DESY TH Workshop, September 2002

# QCD Corrections to Higgs & SUSY Particle Production at the LHC

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- Introduction: Higgs production at the LHC
- Recent progress: QCD corrections to
  - gluon fusion: $gg \to H$
  - $t\bar{t}H$ associated production: $gg/q\bar{q} \to t\bar{t}H$
- Status report: SUSY particle production
- Conclusions

# Introduction

- To establish the SM Higgs mechanism we have to
  - discover the Higgs boson(s),
  - establish the mass generation: $g_{XX\phi} \sim m_X$,
  - and reconstruct the Higgs potential.

- Current experimental limits on $M_H$ (95% C.L.):
  - $e^+e^- \not\longrightarrow ZH$ at LEP2

    $\Rightarrow M_H > 114$ GeV (LEPHIGGS '02).
  - Fit to electroweak precision data

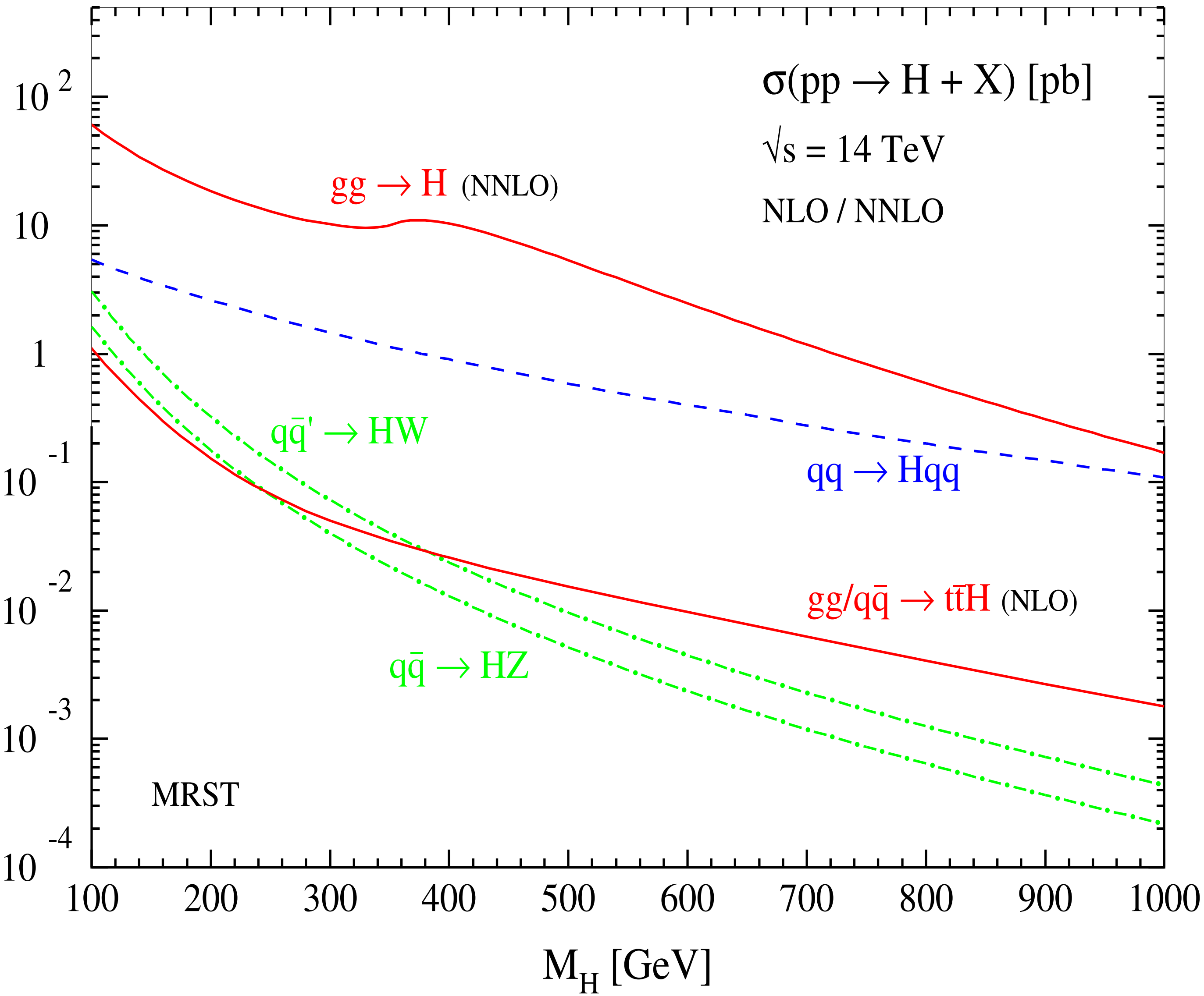
    $\Rightarrow M_H < 193$ GeV (LEPEWWG '02).

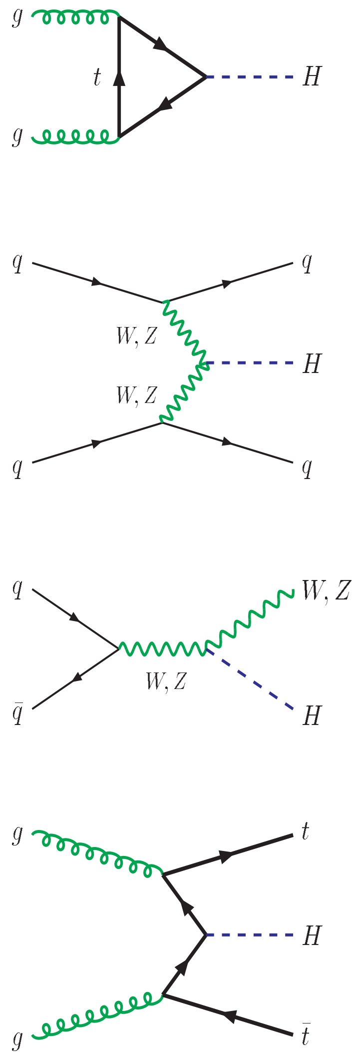
- Present bounds (114 GeV $\lesssim M_H \lesssim$ 200 GeV)
  - consistent with SUSY
  - imply weakly interacting Higgs sector

$\Rightarrow$ extend SM to $M_{\mathrm{GUT}}$

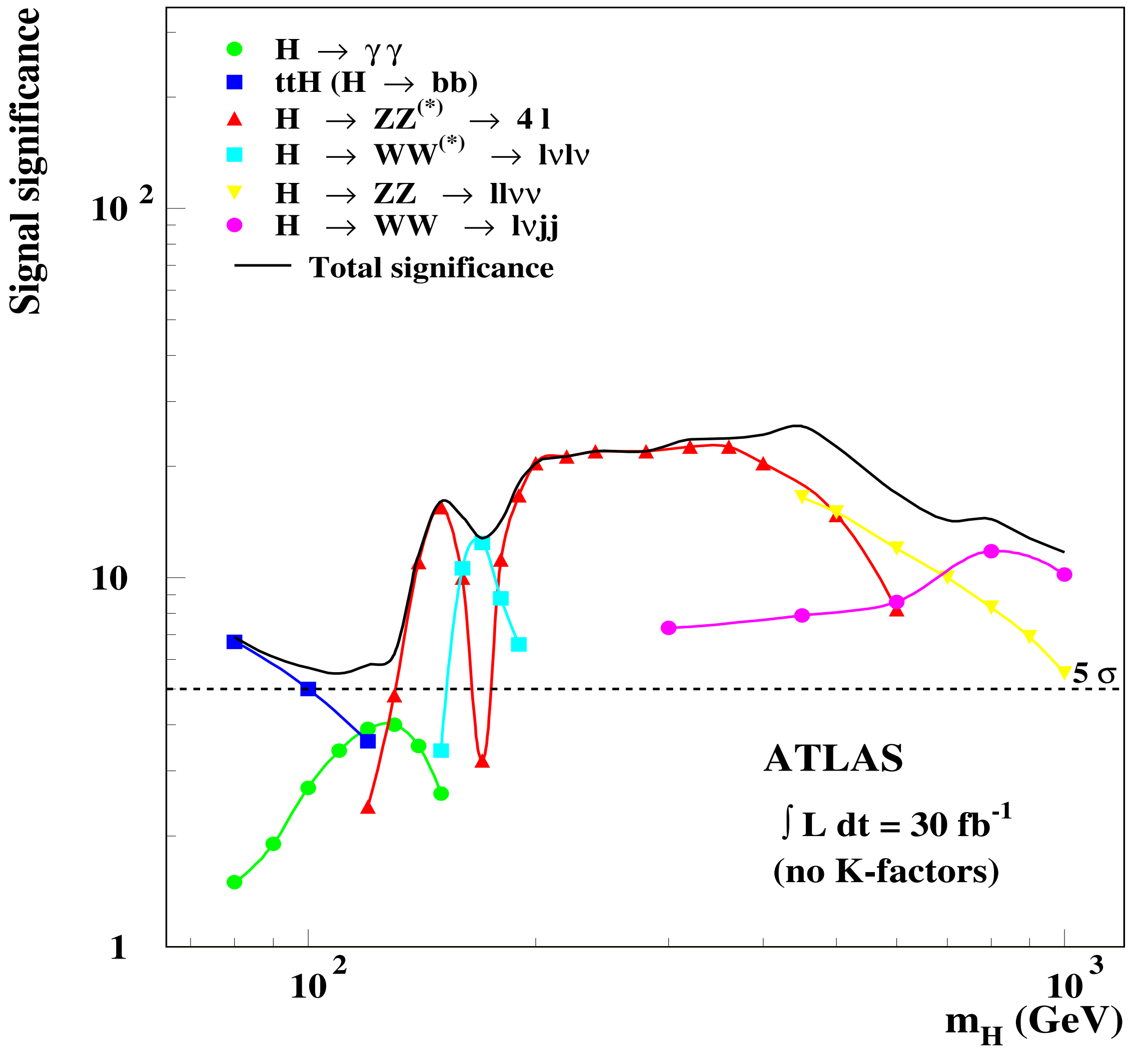
# Higgs boson production at the LHC

Production cross section:



# Higgs boson search at the LHC



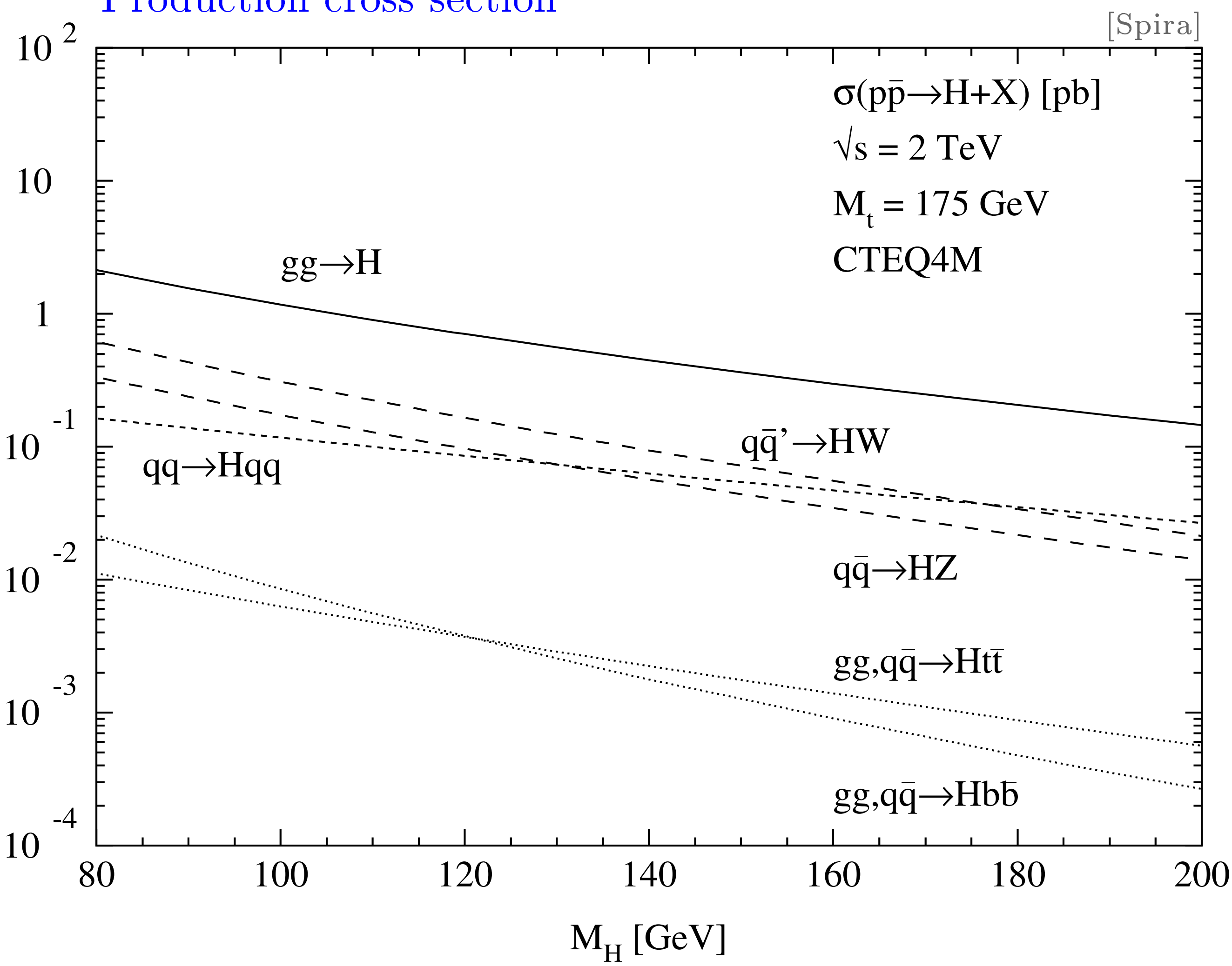

$$M_H \lesssim 2M_Z \ \rightarrow \begin{cases} gg \to H & (H \to \gamma\gamma, ZZ^*, WW^{(*)}) \\ gg/q\bar{q} \to t\bar{t}H & (H \to b\bar{b}, \tau\tau) \\ qq \to qqH & (H \to \gamma\gamma, WW^*, \tau\tau) \\ q\bar{q}' \to WH & (H \to \gamma\gamma) \end{cases}$$

$$M_H \gtrsim 2M_Z \ \rightarrow \begin{cases} gg \to H & (H \to ZZ, WW) \\ qq \to qqH & (H \to ZZ, WW) \end{cases}$$

[ + diffractive Higgs production]

# What about the Tevatron?

Production cross section




– cross section by factor $\approx 10^2 - 10^3$ smaller than at LHC

– combine many channels for Higgs search

– need $\int\mathcal{L} \gtrsim 20$ fb$^{-1}$ to discover Higgs with $M_H = 120$ GeV

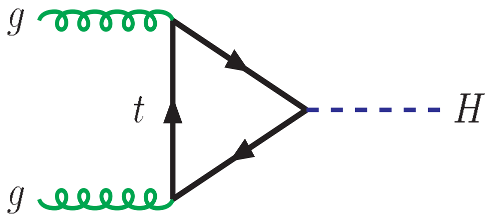
- $t\bar{t}H$ associated production

  only few events ($\sigma \approx 5$fb), but low background

  $\rightarrow$ can reduce $\int\mathcal{L}$ need for Higgs discovery by $\approx 15-20\%$

  [Goldstein et al.; Incandela]

# Higgs boson production in gluon fusion




[Georgi, Glashow, Machacek, Nanopoulos '77]

- NLO corrections large: $K_{\mathrm{NLO}} \approx 1.7$

  [Spira, Djouadi, Graudenz, Zerwas; Dawson, Kauffman]

- $K_{\mathrm{NLO}}(\mathrm{exact}) \approx K_{\mathrm{NLO}}(m_{\mathrm{top}} \gg M_H)$

  $\rightarrow$ Figure

- NNLO corrections: $K_{\mathrm{NNLO}}(m_{\mathrm{top}} \gg M_H) \approx 2$

  [Harlander '00; Harlander, Kilgore; Anastasiou, Melnikov '02]

  – in agreement with previous soft/collinear gluon approximations

    [MK, Laenen, Spira; Catani, de Florian, Grazzini]

  – scale dependence $\lesssim 15\%$

  $\rightarrow$ Figure

- soft gluon resummation $\lesssim 10\%$

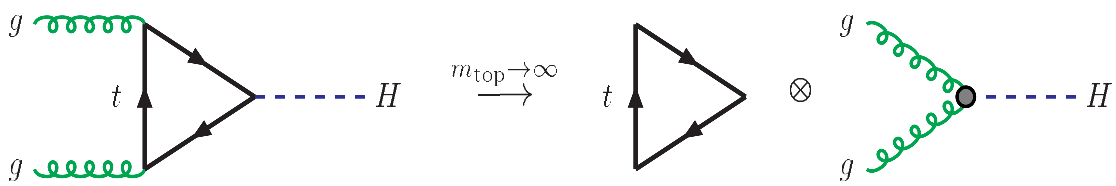
  [Catani, de Florian, Grazzini, Nason '02]

