Search for Heavy Charged Higgs Bosons at FCC-ee

S. Muanza: CPPM Marseille, CNRS-IN2P3 & AMU

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Introduction

- We want to estimate the FCC-ee sensitivity to two BSM Higgs scenarios
  - 5.0 ab^{-1} at $\sqrt{s} = 240$ GeV
  - 1.5 ab^{-1} at $\sqrt{s} = 365$ GeV
  - Well suited to search for light new particles with small couplings
- We are interested in heavy charged Higgs bosons decaying into:
  - the $H^{\pm} \rightarrow W^{\pm} + h^{0}$ channel
  - the $H^{\pm} \rightarrow W^{\pm} + Z^{0}$ channel

Models

- The phenomenological models we consider are:

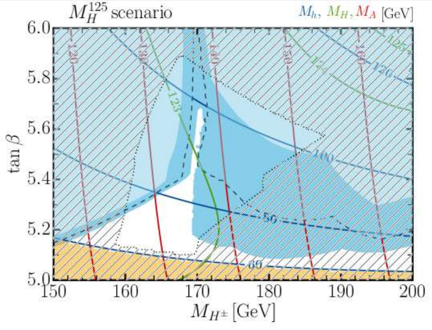
1. The Georgi-Machacek model
   Ref: H. Georgi and M. Machacek, Nucl. Phys. B262 (1985) 463.
2. A $M_H = 125$ GeV MSSM Scenario
   Ref: E. Bagnaschi et al., Eur. Phys. J. C**79** (2019) n^{o}7, 617. arXiv:1808.07542 [hep-ph].

Description

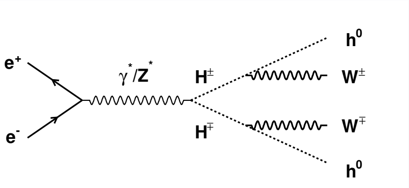
- We consider the MSSM with:
  - $M_{h^0} < M_{H^0} = 125 \pm 3$ GeV,
  - heavy charged Higgs boson decaying dominantly into $H^{\pm} \to W^{\pm} h^0$

Status in Collider Searches

- This scenario is not completely excluded by searches at LHC:



- We consider $H^{\pm}$ pair production at FCC-ee at $\sqrt{s} = 365$ GeV:



MSSM Tool

- FeynHiggs v2.16.0:
  https://wwwth.mpp.mpg.de/members/heinemey/feynhiggs/cFeynHiggs.html (Fortran 77)
- The $M_{H^0} = 125$ GeV MSSM Scenario is described in FeynHiggs (LHCHXSWG):
  - A shell script mH125-MHp-TB produces:
    - either a single FH input file,
    - or a set of FH input files, scanned over $M_{H^\pm}$ and $tan\beta$
  - FH executable run on the FH input files to produce model (MSSM spectra and couplings) files (option enables SLHA format)

$M_{H^0} = 125$ GeV MSSM Scan

- Large scan of 25k model files
- Select 10 models sampling the non excluded parameter space of the previous plot

MSSM Selected Models

Model	m_{h^0} [GeV]	$M_{H^\pm}$ [GeV]	M_{A^0} [GeV]	$\tan\beta$ –	$BR(H^\pm \to W^\pm h^0)$ [%]
Pt01	65.14	160.00	127.32	5.11	91.70
Pt02	60.61	165.00	131.87	5.05	95.85
Pt03	70.04	165.00	132.41	5.14	91.83
Pt04	75.03	165.00	132.72	5.20	85.78
Pt05	60.37	168.00	134.73	5.04	96.53
Pt06	70.33	168.00	135.29	5.13	93.54
Pt07	74.75	168.00	135.56	5.18	90.34
Pt08	70.13	170.00	137.18	5.12	94.52
Pt09	84.98	170.00	138.13	5.31	66.77 ($> BR(H^\pm \to \tau^\pm \nu_\tau)$)
Pt10	95.16	170.00	138.88	5.50	24.44 ($<< BR(H^\pm \to \tau^\pm \nu_\tau)$)

MSSM Tool

- Since MadGraph v5 already contains the MSSM_SLHA2 model UFO, we can directly generate MSSM signal samples using the Pt01-10 SLHA2 files

