$HH \rightarrow bb\tau\tau$ *Analysis*
And
Simulating A Non – Perfect ITk Detector for the ATLAS Experiment

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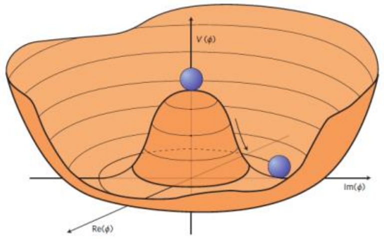
ATLAS EXPERIMENT
DESY.

Di-Higgs

- Discovery of Higgs was announced in 2012 by the ATLAS and CMS collaborations.
- How do we know if this is the SM Higgs?
  - Or if Higgs is responsible for EWSB?
- Answer is, by measuring Higgs self coupling.
  - Validate SM Higgs.
  - By validating the Mexican Hat Shape of the Higgs Potential (see equation below).
  - Which also tests the EWSB
- The Higgs Potential has the form:

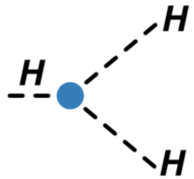


$$V(\phi) = \mu^2 H^2 + \lambda\mu H^3 + \lambda H^4$$

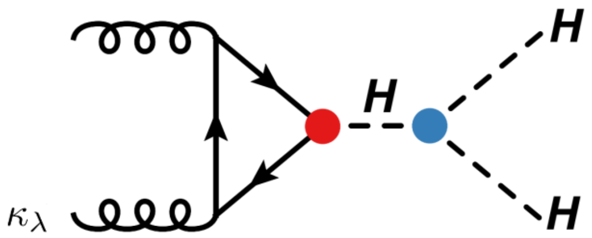
Higgs Quadrilinear Coupling

Higgs mass, $m_H^2 = 2\mu^2$

Di-Higgs/Higgs Trilinear Coupling



- Study of Higgs self coupling requires study of Di-Higgs.
  - Difficulties with Di-Higgs: Production cross section is 1000 times smaller than single Higgs production!
- Feynman diagrams for non-resonant production Di-Higgs.



Gluon-Gluon Fusion (ggF)

$HH \to b\bar{b}\tau^+\tau^-$ Analysis

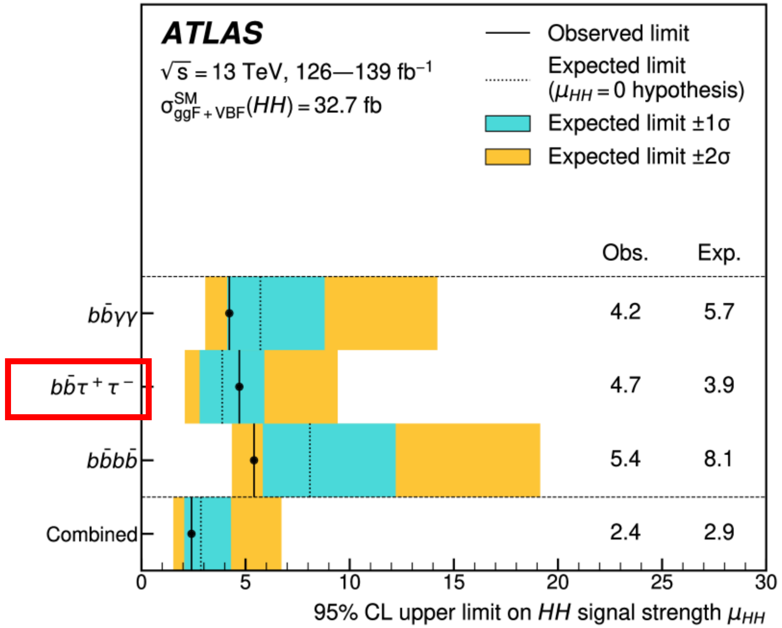
- $HH \to b\bar{b}b\bar{b}$
  - High branching ratio
  - High background from QCD Processes
- $HH \to b\bar{b}\gamma\gamma$
  - Low background
  - Low branching ratio
- $HH \to b\bar{b}\tau^+\tau^-$
  - Significant branching ratio
  - Relatively low background

