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Presentation of the Uppsala THEP group

Johan Rathsman

Partilledagarna, Göteborg 2007-09-20

The Uppsala THEP group

The Higgs sector beyond the Standard Model

QCD effects in searches for new physics

Outlook

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The Uppsala THEP group

People

- Staff: Gunnar Ingelman, Johan Rathsman
- Long term Visitors: Emidio Gabrielli
- Postdocs: Nazila Mahmoudi
- PhD Students: David Eriksson, Oscar Stål
- MSc Students: David Kärsmyr

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Main activities:

Beyond the Standard Model

- Higgs, SUSY and extra dimensions phenomenology @LHC
- B-physics (isospin asymmetry in $B \to K\gamma$, Nazila Mahmoudi)

Interplay between QCD and signals for new physics

- matching matrix-elements and parton showers,
- NLO QCD-corrections (QCD background to $h \to \gamma\gamma$)

Interplay between perturbative and non-pert. QCD

- jet quenching in QCD plasma through scattering,
- diffractive-like processes (rapidity gaps),
- model for pdf's in hadrons (strange sea asymmetry, NuTev)

Astroparticle physics

- lunar satellites as neutrino detectors (coherent radio pulses),
- atmospheric neutrino fluxes (charm contribution)

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The Higgs sector beyond the Standard Model

Why study Higgs sector at LHC?

- direct information about origin of electroweak symmetry breaking (EWSB)
- large variety of SM extensions with extended Higgs sector
- sensitive probe of underlying physics model (additional singlets or doublets, mass-relations, mixings and couplings)
- SM Higgs may be hidden

The Minimal Supersymmetric Standard Model (MSSM)

- Supersymmetry (SUSY) solves finetuning problem of SM ($\delta m_h^2 \propto M^2_{\rm planck} \rightarrow \delta m_h^2 \propto M^2_{\rm SUSY}$)
- two Higgs doublets required by SUSY
- EWSB $\Rightarrow$ five Higgs bosons: h, H, A, H^+, H^-
- relatively simple (two parameters at tree-level, M_A and $\tan\beta = v_2/v_1$)

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Main objectives

- search – phenomenology of finding Higgs bosons
- explore – how to pin down the underlying physics
- interpret – what conclusions can be drawn from a given measurement

Requirements (tools)

- identify useful observables (find particles, measure couplings)
- higher order calculations (QCD and SUSY)
- accurate predictions of complete final state – Monte Carlos (matrix elements, parton showers, pdf's in incoming protons, multiple interactions, underlying events, ...)

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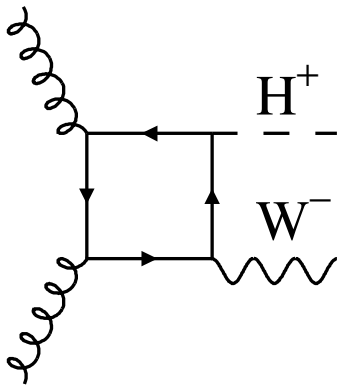
The anatomy of event generation

Example: $pp \to H^+W^-$



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Quite messy. Need simplification – Use factorisation!

$$\sum |\mathcal{M}_{\rm tot}|^2 = \sum |\mathcal{M}_{\rm ME}|^2 \otimes \sum |\mathcal{M}_{\rm pdf}|^2 \otimes \sum |\mathcal{M}_{\rm res}|^2 \otimes \otimes \sum |\mathcal{M}_{\rm PS}|^2 \otimes \sum |\mathcal{M}_{\rm UE}|^2 \otimes \sum |\mathcal{M}_{\rm had}|^2$$

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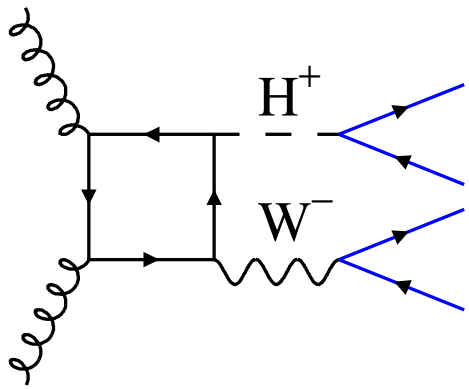

