Exclusive Higgs production in a triplet scenario

Based on
Chaichian, Hoyer, Huitu, Khoze, Pilkington:
JHEP05 (2009) 011

Outline:

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General Higgs representations

A model with $\rho = 1$

- Constraints on the parameters

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Event generation and backgrounds

Doubly charged Higgs bosons

Conclusions

Introduction

- **In the standard model one Higgs doublet**
- **In extensions, typically more than just one doublet**
  - **In MSSM: two doublets**
  - **In models with neutrino seesaw often triplets (also in models with composite Higgs, in little Higgs models)**
- **In such extensions typically charged scalars occur**
- **Many studies on singly or doubly charged scalars**

- **Charged scalars may be heavier than the neutral ones**
  ⇒ useful to find ways to determine the multiplet from the neutral Higgs

General Higgs representations

- **Gauge boson masses from with**

$$L_{kin} = \sum_k \left(D^\mu \phi_k\right)^* \left(D_\mu \phi_k\right) + \frac{1}{2}\sum_i \left(D^\mu \xi_i\right)^T \left(D_\mu \xi_i\right)$$

with $D_\mu = \partial_\mu + igW_\mu^a T^a + \frac{Y}{2} g' B_\mu :$

$$m_Z^2 = \left(g^2 + g'^2\right)\sum_i T_{3i}^2 v_i^2, \quad m_Z^2 = g^2 \sum_i T_{3i}^2 v_i^2$$

- **Doublet VEV decreases, when several representations have nonvanishing VEVs and contribute to the gauge boson masses**

- Left-handed fermions are in doublets. If doublet VEV decreases, the Yukawa coupling increases to generate the fermion mass: $m_f = y_f \, v_{doublet}$
  ➡ the production cross section of Higgs through the top quark loop and in the branching ratio to fermions enhances.
- Restriction to higher representations from the electroweak ρ - parameter:

$$\rho \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = \frac{\sum_{T,Y}\left[4T(T+1) - Y^2\right]\left|V_{T,Y}\right|^2 c_{T,Y}}{\sum_{T,Y} 2Y^2 \left|V_{T,Y}\right|^2} \approx 1$$

$$V_{T,Y} = \langle \phi(T,Y) \rangle, \quad c_{T,Y} = \begin{cases} 1, & (T,Y) \in \text{complex representation} \\ \frac{1}{2}, & (T,Y) \in \text{real representation} \end{cases}$$

ρ =1 → $(2T+1)^2-3Y^2=1$

Thus doublets $\left(T=\frac{1}{2},\ Y=\pm 1\right)$ can be added without problems with ρ.

For the other representations, one has to finetune the VEVs to produce ρ =1. This may be motivated from other considerations.

Electroweak ρ parameter is experimentally $\rho-1=0.0002^{+0.0024}_{-0.0009}$

→ constraints on general Higgs representations;

In the standard model, ρ =1 at the tree level.
The radiative corrections at $m_H = 2m_W$ give

ρ -1 = - 0.00078 + (4-loop and higher corrections)

A model with $\rho = 1$

Georgi, Machacek, Nucl.Phys. B 262 (1985) 463.

- In Georgi-Machacek model triplets $\xi_{Y=0}$ and $\chi_{Y=2}$

$$\phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ \phi^{-} & \phi^{0} \end{pmatrix}, \quad \chi = \begin{pmatrix} \chi^{0} & \xi^{+} & \chi^{++} \\ \chi^{-} & \xi^{0} & \chi^{+} \\ \chi^{--} & \xi^{-} & \chi^{0*} \end{pmatrix} \quad \begin{array}{l} \phi^{-} = -\left(\phi^{+}\right)^{*}, \quad \chi^{--} = \left(\chi^{++}\right)^{*}, \\ \xi^{-} = -\left(\xi^{+}\right)^{*}, \quad \xi^{0} = \left(\xi^{0}\right)^{*} \end{array}$$

