Experimental Study of Higgs Bosons in CP-Violating MSSM Scenario at TESLA

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Contents

- Indirect measurement of the parameters of the CP-violating MSSM scenario at TESLA.
- Analysis of the process $e^+e^- \to H_iH_j \to b\bar{b}b\bar{b}$ at TESLA.

MSSM

CP-Conserving Scenario

5 physical Higgs Bosons:

2 neutral CP-even: H^0, h^0

1 neutral CP-odd: A^0

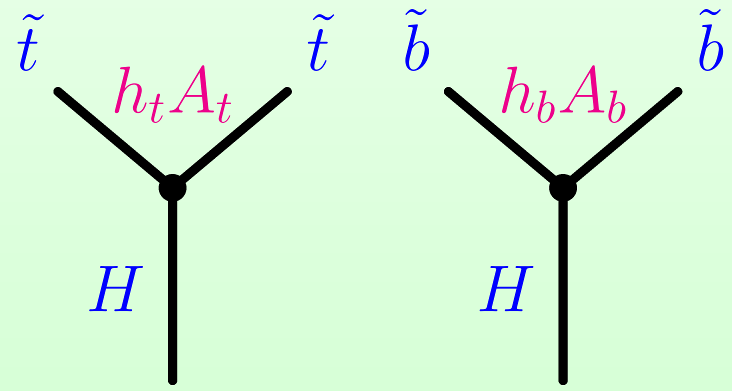
2 CP-even charged: H^+, H^-

mass eigenstates = CP eigenstates

Introduction of $A_{t,b}$:

$A_{t,b}$ - soft SUSY-breaking trilinear coupling of the Higgs boson to top (bottom) squarks.

$h_{t,b}$ - Yukawa couplings.



MSSM

CP-Conserving Scenario

$A_{t,b}$ - Real

$m_{\tilde{g}}$ - Real

$$\boxed{\arg(A_{t,b}) = 0}$$

$$\boxed{\arg(m_{\tilde{g}}) = 0}$$

CP-Violating Scenario

- Description of the cosmological bariogenesis.

$A_{t,b}$ - Complex

$m_{\tilde{g}}$ - Complex

$$\boxed{\arg(A_{t,b}) \neq 0}$$

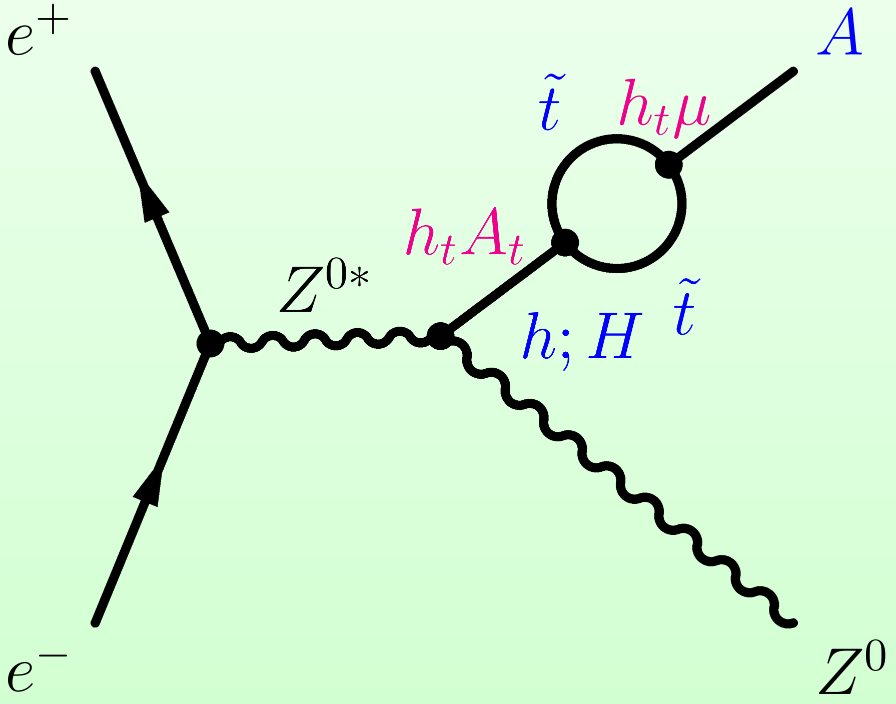
$$\boxed{\arg(m_{\tilde{g}}) \neq 0}$$

mass eigenstates $\neq$ CP eigenstates

CP-Violating Scenario

Loop effects involve CP-violating interactions of Higgs bosons with $\tilde{t}$ $(\tilde{b})$.

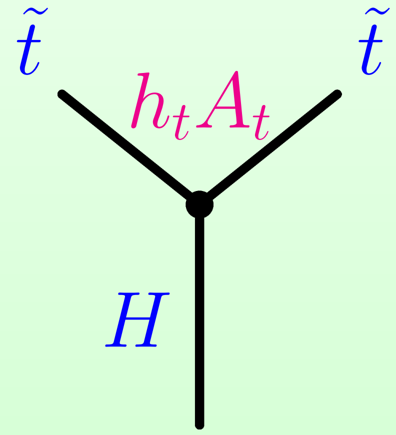
Higgsstrahlung:



3 neutral Higgs Bosons:

$$H_1, H_2, H_3$$

have mixed CP parities



CP-Violating Scenario

Motivation of investigation:

CPX - new benchmark scenario of maximal CP violation (LEP):

M. Carena, J. Ellis, A. Pilaftsis and C.E.M. Wagner (xhep-ph/0009212).

Parametrization of the Higgs sector:

$\boxed{M_{H^+}}$ and $\boxed{tan\beta = \frac{v_2}{v_1}}$

$$\widetilde{M}_Q = \widetilde{M}_t = \widetilde{M}_b = M_{SUSY},$$

$$\mu = 4M_{SUSY},$$

$$|A_t| = |A_b| = 2M_{SUSY},$$

$$\boxed{arg(A_t) = 90^\circ,}$$

$$|m_{\tilde{g}}| = 1TeV, \boxed{arg(m_{\tilde{g}}) = 90^\circ}.$$

TESLA

$\boxed{\arg(A_{t,b}) \text{ - ?}}$

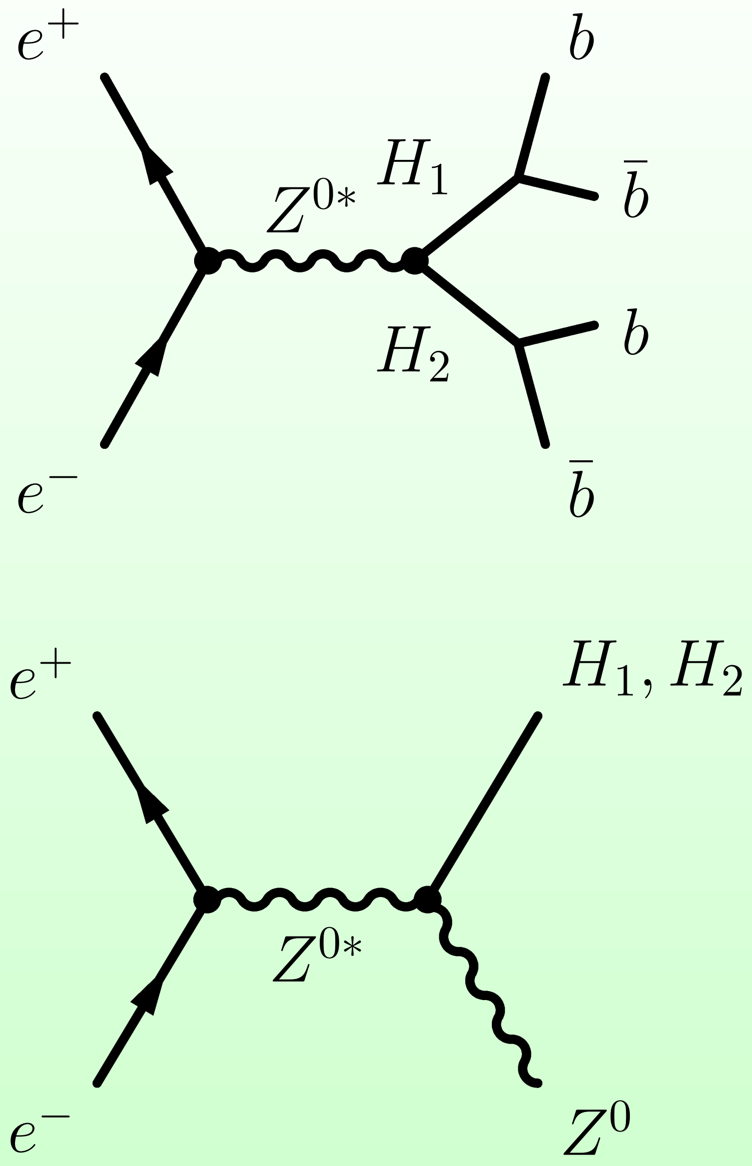
2 parameter scan:

$Re(A_{t,b}), Im(A_{t,b})$ - variables

$\sqrt{s}$ = 500 GeV

$L = 500 fb^{-1}$

Parameter	Value
$\tan\beta$	3
M_{H^+}	200 GeV
M_{SUSY}	500 GeV
μ	2 TeV



Assume, we can measure:

$\boxed{\sigma * BR}$ $\boxed{M_{H_i}}$

Example:

$$\sigma(e^+e^- \to H_1 H_2) *$$
$$BR(H_1 \to b\bar{b}) * BR(H_2 \to b\bar{b})$$

Precision: 10 %

$$M_{H_{1,2}}$$

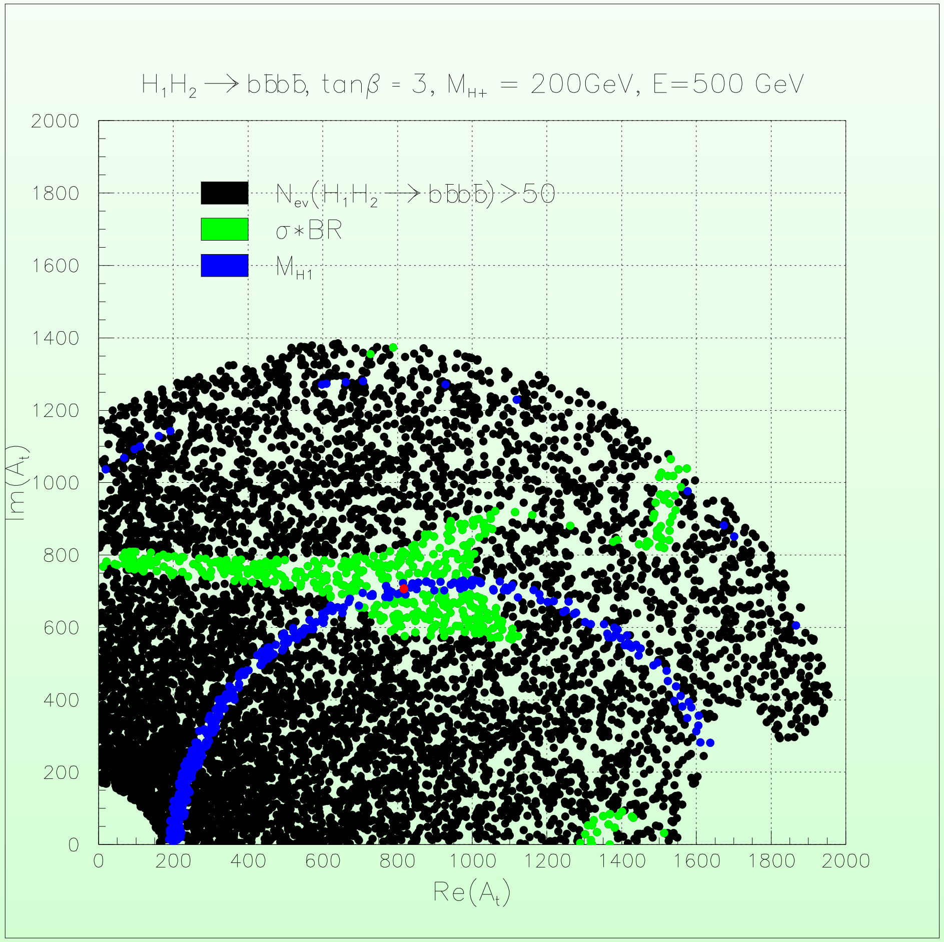
Precision: 1 GeV

Found: we can measure

$\arg(A_{t,b})$ **(indirect)**

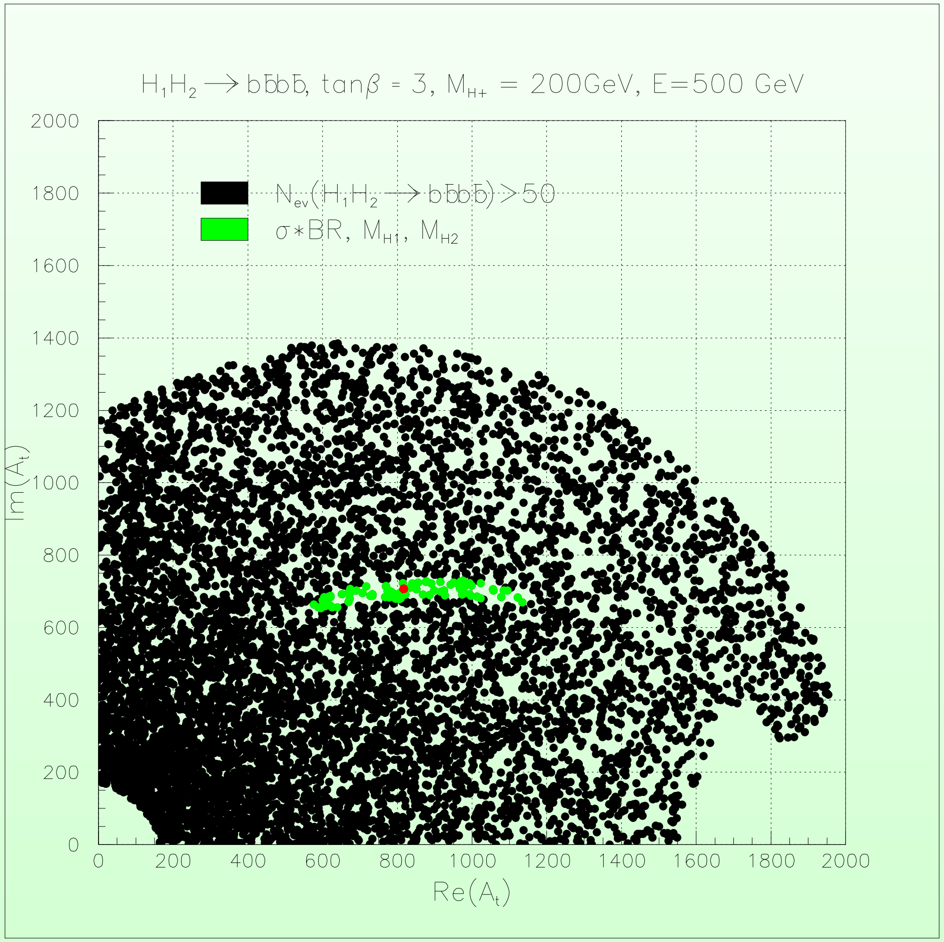
2-Parameter Scan

We know: $\sigma * BR$, M_{H_1}



$$N_{ev}(H_1H_2 \rightarrow b\bar{b}b\bar{b}) > 50$$

We know: $\sigma * BR$, M_{H_1}, M_{H_2}



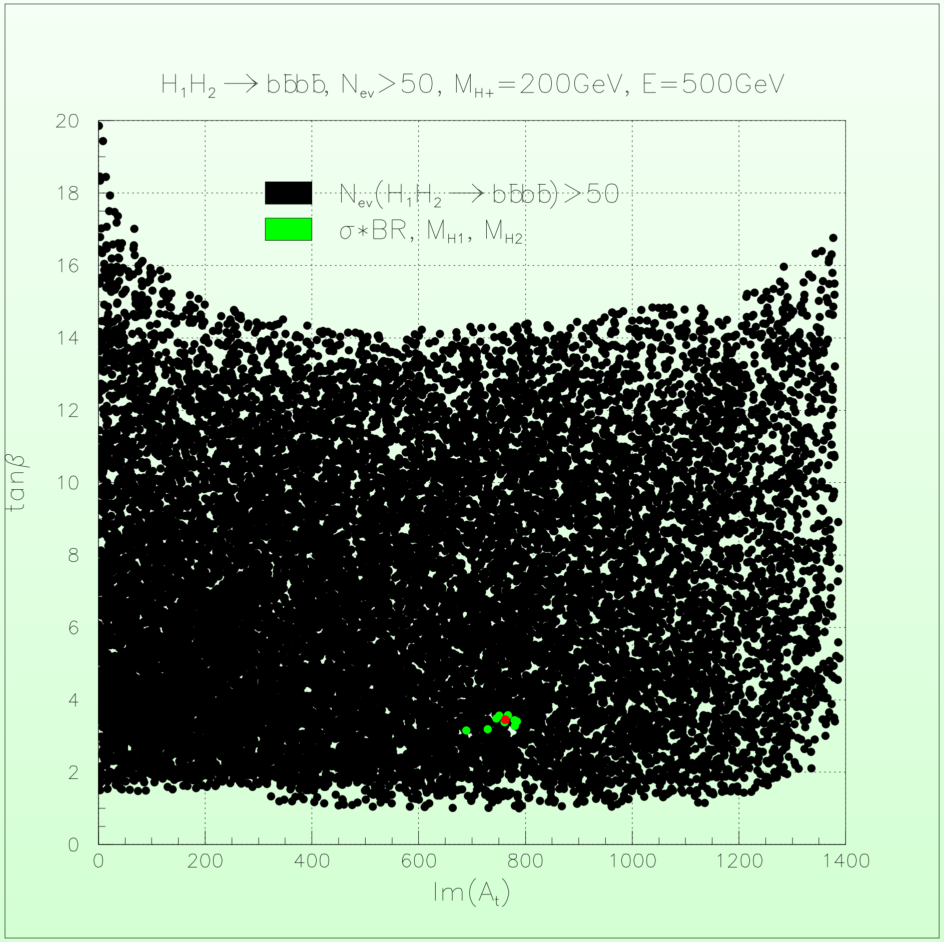
$$Re(A_{t,b}) = (800 \pm 300) GeV$$

$$Im(A_{t,b}) = (700 \pm 50) GeV$$

3-Parameter Scan

Parameter	Value
