INTAS PROPOSAL FOR
INTAS Collaborative Call with CERN 2005 - Research Project

1.1 TITLE:

Experimental study of crystal channeling at CERN SPS for use at the LHC in diffractive physics and halo cleaning

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 : crystal channeling
Free word 2 : diffractive physics
Free word 3 : particle beam collimation

1.1.3 Intended Start Date: February 2006

1.1.4 Duration: 30 Months

1.2 CONSORTIUM

Centre Europeenne pour la Researche Nucleaire - Switzerland
University of Ferrara - Italy
Institute Institute for High Energy Physics - Russia
Petersburg Nuclear Physics Institute - Russia
INFN Pisa - Italy
INFN - National Institute of Nuclear Physics - Italy
Joint Institute for Nuclear Research - Russia

1.3 SUMMARY

The research program aims to create at CERN SPS a facility to test and characterize crystal for channeling and to validate the procedure to obtain a very powerful collimation system for the LHC and a system to increase the experimental possibilities in proton-proton diffractive physics. This has been reviewed in recent workshop held at CERN on March 7 & 8, 2005. The project will proceed with modification to the SPS lattice and hardware (point 1 & 2 in the list below). The new generation silicon crystal will be produced at PNPI Gatchina (point 3) under the provision obtained from the calculation performed for LHC collimation system studies (point 4 & 6) and the diffraction studies (point 5). Before installation in the SPC, the crystals will be tested in laboratories Ferrara University and LNL and be tested in a first characterization run in Protvino accelerator (point 7, 8 & 9). The tasks of the project are:

1.
Lattice calculations and software implementation for extraction- and collimation-modes in the crystal channeling experiments at the SPS.

2.
Simulations for crystal experiments in the SPS for optimal location, choice of the crystal, bending angles and other related issues to provide the basics for proper layout and geometry of the experimental setup for crystal experiments in the SPS.

3.
Simulations for optimal design of a crystal for application in experiments on diffractive proton-proton interactions.

4.
Preparation of bent crystals to be tested at the SPS with 270 GeV/c protons. Development of silicon crystal deflectors for high energy particles.
5.
Surface treatment of crystal samples for usage in the SPS.
6.
New crystalline materials for channeling in the SPS
7.
Morphological and structural characterizations of crystalline materials to be used in the SPS.
8.
First characterization of crystals in the U70 facility at 70 GeV/c.
9.
Preparation of the experimental setup for crystal channeling measurements at the SPS: crystal holders, goniometers, particle detectors and data acquisition.
10.
Perform data taking runs of crystals channeling experiment in the values conditions
11.
Assessment of crystal channeling technique as potential beam instrument at the LHC energies, in particular for the use at LHC in diffractive physics and halo cleaning.
12.
Comparison of experimental results achieved in the SPS measurements with current theories of beam multipass steering by short crystals in a broad range of energies.

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	Senior Scientist
Sex	Male
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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 : Ferrara

2.2.1 Team Description

The Semiconductors and Sensors Group of the University of Ferrara has been involved in the characterization and growth of silicon since twenty years. Fundamental and applied studies on nanostructured semiconductor metal-oxides have been carried out with particular focus on chemo-resistive properties and its applications for gas sensing.
Active research is in the field of photovoltaics with many an application for high efficiency photocells, which have been transferred to industrial partners.
Recently the group implemented a complete facility for micromachining of silicon in clean-room environment equipped with photolithography and low-pressure chemical vapor deposition unit.

The scientists to be involved in this project from U. of Ferrara

1. V. Guidi,
2. M. Fiorini,
3. C. Malagù ,
4. G. Martinelli,
5. E. Milan,
6. M. Stefancich

2.2.2 List of publications

1 V. Guidi, A. Antonini, S. Baricordi, F. Logallo, C. Malagù, E. Milan, A. Ronzoni, M. Stefancich, G. Martinelli, A. Vomiero

"Tayloring of silicon crystals for relativistic–particle channeling"
Nuclear Instrumentation and Methods in Physics Research B 234 (2005) 40-46
2 V.M. Biryukov, V.N. Chepegin, Yu.A. Chesnokov, V. Guidi, W. Scandale
"Crystal collimation as an option for the Large Hadron Collider"
Nuclear Instrumentation and Methods in Physics Research B 234 (2005) 23-30
3 S. Baricordi, V.M. Biryukov, A. Carnera, Yu.A. Chesnokov, G. Della Mea, V. Guidi, Yu.M. Ivanov, G. Martinelli, E. Milan, S. Restello, A. Sambo, W. Scandale, A. Vomiero
"Low-energy-channeling surface analysis on silicon crystals designed for high-energy-channeling in accelerators
Applied Physics Letters 87 (2005) 1

