

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

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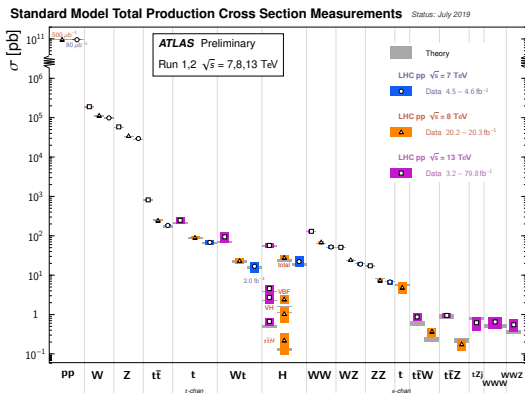


# Outline

- Analysis Motivation
- Event reconstruction and classification
- Background estimation
- Kinematics of  $Z + X$  system
- Kinematic variable in resonance search
- Challenge of the analysis
- Conclusion

# Success and Challenges of the Standard Model

After the observation of Higgs boson in 2012 by 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

## ATLAS Exotics Searches\* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 139) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

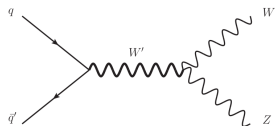
Model	$f, \gamma$	Jets)	$E_{\text{miss}}$	$\mathcal{L}_{\text{eff}} [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{\mu\nu} + g/\ell$	0 $\mu\mu$	1-4)	Yes	3.7 TeV	$n=2$ 1711.0526
	ADD non-resonant $\gamma\gamma$	2 $\gamma$	-	Yes	6.6 TeV	$n=3, 4, 2, \text{NLO}$ 1707.04147
	ADD QBH	-	2)	Yes	37.0 TeV	$n=6$ 1703.09127
	ADD BH high $\sum p_T$	$\geq 1.4 \mu\mu$	$\geq 2$ )	Yes	5.9 TeV	$n=6, M_0 = 3 \text{ TeV}$ vs BH 1608.02085
	ADD BH multijet	-	$\geq 3$ )	Yes	3.55 TeV	$n=6, M_0 = 3 \text{ TeV}$ vs BH 1612.02586
	RS1 $G_{\mu\nu} \rightarrow W\gamma$	2 $\gamma$	-	Yes	6.1 TeV	$\frac{M_0}{\Lambda} = 0.1$ 1707.04147
	Bulk RS $G_{\mu\nu} \rightarrow WW/ZZ$	multi-channel	-	Yes	3.3 TeV	$\frac{M_0}{\Lambda} = 1.0$ 1608.02085
	Bulk RS $G_{\mu\nu} \rightarrow WW \rightarrow \text{qqqq}$	0 $\mu\mu$	2, 3)	Yes	1.39 TeV	$\frac{M_0}{\Lambda} = 1.0$ ATLAS CONF-2018-003
	Bulk RS $G_{\mu\nu} \rightarrow \tau\tau$	1 $\mu\mu$	$\geq 1.6, \geq 1.0$ )	Yes	3.1 TeV	$r = 10\%$ 1604.10823
	GRW/WW	1 $\mu\mu$	$\geq 2.5, \geq 3$ )	Yes	3.5 TeV	$\text{Tex}(0.1,  g e^{i\theta} \rightarrow \tau) = 1$ 1603.06763
Gauge bosons	SSM $Z' \rightarrow \tau\tau$	2 $\mu\mu$	-	Yes	3.1 TeV	1603.06248
	SSM $Z' \rightarrow \tau\tau$	2 $\tau\tau$	-	Yes	3.42 TeV	1709.07240
	Leptoquark $Z' \rightarrow tb$	-	2b)	Yes	3.1 TeV	1605.05098
	Leptoquark $Z' \rightarrow tt$	1 $\mu\mu$	$\geq 1.6, \geq 1.0$ )	Yes	3.1 TeV	$f = 1\%$ 1604.10823
	SSM $W' \rightarrow \tau\nu$	1 $\tau\nu$	-	Yes	3.0 TeV	1712.06519
	SSM $W' \rightarrow \tau\nu$	1 $\tau\nu$	-	Yes	3.7 TeV	1607.04273
CI	HVT $V' \rightarrow WZ \rightarrow \text{qqqq}$ model B	0 $\mu\mu$	2, 3)	Yes	3.8 TeV	$g_V = 3$ ATLAS CONF-2018-003
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	Yes	2.93 TeV	$g_V = 3$ 1712.06519
	LRSM $W_2 \rightarrow tb$	multi-channel	-	Yes	3.35 TeV	1607.04273
LRSM $W_2 \rightarrow tb$	2 $\mu\mu$	1, 3)	Yes	3.0 TeV	$g(N_2) = 0.5 \text{ TeV}, g_V = g_V$ 1604.12679	
DM	CI $\text{qqqq}$	-	2)	Yes	37.0 TeV	1703.09127
	CI $\tau\tau/\text{qq}$	2 $\mu\mu$	-	Yes	21.8 TeV	$\chi_1^0$ 1707.04244
