# Generic Search of Inclusive High pT Z Events Analysis with ATLAS detector

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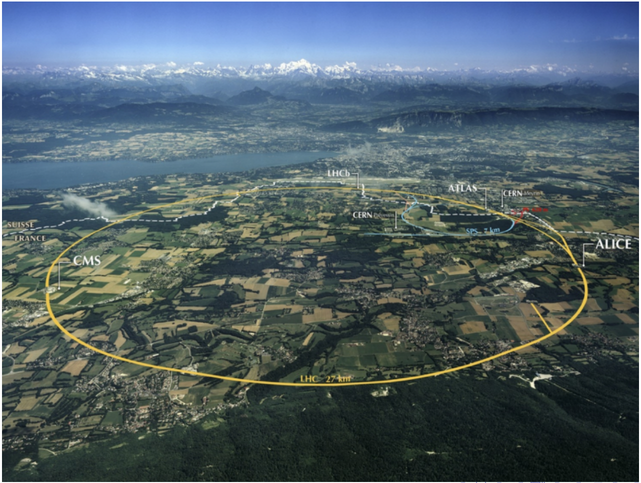
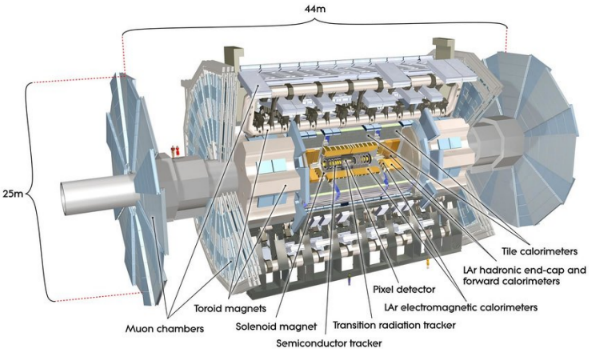
# The Large Hadron Collider

- The worlds largest and most powerful particle accelerator: pp collision at 13 TeV (Run 2)
- Four particle detectors: **ATLAS**, CMS, ALICE, LHCb



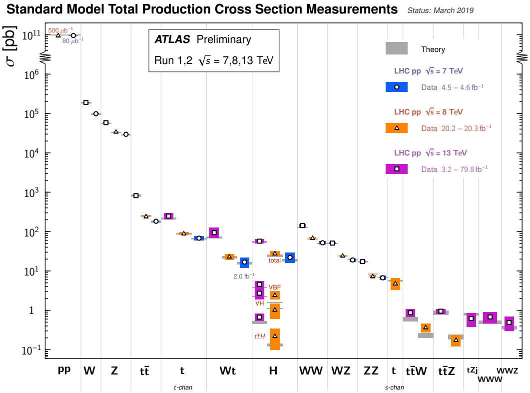
# The ATLAS Detector

- Inner Detector: Pixel, SCT, TRT
- Calorimeters: electromagnetic and hadronic
- Muon spectrometer: RPC, TGC, MDT, CSC
- Magnet system: Solenoid(2T), Toroid(0.5T, 1T)



# Success and Challenges of the Standard Model

After the observation of Higgs boson in 2012 at ATLAS and CMS experiments, all the elementary particles predicted by the Standard Model have been observed.



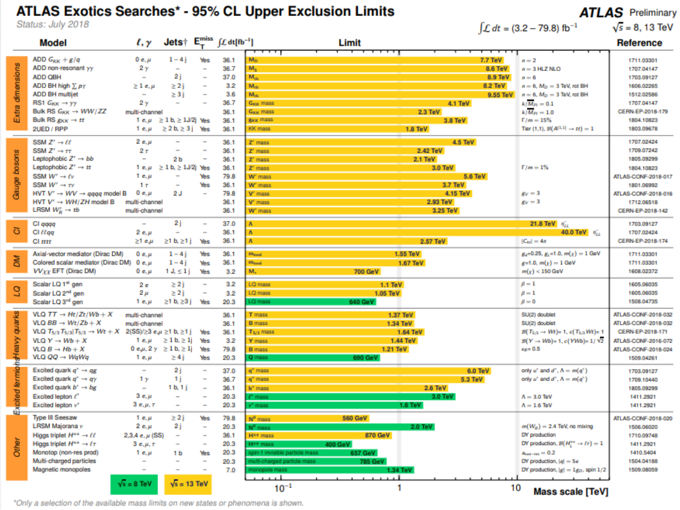

The SM works extremely well but...