4 V.M. Biryukov, Yu.A. Chesnokov, V. Guidi, V.I. Kotov et al.
"Crystal deflector for highly efficient channeling extraction of a proton beam from accelerators"
Rev. Sci. Instrum. 73 (2002) 3170-3173

5 V.M. Biryukov, V.N. Chepegin, Yu.A. Chesnokov, V. Guidi, W. Scandale
"Crystal collimation as an option for the Large Hadron Collider"
Nuclear Instrumentation and Methods in Physics Research B 234 (2005) 23-30

2.2.3 Team Leader and address

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2.2.4 List of Senior Scientists in the team

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   Patronic Name
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   Insitute University of Ferrara
2) First Name Giuliano
   Patronic Name
   Family Name Martinelli
   Year Of Birth 1938
   Insitute University of Ferrara

2.2.5 Statistics

Number of Team Members involved in this project: 6
Number of Team Members under 35: 4
Number of Team Members who have individually received grants in INTAS projects: 0

2.3 Team : IHEP Protvino

2.3.1 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.

2.3.2 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 900GeV 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.

2.3.3 Team Leader and address

Title	Dr
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Sex	Male
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2.3.4 List of Senior Scientists in the team

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   Family Name AFONIN
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2) First Name Vladimir Timofeevich
   Patronic Name
   Family Name BARANOV

Year Of Birth 1939
Insitute IHEP

3) First Name Valery Mikhailovich
Patronic Name
Family Name BIRYUKOV
Year Of Birth 1961
Insitute IHEP

4) First Name Valery Nikolaevich
Patronic Name
Family Name CHEPEGIN
Year Of Birth 1943
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5) First Name Yuri Andreevich
Patronic Name
Family Name CHESNOKOV
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6) First Name Vladilen Ivanovich
Patronic Name
Family Name KOTOV
Year Of Birth 1930
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7) First Name Vladimir Alexandrovich
Patronic Name
Family Name MAISHEEV
Year Of Birth 1947
Insitute IHEP

2.3.5 Statistics

Number of Team Members involved in this project: 10
Number of Team Members under 35: 1
Number of Team Members who have individually received grants in INTAS projects: 6

2.4 Team : PNPI Gatchina

2.4.1 Team Description

The PNPI team is experienced in the application of crystals to studies with X-rays and particle beams. To obtain crystals with parameters needed for these experiments they developed a laboratory-based crystal manufacture. 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 investigated 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.

To date the team involved also in preparation of LHC experiments CMS and TOTEM.

2.4.2 List of publications

1 First results from a study of a 70 GeV proton beam being focused by a bent crystal, A.S.Denisov, ..., V.V.Skorobogatov, A.I.Smirnov, ..., NIM B69(1992)382
2 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, ..., Yu.M.Ivanov, ... A.A.Petrunin, ..., A.I.Smirnov, ..., JETP Lett. 57(1993)400
3 High-efficiency multipass extraction of 70-GeV protons from accelerator with a short bent crystal, A.G.Afonin, ..., A.S.Denisov, M.G.Gordeeva, Yu.M.Ivanov, A.A.Petrunin, V.V.Skorobogatov, Phys. Lett. B435(1998)240.
4 High-efficiency beam extraction and collimation using channeling in very short bent crystals, A.G.Afonin et al., Phys.Rev.Lett. 87(2001)94802.

2.4.3 Team Leader and address

Title	Dr
Position	Head of Laboratory
Sex	Male
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2.4.4 List of Senior Scientists in the team

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

2.4.5 Statistics

Number of Team Members involved in this project: 10
Number of Team Members under 35: 1
Number of Team Members who have individually received grants in INTAS projects: 4

2.5 Team : INFN Pisa

2.5.1 Team Description

The Pisa/Siena group is part of the TOTEM Collaboration whose purpose is to measure the total cross section, elastic scattering and diffraction dissociation at the LHC. They are significantly contributing to the physics optimization, the fabrication process and the instrumentation (front-end electronics and trigger) of the T2 detector, the very small angle telescope based on Gas Electron Multiplier (GEM) detectors. In addition to these hardware contributions, the Pisa/Siena group participates in the simulation and physics studies relevant to the T2 performance. Bent crystals deflecting protons of LHC beams can improve significantly the proton acceptance of the TOTEM Roman Pots, extending the angular sensitivity to

interesting diffractive events.
The Pisa/Siena group plans to provide its experience to the beam tests foreseen for the crystal channeling studies at CERN SPS, as well as to coordinate simulation studies to characterize a crystal quality adequate for the application in the TOTEM diffractive proton proton interactions.
The Team leader participated in the original RD22 Collaboration proposal to test a beam extraction by crystal channeling at the SPS.

