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Production of charged Higgs bosons at hadron colliders

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JA and J. Rathsman JHEP12, 050 (2004) ([hep-ph/0409094](https://arxiv.org/abs/hep-ph/0409094))





Charged Higgs - background

- In supersymmetric extensions to SM need 2 Higgs doublets to give mass to both up and down type fields and for anomaly cancellation

- 8 scalar degrees of freedom $\xrightarrow{\text{Higgs mechanism}}$ 5 Higgs particles:

$$h, H^0, H^+, H^-, A \text{ (pseudoscalar)}$$

- Two parameters in MSSM (7 or more in general 2HDM):

$$\tan(\beta) = \frac{v_1}{v_2} \quad \text{Ratio of vev's for the doublets}$$

$$M_A \quad \text{One of the masses, usually the pseudoscalar}$$

- Finding a charged Higgs would be a **clear signal of physics beyond the Standard Model!**



Charged Higgs studies at Uppsala

Theory group:

- Single charged Higgs accompanied by t and b (JA, J. Rathsman)
 $gb \rightarrow H^\pm t, gg \rightarrow H^\pm tb, q\bar{q} \rightarrow H^\pm tb$
- Charged Higgs pair production accompanied by b quarks
(J. Rathsman with S. Moretti) $gg \rightarrow H^+ H^- b\bar{b}$
- Single charged Higgs accompanied by W^\pm
(D. Eriksson, S. Hesselbach and J. Rathsman) $b\bar{b} \rightarrow H^\pm W^\mp$

ATLAS group:

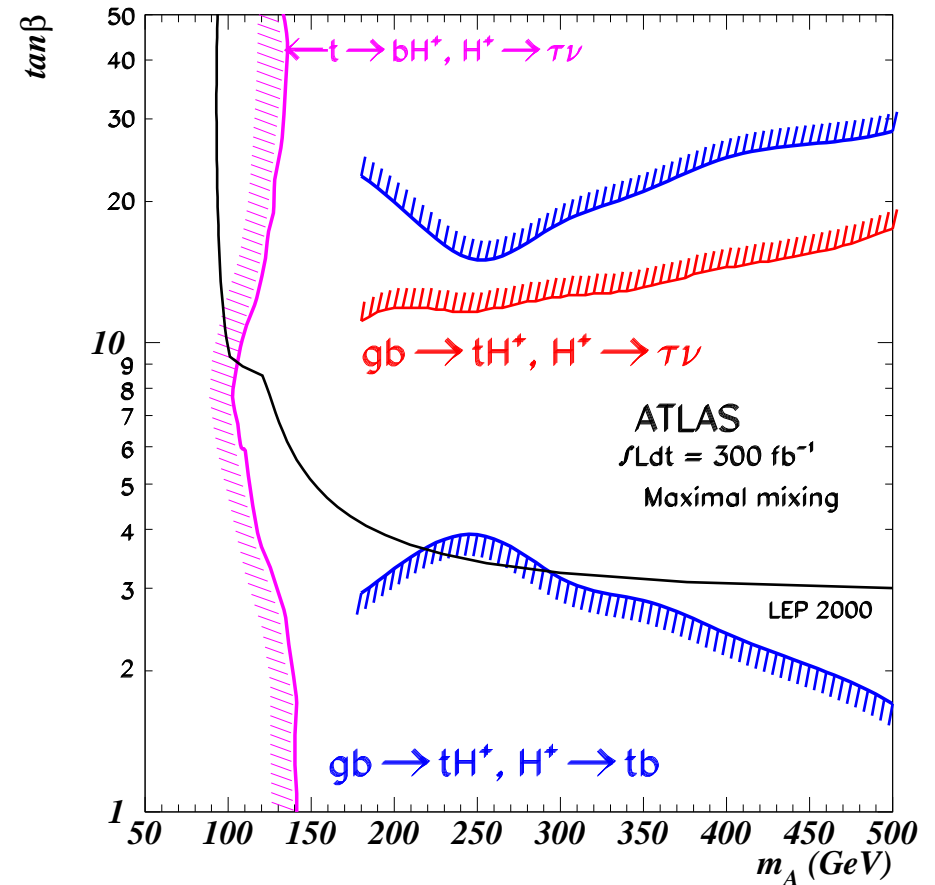
- $gb \rightarrow H^\pm t \rightarrow \tau \nu b W^\mp$ (Y. Coadou with K. Assamagan)
- $gg \rightarrow H^\pm tb \rightarrow tb tb$ (N. Gollub)
- $gb \rightarrow H^\pm t \rightarrow \tilde{\chi}^\pm \tilde{\chi}^0 b W^\mp$ (C. Hansen, N. Gollub)
- Matched $gb \rightarrow H^\pm t, gg \rightarrow H^\pm tb$ (B. Mohn with JA)



Our goal

Need accurate description of Higgs production in event generators to devise search strategies/suppress SM background.

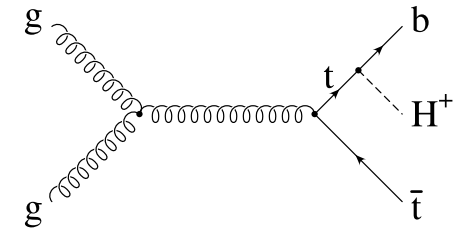
Problematic area:
 H^+ mass \sim top mass



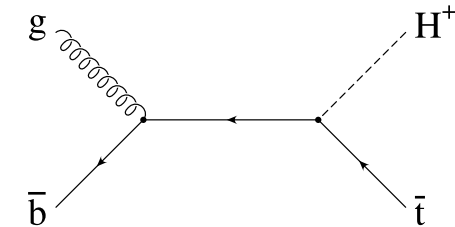


Single charged Higgs accompanied by t and b

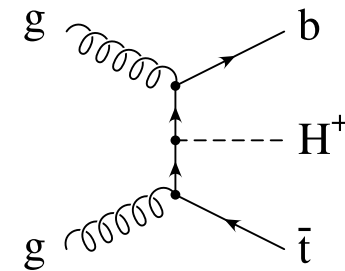
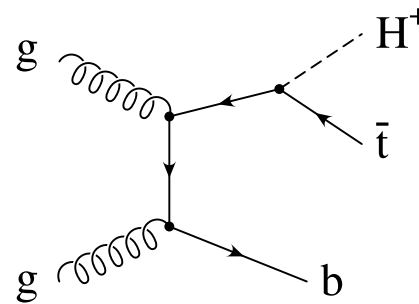
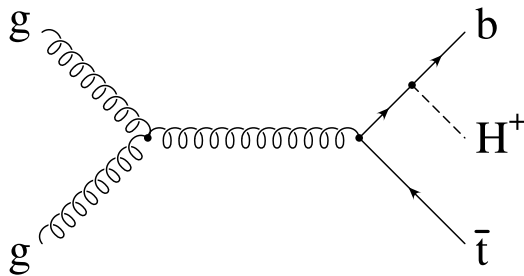
- $gg(q\bar{q}) \rightarrow t\bar{t} \rightarrow bH^+\bar{t}$ ($m_{H^+} \leq m_t - m_b$):



- $g\bar{b} \rightarrow \bar{t}H^+$ ($2 \rightarrow 2$ process):



