

Performance of the PtmissPlusLeptonsFilter

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developed for the invisible Higgs analysis in
HZ channel with $Z \rightarrow \ell\ell$

$Z^0 H^0 \rightarrow l^+ l^-$ invisible initial analysis strategy (Fortran-based ATLFAST, ATL-PHYS-PUB-2005-011)

Trigger: 1 or 2 prompt leptons

Preselection:

- large missing p_T
- 2 leptons of opposite sign and same flavour
- loose cut on Z mass

Final selection:

Use 8 discriminative variables in a likelihood analysis to extract signal



Invisible Higgs decay in HZ channel all MC samples generated with Pythia

Signal:

- $H \rightarrow \chi\chi$ and $Z \rightarrow ll$:
 - Large missing p_T
 - Two prompt leptons forming a Z

Main backgrounds:

- $ZZ \rightarrow ll\nu\nu$
- Z inclusive with $Z \rightarrow ll$ and jets lost in the beam pipe
- $t\bar{t} \rightarrow b l \nu b l \nu$ with bb jets lost in the beam pipe
- $WW \rightarrow l\nu l\nu$
- $WZ \rightarrow ll l\nu$ with one lepton lost in the beam pipe
- ~~$ZZ \rightarrow ll\tau\tau$~~

Most background were rejected at preselection level in ATL-PHYS-PUB-2005-011

| channel | $Z^0 H^0 \rightarrow$ $l^+ l^-$ invisible | $Z^0 Z^0 \rightarrow$ $l^+ l^- \nu \nu$ | Z^0 incl. $\rightarrow l^+ l^-$ | $t\bar{t} \rightarrow$ $b l^+ \nu \quad b l^- \nu$ |
|----------------------------------|--|--|--------------------------------------|---|
| $\sigma * BR$ (pb) | 0.043 | 0.300 | 2804 | 125.1 |
| # events @10 fb ⁻¹ | 426 | 3000 | 28.04 M | 1.251 M |
| preselection | 62.0 | 183.3 | 14.6 | 170.4 |
| \mathcal{L} selection | 54.6 | 151.8 | 3.3 | 6.2 |

Create a filter to emulate preselection cuts:

ptmiss cut, 2 leptons reconstructing a Z with loose mass cut

Missing p_T in reconstruction code

Missing $p_T = - \Sigma$ (visible transverse energies)

- Isolated photons, electrons and muons
- Jets, b-jets and c-jets
- Clusters not accepted as jets
- Non-isolated muons not added to a jet
- Transverse energies in cells not used elsewhere

Missing p_T at generator level

Vectorial sum of transverse momenta of

- Invisible particles (stable Higgs, neutrinos)
- Lost particles: those falling outside the detector acceptance region
 - Calorimeter acceptance: $|\eta| < 5.0$

P_{Tmiss} calculated differently in filter and full reconstruction chain

So we are not comparing the same object

Second handle in filter: leptons

- Two leptons within the tracker acceptance region
- One or both leptons must pass the lepton trigger requirements
- Two leptons of same flavor but opposite sign
- The reconstructed mass must be close to m_Z

Filter versus preselection cuts

Filter cuts: looser cuts

- 2 leptons with $\eta < 2.7$
- Trigger requirements:
 - 1 e with $p_T > 18 \text{ GeV}$ or
 - 2 e with $p_T > 23 \text{ GeV}$ or
 - 1 μ with $p_T > 8 \text{ GeV}$ or
 - 2 μ with $p_T > 13 \text{ GeV}$
- Missing $p_T > 50 \text{ GeV}$
- $m_Z = 55 \text{ GeV}$

Preselection cuts

- 2 leptons with $\eta < 2.5$
- Trigger requirements:
 - 1 e with $p_T > 20 \text{ GeV}$ or
 - 2 e with $p_T > 25 \text{ GeV}$ or
 - 1 μ with $p_T > 10 \text{ GeV}$ or
 - 2 μ with $p_T > 15 \text{ GeV}$
- Missing $p_T > 90 \text{ GeV}$
- $m_Z = 50 \text{ GeV}$

