Higgs boson production at Tevatron and LHC in the k_T-factorization approach

Artem Lipatov

D.V. Scobeltsyn Institute of Nuclear Physics
Moscow State University

in collaboration with N.P. Zotov (SINP MSU)

Content

- Introduction
- Higgs production cross section
- Numerical results
- Conclusions

Introduction

1. Inclusive Higgs production

- ✓ Dominant production mechanism at LHC is the gluon-gluon fusion
  F. Wilczek, Phys. Rev. Lett. **39**, 1304 (1977), H.M. Georgi, S.L. Glashow, M.E. Machacek, D.V. Nanopoulos, Phys. Rev. Lett. **40**, 692 (1978)

- ✓ Calculations can be significanly simplified in the large top mass limit
  J.R. Ellis, M.K. Gaillard, D.V. Nanopoulos, Nucl. Phys. B **106**, 292 (1976), M.A. Shifman, A.I. Vainstein, M.B. Voloshin, V.I. Zakharov, Yad. Fiz. **30**, 1368 (1979)

- ✓ Cross section known now up to NNLO accuracy
  R.V. Harlander, W.B. Kilgore, Phys. Rev. Lett. **88**, 201801 (2002), C. Anastasiou, K. Melnikov, Nucl. Phys. B **646**, 220 (2002), V. Ravindran, J. Smith, W.L. van Neerven, Nucl. Phys. B **665**, 325 (2003)

2. Higgs production in association with one or two jets

- ✓ Dominant production mechanisms at LHC is the gluon-gluon fusion and weak boson fusion (WBF)
  N. Kauer, T. Plehn, D. Rainwater, D. Zeppenfeld, Phys. Lett. B **503**, 113 (2001), T. Plehn, D. Rainwater, D. Zeppenfeld, Phys. Rev. D **61**, 093005 (2000), D. Rainwater, D. Zeppenfeld, JHEP **9712**, 005 (1997)

- ✓ Quite complicated calculations even at lowest order since heavy quark loops

  Higgs + one jet → triangle and box loops occur
  Higgs + two jet → pentagon loops occur

  N. Kauer, T. Plehn, D. Rainwater, D. Zeppenfeld, Phys. Lett. B **503**, 113 (2001), T. Plehn, D. Rainwater, D. Zeppenfeld, Phys. Rev. D **61**, 093005 (2000), D. Rainwater, D. Zeppenfeld, JHEP **9712**, 005 (1997)

3. Gluon-gluon fusion contribution to the Higgs production at LHC and Tevatron is strongly depended on the gluon density in the proton

$$x \sim \frac{m_H}{\sqrt{s}} \sim 0.008 << 1 \text{ for } m_H = 120 \text{ GeV}$$

i.e Higgs production at LHC is a typical k_T-factorization process

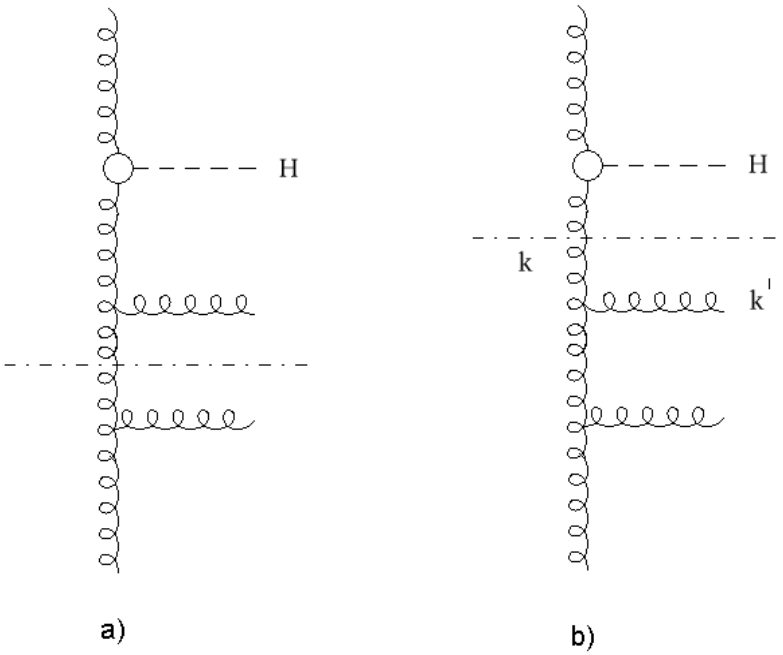
4. The k_T-factorization QCD approach

S. Catani, M. Ciafaloni, F. Hautmann, Nucl. Phys. B **366**, 135 (1991); S. Catani, F. Hautmann, Nucl. Phys. B **427**, 475 (1994); J.C. Collins, R.K. Ellis, Nucl. Phys. B **360**, 3 (1991)

