MSSM Higgses in the intense-coupling regime at a Linear Collider (TESLA)

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Outline

- Introduction
- What is the intense-coupling regime?
- Search at the LHC
- Results for LC
- Concluding Remarks

Simulations done by means of FeynHiggs for parameters;
HDECAY for Brs and widths;
CompHEP for cross sections, distributions, event generation with ISR and Beamstrahlung;
CompHEP-PYTHIA interface and PYTHIA - for FSR and hadronization;
SIMDET for a detector response

A firm prediction of MSSM: 5 Higgs boson states
two CP–even h and H
pseudoscalar A and two charged $H^\pm$ bosons

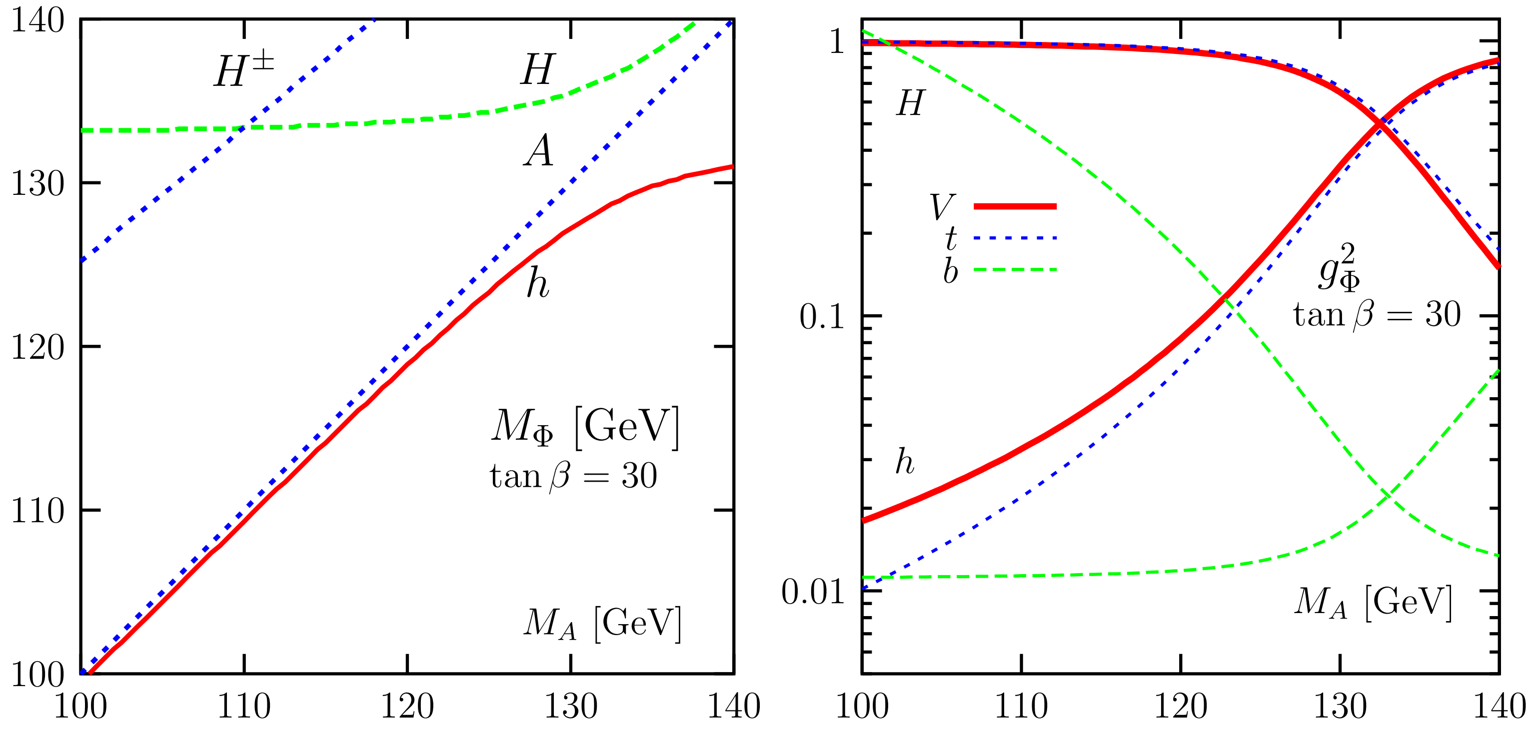
At least the lightest Higgs boson h must have a mass below some value of 130 – 135 GeV
In the decoupling regime H, A and $H^\pm$ are heavy $M_A \sim M_H \sim M_{H^\pm}$
The lightest Higgs particle h is similar to the SM Higgs

Another, more complex, situation is when pseudoscalar A boson is not much larger than h, and $\tan\beta$ is large.

