SM Predictions for Gluon-Fusion Higgs Production

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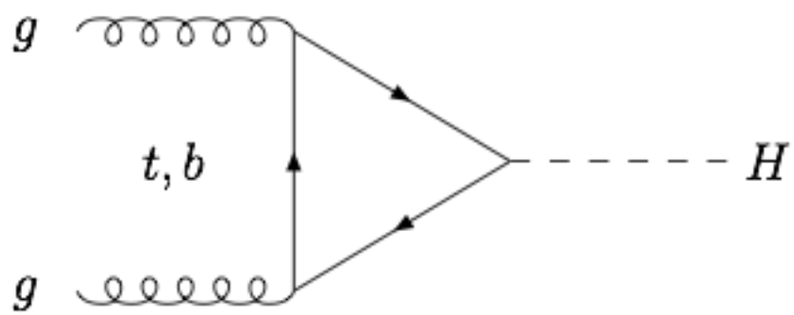
Higgs Workshop, CERN, June 5, 2010

Outline

- Introduction: status of ggH
- Three updates:
  - de Florian-Grazzini
  - Anastasiou-Boughezal-Petriello+Stoeckli
  - Baglio-Djouadi
- Comments
- Summary

gg fusion



The Higgs coupling is proportional to the quark mass

→ top-loop dominates

QCD corrections to the total rate computed more than 15 years ago and found to be large

A. Djouadi, D. Graudenz, M. Spira, P. Zerwas (1991)

They increase the LO result by about 80-100 % !

Next-to-next-to leading order (NNLO) corrections computed in the large-m_{top} limit

R.Harlander (2000)
S. Catani, D. De Florian, Grazzini (2001)
R.Harlander, W.B. Kilgore (2001,2002)
C. Anastasiou, K. Melnikov (2002)
V. Ravindran, J. Smith, W.L.Van Neerven (2003)

Large-m_{top} approximation works extremely well up to m_H=300 GeV (differences of the order of 0.5 % !)

R.Harlander et al. (2009,2010)
M.Steinhauser et al. (2009)

gg fusion

Effects of soft-gluon resummation at Next-to-next-to leading logarithmic (NNLL) accuracy (about 6-15%)

S. Catani, D. De Florian, P. Nason, Grazzini (2003)

Partial N^3LO corrections known (considerably reduced scale dependence)

Moch, Vogt (2005)

Two-loop EW corrections are also known (effect is about O(5%))

U. Aglietti et al. (2004)
G. Degrassi, F. Maltoni (2004)
G. Passarino et al. (2008)

Mixed QCD-EW effects evaluated in EFT approach

Anastasiou, Boughezal, FP (2008)

→ support "complete factorization": EW correction multiplies the full QCD corrected cross section

EW effects for real radiation (effect O(1%))

W.Keung, F.Petriello, (2009)

Updated predictions

Three recent inclusive cross-section results for LHC@7 TeV

- de Florian-Grazzini

  De Florian, Grazzini (2009)

- Anastasiou-Boughezal-Petriello+Stoeckli

  Anastasiou, Boughezal, FP (2009)

- Baglio-Djouadi

  Baglio, Djouadi (2010)

de Florian+Grazzini update

- Use MSTW2008 NNLO partons
- Consider top-quark contribution to the cross section and compute it at NNLL+NNLO in the large-m_{top} limit
- Bottom+top quark mass effects now treated exactly through NLO
- Include EW effects according to the calculation by Passarino et al.
- Use m_t=172.5 GeV and m_b=4.75 GeV pole masses

Anastasiou, Boughezal, Petriello, Stoeckli

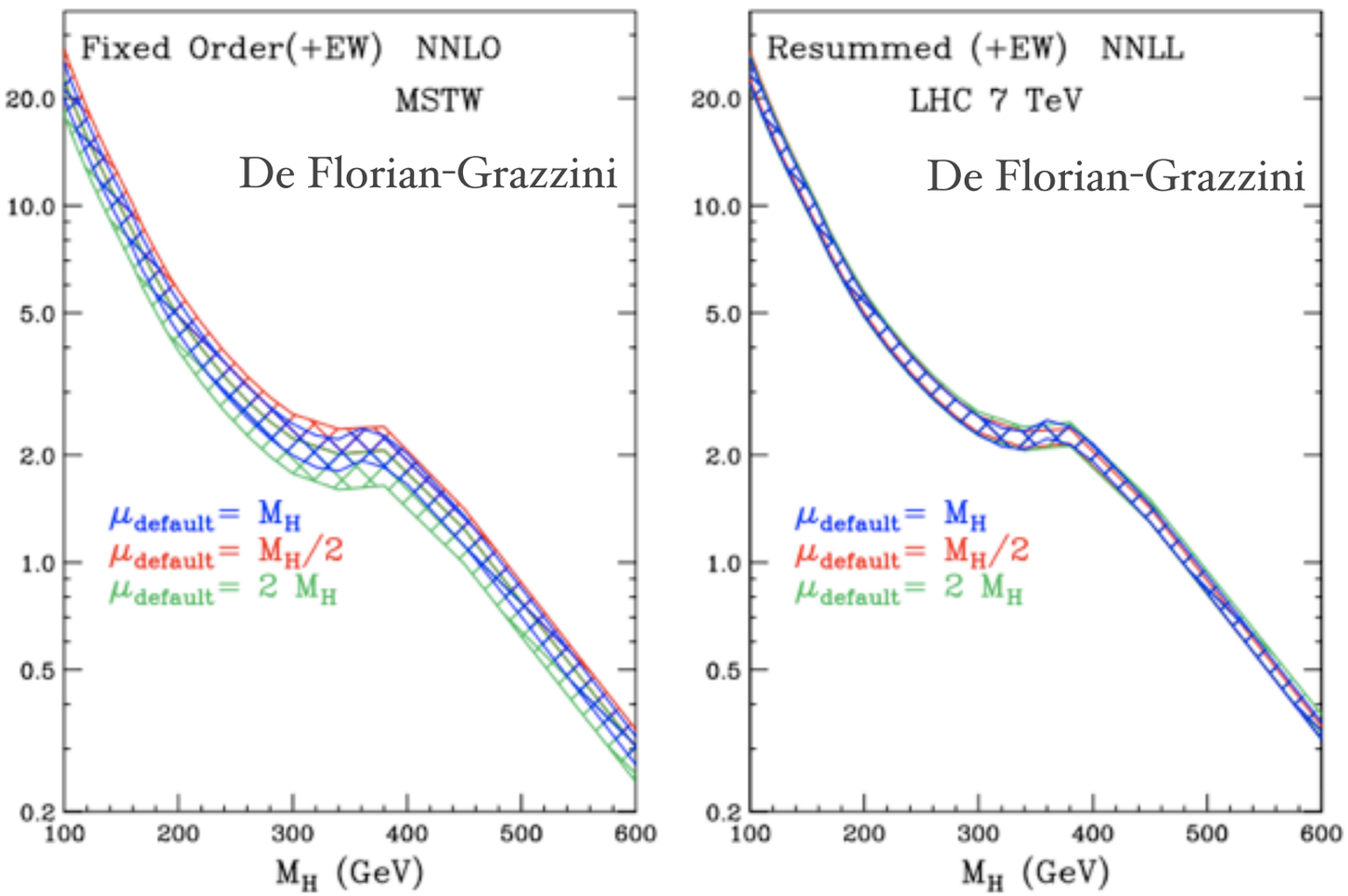
- Start from exact NLO and include NNLO in the large-m_{top} limit
- Choice of scale $\mu_F=\mu_R=m_H/2$; motivated by convergence of perturbative expansion (both before and after cuts!) through NNLO and partial N^3LO, and logarithmic structure of fixed order: $\mu \sim \langle p_T \rangle_{av}$
- Vary $m_h/4 \leq \mu_{F,R} \leq m_h$; physically, no $\mu \sim 2,3\ m_h$ enters this process
- Has the additional effect of reproducing the central value of the resummation result (see also previous slide)
- Includes EFT estimate of mixed QCD-EW effects and effects from EW corrections to real radiation

Anastasiou, Boughezal, FP (2009)
W. Keung, FP (2009)

What is the 'right' 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 $0.5 < \mu_F/\mu_R < 2$).

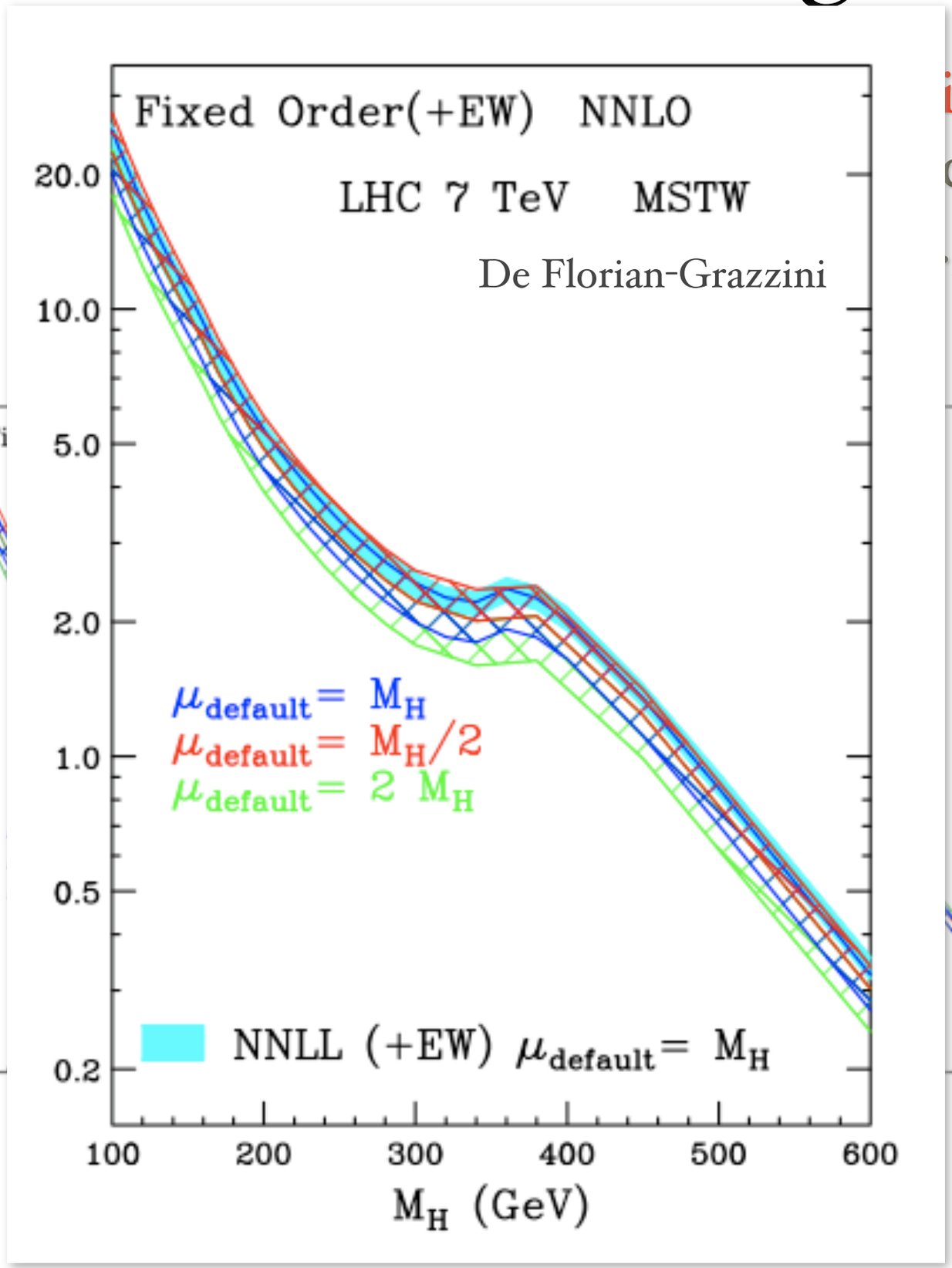
What's the 'right' default scale μ_D?



