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

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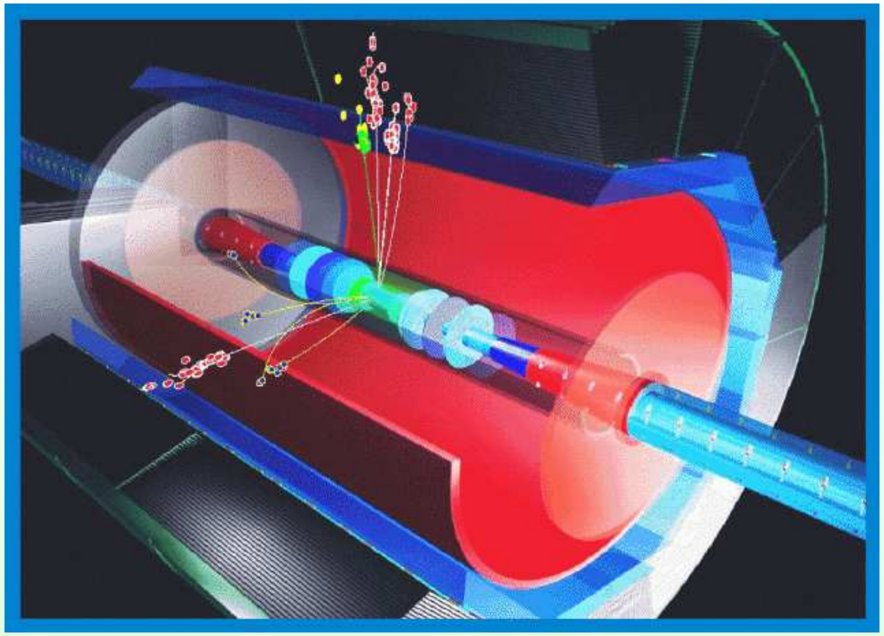
TESLA



Future e^+e^- Linear Collider

Luminosity: 500 fb^{-1}

$\sqrt{s}$ = 500 GeV

Contents:

- **MSSM scenario**
- **Analysis of the process** $e^+e^- \to H_iH_j \to b\bar{b}b\bar{b}$
- **Higgs mass reconstruction:**
  - **Applied cuts**
  - **Energy rescaling**
  - **Kinematic fit**
- **Scan over the Higgs mass grid**
- **Indirect measurement of parameters of CP-violating MSSM scenario**

MSSM

CP-Conserving Scenario:

5 physical Higgs Bosons:

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

1 neutral CP-odd: A^0

2 charged: H^+, H^-

mass eigenstates = CP eigenstates

CP-Violating Scenario:

3 neutral Higgs Bosons:

$$H_1, H_2, H_3$$

$$M_{H_1} \leq M_{H_2} \leq M_{H_3}$$

have mixed CP parities

mass eigenstates $\neq$ CP eigenstates

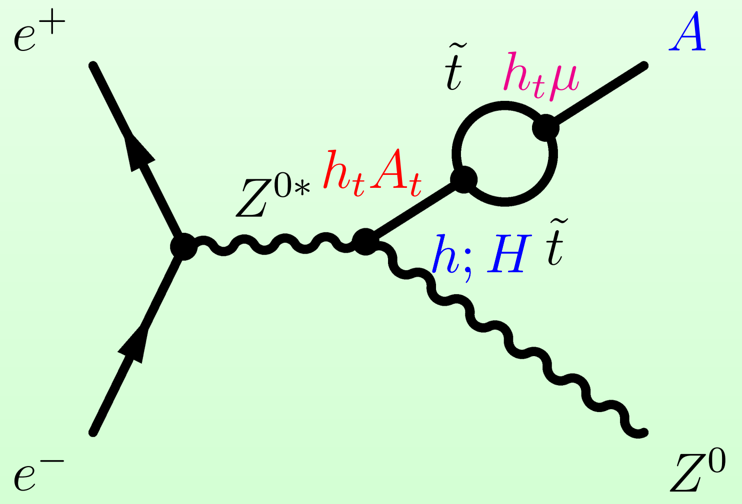
CP-Violation:

$A_{t,b}$ **- Complex** $m_{\tilde{g}}$ **- Complex**

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

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

Higgsstrahlung:

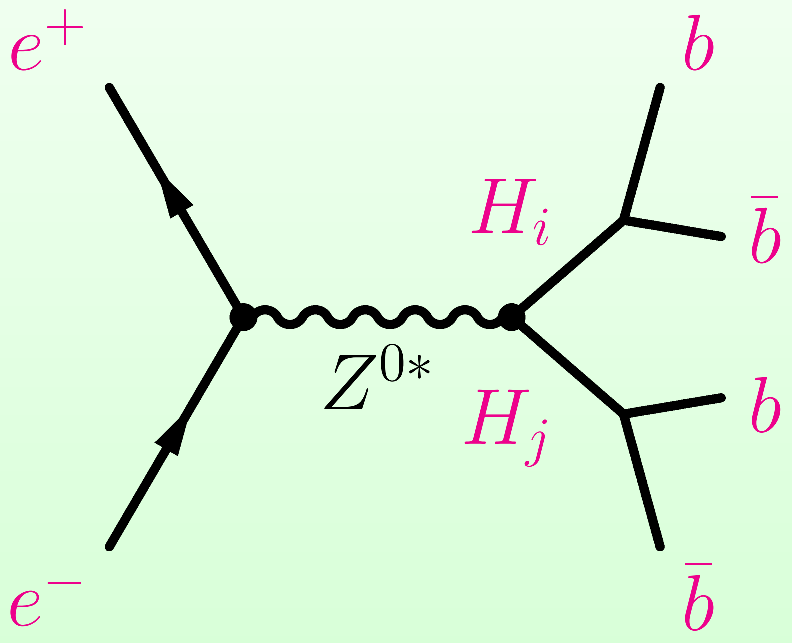


Parametrization of the Higgs sector:

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

TESLA

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



$$\sqrt{s} = 500GeV$$

$$L = 500fb^{-1}$$

Using:

- HZHA (from ALEPH): generation
- SIMDET 4.01: fast simulation
- ZV-TOP (from SLD): b-tagging
- Kinematic Fit (from DELPHI)

$(\sigma * BR)$ - ?

M_{H_i} - ? M_{H_j} - ?

Analysis of $e^+e^- \longrightarrow H_2H_3 \longrightarrow b\bar{b}b\bar{b}$ 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} = 112.0 GeV

M_{H_2} = 140.5 GeV

M_{H_3} = 154.7 GeV

$N_{events}(H_2H_3 \longrightarrow b\bar{b}b\bar{b})$ = 6305

Background: 9.4 million events

Signal and BG samples:

Process	σ [fb]
$H_1H_2 \longrightarrow b\bar{b}b\bar{b}$	0.4196
$H_2H_3 \longrightarrow b\bar{b}b\bar{b}$	12.61
$H_1H_3 \longrightarrow b\bar{b}b\bar{b}$	3.428
$Z^0\gamma^* \longrightarrow 2q$	13580
$W^+W^- \longrightarrow 4q$	4134
$Z^0Z^0 \longrightarrow 4q$	314.3
$H_1Z^0 \longrightarrow b\bar{b}q\bar{q}$	34.63
$H_2Z^0 \longrightarrow b\bar{b}q\bar{q}$	6.043
$t\bar{t} \longrightarrow W^+W^-b\bar{b}$	669.3

Cuts

Against 2-fermion background:

- Hadronic 4-jet events with full energy

Against 4-fermion background:

- Nonforward peaked and spherical events

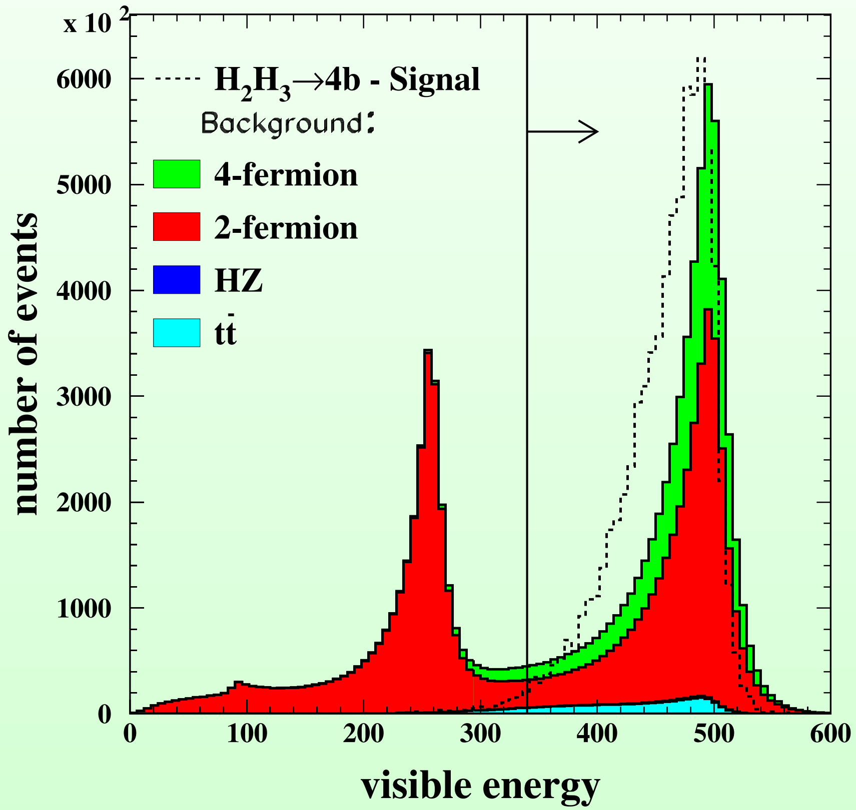
For $t\bar{t}$ background reduction:

- Number of tracks and clusters cut
- Jet resolution parameter cut

Against light flavour quarks:

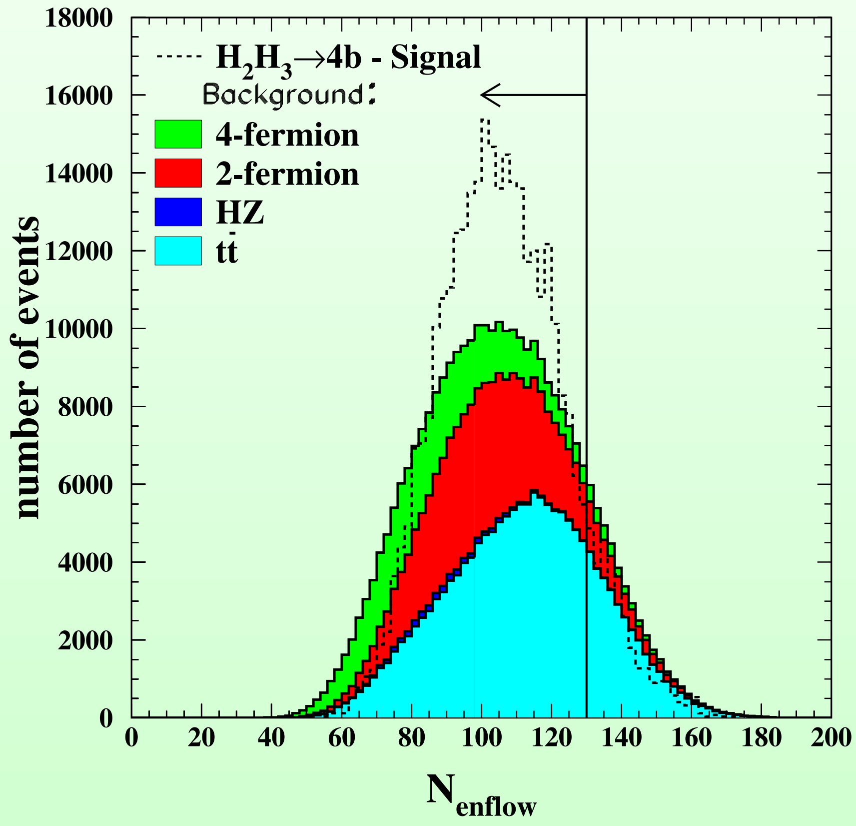
- b-Tag

Visible energy cut

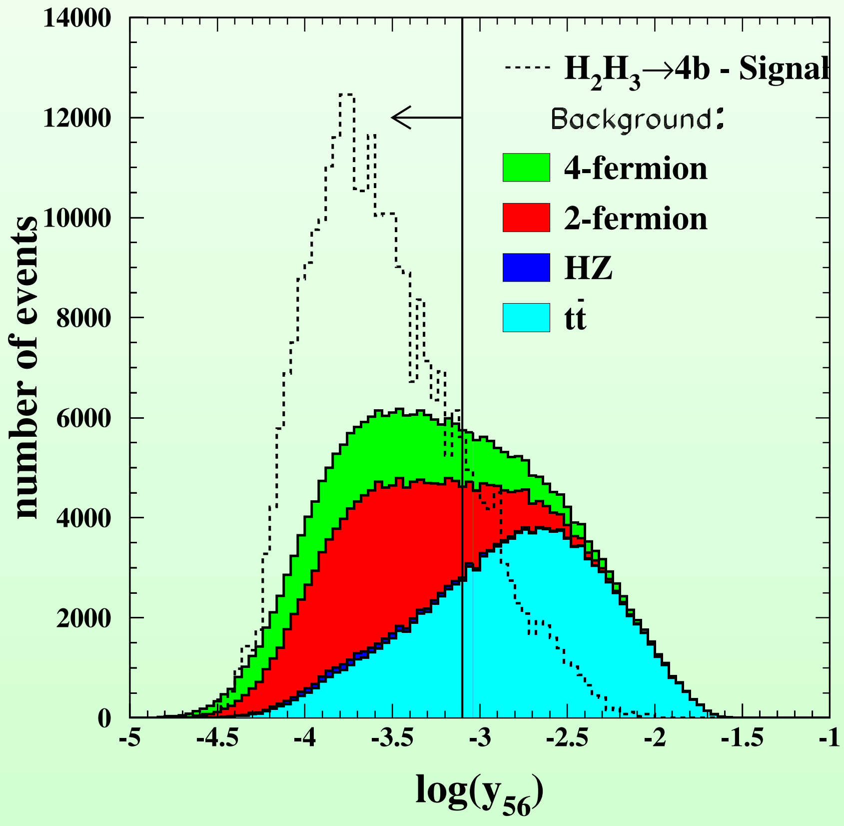


Cuts against $t\bar{t}$ background

Number of "enflow" objects cut



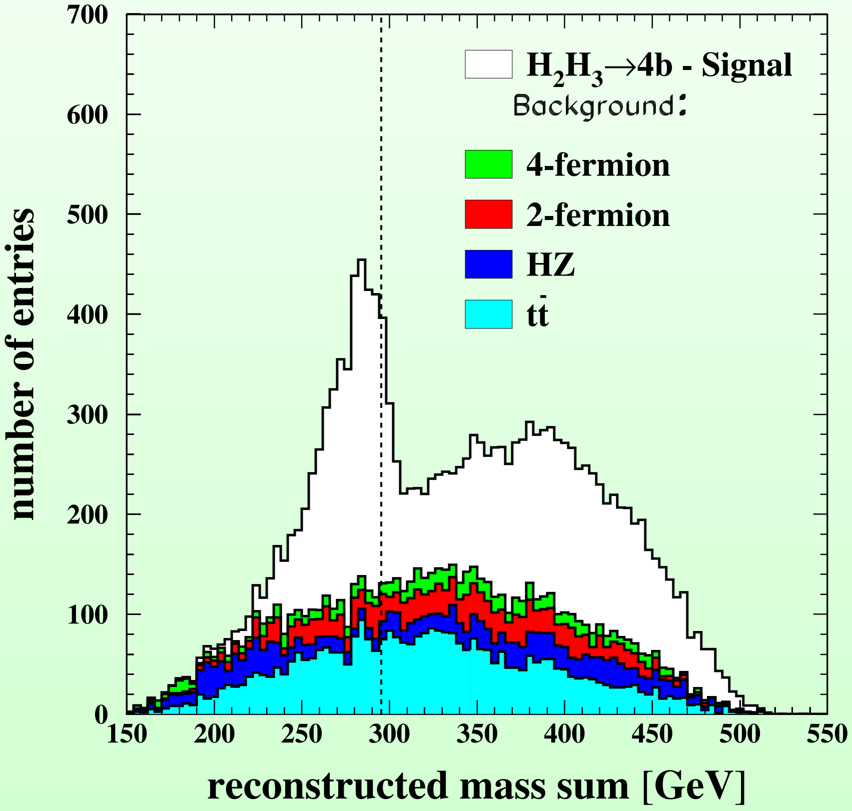
Jet resolution parameter cut



Cuts

Reconstructed Mass Sum after Cuts

3 combinations of 4 jets for 2 masses



Cutflow

Cut	Signal	Eff.	Total BG
no cuts	6305	100.0	9401167
N_{jets}	6305	100.0	9330067
P_{vis}	6247	99.1	6055178
N_{tr}/jet	5943	94.3	2692089
$\cos(thrust)$	5549	88.0	1371713
$thrust$	5189	82.3	339074
$\log(y_{34})$	5074	80.5	309670
N_{eflow}	4608	73.1	268184
$\log(y_{56})$	3853	61.1	150522
B_{12}	3777	59.9	43905
B_{34}	3042	48.3	2485

Mass reconstruction improvement

The reconstructed mass sum is shifted:

Missing energy from decay neutrinos.

$\Rightarrow$ **Energy rescaling:**

$$E_{jet}, \vec{p}_{jet} * \frac{\sqrt{s}}{E_{vis}}$$

$\Rightarrow$ **Kinematic Fit:**

Use of constraints.

$$4cfit : \begin{cases} \sum E_i = \sqrt{s} \\ \sum p_{xi} = 0 \\ \sum p_{yi} = 0 \\ \sum p_{zi} = 0 \end{cases}$$

Kinematic fit:

$$Q(\vec{y}, \vec{\lambda}) = (\vec{y} - \vec{y_0})^T V^{-1} (\vec{y} - \vec{y_0}) + 2\vec{\lambda}\vec{f}(\vec{y})$$

$\vec{f}(\vec{y})$ - constraints

$\vec{y}$ - jet parameters

$\vec{\lambda}$ - Lagrange multipliers

V - error matrix

Error matrix: resolution functions

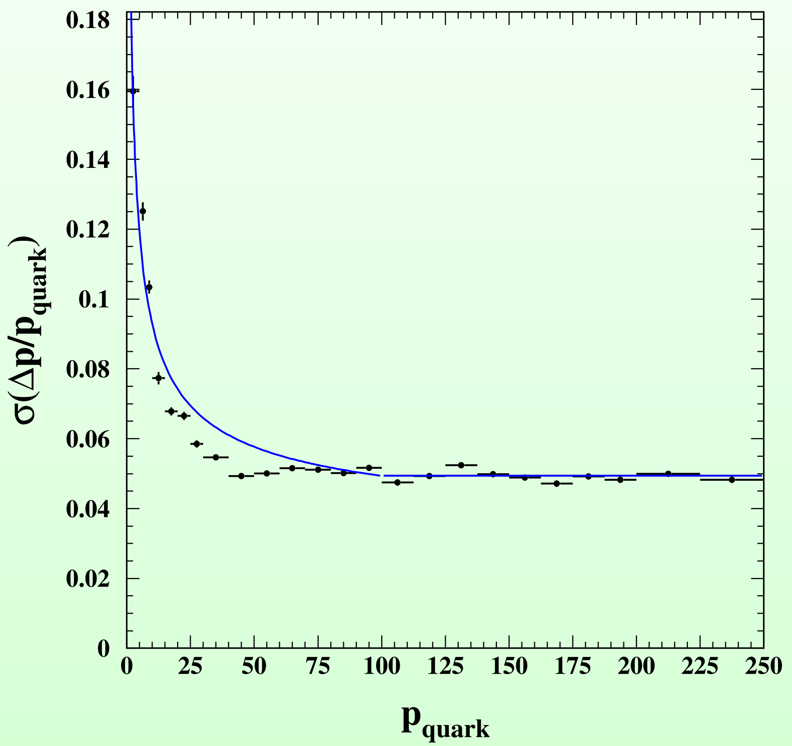
$$\sigma\left(\frac{p_{quark} - p_{jet}}{p_{quark}}\right)(p_{quark})$$

$$\sigma(\phi_{quark} - \phi_{jet})(p_{quark})$$

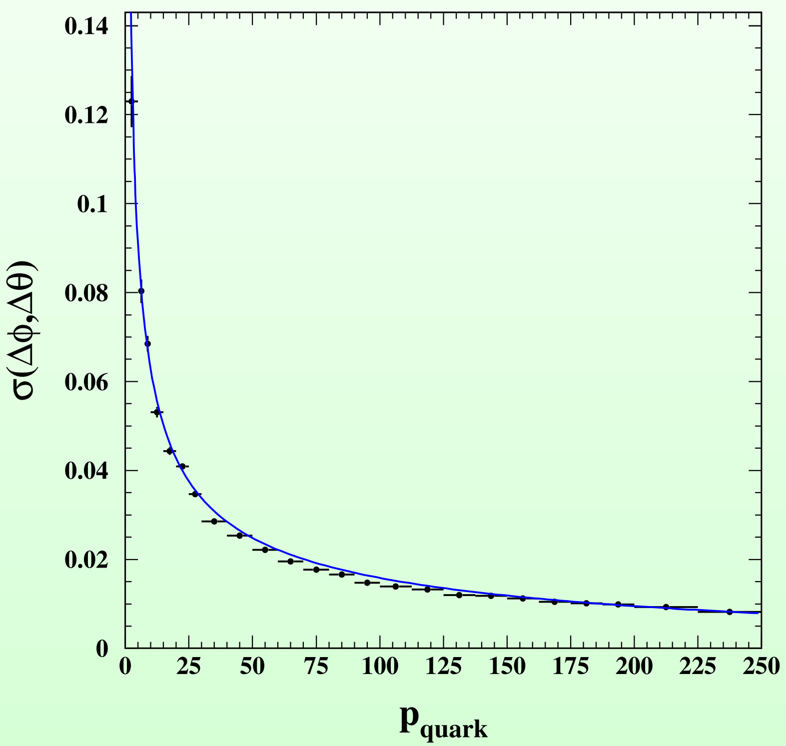
$$\sigma(\theta_{quark} - \theta_{jet})(p_{quark})$$

