The LHC Higgs Cross Section Working Group:

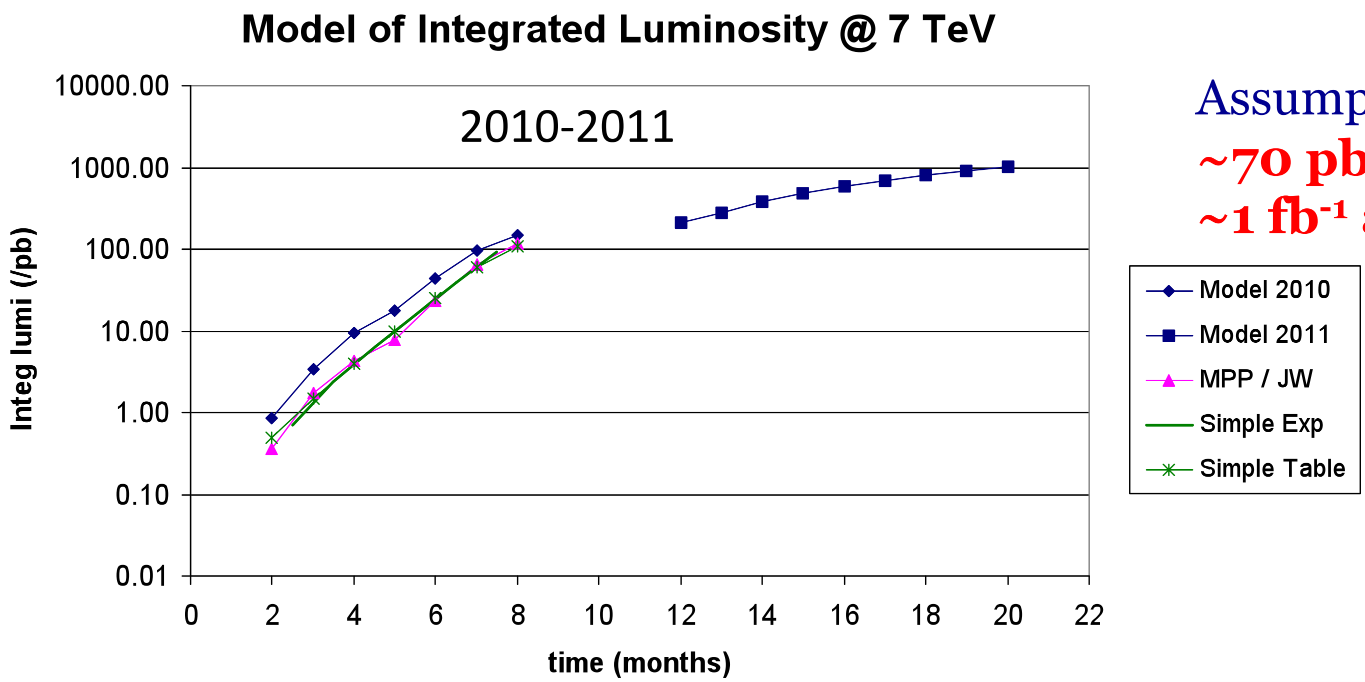
Results and Future Goals

Outline

- Why precision Higgs physics now
- The status of the theoretical calculation and the results at 7 TeV: Cross Section, BR and uncertainties.
- The future work

Thanks to: S. Dittmaier, G.Passarino, R.Tanaka
+ all the contacts and members of the LHC Higgs
Cross Section Working Group

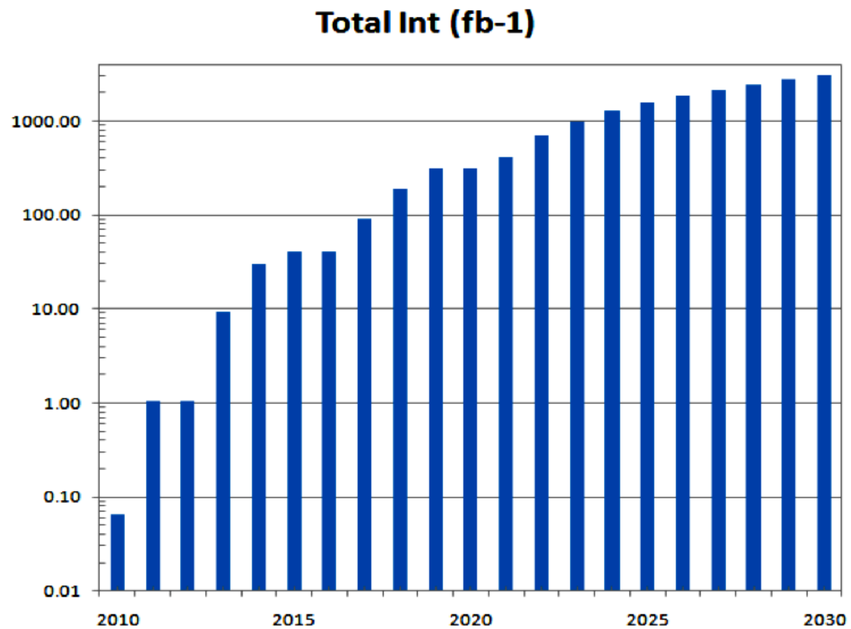
LHC schedule



Assumptions used for planning:

~70 pb^{-1} at the end of 2010

~1 fb^{-1} at the end of 2011



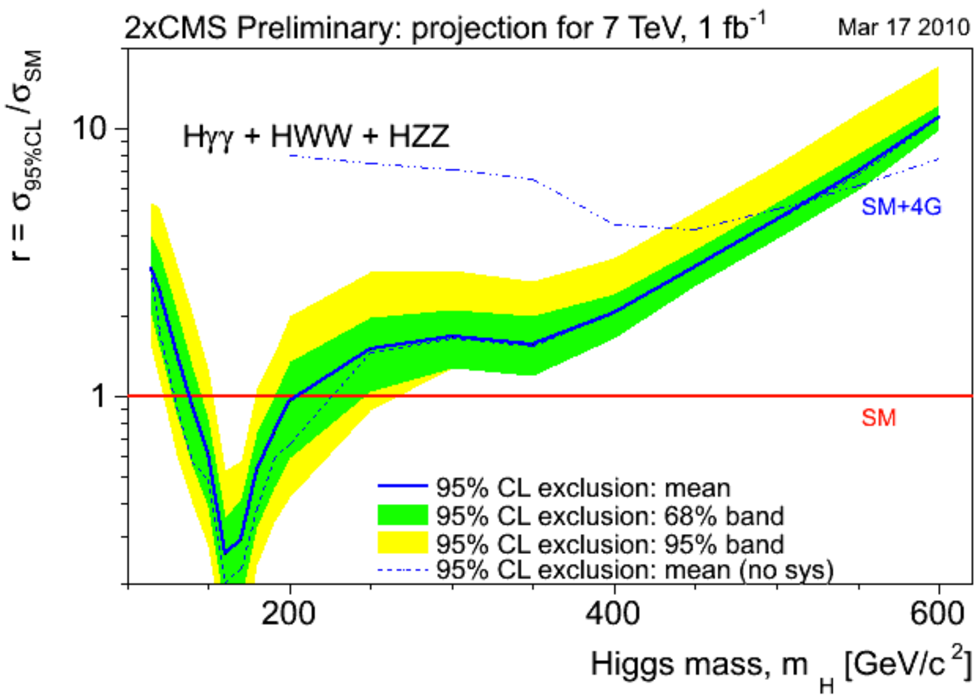
Then: long shutdown to replace the splices. Restart in ~2013 aiming at 14 TeV

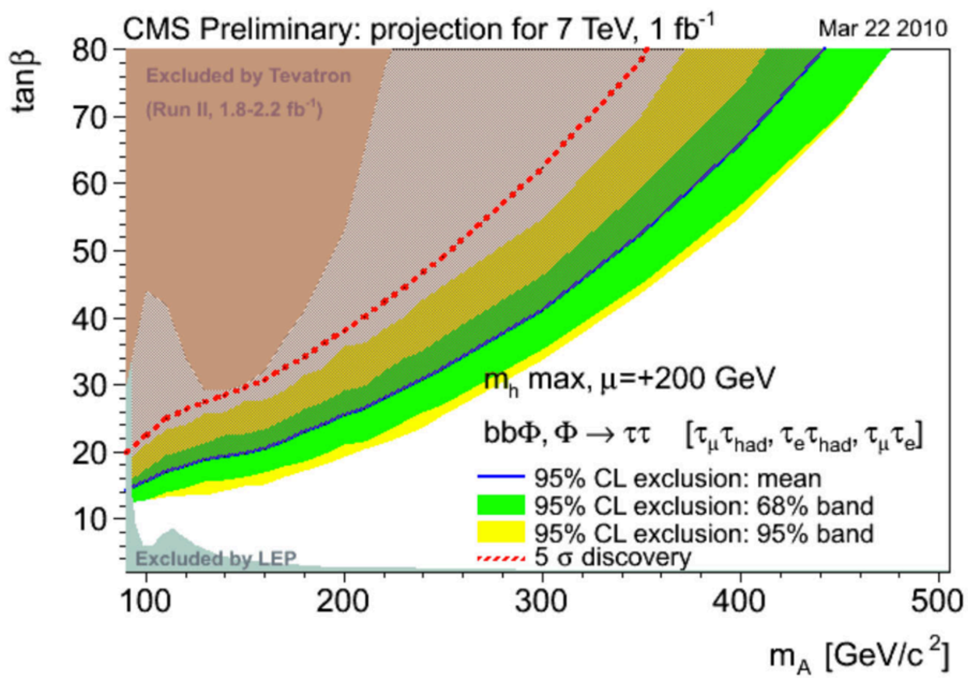
3000 fb^{-1} on tape by the end of the life of the LHC!

250-300 fb^{-1} /year in the second half of the LHC life…

Why ?

- By the end of the 7 TeV run, the luminosity collected will hopefully allow us to probe some Higgs-mass value





The goal of the group

- Access the best theory predictions for the Higgs Cross Section and Branching Ratio

- Experiments will coherently use the common inputs based on the interaction with the theory to facilitate the combination of the individual results

The Higgs XS WG

Preparatory workshop in Torino Nov. 23-24, 2009

Creation announced on January 2010

Kickoff meeting on February 2010

Inauguration workshop in Freiburg April 12-13, 2010

Second workshop at CERN July 5-6,2010

Next workshop in Bari, November 4-5, 2010

Task: SM and MSSM Higgs Cross Section and BRs

- Use the same Standard Model input parameters
- Strategy on uncertainties (scale, α_s, PDF, etc.)
- Monte Carlo at NLO for the signal
- Define pseudo-observables
- Cross sections of background in Higgs region

In the future: Beyond SM and MSSM, Other SUSY scenario NMMSM, Invisible Higgs, Higgsless, etc.

