Light CP-even Higgs searches

Siba Prasad Das

LHeC and FCC-eh Workshop, CERN

Geneva, Switzerland

[NMSSM: SPD, M. Nowakowski, arXiv:1612.07241[hep-ph], to be appeared in Phys.Rev.D]
[2HDM: SPD, J. Hernández-Sánchez, S. Moretti, A. Rosado and R. Xoxocotzi [arXiv:1503.01464,PRD94(055003)2016]]

September 11, 2017

Contents

Abelian Higgs Model

$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$

$D_\mu = \partial_\mu - ieA_\mu;$

$F_{\mu\nu} \equiv \partial_\mu A_\nu - \partial_\nu A_\mu$

$V(\phi) = \mu^2 \mid \phi \mid^2 + \lambda(\mid \phi \mid^2)^2$

By convention: $\lambda > 0$

Case 1: $\mu^2 > 0$

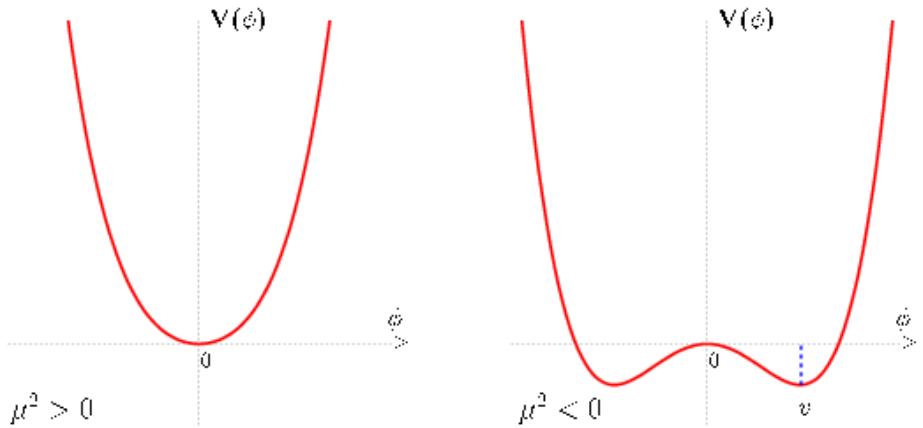
QED with M_A=0 and $m_\phi = \mu$

Unique minimum at ϕ=0

Case 2: $\mu^2 < 0$

Minimum energy state at:

$\langle\phi^0\rangle = \sqrt{-\frac{\mu^2}{2\lambda}} = v/\sqrt{2}$



Vacuum breaks $U(1)$ symmetry

[What fixes sign (μ^2)?]

MSSM Higgs Potential

$$V_H = \left(\mid \mu \mid^2 + m_1^2\right) \mid H_1 \mid^2 + \left(\mid \mu \mid^2 + m_2^2\right) \mid H_2 \mid^2 - \mu B \epsilon_{ij} \left(H_1^i H_2^j + \text{h.c.}\right) + \frac{(g^2 + g'^2)}{8} \left(\mid H_1 \mid^2 - \mid H_2 \mid^2\right)^2 + \frac{1}{2} g^2 \mid H_1^* H_2 \mid^2 \quad (1)$$

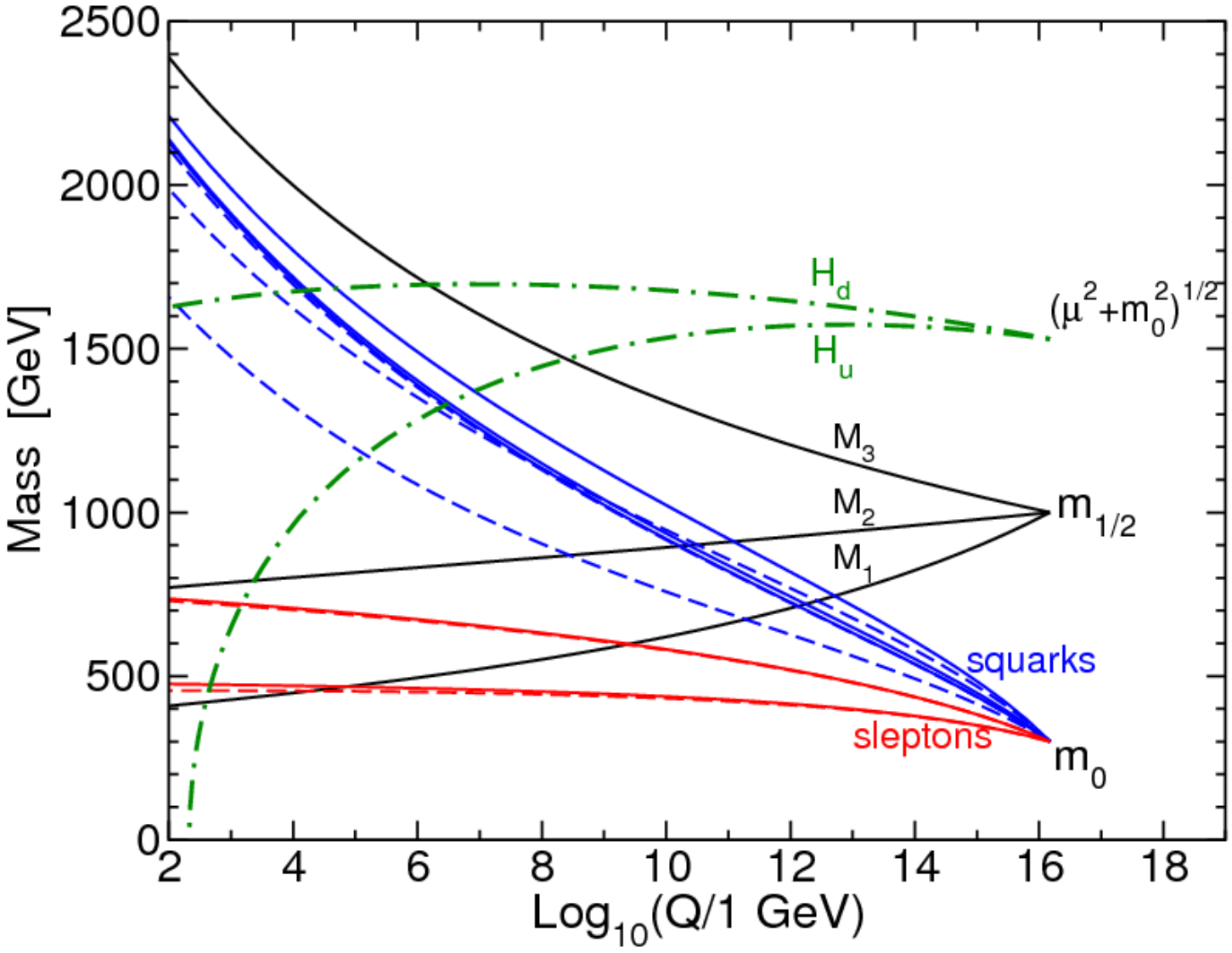
3 independent parameters: $\mid \mu \mid^2 + m_1^2$, $\mid \mu \mid^2 + m_2^2$ and μB must be non-zero for EWSB to take place

$$M_W^2 = \frac{g^2}{2}(v_1^2 + v_2^2) \quad (2)$$

$$\tan\beta \equiv \frac{v_2}{v_1} \quad (3)$$

[Tree-level: $\tan\beta$ and μB]

RG running (e.g., mSUGRA)



[Up-type Higgs soft-mass becomes negative]

Radiative Electro–weak Symmetry breaking

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 - \tan^2\beta\ m_{H_u}^2}{\tan^2\beta - 1} - \mu^2 \tag{4}$$

Moderately large $\tan\beta$:

$$\frac{M_Z^2}{2} \simeq -m_{H_u}^2 - \mu^2 \tag{5}$$

[Up-type Higgs soft-mass and with Z-mass: estimate μ]

μ–problem of MSSM

- What is the value of μ in the MSSM superpotential: $\mu H_u H_d$?
- μ=0: No mixing (any breaking in up-sector could not be communicated to down-sector)

Also hints from LEP limit on Chargino mass (105 GeV)

- $\mu = M_{pl}$: Higgs and Higgsinos are Planck scale (Excessive fine–tuning)

[For phenomenological acceptable solutions: μ is of the order of electro-weak scale]

