

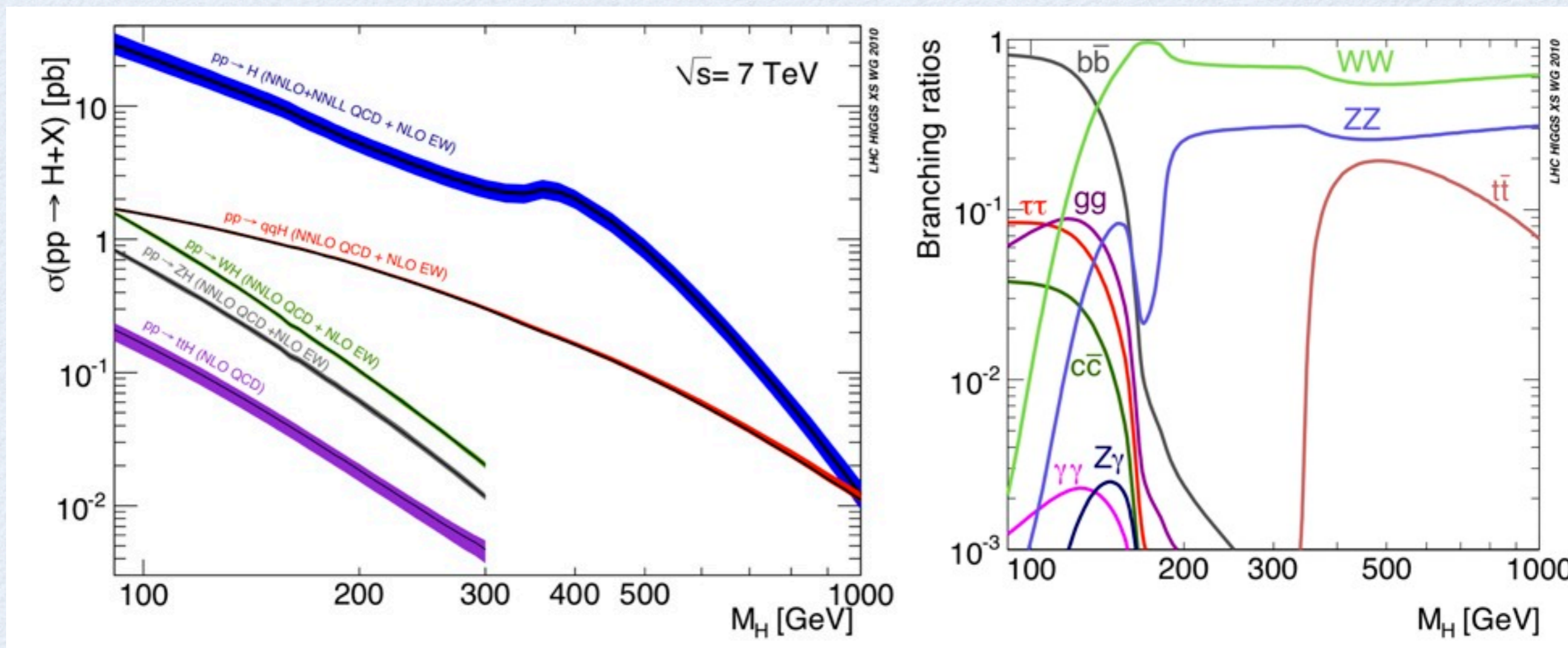
SM HIGGS PRODUCTION CROSS-SECTIONS AND BRANCHING RATIOS

Marco Zaro

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

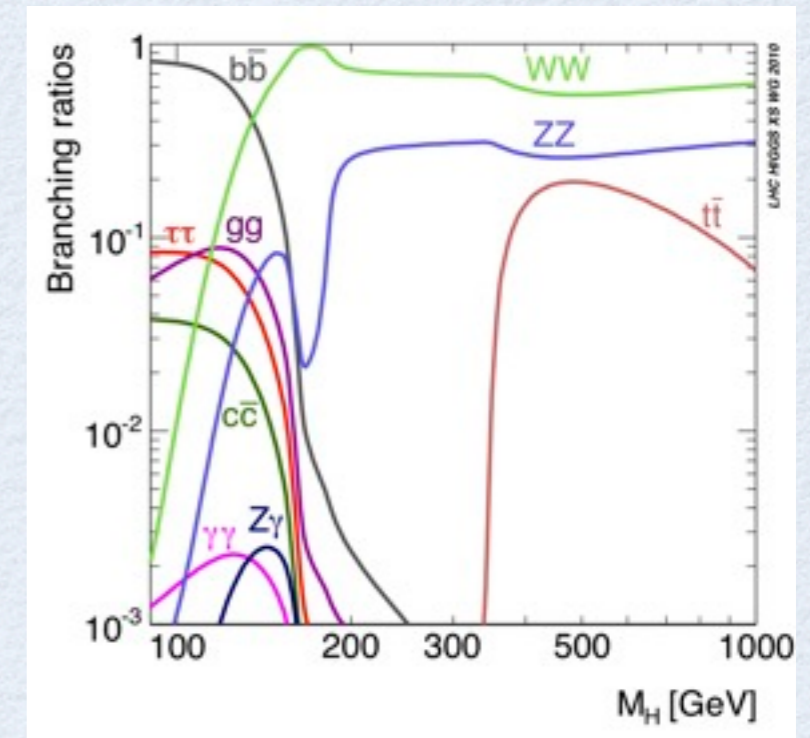
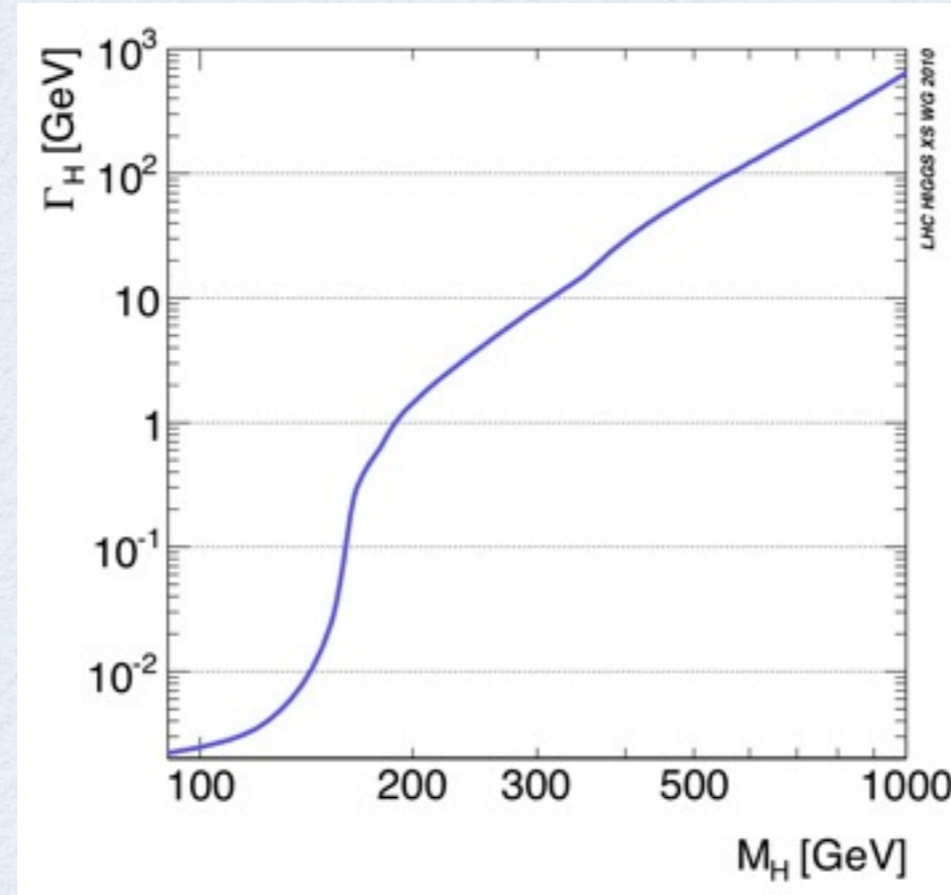
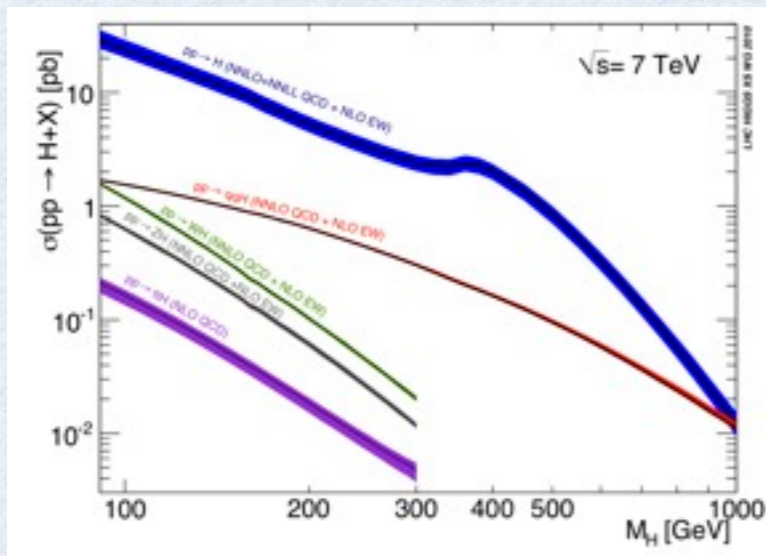
<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections>

