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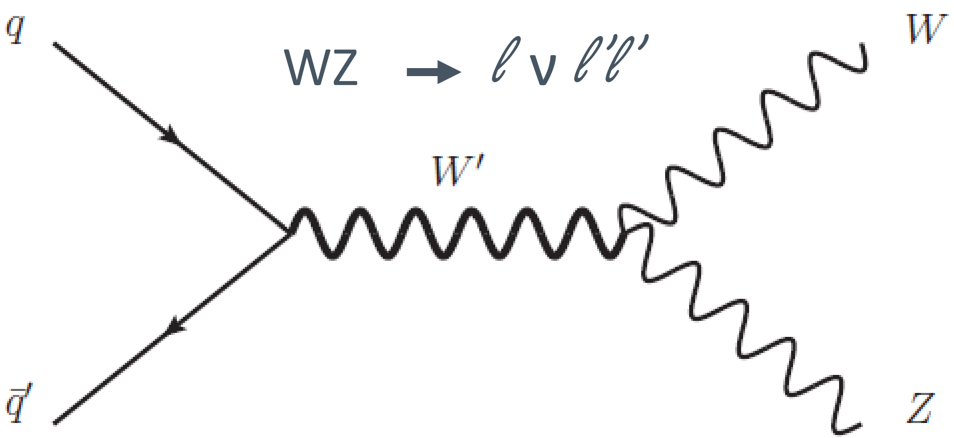
Search for resonant W± Z → lνl'l' Production in Proton-Proton Collisions at √ s = 13 TeV with the ATLAS Detector



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Outline:

1. Introduction .
2. Object selection.
3. Event Selection .
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5. Trigger efficiency .
6. ZZ veto optimisation .
7. VBS, qq category definitions .
8. HVT VBS Signal optimization .
9. Conclusion .

Introduction

- WZ production is sensitive to various extensions of the Standard Model wich predicting heavier versions of the W and Z bosons, the W’ and Z’ .
- The aim of this study is fully leptonic analysis of the WZ decay (e,μ) in inclusive and VBS production modes :
  - ✓ Estimate the gain added by using other triggers, than the single lepton trigger used in this analysis, and improve the trigger efficiency for data15.
  - ✓ Optimize the Veto of four-lepton events.
  - ✓ Estimate the VBS signal efficiency and compare it with the inclusive results.
  - ✓ optimize the Significance for HVT VBS Signal :

$$Significance = \frac{S}{\sqrt{S+B}}$$

Object Selection

Muons

- Combined muons $|\eta|<2.5$
- pT>25 GeV
- d0<1mm cosmic cut
- $|z0 \sin(\theta)| < 0.5$ mm
- $|d0/\sigma_{d0}| < 3$.
- LooseTrackOnly Isolation.

Electrons

- Likelihood loose electrons (medium++ for Z and tight++ for W)
- ET>25 GeV
- Object Quality requirements
- $|z0 \sin(theta)| < 0.5$ mm
- $|d0/\sigma_{d0}| < 5$.
- LooseTrackOnly Isolation.

Jets

- AntiKt4TopoEM Jets
- pT >25 GeV and $|\eta|<$ 2.4 OR pT >30 GeV and 2.4 $>|\eta|<$ 4.5
- Pileup removal reject jets that have pT<50 GeV, eta<2.4, and JVT<0.59
- Jet Cleaning

ET Miss

- Use METMaker tool .
- Original MET container MET_Core_AntiKt4EMTopo.
- Add electrons, muons after corrections and e-μ and e-e corrections
- Add corrected jets (overlap handle by the tool)
- MET rebuilt adding the "soft term" coming from tracks

Overlap removal

- Use overlap removal tool with the preselected leptons.
- e-e Electrons (after electron ID cuts) sharing the same ID-track, keep the electron with highest cluster ET
- e-μ Remove CaloTagged muons which share the same InnerDetector track as the electron
- e-jets Removes jets overlaping with electrons with $\Delta R< 0.2$

Event Selection

- Event cleaning: Reject LAr, Tile and SCT corrupted events and incomplete events.
- Primary vertex: Events are required to have a primary vertex with at least two associated tracks.
- Trigger : Single triggers.
- N leptons : Exactly three leptons passing the Z lepton selection.
- Z Z veto : Less than 4 leptons with pT > 20 GeV (to be optimized) .
- Z leptons :Two same flavor oppositely charged leptons passing Z lepton selection.
- Z Mass window : $|M_{ll} - M_{z}|$< 20 GeV .
- W lepton : Likelihood Tight and Gradient isolation for Muons and electrons.
- Missing transverse Energy: ETmiss > 25 GeV

Data and MC samples Data and MC samples

Data:

- The data used in corresponds to an integrated luminosity of 36 fb-1 :
  - data15_13TeV.periodAllYear_DetStatusv79repro20-01_DQDefects-00-02-02_PHYS_StandardGRL_All_Good_25ns.xml
  - data16_13TeV.periodAllYear_DetStatus-v83pro20-10_DQDefects-00-02-04_PHYS_StandardGRL_All_Good_25ns.xml

Monte Carlo:

Signal	VBS (H5p, HVT) , qq (HVT MadGraphPythia8EvtGen_A14NNPDF23LO_HVT_Agv1_VcWZ_lvll)
WZ	PowhegPy8EG_CT10nloME_AZNLOCTEQ6L1_WZlvll Or (Sherpa_221_NNPDF30NNLO_lllv and Sherpa_CT10_lllvjj_EW6)
ZZ	Sherpa_CT10_ggllll and ZZllll_mll4
Z+jets	Sherpa_221_NNPDF30NNLO_Zee , Sherpa_221_NNPDF30NNLO_Zmumu , Sherpa_221_NNPDF30NNLO_Ztautau
Z+gamma	Sherpa_CT10_eegamma, Sherpa_CT10_mumugamma.
tZ	MadGraphPythiaEvtGen_P2012_tZ.
$t\ \bar{t}$	PowhegPythiaEvtGen_P2012_ttbar, PowhegPythiaEvtGen_P2012_SingleTopSchan
VVV (V= W ; Z)	Sherpa_CT10 : WWZ_4l2v, WZZ_5l1v, ZZZ_6l0v, ZZZ_4l2v
$t\ \bar{t}V$	MadGraphPythia8EvtGen_A14NNPDF23LO_ttZllonshell

Trigger efficiency

Single-Electron triggers (Nominale)	• HLT_e60_lhmedium • HLT_e24_lhmedium_L1EM20VH • HLT_e24_lhmedium_L1EM18VH • HLT_e120_lhloose
Single-Muon triggers (Nominale)	• HLT_mu20_iloose_L1MU15 • HLT_mu50
Di-Electron triggers	• HLT_2e12_lhloose_L12EM10VH
Di-Muon triggers	• HLT_2mu10 • HLT_mu18_mu8noL1
Tri-Electron triggers	• HLT_e17_lhloose_2e9_lhloose
Tri-Muon triggers	• HLT_3mu6 • HLT_3mu6_msonly • HLT_mu18_2mu4noL1
Electron-Muon triggers	• HLT_2e12_lhloose_mu10 • HLT_e12_lhloose_2mu10 • HLT_e7_medium_mu24 • HLT_e17_lhloose_mu14 • HLT_e24_medium_L1EM20VHI_mu8noL1
MET trigger	• HLT_xe60 • HLT_xe70 • HLT_xe80 • HLT_xe100

- Trigger efficiency is defined as

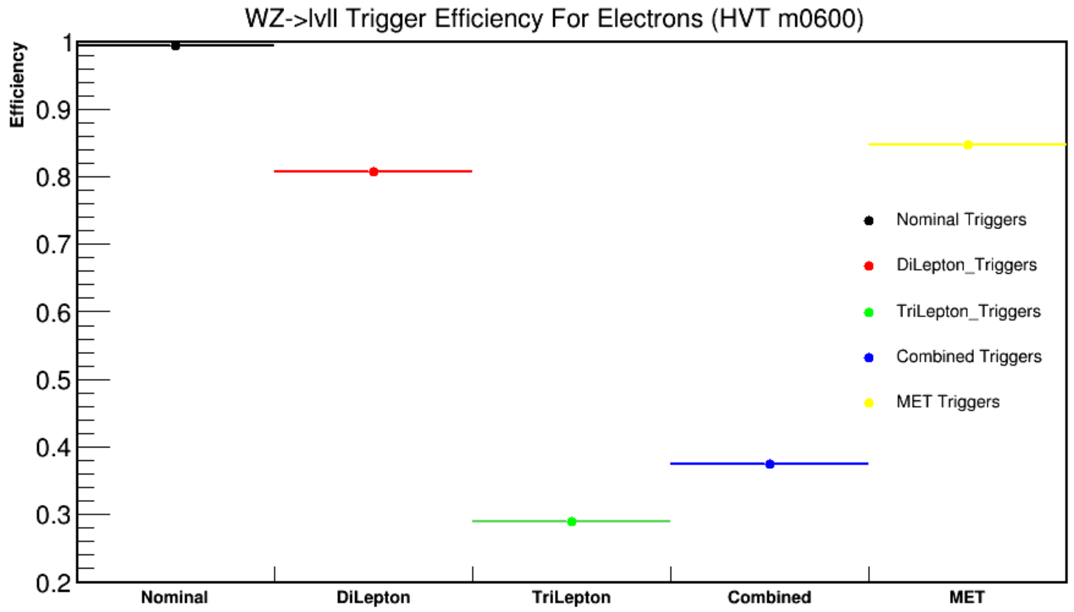
$$\epsilon = \frac{n_+}{n}$$

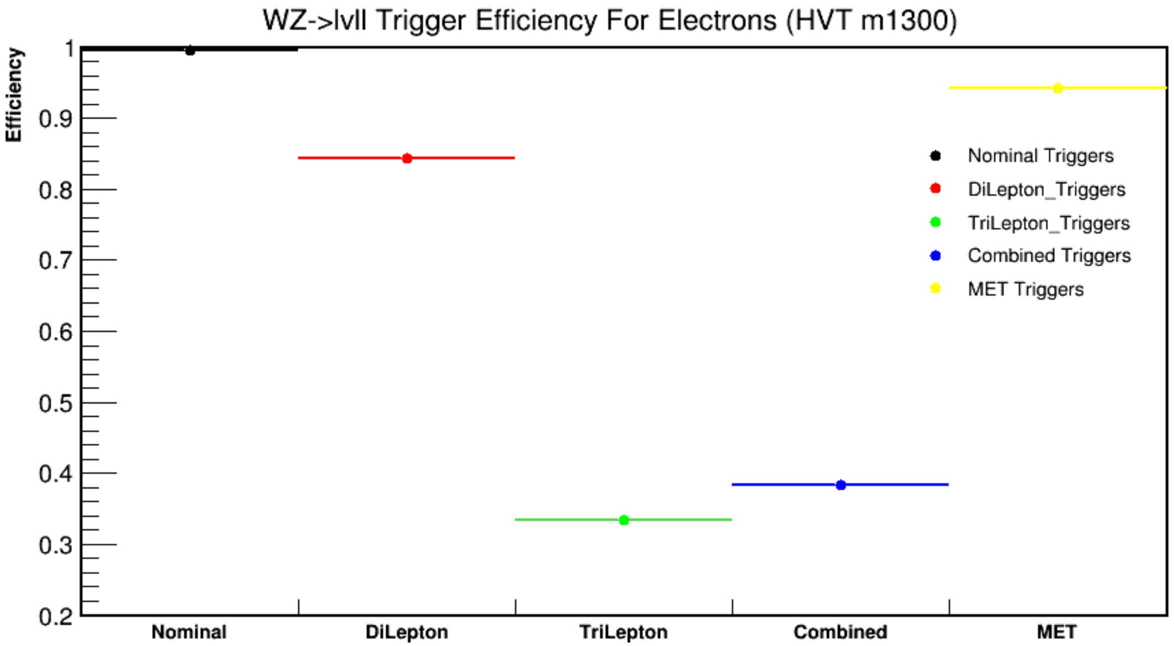
n : number of events passing selection with out any trigger requirement.

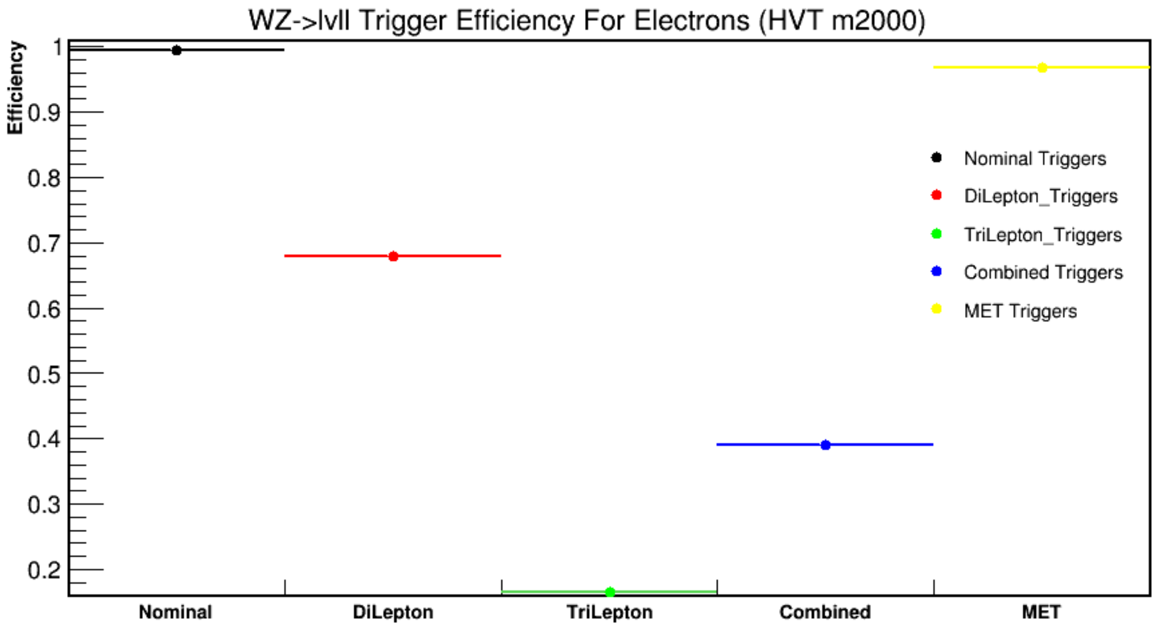
n_+: number of events passing the selection .

n_-: number of events failing the selection .

