Simulation of neutral Higgs pair production processes in PYTHIA using HPAIR matrix elements.

M. El Kacimi[*], **R. Lafaye**[†]

June 5, 2002

Abstract

Double Higgs production is currently not fully implemented in PYTHIA, as only the resonant $H \to hh$ MSSM processes and $f_i\bar{f}_i$ production modes can be generated. Using matrix elements from the HPAIR program we have added in PYTHIA the gluon fusion production modes in SM and MSSM. These matrix elements include resonant processes as well as continuum production, which is relevant for SM and MSSM high $\tan\beta$ scenarios. Comparison between PYTHIA Monte Carlo results and VEGAS integrated cross sections is shown.

ATL-PHYS-2002-015
02 / 07 / 2002

Contents

[*]LPHEA FSSM, Marrakech Morocco
[†]LAPP CNRS, Annecy France

1 Introduction

Scalar Higgs boson pair production at LHC allows to study the trilinear Higgs self couplings in the Minimal Supersymmetric Standard Model (MSSM) scheme. In pp collisions the dominating process is the gluon fusion $gg \to HH$, where H can be any of the MSSM neutral Higgs particles. In PYTHIA neutral Higgs pairs can be generated through the resonance channel $H \to hh$ or via $f_i\bar{f}_i \to AH, Ah$. For Standard Model (SM) and MSSM scenarios with high values of $\tan\beta$ the contribution of s-channel processes becomes negligible, thus PYTHIA alone can not be used to explore this region of the parameter space where the cross section can rise above 1 pb for values of m_A up to 150 GeV.

At LHC the measurement of the trilinear self couplings in the production modes dominated by the gluon fusion would require a huge amount of data. Nonetheless the MSSM high $\tan\beta$ value cases are interesting as a discovery channel, since their cross section is large enough.

This note presents the complete implementation of leading order (LO) matrix elements, calculated with HPAIR[1] [5], into PYTHIA 6.203[1]. This implementation allows a more complete simulation of hh production in the resonance region and of all neutral Higgs pairs in continuum.

After a brief description of the implementation procedure, we will present a comparison between cross section values obtained with the PYTHIA Monte Carlo generated for different MSSM scenarios, and those computed with the VEGAS program [2]. For the SM case, specific implementations as well as a complete study using this PYTHIA modified version, have been done by F. Mazzucato et al.[3].

2 Neutral Higgs pair production implementation in PYTHIA

2.1 Neutral Higgs pair production processes

The following table shows the processes which are already implemented into PYTHIA 6.2.

In	No.	Subprocess
+	299	$f_i\bar{f}_i \to Ah^0$
+	300	$f_i\bar{f}_i \to AH^0$

Although these processes are dominant in most of the MSSM scenarios, they contribute for only 10% of the total cross section when $\tan\beta$ is above 30. For $\tan\beta = 30$ the dominant process is $gg \to AA$ and all other processes contribute for 50% of the total cross section, as can be seen on figure 1.

Thus for a more complete study of the possible MSSM scenarios we have added into PYTHIA, the processes listed in the following table.

[1]HPAIR is a program written by M. Spira from Paul Scherrer Institute, Villigen Switzerland

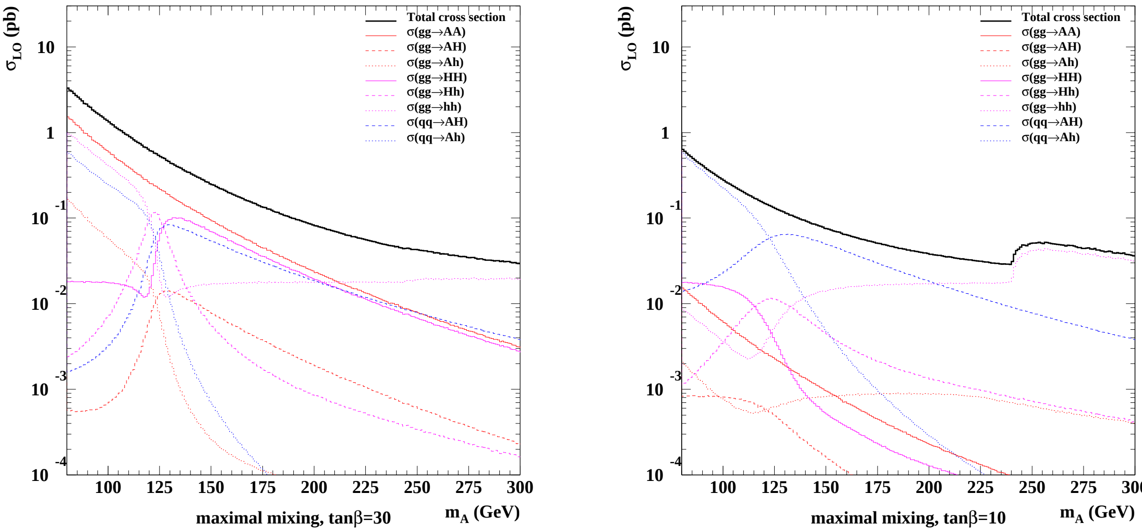

Figure 1: *Neutral Higgs pair LO cross sections as a function of* m_A *in maximal mixing, using HPAIR. For* $\tan\beta = 30$ *(left plot) and for* $\tan\beta = 10$ *(right plot). Below the transition limit, the cross section is dominated by* AA*,* Ah *and* hh *production, while above* AA*,* AH *and* HH *dominate. At the transition region* A*,* H *and* h *have all very similar masses and all possible Higgs pairs can be produced. For this particular case, different Higgs can not be disentangled since they have similar masses and branching ratios.*

