

Higgs production via vector-boson fusion at NNLO in QCD

Marco Zaro,
Paolo Bolzoni, Fabio Maltoni, Sven-Olaf Moch

ArXiv:1003.4451, Phys. Rev. Lett. 105, 011801 (2010)
ArXiv:11???.????

Center for Cosmology, Particle Physics and Phenomenology (CP3)
Université Catholique de Louvain

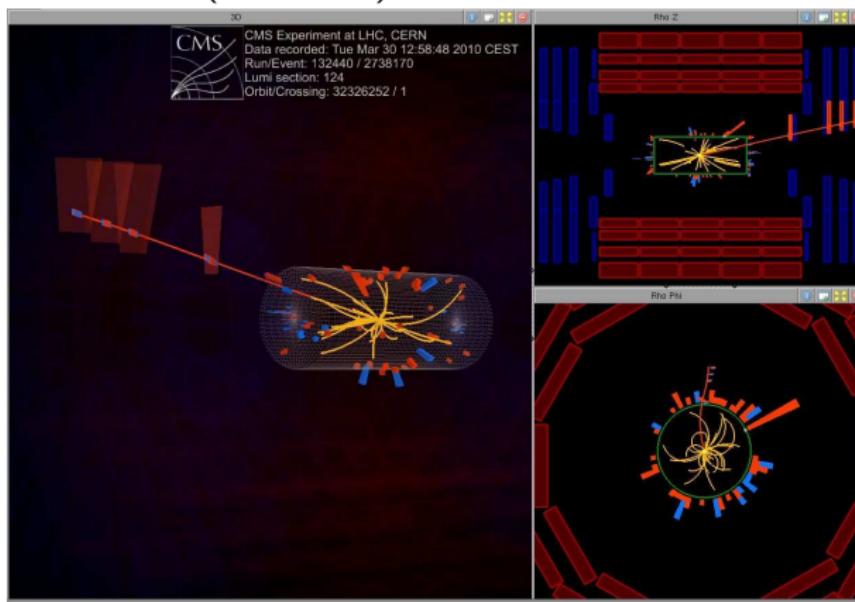
Zurich, March 10, 2011

Outline:

- 1 Introduction: The quest for the Higgs boson
- 2 Higgs production channels @LHC
- 3 The VBF cross-section
- 4 Results at colliders
- 5 Charged VBF
- 6 Web interface
- 7 Conclusions

LHC is running (again)!

- LHC is running at 7 TeV, 40 pb^{-1} collected (end 2010),
forseen 3 fb^{-1} (end 2011)



LHC is running (again)!

- LHC is running at 7 TeV, 40 pb^{-1} collected (end 2010),
forseen 3 fb^{-1} (end 2011)
- It's time to find the Higgs...

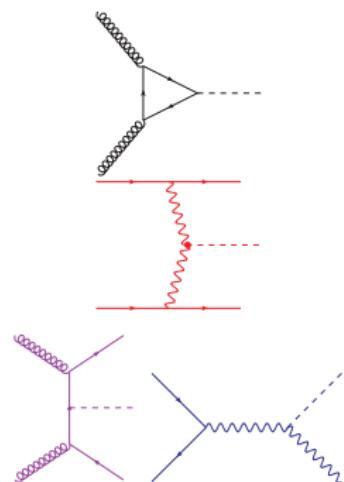
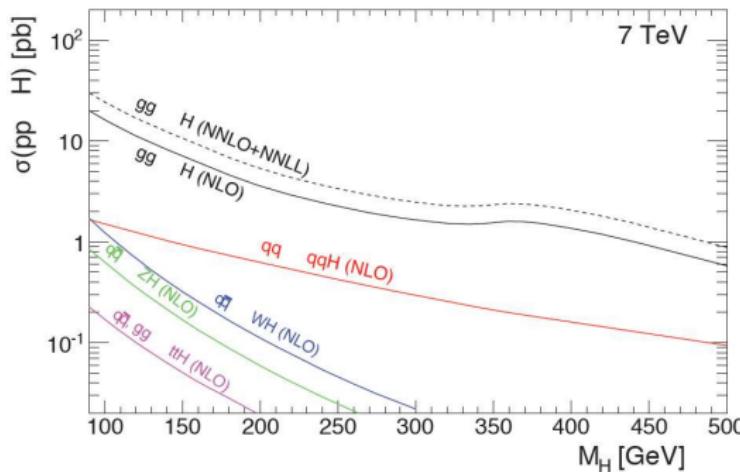


LHC is running (again)!

