Alla ricerca del bosone di Higgs

Massimiliano Grazzini (INFN, Sezione di Firenze)

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Outline

- Introduction: Standard Model physics in Florence
- An example of recent (important) results:

  Higgs boson search at the Tevatron and the LHC

  - Theoretical predictions
  - The importance of QCD radiative corrections
- Summary/Perspective

SM physics in Florence

QCD and Electroweak theory + phenomenology at high energies (LEP, SLC, HERA, Tevatron, LHC...)

Research activity with solid and long (~30 years) tradition in Florence (Univ.+INFN)

M. Ciafaloni (1980)

People:

Stefano Catani, Dir. Ric. INFN
Marcello Ciafaloni, Prof. Univ.
Dimitri Colferai, Ric. Univ.
Giancarlo Ferrera, Assegn. Univ+INFN
Damiano Tommasini, Dottorando
MG, Ric. INFN

Collaborations

Some of main collaborators in other institutes:

R. Bonciani (Grenoble)
D. de Florian (Buenos Aires)
G. Rodrigo (Valencia)
I. Birenmaum (Valencia)
B. Webber (Cambridge)
P. Ciafaloni (Lecce)
S. Wallon (Orsay)
F. Krauss (Durham)
T. Gleisberg (SLAC)
R. Frederix (Zurich Univ.)
....

G. Bozzi (Milano)
G. Salam (Paris)
A. Stasto (Penn State Univ.)
C. Anastasiou (ETH Zurich)
G.Dissertori (ETH Zurich)
L. Szymanowski (Palaiseau)
J. Winter (Fermilab)
J.Winter (Fermilab)
P. Nason (Milano)
F. Stoeckli (CERN)
....

The heritage

Standard Electroweak theory based on $SU(2)_L \otimes U(1)_Y$ gauge theory


A. Salam


S. Weinberg


S. Glashow

Quantum Chromo Dynamics (QCD): $SU(3)_c$ gauge theory


D. Gross


F. Wilczek


D. Politzer

Altogether a beautiful theory describing high-energy phenomena at a surprizing level of accuracy

But how do elementary particles acquire their mass ?

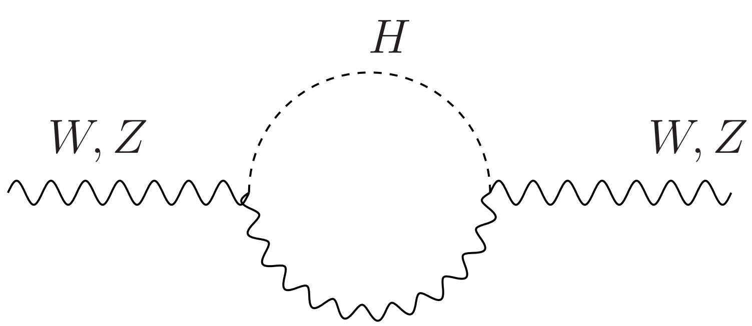
The last mistery

- The solution: masses are generated by the Higgs boson (scalar particle) through Spontaneous Symmetry Breaking
- The mass of the Higgs boson is not predicted by the theory
- Theoretical arguments (or prejudices) suggest $50\,\mathrm{GeV} \lesssim m_H \lesssim 800\,\mathrm{GeV}$ (with new physics at the TeV scale)
- LEP has put a lower limit on the mass of the SM Higgs boson at $m_H \geq 114.4$ GeV at 95% CL
- The most sought particle in history (LEP, Tevatron, LHC) !

Other constraints come from:

- **Precision electroweak data: radiative corrections are sensitive to the mass of virtual particles**

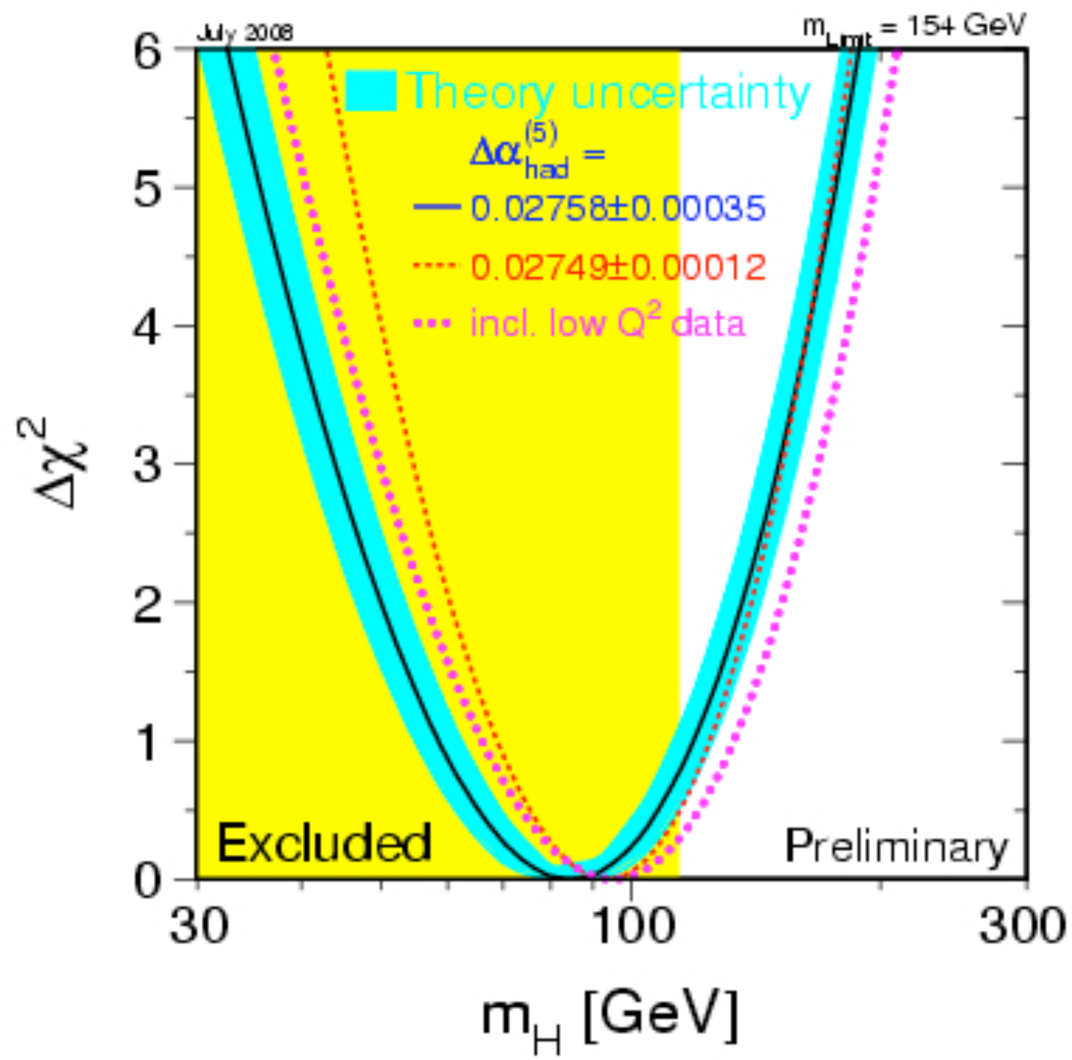
.... but screening effect: the dependence is only logarithmic at one loop (for top quark the dependence is quadratic → m_{top} predicted before discovery !)



$$m_H = 87^{+35}_{-26}\ \text{GeV}$$

$$m_H < 157\ \text{GeV}\ \ \text{at 95 \% CL}$$

LEP EWWG, summer 2009

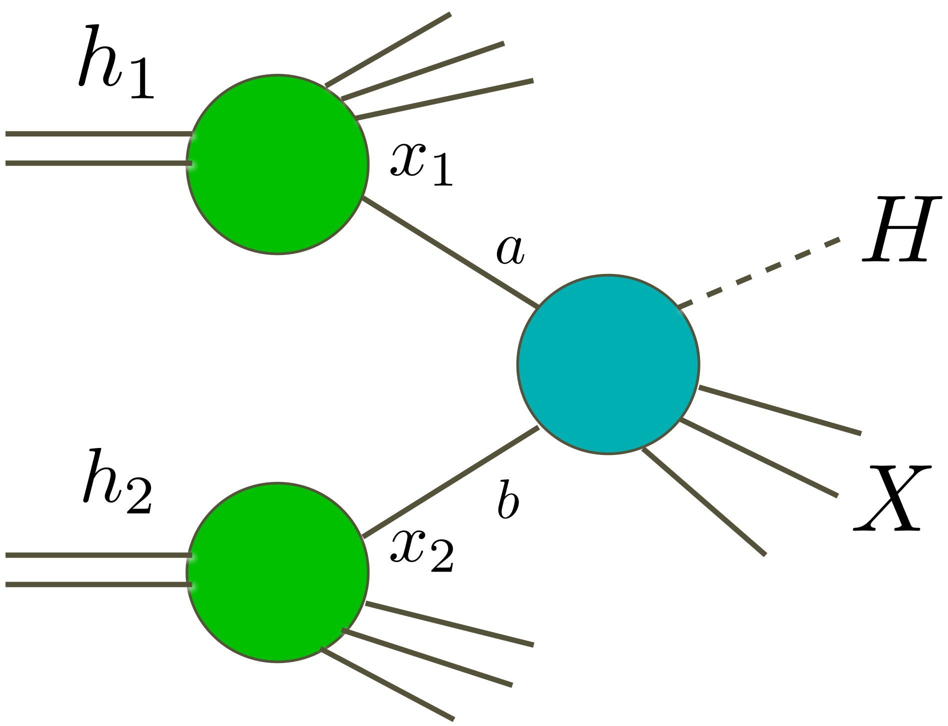


Taking into account LEP limit:

$$m_H < 186\ \text{GeV}\ \ \text{at 95 \% CL}$$

Theoretical predictions at hadron colliders

The framework: QCD factorization theorem



$$\sigma(p_1, p_2; M_H) = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_{h_1,a}(x_1, \mu_F^2)\, f_{h_2,b}(x_2, \mu_F^2) \times \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2, \alpha_S(\mu_R^2); \mu_F^2)$$