  $\rightarrow$ Figure

$\Rightarrow$ Cross section prediction under control

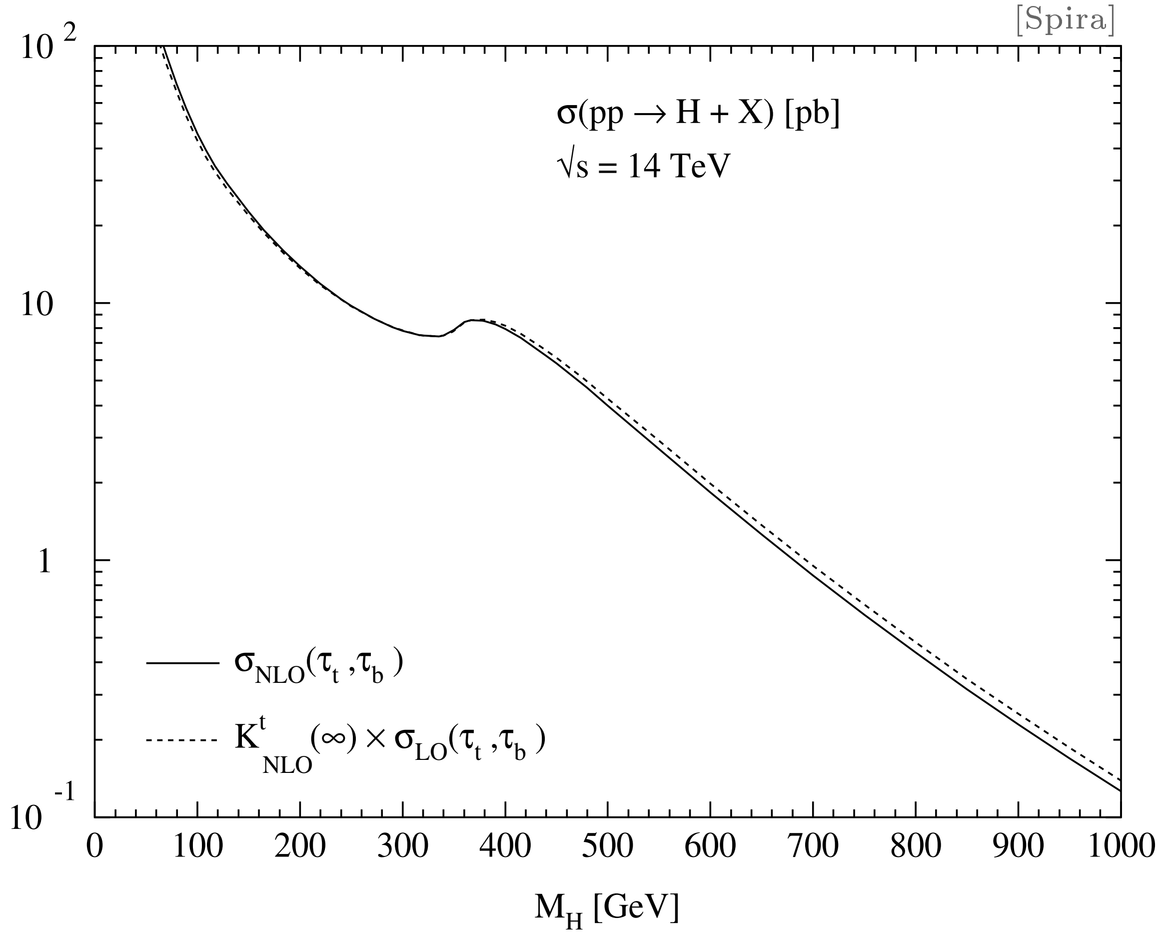
# The $m_{\rm top} \gg M_H$ approximation

- use effective Lagrangian
  [Ellis, Gaillard, Nanopoulos, Sachrajda; ... ;
  Chetyrkin, Kniehl, Steinhauser; Spira]




- excellent approximation for $K$ factor

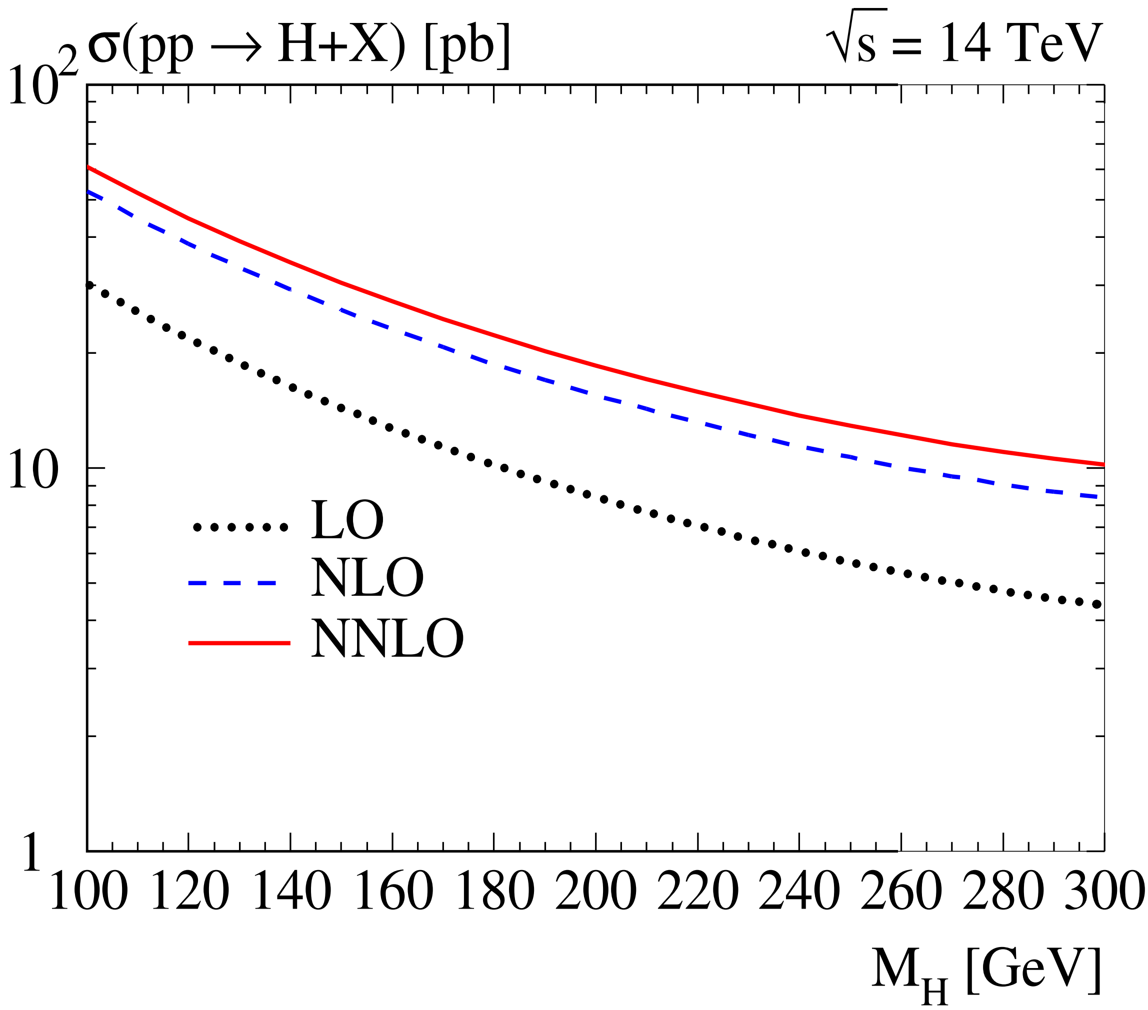
[Spira]




- corrections dominated by soft/collinear gluon emission
  [MK, Laenen, Spira; Harlander, Kilgore, Catani, de Florian, Grazzini]

# The total cross section $gg \to H$

[Harlander, Kilgore '02]

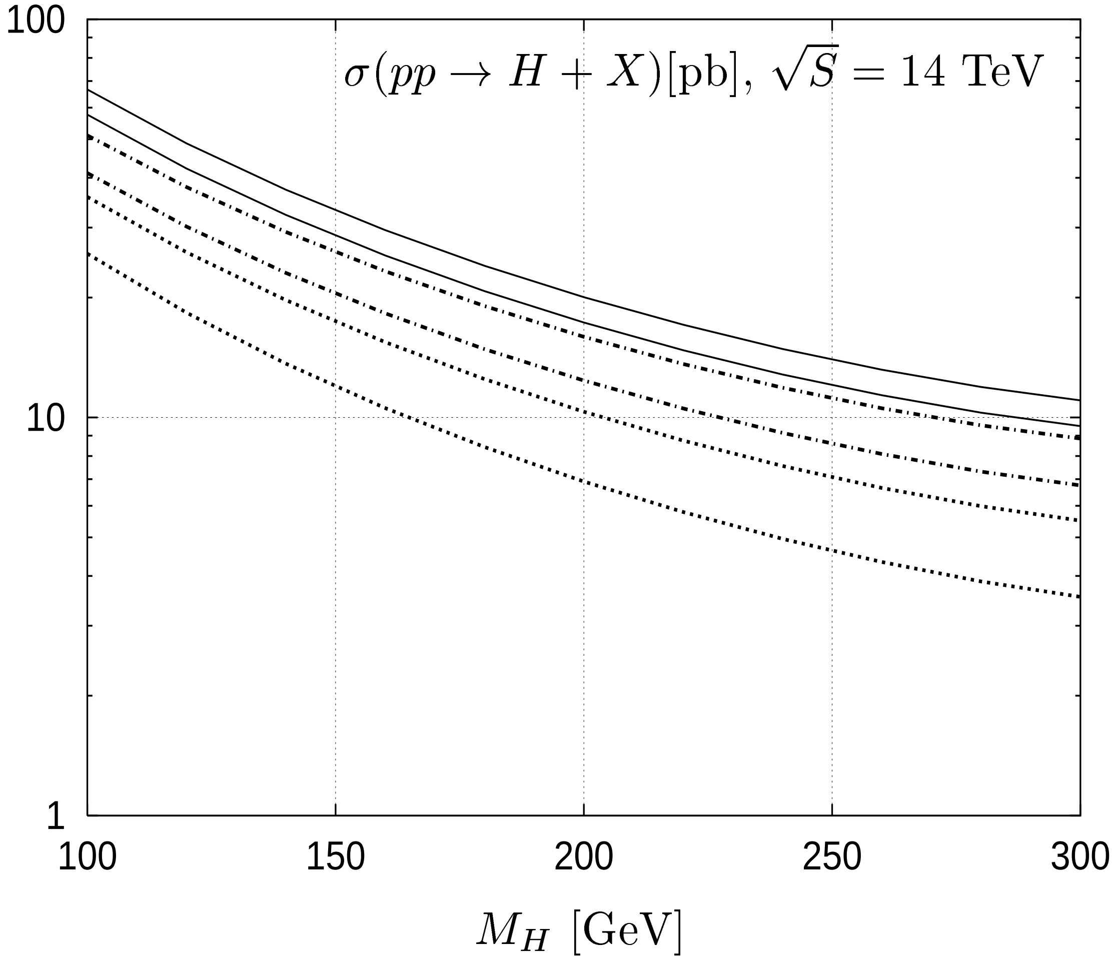



- perturbative expansion well behaved
- (approximate) NNLO PDFs important

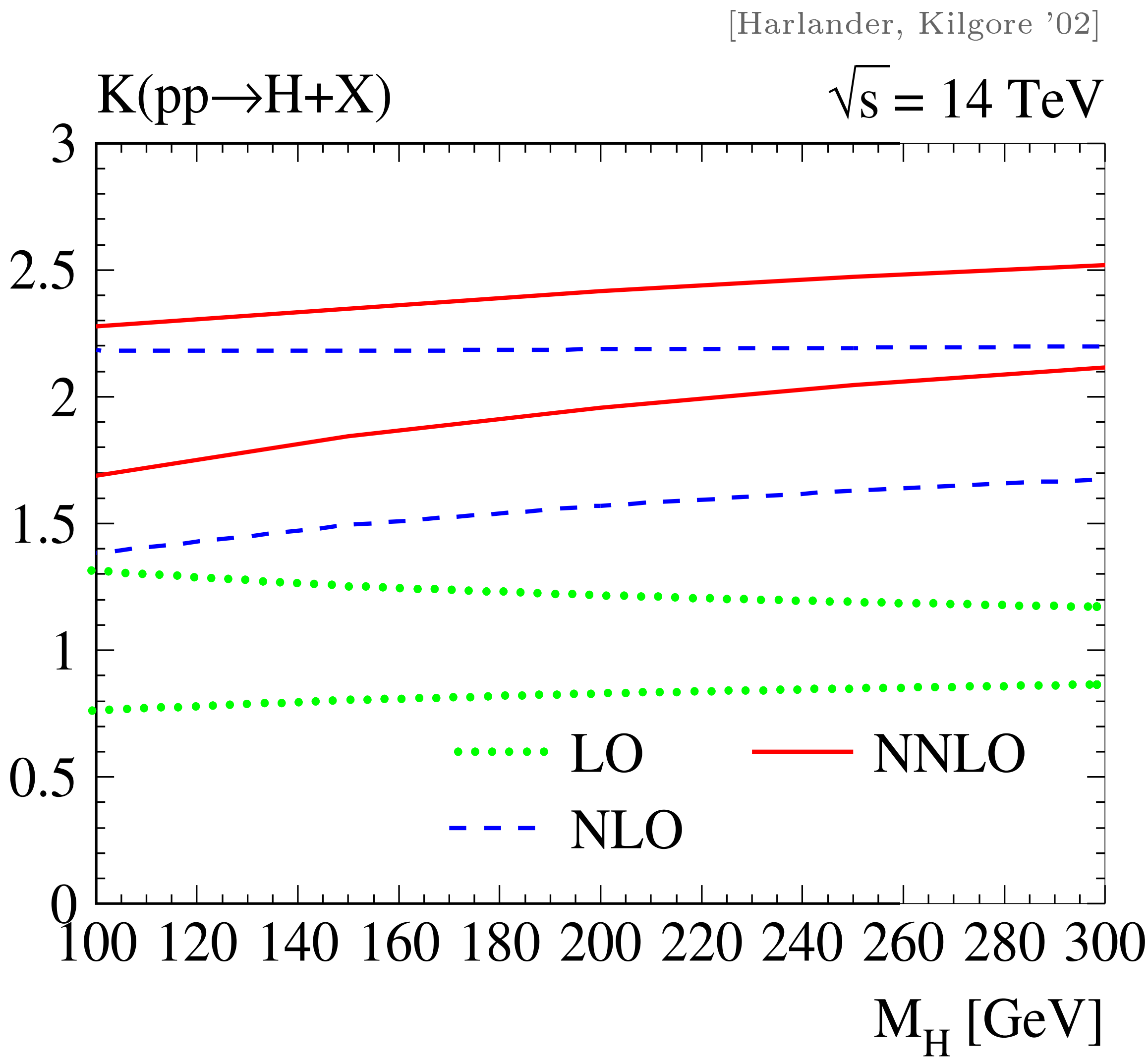
  [Martin, Roberts, Stirling, Thorne '02; Retéy, Vermaseren; van Neerven, Vogt]

# The total cross section $gg \to H$

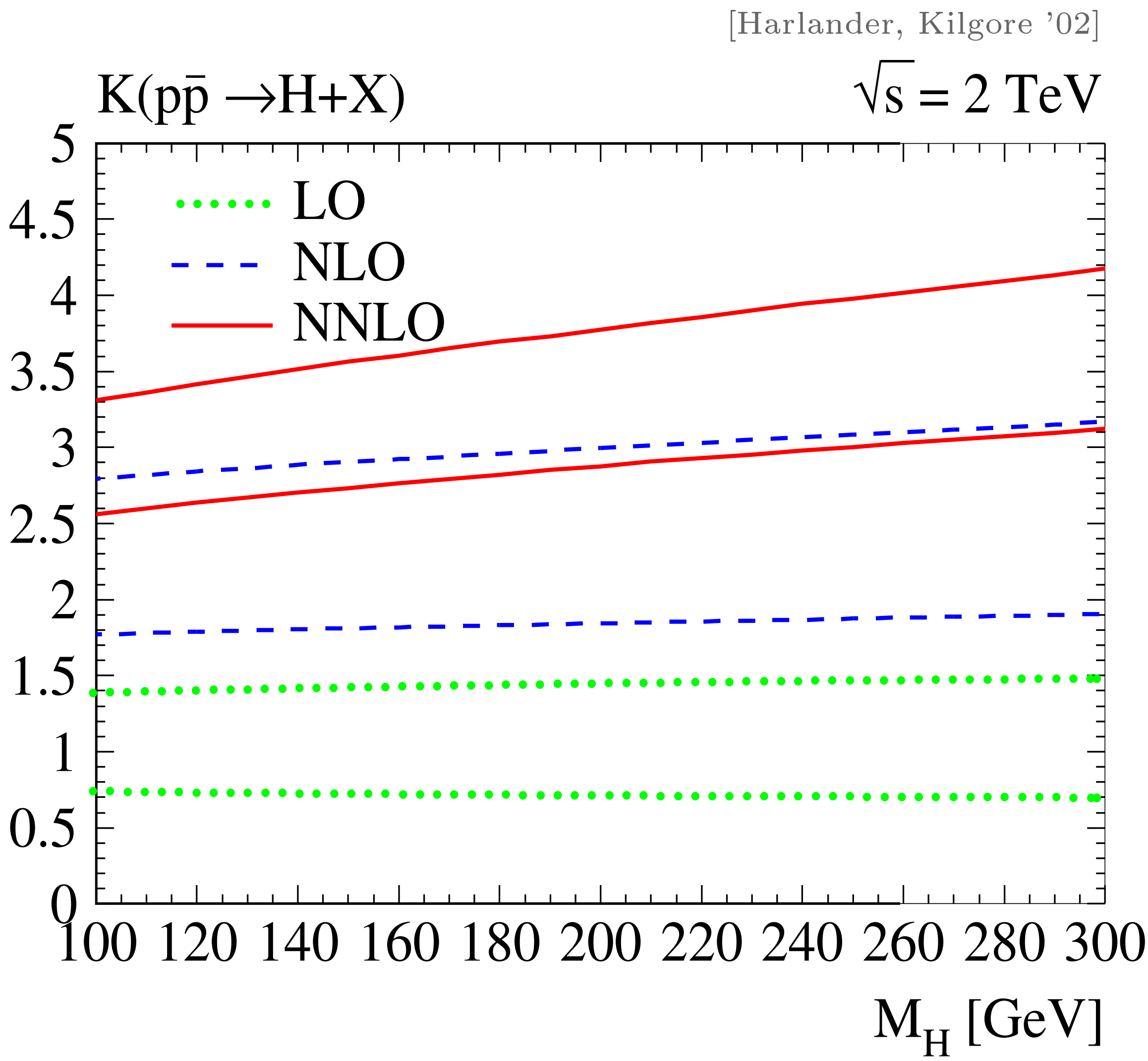
[Anastasiou, Melnikov '02]