	CI $\text{qq}\tau$	$\geq 1 \mu\mu$	$\geq 1.6, \geq 1.1$ )	Yes	35.1 TeV	$\chi_1^0$ 1611.05262
DM	Axial-vector mediator (Dirac DM)	0 $\mu\mu$	1-4)	Yes	3.6 TeV	$g_V = 0.25, g_A = 1.0, m_\chi = 1 \text{ GeV}$ 1711.05262
	Colored scalar mediator (Dirac DM)	0 $\mu\mu$	1-4)	Yes	3.6 TeV	$g_V = 0.8, m_\chi = 1 \text{ GeV}$ 1711.05262
	VVVV, EP1 (Dirac DM)	0 $\mu\mu$	$1, \Delta \leq 1$ )	Yes	3.2 TeV	$m_\chi = 110 \text{ GeV}$ 1608.02079
	Scalar reson. $\beta = \gamma$ (Dirac DM)	0 $\mu\mu$	$1, \Delta \leq 1$ )	Yes	3.4 TeV	$r = 0.4, \Delta = 0.2, m_\chi = 10 \text{ GeV}$ 1612.02586
LO	Scalar LG 1 <sup>st</sup> gen	1, 2 $\mu\mu$	$\geq 2$ )	Yes	1.9 TeV	$\beta = 1$ 1602.00277
	Scalar LG 2 <sup>nd</sup> gen	1, 2 $\mu\mu$	$\geq 2$ )	Yes	1.35 TeV	$\beta = 1$ 1602.00277
	Scalar LG 3 <sup>rd</sup> gen	2 $\tau\tau$	-	Yes	1.23 TeV	$ \text{Re}(Q_V - A_V)  = 1$ 1602.00277
	Scalar LG 3 <sup>rd</sup> gen	0-1 $\mu\mu$	2b)	Yes	670 GeV	$ \text{Re}(Q_V^2 - r_V^2)  = 0$ 1602.00277
Heavy quarks	VLO $T\bar{T} \rightarrow W\gamma/Z/\text{WB} + X$	multi-channel	-	Yes	1.27 TeV	SU(2) doublet 1608.02043
	VLO $\text{WB} \rightarrow W\gamma/Z/\text{WB} + X$	multi-channel	-	Yes	1.34 TeV	SU(2) doublet 1608.02043
	VLO $\text{TC}_{1,2} \text{TC}_{1,2} \rightarrow W\gamma + X$	$2(200) \rightarrow 2(1b, 2l)$	Yes	36.1 TeV	$ \text{Re}(Q_V - A_V)  = 1$ 1612.02586	
	VLO $V \rightarrow \text{WB} + X$	1 $\mu\mu$	$\geq 1.6, \geq 1.1$ )	Yes	1.35 TeV	$ \text{Re}(V - W\beta)_1, \text{c}_2(\text{WB}) = 1$ 1612.02586
	VLO $\text{B} \rightarrow \text{RB} + X$	0 $\mu\mu$	2, 3)	Yes	1.21 TeV	$\kappa_V = 0.5$ ATLAS CONF-2018-004
VLO $\text{CQ} \rightarrow \text{WbWb}$	1 $\mu\mu$	$\geq 4$ )	Yes	20.3 TeV		
Exotic resonances	Excited quark $q^* \rightarrow \text{qq}$	-	2)	Yes	6.7 TeV	only $u^*$ and $d^*$ , $A = m(q^*)$ ATLAS CONF-2018-007
	Excited quark $q^* \rightarrow \text{q}\gamma$	-	1 $\gamma$	Yes	3.3 TeV	only $u^*$ and $d^*$ , $A = m(q^*)$ 1709.10440
	Excited quark $q^* \rightarrow \text{qg}$	-	1b, 1)	Yes	3.1 TeV	1605.05098
	Excited lepton $l^*$	3 $\mu\mu$	-	Yes	3.0 TeV	$A = 1.0 \text{ TeV}$ 1411.26261
	Excited lepton $\nu^*$	3 $\mu\mu, \tau$	-	Yes	1.6 TeV	$A = 1.6 \text{ TeV}$ 1411.26261
Other	Type II Seesaw	1 $\mu\mu$	$\geq 2$ )	Yes	79.8 TeV	$m^2$ mass 380 GeV ATLAS CONF-2018-030
	LRSM Majorana $\nu$	2 $\mu\mu$	-	Yes	3.2 TeV	$m^2$ mass 870 GeV 1716.07474
	Higgs Inert $H^{\text{SM}} \rightarrow Z\tau$	2, 3, 4 $\mu\mu$ (SS)	-	Yes	30.3 TeV	DF production, $\beta(\text{H}^{\text{SM}} \rightarrow \tau\tau) = 1$ 1411.26261
	Higgs Inert $H^{\text{SM}} \rightarrow \tau\tau$	2, 3, 4 $\mu\mu$	-	Yes	30.3 TeV	DF production, $\beta(\text{H}^{\text{SM}} \rightarrow \tau\tau) = 1$ 1411.26261
	Multi-charged particles	-	-	Yes	3.2 TeV	DF production, $ \beta  =  g_{\mu\nu} \text{spin } 1/2 $ 1605.10130
	Magnetic monopoles	-	-	Yes	34.4 TeV	