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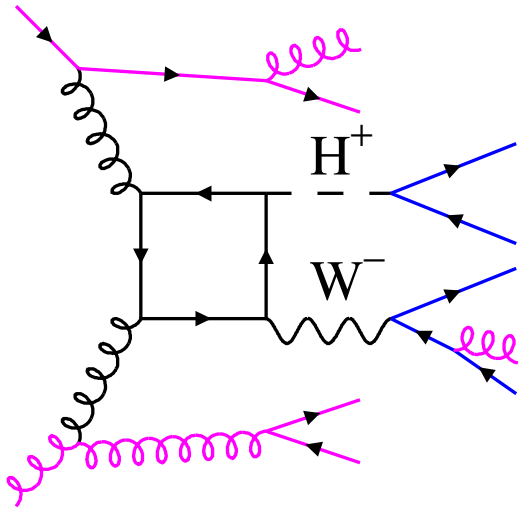

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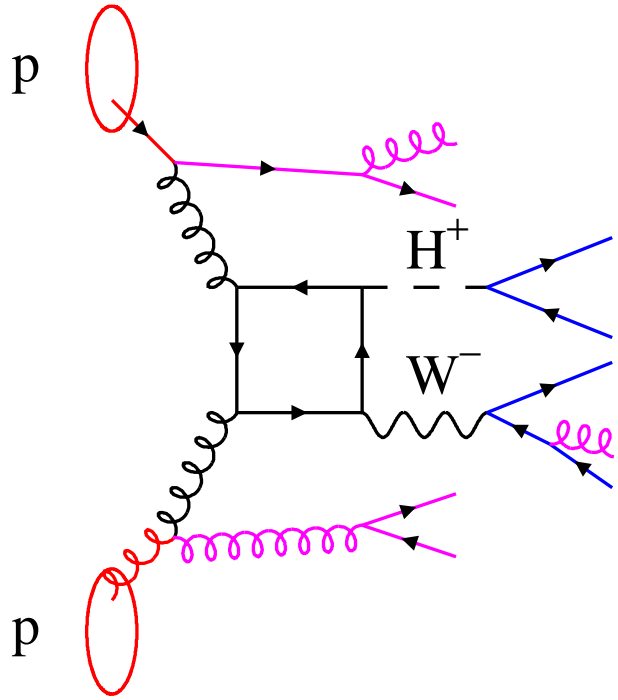

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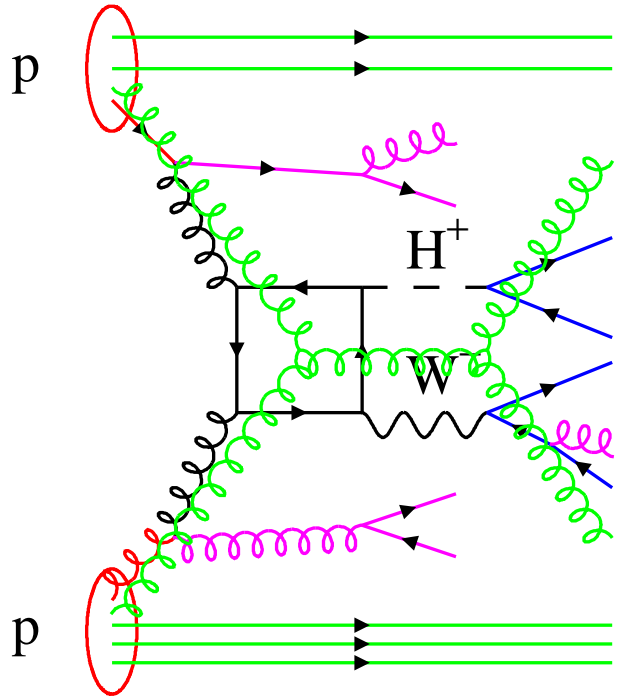