- Here $\left\langle \phi^{0} \right\rangle = \frac{a}{\sqrt{2}}, \quad \left\langle \chi^{0} \right\rangle = \left\langle \xi^{0} \right\rangle = b,$

- Define $c_H = \frac{a}{\sqrt{a^2 + 8b^2}}, \quad s_H = \frac{8b}{\sqrt{a^2 + 8b^2}}, \quad v^2 = a^2 + 8b^2$

- **Potential of the model is**

$$
\begin{aligned}
V \;=\; & \lambda_1(\mathrm{Tr}\phi^\dagger\phi - c_H^2 v^2)^2 + \lambda_2(\mathrm{Tr}\chi^\dagger\chi - \frac{3}{8}s_H^2 v^2)^2 \\
& +\lambda_3(\mathrm{Tr}\phi^\dagger\phi - c_H^2 v^2 + \mathrm{Tr}\chi^\dagger\chi - \frac{3}{8}s_H^2 v^2)^2 \\
& -\lambda_4\left(\mathrm{Tr}\phi^\dagger\phi\mathrm{Tr}\chi^\dagger\chi - 2\sum_{ij}\mathrm{Tr}(\phi^\dagger\tau_i\phi\tau_j)\mathrm{Tr}(\chi^\dagger t_i\chi t_j)\right. \\
& +\lambda_5\left(3\mathrm{Tr}(\chi^\dagger\chi\chi^\dagger\chi) - (\mathrm{Tr}\chi^\dagger\chi)^2\right),
\end{aligned}
$$

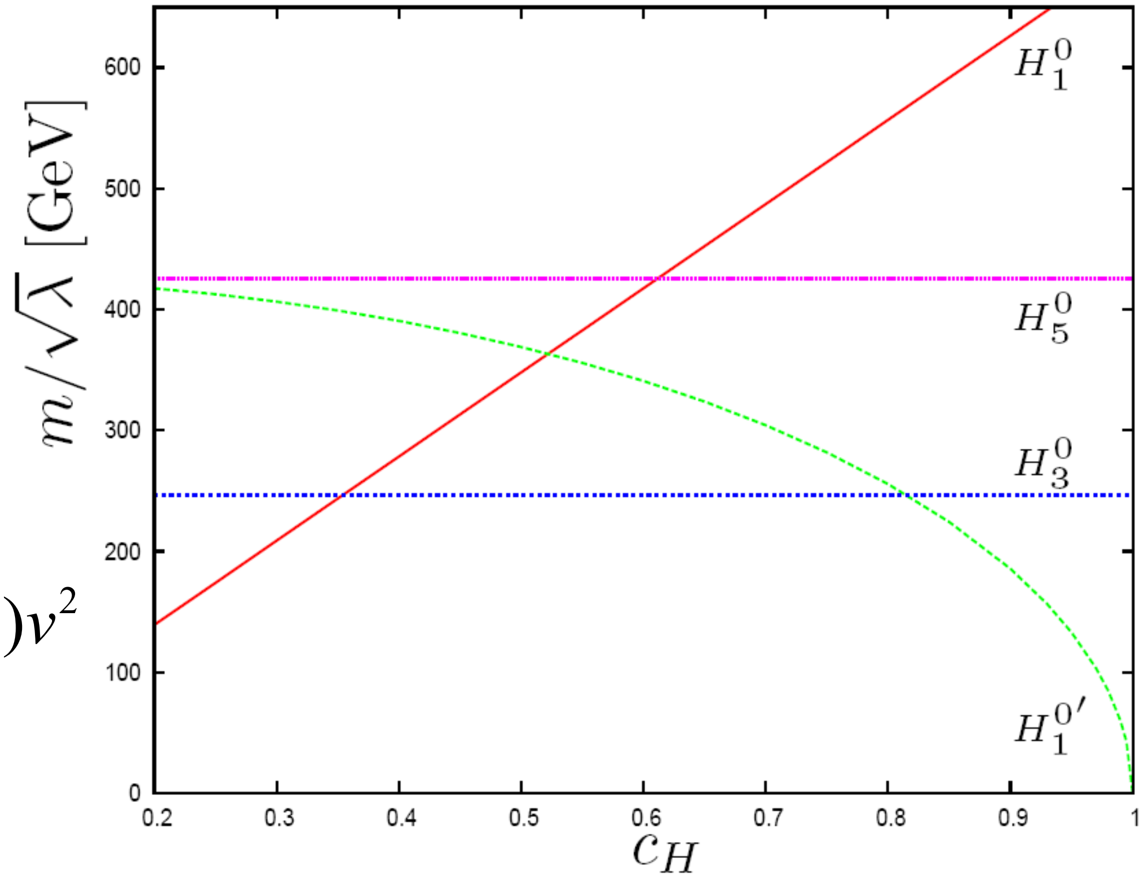
We take $\lambda_3 = 0, \quad \lambda_4 = \lambda_5$