\*Only a selection of the available mass limits on new states or phenomena is shown.

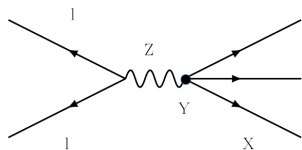
† Small-radius (large-radius) jets are denoted by the letter j (J).

# Motivation

- 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:  $pp \rightarrow (\mathbf{Y}) \rightarrow Z + \mathbf{X}$ , the resonances could be  $\mathbf{X}$  or  $\mathbf{Y}$
- 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)



Feynman diagrams for  $W' \rightarrow WZ$  process



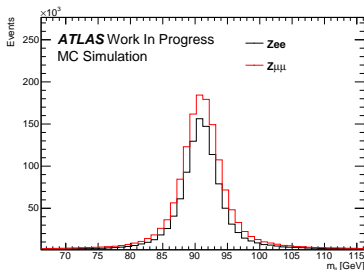
Event topology in Feynman diagrams' style

# Event selections

Data sample:

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

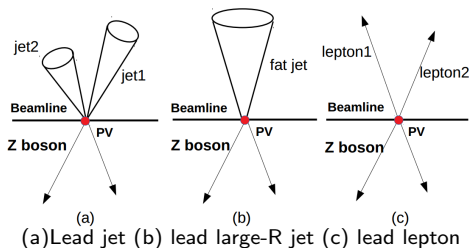
Event Selections	
<i>Trigger selections</i>	
$N_{e^+e^-} \geq 1$ or $N_{\mu^+\mu^-} \geq 1$	
Select Z candidate, closest to PDG mass	
$p_{T,(sub)lead \text{ lepton}} > 27 \text{ GeV}$	
$66 \text{ GeV} < m_{ll} < 116 \text{ GeV}$	
$p_{T,ll} > 50 \text{ GeV}$	
<i>Low <math>p_T</math> Region</i>	<i>High <math>p_T</math> Region</i>
$p_{T,ll} \leq 100 \text{ GeV}$	$p_{T,ll} > 100 \text{ GeV}$



