Implementation of the process $gg(q\bar{q}) \to \bar{t}bH^+$ in PYTHIA

Johan Alwall (Uppsala)

Nordic LHC Workshop in Lund, November 28, 2003

Masses in the Standard Model

Before spontaneous symmetry breaking:

$$\text{Bosons:} \quad \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix} \quad W_\mu \quad W_\mu^\dagger \quad W_{3\mu} \quad B_\mu$$

$$\text{Fermions:} \quad \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix} \quad \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad e_R \quad u_R \quad d_R$$

After spontaneous symmetry breaking:

$$\text{Bosons:} \quad h \quad W_\mu^+ \quad W_\mu^- \quad Z_\mu^0 \quad A_\mu$$

$$\text{Fermions:} \quad e \quad \nu_L \quad u \quad d$$

The Higgs mechanism

- One of the Higgs components gets a vacuum expectation value (vev) v
- Three of the four scalar degrees of freedom are absorbed by the three massive vector fields
- The down-type fields get mass through coupling to the Higgs doublet $\mathbf{\Phi}$, the up-type fields through coupling to $\widetilde{\mathbf{\Phi}} = -i\left[\mathbf{\Phi}^\dagger \tau_2\right]^\mathsf{T}$.

Supersymmetric extensions

In a supersymmetric Lagrangean, one cannot make the transformation $\widetilde{\mathbf{\Phi}} = -i\left[\mathbf{\Phi}^{\dagger}\tau_2\right]^{\mathsf{T}}$ of the Higgs doublet

$$\Downarrow$$

Must have (at least) two Higgs doublets to give mass to both up-type and down-type fields

This is an example of a type II Two Higgs Doublet Model (2HDM)

Two Higgs Doublet Models

- 8 scalar degrees of freedom $\Longrightarrow$ 5 Higgs particles:

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

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

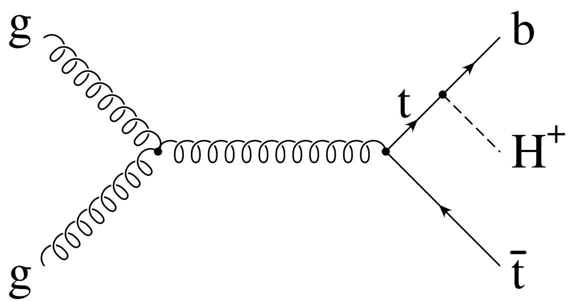
$\tan(\beta) = \frac{v_1}{v_2}$	Ratio of vev's for the doublets
M_A	One of the masses, usually the pseudoscalar

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

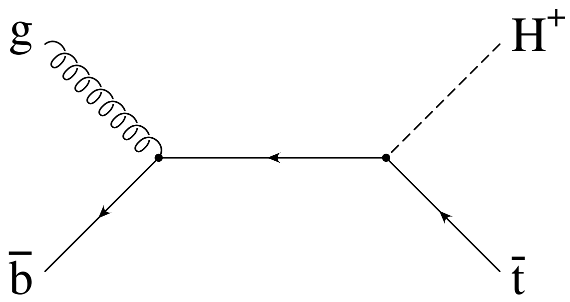
Production of single charged Higgs

Three main production channels in pp ($p\bar{p}$) collisions:

- $gg(q\bar{q}) \longrightarrow t\bar{t} \longrightarrow bH^+\bar{t} +$ c.c.



- $g\bar{b} \longrightarrow \bar{t}H^+ +$ c.c.



- $gg(q\bar{q}) \longrightarrow \bar{t}bH^+ +$ c.c.

