

Charged Higgses production via vector-boson fusion at NNLO in QCD

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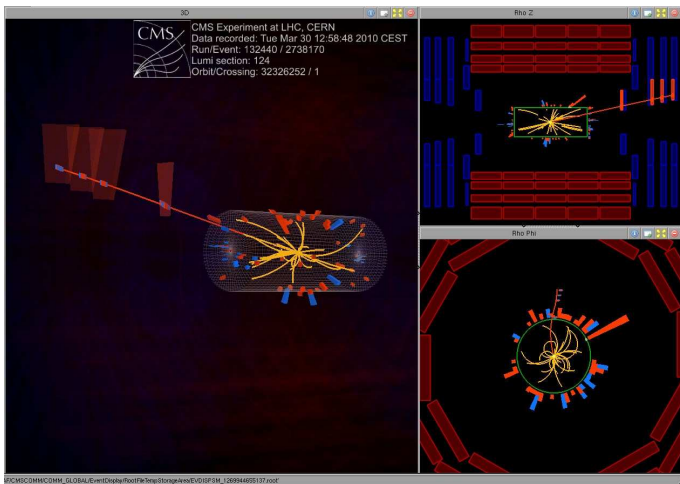
Center for Particle Physics and Phenomenology (CP3)
Université Catholique de Louvain
Deutsches Elektronen Synchrotron (DESY), Zeuthen

Uppsala, September 28, 2010

ArXiv:1003.4451
Phys. Rev. Lett. 105, 011801 (2010)

LHC is running!

- LHC is running at 7 TeV!



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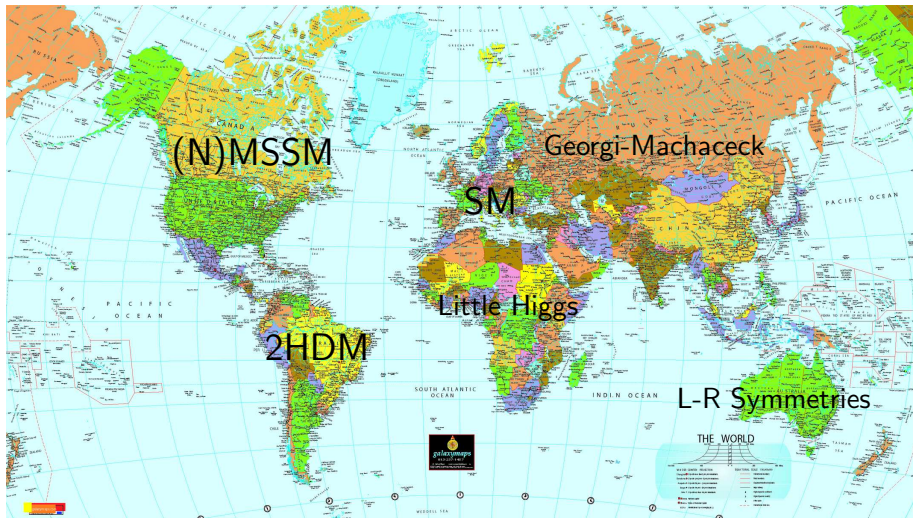


Higgs or Higgses?

What's there outside the SM?



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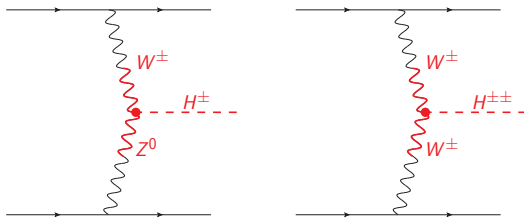


What's there outside the SM?

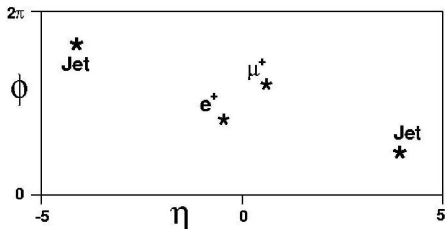
- Several models
- Different representation for Higgs multiplets
 - Triplet models (LH, GM, L-R) contain a $W^\pm Z^0 \rightarrow H^\pm$ vertex at tree level
 - Doubly charged Higgs included in these models
 - Charged Higgs production via VBF allowed and visible @LHC

for a review of feynman rules, see **Godfrey, Moats: arXiv:1003.3033**

Asakawa, Kanemura, Kanazaki: arXiv:hep-ph/0612271



VBF signature

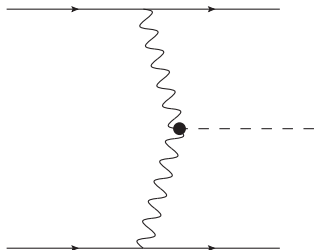


- 2 hard tagging jets
- Large rapidity separation between jets
- No (or small) hadronic activity between tagging jets
- Higgs decay in the central rapidity region
- Possibility to measure VVH couplings → **distinguish among different models**

