MSSM Higgs Searches

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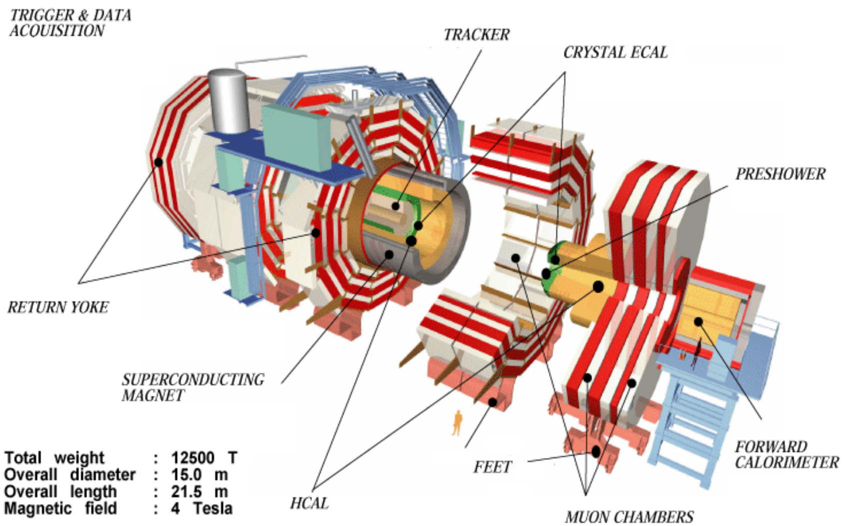
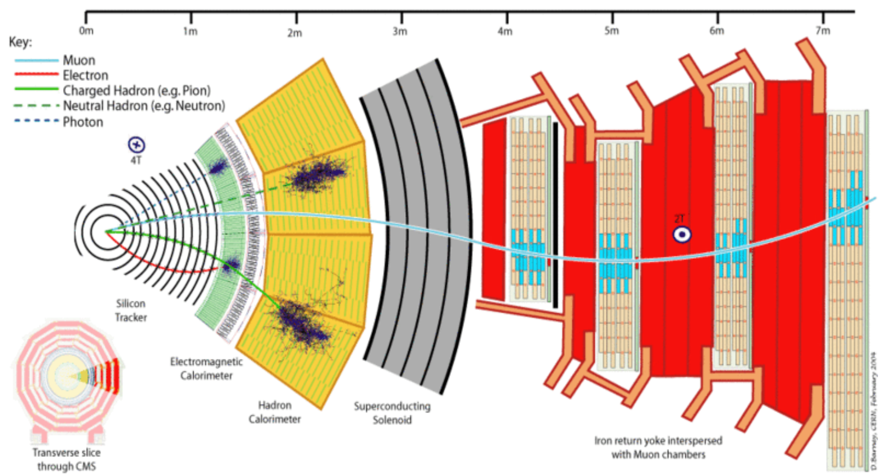
Outlines

- The CMS
- The Standard Model
- Motivations from the Higgs Sector
- MSSM
- Summary of Exo-Higgs Searches
- Heavy Higgs decaying to $t\bar{t}$
- Conclusion

The CMS





- Tracker: Cocentric layers of silicon sensors, measure charged particles trajectories
- Electromagnetic Calorimeter: Lead-Tungstate crystals, electrons – positrons – photons interact there and their energy is measured
- Hadronic Calorimeter: Hadrons interact brass layers and produce a shower of charged particles
- Solenoid Magnet: Largest solenoid ever built, creates 4T field that bends the charged particle trajectories
- Return Yoke: Magnetic field created from the solenoid is returned in the iron yoke. Offers support structure for the detector
- Muon Chambers: Located in the iron yoke, measure energy of muons

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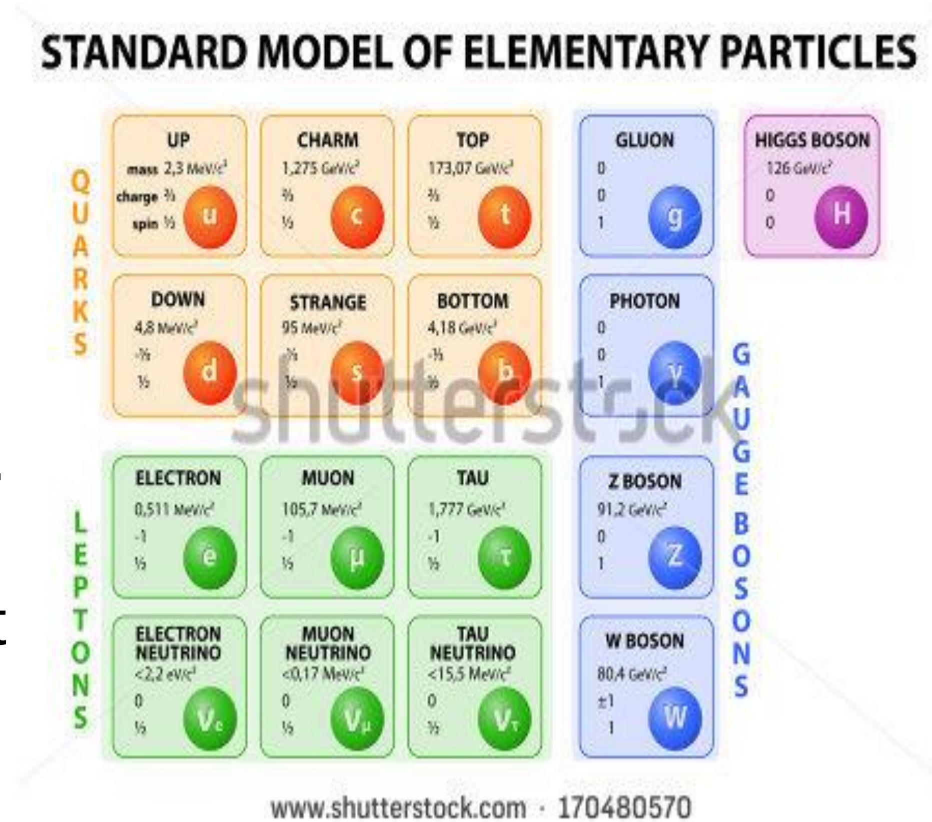
The Standard Model

- Three families of quarks
- Three families of leptons
- The gauge bosons
- The recently discovered Higgs boson by CMS and ATLAS with a mass 125.3 ±0.4(stat.)±0.5(syst.)GeV. [1]
- Higgs boson was the last missing piece in the SM