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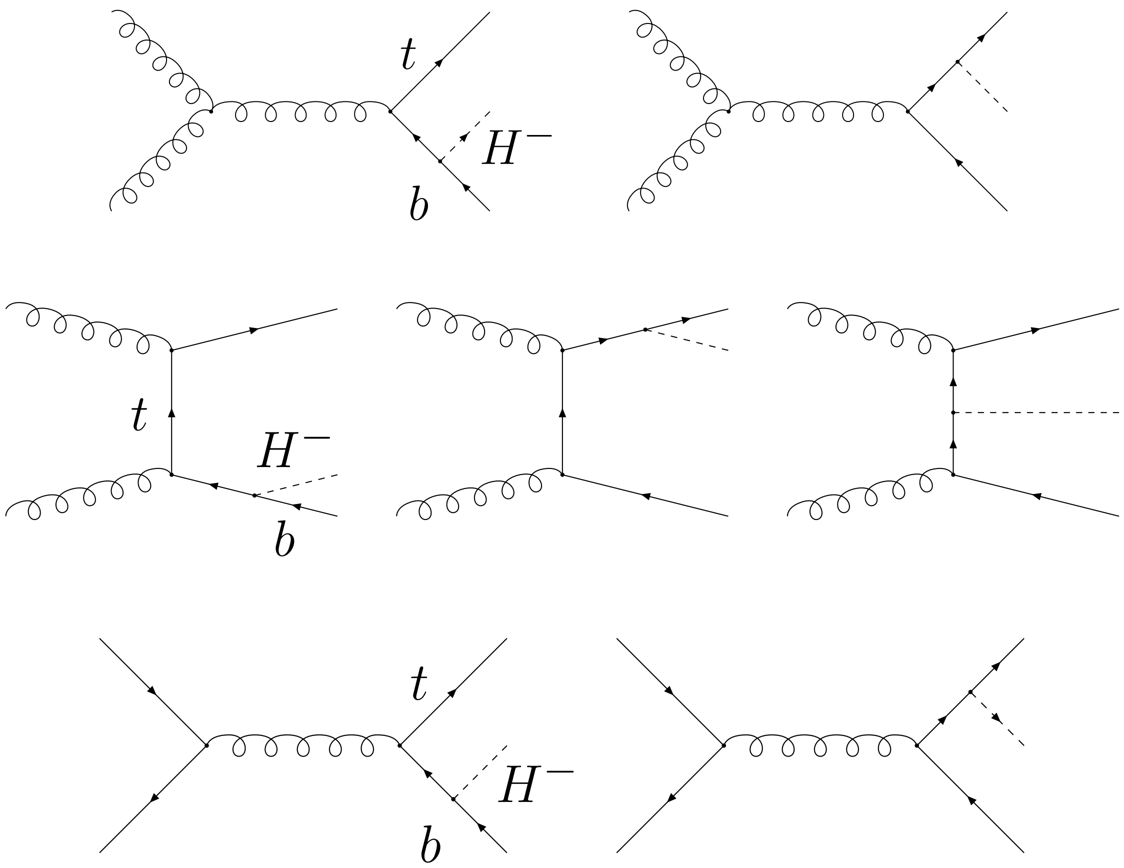
Diagrams for $gg(q\bar{q}) \to \bar{t}bH^+$



Importance of the H^+ production processes

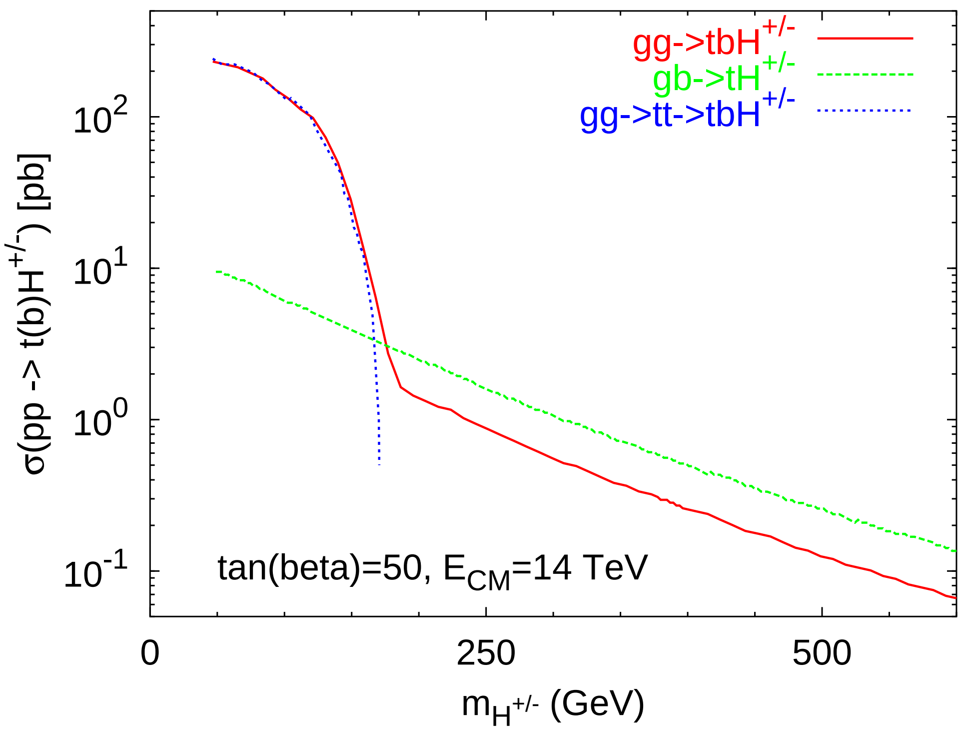
- $gg(q\bar{q}) \to t\bar{t} \to bH^+\bar{t}$ is an approximation of $gg(q\bar{q}) \to \bar{t}bH^+$ which works well for small Higgs masses $m_{H^+} < m_t$, when the main contribution comes from t close to the mass shell