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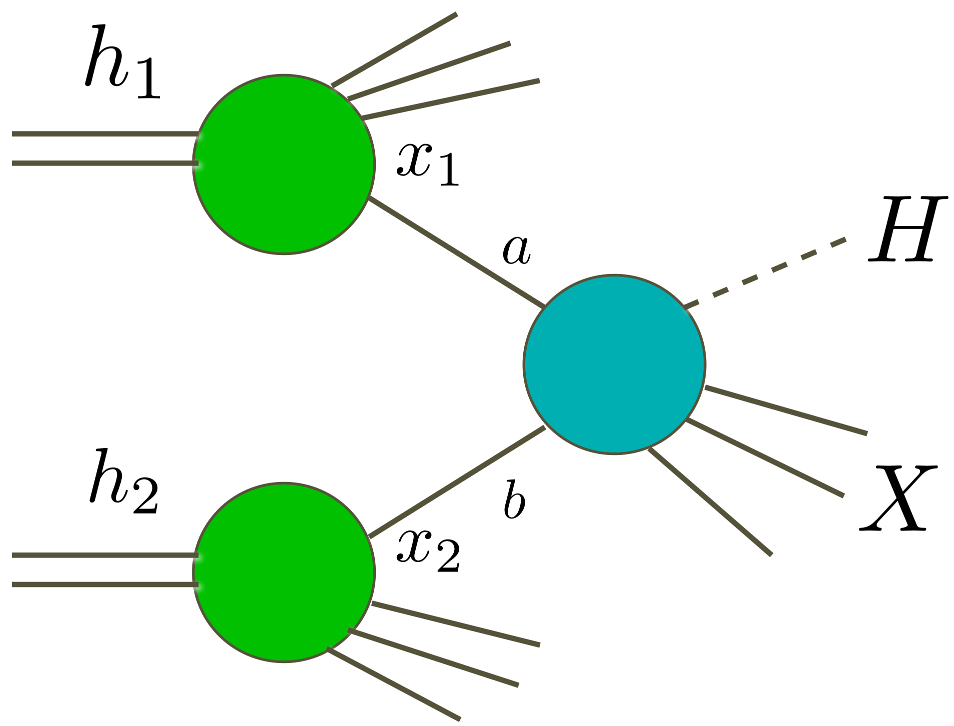

Parton distributions

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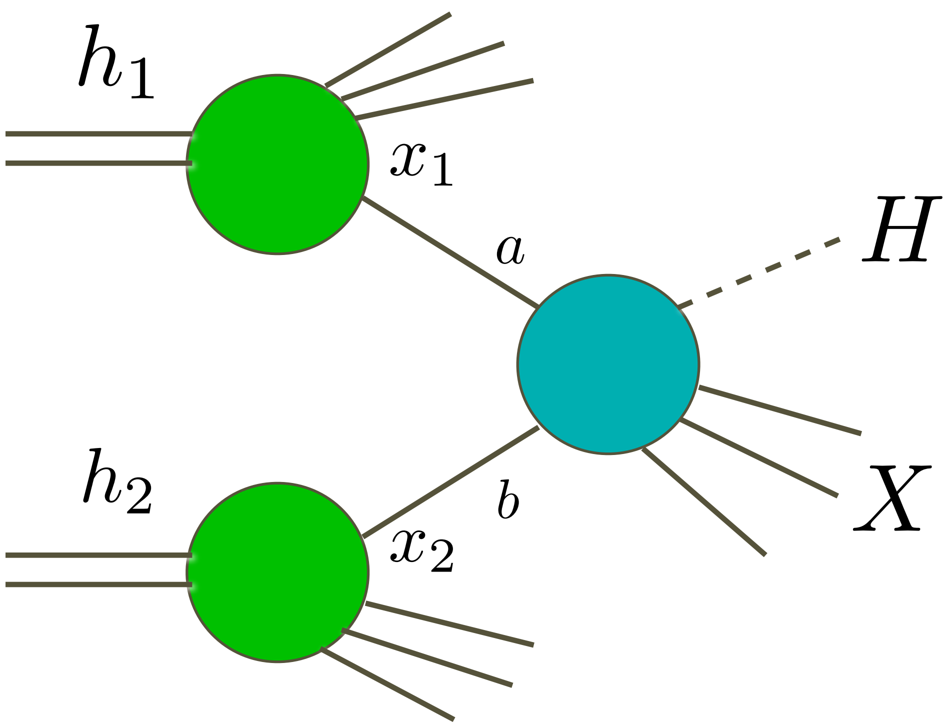


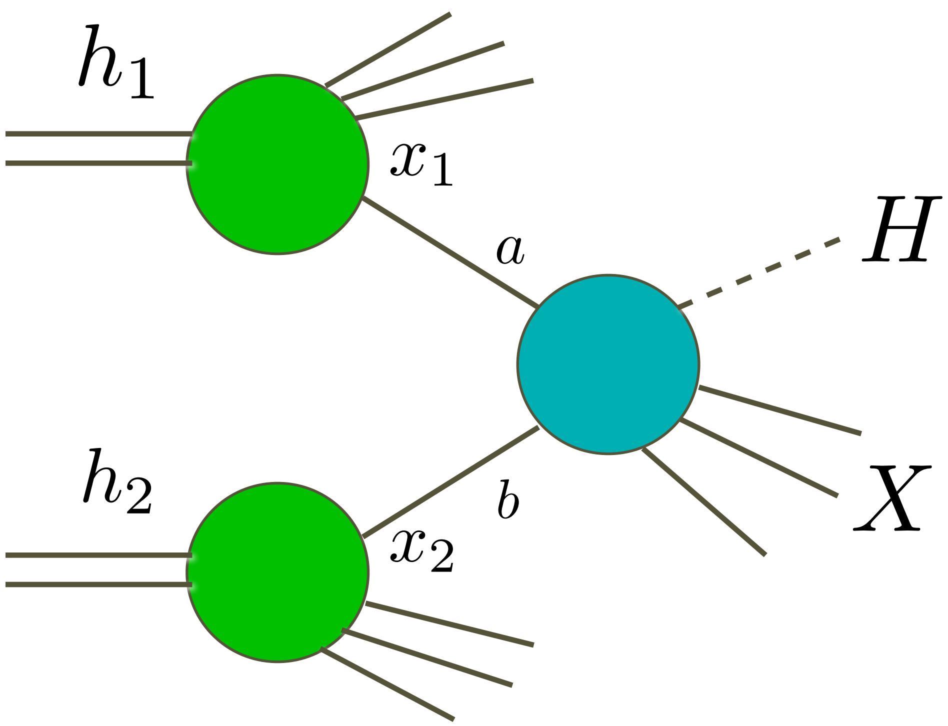
Parton distributions

Partonic cross section

$$\sigma(p_1, p_2; M_H) = \sum_{a,b} \int_0^1 dx_1 dx_2 \, f_{h_1,a}(x_1, \mu_F^2) \, f_{h_2,b}(x_2, \mu_F^2) \times \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2, \alpha_S(\mu_R^2); \mu_F^2)$$