Next-to-MSSM

NMSSM

$$W_{\rm Higgs} = (\mu + \lambda \widehat{S})\, \widehat{H}_u \cdot \widehat{H}_d + \xi_F \widehat{S} + \frac{1}{2}\mu' \widehat{S}^2 + \frac{\kappa}{3}\widehat{S}^3 \tag{6}$$

$$W_{\rm Yukawa} = h_u\, \widehat{Q} \cdot \widehat{H}_u\, \widehat{U}^c_R + h_d\, \widehat{H}_d \cdot \widehat{Q}\, \widehat{D}^c_R + h_e\, \widehat{H}_d \cdot \widehat{L}\, \widehat{E}^c_R \tag{7}$$

$$\begin{aligned} -\mathcal{L}_{\rm soft} \;=\; & m^2_{H_u}|H_u|^2 + m^2_{H_d}|H_d|^2 + m^2_S|S|^2 + m^2_Q|Q^2| + m^2_U|U^2_R| \\ & + m^2_D|D^2_R| + m^2_L|L^2| + m^2_E|E^2_R| \\ & + (h_u A_u\, Q \cdot H_u\, U^c_R - h_d A_d\, Q \cdot H_d\, D^c_R - h_e A_e\, L \cdot H_d\, E^c_R \\ & + \lambda A_\lambda\, H_u \cdot H_d\, S + \frac{1}{3}\kappa A_\kappa\, S^3 + m^2_3\, H_u \cdot H_d + \frac{1}{2} m'^2_S\, S^2 + \xi_S\, S) \end{aligned} \tag{8}$$

Simpler ($\mathbb{Z}_3$) scenario:$\mu = \mu' = \xi_F = 0$ and $m^2_3 = m'^2_S = \xi_S = 0$

$$W_{\rm sc.inv.} = \lambda \widehat{S}\, \widehat{H}_u \cdot \widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3 \tag{9}$$

$$\mu_{\rm eff} = \lambda s \tag{10}$$

[s:Singlet VEV]

[Ellwanger, Hugonie and Teixeira: 0910.1785[hep-ph]]

Higgs Potential

$$\lambda,\ \kappa,\ m_{H_u}^2,\ m_{H_d}^2,\ m_S^2,\ A_\lambda \text{ and } A_\kappa \tag{11}$$

$$\begin{aligned} V_{\rm Higgs} \quad = \quad & \left|\lambda\left(H_u^+ H_d^- - H_u^0 H_d^0\right) + \kappa S^2 + \mu' S + \xi_F\right|^2 \\ & + \left(m_{H_u}^2 + |\mu + \lambda S|^2\right)\left(\left|H_u^0\right|^2 + \left|H_u^+\right|^2\right) + \left(m_{H_d}^2 + |\mu + \lambda S|^2\right)\left(\left|H_d^0\right|^2 + \left|H_d^-\right|^2\right) \\ & + \frac{g_1^2 + g_2^2}{8}\left(\left|H_u^0\right|^2 + \left|H_u^+\right|^2 - \left|H_d^0\right|^2 - \left|H_d^-\right|^2\right)^2 + \frac{g_2^2}{2}\left|H_u^+ H_d^{0*} + H_u^0 H_d^{-*}\right|^2 \\ & + m_S^2|S|^2 + \left(\lambda A_\lambda\left(H_u^+ H_d^- - H_u^0 H_d^0\right) S + \frac{1}{3}\kappa A_\kappa\, S^3 + m_3^2\left(H_u^+ H_d^- - H_u^0 H_d^0\right)\right. \\ & \left. + \frac{1}{2} m_S'^2\, S^2 + \xi_S\, S + \text{h.c.}\right) \end{aligned} \tag{12}$$

$$M_Z^2 = g^2 v^2 \tag{13}$$

$$B_{\rm eff} = A_\lambda + \kappa s, \quad \widehat{m}_3^2 = m_3^2 + \lambda(\mu' s + \xi_F) \tag{14}$$

$$\frac{v_u v_d}{v^2} \equiv \frac{1}{2}\sin 2\beta = \frac{\mu_{\rm eff} B_{\rm eff} + \widehat{m}_3^2}{m_{H_u}^2 + m_{H_d}^2 + 2\mu_{\rm eff}^2 + \lambda^2 v^2}\ ; \tag{15}$$

$$\lambda,\ \kappa,\ A_\lambda,\ A_\kappa,\ \tan\beta,\ \mu_{\rm eff} \tag{16}$$

[7 to 6 parameters: by minimization condition]

Higgses: Doublet-Singlet Mixing

$$
\begin{aligned}
H_1 &= S_{1,d}\, H_d + S_{1,u}\, H_u + S_{1,s}\, S \,, \\
H_2 &= S_{2,d}\, H_d + S_{2,u}\, H_u + S_{2,s}\, S \,, \\
H_3 &= S_{3,d}\, H_d + S_{3,u}\, H_u + S_{3,s}\, S \,.
\end{aligned} \tag{17}
$$

$$
\begin{aligned}
\frac{g_{H_i bb}}{g_{H_{SM} bb}} = \frac{g_{H_i \tau\tau}}{g_{H_{SM}\tau\tau}} &= \frac{S_{i,d}}{\cos\beta} \,, \qquad \frac{g_{H_i tt}}{g_{H_{SM} tt}} = \frac{S_{i,u}}{\sin\beta} \,, \\
\bar{g}_i \equiv \frac{g_{H_i VV}}{g_{H_{SM} VV}} &= \cos\beta\, S_{i,d} + \sin\beta\, S_{i,u} \,.
\end{aligned} \tag{18}
$$

[Generically SM Higgs either: H_1 or H_2; also couplings changes and hence BRs]

Neutralinos

$$\mathcal{L} = \frac{1}{2} M_1 \lambda_1 \lambda_1 + \frac{1}{2} M_2 \lambda_2^i \lambda_2^i + \frac{1}{2} M_3 \lambda_3^a \lambda_3^a \, . \tag{19}$$

$$\mathcal{L} = -\frac{1}{2} (\psi^0)^T \mathcal{M}_0 (\psi^0) + \text{h.c.} \tag{20}$$

$$\mathcal{M}_0 = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu_{\text{eff}} & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & 2\kappa s + \mu' \end{pmatrix} \tag{21}$$

[χ_1^0: DM candidate; Substantial singlet component and changes the Phenomenology]

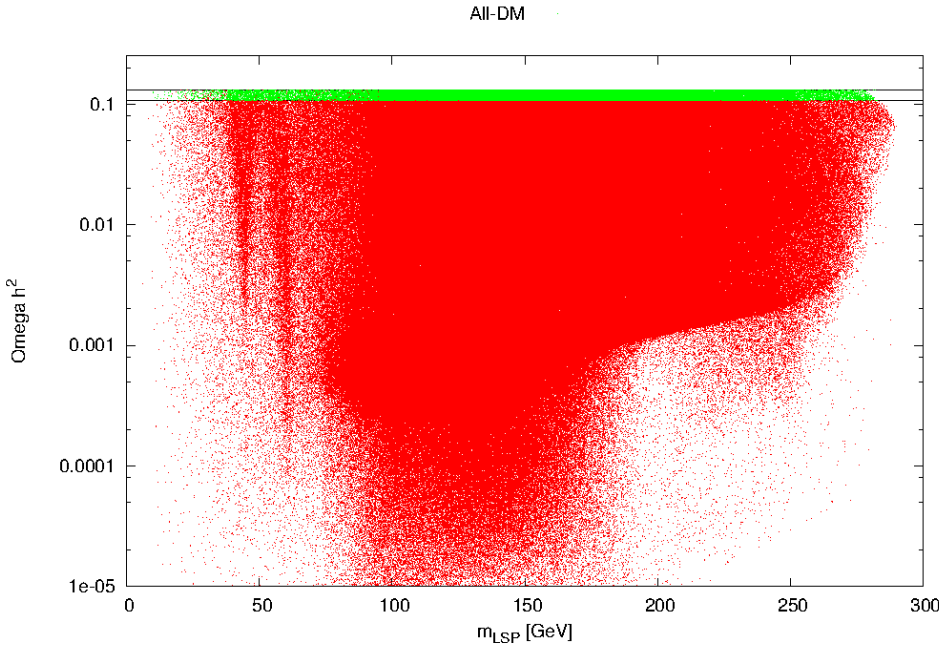
Dark Matter

$$\Omega_\chi h^2 \simeq \frac{0.1 \text{ pb} \cdot c}{\langle \sigma_A v \rangle} \tag{22}$$

$\sigma(\chi_1^0 \chi_1^0 \xrightarrow{H_a} X X')$;

$\sigma(\chi_1^0 \chi_1^0 \xrightarrow{\chi_i^0} H_1 A_1)$ etc...

