CP-violating Higgs at Tevatron

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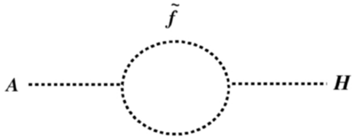
Outline

Explicit CP-violation and Higgs sector

The soft breaking parameters in MSSM can be complex.



$$\propto \frac{m_f^2}{m_{\tilde{f}_1}^2 - m_{\tilde{f}_2}^2} \Im m(A_f \mu)$$

$\Rightarrow$ Non vanishing CP-phases lead to mixing among CP-even and CP-odd Higgses.

References:

A. Pilaftsis, Phys.Rev.D58:096010,1998;
D. A. Demir, Phys.Rev.D60:055006,1999;
Choi etal. Phys.Lett.B481:57-66,2000;
Carena etal., Nucl.Phys.B659:145-178,2003 and etc.

Explicit CP-violation and Higgs sector contd.

$$(\phi_1, \phi_2, a)^T_\alpha = O_{\alpha i}(H_1, H_2, H_3)^T_i \,, \tag{1}$$

$$\mathcal{L}_{HVV} = g\, M_W \left(W^+_\mu W^{-\mu} + \frac{1}{2c^2_W} Z_\mu Z^\mu \right) \sum_i g_{H_i VV}\, H_i \,, \tag{2}$$

$$\begin{aligned} g_{H_i VV} &= c_\beta\, O_{\phi_1 i} + s_\beta\, O_{\phi_2 i} \,, \\ g_{H_i H_j Z} &= sign[det(O)]\, \varepsilon_{ijk}\, g_{H_k VV} \,, \\ g_{H_i H^+ W^-} &= c_\beta\, O_{\phi_2 i} - s_\beta\, O_{\phi_1 i} - i O_{ai} \,, \end{aligned} \tag{3}$$

$$\sum_{i=1}^{3} g^2_{H_i VV} = 1 \quad and \quad g^2_{H_i VV} + |g_{H_i H^+ W^-}|^2 = 1 \quad for\ each\ i \,. \tag{4}$$

CPX-scenario

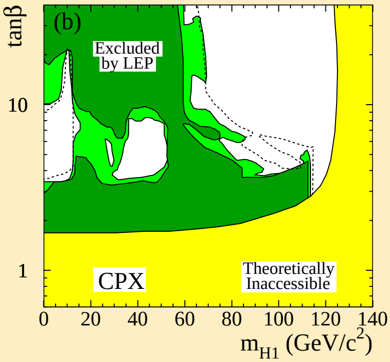
$$\mathcal{M}^2_{SP} \sim \frac{m_t^4}{v^2}\frac{Im\,(\mu A_t)}{32\pi^2\,M^2_{SUSY}}\left(1,\ \frac{|A_t|^2}{M^2_{SUSY}},\ \frac{|\mu|^2}{\tan\beta\,M^2_{SUSY}},\ \frac{2Re\,(\mu A_t)}{M^2_{SUSY}}\right), \tag{5}$$

$$\begin{aligned} \widetilde{M}_Q &= \widetilde{M}_t = \widetilde{M}_b = M_{SUSY} = 500\,GeV, \qquad \mu = 4M_{SUSY}, \\ |A_t| &= |A_b| = 2M_{SUSY}, \qquad arg(A_t) = arg(A_b) = 90^\circ, \\ |m_{\tilde{g}}| &= 1\ TeV, \qquad arg(m_{\tilde{g}}) = 90^\circ, \end{aligned} \tag{6}$$

Recent work similar to our study:

Carena etal., arXiv:0712.2466 [hep-ph];
Bandyopadhyay etal., arXiv:0710.3016 [hep-ph]

LEP allowed region for m_t=174.3 GeV



Ref: hep-ex/0602042

$\Rightarrow$ $e^+e^- \rightarrow H_1 Z / H_1 H_2$, $g_{H_1 ZZ}$ is suppressed for maximal CP-violation.

$\Rightarrow$ H_1 decay dominantly into $b\bar{b}$ mode.

$\Rightarrow$ Allowed regions shrink if m_t decreases.