- ✓ BFKL or CCFM evolution equations
  BFKL: E.A. Kuraev, L.N. Lipatov, V.S. Fadin, Sov. Phys. JETP **44**, 443 (1976); **45**, 199 (1977), Yu.Yu. Balitsky, L.N. Lipatov, Sov. J. Nucl. Phys. **28**, 822 (1978)
  CCFM: M. Ciafoloni, Nucl. Phys. B **296**, 49 (1988); S. Catani, F. Fiorani, G. Marchesini, Phys. Lett. B **234**, 339 (1990); S. Catani, F. Fiorani, G. Marchesini, Nucl. Phys. B **336**, 18 (1990); G. Marchesini, Nucl. Phys. B **445**, 49 (1995)

- ✓ The possibility to take into account ln $1/x$ contributions, not included in the collinear (DGLAP-based) calculations

- ✓ Inclusion a main part of the high-order collinear QCD corrections
  B. Andersson *et al.* (Small-x Collaboration), Eur. Phys. J. C **25**, 77 (2002)
  J. Andersen *et al.* (Small-x Collaboration), Eur. Phys. J. C **35**, 67 (2004)



- ✓ The possibility to investigate the semi-inclusive Higgs production rates in much more simpler way than it can be done in collinear factorization
- ✓ Incorporates already soft gluon resummation formulas
  A. Gawron, J. Kwiecinski, Phys. Rev. D **70**, 014003 (2004)

Higgs production cross section

1. The effective Lagrangian for the Higgs boson coupling to gluons reads

$$L_{eff} = \frac{\alpha_S}{12\pi}\left(G_F\sqrt{2}\right)^{1/2} G^a_{\mu\nu} G^{a\,\mu\nu} H$$

2. The triangle vertex for two off-shell gluons having four-momenta k_1 and k_2 can be easily obtained from the effective Lagrangian

$$T^{\mu\nu}(k_1,k_2) = i\delta^{ab}\frac{\alpha_S}{3\pi}\left(G_F\sqrt{2}\right)^{1/2}\left[k_2^\mu k_1^\nu - (k_1\cdot k_2)g^{\mu\nu}\right]$$

3. The off-shell matrix element for $g^* g^* \to H$ subprocess have simple form

$$\left|\overline{M}\right|^2 = \frac{\alpha_S^2}{576\pi^2} G_F\sqrt{2}\left(m_H^2 + p_T^2\right)\cos^2\phi$$

$$p_T^2 = k_{1T}^2 + k_{2T}^2 - 2k_{1T}k_{2T}\cos\phi$$

This expression differs from the one obtained by F. Hautmann
F. Hautmann, Phys. Lett. B **535**, 159 (2002)

4. The Higgs production cross section in the k_T-factorization approach can be written as

$$\frac{d\sigma}{dy} = \int \frac{\alpha_S^2}{288\pi}\frac{G_F\sqrt{2}}{x_1 x_2 m_H^2 s}\left(m_H^2 + p_T^2\right)^2 A\left(x_1,k_{1T}^2,\mu^2\right)A\left(x_2,k_{2T}^2,\mu^2\right)dk_{1T}^2\,dk_{2T}^2\,\frac{d\phi}{2\pi}\cos^2\phi$$

In the collinear limit this expression coincide with the well-known leading-order formula

$$d\sigma = \frac{\alpha_S^2}{576\pi}\frac{G_F\sqrt{2}}{x_1 x_2 m_H^2 s} m_H^2\, x_1 G\left(x_1,\mu^2\right) x_2 G\left(x_2,\mu^2\right) dy$$

