# MULTIPLE HIGGS PRODUCTION IN THE MSSM

($H \to hh \to b\bar{b}b\bar{b}$)

## OUTLINE

1 BRIEF REVIEW OF THE MSSM

2 ABOUT $H \to hh \to b\bar{b}b\bar{b}$

3 ONGOING ANALYSIS, NUMBERS

# 1 BRIEF REVIEW OF THE MSSM

- SUSY: a symmetry between bosons and fermions
  (relevant to hierarchy problem, string theory, gravity, ...)

MSSM: Minimal Supersymmetric Standard Model
is the simplest supersymmetric extension of SM

Particle content of the MSSM:

- SM fermions ($s=\frac{1}{2}$) + NEW spin 0 superpartners (Chiral supermultiplet)
- SM gauge bosons ($s=1$) + NEW spin $\frac{1}{2}$ superpartners (Gauge supermultiplet)
- NEW Higgsinos ($s=\frac{1}{2}$) + EXTENDED Higgs sector ($s=0$) (Chiral supermultiplet)

SUSY must be broken

- Soft susy breaking:
  - to naturally solve the hierarchy problem
  - Next accelerators provide these energies

- Broken by hand: 105 new parameters
  Exp. constraints ($\not{CP}$, FCNC)

# Higgs sector in the MSSM

SM : 1 Higgs doublet (4 dof) $\xrightarrow{\text{mass to } Z, W^\pm}$ 1 Higgs particle (1 dof)

MSSM: 2 Higgs doublets (8 dof) $\xrightarrow{\text{mass to } Z, W^\pm}$ 5 Higgs particles (5 dof)
$H^\pm, A, H, h$

At tree level described by $m_A$ and $\tan\beta = v_u/v_d$

Loop corrections involve more parameters

$M_h \lesssim 130$ GeV ($m_h \leq 150$ GeV) (for $m_{susy} \lesssim 1$ TeV)

Usual choice of parameters:

- simplification of mass matrices (where most of the new parameters sit)
- $m_{susy} = 1$ TeV ($\Rightarrow$ Higgs decay not involving spartides)
- $A_t, \mu$ often varied (maximal/minimal mixing ~ mass of $h$)

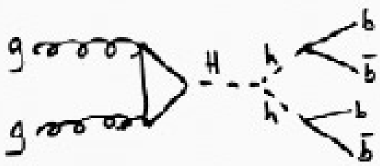
# 2 About $H \to hh \to b\bar{b}b\bar{b}$

$2m_h \leq m_H < 2m_t$

Resonant process in PYTHIA: dominant at low $\tan\beta$

$gg \to H \to hh \to b\bar{b}b\bar{b}$

$q\bar{q}\ (b\bar{b}) \to H \to hh \to b\bar{b}b\bar{b}$





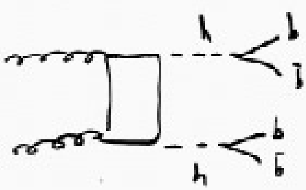
$\sigma_{gg \to H} = 1{,}18$ pb (78%)

$\sigma_{q\bar{q} \to H} = 0{,}33$ pb (22%)

High $\tan\beta$: $BR(H \to hh) \to 0$

> NB: inconsistency in PYTHIA for large $\tan\beta$?
> $\sigma_{H \to hh} \neq \sigma_H \cdot BR(H \to hh)$

Continuum production is dominant




(Not in official PYTHIA)

Does not involve $\lambda_{Hhh}$

So, $\lambda_{Hhh}$ only accessible at low $\tan\beta$

# 3 ONGOING ANALYSIS

Look at resonant production.

Similar study by E. Richter-Wás (1997)

First step: reproduce some of her results

Parameter setup:

$$\left.\begin{array}{l} m_{SUSY} = \mu = A_t = 1\,\text{TeV} \\ \tan\beta = 3.0 \\ m_A \simeq 294\ \text{GeV} \end{array}\right\} \Rightarrow \begin{array}{l} m_H = 300\ \text{GeV} \\ m_h \doteq 100\ \text{GeV} \\ BR(H\to hh) = 0{,}589 \\ BR(h\to b\bar{b}) = 0{,}863 \\ (BR(h\to\gamma\gamma) = 0{,}00259) \\ \sigma(gg, q\bar{q}\to H) = 1{,}50\ \text{pb} \end{array}$$

Signal:

$\sigma(gg, q\bar{q} \to H \to hh \to b\bar{b}b\bar{b}) = 0{,}659$ pb  [E. Richter-Wás : $\sigma = 0{,}76$ pb]

Background:

Any multijet final state where 4 jets are tagged as b-jets.

Ex.:  ...

In PYTHIA processes not included in this form.

They are generated "randomly" by FSR of a $2\to 2$ process, e.g. 