Trigger efficiency for HVT in electron channel

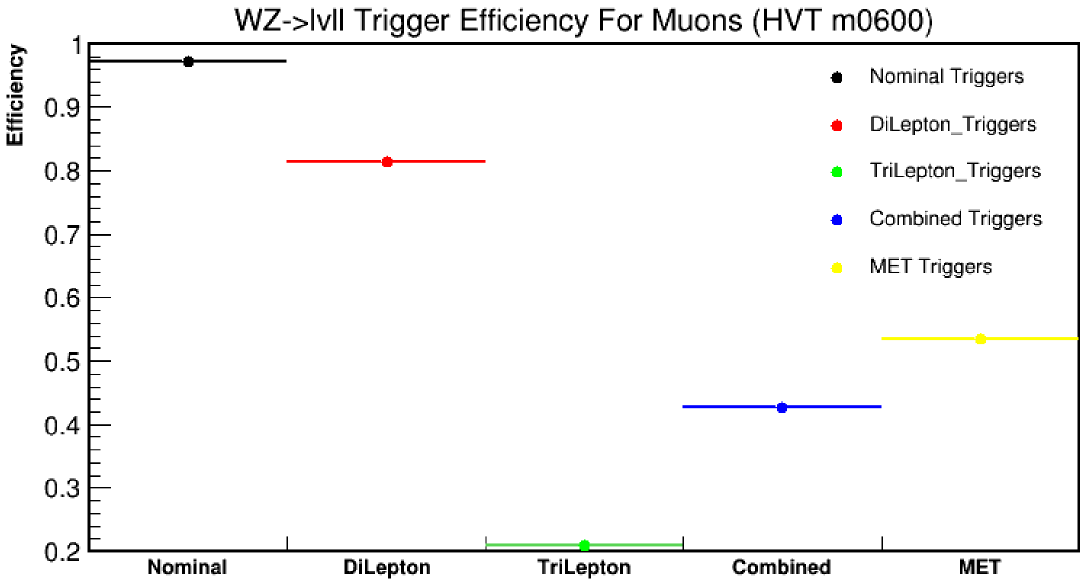


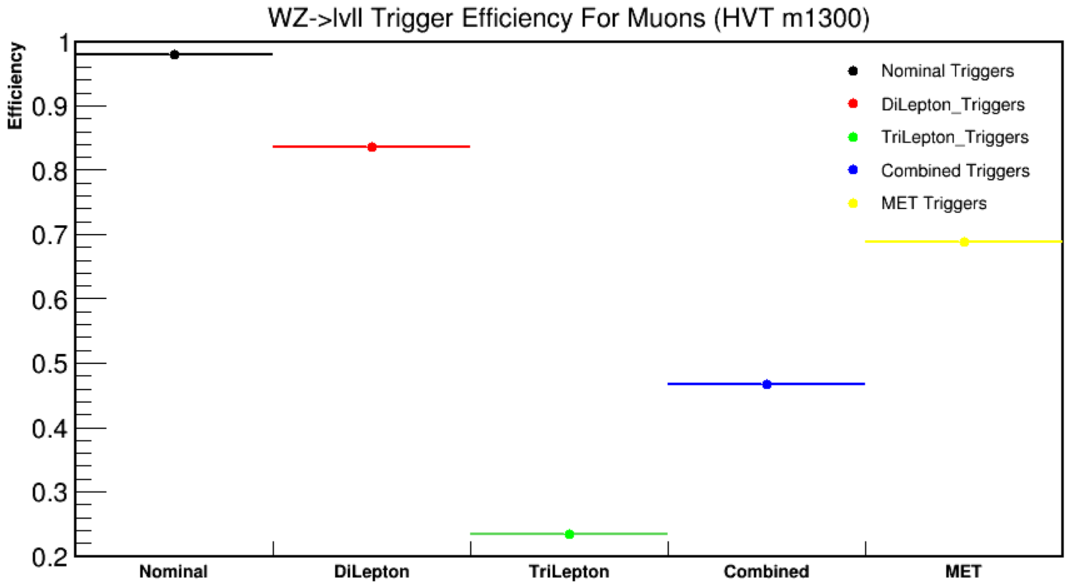


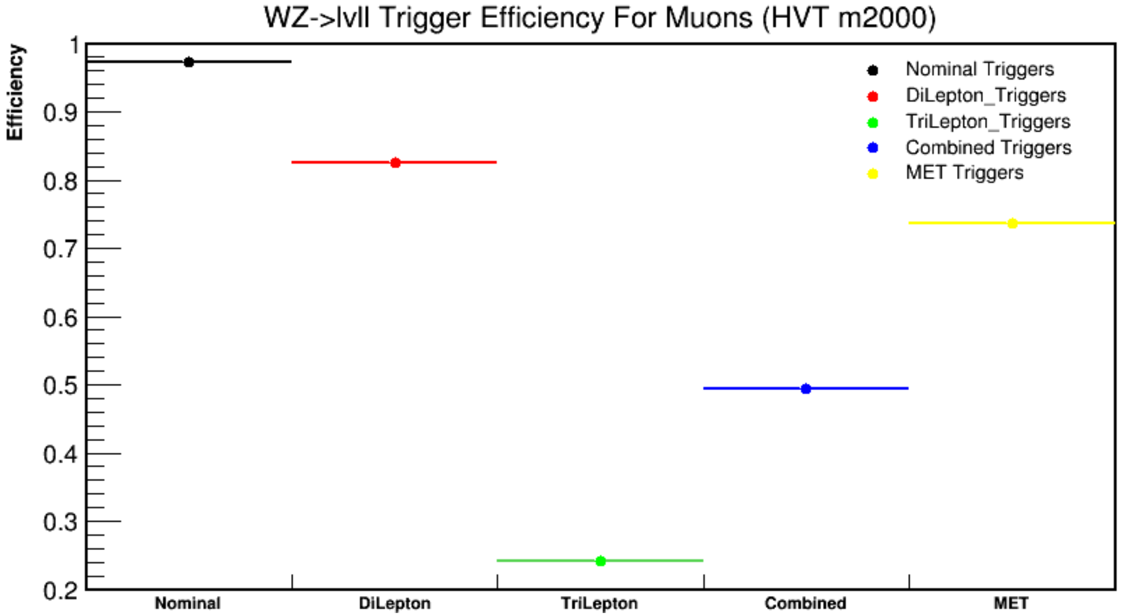


Single lepton trigger is the trigger that provide the highest efficiency For electrons

Trigger efficiency for HVT in muon channel

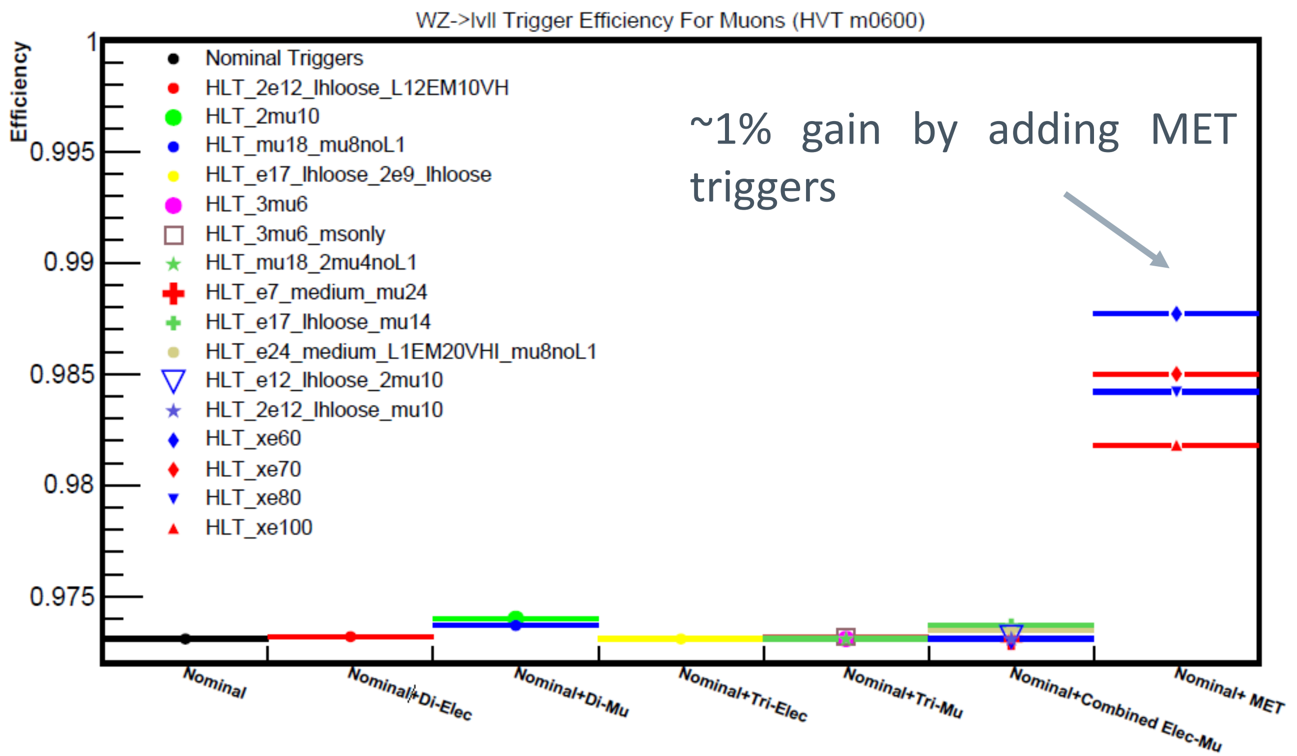


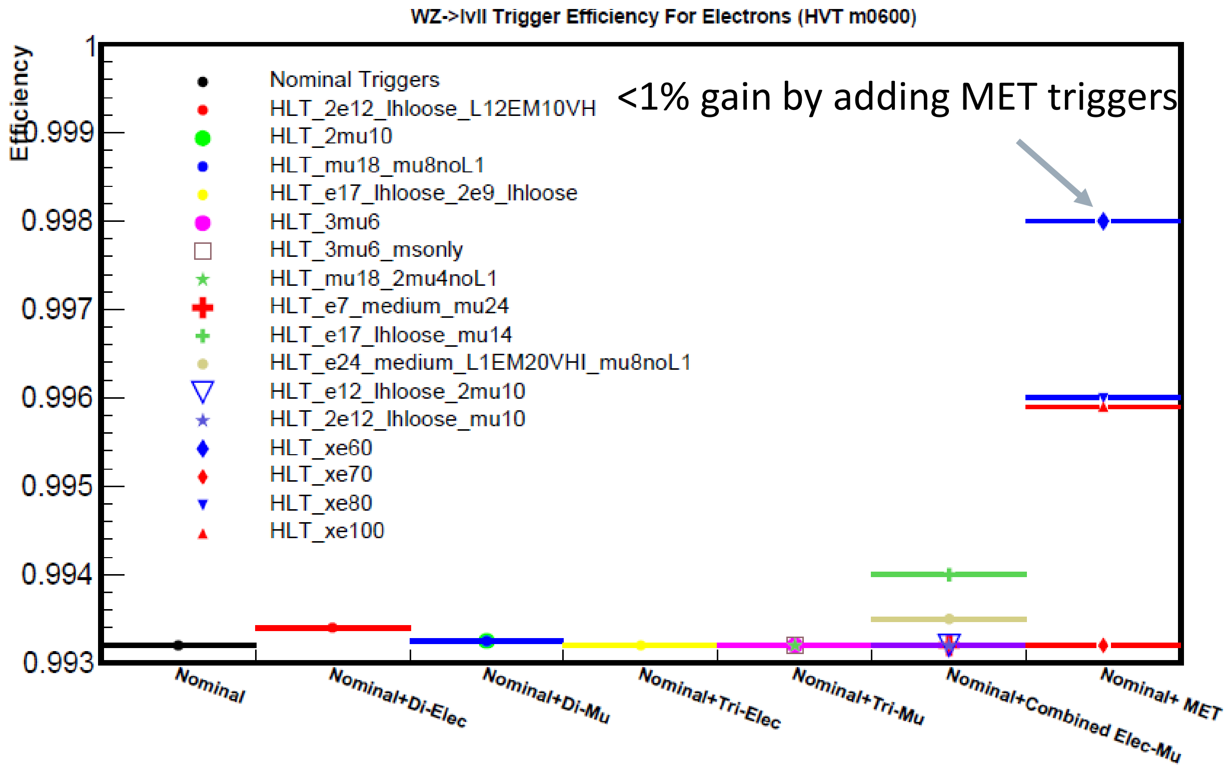




Single lepton trigger is the trigger that provide the highest efficiency for Muons.

Adding trigges to Nominal triggers





- Less than 1% gain by adding MET triggers to Nominal triggers for Muons Channel
- About 1% gain by adding MET triggers to Nominal triggers for Electrons Channel

Trigger efficiency per Channel For WZ SM

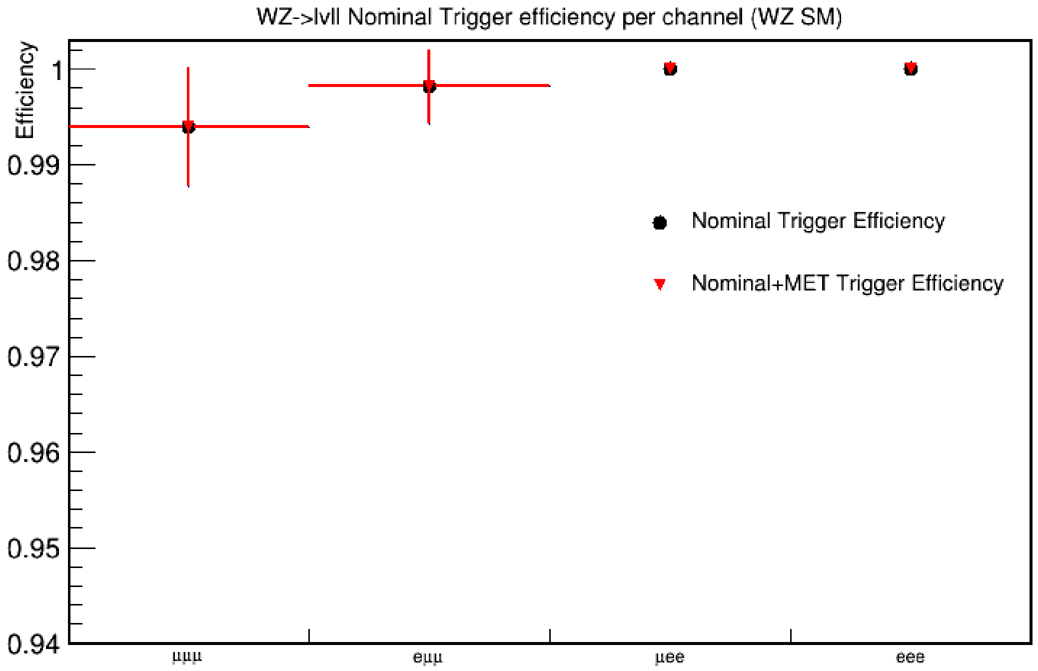
- Calculate trigger efficiency using the SM sample:

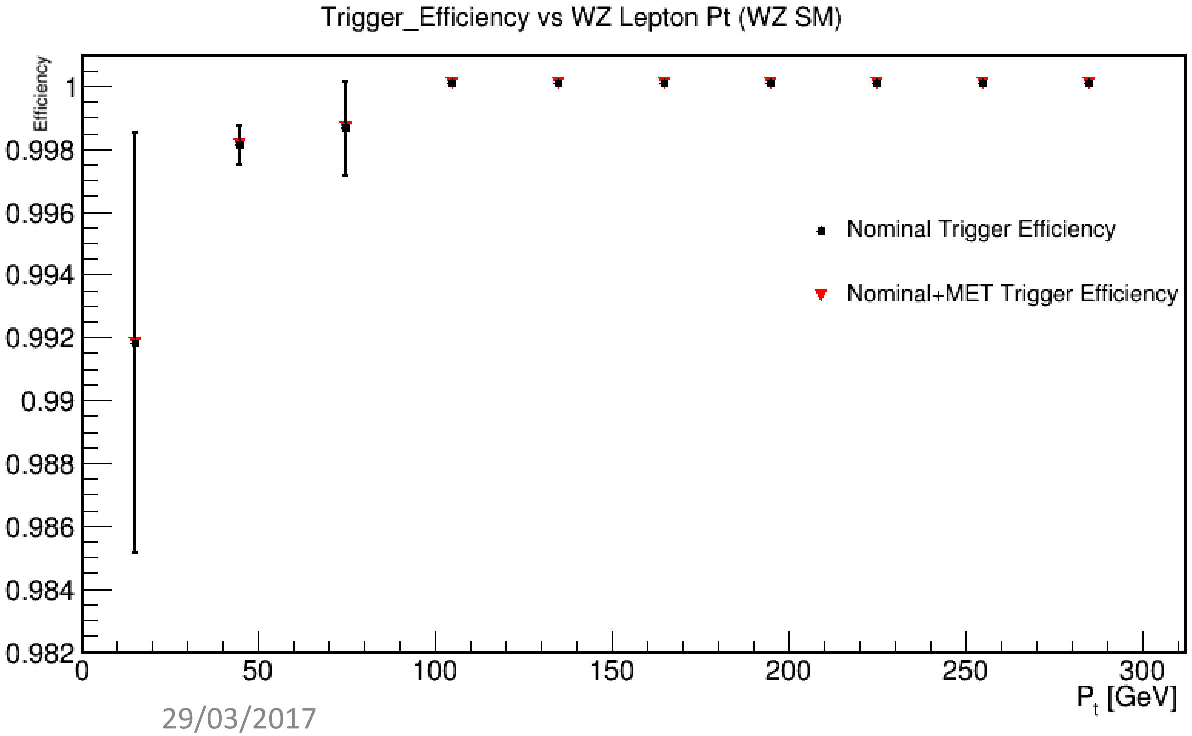
  - Nominal triggers

  - Nominal+MET triggers

- Looked also at the lepton PT distribution

- There is no efficiency gain by adding MET triggers in the SM sample

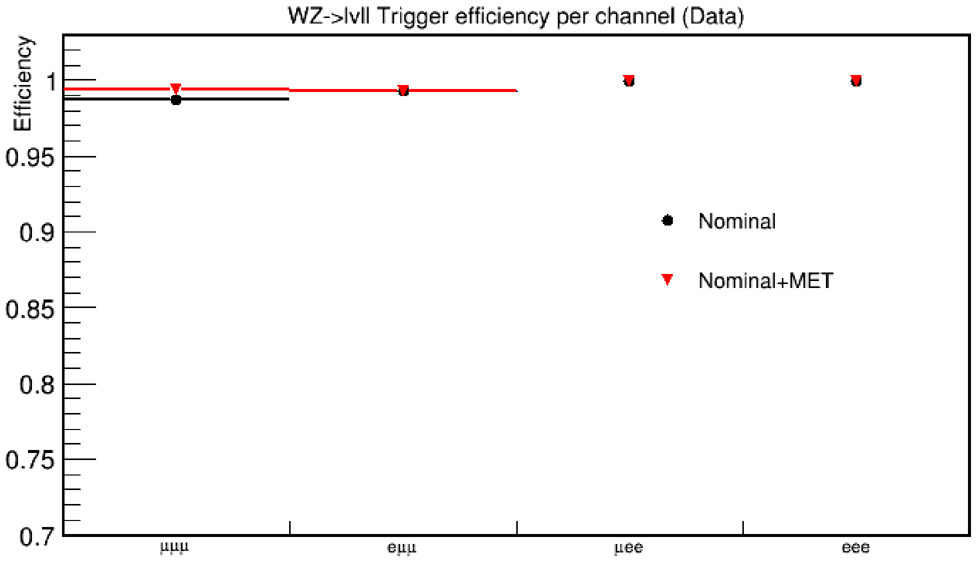


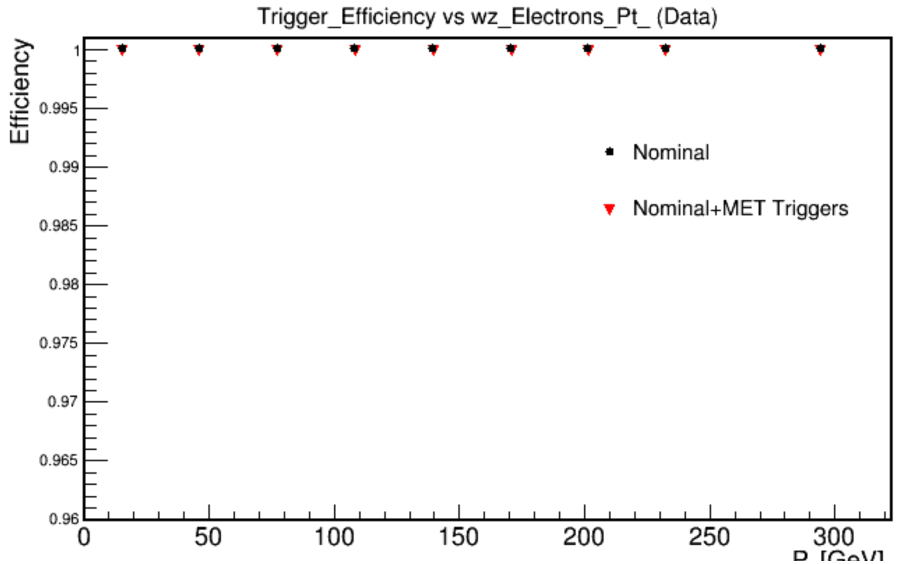


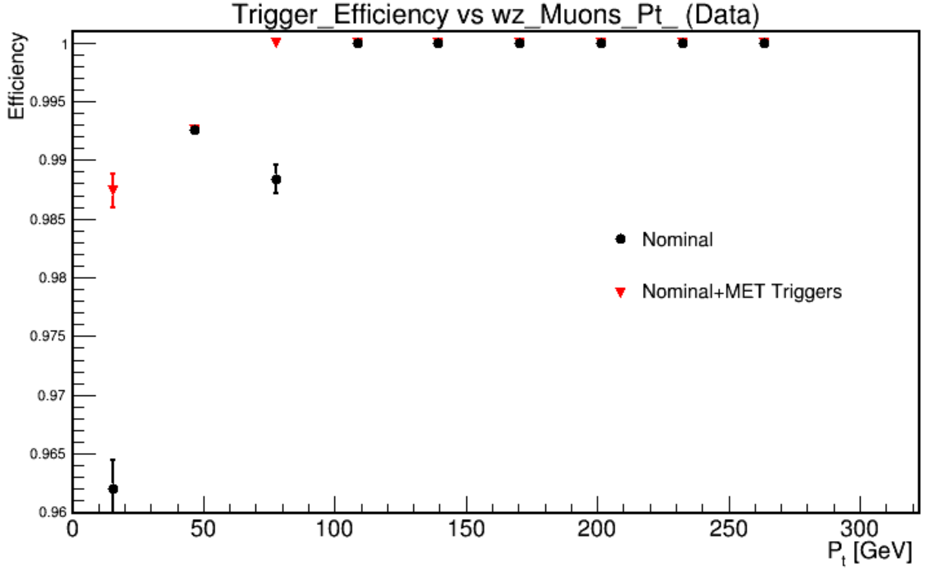
WZ SM Efficiency				
Triggers	μμμ	eμμ	μee	eee
Nominal+MET	99.4 %	99.8 %	100 %	100 %
Nominal	99.4 %	99.8 %	100 %	100 %
Gain %	0	0	0	0

