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JINR PARTICIPATION IN THE ATLAS PHYSICS PROGRAM

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Current status of JINR participation in the ATLAS physical program is briefly reviewed. In particular, JINR short- and long-term plans and activities in the ATLAS Higgs, top, SUSY and exotic physics as well as in the standard model physics are discussed.

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1. *Introduction*

With the highest energies of the Large Hadron Collider (LHC), one enters in the field of an extremely rare-event physics. When looking for a signal event, one has to single it out from about 10^{13} background events. To perform such incredible task, one has to create a new, huge apparatus, like for example the giant detector of the ATLAS experiment. Indeed, this detector is the biggest one in the world (Fig. 1), it has the diameter of 25 m, the length of the barrel toroid of 26 m and its overall weight is about 7000 tons.

The ATLAS is a many-purpose particle physics experiment that will explore the fundamental nature of matter and the basic forces that shape our universe. The ATLAS detector will search for new discoveries in collisions of protons of extraordinarily high energy of 14 TeV [2]. It is located at CERN (Geneva) about 100 m underground where protons accelerated by the LHC will collide.

The proposal for the participation of the Joint Institute for Nuclear Research (JINR), Dubna, in the ATLAS experiment was firstly presented in 1995. The JINR PAC recommended this project for approval on 24 November 1995. At that time, 6567 kUSD and 140 khours of workshop were requested, including 4069 kUSD from

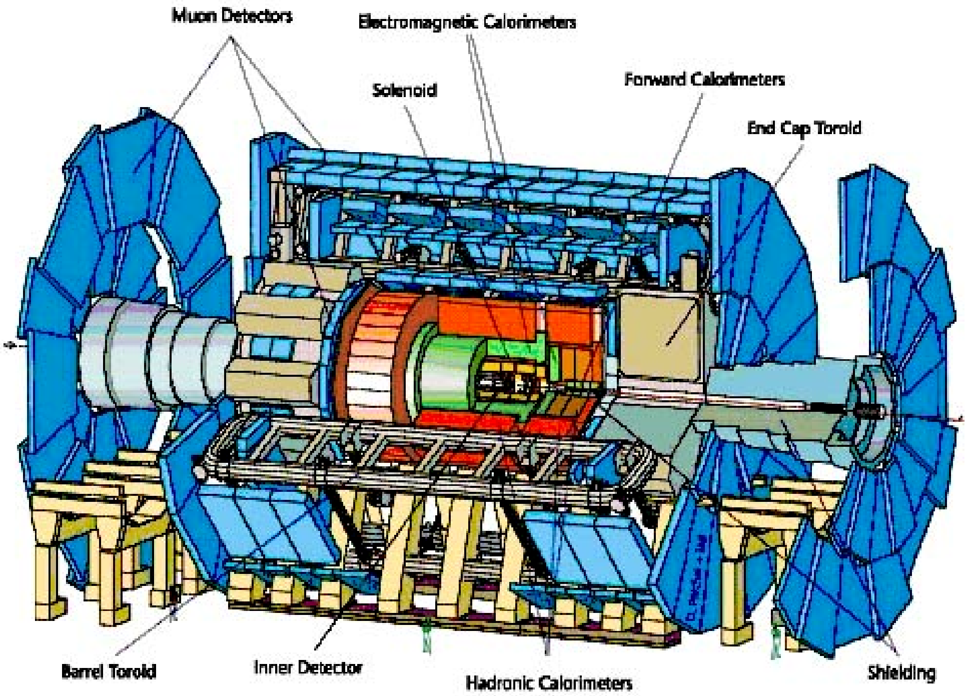


Fig. 1. The ATLAS detector. From Ref. [1].

the JINR budget. Since this historical date status reports on this project have been regularly discussed at PAC and JINR Scientific Council meetings. Over the last decade, JINR-ATLAS team was deeply involved in designing, construction, tests and assembly of the major systems of ATLAS Inner Detector [3], Tile Calorimeter [4, 5], Liquid Argon End Cap Calorimeter [6], Muon Detector [7] and Common Items (like Toroid Warm Structure and others). Participation in the physics program was always considered as the most important target. Till 2003, this work has been performed mainly in a "background" regime, essentially based on individual efforts, promoted with limited resources case-by-case as well as for software developments and general computing infrastructure of ATLAS.