$$m^2_{H_1^0} = 8c_H^2 \lambda_1 v^2$$

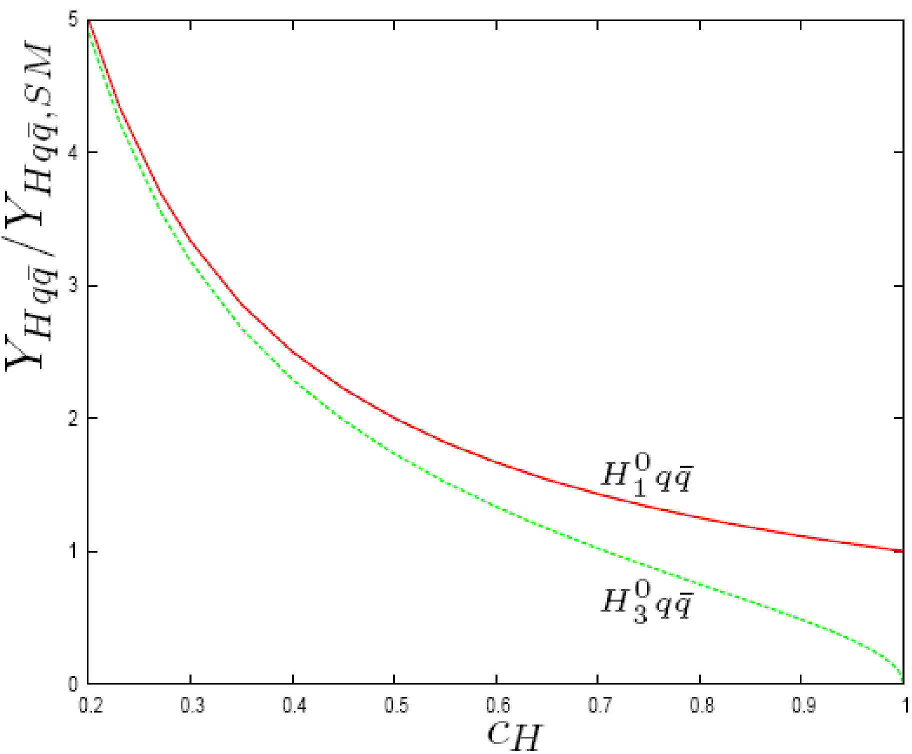
$$m^2_{H_1^{0'}} = 3s_H^2 \lambda_2 v^2$$

