The Form No. 24

Upgrade of the ATLAS Detector

ATLAS Collaboration

Theme 02-0-1081-2009/2019

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DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD _________

DATE OF THE LABORATORY STC _________ DOCUMENT NUMBER _________

STARTING DATE OF PROJECT _________
(FOR EXTENSION OF PROJECT — DATE OF ITS FIRST APPROVAL) _________

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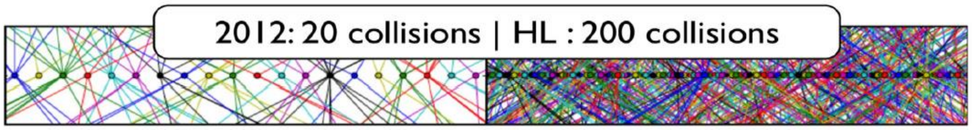
ABSTRACT

The ATLAS detector upgrade programme follows the LHC upgrade scenario. The installation period of the ongoing Phase-I upgrade will start in the second long shutdown (LS2) in 2019-2020. The High Luminosity upgrade of the LHC (HL-LHC) is currently expected to begin operations in the second half of 2026, with an ultimate luminosity of $L \approx 7.5\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ corresponding to an average $\mu=200$ inelastic pp collisions per bunch-crossing and providing a total integrated luminosity of 3000 fb^{-1} by 2035. It will provide rather challenging environment for detector operation:



The high luminosity and the resulting high number of collisions per crossing will result in degradation of the physics performance of ATLAS unless the detector systems are upgraded. To maintain the requirement of being able to trigger low pT leptons, a new trigger architecture is proposed. This requires the upgrade of the readout systems of the detectors: Tracker, Liquid Argon and Tile calorimeters and the Muon Spectrometer. The Tracker system will need to be completely replaced to maintain tracking performance in the high occupancy environment and to cope with the corresponding data rates and approximately factor of ten increase in total radiation fluence. Additional detectors will allow the Muon Spectrometer to suppress contribution from the fake muons. The increased fluence may also potentially lead to unacceptable degradation of the cold front-end electronics in the liquid argon hadronic endcap calorimeter and new technologies are explored that will provide the required radiation hardness. The performance of the Forward Calorimeter is degraded by space-charge effects due to the increase in the instantaneous luminosity and new designs are being developed that could be deployed to address this.

The JINR group is involved in the ATLAS Upgrade projects (both, Phase-I and Phase-II) for Muon Spectrometer and Calorimeters. In this document we report our main achievements in 2015-2017 and future plans for period of 2019-2021 and beyond.

INTRODUCTION

The ATLAS experiment upgrade is organized in two phases, in step with the planned upgrades of the LHC. The Phase-I Upgrade is targeted primarily for installation during the second long shutdown (LS2) in 2019-2020, and Phase-II (HL-LHC era) during LS3 in 2024-26 (see Fig.1).

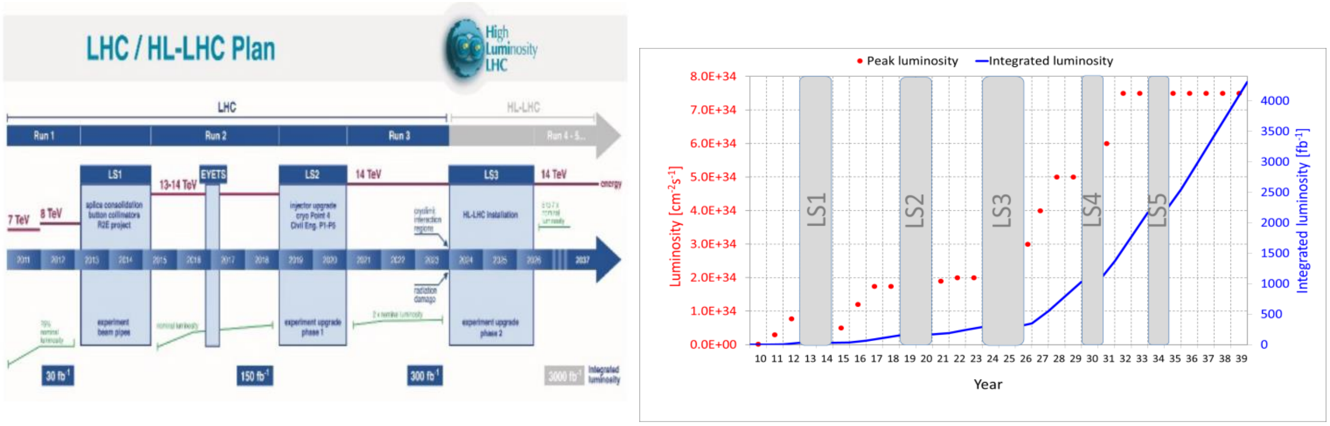


Fig.1. *The new LHC and HL-LHC timeline as endorsed by CERN management (last update 21.07.2015) and expected luminosity profile.*

Detector improvements for Phase-I should provide operation at the peak instantaneous luminosities of up to 2.2×10^{34} $cm^{-2}s^{-1}$. Improvements focus primarily on enhancing trigger capabilities in order to maintain good physics selectivity despite much higher data and background rates. Majority of the upgrade works are designed to satisfy Phase-II requirements, and will continue operating in ATLAS throughout the Phase-II period.

A total integrated luminosity of 3000 fb^{-1} will be provided by 2035. This will present a unique opportunity to significantly extend the study of the properties of the Higgs boson, probing a number of rare decays for the first time and significantly improving the precision of coupling measurements and allowing access to the Higgs self-coupling, along with providing substantial additional mass reach in searches for many signatures of new physics (in several cases well into the multi-TeV region).