Numerical Analysis

- Tevatron Run-II: $\sqrt{s}$ =1.96TeV, Q= $\sqrt{\hat{s}}$ and CTEQ5L PDF
- CPsuperH: Spectrum and Couplings;
  Refs: hep-ph/0307377 and arXiv:0712.2360 [hep-ph],(also FeynHiggs);
- Pythia 6.408: Signal with SLHA input file;
- MadGraph/MadEvent v4.2.8 :SM backgrounds;
- ISR/FSR, Hadronization and Fragmentation ;
- Gaussian smearing of jet and lepton;
- PYCELL Granularity: $|\eta| \leq$ 3.6, $\delta\eta$=.16 ,$\delta\phi$=0.098;
- ΔR=0.4;
- m_t=172.6 GeV;

Signature

$p\bar{p} \rightarrow WH_2 \rightarrow \ell\nu_\ell H_1 H_1 \rightarrow \ell\nu_\ell b\bar{b}b\bar{b}$:

$\ell + 4 - jets + \not{E}_T$, where $\ell = e \; or \; \mu$

$$C_{211_{4b}} = \sigma_{SM}(p\bar{p} \rightarrow WH_2) g^2_{h2VV} Br(H_2 \rightarrow H_1 H_1) \times Br(H_1 \rightarrow b\bar{b})^2 2Br(W \rightarrow e\nu_e);$$

W $\rightarrow W^\pm$ and 2 is for $\ell = e \; and \; \mu$.

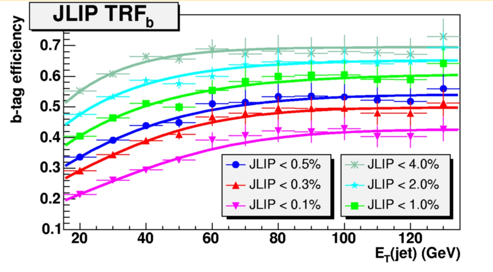
CPX-Benchmark points

CPX	$m_{H^\pm}$	$tan\beta$	m_{H_1}	m_{H_2}	σ_{SM}(pb)	$C_{211_{4b}}(pb)$
1	132.0	4.0	36.0	101.6	108.5	21.6
2	141.0	3.4	40.5	104.4	97.9	12.3
3	135.5	4.2	51.1	103.8	102.2	14.6
4	131.5	4.4	44.2	102.4	106.6	19.9
5	128.5	5.8	51.5	104.0	99.3	9.0

Selection

- S1: $N_{jet} \geq 4$.
- S2: $E_T^{j1,j2,j3,j4} > 10.0$ GeV and $|\eta^{j1,j2,j3,j4}| < 3.0$.
- S3: $N_{lepton} \geq 1$, $E_T^l > 15.0$ GeV and $|\eta^l| < 2.0$.
- S4: $\not{E}_T > 15$ GeV where $\not{E}_T$ from visible object.
- S5a(b):$N_{btag} \geq 2(3)$; $|\eta^{b-jet}| < 1.2$,$\Delta R(j, B - hadron) \leq 0.2$.
- S6: $H_T = \not{E}_T + \sum_{obj} E_T \leq 300 GeV$.
- S7a(b): $\Delta\phi(b1, b2) \leq 2.61(2.09)$.
- S8: $N_{obj} = N_{lepton} + N_{jet} \leq 6$.

b-tagging



Refs: K. Hanagaki, FERMILAB-CONF-05-647-E; C. Neu, FERMILAB-CONF-06-162-E; T. Wright, arxiv: 0707.0712[hep-ex];

$\Rightarrow$ E_T^{jet} dependent b-tagging efficiencies.

$\Rightarrow$ Scale $\approx$ 1 with CDF $t\bar{t}$ analysis, Phys.Rev.D71:052003,2005.

Response

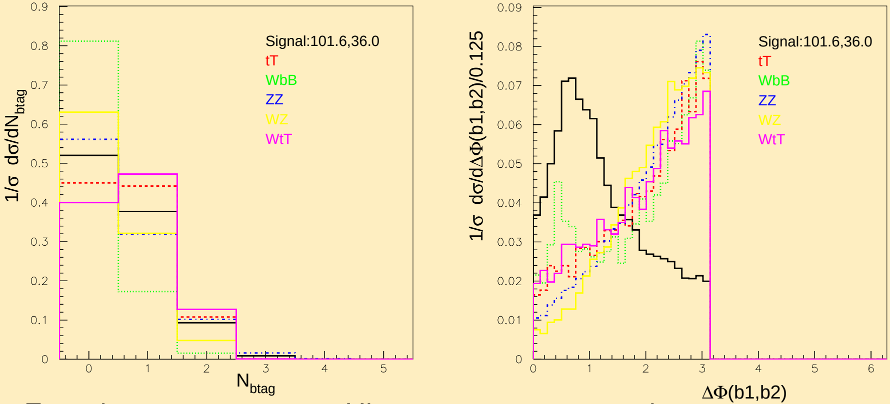
Efficiencies						
m_{H_2}, m_{H_1}	C1-4	I5a	I5b	I7a	I7b	I6
101.6,36.0	.155	.102	.009	.914	.810	.937
104.4,40.5	.172	.105	.009	.923	.832	.950
103.8,51.1	.201	.102	.010	.929	.851	.937
102.4,44.2	.174	.097	.008	.935	.855	.938
104.0,51.5	.202	.103	.010	.930	.849	.937
$t\bar{t}$	.511	.108	.00021	.705	.481	.462
$Wb\bar{b}$	.014	.015	.00002	.694	.502	.986
ZZ	.026	.118	.01735	.679	.434	.945
WZ	.054	.048	.00008	.696	.432	.968
$Wt\bar{t}$	.619	.127	.00062	.738	.530	.102

