Preliminary investigations towards the measurement of the Higgs boson self-coupling with $hh \to bb^{-}\tau^{+}\tau^{-}$

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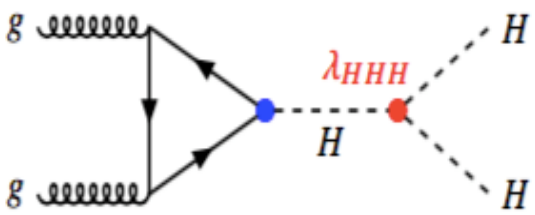
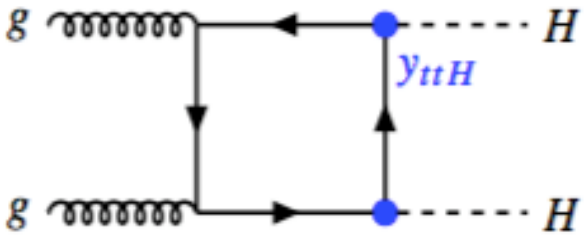
Higgs boson self-coupling modifier

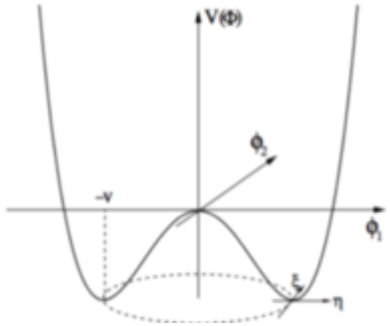
- The BEH mechanism not only predicts the existence of a massive scalar particle, but also requires this scalar particle to couple to itself.

Higgs potential: $$V(\phi) = \frac{1}{2}m_h^2 h^2 + \lambda v h^3 + \frac{\lambda}{4}h^4 = m_h^2\frac{h^2}{2} + \lambda_{HHH}\frac{h^3}{3!} + \lambda_{HHHH}\frac{h^4}{4!}$$



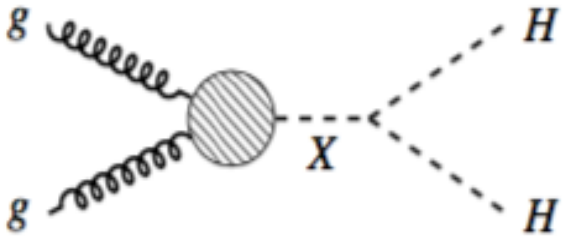


A direct probe to λ_{HHH} is to measure the non-resonant di-Higgs production via the triangle diagram



- The Higgs boson self-coupling modifier due to BSM scenarios is defined as $\kappa\lambda = \lambda_{HHH}/\lambda_{SM}$.
- In the SM, pairs of Higgs bosons at the LHC are dominantly produced in gluon-gluon fusion (ggF) processes, namely via a loop of top quarks

Observing the production of Higgs boson pairs (*HH*) and measuring the Higgs boson trilinear self-coupling λ_{HHH} is a crucial validation of the BEH mechanism



BSM theories predict heavy resonances that could decay into a pair of the SM Higgs bosons, such as a heavy spin-0 scalar *X* in two-Higgs-doublet models

Experimental Signatures

	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%

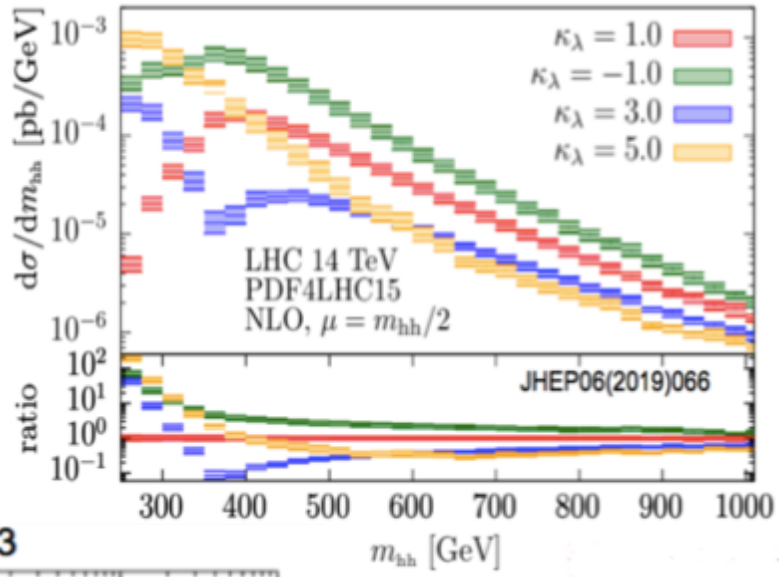
- Relatively small background
- Relatively high branching ratio
- High trigger efficiency

Kinematics depend on Higgs self-coupling

- Additional handle to κ_λ

HH: multiple final states

- H→bb is the protagonist



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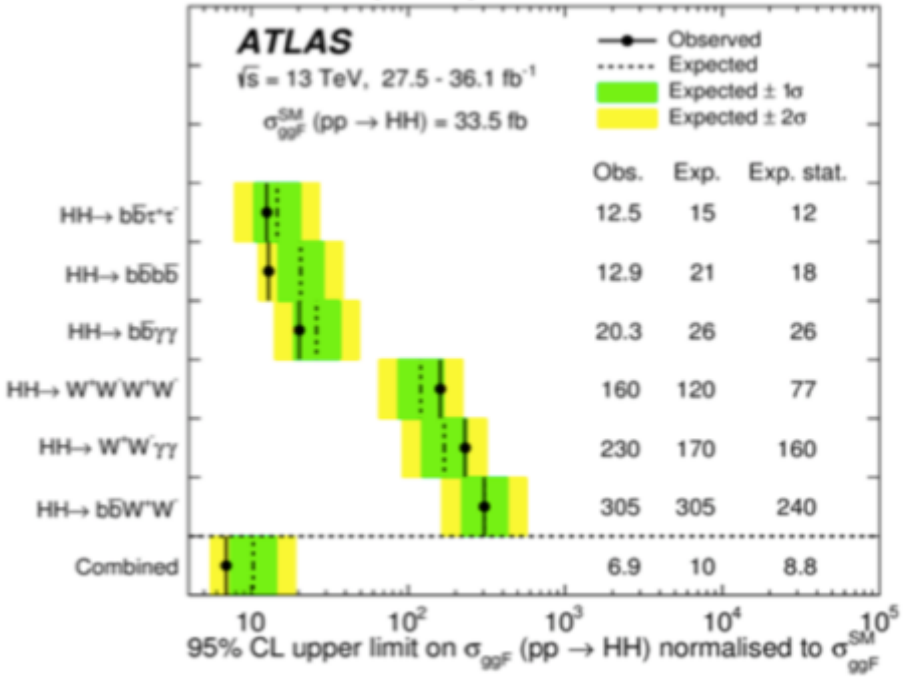
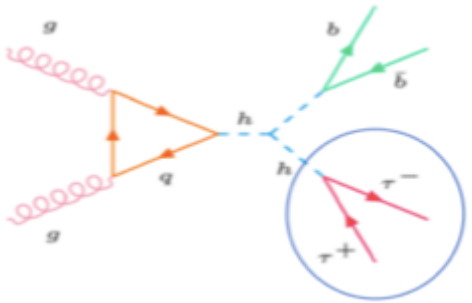
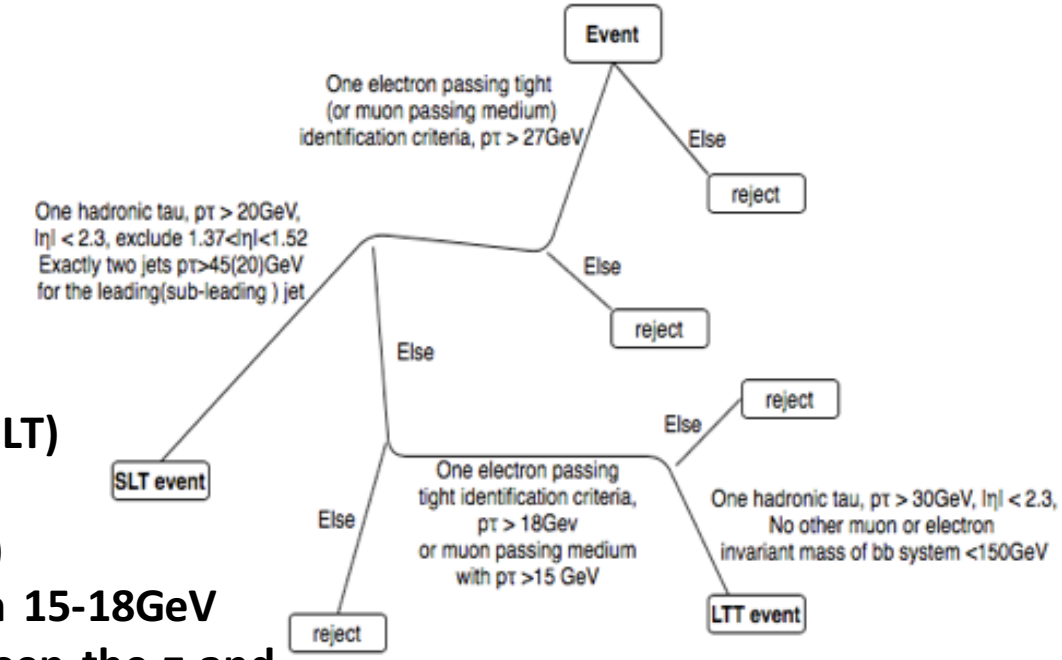