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

- $HH \to bb\tau\tau$

  →highest sensitivity to Di-Higgs Coupling

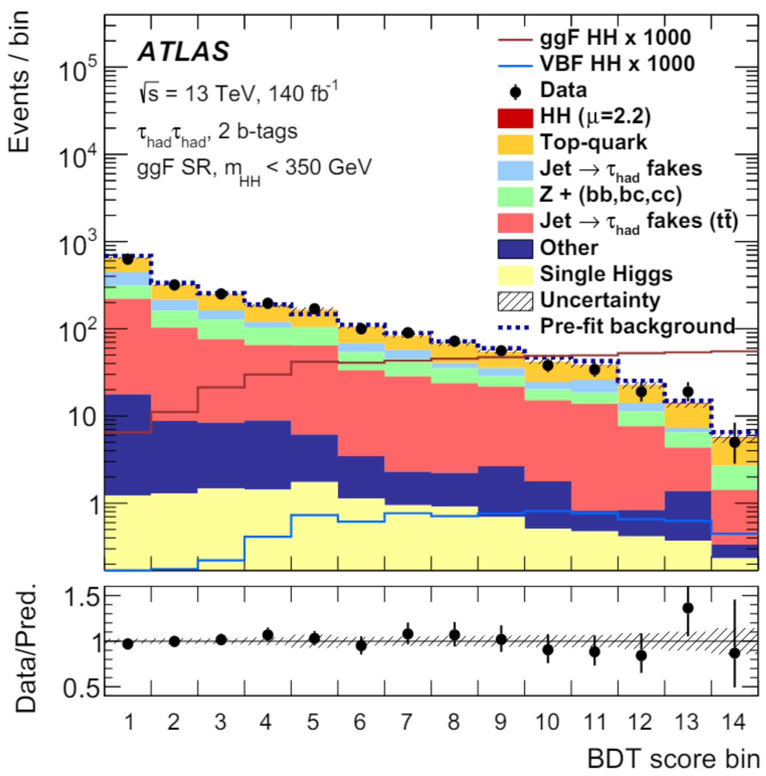
  →I will be looking at events with hadronic tau decays for Run2+Run3.

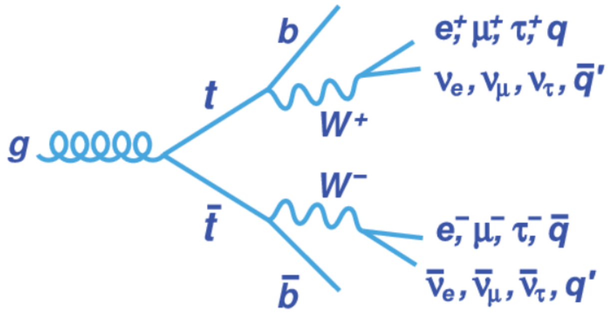


TauTau decay channels.

Background in $HH \rightarrow b\bar{b}\tau^{+}\tau^{-}$

- ttbar and Z processes form the most dominant background in this channel.
- ttbar decays into bbWW and subsequently the Ws decays hadronically or leptonically.
- If both Ws decay leptonically into τ, it will have the same signature as the signal. i.e.
  ttbar $\longrightarrow b\bar{b}W^{-}W^{+} \longrightarrow b\bar{b}\tau^{+}\tau^{-}$
- Currently focusing on studying Top Bkg modelling using a dedicated TopCR in the current analysis framework.