Resolution functions

Momentum resolution



Angular resolution

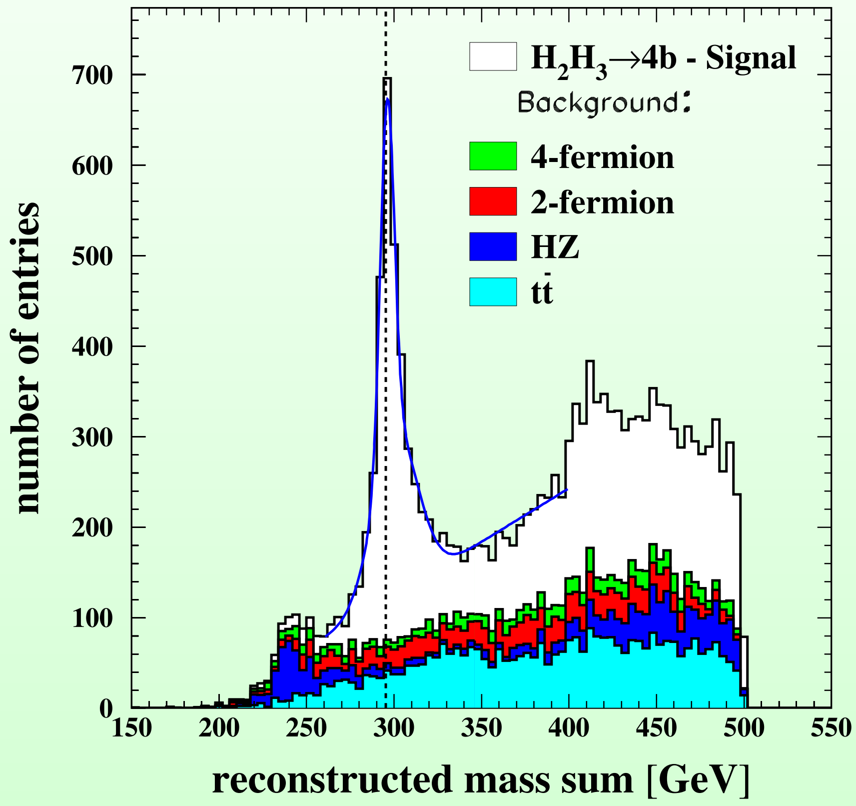


$$\sigma\left(\frac{\Delta p}{p_{quark}}\right) = \begin{cases} 0.03 + \frac{0.20}{\sqrt{p_{quark}}}, & p_{quark} < 100GeV \\ 0.05, & p_{quark} \geq 100GeV \end{cases}$$