$\Rightarrow$ I5a(b) $\rightarrow$ 2(3)b-tag;I7a(b) $\rightarrow \Delta\phi(b1, b2) \leq 2.61(2.09)$.

$\Rightarrow$ 3-btag might be helpful, however, mis-tagging required.

$\Rightarrow \Delta\phi(b1, b2) \leq 2.09 \rightarrow$ Signal(Backgd) $\approx$ 10(20-25)% .

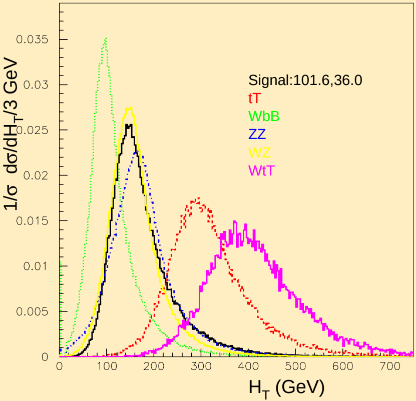
N_{btag} and $\Delta\phi(b1, b2)$

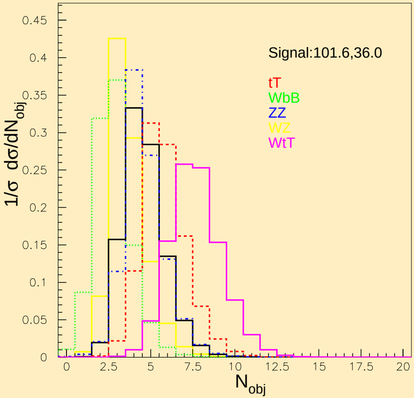


⇒ For 3-btag, more correct Higgs mass reconstruction.

⇒ $\Delta\phi(b1, b2)$ is the crucial discriminator.

H_T and N_{obj}





⇒ More strict Veto on H_T and also on N_{obj}.

Events for $\int \mathcal{L} dt = 10 fb^{-1}$

Events								
m_{H_2}, m_{H_1}	C1	C2	C3	C4	C5a	C6	C7b	C8
101.6,36.0	126.0	68.0	36.5	33.5	5.6	3.7	3.3	2.7
104.4,40.5	76.1	42.2	23.1	21.2	3.4	2.3	2.1	1.7
103.8,51.1	99.7	57.1	32.0	29.5	4.7	3.3	3.0	2.4
102.4,44.2	126.5	68.6	37.9	34.7	5.4	3.6	3.3	2.7
104.0,51.5	61.9	35.6	19.9	18.3	2.9	2.0	1.8	1.4
$t\bar{t}/100$	154	141	94	88	9.7	2.2	1.6	1.3
$Wb\bar{b}/100$	83.8	32.2	12.4	11.5	.75	.39	.29	.27
$ZZ/10$	216	162	27.4	10.5	.73	.35	.2	.16
WZ	202	106	42	39	2.2	1.3	.9	.7
$Wt\bar{t}$	8.1	8.0	5.4	5.0	.6	.03	.02	.01

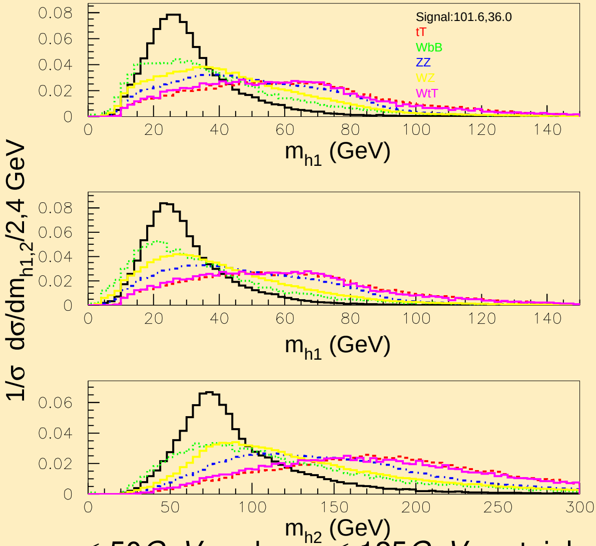
$\Rightarrow$ Very poor Significance ≈ 0.22.

