INTAS PROPOSAL FOR
CERN - INTAS Call 2003 - Research Project

1.1 **TITLE:**
Crystal Technique for Halo Cleaning in the LHC

1.1.1 **Keyword 1 : High Energy, Particle Accelerators**
Keyword 2 : Nuclear Instrumentation and Applications
Keyword 3 : Crystalline Strucure, Structural Phase Transitionsn, Defects, Mechanical Properties

1.1.2 **Free word 1 : channeling**
Free word 2 : collimation
Free word 3 : bent crystal

1.1.3 **Intended Start Date: January 2004**

1.1.4 **Duration: 36 Months**

1.2 **CONSORTIUM**
CERN - Switzerland
Institute for High Energy Physics - Russia
Ferrara University - Italy
Petersburg Nuclear Physics Institute - Russia
Research Institute of Nuclear Problems - Belarus
University of the Witwatersrand - South Africa

1.3 **SUMMARY**
Crystal Technique for Halo Cleaning in the LHC

The research program aims to develop a high-efficiency technique for steering of halo particles in a large hadron collider using bent channeling crystal. The technique can be used to strongly enhance the efficiency of beam cleaning system if a bent crystal serves as a primary element in the LHC beam collimation system, reducing the beam-related backgrounds in the collider experiments by an order of magnitude as estimated. Whenever required, the same technique can be used for slow parasitic extraction from the LHC halo without interfering with collider work, with extraction efficiency between
50-90% according to simulations. The main objectives of the project are:

1 To design and build prototypes of optimal channeling scraper for the LHC, and test them experimentally with 70-GeV protons
2 To perform detailed realistic simulations of crystal-assisted cleaning of protons and heavy ions from the LHC beam halo, optimise the efficiency, evaluate requirements and limitations for the method, and find the achievable scraping efficiency
3 To adapt the channeling scraper to the lattice of the LHC by means of simulations aiming to understand the effect of accelerator functions on the efficiency of crystal cleaning system
4 To find in simulations the requirements for the crystal scraper quality (surface quality, angular distortions, crystal lattice perfection) adequate for the application in the LHC, as well as the requirements for the accuracy of its positioning and angling

5 To study a high-efficiency multipass mode of collimation and extraction from accelerator using bent crystals in experiments at 70 GeV, in order to research crystal collimation as a technique for the LHC by means of experimental tests at 70 GeV and realistic simulations
6 To develop a theory of beam multipass steering by short crystals in a broad range of energies, and to support by Monte Carlo simulations the experimental studies of extraction and collimation
7 To achieve electron-microscopy and x-ray characterisations of bent crystals in order to study defects
8 To develop the technique for preparation of highly perfect surfaces of channeling silicon crystals and the means for protection of these surfaces (from oxidation etc.) until installation into vacuum environment of accelerator
9 To research a broad range of crystal lattices (diamond to germanium) with atomic number much lower and much higher than that of silicon as candidates for crystal scraper
10 To invent and test principally new approaches to crystalline devices for beam steering; to perform detailed Monte Carlo simulations to properly assess their bending efficiency
11 To study - by means of Monte Carlo simulations and proof-of-principle experiments with high-energy protons - the possibilities to use nanostructured material for beam channeling with a potential of application at the LHC.

2 TEAM INFORMATION

2.1 Team : CERN

2.1.1 Team Description

The collaborator at CERN is responsible for the coordination of the research programme, outline of the physically interesting fields of
experimentation, and foresight of applications. His contribution is also essential for the research of crystal collimation/extraction
as a possible technique for the present and future high-energy accelerators. The collaborator at CERN is well known for his studies of beam dynamics at high energy accelerators. He has
strong experience in the crystal extraction technique, having been the proponent of the CERN RD22 collaboration on studies of the crystal extraction at the SPS. Since 1998 he collaborates with IHEP in all crystal activities on IHEP accelerator (see refs).

2.1.2 List of publications

1 A.G. Afonin et al. Phys. Rev. Lett. 87 (2001) 094802. "High-Efficiency Beam Extraction and Collimation Using Channeling in Very Short Bent Crystals".
2 V.M. Biryukov, Yu.A. Chesnokov, V. Guidi, V.I. Kotov et al. Rev. Sci. Instrum. 73 (2002) 3170-3173 "Crystal deflector for highly efficient channeling extraction of a proton beam from accelerators".

3 A.G. Afonin et al. Phys. Lett. B 435 (1998) 240-244. "High efficiency multipass extraction of 70-GeV protons from accelerator with a short bent crystal".
4 A. Afonine, V.T. Baranov, V.M. Biryukov, V.N. Chepegin, Y.A. Chesnokov, Y.S. Fedotov, V.I. Kotov, V.A. Maisheev, V.I. Terekhov, E.F. Troyanov, D. Trbojevic, W. Scandale, M.B.H. Breese, V. Guidi, G. Martinelli, M. Stefancich, D. Vincenzi. EPAC 2002 Proceedings (Paris), p.2511. The Investigations of Beam Extraction and Collimation at U-70 Proton Synchrotron of IHEP by Using Short Silicon Crystals.
5 H.Akbari,... V.Biryukov,... W.Scandale et al. (RD22 Collab.), First results on proton extraction from the CERN-SPS with a bent crystal,
Phys. Lett. B 313 (1993) 491

2.1.3 Team Leader and address

Title	Dr.
Position	Staff member
Sex	Male
Date Of Birth	05/05/1946
First Name	Walter
Patronic Name	
Family Name	Scandale
Organisation Type	Public
Organisation Registration Nr.	
Academy / Branch	
Organisation / University / Institute	CERN
Department	LHC

Laboratory

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Website	

2.1.4 List of Senior Scientists in the team

2.1.5 Statistics

Number of Team Members involved in this project: 1
Number of Team Members under 35: 0
Number of Team Members who have individually received grants in INTAS projects: 0

2.2 Team : IHEP Protvino

2.2.1 Team Description

The IHEP team has been involved in high energy channeling research since 1985. Detailed experimental studies were done on feeding-out and feeding-in in bent crystals, radiation damage, world first focussing of a beam by a
bent crystal, bending channeled beams at extreme angles up to 150 mrad, crystal extraction and collimation with efficiency 85% at intensity over
1.E12/s. The team has contributed to the theory of beam steering by crystals, notably for beam extraction, taking into account crystal imperfection, bending, and beam dynamics in accelerator. A computer code CATCH was designed for crystal channeling simulations; its predictions were successfully tested in the CERN SPS, FNAL, BNL and IHEP experiments. IHEP physicists collaborated with CERN, FNAL, and BNL in crystal extraction experiments on Western machines in 1992-2003. The members of the team have written the world first monograph on bent crystal channeling and its applications at accelerators. In 1996, they received (together with Tsyganov et al.) the State Prize for invention of this technique from the President of Russia.

2.2.2 List of publications

1 Phys. Rev. Lett. 87 (2001) 094802. "High-Efficiency Beam Extraction and Collimation Using Channeling in Very Short Bent Crystals". A.G. Afonin et al.

