HIGGS WG:
THEORY PART

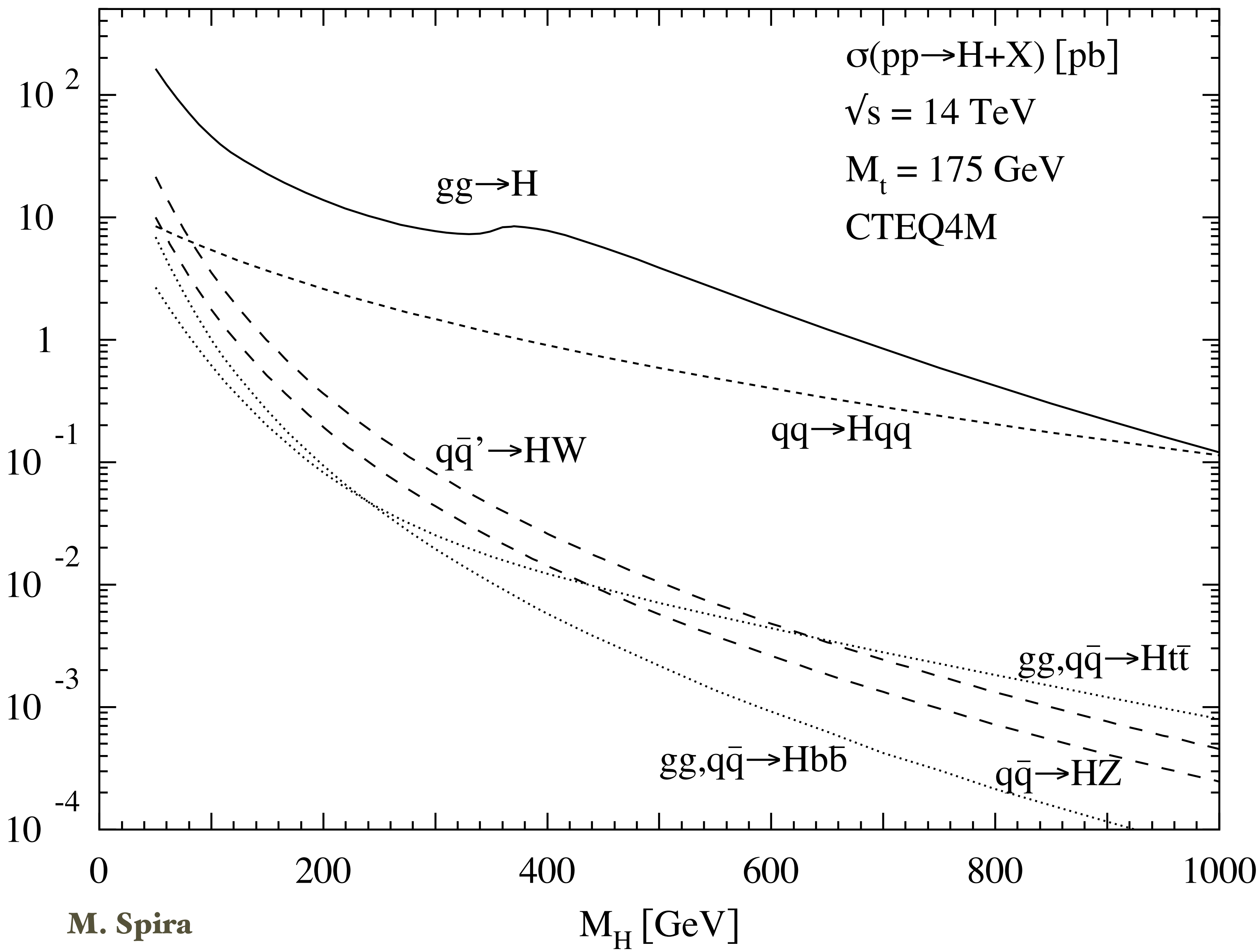
Massimiliano Grazzini (INFN, Firenze)

Les Houches, june 2007

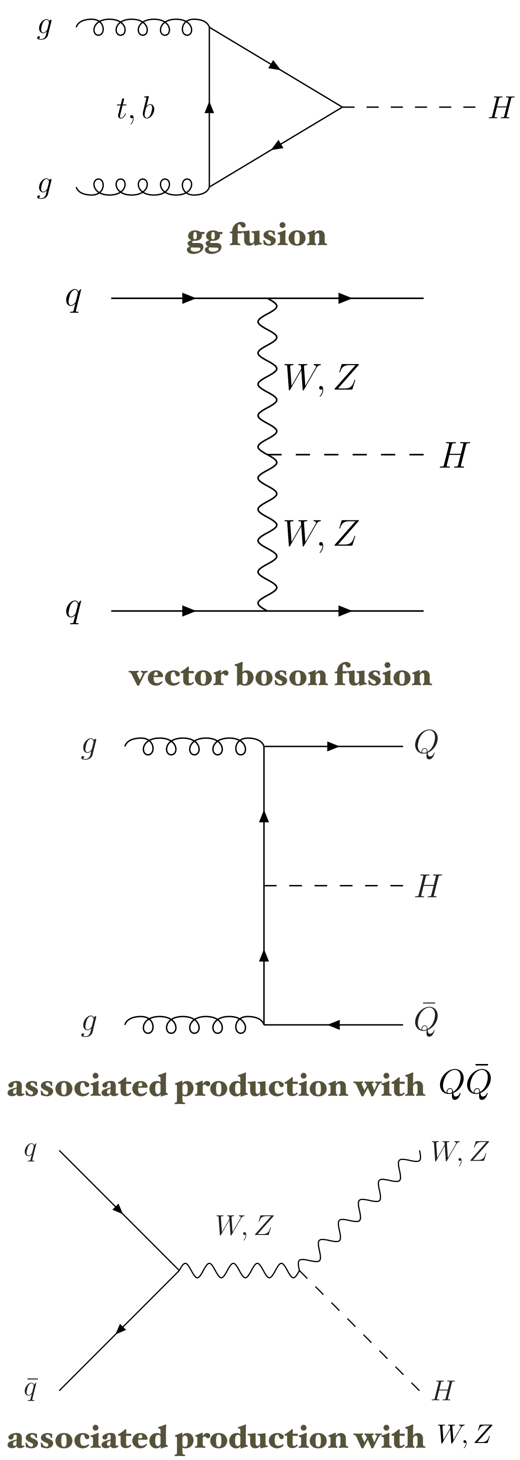
Outline

- Introduction
- Higgs boson production
- Backgrounds
- Outlook

Higgs production at the LHC

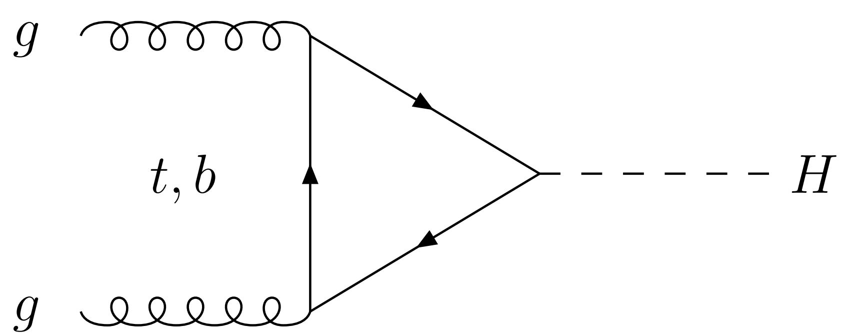


M. Spira



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

gg fusion



SM: The Higgs coupling is proportional to the quark mass

→ top-loop dominates

NLO 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 % !

