Two Higgs Doublet Model (2HDM) search projections for high-luminosity LHC

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Outline

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- Two Higgs Doublet Model (2HDM)
- Analysis Strategy
- Results for H→ZZ→4l
- Results for A → Zh→2l2b
- Summary

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Delphes Simulation

- Delphes[1] is a C++ framework for the parameterized simulation of a generic collider experiment
  - Was used extensively for Snowmass and ECFA workshops last year
- Has inherent flexibility to tune to the object reconstruction efficiencies and resolutions of a given detector
- Event processing is fast enough to allow generation of large MC samples very quickly
- Incorporates pileup simulation and subtraction
  - Charged particles from pileup are removed using tracking information
    - ✓ Remove tracks inconsistent with the primary vertex
  - Neutral particle subtraction using fastjet area method (ρ*A) method
- Crucial tool to have reliable physics predictions at high luminosity and high pileup expected in future LHC runs

[1] http://arxiv.org/abs/0903.2225

Two Higgs Doublet Model (2HDM)

- Standard Model (SM) contains a minimal Higgs sector
  - There is only one scalar responsible for Electroweak Symmetry Breaking
- Many natural models beyond the SM predict extended Higgs sector
  - Can be described at low energy by 2HDM

2HDM Type
Type I
Type II
Lepton Specific
Flipped

- 2HDM
  - 5 Higgs bosons
    - ✓ h, H, A, $H^{\pm}$

CP-even

CP-odd

- Large parameter space, but many simplifications possible
  - ✓ No CP violation, No FCNC, MSSM quadratic couplings
    - Four 2HDM types with 6 parameters: 4 masses & 2 angles (α, β)

- Assume the recently discovered h(125) to be the lighter of CP-even 2HDM scalars
  - Constrain 2HDM parameter space using current measurements of Higgs boson couplings

- Focus on search sensitivity for 2HDM neutral Higgs bosons (H & A)

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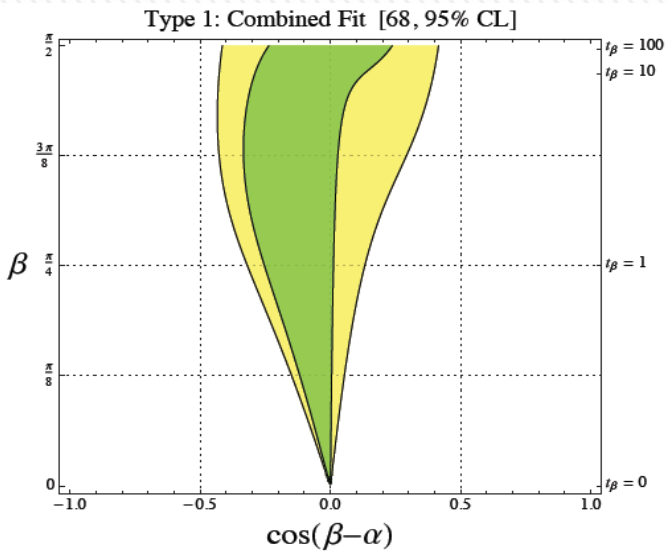
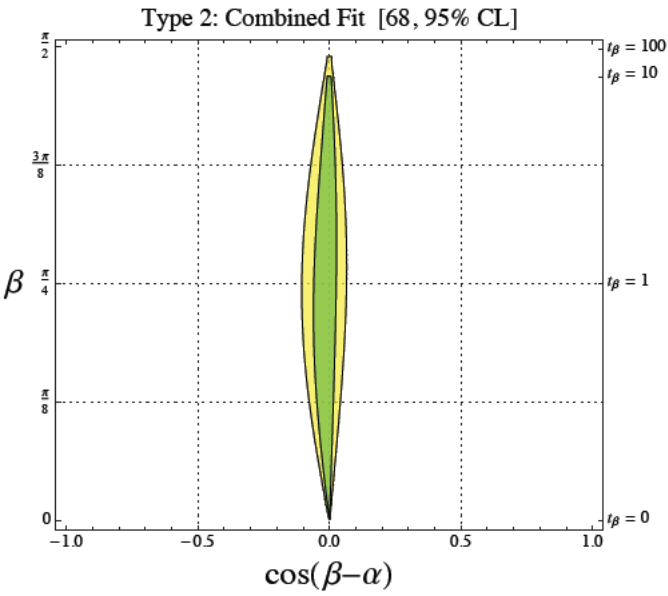
Probing the 2HDM

- Two strategies available to probe 2HDM
- Precision measurements of h(125) couplings
  - Couplings of h_{2HDM} differs from h_{SM}
  - Not sensitive in alignment limit (AL)
    - ✓For $Cos(\beta-\alpha) = 0$, $y_{2HDM}/y_{SM} = 1$
- Direct searches for additional scalars
  - Complementary approach
  - Focus on gluon-fusion production
    - ✓HVV coupling proportional to $Cos(\beta-\alpha)$
      - VBF & associated production suppressed
    - ✓No AVV tree-level coupling
      - No VBF or associated production
- We focus on the search for H→ZZ & A→Zh