WMAP within Standard Cosmology: [0.107 – 0.131]



[M. Drees and G. Gerbier, PDG review, arXiv:1204.2373 [hep-ph]]

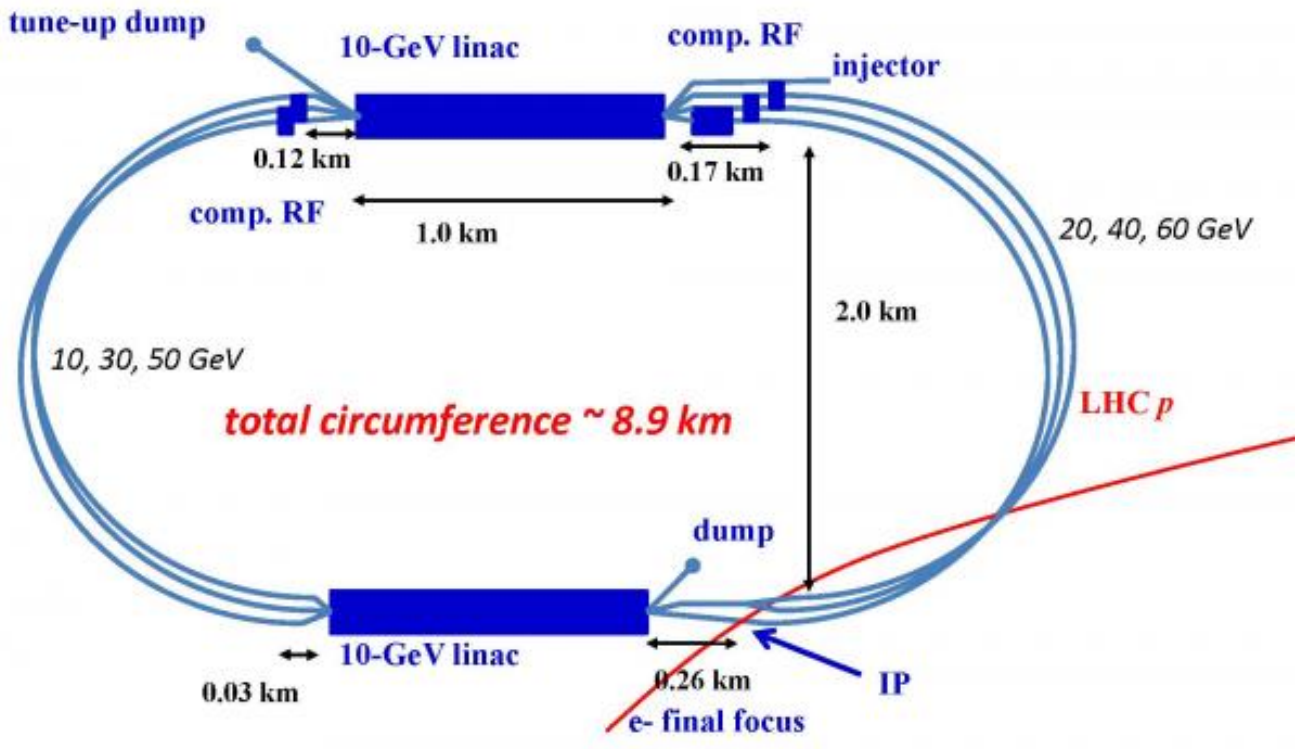
Parameters and Constraints (Couplings, Signal Strength)

Parameters	Min	Max
λ	0.001	0.7
κ	0.001	0.7
A_λ	100.0	3000.0
A_κ	-2000.0	1000.0
$tan\beta$	1.5	60.0
μ_{eff}	100.0	500.0
M_1	100.0	400.0
M_2	100.0	500.0
$\tilde{q}_L$	500.0	1500.0
A_t=A_b	-3000.0	3000.0
M_A	100.0	500.0
M_P	100.0	3000.0

Parameters	Min	Max	Parameters	Min	Max
κ_W	0.81	0.99	$\mu^{\tau\tau}_{VBF}$	0.50	2.10
κ_t	0.99	1.89	$\mu^{\tau\tau}_{ggF}$	-0.20	2.20
$\lvert\kappa_\gamma\rvert$	0.72	1.10	μ^{bb}_{VH}	0.00	2.00
$\lvert\kappa_g\rvert$	0.61	1.07	μ^{bb}_{ttH}	-0.90	3.10
$\lvert\kappa_\tau\rvert$	0.65	1.11	μ^{WW}_{VBF}	0.40	2.00
$\lvert\kappa_b\rvert$	0.25	0.89	μ^{ZZ}_{ggF}	0.51	1.81
$Br(h_{SM} \rightarrow inv)$		0.25	$\mu^{\gamma\gamma}_{VBF}$	0.30	2.30
			$\mu^{\gamma\gamma}_{ggF}$	0.66	1.56

[Perturbative, B-physics, Sparticle masses and etc..]

LHeC Collider

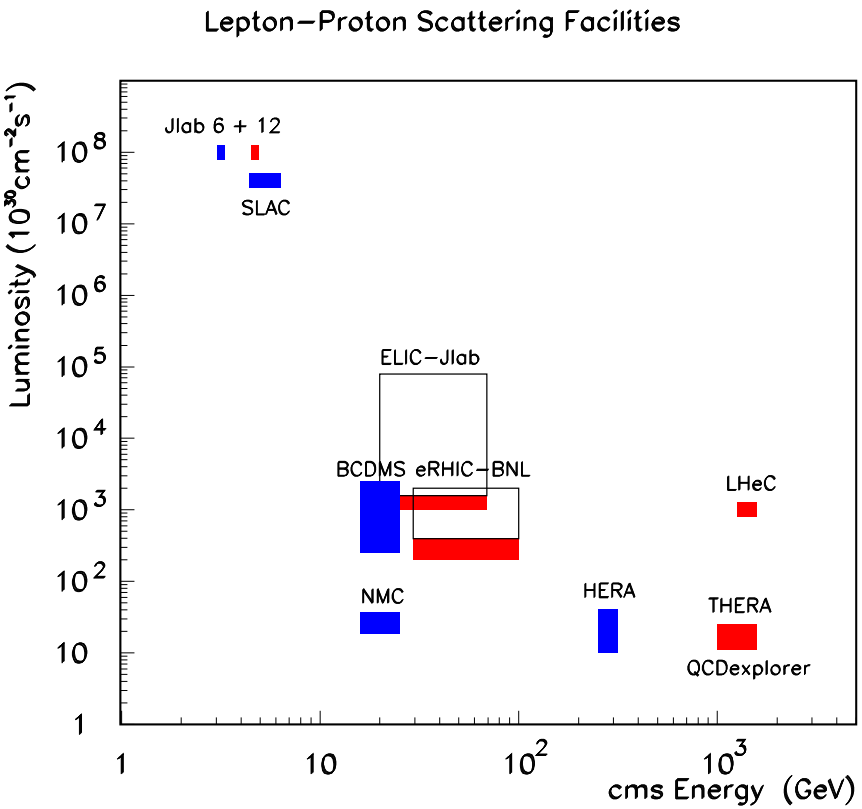


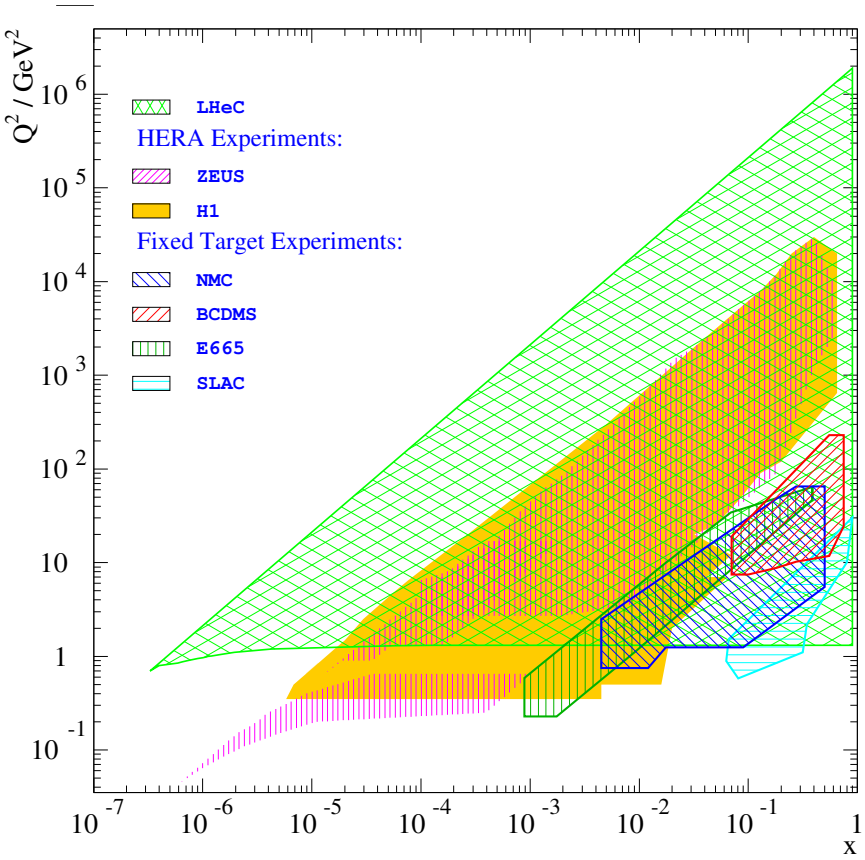
$\sqrt{s} = \sqrt{(E_e E_p)} = 1.296$ TeV (e-=60GeV with p=7 TeV) with 100/fb