$Re(A_{t,b})$	**variable**
$Im(A_{t,b})$	**variable**
$\tan\beta$	**variable**
μ	**2 TeV**
M_{H+}	**200 GeV**

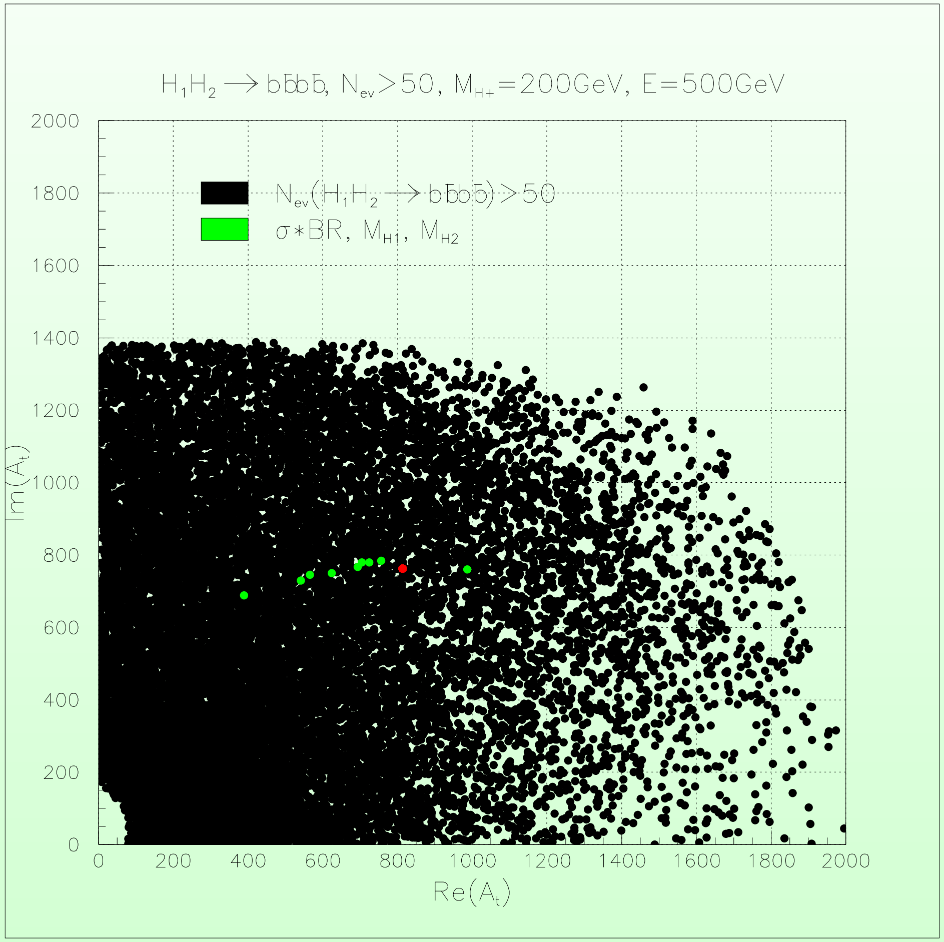
We know: $\sigma * BR$, M_{H_1}, M_{H_2}



$$N_{ev}(H_1H_2 \to b\bar{b}b\bar{b}) > 50$$

3-Parameter Scan

We know: $\sigma * BR$, M_{H_1}, M_{H_2}



$$N_{ev}(H_1 H_2 \to b\bar{b}b\bar{b}) > 50$$

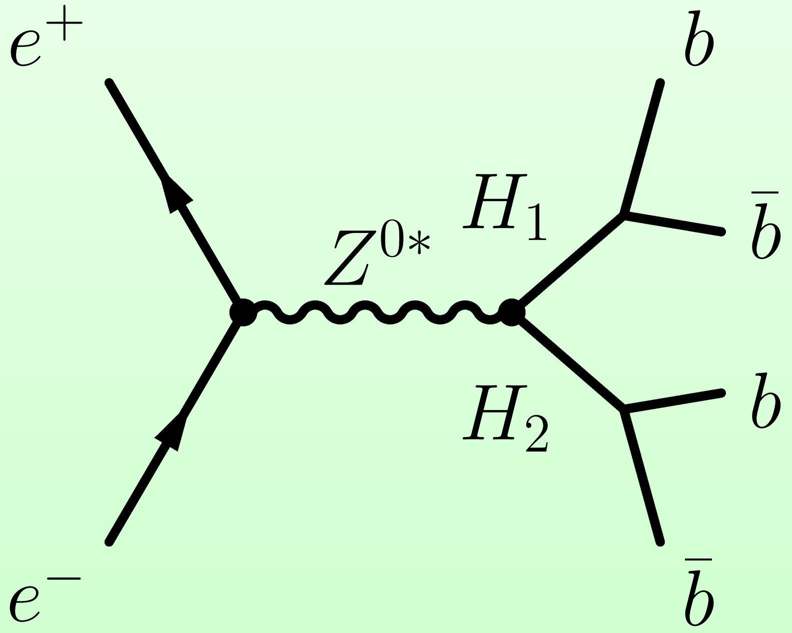
Sensitivity:

Parameter	**Value**
$Re(A_{t,b})$	**800 $\pm$ 250 GeV**
$Im(A_{t,b})$	**750 $\pm$ 50 GeV**
$\tan\beta$	**3.0 $\pm$ 0.5**

TESLA

Preliminary Analysis.

$$\boxed{e^+e^- \rightarrow H_iH_j \rightarrow b\bar{b}b\bar{b}}$$



Using:

- HZHA: generation
- SIMDET 4.01: simulation
- ZV-TOP: b-tagging

  (SLD b-tagger)

Analysis of $e^+e^- \rightarrow H_iH_j \rightarrow b\bar{b}b\bar{b}$ at TESLA.

