УДК 539.125.4, 539.12-1

ON THE APPLICATION OF «$Z^0 + \mathrm{jet}$» EVENTS FOR DETERMINING THE GLUON DISTRIBUTION IN A PROTON AT THE LHC

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It is shown that the samples of «Z^0+jet» events, collected at the LHC with the integrated luminosity $L_{\rm int} = 20$ fb^{-1}, may have enough statistics for determining the gluon distribution inside a proton in the region of $2 \cdot 10^{-4} \leqslant x \leqslant 1.0$ at Q^2 values in the interval of $0.9 \cdot 10^3 \leqslant Q^2 \leqslant 4 \cdot 10^4$ (GeV/c)^2. A possibility of the background events suppression by the use of the «$Z^0 + $jet» events selection criteria is also demonstrated.

Показано, что события «$Z^0 +$ струя», набранные на LHC с интегральной светимостью $L_{\rm int} =$ 20 фб$^{-1}$, могут обладать достаточной статистикой для определения глюонного распределения в протоне в области $2{\cdot}10^{-4} \leqslant x \leqslant 1{,}0$ при значениях Q^2 в интервале $0{,}9{\cdot}10^3 \leqslant Q^2 \leqslant 4{\cdot}10^4$ (ГэВ/c)^2. С использованием критериев отбора событий «$Z^0 +$ струя» показана возможность подавления фоновых событий.

INTRODUCTION

Many important predictions for the production processes of new particles at the LHC require a good knowledge of the gluon distribution function in a proton $f_g^p(x, Q^2)$. Thus, determining the proton gluon density directly in the LHC experiments, especially in the region of small x and high Q^2, would be very useful.

One of promising channels that can be used for measuring $f_g^p(x, Q^2)$ is the direct photon production process in association with one jet $pp \to \gamma^{\rm dir} + 1\,{\rm jet} + X$.

It was studied in detail in [1–3][3].

Here for the same aim we consider the «$Z^0 + $jet» production process (see also [4, 5]), analogous to the «$\gamma + $jet» process mentioned above:

$$pp \to Z^0 \ + \ 1\,{\rm jet} + X. \tag{1}$$

The process (1) is caused at the parton level by two subprocesses: Compton-like scattering

$$qg \to q + Z^0 \tag{2a}$$

and the annihilation process

$$q\bar{q} \to g + Z^0. \tag{2b}$$

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[3] See also [4].

Below we suppose that Z^0 boson decays via leptonic channels $Z^0 \to \mu^+\mu^-, e^+e^-$, the signals from which can be well reconstructed by using electromagnetic calorimeter, tracker and muon system [7–10][1].

In the case of $pp \to Z^0/\gamma^{\rm dir} + 1\,{\rm jet} + X$ in the region of ${P_t}^{Z/\gamma} \geqslant 30$ GeV/c (where k_T smearing effects are not important [6]) the cross section of «$Z^0+{\rm jet}$» production is expressed *directly*[2] in terms of parton distribution functions $f_a^p(x_a, Q^2)$ and the cross sections of the elementary scattering subprocesses (e. g., see [11]):

$$\frac{d\sigma}{d\eta_1 d\eta_2 d{P_t}^2} = \sum_{a,b} x_a\, f_a^p(x_a, Q^2)\, x_b\, f_b^p(x_b, Q^2) \frac{d\sigma}{d\hat{t}}(a\, b \to 1\, 2), \tag{3}$$

where the incident parton momentum fractions $x_{a,b}$ can be found from the Z^0 and jet parameters via

$$x_{a,b} = P_t/\sqrt{s}\,(\exp{(\pm\eta_1)} + \exp{(\pm\eta_2)}). \tag{4}$$

We also used the following designations above: $\eta_1 = \eta^Z$, $\eta_2 = \eta^{\rm jet}$; $P_t = {P_t}^Z$; $a, b = q, \bar{q}, g$; $1, 2 = q, \bar{q}, g, Z^0$. Formula (3) and the knowledge of the results of independent measurements of q, $\bar{q}$ distributions [4] allow the gluon distribution $f_g^p(x, Q^2)$ to be determined in different x and Q^2 intervals after a suppression of the background events contribution.

