Higgs CP invariance test in the H$\tau\tau$ decay

A. De Maria

Nanjing University

Higgs CP invariance test in the H$\tau\tau$ decay

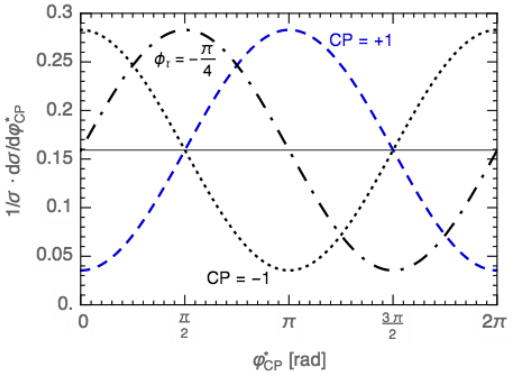
- Information about CP violation encoded in the correlation between spin components of the taus

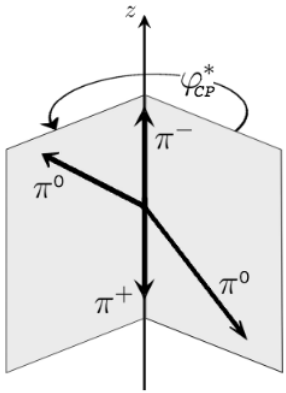
$$\mathcal{L}_Y = -g_\tau(\cos\phi_\tau \bar{\tau}\tau + \sin\phi_\tau \bar{\tau} i\gamma_5 \tau)h$$

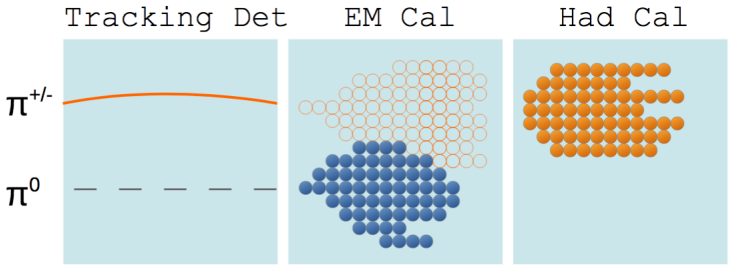
- Access the spin correlation by reconstructing the angle ϕ^*_{CP} between the tau decay planes
  - distribution of the angle has a sine shape and the phase depends on the mixing parameter CP even/odd

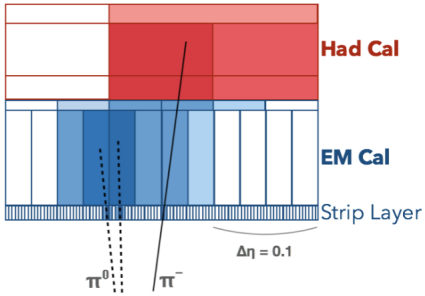
- Two method to reconstruct the τ decay planes:
  - Impact parameter method (used in 1p0n decay); uses info from track momentum and impact parameter
  - Rho decay plane method (used in 1p1n decay); uses the charged and neutral decay products

- Analysis key is the τ decay mode reconstruction to access τ decay products









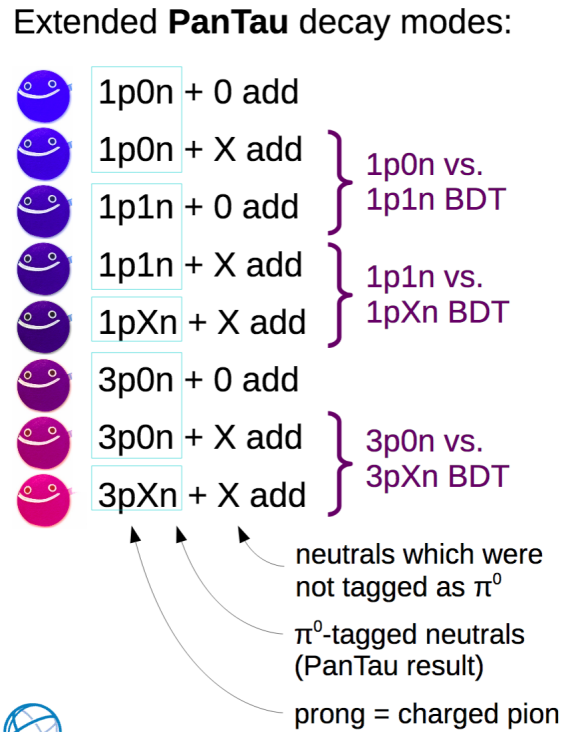
- Reconstruct all the decay products to determine decay mode

