X->Zγ high mass search

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Introduction

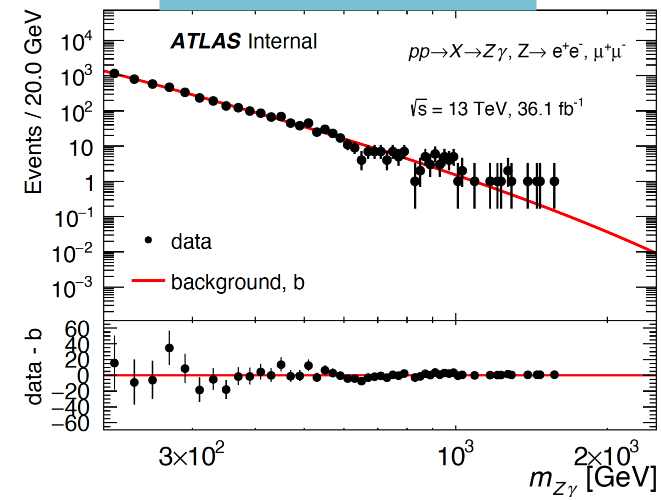
High mass search X->Zγ:

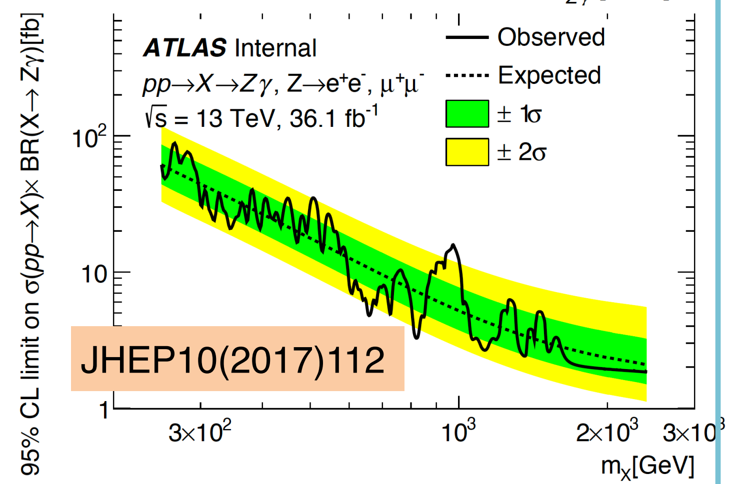
- aims to find BSM physics, can occur through either an extension of the Higgs sector or additional gauge fields
- Similar final state to Higgs->Zγ => similar selection procedure:
    - we consider Z boson decays only to di-electron or di-muon: **good mass resolution and background rejection**

Full Run2 update:

- extended range: **200 GeV - 5 TeV**
- major improvement for electron channels is required to the **boosting effect**, causing the electrons to be collimated (merged) and hard to reconstruct individually

Previous results:





- search range: 250 GeV - 2.4 TeV
- No excess found, upper limits on σ×BR (between 88 fb and 2.8 fb)

Event selection & samples

- GRL, PV and Event quality selection
- Triggers: leptonic ones + high photon pT triggers to the high mass (> 1 TeV):
  - HLT_g120_loose, HLT_g140_loose, HLT_g200_etcut and HLT_g300_etcut,HLT_g200_loose
- Overlap removal (ee, γe, γμ and jet-e/γ/μ)
- >= 2 good leptons and opposite sign
- mll > 45 GeV
- Trigger Matching
- 76.18 GeV < mll < 106.18 GeV
- photon selection: pT> 15 GeV; Tight ID and FixedCutLoose isolation
- mllγ > 200 GeV
- ph. rel. pT (mllγ/pT) > **0.2** (previously was 0.3)

Samples:

- fun Run2 data
- MC16 signal ggH 200 GeV - 5 TeV
- MC16 bkg Zgamma

$l^{-/+}\ (l = e/\mu)$

candidates	channel	single/di-lepton	trigger name
2015 data	$Z(\to ee)\gamma$	single electron	HLT_e24_lhmedium_L1EM20VH
			HLT_e60_lhmedium, HLT_e120_lhloose
2015 data	$Z(\to ee)\gamma$	di-electron	HLT_2e12_lhloose_L12EM10VH
2016 data	$Z(\to ee)\gamma$	single electron	HLT_e26_lhtight_nod0_ivarloose
			HLT_e60_lhmedium_nod0, HLT_e140_lhloose_nod0
2016 data	$Z(\to ee)\gamma$	di-electron	HLT_2e17_lhvloose_nod0
2017-2018 data	$Z(\to ee)\gamma$	single electron	HLT_e26_lhtight_nod0_ivarloose
			HLT_e60_lhmedium_nod0, HLT_e140_lhloose_nod0
2017-2018 data	$Z(\to ee)\gamma$	di-electron	HLT_2e24_lhvloose_nod0
2015 data	$Z(\to \mu\mu)\gamma$	single muon	HLT_mu26_imedium, HLT_mu50
2015 data	$Z(\to \mu\mu)\gamma$	di-muon	HLT_mu22_mu8noL1
2016 data	$Z(\to \mu\mu)\gamma$	single muon	HLT_mu26_imedium
			HLT_mu26_ivarmedium, HLT_mu50
2016 data	$Z(\to \mu\mu)\gamma$	di-muon	HLT_mu22_mu8noL1
2017-2018 data	$Z(\to \mu\mu)\gamma$	single muon	HLT_mu26_ivarmedium, HLT_mu50
2017-2018 data	$Z(\to \mu\mu)\gamma$	di-muon	HLT_mu22_mu8noL1

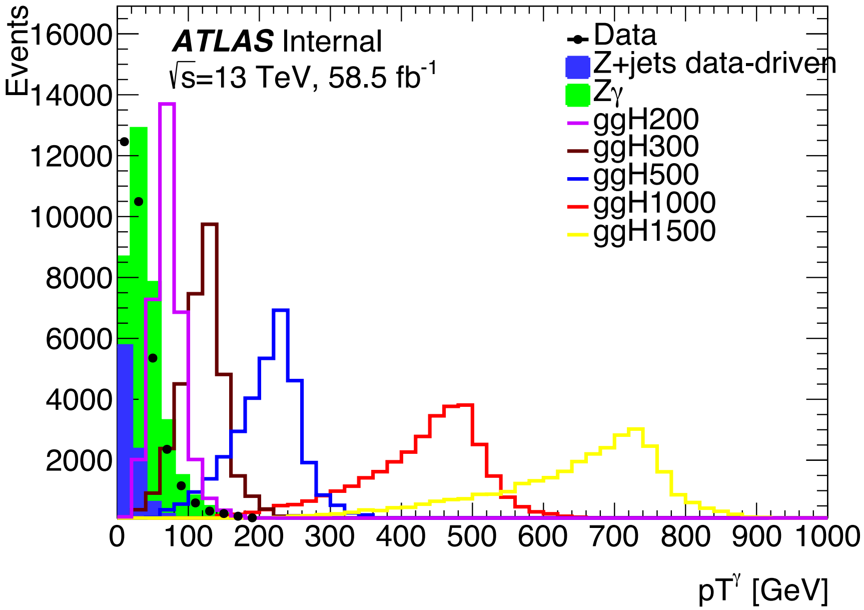
Lepton and Photon Preselection (before overlap removal)

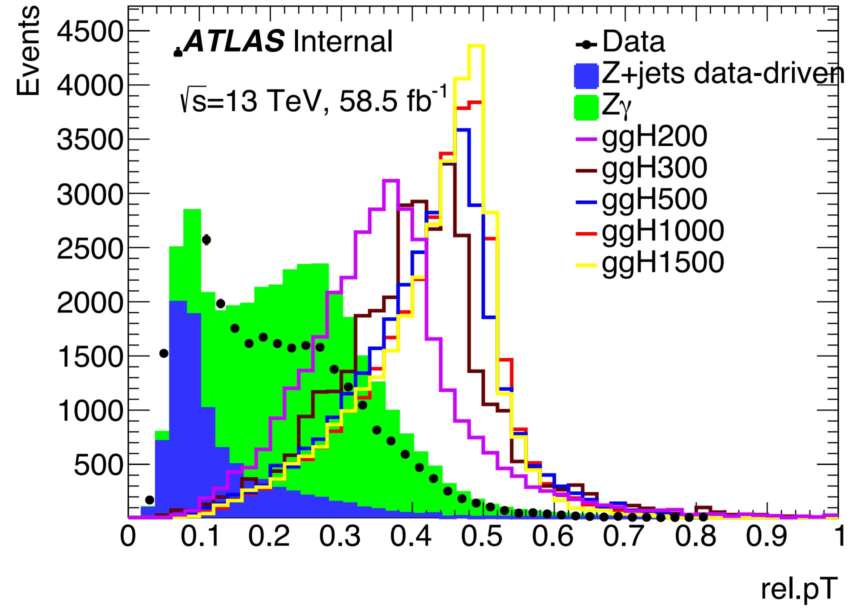
Cut	Electrons	Muons	Photons
p_T	> 10 GeV	> 10 GeV	> 10 GeV
$\|\eta\|$	$\|\eta\| < 2.47$	$\|\eta\| < 2.7$	$\|\eta\| < 2.37$
	exclude $1.37 < \|\eta\| < 1.52$	-	exclude $1.37 < \|\eta\| < 1.52$
$\|d_0\|/\sigma_{d_0}$	< 5	< 3	-
$z_0 \sin\theta$	< 0.5 mm	< 0.5 mm	-
Identification	Loose	Medium	Loose
Isolation	FCLoose	~~FCLoose~~	-

instead: Loose_VarRad for Mx < 1 TeV
TightTrackOnly_VarRad for Mx > 1 TeV

Low mass signal efficiencies

Check of Data18, bkg Zgamma MC16e + DD bkg Z+jets, signal ggH Mx samples





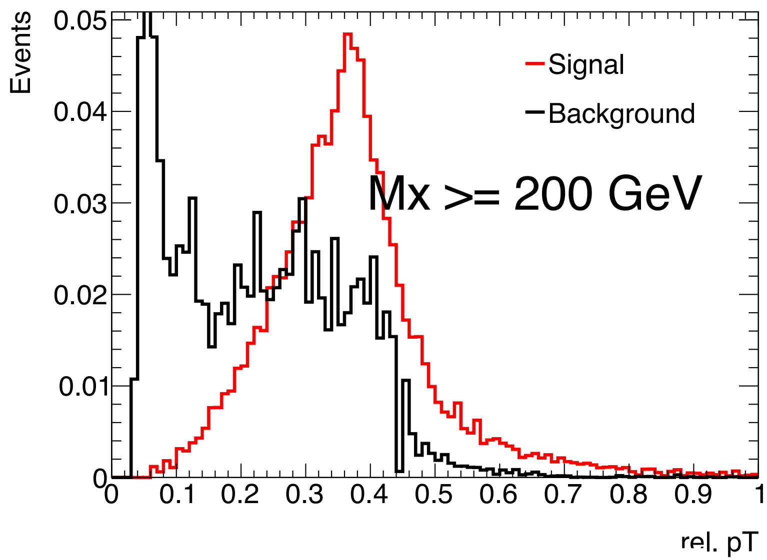
Revisiting photon pT vs rel.pT cuts:

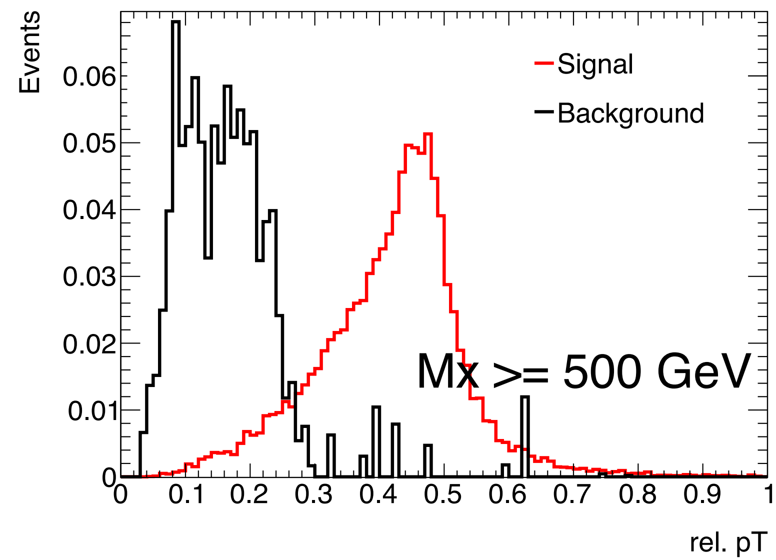
- Checking possibility to use photon pT: as expected photon pT distribution varies significantly with Mx range, hard to choose universal cut point

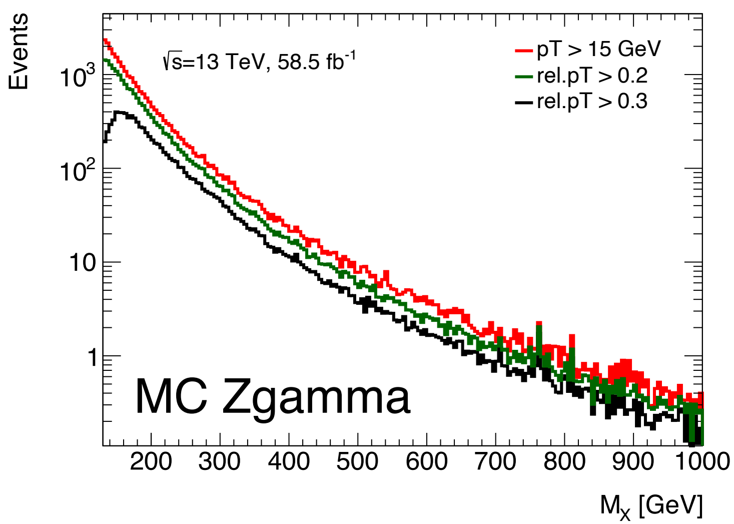
- Use of rel. pT cut: similar shapes for different Mx ranges, signal distributions move slightly to the right with higher Mx, still possible to choose ~1 cut point to suppress background

rel.pT cut optimisation

Check of Data18, bkg Zgamma MC16e + data-driven background Z+jets samples



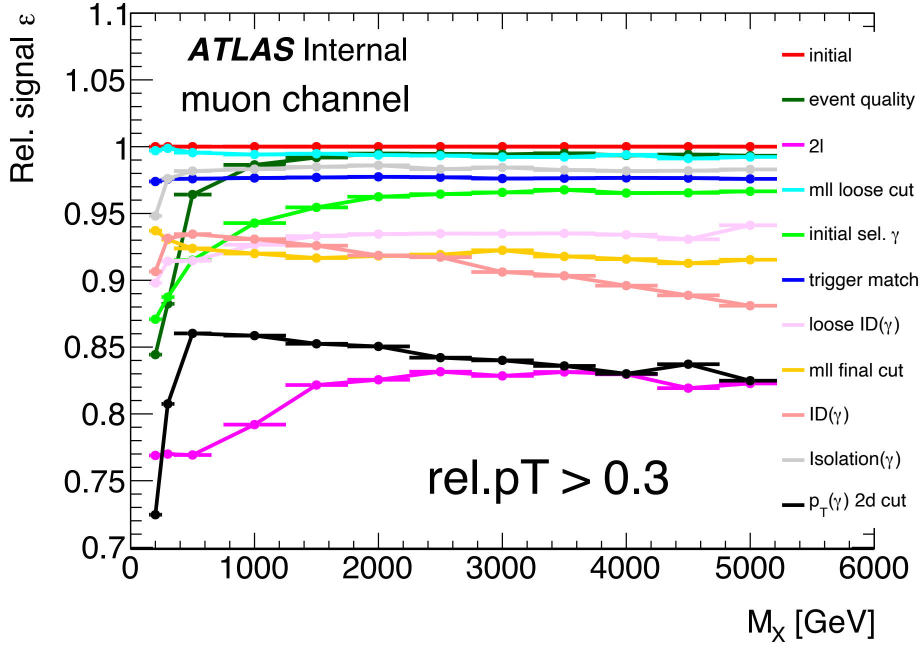


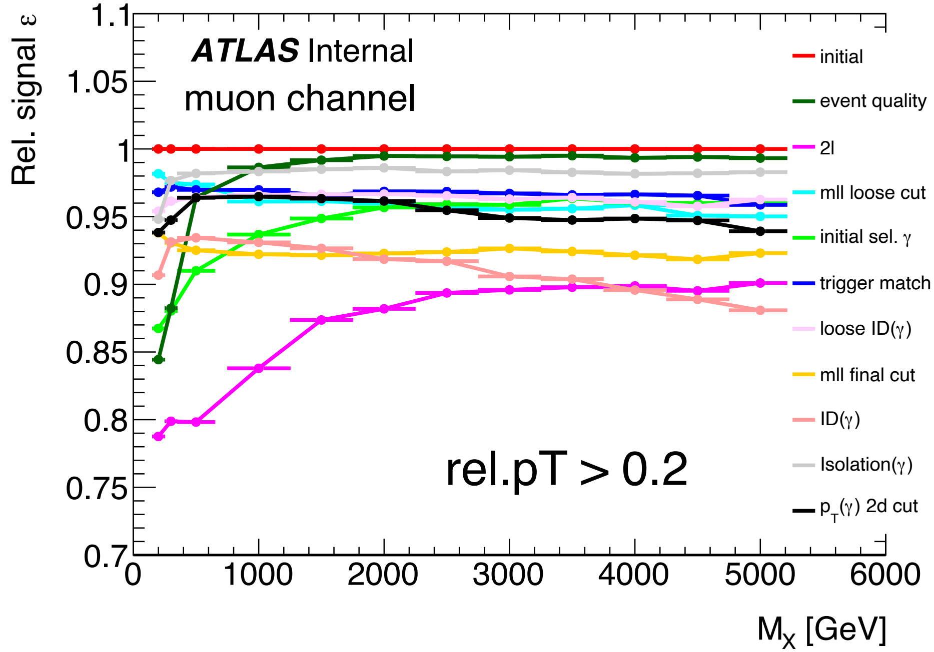


peak of signal distribution is moving with higher mass, while for background is ~same => cut at 0.3 cuts more events at low masses than at high masses

Turn-on effect is seen for rel.pT > 0.3 for Mx < 200 GeV but not seen for rel.pT > 0.2

