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Matching top-bottom processes in charged Higgs production

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TOP2006, Coimbra, Portugal, 12 Jan 2006

JA and J. Rathsman, JHEP12, 050 (2004) (hep-ph/0409094)

http://www.isv.uu.se/thep/MC/matchig/

Two Higgs Doublet-Models

- Supersymmetric extentions of Standard Model need (at least) two Higgs doublets
- 8 scalar degrees of freedom $\xrightarrow{\text{Higgs mechanism}}$ 5 Higgs particles

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

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

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

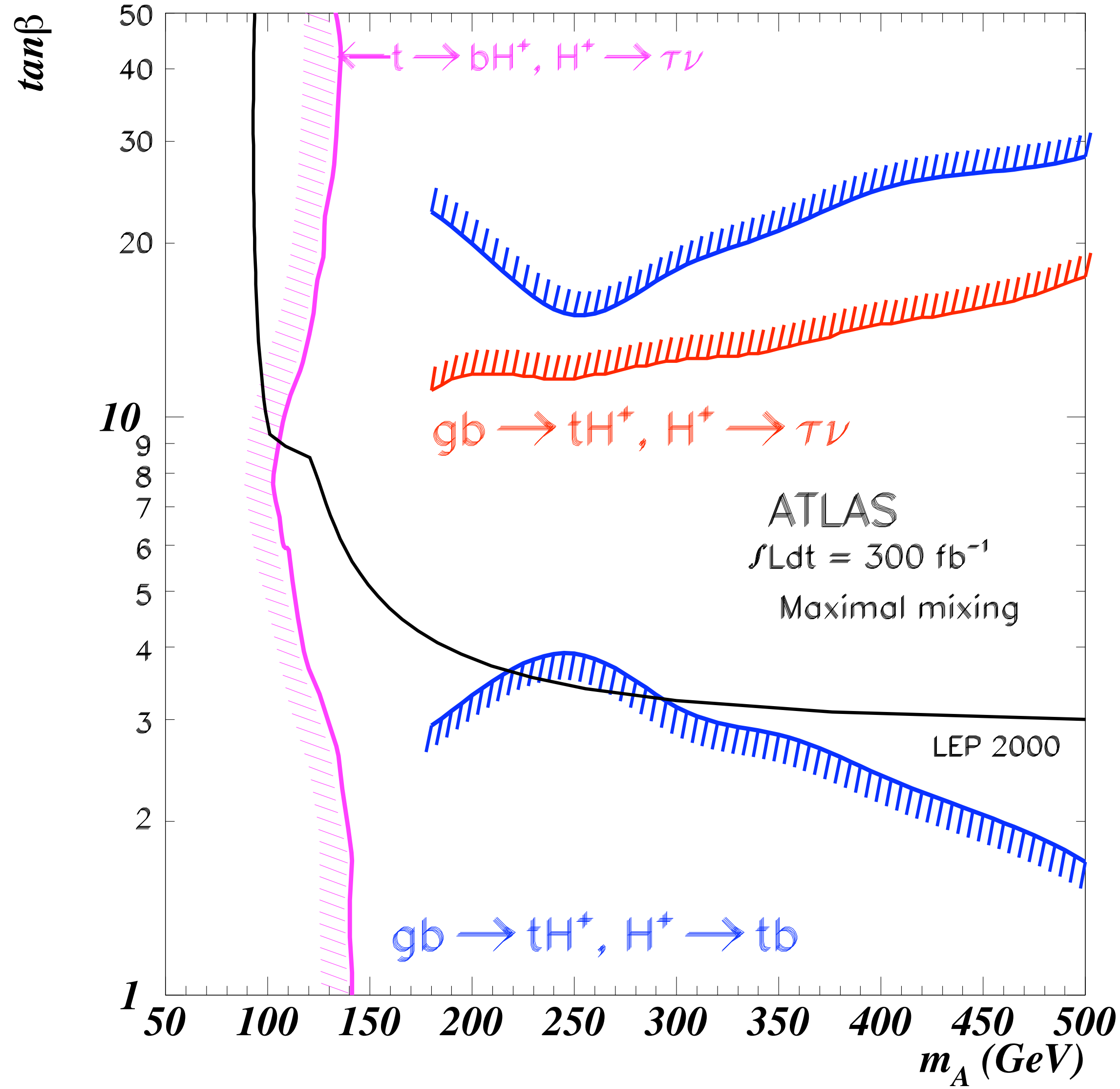
  M_A One of the masses, usually the pseudoscalar

- Strong coupling to top due to Yukawa coupling ~ 1
- A charged Higgs boson would be a clear signal of physics beyond the Standard Model

Our goal

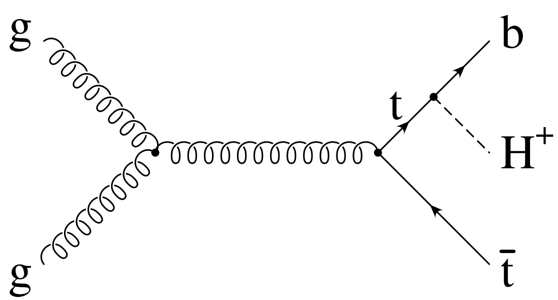
Need accurate description of Higgs production in event generators to devise search strategies/ suppress SM background.

Problematic region: H^{+}mass ~ top mass

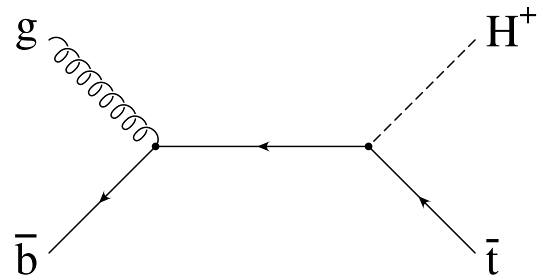


Single charged Higgs accompanied by t and b

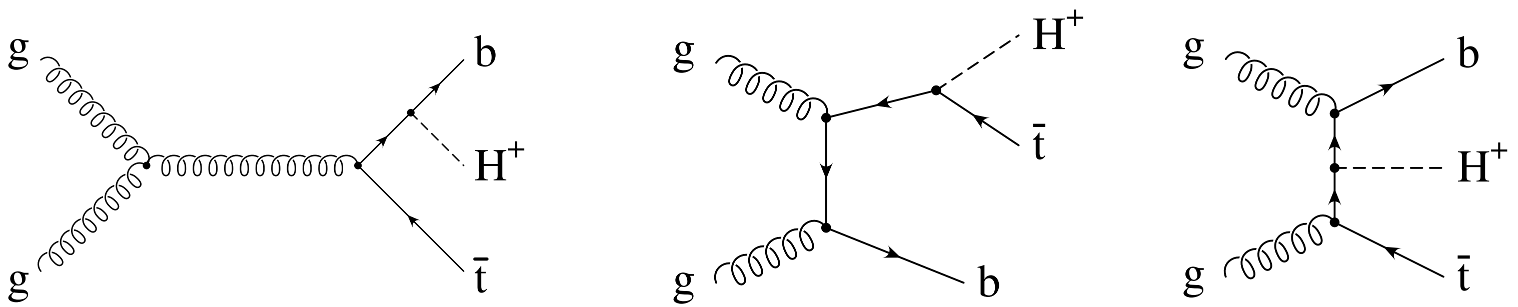
- $gg(q\bar{q}) \to t\bar{t} \to bH^+\bar{t}$ $(m_{H^+} \leq m_t - m_b)$:



