sum of all objects including $E_T^{miss}$)

# Expected mass spectrum of SM background

- Distributions normalized to 36.2 $fb^{-1}$



# Trigger and event selections

Data sample:

- 2015+2016 ($36.2\ \mathrm{fb}^{-1}$) data samples are used for defining the analysis
- Final analysis will use full Run2 data of about 140 $\mathrm{fb}^{-1}$

Event selection:

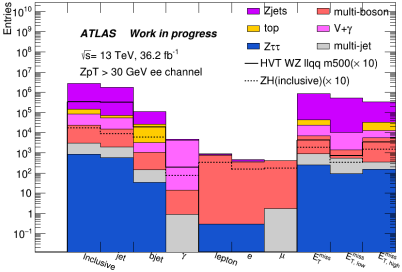
- Events selected with single lepton and dilepton triggers
- At least one lepton matched with a triggered object
- At least one electron / muon pair with opposite charge
- The $Z$ candidate has 66 GeV$< m_{ll} <$ 116 GeV
- Different $Z$ boson $p_{\mathrm{T}}$ thresholds considered

# Analysis strategy

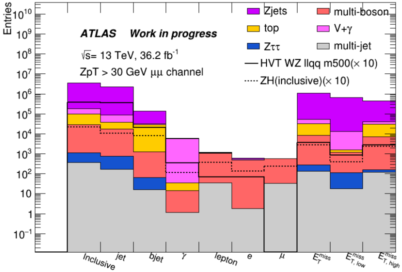
1. Identify leading $p_{\mathrm{T}}$ object in the remaining final state $X$
2. Define semi-inclusive channels with the leading $p_{\mathrm{T}}$ object in the event:
    - leadJ: jet + ...
    - leadB: b-jet + ...
    - leadP: photon + ...
    - leadL: lepton(e/$\mu$) + ...
    - leadMET: MissingET + ... (MET significance > 2.5)
3. Study all kinematic distributions for every given channel
    - of the leading $p_{\mathrm{T}}$ object
    - of $X$ = leading $p_{\mathrm{T}}$ object + other final state
    - of $Y = Z + X$

# Event yield of different semi-inclusive channels

- The inclusive channel includes all other channels
- The leading jet channel dominates in statistics
- The leading lepton channel is further separated in leading $e$ and $\mu$ channels




$Z \to ee$



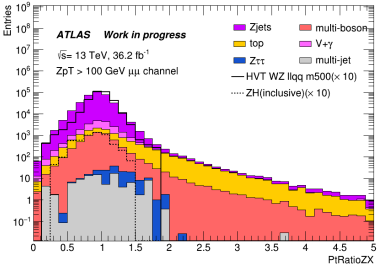

$Z \to \mu\mu$

# Background estimation

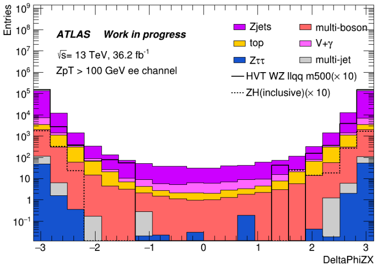
- The dominant background is from $Z+$ jets for all channels except for the leading $\gamma$ and lepton channels where $Z+\gamma$ and multi-boson background dominates, respectively
- Background with misidentified or fake leptons is small and data-driven
- All other background is based on MC simulation with cross sections normalized to best known predictions

# Distribution of $Z + X$ system

- At LO, $p_{\rm T}^{Z}$=0, large $p_{\rm T}^{Z}$ implies QCD radiation in the SM or new resonance $X$ production
- Expected $X - Z$ balance in $p_{\rm T}$ in e.g. the leading jet channel, HVT or ZH signal with $p_{\rm T}^{Z} > 100$ GeV



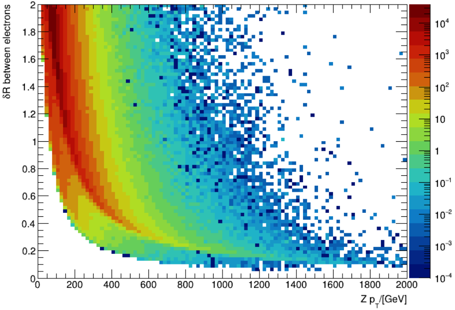

muon channel

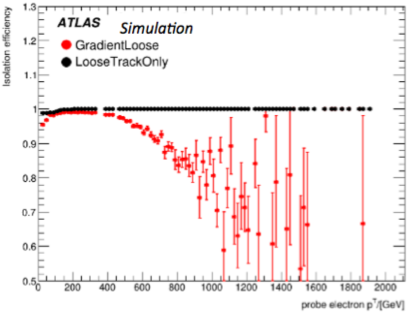



electron channel

# Challenge of the analysis

- One of the challenges is the highly boosted $Z$ bosons making the two decaying electrons non-isolated at high $p_{\mathrm{T}}$
- Aim to gain efficiency by developing fat-electron identification