In	No.	Subprocess	Reference
	303	$gg \to h^0 h^0$	[4, 5, 6]
	304	$gg \to H^0 h^0$	[4, 5, 6]
	305	$gg \to H^0 H^0$	[4, 5, 6]
	306	$gg \to A h^0$	[4, 5, 6]
	307	$gg \to A H^0$	[4, 5, 6]
	308	$gg \to AA$	[4, 5, 6]

2.2 Implementation overview

All subprocesses (303 to 308) listed above were implemented in a private version of PYTHIA, as standard $2 \to 2$ PYTHIA processes. We choose not to use the PYUPEV scheme, but we tried to keep the modifications into PYTHIA to the minimum. The following routines have been modified or included to take into account the new processes:

- **PYDATA** to setup processes data.
- **PYSIGH** to compute differential cross sections.

- **PYMAXI**, **PYSCAT** and **PYRAND** to take into account possible resonant production modes.

- **PYHPAIR** is a new routine which does the interface between PYTHIA and HPAIR. It fills HPAIR parameters with PYTHIA values and calls the matrix element computation routine.

For each event, the kinematic is chosen by PYTHIA, taking into account resonance and continuum production in the shape of the phase space.

The PYSIGH routine then calls the PYHPAIR function to get the differential cross section. This differential cross section is computed with HPAIR Matrix Elements using PYTHIA parameters. As the Higgs spectrum might be slightly different between PYTHIA and HDECAY, running HPAIR standalone and interfaced to PYTHIA might lead to different numbers.

Finally, the event is selected or rejected according to the PYTHIA standard Monte-Carlo procedure.

2.3 Kinematic variables generation

The kinematic variables used to describe the processes are τ, the fraction of $s = E_{cm}^2$ carried by the two partons in the initial state, y, the center of mass boost of the two partons and $z = \cos\theta$, where θ is the angle of one of the two final particles with respect to the beam direction.

These variables are generated using the PYTHIA standard distributions for $2 \rightarrow 2$ processes, h_τ, h_y and h_z. Contributions to the cross section are expressed by separate terms which account for resonant s-channels (when relevant) and continuum productions. This procedure reduces the differences between the real and the approximated cross section (used in the distributions) and increases therefore the Monte Carlo efficiency. The analytic expressions of the used distributions are (see PYTHIA manual [1], page 90):

$$h_\tau(\tau) = \frac{c_1}{I_1}\frac{1}{\tau} + \frac{c_2}{I_2}\frac{1}{\tau^2} + \frac{c_3}{I_3}\frac{1}{\tau(\tau + m_H^2/s)} + \frac{c_4}{I_4}\frac{1}{(s\tau - m_H^2)^2 + m_H^2\Gamma_H^2}$$

$$h_y(y) = \frac{c_1}{I_1}(y - y_{min}) + \frac{c_2}{I_2}(y_{max} - y) + \frac{c_3}{I_3}\frac{1}{\cosh(y)}$$

$$h_z(z) = \frac{c_1}{I_1} + \frac{c_2}{I_2}\frac{1}{a-z} + \frac{c_3}{I_3}\frac{1}{a+z} + \frac{c_4}{I_4}\frac{1}{(a-z)^2} + \frac{c_5}{I_5}\frac{1}{(a+z)^2}$$

With $a = 1 + 2m_h^4/\hat{s}^2$. In h_τ the first two terms represent the dependence for continuum production and the last two terms take into account the s-channel production (the H or Z resonance). The two first terms of h_y are for a uniform distribution for positive and negative values. The third term describes the cross section behaviour for small values of y. The second and fourth term of h_z are for the $1/t$ and $1/t^2$ dependencies while the third and fifth term are for the $1/u$ and $1/u^2$ dependencies. The I_i factors are the total integrated values of each term in the allowed range. The c_i factors are weights for each term normalized for every distribution and are optimized during PYTHIA initialization.

The implemented processes for which a resonance production is possible are the following:

No.	Subprocess	Possible resonance
303	$gg \to h^0 h^0$	H^0
306	$gg \to A h^0$	Z^0
307	$gg \to A H^0$	Z^0
308	$gg \to AA$	H^0

Note that, the reactions $Z \to AH$, $Z \to Ah$ and $H \to AA$ are not CP allowed. So in these cases, the resonance production is very unlikely to appear.

2.4 Differential cross section computation

The HPAIR routines provide the differential cross section as function of the Mandelstam variables $\hat{s}$, $\hat{t}$ and $\hat{u}$ which are derived from the generated τ, y and z values. These routines use the formula[5]:

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t} = [\frac{1}{2}]\frac{2\alpha_S^2}{(4\pi)^2}\frac{1}{256 \cdot 16\pi\hat{s}^2}\mathcal{M}^2$$

where $\mathcal{M}$ is the matrix element, and the 1/2 factor is only present if we have two identical particles in the final state, that is AA, HH or hh.