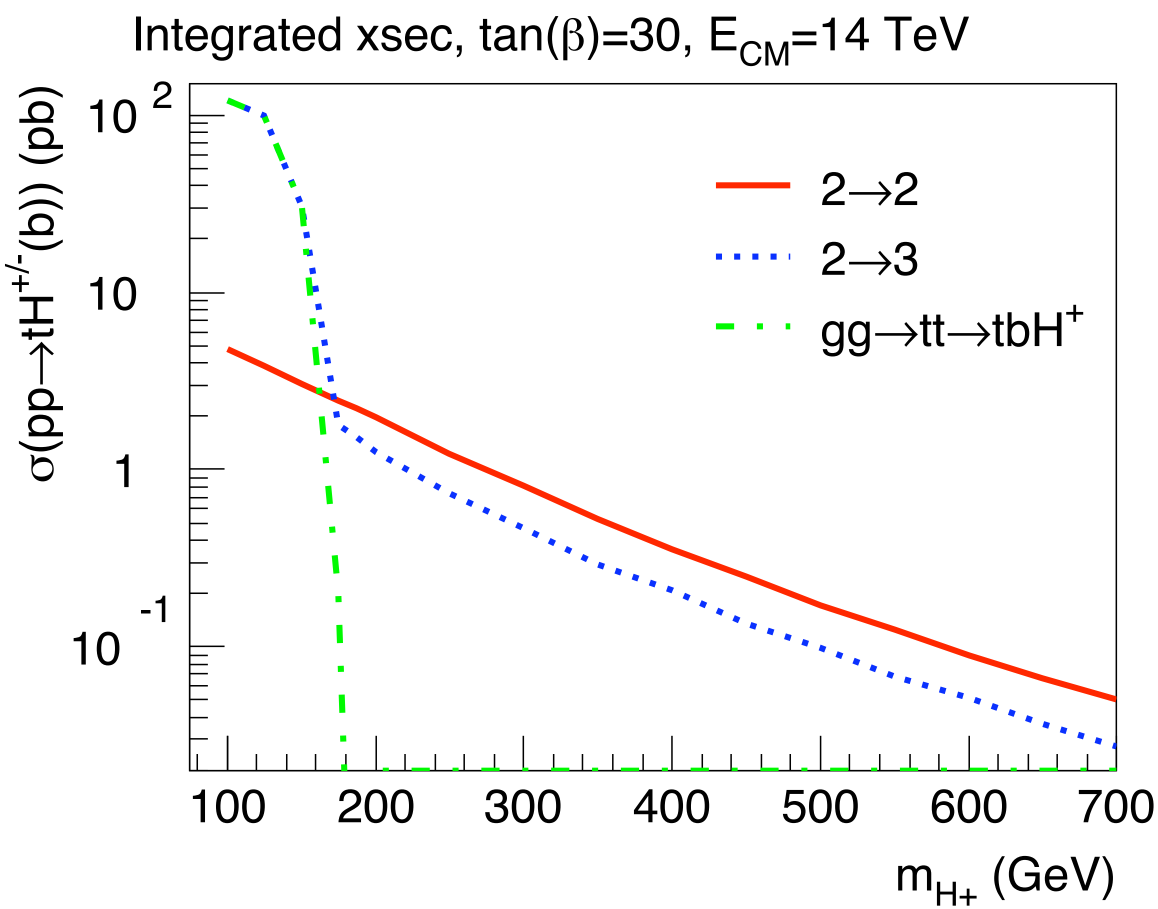
- $g\bar{b} \to \bar{t}H^+$ (2 $\to$ 2 process):



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

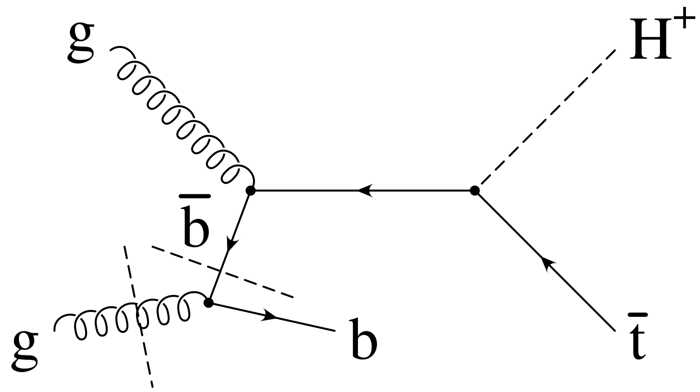


Importance of the H^+ production processes



- 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 to take both $gb \to H^{\pm}t$ and $gg \to H^{\pm}tb$ into account