- LHC is running at 7 TeV, 40 pb^{-1} collected (end 2010),
forseen 3 fb^{-1} (end 2011)
- It's time to find the Higgs...
- ... and to study its properties
 - need for precise theoretical predictions
LO (cross-section estimate)
→ NLO (inclusion of radiative corrections)
→ NNLO (theoretical uncertainty reduction)

Higgs production channels @LHC

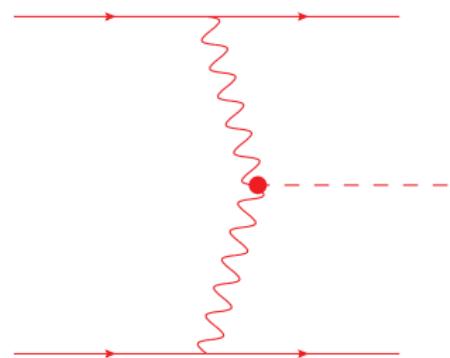
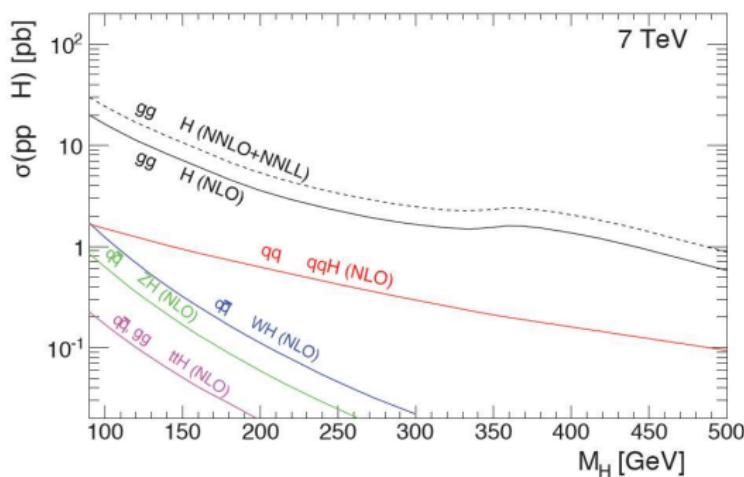
The Higgs production channels



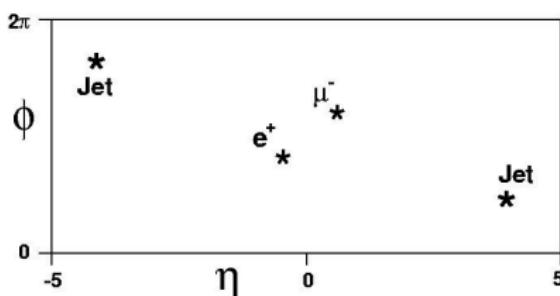
- What is a "channel"?
- Intrinsic uncertainty due to interference with other channels.
For VBF $\simeq 1\%$

The VBF production channel

VBF: color singlet exchange between the protons



VBF signature



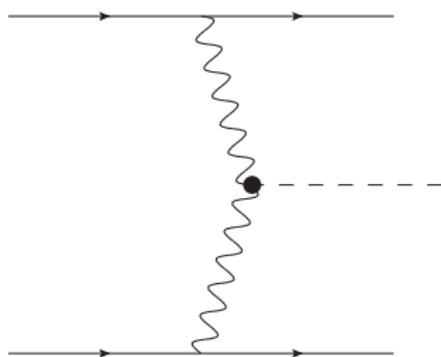
- 2 hard tagging jets
- Large rapidity separation between jets
- No (or small) hadronic activity between tagging jets
- Higgs decay in the central rapidity region
- Possibility to measure VVH couplings → **distinguish among different models**

(See also **E. Gabrielli, B. Mele**, arXiv:1005.2498 [hep-ph])