## The $K$ factor $gg \to H$

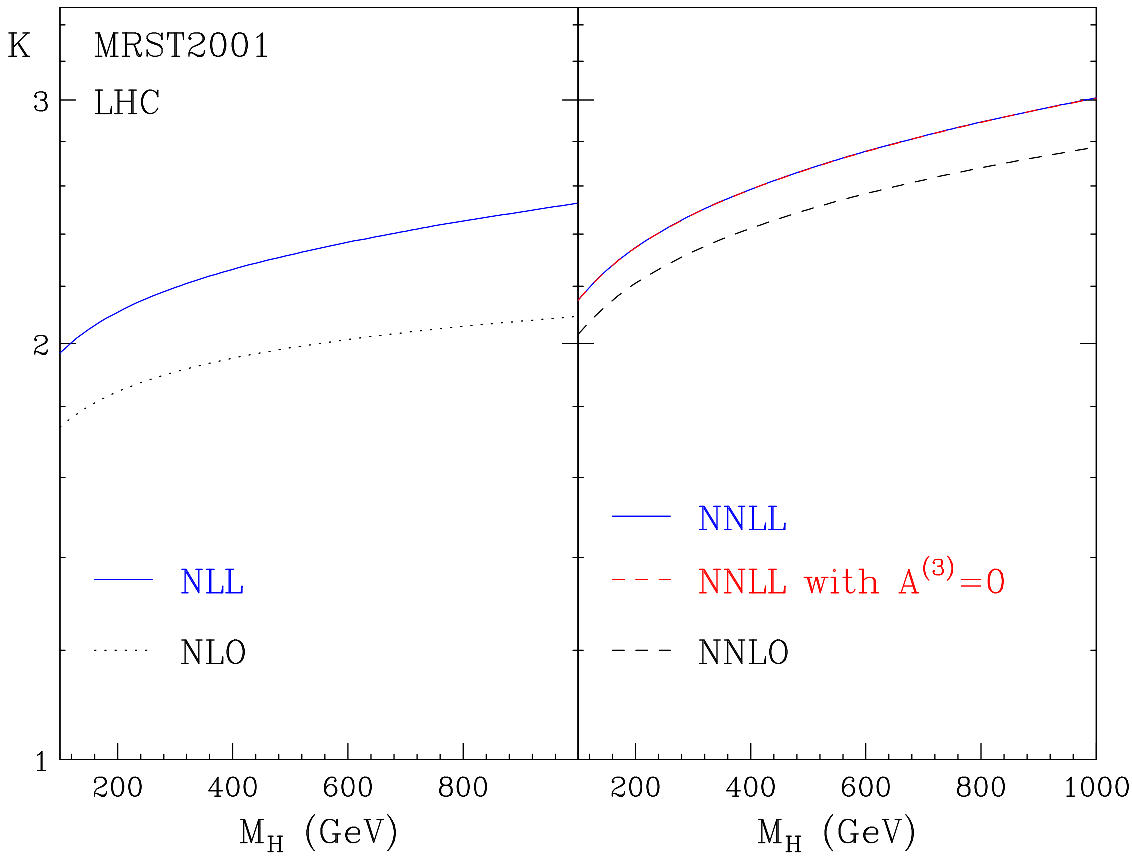


# The $K$ factor $gg \to H$: Tevatron



# Soft gluon summation

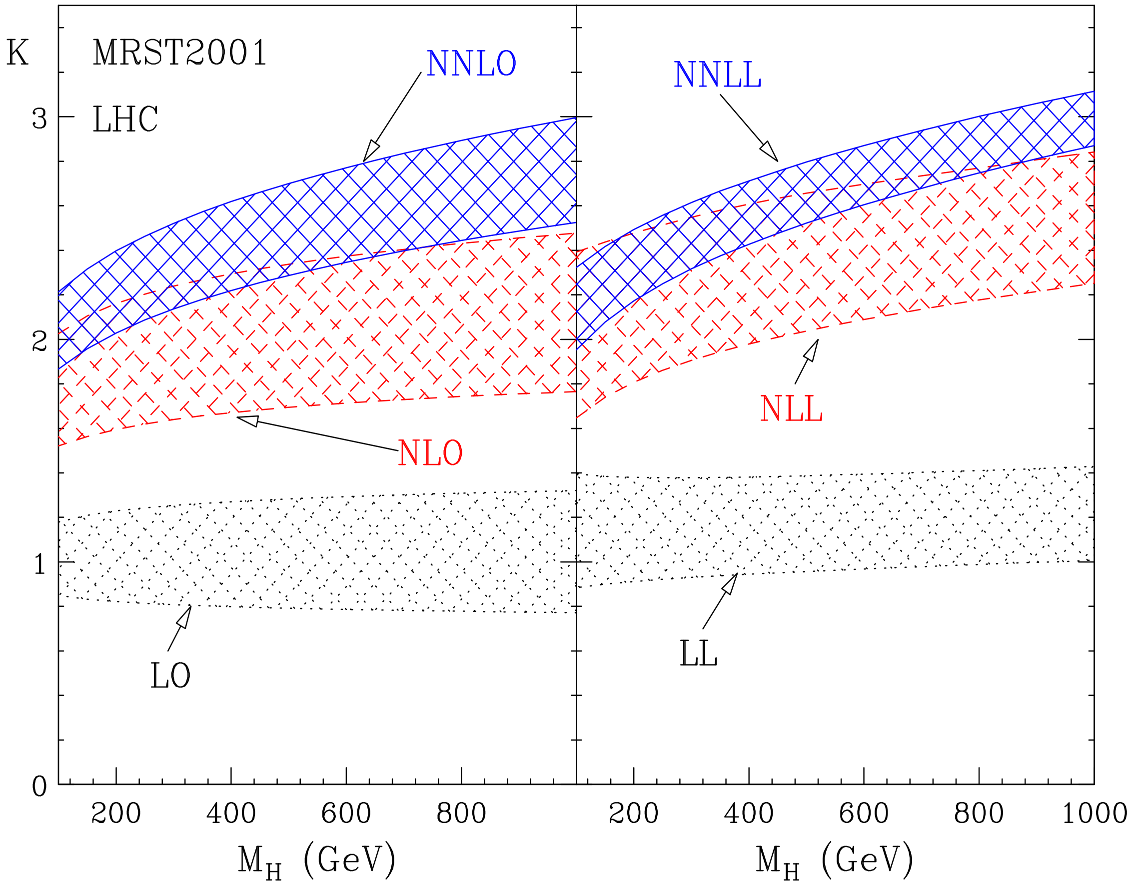
[Catani, de Florian, Grazzini, Nason '02]




- NNLL $\lesssim +10\%$ w.r.t. NNLO

# Soft gluon summation

[Catani, de Florian, Grazzini, Nason '02]

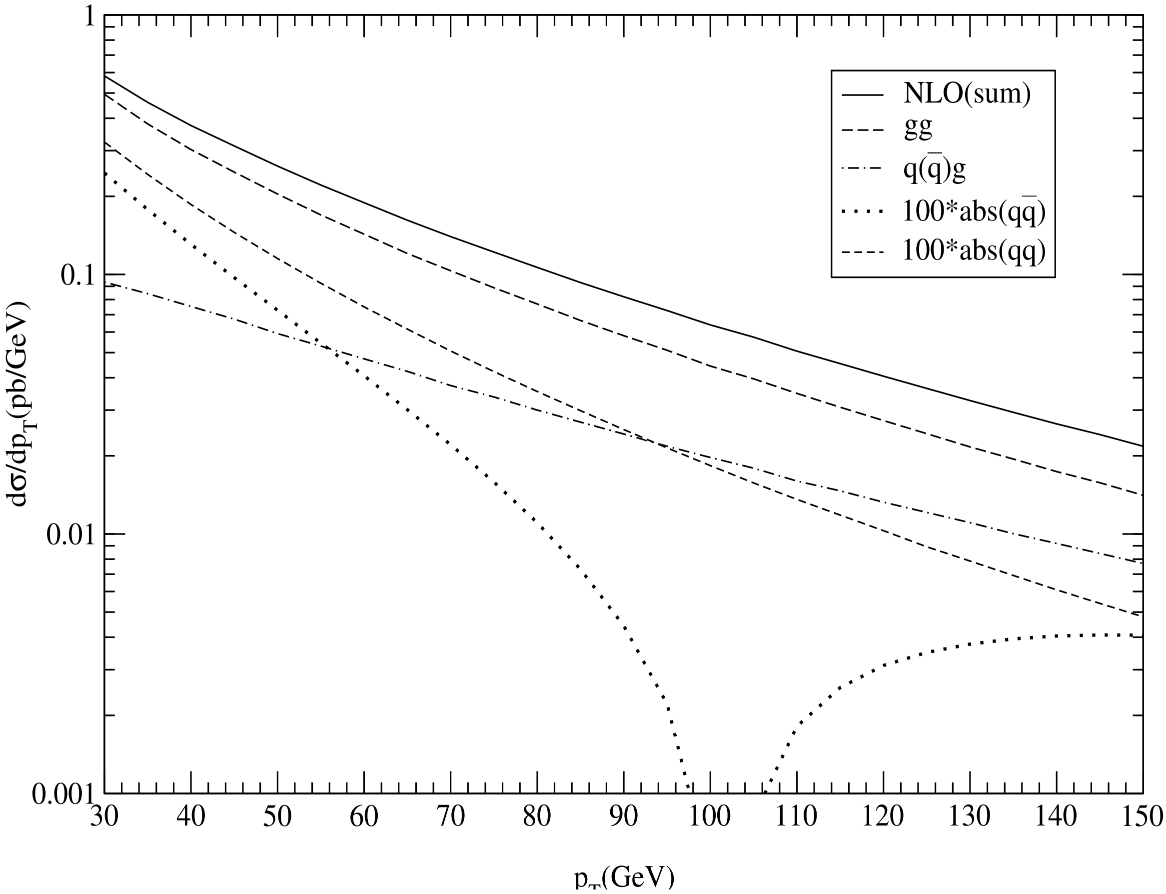


# Differential distributions

- NLO predictions for $d^2\sigma/dp_T/dy$, $d\sigma/dp_T$ and $d\sigma/dy$

  [de Florian, Grazzini, Kunszt '99; Ravindran, Smith, van Neerven '02; Glosser, Schmidt '02]

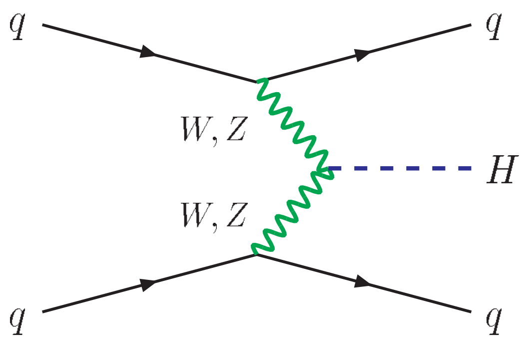
[Ravindran, Smith, van Neerven '02]




- Summation of soft gluon effects

  [C. Balazs, C.-P. Yuan; D. de Florian, M. Grazzini]

# Vector boson fusion

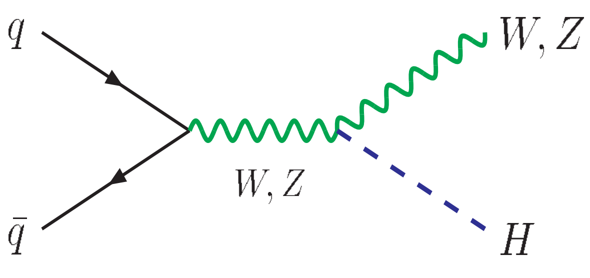



[Cahn, Dawson; Hikasa; Altarelli, Mele, Pitolli]

- discovery channel & measurement of Higgs couplings
  [Kauer, Plehn, Rainwater, Zeppenfeld]

- QCD corrections (cf DIS) $\approx 10\%$
  [Han, Valencia, Willenbrock]

# Associated VH production




[Glashow, Nanopoulos, Yildiz; Kleiss, Kunszt, Stirling; Kunszt, Trocsanyi, Stirling]

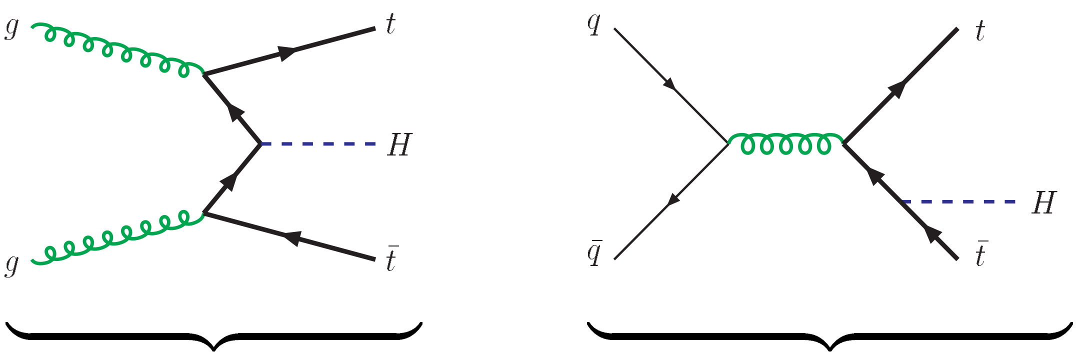
- crucial for Tevatron search ($M_H \lesssim 130$ GeV)

- QCD corrections (cf Drell Yan) $\approx (30-40)\%$
  [Han, Willenbrock]

# $t\bar{t}H$ associated production

- through $gg$ fusion and $q\bar{q}$ annihilation

  [Kunszt '84; Gunion '91; Marciano, Paige '91]




dominant at LHC — dominant at Tevatron

→ Figure

- $\sigma(t\bar{t}H) \lesssim 1$ pb (LHC, $M_H > 115$ GeV)

  but: distinctive final state:

  $pp \to t(\to W^+b)\,\bar{t}(\to W^-\bar{b})\,H(\to b\bar{b})$

  $\to$ important contribution to $5\sigma$ discovery
  for $M_H \lesssim 130$ GeV

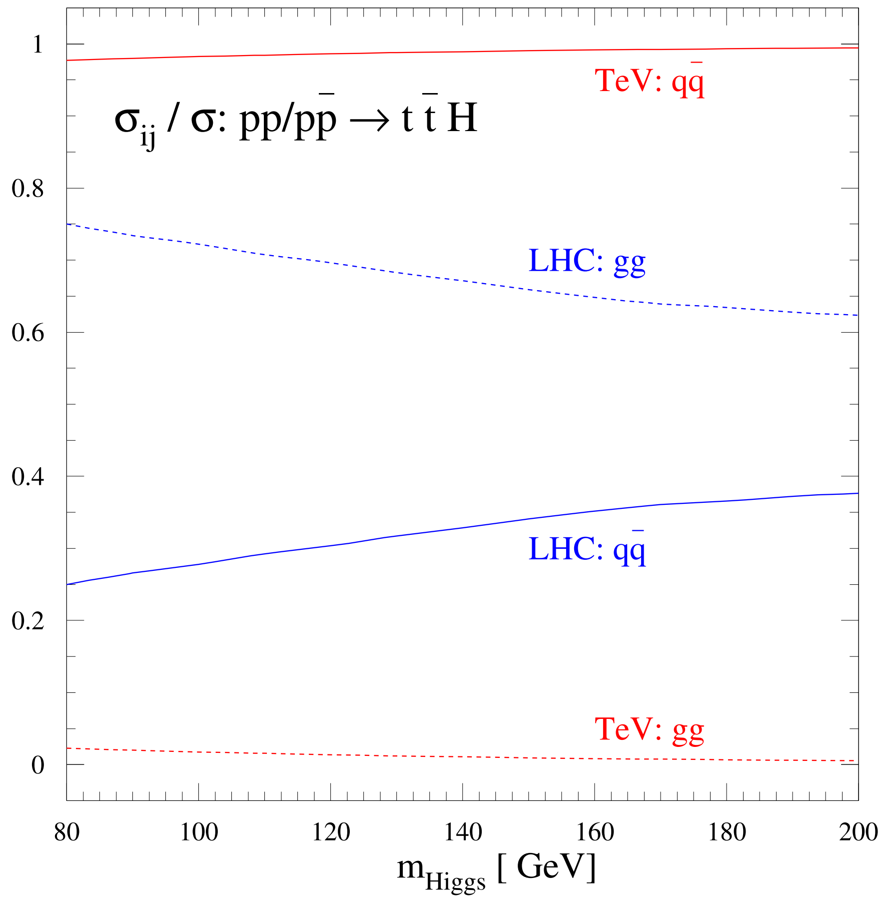
- cross section $\propto g^2_{ttH}$

  $\Rightarrow$ direct measurement of top Yukawa coupling

  $\delta g_{ttH}/g_{ttH} \approx 15\%$ (exp.)