***bbττ* is the most sensitive decay channel with 36 fb^{-1} data**

Event Selection and Background Estimation

The $b\bar{b}\tau^+\tau^-$ analysis looks for final states with two b-tagged jets and two τ-leptons. In the $\tau_{lep}\tau_{had}$ channel, events are triggered by single lepton triggers (SLT), requiring an electron or a muon in the final state, or by the coincidence of a lepton trigger with a hadronic τ trigger, Lepton Tau Triggers(LTT)





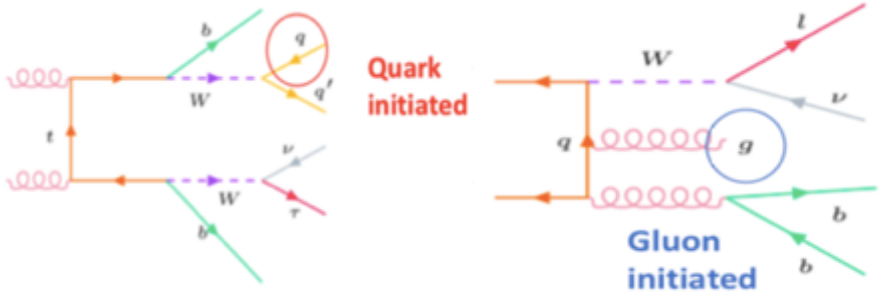
- **Single Lepton Triggers (SLT)**
  - e/μ **triggers >26GeV**
- **Lepton tau triggers (LTT)**
  - **Thresholds between 15-18GeV**
  - **Opposite sign between the τ and the lepton**
  - **Exactly two *b*-tagged jets**

The selection for τ, η to be less than 2.3 differs from the selection in the hadhad channel, and has been chosen as an analysis optimization choice from previous rounds of the analysis

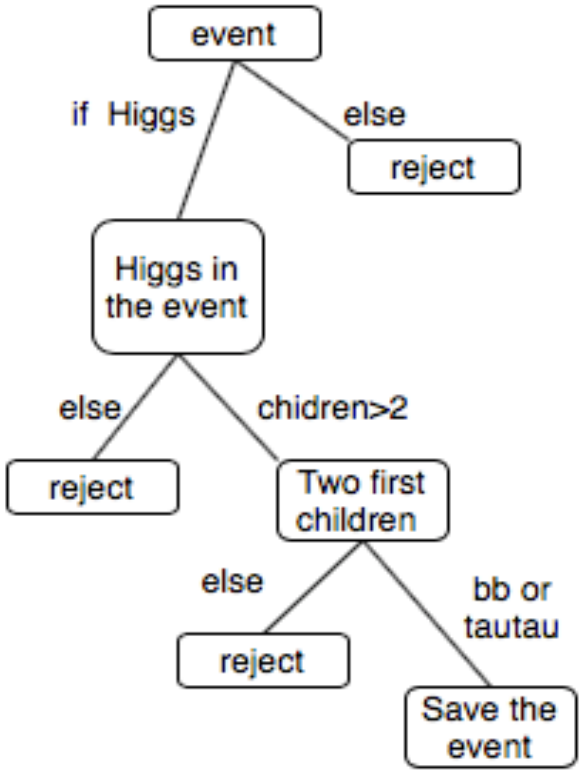
The background due to a jet faking the τ_{had} is estimated by a data driven fake factor method

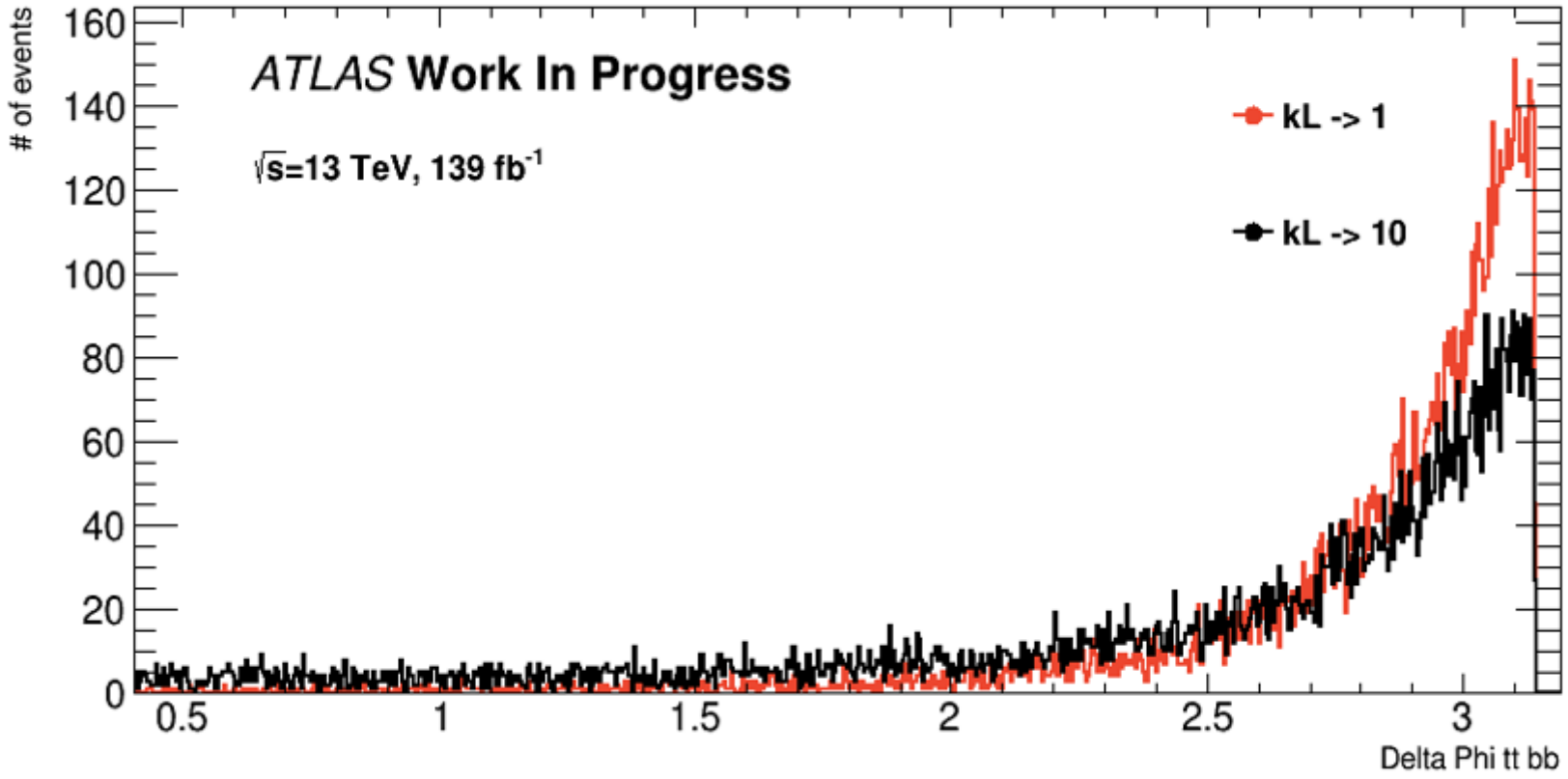
- FFs computed separately for each process ($t\bar{t}$, W+jets, multi-jets) in a dedicated CR
- Contribution from true taus and other backgrounds is subtracted
- $FF = \frac{N_{tau}}{N_{anti-tau}}$, $NA = FF \times NB$. FF is calculated for each CR, depends on channel/targeted process

Lephad: a combined ***FF*** is calculated for combining the Gluon initiated and quark initiated ***FFs***