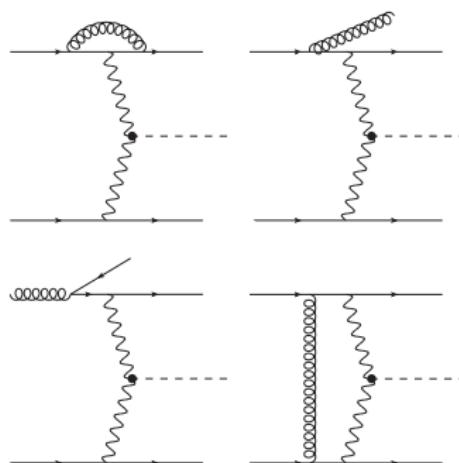
VBF total cross-section: computation

QCD corrections to VBF

LO

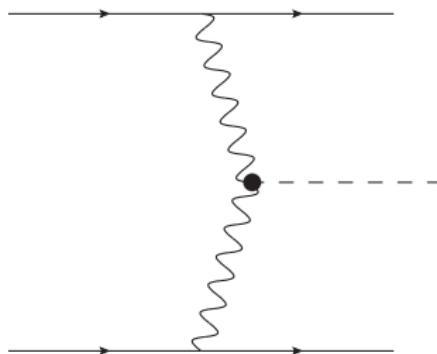


NLO

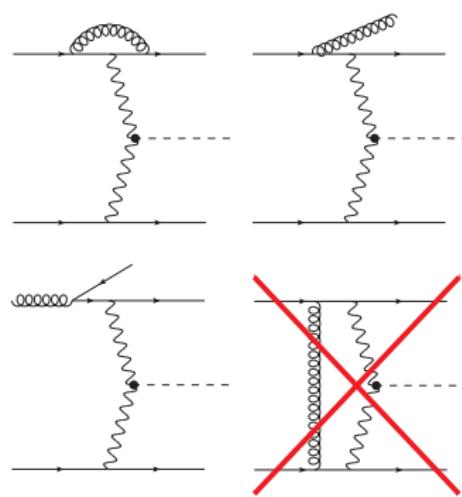


QCD corrections to VBF

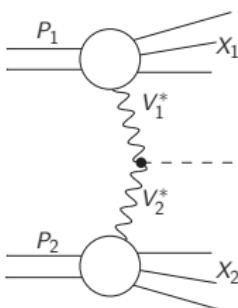
LO



NLO



Structure function approach

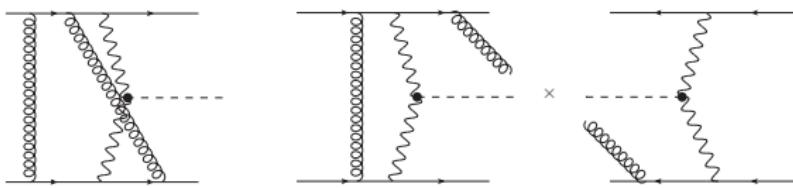


$$d\sigma = \frac{1}{S} \frac{G_F^2 M_{V_1}^2 M_{V_2}^2}{(Q_1^2 + M_{V_1}^2)^2 (Q_2^2 + M_{V_2}^2)^2} W_{\mu\nu}^{DIS}(x_1, Q_1^2) \mathcal{M}_{VVH}^{\mu\rho} \mathcal{M}_{VVH}^{*\nu\sigma} W_{\rho\sigma}^{DIS}(x_2, Q_2^2) \times \\ \times \frac{d^3 P_{X_1}}{(2\pi)^3 2E_{X_1}} \frac{d^3 P_{X_2}}{(2\pi)^3 2E_{X_2}} ds_1 ds_2 \frac{d^3 P_H}{(2\pi)^3 2E_H} (2\pi)^4 \delta^4 (P_1 + P_2 - P_{X_1} - P_{X_2} - P_H)$$

- QCD correction factorize!
- Factorization holds up to NNLO at leading N_c

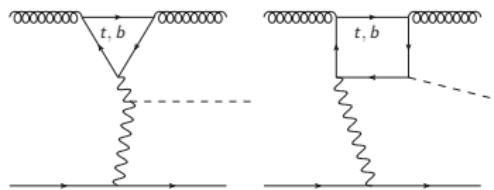
The structure function approach to VBF @ NNLO

- structure function approach is not exact at NNLO
- (in principle) need to consider extra diagrams
 - double gluon-exchange diagrams (real and virtual):
 - $1/N_c^2$ suppressed, gauge invariant
 - kinematically suppressed
 - at “NLO” typically 10% of the DIS-like corrections



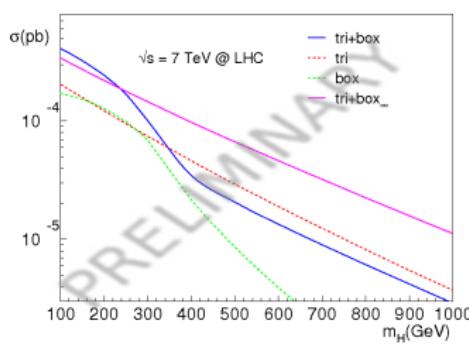
The structure function approach to VBF @ NNLO

- structure function approach is not exact at NNLO
- (in principle) need to consider extra diagrams
 - t/b loop diagrams:
 - Gauge Invariant
 - Below per-mil of the total cross-section
 - Important in Higgstrahlung, not in VBF

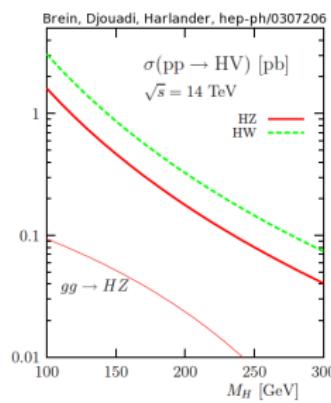


The structure function approach to VBF @ NNLO

- structure function approach is not exact at NNLO
- (in principle) need to consider extra diagrams
 - t/b loop diagrams:



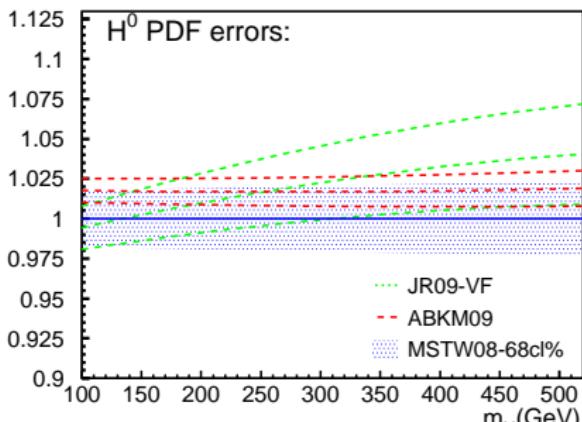
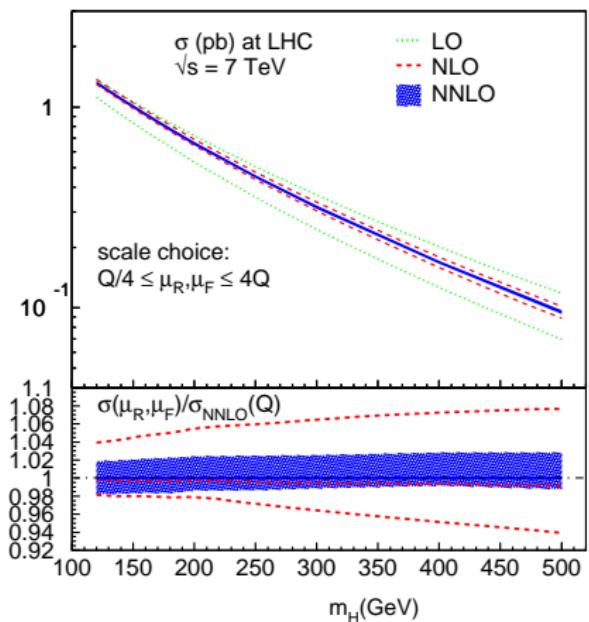
VBF