1. DEFINITION OF SELECTION RULES

1. We shall select the events with Z^0 boson[3] and one jet with

$${P_t}^Z \geqslant 30\ {\rm GeV}/c \quad \text{and} \quad {P_t}^{\rm jet} \geqslant 25\ {\rm GeV}/c. \tag{5}$$

The jet is defined according to the PYTHIA [15] jet-finding algorithm LUCELL having the cone radius counted from the jet initiator cell (ic) $R_{\rm ic} = ((\Delta\eta)^2 + (\Delta\phi)^2)^{1/2} = 0.7$. A jet pseudorapidity $|\eta^{\rm jet}|$ is limited by 5.0 according to the CMS detector geometry.

2. To guarantee a clear track identification of a lepton from the decays of $Z^0 \to \mu^+\mu^-, e^+e^-$ in the tracker and muon systems and most precise determination of its parameters, we put the following restrictions on leptons[4]:

(a) on the transverse momentum value ${P_t}^l$ of any considered lepton:

$${P_t}^l \geqslant 10\ {\rm GeV}/c; \tag{6}$$

(b) on the P_t value of the most energetic lepton in a pair:

$$P_{t\,\max}^l \geqslant P_{t\,\rm CUT}^l. \tag{7}$$

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[1] The estimations done here are based on the geometry of the CMS detector [7].

[2] In contrast to, for instance, the cross section of the inclusive photon production process, also used for the extraction of data on $f_g^p(x, Q^2)$, that is expressed as integral over the proton momentum fractions x_a multiplied by $f_a^p(x, Q^2)$.

[3] Here and below in the paper, speaking about Z^0 boson we imply a signal reconstructed from the lepton pair with leptons selected by criteria 2–4 of this section.

[4] Most of the e, μ selection cuts are taken from [8, 9, 12].

This cut depends on the energy scale [10]. So, we have taken $P_{t\,\mathrm{CUT}}^{l} = 20$ GeV/c for events with ${P_t}^Z \geqslant 40$ GeV/c and $P_{t\,\mathrm{CUT}}^{l} = 50$ GeV/c for events with ${P_t}^Z \geqslant 100$ GeV/c;

(c) on the value of the ratio of ${P_t}^{\mathrm{isol}}$, i. e., the scalar sum of P_t of all particles surrounding a lepton, to ${P_t}^l$ (${P_t}^{\mathrm{isol}}/{P_t}^l$) in the cone of radius $R = 0.3$ and on the value of maximal P_t of a charged particle surrounding a lepton in this cone:

$$ {P_t}^{\mathrm{isol}}/{P_t}^l \leqslant 0.10, \quad {P_t}^{\mathrm{ch}} \leqslant 2 \ \mathrm{GeV}/c. \tag{8} $$

The isolated high-P_t tracks (what takes place in case of the leptonic Z^0 decays) should be reconstructed with a higher efficiency and with generation of a lower number of fake and ghost tracks [8, 9].

3. A lepton is selected in the acceptance region [8, 9]:

$$ |\eta^l| < 2.4. \tag{9} $$

4. To select lepton pairs only from Z^0 decay, we limit the value of the lepton pair invariant mass M_{inv}^{ll} by[1]

$$ |M^Z - M_{\mathrm{inv}}^{ll}| \leqslant 5 \ \mathrm{GeV}/c^2 \tag{10} $$

with M^Z taken to be 91.2 GeV/c^2.

