Prospects for observing CP-violating Higgs at Tevatron and LHC

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Outline

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   - Higgs searches at LEP
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3. Summary

CP-conserving Higgs sector

The Higgs sector of the MSSM consists of two doublets:

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} ; \quad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} . \tag{1}$$

$$H_1^0 = \frac{1}{\sqrt{2}}(\phi_1 - i a_1) , \quad H_2^0 = \frac{1}{\sqrt{2}}(\phi_2 + i a_2)\Omega \tag{2}$$

⇒ $\phi_{1,2}$ (CP-even) and $a_{1,2}$ (CP-odd).
⇒ After EWSB , $\langle\phi_1\rangle = v\cos\beta$ and $\langle\phi_2\rangle = v\sin\beta$
⇒2 charged and 3 neutral.

Mass states

⇒1 CP-odd state, $A = -a_1 \sin\beta + a_2 \cos\beta$,
⇒ 2 CP-even , h and H mixes, α:

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_2 \\ \phi_1 \end{pmatrix} . \tag{3}$$

Explicit CP-violation and Higgs sector

Superpotential, $W \supset \mu \hat{H}_2 \cdot \hat{H}_1$, and the soft-SUSY breaking terms:

$$
\begin{aligned}
-\mathcal{L}_{\rm soft} \supset\ & \frac{1}{2}(M_3\, \widetilde{g}\widetilde{g} + M_2\, \widetilde{W}\widetilde{W} + M_1\, \widetilde{B}\widetilde{B} + \mathrm{h.c.}) \\
& + \widetilde{Q}^\dagger\, \mathbf{M}^2_{\widetilde{\mathbf{Q}}}\, \widetilde{Q} + \widetilde{L}^\dagger\, \mathbf{M}^2_{\widetilde{\mathbf{L}}}\, \widetilde{L} + \widetilde{u}^*_R\, \mathbf{M}^2_{\widetilde{\mathbf{u}}}\, \widetilde{u}_R + \widetilde{d}^*_R\, \mathbf{M}^2_{\widetilde{\mathbf{d}}}\, \widetilde{d}_R + \widetilde{e}^*_R\, \mathbf{M}^2_{\widetilde{\mathbf{e}}}\, \widetilde{e}_R \\
& + (\widetilde{u}^*_R\, \mathbf{A_u}\, \widetilde{Q}H_2 - \widetilde{d}^*_R\, \mathbf{A_d}\, \widetilde{Q}H_1 - \widetilde{e}^*_R\, \mathbf{A_e}\, \widetilde{L}H_1 + \mathrm{h.c.}) \\
& - (m^2_{12} H_1 H_2 + \mathrm{h.c.})\,. \qquad (4)
\end{aligned}
$$

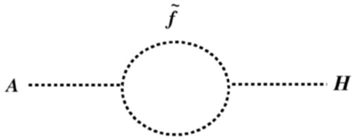
$\Rightarrow$ Physical observables depend on: $\mathrm{Arg}(M_i \mu m^2_{12})$ and $\mathrm{Arg}(A_f \mu m^2_{12})$

[Dugan, Grinstein,Hall]

$\Rightarrow$ Higgs sector: most relevant 3rd generation: top and bottom

Explicit CP-violation and Higgs sector contd.

⇒ The complex soft breaking parameters through loop:



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

⇒ Non vanishing CP-phases lead to mixing among CP-even and CP-odd Higgses.

[Pilaftsis, Demir, Choi etal.,Carena etal., Bechtle, recently Lee: hep-ph/0808.2014]

Explicit CP-violation and Higgs sector contd.

$$(\phi_1, \phi_2, a)^T_\alpha = O_{\alpha i}(H_1, H_2, H_3)^T_i \,, \tag{5}$$

$$\mathcal{L}_{HVV} = g\, M_W \left(W^+_\mu W^{-\mu} + \frac{1}{2c_W^2} Z_\mu Z^\mu \right) \sum_i g_{H_iVV}\, H_i \,, \tag{6}$$

$$\begin{aligned} g_{H_iVV} &= c_\beta\, O_{\phi_1 i} + s_\beta\, O_{\phi_2 i} \,, \\ g_{H_iH_jZ} &= sign[det(O)]\; \varepsilon_{ijk}\, g_{H_kVV} \,, \\ g_{H_iH^+W^-} &= c_\beta\, O_{\phi_2 i} - s_\beta\, O_{\phi_1 i} - iO_{ai} \,, \end{aligned} \tag{7}$$

$$\sum_{i=1}^{3} g^2_{H_iVV} = 1 \quad and \quad g^2_{H_iVV} + |g_{H_iH^+W^-}|^2 = 1 \quad for\ each\ i \,. \tag{8}$$