- Use tracks to identify $\pi^{\pm}$
- Use energy deposition in Had Cal and tracking to determine the $\pi^{\pm}$ in the EM Cal
- Subtract the $\pi^{\pm}$ energy from matched cluster in the EM Cal
- Identify neutral particles from remnants clusters
- Use strip-layer information to identify neutral pions (2 photons shots)

τ Decay Mode classification

- Decay mode classification using 3 BDTs
  - can be superseded by RNN based identification
- Classification of τ decay mode using:
  - decay products kinematics
  - π^0 identification
  - number of photons
- Output information for analyses
  - decay mode
  - τ 4-momentum = 4-momentum of charged + neutral pions

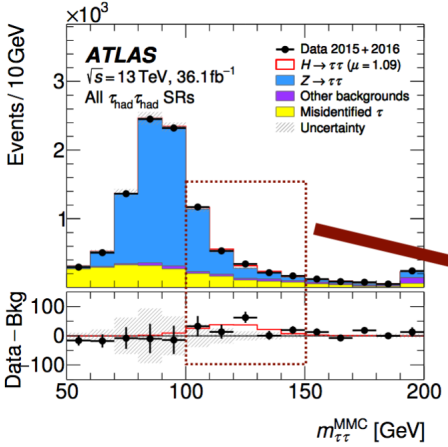
τ Decay Mode	BR [%]
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	17.4
$\tau^- \to h^- \nu_\tau$	11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$	4.8
Others	3.2

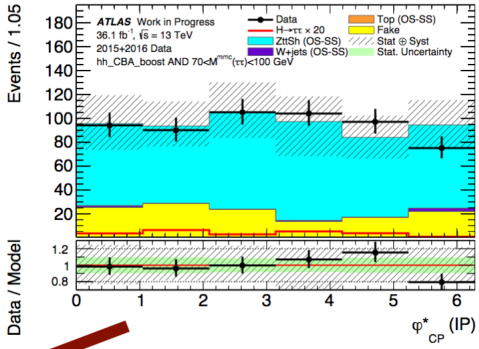


https://link.springer.com/article/10.1140/epjc/s10052-016-4110-0

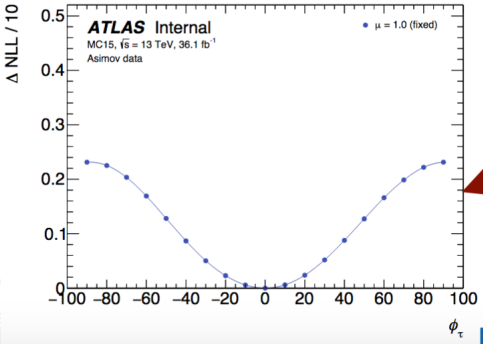
(2*boosted + 1*VBF) * (3 decay mode combinations) * (2 sub-categories) = 18 SRs

Use φ^*_{CP} in Higgs mass window (SRs)





Perform fit for different ϕ_τ hypotheses and determine minimum in dNLL



- Still far from 1σ exclusion limit

Analysis status in R21

- Focusing on hadron-hadron final state with all combinations of 1p0n and 1p1n decays
  - 3 combinations : 1p0n-1p0n (IP-IP), 1p0n-1p1n (IP-ρ), 1p1n-1p1n ($\rho - \rho$)
- Stay close to H$\rightarrow$ coupling analysis $\rightarrow$ select VBF and ggF enriched sub-categories : *Boosted Loose/Tight* and *VBF* categories
- Analysis chain has been implemented in BOOM:
  - dedicated gitlab repository: `https://gitlab.cern.ch/ATauLeptonAnalysiS/boom_CP`
  - main channels and signal regions already implemented
- Main guidance to implement analysis cuts:
  - kick-off meeting: `https://indico.cern.ch/event/804794/contributions/3361014/attachments/1814893/2966800/2019-03-20_Htt-CP-decay-overview.pdf`
  - HLep+Tau workshop : `https://indico.cern.ch/event/798098/contributions/3426905/attachments/1855464/3047366/talk.pdf`
- Currently working on V02 had-had ntuples
  - using signal samples from M. Hubner $\rightarrow$ use *Tau Spinner* to get different CP-mixing angles
  - no TauID and Tau trigger SFs (implemented but still not used)
    - Decay Mode SFs available in latest ABR (21.2.81)

