MSSM Higgs Boson Pair Production at 800 GeV and Final Results for 500 GeV.

Tatsiana Klimkovich

Alexei Raspereza

DESY, Hamburg

Contents

- Motivation
- MSSM scenario
- Analysis of the processes

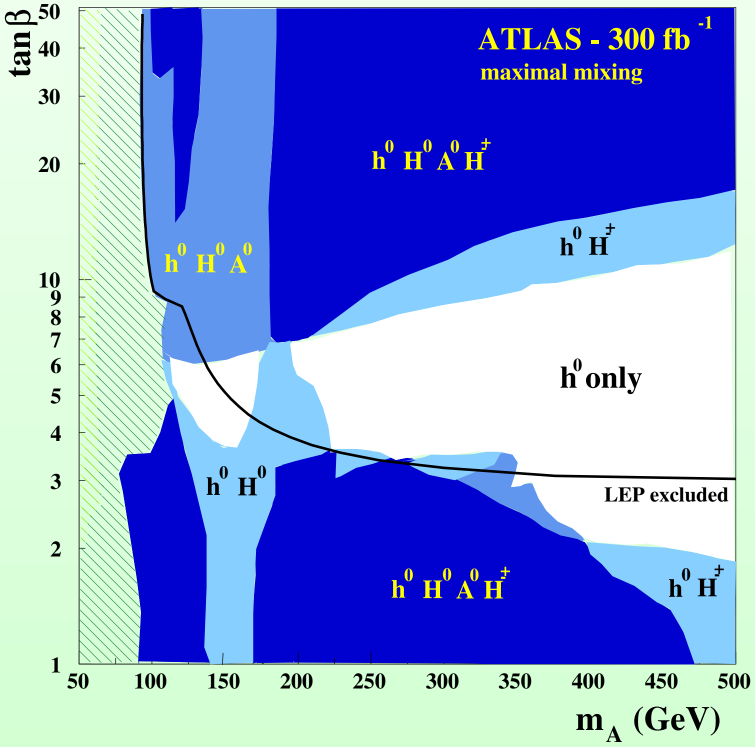
$$e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$$
$$e^+e^- \rightarrow HA \rightarrow b\bar{b}\tau^+\tau^-$$
$$e^+e^- \rightarrow HA \rightarrow \tau^+\tau^-b\bar{b}$$

- Scan over different Higgs mass combinations
- First try of the Higgs width reconstruction

Motivation

- Heavy neutral Higgs bosons are not well studied for TDR
  - discovery reach?
  - precision of mass, cross-section, branching ratios?
  - width?
- Basis for quantitative comparison with single production at $\gamma\gamma$-collider ($\gamma\gamma \to A, \gamma\gamma \to H$)

- LHC "wedge" region $\Longrightarrow$ might even be a "discovery channel"!



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

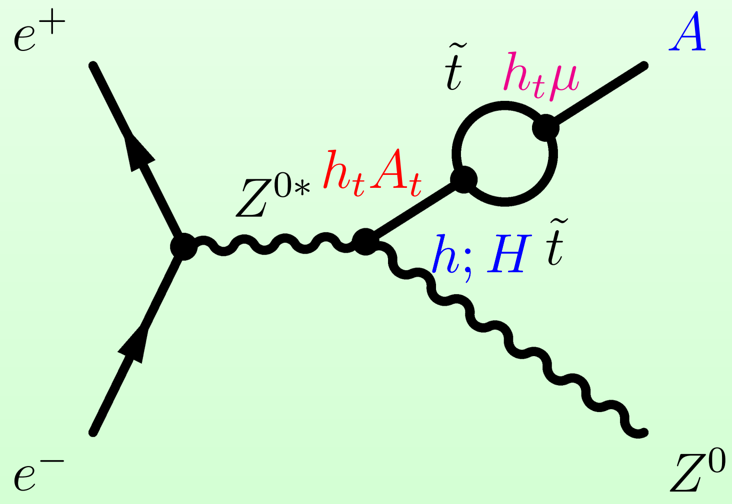
CP-Violation:

$A_{t,b}$ **- 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:

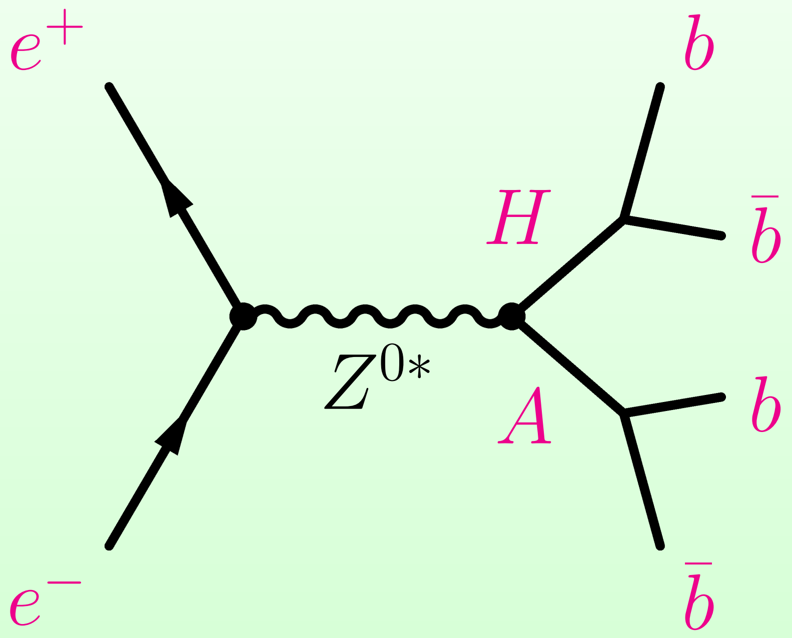
M_{H^+} **and** $tan\beta = \frac{v_2}{v_1}$

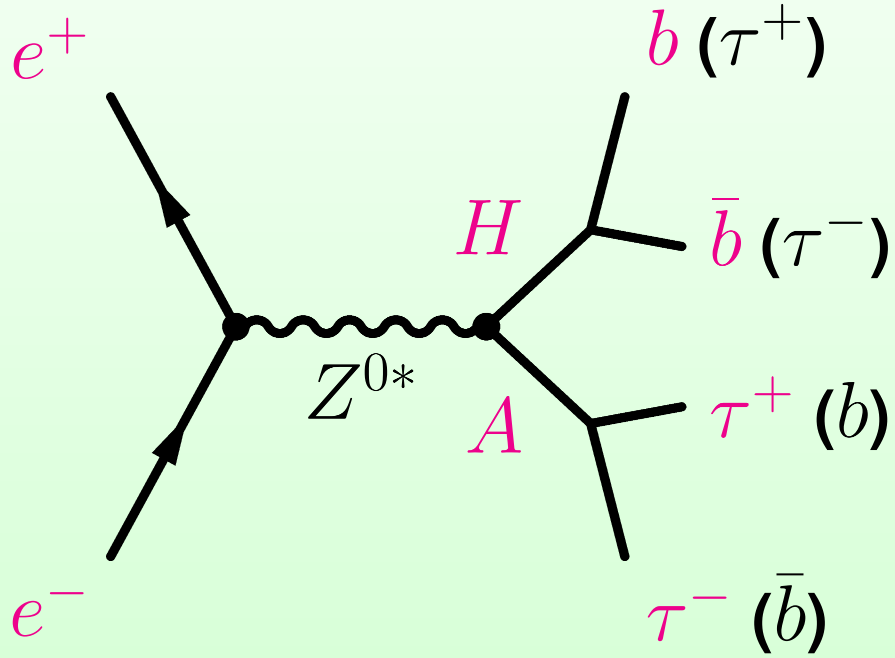
MSSM Higgs Pair Production

Two model independent analyses:

$HA \to b\bar{b}b\bar{b}$

$HA \to b\bar{b}\tau^+\tau^-$ **(**$\tau^+\tau^- b\bar{b}$**)**





$\sqrt{s} = 500GeV, 800GeV$

$L = 500 fb^{-1}$

($\sigma * BR$) - ?

M_H - ? M_A - ?