Theoretical predictions at hadron colliders

The framework: QCD factorization theorem



Parton distributions

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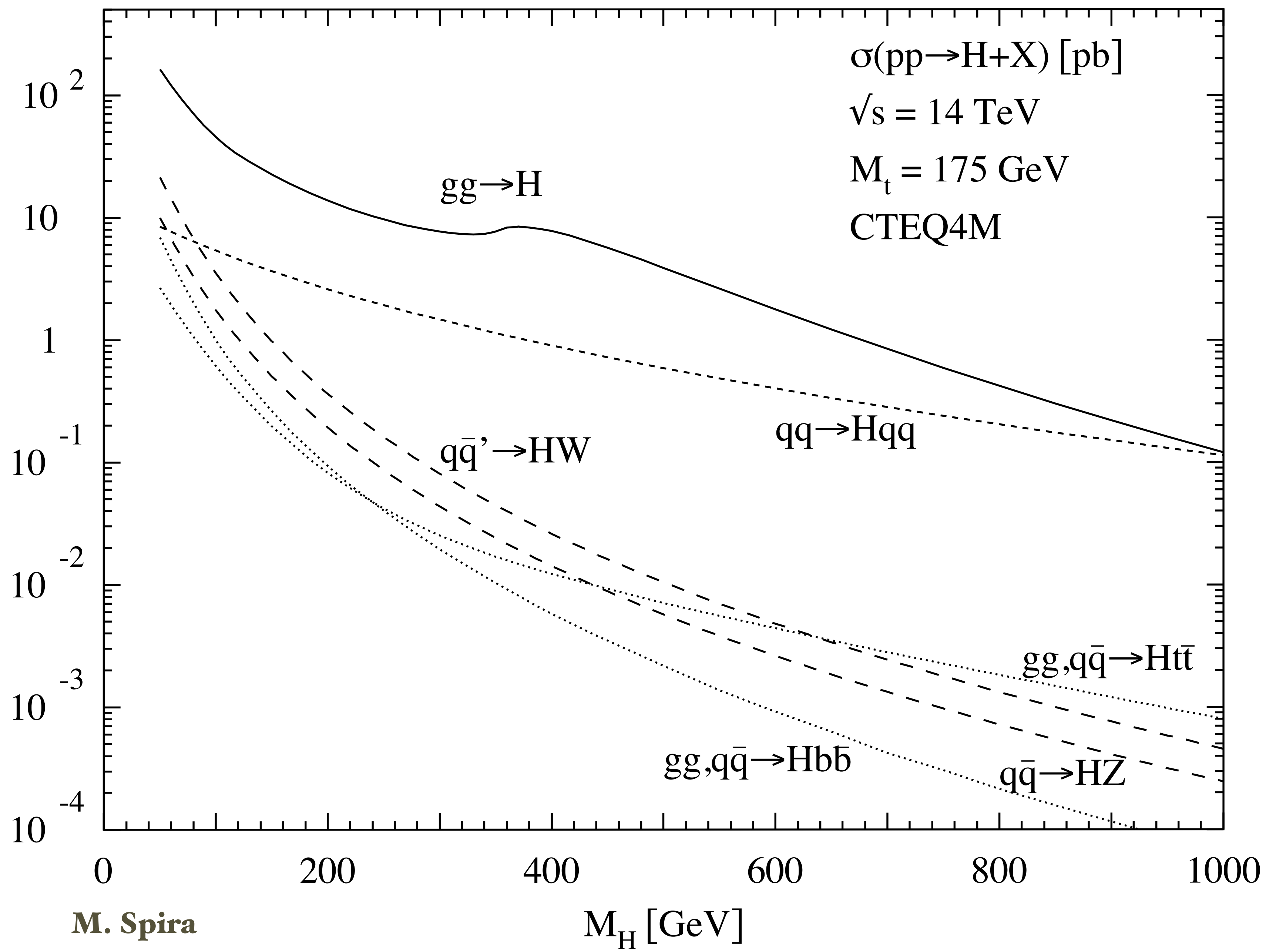
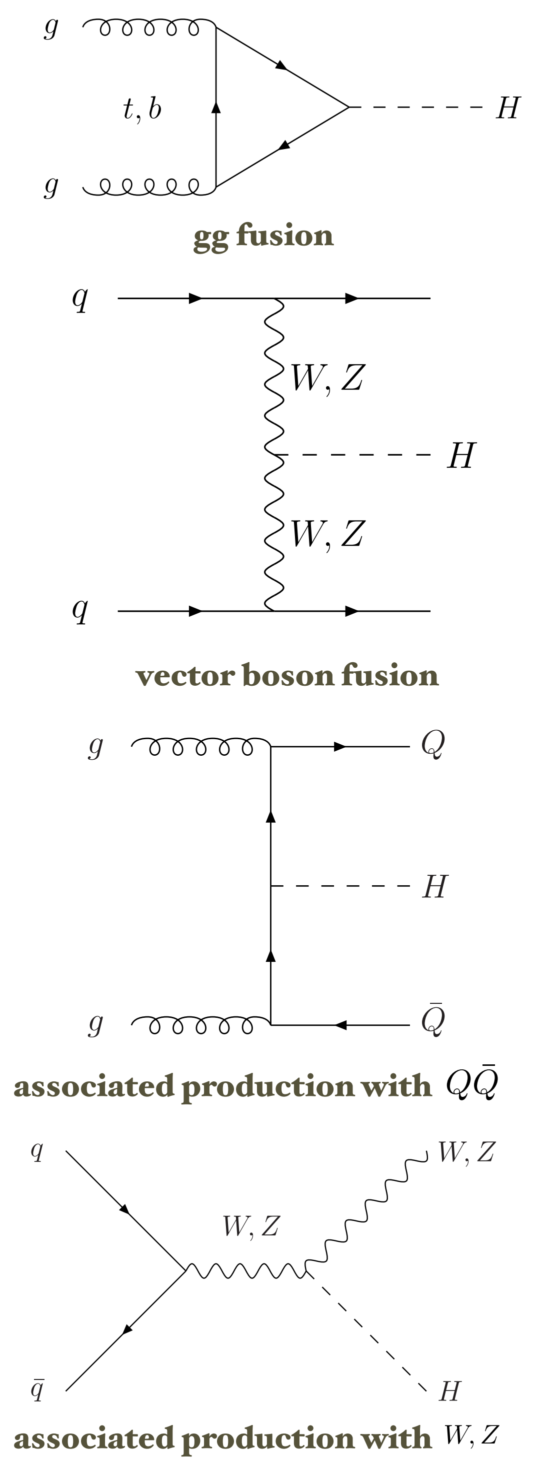
Precise predictions for σ depend on good knowledge of BOTH $\hat{\sigma}_{ab}$ and $f_{h,a}(x, \mu_F^2)$

Higgs production at hadron colliders

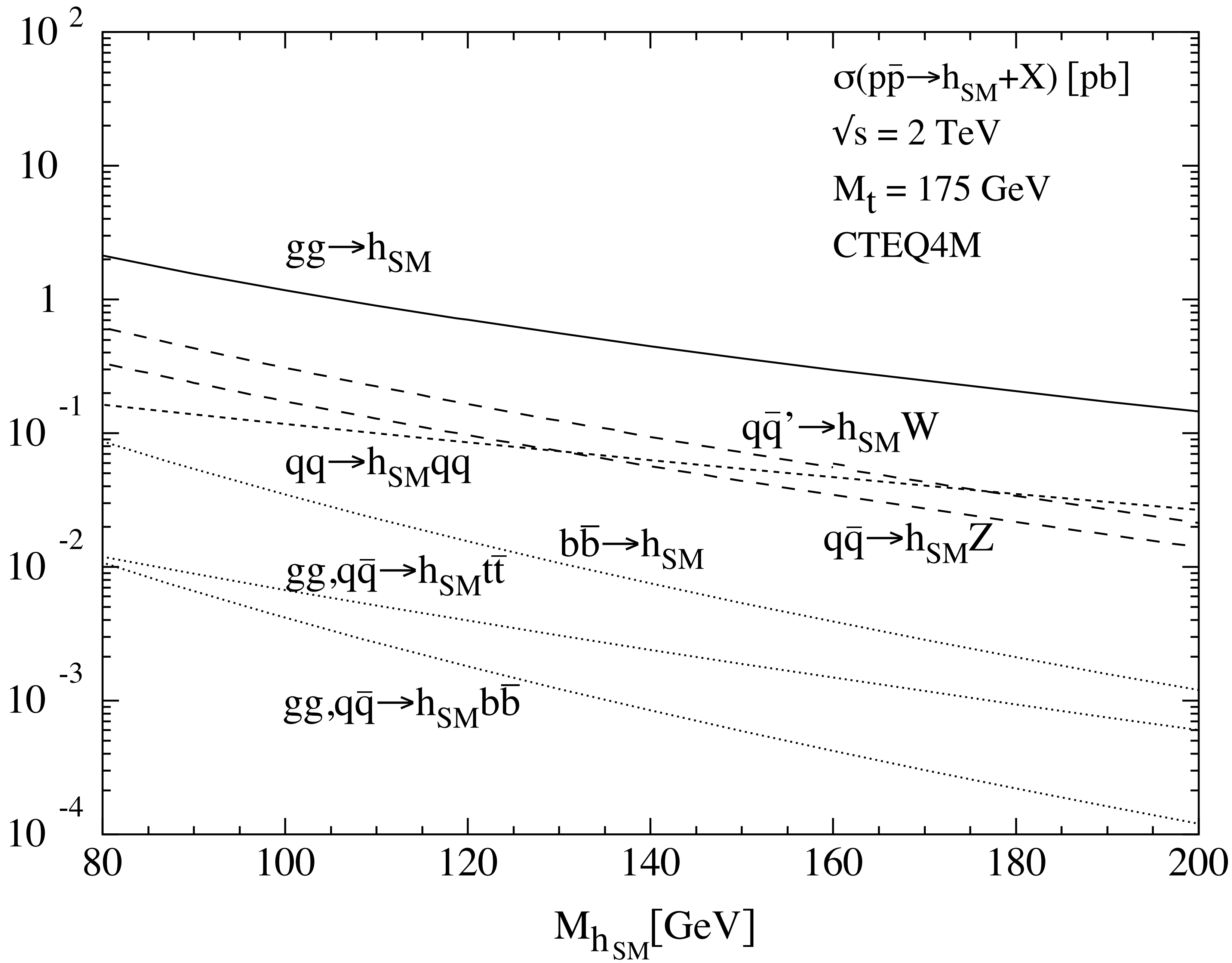


M. Spira



Large gluon luminosity → gg fusion is the dominant production channel over the whole range of m_H