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

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

What is the 'right' scale choice?



independent variations of
cales around some default scale
$.5 < \mu_F/\mu_R < 2$).

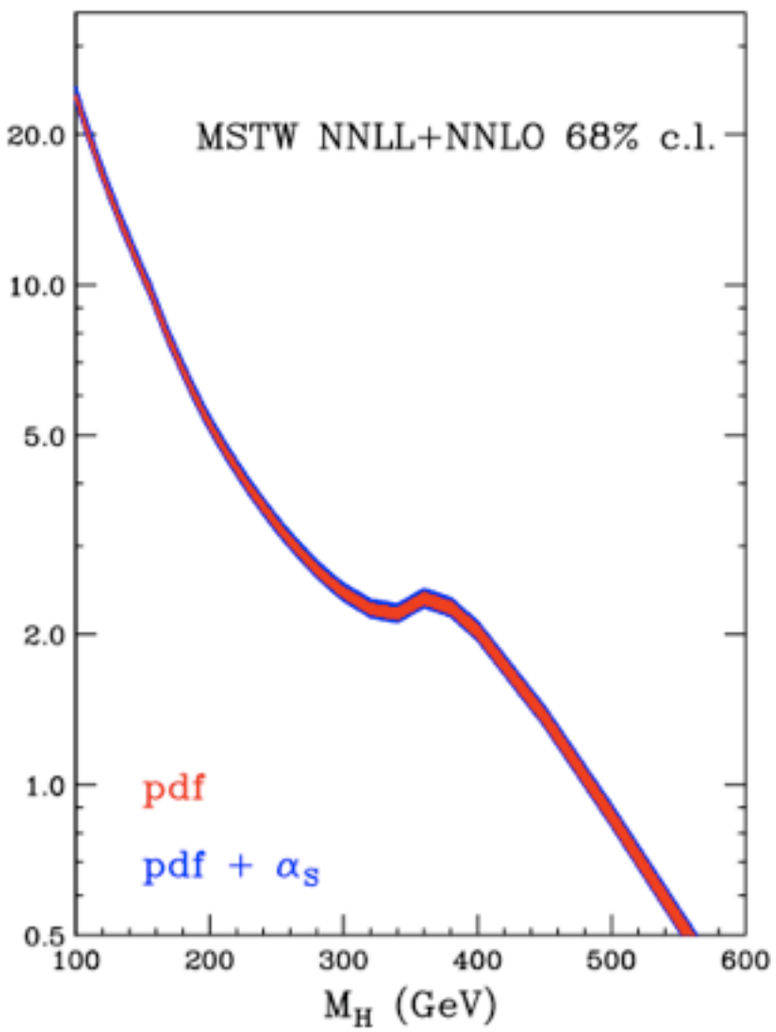
Resummed calc. not very sensitive to default scale choice (right).

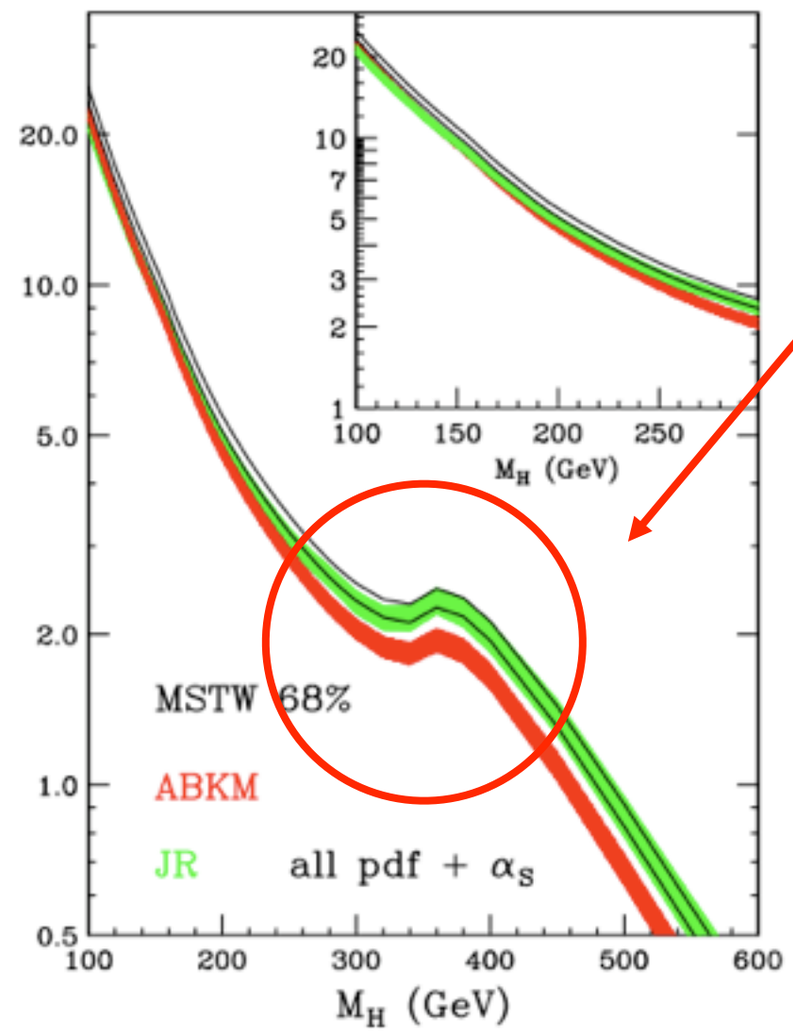
Fixed-order calc. more sensitive (left part).

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.

PDF Errors and Combination

- To estimate the uncertainty from alpha + PDFs we use the method described by the MSTW group.
- We do NOT apply the proposed smearing factor of ~2 to the PDF error in these tables. The results including this scaling are in the backup slides.





Should be discussed at this meeting!

Results (Numbers 1)

	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + $_s$)	[fb]	(μ_R, μ_F)	(PDF + $_s$)
95	27541.26	$^{-10.76}_{+9.93}$ %	$^{-3.13}_{+4.14}$ %	26477.5	$^{-8.56}_{+8.04}$ %	$^{-3.05}_{+4.04}$ %
100	24810.73	$^{-10.49}_{+9.69}$ %	$^{-3.12}_{+4.12}$ %	23968.5	$^{-8.40}_{+7.82}$ %	$^{-3.04}_{+4.02}$ %
105	22469.98	$^{-10.28}_{+9.41}$ %	$^{-3.11}_{+4.11}$ %	21743.9	$^{-8.26}_{+7.65}$ %	$^{-3.04}_{+4.00}$ %
110	20443.02	$^{-10.12}_{+9.19}$ %	$^{-3.11}_{+4.09}$ %	19809.3	$^{-8.13}_{+7.50}$ %	$^{-3.04}_{+3.99}$ %
115	18672.71	$^{-9.96}_{+8.94}$ %	$^{-3.12}_{+4.10}$ %	18115.0	$^{-8.01}_{+7.36}$ %	$^{-3.04}_{+3.98}$ %
120	17116.91	$^{-9.84}_{+8.70}$ %	$^{-3.12}_{+4.06}$ %	16626.9	$^{-7.91}_{+7.23}$ %	$^{-3.05}_{+3.96}$ %
125	15735.73	$^{-9.69}_{+8.56}$ %	$^{-3.13}_{+4.05}$ %	15305.5	$^{-7.80}_{+7.11}$ %	$^{-3.06}_{+3.95}$ %
130	14516.09	$^{-9.55}_{+8.34}$ %	$^{-3.13}_{+4.04}$ %	14131.7	$^{-7.71}_{+6.99}$ %	$^{-3.06}_{+3.95}$ %
135	13425.19	$^{-9.42}_{+8.22}$ %	$^{-3.14}_{+4.00}$ %	13081.7	$^{-7.61}_{+6.88}$ %	$^{-3.07}_{+3.94}$ %
140	12448.41	$^{-9.34}_{+8.12}$ %	$^{-3.15}_{+4.04}$ %	12137.9	$^{-7.53}_{+6.78}$ %	$^{-3.09}_{+3.94}$ %
145	11576.51	$^{-9.29}_{+8.00}$ %	$^{-3.16}_{+4.05}$ %	11288.8	$^{-7.45}_{+6.69}$ %	$^{-3.10}_{+3.93}$ %
150	10792.58	$^{-9.27}_{+7.86}$ %	$^{-3.18}_{+4.03}$ %	10517.8	$^{-7.37}_{+6.60}$ %	$^{-3.11}_{+3.93}$ %
155	10078.16	$^{-9.24}_{+7.72}$ %	$^{-3.19}_{+4.01}$ %	9797.8	$^{-7.30}_{+6.52}$ %	$^{-3.13}_{+3.93}$ %
160	9363.22	$^{-9.20}_{+7.60}$ %	$^{-3.21}_{+4.01}$ %	9076.3	$^{-7.23}_{+6.44}$ %	$^{-3.15}_{+3.92}$ %
165	8536.45	$^{-9.19}_{+7.54}$ %	$^{-3.23}_{+4.02}$ %	8351.9	$^{-7.16}_{+6.37}$ %	$^{-3.16}_{+3.92}$ %
170	7919.50	$^{-9.22}_{+7.45}$ %	$^{-3.25}_{+4.02}$ %	7760.7	$^{-7.10}_{+6.29}$ %	$^{-3.18}_{+3.93}$ %
175	7400.22	$^{-9.17}_{+7.39}$ %	$^{-3.27}_{+4.03}$ %	7240.9	$^{-7.04}_{+6.22}$ %	$^{-3.20}_{+3.93}$ %