Numerical results

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

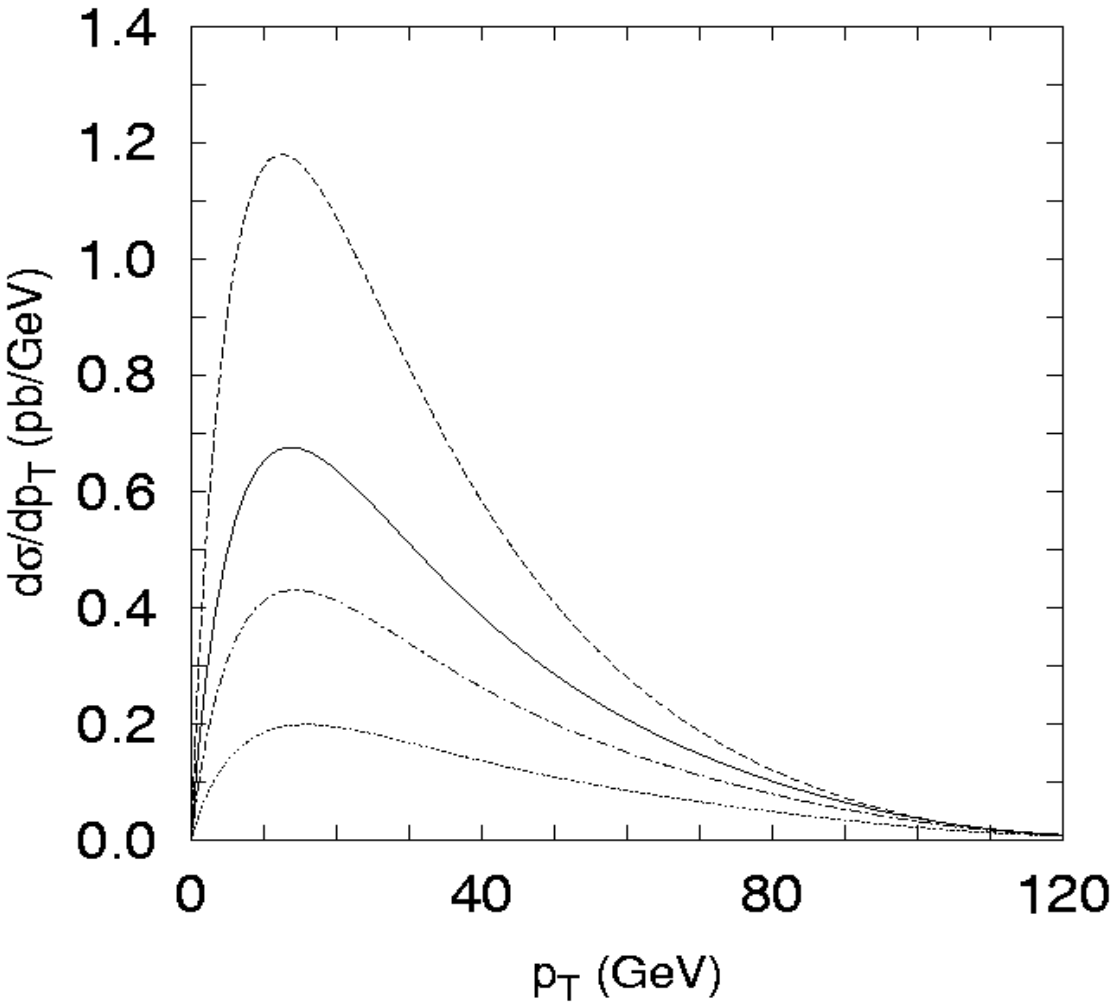


Figure 1. Differential cross section $d\sigma/dp_T$ for inclusive Higgs boson production at LHC. The solid, dashed, dash-dotted and dotted lines correspond $m_H = 125$ GeV, $m_H = 100$ GeV, $m_H = 150$ GeV (where WW decay channel is dominant) and $m_H = 200$ GeV (above WW and ZZ decay tresholds), respectively.

