Measurement of the $H \to \tau\tau$ coupling exploiting tau lepton decay mode classification in the semi-leptonic final state at ATLAS

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ATLAS EXPERIMENT

UNIVERSITÄT BONN

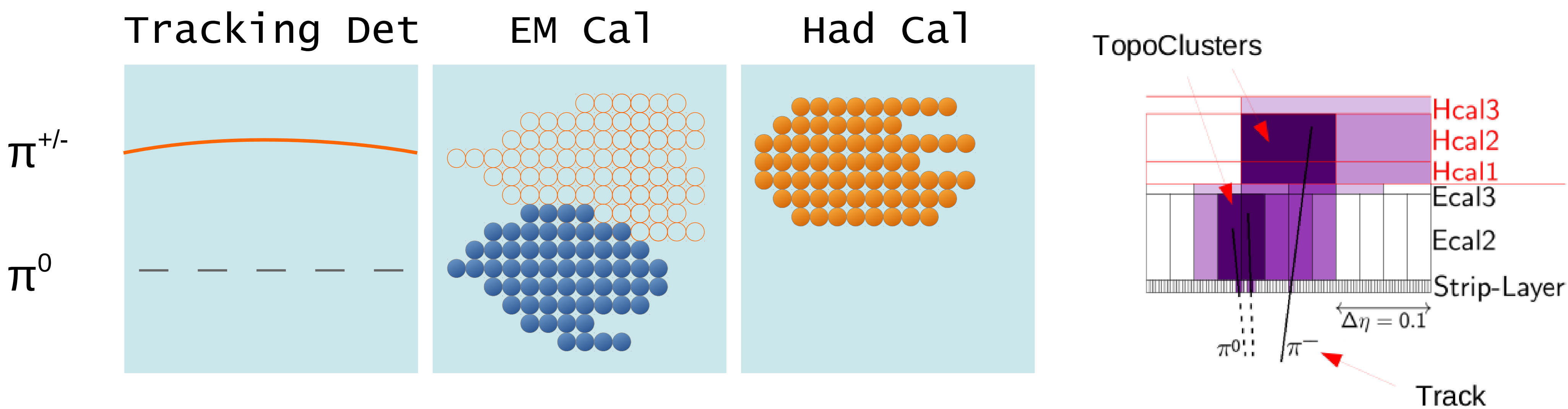
Introduction

- New tuning of tau decay mode classification algorithm for run 2

- How can tau decay mode information be exploited in H$\rightarrow$ tau tau analysis?

- Do we gain sensitivity by splitting the signal regions in decay modes?

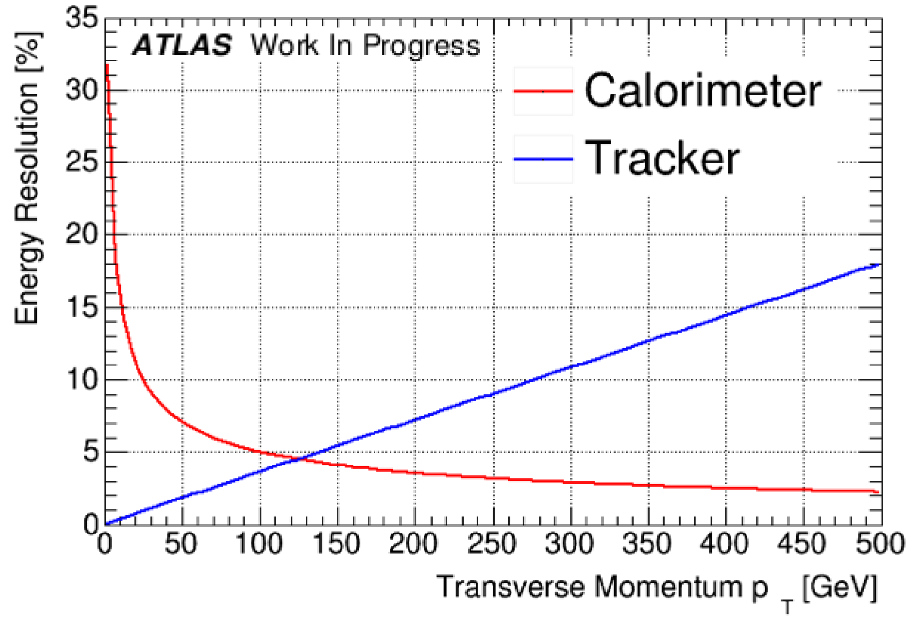
Particle Flow



Idea: reconstruct all decay products to determine decay mode

- use tracks to identify $\pi^{+/-}$
- use energy deposition in had calo and tracking detector to determine the $\pi^{+/-}$ energy in the EM calo
- subtract the $\pi^{+/-}$ energy from matched cluster in the EM calo
- identify neutral particles from remnant clusters
- use strip-layer information to identify neutral pions (2 photon shots)

Tau Substructure Reconstruction



Particle flow algorithm

measure tau 4-momentum with tracking detector instead of using calorimeter information only

Paper on tau substructure reconstruction (Eur. Phys. J. C. (2016) 76:295)

Most pions from taus have pT < 100 GeV
→ Tracker energy resolution is superior in low pT regime

PanTau: Decay mode classification algorithm & 4-momentum builder

- improvement of energy and spatial resolution
- information on tau decay mode

Tau Decay Mode Classification

Extended **PanTau** decay modes:

- 1p0n + 0 add
- 1p0n + X add
- 1p1n + 0 add
- 1p1n + X add
- 1pXn + X add
- 3p0n + 0 add
- 3p0n + X add
- 3pXn + X add

1p0n vs. 1p1n BDT (1p0n + X add, 1p1n + 0 add)

1p1n vs. 1pXn BDT (1p1n + X add, 1pXn + X add)

3p0n vs. 3pXn BDT (3p0n + X add, 3pXn + X add)

neutrals which were not tagged as pi0

pi0-tagged neutrals (PanTau result)

prong = charged pion

INPUT

Classify τ decay mode using
- decay kinematics
- π^0-ID
- number of photons

METHOD

Improving decay mode classification with machine learning techniques in Boosted Decision Trees (BDT)

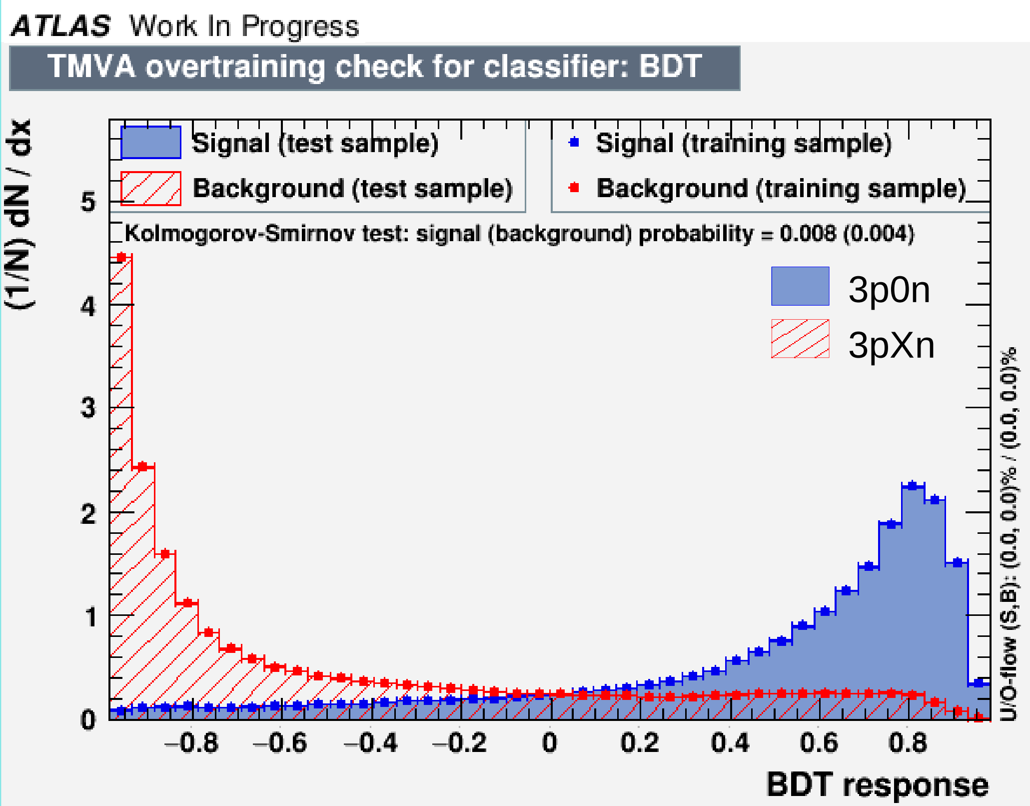
OUTPUT

Resulting information for analyses:
- decay mode
- preliminary tau 4-vector = 4-vectors of charged + neutral pions

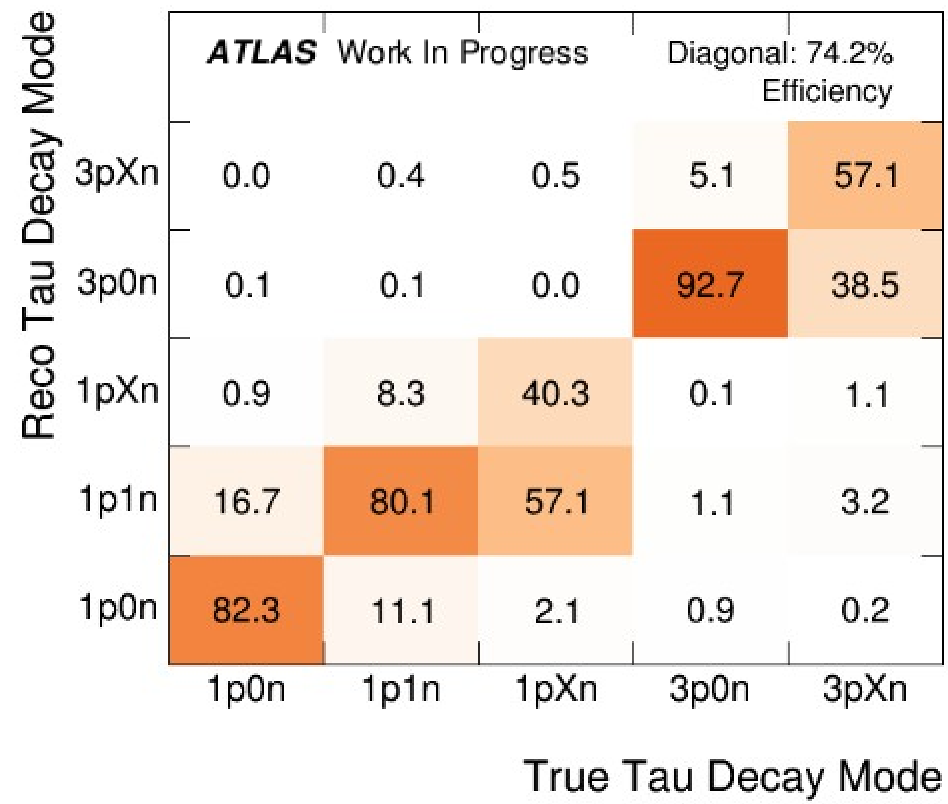
PanTau Performance

- Increase of decay mode classification efficiency after re-training of the three PanTau BDTs