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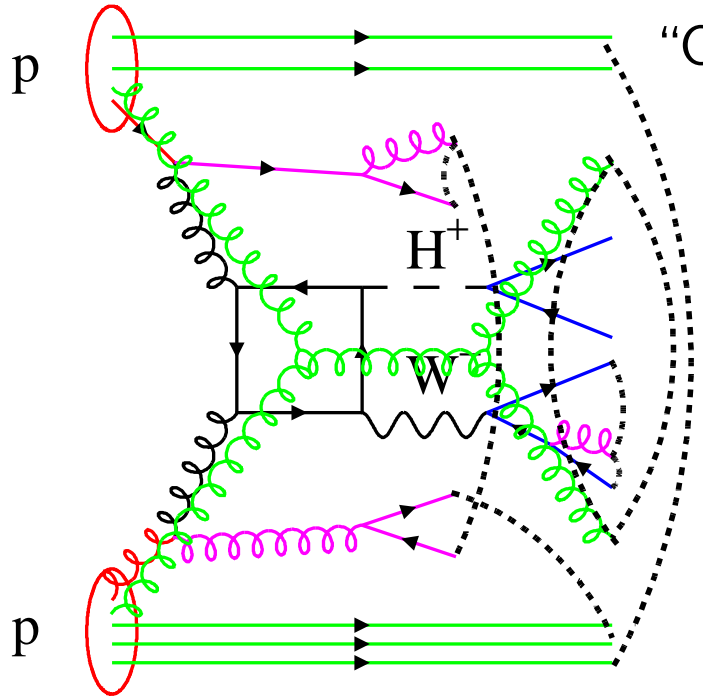

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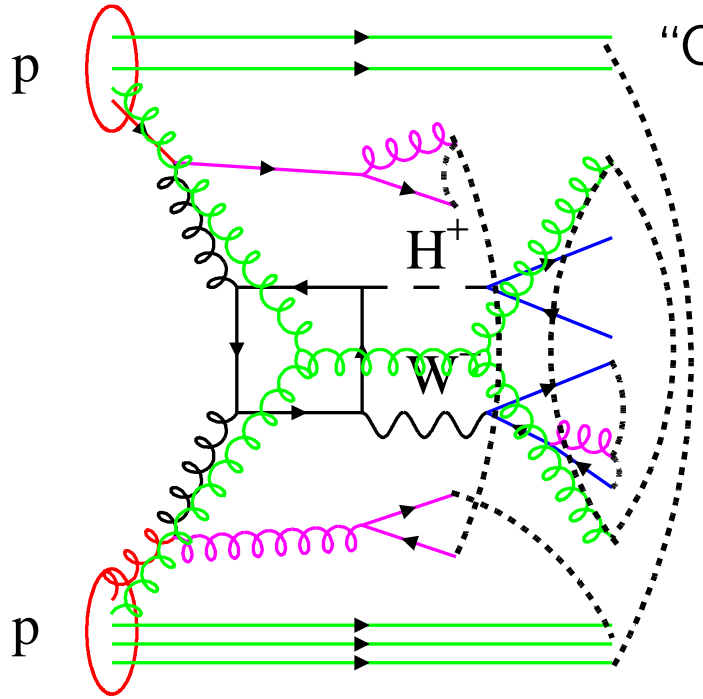