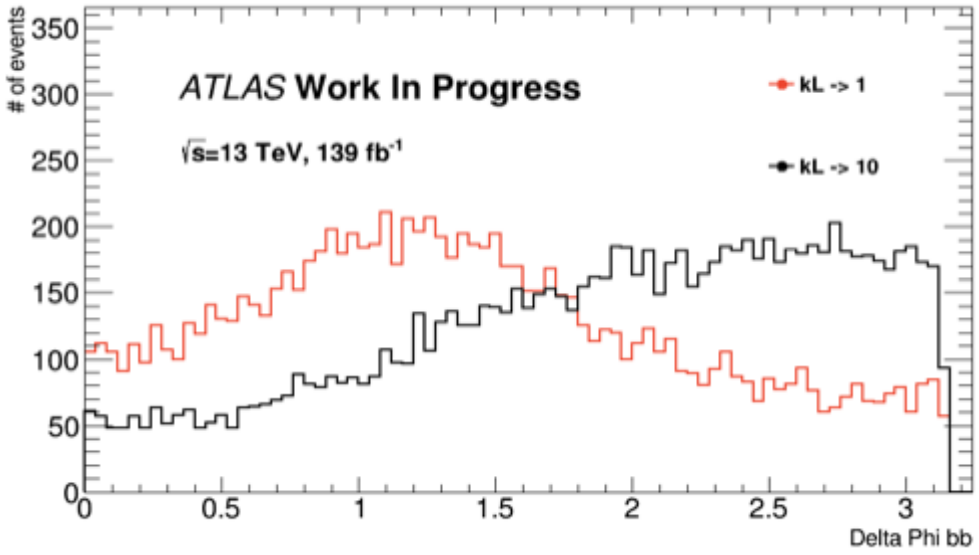
Generator Level Kinematic Variables

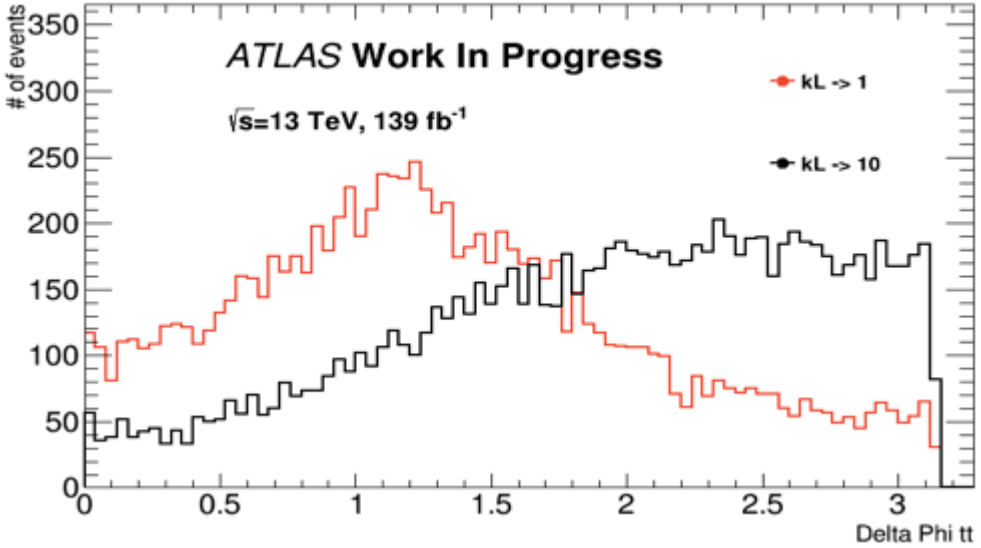


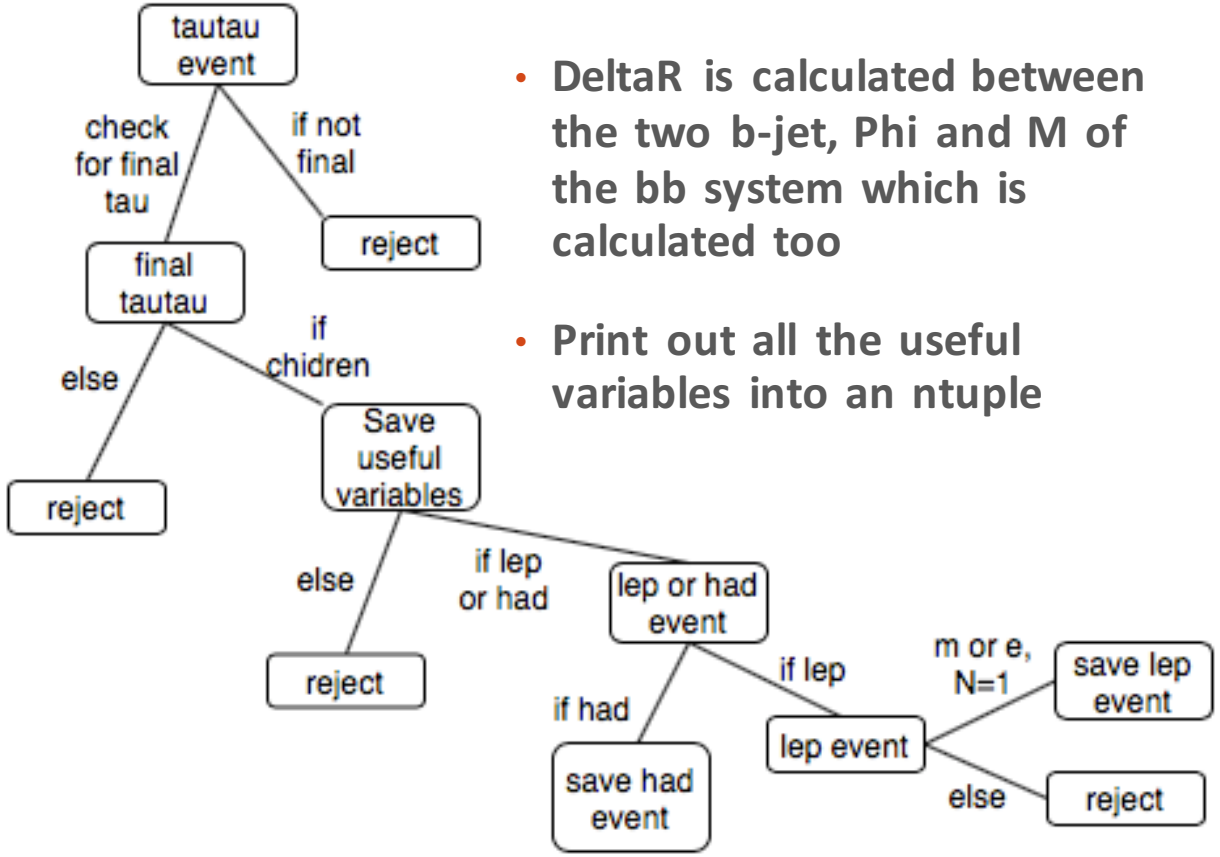


- From each particle 4-vector, we extract useful variables such as Pt,eta,Phi,M and the 4-vector of the system of particles
- Keeps particles that at the same event contain Higgs that decay to bb and tautau

