SM/MSSM Higgs production at LHC

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HERA-LHC II workshop - CERN 08/06 2006

BG+Pile-up effect for DPE processes
MSSM estimates for DPE signal
Double Pomeron Exch. Higgs Production

Exclusive DPE Higgs production $pp \rightarrow p \ H \ p : \ 3-10 \ fb$
Inclusive DPE Higgs production $pp \rightarrow p+X+H+Y+p : \ 50-200 \ fb$

$M_h^2$ measured in RP via missing mass as $\xi_1*\xi_2*s$

$bb$: $Jz=0$ suppression of $gg\rightarrow bb$ bg $\mid$ $WW$: bg almost negligible

$bb$: L1-trigger of “central CMS+220 RP” type extensively studied by CMS/Totem group – see Monika’s talk.

$WW$: Extremely promising for $M_h>130$ GeV. Relevant triggers already exist.
Better $M_h$ resolution for higher $M_h$. 

E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. ...
V.Petrov et al.
DPE Higgs event generators

1. **DPEMC 2.4** (M. Boonekamp, T. Kucs)
   - Bialas-Landshof model for Pomeron flux within proton
   - Rap.gap survival probability = 0.03
   - Herwig for hadronization

2. **EDDE 1.2** (V. Petrov, R. Ryutin)
   - Regge-eikonal approach to calculate soft proton vertices
   - Sudakov factor to suppress radiation into rap.gap
   - Pythia for hadronization

3. **ExHuMe 1.3.1** (J. Monk, A. Pilkington)
   - Durham model for exclusive diffraction (pert calc. by KMR)
   - Improved unintegrated gluon pdfs
   - Sudakov factor to suppress radiation into rap.gap + rap.gap survival prob. = 0.03
   - Pythia for hadronization

All three models available in the fast CMS simulation
Difference between DPEMC and (EDDE/ExHuMe) is an effect of Sudakov suppression factor growing as the available phase space for gluon emission increases with increasing mass of the central system.

Models predict different physics potentials!
Both the signal and bg studied at detector level using FAMOS.
The following packages used in the analyses:
   - Fastcalorimetry
   - FastTsim, FastBtag
   - FastJets,
   - FastMuon, FastMuonTrigger
   - FastTotem (just Roman Pots)

Jet algorithm:
   o) Iterative cone, Cone radius = 0.7
   o) Jet energy scale corections applied to detector level jets
Roman Pot acceptances

**Acceptance 220 m ($\beta^* = 0.55 \ m$)**

- **beam1**: Interval of 50% acceptance: $1.6 \% < \xi < 18 \%$
- **beam2**: Interval of 50% acceptance: $1.9 \% < \xi < 18 \%$
- Acceptance for elastics

**Acceptance 420 m ($\beta^* = 0.55 \ m$)**

- **beam1**: Interval of 50% acceptance: $0.25 \% < \xi < 1.9 \%$
- **beam2**: Interval of 50% acceptance: $0.2 \% < \xi < 1.7 \%$

Graph showing acceptance as a function of $M_H$ for different models.
Excl. DPE $H \rightarrow WW$: Event yields per $L=30$ fb$^{-1}$

- Both protons accepted in one of two RP's (220, 420)
- (L1 muons taken from FAMOS. El.+quarks correspond to parton level)
- Various cut scenarios acc.to current CMS L1 thresholds:

- **Semi-leptonic W decay:**
  - 1e (pt$>29$ GeV, $|\eta|<2.5$) or 1μ (pt$>14$ GeV, $|\eta|<2.1$) or
  - 1e (pt$>20$ GeV, $|\eta|<2.5$) + 2 quarks (pt$>25$ GeV, $|\eta|<5$) or
  - 1μ (pt$>10$ GeV, $|\eta|<2.1$) + 2 quarks (pt$>25$ GeV, $|\eta|<5$)

- **Fully leptonic W decay:**
  - 2e (pt$>17$ GeV, $|\eta|<2.5$) or 2μ (pt$>3$ GeV, $|\eta|<2.1$) or
  - eμ (pte$>17$ GeV, $|\eta|<2.5$ and ptμ$>3$ GeV, $|\eta|<2.1$) or
  - 2e (ptmax$>29$ GeV, $|\eta|<2.5$) or 2μ (ptmax$>14$ GeV, $|\eta|<2.1$) or
  - eμ (pte$>29$ GeV, $|\eta|<2.5$ or ptμ$>14$ GeV, $|\eta|<2.1$)
### Excl. DPE $H \rightarrow WW$: Event yield for $L=30$ fb$^{-1}$