⇒ Need to generate a lot of events and pick out the interesting ones

Background:

$\sigma(gg \to gg) \sim 10^{12}$ pb

$\sigma(gg \to gg) \sim 10^{8}$ pb
(ckin(3) = 30)

$\sigma(gg, q\bar{q} \to b\bar{b}) = 725$ pb

Need to discriminate the background

1. Consider all jets in event with $p_T > 40$ GeV
2. Choose the best combination by minimising
   $$\chi^2 = (m_{jj1} - m_h)^2 + (m_{jj2} - m_h)^2$$
3. Require that the best combination consist of jets which are b-tagged
4. Require $|m_{jj} - m_h| < 25$ GeV
5. Require $|m_{jjjj} - m_H| < 20$ GeV

| SIGNAL: gg,qq_-> H -> hh -> bb_bb_ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GENERATED: | | | | | SCALED TO LUMINOSITY 300000 pb-1 | | | | |
| | xsec(pb) | #Gen. | Ref 2 | Ref 3 | Ref 4 | Ref 5 | #Total | Ref 2 | Ref 3 | Ref 4 | Ref 5 |
| This an.: | 0.76 | 1e+05 | 2.3e+04 | 433 | 346 | 167 | 228000 | 51984 | 986 | 788 | 381 |
| | | | | E.Richter-Was: | | | | 58000 | 640 | 470 | 360 |

Reconstr. 4 jets with $p_t > 40$ → Ref 2; b-tagged → Ref 3; mass constr. 1 → Ref 4; mass constr. 2 → Ref 5

| Process: gg,qq_->QQ_ | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GENERATED: | | | | | SCALED TO LUMINOSITY 300000 pb-1 | | | | |
| CKIN | | xsec(pb) | #Gen. | Ref 2 | Ref 3 | Ref 4 | Ref 5 | #Total | Ref 2 | Ref 3 | Ref 4 | Ref 5 |
| 0-60 | * | 146 | 1e+06 | 3.3e+05 | 170 | 68 | 9 | 4.4e+07 | 1.5e+07 | 7456 | 2992 | 382 |
| 60-100 | * | 181 | 1e+06 | 4.0e+05 | 169 | 65 | 11 | 5.4e+07 | 2.2e+07 | 9173 | 3551 | 604 |
| 100-120 | * | 84 | 1e+06 | 4.7e+05 | 187 | 69 | 13 | 2.5e+07 | 1.2e+07 | 4728 | 1731 | 315 |
| 120-180 | * | 181 | 1e+06 | 5.5e+05 | 206 | 61 | 11 | 5.4e+07 | 3.0e+07 | 11201 | 3328 | 593 |
| 180-200 | * | 34 | 1e+06 | 6.4e+05 | 264 | 73 | 9 | 1.0e+07 | 6.5e+06 | 2701 | 743 | 94 |
| 200-300 | * | 78 | 1e+06 | 7.0e+05 | 343 | 86 | 11 | 2.3e+07 | 1.6e+07 | 8057 | 2027 | 247 |
| 300-450 | * | 21 | 1.3e+06 | 1.0e+06 | 906 | 269 | 17 | 6.2e+06 | 4.9e+06 | 4351 | 1290 | 81 |
| 450-> | * | 4 | 1e+06 | 7.9e+05 | 2403 | 579 | 13 | 1.3e+06 | 1.0e+06 | 3136 | 755 | 17 |
| | | | | | | | | | | (2100) | (2.8) | (7.9) |
| | | | | | This analysis: | | | 2.2e+08 | 1.1e+08 | 50803 | 16417 | 2333 |
| | | | | | | | | | | | | |
| | | | | | E.Richter-Was: | | | | 2.0e+08 | 140000 | 3000 | 500 |
| | | | | | | | | | | (1400) | (47) | (6) |

CKIN: Range of allowed $p_\perp$ values for hard 2→2 process with $p_t$ defined in the restframe of the hard interaction

- statistical "acceptable" amounts
- considerably higher than E.Richter-Was, different factors
- Need all the bins ?

| Process: gg->gg | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GENERATED: | | | | | SCALED TO LUMINOSITY 300000 pb-1 | | | | |
| CKIN | xsec(pb) | #Gen. | Ref 2 | Ref 3 | Ref 4 | Ref 5 | #Total | Ref 2 | Ref 3 | Ref 4 | Ref 5 |
| 0-30 | 2.1e+12 | | | | | | | | | | |
| 30-40 | 7.7e+07 | 1.93e+07 | 76 | 0 | 0 | 0 | 2.3e+13 | 9.0e+07 | 0 | 0 | 0 |
| 40-100 | | | | | | | | | | | |
| 100-110 | 2.9e+05 | 1.04e+07 | 1.1e+05 | 28 | 4.8 | 0 | 8.8e+10 | 9.3e+08 | 2.4e+05 | 4.1e+04 | 0 |
| 110-140 | 3.8e+05 | 9.79e+06 | 1.7e+05 | 48 | 8.7 | 1.1 | 1.1e+11 | 2.0e+09 | 5.5e+05 | 1.0e+05 | 12674 |
| 140-170 | 1.2e+05 | 9.03e+06 | 2.5e+05 | 90 | 8.5 | 0.9 | 3.5e+10 | 9.6e+08 | 3.5e+05 | 3.3e+04 | 3468 |
| 170-200 | 4.3e+04 | 8.44e+06 | 3.6e+05 | 171 | 18.2 | 1.4 | 1.3e+10 | 5.6e+08 | 2.6e+05 | 2.8e+04 | 2135 |
| 200-> | 3.6e+04 | 7.70e+06 | 4.9e+05 | 269 | 37.5 | 4.6 | 1.1e+10 | 7.0e+08 | 3.8e+05 | 5.3e+04 | 6524 |
| | | | | | | | | (3,2·10^3) | (9) | (11) | |
| | | | | This analysis: | | | 2.3e+13 | 5.2e+09 | 1.8e+06 | 2.5e+05 | 24801 |
| | | | | E.Richter-Was: | | | | 1.7e+10 | 1.9e+05 | 1.4e+04 | 1000 |
| | | | | | | | | (8,9·10^4) | (14) | (14) | |

- Binning necessary
- Problem of zero
- Problem of small amounts

- Huge difference in results, factor