Higgs production at hadron colliders



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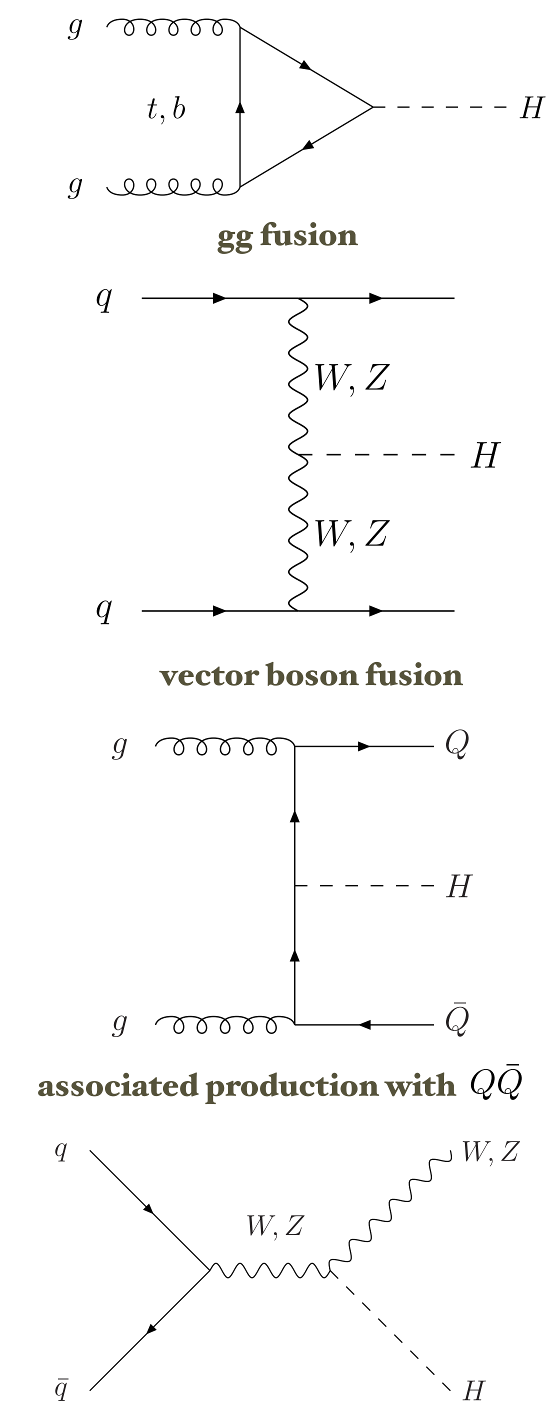


Similar situation at the Tevatron
(although gg dominance less pronounced)

Parton distribution functions

Gluon, quark, antiquark densities determined by data vs theory at lower scales

then evolution to higher scales by DGLAP eqs

$$\frac{dg(x,Q)}{d\ln Q} \sim P(\alpha_S(Q),x) \otimes g(x,Q)$$

perturbative kernel

$$P(\alpha_S,x) = \alpha_S P_{LO}(x) + \alpha_S^2 P_{NLO}(x) + \alpha_S^3 P_{NNLO}(x) + \ldots.$$

- Small x issue (high energy)

$$P(\alpha_S,x) \sim \alpha_S^n \ln^n x + \alpha_S^n \ln^{(n-1)} x + \ldots$$

LL NLL

$\alpha_S(Q) \sim 0.1 - 0.2$ small but large order by order coefficients

ln 1/x=	4.6	$x=10^{-1}$
	6.9	$x=10^{-2}$
	9.2	$x=10^{-3}$

Is standard (DGLAP) approach reliable at small x ?

Solution: all-order resummation

Parton distribution functions

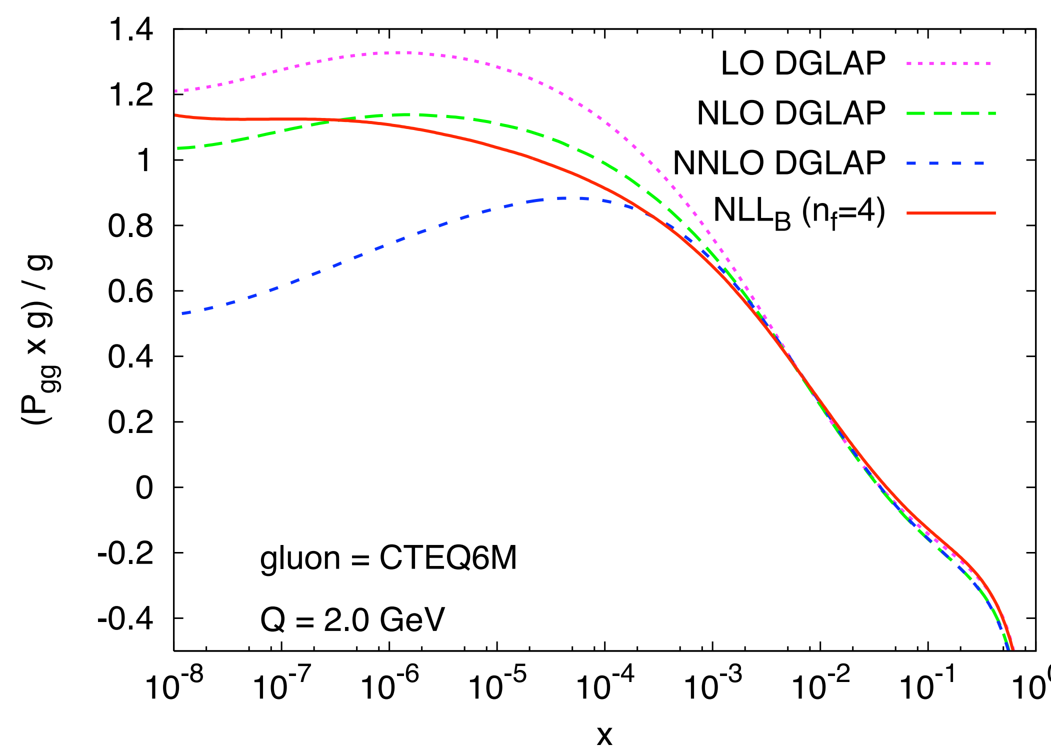
Small-x resummation ("fall and rise of gluon splitting function")
To make a long story short:

Ciafaloni, Colferai, Salam, Stasto

- LL res. (BFKL, 1978)
  very large increase

- NLL res. (Camici-Ciafaloni
  Fadin-Lipatov, 1998)
  very large decreasing corrections (eventually negative gluon and cross sections

- NLL + subleading (constraints from: renormalization group invariance+ energy conservation

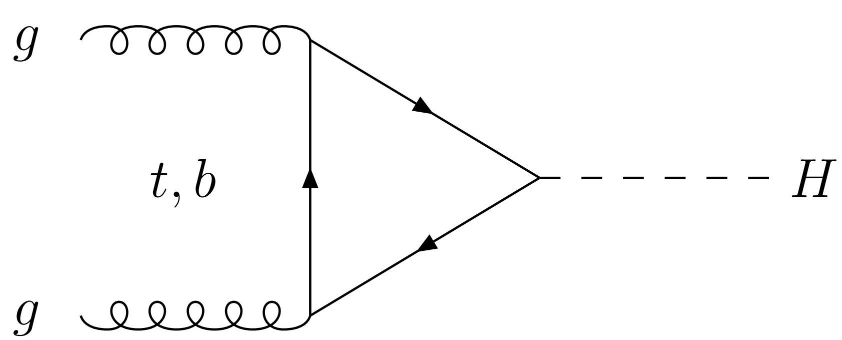


perturbative features stabilized

→ **DGLAP safe at moderate (small) x (e.g. Higgs at Tevatron and LHC)**

Ciafaloni, Colferai, Salam, Stasto (2003,2004)
Altarelli, Ball, Forte (2003,2004)

