Report from the $H^+ \rightarrow$ SUSY Working Group

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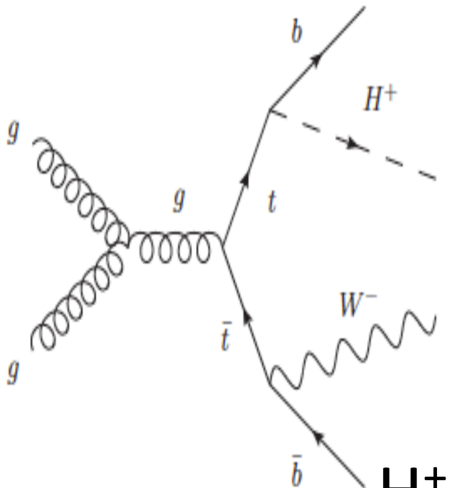
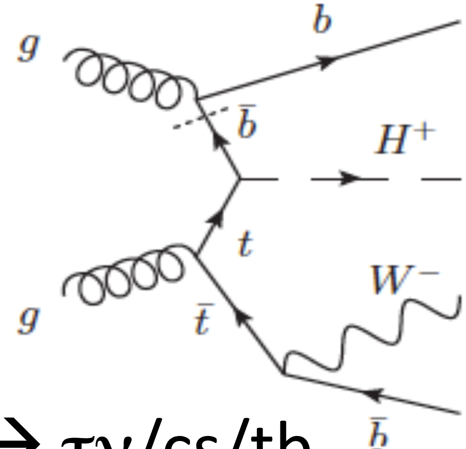
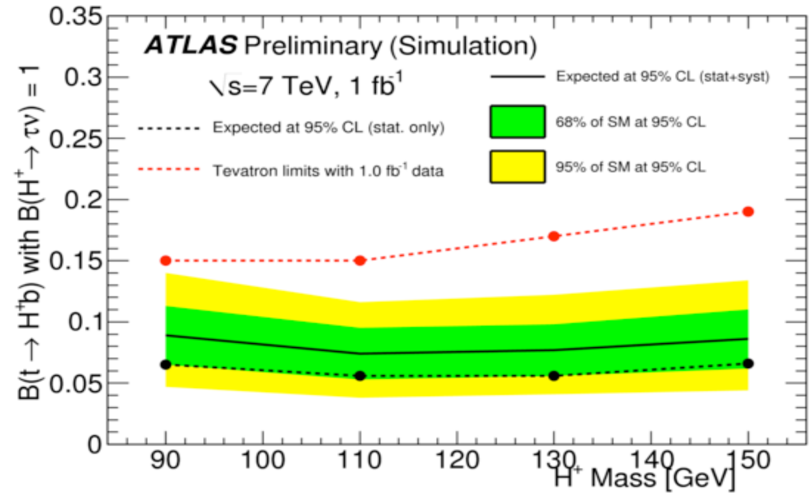
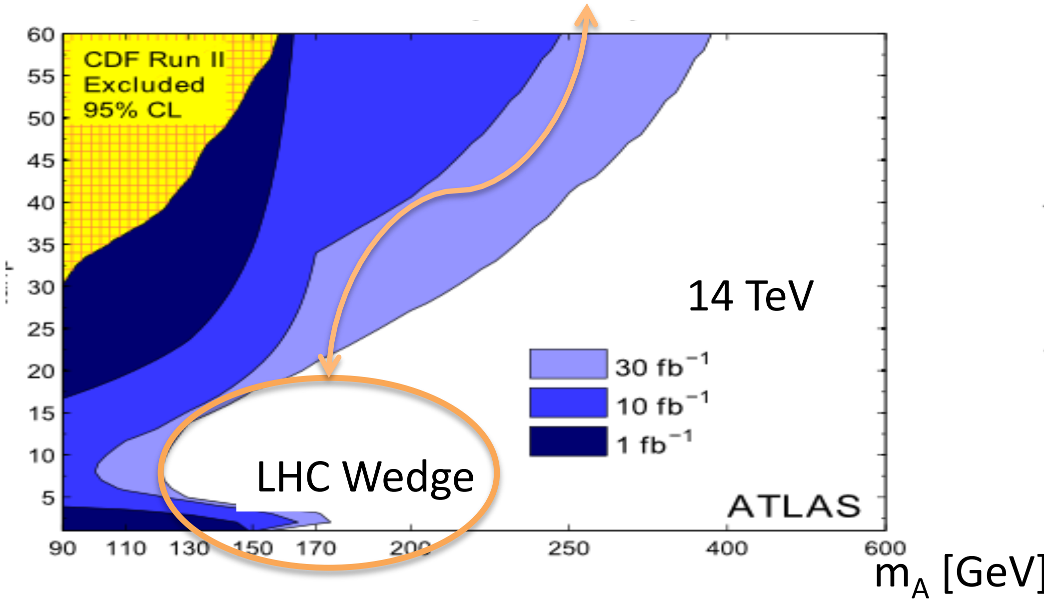
H^+ Searches