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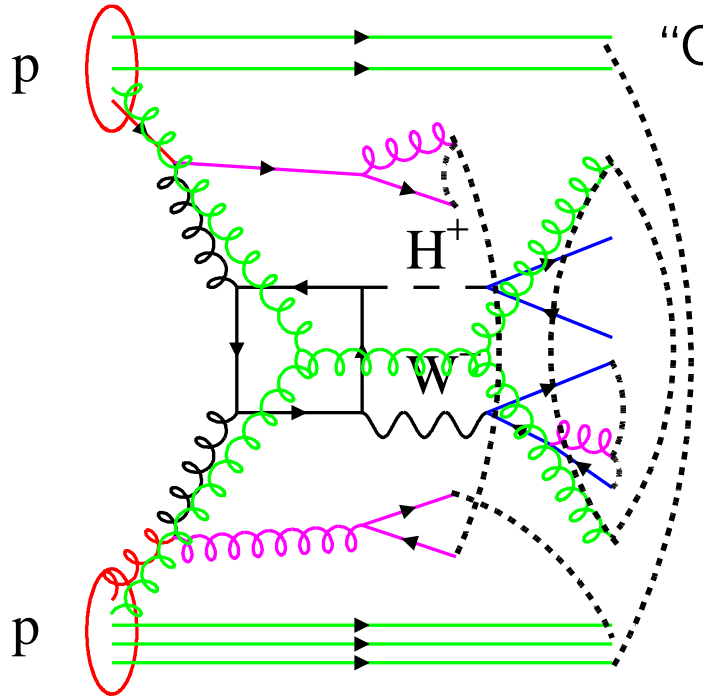

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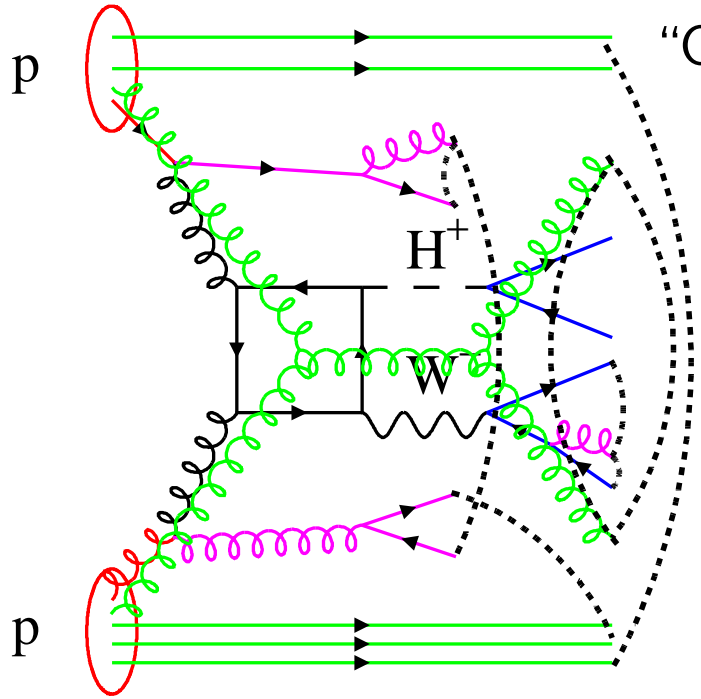

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Simplicity of Higgs potential

The 2HDM potential (recall SM, $V = \mu^2 \Phi^\dagger \Phi - \frac{1}{2}\lambda \left(\Phi^\dagger \Phi\right)^2$)

$$
\begin{aligned}
V \quad = \quad & m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left\{ m_{12}^2 \Phi_1^\dagger \Phi_2 + h.c. \right\} + \\
& + \frac{1}{2}\lambda_1 \left(\Phi_1^\dagger \Phi_1\right)^2 + \frac{1}{2}\lambda_2 \left(\Phi_2^\dagger \Phi_2\right)^2 + \lambda_3 \left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) + \\
& + \lambda_4 \left(\Phi_1^\dagger \Phi_2\right)\left(\Phi_2^\dagger \Phi_1\right) + \left\{ \frac{1}{2}\lambda_5 \left(\Phi_1^\dagger \Phi_2\right)^2 + h.c. \right\}
\end{aligned}
$$

Tree-level MSSM ($v \approx 174$ GeV):

$$\lambda_1 = \lambda_2 = \frac{m_Z^2}{2v^2}, \lambda_3 = \frac{2m_W^2 - m_Z^2}{2v^2}, \lambda_4 = -\frac{m_W^2}{v^2}, \lambda_5 = 0$$