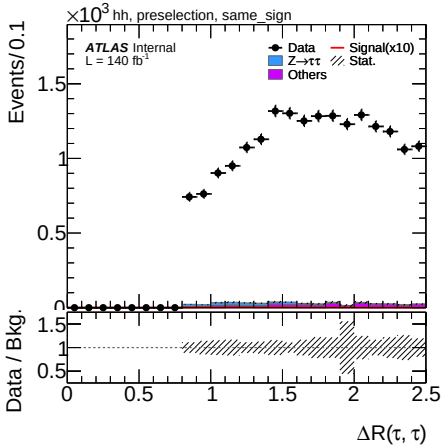
Background Estimate

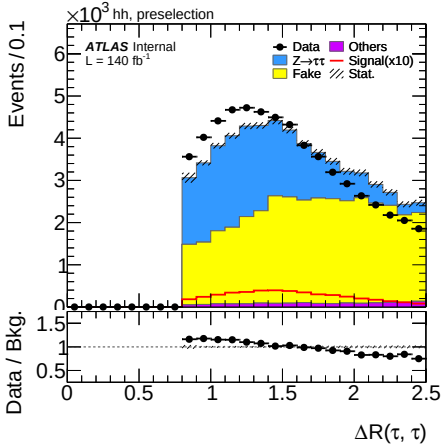
- Similar to $H \to \tau\tau$ coupling analysis
- MC estimated background
  - Sherpa NLO $Z \to \tau\tau$
  - Powheg+Pythia 8 $t\bar{t}$
  - Sherpa NLO Diboson
- Fake τ estimate (double fakes)

$$N_{fakes} = (SS^{data} - SS^{MC}) \times rQCD$$

$$rQCD = \frac{(Data - MC)_{Presel-OS}}{(Data - MC)_{Presel-SS}}$$

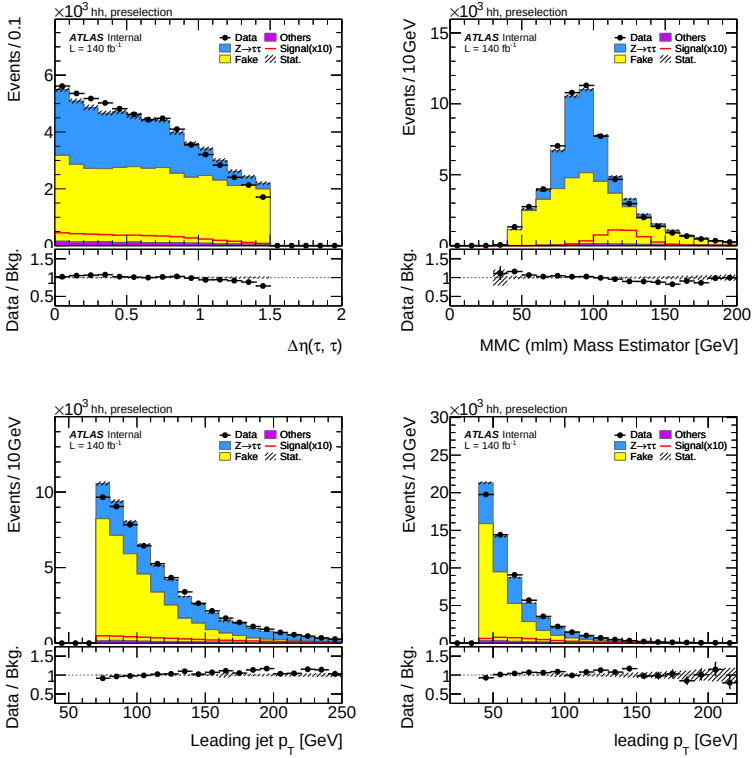
Comb.	Value
1p0n 1p0n	2.244
1p1n 1p0n	1.995
1p0n 1p1n	2.001
1p1n 1p1n	1.962





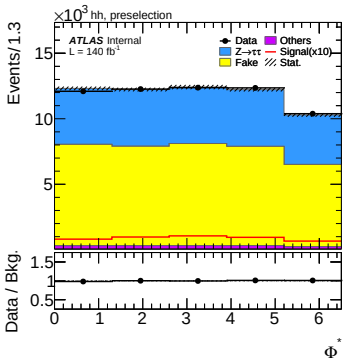
Modelling at Preselection

- This is the region in which rQCD has been derived
  - Overall normalisation good by construction, only shape effects are relevant