$$\sigma(\Delta\phi, \Delta\theta) = -0.01 + \frac{0.21}{\sqrt{p_{quark}}}$$

Mass reconstruction after fit

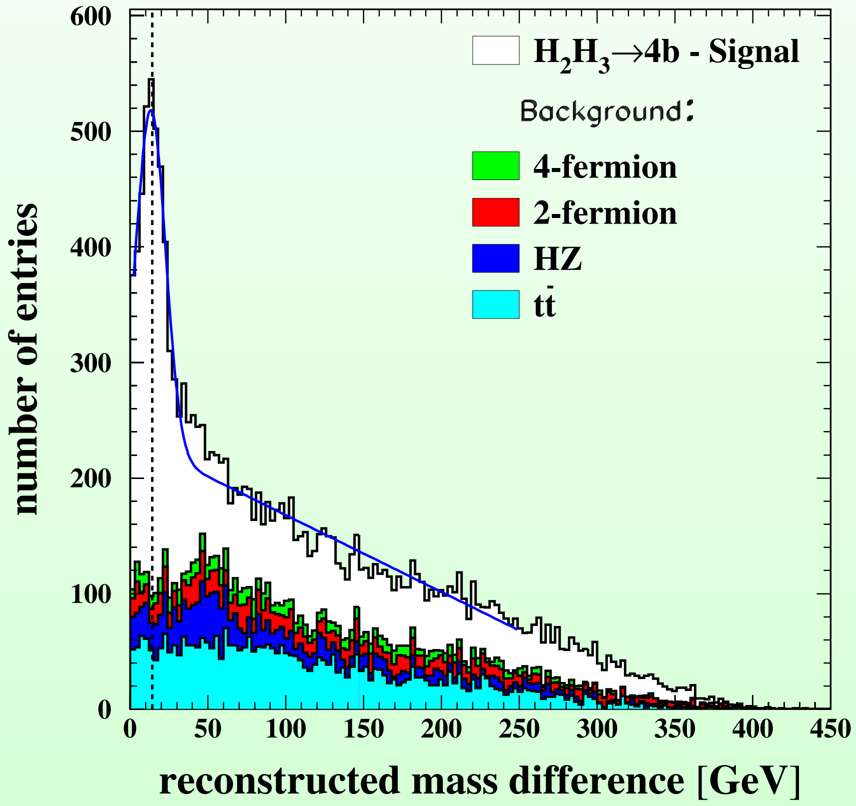
Reconstructed Mass Sum



ΣM = (296.1 $\pm$ 0.3) GeV

Width = (4.0 $\pm$ 0.5) GeV

Reconstructed Mass Difference

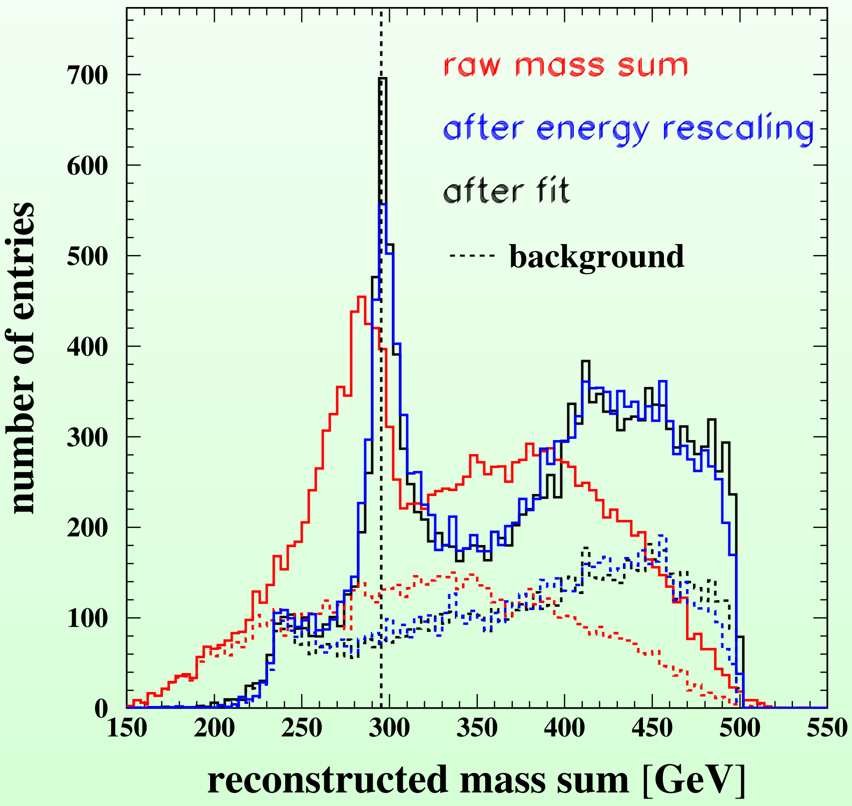


ΔM = (13.5 $\pm$ 0.4) GeV

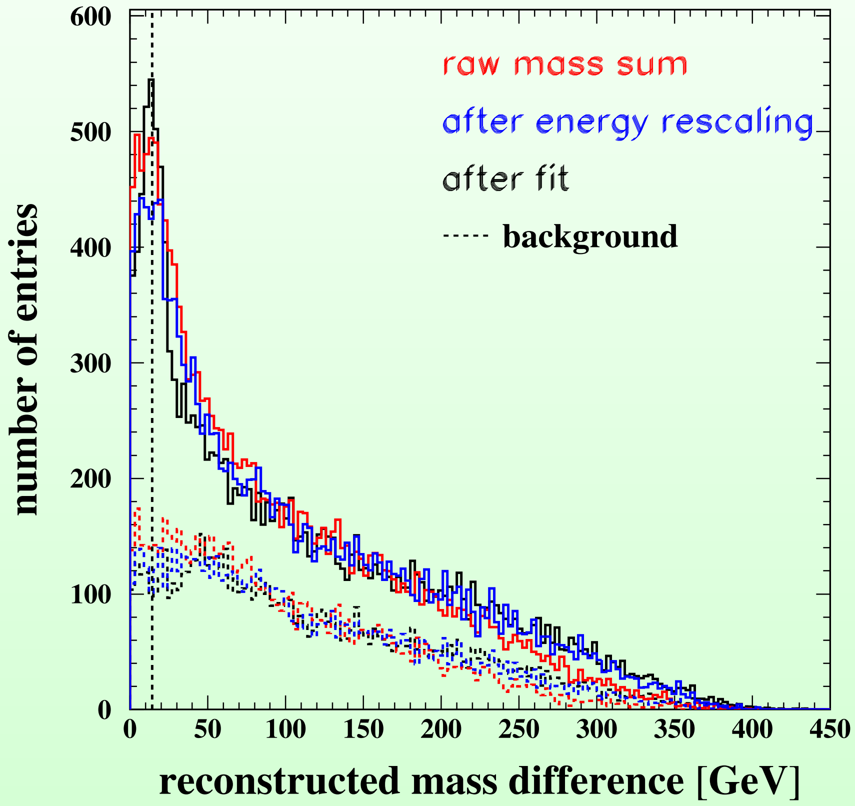
Width = (9.3 $\pm$ 0.6) GeV

Improved mass reconstruction

Mass Sum

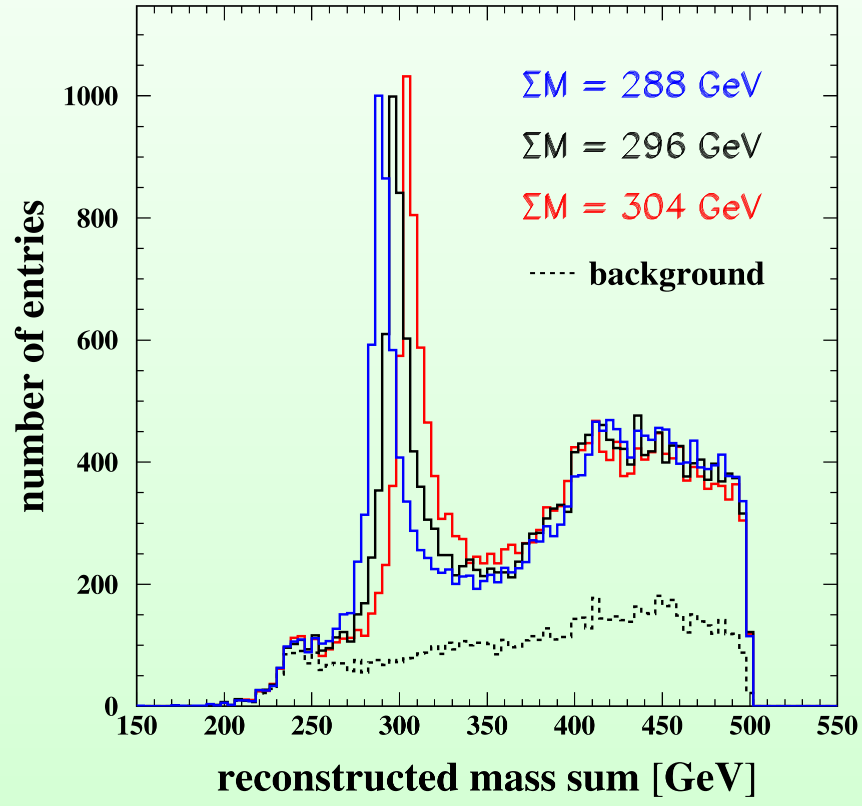


Mass Difference

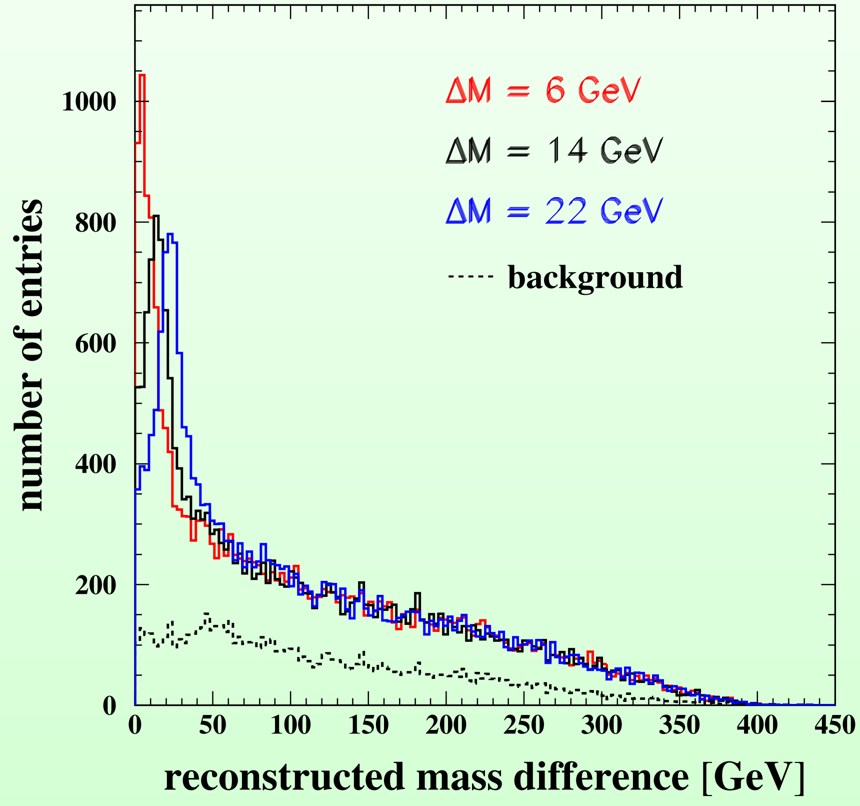


Mass distinction

Mass Sum



Mass Difference



Mass grid

N	(M_{H_2}, M_{H_3}) [GeV]	N_{events}	Eff. [%]	$\delta\sigma/\sigma$ [%]
1	(90,100)	15000	4.09	26.93
2	(100,150)	12100	45.13	1.66
3	(100,200)	9140	43.17	2.11
4	(100,250)	6000	37.16	3.04
5	(140,150)	10300	47.88	1.78
6	(150,200)	6810	43.78	2.55
7	(150,250)	3850	37.70	4.21
8	(190,200)	4650	39.23	3.27
9	(200,250)	1550	31.58	8.52
10	(240,250)	150	25.44	44.19
an.point	(141,155)	6305	48.30	2.28

