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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)

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Charged Higgs studies at Uppsala

Theory group:

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

ATLAS group:

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

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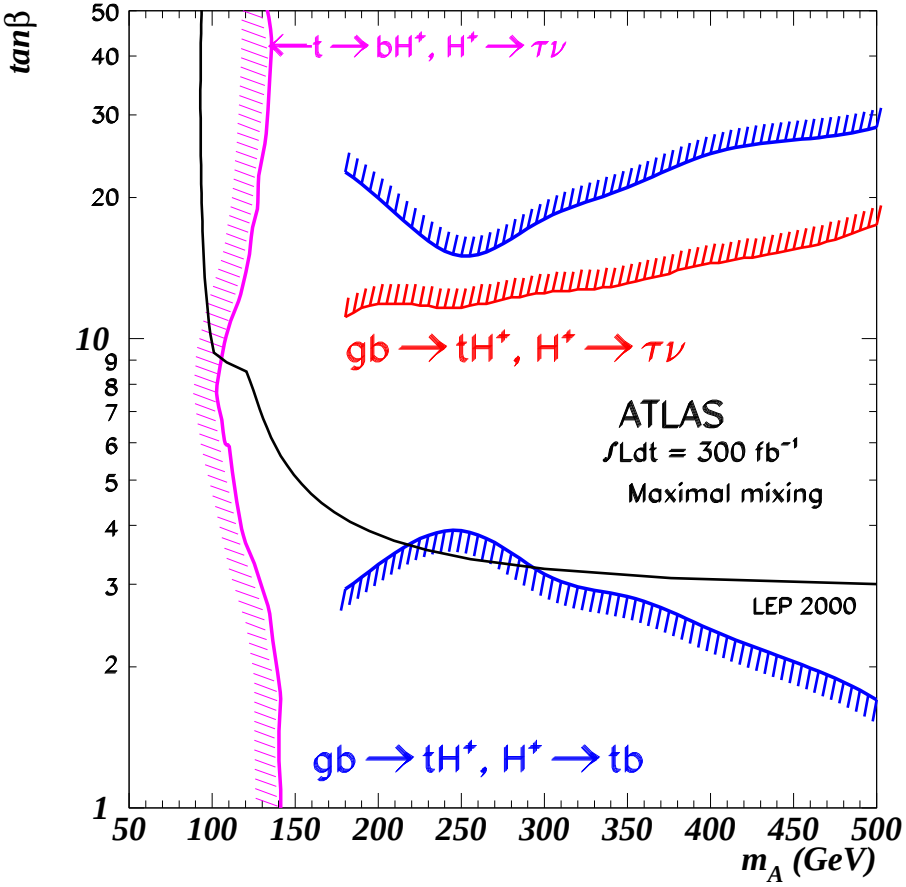
Our goal

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

Problematic area:
H^+ mass $\sim$ top mass



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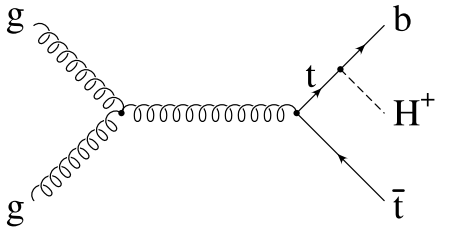
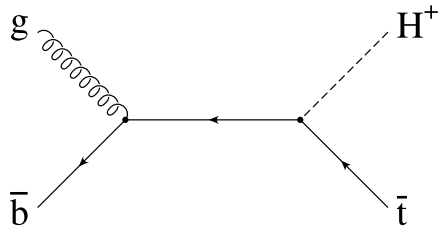
Single charged Higgs accompanied by t and b

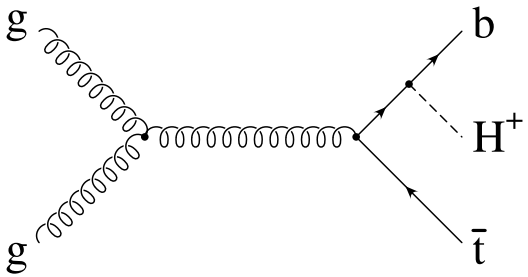
- $gg(q\bar{q}) \to t\bar{t} \to bH^+\bar{t}$ $(m_{H^+} \leq m_t - m_b)$:

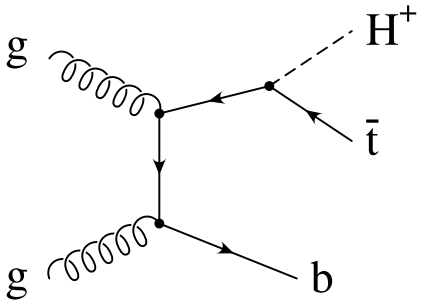


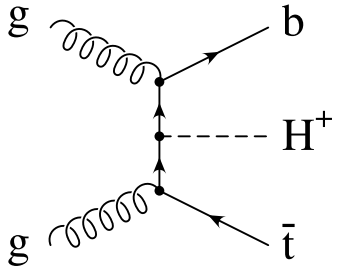
- $g\bar{b} \to \bar{t}H^+$ $(2 \to 2$ process):