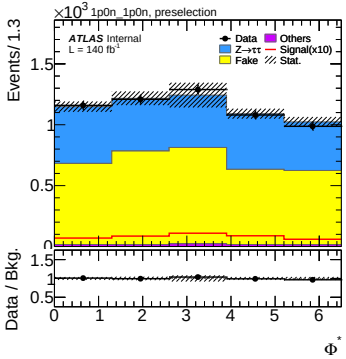


Φ^* modelling at Preselection

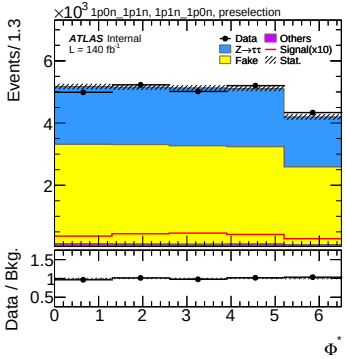
Inclusive



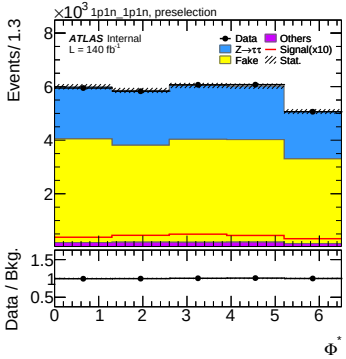
IP-IP



IP-ρ



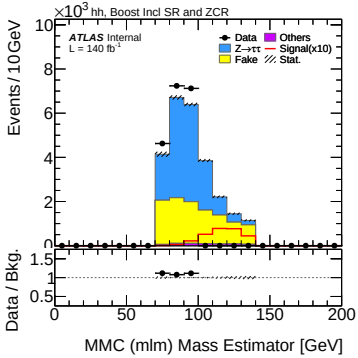
ρ-ρ

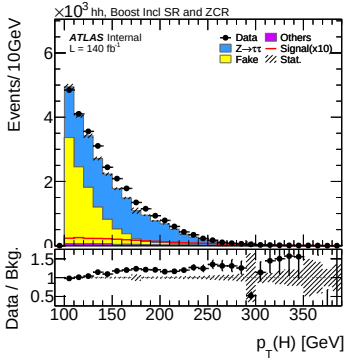


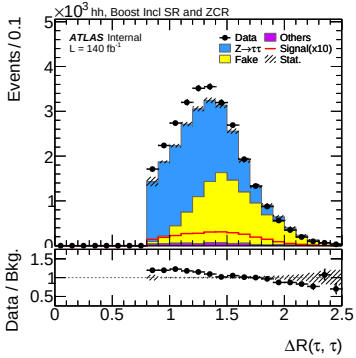
- Good modelling for Φ^* for all the different combinations
- lowest stat from IP-IP combination (expected)

Modelling in Inclusive Boosted/VBF regions

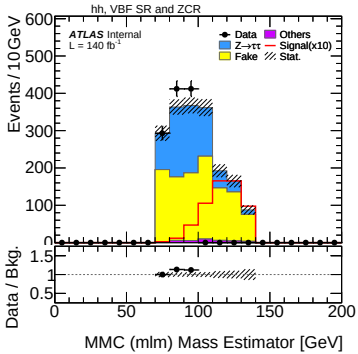
Boosted

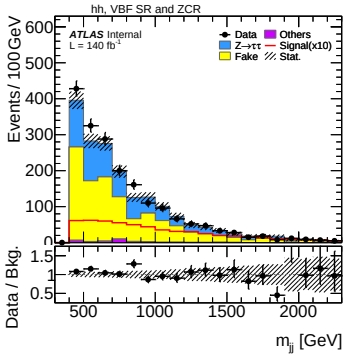


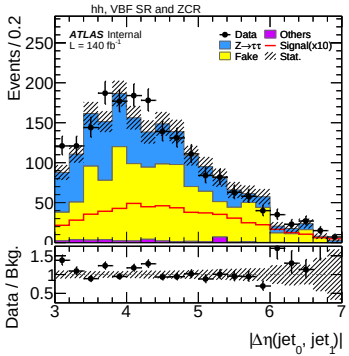




VBF



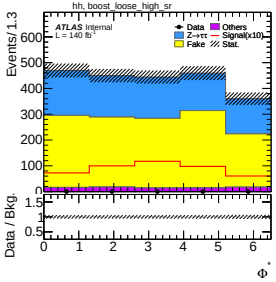




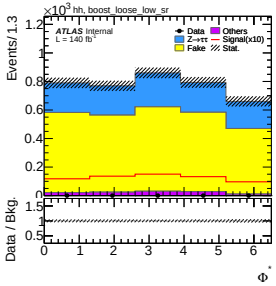
- Overall *decent* modelling in inclusive regions
- Cut on MMC to define:
  - SR : 100 GeV < MMC < 140 GeV $\rightarrow$ enriched in signal events
  - ZCR : MMC < 100 GeV $\rightarrow Z \rightarrow \tau\tau$ enriched region