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

Overall Contacts

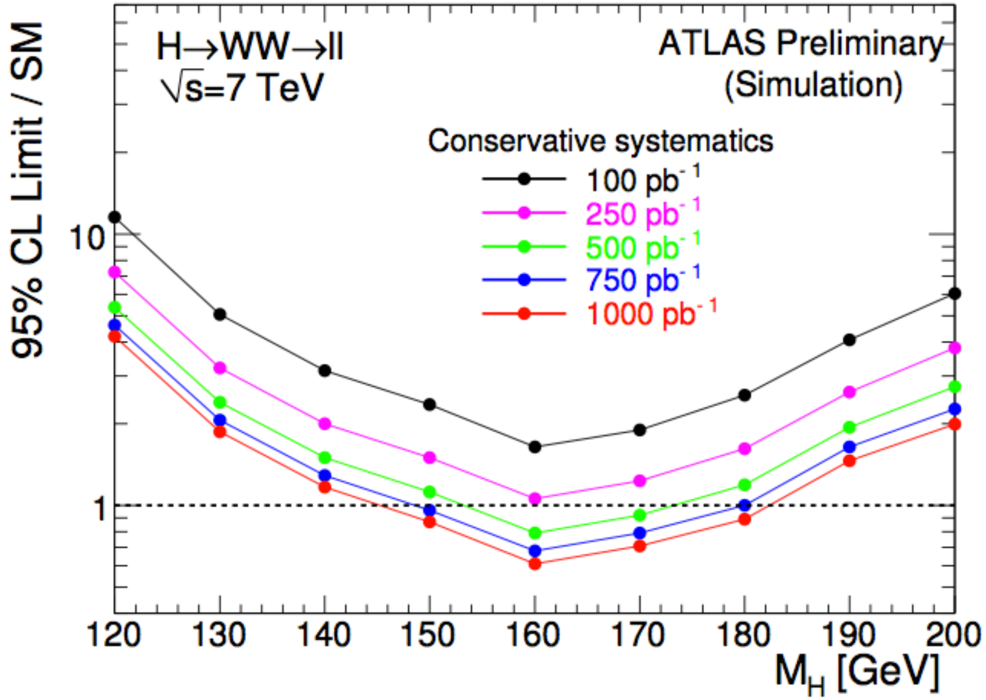
ATLAS	CMS	THEORY	
Reisaburo Tanaka (LAL)	Chiara Mariotti (Torino)	Stefan Dittmaier (Freiburg)	Giampiero Passarino (Torino)

Subgroup Contacts and Link for Subgroup Wiki

Group	ATLAS	CMS	LHCb	THEORY	
1. ***ggF***	Jianming Qian (Michigan)	Fabian Stöckli (CERN)		Massimiliano Grazzini (Firenze)	Frank Petriello (Wisconsin)
2. ***VBF***	Daniela Rebuzzi (Pavia) Sinead Farrington (Oxford)	Christoph Hackstein (Karlsruhe)		Ansgar Denner (PSI)	Carlo Oleari (Milano-Bicocca)
3. ***WH/ZH***	Giacinto Piacquadio (CERN)	Jim Olsen (Princeton)	Clara Matteuzzi (Milano-Bicocca)	Stefan Dittmaier (Freiburg)	Robert Harlander (Wuppertal)
4. ***ttH***	Simon Dean (UCL)	Chris Neu (Virginia)		Laura Reina (Florida)	Michael Spira (PSI)
5. ***MSSM neutral***	Markus Warsinsky (Freiburg)	Monica Vazquez Acosta (IC)		Michael Spira (PSI)	Georg Weiglein (DESY)
6. ***MSSM charged***	Martin Flechl (Freiburg)	Sami Lehti (Helsinki)		Michael Krämer (Aachen)	Tilman Plehn (Heidelberg)
7. ***PDF***	Joey Huston (Michigan State)	Kajari Mazumdar (TIFR)		Stefano Forte (Milano)	Robert Thorne (UCL)
8. ***Branching ratios***	Daniela Rebuzzi (Pavia)	Ivica Puljak (Split)		Ansgar Denner (PSI)	Sven Heinemeyer (IFCA)
9. ***NLO MC***	Jae Yu (Texas)	Marta Felcini (UCLA/IFCA)		Fabio Maltoni (Louvain)	Paolo Nason (Milano-Bicocca)
10. ***Pseudo-observables***	Michael Dührssen (CERN)	Marta Felcini (UCLA/IFCA)		Sven Heinemeyer (IFCA)	Giampiero Passarino (Torino)

The first Higgs search at LHC

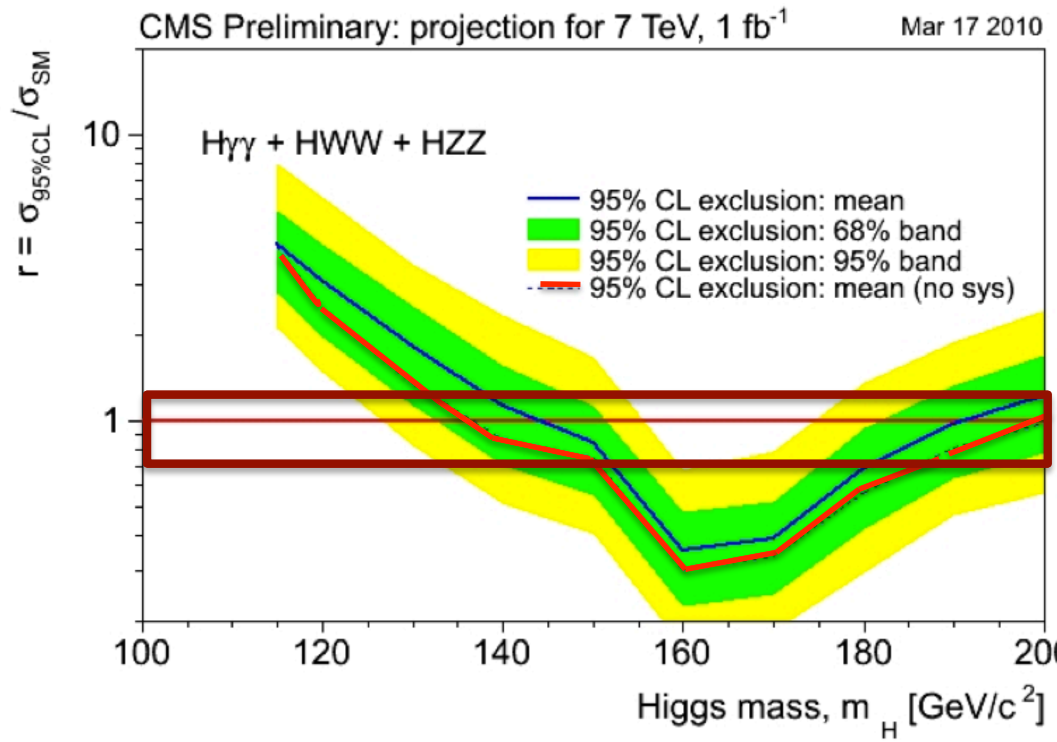
- The analyses from the experiments will first provide independent exclusions.



- To produce similar plot we will need: the experimental "curve" and the theoretical prediction, i.e. the line at "1".

Uncertainties

- The experimental uncertainties will determine the blue/red lines + the green/yellow band
- The theoretical uncertainties on the signal will determine where is the horizontal line. The theoretical uncertainties on the background will contribute to the red/blue line +green/yellow band



Theory Uncertainties

- Common and correlated theoretical inputs, like cross sections, PDF, SM inputs etc. are discussed in the group.
- The goal is to give precise **COMMON INPUTS** to the experiments to facilitate the combination.
- The experimental uncertainties are **not** discussed in the group.

The Higgs Signal

- All the Higgs production modes cross sections have been calculated at NLO or at NNLO
- ALL THE **inclusive Cross Sections at 7 TeV** have been computed and the uncertainty estimated
- The uncertainties have been computed in a uniform manner across the channels:
  - PDF: the groups followed the PDF4LHC prescription.
  - α_S: added in quadrature to the PDF variation. Still debate on the total uncertainty:

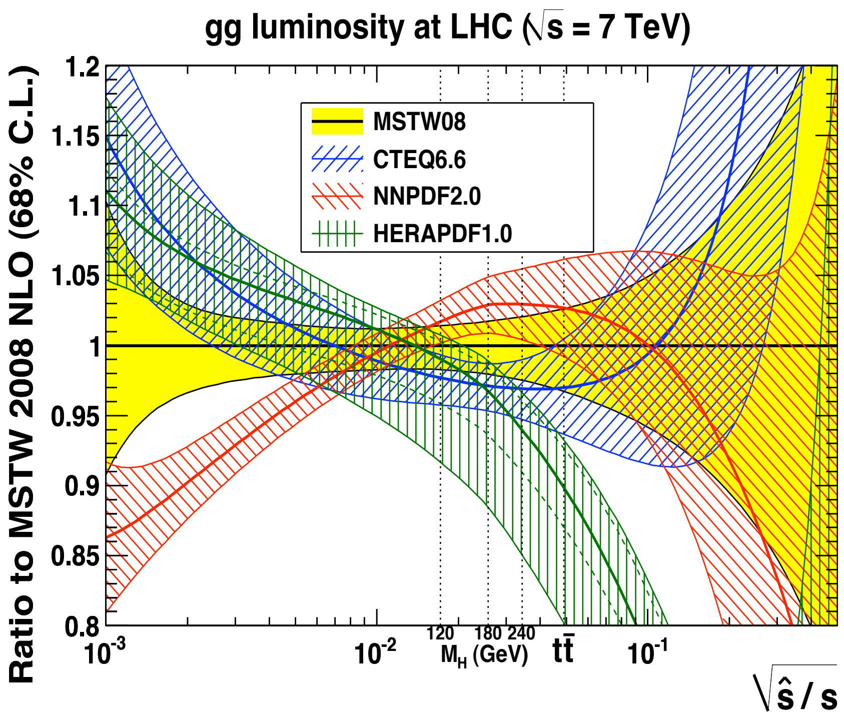
    $\delta\alpha_S = 0.0007 - 0.002 - 0.0044$?

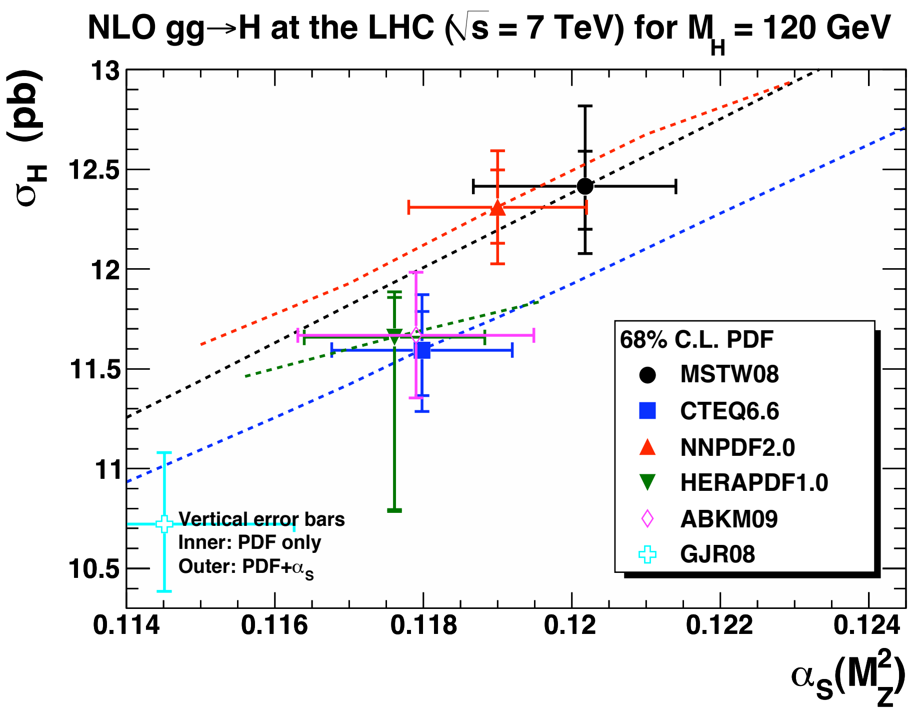
    → should be solved!
  - QCD scale: it gives the largest of the effect. It has been varied with reasonable criteria in order to cover the "unknows"

PDF4LHC prescription

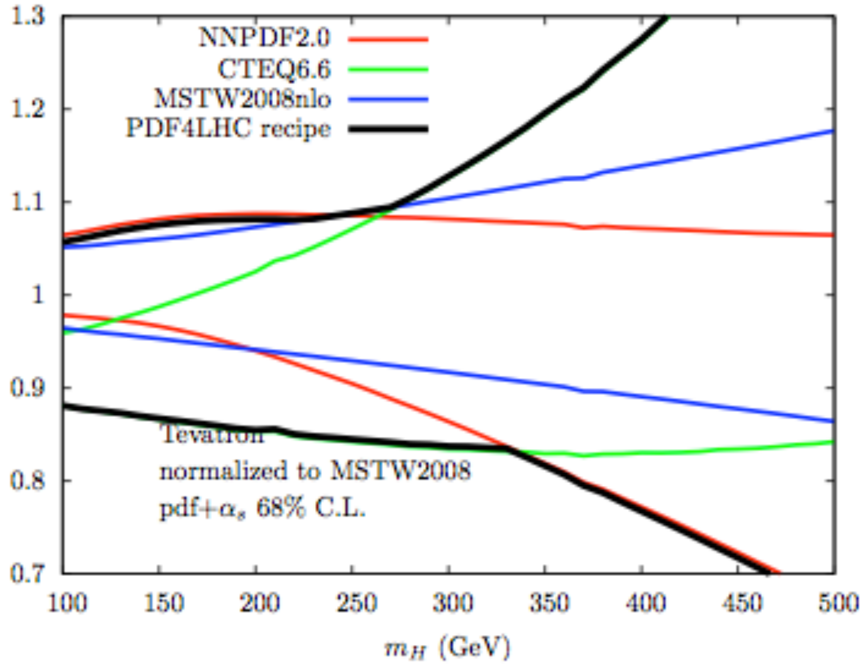
- 3 PDF are used to compute cross sections at NLO: MSTW2008, NNPDF, CTEQ. Each of them at their preferred α_S value.