Generator Level level bbττ



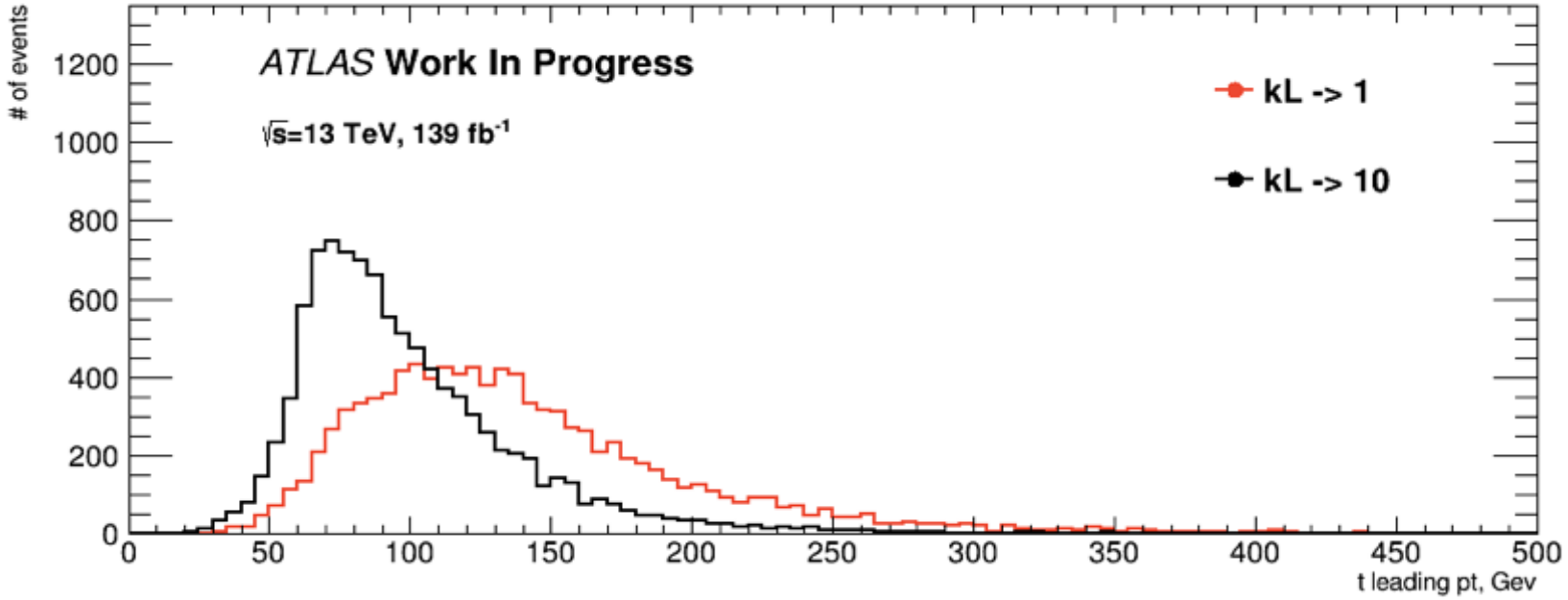


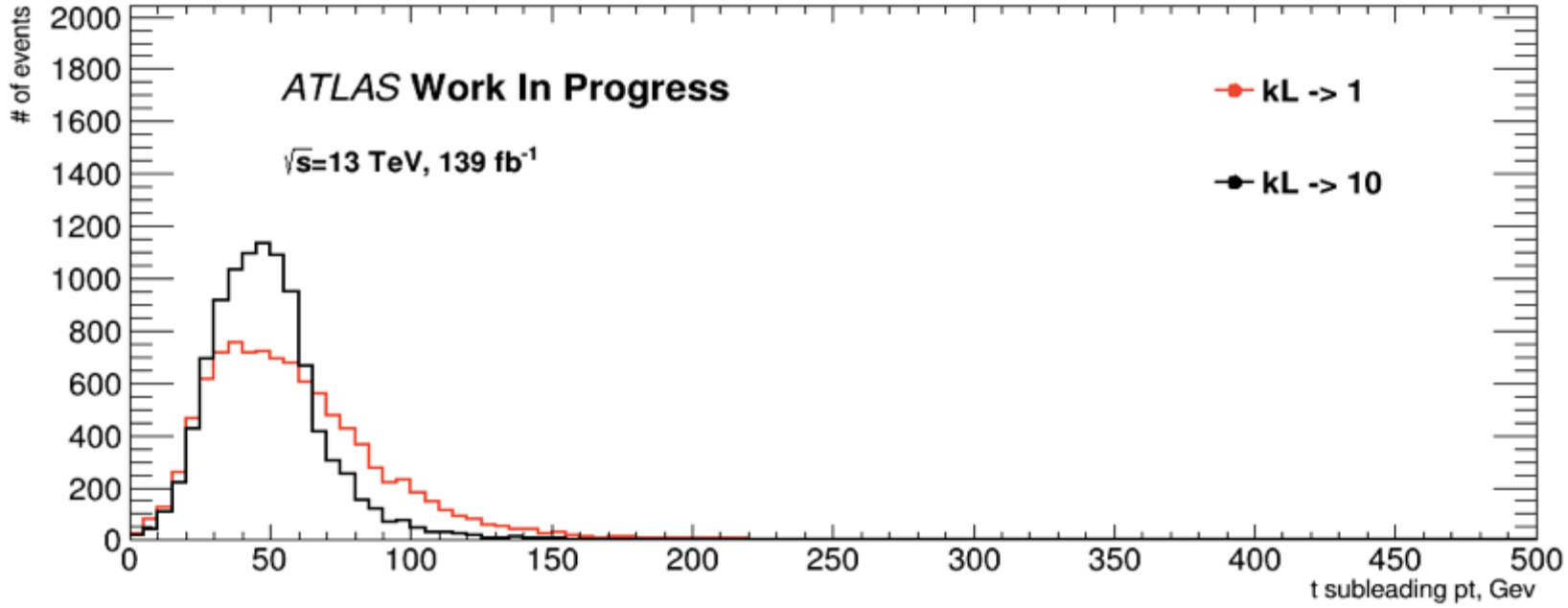


- Tlorentzvectors of bb to calculate the m_{bb} and other variables of their system from the 4 vector of it
- DeltaR is calculated between the two b-jet, Phi and M of the bb system which is calculated too
- Print out all the useful variables into an ntuple

- From each tau and child we keep pdgId, status, barcode and pt
- From t_{lep} and t_{had} we need pt, eta, phi, m, E and get their 4 vectors

Pre-Selection useful variables





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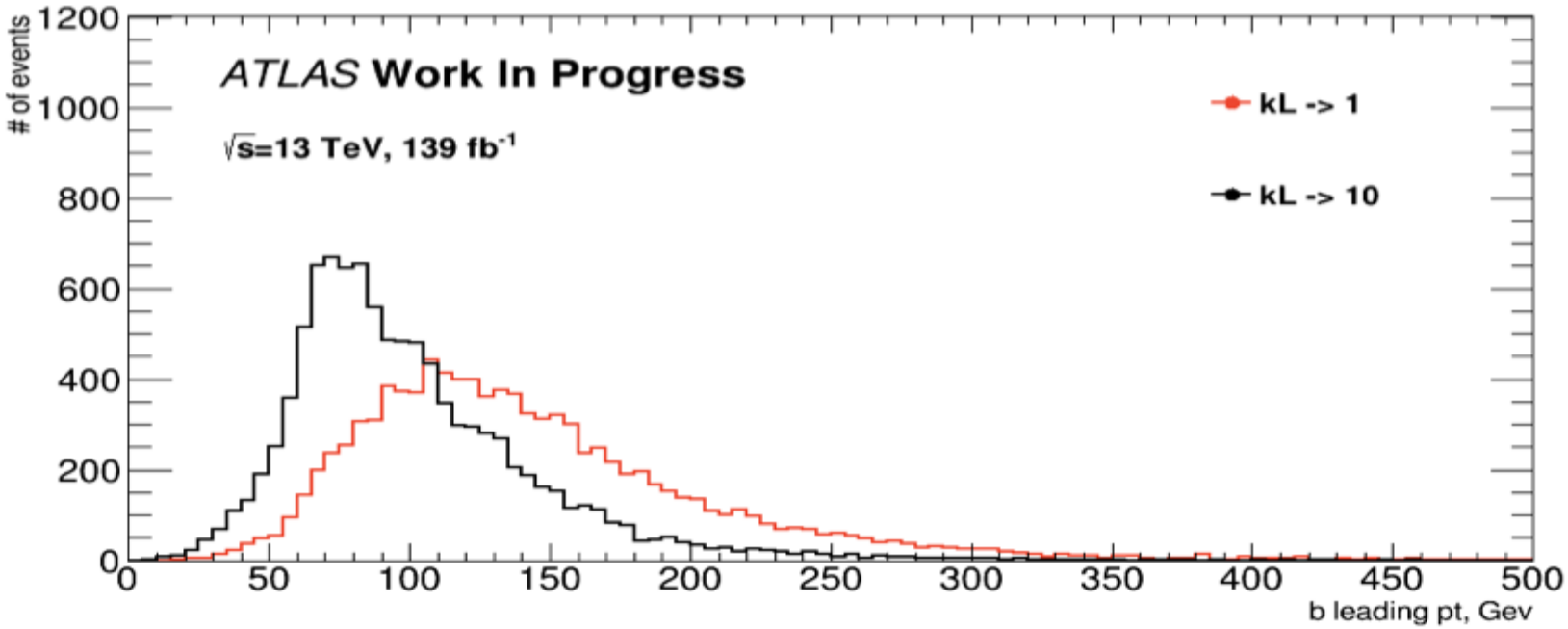