2.5 Treatment of the off-shell bosons

In SM and MSSM large $\tan\beta$ scenarios, the Higgs width might be non negligible and Higgs particles might be produced off-shell. This case must be taken into account in order to reproduce correctly the kinematics of the events,

When the Higgs width is not negligible ($\geq$ 0.020 GeV), like for the other kinematical variables, PYTHIA can generate the Higgs mass along a $f(m^2)$ distribution taking account the resonance. This generation is controlled by $MSTP(42) = 1$. The $f(m^2)$ distribution is made of 3 terms, with the first one being a Breit-Wigner. Each term is weighted with a fixed coefficient. This coefficient is 80% for the first term. The Breit-Wigner does well reproduce the shape of the resonance when substituting the width Γ with $m^*\Gamma^*/m_R$ in its formula. Γ^* being the Higgs width at the generated mass m^* scale. For each event, the cross section is then weighted with a factor B_H^*/B_H defined as follow:

$$B_H^* = \frac{m_H \Gamma_H^*}{(m_H^{*2} - m_H^2)^2 + m_H^{*2}\Gamma_H^{*2}}$$

and

$$B_H = \frac{m_H \Gamma_H}{(m_H^{*2} - m_H^2)^2 + m_H^2\Gamma_H^2}$$

where H can be any of A, H and h, and '$*$' denotes the off-shell bosons. The total cross section weight factor is then:

$$B^*_{H_1}/B_{H_1} \cdot B^*_{H_2}/B_{H_1} \cdot \frac{m_{H_1^*} m_{H_2^*}}{m_H^2}$$

where $i = 1, 2$ denotes the two final states Higgs bosons.

In this case, the generation of events is much slower and can lead to very high and unphysical differential cross sections. Thus, except for the study of the event kinematics, one should rely on on-shell bosons production.

2.6 Event generation and total cross section

Each Monte Carlo event is weighted using the differential cross section and kinematical variables. In this way, the total cross section is obtained from all the generated events, with (see PYTHIA manual [1], page 92):

$$\sigma = \left\langle \frac{\pi}{s} \frac{\beta_{34}}{\tau^2 h_\tau(\tau) h_y(y) 2 h_z(z)} x_1 f_1(x_1, Q^2) x_2 f_2(x_2, Q^2) \frac{\hat{\sigma}^2}{\pi} \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t} \right\rangle$$

where the f_i are the structure functions and the x_i denote the fraction of energy carried by the incoming partons.

2.7 User instructions

The modified version of PYTHIA described here is available through the web at the address:

http://lafaye.home.cern.ch/lafaye/HiggsPairs/HiggsPairs.html

or under the following directory:

/afs/cern.ch/user/l/lafaye/public/pythia/pythia6203-hpair

This directory includes the FORTRAN source, as well as the Linux RedHat 6.0 compiled library *libpythia.a*, which should be linked with the program. The above directory also includes a test file *pythia62.F* and a *Makefile* to compile it, together with an input file *pythia.in*.

The new processes were implemented in PYTHIA 6.2. Since they include also the resonance production, process 152 should be turned off to avoid double counting.

The PYTHIA MSSM parameters $\tan\beta$ and m_A can be set respectively with RMSS(5) and RMSS(19). Another useful PYTHIA parameter is MSTP(42), which allows to turn on or off the off-shell boson generation.

The parameters used in the tests described in the following sections, for maximal mixing scenario are:

```
MSTP(52)  = 2
MSTP(51)  = 4046          ! use CTEQ5L
MSTU(112) = 5             ! number of flavors
MSTP(3)   = 1
MSTP(32)  = 4
PARP(1)   = 0.146D0       ! lambda
MDCY(6,1) = 1             ! top quark decay allowed
MSTP(48)  = 1             ! top quark decay before fragmentation
MSTP(61)  = 1             ! initial state QCD and QED radiation on
MSTP(71)  = 1             ! final state QCD and QED radiation on
MSTP(81)  = 1             ! multiple interactions on
MSTP(111) = 1             ! fragmentation and decay on
MSTJ(41)  = 1             ! only QCD showering
MSTJ(11)  = 3             ! Peterson fragmentation function for b and c
PARJ(54)  = -0.07         ! fragmentation of flavor c
PARJ(55)  = -0.006        ! fragmentation of flavor b
MSTP(42)  = 0             ! select off-shell bosons production
MSTP(123) = 1             ! reaction to violation of maximum
IMSS(1)   = 1             ! SUSY parameters
IMSS(2)   = 3
IMSS(4)   = 1
IMSS(5)   = 0
IMSS(8)   = 0
IMSS(9)   = 1
PMAS(3,1) = 0.190D0       ! quark masses
PMAS(4,1) = 1.5D0
PMAS(5,1) = 5.0D0
PMAS(6,1) = 175.D0
PMAS(13,1)= 0.1056583D0   ! leptons masses
PMAS(15,1)= 1.7771D0
PARU(101) = 137.03598D0   ! 1/alpha QED
PMAS(23,1)= 91.187D0      ! weak bosons masses
PMAS(24,1)= 80.330D0
RMSS(4)   = 200.D0        ! mu for maximal mixing scenario
RMSS(2)   = 1000.D0       ! gaugino mass parameter
RMSS(6)   = 1000.D0       ! left handed sleptons
RMSS(7)   = 1000.D0       ! right handed sleptons
RMSS(8)   = 1000.D0       ! left handed up squarks
RMSS(22)  = 1000.D0       ! right handed up squarks
RMSS(9)   = 1000.D0       ! right handed down squarks
RMSS(13)  = 1000.D0       ! left handed staus
RMSS(14)  = 1000.D0       ! right handed staus
RMSS(10)  = 1000.D0       ! left stop mass
```

```
RMSS(12)  = 1000.D0      ! right stop mass
RMSS(11)  = 1000.D0      ! right sbottom mass
RMSS(17)  = 2450.D0      ! stau trilinear coupling
RMSS(16)  = 2450.D0      ! stop trilinear coupling
RMSS(15)  = 2450.D0      ! sbottom trilinear coupling
```

