Recast of CMS Invisible Higgs search

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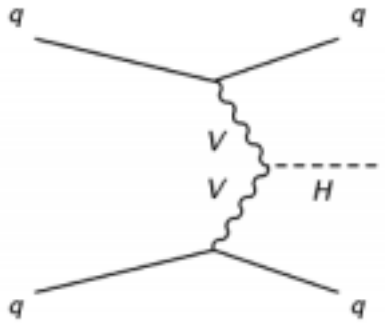
Introduction

- Found a Higgs boson measured with a mass of 125 GeV
- All current measurements of this Higgs are compatible with SM Higgs
  - Associated uncertainties are large and possibility of non-SM physics remains
- Interactions of Higgs with unknown Dark Matter (DM) can introduce invisible decay modes
- Higgs now becomes a mediator (‘portal’) between SM particle and DM particle
- Indirect constraints are inferred from measured SM decay modes
- Direct searches performed for Higgs decaying invisibly

CMS Invisible Higgs

- Channels VBF H (Inv), Z(ll) H(Inv), Z(bb) H(Inv)
- Most sensitive is VBF.
  - Simple cut and count
  - Good for reinterpretation with another model
- VBF H(Inv) Signature:
  - Two jets with large dijet mass and well separated in η
  - Missing energy for invisibly decaying Higgs
- Backgrounds include V+ jets and QCD
  - Estimated from data
- *"Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes"* , CMS Collaboration, Eur.Phys.J. C74 (2014) 8, 2980
  - Limit on the Bf(H->Inv) < 0.58 (0.44 expected)



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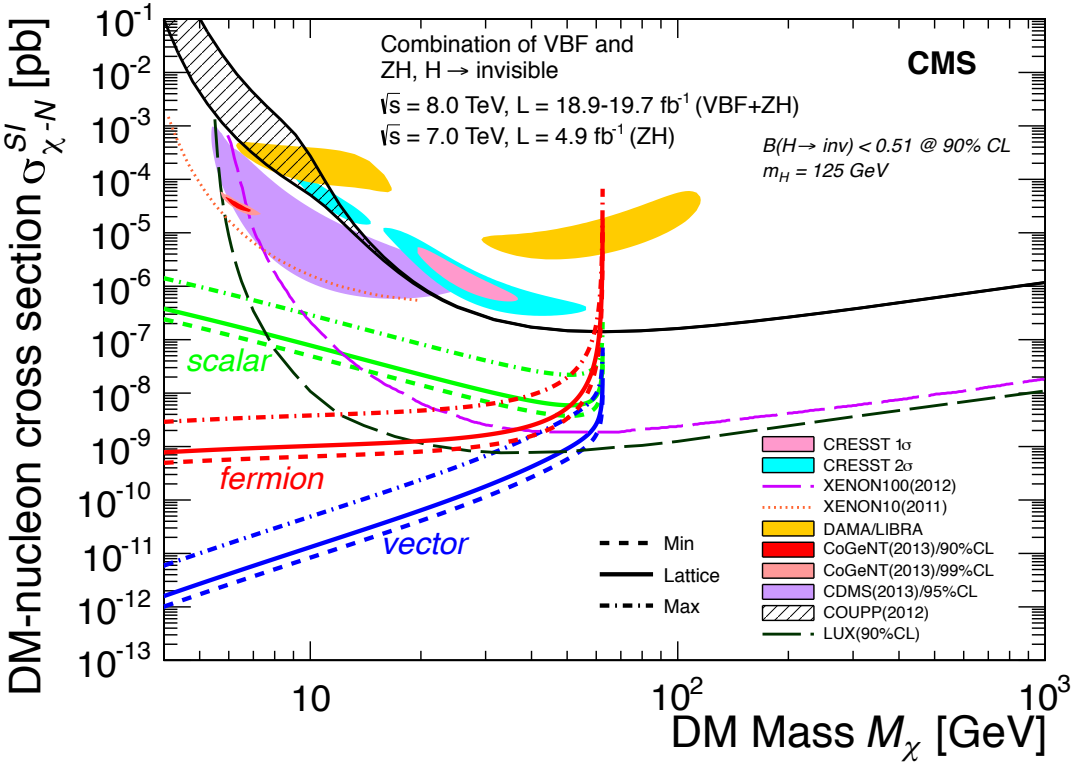
Higgs Portal Interpretation