rel.pT cut optimisation



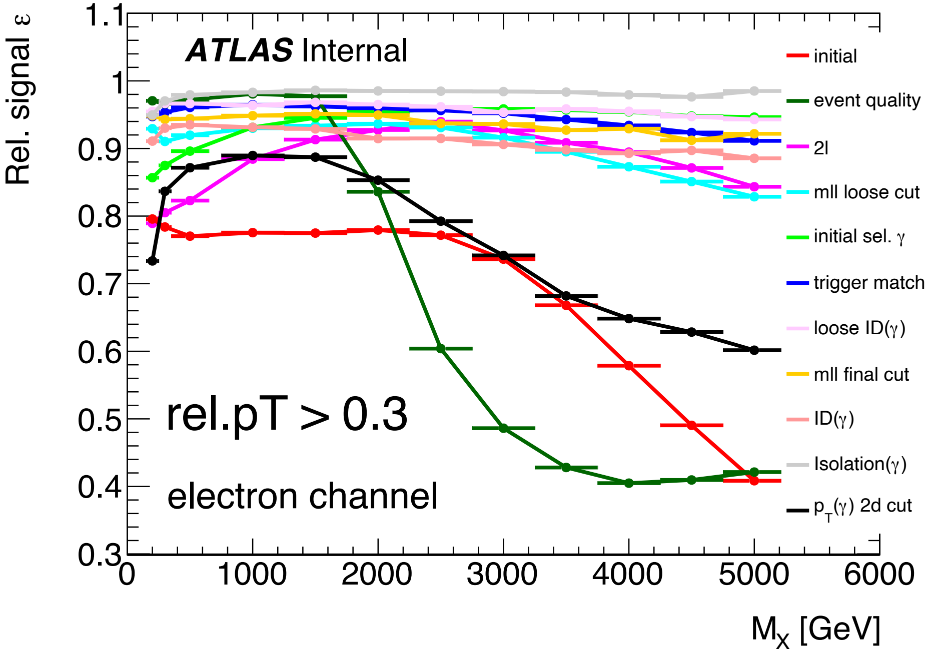


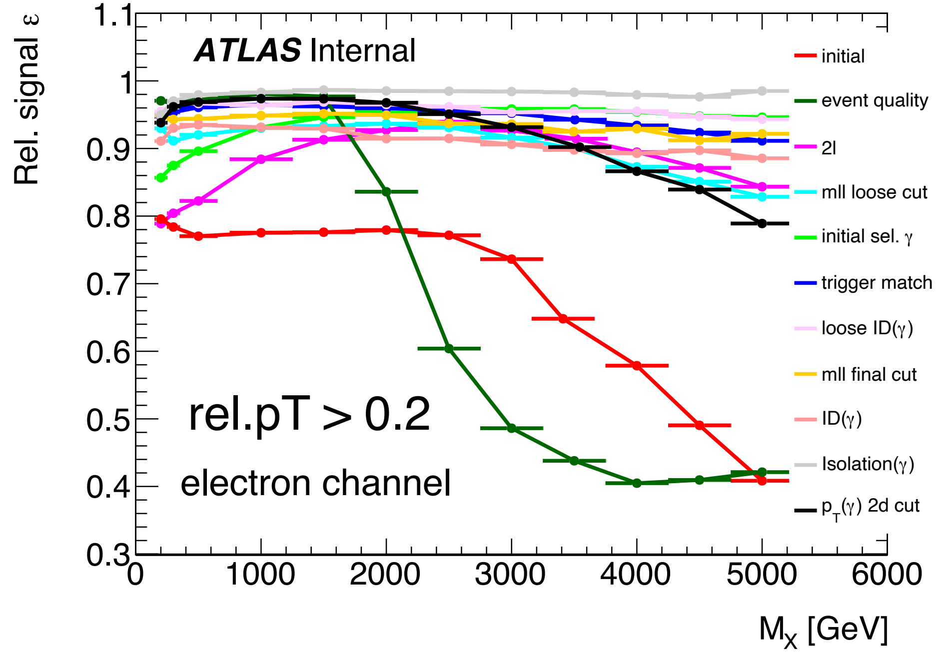
differences in lepton (pink curve) efficiency are caused by ID&Isolation cuts applied at later stages

Checking the possibility to optimise last applied cut -

- rel.pT > 0.3 (black curve)
- increased signal efficiency with rel.pT > 0.2 for both low and high mass regions (from 75-85% efficiency -> ~95% efficiency)

Low mass signal efficiencies





differences in lepton (pink curve) efficiency are caused by ID&Isolation cuts applied at later stages

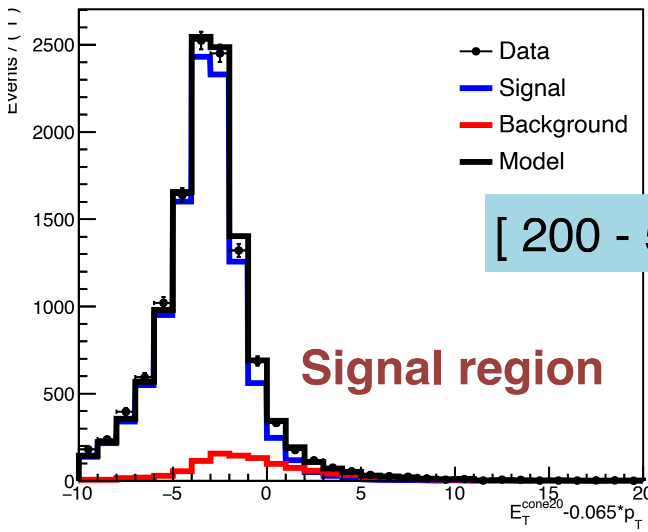
Checking the possibility to optimise last applied cut -

- rel.pT > 0.3 (black curve)
- increased signal efficiency with rel.pT > 0.2 for both low and high mass regions (from 65-90% efficiency -> ~85-95% efficiency)

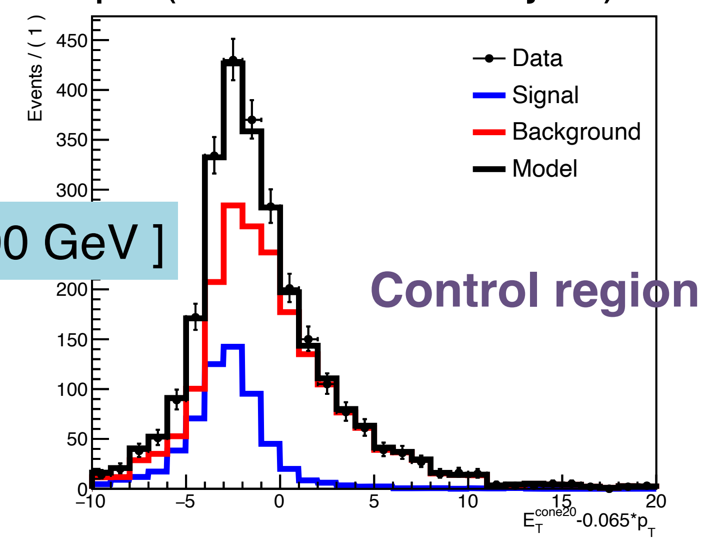
Background composition

Check of full Run2 Data, bkg Zgamma MC16 + data-driven bkg Z+jets samples

- **Template fit method**: fraction of Z+jets events is estimated from binned fit to calorimeter isolation
  - fit is performed to signal & control regions: **signal region** is defined as photons passing Tight ID; **control region** is defined as photons failing Tight ID but passing Loose’4
  - fit extracts Zgamma yield and shape (and same for Z+jets) from 2 regions



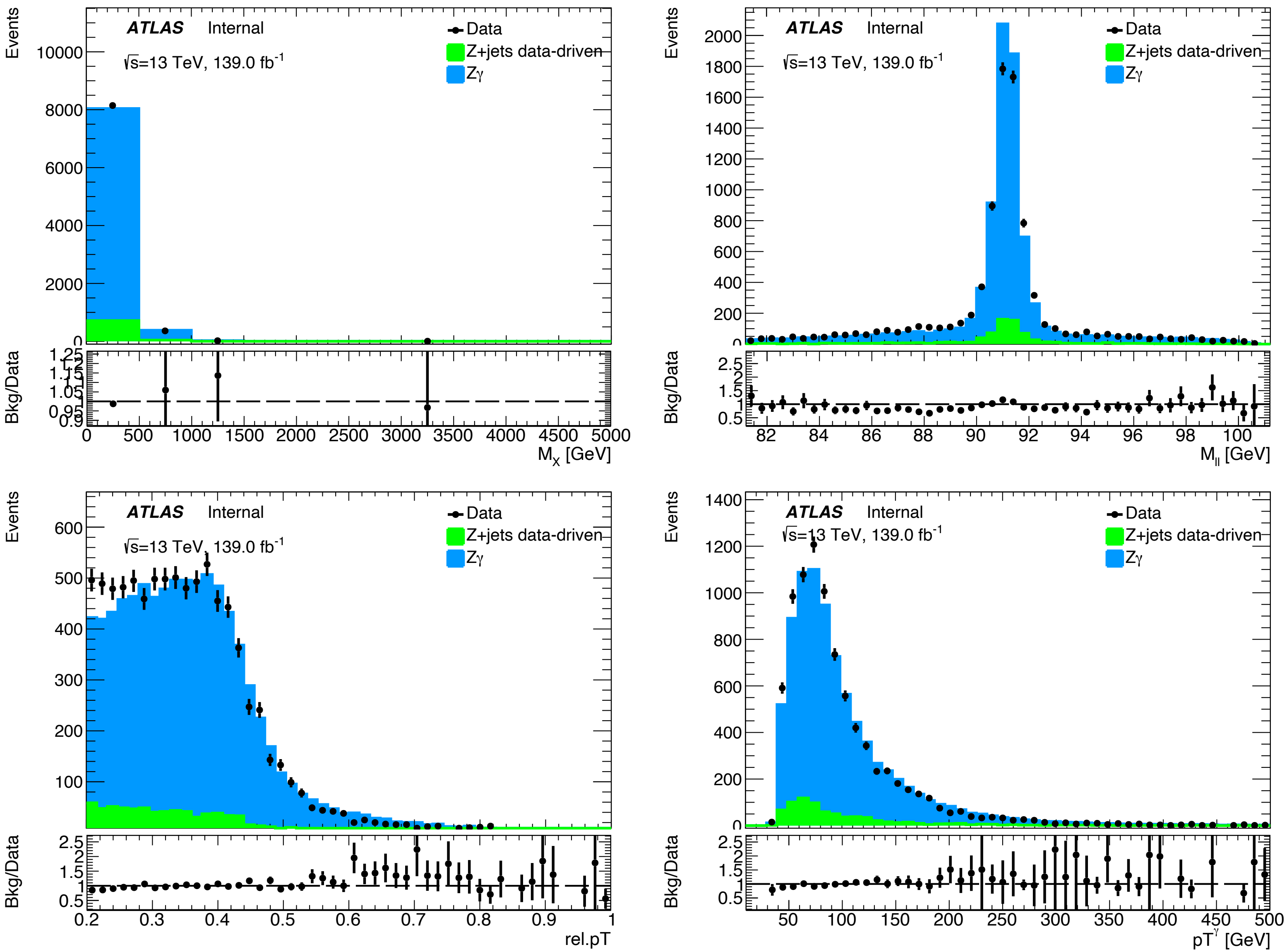
[200 - 5000 GeV]