Motivations from the Higgs sector

- Hierarchy problem in the SM Higgs sector
  - Quantum corrections to the H mass have quadratic divergences
- The answer can be searched in SUSY
  - By introducing supersymmetric partners for the SM particles
  - Quadratic divergences are cancelled

Particles				Sparticles			
quarks	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	u_R	d_R	squarks	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$	$\tilde{u}_R$	$\tilde{d}_R$
leptons	$\begin{pmatrix} e_L \\ \nu_L \end{pmatrix}$	e_R		sleptons	$\begin{pmatrix} \tilde{e}_L \\ \tilde{\nu}_L \end{pmatrix}$	$\tilde{e}_R$	
Higgs doublet	H_1, H_2			Higgsinos	$\tilde{H}_1, \tilde{H}_2$		
bosons	$W_\mu^\pm, W_\mu^3$			winos	$\tilde{\omega}^\pm, \tilde{\omega}^3$		
	B_μ			bino	$\tilde{b}$		
	G_μ^A			gluinos	$\tilde{g}^A$		

$$\text{particle (spin } J) \quad \overset{\text{SUSY}}{\longleftrightarrow} \quad \text{sparticle (spin } J \pm \tfrac{1}{2})$$

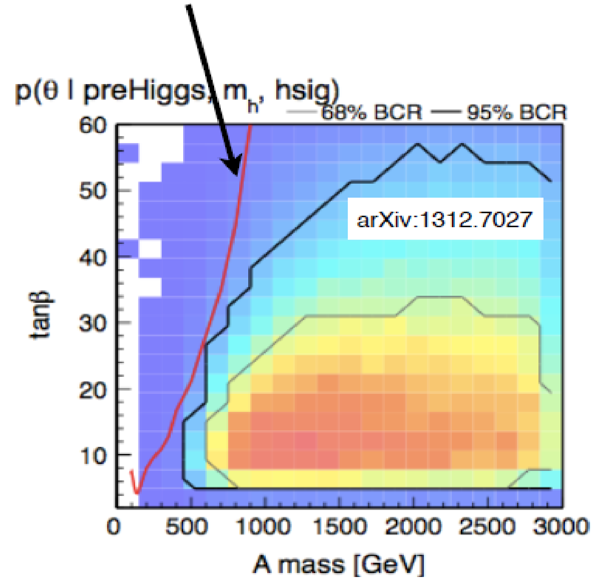
SUSY relates states with spins that differ by $\frac{1}{2}$.

Particles and their spartners have the same mass.

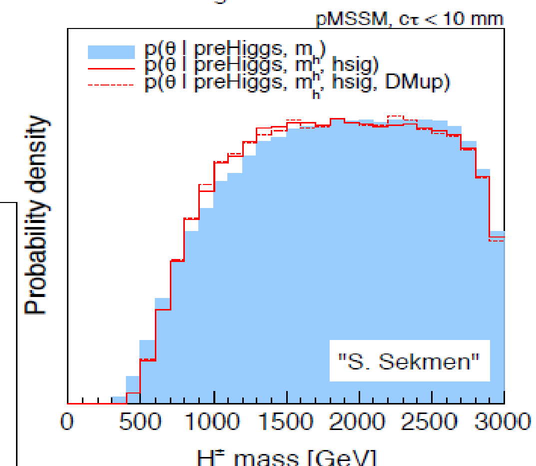
MSSM

- MSSM is the minimal extension to the standard model that realizes supersymmetry
- Higgs sector of MSSM consist of five states
  - h^0, H^0, A^0, $H^\pm$
- Higgs sector can be described by $\tan\beta$ and m_A
- Our channel for Higgs searches
  - $H^\pm \rightarrow h^0 + W^\pm$
    - $h^0 \rightarrow bb$, $W^\pm \rightarrow jj$
- $H^\pm$ can be produced with a top quark
  - $H^\pm t$, $t \rightarrow W + b$, $W \rightarrow l + \nu_l$

"CMS exclusion limit"



"fixing h0=123-128 GeV"



"fixing h0=123-128 GeV"

MSSM parameters:
mass h^0 = 125 GeV
mass H^0 = 300 GeV
mass A^0 = 300 GeV
mass $H^\pm$ = 310 GeV
$\tan\beta$ = 3

Event Selection & Applied Cuts

Event (1 lepton, 3 b-jets, 2 non b-jets, MET)

ΔR (l, j) > 0.5, lepton$_{(e, \mu)}$ Pt > 30 GeV, jet |η| 2.4, b-jets CVS > 0.679

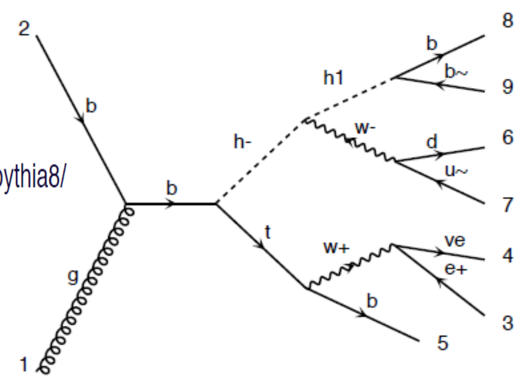
PAT Electron, Muon, Jets and MET (Type 0, 1, 2 correction)

- Electron Channel
  - Number of e = 1
  - Number of muon = 0
  - MET > 40 GeV
  - Number of b-jets ≥ 3
  - Number of non b-jets ≥ 2
  - Electron |η| < 2.5

- Muon Channel
  - Number of e = 0
  - Number of muon = 1
  - MET > 40 GeV
  - Number of b-jets ≥ 3
  - Number of non b-jets ≥ 2
  - Muon |η| < 2.4

Signal

/THmTToLBNuHpTo2B2J_MHp-310_Mh1-125_8TeV-madgraph5-pythia8/Summer12_DR53X-PU_S10_START53_V19-v1/AODSIM