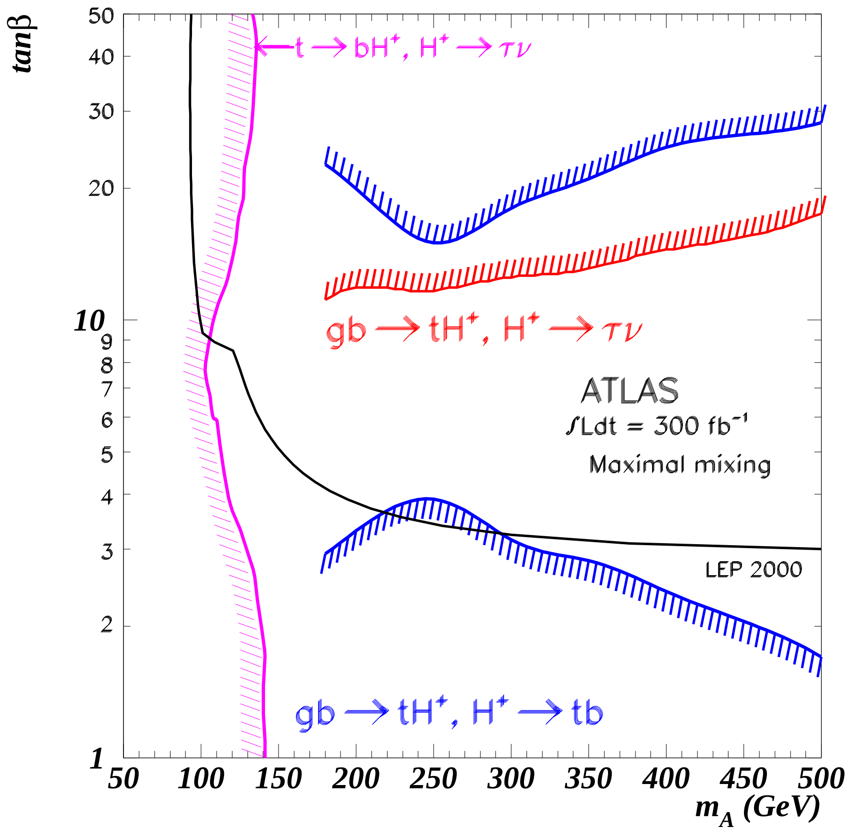
- For large Higgs masses, $g\bar{b} \to \bar{t}H^+$ gives larger cross-section than $gg(q\bar{q}) \to \bar{t}bH^+$ and similar $p_\perp$-distributions for the t and H^+

- If one wants to tag the extra b quark for $m_{H^+} > m_t$, $gg(q\bar{q}) \to \bar{t}bH^+$ is necessary

- For H^+ masses close to the t mass, $gg(q\bar{q}) \to \bar{t}bH^+$ is necessary