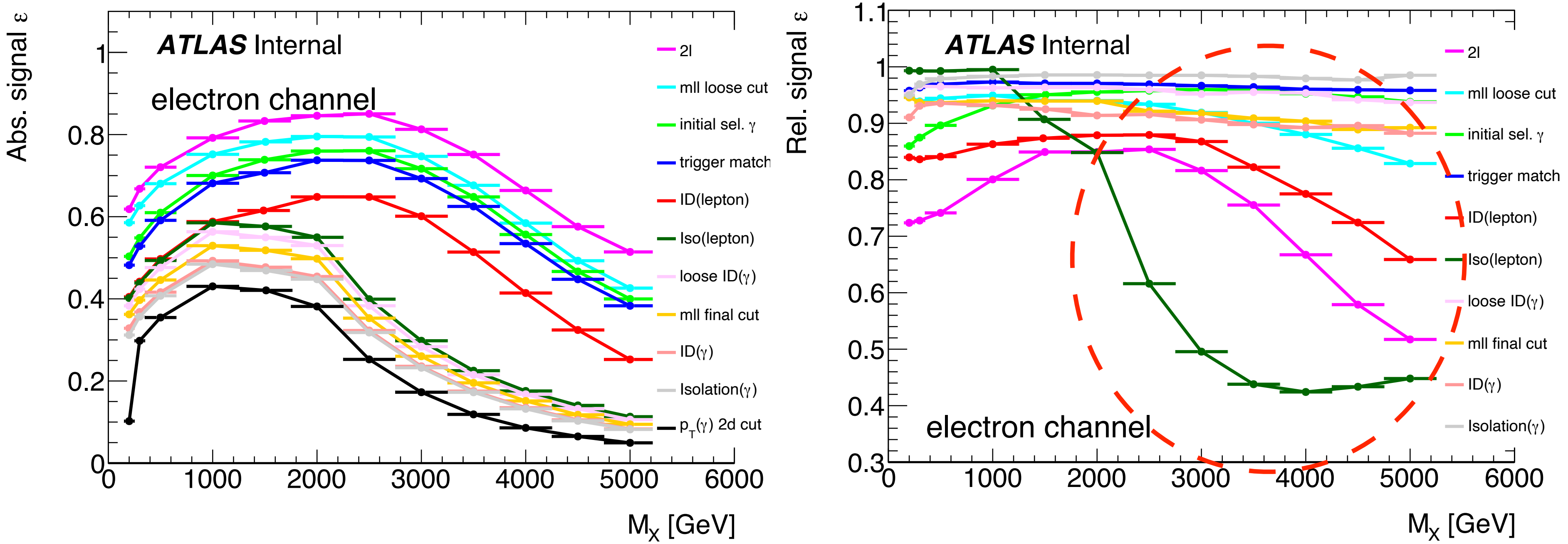
	Nominal Purity	Range	Ns	Nb
Inclusive: Mx in [200, 5000]	0.91 ± 0.01	[0.90, 0.96]	6010.30 ± 97.697	585.58 ± 61.95

Data/Background plots

Fraction of Zgamma/Zjets events is estimated with template fit method



Electron signal efficiencies



Drop of signal efficiency at high mass (> 1 TeV) due to electron being highly collimated (boost effect):

- two cluster of energies are merged as one and only one electron is reconstructed
  - we can't do much about ID, but maybe **isolation** can be improved?
  - or do we need isolation applied at all since there might be no significant background at these energies?
  - Current choice of electron isolation: **FCLoose**

- no problem is seen for muons as since Run 2 muon reconstruction can resolve close by muons within an angular resolution of the order of 0.01-0.02

Electron signal efficiencies

- Signal efficiency for electrons show large drop for leptons for high masses
- Several proposals concerning electron isolation:

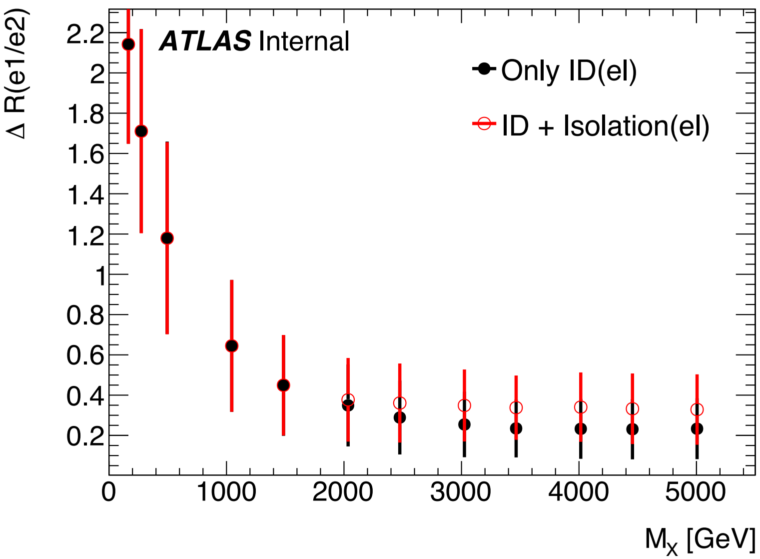
1) check separately impact of electron ID and isolation

2) check dR vs Mx:

A) events with deltaR > 0.31 (mostly low Mx)
B) events with the two electrons explicitly reconstructed as two electron objects with deltaR < 0.31 (up to intermediate Mx)
C) events where the two electrons are so collimated that only a single electron is reconstructed (very high M_X signals)

Isolation closeBy correction tool can help only with **B)** case

Electron signal efficiencies



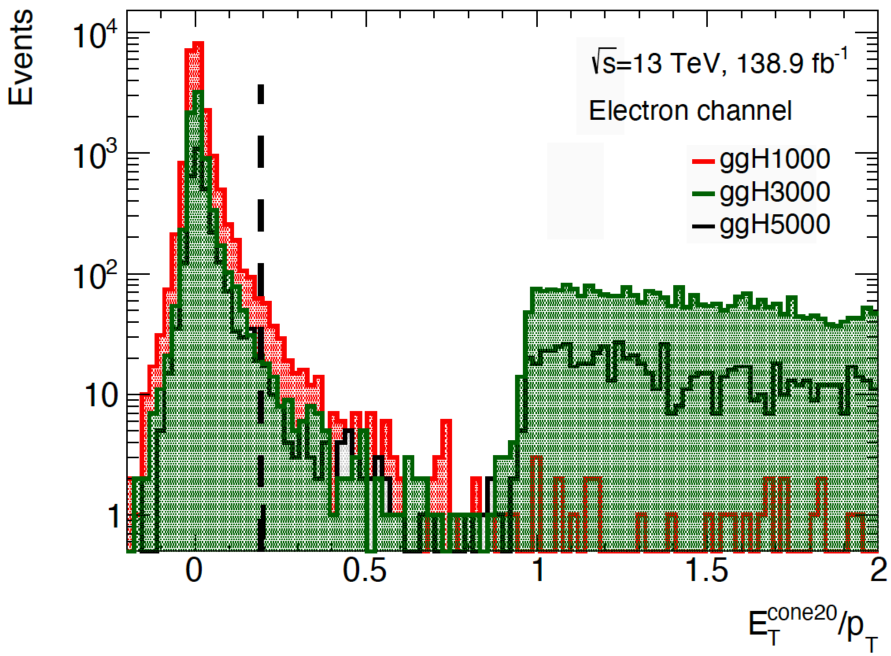
dR between two electrons as function of resonant mass:

- small improvement with applied isolation + closeBy correction tool at high mass
- dR ~ 0.2 with no isolation, ~0.3 with isolation

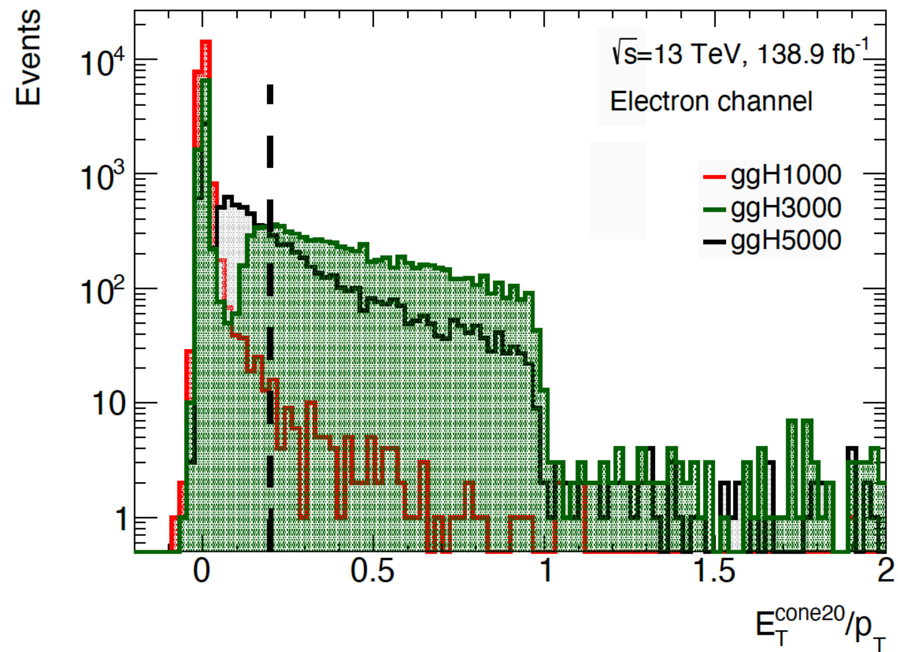
Electron signal efficiencies

Check of topoetcone20/pT with NO isolation closeBy correction applied

[leading lepton]



[subleading lepton]

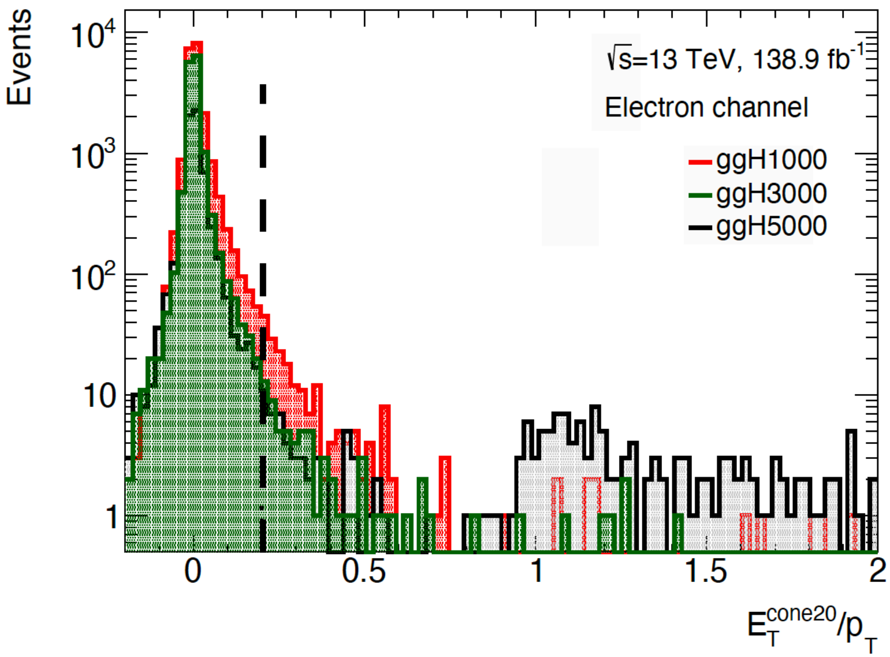


- previous version - distribution was up to 0.4 only (in backup)
  - Feedback from IFF - check wider distribution
- large number of events is cut off after isolation is applied for higher mass samples (> 3 TeV)
- isolation seems to show distribution for two collimated electrons