Although the increase of HL-LHC energy is moderate, the incredibly high statistics will allow rather precision measurements. Let us illustrate the prospects of the ATLAS physics in the HL-LHC era when about 150M of Higgs bosons and 120K of Di-Higgs events will be recorded by the detector. Fig.2 demonstrates expected relative uncertainty on the signal strength for Higgs final states in the different experimental categories. It was shown that the HL-LHC would be able to probe Higgs couplings deviations w.r.t. SM with a precision of a few percent. It will be possible to measure rare Higgs decay and production modes as $H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$ and ttH, and get evidence for Higgs pair-production.

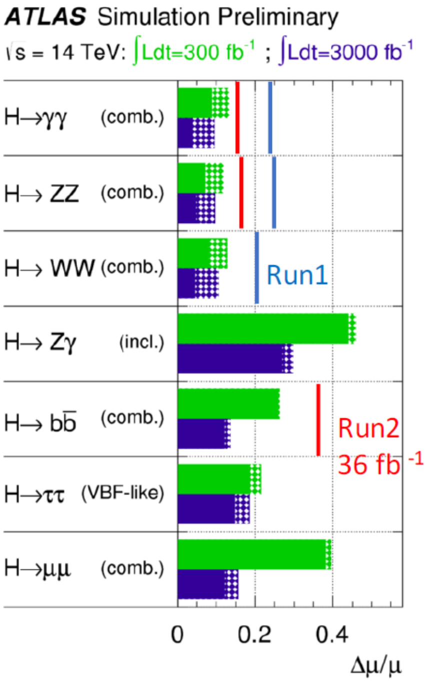


Fig.2. *Relative uncertainty of the signal strength μ.*

The JINR group commitments in Phase-I upgrade were defined in the corresponding Technical Design Reports [1-4] and Memoranda of Understanding [6-8]. Four major ATLAS Phase-I Upgrade projects were approved in 2014. Three of these projects are now advancing largely according to plan, while the New Small Wheel (NSW) is significantly delayed because of poor quality of the initially delivered PCB materials.

The **New Small Wheel (NSW)** will replace the present innermost stations of the endcap Muon Spectrometer, the so-called Small Wheels, with a new improved performance detector assembly. The NSW uses two detector technologies, Micro-Mesh Gaseous Structures (Micromegas, MM) and small-strip Thin Gap Chambers (sTGC). Both chamber types provide tracking and triggering capability with track reconstruction resolution of better than 100 µm per detection plane. Five production sites for MM chamber production (including Dubna) passed their Production Readiness Reviews in 2017. All sites now have production readout PCBs and started series production of MM chambers. The goal is to achieve a production rate of one quadruplet every two weeks in each production consortia, with additional contingency time for repairs, etc. This should allow integration of the chambers in time for installation in LS2.

The **LAr Phase-I upgrade** is aimed at improving the Level-1 calorimeter decision for Run 3 and beyond by enhancing jet rejection and pile-up subtraction capabilities. To achieve this goal, the trigger decision will be based on increased information about the calorimeter energy deposits in both the transverse and longitudinal directions by defining 10 “supercells” for each of the previous trigger towers. This new information is digitized on the detector, and transmitted by optical fibers, where it undergoes further processing and calibration, and is transmitted to the new Phase-I Level-1 calorimeter trigger system. This upgrade requires the replacement of existing on-detector trigger electronics with new layer-summing boards and baseplanes to extract the new supercell signals, new trigger boards (LAr Trigger Digitizer Boards, LTDB) to digitize the supercell signals, and optical data transmission hardware. The JINR group contributed to the development of the digital trigger electronics and baseplanes. We also participated in testing and production of the TILE calorimeter scintillators, as well as in development of the Demonstrator project for readout electronics.

The Phase-I projects have made very substantial progress. The commitments of the JINR group for the ATLAS upgrade are being successfully implemented. The ATLAS plan for the next stage of the detector upgrade is documented in the Phase-II Upgrade Scoping Document [9]. The high particle densities and substantial integrated radiation expected in the HL-LHC environment require a number of highly innovative technology developments to be able to achieve the required physics sensitivity. In addition to the necessity of completely replacing the current inner tracker, much of the electronics on the other detector systems will need major upgrades to be able to cope with the higher trigger and readout rates required at the HL-LHC. The corresponding Phase-II TDRs for the main ATLAS subsystems should be submitted by the end of 2017, and all reviews should be completed by April 2018. In the meantime, all Phase-II projects will begin preparing their Phase-II MoUs for signatures.

In this document we report the main results obtained by the JINR participants in 2015-2017 and our future plans.

Upgrade of the ATLAS Calorimeters

Until the end of 2016 several options of the LAr calorimeter upgrade were remained relevant. In particular, it was unclear whether “cold electronics” of the hadronic endcap calorimeter (HEC) immersed into the LAr cryostat will withstand harsh radiation environment, there were several options for the new forward calorimeter, so called mini-FCal (Xe-gas, diamond sensors, small gap LAr), very important work was also ongoing on development of the new readout electronics.

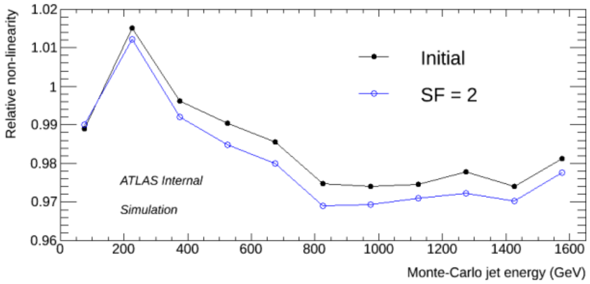


Fig. 3. *Relative non-linearity of the jet energy.*

The results of the radiation hardness tests performed at the IBR-2 reactor in 1990’s were used for simulation of the di-jet events in the ATLAS geometry. Degradation effect for the jet energy non-linearity is shown in Fig.3 for twice higher value of the total luminosity expected at HL-LHC (3000 fb^{-1}). HEC performance degradation does not exceed the acceptable level of ~0.5%. This important result allowed the Collaboration to avoid an expensive and very risky operation of the cryostat opening.