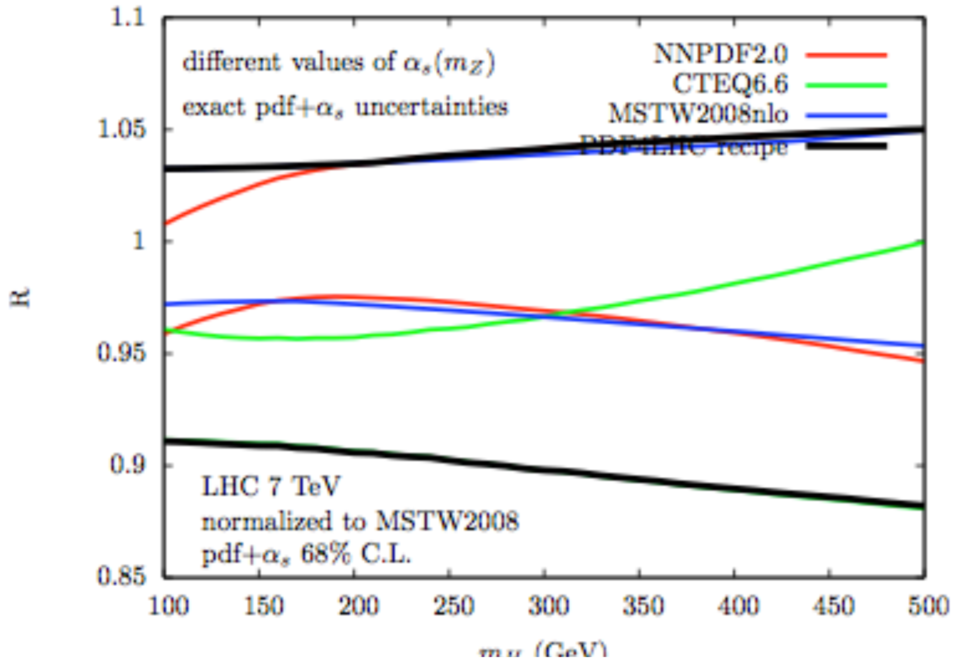
- 1 PDF is used for NNLO: MSTW2008 (but check with ABKM and soon with NNPDF)





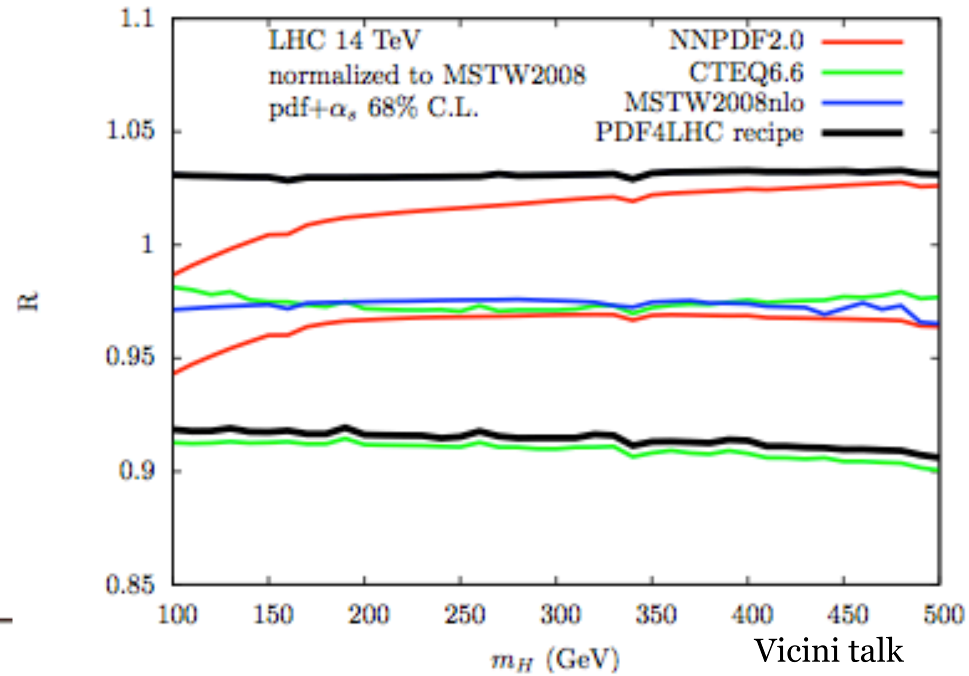
gluon gluon luminosities





- Bands including PDF+α_S uncertainty (norm to MSTW2008)
- The ENVELOPE represents the results of the PDF4LHC recipie
- LHC 7 TeV:

  5.5% (MH=100) → 6.5%(MH=250)
- $\delta\alpha_S^{NLO}$(68%)= 0.0012

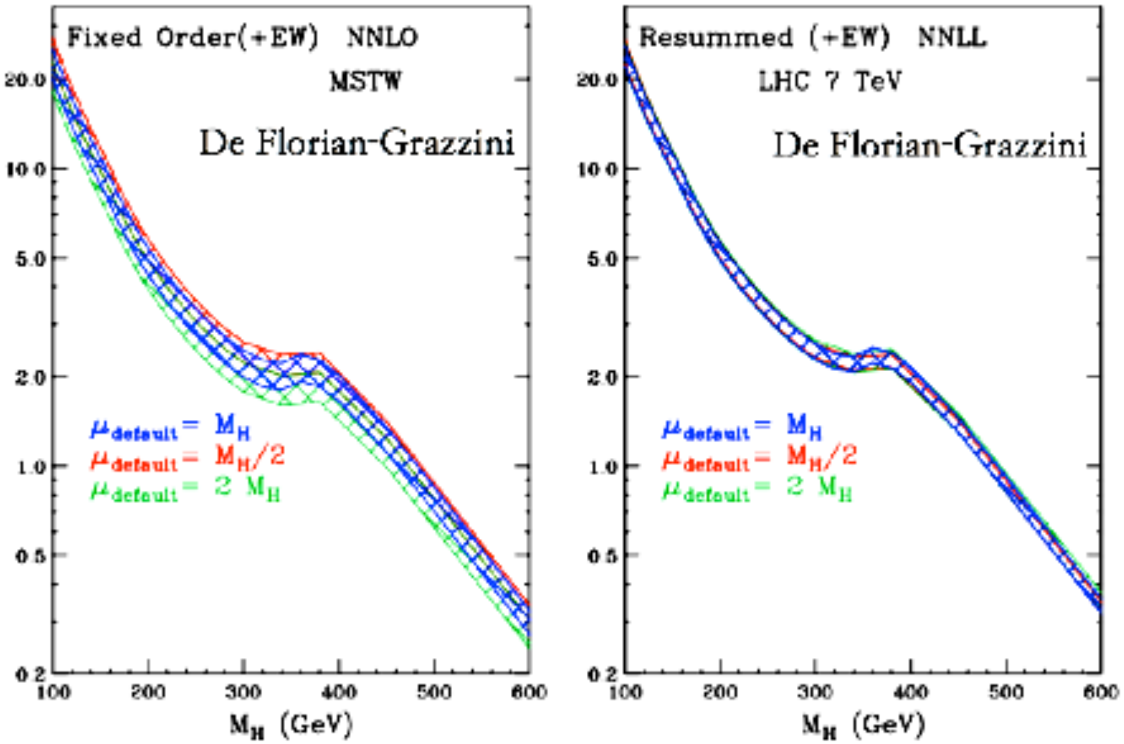


Vicini talk

QCD Scale Choice

Scale uncertainties computed with independent variations of renormalization and factorization scales around some default scale μ_D (with $0.5\ \mu_D < \mu_F, \mu_R < 2\ \mu_D$ and $0.5 < \mu_F/\mu_R < 2$).

What's the 'right' default scale μ_D?

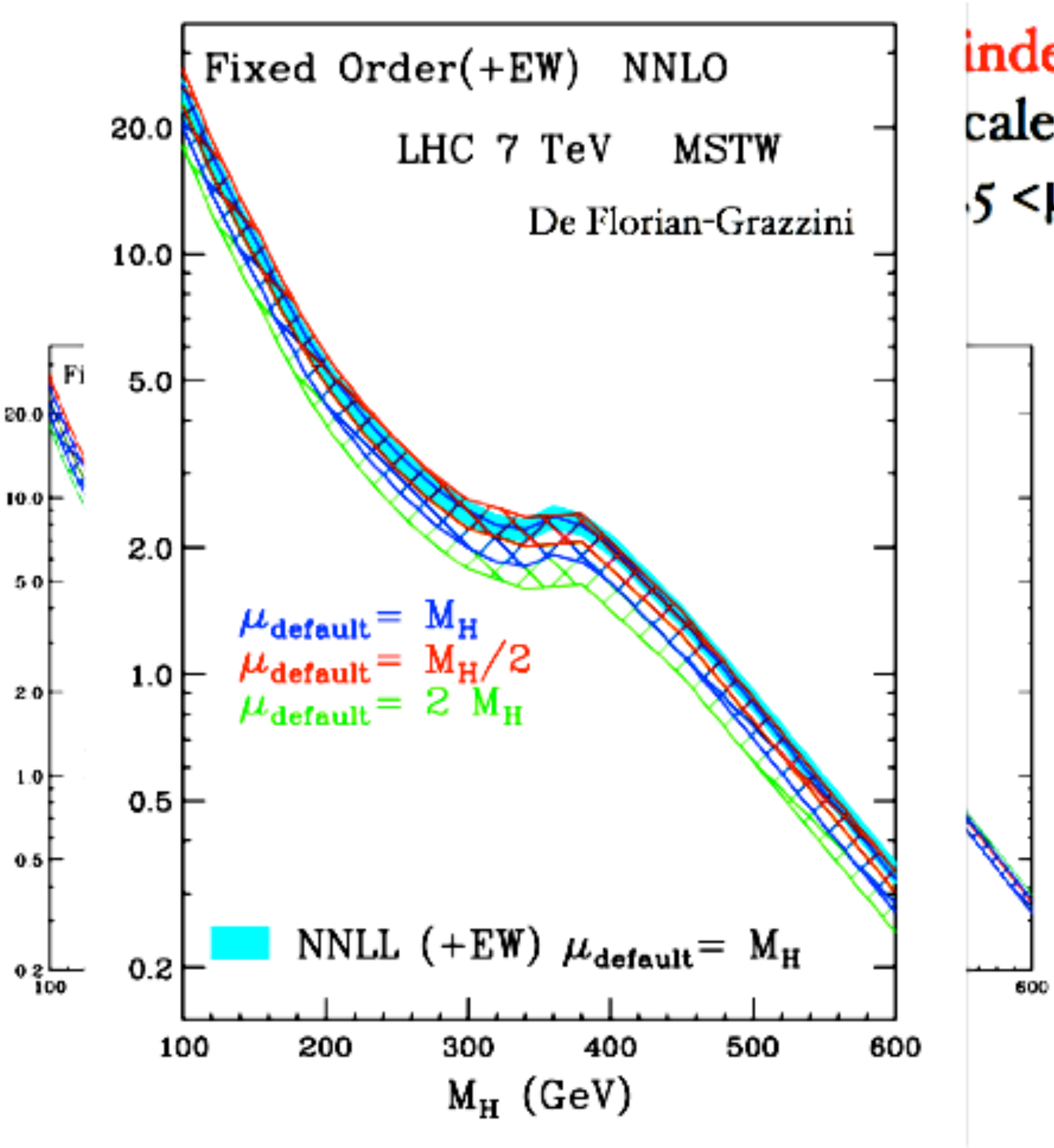


Resummed calc. not very sensitive to default scale choice (right).

Fixed-order calc. more sensitive (left part).

Petriello talk

QCD Scale Choice



independent variations of
cales around some default scale
.5 < μ_F/μ_R < 2).