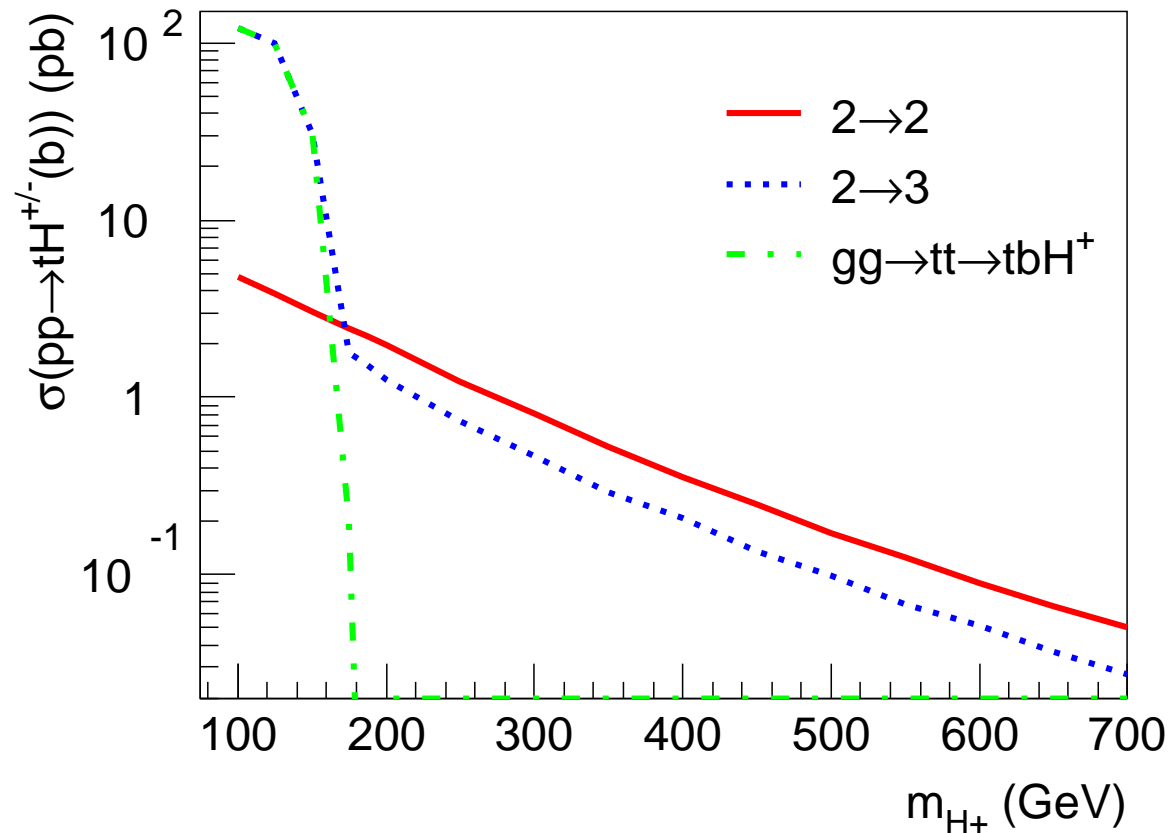
- $gg(q\bar{q}) \rightarrow \bar{t}bH^+$ ($2 \rightarrow 3$ process):





Importance of the H^+ production processes

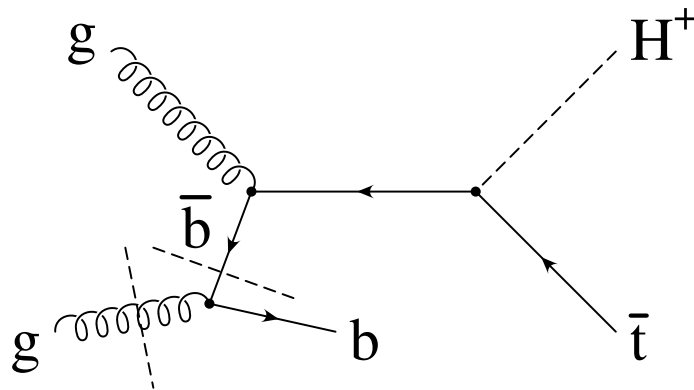
Integrated xsec, $\tan(\beta)=30$, $E_{\text{CM}}=14$ TeV



- For low m_{H^+} ($< m_t - m_b$): Large $2 \rightarrow 3$ cross-section ($t \rightarrow bH^+$)
- For large $m_{H^+} > m_t$: $gb \rightarrow H^\pm t$ leading order process
- Intermediate region, $m_{H^+} \sim m_t$: Need to take both $gb \rightarrow H^\pm t$ and $gg \rightarrow H^\pm tb$ into account



Importance of the H^+ production processes (cont.)

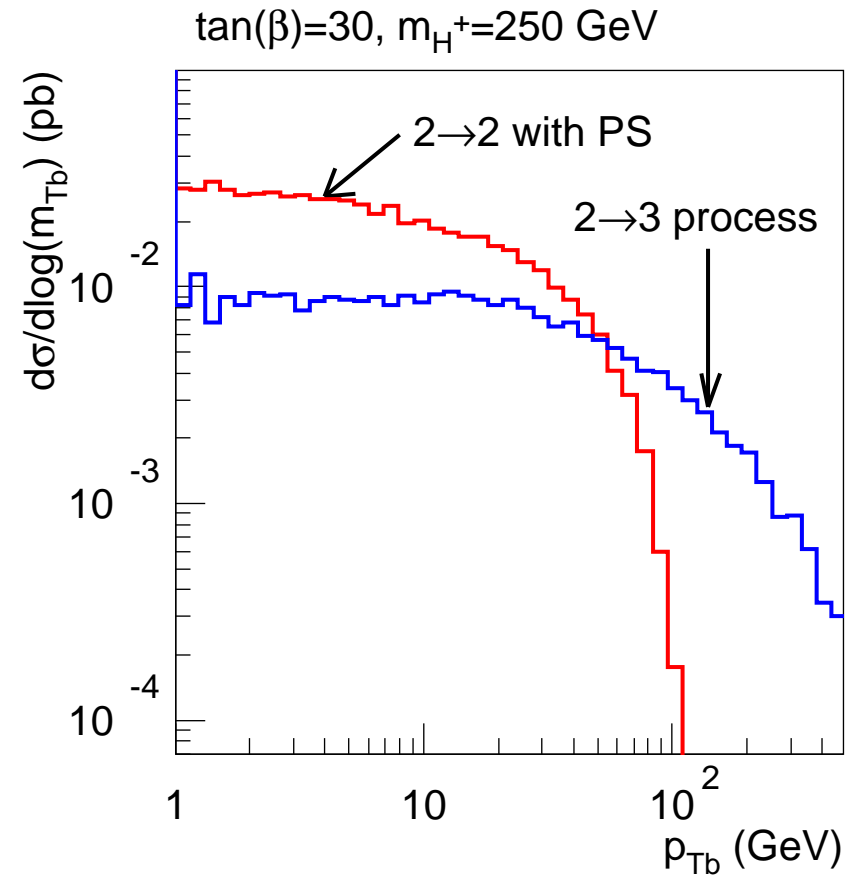


$2 \rightarrow 2$:

The b -density resums collinear logs $\left(\alpha_s \ln \frac{\mu_F^2}{m_b^2}\right)^n$
 \implies Better description of total cross-section and small $p_{\perp,b}$

$2 \rightarrow 3$:

Gives a better description of large p_{\perp} of b -quark

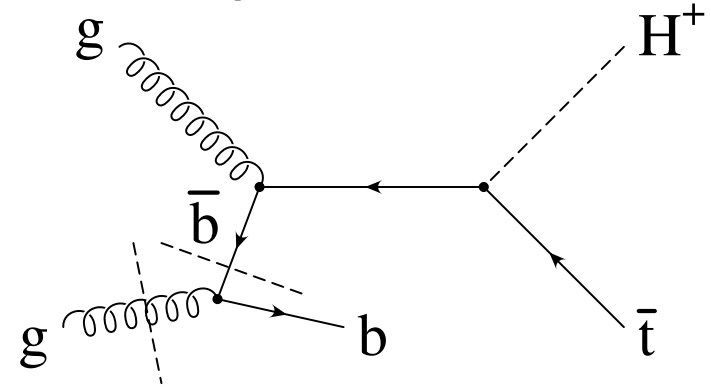




Matching the $2 \rightarrow 2$ and $2 \rightarrow 3$ processes

For small $p_{\perp,b}$,

$$\sigma_{2 \rightarrow 3} \propto P_{g \rightarrow b\bar{b}} \otimes \sigma_{2 \rightarrow 2}$$