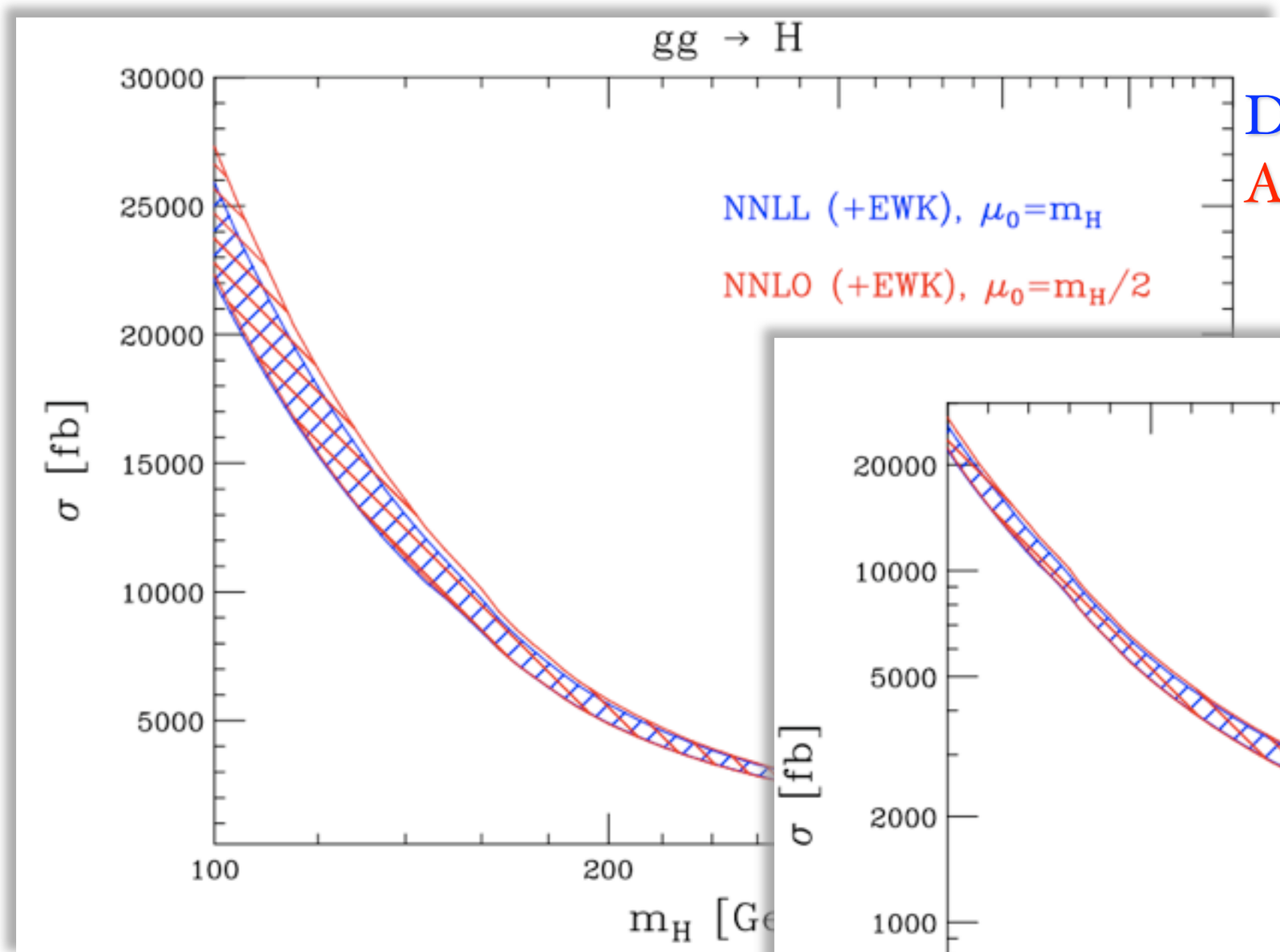
Results (Numbers 2)

	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + s)	[fb]	(μ_R, μ_F)	(PDF + s)
180	6932.75	$^{-9.13}_{+7.29}$ %	$^{-3.28}_{+4.03}$ %	6763.3	$^{-6.98}_{+6.15}$ %	$^{-3.22}_{+3.93}$ %
185	6444.78	$^{-9.11}_{+7.24}$ %	$^{-3.31}_{+4.03}$ %	6324.1	$^{-6.92}_{+6.12}$ %	$^{-3.24}_{+3.94}$ %
190	6026.63	$^{-9.06}_{+7.24}$ %	$^{-3.33}_{+4.04}$ %	5923.5	$^{-6.87}_{+6.09}$ %	$^{-3.26}_{+3.94}$ %
200	5361.79	$^{-9.05}_{+7.12}$ %	$^{-3.38}_{+4.07}$ %	5266.8	$^{-6.76}_{+6.04}$ %	$^{-3.30}_{+3.96}$ %
210	4821.25	$^{-9.07}_{+7.05}$ %	$^{-3.39}_{+4.05}$ %	4737.5	$^{-6.67}_{+6.00}$ %	$^{-3.35}_{+3.97}$ %
220	4365.69	$^{-8.98}_{+6.97}$ %	$^{-3.46}_{+4.08}$ %	4293.2	$^{-6.58}_{+6.48}$ %	$^{-3.39}_{+3.99}$ %
230	3982.55	$^{-8.99}_{+6.82}$ %	$^{-3.51}_{+4.10}$ %	3915.3	$^{-6.49}_{+5.92}$ %	$^{-3.44}_{+4.02}$ %
240	3652.59	$^{-9.03}_{+6.77}$ %	$^{-3.55}_{+4.13}$ %	3592.6	$^{-6.41}_{+5.88}$ %	$^{-3.49}_{+4.04}$ %
250	3368.02	$^{-8.99}_{+6.69}$ %	$^{-3.59}_{+4.15}$ %	3315.9	$^{-6.34}_{+5.85}$ %	$^{-3.53}_{+4.07}$ %
260	3123.59	$^{-9.01}_{+6.60}$ %	$^{-3.64}_{+4.18}$ %	3077.9	$^{-6.27}_{+5.83}$ %	$^{-3.57}_{+4.10}$ %
270	2913.74	$^{-9.03}_{+6.55}$ %	$^{-3.69}_{+4.21}$ %	2872.7	$^{-6.20}_{+5.83}$ %	$^{-3.62}_{+4.13}$ %
280	2731.71	$^{-8.96}_{+6.58}$ %	$^{-3.74}_{+4.25}$ %	2696.9	$^{-6.14}_{+5.82}$ %	$^{-3.68}_{+4.16}$ %
290	2578.05	$^{-8.90}_{+6.62}$ %	$^{-3.79}_{+4.28}$ %	2547.8	$^{-6.08}_{+5.81}$ %	$^{-3.72}_{+4.19}$ %
300	2452.26	$^{-8.88}_{+6.54}$ %	$^{-3.83}_{+4.31}$ %	2424.5	$^{-6.03}_{+5.80}$ %	$^{-3.76}_{+4.23}$ %
320	2276.50	$^{-9.00}_{+6.49}$ %	$^{-3.93}_{+4.39}$ %	2249.6	$^{-5.95}_{+5.76}$ %	$^{-3.87}_{+4.31}$ %
340	2245.37	$^{-9.16}_{+6.70}$ %	$^{-4.04}_{+4.47}$ %	2198.9	$^{-5.92}_{+5.76}$ %	$^{-3.97}_{+4.39}$ %
360	2438.17	$^{-9.21}_{+6.77}$ %	$^{-4.13}_{+4.55}$ %	2361.2	$^{-5.86}_{+5.85}$ %	$^{-4.06}_{+4.48}$ %

Results (Numbers 3)