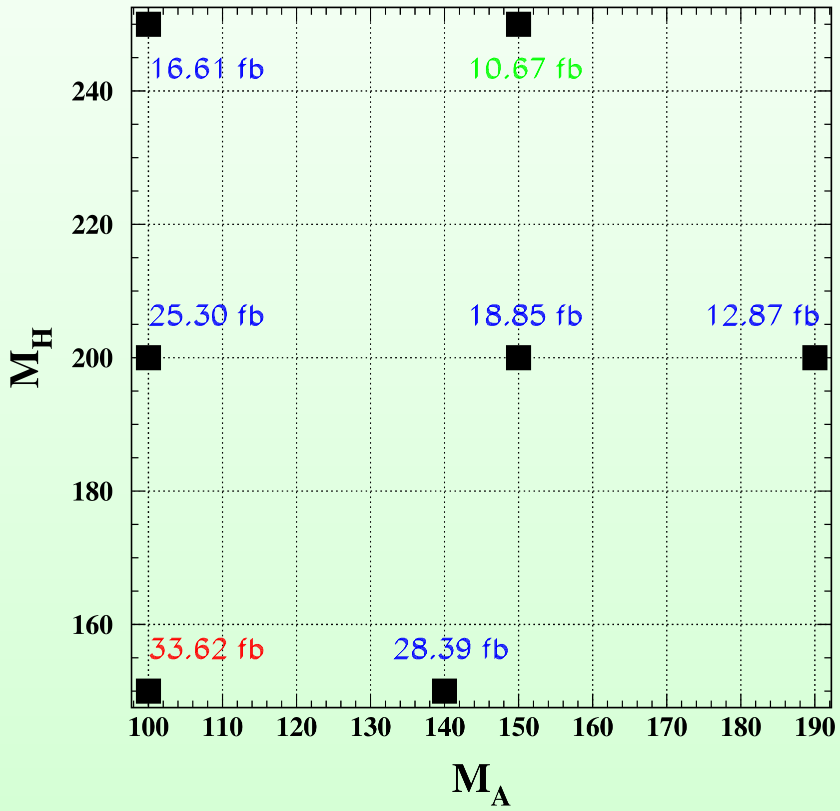
$\Gamma_{H,A}$ - ?

Tools

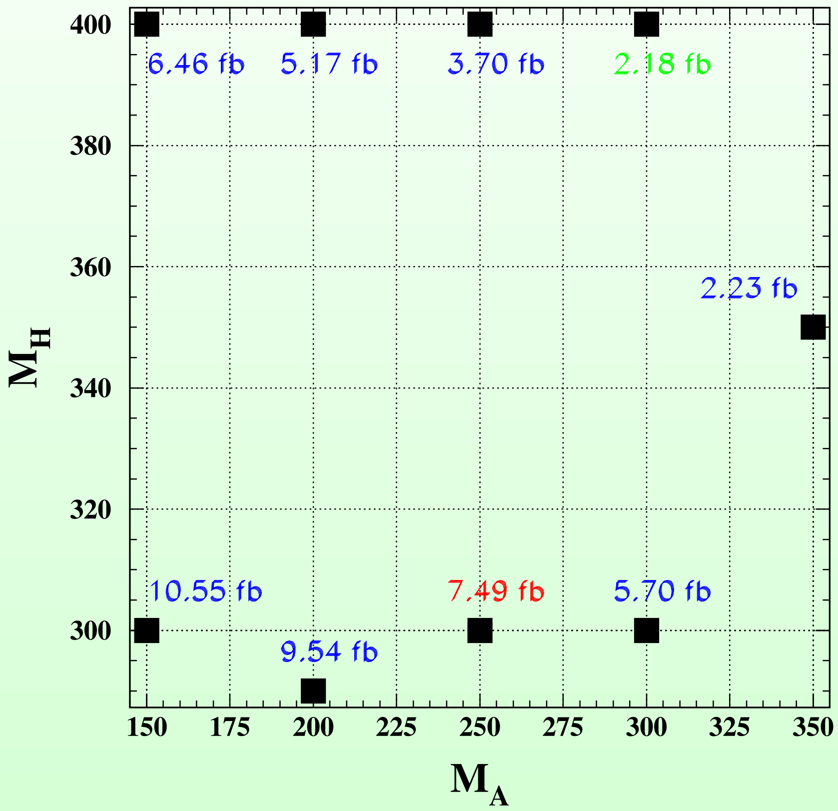
- PYTHIA: event generation (signal and background)
- CIRCE: beamstrahlung
- SIMDET 4.01: fast simulation
- ZV-TOP (from SLD): b-tagging
- Kinematic Fit (from DELPHI)
- Lepton ID (A. Raspereza)

Mass combinations

500 GeV



800 GeV



Assumptions:

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

BR($H, A \to b\bar{b}$) **= 0.85**

BR($H, A \to \tau^+\tau^-$) **= 0.15**

$\Big\}$ **typical in MSSM**

$e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$

BG samples:

Process	$\sigma \times BR$ [fb]	
	500 GeV	800 GeV
$Z^0Z^0 \rightarrow 4q$	314.3	174.3
$W^+W^- \rightarrow 4q$	4134.0	2335.0
$Z^0/\gamma^* \rightarrow 2q$	13580.0	5453.0
$t\bar{t} \rightarrow W^+W^-b\bar{b}$	669.3	165.2

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 (for 500 GeV)
- Jet resolution parameter cut

Against light flavour quarks:

- b-Tag

$e^+e^- \rightarrow HA \rightarrow b\bar{b}\tau^+\tau^-$

BG samples:

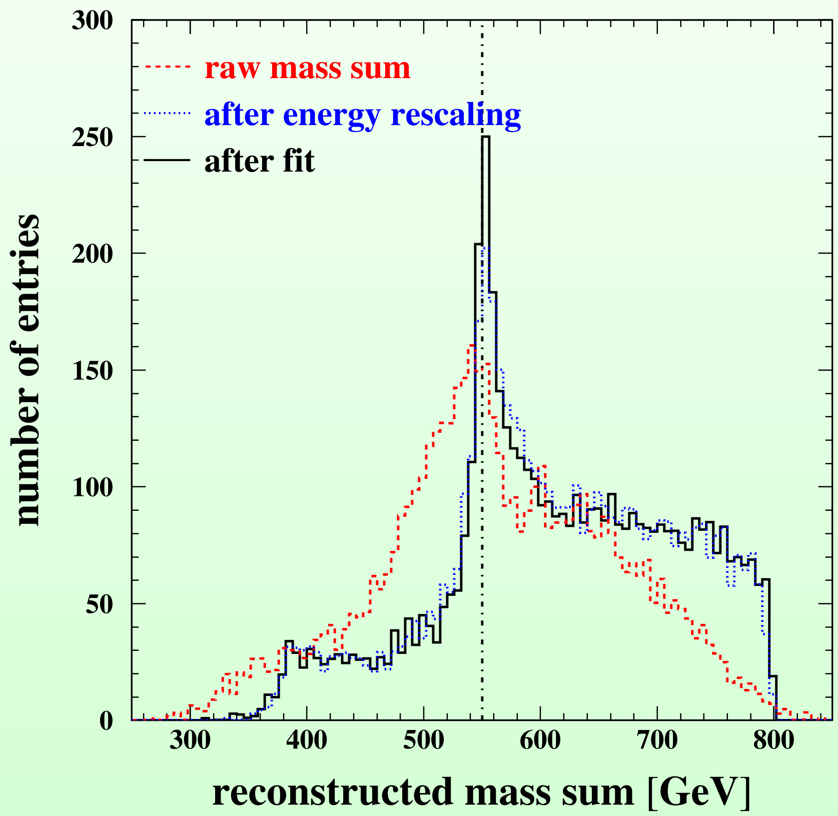
Process	$\sigma \times BR$ [fb]	
	500 GeV	800 GeV
$Z^0Z^0 \rightarrow 4q$	314.3	174.3
$Z^0Z^0 \rightarrow q\bar{q}l^+l^-$	89.0	49.8
$Z^0Z^0 \rightarrow q\bar{q}\nu^+\nu^-$	178.0	99.6
$W^+W^- \rightarrow 4q$	4134.0	2335.0
$W^+W^- \rightarrow q\bar{q}l\nu_l$	3730.0	2197.6
$Z^0/\gamma^* \rightarrow 2q$	13580.0	5453.0
$t\bar{t} \rightarrow W^+W^-b\bar{b}$	669.3	165.2
$We\nu \rightarrow q\bar{q}e\nu$	5080.0	-
$Ze^+e^- \rightarrow q\bar{q}e^+e^-$	4460.0	-