⇒ Neutral Higgs do not have any definite CP-parity

⇒ Couplings to SM and SUSY particles modified significantly

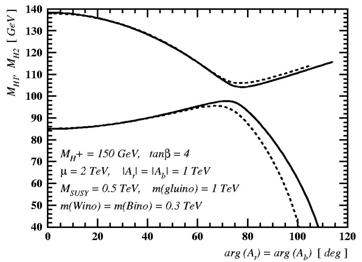
Benchmark: CPX-scenario

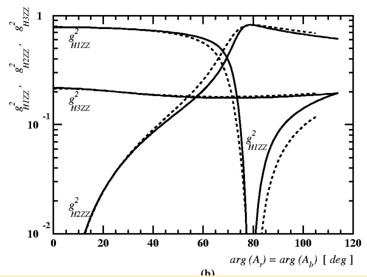
$$\mathcal{M}^2_{SP} \sim \frac{m_t^4}{v^2} \frac{Im\,(\mu A_t)}{32\pi^2\, M^2_{SUSY}}\,, \tag{9}$$

$$\begin{aligned} \widetilde{M}_Q &= \widetilde{M}_t = \widetilde{M}_b = M_{SUSY} = 500\,GeV, \qquad \mu = 4M_{SUSY}\,, \\ |A_t| &= |A_b| = 2M_{SUSY}\,, \qquad arg(A_t) = arg(A_b) = 90^\circ\,, \\ |m_{\tilde{g}}| &= 1\ TeV\,, \qquad arg(m_{\tilde{g}}) = 90^\circ\,, \end{aligned} \tag{10}$$

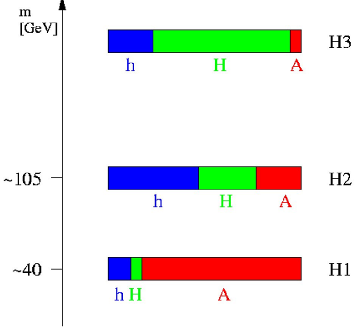
$\Rightarrow$ Maximal CP-violation occurs in the Higgs sectors.
$\Rightarrow$ Masses(H_i) and $H_i VV$ couplings changes appreciably.

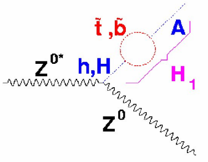
Higgs masses (H_i) and $H_i VV$ couplings





⇒ CP violation affects appreaciably: masses, couplings etc.
Fig. from Carena etal. NPB586 (2000) 92.
⇒ $H_2 \rightarrow H_1 H_1$ is possible
⇒ σ_{WH_2} is large





Production

[Bechtle's talk]

Masses and compositions

⇒ We are interested to study the CPV from production and decay;

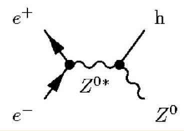
⇒ So the sum rules are important.

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

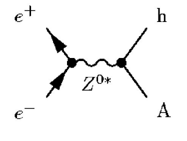
⇒ ZZh_1 low at LEP; thus at Hadron Colliders: ZZh_2, WWh_2 are relatively large

Higgs searches at LEP

⇒LEP combined; no Higgs evidence; LEP lower limit 114.6 GeV



$sin^2(\beta - \alpha)$ Higgsstrahlung



$cos^2(\beta - \alpha)$ Pair production

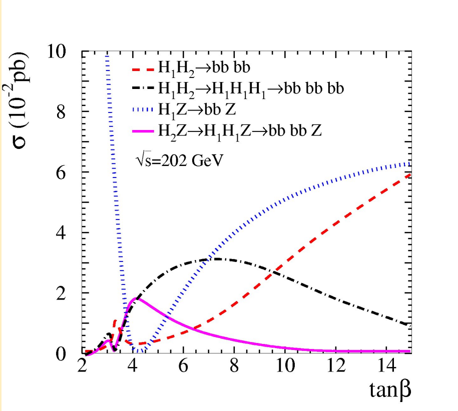
- Complementary and cover whole kinematical masses;
- low (high) tanβ Higgsstrahlung (Pair production) dominant;
- Upper bounds on σ on various Higgs like event topologies;
- Limits on CP-conserving MSSM-benchmarks.

From CP-violation: ⇒ $h_i Z$ all produced by Higgsstrahlung → complementary lost; h_2 and h_3 heavy

⇒ $h_i h_j (i \neq j)$ pair production

⇒ $m_{h_2} - m_{h_1}$ is large; $h_2 \rightarrow h_1 h_1$ with large BR.