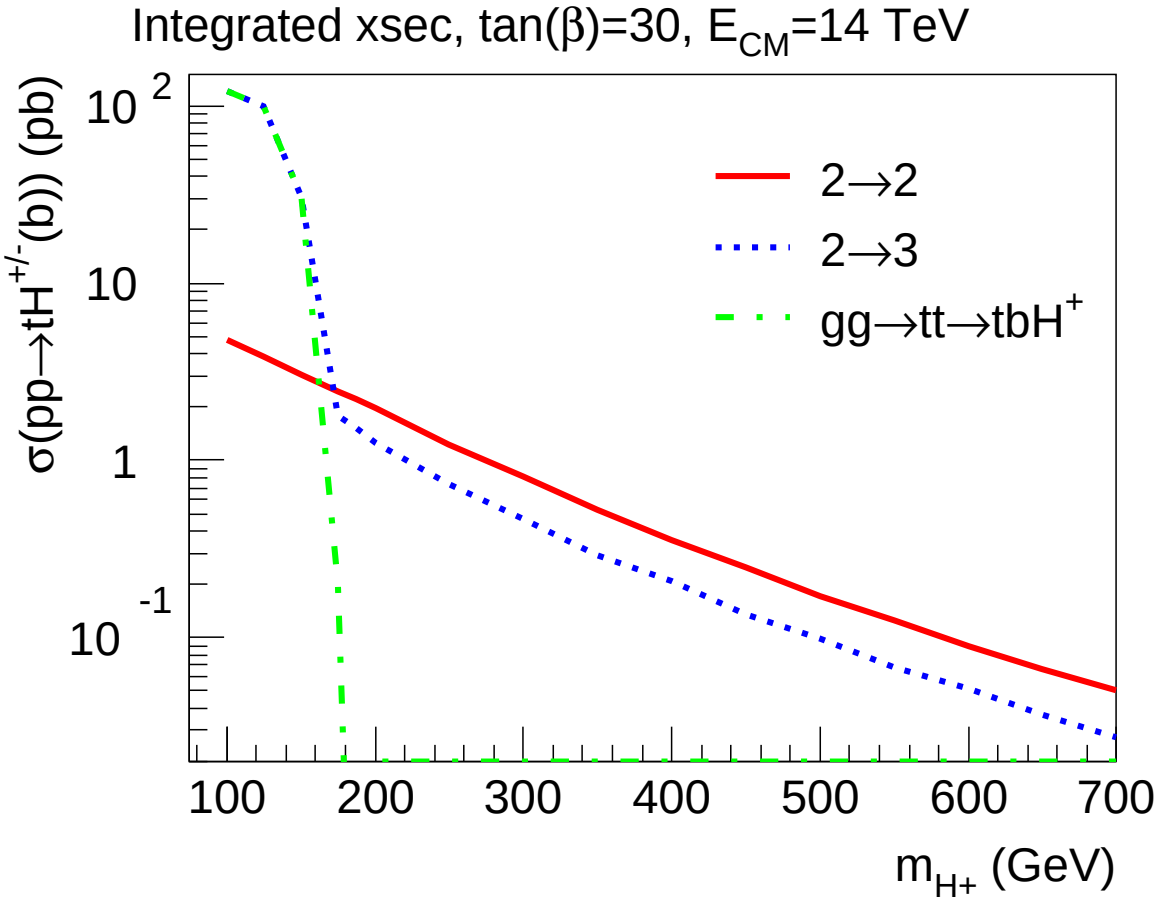
- $gg(q\bar{q}) \to \bar{t}bH^+$ $(2 \to 3$ process):







Importance of the H^+ production processes



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

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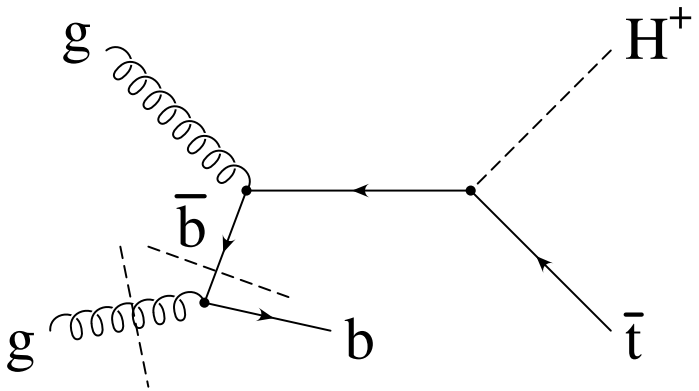
Importance of the H^+ production processes (cont.)



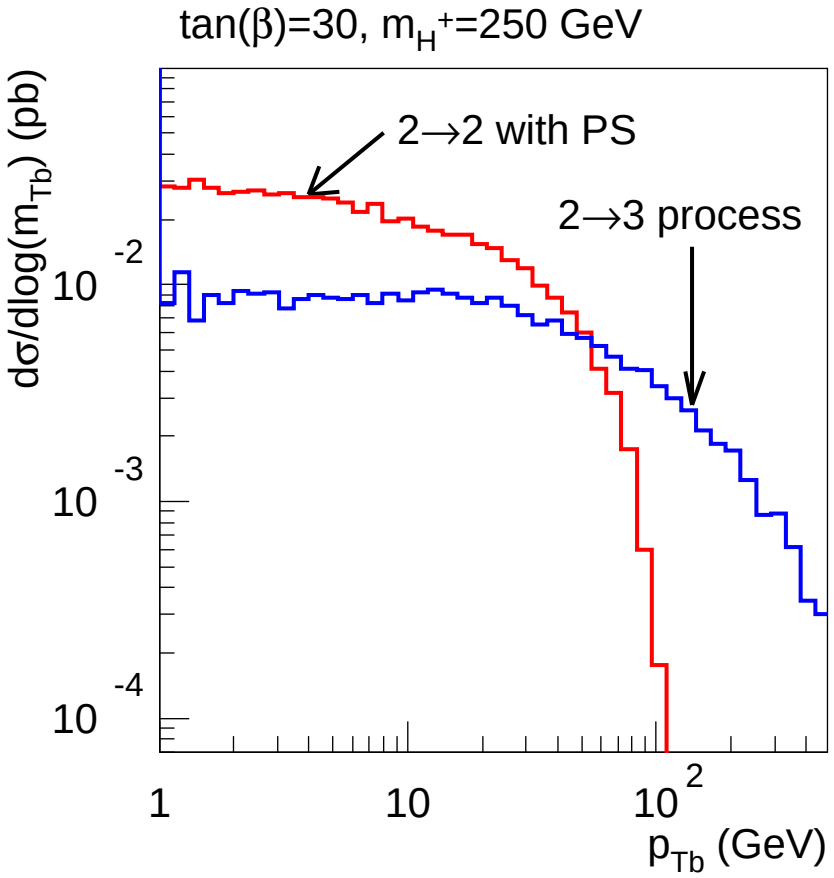
$2 \to 2$:

The b-density resums collinear logs $\left(\alpha_s \ln \frac{\mu_F^2}{m_b^2}\right)^n$

$\Longrightarrow$ Better description of total cross-section and small $p_{\perp,b}$

$2 \to 3$:

Gives a better discription of large $p_\perp$ of b-quark



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

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

$$\sigma_{2\to3} \propto P_{g\to b\bar{b}} \otimes \sigma_{2\to2}$$

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

$\Longrightarrow$ Must subtract collinear double counting term

$$\sigma_{\mathrm{DC}} = \int dx_1 dx_2 \left[g(x_1) b'(x_2) \frac{d\sigma_{2\to2}}{dx_1 dx_2}(x_1, x_2) + x_1 \leftrightarrow x_2 \right]$$

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

(The first logarithm in the b quark density)