Background

/TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM

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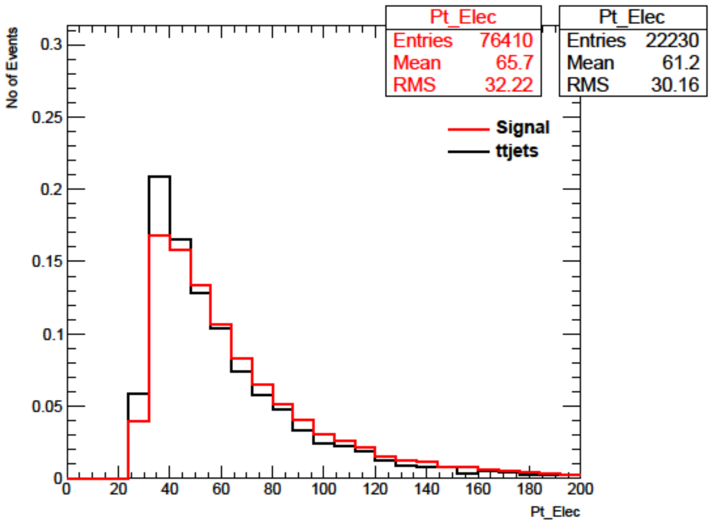
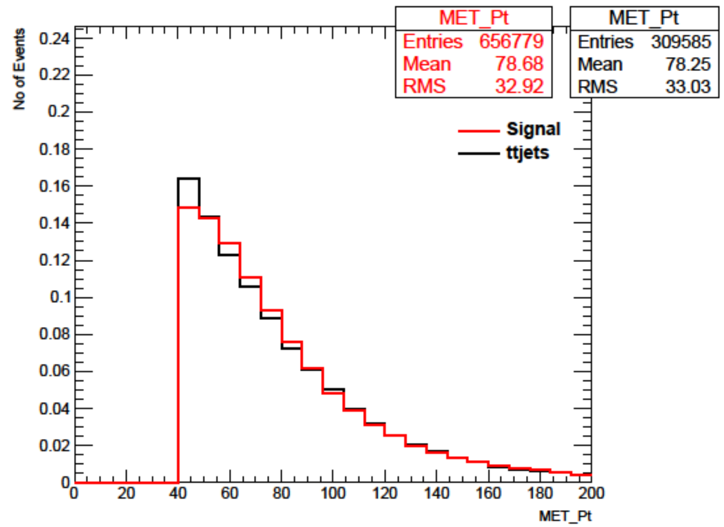
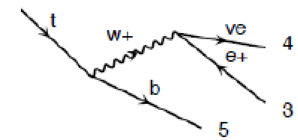