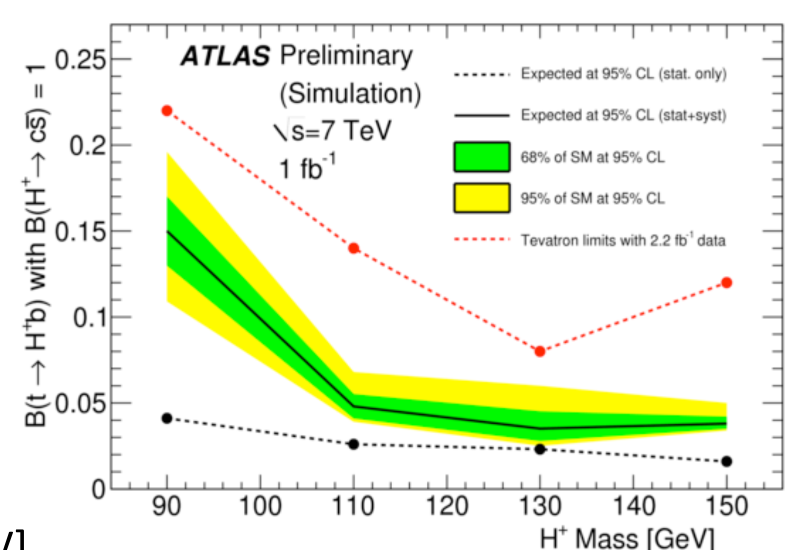




$H^+ \rightarrow \tau\nu/cs/tb$





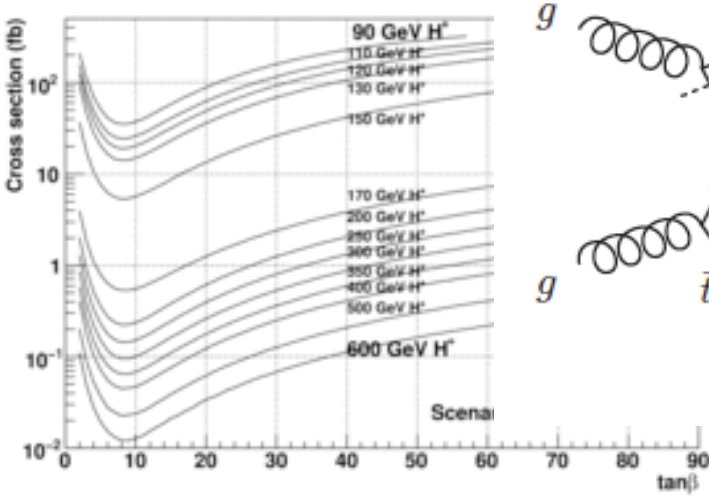


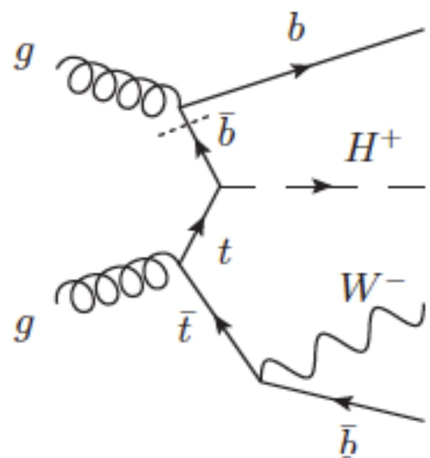
tbH+ coupling $\sim (m_b \tan\beta + m_t \cot\beta)$ has a minimum at $\tan\beta = \sqrt{m_t/m_b} \approx 7$

For $H^+ \rightarrow tb$, the coupling appears in the production and in the decay

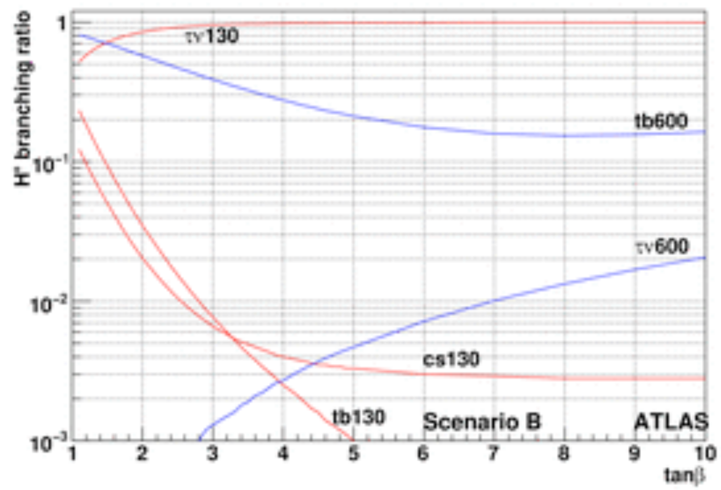
$H^+ \rightarrow$ SUSY

- Explore $H^+ \rightarrow$ SUSY to cover the LHC wedge: $H^\pm \rightarrow \chi_i^\pm \chi_j^0$
- Was studied before
  - ATLAS. See Hansen et al. arXiv:hep-ph/0504216
  - CMS: see Bisset et al. arXiv:hep-ph/0303093, 0709.1029
- Production, still:





- In the decay
  - $H^+ \rightarrow$SUSY may be more favorable the cover the intermediate $\tan\beta$ region where $H^+ \rightarrow$tb does not help

