# MEM to improve future searches for HH
# $HH \to b\bar{b}WW \to b\bar{b}l\nu l\nu$

Christophe Delaere, Brieuc Francois, Vincent Lemaitre
**Miguel Vidal**

Universite catholique de Louvain - CP3

**Scalar Search and Study in Belgium**
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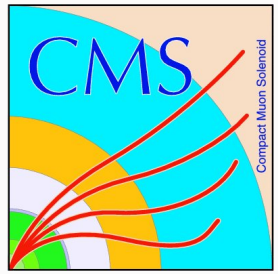
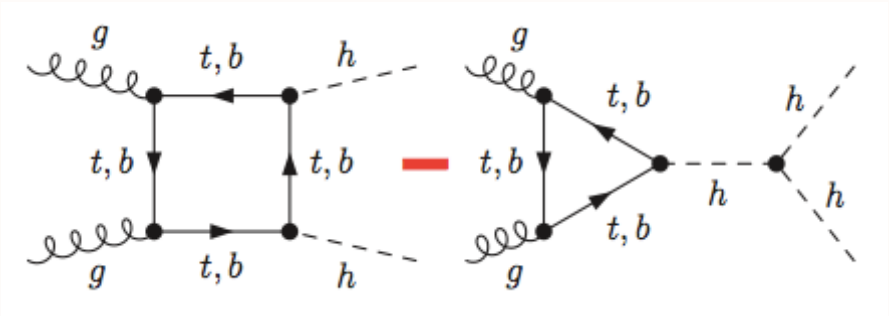


# HH production - The SM case

Why is the higgs boson pair production interesting?

**Measuring the Higgs selfcoupling**



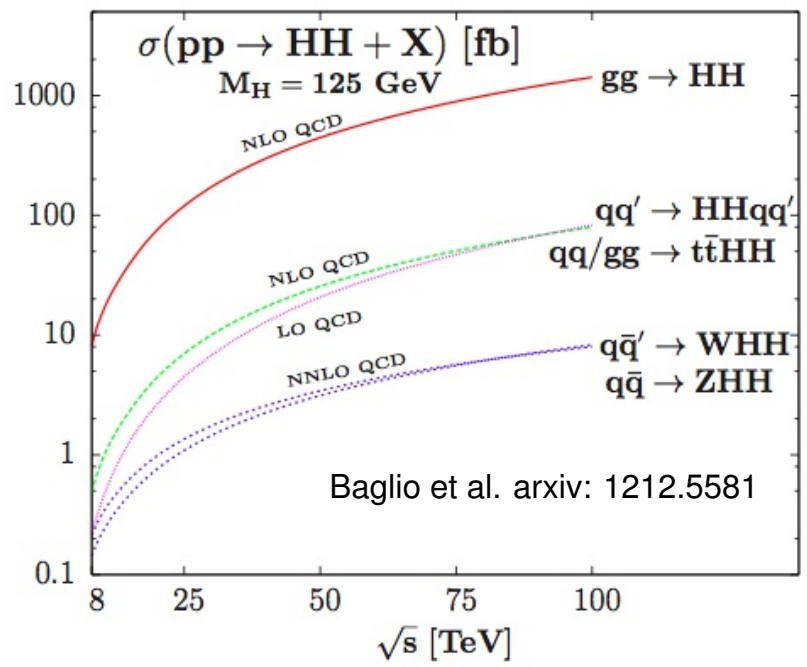

- With data in hand, let's say thousands of $fb^{-1}$, it is interesting for obvious reasons. Being in the position of measuring something in HE Physics is more and more complicated...
- Now we have to see if is worthy to do it and in which final states.