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

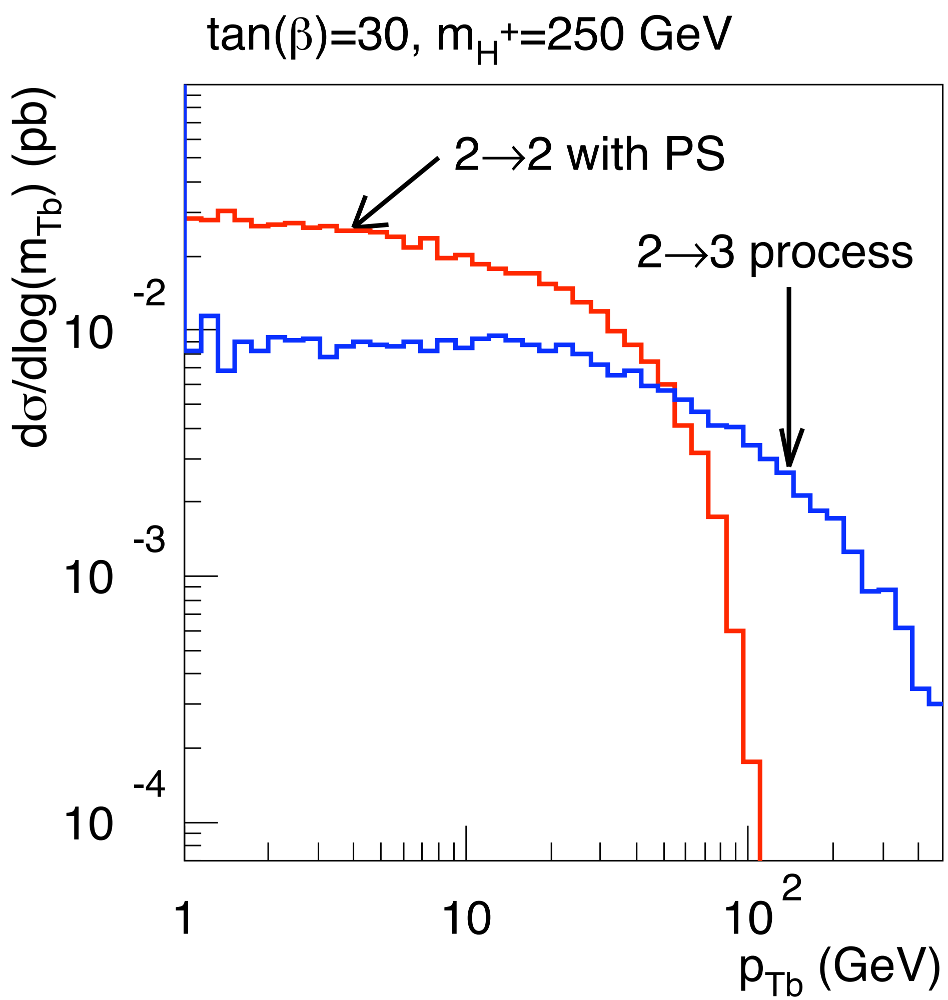


$2 \rightarrow 2$:

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

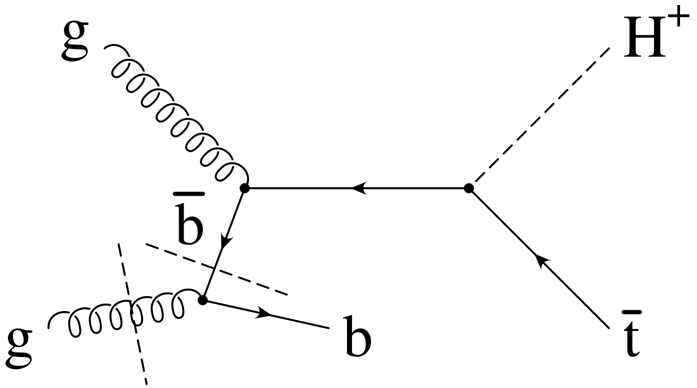


Want to combine these virtues!

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

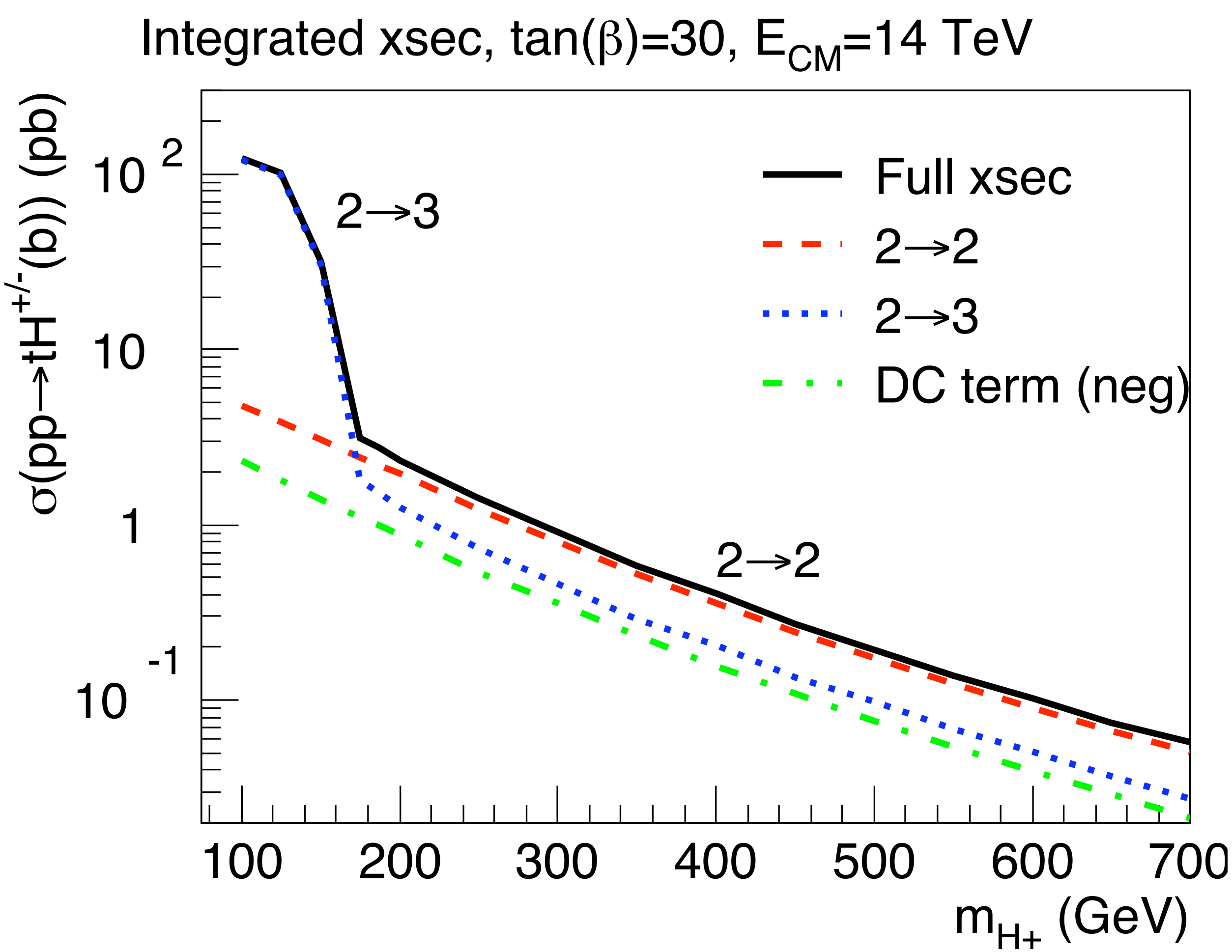
$$\sigma_{\rm DC} = \int dx_1 dx_2 \left[g(x_1) b'(x_2) \frac{d\sigma_{2\to2}}{dx_1 dx_2}(x_1, x_2) + x_1 \leftrightarrow x_2 \right]$$

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

(The first logarithm in the b quark density)

The matched integrated cross-section

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



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

Matching the differential cross-section

Would like fully differential Monte Carlo to apply cuts and detector simulation.

