# Preliminary study on $4\ell$ analysis

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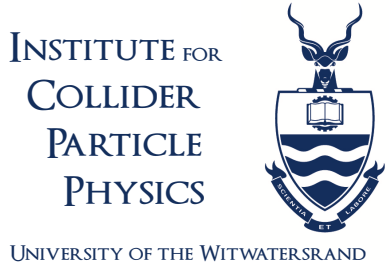


# Contents

# Signal and background samples



| Background samples | | | Signal sample | |
|---|---|---|---|---|
| Process | DSID | Final state | DSID | Final state |
| $qq \to ZZ$ | 364250, 364253 | $4\ell$, $3\ell\nu$ | 450663 | $4\ell$ with no b-jet |
| $gg \to ZZ$ | - | - | | |
| $t\bar{t}Z$ | 410156, 410157, 410218, 410219, 410220 | $t\bar{t}Z\nu\nu$, $t\bar{t}Zqq$, $t\bar{t}ee$, $t\bar{t}\mu\mu$, $t\bar{t}\tau\tau$ | | |
| $Z + jets$ | - | - | | |
| $t\bar{t}$ | 410472/410470 | | | |
| $VVV$ | 364242, 364243, 364244, 364245, 364246, 364247, 364248, 364249 | $WWW3\ell3\nu$, $WWZ4\ell2\nu$, $WWZ2\ell4\nu$, $WZZ5\ell\nu$, $WZZ3\ell3\nu$, $ZZZ6\ell0\nu$, $ZZZ4\ell2\nu$, $ZZZ2\ell4\nu$ | | |
| $WZ$ | - | - | | |

- $gg \to ZZ$, $Z + jets$ and $WZ$ are missing;
- So we didn't consider them in the preliminary study; and
- The results shown here are prduced with mc16a only.

# Cut-flow table
## Signal and background efficiencies



| | Non-Res | $qq \to ZZ$ | $t\bar{t}Z$ | $t\bar{t}$ | $VVV$ | Total background |
|---|---|---|---|---|---|---|
| $4\ell$ | 1757.97±61.79 | 1272.87±4.05 | 74.56±0.62 | 400.04±5.74 | 10.49±0.10 | 1757.96±10.52 |
| Total charge = 0 | 1654.91±59.87 | 1238.84±3.99 | 66.10±0.58 | 317.33±5.12 | 9.79±0.10 | 1632.06±9.79 |
| Trigger Match | 1640.60±59.08 | 1202.70±3.94 | 65.56±0.58 | 296.34±4.95 | 9.75±0.10 | 1574.36±9.57 |
| Iso FixedCutLoose | 1268.06±52.69 | 1023.85±3.70 | 51.04±0.50 | 11.89±1.00 | 8.95±0.10 | 1095.73±5.29 |
| $m_{\ell^+\ell^-}$(SFOS) $>$ 4 GeV | 1182.34±50.83 | 846.44±3.44 | 46.97±0.48 | 11.21±0.97 | 8.18±0.09 | 912.80±4.98 |
| b-jet-veto | 1047.90±45.98 | 806.56±3.40 | 5.79±0.16 | 6.66±0.74 | 7.54±0.09 | 826.55±4.39 |
| Efficiency | 60% | 63% | 8% | 2% | 728% | 47% |

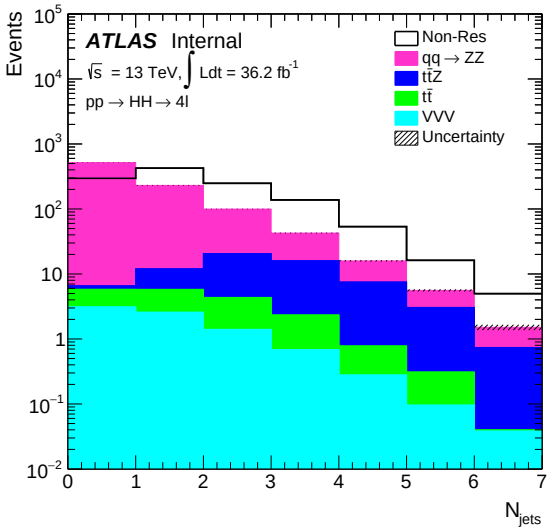
Table: The expected yields for non-resonant di-Higgs boson signal, and the total background calculated from the state-of-the-art MC simulation with an integrated luminosity of 36.2 fb$^{-1}$. The uncertainties included on the table are statistical uncertainty. The signal is normalised to the total number of background.

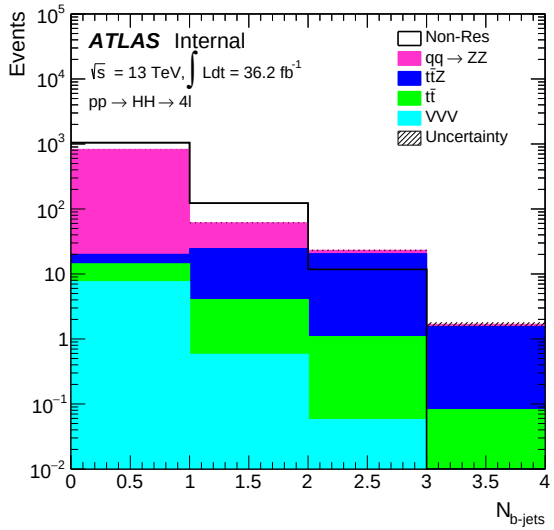
- No lepton identifications, and $p_{\mathrm{T}}$-requirement are applied;
- Soft requirements on lepton identification and $p_{\mathrm{T}}$ are already implemented on the production level, no?
- Events with $4\ell$, total charge equal zero, and $\eta$ cut are selected;
- For electrons: $|\eta^e| < 2.47$ excluding $1.37 < |\eta^e| < 1.52$; and
- Muons: $|\eta^e| < 2.5$.