**ExhuMe 1.3 and new RP acceptances**

<table>
<thead>
<tr>
<th>$M_h$ [GeV]</th>
<th>$\sigma_{\text{XBR}}$ [fb]</th>
<th>Acc. [%]</th>
<th><strong>Fully-lept</strong></th>
<th></th>
<th><strong>Semi-lept</strong></th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CMS</td>
<td>Atlas</td>
<td>CMS</td>
<td>Atlas</td>
</tr>
<tr>
<td>120</td>
<td>0.37</td>
<td>57</td>
<td>0.2</td>
<td>0</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>135</td>
<td>0.77</td>
<td>62</td>
<td>0.6</td>
<td></td>
<td>3.1</td>
<td></td>
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<td>140</td>
<td>0.87</td>
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<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>150</td>
<td>1.00</td>
<td>66</td>
<td>1.0</td>
<td></td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>1.08</td>
<td>69</td>
<td>1.0</td>
<td>1</td>
<td>6.0</td>
<td>5</td>
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<tr>
<td>170</td>
<td>0.94</td>
<td>71</td>
<td>1.0</td>
<td></td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>0.76</td>
<td>74</td>
<td>0.8</td>
<td>1</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>200</td>
<td>0.44</td>
<td>78</td>
<td>0.6</td>
<td>1</td>
<td>2.9</td>
<td>2</td>
</tr>
</tbody>
</table>
High Lumi selection cuts at detector level (for all $M_h$):

0) Both protons detected in RPs (420+420 or 420+220 or 220+420) 
1) $N_{jet} > 1$
2) $45 < E_{t1}^{*JESCor} < 85$ GeV, $E_{t2}^{*JESCor} > 30$ GeV 
3) $|\eta_{j1,2}| < 2.5$
4) $|\eta_{j1} - \eta_{j2}| < 1.8$
5) $2.8 < |\phi_{j1} - \phi_{j2}| < 3.48$
6) $M_{j1j2}/M_{miss.mass} > 0.8$
7) Both jets b-tagged
Excl. DPE H→bb: Mh dependence

Signal numbers come from ExHuMe (DPEMC gives similar predictions for Mh=120 GeV). BG numbers come from DPEMC (just for technical reasons). EDDE gives 10x smaller xsections for BG.

BG processes studied: DPE gg→bb + QCD gg→gg

Mass windows (ΔM) used only for S/B studies.
Two window widths used: narrower for (420+420) and broader for combined RP configs.

Mh=120: resolution=1.6%→ΔM=4GeV for 420+420 config.
resolution=5.6%→ΔM=10GeV for combined config.
Excl. DPE $H\to bb$: $M_h$ dependence, $L=30$ fb$^{-1}$

<table>
<thead>
<tr>
<th>$M_h$[GeV]</th>
<th>$\sigma$[fb]</th>
<th>$S_{ideal}$</th>
<th>Acc[%]</th>
<th>$\varepsilon_{btag}$[%]</th>
</tr>
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<tbody>
<tr>
<td>120</td>
<td>1.9</td>
<td>57</td>
<td>57</td>
<td>33</td>
</tr>
<tr>
<td>140</td>
<td>0.6</td>
<td>18</td>
<td>63</td>
<td>37</td>
</tr>
<tr>
<td>160</td>
<td>0.045</td>
<td>1.35</td>
<td>69</td>
<td>40</td>
</tr>
<tr>
<td>180</td>
<td>0.0042</td>
<td>0.13</td>
<td>74</td>
<td>42</td>
</tr>
<tr>
<td>200</td>
<td>0.00156</td>
<td>0.047</td>
<td>78</td>
<td>43</td>
</tr>
</tbody>
</table>

WITHOUT PILE-UP

The event yields at higher masses negligible in SM. But in MSSM the cross-sections sometimes enhanced by a factor of 100 wrt SM.

Event selection eff. grows from 7% ($M_h=120$) to 14% ($M_h=200$). Loss of stat. at $M_h = 120$ GeV:
Etjet cut (55%), b-tag (67%) and RP Acc. (43%).
Effect of pile-up events

What is the number of fake signal events per bunch crossing ($N_{\text{fake}}/\text{BX}$) caused by PU events?