Solution 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):

$$\sigma_{\rm DC} = \int_{\tau_{\rm min}}^{1} \frac{d\tau}{\tau} \int_{\frac{1}{2}\log\tau}^{-\frac{1}{2}\log\tau} dy^* \frac{\pi}{\hat{s}} \int_{-1}^{1} \frac{\beta_{34}}{2} d(\cos\hat{\theta}) \left|\mathcal{M}_{2\to 2}\right|^2 x_1 g(x_1, \mu_F^2) \times$$

$$\frac{\alpha_s(\mu_R^2)}{2\pi} \left[\int_{x_2}^{z_{\rm max}} dz P_{g\to q\bar{q}}(z) \frac{x_2}{z} g(\frac{x_2}{z}, \mu_F^2) \int_{Q^2_{\rm min}}^{Q^2_{\rm max}} \frac{d(Q^2)}{Q^2 + m_b^2} + x_1 \leftrightarrow x_2 \right]$$

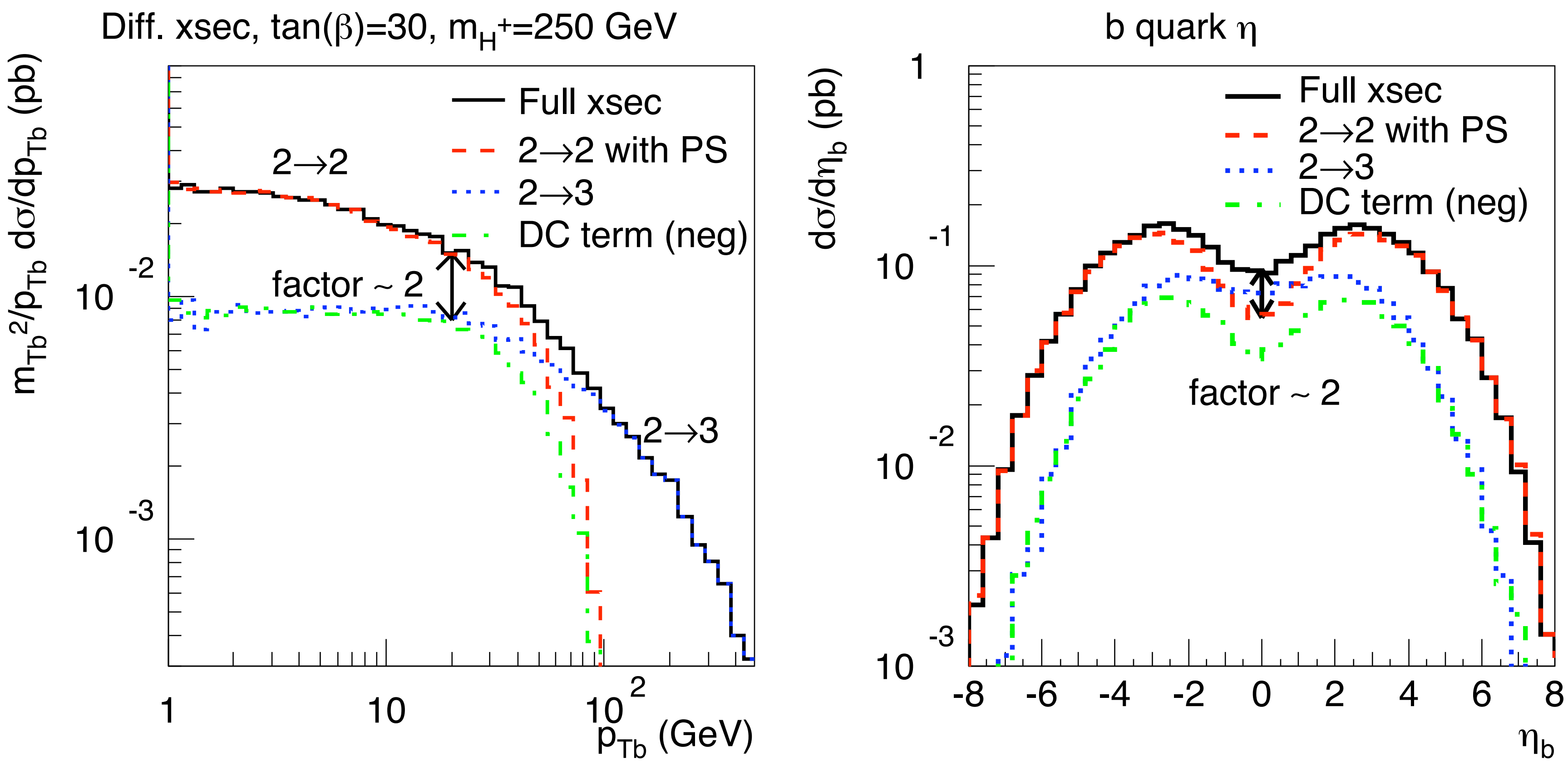
We identify $z = \hat{s}_{2\to 2}/\hat{s}_{2\to 3}$. Q^2 limits are given by: $p^2_{\perp,b} = Q^2 - z\frac{(\hat{s}+Q^2)(m_b^2+Q^2)}{\hat{s}}$

Subtract double-counting events in final analysis!

