Discovery of H^+ through $\gamma\gamma$ final states

Werner Porod

Universität Würzburg

in coll. with D. Das and L. Mitzka, see also arXiv:1408.1704

Idea and set-up

- Higgs sector of the NMSSM
- hierarchy: $m_{a_1,h_1} < m_{H^+} < m_t$, where a_1, h_1 are mainly gauge singlets
- process: $pp \to t\bar{t} \to W^{\pm}H^{\mp}b\bar{b} \to W^+W^-b\bar{b}a_1/h_1 \to W^+W^-b\bar{b}\gamma\gamma$
- Monte Carlo results
- preliminary DELPHES results

Higgs within NMSSM in nut-shell

$$W_{NMSSM} = \hat{H}_d \hat{L} Y_e \hat{E}^C + \hat{H}_d \hat{Q} Y_d \hat{D}^C + \hat{H}_u \hat{Q} Y_u \hat{U}^C - \lambda \hat{H}_d \hat{H}_u \hat{S} + \frac{\kappa}{3} \hat{S}^3$$

$$-\mathcal{L}^{Soft}_{NMSSM} = m_S^2 |S|^2 + \left(\lambda A_\lambda \, H_u H_d \, S + \frac{1}{3} \kappa A_\kappa \, S^3 + \text{h.c.} \right) + ...$$

- $\mu_{eff} = \lambda s$, $s = \langle S \rangle$
- Higgs sector: h_i^0 (i=1,2,3), a_i^0 (i=1,2), $H^\pm$
  - $$m^2_{H_{SM}} \simeq M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \frac{4\lambda^2 s^2 v^2 (\lambda - \kappa \sin 2\beta)^2}{\overline{M}^2_{H_{SM}} - M_S^2} + \text{radcorrs}$$
  - $$M^2_{H^\pm} \simeq M^2_{A,MSSM} + v^2 \left(\frac{g_2^2}{2} - \lambda^2 \right)$$

Constraints

- Higgs physics: `HiggsBounds-4.1.1`
- Squark- and gluino masses: 1.5 TeV except 3rd generation squarks
- search for charginos/neutralinos: lightest states are Higgsinos, nearly mass degenerate
- B-physics:
  $BR(b \to s\gamma) = (3.43 \pm 0.21 \pm 0.07 \pm 0.24^{th}) \times 10^{-4}$,
  $\Delta M_{B_s} = 17.69 \pm 0.08 \pm 3.3^{th}$ ps^{-1},
  $\Delta M_{B_d} = 0.507 \pm 0.004 \pm 0.091^{th}$ ps^{-1},
  $BR(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7 \pm 0.29^{th})10^{-9}$

  $BR(b \to s\gamma)$ and ΔM_{B_s} require non-trivial flavour structure in the squark sector and most likely $m_{\tilde{t}_1} \lesssim 750$ GeV

Benchmark points

parameter	BMP-A	BMP-B	Branching ratios	BMP-A	BMP-B
$\tan\beta$	1.68	1.45	$Br(t \to bH^+)$	3.3×10^{-3}	1.8×10^{-2}
κ	0.596	0.94	$Br(H^+ \to W^+ H_1)$	0.68	0
λ	0.596	0.62	$Br(H^+ \to W^+ A_1)$	0	0.86
μ_{eff}	131.5	143.7	$Br(H_1 \to \gamma\gamma)$	6.1×10^{-3}	1.76×10^{-3}
$m_{H_1^0}$	73.8	126.8	$Br(A_1 \to \gamma\gamma)$	2.6×10^{-5}	1.0×10^{-4}
$m_{H_2^0}$	126.7	172.0	$Br(H_1 \to b\bar{b})$	0.24	0.72
$m_{H_3^0}$	192.6	364.1	$Br(A_1 \to b\bar{b})$	0.11	0.86
$m_{A_1^0}$	155.4	66.6	$Br(H_1 \to c\bar{c})$	0.32	0
$m_{A_2^0}$	428.4	402.0	$Br(A_1 \to c\bar{c})$	0	0
$m_{H^\pm}$	161.9	149.4	$Br(H_1 \to g\ g)$	0.4	0.02
$m_{\tilde{t}_1}$	645.4	656.2	$Br(A_1 \to g\ g)$	0	0.02
$m_{\tilde{b}_1}$	883.5	879.0			

`SARAH` generated NMSSM `SPheno` version, cross-check with `NMSSMtools`

Benchmark points

Channel:	8 TeV	13 TeV	14 TeV
$\sigma_{NLO+NNLL}(pp \to t\bar{t})$ [pb]*	228	746	882
$\sigma_{LO-MG5}(pp \to t\bar{t})$ [pb]	135	463	555