2 Phys. Rev. Lett. 90 (2003) 034801 "Experimental study for the feasibility of a crystalline undulator". S. Bellucci et al.

3 V.M.Biryukov, Yu.A.Chesnokov, V.I.Kotov. Crystal Channeling and its Application at High Energy Accelerators. (Springer, Berlin:1997) 219 pages.
4 Phys. Rev. ST Accel. Beams 5 (2002) 043501 Beam Extraction Studies At 900-GeV Using A Channeling Crystal. R.A. Carrigan et al.

5 Phys. Lett. B 542 (2002) 111 ``Nanotube diameter optimal for channeling of high-energy particle beam'', [arXiv:physics/0205023]. V.M. Biryukov and S. Bellucci.

2.2.3 Team Leader and address

Title	Dr.
Position	Senior scientist
Sex	Male
Date Of Birth	17/02/1961
First Name	Valery
Patronic Name	
Family Name	Biryukov
Organisation Type	Public
Organisation Registration Nr.	
Academy / Branch	
Organisation / University / Institute	Institute for High Energy Physics
Department	Beam Dept
Laboratory	
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Email 2	
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2.2.4 List of Senior Scientists in the team

1) First Name	Yuri
Patronic Name	
Family Name	Chesnokov
Year Of Birth	1955

Insitute IHEP

2.2.5 Statistics

Number of Team Members involved in this project: 18
Number of Team Members under 35: 2
Number of Team Members who have individually received grants in INTAS projects: 10

2.3 Team : Ferrara

2.3.1 Team Description

The Semiconductor and Sensors Group of the University of Ferrara has been involved in the characterisation and growth of silicon since more than ten years. Deep studies on crystalline potentials and interface defects have been successfully carried out and published on
international journals. Since 1992 this group is collaborating with Siemens A.G. for the characterisation of a new kind of tri-crystalline silicon with enhaced mechanical properties with respect to conventional monocrystals. The group possesses advanced facilities for micromachining of silicon under ultra-clean environment.

2.3.2 List of publications

1 V.M. Biryukov, Yu.A. Chesnokov, V. Guidi, V.I. Kotov et al. Rev. Sci. Instrum. 73 (2002) 3170-3173 "Crystal deflector for highly efficient channeling extraction of a proton beam from accelerators".
2 V. Guidi, M.C. Carotta, M. Ferroni, G. Martinelli, M. Sacerdoti
Journal of Physical Chemistry B 107 (2003) 120-124
"Effect of dopants on grain coalescence and oxygen mobility in nanostructured titania anatase and rutile"
3 A.G. Afonin et al. Phys. Rev. Lett. 87 (2001) 094802. "High-Efficiency Beam Extraction and Collimation Using Channeling in Very Short Bent Crystals".
4 D. Vincenzi, M.A. Butturi, V. Guidi, M.C. Carotta, G. Martinelli, V.
Guarnieri, S. Brida, B. Margesin, F. Giacomozzi, M. Zen, D. Giusti, G. Soncini, A.A. Vasiliev and A.V. Pisliakov
Journal of Vacuum Science and Technology B 18 (2000) 2441-2445
"Gas-sensing device implemented on a micromachined membrane: A combination of
thick-film and very large scale integrated technologies"
5 C. Malagщ, V. Guidi, M. Stefancich, M.C. Carotta and G. Martinelli
Journal of Applied Physics 91 (2002) 808-814
"A model for Schottky barrier and surface states in nanostructured n-type semiconductors"

2.3.3 Team Leader and address

Title	Dr.
Position	Staff member
Sex	Male
Date Of Birth	06/05/1965
First Name	Vincenzo
Patronic Name	
Family Name	Guidi
Organisation Type	Public

Organisation Registration Nr.

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Website	

2.3.4 List of Senior Scientists in the team

1) First Name Guido
   Patronic Name
   Family Name Martinelli
   Year Of Birth 1938
   Insitute Ferrara University

2.3.5 Statistics

Number of Team Members involved in this project: 5
Number of Team Members under 35: 3
Number of Team Members who have individually received grants in INTAS projects: 0

2.4 Team : PNPI Gatchina

2.4.1 Team Description

The PNPI team fulfilled the most precise measurements of negative pion, kaon and sigma-hyperon masses using its own original technique (mesoatomic X-ray crystal diffraction spectrometer with special target configuration on the high energy proton beam).

In collaboration with other groups the team participated in several particle physics experiments at PNPI, IHEP, PSI, CERN, FNAL, BNL, being responsible for development and operation of subsystems of experimental setups.

The PNPI team is especially experienced in precise measurements (using crystal diffraction and semiconductor technique) of X-rays and gamma-rays from targets being irradiated by neutrons and high energy protons.

The team has large practice in development of fine mechanics and crystal optics instrumentation, as crystal diffraction spectrometers for studies of exotic atoms at PNPI, IHEP and PSI, the X-ray beam directing device at CERN for testing LHC detectors , in designing and fabrication of various detectors for X-rays and charged particles.

To provide high quality crystals with parameters needed for X-ray diffraction experiments the team developed a laboratory crystal manufacture equipped with instrumentation to orientate, cut, grind, and polish crystals, and to control their surface and volume properties.

The team has been involved in channeling research since 1991, in tight cooperation with IHEP. The team (A.I.Smirnov) proposed a principle of focusing a beam using a bent crystal with a specific back end face, had designed and manufactured the appropriate crystal device which was successfully tested at IHEP. The team participated in the studies of efficiency of beam steering and beam extraction by crystals at IHEP providing the crystal devices and proportional chambers for the experiments.

The team is responsible for the tasks 2 and 3 and participates in all other tasks of the research program.

The scientists to be involved in this project from the PNPI

1. A.S.Denisov, PNPI
2. A.A.Fedorova, PNPI, 23 years old
3. M.G.Gordeeva, PNPI, 35 years old
4. V.V.Ivanov, PNPI
5. Yu.M.Ivanov, PNPI
6. L.P.Lapina, PNPI
7. A.A.Petrunin, PNPI
8. V.V.Skorobogatov, PNPI
9. S.A.Vavilov, PNPI

2.4.2 List of publications

1 New measurement of the mass of the K- meson,
A.S. Denisov, A.V. Zhelamkov, Yu.M. Ivanov, L.P. Lapina, P.M. Levchenko, V.D. Malakhov, A.A. Petrunin, A.G. Sergeev, A.I. Smirnov, V.M. Suvorov, O.L. Fedin (PNPI), JETP Lett.54:558-563, 1991.

2 First results on studying 70-GeV proton beam focusing by bent crystal,
A.S. Denisov, O.L. Fedin, M.A. Gordeeva, M.P. Gurev, Yu.P. Platonov, A.I. Schetkovsky, V.V. Skorobogatov, A.I. Smirnov (PNPI), V.I. Baranov, Yu.A. Chesnokov, V.V. Dudenko, N.A. Galyaev, V.I. Kotov, S.V. Tsarik, V.N. Zapolsky (IHEP), JETP Lett.54:487-490,1991.