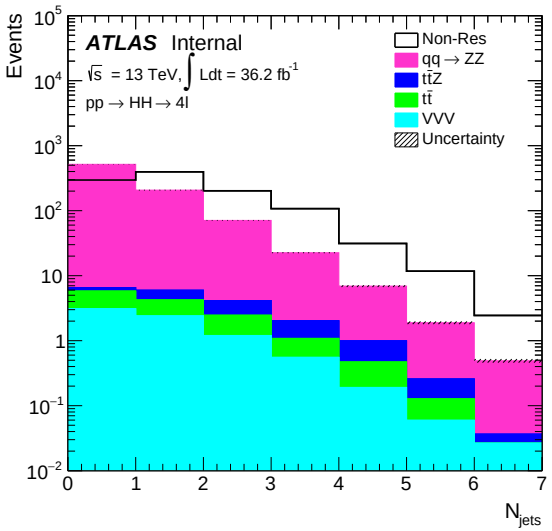
# Kinematic distributions

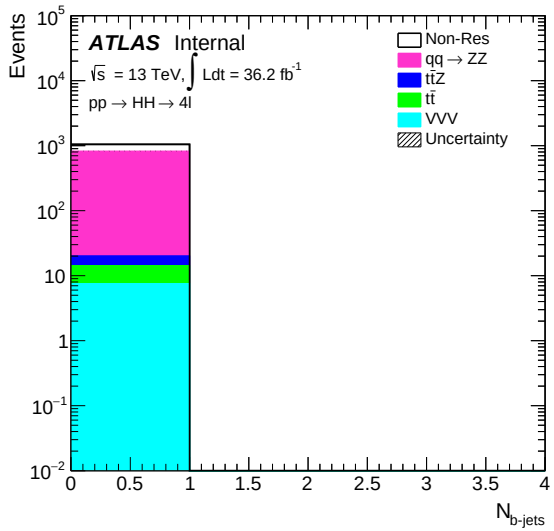
## Number of the jet multiplicity and the b-tagged as jet





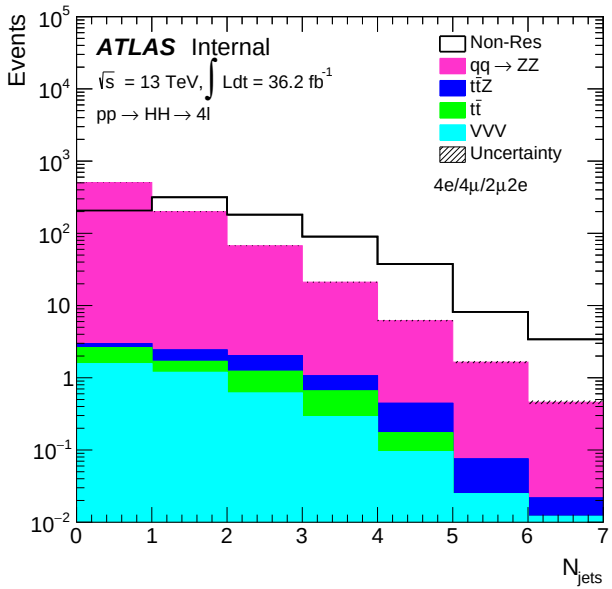



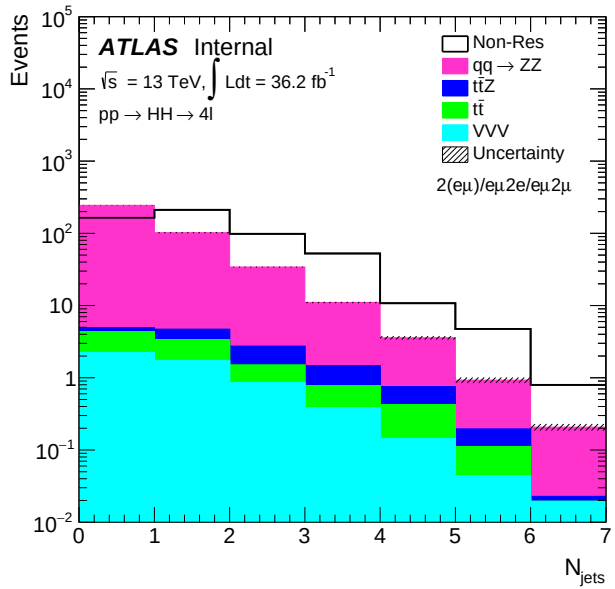



# Events categorisation



- Events categorized depending on the SFOS lepton pairs;
- First category: $4e/4\mu/2\mu2e \Rightarrow$ 2-SFOS;
- Second category: $2(e\mu)/e\mu2e/e\mu2\mu \Rightarrow$ 0/1-SFOS;
- Using only the pre-selection we compare kinematics distributions.




- The motivation: Because of the difference in background composition and statistics for each category.

# Events categorisation

## Cut-flow for the two categories



| | Non-Res | $qq \to ZZ$ | $t\bar{t}Z$ | $t\bar{t}$ | $VVV$ | Total background |
|---|---|---|---|---|---|---|
| $4e/4\mu/2\mu 2e$ | 1479.56±72.56 | 1237.97±3.98 | 37.22±0.44 | 198.66±4.04 | 5.71±0.07 | 1479.56±8.53 |
| Total charge = 0 | 1397.78±70.58 | 1212.57±3.93 | 33.08±0.41 | 158.59±3.62 | 5.38±0.07 | 1409.61±8.04 |
| Trigger Match | 1396.23±69.87 | 1177.63±3.89 | 32.81±0.41 | 147.58±3.49 | 5.35±0.07 | 1363.37±7.87 |
| Iso FixedCutLoose | 1073.33±62.73 | 1008.64±3.67 | 25.80±0.36 | 5.12±0.64 | 4.89±0.07 | 1044.44±4.73 |
| $m_{\ell^+\ell^-}$(SFOS) $>$ 4 GeV | 942.52±59.05 | 831.22±3.41 | 21.73±0.33 | 4.45±0.60 | 4.11±0.06 | 861.51±4.39 |
| b-jet-veto | 843.16±51.92 | 792.22±3.37 | 2.64±0.11 | 2.61±0.45 | 3.78±0.06 | 801.25±3.99 |
| Efficiency | 60% | 64% | 7% | 1% | 66% | 54% |

