Serach for the MSSM Higgses in the intense-coupling regime

Edward Boos
Theory Division of the Institute of Nuclear Physics
Moscow State University
in collaboration with Abdel Djouadi and Sasha Nikitenko

Outline

- Introduction
- What is the intense-coupling regime?
- $pp \to \mu^+\mu^-$ channel
- $pp \to b\bar{b}\mu^+\mu^-$ channel
- Discussion

Simulations done by means of FeynHiggs for paramaters,
HDECAY for Brs and widths,
CompHEP for cross sections, distributions, event generation,
CompHEP-PYTHIA interface and PYTHIA - for ISR/FSR and hadronization,
CMSJET (FAMOS in future) - for detector muon smearing

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 130 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.
So, phenomenology might be different.

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

Higgs masses can be approximated to an accuracy of a few persent

$$M_{h,H}^2 = \frac{1}{2}(M_A^2 + M_Z^2 + \epsilon)$$

$$\left[1 \mp \sqrt{1 - 4\frac{M_Z^2 M_A^2 \cos^2 2\beta + \epsilon(M_A^2 \sin^2\beta + M_Z^2 \cos^2\beta)}{(M_A^2 + M_Z^2 + \epsilon)^2}}\right]$$

The mixing angle α is given in terms of $M_A, \tan\beta, \epsilon$ and ϵ', by

$$\tan 2\alpha = \tan 2\beta \, \frac{M_A^2 + M_Z^2 - \epsilon'/\sin 2\beta}{M_A^2 - M_Z^2 + \epsilon/\cos 2\beta} \ ,$$

$$-\frac{\pi}{2} \leq \alpha \leq 0 \ .$$

ϵ and ϵ' parametrize the main radiative corrections:

$$\epsilon = \frac{3G_F\overline{m}_t^4}{\sqrt{2}\pi^2\sin^2\beta}\left[t + \frac{X_t}{2}\right] -$$

$$-\frac{3G_F}{\sqrt{2}\pi^2}\left[\frac{\overline{m}_t^2 M_Z^2 t}{2} + \frac{2\alpha_S}{\pi}\frac{\overline{m}_t^4}{\sin^2\beta}(X_t t + t^2)\right]$$

with

$$t = \log\left(\frac{M_S^2}{m_t^2}\right) \quad , \quad X_t = \frac{2A_t^2}{M_S^2}\left(1 - \frac{A_t^2}{12M_S^2}\right)$$

and

$$\epsilon' = \frac{G_F\overline{m}_t^4}{2\sqrt{2}\pi^2\sin^2\beta}\frac{\mu}{M_S}\left[\frac{A_t^3}{M_S^3} - \frac{6A_t}{M_S}\right]\left[1 - \frac{4\alpha_S t}{\pi}\right]$$

where $\overline{m}_t$ is the running $\overline{\mathrm{MS}}$ top quark mass

In the intense-coupling regime the two CP–even Higgs bosons h and H are almost degenerate, $M_h \simeq M_H$.

In the limit $M_h = M_H$ one gets a second order polynomial equation in the variable M_A^2

$$M_A^4 + 2M_A^2[M_Z^2(1 - 2\cos^2 2\beta) + \epsilon\cos 2\beta] +$$

$$+ M_Z^4 + \epsilon^2 - 2M_Z^2\epsilon\cos 2\beta = 0$$

One obtains a discriminant

$\Delta' = -\sin^2 2\beta(2M_Z^2\cos 2\beta - \epsilon)^2 \leq 0$

The only way for the solution to be real is either $\sin 2\beta = 0$ or $\epsilon = 2M_Z^2\cos 2\beta$. The last possibility gives $M_A^2 = -M_Z^2$ which has to be rejected, while the former possibility gives $M_A^2 = M_Z^2 + \epsilon$ with $\beta = \frac{\pi}{2}$ (or $\tan\beta$ is infinite).

