First Year Presentation :
Search for Higgs pair production at LHC Collider : First Measurement for Higgs Potential and Search of new physics

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ATLAS EXPERIMENT · CERN · LAPP Laboratoire d'Annecy de Physique des Particules · CNRS IN2P3 Les deux infinis · UNIVERSITÉ SAVOIE MONT BLANC

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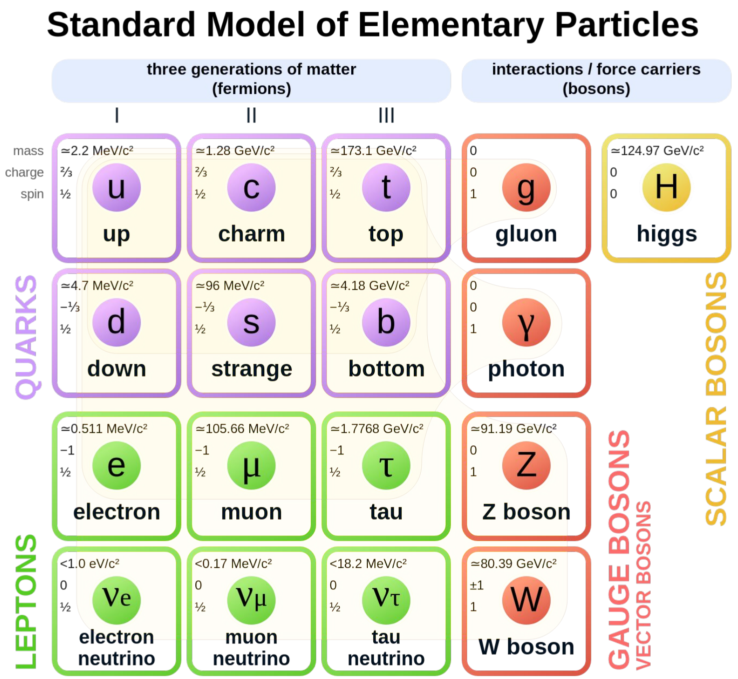
Introduction

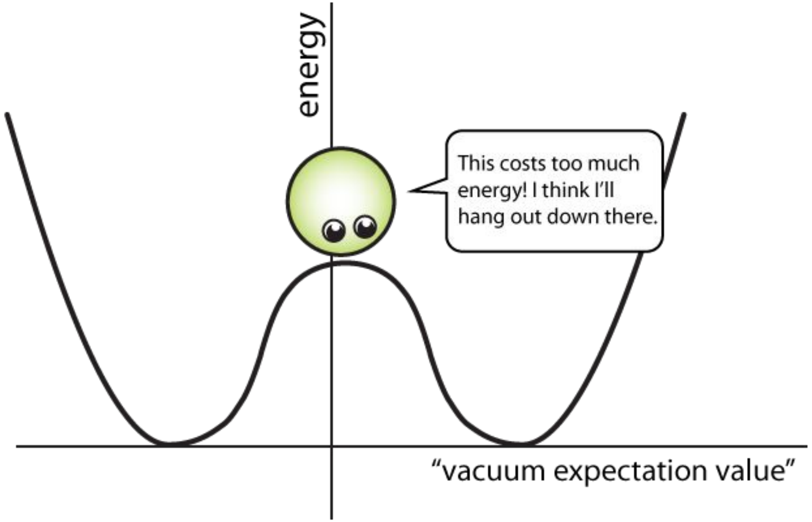
- Keywords : Higgs, Higgs Potential, Higgs pair production, New Physics.
- Higgs : massive (~125 GeV) elementary particle discovered in 2012 at CERN by the two largest experiments ATLAS & CMS.
    - Responsible of mass generation to other particles via spontaneous symmetry breaking EWSB.



Higgs Potential

- Scalar field of energy exist in every region of the universe.

- Variation around the minimum gives:



$$V(\phi) = -\frac{1}{2}m_H^2 h^2(x) + \lambda_{HHH} h^3(x) + \lambda_{HHHH} h^4(x)$$

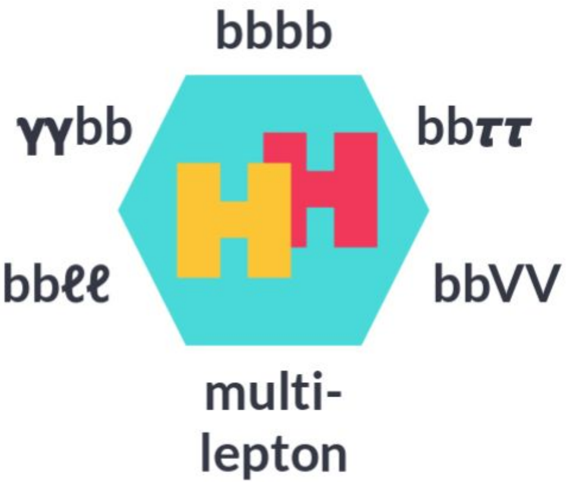
Higgs field

Trilinear coupling

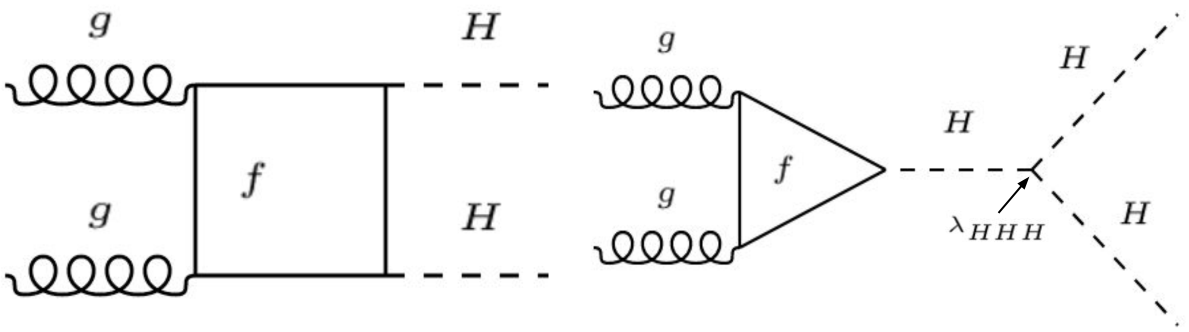
What we want to know!

Higgs pair production - HH

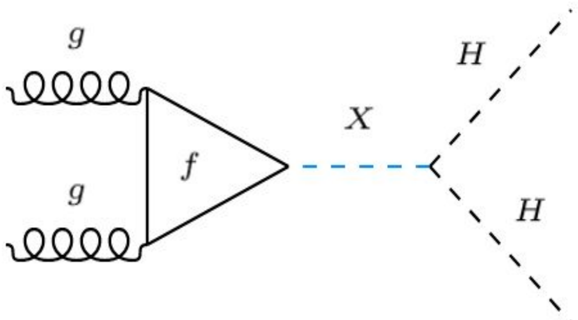
- Two Higgs bosons produced in a single pp collision.
- Provide a direct access to Higgs self-coupling.