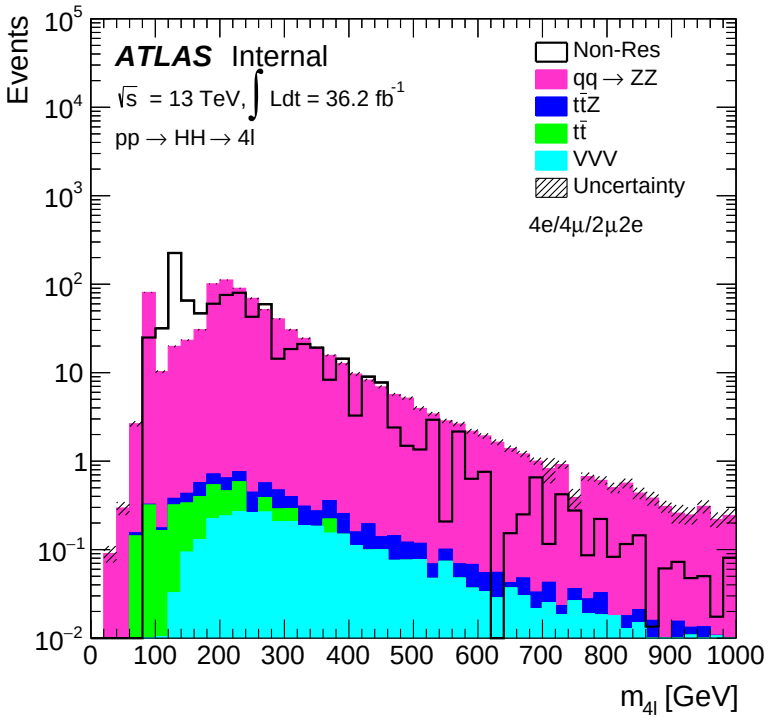
| | Non-Res | $qq \to ZZ$ | $t\bar{t}Z$ | $t\bar{t}$ | $VVV$ | Total background |
|---|---|---|---|---|---|---|
| $2(e\mu)/e\mu 2e/e\mu 2\mu$ | 847.07±36.21 | 497.38±2.78 | 49.56±0.51 | 293.24±4.92 | 6.90±0.08 | 847.07±8.29 |
| Total charge = 0 | 800.34±35.20 | 478.09±2.72 | 43.92±0.47 | 230.33±4.36 | 6.39±0.08 | 758.73±7.64 |
| Trigger Match | 791.61±34.61 | 468.59±2.70 | 43.61±0.47 | 215.61±4.22 | 6.38±0.08 | 734.19±7.47 |
| Iso FixedCutLoose | 598.80±30.79 | 400.05±2.56 | 33.90±0.41 | 8.54±0.85 | 5.87±0.08 | 448.35±3.90 |
| $m_{\ell^+\ell^-}$(SFOS) $>$ 4 GeV | 598.80±30.79 | 400.05±2.56 | 33.90±0.41 | 8.54±0.85 | 5.87±0.08 | 448.35±3.90 |
| b-jet-veto | 542.94±27.57 | 381.50±2.54 | 4.16±0.14 | 5.18±0.66 | 5.40±0.07 | 396.25±3.41 |
| Efficiency | 64% | 77% | 8% | 2% | 78% | 47% |

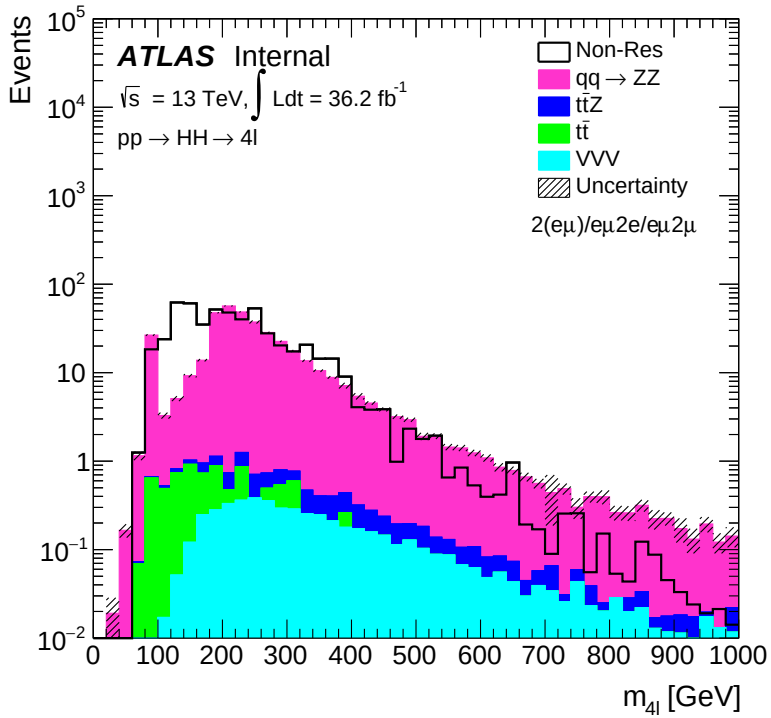
Table: The expected yields for non-resonant di-Higgs boson signal, and the total background calculated from the state-of-the-art MC simulation with an integrated luminosity of 36.2 fb$^{-1}$. The uncertainties included on the table are statistical uncertainty. For 2-SFOS (top) and 0/1-SFOS (bottom). The signal is normalised to the total number of background for each category.