$\sqrt{s}$ = 500 GeV

L = 500 fb^{-1}

BR($H \rightarrow b\bar{b}$) = 0.85

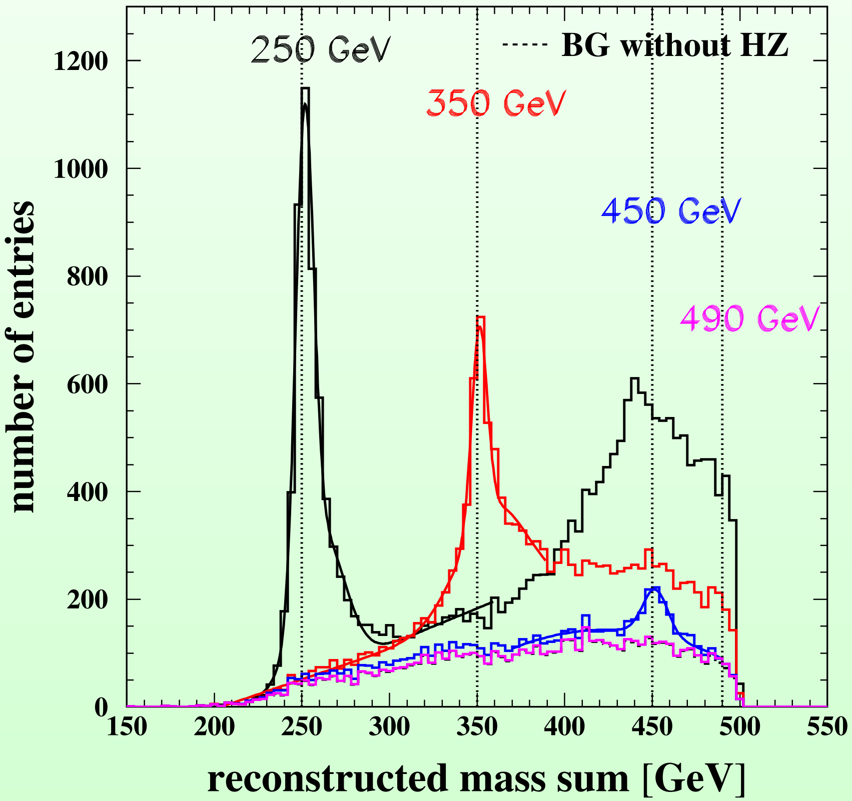
$$\sin^2(\beta - \alpha) = 1$$

Cross section relative error:

$$\frac{\sqrt{N_{Signal}+N_{BG}}}{N_{Signal}}$$

Mass grid

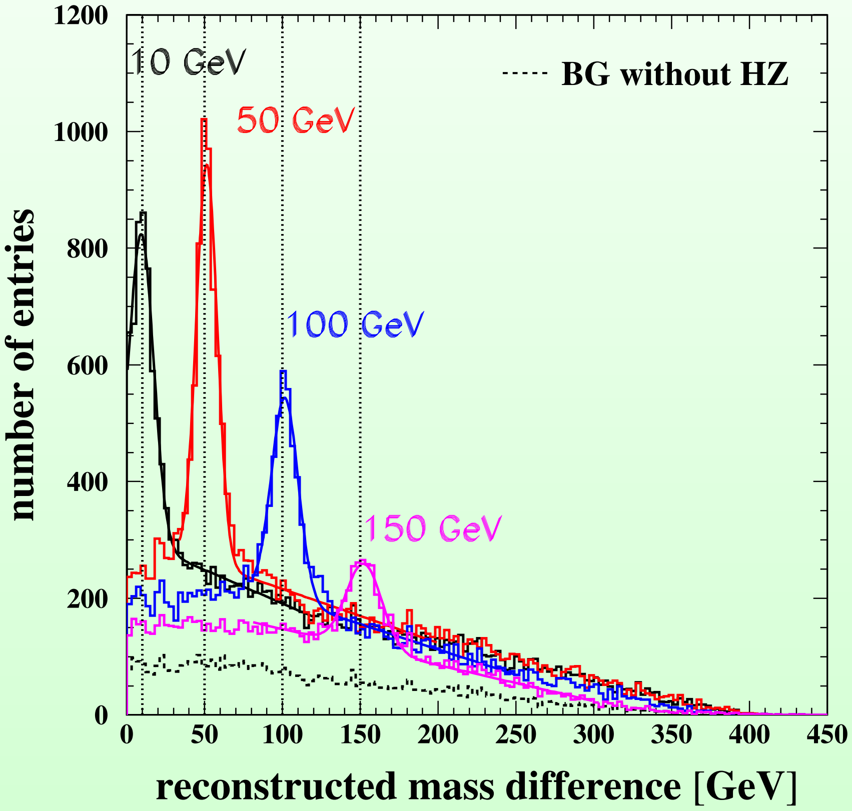
Reconstructed Mass Sum



ΣM_{point}	ΣM_{rec} [GeV]	Width [GeV]
250	251.52 ± 0.18	5.11
(295)	296.10 ± 0.30	4.00
350	351.31 ± 0.30	4.43
450	451.70 ± 0.92	7.11

Mass grid

Reconstructed Mass Difference



ΔM_{point}	ΔM_{rec} [GeV]	Width [GeV]
10	9.37 ± 0.31	7.91
50	51.42 ± 0.17	6.73
100	101.57 ± 0.30	8.65
150	152.42 ± 0.59	11.51

Measurement of parameters of CP-violating MSSM scenario

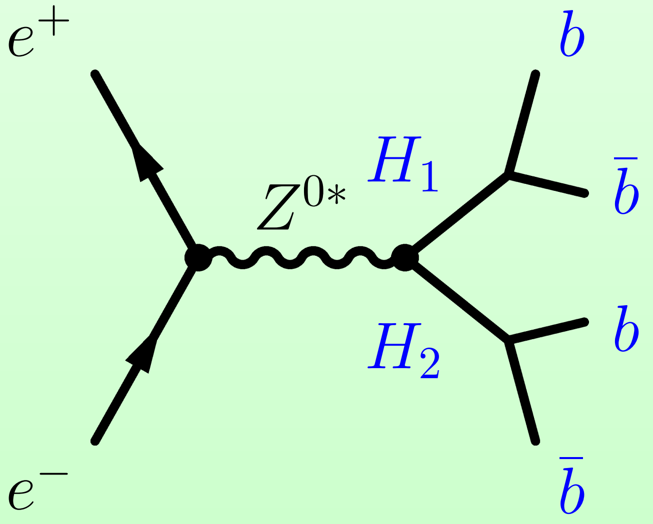
CP-Violating Scenario:

$\boxed{A_{t,b}}$ **- Complex** $\boxed{m_{\tilde{g}}}$ **- Complex**

We measured: $\sigma * BR$, ΣM, ΔM

$\Rightarrow$**We know:** $\boxed{\sigma * BR}$ $\boxed{M_{H_i}}$ $\boxed{M_{H_j}}$

Example:



We know:

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

with precision 10 %

$$M_{H_1}, M_{H_2}$$

with precision 1 GeV

It is found:

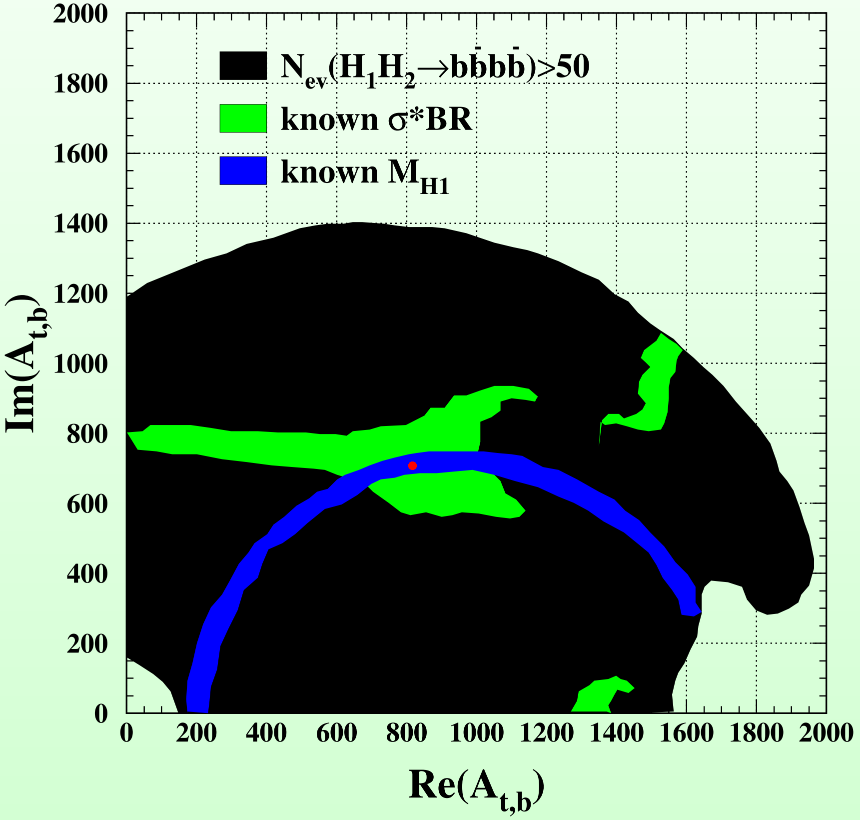
we can measure $\boxed{\arg(A_{t,b})}$

(indirect)