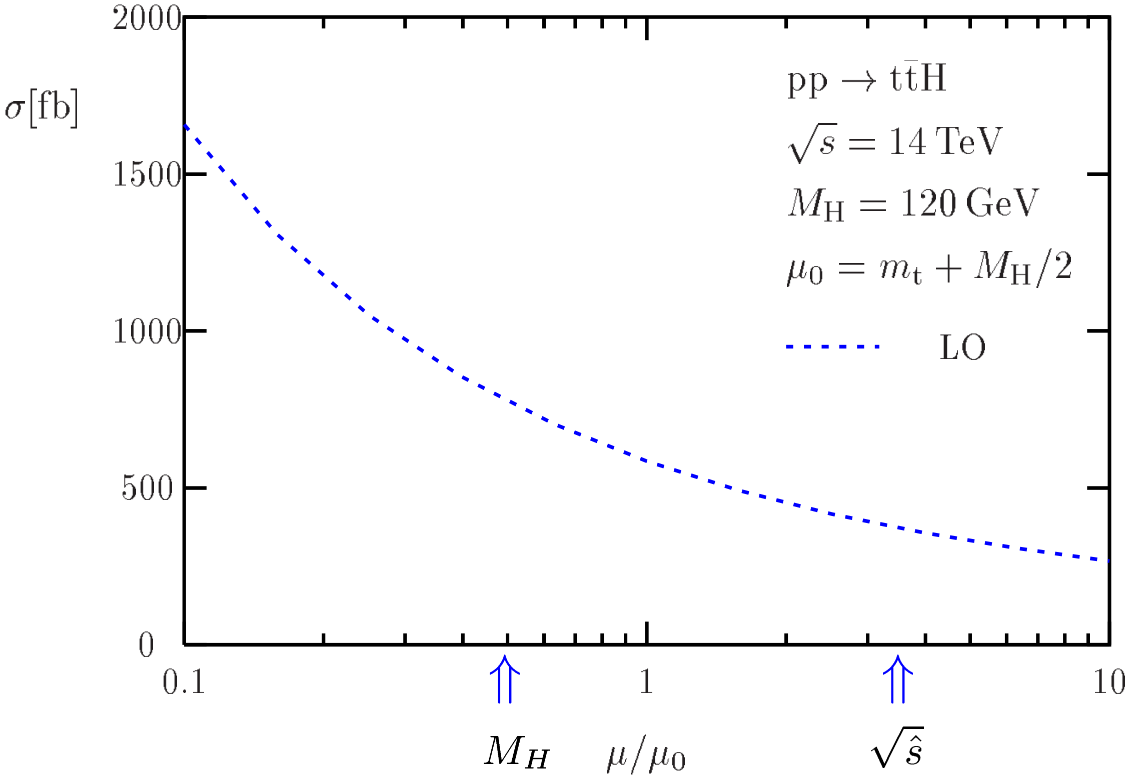
  [Drollinger, Müller, Denegri]

- relative contribution of $q\bar{q}/gg$ channels




$$\left.\begin{array}{l}\text{Tevatron}\\\text{LHC}\end{array}\right\}\ \text{cross section dominated by}\ \left\{\begin{array}{l}q\bar{q}\ \text{annihilation}\\ gg\ \text{fusion}\end{array}\right.$$

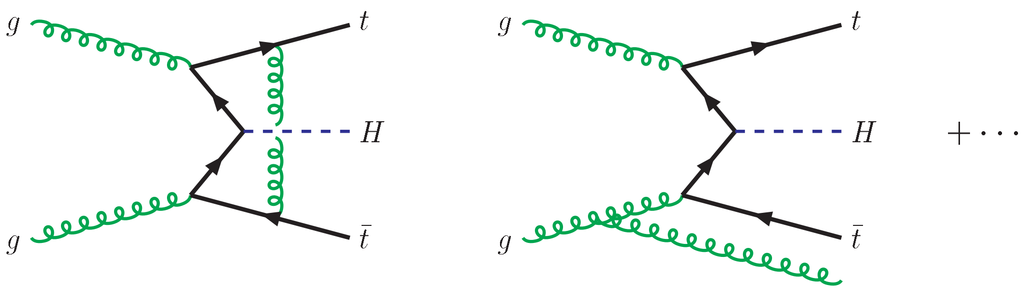
- Scale dependence of LO cross section




$$\frac{\delta\sigma_{\mathrm{LO}}}{\sigma_{\mathrm{LO}}} \approx 70\%$$

- NLO calculation

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas '01]




independent NLO calculation for $q\bar{q}$ initial state

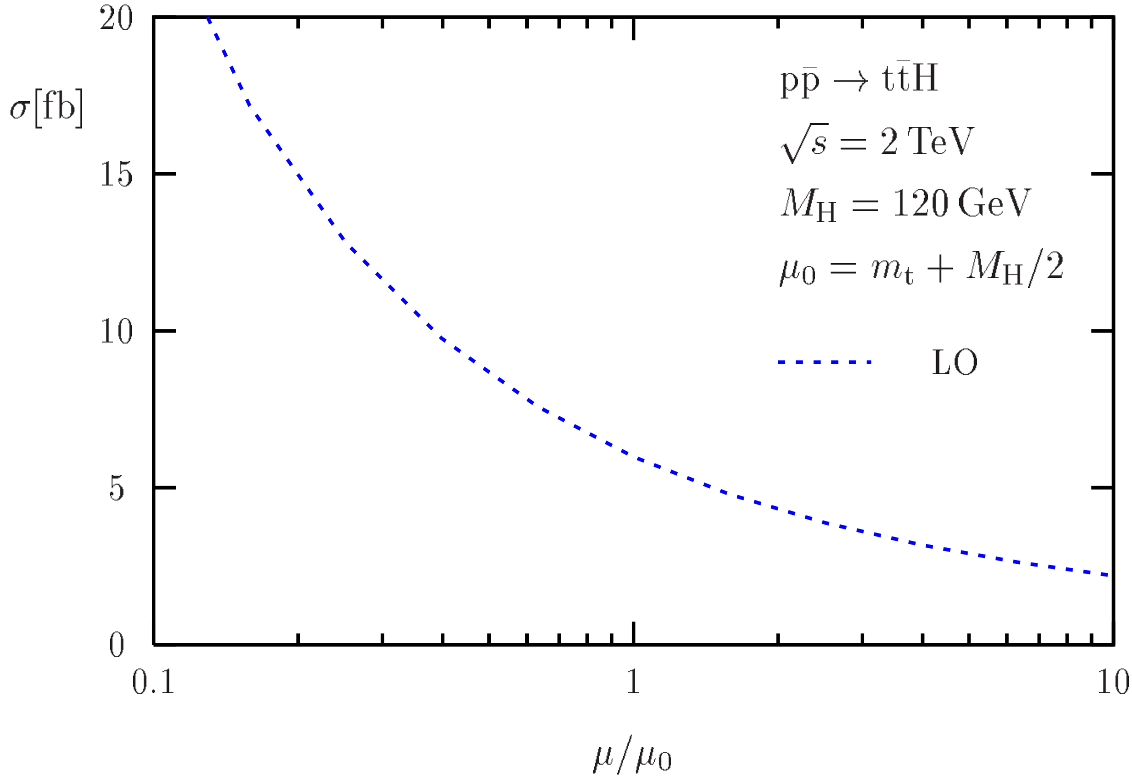
[Reina, Dawson, Wackeroth '01]

independent NLO calculation for $gg$ initial state in progress

[Dawson, Orr, Reina, Wackeroth]

- Scale dependence of LO cross section

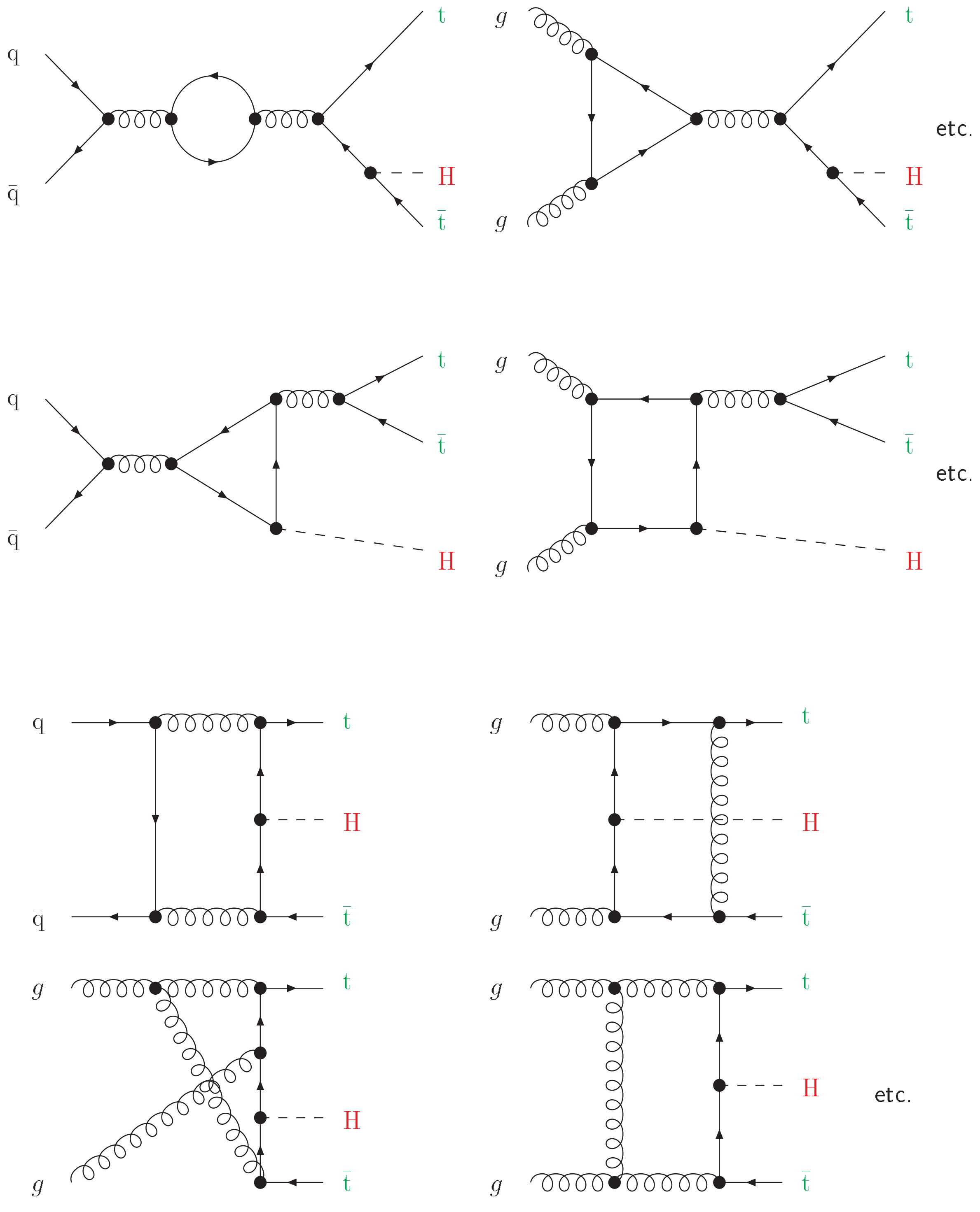
at the Tevatron



# NLO corrections to $q\bar{q}/gg \to t\bar{t}H$

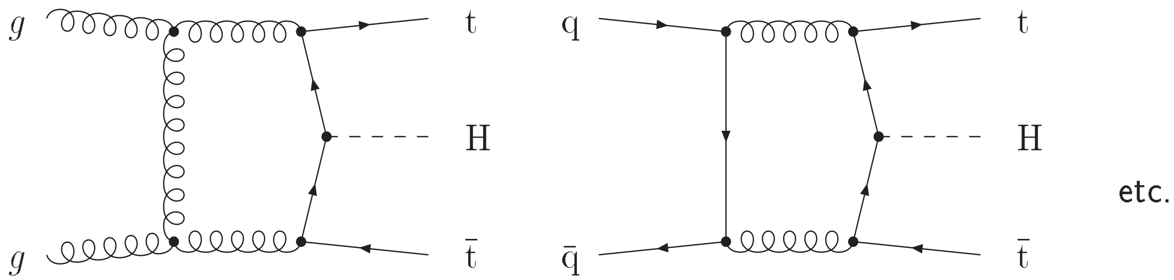
- Virtual corrections

generic set of Feynman diagrams



# Challenges in the virtual corrections

## Pentagon diagrams




$\rightarrow$ one-loop integrals of the form

$$E_{\mu\nu\cdots} = \frac{(2\pi\mu)^{4-D}}{i\pi^2} \int d^D q \frac{q_\mu q_\nu \cdots}{[(q+p_1)^2 - m_1^2] \cdots [(q+p_5)^2 - m_5^2]}$$

– determine singularity structure $E_{\mathrm{sing}}^{(D)}$ in $D$ dimensions
 $\rightarrow$ three-point subintegrals

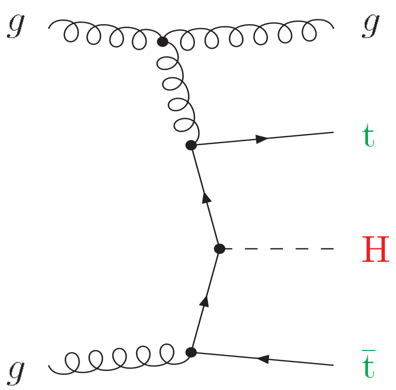
– translate (finite) difference $E^{(D)} - E_{\mathrm{sing}}^{(D)}$ into mass regularisation
 $\rightarrow$ can be decomposed into four-point subintegrals

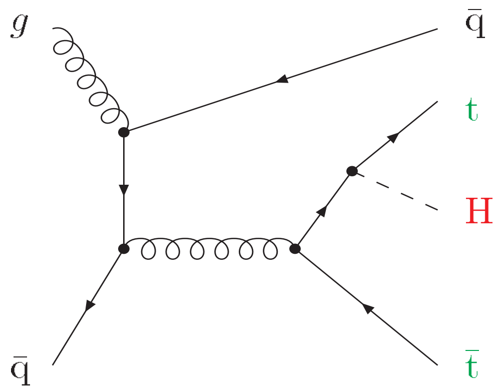
$\Rightarrow$ $E^{(D)} = E_{\mathrm{sing}}^{(D)} + \left[E^{(\mathrm{mass},D=4)} - E_{\mathrm{sing}}^{(\mathrm{mass},D=4)}\right]$

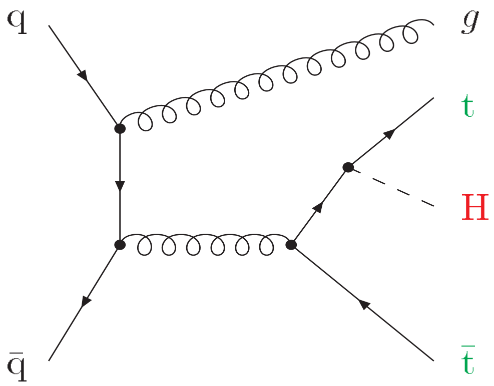
expressed in terms of three- and four-point functions

- Real corrections

generic set of Feynman diagrams




etc.