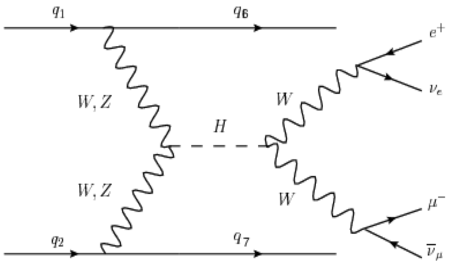


Fig. 4. *Feynman diagram for VBF process.*

Simulation activity continued within the so called sFCal project aimed on replacement of the existing FCal calorimeter by the new one with a similar structure but thinner LAr gaps. As a benchmark process the heavy Higgs boson production via the vector boson fusion (VBF) mechanism was considered (Fig. 4). These processes could be triggered by reconstructing two forward jets, there should be no central jets and hadron production in the central region is suppressed (“rapidity gap”). Degradation of the FCal was mimicked by removing from the reconstruction algorithms the calorimeter signals from the readout cells near the beam pipe (high pseudorapidities η). The “dead” area of the calorimeter was expanded by decreasing the η-cut. Fig.5 demonstrates relative losses of the signal acceptance under the assumption that the front longitudinal segment of the forward calorimeter is affected by the charge built-up in the LAr gap and HV sagging. Again, the 50% loss of the VBH signal (for m_H = 2.6 TeV) when the whole FCal is “switched off” as well as simulation results of several other groups, were not convincing enough for taking decision on replacement of the FCal.

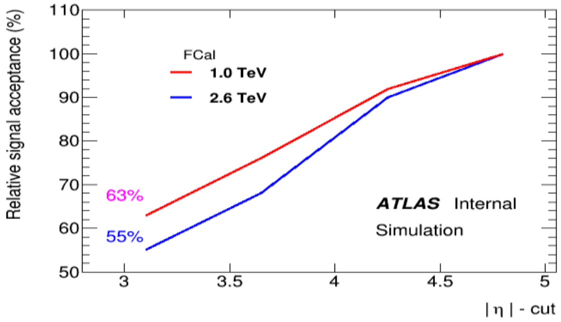


Fig. 5. *Relative acceptance of VBF signal.*

Irradiation programme at IBR-2 reactor included tests of various components of the mini-FCal candidates – different readout electrodes, polycrystalline and single crystal diamond sensors, etc. Fig. 6 shows compilation of the irradiation tests [10] performed on diamond sensors in various beams (see legend). The bottom curve made of small red and blue dots represents data we obtained for two poly-crystalline sensors (DD1 and DD4): only 2% of the initial response remained after the fluence of 10^{17} n cm^{-2}. The tests performed on a single-crystal sensors from the Nanjing University (China) and labelled as CH1 [11] show much better resistance to neutron irradiation. These sensors are therefore promising candidates for a future application in high energy physics experiments.

Irradiation tests of the HEC baseplane prototypes were performed in several runs at the IBR-2. Various parameters of the prototype were checked. In particular, the interconnectors impedance was measured before and after the irradiation and found unchanged within 2% (±1 Ohm) with no systematic deviations. These results allowed the ATLAS Collaboration to approve application of the HEC baseplane for the LAr Phase-II upgrade.

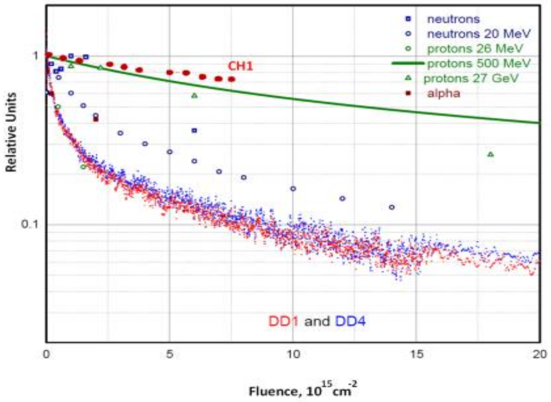


Fig. 6. *Degradation of diamond sensors.*

The JINR group has participated actively in HiLum-1 and HiLum-2 experiments at U-70 accelerator in Protvino. Several prototype modules of the ATLAS forward calorimeters were tested in high-intensity proton beams addressing, in particular, the effect of space charge on the pulse shape which affects the detector performance.

The early beam-test results for two modules, one with a narrow LAr gap (119 μm) and another with nominal (269 μm) electrodes are compared in Fig. 7. Whereas the latter (shown in the inset) shows the fall of response at a critical beam intensity corresponding to the nominal LHC luminosity, 10^{34} cm^{-2} s^{-1}, the narrow-gap electrodes demonstrate a stable response up to ten times higher intensities.

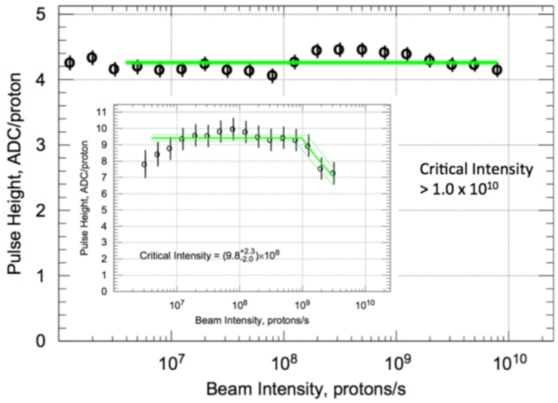


Fig. 7. *Response from the test cells of the FCal (signal pulse height) to the increase of proton beam intensity.*

The goal of the HiLum-2 experiment is precision measurements of space charge effect in LAr which will be used for the analysis of the FCal signals in the HL-LHC environment. The HiLum-1 facility was upgraded in 2015 and prepared for the physics run. In particular, the amplifiers were fabricated and a digitization system for ionization chamber was created for the proton bunches monitoring. Some other equipment was purchased. Two physics runs took place in April 2016 and April 2017. Responses from four test mini-modules were recorded at various values of the high voltage – nominal, low, high and inverse bias voltages. The measurements were done at different intensities of the proton beam corresponding to the nominal LHC luminosity as well as the HI_LHC