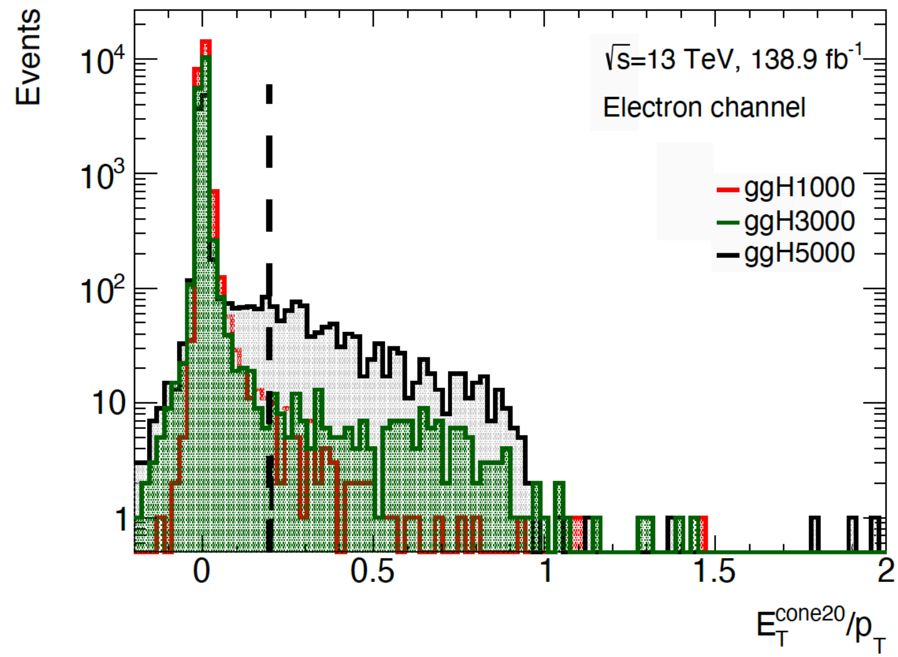
Electron signal efficiencies

Check of topoetcone20/pT with isolation closeBy correction applied

[leading lepton]



[subleading lepton]

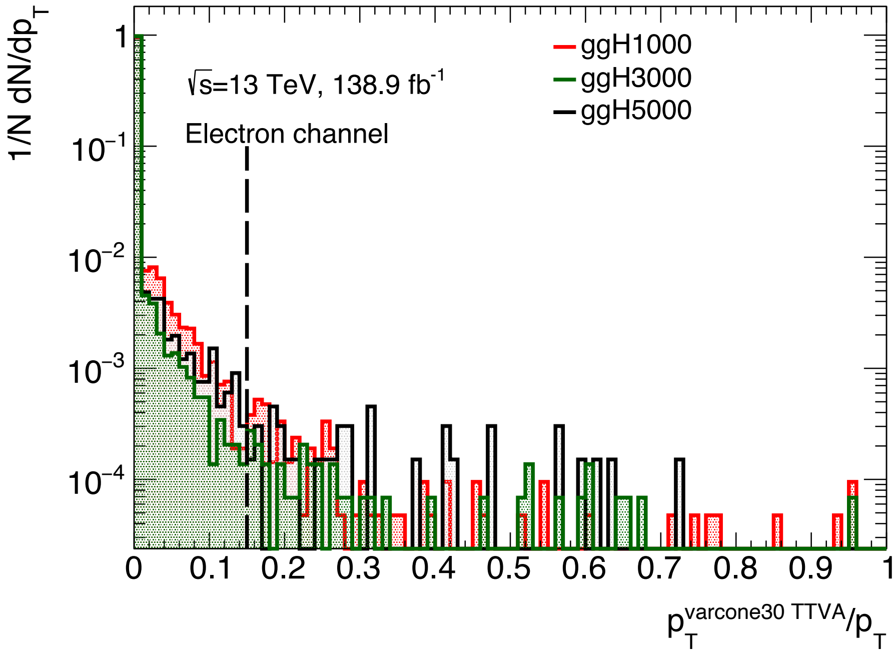


- large number of events is cut off after isolation is applied for higher mass samples (> 3 TeV)
- more events are now in the peak of the distribution after closeBy correction tool
- distributions of the two leptons are corrected to the resolved shape
  - <u>Decision is to not apply isolation on masses > 2.5 TeV</u>

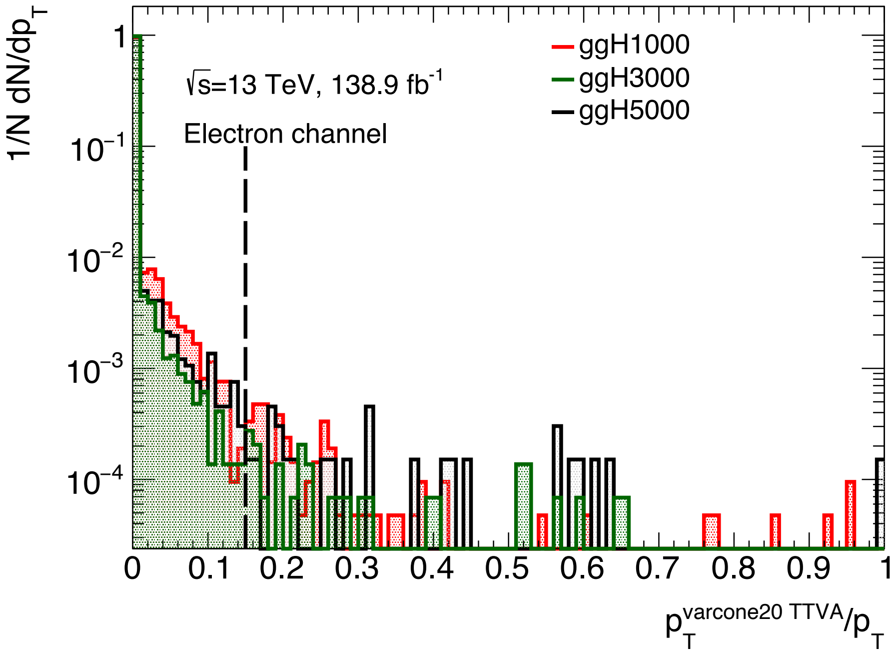
Electron signal efficiencies

Check of isolation variables entering FCLoose isolation:
ptvarcone20_TightTTVA_pt1000/pT

[No isolation closeBy correction applied]



[With isolation closeBy correction applied]



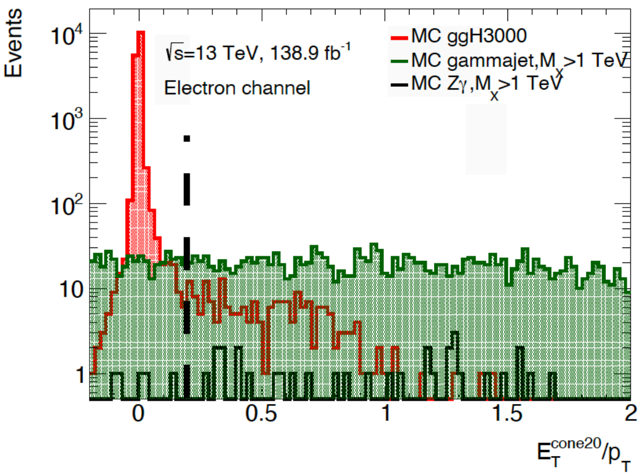
- Distribution for subleading lepton
- larger number of events is cut off for higher mass samples
- possibility that due to varied cone size *min(10 GeV/particle->pt(), 0.2)* at high mass (for 1 TeV electron the cone size is 0.1) second track is missed?
- Decision is to not apply isolation on masses > 2.5 TeV

Background studies

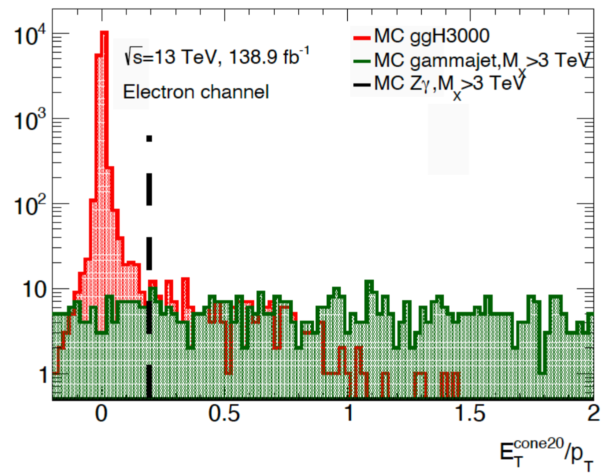
Extra set of MC background samples:

- MC16e Pythia8 gammajet (800000-800013)
- Distributions are shown only for leading lepton

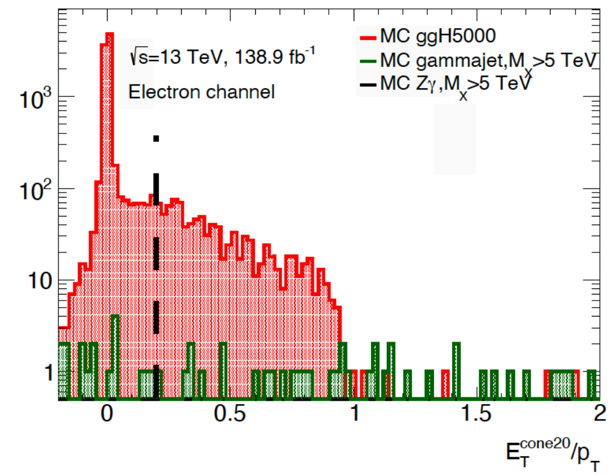
[Mx > 1 TeV]