2.5.2 List of publications

1 K. Eggert, `Can Micro Channeling Improve the TOTEM Experiment?', CARE-HHH workshop CC-2005, CERN, 7-8 March 2005.

2 The TOTEM Collaboration, CERN-LHCC-2004-002 (2004), "TOTEM Technical Design Report"; CERN-LHCC-2004-020 (2004), "TOTEM TDR - Addendum".
3 R. Bellazzini, S. Lami et al., CERN-PPE/91-26 (1991) "A proposal to test beam extraction by crystal channeling at the SPS: a first step towards a LHC extracted beam" (RD22 proposal).

2.5.3 Team Leader and address

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Position	Staff Member
Sex	Male
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2.5.4 List of Senior Scientists in the team

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   Year Of Birth 1959
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2) First Name Angelo
   Patronic Name
   Family Name SCRIBANO
   Year Of Birth 1900
   Insitute INFN Pisa

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 : LNL Legnaro

2.6.1 Team Description

The INFN Legnaro National Laboratories partecipated since seventies to the development of surface analytical techniques using ion beams. Fundamental and applied studies on low energy channeling for structural characterization of crystals were continuously carried out, focussing on materials to be applied in microelectronics.
High competence in design and set-up of high precision positioning systems was developed along the years to build up fully automated holders for alignment of crystalline samples and beam direction.
Additional techniques for surface analysis such as scanning electron microscopy and atomic force microscopy have been recently gained.
The Legnaro group is responsible for task 6 in the research program.

The scientists to be involved in this project from LNL are:

1. A. Vomiero
2. E. Boscolo Marchi
3. A. Carnera
4. G. Della Mea
5. G. Maggioni
6. R. Milan

2.6.2 List of publications

1 V. Guidi, A. Antonini, S. Baricordi, F. Logallo, C. Malagu, E. Mila, A. Ronzoni, M. Stefancich, G. Martinelli, and A. Vomiero
"Tayloring of silicon crystals for relativistic-particle channeling"
Nuclear Instruments and Methods in Physics Resaearch B 234 (2005) 40.

2 S. Baricordi, V.M. Biryukov, A. Carnera, Yu.A. Chesnokov, G. Della Mea, V. Guidi, Yu.M. Ivanov, G. Martinelli, S. Restello, A. Sambo, W. Scandale, and A. Vomiero
"Low-energy-channeling suerface analysis on silicon crystals designed for high-energy-channeling in accelerators"
Applied Physics Letters 87 (2005) 094102
3 G. Della Mea, A.V. Drigo, S. Lo Russo, P. Mazzoldi, and G. Bentini
"Energy loss of H, D and 4He ions channeled through thin single crystals of silicon"
Physical Review Letters 27 (1971) 1194
4 G. Della Mea, A.V. Drigo, S. Lo Russo, P. Mazzoldi, G.G. Bentini, A. Desalvo, and R. Rosa
"Axial- to planar- channeling transition"
Physical Review B 7 (1973) 4029
5 A. Vomiero, S. Restello, C. Scian, G. Della Mea, V. Guidi, E. Milan, S. Baricordi, G. Martinelli, A. Carnera, and A. Sambo
"Structure and morphology of surface of silicon crystals to be applied for channeling at relativistic energies"

2.6.3 Team Leader and address

Title	Dr
Position	Staff Member
Sex	Male
Date Of Birth	22/03/1974
First Name	Alberto
Patronic Name	
Family Name	Vomiero
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Organisation Registration Nr	
Academy / Branch	
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2.6.4 List of Senior Scientists in the team

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Year Of Birth 1951
Insitute INFN - LNL
2) First Name Gianantonio
Patronic Name
Family Name Della Mea
Year Of Birth 1944
Insitute INFN - LNL

2.6.5 Statistics

Number of Team Members involved in this project: 6
Number of Team Members under 35: 3
Number of Team Members who have individually received grants in INTAS projects: 0