Φ^* distributions in SRs

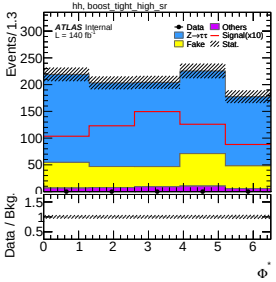
Boost Loose High



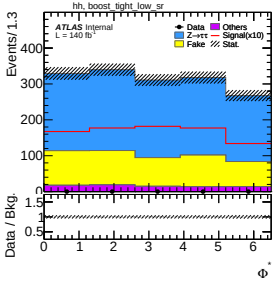
Boost Loose Low



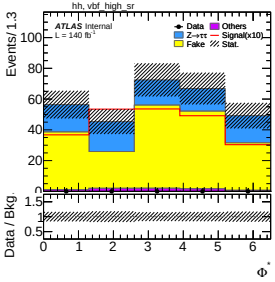
Boost Tight High



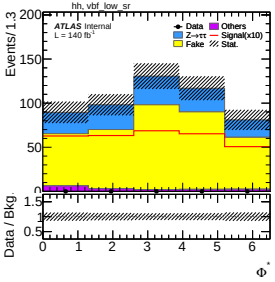
Boost Tight Low



VBF High



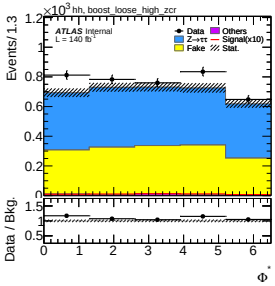
VBF Low



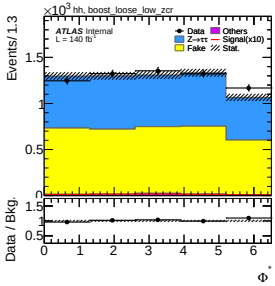
- Expected ϕ^* flat distribution for background
- Binning optimisation studies ongoing
- Distributions for different decay mode combinations in backup

Φ^* distributions in Z CRs

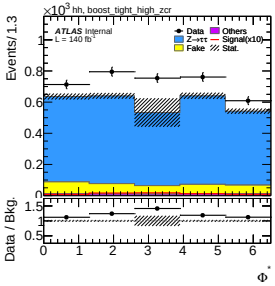
Boost Loose High



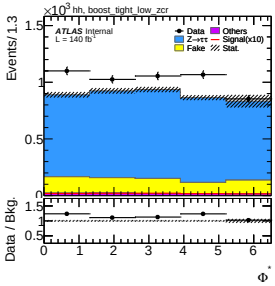
Boost Loose Low



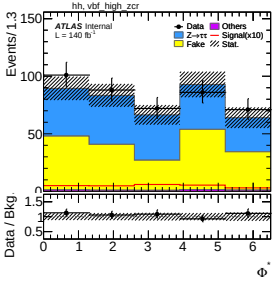
Boost Tight High



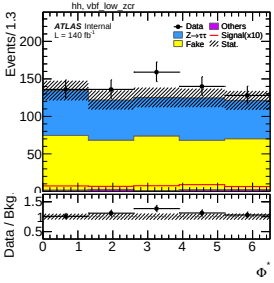
Boost Tight Low



VBF High



VBF Low



- This region can be used to extract $Z \to \tau\tau$ normalisation factor
- Large *Fake* contamination both in Boost Loose and VBF region (expected)
- Distributions for different decay mode combinations in backup

Conclusion and next steps

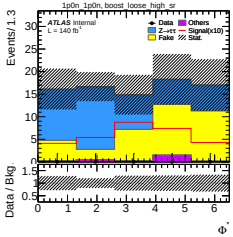
- First results using BOOM for HiggsCP analysis have been showed
  - different kind of plots already available and added can be added based on needed studies
  - modelling looks good in most of the cases, but τ-related SFs are missing
  - distributions for main variables used to define Boosted/VBF regions have been showed

- Workspace example available here:
  `/afs/cern.ch/user/a/ademaria/public/ForHiggsCP/wsi_15161718_hhdecays_sr_2019.6.26_fakesummed.root`
  - includes templates for different CP mixing angles
  - includes nominal + some weight systematics
  - includes theory systematics for $Z \to \tau\tau$ and signal
  - mainly check region nomenclature and split are as expected

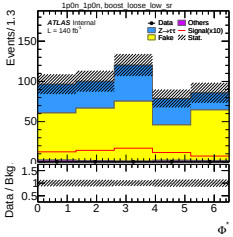
Φ^* distributions in Boost Loose SRs (split in decay mode comb.)