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

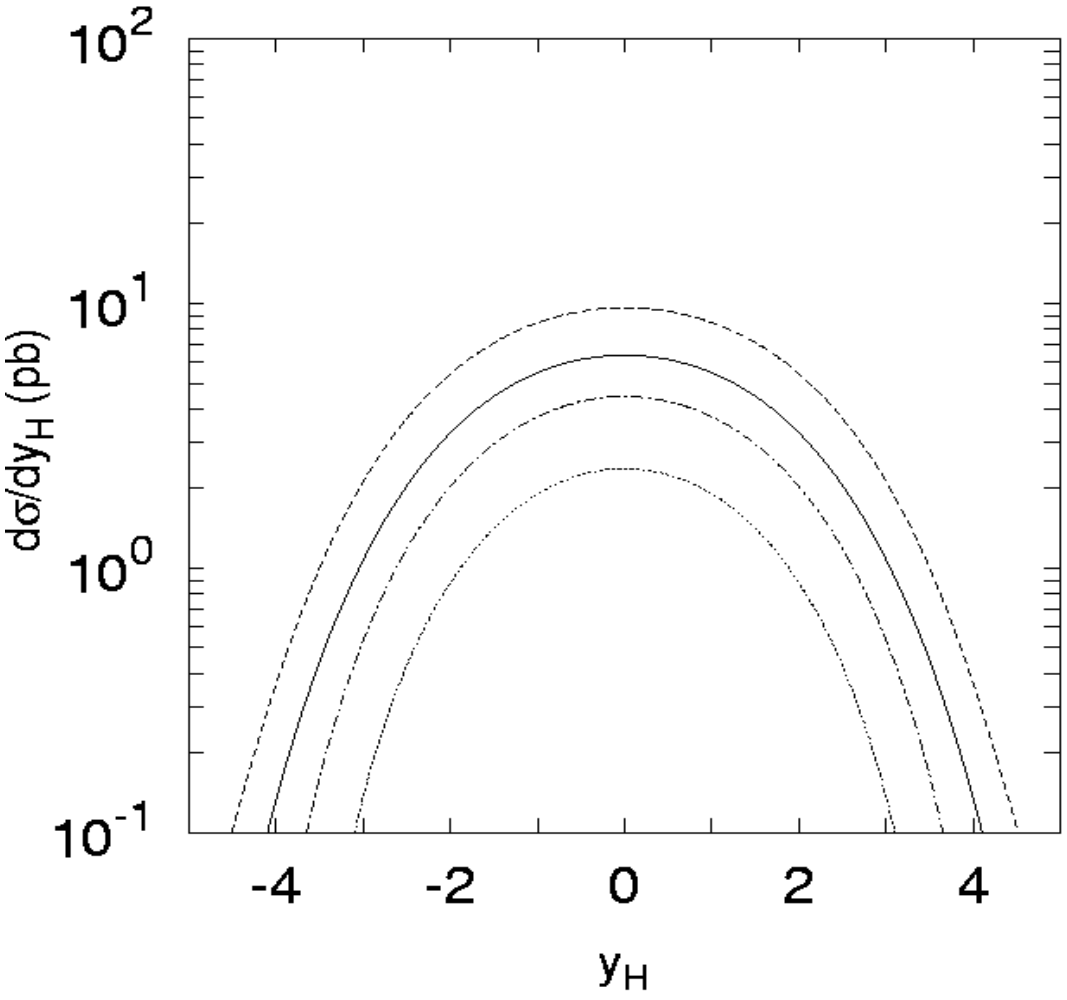


Figure 2. Differential cross section $d\sigma/dp_T$ for inclusive Higgs boson production at LHC. All curves are the same as in Figure 1.

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = \varsigma\, m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