They are well approximated by the large- m_{top} limit (differences range from 1 to 4 % for $M_H < 200$ GeV)

S.Dawson (1991)
M.Kramer, E. Laenen, M.Spira(1998)

NNLO corrections to $\sigma_H^{\rm tot}$ computed in the large m_{top} limit

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)

Effect ranges from 15 to 20 % for $M_H < 200$ GeV

Effects of soft-gluon resummation: additional +6 %

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

EW two-loop effects also known (+5-8 %)

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

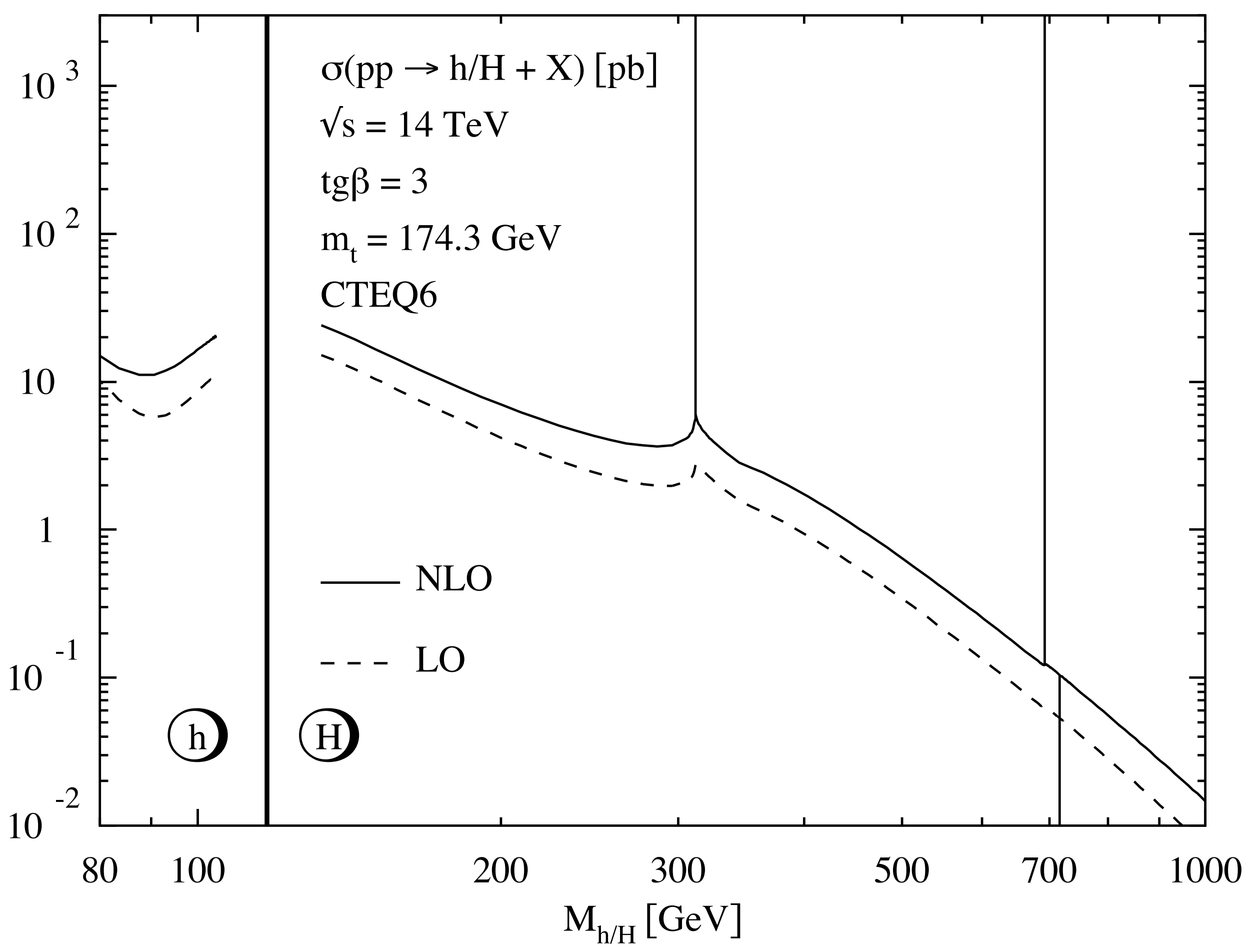
MSSM: 2 Higgs doublets → 5 physical Higgs bosons $h, H, A, H^{\pm}$