Non-Resonant



Resonant



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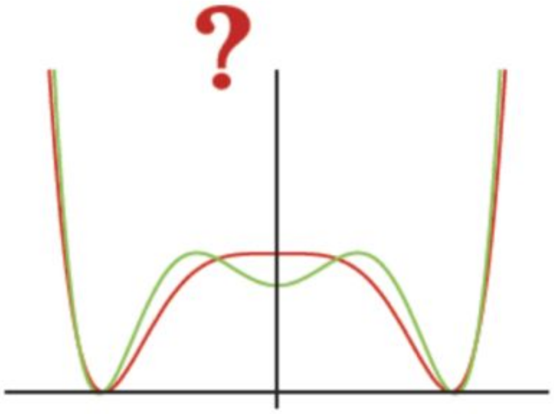
New Physics ?



- Self-coupling value not known yet,
  What if the real value is different from its SM value?
- This variation opens windows to new physics.
- Quantified by :

$$\kappa_\lambda = \frac{\lambda_{BSM}}{\lambda_{SM}}$$

- Full Run-2 data will provide best limit in the world to:

$$\frac{\sigma_{BSM}(gg \to HH)}{\sigma_{SM}(gg \to HH)}$$

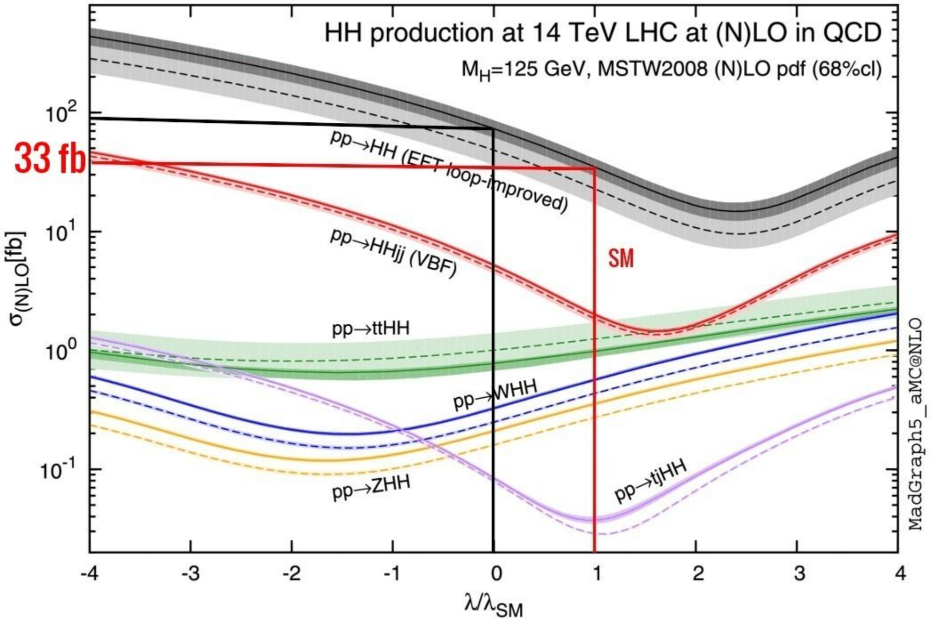
Cross section

$$\kappa_\lambda = \frac{\lambda_{BSM}}{\lambda_{SM}}$$

Self-coupling

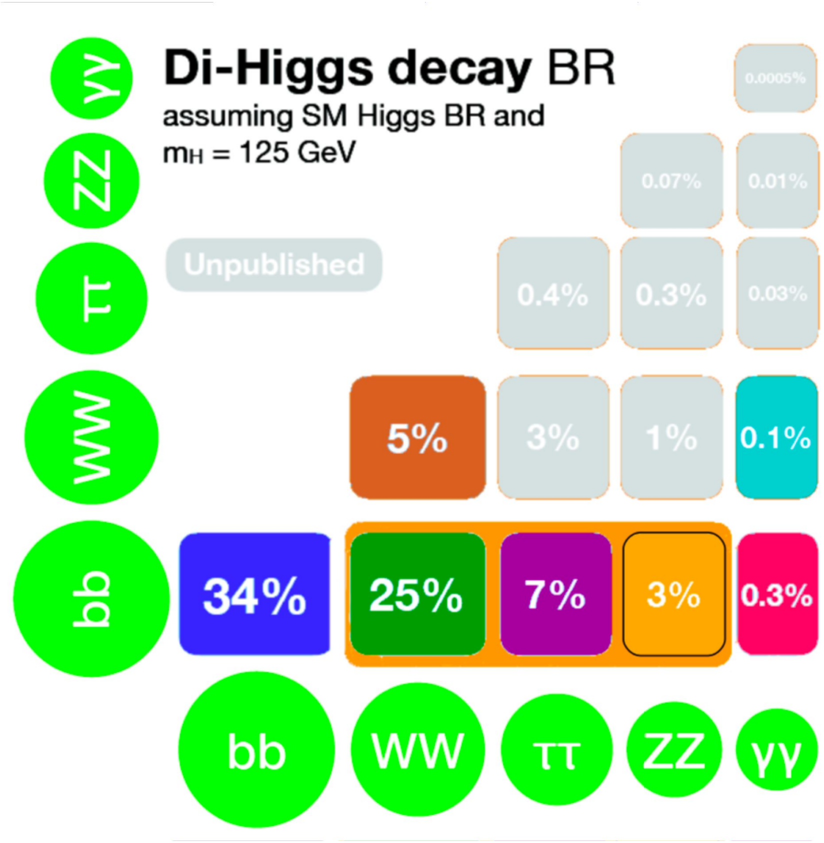
HH cross section

- ~1000x smaller than single Higgs
- BSM effects could enhance this rate.



HH decay channels

- Different decay modes, combination of single Higgs decay channels.
- LAPP : HH → bb$\gamma\gamma$



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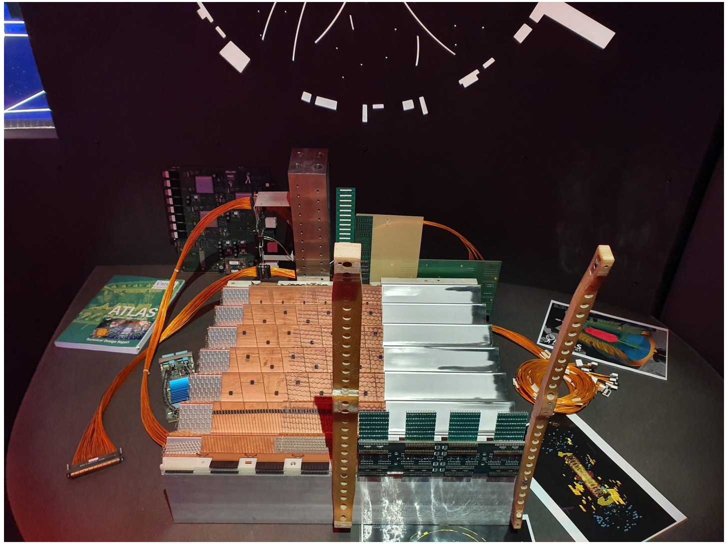
Why bb$\gamma\gamma$?