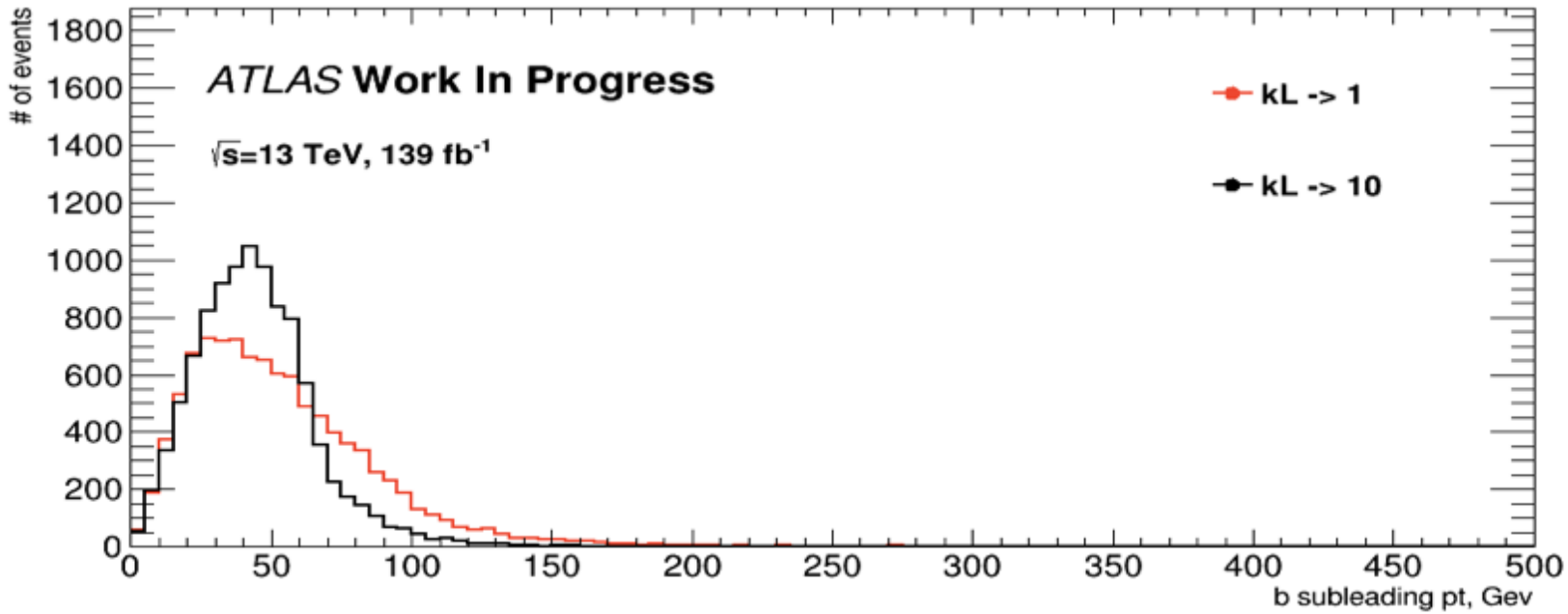

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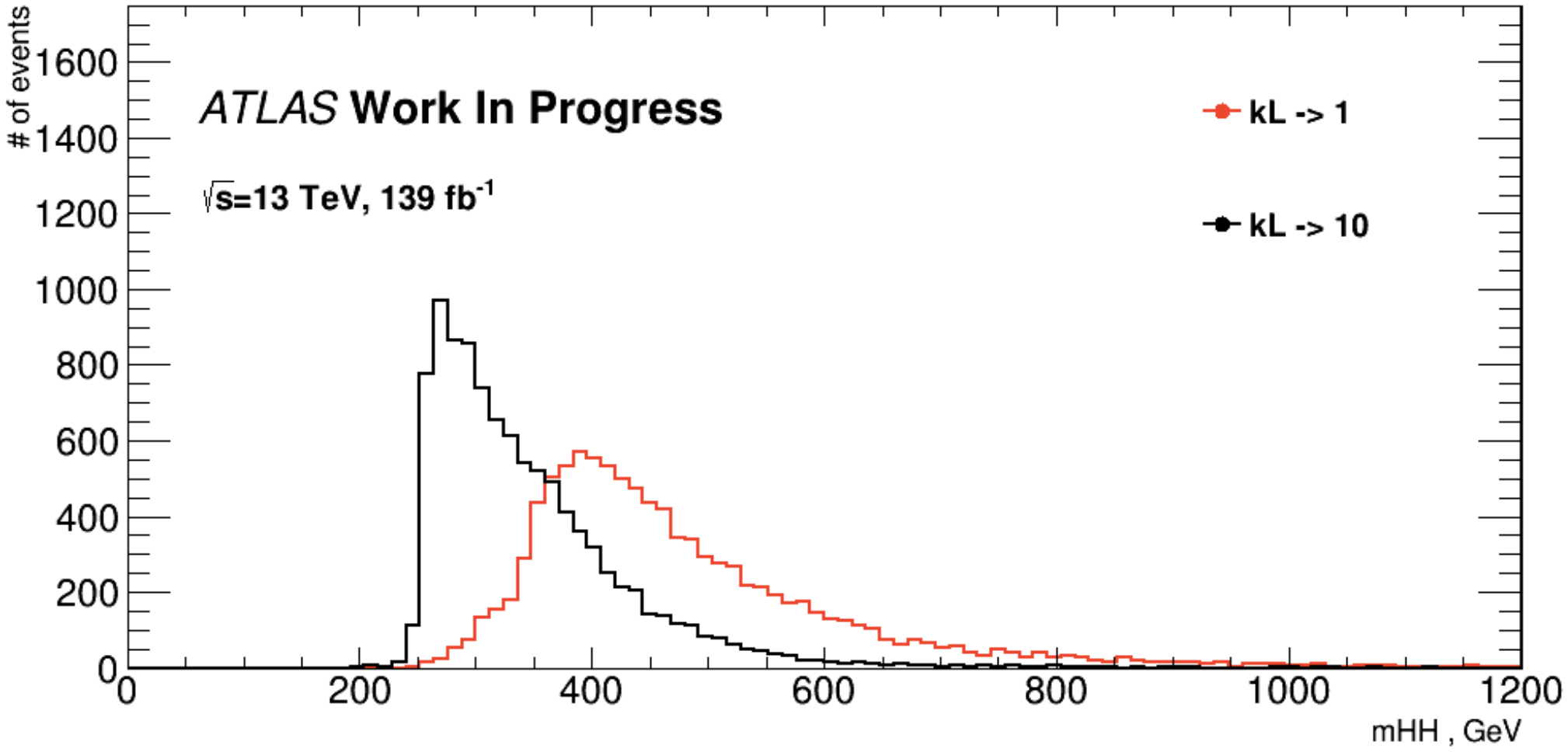
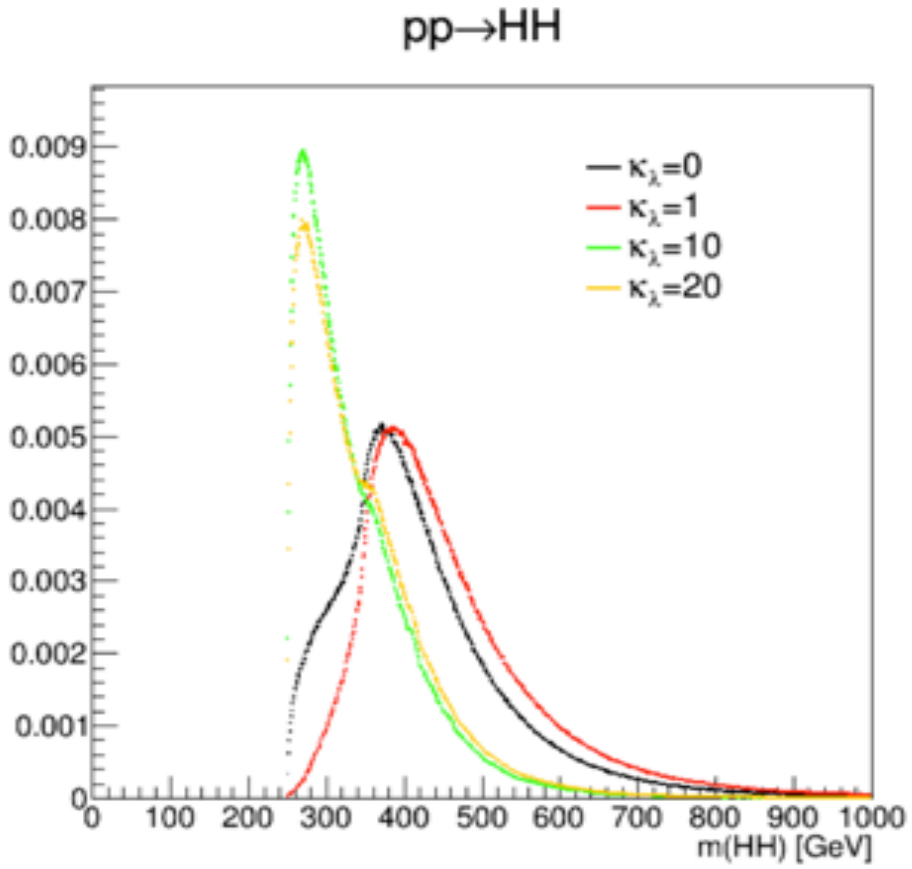


Reweighting Tool

DiHiggs analyses need simulations of many κ_λ

- Computationally expensive (full simulation)
- Reweighting only requires fully simulated $\kappa_\lambda = 1$



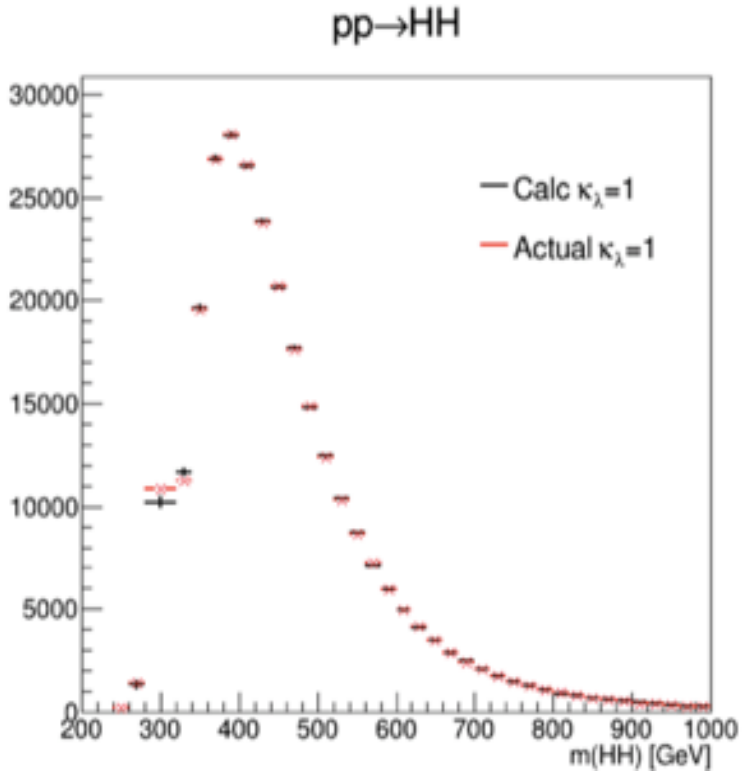
- Use of m_{HH} branches to generate the different κ_λ
- Generated κ_λ from -30 to 30, increments of 0.2

