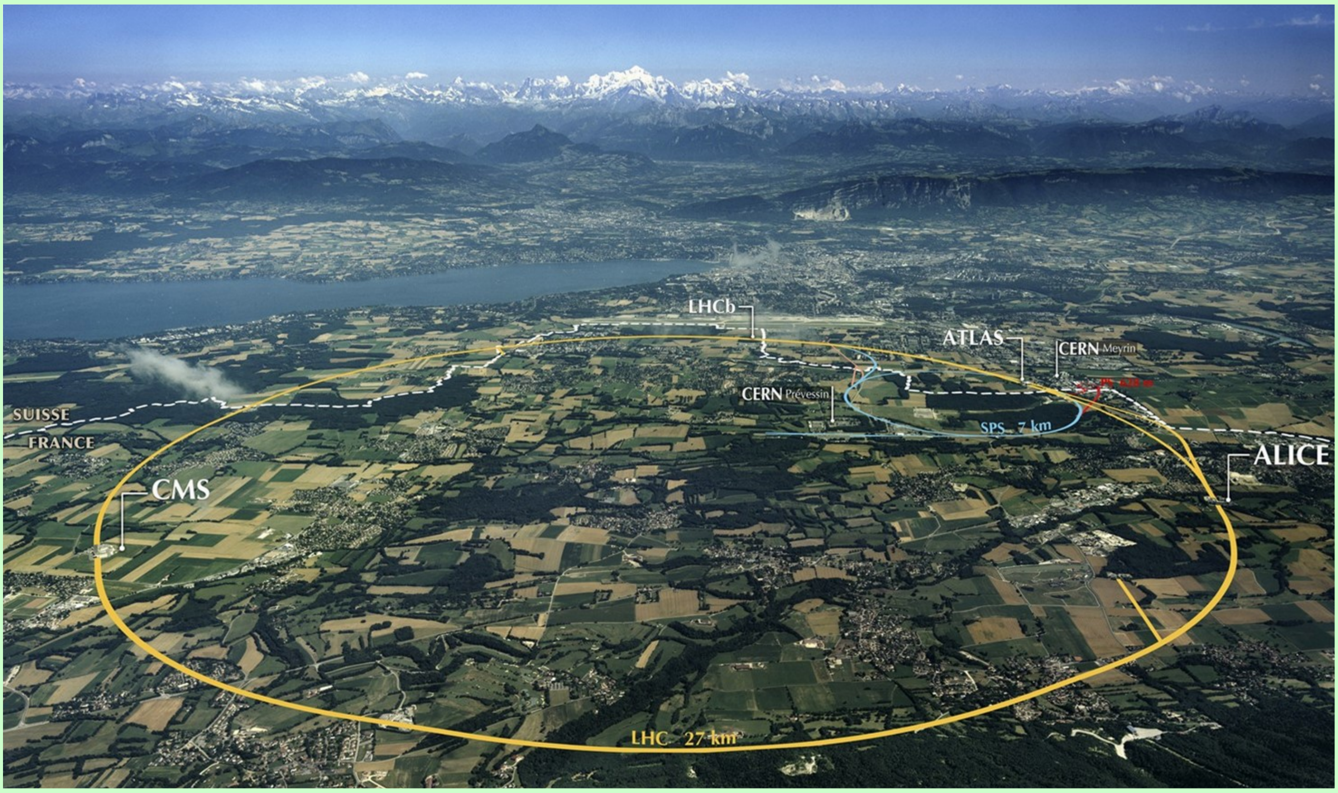
BELARUS AND CERN COOPERATION

HISTORY AND PROSPECTS



Alexander Shumilin, Chairman of the State Committee on Science and Technology of the Republic of Belarus

Belarus is proud of the long term and fruitful multilateral cooperation with European Organization for Nuclear Research – CERN.

Numerous engineers and manufacturers from our country contributed essentially to production and assembling of the wide range of hardware for front-end experiments performed in CERN.

International scientific community highly estimates substantial participation of Belarusian group in physical program of experiments in CERN based on strong foundation established by famous Belarusian scientist – Academician F.I. Fedorov and the next generation of theoreticians (A.A. Bogush, L.M. Tomilchik, V.G. Baryshevsky, N.M. Shumeiko, L.I. Komarov, G.V. Shishkin and many others).

The collaboration between CERN and Belarus provides exceptional opportunities for our industry to access and apply cutting-edge technologies in electronics, computing and material science and engineering.

It is also worth noticing that participation of our students and post-graduates in CERN projects opens unique opportunities to improve their professional skills that will be further actively introduced into the educational process as well as into the research activities and engineering in Belarus.

There is no doubts that close cooperation of Belarus and CERN will promote new wonderful discoveries in physics of microworld and will significantly increase the potential of high-tech industry of our country.

Chairman
of the State Committee on Science and Technology
of the Republic of Belarus

Alexander Shumilin

The first scientific research in the field of elementary particle physics in Belarus was carried out by Fedor Ivanovich Fedorov (1911–1994). The young Belarusian physicist was a post-graduate student in Institute of Physics at Leningrad State University (1933-1936) under supervision of Academician V.A. Fock. The first F.I. Fedorov research was concerned with application of the novel method of Fock functionals to the actual problems of quantum field theory. In particular, he calculated the natural width of spectral lines and the cross-section of Compton scattering.

Academician F.I. Fedorov (1911-1994)

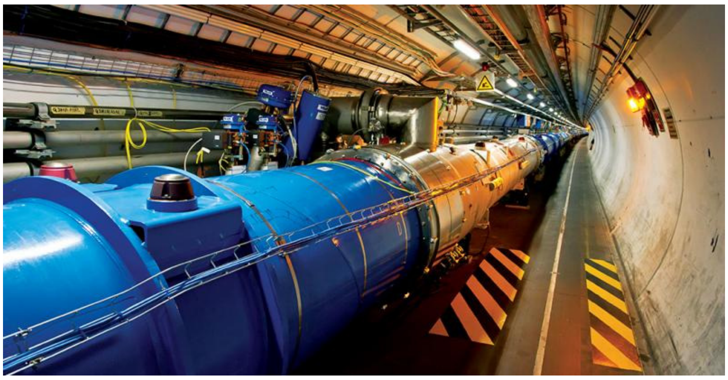
Academician F.I. Fedorov became widely known in world scientific community for his results in theoretical optics (Drude-Born-Fedorov constitutive relations in electrodynamics, Fedorov light beam shift under reflections of the electromagnetic waves from plane bodies of the media with special electromagnetic properties), acoustics and particles physics. The basic ideas of the Fedorov covariant approach to the elementary particle physics were developed in the book F.I. Fedorov, *Lorents group*. [1979, 2003].

Many known Belarusian scientists consider themselves as followers of F.I. Fedorov scientific school. Among them are Corresponding members of NASB A.A. Bogush and L.M. Tomilchik, Prof. E.A. Tolkachev, L.G. Moroz, I.S. Satsunkevich.

Academician P. Apanasevich, Prof. Yu. Budagov (JINR), academician F. Fedorov, Corresponding member of NASB A. Bogush and L. Moroz (from left to right)

Academicians N.A. Borisevich, B.I. Stepanov, F.I. Fedorov and Nobel Prize winner Academician N.G. Basov (from right to left)

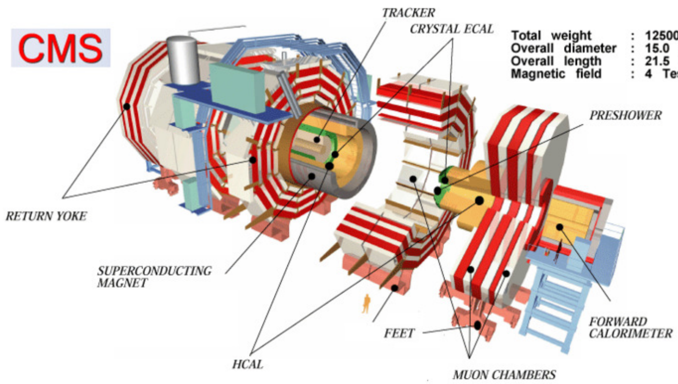
CERN, the European Organization for Nuclear Research, the one of the world's largest and most respected centres for scientific research, is located astride the Franco-Swiss border near Geneva. The main area of research is particle physics – the study of the fundamental constituents of matter and the forces acting between them.



Inside LHC tunnel

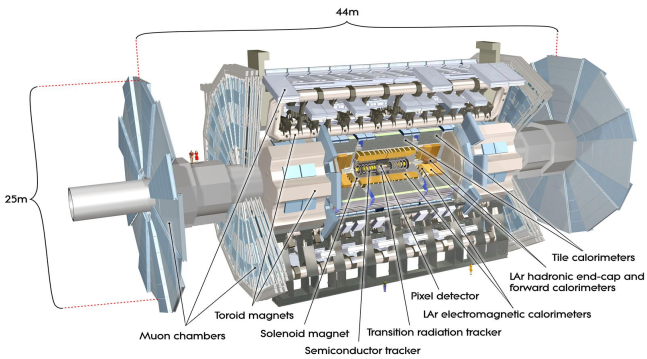
The instruments used at CERN are purpose-built particle accelerators and detectors. Accelerators boost beams of particles to high energies before the beams are made to collide with each other or with stationary targets. Detectors observe and record the results of these collisions. The process gives the physicists clues about how the particles interact, and provides insights into the fundamental laws of nature.

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. The LHC consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way. Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide. LHC use detectors to analyse the myriad of particles produced by collisions in the accelerator. These experiments are run by collaborations of scientists from institutes all over the world. Each experiment is distinct, and characterized by its detectors.