LHC Higgs Cross Sections Working Group (many people, ..., MZ), arXiv:1101.0593



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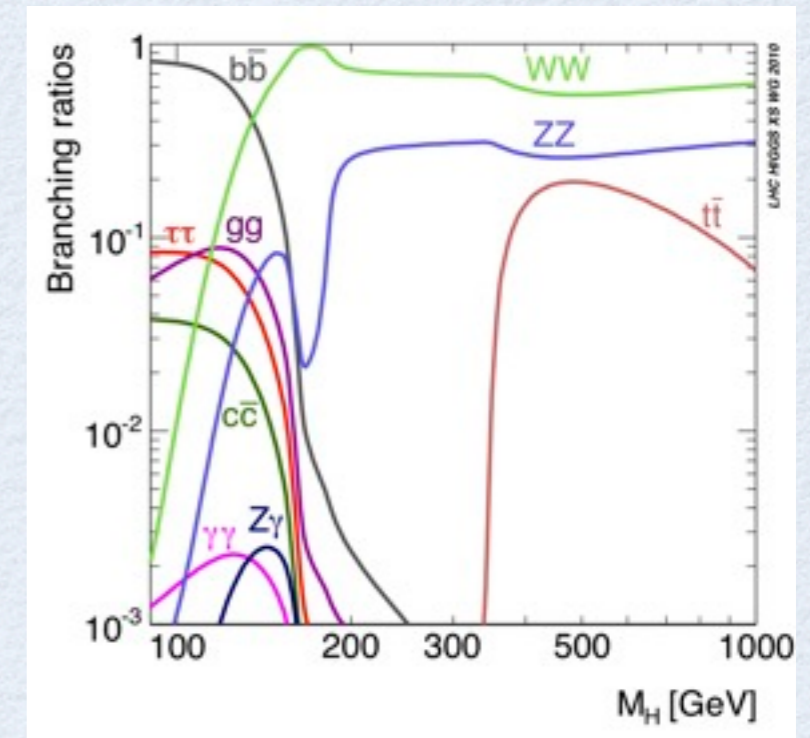
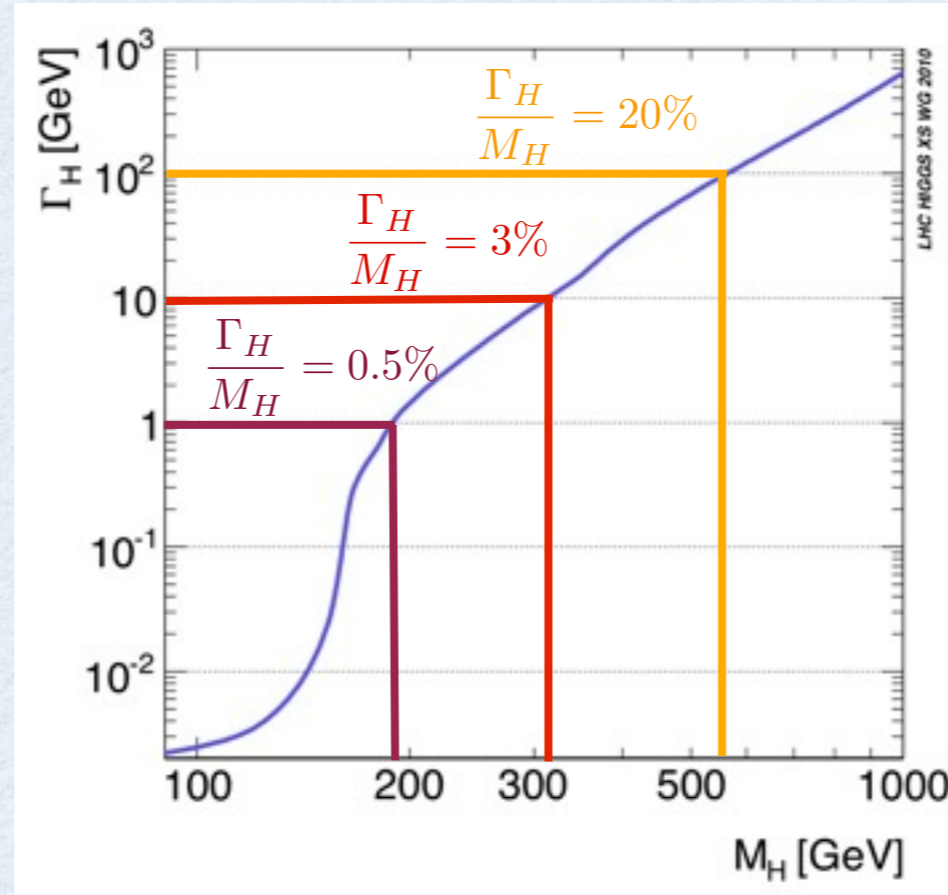
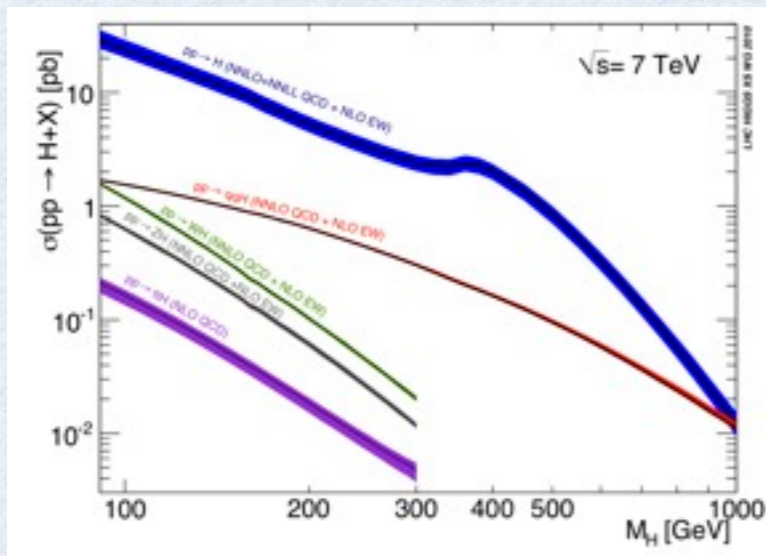
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- Warning! $\sigma \times \text{BR}$ can be a too crude approximation
 - Finite width & PDFs change the cross-section
 - Interference with background
 - The heavier the Higgs the larger the off-shell effects

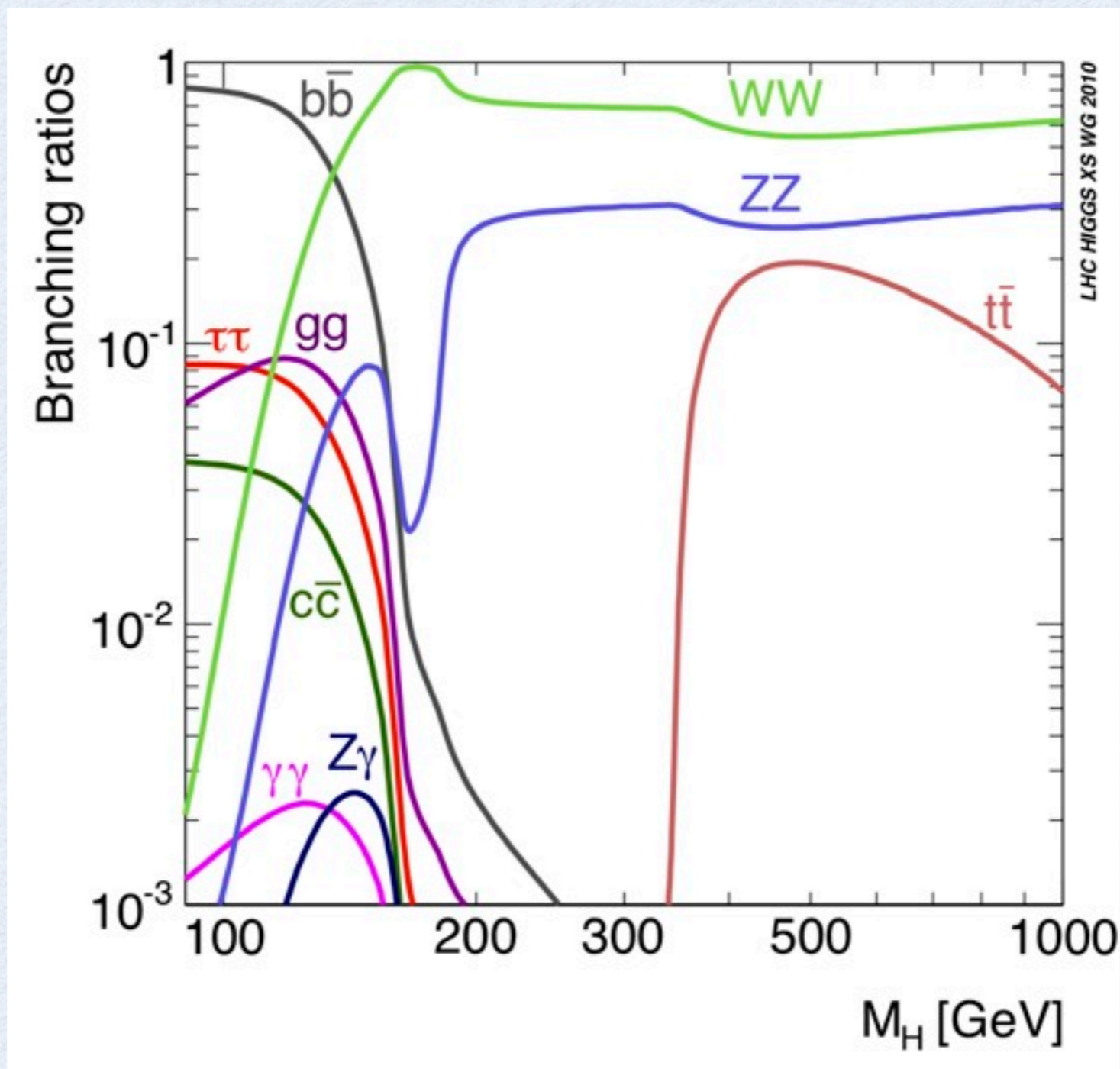
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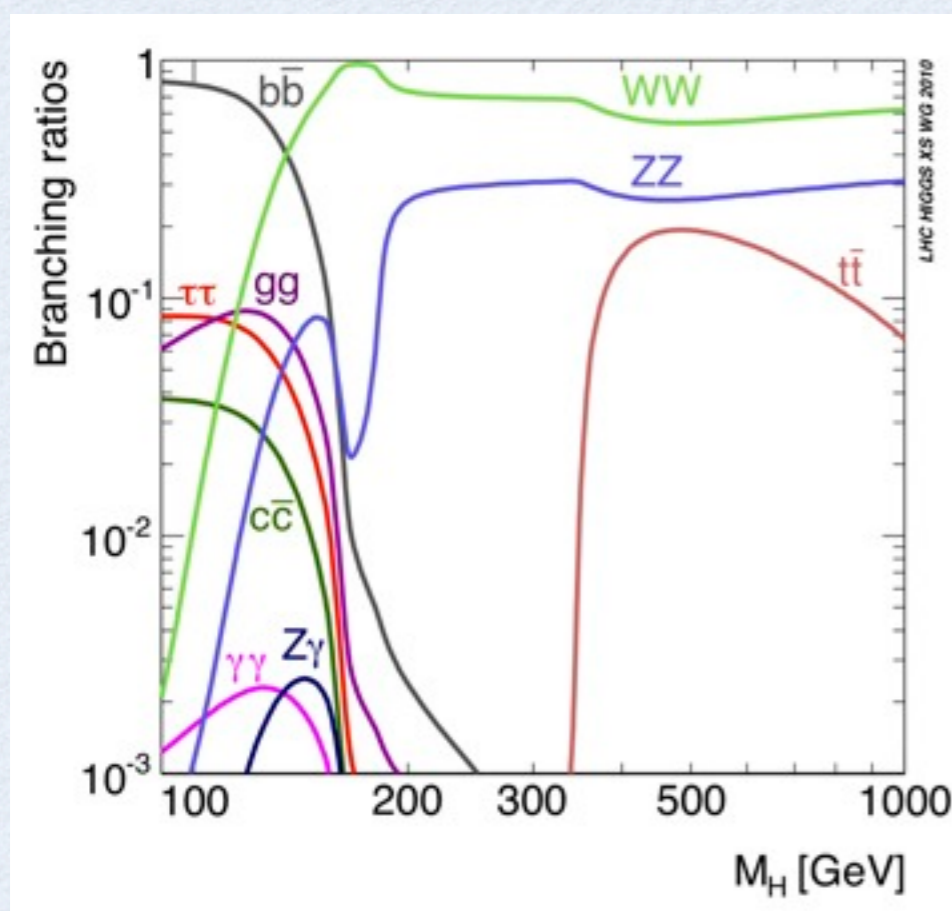
DECAY CHANNELS



DECAY CHANNELS



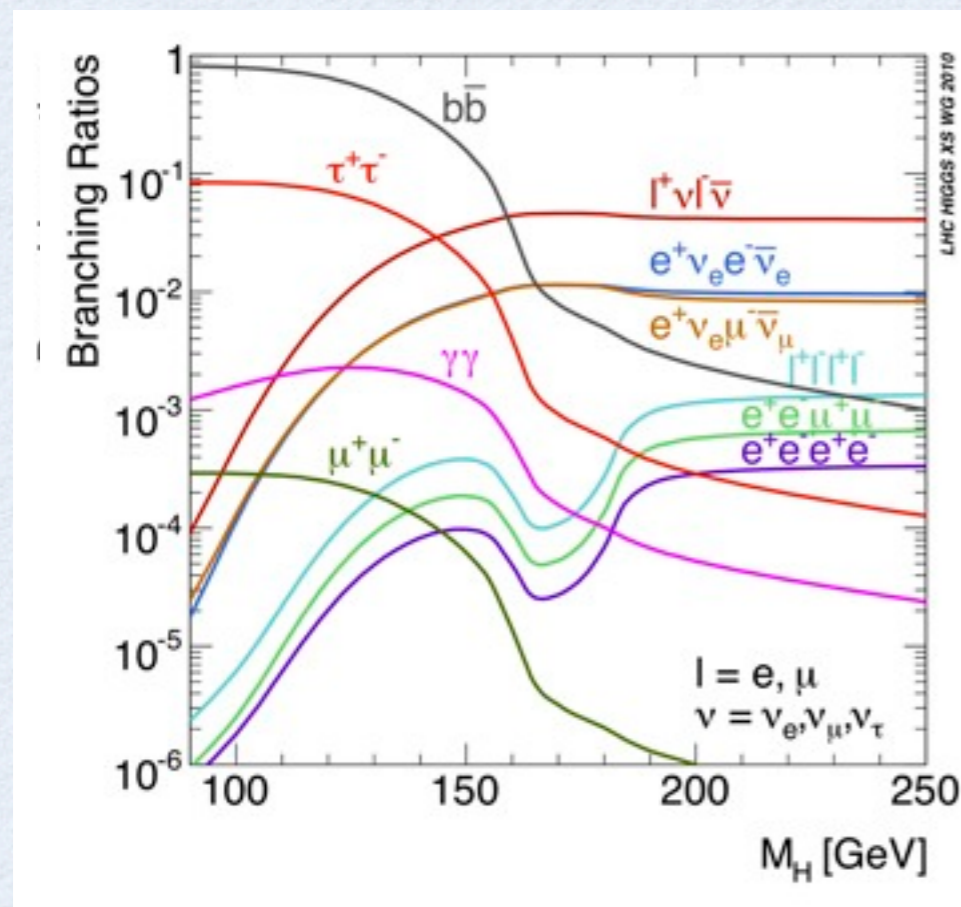
<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR>



- Remember:
 - Decay products must be visible at a hadron collider!
 - W and Z are unstable particles!