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Analysis Strategy

- We explore H→ZZ & A→Zh channels with Z→ ll (l= e/μ) & h→bbar
- Signal and background samples based on Delphes fast detector simulation
- Run conditions considered
  - √s = 14 TeV
  - ∫Ldt = 3000 fb^{-1}
  - $<N_{PU}>$ = 140
- Trigger
  - Assume trigger thresholds remain similar to the current scenario
  - Require p_T (l_1) > 30 GeV or p_T (l_1) > 20 GeV & p_T (l_2) > 10 GeV

- Object Selection
  - Lepton (e, μ)
    - ✓ p_T > 5/10 GeV (μ/e) & |η| < 2.5
    - ✓ Relative isolation < 0.1
  - b-Jet
    - ✓ p_T > 20 GeV & |η| < 2.5
    - ✓ Efficiency = 70% (60%) for |η| < 1.2 (> 1.2)
    - ✓ 0.1% light jet mistag rate

- Event Selection
  - H→ ZZ
    - ✓ Exactly 4 leptons
    - ✓ Exactly 2 Z candidates
  - A→Zh
    - ✓ Exactly 2 b-jets
    - ✓ Exactly 2 leptons
    - ✓ Exactly 1 Z & h candidate

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$H \rightarrow ZZ \rightarrow 4l$

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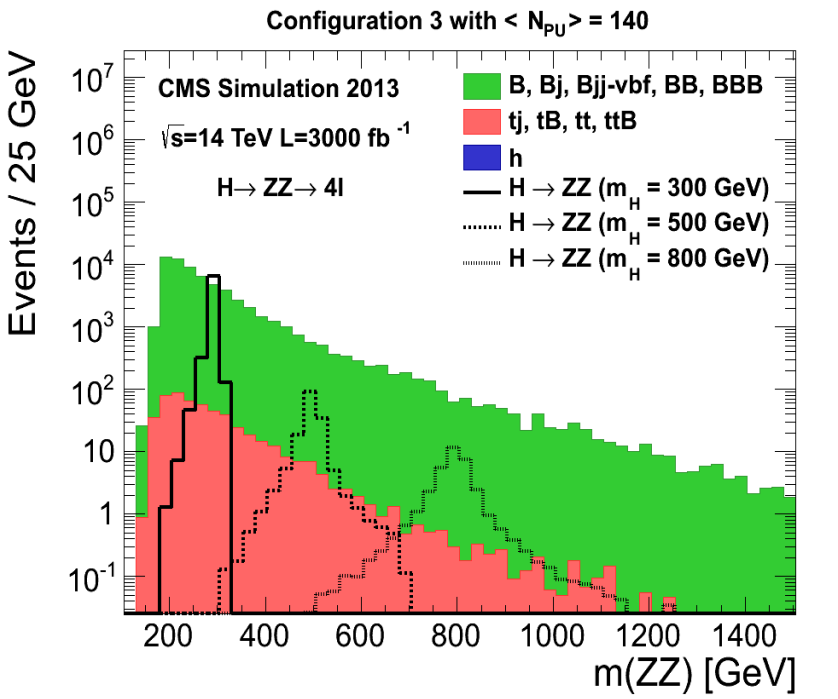
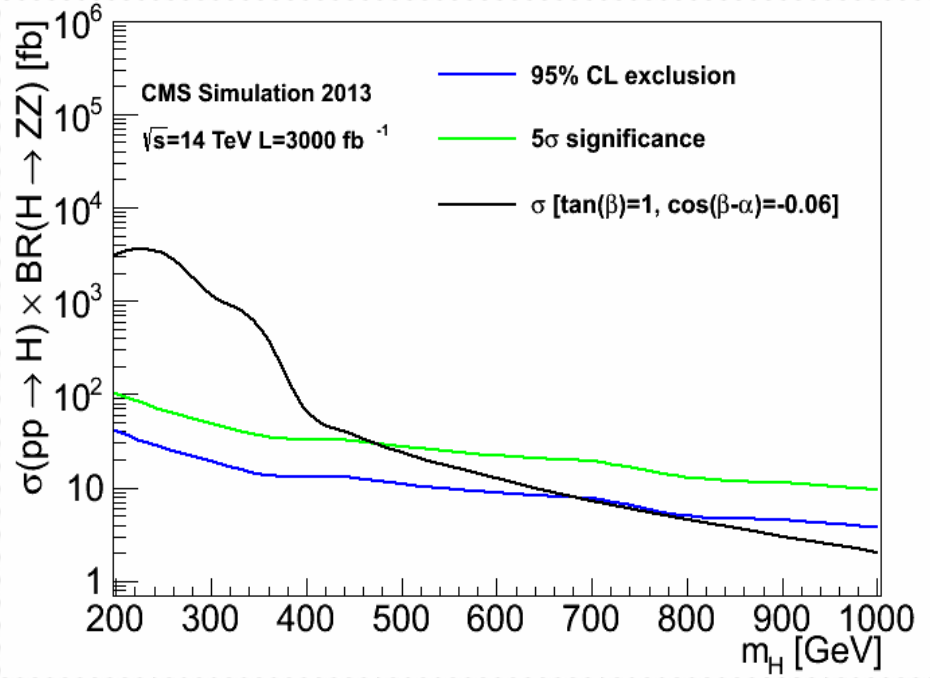
(a) Results for H→ZZ→4l