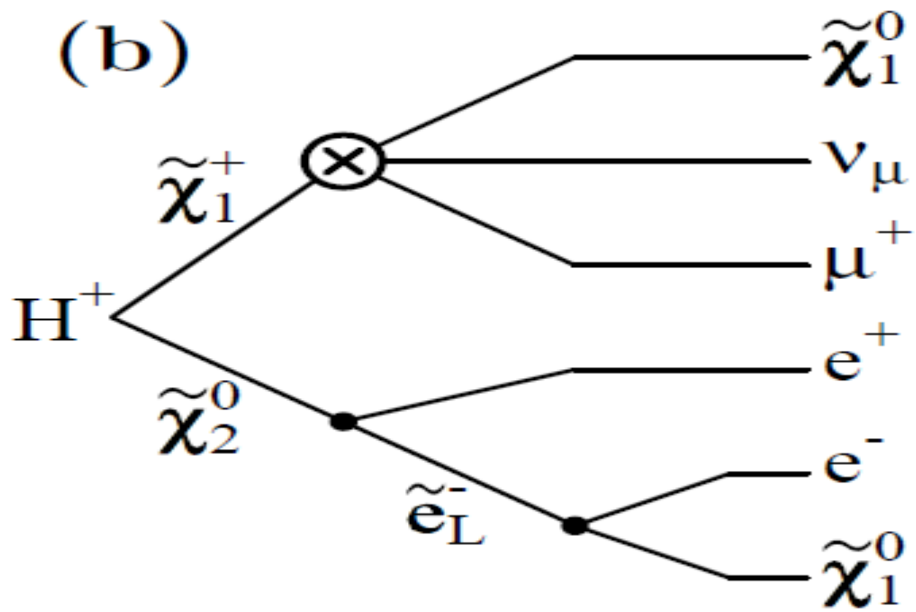


The opening of $H^+ \rightarrow$ SUSY would mean that the $H^+ \rightarrow$ SM are reduced: current projections based on $H^+ \rightarrow$ SM too optimistic

$H^+ \rightarrow$ SUSY

We are interested in the following channel:

$$pp \to H^\pm + X, \quad H^\pm \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell + E_T^{\rm miss}$$