$p_{T_{min}}(j)$	$p_{T_{min}}(\gamma)$	$p_{T_{min}}(\ell)$	$\|\eta\|_{max}(j)$	$\|\eta\|_{max}(\gamma)$	$\|\eta\|_{max}(\ell)$	ΔR
20 GeV	10 GeV	10 GeV	5	2.5	2.5	0.4

Basic cuts

CM energy	$\mathcal{L}(fb^{-1})$	BMP-A ($\mathcal{S}^{H_1}_{2b+2W+2\gamma}$)	BMP-B ($\mathcal{S}^{A_1}_{2b+2W+2\gamma}$)
8 TeV	20	121	14
13 TeV	100	1987	228
14 TeV	100	2351	270

$$S^{\Phi}_{2b+2W+2\gamma} = 2 \times \sigma_{LO-MG5}(pp \to t\bar{t}) \times Br(t \to bH^+) \times Br(\bar{t} \to \bar{b}W^-)$$
$$\times Br(H^+ \to W^+\Phi) \times Br(\Phi \to \gamma\gamma) \times \mathcal{L}$$

using `MadGraph 5.1.5.13`; * http://www.lpthe.jussieu.fr/∼cacciari/ttbar/

Background

$p_{T_{min}}(j)$	$p_{T_{min}}(\gamma)$	$p_{T_{min}}(\ell)$	$\|\eta\|_{max}(j)$	$\|\eta\|_{max}(\gamma)$	$\|\eta\|_{max}(\ell)$	ΔR
20 GeV	10 GeV	10 GeV	5	2.5	2.5	0.4

Basic cuts

Background events	8 TeV	13 TeV	14 TeV
$pp \to W^+W^- b\bar{b}\gamma\gamma$	181	2859	3353
$pp \to W^+W^- \overset{(-)}{b} j\gamma\gamma$	5	146	261
$pp \to W^+W^- \overset{(-)}{b} \gamma\gamma$	9	194	240