Analysis Strategy

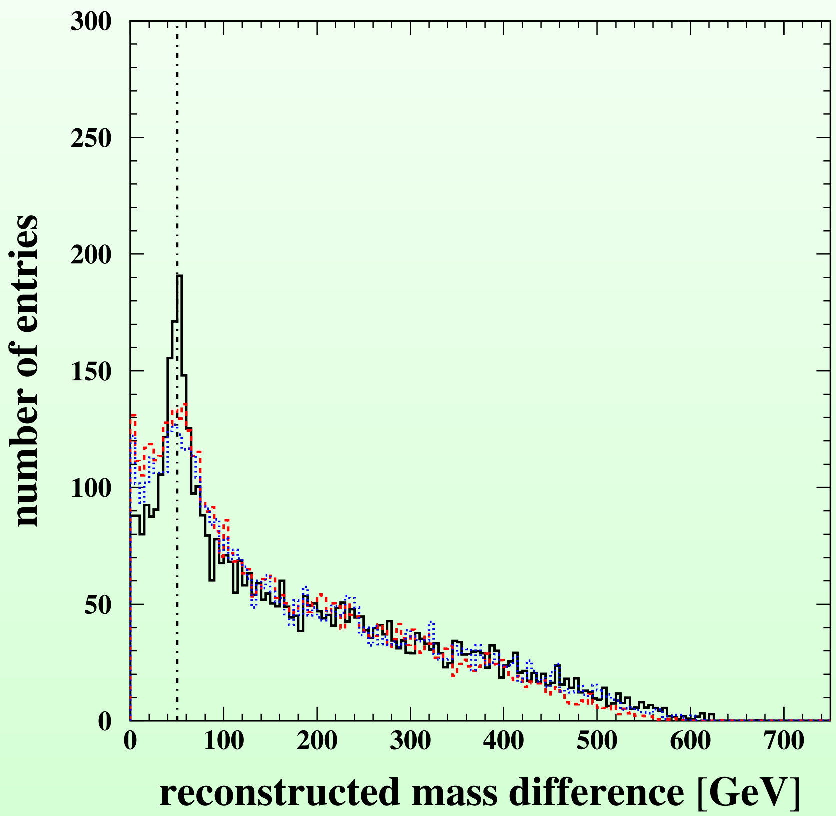
- Selection 4-jet events
- 2 b-jets + 2 τ-jets
- Kinematic fit $\Longrightarrow$ improvement of mass resolution
- Analysis of $m_{b\bar{b}}$ and $m_{\tau^+\tau^-}$ spectra $\Longrightarrow$ mass and cross section determination

Improved mass reconstruction for $b\bar{b}b\bar{b}$ at 800GeV

Mass Sum



Mass Difference

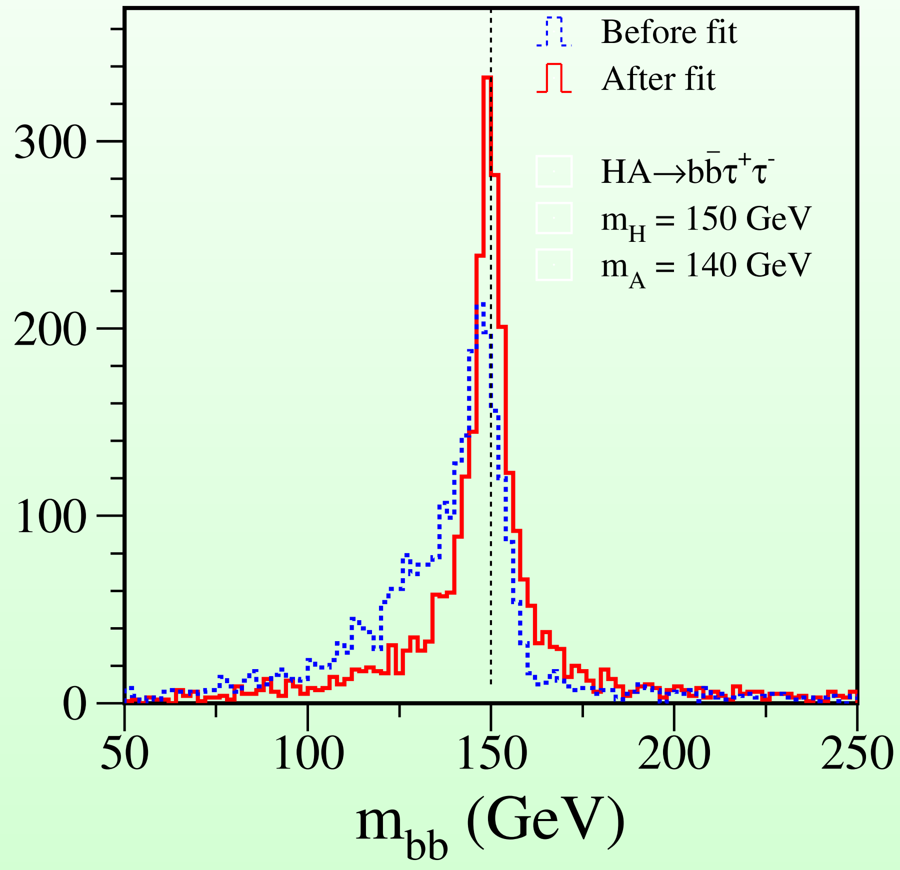


Energy rescaling: $E_{jet}, \vec{p}_{jet} * \frac{\sqrt{s}}{E_{vis}}$

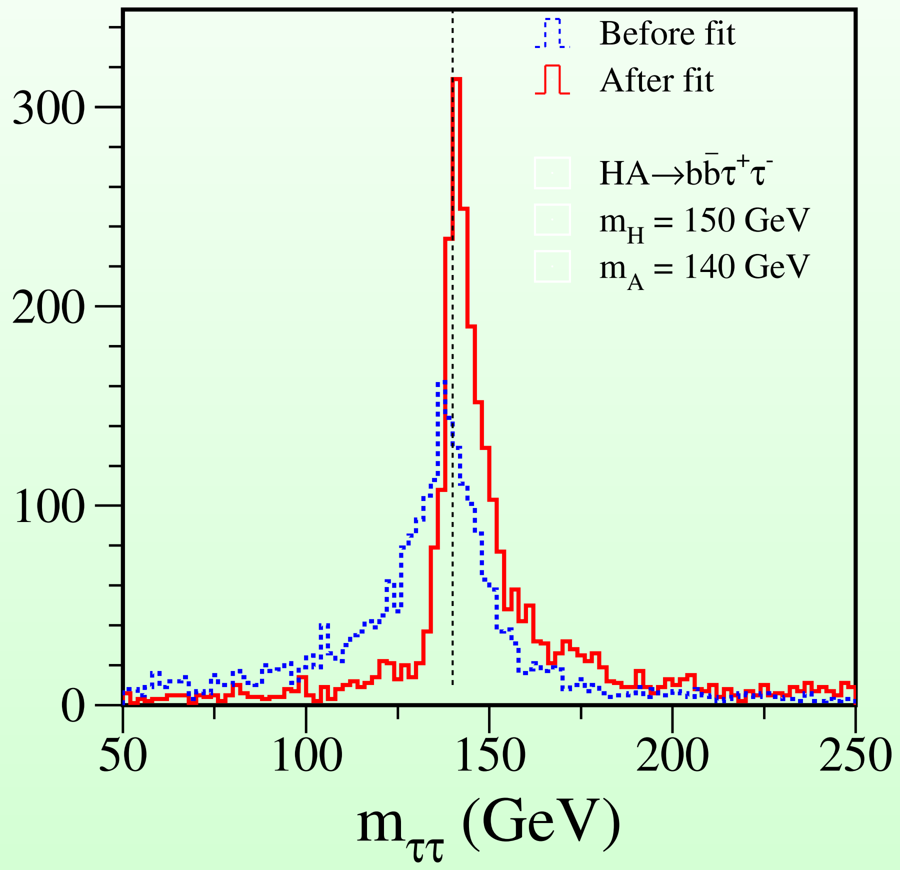
Kinematic fit: 4 constraints (E,p)