Trigger efficiency per Channel For data15

atlas_lumi = 3.2 fb-1



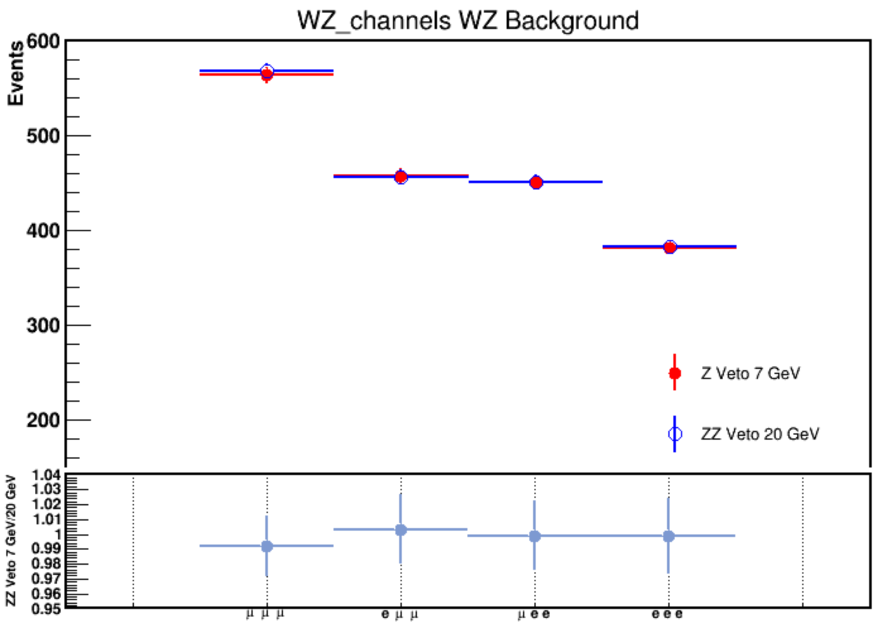


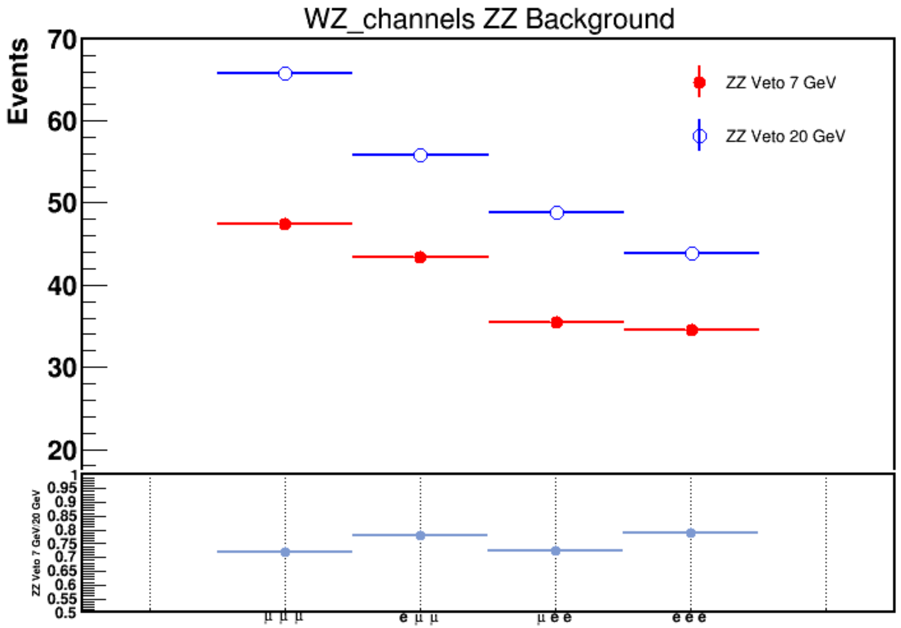


WZ SM Efficiency				
Triggers	μμμ	eμμ	μee	eee
Nominal+MET	99.40 %	99.25 %	100 %	100 %
Nominal	98.80 %	99.25 %	100 %	100 %
Gain %	0.6 %	0	0	0

- Adding MET triggers to the nominal selection we see a gain in efficiency in the mmm channel (0.6 %)
- Single lepton trigger (Nominal triggers) is 100% efficient for electrons .

ZZ veto optimisation .



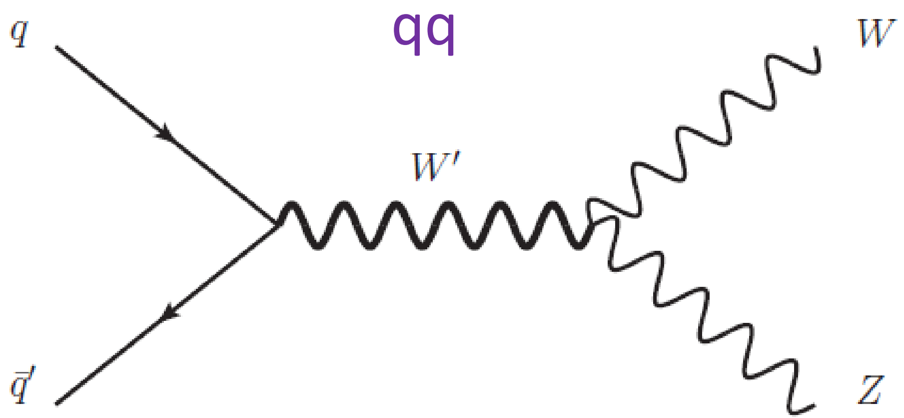


WZ					
Veto	μμμ	eμμ	μee	eee	Total
20 GeV	568.27	456.34	451.18	382.61	1858.4
7 GeV	563.67	457.78	450.71	382.17	1854.33
Ratio %	0.81	-0.31	0.1	0.115	0.22

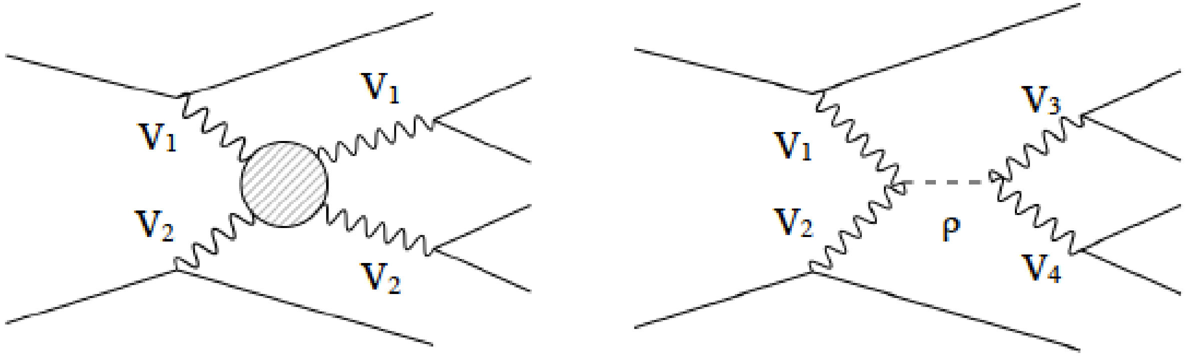
ZZ					
Veto	μμμ	eμμ	μee	eee	Total
20 GeV	65.75	55.77	48.88	43.83	214.77
7 GeV	47.42	43.35	35.45	34.49	160.71
Ratio %	28	22	27	21	25

Decreasing the ZZ veto pt lepton cut from 20 GeV to 7 GeV, reduces the ZZ background by more than 25%. While the dominant background WZ SM is not affected by this cut.

VBS, qq category definitions .



VBS/VBF



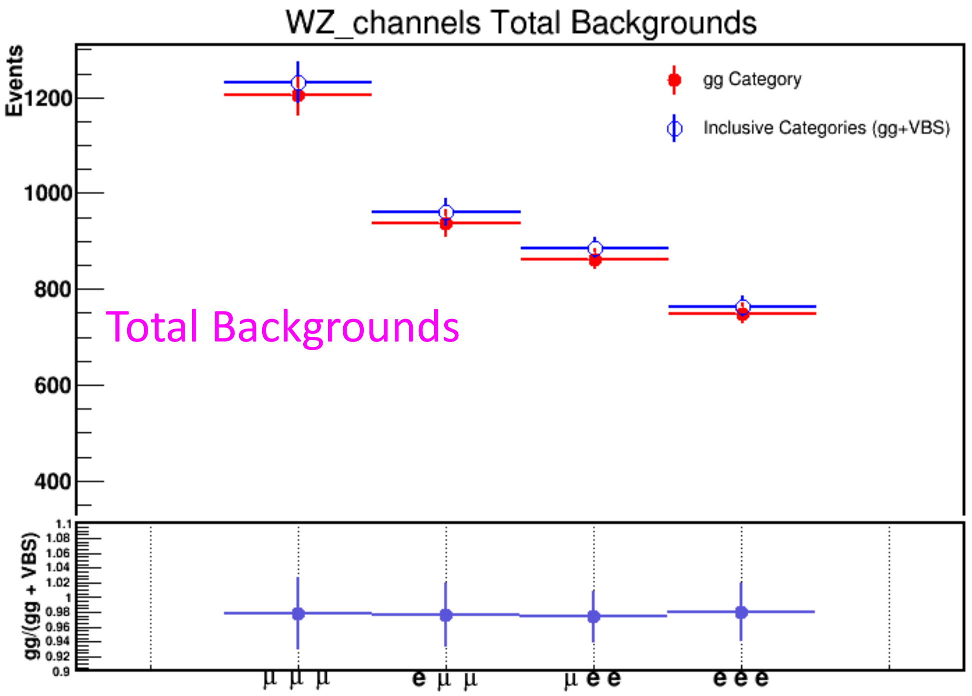
- After selection the W and Z condidates.
  - ✓ VBS Category is defined :
    - ✓ Select first good Z and W boson selction
    - ✓ Only events with $N_{jet} \geq 2$ are considred for the analysis VBS.
    - ✓ Apply : Pt_j>20 GeV η_{jj}<4.5
    - ✓ Apply : m_{jj} >500 GeV and $\Delta\eta_{jj}$ >3.5
  - ✓ qq Category : (qq category is orthogonal to VBS) all the events that do not satisfy the VBF/VBS criteria above will fall in qq category.

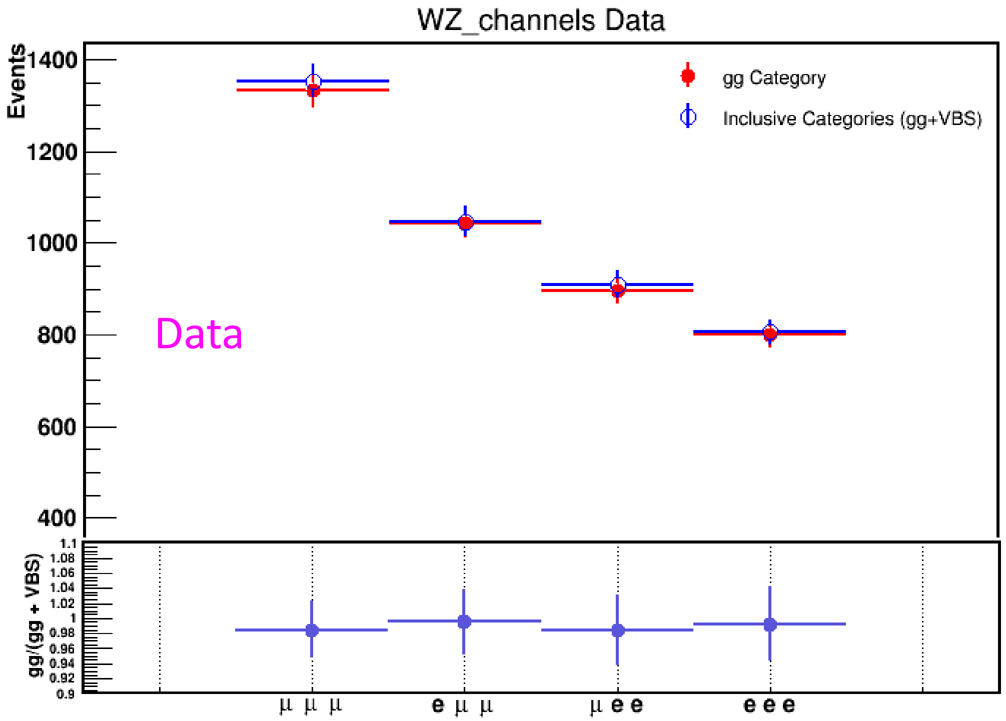
HVT Signal : inclusive and qq comparison

HVT Mass [GeV]	N (Inclusive VBS + qq)	N(qq)	Ratio [%]
500	1400+03+-22.3	1380+-22.1	1.43
700	433+-7.55	426+-7.5	1.62
800	272+-3.99	268+-3.96	1.47
900	180+-2.3	177+-2.28	1.67
1000	118+-2.09	115+-2.07	2.54
1100	82.7	80.6+-1.32	2.53
1200	56+-0.684	54.9+-0.678	1.96
1300	37.6+-0.801	37+-0.795	1.59
1400	28.3+-0.339	27.7+-0.335	2.12
1500	19.7+-0.24	19.3+-0.238	2.3
1600	14.7+-0.177	14.3+-0.175	2.72
1700	11+-0.134	10.7+-0.133	2.72
1800	8.25+-0.0992	8.05+-0.0979	2.42
1900	6.23+-0.0751	6.08+-0.0741	2.41
2000	4.88+-0.076	4.76+-0.0752	2.46
2200	2.86+-0.0855	2.79+-0.0845	2.45
2400	1.69+-0.0289	1.65+-0.0286	2.37
2600	1.02+-0.0125	0.988+-0.0124	3.14
2800	0.579+-0.00747	0.563+-0.00737	2.76
3000	0.351+-0.00574	0.341+-0.00566	2.85
3500	0.0941+-0.00153	0.0918+-0.00152	2.44
4000	0.0283+-0.000451	0.0274+-0.000445	3.18
4500	0.00842+-0.000158	0.00822+-0.000156	2.37
5000	0.00391+-7.03e-05	0.00383+-6.96e-05	2.4

- Compare the number of HVT signal events passing all the selection cuts in exclusive and qq categories
- Less than 3% efficiency loss is found compared to inclusive analysis
- It seems that the HVT samples are quite pure and contain only qq events

Effect on total Background and data : inclusive and qq comparison





Channel	μμμ	eμμ	μee	eee	Inclusive
qq+VBS	1231.35	960.56	885.64	764.04	3841.59
qq	1205.29	937.59	862.31	749.12	3754.31
Ratio [%]	2.14	2.40	2.63	1.95	2.27

Channel	μμμ	eμμ	μee	eee	Inclusive
Qq +VBS	1353	1047	910	805	4115
qq	1332	1042	896	799	4069
Ratio [%]	1.55	0.48	1.54	0.74	1.12