Comparison with ATLFAST 10.5.0

| | |
|---|--|
| Filter $p_{Tmiss} > 50 \text{ GeV}$ $ \eta _{lost} > 5.0, p_{Tlost} > 5 \text{ GeV}$ $ \eta _{lepton} < 2.7, p_{Tlepton} > 5 \text{ GeV}$ | ATLFAST AOD $p_{Tmiss} > 90 \text{ GeV}$ and trigger $ \eta _{lost} > 5.0$ $ \eta _{lepton} < 2.5$ |
|---|--|

| | $HZ \rightarrow \chi\chi l^+ l^-$ Weight = 0.0043 | | $ZZ \rightarrow l^+ l^- \nu\nu$ Weight = 0.0300 | | Z incl. Weight = 280.4 | | $t\bar{t}$ Weight = 0.0126 | |
|------------------|--|-------|--|--------|---------------------------|--------|-------------------------------|--------|
| | Filter | AOD | Filter | AOD | Filter | AOD | Filter | AOD |
| Generated | 99034 | 99034 | 100000 | 100000 | 100000 | 100000 | 475000 | 475000 |
| Selected | 56424 | 23455 | 35720 | 10506 | 1 | 0 | 103218 | 3018 |
| Unmatched | 32969 | 0 | 25214 | 2 | 1 | 0 | 100202 | 2 |

Conclusion: no significant event loss at the filter level w.r.t. ATLFAST with 10.5.0 or 11.0.41 (+ m_Z cut)

Cross-check: no statistical difference between filtered and unfiltered events at AOD level

| | unfiltered HZ events | | filtered HZ events | |
|------------------------------------|----------------------|---------|--------------------|---------|
| Events generated in 11.0.41 | 20000 | 100.00% | 20000 | 100.00% |
| Events after filter | 20000 | 100.00% | 10226 | 51.13% |
| Events after p _{miss} cut | 12668 | 63.34% | 6740 | 33.70% |
| Events after # leptons cut: | 12668 | 63.34% | 6740 | 33.70% |
| Events after lepton η cut: | 12667 | 63.34% | 6739 | 33.70% |
| Events after trigger: | 4770 | 23.85% | 4772 | 23.86% |
| Events after lepton id cut: | 4765 | 23.83% | 4768 | 23.84% |
| Events after m_Z cut: | 4663 | 23.32% | 4664 | 23.32% |
| Events after b-tag cut: | 4520 | 22.60% | 4512 | 22.56% |

Small difference due to random smearing in ATLFAST

CPU time savings to simulate 100 fb^{-1} of data

| | $Z^0 H^0 \rightarrow$ $\chi\chi \text{ l}^+\text{l}^-$ | $Z^0 Z^0 \rightarrow$ $\text{l}^+\text{l}^- \nu\nu$ | $Z^0 \text{ incl.}$ $\rightarrow \text{l}^+\text{l}^-$ | $\text{t}\bar{\text{t}} \rightarrow$ $\text{bl}^+\nu \text{ bl}^-\nu$ |
|---------------------------|---|--|---|--|
| $\sigma * \text{BR (pb)}$ | 0.043 | 0.300 | 2804 | 125.1 |
| unfiltered | 4260 | 30000 | 280.4 M | 12.5 M |
| filtered | ~2230 | ~9470 | ~12000 | ~662600 |