DECAY CHANNELS

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- Remember:
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- State of the art: HDECAY & Prophecy4f

HDECAY: M. Spira et al., hep-ph/9610350
Prophecy4f: A. bredenstein et al., hep-ph/0604011

- HDECAY:

- NLO QCD corrections for qq and gg final state
- EW corrections for $gg, \gamma\gamma$

- Prophecy4f:

- EW+NLO QCD for all $VV \rightarrow 4f$ final states, + interferences

arXiv:1101.0593 **Table 25:** Estimate of theoretical uncertainties from missing higher orders

partial width	QCD	electroweak	total
$H \rightarrow bb/cc$	$\sim 0.1-0.2\%$	$\sim 1-2\%$ for $M_H \lesssim 135$ GeV	$\sim 1-2\%$
$H \rightarrow \tau\tau$		$\sim 1-2\%$ for $M_H \lesssim 135$ GeV	$\sim 1-2\%$
$H \rightarrow tt$	$\sim 5\%$	$\lesssim 2-5\%$ for $M_H < 500$ GeV $\sim 0.1(M_H/1 \text{ TeV})^4$ for $M_H > 500$ GeV	$\sim 5-10\%$
$H \rightarrow gg$	$\sim 10\%$	$\sim 1\%$	$\sim 10\%$
$H \rightarrow \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$H \rightarrow WW/ZZ \rightarrow 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500$ GeV $\sim 0.17(M_H/1 \text{ TeV})^4$ for $M_H > 500$ GeV	$\sim 0.5-15\%$

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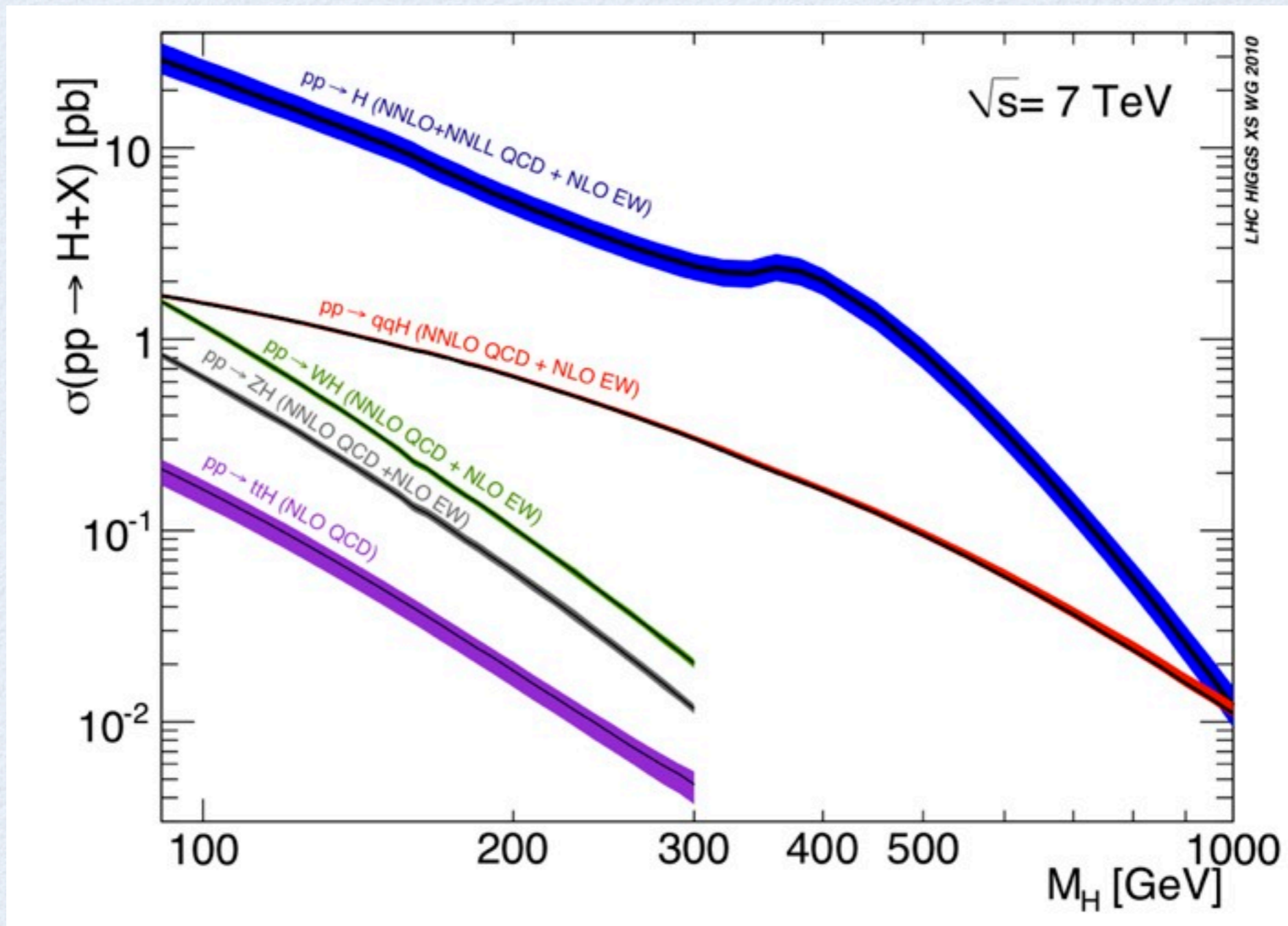
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arXiv:1101.0593 **Table 25:** Estimate of theoretical uncertainties from missing higher orders

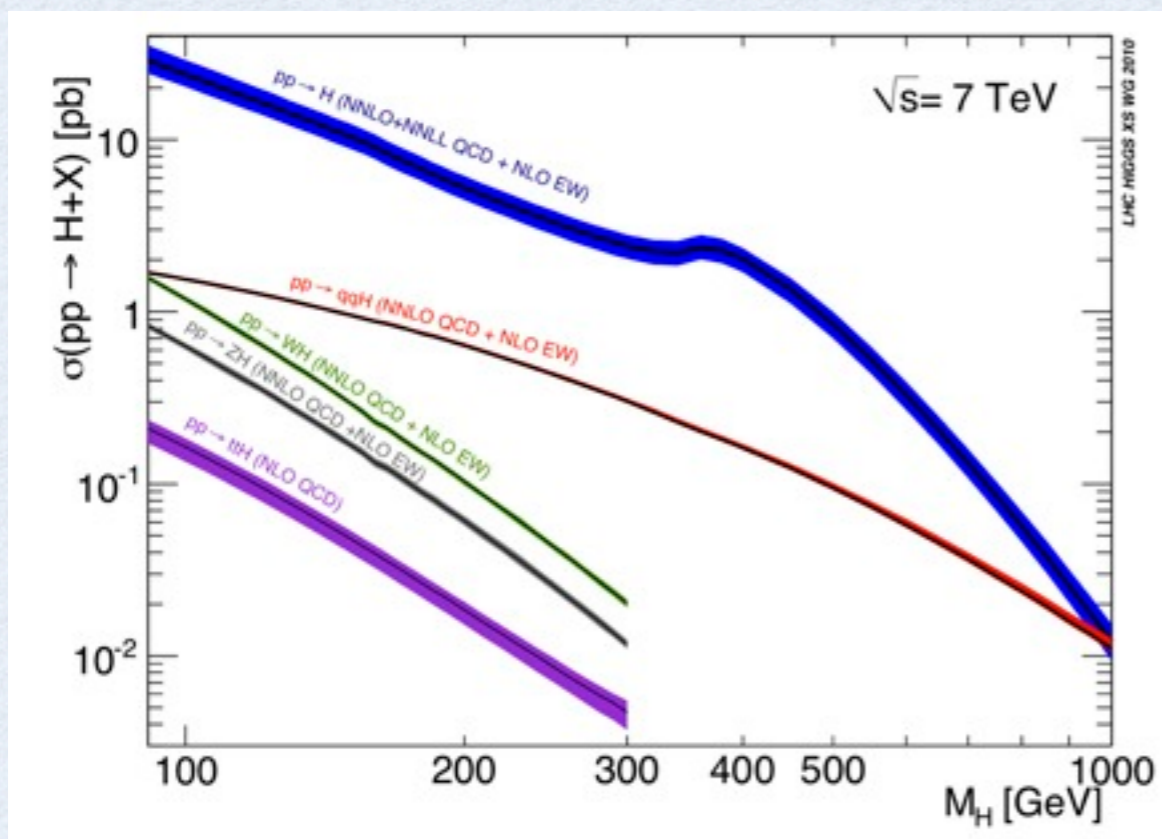
Need to consider also error on quark masses - Baglio, Djouadi, 1012.0530

partial width	QCD	electroweak	total
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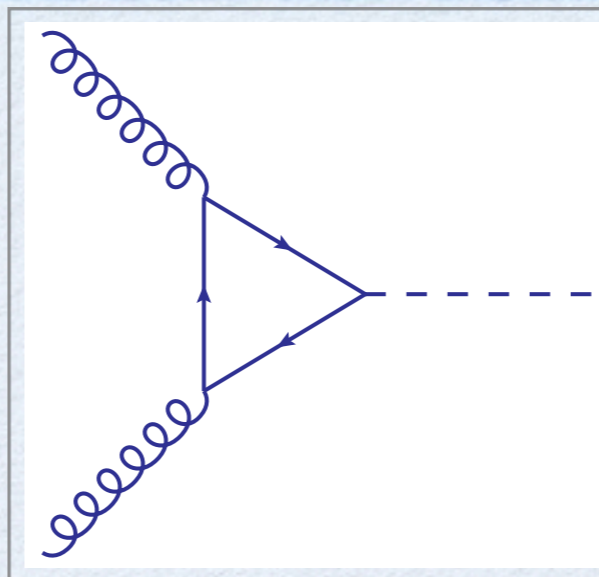
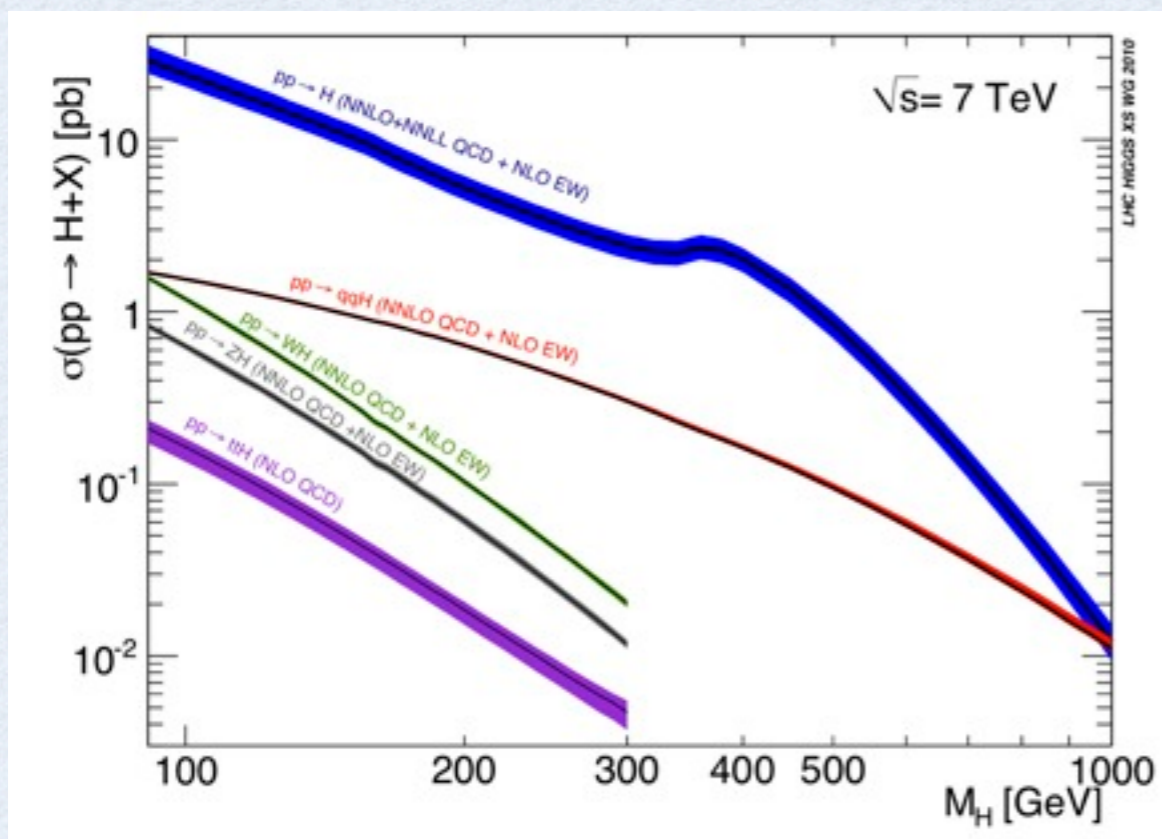
PRODUCTION CHANNELS