$m_{ll}$  after event selections

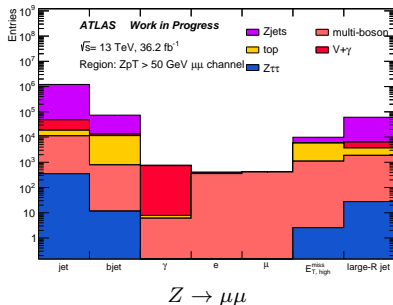
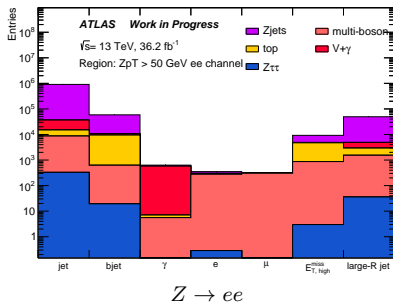
# Analysis strategy

- 1 Identify leading  $p_T$  object in the remaining final state  $X$
- 2 Define channels with the leading  $p_T$  object in the event:
  - leadJ: jet + ...
  - leadB: b-jet + ...
  - leadP: photon + ...
  - leadL: lepton( $e/\mu$ ) + ...
  - leadFatJ: large-R jet + ...
  - leadMET: MissingET + ... ( $MET/\sqrt{SumET} > 5.0$ )
- 3 Study all kinematic distributions for every given channel



# Event yield of different channels

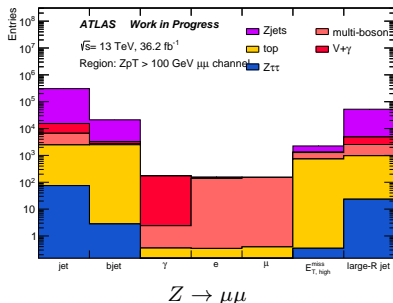
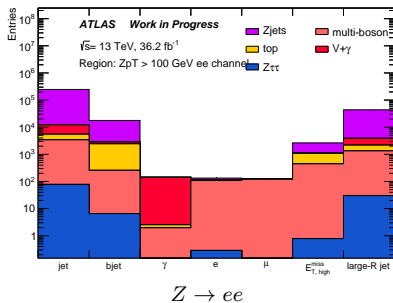
- The leading jet channel dominates in statistics
- The leading lepton channel is further separated in leading  $e$  and  $\mu$  channels





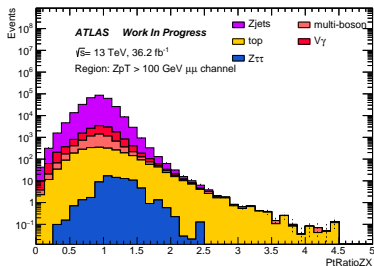
# Background estimation

- Dominant background process varies with different channels.
- Background from fake contribution is small and data-driven
- All other background is based on MC simulation

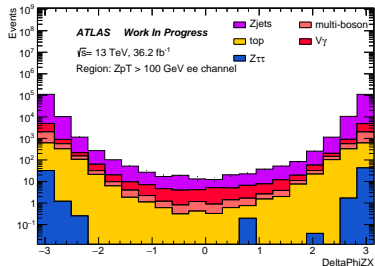


# Kinematics of $Z + X$ system

- 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 with  $p_T^Z > 100$  GeV
  - PtRatioZX:  $p_T^X / p_T^Z$
  - DeltaPhiZX:  $\phi_Z - \phi_X$



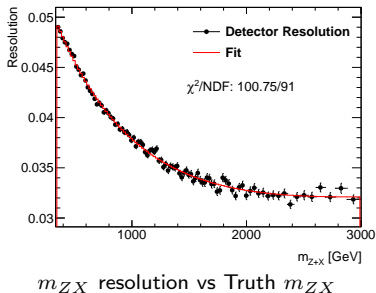
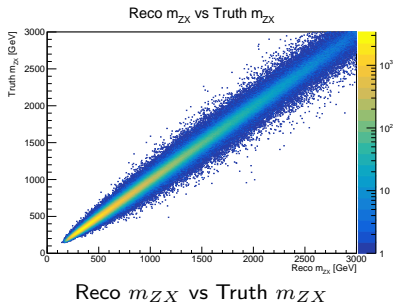
muon channel