$\Rightarrow$ NLO factor (≈ 1.3) Significance ≈ 0.24.

$\Rightarrow$ Veto on S8 improve the correct m_{H_1} and m_{H_2} reconstruction.

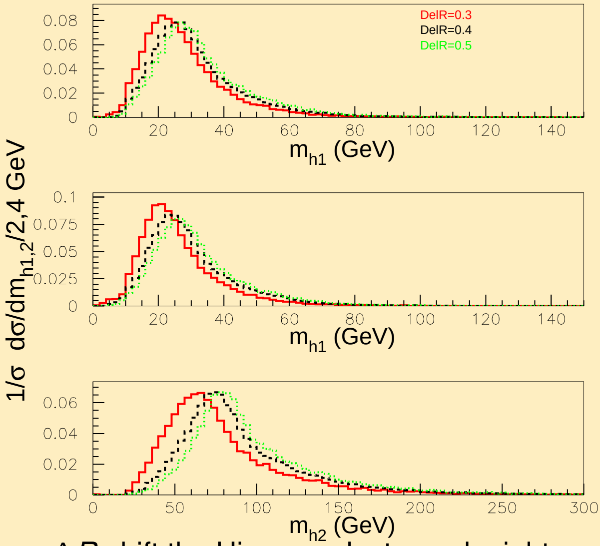
Mass reconstruction

⇒ Pair of jets → $|M_{ab} - M_{cd}|$ minimum and sum ≥ 20 GeV;



⇒ Veto $m_{H_1} \leq 50 GeV$ and $m_{H_2} \leq 125 GeV$ certainly help.

Mass reconstruction for different ΔR



$\Rightarrow$ Larger ΔR shift the Higgs peaks towards right.

LHC Selections and Efficiencies (preliminary)

- S2: $E_T^j > 25.0$ GeV,$|\eta^j| < 4.5$ and $E_T^{js} \leq 100, 80, 70, 60$ GeV .
- S3: $N_{lepton} \geq 1$, $E_T^l > 20.0$ GeV and $|\eta^l| < 2.5$.
- S5: $N_{btag} \geq 2$; $|\eta^{b-jet}| < 2.5$,$\Delta R(j, B - hadron) \leq 0.2$.
- S6: $H_T = \not{E}_T + \sum_{obj} E_T \leq 250 GeV$.
- S7: $\Delta\phi(b1, b2) \leq 2.09$.
- S8: $N_{obj} \leq 6$; S1 and S4 are same as Tevatron

Efficiencies								
m_{H_2}, m_{H_1}	S1	S2	S3	S4	S5	S6	S7	C8
101.6,36.0	.40	.03	.62	.91	.065	.80	.92	.0001
$t\bar{t}$	.89	.20	.68	.94	.133	.15	.51	.0005

⇒ Signal: 5 and $t\bar{t}$: 8580 for $\int \mathcal{L}dt = 100 fb^{-1}$.
⇒ Veto on Jets E_T, 3b-tag and N_{obj}.
work in progress with M. Maity.

Summary and Outlook:

- LEP allowed lighter Higgs masses at Tevatron.
- $p\bar{p} \to WH_2 \to \ell + 4 - jets(2b - jets) + \not{E}_T$.
- E_T^{jet} dependent b-tagging efficiencies.
- Selection efficiencies are very poor, so the Significance.
- 3b-tagging will improve the Signal, however, mis-tagging is required.
- $\Delta\phi(b1, b2)$ is one of the crucial discriminator.
- More stringent veto on H_T and N_{obj} certainly improve the Significance.
- m_{H_1} and m_{H_2} peaks are very prominent over Backgrounds.
- LHC: preliminary, Jet Veto, 3b-tag, N_{obj} and overall optimization.
- Other decay modes (e.g., $H_1 \to \tau\tau$).

Cross-sections

cross-section in pb		
Process	σ	BR
Signal TeV	0.0216	1.0
$t\bar{t}$	5.0	0.34
$Wb\bar{b}$	36.0	0.21
ZZ	0.9	0.44
WZ	2.16	0.03
$Wt\bar{t}$	0.006	0.13
Signal LHC	0.39	1.0
$t\bar{t}$	500.0	0.34