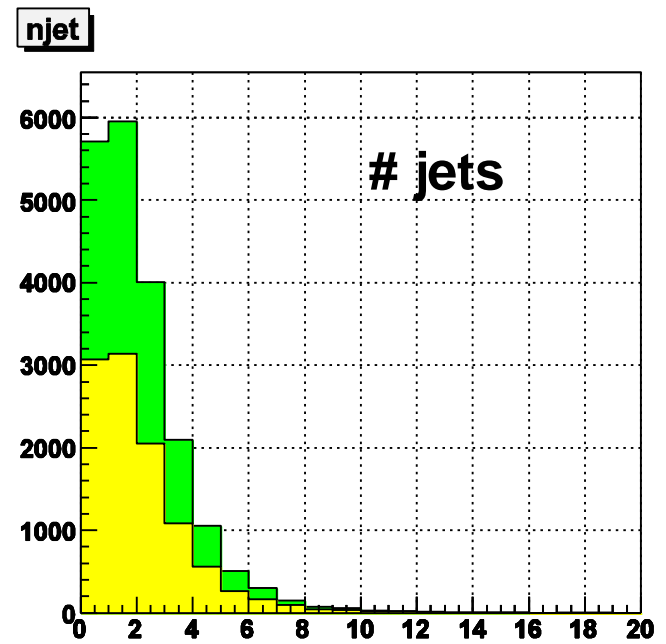
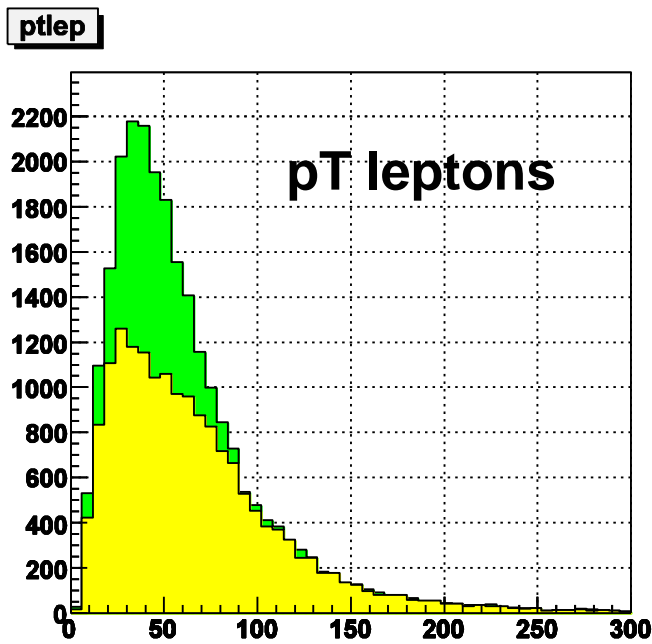
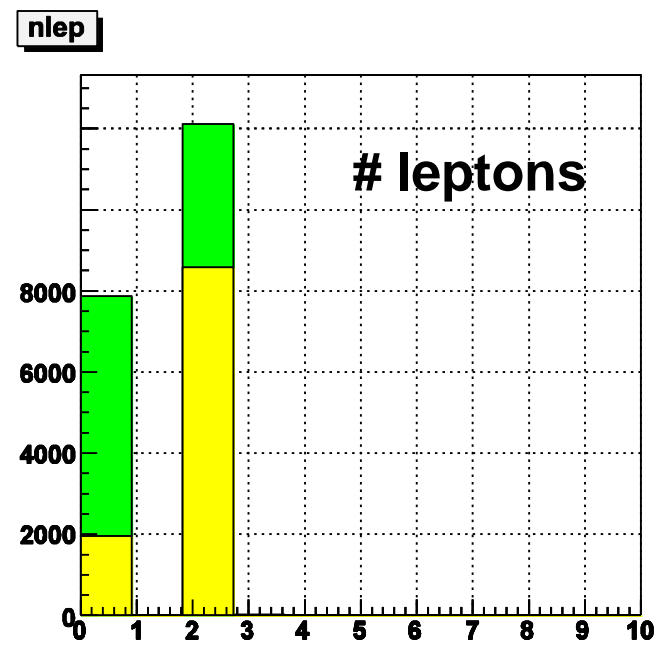
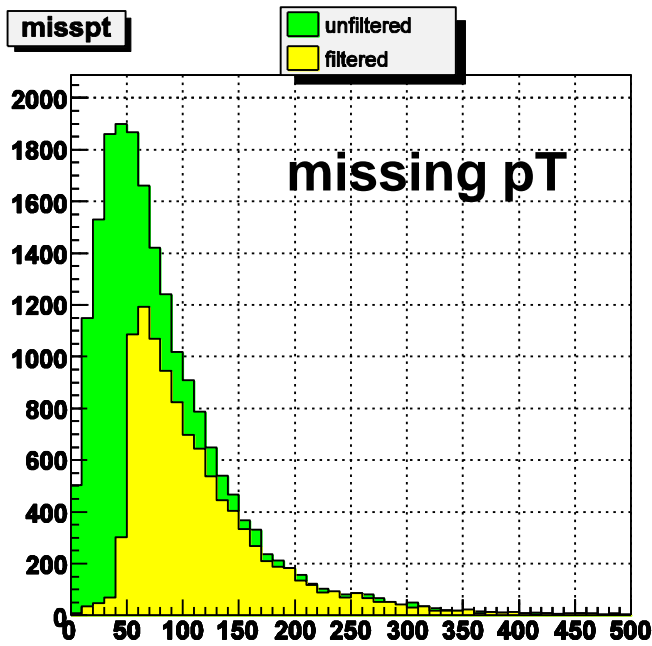
From 8360 CPU years down to 20 CPU years...