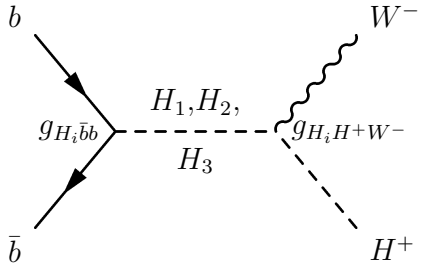
(m_{11}^2, m_{22}^2 and m_{12}^2 given by $v_1 = v\cos\beta$, $v_2 = v\sin\beta$ and m_A)

- Important (SUSY) loop-corrections to all λ_i (also CP-violating)
- V can also be used as effective theory for Beyond the MSSM

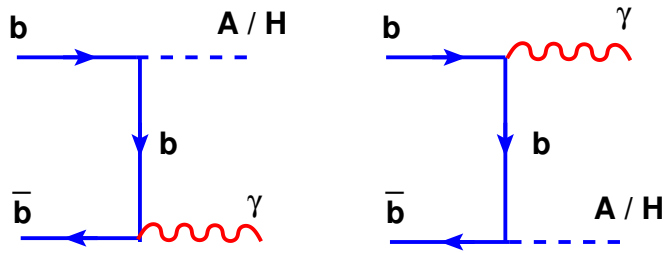
In general seven parameters for CP-conserving type II 2HDM and twelve when allowing CP-violation

Selection of Higgs phenomenology projects

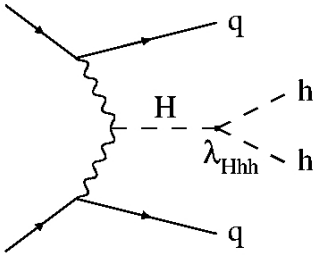
- $pp \to H^{\pm} W^{\mp}$ (David Eriksson, Stefan Hesselbach, JR)
  - complement to $gb \to H^- t$ for large $\tan\beta$ and $m_{H^+} \sim m_t$
  - possible resonant enhancement if $m_H, m_A > m_{H^+} + m_W$



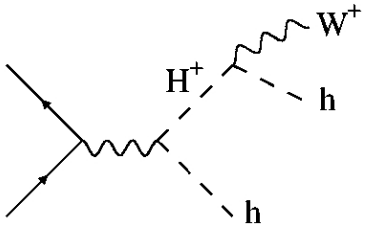
- Exploration of spin correlations in $pp \to t\bar{t} \to H^+ b W^- \bar{b}$ (David Eriksson, Gunnar Ingelman, JR, Oscar Stål)
- Probing the b-quark Yukawa and pdf in $pp \to A\gamma$ (Emidio Gabrielli, Barbara Mele, JR)



- Indirect probes of Higgs sector through h-pair production even if only h is discovered (Stefano Moretti, JR et al)
  - vector boson fusion, $pp \longrightarrow j_{\rm fwd} j_{\rm bwd} hh$, probes triple Higgs coupling λ_{Hhh}



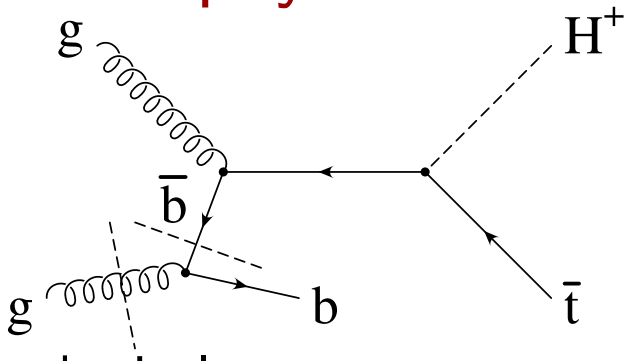
  - double Higgs strahlung, $pp \longrightarrow Whh$ and $pp \longrightarrow Ahh$, probes $\lambda_{H^+W^-h}$, λ_{AZh}



  sensitive to general 2HDM's but not MSSM
- $pp \longrightarrow AH^{\pm}$ (David Kärsmyr)
  - independent of $\tan\beta$
  - also sensitive to BMSSM with light A