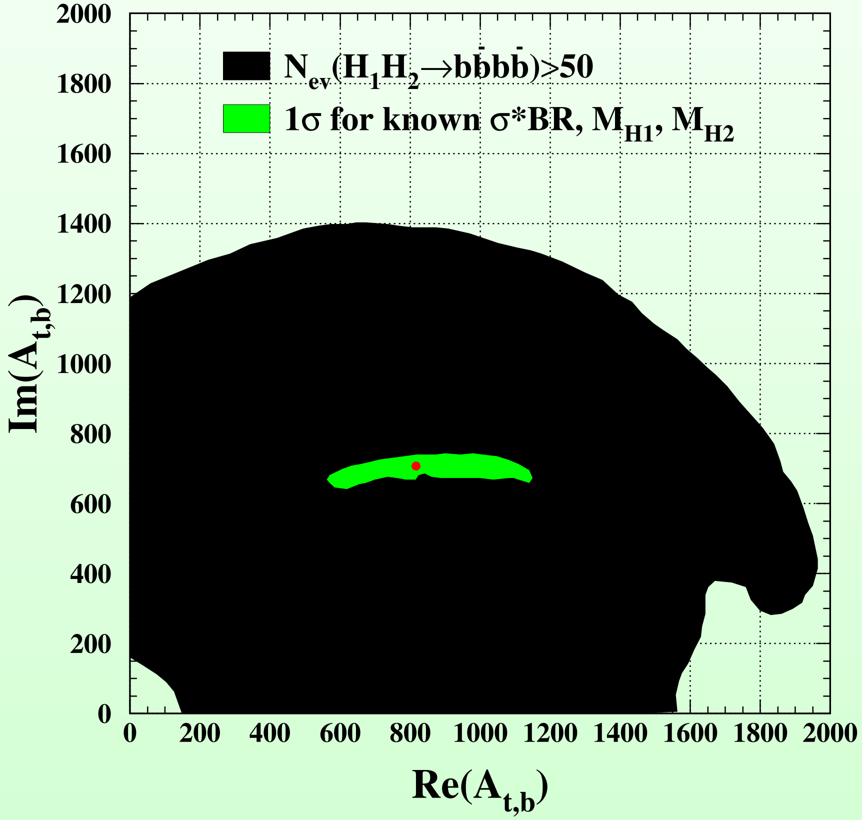
2-Parameter Scan

$\sqrt{s} = 500 GeV \quad L = 500 fb^{-1}$ $\quad \tan\beta = 3 \quad M_{H^+} = 200 GeV$

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



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



Sensitivity:

$$Re(A_{t,b}) = (800 \pm 300) GeV$$
$$Im(A_{t,b}) = (700 \pm 50) GeV$$

Summary

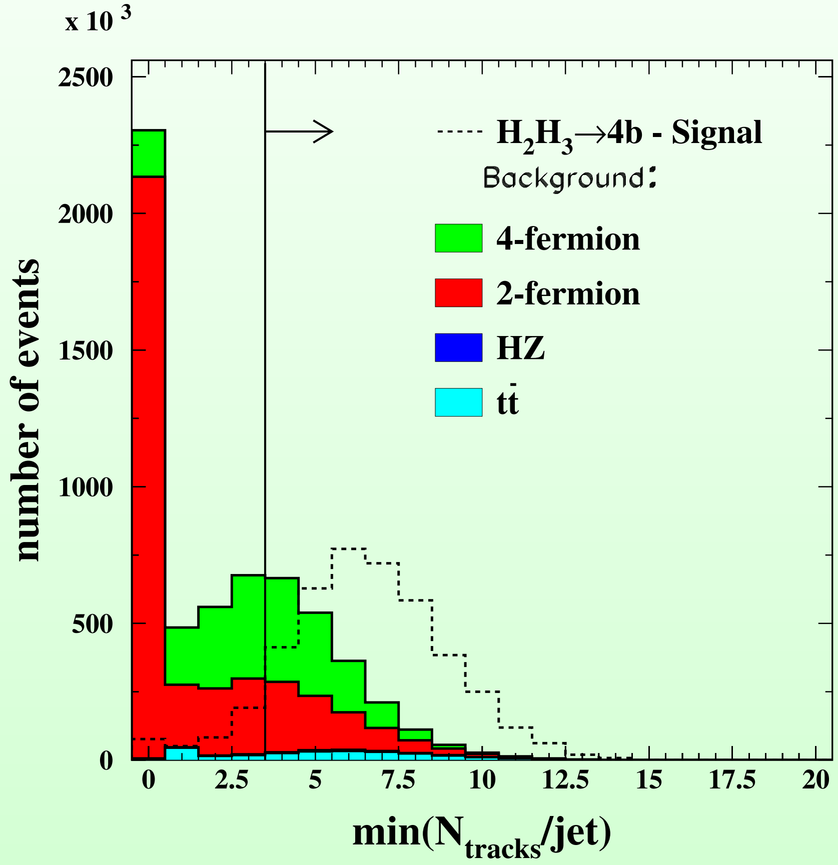
- Cut analysis for the process $e^+e^- \to H_iH_j \to b\bar{b}b\bar{b}$ at TESLA is made.
- Kinematic fit for the mass spectra is promising. Accuracy for the Higgs mass determination is several hudred MeV.
- Analysis is extended into the Higgs mass grid.
- Relative errors for the cross section are estimated.
- The prospects for CP-violating MSSM parameters measurements at TESLA are good.

Outlook

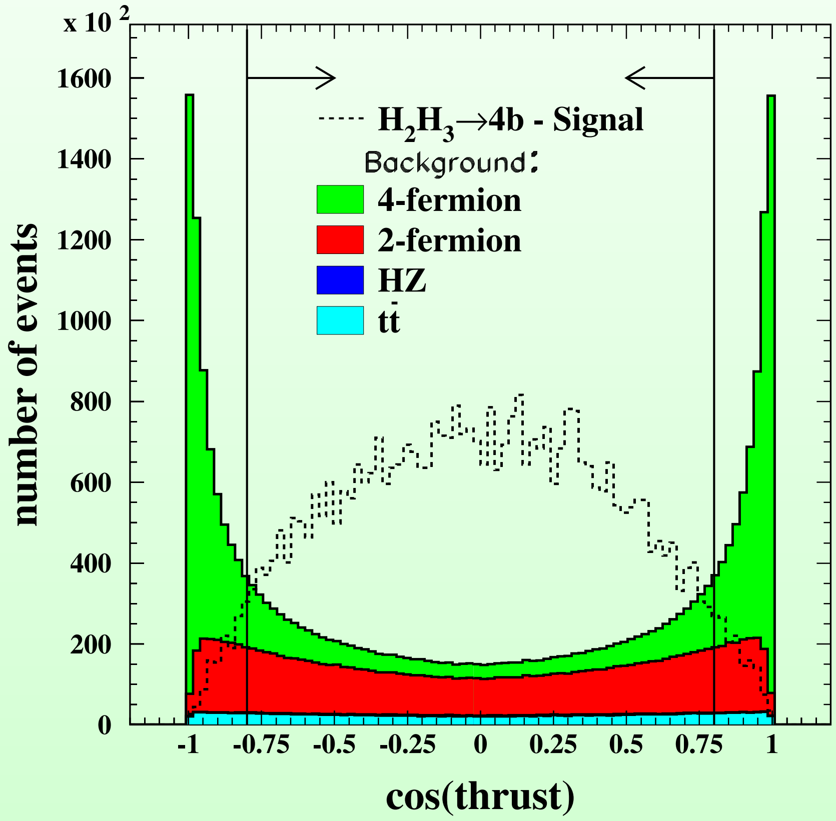
- **Analysis improvement:**
  - Implementation of the lepton veto against $t\bar{t}$ background.
  - s' tag.
  - Proper treatment of the HZ background for the mass grid.
- **Interpretation:**
  - Combined $4b$, $b\bar{b}\tau^+\tau^-$ and HZ analysis.
  - Interpretation for the Snowmass points in MSSM.
  - Analysis in the frame of CP-violating scenario.
  - Model independent interpretation.