Matched differential cross-sections

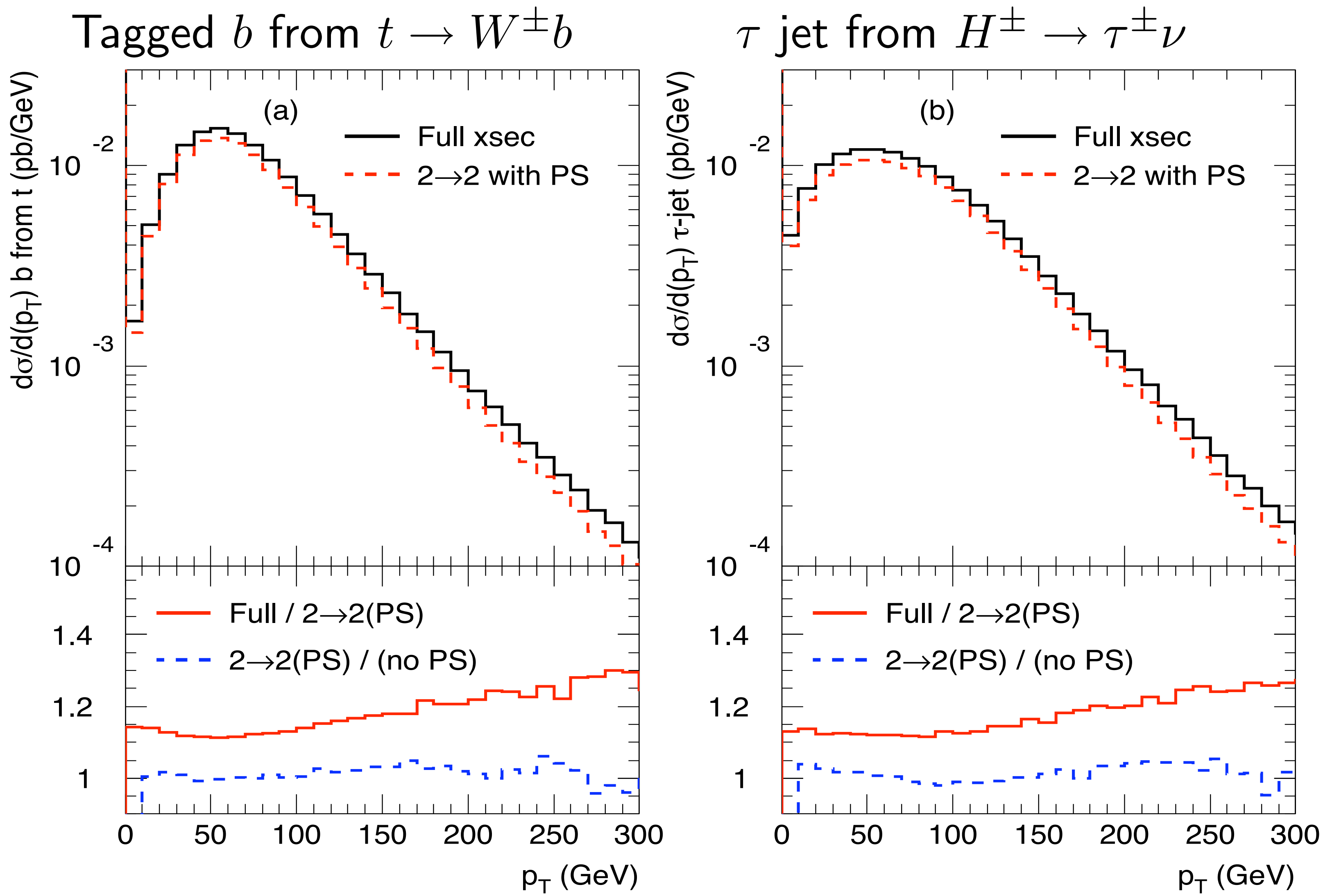
Case study: $m_{H^+} = 250$ GeV, $\tan\beta = 30$

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



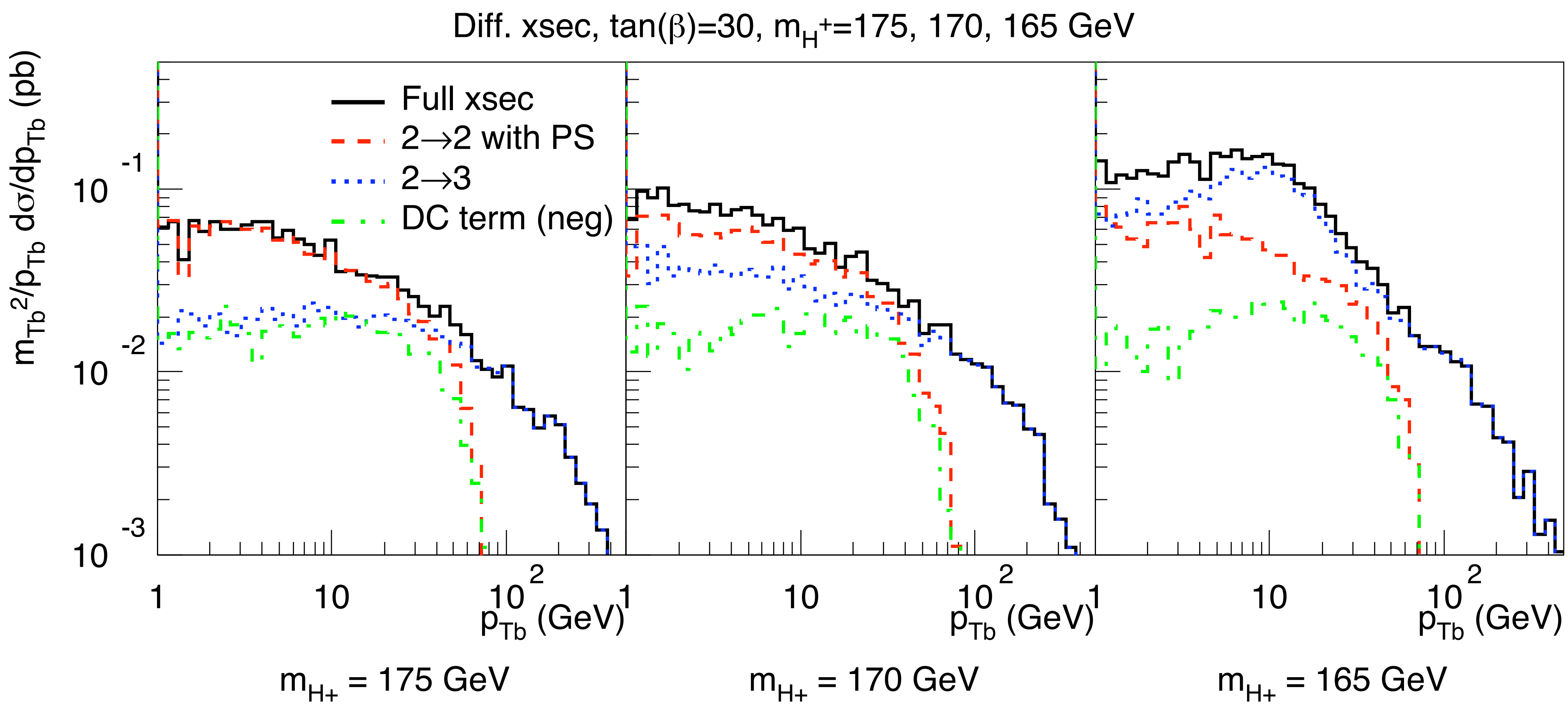
Smooth interpolation between $2 \to 2$ and $2 \to 3$ processes

More results of matching



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

$p_{\perp,b}$ -distributions for smaller masses



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

Improving the discovery contour

Work in progress using matched processes:

- Improve discovery region close to $m_{H^+} = m_t$
- Most promising charged Higgs decay: $H^+ \to \tau^+ \nu$
- Main background:

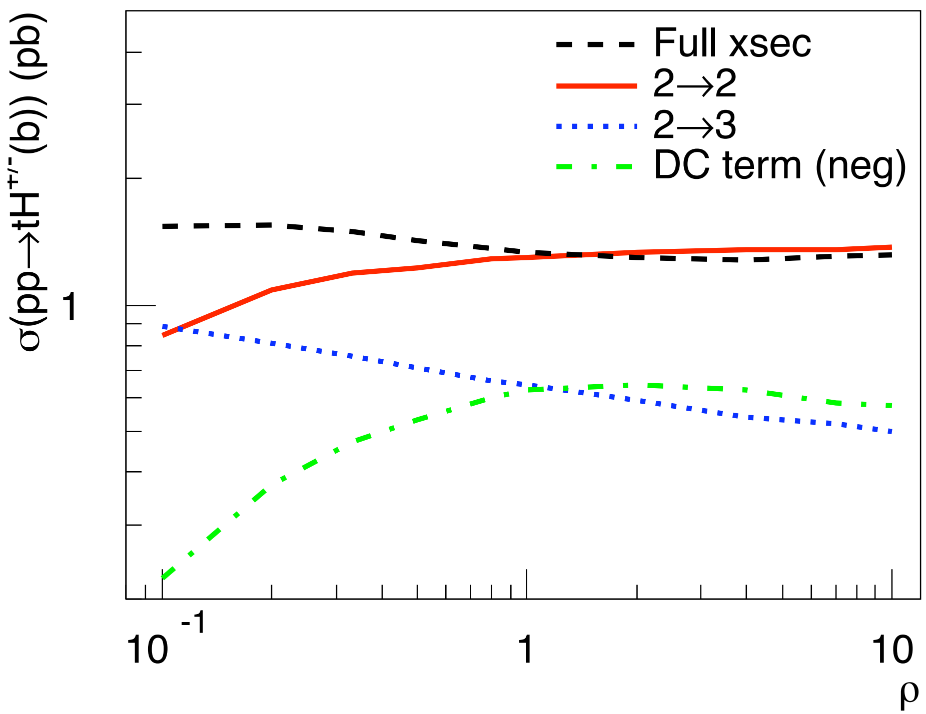
  $W^+ \to \tau\nu$ from $t\bar{t}$ and $tbW^\pm$ production
- Take extra b-quark into account in "sliding" way (b-jet veto increasingly bad for small masses)
- Interesting features: τ polarization, p_T^b / p_T^τ ratio

Together with ATLAS PhD student Bjarte Mohn

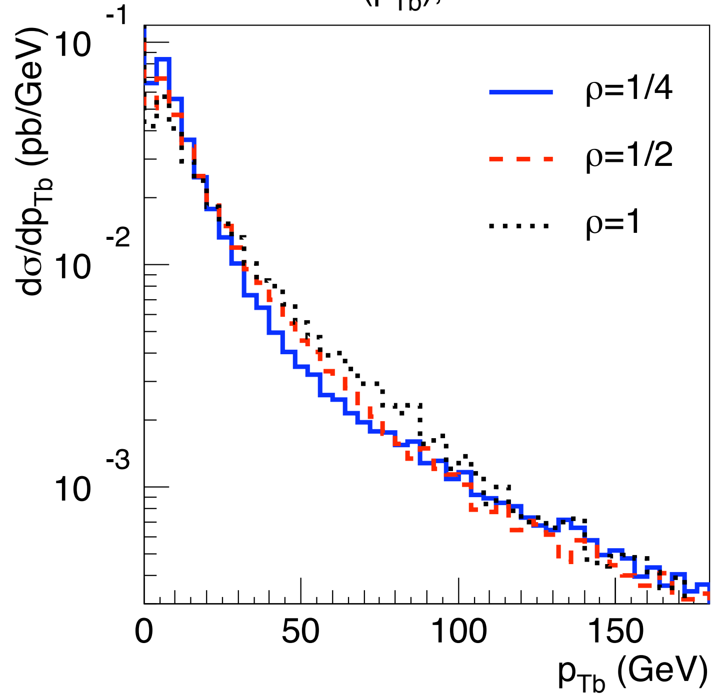
Theoretical improvements

- Reduced factorisation scale dependence

Integrated xsec as function of $\mu_F = \rho\, m_{av}$



Matched diff. xsec (p_{Tb}), linear scale



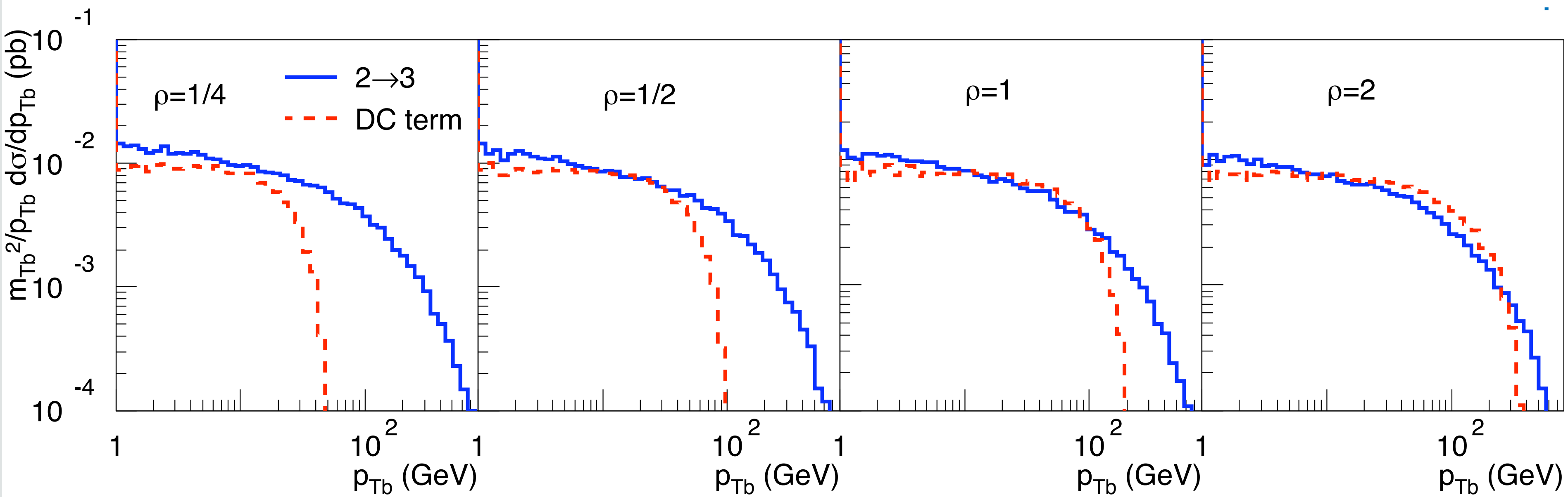
$\mu_F = \rho\,\frac{m_{H^+}+m_t}{2}$ - scale where the parton densities are evaluated