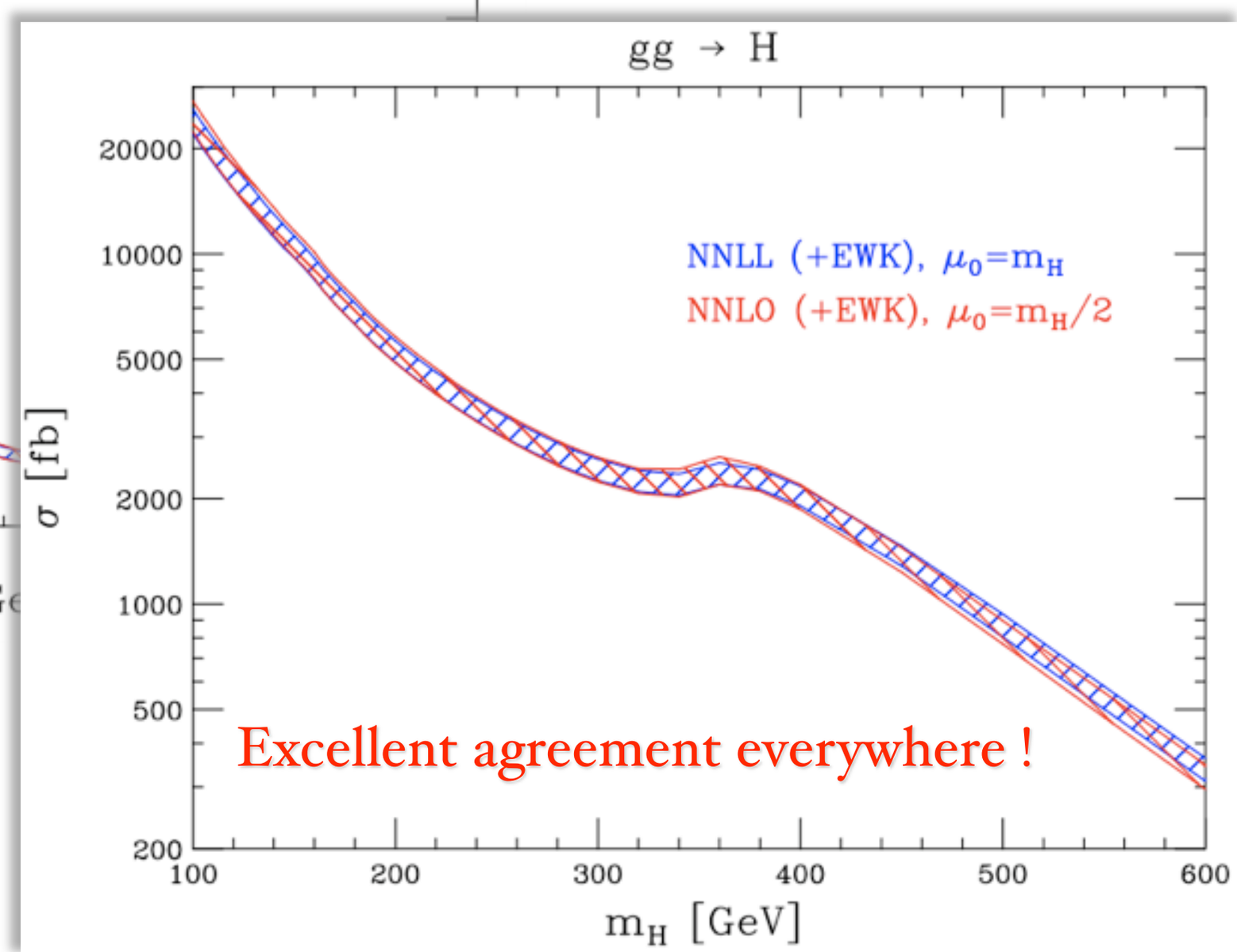
	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + $_s$)	[fb]	(μ_R, μ_F)	(PDF + $_s$)
380	2309.47	$^{-8.87}_{+6.13}$ %	$^{-4.22}_{+4.63}$ %	2262.6	$^{-5.63}_{+5.90}$ %	$^{-4.16}_{+4.51}$ %
400	2047.39	$^{-8.55}_{+5.65}$ %	$^{-4.32}_{+4.79}$ %	2026.7	$^{-5.43}_{+5.91}$ %	$^{-4.26}_{+4.71}$ %
450	1352.52	$^{-8.19}_{+4.75}$ %	$^{-4.57}_{+5.19}$ %	1365.7	$^{-5.28}_{+5.93}$ %	$^{-4.50}_{+5.04}$ %
500	843.74	$^{-7.90}_{+4.21}$ %	$^{-4.83}_{+5.54}$ %	865.4	$^{-5.22}_{+5.97}$ %	$^{-4.75}_{+5.41}$ %
550	521.67	$^{-7.69}_{+3.79}$ %	$^{-5.11}_{+5.98}$ %	538.1	$^{-5.16}_{+6.01}$ %	$^{-5.01}_{+5.79}$ %
600	324.59	$^{-7.50}_{+3.53}$ %	$^{-5.38}_{+6.37}$ %	335.6	$^{-5.16}_{+6.11}$ %	$^{-5.26}_{+6.16}$ %
650	204.62	$^{-7.39}_{+3.34}$ %	$^{-5.64}_{+6.76}$ %	212.4	$^{-5.21}_{+6.17}$ %	$^{-5.53}_{+6.53}$ %
700	130.93	$^{-7.28}_{+3.19}$ %	$^{-5.93}_{+7.14}$ %	136.4	$^{-5.27}_{+6.26}$ %	$^{-5.79}_{+6.89}$ %
750	85.01	$^{-7.22}_{+3.08}$ %	$^{-6.23}_{+7.53}$ %	88.9	$^{-5.36}_{+6.37}$ %	$^{-6.06}_{+7.25}$ %
800	55.99	$^{-7.17}_{+2.96}$ %	$^{-6.54}_{+7.91}$ %	58.8	$^{-5.42}_{+6.45}$ %	$^{-6.34}_{+7.61}$ %
850	37.37	$^{-7.13}_{+2.87}$ %	$^{-6.84}_{+8.30}$ %	39.4	$^{-5.49}_{+6.55}$ %	$^{-6.62}_{+7.98}$ %
900	25.26	$^{-7.10}_{+2.80}$ %	$^{-7.16}_{+8.69}$ %	26.7	$^{-5.59}_{+6.66}$ %	$^{-6.91}_{+8.34}$ %
950	17.27	$^{-7.13}_{+2.75}$ %	$^{-7.47}_{+9.08}$ %	18.3	$^{-5.66}_{+6.79}$ %	$^{-7.20}_{+8.75}$ %
1000	11.94	$^{-7.12}_{+2.68}$ %	$^{-7.79}_{+9.50}$ %	12.7	$^{-5.74}_{+6.97}$ %	$^{-7.49}_{+9.09}$ %

Results (Comparison)



De Florian-Grazzini

Anastasiou-Boughezal-FP



Excellent agreement everywhere !

Additional sources of errors

- Finite top mass effects: calculations of $1/m_t$ suppressed operators + matching to k_t factorization supports ±1% as estimate

- Bottom quark effects: changing from pole to MS mass induces 1-2% effect on cross section, estimate ±2%

- EW effects: reach a maximum of only 5% to begin with... normalize 2-loop exact result to 3-loop EFT estimate. Just like top-quark EFT works up to m_h=1 TeV (to 10-15% level), expect this to also for Higgs masses up to ~300 GeV. Estimate ±1% below 300 GeV

- How to combine them: linearly, quadratically with other errors? Should discuss! Personal opinion: no reason to expect correlation between these, and no surprises expected at higher orders for these effects; also sub-dominant to others ⇒ quadratically sufficient

The calculation by Baglio-Djouadi

- Start from exact NLO (HIGLU) and add NNLO corrections in the large-m_{top} limit
- Neglect resummation effect (+9-10 %), argue it might not survive cuts
- Add NLO EW corrections (-5 %)
- Add estimate for mixed EW-QCD corrections
- First detailed study of the various sources of uncertainties

Following JB+Djouadi, arXiv:1003.4266

Scale variation: obtained with μ_R, μ_F variation around central $\mu_0 = M_H$:

$$M_H/\kappa \leq \mu_R, \mu_F \leq \kappa M_H$$

$\kappa = 2$ enough at ℓHC

$\sigma^{\rm NNLO}_{gg\to H}$: $\simeq$ **+13%, −10% scale variation**

PDF+$\Delta^{\rm exp+th}\alpha_s$:

use MSTW PDF+$\Delta^{\rm exp}\alpha_s$ correlations set

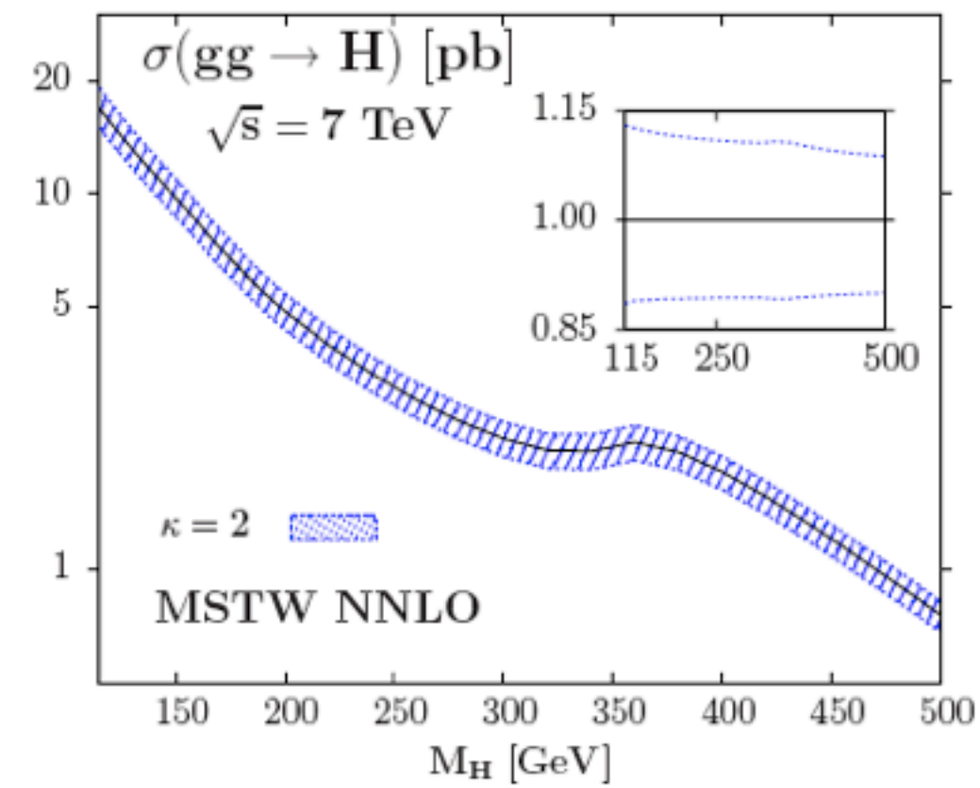
$\Delta^{\rm th}\alpha_s = 0.003$ with MSTW fixed-α_s central sets