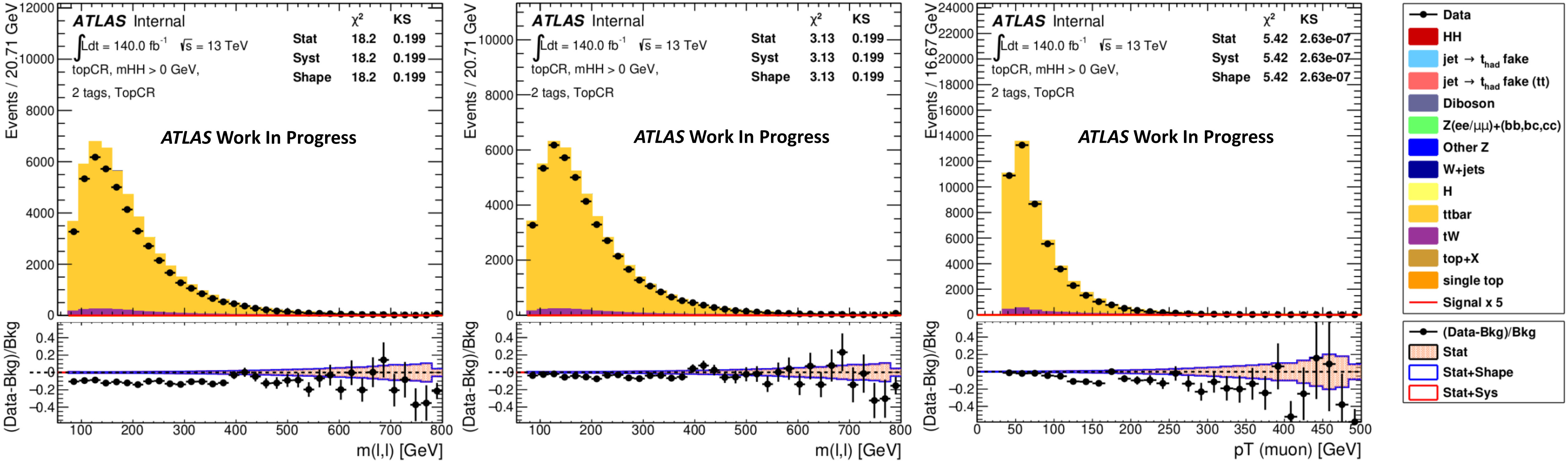




Feynman Diagram showing a gluon decaying into a pair of Top quarks which then decay in b and W.

TopCR in $HH \rightarrow b\bar{b}\tau^{+}\tau^{-}$

- Cuts applied are:
  - Two b-jets
  - The two opposite sign leptons that are required be an electron and a muon
- First attempt at reproducing results for Run2:



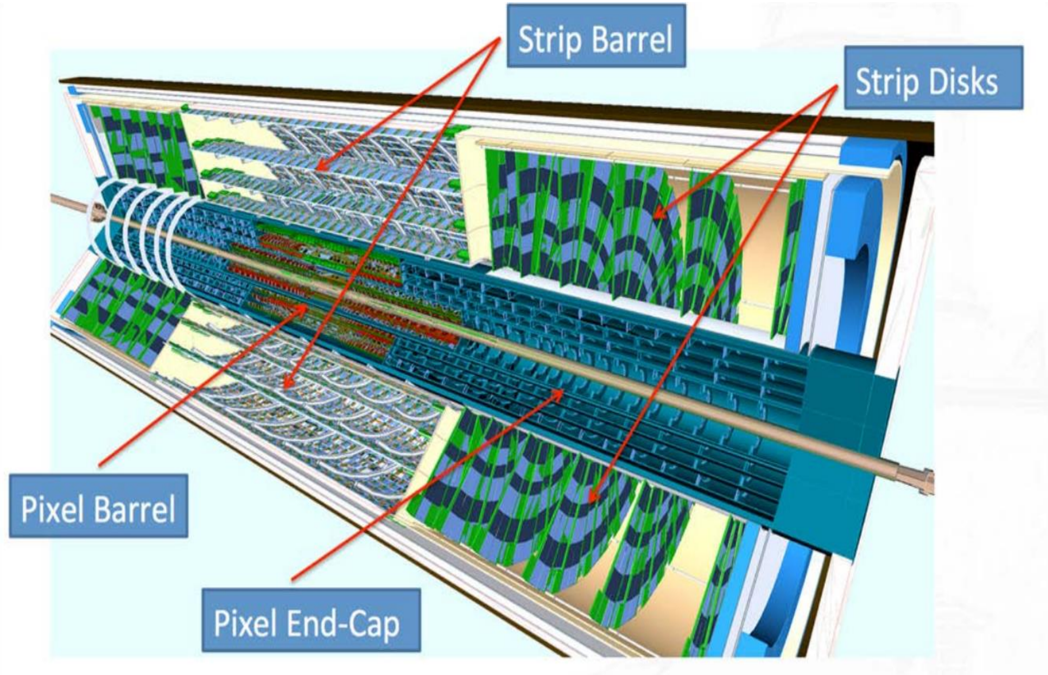
Invariant mass of the two Leptons Before normalizing.

Invariant mass of the two Leptons After normalizing with SF = 0.93

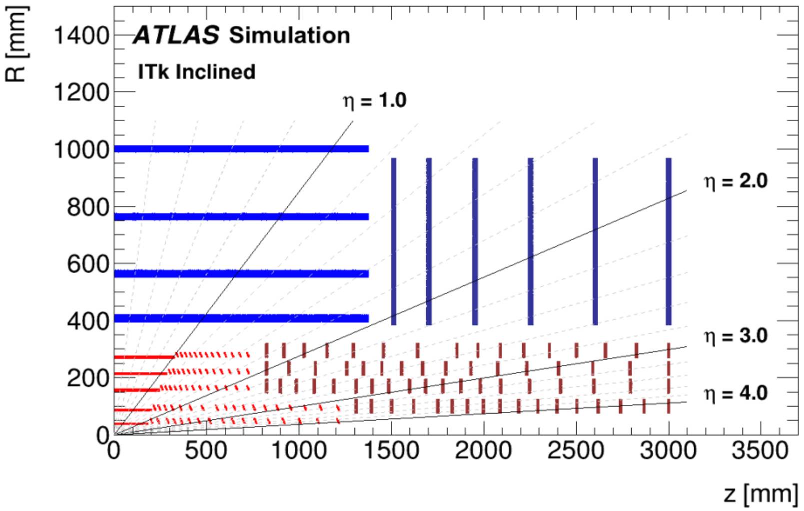
MC overestimates data at high pT After normalizing with SF = 0.93