Phenomena not explained

- Gravity
- Dark Matter & Dark Energy
- Neutrino mass
- ...

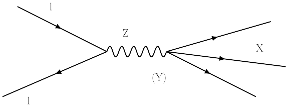
# Beyond the Standard Model

Many theories beyond the Standard Model solving the challenges, predict new phenomena accessible by the LHC



# Motivation

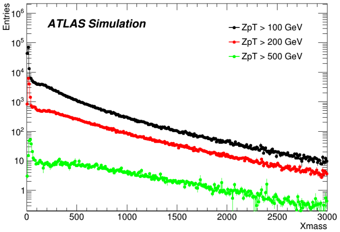
- Model independent search for new resonances in high $P_{\mathrm{T}}$ $Z$ events
- Leptonic $Z$ decays provide a clean tag and fully triggered sample

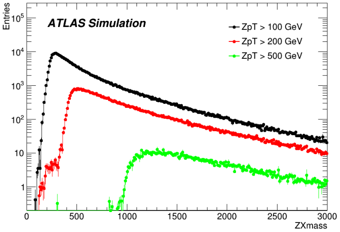


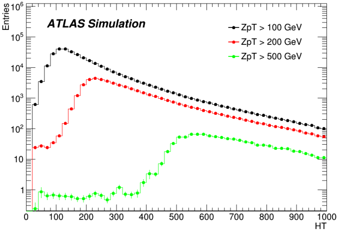

- Signal process: $pp \rightarrow (Y) \rightarrow ZX$, the resonances could be $X$ or $Y$
- A generic search in the sense that $X$ can have all possible final states
- Relevant variables: $\mathrm{m}_X$, $\mathrm{m}_{ZX}$ or $\mathrm{H}_{\mathrm{T}}$ (scalar sum of all objects including $E_{\mathrm{T}}^{\mathrm{miss}}$)

# 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:

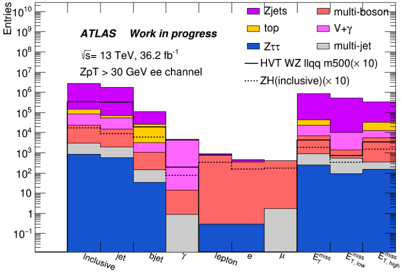
- Events selected with single lepton and dilepton triggers
- At least one lepton matched with a triggered object
- At least one electron / muon pair with opposite charge
- The $Z$ candidate has 66 GeV$< m_{ll} <$ 116 GeV
- Different $Z$ boson $p_{\mathrm{T}}$ thresholds considered

# Analysis strategy

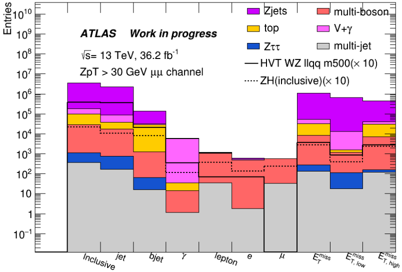
1. Identify leading $p_{\mathrm{T}}$ object in the remaining final state $X$
2. Define semi-inclusive channels with the leading $p_{\mathrm{T}}$ object in the event:
    - leadJ: jet + ...
    - leadB: b-jet + ...
    - leadP: photon + ...
    - leadL: lepton(e/$\mu$) + ...
    - leadMET: MissingET + ... (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