Partonic cross section: 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 (excellent approx. for a light Higgs)

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

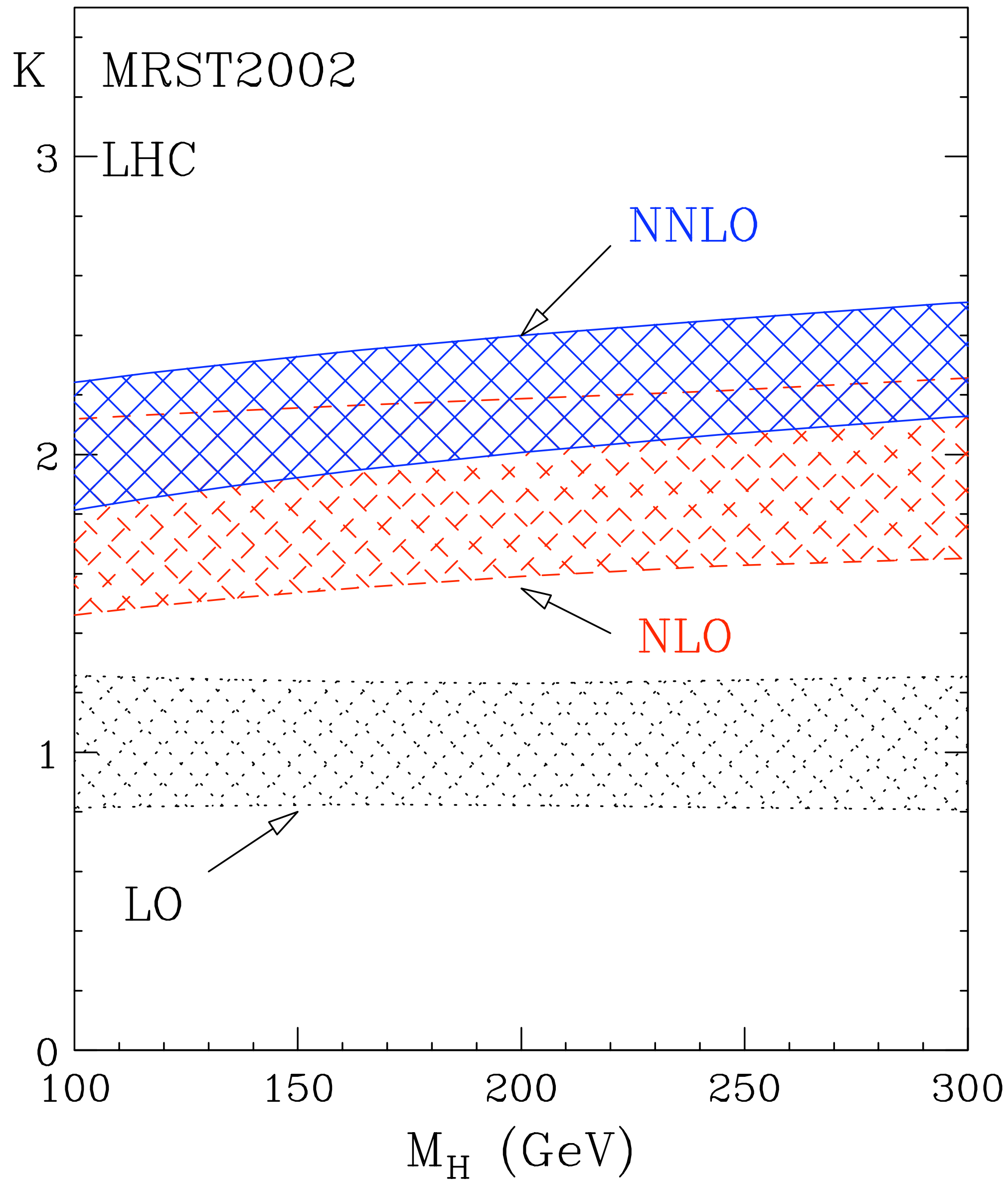
Effects of soft-gluon resummation at Next-to-next-to leading logarithmic (NNLL) accuracy

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

EW corrections are also known (effect is about 5%)

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

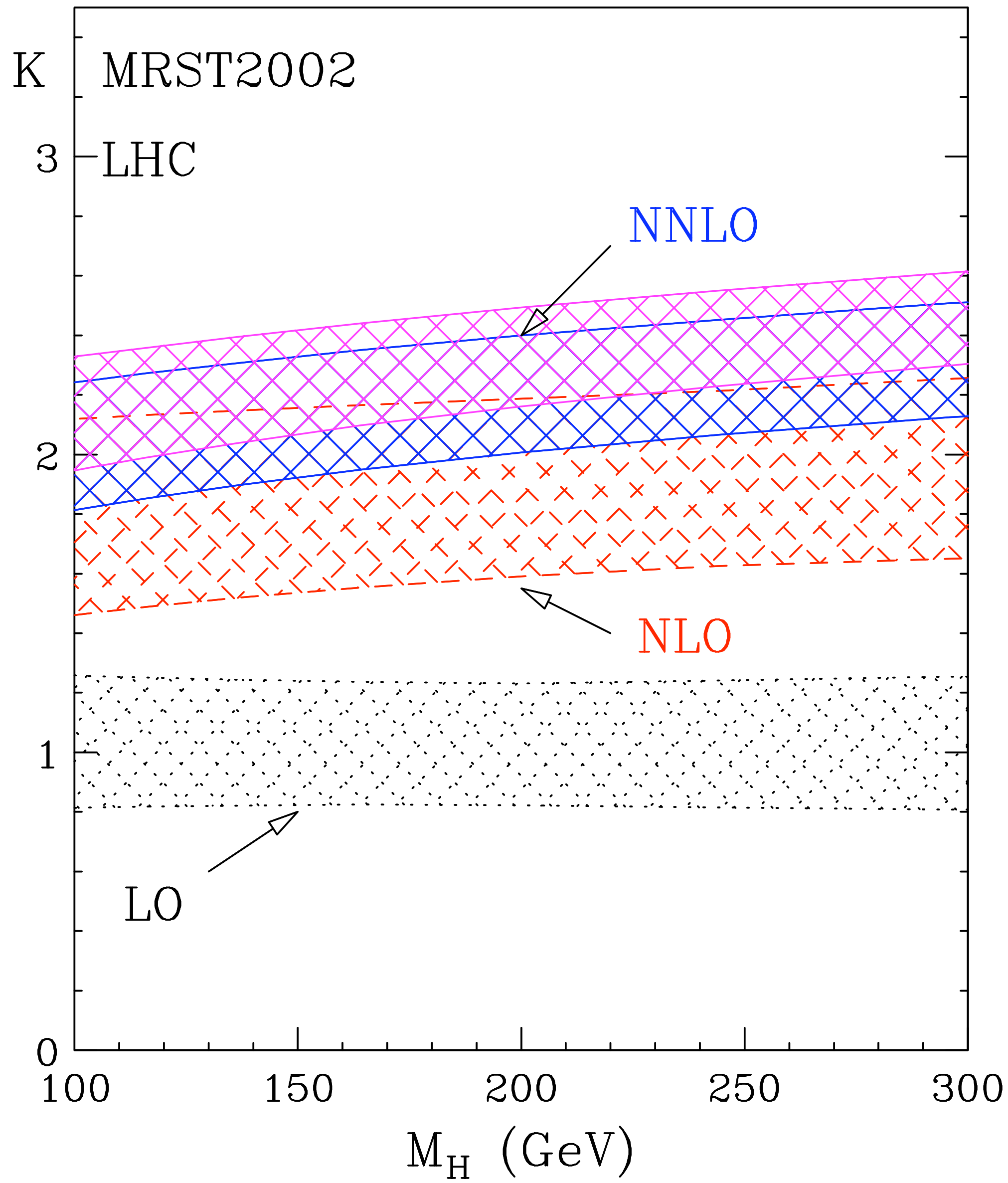
Inclusive results at the LHC



For a light Higgs:
NNLO effect $+15-20\,\%$

- K-factors defined with respect $\sigma_{LO}(\mu_F=\mu_R=M_H)$
- With $\mu_{F(R)}=\chi_{L(R)}M_H$ and $0.5\leq\chi_{L(R)}\leq 2$ but $0.5\leq\chi_F/\chi_R\leq 2$