The ITk Detector

- ITk is the New Detector to replace the current Inner Tracking Detector for HL-LHC.
- Why replace current detector?
  - High Luminosity will lead to:
    - More pile-up (<μ> = 200)
    - As a consequence larger data collection rates
    - More radiation damage
  - The new all-silicon tracker will:
    - Maintain its performance
    - Tolerate about ten times more radiation dose



ITk Layout



- Pixel Detector
  - Five pixel layers with replaceable inner 2 layers and end-cap layers
  - Covers the region, $|\eta| < 4$
- Strip Detector
  - Four layers of paired stereo modules in the barrel regions and 6 at the end-caps
  - Covers the region, $|\eta| < 2.7$

Simulating Non-Perfect ITk

- No detector is perfect => It is important to study a non-perfect ITk which may have some non-functional modules, staves or some of the modules are noisy. It is crucial to simulate the detector performance e.g. for b-tagging or tau-identification. This requires the simulation of non-perfect detector beforehand.

- Two methods were added to Athena (ATLAS Data Analysis Framework) that can mask the modules.

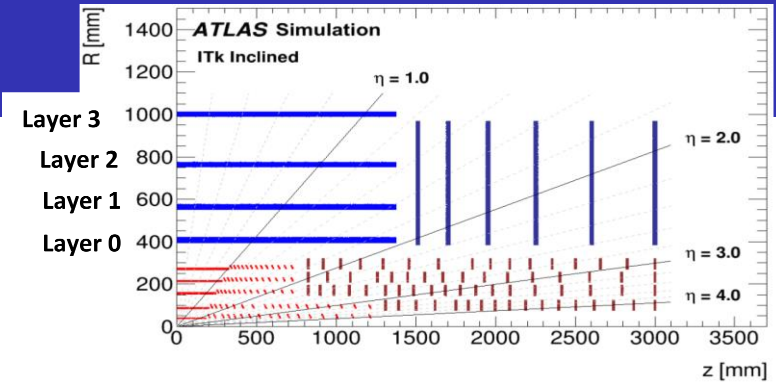
- These methods allow masking of layers, modules, regions in eta or phi (e.g. staves), a random percentage etc.

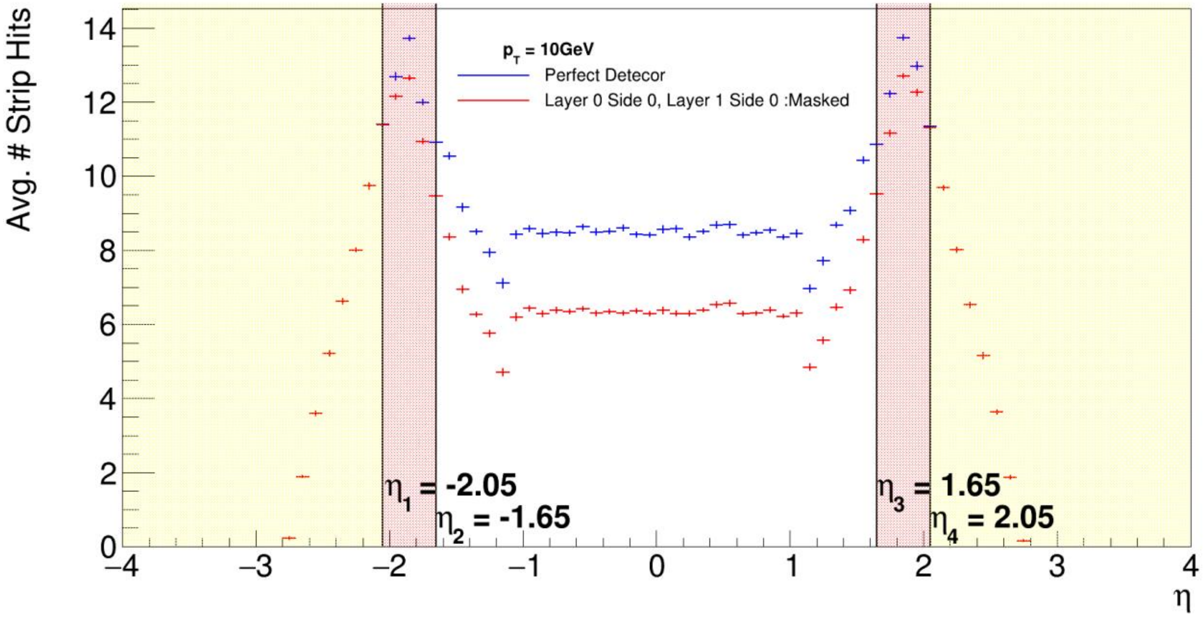
- Each module in ITk has an ID. This ID can be passed to Athena in two formats JSON or SQLite Database.