✓ Small impact (less than 3%) is seen both for total MC background and in data

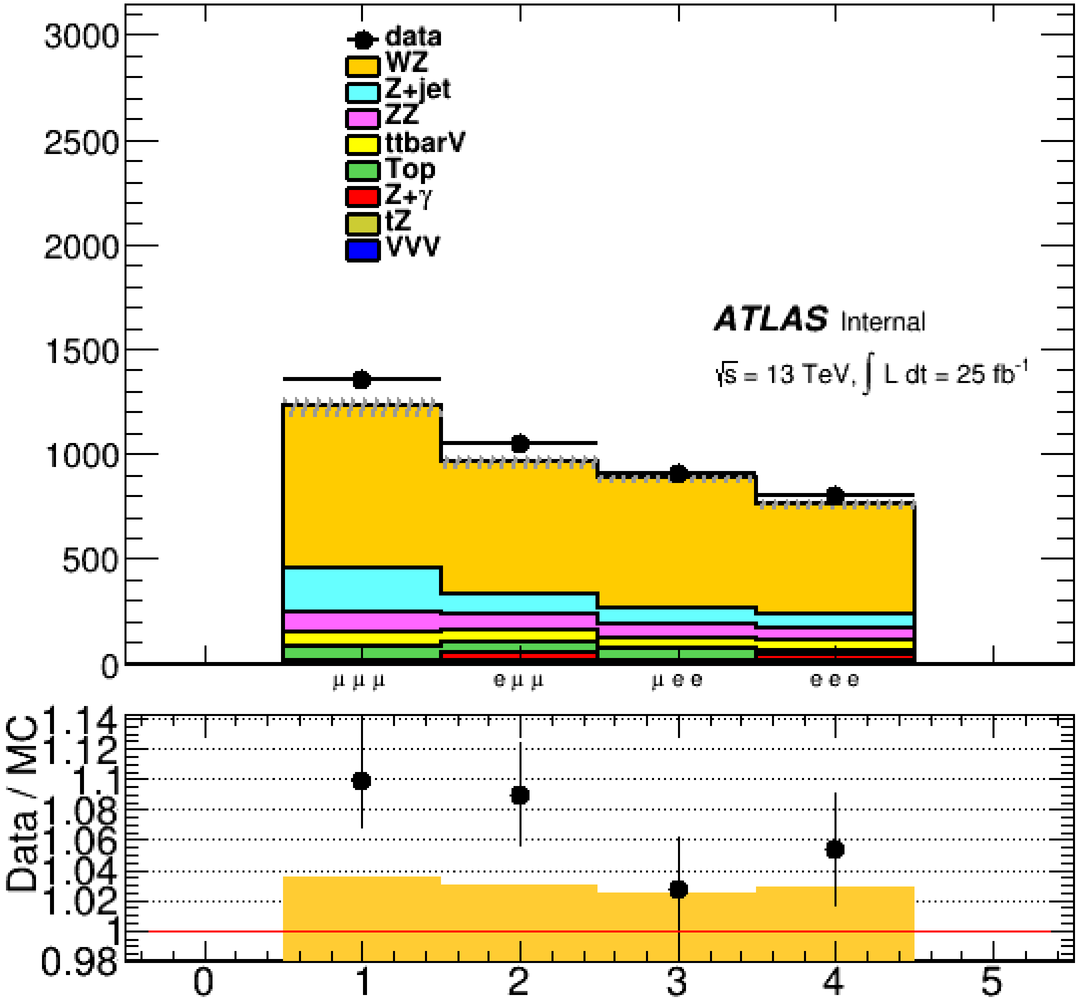
Kinematic distributions

Inclusive VBS and qq Signal

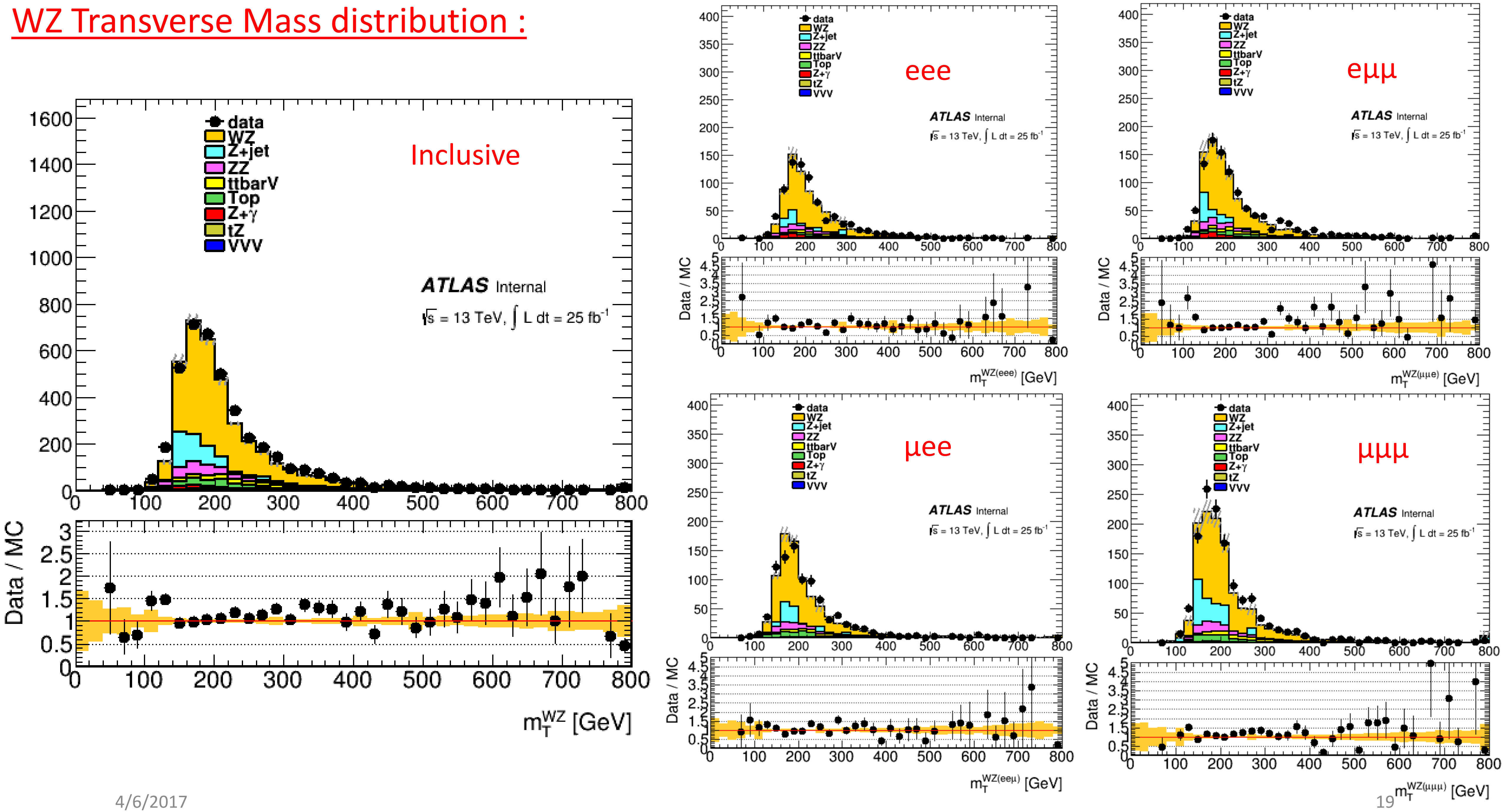
Before signal optimization cut selection cuts :

- Cutflowselection after selection W and Z candidates.
- Good data/MC agreement in μee and eee channels.

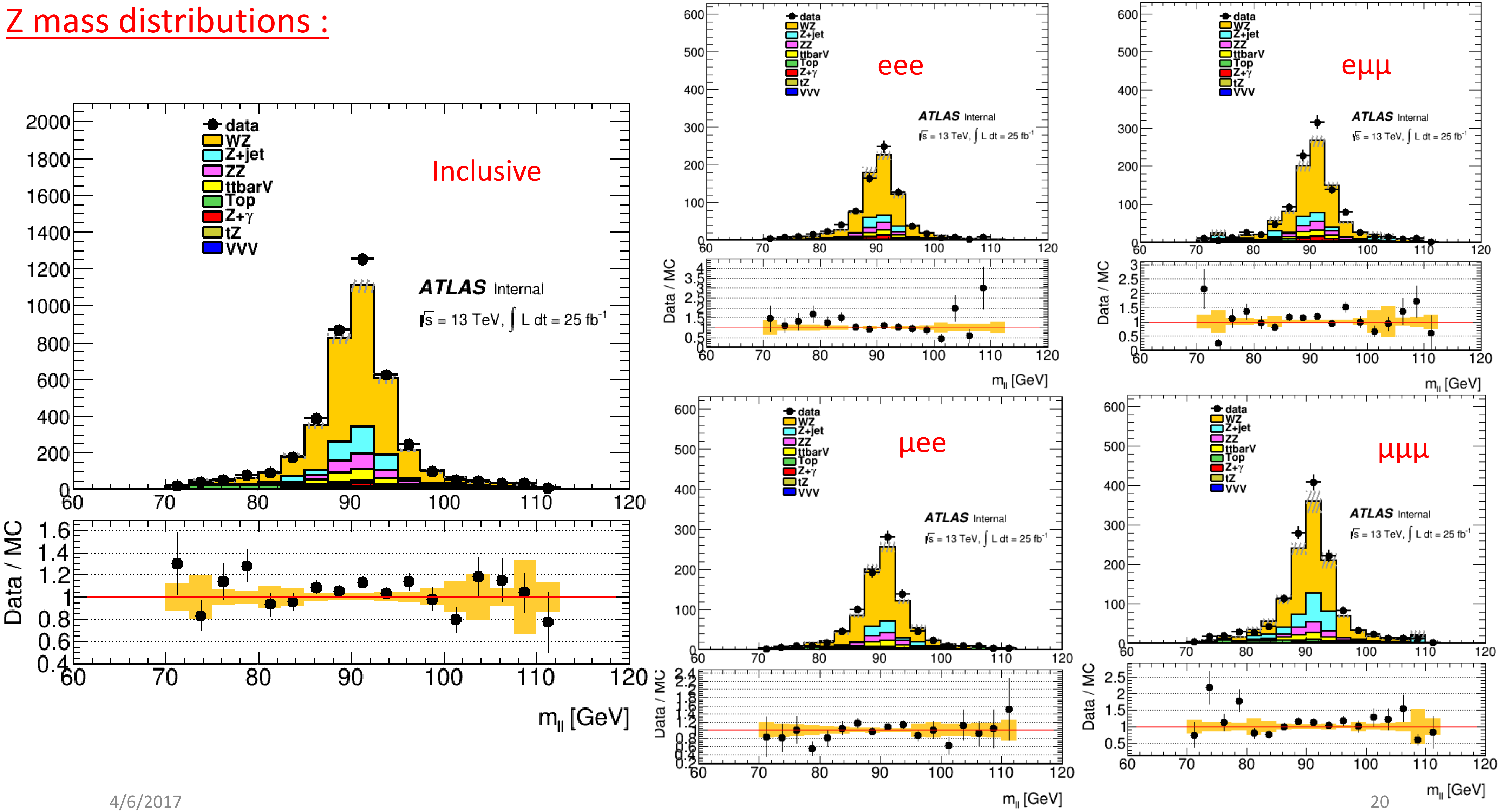
Channel	μμμ	eμμ	μee	eee	Inclusive
Data	1353	1047	910	805	4115
Total MC	1231.35+-43.33	960.56+-29.45	885.64+-22.34	764.04+-21.8	3841.59+-60.99
WZ	777.81+-11.43	624.61+-10.31	617.55+-10.30	523.68+-9.49	2543.65+-20.79
Z+Jets	210+-41.5	103+-27.1	79.5+-19.3	68.7+-19.3	461+-56.6
ZZ	90+-0.98	76.33+-0.89	66.91+-0.85	60.00+-0.82	293.24+-1.77
VVV	2.84+-0.09	2.45+-0.07	2.36+-0.075	1.95+-0.07	9.60+-0.15
Z+g	2.01.+-0.97	40.78+-3.49	0.88+-0.42	33.48+-2.69	77.15+-4.54
top	66.6+-4.65	43.9+-3.77	55.1+-4.31	21.7+-2.47	187+-7.78
ttbarV	67.92+-0.46	57.65+-0.43	51.53+-0.38	44.72+-0.36	221.82+-0.82
tZ	14.47+-0.069	11.85+-0.063	11.74+-0.063	9.80+-0.058	47.87+-0.13
Data/MC	1.1	1.09	1.03	1.05	1.07



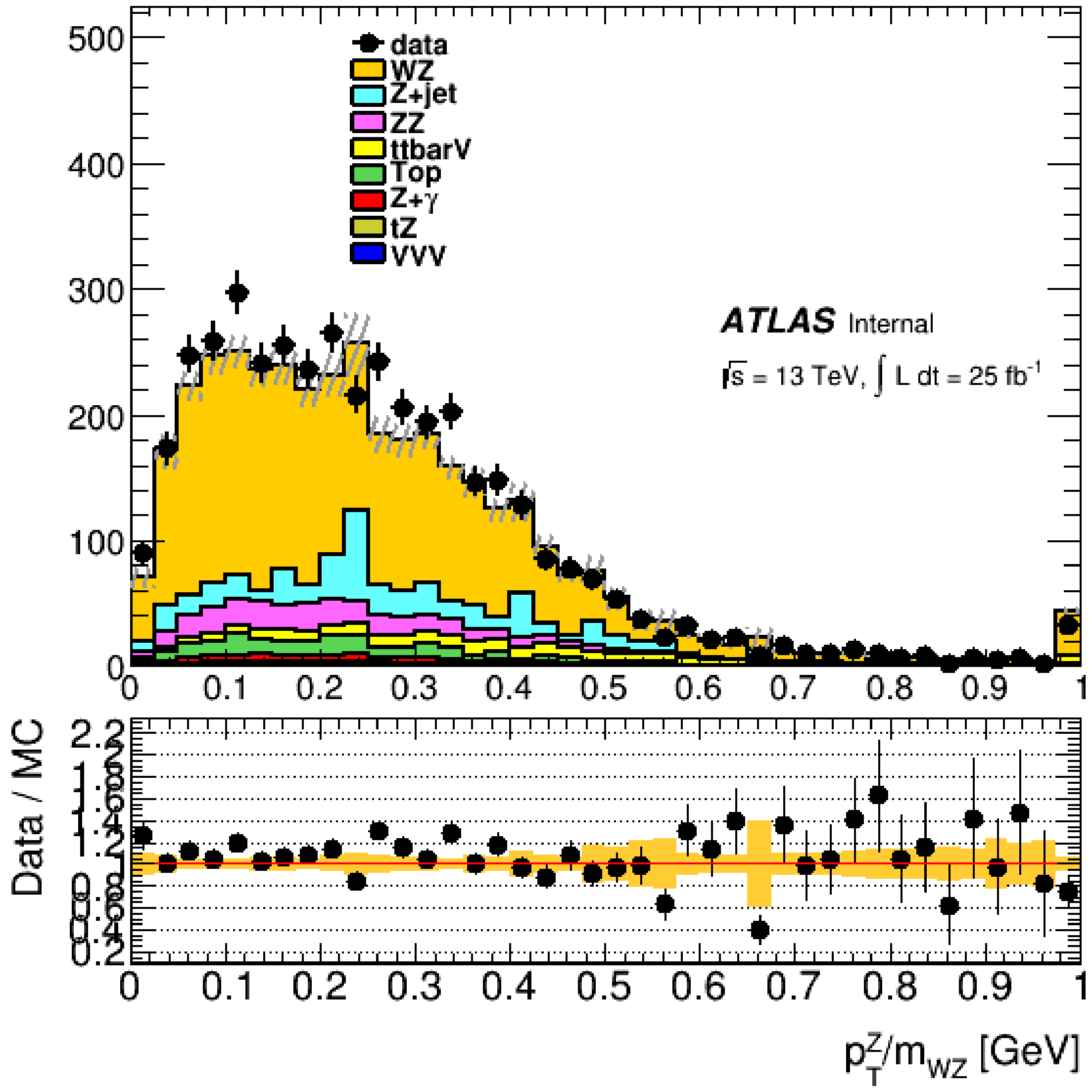
WZ Transverse Mass distribution :

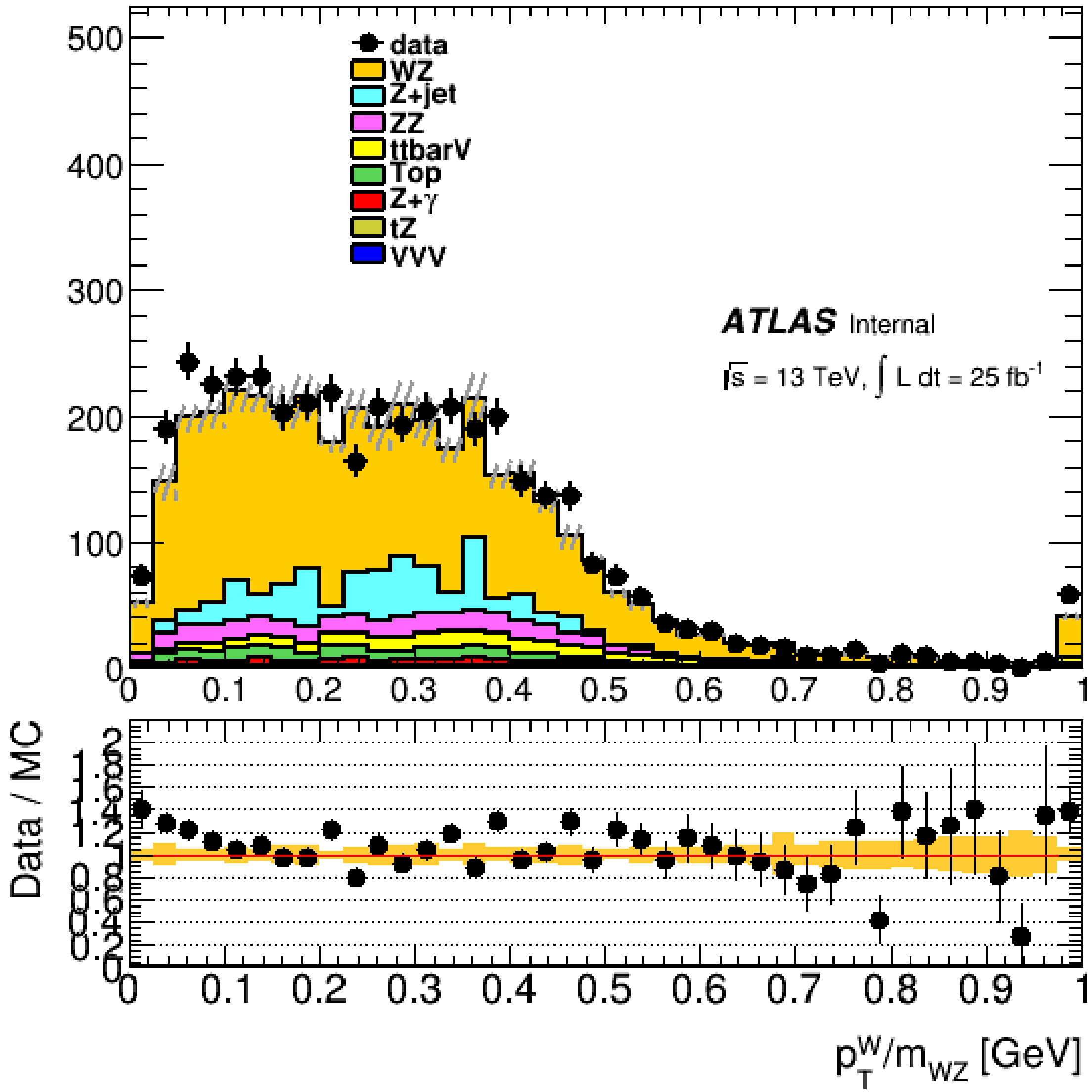


Z mass distributions :