Inclusive results at the LHC



Inclusion of soft-gluon effects at all orders

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

For a light Higgs:
NNLO effect $+15-20\,\%$

NNLL effect $+6\%$

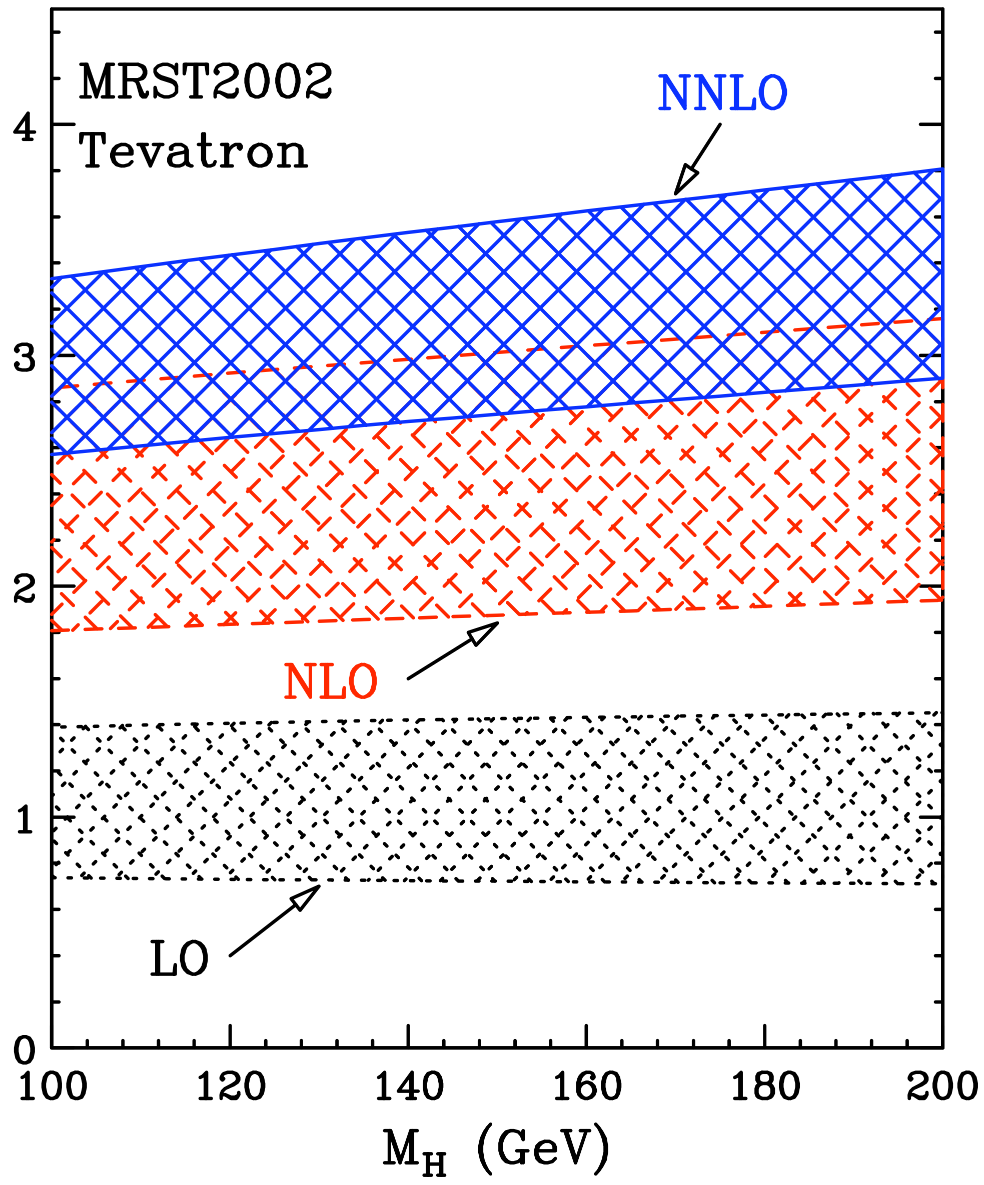
Good stability of perturbative result

Nicely confirmed by computation of soft terms at N^{3}LO

S. Moch, A. Vogt (2005), E. Laenen, L. Magnea (2005)

- K-factors defined with respect $\sigma_{LO}(\mu_F=\mu_R=M_H)$
- With $\mu_{F(R)}=\chi_{L(R)}M_H$ and $0.5\leq\chi_{L(R)}\leq 2$ but $0.5\leq\chi_F/\chi_R\leq 2$

Inclusive results at the Tevatron



For a light Higgs:
NNLO effect $+40\%$

- K-factors defined with respect $\sigma_{LO}(\mu_F = \mu_R = M_H)$
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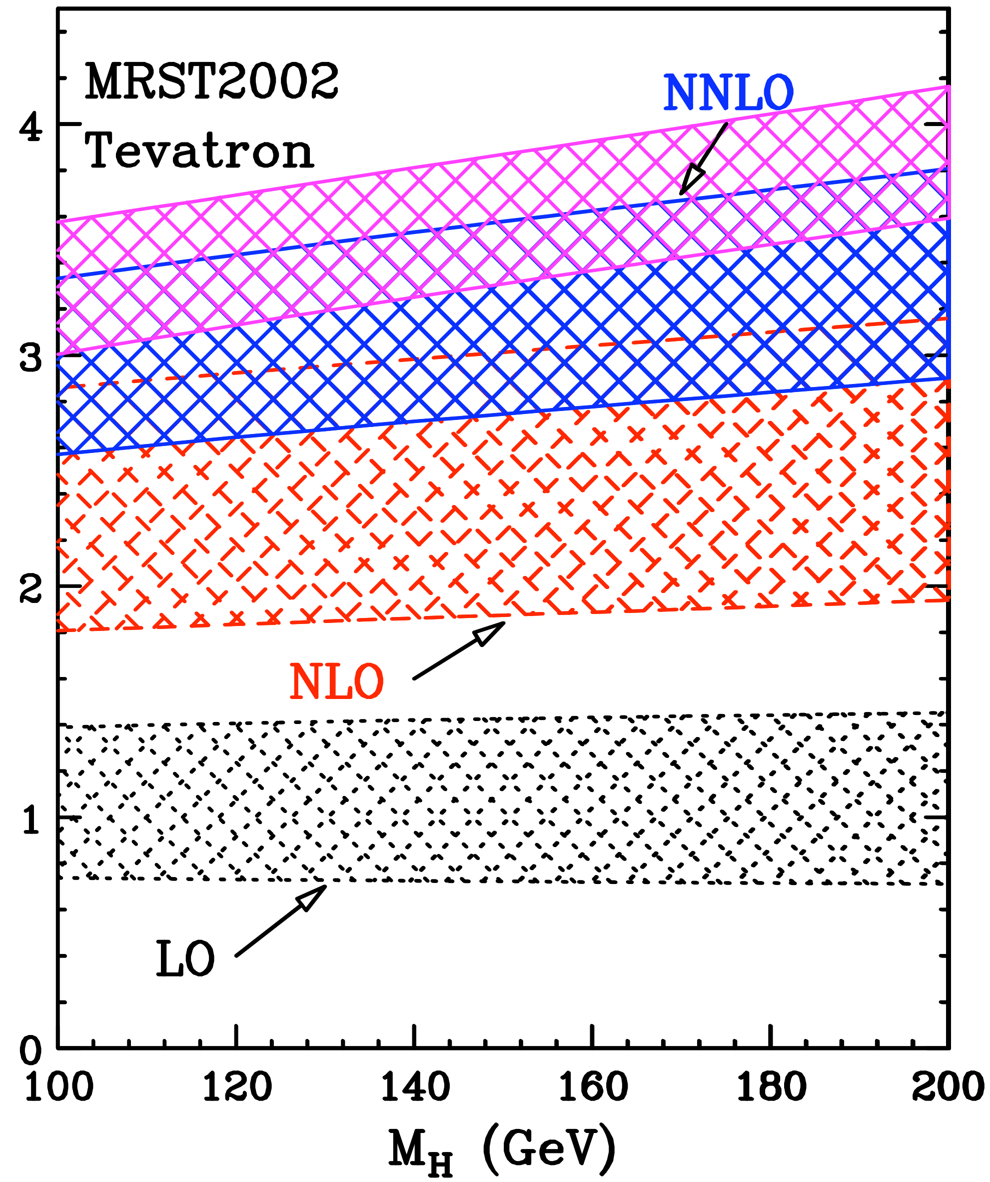