$=$ hardest scale of collinear parton radiation

Bonus - choice of factorisation scale

- Hint to correct factorisation scale:

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



Double-counting term should account for log-enhanced (collinear) part of $2 \to 2$ term *already included* in $2 \to 3$ term

For $\rho \gtrsim 1$ double counting term overshoots $2 \to 3$ term
⇒ Too large factorisation scale

Application to other processes

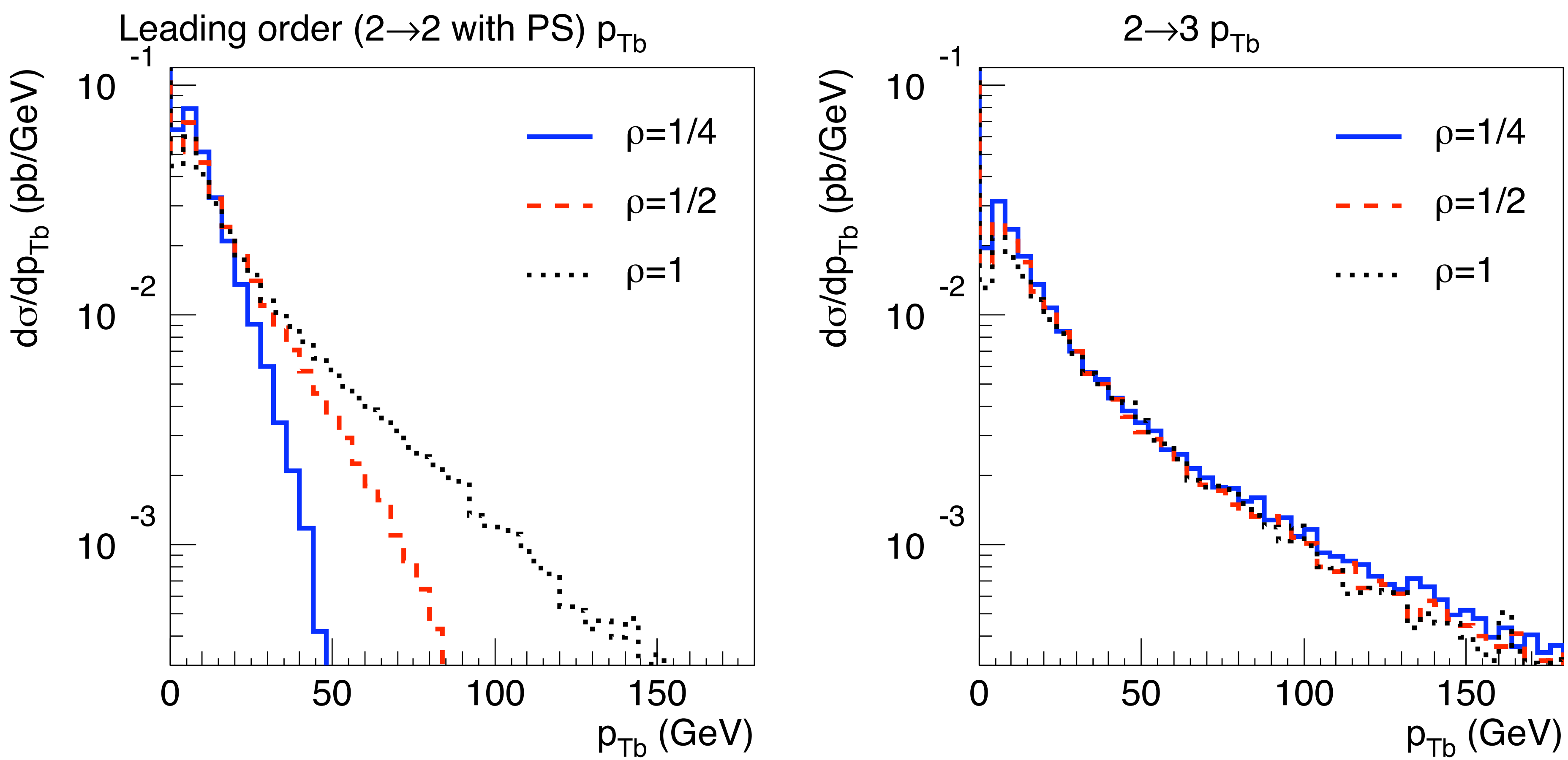
- Same approach easily extended to other similar processes:
  - ➡ Standard model single top production
  - ➡ Single heavy right-handed W_R^+ production
- Also b-induced neutral resonance processes
  - ➡ 2HDM Neutral Higgs – matching of $b\bar{b} \to H$, $bg \to Hb$ and $gg \to Hb\bar{b}$
- Works (in principle) for any resonances strongly coupled to b quarks

Conclusions

- Discovery of charged Higgs bosons – clear signal for new physics
- Mainly produced in association with top quarks
- Problematic region for H^+ mass close to top mass
  - Need matching of $gb \to tH^+$ and $gg \to tbH^+$
- Work in progress on improving discovery contour of ATLAS
- Matching procedure can be adopted to other b-quark-induced processes
- Double-counting term available as add-on to Pythia from: http://www.isv.uu.se/thep/MC/matchig/