- Invariant mass distribution of Higgs candidate
- Use this to determine cross-section times branching ratio which can be excluded or yield discovery

- B = $W^{\pm}$, Z & t= top, antitop
- Assume 20% systematic uncertainty on the background prediction
- Interpret these results in terms of parameter space of two Higgs doublet model (next slide)

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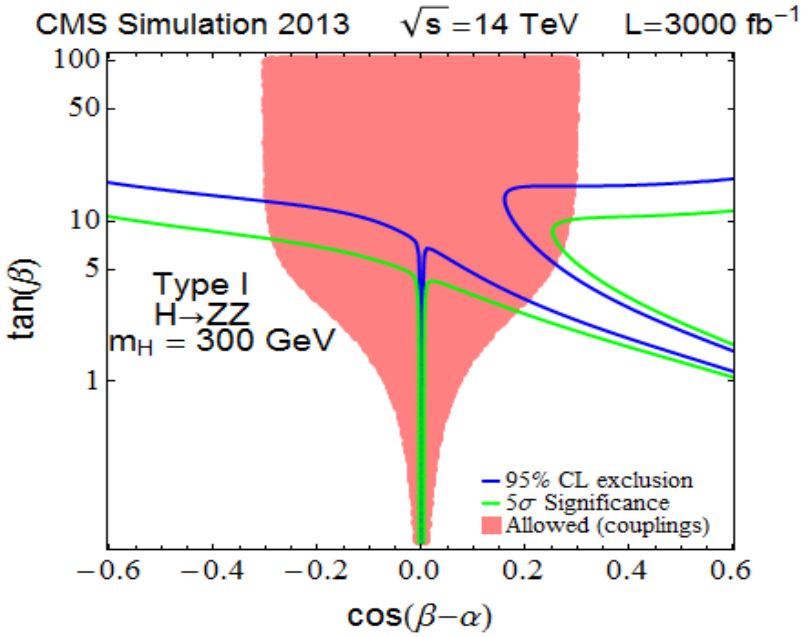
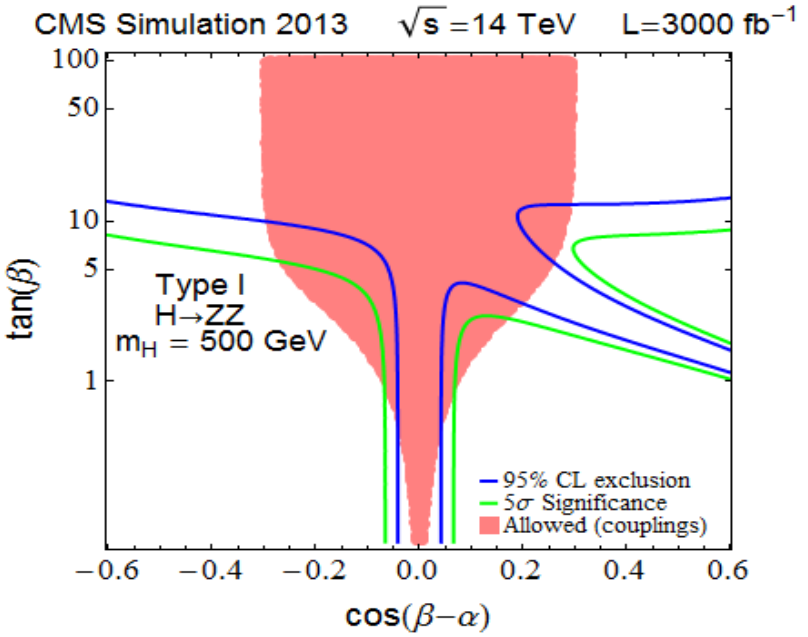
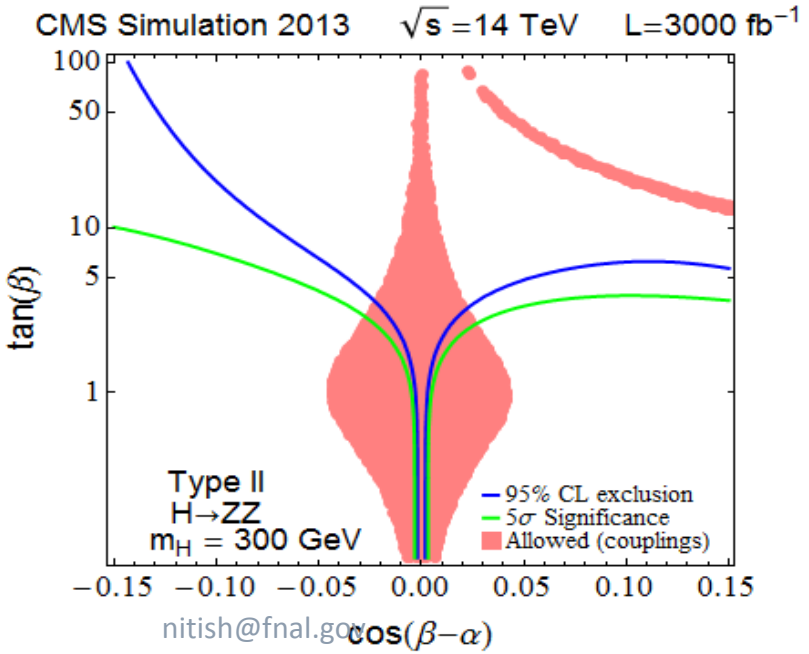
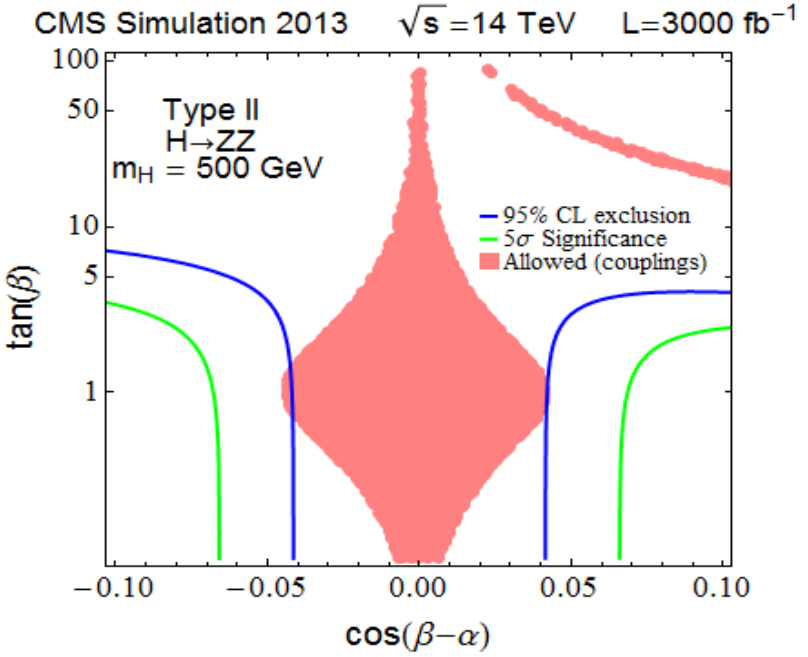
(b) Results for H→ZZ→4l