3 First measurement of the X-ray emission of sigma-minus atoms by means of a crystal-diffraction spectrometer, M.P. Gur'ev, A.S. Denisov, A.V. Zhelamkov, Yu.M. Ivanov, P.M. Levchenko, V.D. Malakhov, A.A. Petrunin, Yu.P. Platonov, A.G. Sergeev, A.I. Smirnov, V.M. Suvorov, O.L. Fedin (PNPI), JETP Lett.57:400-405,1993.

4 High-efficiency multipass extraction of 70-GeV protons from accelerator with a short bent crystal, A.G.Afonin, A.A.Arkhipenko, V.I.Baranov, V.M.Biryukov, Yu.A.Chesnokov, V.A.Gavrilushkin, V.N.Gres, V.I.Kotov, V.A.Maisheev,

A.V.Minchenko, V.I.Terekhov, E.F.Troyanov, V.A.Zelenov (IHEP), B.A.Chunin, A.S.Denisov, M.G.Gordeeva, Yu.M.Ivanov, A.A.Petrunin, V.V.Skorobogatov (PNPI),
Phys.Lett.B435:240-244, 1998.
5 High-efficiency beam extraction and collimation using channeling in very short bent crystals, A.G. Afonin, V.T. Baranov, V.M. Biryukov, M.B.H. Breese, V.N. Chepegin, Yu.A. Chesnokov, V. Guidi, Yu.M. Ivanov, V.I. Kotov, G. Martinelli, W. Scandale, M. Stefancich, V.I. Terekhov, D. Trbojevic, E.F. Troyanov, D. Vincenzi (IHEP & Surrey U. & Ferrara U. & INFN, Ferrara & INFM, Ferrara & PNPI & CERN & BNL), Phys.Rev.Lett.87:094802,2001.

2.4.3 Team Leader and address

Title	Dr.
Position	Head of laboratory
Sex	Male
Date Of Birth	07/03/1955
First Name	Yuri
Patronic Name	Mikhailovich
Family Name	Ivanov
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Organisation Registration Nr.	
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2.4.4 List of Senior Scientists in the team

1) First Name Vyacheslav
Patronic Name Vladimirovich
Family Name Skorobogatov
Year Of Birth 1938
Insitute Petersburg Nuclear Physics Institute

2.4.5 Statistics

Number of Team Members involved in this project: 9
Number of Team Members under 35: 2
Number of Team Members who have individually received grants in INTAS projects: 0

2.5 Team : INP Minsk

2.5.1 Team Description

From the seventies INP team is involved in studies of channeling phenomena. It made significant contributions into theoretical description of interactions between elementary particles and crystal lattice and several important for high-energy physics predictions.

In particular, INP team had elaborated the idea of being the rotation of spin of a particle moving in a bent crystal, which was experimental observed in 1990-1992 at the Fermi Laboratory, USA. This work paved the basis for the method of measurement of anomalous magnetic moments of short-lived elementary particles.

Team also shown that positron channeling in bent crystals can be used for measuring dependence of anomalous magnetic moment of positron on an electric field acting on it inside the crystal.

Team suggested new approach for measurement of quadrupole moment of omega+ hyperons when passing through a crystal.

Team developed proposal on using crystals for obtaining beams of polarized particles of high energies.

Team has large experience in Monte-Carlo calculations which was extensively used for simulation and description of the above phenomena.

The scientists to be involved in this project from the INP:

1. V.G.Baryshevsky
2. V.V.Tikhomirov
3. A.A.Gurinovich
4. A.O.Grubich
5. S.Yuralevich, 26 years old

2.5.2 List of publications

1 Self-polarization of high-energy particle spin in bent crystals, V.G. Baryshevsky, A.O. Grubich, Pisma v Zh. Tech. Fiz. v5, N24, 1527-1530, 1979.
2 Self-polarization and spin precession of channeling particles, V.G. Baryshevsky, A.O. Grubich, Yadernaya Fizika v.37, N 5, 1093-1100, 1983.

3 Synchrotron Type Radiation Processes in Crystals and Polarization Phenomena Accompanying Them, V.G. Baryshevsky, V.V. Tikhomirov, Sov.Phys.Usp.32:1013-1032,1989, Usp.Fiz.Nauk 159:529-565,1989.
4 Relativistic particle spin rotation and depolarization at passing through a crystal, V.G.Baryshevsky, NIM B44 (1990) 266-272.
5 Spin oscillation and the possibility of quadrupole moment measurement for omega- hyperons moving in a crystal, V.G. Baryshevsky, A.G.Shechtman, Nucl.Instrum.Meth. B83:250-254,1993.

2.5.3 Team Leader and address

Title	Prof.
Position	Director
Sex	Male
Date Of Birth	01/07/1940
First Name	Vladimir
Patronic Name	Grigorievich
Family Name	Baryshevsky
Organisation Type	Public
Organisation Registration Nr.	
Academy / Branch	
Organisation / University / Institute	Research Institute of Nuclear Problems
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Laboratory	
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Website	

2.5.4 List of Senior Scientists in the team

1) First Name	Andrey
Patronic Name	Olegovich
Family Name	Grubich
Year Of Birth	1949

Insitute INP
2) First Name Victor
Patronic Name Vasilievich
Family Name Tikhomirov
Year Of Birth 1958
Insitute INP

2.5.5 Statistics

Number of Team Members involved in this project: 5
Number of Team Members under 35: 1
Number of Team Members who have individually received grants in INTAS projects: 0

2.6 Team : Schonland

2.6.1 Team Description

The Schonland Research Institute for Nuclear Sciences is situated at the Northern most point of the East Campus of the University of the Witwatersrand in Johannesburg, the financial and industrial capital of South Africa. The Centre was founded as the Nuclear Physics Research Unit (NPRU) in 1958 under its first director Prof JPF Sellschop. It was part of the Physics Department until 1963 when it became a separate research entity directly funded from the University's research budget. As of January 1998 the centre was restructured according to a plan of the physics department whereby the centre became essentially an umbrella of autonomous research entities each with its own leader, research programme and independent recognition by and funding from the University Research Comittee.
The team has a strong record of diamond research and applications at high-energy accelerators over recent decades. E.g., high quality single crystal diamonds were used in experiment NA48 at CERN as targets for electron beams with energies up to 250 GeV to investigate strong field and coherent effects in Quantum Electro Dynamics.
Part of the work was honored by CERN Press Office and selected as the "photo of the month". The diamonds are (very large) 8x8x4 mm3 high quality synthetics grown by DeBeers for the CERN experiment NA59. The grown diamonds were engineered (prepared for high energy physics experiments) and then mounted and aligned. The diamonds have a quality that yields a near Darwin Line width for X-ray scattering, and are mutually aligned to about 35 micro-radians.
Bent Diamond X-Ray Monochromators: A curved diamond monochromator mounted with a strain free eutectic bond in a bending device has been made. Large synthetic diamonds produced by DeBeers are processed using laser cutting, cleaving and a variety of polishing processes to produce the highest quality single crystal diamond monochromators (<111> orientation) currently available. This work is part of a team providing these devices for a consortium which includes the worlds high intensity synchrotron X-ray sources. The theoretically superior performance of diamond over silicon (a factor of about 500) is almost realised.