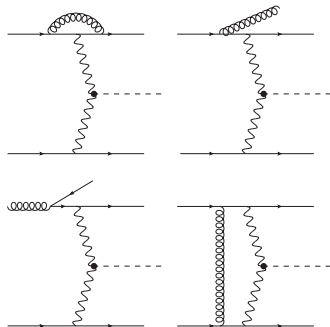
QCD corrections to VBF

QCD corrections to VBF

LO

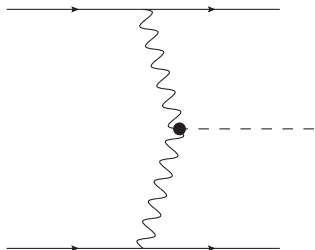


NLO

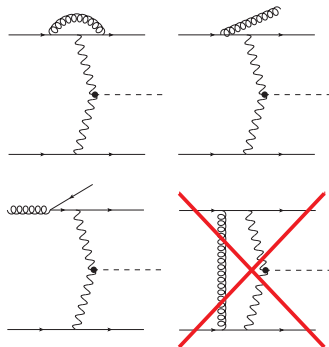


QCD corrections to VBF

LO

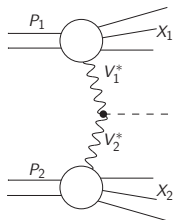


NLO



QCD corrections to VBF

At NLO:

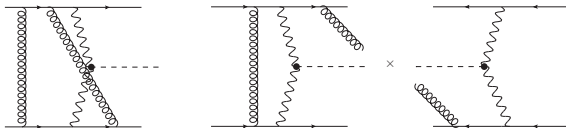


$$d\sigma = \frac{1}{S} \frac{G_F^2 M_{V_1}^2 M_{V_2}^2}{(Q_1^2 + M_{V_1}^2)^2 (Q_2^2 + M_{V_2}^2)^2} W_{\mu\nu}^{DIS}(x_1, Q_1^2) M_{VVH}^{\mu\rho} M_{VVH}^{*\nu\sigma} W_{\rho\sigma}^{DIS}(x_2, Q_2^2) \times$$

$$\times \frac{d^3 P_{X_1}}{(2\pi)^3 2E_{X_1}} \frac{d^3 P_{X_2}}{(2\pi)^3 2E_{X_2}} ds_1 ds_2 \frac{d^3 P_H}{(2\pi)^3 2E_H} (2\pi)^4 \delta^4(P_1 + P_2 - P_{X_1} - P_{X_2} - P_H)$$

The structure function approach to VBF @ NNLO

- structure function approach is not exact at NNLO
- (in principle) need to consider extra contributes
 - double gluon-exchange diagrams (real and virtual)




- t/b loop diagrams



Results at colliders

- $V_1 V_2 H$ Feynman rule:

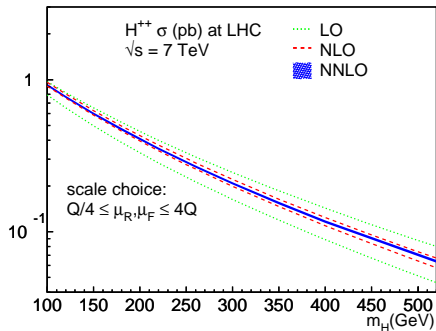
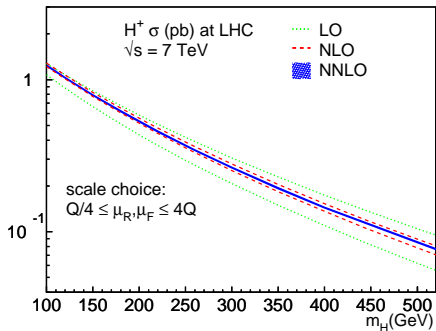


The diagram shows a vertex where two wavy lines representing vector bosons, labeled V_i and V_j , meet at a central point. The V_i line is oriented upwards and to the left, with a Greek letter μ at its top end. The V_j line is oriented downwards and to the left. A dashed line representing a Higgs boson H extends to the right from the vertex. To the right of the dashed line is the mathematical expression for the Feynman rule.