## Challenges

– evaluation of complicated matrix elements

$\rightarrow$ application of conventional trace techniques and use of helicity amplitudes (`Madgraph`, Stelzer, Long)

– extraction of soft and collinear divergences

$\rightarrow$ use dipole subtraction formalism

(additional check: phase space slicing for $q\bar{q}$ channel)

# Dipole subtraction formalism:

[Catani, Seymour '96; Dittmaier '99, Roth '99;
Phaf, Weinzierl '01; Catani, Dittmaier, Seymour, Trócsányi '01]

→ process-independent treatment of singularities
in real NLO corrections

idea: NLO correction to process with $m$ partons

$$\sigma^{\mathrm{NLO}} = \underbrace{\int_{m+1}\left[d\sigma^{\mathrm{real}} - d\sigma^{\mathrm{sub}}\right]}_{\text{finite}} + \underbrace{\int_{m}\left[d\sigma^{\mathrm{virtual}} + d\bar{\sigma}_1^{\mathrm{sub}}\right]}_{\text{finite}}$$

$$+ \int_0^1 dx \underbrace{\int_m \left[d\sigma^{\mathrm{fact}}(x) + \left(d\bar{\sigma}^{\mathrm{sub}}(x)\right)_+\right]}_{\text{finite}}$$

conditions on $d\sigma^{\mathrm{sub}}$:

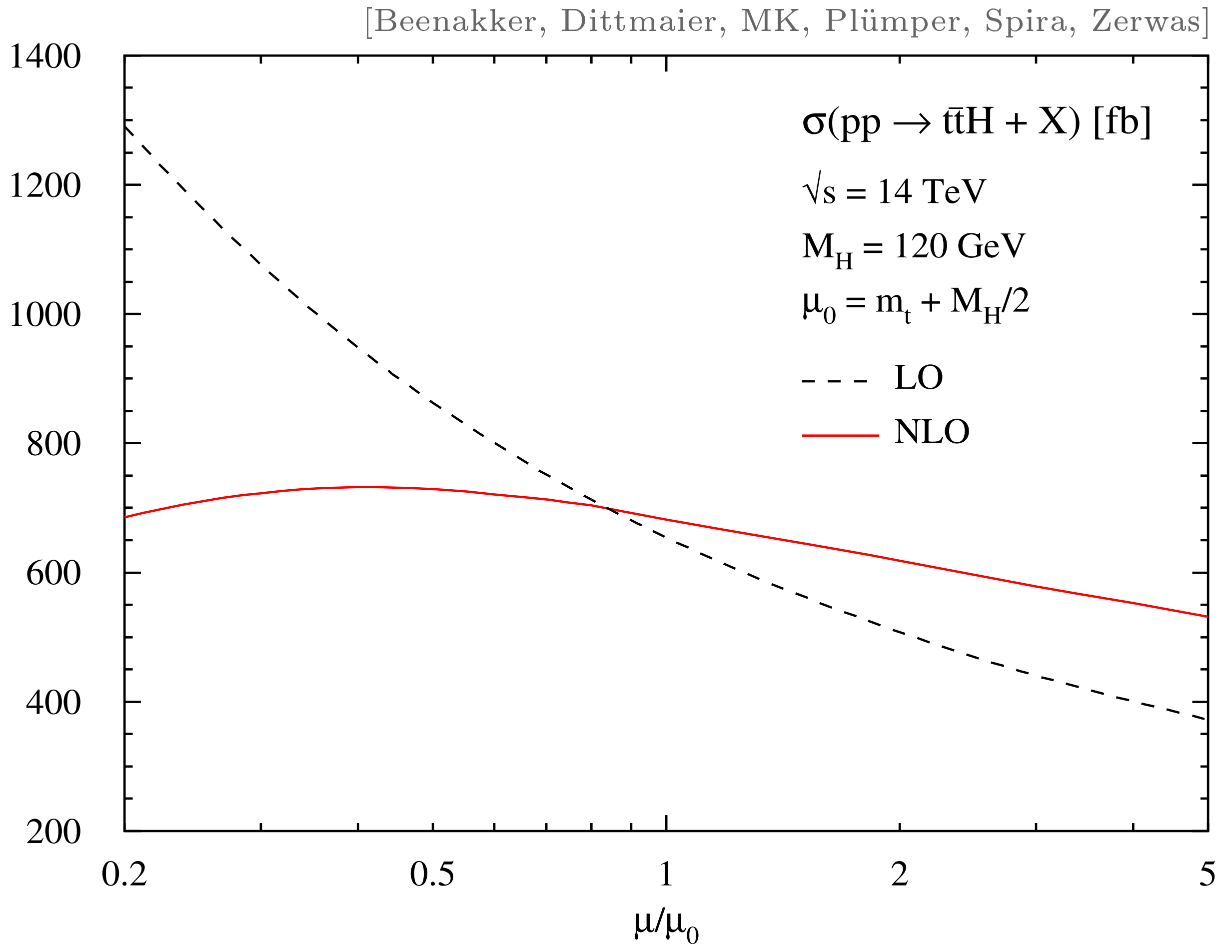
- sum rule:

$$-\int_{m+1} d\sigma^{\mathrm{sub}} + \int_m d\bar{\sigma}_1^{\mathrm{sub}} + \int_0^1 dx \int_m \left(d\bar{\sigma}^{\mathrm{sub}}(x)\right)_+ = 0$$

- asymptotics:

$$\sigma^{\mathrm{sub}} \sim \sigma^{\mathrm{real}} \quad \text{in all collinear/IR regions}$$

# $t\bar{t}H$: scale dependence at NLO



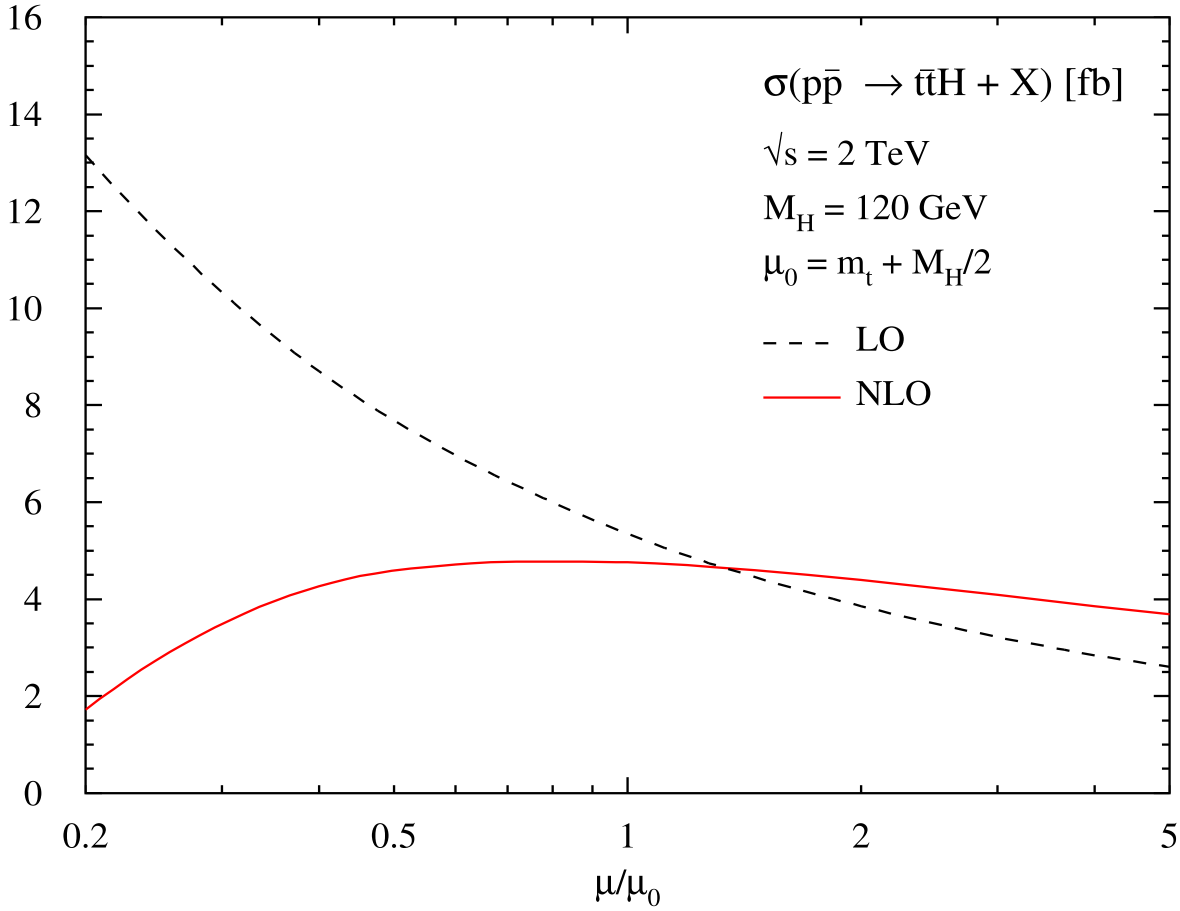

Scale variation within $\mu_0/3 \lesssim \mu \lesssim 3\mu_0$:

$$\frac{\delta\sigma_{\rm LO}}{\sigma_{\rm LO}} \approx 70\% \qquad \frac{\delta\sigma_{\rm NLO}}{\sigma_{\rm NLO}} \approx 15\%$$

## $t\bar{t}H$: scale dependence at NLO

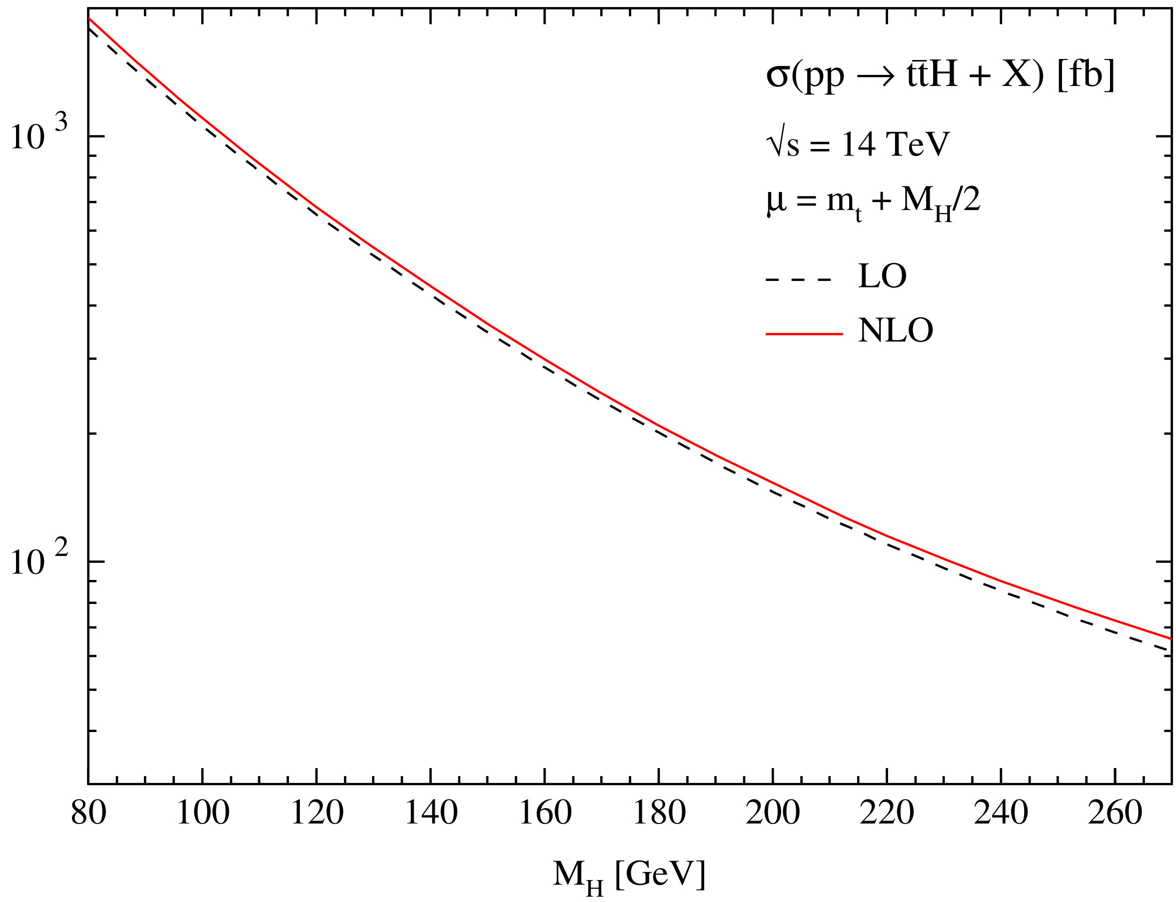
at the Tevatron:

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



## $t\bar{t}H$: total cross section

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



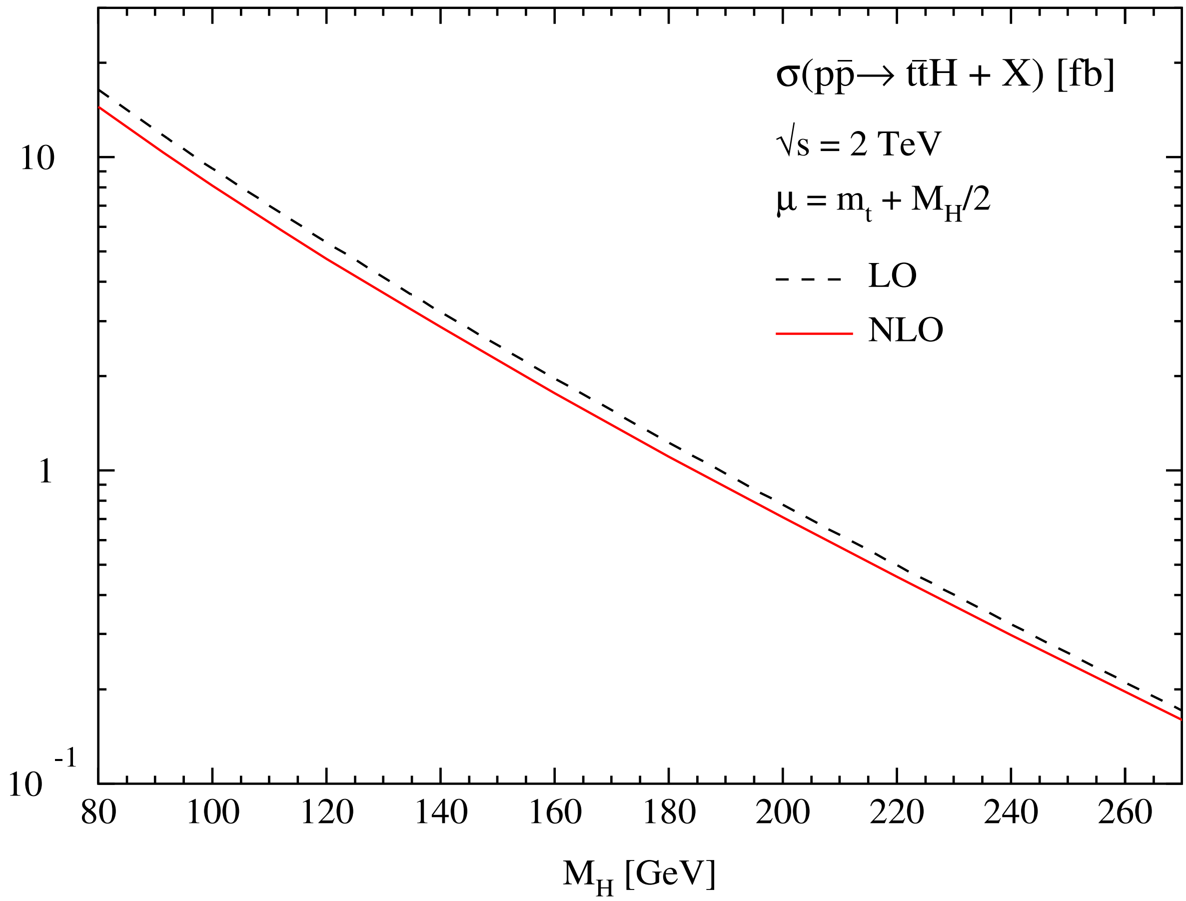

Relative correction for $\mu = \mu_0 = (2m_t + M_H)/2$:

$$K = \frac{\sigma_{\mathrm{NLO}}}{\sigma_{LO}} \approx 1.2$$

# $t\bar{t}H$: total cross section

at the Tevatron:

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]

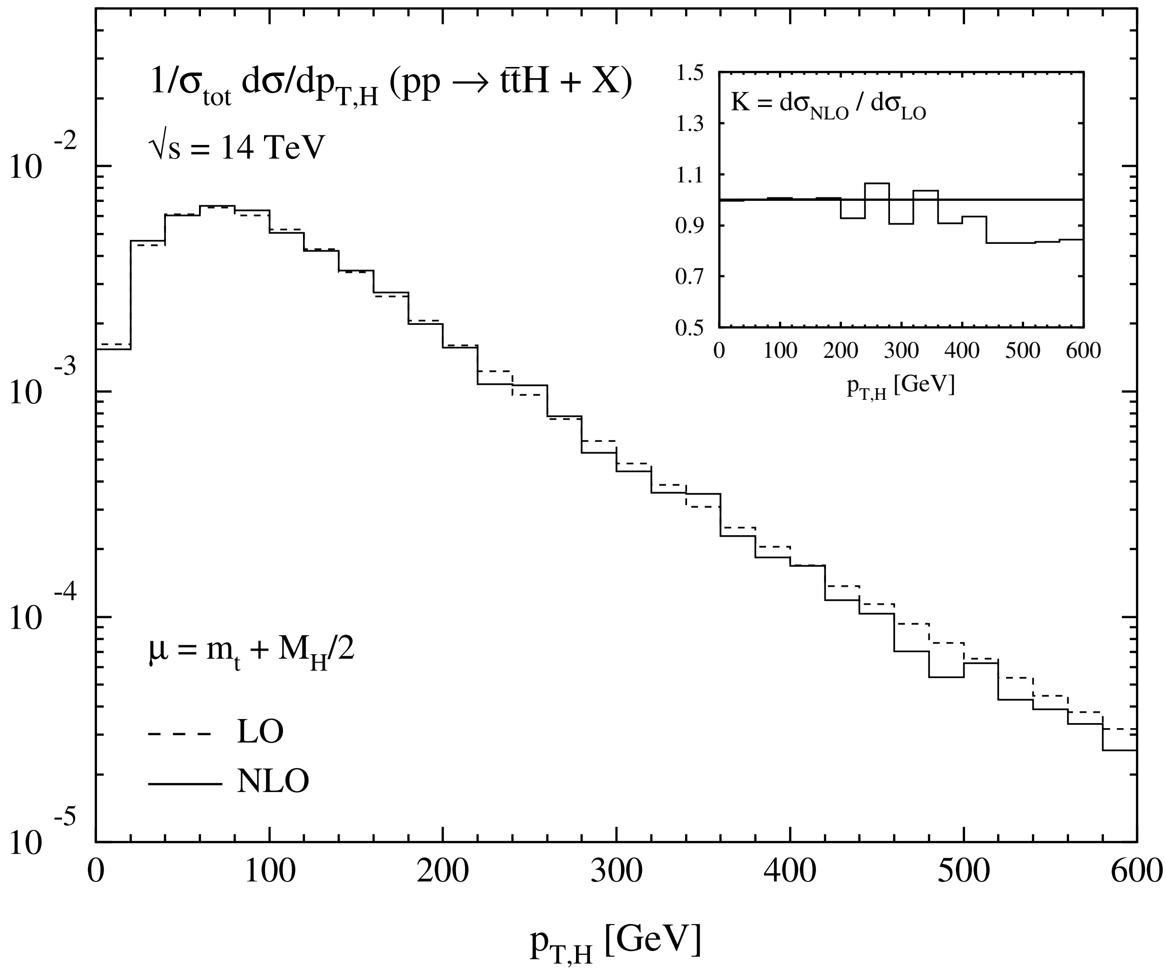



Relative correction for $\mu = \mu_0 = (2m_t + M_H)/2$:

$$K = \frac{\sigma_{\text{NLO}}}{\sigma_{LO}} \approx 0.8$$

# Higgs transverse momentum distribution

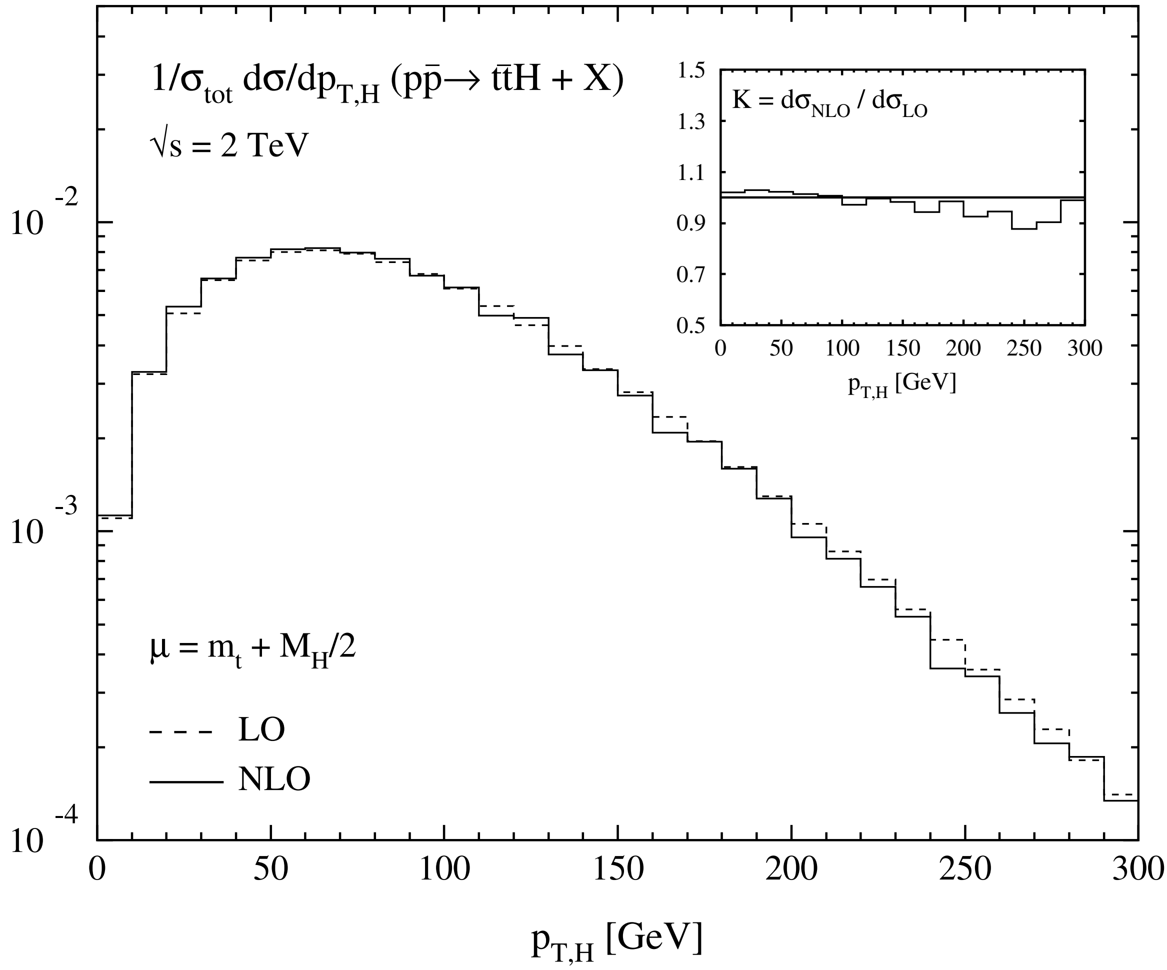
[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



# Higgs transverse momentum distribution

at the Tevatron:

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



# Higgs background calculations

Example: $gg \to H \to \gamma\gamma/WW$

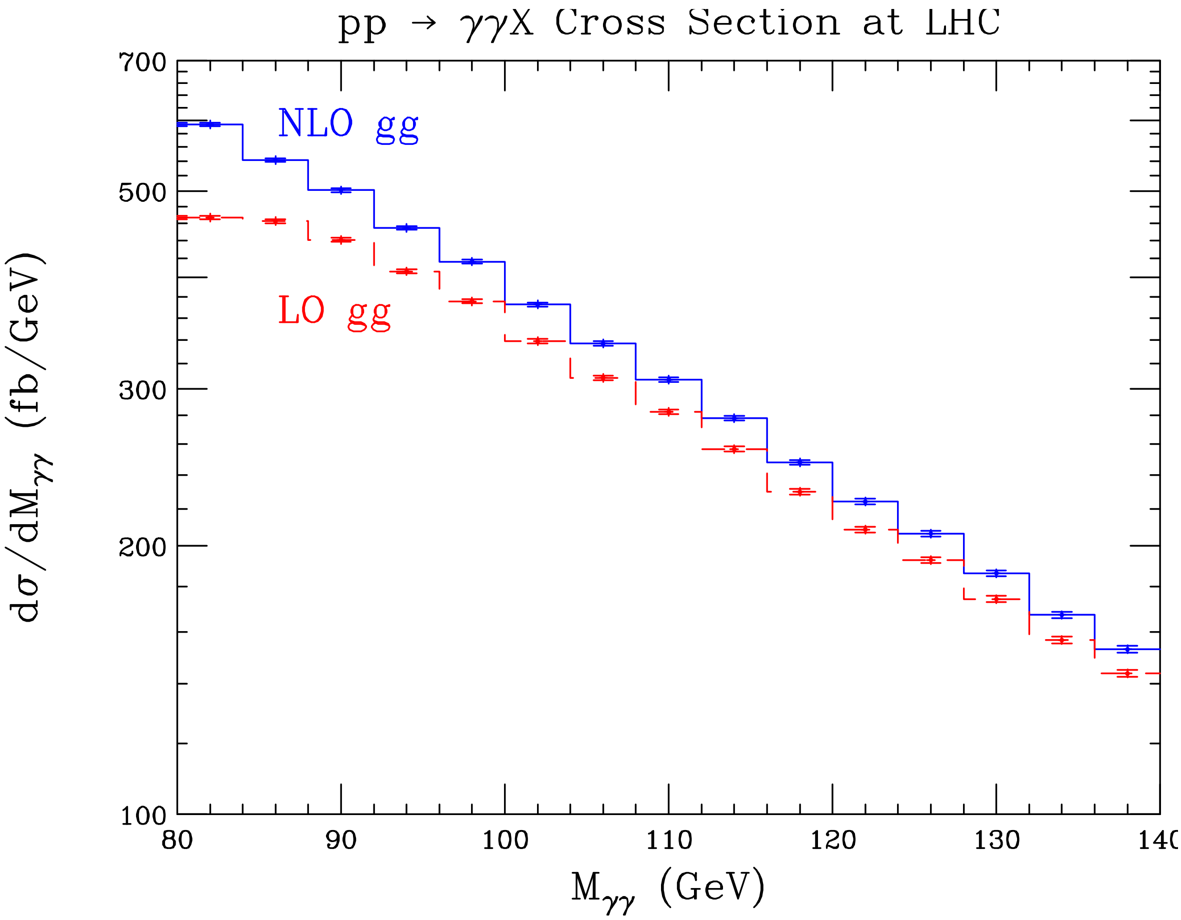
- $\gamma\gamma$ background
  - NLO parton level MC program $pp \to \gamma\gamma$ (DIPHOX)
    [Binoth, Guillet, Pilon, Werlen]
  - $gg \to \gamma\gamma$ at NLO (2-loop): moderate
    [Bern, De Freitas, Dixon, Schmidt '02]
    $\to$ Figure
- $WW$ background
  - jet veto effects
    [Catani, De Florian, Grazzini]
  - NLO parton level MC program $pp \to W^+W^-$
    [Frixione, Nason, Ridolfi; Baur, Han, Ohnemus]
  - NLO spin correlations in leptonic $W$ decays
    [Dixon, Kunszt, Signer]
  - $t\bar{t}$ backgrounds including finite width effects
    [Kauer, Zeppenfeld]
  - NLO parton level MC program $pp \to W/Z + b\bar{b}$
    [Campbell, Ellis, Veseli]

much more work done/needed for backgrounds to
$qq \to qqH$, $gg/q\bar{q} \to t\bar{t}H$, $q\bar{q}' \to WH$

[see e.g. Rainwater, Spira, Zeppenfeld and references therein]

## $gg \to \gamma\gamma$ at NLO

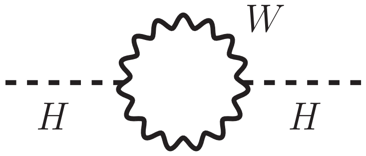
[Bern, Dixon, Schmidt '02]




$\Rightarrow \delta\sqrt{B} \lesssim 5\%$ (115 GeV $< M_H <$ 140 GeV)

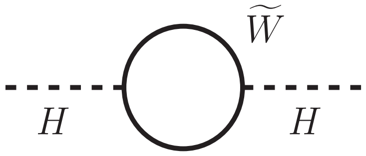
# SUSY particle production

- quadratically divergent radiative corr. to $M_H$




$\rightarrow \quad \delta m_H^2 \sim \frac{\alpha}{\pi}(\Lambda^2 + M^2)$

cancelled by supersymmetry




$\rightarrow \quad \delta m_H^2 \sim -\frac{\alpha}{\pi}(\Lambda^2 + \widetilde{M}^2)$

$\Rightarrow \delta m_H^2 \sim \frac{\alpha}{\pi}\,|M^2 - \widetilde{M}^2|$

no fine-tuning $\Rightarrow$ SUSY masses $\widetilde{M} \lesssim \mathcal{O}(1\text{ TeV})$

- Tevatron & LHC

  $\rightarrow$ large cross section for strongly interacting particles: squarks and gluinos

discovery reach:

| $\widetilde{M}$ | Tevatron | LHC |
|---|---|---|
| gluino | $\sim$ 500 GeV | $\sim$ 2 TeV |
| squark | $\sim$ 500 GeV | $\sim$ 2 TeV |

$\Longrightarrow$ LHC will discover or exclude low-energy supersymmetry

# Minimal Supersymmetric Standard Model

| | |
|---|---|
| Gauge Bosons $S=1$<br>gluon, $W^\pm, Z, \gamma$ | Gauginos $S=1/2$<br>gluino, $\widetilde{W}, \widetilde{Z}, \widetilde{\gamma}$ |
| Fermions $S=1/2$<br>$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \begin{pmatrix} \nu_L^e \\ e_L \end{pmatrix}$<br>$u_R, d_R, e_R$ | Sfermions $S=0$<br>$\begin{pmatrix} \widetilde{u}_L \\ \widetilde{d}_L \end{pmatrix} \begin{pmatrix} \widetilde{\nu}_L^e \\ \widetilde{e}_L \end{pmatrix}$<br>$\widetilde{u}_R, \widetilde{d}_R, \widetilde{e}_R$ |
| Higgs<br>$\begin{pmatrix} H_2^0 \\ H_2^- \end{pmatrix} \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix}$ | Higgsinos<br>$\begin{pmatrix} \widetilde{H}_2^0 \\ \widetilde{H}_2^- \end{pmatrix} \begin{pmatrix} \widetilde{H}_1^+ \\ \widetilde{H}_1^0 \end{pmatrix}$ |

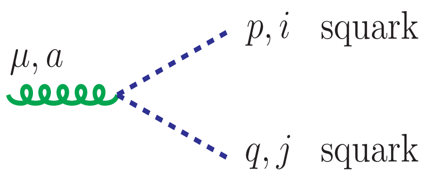
- Baryon & lepton number conservation to avoid proton decay

  impose symmetry $R = (-1)^{3B+L+2S} \begin{cases} = +1 & \text{SM} \\ = -1 & \text{SUSY} \end{cases}$

  $\Rightarrow$ SUSY particles produced pairwise

  $\Rightarrow$ lightest SUSY particle stable

- interactions of MSSM particles:

example: gluon 


$= -i\, g_s\, (T_a)_{ij} (p+q)^\mu$

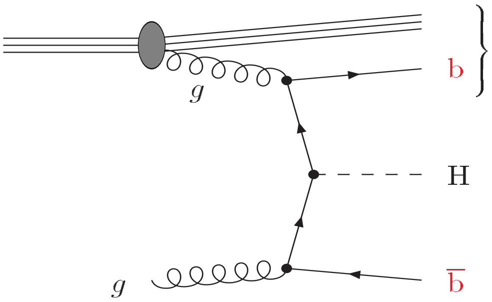
$\Rightarrow$ no new coupling!

# The MSSM Higgs sector

- 2 Higgs doublets $\rightarrow$ 5 Higgs bosons: $h, H, A, H^\pm$
- production processes similar to SM, but:
  - modified couplings
  - extended (s)particle spectrum
  - negative parity of $A$ boson
- $b\bar{b}h$ coupling enhanced for large $\tan\beta$

  $\rightarrow$ $pp/p\bar{p} \rightarrow b\bar{b}h$ is potential discovery channel

Problem:




small $p_{\mathrm{b,T}}$ leads to large terms $\propto \alpha_{\mathrm{s}} \ln(m_{\mathrm{b}}^2/M_{\mathrm{H}}^2)$

Summation of $\alpha_s \ln(m_b^2/M_H^2)$ terms by introducing $b$-quark density $b(x,\mu)$ $\rightarrow$ LO process: $b\bar{b} \rightarrow H$

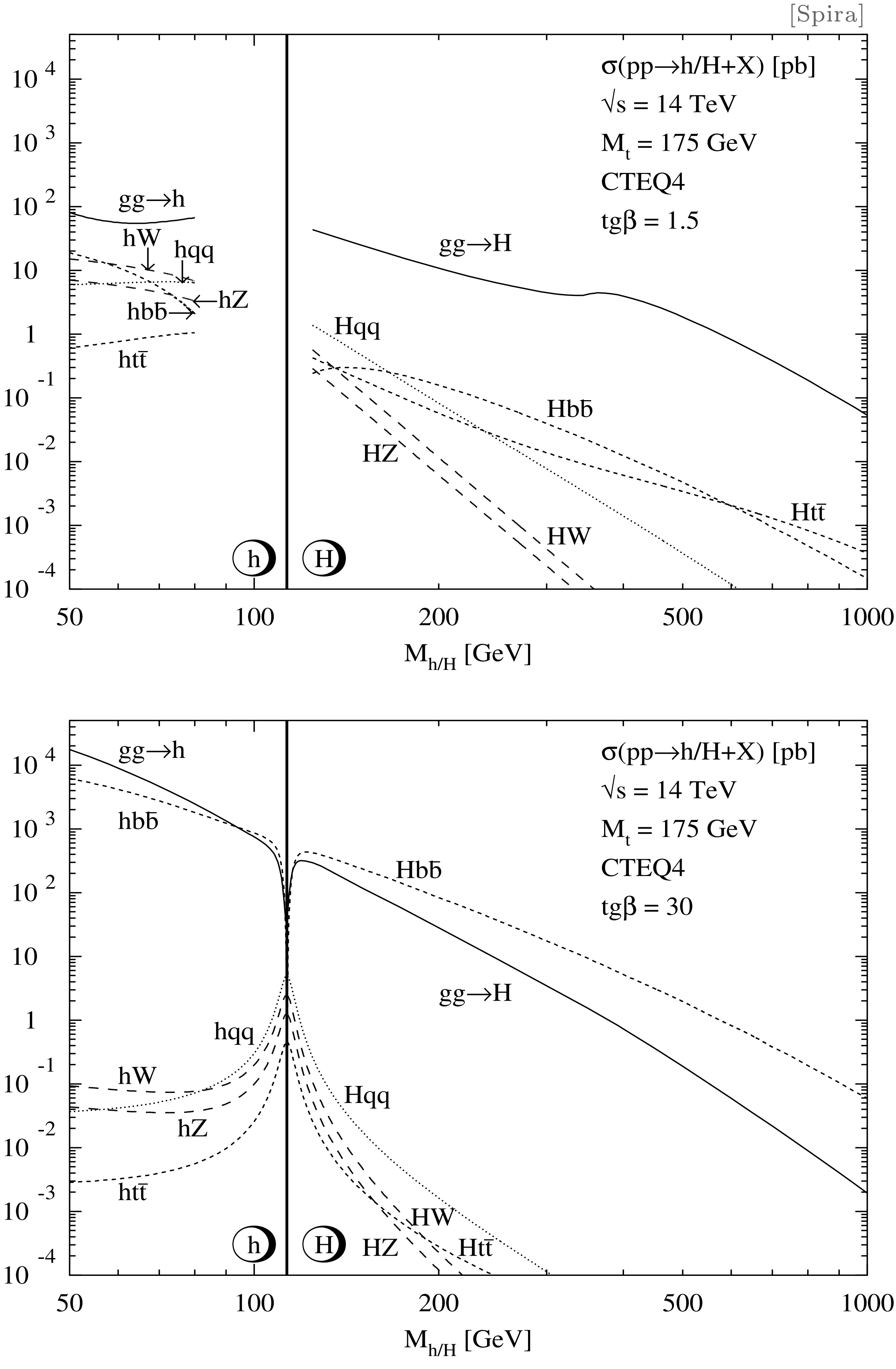
[Barnett, Haber, Soper; Dicus, Stelzer, Sullivan, Willenbrock; Balazs, He, Yuan]

Shortcomings: $b$ quark mass neglected
$p_T$ of $b$ quarks neglected
$\rightarrow$ how to deal with tagged $b$ quarks?