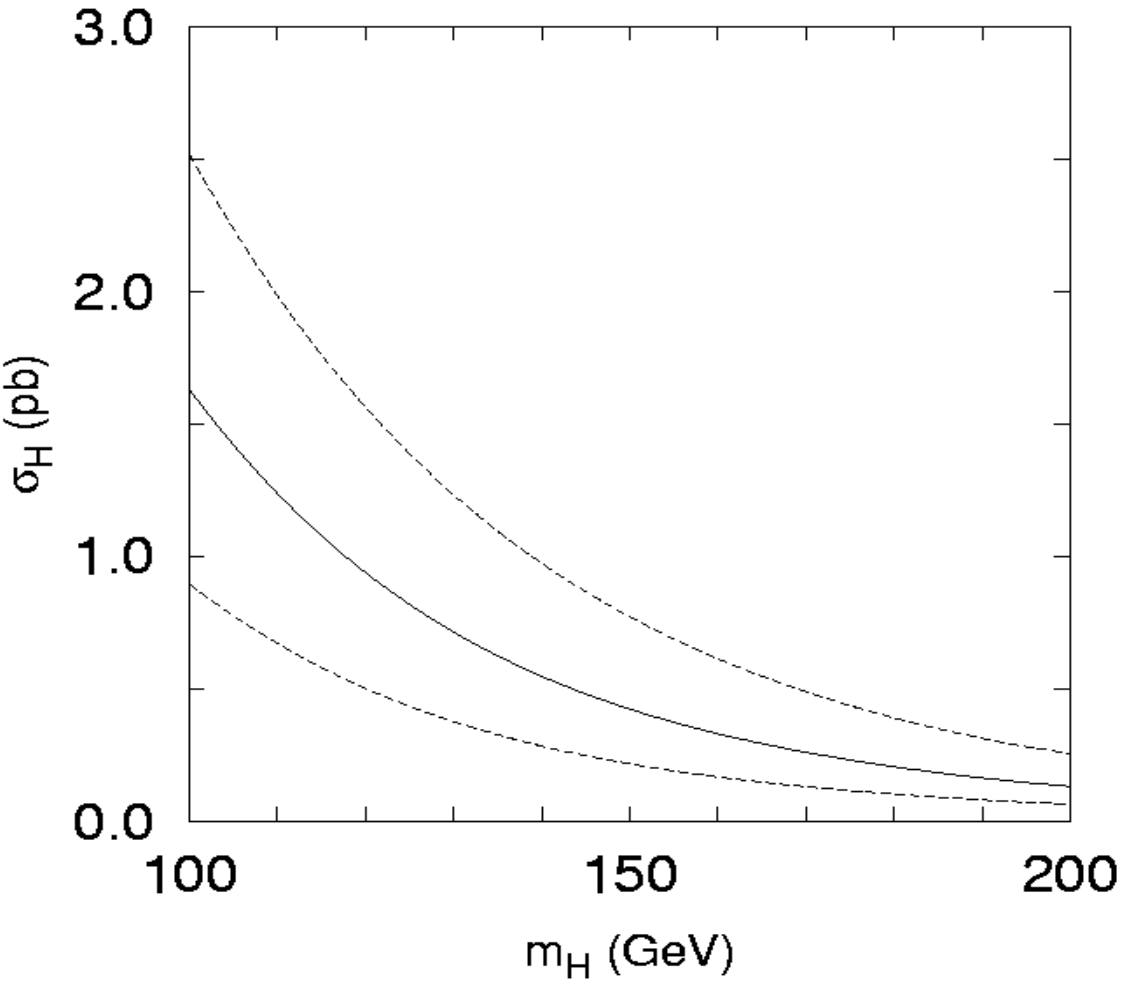


Figure 3. Total cross section of inclusive Higgs boson production as a function of Higgs mass at Tevatron. The solid line corresponds to the default scale $\mu = m_H$, whereas upper and lower dashed lines correspond to the $\mu = m_H/2$ and $\mu = 2m_H$ scales, respectively.

At $m_H = 120$ GeV $\sigma = 0.84$ pb.

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = \varsigma\, m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

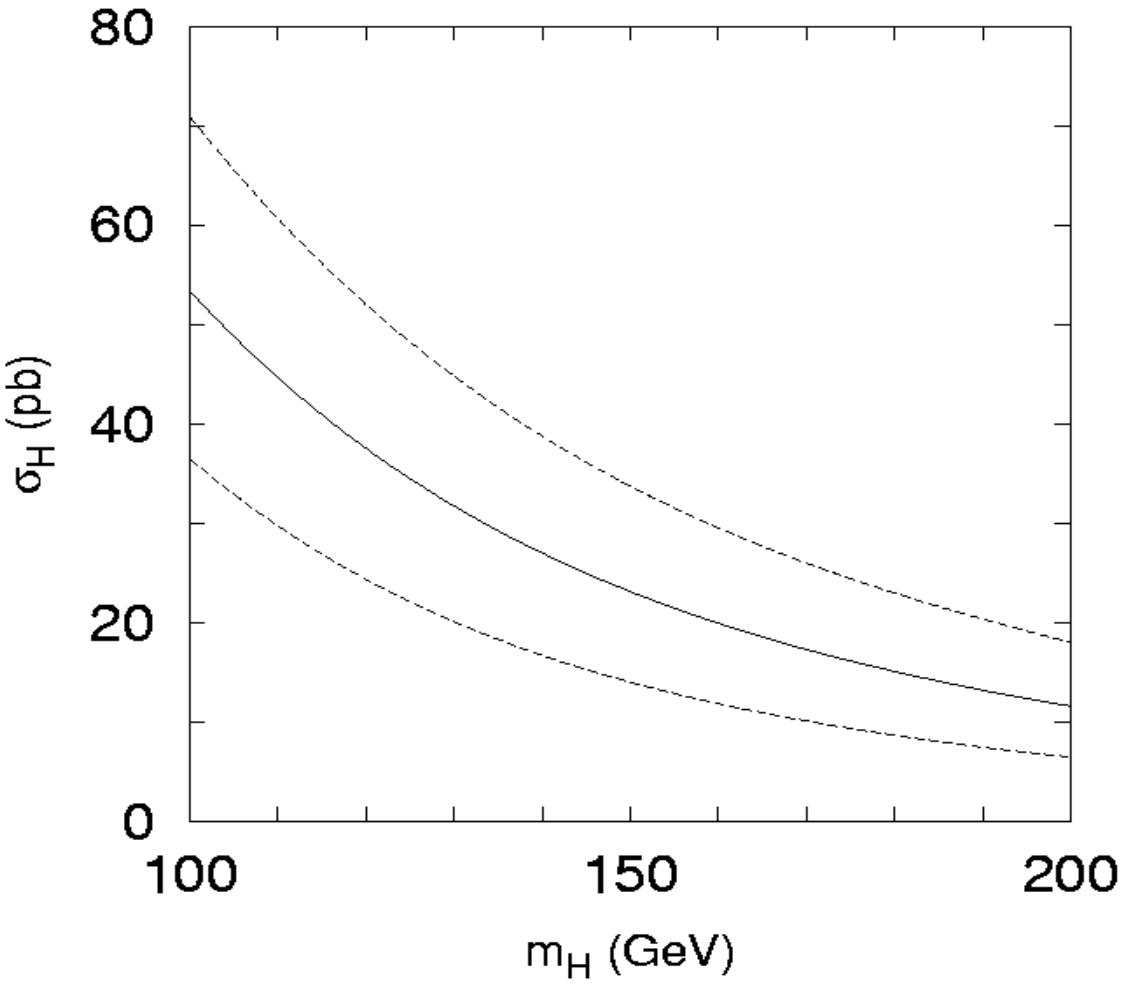


Figure 4. Total cross section of inclusive Higgs boson production as a function of Higgs mass at LHC. The solid line corresponds to the default scale $\mu = m_H$, whereas upper and lower dashed lines correspond to the $\mu = m_H/2$ and $\mu = 2m_H$ scales, respectively.