# Events categorisation

## Kinematic distributions of the invariant mass of the $4\ell$





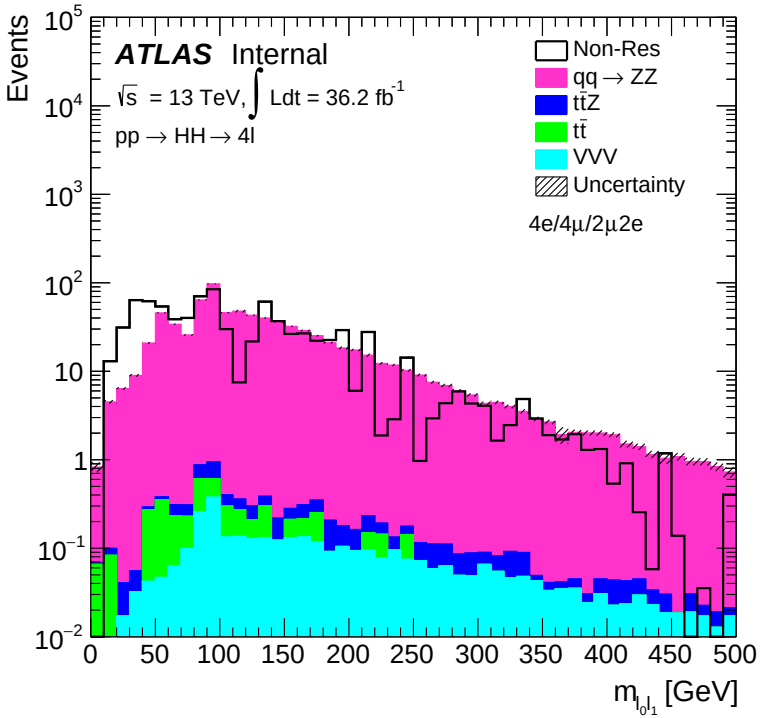



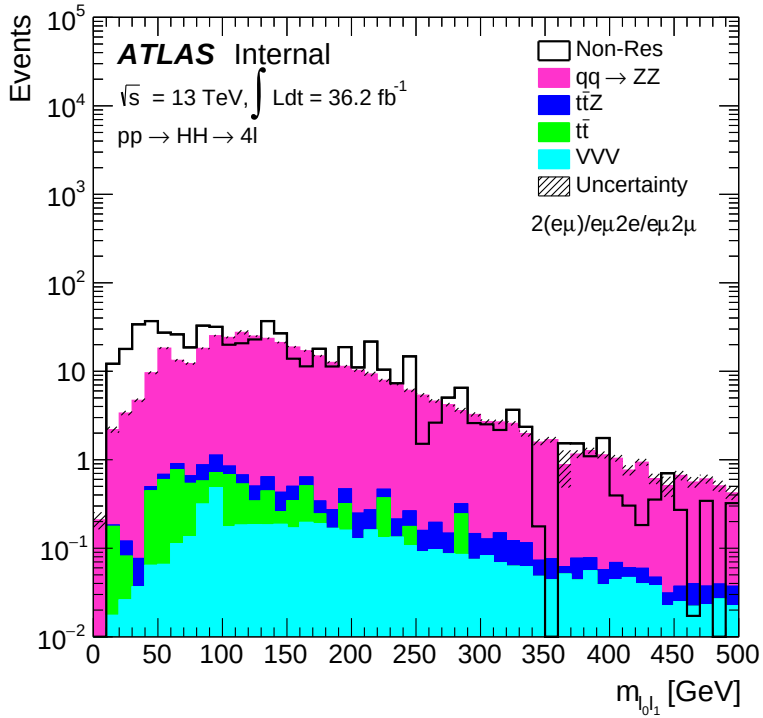

- Define two regions $m_{4\ell}[110 - 150]$ GeV and $m_{4\ell} > 150$ GeV.
- The two peaks of the $qq \to ZZ$: One form on-shell $Z$ boson and the other one from the off-shell $Z$ boson