Selection criteria for signal events (Higgs in DPE):

[2 protons in RPs, each on opposite side] x [Jet cuts] x [Mass window]

For the moment (till I get the final results), assume we can factorize the task the above way:

$$N_{\text{fake}} = N_{\text{RP}} \times [\text{Jet cuts}] \times [\text{Mass window}]$$

Estimate of $N_{\text{RP}}$: 1. Rough-but-Fast
  2. Precise-but-Slow

All RP acceptances are taken as means.
### Phojet generation of PU events

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Purity (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All processes</td>
<td>118 mb</td>
</tr>
<tr>
<td>Non-diff. inelastic</td>
<td>68 mb</td>
</tr>
<tr>
<td>Elastic</td>
<td>34 mb</td>
</tr>
<tr>
<td>Single Diffr. (1)</td>
<td>5.7 mb</td>
</tr>
<tr>
<td>Single Diffr. (2)</td>
<td>5.7 mb</td>
</tr>
<tr>
<td>Double Diffr.</td>
<td>3.9 mb</td>
</tr>
<tr>
<td>DPE</td>
<td>1.4 mb</td>
</tr>
</tbody>
</table>

Number of pile-up events per bunch crossing (BX) \( \Xi N_{PU} = \) Lumi x cross section x bunch time width = LHC bunches/filled bunches =

\[
10^{34}\text{cm}^{-2}\text{s}^{-1} \times 10^4\text{cm}^2/\text{m}^2 \times 10^{-28}\text{m}^2/\text{b} \times 110\text{mb} \times 10^{-3}\text{b/mb} \times 25 \times 10^{-9}\text{s} \\
\times 3564/2808 \approx 35
\]

\[5 \times 10^{33} \approx 17.6, \quad 2 \times 10^{33} \approx 7.0, \quad 1 \times 10^{33} \approx 3.5, \quad 1 \times 10^{32} \approx 0\]
N_{RP} estimate – fast method

1. Derived only from PU events, no mixing with signal nor bg events

There are 2 cases: “DD” – 2 protons from one DD event
“2SD” – 2 protons from a sum of 2 SD events

\[ N_{RP}(1) = N_{DD} + N_{2SD} = \langle N_{PU} \rangle \cdot A_{DD} + \langle N_{PU} \rangle \cdot (\langle N_{PU} \rangle - 1) \cdot A_{SD-L} \cdot A_{SD-R} \]

\[ A_{DD} = A_{420} + A_{220} + A_{comb} - A_{overlap} \]

\[ = A_{420}^L \cdot A_{420}^R + A_{220}^L \cdot A_{220}^R + A_{420}^L \cdot A_{220}^R + A_{420}^R \cdot A_{220}^L - A_{overlap} \]

\[ = 1.9\% \]

\[ A_{SD-L} = A_{420}^L + A_{220}^L = 12.1\%, \quad A_{SD-R} = A_{420}^R + A_{220}^R = 12.6\% \]

\[ N_{RP}(1) = \langle N_{PU} \rangle \cdot 0.019 + \langle N_{PU} \rangle \cdot (\langle N_{PU} \rangle - 1) \cdot 0.0152 \]
N\textsuperscript{RP} estimate - precise method

2. Mix PU events with signal or bg - using FAMOS
   - Sum RP acceptances over all possible proton pairs in all PU events in one BX and then look at mean over all signal or bg events. \(N\textsuperscript{PU}\) properly smeared using Poisson dist.

E.g. \(N\textsuperscript{RP}_{420} = \left< \sum_i^{N\textsuperscript{PU}(n)} \sum_j^{N\textsuperscript{PU}(n)} A\textsuperscript{L}_{420}(i) \times A\textsuperscript{R}_{420}(j) \right>_{n=5k}\) signal or bg events

Mean nr. of PU events with 2 p's seen in opposite 420 RPs

<table>
<thead>
<tr>
<th>(&lt;N\textsuperscript{PU}&gt;)</th>
<th>(N\textsuperscript{RP}_{420})</th>
<th>(N\textsuperscript{RP}_{220})</th>
<th>(N\textsuperscript{RP}_{\text{comb}})</th>
<th>(N\textsuperscript{RP}(2))</th>
<th>(N\textsuperscript{RP}(1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>0.015</td>
<td>0.08</td>
<td>0.08</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>7.0</td>
<td>0.05</td>
<td>0.23</td>
<td>0.23</td>
<td>0.47</td>
<td>0.65</td>
</tr>
<tr>
<td>17.6</td>
<td>0.18</td>
<td>0.96</td>
<td>0.93</td>
<td>1.99</td>
<td>4.78</td>
</tr>
<tr>
<td>25.0</td>
<td>0.32</td>
<td>1.78</td>
<td>1.57</td>
<td>3.49</td>
<td>9.61</td>
</tr>
<tr>
<td>35.0</td>
<td>0.61</td>
<td>3.04</td>
<td>2.77</td>
<td>5.73</td>
<td>18.79</td>
</tr>
</tbody>
</table>
How PU events affect jets

Just indications derived from signal sample DPE H→bb (because of sufficient statistics): compare nr. of selected events in two samples: one with, the other without PU events mixed. Both have the same RP acceptances. Calculate $K_{jets} = \frac{N_{ev}(PU)}{N_{ev}(no\ PU)}$.