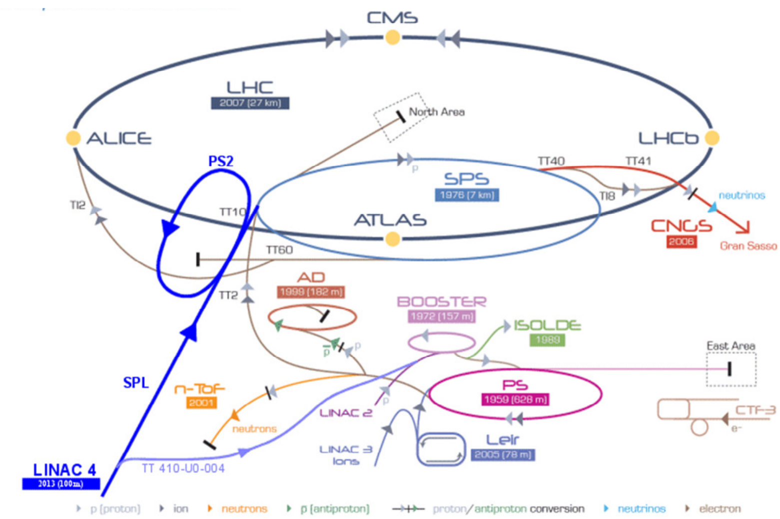


CMS detector at LHC

The biggest experiments on LHC, ATLAS and CMS, use general-purpose detectors to investigate the largest range of physics possible. ALICE, LHCb, TOTEM, LHCf and MoEDAL experiments are focused on specific phenomena.



ATLAS detector at LHC



Accelerators and experiments at CERN

The non-LHC experiments are also an important part of CERN activity. In particular, the COMPASS, NA61/SHINE, DIRAC experiments looks at the structure of hadrons using beams from the Super Proton Synchrotron (SPS) and the Proton Synchrotron (PS). The ACE, AEGIS, ALPHA, ASACUSA, and ATRAP experiments use antiprotons from the Antiproton Decelerator, while CAST is looking for hypothetical particles coming from the Sun. CERN facilities include the Radioactive Ion Beam facility (ISOLDE) and the neutron time-of-flight facility (nTOF).

Being established in 1954, today CERN is an joint venture of 22 *Member State* countries. The six countries are the *Associate Members*. The three countries and three international organizations are *observers*. The 42 non-member states have signed *co-operation agreements* with CERN. The one of them is Belarus.

The co-operation agreement of CERN and Belarus was signed in 1994.

Since 1992 under the leadership of Prof. N.M. Shumeiko (National Center for Particle and High Energy Physics BSU, later – Institute for Nuclear Problems BSU) Belarusian scientists and engineers were actively involved in preparation of the CMS experiment.

Since 1995 Belarus takes active part in CMS Russia Dubna Member States (RDMS CMS) collaboration.

Since 1994 Belarusian scientists take an active part in the preparation of ATLAS experiment at LHC. The Belarusian contribution covers both the detector elements design and production at Belarusian enterprises and the development of the physics program. Nowadays Belarusian group takes active part in experiment data analysis.

Belarusian scientists have joined the recently formed international collaborations for future colliders preparation: Future Circular Collider (FCC collaboration), Compact Linear Collider (CLIC/CTF3 and CLICdp collaborations).

Nikolai Shumeiko
(1942–2016)

Participants of the Belarus–CERN Workshop,
National Center for Particle and High Energy Physics BSU, Minsk, 1996

The five Belarusian Institutes have signed a Memorandum of Understanding with CERN:

CERN Director General Sir Christopher L. Smith, Chairman of the SCST of Belarus Victor Gaisyonok, and NC PHEP BSU Director Nikolai Shumeiko

• **Institute for Nuclear Problems** of Belarusian State University (INP BSU), Minsk
  • *member of CMS, ATLAS, FCC and CLICdp collaborations*

• **B.I. Stepanov Institute of Physics**, National Academy of Sciences (IP NASB), Minsk
  • *member of ATLAS collaboration*

• **Belarusian State University** (BSU), Minsk
  • *member of CMS collaboration*

• **A.N. Sevchenko Institute for Applied Physical Problems** of Belarusian State University (IAPP BSU), Minsk
  • *member of CMS collaboration*

• **Joint Institute for Power and Nuclear Research – Sosny**, National Academy of Sciences (JIPNR-Sosny NASB), Minsk
  • *member of CLIC/CTF3 collaboration*

Chairman of the SCST of Belarus Igor Voitov and CERN Director General Rolf-Dieter Heuer

The scientists from other Belarusian institutes are also involved in CERN activity:

• **P.O. Sukhoi State Technical University of Gomel** (*GSTU*), Gomel

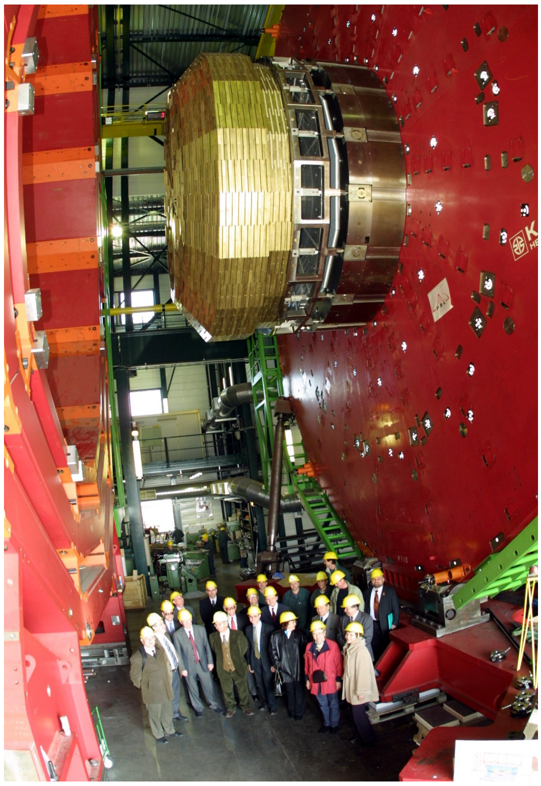
• **F. Skorina Gomel State University** (*GSU*), Gomel

• **Belarusian Powder Metallurgy Association**, National Academy of Sciences (SRPPMA NASB), Minsk

Valentin Gilewsky (JIPNR–Sosny NASB), JINR Chief Scientific secretary Nikolai Russakovich, Spokesperson of ATLAS Collaboration Peter Jenni, NC PHEP BSU Director Nikolai Shumeiko, Vice director of IP NASB Yurii Kurochkin, IP NASB Director Vladimir Kabanov,, Corresponding Member of NASB Andrey Bogush, Institute of Physics NASB, Minsk, Head of BRFFI Scientific Council Academician Valentin Orlovich (from left to right)

In collaboration with JINR (Dubna, Russia) Belarusian scientists and engineers were responsible for manufacturing and installation of the end-cap hadron calorimeter, the important part of the CMS detector.

The Republican Enterprise «MZOR» manufactured the absorber plates and interfaces for the CMS hadron calorimeter end-caps, and also produced special assembly tooling. The work was supervised by National Centre for Particle and High Energy Physics BSU (NC PHEP BSU).



Due to excellent quality of the supplied hardware this work became a hallmark of Belarusian contribution to CERN facilities.

The work was awarded the CMS Gold Medal in 2003.

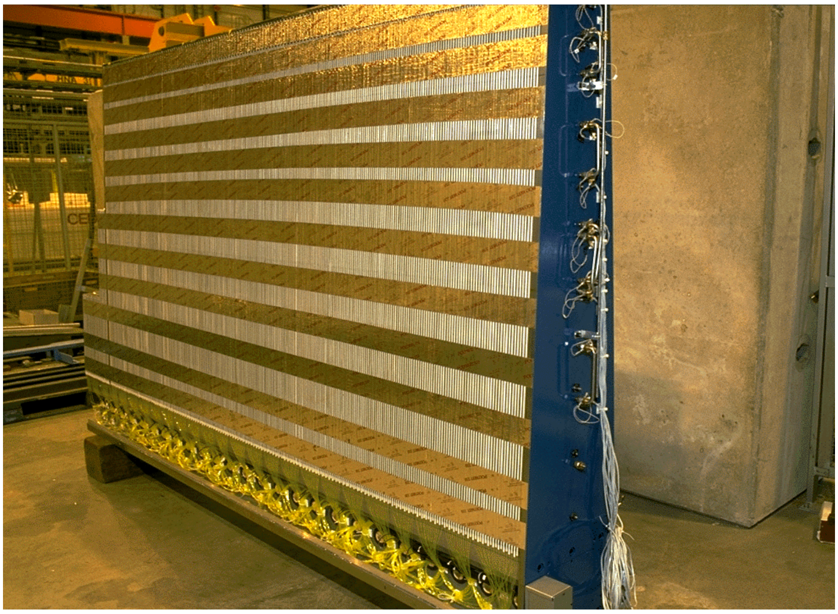
International inspection of CMS end-cap hadron calorimeter absorbers at the Republican Enterprise «MZOR» facility, 2001

Russian and Belarusian engineers receive CMS Gold Awards, CERN, 2003

Russian and Belarusian engineers at CMS end-cap hadron calorimeter, CERN

Prof. Felicitas Pauss, Deputy Chair of the CMS Collaboration Board, presents a CMS Gold Award to Dr. Mikhail Krivomaz, Director-General of the Republican Enterprise «MZOR»

Belarusian engineers were also involved in design and manufacturing of ATLAS project equipment used for calorimetric, muon and magnetic subsystems of the detector. The hardware production was performed by BELARUS MINSK TRACTOR WORKS Republican Enterprises «Minsk Tractor Works» and «MZOR» under the supervision by engineers from NC PHEP BSU (V. Rumyantsev et al.).



ATLAS tile hadron calorimeter manufactured using Belarusian equipment

Viktor Rumyantsev, head of LPP laboratory in NC PHEP BSU

ATLAS Supplier Award

In recognition of excellent supplier performance

ATLAS Supplier Award for MZOR in Minsk

Precise Machining of Al alloy Connection Boxes and Voussoirs for the Barrel Toroid

Minsk Machine-Tool Production Plant MZOR has supplied all 64 Connection Boxes and 48 Voussoirs, essential construction elements required to link the 8 superconducting coils in the Barrel Toroid. The Al alloy blanks, roughly shaped by forging, were supplied to MZOR, and MZOR undertook the rough and fine machining of the elements.