$Z \to ee$



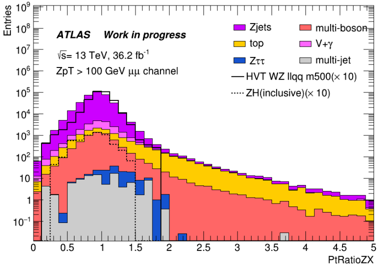

$Z \to \mu\mu$

# Background estimation

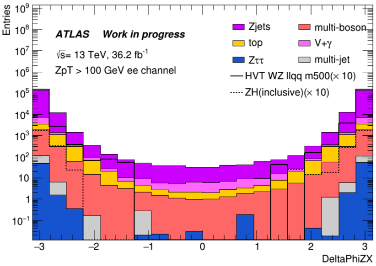
- The dominant background is from $Z+$ jets for all channels except for the leading $\gamma$ and lepton channels where $Z+\gamma$ and multi-boson background dominates, respectively
- Background with misidentified or fake leptons is small and data-driven
- All other background is based on MC simulation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

# Distribution of $Z + X$ system

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




muon channel



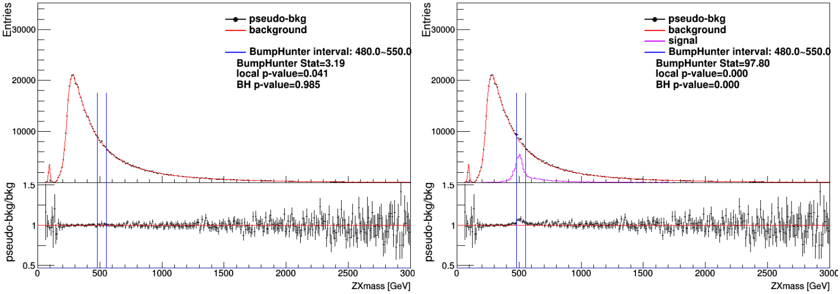

electron channel

# 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

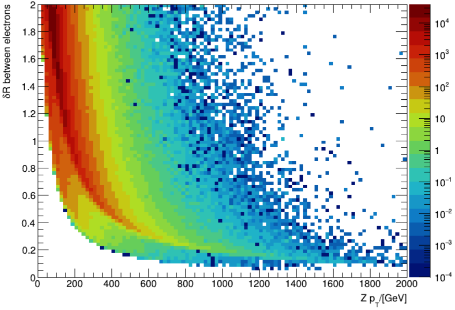
- The largest excess from background only distribution is consistent with statistical fluctuation (large $p$-value)
- Correctly locate the excess for an injected HVT signal ($ZW \rightarrow llqq$ 500 GeV)

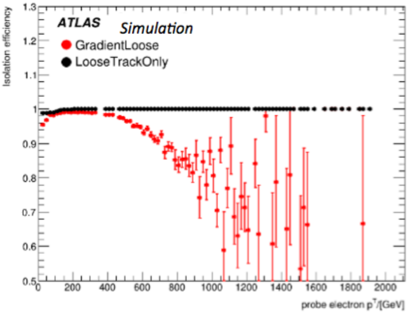



background only    background+injected signal

# 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



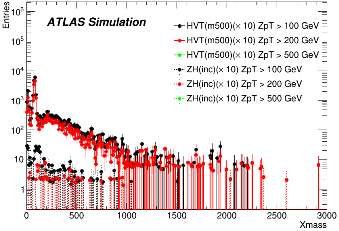
# Summary

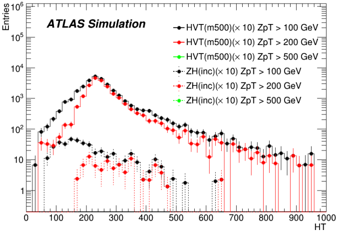
- 2015+2016 data and MC samples are used to test the proposed analysis strategy.
- The search algorithm is defined and test
- A new fat-electron object is developed to increase statistics in extremely high $p_{\mathrm{T}}$ regions.
- The analysis is still ongoing and will include full Run2 ATLAS data