Distributions of $p_T^Z/Mass_{WZ}$ and $p_T^W/Mass_{WZ}$:



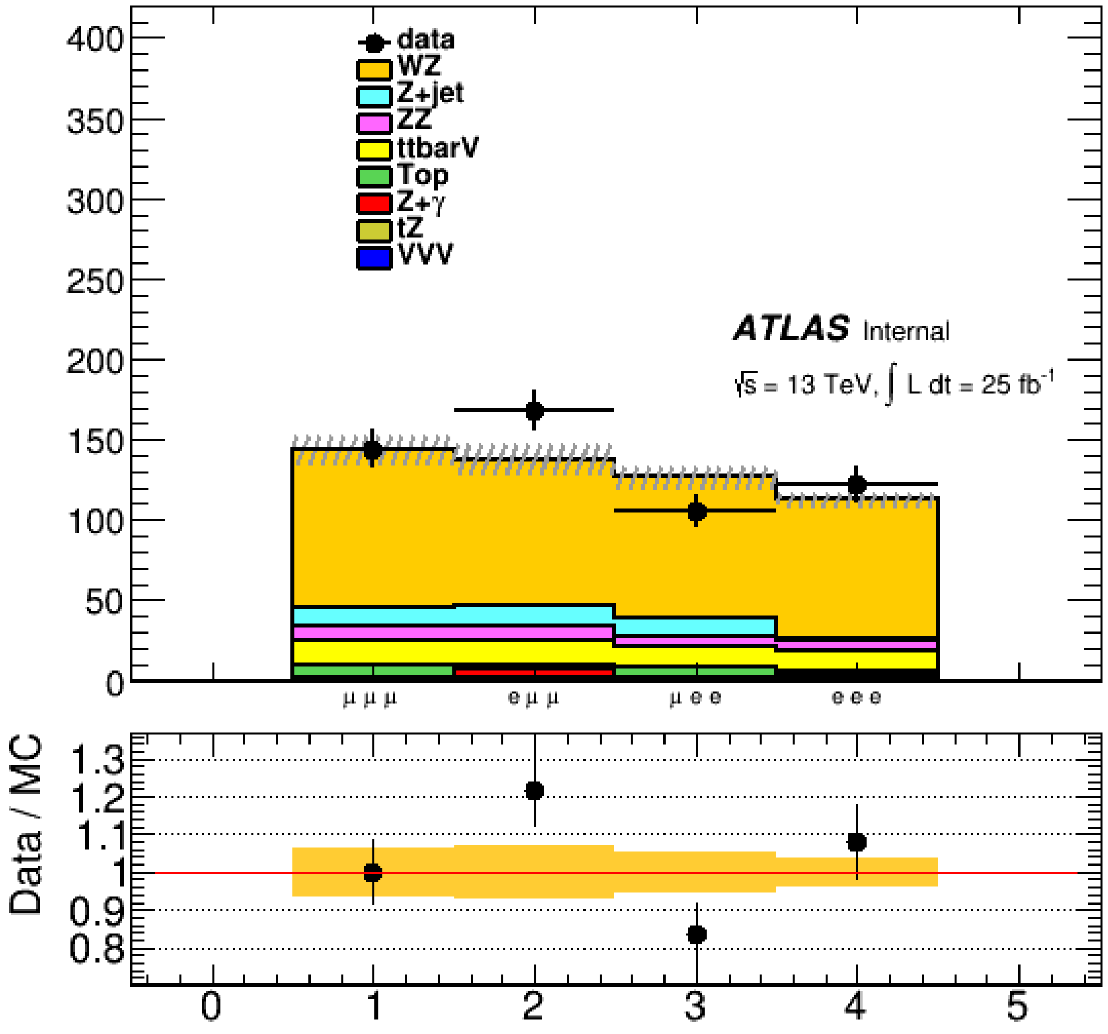


After signal optimization cut selection cuts :

- Cutflow selection after applying :

$$p_T^Z/Mass_{WZ} > 0.35 \text{ and } p_T^W/Mass_{WZ} > 0.35$$

Channel	μμμ	eμμ	μee	eee	Inclusive
Data	144	168	106	122	540
Total MC	143.8+-9.19	138.07+-9.79	126.61+-6.92	112.78+-4.43	521.26+-15.75
WZ	98.57+-4	91.04+-3.94	87.69+-3.93	85.83+-3.91	363.13+-7.89
Z+Jets	4.96+-3.59	3.05+-2.15	10.83+-5.49	1.94+-1.94	20.78+-7.17
ZZ	8.91+-0.31	8.50+-0.30	6.58+-0.26	6.69+-0.27	30.70+-0.58
VVV	0.47+-0.02	0.44+-0.02	0.39+-0.02	0.40+-0.03	1.71+-0.06
Z+g	0.27+-0.27	5.35+-1.42	0.003+-0.003	2.49+-0.51	8.12+-1.53
top	6.59+-1.59	2.44+-1.01	6.04+-1.46	1.45+-0.49	16.53+-2.4
ttbarV	15.95+-0.22	15.49+-0.22	13.36+-0.19	12.43+-0.19	57.24+-0.41
tZ	1.91+-0.025	1.72+-0.024	1.69+-0.024	1.54+-0.023	6.86+-0.048
Data/MC	1.001	1.21	0.84	1.08	1.03



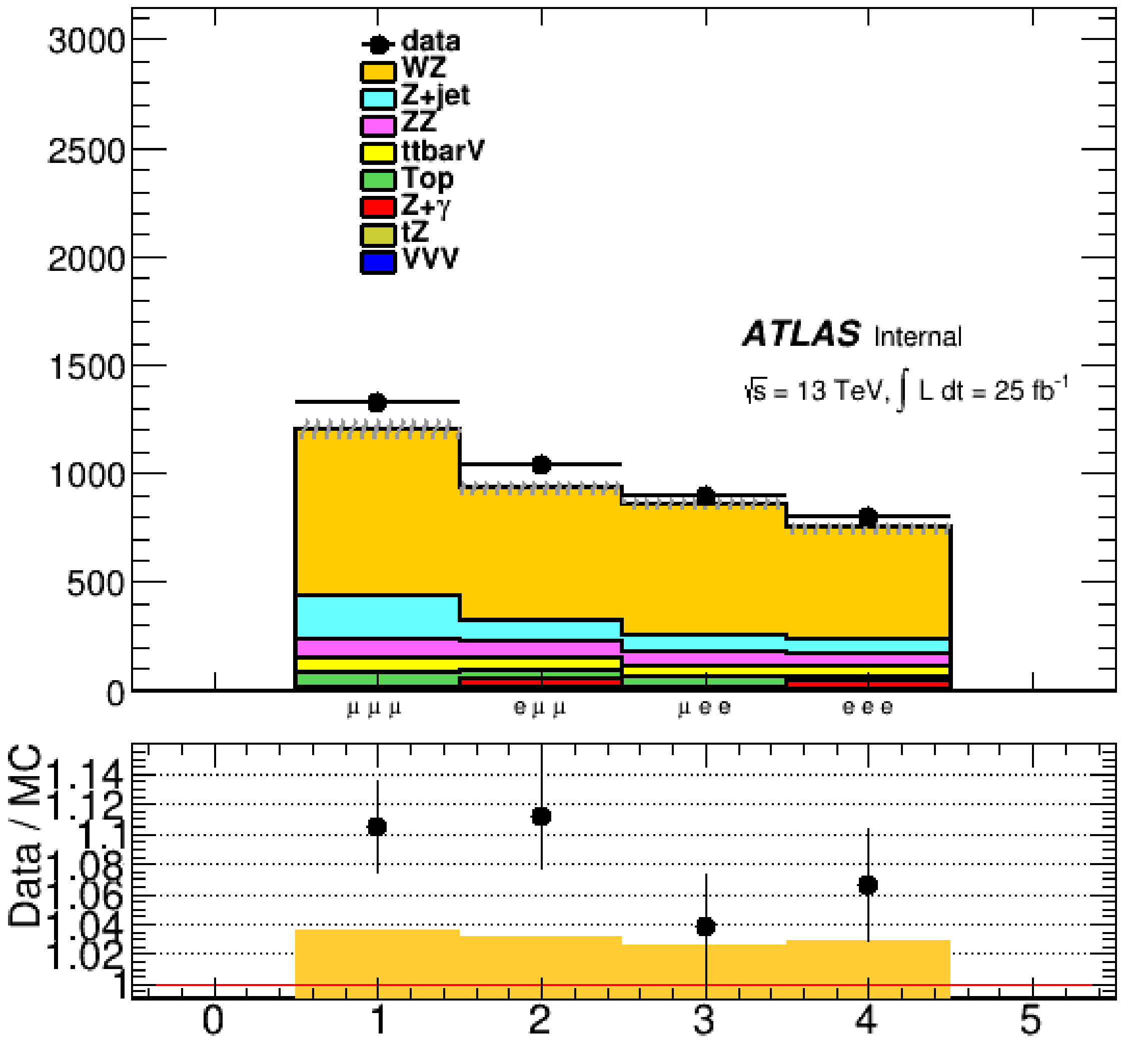
Kinematic distributions

qq Category

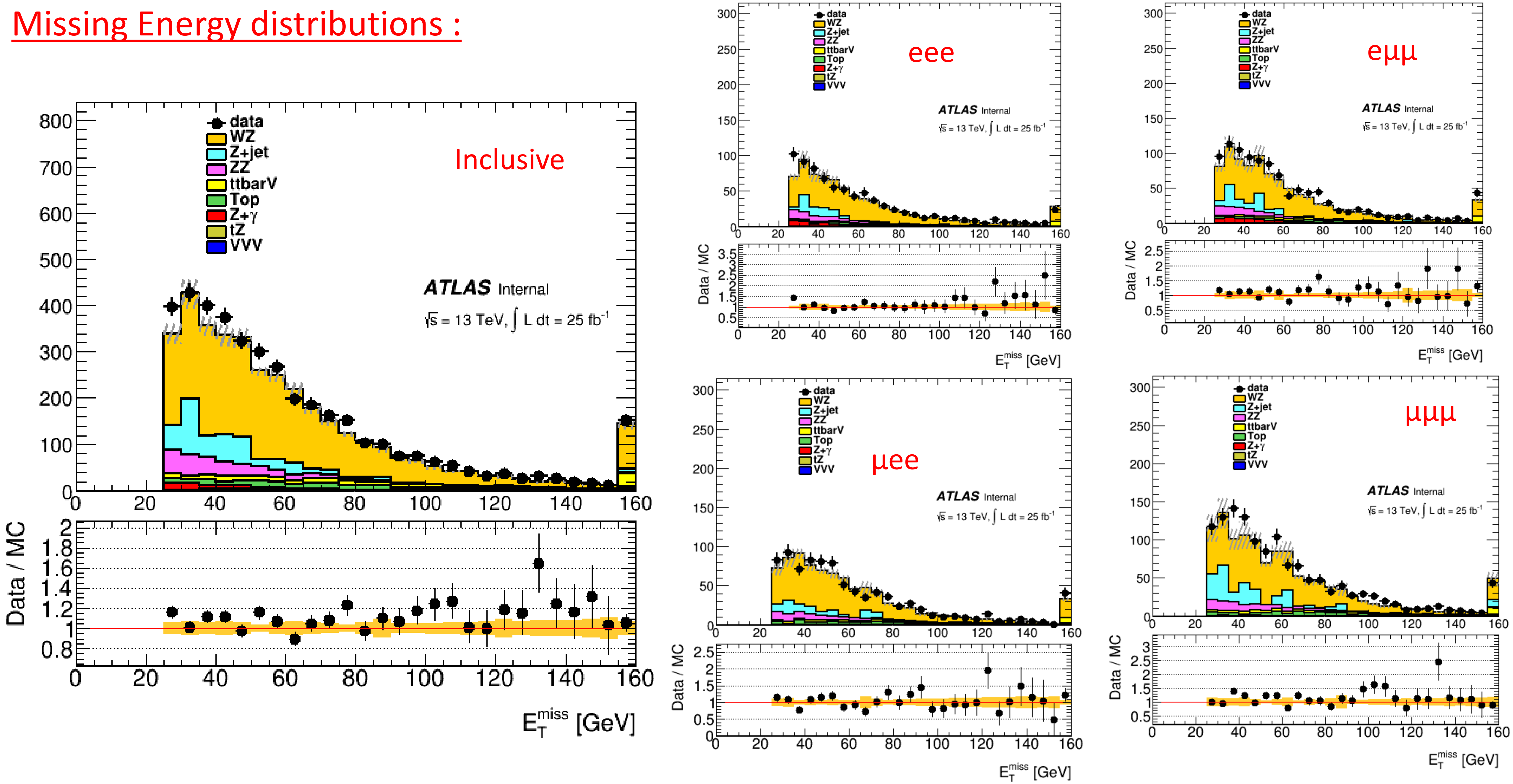
Before signal optimization cut selection cuts :

- Cutflowselection after selection W and Z candidates.
- Good data/MC agreement in μee and eee channels.

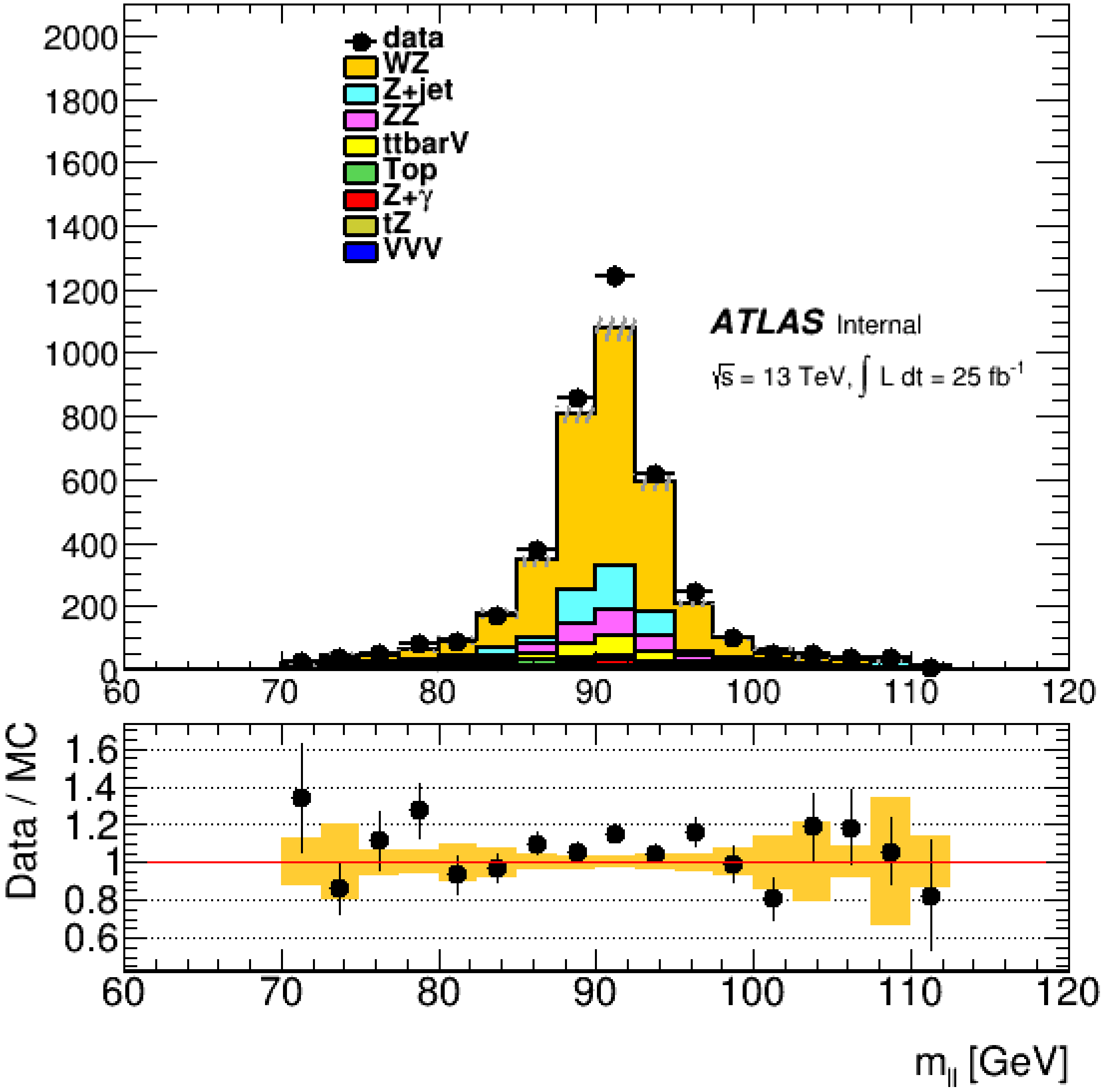
Channel	μμμ	eμμ	μee	eee	Inclusive
Data	1332	1042	896	799	4069
Total MC	1205.29+-42.75	937.59+-29.22	862.31+-22.10	749.12+-21.77	3754.31+-60.36
WZ	766.53+-11.34	613.43+-10.21	605.28+-10.16	514.92+-9.42	2500.17+-20.61
Z+Jets	202.72+-40.94	99.80+-26.89	76.90+-19.15	68.66+-19.26	448.08+-56.01
ZZ	89.20+-0.97	74.98+-0.88	66.29+-0.85	58.63+-0.81	289.09+-1.76
VVV	2.75+-0.087	2.38+-0.075	2.29+-0.075	1.89+-0.066	9.31+-0.15
Z+g	2.01+-0.97	39.79+-3.46	0.62+-0.33	32.86+-2.67	75.28+-4.49
top	64.34+-4.56	41.74+-3.64	51.96+-4.19	21.29+-2.45	179.35+-7.59
ttbarV	65.51+-0.45	55.53+-0.42	49.17+-0.38	42.68+-0.35	212.90+-0.81
tZ	12.23+-0.064	9.93+-0.057	9.79+-0.058	8.17+-0.053	40.13+-0.11
Data/MC	1.10	1.11	1.04	1.06	1.08