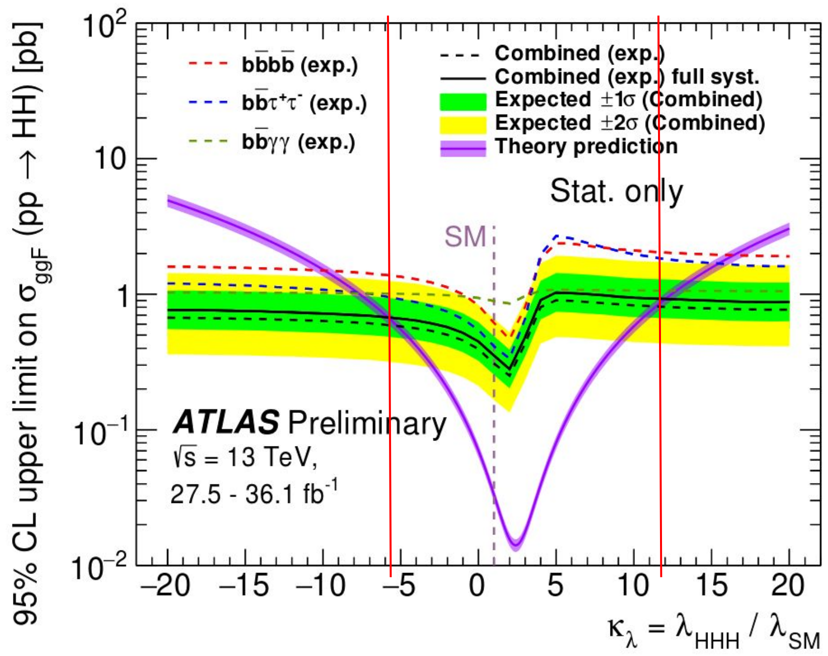
- It's a golden channel because :
  - Experimental reason :
    - High H→bb branching ratio → more events
    - Best photon resolution → best $m_{\gamma\gamma}$ resolution
  - Historical reason :
    - Photons : LAPP built EM calorimeter.
    - B-Jet : LAPP built IBL (pixel detector).



Order of magnitude

- Current limit (~36fb^{-1}): [-5.2,11.4] (Best limit in the world until now).
- Full Run 2 integrated luminosity : 139 fb^{-1}

- Gain ~√139/36 with full Run 2 data.
- Can gain more ?



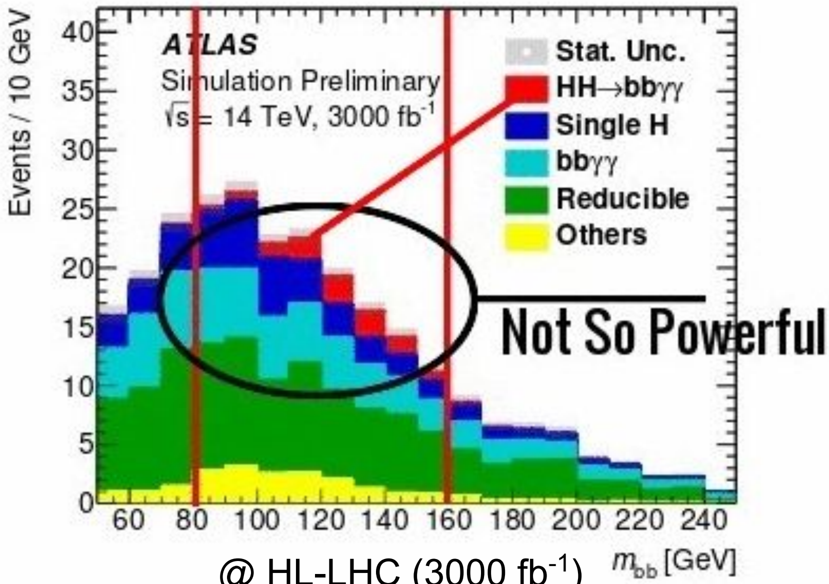
Single Higgs	HH	HH→bbγγ	selection
1 event / 1s	3 events / 1h	1 event / 5day	1 event / 100day

How to enhance the selection to select more HH events?

M_{bb} resolution

- One of the reasons behind the low selection is : **m_{bb} resolution**
- Worst resolution :
  - reduce m_{bb} separation power.
- The b-jet energy is not fully reconstructed.

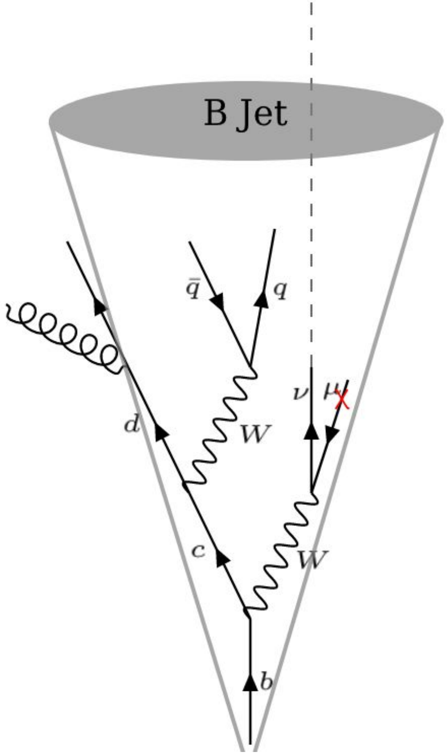
➔ Calibrate the b-jet energy
in order to recover the missing energy.



@ HL-LHC (3000 fb^{-1})

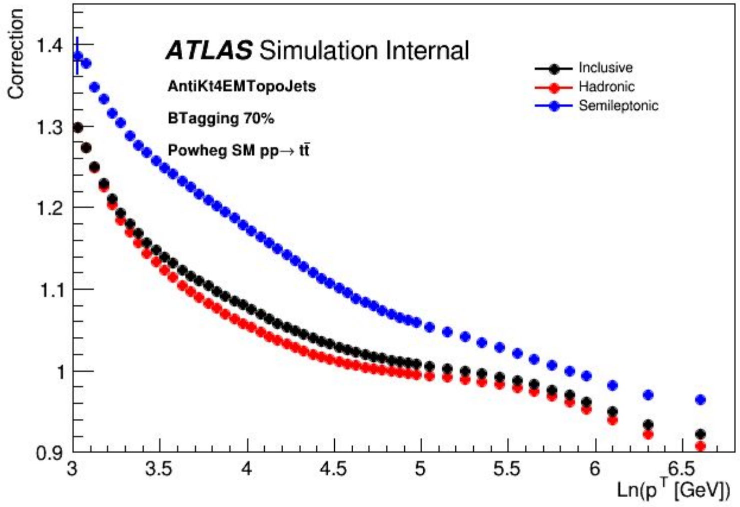
B-Jet Calibration

- B-jet : large fraction of missing energy
  - B-hadron decay
    - Presence of muons
    - Neutrions
  - Out of cone radiation
- Not handled by the current calibration mechanism.
- Proposal solution, a jet-by-jet correction : **B-Jet Calibration**
  - A decoupled method to correct those effects.
  - Not only for HH but for any analysis include b-jet in the final state.