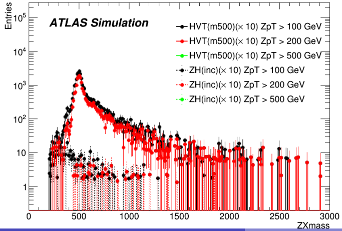
# Backup

# 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)

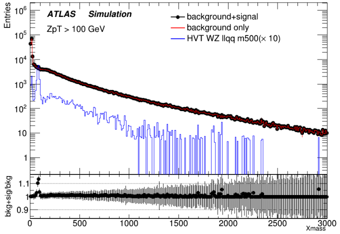


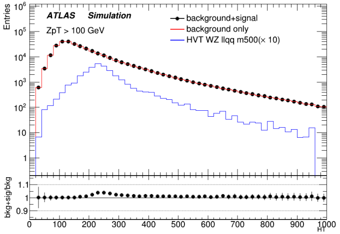



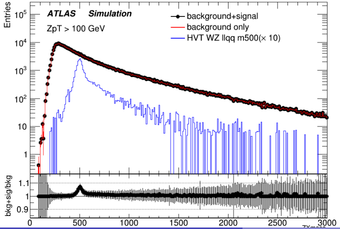



# Expected mass spectrum after injectting signal-like samples

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

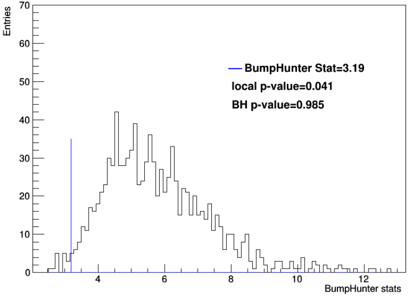


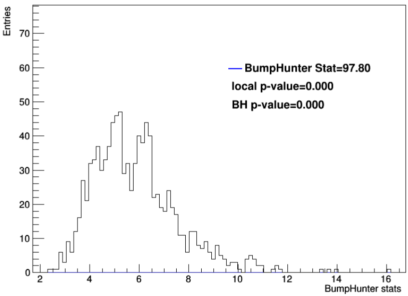



# Injection test of a new resonance signal

- The blue line is the observed BH test statistics results



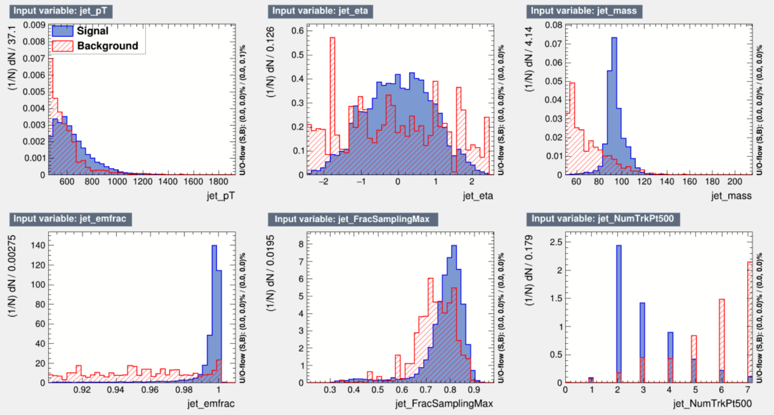

background only




background+injected signal

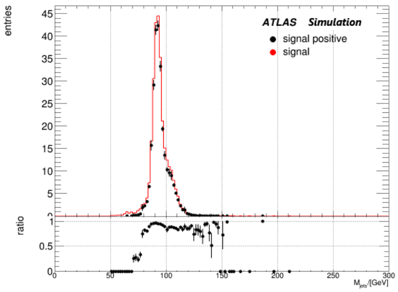
# Fat-electron identification

- A MVA method is developed to identify fat-electron objects.
- Fat-electron candidates have to pass preselection requirements.(p20)
- Signal candidates are extracted by matching with truth Z bosons.

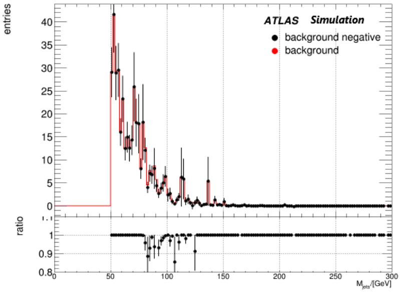


# Fat-electron identification

- After training, the signal efficiency and background rejection are estimated in test samples.