2.6.2 List of publications

1 A. Baurichter, K. Kirsebom, Yu.V. Kononets, R. Medenwaldt, U. Mikkelsen, S.P. Moeller, E. Uggerhoej, T. Worm, K. Elsener, S. Ballestrero, P. Sona, J. Romano, S.H. Connell, J.P.F. Sellschop, R.O. Avakian, A.E. Avetisian, S.P. Taroian. RADIATION EMISSION AND ITS INFLUENCE ON THE MOTION OF MULTI-GEV ELECTRONS AND POSITRONS IN STRONG CRYSTALLINE FIELDS. Phys.Rev.Lett.79:3415-3418,1997

2 K. Kirsebom, U. Mikkelsen, E. Uggerhoj, K. Elsener, S. Ballestrero, P. Sona, S.H. Connell, J.P.F. Sellschop, Z.Z. Vilakazi. RADIATION EMISSION AND ITS INFLUENCE ON THE MOTION OF MULTI-GEV ELECTRONS AND POSITRONS INCIDENT ON A SINGLE DIAMOND CRYSTAL. Nucl.Instrum.Meth.B174:274-296,2001

3 G. Unel, A. Apian, R.O. Avakian, S. Ballestrero, C. Biino, P. Cenci, S.H. Connell, S. Eichblatt, T. Fonseca, A. Freund, A. Gianoli, R. Groess, B. Gorini, K. Ispirian, T. Ketel, A. Lopez, S. Luitz, U. Mikkelsen, E. Menichetti, A. Perego, B. van Rens, J.P.F. Sellschop, P. Sona, V. Strakhovenko, E. Uggerhoj, M. Velasco, Z.Z. Vilakazi, O. Wessely. NA59 EXPERIMENT AT CERN.
Int.J.Mod.Phys.A16S1C:1071-1073,2001

4 K. Kirsebom, Yu.V. Kononets, U. Mikkelsen, S.P. Moller, E. Uggerhoj, T. Worm, K. Elsener, C. Biino, S. Ballestrero, P. Sona, R.O. Avakian, K.A. Ispirian, S.P. Taroian, S.H. Connell, J.P.F. Sellschop, Z.Z. Vilakazi. GENERATION AND DETECTION OF THE POLARIZATION OF MULTI-GEV PHOTONS BY USE OF TWO DIAMOND CRYSTALS.
Phys.Lett.B459:347-353,1999

5 A. Baurichter, K. Kirsebom, R. Medenwaldt, U. Mikkelsen, S.P. Moller, E. Uggerhoj, T. Worm, Yu.V. Kononets, K. Elsener, S. Ballestrero, P. Sona, C. Biino, S.H. Connell, J.P.F. Sellschop, Z.Z. Vilakazi, A.B. Apian, R.O. Avakian, K.A. Ispirian, S.P. Taroian. ENHANCED ELECTROMAGNETIC SHOWERS INITIATED BY 20-GEV TO 180-GEV GAMMA-RAYS ON ALIGNED THICK GERMANIUM CRYSTALS.
Nucl.Instrum.Meth.B152:472-478,1999

2.6.3 Team Leader and address

Title	Dr.
Position	Director
Sex	Male
Date Of Birth	02/03/1961
First Name	Simon
Patronic Name	
Family Name	Connell
Organisation Type	Public
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2.6.4 List of Senior Scientists in the team

2.6.5 Statistics

Number of Team Members involved in this project: 3
Number of Team Members under 35: 0
Number of Team Members who have individually received grants in INTAS projects: 0

3 OBJECTIVES

3.1 RESEARCH OBJECTIVES

Crystal Technique for Halo Cleaning in the LHC

Objectives

1. To design and build prototypes of optimal channeling scraper for the LHC, and test them experimentally with 70-GeV protons
2. To perform detailed realistic simulations of crystal-assisted cleaning of protons and heavy ions from the LHC beam halo, optimise the efficiency, evaluate requirements and limitations for the method, and find the achievable scraping efficiency
3. To adapt the channeling scraper to the lattice of the LHC by means of simulations aiming to understand the effect of accelerator functions on the efficiency of crystal cleaning system
4. To find in simulations the requirements for the crystal scraper quality (surface quality, angular distortions, crystal lattice perfection) adequate for the application in the LHC, as well as the requirements for the accuracy of its positioning and angling
5. To study a high-efficiency multipass mode of collimation and extraction from accelerator using bent crystals in experiments at 70 GeV, in order to research crystal collimation as a technique for the LHC by means of experimental tests at 70 GeV and realistic simulations
6. To develop a theory of beam multipass steering by short crystals in a broad range of energies, and to support by Monte Carlo simulations the experimental studies of extraction and collimation
7. To achieve electron-microscopy and x-ray characterisations of bent crystals in order to study defects
8. To develop the technique for preparation of highly perfect surfaces of channeling silicon crystals and the means for protection of these surfaces (from oxidation etc.) until installation into vacuum environment of accelerator
9. To research a broad range of crystal lattices (diamond to germanium) with atomic number much lower and much higher than that of silicon as candidates for crystal scraper
10. To invent and test principally new approaches to crystalline devices for beam steering and test them at beam energies up to 70 GeV; to perform detailed Monte Carlo simulations to properly assess the bending efficiency
11. To study - by means of Monte Carlo simulations and proof-of-principle experiments with high-energy protons - the possibilities to use nanostructured material for beam channeling with a potential of application at the LHC

3.2 Background and Justification

Crystal Technique for Halo Cleaning in the LHC

Background & Justification for Undertaking the Project

Classic two-stage collimation systems for loss localisation in accelerators typically use a small scattering target as a primary element, whereas the secondary element is a bulk absorber [1]. Normally in colliders the halo diffusion is pretty slow, therefore the first touch of a halo particle with the aperture-restricting collimator is rather a glancing touch, with the impact parameter on the order of micron. Such a near-surface particle is easiely scattered out of the collimator material. The role of the primary element is to give a substantial angular kick to incoming halo particles in order to increase the impact parameter of the particles on the secondary element placed in some position, optimised transversally and longitudinally for better interception.

Naturally, an amorphous target scatters particles in all possible directions. Ideally, one would prefer a "smart target" that kicks all particles in only one direction: for instance, only in radial plane, only outward, and only into the preferred angular range corresponding to the center of absorber (to exclude escapes). Bent crystal is the first idea for such a smart target: it traps particles and convenes them into desired direction. In physics language, we replace the scattering on single atoms of amorphous target by a coherent scattering on atomic planes of aligned monocrystal.