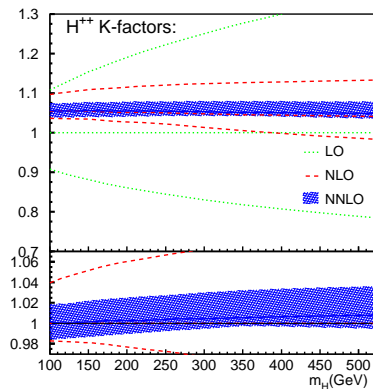
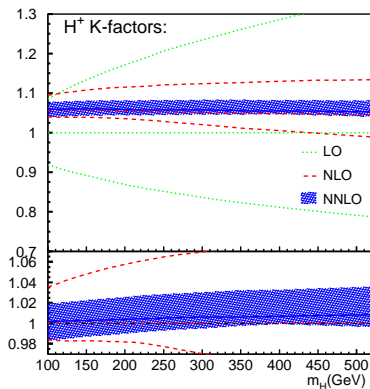
$$= 2(\sqrt{2}G_F)^{1/2} M_i M_j F_{ij} (-i g_{\mu\nu})$$

- F_{ij} **model dependent**
- All numbers computed with $F_{ij} = 1$

Total cross-sections @LHC - $\sqrt{s} = 7\text{TeV}$

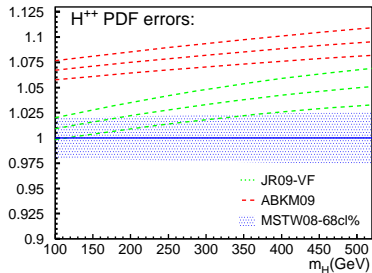
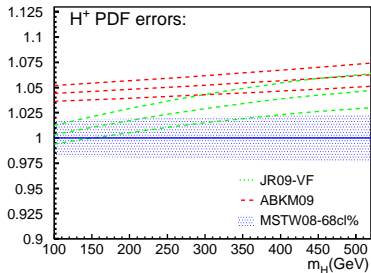


K-factors @LHC - $\sqrt{s} = 7\text{TeV}$

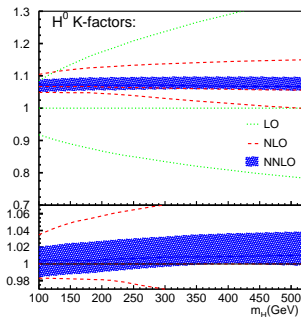
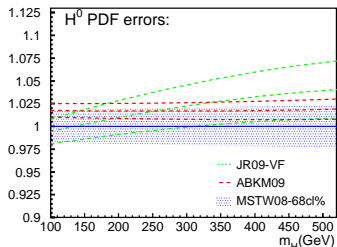
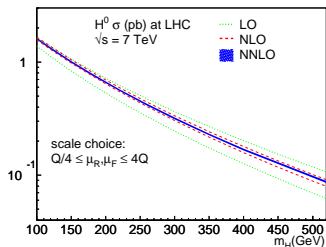


Scale choice: $1/4Q \leq \mu_R, \mu_F \leq 4Q$

NNLO PDF errors @LHC - $\sqrt{s} = 7\text{TeV}$



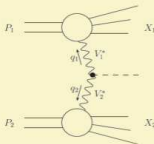
The SM Higgs @LHC - $\sqrt{s} = 7\text{TeV}$



VBF @ NNLO : Cross-Section Calculator

by P. Bolzoni, F. Maltoni, S.-O. Moch and M. Zaro

Version 0.5 -- 31 August 2010



Higgs production in vector-boson fusion (VBF) is computed via a structure-function approach, as reported in [ArXiv:1003.4451 \[hep-ph\]](https://arxiv.org/abs/1003.4451). In addition to the SM Higgs boson, it is also possible to compute the VBF process for a generic scalar (neutral, singly or doubly charged) that *couple*s to the SM vector bosons.