[FCC-eh: e-=60 GeV with p=50 TeV (with e-=80% polarization)]

[J. L. Abelleira Fernandez [arXiv:1206.2913 [physics.acc-ph]]

Energy-Luminosity and x-Q^2

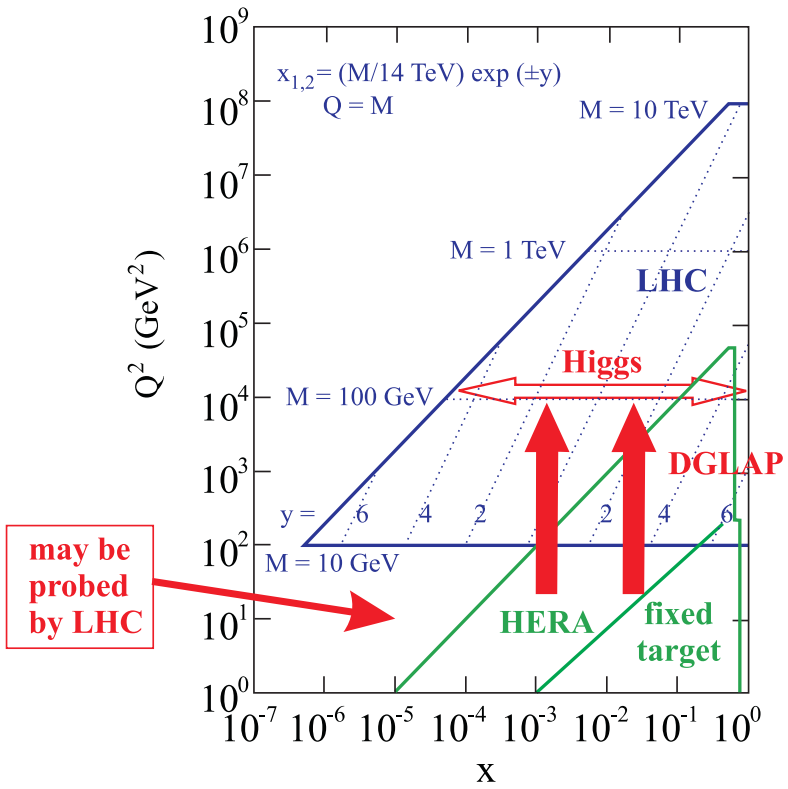


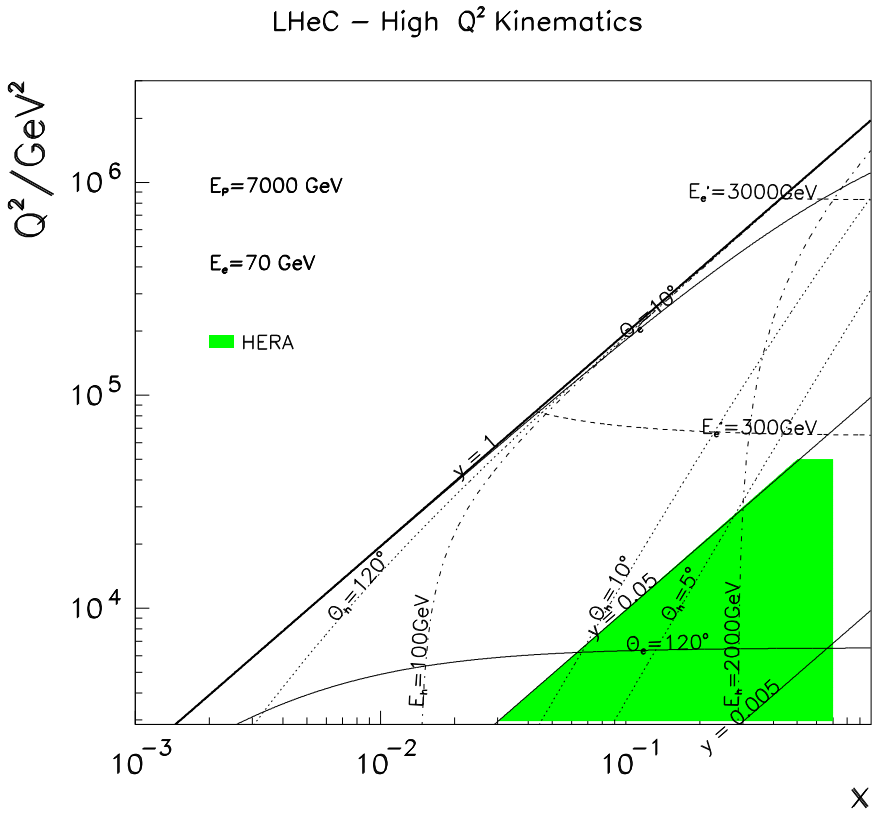


[High Q^2 with small Bjorken-x]

[J. B. Dainton et.al. arXiv:hep-ex/0603016, JINST 1:P10001,2006]

Kinematic planes: Mass reach with Rapidity and Bjorken-x



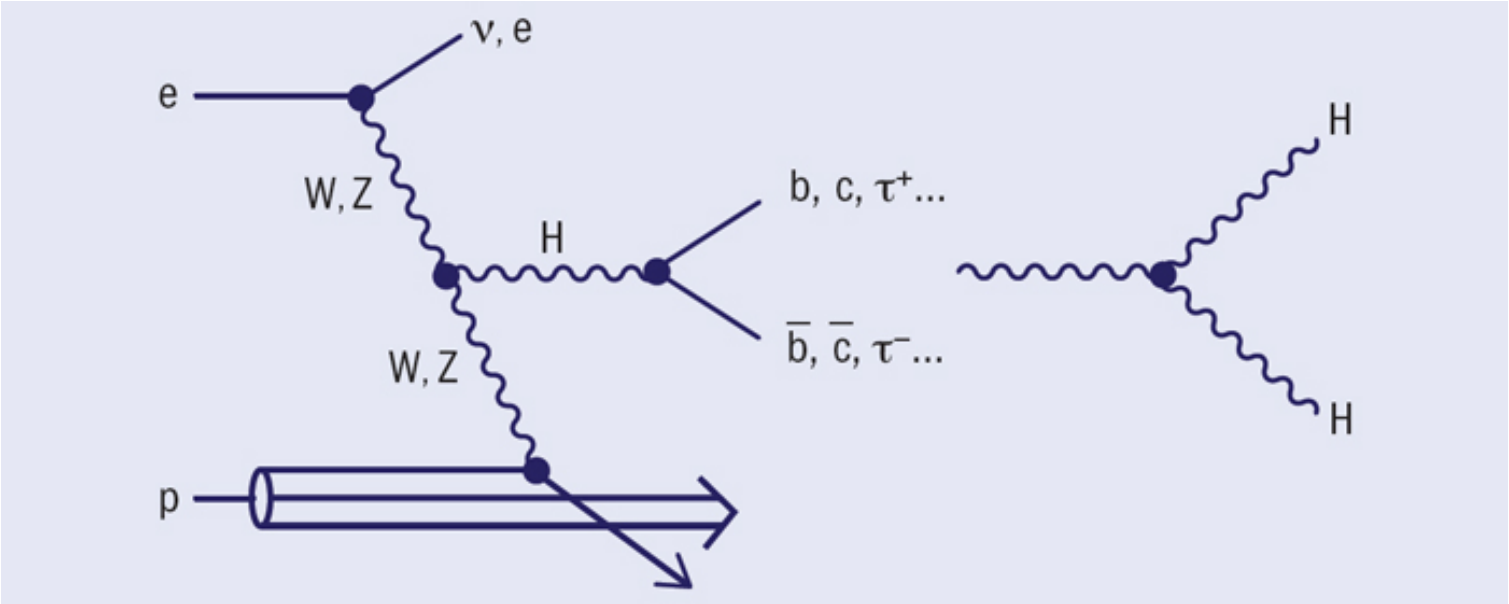


[A. D. Martin, hep-ph/0802.01610, Acta Phys.Polon.B39:2025-2062,2008]