3 Cross section results

3.1 Cross sections for different MSSM scenarios

Studies were made using three different scenarios, maximal, typical and minimal mixing. They were defined as:

- Maximal mixing: $A_U = A_D = 2450$ TeV and $\mu = 200$ TeV
- Typical mixing: $A_U = A_D = 1000$ TeV and $\mu = -1000$ TeV
- Minimal mixing: $A_U = A_D = \mu = 0$

All cross sections were computed using the CTEQ5L structure functions, otherwise specified.

As can be seen on figure 2, the main difference between maximal and typical mixing comes from the fact that the transition region is much narrower for typical mixing. Below the transition region A and h are degenerated, while above that region, A and H are degenerated. At large $\tan\beta$ Higgs masses can get very close, making it almost impossible to differentiate between A and H or h. In the transition region, A, H and h all have almost the same mass and would be seen as the same object in accelerators such as the LHC.

Note that, while all different processes may behave very differently when changing MSSM parameters, the overall total cross section shape is more predictable, as shown on figure 3.

3.2 Comparison between Monte Carlo and integrated results

The standalone HPAIR program uses VEGAS to integrate the total cross section of Higgs pair production processes. The program allows also to compute the NLO contribution with QCD corrections, which are valid for m_A up to 200 GeV. Figure 4 shows respectively LO and NLO cross sections obtained with HPAIR and VEGAS as a function of m_A for different values of $\tan\beta$ in the typical mixing. One can see that the NLO cross sections are a factor 1.5 above LO cross sections.

As a check, one can compare cross section obtained using PYTHIA and VEGAS with the same matrix elements. Figures 5 and 6 show some results obtained with 1000 VEGAS iterations and 100 PYTHIA events per bin. Unfortunately, the stand alone HPAIR code and PYTHIA have some small differences in the algorithms which implement the running of α_S and the Higgs mass spectrum. For this reason, the cross cross section using the two codes might be slightly different. This is especially true when the cross section is very

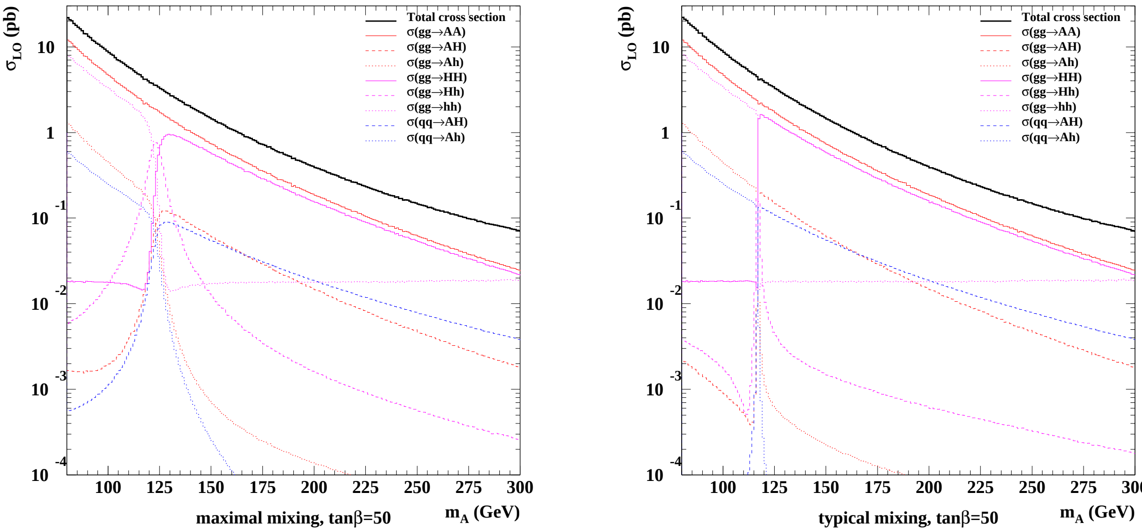

Figure 2: *Neutral Higgs pair LO cross sections as a function of* m_A *for* $\tan\beta = 50$*, obtained using HPAIR. For maximal mixing (left plot) and typical mixing (right plot). For the typical mixing scenario, the transition region is much narrower than in maximal or minimal mixing cases.*

sensitive on the H and h mass difference like for the resonance $gg \to H \to hh$ process at low $\tan\beta$. However for the SM case, where the Higgs mass is fixed, using the same algorithm for the running of α_S gives a good agreement between PYTHIA and HPAIR. This is also the case for MSSM scenarios when we use the same algorithms for the running of α_S and the Higgs mass spectrum.