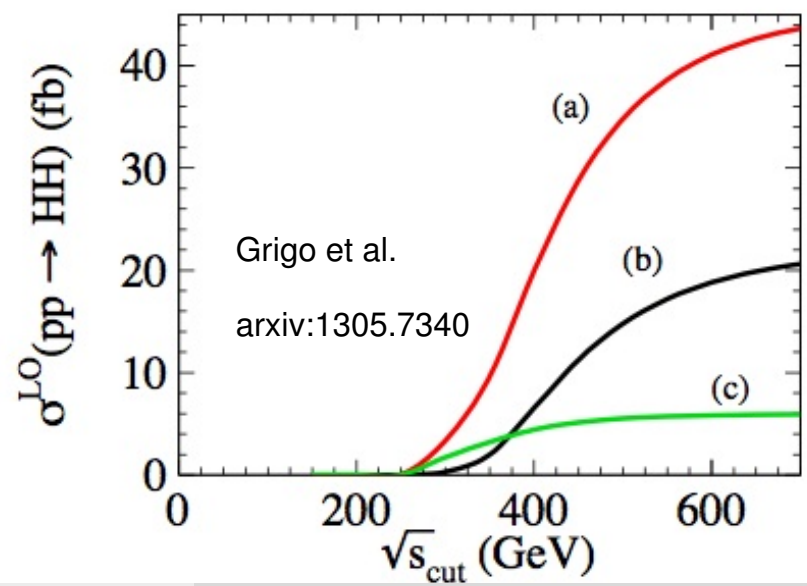
# HH production - The SM case

- **Gluon-gluon fusion** is the dominant contribution
- Via the box and the triangle diagrams.
- Big cancellation between the two diagrams

(a)-> Box, (b)->Total, and (c)->Triangle

- $\sigma^{LO} \sim 20 fb$
- $\sigma^{NLO} \sim 30 - 40 fb$ from theory predictions



# HH production with MadGraph 5

**HH production with MadGraph**

- Model calculating full theory with form factors.
- Already available in MG4, not distributed with the official package. Current CMS samples produced in this way.
- New version available in MG5, not distributed with the official package. Plots in this talk produced with the new version.

Model in MG5 by **Eleni Vryonidou and Fabio Maltoni (UCL-CP3)**

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - Cut based

- First look using HH and $t\bar{t}$ as only background, at **Delphes** level
- Cuts applied by eye, no proper S/B optimization
- The idea is to have a rough yield estimation as function of the future luminosity

Samples:

- HH & $t\bar{t}$ @14 TeV: MadGraph+Pythia+Delphes into 2b2l2nu. Private samples.

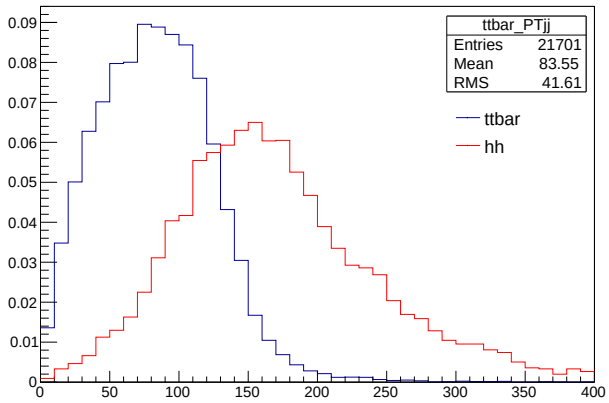
Preselection:

- 2 OS leptons: $p_T > 20 GeV$, $\eta < 2.4$
- Njets = 2, requiring 2 btags: $p_T > 30 GeV$, $\eta < 2.4$

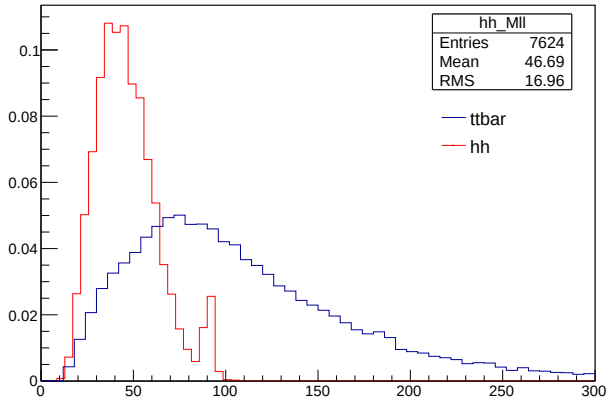
# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - Cut based - Preselection

Over the preselected events we apply some optimization cuts ("by eye") not properly driven by any S/B calculation.

