Inclusive Higgs boson production at LHC within the k_T-factorization approach

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Introduction

The recent discovery of Higgs boson is a triumph of the Glashow-Salam-Weinberg theory of electroweak interactions and simultaneously marks the commencement of a new era in high-energy physics.

The subprocess of gluon–gluon fusion, $gg \to H$, is the basic mechanism of inclusive Higgs boson production in proton–proton collisions at the LHC energy. Dominant contribution to the respective cross section comes from diagrams that involve a triangle loop of heavy (primarily t) quarks.

In the conventional collinear QCD approach good description of the Higgs boson production is only achieved if higher orders diagrams are taken into account.

Introduction

Higgs boson production in the k_T-factorization approach has been intensively studied in the last decade:

- 2005: the process was investigated in [Lipatov, Zotov, Eur.Phys.J. **C44**, 559], p_T-distributions were presented. Good description is achieved in the lowest perturbative order!
- 2006: finite m_t-mass was correctly introduced in [Pasechnik, Teryaev, Szczurek, Eur.Phys.J. **C47**, 429].
- 2011: the k_T-factorization formula for Higgs production was rigorously proven ([Sun, Xiao, Yan, Phys. Rev. D84, 094005 (2011)], see also a review by Boer, arxiv:1502.00899 [hep-ph] and references therein)

Introduction

Recently the ATLAS Collaboration has reported first measurements of the Higgs boson differential cross sections in the diphoton decay mode. In particular, the distributions with respect to the diphoton transverse momentum p_T, rapidity y and helicity angle $|\cos \theta^*|$ have been presented.

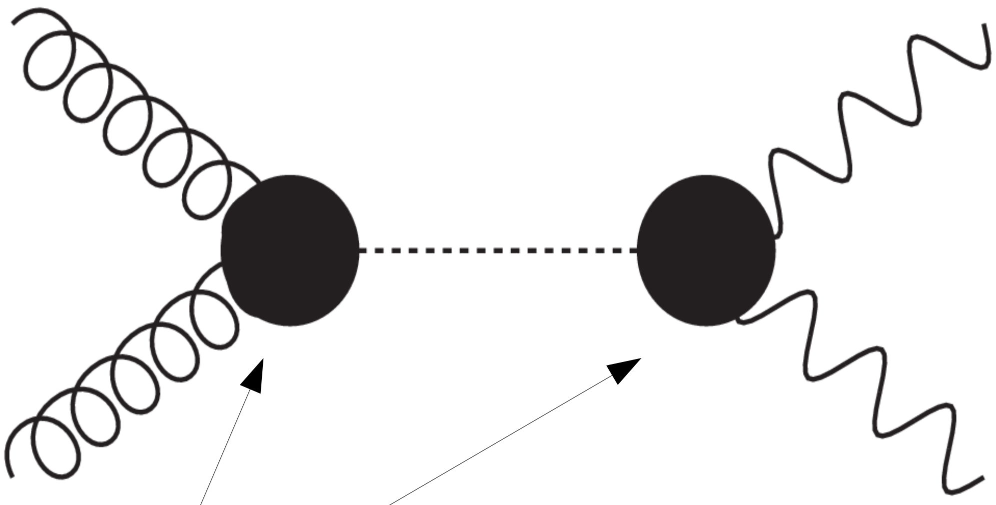
Here we for the first time in the k_{T}-factorization approach describe those experimental data.

k_T-factorization approach

1. Unintegrated (or TMD) parton distributions
2. Matrix elements which depend on the transverse momenta of incoming gluons.

Off-shell matrix element

$$g^*g^* \to H \to \gamma\,\gamma$$



Effective vertices
(t-quark loops, $m_t \to \infty$; for diphoton production — also W-loops)

Effective vertices

The effective lagrangian for the gluon fusion subpocess $gg \to H$ in the limit $m_t \to \infty$ takes the form:

$$\mathcal{L} = \frac{\alpha_s}{12\pi}(G_F\sqrt{2})^{1/2} G^a_{\mu\nu} G^{a\mu\nu} H$$

The effective vertex:

$$T^{\mu\nu,ab}_{ggH}(k_1,k_2) = i\delta^{ab}\frac{\alpha_s}{3\pi}(G_F\sqrt{2})(k_2^\mu k_1^\nu - (k_1k_2)g^{\mu\nu})$$