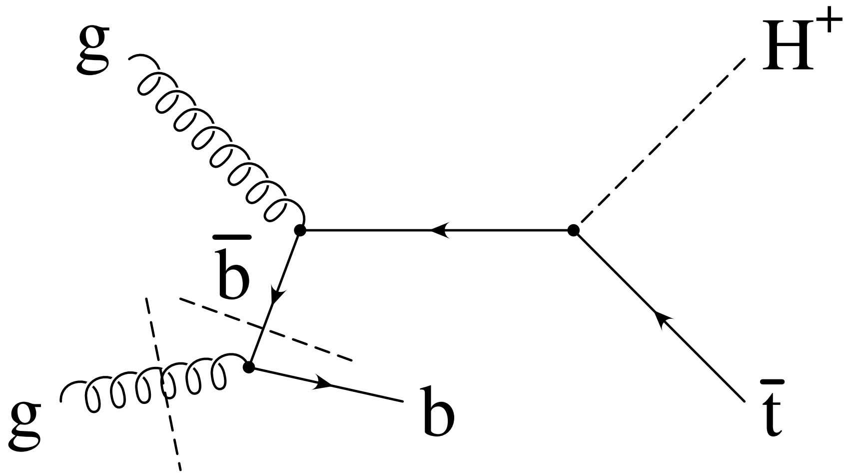
Importance of the H^+ production processes (contd.)





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

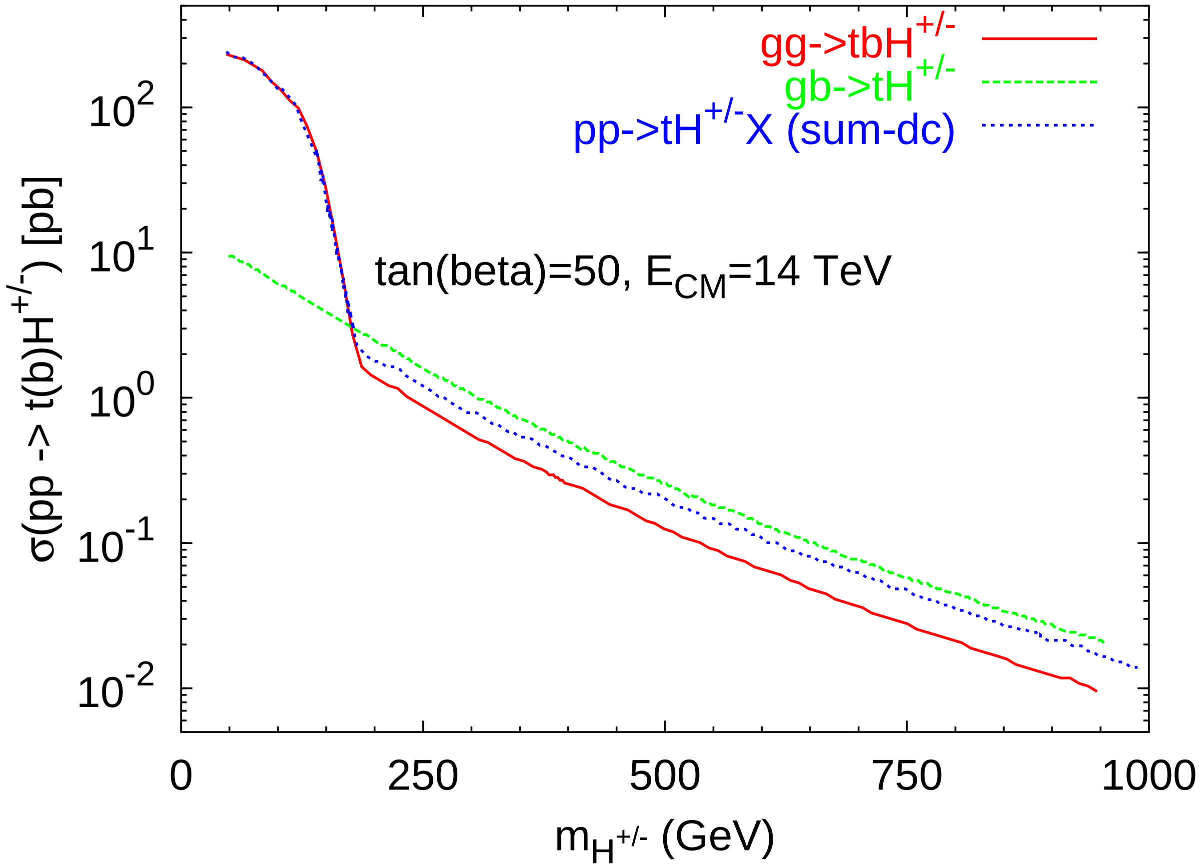
The $g\bar{b} \to \bar{t}H^+$ $(2 \to 2)$ and $gg \to \bar{t}bH^+$ $(2 \to 3)$ processes overlap when the b of the $2 \to 3$ process is collinear with the beam