3.3 Monte Carlo efficiency

To ensure that the kinematic variable distributions used in the Monte-Carlo do well reproduce the real ones, we compared the number of generated events with the number of tried events. With PYTHIA using the existing process ISUB=152 to generate $gg \to H \to hh$ we obtain, for maximal mixing scenario, the following numbers:

$\tan\beta$	m_A (GeV)	m_h (GeV)	Γ_h	σ (pb)	Number of generated events	Number of tried events
3	300	110.8	4.5 MeV	0.57	10000	26027
5	300	118.4	5.2 MeV	0.17	10000	25451
10	300	122.3	5.5 MeV	0.019	10000	27346
20	300	123.3	5.6 MeV	0.0031	10000	35363

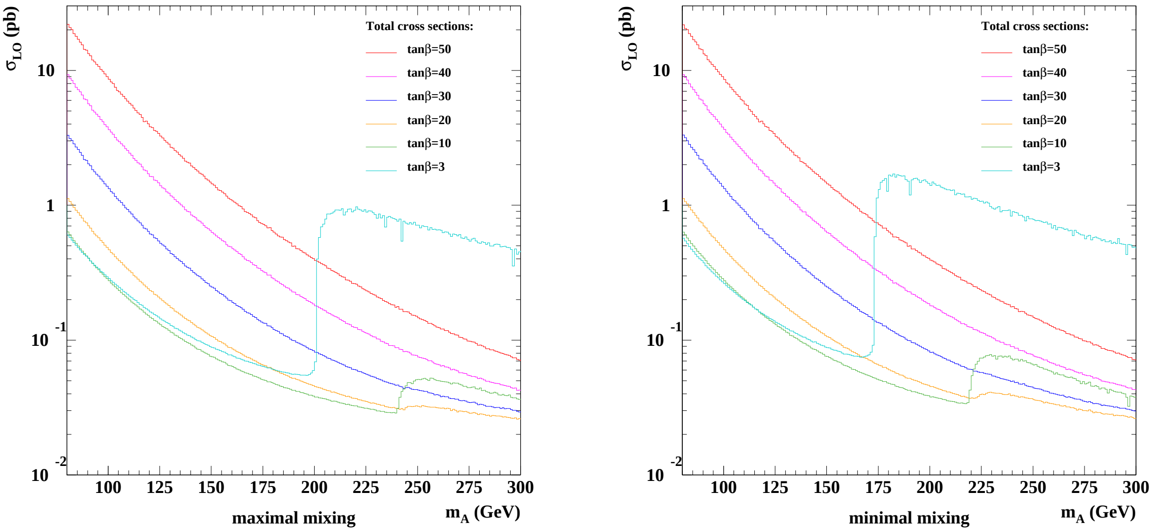

Figure 3: *Total neutral Higgs pair LO cross sections as a function of* m_A *for different values of* $\tan\beta$*, using HPAIR, for maximal mixing (left plot) and minimal mixing (right plot).*

Using the process ISUB=152, only the resonance production is simulated and thus, the cross section is lower than the total cross section obtained with HPAIR matrix elements. With our implementation of HPAIR matrix elements in PYTHIA we obtain, for MSSM maximal mixing scenario and SM, the following total $gg \to hh$ cross sections:

$\tan\beta$	m_A (GeV)	m_h (GeV)	Γ_h	σ (pb)	Number of generated events	Number of tried events
3	300	110.8	4.5 MeV	0.60	10000	53567
5	300	118.4	5.2 MeV	0.19	10000	53531
10	300	122.3	5.5 MeV	0.048	10000	62464
20	300	123.3	5.6 MeV	0.022	10000	101631
30	110	109.1	2.4 GeV	0.32	10000	47454
40	110	109.1	4.4 GeV	1.05	10000	46833
50	110	108.9	6.9 GeV	2.62	10000	47394
SM	-	115.0	3.3 MeV	0.021	10000	97743
SM	-	300.0	8.4 GeV	0.0013	10000	50972