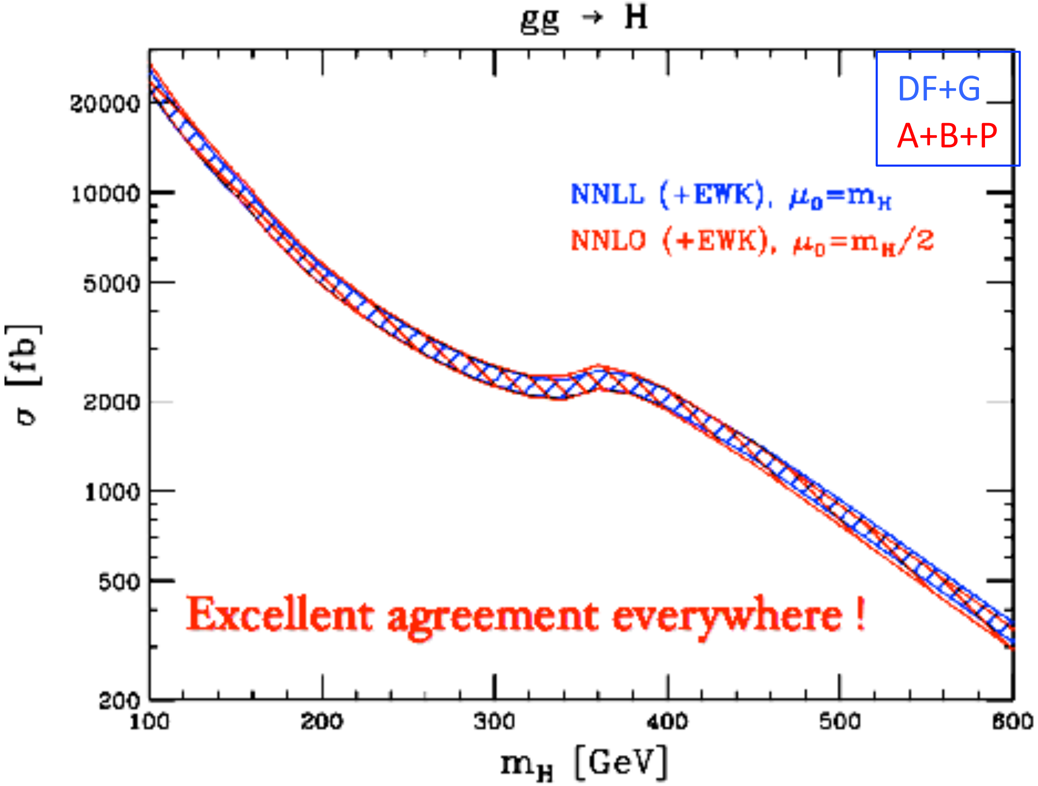
Resummed calc. not very sensitive to default scale choice (right).

Fixed-order calc. more sensitive (left part).

NNLL using $\mu_D = M_H$ (magenta band) agrees very well with NNLO using $\mu_D = M_H/2$ (red band). These are our default choices.

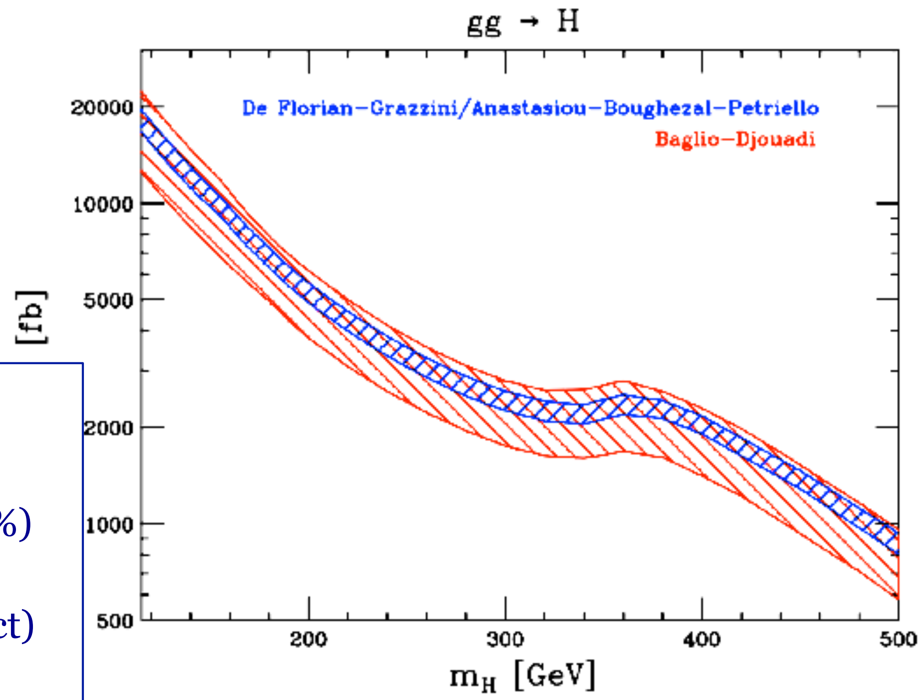
Petriello talk

gg fusion at NNLO



Uncertainty from:

top mass effect	1%
Bottom mass effect	2%
EW effect	1 ÷ 5 %
Scale	10 ÷ 3%
PDF+α_S	3 ÷ 9%



3 different groups - in the large m_{top} limit:

De Florian-Grazzini: NNLL

(soft-gluon resummation -> 6-10% - and EW effect -> 5%)

Anastasiou et al : NNLO

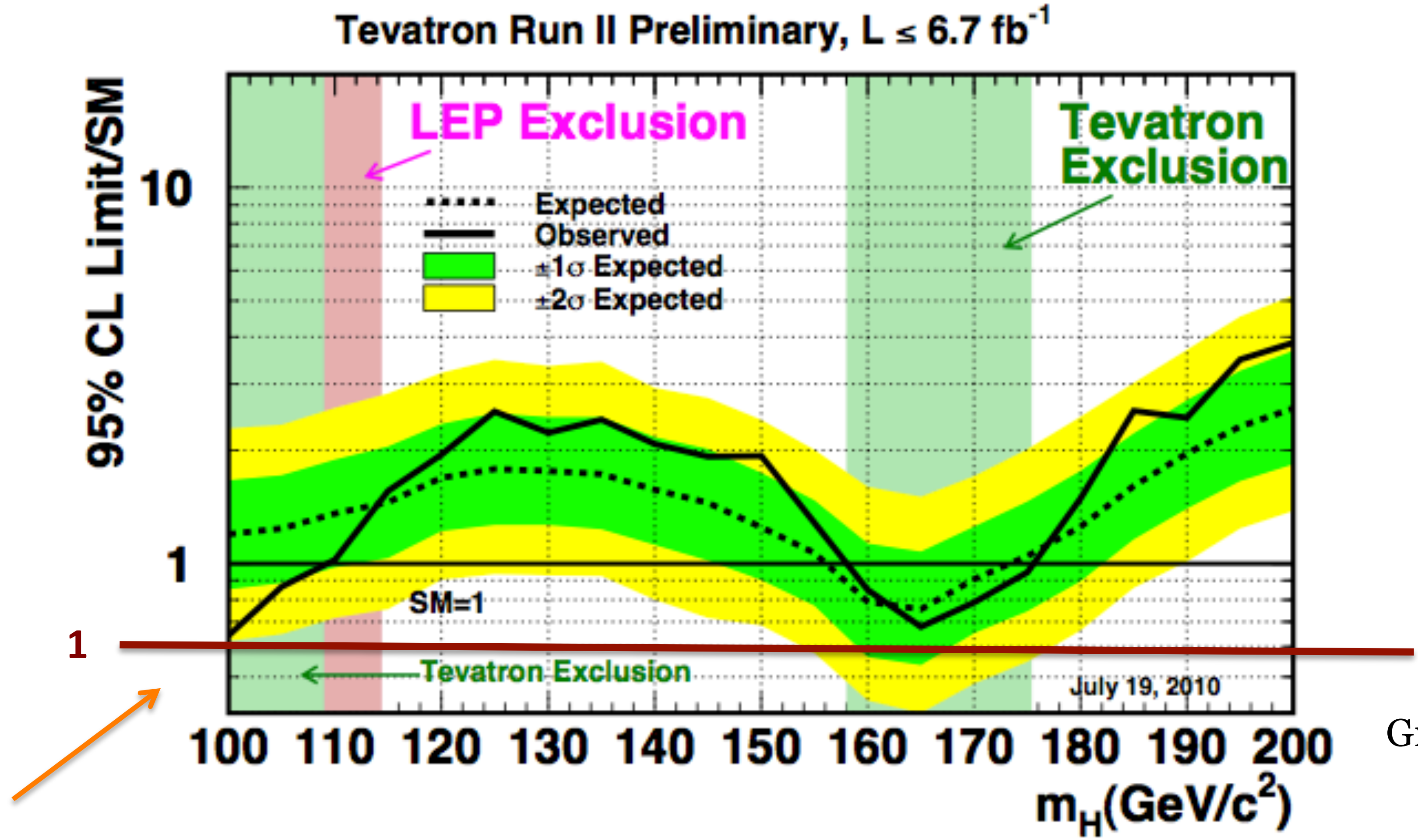
(resummation mimic by $\mu_F = \mu_R = mH/2$ –and EW effect)

Baglio - Djouadi

(EW effects included – no resumm.)

EW correction, Passarino et al.

The relevance of higher order

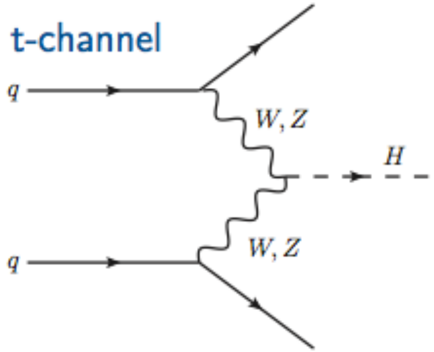


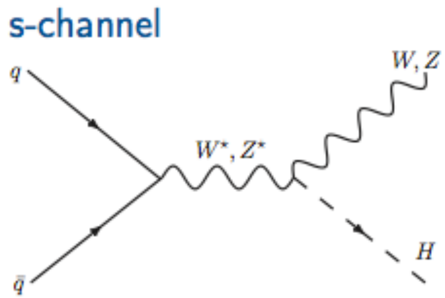
Grazzini talk

This would be the situation if the NLO result had been used

But how well do we know NNLO?

Vector Boson Fusion





Process calculated up to : NNLO QCD and NLO EW

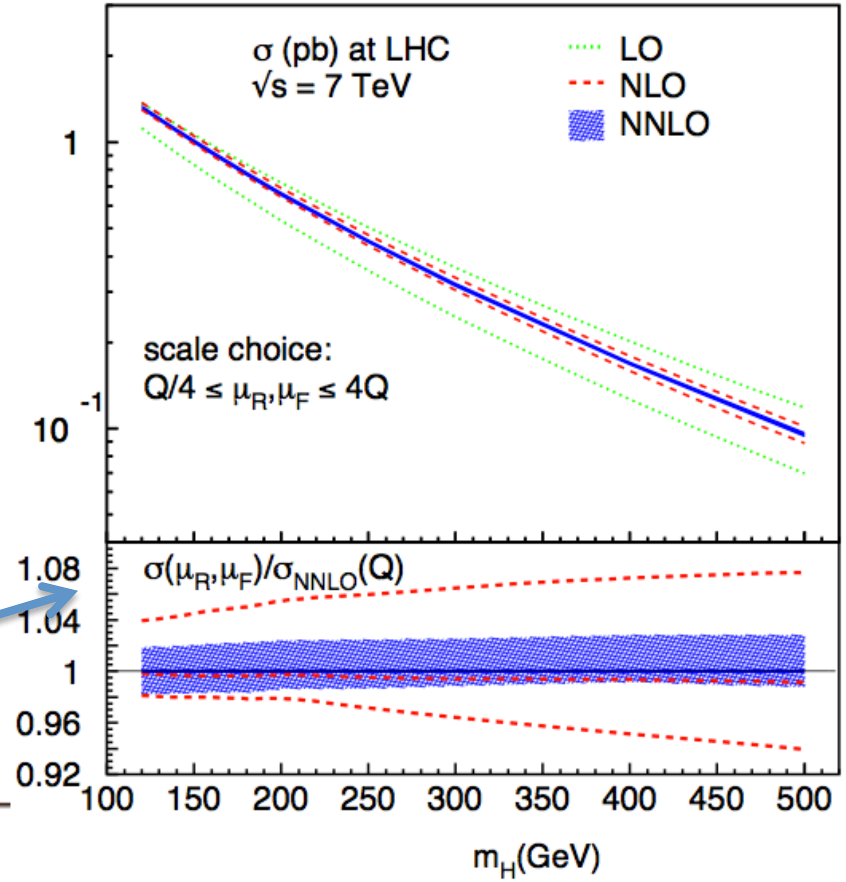
Available Calculation and Programs:

•**VV2H** (Spira): only t-channel, NLO QCD

•**VBF@NLO** (Zeppenfeld et al): only t-channel NLO QCD

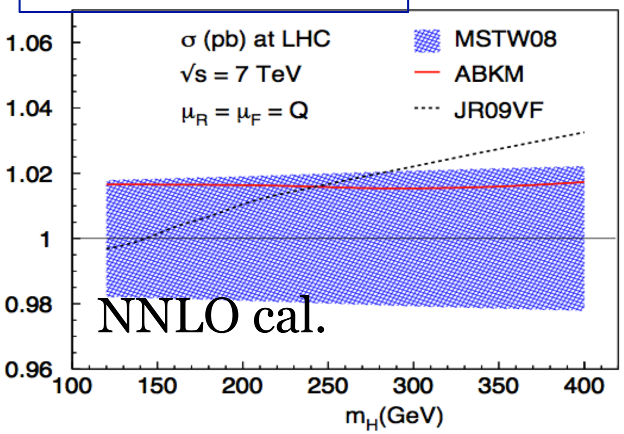
•**HAWK** (Ciccolini et al): s+t channel, NLO QCD + NLO EW

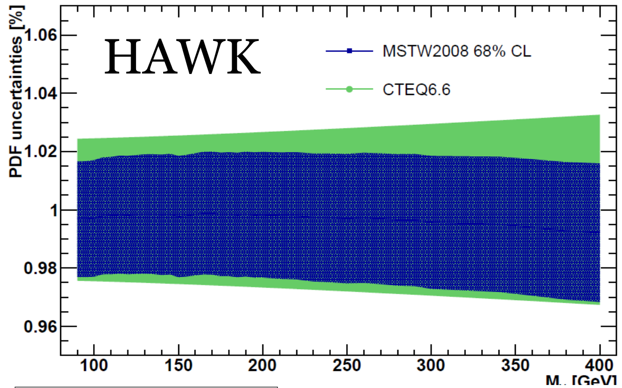
•**NNLO QCD** calculation (Bolzoni et al)

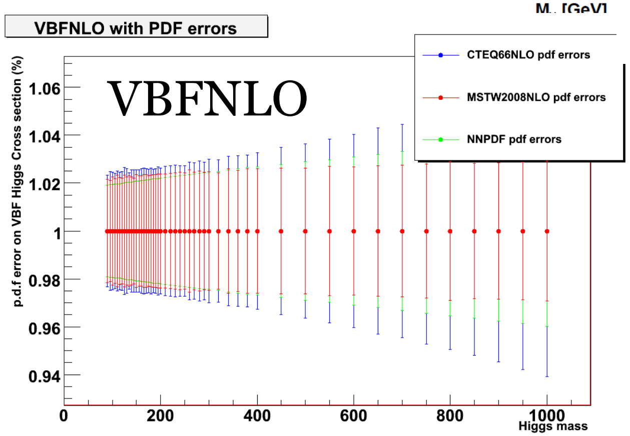


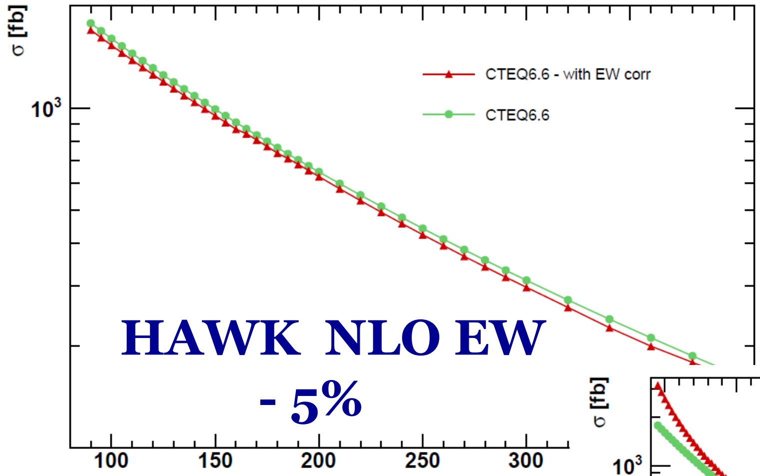
VBF: Uncertainties

2% PDF uncert.

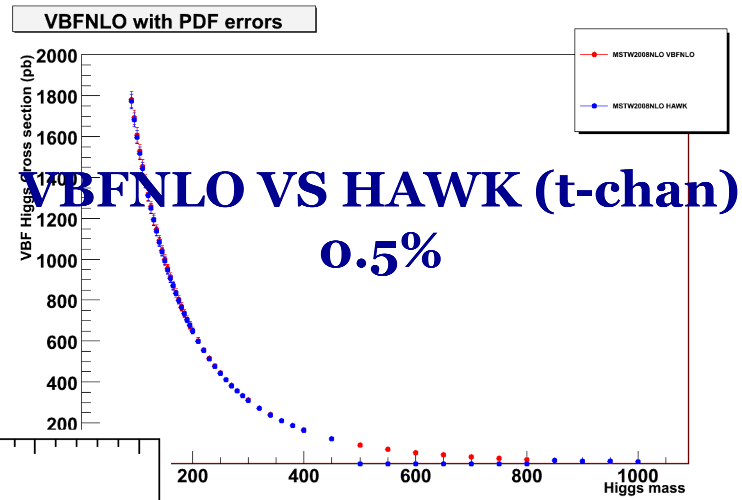




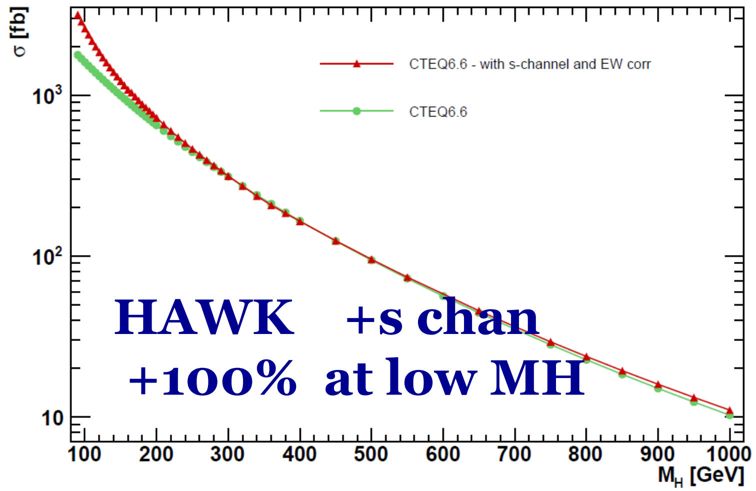




HAWK NLO EW
- 5%



VBFNLO VS HAWK (t-chan)
0.5%

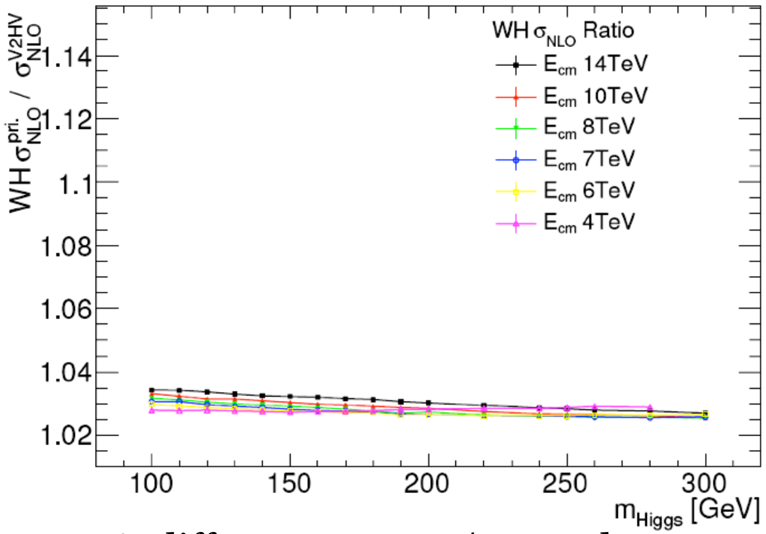


HAWK +s chan
+100% at low MH

WH/ZH

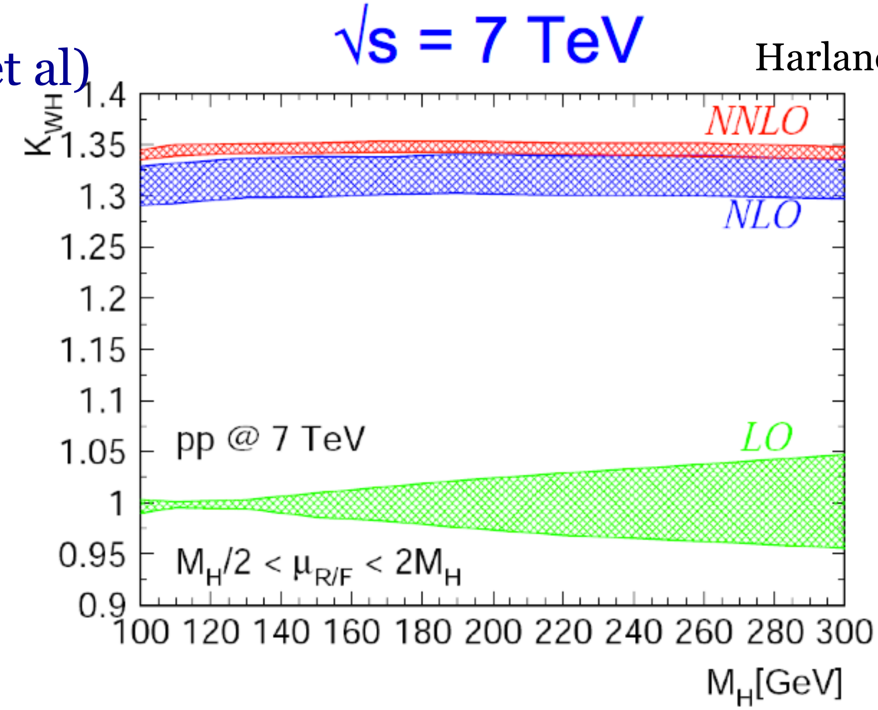
Available calculations and programs

- **NNLO QCD** (Brein et al)
- NLO QCD+EW in **HAWK** (Ciccolini et al)
- NLO QCD **V2HV** (Spira et al)
- NLO QCD **MCFM** (Cambell et al)



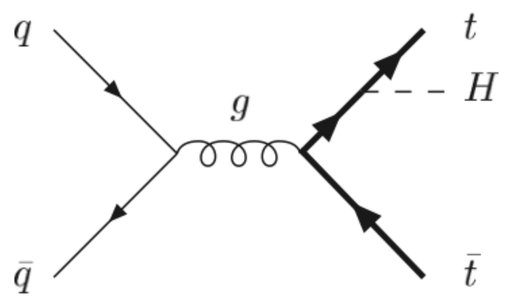
3% difference HAWK/V2HV due to CKM matrix not in v2hv

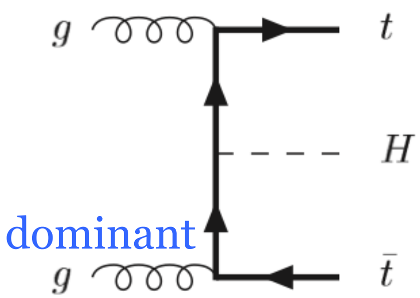
Harlander



Uncertainties have to be computed for PDF and α_S

ttH





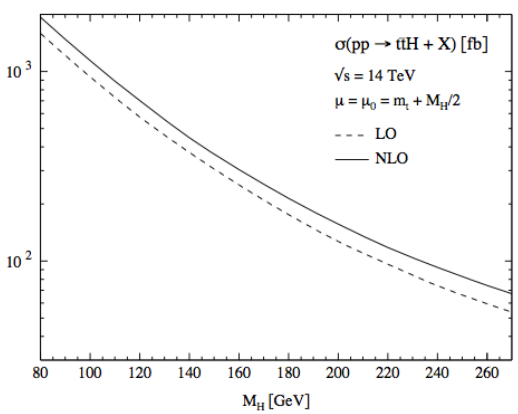
Crucial to determine top Yukawa coupling

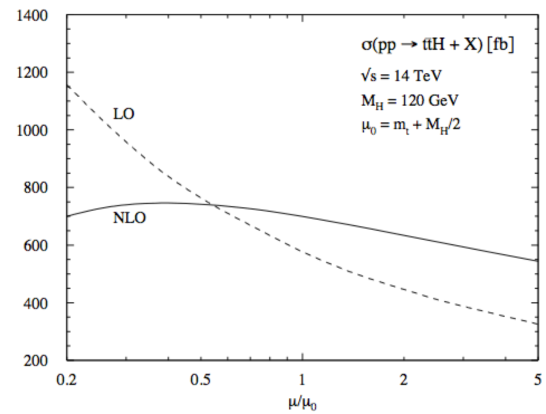
Available programs at LO:

- HQQ (Spira)
- Madgraph (Maltoni et al)
- MCFM (Campbell et al)

Uncertainties:
QCD Scale : -25+40 % at LO
-9 +3% at NLO
alpha_s : 0.5%
PDF : 3-5 %
But differences MSTW-CTEQ: 8%

QCD correction ~ 20% (Dawson et al)
NLO calculation
for S and B …
to become available
in Powheg?