This simple interface allows any [registered](#) user to obtain a cross section up to NNLO in QCD, including an estimate of the theoretical uncertainties coming from scale variation and PDF uncertainties.

The electro-weak parameters used for the cross-section computation are set to their respective [PDG](#) values (see the list [here](#)).

The code runs over the CP3-MadGraph cluster and *might take up to a few hours* depending on the actual request. An e-mail with a link to the results page is sent to the user as soon as results are available. The possibility of requesting multiruns, i.e. runs corresponding to a series of Higgs mass values and/or collider energies, will be available soon upon e-mail request.

[Registration](#)

[Talks & Conferences](#)

[HNNLO web page \(gg->H\)](#)

Please note that processes other than "SM Higgs" have not been carefully tested yet.

Process: : [VVH Couplings](#)
Up to order: :
Collider type: :
Center of mass energy: GeV
Higgs boson mass: GeV
PDF set: : [Description](#)
PDF uncertainties: :
Reference scale: : [Description](#)
Scale uncertainties: : [Description](#)

Please send comments/requests/bug reports to Marco Zaro (e-mail: Marco.Zaro@uclouvain.be).

Please note that processes other than "SM Higgs" have not been carefully tested yet.

Process:	<input type="text" value="H+ /H-"/>	VVH Couplings
Up to order:	<input type="text" value="NNLO"/>	
Collider type:	<input type="text" value="p-p"/>	
Center of mass energy:	<input type="text" value="7000"/>	GeV
Higgs boson mass:	<input type="text" value="120"/>	GeV
PDF set:	<input type="text" value="MSTW08 68%cl (LO-NLO-NNLO)"/>	Description
PDF uncertainties:	<input type="text" value="no"/>	
Reference scale:	<input type="text" value="Q (recommended)"/>	Description
Scale uncertainties:	<input type="text" value="conservative"/>	Description

VBF @ p-p collider

Request sent on 2010-09-13

Process requested: H^+H^- production

$m_h=120$ GeV, $\sqrt{s}=7$ TeV, up to NNLO

PDF set: MSTW08 68%CL (LO-NLO-NNLO), PDF error: no

Scale reference: Q

Theoretical uncertainty: conservative

H^-	LO	NLO	NNLO
$\sigma(\text{pb})$:	0.602966	0.646475	0.649579
theo err +:	0.055817	0.024415	0.010770
theo err -:	0.053312	0.009957	0.012742
pdf err +/-:	not req.	not req.	not req.

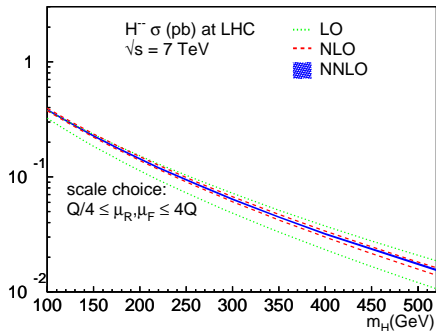
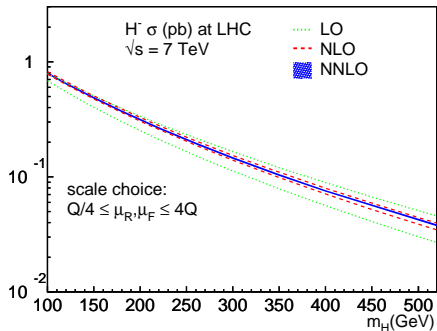
H^+	LO	NLO	NNLO
$\sigma(\text{pb})$:	0.975395	1.029000	1.032120
theo err +:	0.103095	0.044460	0.016400
theo err -:	0.090171	0.015910	0.020440
pdf err +/-:	not req.	not req.	not req.