[J. B. Dainton et.al. arXiv:hep-ex/0603016, JINST 1:P10001,2006]

[For the same M and y, FCC-eh probes values of x smaller by 0.14 as compared to LHeC]

Process: $ep \to eHq$ and νHq



[Vector Boson Fusion (VBF): h_2–SM scenario, also Higgs to (low-mass) Higgses at FCC-eh]

[SPD, M. Nowakowski, arXiv:1612.07241[hep-ph], to be appeared in Phys.Rev.D]

t-channel VBF

$fa \to f'X$ via Gauge boson V:

$$\sigma(fa \to f'X) \approx \int dx\ dp_T^2\ P_{V/f}(x, p_T^2)\ \sigma(Va \to X) \tag{23}$$

$s \gg M_V^2$:

$$P_{V/f}^T(x, p_T^2) = \frac{g_V^2 + g_A^2}{8\pi^2} \frac{1 + (1-x)^2}{x} \frac{p_T^2}{\left(p_T^2 + (1-x)M_V^2\right)^2} \tag{24}$$

$$P_{V/f}^L(x, p_T^2) = \frac{g_V^2 + g_A^2}{4\pi^2} \frac{1 - x}{x} \frac{(1-x)M_V^2}{\left(p_T^2 + (1-x)M_V^2\right)^2}. \tag{25}$$

[R. N. Cahn and S.Dawson, PLB**136** (1984) 196]**,** [M. S. Chanowitz and M. K.Gaillard, PLB **142** (1984) 85]

[G. L.Kane, W. W.Repko and W. B.Rolnick, PLB **148** (1984) 367]

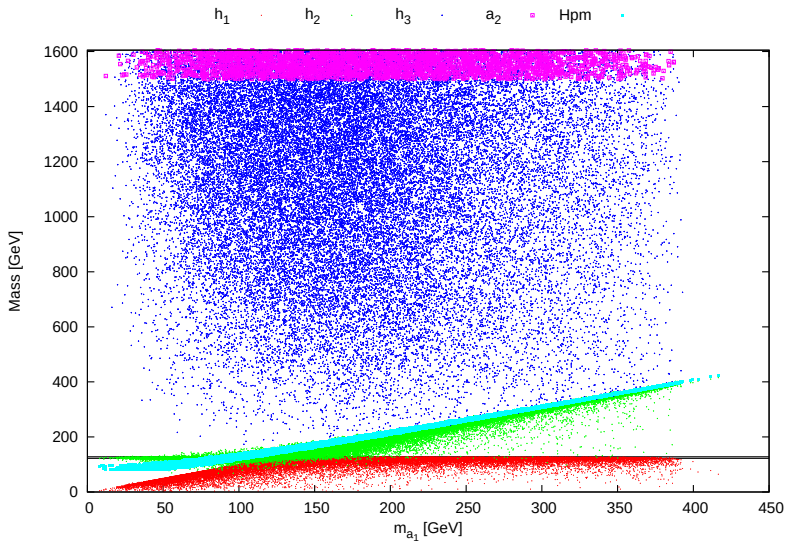
[T. Han and B. Mellado, PRD **82** (2010) 016009, arXiv:0909.2460 [hep-ph]]

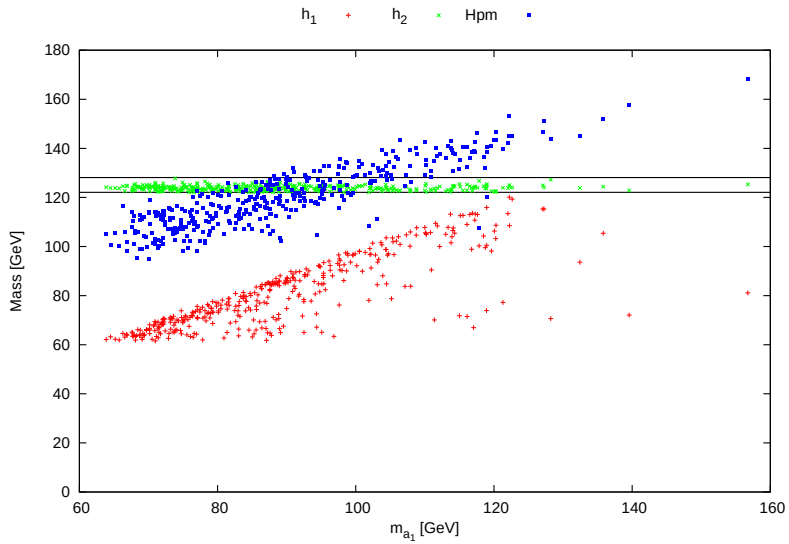
[At high p_T, transversely polarized gauge boson enhances]

Analysis set-up

- `NMSSMTools 5.0.1`
- `MadGraph v 2.4.3`
- $p_T^{q,e} > 10$ GeV, $\eta^{q,e} < 5.0$, $\Delta R(qq, qe) > 0.2$
- $Q^2 = \hat{s}$ $(\hat{t})$, NN23LO, α_s(4-flavor)
- `PYTHIA` v.6.428
- Shower scale: Q
- Jet reconstruction: PYCELL, Cone-algorithm, $\Delta R(j)$=0.5, E_T 15 GeV, $|\eta| < 5.5$
- Lepton: E_T 15 GeV, $|\eta| < 3.5$, isolation: $\Delta R(j - \ell) \leq 0.5$ and $0.8 \leq E_T^j / E_T^\ell \leq 1.2$
- Granularity: $\Delta\eta \times \Delta\phi = 0.0359 \times 0.0314$
- Smearing: $\frac{\Delta E}{E} = \frac{a}{\sqrt{E}} \oplus b$; $a = 0.32, b = 0.086$(j) $a = 0.085, b = 0.003$(l)
- b-tag: $|\eta^j| < 2.5$ $\Delta R(j, B - \text{hadron}) < 0.2$, $\epsilon_{b,c,q}$=0.50,0.10,0.01

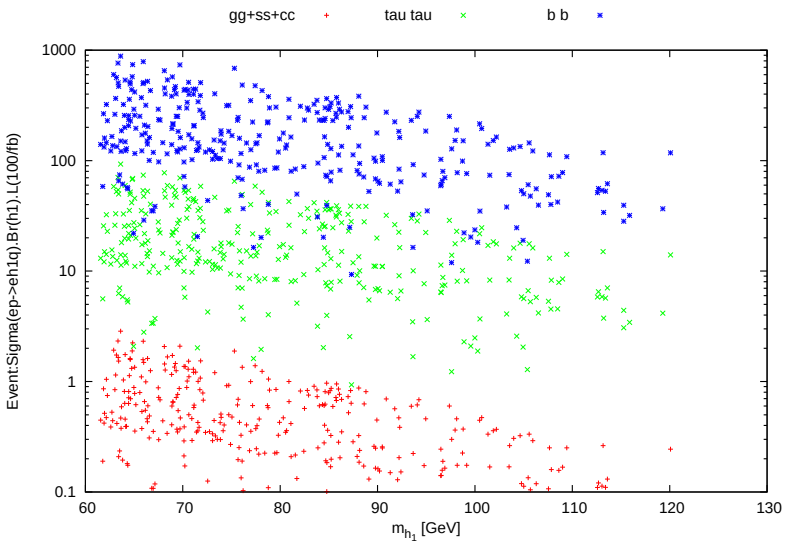
NMSSM: Higgs masses and h_2–SM scenario

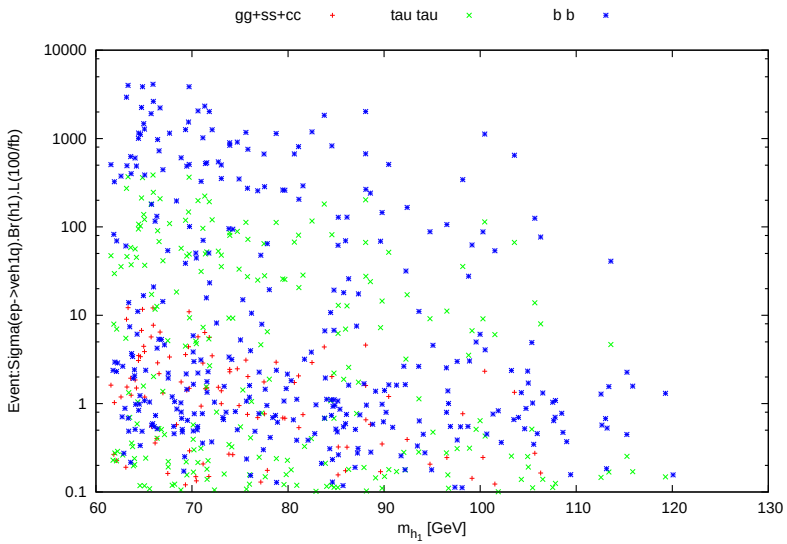




[With all Higgs constraints: masses, couplings]