- However, many other models may result in Invisibly Decaying Higgs

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IPPP CW + Higgs Portal Model

- Coleman-Weinberg (CW) mechanism generates a mass scale from radiative corrections, within a scale invariant theory

- However, simply applying CW to SM generates far too low m_H

- *"Emergence of the Electroweak Scale through the Higgs Portal",* Englert Jaeckel, Khoze, Spannowsky, JHEP 1304 (2013) 060

    - Generates the mass scale in a hidden sector, coupled to SM via Higgs-portal

- Phenomenology : additional scalar (h2) that may decay invisibly

Workflow

- Produce hard scatter with *VBFNLO*
  - Samples provided by IPPP with Parton Level Cuts already applied

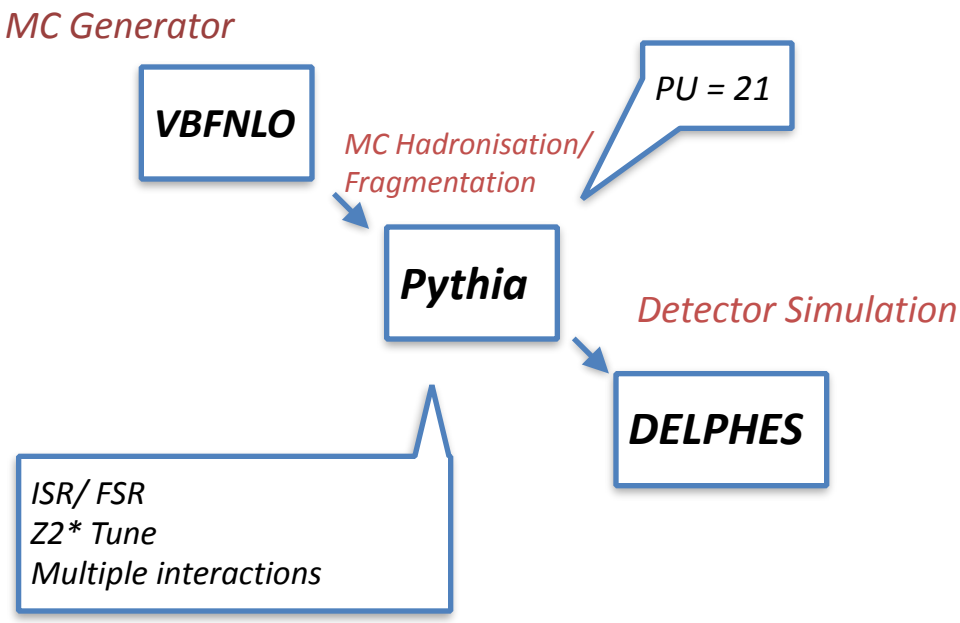
- **Parton Level Cuts:**
  - $P_T^{q1} > 30$ GeV
  - $P_T^{q2} > 30$ GeV
  - $M_{q1,q2} > 600$ GeV

- Hadronise with *Pythia 6.4.28*

- Detector simulation with *DELPHES 3.1.2*

- Verify we can reproduce the CMS result
  - Match yields after full selection criteria

- Calculate acceptances for other models
  - Allows to place limits on those models