<table>
<thead>
<tr>
<th>$&lt;N_{PU}&gt;$</th>
<th>$N_{RP}^{420}$</th>
<th>$N_{RP}^{220}$</th>
<th>$N_{RP}^{comb}$</th>
<th>$N_{RP}(2)$</th>
<th>$N_{RP}(1)$</th>
<th>$K_{jets}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>0.015</td>
<td>0.08</td>
<td>0.08</td>
<td>0.17</td>
<td>0.20</td>
<td>1.03</td>
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<tr>
<td>7.0</td>
<td>0.05</td>
<td>0.23</td>
<td>0.23</td>
<td>0.47</td>
<td>0.65</td>
<td>1.01</td>
</tr>
<tr>
<td>17.6</td>
<td>0.18</td>
<td>0.96</td>
<td>0.93</td>
<td>1.99</td>
<td>4.78</td>
<td>1.00</td>
</tr>
<tr>
<td>25.0</td>
<td>0.32</td>
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<td>1.57</td>
<td>3.49</td>
<td>9.61</td>
<td>0.82</td>
</tr>
<tr>
<td>35.0</td>
<td>0.61</td>
<td>3.04</td>
<td>2.77</td>
<td>5.73</td>
<td>18.79</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Valery Khoze's talk at FP420 meeting on 16.02.06:

_Diffrautive processes at the LHC as a means to study SUSY Higgs sector_

(V.A. Khoze (IPPP, Durham) in collaboration with S. Heinemeyer, M. Ryskin, W.J. Stirling, M. Tasevsky and G. Weiglein)

Main aims:
- to demonstrate that Double Proton Tagging @LHC is especially beneficial for the detailed studies of the MSSM Higgs bosons
- to illustrate and to compare the salient features of the three main decay channels (bb, WW, tt) for studies in the forward proton mode
- hunting the CP-odd Higgs in the diffractive environment

😊 If the potential experimental challenges are resolved, then there is a very real chance that for some areas of the MSSM parameter space the DPT could be the LHC Higgs discovery channel!

_Disclaimer_: some of the results are (very) preliminary and should be taken only as a snapshot of the current understanding. Studies are still ongoing.
CED production processes for \( h, H \)

Signal processes: use approximate formula

\[
\sigma^{\text{excl}} = 3 \text{fb} \times \left( \frac{136}{16 + m} \right)^{3.3} \left( \frac{120}{m} \right)^3 \cdot \frac{\Gamma(h/H \rightarrow gg)}{0.25 \text{ MeV}} \cdot \frac{\text{BR}^{\text{MSSM}}}{\text{BR}^{\text{SM}}}
\]

\( \Gamma(h/H \rightarrow gg), \text{BR}^{\text{MSSM}}, \text{BR}^{\text{SM}} \) evaluated with \text{FeynHiggs}

Background for \( h, H \rightarrow b\bar{b} \) obtained from

\[
\sigma_B \approx 2 \text{fb} \left[ \frac{3}{4} \frac{\Delta M}{(4 \text{ GeV})} \left( \frac{120}{M} \right)^6 + \frac{1}{4} \frac{\Delta M}{(4 \text{ GeV})} \left( \frac{120}{M} \right)^8 \right]
\]

Background for \( h, H \rightarrow \tau^+\tau^- \) neglected in the following

Show “5\( \sigma \)” contours, where \( S/\sqrt{S + B} = 5 \)

(more on the pessimistic side, studies based on the CMS Higgs group procedure - still to come)
$h \rightarrow bb$

mhmax scenario, $\mu = 200$ GeV, $M_{\text{susy}} = 1000$ GeV
$h \to \tau \tau$
$h \rightarrow WW$

$m_h \approx 121-123 \text{ GeV}$

for the SM Higgs
at $M = 120 \text{ GeV}$ $\sigma = 0.4 \text{ fb}$,

at $M = 140 \text{ GeV}$ $\sigma = 1 \text{ fb}$
Sigma=5 contours for H->bb (mhmax scenario)
Summary

Diffractive Higgs production is a rich and very interesting chapter. Still many things need to be done:

1. Tune selection cuts – e.g. just one b-tag?
2. Add b→μ processes to the signal H→bb
3. Apply L1 trigger conditions
4. Check W production as bg to H→bb