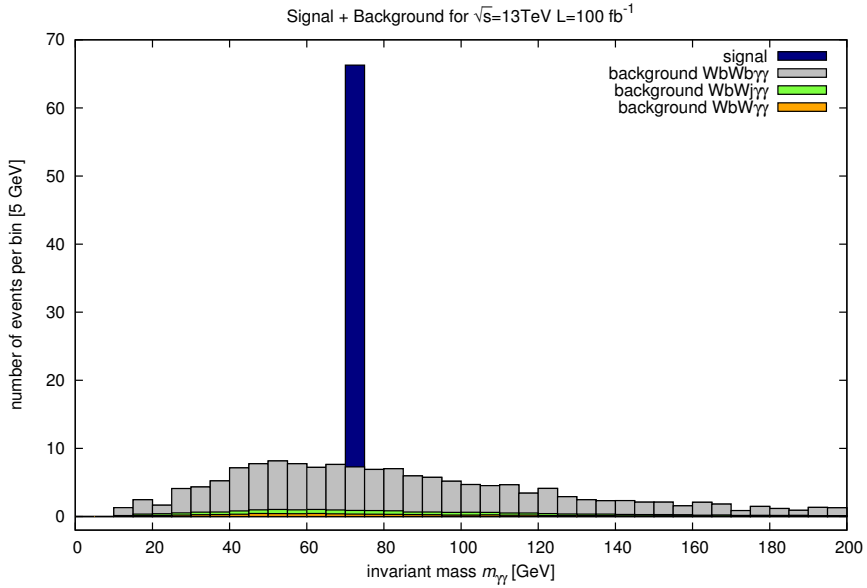
using `MadGraph 5.1.5.13`

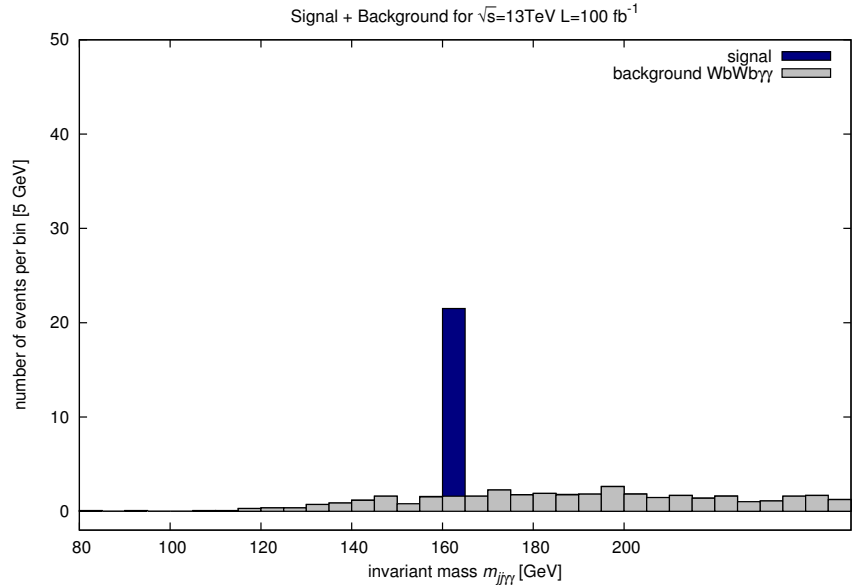
Results, Monte Carlo Level, BMP-A

Signal: $pp \to t\bar{t} \to b(b)WH \to b(b)WWh_1 \to b(b)jjl\nu\gamma\gamma$

$p_T(j)$	$\lvert m_{jj} - m_W \rvert$	$p_T(b_1)$	$p_T(\gamma), p_T(\ell)$	$m_{\gamma\gamma}$	$\lvert\eta\rvert$	ΔR
$\geq$ 20 GeV	$\leq$ 20 GeV	$\geq$ 40 GeV	$\geq$ 10 GeV	$\geq$ 10 GeV	$\leq$ 2.5	$\geq$ 0.4

Applied cuts; $b_1 =$ hardest b-jet





LO result

DELPHES simulation, preliminary

take the CheckMATE hack with ATLAS detector card
object selection:

- jets: anti-kt algorithm, $p_T \geq 20$ GeV, $\Delta R \leq 0.4$, $|\eta| \leq 2.5$
- identification of b-jets is performed with a working point of 70%
- e: $p_T \geq 10$ GeV, $|\eta| \leq 2.47$
- μ: $p_T \geq 10$ GeV, $|\eta| \leq 2.4$
- γ: $p_T \geq 20$ GeV, $|\eta| \leq 2.37$

overlap removal:

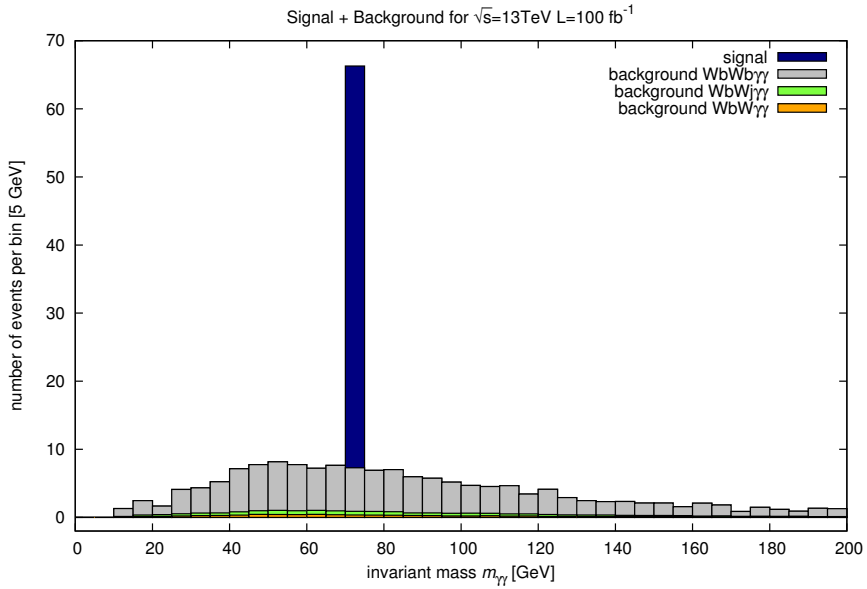
- jets are removed if $\Delta_R < 0.2$ to electrons
- electrons are removed if $\Delta_R < 0.4$ to surviving jets
- muons are removed if $\Delta_R < 0.4$ to surviving jets

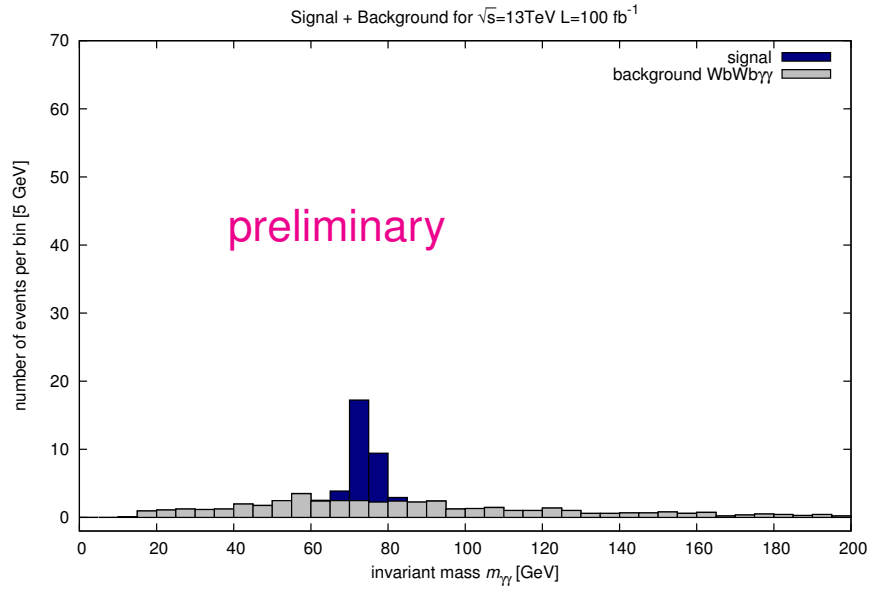
photon isolation criteria based on ATLAS-CONF-2014-001