2.7 Team : JINR Dubna

2.7.1 Team Description

The JINR team has a big experience in simulation of particle channeling in bent crystals and circulating beam extraction from accelerator with a bent crystal. We have studied first the peculiarities of particle dechanneling in bent crystals, the effects of volume capture and volume reflection of quasi-channeled particles and the contribution of multiple passages of circulating particles through the bent crystal during extraction (multi-turn beam extraction). We took part in preparation of proposal to extract beam halo from the SSC and in analysis of experimental results of proton beam extraction from the SPS (RD22 collaboration). We suggested using a thin crystal mirror to throw collider halo particles through the imperfect layer at the bent crystal surface to increase the extraction efficiency. Our simulation results for deflection of proton and Pb nuclei beam of the SPS by silicon crystals are in good agreement with the experimental results (the discrepancy is about 10-15%).
There is a big experience in construction and production of accelerators in JINR. The superconducting synchrotron, the Nuclotron, is under operation in the Laboratory of High Energies, JINR.
The team has an experience in assembling and working with GEM detectors, microstrip detectors and scintillation detectors.
o Experimental workshops of JINR are capable to produce magnetic optical systems, particle detectors and elements of electronics (printed boards, proportional chambers, scintillation detectors, streamer plastic tubes and others). Electronic engineer group has produced multi channel HV systems, elements of DAQ system including fast ADC and trigger logic for CERN experiments (Atlas and CMS).

2.7.2 List of publications

1 M. Adinolfi, .V.Golovatyuk. et all. The KLOE DRIFT CHAMBER. Nucl.Instrum.Meth.A461:25-28,2001, Nucl.Instrum.Meth.A494 (2002) 163-172

2 V.Golovatyuk et. all. PERFORMANCE OF A SILICON MICROSTRIP DETECTOR IN A VERY HIGH RATE ENVIRONMENT. IEEE Trans.Nucl.Sci.39 (1992)1249.
3 Tsyganov E., Taratin A., Zinchenko A. Innovations in accelerator technology. Phys.Part.Nucl. 27(3), May-June 1996, p.279.
4 Biino C., Clement.M., Doble N., Elsener K., Gatignon L., Grafstrom P., Heer W., Keppler P., Major J., Mikkelsen U., Taratin A., Velasco M. Deflection of 33 TeV/c fully stripped Pb ions by means of a bent Si crystal. Nucl.Instr.Meth.B., 160 (2000) 536-543.
5 A.D. Kovalenko. "Status of the Nuclotron", EPAC'94, London, June 1994. Proceedings, v.1, p.p. 161-164, (1995).

2.7.3 Team Leader and address

Title	Dr
Position	Head of Department
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2.7.4 List of Senior Scientists in the team

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2) First Name Aleksander
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Year Of Birth 1944
Insitute JINR

3) First Name Alexei
Patronic Name
Family Name SHABUNOV
Year Of Birth 1959
Insitute JINR

4) First Name Alexander
Patronic Name
Family Name TARATIN
Year Of Birth 1950
Insitute JINR

5) First Name Vladimir
Patronic Name
Family Name UZHINSKII
Year Of Birth 1951
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2.7.5 Statistics

Number of Team Members involved in this project: 7
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

The recent workshop on crystal channeling held in CERN on March 7 and 8, 2005, has established the present situation of crystal channeling in all its aspects and demonstrated the essential role of an experiment at CERN SPS to access the feasibility of using crystal channeling for a successful LHC experimental program up to maximum luminosity.

Bent-crystal techniques are well established as a means for extracting high-energy beams from accelerators. Following the pioneering proposals [1,2], experiments in Protvino [3], at the CERN SPS [4] and at the Tevatron [5] have observed extraction efficiencies in good agreement with simulations, up to beam energies of 900 GeV. Highest efficiencies of 50-80% were achieved in the Protvino experiments using a thin (3-5 mm) *Si* crystal with 0.5-1.5 mrad bending angle.

In 1991 it was proposed to apply crystals for halo collimation in the SSC [6]. The underlying idea was that a bent crystal as primary collimator should extract incident halo particles onto a subsequent secondary collimator. Indeed, simulations with the STRUCT/MARS codes showed that the addition of bent crystals reduced beam losses by about three orders of magnitude. More recently, based on realistic modeling it was decided to implement a bent-crystal collimation system in the Tevatron, which is expected to reduce beam loss in the superconducting magnets by a factor of 4 and the detector background by up to an order of magnitude [7]. Commissioning of the bent-crystal collimation system at the Tevatron will start in 2005. The first crystal which will be used at the Tevatron was previously employed in a crystal-collimation attempt at RHIC. The RHIC experiment [8] was unsuccessful, which has been ascribed to the non-optimal configuration of experiment.