Signal (example point):

Parameter	Value
$\tan\beta$	19
M_{H^+}	164 GeV
$Re(A_t)$	285 GeV
$Im(A_t)$	771 GeV

M_{H_1}	112 GeV
M_{H_2}	141 GeV
M_{H_3}	155 GeV
$N_{ev}(H_1H_2 \rightarrow b\bar{b}b\bar{b})$	200
$N_{ev}(H_2H_3 \rightarrow b\bar{b}b\bar{b})$	7000
$N_{ev}(H_1H_3 \rightarrow b\bar{b}b\bar{b})$	1720

Signal and BG samples:

Process	SX (fb)	N_{events}
$H_1H_2 \rightarrow b\bar{b}b\bar{b}$	0.4196	10000
$H_2H_3 \rightarrow b\bar{b}b\bar{b}$	12.61	10000
$H_1H_3 \rightarrow b\bar{b}b\bar{b}$	3.428	10000
$Z^0\gamma^* \rightarrow 2f$	13580	800000
$W^+W^- \rightarrow 4q$	4134	300000
$Z^0Z^0 \rightarrow 4q$	314.3	100000
$H_1Z^0 \rightarrow b\bar{b}q\bar{q}$	34.63	10000
$H_2Z^0 \rightarrow b\bar{b}q\bar{q}$	6.043	10000

Cuts

N	Variable	Cut value
1	N_{jets}	4
2	P_{vis}	$\geq$340 GeV
3	$min(N_{tracks}/jet)$	$\geq$3
4	$\lvert\cos(thrust)\rvert$	$\leq$0.8
5	$thrust$	$\leq$0.90
6	$\log(y_{34})$	$\geq$-2.9
7	B_{12}	$\geq$0.75
8	B_{34}	$\geq$0.03

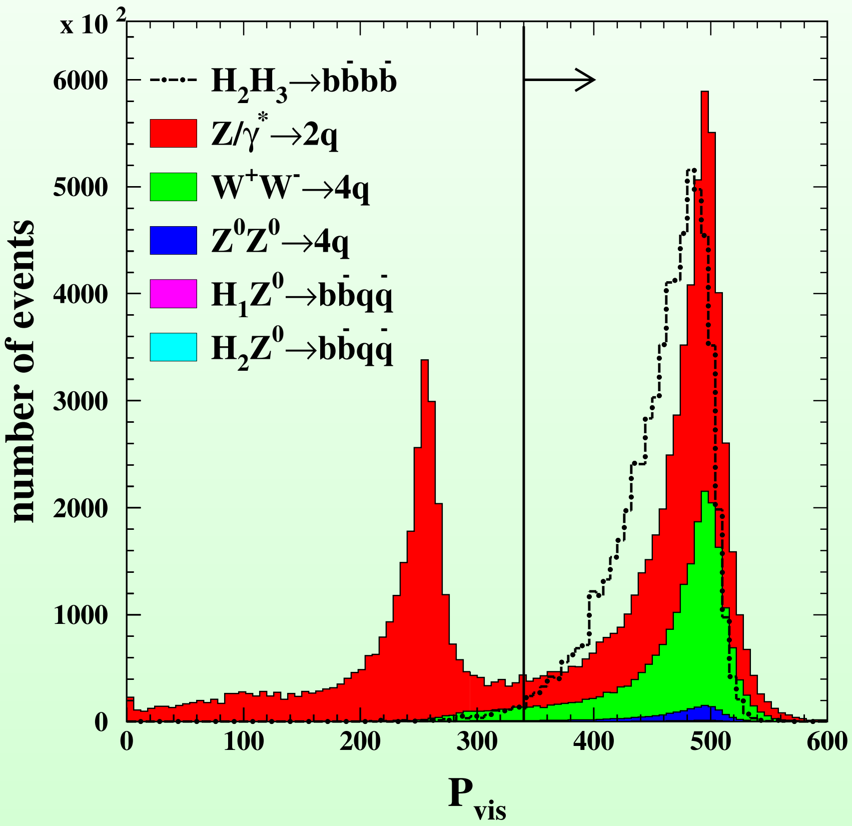
$$B_1 > B_2 > B_3 > B_4$$

$$B_{12} = \frac{B_1 B_2}{B_1 B_2 + (1 - B_1)(1 - B_2)}$$

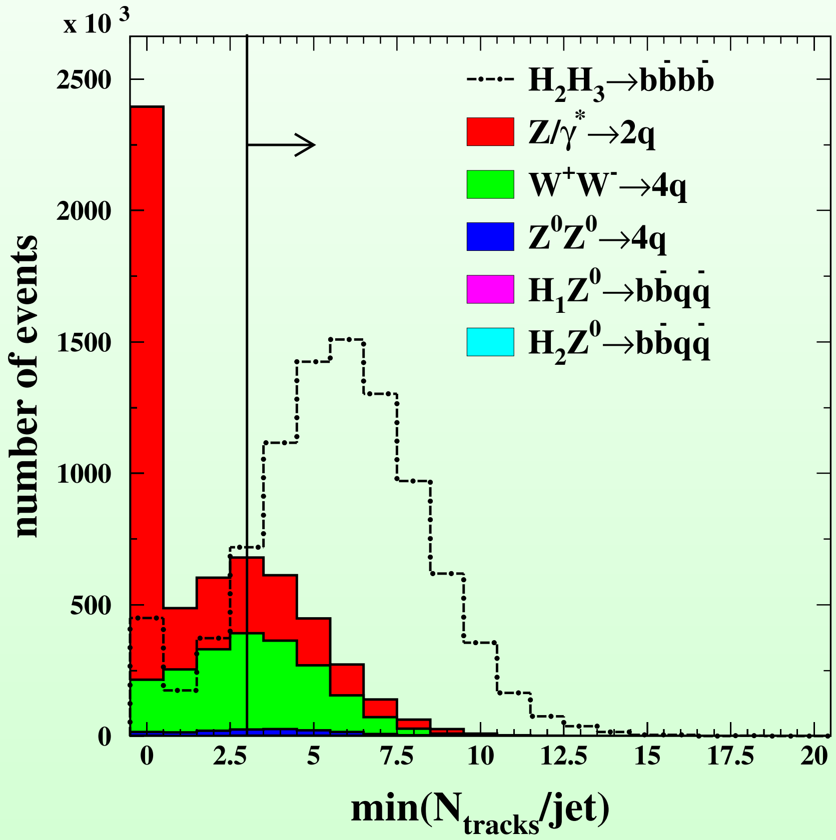
$$B_{34} = \frac{B_3 B_4}{B_3 B_4 + (1 - B_3)(1 - B_4)}$$