HV

Results at colliders

Results at the LHC @7 TeV



- $\Delta_{NNLO}/NLO < 1\%$
- Theoretical uncertainties @NNLO:
 $\pm 2\%|_{SC} \pm 3\%|_{PDF}$
- Natural scale of the process:
 $Q \simeq 20$ GeV $< m_H$

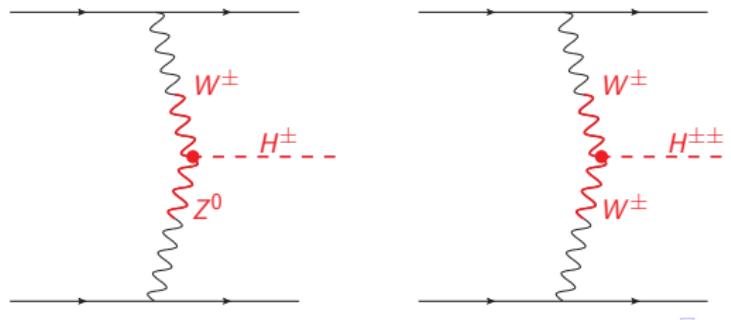
Going BSM: charged Higgses and more...

- **Triplet models**

- Allow $W^\pm Z H^\mp$ and $W^\pm W^\pm H^{\mp\mp}$ vertices at tree level
- Vertices are proportional to $\frac{v_T}{v}$
- If $\frac{v_T}{v} = O(1)$ (more triplets, ...) charged VBF can be studied at the LHC

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

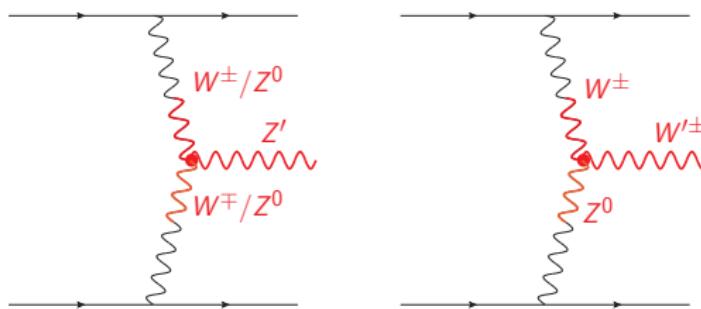
- Powerful channel to measure v_T , discrimination among models
- Doubly charged Higgses carry lepton number → Amazing signatures!



Going BSM: charged Higgses and more...

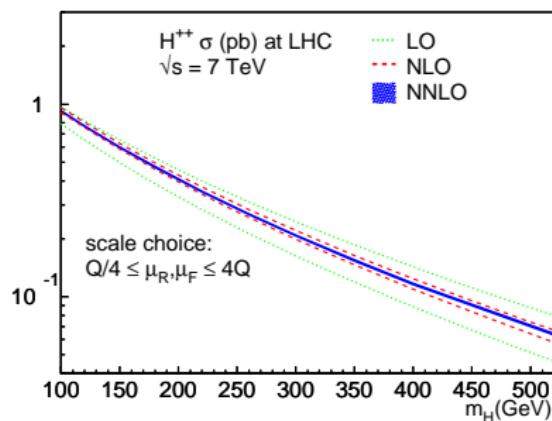
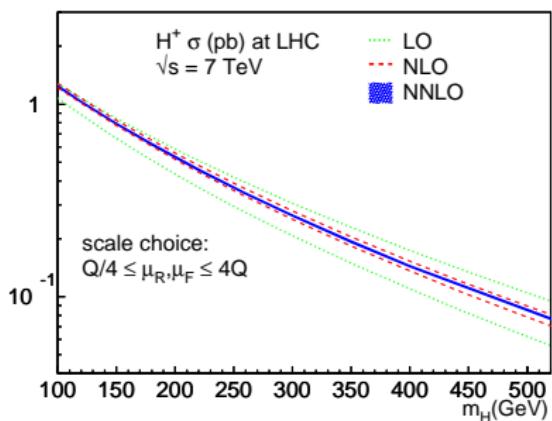
• Fermiophobia