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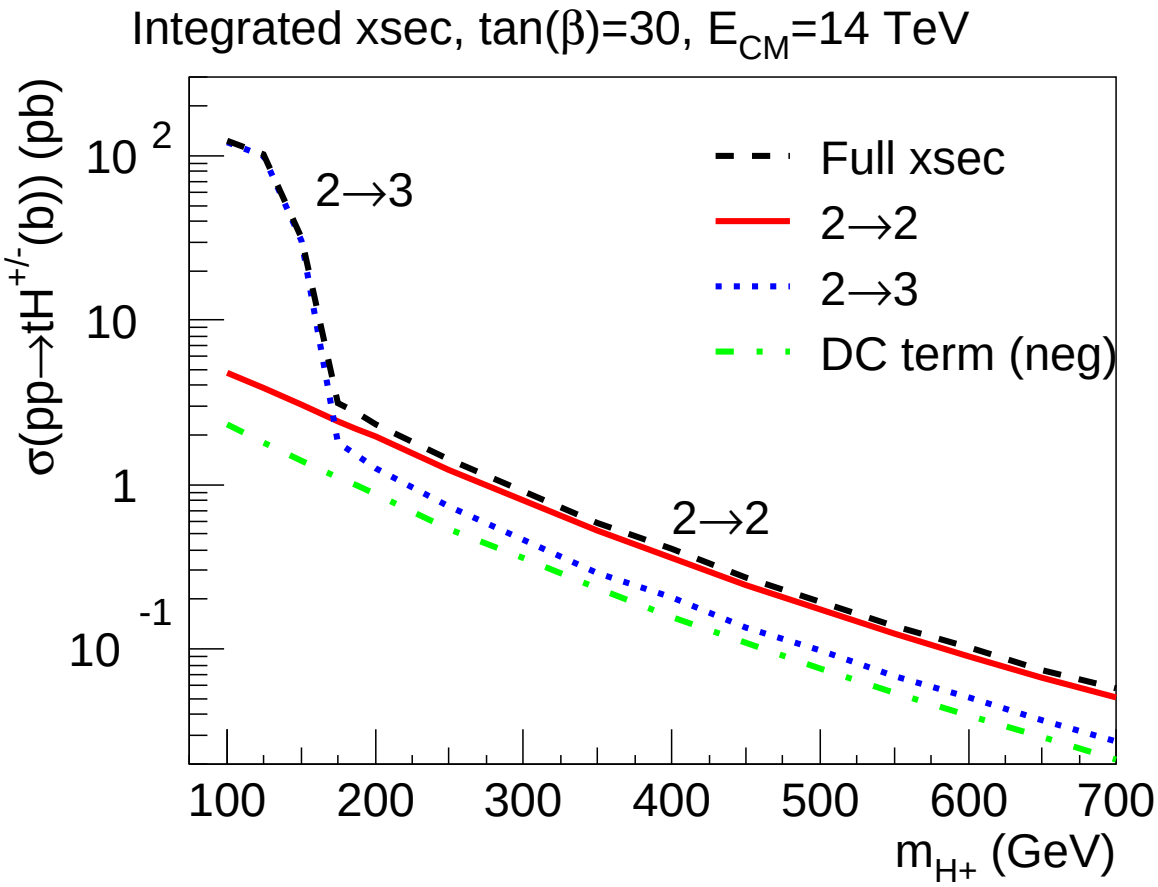
Matching the integrated cross-section

For matched cross-section: $\sigma = \sigma_{2\to2} + \sigma_{2\to3} - \sigma_{\mathrm{DC}}$



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):

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

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

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

Subtract double-counting events in final analysis!

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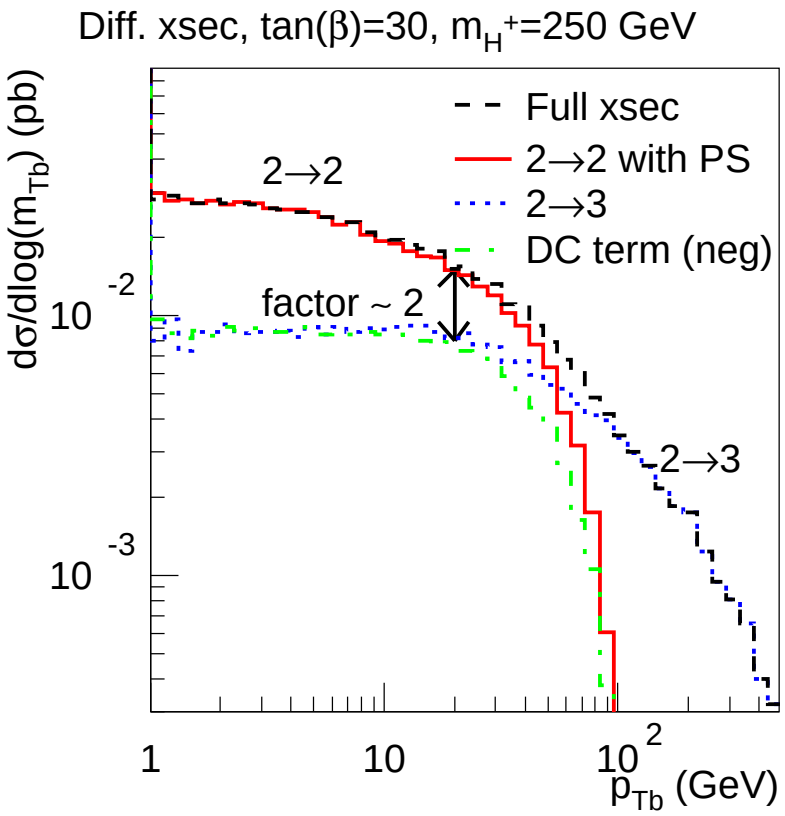
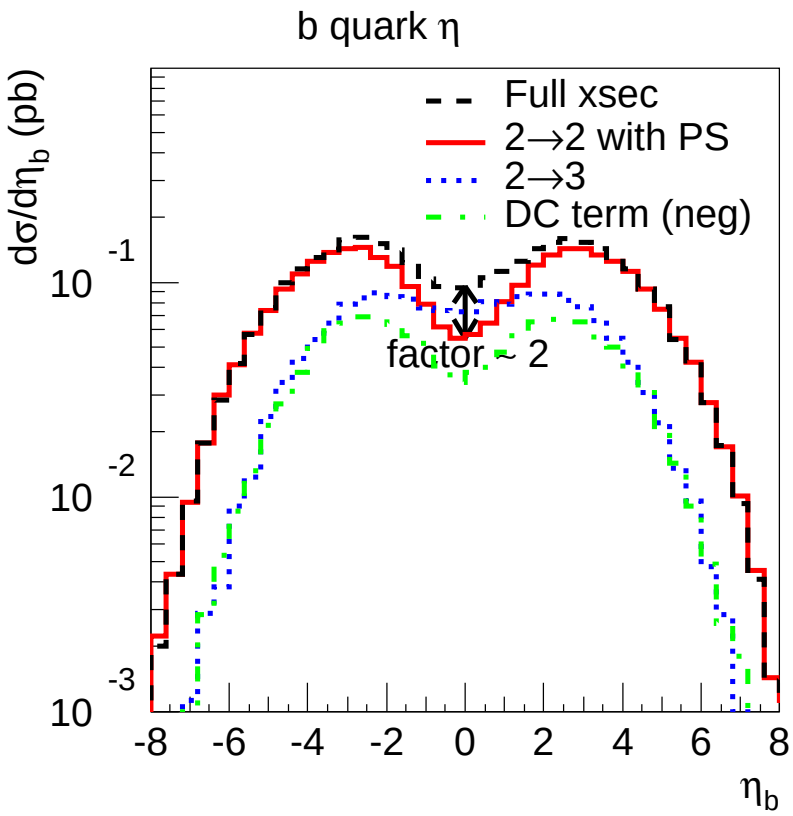
Matched differential cross-sections