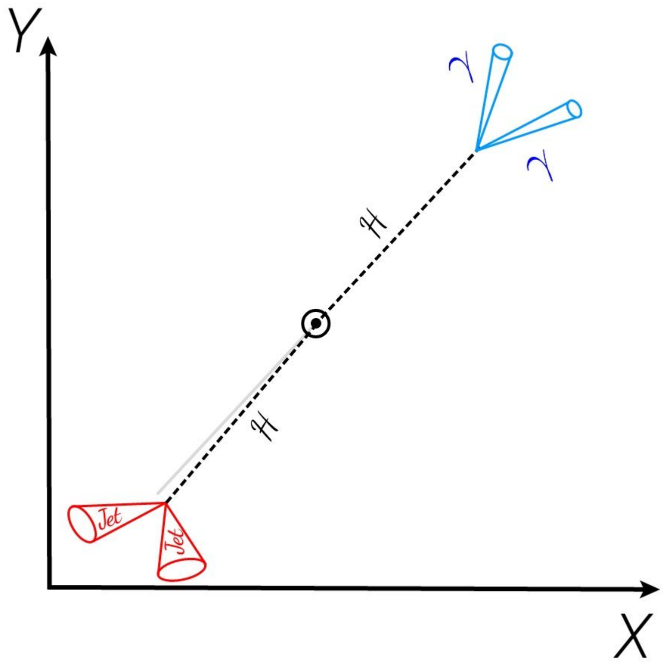
BJetCalibrationTool

- I develop a tool to correct b-jet via two corrections:
  - Muon-in-jet correction :
    - Correct muon effect, by adding the muon to jet.
  - pTReco correction :
    - Correct the out-of-cone and neutrino effects by scaling initial jet 4-vector.
- Similar improvement as advanced methods (Machine Learning).
- Presented in different ATLAS groups.
  - Talk at DiHiggs Workshop @ CERN, March 2019
  - Poster at HDBS Workshop @ Naples, June 2019

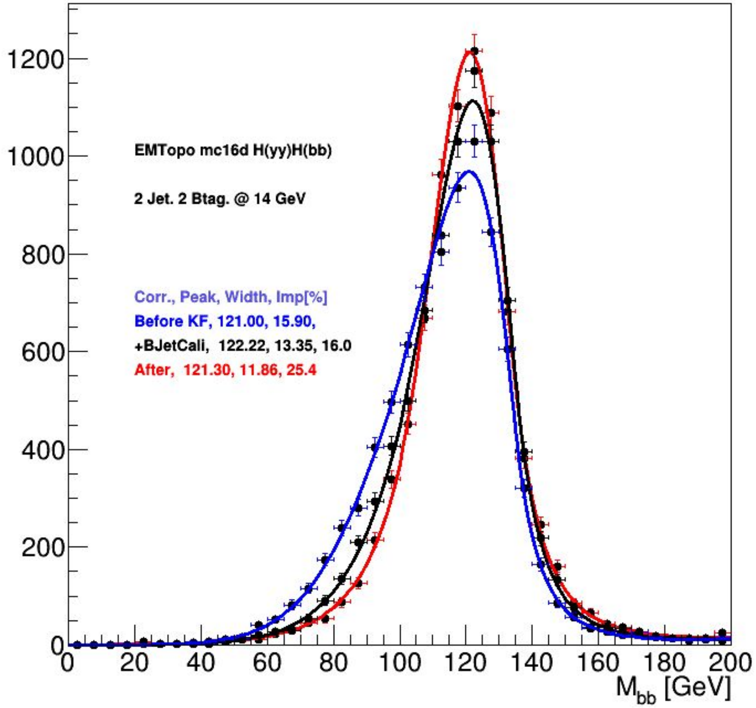


Kinematic Fit

- Additional to jet-by-jet correction.
- An Event-by-Event correction : **Kinematic Fit**
  - Profit from very good $m_{\gamma\gamma}$ resolution.
  - Constrain the HH system using a likelihood.
  - Calibrate the HH event.
- Aim to better HH reconstruction.
- Relevant only for HH → bb$\gamma\gamma$.
- Kinematic Fit Tool developed.

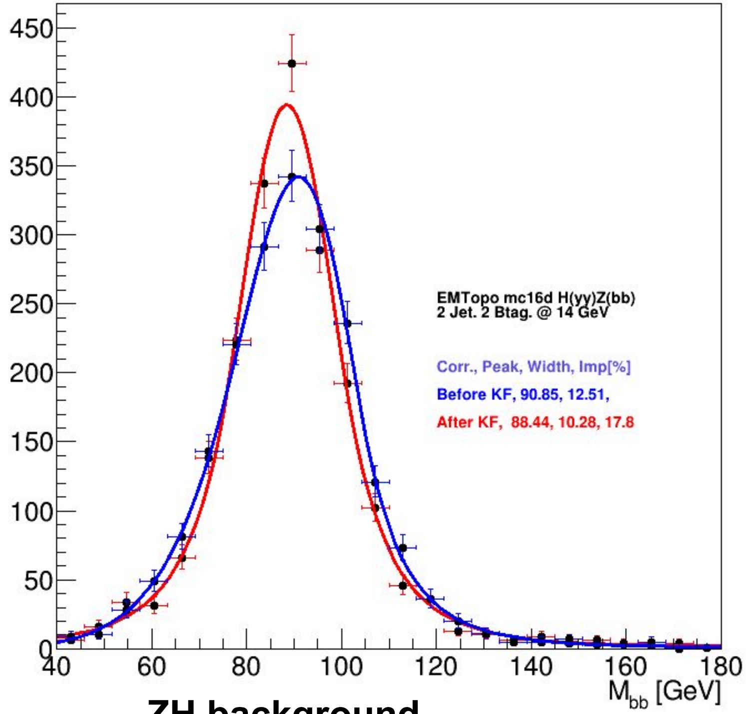


Results - Signal

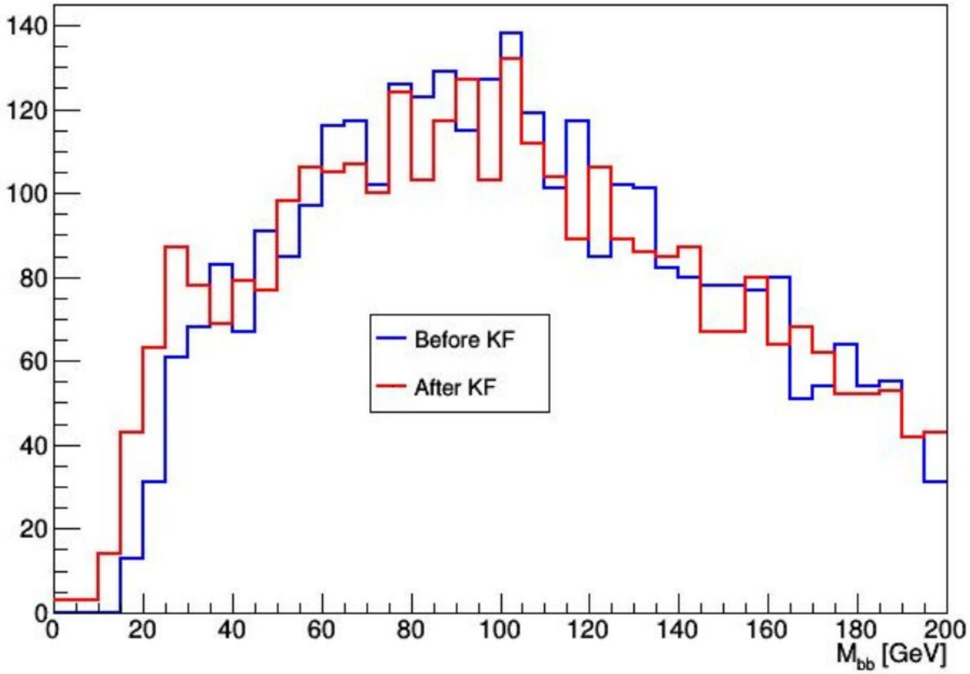


- More than 25% improvement in m_{bb} resolution → better signal-background separation
- Expected improvement of ~12% in $S/\sqrt{B}$