# Events categorisation

## Kinematic distributions of the invariant mass of the first pairs





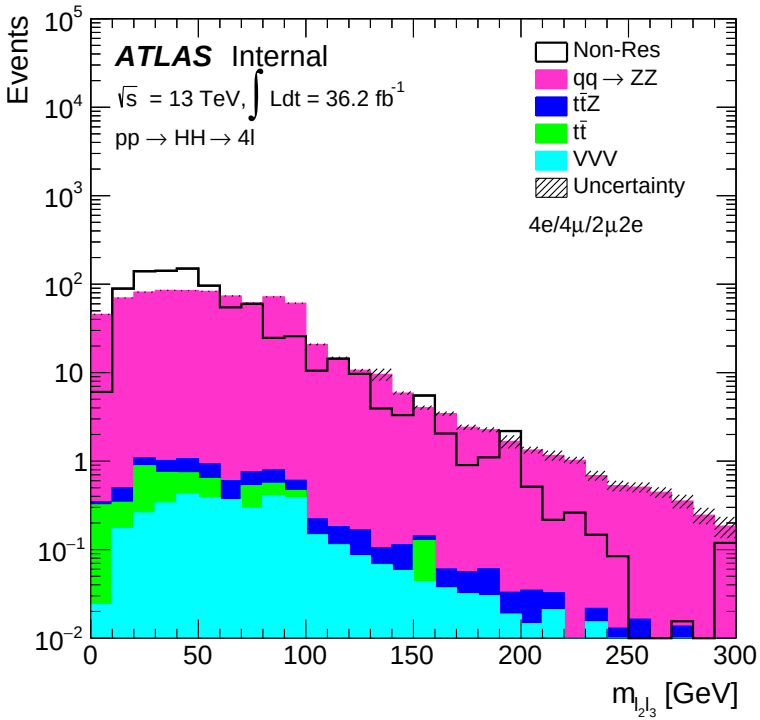



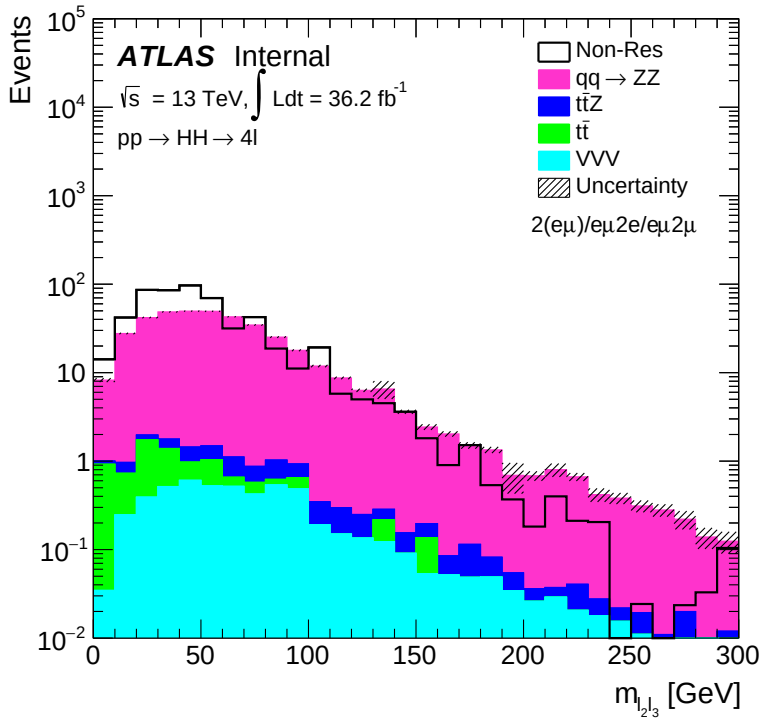

- The remnant SFOS pairs after selecting the leptons with mass closest to the Z-boson peak.

# Events categorisation

## Kinematic distributions of the invariant mass of the second pairs






- SFOS pairs with invariant mass closest to the Z-boson peak.

# Summary



- What we showed here was a very preliminary study for the $4\ell$ analysis;
- The expected yields for the signal vs background processes are shown;
- For the current cuts— 60% of the signal and 47% of the background survived in the inclusive channel;
- The b-veto does a good job to suppress $t\bar{t}Z$ events;
- The $qq \to ZZ$ background is the dominant background, $gg \to ZZ$? and

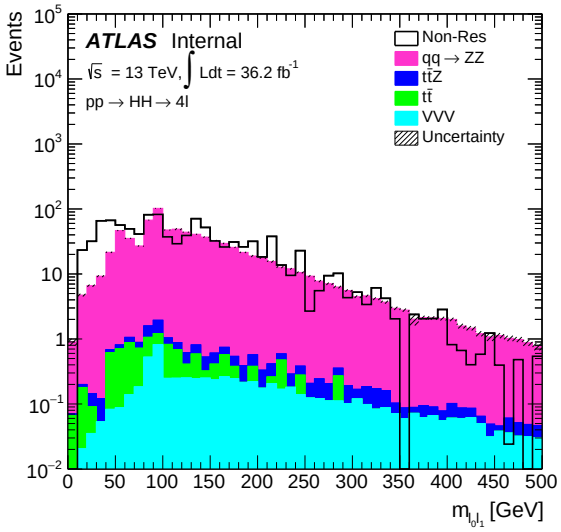
## Next plans . . .

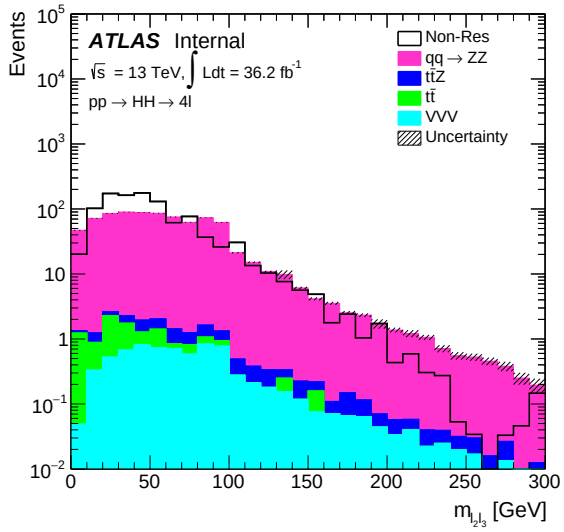
- Try to get the other missing background processes; and
- See if we can use kinematics such as $m_{l_0 l_1}$, $m_{l_0 l_1}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, . . .
- To optimization the signal and suppress background events.

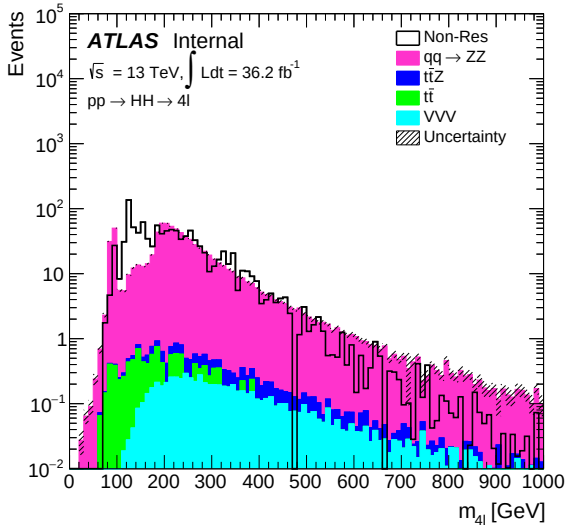
# Thank you!