Bent crystal serves as a miniature strong-field septum with a minimal "septum width" (down to Angstrem, in principle). Feasibility of crystal extraction from circular accelerators has been demonstrated worldwide at energies from 4 to 900 GeV [2], with the present team having participated in all major crystal extraction and collimation experiments - at CERN SPS [3], FNAL Tevatron [4], RHIC [5], and IHEP [6]. At IHEP Protvino this technique has been routinely used since 1987 to deliver a 70 GeV beam to particle physics experiments [2]. The theory of crystal extraction is based mainly on detailed Monte Carlo simulations tracking the particles through a curved crystal lattice and the accelerator environment in a multipass mode. The predictions of IHEP code CATCH were successfully tested at CERN, FNAL, BNL, IHEP in 1992-2003 [2-6].

Crystal extraction efficiency can be boosted due to multiple character of particle encounters with a radically shortened crystal ("multipass" extraction) [7,8]. This idea has been proven by recent 70 GeV experiments at IHEP [6] making use of tiny (about 2 mm) crystals to extract about 1.E12 protons/s with efficiency of 85%, i.e. for the first time comparable to the traditional techniques of slow extraction. Having demonstrated a breakthrough in high-efficiency extraction using short crystals, it is essential to develop this method into a new concept of efficient slow extraction from accelerators and control of halos in storage rings. As demonstrated e.g. at Tevatron, crystals can work in parasitic mode in collider [4].

Producing bent crystal deflectors of required size and curvature is not an easy task, moreover as one takes into account that deflector has to be placed in a circulating beam and any extra disturbance to halo particles must be avoided. Excellent crystalline deflectors used at IHEP were
produced by PNPI and Ferrara teams. In PNPI, a novel technique of "O"-shaped crystals of tiny size was invented and several new approaches are being studied. In Ferrara, a "strip"-type crystals were produced which have demonstrated record 85% efficiency of channeling.

If crystal channeling efficiency were 100%, the crystal would kick all the halo particles deeply onto the collimator for safe absorption. As a real crystal is not 100% efficient, only part of the halo goes into safe place. The collimator then has only to deal with the few remaining particles unchanneled in the crystal. In multi-stage collimation, the primary scatterer can be replaced by a crystal. Notice that no change in collimation optics is necessary. The crystal material can be varied (C, Si, and Ge bent crystals are existing) [8] to match the material choice of amorphous scatterer. For unchanneled particles the system works as if it were amorphous.

For application one can take even a 100%-safe approach, using a short (eg, 1 cm Si) crystal together (just in front) with normal primary scraper of the collimation system, in the same location. First, this ensures that if crystal is not channeling then system works as usual. When crystal is brought to channeling condition, it works just as a "crystalline edge" for the primary target, deflecting ("shaving off") at a fraction of mrad as much halo as possible. In this way, the deflected particles will also be scattered then in the primary target, therefore the actual resulting deflection will be in some range; this may even have an additional positive effect, spreading the beam load on the absorber over some larger area.

As experimentally studied, the heating and radiation damage in a crystal would be of no concern at the LHC. The IHEP practice shows that channeling of 1.E12 protons/s is feasible without cooling measures taken and no degradation seen [6]. CERN experiment shows that radiation damage starts
to be seen at about 5.E20 of 450 GeV protons/sq.cm [9]. One of the IHEP crystals did extract 70 GeV protons over 10 years without replacement!

Monte Carlo simulations for Tevatron Run-II show that accelerator backgrounds in D0 and CDF experiments are reduced by factor of 7-14 with crystal as compared to newly designed amorphous cleaning system [10]. A proof-of-principle experiment on crystal collimation has been performed by our collaboration in IHEP 70 GeV experiment where a crystal was channeling halo protons into an absorber, being a part of the halo cleaning system [6]. A crystal collimation experiment for gold ions has been performed at RHIC by IHEP-BNL collaboration [5]. The measured data is in good agreement with computer model prediction; the channeling efficiency was about 25-30% matching poor beam condition. A thorough study of crystal collimation as an option for the Large Hadron Collider seems very necessary.

In 2001-2003 the present collaboration has done research under INTAS-CERN project 132-2000 with the same subject. The collaboration has demonstrated the efficiency of crystal channeling extraction and collimation at 70-GeV proton accelerator of 85% for the beams of very high intensity, over 1E12. A broad range of energies, 1.3 to 70 GeV, has also been investigated in the crystal collimation experiment in the main ring of IHEP U70, and world record high efficiencies were observed in each case [6,11]. The observed results followed the prediction of computer model.
Herewith we suggest to continue the project in 2004-2006 in order to elaborate an efficient option for the LHC beam cleaning system based on channeling.

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4 SCIENTIFIC / TECHNICAL DESCRIPTION
4.1 Research Programme

Crystal Technique for Halo Cleaning in the LHC

RESEARCH PROGRAMME

The research program aims to develop a high-efficiency technique for steering of halo particles in a large hadron collider using bent channeling crystal. The technique can be used to strongly enhance the efficiency of beam cleaning system if a bent crystal serves as a primary element in the LHC beam collimation system, reducing the beam-related backgrounds in the collider experiments by an order of magnitude. Whenever required, the same technique can be used for slow parasitic extraction from the LHC halo without interfering with collider work, with extraction efficiency between 50-90% according to simulations. Within this project, we foresee the following research directions:

1 To design and build prototypes of optimal channeling scraper for the LHC, and test them experimentally with 70-GeV protons
2 To perform detailed realistic simulations of crystal-assisted cleaning of protons and heavy ions from the LHC beam halo, optimise the efficiency, evaluate requirements and limitations for the method, and find the achievable scraping efficiency
3 To adapt the channeling scraper to the lattice of the LHC by means of simulations aiming to understand the effect of accelerator functions on the efficiency of crystal cleaning system
4 To find in simulations the requirements for the crystal scraper quality (surface quality, angular distortions, crystal lattice perfection) adequate for the application in the LHC, as well as the requirements for the accuracy of its positioning and angling
5 To study a high-efficiency multipass mode of collimation and extraction from accelerator using bent crystals in experiments at 70 GeV, in order to research crystal collimation as a technique for the LHC by means of experimental tests at 70 GeV and realistic simulations
6 To develop a theory of beam multipass steering by short crystals in a broad range of energies, and to support by Monte Carlo simulations the experimental studies of extraction and collimation
7 To achieve electron-microscopy and x-ray characterisations of bent crystals in order to study defects
8 To develop the technique for preparation of highly perfect surfaces of channeling silicon crystals and the means for protection of these surfaces (from oxidation etc.) until installation into vacuum environment of accelerator
9 To research a broad range of crystal lattices (diamond to germanium) with atomic number much lower and much higher than that of silicon as candidates for crystal scraper
10 To invent and test principally new approaches to crystalline devices for beam steering and test them at beam energies up to 70 GeV; to perform detailed Monte Carlo simulations to properly assess the bending efficiency

11 To study - by means of Monte Carlo simulations and proof-of-principle experiments with high-energy protons - the possibilities to use nanostructured material for beam channeling with a potential of application at the LHC.