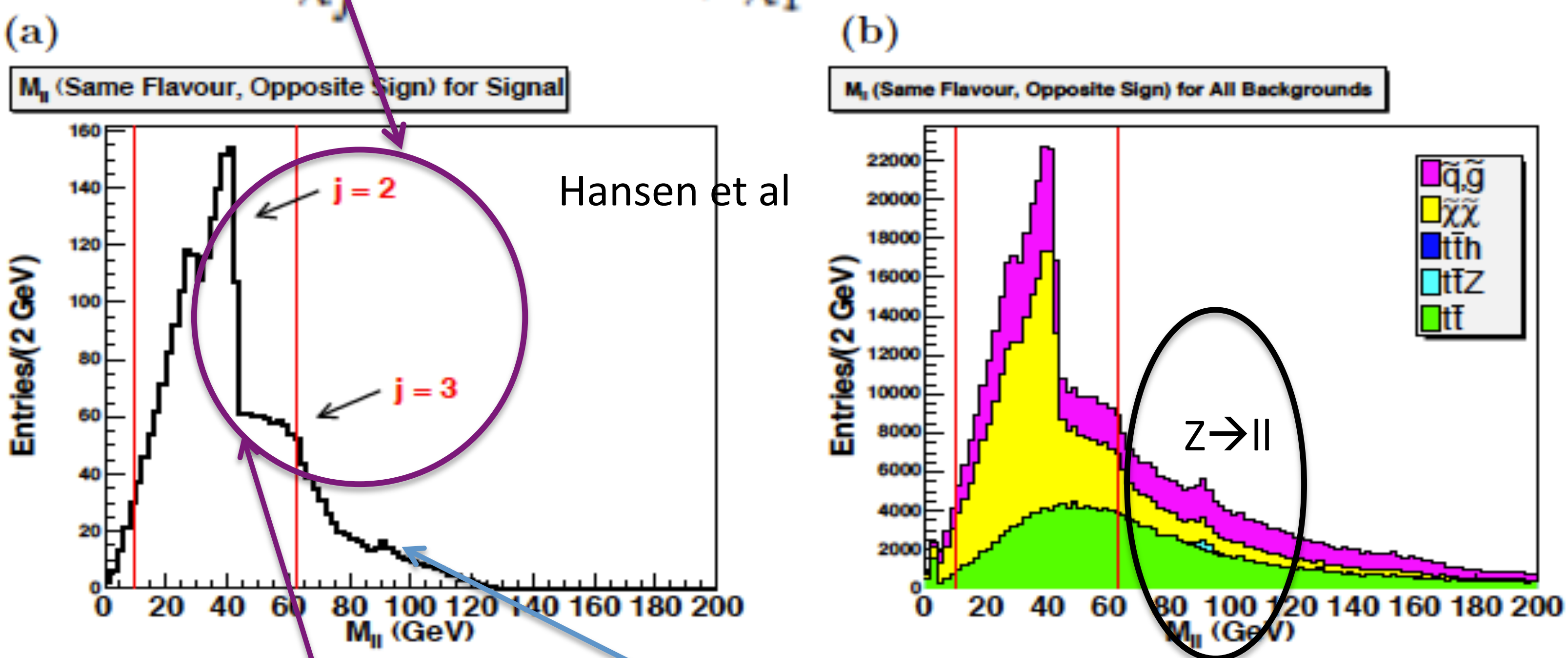
The $\otimes$ means either $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 + W^+$ where $W^+ \to \nu_\mu + \mu^+$ or $\tilde{\chi}_1^+ \to \tilde{\mu}^+ + \nu_\mu$ where $\tilde{\mu}^+ \to \tilde{\chi}_1^0 + \mu^+$ or $\tilde{\chi}_1^+ \to \tilde{\nu}_\mu + \mu^+$ where $\tilde{\nu}_\mu \to \tilde{\chi}_1^0 + \nu_\mu$.