Inclusion of soft-gluon effects at all orders

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

For a light Higgs:
NNLO effect $+40\%$

NNLL effect $+12-15\%$

Impact of higher order effects larger than at LHC

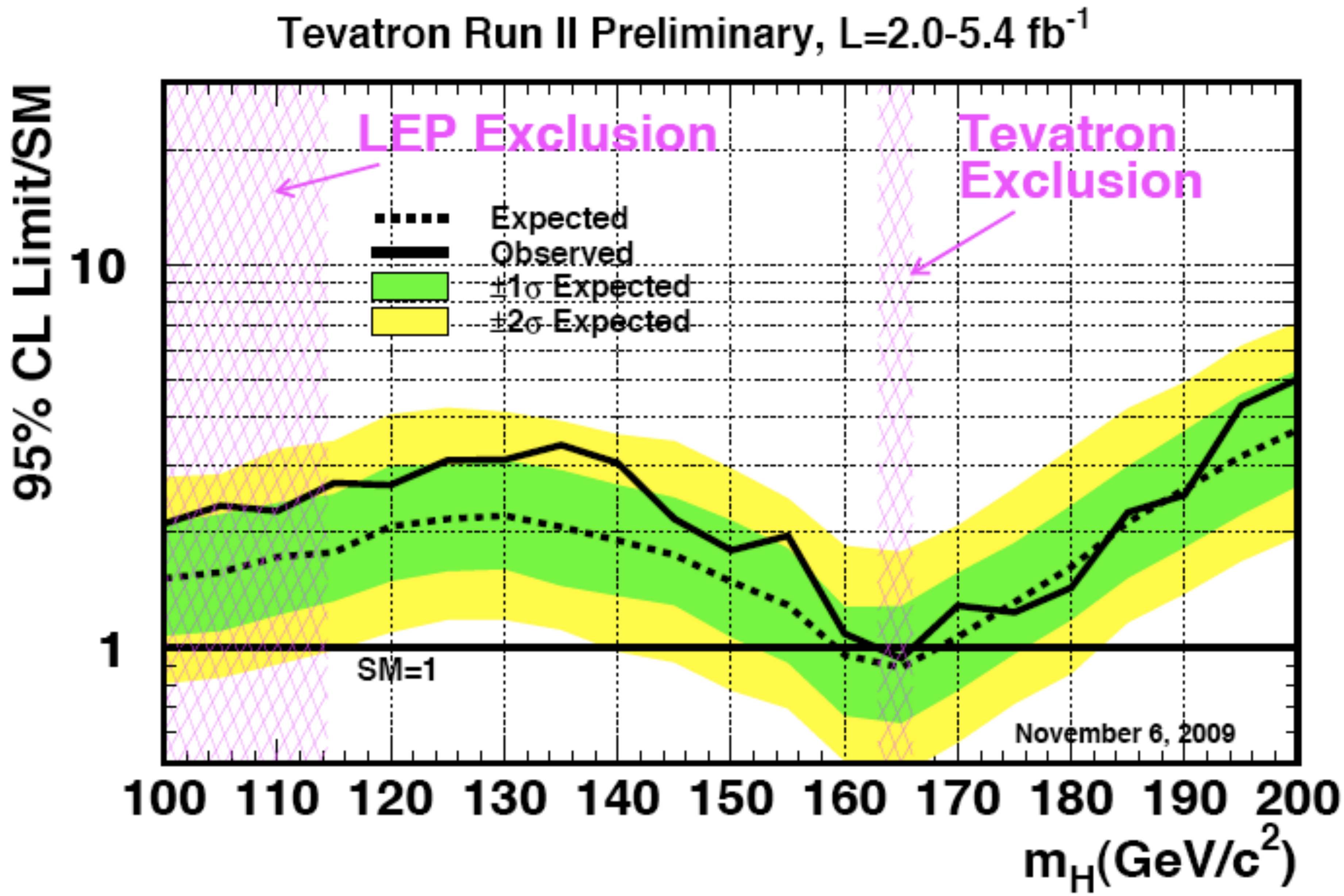
- K-factors defined with respect $\sigma_{LO}(\mu_F = \mu_R = M_H)$
- With $\mu_{F(R)} = \chi_{L(R)} M_H$ and $0.5 \leq \chi_{L(R)} \leq 2$ but $0.5 \leq \chi_F/\chi_R \leq 2$

Tevatron results

Latest results presented up to L=5.4 fb^{-1}

Expressed in terms of R=95 % CL limits/SM

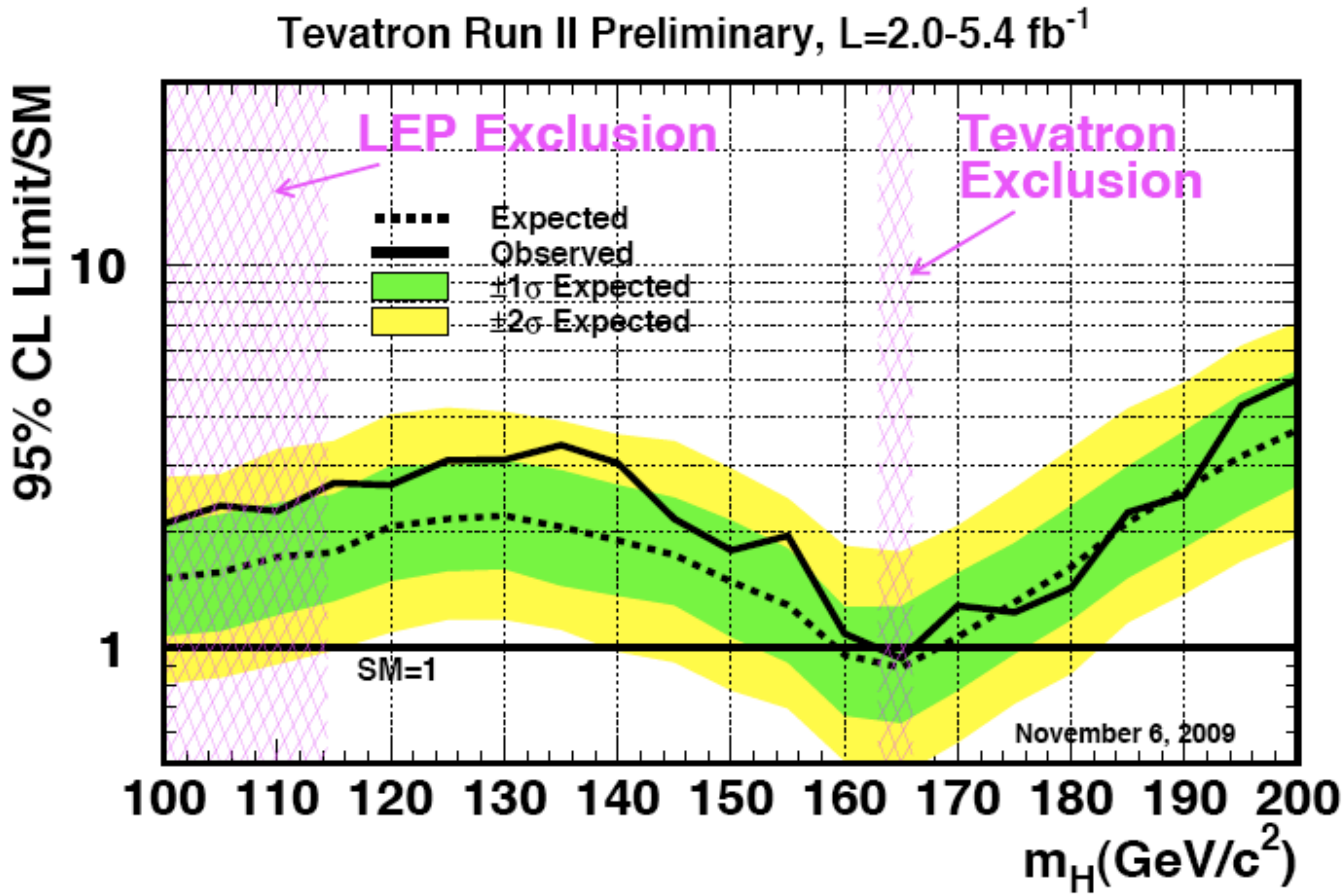
Now sensitive to the region m_H≈160-170 GeV