An efficient and robust collimation system is mandatory for any superconducting hadron collider, in particular for the LHC, which will store a beam of unprecedented high intensity and energy. The present LHC baseline collimation system is known to fail at above half the design intensity, where its impedance is predicted to drive the LHC beam unstable. Highly efficient and short primary bent-crystal collimators offer the prospect of retracting the secondary collimators, so as to reach nominal and ultimate intensity. The LHC experiments have suggested other interesting applications of bent crystals notably their use in diffractive proton proton interactions in conjunction with Roman pots to significantly extend the angular sensitivity to diffractive Higgs events [9]. Yet a further possible role of crystals LHC would be the use as a last resort for safely extracting the LHC beam in the unlikely event of a complete dump kicker failure. In addition, with an optimized crystal-based collimation system at the LHC, one can expect a substantial reduction of beam loss rates and accelerator-related beam background in the detectors [7].

Over the last years, groups in Russia (St. Petersburg) [10] and Italy (Ferrara) [11] have developed crystal production methods, which are reported to considerably improve the crystal quality as compared to the previous experiments.

In view of the imminent crystal-collimation experiments at the Tevatron, the potential improvement compared with the phase-1 LHC collimation system, and the recent progress in crystal technology, we propose to start as soon as possible a series of crystal experiments in the SPS, which could address a number of objectives:

1) qualification of the new crystals to be used in the Tevatron collimation experiment (e.g., measuring their channeling efficiency) and confirmation of the recode extraction efficiencies measured in Protvino;
2) measuring the channeling efficiency of long crystals with 1 mrad and/or 8 mrad bending angle;
3) modeling the crystal set up for performing diffractive physics(this requires a 2-stage crystal system and Roman pots);
4) extraction of the full SPS beam with crystals (for use as LHC protection device in the rare case of dump kicker failure);
5) comparison of loss patterns around the ring for a crystal with one for amorphous material, e.g., for benchmarking simulations of crystal-collimation efficiency.

From the scientific arguments presented above, we perceive a high probability to improve the LHC halo collimation with bent-crystal scrapers. This is an important issue because of the extreme requirements posed by the LHC machine, especially for its nominal and ultimate intensity. It is not much time left to develop a detailed technical design of crystal scrapers for the LHC, and we consider it not as wise to wait for further scientific justification from outside CERN. We note that the SPS is an ideal machine for this type of experiments, since its properties are well understood, and since it will not be under the same pressure as the Tevatron and later the LHC. Any additional data from Fermilab, Protvino, and other laboratories would be very welcome, and will strengthen the case. However, in our opinion, CERN should now aim to take a leadership role of the development, since CERN is solely responsible for the success of the LHC program.

References

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3.2 Background and Justification

The present proposal is a part of an international effort in the field of crystal channeling, coordinated by CERN and aimed to realizing a full potential of LHC accelerator for elementary particle physics. Such an effort includes studies done and/or planned at IHEP (Russia), BNL (USA), FNAL (USA), CERN (Switzerland). Some of these studies were already supported by collaborative INTAS-CERN grants.

Firstly, the project 132-2000 carried out within 2001-2003, which resulted in crystal channeling extraction and collimation at IHEP 70-GeV proton accelerator with world record efficiency of 85% for beams intensity over 1E12.

Secondly, the project 03-52-6155, currently funded by INTAS-CERN, is the continuation of the project 132-2000. That project is devoted to development of crystal techniques for halo cleaning in the LHC and relies on the usege of IHEP 70-GeV accelerator as a test bench for the studies.

The present proposal is a new project aimed to provide a bridge from IHEP 70-GeV energy to LHC energies by studying a new crystal technique at CERN SPS accelerator with 270-GeV proton beam and further for development of the technique for diffractive physics experiments at LHC.

4 SCIENTIFIC / TECHNICAL DESCRIPTION

4.1 Research Programme

The research program of the project aims to establishing a facility at CERN SPS for tests and characterization of crystals to be used for particle channeling studies in the SPS with a 270 GeV/c proton coasting beam.

The experimental layout consists of two locations for the crystals: one for deflection at low angle (200 μrad) and another for larger bending angles (some mrad). Measurements will be performed to obtain the channeling efficiency. Required deflection angles will be possible through the established techniques of crystal bending. Alternative candidates to silicon will be experimented, too.