Cuts

$P_{vis} \geq 340GeV$

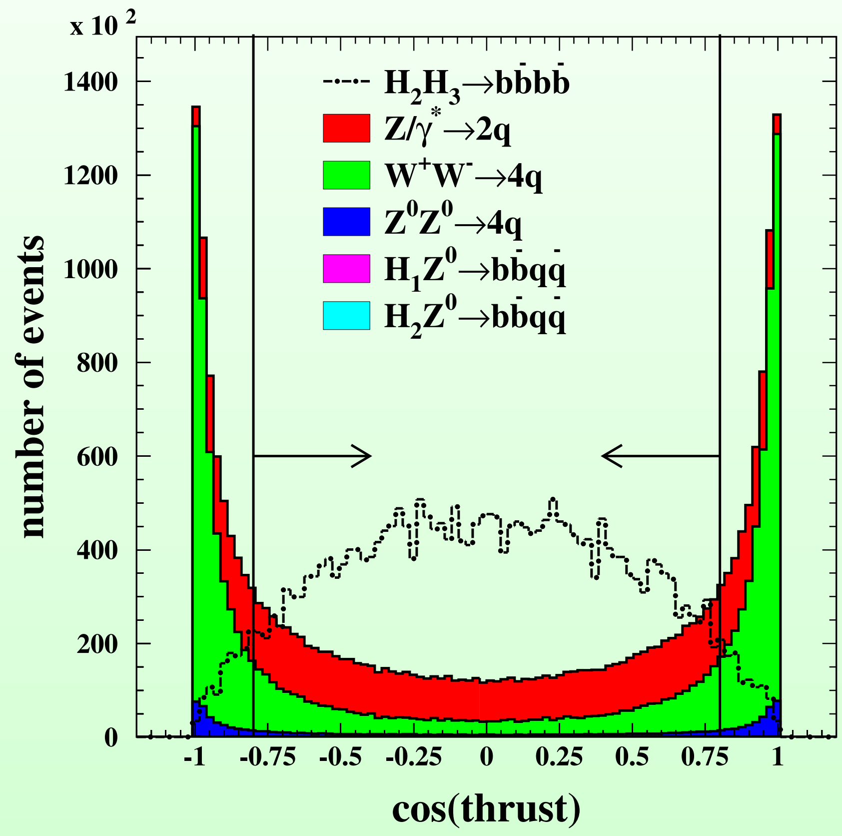


$min(N_{tracks}/jet) \geq 3$

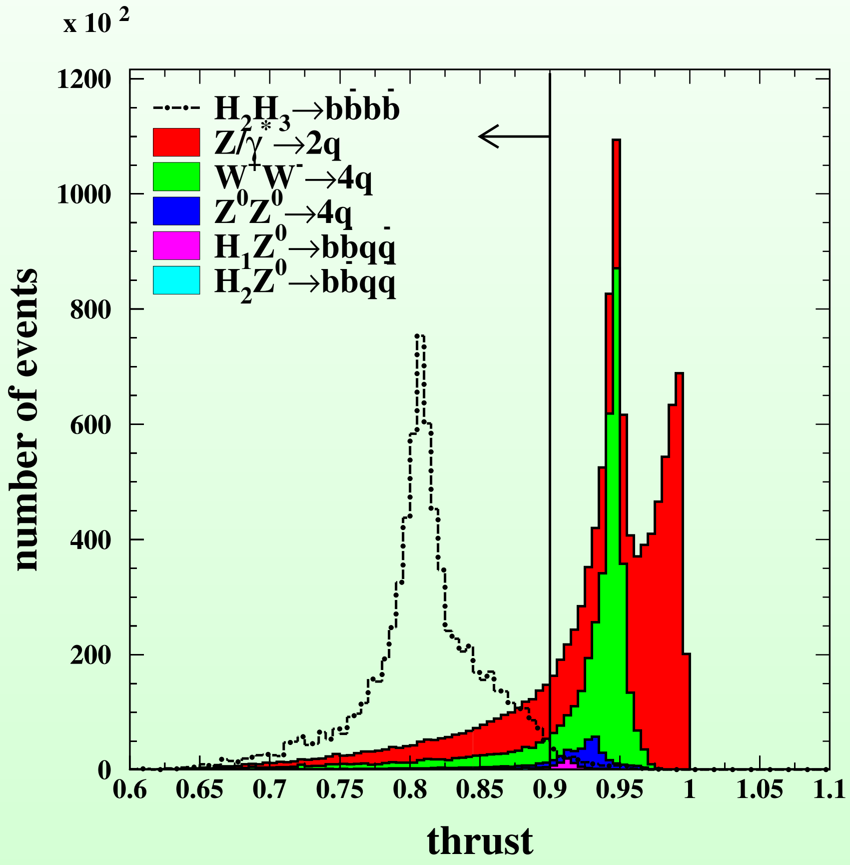


Cuts

$|\cos(thrust)| \leq 0.8$



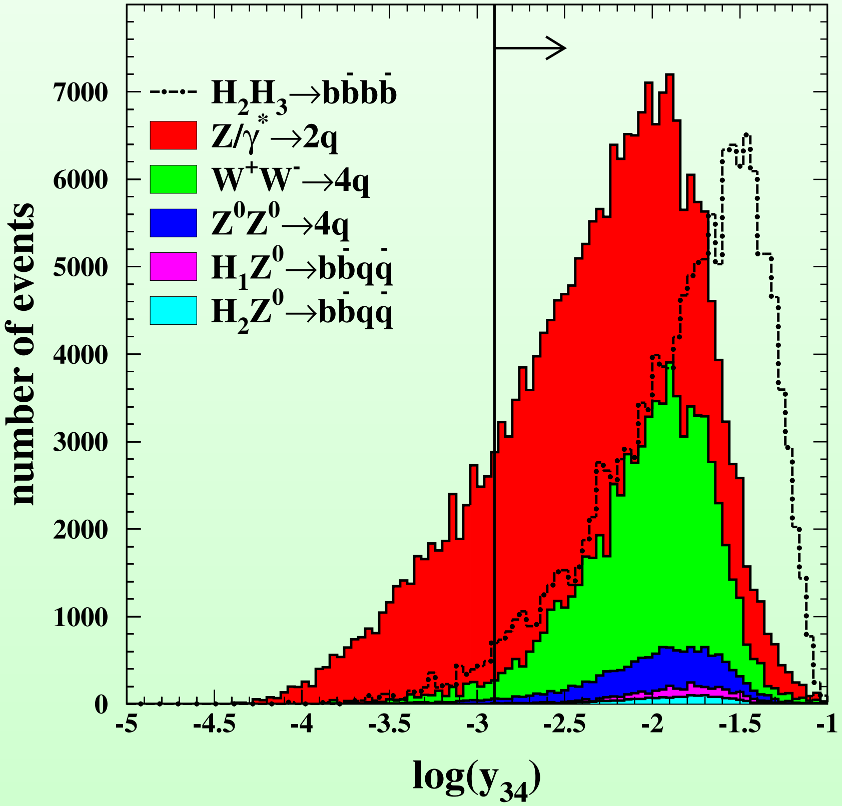
$thrust \leq 0.90$



Cuts

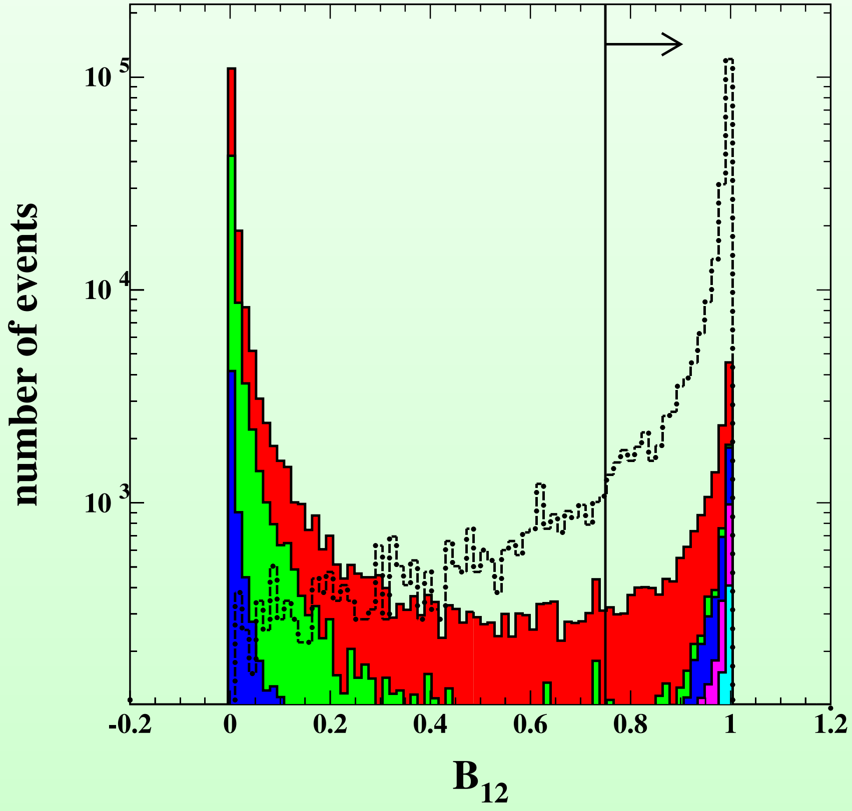
Jet resolution parameter

$$\log(y_{34}) \geq -2.9$$



$$B_{12} \geq 0.75$$

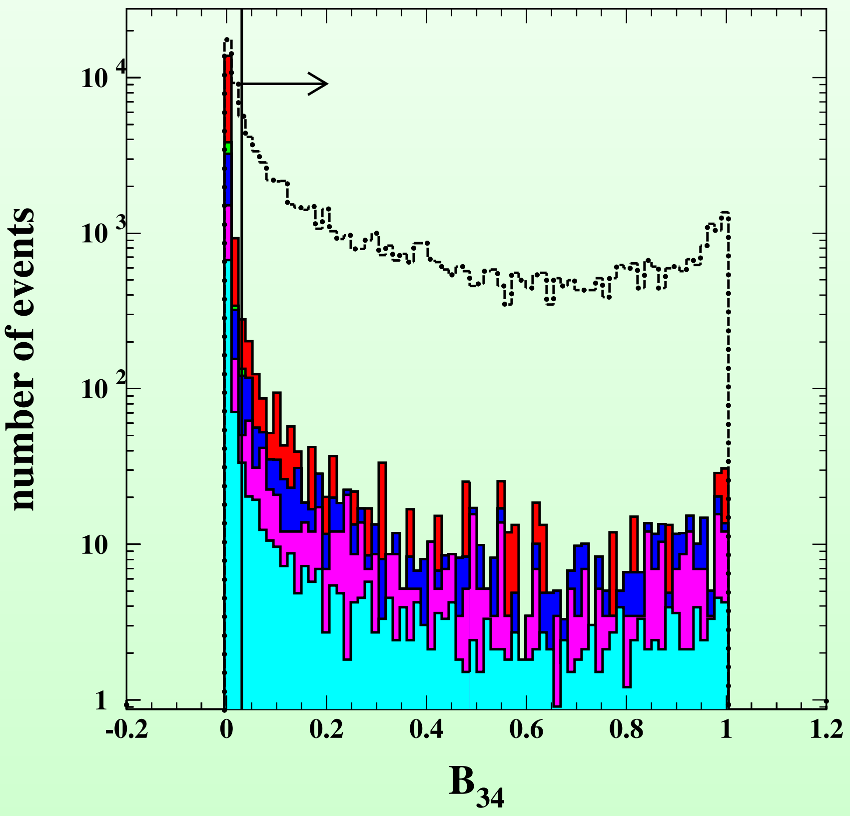
$$B_{12} = \frac{B_1 B_2}{B_1 B_2 + (1-B_1)(1-B_2)}$$



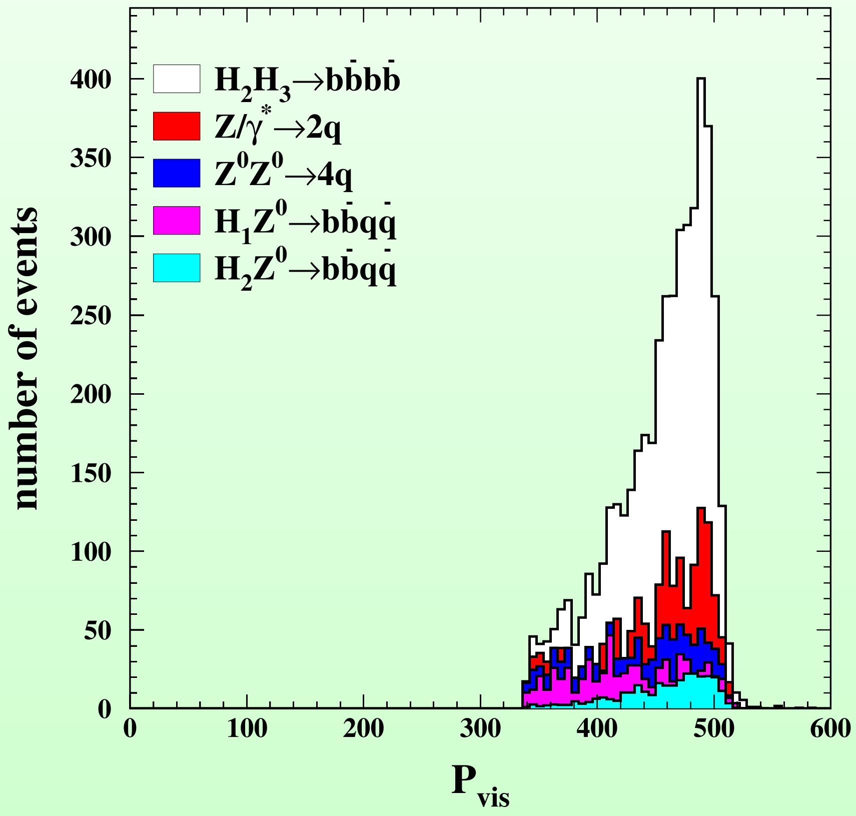
Cuts

$B_{34} \geq 0.03$

$$B_{34} = \frac{B_3 B_4}{B_3 B_4 + (1-B_3)(1-B_4)}$$



P_{vis} **after all cuts**



Cutflow