BDT response for re-training of
3p0n vs 3pXn BDT



PanTau migration matrix
after BDT re-training
74.2 % diagonal efficiency



Using decay mode info in H → tau tau

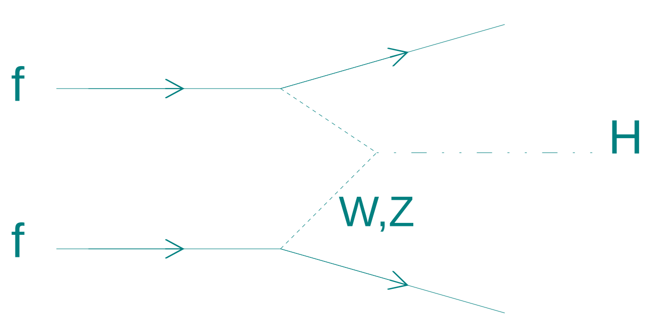
- adopted 4 signal regions from lep-had channel

VBF Higgs Signal Region

- at least 2 jets
- cuts on jet kinematics

tight region
- kinematic cuts on Higgs, jets, light lepton and tau

loose region
- not tight



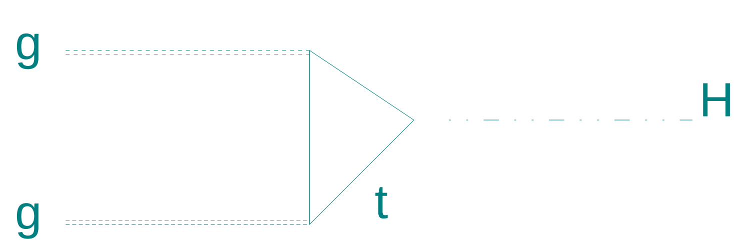
Boosted (ggF) Higgs Signal Region

- not passing VBF selection
- large Higgs transverse momentum

high boosted region
- kinematic cuts on Higgs, light lepton and tau

low boosted region
- not high boosted

4 Signal Regions



Setup

- using ntuples from 03/2017 production, filtered samples, Sherpa 2.21 Z samples, cross sections updated, no scale-factors
- Fakes estimate by Same Sign method (will switch to Fake Factors method)
  - Decay mode split fake factors required
- considered systematics:

weight systematics
TauJetBDTmedium
TauTESDetector
HadTauEleOLR
VeryLooseLlhEleOLR
CentralJetsGlobalEff/Ineff
ForwardJetsGlobalEff/Ineff
JetsGlobalEff/IneffMVX

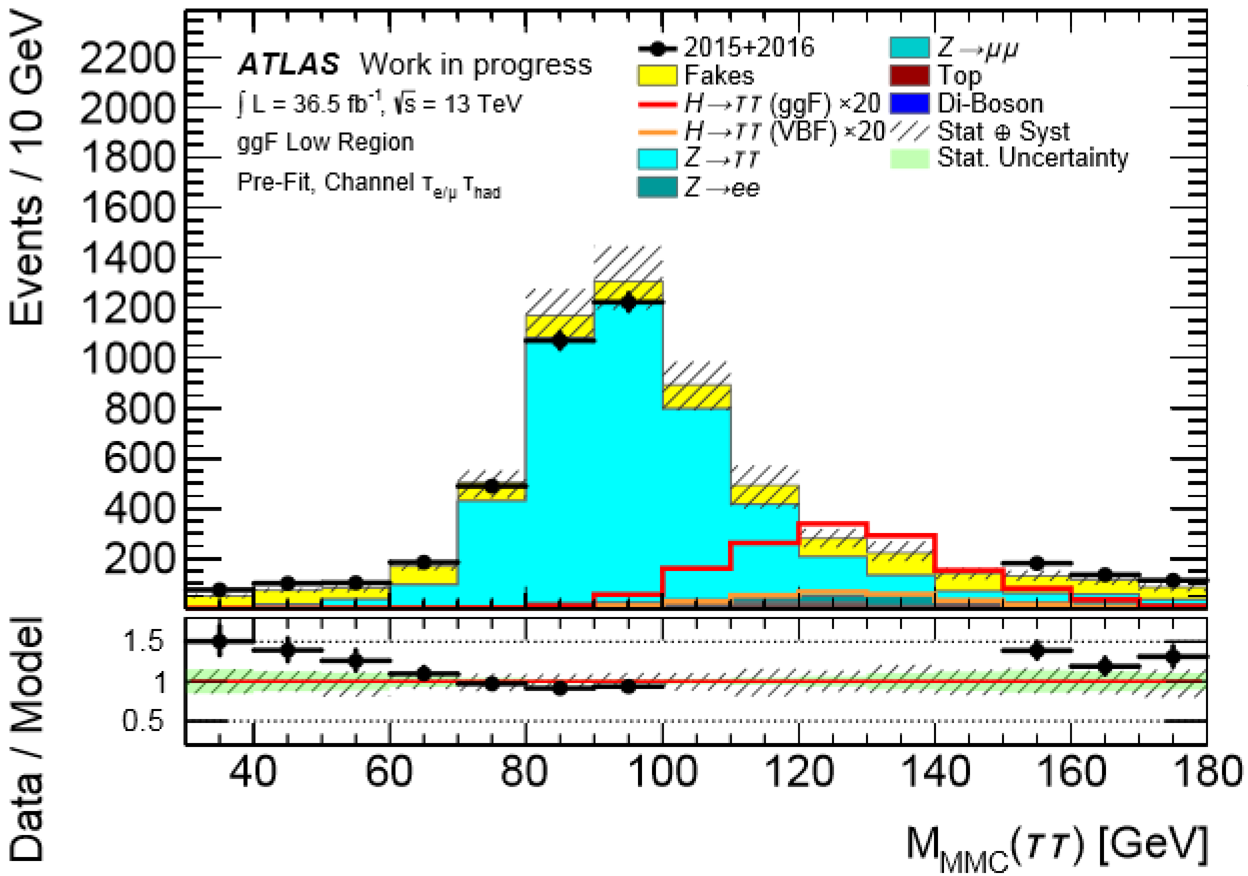
systematic uncertainties on jet BDT score, tau energy scale, electron overlap removal, global jet efficiencies