Improved mass reconstruction for $b\bar{b}\tau^+\tau^-$ at 500GeV

Reconstructed dijet mass



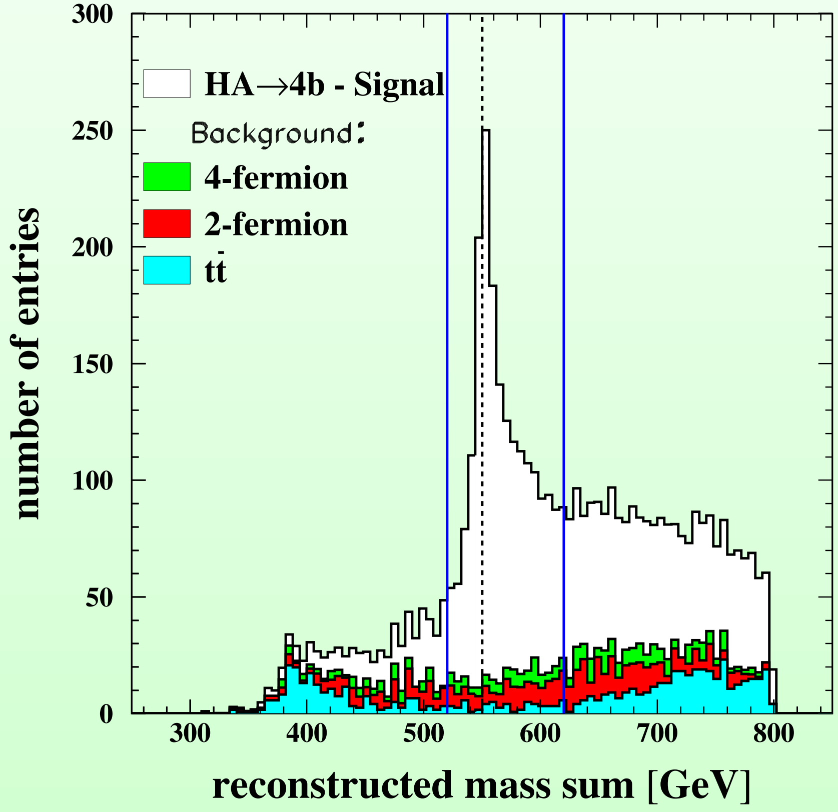
Reconstructed ditau mass



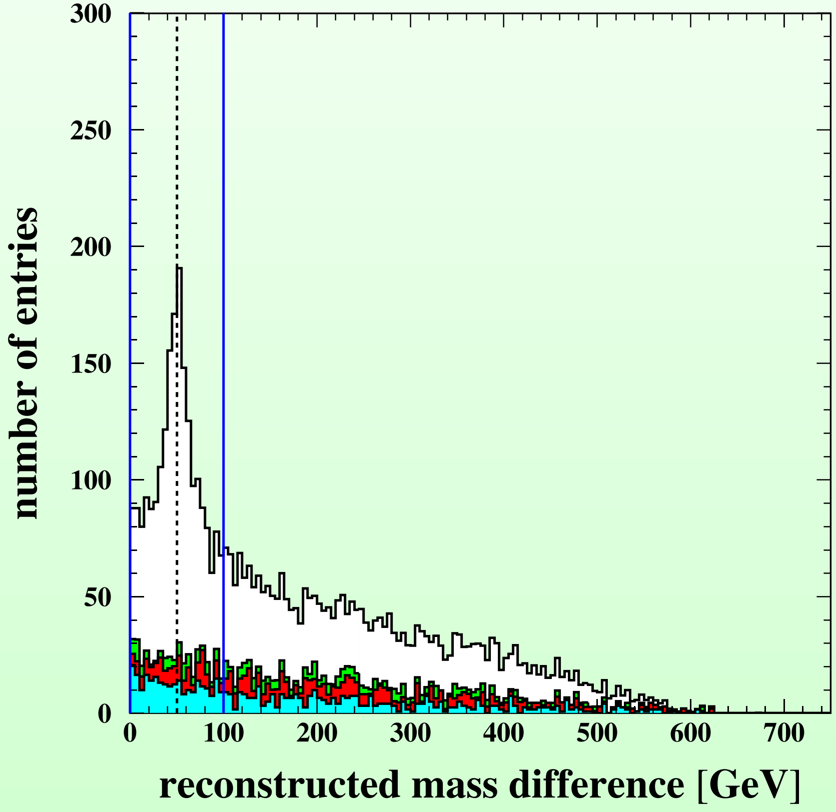
2c fit: directions of τ decay products = direction of τ, 4P conservation