Cross-section in different decay modes at LEP

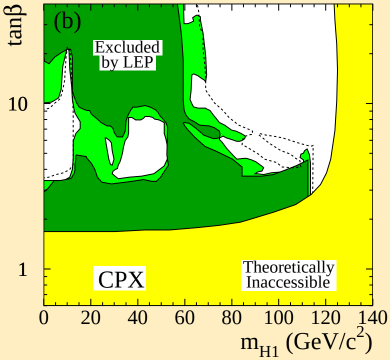


[hep-ex/0602042]

⇒ $\sqrt{s}$=202 GeV; m_{h_1}=35-45 GeV; m_t=175 GeV.

⇒ tan$\beta \approx 4 \rightarrow h_2$Z decay mode is dominant.

LEP allowed regions for m_t=174.3 GeV



[hep-ex/0602042]

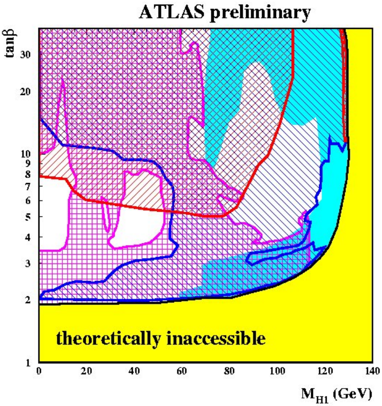
⇒ Intermediate tanβ: All low production;

h_1 CP-odd no Higgsstrhaulng; h_2 heavy; $h_2 \rightarrow h_1 h_1$

⇒ h_1 decay dominantly into $b\bar{b}$ mode.

⇒ Allowed regions shrink if m_t decreases. [HiggsBounds]

The LEP allowed regions at LHC



⇒ gg→ $H_i(\gamma\gamma, ZZ)$; $t\bar{t}H_i(b\bar{b})$; $b\bar{b}H_i(\mu\mu)$; WW→ $H_i(WW, \tau\tau)$, t$H^{\pm}$ for 300 fb^{-1}
[Schumacher, CPNSH, hep-ph/0608079, Carena etal NPB659(2003)145.]
⇒ LEP hole still exists

Signature

$p\bar{p}/pp \rightarrow Wh_2 \rightarrow \ell\nu_\ell h_1 h_1 \rightarrow \ell\nu_\ell b\bar{b}b\bar{b}$:
$\ell + 4 - jets + \not{E}_T$, where $\ell = e \; or \; \mu$

$$C_{211_{4b}} = \sigma_{SM}(p\bar{p}/pp \rightarrow Wh_2) g^2_{h2VV} Br(h_2 \rightarrow h_1 h_1) \times Br(h_1 \rightarrow b\bar{b})^2 2Br(W \rightarrow e\nu_e);$$

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

⇒ CPsuperH (one can also use FeynHiggs)
⇒ CPX-1: $tan\beta$,$m_{H^\pm}$: 4.02,131.8 $\rightarrow m_{h_1}, m_{h_2}$:36,101.6 lower
⇒ CPX-2: $tan\beta$,$m_{H^\pm}$: 4.39,131.8 $\rightarrow m_{h_1}, m_{h_2}$:45,102.6 upper
⇒ Model-independent:m_{h_1}, m_{h_2}:30, 90-130; model independent searches and subdominant CP-odd component and also WW^*/ZZ^* dominant → Br($h_2 \rightarrow h_1 h_1$) reduced.
Other models: recently [Ham etal., Chang etal.,Ellwanger etal.]
⇒ Carena etal. 0712.2466 [hep-ph] in parton level.
⇒ We performed event generator level simulation using Pythia.

Cross-sections at Tevatron (1.96 TeV) and LHC(14 TeV)