tree systematics
TAUS_TRUEHADTAU_SME_TES_DETECTOR
TAUS_TRUEHADTAU_SME_TES_INSITU
TAUS_TRUEHADTAU_SME_TES_MODEL

Boosted low

Inclusive plot of MMC mass in boosted low region

Missing **M**ass **C**alculator

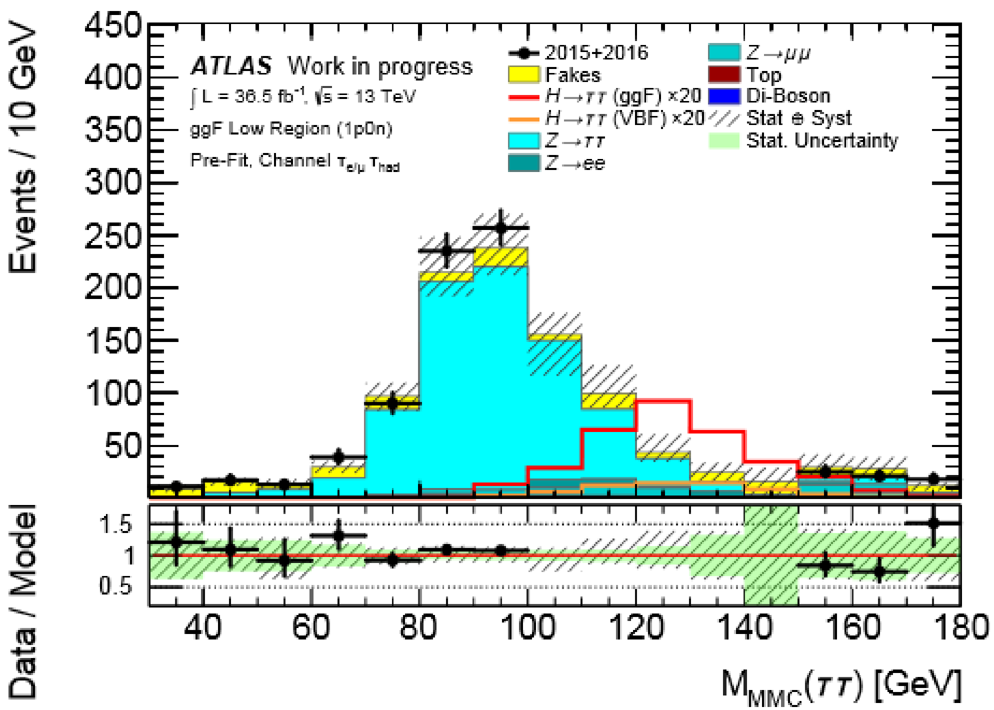


blinded in mass window:
100-150 GeV

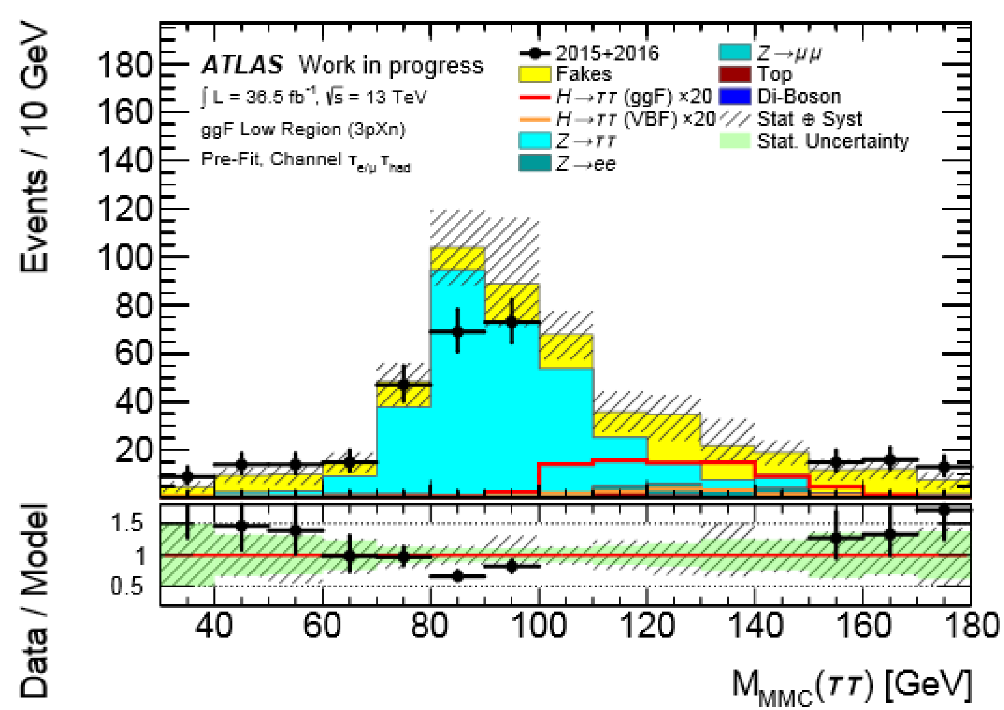
Boosted low

Comparison of Higgs MMC mass in 1p0n and 3pXn modes

1p0n



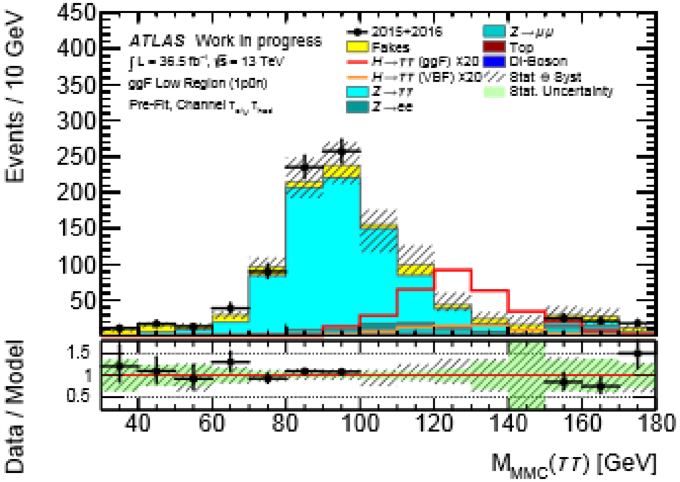
3pXn



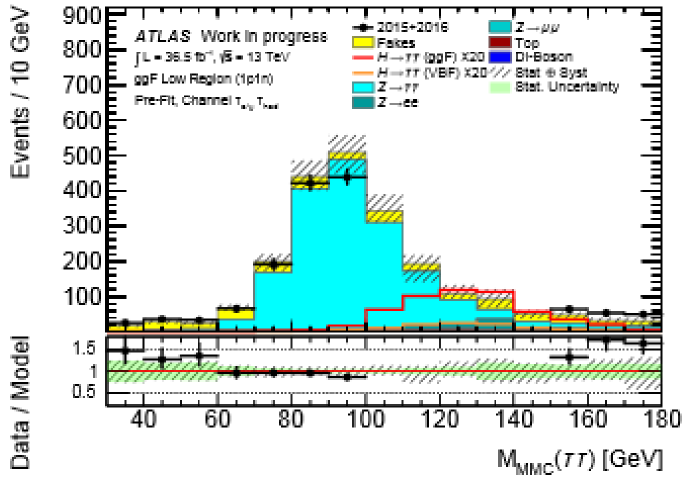
- Large Fakes contribution in decay modes with neutral constituents
- Study possibility to loosen kinematic cuts in low Fakes regions for higher signal significance

Boosted low

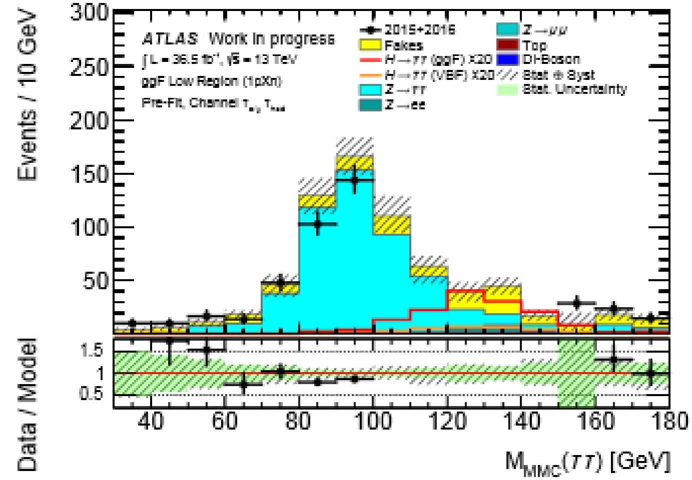
1p0n



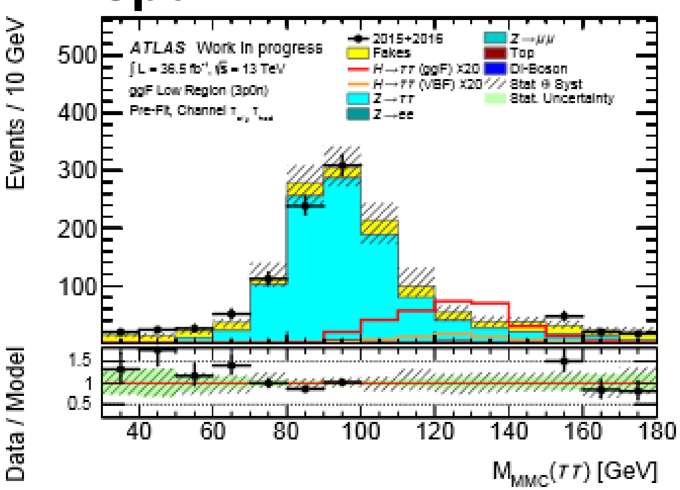
1p1n



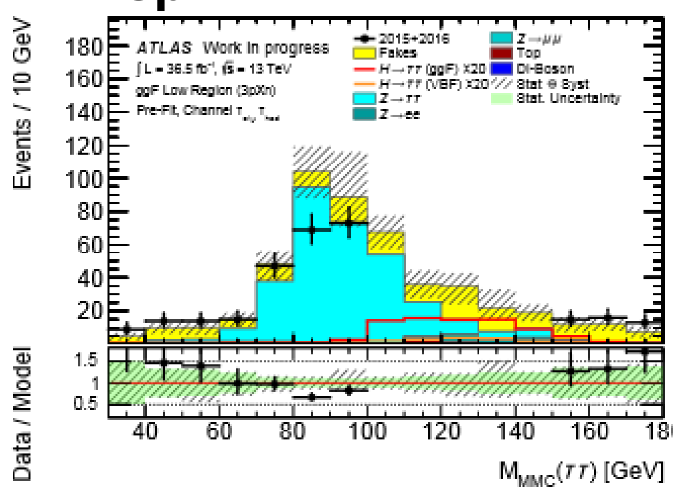
1pXn



3p0n

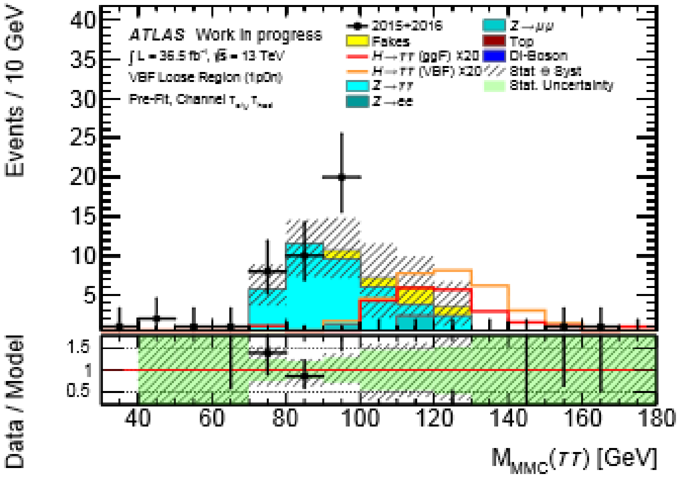


3pXn

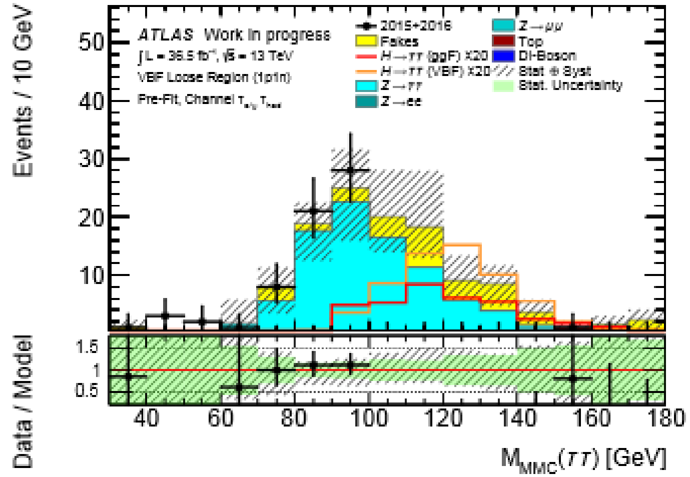


VBF loose

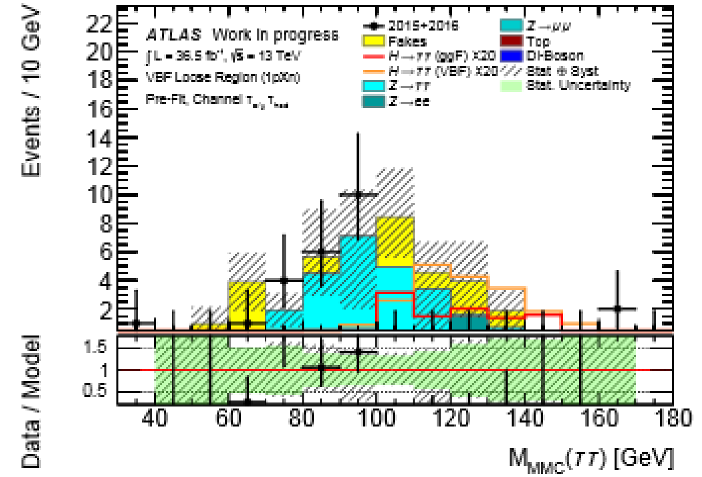
1p0n



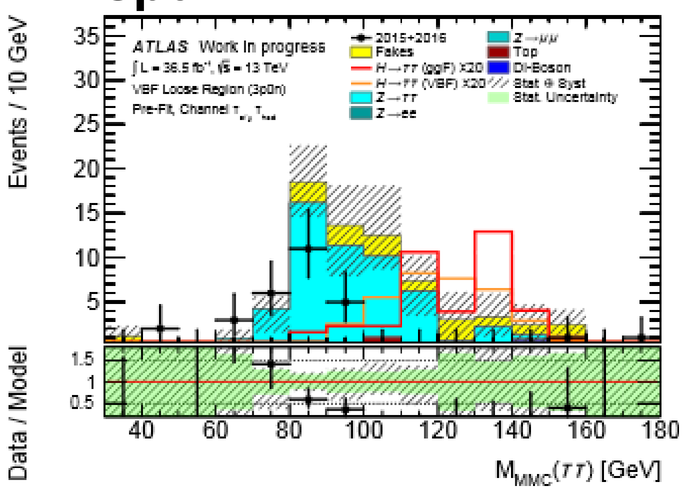
1p1n



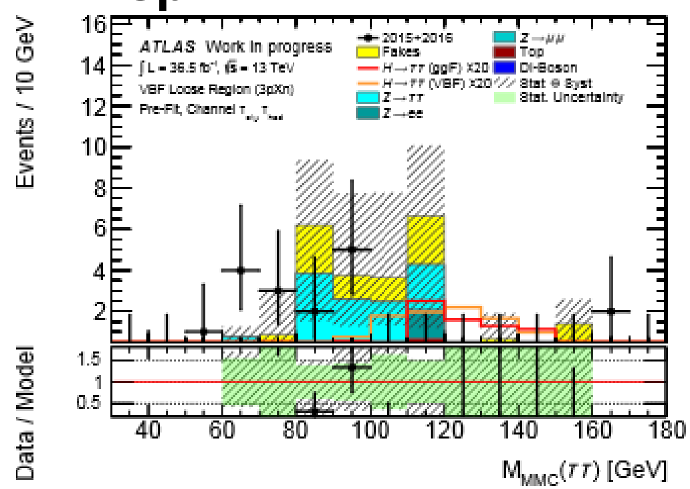
1pXn



3p0n



3pXn



Signal Significance

Summary of s/√b ratios (stats-only significance) for all signal regions in MMC mass window 110-140 GeV