The production at MZOR was organized in a strategic collaboration between the National Scientific and Educational Center for Particle and High Energy Physics (NC PHEP) of the Belarusian State University and the Joint Institute of Nuclear Research JINR in Dubna, Russia. Through this production at MZOR the Belarus and Russian institutes could make an important in-kind contribution to the ATLAS Experiment.

MZOR undertook the precision machining of these large-size objects with great care and managed in a professional way the on-time delivery of the structure elements at CERN.

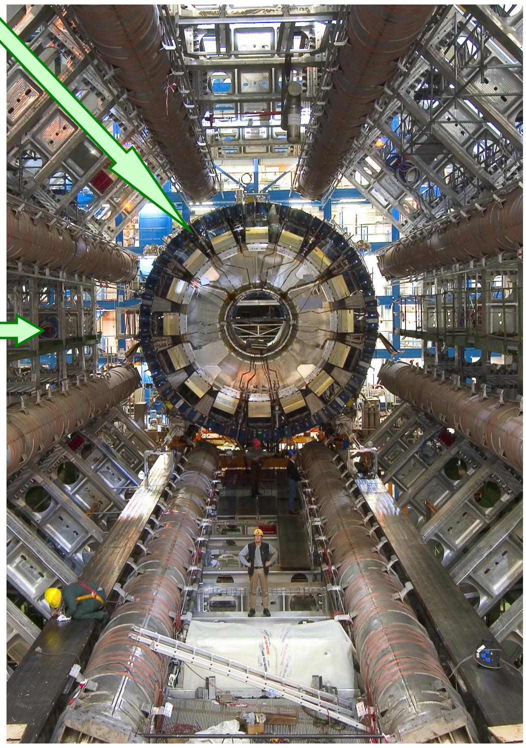
The ATLAS Collaboration expresses its sincere appreciation for MZOR's effort, pleasant cooperation and excellent performance.

Geneva, May 2005

Dr. Peter Jenni
ATLAS Spokesperson

Dr. Maximilian Metzger
CERN Secretary-General

The ATLAS supplier award for Republican Enterprise «MZOR» for the excellent performance in machining the construction elements of the ATLAS Barrel toroid magnets, 2005



The installation of the calorimeter manufactured using Belarusian equipment into ATLAS detector at CERN. The eight toroid magnets surround the calorimeter.

IP NASB (Corresponding member of NASB A. Bogush, Yu. Kulchitsky, Yu. Kurochkin et al.) was adopted in ATLAS Collaboration in 1994. The team of IP NASB is the author of the ATLAS technical proposal (1994). The scientists took active part in the ATLAS hadronic barrel iron-scintillator Tile calorimeter (TileCal) design, module mass production, construction, installation in the cavern [*JINST, 2013*], and study of the ATLAS combined barrel calorimeter and TileCal performance in the test-beam on SPS (CERN) in pion, proton, electron and muon beams with energy from 3 to 350 GeV. The study of the possibility to use a laser cutting system for production of TileCal master and spacer plates was performed in cooperation with JINR and Physical-Technical Institute of NASB (Minsk).

The electromagnetic calibration of the TileCal production modules was performed. The obtained calibration constants were included into TileCal calibration database.

Yuri Kulchitsky (IP NASB and JINR) with colleagues in ATLAS experiment hall

The energy linearity and resolution of calorimeter were measured. The energy resolution was found to be close to the projected value. The non-compensation of the TileCal was also measured, $e/h=1.33\pm0.06\pm0.02$. The unique energy resolution was achieved for reconstruction of 10–350 GeV hadrons at an incident angle of about 12^{o}. The energy linearity was found equal to $\pm 1\%$.

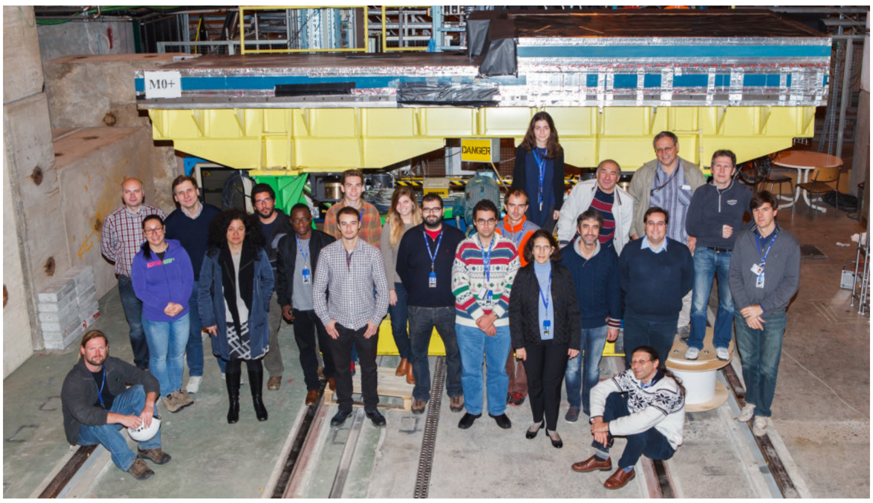
Yuri Kulchitsky participates in ATLAS Control room shifts during Physics Runs for collecting of experimental data and investigation of calorimeters Data Quality.

IP NASB scientists (Yu. Kulchitsky at al.) took active part in development and application of new methods for calorimeter performance investigation:

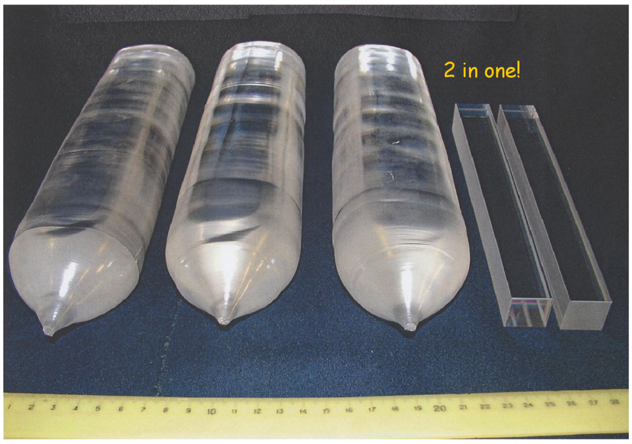
- non-parametrical method of energy reconstruction for combined calorimeters,
- method of measurement of a non-compensation for thin electromagnetic calorimeter,
- analytic description of hadronic showers in calorimeter,
- method of local hadronic calibration for energy reconstruction in a combined calorimeter and others.

Yu. Kulchitsky (IP NASB and JINR) was one of the editors of calorimeter performance section of the TileCal TDR (1996) and works as TileCal Data Quality Leader or Validator in shifts for analysis data quality of Tile calorimeter information.

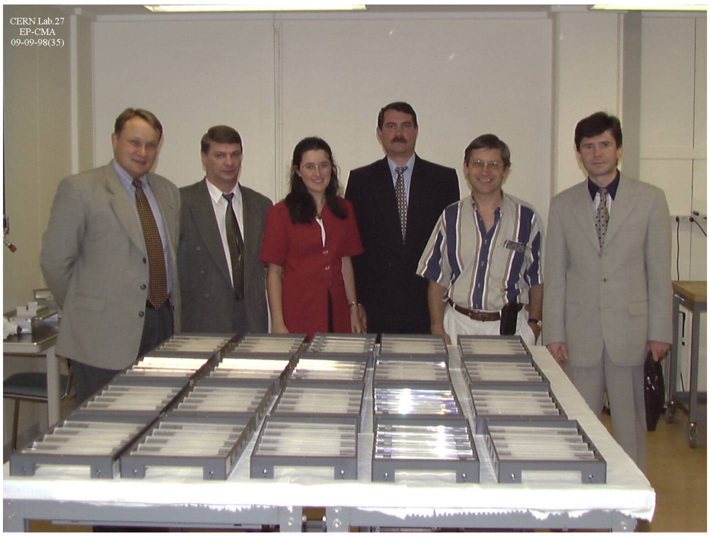
Siarhei Harkusha (IP NASB) takes part in test beam activity and in software development used in the ATLAS hadronic Tile calorimeter. (CERN, 2015)



A new class of scintillation materials – PWO was developed in INP BSU (M. Korjik et al.) in co-operation with CERN. On the basis of the heavy lead tungstate scintillator the electromagnetic calorimeters for CMS and ALICE detectors were built. The 90 thousands of the crystals were grown for 8 years in the framework of international collaboration at Russian plants under the scientific supervision of INP BSU scientists. The novel scintillation materials combine high density, high output and outstanding radiation hardness.