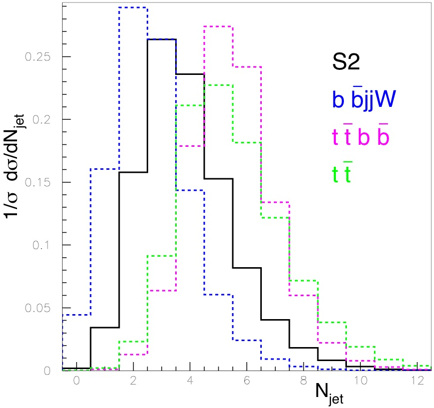
Proc	explicit	$j/\bar{j}$	σ(TeV) *fb*	σ(LHC)*fb*
S1	130,30	$b\bar{b}b\bar{b}$	89.9	1091.1
S2	120,30	$b\bar{b}b\bar{b}$	121.7	1401.5
S3	110,30	$b\bar{b}b\bar{b}$	162.5	1850.8
S4	100,30	$b\bar{b}b\bar{b}$	223.5	2472.0
S5	90,30	$b\bar{b}b\bar{b}$	315.1	3317.4
CPX-1	101.6,36.	$b\bar{b}b\bar{b}$	212.0	2367.1
CPX-2	102.6,45.	$b\bar{b}b\bar{b}$	206.5	2283.8
p1	$t\bar{t}\rightarrow b\bar{b}\ W^+\ W^-$	$b\bar{b}q\bar{q}'$	5000.0	500000.0
p2	$b\bar{b}b\bar{b}\ W^\pm$	$b\bar{b}b\bar{b}$	14.5	156.0
p3*	$b\bar{b}bj\ W^\pm$, $\bar{b}b\bar{b}j\ W^\pm$	$udscg$	0.05	10.7
p4	$b\bar{b}cj\ W^-$, $b\bar{b}\bar{c}j\ W^+$	$udsg$	151.6	33813.7
p5	$b\bar{b}c\bar{c}\ W^\pm$	$b\bar{b}c\bar{c}$	51.4	520.5
p6	$b\bar{b}jj\ W^\pm$	$udsg$	5985.3	247534.0
p7*	$bjjj\ W^\pm$,$\bar{b}jjj\ W^\pm$	$udcsg$	16.5	3324.6
p8	$jjjj\ W^\pm$	$udcsg$	447870.0	29252000.0
p9	$t\bar{t}b\bar{b}\rightarrow b\bar{b}b\bar{b}W^+\ W^-$	$b\bar{b}b\bar{b}q\bar{q}'$	8.9	2988.8
p10	$t\bar{t}c\bar{c}\rightarrow b\bar{b}c\bar{c}W^+\ W^-$	$b\bar{b}c\bar{c}q\bar{q}'$	16.0	4862.5
p8.1	$gggg\ W^\pm$	$gggg$	93385.8	918552.0
p8.2	$gggj\ W^\pm$	$udcs$	206421.0	19678100.0
p8.n	...	...	...	...
p8.9	$jjjj\ W^\pm$	uds	2666.3	99443.8
S-p8	$jjjj\ W^\pm$	$udcsg$	443627.1	27586307.6
ToB			450355.5	28374655.9

$\Rightarrow$ Q= $\sqrt{\hat{s}}$ and CTEQ5L PDF

$\Rightarrow$S(B) approx. 10(100) times at LHC compare to Tevatron

$\Rightarrow$Signal SLHA; Bgs(splitting): MadGraph/MadEvent $\rightarrow$ Pythia 6.408 for showering

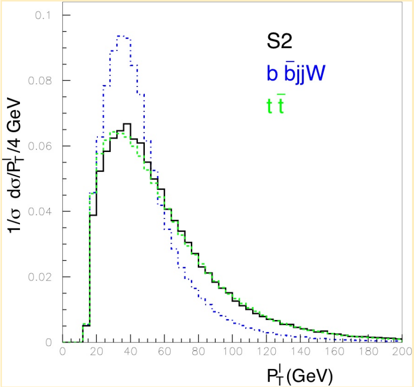
Events characteristics at LHC: Number of Jets

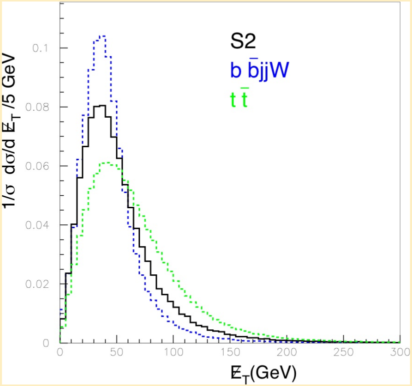


⇒ C1: $N_{\rm jet} \geq 4$, $E_T^{j=1-4} > 15.0$ and $|\eta^{j=1-4}| < 5.0$;

⇒ Basic Efficiencies and Higgs mass reconstruction

Lepton P_T and $\not{E}_T$ at LHC



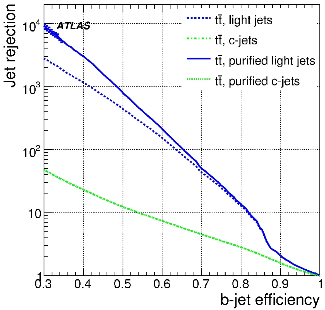


⇒ C2: $N_{\text{lepton}} \geq 1$, $E_T^{\ell} > 20.0$ and $|\eta^{\ell}| < 2.5$;

⇒ C3: $\not{E}_T > 20$ from all visible objects

b-tagging and mistagging at LHC

⇒Identification of jets/hadrons which contains a b-quark.