# Additional slides
## Inclusive channel



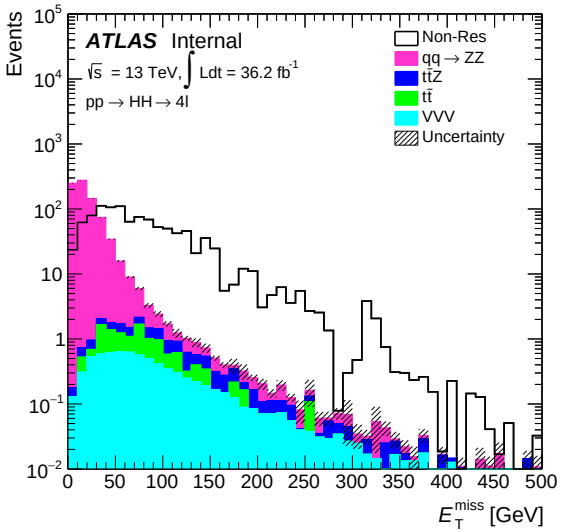


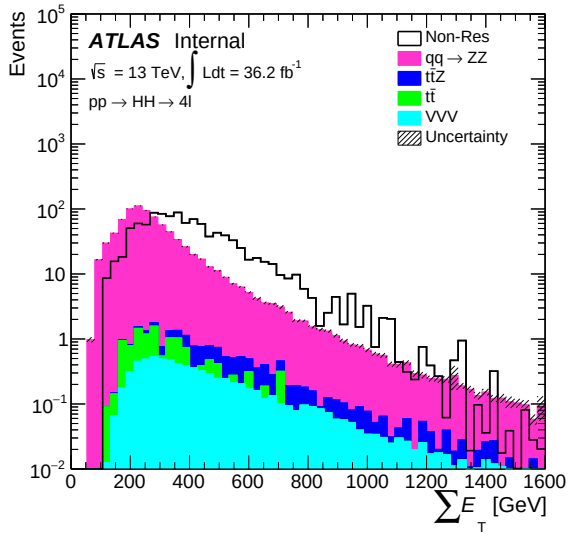



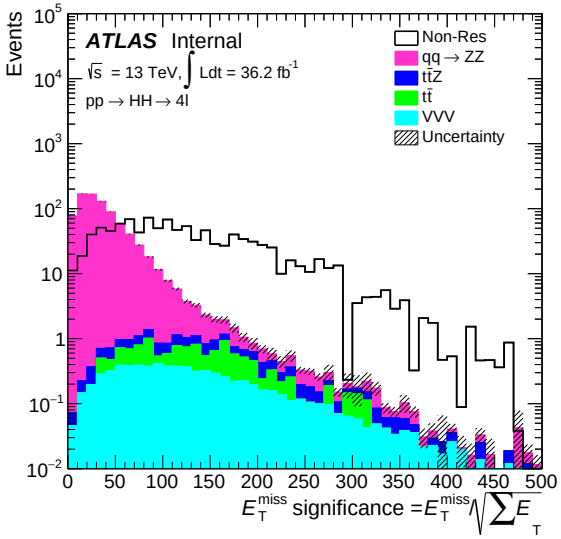



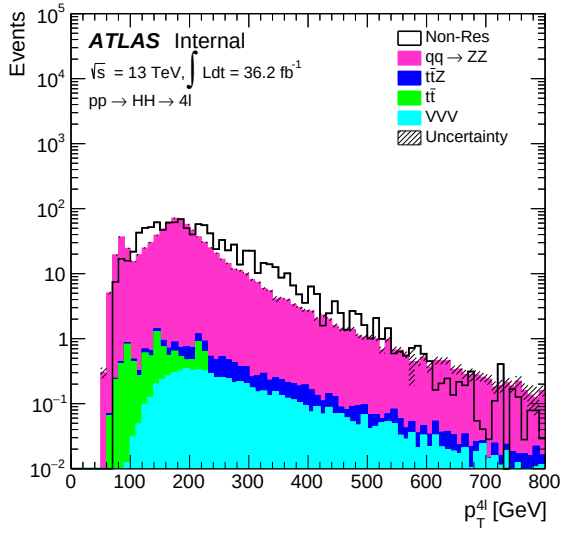
# Additional slides
## Inclusive channel