Decay mode specific and combined (quadratic sum)

region	$S/\sqrt{B}$						
	inclusive	1p0n	1p1n	1pXn	3p0n	3pXn	combined
ggF high	2.55	1.31	1.51	0.77	1.31	0.60	2.58
ggF low	1.41	0.85	0.84	0.39	0.72	0.24	1.47
VBF tight	2.71	1.30	1.96	1.22	1.15	0.37	2.90
VBF loose	0.58	0.37	0.33	0.20	0.30	0.11	0.62

Increased signal significance by combining the SRs which were split in decay modes

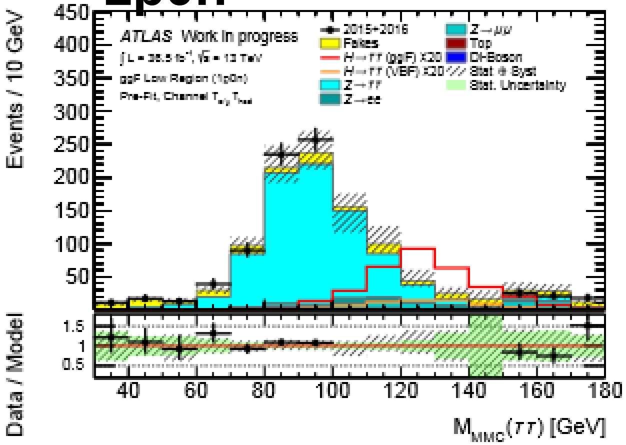
Signal Significance

How can we continue from here to increase the signal significance?

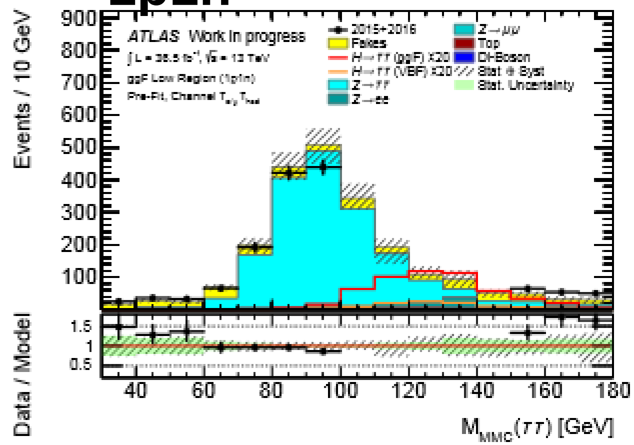
- Find selection cuts which can be loosened in the pure decay mode regions to increase signal while keeping background moderate
- One of these requirements: Tau ID
- Another one: missing transverse energy

Tau ID study

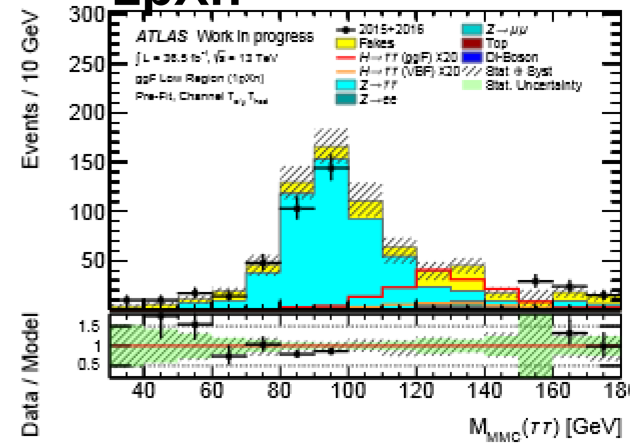
1p0n



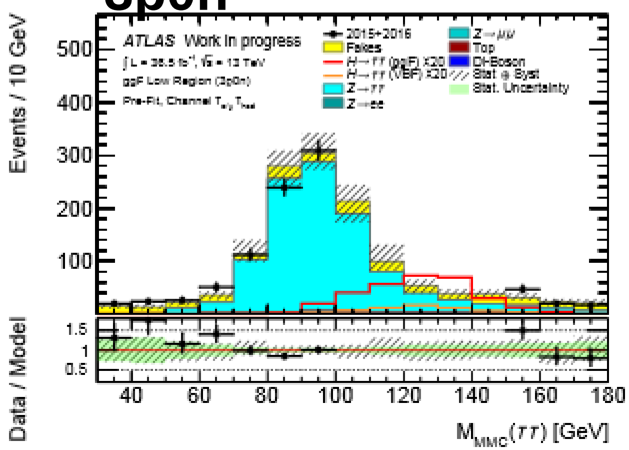
1p1n



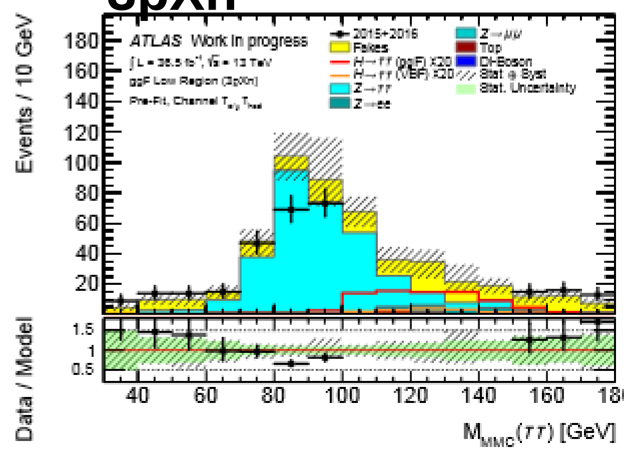
1pXn



3p0n



3pXn

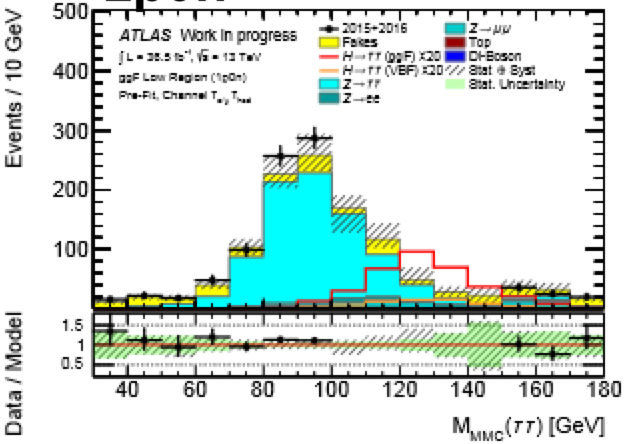


medium Tau ID

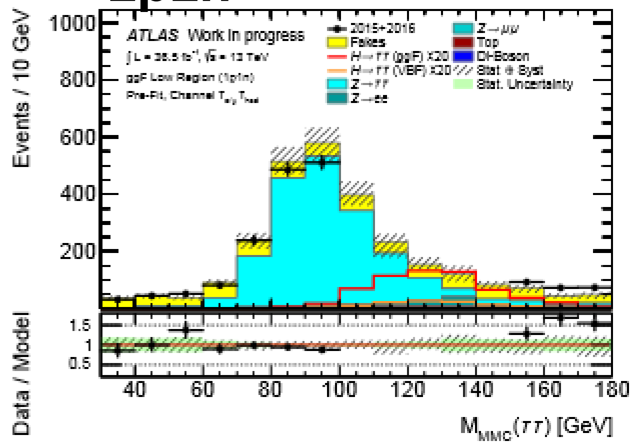
Here: boosted low region with medium TauID
Study effect of looser Tau ID in decay mode splitting

Tau ID study

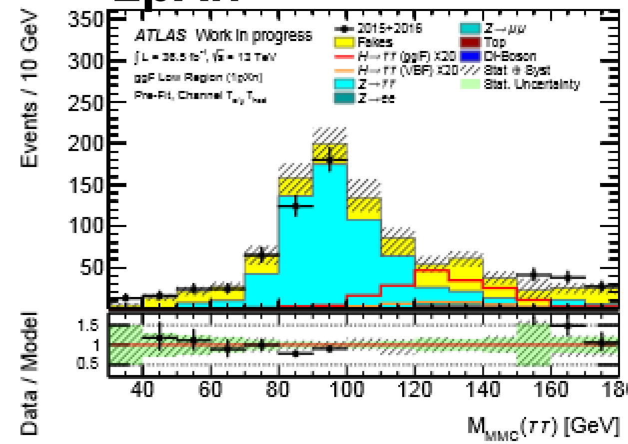
1p0n



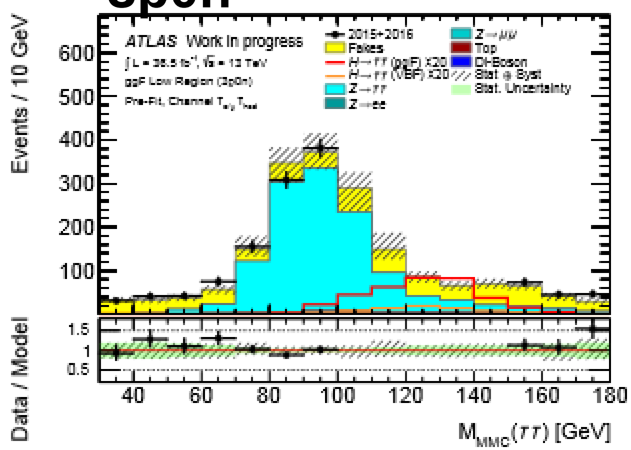
1p1n



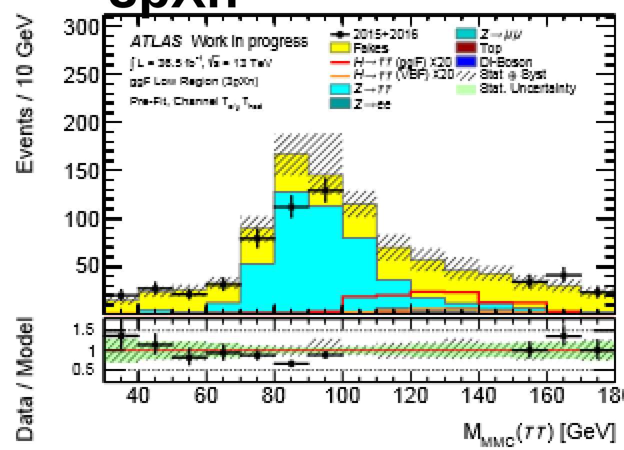
1pXn



3p0n



3pXn



loose Tau ID

Here: boosted low region with loose TauID

- Increase of Fakes especially in decay modes with large number of neutrals

Tau ID study

Looser Tau ID gives larger statistics

Signal events in mass window 110 < m < 140 GeV:

Boosted low region	Tau ID	
	medium	loose
inclusive	44.62	50.81
1p0n	11.03	11.69
1p1n	16.66	18.84
1pXn	4.71	5.46
3p0n	9.95	11.47
3pXn	2.27	3.35

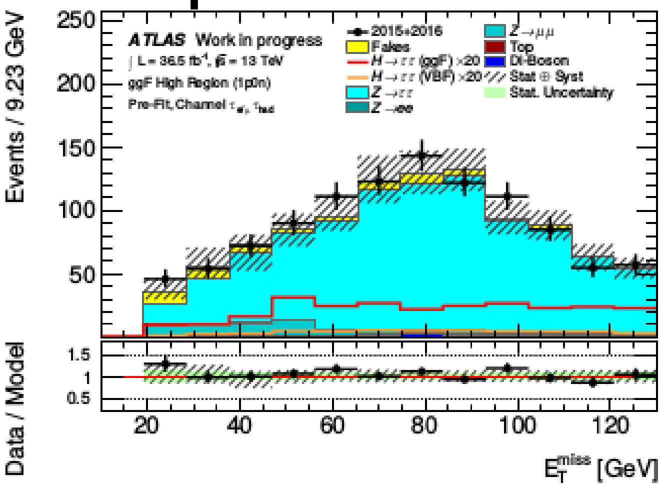
more Signal events with loose Tau ID

→ results in better $s/\sqrt{b}$ ratio
(reduction of TES uncertainty, but additional Tau ID uncertainty)

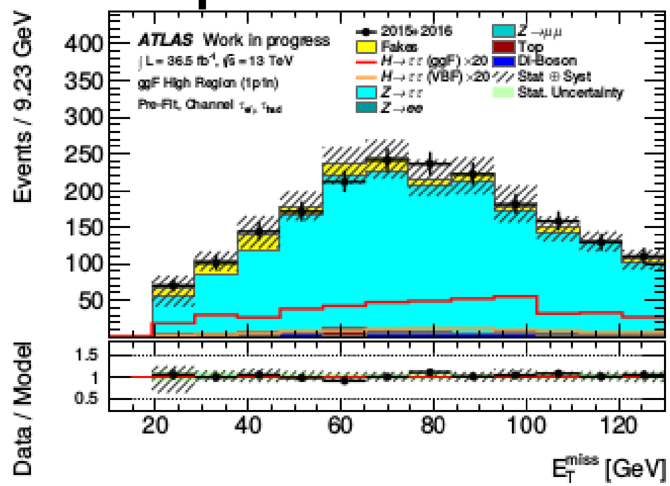
Exploit this in the pure decay modes (1p0n, 1p1n)