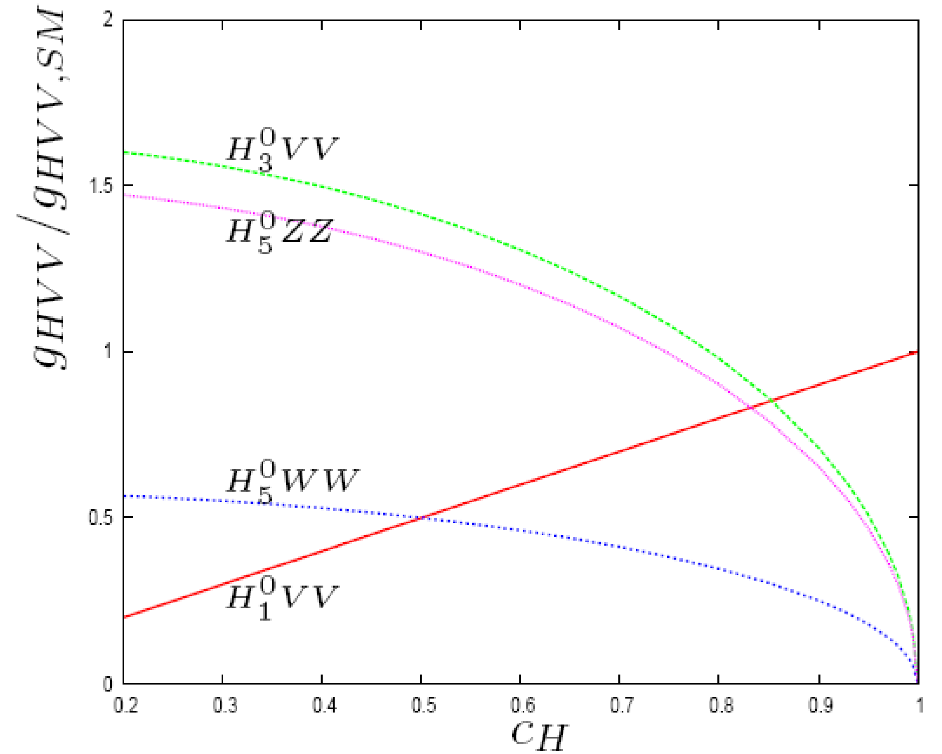
$$m^2_{H_3^0} = \lambda_4 v^2$$

$$m^2_{H_5^0} = 3(\lambda_5 s_H^2 + \lambda_4 c_H^2) v^2$$



For small c_H or λ_1, H_1^0 can be the lightest Higgs boson.