$\Longrightarrow$ Must subtract double counting term.

Borzumati et al., Phys.Rev. D60,115011, Belyaev et al., hep-ph/0203031

Summing the $2 \to 2$ and $2 \to 3$ processes (cont)



$2 \to 3$ processes in PYTHIA

Phase space for a $2 \to 3$ process:

$$d(PS) = \left(\prod_{i=3}^{5} \frac{1}{(2\pi)^3} \frac{d^3 p_i}{2E_i} \right) (2\pi)^4 \delta^{(4)}(p_3 + p_4 + p_5 - p_1 - p_2)$$

In PYTHIA:

$$d(PS) = \frac{1}{(2\pi)^5} \frac{\pi^2}{4\sqrt{\lambda_{\perp 34}}} dp_{\perp 3}^2 \frac{d\varphi_3}{2\pi} dp_{\perp 4}^2 \frac{d\varphi_4}{2\pi} dy_5 \ ,$$

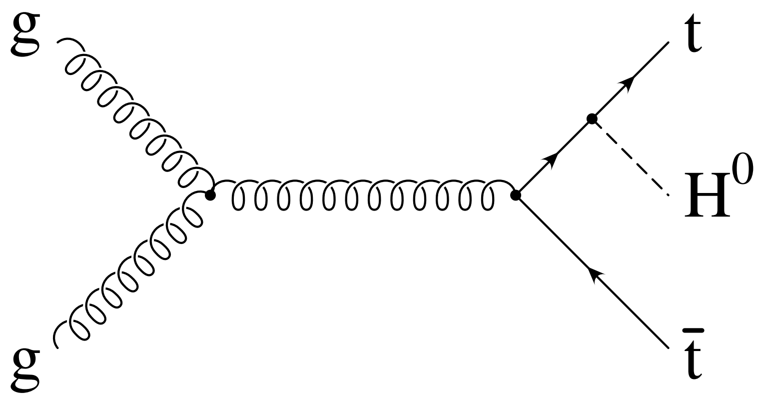
where $\lambda_{\perp 34} = (m_{\perp 34}^2 - m_{\perp 3}^2 - m_{\perp 4}^2)^2 - 4m_{\perp 3}^2 m_{\perp 4}^2$

$+$ variables $\tau = \frac{m_{H^+}^2}{s}$, $\tau' = x_1 x_2$, $y^* = \frac{1}{2} \ln \frac{x_1}{x_2}$

$\Longrightarrow$ Events chosen from distribution in 8 variables

Implementation of $gg(q\bar{q}) \to \bar{t}bH^+$

I have basically followed the implementation of $gg(q\bar{q}) \to \bar{t}tH^0$,



Difference: 3 final-state particles with different masses
(first process in PYTHIA)

All features of existing processes, such as width of H^+ mass.

Activities so far

- Checks against Herwig and publications

- Efficiency tests: 10000 events with full fragmentation etc.$\sim$ 16 min on standard PC, $m_{H^+} = 250$ (670 tries/event)

- Test of differences between $gg(q\bar{q}) \to t\bar{t} \to bH^+\bar{t}$ and $gg(q\bar{q}) \to \bar{t}bH^+$ together with Johan Rathsman and Andre Sopczak

- Properly matching the $2 \to 2$ and $2 \to 3$ processes (work in progress)

Results

Results on difference between $gg(q\bar{q}) \to t\bar{t} \to bH^+\bar{t}$ and $gg(q\bar{q}) \to \bar{t}bH^+$ at the Tevatron, $m_{H^+} = 165$ GeV.