Double-counting when the b of the $2 \rightarrow 3$ process is collinear with the beam

\implies Must subtract **collinear double counting term**

$$\sigma_{\text{DC}} = \int dx_1 dx_2 \left[g(x_1) b'(x_2) \frac{d\sigma_{2 \rightarrow 2}}{dx_1 dx_2}(x_1, x_2) + x_1 \leftrightarrow x_2 \right]$$

$$b'(x, \mu_F^2) = \frac{\alpha_s}{\pi} \log \frac{\mu_F^2}{m_b^2} \int P_{g \rightarrow q\bar{q}}(z) g(x/z, \mu^2) dz$$

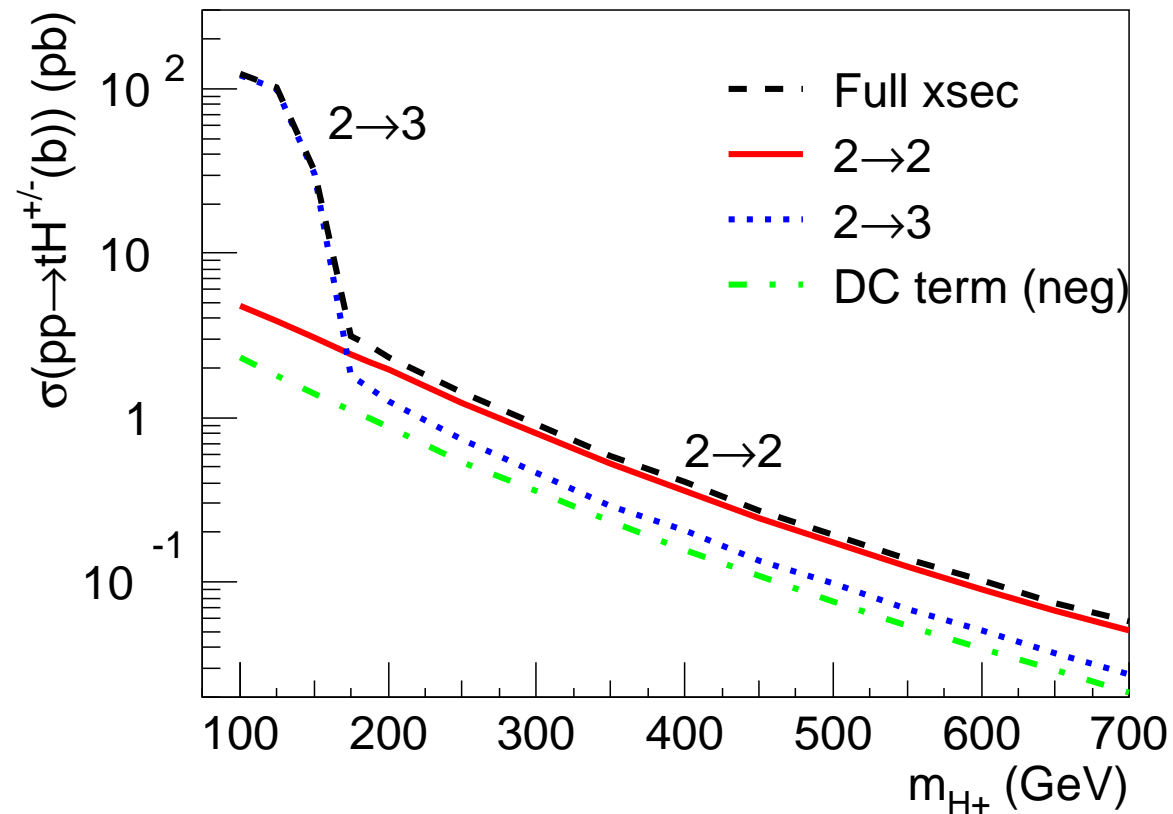
(The first logarithm in the b quark density)



Matching the integrated cross-section

For matched cross-section: $\sigma = \sigma_{2\rightarrow 2} + \sigma_{2\rightarrow 3} - \sigma_{\text{DC}}$

Integrated xsec, $\tan(\beta)=30$, $E_{\text{CM}}=14$ TeV



Interpolates between small and large m_{H^+} regions



Matching the differential cross-section

For the differential cross-section: View double-counting term as distribution in kinematic variables and pick events

Full double-counting distribution (taking into account finite CoM energy and b mass):

$$\sigma_{\text{DC}} = \int_{\tau_{\min}}^1 \frac{d\tau}{\tau} \int_{\frac{1}{2} \log \tau}^{-\frac{1}{2} \log \tau} dy^* \frac{\pi}{\hat{s}} \int_{-1}^1 \frac{\beta_{34}}{2} d(\cos \hat{\theta}) |\mathcal{M}_{2 \rightarrow 2}|^2 x_1 g(x_1, \mu_F^2) \times$$
$$\frac{\alpha_s(\mu_R^2)}{2\pi} \left[\int_{x_2}^{z_{\max}} dz P_{g \rightarrow q\bar{q}}(z) \frac{x_2}{z} g\left(\frac{x_2}{z}, \mu_F^2\right) \int_{Q_{\min}^2}^{Q_{\max}^2} \frac{d(Q^2)}{Q^2 + m_b^2} + x_1 \leftrightarrow x_2 \right]$$

We identify $z = \hat{s}_{2 \rightarrow 2} / \hat{s}_{2 \rightarrow 3}$.

Q^2 limits are given by: $p_{\perp, b}^2 = Q^2 - z \frac{(\hat{s} + Q^2)(m_b^2 + Q^2)}{\hat{s}}$