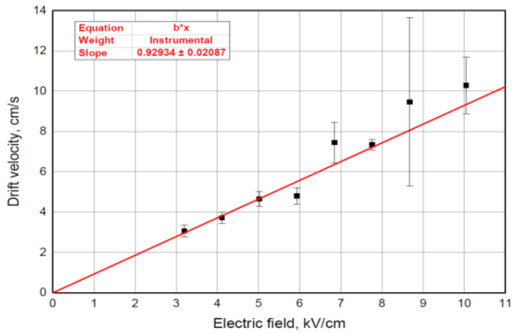


Fig. 8. *Drift velocity of ions in liquid argon.*

conditions. The first results show good quality of the experimental data. Preliminary estimates of the drift velocity of ions as a function of high voltage value in LAr gap are presented in Fig. 8. The ion mobility is in a good agreement with the previous measurements. The experiment will continue within the Collaboration activity aimed on development of the global model for the ATLAS calorimeter behavior in the HL-LHC era.

The JINR group participates in electronics development of the ATLAS LAr calorimeters for both, Phase-I and Phase-II upgrade programmes.

The LAr read-out electronics to be installed for the HL-LHC phase will implement radiation tolerant front-end electronics which performs the pre-amplification and shaping of the analog signals of all 183.000 LAr detector channels and an early analog-to-digital conversion without on-detector buffering of data. The replacement of the LAr read-out electronics will allow an optimization of the analog and digital signal processing in order to improve the trigger and physics input during high-luminosity operation and to mitigate pile-up effects. A new electronics for the level-1 trigger is being developed in Phase-I period. The analog trigger signal will be shaped and digitized in the new module, the LAr Trigger Digitizer Board (LTDB). There will be 200 LTDB modules of five different types in ATLAS. One type of LTDB will serve the HEC, it has different configuration of the input part for analog signals. The JINR group will test the performances of various module schematics developed at CEA, France. At the first stage the Spice simulation will be done for the analog part of the LTDB to study possible distortion of the HEC signals. At second stage a single-channel version of the input cascade will be made, and full cycle of measurements will be performed at a special automated stand. This study must be completed by the end of 2018.

The LAr readout electronics will be replaced during Phase-II upgrade, including readout electronics of the “cold” preamplifiers for HEC. The analog blocks will be integrated into CMOS ICs, and we would need special schematics for these preshapers. A detailed Spice simulation of the HEC preshapers was performed in 2015-2016. The prototype was developed and tested at the automatic stand. The measurements confirmed the agreement of the scheme parameters and simulation. The next step will be development of the final prototype made of discrete CMOS transistors with the functionality close to the final circuit.

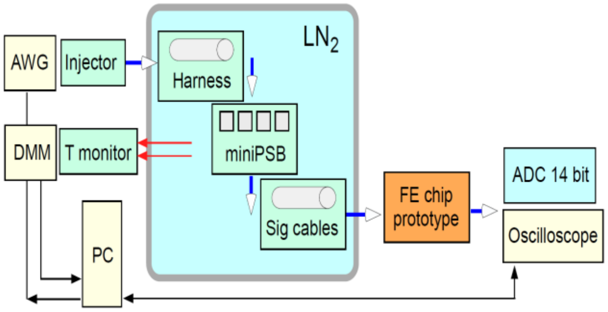


Fig. 9. *Upgraded stand of electrical prototype testing.*

In parallel to the preshaper development we have started modernization of the test bench for testing the new prototypes. The block diagram of the new stand is presented in Fig. 9. In addition to the existing equipment, which comprises AWG generator, DMM multimeter, scope, computer and power suppliers, a mock-up of the HEC cryogenic electronics (input and output cables, and “cold” preamplifiers) will be built in 2018. It will allow us to test electronics in the same conditions like they are in the ATLAS experiment. In addition to the scope measurements the signals will be digitized at fast 14 bit ADC (the same type as in the HEC electronics). This modernization will be done in collaborative work with TRIUMF, Canada.

The Minimum Bias Trigger Scintillators (MBTS) were installed in the endcap area of the LAr calorimeters and delivered the primary triggers for selecting events from real LHC collisions with the smallest bias. During Run I these scintillators operated in harsh radiation environment and some deterioration of scintillator's light output was noticed. It was decided to replace existing MBTS counters with the new ones. The JINR group made a proposal to use radiation hard scintillators in the "hot" area of the ATLAS detector and provided new scintillator slabs for the MBTS renewal. New tiles were cut at CERN from the slabs. In the new MBTS scintillator counters grooves are now close to border and straighten for better uniformity and light collection. Fig. 10 shows details of the old (left) and new (right) MBTS counters. The new MBTS scintillation counters were installed just before the start of Run II of LHC.

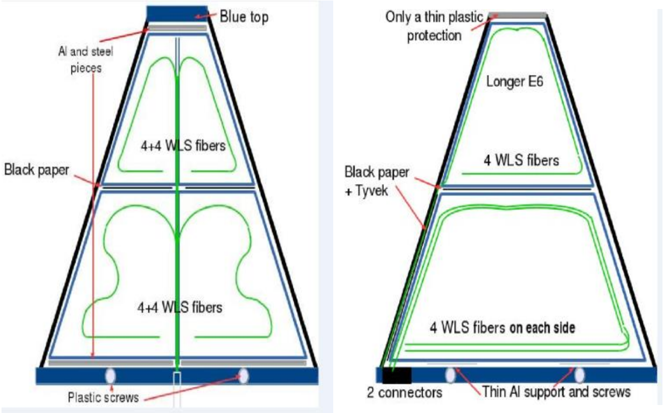


Fig. 10. *The old (left) and the new (right) design of the MBTS counters.*

Fig. 11. *Movable platform during test beam.*

The JINR group also participated in design and bench tests of the new readout electronics for the TILE hadron calorimeter, so-called Demonstrator. New control system for movable test beam table in H6 area at SPS CERN was developed allowing the precision of the table settings of ±0.5cm for X,Y and Z coordinates and ±0.5° for η and φ (relative to the beam direction). During the 1st test beam one long and one extended barrel modules were placed on the table, 35 tons of materials in total (see Fig. 11). Full capacity of the table is 100 tons. Our group was actively participated in the test beam data taking and analysis.