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A→Zh→2l2b

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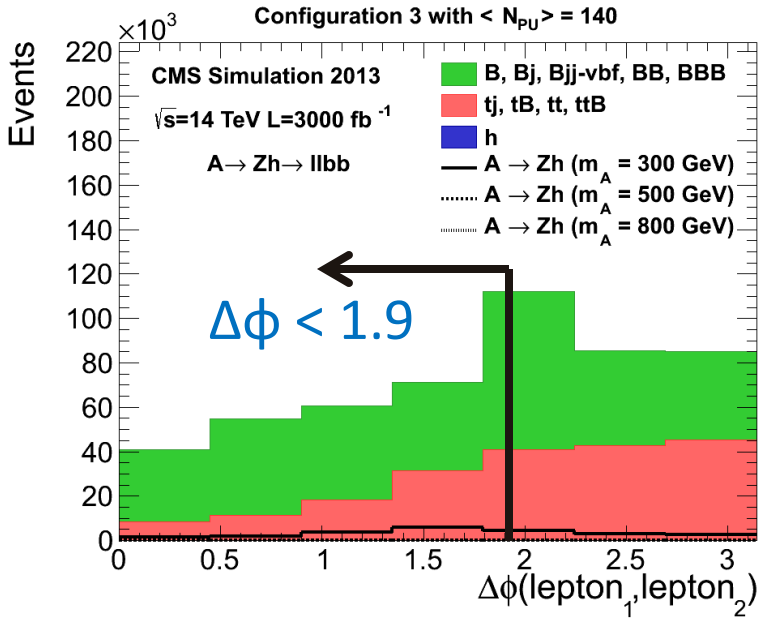
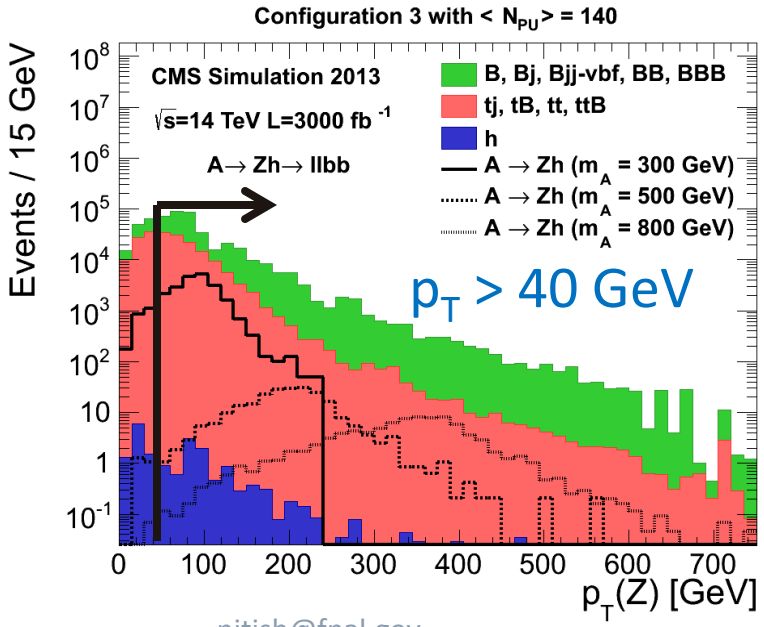
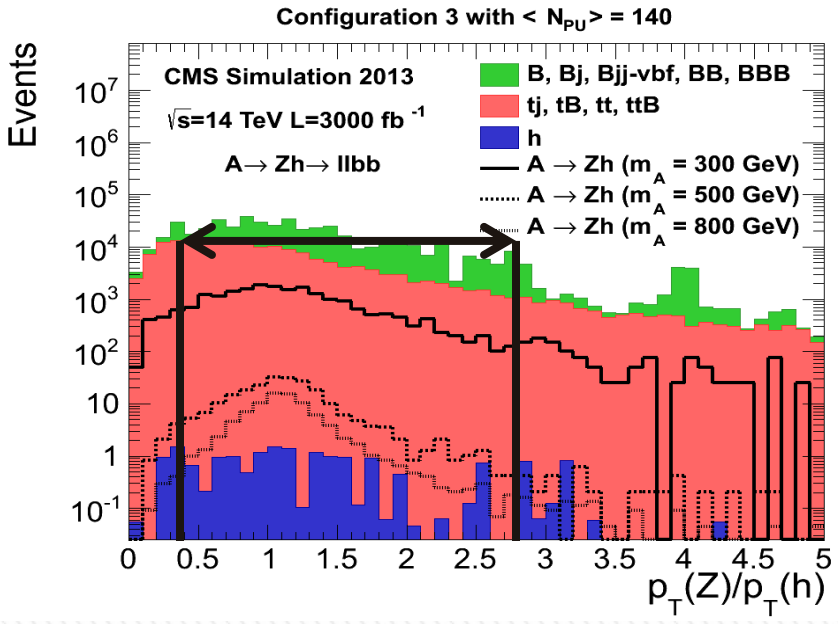
Preselection Kinematics for A→Zh→2l2b