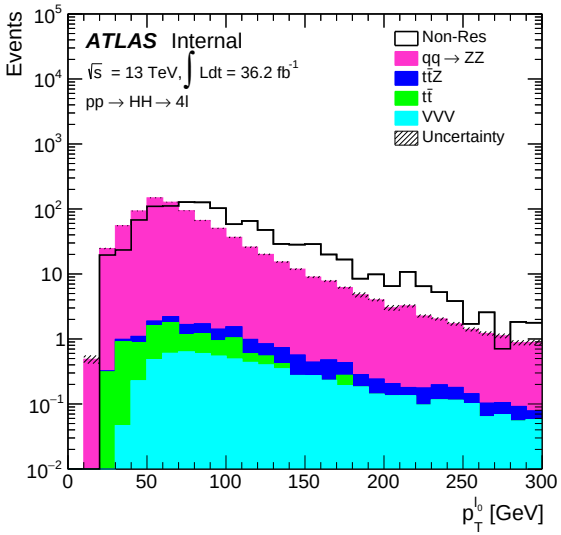



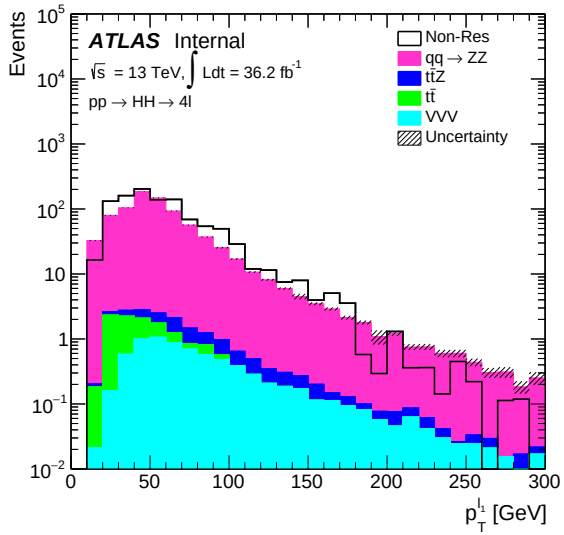



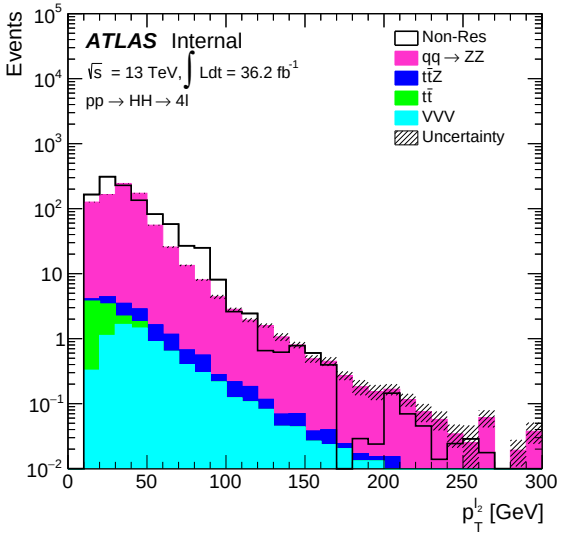



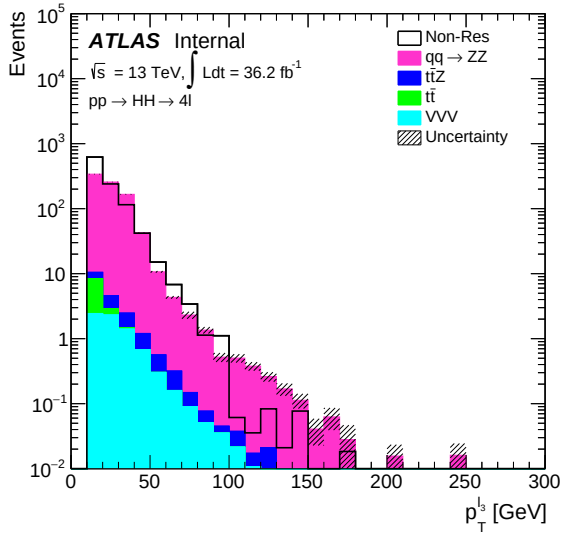
# Additional slides
## Inclusive channel





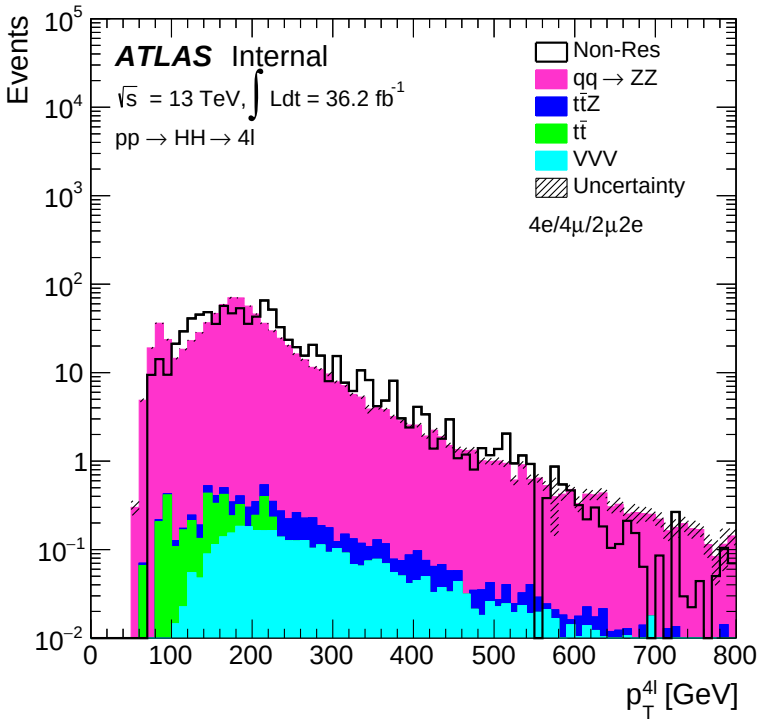



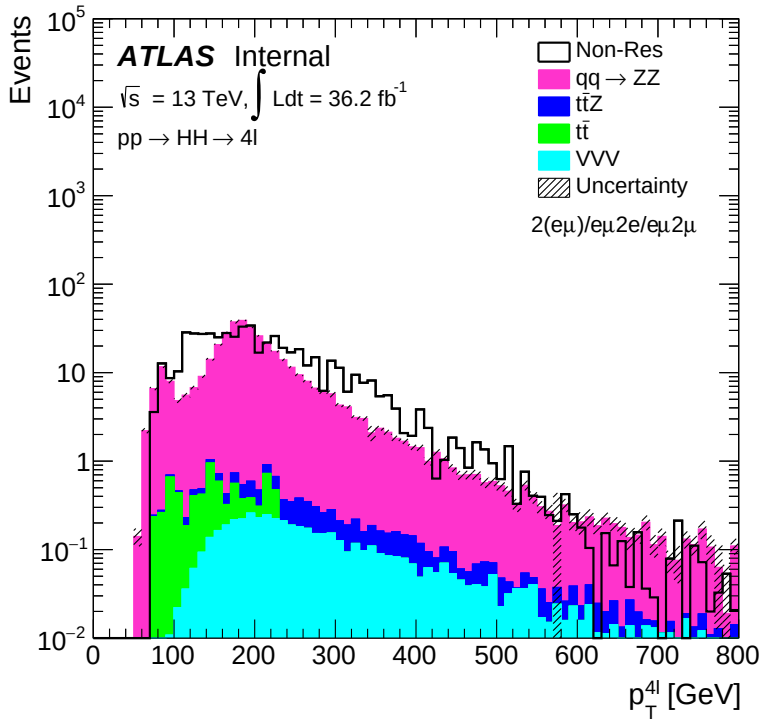



# Additional slides





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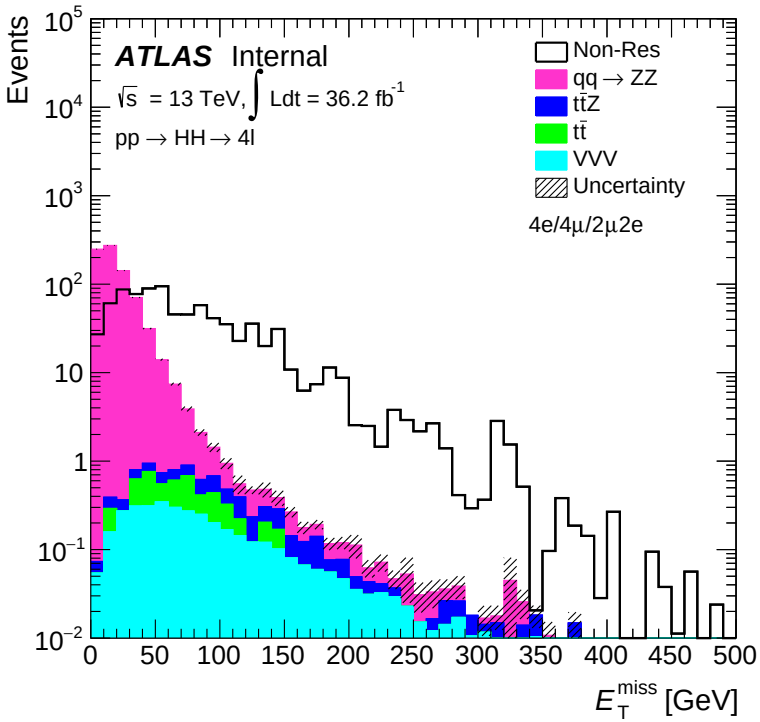