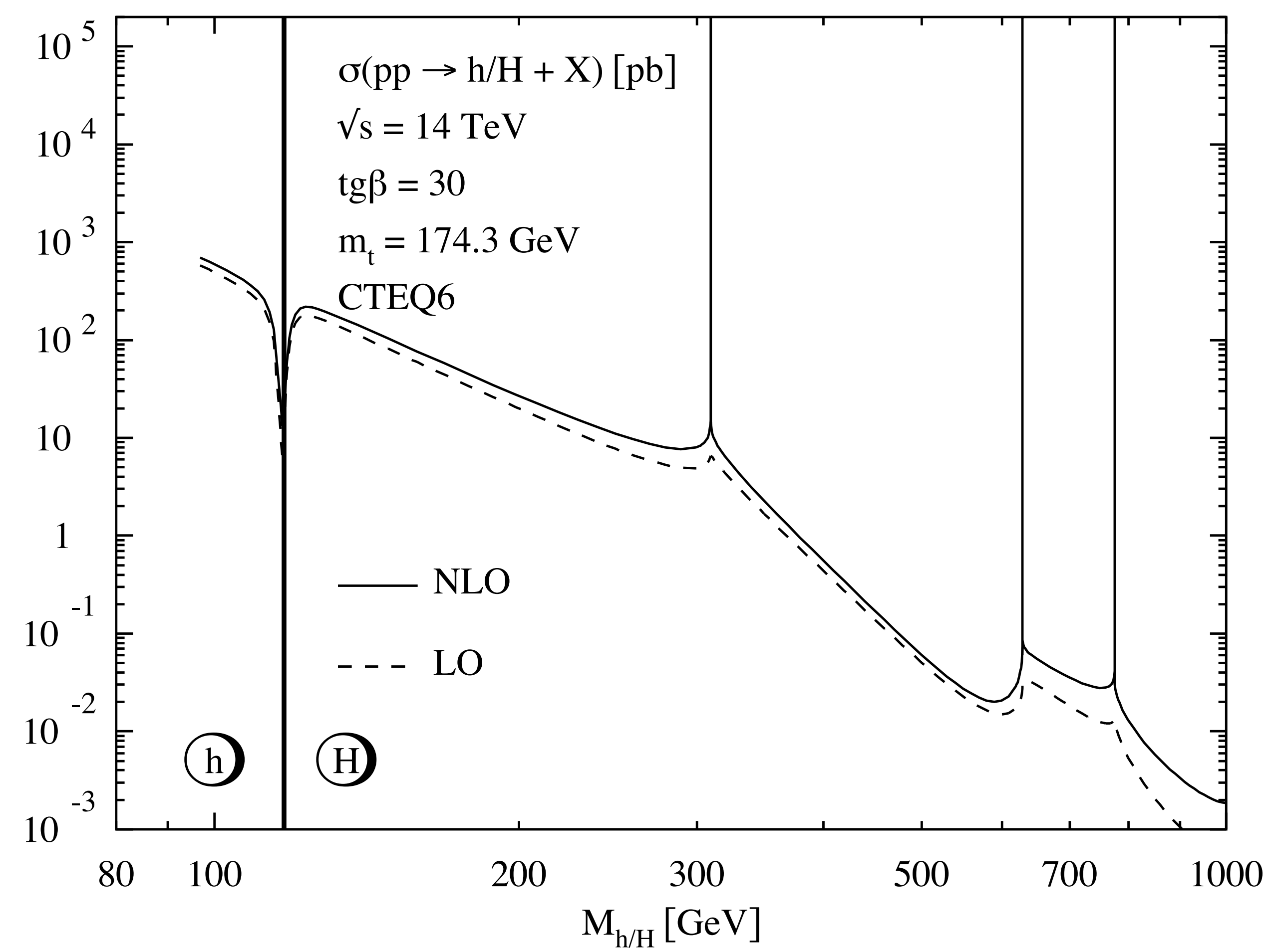
SM results can be extrapolated only for small $\mathrm{tg}\beta$

NLO corrections to squark loops known for large squark masses — S. Dawson, A. Djouadi, M. Spira (1991)

Full SUSY-QCD corrections in limit of the heavy SUSY masses — R. Harlander, M. Steihauser (2003)

Recently full NLO calculation of squarks contribution completed — M. Muhlleitner, M. Spira (2006)





Further step towards full NLO SUSY QCD calculation

Up to now only total cross sections but......
More exclusive observables are needed !

Back to the SM:

NNLO corrections computed for arbitrary cuts for $H \to \gamma\gamma$ → FEHIP

C. Anastasiou, K. Melnikov, F. Petrello(2005)

- H+ 1 jet: NLO corrections known

D. de Florian, Z. Kunszt, MG (1999)
J. Campbell, K.Ellis (MCFM)

- H+ 2 jet: NLO corrections recently computed
→ background for VBF

J. Campbell, K.Ellis, G. Zanderighi (2006)

All these predictions are obtained in the large-m_{top} limit

→ (it is a good approximation for small transverse momenta of the accompanying jets)

Del Duca et al. (2001)

MSSM:

O. Brein, W. Hollik (2003)

h+ 1 jet known at LO only

NEW: An NNLO MC for $gg \to H$

We have implemented the NNLO calculation in a fully exclusive parton level generator including the $H \to \gamma\gamma$ and $H \to WW$ decays