This solution or critical mass corresponds to the maximal value allowed for M_h and the minimal value that M_H can take,

$$M_C = M_h^{\max} = M_H^{\min} = \sqrt{M_Z^2 + \epsilon}$$

If $\tan\beta$ is very large but finite the equestions for masses simplifies to

$$M^2_{h,H} = \frac{1}{2}(M^2_A + M^2_Z + \epsilon \mp |M^2_A - M^2_Z - \epsilon|)$$

which means that

$$M_A \geq M_C \Rightarrow M_H = M_A \quad \text{and} \quad M_h = M_C$$

$$M_A \leq M_C \Rightarrow M_h = M_A \quad \text{and} \quad M_H = M_C$$

and therefore the A boson is degenerate in mass with one of the CP–even Higgs bosons

One CP even Higgs is similar to the SM Higgs and the other one is similar to A.

If $M_A \geq M_C$ h is similar to H0 and H to A
If $M_A \leq M_C$ h is similar to A and H to H0

Neutral Higgs boson couplings to fermions and gauge bosons in the MSSM normalized to the SM Higgs boson couplings, and their limits for $\tan\beta \gg 1$ for $M_A \geq M_C$ (upper values) and $M_A < M_C$ (lower values).

E.B.,A.Djouadi,M.Mühlleitner,A.Vologdin

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$
h	$\frac{\cos\alpha}{\sin\beta}{}^{\to 1}_{\to -f_1+f_2/\tan\beta}$	$-\frac{\sin\alpha}{\cos\beta}{}^{\to -f_1\tan\beta+f_2}_{\to \tan\beta}$	$\sin(\beta-\alpha)^{\to 1}_{\to -f_1+(1+f_2)/\tan\beta}$
H	$\frac{\sin\alpha}{\sin\beta}{}^{\to f_1-f_2/\tan\beta}_{\to -1}$	$\frac{\cos\alpha}{\cos\beta}{}^{\to \tan\beta}_{\to -f_1\tan\beta+f_2}$	$\cos(\beta-\alpha)^{\to f_1+(1-f_2)/\tan\beta}_{\to -1}$
A	$1/\tan\beta$	$\tan\beta$	0

where

$$f_1 = \frac{\epsilon'/2}{M_H^2 - M_h^2}, f_2 = \frac{M_A^2 + M_Z^2}{M_H^2 - M_h^2}$$

HDECAY/FeynHiggs

MHA	ML	MH	W(h)	W(H)	W(A)	
90.00	89.59	133.0	1.895	0.018	1.919	
95.00	94.52	133.1	1.976	0.022	2.004	
100.0	99.48	133.2	2.055	0.029	2.089	
105.0	104.4	133.2	2.128	0.041	2.174	
110.0	109.3	133.4	2.193	0.061	2.258	
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	
140.0	131.0	141.7	0.454	2.296	2.752	

How to resolve?

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

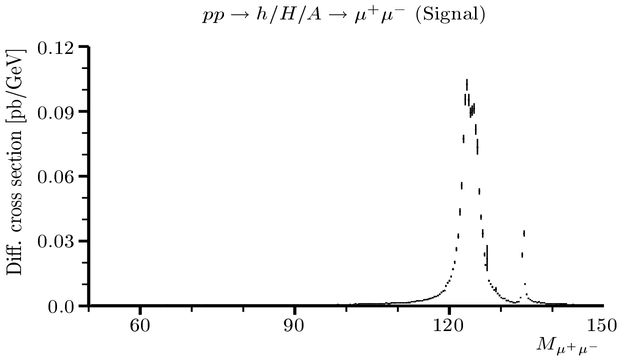
$b\bar{b}$ and $\tau^+\tau^-$ modes - energy resolution is not enough

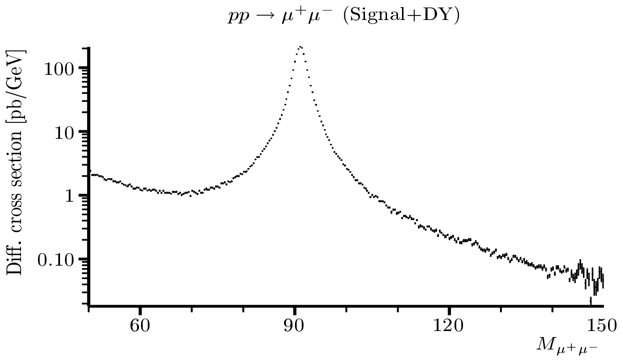
More promising - $\mu^+\mu^-$ channel:

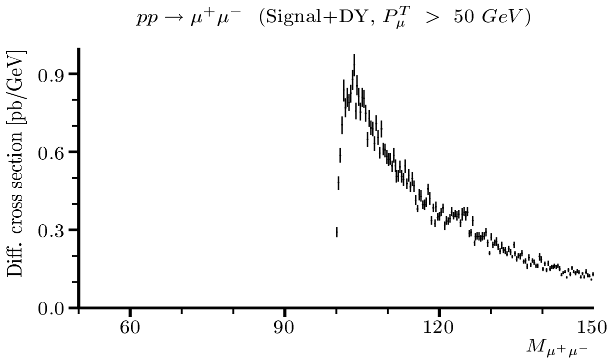
Br$(h, H, A \to \mu^+\mu^-) \sim 3 - 3.5\ 10^{-4}$

Energy resolution for muons $\sim 1 - 1.5\ GeV$

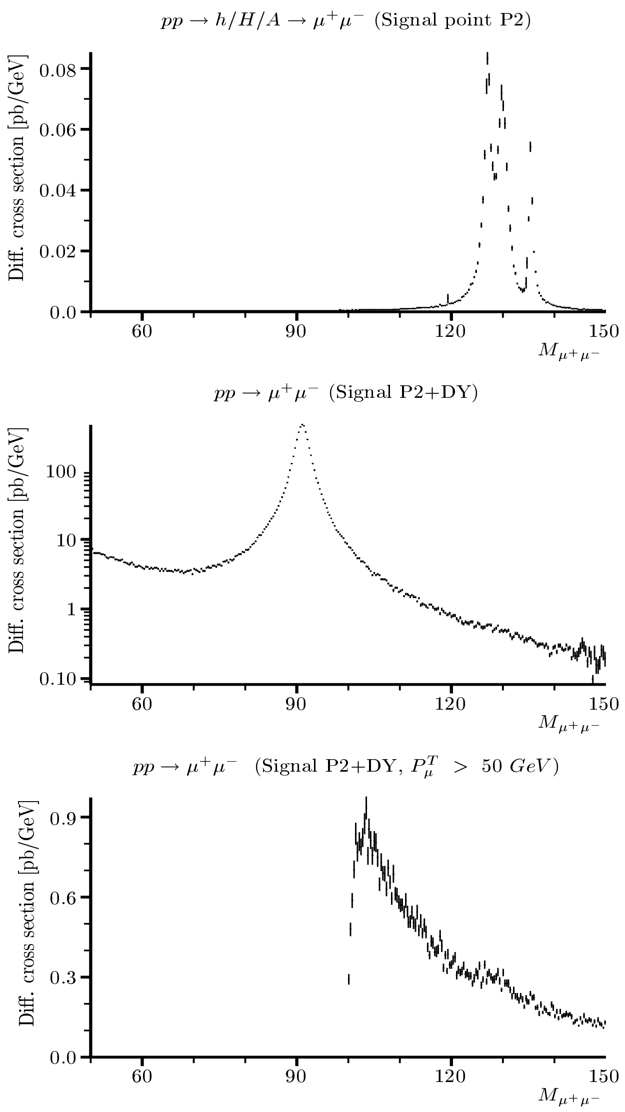
The cross section $pp \to h/H/A \to \mu^+\mu^-$ comes from the NNLO $b\bar{b}$ (V.Harlander,W.Kilgore) and NNLO gg (C.Anastasiou,K.Melnikov; V.Harlander,W.Kilgore) to be about 580 fb (500 fb) for points P1 (P2)