Cut flow on ATLFAST AOD after filter with m_Z cut

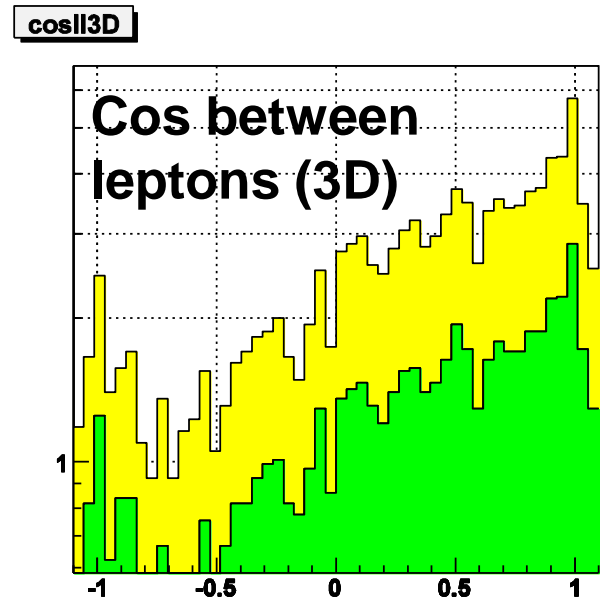
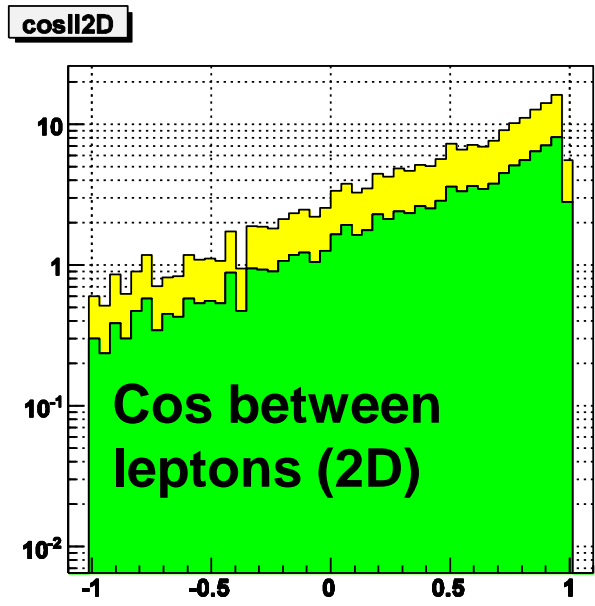
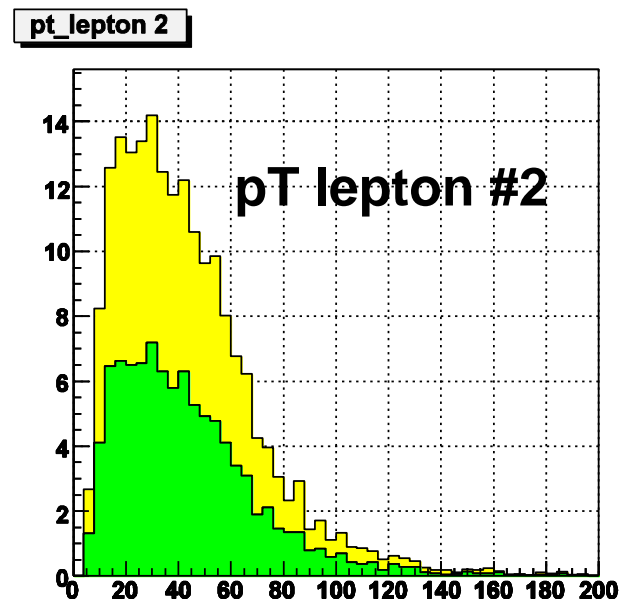
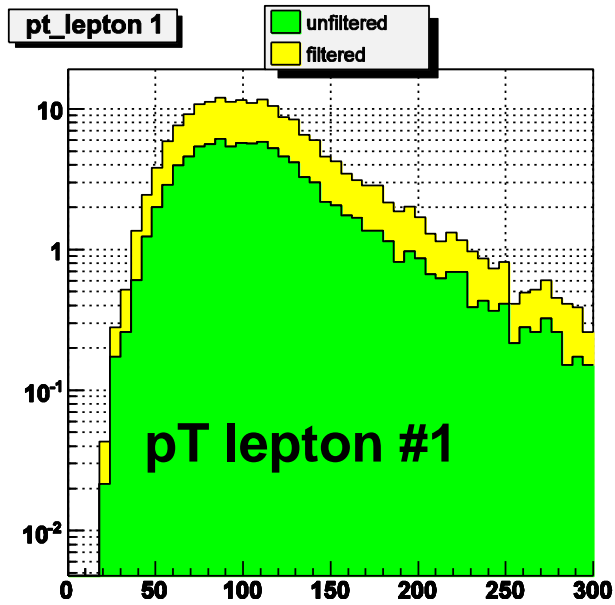
| full filter | HZ | | ZZ -> llnunu | | Z incl. | | ttbar | |
|------------------------------------|--------|-------|--------------|-------|---------|---------|---------|-------|
| # of generated events | 100 K | | 100 K | | 20.47 M | | 14 K | |
| event weight | 0.0043 | | 0.03 | | 1.37 | | 90.03 | |
| Events at 10 fb ⁻¹ | 430 | 100% | 3000 | 100% | 28.4 M | 100% | 1251000 | 100% |
| Events after filter | 223 | 51.8% | 947 | 31.6% | 1218 | 0.0043% | 66929 | 5.35% |
| Events after ptmiss cut @ 90 GeV | 122 | 28.5% | 386 | 12.9% | 135 | 0.0005% | 27772 | 2.22% |
| Events after nlep cut | 108 | 25.1% | 315 | 10.5% | 96 | 0.0003% | 12385 | 0.99% |
| Events after full trigger | 108 | 25.0% | 315 | 10.5% | 94 | 0.0003% | 11759 | 0.94% |
| Events after mZll cut @ +/- 50 GeV | 108 | 25.0% | 313 | 10.4% | 94 | 0.0003% | 10133 | 0.81% |
| Events after btag | 104 | 24.3% | 303 | 10.1% | 46 | 0.0002% | 3128 | 0.25% |
| old ATLFAST analysis | 62 | 14.4% | 183.3 | 6.1% | 14.6 | 0.0001% | 170.4 | 0.0% |