Early 2004, the JINR-ATLAS team management decided to establish a regular framework (series of workshops) to promote physics-oriented activities at JINR. The workshops open the door for new ideas, attract new collaborators, interested in future physics at LHC, allow monitoring of ongoing activities and selection of most promising ones to provide the necessary support, in particular for visiting conferences and dedicated ATLAS meetings. Other goals of the workshops are to enrich "home community" by involving physicists from JINR member countries who have less possibilities in computing and networking, to make JINR-ATLAS resources and experience widely available. Already seven workshops took place at the Dzhelepov Laboratory of Nuclear Problems of JINR. Since that time many

ATLAS physics topics have been discussed, a dedicated site has been created [8].

With the only exception of B-quark physics, JINR scientists take part in researches in the all other main ATLAS physics directions: the standard model (SM), Higgs boson, supersymmetry (SUSY), exotics, top quark physics and heavy ions physics. The JINR ATLAS physics team counts about 20 actively working members. In the next Section we briefly describe our most important activities in the field.

2. *JINR results in the ATLAS physics*

The very ambitious project (leader D. Y. Bardin, homepage http://brg.jinr.ru/) is aimed to support analytical and numerical calculations (SANC) for experiments at hadron and lepton colliders. This project starts to produce applications (generators) which allow investigations of prospects for observation of the physical phenomena at the LHC with ATLAS detector [9]. In particular, new Monte-Carlo generator for SM Higgs boson decay $H \to 4\mu$ in the single-resonance approximation was created, taking into account both 1-loop corrections and identity effects that was never done before (Fig. 2 left).

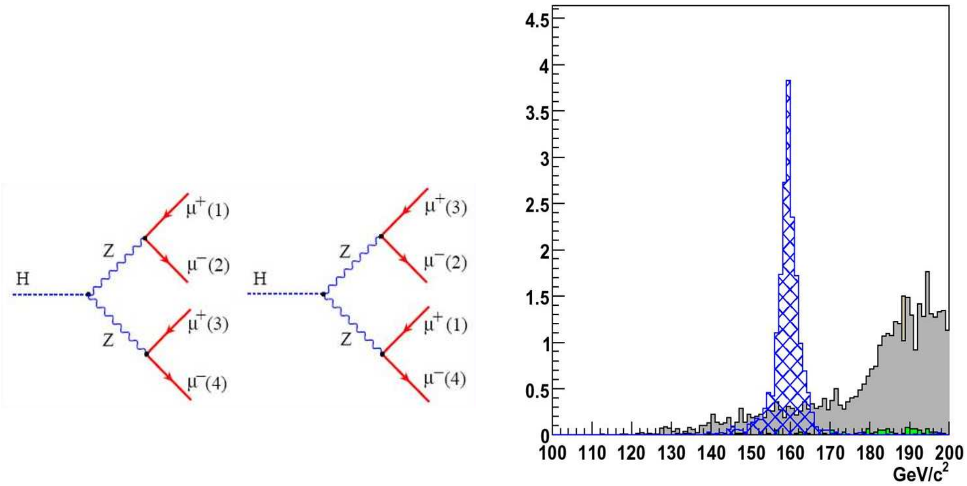


Fig. 2. The identity effects in the Higgs decay $H \to 4\mu$ (left). Fully reconstructed SM Higgs boson with mass 160 GeV/c^2 via its decay $H \to 4\mu$ (right).

In particular, in 2007 preparation was started for very accurate analysis (including loop corrections) of single top quark production in proton-proton collisions at LHC within the SANC framework. Accurate study of the reaction $pp \to ZZ$ as background for $H \to ZZ$ decay is under way. Investigation of possibility to apply precise Drell-Yan calculations for LHC luminosity monitoring and parton-distribution-function (PDF) measurements is now carried out within the SANC project.

2.1. Higgs physics

Prospects for searching the SM Higgs boson via decay $H \to 4\mu$ were studied on the basis of full ATLAS detector simulation by group of G. A. Chelkov [10]. The Higgs decays (30 000 events) were generated at CERN with the SANC generator for $M_H = 130$, 160 GeV/c^2. Background 30 000 events from $pp \to ZZ$, $pp \to Zbb$, with 4 final state muons were simulated with PYTHIA and ACERMC generators. Single Z boson overlapping events "$Z + Z$" were also simulated. Almost all background events (1/3 of all data) were simulated at LIT farm in Dubna, where modern ATLAS software is installed. Detector simulation and event reconstruction were carried out completely within modern ATLAS software (C++, ATHENA, GEANT-4, AOD, Root).