$PT_{jj}$

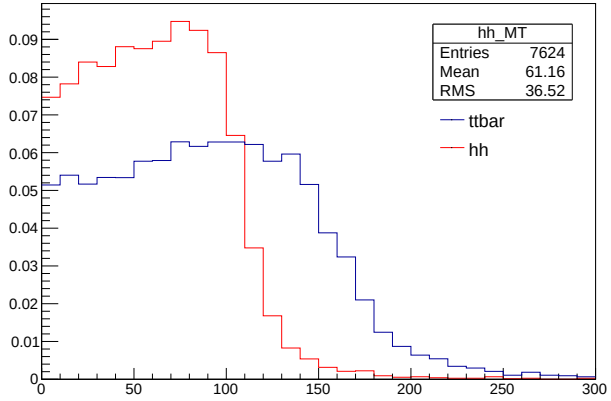



Invariant mass of the two leptons



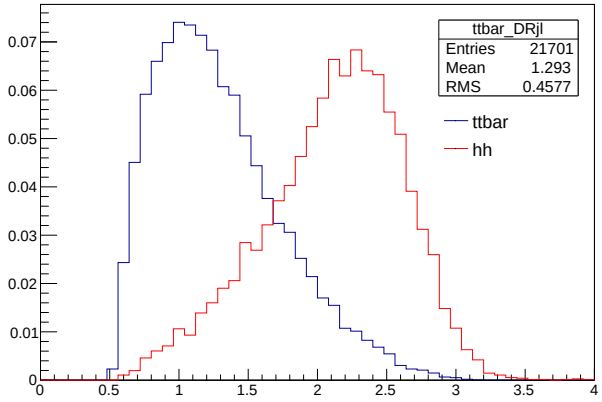

$12 < M_{ll} < 70$ GeV

Transverse mass



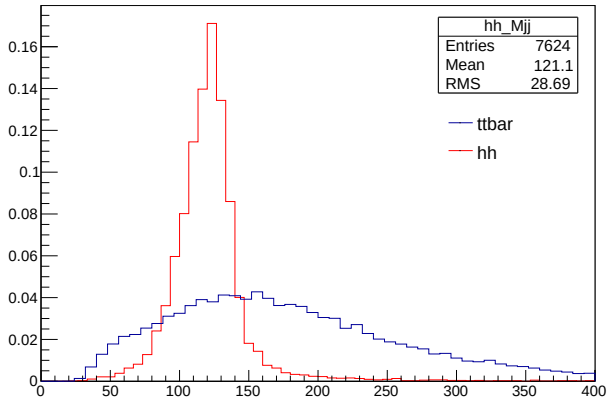

$M_T < 200$ GeV

Minimal DR between jets and leptons



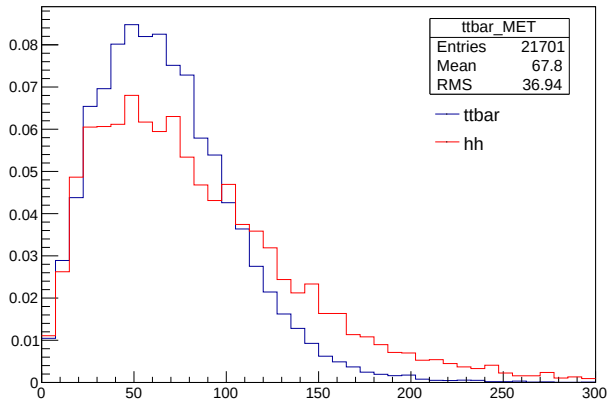

$\min\Delta R_{l,j} > 1.8$

Invariant mass of the two jets




$80 < M_{jj} < 150$ GeV

MET

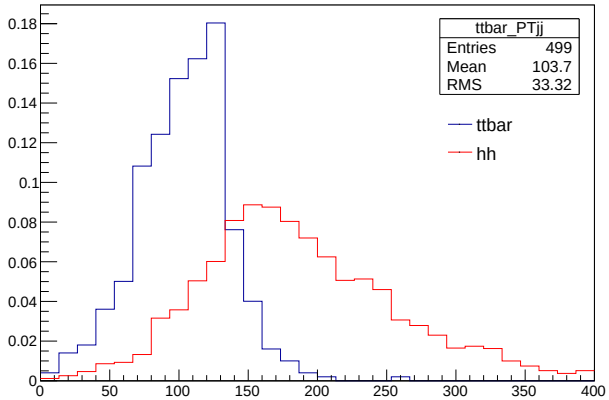



$\not{E}_T > 20$ GeV

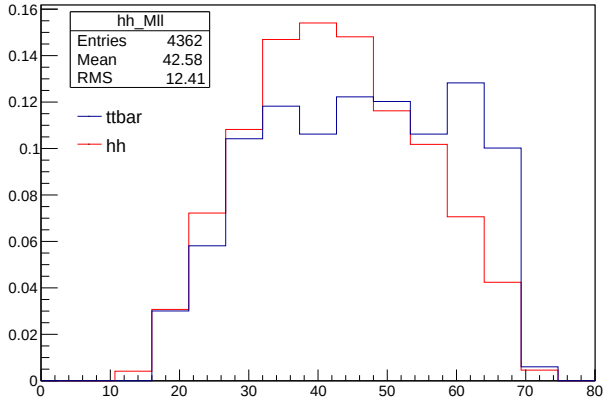
# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - Cut based - Optimization