Effective vertices

For the decay $H \to \gamma\gamma$ one has:

$$\mathcal{L} = \frac{\alpha_s}{8\pi}\mathcal{A}(G_F\sqrt{2})^{1/2}F^{\mu\nu}F_{\mu\nu}H$$

$$T^{\mu\nu}_{\gamma\gamma H}(p_1, p_2) = i\frac{\alpha}{2\pi}(G_F\sqrt{2})(p_2^\mu p_1^\nu - (p_1p_2)g^{\mu\nu})$$

where

$$\mathcal{A} = \mathcal{A}_W(m_H^2/4m_W^2) + N_c\sum_f Q_f^2\mathcal{A}_f(m_H^2/4m_W^2)$$

$$\mathcal{A}_f(\tau) = 2[\tau + (\tau - 1)f(\tau)]/\tau^2$$

$$\mathcal{A}_W(\tau) = -[2\tau^2 + 3\tau + 3(2\tau - 1)f(\tau)]/\tau^2$$

$$f = \begin{cases} \arcsin^2(\sqrt{\tau}), & \tau \le 1; \\ -\frac{1}{4}\left[\log\frac{1+\sqrt{1-1/\tau}}{1+\sqrt{1-1/\tau}} - i\pi\right]^2, & \tau > 1. \end{cases}$$

Cross section

$$\overline{|\mathcal{M}|}^2 = \frac{1}{1152\pi^4}\alpha^2\alpha_S^2 G_F^2 |\mathcal{A}|^2 \frac{\hat{s}^2(\hat{s}+\mathbf{p}_T^2)^2}{(\hat{s}-m_H^2)^2+m_H^2\Gamma_H^2}\cos^2\phi$$

$$\sigma = \int \frac{\overline{|\mathcal{M}|}^2}{16\pi(x_1x_2s)^2} f_g(x_1,\mathbf{k}_{1T}^2,\mu^2) f_g(x_2,\mathbf{k}_{2T}^2,\mu^2) d\mathbf{p}_{1T}^2 d\mathbf{k}_{1T}^2 d\mathbf{k}_{2T}^2 dy_1 dy_2 \frac{d\phi_1}{2\pi}\frac{d\phi_2}{2\pi}$$

Unintegrated parton distributions

1. KMR approach(Kimber, Martin, Ryskin) [M.A. Kimber, A.D. Martin, M.G. Ryskin, 2001; G. Watt, A.D. Martin, M.G. Ryskin, 2003]. The TMD distributions are obtained from the conventional collinear ones.

2. CCFM unintegrated distributions

[H. Jung, 2004; M. Deak, H. Jung, K. Kutak, 2008]. Numerical solutions of CCFM equation. The starting distribution is chosen to satisfy proton structure function $F_2(x, \mu^2)$. Two sets of parameters describe $F_2(x, \mu^2)$ equally well. We use just one of them (so called A0 set).