At $m_H = 120$ GeV $\sigma = 35.9$ pb.

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

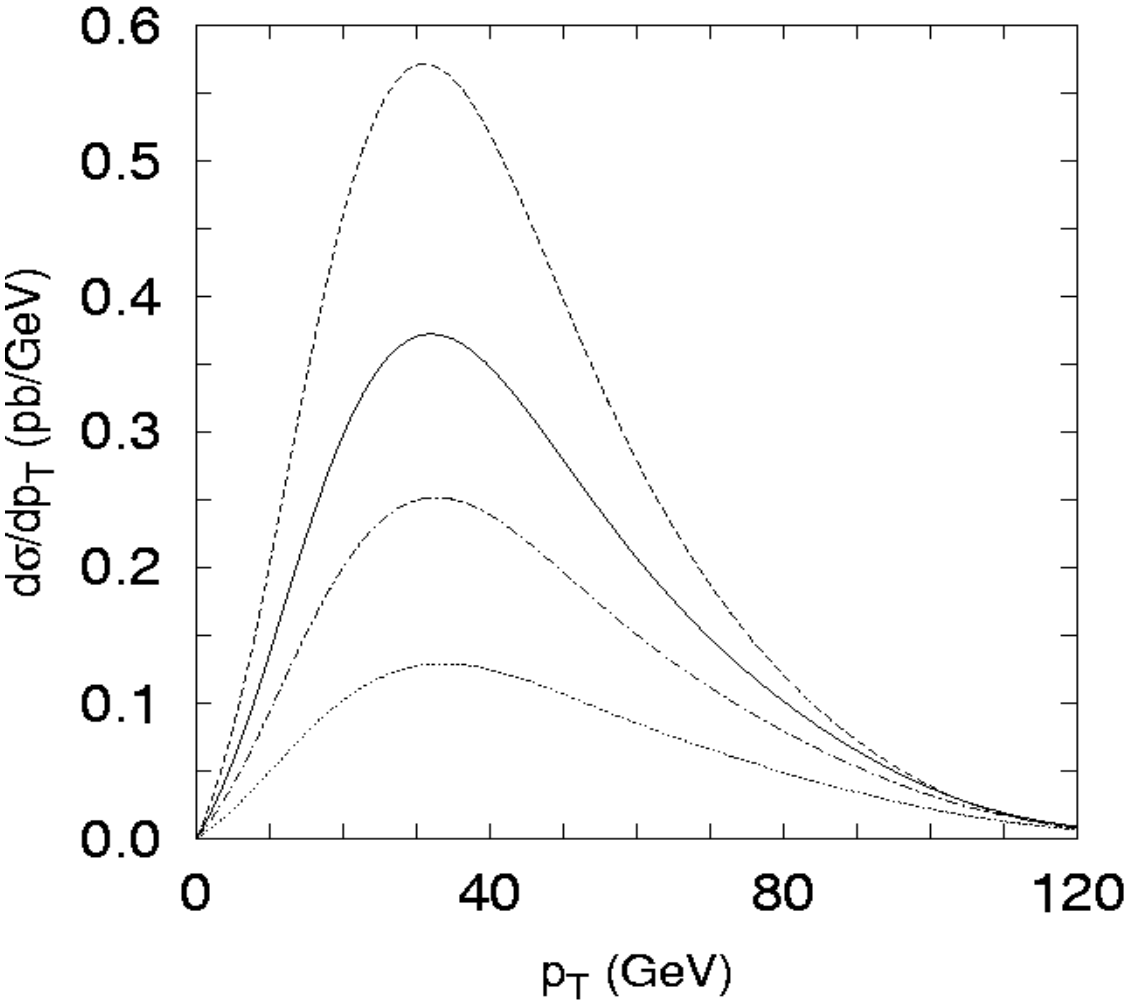


Figure 5. Differential cross section $d\sigma/dp_T$ for Higgs + one jet production at LHC. The solid, dashed, dash-dotted and dotted lines correspond $m_H = 125$ GeV, $m_H = 100$ GeV, $m_H = 150$ GeV (where WW decay channel is dominant) and $m_H = 200$ GeV (above WW and ZZ decay tresholds), respectively. The kinematical cut $p_T^{\rm jet} > 20$ GeV was applied.