[Mx > 3 TeV]



[Mx > 5 TeV]



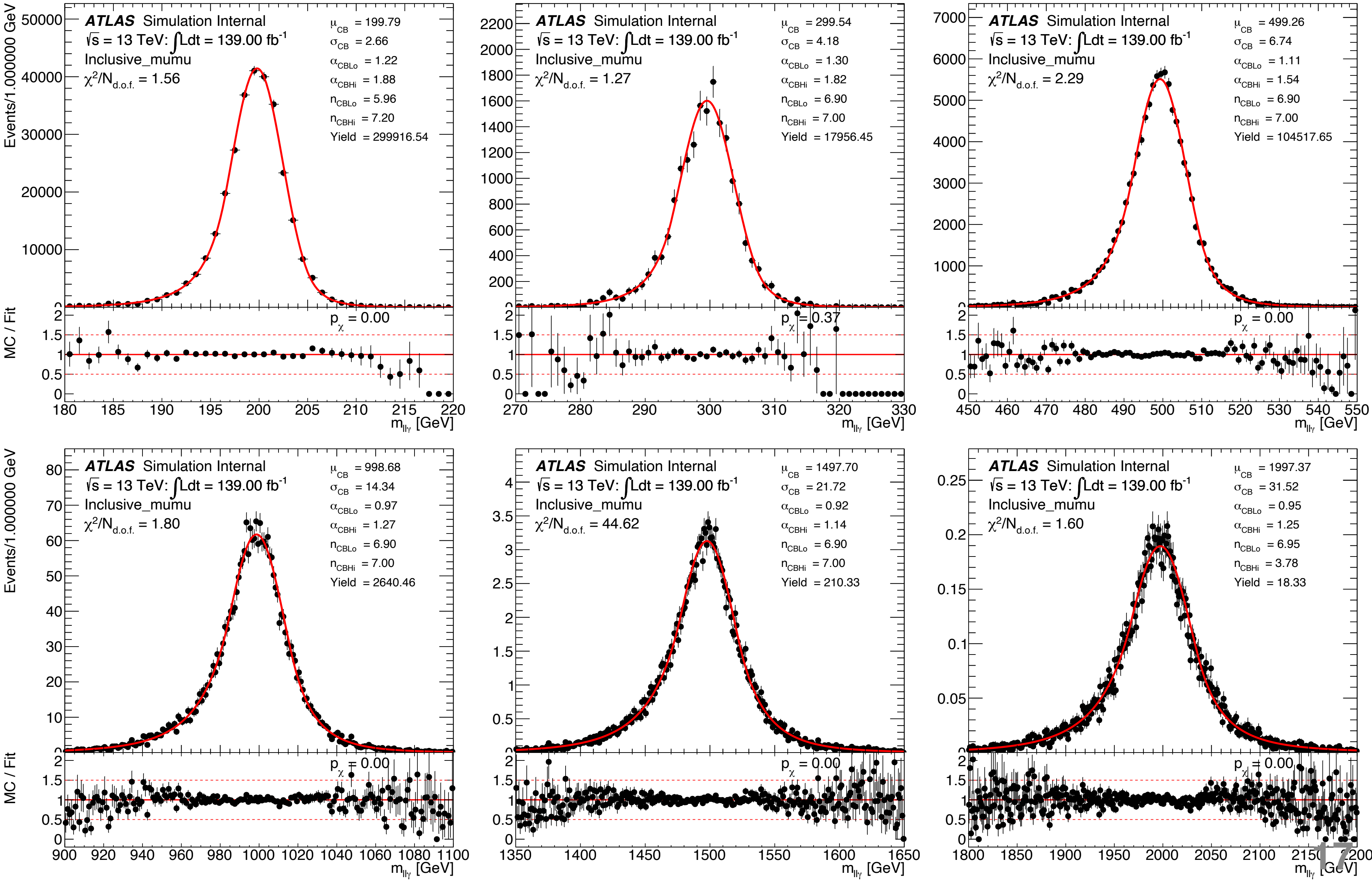
calorimeter & track isolation for subleading lepton is in backup

Should we treat this background for our studies as well?

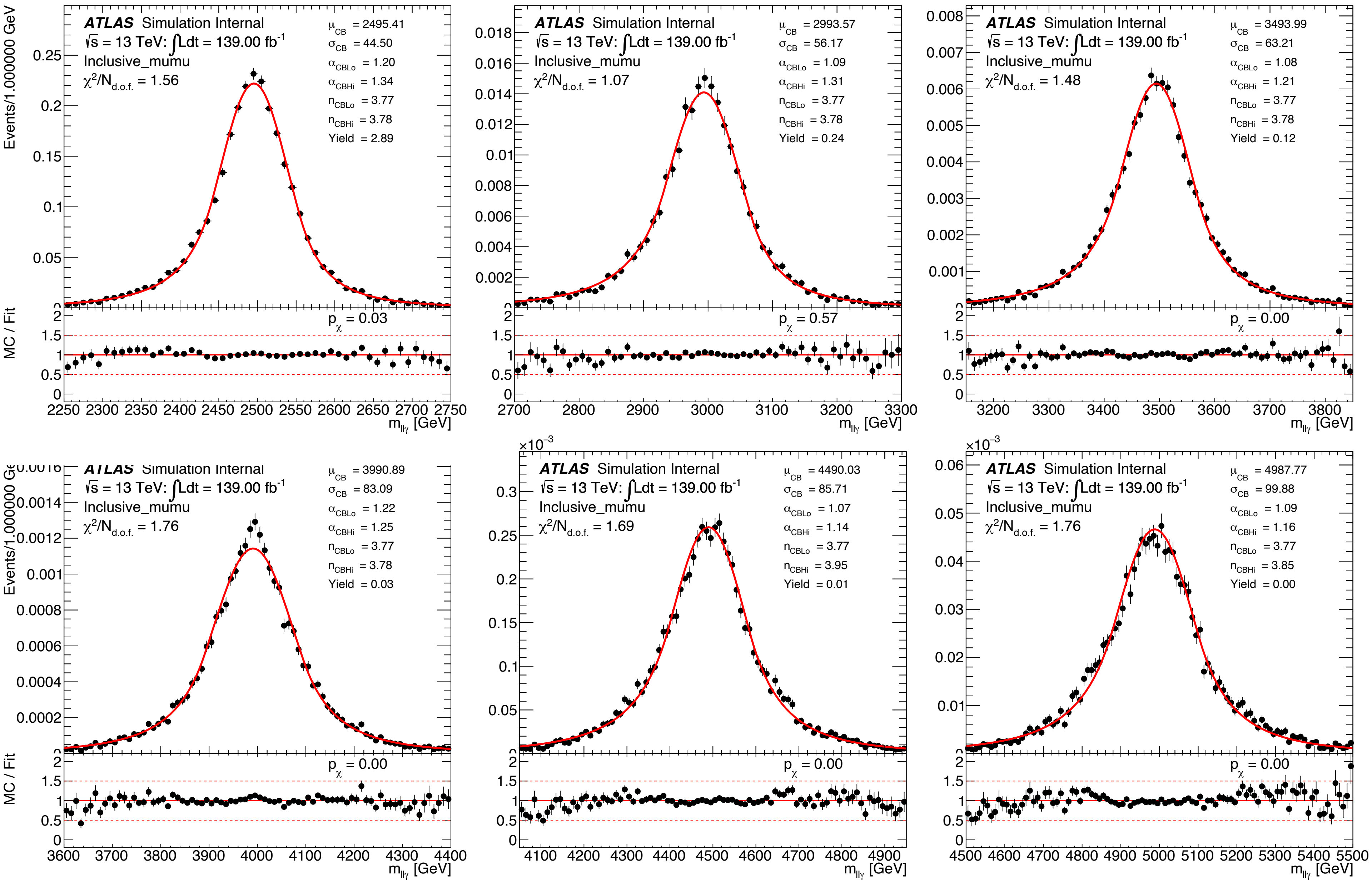
Negligible background for Mx > 3 TeV - we can drop lepton isolation for that region