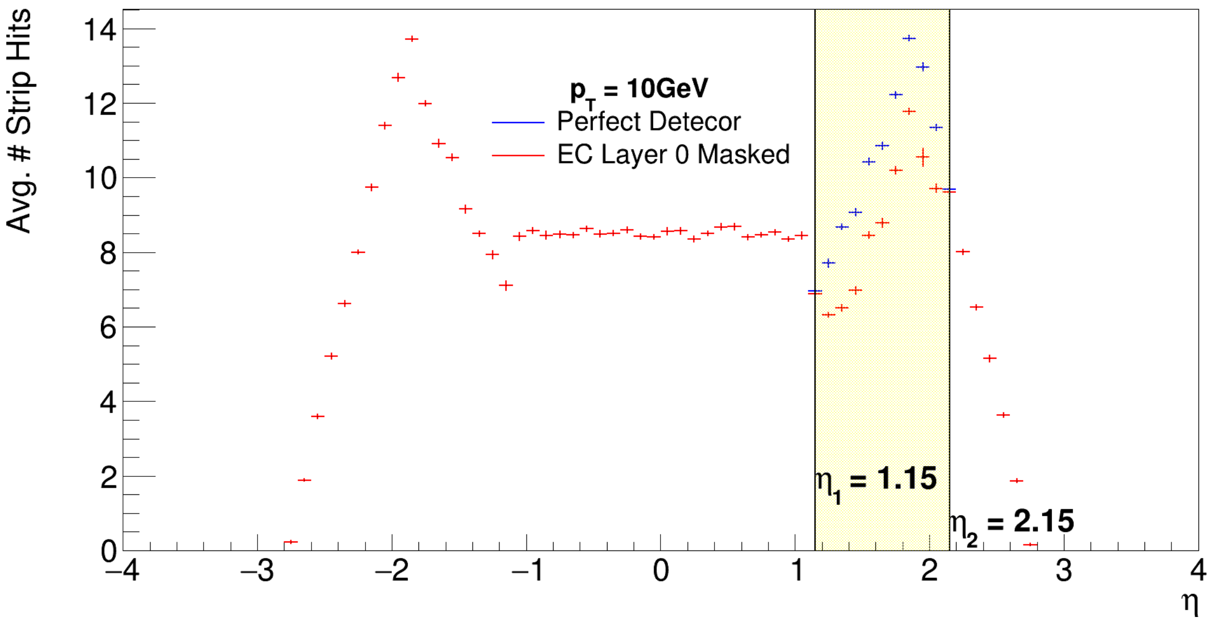
- Athena masks these modules in simulation.

- My code is now part of the official ATLAS Reconstruction Framework.(link).

Results from Masking of Modules







Masking Layer 0 Side 0 and Layer 1 Side 0

The Avg. number of hits drops by 2 for the particles passing through both layers and drops by 1 for the pseudorapidity region from layer 1 to layer 2 i.e. when the particles pass through a single layer.

Masking EndCap Layer 0

The Avg. number of hits drops by 2 in the pseudorapidity region corresponding to the End-cap layer 0.

Summary and Future Work

- Started working on analysis for my thesis i.e. HH→bbtautau channel with Run2 + Run3 data.
- Combined with other channels this will give sensitivity close to SM cross-section.
- Current working on evaluating the modelling of the main ttbar background and the related sysematic uncertainties.
- TopCR has been added to the Di-Higgs Analysis Framework.
- Looked at TopCR with Run2 Data, next step will be to use Run3 Data.
- Attempt to add tW validation region as well.

- Added tools to model a more realistic ITk, now qualified as ATLAS author.
- Module masking tools for the Strip Detector of ITk have been added.
- Further working on developing and adding Noise simulation tools for the ITk.

Thank you