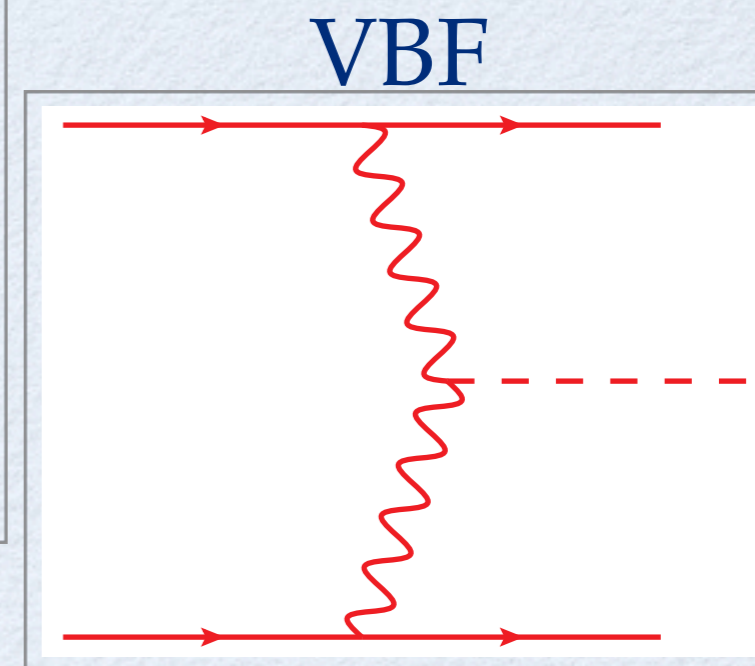
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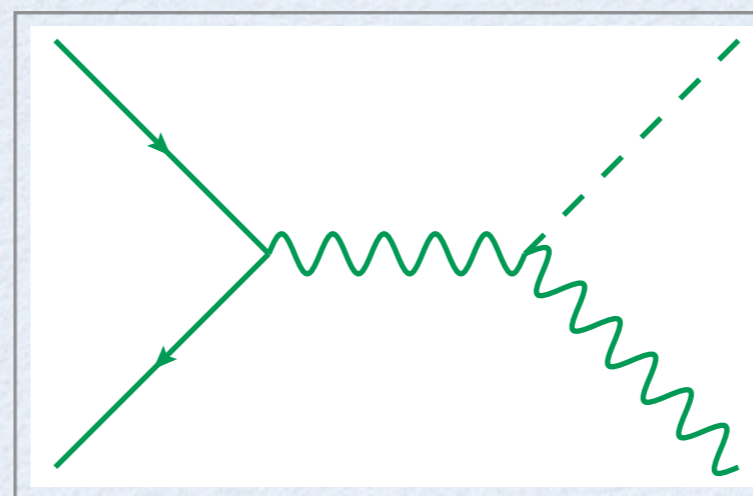
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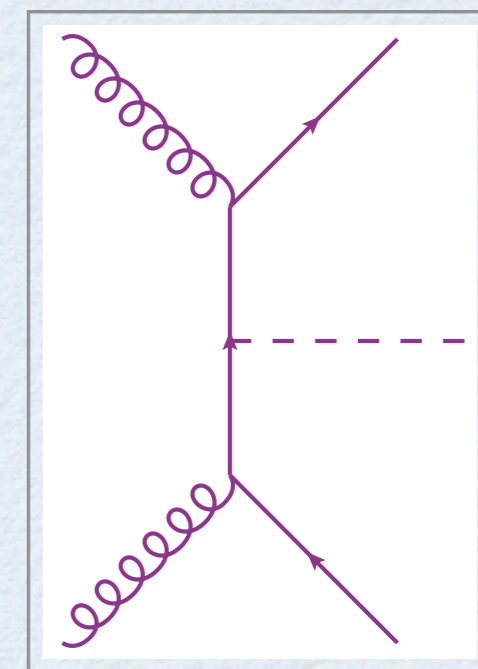
ggH



VBF



W/ZH



ttH

CHANNELS?



CHANNELS?



- What is “a channel”?

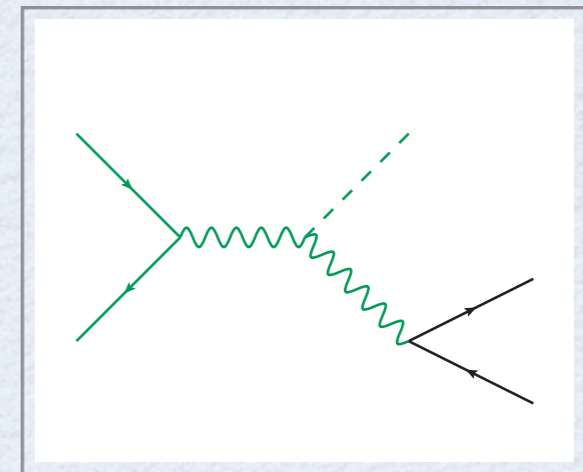
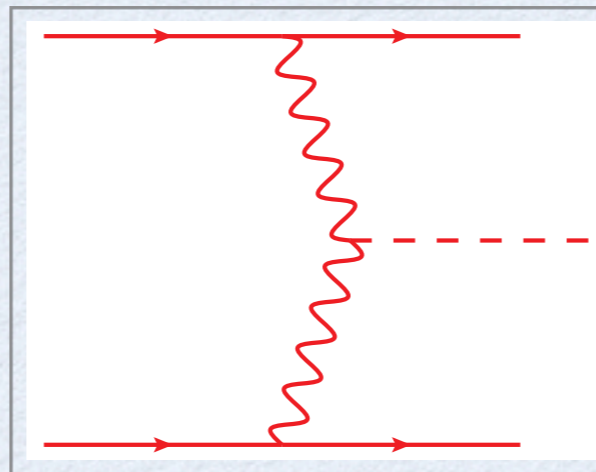
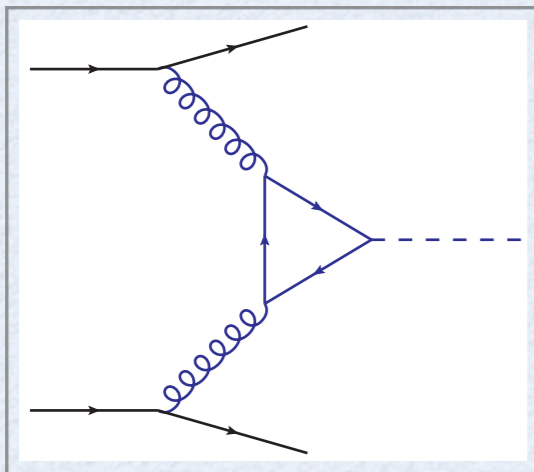
CHANNELS?



- What is “a channel”?
 - Exercise: Try to define VBF in a QM correct way

CHANNELS?

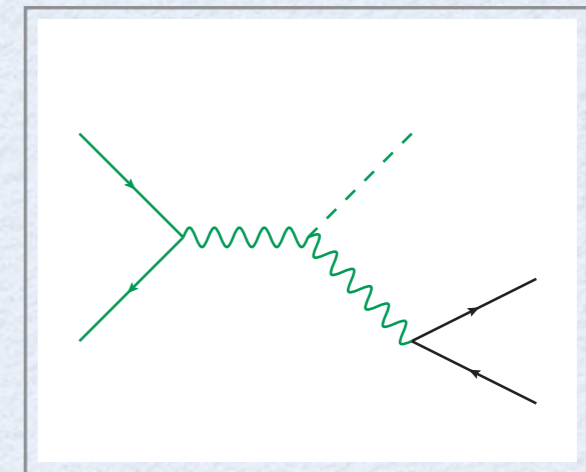
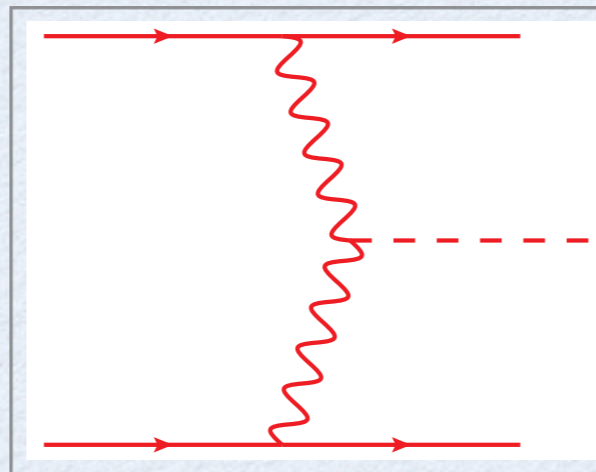
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CHANNELS?



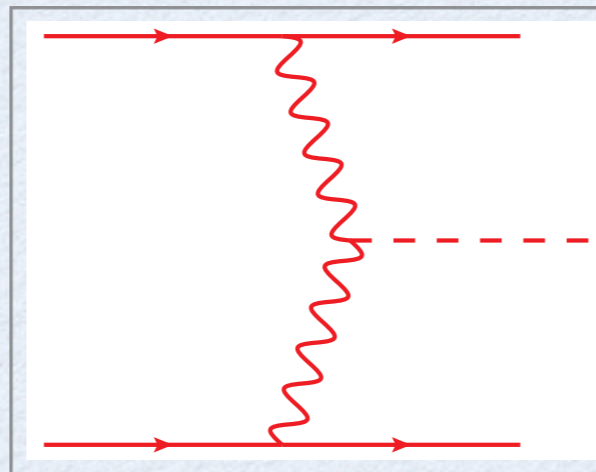
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CHANNELS?



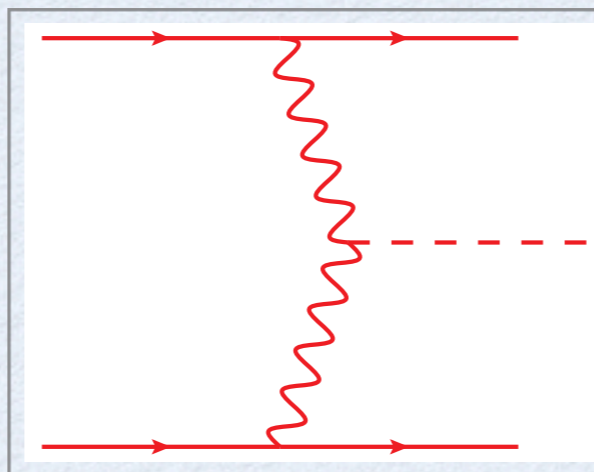
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 - 3rd try: ...without color exchange between the protons



CHANNELS?