Sample	Fluence, n/cm^2
S1	$1.8\cdot10^{14}$
S2	$1.7\cdot10^{13}$
S3	$3.8\cdot10^{12}$

Table 1. *Neutron fluence values.*

Study of radiation hardness of plastic scintillators for the Inter-TileCal (ITCS for Gap & Crack) ATLAS detector counters is in progress. Samples of UPS-923A scintillators were irradiated at the IBR-2M pulsed reactor to neutron fluence between $3.8\cdot10^{12}$ and $1.8\cdot10^{14}$ n/cm^2 (see Table 1). Fig. 12 demonstrates light yield of irradiated samples relative to the non-irradiated sample. Light yield was estimated from measurements of PMT current by Keithley 6487. The light yield of a most irradiated sample (S1) is degraded by about 28%.

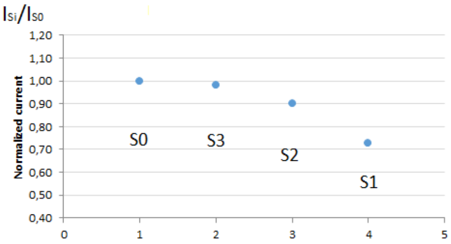


Fig. 12. *Signal degradation.*

We plan to continue our work on the study of new radiation hard scintillators. A new electronics (software & hardware) will be developed for the test stand of PMT blocks as part of Phase-II Upgrade project. We also plan to participate in tests, installation and commissioning of the new MBTS scintillators in 2018-19.

Upgrade of the ATLAS Muon Spectrometer

Very significant achievement of the JINR group since our report to the PAC PP was construction of the workshop for the MicroMegas chambers production and the quadruplets assembly in the framework of the NSW ATLAS project of the Phase-I Upgrade. It is located in the Dzhelepov Laboratory of Nuclear Physics.

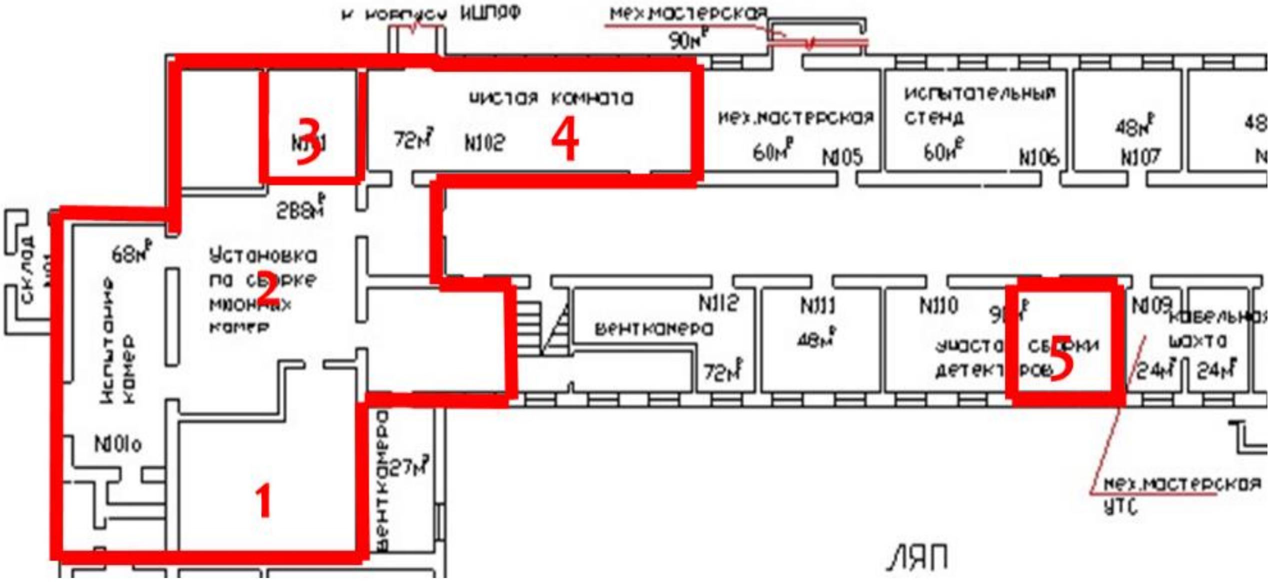


Fig. 13. *MM production workshop: 1 – panel production, 2 – cosmic stand, 3 – gas leak tests, 4 – quadruplets assembly and testing, 5 – room for panel washing.*

All necessary equipment was purchased and put into operation. The site was commissioned and mass-production of the MM chambers has started in 2017. The workshop comprises 5 premises, as shown in Fig. 13 - clean room (72 m^2, purity class ISO 7) for production of read-out panels and testing of their geometrical characteristics; hall (~150 m^2) for testing quadruplets at the stand with cosmic rays; room (~25 m^2) for gas leak testing of panels; clean room (~50 m^2, purity class ISO 6) for assembly and testing of quadruplets, and premises (~25 m^2) for panels washing. The air-conditioning system and supply/extraction ventilation have been completely upgraded in the clean room for the readout panel assembly. In both clean rooms the control of temperature and humidity is carried out (±0,5°C and ±10%). Some details about the workshop and MM panel production are presented below.