[ATLAS arXiv:0901.0512 [hep-ex]]

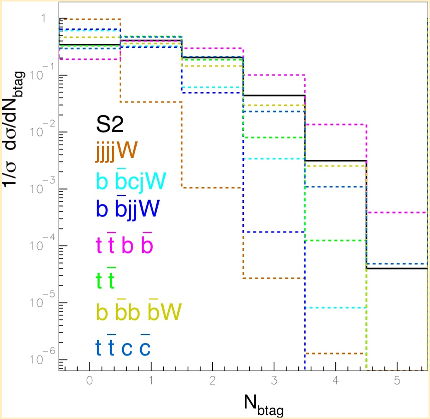
⇒Matching:ΔR(j-q) and Et ratio: identify the flavor of the jets(b,c,q)

⇒For $\epsilon_b \approx 50\% \rightarrow \epsilon_c \approx 10\%$ and $\epsilon_j \approx 0.25\%$

Tagging and Mistagging at LHC

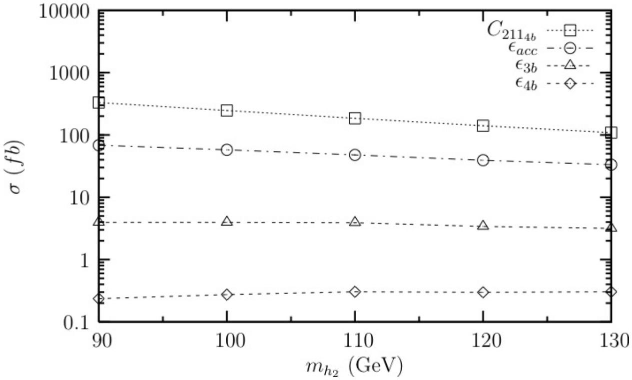
⇒ C4a(b): $|\eta^{b-jet}| < 2.5$, $\Delta R(j, B) \leq 0.2$;

⇒ Br is included, B and C-hadron counting imposed to avoid doubling among different Bgs.



⇒ $N_{btag} \geq 3$ (4);

Signal Cross-section at LHC



⇒ ϵ_{acc}: jet ⊗ lepton ⊗ MET;

⇒ 4b too low so use 3b-tagging (however, statistics is not large)

⇒ 3b-taggable → find flavor of the jet using matching and weight accordingly

Overall Events: using Tagging probability

$\Rightarrow$ C6: $N_{\rm jet} = 4(t\bar{t}, t\bar{t}b\bar{b}, t\bar{t}c\bar{c}$ more supression) less combinatorics.

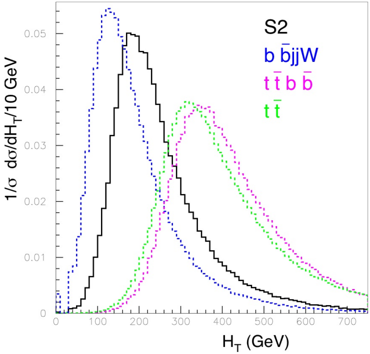
$\Rightarrow$ Effective cross-section (EffC):
C6 $\otimes$ C2(lep) $\otimes$ 3b $\otimes$ B-hadron $\leq$ b-parton $\otimes$ C-hadron $\leq$ c-parton;

$\Rightarrow$ EffT: Used tagging probability; j-q matching: $N_{b_{taggable}} \geq 3$;

$\Rightarrow$ If the efficiencies are stablizied (for large sample MC events) then the two approaches agree.

$\Rightarrow$ If not stablizied, for low stat MC events, EffT is useful to increase the statistics virtually.

Mass scale: $H_T = \not{E}_T + \sum_{\ell,\mathrm{j}} E_T$



$\Rightarrow$ $H_T <$ 220 GeV approx. to m_{h_2} $<$140 GeV veto.

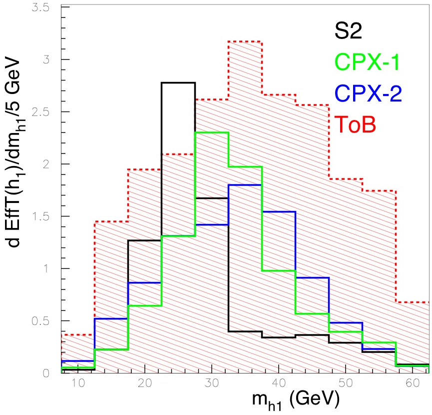
Events splitting: 4jW and subprocesses at the LHC