Recent NLO calculations:

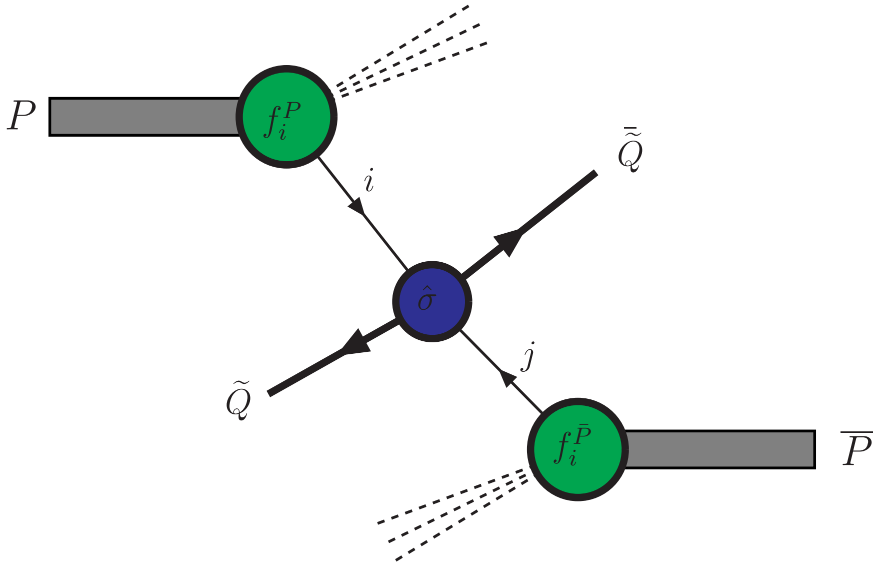
- $gb \rightarrow hb$ [Campbell, Ellis, Maltoni, Willenbrock '02]
- $gb \rightarrow H^- t$ [Plehn '02]

# MSSM Higgs production at the LHC



# MSSM Particle Production at Hadron Colliders

- production dynamics




$$\sigma(pp/p\bar{p} \to \tilde{q}\bar{\tilde{q}}) \;=\; \int \mathrm{d}x_1 \mathrm{d}x_2 f_i^P(x_1,\mu) f_j^P(x_2,\mu)\, \sigma(ij \to \tilde{q}\bar{\tilde{q}}) + \mathcal{O}(\Lambda/M_{\tilde{q}})$$

- MSSM processes relevant for LHC searches

– squarks & gluinos $\quad pp \to \tilde{q}\bar{\tilde{q}}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$

– stops $\quad pp \to \tilde{t}\bar{\tilde{t}}$

– gauginos $\quad pp \to \tilde{\chi}^0\tilde{\chi}^0, \tilde{\chi}^\pm\tilde{\chi}^0, \tilde{\chi}^+\tilde{\chi}^-$

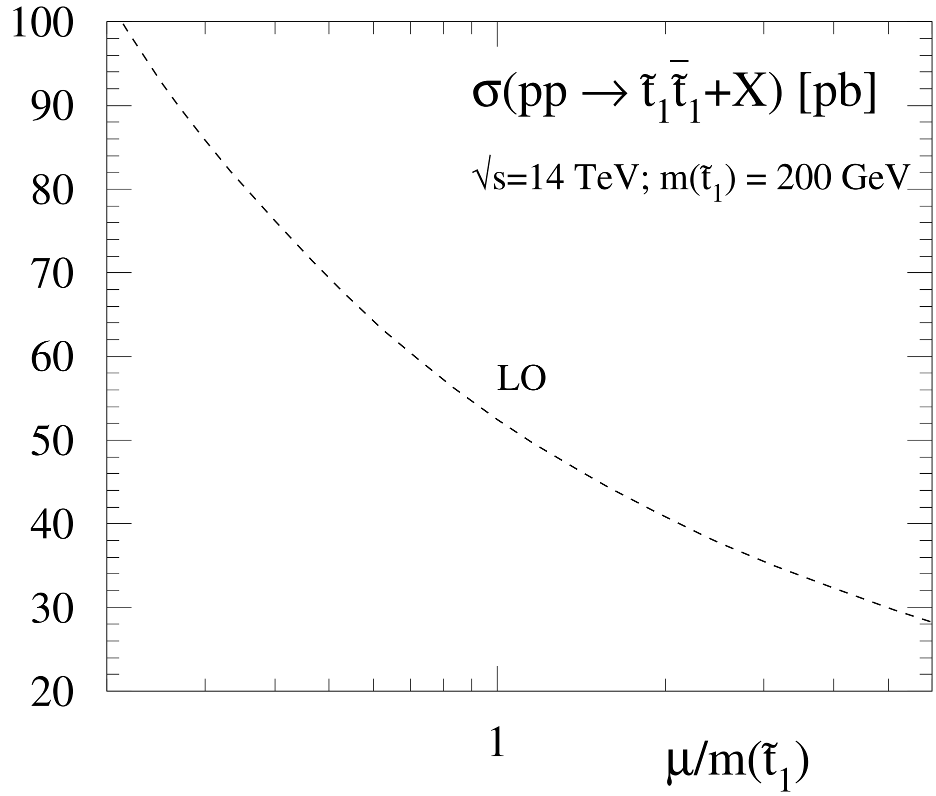
– sleptons $\quad pp \to \tilde{l}\tilde{l}$

– associated prod. $\quad pp \to \tilde{q}\tilde{\chi}, \tilde{g}\tilde{\chi}$

- LO cross sections:

G.L. Kane and J.P. Leveillé, 1982
P.R. Harrison and C.H. Llewellyn Smith, 1983
E. Reya and D.P. Roy, 1985
S. Dawson, E. Eichten and C. Quigg, 1985
H. Baer and X. Tata, 1985

renormalization/factorization scale dependence




$\rightarrow$ theoretical uncertainty $\approx 60\%$ at LO

$\Rightarrow$ must include NLO corrections

# Top squark production

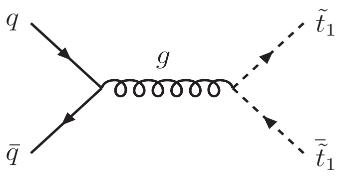
$\widetilde{t}_L, \widetilde{t}_R$ mix to form mass states $\widetilde{t}_1, \widetilde{t}_2$

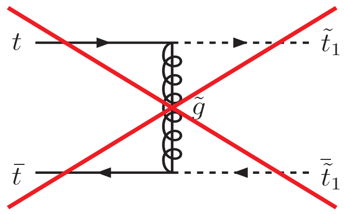
$\rightarrow$ potentially small stop masses

$\rightarrow$ potentially large cross sections at the Tevatron/LHC

- LO parton reactions

$$q + \bar{q} \rightarrow \widetilde{t}_i + \bar{\widetilde{t}}_i \quad (i = 1, 2)$$

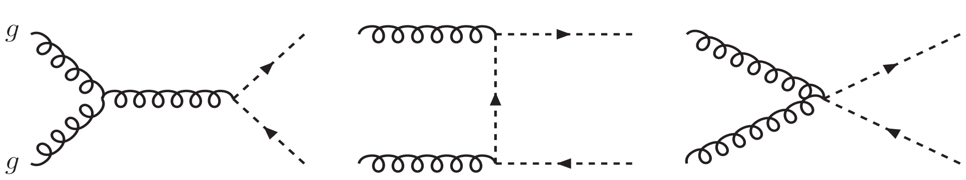



$$\hat{\sigma}_{\mathrm{LO}}[q\bar{q}] = \frac{\alpha_s^2 \pi}{s} \frac{2}{27} \beta^3 \qquad (\beta^2 = 1 - 4m^2/s)$$

$$\left( \begin{array}{l} \text{c.f. top production:} \quad \hat{\sigma}_{\mathrm{LO}}[q\bar{q}] \approx \frac{\alpha_s^2 \pi}{s} \frac{12}{27} \beta \\ \rightarrow \sigma^{\mathrm{top}}/\sigma^{\mathrm{stop}} \sim 10 \quad \text{at the Tevatron} \end{array} \right)$$

$$g + \bar{g} \rightarrow \widetilde{t}_i + \bar{\widetilde{t}}_i \quad (i = 1, 2)$$

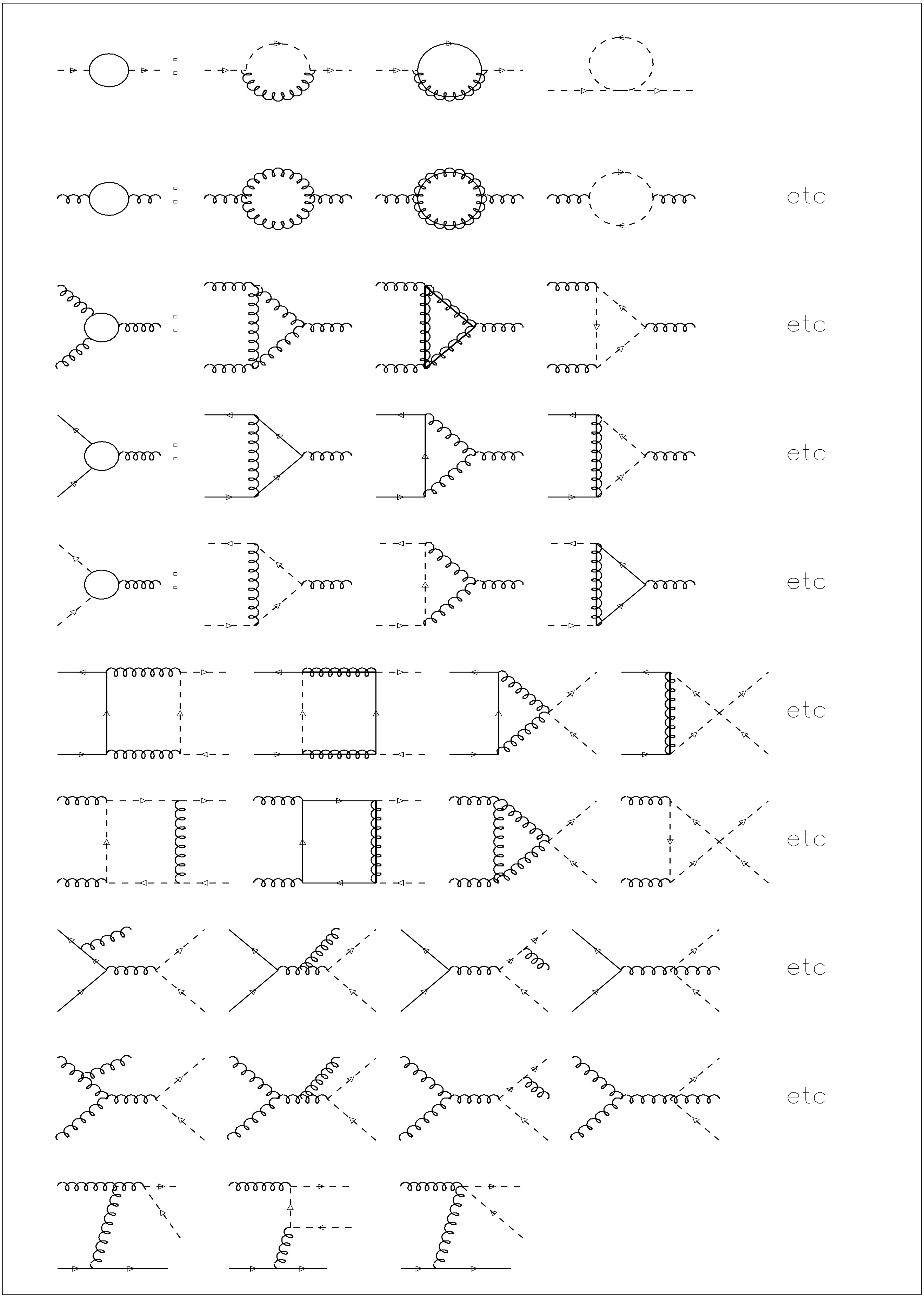



$$\hat{\sigma}_{\mathrm{LO}}[gg] = \frac{\alpha_s^2 \pi}{s} \left[ \beta \left( \frac{5}{48} + \frac{31m^2}{24s} \right) + \left( \frac{2m^2}{3s} + \frac{m^4}{6s^2} \right) \log \frac{1-\beta}{1+\beta} \right]$$

$\Rightarrow$ no MSSM parameter dependence

• SUSY-QCD corrections (generic diagrams)

[Beenakker, MK, Plehn, Spira, Zerwas; Nucl. Phys. B 515 (98)]



- NLO corrections:

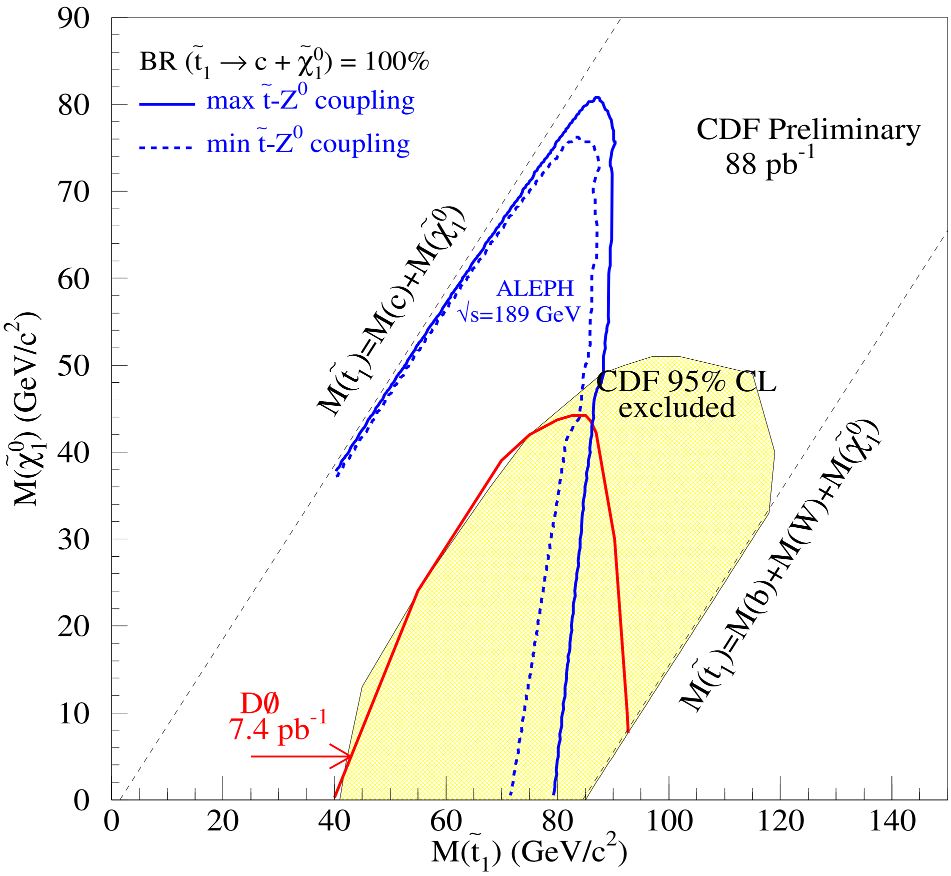
  improve accuracy of cross section prediction

  - reduced scale dependence $\lesssim 15\%$ $\rightarrow$ Figure
  - $K$ factors $\rightarrow$ Figure

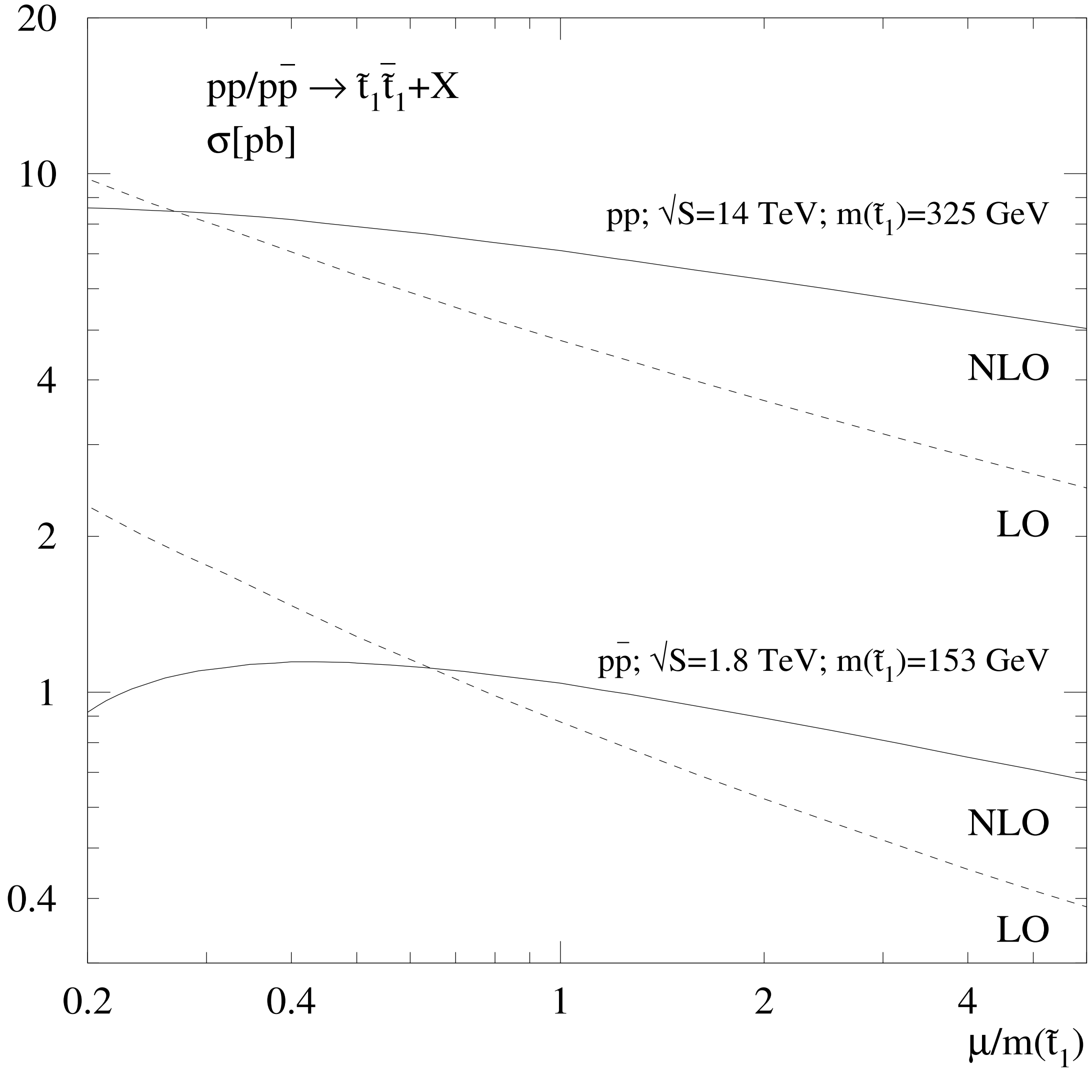
$$\Rightarrow \quad \text{improved} \quad \left\{ \begin{array}{l} \text{exclusion limits} \\ \text{mass determination} \end{array} \right.$$