Muon channel: Signal modelling

Trying to model signal shape with DSCB for the range from 140 GeV - 5 TeV

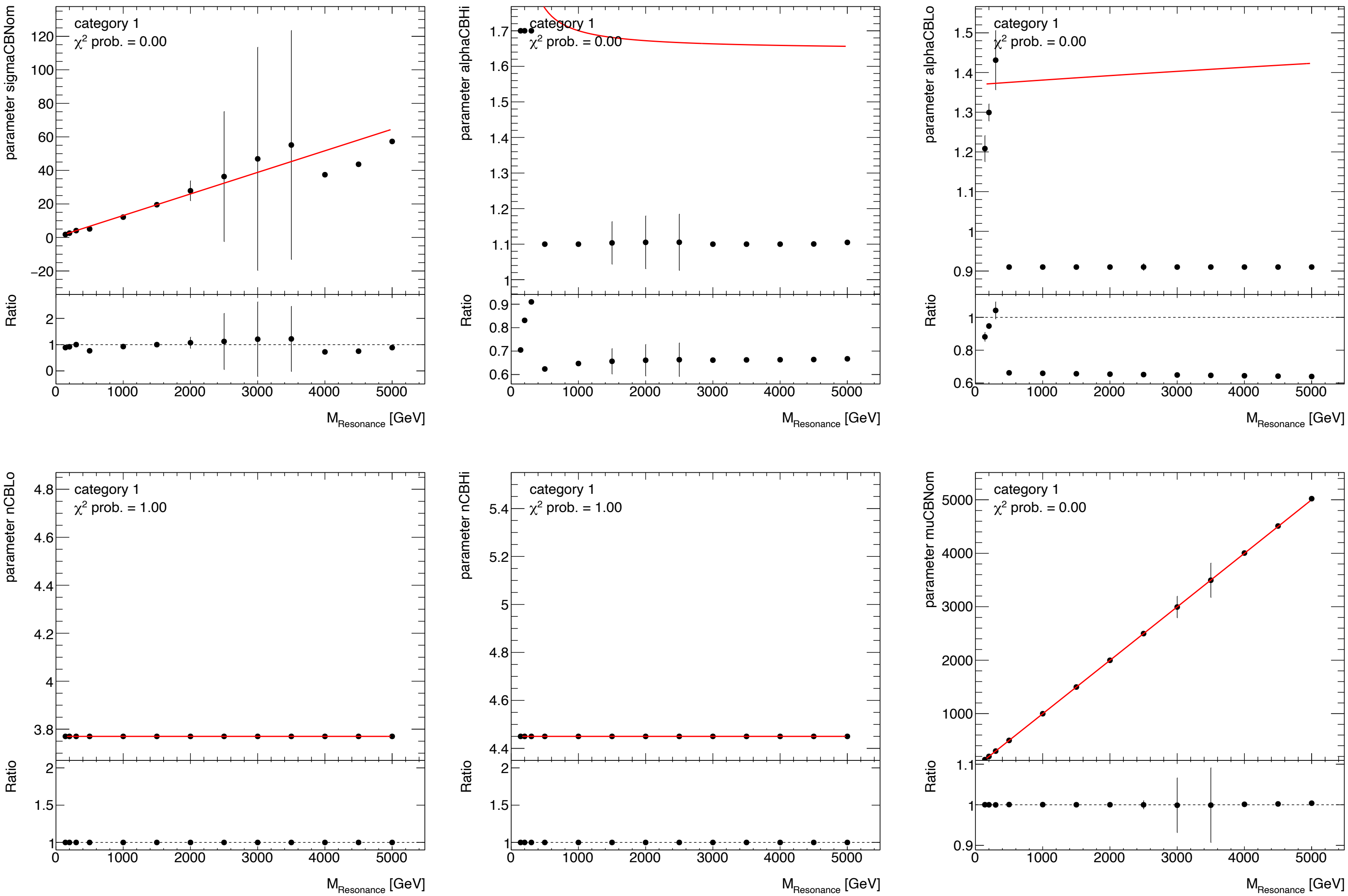


Muon channel: Signal modelling



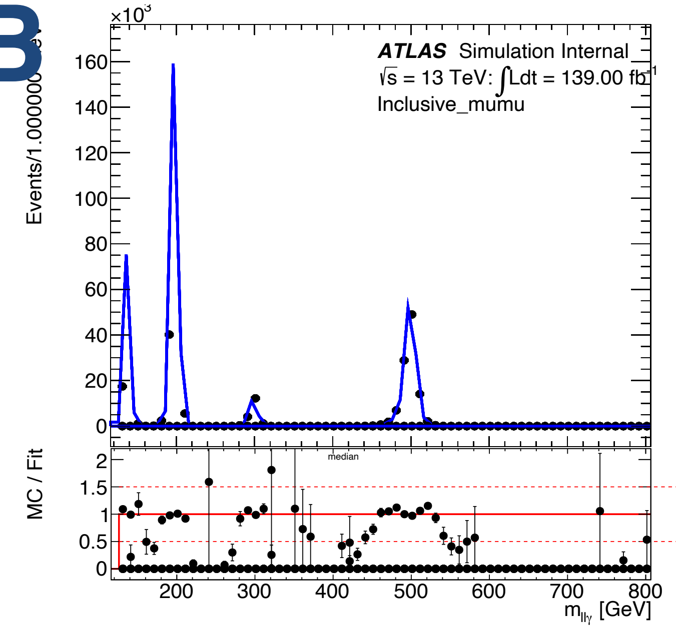
for Mx > 2.5 GeV Nbins are divided by 10 to have correct chi2 computation

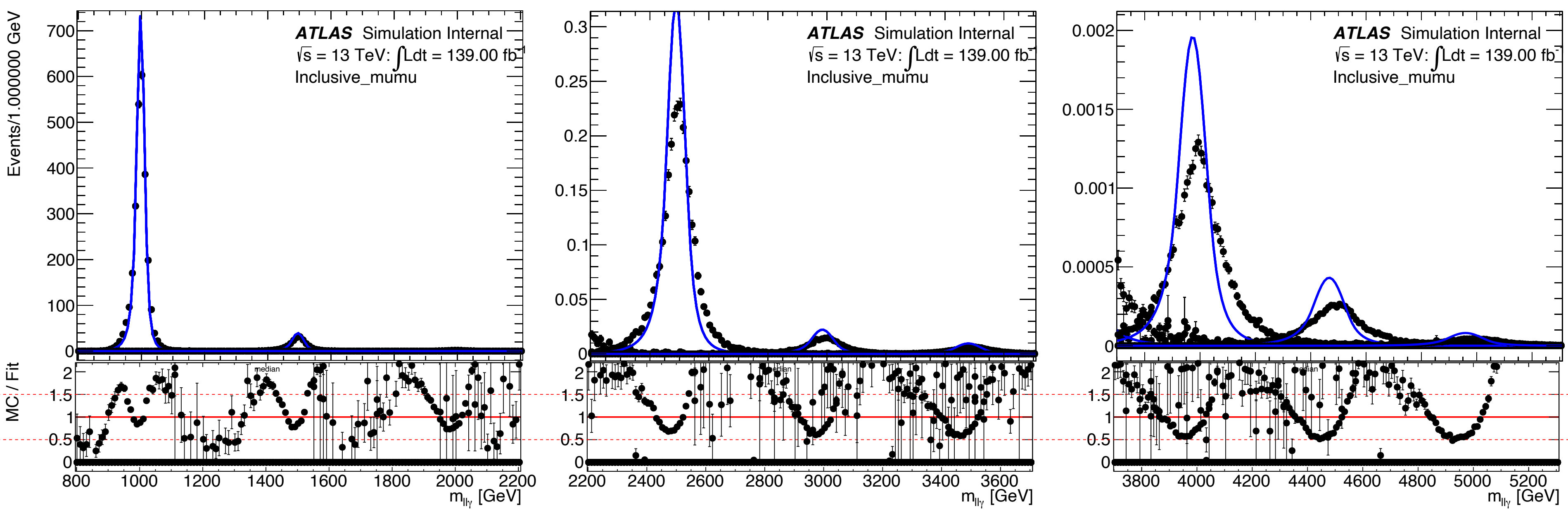
Signal modelling with DSCB



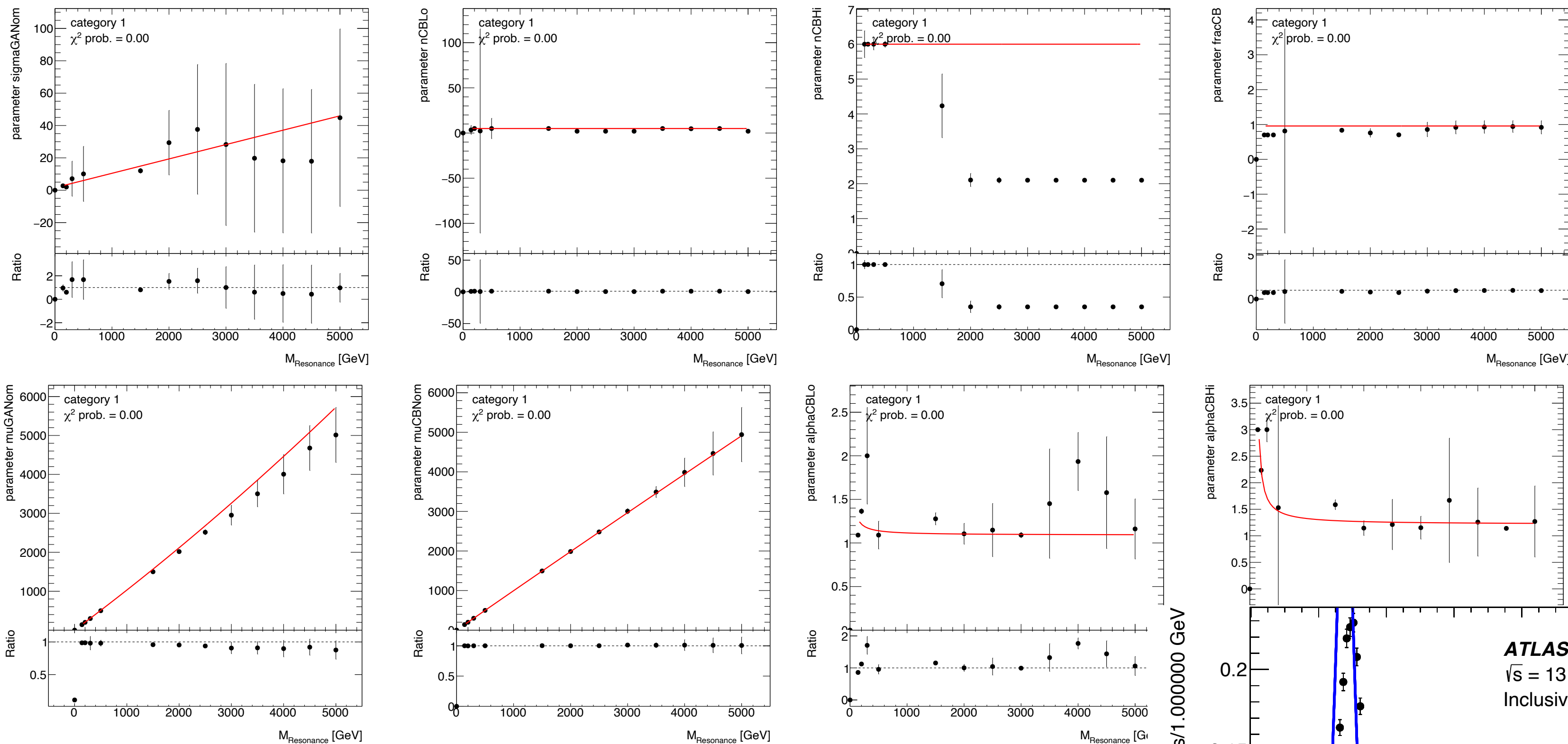
Signal modelling, DSCB

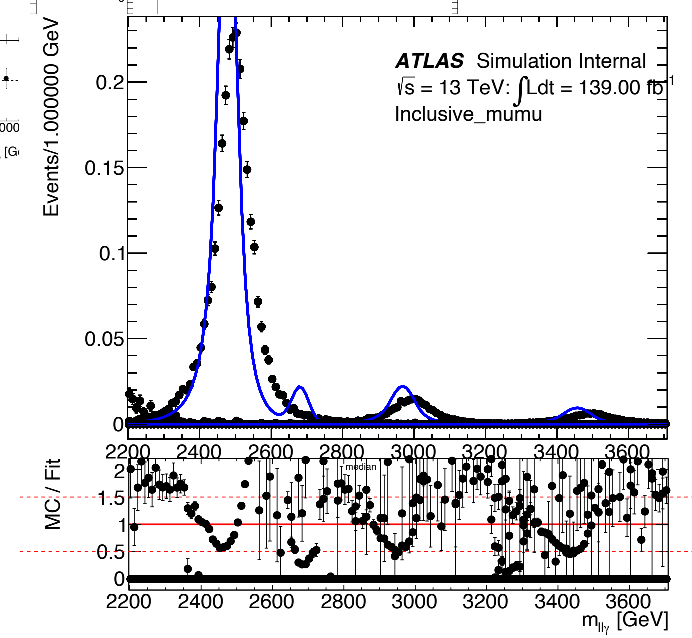
- parameters are taken the same as for individual fits
- simultaneous fit is done for the whole range
- higher mass fits need improvement - not very clear why there's such difference wrt individual fits