- Apply additional selections to enhance signal sensitivity
  - $\Delta\phi < 1.9$
  - $p_T > 40$ GeV
  - $0.4 < p_T(Z)/p_T(h) < 2.75$
- Cuts are optimized by varying them simultaneously to achieve the best limit





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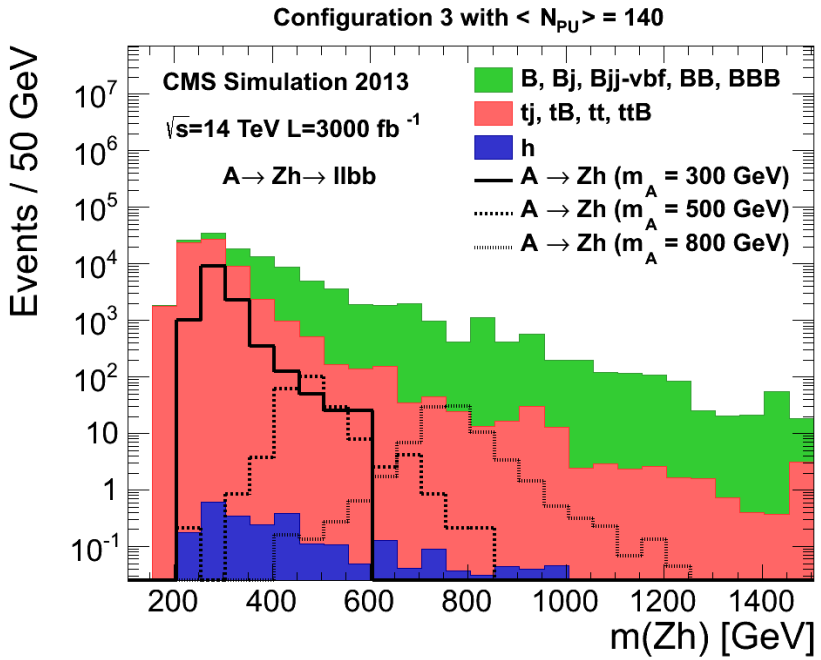
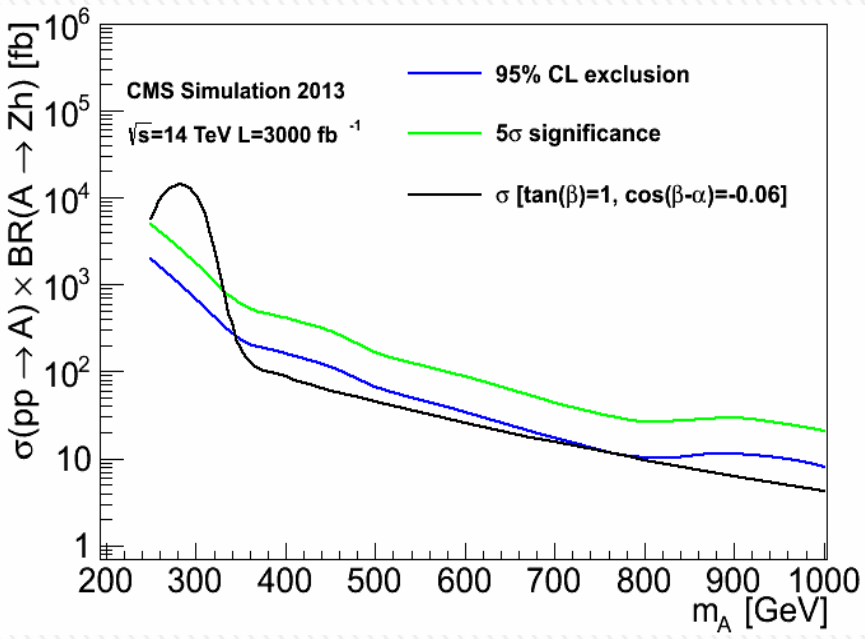
(a) Results for A→Zh→2l2b