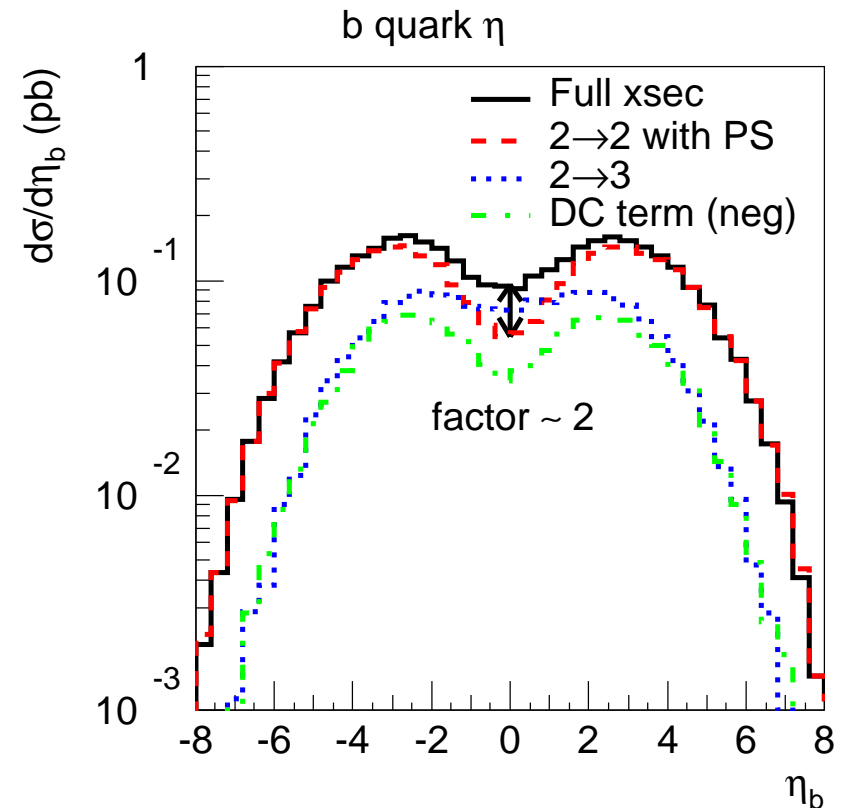
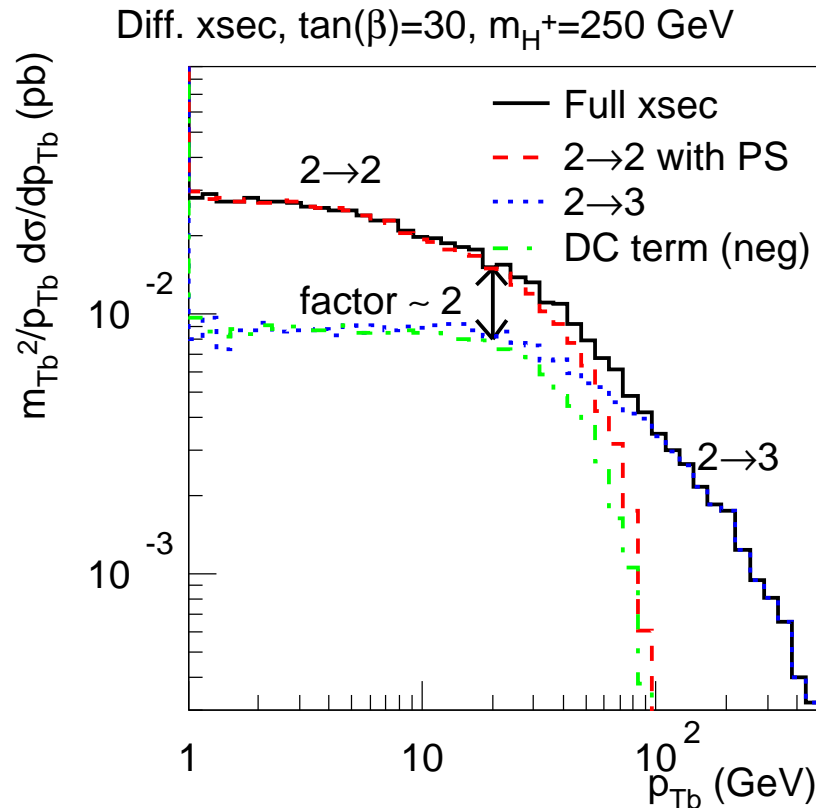
Subtract double-counting events in final analysis!



Matched differential cross-sections

Case study: $m_{H^+} = 250$ GeV, $\tan \beta = 30$

Note: $\sigma \propto m_b^2 \tan^2 \beta + m_t^2 \cot^2 \beta \implies \tan \beta$ only scales cross-section