## Distributions after the cuts

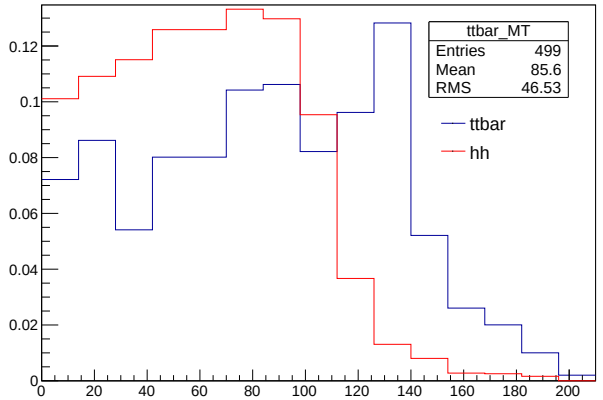
$PT_{jj}$



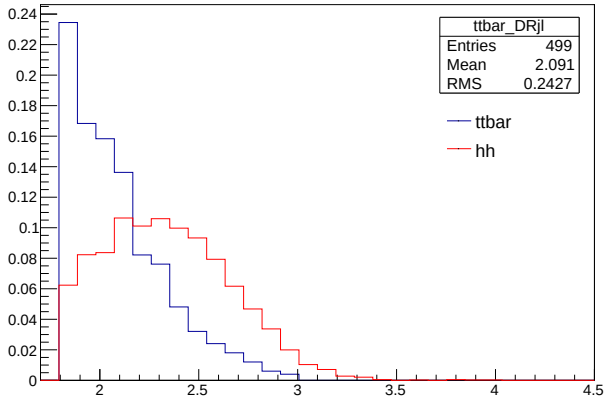

Invariant mass of the two leptons



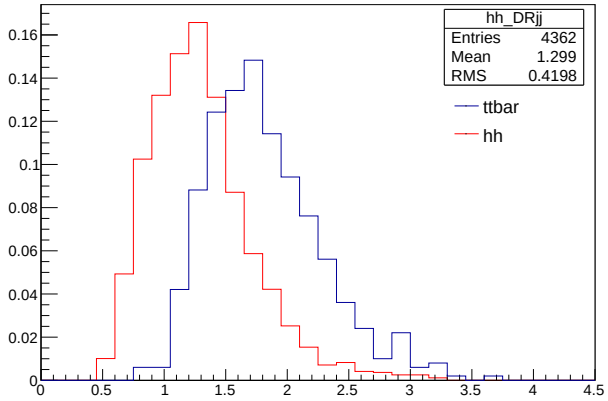

Transverse mass



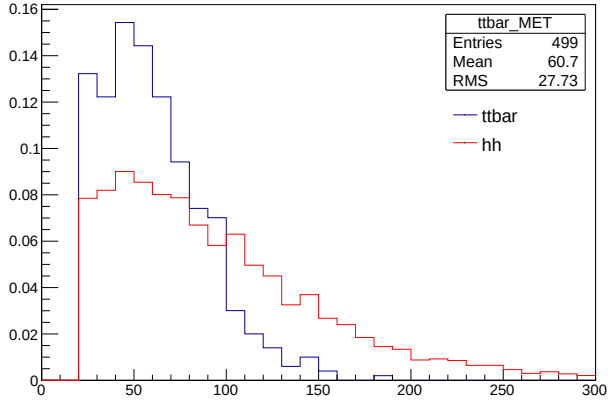

Minimal DR between jets and leptons




DR between jets

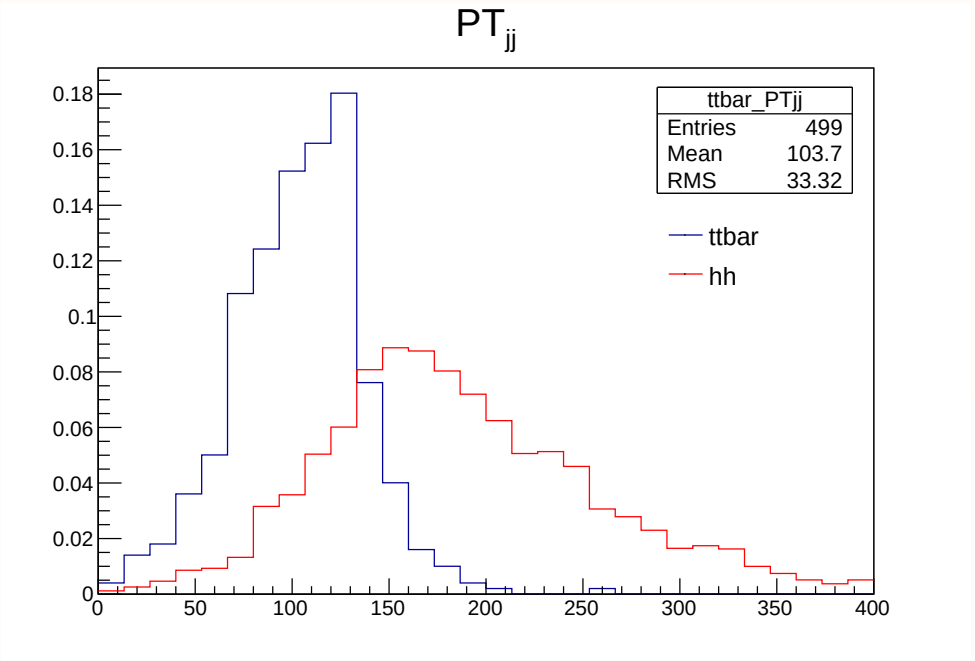



MET



# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - Cut based - Final yields

- Still some discrimination power by cutting on $P_T^{jj} > 140$ GeV
- After that, we are running out of statistics in the $t\bar{t}$ sample, so it is not helpful to look at plots any more.




But we can do some math with the final yields.

- HH = **0.1** events @ 100fb$^{-1}$ $\Rightarrow$ **0.64** events @ 600fb$^{-1}$
- $t\bar{t}$ = 157 events @ 100fb$^{-1}$ $\Rightarrow$ 941 events @ 600fb$^{-1}$

Signal efficiency 43% while reducing the background by a factor 400

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

Matrix Element method* provide probability that an experimental event corresponds to a specific process (hypothesis).

$$P(x^{vis}|\alpha) = \frac{1}{\sigma_\alpha} \int dx_1 dx_2 f(x_1) f(x_2) \int d\Phi |M(p)_\alpha|^2 W(p^{vis}, p)$$

Where :

- $p^{vis}$ : experimental event : {(Pt,eta,phi,E,B-tag,…)$_{jet1}$ ; (Pt,eta,phi,E,B-tag,…)$_{jet2}$ ; (Pt,eta,phi,E,charge,…)$_{lep1}$ ; (Pt,eta,phi,E,charge,…)$_{lep2}$ ; (Et,phi…)$_{met}$ }
- p : partonic state
- $f(x_1)$ $f(x_2)$ : integration on pdf
- $\alpha$ : set of parameter defining the theoretical frame ( $\alpha$ is fixed in this analysis).
- $|M(p)|^2$ Matrix element @ L.O.
- $W(p,p^{vis})$ : transfer function. Conditional probability that an observed quantity ($p^{vis}$) is the evolution of a partonic level one (p).