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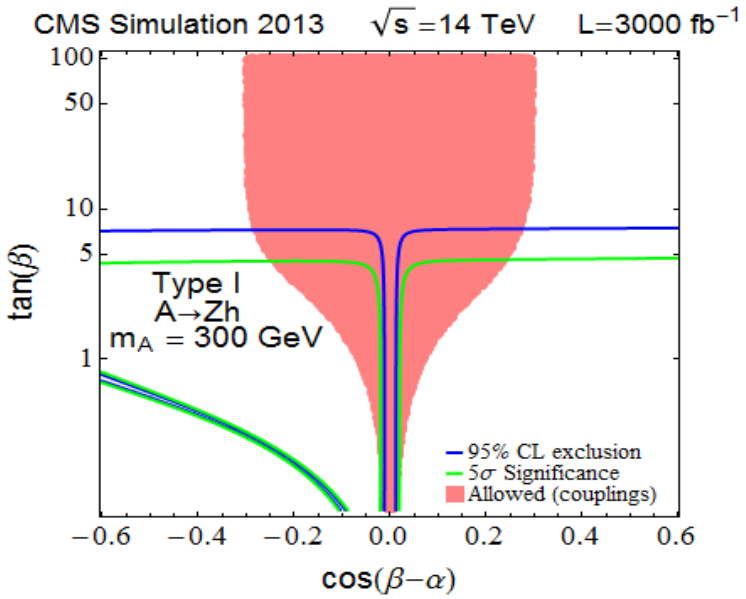