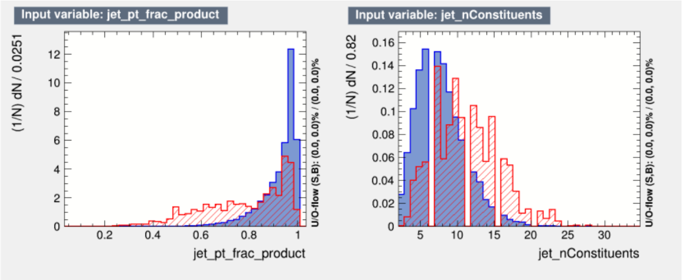

Signal efficiency




background rejection

# Fat-electron objects preselctions

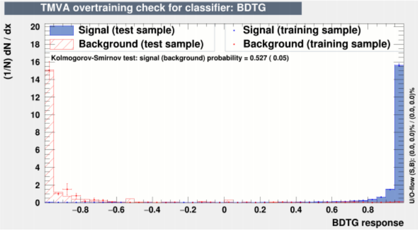
- jet$p_{\mathrm{T}} > 450$GeV
- $|\eta| < 2.47$
- $M_{jet} > 50$GeV
- EMfrac $> 0.9$
- NumTrkPt500 $\leq 7$



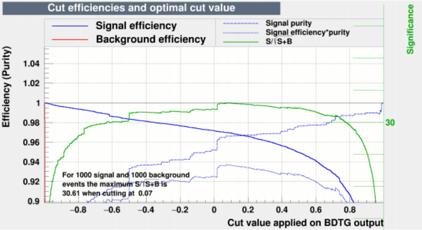

The rest of input variables

# BDT score output of MVA method

- Cut at BDT score where signal has 90% efficiency at least



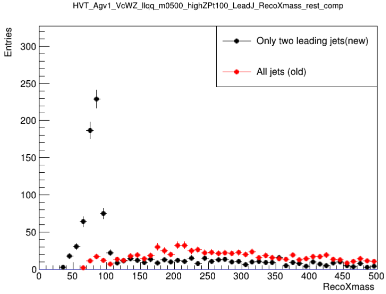

Gradient BDT score



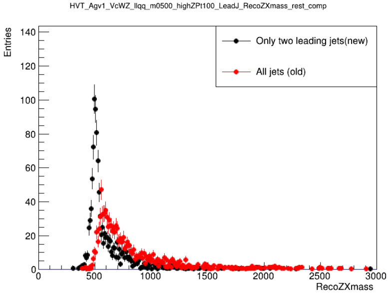

Gradient BDT score cut

# Improvement on analysis strategy

- In the current strategy, X object are reconstructed by all remaining final states(excluding 2 signal leptons)
- The possible resonance will be smeared or shifted.
- Limit the selection of objects will improve the distributions.
- In LeadJ category, the first two leading $p_T$ jets are taken.

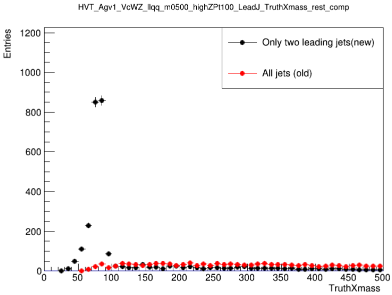



$m_X$

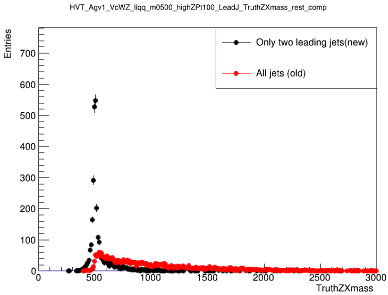



$m_{ZX}$

# New strategy comparison in truth level




$m_X$




$m_{ZX}$