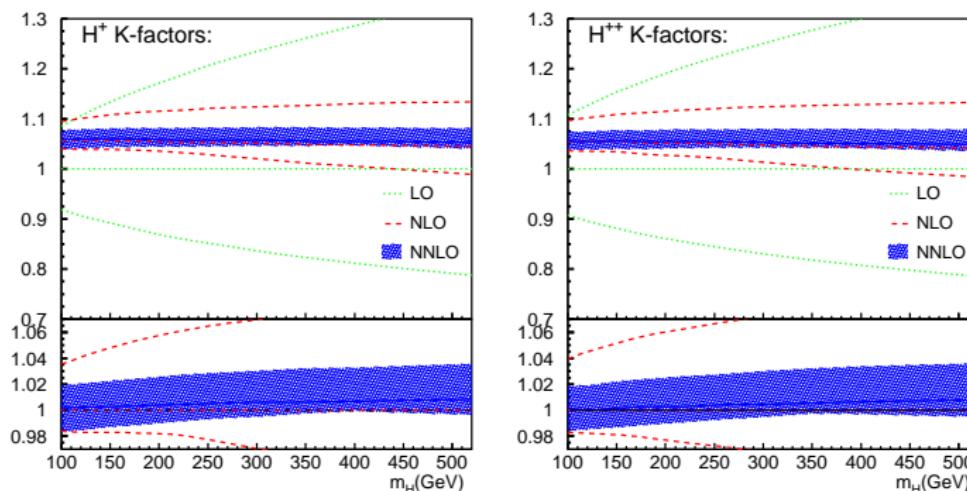
- VBF becomes the main production channel for Higgs boson(s)
- Easy extension to FP vector resonances (Z' , W')
- Possibility to include anomalous couplings



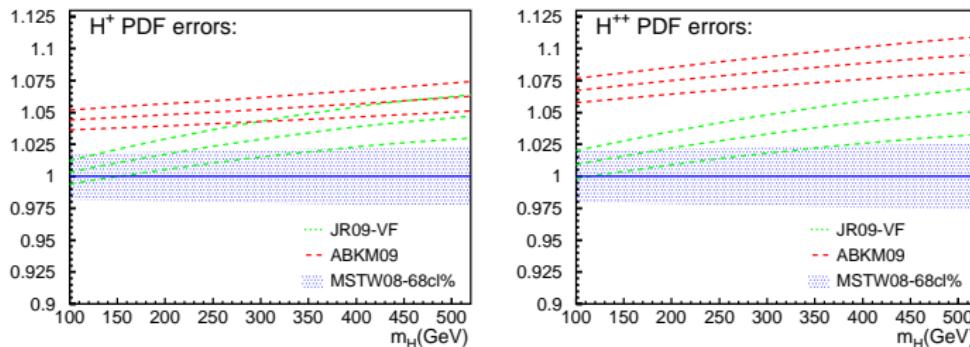
Total cross-sections @LHC - $\sqrt{s} = 7\text{TeV}$

$$\Gamma_{V_i V_j H}^{\mu\nu} = 2 \left(\sqrt{2} G_F \right)^{1/2} m_i m_j (-i g^{\mu\nu})$$



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

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

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

PDF errors larger than for SM Higgs: due to valence quarks?

Web interface: <http://vbf-nnlo.phys.ucl.ac.be>

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 \[hep-ph\]](#). 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 [couples](#) 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 [PDF](#) 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:	<input type="button" value="SM Higgs"/>	VBF Couplings
Up to order:	<input type="button" value="NNLO"/>	
Collider type:	<input type="button" 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="button" value="MSTW08 68%cl (LO-NLO-NNLO)"/> Description	
PDF uncertainties:	<input type="button" value="no"/>	
Reference scale:	<input type="button" value="Q (recommended)"/>	Description
Scale uncertainties:	<input type="button" value="no"/>	Description

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

Web interface: <http://vbf-nnlo.phys.ucl.ac.be>

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

Process:	<input type="button" value="H+ /H-"/>	V VH Couplings
Up to order:	<input type="button" value="NNLO"/>	
Collider type:	<input type="button" 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="button" value="MSTW08 68%cl (LO-NLO-NNLO)"/>	Description
PDF uncertainties:	<input type="button" value="no"/>	
Reference scale:	<input type="button" value="Q (recommended)"/>	Description
Scale uncertainties:	<input type="button" value="conservative"/>	Description

Web interface: <http://vbf-nnlo.phys.ucl.ac.be>

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:

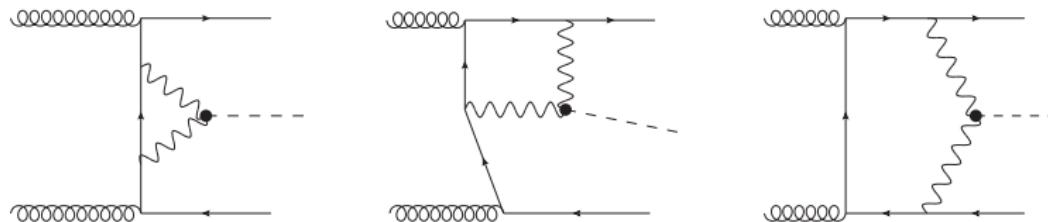
- VBF is a very interesting channel for Higgs discovery and precision physics
- First computation of the NNLO QCD corrections to VBF
- Excellent convergence of perturbative series
- Great improvement of theoretical uncertainties at NNLO
- Extension to charged Higgses and to FP W' , Z' , ...
- Possible extension also to $VV \rightarrow HH$, ...
- Flexible web interface available
- More exclusive approach needed

Thank you!