Cuts

$min(N_{tracks}/jet)$

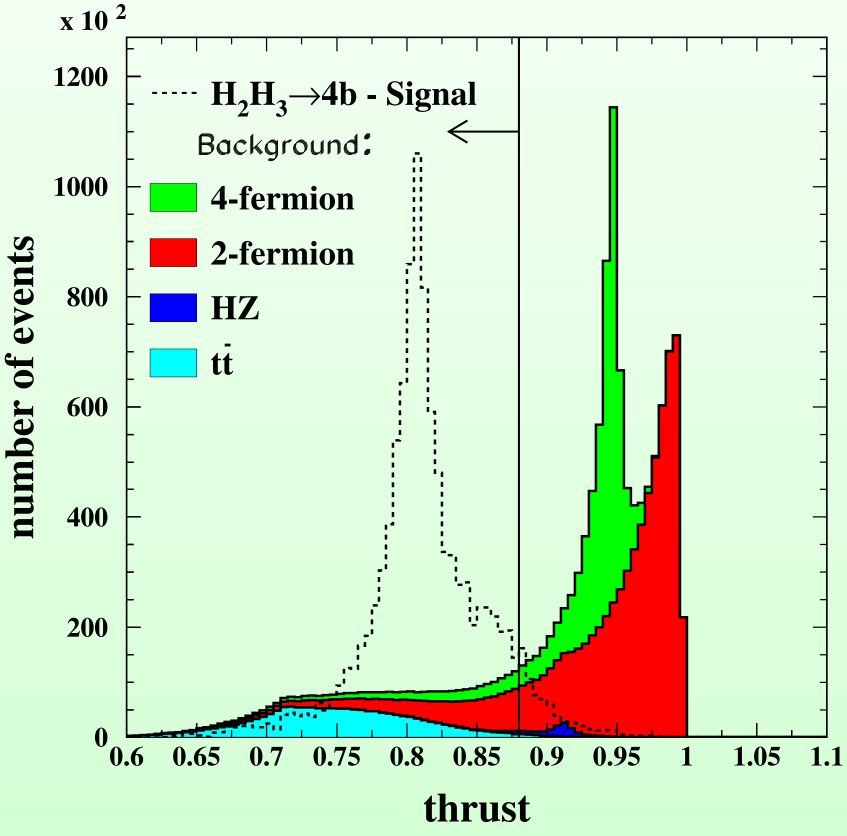


$cos(thrust)$

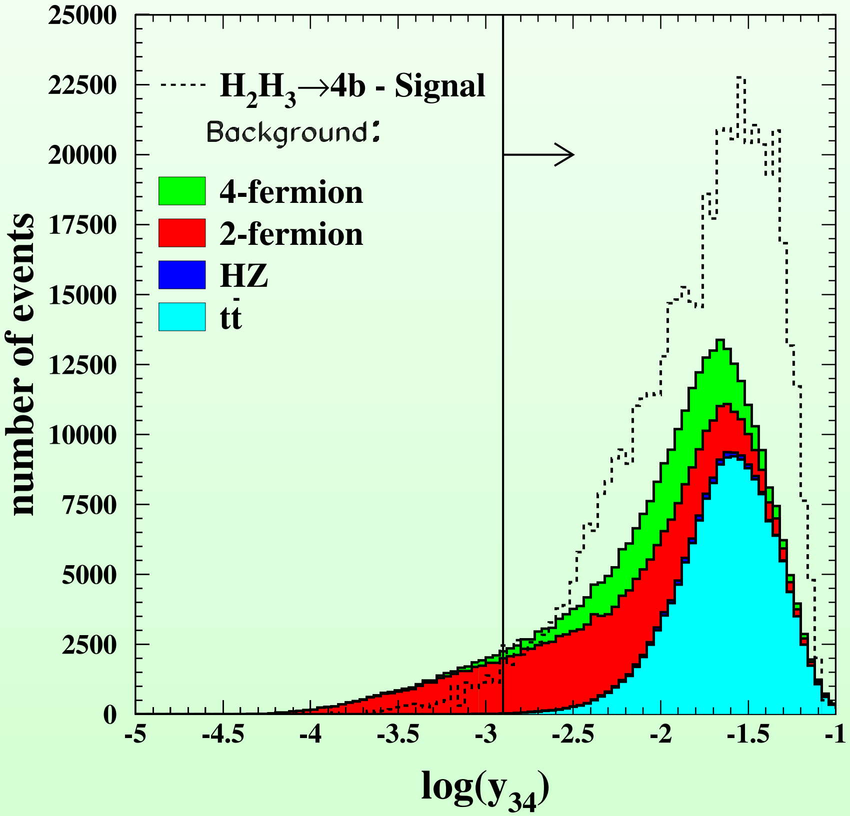


Cuts

thrust value

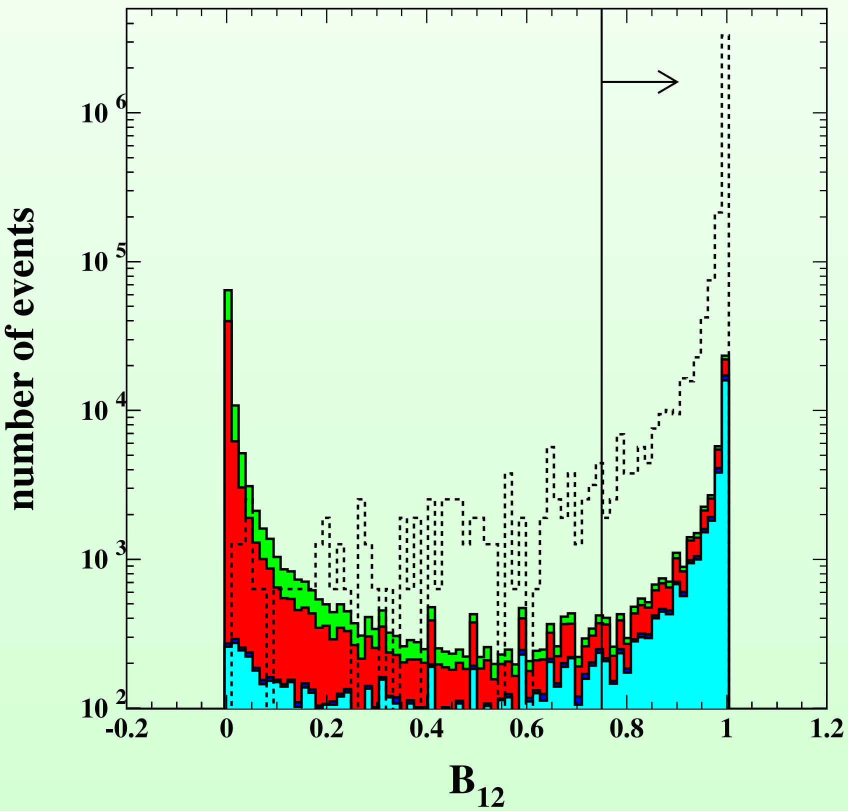


$log(y_{34})$



Cuts

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



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