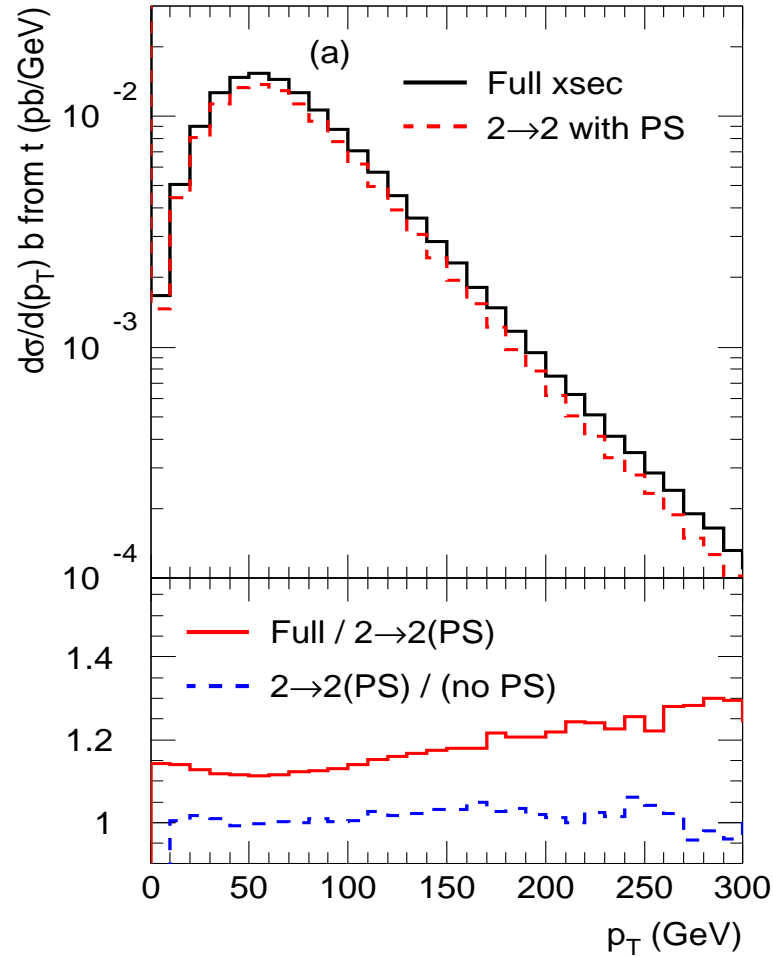


Smooth interpolation between $2 \rightarrow 2$ and $2 \rightarrow 3$ processes

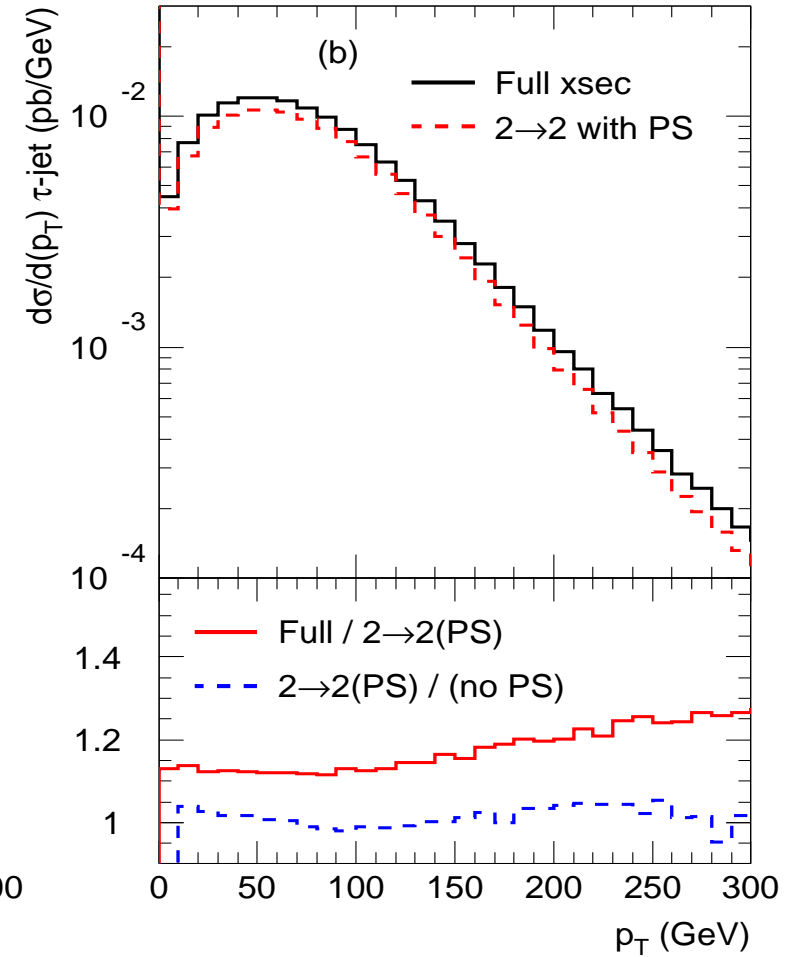


More results from matching of processes

Tagged b from $t \rightarrow W^\pm b$



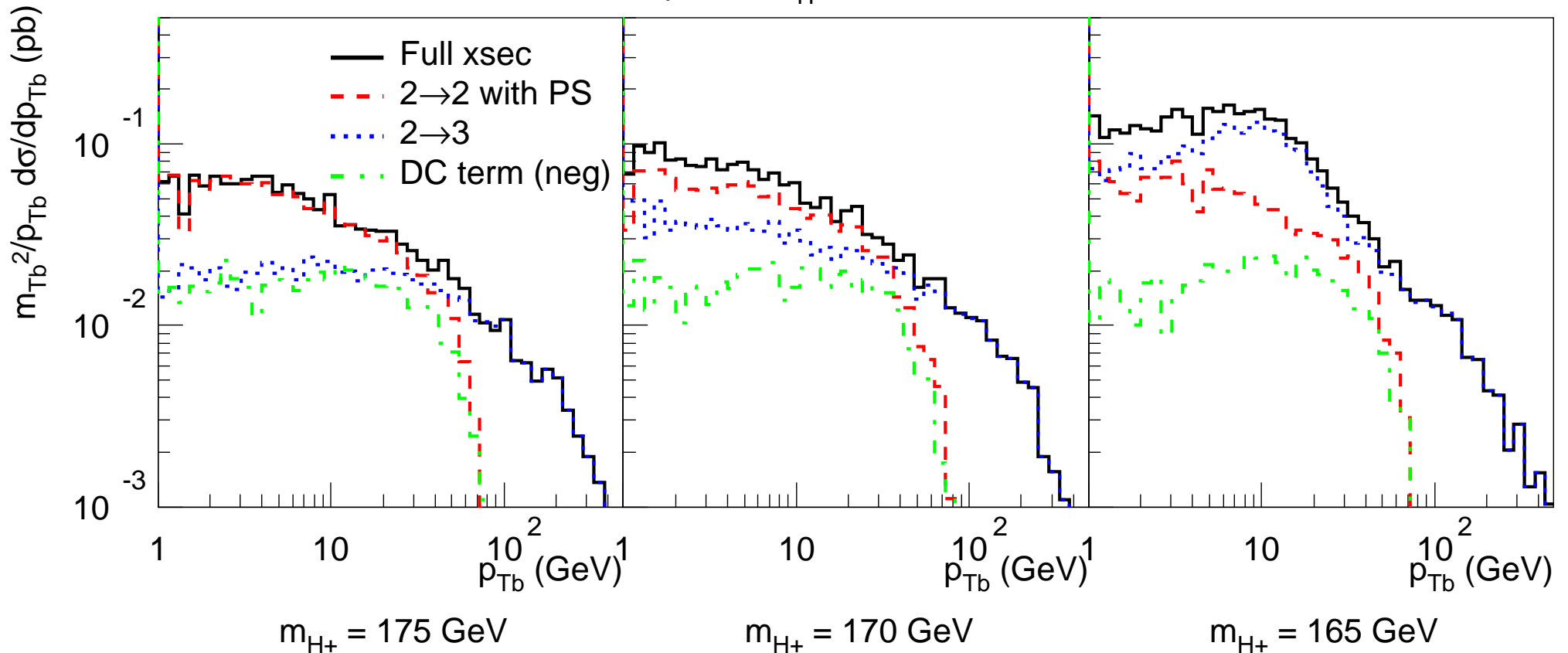
τ jet from $H^\pm \rightarrow \tau^\pm \nu$



~ 10 – 20% Effect even if b -quark not tagged

$p_{\perp,b}$ distributions for lower H^+ masses

Diff. xsec, $\tan(\beta)=30$, $m_{H^+}=175, 170, 165$ GeV



For $m_{H^+} < m_t$ the $2 \rightarrow 3$ process increasingly important even for low $p_{\perp,b}$

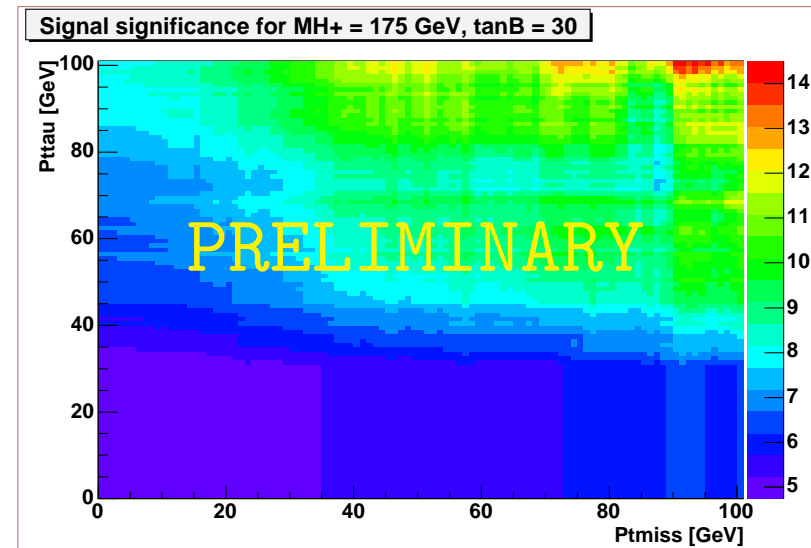
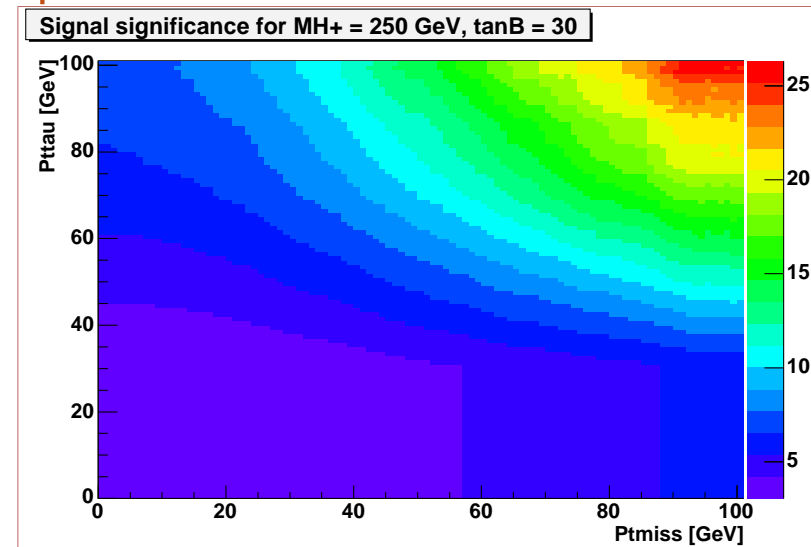


Improving the discovery contour

Work in progress using matched processes:

- Look at extra b quark:
Improved discovery region
for $m_{H^+} > m_t$
- Find discovery contour
around $m_{H^+} = m_t$
- Most promising charged
Higgs decay: $H^+ \rightarrow \tau^+ \nu$
- Main background: $W^+ \rightarrow$
 $\tau \nu$ from $t\bar{t}$ and tbW^\pm
production