$H^\pm$ MC Samples $\sqrt{s} = 365$ GeV

Model	$(m_{H^\pm}, m_{h^0})$ [GeV]	$\sigma(e^+e^- \to H^\pm H^\mp)$ [fb]	$\begin{cases} BR(H^\pm \to W^\pm h^0) \\ BR(h^0 \to b\bar{b}) \end{cases}$ [%]
Pt01	(160.00, 65.14)	26.20 ± 0.03	91.70 85.71
Pt02	(165.00, 60.61)	18.37 ± 0.02	95.85 85.84
Pt03	(165.00, 70.04)	18.37 ± 0.02	91.83 85.46
Pt04	(165.00, 75.03)	18.37 ± 0.02	85.78 85.25
Pt05	(168.00, 60.37)	14.01 ± 0.01	96.53 85.82
Pt06	(168.00, 70.33)	14.03 ± 0.02	93.54 85.41
Pt07	(168.00, 74.75)	14.02 ± 0.01	90.34 85.23
Pt08	(170.00, 70.13)	11.31 ± 0.01	94.52 85.40
Pt09	(170.00, 84.98)	11.33 ± 0.01	66.77 84.87
Pt10	(170.00, 95.16)	11.33 ± 0.01	24.44 84.43

- MSSM MC Samples:
  - Restricted to $H^\pm$ decaying into on-shell $W^\pm$ and h^0 (hence excluding Pt10)
  - Higgs decays from SLHA2

$H^{\pm}$ MC Samples $\sqrt{s} = 365$ GeV

Physics Process	Cross Section [fb]	Number of generated events [k Evts]
SM Higgs Production		
$e^+e^- \to HZ$	$\sigma_{LO} = 111.9 \pm 3.5(Stat)$ MadSpin	36
$e^+e^- \to H\nu_e\bar{\nu}_e$	$\sigma_{LO} = 38.90 \pm 0.02(Stat)$ MadSpin	36
$e^+e^- \to He^+e^-$	$\sigma_{LO} = 6.45 \pm 0.06(Stat)$ MadSpin	13
Other Background Processes		
$e^+e^- \to W^+W^-$	$\sigma_{LO} = 10,748.7 \pm 170.0(Stat)$ MadSpin	2,500
$e^+e^- \to ZZ$	$\sigma_{LO} = 545.4 \pm 8.8(Stat)$ MadSpin	2,004
$e^+e^- \to W^{\pm}e^{\mp}\nu_e$	$\sigma_{LO} = 2,815.3 \pm 12.6(Stat)$ MadSpin	200
$e^+e^- \to Ze^+e^-$	$\sigma_{LO} = 137.2 \pm 6.1(Stat)$ MadSpin	200
$e^+e^- \to t\bar{t} + (0/1)lp$	$\sigma_{NLO} = 727.7 \pm 1.1\ (Stat) \begin{cases} +3.1\% \\ -2.6\% \end{cases} (Scale)$ MadSpin, NLO FxFx Matching	2,000

Kinematic Fit

- Reconstruct as precisely as possible both h^0's and both $W^\pm$'s
- Use a kinematic fit:
  - primarily to resolve the large objects combinatorics
  - to improve mass resolutions
  - exploit separately exclusive event topologies
  - Example in $\ell^\pm\ell^\mp + 4j, 2b + \not{E}$ search topology

$$\chi^2_{C1} = \sum_{i=1}^{2} \frac{\left[E^{Meas}(\ell_i^\pm) - E^{Fit}(\ell_i^\pm)\right]^2}{\sigma^2_{E(\ell\pm)}} + \sum_{k=1}^{N_j} \frac{\left[E^{Meas}(j_k) - E^{Fit}(j_k)\right]^2}{\sigma^2_{E(j)}} + \sum_{x,y} \frac{\left[\not{P}^{Meas}_{x,y} - \not{P}^{Fit}_{x,y}\right]^2}{\sigma^2_{\not{p}_T}}$$
$$+ \frac{\left[M(\ell_1^\pm, \nu_2) - M_W\right]^2}{\Gamma^2_W} + \frac{\left[M(\ell_2^\pm, \nu_1) - M_W\right]^2}{\Gamma^2_W} + \frac{[M(bj_1, bj_2) - M_h]^2}{\Gamma^2_h} + \frac{[M(j_1, j_2) - M_h]^2}{\Gamma^2_h} \quad (1)$$

$$\text{with} \begin{cases} M(\nu_1) = M(\nu_2) = 0 \\ \not{P} = P(\nu_1) + P(\nu_2) \end{cases} \quad (2)$$