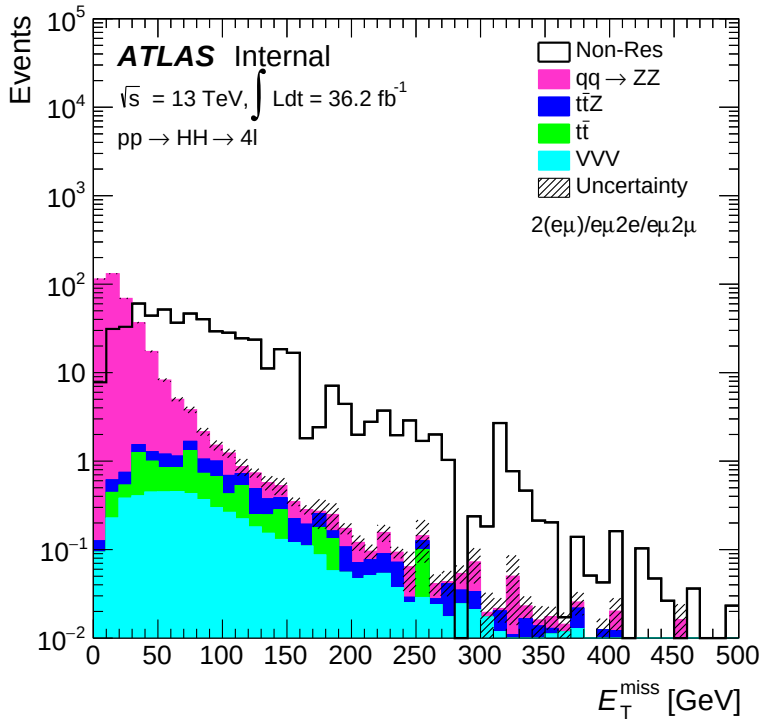

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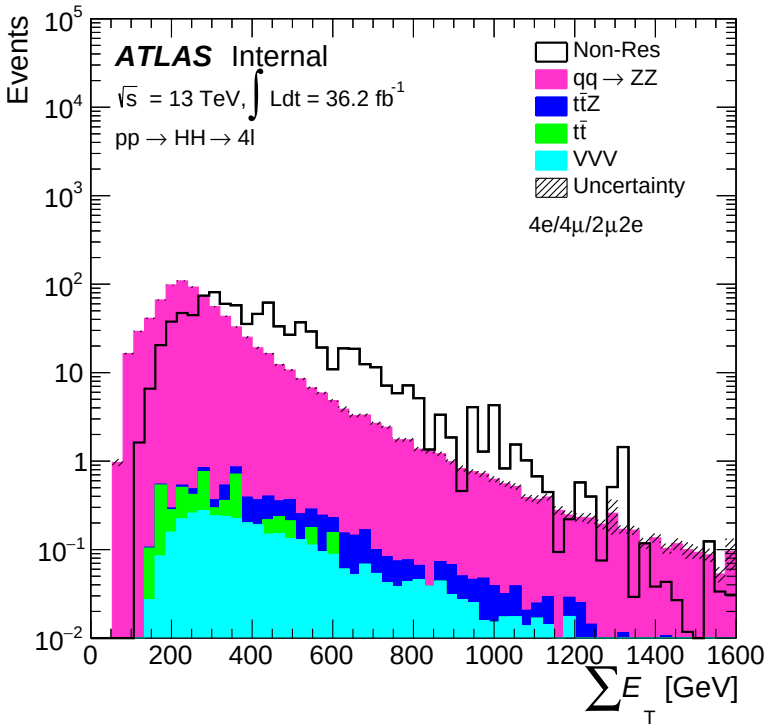


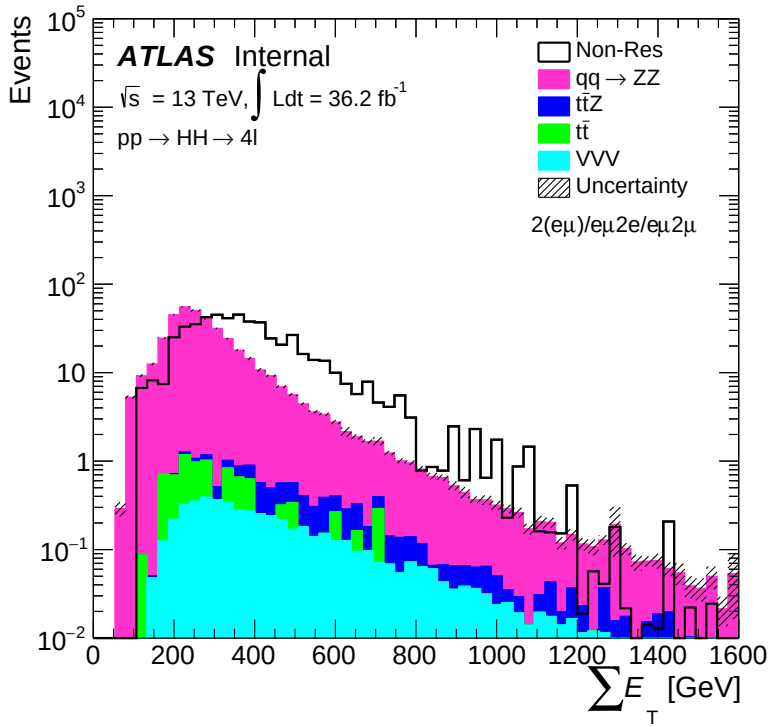

# Additional slides