- Unintegrated gluon density J2003 set 1
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)
- Factorization/renormalization scale $\mu = m_H$
- One loop strong coupling constant α_S with $n_f = 4$ and $\Lambda_{\rm QCD} = 200$ MeV

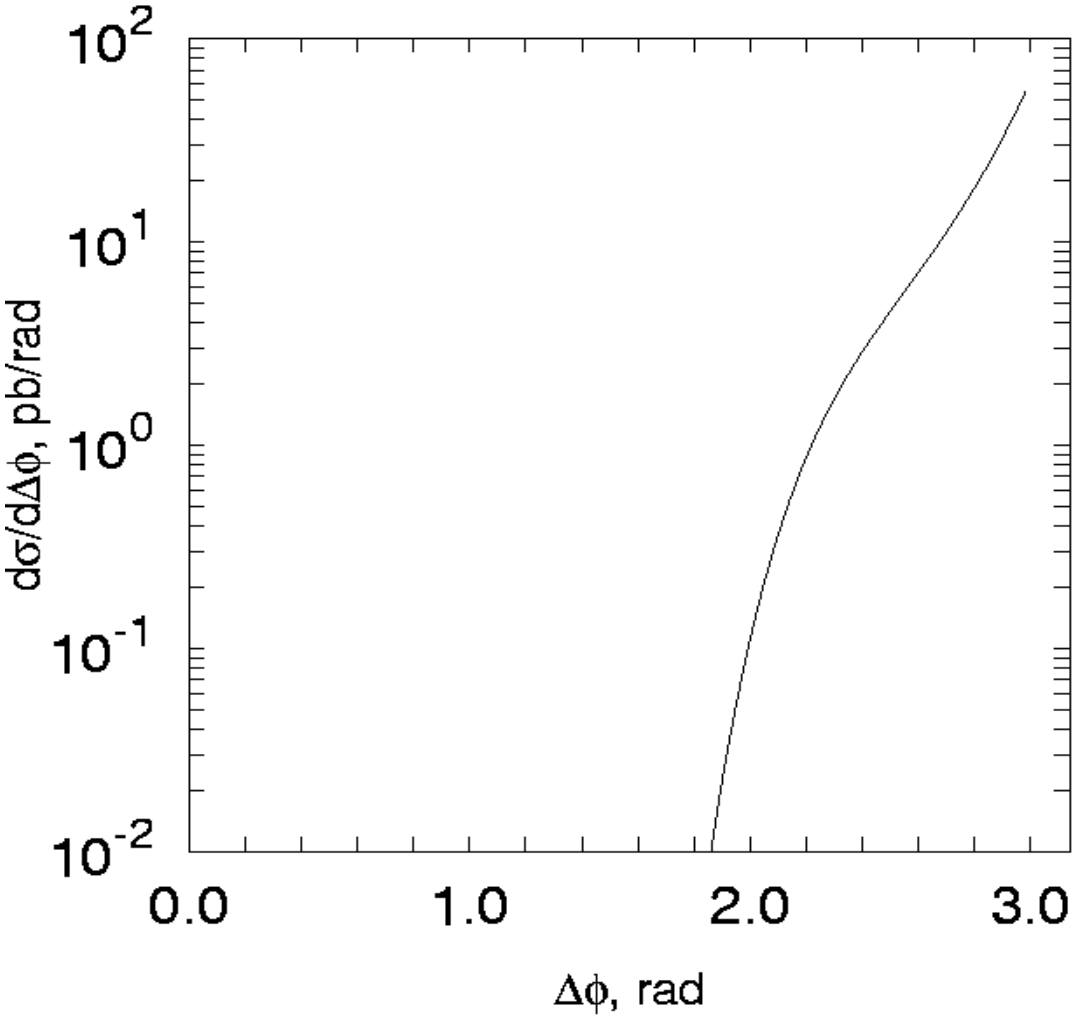


Figure 6. The Higg-jet azimutal angle distribution in the Higgs boson + one jet production atLHC. The kinematical cut $p_T^{\rm jet} > 20$ GeV was applied.