Electron Pt

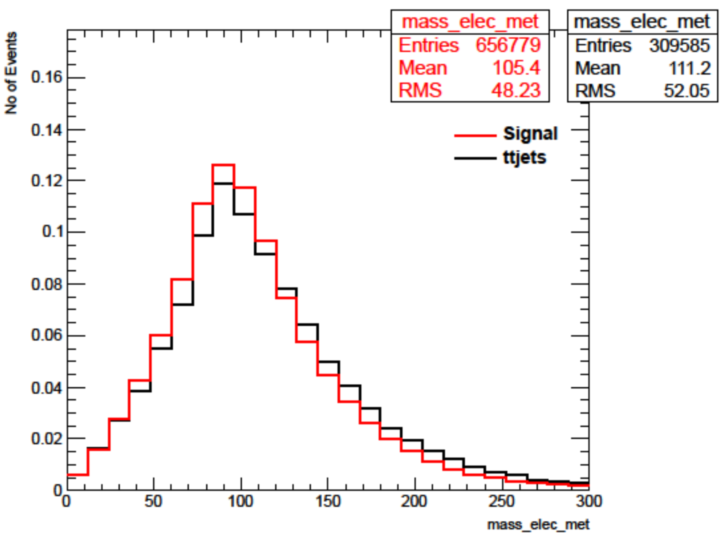


MET

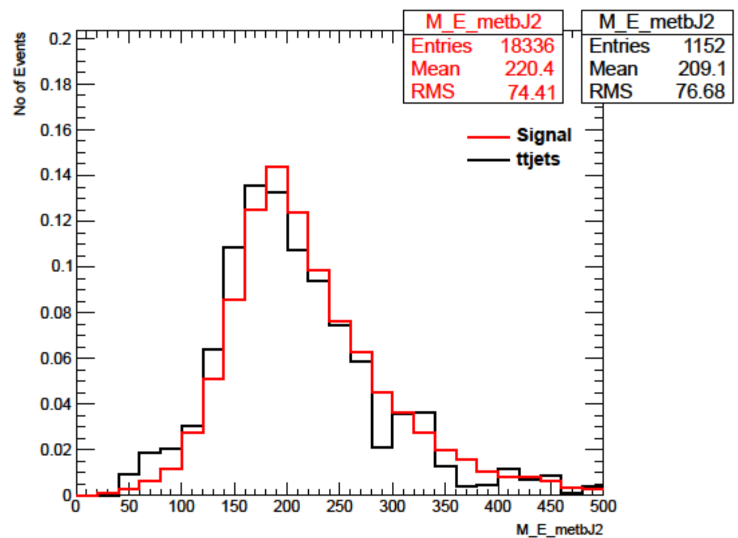


t→ W+b

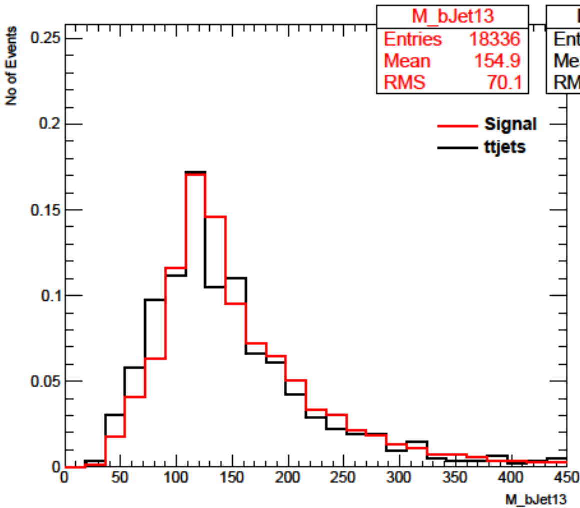
W→ e+ν_e



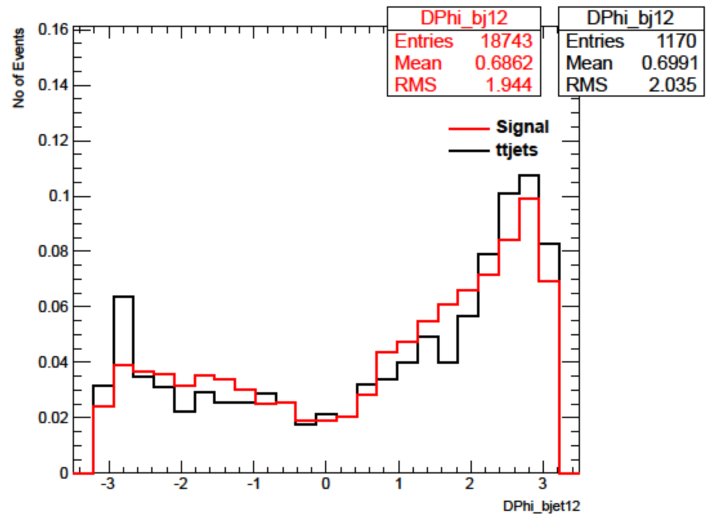
Leptonic W mass



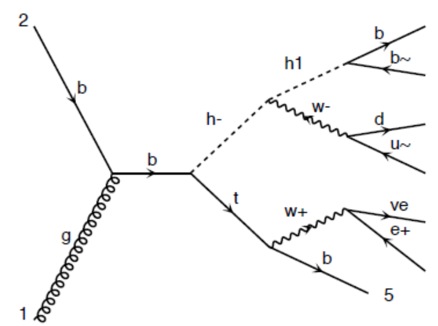
Leptonic Top mass

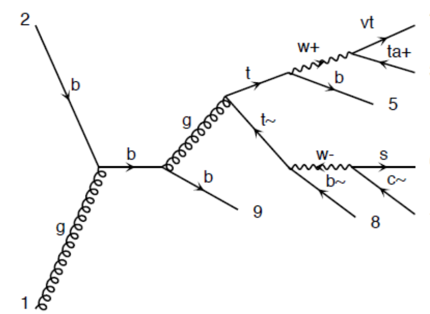


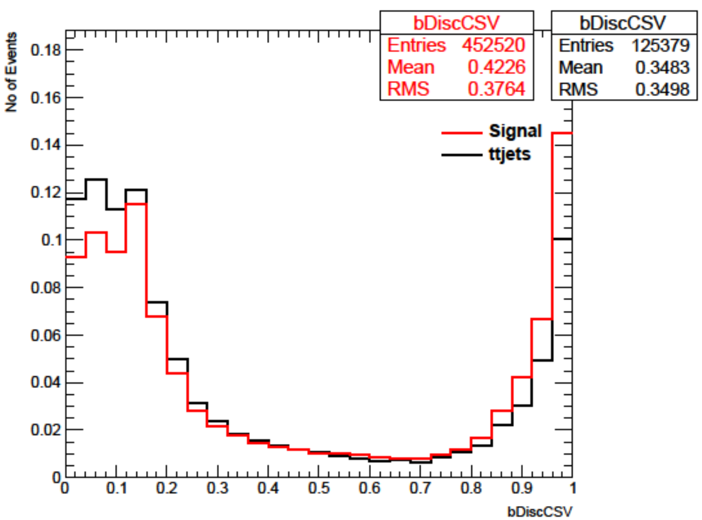
Mass of h^0



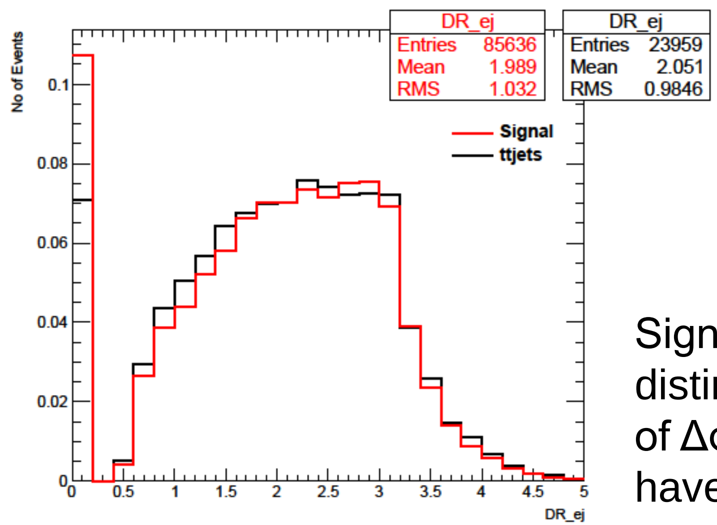
$\Delta\phi$ (bj1, bj2)







CSV for b-tag



ΔR (e, j)

Signal can't be distinguish on the basis of $\Delta\varphi$ (bj1, bj2) as both have the same shape

Cross sections, BRs and Cut Flow Table

	Signal
$\sigma(\mathrm{tH}^-)$	$3.6{\cdot}10^{-2}$ pb
$\mathrm{BR}(t \to bW^+) \times \mathrm{BR}(W^+ \to e^+\nu_e)$	1×0.107
$\mathrm{BR}(H^- \to hW^-) \times \mathrm{BR}(W^- \to q\bar{q}) \times \mathrm{BR}(h^0 \to bb)$	$0.035 \times 0.676 \times 0.708$
$\sigma(tH^- \to bW^+h^0W^- \to b\, e^+\nu_e\, bb\, q\bar{q})$	$6.6{\cdot}10^{-5}$ pb

	Background
$\sigma(\mathrm{t\bar{t}})$	245 pb
$\mathrm{BR}(t \to bW^+) \times \mathrm{BR}(W^+ \to e^+\nu_e)$	1×0.107
$\mathrm{BR}(\bar{t} \to bW^-) \times \mathrm{BR}(W^- \to q\bar{q})$	1×0.676
$\sigma(\mathrm{t\bar{t}} \to bW^+\, bW^- \to b\, e^+\nu_e\, bq\bar{q})$	17.80 pb

Cross section and branching ratios for signal and background at $\sqrt{s}$=8TeV

Cut Flow table for electron channel

Electron Channel	Signal N_{event}	Signal in %	Background N_{event}	Background in %	Significance $\mathrm{S}/\sqrt{\mathrm{B}}$
Before cuts	1.292	100	3.5e+05	100	2.193e-03
Number of electron =1	0.502	38.6	8.1e+04	23.26	1.7e-03
Number of muon =0	0.413	31.7	7.1e+04	20.28	1.5e-03
MET $p_T > 40$ GeV	0.299	22.9	4.2e+04	12.10	1.4e-03
Number of non-b jets ≥ 2	0.299	22.3	3.8e+04	10.95	1.5e-03
Number of b jets ≥ 3	0.056	4.3	9.0e+02	0.25	1.8e-03
ΔR(lepton,jet)>0.5	0.050	3.8	8.1e+02	0.23	1.7e-03
$\|m_{jj} - m_W\| < 25$ GeV	0.035	2.7	4.6e+02	0.13	1.6e-03
$\|m_{e\nu b} - m_t\| < 25$ GeV	0.022	1.7	2.8e+02	0.08	1.2e-03
$\|m_{b\bar{b}} - m_h\| < 25$ GeV	0.018	1.3	2.1e+02	0.06	1.2e-03
$\|m_{jjb\bar{b}} - m_H\| < 25$ GeV	0.016	1.2	1.5e+02	0.04	1.2e-03
$\|m_{jjbb\bar{b}e\nu} - m_H\| < 25$ GeV	0.006	0.4	6.2e+01	0.01	7.5e-04

Conclusion:

The number of events are normalized with £=19.7fb^{-1}and σ_s=3.6*10-2pb, σ_{bkg}=245pb.
The initial number of events ~ 1 and significance ~ 10^{-3} which becomes worse after the cuts applied.