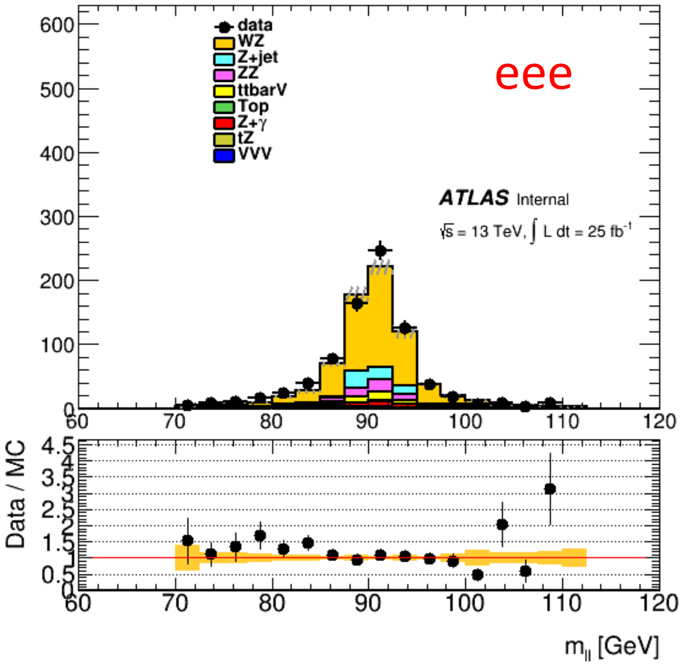


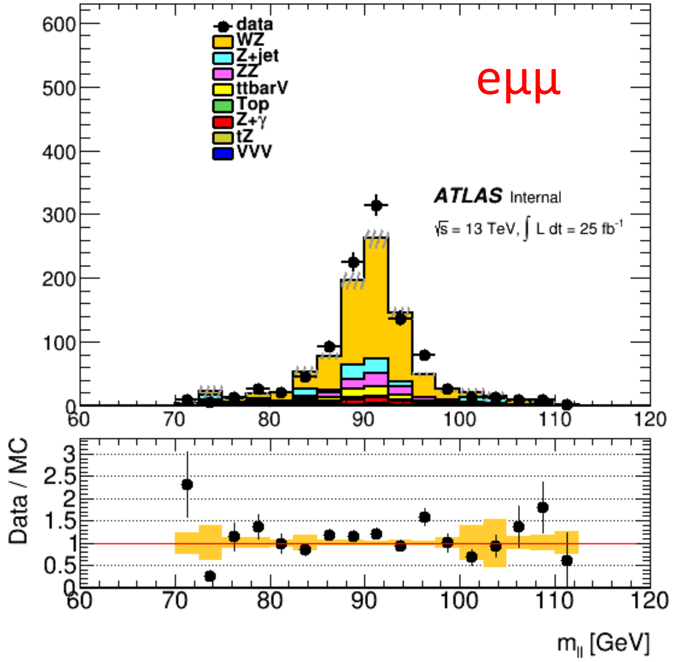
Missing Energy distributions :

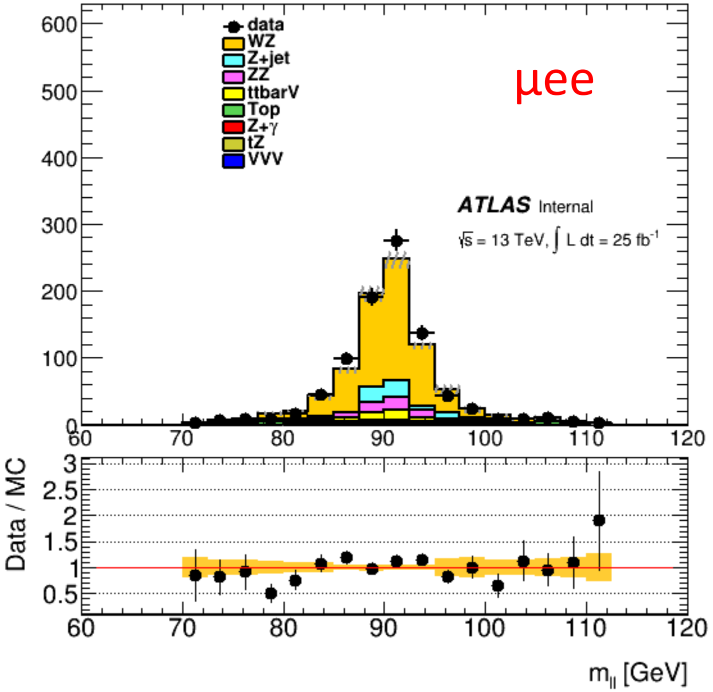


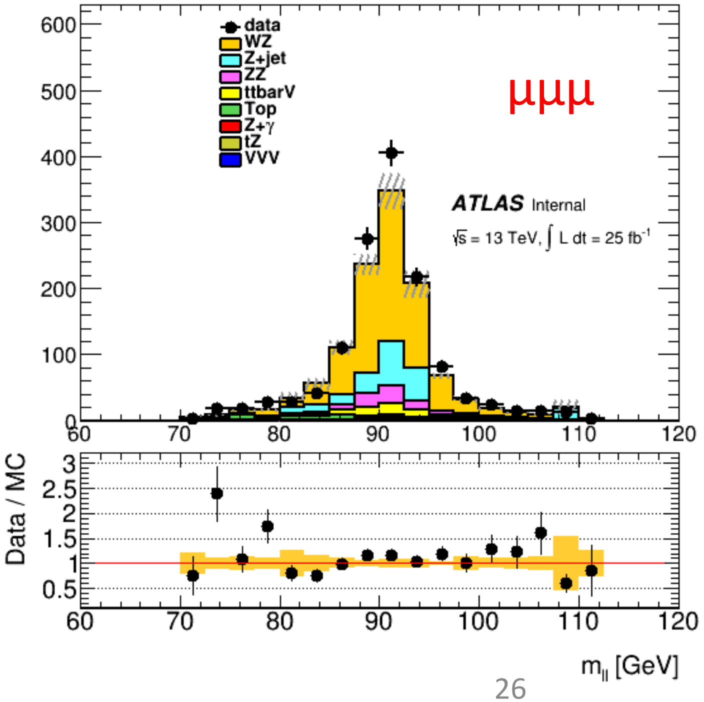
Z mass distributions :



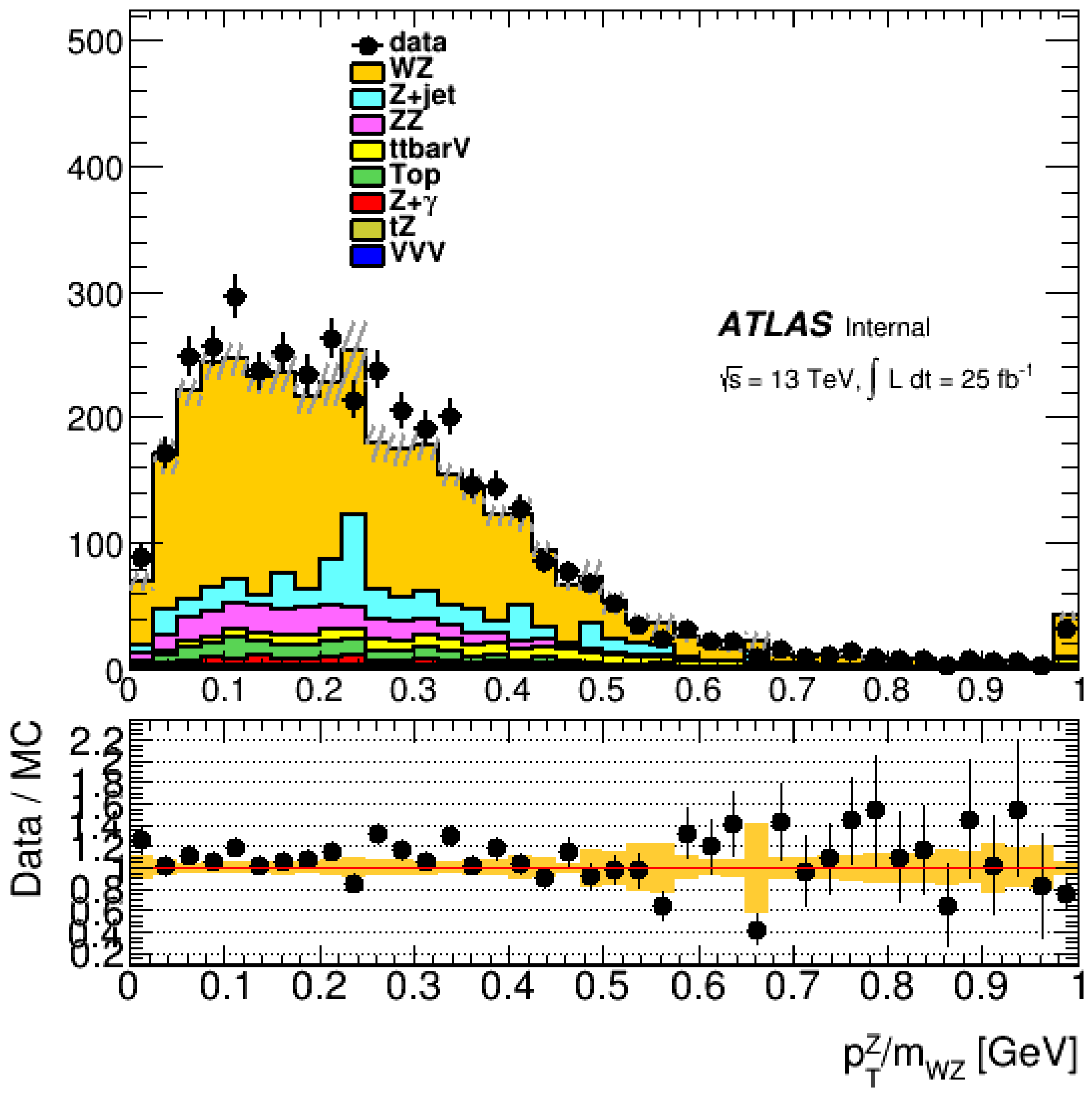


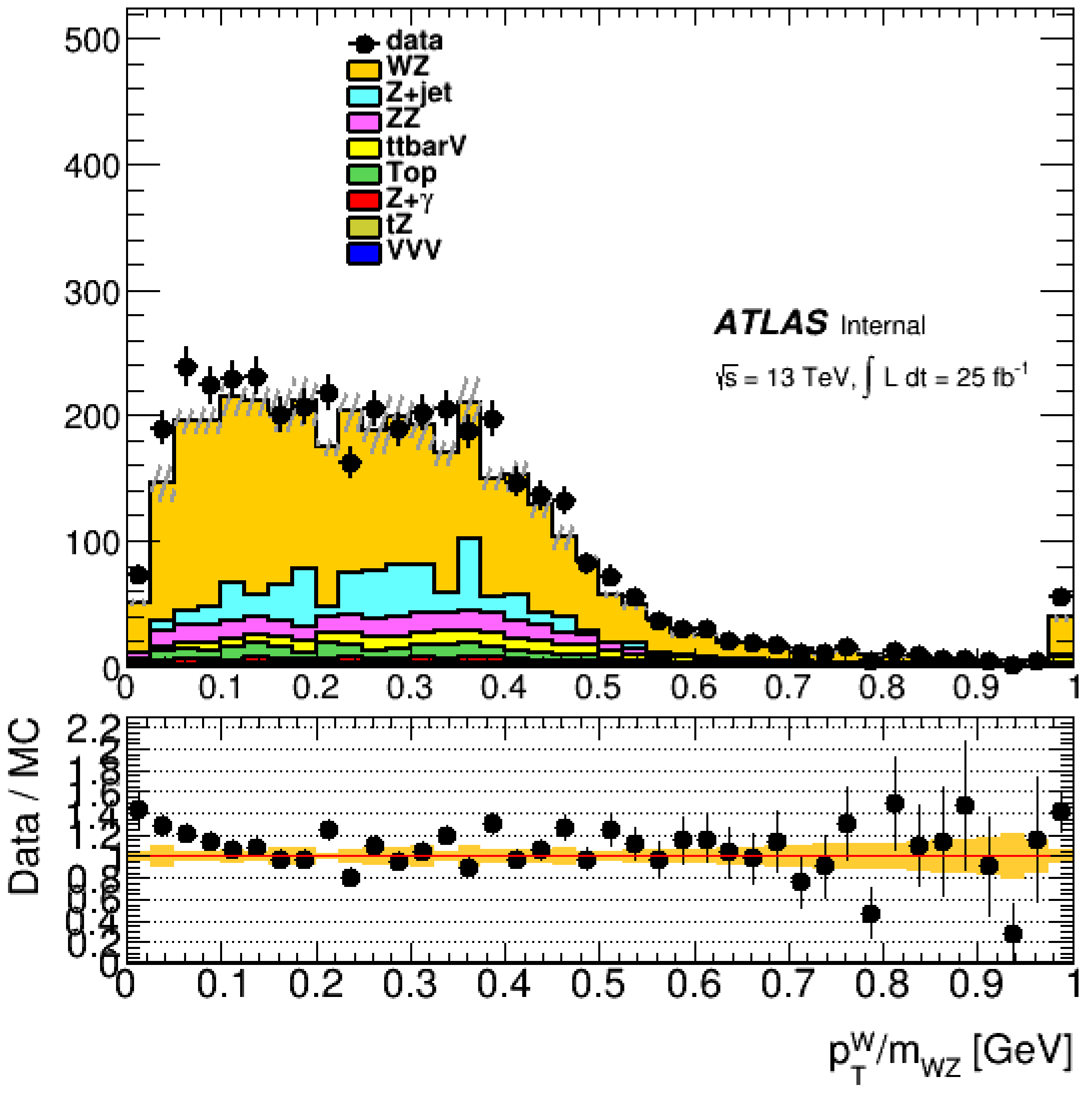






Distributions of $p_T^Z/Mass_{WZ}$ and $p_T^W/Mass_{WZ}$:



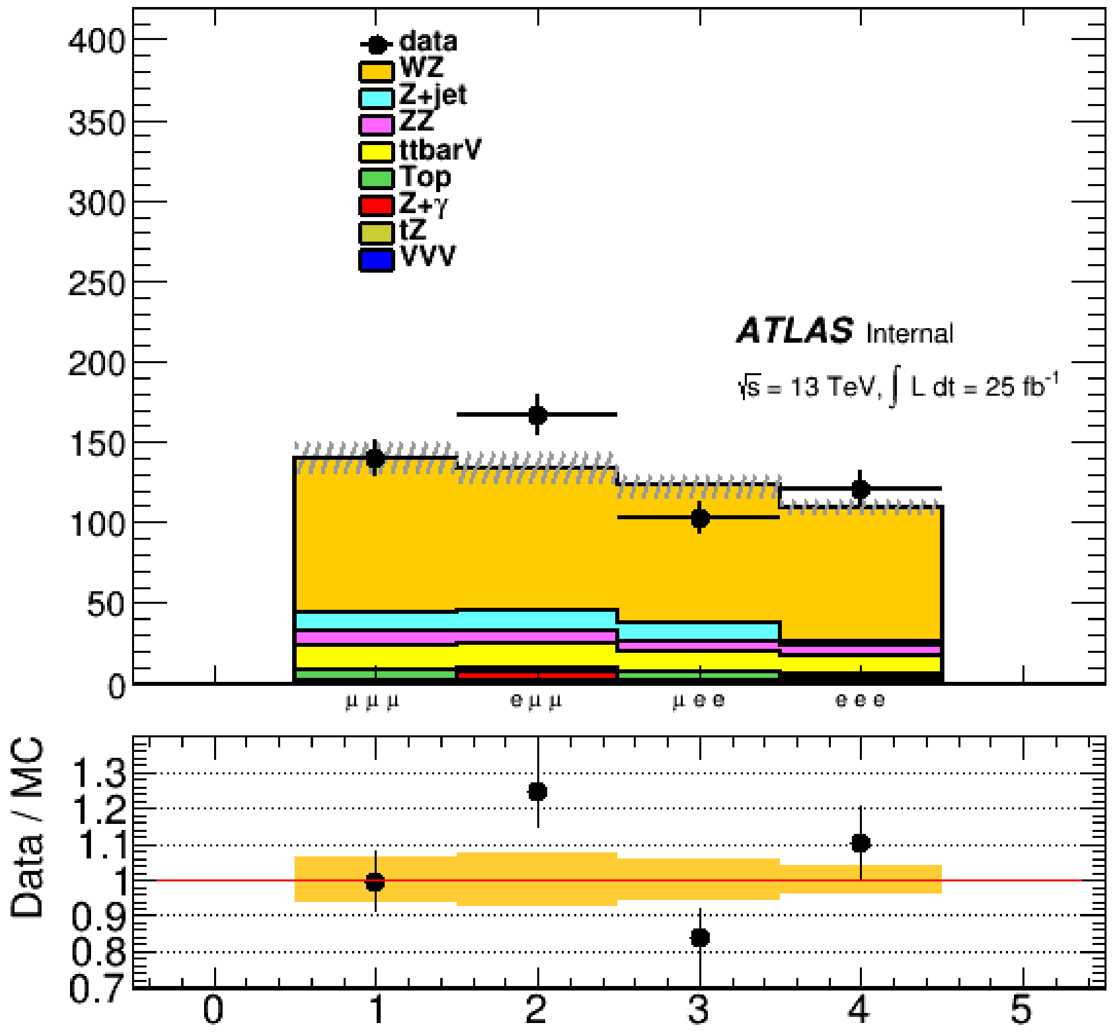


After signal optimization cut selection cuts :

- Cutflow selection after applying :

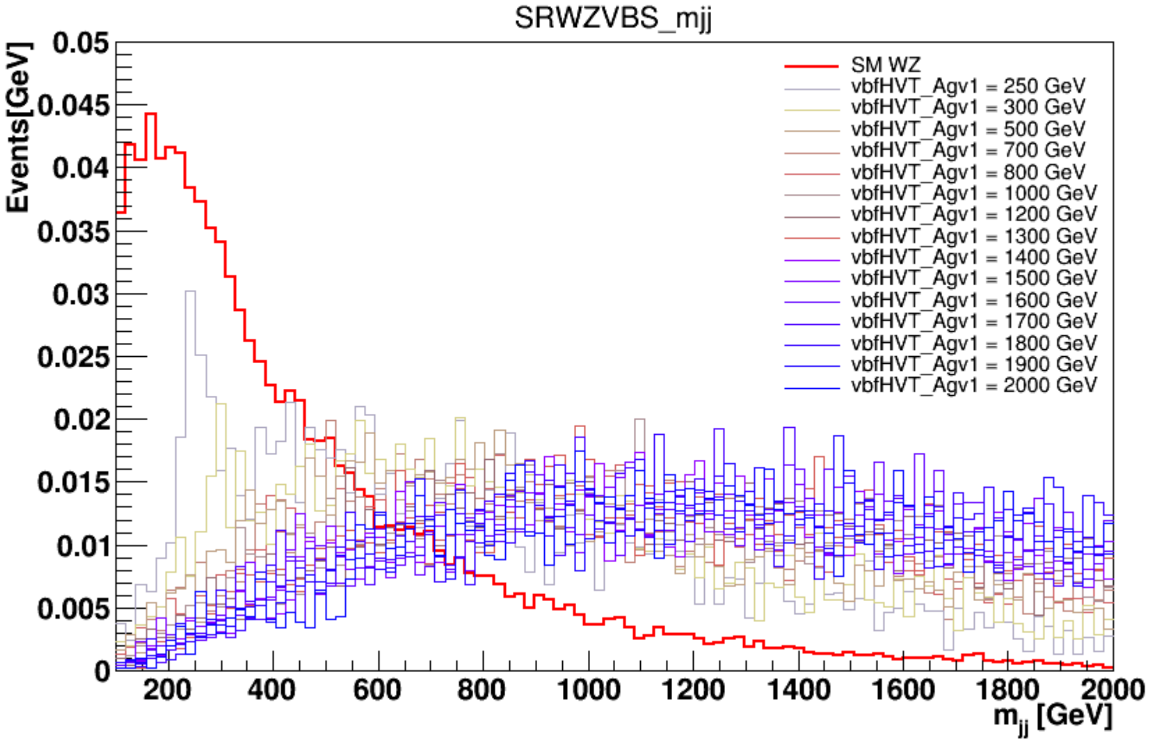
$$p_T^Z/Mass_{WZ} > 0.35 \text{ and } p_T^W/Mass_{WZ} > 0.35$$

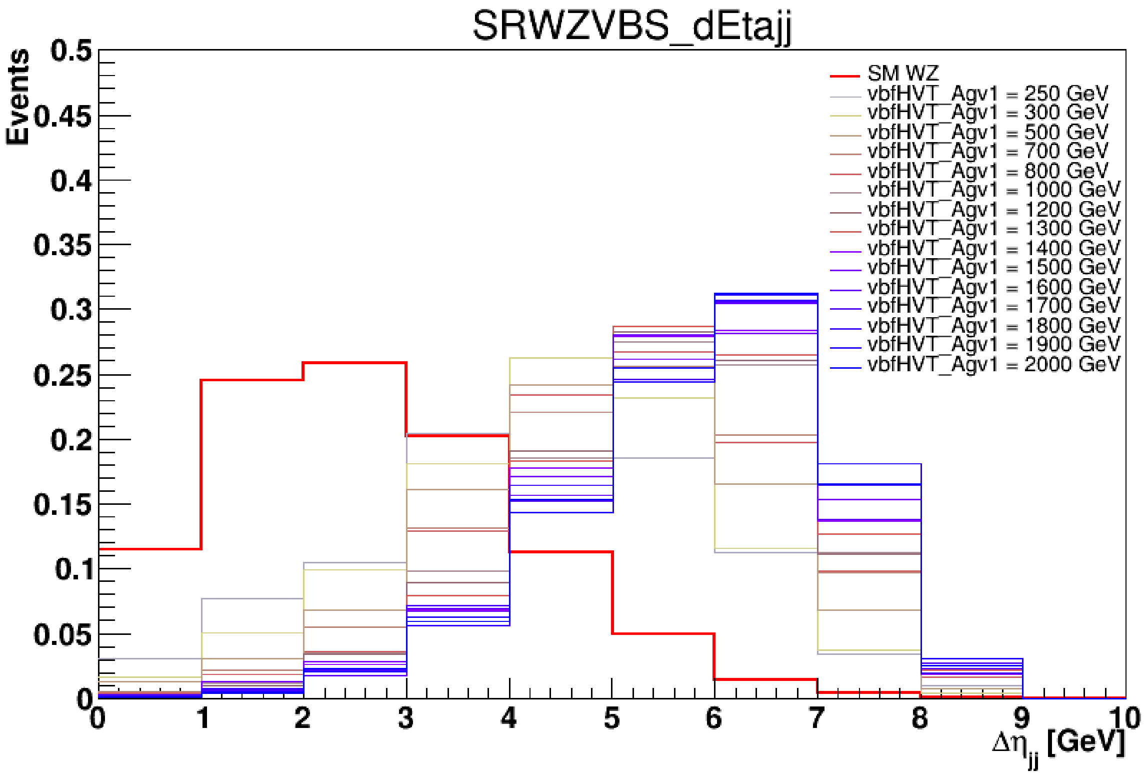
Channel	μμμ	eμμ	μee	eee	Inclusive
Data	140	167	103	121	531
Total MC	140.43+-9.17	134.23+-9.76	122.91+-6.88	109.66+-4.41	507.24+-15.69
WZ	96.42+-3.96	88.16+-3.87	85.14+-3.86	83.69+-3.88	353.42+-7.78
Z+Jets	11.12+-8.11	13.07+-8.78	10.83+-5.49	1.94+-1.94	36.97+-13.30
ZZ	8.80+-0.31	8.36+-0.30	6.45+-0.26	6.49+-0.27	30.12+-0.57
VVV	0.45+-0.029	0.42+-0.027	0.38+-0.026	0.38+-0.032	1.64+-0.057
Z+g	0.27+-0.27	5.33+-1.42	0.0034+-0.003	2.48+-0.51	8.09+-1.53
top	6.29+-1.58	2.44+-1.01	5.91+-1.46	1.45+-0.49	16.11+-2.43
ttbarV	15.41+-0.22	14.96+-0.22	12.72+-0.19	11.92+-0.18	55.015+-0.41
tZ	1.65+-0.024	1.48+-0.022	1.45+-0.022	1.30+-0.021	5.88+-0.045
Data/MC	0.997	1.24	0.84	1.1	1.05



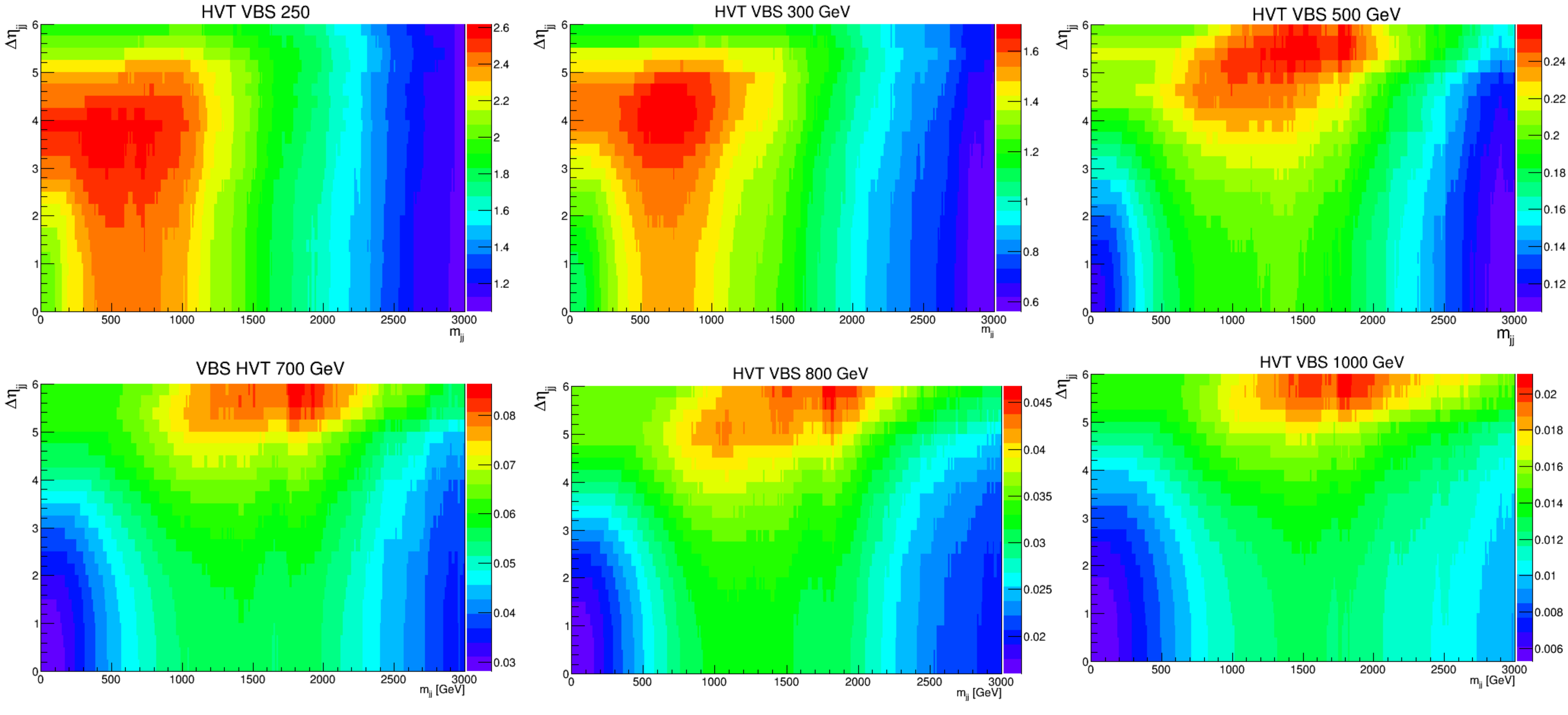
HVT VBS Signal optimization

- the Significance for HVT VBS Signal : $Significance = \frac{S}{\sqrt{S+B}}$
- Cut applied :
  - ✓ Selection W and Z condidates.
  - ✓ Only events with $N_{jet} \geq 2$ are considred for the analysis VBS.
  - ✓ Applying a scan cut in m_{jj} and $\Delta\eta_{jj}$.

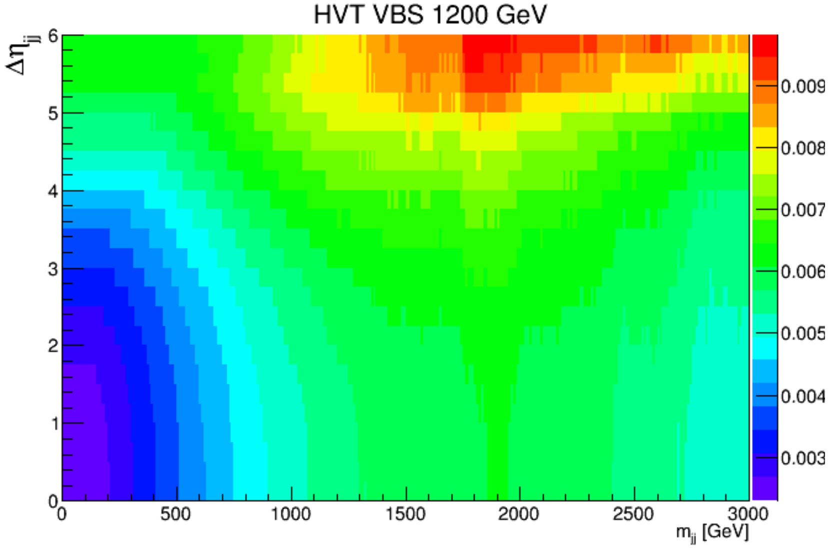


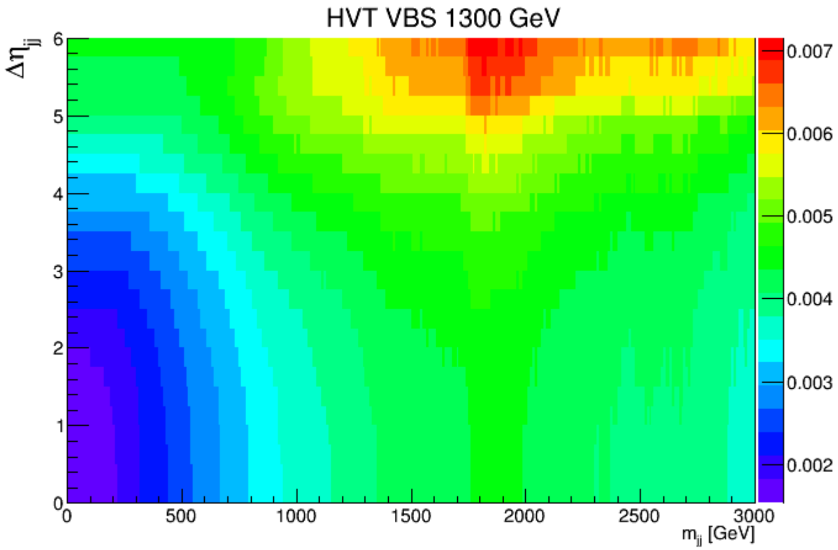


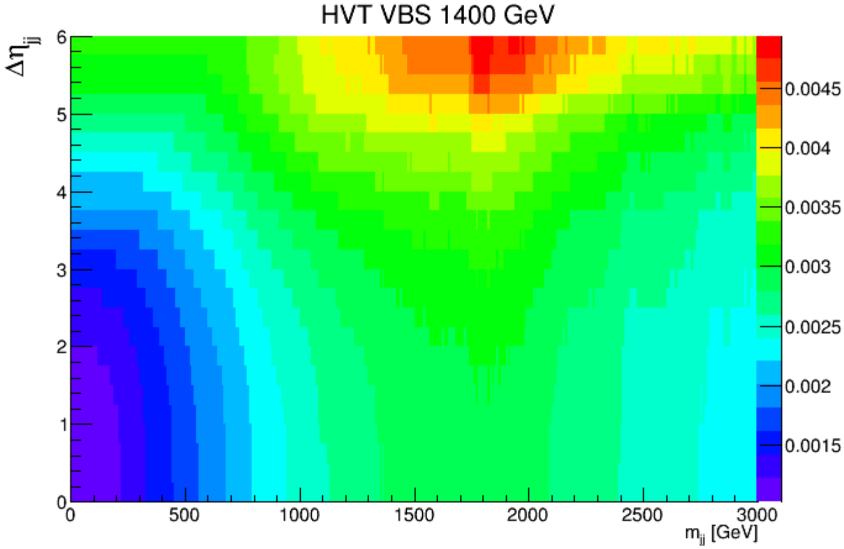
Significance as a function of m_{jj} and $\Delta\eta_{jj}$ cuts:

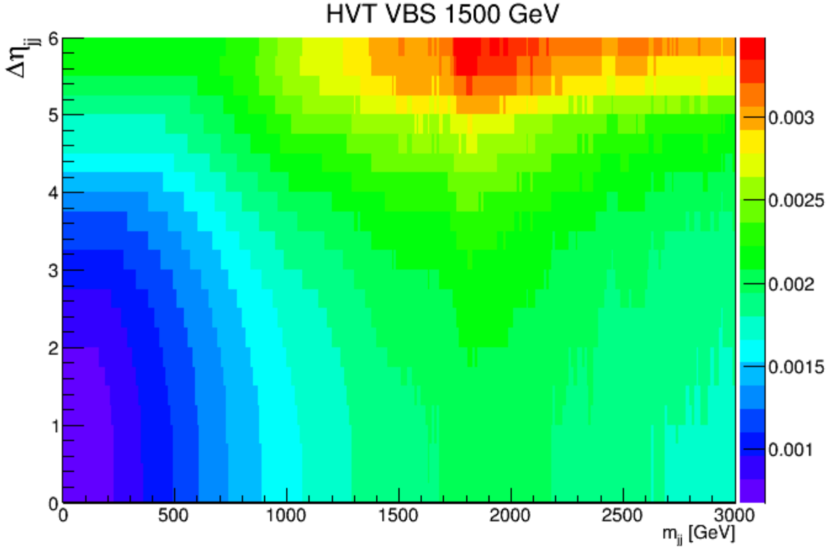


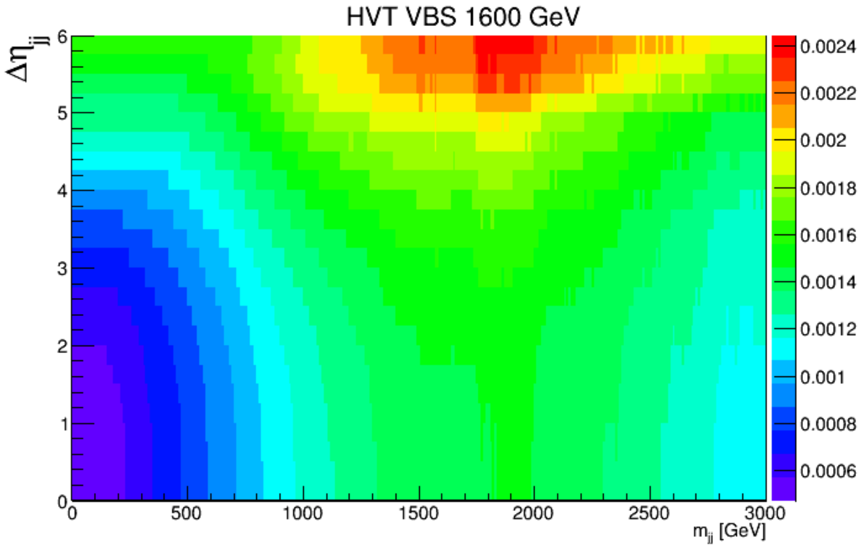
Significance as a function of m_{jj} and $\Delta\eta_{jj}$ cuts:

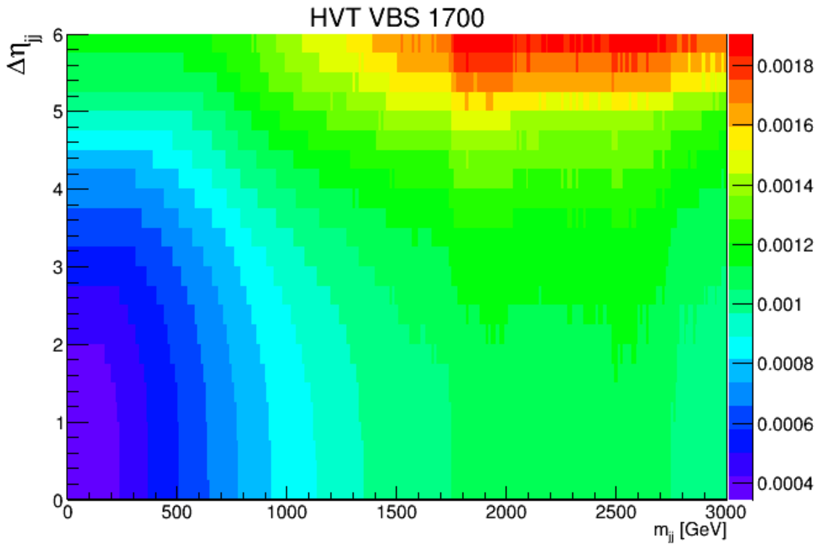




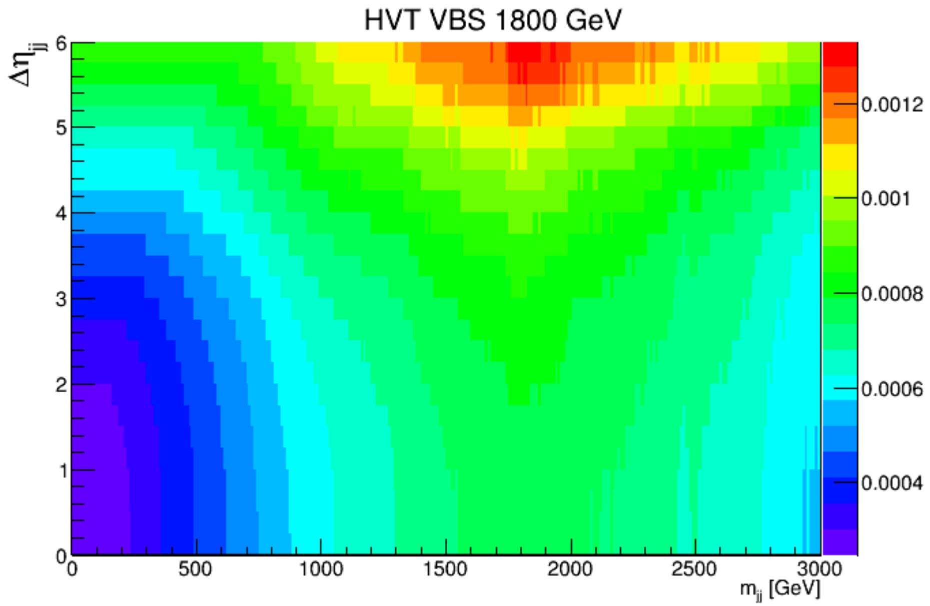


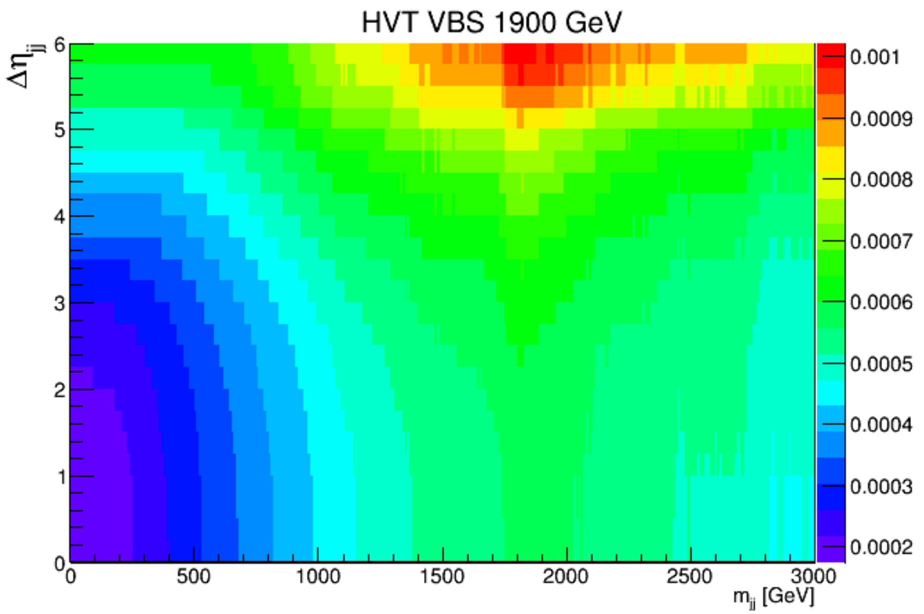


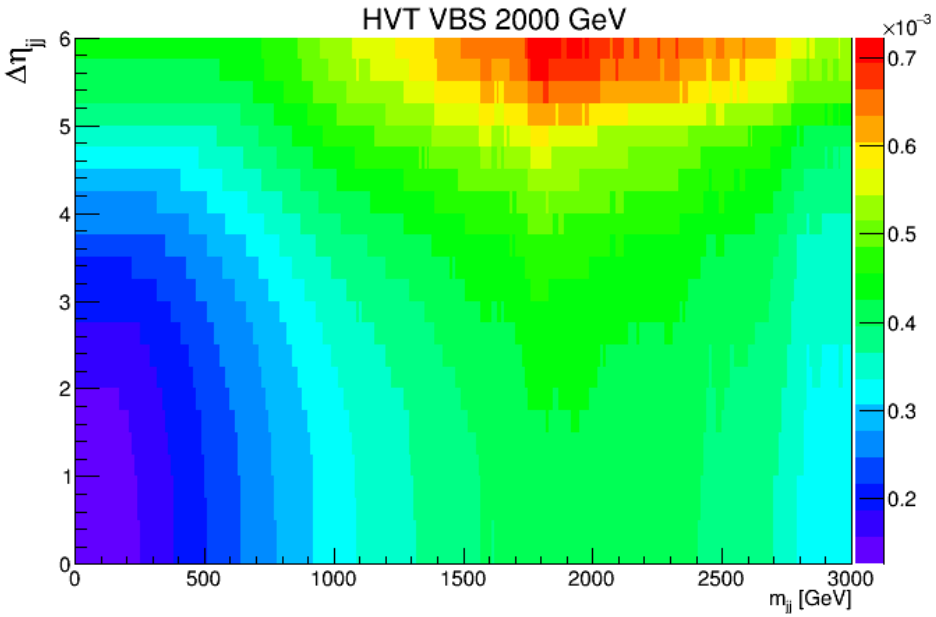




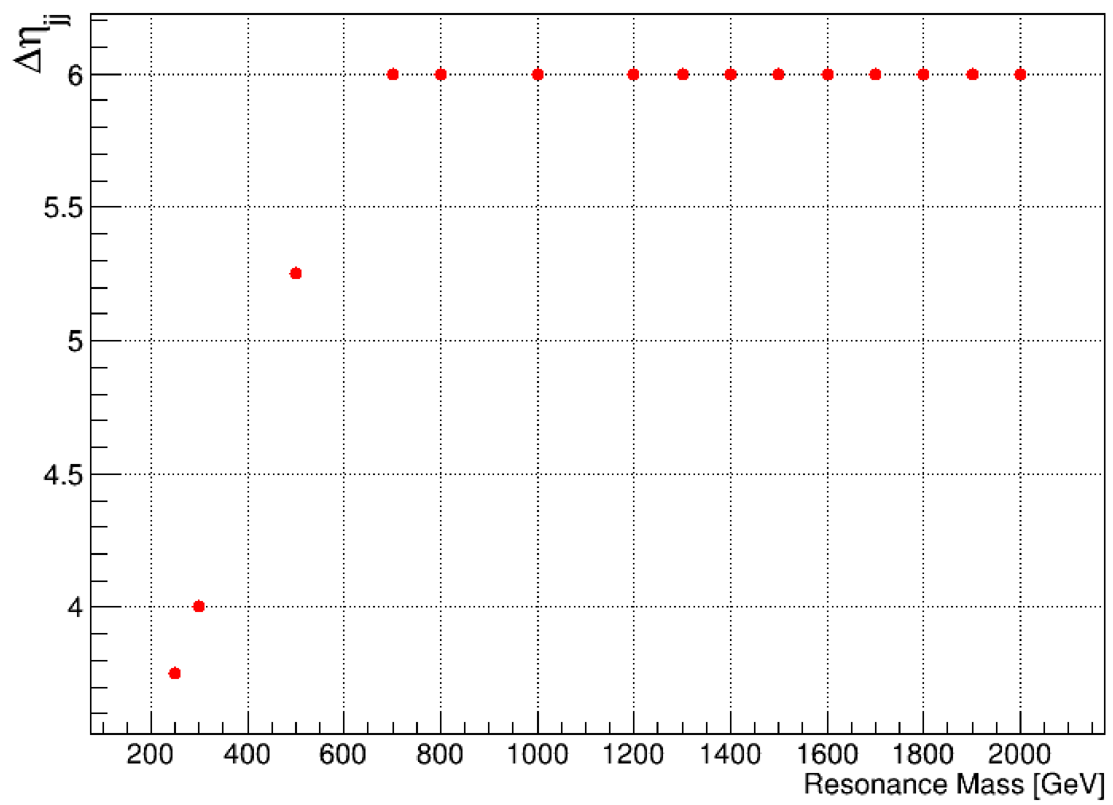
Significance as a function of m_{jj} and $\Delta\eta_{jj}$ cuts:

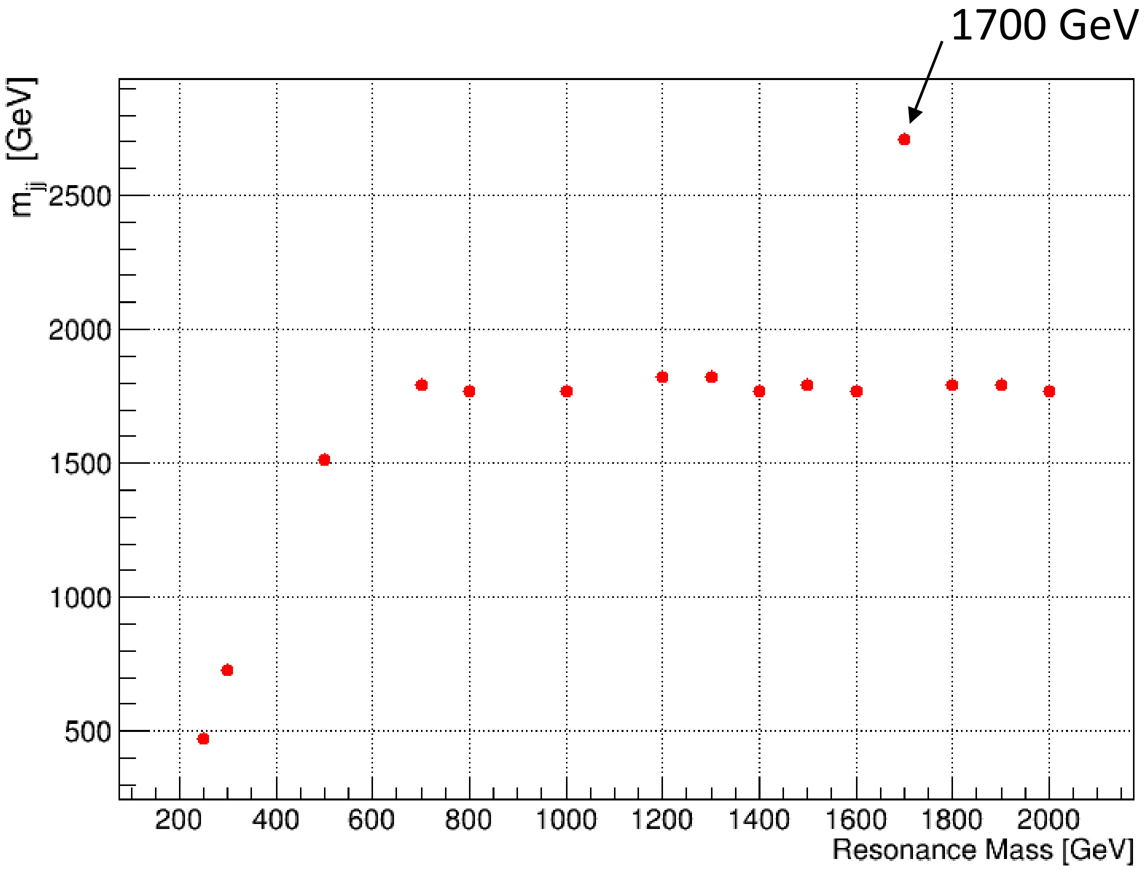






Variation of m_{jj} and $\Delta\eta_{jj}$ cuts as a function of resonance Mass with Maximum Significance:





$\Delta\eta_{jj}$ cuts for $m_{jj} = 500$ GeV for all resonance Mass point with Maximum Significance:

$\Delta\eta_{jj}$	Mass Points [GeV]	Signal Yield	Backgrounds Yield	Significance
3.75	250	24.4053	64.8122	2.5838
4	300	13.9297	56.0098	1.66564
4.5	500	1.4278	39.642	0.222796
5.75	700	0.209251	10.8631	0.0628853
5	800	0.184377	25.8282	0.0361506
6	1000	0.041574	7.70172	0.0149403
6	1200	0.0179707	7.70172	0.00646792
6	1300	0.0127084	7.70172	0.0045755
6	1400	0.00903147	7.70172	0.00325245
6	1500	0.00618078	7.70172	0.00222626
6	1600	0.00440858	7.70172	0.00158811
6	1700	0.00342035	7.70172	0.0012322
6	1800	0.00242837	7.70172	0.000874888
6	1900	0.0018197	7.70172	0.000655625
6	2000	0.0012751	7.70172	0.000459425

Conclusion :

- By looking at the HVT signal at the lepton pre-selection level less than 1% gain by adding MET .
- Using the single lepton triggers for HVT signals, we have an efficiency of ~99 % . Not evident gain in signal HVT or WZ SM by adding MET triggers to our final selection.
- Small gain in trigger efficiency was seen in data by adding MET triggers to the nominal selection.
- Decreasing the ZZ veto pt lepton cut from 20 GeV to 7 GeV, reduces the ZZ background by more than 25%. While the dominant background WZ SM is not affected by this cut.
- VBS and qq signal categories were defined
- The HVT signal efficiency was compared between inclusive and qq categories. A small effect of less than 3% was found for all mass points.
- Very little impact was also found on the background
- No effect is seen on kinematic distribution
- A cuts scan in m_{jj} and $\Delta\eta_{jj}$ for different HVT VBS Mass point was applied .