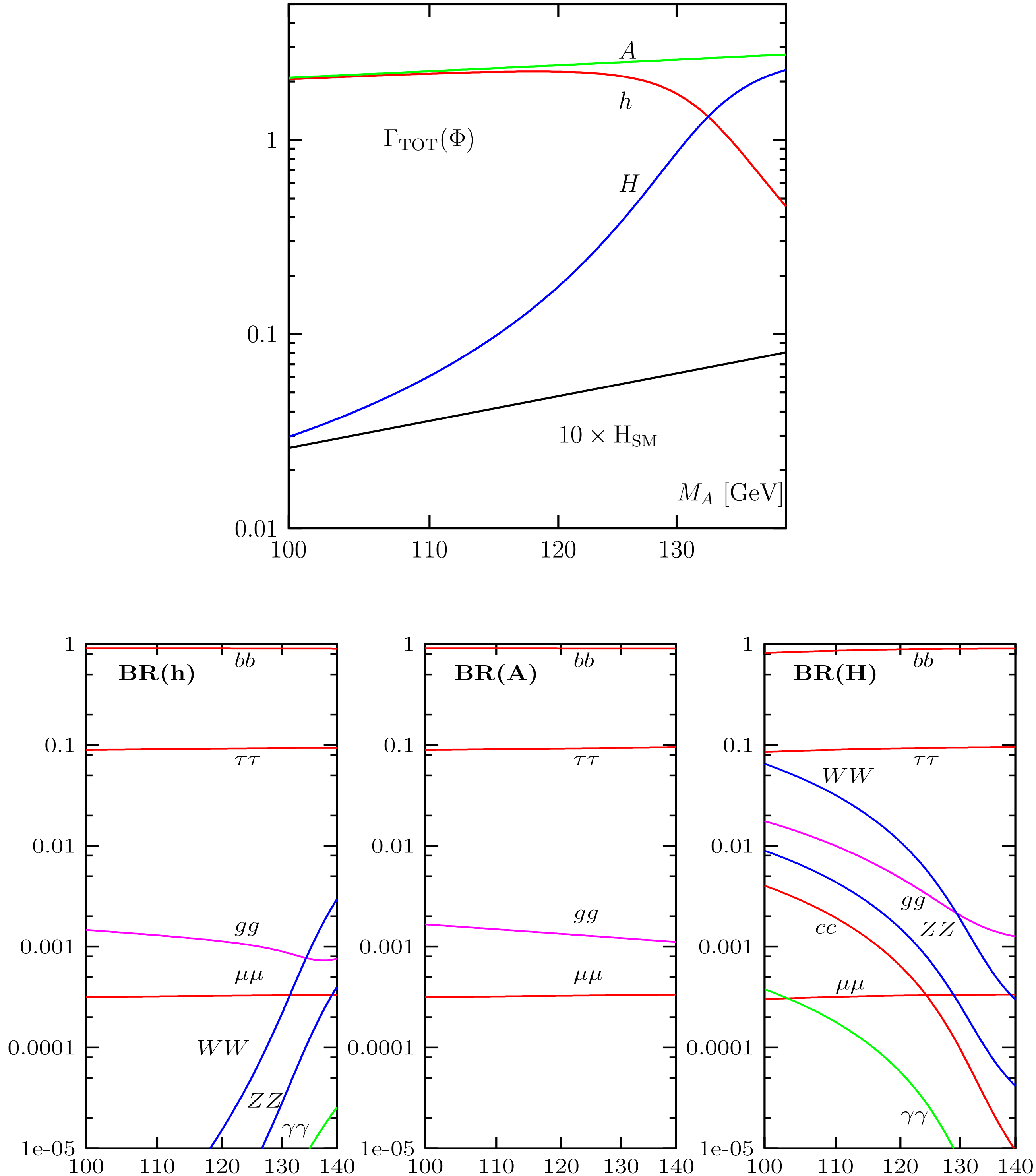
Masses could be rather close.
Widths are large.
Couplings and Br-fractions in some cases are significantly different from SM or decoupling regime.
So, the phenomenology is different.

Such a scenario was called the Intense-coupling regime
(E.B., A.Djouadi, M.Mühlleitner, A.Vologdin)

The masses of the MSSM Higgs bosons (left) and the normalized couplings of the CP-even Higgs bosons to vector bosons and third-generation quarks (right) as a function of M_A and $tan\beta = 30$. For the b-quark couplings, the values $10 \times g_{\Phi bb}^{-2}$ are plotted.



Total Width and Branching Fractions



HDECAY/FeynHiggs

MHA	ML	MH	W(h)	W(H)	W(A)	
115.0	114.1	133.5	2.240	0.098	2.341	
120.0	118.9	133.8	2.246	0.176	2.424	
125.0	123.3	134.3	2.139	0.365	2.507	P1*
130.0	127.2	135.5	1.731	0.856	2.589	P2*
135.0	129.8	137.9	0.978	1.691	2.670	P3*
140.0	131.0	141.7	0.454	2.296	2.752	

How to resolve?