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

Note: $\tan\beta$ only scales cross-section





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

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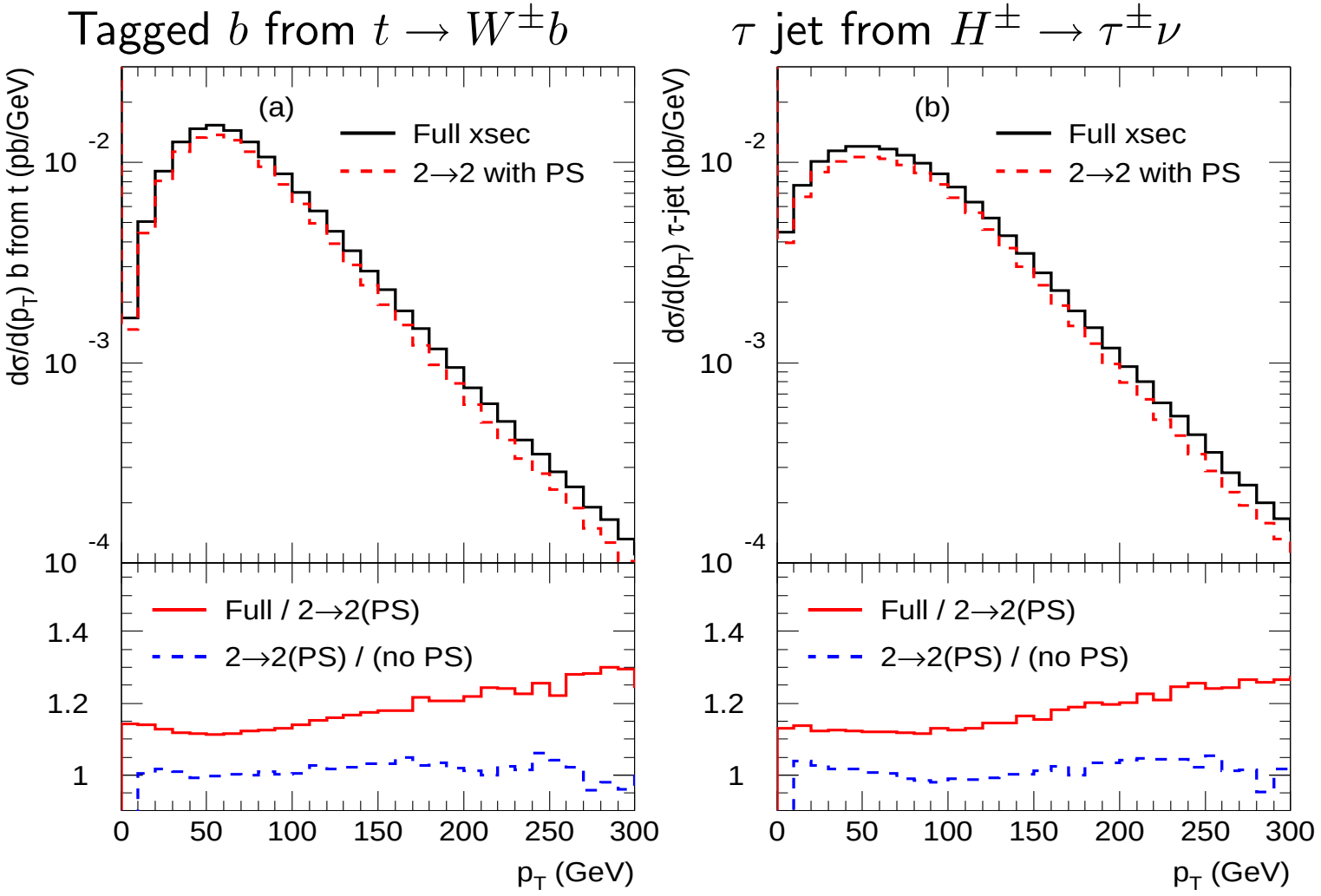
More results from matching of processes



$\sim 10 - 20\%$ Effect even if b-quark not tagged

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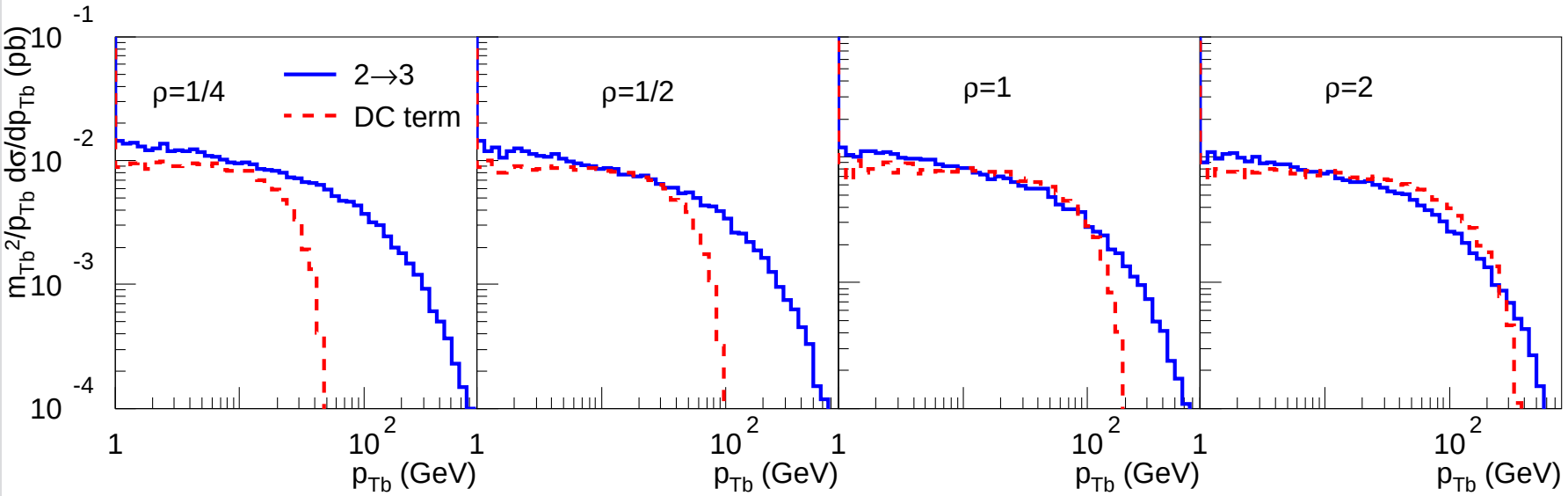
Bonus: Choice of factorization scale