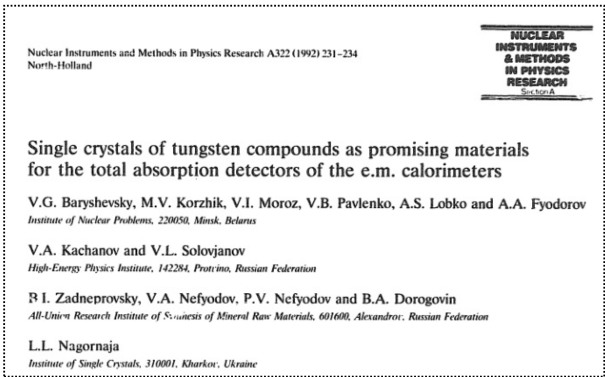


Lead tungstate crystals for electromagnetic calorimetry at LHC experiments



Mikhail Korzhik (INP BSU, at left),
V. Kostylev (BTCP, Russia),
E. Auffray (CERN),
A. Annenkov (BTCP, Russia),
P. Lecoq (CERN),
I. Tyurin (ISTC)
with first batch of PWO crystals for CMS ECAL

The first paper and monograph



Nuclear Instruments and Methods in Physics Research A322 (1992) 231–234
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

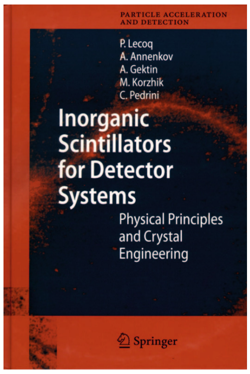
Single crystals of tungsten compounds as promising materials for the total absorption detectors of the e.m. calorimeters

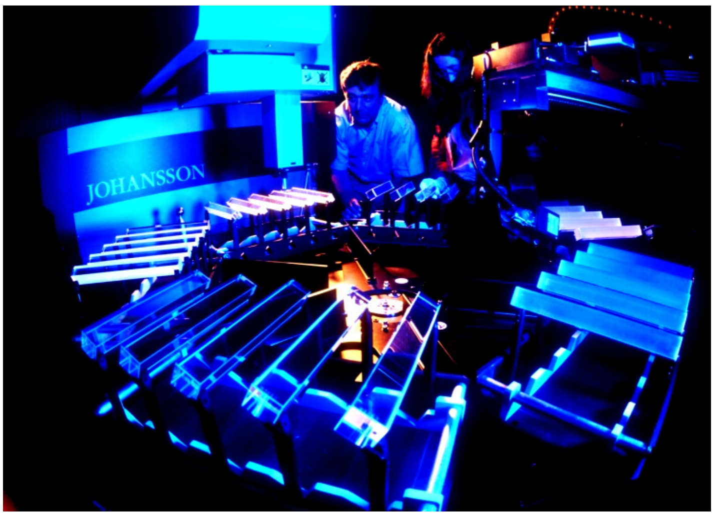
V.G. Baryshevsky, M.V. Korzhik, V.I. Moroz, V.B. Pavlenko, A.S. Lobko and A.A. Fyodorov
Institute of Nuclear Problems, 220050, Minsk, Belarus

V.A. Kachanov and V.L. Solovjanov
High-Energy Physics Institute, 142284, Protvino, Russian Federation

B.I. Zadneprovsky, V.A. Nefyodov, P.V. Nefyodov and B.A. Dorogovin
All-Union Research Institute of Synthesis of Mineral Raw Materials, 601600, Alexandrov, Russian Federation

L.L. Nagornaja
Institute of Single Crystals, 310001, Kharkov, Ukraine

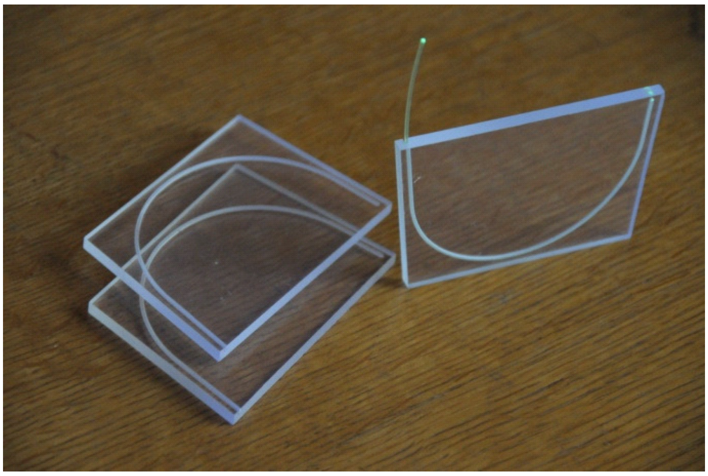




The automated crystal quality control system was developed in INP BSU, which became a standard for manufacturers of inorganic scintillation crystals worldwide. The development and implementation of PWO scintillators for experimental high energy physics is one of the most noticeable implementations into international projects made by CIS scientists over the past twenty years.

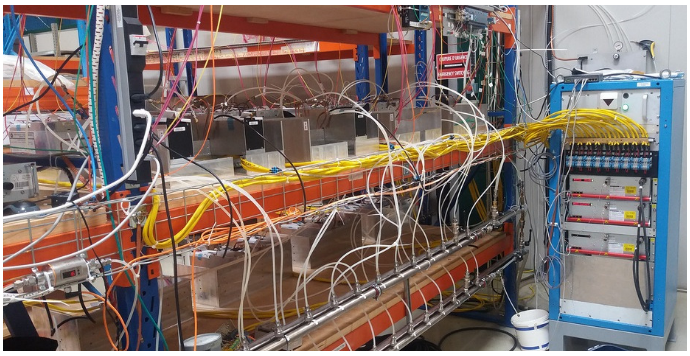
Automatic COntrol Crystal System (ACCOS) used for the characterisation of PWO crystals in CERN/Lab27 Regional Center

INP BSU scientists (I. Emeliantchik et al.) in collaboration with JINR have performed investigation of early degradation of CMS end-cap hadron calorimeter plastic scintillators, which prevented its use in High Luminosity mode. The cause of this degradation was found, and recommendations on its overcoming were formulated.



Active elements of the end-cap hadron calorimeter in the CMS experiment

In the framework of CMS upgrade program INP BSU scientists (A. Litomin et al., INP BSU) and engineers (S. Savitsky et al., «Artmash» enterprise) are responsible for design and manufacturing of «Readout Box» mechanical equipment for new elements of readout electronics of barrel (HB RBX) and end-cap (HE RBX) sub-systems of CMS hadron calorimeter.

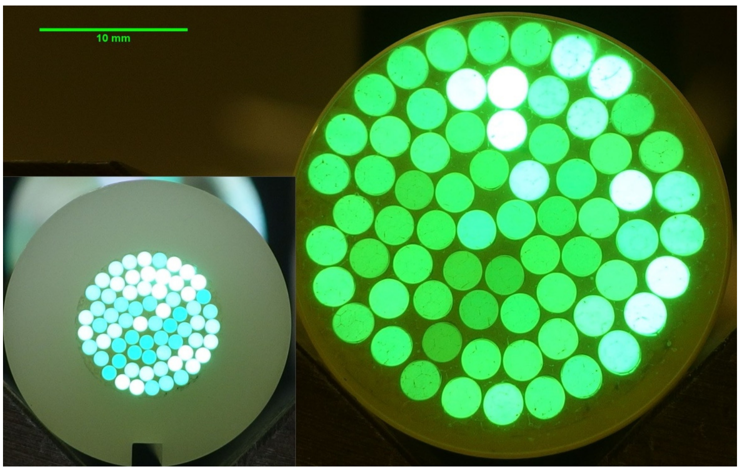


Readout Box mechanical equipment installed in HE burn-in station at CERN

The following types of works were performed by the joint working group: check of completeness of scientific-technical samples HE RMs according to the technical documentation; test on mechanical compatibility of the RM; assembly of HE RMs with appropriate pins; installation of HE RBXs on the HE burn-in station; cooling test for the very first HE RBX.

The NC PHEP BSU scientists (V. Gilewsky, A. Solin et al.) were responsible for low voltage power supply modules for ATLAS TileCal.

The feasibility study for improving ATLAS TileCal granularity is performed by INP BSU scientists.



Testbench measurements show that fiber lightguide have about 50% light loss, and defocuses quickly with increase in the airgap. An alternative device was proposed, so called focon

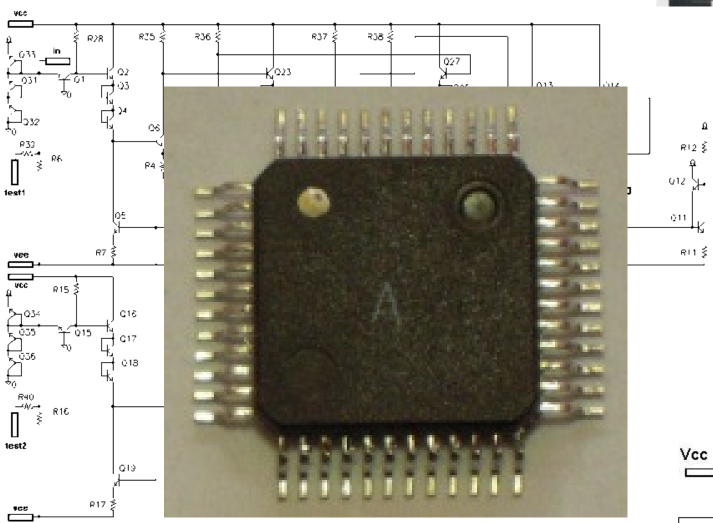
Belarusian scientists at CERN

Front-end electronics for COMPASS muon system

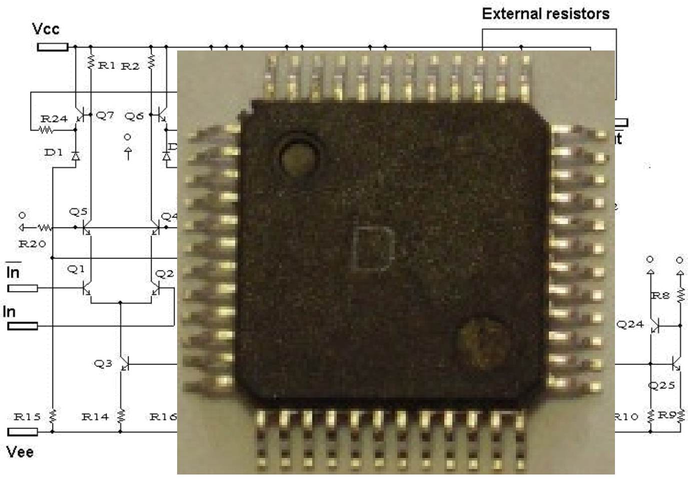
Since 2003 Muon System of COMPASS detector operates using Front-End electronics based on custom ICs of INP BSU design (M. Batouritski et al.) and JSC INTEGRAL (Minsk) production, namely 8-channel transimpedance amplifiers Ampl-8.3 and comparators Disc-8.3 of D0M family, the acronym for the Dubna-D0-Minsk cooperation. This electronics picks signals off anode wires of Mini-Drift Tubes (MDT) produced in JINR, digitizes and transfers them to the following processing. There were total 400 modules of 32-channel Analog-digital Board (ADB 32) produced for COMPASS Muon System.