At the LHC:

$\mathrm{Br}(h, H, A \to \gamma\gamma) \sim 10^{-5} - 10^{-6}$ - too small

$b\bar{b}$ and $\tau^+\tau^-$ modes - energy resolution is not enough

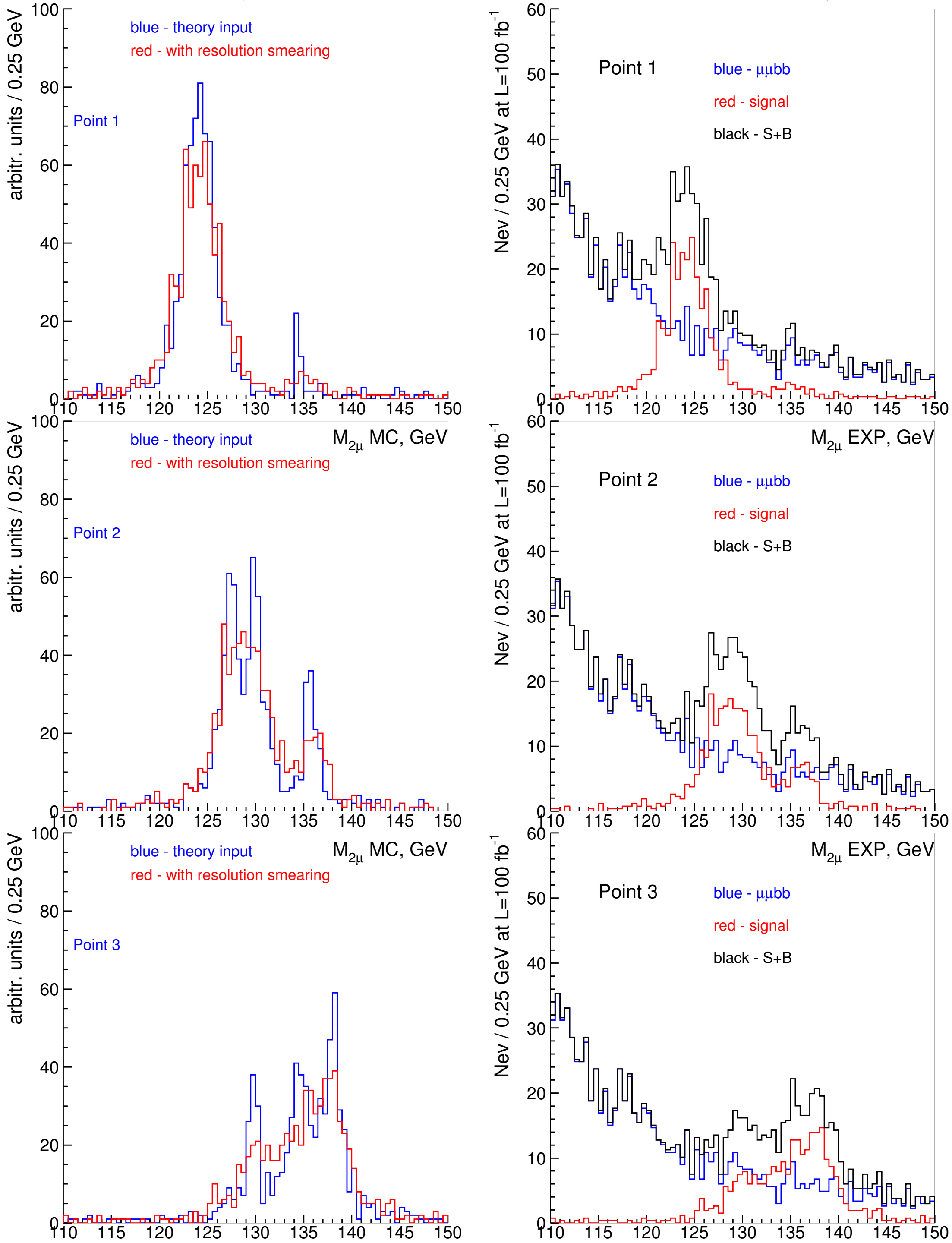
More promising - $\mu^+\mu^-$ Higgs decay in $b\bar{b} + h, H, A$ production:

$\mathrm{Br}(h, H, A \to \mu^+\mu^-) \sim 3 - 3.5\ 10^{-4}$, Energy resolution for muons $\sim 1 - 1.5\ GeV$, Tagging b-jets

At LC a multichannel analysis should be used:

1. $b\bar{b}l^+l^-$ mode using recoil mass for the Higgsstrahlung
2. $b\bar{b}b\bar{b}$ and/or $b\bar{b}\tau^+\tau^-$ modes for the Higgs pair production

$\mu^+\mu^-$ pair invariant mass distributions at the LHC for the signal before and after detector resolution smearing (left) and for the signal and the background (right) for P1, P2 and P3 parameter points. (E.Boos., A.Djouadi, A.Nikitenko)



Main processes at LC to search for MSSM intense coupling Higgses:

Zh, ZH, Ah, AH

Mostly interesting signatures after examining various possibilities:

$Zh, ZH \rightarrow l^+l^-b\bar{b}$

$Ah, AH \rightarrow b\bar{b}b\bar{b}$

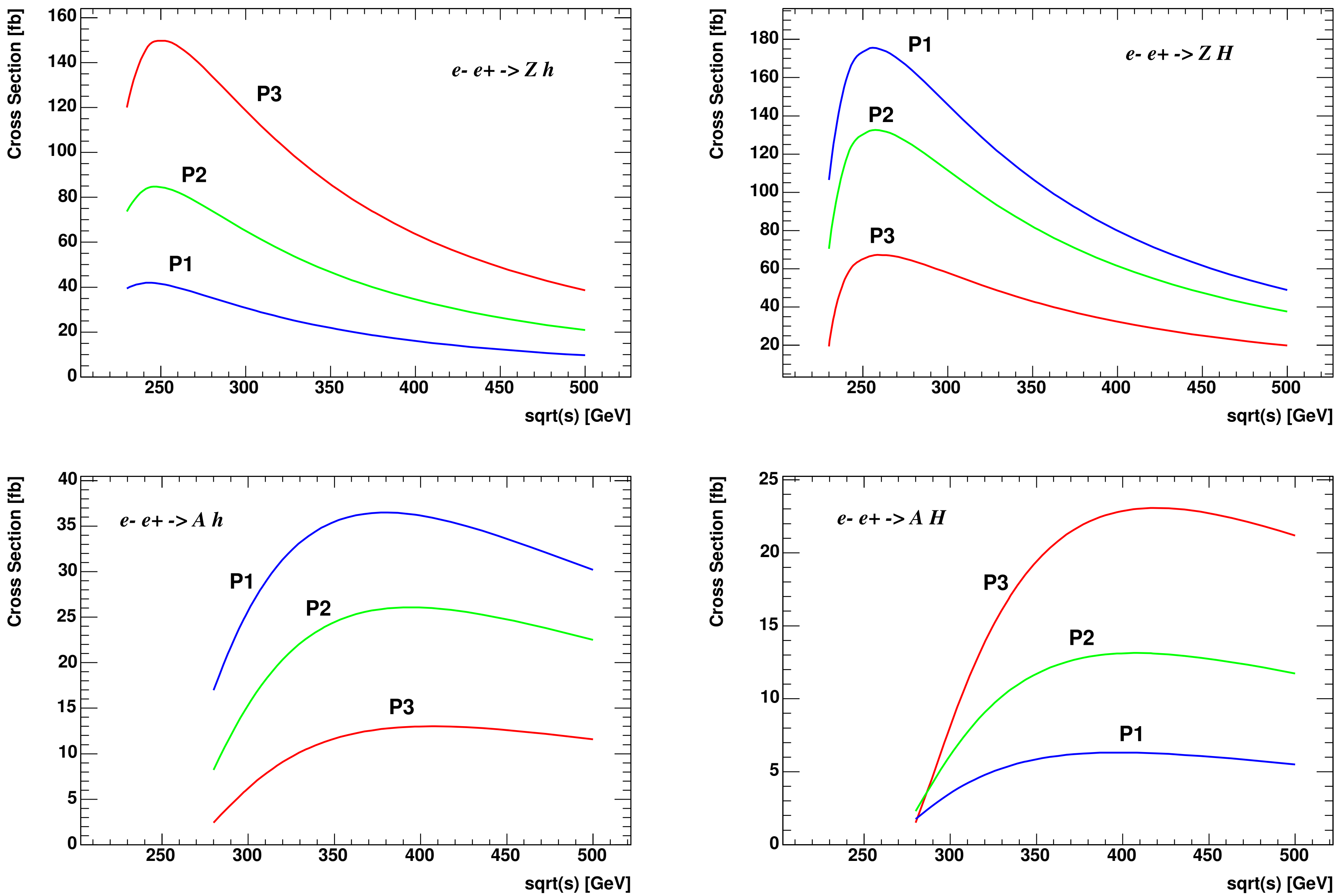
All simulations for the colliding energy 300 and 500 GeV integrated luminosity 500 and 1000 fb^{-1}

Analysis in the decoupling regime (only two Higgses are closed in masses) - K.Desch, T.Kljmkovich, T.Kuhl, A.Raspereza

Strategy

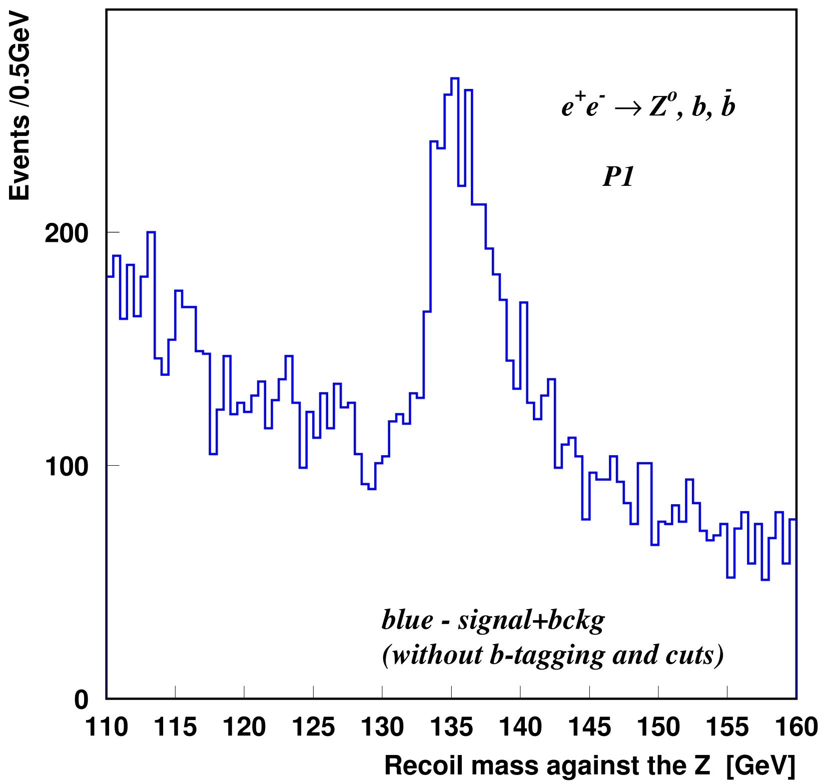
- Reciol Z mass technique in the $l^+l^-b\bar{b}$ sample. Only h and H contribute
- 4 b-jet sample. "Combinatorial mass difference method" to extract A-boson mass using the measured h and H masses