Jets Combinatorics (4j)

- $\ell^{\pm}\ell^{\mp} + 4j, 2b + \not{E}$: 3 Combinations
  - C_1: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(bj_2)$ & $P(h_2^0) = P^{Fit}(j_1) + P^{Fit}(j_2)$,
  - C_2: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(j_1)$ & $P(h_2^0) = P^{Fit}(bj_2) + P^{Fit}(j_2)$,
  - C_3: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(j_2)$ & $P(h_2^0) = P^{Fit}(bj_2) + P^{Fit}(j_1)$
- $\ell^{\pm}\ell^{\mp} + 4j, 3b + \not{E}$: 3 Combinations
- $\ell^{\pm}\ell^{\mp} + 4j, 4b + \not{E}$: 3 Combinations
- Choose the combination with $Min(\chi^2_{C_i})$'s

Jets Combinatorics (5j & 6j)

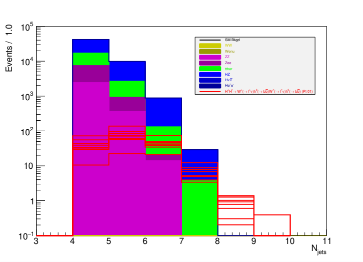
- $\ell^{\pm}\ell^{\mp} + 5j, 2b + \not{E}$: 10 Combinations
  - 3 Combinations:
  - C_1: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(bj_2) + P^{Fit}(j_1)$ & $P(h_2^0) = P^{Fit}(j_2) + P^{Fit}(j_3)$,
  - C_2: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(bj_2) + P^{Fit}(j_3)$ & $P(h_2^0) = P^{Fit}(j_1) + P^{Fit}(j_2)$,
  - C_4: $P(h_1^0) = P^{Fit}(bj_1) + P^{Fit}(j_2) + P^{Fit}(j_3)$ & $P(h_2^0) = P^{Fit}(bj_2) + P^{Fit}(j_1)$,...
- Both $\ell^{\pm}\ell^{\mp} + 5j, 3b + \not{E}$, $\ell^{\pm}\ell^{\mp} + 5j, 4b + \not{E}$ also have 10 Combinations
- The situation will obviously get worse w/ 6j events, and even more so in the $1\ell^{\pm} + Jets + \not{E}$ and in the fully hadronic topologies
- Find a ranking of the combinations so as to calculate a limited number of χ^2's
- Before kin. fit: $d(C_i) = |M(bj_1, bj_2) - M_h| + |M(j_1, j_2) - M_h|$ (work in progress...)

Reconstructed Objects

- Fast simulation of the IDEA detector using Delphes (IDEAtrkCov)
- Electrons & Muons:
  - $p_T > 10$ GeV
  - $|\eta| < 3.0$
  - $\mathrm{IsolationVar}(\Delta \mathrm{R} < 0.5) = \frac{\sum_{\mathrm{i} \neq \mathrm{j}} \mathrm{p_T(i)}}{\mathrm{p_T(j)}} < 5 \times 10^{-3}$
- Jets:
  - anti-k_T with $\Delta R = 0.4$
  - $p_T > 15$ GeV
  - $|\eta| < 3.0$
  - B-tagging working point: $\epsilon_b = 80\%$, $\epsilon_c = 10\%$, $\epsilon_{light} = 1\%$

Event Preselection in 4j Topologies

- $N_{\ell^\pm} = 2$ ($\ell^\pm = e^\pm$ or $\mu^\pm$), opposite charge, isolated leptons
- $N_j \geq 4$, $N_{bj} \geq 2$
- $\ell^\pm \ell^\mp + 4j, 2b + \not{E}$ channel:
  - Additional cuts:
  - $N_{bj} = 2$
  - $40\% \frac{E_{vis}}{\sqrt{s}} < 80\%$



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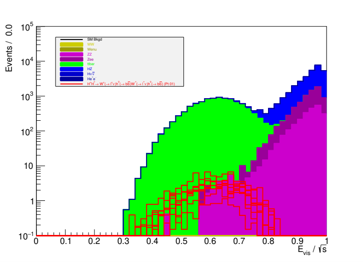