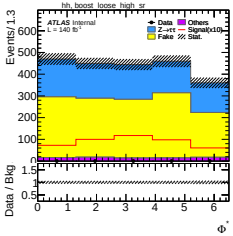
Boost Loose High (Incl) | Boost Loose High (Split) | Boost Loose Low (Incl) | Boost Loose Low (Spli

IP-IP

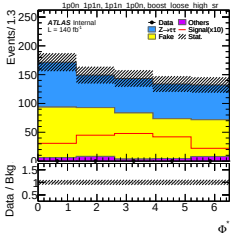


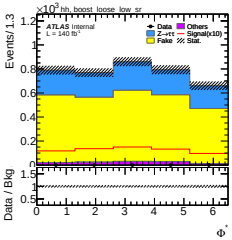
IP-IP



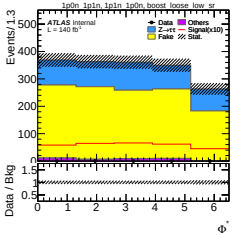


IP-ρ

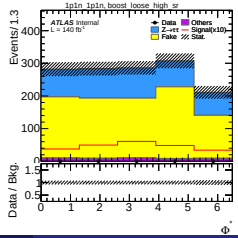




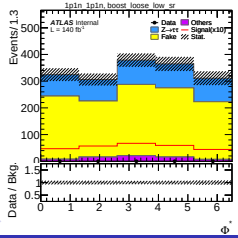
IP-ρ



ρ-ρ



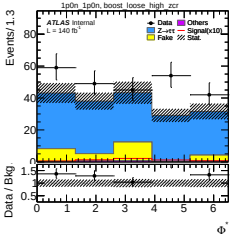
ρ-ρ

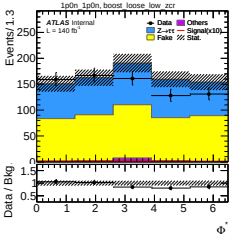


Φ^* distributions in Boost Loose Z CRs (split in decay mode comb.)

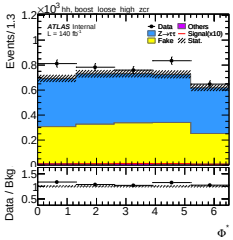
Boost Loose High (Incl) | Boost Loose High (Split) | Boost Loose Low (Incl) | Boost Loose Low (Spli

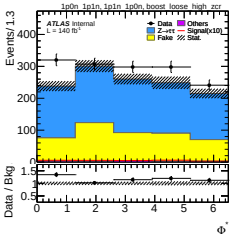
IP-IP

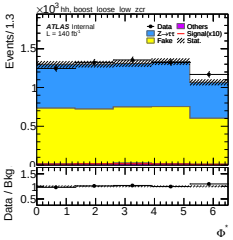


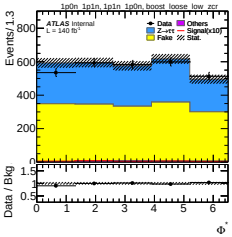


IP-ρ

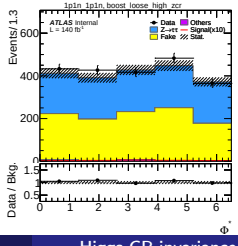


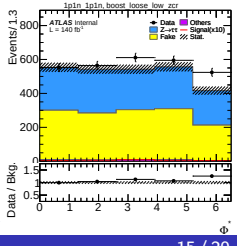






ρ-ρ

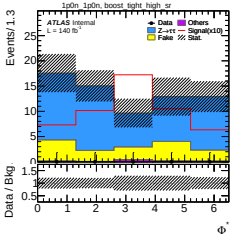


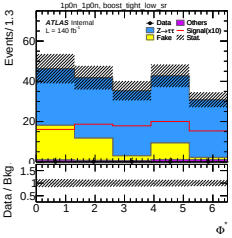


Φ^* distributions in Boost Tight SRs (split in decay mode comb.)