Weights are defined as : $W = \sigma \times P$

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

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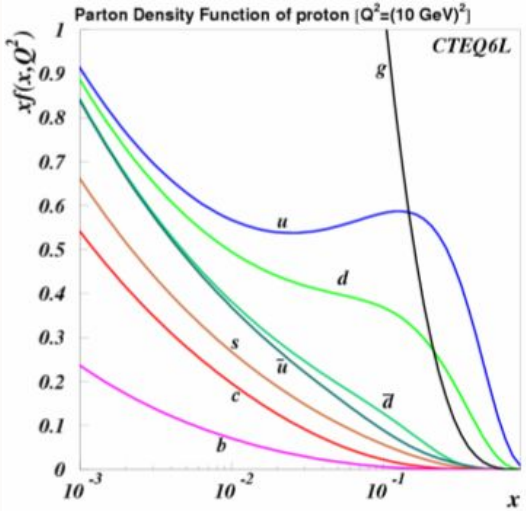
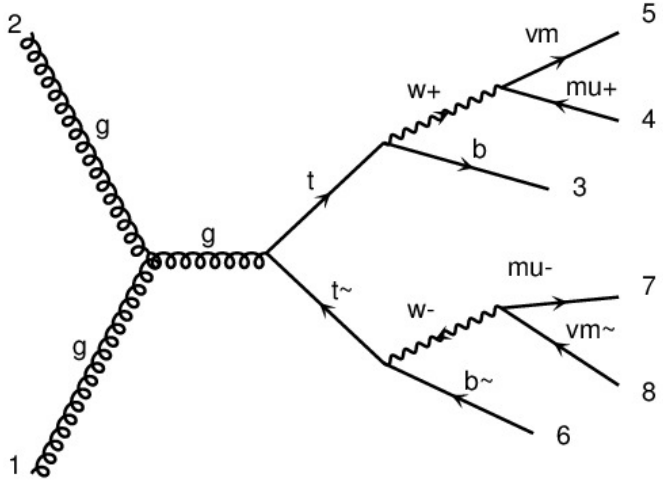
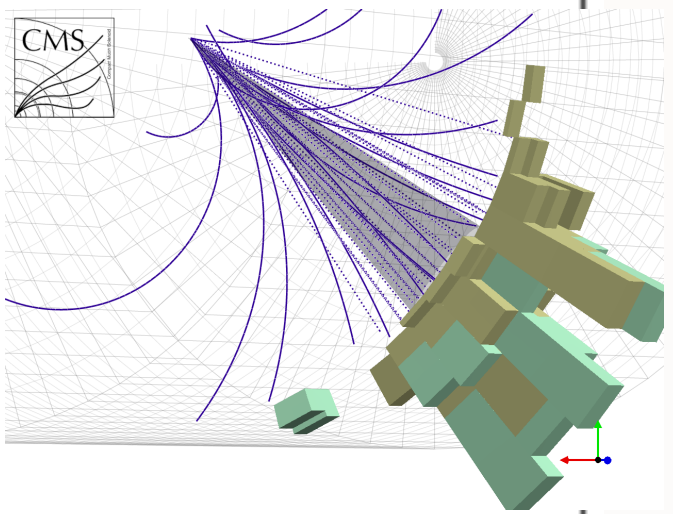