QCD effects in searches for new physics

Example: matching $g\bar{b} \to \bar{t}H^+$ and $gg \to b\bar{t}H^+$ using MatCHig by Johan Alwall (now at SLAC)



different approximations to the same physical process

- $g\bar{b} \to \bar{t}H^+$: b-density resums collinear logs $\left(\alpha_s \log \frac{\mu_F^2}{m_b^2}\right)^n$
- $gg \to b\bar{t}H^+$: exact kinematics for b-quark to $\mathcal{O}(\alpha_s^2)$

collinear part of $gg \to \bar{b}tH^-$ ($\propto \alpha_s \log \frac{\mu_F^2}{m_b^2}$) included in both

$\Rightarrow$ needs to be subtracted differentially

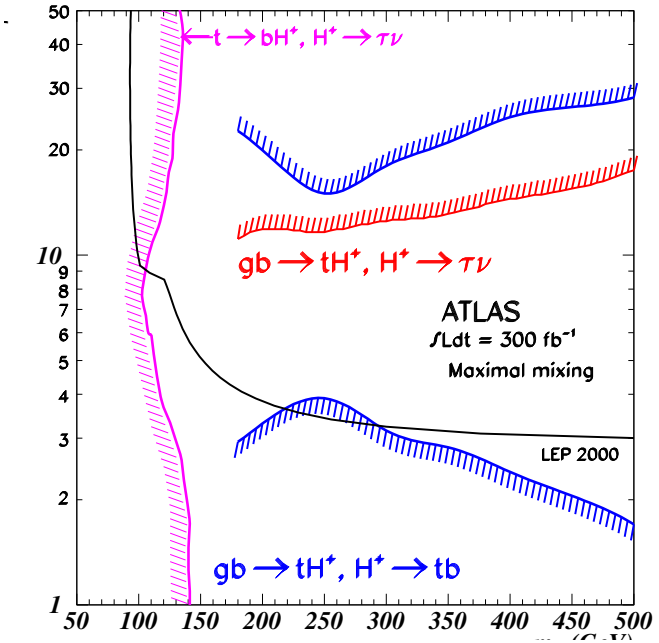
$$d\sigma_{\text{matched}} = d\sigma_{gb\to tH^-} + d\sigma_{gg\to \bar{b}tH^-} - d\sigma_{d.c.}$$

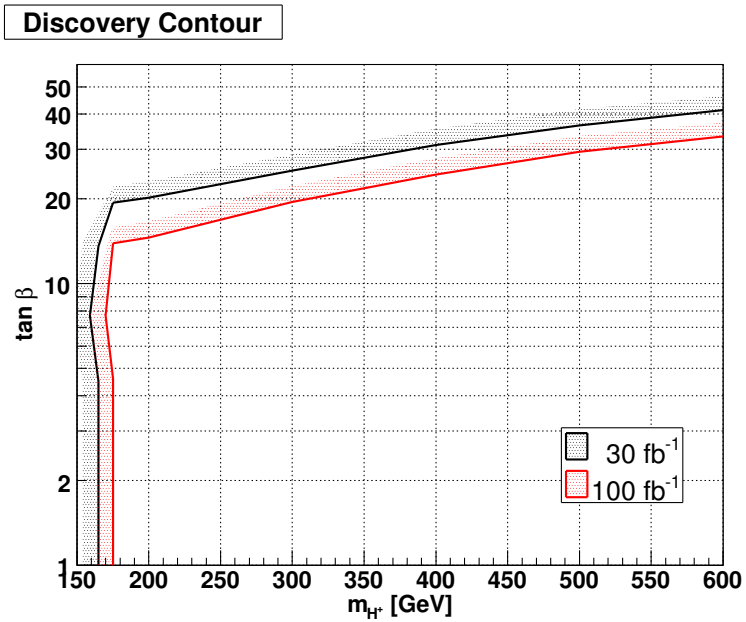
$d\sigma_{d.c.}$ same as $d\sigma_{gb\to tH^-}$ but b-density replaced by

$$b'(x,\mu_F^2) = \frac{\alpha_s(\mu_R^2)}{2\pi} \int \frac{dz}{z} \int \frac{dQ^2}{Q^2+m_b^2} P_{g\to b\bar{b}}(z)\, g\left(\frac{x}{z}, \mu_F^2\right)$$