5. We select the events with the vector $\mathbf{P}_t^{\mathrm{jet}}$ being «back-to-back» to the vector $\mathbf{P}_t^Z$ (in the plane transverse to the beam line) within the azimuthal angle interval $\Delta\phi$ defined by the equation

$$ \phi_{(Z,\,\mathrm{jet})} = 180^\circ \pm \Delta\phi, \tag{11} $$

where $\phi_{(Z,\,\mathrm{jet})}$ is the angle between the $\mathbf{P}_t^Z$ and $\mathbf{P}_t^{\mathrm{jet}}$ vectors: $\mathbf{P}_t^Z \mathbf{P}_t^{\mathrm{jet}} = {P_t}^Z {P_t}^{\mathrm{jet}} \times \cos(\phi_{(Z,\,\mathrm{jet})})$, with ${P_t}^Z = |\mathbf{P}_t^Z|$, ${P_t}^{\mathrm{jet}} = |\mathbf{P}_t^{\mathrm{jet}}|$. Here we limit $\Delta\phi$ values by 15°.

6. The initial and final state radiations manifest themselves most clearly as some final state minijets or clusters activity [10, 13, 14]. To suppress it, we impose a new cut condition that was not formulated in an evident form in previous experiments: we select the «$Z^0 + \mathrm{jet}$» events that do not have any other jet-like or cluster high P_t activity by taking values of ${P_t}^{\mathrm{clust}}$ (with the cluster cone of $R_{\mathrm{clust}} = 0.7$), being smaller than some threshold $P_{t\,\mathrm{CUT}}^{\mathrm{clust}}$ value; i. e., we select the events with

$$ {P_t}^{\mathrm{clust}} \leqslant P_{t\,\mathrm{CUT}}^{\mathrm{clust}}. \tag{12} $$

7. We limit the value of the modulus of the vector sum of $\mathbf{P}_t$ of all particles that do not belong to the «$Z^0 + \mathrm{jet}$» system but fit into the region $|\eta| < 5$ covered by the calorimeter system; i. e., we limit the signal in the cells «beyond the jet and Z^0» regions by the following cut:

$$ \left| \sum_{i \notin \mathrm{jet}, Z^0} \mathbf{P}_t^i \right| \equiv {P_t}^{\mathrm{out}} \leqslant P_{t\,\mathrm{CUT}}^{\mathrm{out}}, \quad |\eta^i| < 5. \tag{13} $$

The importance of $P_{t\,\mathrm{CUT}}^{\mathrm{out}}$ and $P_{t\,\mathrm{CUT}}^{\mathrm{clust}}$ for selection of events with a good balance of P_t^Z and P_t^{jet} was already shown in [10, 13, 14]. In the present paper they are fixed as $P_{t\,\mathrm{CUT}}^{\mathrm{out}} = 10$ GeV/c and $P_{t\,\mathrm{CUT}}^{\mathrm{out}} = 10$ GeV/c.

As we show below, the presented selection criteria guarantee practically a complete suppression of the background events.

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[1]A narrower mass window can be used with the statistics growth.

2. THE STUDY OF BACKGROUND SUPPRESSION

In principle, there is a probability that some combination of $\mu^+\mu^-$ or e^+e^- pairs in the events, based on the QCD subprocesses with much larger cross sections (by about five orders of magnitude) than ones of the signal subprocesses (2a) and (2b), can be registered as the Z^0 signal.

Firstly, to study a rejection possibility of such type of events about 40 million events with a mixture of all QCD and SM subprocesses with large cross sections existing in PYTHIA[1] including also the signal subprocesses[2] were generated with the only Z^0 decay mode allowed: $Z^0 \to \mu^+\mu^-$. Three generations were performed with different minimal P_t of the hard $2 \to 2$ subprocess[3] $\hat{p}_\perp^{\min}$ values: $\hat{p}_\perp^{\min} = 40$, 70 and 100 GeV/$c$. The cross sections of different subprocesses serve in simulation as weight factors and, thus, determine the final statistics of the corresponding physical events. The generated events were analyzed by using the cuts given in Table 1 (see also Sec. 1)[4].