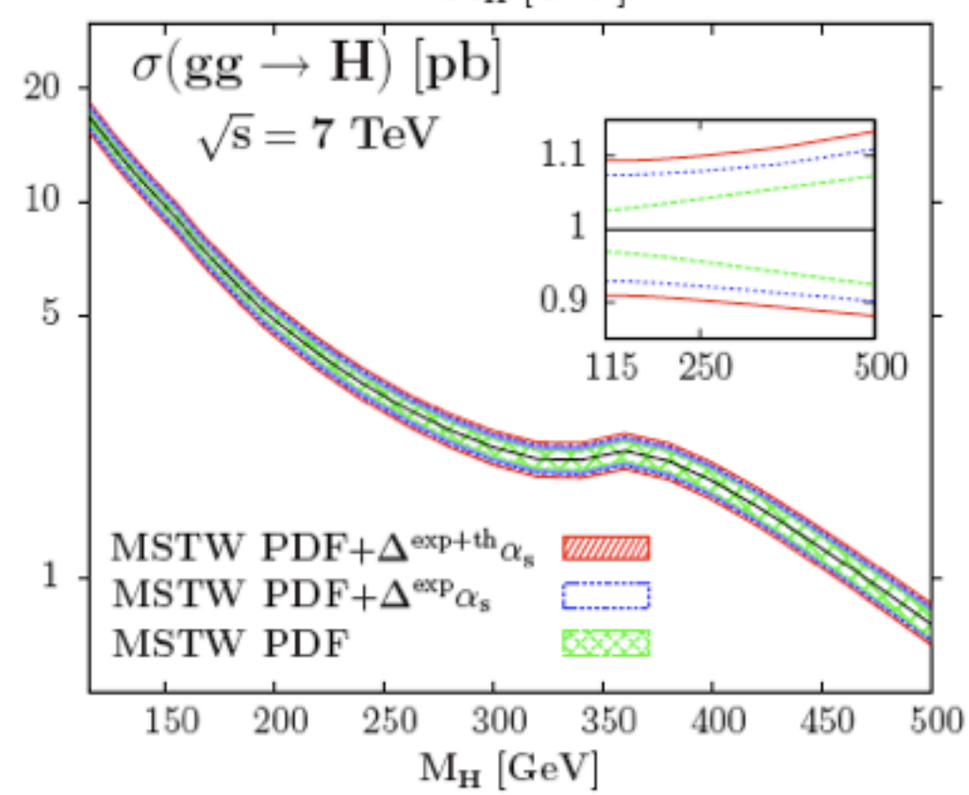
$\sigma^{\rm NNLO}_{gg\to H}$: $\simeq$ **10 − 13% error from PDFs**

Error from use of EFT at NNLO: few %

Missing b–loop at NNLO and ($m_b^{\rm OS,\overline{MS}}$)

Error on mixed QCD–EW corrections





Results

M_H	σ [pb]	total	% total
115	16.92	$^{+5.34}_{-4.40}$	$^{+32\%}_{-26\%}$
120	15.51	$^{+4.86}_{-3.99}$	$^{+31\%}_{-26\%}$
125	14.27	$^{+4.44}_{-3.64}$	$^{+31\%}_{-26\%}$
130	13.16	$^{+4.07}_{-3.35}$	$^{+31\%}_{-25\%}$
135	12.17	$^{+3.74}_{-3.08}$	$^{+31\%}_{-25\%}$
140	11.28	$^{+3.45}_{-2.85}$	$^{+31\%}_{-25\%}$
145	10.48	$^{+3.18}_{-2.64}$	$^{+30\%}_{-25\%}$
150	9.76	$^{+2.94}_{-2.45}$	$^{+30\%}_{-25\%}$
155	9.09	$^{+2.72}_{-2.27}$	$^{+30\%}_{-25\%}$
160	8.41	$^{+2.45}_{-2.04}$	$^{+29\%}_{-24\%}$
165	7.75	$^{+2.17}_{-1.79}$	$^{+28\%}_{-23\%}$

M_H	σ [pb]	total	% total
170	7.19	$^{+1.95}_{-1.61}$	$^{+27\%}_{-22\%}$
175	6.71	$^{+1.78}_{-1.46}$	$^{+26\%}_{-22\%}$
180	6.27	$^{+1.62}_{-1.33}$	$^{+26\%}_{-21\%}$
185	5.85	$^{+1.50}_{-1.23}$	$^{+26\%}_{-21\%}$
190	5.48	$^{+1.43}_{-1.18}$	$^{+26\%}_{-22\%}$
195	5.16	$^{+1.35}_{-1.12}$	$^{+26\%}_{-22\%}$
200	4.87	$^{+1.28}_{-1.07}$	$^{+26\%}_{-22\%}$
220	3.96	$^{+1.04}_{-0.87}$	$^{+26\%}_{-22\%}$
240	3.31	$^{+0.85}_{-0.72}$	$^{+26\%}_{-22\%}$
260	2.83	$^{+0.72}_{-0.61}$	$^{+26\%}_{-22\%}$
280	2.48	$^{+0.63}_{-0.53}$	$^{+25\%}_{-21\%}$

M_H	σ [pb]	total	% total
300	2.23	$^{+0.56}_{-0.48}$	$^{+25\%}_{-21\%}$
320	2.08	$^{+0.53}_{-0.45}$	$^{+25\%}_{-22\%}$
340	2.07	$^{+0.55}_{-0.47}$	$^{+27\%}_{-23\%}$
360	2.19	$^{+0.60}_{-0.51}$	$^{+27\%}_{-23\%}$
380	2.06	$^{+0.53}_{-0.45}$	$^{+26\%}_{-22\%}$
400	1.82	$^{+0.47}_{-0.41}$	$^{+26\%}_{-22\%}$
420	1.57	$^{+0.41}_{-0.35}$	$^{+26\%}_{-23\%}$
440	1.32	$^{+0.35}_{-0.30}$	$^{+26\%}_{-23\%}$
460	1.10	$^{+0.29}_{-0.25}$	$^{+26\%}_{-23\%}$
480	0.92	$^{+0.24}_{-0.21}$	$^{+27\%}_{-23\%}$
500	0.76	$^{+0.20}_{-0.18}$	$^{+27\%}_{-23\%}$

The total uncertainties are of order 25-30 %

Comments

- From the point of view of the fixed-order calculation, better convergence of expansion for $\mu_F=\mu_R=m_H/2$ at both Tevatron and LHC ⇒ supports central value of resummation...

- ... as long as acceptance is treated correctly! Typically smaller for this scale choice (more later)

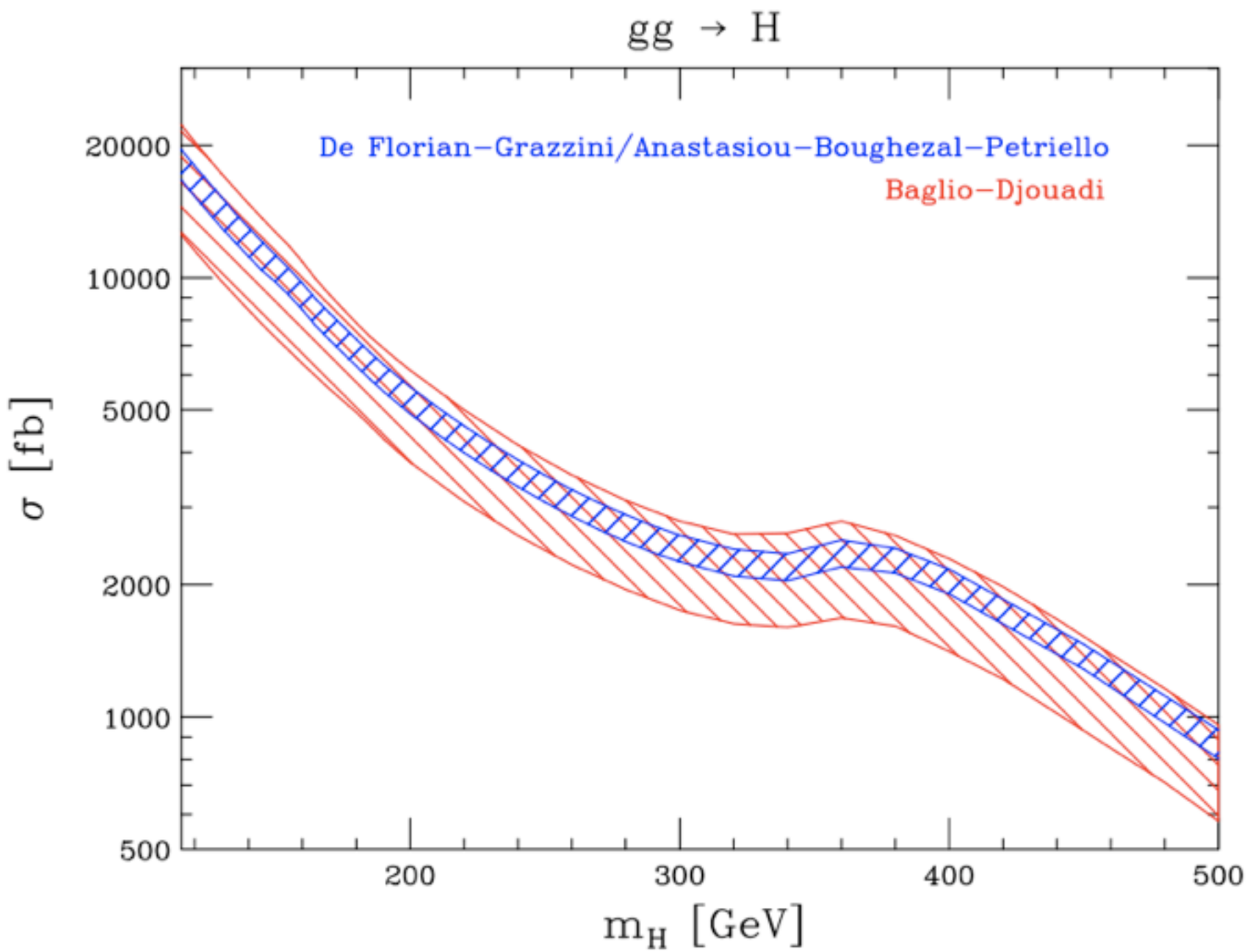
- Fully independent scale variations lead to $0.25< \mu_F/\mu_R <4$: introduces somewhat large logs

- Additional theory uncertainty in α_S of 0.003; should discuss!