  Look at statistical errors for 5, 10 and 20 GeV bins

Events used to generate the arbitrary κ_λ **at generator level**

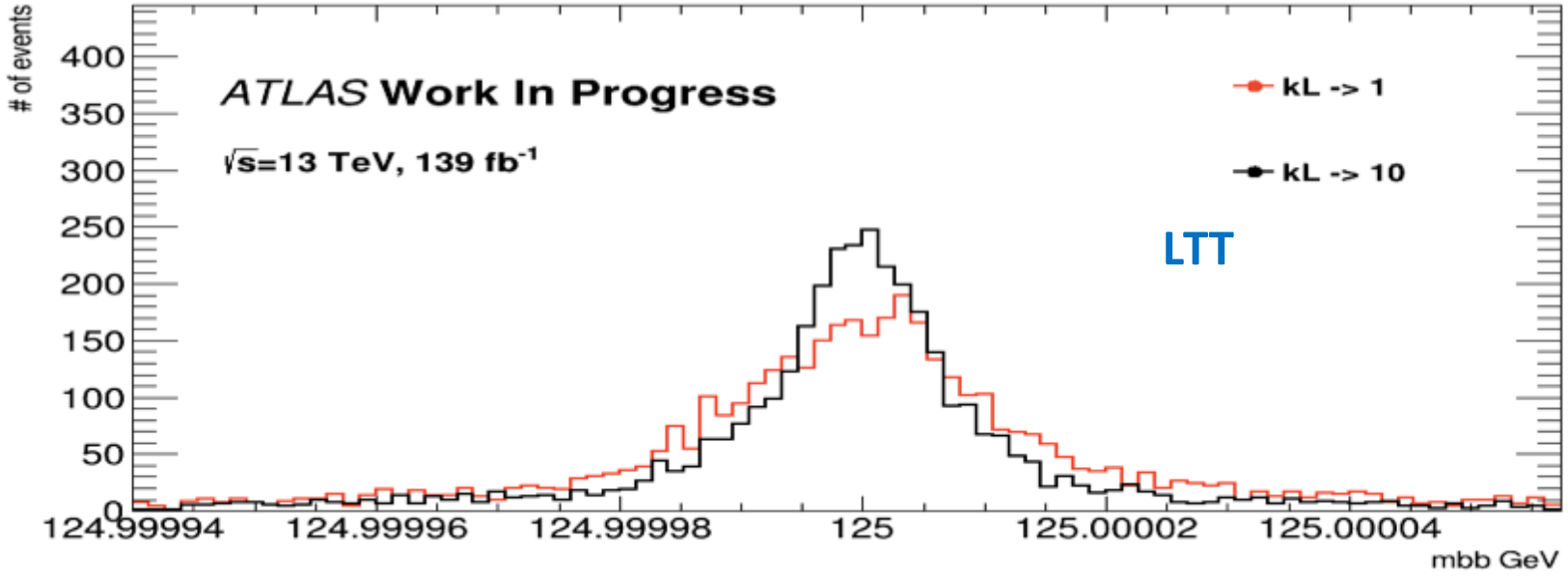
$$\frac{d\sigma}{dm_{HH}}(m_{HH}) = A(m_{HH}) + B(m_{HH})\kappa_\lambda + C(m_{HH})\kappa_\lambda^2$$

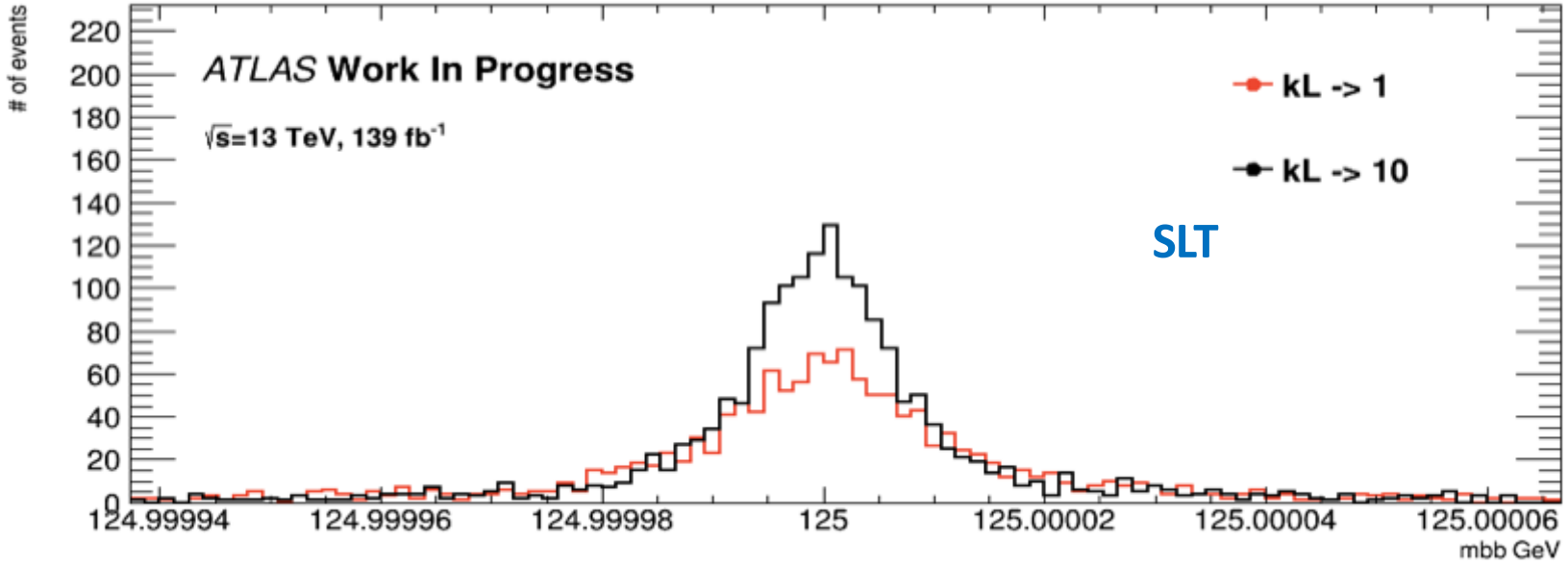
Validate using remaining generated κ_λ



Selection useful variables

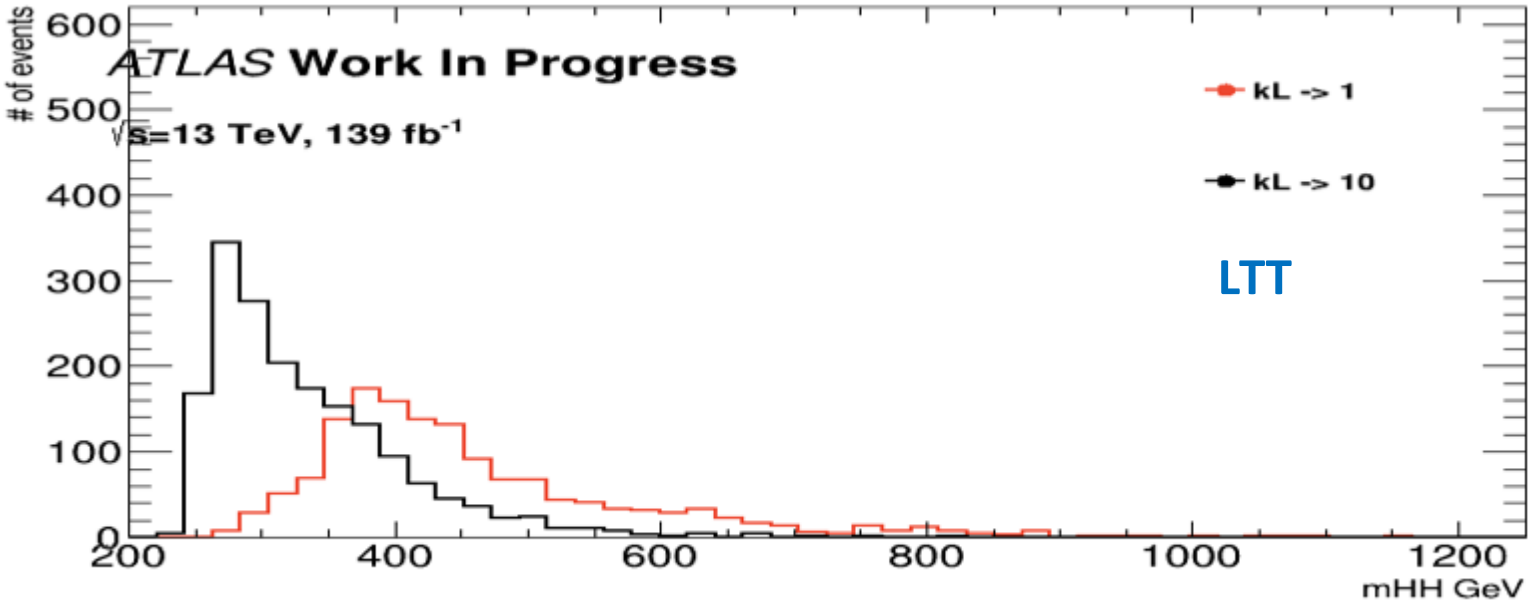
- m_{bb} is calculated from the 4-Vector of the di-*b*-jet system