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



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

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

$\Longrightarrow$ too large μ_F!

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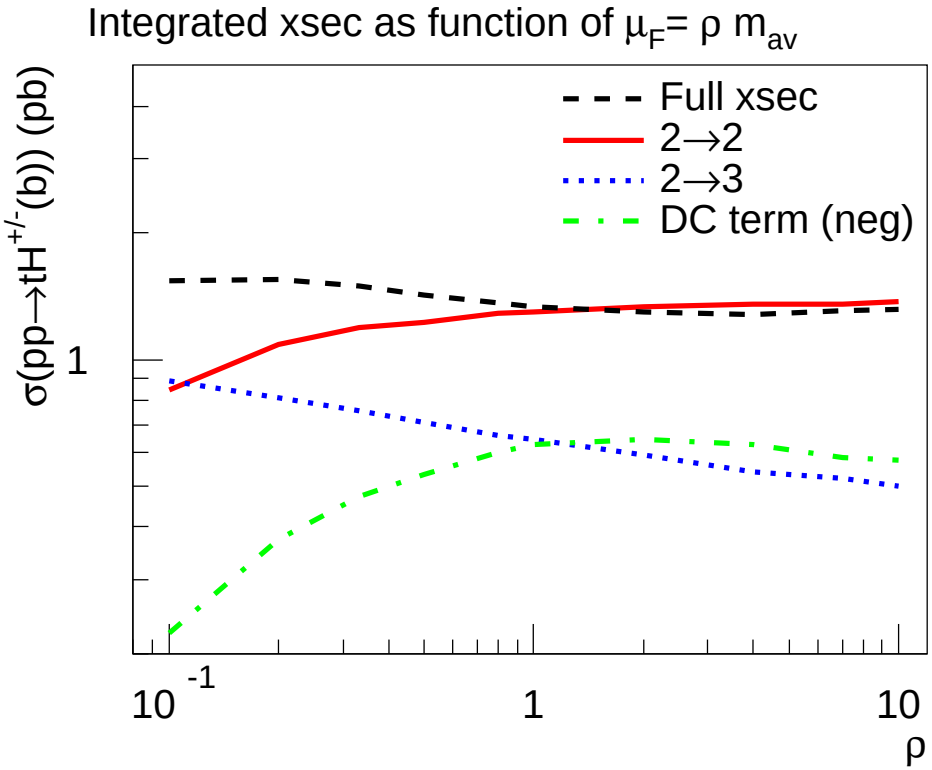
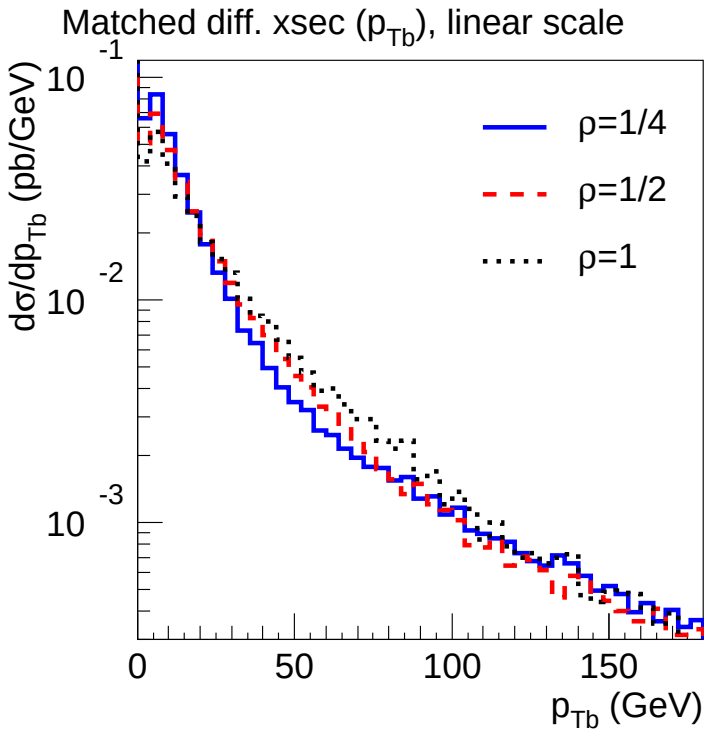
More factorization scale effects





Matched cross-section much less factorization scale dependent!