The "golden channel" $H \to 4$ leptons is one of the most promising for the early discovery. For the light Higgs ($120 - 160$ GeV/c^2), the signal is low (tens events per year), but the selection efficiency is high and the background is almost zero. The full simulation study shows that $H \to 4\mu$ alone ensures about 5σ discovery after one year of nominal luminosity (Fig. 2 right). This work is completed.

Another fast and full simulation study of SM Higgs boson production via $pp \to HX \to Z\gamma X$ is under way at JINR [8]. The process is studied for Higgs boson with mass $115 - 160$ GeV/c^2 by means of decay $H \to Z + \gamma$ and $Z \to 2$ leptons within ATLAS software ATHENA. The measurement of the $H \to Z + \gamma$ decay branching ratio could be the unique source to measure the $H\,Z\gamma$ coupling constant.

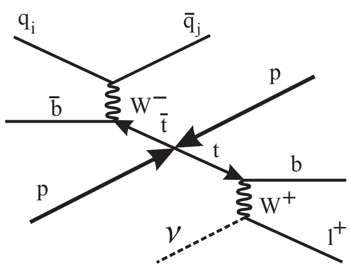
Furthermore, JINR team plans to carry out two other studies. First one is the search for the Higgs boson with mass $115 - 160$ GeV/c^2 by means of associative production of Higgs and gauge bosons ($pp \to W(Z) + H + X$) and Higgs decay into $b\bar{b}$-pair ($H \to 2b \to 2b$-jets). Second one is study of the ATLAS discovery potential of large-mass SM Higgs boson by means of reactions $H \to 2W \to 2l\nu$, $H \to 2W \to l\nu jj$, and $H \to 2Z \to 2l\nu$, $H \to 2Z \to 2lljj$ (j denotes here a jet). Proposals rely on the Higgs boson production via the vector boson fusion mechanism (when the two accompanying forward jets allow very good background reduction) and on the maximal Higgs decay rates into WW- or ZZ-pair at $M = 400 \div 1000$ GeV/c^2.

The Higgs boson searches and investigations of its properties have to be carried out coherently. The important question is: how a Higgs boson decaying, for example, into 4 muons "shows" itself in the other allowed decays (into 2 photons, bb-pair, etc)? In the other words, is the detected Higgs boson always the same? One needs this for the "Higgs cross-check" and verification of the SM electro-weak symmetry breaking mechanism.

2.2. Top quark physics

Prospects for the verification of the electric charge of the top-quark (for example, is it equal to 2/3 or −4/3 of the proton electric charge?) were studied by means of the determination of charges of the top quark decay products. Full and fast ATLAS detector simulation was carried out. It was shown that with the ATLAS detector it will be possible to verify the top quark charge after analyzing of data taken during 1–2 weeks of the LHC operation. The work is completed [11].

Prospects for the observation of a narrow $t\bar{t}$-resonance at the LHC with the ATLAS detector are studied. As a typical example of the $t\bar{t}$-resonance, an extra neutral Z' boson with masses of 1.0, 1.5 and 2.0 TeV/c^2 was explored. The full and fast simulation of the ATLAS detector was performed within the ATLAS software ATHENA. In fact, the fast simulated background sample with the number of $t\bar{t}$ events corresponding to about 5 fb^{-1} of expected data statistics, as well as fast and fully simulated signal samples with presence of the Z' boson decaying into the $t\bar{t}$ pair were considered. The "lepton plus jets" decay mode is used for the separation of the $t\bar{t}$ pair from the background. The introduced "P_T^{top} cut-off" method allowed one to improve the accuracy of reconstructed invariant mass of the $t\bar{t}$ system. After full reconstruction of the ATLAS detector, this method allowed one to estimate the minimal cross-sections of the Z'-like $t\bar{t}$ resonance production at the LHC, which promise observation of this $t\bar{t}$-resonance state at the 5σ confidence level (Fig. 3) on the basis of 5, 10 and 100 fb^{-1} of data statistics [12].