#jet and b-tag values not yet reliable in ATLFAST

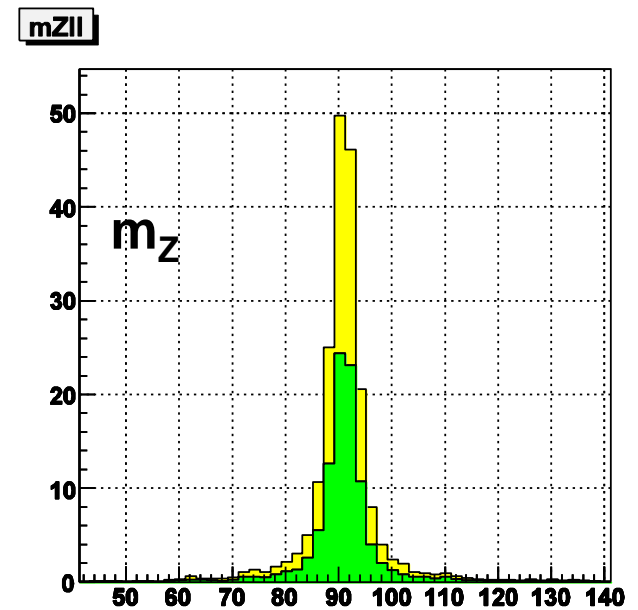
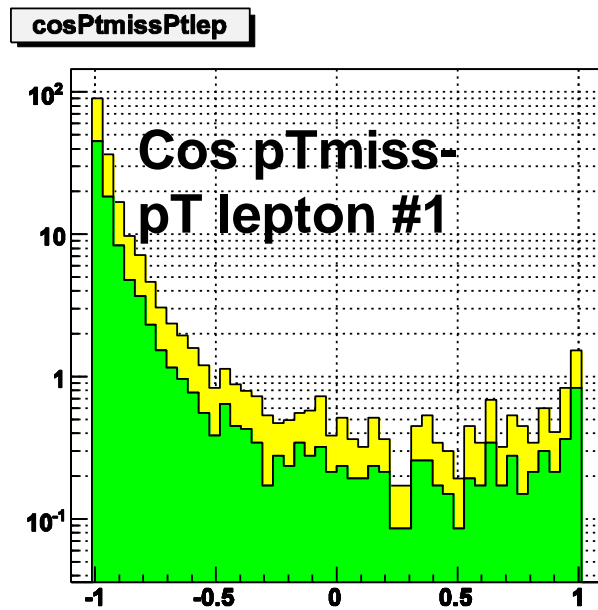
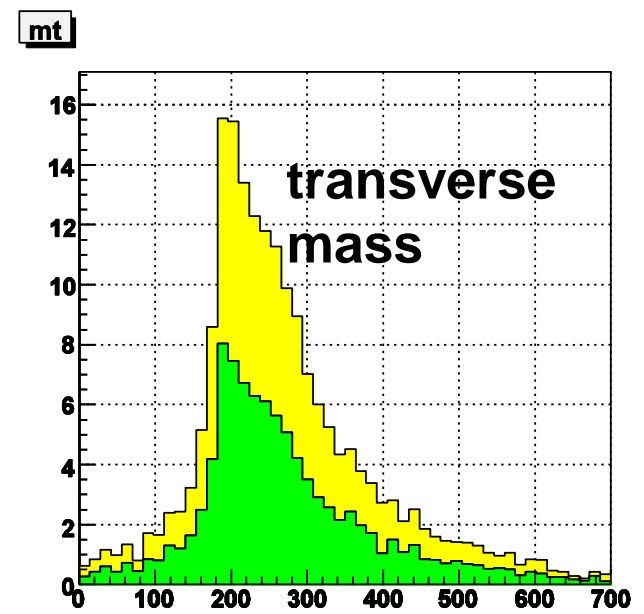
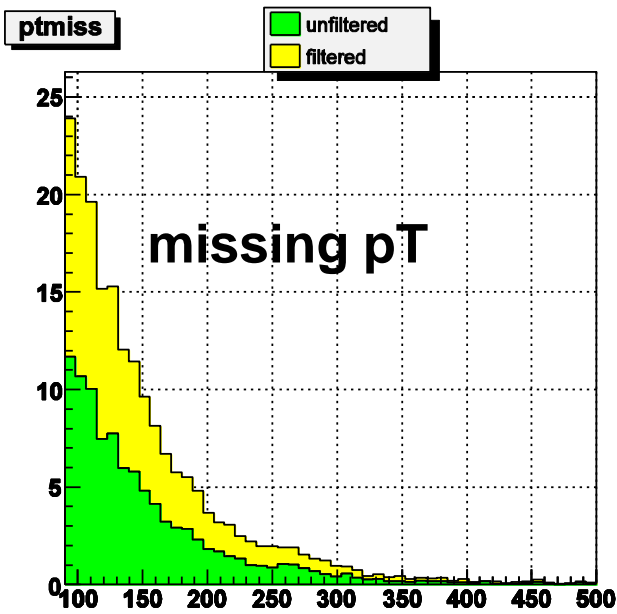
Reference plots done with ATLFast AOD for
unfiltered and filtered before selection
for HZ events (plots are superimposed)