Results - Background



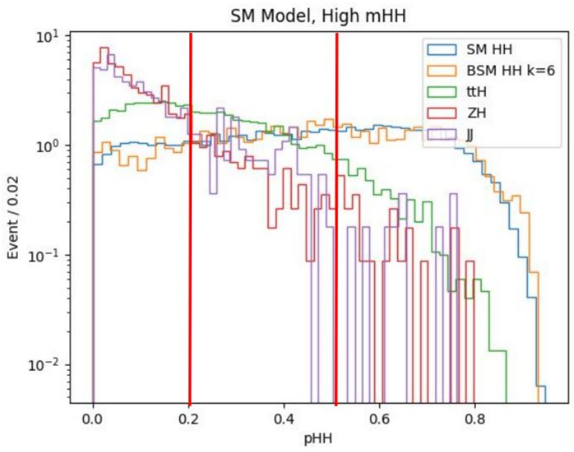
ZH background

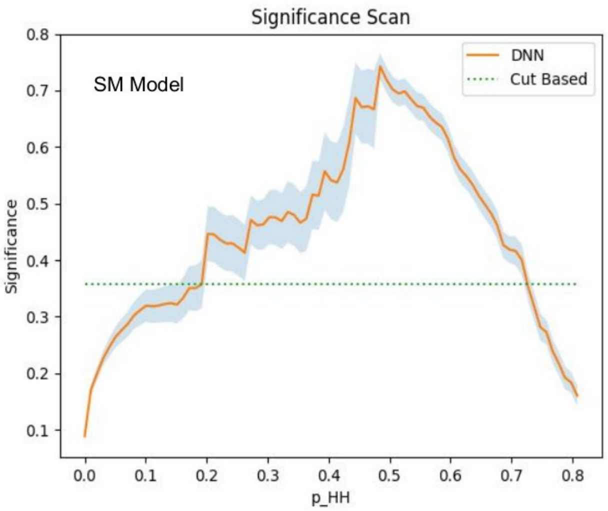


Continuum Background

Analysis Strategy

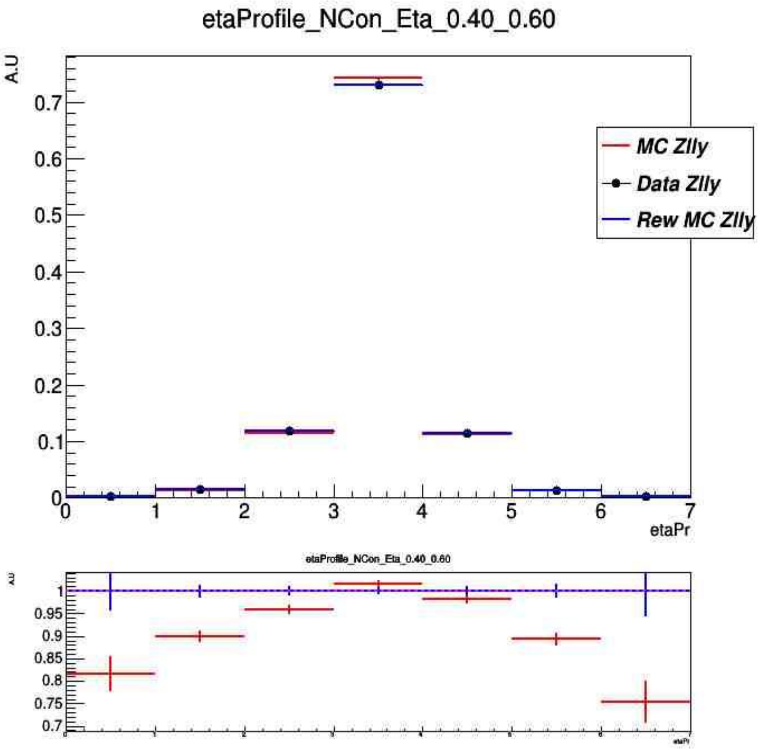
- Improve signal to backgrounds separation, with ML technics.
  - DNN approach chosen
- Additional to the DNN, I include a new set of variables which improve the separation by ~7%.
- Preliminary results :
  - Significance improve by ~100% versus Cut based.





Shower shape reweighting

- In parallel to the analysis work, an ATLAS qualification task (QT) to get the autorship.
- QT object : calibrate simulated photon shower shape to reduce the Data/MC discrepancy.
  - Discrepancy → large systematic in H→ yy.
  - This discrepancy has many sources : Shower modeling, detector matter …
  - Reweighting approach is designed to correct those effects at cell level.
  - My work is :
    - Select Z→eey events and retrieve EM cells.
    - Attempt to apply electron method to photons.
    - ➔ Develop more evolved reweighting method.
- This work should finish next month.



What’s next?

- Documentation of B-jet Calibration and Kinematic Fit.
- Finalise the DNN approach and QT.
- Contribute to HH combination.
- Start new machine learning approach for photon identification @ cell level.
- Participation in supervising of a ukrainian M1 student.

Schools and Workshops

- Schools :
  - Machine Learning summer school @ Desy, July 2019
- Validation of 80/120 h courses requested by ED.
- Accepted for RES label (To be completed in the following 2 years).

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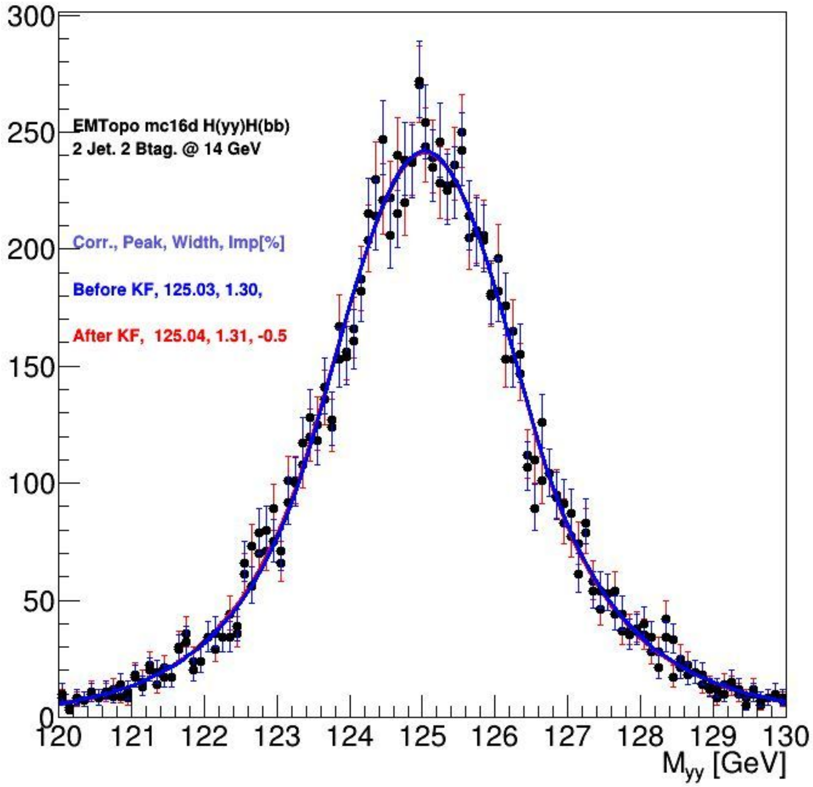
Summary