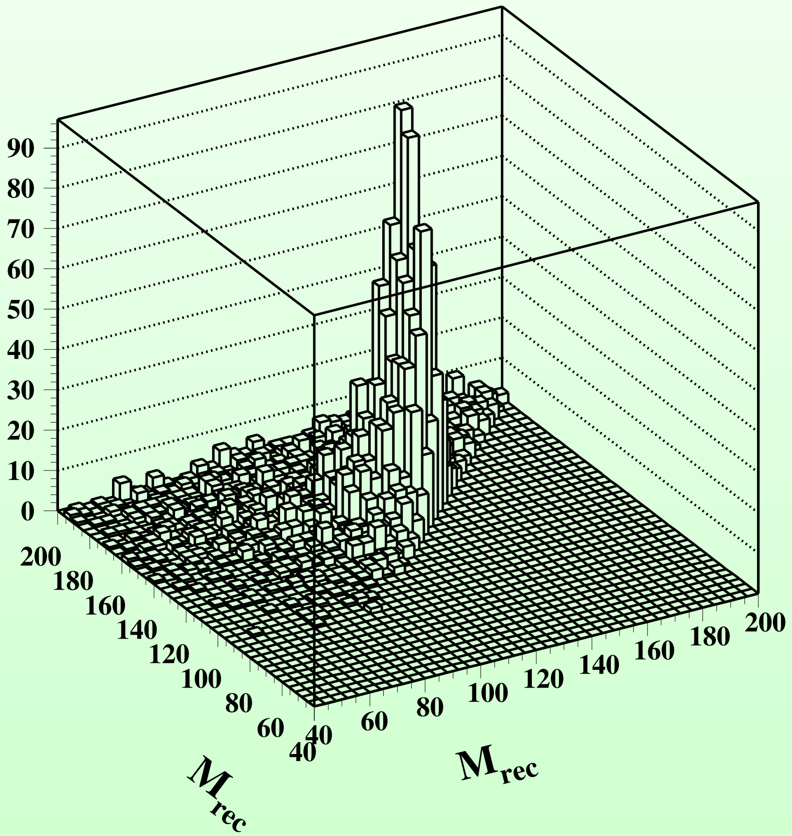
Cut	H_1H_2		H_1H_3		H_2H_3		
	Signal	Eff.	Signal	Eff.	Signal	Eff.	Total BG
no cuts	209.81	100.00	1713.9	100.00	6304.9	100.00	9040126.7
N_{jets}	209.81	100.00	1713.9	100.00	6304.9	100.00	8968126.7
P_{vis}	204.27	97.36	1677.4	97.87	6219.8	98.65	5752461.1
$min(N_{tr}/jet)$	178.17	84.92	1483.9	86.58	5554.1	88.09	2265428.6
$\cos(thrust)$	164.74	78.52	1369.6	79.91	5111.0	81.06	1131339.9
$thrust$	152.45	72.66	1284.9	74.97	4993.7	79.20	226355.0
$\log(y_{34})$	149.03	71.03	1252.7	73.09	4848.1	76.89	188286.1
B_{12}	132.60	63.20	1115.9	65.11	4295.3	68.13	17520.1
B_{34}	93.70	44.66	785.3	45.82	2965.4	47.03	1937.6