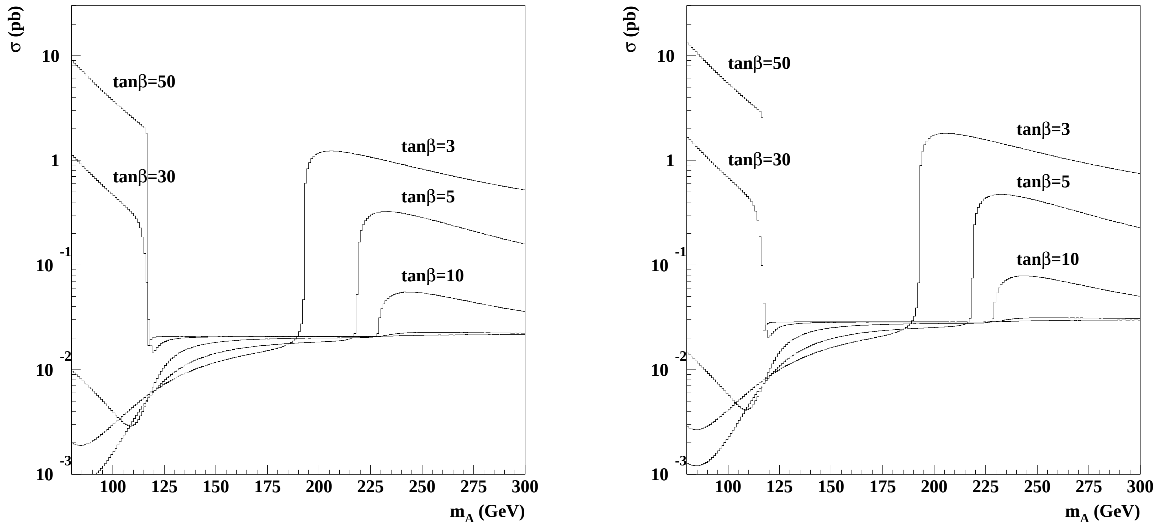

Figure 4: *$gg \to hh$ cross sections as a function of m_A for different values of $\tan\beta$ obtained with HPAIR and CTEQ4L structure functions, in the typical mixing scenario. For Leading Order (left plot) and Next to Leading Order cross sections (right plot).*

Our implementation is about twice less efficient, but, as we are comparing a $2 \to 2$ with a $2 \to 1$ process, this is still acceptable. However, when the light Higgs width increases, the corresponding Higgs mass should be generated with a Breit-Wigner shape to correctly reproduce the kinematics of the events.

In this case, where the final state Higgs bosons are generated off-shell, the Monte-Carlo efficiency is greatly reduced:

$\tan\beta$	m_A	m_h (GeV)	Γ_h	σ (pb)	Number of generated events	Number of tried events	Warnings
30	110	109.1	2.4 GeV	0.31	10000	151129	0
40	110	109.1	4.4 GeV	1.00	10000	150090	2
50	110	108.9	6.9 GeV	2.50	10000	148759	3
SM	-	300.0	8.4 GeV	0.0014	10000	155741	8

The last row of the table gives the number of advisory warning due to a maximum violation in the computed differential cross section. This number gets higher when the Higgs width increases. Maximum violation should only occurs when off-shell bosons production is selected, as PYTHIA always search for the maximum of the differential cross section using on-shell particles. One should then, take care that the maximum increases only by a

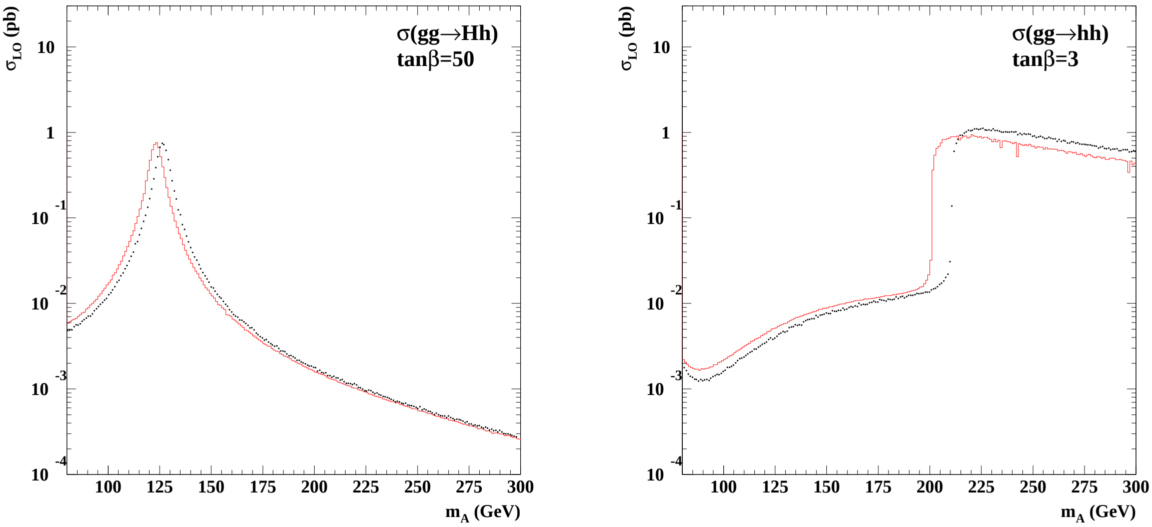

Figure 5: *Neutral Higgs pair cross sections as a function of m_A obtained with HPAIR-VEGAS and HPAIR-PYTHIA. For $gg \to Hh$ process at $\tan\beta = 50$ (left plot) and $gg \to hh$ at $\tan\beta = 3$ for maximal mixing (right plot). The histograms are the VEGAS results and the black dots were obtained with PYTHIA. The main differences between PYTHIA and HPAIR come from the running of α_S and, especially for resonant processes, from the Higgs mass spectrum.*

small amount. Otherwise, one should set the PYTHIA parameter MSTP(123)=1, so that the maximum will not be increased.