- Linear combination of various sources of uncertainties is probably too conservative

Comparison with other Results

- Error bands typically large by a factor 2-3
- Within errors, very good agreement with other numbers



Differential NNLO

NNLO computation is now implemented at fully exclusive level

FEHIP: Based on sector decomposition: computes NNLO corrections for $H \to \gamma\gamma$ and $H \to WW \to l\nu l\nu$

C. Anastasiou,
K. Melnikov, FP (2005)

HNNLO: Parton level Monte Carlo program that computes NNLO corrections for $H \to \gamma\gamma$
$H \to WW \to l\nu l\nu$ and $H \to ZZ \to 4l$

S. Catani, M. Grazzini (2007)
M. Grazzini (2008)

With these programs it is possible to study the impact of higher order corrections with the cuts used in the experimental analysis

Now being used at the Tevatron

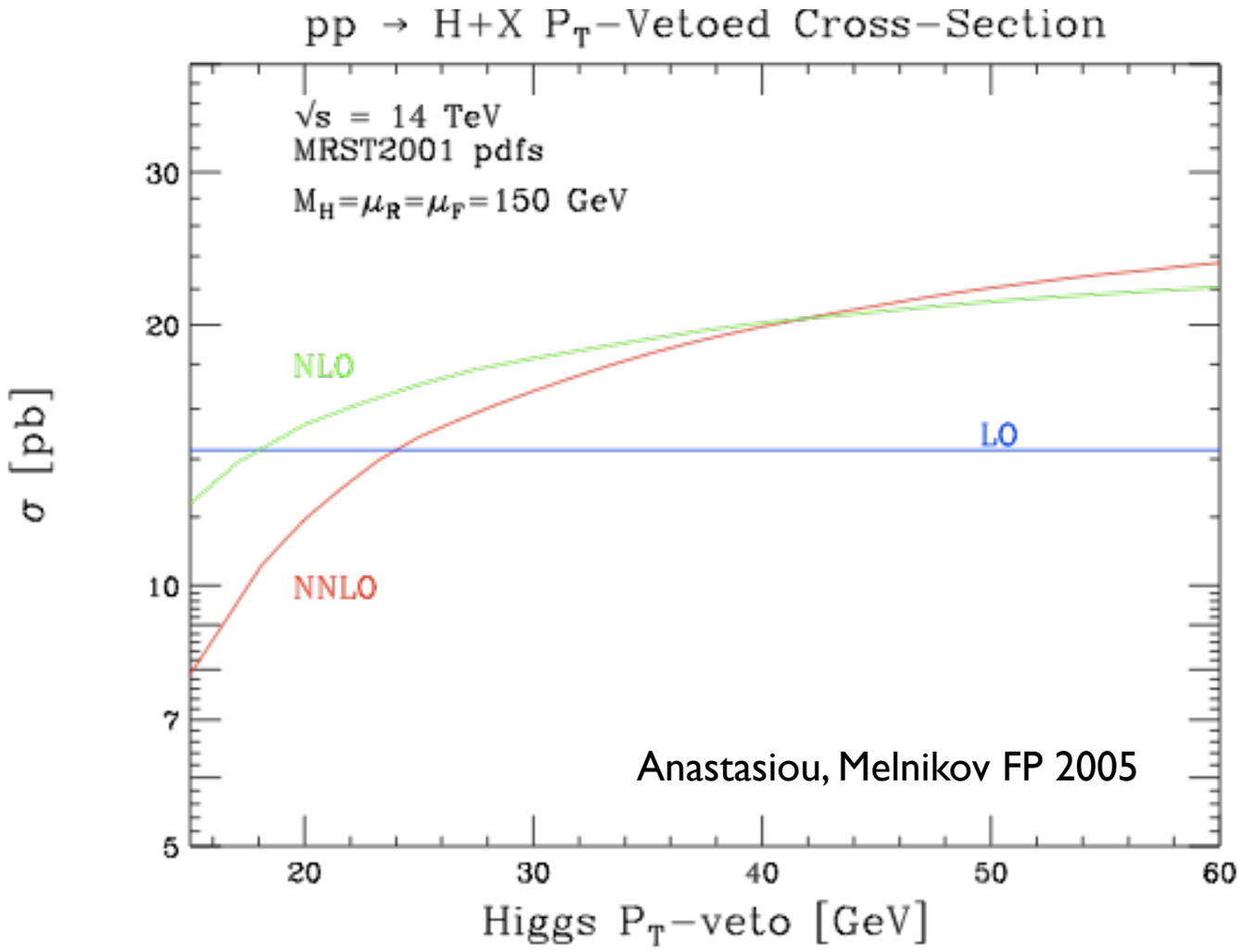
Acceptances

- Changes value of cross section and pattern of corrections!

σ(fb)	LO	NLO	NNLO
$\mu = \frac{M_h}{2}$	21.002 ± 0.021	22.47 ± 0.11	18.45 ± 0.54
$\mu = M_h$	17.413 ± 0.017	21.07 ± 0.11	18.75 ± 0.37
$\mu = 2M_h$	14.529 ± 0.014	19.50 ± 0.10	19.01 ± 0.27

Anastasiou, Dissertori, Stoeckli 2007

Table 3: Cross-section through NNLO for the *signal cuts* of Section 3.



Anastasiou, Melnikov FP 2005

1. the charged leptons should have a transverse momentum of $p_T > 25\,\text{GeV}$ and a pseudorapidity $|\eta| < 2$;
2. these leptons must be isolated from hadrons; the hadronic energy within a cone of $R = 0.4$ around each lepton must not exceed 10% of the corresponding lepton transverse momentum;
3. the di-lepton mass should fall into the range $12\,\text{GeV} < M_{\ell\ell} < 40\,\text{GeV}$. The lower cut reduces potential backgrounds from b-resonances;
4. the missing transverse energy in the event, E_T^{miss}, has to exceed 50 GeV;
5. the opening angle $\phi_{\ell\ell}$ between the two leptons in the transverse plane should be smaller than 45°;
6. there should be no jet with a transverse momentum larger than 25 GeV [2] and pseudorapidity $|\eta| < 2.5$. Jets are found using a cone algorithm with a cone size of $R = 0.4$;
7. the harder lepton is required to have $30\,\text{GeV} < p_T^{lept} < 55\,\text{GeV}$.

Different differential calculations

Anastasiou et al. 2008

$\sigma_{\rm acc}$ [fb] jet algorithm	$\mu = \frac{m_{\rm H}}{2}$ SISCone	$\mu = \frac{m_{\rm H}}{2}$ $k_{\rm T}$	$\mu = 2\, m_{\rm H}$ SISCone	$\mu = 2\, m_{\rm H}$ $k_{\rm T}$
LO	21.00 ± 0.02		14.53 ± 0.01	
HERWIG	11.16 ± 0.04	11.59 ± 0.04	7.60 ± 0.03	7.89 ± 0.03
NLO	22.40 ± 0.06		19.52 ± 0.05	
MC@NLO	17.42 ± 0.08	18.42 ± 0.08	13.60 ± 0.06	14.39 ± 0.06
$R^{\rm NLO}$(HERWIG)	19.79 ± 0.07	20.56 ± 0.07	14.61 ± 0.05	15.17 ± 0.05
NNLO	18.18 ± 0.43	18.45 ± 0.54	18.76 ± 0.31	19.01 ± 0.27
$R^{\rm NNLO}$(MC@NLO)	19.33 ± 0.09	20.43 ± 0.09	17.24 ± 0.07	18.24 ± 0.07
$R^{\rm NNLO}$(HERWIG)	22.02 ± 0.08	22.88 ± 0.08	18.65 ± 0.07	19.38 ± 0.07

Table 1: Cross-sections after the *signal cuts* of Ref. [33] are applied for different calculation methods. The statistical integration errors are shown expicitly. The MC@NLO and HERWIG cross-sections are evaluated with 1,000,000 generated events. The fixed-order results were computed in Ref. [33] and require the Monte-Carlo integration of multiple sectors [17].

- Good agreement between NNLO differential codes and MC@NLO, HERWIG rescaled to correct inclusive result

Referencing: a theorist's view

- Heroic efforts over many years, without which we wouldn't be talking about Higgs discovery/exclusion at Tevatron/LHC
- Must be directly acknowledged in experimental work!

Essentials:

☑ LO: Georgi, Glashow, Machacek, Nanopoulos, PRL 40 692 (1977)
☑ NLO ($m_t \to \infty$): Djouadi, Spira, Zerwas, PLB 264 400 (1991); S. Dawson NPB 359 283 (1991)
☑ NLO (exact mass): Djouadi, Graudenz, Spira, Zerwas NPB 453 17 (1995)
☑ NNLO ($m_t \to \infty$); Harlander, Kilgore PRL 88 201801(2002); Anastasiou, Melnikov NPB 646 220 (2002); Ravindran, Smith, van Neerven NPB 665 325 (2003)

Do we understand cuts (differential NNLO):

☑ Anastasiou, Melnikov, FP, PRL 93 262002 (2004), NPB 724 197 (2005)
☑ Catani, Grazzini, PRL 98 222002 (2007), 0802.1410

Refinements:

☑ Resummation: Catani, de Florian Grazzini, Nason, JHEP 0307 028 (2003)
☑ EW: Uglietti, Bonciani, Degrassi, Vicini PLB 595 432 (2004); Actis, Passarino, Sturm, Uccirati, PLB 670 12 (2008); Anastasiou, Boughezal, FP, JHEP 0904 003 (2009)

Putting it all together (how to combine):

☑ Anastasiou, Boughezal, FP, JHEP 0904 003 (2009)
☑ de Florian, Grazzini, PLB 674 291(2009)

Summary

- Gluon-gluon fusion is the dominant production channel for the SM Higgs boson at hadron colliders for a wide range of m_H
- QCD corrections are important and are known up to NNLO; many improvements (resummation, finite top-mass effects at NNLO, EW effects) support that the theory is under control ⇒ we know what we're doing
- Have presented three updated predictions for LHC@7 TeV: consistent within errors
- We should not focus only on total cross sections, but take into account that there are also fully exclusive NNLO programs that allow us to compute radiative corrections in the presence of cuts
- We should be ready to use these programs and any other theoretical tool that will become available !