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Selection criteria

*L1 MET in CMS is calculated over $\eta < 3$
-Not modelled in Delphes

- **L1 Trigger:**

$\not{E}_T^* > 40$ GeV

HLT

$\not{E}_T^* > 65$ GeV

P_T^{j1} , $P_T^{j2} > 40$ GeV

$\Delta\eta_{j1,j2} > 3.5$

$M_{j1,j2} > 800$ GeV

Offline

Veto e/μ with $P_T > 10$ Gev

Tag jet pair $P_T > 50$ GeV

$|\eta| < 4.7$

$\eta_{j1}.\eta_{j2} < 0$

$\Delta\eta_{j1,j2} > 4.2$

$M_{j1,j2} > 1.1$ TeV

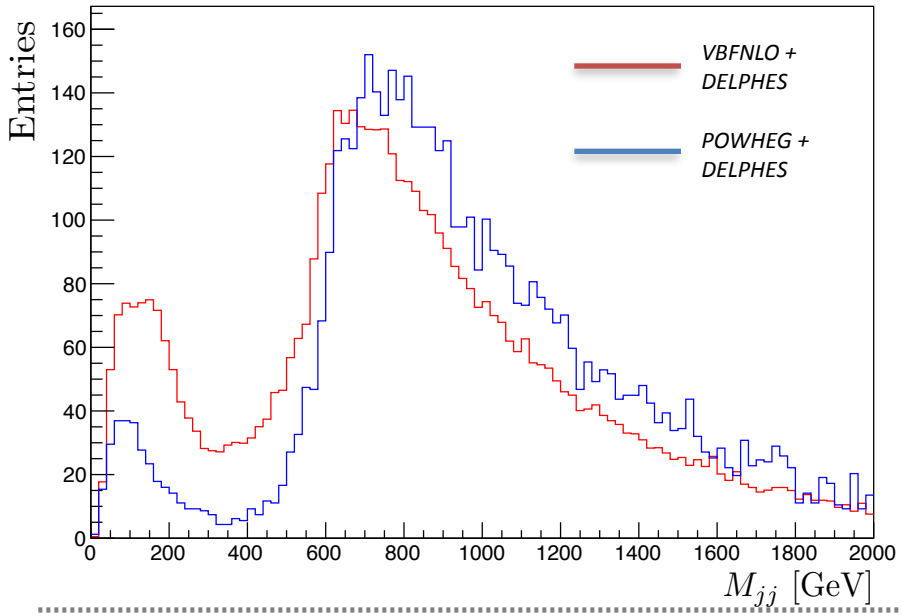
$\not{E}_T > 130$ GeV

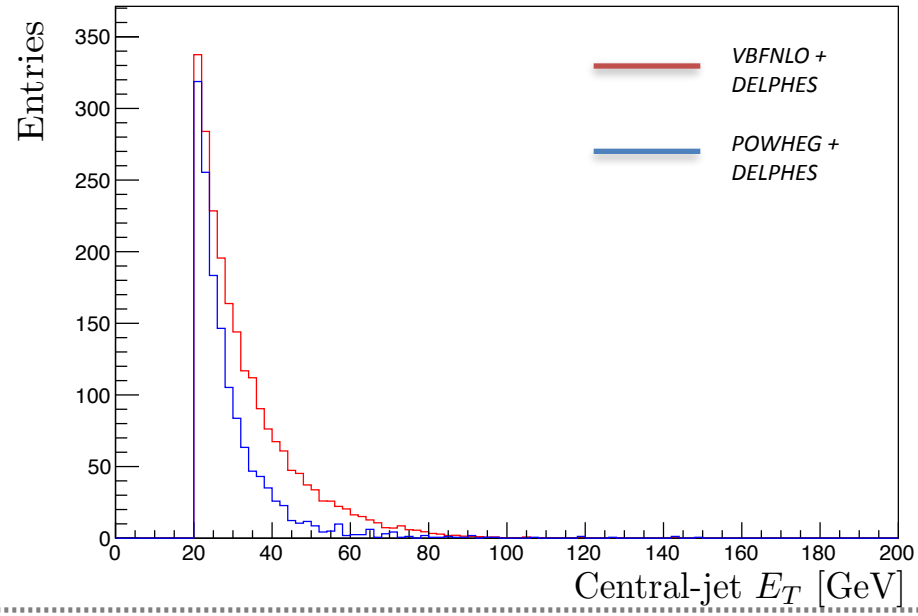
$\Delta\phi_{j1,j2} < 1$ radian

Central Jet Veto on additional jet with $P_T > 30$ GeV in between tag jet pair

Issues with *VBFNLO (cutting a long story short)*

- With *VBFNLO* as the MC Generator and *DELPHES* as the detector simulator, we compared distributions and yields to the CMS Analysis
- Unable to reproduce the CMS yield
- CMS Paper used *POWHEG* as their MC Generator
- Source of discrepancy illustrated below