Although, the HPAIR matrix elements can be used to compute off-shell bosons differential cross sections, one should rather trust cross sections obtained with on-shell bosons for Higgs pair production. But off-shell bosons events are still very interesting for kinematics studies.

3.4 Kinematic distributions

Kinematic distributions have been studied for the 4 b final state, that is when both Higgs disintegrate to $b\bar{b}$. The most important one for this final state is the p_T distribution of the b, as current selection algorithms ask for b with a p_T above 40 GeV. In addition, as there is no b-trigger in ATLAS, higher p_T jets will be more likely to pass the jet trigger thresholds.

First of all the distributions in η and p_T of the b for the existing $gg \to H \to hh$ PYTHIA process 152 and our implemented process $gg \to hh$ process in the resonance region ($\tan\beta = 3$ and $m_A = 300$ GeV) are very similar.

For the p_T distribution of the b and the mass resolution of the b pairs we have used $\tan\beta = 50$ and $m_H = 150$ GeV in the maximal mixing scenario. All Higgs pair production processes were turned on, including the already existing $f\bar{f} \to AH$ and $f\bar{f} \to Ah$. For

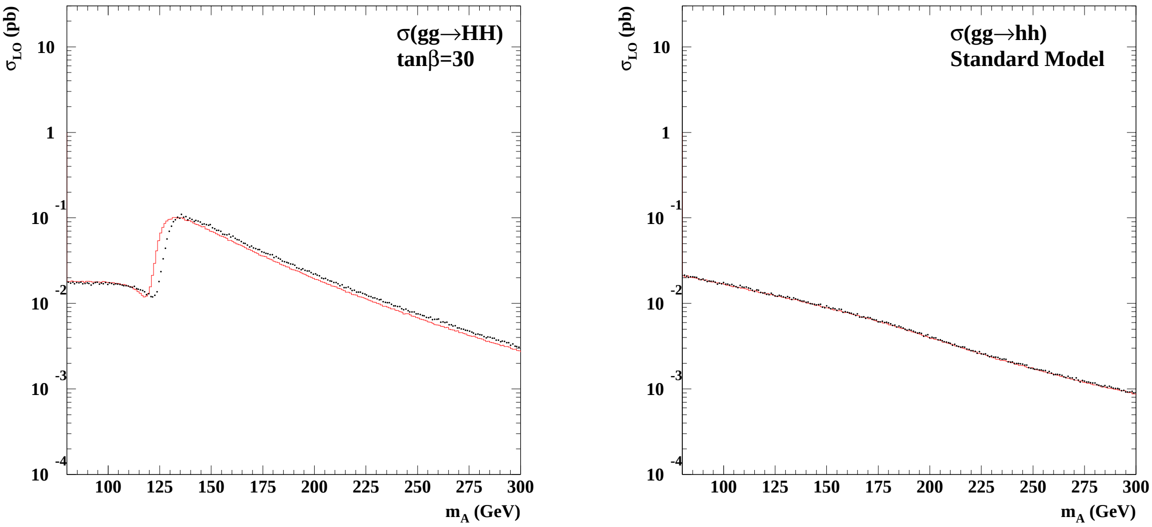

Figure 6: *Neutral Higgs pair cross sections obtained with HPAIR-VEGAS and HPAIR-PYTHIA. For $gg \to HH$ process at $\tan\beta = 30$, as a function of m_A for maximal mixing (left plot) and $gg \to HH$ in the Standard Model, as a function of m_H (right plot). The histograms are the VEGAS results and the black dots were obtained with PYTHIA. In this case we used the same routine for the running of α_S, thus obtaining a better agreement and leaving only the Higgs mass spectrum difference for the MSSM case.*

this set of MSSM parameters, Higgs pair production are largely dominated by A and H pairs. The following table summarizes the MSSM parameters and cross sections obtained for these processes:

$\tan\beta$	m_A	m_H (GeV)	Γ_H	σ (pb)	Number of generated events	Number of tried events	Warnings
50	148.9	150.0	9.1 GeV	1.46	20000	113186	1
50	148.9	150.0	9.1 GeV	1.45	20000	334236	5

Where the first line of the table stands for on-shell ($MSTP(42) = 0$) and the last line for off-shell bosons ($MSTP(42) = 1$). Events were then analyzed with the ATLAS fast simulation, ATLFAST, to take into account the detector acceptance and resolution. As can be seen on figure 7 the b pair invariant mass resolution is convoluted with the Higgs width, when bosons are produced off-shell, as expected. The distribution of the jet p_T is very similar and makes very little difference.