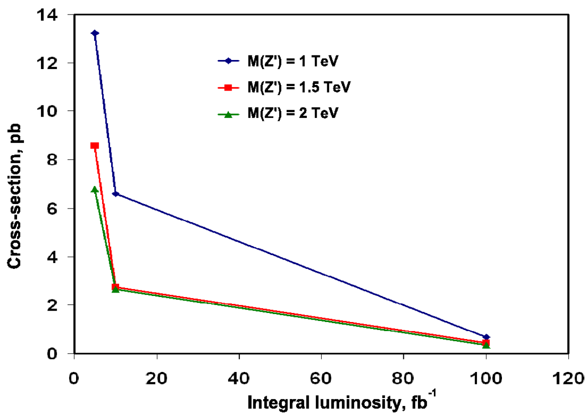


Fig. 3. Lepton+jets channel of the top-anti-top pair decay (left). The 5-sigma confidence level for observation of the $t\bar{t}$-resonance (right).

In 2007 in JINR the first, preliminary work (within modern ATLAS software) has been started on prospects for registration of associative Higgs boson production together with the top-antitop pair $pp \to Ht\bar{t}X \to l^+l^- + t\bar{t} + X$, where $H \to l^+l^-$ [8].

In fact, the top-quark physics is a good example for the LHC early physics. It can provide rather quickly some significant results, like precise test of the standard model (via measurement of top-quark electric charge and top mass, via answering the question: is the top quark "the same" in all top-like observables?). Furthermore, accurate knowledge of the top quark properties is very important (as background and/or as an instrument for investigation) for further SUSY and exotics studies. High top-quark mass value is also a unique benchmark for accurate energy detector calibration (together with Z- and W-boson masses) at the LHC energies.

2.3. Exotic physics

In 2006, the search for and identification of the graviton-like Kaluza-Klein states (from the extra dimension models) in the lepton-pair production at LHC via new center-edge asymmetry (A_{CE}) was proposed by our colleague A. Pankov from Gomel University [8]. It was proved theoretically that this asymmetry A_{CE} allows a clear isolation of the spin-2 graviton contribution. Therefore, the asymmetry is a unique graviton exchange signature. In 2007, the work on the subject entered the simulation phase.

Preliminary study of the prospect for the observation with the ATLAS detector at the LHC of the rare lepton-flavor violating (LFV) tau decays ($\tau \to 3\mu$ and $\tau \to \mu\gamma$) was carried out at JINR. In particular, these decays can be connected with neutrino oscillation phenomena and there are a lot of interesting predictions for these decays beyond the SM model. It was shown that the potential of ATLAS sensitivity to these decays is about 10^{-8} for $\tau \to 3\mu$ (it is one order of magnitude better then the current limit) and 10^{-7} for $\tau \to \mu\gamma$ [13].

Prospects for the two-photon production (Fig. 4) and detection of the monopole-antimonopole pairs at LHC will be studied at JINR in tight collaboration with physicists from Minsk, Belarus. The basic idea of the monopole detection relies on the monopole very large ionization power (comparable with Z=70 ions) [8]. To perform the study we need, first of all, a reliable generator for the monopole propagation through the condense medium of the ATLAS detector.

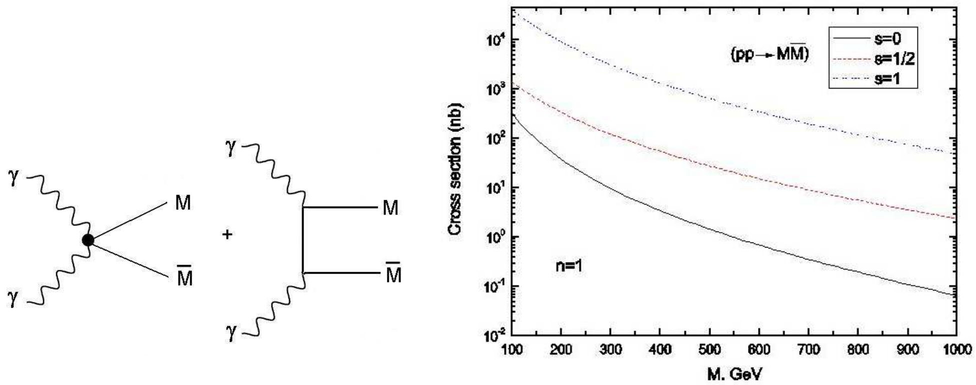


Fig. 4. The two-photon production of the monopole-antimonopole pairs at the LHC (left). Cross sections of the process for monopoles of different spin (right).