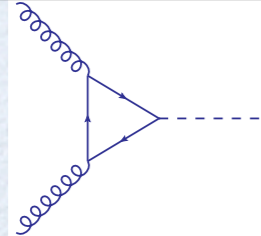
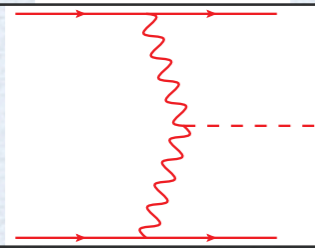
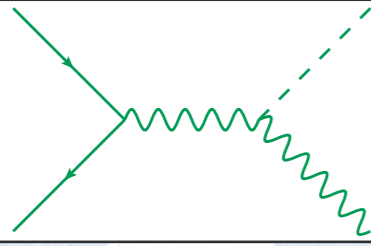
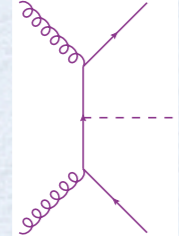
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- The definition of a “channel” is not so-trivial, interferences occur
- Higher order corrections contribute in mixing up
- Interferences are small (specially after imposing selection cuts) **but** precision on cross-sections is highly improving

- @LHC, we **never** directly measure a total x-section
- We have accurate predictions for total x-sections
- We need accurate predictions for less-inclusive observables:
 - cross-sections between cuts
 - distributions
 - ...

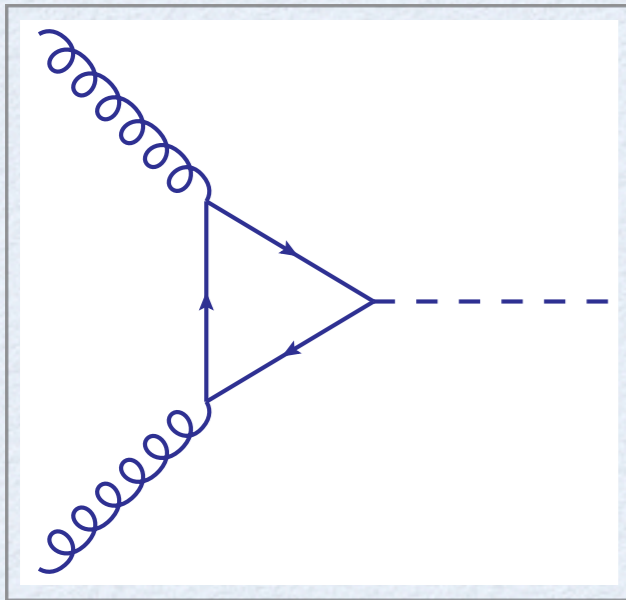
Where are we now?

	NLO QCD (parton level)	NLO QCD + PS	NLO EW (parton level)	NNLO (parton level)
		POWHEG MC@NLO	Degrassi et al. (2004)	Anastasiou et al. (2004)
	MCFM (and refs therein)	POWHEG	Ciccolini et al. (2007) HAWK	Can be done
		POWHEG MC@NLO	Kramer et al. (2003)	Almost done
	Benakker et al. (2002) Dawson et al. (2002) Dittmaier et al., (2004)	aMC@NLO (apr 2011)	Can be done	

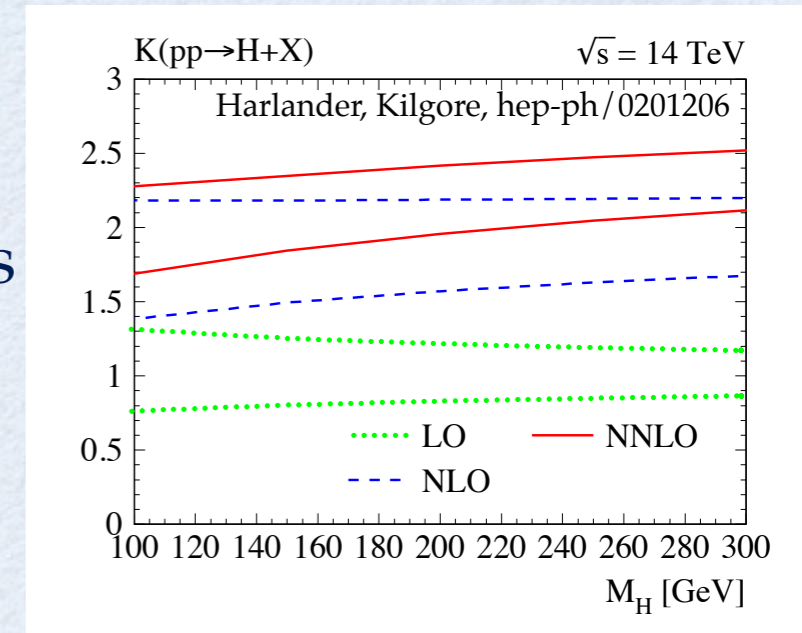
GLUON FUSION



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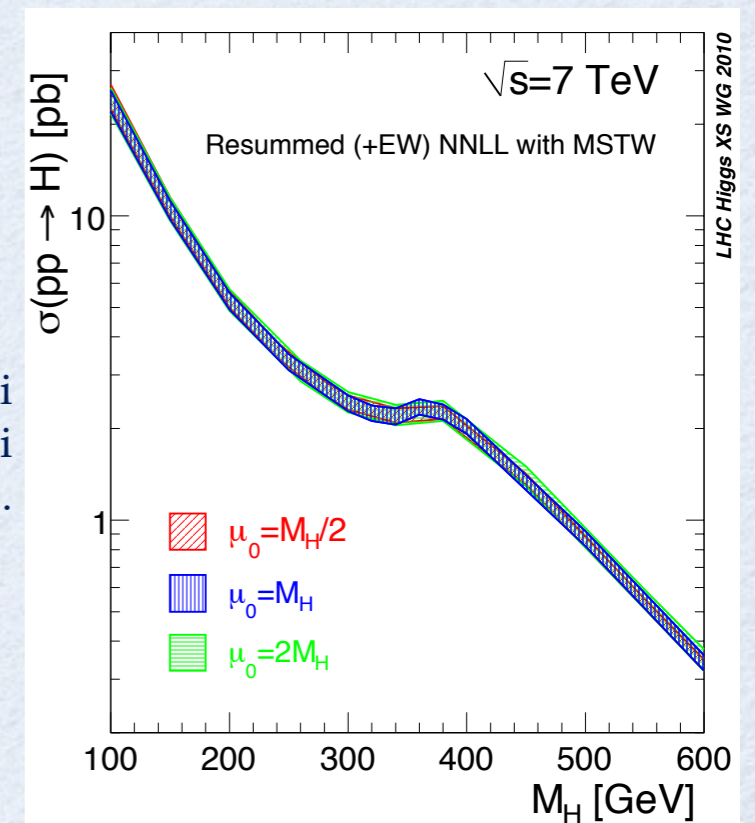
- Dominant production channel
- Large fixed order QCD corrections
 - $\Delta\text{NLO} \simeq 90\%$
 - LO prediction is not reliable
 - need for resummation



- Lot of QCD activity
 - look for clean decay channels ($\gamma\gamma$ or leptons)
- Currently known up to NNLO + NNLL QCD, NLO EW (finite top-mass up to NLO)

de Florian, Grazzini
Anastasiou, Boughezal, Petriello, Stoeckli

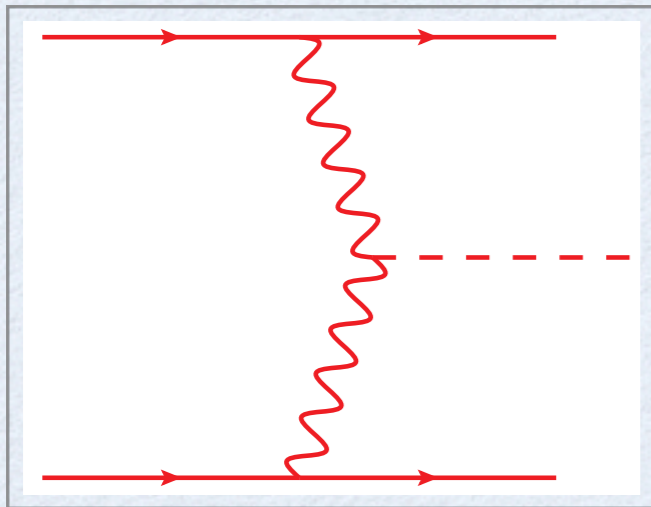
- Residual uncertainties on total cross-section $\sim 15\%$
- Sensitive to new heavy fermions (4th gen, ...)



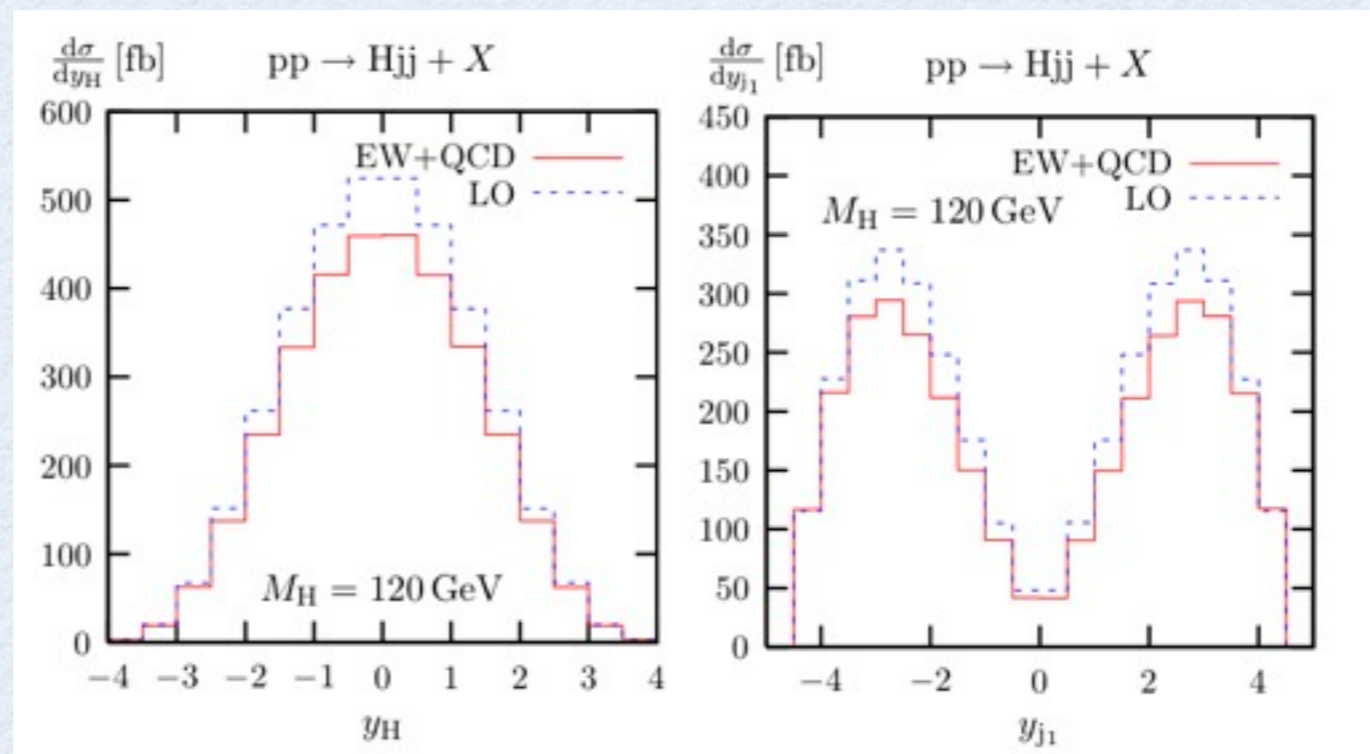
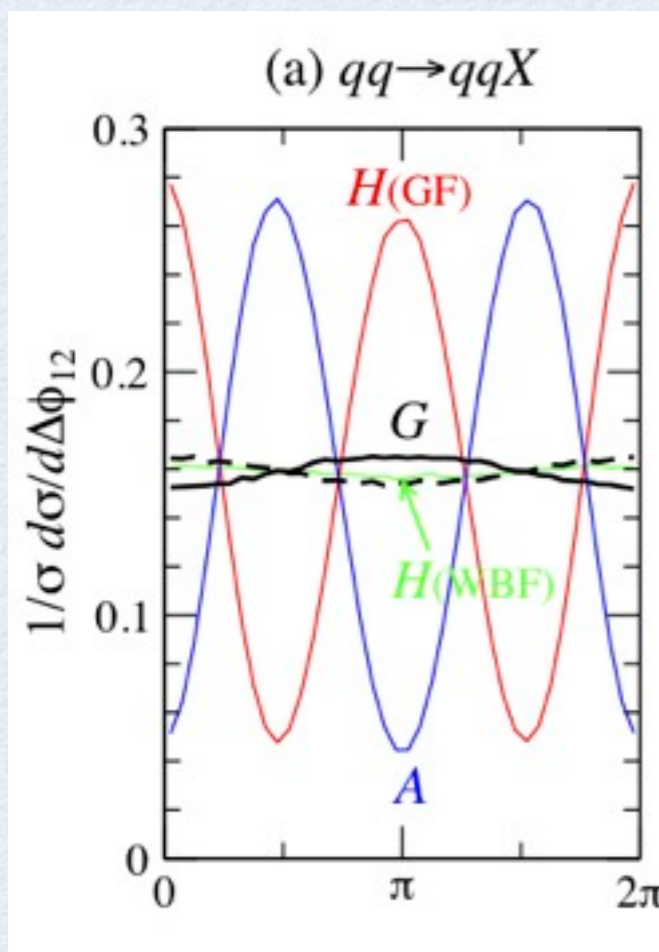
WEAK BOSON FUSION



