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THEP UU

Johan Rathsman

THEP@UU

Higgs in BSM

QCD and BSM

Outlook

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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People
Activities

Higgs in BSM

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The Uppsala THEP group

People

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





Main activities:

Beyond the Standard Model

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

Interplay between QCD and signals for new physics

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

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 ($\delta m_h^2 \propto M_{\text{planck}}^2 \rightarrow \delta m_h^2 \propto M_{\text{SUSY}}^2$)
- ▶ 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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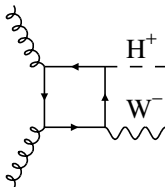
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The anatomy of event generation

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



“Complete” description

- ▶ Matrix-element: $gg \rightarrow H^+ W^-$
- ▶ Decays of resonances
- ▶ Final and Initial Parton Showers
- ▶ Parton densities: $q(x, Q^2)$, $g(x, Q^2)$
- ▶ Multiple interactions and beam remnants (underlying event)
- ▶ Hadronisation (Lund string) and hadron decays

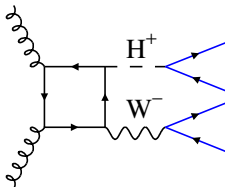
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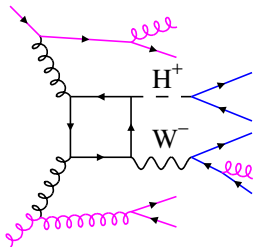
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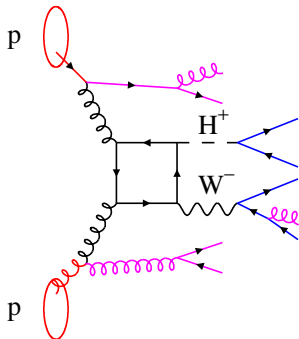
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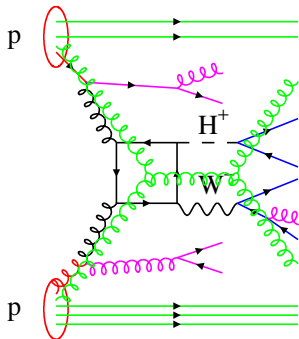
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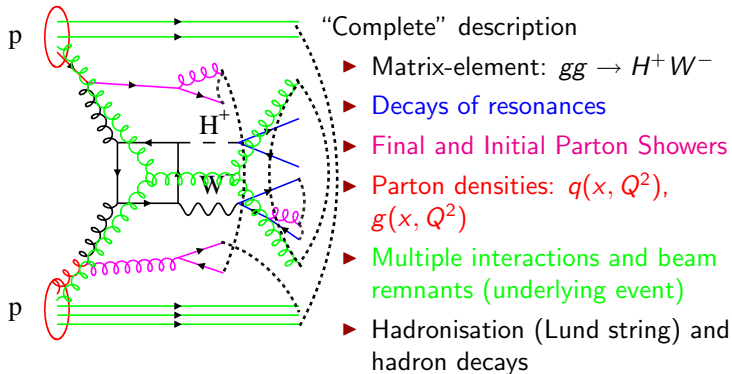
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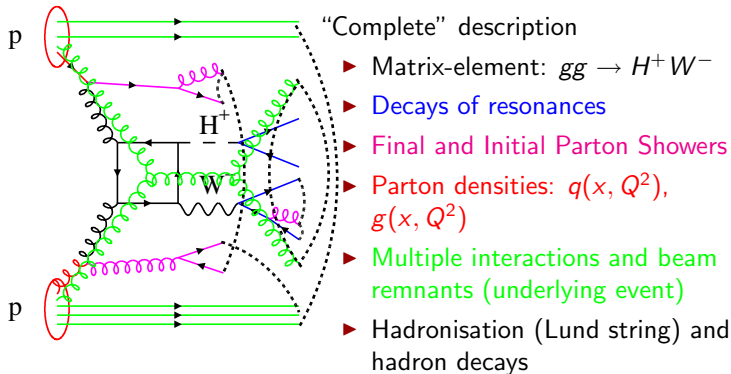
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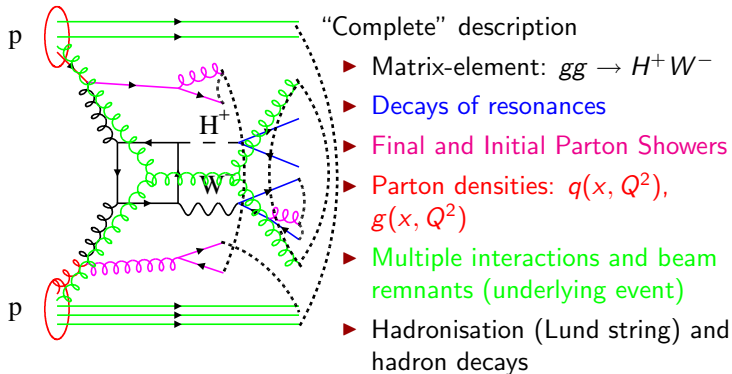
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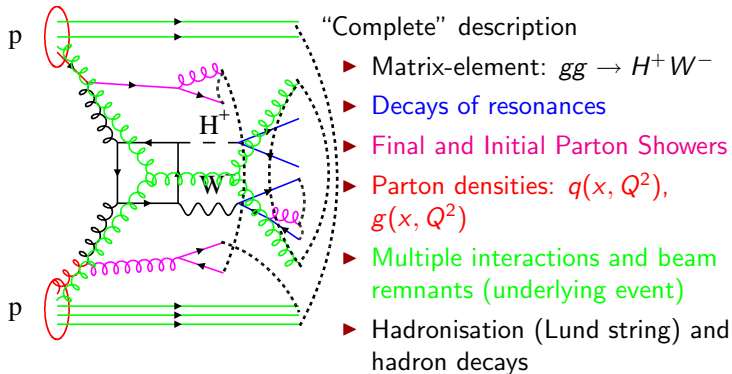
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Simplicity of Higgs potential