S. Catani, MG (2007)

ecompasses previous calculations in a single stand-alone numerical code

it makes possible to apply arbitrary cuts

good agreement with FEHIP for $H \to \gamma\gamma$

Example for $H \to \gamma\gamma$

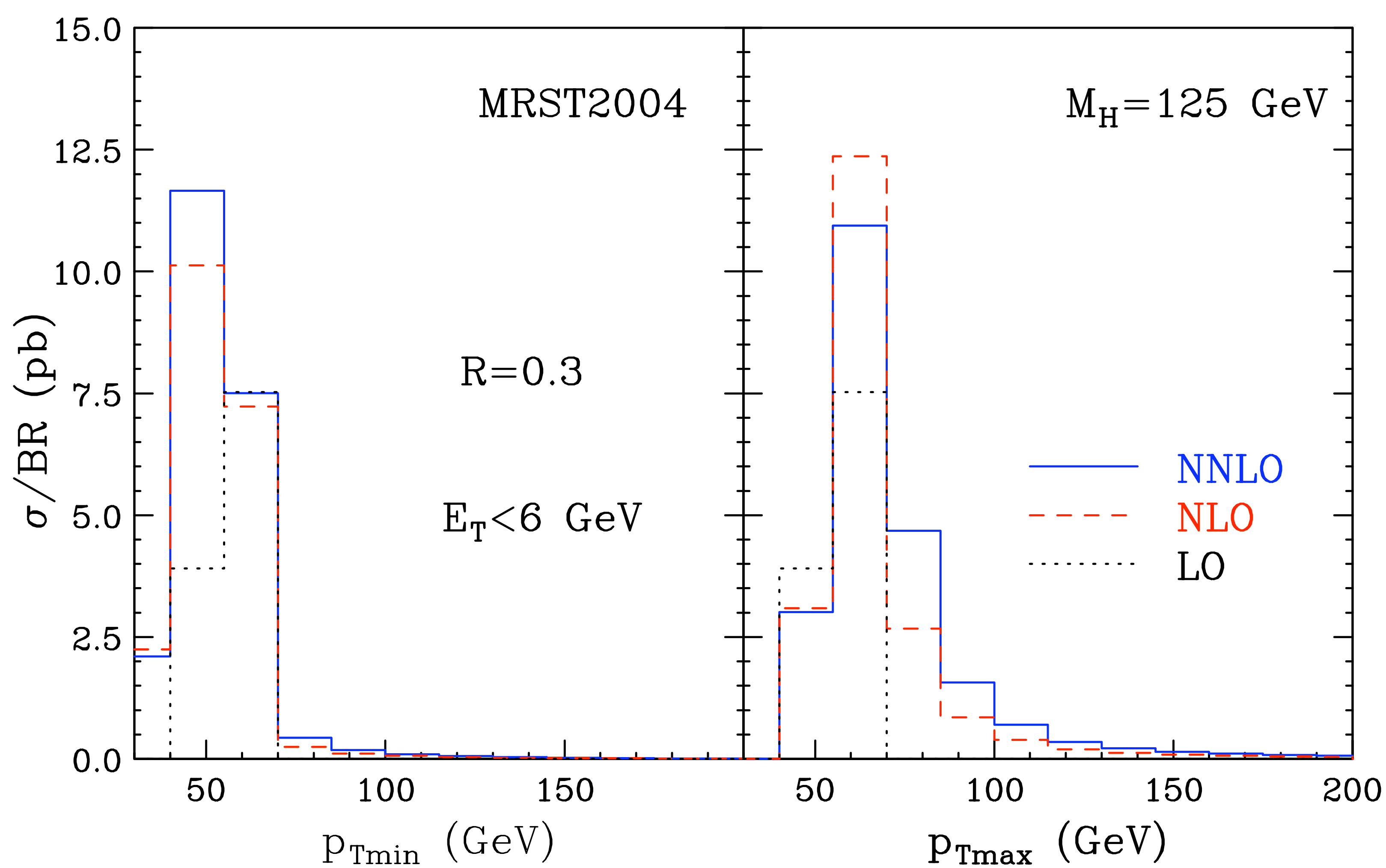
$p_T^{\min} > 35$ GeV

$p_T^{\max} > 40$ GeV

$|y| < 2.5$

Photons should be isolated: total transverse energy in a cone of radius $R = 0.3$ should be smaller than 6 GeV

(from CMS TDR)



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Example for $H \to WW \to l\nu l\nu$