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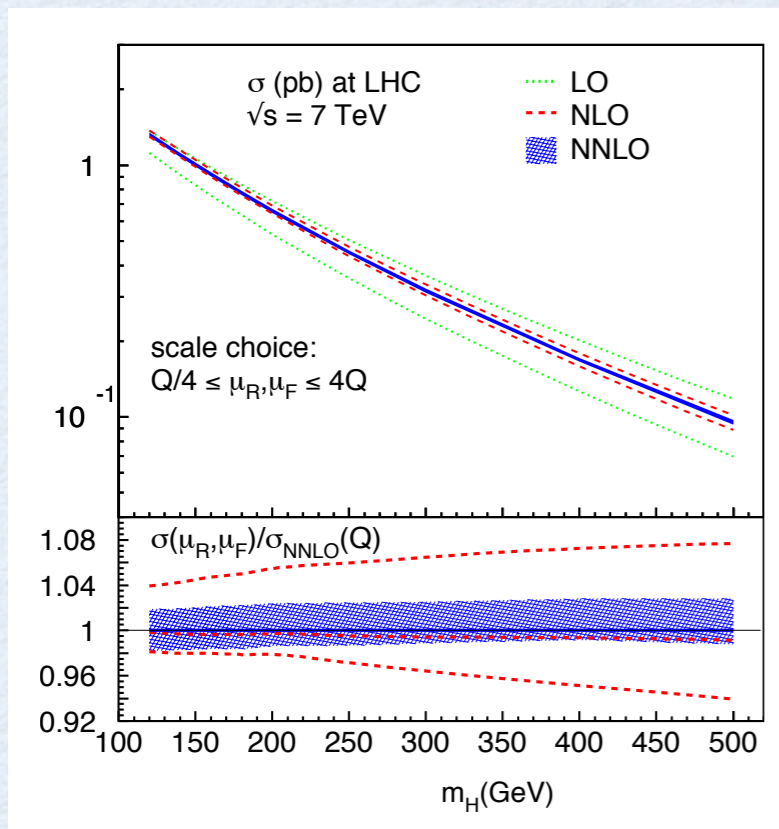
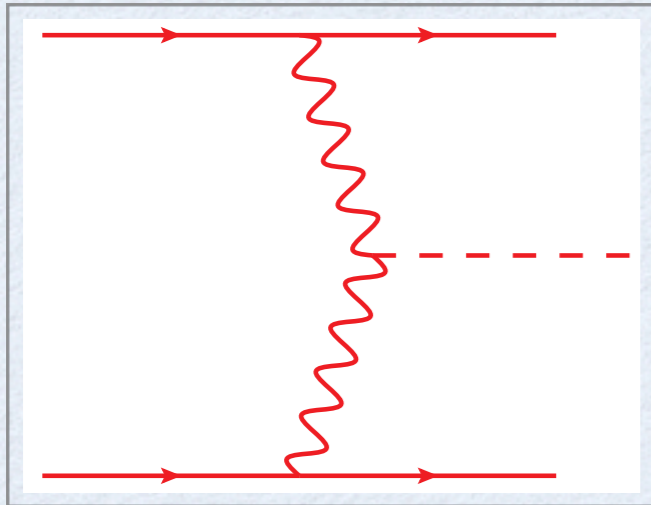
- Important channel in the whole mass range
- Clean experimental signature:
 - 2 Tagging jets
 - Little QCD activity in the central region (central jet veto)
 - Higgs mainly produced in the central region
 - Clean decay observation ($\tau\tau$ feasible): extraction of couplings
 - Jet correlations: extra discrimination power
 - Crucial to separate VBF from gluon fusion



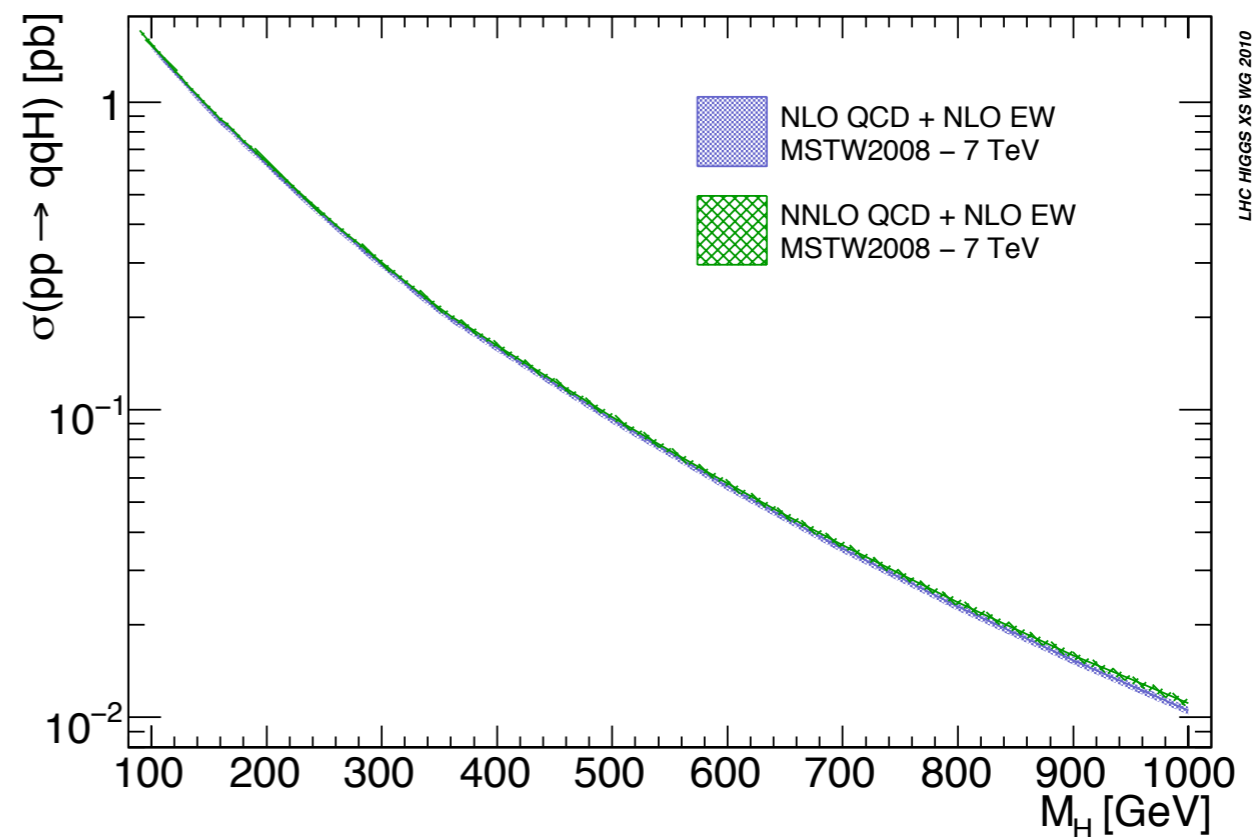
WEAK BOSON FUSION



- QCD corrections are small
 - known up to NNLO QCD + NLO EW
 - NLO QCD + EW: Ciccolini, Denner, Dittmaier
 - NNLO QCD: Bolzoni, Maltoni, Moch, MZ
- Small residual uncertainties
- (Probably) The best known x-sect @LHC



Bolzoni, Maltoni, Moch, MZ, arXiv:1003.4451



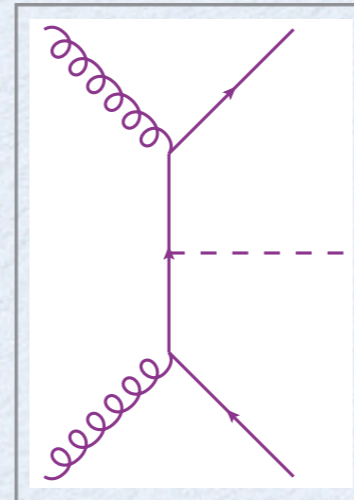
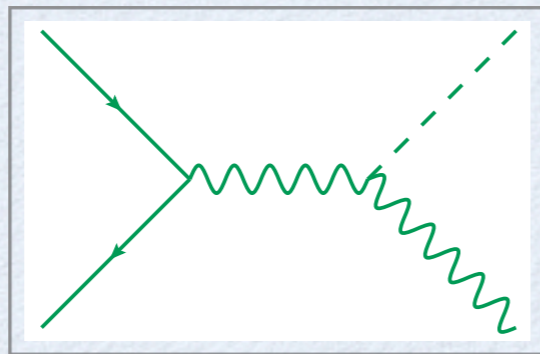
VH, $\tau\tau$ PRODUCTION



VH, TT̄H PRODUCTION



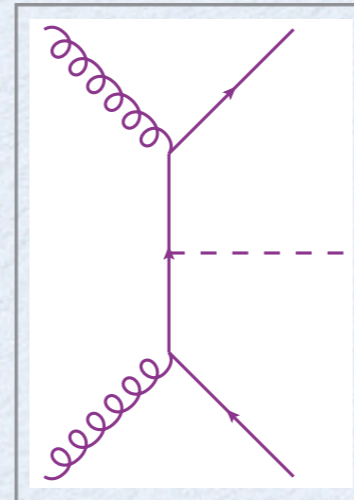
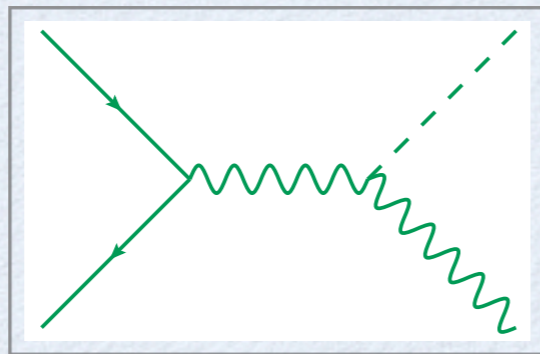
- Unique chances to extract Higgs coupling to top and vector bosons
- Considered (till 2008-2009) unfeasible channels @LHC
 - Small x-sect, quickly decreasing with the Higgs mass
 - Too large background for $H \rightarrow b\bar{b}$ decay (other BRs too small)