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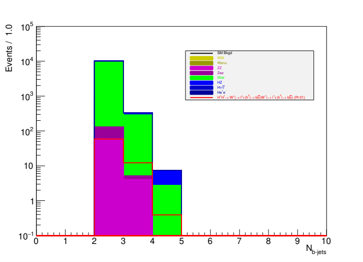
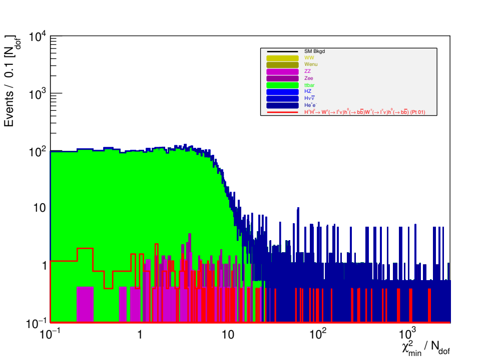


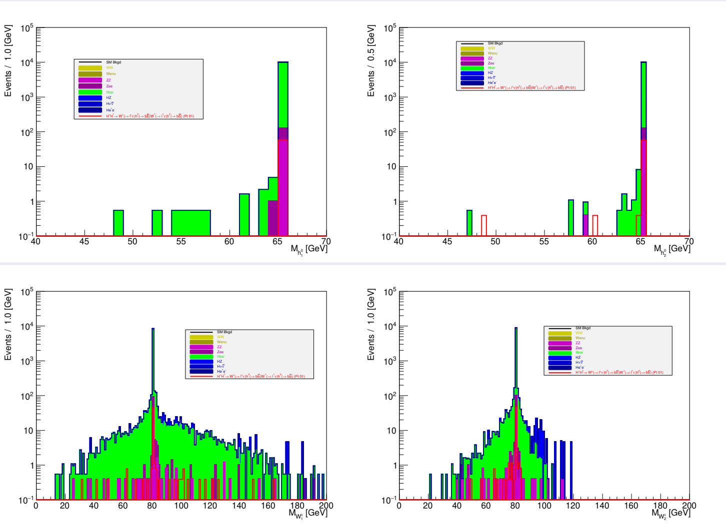
Event Yields (4j2b Excl.)

Process	N_{pass} (Evts)	N_{gen} (Evts)	$\epsilon \pm \delta\epsilon$ (%)	$N_{exp} \pm \delta N_{exp}$ (Evts)
$W^{\pm}W^{\mp}$	0.00	2,500,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
$W^{\pm}e^{\mp}\nu_e$	0.00	200,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
ZZ	145.00	2,003,843.00	(0.01 $\pm$ 0.00)	(59.20 $\pm$ 12.04)
Ze^+e^-	68.00	200,000.00	(0.03 $\pm$ 0.00)	(70.00 $\pm$ 8.24)
$t\bar{t}$	16,753.00	1,998,053.00	(0.84 $\pm$ 0.01)	(9,161.50 $\pm$ 128.89)
HZ	182.00	36,000.00	(0.51 $\pm$ 0.04)	(848.67 $\pm$ 13.46)
$H\nu_e\bar{\nu}_e$	0.00	36,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
He^+e^-	9.00	13,000.00	(0.07 $\pm$ 0.02)	(6.69 $\pm$ 3.00)
BKGD Sum	–	–	–	(10,146.06 $\pm$ 130.4)
$H^{\pm}H^{\mp}$ (MSSM Pt01)	149.00	100,000.00	(0.15 $\pm$ 0.01)	(58.55 $\pm$ 0.01)
$H^{\pm}H^{\mp}$ (MSSM Pt02)	193.00	100,000.00	(0.19 $\pm$ 0.01)	(48.88 $\pm$ 0.01)
$H^{\pm}H^{\mp}$ (MSSM Pt03)	139.00	100,000.00	(0.14 $\pm$ 0.01)	(32.30 $\pm$ 0.00)
$H^{\pm}H^{\mp}$ (MSSM Pt04)	131.00	100,000.00	(0.13 $\pm$ 0.01)	(26.56 $\pm$ 0.00)
$H^{\pm}H^{\mp}$ (MSSM Pt05)	194.00	100,000.00	(0.19 $\pm$ 0.01)	(37.99 $\pm$ 0.01)
$H^{\pm}H^{\mp}$ (MSSM Pt06)	152.00	100,000.00	(0.15 $\pm$ 0.01)	(27.98 $\pm$ 0.00)
$H^{\pm}H^{\mp}$ (MSSM Pt07)	172.00	100,000.00	(0.17 $\pm$ 0.01)	(29.52 $\pm$ 0.00)
$H^{\pm}H^{\mp}$ (MSSM Pt08)	173.00	100,000.00	(0.17 $\pm$ 0.01)	(26.22 $\pm$ 0.00)
$H^{\pm}H^{\mp}$ (MSSM Pt09)	111.00	100,000.00	(0.11 $\pm$ 0.01)	(8.41 $\pm$ 0.00)

4j2b Evt Selection for Pt01



4j2b Evt Selection for Pt01



Event Yields (4j2b Excl.)