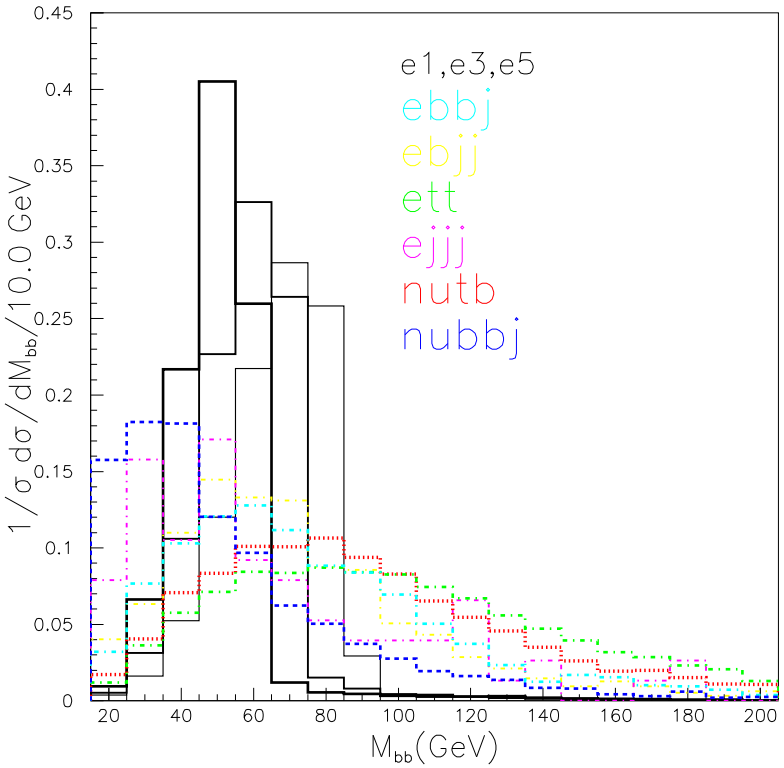
Event Rates in NMSSM

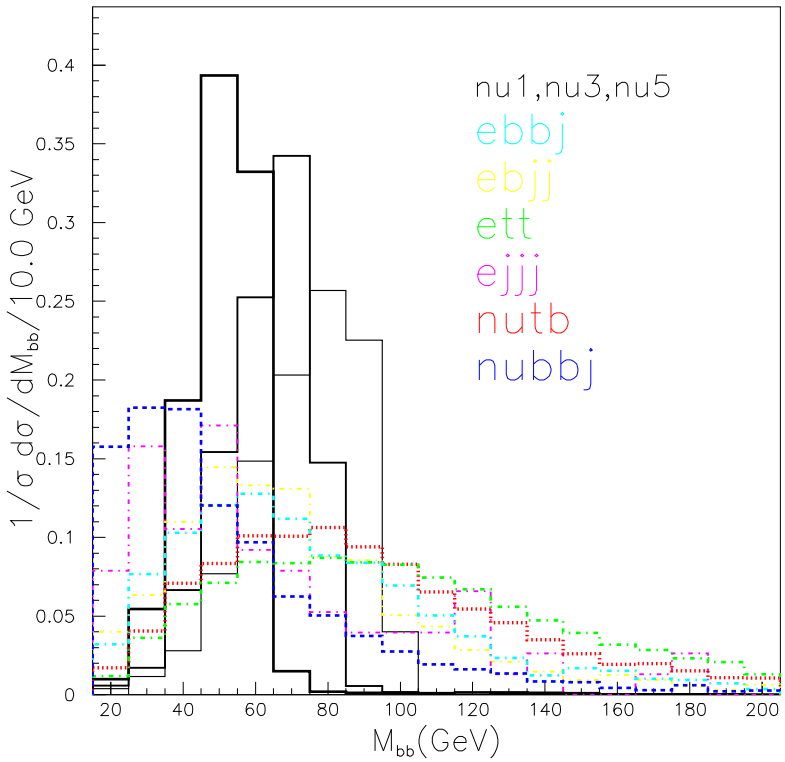




[e(ν)-channel: Neutral (Charged) current rate is smaller(larger)]

NMSSM: M_{bb} in electron and MET channels

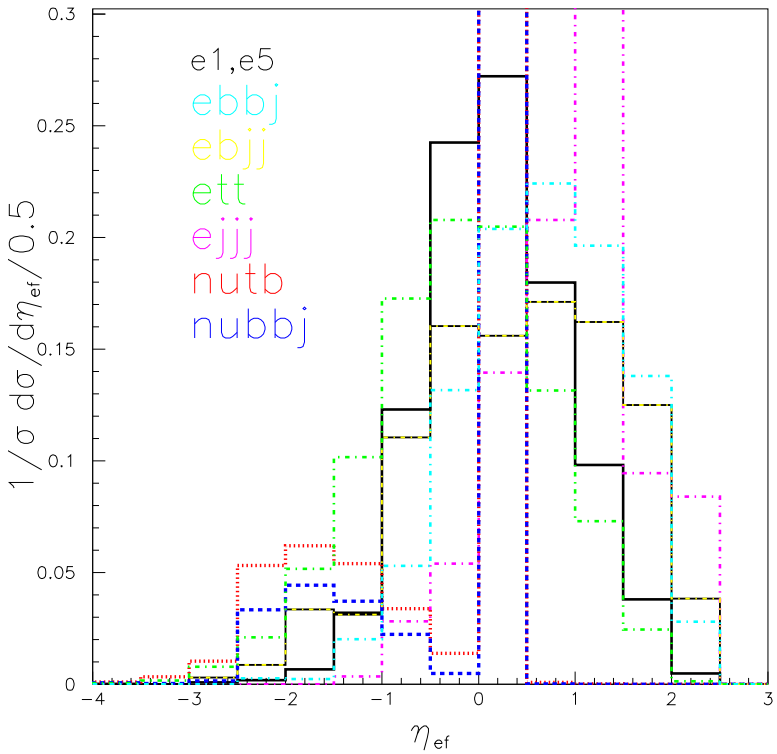


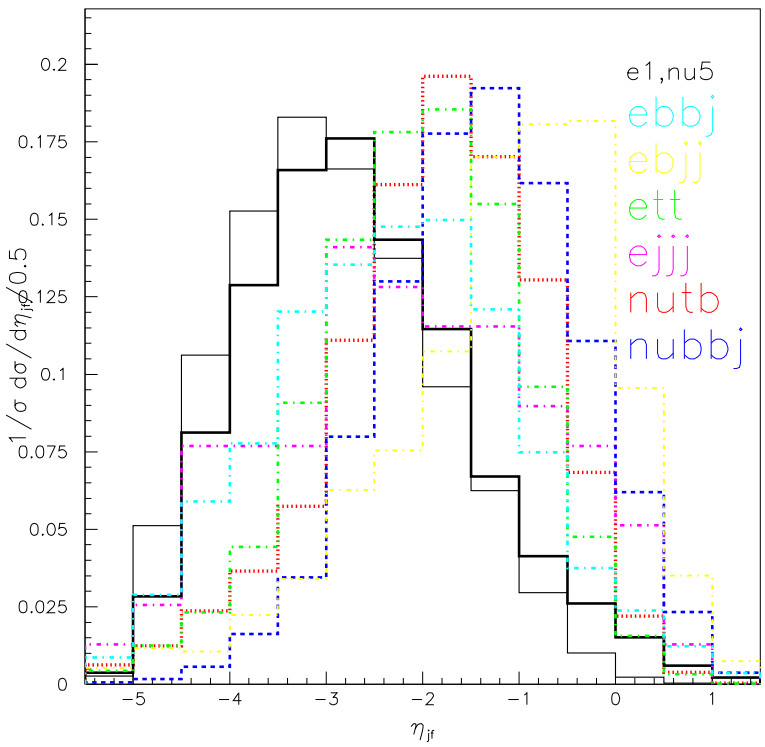


[Reconstruction of Higgs mass]