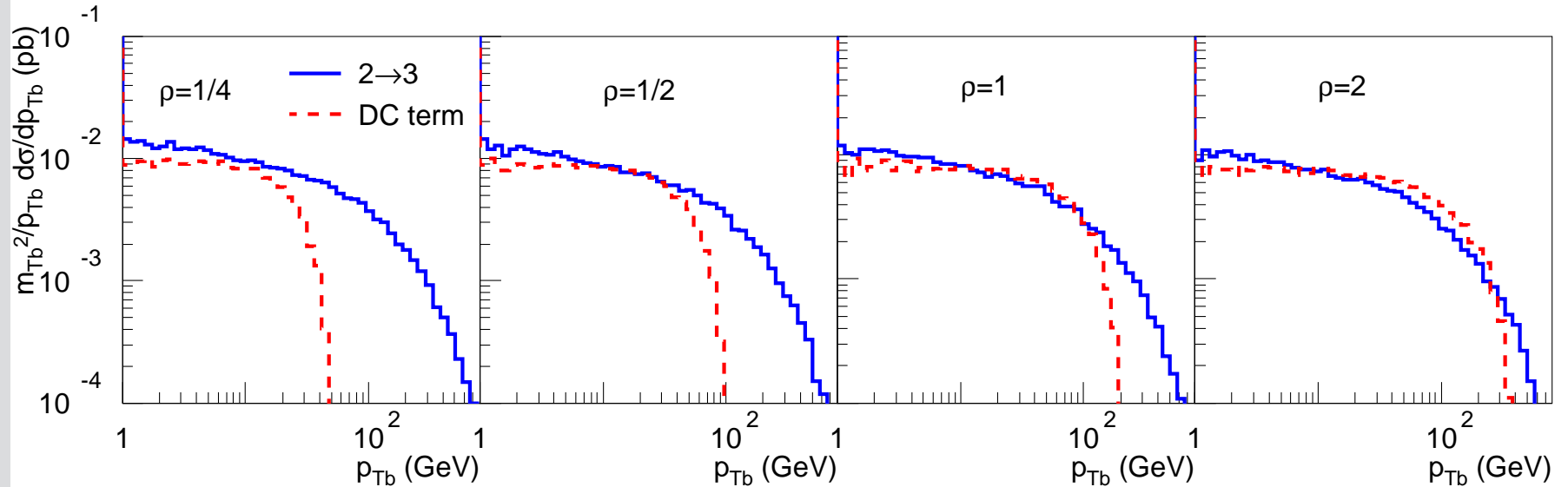
Together with ATLAS PhD
student Bjarte Mohn





Bonus: Choice of factorization scale

$\mu_F = \rho \frac{m_{H^+} + m_t}{2}$ - scale where the parton densities are evaluated



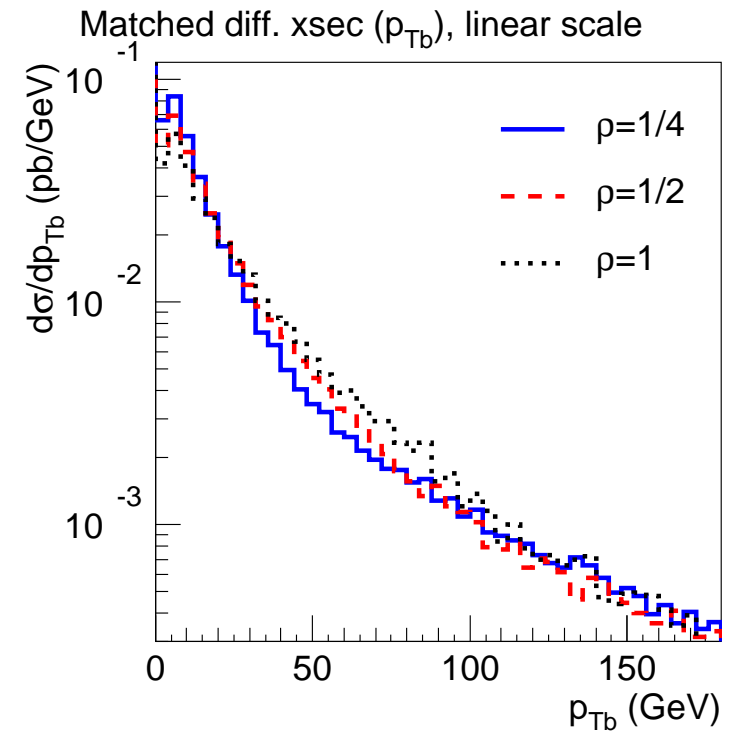
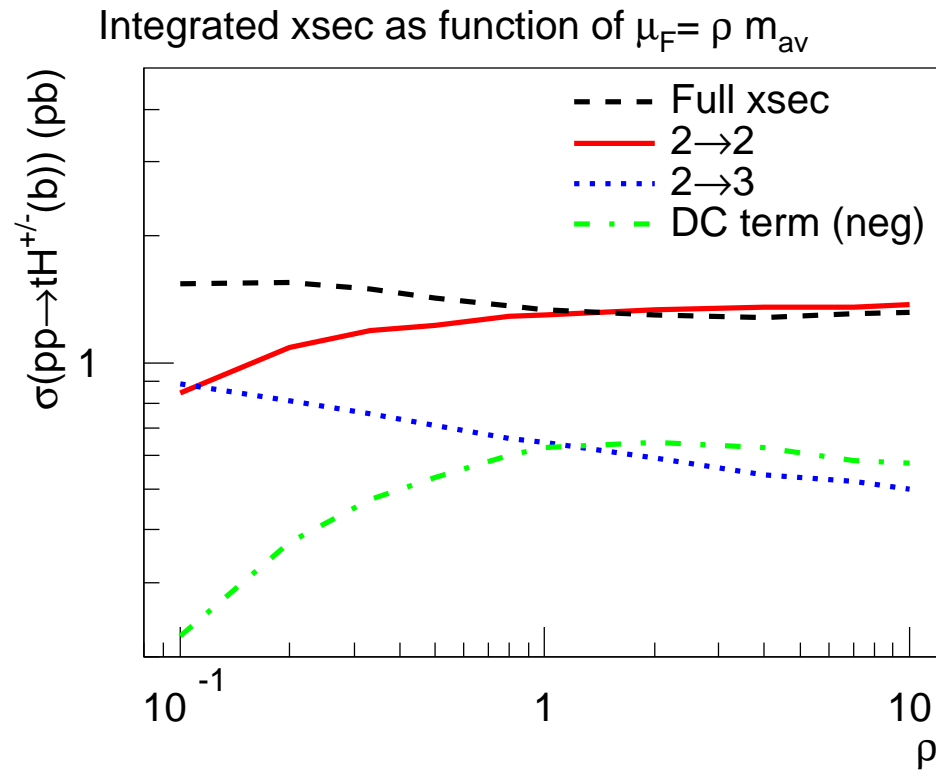
Double-counting term should account for log-enhanced part of $2 \rightarrow 3$ term already included in $2 \rightarrow 2$ term