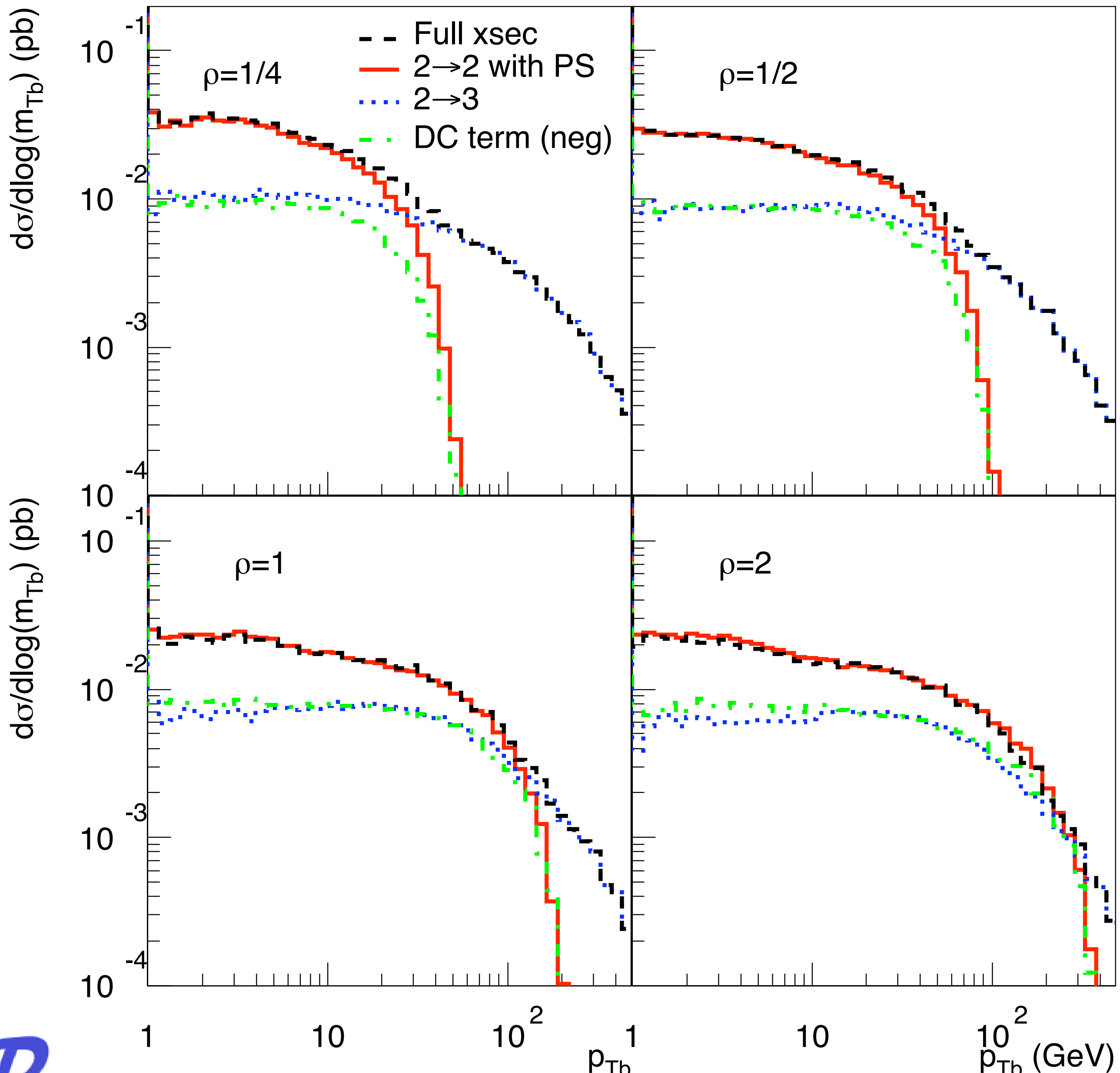
Backup slides

Factorisation scale effects on the $2 \to 2$ and $2 \to 3$ processes



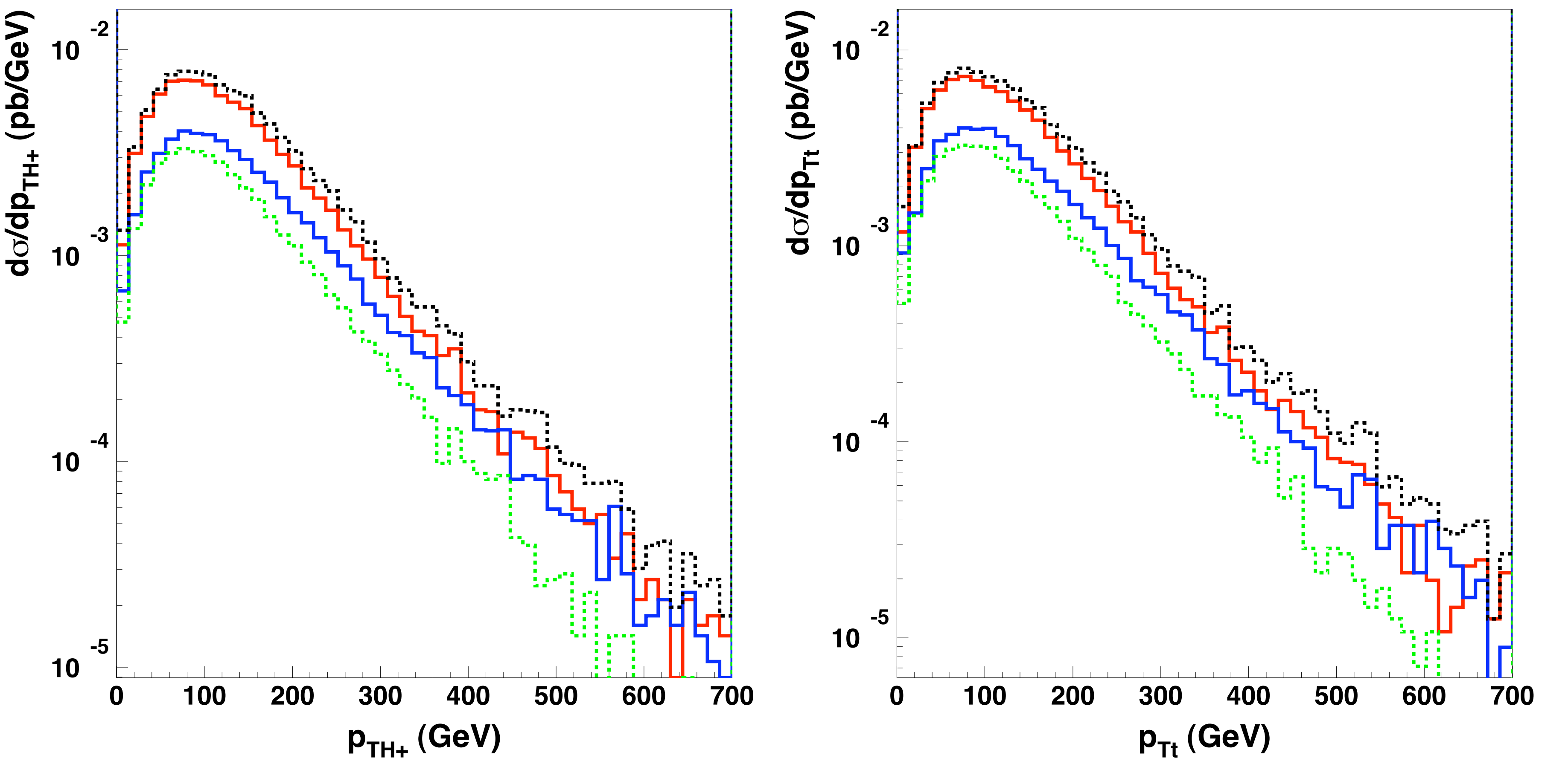
$$\mu_F = \rho \, \frac{m_{H^+} + m_t}{2}$$

Comparison of factorisation scales



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

Differential distributions for H^+ and t



More differential distributions for H^+ and t