This equipment is characterized by high robust operation, which is explained by very high resistance to overvoltage breakdown, tolerance to self-excitation and low level of cross-talks (not more than –47dB)

COMPASS Muon System Front-End ADB 32 (top and bottom view)

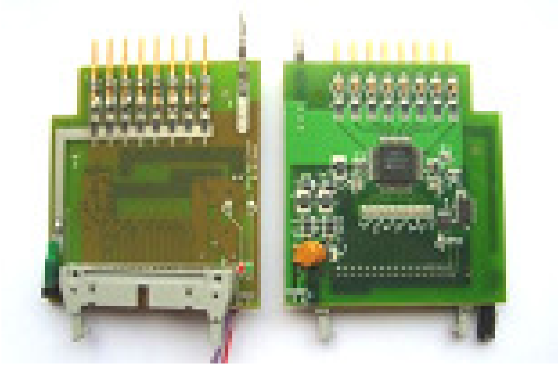


Amplifier IC Ample-8.3



Comparator IC Disc-8.3

Full Scale 9-tons Prototype (FSP) for P̄ANDA experiment (Darmstadt, Germany) Muon System was tested at CERN at COMPASS facilities. It contains MDTs, which produce two coordinate detection of particle registration. Signals from 4000 anode wires and stips are picked up by amplifier and comparator ICs Ample-8.3 and Disc-8.3.



FSP High Voltage System board based on the IC Ampl-8.3

INP BSU scientists and engineers (V. Tchekhovski et al.) are actively involved in research and development work on creating the microelectronics for signals registration in CMS muon detector at LHC, on build and commissioning of the end-cap of the CMS muon detector.

In collaboration with colleagues from JINR and CERN Belarusian scientists were responsible for testing, installation and putting into exploitation of the ME1/1 cathode strip chambers (CSC), the elements of CMS muon detector. The end-cap part of the detector systems has been commissioned and adjusted to detect defects and to optimize the operation modes. Belarusian scientists are co-authors of engineering documentation on the CMS muon detector. The works was awarded the CMS collaboration prize «*Achievement Award for CMS Construction*» (2010).

The Compact Muon Solenoid Collaboration
confers on
Vladimir Tchekhovski
the
Achievement Award for CMS Construction
for
Significant Contribution to the ME1/1 Chambers

The Collaboration Board Chairperson (Dan Green)

The Experiment Spokesperson (Guido Tonelli)

March 15th 2010

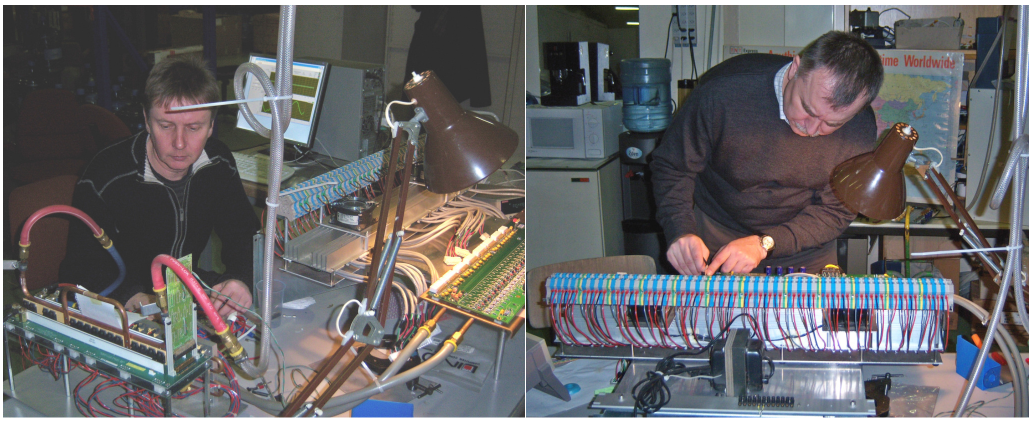
Alexander Litomin and Vladimir Tchekhovski (INP BSU)

Belarusian scientists (V. Tchekhovski et al., INP BSU) in collaboration with JINR were responsible for design and construction of Low Voltage Distributions Boards (LVDB) for for Muon Endcap CSC in CMS detector.

Belarusian scientists make significant contribution in CMS Endcap Muon system Phase 1 Upgrade during LS1 period participating in the ME1/1 electronics upgrade project, including refurbishing, testing and commissioning of ME1/1 chambers with a new electronics.

Electronic module for low voltage power supply system of CMS muon detecror

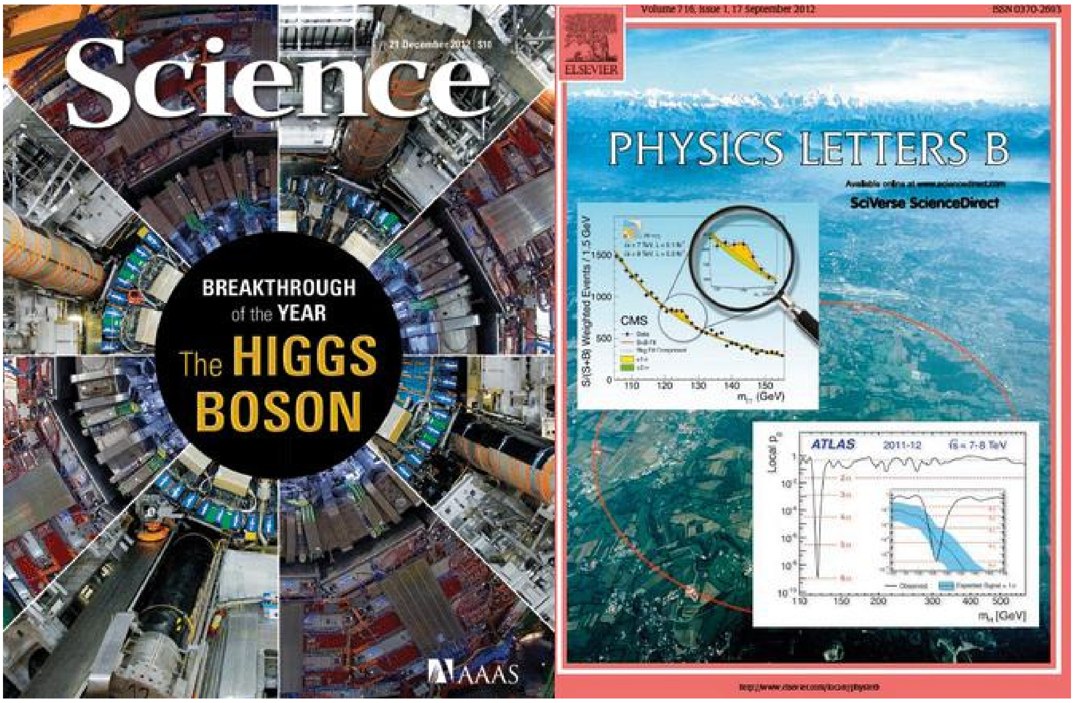
In the Muon System LS2 Upgrade project INP BSU and JINR are responsible for design and construction of 120 new Low Voltage Distributions Boards (LVDB5) for 108 Muon Endcap inner rings (MEX/1) detectors.



In the framework of CMS upgrade program the electronic system for CSC on-chamber electronics for muon detector was designed and manufactured (Nanotech Ltd., Minsk)

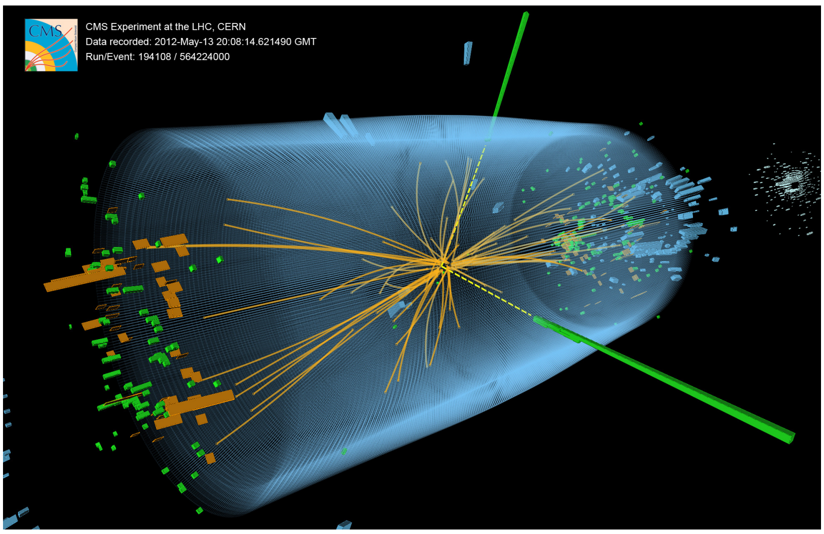
The search of the Higgs boson was one of the first and biggest challenges for the LHC experiments. The discovery allowed to finally enthrone the Standard model as the self-consistent theory of electroweak interaction. The authors of the symmetry breaking mechanism theory (Peter Higgs and François Englert) were awarded the Nobel Prize in Physics in 2013.

The journal covers of publications on Higgs boson discovery

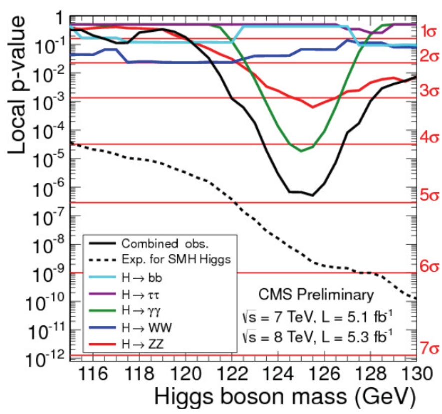


The 20 Belarusian scientists from CMS and ATLAS collaborations are co-authors of the Higgs boson discovery publications.