Table 1. **List of the applied cuts used in Tables 2, 3**

0	Total number of l^+l^- pairs (no selection)
1	${P_t}^l > 10$ GeV/c, $\lvert\eta^l\rvert < 2.4$
2	$\lvert M_{\mathbf{Z}} - M_{\rm inv}^{ll}\rvert < 20$ GeV/c^2
3	One-jet events selected
4	${P_t}^{\rm isol}/{P_t}^l \leqslant 0.10$, ${P_t}^{\rm ch} < 2$ GeV/c
5	$\lvert M_{\mathbf{Z}} - M_{\rm inv}^{ll}\rvert < 5$ GeV/c^2
6	$\Delta\phi < 15^\circ$

To trace the effect of their application, let us consider first the case of one (intermediate) energy, i. e., the generation with $\hat{p}_\perp^{\min} = 70$ GeV/c. Each line of Table 2 corresponds to the respective cut of Table 1. The numbers in the columns «Signal» and «Bkgd» show the number of muon pairs in the signal and (combinatorial) background events that remained after a cut. The column «Eff$_{S(B)}$» demonstrates the efficiency of a cut. The efficiencies Eff$_{S(B)}$ (with their errors) are defined as a ratio of the number of the signal (background) events that passed under a cut (1–6) to the number of the preselected events after the first cut of Table 1[5].

We see from Table 2 that the initial ratio of $\mu^+\mu^-$ pairs in signal and background events is very small $(5 \cdot 10^{-4})$[6]. A weak restriction of the muon transverse momentum and pseudorapidity in the first selection increase S/B by about two orders (as $5 \cdot 10^{-4} \to 2 \cdot 10^{-2}$). The invariant mass criterion and one-jet events selection make $S/B = 18.0$, and the last criterion on the azimuthal angle between Z^0 and jet $(\Delta\phi < 15^\circ)$ suppresses the background events completely.

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[1]Namely, having ISUB = 11–20, 28–31, 53, 68 in PYTHIA [15].

[2]ISUB = 15 and 30 in PYTHIA [15].

[3]I. e., CKIN(3) parameter in PYTHIA [15].

[4]Notice that the cuts used in Table 1 are weak enough. For instance, they do not limit (directly) ${P_t}^Z$, P_t of the most energetic lepton in the pair (as well as they do not include ${P_t}_{\rm CUT}^{\rm clust}$ and ${P_t}_{\rm CUT}^{\rm out}$).

[5]The number of events after the first cuts is taken as 100 %.

[6]That is mainly due to the huge difference in the cross sections of «Z^0 + jet» events (from subprocesses (2a), (2b)) and the QCD events.

Table 2. **A demonstration of cut-by-cut efficiencies and S/B ratios for generation with $\hat{p}_{\perp}^{\min} =$ 70 GeV/c ($Z^0 \to \mu^+\mu^-$)**

Selection	Signal	Bkgd	$\text{Eff}_S, \%$	$\text{Eff}_B, \%$	S/B
0	401	850821			$5 \cdot 10^{-4}$
1	245	15842	100.00±0.00	100.00±0.000	0.02
2	226	467	92.24±8.51	2.948±0.138	0.5
3	99	12	40.41±4.81	0.076±0.022	8.3
4	81	10	33.00±4.24	0.063±0.020	8.1
5	72	4	29.39±3.94	0.025±0.013	18.0
6	62	0	25.31±3.60	0.000±0.000	—

Table 3. **Values of efficiencies and S/B ratios for generations with $\hat{p}_{\perp}^{\min} =$ 40, 70 and 100 GeV/c ($Z^0 \to \mu^+\mu^-$)**

$\hat{p}_{\perp}^{\min}$, GeV/c	Cuts	Signal	Bkgd	$\text{Eff}_S, \%$	$\text{Eff}_B, \%$	S/B
40	Preselection (1)	89	1090	100.00±0.00	100.00±0.00	0.08
	Main (1–5)	30	0	33.71±7.12	0.000±0.000	—
70	Preselection (1)	245	15842	100.00±0.00	100.00±0.00	0.02
	Main (1–5)	72	4	29.39±3.94	0.025±0.013	18.0
100	Preselection (1)	497	37118	100.00±0.00	100.00±0.00	0.01
	Main (1–5)	127	4	25.55±2.54	0.011±0.005	31.8