- Example: stop search in $\tilde{t}_1 \rightarrow c + \tilde{\chi}_1^0$ decays

  (CDF Collaboration, FERMILAB-PUB-99/340-E)

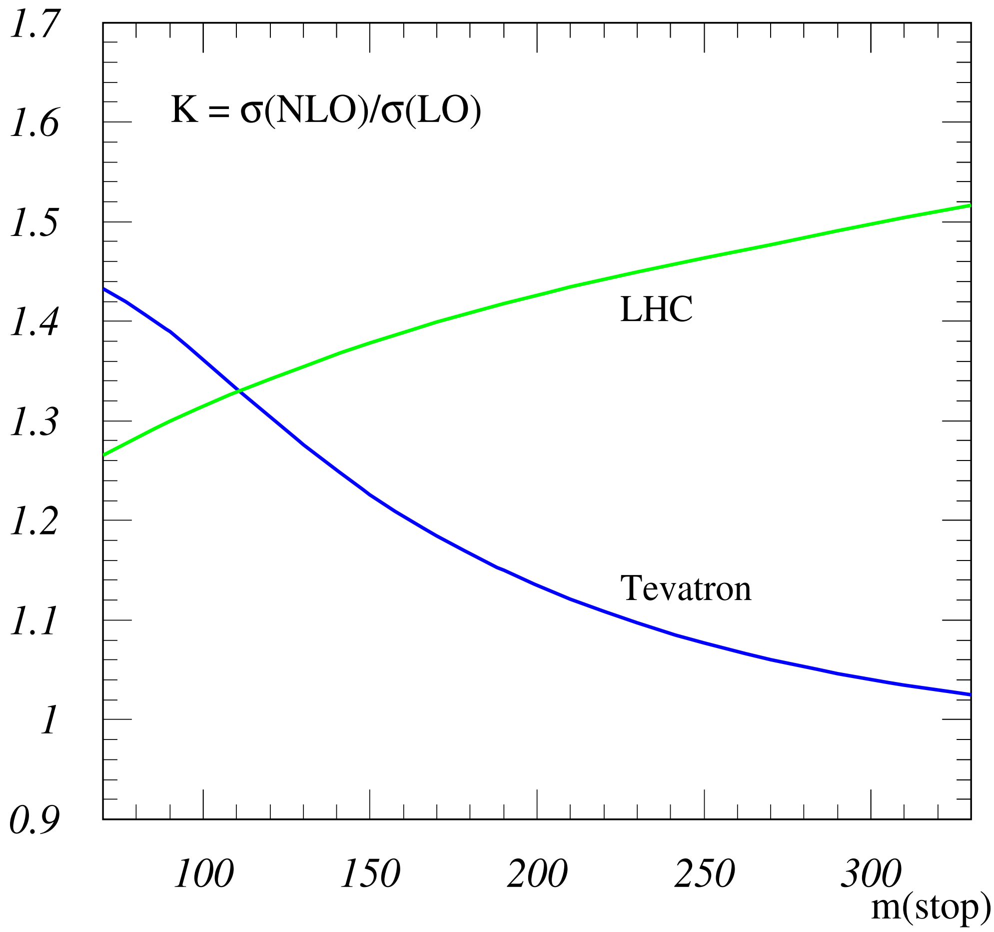


# Scale Dependence




→ significantly reduced in NLO

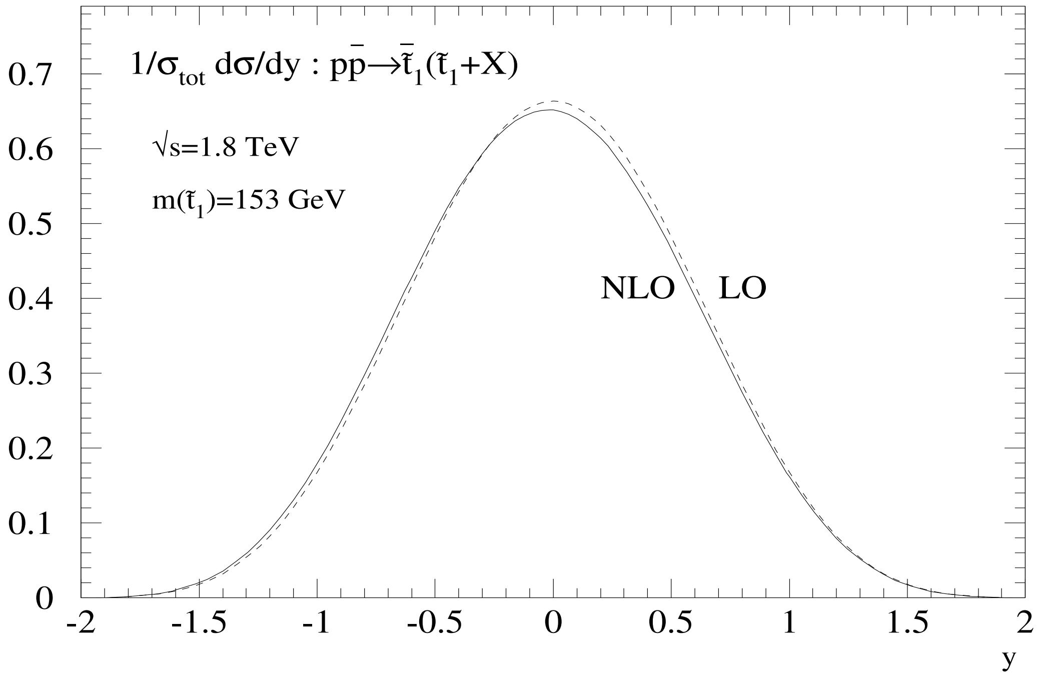
# $K$ factor



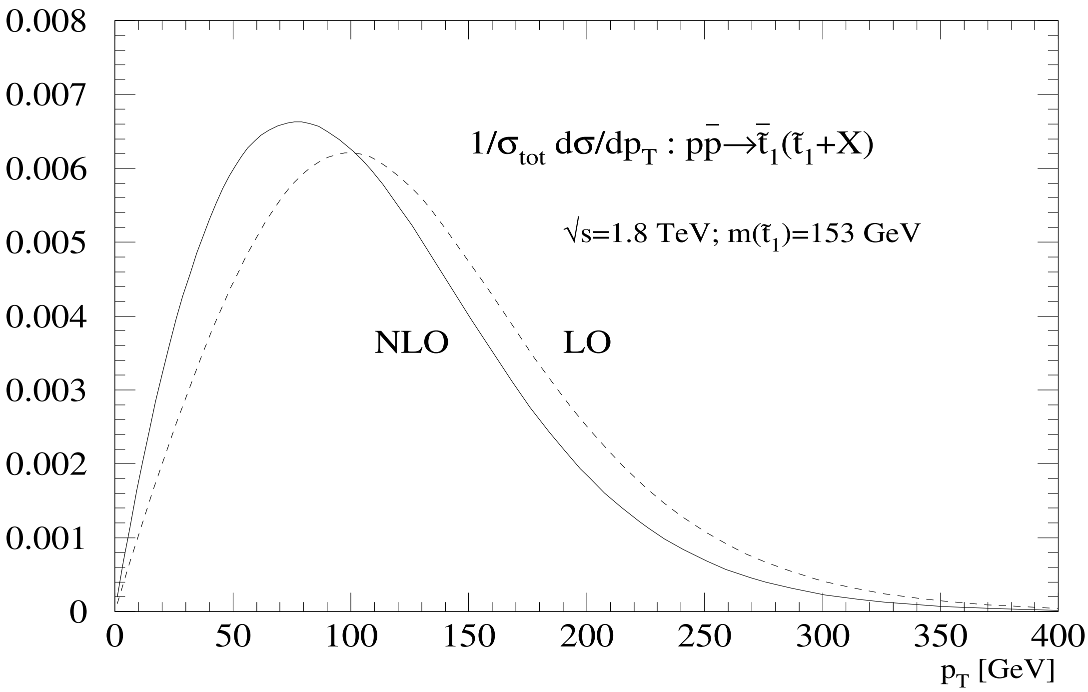

$$K = \begin{cases} 1 - 1.4 & \text{Tevatron} \\ 1.3 - 1.5 & \text{LHC} \end{cases}$$

# Differential Cross Sections

## rapidity



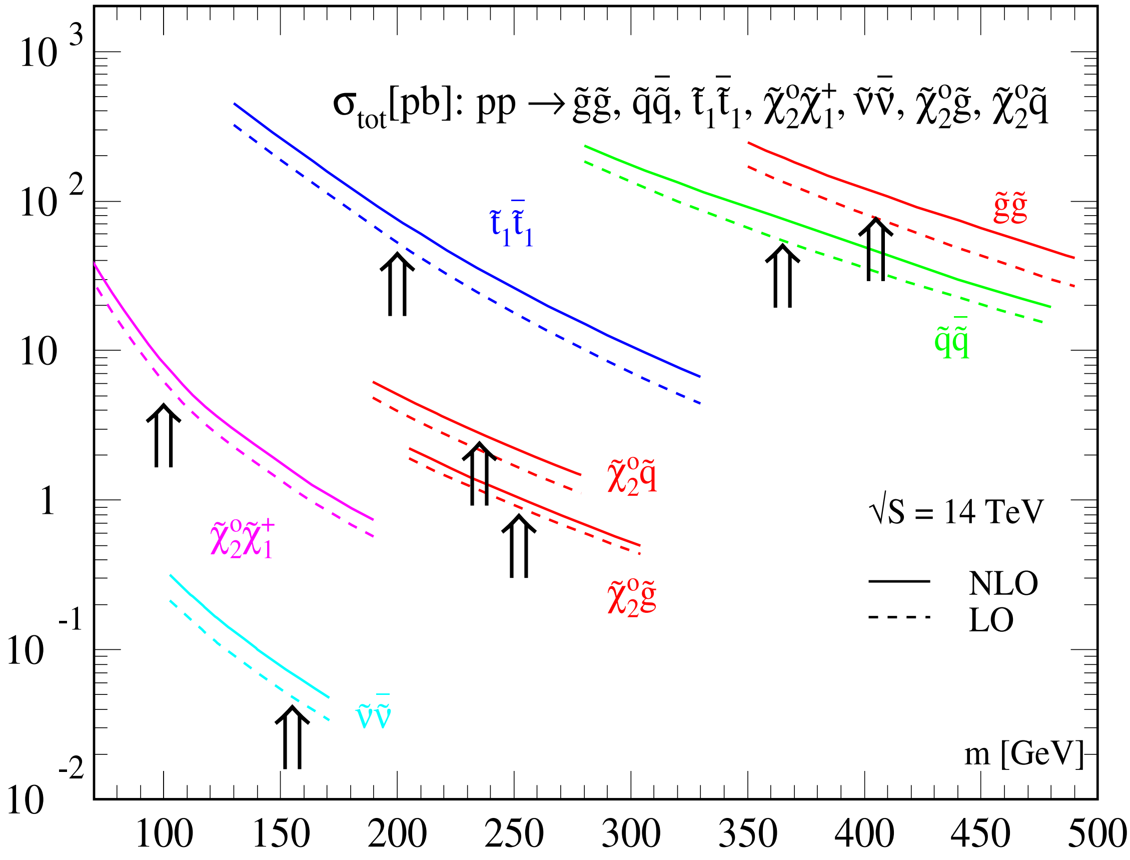

## transverse momentum




- rapidity distribution similar in LO and NLO
- $p_t$ distribution shifted to smaller $p_t$ in NLO

# MSSM Particle Production at the LHC

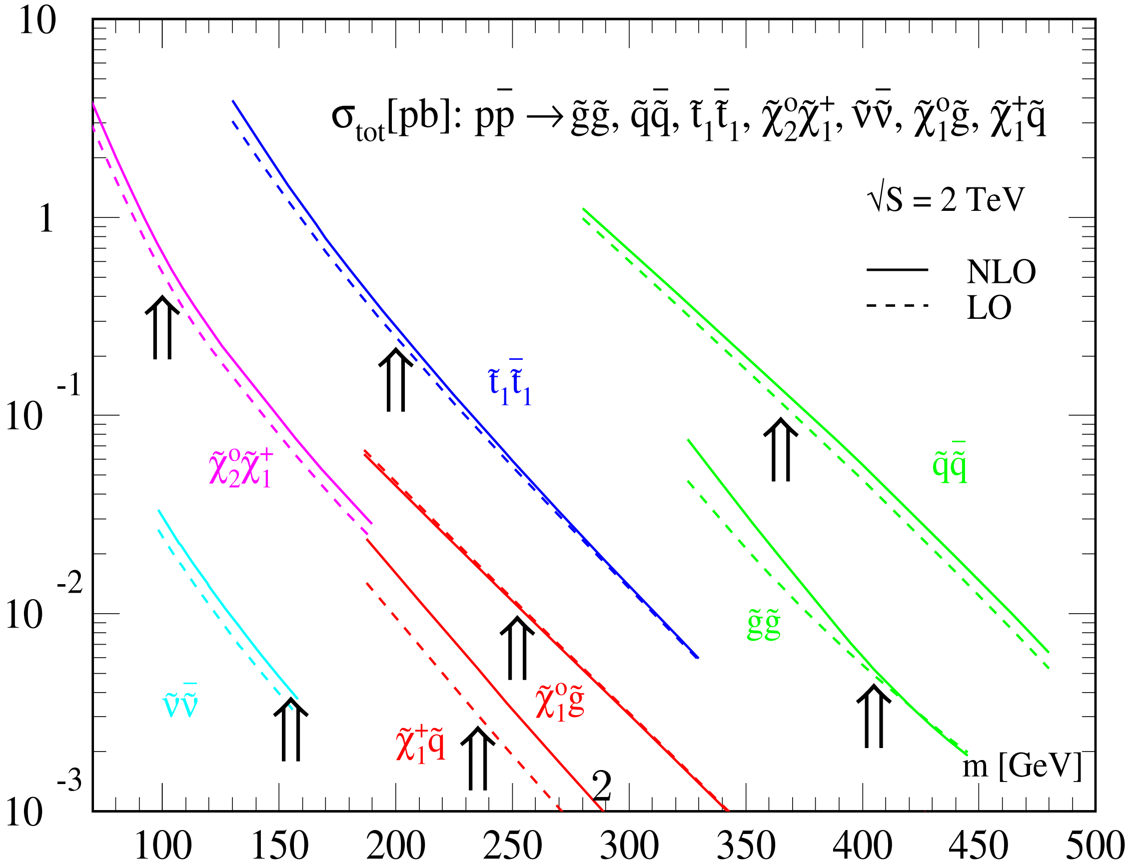
– squarks & gluinos
  Beenakker, Höpker, Spira, Zerwas, PRL 74 (95), NPB 492 (97)
– stops
  Beenakker, MK, Plehn, Spira, Zerwas, NPB 515 (98)
– gauginos
  Beenakker, Klasen, MK, Plehn, Spira, Zerwas, PRL 83 (99)
– sleptons
  Baer, Hall, Reno (QCD), PRD 57 5871 (98)
  Beenakker, Klasen, MK, Plehn, Spira, Zerwas, PRL 83 (99)
– associated production
  Beenakker, MK, Plehn, Spira, Zerwas
  Berger, Klasen, Tait ($\tilde{\chi}\tilde{g}$), PRD 62 (00)




→ all results will be available in PROSPINO

[Beenakker, Höpker, MK, Plehn, Spira, Zerwas)

# MSSM Particle Production at the Tevatron



# Conclusions

- SM Higgs production
  - recent progress: $gg \to H$ at NNLO
    $gg/q\bar{q} \to t\bar{t}H$ at NLO
  - (N)NLO QCD corrections to all relevant production processes available
  - scale uncertainty $\lesssim 15\%$
  - more work needed on backgrounds
- MSSM Higgs production
  - theoretical description more involved
  - much work done, more in progress...
- SUSY particle production
  - NLO SUSY-QCD corrections to MSSM particle production available
  - scale uncertainty $\lesssim 15\%$
  - (all) results (will be) available in `PROSPINO`

We need to understand QCD to explore EWSB and to discover new physics at the LHC