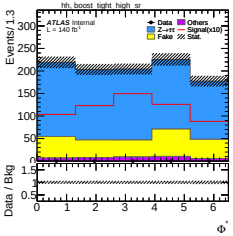
Boost Tight High (Incl) | Boost Tight High (Split) | Boost Tight Low (Incl) | Boost Tight Low (Split)

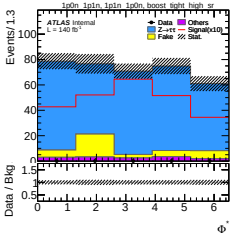
IP-IP

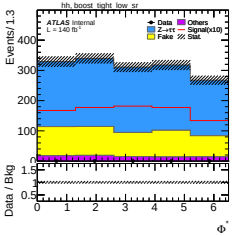


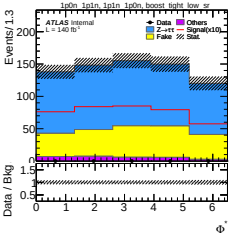


IP-ρ

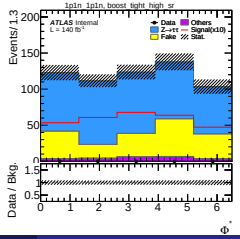


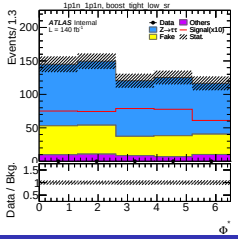






ρ-ρ

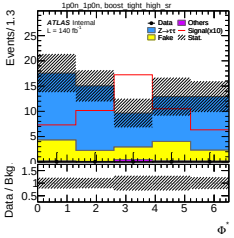


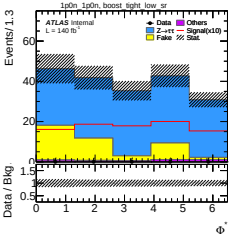


Φ^* distributions in Boost Tight SRs (split in decay mode comb.)

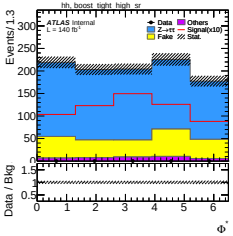
Boost Tight High (Incl) | Boost Tight High (Split) | Boost Tight Low (Incl) | Boost Tight Low (Split

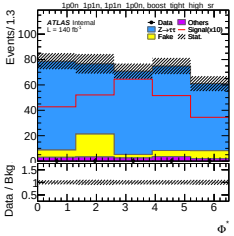
IP-IP

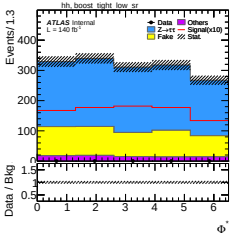


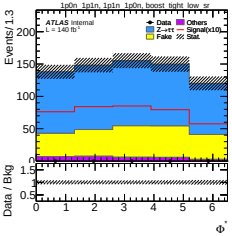


IP-ρ

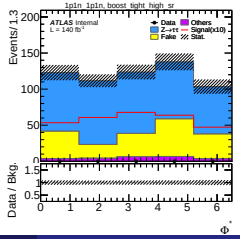


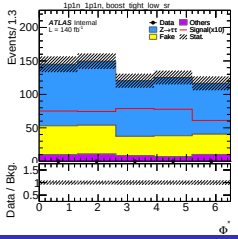






ρ-ρ

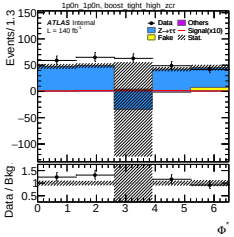


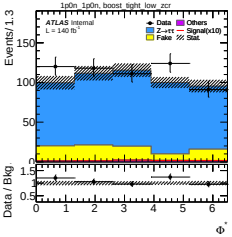


Φ^* distributions in Boost Tight Z CRs (split in decay mode comb.)