Basic cross sections for all the tree MSSM points P1, P2, P3



Recoil mass in the llbb sample at 300 GeV LC

If no cuts and no b-tagging is applied:



The small Higgs is not resolved.

The backgrounds here are 4-fermion backgrounds (CompHEP+PYTHIA):

$l^+l^- + 2\ b\ jets$ $\qquad$ $l^+l^- + 2\ light\ jets$

b-tagging and simple cuts

- $M_{l^+l^-} = 90 \pm 6$ GeV
- $E_j \geq 12$ GeV
- $\theta(j1, j2) \geq 95^0$
- only 2 jets

Efficiencies:

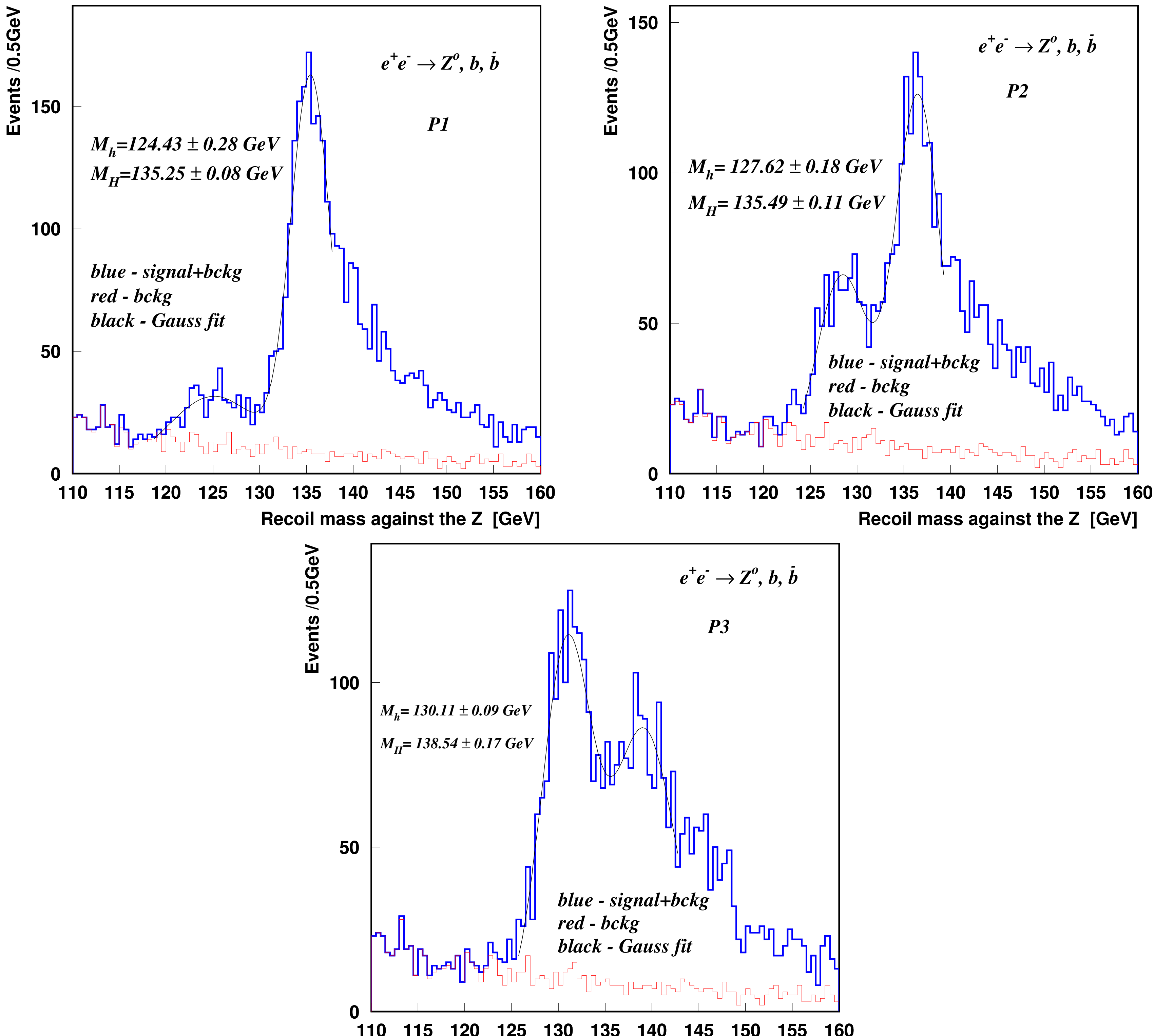
for the signal 68%

for $l^+l^-b\bar{b}$ background 22%

for $l^+l^-c\bar{c}$ background 6.4%

for $l^+l^- + 2$ background light jets 0.1%

Recoil mass in the Zbb sample at 300 GeV LC

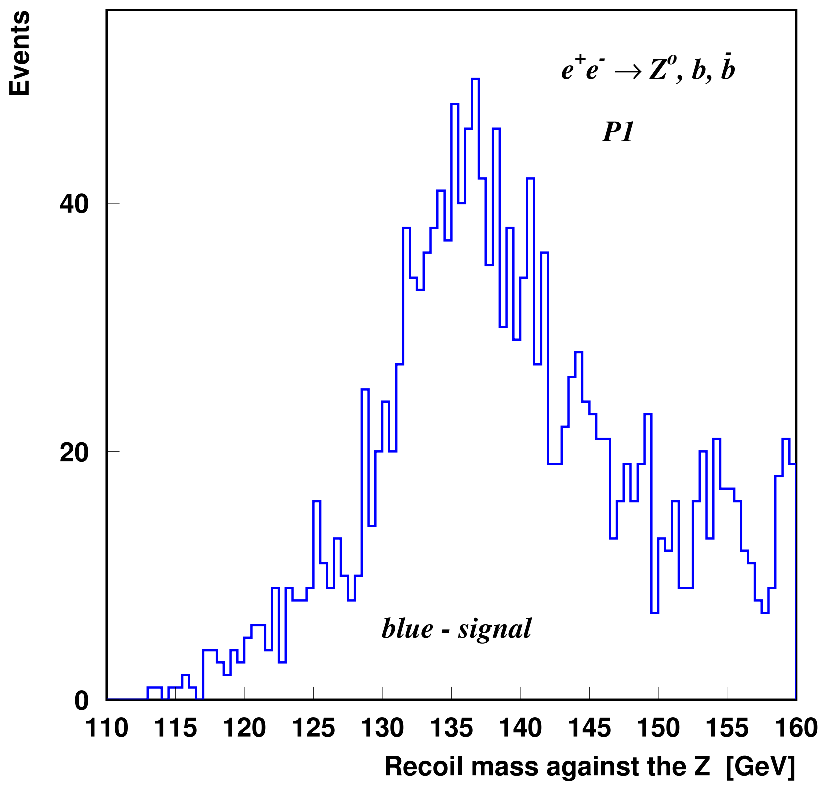