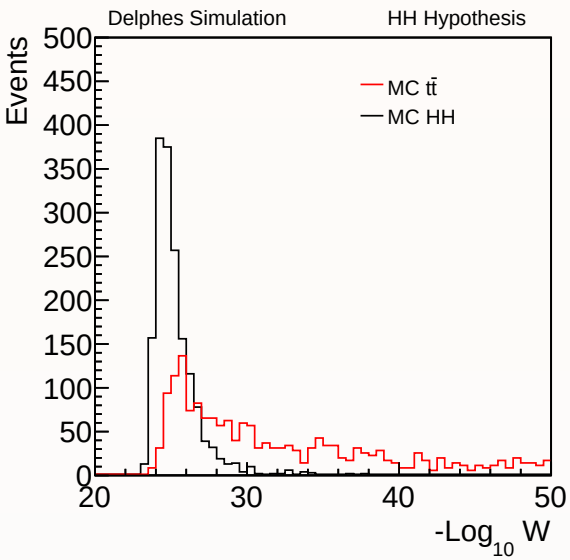



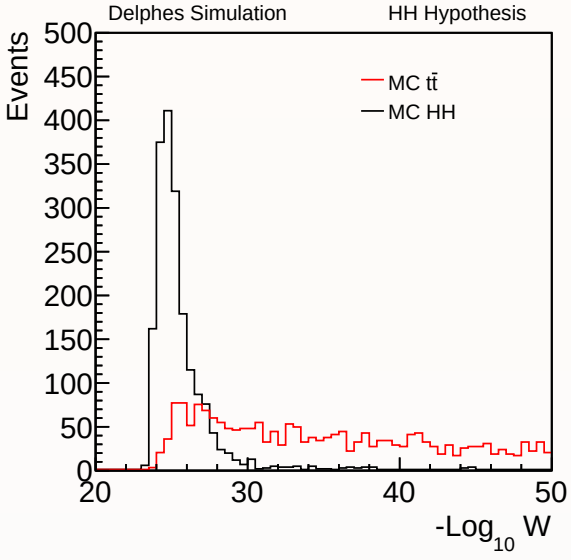

Weights are defined as : $W = \sigma \times P$

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

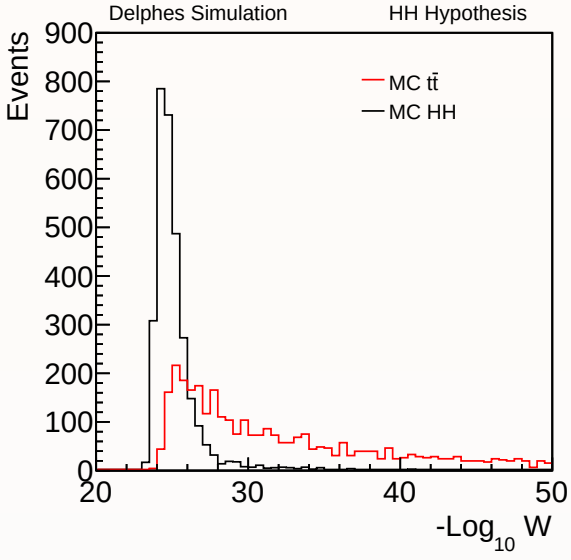
## HH hypothesis




ee Channel




$\mu\mu$ Channel

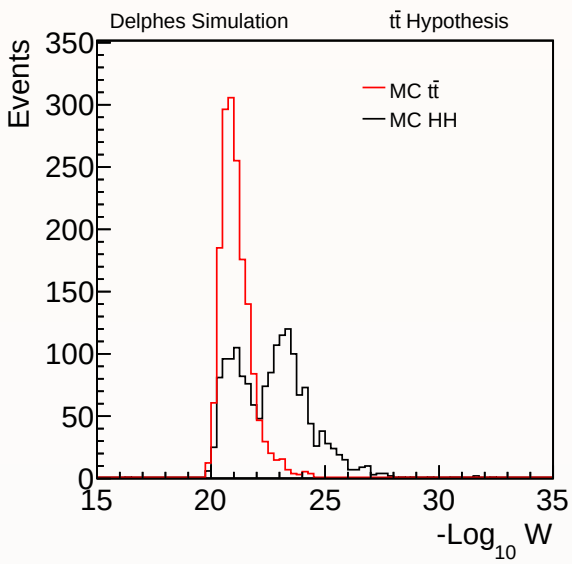



e$\mu$ Channel

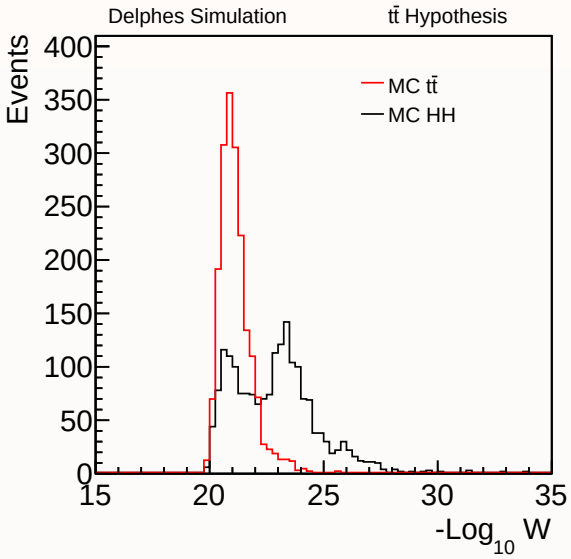
Plots normalized to same area (showed in the x axis). Events with 0 weight removed from the plot. Shape comparison only.