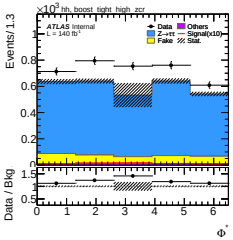
Boost Tight High (Incl) | Boost Tight High (Split) | Boost Tight Low (Incl) | Boost Tight Low (Split

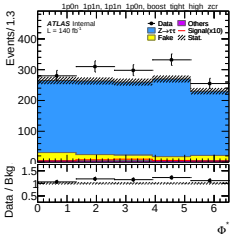
IP-IP

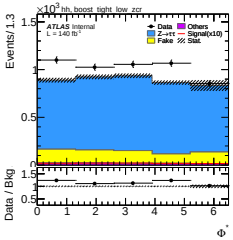


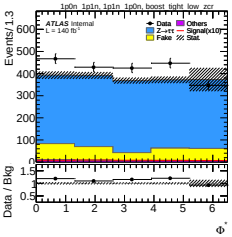


IP-ρ

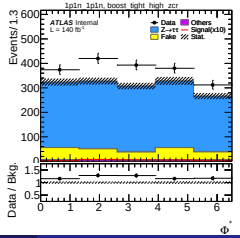


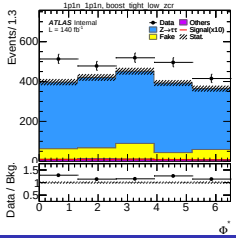






ρ-ρ

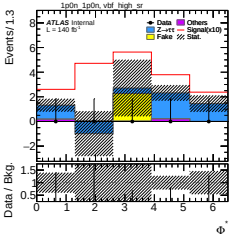


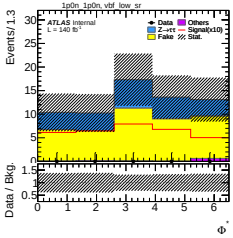


Φ^* distributions in VBF SRs (split in decay mode comb.)

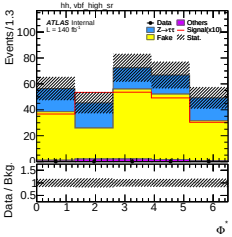
VBF High (Incl) | VBF High (Split) | VBF Low (Incl) | VBF Low (Split)

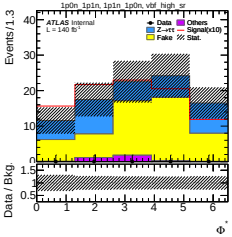
IP-IP

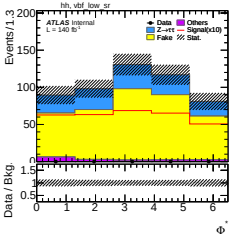


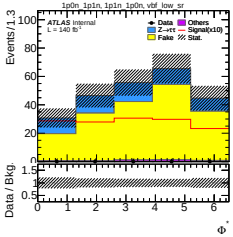


IP-ρ

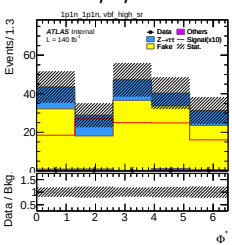


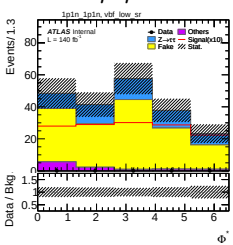






ρ-ρ





Φ^* distributions in VBF Z CRs (split in decay mode comb.)

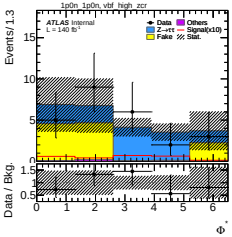
VBF High (Incl)

VBF High (Split)

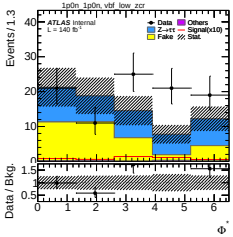
VBF Low (Incl)

VBF Low (Split)

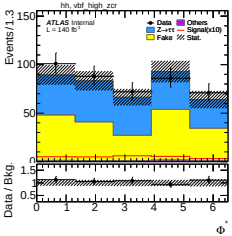
IP-IP



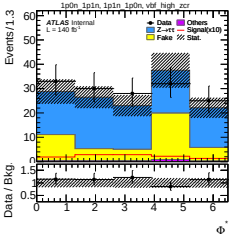
IP-IP

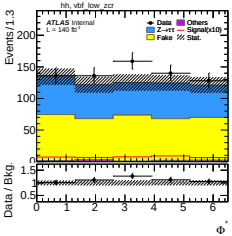


IP-ρ

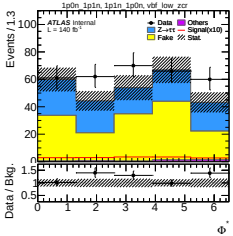


IP-ρ

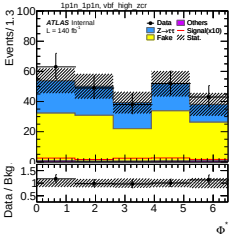




IP-ρ



ρ-ρ



ρ-ρ