Proc	RawEvt	ϵ_{acc}	3b	EffC(h2,+h1)	EffT(h2,+h1)
p8	63301328.	4531109.	0.00	.000 (.000,.000)	4.34 (.336,.322)
p8.1	1987746.	98083.	0.00	.000(.000,.000)	.003(.001,.001)
p8.2	42583408.	2817659.	0.00	.000(.000,.000)	.360(.064,.062)
p8.3	13745078.	1235224.	0.00	.000(.000,.000)	.372(.070,.069)
p8.4	4896179.	434584.	0.00	.000(.000,.000)	3.26(.522,.510)
p8.5	110172.	12081.	0.00	.000(.000,.000)	.007(.001,.001)
p8.6	72009.	7587.	0.00	.000(.000,.000)	.088(.010,.010)
p8.7	32402.	3120.	1.56	.778(.000,.000)	.703(.108,.100)
p8.8	1019.	69.9	0.15	.112(.051,.051)	.056(.015,.014)
p8.9	215196.	24429.	0.00	.000(.000,.000)	.001(.000,.000)
p8.2.1	20128532.	1191931.	0.00	.000(.000,.000)	.036(.005,.005)
p8.2.2	4010779.	299075.	0.00	.000(.000,.000)	.008(.002,.002)
p8.2.3	10848067.	711286.	0.00	.000(.000,.000)	.021(.003,.003)
p8.2.4	3381185.	252290.	0.00	.000(.000,.000)	.007(.002,.002)
S-p8.2	38368563.	2454582.	0.00	.000(.000,.000)	.072(.012,.012)
p8.3.1	6817573.	741642.	0.00	.000(.000,.000)	.200(.048,.045)
p8.3.2	7195905.	554890.	0.00	.000(.000,.000)	.181(.034,.032)
S-p8.3	14013478.	1296532.	0.00	.000(.000,.000)	.381(.082,.077)
S-p8	59696764.	4331068.	1.71	.089(.051,.051)	4.57(.751,.725)

⇒ h2:$M_{h_2} \lesssim 140$; h1:$60 \lesssim M_{h_2} \lesssim 140 \otimes 10 \lesssim M_{h_1} \lesssim 60$(hole);

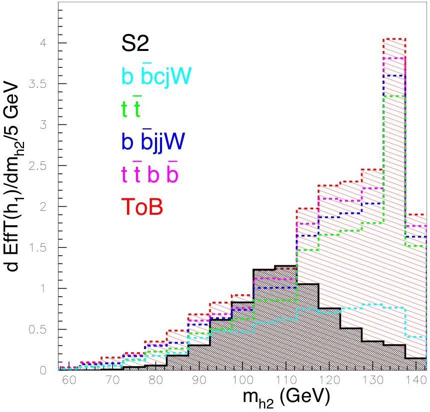
⇒ Splitting is useful to get the correct results and weighting to get EffT.

Lighter Higgs mass (m_{h_1}) reconstruction at LHC



$\Rightarrow |h_1(j_i j_j)$ - $h_1(j_k j_l|)$ is minimmum

Intermediate Higgs mass (m_{h_2}=$m_{j_1j_2j_3j_4}$) reconstruction at LHC



⇒ Higgs signal showed up just above the Total Backgrounds.

Events at the LHC with $10\mathrm{fb}^{-1}$

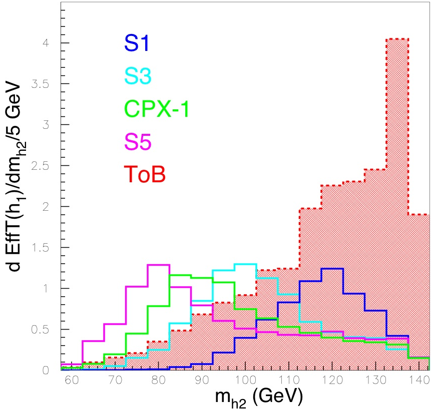
Proc	RawEvt	ϵ_{acc}	3b	EffC(h2,+h1)	EffT(h2,+h1)
S1	1091.1	332.4	31.58	13.20(6.53,6.41)	13.18(6.89,6.76)
S2	1401.5	393.5	33.97	14.51(7.43,7.29)	14.49(7.83,7.66)
S3	1850.8	478.8	39.09	15.64(8.11,7.92)	16.05(8.90,8.70)
CPX-1	2367.1	567.2	38.80	16.05(8.71,8.47)	16.25(9.02,8.81)
CPX-2	2283.8	563.8	39.46	15.83(9.04,8.88)	15.93(9.55,9.26)
p1	1690000.	818597.	7623.	1458.(11.83,10.14)	1467.(8.90,8.18)
p2	337.6	31.9	4.07	2.98 (0.549, 0.491)	2.95(0.635,0.583)
p3	23.3	2.3	0.14	0.104 (0.012,0.012)	0.113 (0.016,0.015)
p4	73172.	7371.	83.71	62.9 (9.36,8.78)	56.4 (7.89,7.34)
p5	1126.	90.8	1.49	1.07 (0.237,0.225)	1.15 (0.274,0.256)
p6	535663.	45904.	30.0	14.9 (2.14,2.14)	17.8 (2.25,2.09)
p7	7194.	587.5	0.17	0.115 (0.000,0.000)	0.046 (0.007,0.007)
p8	63301328.	4531109.	0.00	0.000 (0.000,0.000)	4.34 (0.336,0.322)
p9	10102.	5698.	746.3	73.5 (0.889,0.889)	72.7 (1.49,1.43)
p10	16435.	9202.	255.0	31.8 (0.394,0.263)	31.4 (0.554,0.513)
S-p8	59696764.	4331068.	1.71	0.089(0.051,0.051)	4.57(0.751,0.725)
ToB	62030817.	5218552.	8745.6	1646.(25.4,22.9)	1654.(22.8,21.1)
$\frac{S2}{\sqrt{B}}$	0.177	0.172	0.369	0.357(1.47,1.52)	0.356(1.64,1.66)