For the papameter point P2



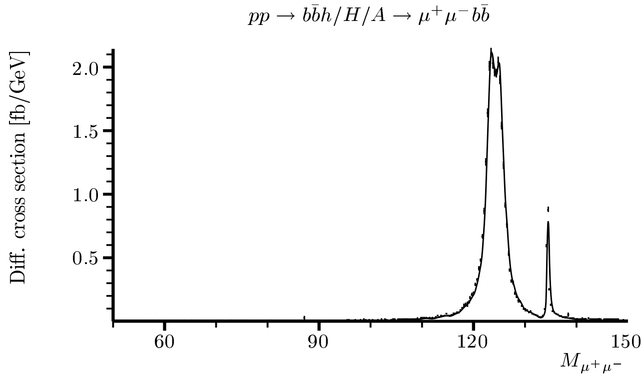
Inclusive channel - seems NO WAY

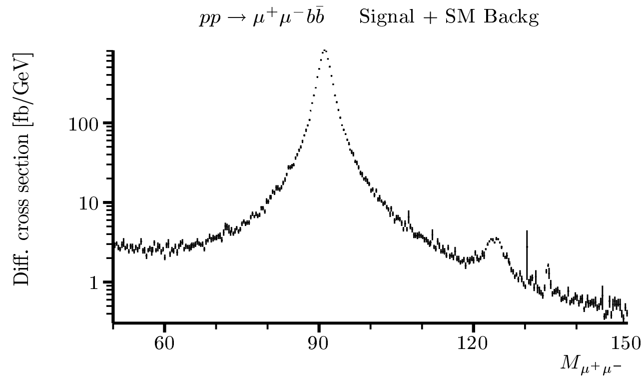
What about exclusive channel?

Situation looks much better if one requires two b-jets with $P^t_{b,\bar{b}} \geq 20\ GeV$ Point P1