4.2 Project Structure

4.2.1 Task Title : Monte Carlo Simulation

Task coordinator : Biryukov, belonging to team: IHEP Protvino

Objectives :

1 To perform detailed realistic simulations of crystal-assisted cleaning of protons and heavy ions from the LHC beam halo, optimise the efficiency, evaluate requirements and limitations for the method, and find the achievable scraping efficiency.

2 To adapt the channeling scraper to the lattice of the LHC by means of simulations aiming to understand the effect of accelerator functions on the efficiency of crystal cleaning system.

3 To find in simulations the requirements for the crystal scraper quality (surface quality, angular distortions, crystal lattice perfection) adequate for the application in the LHC, as well as the requirements for the accuracy of its positioning and angling.

4 To simulate the crystal collimation experiments at 70 GeV: optimization, prediction of efficiency and characteristics. To develop a theory of beam multipass steering by short crystals in a broad range of energies, and to support by Monte Carlo simulations the experimental studies of extraction and collimation.

5 To research a broad range of crystal lattices (diamond to germanium) with atomic number much lower and much higher than that of silicon as candidates for crystal scraper.

6 To simulate channeling physics in a nanostructured material with a study of potential applications for the LHC.

Methodology :

This activity will use the Monte Carlo codes for simulation of channeling in deformed crystal lattices and nanotubes and related processes, with major attention to accelerator environment with tracking particles multi-turn along the ring. The CATCH program tracks a charged particle through a distorted crystal lattice using the continuous-potential approximation and taking into account the processes of both single and multiple scattering on electrons and nuclei. In the framework of the recent experiments - RD22 (CERN), E853 (Fermilab), RHIC crystal collimation (BNL) and many at IHEP, the code was proven to adequately predict a wide range of channeling phenomena: feed-out and feed-in rates, energy loss spectra, beam bending and extraction efficiencies, dislocation dechanneling in bent single crystals.
Another computer code developed at IHEP simulates the interaction of high-energy particles with curved nanotubes (SWNT, MWNT).
Strong experience in channeling theory at Minsk INP will be involved in order to build a comprehensive model for the present studies.

Task Input:
The computer modeling of a crystal deflector has to be made in contact with the people working on its manufacturing, in order to obtain the realistic input to the model and to provide insights into what kind of deflector has to be manufactured for the experiment. Equally essential is the information on the side of accelerator (beam quality, set-up comfiguration), detector resolution, etc.

Result, milestones :
Monte Carlo simulations of particle channeling aim at finding the deflector configuration optimal for the IHEP experiments and specifically for its application at the LHC. The major deliverable should be the design optimised for the LHC, taking into account also the realistic details like the LHC lattice, collimation settings in the LHC, beam quality, and all the processes relevant to particle interaction with crystal. The model should give clear prediction to be verified in IHEP experiments.

4.2.2 Task Title : Design and Manufacture

Task coordinator : Ivanov, belonging to team: PNPI Gatchina

Objectives :
The experimental program of the project requires bent silicon crystals with parameters which vary over a wide range. The crystal length along the beam is proposed to be from a fraction of mm to a few millimetres; crystal width across the beam - from a fraction of a millimetre up to several millimetres; a required curvature radius of a bent crystal - from a fraction of meter up to several meters. The angle between the chosen atomic plane and the face of a crystal plate (and the face parallelness to each other) should be better than 200 microrad in some cases, the typical deviation from flatness is less than 1 micron and the roughness is 0.02-0.04 micron, or better.

Methodology :
The required properties of crystals will be provided by an appropriate production technology developed at PNPI after years of manufacturing bent crystals for experiments on X-ray diffraction and charged particle channeling. To prepare a very short crystalline deflectors (not an easy job for traditional techniques) it is planned to use several new approaches. The previous basic approach was the production of "O"-shaped monocrystals. Recently, PNPI team has produced first crystals of a very new design with the length down to 0.3 mm along the beam and the bending of up to 0.5 mrad which have already been successfully tested with 70-GeV protons.

An alternative approach to produce record-short crystal deflectors with high-quality surface will be taken by Ferrara team. Instead of abrasive technique of fine polishing as used in PNPI, Ferrara team will try a variety of techniques basing mostly on chemical etching to ensure a fine surface of crystal septa. Another essential feature of these alternative deflectors is a different design: they are made in a shape of "strip" about 0.5-1 mm along the beam and sort of 50 mm high. This is to serve for a different class of bending device developed in IHEP in the course of INTAS-132. Here "anticlastic bending" (parasitic effect normally) serves for beam deflection. This type of deflector has demonstrated record high efficiency of channeling 85% in 70-GeV proton extraction and collimation at intensities over 1.E12.

Task Input:

The task is depending on : Monte Carlo Simulation
The infrastructure issues are adressed in sub-tasks.

Result, milestones :
Crystal deflectors.

4.2.2.1 Task Title : Gatchina workshop

Task coordinator : Ivanov, belonging to team: PNPI Gatchina

Objectives :
To design and build prototypes of optimal channeling scraper for the LHC, to be tested experimentally with 70-GeV protons.
To invent and test principally new approaches to crystalline devices for beam steering to be tested at beam energies up to 70 GeV.

Methodology :
The required properties of crystals will be provided by an appropriate production technology developed at PNPI after years of manufacturing bent crystals for experiments on X-ray diffraction and charged particle channeling. To prepare a very short crystalline deflectors (not an easy job for traditional techniques) it is planned to use several new approaches. The previous basic approach was the production of "O"-shaped monocrystals (a slab with an extracted central part); the required bending is produced by compressing the crystal in the middle.
Recently, PNPI team has produced first crystals of a very new design with the length down to 0.3 mm along the beam and the bending of up to 0.5 mrad which have already been successfully tested with 70-GeV protons.

Task Input:

The task is depending on : Monte Carlo Simulation
The infrastructure existing from the project INTAS-CERN 132-2000 can be upgraded.

Result, milestones :
Crystal deflectors.

4.2.2.2 Task Title : Ferrara workshop

Task coordinator : Guidi, belonging to team: Ferrara

Objectives :
To design and build prototypes of optimal channeling scraper for the LHC, to be tested experimentally with 70-GeV protons.
To develop the technique for preparation of highly perfect surfaces of channeling silicon crystals and the means for protection of these surfaces (from oxidation etc.) until installation into vacuum environment of accelerator.