The relevance of higher orders

The recent Tevatron exclusion is based on our recent (updated) result

D. De Florian, MG (2009)



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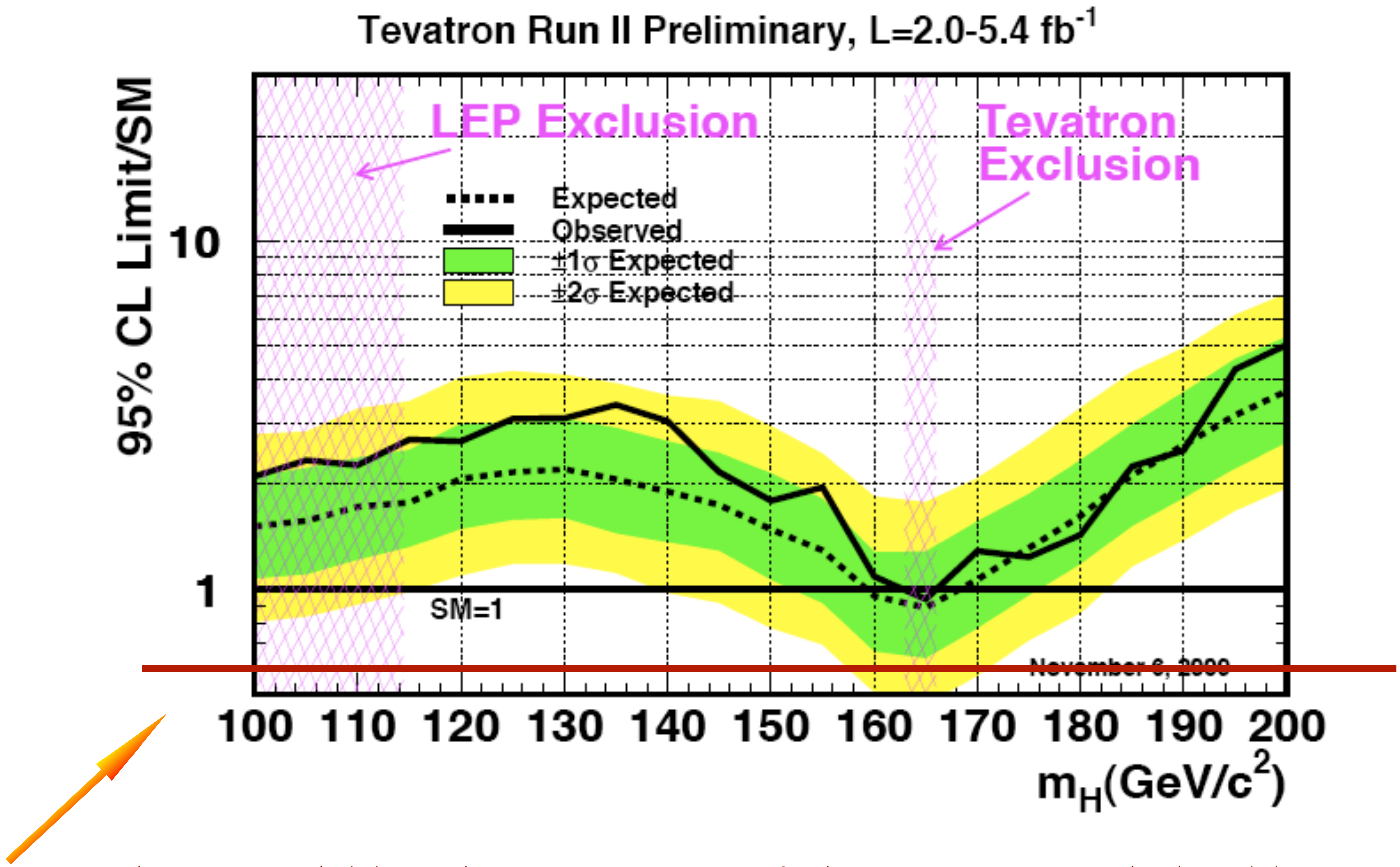


This would be the situation if the NLO result had been used !

Summary/Perspective

Research activity in SM Theory + Phenomenology in Florence is

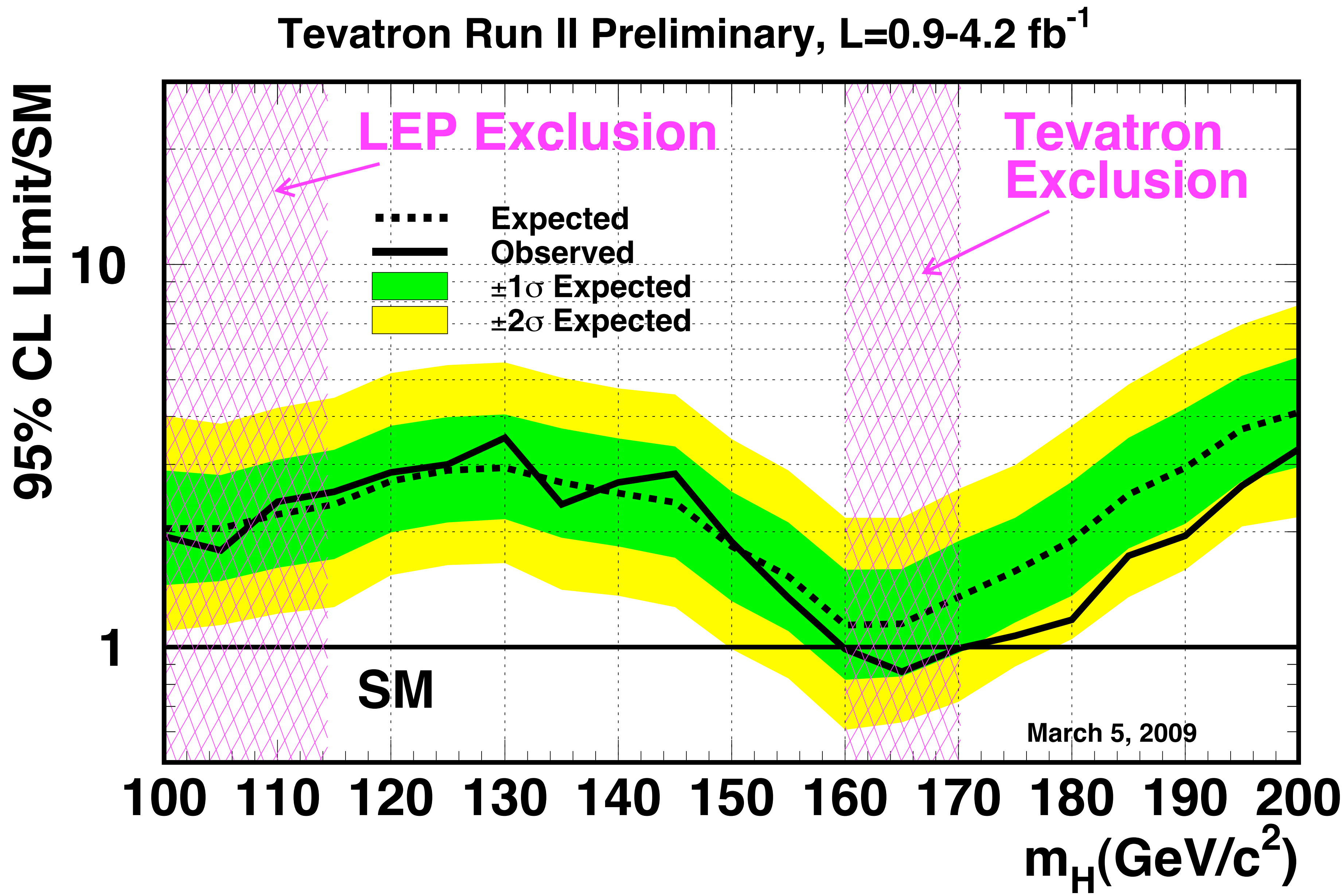
- In good health and making progress
- Essential in the LHC era:
  any signal of new physics discovery (and the corresponding backgrounds) are driven by QCD
- Florence is giving a VALUABLE contribution
- We plan to continue to work hard but.....
- ....we need more brain (human) power (and positions for good, young, enthusiastic researchers) !

Some recent papers

- S. Catani, G. Ferrera and M. Grazzini, *W boson production at hadron colliders: the lepton charge asymmetry in NNLO QCD*, arXiv:1002.3115 [hep-ph].
- D. Colferai, F. Schwennsen, L. Szymanowski and S. Wallon, *Mueller Navelet jets at LHC - complete NLL BFKL calculation*, arXiv:1002.1365 [hep-ph].
- M. Ciafaloni, P. Ciafaloni and D. Comelli, *Anomalous Sudakov Form Factors*, arXiv:0909.1657 [hep-ph].
- C. Anastasiou, G. Dissertori, M. Grazzini, F. Stockli and B. R. Webber, *Perturbative QCD effects and the search for a* $H \to WW \to l\nu l\nu$ *signal at the Tevatron*, JHEP **0908** (2009) 099 [arXiv:0905.3529 [hep-ph]].
- S. Catani, L. Cieri, G. Ferrera, D. de Florian and M. Grazzini, *Vector boson production at hadron colliders: a fully exclusive QCD calculation at NNLO*, Phys. Rev. Lett. **103** (2009) 082001 [arXiv:0903.2120 [hep-ph]].
- D. de Florian and M. Grazzini, *Higgs production through gluon fusion: updated cross sections at the Tevatron and the LHC*, Phys. Lett. B **674** (2009) 291 [arXiv:0901.2427 [hep-ph]].
- G. Bozzi, S. Catani, G. Ferrera, D. de Florian and M. Grazzini, *Transverse-momentum resummation: a perturbative study of Z production at the Tevatron*, Nucl. Phys. B **815** (2009) 174 [arXiv:0812.2862 [hep-ph]].
- S. Catani, T. Gleisberg, F. Krauss, G. Rodrigo and J. C. Winter, *From loops to trees bypassing Feynman's theorem*, JHEP **0809** (2008) 065 [arXiv:0804.3170 [hep-ph]].
- M. Ciafaloni, P. Ciafaloni and D. Comelli, *Electroweak double-logs at small* x, JHEP **0805** (2008) 039 [arXiv:0802.0168 [hep-ph]].
- M. Grazzini, *NNLO predictions for the Higgs boson signal in the* $H \to WW \to l\nu l\nu$ *and* $H \to ZZ \to 4l$ *decay channels*, JHEP **0802** (2008) 043 [arXiv:0801.3232 [hep-ph]].

Tevatron results

Results with up to $L=4.2\ fb^{-1}$



Deficit of events at m_H ~ 160-170 GeV gave wider excluded region