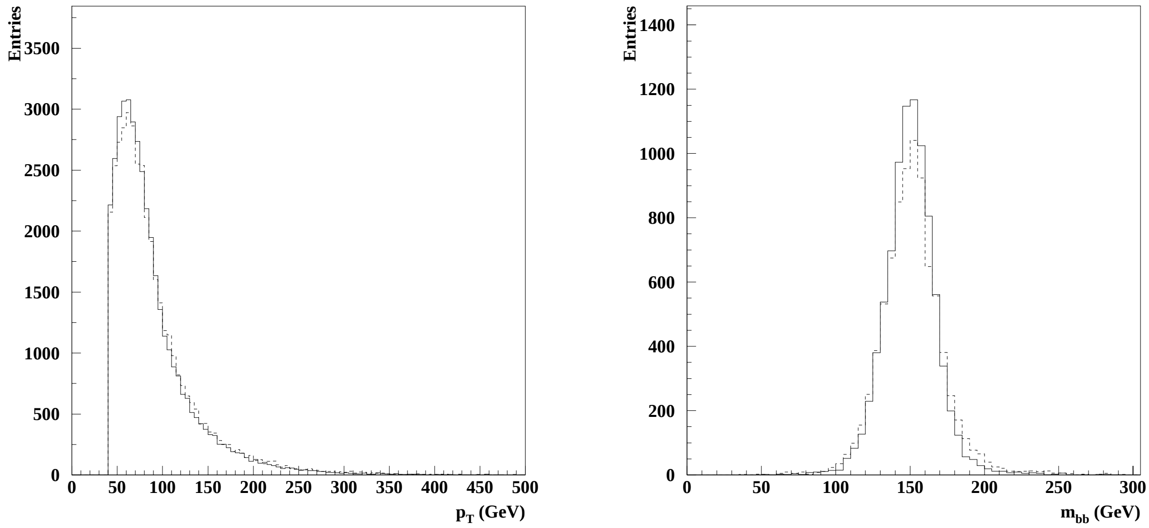

Figure 7: *Kinematic distributions obtained with on-shell (black line) and off-shell Higgs bosons production (dashed line) for* $\tan\beta = 50$ *and* $m_H = 150$ *GeV. Left* p_T *distribution of all jets and right bb invariant mass. The mass resolution of the b jet pairs is of 15.5 GeV for on-shell bosons while it is of 17.5 GeV when Higgs bosons are produced off-shell.*

4 Conclusion and prospects

Higgs pair production processes have been successfully implemented in PYTHIA 6.203. Nevertheless in some rare points of the parameters space when using off-shell bosons the behaviour of the matrix elements has still to be investigated.

The analysis of the MSSM neutral Higgs boson production has two main reasons of interests[7, 8, 9, 10]. The first is Higgs discovery which could be achieved either through the study of the resonance production (in this case the cross section according to NLO predictions is of the order of 2 pb) or for high values of $\tan\beta$ where the cross section for $\tan\beta = 50$ can reach 30 pb. The first case as already been studied in [11] while the second is under analysis.

A second reason of interest is the reconstruction of the Higgs potential which implies the measurement of the Higgs self couplings like λ_{Hhh}. Whether this coupling can be measured for double Higgs resonance production with sufficient integrated luminosity at the LHC is under investigation.

References

[1] *PYTHIA 6.2 Physics and Manual.*

T. Sjöstrand and L. Lönnblad. hep-ph/0108264, LU TP 01-21, August 2001.
See also T. Sjöstrand, Web page at
http://www.thep.lu.se/tf2/staff/torbjorn/Pythia.html

[2] *VEGAS - an adaptive multi-dimensional integration program.*
G. P. Lepage. CLNS-447. - Ithaca, NY : Cornell Univ. Lab. Nucl. Stud. , Mar 1980.

[3] *Studies on the measurement of the SM Higgs self-couplings.*
A. Blondel, A. Clark, F. Mazzucato. ATL-COM-PHYS-2002-005, 21 Feb 2002.

Two loop QCD corrections to Higgs pair production at the LHC.
S. Dawson, S. Dittmaier and M. Spira. Acta Phys. Polon. B29 2875-2882, 1998.

[4] *Pair production of neutral Higgs particles in gluon-gluon collisions.*
T. Plehn, M. Spira, P.M. Zerwas. Nucl. Phys. B479 46-64, 1996, Erratum-ibid. B531 655, 1998.

[5] *Neutral Higgs-boson pair production at hadron colliders: QCD corrections.*
S. Dawson, S. Dittmaier and M. Spira. Phys. Rev. D58 115012, 1998.
See also M. Spira, Web page and program list at
http://mspira.home.cern.ch/mspira/proglist.html

[6] *Two loop QCD corrections to Higgs pair production at the LHC.*
S. Dawson, S. Dittmaier and M. Spira. Acta Phys. Polon. B29 2875-2882, 1998.

[7] *Production of neutral Higgs-boson pairs at LHC.*
A. Djouadi, W. Killian, M. Mühlleitner and P.M. Zerwas. Eur. Phys. J. C10 45-49, 1999.

[8] *The reconstruction of trilinear Higgs couplings.*
A. Djouadi, W. Killian, M. Mühlleitner and P.M. Zerwas. hep-ph/0203056

[9] *The Higgs working group: summary report.*
Les Houches 1999 Higgs Working Group. hep-ph/0002258 page 67.

[10] *The Higgs working group: summary report.*
Les Houches 2001 Higgs Working Group. hep-ph/0203056 page 29.

[11] *MSSM Higgs searches in multi-b-jet final states.*
E. Richter-Was and D. Froidevaux. ATLAS-NOTE-PHYS-104 1997.

[12] *ATLAS Detector and Physics Performance TDR.*
ATLAS Collaboration. CERN/LHCC/99-15 1999.