- For CMS Collaboration: *V. Chekhovsky, I. Emeliantchik, A. Fedorov, M. Korzhik, A. Litomin, V. Makarenko, O. Missevitch, V. Mossolov, N. Shumeiko, A. Solin, R. Stefanovitch, J. Suarez Gonzalez, R. Zuyeuski* (INP BSU).
- For ATLAS Collaboration: *A. Bogouch, S. Harkusha, Yu. Kulchitsky, Yu. Kurochkin, I. Satsounkevitch, P. Tsiareshka* (IP NASB), *S. Yanush* (NC PHEP BSU).



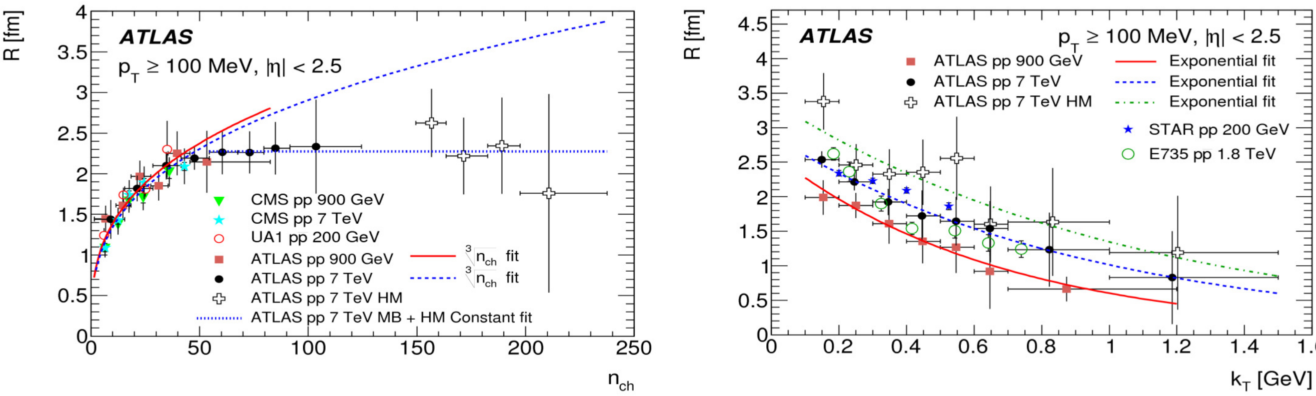
Higgs Boson production event display in CMS experiment. The boson has been decayed to pair of photons with invariant mass of 125 GeV. The straight green lines indicates the energy measured in electromagnetic calorimeter



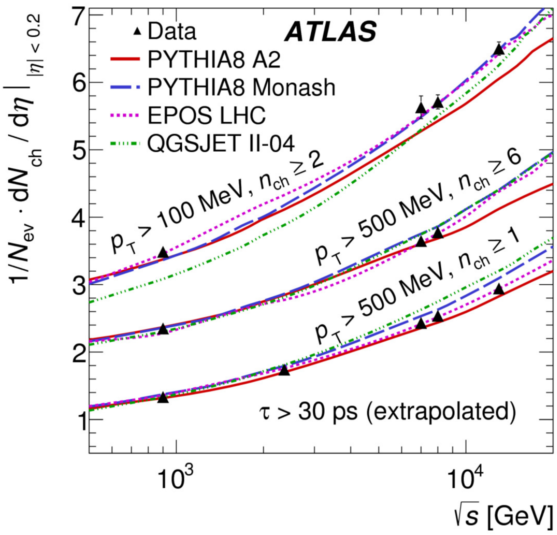
The local p-value plot shows the probability of the «no-Higgs boson» hypothesis. The 5σ value means the only 10^{-6} chance that no new particle is observed

IP NASB scientists (Yu. Kulchitsky et al.) takes active part in the physics analysis of experimental data in pp-interactions in ATLAS experiment. IP NASB team performed the leading role in the Bose–Einstein Correlations (BEC) study with the ATLAS detector.

The multiplicity dependence of the BEC parameters characterizing the correlation strength and the correlation source size were investigated for the first time, for charged-particle multiplicities of up to 9 mean multiplicity. The saturation effect in the multiplicity dependence of the correlation source size parameter was first observed using the high-multiplicity 7 TeV data sample, and confirmed at 13 TeV. The dependence of the BEC parameters on the average transverse momentum of the particle pair was also investigated.

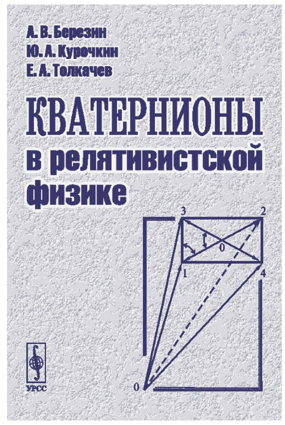


Multiplicity (n_{ch}) transverse momentum (k_T) dependence of the parameter R obtained from the exponential fit to the two-particle double-ratio correlation functions R2(Q) at $\sqrt{s}$ =0.9 TeV, 7 TeV and 7 TeV high-multiplicity events. Left: the solid and dashed curves are the results of $\sqrt{3}$ nch for $n_{ch} < 55$ fits, the dotted line is a result of a constant fit to minimum-bias and high-multiplicity events data at 7 TeV for $n_{ch} \geq 55$. Right: the solid, dashed and dash-dotted curves are results of the exponential fits for 0.9 TeV, 7 TeV and 7 TeV high-multiplicity data, respectively; the results are compared to the corresponding measurements by the E735 experiment at the Tevatron, and by the STAR experiment at RHIC. The error bars represent the quadratic sum of the statistical and systematic uncertainties.



The average primary charged-particle multiplicity in pp interactions per unit of pseudorapidity η for |η| < 0.2 as a function of the centre-of-mass energy $\sqrt{s}$. The data are shown as black triangles with vertical errors bars representing the total uncertainty. They are compared to various MC predictions which are shown as coloured lines.

The distributions of charged particles produced in proton–proton collisions with a centre-of-mass energy of 13 TeV were measured. The results are corrected for detector effects and compared to the predictions from several Monte Carlo event generators. The mean number of primary charged particles per unit pseudorapidity in the central η region is measured to be 6.5±0.1(syst.) for p_T>100 MeV and 2.87±0.03(syst.) for p_T>500 MeV, by averaging over |η| < 0.2; the statistical uncertainty is negligible. This result is compared to previous measurements at different energy values. The predictions from EPOS match the data well.

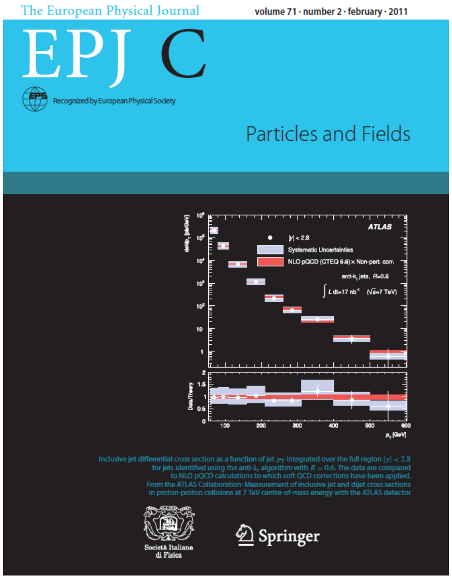


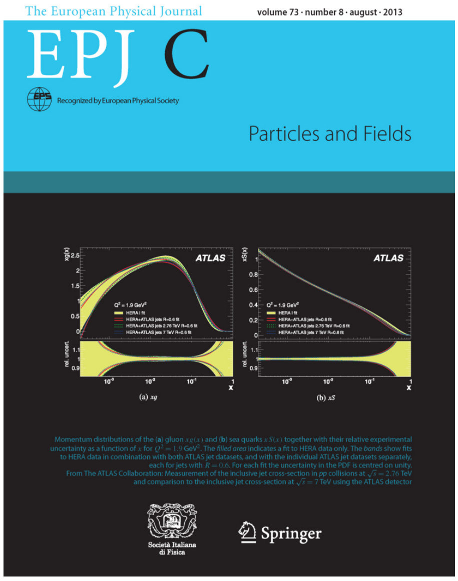
The ideas of F.I. Fedorov of covariant approach to the parametrization of the Lorents group were significantly improved and applied to classical quaternion calculation and to novel methods in kinematics of particles collisions and relativistic dynamics [A.V. Berezin, Yu.A. Kurochkin, E.A. Tolkachev, *Quaternions in the relativistic physics* 1989, 2003].

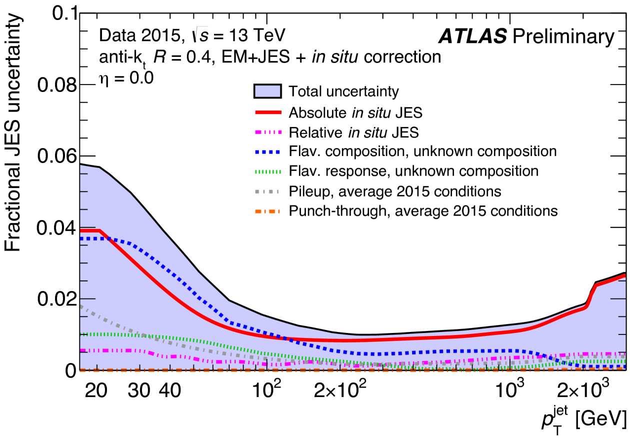
INP BSU scientists (P. Starovoitov, A. Hrynevich et al.) are focused on the measurements of jets, collimated sprays of hadrons, arising in LHC collisions, in the framework of the ATLAS experiment. The measurements of the inclusive jets, dijet and three jet production differential cross-sections has been performed, providing a valuable test of Quantum Chromo-dynamics in the multi-TeV regime never touched in experiments before the LHC era.