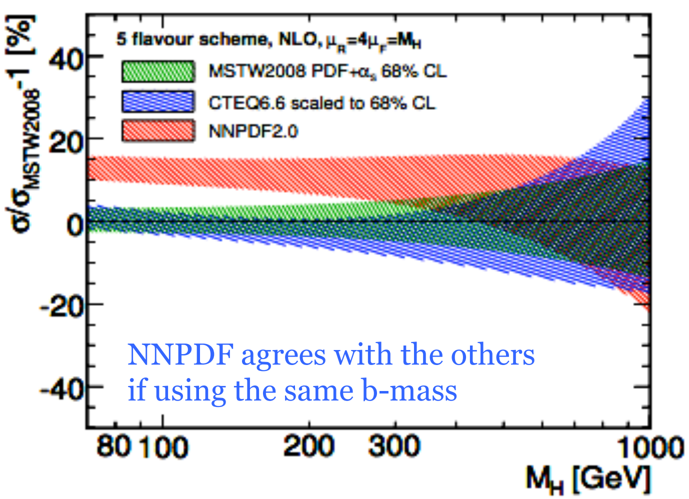
Neutral MSSM H: bbH, ggH

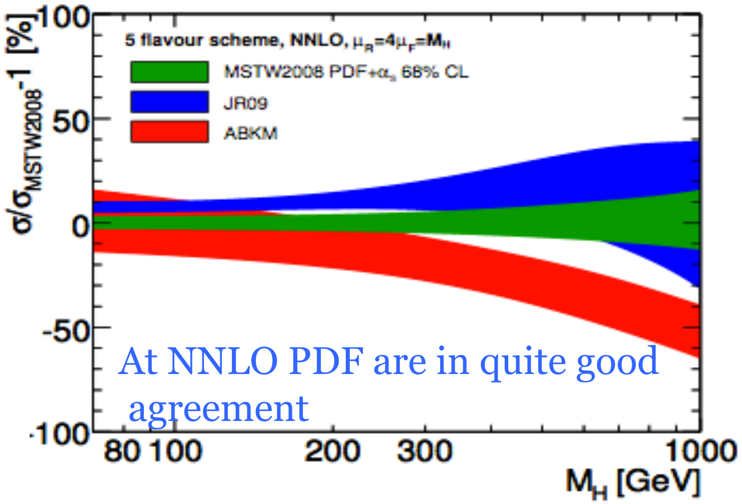
- **bbH**

NNLO needed to reduce scale uncert. → bbH@nnlo (Harlander et al)

PDF sets: a large effect come from m_b value -> to be taken into account.

Good agreement between 4FS and 5FS for $\mu=M_H/4$





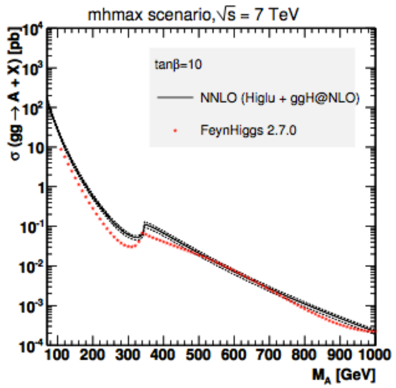
- **ggH**

H $\sigma^{MSSM} = \left(\frac{g_t^{MSSM}}{g_t^{SM}}\right)^2 \sigma_{tt}^{NNLO} + \left(\frac{g_b^{MSSM}}{g_b^{SM}}\right)^2 \sigma_{bb} + \frac{g_t^{MSSM}}{g_t^{SM}}\frac{g_b^{MSSM}}{g_b^{SM}}\sigma_{tb}$

Feynhiggs couplings and masses!

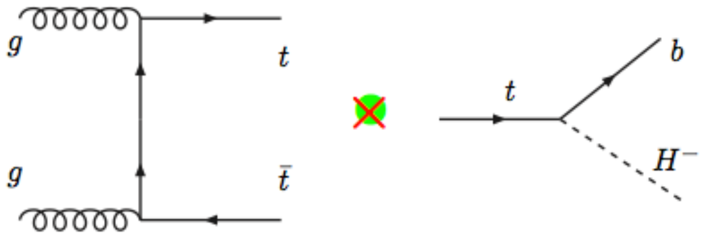
ggh@nnlo, as we know more for the top-loop

HIGLU full m_b, m_t dependence @ NLO

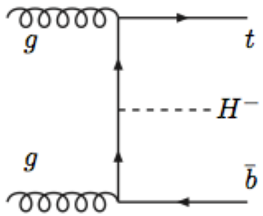


Disagreement between HIGLU and FeynHiggs for H, A and especially h, to be understood

Charged MSSM H

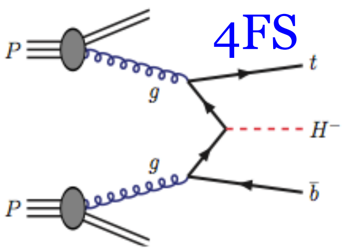


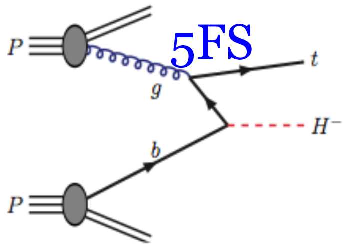
pp→tt , t->bH±, for $m_H^{\pm} < m_{top}$



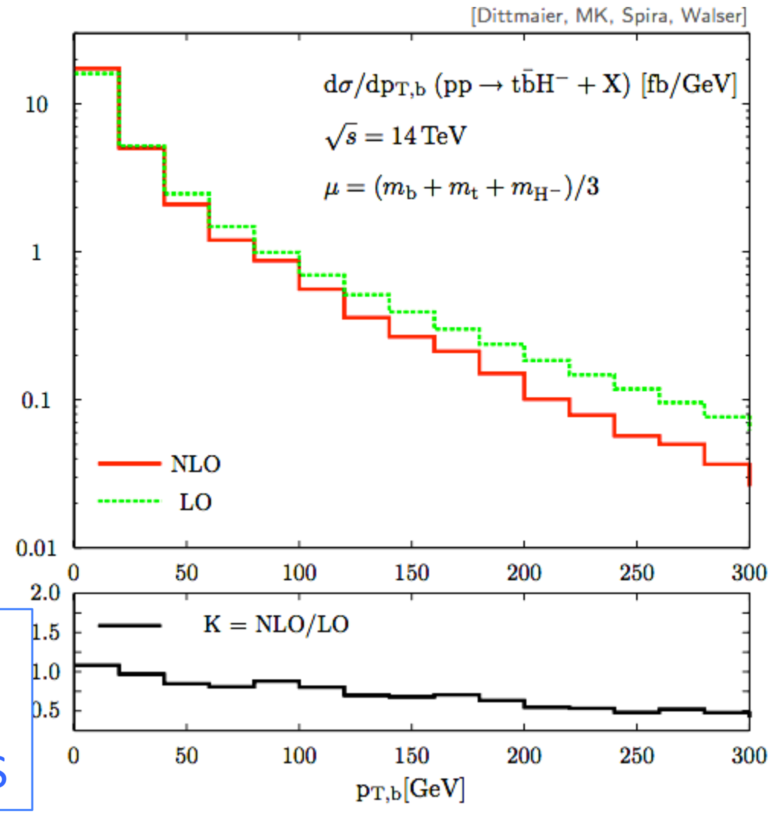
pp→tbH±, for $m_H^{\pm} > m_{top}$

- 5FS NLO SUSY-QCD [Plehn; Berger et al.]
- 5FS in MC@NLO [Weydert et al.]
- 5FS NNLL/NNLO$_{approx.}$ [Kidonakis]
- 5FS SUSY-EWK [Jin et al., Belyaev et al., Beccaria et al.]
- 4FS NLO SUSY-QCD [Peng et al.; Dittmaier et al.]
- LO 4 and 5FS matched [Borzumati et al.; Alwall, Rathsman]





Still discrepancies
at NLO between
The 4FS and the 5FS



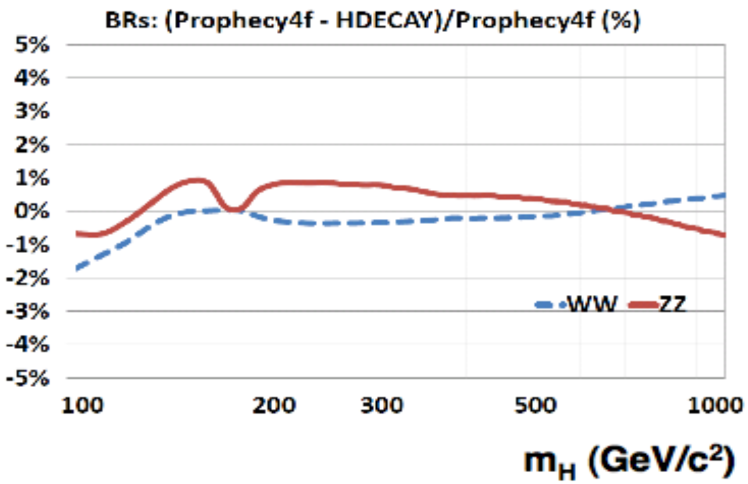
Branching Ratios

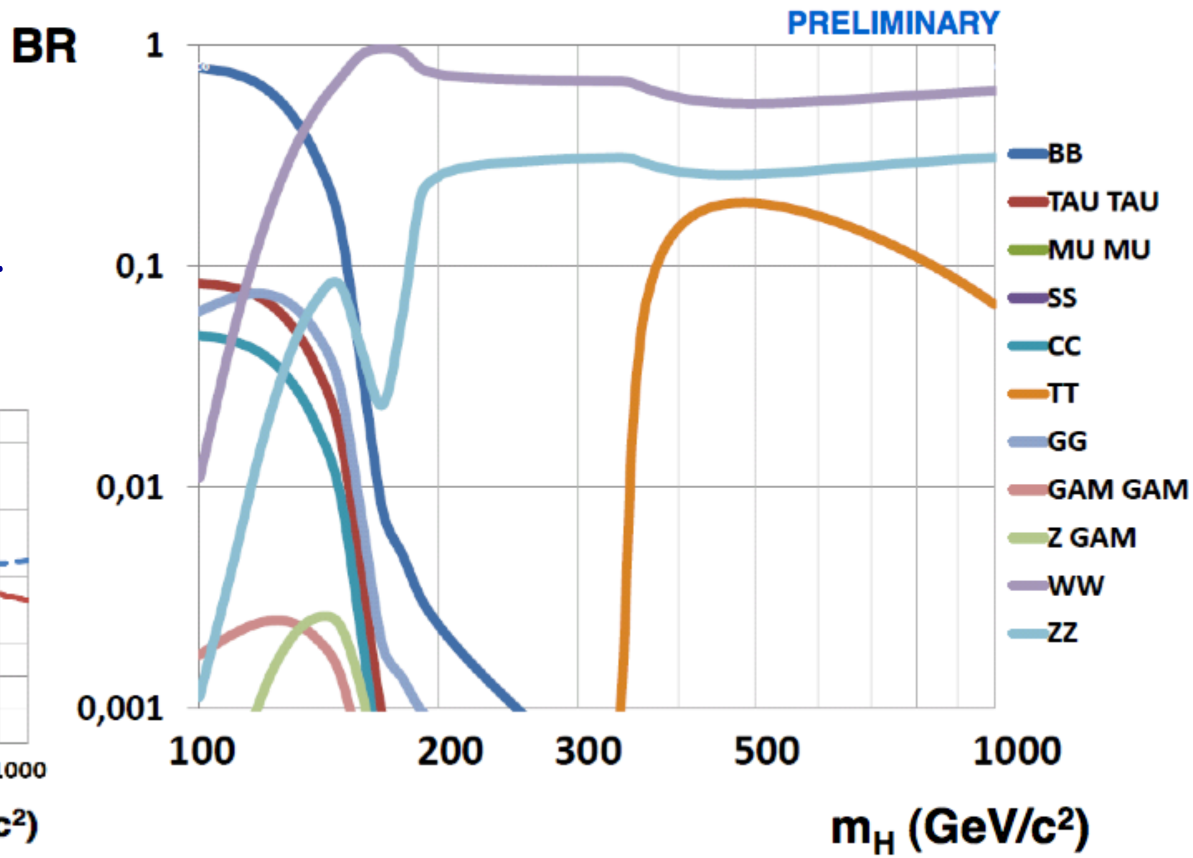
$$\Gamma_H = \Gamma^{HD} - \Gamma^{HD}_{ZZ} - \Gamma^{HD}_{WW} + \Gamma^{Proph.}_{4f} + \Gamma^{HD}_{\gamma\gamma}\delta^{QED}_{\gamma f f}$$

partial width	QCD	electroweak	total
$H \to b\bar{b}/c\bar{c}$	$\sim 0.1–0.2\%$	$\sim 1–2\%$ for $M_H \lesssim 135\,GeV$	$\sim 1–2\%$
$H \to \tau\tau$		$\sim 1–2\%$ for $M_H \lesssim 135\,GeV$	$\sim 1–2\%$
$H \to t\bar{t}$	$\lesssim 5\%$ [a]	$\sim 2\%$ for $M_H < 500\,GeV$	$\sim 5\%$
		$\sim 0.1(\frac{M_H}{1\,TeV})^4$ for $M_H > 500\,GeV$	$\sim 5–10\%$
$H \to gg$	$\sim 10\%$ [b]	$\sim 1\%$	$\sim 10\%$
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$H \to WW/ZZ$		$\sim 0.5\%$ for $M_H < 500\,GeV$	$\sim 0.5\%$
$\to 4f$		$\sim 0.17(\frac{M_H}{1\,TeV})^4$ for $M_H > 500\,GeV$	$\sim 0.5–15\%$