⇒ p1($t\bar{t}$),p2(4bW),p3(3bjW),p4(2bcj),p5(2b2c),p6(2b2j),p7(b3j),p8(4j),p9($t\bar{t}b\bar{b}$),p10($t\bar{t}c\bar{c}$)

⇒ Low stat events (e.g.,p2,p3,p5...) are well matched;

⇒ $t\bar{t}$,2bcj,2b2j,2t2b are the main contributions; few ten Signal Events

Other benchmark points at LHC



$\Rightarrow$ Might be show up around 115 GeV

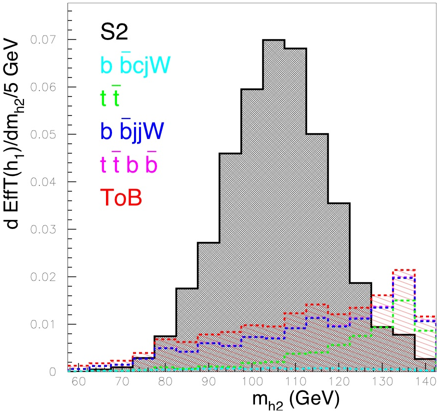
Events at the Tevatron with 4 fb^{-1}

Proc	RawEvt	N_{acc}	N_{3b}	EffC(h2,+h1)	EffT(h2,+h1)
S1	36.0	10.5	0.73	.504(.394,.385)	.460(.397,.387)
S2	48.7	13.1	0.78	.523(.423,.417)	.486(.430,.424)
S3	65.0	15.6	0.81	.549(.445,.439)	.510(.455,.447)
CPX-1	84.8	19.1	0.77	.505(.423,.416)	.461(.413,.405)
CPX-2	82.6	21.2	0.83	.525(.444,.439)	.498(.457,.447)
p1	6760.0	3540.5	26.51	10.62(.081,.081)	9.60(.062,.054)
p2	12.6	1.5	0.06	.035(.012,.011)	.034(.014,.013)
p3	.043	.0063	0.00	.000(.000,.000)	.000(.000,.000)
p4	131.2	17.5	0.05	.021(.009,.008)	.019(.009,.008)
p5	44.5	5.6	0.04	.020(.009,.008)	.014(.007,.007)
p6	5180.9	611.1	0.31	.207(.104,.104)	.155(.069,.063)
p7	14.3	2.0	0.00	.000(.000,.000)	.000(.000,.000)
p8	387676.3	46172.2	0.00	.000(.000,.000)	.020(.009,.007)
p9	12.1	6.8	0.44	.028(.001,.001)	.026(.001,.001)
p10	21.7	13.7	0.21	.015(.001,.001)	.016(.001,.000)
S-p8	384003.9	47414.4	0.00	.001(.001,.001)	.028(.012,.010)
ToB	396181.2	51613.1	27.62	10.95(.218,.215)	9.89(.175,.156)
$\frac{S2}{\sqrt{B}}$	.077	.057	.148	.158(.907,.900)	.154(1.02,1.07)

⇒p1($t\bar{t}$),p2(4bW),p3(3bjW),p4(2bcj),p5(2b2c),p6(2b2j),p7(b3j),p8(4j),p9($t\bar{t}b\bar{b}$),p10($t\bar{t}c\bar{c}$)

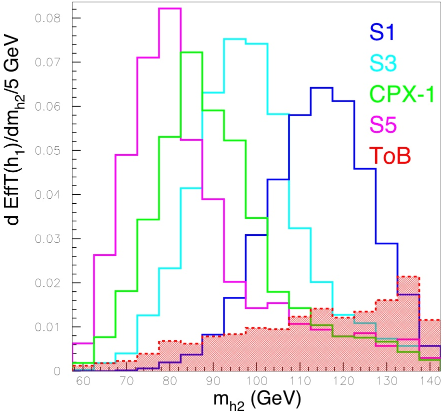
⇒ Signal events is very very low using 3b-tagged in 4fb^{-1}.