Signal modelling with DSCB + Gaus





- DSCB + Gaussian function is used
- sometimes second peak is introduced

Categorisation & Electron channel

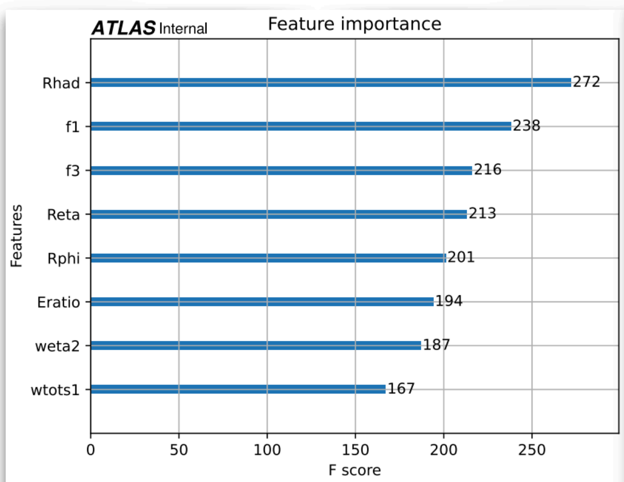
There's ongoing effort on categorising events in three categories:

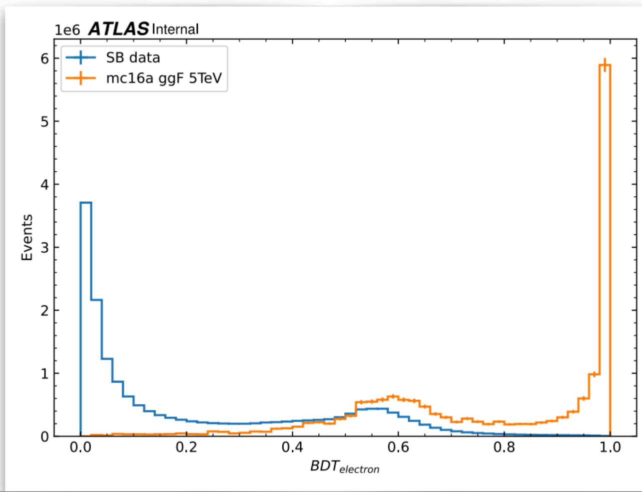
- muon channel, electron channel & merged channel

Electron channel:

- development of new electron identification menu

- **Input variables:** $R_{had}, f_3, R_\eta, w_{\eta 2}, R_\phi, w_{s1\ tot}, E_{ratio}, f_1$
- **Sig:** mc16a **ggF 5 TeV**
- **Bkg:** Side-band **data 2015-2016** (Non-Z bkg: Exclude 76.2 GeV < m_{ll} < 106.2 GeV events)





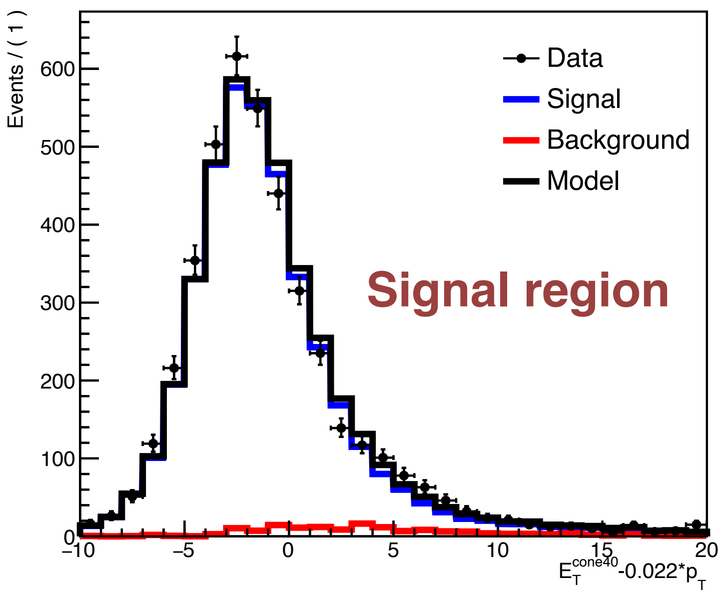
- **Next**
  - Scan the BDT to find the optimal cut point
  - **Criterial?** (High **sig eff** x high **bkg rejection fraction**?)

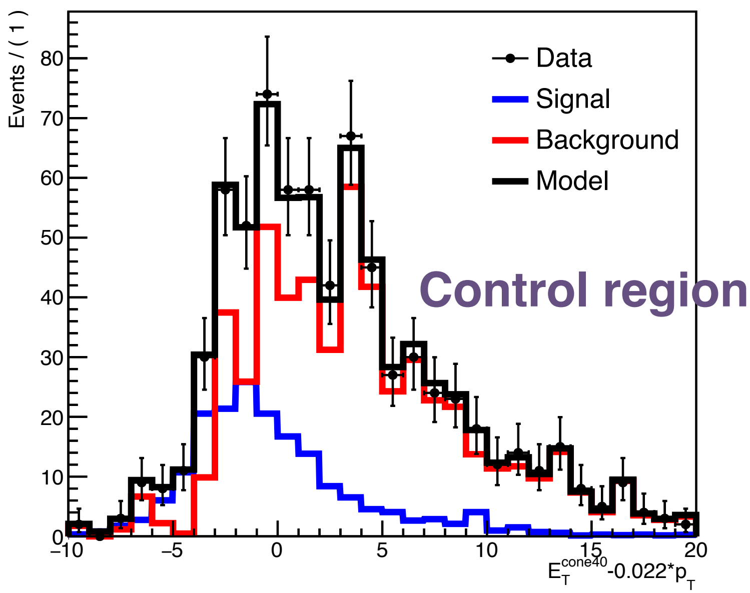
Backup slides

Background composition

Variation of nominal parameters: Loose’2/3/5 and topoetcone40
(instead of Loose’4 and topoetcone20)

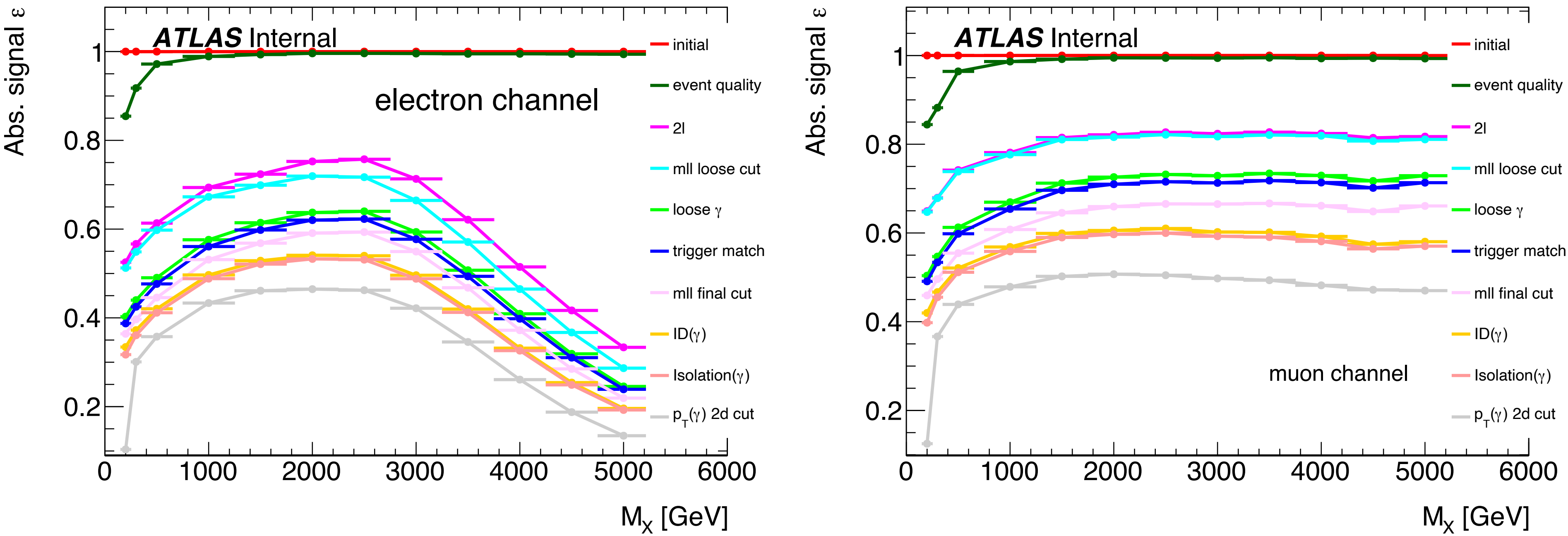
[topoetcone40]





Results are tested for rel.pT > 0.2. Similar results obtained for rel.pT > 0.3 with purity higher ~2%

Absolute signal efficiencies



Muon signal efficiencies