Masses of the h and H Higgses could be extracted with an accuracy of about 80-280 MeV at 300 GeV collider with 500 fb^{-1}
(about 50-70 MeV for the SM Higgs mass. See TDR)

Recoil mass technique in the llbb sample at 500 GeV LC works worse

- cross section is smaller
- energy resolution for higher momentum leptons from moving faster Z boson is worse
- ISR influence is larger

Only the signal at 500 GeV with even 1000 fb^{-1}



It is problematic to resolve the peaks

At the next step

$Ah, \; AH \to b\bar{b}b\bar{b}$

The irreducible backgrounds to Higgs pair production include now
4b SM backgrounds from all the possible contributions
$Zh, \; ZH \to b\bar{b}b\bar{b}$

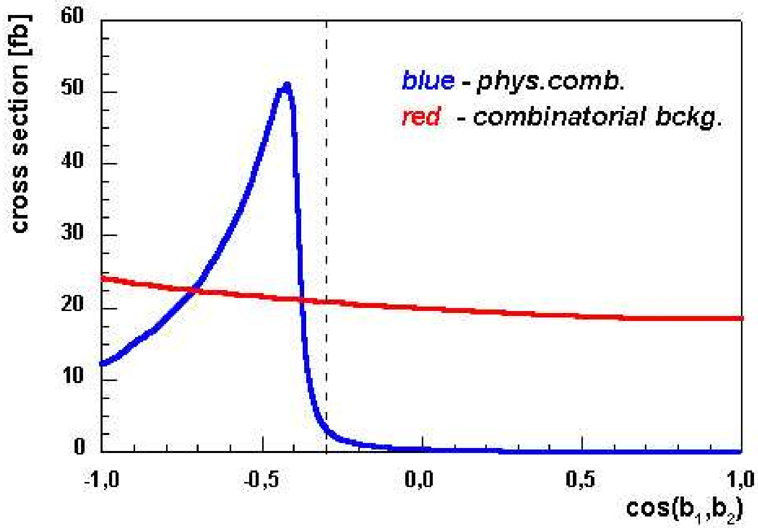
All three Higgses contribute but masses of h and H are already known