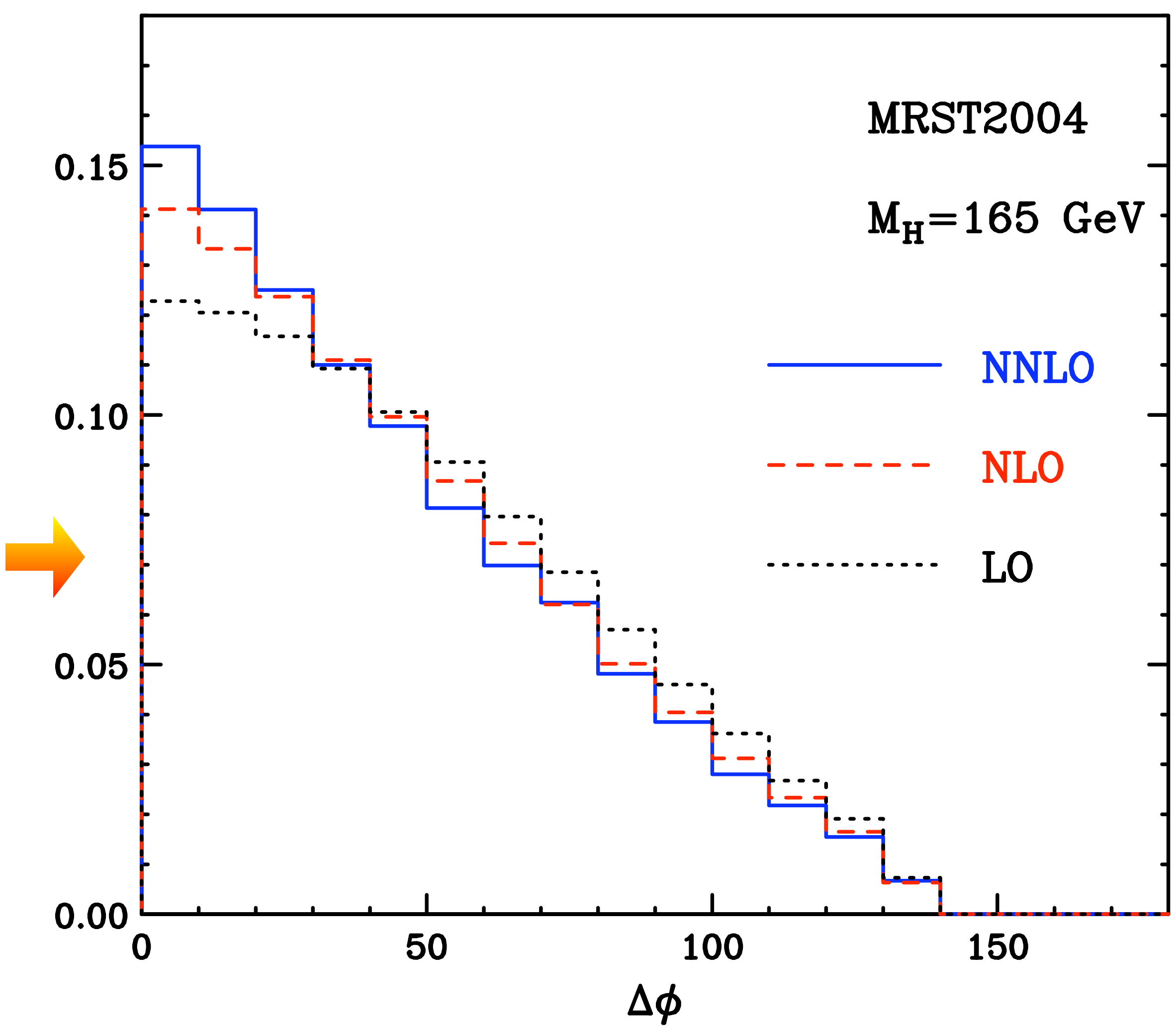
$p_T^l > 20$ GeV $\quad |y_l| < 2$

$p_T^{\rm miss} > 20$ GeV

$m_{ll} < 80$ GeV

$\Delta\phi < 135^o$

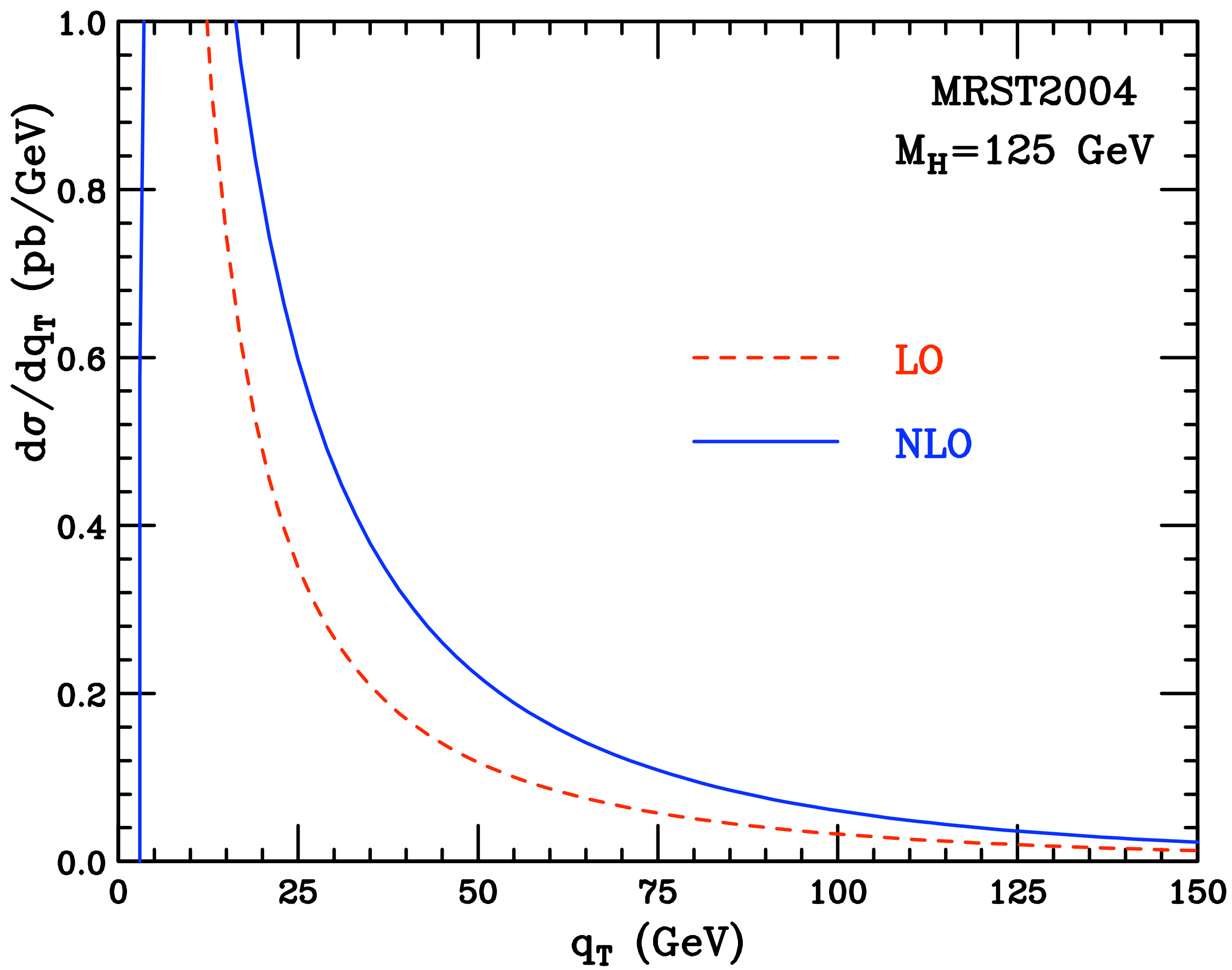
normalized $\Delta\phi$ distribution →



The transverse momentum (q_T) spectrum

A precise knowledge of the q_T spectrum may help to find strategies to improve statistical significance

The region $q_T \ll M_H$ where most of the events are expected is affected by large logarithmic contributions of the form $\alpha_S^n \ln^{2n} M_H^2/q_T^2$ that must be resummed to all orders



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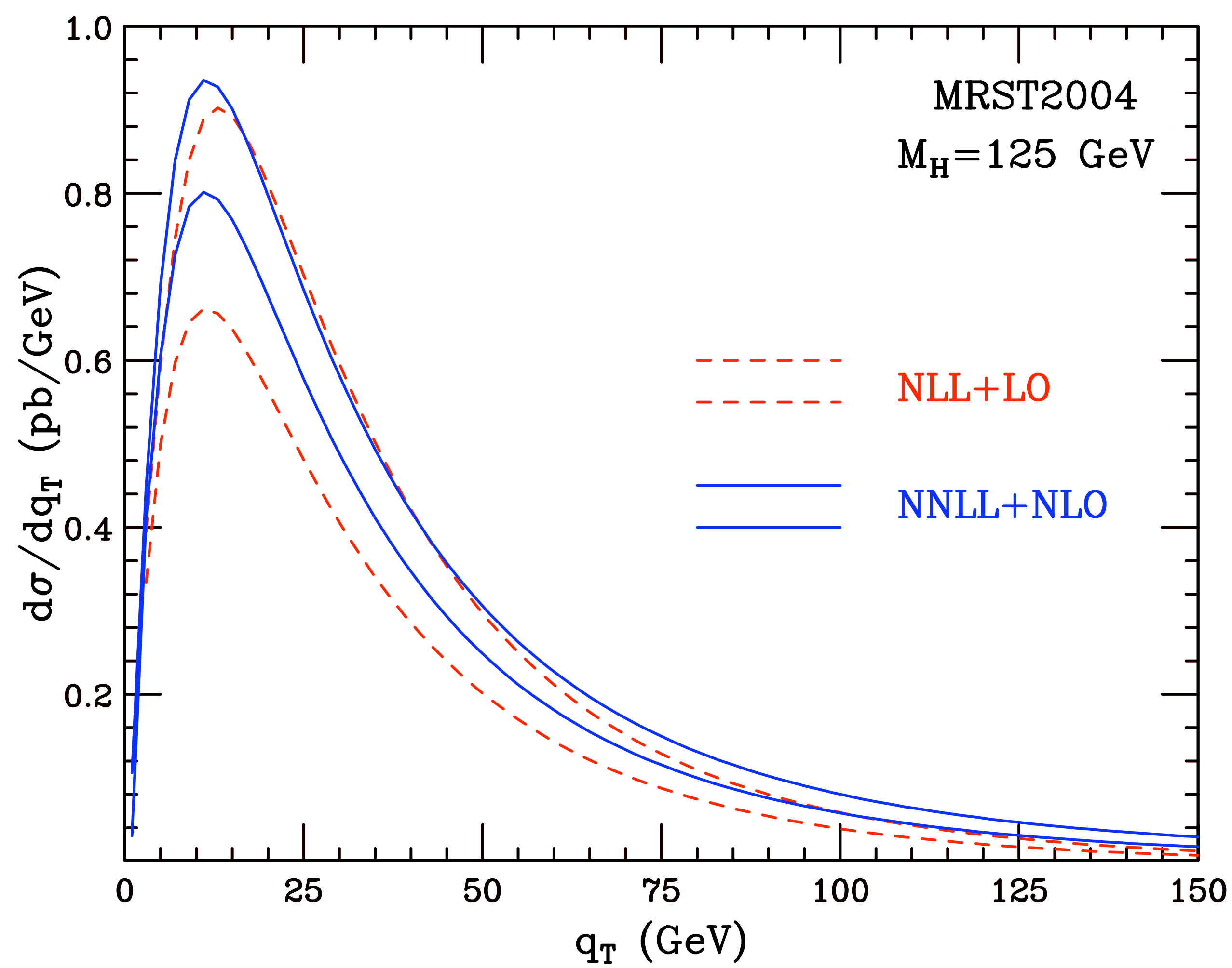
G. Bozzi, S. Catani,
D. de Florian, MG (2003, 2005)