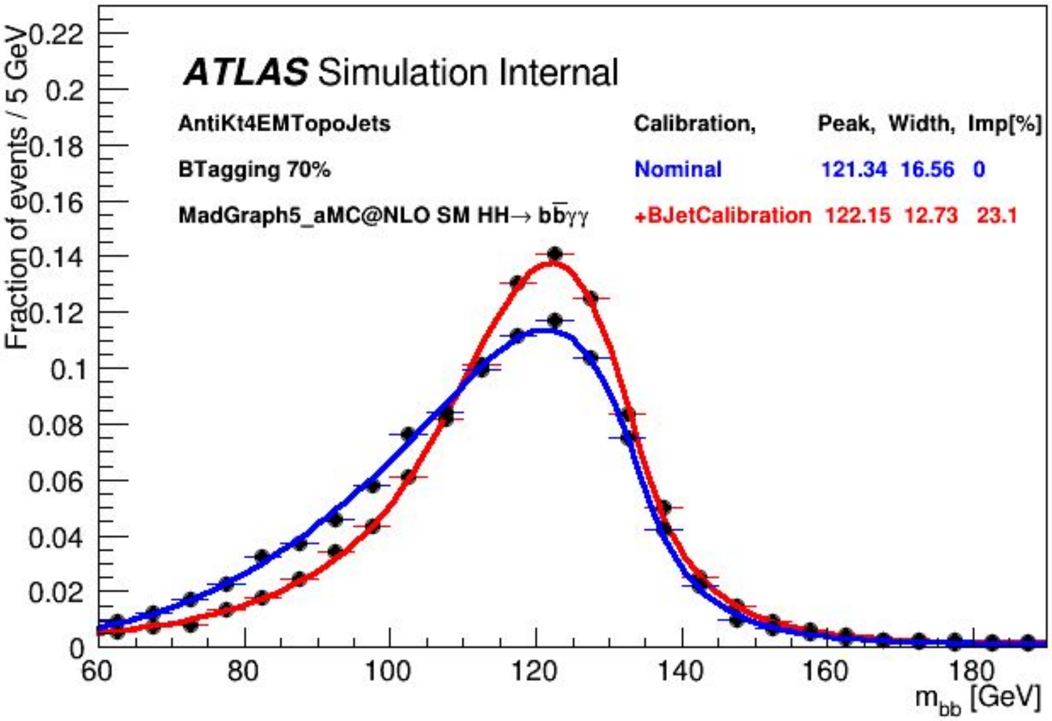
- Di Higgs Production with full Run 2
  - Jet-by-jet correction : BJetCalibrationTool BJetCorrectionTWiki
  - Event-by-event correction : KinematicFitTool
  - Analysis Strategy : DNN + New Variables
- QT : Shower shapes :
  - ATLAS authorship
- Next :
  - HH non-resonance combination
  - PhotonID @ cell level

Backup

Photon resolution



B-Jet resolution



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Likelihood

$$\mathcal{L} = \prod_{i=1}^{2} G_{\gamma_i}(\phi^*;\phi,\sigma_\phi) \times G_{\gamma_i}(\eta^*;\eta,\sigma_\eta) \times G_{\gamma_i}(E^*;E,\sigma_E)$$
$$\times \prod_{k=1}^{njets} G_{jet_k}(\phi^*;\phi,\sigma_\phi) \times G_{jet_k}(\eta^*;\eta,\sigma_\eta) \times G_{jet_k}(E^*;E\times\mu_E,\sigma_E) \times L^{b-jets} \quad (1)$$
$$\times\, G(\sum_{i=1} P_x^{\gamma_i} + \sum_{k=1} P_x^{jet_k};0,\sigma_{P_{xy}{}^{b\bar{b}\gamma\gamma}}) \times G(\sum_{i=1} P_y^{\gamma_i} + \sum_{k=1} P_y^{jet_k};0,\sigma_{P_{xy}{}^{b\bar{b}\gamma\gamma}}),$$

$$\sigma_E = \sigma_E(P_T^{jet_k}),\ \mu_E = \mu_E(P_T^{jet_k}),\ L^{b-jets} = L^{b-jets}(P_T^{jet_k}) \quad (2)$$

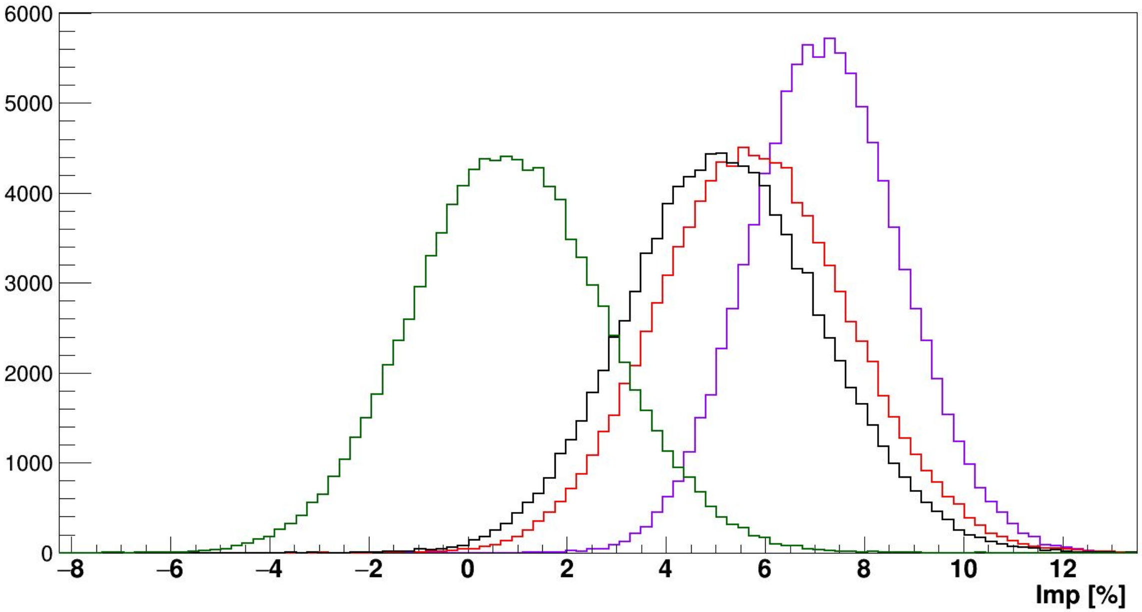
where i number of $photons\ (2)$ and k number of $jets\ (2\ B - Jet + Add.\ Jet)$.