- Adding few cuts:
  - 1 Gev window aroung M_h's and 4 GeV window around M_W
  - $M(j_1) + M(j_2) < 0.1$ to reject gluon jets in $t\bar{t}$ events

Process	N_{pass} (Evts)	N_{gen} (Evts)	$\epsilon \pm \delta\epsilon$ (%)	$N_{exp} \pm \delta N_{exp}$ (Evts)
$W^{\pm}W^{\mp}$	0.00	2,500,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
$W^{\pm}e^{\mp}\nu_e$	0.00	200,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
ZZ	50.00	2,003,843.00	(0.00 $\pm$ 0.00)	(20.41 $\pm$ 7.07)
Ze^+e^-	16.00	200,000.00	(0.01 $\pm$ 0.00)	(16.47 $\pm$ 4.00)
$t\bar{t}$	9568.00	1,998,053.00	(0.48 $\pm$ 0.00)	(5,232.33 $\pm$ 97.58)
HZ	62.00	36,000.00	(0.17 $\pm$ 0.02)	(289.11 $\pm$ 7.87)
$H\nu_e\bar{\nu}_e$	0.00	36,000.00	(0.00 $\pm$ 0.00)	(0.00 $\pm$ 0.00)
He^+e^-	4.00	13,000.00	(0.03 $\pm$ 0.02)	(2.97 $\pm$ 2.00)
BKGD Sum	–	–	–	(5,382.1 $\pm$ 98.3)
$H^{\pm}H^{\mp}$ (MSSM Pt01)	148.00	100,000.00	(0.15 $\pm$ 0.01)	(58.16 $\pm$ 0.01)

Outlook

- Identified 2 scenarios motivating the search for heavy charged Higgs bosons at FCC-ee: MSSM and GM
- Generated MC samples for signals and main background processes at $\sqrt{s} = 365$ GeV
- Testing the search strategy based upon combination of exclusive topologies where the jets combinatorics is handled through kinematic fits
- To Do List: assess the sensitivity for the chosen benchmark points in MSSM, then GM

BACK-UP

GM Extended Higgs Sector (Courtesy: Heather Logan)

Georgi-Machacek model   Georgi & Machacek 1985; Chanowitz & Golden 1985

SM Higgs (bi-)doublet + triplets $(1,0)+(1,1)$ in a bi-triplet:

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^+ \\ -\phi^{+*} & \phi^0 \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

Global $SU(2)_L \times SU(2)_R \rightarrow$ custodial symmetry $\langle \chi^0 \rangle = \langle \xi^0 \rangle \equiv v_\chi$

(ensures $\rho = 1$)

Most general scalar potential invariant under $SU(2)_L \times SU(2)_R$:

$$\begin{aligned} V(\Phi, X) \;=\; & \frac{\mu_2^2}{2}\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{\mu_3^2}{2}\mathrm{Tr}(X^\dagger X) + \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 \\ & + \lambda_2 \mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(X^\dagger X) + \lambda_3 \mathrm{Tr}(X^\dagger X X^\dagger X) \\ & + \lambda_4[\mathrm{Tr}(X^\dagger X)]^2 - \lambda_5 \mathrm{Tr}(\Phi^\dagger \tau^a \Phi \tau^b)\mathrm{Tr}(X^\dagger t^a X t^b) \\ & - M_1 \mathrm{Tr}(\Phi^\dagger \tau^a \Phi \tau^b)(U X U^\dagger)_{ab} - M_2 \mathrm{Tr}(X^\dagger t^a X t^b)(U X U^\dagger)_{ab} \end{aligned}$$

9 parameters, 2 fixed by G_F and $m_h \rightarrow$ 7 free parameters.   Aoki & Kanemura, 0712.4053

Chiang & Yagyu, 1211.2658; Chiang, Kuo & Yagyu, 1307.7526

Hartling, Kumar & HEL, 1404.2640

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Georgi-Machacek model Georgi & Machacek 1985; Chanowitz & Golden 1985