Methodology :
An alternative approach to produce record-short crystal deflectors with high-quality surface will be taken by Ferrara team. Instead of abrasive technique of fine polishing as used in PNPI, Ferrara team will try a variety of techniques basing mostly on chemical etching to ensure a fine surface of crystal septa. Another essential feature of these alternative deflectors is a different design: they are made in a shape of "strip" about 0.5-1 mm along the

beam and sort of 50 mm high. This is to serve
for a different class of bending device developed in IHEP in the course of INTAS-132. Here "anticlastic bending" (parasitic effect normally) serves for beam deflection. This type of deflector has demonstrated record high efficiency of channeling 85% in 70-GeV proton extraction and collimation at intensities over 1.E12. Ferrara team will work on development of the technique for preparation of highly perfect surfaces of channeling silicon crystals and the means for protection of these surfaces (from oxidation etc.) until installation into vacuum environment of accelerator.

Task Input:

The task is depending on : Monte Carlo Simulation
The infrastructure is available from the project INTAS-CERN 132-2000 and cab upgraded.

Result, milestones :
Crystal deflectors.

4.2.2.3 Task Title : Diamond research

Task coordinator : Connell, belonging to team: Schonland

Objectives :
To make feasibility study for bent diamond deflectors for the use in experiments at the IHEP Protvino with potential application at the LHC.

Methodology :
Very large (like 8x8x4 mm3 and larger) high quality synthetic diamonds are grown by DeBeers for physics experiments, actually with a rich history of collaboration with CERN. The quality is highly controlled. Very important for us, diamonds have already been bent with a a bending radius quite suitable for a possible accelerator experiment at IHEP.

Task Input:

The task is depending on : Monte Carlo Simulation
At Schonland Research Centre there exists a developed infrastructure for diamond research.

Result, milestones :
Based on the success of feasibility studies, a channeling deflector made of bent diamond will be manufactured for 70-GeV proton tests.

4.2.3 Task Title : Crystal Characterisation

Task coordinator : Guidi, belonging to team: Ferrara

Objectives :
On the basis of the long experience on crystalline silicon characterisation, University of Ferrara will perform investigations aimed at studying defects in bent crystals. The study of
microscopic structure of these crystals may be of tremendous importance in order to achieve useful information for description of dechanneling phenomena. Moreover it is possible to follow aging
effects of bent crystals due to fluence of particles through them. On the basis of

the experience gained through structural
characterisation, the possibility to consider diverse approach to the preparation of bent crystal will also be addressed.

Methodology :
University of Ferrara can count scanning electron microscopy (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) other than several collaborations with research institutions are presently active and this makes possible to perform high-resolution transmission electron microscopy (HREM) and x-ray analyses.
To check properties of fabricated crystals and to study features of their bending with different techniques we plan to use crystal
diffraction X-ray instrumentation developed at PNPI. The instrumentation provides narrow monochromatic X-ray beams with size of about 100 micrometers and energy in 6-60 keV region,
positioning and scanning of samples relative to the X-ray beam with accuracy of several micrometers, measuring of diffraction angles with
accuracy of several microradians. With this instrumentation rocking curves from crystals can be measured in Bragg and Laue geometries
providing information on surface and volume properties of crystals which makes possible to study and select crystal samples and to research and develop new designs of bending devices
for accelerator experiments.

Task Input:

The task is depending on : Design and Manufacture
Manufactured crystals serve as an input for this task, and the feedbacks from the channeling tests are essential.

Result, milestones :
Information on surface and volume properties of crystals, in particular precise characterisation of the bending function of the samples.

4.2.4 Task Title : Channeling tests in external beam

Task coordinator : Chesnokov, belonging to team: IHEP Protvino

Objectives :
In order to precisely measure the efficiency and bending characteristics of the crystals before installing them into the accelerator vacuum chamber we plan to expose the crystals in the
external beams using various detectors.

Methodology :
The best resolution is to be achieved with a set of nuclear photo emulsions placed at several distances from the crystal. We have used this technique for several years, in particular for the pioneering experiments on crystal focusing of a 70 GeV beam. The technique allows a
coordinate precision of 1 micron, which is quite sufficient to fully analyse the spatial and angular characteristics of the deflected and undeflected beams. In parallel, the beam deflection is monitored also by proportional chambers with a resolution of 0.1 mm. To initially align the crystal, we use a goniometer and scintillation counters. It is interesting to say that the external 70 GeV beam for these measurements is provided by a special 150-mrad

bent crystal; this channeled beam of low divergence has been routinely exploited since 1994 as a source for various experiments.

Task Input:

The task is depending on : Design and Manufacture
This work will require samples of crystal deflectors manufactured within our project by other groups, and will use the existing set-ups of IHEP Protvino regularly used for channeling studies over decades.

Result, milestones :
We precisely measure the spatial and angular distributions of the channeled particles downstream of the crystal in order to observe (and guarantee before going to collimation studies) the channeling efficiency across the cross-section of crystal, in particular to see if the manufacturing has not disrupted the channeling properties in parts of the sample.

4.2.5 Task Title : Crystal Extraction Experiment

Task coordinator : Chesnokov, belonging to team: IHEP Protvino

Objectives :
The breakthrough in crystal channeling at IHEP accelerator was achieved with 2-mm "strip"-shaped Si crystals bent 1 mrad. We shall continue the extraction studies on several locations in the 70 GeV main ring, bringing the crystal length as close to optimum (of the order of 1 mm) as feasible, in tight cooperation with Gatchina and Ferrara teams.

Methodology :
The experiments will use "mechanically-bent" crystals of various designs as created at Petersburg and Ferrara; further experiments can take advantage of the use of new designs of deflectors. The new technique from PNPI allows the use of crystals bent about 0.5 mrad with the "length" along the beam significantly less than 1 mm and a very big cross-section at the same time; much work is still needed here. This design is perfectly suited for the 70 GeV accelerator environment and we plan to reach over 90% efficiency of crystal channeling in collimation and extraction experiments at 70 GeV. Finally, very interesting experiments can be done with non-silicon channeling structures: bent diamond and germanium crystals (low Z andd high Z materials respectively), and nanotube deflectors (made of SWNT or MWNT).

Task Input:
The success of the accelerator experiment will depend to large extent on the progress with designing and manufacturing of crystal deflectors. The infrastructure does exist and has been extensively used in the course of INTAS-CERN project 132-2000.

Result, milestones :
The demonstration of highly efficient channeling extraction and collimation, verification of the new technological approaches to efficient crystal deflectors, verification of computer models, test of real prototypes for the LHC.

4.2.6 Task Title : Crystal Collimation Experiment

Task coordinator : Chesnokov, belonging to team: IHEP Protvino

Objectives :

Based on the existing set-up where we have performed world first proof-of-principle experiment on crystal collimation, we plan to develop it into a highly efficient method of halo scraping.

Methodology :
With a heavy collimator normally used for beam emittance formation, and with radiation detectors installed along the accelerator ring, we shall evaluate the collimation efficiency with and without a bent crystal.
Various bent crystals will be studied as active scrapers deflecting channeled particles toward the bulk of the collimator; the change in radiation background will be monitored, scraping efficiency and characteristics studied. Crystal temperature effects in intense beam (over 3.E12 circulating protons) will be experimentally studied.