Uncertainties from missing higher order

HDecay (Spira)
Prophecy4f (Denner et al.)
QED from Passarino+Spira





Theory: Next Step

- Differential distributions: careful comparison between different generators done in Les Houches and in the group (Maltoni, Nason et al)

- NLO w PS montecarlo vs differential calculation at NNLO

gg→H→WW→lvlv

σ_{acc} [fb] jet algorithm	$\mu = \frac{m_H}{2}$ SISCone	$\mu = \frac{m_H}{2}$ k_T	$\mu = 2\,m_H$ SISCone	$\mu = 2\,m_H$ k_T
NNLO	18.18 ± 0.43	18.45 ± 0.54	18.76 ± 0.31	19.01 ± 0.27
R^{NNLO}(MC@NLO)	19.33 ± 0.09	20.43 ± 0.09	17.24 ± 0.07	18.24 ± 0.07
R^{NNLO}(HERWIG)	22.02 ± 0.08	22.88 ± 0.08	18.65 ± 0.07	19.38 ± 0.07

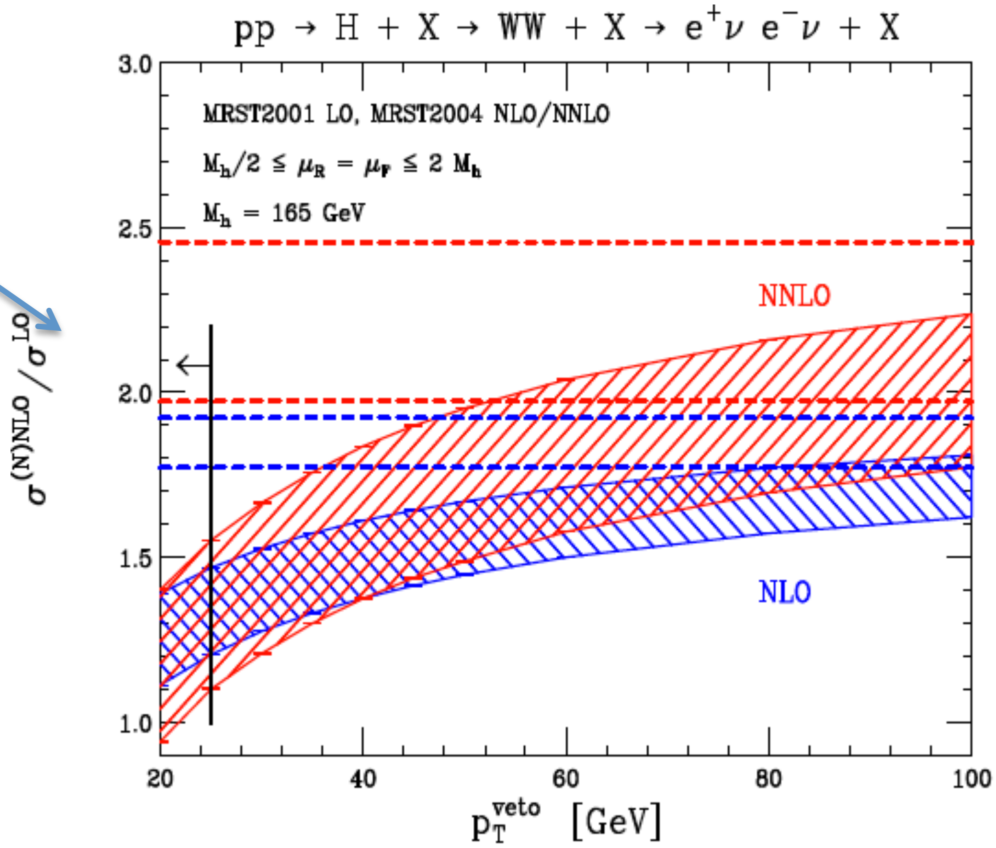
Anastasiou et al

- Cross section with acceptance cuts (how much the K factor change? i.e. see next page)

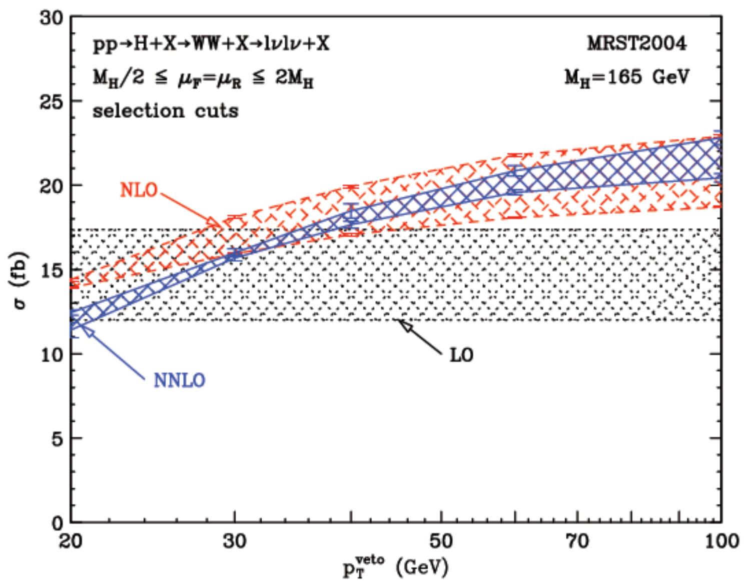
Inclusive XS vs XS with cuts

Impact of higher order corrections strongly reduced by selection cuts

$$K_{(N)NLO}(\mu) = \frac{\sigma_{(N)NLO}(\mu)}{\sigma_{LO}(\mu)}$$



The NNLO band overlaps with the NLO one for $p_T^{veto} \geq 30$ GeV



Studies done by Anatastiou et al., Grazzini

ino

Proposal of future work

- To compute cross section within acceptance:
  establish a common ATLAS and CMS
  "MInimal but ReAlistiC AnaLysis Setup" (MIRACLES) for first analysis in each channel group.

  © Maltoni

- Study and provide guidelines for TH uncertainties

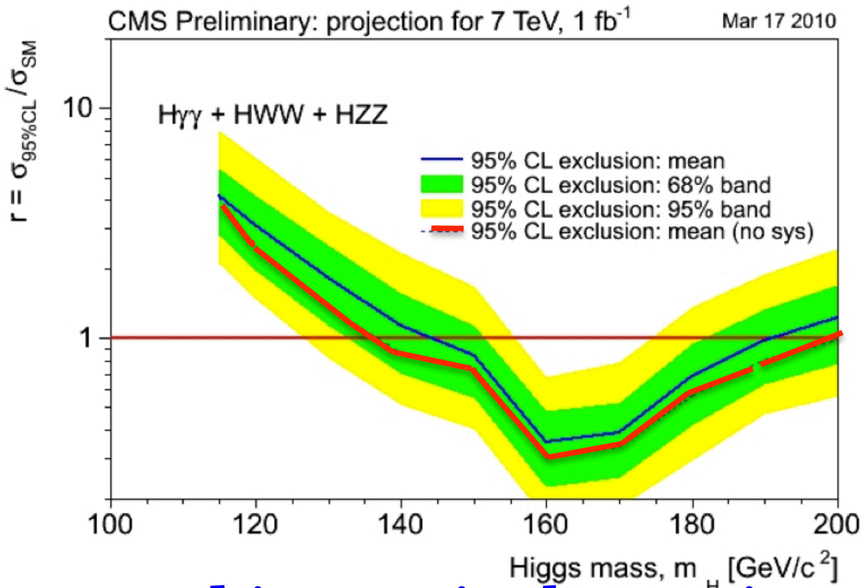
- Identify the **background** of a given "production * decay" channel

- TH uncertainties on the background, and then use the data to validate/tune the background MC estimations.

- Start addressing more advance question: are there ways to use data to validate the signal MC?

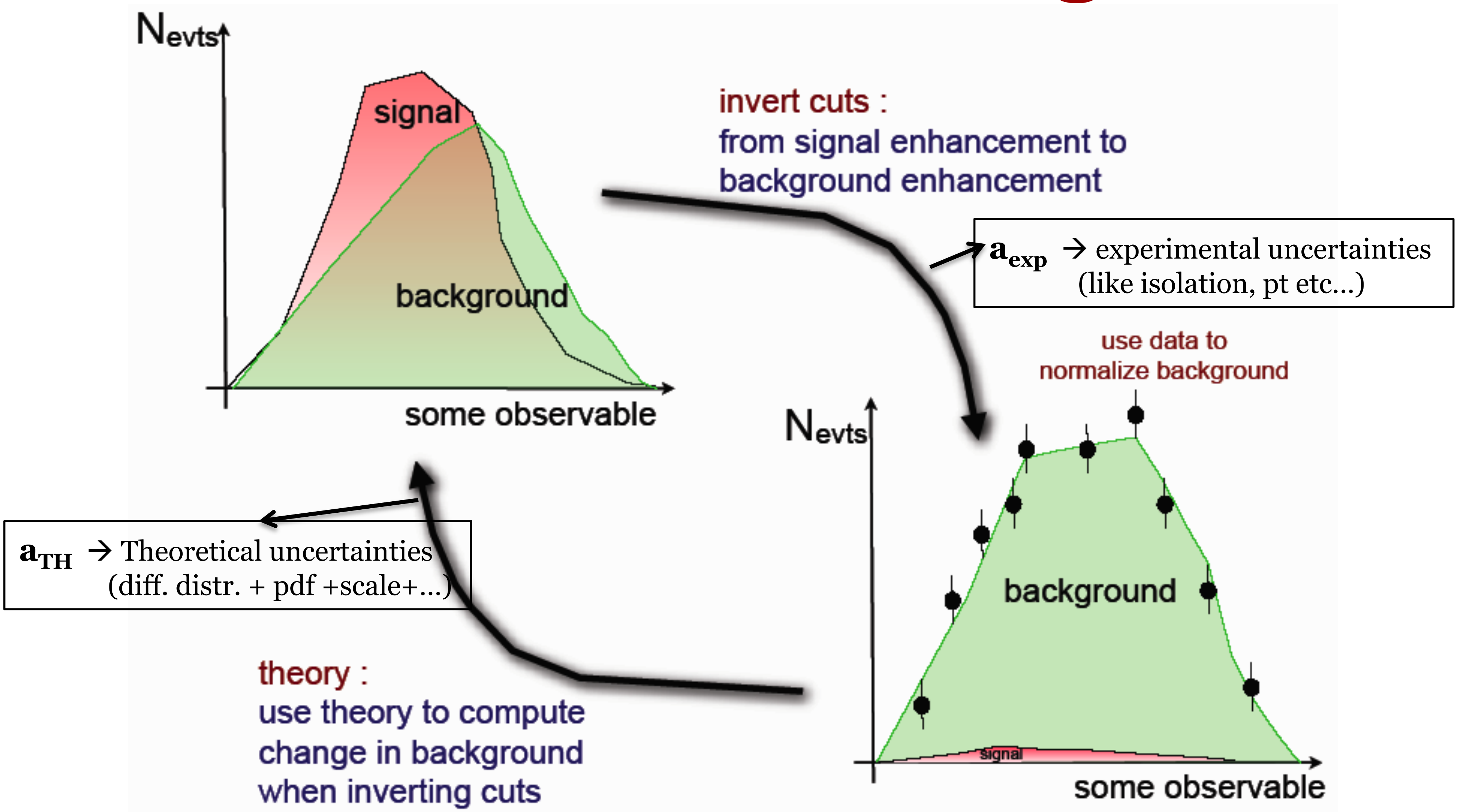
The experimental side

- The first step is "exclusion". This mean background understanding. In case of no Higgs signal, what we observe is "background only".