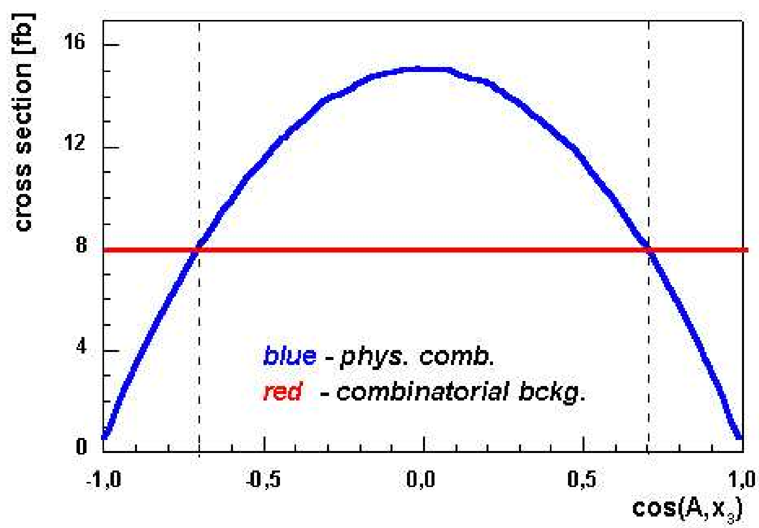
Combinatorial mass difference method is used in the 4 b-jet event sample
to extract the A-boson mass

Kinematic $e^+e^- \rightarrow A,(h/H) \rightarrow (b\bar{b})(b\bar{b})$

- $angle(b\bar{b}) \approx 2 * arctg\left(2 * \sqrt{\frac{M_A^2 - 4m_b^2}{(\sqrt{s})^2 - 4M_A^2}}\right) \approx 115^0$
- $central\ decays\ e^+e^- \rightarrow A,(h/H)$
- $(b\bar{b})(b\bar{b})$ - physical combination
- $(bb)(\bar{b}\bar{b})\ and\ (\bar{b}\bar{b})(bb)$ - combinatorial bckgr.

Angle distributions for 4-b sample at 300 GeV LC





- *Cuts :*

  $0.95 < cos(b\bar{b}) < 0.3$

  $|cos(\Theta_{bb-pair})| < 0.7$

- Total Efficiencies:

  for the physical combination 85%

  for combinatorial bckg. 20%

Combinatorial mass difference method:

- $\bar{M} = \frac{M_2+M_1}{2}$
- if $\bar{M}$ is closer to $M_h \quad \longrightarrow \quad hA - pair$

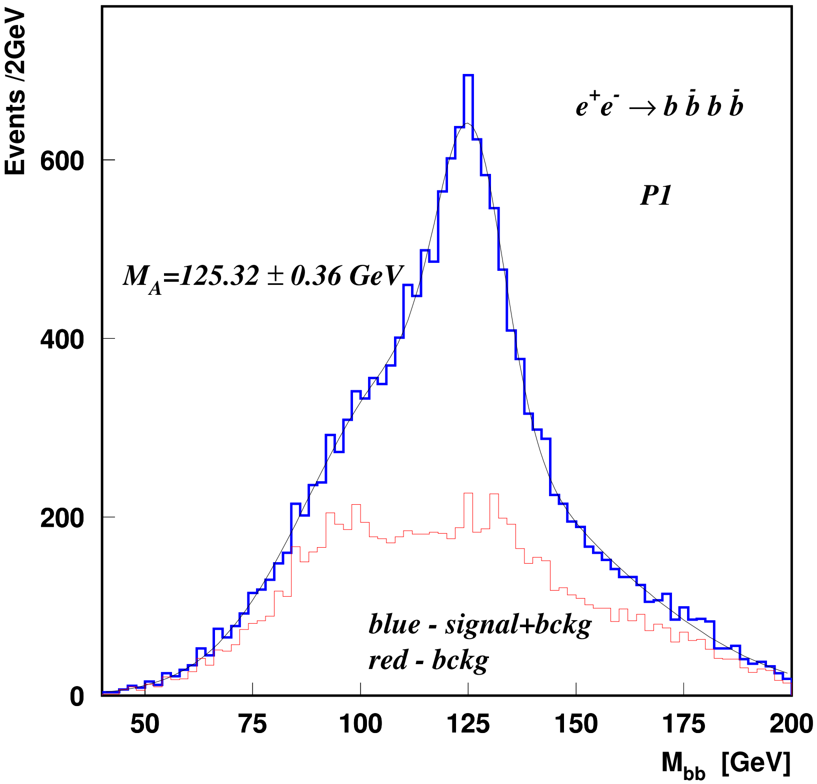
  $if \ \bar{M}$ is closer to $M_H \quad \longrightarrow \quad AH - pair$
- in case hA-pair:

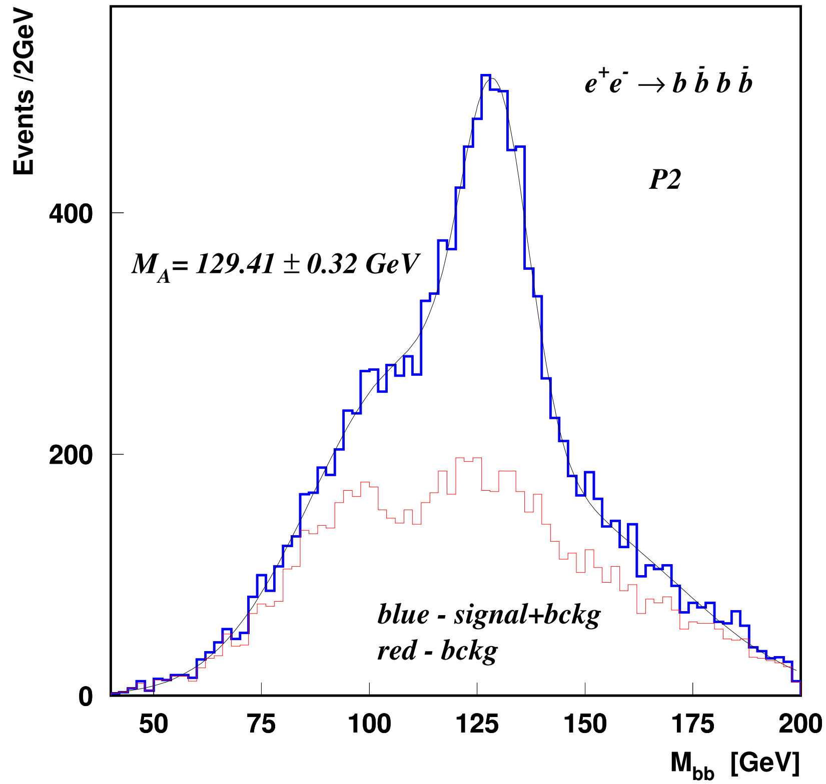
  function $prob = \frac{1}{2} + \frac{1}{2} * \frac{M_2-M_1}{M_2+M_1}$ $shows\ a\ probability\ that\ M_1\ is\ the\ M_h$
- $random = [0, 1]$

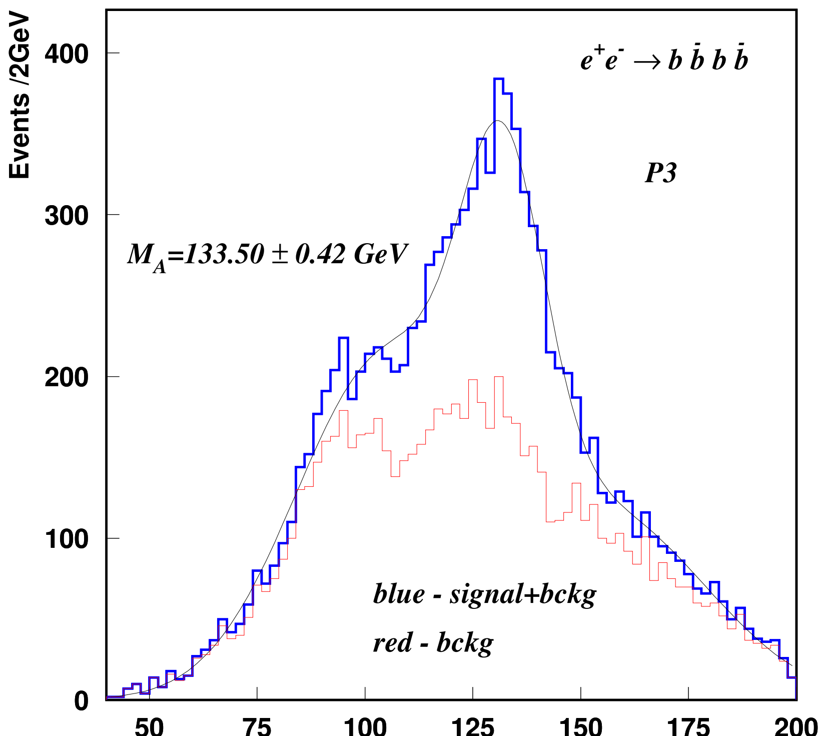
  $if\ prob < random \quad \longrightarrow \quad M_h = M_1,\ M_A = M_2$

  $if\ prob < random \quad \longrightarrow \quad M_h = M_2,\ M_A = M_1$

The 4 b-jet sample at 300 GeV LC







Conclusions

- The intense coupling regime - one of the most difficult scenario to be resolved completely
  (At the LHC - one can separate states if mass differences are about 5 GeV or more)
- At LC - h and H masses could be measured to about 80-280 MeV accuracy at energies about 300 GeV and 500 fb^{-1} lumi in the 2 leptons + 2 b-jets mode using the recoil mass technique
- Mass of the A Higgs bosons can be measured to a similar accuracy in the 4 b-jet mode (Ah+AH) using measured values M_h and M_H and applying the "combinatorial mass difference" analysis
- This is a first "semi-theoretical" analysis. There are many missing things which remain to be done: other irreducible backgrounds; optimization of cuts and a search strategy; better methods like Nueral Networks; $b\bar{b}\tau^+\tau^-$ channel may be using tau polarization to discriminate (h,H) and A bosons; the threshold scan etc.