SM Higgs (bi-)doublet + triplets $(1, 0) + (1, 1)$ in a bi-triplet:

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix}$$

Global $SU(2)_L \times SU(2)_R$ → custodial symmetry $\langle \chi^0 \rangle = \langle \xi^0 \rangle \equiv v_\chi$

Physical spectrum:

Bi-doublet: $2 \otimes 2 \to 1 \oplus 3$ Bi-triplet: $3 \otimes 3 \to 1 \oplus 3 \oplus 5$

- Two custodial singlets mix → h^0, H^0 m_h, m_H, angle α
  Usually identify $h^0 = h(125)$
- Two custodial triplets mix → (H_3^+, H_3^0, H_3^-) m_3 + Goldstones
  Phenomenology very similar to $H^\pm, A^0$ in 2HDM Type I, $\tan\beta \to \cot\theta_H$
- Custodial fiveplet $(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$ m_5
  Fermiophobic; H_5VV couplings $\propto s_H \equiv \sqrt{8}v_\chi/v_{SM}$
  $s_H^2 \equiv$ exotic fraction of M_W^2, M_Z^2

GM Tool (1/2)

- GMCALC: http://people.physics.carleton.ca/ logan/gmcalc (Fortran 77)
- gmpoint.f: calculate single GM model from a set of parameters
  Example: for INPUTSET = 3, set (m_h, m_H), m_3, m_5, $sin(\theta_H)$, $sin(\alpha)$, M_1, M_2
- gmscan.f: calculate GM models from scan over sets of the parameters
  - Reject models for which:
    - $\lambda_{1,..,5}$ fail perturbative unitarity
    - scalar potential is unbouded from below
    - minimum of this potential does not correspond to right EWSB
  - $m_h = 125.0 \pm 0.5$ GeV or $m_H = 125.0 \pm 0.5$ GeV, choose the one w/ largest $|\kappa_V|$
- gmmg5.f: produce MadGraph v5 "param_cards" for LO, LO-EFT and NLO for a valid and complete GM model (not meant for Simplified Model)

GM Scan

- gmscan.f: large scan to produce 100k good models
  - Common features: $m_h = 125.0 \pm 0.5\ \mathrm{GeV} < \mathrm{m_H}$ and $0 < sin(\theta_H) < 1$
  - Select 6 models w/: $M_3 > M_5$ where we scan over $M_5 \in [105, 225]$ GeV by steps of $\approx$ 25 GeV
  - Select 4 models w/: $M_3 < M_5$ with $M_5 \in [135, 345]$ GeV

GM Tool (2/2)

- GM UFO: http://feynrules.irmp.ucl.ac.be/wiki/GeorgiMachacekModel (Python)
- We use GM_UFO_LO_EFF.tar.gz to import the GM model within MadGraph v5

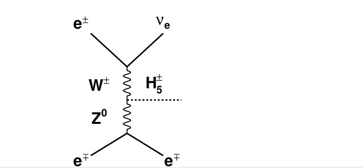
GM Selected Models

Model	m_H [GeV]	M_3 [GeV]	M_5 [GeV]	$sin(\theta_H)$ –	$sin(\alpha)$ –	M_1 [GeV]	M_2 [GeV]
Pt01	260.301	203.017	103.294	0.399	-0.150	117.639	26.813
Pt02	196.267	169.788	124.937	0.264	0.081	57.563	42.320
Pt03	475.447	399.066	149.904	0.573	-0.388	402.246	-208.689
Pt04	317.902	298.968	172.986	0.690	-0.033	369.654	10.861
Pt05	484.088	500.390	200.909	0.790	0.016	1367.034	65.990
Pt06	338.066	303.945	225.334	0.233	-0.119	147.314	28.420
Pt07	264.162	128.679	134.004	0.137	-0.988	12.446	7.888
Pt08	235.424	182.916	216.817	0.613	-0.402	152.144	122.127
Pt09	281.000	212.484	248.259	0.620	-0.605	119.762	82.499
Pt10	375.850	225.230	345.360	0.194	-0.996	26.502	101.384