Fraction of events

Category	0 Add. Jet	1 Add. Jet	> 2 Add. Jet
Fraction [%]	19	31	50

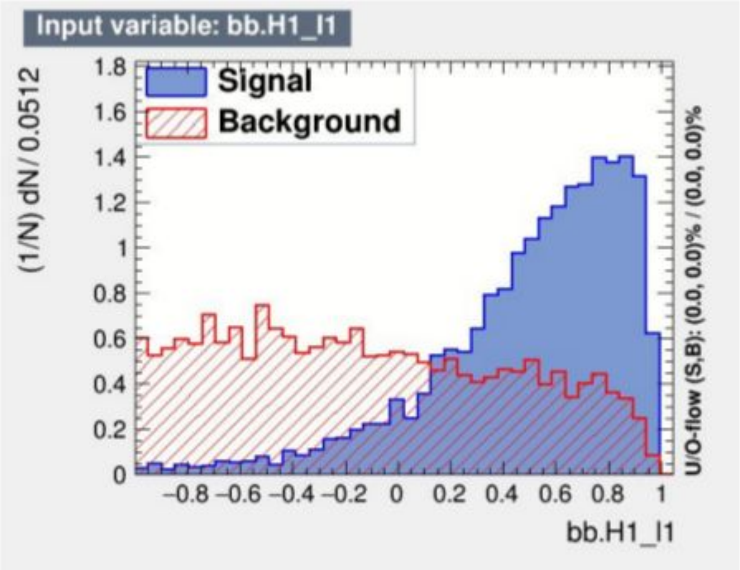
Bootstrap

- Use bootstrap method to estimate the improvement in Significance



Fox-Wolfram moments

- Rotationally invariant observables which characterizes the shapes of events.



$$H_l^x = \sum_{\substack{i,j \\ i \neq j}}^{N} W_{ij}^x P_l(\cos\Omega_{ij})$$

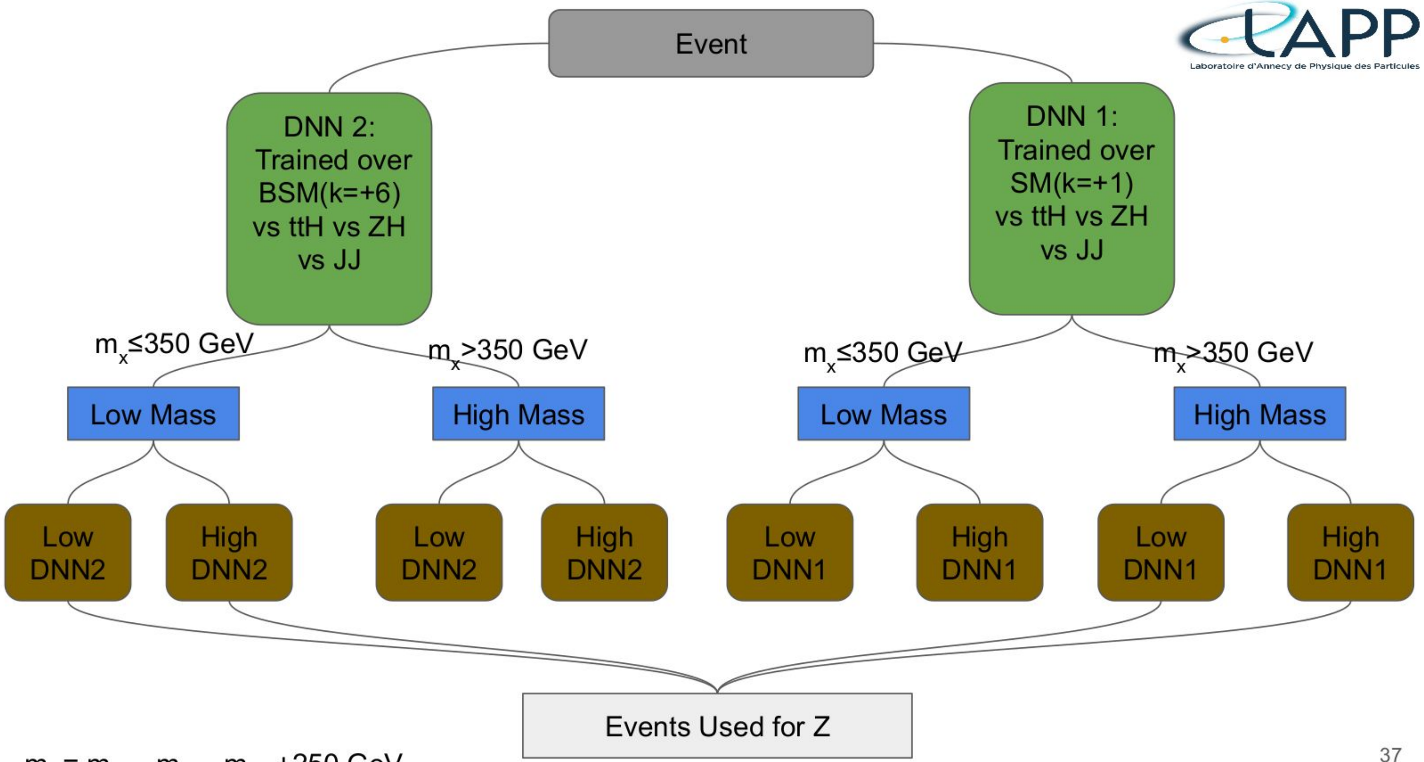
$$W_{ij}^T = \frac{P_{Ti} P_{Tj}}{(\sum P_{Ti})^2}$$

$$W_{ij}^P = \frac{P_i P_j}{(\sum P_i)^2}$$

$$W_{ij}^1 = 1$$

$$W_{ij}^\eta = \frac{|\eta_i - \bar{\eta}|^{-1} |\eta_j - \bar{\eta}|^{-1}}{(\sum |\eta_i - \bar{\eta}|^{-1})^2} \; ; \; \bar{\eta} = \frac{1}{2}(\eta_i + \eta_j)$$