$M_h = 123.3 \quad M_A = 125 \quad M_H = 134.4$

$\Gamma_h = 2.0 \quad \Gamma_A = 2.3 \quad \Gamma_H = 0.33$

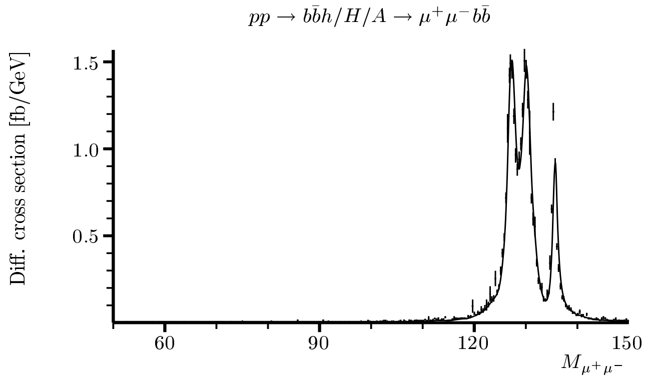


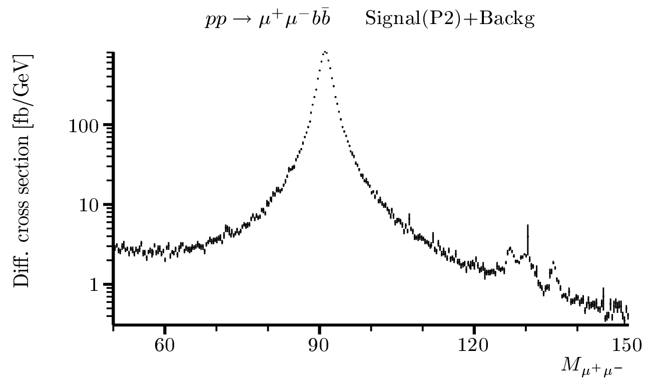


Parameter point P2. Two b-jets with $P^t_{b,\bar{b}} \geq 20\ GeV$

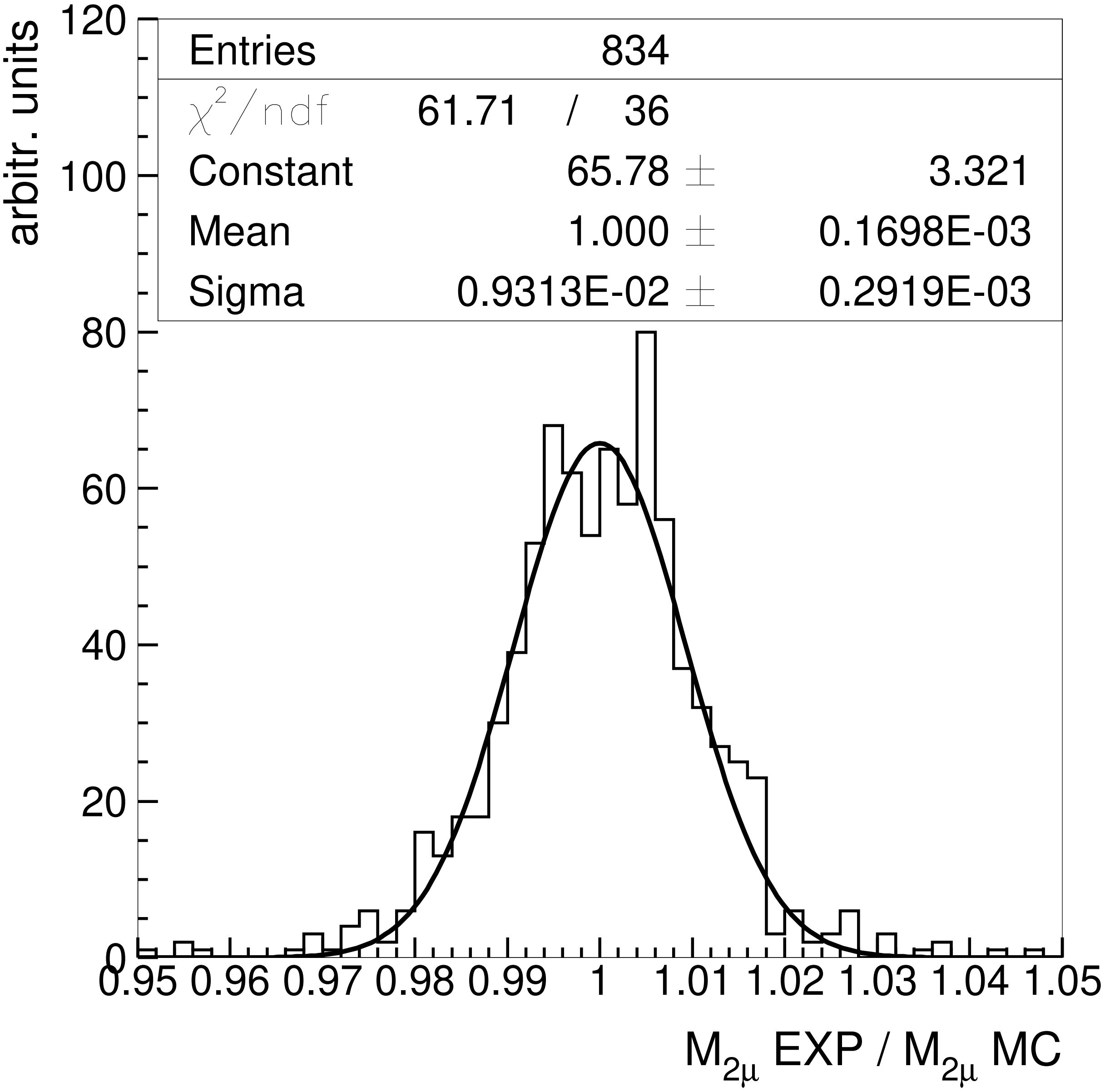
$M_h = 127.2 \quad M_A = 130 \quad M_H = 135.5$

$\Gamma_h = 1.6 \quad \Gamma_A = 2.4 \quad \Gamma_H = 0.8$





The CMS detector resolution for the muon pair invariant mass



The signal after detector smearing