2.4. SUSY physics

Prospects for the ATLAS observation of a SUSY-like signal from two gluinos $\tilde{g}\tilde{g}$ were investigated within a certain region of the mSUGRA parameter space, where the cross-section of the two gluinos production in pp-collisions at LHC ($\sqrt{s}$ = 14 TeV) via gluon-gluon fusion, $gg \to \tilde{g}\tilde{g}$, is estimated at a rather high level of 17.3 pb. In this so-called EGRET region, the lightest stable neutralinos can serve as cold dark matter particles, and can naturally explain the excess of diffuse galactic gamma rays observed by EGRET space apparatus. The $\tilde{g}\tilde{g}$-event selection relies on a very clear signature when decay products of each gluino are b–anti-b and lepton–anti-lepton pair, light-jet pair and the neutralino. Rather high transverse missing energy carried away by two neutralinos is an essential signature of the events and allows the relevant SM background to be reduced significantly. The generation and reconstruction processes were performed by means of the ATLAS common software framework ATHENA. In particular, it was found that the clear signatures of selected processes allow one to discover the SUSY gluinos (Fig. 5 right), and further to distinguish different SUSY parameters within the EGRET region at more than 5σ confidence level [14].

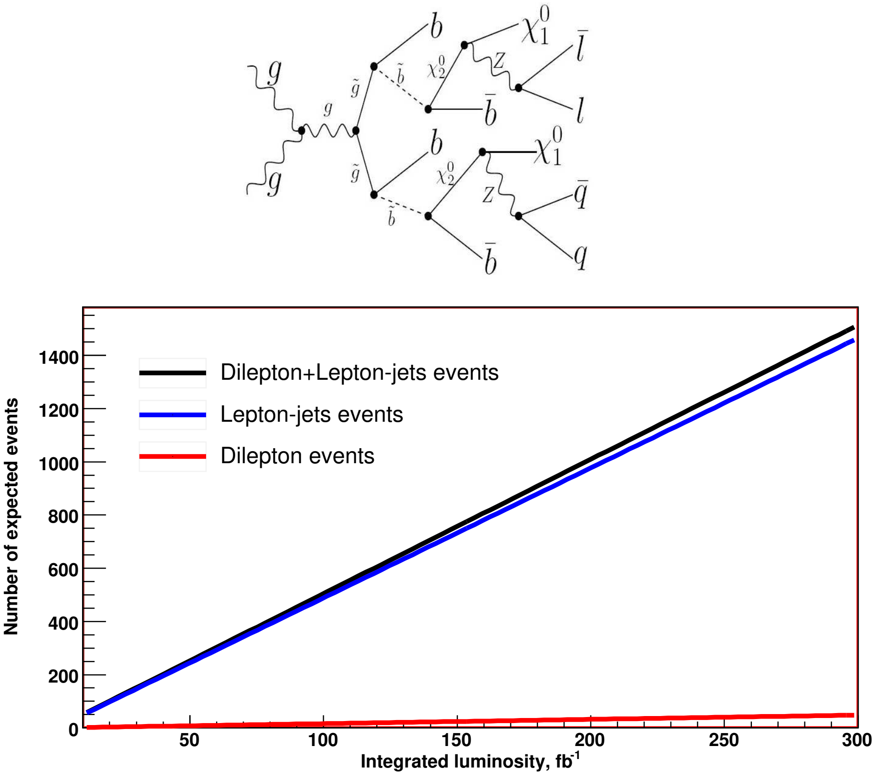


Fig. 5. The "lepton+jets" channel of two gluino decay (top). Number of expected "lepton+jets" (blue line), "dilepton" (red line) and their sum (black line) events at different integrated luminosity with $m_{1/2} = 180$ GeV (bottom).

In 2008, the JINR team in collaboration with CERN colleagues has very ambiguous plans with SUSY, which included

1) Full ATLAS simulation study of prospects for registration the SUSY gluinos at very promising EGRET MSSM region by means of two main gluino decay channels (4 b-quarks+4 leptons+$E_{\rm missing}$ and 4 b-quarks+2 jets+2 leptons-$E_{\rm missing}$).

2) Search for and investigation of all possible background processes (QCD, $qq(gg) \to 4b + 2l + 2q$, etc.) for the above-mentioned SUSY processes. Study of influence of relevant miss-tagging of b-jets and muons.

3) Study of prospects for registration of "weak SUSY" processes at the same EGRET MSSM region (complimentary to the above-mentioned gluino production). In these processes one expects, for example, 3 leptons+neutrino+$E_{\rm missing}$ (due to the two lightest neutralinos which escape detection) and one isolated lepton (or jet) accompanied by (very) large missed "transverse" energy (due to W boson decay into neutralino and chargino). Both (gluino and "weak") investigations are very important for the coherent SUSY search strategy.