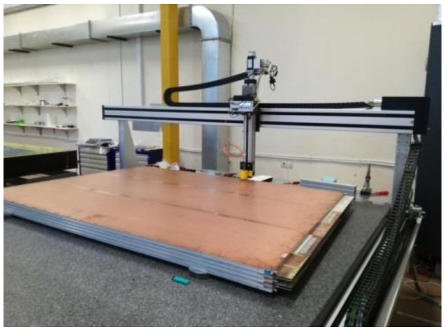


Fig. 14. *Stand for semi-automatic measurements of geometric characteristics of readout panels and quadruplets.*

Test stand was constructed (see Fig. 14) and tuned for semi-automatic measurements of geometric characteristics of readout panels and quadruplets (2990mm x 2500mm x 500mm working area).

Stand for the testing of panels and quadruplets for gas leakage (see Fig. 15) consists of a differential pressure manometer, gas mixer and the panel holder.

Special stand was constructed to assemble quadruplets from drift panels of Micromegas chambers (Fig. 16).

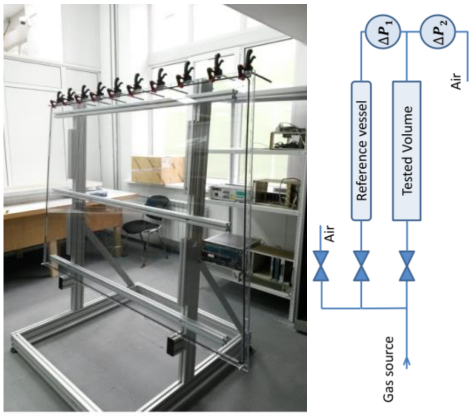


Fig. 15. *Stand for gas leak tests of panels and quadruplets.*

Fig. 16*. Stand for quadruplets assembly.*

Quality control of the quadruplets performs with cosmic muons. Testing facility consists of a load-bearing construction with moving cartridges to attach quadruplets, a power supply with a floating ground, two planes of scintillators (2,5x2m^2 and 3x2 m^2) with built-in power sources, amplifiers and discriminators, and NIM coincidence modules to create a trigger signal. All these elements together with the gas line from the mixer are shown in Fig. 17.

The high voltage stand for readout panels testing includes the power suppliers CAEN R1471ETD (8 channels, precision of 0.5 nA) and SY5527LC, and three A7435DP (36 channels, 1 nA), Giga Ohm Meter and a small imitation of grid to detect trouble spots.

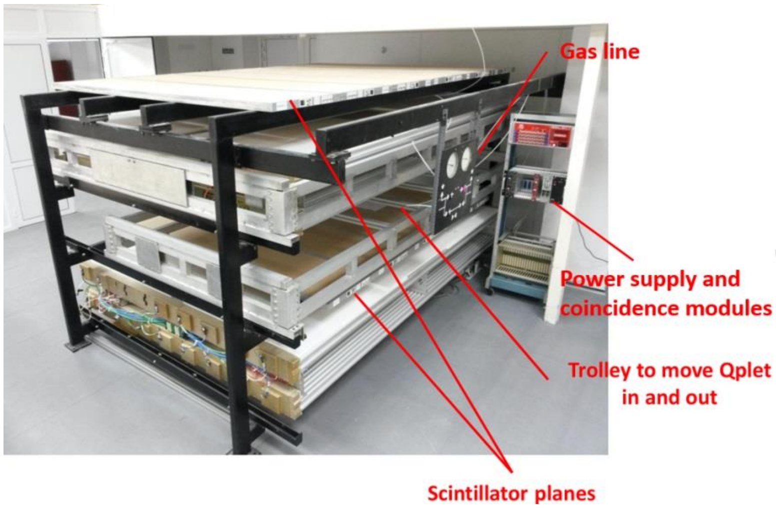


Fig. 17. *Stand for quadruplets tests at cosmic muons.*

In order to accelerate the process of panel assembly we have developed and constructed semi-automatic gluing system (Fig. 18). The system is currently being tested and debugged.

Production of read-out panels of MicroMegas chambers has started once the JINR site was commissioned. Four readout panels of MicroMegas chambers have been made by November 2017. All of them were tested for gas leakage. Geometric characteristics (thickness and

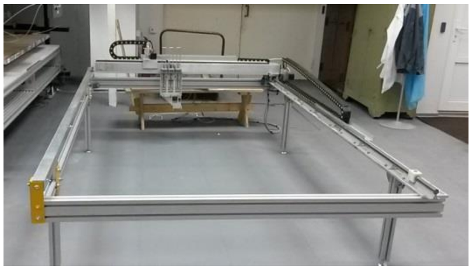


Fig. 18. *Semi-automatic gluing system.*

planarity) were also estimated using the stand for semi-automatic measurements. The measurement results satisfy the requirements of the NSW Collaboration. In Fig. 19 different stages of panel production are presented, from gluing to the final assembly.

Fig. 19. *Stages of panel production.*

Two readout panels and three drift panels were used for the quadruplet assembly. The quadruplet planarity was measured (Fig. 20) and it was tested for gas leakage. The measurement results met requirements of the NSW Collaboration.

Fig. 20. *Measurements of quadruplet planarity.*

The JINR group will ensure the production and testing of 64 read-out panels and subsequent production and testing of 32 quadruplets in collaboration with the University of Thessaloniki, Greece, in the period of 2017-2019. We will also participate in the integration of the quadruplets in the NSW structure and commissioning of the NSW detector during the long shutdown of the LHC, LS2, in 2019. In the ATLAS Phase-II Upgrade program the group will be engaged in development and production of the new Resistive Plate Chambers (RPC). A new layer of RPC chambers will reduce acceptance losses and will increase system redundancy.

Very important addition to the ATLAS production site was made in DLNP in 2015-2017. A new workshop for production of "small-sized" (600mm x 1000 mm) MicroMegas chambers for research and advanced applications was built in the Dzhelepov Laboratory. All necessary equipment has been purchased, installed and tested to allow complete production cycle. This enables the Institute staff to participate more effectively in different physics experiments and in applied researches. Mass-production of the “small-sized” MicroMegas chamber will start in DLNP in coming years (2018-2020).