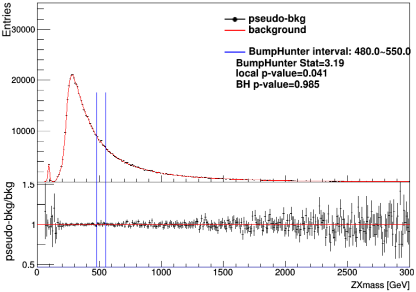



# Search algorithm

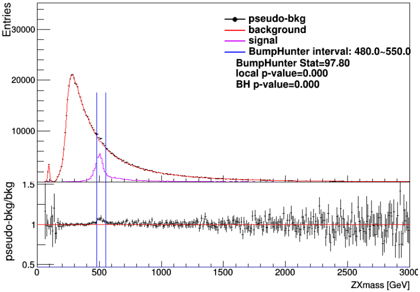
- Trying the BumpHunter (BH) algorithm [arXiv:1101.0390v2] to search for excess in a model independently way
- Need to define the binning of the $m_X$, $m_{ZX}$ and $H_T$ distributions according to detector resolution
- The largest deviation is evaluated with:
  - Local *p*-value: $p_0 = \sum_{n=d}^{\infty} \frac{b^n}{n!} e^{-b} (d > b)$
  - BH test statistic: $t = -\log(p_0^{\min})$
- Before the data will be unblinded, apply the BH algorithm to pseudo data with or without injected signal

# Test with background and injected signal

- The largest excess from background only distribution is consistent with statistical fluctuation (large $p$-value)
- Correctly locate the excess for an injected HVT signal ($ZW \to llqq$ 500 GeV)




background only




background+injected signal

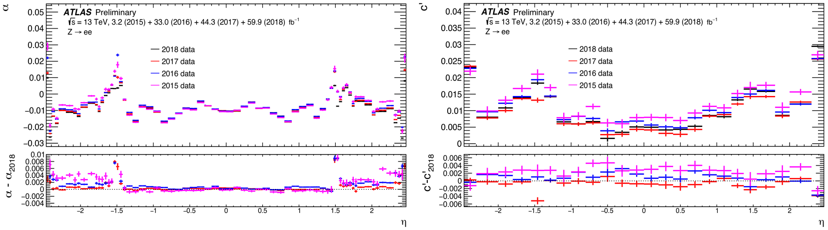
# Summary

- Fruitful collaboration since many years
- Two projects actively going on

# Backup

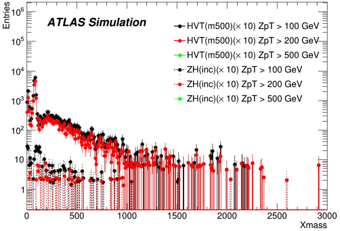
# Electron scale factor and additional constant term

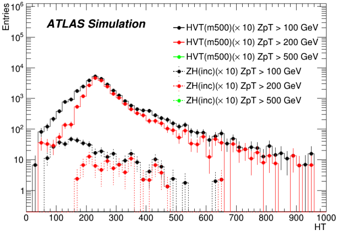
- Energy scale $\alpha$: applied to data matching energy response in MC
- Additional constant term c': applied to MC matching energy resolution in data

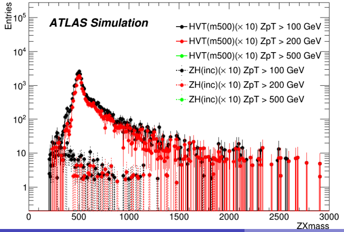


# Expected mass spectrum of signal-like samples

- Distributions normalized to 36.2 $fb^{-1}$
- Resonance **Y**: HVT WZ llqq 500GeV; **X**: Z(ll)H(125GeV)

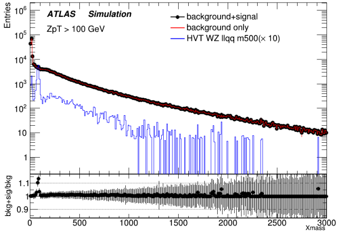


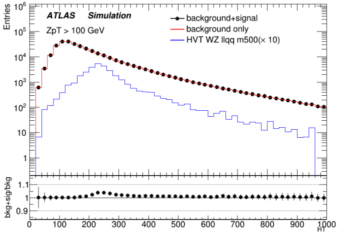



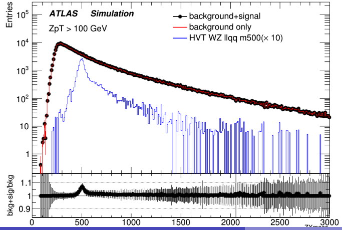



# Expected mass spectrum after injectting signal-like samples

- Distributions normalized to 36.2 $\text{fb}^{-1}$
- Resonance **Y**: HVT WZ llqq 500GeV

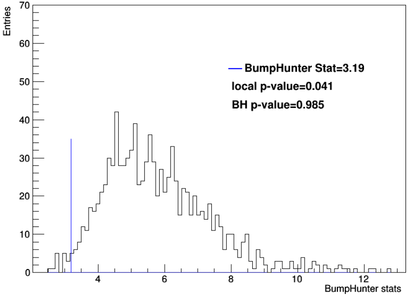


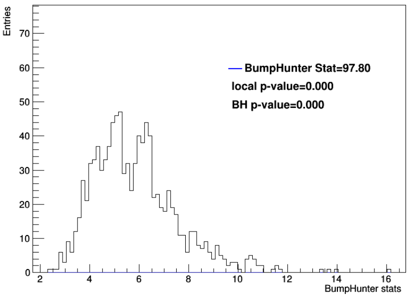



# Injection test of a new resonance signal

- The blue line is the observed BH test statistics results




background only




background+injected signal