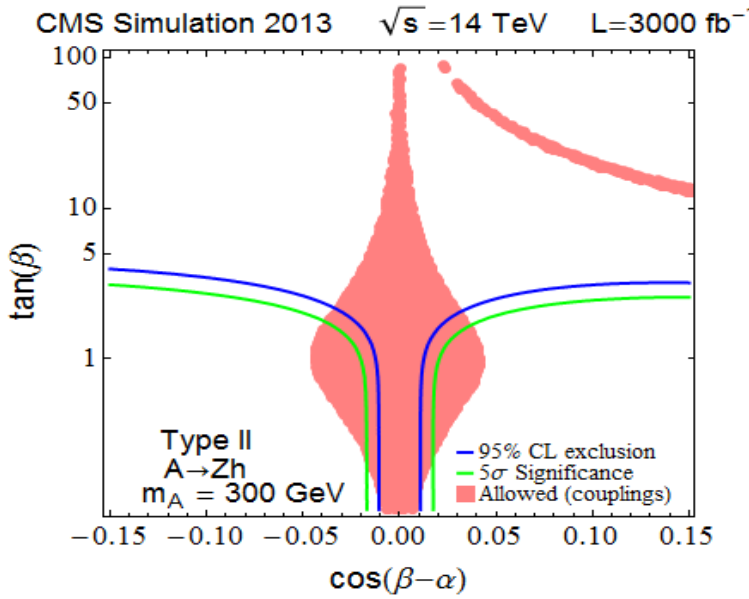

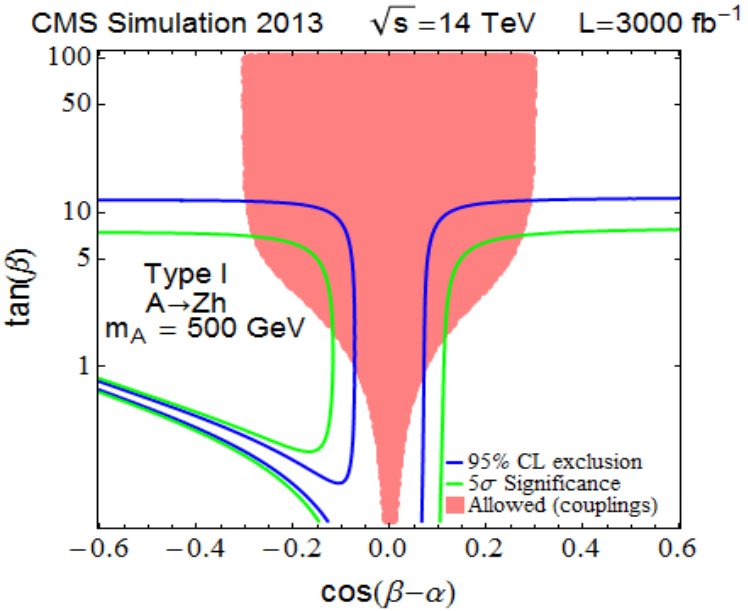

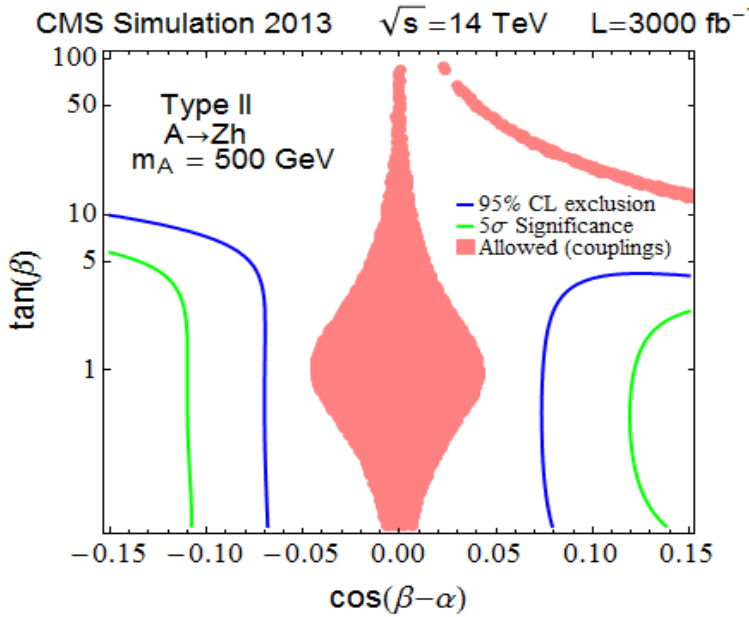

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Summary

- It is crucial to explore Higgs sector completely
- Precision measurements of h(125) couplings can constrain the parameter space of Two Higgs Doublet Model
  - Little (no) sensitivity near (at) alignment limit: $\cos(\beta-\alpha) = 0$
- Direct searches for neutral Higgs boson provide a unique opportunity to probe regions of 2HDM parameter space near the alignment limit
- It is very important to pursue both coupling measurements and the direct searches
- With the upgraded CMS detector and future runs of LHC machine it is possible to exclude or discover significant regions of the 2HDM parameter space

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Back Up

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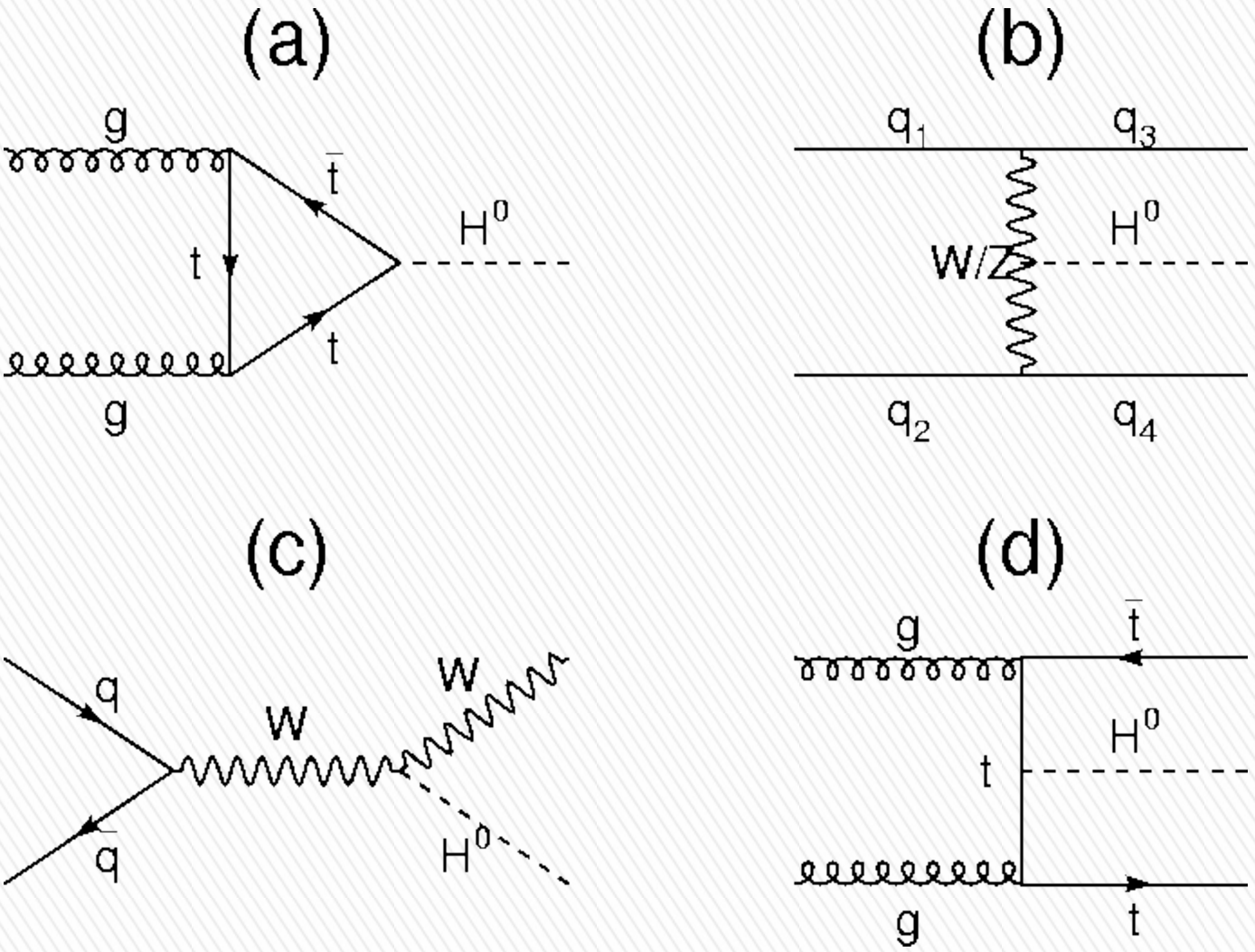
Higgs Production Feynman Diagrams