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Conclusion:

- The analysis shows that the search for $H^\pm$ using this channel is not feasible at √s = 8TeV.
- For √s =14 TeV the σ_s= 0.19pb using same parameters.
- At √s =14 TeV, £=1000 fb^{-1} it might me possible to observe this channel using a multivariate analysis.

CMS Analysis Note

The content of this note is intended for CMS internal use and distribution only

Updated: 23 July 2014

Search for a heavy charged MSSM Higgs production with $gb \to tH^\pm \to (hW^\pm)(bW^-)$ at $\sqrt{s}$ =8 TeV

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[2] Ghent University, Ghent, Belgium

Abstract

The feasibility of the search for a heavy charged MSSM Higgs boson through $gb \to H^\pm t$ production process is presented. The full production and decay chain studied is $gb \to H^\pm t \to (hW^\pm)(bW^+) \to (b\bar{b})(jj)(bl\nu_l)$. The analysis is performed using CMS proton proton collision simulation at $\sqrt{s} = 8$ TeV. The study shows that it is not feasible to do this search with $19.7\ fb^{-1}$ of LHC taken at $\sqrt{s} = 8$ TeV.

Version 0

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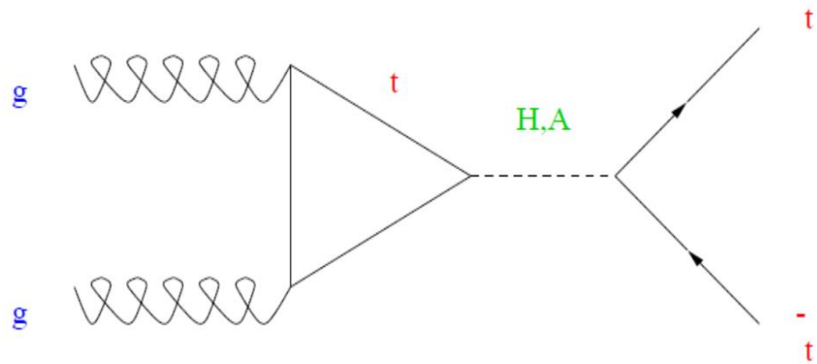
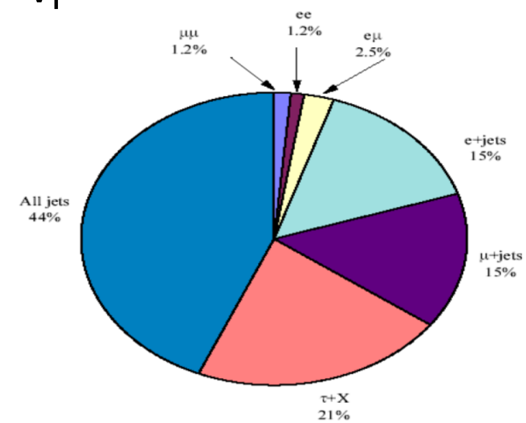
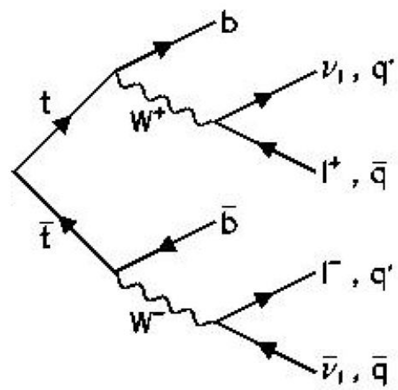
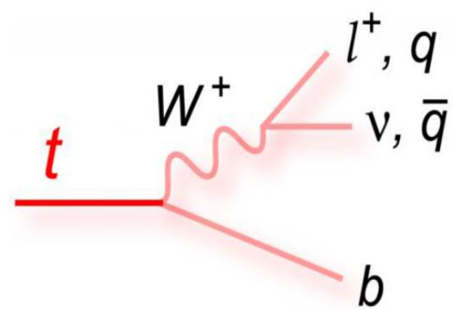
New Channel for Heavy H searches

- At 19.7 fb^{-1}, the previous channel is not suitable because of low cross section.
- A new channel will be adopted for H searches.
  - pp --> H --> tt^-, tt^- -->WW bb, W --> jj, W --> $l+\nu_l$