Mass reconstruction after fit for $b\bar{b}b\bar{b}$ at 800 GeV

Reconstructed Mass Sum

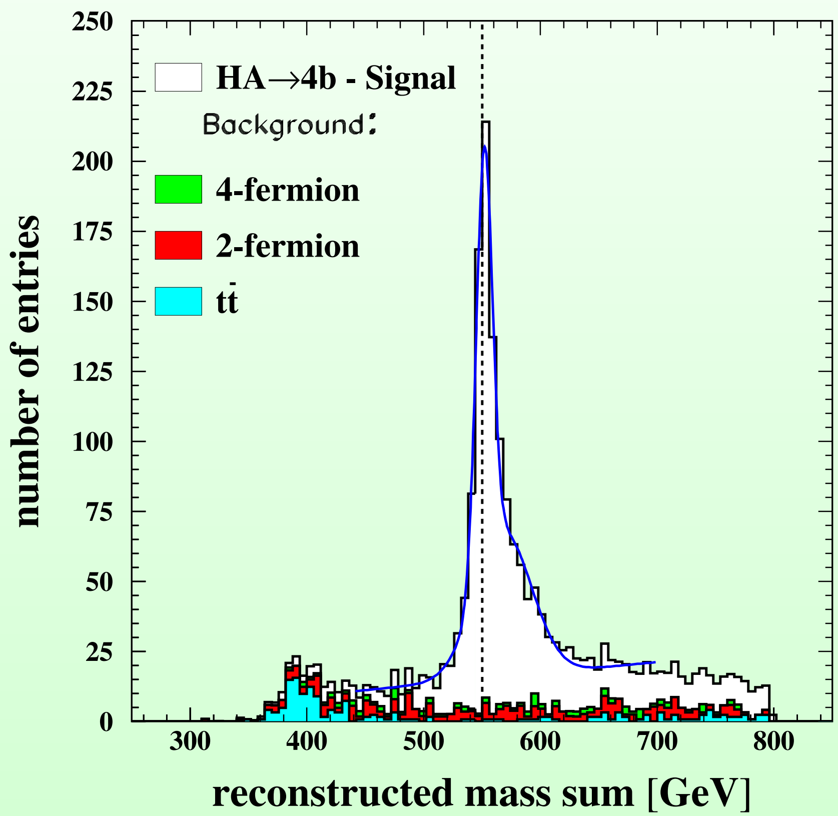


Reconstructed Mass Difference



Fitting mass spectra for $b\bar{b}b\bar{b}$ at 800 GeV

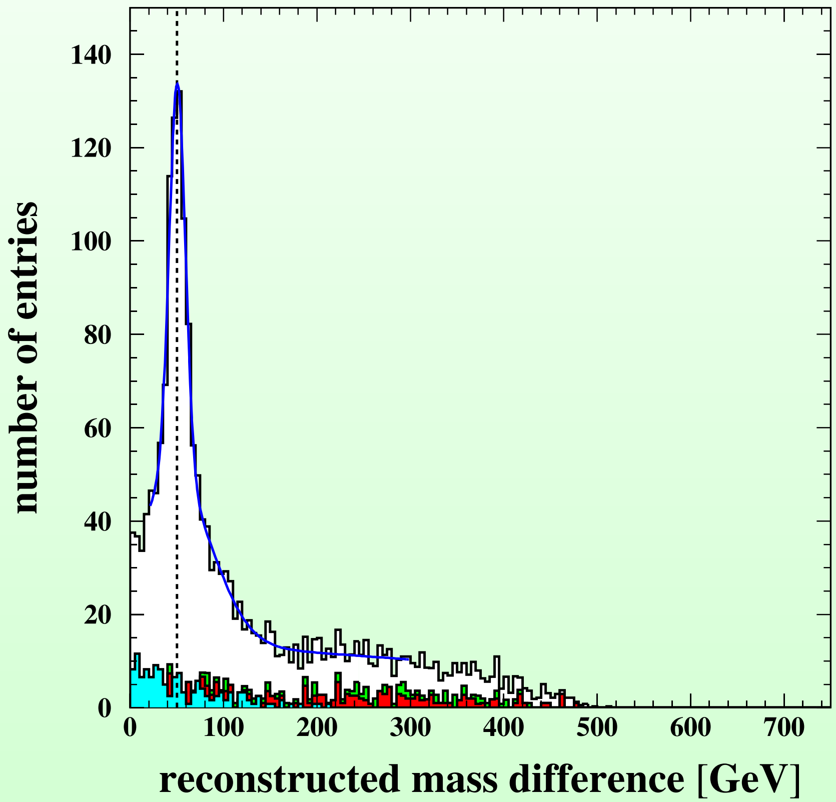
Reconstructed Mass Sum



ΣM = (251.84 $\pm$ 0.59) GeV

Resolution = (6.94 $\pm$ 0.79) GeV

Reconstructed Mass Difference

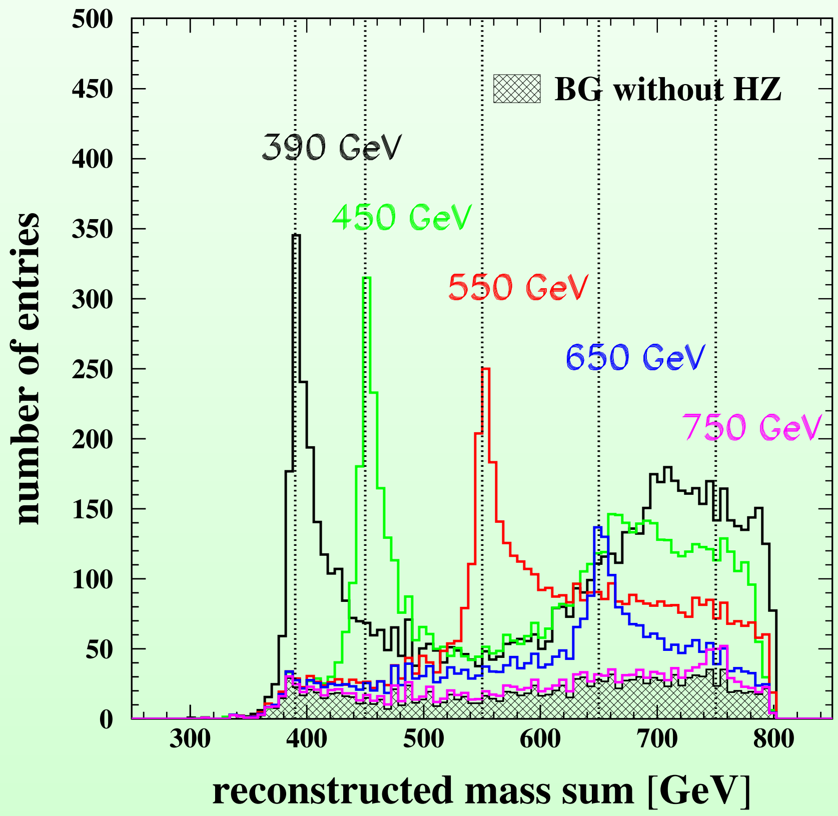


ΔM = (50.76 $\pm$ 0.78) GeV

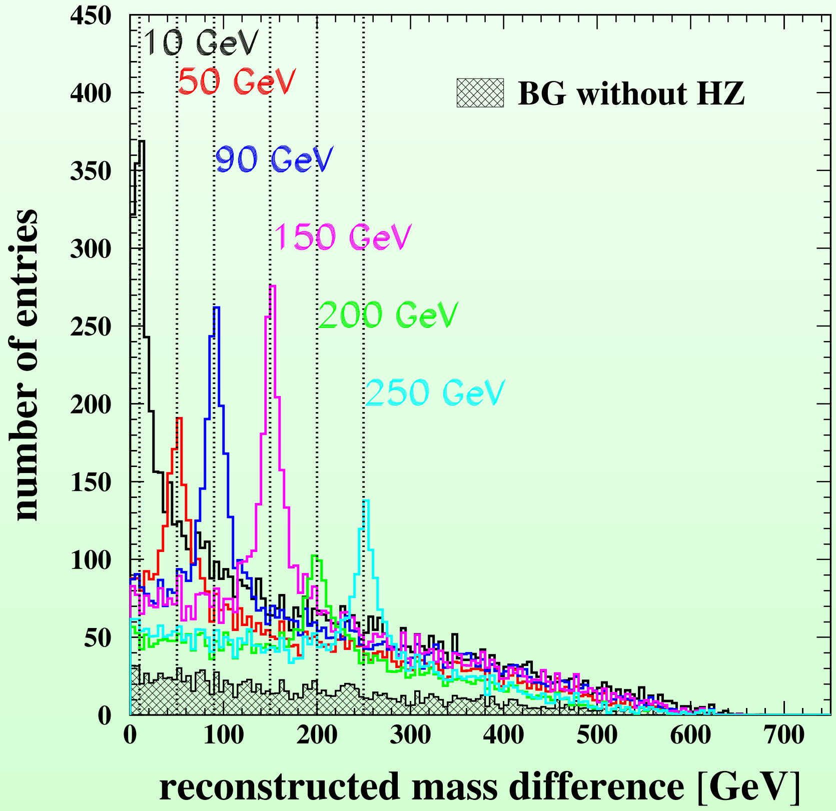
Resolution = (14.67 $\pm$ 0.31) GeV

Results for various mass combinations at 800 GeV

Reconstructed Mass Sum

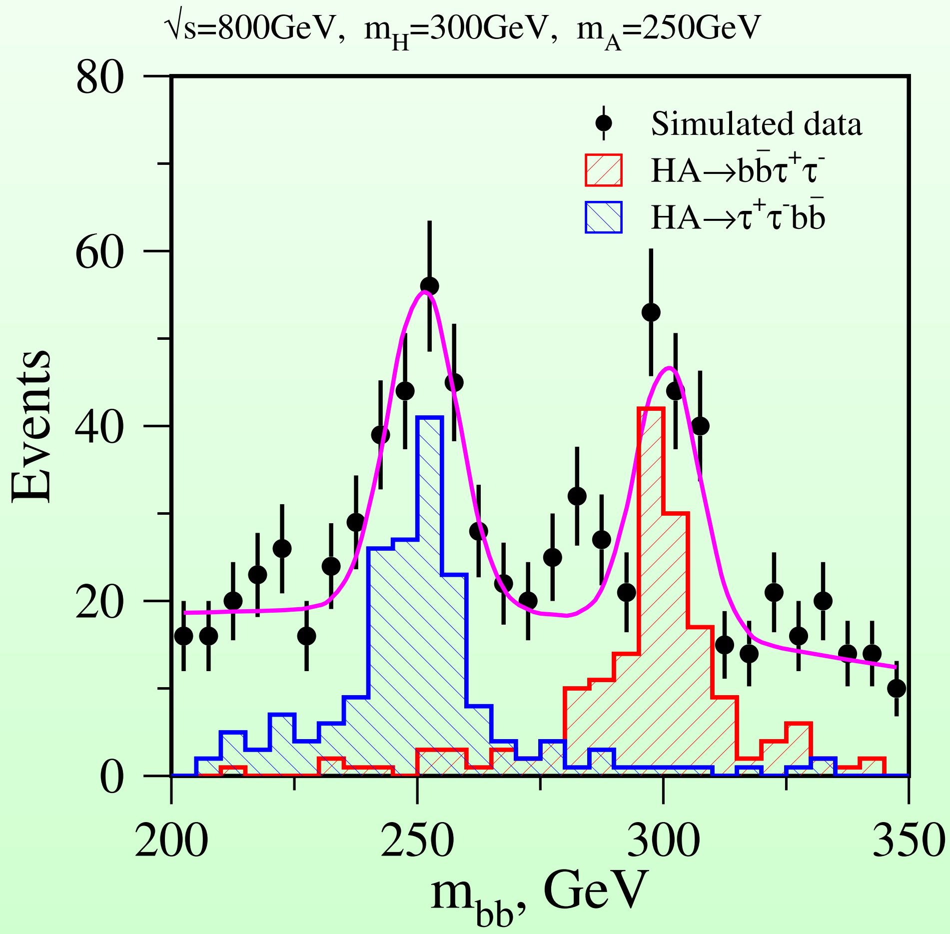


Reconstructed Mass Difference

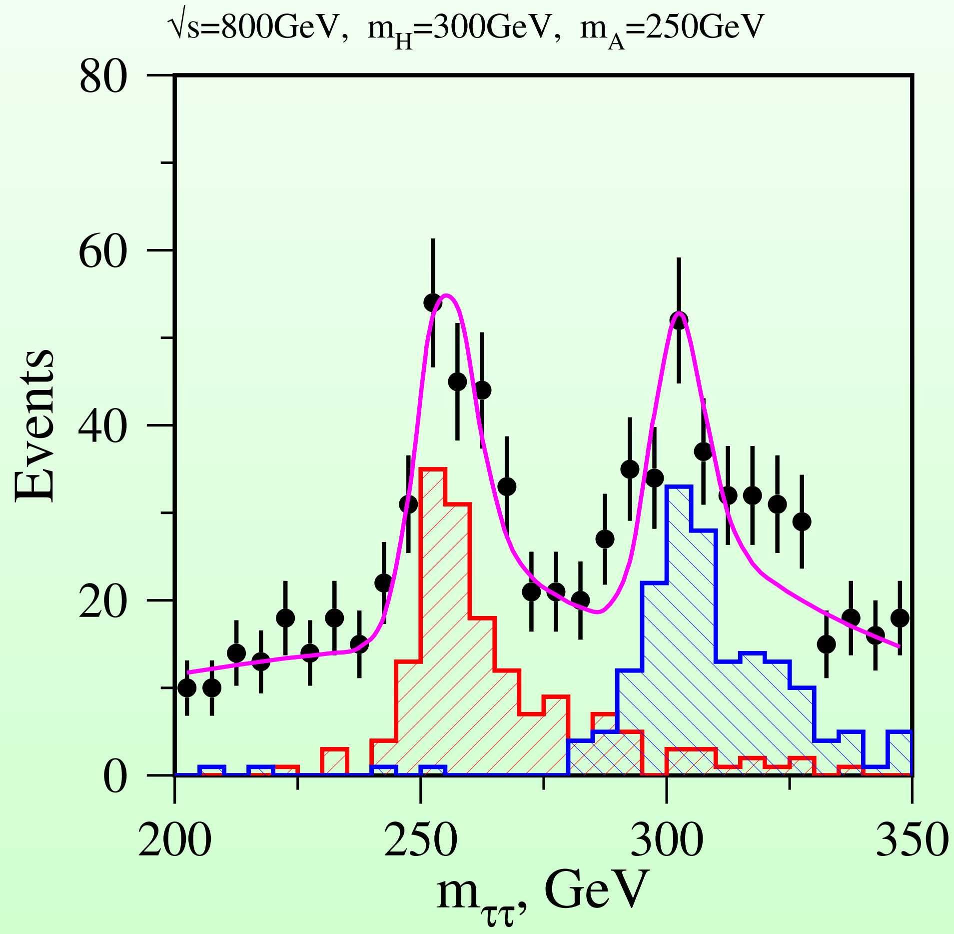


Mass reconstruction for $b\bar{b}\tau^+\tau^-$ at 800 GeV

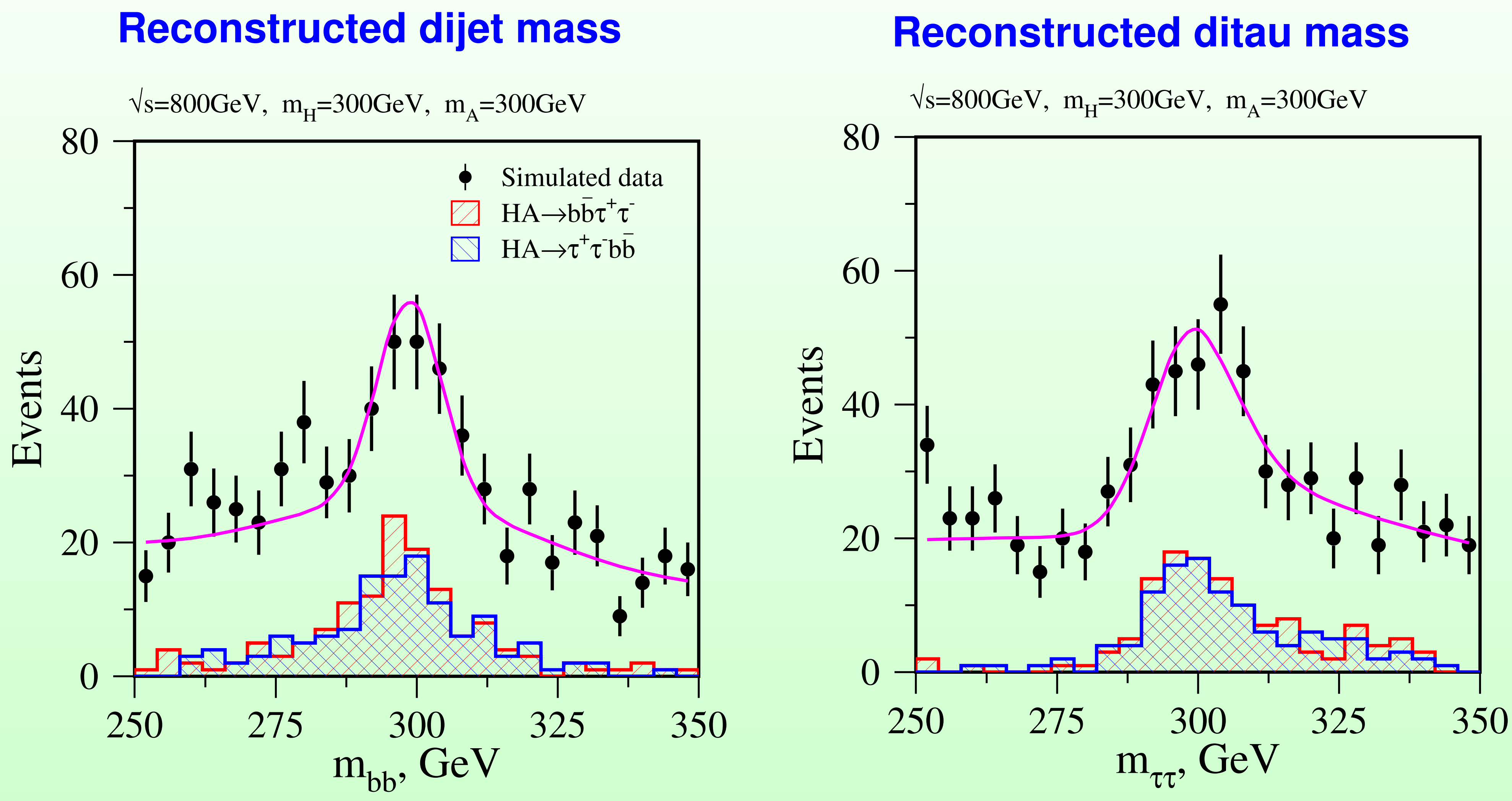
Reconstructed dijet mass



Reconstructed ditau mass



Mass reconstruction for $b\bar{b}\tau^+\tau^-$ at 800 GeV