Conclusions:

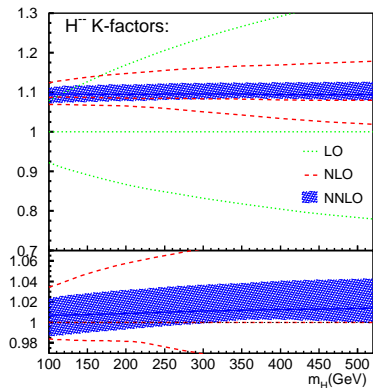
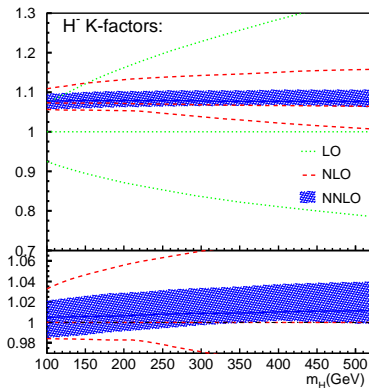
- Triplet models allow sizable VBF production for charged Higgses
- QCD corrections to VBF can be computed via a structure function approach
- VBF total cross-sections and K-factors available at NNLO (H^\pm , $H^{\pm\pm}$)
- Excellent convergence of perturbative series
- Theoretical uncertainties reduced at $\pm 2\%_{SC} \pm 5\%_{PDF}$ level at NNLO
- Flexible web interface available
- Easy extension to different Lorentz structures for the VVH vertex
- TO DO: Differential calculation (at least at NLO)

Backup slides

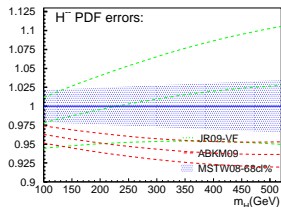
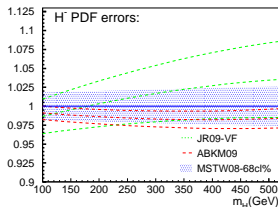
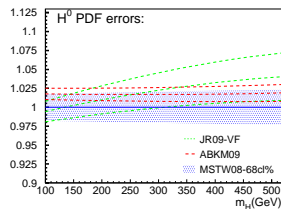
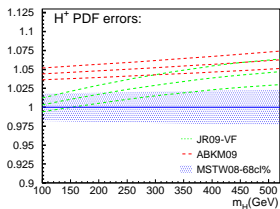
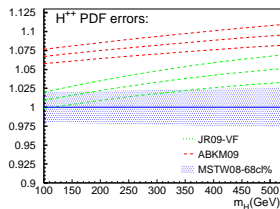
Total cross-sections @LHC - $\sqrt{s} = 7\text{TeV}$



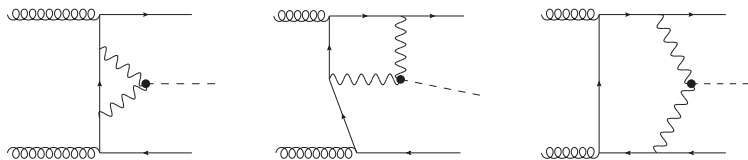
K-factors @LHC - $\sqrt{s} = 7\text{TeV}$



Are pdf uncertainties correlated to the Higgs charge?

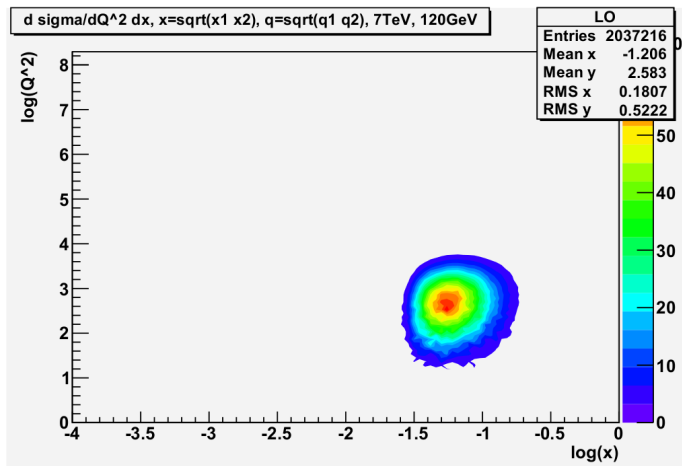


Single quark line (SQL) diagrams



- Gauge invariant class
- Not “pure” VBF process (colour exchanged between protons)
- Not IR-safe
- Studied by R. V. Harlander, J. Vollinga and M. M. Weber, Phys. Rev. D **77**, 053010 (2008) [arXiv:0801.3355 [hep-ph]]
- Impact on the VBF cross section (after VBF cuts) $\mathcal{O}(10^{-3})$

Kinematics in the x vs. Q^2 plane



$$\langle Q^2 \rangle \simeq (20\text{GeV})^2$$

$$\langle x \rangle \simeq 6 \cdot 10^{-2}$$