Parameters

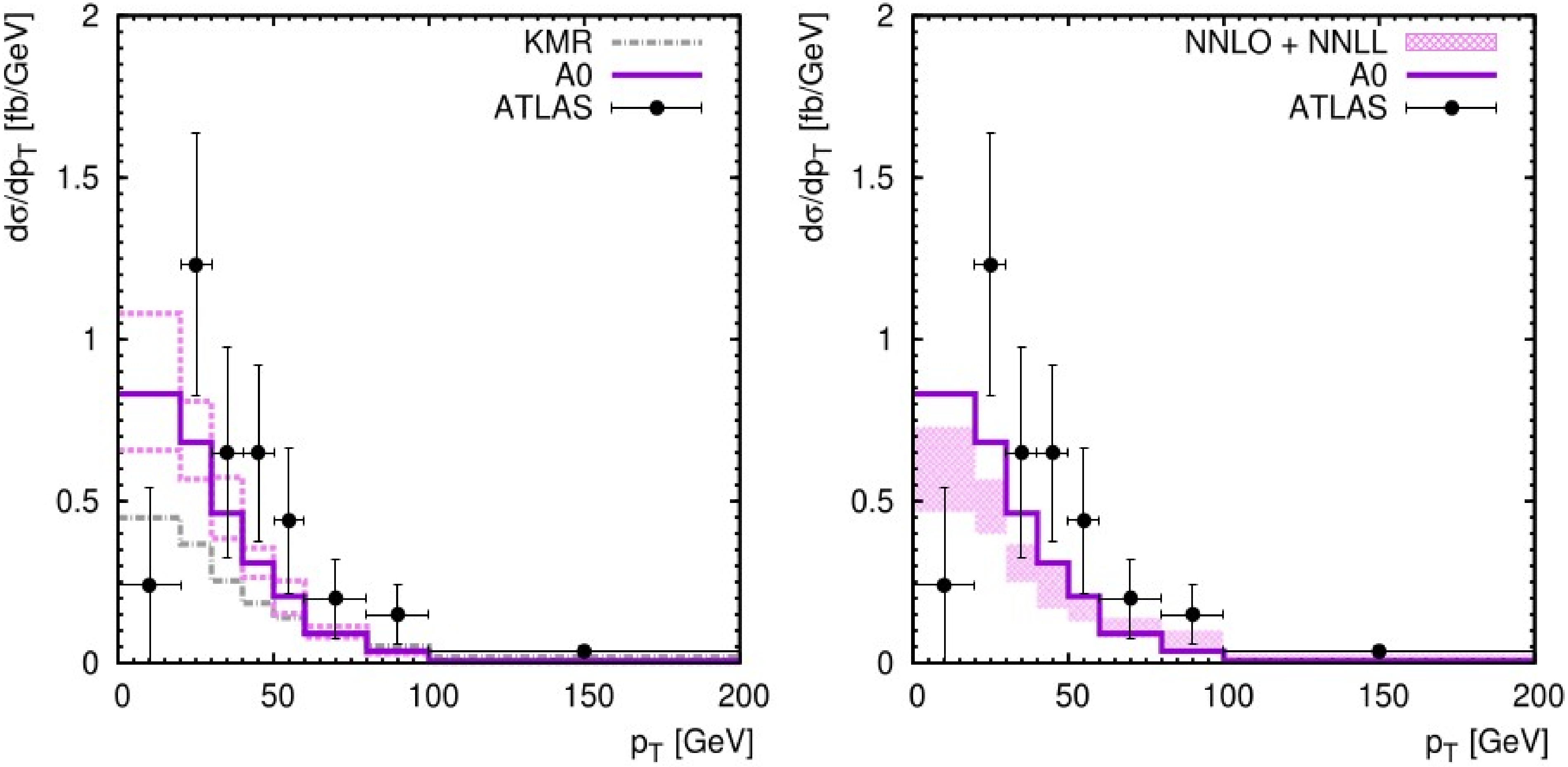
- Theoretical uncertainties are connected with the choice of the factorization and renormalization scales. We took $\mu_R = \mu_F = \mu = \xi m_H$. We varied the scale parameter ξ between $1/2$ and 2 about the default value $\xi = 1$.

- We set m_H=126.8 GeV and Γ_H=4.3 MeV

- For completeness, we use LO formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavors at $\Lambda_{QCD} = 200$ MeV. Also we use running QED coupling constant $\alpha(\mu^2)$.