Resummed calculation at low q_T matched to fixed order at large with the correct normalization

Highly stable results ➡ HqT

http://theory.fi.infn.it/grazzini/codes.html

Extended to include rapidity dependence:
new version to be released soon



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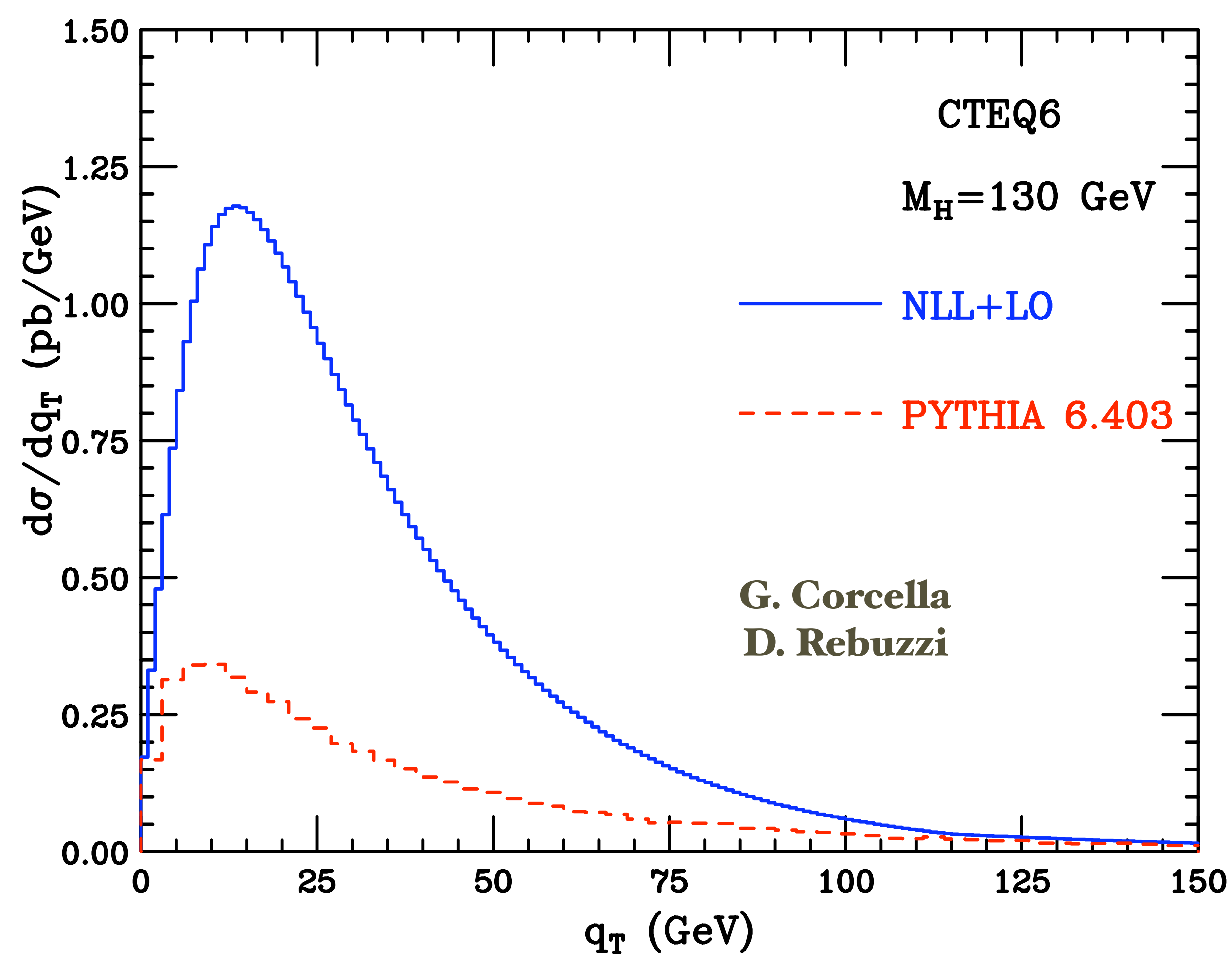
Resummed calculation at low q_T matched to fixed order at large with the correct normalization

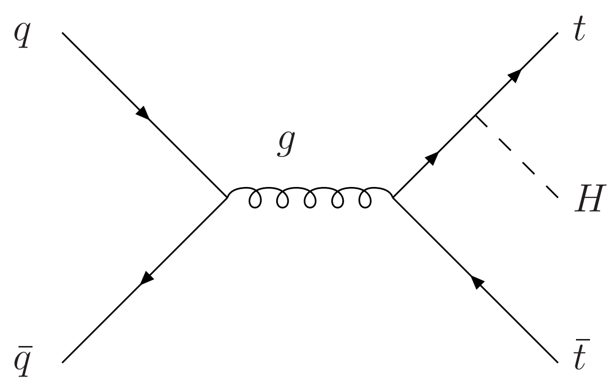
Highly stable results → HqT

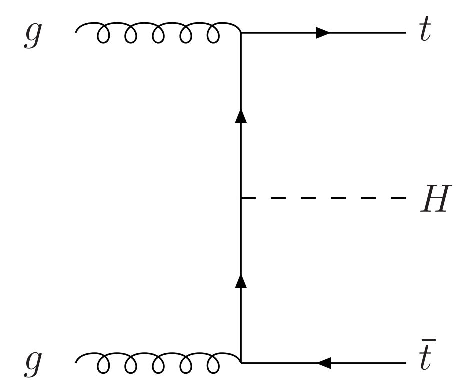
The resummation is effectively performed through standard MC event generators.....

PYTHIA PEAK STILL SOFTER !