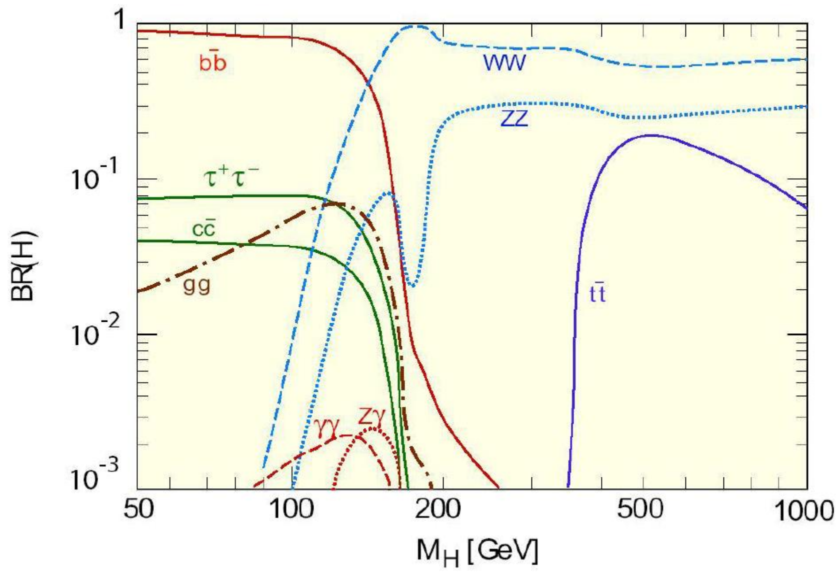


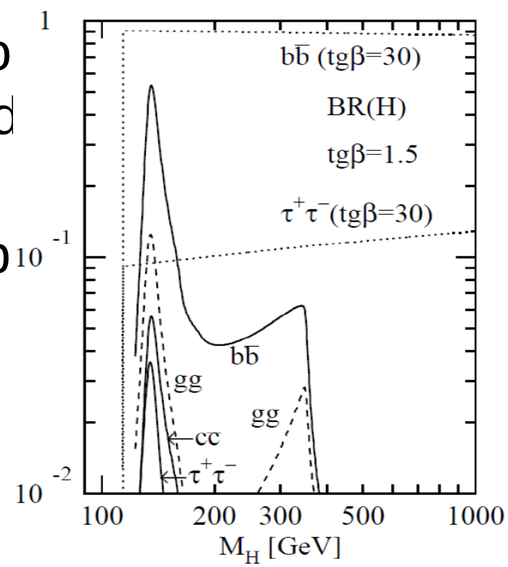


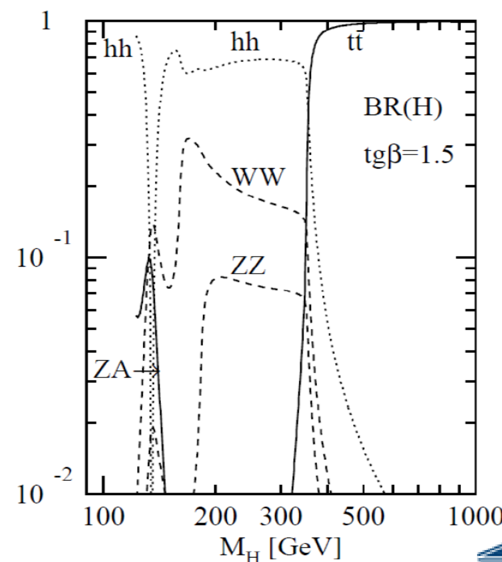


BRs of Higgs in same mass range in SM and MSSM

- The SM H-->tt^- BR is smaller than that of MSSM in the same mass region.
- For m_A, $m_H > 2m_t$ and tanβ ~ 1 the BR of H--> tt^- is 100%
- For tanβ >> 1, coupling to top quark suppressed and bottom quark enhanced.
- Its production via a b loop and decay into bb^- is non negligible