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POWHEG & Detector Investigation

- Using *POWHEG* as the default MC Generator and retaining the same *Pythia* settings we can produce some plots and calculations from the CMS paper
- See next slide

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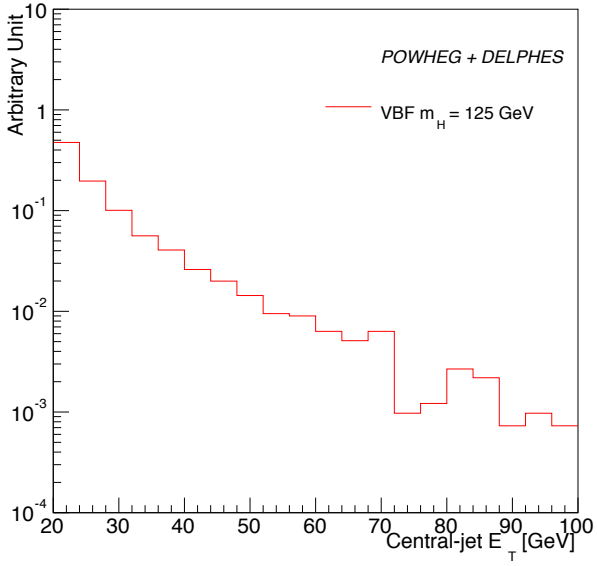
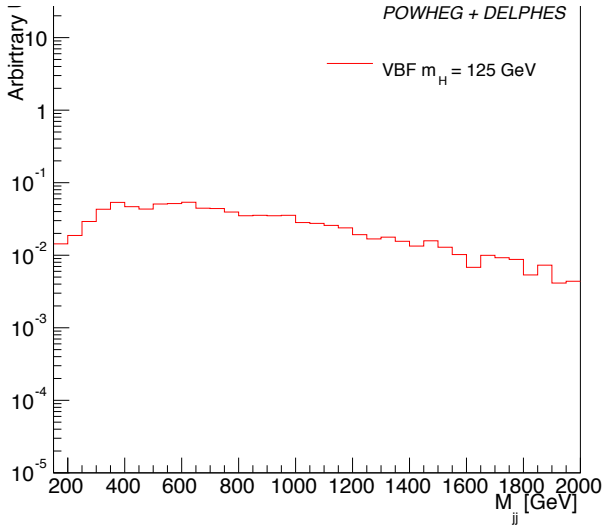
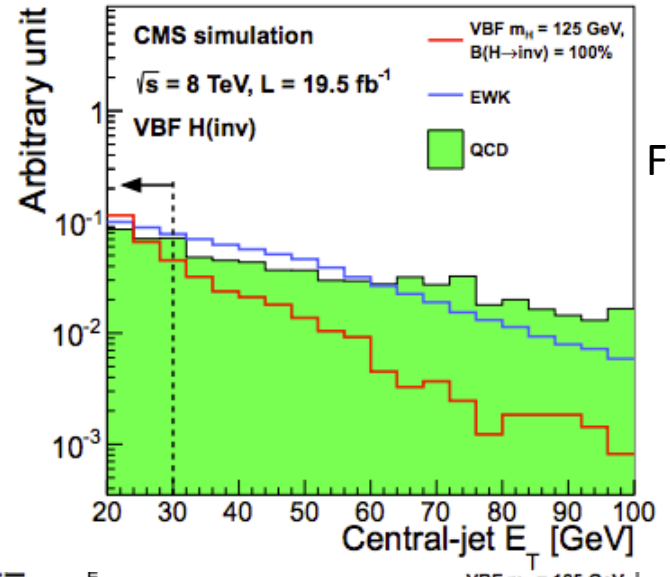
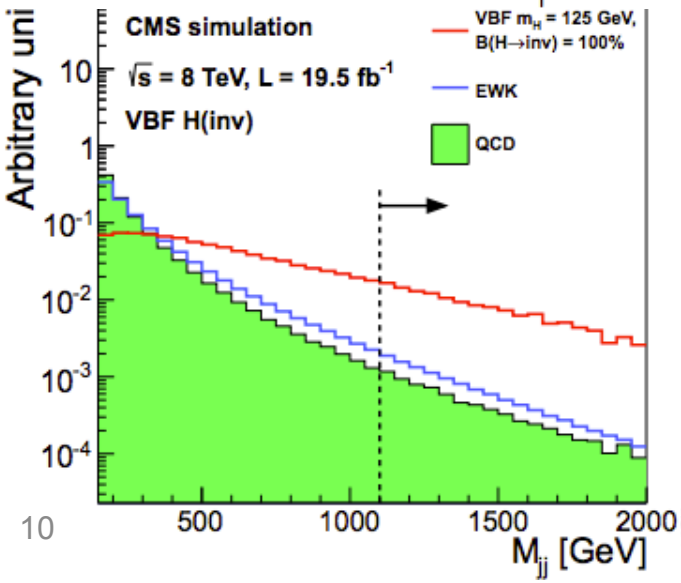
POWHEG & Detector Investigation