VH, ttH PRODUCTION

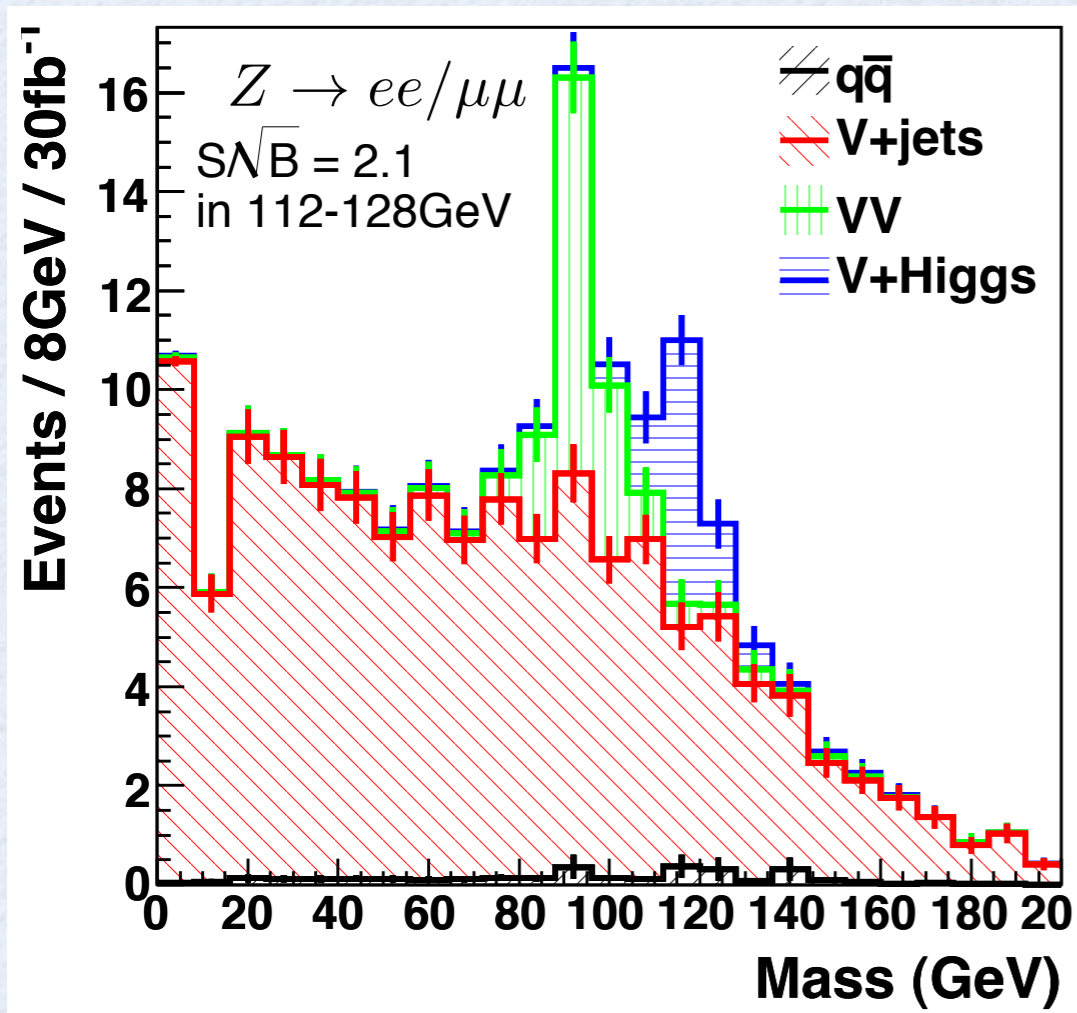


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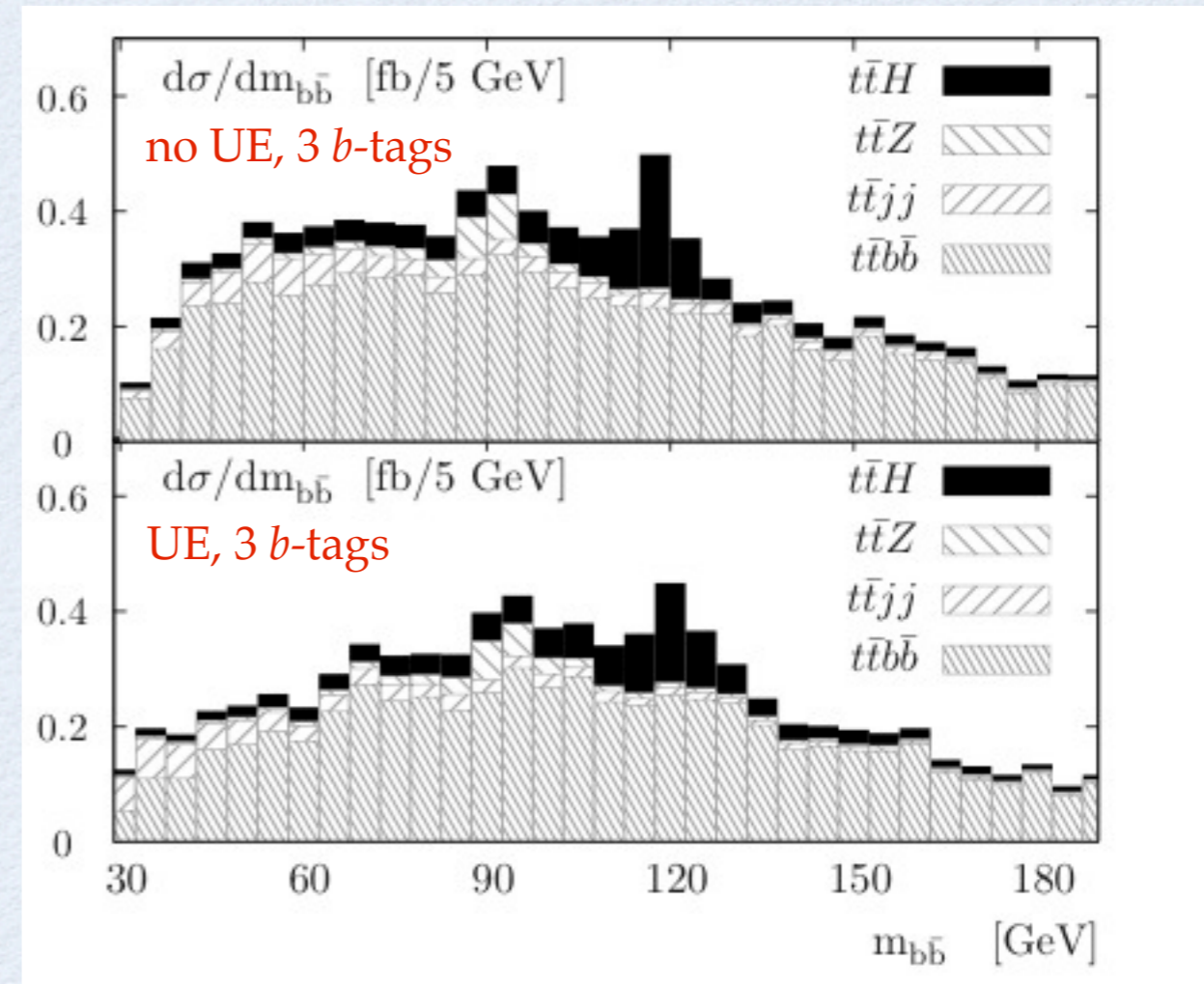


- **fat-jets:** VH and ttH production back on the scene!
 - Look for boosted (high- p_T) Higgses and tops, which appear as fat jets
 - Look inside the fat jet structure (undo clustering) to reconstruct the decay
 - High- p_T particles are produced at central rapidities (easier to tag)
 - High background reduction, VH possible **discovery** channel for a 120 GeV Higgs at 30 fb^{-1} , ttH at 100 fb^{-1} (@ 14 TeV)

VH, $\tau\tau H$ PRODUCTION

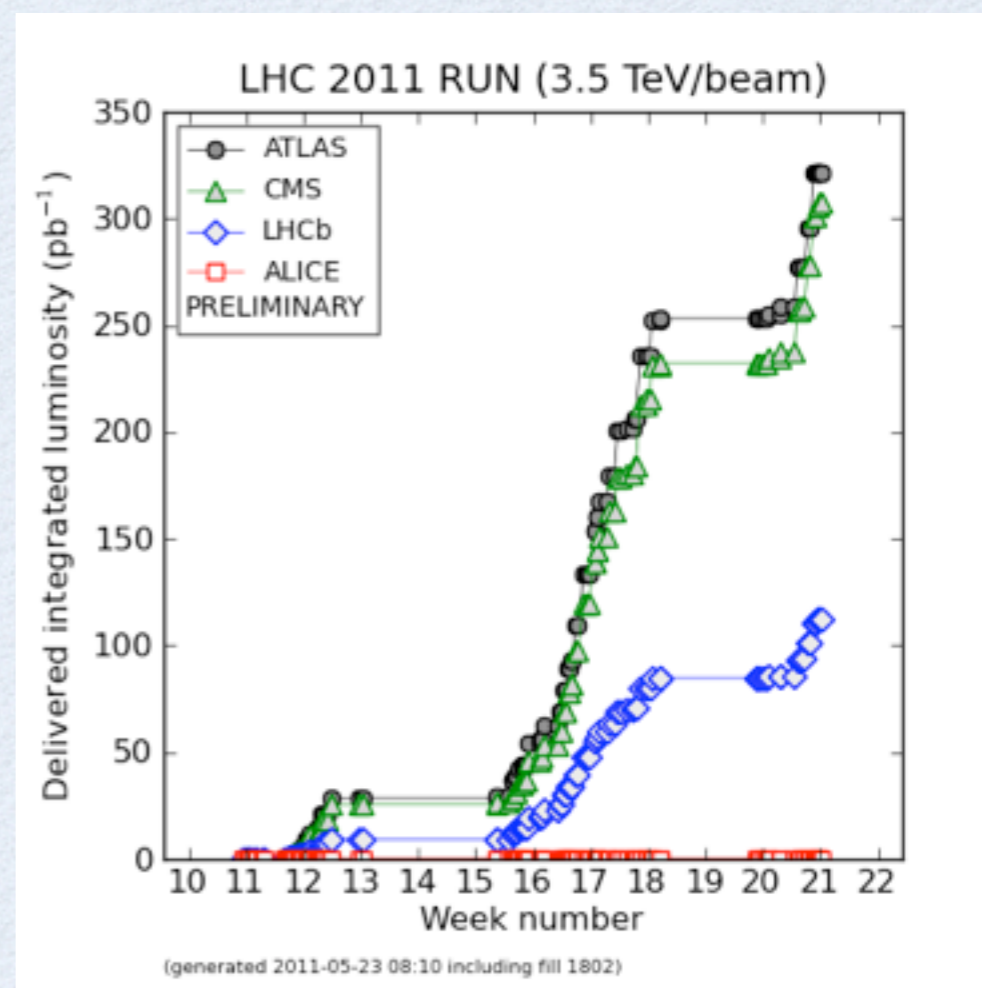


Butterworth, Davison, Rubin, Salam, arXiv:0802.2470



Plehn, Salam, Spannowsky, arXiv:0910.5472

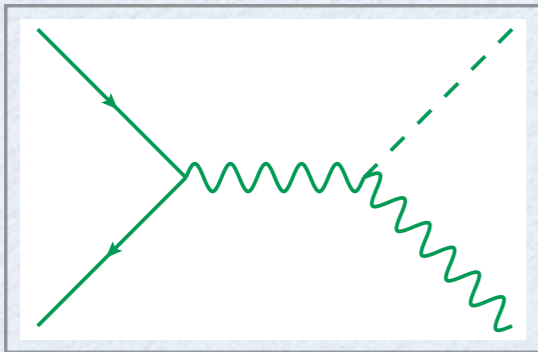
- LHC is running and taking lot of data
 - 100 pb^{-1} per week @ATLAS, CMS
- We do not only want to discover the Higgs, but also to measure its properties
 - Need for precise theoretical predictions
 - Interplay of **all** production/decay channels
 - fat-jets “revolution”
- Much progress has been done recently to push theoretical uncertainties as low as possible
 - **all** production channels @NLO QCD+PS
 - total rates known to higher orders (NLO EW, NNLO QCD)
 - all decay channels @NLO QCD+EW
 - uncertainties small, except for heavy quarks