electron channel

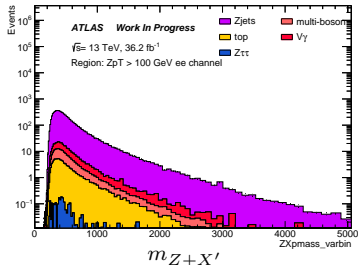
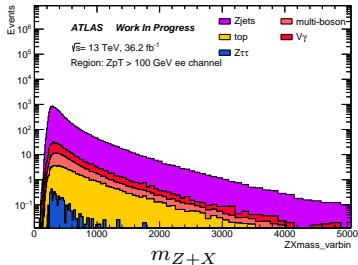
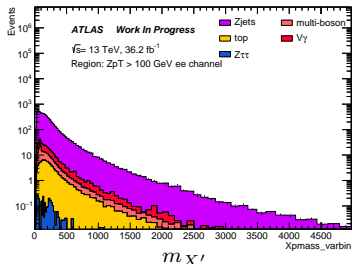
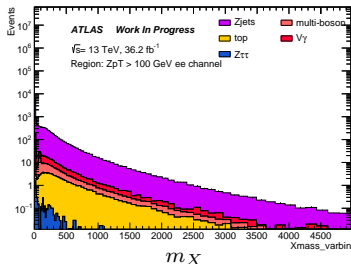
# Kinematic variables in resonance search

- The kinematic variables used for model-independent resonance search:
  - $H_T$ : scalar sum of transverse momentum of all visible objects
  - $m_X$ : invariant mass of visible objects in recoil system
  - $m_{Z+X}$ : invariant mass of all final states
  - $m_{X'}$  and  $m_{Z+X'}$ : from only two leading  $p_T$  objects of the same type.
- The mass detector resolution is derived given by the difference between reconstruction and truth info.



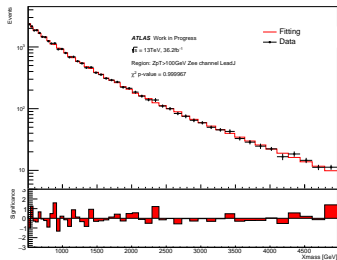
# Kinematic variables in resonance search

Plots taken from LeadJ category in highZPt100 region in Zee channel.

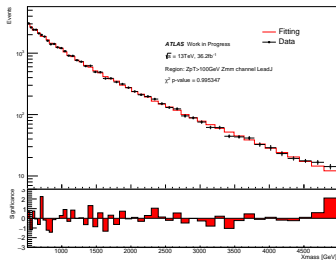


# Fitting on mass spectrum

- Hard to model well in all categories using MC simulation.
- Assume the shape of background smoothly falling-down.
- Perform a fit to estimate the background contribution.



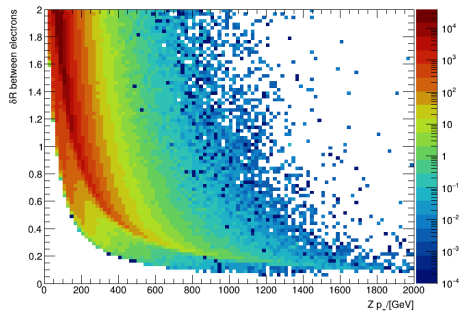
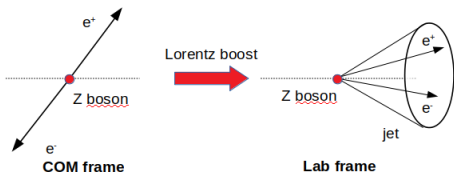
electron channel  $m_{XX}$