From CMS Paper



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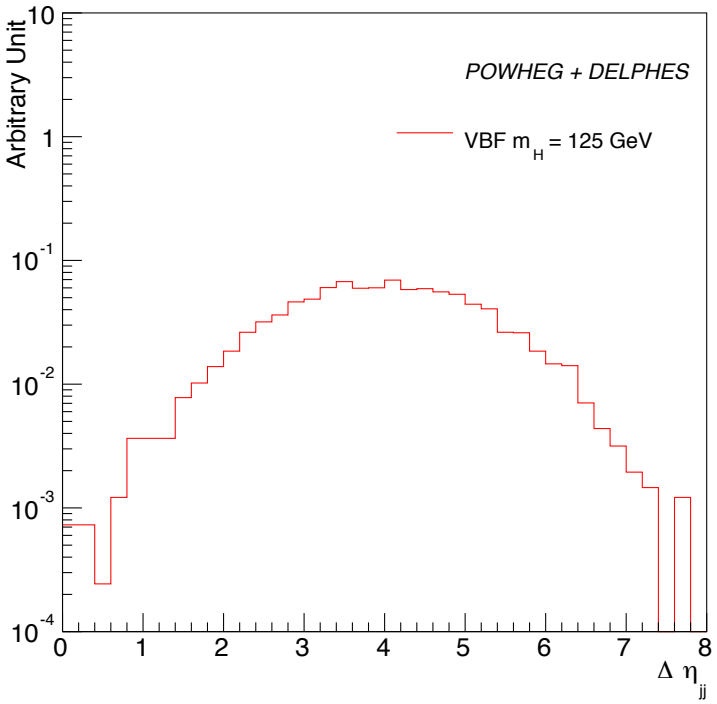
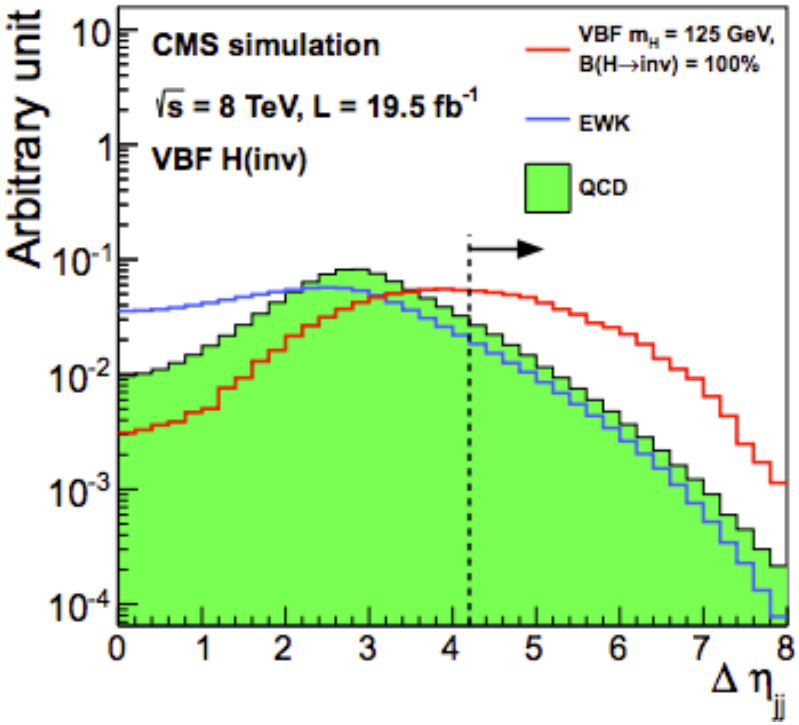
POWHEG & Detector Investigation