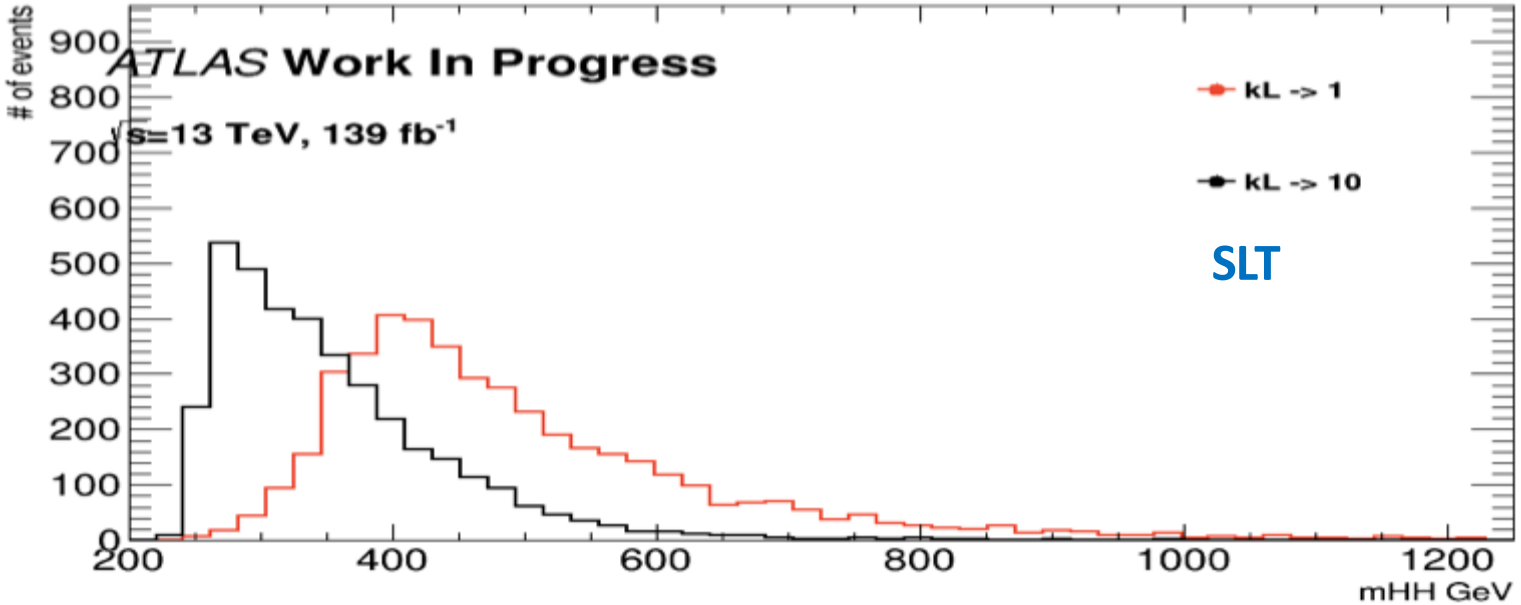




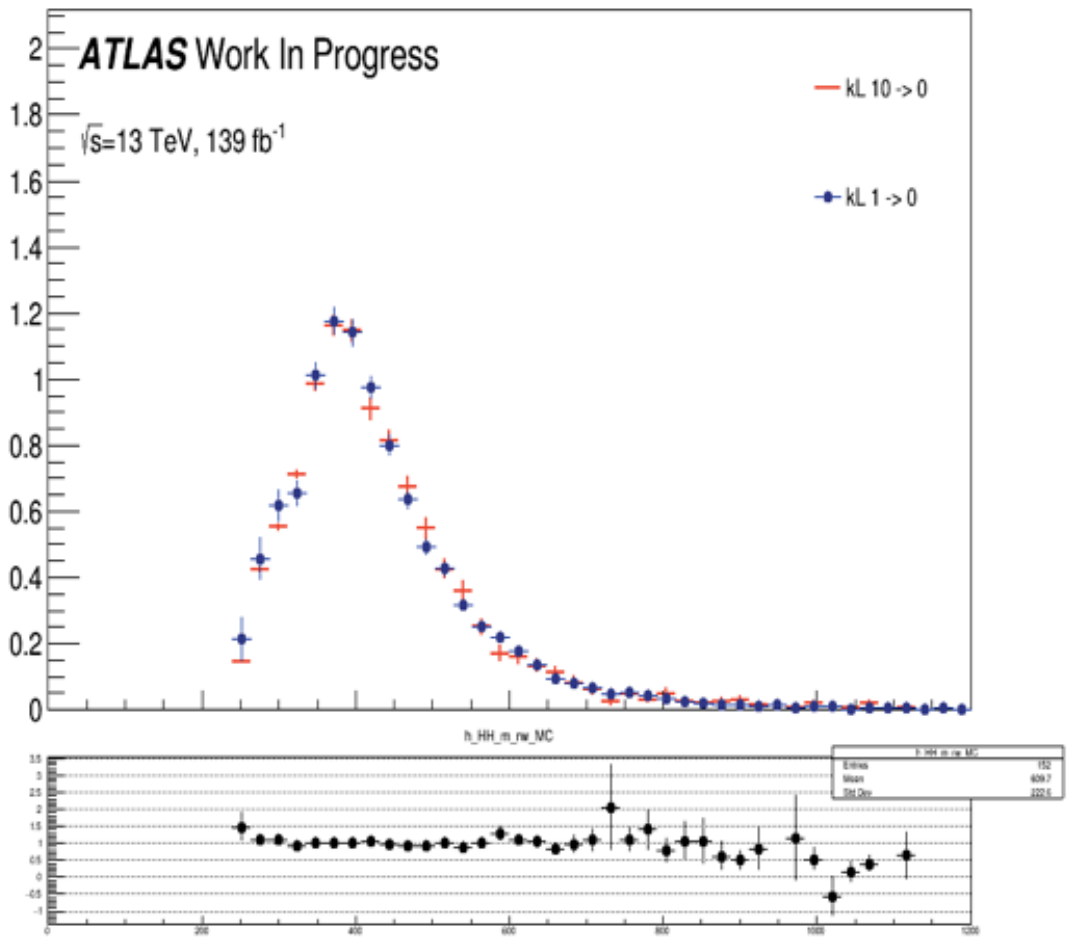
Selection useful variables

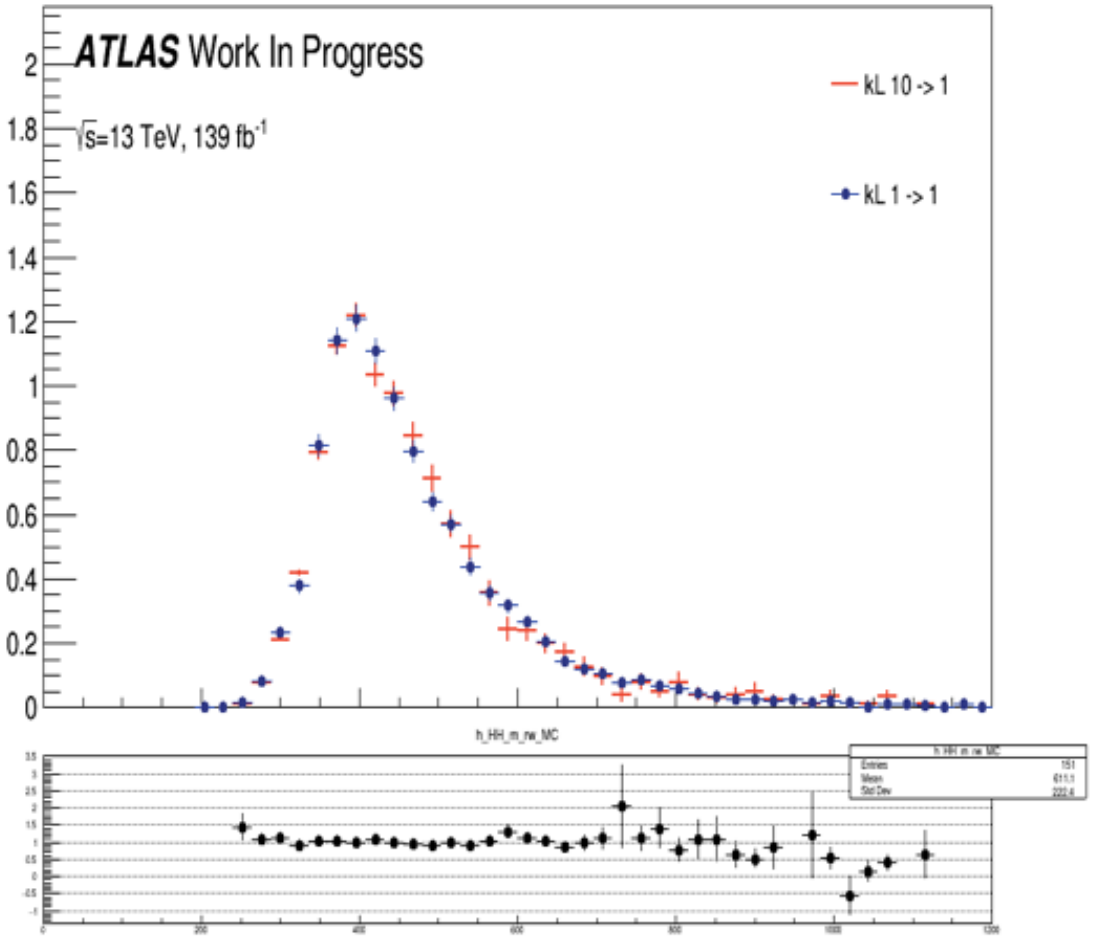
- m_{HH}: The invariant mass of the di-Higgs system is reconstructed from the di-τ and di-*b*-jet 4-vectors