muon channel  $m_{XX}$

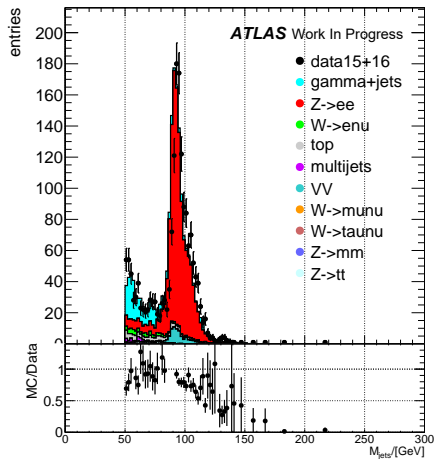
# Challenge of the analysis

- The highly boosted Z bosons make the two decaying electrons non-isolated at high  $p_T$
- Aim to gain efficiency by developing "fat-electron" identification
- Recover the events with small-R (0.4) jet instead of 2 ID-electrons.



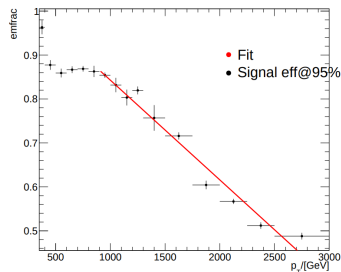
$\Delta R(e, e)$  vs  $p_T^Z$  in truth

# "Fat-electron" candidates



Jets satisfy:

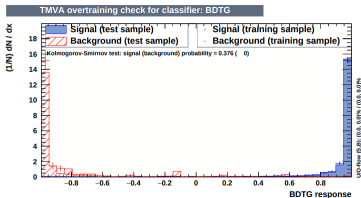
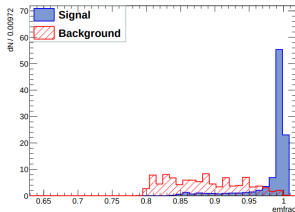
- $p_T > 450 \text{ GeV}$ ,  $|\eta| < 2.5$
- $m_{jet} > 50 \text{ GeV}$
- $0 < N_{track, p_T > 500 \text{ MeV}} \leq 7$
- EMfrac: fraction of deposited energy in EM calorimeter,  $p_T$ -dependent cut



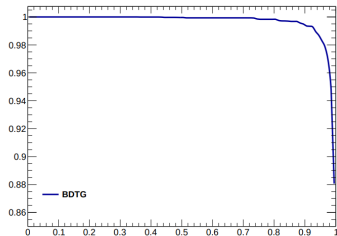
# BDT selections

- The BDTG(Gradient Boost Decision Trees) model is trained to select fat-electrons.
- Trained signal from HVT  $VcWZ \rightarrow llqq$  samples
- Background from  $\gamma + jets$ ,  $W(e\nu)jets$  and top processes

jet\_emfrac



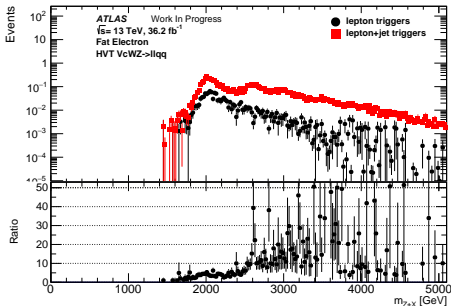
MVA\_BDTG



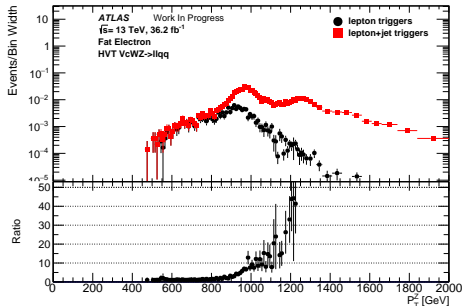


# Inefficiency of lepton triggers

- In extremely high  $p_T^Z$  region of electron channel, the lepton triggers will also suffer from the boost issues.
- Jet triggers added to recover the efficiency loss.
- Plots below show the comparison of different trigger selections for signal MC samples.



$m_{Z+X}$



$p_T^Z$

# Summary

- 2015+2016 data and MC samples are used to test the proposed analysis strategy.
- The search algorithm is defined and tested
- The fat-electron object and jet triggers increase statistics in extremely high  $p_T$  regions.
- The analysis is still ongoing and will include full Run2 ATLAS data

# Thanks for your attention!

# Backup