[2HDM:SPD, J. Hernández-Sánchez, S. Moretti, A. Rosado and R. Xoxocotzi [arXiv:1503.01464,PRD94(055003)2016]]

NMSSM: Forward rapidity: lepton and jet





[Opposite hemisphere: Rapidity Gap between lepton-jet (e-channel)]

NMSSM: Electron channel

m_h	RawEvt	3j(P_T,η) 15,5.5	1l(P_T,η) 15,3.0	2b($\epsilon_{b,c}$) 0.5,0.1	$M_{bb} - M_{h_1}$ +5,-15	η_{j_f} $[-5.5 : -0.5]$	$n_j n_l$ < 0	M_{bbj_f} >190	H_T=$\sum \lvert Pt_j \rvert$ >100	$\lvert \vec{H}_T \rvert$ >50	$\mathcal{S}$
e1,63.59	882.4	351.2	330.0	45.3	24.5	23.9	12.8	6.3	6.0	2.2	0.40(1.3)
$ebbj$	2688390.0	176102.0	135388.5	15530.5	3759.5	3461.2	2655.6	343.1	179.0	29.8	
$ebjj$	330834.0	31317.5	23381.6	575.6	146.4	110.8	74.4	3.3	2.5	0.8	
$et\bar{t}$	1425.5	1313.8	1136.9	131.8	20.2	19.9	7.9	0.4	0.4	0.2	
$ejjj$	37224100.0	4943049.0	3940097.5	8862.8	1611.4	966.9	805.7	161.1	0.0	0.0	B=30.8
νbbj	21385.4	4040.5	112.0	10.9	2.2	1.8	0.0	0.0	0.0	0.0	
νbjj	4077.8	985.1	13.3	0.4	0.1	0.1	0.0	0.0	0.0	0.0	
νtb	84395.2	51227.5	3848.3	405.4	73.3	70.6	0.7	0.0	0.0	0.0	
νjjj	3870920.0	718974.7	1675.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
e2,70.59	512.1	219.2	206.2	28.4	13.6	13.2	7.3	3.8	3.6	1.3	0.33(1.0)
e3,75.29	685.0	310.1	291.6	42.0	18.2	17.9	10.0	4.9	4.7	1.5	0.38(1.2)
e4,82.24	433.8	210.9	198.6	28.0	10.8	10.6	6.2	3.3	3.1	1.1	0.28(0.9)
e5,88.07	383.2	198.0	186.2	27.2	9.5	9.3	5.2	2.6	2.6	0.83	0.12(0.4)

Optimization: $\eta_l(1.0, 2.5, 0.1)$ up; $\eta_l(-2.5, -1.0, 0.1)$ down; $\Delta\eta_{jl}$ $(0.0, 1.5, 0.1)$ up; $\Delta\eta_{jl}$ in $(-6.0, -3.0, 0.1)$ down;

$m_{\phi j}$: [80,180,10] ;H_T^j: [70,140,10] ;$|\vec{H}_T^j|$: [30,60,10]

BP,m_h	η_l,$\Delta\eta_{jl}$,$m_{\phi j}$,H_T,$\vec{H}_T$	S	B	$\mathcal{S}$	η_l,$\Delta\eta_{jl}$,$m_{\phi j}$,H_T, $\vec{H}_T$	S	B	$\mathcal{S}$
e1, 63.59	$(1.0, -1.0), (0.0, -4.3), 180, 130, 60$	4.9	162.3	0.38(1.2)	$(1.6, -2.5), (0.3, -6.0), 100, 140, 30$	12.8	412.7	0.63(1.99)
e2,70.59	$(1.0, -1.0), (0.0, -3.0), 180, 140, 60$	2.7	1.3	2.36(7.5)	$(1.1, -2.5), (0.2, -5.7), 90, 90, 30$	10.1	1295.3	0.28(0.89)
e3,75.29	$(1.0, -2.5), (0.4, -3.4), 180, 140, 60$	3.1	1.5	2.53(8.0)	$(1.0, -2.1), (0.4, -6.0), 120, 110, 30$	11.6	565.2	0.49(1.54)
e4, 82.24	$(1.0, -1.4), (0.0, -3.4), 180, 140, 60$	1.6	0.6	2.09(6.6)	$(1.0, -2.1), (0.1, -3.4), 110, 140, 30$	4.1	154.1	0.32(1.0)
e5,88.07	$(1.0, -1.8), (0.0, -3.0), 180, 140, 60$	1.3	2.4	0.85(2.7)	$(1.3, -2.1), (0.1, -5.9), 150, 140, 30$	4.8	340.0	0.26(0.82)

[Mass, Cross-section interplay: Optimization enhances the Significances]

NMSSM: MET channel

m_h	RawEvt	3j(P_T,η) 15,5.5	0l(P_T,η) 15,3.0	2b($\epsilon_{b,c}$) 0.5,0.1	$M_{bb} - M_{h_1}$ +5,-15	η_{j_f} $[-5.5 : -0.5]$	$\not{E}_T$ >15	M_{bbj_f} >210	H_T=$\sum\|Pt_j\|$ >100	$\|\vec{H}_T\|$ >50	$\mathcal{S}$
ν-1,65.93	4114.1	1540.7	1475.6	200.6	112.5	111.2	102.0	49.8	47.8	26.0	3.34(10.6)
νbbj	21385.4	4040.5	3928.5	244.7	43.0	33.1	32.1	5.3	5.2	4.1	
νbjj	4077.8	985.1	971.8	16.4	4.6	3.0	2.8	0.1	0.1	0.0	
νtb	84395.2	51227.5	47379.2	3671.2	709.1	661.3	598.4	27.7	26.3	12.5	
νjjj	3870920.0	718974.7	717299.2	722.2	173.3	144.4	144.4	28.9	28.9	28.9	B=60.5
$ebbj$	2688390.0	176148.3	40728.9	5302.1	1389.0	1254.6	507.8	149.4	104.5	14.9	
$ebjj$	330834.0	31317.5	7935.9	214.2	58.7	34.7	11.6	0.8	0.8	0.0	
$et\bar{t}$	1425.5	1313.8	176.9	21.7	3.0	3.0	2.5	0.1	0.1	0.1	
$ejjj$	37224100.0	4943049.0	1002951.5	3706.3	644.6	644.6	0.0	0.0	0.0	0.0	
ν-2,71.32	2323.5	917.2	879.1	123.5	61.4	60.9	55.8	27.3	26.1	14.2	1.84(5.8)
ν-3,83.77	1830.6	845.3	809.8	116.0	44.0	43.4	40.0	21.2	20.7	11.1	1.54(4.9)
ν-4,88.07	2018.0	975.7	932.1	133.8	47.0	46.5	42.8	23.9	23.5	12.6	1.75(5.5)
ν-5,100.47	1125.0	613.9	585.0	88.2	23.5	23.3	21.5	12.0	11.9	6.1	1.41(4.5)

Optimization: $\not{E}_T$: [10,40,5] ; $m_{\phi j}$: [80,180,10] ;H_T^j: [70,140,10] ;$|\vec{H}_T^j|$: [30,60,10]