Associated production with a $t\bar{t}$ pair





LO result known since long time

Z. Kunszt (1984)

It was considered as an important discovery channel in low mass region:

$H \to b\bar{b}$ triggering on the leptonic decay of one of the top

➡ Requires good b-tagging efficiency

relevant also to measure $t\bar{t}H$ Yukawa coupling

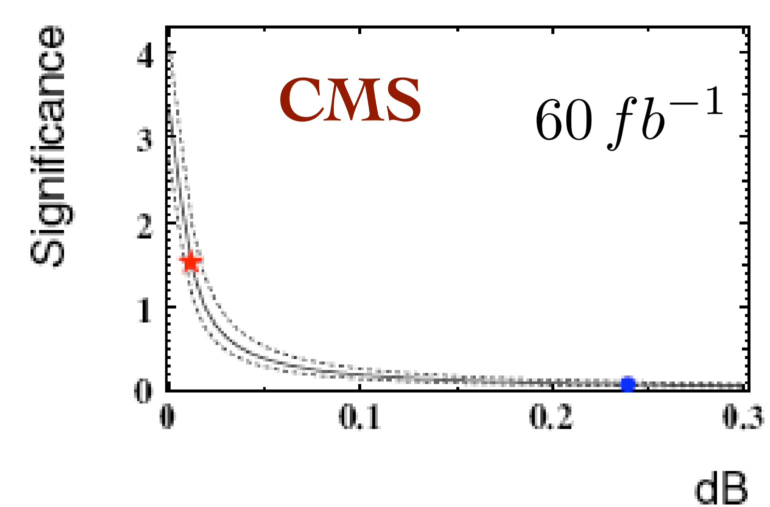
NLO corrections computed by two groups

They increase the cross section by about 20 %

W.Beenakker, S. Dittmaier, B.Plumper, M. Spira, P. Zerwas (2002)
S.Dawson, L.Reina (2003)

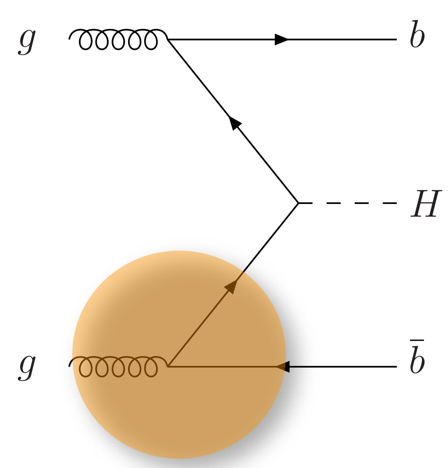
BUT....

full detector simulation and better background evaluation lead to more pessimistic view



Associated production with a $b\bar{b}$ pair

In the SM the cross section is very small but it becomes dominant in the MSSM at large $\tan\beta = v_u/v_d$



Already at LO there are large contributions of the form $\alpha_S \log M_H/m_b$ originating from the collinear splitting $g \to b\bar{b}$

two computational schemes:

- four-flavour scheme (begins with $gg \to b\bar{b}H$ at LO)
- five-flavour scheme: introduces bottom pdf (begins with $b\bar{b} \to H$ at LO)

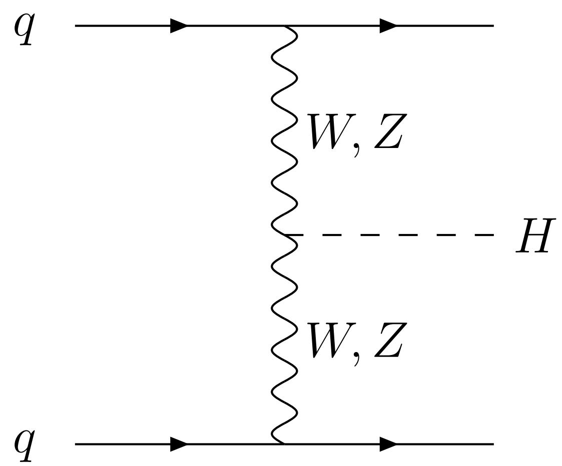
Higher order corrections computed in the two schemes

R.Harlander, W.Kilgore (2003)
S. Dittmaier, M. Kramer, M. Spira(2003)
S.Dawson, C. Jackson, L.Reina, D. Wackeroth (2003)
J.Campbell, K. Ellis, F.Maltoni, S. Willenbrock (2003)

Careful comparison performed in recent years

Initial differences reduced if more consistent comparison is performed

Vector boson fusion



Valence quarks pdf peaked around $x \sim 0.1 - 0.2$

Transverse momentum of final state quarks of order of a fraction of the W(Z) mass

→ Tends to produce two highly energetic jets with a large rapidity interval between them

Since the exchanged boson is colourless, there is no hadronic activity between the quark jets

QCD corrections to the total rate increase the LO result by $5-10\%$

T. Han, S. Willenbrock (1991)

Now implemented for distributions

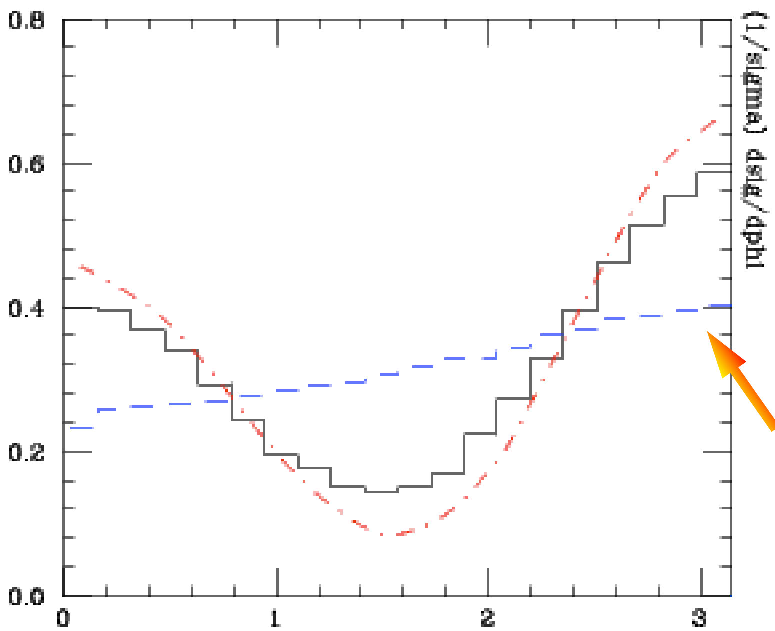
T. Figy, C. Oleari, D. Zeppenfeld (2003)
J. Campbell, K. Ellis (2003)

→ even if the cross section is almost one order of magnitude smaller than for gg fusion this channel is very attractive both for discovery and for precision measurements of the Higgs couplings

Gluon fusion as well gives rise to events with two jets in the final state → how to separate it from VBF ?