Results for $HA \longrightarrow b\bar{b}b\bar{b}$ at 500 GeV

(M_A, M_H) [GeV]	Eff. [%]	$\delta\sigma/\sigma$ [%]	$\delta(\Sigma M)$[MeV]	$\delta(\Delta M)$[MeV]
(100,150)	42.22	1.67	316	150
(100,200)	40.92	2.11	240	294
(100,250)	35.99	2.61	318	446
(140,150)	47.56	1.57	102	224
(150,200)	41.84	2.50	202	667
(150,250)	35.50	3.75	517	936
(190,200)	37.66	3.13	333	1684
(200,250)	29.89	7.08	-	-

Results for for $HA \longrightarrow b\bar{b}\tau^+\tau^-$ at 500 GeV

(M_A, M_H) [GeV]	$HA \to b\bar{b}\tau^+\tau^-$		$HA \to \tau^+\tau^-b\bar{b}$		$\delta(M_H)$[MeV]	$\delta(M_A)$[MeV]
	Eff. [%]	$\delta\sigma/\sigma$ [%]	Eff. [%]	$\delta\sigma/\sigma$ [%]		
(100,150)	41.7	4.3	44.2	4.0	200	150
(100,200)	38.5	5.9	42.2	4.8	400	270
(100,250)	21.1	13.1	27.5	7.3	800	600
(140,150)	40.9	5.9	41.8	5.2	290	250
(150,200)	33.9	6.9	37.5	6.3	360	360
(150,250)	30.0	17.1	35.3	9.8	700	660
(190,200)	26.7	11.8	29.2	10.2	870	780