Thank you!

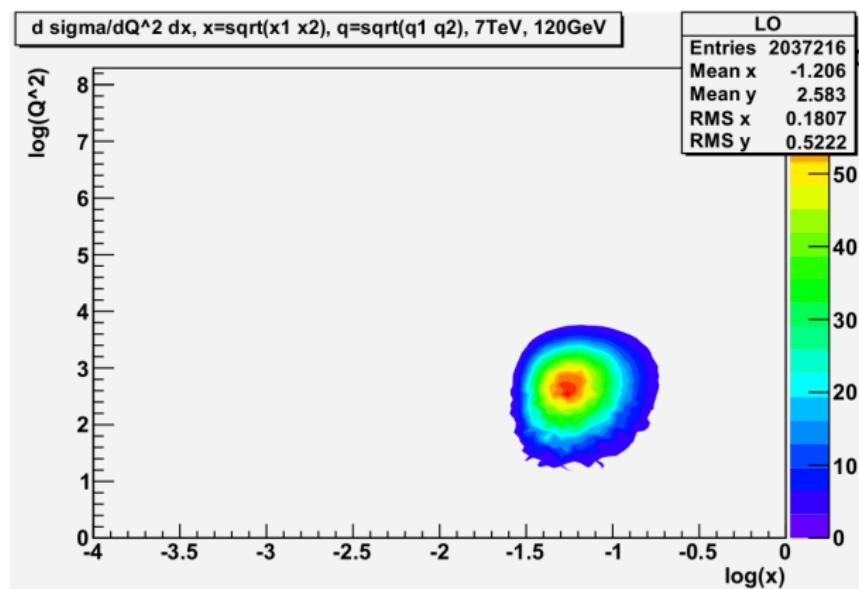
Backup slides

Single quark line (SQL) diagrams



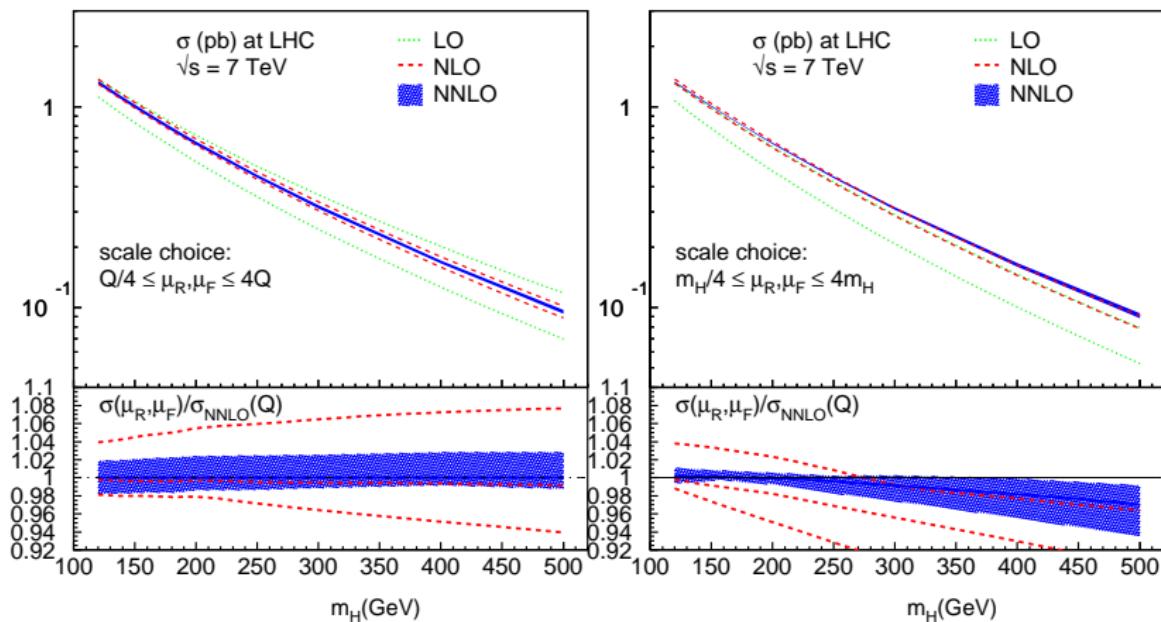
- Gauge invariant class
- Not “pure” VBF process (colour exchanged between protons)
- Not IR-safe
- Studied by R. V. Harlander, J. Vollinga and M. M. Weber, Phys. Rev. D **77**, 053010 (2008) [arXiv:0801.3355 [hep-ph]]
- Impact on the VBF cross section (after VBF cuts) $\mathcal{O}(10^{-3})$