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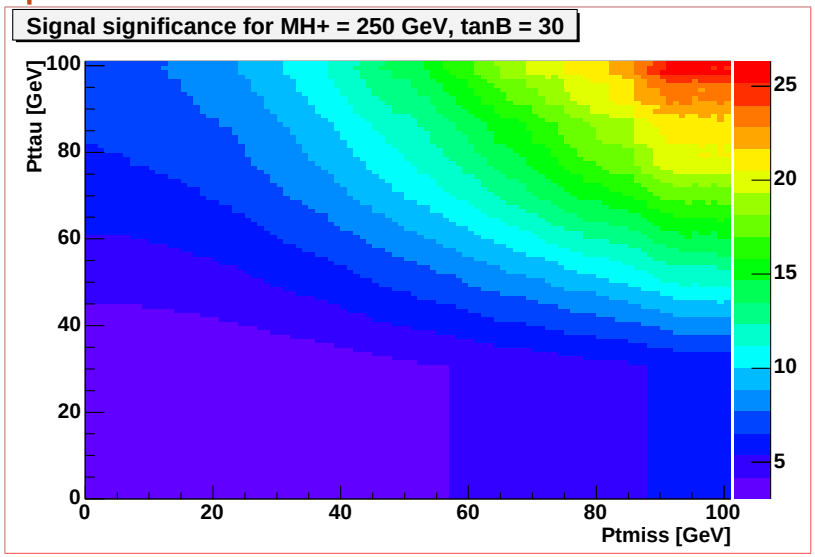
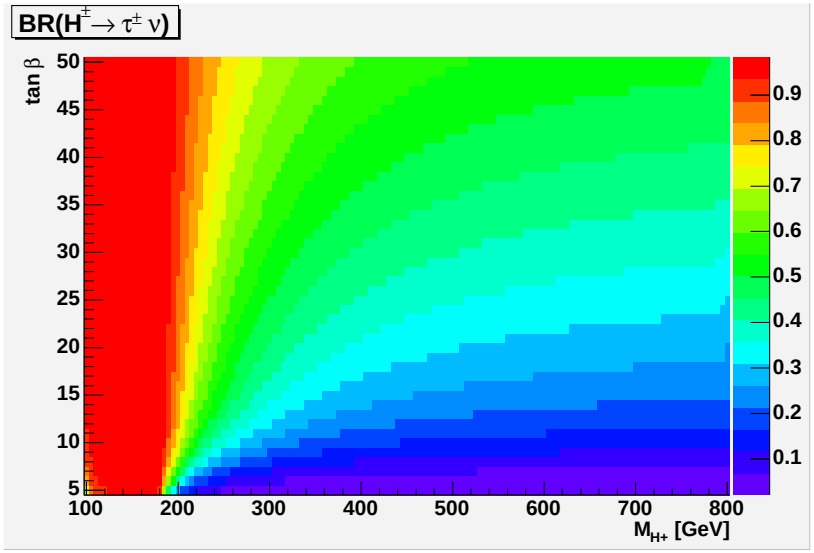
Improving the discovery contour

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: $H^+ \longrightarrow \tau^+\nu$
- Main background: $W^+ \longrightarrow \tau\nu$ from $t\bar{t}$ and $tbW^{\pm}$ production

Together with ATLAS PhD student Bjarte Mohn





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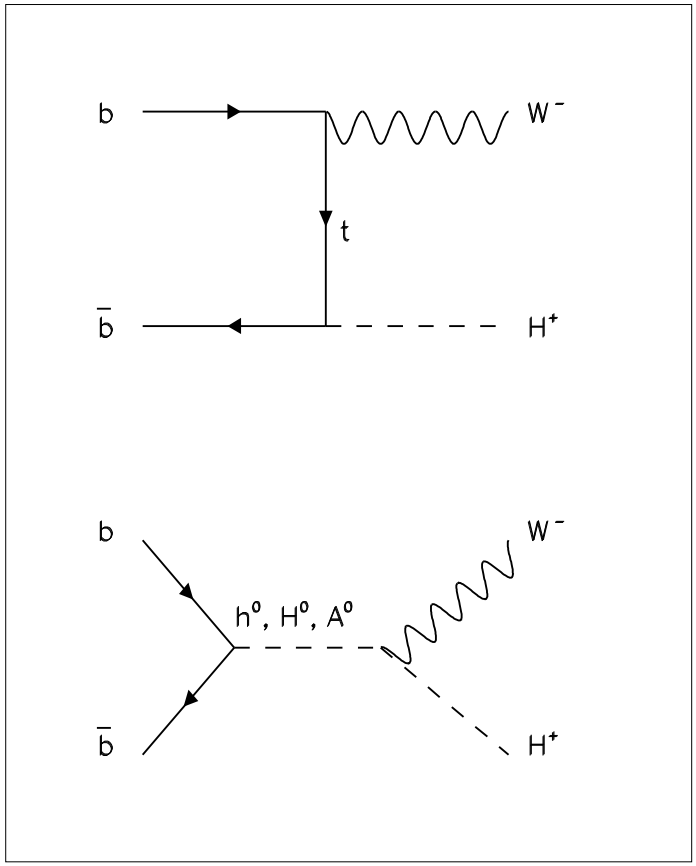
Alternative: Look at other production processes

David Eriksson, Stefan Hesselbach and Johan Rathsman:

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

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



In MSSM:
Strong destructive interference

With CP-breaking MSSM:
Might get constructive interference
$\Longrightarrow$ Enhanced cross-section

In general 2HDM:
Possible resonance production if $m_{H^0} \geq m_{H^+} + m_{W^+}$

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Charged Higgs pair production study

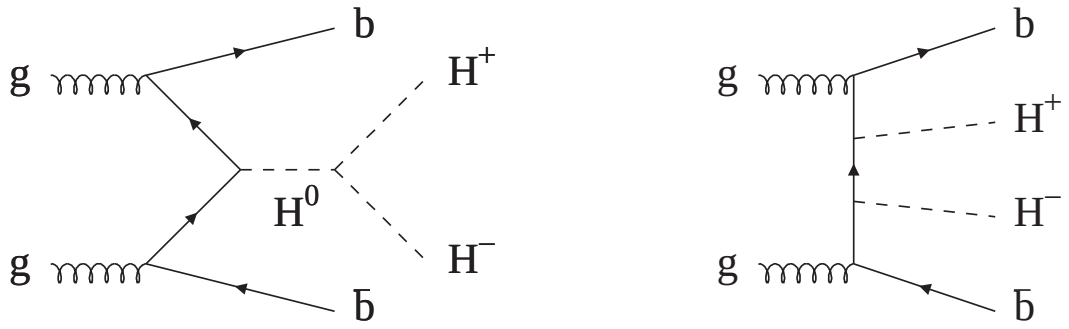
Johan Rathsman and Stefano Moretti, EPJ C 33 (2994) 41

Scenario: Charged Higgs discovered with $m_{H^\pm} > m_t$ and $\tan\beta$ is large.