Backup: fixed-order vs. resummed p_T

Anastasiou et al. 2008

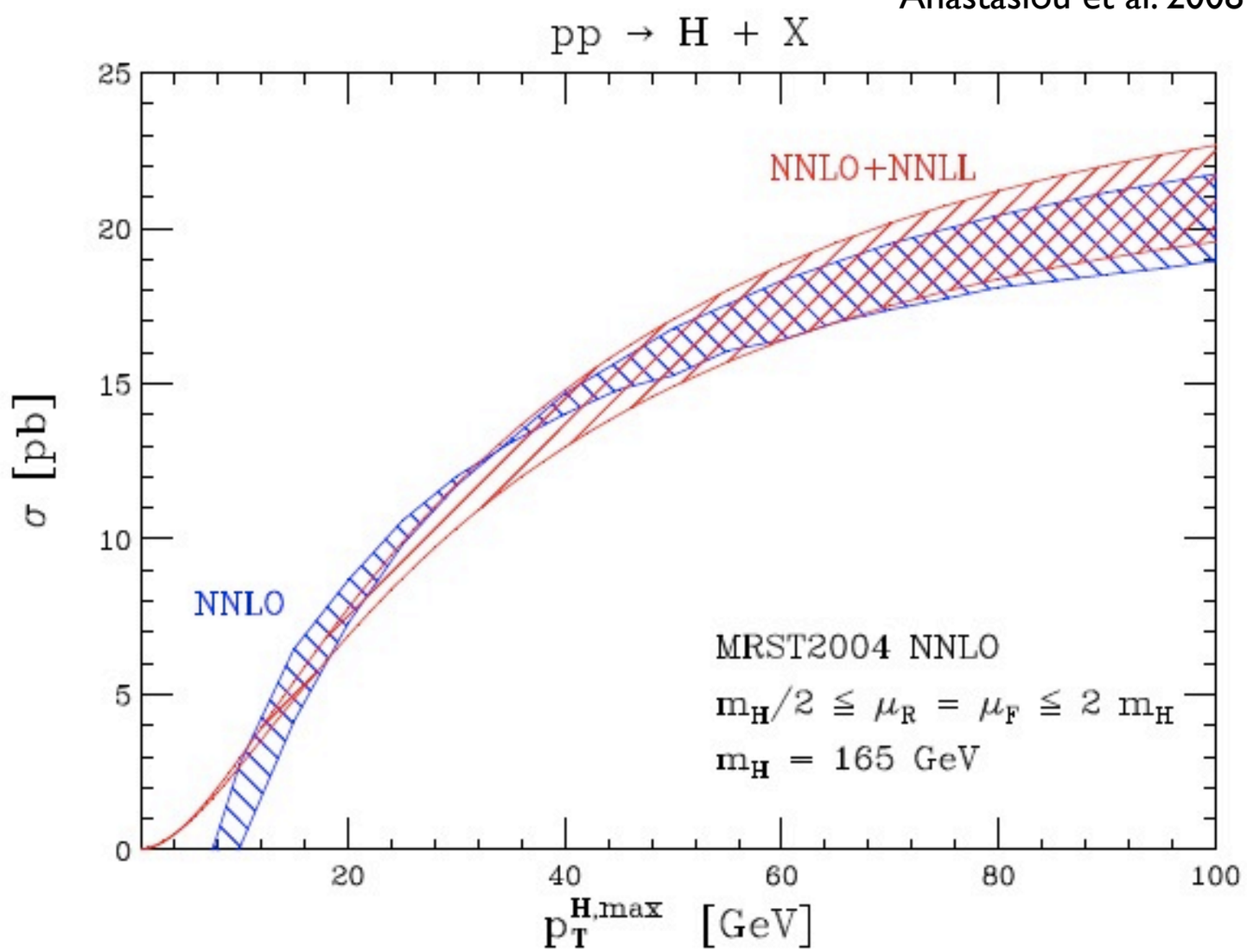


Figure 3: Cumulative cross-section for the Higgs transverse momentum distribution at NNLO in fixed order and with NNLL resummation [38]. The two approaches agree very well in the kinematic range which is relevant for the envisaged experimental cuts.

Results (with PDF error scaled)

	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + $_s$)	[fb]	(μ_R, μ_F)	(PDF + $_s$)
95	27541.26	$^{-10.76}_{+9.93}$ %	$^{-6.26}_{+8.28}$ %	26477.5	$^{-8.56}_{+8.04}$ %	$^{-6.10}_{+8.08}$ %
100	24810.73	$^{-10.49}_{+9.69}$ %	$^{-6.24}_{+8.24}$ %	23968.5	$^{-8.40}_{+7.82}$ %	$^{-6.08}_{+8.04}$ %
105	22469.98	$^{-10.28}_{+9.41}$ %	$^{-6.22}_{+8.22}$ %	21743.9	$^{-8.26}_{+7.65}$ %	$^{-6.08}_{+8.00}$ %
110	20443.02	$^{-10.12}_{+9.19}$ %	$^{-6.22}_{+8.18}$ %	19809.3	$^{-8.13}_{+7.50}$ %	$^{-6.08}_{+7.98}$ %
115	18672.71	$^{-9.96}_{+8.94}$ %	$^{-6.24}_{+8.20}$ %	18115.0	$^{-8.01}_{+7.36}$ %	$^{-6.08}_{+7.96}$ %
120	17116.91	$^{-9.84}_{+8.70}$ %	$^{-6.24}_{+8.12}$ %	16626.9	$^{-7.91}_{+7.23}$ %	$^{-6.10}_{+7.92}$ %
125	15735.73	$^{-9.69}_{+8.56}$ %	$^{-6.26}_{+8.10}$ %	15305.5	$^{-7.80}_{+7.11}$ %	$^{-6.12}_{+7.90}$ %
130	14516.09	$^{-9.55}_{+8.34}$ %	$^{-6.26}_{+8.08}$ %	14131.7	$^{-7.71}_{+6.99}$ %	$^{-6.12}_{+7.90}$ %
135	13425.19	$^{-9.42}_{+8.22}$ %	$^{-6.28}_{+8.00}$ %	13081.7	$^{-7.61}_{+6.88}$ %	$^{-6.14}_{+7.88}$ %
140	12448.41	$^{-9.34}_{+8.12}$ %	$^{-6.30}_{+8.08}$ %	12137.9	$^{-7.53}_{+6.78}$ %	$^{-6.18}_{+7.88}$ %
145	11576.51	$^{-9.29}_{+8.00}$ %	$^{-6.32}_{+8.10}$ %	11288.8	$^{-7.45}_{+6.69}$ %	$^{-6.20}_{+7.86}$ %
150	10792.58	$^{-9.27}_{+7.86}$ %	$^{-6.36}_{+8.06}$ %	10517.8	$^{-7.37}_{+6.60}$ %	$^{-6.22}_{+7.86}$ %
155	10078.16	$^{-9.24}_{+7.72}$ %	$^{-6.38}_{+8.02}$ %	9797.8	$^{-7.30}_{+6.52}$ %	$^{-6.26}_{+7.86}$ %
160	9363.22	$^{-9.20}_{+7.60}$ %	$^{-6.42}_{+8.02}$ %	9076.3	$^{-7.23}_{+6.44}$ %	$^{-6.30}_{+7.84}$ %
165	8536.45	$^{-9.19}_{+7.54}$ %	$^{-6.46}_{+8.04}$ %	8351.9	$^{-7.16}_{+6.37}$ %	$^{-6.32}_{+7.84}$ %
170	7919.50	$^{-9.22}_{+7.45}$ %	$^{-6.50}_{+8.04}$ %	7760.7	$^{-7.10}_{+6.29}$ %	$^{-6.36}_{+7.86}$ %
175	7400.22	$^{-9.17}_{+7.39}$ %	$^{-6.54}_{+8.06}$ %	7240.9	$^{-7.04}_{+6.22}$ %	$^{-6.40}_{+7.86}$ %

Results (with PDF error scaled)

	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + s)	[fb]	(μ_R, μ_F)	(PDF + s)
180	6932.75	$^{-9.13}_{+7.29}$ %	$^{-6.56}_{+8.06}$ %	6763.3	$^{-6.98}_{+6.15}$ %	$^{-6.44}_{+7.86}$ %
185	6444.78	$^{-9.11}_{+7.24}$ %	$^{-6.62}_{+8.06}$ %	6324.1	$^{-6.92}_{+6.12}$ %	$^{-6.48}_{+7.88}$ %
190	6026.63	$^{-9.06}_{+7.24}$ %	$^{-6.66}_{+8.08}$ %	5923.5	$^{-6.87}_{+6.09}$ %	$^{-6.52}_{+7.88}$ %
200	5361.79	$^{-9.05}_{+7.12}$ %	$^{-6.76}_{+8.14}$ %	5266.8	$^{-6.76}_{+6.04}$ %	$^{-6.60}_{+7.92}$ %
210	4821.25	$^{-9.07}_{+7.05}$ %	$^{-6.78}_{+8.10}$ %	4737.5	$^{-6.67}_{+6.00}$ %	$^{-6.70}_{+7.94}$ %
220	4365.69	$^{-8.98}_{+6.97}$ %	$^{-6.92}_{+8.16}$ %	4293.2	$^{-6.58}_{+6.48}$ %	$^{-6.78}_{+7.98}$ %
230	3982.55	$^{-8.99}_{+6.82}$ %	$^{-7.02}_{+8.20}$ %	3915.3	$^{-6.49}_{+5.92}$ %	$^{-6.88}_{+8.04}$ %
240	3652.59	$^{-9.03}_{+6.77}$ %	$^{-7.10}_{+8.26}$ %	3592.6	$^{-6.41}_{+5.88}$ %	$^{-6.98}_{+8.08}$ %
250	3368.02	$^{-8.99}_{+6.69}$ %	$^{-7.18}_{+8.30}$ %	3315.9	$^{-6.34}_{+5.85}$ %	$^{-7.06}_{+8.14}$ %
260	3123.59	$^{-9.01}_{+6.60}$ %	$^{-7.28}_{+8.36}$ %	3077.9	$^{-6.27}_{+5.83}$ %	$^{-7.14}_{+8.20}$ %
270	2913.74	$^{-9.03}_{+6.55}$ %	$^{-7.38}_{+8.42}$ %	2872.7	$^{-6.20}_{+5.83}$ %	$^{-7.24}_{+8.26}$ %
280	2731.71	$^{-8.96}_{+6.58}$ %	$^{-7.48}_{+8.50}$ %	2696.9	$^{-6.14}_{+5.82}$ %	$^{-7.36}_{+8.32}$ %
290	2578.05	$^{-8.90}_{+6.62}$ %	$^{-7.58}_{+8.56}$ %	2547.8	$^{-6.08}_{+5.81}$ %	$^{-7.44}_{+8.38}$ %
300	2452.26	$^{-8.88}_{+6.54}$ %	$^{-7.66}_{+8.62}$ %	2424.5	$^{-6.03}_{+5.80}$ %	$^{-7.52}_{+8.46}$ %
320	2276.50	$^{-9.00}_{+6.49}$ %	$^{-7.86}_{+8.78}$ %	2249.6	$^{-5.95}_{+5.76}$ %	$^{-7.74}_{+8.62}$ %
340	2245.37	$^{-9.16}_{+6.70}$ %	$^{-8.08}_{+8.94}$ %	2198.9	$^{-5.92}_{+5.76}$ %	$^{-7.94}_{+8.78}$ %
360	2438.17	$^{-9.21}_{+6.77}$ %	$^{-8.26}_{+9.10}$ %	2361.2	$^{-5.86}_{+5.85}$ %	$^{-8.12}_{+8.96}$ %