Azimuthal correlations between tagging jets

correlation is more pronounced in gg fusion
only mildly affected by PS effects



gg fusion

VBF

V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt, D. Zeppenfeld (2001)
V. Del Duca,G. Klamke, D. Zeppenfeld, M.L.Mangano,
M. Moretti, F. Piccinini, R. Pittau, A. Polosa (2006)

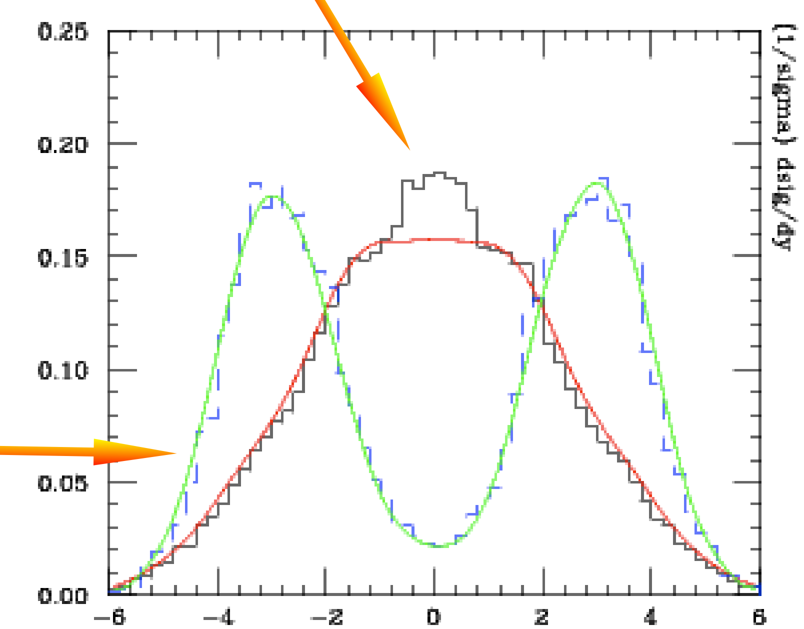
gg fusion

Rapidity of third hardest jet with respect to the average of the first two

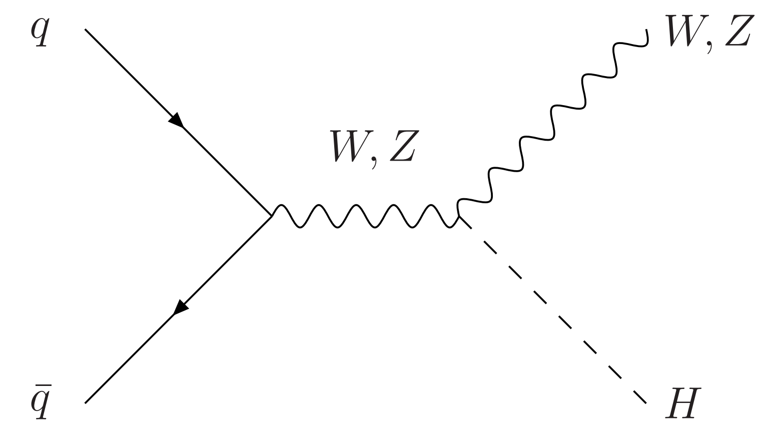
→ Apply central jet veto

Impact of $\ln M_H/p_T^{\rm veto}$?

VBF



Associated production with a W or Z



Most important channel for low mass at the Tevatron

➡ lepton(s) provide the necessary background rejection

QCD corrections can be obtained from those to Drell-Yan: +30 %

T. Han, S. Willenbrock (1990)

W. Van Neerven e al. (1991)

For ZH at NNLO additional diagrams from gg initial state must be considered: important at the LHC

O. Brein, R. Harlander, A. Djouadi (2000)

Full EW corrections known: they decrease the cross section by 5-10 %

M.L. Ciccolini, S. Dittmaier, M. Kramer (2003)

Backgrounds

- $\gamma\gamma$ → can be measured from sidebands

Background known at NLO
(DIPHOX package, fragmentation included) T. Binoth et al (2000)

Contribution from gg fusion included at $\mathrm{N}^3\mathrm{LO}$ Z. Bern et al (2003)

$\gamma\gamma + 1$ jet also known at NLO V. Del Duca et al (2003)

- $WW \to l\nu l\nu$ a lot of work done since LH 2005

L.Dixon et al. (1999)
J. Campbell , K. Ellis (1999)

NLO corrections known
NLO+soft-gluon resummation MG (2005)
Inclusion of spin correlations essential for $\Delta\phi$ distribution:
done in MC@NLO

Contribution from gg fusion included at NNLO: T. Binoth et al (2005)
it turns out to be important when selection cuts are applied Duhrssen et al (2005)

- $ZZ \rightarrow 4l$ → can be measured from sidebands

NLO corrections known
Spin correlations not included in MC@NLO

L.Dixon et al. (1999)
J. Campbell , K. Ellis (1999)

Calculation of contribution from gg fusion in progress

N. Kauer

- $t\bar{t}$

LO with spin correlations + finite width effects (WWbb,Wtb)

N. Kauer, D. Zeppenfeld (2001)

NLO: total cross section and distributions

S. Dawson, P. Nason, K. Ellis (1988,1989)

NLO+soft gluon resummation

R. Bonciani, S. Catani, M.L.Mangano, P. Nason (1998)

NLO with spin correlations

P. Uwer et al. (2001)

Implemented in MC@NLO (spin correlations now included)

$t\bar{t} + \text{jet}$: NLO calculation recently completed

S. Dittmaier, P. Uwer, S. Weinzierl (2007)

- VV via VBF at NLO

B.Jaeger, C.Oleari, D.Zeppenfeld (2006)
G.Bozzi, B.Jaeger, C.Oleari, D.Zeppenfeld (2007)

What else we should have at NLO?

- $t\bar{t}$ with finite width effects (bb+4f)
- $VV + \mathrm{jet(s)}$
- $Vt\bar{t}$
- $VV + b\bar{b}$
- $t\bar{t}jj$
- $t\bar{t}b\bar{b}$

....

→ **A lot of work for our NLM friends !**

Our plans...

- Understanding higher order corrections for both Higgs signals and backgrounds and their impact on the corresponding kinematics
  - $gg \rightarrow H + 2$ jets background to VBF
  - $gg \rightarrow ZZ(\gamma^*)$ background to $H \rightarrow ZZ$
  - $\gamma\gamma(j)$ kinematics with DIPHOX; matching with experimental like isolation criteria
- Measurements of the background to Higgs production from the data
  - Central Jet Veto efficiency measurement from Z+jets, Z->ll; CJV vs track veto in rapidity gap
- Higgs rates as signals for physics beyond the SM
- Early ($< 30 - 60$ fb^{-1}) non SM Higgs signatures in NMSSM, CPV MSSM, Little Higgs, Models with extra singlets/triplets...