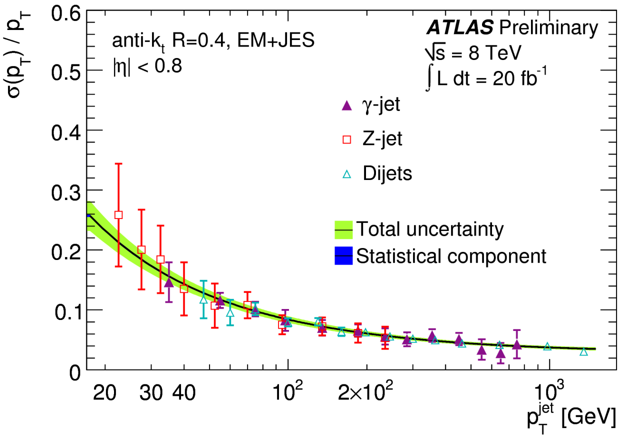
The results were used to obtain the new constraints of the quarks and gluons distribution functions inside the proton and to determine the fundamental property of the strong interactions, the strong coupling constant.

The results of the jet measurements were selected to be at the cover of the European Physics Journal C, showing the high interest of the international high energy physics community







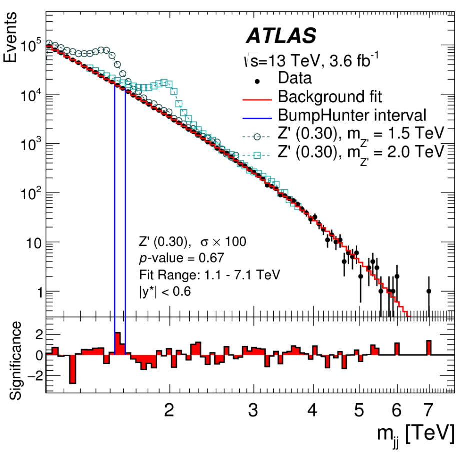


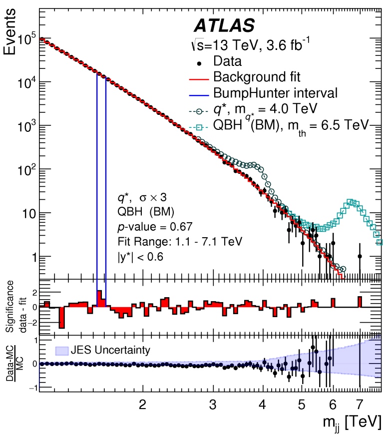
The ATLAS jet energy scale measured up to the accuracy of 1% improves the precision of the measurements within the Standard Model of particle physics, as well as in searches of the "new-physics" Beyond the Standard Model

The measurement of the noise arising due to multiple soft interactions in high luminosity LHC collisions, generally called pile-up noise, in the cells of hadronic Tile Calorimeter, as well as the development of new algorithms for pile-up jets suppression allowed to reduce the ATLAS jet energy resolution

The searches of the quantum black holes, excited quarks, W' and Z' in dijet events were performed in proton-proton collisions data with 13 TeV centre-of-mass energy.

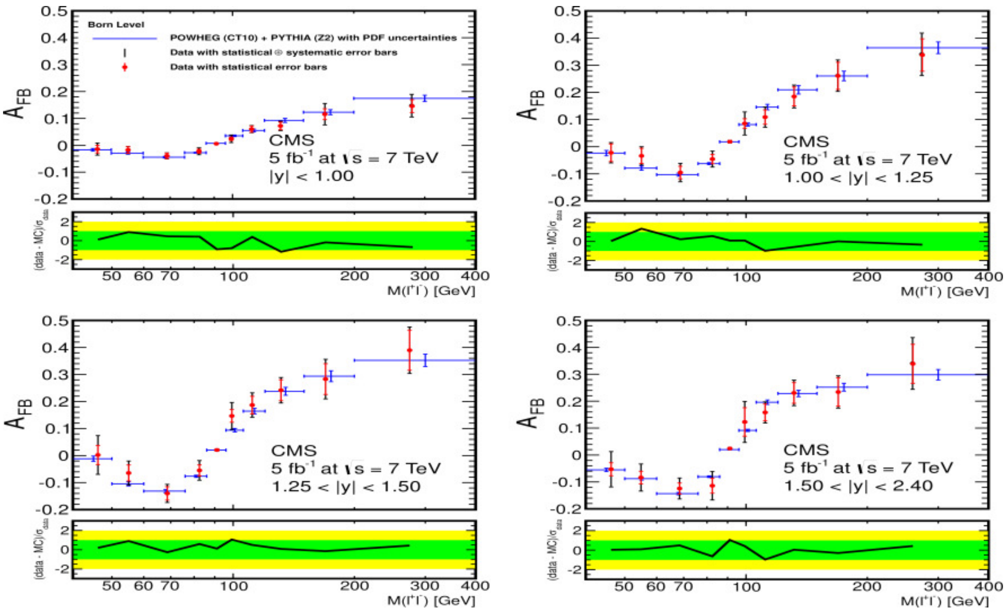
The 95% Confidence Level limits on the cross sections for the new processes were set





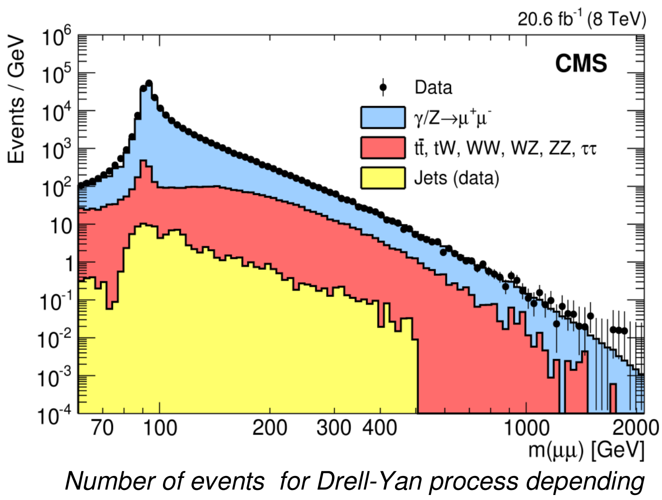
The scientific school was founded in INP BSU (Prof. N. Shumeiko) on the basis of both Belarusian school by Academician F.I. Fedorov and Russian schools by S.M. Bilenky and Academician D.V. Shirkov. The new methods were developed for the covariant calculation of radiative effects for observables of fundamental processes in high energy physics (known as the Bardin-Shumeiko approach).

Scientists from INP BSU (Prof. N. Shumeiko, J. Suarez et al.) have developed a number of generator codes to simulate the behavior of processes of elastic and inelastic particle scattering in the number of modern and future experiments at CERN. The generator LPPG (Lepton Pair Production Generator) aimed to simulate with high accuracy the Drell-Yan process under kinematical conditions at LHC.

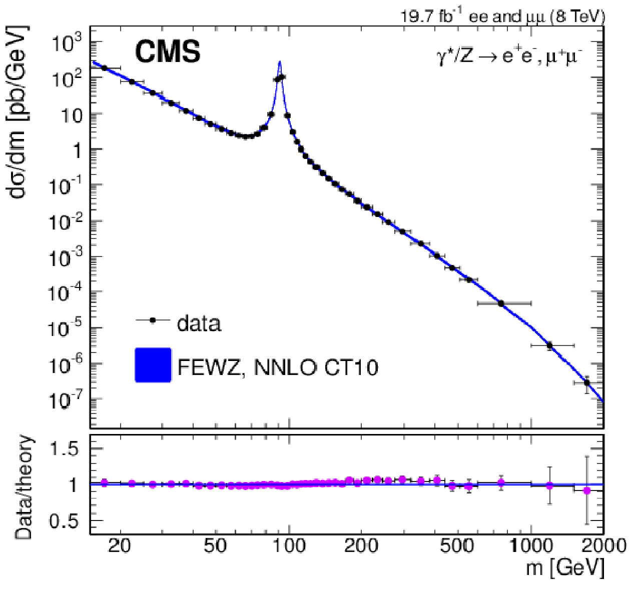


Forward-backward asymmetry for the Drell-Yan process depending in the invariant mass of the lepton pair. The obtained results are worth for pdf constraints and searches for new physics

The hallmark of the group is to carry out work on the precision analytical calculation and numerical analysis of high-order perturbation theory effects under different kinematic conditions of the experiment.



Number of events for Drell-Yan process depending on the invariant mass of the muon pair



The differential cross section for the Drell-Yan process depending on the invariant mass of the lepton pair

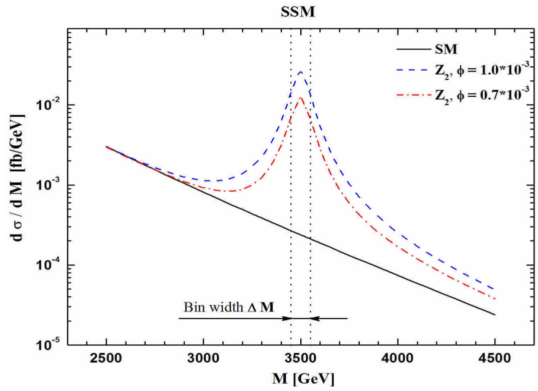
The work is ongoing on the analysis of the differential cross-section and forward-backward asymmetry of Drell-Yan process in CMS events with energies 7, 8 and 13 TeV.

Some Belarusian scientists (S. Shulga, V. Zykunov et al.) take active part in the CMS experiment data analysis within JINR groups. The studies concern Drell-Yan process, new heavy gauge bosons and microscopic black holes search, hadronic jet correlation and Higgs boson physics.