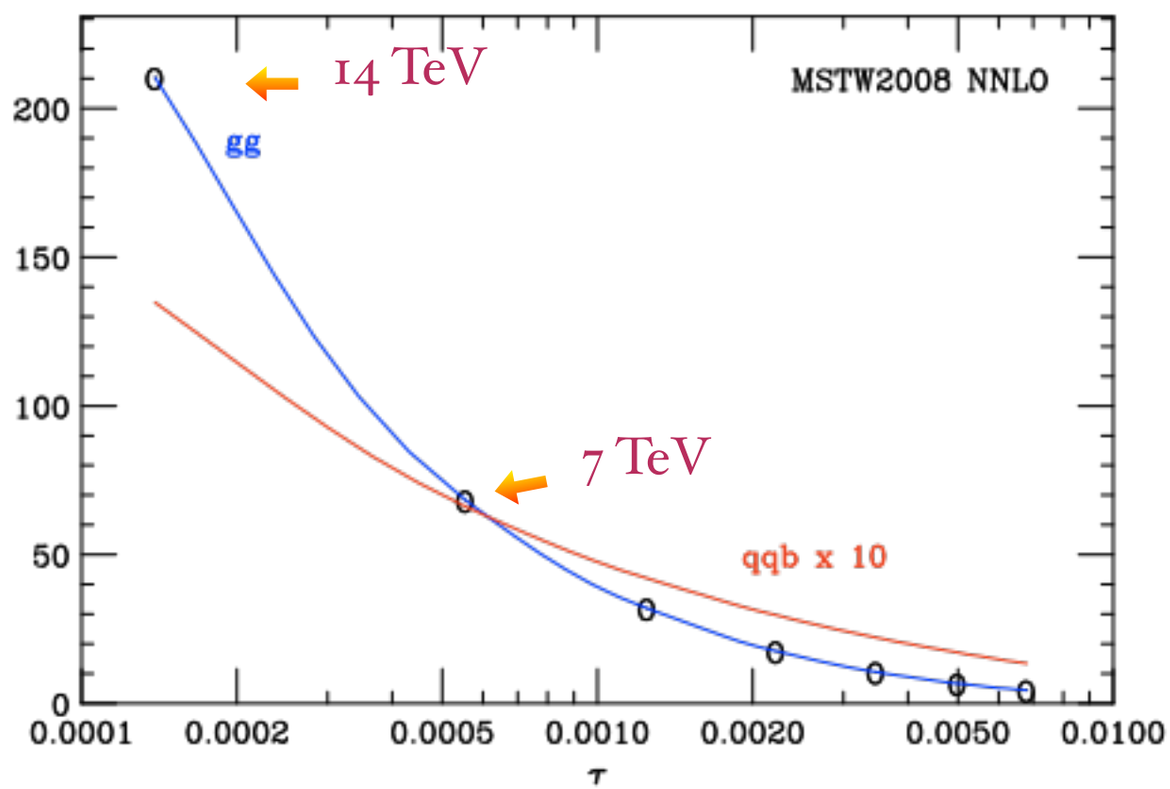
Results (with PDF error scaled)

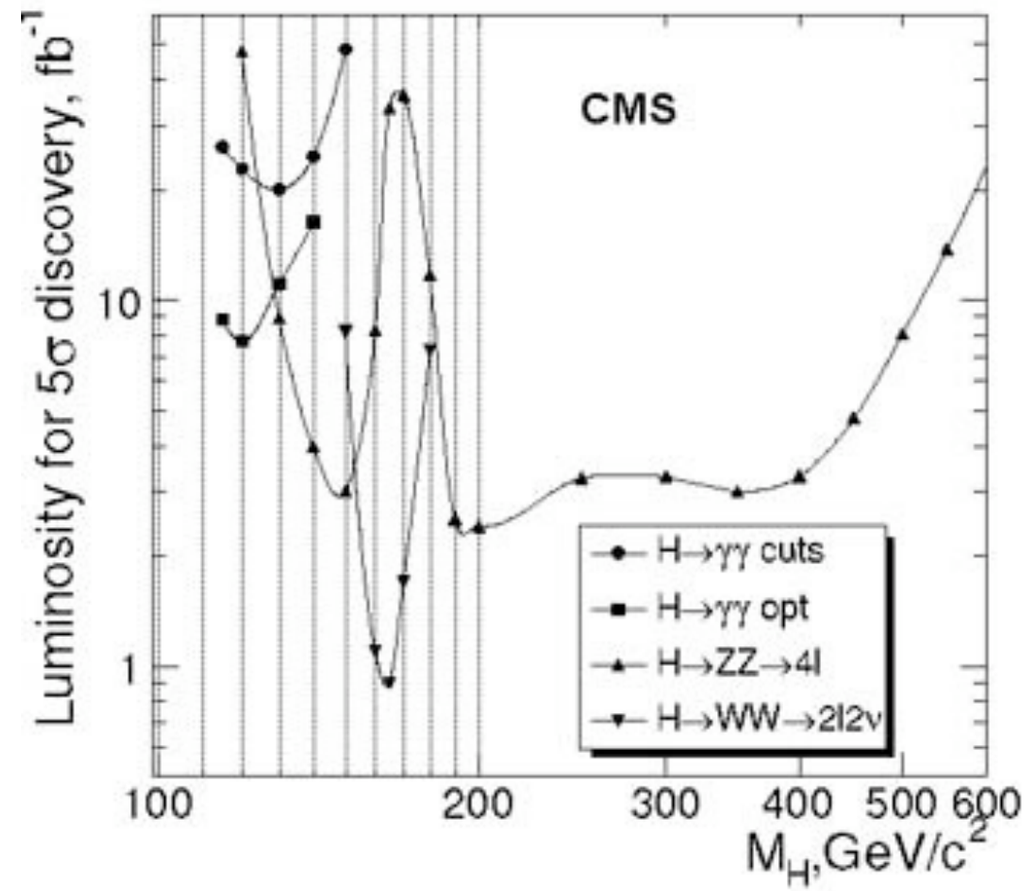
	Anastasiou-Boughezal-Petriello+Stoeckli			de Florian-Grazzini		
m_H	[fb]	(μ_R, μ_F)	(PDF + s)	[fb]	(μ_R, μ_F)	(PDF + s)
380	2309.47	$^{-8.87}_{+6.13}$ %	$^{-8.44}_{+9.26}$ %	2262.6	$^{-5.63}_{+5.90}$ %	$^{-8.32}_{+9.02}$ %
400	2047.39	$^{-8.55}_{+5.65}$ %	$^{-8.64}_{+9.58}$ %	2026.7	$^{-5.43}_{+5.91}$ %	$^{-8.52}_{+9.42}$ %
450	1352.52	$^{-8.19}_{+4.75}$ %	$^{-9.14}_{+10.38}$ %	1365.7	$^{-5.28}_{+5.93}$ %	$^{-9.00}_{+10.08}$ %
500	843.74	$^{-7.90}_{+4.21}$ %	$^{-9.66}_{+11.08}$ %	865.4	$^{-5.22}_{+5.97}$ %	$^{-9.50}_{+10.82}$ %
550	521.67	$^{-7.69}_{+3.79}$ %	$^{-10.22}_{+11.96}$ %	538.1	$^{-5.16}_{+6.01}$ %	$^{-10.02}_{+11.58}$ %
600	324.59	$^{-7.50}_{+3.53}$ %	$^{-10.76}_{+12.74}$ %	335.6	$^{-5.16}_{+6.11}$ %	$^{-10.52}_{+12.32}$ %
650	204.62	$^{-7.39}_{+3.34}$ %	$^{-11.28}_{+13.52}$ %	212.4	$^{-5.21}_{+6.17}$ %	$^{-11.06}_{+13.06}$ %
700	130.93	$^{-7.28}_{+3.19}$ %	$^{-11.86}_{+14.28}$ %	136.4	$^{-5.27}_{+6.26}$ %	$^{-11.58}_{+13.78}$ %
750	85.01	$^{-7.22}_{+3.08}$ %	$^{-12.46}_{+15.06}$ %	88.9	$^{-5.36}_{+6.37}$ %	$^{-12.12}_{+14.50}$ %
800	55.99	$^{-7.17}_{+2.96}$ %	$^{-13.08}_{+15.82}$ %	58.8	$^{-5.42}_{+6.45}$ %	$^{-12.68}_{+15.22}$ %
850	37.37	$^{-7.13}_{+2.87}$ %	$^{-13.68}_{+16.60}$ %	39.4	$^{-5.49}_{+6.55}$ %	$^{-13.24}_{+15.96}$ %
900	25.26	$^{-7.10}_{+2.80}$ %	$^{-14.32}_{+17.38}$ %	26.7	$^{-5.59}_{+6.66}$ %	$^{-13.82}_{+16.68}$ %
950	17.27	$^{-7.13}_{+2.75}$ %	$^{-14.94}_{+18.16}$ %	18.3	$^{-5.66}_{+6.79}$ %	$^{-14.40}_{+17.50}$ %
1000	11.94	$^{-7.12}_{+2.68}$ %	$^{-15.58}_{+19.00}$ %	12.7	$^{-5.74}_{+6.97}$ %	$^{-14.98}_{+18.18}$ %

LHC @ 7 TeV

At 14 TeV a SM Higgs boson with m_H ~ 160 GeV can be discovered with about 1 fb^{-1}

From 14 to 7 TeV both signal and background cross sections decrease





But gg parton luminosity drops faster

$$\mathcal{L}_{c\bar{c}}(\tau, \mu_F^2) = \int_\tau^1 \frac{dx}{x} f_c(x, \mu_F^2) f_{\bar{c}}(\tau/x, \mu_F^2)$$

Recent NLO study shows that luminosity needed for discovery may be a factor 6-7 larger

E.Berger et al. (2010)

LHC @ 7 TeV

Why not to focus on the region where we have some (small) chance in the next few years ?

m_H=165 GeV

$$\sigma = 8.45^{+0.64}_{-0.66}\ (\text{scale})^{+0.33}_{-0.27}(\text{PDF} + \alpha_S\ @\,68\%\ \text{CL})$$

de Florian, Grazzini

$$\sigma = 8.54^{+0.64}_{-0.78}\ (\text{scale})^{+0.34}_{-0.28}(\text{PDF} + \alpha_S\ @\,68\%\ \text{CL})$$

Anastasiou, Boughezal, FP

$$\sigma = 7.75^{+2.17}_{-1.79}\ \text{pb}$$

Baglio, Djouadi

The three predictions are perfectly consistent