- important effects on $p_\perp$-spectrum of accompanying b-jet
- smooth transition above and below threshold for production via t-decay

⇒ Improved discovery reach at the LHC [Flechl, Mohn, Alwall]





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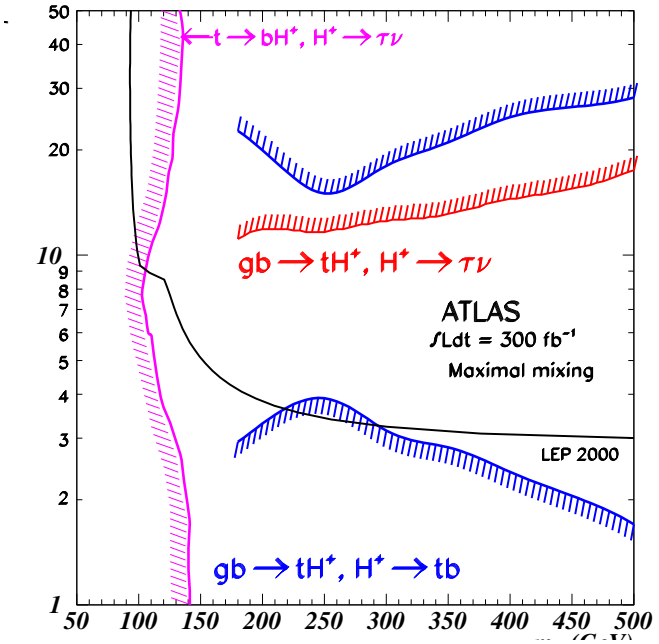

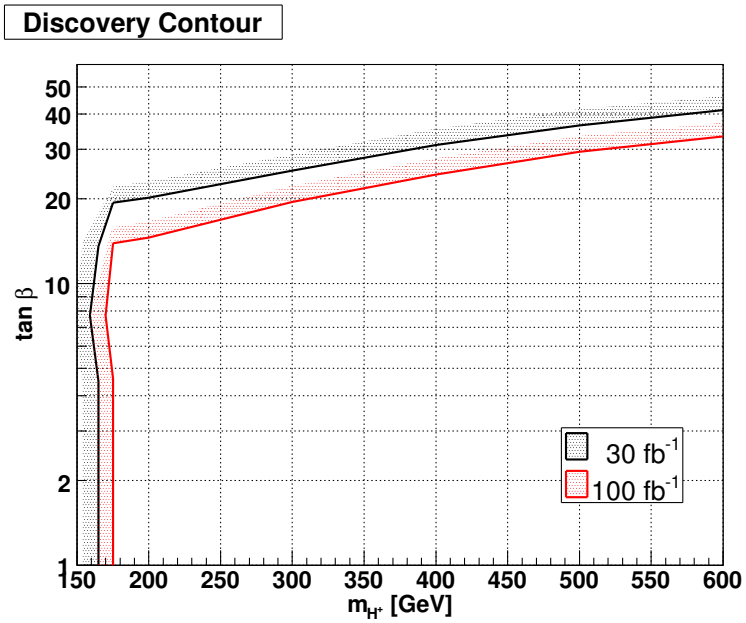

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- many viable SM extensions (BMSSM, hidden Higgs)
- only specific (real) MSSM scenarios thoroughly explored

Connection with cosmology

- constraints from observations
- identification of dark matter particles @LHC

Increasing precision in indirect searches

- still no sign of new physics $\Rightarrow$ severe (model-dependent) constraints

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