Study of R-hadron detection possibility with ATLAS has been started. By definition, inside the R-hadron one quark is substituted by one SUSY (rather stable) sparticle (gluino, squark, or neutralino). This makes R-hadrons properties rather unusual. At the LHC energies, the R-hadron signatures are the following: a high transverse momentum for charged hadrons, and high ionization losses in the tracking system. There is a missing transverse energy due to the large R-hadron mass. One expect also large time-of-flight for the R-hadrons, which can be measured with the muon chambers and the Tile Calorimeter [15].

2.5. Heavy ion physics

In 2007 full ATLAS simulation of $Z \to \mu^+\mu^-$ in pp and heavy ion collisions was carried out. The point-like Z-boson production is not influenced by the quark gluon plasma (QGP), so the study of the jet quenching is provided by Z-boson tagging. One month of LHC running with heavy ions gives about 5000 Z-boson decays into pairs of the muons. The use of this decay mode is helpful in the study of the jet quenching. Back-to-back configuration of Z+jet event is a tool for the jet reconstruction. The LHC with heavy ions is a powerful (as Z^4) source of quasi-real photons in the energy region up to 100 GeV [8]. Expected large collider luminosity allows to consider measurements of 1) accurate calculable process of lepton pair production, 2) high p_T jets and open charm production, both aimed to study (mainly) gluon component of the photon, 3) charmed meson production and 4) search for bottomonium states.

2.6. Standard model physics

The gluon distributions in the proton (PDF) can be estimated by means of simultaneous registration (Fig. 6 right) of the direct photons (or Z-bosons) and jets ("gamma/Z+jet" events). This channel is studied by our colleagues from D0 collaboration at FNAL [16]. The possibilities of measuring the gluon PDF with ATLAS is under investigation.

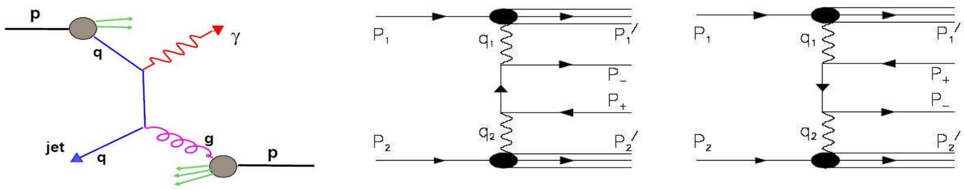


Fig. 6. Determination of gluon distribution in the proton by means of "gamma/Z+jet" events (left). Two-photon Drell-Yan process (right).

It was shown by our colleagues from Minsk that the two-photon creation of lepton pairs (Fig. 6 right) in hadronic processes (so-called Drell-Yan process) is important and has a measurable cross section in forward and backward regions and for a small lepton pair mass [8].

In 2007, development of a new generator for PDFs which obey QCD evolution equations at very low Feynman x and study of their influence on the cross sections of the basic LHC processes has been started. Proposal for PDF monitoring via D- or B-meson yields was given. Both these activities are in initial stage [8].

Since January 2007, JINR site is successfully integrated in the ATLAS distributed data management (DDM) system. Training of usage of distributed analysis tools (GANGA) is ongoing. Recent versions of ATLAS software are installed at JINR (11.0.41, 12.0.31, 12.0.6, 12.5.0). The Tutorial on ATLAS Grid tools and distributed data analysis took place at JINR on 19.04.2007. This was the premier in Russian ATLAS Tier-2.

3. Conclusion

At JINR, many attractive ideas in the ATLAS research program have been investigated. Some of above-mentioned proposals (Higgs, top, SUSY) have already passed the procedures of simulations, background estimates and reconstructions in the ATLAS. JINR has well established contacts with Russian ATLAS community, and these contacts should be extended and improved. Official ATLAS software has been installed at JINR, GRID structures are constructed and already have been used for data generation within the ATLAS community. With these tools we are ready to meet the first real data from the LHC.

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SUDJELOVANJE JINR U ISTRAŽIVAČKOM PROGRAMU ATLAS

Daje se kraći pregled sudjelovanja JINR u istraživačkom programu ATLAS. Posebice se raspravljaju kratko- i dugoročni planovi i djelatnosti u fizici Higgsa, top kvarka, SUSY, te egzotične fizike i standardnog modela.