Task Input:

The task is depending on : Design and Manufacture
The infrastructure (ring collimator, two crystal locations at different distances w.r.t. the collimator, equipped with target units each capable of hadling several (2-3) crystal scrapers with translation and rotation, irradiation monitors) is available. A target unit with possibility of 2-D rotation of a sample (of supposedly nanotubes) is in preparation.

Result, milestones :
Crystal work as a scraper in the environment of a two-stage cleaning system will have to be assessed and studied as a function of not only crystal parameters but accelerator settings as well.

4.3 Project Management

4.3.1 Planning & Task allocation

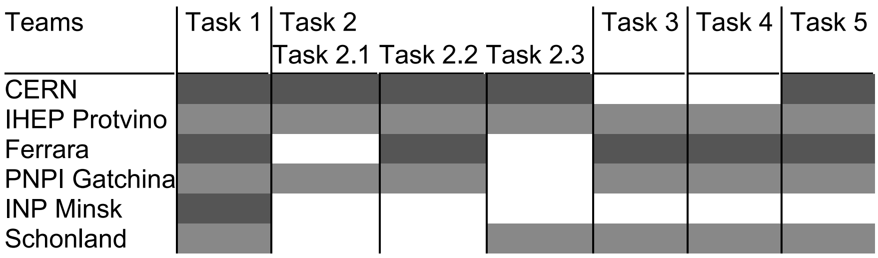
4.3.1.1 List of Task Titles

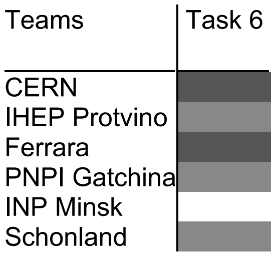
1. Monte Carlo Simulation
2. Design and Manufacture
    - 2.1 Gatchina workshop
    - 2.2 Ferrara workshop
    - 2.3 Diamond research
3. Crystal Characterisation
4. Channeling tests in external beam
5. Crystal Extraction Experiment
6. Crystal Collimation Experiment

4.3.1.2 The project will last 36 months with the activities as indicated in the diagram below

Task / SubTasks	Months 1-6	Months 7-12	Months 13-18	Months 19-24	Months 25-30	Months 31-36
Task 1						
Task 2						
SubTask 2.1						
SubTask 2.2						
SubTask 2.3						
Task 3						
Task 4						
Task 5						
Task 6						

4.3.1.3 Team involvement





4.3.2 Project Management Description

The research results will be published as preprints of the participating Institutions, submitted to leading journals in the field and presented at scientific conferences. The computer programs developed under this project will be available to interested users. Original technological developments will be patented, intellectual property rights are protected. With the progress made under this project we will develop detailed proposals for application in the fields that may benefit. Besides articles publication, patents, workshops, an essential part of management of knowledge will be work towards public understanding of science activities (broadcasting, internet site), contacting manufactures, industry, searching for the potential applications in physics and medicine.

The management of the project and the co-operation between the participants will be carried out primarily by electronic means of communication. We foresee a regular exchange of scientists between the teams in order to facilitate the development of new technology of crystal deflectors, to jointly participate in the accelerator runs at IHEP Protvino, and to discuss the results and to plan further directions in the activities. This has been our practice during collaboration 2001-2003 indeed. Visits from INTAS teams to IHEP are planned to be about two times per year to match the accelerator schedule, with 2-3 persons from abroad present at every IHEP run. Visits from NIS to INTAS teams will be (and are at present) scheduled so as to ensure the timely preparation of crystals for experiments at IHEP. An important management resource is the meetings at accelerator workshops such as EPACs, to be used by us for principle coordination.

4.4 Project costs

4.4.1 Cost Table

The breakdown of costs of the INTAS contribution (in EURO) is given in the tables below.

INTAS MEMBER STATE TEAMS								
	Team name	Cost categories						TOTAL
		Labour Costs	Overheads	Travel & subs.	Consumables	Equipment	Other	(EURO)
1	CERN	0	0	0	0	0	0	0
2	Ferrara	10000	1000	4000	1000	0	0	16000
SUBTOTAL	(EURO)	10000	1000	4000	1000	0	0	16000

NIS TEAMS								
	Team name	Cost categories						TOTAL
		Labour Costs	Overheads	Travel & subs.	Consumables	Equipment	Other	(EURO)
3	IHEP Protvino...	70530	0	13500	3000	3000	0	90030
4	PNPI Gatchina...	27000	0	3000	3000	3000	0	36000
5	INP Minsk	16020	900	1080	0	0	0	18000
SUBTOTAL	(EURO)	113550	900	17580	6000	6000	0	144030

TOTAL	(EURO)	123550	1900	21580	7000	6000	0	160030

4.4.2 Justification of Costs

4.4.2.1 Labour costs (only for NIS teams)

Team name: IHEP Protvino

Number of individual grants		Cost per month	Total number of man months	Total cost (EURO)
Team Leader	1	500	36	18000
Senior Researcher	1	400	36	14400
Scientist / Engineer	7	155	246	38130
Technical or Other	0	0	0	0
TOTAL				70530

Team name: PNPI Gatchina

Number of individual grants		Cost per month	Total number of man months	Total cost (EURO)
Team Leader	1	250	36	9000
Senior Researcher	1	150	36	5400
Scientist / Engineer	6	100	108	10800
Technical or Other	1	50	36	1800
TOTAL				27000

Team name: INP Minsk

Number of individual grants		Cost per month	Total number of man months	Total cost (EURO)
Team Leader	1	110	36	3960
Senior Researcher	2	110	54	5940
Scientist / Engineer	2	85	72	6120
Technical or Other	0	0	0	0
TOTAL				16020

4.4.2.2 Travel and subsistence

Team 1 (CERN)

Team 2 (Ferrara)

Participation in accelerator runs at the IHEP Protvino.

Team 3 (IHEP Protvino)

Team 4 (PNPI Gatchina)

Team 5 (INP Minsk)

4.4.2.3 Consumables

Team 1 (CERN)

Team 2 (Ferrara)

Team 3 (IHEP Protvino)

Team 4 (PNPI Gatchina)

Team 5 (INP Minsk)

4.4.2.3 Equipment

Team 1 (CERN)

Team 2 (Ferrara)

Team 3 (IHEP Protvino)

Team 4 (PNPI Gatchina)

Team 5 (INP Minsk)

4.4.2.4 Other Costs

Team 1 (CERN)

Team 2 (Ferrara)

Team 3 (IHEP Protvino)

Team 4 (PNPI Gatchina)

Team 5 (INP Minsk)

4.5 Project innovation potential and dissemination of results

Having understood the ways of efficient steering of high-energy particle beams by applying crystal channeling, it is essential to develop this method into a new concept of efficient slow extraction from accelerators and control of halos in storage rings. The direct outcome of this project is an order of magnitude reduction of the accelerator-related backgrounds in collider detectors, respective reduction of the irradiation of superconducting elements in the machine. Efficient steering of halo particles by crystal may turn to be an easy instrument for parasitic extraction when required by users of the LHC.