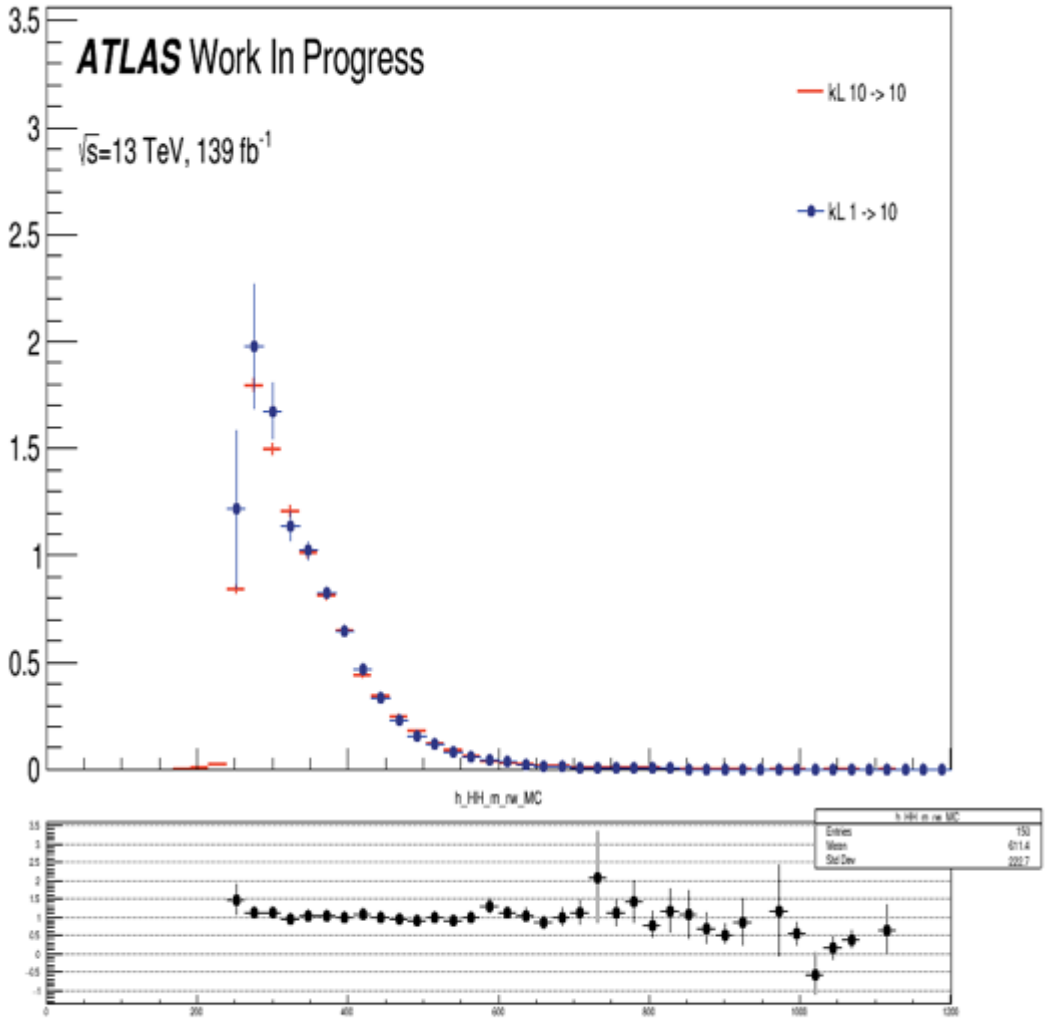
Reweight from κ_λ = 1 and 10 m_{HH} comparison:

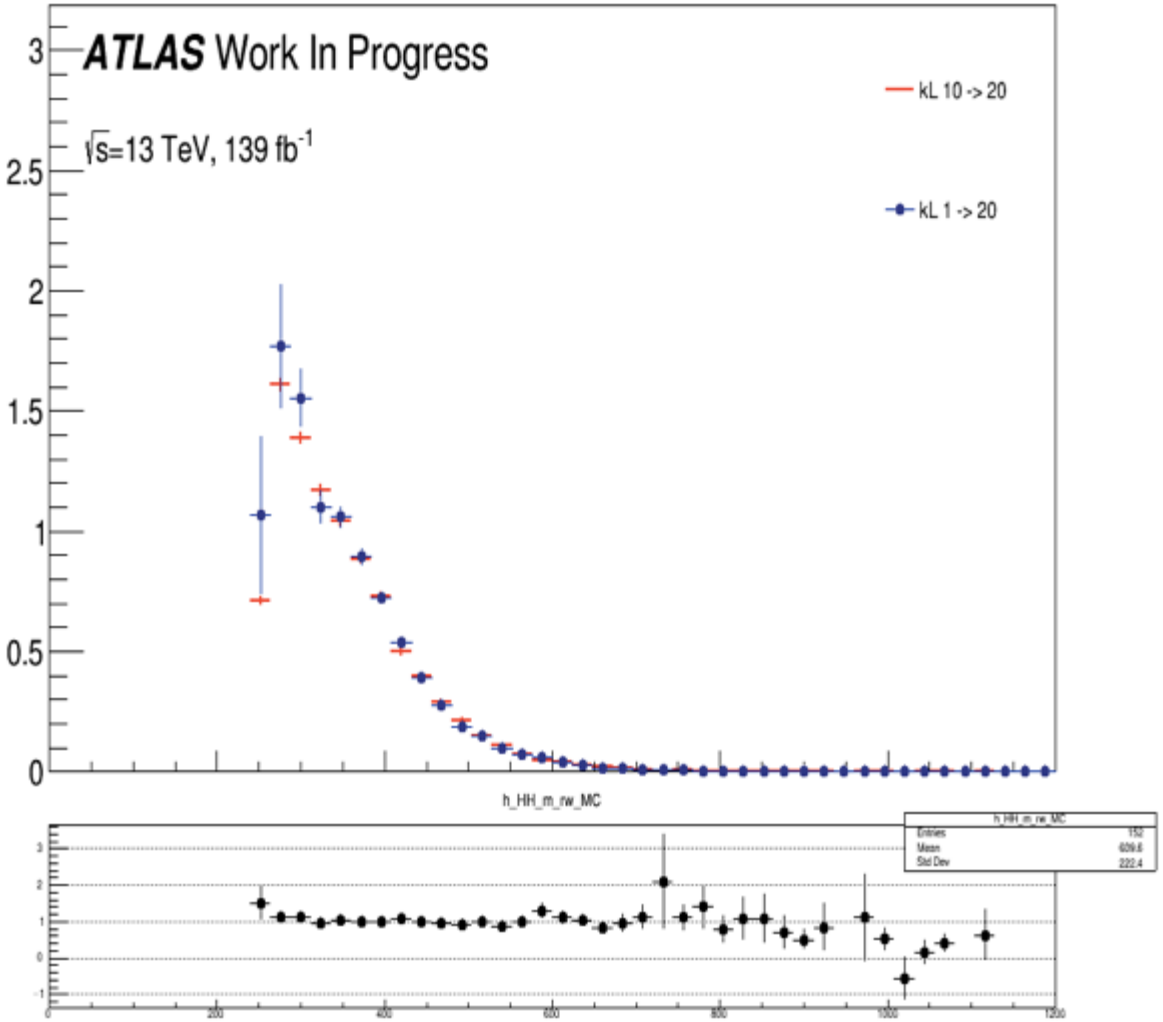




- Use KLambdaReweightTool for truth-level reweighting of samples towards other κ_λ hypotheses
- Use of specific weight factors (Filter Efficiency, Luminocity,Cross Section, WeightGeneralMC)

Reweight from κ_λ = 1 and 10 m_{HH} comparison:





Summary

- SM HH production cross-section is very small: 33.41 fb at 13 TeV
- To study a rare process like HH production need to look at the H decay channels with high BRs
- bbττ has the third highest accessible BR is the most sensitive decay channel
- It is relatively clean compared to other channels with higher BR but also larger background and more difficult reconstruction
  → **very promising !!!**

- Focusing on obtaining the best possible result for the non-resonant SM di-Higgs production through $\tau_{lep}\tau_{had}$ channel