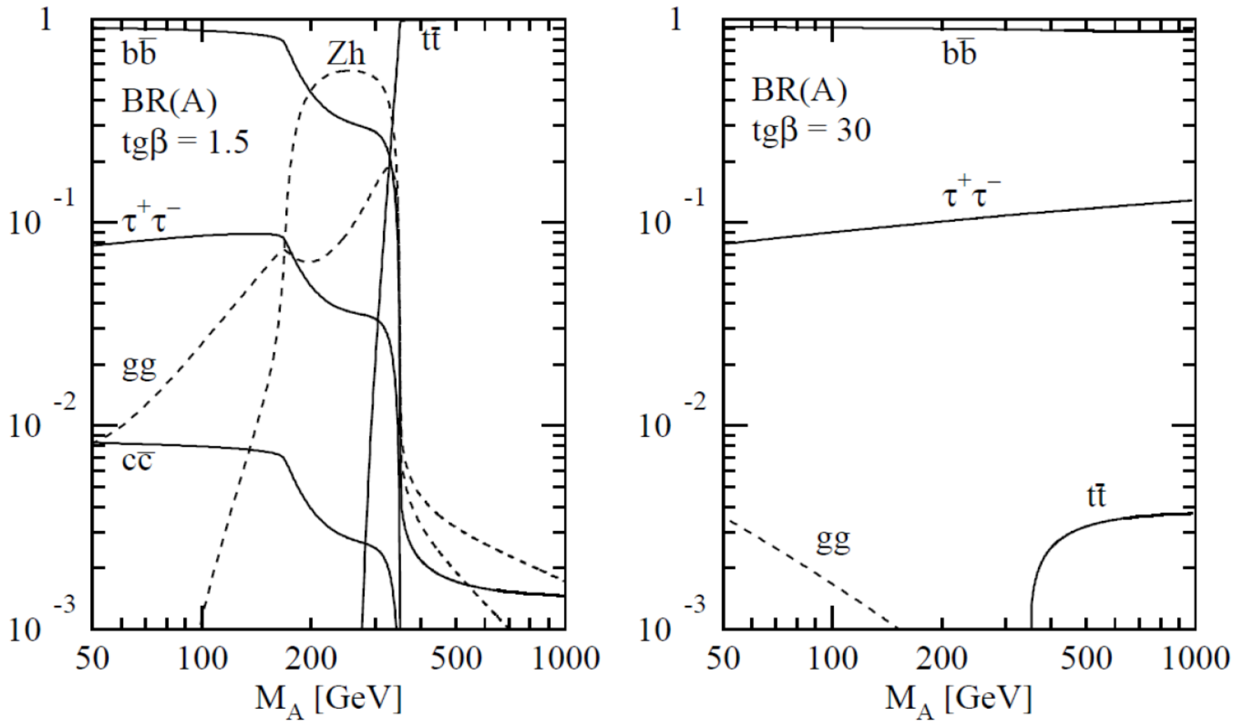






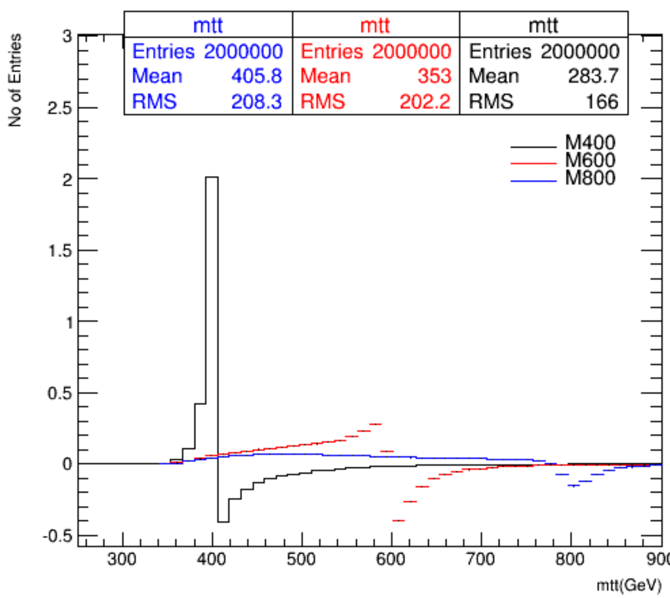
Distinguish H from A

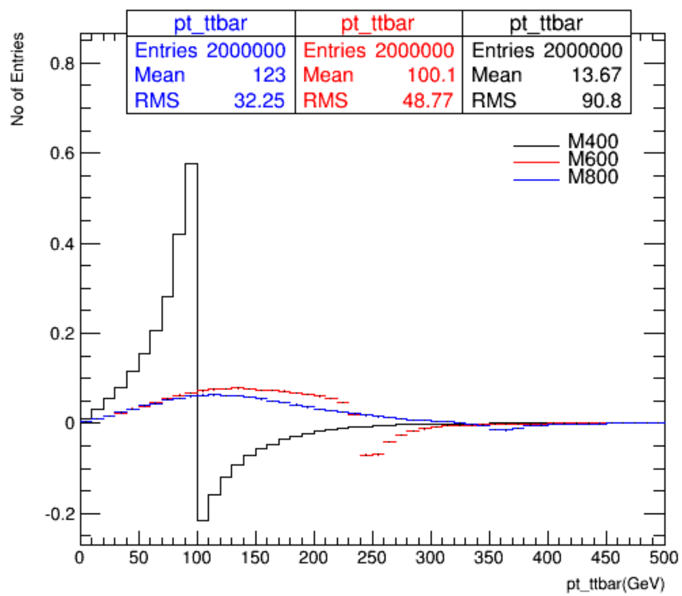
- H and A are almost degenerate in mass in the relevant region of parameter space (m_A, tanβ).
- H--> $t\bar{t}$ and A--> $t\bar{t}$ can't be distinguish experimentally.
- For tanβ ~ 1, A couples to top but doesn't to weak boson.
- For tanβ >> 1, the coupling of A to top is suppressed.



Mass and pt of ttbar

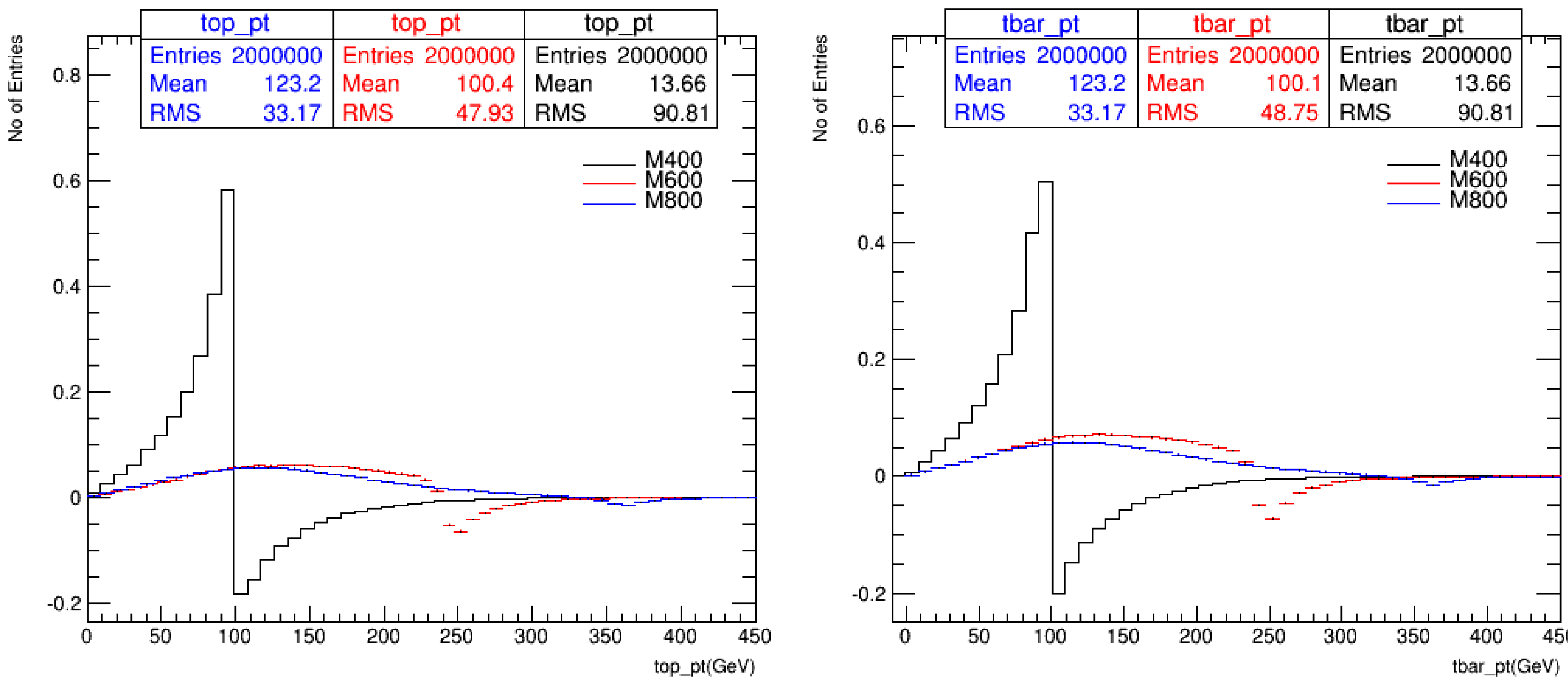
- Events have generated using madGraph
- The interference phenomenon has included
- Higgs has been produced using mass range from 400-800 GeV and energy is 13TeV
- Reconstructed mass and pt of ttbar are plotted





Pt of top and tbar

- Top and tbar goes back to back



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Conclusion

- A cut and count analysis is performed for Charged Higgs associated with top quark.
- The number of events for Signal and Background are normalized to £=19.7 fb^{-1} and Ϭ=3.6*10^{-2} pb.
- The signal significance is ~ 10^{-3}.
- This channel is not feasible at √s = 8TeV.
- At √s = 14TeV charged higgs can be searched for with a high statistics sample.
- For LHC Run II, H--> tt^{-} is a promising channel for heavy Higgs searches.

References

1. arXiv:1207.7235[hep-ex]
2. http://cms.web.cern.ch/news/cms-closes-major-chapter-higgs-measurements

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/MSSMCharged

AN

http://cms.cern.ch/iCMS/jsp/openfile.jsp?tp=draft&files=AN2014_193_v1.pdf

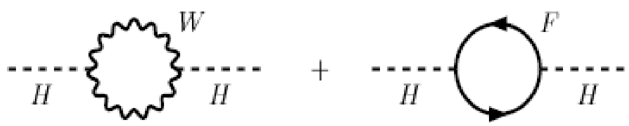
Thanks

Back Up Slides

SuperSymmetry (motivation from Higgs sector)

- Hierarchy problem in the SM Higgs sector:

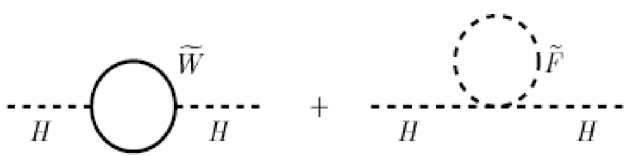
Quantum corrections to the H mass have quadratic divergencies



$$\rightarrow \delta m_H^2 \sim \frac{\alpha}{\pi}(\Lambda^2 + m_F^2)$$

The cutoff Λ represents the scale up to which the Standard Model remains valid.