- photon is removed if $> 4GeV$ transverse energy in a cone of $\Delta R < 0.4$

Results, DELPHES, BMP-A, preliminary

- exactly 2 γ and $m_{\gamma\gamma} \geq 10$ GeV
- at least one b-jet with $p_T \geq 40$ GeV
- at least two none-b jets, and two of them fullfill $|m_{jj} - m_W| \leq 20$ GeV
- exactly one lepton (e, μ)

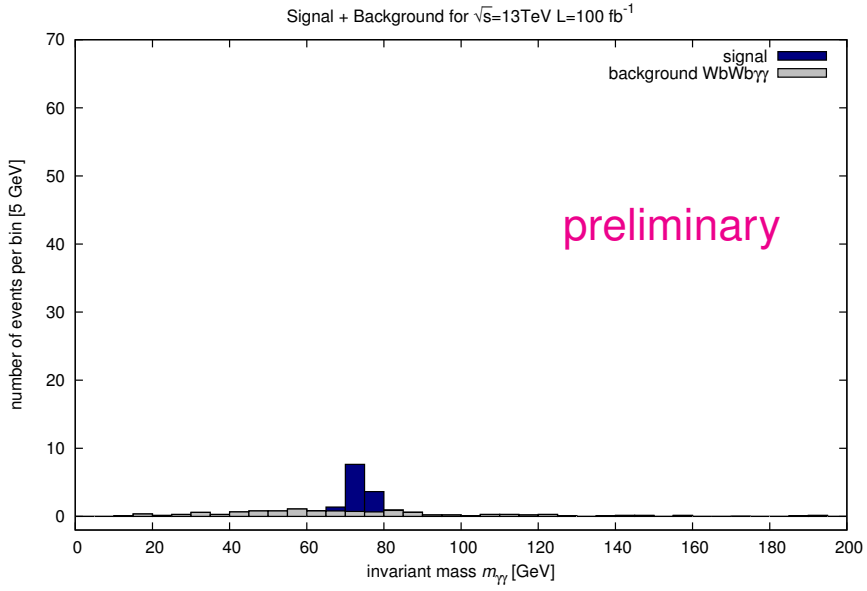


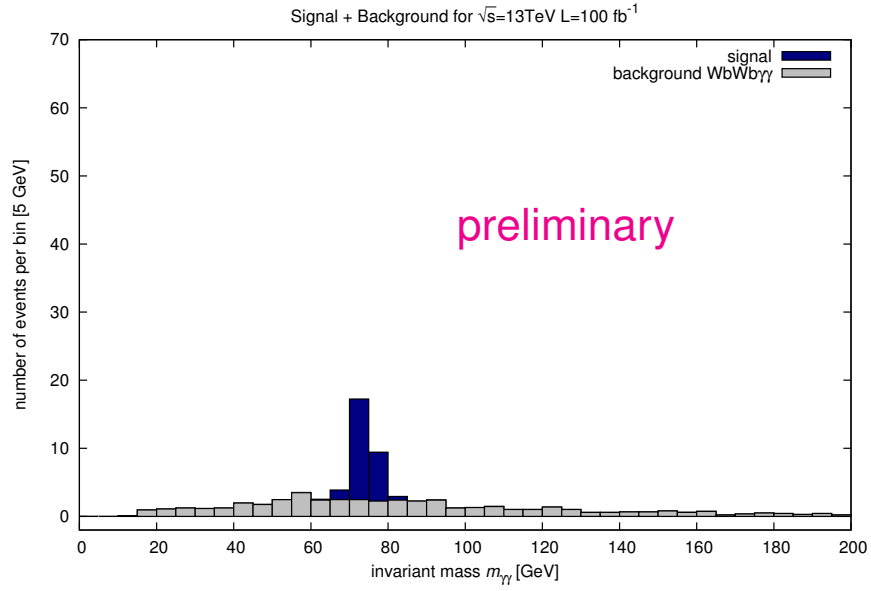


LO result

Results, DELPHES, BMP-A, preliminary, something puzzling

two hardest jets with $|m_{jj} - m_W| \leq 20$ GeV $\Leftrightarrow$ two jets with $|m_{jj} - m_W| \leq 20$ GeV





LO result