Investigating kinematic fit to improve sensitivity to Di-Higgs searches with the ATLAS detector

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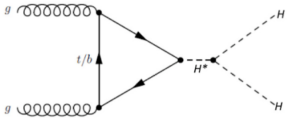
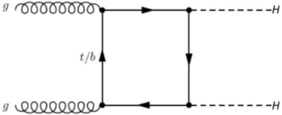
Non-resonant Higgs boson pair production





- We need to verify the SM prediction that the trilinear (λ_3) is given by:

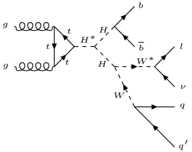
$$\lambda_3 = \frac{m_H^2}{2v^2}$$

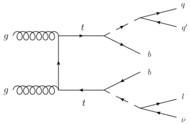
where $v = Higgs\, vacuum\, expectation\, value\, \simeq 246GeV$.

- Di-Higgs production is sensitive to the trilinear Higgs coupling $\Rightarrow$ Reason why we want to study Di-Higgs production.
- Some Beyond the Standard Model scenarios allow deviation of λ_3 from SM predicted value which can result in enhanced Di-Higgs cross-section.

What is Kinematic Fitting?

- It is a technique of exploiting the physical laws governing particle interaction to improve measurements.
- Example: Suppose we have an event with final state $bbqql\nu$. This final state could be a result of, among other things, the decay of top quark pair or decay of Higgs boson pair:





- We can impose a constraint that the sum of invariant masses of two jets from W boson be equal to its invariant mass.
- Under the $t\bar{t}$ hypothesis we can also impose the constraint that the sum of invariant masses of a bottom quark and W boson be equal to invariant mass of top quark.
- Various methods for kinematic fitting: p_T^{max} method, χ^2 method, Likelihood-based method, etc.

Likelihood

- We use KLFitter (Kinematic Likelihood Fitter) for kinematic fitting, which is a standard tool in ATLAS.
- Assuming the measurements are independent, we can write out a Likelihood function for each event which is function of the unknown parameters α

$$L(\alpha) = \prod f(x|\alpha)$$

where $f(x|\alpha)$ is probability density of X=x given α. In the case of $t\bar{t}$ the likelihood function is

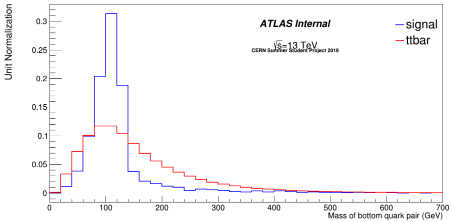
$$\begin{aligned}\mathcal{L} =& \mathcal{B}\left(m_{q_1 q_2 q_3} | m_t, \Gamma_t\right) \cdot \mathcal{B}\left(m_{q_1 q_2} | m_W, \Gamma_W\right) \cdot \\ & \mathcal{B}\left(m_{q_4 \ell \nu} | m_t, \Gamma_t\right) \cdot \mathcal{B}\left(m_{\ell \nu} | m_W, \Gamma_W\right) \cdot \\ & \prod_{i=1}^{4} W_{\text{jet}}\left(E_{\text{jet},i}^{\text{meas}} | E_{\text{jet},i}\right) \cdot W_{\ell}\left(E_{\ell}^{\text{meas}} | E_{\ell}\right) \cdot \\ & W_{\text{miss}}\left(E_x^{\text{miss}} | p_x^{\nu}\right) \cdot W_{\text{miss}}\left(E_y^{\text{miss}} | p_y^{\nu}\right)\end{aligned}$$

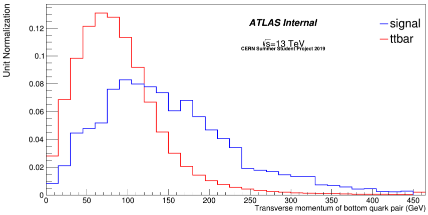
- Then we can find out the values of α which maximize $L(\alpha)$. In case of KLFitter, it minimizes $-lnL(\alpha)$. These values are taken as the fitted value of the unknown parameters.