Results for $HA \longrightarrow b\bar{b}b\bar{b}$ at 800 GeV

(M_A, M_H) [GeV]	Eff. [%]	$\delta\sigma/\sigma$ [MeV]	$\delta(\Sigma M)$ [MeV]	$\delta(\Delta M)$ [MeV]
(150,300)	42.72	2.85	602	487
(200,290)	45.67	2.89	431	740
(250,300)	44.92	3.21	587	779
(300,300)	43.74	3.76	647	-
(350,350)	37.24	7.07	1258	-
(150,400)	37.00	4.15	596	780
(200,400)	39.87	4.54	775	1106
(250,400)	39.81	5.53	940	1897
(300,400)	36.97	7.39	1243	1313

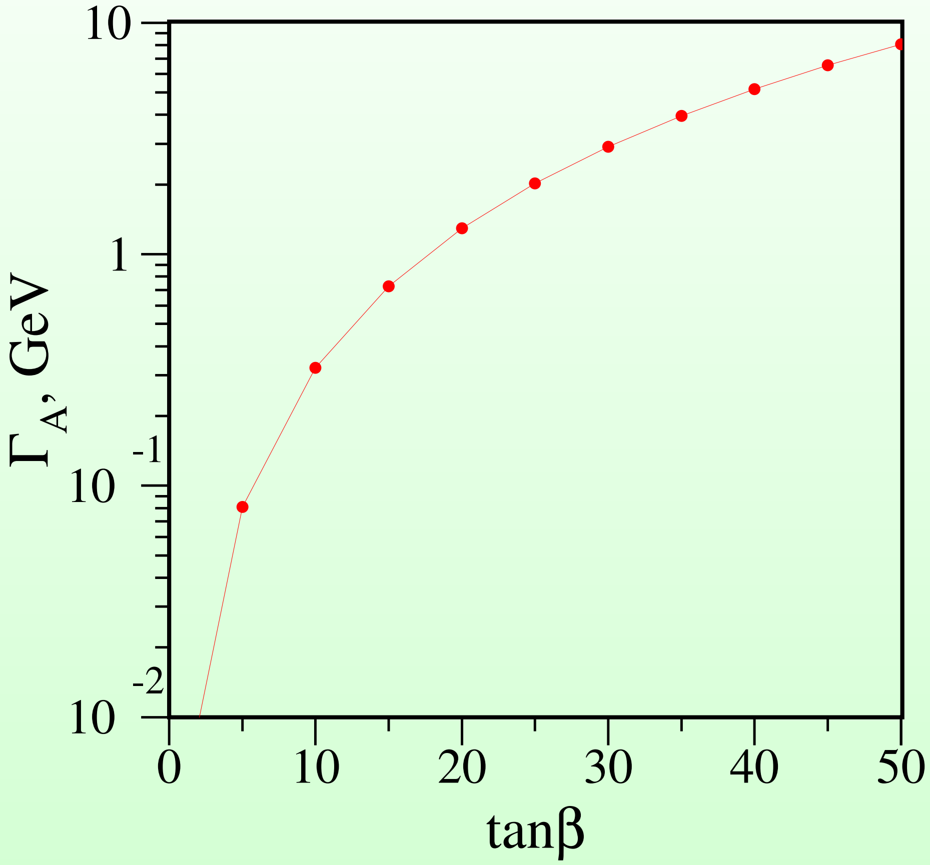
Results for $HA \rightarrow b\bar{b}\tau^+\tau^-$ at 800 GeV

(M_A, M_H) [GeV]	$HA \rightarrow b\bar{b}\tau^+\tau^-$		$HA \rightarrow \tau^+\tau^- b\bar{b}$		$\delta(M_H)$[MeV]	$\delta(M_A)$[MeV]
	Eff. [%]	$\delta\sigma/\sigma$ [%]	Eff. [%]	$\delta\sigma/\sigma$ [%]		
(150,300)	41.1	8.2	44.7	7.4	420	380
(200,290)	41.0	8.6	42.9	7.8	700	700
(250,300)	38.2	10.0	42.1	9.6	770	750
(150,400)	35.4	13.2	44.8	10.0	820	690
(200,400)	36.6	19.2	44.7	16.2	1500	1380
(250,400)	38.1	22.2	45.0	19.3	2000	1780

(M_A, M_H) [GeV]	Eff. [%]	$\delta\sigma/\sigma_{bb\tau\tau,\tau\tau bb}$ [%]	$\delta(\frac{M_A+M_H}{2})$ [MeV]
(300,300)	42.9	8.1	710
(350,350)	38.9	14.7	1760

First try of the Higgs width reconstruction

CP conserving MSSM, M_h - max

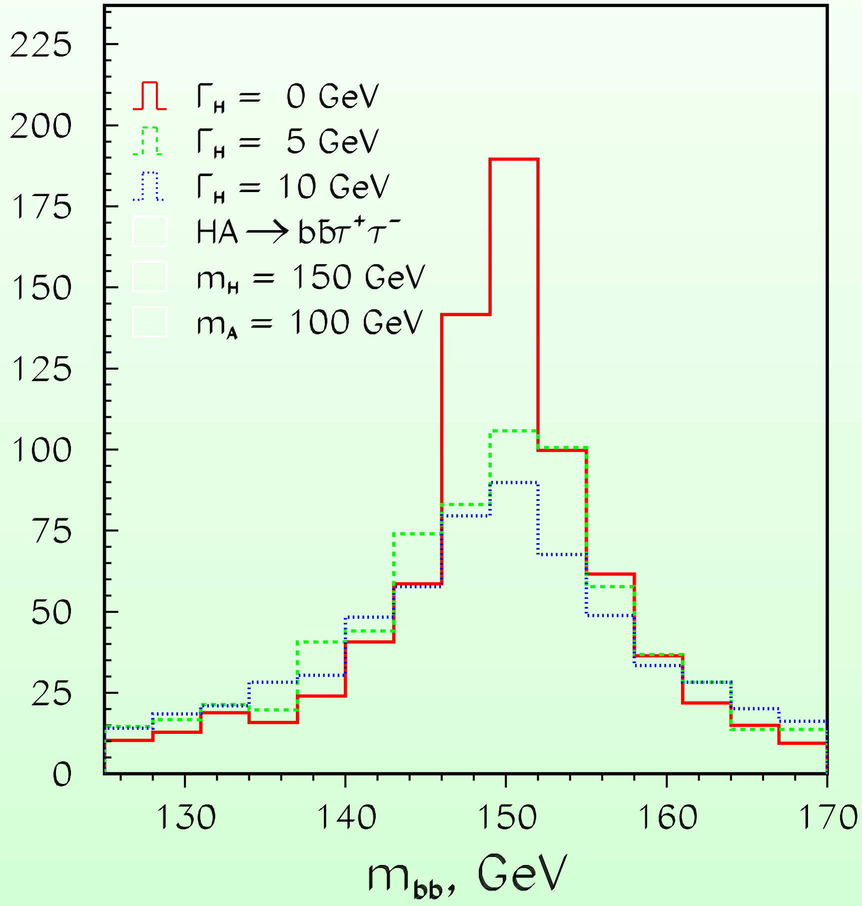


Motivation:

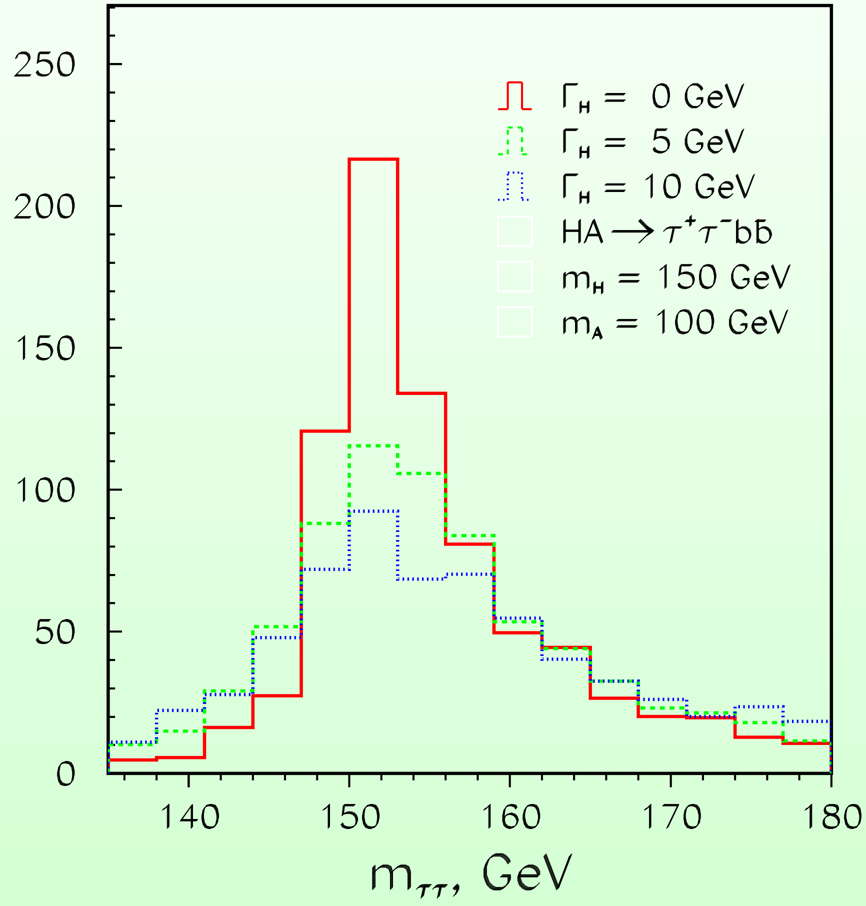
- **Typically** $\Gamma_A \approx \Gamma_H \sim \tan^2\beta$
- **From width reconstruction** $\Longrightarrow$ **measure** $\tan\beta$**?**
- **The case of large mass splitting is considered so far: (100,150) GeV**
- $HA \to b\bar{b}\tau^+\tau^-$ **at 500 GeV**

First try of the Higgs width reconstruction

Reconstructed dijet mass



Reconstructed ditau mass



Observed width =

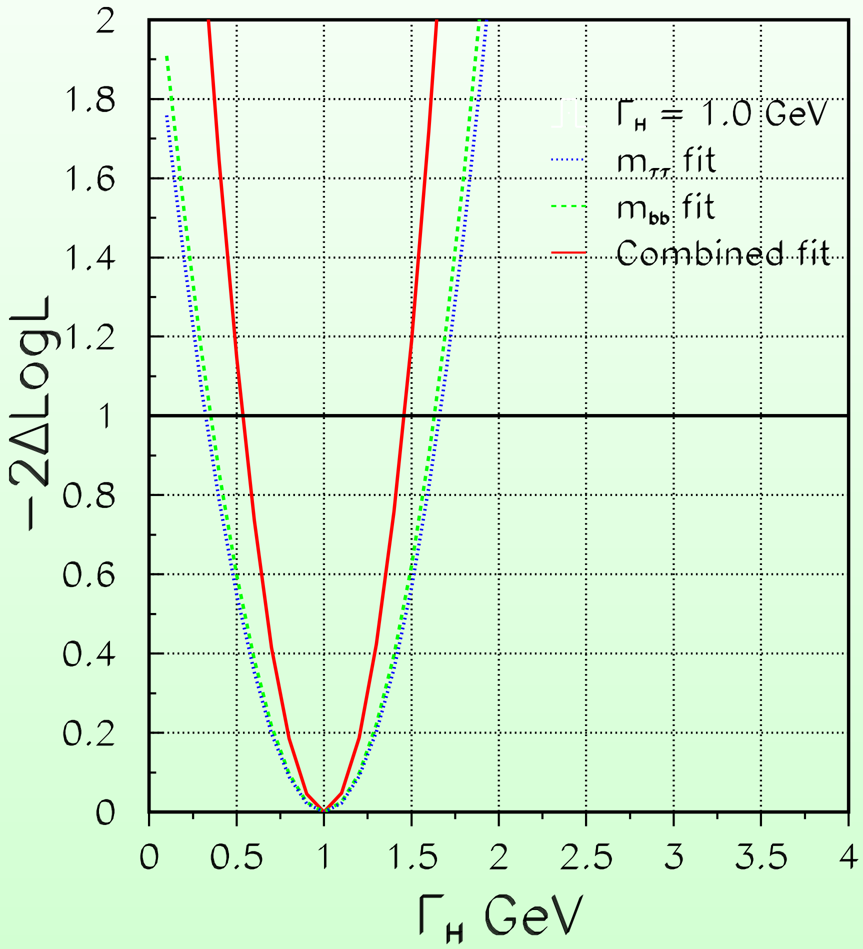
detector resolution + natural width

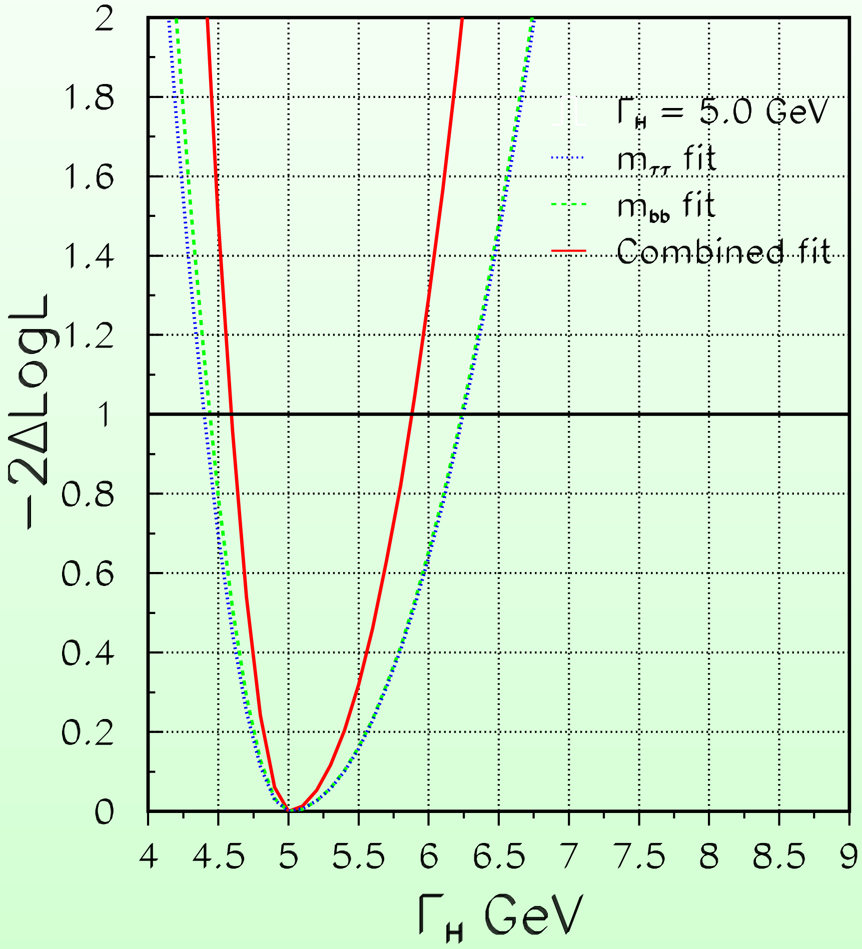
Strategy of the Higgs width reconstruction

- Take M_A and M_H from $HA \rightarrow b\bar{b}b\bar{b}$ analysis
- Perform loglikelihood fit with normalization factor for $HA \rightarrow b\bar{b}\tau^+\tau^-$, $HA \rightarrow \tau^+\tau^- b\bar{b}$ and Γ_A, Γ_H as free parameters
- $\Longrightarrow N_{HA\rightarrow bb\tau\tau}$, $N_{HA\rightarrow \tau\tau bb}$, Γ_A, Γ_H

First try of the Higgs width reconstruction

$\log L - \log L_{min}$





$\Gamma_H = (1 \pm 0.5) GeV$

$\Gamma_H = 5^{+0.8}_{-0.3} GeV$

Conclusions and Outlook

- **MSSM Higgs pair production is extended into the 800 GeV case.**
- **Higgs observation up to $M_{H,A} \lesssim (\frac{\sqrt{s}}{2} - 50)$ GeV**
- **Typical precisions:**

	500 GeV		800 GeV	
	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$
δ(mass) [MeV]	180-550	150 - 800	380-1050	400 - 2000
$\delta\sigma/\sigma$ [%]	1.6 - 3.7	4.0 - 17.0	3.2 - 7.4	7.4 - 22.0

- **First look in width measurements: seems possible in $bb\tau\tau$ case**
- **Paper/LC note soon**
- **Input for interpretation in CP conserving and CP violating scenarios**