Kinematics in the x vs. Q^2 plane

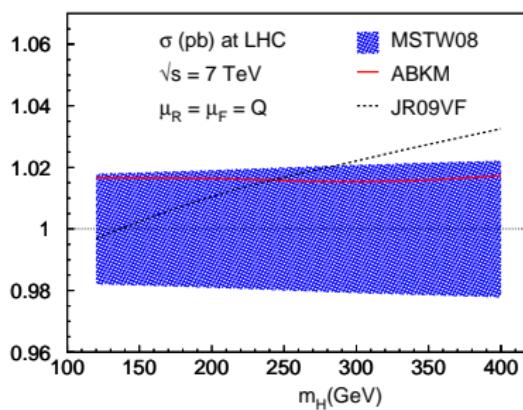


$$\langle Q^2 \rangle \simeq (20\text{GeV})^2 \quad \langle x \rangle \simeq 6 \cdot 10^{-2}$$

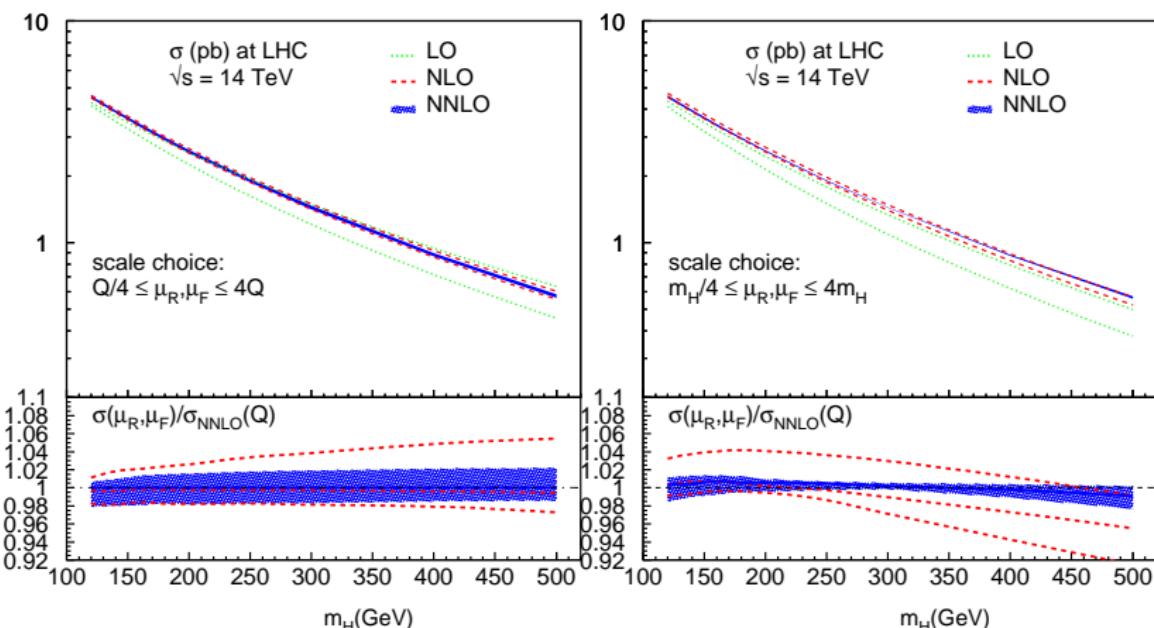
Results at the LHC @7 TeV



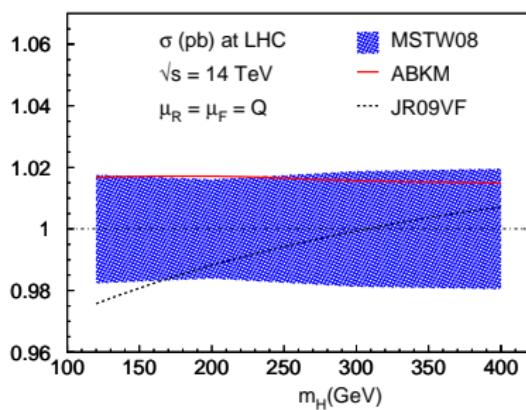
PDF uncertainties at the LHC @7 TeV



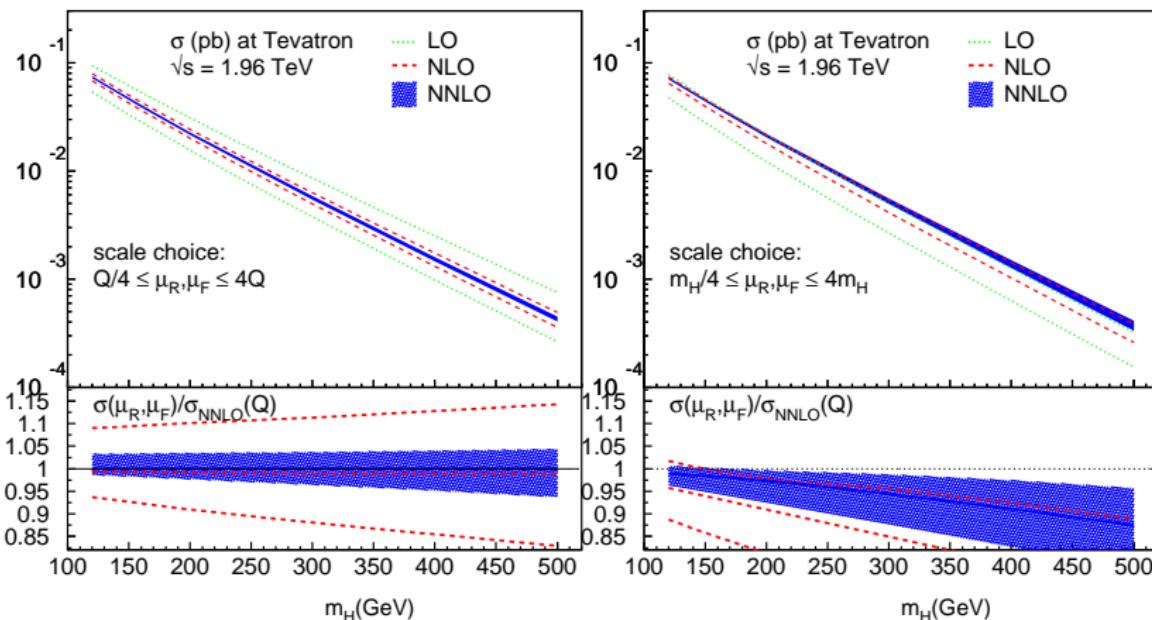
Results at the LHC @14 TeV