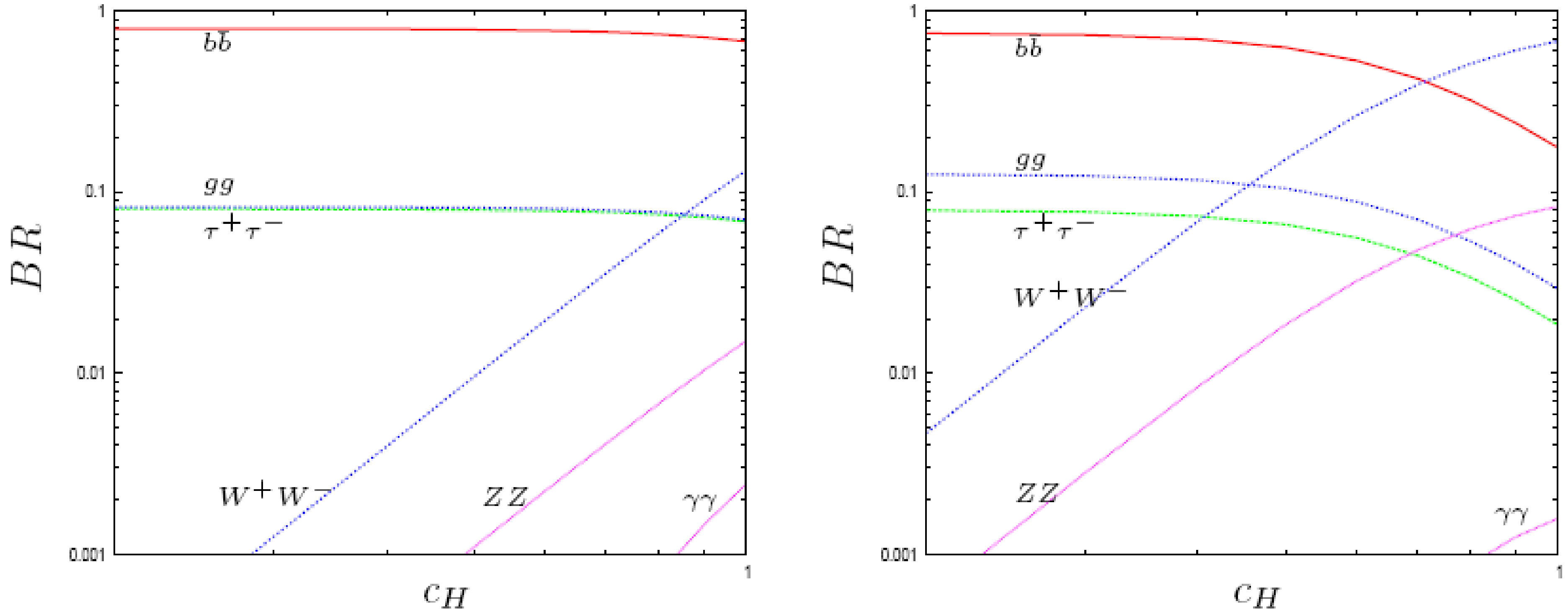




H_1^0 becomes the standard model Higgs boson for vanishing doublet triplet coupling.

H_1^0 branching ratios:

m_H=120 GeV **m_H=150 GeV**



Coupling is increased by *$1/c_H$* to fermions and suppressed by *c_H* to gauge bosons;
width to $\gamma\gamma$ increases because of the top-loop, but the total width increases more

Constraints on the parameters

- **Perturbativity** → $\frac{gm_{top}}{2m_W c_H} < \sqrt{4\pi}$ → $c_H > 0.2$

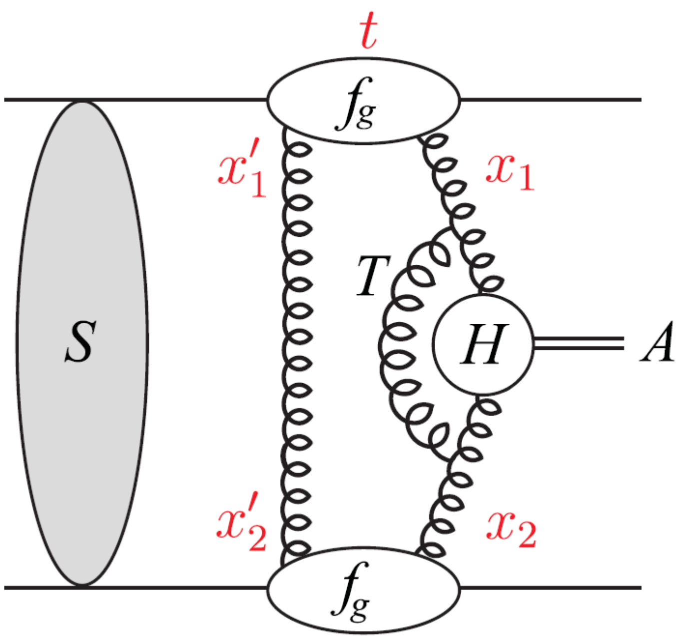
- **Radiative corrections to** $Zb\bar{b}$ **vertex**

  → $c_H > 0.3$ **with** 99.9 C.L. **for** $m_{H_3} \sim 1$ TeV

- **The mass limits for H_1^0 from LEP: reduced production from Higgsstrahlung, but only small change in the decay branching ratio to *b*-quark pair**

  → **m_H>73 GeV (40 GeV) for c_H=0.5 (0.2)**

Central exclusive production



$$pp \to p \oplus H \oplus p$$

Main decay channels of the central system available:

$b\bar{b}, W^+W^-, \tau^+\tau^-$

Possibility to study the Higgs coupling to *b*-quarks!

$$\sigma \propto \frac{\Gamma(H \to gg)}{m_H^3} BR(H \to b\bar{b})$$

	$m_H = 120$ GeV		$m_H = 150$ GeV	
	$\Gamma(H \to gg)$	$\mathrm{BR}(H \to b\bar{b})$	$\Gamma(H \to gg)$	$\mathrm{BR}(H \to b\bar{b})$
$c_H = 0.2$	6.35×10^{-3}	0.80	1.22×10^{-2}	0.75
$c_H = 0.5$	1.01×10^{-3}	0.79	1.95×10^{-3}	0.63
$c_H = 0.8$	3.97×10^{-4}	0.74	7.63×10^{-3}	0.32
SM	2.49×10^{-4}	0.68	4.79×10^{-4}	0.18

Generator level cross section:

$\sigma_{H\to b\bar{b}}$ (fb)	$m_H = 120$ GeV	$m_H = 150$ GeV
$c_H = 0.2$	113.5	55.2
$c_H = 0.5$	18.0	7.4
$c_H = 0.8$	6.6	1.5

Event generation and backgrounds
(by ExHuMe)

Main backgrounds:

- Central exclusive $b\bar{b}$ production
- Central exclusive gg production with gluon misidentification (1.3 % for b-tagging efficiency of 60 %)
- Overlap backgrounds
  - important for large number of pp interactions in bunch crossings;
  - 3-fold coincidence: two soft events pp→pX, with in acceptance of forward detectors and inelastic hard scatter pp→X (vertex matching)
- In simulation central mass 80 GeV < M < 250 GeV

Experimental cuts

(following Cox, Loebinger, Pilkington, JHEP 0710 (2007) 090)

- di-jet mass fraction R_j

$$0.85 \quad \leq \quad R_j = \frac{2E_T^1}{M} \cosh\left(\eta_1 - \mathrm{y}\right) \quad \leq \quad 1.1$$

- rapidity of central system same as calculated from the jets

$$\Delta y = \left| y - \left(\frac{\eta_1 + \eta_2}{2} \right) \right| \leq 0.06$$

- di-jets back to back in azimuth

$$|\pi - \Delta\phi| \leq 0.15,$$

- less charged tracks in signal than in background

Tagging of forward protons:

at 220 m and at 420 m in either side of the interaction point:

Symmetric tagging: both protons detected at 420 m

Asymmetric tagging: one proton at 420 m and one at 220 m

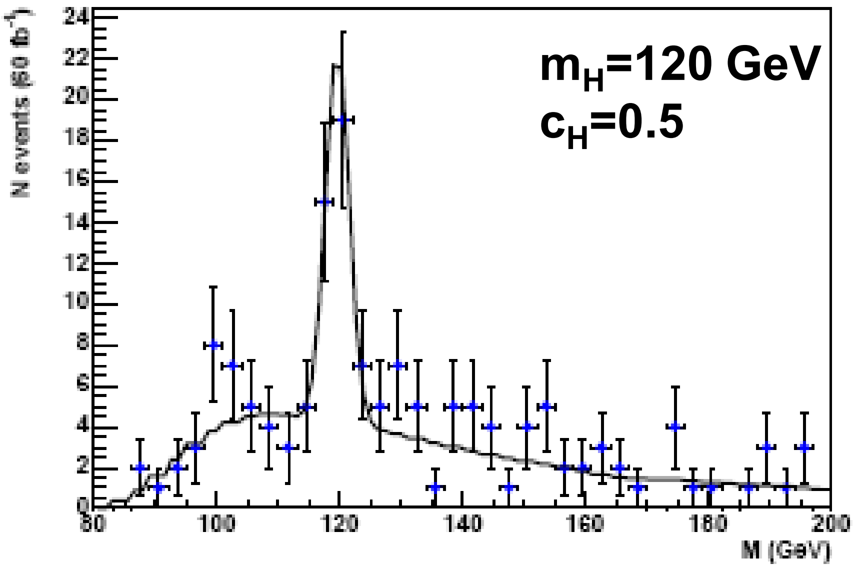
Accuracy of time of flight measurement from the interaction point: 10 ps