Missing transverse energy

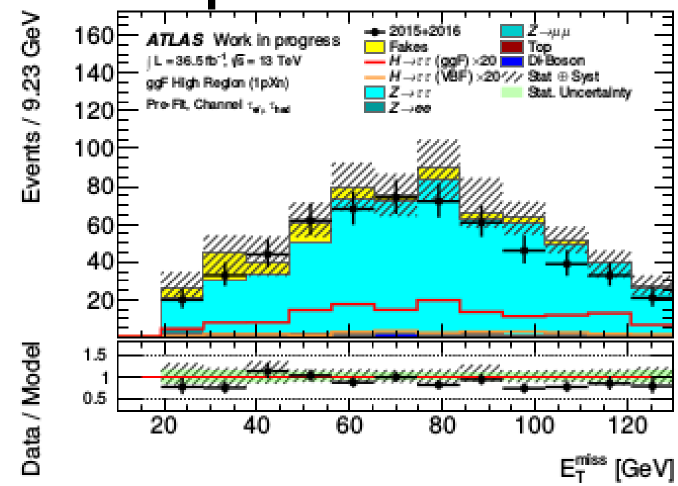
1p0n



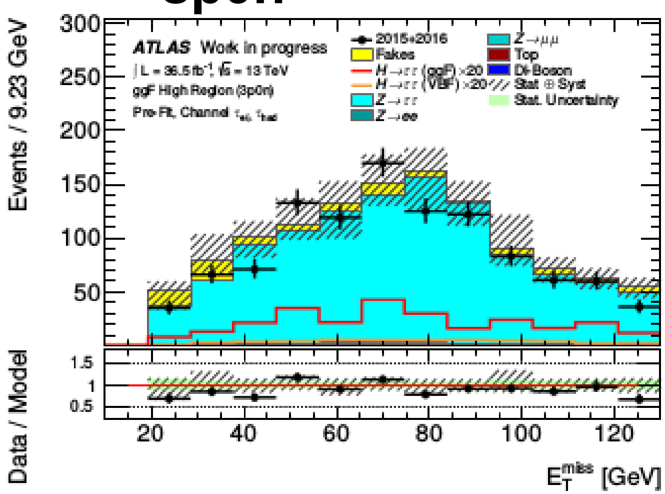
1p1n



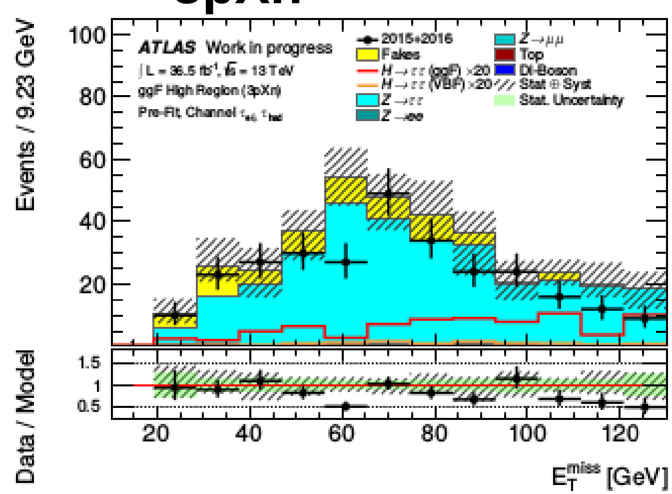
1pXn



3p0n



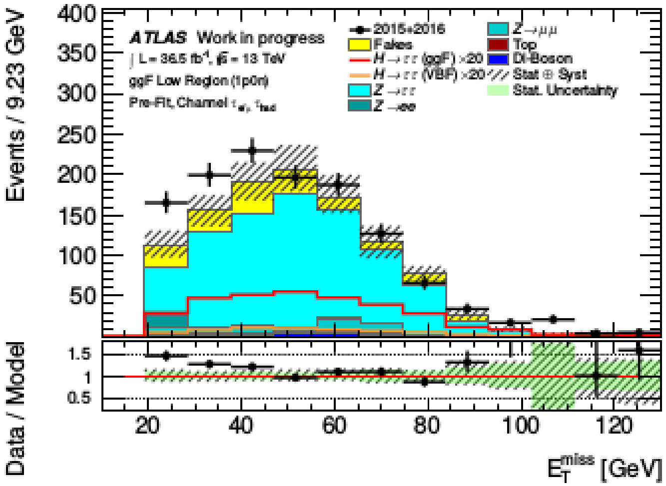
3pXn



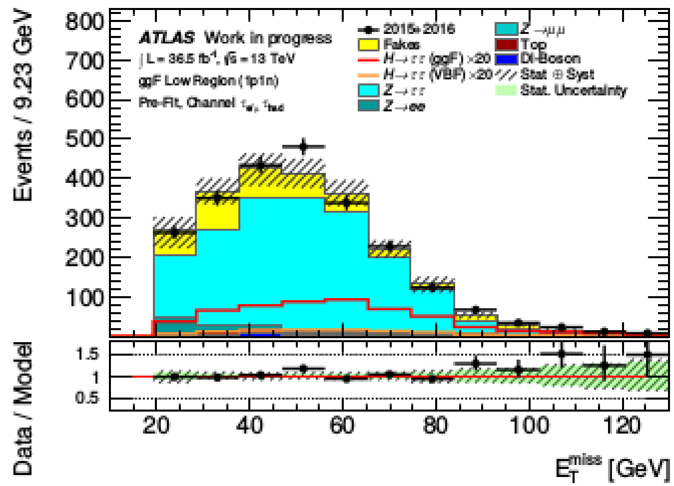
- High boosted region

Missing transverse energy

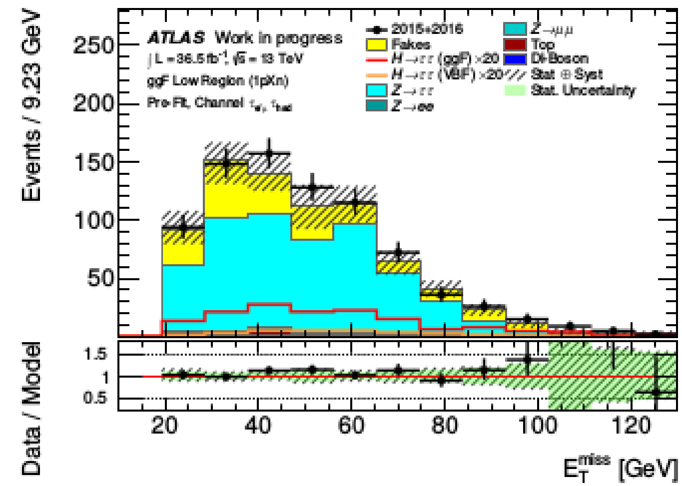
1p0n



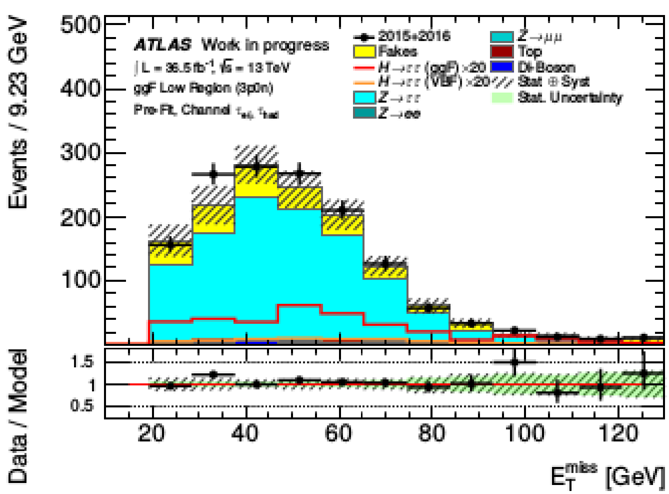
1p1n



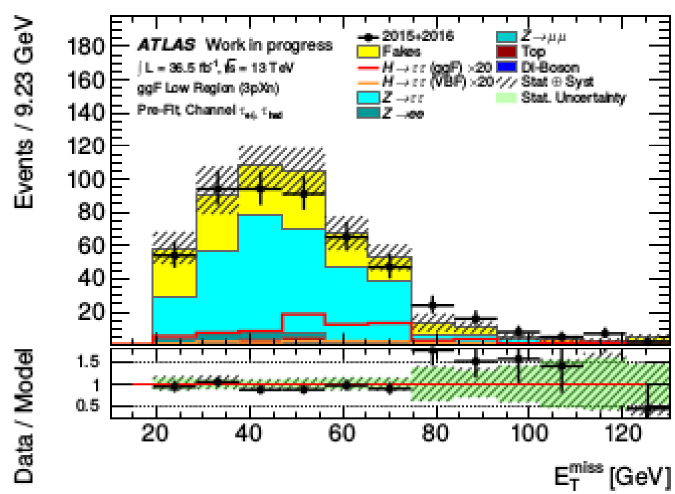
1pXn



3p0n



3pXn



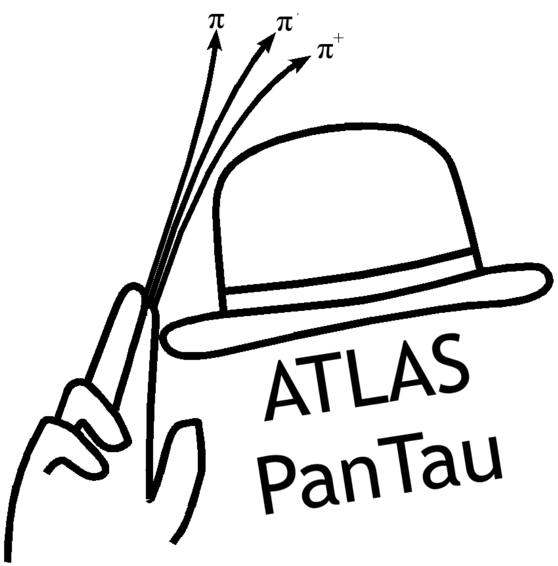
- Low boosted region

Outlook

- Replace SS Fakes estimate by Fake Factors method (decay mode splitting)
- Switch to newest ntuples
- Include further systematics
- Split decay modes in additional variables
  (lep & tau & jet pT, Higgs pT, m_jj etc.)
- Find kinematic cuts that can be loosened in decay mode splitting for more signal efficiency
- Check control regions
- Split in electron/muon channel
- Future ideas: BDT for sig vs. bkg classification in split decay modes

Summary

- Tau substructure reconstruction improves energy and spatial tau resolution
- PanTau: Tau decay mode classification and 4-momentum builder algorithm with improved decay mode classification efficiency in run-2
- Gain sensitivity in H→tau tau by splitting in tau decay modes



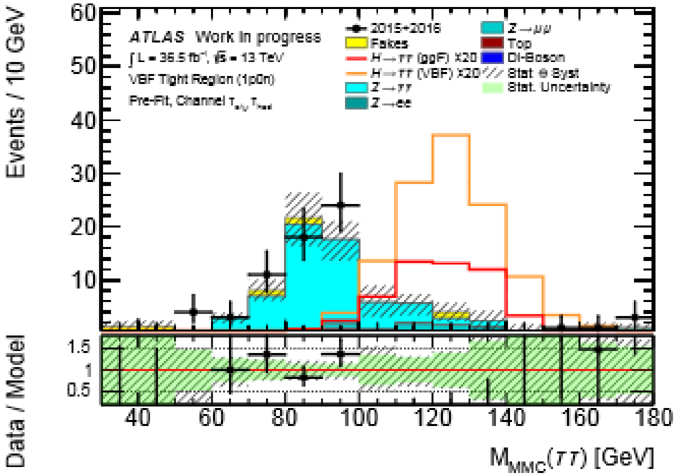
Thanks for your attention

Questions?

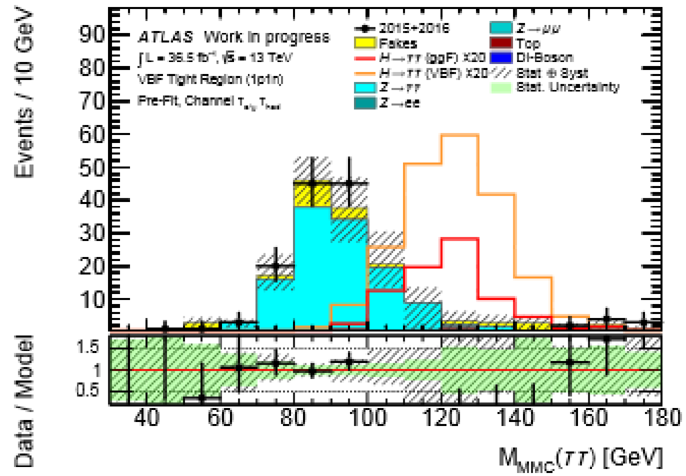
Bonus

VBF tight

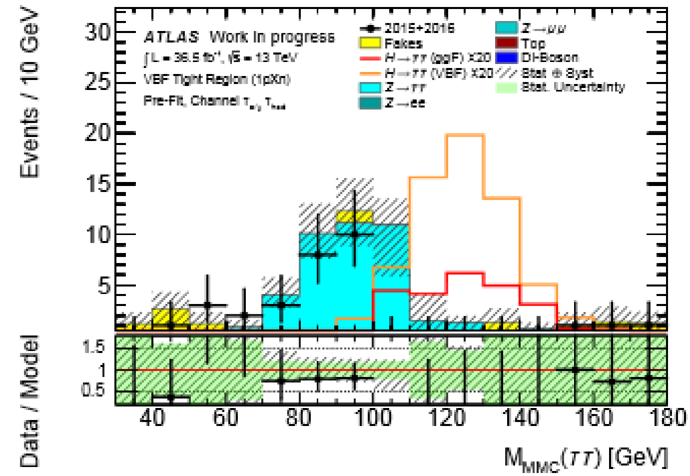
1p0n



1p1n



1pXn



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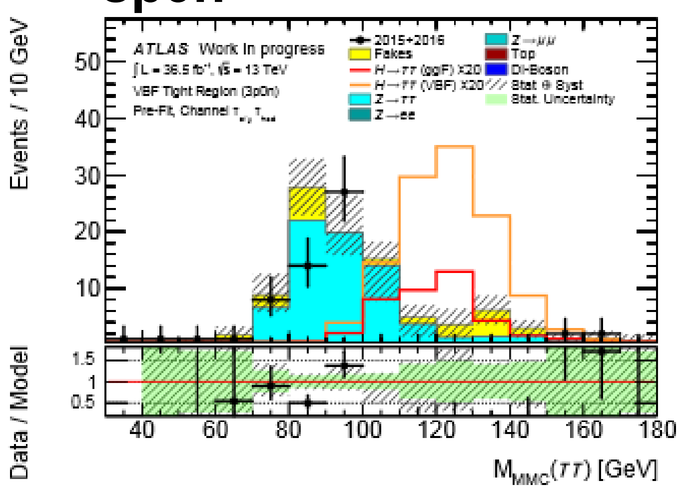

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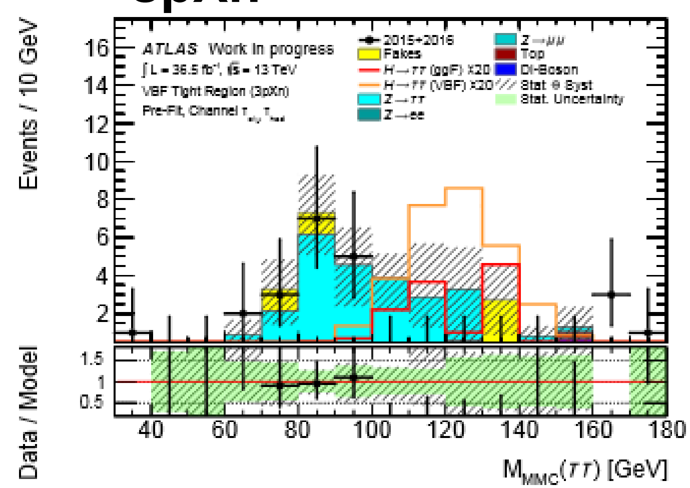
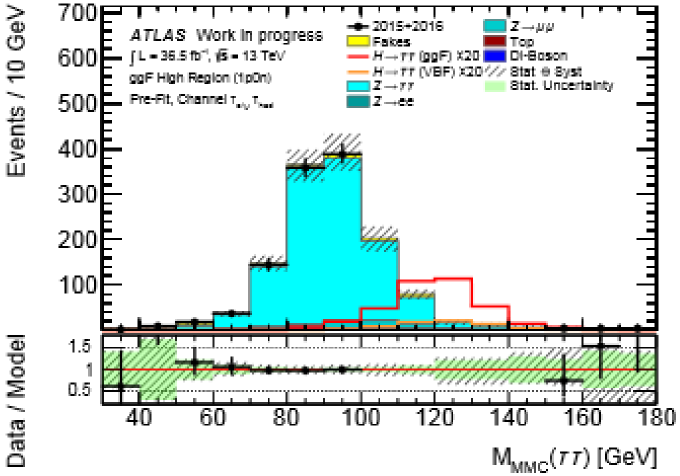
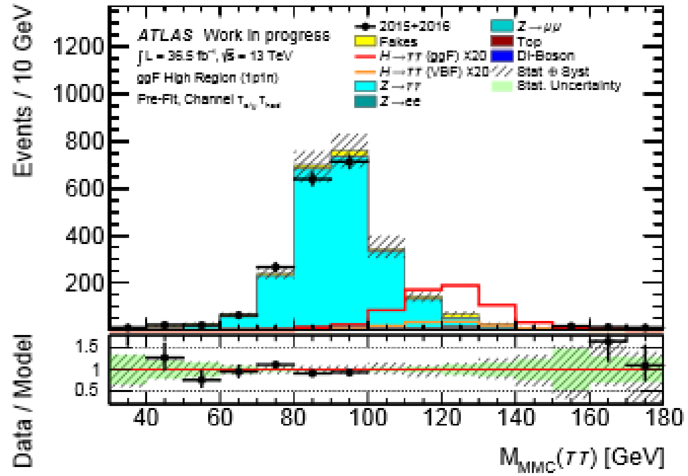