ATLAS Collaboration considers seriously safety and radioprotection aspects of the detector operation. The JINR group in collaboration with Tomsk University, Russia, Czech Technical University in Prague, Institute of Experimental and Applied Physics, Czech Republic and CERN made a proposal for development of a novel technology for semiconductor pixel detectors based on GaAs:Cr material construction. These detectors has significantly higher efficiency for registration of gamma’s and neutrons than the standard Si-based detectors. Ten GaAsTimepix pixel detectors were produced, tested and installed in the ATLAS cavern as the radiation background monitors.

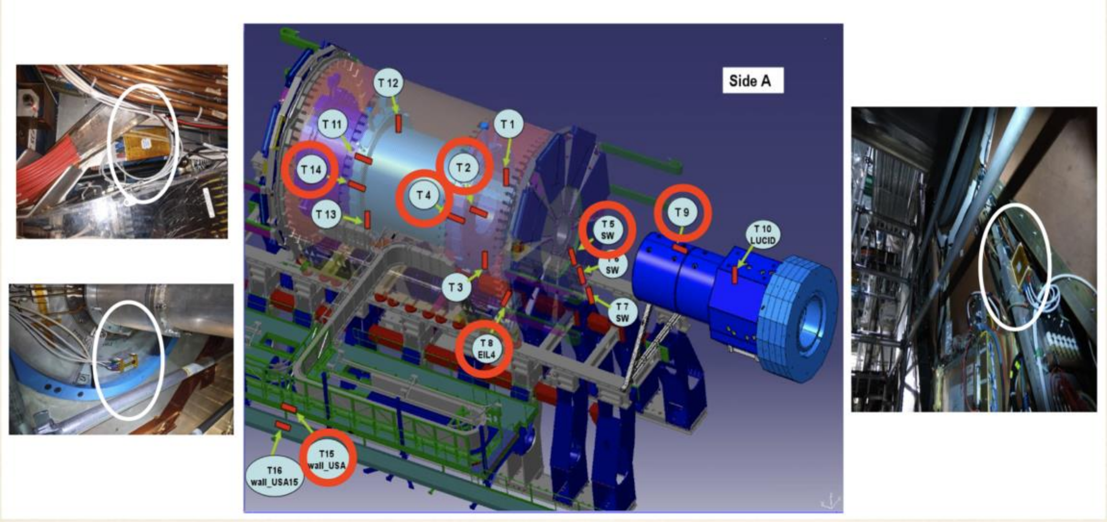


Fig. 21. *Scheme of the GaAs monitors placing in the ATLAS detector, and photos of individual detectors at their locations.*

Fig. 21 shows scheme of the GaAsPix monitors in the ATLAS detector. The work is ongoing on development of the effective patter recognition algorithms. These monitors allow registration of the neutron induced activity and the neutron fluence measurements at various locations of the ATLAS detector. Registration and identification of the background particles is carried out on-line. The work is ongoing to get the live pictures and the data available in Dubna for the monitoring and analysis.

The ATLAS magnet system includes a central solenoid, barrel toroid and two end-cap toroids servicing the muon spectrometer. The magnet system comprises stations of pumps maintaining insulation vacuum for the four cryostats; a cryogenic plant for supply of liquid helium; proximity cryogenics enforcing helium circulation on the cold masses; two power converters for energizing the solenoid and toroids and their electrical circuits with switchers, bus-bars and diod-resistor units for absorbing the stored energy in the case of a slow dump. For guaranteeing a long-term trouble-free operation of the magnet system a thorough maintenance and consolidation plan id needed for the conventional part of the system as the magnets themselves are rather stable in performance. In cryogenics the work continues on the commissioning the new 10kL solenoid storage dewar. After resent successful commissioning the system of toroids is now equipped with a modern safety system. In the meantime, the magnet team is preparing the maintenance activities planned for the winter stop 2017 as well as the more voluminous consolidation activities during the next LHC long shutdown which will start in December 2018.

Human Resources

A total number of personnel in the JINR group participating in the ATLAS Upgrade program are 44 providing 27 FTE. They are 27 physicists, 13 engineers and 4 technicians. Major part of them is engaged in the project for many years. They have well recognized reputation within the Collaboration and beyond, solid expertize and necessary skills to fulfil all our obligations.

Estimation of Budget

Our commitments in the ATLAS Phase-I Upgrade should be fulfilled by 2018-2019. The work on Phase-II already goes in parallel. As far as the ATLAS Phase-II concerned, three different upgrade configurations of the ATLAS detector have been defined, corresponding to three costing scenarios, with total CORE[1] costs of about 200 MCHF, 235 MCHF, and 275 MCHF respectively. It is expected that participating institutions share the financial cost of the detector upgrade. The JINR share in Phase-II Upgrade program is about 3 MCHF. These costs are included in the Seven Year Plan for the Development of JINR (2017-2023). Our goal is to maximize the JINR in-kind contribution. The breakdown of the planned expenses is presented below.

Within the upgrade project for Calorimeters we will continue R&D work on development of the front-end readout electronics, new scintillators, testing and products certification.

- Study and development of the analog part of the HEC LTDB trigger block, mock-up construction, test bench and tests of the performance – 30kUSD
- Development of the analog part of amplification block of the main HEC FEB ASIC, including simulation, prototyping and mock-up for the performance tests- 30kUSD
- Purchase and performance study of the integral version of the main amplifying chip for HEC FEB: purchase - 100kUSD, test stand construction - 30kUSD, clean room equipment - 5kUSD
- Radiation tests of the LAr readout electronics: 10kUSD
- Development of gap/crack scintillators for TILE Calorimeter and radiation hardness tests, purchase of composite scintillators-50kUSD
- Test bench upgrade for TILE electronics: scope, FADC, power suppliers, FRGA - 50kUSD
- Development of PMT blocks and their certification: test stand for electronics development -25kUSD

Within the upgrade project for Muon Spectrometer we will continue intensive mass-production of the MicroMegas chambers and quadruplets assembly for the NSW projects. The chambers will be supplied to CERN and our team will participate in their integration in the NSW structure and final detector commissioning.