Idea:

Use $gg \to H^+H^-b\bar{b}$ to study magnitude of triple-Higgs coupling $\lambda_{H^0H^+H^-}$

($b\bar{b}$ pair gives well defined production process and extra handle against backgrounds)



- $\lambda_{H^0H^+H^-}$ arbitrary (up to unitarity constraints etc) in general 2HDM
- $m_{H^0} \gtrsim 2m_{H^\pm}$ is possible in general 2HDM giving extra resonant enhancement (in MSSM $m_{H^0} \approx m_{H^\pm}$)

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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:
  $\hookrightarrow$ Need matching of $gb \to tH^+$ and $gg \to tbH^+$ for correct description
  $\hookrightarrow$ Matching can help determine correct factorization scale
- Alternative channel under investigation: $b\bar{b} \to H^{\pm}W^{\mp}$

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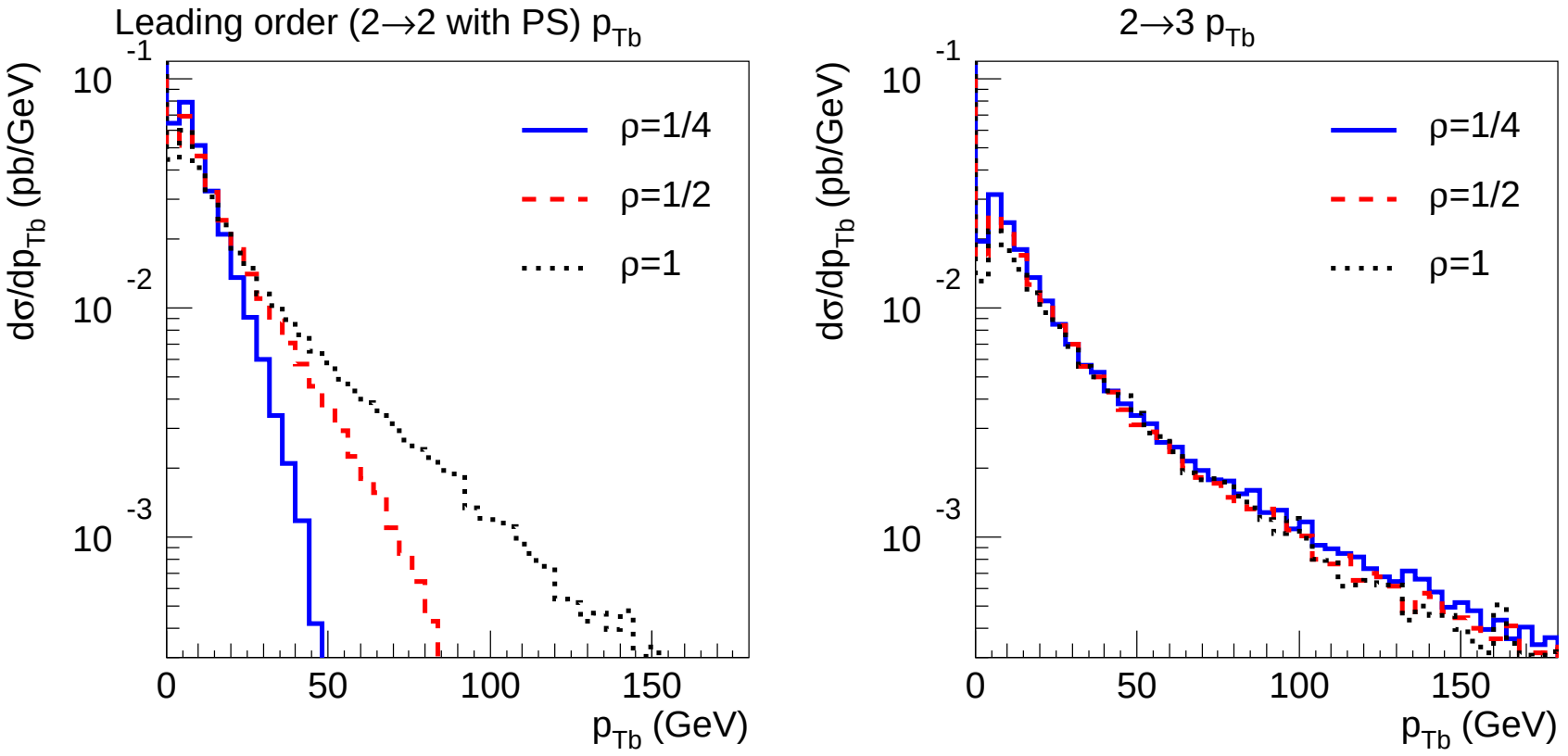
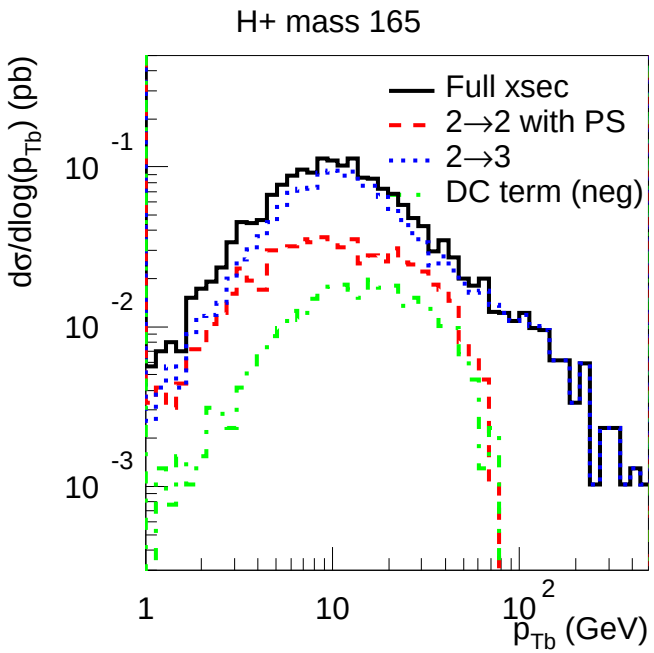
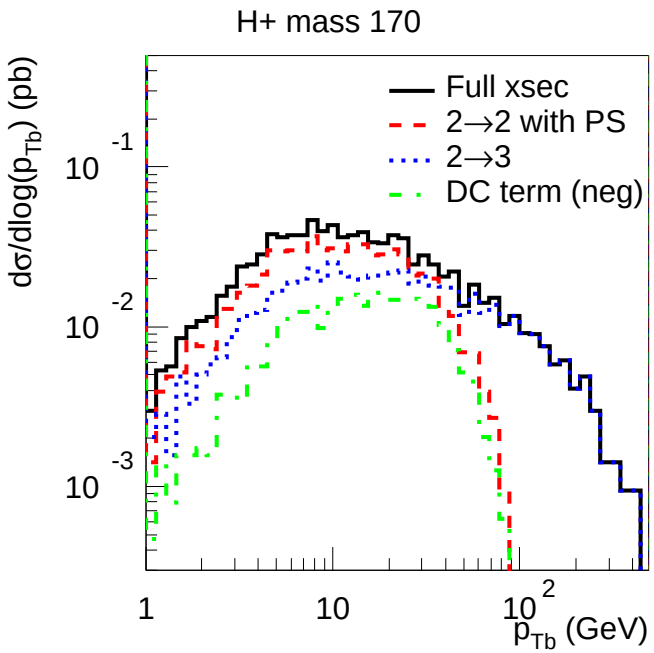
Factorization scale effects on $2 \to 2$ and $2 \to 3$