- Good reproduction of CMS Distributions using *POWHEG* and *DELPHES*

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Conclusion

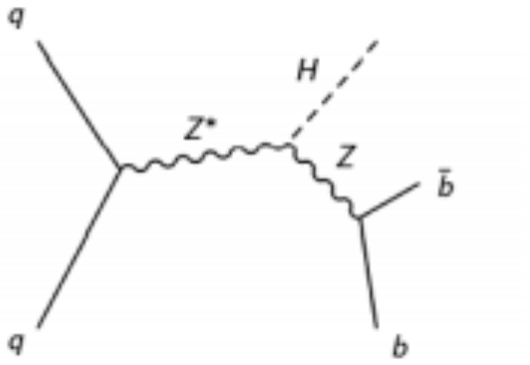
- Good agreement between CMS Paper FullSim distributions and *DELPHES* with *POWHEG* as MC generator
- The CMS Signal yield for a Higgs produced via the VBF process and decaying invisibly is
  - $210 \pm 29\ (\mathrm{syst})$
- Still ongoing work to verify signal yields with *POWHEG* and *DELPHES*

- The next steps are to simulate events with *POWHEG* for a range of M_H
- Reproduce CMS cross-section limits
- Set limits in the parameter space of the IPPP model
- M_{h2} (mass of h2)
- μ (mixing angle)

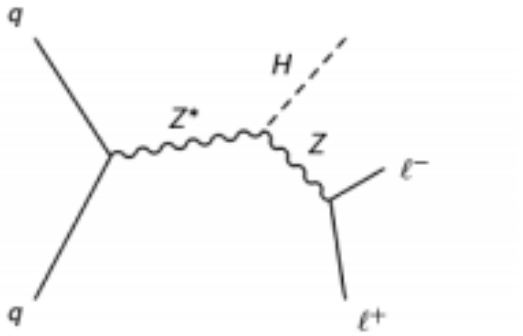
Backup

- Other SM Higgs production channels

Z(bb) H(Inv)



Z(ll) H(Inv)



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Backup

- *DELPHES* calculation of $\not{E}_T$ takes as input Calorimeter tracks, photons and neutral hadrons and merges transverse momenta into one output array.

$$\vec{E}_T^{miss} = - \sum_i \vec{p}_T \ (\mathrm{i})$$

http://arxiv.org/pdf/1307.6346v3

$$H_T = \sum_i |\vec{p}_T(i)|$$

- PileUp subtraction is not applied on the missing energy variable in *DELPHES*
  - Only on Jets and the Isolation Variable (in determining whether an electron, muon or photon is isolated)