Higgs mass reconstruction at Tevatron



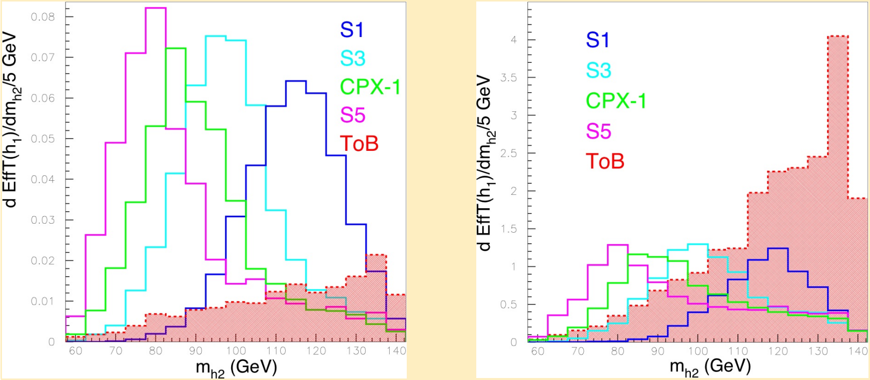
⇒ Higgs mass peak in simulation show up but with fractional events due to poor eff.

Other benchmark points at Tevatron



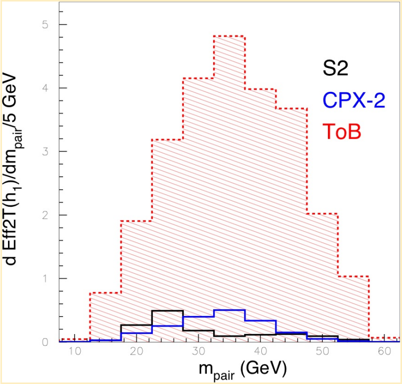
⇒ Good but again no more than 1 event in all benchmark points (factor of 5 final Tevatron combined Luminosity).

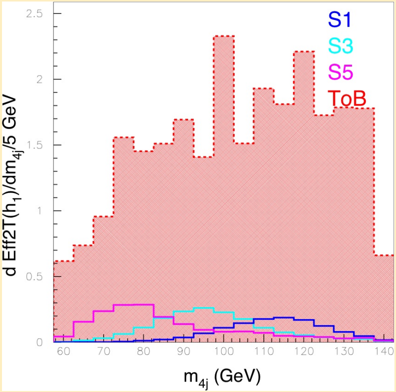
Signal and Backgrounds at Tevatron and LHC



$\Rightarrow$ Tevatron very hard and LHC in the vicinity of present LEP exclusion.

2b-tagging at Tevatron (minor changes,e.g., averaging the masses)





Tevatron with 20 fb^{-1}

Signal(Bgs)	Significance: $S/\sqrt{B}$ $N_b \geq 2$	$N_b \geq 3$
S1(B)	4.12(31.93),1.	1.34(0.61),2.
S3(B)	4.85(23.60),1.	1.31(0.63),2.
S5(B)	5.95(33.48),1.	1.36(0.44),2.
CPX-1(B)	6.12(48.79),1.	1.44(0.76),2.

$$\begin{aligned} 0.6 m_{h_1} &\leq m_{\rm pair} \leq m_{h_1} + 5\ \mathrm{GeV}\,; \\ 0.7 m_{h_2} &\leq m_{4j} \leq m_{h_2} + 10\ \mathrm{GeV}\,. \end{aligned} \tag{11}$$

$\Rightarrow$ Double peaks and one would need to try different combinations for Higgs masses peaks.

Summary and Outlook:

- LEP found no Higgs signal; hence put upper limits and exclusions.
- $p\bar{p} \rightarrow Wh_2 \rightarrow \ell + 4 - jets(2b - jets) + \not{E}_T$.
- b,c-tagging and low flavor-mistagging jet-by-jet basis in an event.
- All SM backgrounds; some of them are statistics limited.
- Identifying flavor of the jets and weight accordingly with tagging probability.
- Efficiencies are very poor at Tevatron and thus the events.
- Few ten events at LHC and S:B $\sim$ 1:2, promising at 100 fb^{-1}.
- Tevatron very hard and at LHC might be show up $\sim$ 115 GeV.
- Look elsewhere effect with Double peaks (although overestimates) with 20 fb^{-1} is also not helping.
- Other channels and also in different models.