For $\rho \gtrsim 1$ double counting term overshoots $2 \rightarrow 3$ term

\implies too large $\mu_F!$



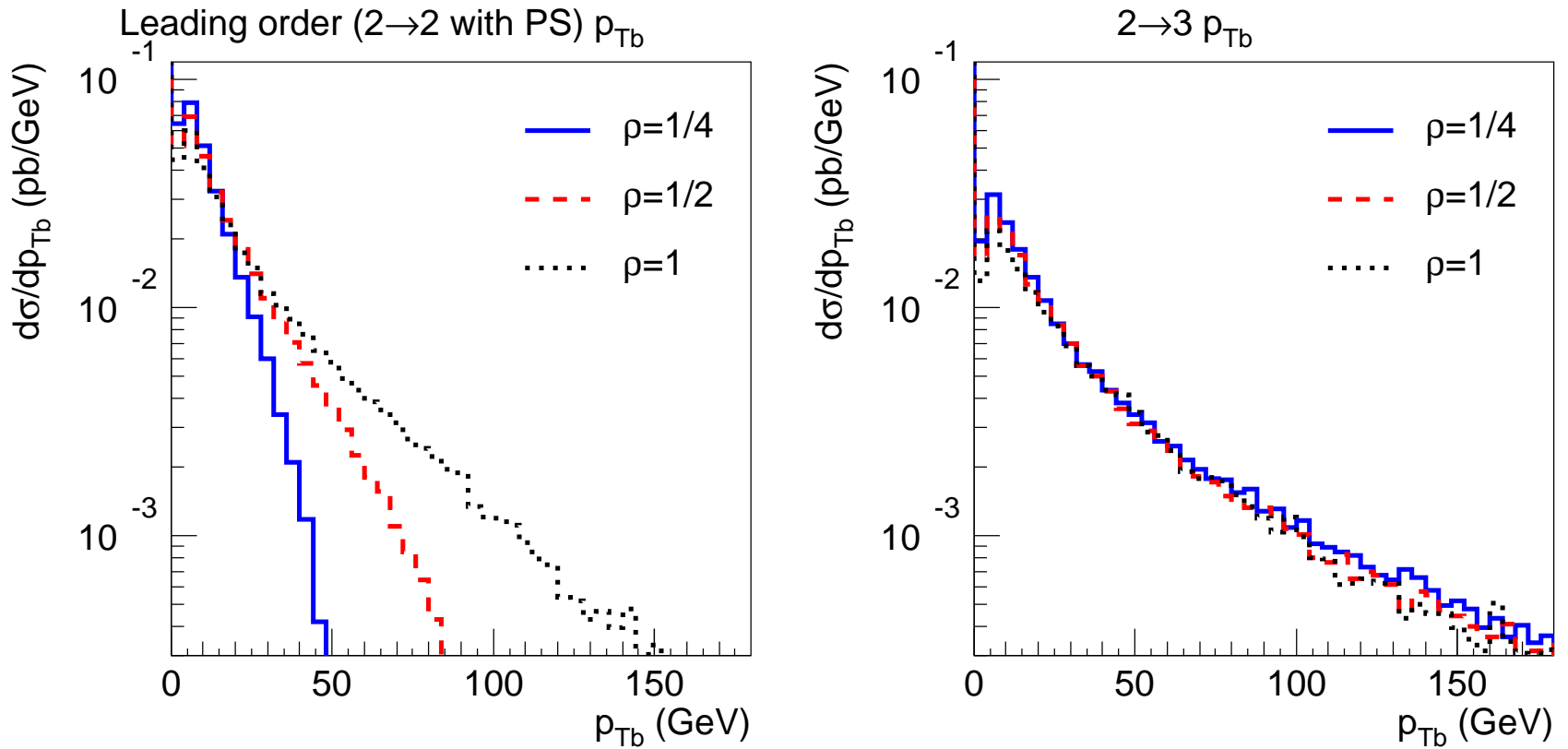
More factorization scale effects



Matched cross-section much less factorization scale dependent!



Factorization scale effects on $2 \rightarrow 2$ and $2 \rightarrow 3$



$$\mu_F = \rho \frac{m_{H^+} + m_t}{2}$$



Alternative: Look at other production processes

David Eriksson, Stefan Hesselbach and Johan Rathsman (work in progress)

H^+ production in association with W^\pm bosons instead of top

- No “funny behaviour” near $t \rightarrow H^+ b$ threshold
- Small background with $W^\pm \rightarrow jj, H^\pm \rightarrow \tau\nu$

In MSSM:

Strong destructive interference

In general 2HDM:

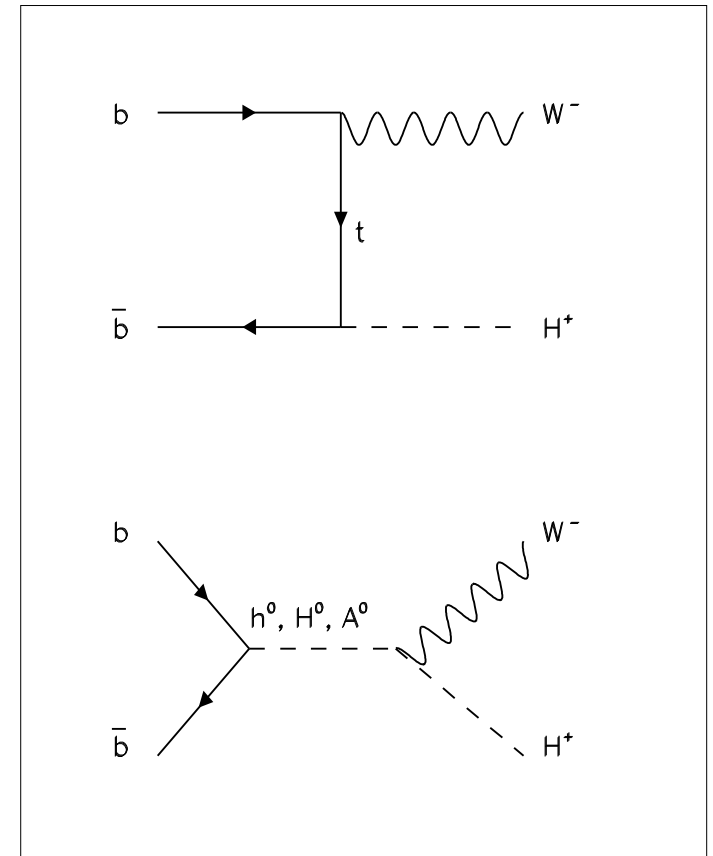
Possible resonance production if

$$m_{H^0} \geq m_{H^+} + m_{W^+}$$

With CP-breaking 2HDM:

Might get constructive interference

\implies Enhanced cross-section



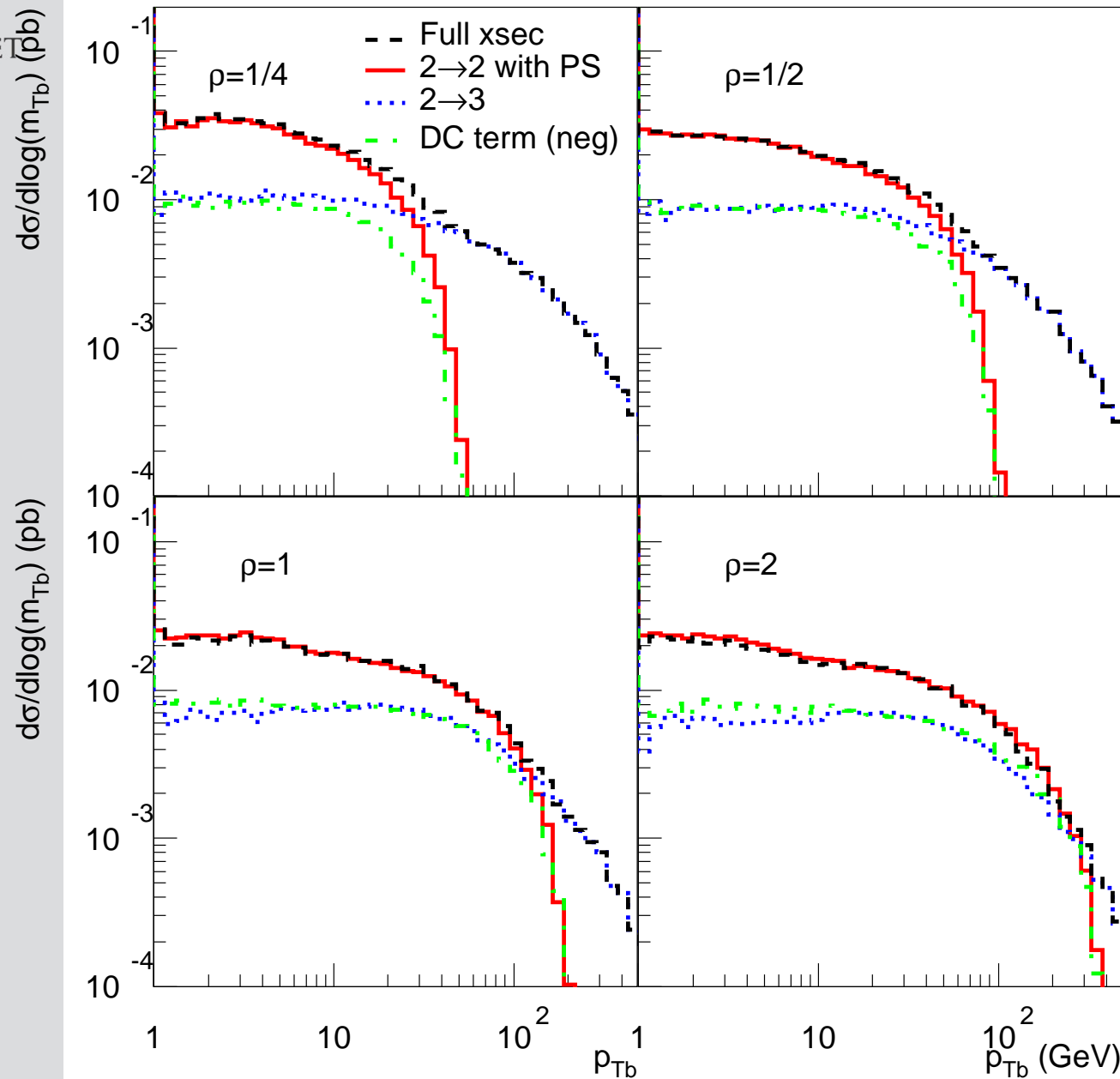


Conclusions

- Discovery of a charged scalar particle would be a clear signal of new physics
- Large effort in study of charged Higgs bosons at Uppsala
- Problematic region m_{H^+} near m_t
- For charged Higgs production in association with top quarks:
 - ↪ Need matching of $gb \rightarrow tH^+$ and $gg \rightarrow tbH^+$ for correct description
 - ↪ Matching can help determine correct factorization scale
- Work in progress on improving the discovery contour for ATLAS
- Alternative channel under investigation: $b\bar{b} \rightarrow H^\pm W^\mp$



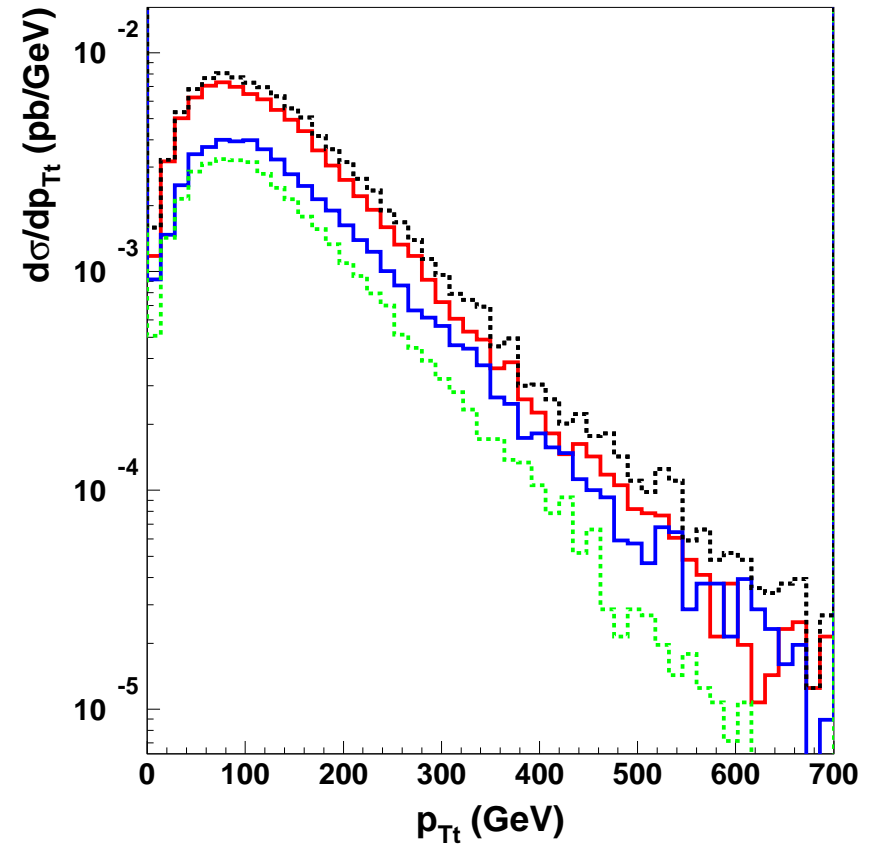
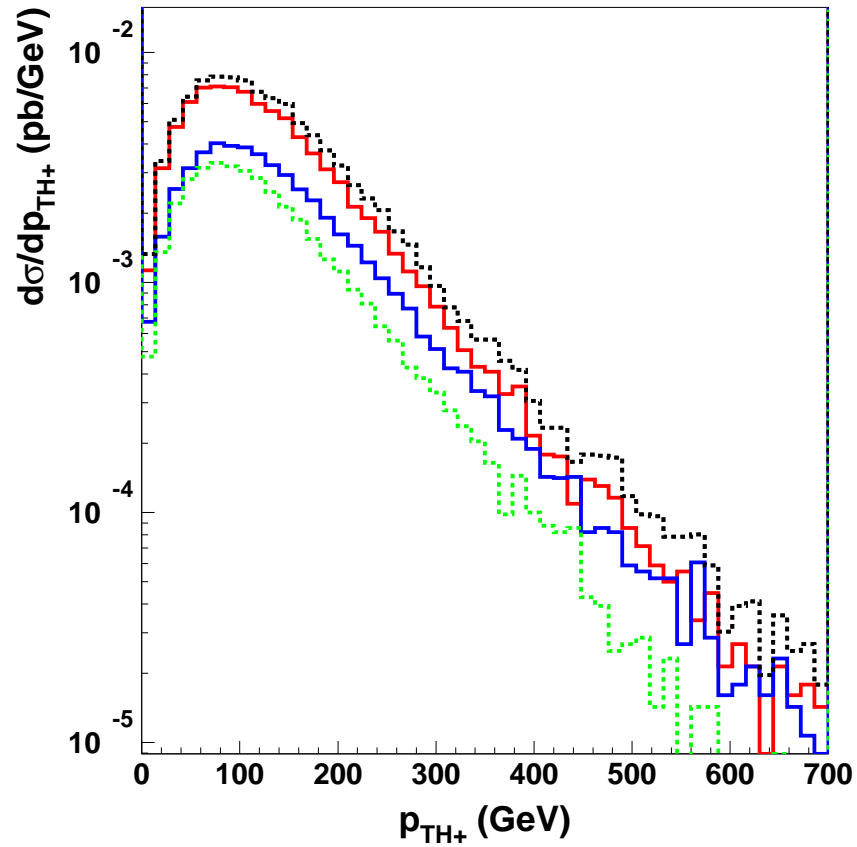
Comparison of factorization scales



$$\mu_F = \rho \frac{m_{H^+} + m_t}{2}$$



Differential distributions for H^+ and t





More differential distributions for H^+ and t