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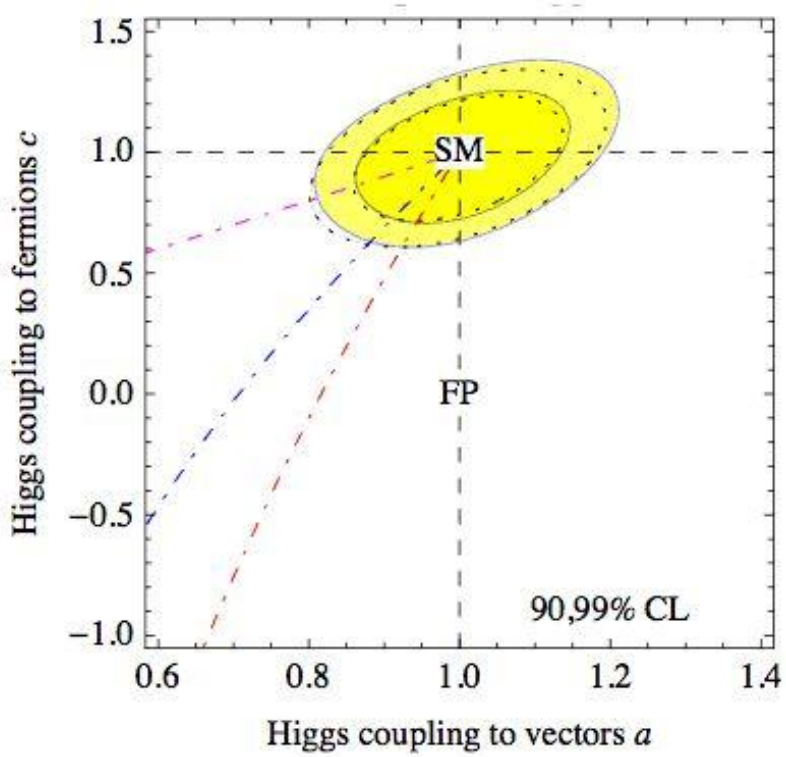
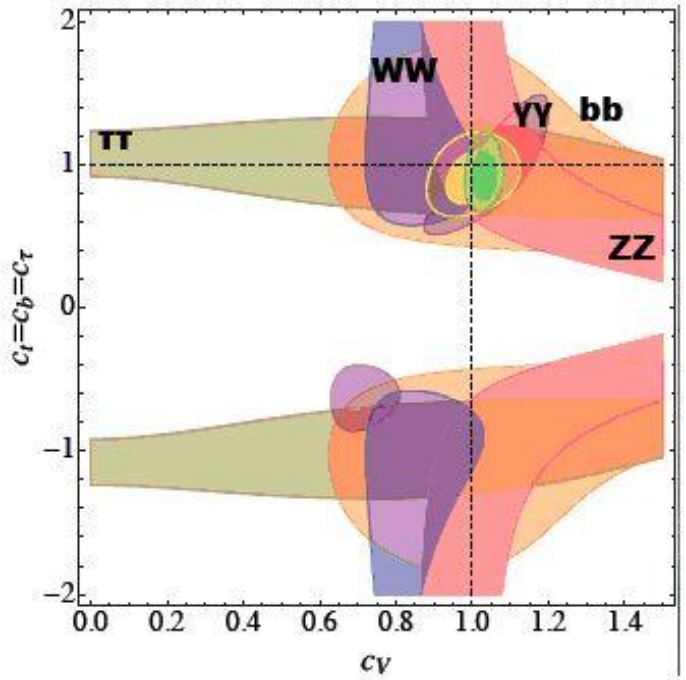
Higgs Couplings to Fermions and Vector Bosons





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