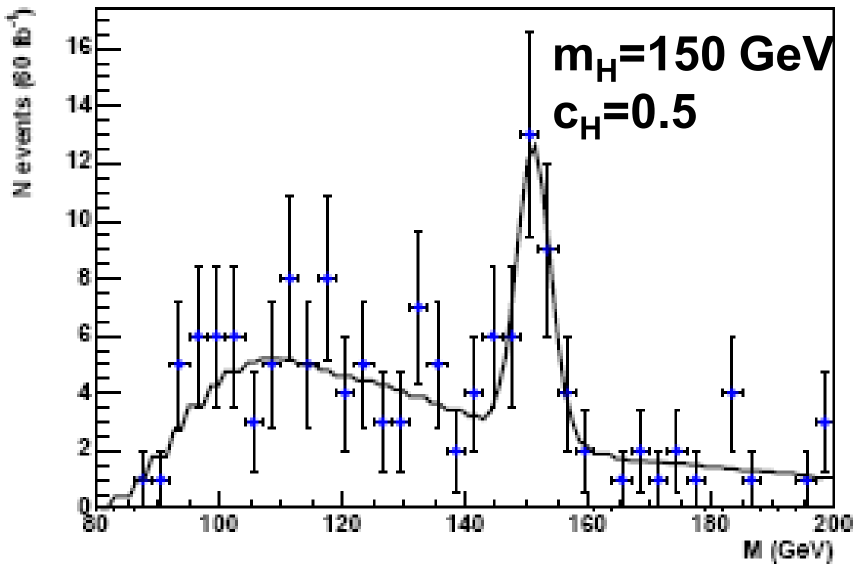
Signal and background cross sections with m_H=120 GeV, c_H=0.5

Generator	Process	$\sigma_{420-420}$ (fb)	$\sigma_{420-220}$ (fb)
ExHuME	$H \to b\bar{b}$	0.53	0.28
	$b\bar{b}$	0.53	0.27
	gg	1.08	0.91
Overlap (L)	$b\bar{b}$	0.07	0.09
Overlap (H)	$b\bar{b}$	11.0	13.7
Total bgrd (L)		1.68	1.27
Total bgrd (H)		12.6	14.9

Various triggering strategies including
jet with E_T > 40 GeV and proton in a detector at 220 m;
jets with E_T > 40 GeV and use of HLT with in time protons;
muon in the event

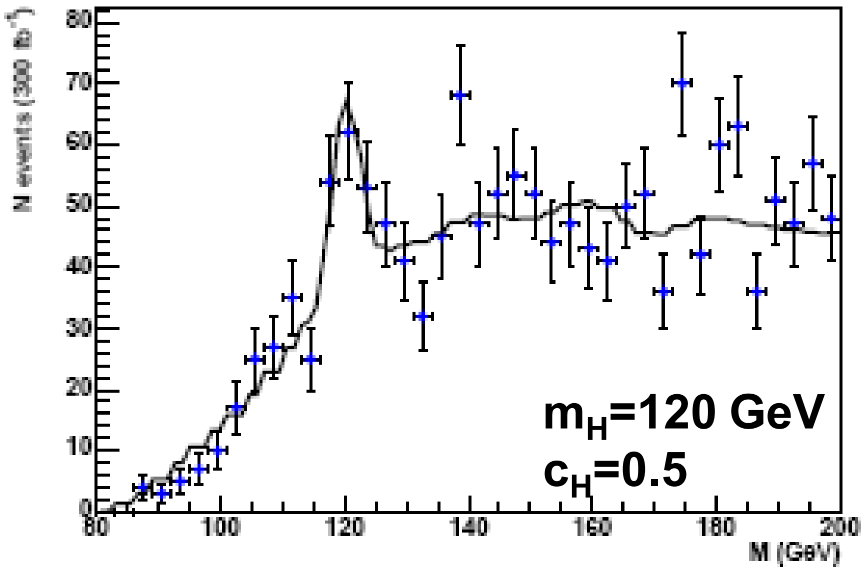
60 fb^{-1} of data, 2 x 10^{33} cm^{-2} s^{-1}