MET from the neutrinos and the LSP. Two of the leptons are same flavor, opposite sign

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET

$$\tilde{\chi}_j^0 \rightarrow \ell\tilde{\ell} \rightarrow 2\ell + \tilde{\chi}_1^0$$

(2 SF, OS leptons from χ^0 decay)



$\chi^0_j \rightarrow Z + \chi^0_1 \rightarrow ll + \chi^0_1$

$$M_{\ell\ell_{max}} = \sqrt{\left(m^2_{\tilde{\chi}^0_j} - m^2_{\tilde{\ell}}\right)\left(m^2_{\tilde{\ell}} - m^2_{\tilde{\chi}^0_1}\right)/m^2_{\tilde{\ell}}}$$

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET: benchmark points

1. We fix $M_{H^\pm}$ and $\tan\beta$ to interesting values.
   Since we are interested in parameter points in the "LHC wedge" we start with the choice:

$$M_{H^\pm} = 400 \text{ GeV}, \tan\beta = 7 \; , \tag{11}$$
$$M_{H^\pm} = 400 \text{ GeV}, \tan\beta = 15 \; . \tag{12}$$

2. We fix the SUSY parameters not entering the scalar lepton sector. Our choice is inspired by the $m_h^{\max}$ scenario:

$$\begin{aligned} M_{\text{SUSY}} &= 1000 \text{ GeV}, A_t = A_b = \ldots = 2000 \text{ GeV}, \\ m_{\tilde{g}} &= 800 \text{ GeV}, \\ m_t^{\text{pole}} &= 172.4 \text{ GeV}, m_b(m_b) = 4.25 \text{ GeV} \; . \end{aligned} \tag{13}$$

3. We fix the scalar lepton parameter such that we have a favorable scenario. According to Refs. [1,2] this is

$$\begin{aligned} M_{\tilde{\tau}_{L,R}} &= 250 \text{ GeV}, \\ M_{\tilde{l}_{L,R}} &= 150 \text{ GeV}, \\ A_\tau &= A_l = 0 \; . \end{aligned} \tag{14}$$

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET: benchmark points

4. We fix the parameters governing the chargino/neutralino sector to a favorable starting point [1,2]

$$(A): \quad \mu = 135 \text{ GeV}, \quad M_2 = 210 \text{ GeV} . \tag{15}$$

A mass combination of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ closer to the kinematic limit could lead to a different phenomenology of outgoing leptons. In order to investigate this case as well, we choose in addition to case (A),