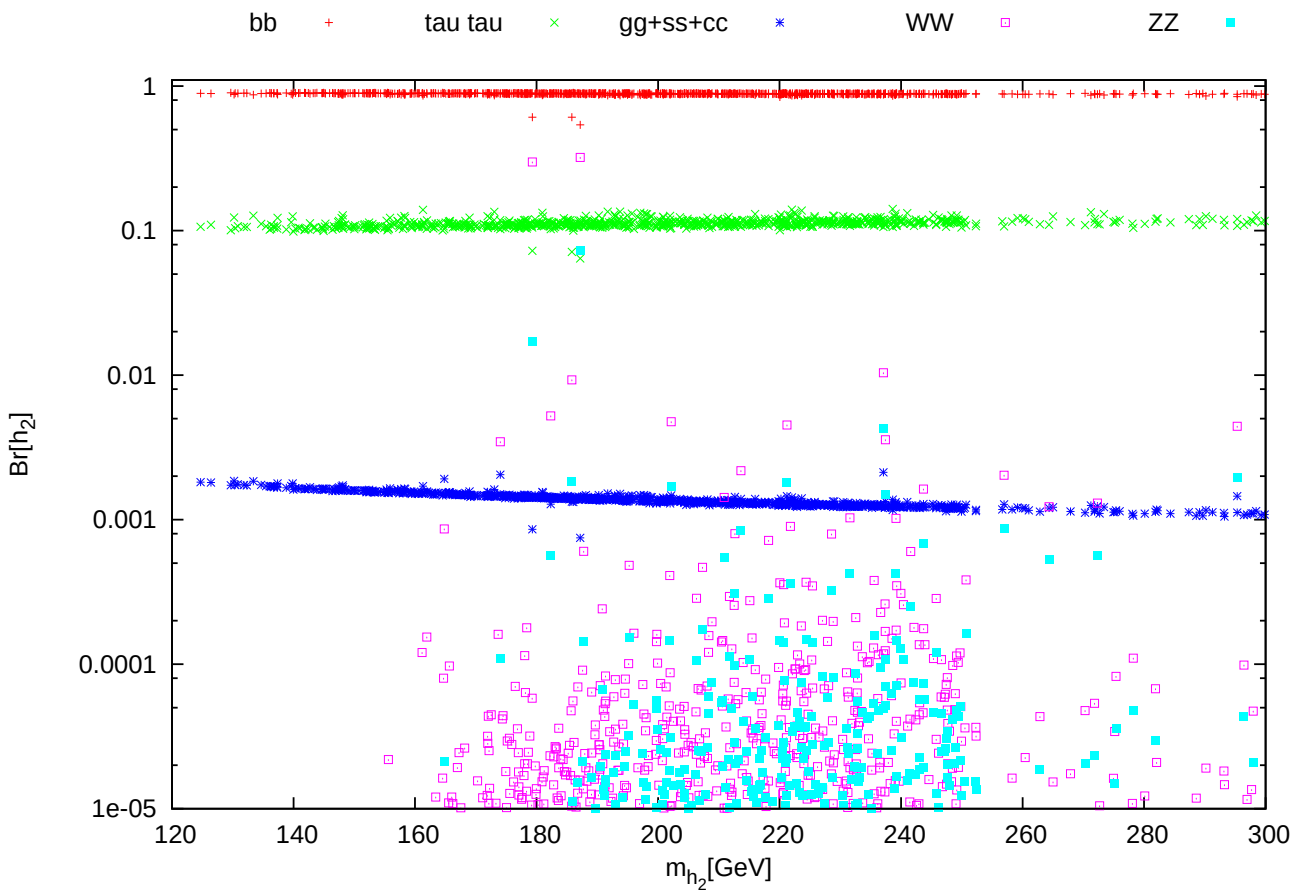
BP,m_h	$\not{E}_T$,$m_{\phi j}$,H_T,$\vec{H}_T$	S	B	$\mathcal{S}$	$\not{E}_T$,$m_{\phi j}$,H_T,$\vec{H}_T$	S	B	$\mathcal{S}$
ν1,65.93	35, 180, 70, 30	44.9	90.7	4.7(14.9)	10, 170, 70, 60	28.6	63.9	3.57(11.4)
ν2,71.32	35, 180, 70, 30	25.3	83.2	2.8(8.9)	40, 170, 70, 50	19.6	75.7	2.3(7.2)
ν3,83.77	30, 180, 70, 30	20.1	97.4	2.0(6.5)	30, 180, 90, 30	19.9	96.7	2.0(6.5)
ν4,88.07	30, 180, 90, 30	23.5	97.6	2.4(7.6)	35, 180, 120, 30	19.6	92.3	2.0(6.5)
ν5,100.47	30, 180, 100, 30	12.3	105.8	1.2(3.8)	25, 180, 100, 50	7.9	45.0	1.2(3.7)

eh_2q (h_1-SM); eA_1q; $\nu h^{\pm}q$ and adopting: TMVA

Analysis based on CPV Higgs: SPD, A. Datta and M. Drees, AIP Conf. Proc. 1078, 223 (2009) [arXiv:0809.2209] ;

SPD, M. Drees, arXiv:1010.3701, Phys.Rev.D83:035003,2011

NMSSM: h1-SM scenario

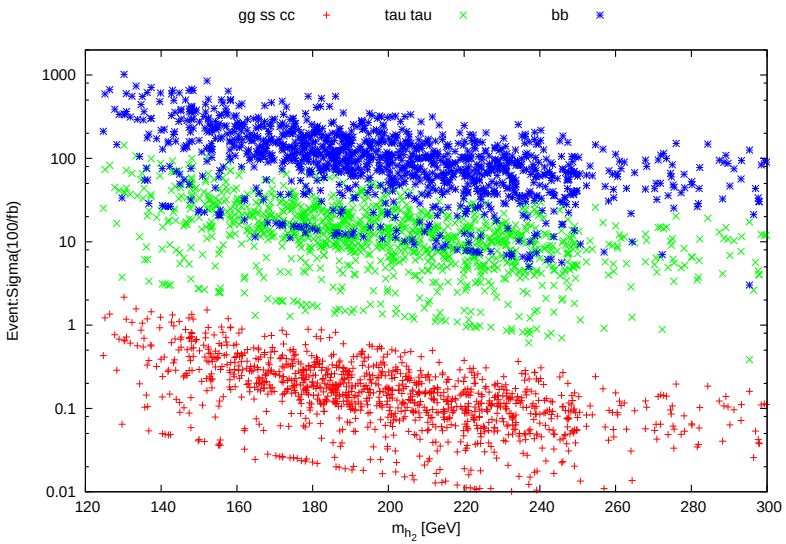


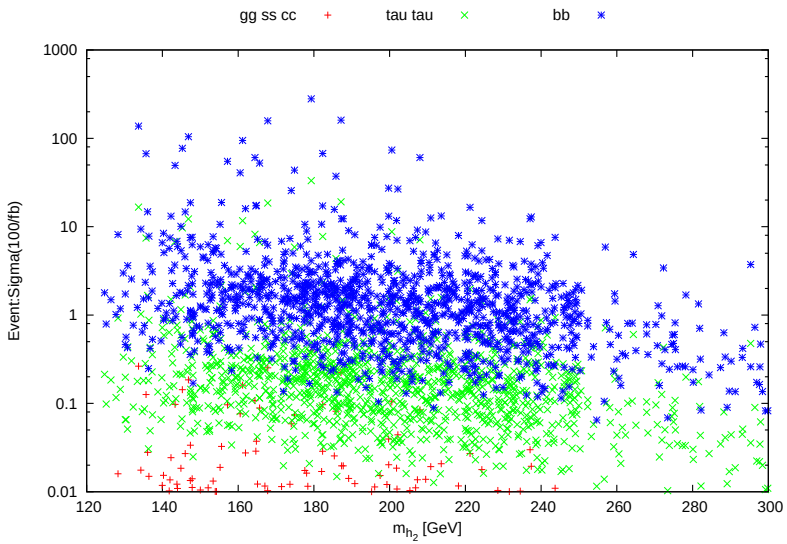
h2: If doublet type with WW and/or ZZ threshold open, then BRs enhancement

[h2: mostly Singlet type (with h1: Doublet) and $m_{h_2} > m_{h_1} = 125$ GeV, rate limited at LHeC]

Event Rates: eh_2q (Left), νh_2q (Right) at FCC-eh

[FCC-eh: e-=60 GeV with p=50 TeV]





[e-channel is larger than ν-channel: High p_T Gauge boson from $qq > V$, q-PDF is low]

Summary and Outlook

- NMSSM: MSSM + h + A ; Couplings, Brs changes considerably
- LSP: Singlet component, many more Dark Matter annihilation channels
- LHeC: 60 GeV + 7 TeV with 100/fb [FCC-eh: 60 GeV + 50 TeV]
- h2-SM: h1 is non-Std. (singlet) simple cut-based can probe upto 90 GeV
- h1-SM: h2 is non-Std. (singlet) also high mass only at FCC-eh
- Other Higgses (low mass) channels: eA_1q, $\nu h^{\pm}q$
- SUSY processes, e.g. $\sigma(\tilde{e}\tilde{t_1}t)$ only at FCC-eh: $\mathcal{O}(fb)$

[Thank you so much!]