- Development of the project for data analysis and visualization (station of 5 PC, ethernet link blocks, measurement tools - generator, FPGA)~35kUSD
- LM2 quadruplets production, transportation, integration and final commissioning:
  - Transportation tools for quadruplets, lifting tools for quadruplets integration into NSW frame, rotating tools for LM2 quadruplets – 55 kUSD
  - LM2 quadruplets shipment to CERN – 15 kUSD
  - FE electronics for ATLAS Micromegas chambers, purchase – 40 kUSD
  - Precise aluminum profiles, epoxy glue and Mixer-dispenser for MM production and the quadruplets assembling – 30 kUSD
  - Low-noise preamplifier chips production for Micromegas – 30 kUSD
  - Trigger system for large-area detector’s cosmic tests – 60 kUSD
  - Accompanying laboratory equipment (power supplies, oscilloscope, Keithley HV picoampermeter, profilometer, optical ruler, etc.) – 60 kUSD
- R&Ds for Micromegas chambers and sRPC – 40 kUSD

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[1] The CORE (Cost of Resource Exchange) value identifies only the deliverable’s direct cost; it excludes associated manpower costs, exchange rate fluctuations, prototyping cost, R&D costs, etc. It includes items such as components, industrial stuff (but not institute staff) for production, outsourced parts of assembly, installation, test and commissioning.

SWOT Analysis

The approach developed by our Dutch colleagues from the Nikhef [12] was used as a good starting point for the present analysis.

Strength

1. Participation in a large and challenging international projects in a competitive and high-tech, internationally oriented, research arena.
2. Excellent scientific publication and citation records.
3. Collaborations with groups at the leading international accelerator center (CERN) and other physics laboratories.
4. Large interest of the general public and media.

Weaknesses

1. The growing age of staff scientists and engineers.
    - The efforts are undertaking to attract young students to join the project.
    - JINR and CERN are the founder of the Russian Language Teacher Programme [13].

Opportunities

1. LHC shows huge discovery potential which attracts scientists at all levels (master students, PhD students, postdocs and staff physicists alike).
2. JINR experiments often require completely new and challenging technologies and ATLAS offers our technical departments possibilities and contacts with new research communities. New technology of MM is already brought to JINR.
3. The experience gained in the ATLAS experiment is shared with our colleagues from the NICA project.
4. The BiG Grid - e-science grid–project JINR-LCG2 - provides researchers at JINR with state-of-the-art computing services and an opportunity to establish contacts and/or collaborations with many other research disciplines.

Threats

1. Project delays due to lack of funding for large projects (>3 M€ investment cost)
    - ATLAS physicists are very active in the relevant committees that should attract additional funding. JINR has already brought the LHC upgrade plans to the attention of MEO RF. CERN management is also helping us to get funding.
2. Some cases of excessive commitments for a single person.
    - Negotiating with the directorates on a proper balance of responsibilities.

Conclusions

The JINR is among the founders of the ATLAS experiment and continues an active participation in various activities within the Collaboration, including data analysis, detector operation & maintenance, and modernization of the detector subsystems.

During past years the JINR group made significant contribution to the upgrade of the ATLAS detector subsystems – Muon Spectrometer and Calorimeters:

- production site for MicroMegas chambers was built and commissioned in 2017;
- the MM mass-production has started and the first 8 chambers have been produced;

- novel semiconductor sensors have been developed in collaboration with Tomsk University, new detectors were made and installed in the ATLAS cavern to monitor the radiation background;
- several prototypes of new readout electronics for LAr calorimeter were developed and tested, including baseplane and HEC preshaper;
- good results were demonstrated in comprehensive tests of the new readout electronics for TILE calorimeter, new radiation hard scintillators were tested and supplied to ATLAS to be used in the "hot" zones;
- a series of radiation tests was carried out at the IBR-2 reactor.

<u>All these activities will continue as detailed in the document. We ask PAC PP to approve the JINR group participation in the ATLAS Upgrade project for the next 3 years (2019-2021)</u>

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12. https://www.nikhef.nl/wp-content/uploads/2016/04/Strategisch_Plan_2011.pdf
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Appendix 3

Form No. 26

Schedule proposal and resources required for the implementation of the Project

Upgrade of the ATLAS Detector

Expenditures, resources, financing sources			Costs (kUSD) Resource requirements	Proposals of the Laboratory on spending profile - finances and resources		
				1st year	2nd year	3rd year
Expenditures		LM2 quadruplets production, transportation, integration and commissioning	220	90	70	60
		R&D for LAr electronics	95	10	55	30
		GaAsPix visualization project	45	15	15	15
		R&D for TILE scintillators and electronics	55	15	15	15
		Construction/repair of premises				
		Materials:				
		FE electronics for ATLAS MM	40	40		
		Aluminum profiles and corners	15	15		
		Epoxy glue	5	5		
		Different materials	6	2	2	2
		LAr readout chips	10		5	5
		Rad.hard scintillators	30	10	10	10
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator; – computer. Operating costs.				
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	511	202	172	137
	External resources	Contributions by collaborators. Grants. Contributions by sponsors. Contracts. Other financial resources, etc.	180	180	?	?

PROJECT LEADER

Appendix 4

Form No. 29

Estimated expenditures for the Project “Upgrade of the ATLAS Detector”

	Expenditure items	Full cost, kUSD	1st year	2nd year	3rd year
	Direct expenses for the Project				
1.	Accelerator, reactor (hours)	800h	400	200	200
2.	Materials	106	72	17	17
3.	Equipment	405	130	155	120
4.	Payments for agreement-based research	100	100		
5.	Travel allowance, including:	296			
	a) non-rouble zone countries	290	90	100	100
	b) rouble zone countries	6	2	2	2
	c) protocol-based				
	Total direct expenses	907	394	274	239

PROJECT LEADER

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER-ECONOMIST