GM Selected Models Decay Modes

Model	M_5 [GeV]	$\Gamma(H_5^\pm)$ [GeV]	$BR(H_5^\pm \to W^\pm Z^0)$	$\begin{cases} BR(H_3^\pm \to W^\pm Z^0) \\ BR(H_3^0 \to h_{125}^0 Z^0) \end{cases}$	$\begin{cases} BR(H_5^\pm \to W^\pm H_3^0) \\ BR(H_5^\pm \to H_3^\pm Z^0) \end{cases}$
Pt01	103.294	3.5×10^{-6}	93.47%	0% / –	0% / –
Pt02	124.937	2.9×10^{-5}	99.71%	0% / –	0% / –
Pt03	149.904	1.3×10^{-3}	97.85%	0% / –	0% / –
Pt04	172.986	5.1×10^{-2}	99.94%	0% / –	0% / –
Pt05	200.909	0.339	99.98%	0% / –	0% / –
Pt06	225.334	8.1×10^{-2}	99.99%	0% / –	0% / –
Pt07	134.004	2.1×10^{-5}	99.57%	0% / –	0% / –
Pt08	216.817	0.359	99.98%	0% / –	0% / –
Pt09	248.259	0.678	99.98%	0% / –	0% / –
Pt10	345.360	1.973	17.37%	49.58% / 99.87%	33.04% / 88.76%

$H_5^{\pm}$ Production Mechanism and LO Cross Section



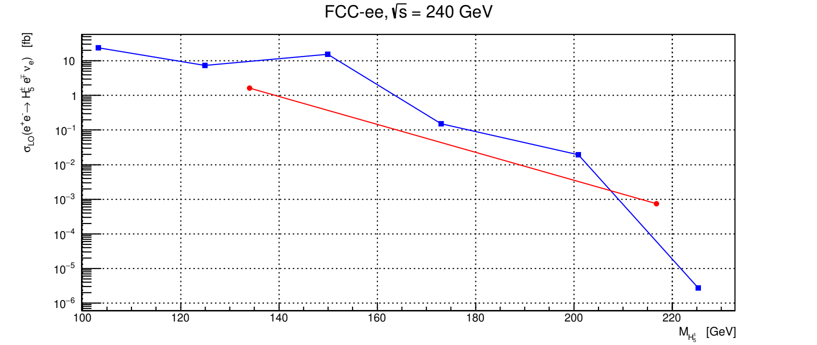
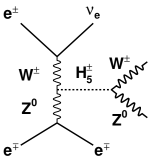


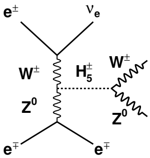
Figure: Bottom plot: in blue for $M_3 > M_5$, in red for $M_5 > M_3$



$H_5^{\pm}$ MC Samples $\sqrt{s} = 240$ GeV

Model	m_H [GeV]	N_{gen}	$\sigma(e^+e^- \to H_5^{\pm} e^{\mp} \nu_e)$ [fb]
Pt04	317.902	100k	0.152 ± 0.0002
Pt05	484.088	100k	0.0193 ± 0.00002
Pt06	338.066	100k	$(2.72 \pm 0.0024) \times 10^{-6}$
Pt08	235.424	100K	$(7.55 \pm 0.006) \times 10^{-4}$

- GM MC Samples:
  - restricted to $H_5^{\pm}$ decaying into on-shell $W^{\pm}$ and Z^0
  - forced subsequent decays: $W^{\pm} \to \ell^{\pm}\nu$ and $Z^0 \to b\bar{b}$
  - Conclusion: not enough sensitivity at $\sqrt{s} = 240$ GeV !



$H_5^{\pm}$ MC Samples $\sqrt{s} = 365$ GeV

Model	m_H [GeV]	N_{gen}	$\sigma(e^+e^- \to H_5^{\pm} e^{\mp} \nu_e)$ [fb]
Pt04		100k	21.11 ± 0.019
Pt05		100k	19.95 ± 0.023
Pt06		100k	1.213 ± 0.001
Pt08		100K	9.646 ± 0.011
Pt09		100K	5.548 ± 0.007
Pt10		100K	$(1.339 \pm 0.001) \times 10^{-5}$

- GM MC Samples:
  - restricted to $H_5^{\pm}$ decaying into on-shell $W^{\pm}$ and Z^0
  - forced subsequent decays: $W^{\pm} \to \ell^{\pm}\nu$ and $Z^0 \to b\bar{b}$
  - Conclusion: not enough sensitivity for Pt06 and Pt10 at $\sqrt{s} = 365$ GeV; Pt04,05,08,09 should be analyzed