- By introducing supersymmetric partners for the SM particles



$$\rightarrow \delta m_H^2 \sim -\frac{\alpha}{\pi}(\Lambda^2 + \widetilde{m}_F^2)$$

- quadratic divergencies are cancelled

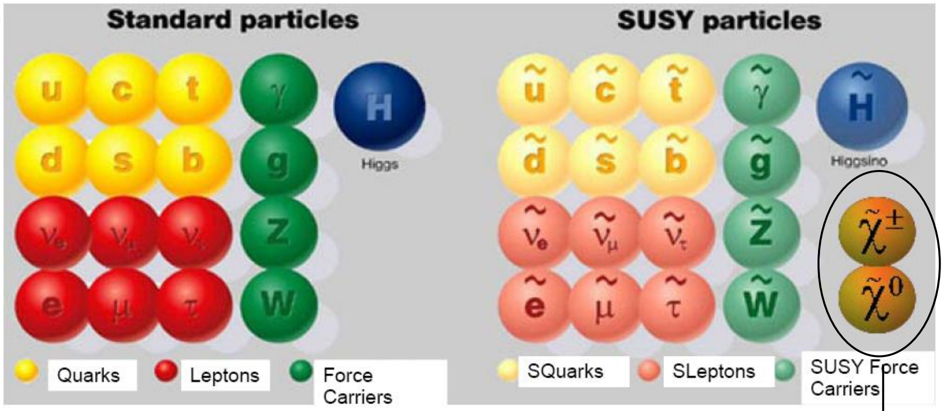
$$\delta m_H^2 \sim \frac{\alpha}{\pi}(m_F^2 - \widetilde{m}_F^2)$$

Supersymmetry

- New spin-based symmetry relating fermions and bosons:

  Q | Boson> = Fermion

  Q | Fermion> = Boson

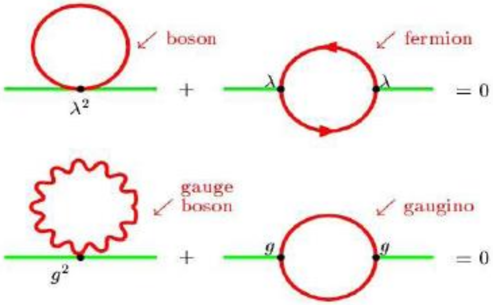


gaugino/higgsino mixing

- Minimal SuperSymmetric SM (MSSM):
  - Mirror spectrum of particles
  - Enlarged Higgs sector: two doublets with 5 physical states

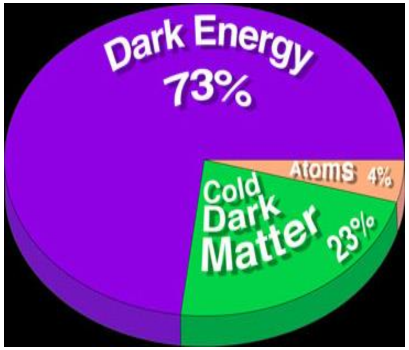
$$H_U, H_D \longrightarrow h, H, A, H^{\pm}$$

Naturally solve the hierarchy problem



- Define R-parity = $(-1)^{3(B-L)+2s}$
  - R = 1 for SM particles
  - R = -1 for MSSM partners

If conserved, provides Dark Matter Candidate (Lightest Supersymmetric Particle)



MSSM Higgs sector

MSSM HIGGS sector

- **To provide masses to both up-type and down-type quarks, and to ensure anomaly cancellation,the MSSM has two Higgs complex-doublet superfields**

$$\Phi_d = (\Phi_d^0, \Phi_d^-) \text{ and } \Phi_u = (\Phi_u^+, \Phi_u^0) \qquad \langle \Phi_d \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} v_d \\ 0 \end{pmatrix}, \quad \langle \Phi_u \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_u \end{pmatrix},$$

where $\sqrt{v_d^2 + v_u^2} = 2M_W/g = 246 \text{ GeV}$

- **Out of 8 DOF, 3 serve as GB, absorbed into longitudinal components of the W and Z, 5 DOF remains:**

$$h = -(\sqrt{2}\text{Re } \Phi_d^0 - v_d)\sin\alpha + (\sqrt{2}\text{Re } \Phi_u^0 - v_u)\cos\alpha$$

$$H = (\sqrt{2}\text{Re } \Phi_d^0 - v_d)\cos\alpha + (\sqrt{2}\text{Re } \Phi_u^0 - v_u)\sin\alpha$$

$$A = \sqrt{2}(\text{Im } \Phi_d^0 \sin\beta + \text{Im } \Phi_u^0 \cos\beta), \quad H^\pm = \Phi_d^\pm \sin\beta + \Phi_u^\pm \cos\beta$$

α is (h, H) mixing angle

$\tan\beta = v_u/v_d$ and M_A is the conventional choice to define the Higgs sector:

$M_{H^\pm} = \sqrt{M_A^2 + M_W^2}$

$M_{h,H}^2 = \frac{1}{2}\left[(M_A^2 + M_Z^2) \mp \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}\right], \quad M_h < M_Z$

h/H/A couplings

❖ $g_{MSSM} = \xi \, g_{SM}$

ξ	t	b/τ	W/Z
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\alpha-\beta)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\alpha-\beta)$
A	$\cot\beta$	$\tan\beta$	-----

- no coupling of A to W/Z
- small $\alpha \rightarrow$ small BR($h \rightarrow \tau\tau$,bb)
- large $\beta \rightarrow$ large BR(h,H,$A \rightarrow \tau\tau$,bb)

α = mixing btw. CP-even neutral Higgs bosons

Parameters used for Generation

- Mass of Heavy Higgs = 400, 600 & 800 GeV
- Mass of SM Higgs = 125 GeV
- Mass of top quark = 174.3 GeV
- Energy = 13 TeV
- LHAPDF set = CT10
- LHAPDF ID = 10800
- Cross section:
  - For mH = 400GeV, xsec = 1.578 ± 0.02 pb
  - For mH = 800 GeV, xsec = 0.3068 ± 9.25e^{-5} pb

- Model = topBSM
- Applied cuts:
  - Pt of jets ≥ 20 GeV
  - Charged lepton pt ≥ 10 GeV
  - Dr (j,j) ≥ 0.4
  - Dr (l,l) ≥ 0.4
  - Dr (j,l) ≥ 0.4
- No. of events = 2 million
- All plots are scaled to 1