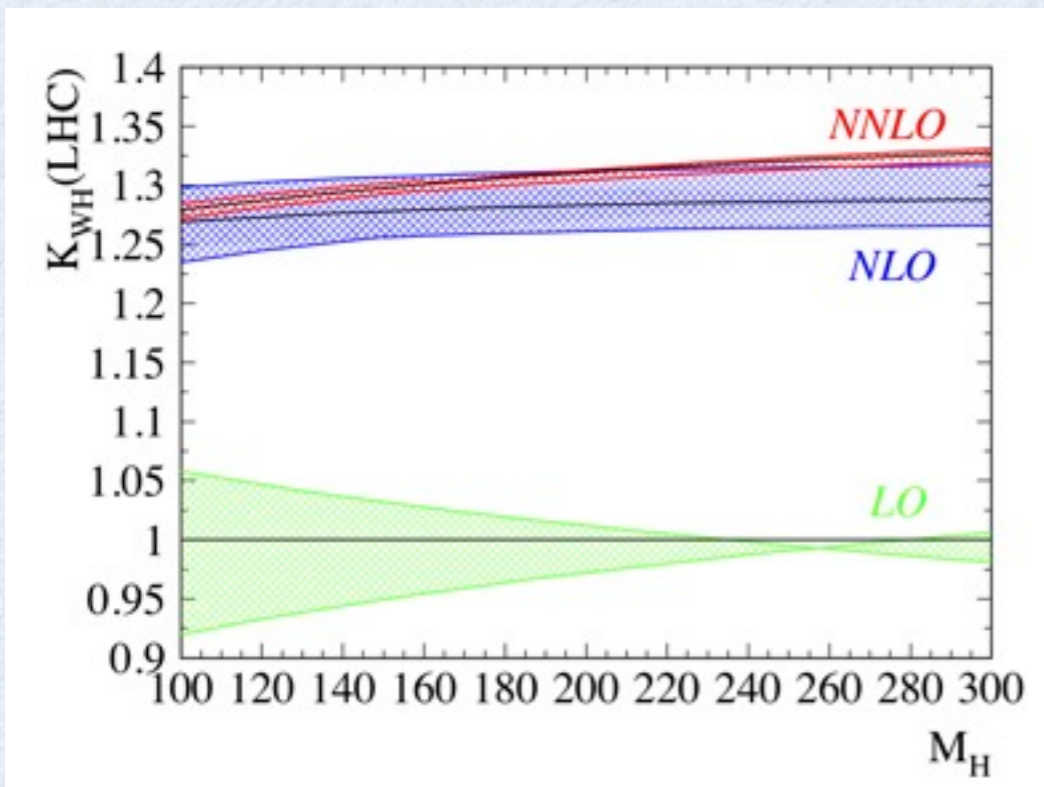


THANK YOU!

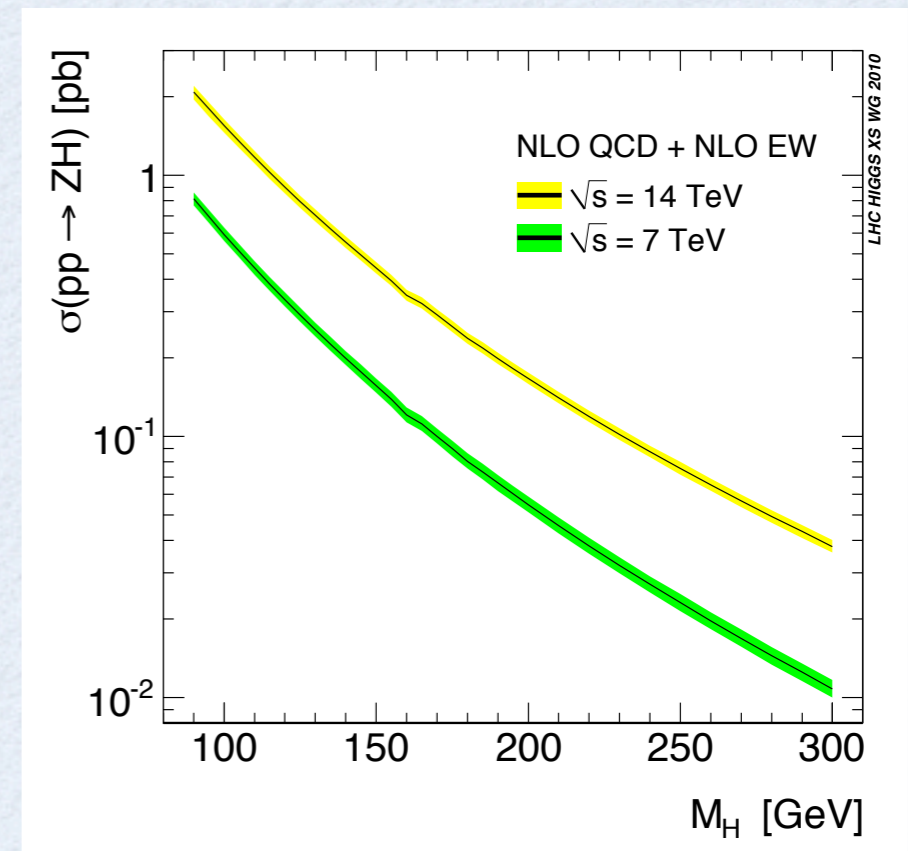
VH: UNCERTAINTIES



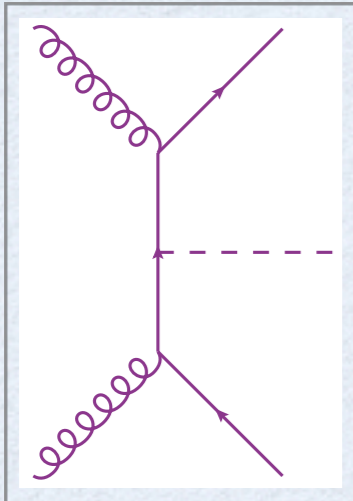
- EW corrections negative, 5-10% of total cross-section
- Residual uncertainty (NNLO QCD + NLO EW):
2-3% (scale), 4-5% (PDF)



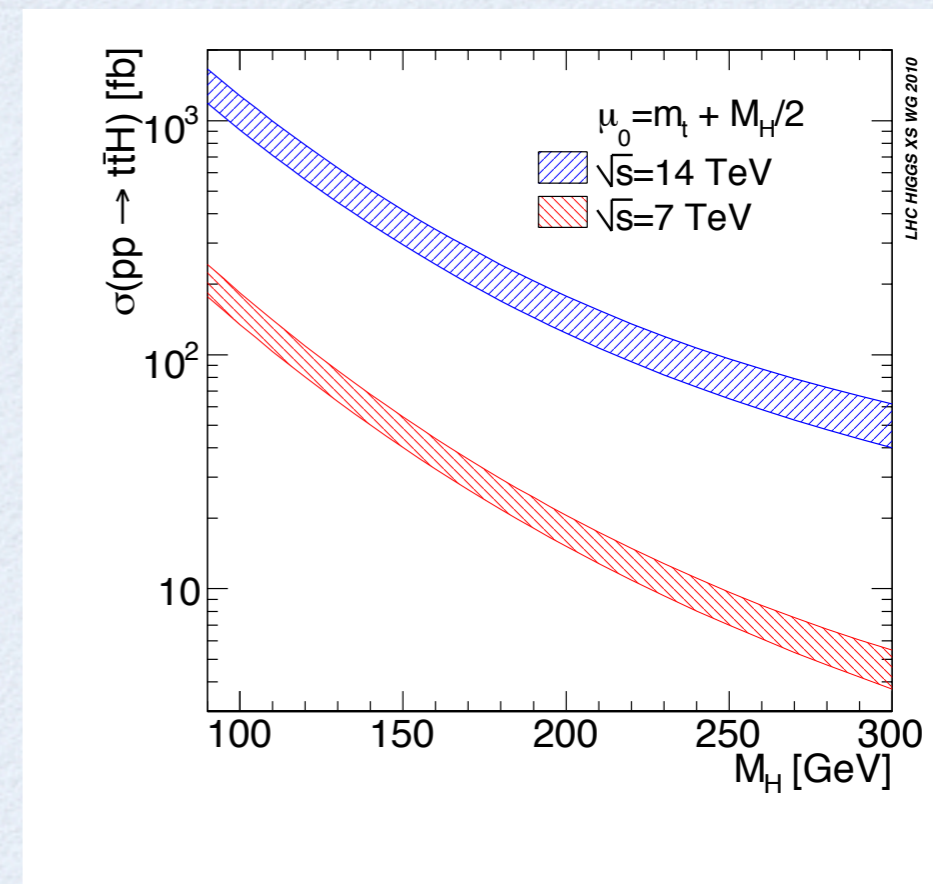
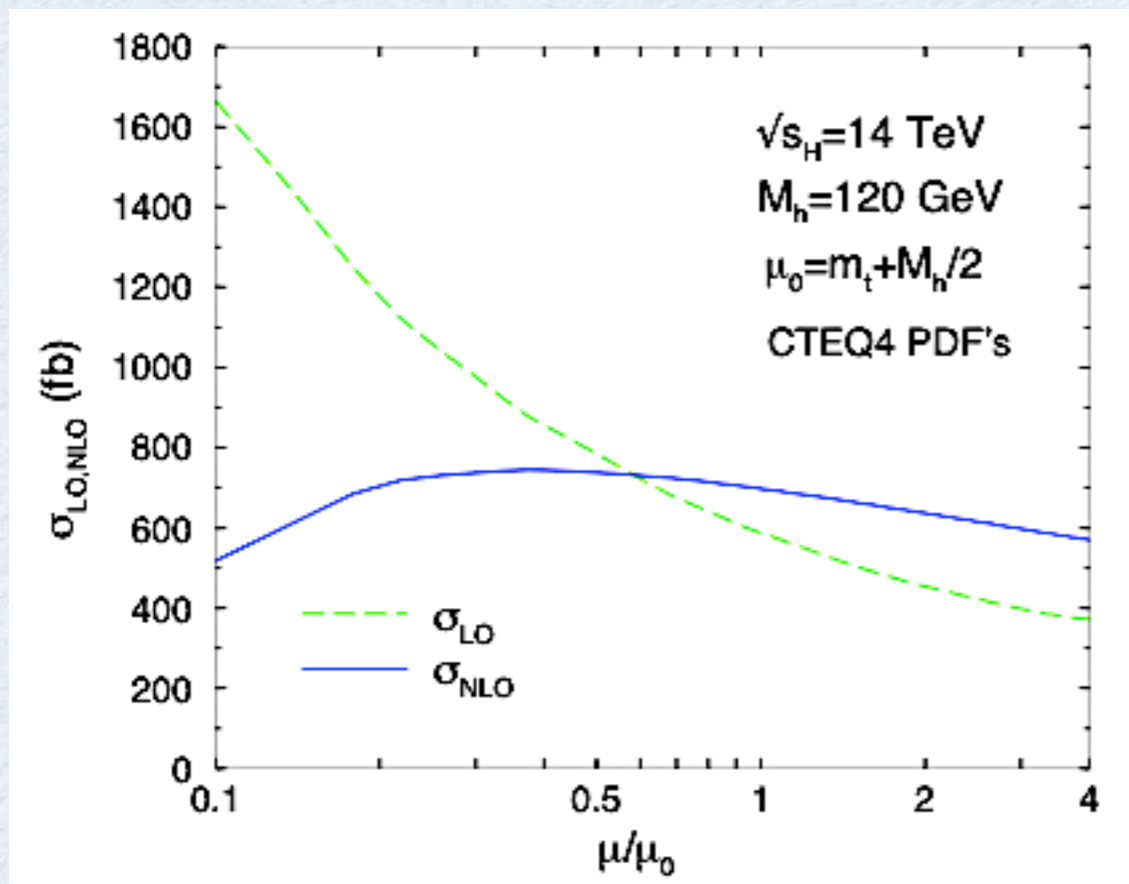
Brein, Djouadi, Harlander, hep-ph/0307206



ttH: UNCERTAINTIES



- Scale uncertainties greatly improve from LO to NLO
- Residual uncertainty: 10-15%



Dawson, Orr, Reina, Wackerth, hep-ph/0211438