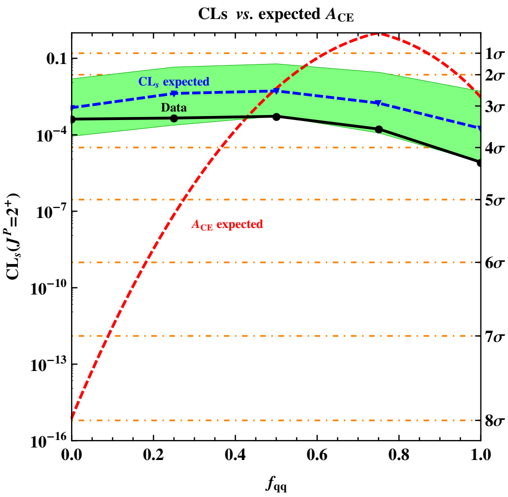
Physics studies: phenomenology of SM and beyond at HE colliders

Belarusian researchers (Project leader Prof. A. Pankov with I. Serenkova and A. Tsytrinov et al.) of the Abdus Salam ICTP affiliated centre (ICAC) at Technical University of Gomel are exploring phenomenology at the Large Hadron Collider and other high-energy colliders. The ICAC group, supported by the ICTP, INFN and JINR, made (and is making) significant contribution to precise test of the Standard Model (SM) and searches for new physics:

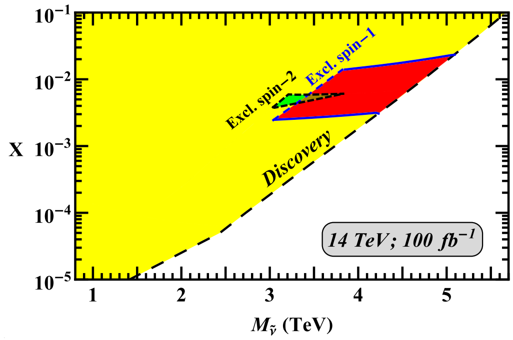
- spin identification of the Higgs boson,
- hunt for extra spatial dimensions at the LHC in dilepton and diphoton channels,
- probing Z' bosons: spin and model identification, precise determination of Z-Z' mixing,
- R-parity violating SUSY at LHC etc.



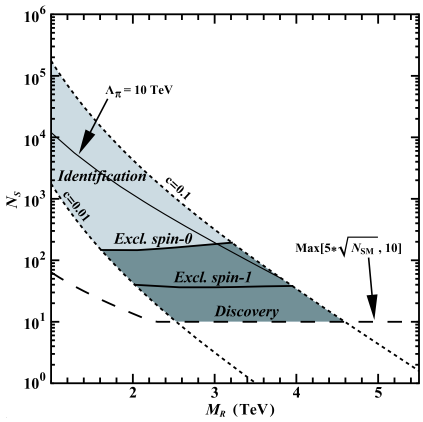
Invariant mass distribution of W pairs in SM and Z'$_{SSM}$ at the LHC. [Phys.Rev.D 2014, PEPAN Lett.2016]



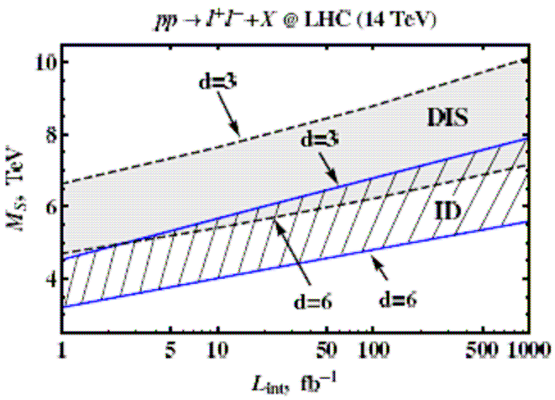
Comparison of the expected and observed confidence levels, CLs($J^P=2^+$), of the $J^P=2^+$ hypothesis for Higgs boson as functions of the fraction of qq production (fqq) of the spin-2 signal in the diphoton channel at the LHC (8 TeV, 20/fb). [EPJC 2015]



Discovery reach and spin-0 sneutrino identification domain from lepton pair production at the LHC [Phys.Rev.D 2010]



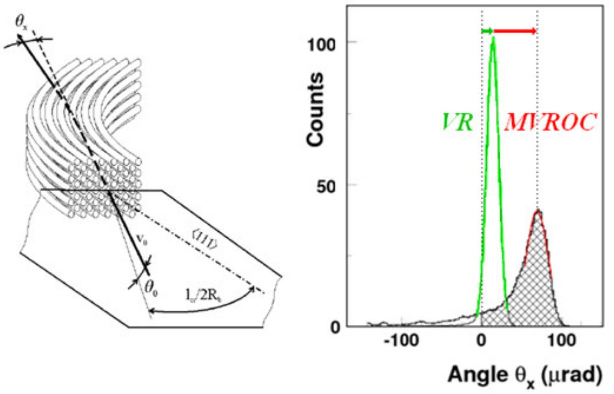
Minimal numbers of resonance events required to discriminate the spin-2 RS graviton from the spin-0 and spin-1 hypotheses at the LHC. [Phys.Rev.D 2008, PEPAN2017]



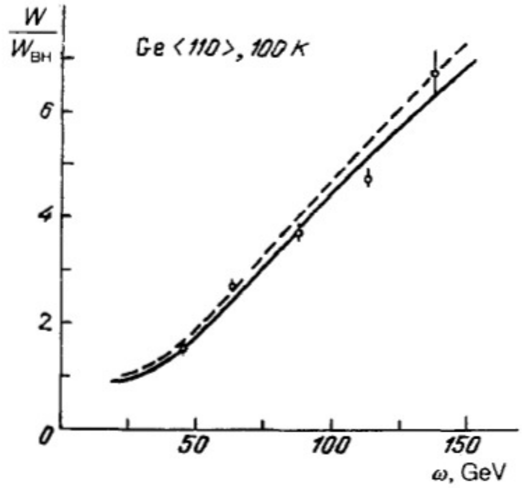
Discovery (DIS) and identification (ID) reaches for KK graviton towers in terms of cutoff parameter vs. integrated luminosity for numbers of extra spatial dimensions. [Phys.Rev.D 2004, 2009; Phys.At.Nucl.2015]

High energy beam deflection, radiation and polarization in the strong fields of oriented crystals

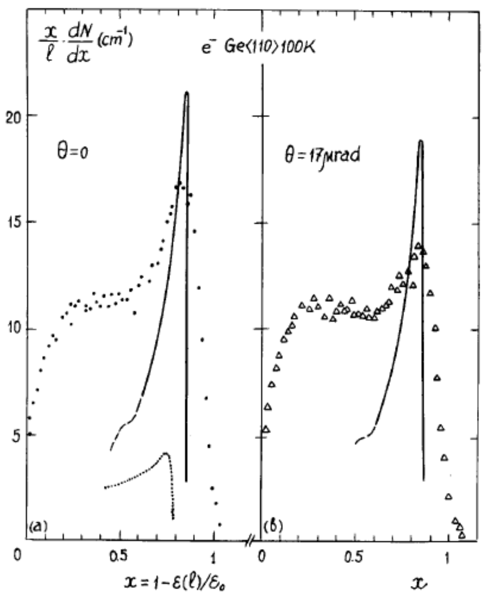
A wide range of unique effects in oriented crystals has been predicted for 40 years which are abundantly confirmed experimentally, recognized world-wide and meet various needs of both particle and accelerator physics.



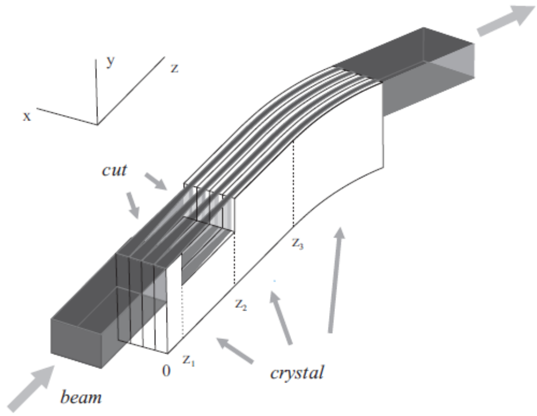
The effects of multiple volume reflection from different atomic planes of a bent crystal and accompanying electron radiation were predicted [PLB 2007,2009; PRA 2012, PRL 2013] which can be used for both high energy beam collimation and electron gamma radiation enhancement



Synhrotron-like radiation and pair production in crystals, accompanied by diverse polarization phenomena, were predicted [PLA 1982, 1983], which result in electromagnetic shower acceleration in particle detectors and gamma-telescopes

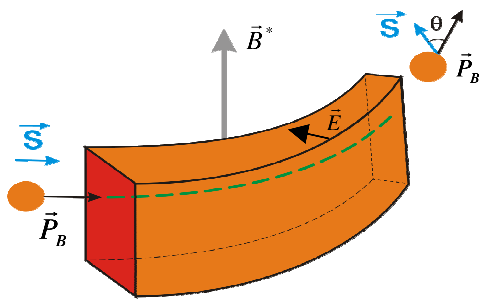


Radiative cooling effect was predicted [PLA 1977] and applied [PLA 1987, NIMB 1989] to interpret the CERN experiment on electron radiation in thin Ge crystal, opening up a possibility to reach petaelectronvolt particle energies in crystal accelerators



A possibility to increase channeling efficiency by a crystal cut was suggested which can be used to facilitate both high energy beam collimation and extraction [JINST 2007]

INP BSU scientists (Prof. V. Baryshevsky et al) suggest to observe the phenomena of spin rotation and depolarization of high-energy particles in bent and straight crystals at Large Hadron Collider and Future Circular Colliders energies and the possibility to measure the anomalous magnetic moments of short-lived particles (charm and beauty baryons).



Polarized particles spin rotation in bent crystal

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