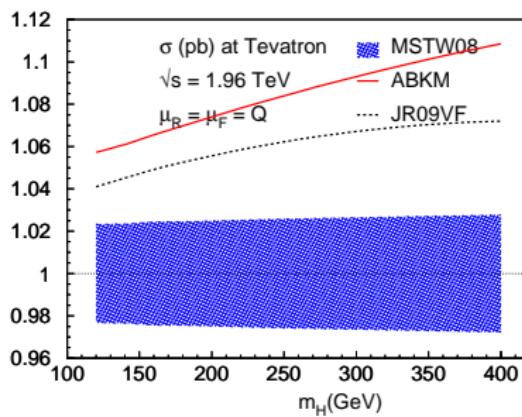
PDF uncertainties at the LHC @14 TeV



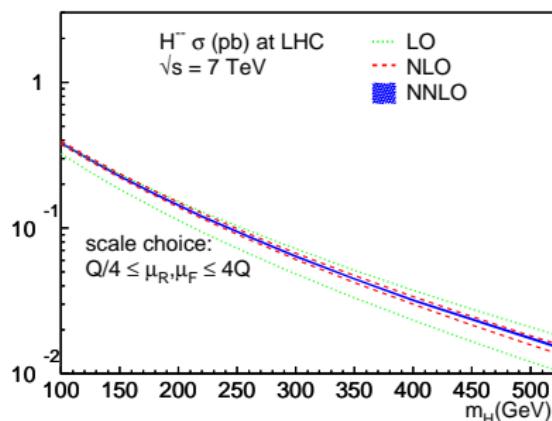
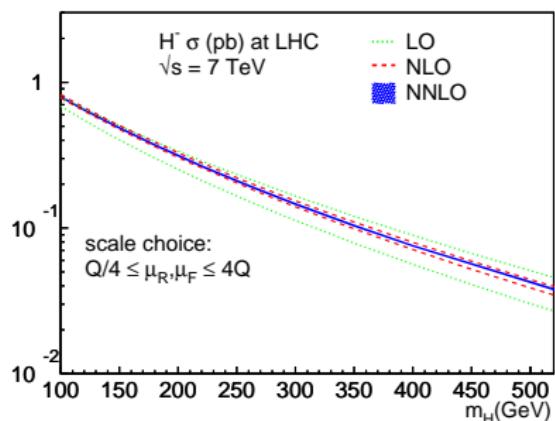
Results at the Tevatron @1.96 TeV

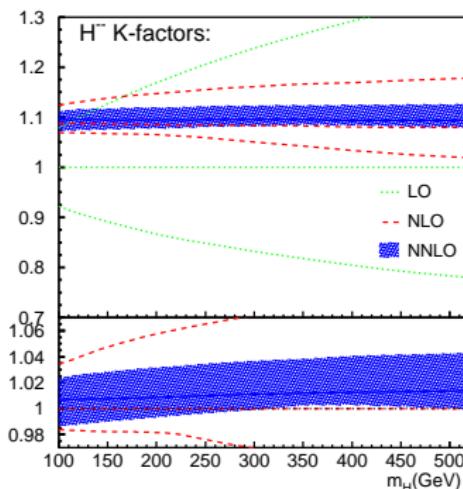
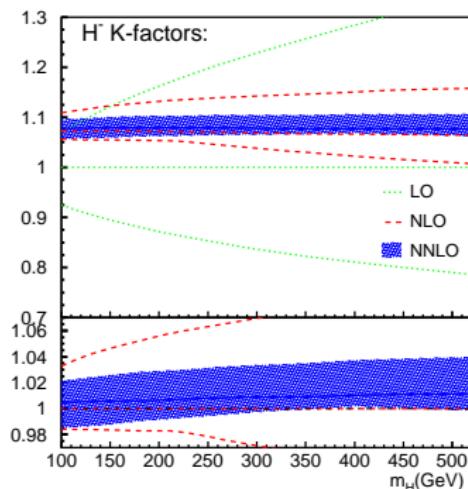


PDF uncertainties at the Tevatron @1.96 TeV



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?