Table 4. **Values of efficiencies and S/B ratios for generations with $\hat{p}_{\perp}^{\min} =$ 40, 70 and 100 GeV/c ($Z^0 \to e^+e^-$)**

$\hat{p}_{\perp}^{\min}$, GeV/c	Selections	Signal	Bkgd	$\text{Eff}_S, \%$	$\text{Eff}_B, \%$	S/B
40	Preselected (1)	48	1404	100.00±0.00	100.00±0.00	0.03
	Main (1–5)	20	3	41.67±11.09	0.214±0.123	6.7
70	Preselected (1)	95	5396	100.00±0.00	100.00±0.00	0.02
	Main (1–5)	35	2	36.32±7.32	0.037±0.026	17.5
100	Preselected (1)	191	18158	100.00±0.00	100.00±0.00	0.01
	Main (1–5)	61	2	31.68±4.67	0.008±0.007	30.5

The information on other intervals (i. e., on the event generations with $\hat{p}_{\perp}^{\min} = 40$ and $\hat{p}_{\perp}^{\min} = 100$ GeV/c) is presented in Table 3. The line «Preselection (1)» corresponds to the first cuts in Table 1 (${P_t}^{\mu} > 10$ GeV/c, $|\eta^{\mu}| < 2.4$) while the line «Main (1–5)» corresponds to the result of application of criteria from 1 to 5 of Table 1. *After application of all six criteria of Table 1 we have observed no background events in all of the ${P_t}^Z$ intervals* with a signal events selection efficiency of 25–33 %.

Analogous simulations in PYTHIA were done to estimate a background to the «$Z^0 + \text{jet}$» events with the subsequent Z^0 decay via e^+e^- channel. About 20 million events were generated at $\hat{p}_{\perp}^{\min} = 40$, 70 and 100 GeV/$c$ with a mixture of all QCD and SM subprocesses. The results are given in Table 4. As in the case of $Z^0 \to \mu^+\mu^-$, no background events were found after application of all criteria of Table 1.

The practical absence of a background to the «$Z^0 + \text{jet}$» events allows one to use them for an extraction of the gluon distribution in a proton $f_g^p(x, Q^2)$.

3. ESTIMATION OF RATES FOR GLUON DISTRIBUTION DETERMINATION

In Table 5 we present the distribution of the number of the events, based on the subprocesses $qg \to Z^0 + q$ and $q\bar{q} \to g + Z^0$ (with the decays $Z^0 \to \mu^+\mu^-, e^+e^-$), at integrated luminosity $L_{\rm int} = 20$ fb^{-1} in different x (defined by (4)) and $Q^2 (\equiv (P_t{}^Z)^2)$ intervals. These events satisfy the cuts (5)–(13) of Sec. 1. We see that at $L_{\rm int} = 20$ fb^{-1} one can collect about half a million of «$Z^0 + \text{jet}$» events in the interval of $30 \leqslant P_t{}^Z \leqslant 200$ GeV/c.

Table 5. **Numbers of «$Z^0 + \text{jet}$» events (with $Z^0 \to \mu^+\mu^-, e^+e^-$) in Q^2 and x intervals for $L_{\rm int} =$ 20 fb^{-1}**

Q^2, (GeV/c)^2	x values of a parton				All x	$P_t{}^Z$,
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}	GeV/c
900–1600	36818	91689	94905	4957	228369	30–40
1600–2500	14833	56722	57403	3708	132667	40–50
2500–3600	4957	33148	38029	3065	79199	50–60
3600–5000	2195	20812	25882	3065	51954	60–71
5000–6400	454	11693	13887	2043	28077	71–80
6400–8100	341	8476	10860	1249	20925	80–90
8100–10000	38	5979	8098	1438	15552	90–100
10000–14400	38	5638	9157	1816	16650	100–120
14400–20000	0	2800	5562	908	9271	120–141
20000–40000	0	1816	4389	1438	7644	141–200
					590 308	