- Unintegrated gluon density J2003 set 1 and set 2
  H. Jung, Mod. Phys. Lett. A **19**, 1 (2004)

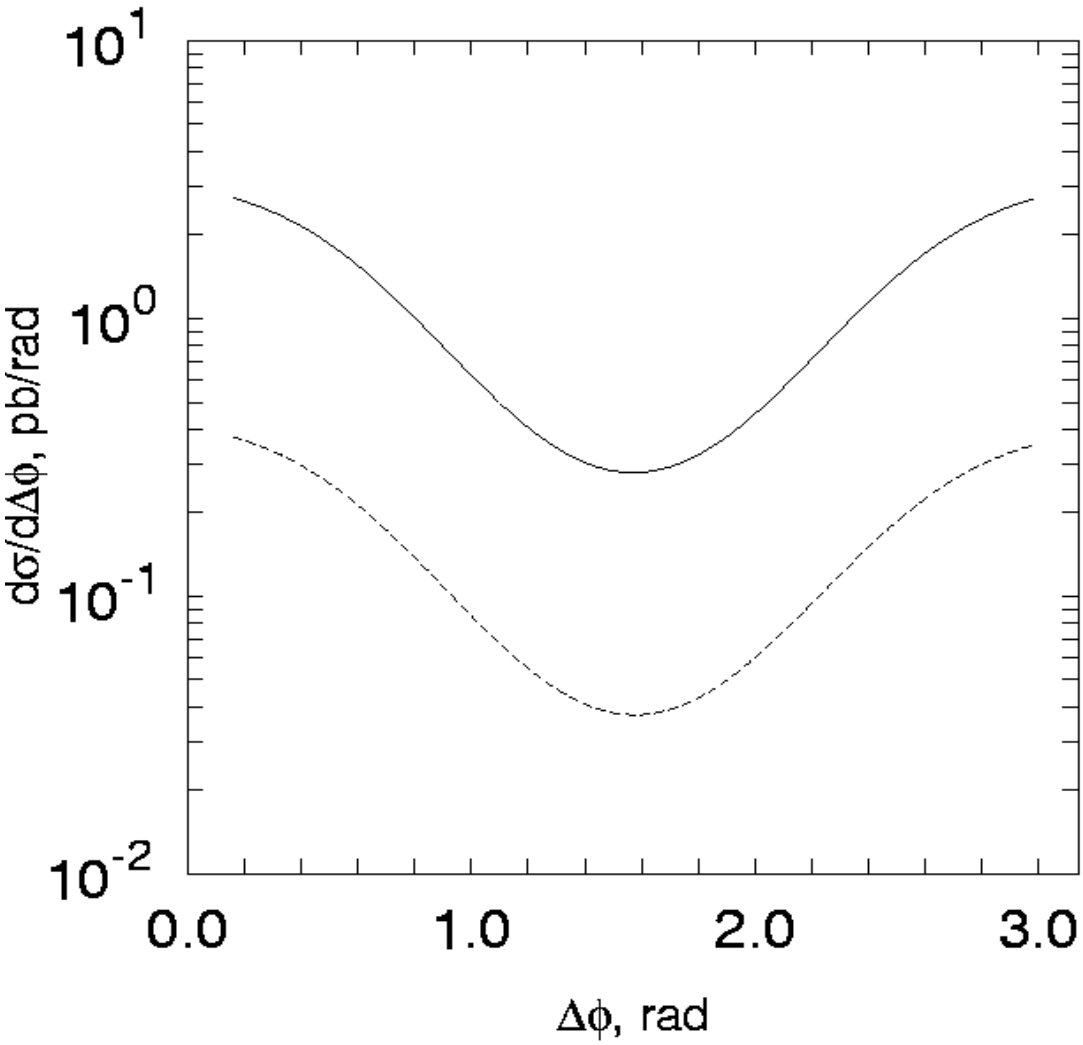


Figure 7. The jet-jet azimutal angle distribution in the Higgs boson + two jet production at LHC. The kinematical cut $p_T^{\text{jet}} > 20$ GeV was applied for both jets. Solid and dashed lines correspond to the J2003 set 1 and J2003 set 2 unintegrated gluon distributions, respectively.

We reproduce easily results of the cumbersome collinear pQCD calculations
V. Del Duca, W. Kilgore, C. Olear, C. Schmidt, D. Zeppenfeld, Nucl. Phys. B **616**, 367 (2001), Phys. Rev. D **67**, 073003 (2003).

Conclusions

- We have studied Higgs boson production via gluon-gluon fusion at Tevatron and LHC with k_T-factorization
- We demonstrate that k_T-factorization gives a possibility to investigate the associated Higgs boson and jets production in much more simple manner, than it can be done in the collinear factorization
- We find that k_T-factorization formalism gives the very similar to NNLO collinear pQCD results for the inclusive Higgs production total cross sections
- The k_T-factorization approach reproduces main features of the collinear high-order pQCD calculations for the Higgs + jets production
- We demonstrate the importance of the high-order correction within the k_T-factorization approach. These corrections should be developed and taken into account in the future applications
- The experimental study of such processes at LHC will give important information about non-collinear gluon evolution dynamics