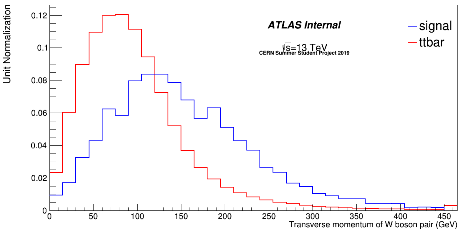
History

- Prior to the present work the following cuts were placed for the published bbWW non-resonant analysis:

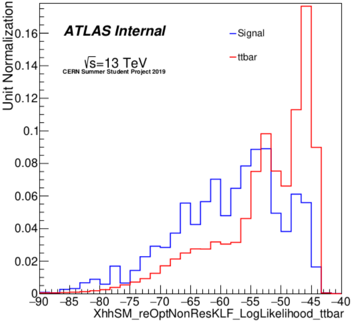
E_T^{miss} [GeV]	>25
m_{WW^*} [GeV]	<130
$p_T^{b\bar{b}}$	>300
$p_T^{WW^*}$ [GeV]	>250
$m_{b\bar{b}}$ [GeV]	105-135







What did we do?



- We imposed these additional cuts after all other cuts that were previously used and computed the sensitivity $\left(\frac{S}{\sqrt{B}}\right)$.
- Here we take the ratio of number of signal events to the square root of number of $t\bar{t}$ background events as sensitivity.

Results

LogLikelihood_ttbar< -55

$\frac{S}{\sqrt{B}}$ before the likelihood cut	1.3951
$\frac{S}{\sqrt{B}}$ after the likelihood cut	1.4906

LogLikelihood_ttbar< -48

$\frac{S}{\sqrt{B}}$ before the likelihood cut	0.8071
$\frac{S}{\sqrt{B}}$ after the likelihood cut	0.8871

- These correspond to about 7% and 10% increase in the sensitivity.

Additional result: mass of hadronically decaying top quark in $t\bar{t}$ decay

Before Likelihood cut

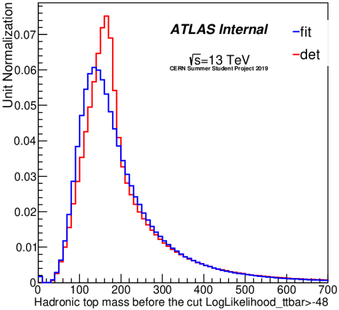
Detector	
Mean [GeV]	sd [GeV]
208.6	123.7

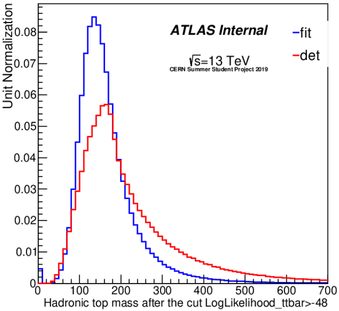
Fit	
Mean [GeV]	sd [GeV]
203.5	121.7

After Likelihood cut

Detector	
Mean [GeV]	sd [GeV]
224.1	137.2

Fit	
Mean [GeV]	sd [GeV]
166.3	75.77





Summary and Outlook

Summary

- Sensitivity seems to increase after applying the cut LogLikelihood_ttbar $<$ -55 (and also LogLikelihood_ttbar $<$ -48).
- The mean mass of hadronically decaying top quark in $t\bar{t}$ decay comes out to be closer to the measured value and the resolution increases when the cut LogLikelihood_ttbar $>$ -48 is applied.

Outlook

- Optimize the LogLikelihood cut for the best sensitivity.
- Look at Loglikelihood of diHiggs to see if we can improve sensitivity by imposing cuts on it.
- Take other backgrounds such as multijet events, dibosons, etc into consideration.
- Test the kinematic fit performance in Rel21 bbVV Analysis framework.