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

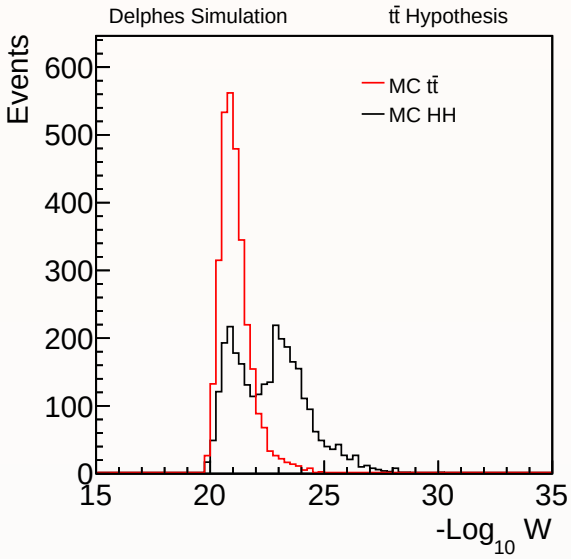
## Backgound hypothesis ($t\bar{t}$ only)




ee Channel




$\mu\mu$ Channel




e$\mu$ Channel

Plots normalized to same area (showed in the x axis). Events with 0 weight removed from the plot. Shape comparison only.

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

First look cutting on the previous plots (by eye) to get the $\sim$number of background events in the cut bases approach. We should cut in both plots at the same time taking into account correlations, not done yet ...

| | Cut Based | | MEM (HH hypo only) | |
|---|---|---|---|---|
| | $100fb^{-1}$ | $600fb^{-1}$ | $100fb^{-1}$ | $600fb^{-1}$ |
| HH | 0.10 | 0.64 | 0.07 | 0.43 |
| $t\bar{t}$ | 157 | 941 | 145 | 873 |

First attempt with the MEM, many things have to be tunned...

The information from HH and background hypothesis can be combined in a smarter way (i.e with a MVA), but this also apply to the cut based approach...

# Summary

- Model to produce HH in MadGraph 5, up and running
- First look using Delphes and suboptimal optimisations
- Not really promising in the near future because of the xsection
- The SM search targets HL-LHC
- **Interesting benchmark for BSM approach**

**From the point of view of the MEM:**

- It looks promising, many things have to be tunned
- Proper comparison needed: **MEM** (MadWeight) vs Cut based
- Still learning and enjoying the MEM in the 2l2b+MET final state

# Backup Slides

Bibliography:

- History - Higgs pair production 1987:

  https://cds.cern.ch/record/183945/files/198802013.pdf

- $hh \rightarrow bbWW \rightarrow bbjjl\nu$: http://arxiv.org/pdf/1209.1489v2.pdf

- $hh \rightarrow bb\tau\tau$: http://arxiv.org/pdf/1309.6318v1.pdf

- Talk about theory perspectives in the HL-LHC from the ECFA meeting:

  http://indico.cern.ch/getFile.py/access?contribId=7&sessionId=3&resId=0&materialId=slides&confId=252045

# $HH \to b\bar{b}WW \to b\bar{b}ll\not{E}_T$ - MEM Based

| | Cut Based | | MEM (HH hypo only) | | MEM ($t\bar{t}$ hypo only) | |
|---|---|---|---|---|---|---|
| | $100fb^{-1}$ | $600fb^{-1}$ | $100fb^{-1}$ | $600fb^{-1}$ | $100fb^{-1}$ | $600fb^{-1}$ |
| HH | 0.10 | 0.64 | 0.07 | 0.43 | 0.04 | 0.26 |
| $t\bar{t}$ | 157 | 941 | 145 | 873 | 131 | 787 |