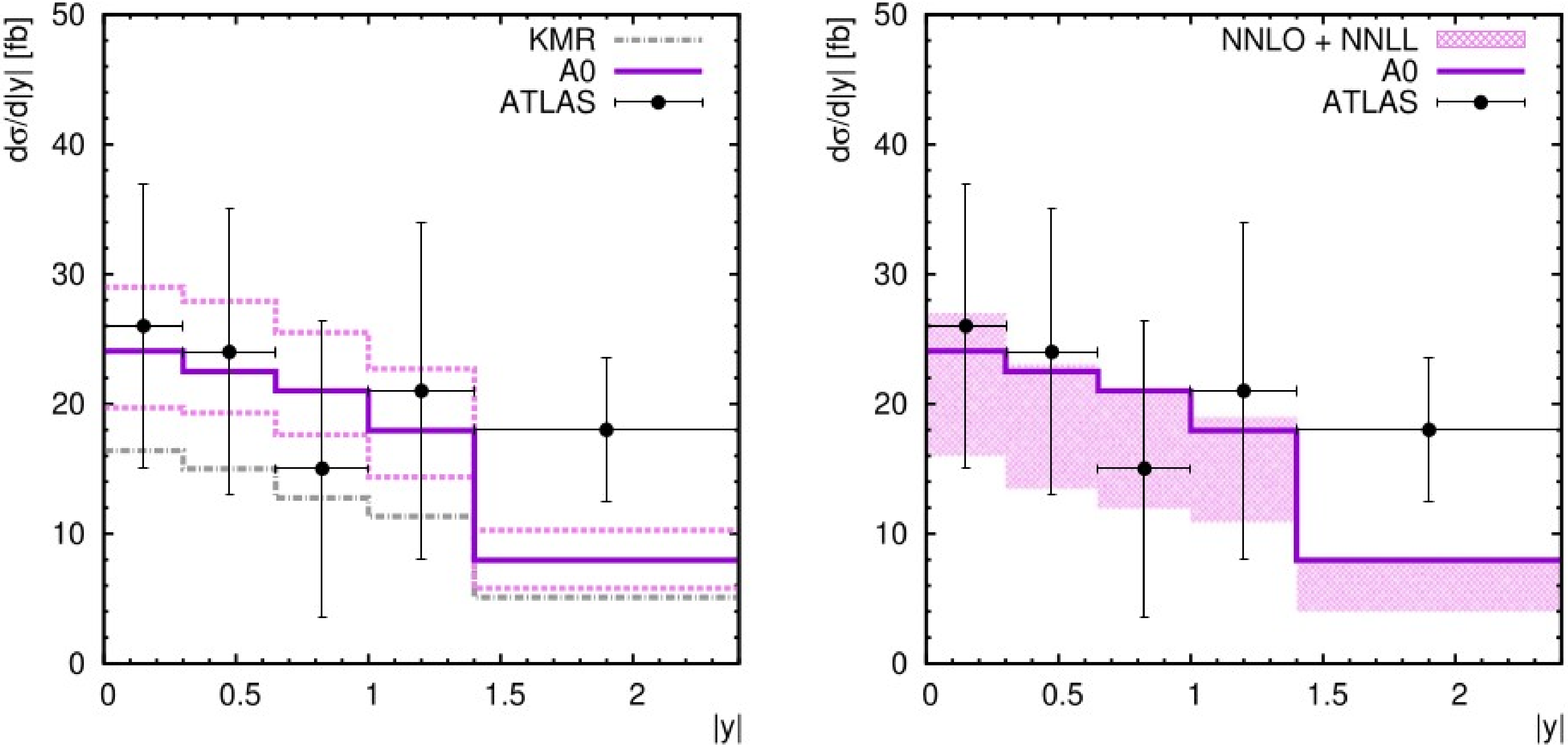
Numerical results

1. The differential cross section of the Higgs boson production in *pp* collisions at the LHC as a function of diphoton transverse momentum. Dashed histograms on the left panel show the scale variations of CCFM A0-based calculations