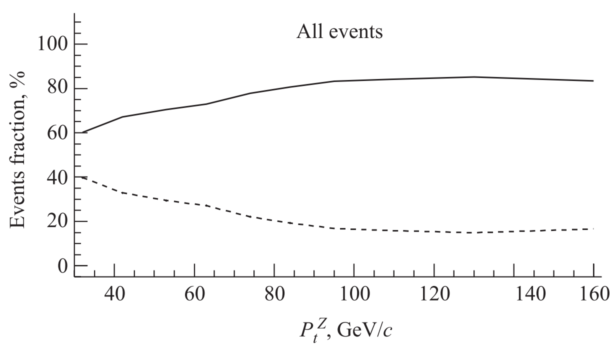

Fig. 1. The contributions of the events originated from the subprocesses (2a) and (2b) as a function of $P_t{}^Z$. Full line corresponds to the «$qg \to q + Z^0$» events, dashed line to the «$q\bar{q} \to g + Z^0$» events

The contributions (in percentage) of the events that originated from the subprocesses (2a) and (2b)[1] as functions of $P_t{}^Z$ are presented in Fig. 1. From this figure one can see that the fraction of the «gluonic» events originating from the Compton scattering (2a) noticeably dominates over all considered $P_t{}^Z$ interval and varies from about $60\,\%$ at $P_t{}^Z \approx 30$ GeV/c to about $85\,\%$ at $P_t{}^Z \geqslant 100$ GeV/c.

The x–Q^2 kinematic area in which one can study the gluon distribution $f_g^p(x, Q^2)$ by selecting «$Z^0 +$ jet» events (with the leptonic decay modes of Z^0) is also shown in Fig. 2. From this figure (and Table 5) it is seen that during first two years of LHC running at low luminosity ($L = 10^{33}$ cm$^{-2} \cdot$ s^{-1}) it would be possible to extract an information for determination of $f_g^p(x, Q^2)$ in the region of $0.9 \cdot 10^3 \leqslant Q^2 \leqslant 4 \cdot 10^4$ (GeV/c)^2 with as small x values as accessible at HERA but at higher Q^2 values (by 1–2 orders of magnitude). It is also worth emphasizing that the sample of the «$Z^0 +$jet» events selected for this aim can be used to perform a cross-check of $f_g^p(x, Q^2)$ determination by using «$\gamma^{\rm dir} +$ jet» events [1–3]. It is especially important in the region of lower Q^2 where we have quite a sufficient statistics of «$Z^0 +$jet» events, on the one hand, and a higher background contribution to the «$\gamma^{\rm dir} +$jet» events, on the other hand. The area that can be covered with «$\gamma^{\rm dir} +$jet» events is also shown in Fig. 2 by dashed lines.

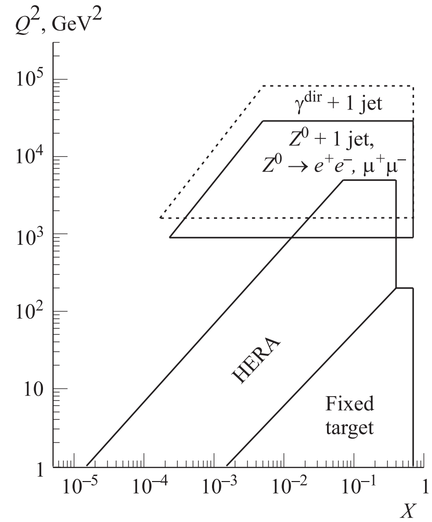

Fig. 2. LHC (x, Q^2) kinematic region for the process $pp \to Z^0 +$ jet $+ X$ (with $Z^0 \to \mu^+\mu^-, e^+e^-$)