Reference plots after selection
unfiltered and filtered HZ events
(stacked histograms)



Reference plots after selection
unfiltered and filtered HZ events
(stacked histograms)



Filter performance with full AOD

- Tested with 1000 fully reconstructed events for $HZ \rightarrow \chi\chi ll$ and for $ZZ \rightarrow ll\nu\nu$
- More checks in progress with $t\bar{t}$ samples
- All events preselected on fully reconstructed AOD events were retained by the filter

This filter should be used when producing signal and background samples for $HZ \rightarrow \chi\chi ll$ analysis

Comparison of cut flow for fast and full reconstruction

| | HZ | | ZZ \rightarrow ll $\nu\nu$ | |
|-------------------------------------|-------|-------|------------------------------|-------|
| | FAST | FULL | FAST | FULL |
| # of generated events | 100 K | 1 K | 100 K | 1 K |
| Events after filter | 52.7% | 52.7% | 33.6% | 33.6% |
| Events after full missing p_T cut | 29.1% | 29.7% | 13.7% | 13.2% |
| Events after # leptons cut | 28.5% | 27.2% | 11.1% | 12.5% |
| Events after full trigger | 28.5% | 26.9% | 11.1% | 12.2% |
| Events after lepton id cut | 28.5% | 20.8% | 11.1% | 9.1% |
| Events after full m_Z cut | 28.1% | 17.7% | 10.5% | 7.5% |
| Events after b-tagging | 27.4% | 17.2% | 10.1% | 7.3% |

Reconstruction problems

Conclusion

- This filter significantly reduces the amount of events to be reconstructed
- There is no significant loss of events for signal and main backgrounds w.r.t. events preselected with ATLFAST and full simulation AOD
- Filter has been tested with releases 10.5.0 and 11.0.41 yielding consistent results
- This filter should be used for official signal and background production for invisible Higgs in HZ channel
- Filter is going to be in release 11.5.0