Boosted high

1p0n



1p1n



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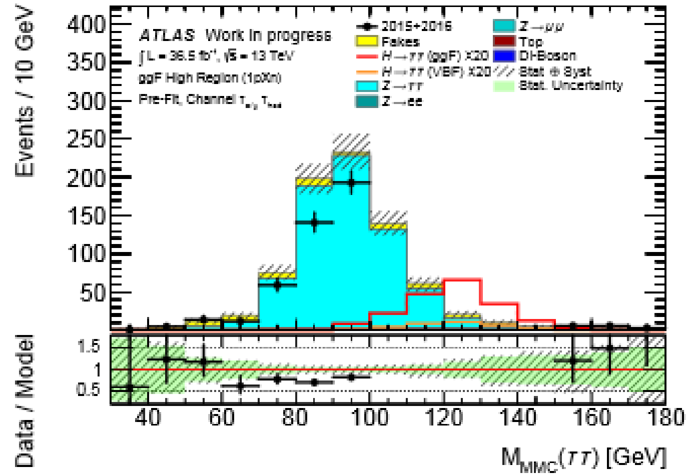
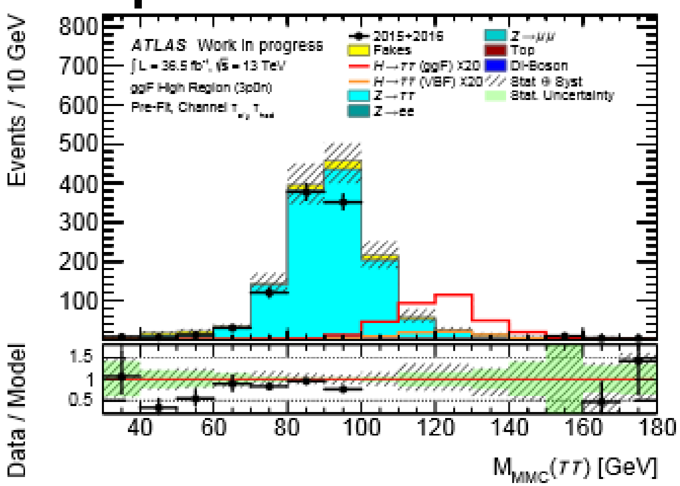
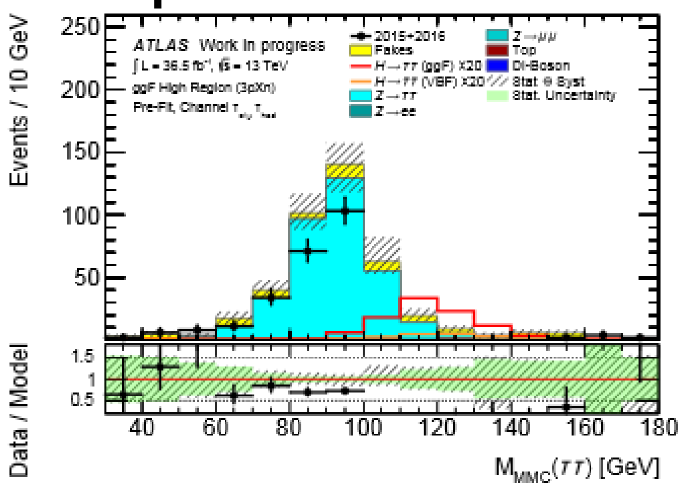


3p0n



3pXn



Signal Significance

medium Tau ID:

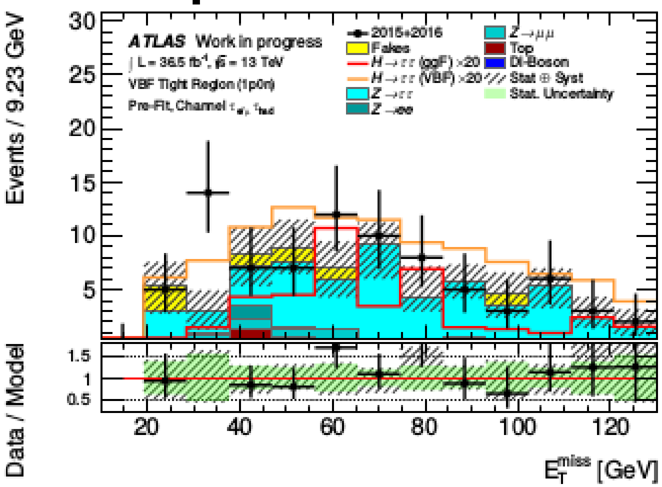
region	$S/\sqrt{B}$						
	inclusive	1p0n	1p1n	1pXn	3p0n	3pXn	combined
ggF high	2.55	1.31	1.51	0.77	1.31	0.60	2.58
ggF low	1.41	0.85	0.84	0.39	0.72	0.24	1.47
VBF tight	2.71	1.30	1.96	1.22	1.15	0.37	2.90
VBF loose	0.58	0.37	0.33	0.20	0.30	0.11	0.62

loose Tau ID:

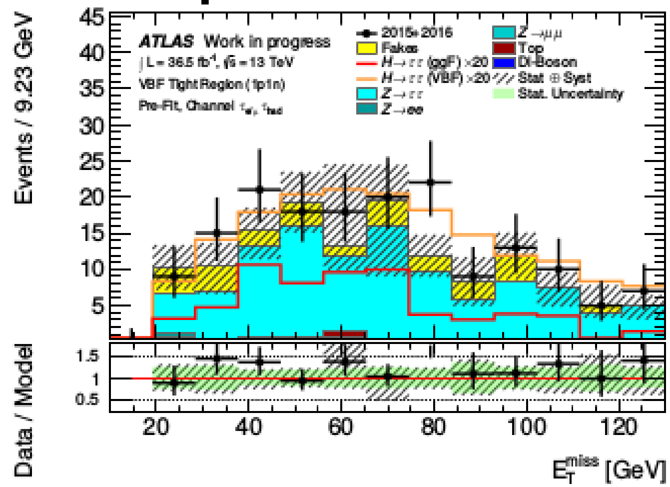
region	$S/\sqrt{B}$						
	inclusive	1p0n	1p1n	1pXn	3p0n	3pXn	combined
ggF high	2.60	1.32	1.51	0.80	1.35	0.67	2.63
ggF low	1.37	0.84	0.84	0.39	0.66	0.26	1.43
VBF tight	2.58	1.36	1.75	1.06	1.01	0.54	2.71
VBF loose	0.57	0.31	0.32	0.22	0.29	0.13	0.59

Missing transverse energy

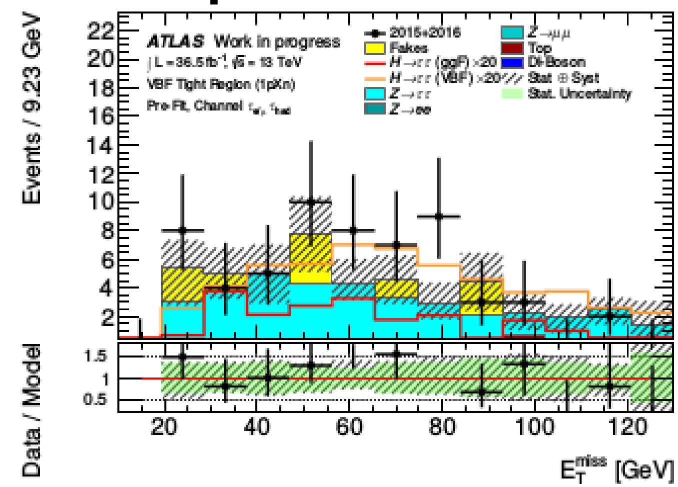
1p0n



1p1n



1pXn



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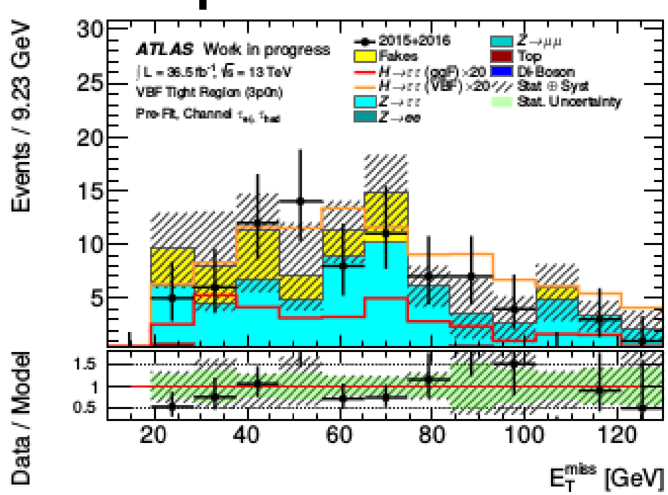

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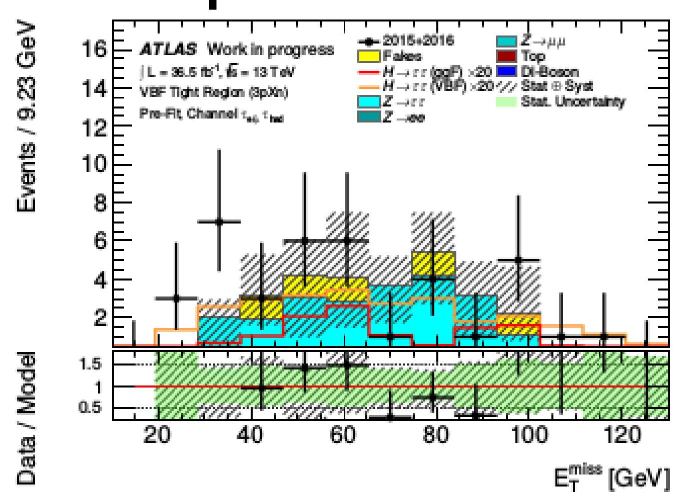
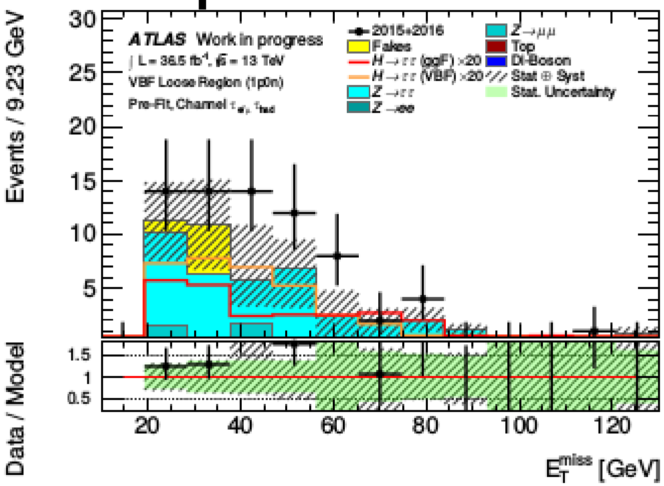


- VBF tight region

Missing transverse energy

1p0n



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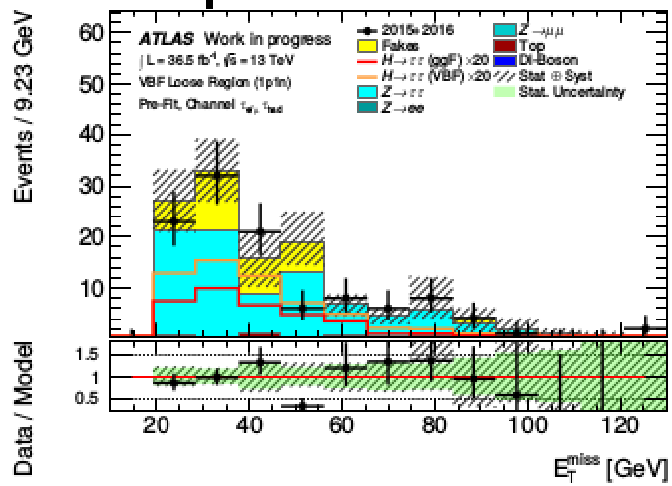

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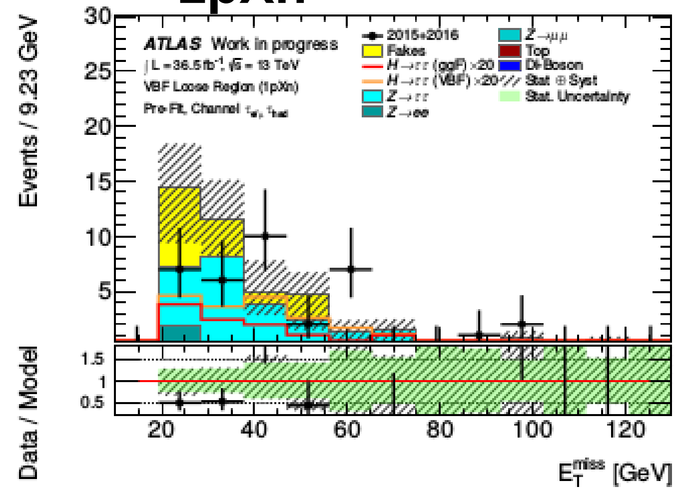