SUMMARY

It is shown that the samples of «$Z^0 +$jet» events with a clean topology, most suitable for the absolute jet energy scale setting[2] [10] and with the suppressed combinatorial background contribution from the QCD events, can provide useful information for the gluon density determination inside a proton. The corresponding measurements can be done in a new kinematic region, not covered in any previous experiments, of $2 \cdot 10^{-4} \leqslant x \leqslant 1.0$ with $0.9 \cdot 10^3 \leqslant Q^2 \leqslant 4 \cdot 10^4$ (GeV/c)^2. The study of gluon distribution $f_g^p(x, Q^2)$ obtained from the analysis of «$Z^0 +$jet» events can be used as the independent cross-check of the $f_g^p(x, Q^2)$ determination from the «$\gamma^{\rm dir} +$jet» events [1–3] as well as from the analytical solutions of the DGLAP equations describing the Q^2 evolution of parton distributions at small x [16].

Acknowledgements. We thank P. Aurenche, D. Denegri, M. Dittmar, M. Fontannaz, J. Ph. Guillet, M. L. Mangano, E. Pilon and S. Tapprogge for helpful discussions.

[1] And passed selection cuts (5)–(13).

[2] As was shown in [10], the chosen cut conditions noticeably suppress initial and final state radiations, i. e., the contributions from the events caused by next-to-leading order diagrams.

REFERENCES

1. *Bandurin D. V., Konoplyanikov V. F., Skachkov N. B.* «$\gamma^{\rm dir} + {\rm jet}$» events rate estimation for gluon distribution determination at LHC // Part. Nucl., Lett. 2000. No. 6[103]. P. 34–43; hep-ex/0011015.
2. *Bandurin D. V., Konoplyanikov V. F., Skachkov N. B.* Events rate estimation for gluon distribution determination at LHC. hep-ex/0207028; Proc. of the XV ISHEP «Relativistic Nuclear Physics and Quantum Chromodynamics», Dubna, 2000 / Eds. A. M. Baldin, V. V. Burov, A. I. Malakhov. Dubna, 2001. V. I. P.375–383.
3. *Bandurin D. V., Skachkov N. B.* On the possibility of measuring the gluon distribution in proton with «$\gamma + {\rm jet}$» events at LHC. hep-ex/0210004 (to appear as CMS Note).
4. *Dittmar M., Pauss F., Zurcher D.* // Phys. Rev. D. 1997. V. 56. P. 7284.
5. *Womersley J.* A talk at CMS Week meeting, Aachen, 1997.
6. *Huston J.* ATLAS Note ATL-Phys-99-008. CERN. 1999.
7. CMS, Technical proposal. CERN/LHCC 94-38.
8. The CMS Tracker Project. CERN/LHCC 98-6, CMS TDR 5. CERN. 1999.
9. The CMS Muon Project. CERN/LHCC 97-32, CMS TDR 3. CERN. 1997.
10. *Bandurin D. V., Skachkov N. B.* On the application of «$Z^0 + {\rm jet}$» events for setting the absolute jet energy scale and determining the gluon distribution in a proton at the LHC. hep-ex/0209039.
11. *Owens J. F.* // Rev. Mod. Phys. 1987. V. 59. P. 465.
12. *Abdullin S., Khanov A., Stepanov N.* CMS Note CMS TN/94-180 «CMSJET».
13. *Bandurin D. V., Konoplyanikov V. F., Skachkov N. B.* Jet energy scale setting with «$\gamma^{\rm dir} + {\rm jet}$» events at LHC energies. JINR Preprints E2-2000-251–E2-2000-255. Dubna, 2000.
14. *Bandurin D. V., Skachkov N. B.* «$\gamma^{\rm dir} + {\rm jet}$» process application for setting the absolute scale of jet energy and determining the gluon distribution at the Tevatron Run II. D0 Note 3948. 2002.
15. *Sjostrand T.* // Comp. Phys. Commun. 1994. V. 82. P. 74.
16. *Kotikov A. V., Parente G.* // Nucl. Phys. B. 1999. V. 549. P. 242.

Received om June 16, 2003.