DNN



$m_x = m_{hh} - m_{yy} - m_{bb}$ +250 GeV

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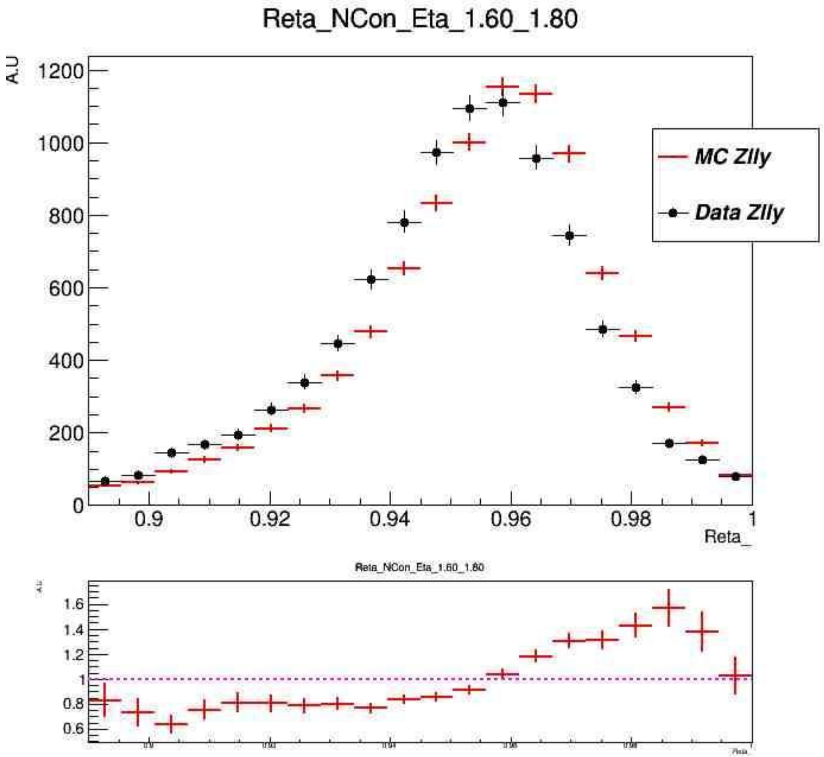
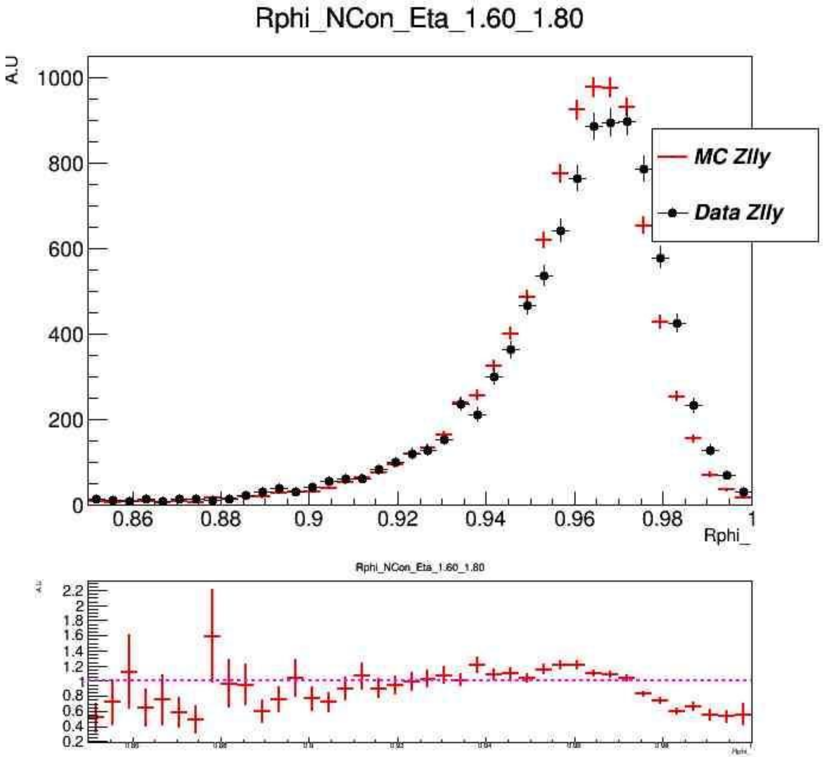
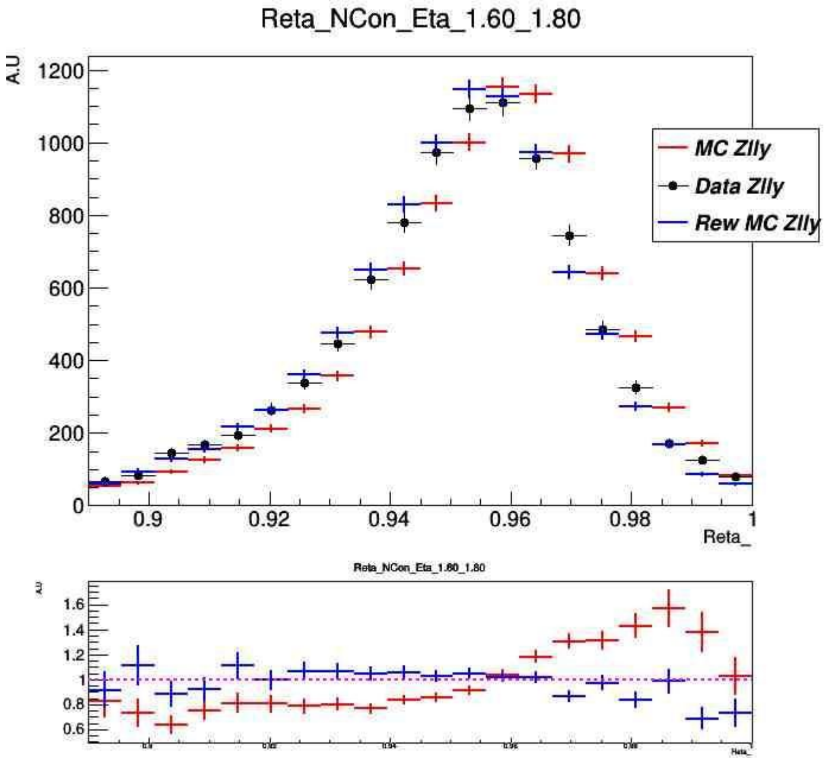
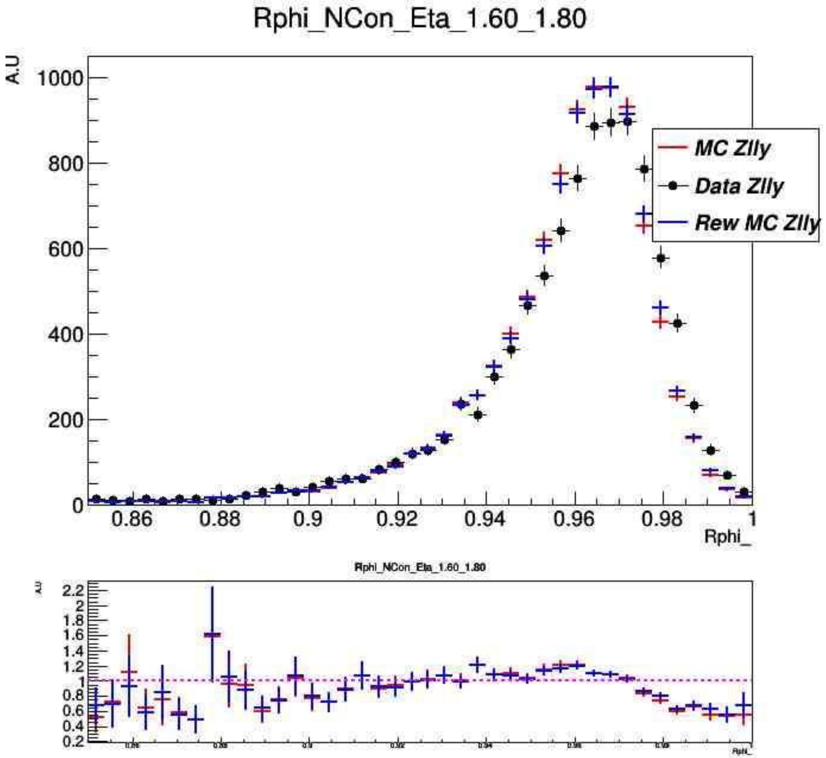
Shower shape (1)





Shower shape (2)





Current limit

Search channel	Allowed κ_λ interval at 95% CL		
	obs.	exp.	exp. stat.
$HH \to b\bar{b}b\bar{b}$	−10.9 – 20.1	−11.6 – 18.7	−9.9 – 16.4
$HH \to b\bar{b}\tau^+\tau^-$	−7.3 – 15.7	−8.8 – 16.7	−7.8 – 15.4
$HH \to b\bar{b}\gamma\gamma$	−8.1 – 13.2	−8.2 – 13.2	−7.7 – 12.7
Combination	−5.0 – 12.1	−5.8 – 12.0	−5.2 – 11.4

Table 1: Allowed κ_λ intervals at 95% CL for each search channel and their combination. The column "obs." represents the observed κ_λ intervals, "exp." the expected κ_λ intervals with all statistical and systematic uncertainties, and "exp. stat." the expected κ_λ intervals obtained with statistical uncertainties only.