- BUT background in particular region of the parameters.
- Experiments should validate the MC in these regions and in the "control regions" , where the experiments control the background with "data driven methods"

The control of the background



- $N^B_{(\text{signal region})} = a_{exp} * a_{TH} * N^B_{\text{control region}}$

a_{exp} - uncorr between exp
a_{TH} - 100% correlated

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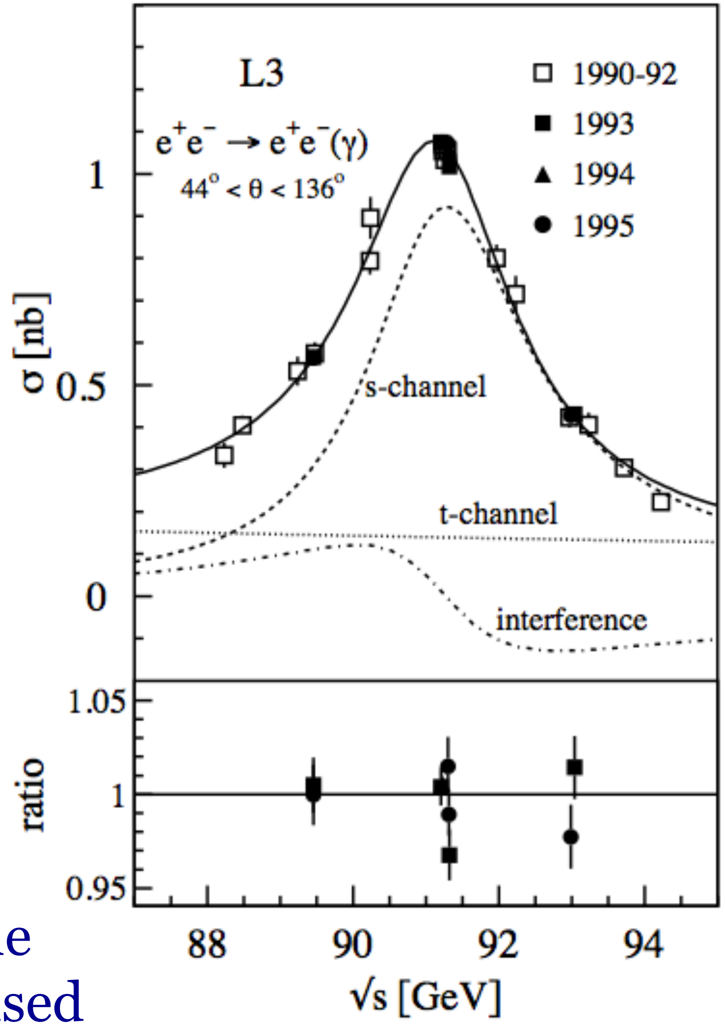
Pseudo Observables

- What the experiments observe in the final state is not always directly connected to the theoretical variable.
  In between there is
  - the acceptance of the detector (cuts),
  - the interference of signal and background
  - and "approximations"
    (like production x decay)

- A corrected definition of the Higgs mass and width, i.e. of all the "pseudo-observables" is needed.

- Ex: The mass is the real part of the complex pole of the propagator → is this correct definition used in the MC generators?



Passarino

Summary

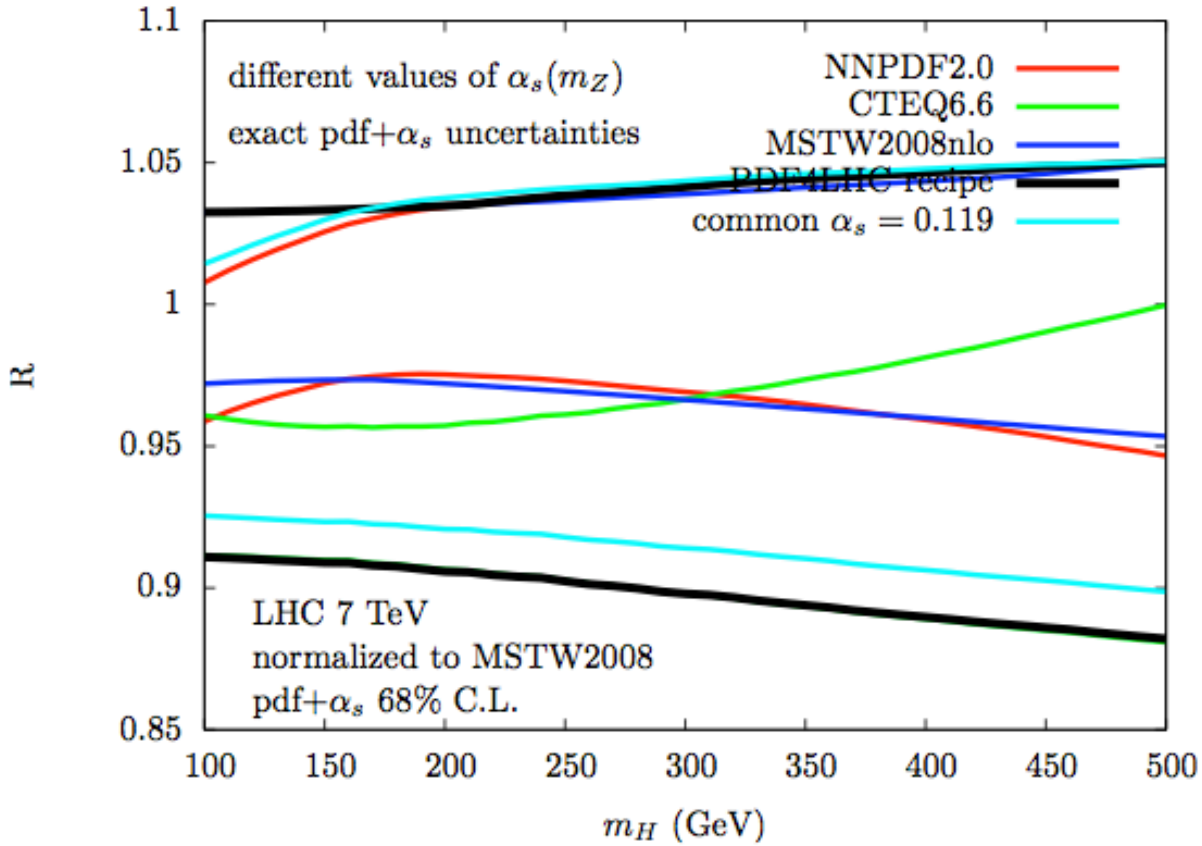
- The goal of the group is to provide commons set of Higgs production XS and Br with associated uncertainties to optimized the combination of independent results
- Very first results of this WG → Public Report (Dic 2010)
- Next steps:
  - Cross section within acceptances
  - Evaluation the impact of theory uncertainties on the estimation of the background in the "control regions" and in the signal regions
  - Pseudo-observables

→ We want to use the BEST of our knowledge to probe EWSB

Backup

A different prescription

- PDF computed all at the same value of α_s vs PDF4LHC prescription



VICINI

MSSM Branching Ratio

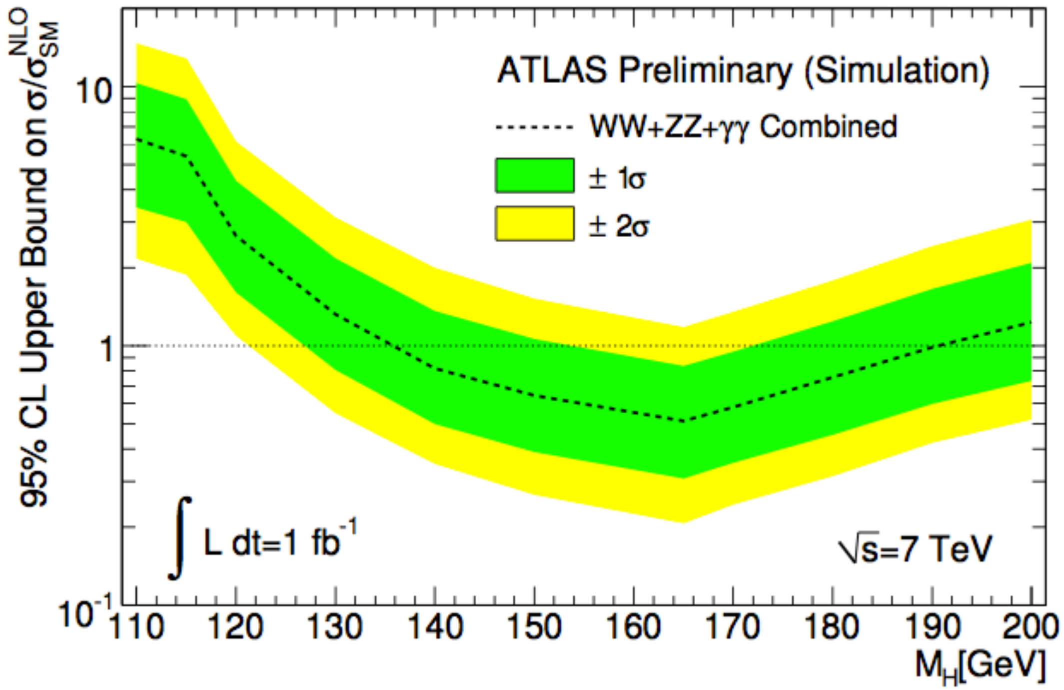
Comparison in m_h^{max} and no-mixing scenario

- FeynHiggs (Hahn et al.)
- CPsuperH (Lee et al.)
- Hdecay (Spira)

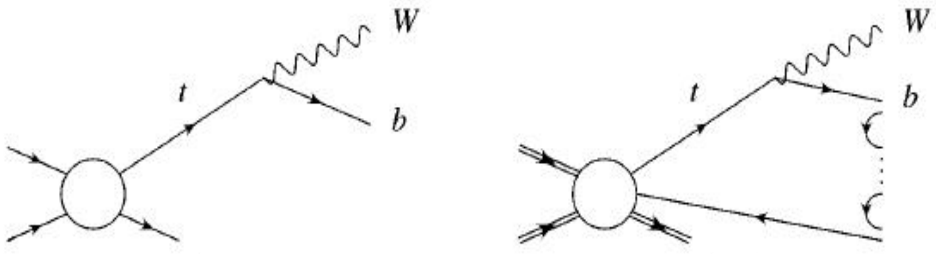
Sizeable differences for certain regions

For charge Higgs also:

- Sdecay


ATLAS Preliminary (Simulation)
WW+ZZ+γγ Combined
± 1σ
± 2σ
∫ L dt=1 fb⁻¹
√s=7 TeV
95% CL Upper Bound on σ/σ_SM^NLO
M_H[GeV]
10
1
10⁻¹
110
120
130
140
150
160
170
180
190
200

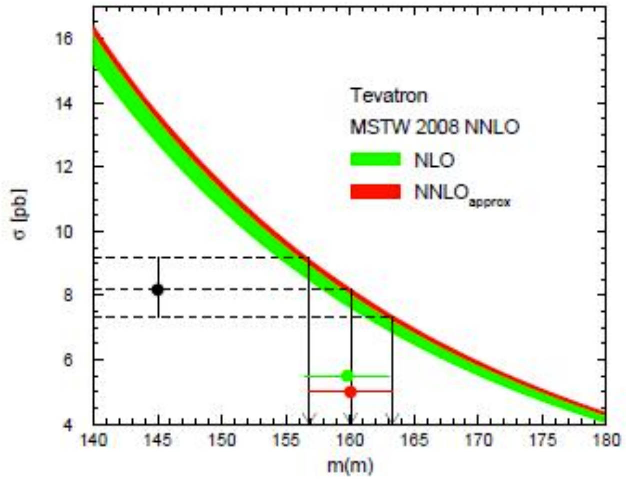
Pseudo Observables



Because of NLO, the Wb invariant mass from the reconstructed final state is NOT equal to the pole mass

By measuring the "running mass" from the cross section value, the result is:

M_{top} $(M_{top})_{\overline{MS}}$ = 160.0 ±3.3 GeV



That translates into a pole mass of 168.2±3.6 GeV

While the measured mas is: 173.1 ± 1.3