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

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

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

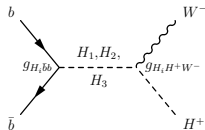
In general seven parameters for CP-conserving type II 2HDM and twelve when allowing CP-violation



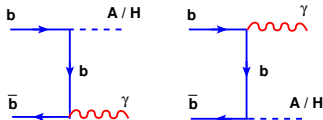
Selection of Higgs phenomenology projects

- ▶ $pp \rightarrow H^\pm W^\mp$ (David Eriksson, Stefan Hesselbach, JR)

- ▶ complement to $gb \rightarrow H^- t$ for large $\tan \beta$ and $m_{H^+} \sim m_t$
- ▶ possible resonant enhancement if $m_H, m_A > m_{H^+} + m_W$



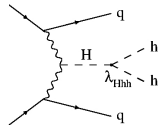
- ▶ Exploration of spin correlations in $pp \rightarrow t\bar{t} \rightarrow H^+ b W^- \bar{b}$ (David Eriksson, Gunnar Ingelman, JR, Oscar Stål)
- ▶ Probing the b -quark Yukawa and pdf in $pp \rightarrow A\gamma$ (Emidio Gabrielli, Barbara Mele, JR)



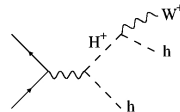


- ▶ Indirect probes of Higgs sector through h -pair production even if only h is discovered (Stefano Moretti, JR et al)

- ▶ vector boson fusion, $pp \rightarrow j_{\text{fwd}} j_{\text{bwd}} hh$, probes triple Higgs coupling λ_{Hhh}



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



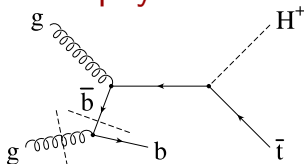
sensitive to general 2HDM's but not MSSM

- ▶ $pp \rightarrow AH^\pm$ (David Kärsmyr)
 - ▶ independent of $\tan \beta$
 - ▶ also sensitive to BMSSM with light A



QCD effects in searches for new physics

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



different approximations to the same physical process

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

collinear part of $gg \rightarrow \bar{b}tH^-$ ($\propto \alpha_s \log \frac{\mu_F^2}{m_b^2}$) included in both
 \Rightarrow needs to be subtracted **differentially**

$$d\sigma_{\text{matched}} = d\sigma_{g\bar{b} \rightarrow \bar{t}H^+} + d\sigma_{gg \rightarrow b\bar{t}H^+} - d\sigma_{d.c.}$$

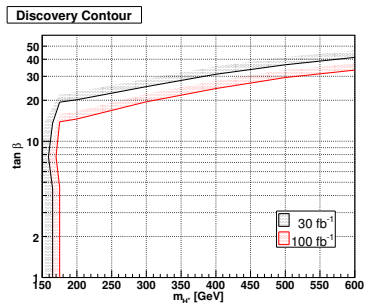
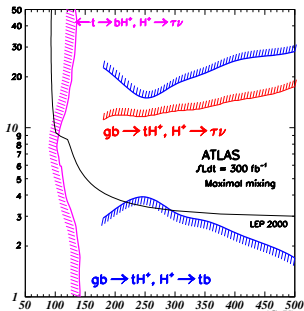
$d\sigma_{d.c.}$ same as $d\sigma_{g\bar{b} \rightarrow \bar{t}H^+}$ but b -density replaced by

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

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



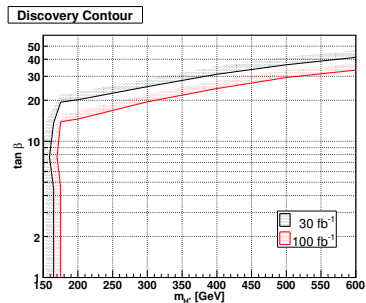
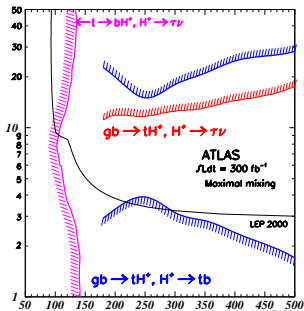
⇒ Improved discovery reach at the LHC [Flechl, Mohn, Alwall]



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- ▶ 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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