$$(B): \quad \mu = 200 \text{ GeV}, \quad M_2 = 310 \text{ GeV} . \tag{16}$$

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET: benchmark points

	(A) $\tan\beta = 7$	(A) $\tan\beta = 15$	(B) $\tan\beta = 7$	(B) $\tan\beta = 15$
$m_{\tilde{t}_1}$	834	832	835	833
$m_{\tilde{t}_2}$	1165	1165	1164	1165
$m_{\tilde{b}_1}$	1000	1000	1000	1000
$m_{\tilde{b}_2}$	1005	1005	1005	1005
$m_{\tilde{\tau}_1}$	250	247	249	243
$m_{\tilde{\tau}_2}$	257	261	259	264
$m_{\tilde{\nu}_\tau}$	242	242	242	242
$m_{\tilde{c}_1}$	998	998	998	998
$m_{\tilde{c}_2}$	1000	1000	1000	1000
$m_{\tilde{s}_1}$	1000	1000	1000	1000
$m_{\tilde{s}_2}$	1002	1002	1002	1002
$m_{\tilde{\mu}_1}$	156	156	156	155
$m_{\tilde{\mu}_2}$	157	158	157	158
$m_{\tilde{\nu}_\mu}$	136	136	136	136
$m_{\tilde{u}_1}$	999	999	999	999
$m_{\tilde{u}_2}$	999	999	999	999
$m_{\tilde{d}_1}$	1000	1000	1000	1000
$m_{\tilde{d}_2}$	1002	1002	1002	1002
$m_{\tilde{e}_1}$	156	156	156	156
$m_{\tilde{e}_2}$	157	157	157	157
$m_{\tilde{\nu}_e}$	136	136	136	136
$m_{\tilde{\chi}_1^0}$	73	77	128	131
$m_{\tilde{\chi}_2^0}$	127	128	192	193
$m_{\tilde{\chi}_3^0}$	144	147	207	208
$m_{\tilde{\chi}_4^0}$	254	252	345	342
$m_{\tilde{\chi}_1^\pm}$	105	109	175	179
$m_{\tilde{\chi}_2^\pm}$	254	252	344	342
M_h	127	129	127	129
M_H	393	392	393	392
M_A	392	392	392	392

Table 1: Masses for the four scenarios: $m_h^{\max}$ with $M_{H^\pm} = 400$ GeV and (A) $\mu = 135$ GeV, $M_2 = 210$ GeV, (B) $\mu = 200$ GeV, $M_2 = 310$ GeV. All masses are in GeV (and rounded to one GeV). The numbers have been obtained with FeynHiggs [9].

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET: benchmark points

	(A) $\tan\beta = 7$	(A) $\tan\beta = 15$	(B) $\tan\beta = 7$	(B) $\tan\beta = 15$
$\mathrm{BR}(H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_1^0)$	11%	9%	21%	13%
$\mathrm{BR}(H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_2^0)$	15%	12%	8%	4%
$\mathrm{BR}(H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_3^0)$	10%	7%	6%	2%
$\mathrm{BR}(H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_4^0)$	15%	11%	—	—
$\mathrm{BR}(H^+ \to \tilde{\chi}_2^+ \tilde{\chi}_1^0)$	11%	9%	—	—
$\mathrm{BR}(H^+ \to \tilde{\chi}_2^+ \tilde{\chi}_2^0)$	10%	8%	—	—
$\mathrm{BR}(H^+ \to \tilde{\chi}_2^+ \tilde{\chi}_3^0)$	3%	2%	—	—
$\mathrm{BR}(H^+ \to \tilde{\chi}_2^+ \tilde{\chi}_4^0)$	—	—	—	—
$\sum_{\tilde{\chi}_i^+ \tilde{\chi}_{j>1}^0}$	53%	40%	14%	7%
$\mathrm{BR}(H^+ \to t\bar{b})$	23%	36%	58%	67%
$\mathrm{BR}(H^+ \to \tau^+ \nu_\tau)$	2%	7%	5%	13%

Table 2: BR's for the four scenarios: $m_h^{\max}$ with $M_{H^\pm} = 400$ GeV and (A) $\mu = 135$ GeV, $M_2 = 210$ GeV, (B) $\mu = 200$ GeV, $M_2 = 310$ GeV. The BR's have been rounded to one percent. BR's not shown are below 1%. "—" denotes a closed channel due to the kinematical limit. The numbers have been obtained with FeynHiggs [9].