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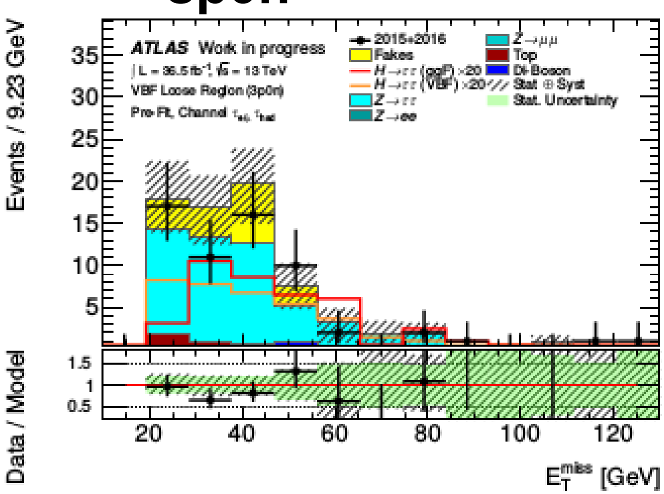

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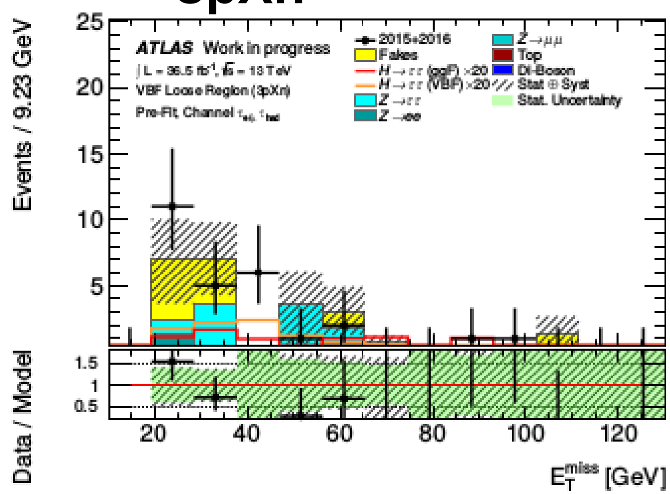
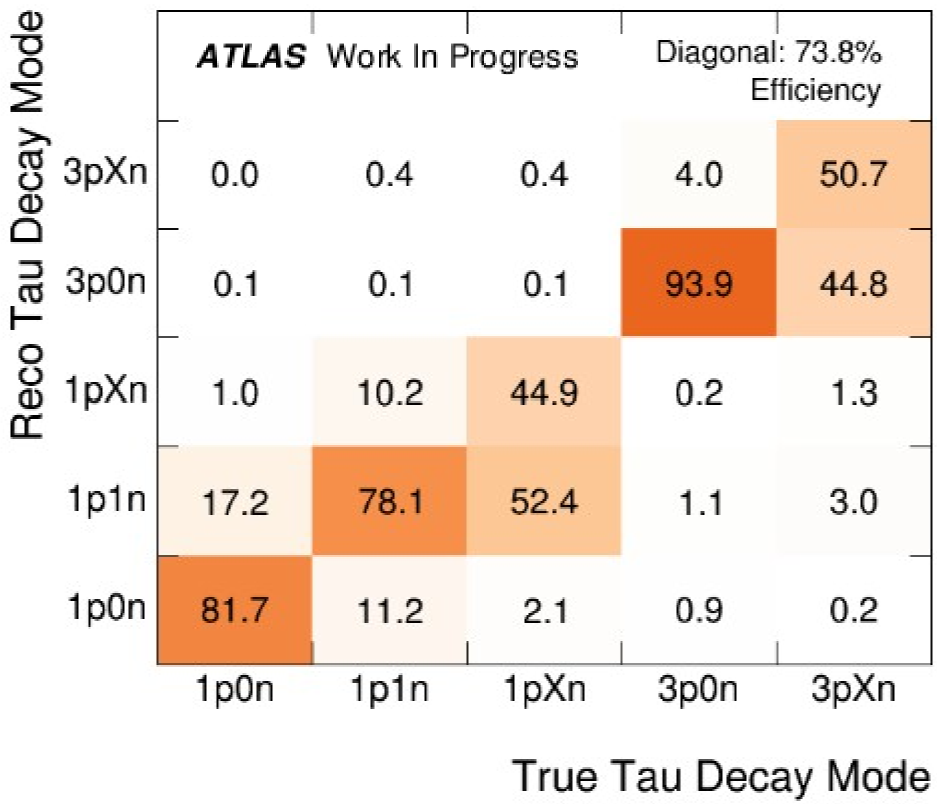


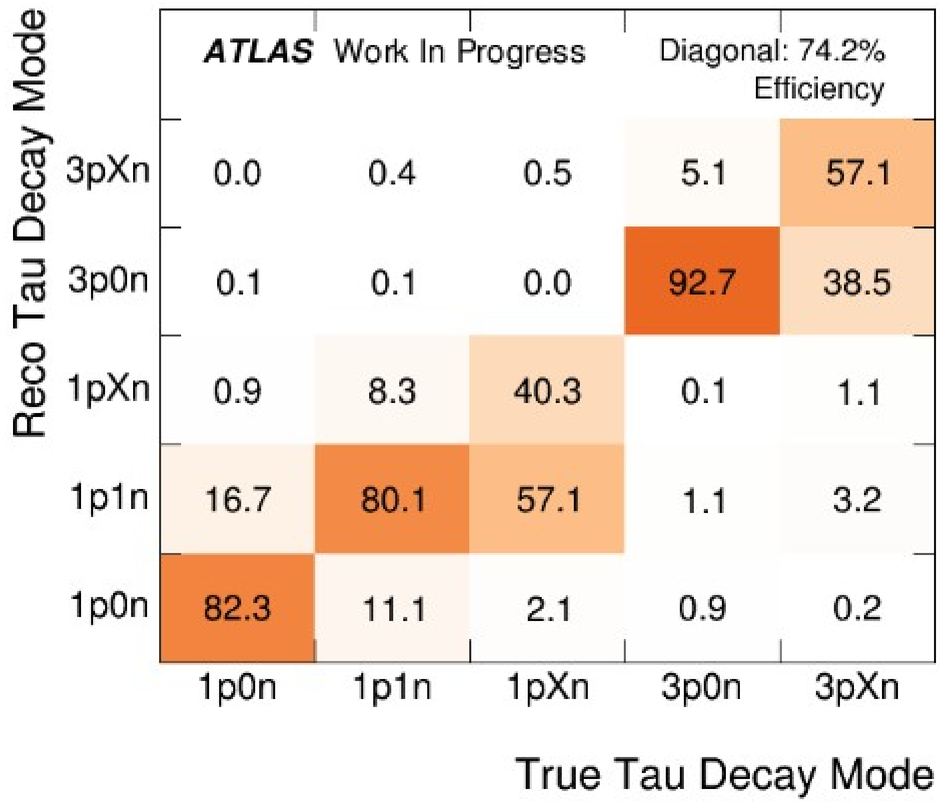
- VBF loose region

PanTau Migration Matrix

before PanTau BDT retraining
73.8 % efficiency



after PanTau BDT retraining
74.2 % efficiency

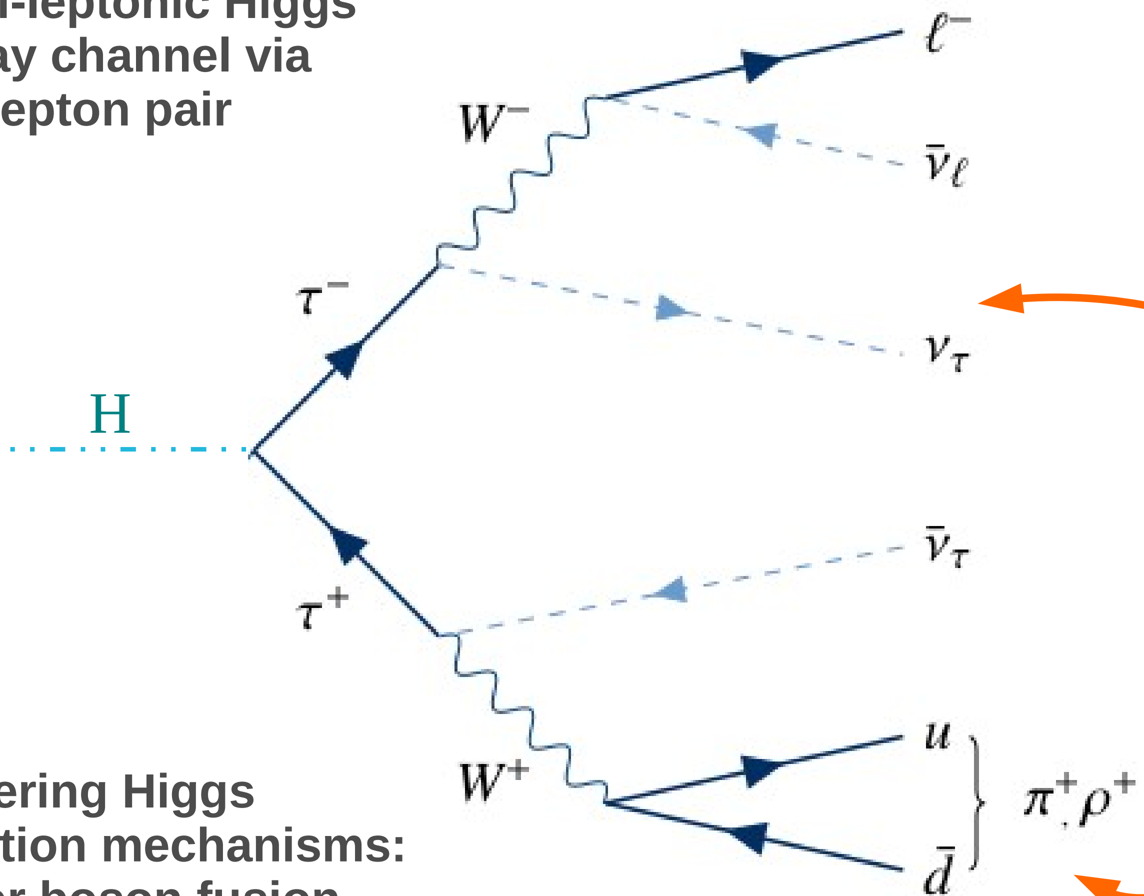


- evaluation on Ztautau sample
- overall increase of diagonal efficiency through new PanTau BDT re-training

Event Selection

H → tau tau coupling measurement

- semi-leptonic Higgs decay channel via tau lepton pair



1 light lepton

missing transverse energy

1 hadronically decaying tau

considering Higgs production mechanisms:
- vector boson fusion
- gluon gluon fusion

The Tau Lepton

- heaviest lepton
  m_τ = 1777 MeV
- extreme short lifetime
  of $290 \cdot 10^{-15}$ s
- decay length of 87 μm