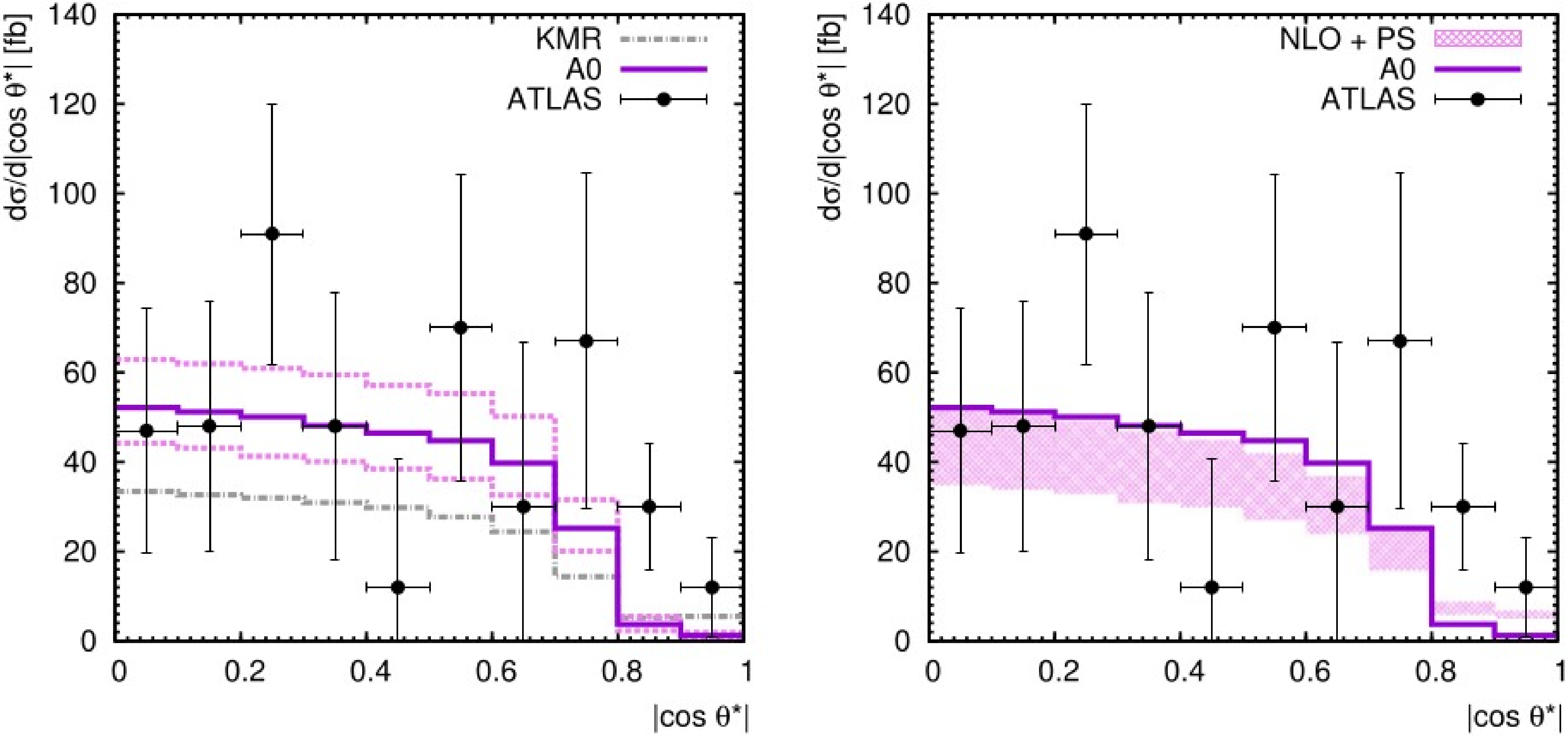
Numerical results

2. The differential cross section of the Higgs boson production in *pp* collisions at the LHC as a function of diphoton rapidity. Dashed histograms on the left panel show the scale variations of CCFM A0-based calculations



Numerical results

3. The differential cross section of the Higgs boson production in *pp* collisions at the LHC as a function of the helicity angle. Dashed histograms on the left panel show the scale variations of CCFM A0-based calculations



Conclusion

In the presented work process of the inclusive Higgs boson production with its subsequent decay to diphoton pair in the k_T-factorization QCD approach at LHC energies has been studied for the first time.

The off-shell matrix element for $g^*g^* \to H \to \gamma\gamma$ subprocess has been evaluated.

Reasonably good description of ATLAS data for the inclusive production of Higgs boson, decaying to diphoton pair, at LHC has been obtained. The CCFM A0 results give the upper limit of NNLO+NNLL predictions, which shows the effective including of higher orders corrections in the k_T-factorization approach.

We have demonstrated that the k_T-factorization approach can be used to study processes incorporating Higgs bosons decays and that the experimental data give limitations on the TMDs. Future experimental analyses are necessary in order to discriminate between NNLO+NNLL and k_T-factorization predictions.

Back up

Unintegrated parton distributions

In the KMR approach the distribution functions start to depend on the transverse momenta of the partons, and $f_a(x,\mathbf{k}_T^2)=const$, if $\mathbf{k}_T^2<\mu_0^2\sim 1$ GeV^2, otherwise they take the form:

$$f_q(x,\mathbf{k}_T^2,\mu^2) = T_q(\mathbf{k}_T^2,\mu^2)\frac{\alpha_s(\mathbf{k}_T^2)}{2\pi}\times$$
$$\times\int\limits_x^1 dz\left[P_{qq}(z)\frac{x}{z}q\left(\frac{x}{z},\mathbf{k}_T^2\right)\Theta\left(\Delta-z\right)+P_{qg}(z)\frac{x}{z}g\left(\frac{x}{z},\mathbf{k}_T^2\right)\right],$$

$$f_g(x,\mathbf{k}_T^2,\mu^2) = T_g(\mathbf{k}_T^2,\mu^2)\frac{\alpha_s(\mathbf{k}_T^2)}{2\pi}\times$$
$$\times\int\limits_x^1 dz\left[\sum_q P_{gq}(z)\frac{x}{z}q\left(\frac{x}{z},\mathbf{k}_T^2\right)+P_{gg}(z)\frac{x}{z}g\left(\frac{x}{z},\mathbf{k}_T^2\right)\Theta\left(\Delta-z\right)\right],$$

As the input we use MSTW2008 set.