H^+ → SUSY → 3l+MET: benchmark points

5. The analysis with these parameters is performed at the generator level.

6. Once this is successfully done we expand further in M_2 and μ.

The general idea behind: we explore which parts of the μ–M_2 planes are accessible. What happens outside these areas? Which other channels could help there?

3 Investigation of $M_{H^\pm} \leq m_t$

For $M_{H^\pm} \leq m_t$ the decay

$$H^\pm \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell + E_T^{\text{miss}} \tag{17}$$

From experimental searches, the lightest charginos should be heavier than ~100 GeV. Some of the neutralino masses would be governed by our choices of μ and M_2. Scanning the parameter space, taking into the account the experimental bound on the lightest chargino leads to

$$|\mu|,\ M_2 \gtrsim 100\ \text{GeV}$$

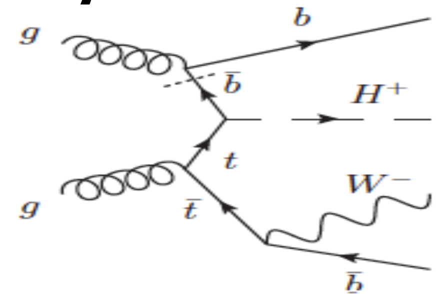
Taking this constraint in to account, the second lightest neutralino is also heavier than ~100 GeV. Consequently

$m_{\tilde{\chi}_2^0} + m_{\tilde{\chi}_1^\pm} \gtrsim 200\ \text{GeV} > m_t$ and for $M_{H^\pm} < m_t$ the channel (17) is kinematically closed.

H^+ → SUSY → 3l+MET: the backgrounds

- SM sources of 3l+MET
  - ttbar → 3l+MET
  - WZ → 3l+MET
  - ttZ → 3l+MET
- The main background is generic SUSY → 3l+MET
  - SUSY direct $\chi^+_i\chi^0_j$ production or SUSY cascades to 3l+MET
  - If an excess of 3l+MET events is observed, it could just be SUSY, SUSY + H^+ → SUSY, something else, all the above
  - Start by working with the SUSY 3l+MET sub-group. A lot to do in common
- At 10 TeV, we have the signal and the al the backgrounds. Signal and all backgrounds also available at 7 TeV

$H^+ \rightarrow$ SUSY $\rightarrow$ 3l+MET: Analysis



- pp $\rightarrow$ tH^+/tbH^+
  - Originally started with Herwig
  - But now using Matchig/Pythia
  - Filter on 3l at the generator, $p_T > 7$ GeV, $|\eta|<10$. But 2-lepton filter for fake lepton study
  - Pythia/Matchig versus Herwig validation done at the generator level
- SM and SUSY background production
- ATLAS analysis started at 10 TeV, now proceeding at 7 TeV. Working on common strategy with the SUSY 3l+MET sub-group
- Thesis topic for Caleb Lampen, to focus on muon final states. A group from Dubna (A. Cheplakov et al. starting on electron final state)
- Results are not yet approved to be shown outside

Conclusions

- Since Charged Higgs 2008, there has been progress
  - Some benchmark points have been proposed. The idea being to fix m_A and $\tan\beta$ and explore the μ and M_2 parameter space
  - Analysis started at 10 TeV. Moving to 7 TeV. Thesis topic for Caleb Lampen (muon final state).
  - Dubna has joined the efforts (on the electron final state)
  - Close collaboration with SUSY 3l+MET working group
  - Results are preliminary, not yet approved to be shown outside ATLAS
- Should expect approved results before and at Charged Higgs 2012

References

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M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *JHEP* **02** (2007) 047 [arXiv:hep-ph/0611326];
the code is accessible via `www.feynhiggs.de` .