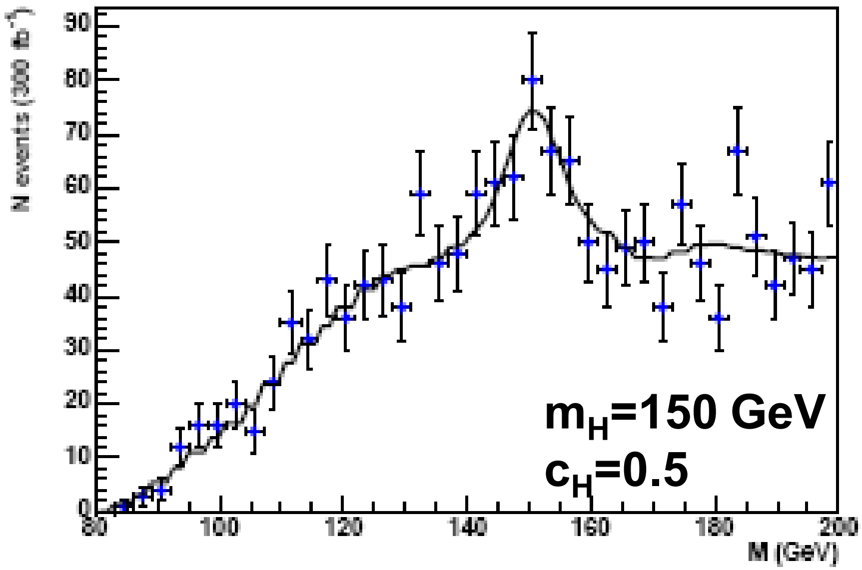




Signal peaked at m_H. The background evenly distributed in the range 80 GeV < M < 250 GeV.

300 fb^{-1} of data, 10^{34} cm^{-2} s^{-1}





m_H (GeV)	c_H	Significance (σ) 60 fb^{-1}	300 fb^{-1}
120	0.2	12.7	13.7
	0.5	4.5	4.3
	0.8	2.6	2.5
150	0.2	11.9	12.7
	0.5	3.9	4.3
	0.8	2.0	2.1

m_H (GeV)	c_H	σ_{m_H} (GeV) 60 fb^{-1}	300 fb^{-1}
120	0.2	0.2	0.3
	0.5	0.8	4.5
150	0.2	0.2	0.3
	0.5	1.8	2.4

Doubly charged Higgs bosons

- **In the triplet model also a very interesting doubly charged Higgs boson.**
- **Possible production method:**

$$pp \to p \oplus H^{++} H^{--} \oplus p$$

- **$H^{++} \to W^+W^+$, W^+H^+, H^+H^+, l^+l^+ :standard e,μ trigger strategies**
- **Possible to study doubly charged particles up to ~300 GeV (cross section ~0.3 fb)**
- **Although the mass range is smaller than in the process $pp \to H^{++} H^{--} X$, the background is easier and mass measurement more accurate.**

Conclusions

- ***For higher Higgs representations the doublet couplings are enhanced***
  ➡ **With forward processes possible to study the representation using the neutral Higgses**
- **The forward production complementary to the usual one**
- **In the triplet model with $\rho = 1$:**
  $c_H < 0.5$, 120 GeV < m_H < 150 GeV
  ➡ **H_1^0 observed with 4σ or better,**
  m_H measurement better than 2 GeV for low luminosity