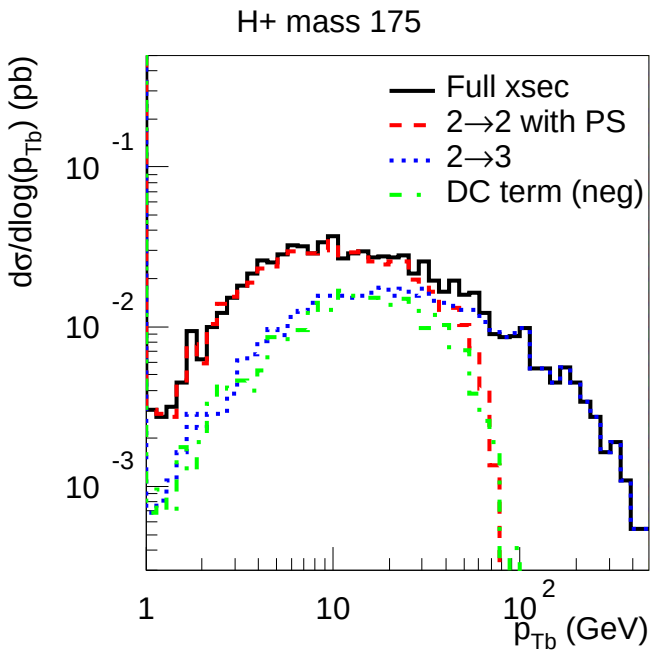


$$\mu_F = \rho \frac{m_{H^+} + m_t}{2}$$

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







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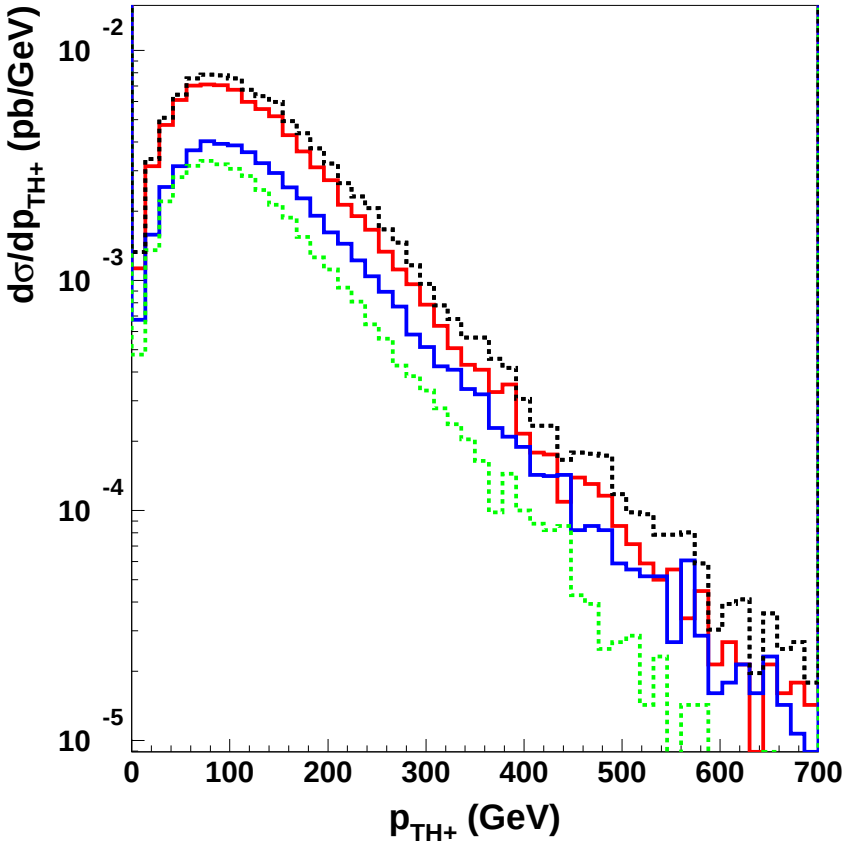
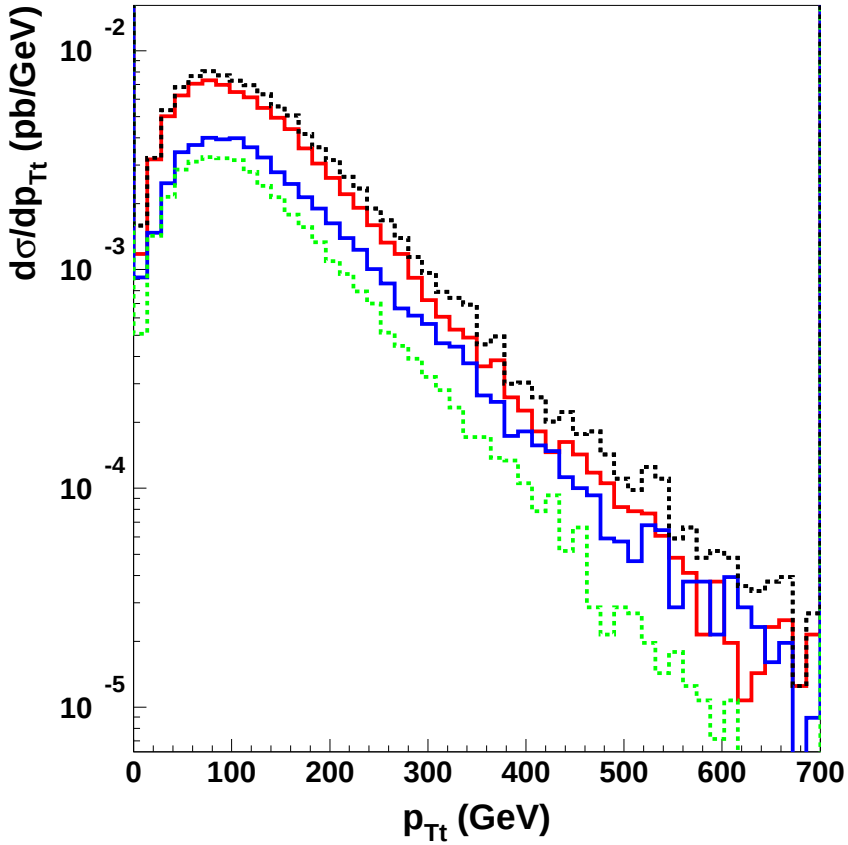
Differential distributions for H^+ and t





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More differential distributions for H^+ and t