Mass reconstruction

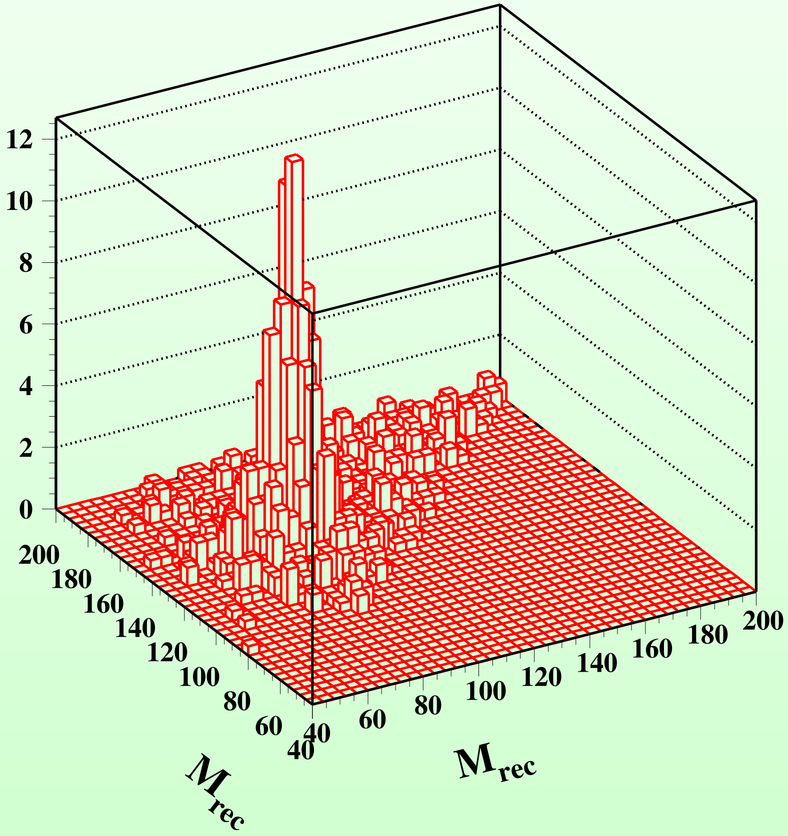
Signal

$H_2 \simeq 141 GeV$

$H_3 \simeq 155 GeV$

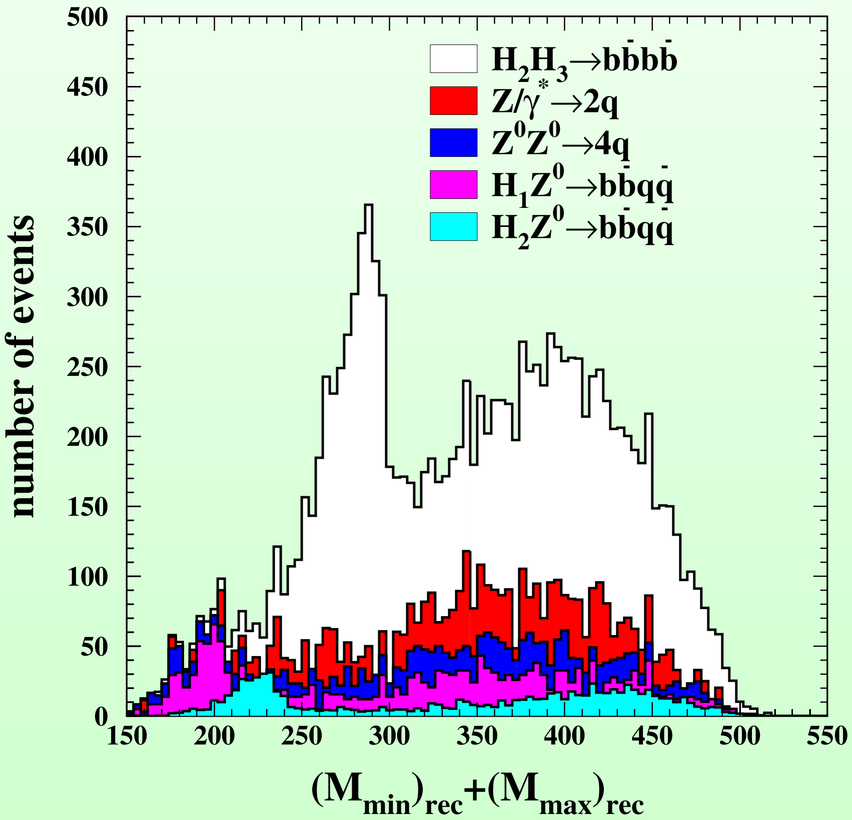


Background

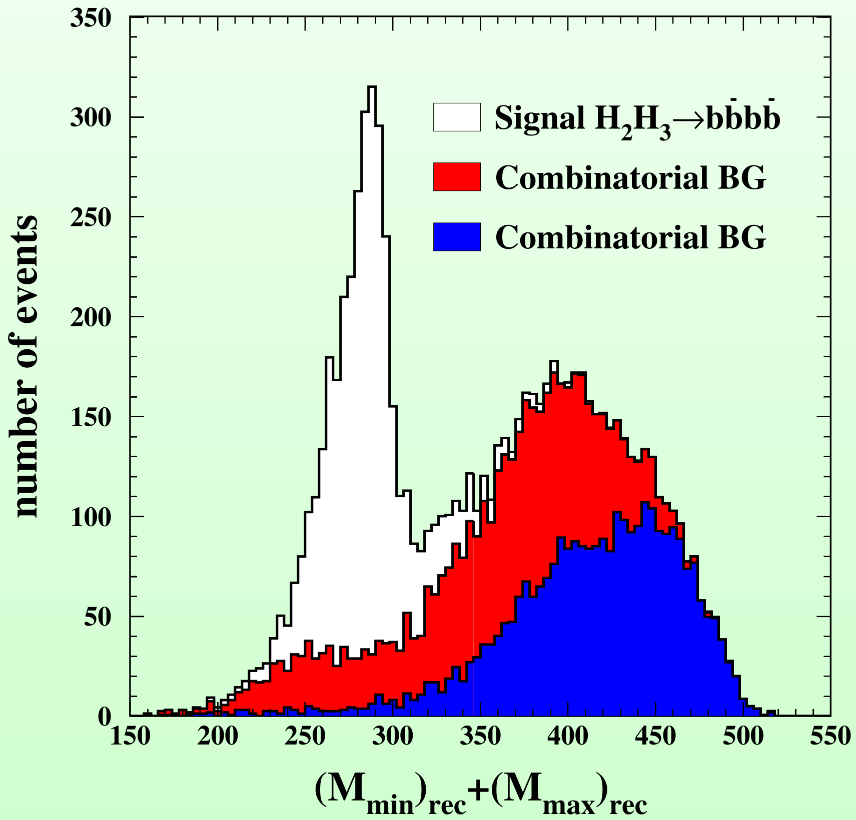


Sum of the Reconstructed Masses

Signal + Combinatorial BG + BG

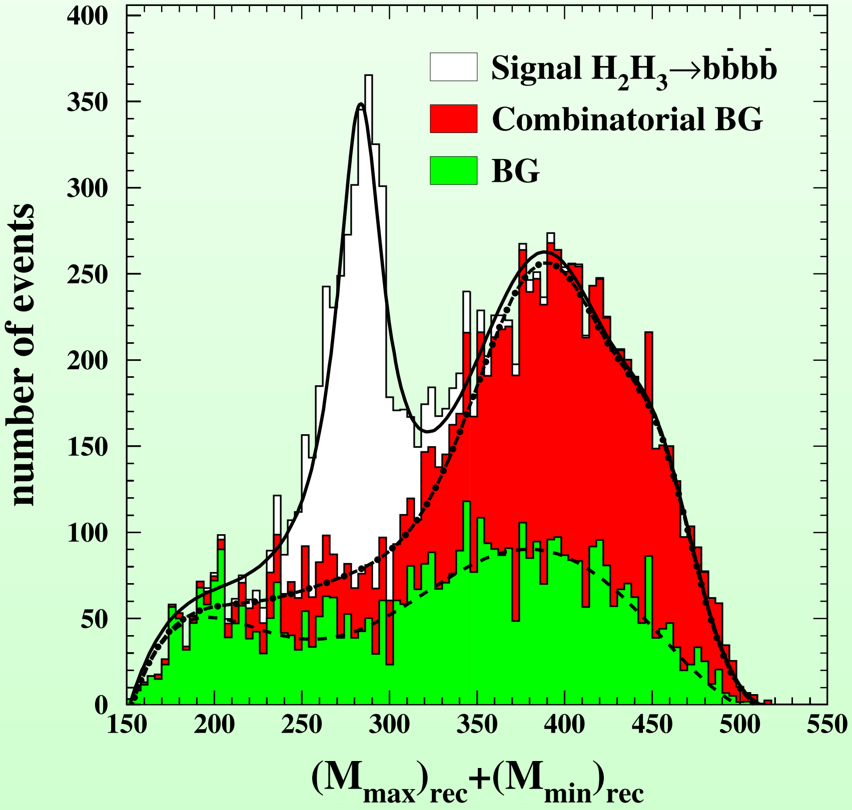


Signal + Combinatorial BG



Sum of the Reconstructed Masses

Fit



Signal: Breit-Wigner

Combinatorial BG: 3 Gaussian

BG: Polynomial

Results:

$$M_{min} + M_{max} = (283.3 \pm 0.5) GeV$$

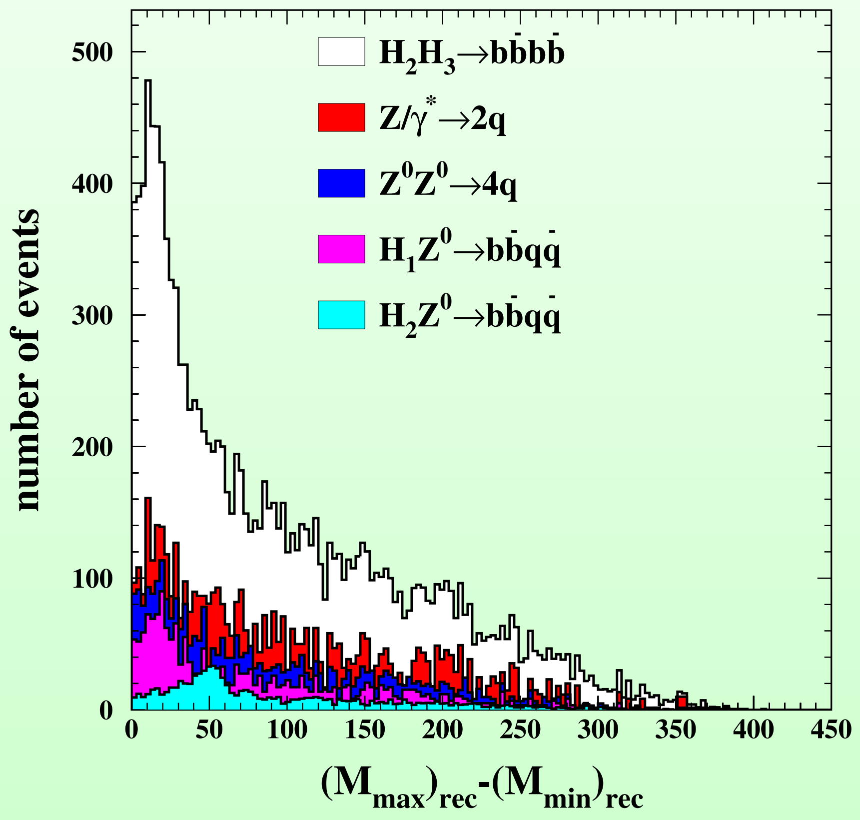
$$\Gamma = (32.6 \pm 1.3) GeV$$

Model point:

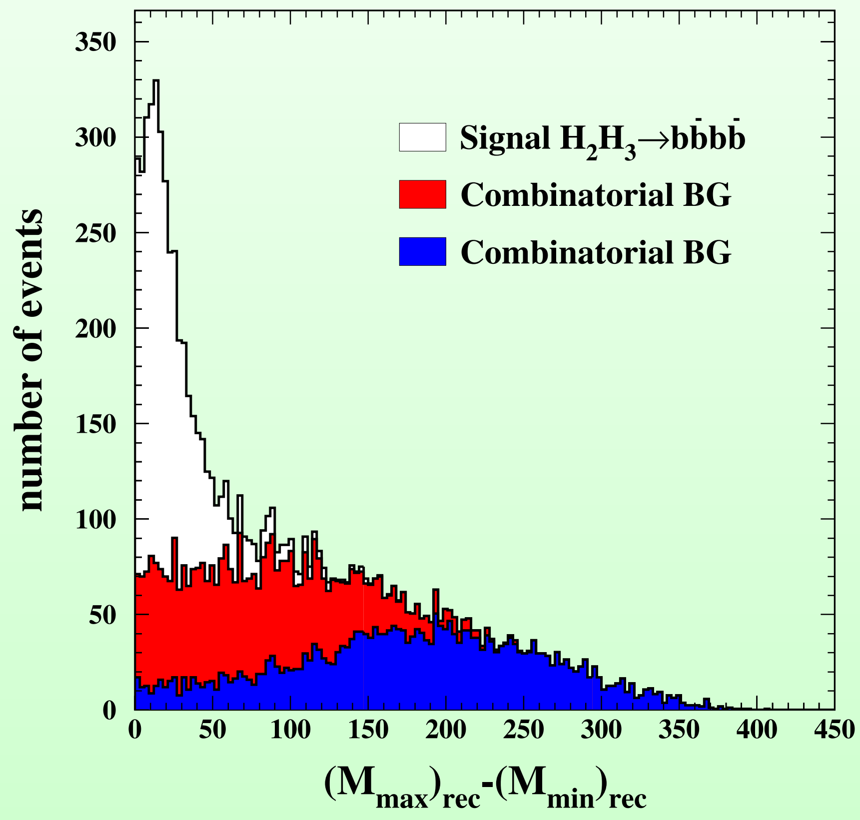
$$M_{H_2} + M_{H_3} \simeq 296 GeV$$

Difference of the Reconstructed Masses

Signal + Combinatorial BG + BG

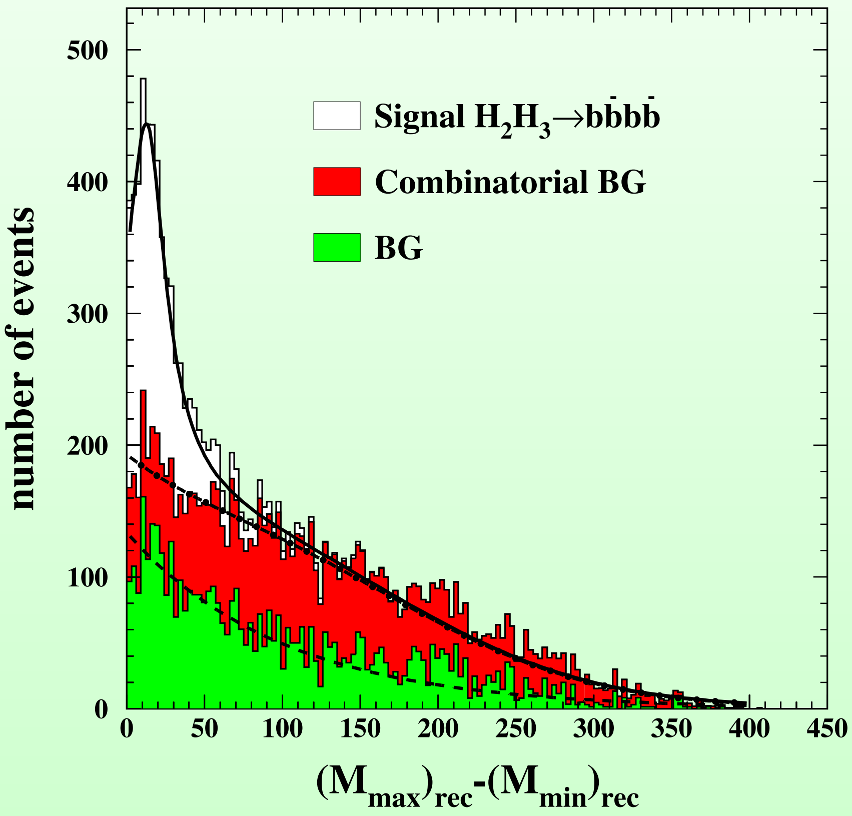


Signal + Combinatorial BG



Difference of the Reconstructed Masses

Fit



Signal: Breit-Wigner

Combinatorial BG: Gaussian

BG: Exponential

Results:

$$M_{max} - M_{min} = (12.8 \pm 0.5) GeV$$
$$\Gamma = (29.4 \pm 0.8) GeV$$

Model point:

$$M_{H_3} - M_{H_2} \simeq 14 GeV$$

Summary

- CP-violating MSSM parameters scans for 2, 3 dimensional cases are demonstrated.
- The possibilities for measurement of CP-violating MSSM parameters at TESLA are shown.
- Cut analysis for the process $e^+e^- \rightarrow H_iH_j \rightarrow b\bar{b}b\bar{b}$ at TESLA is made.
- 50% efficiency after all cuts is obtained.
- High BG reduction factor.
- The precision for the Higgs masses measurements is obtained.

Outlook

- Errors for indirect measurement of $\arg(A_{t,b})$ at TESLA.
- Use of the other processes for $\arg(A_{t,b})$ measurement at TESLA, for example Higgsstrahlung.
- Far future: Full CP-violating MSSM parameters scan.