Research program will take advantage of the experience gained in previous and ongoing research projects in this field. The first part of the program will be devoted to determine the beam characteristics for optimal location and parameters of the crystals and of the proton detecting stations.

The second part will be the construction, implementation and test of hardware components in the SPS: special vacuum tanks, goniometers to orient the crystal, near beam particle detectors, Roman pot stations and external telescope. In this phase it is essential to implement the software programs for crystal movements and safety interlocks in the machine control system and in the data acquisition system as well.

Crystal design will be achieved through currently available most sophisticated software (IHEP, JINR). Crystal production and surface treatment will be accomplished at PNPI and Ferrara (Semiconductors and Sensors Group). Morphological and structural characterizations will take place at LNL and PNPI.
Prior to installation into the SPS, the crystals will be tested for channeling in the U70 accelerator (IHEP), which has a paramount experience in the field.

The final goal is to have good experience for possible usage of channeling techniques in the LHC collimation system and to promote new schemes for proton-proton diffractive physics.

This facility is foreseen to stay in running mode until the crystals for LHC collimation will be produced.

4.2 Project Structure

4.2.1 Task Title : SPS lattice study

Task coordinator : Walter Scandale, belonging to team: CERN

Objectives :
Detailed study and comparison of possible places for crystal channeling experiment.

Methodology :

Lattice calculations and software implementation for extraction and collimation modes in the crystal channeling experiments at the SPS.

Task Input:
Magnet structure of SPS.

Result, milestones :
Choice of place for crystal channeling experiment relative to SPS ring.

4.2.2 Task Title : Simulation of crystals for halo cleaning

Task coordinator : Alexander Taratin, belonging to team: JINR Dubna

Objectives :
Simulations for crystal experiments in the SPS for optimal location, choice of the crystal, bending angles and other related issues to provide the basics for proper layout and geometry of the experimental setup for crystal experiments in the SPS.

Methodology :
Computer simulations for multi-turn collimation (extraction) for proton beam and bent crystals with and without imperfections. The set of similar calculations for nuclear beam. Simulation of the process with the using additional thin crystal mirror to throw particles over the imperfect layer of a bent crystal.

Monte Carlo code CATCH [1] will be applied for simulation of channeling in deformed crystal lattices, with major attention to accelerator environment with tracking particles multi-turn along the ring. In the framework of experiments of recent decades: RD22 (CERN SPS), E853 (Tevatron, FNAL), RHIC crystal collimation (BNL-IHEP) and many at IHEP U70, the code was proven to adequately predict a wide range of channeling phenomena, in particular beam deflection and extraction/collimation efficiencies.
[1] V. Biryukov “CATCH 1.4 User’s Guide”. CERN SL Note 93-74 AP (1993)

Task Input:

The task is depending on : SPS lattice study
The task is depending on lattice calculations, crystal structural characterization and general scheme of the experiment including preliminary layout.

Result, milestones :
Accurate simulation data for crystal experiments at SPS, including bending angles, efficiency and other related issues in accordance with the project schedule.

4.2.3 Task Title : Simulation of crystals for diffraction physics

Task coordinator : Stefano Lami, belonging to team: INFN Pisa

Objectives :
Simulations for optimal design of a crystal for application in experiments on diffractive proton-proton interactions.

Methodology :
To find in simulations the requirements for the crystal quality (surface quality, angular distortions, crystal lattice perfection) adequate for the application in the experiment of diffractive proton proton interactions.

Bent crystals placed at 6 sigma from the LHC beam, deflecting the protons, can improve significantly the proton acceptance of the TOTEM Roman Pots, extending the angular sensitivity to diffractive Higgs events.

Task Input:

The task is depending on : Simulation of crystals for halo cleaning
The TOTEM collaboration (CERN) will provide all necessary inputs for execution of the simulations.

Result, milestones :
Feasibility of diffractive experiments via crystal channeling at LHC

4.2.4 Task Title : Crystal fabrication

Task coordinator : Yuri Ivanov, belonging to team: PNPI Gatchina

Objectives :
Preparation of bent crystals to be tested at the SPS with 270 GeV/c protons.
Development of silicon crystal deflectors for high energy particles.

Methodology :
It is based upon theoretical description of deformed anisotropic solids, mechano-optical and chemical processing of silicon crystals, optical and X-ray control measurements. Necessary facilities and equipment will be provided by PNPI, U. of Ferrara, LNL.

Task Input:

The task is depending on : Simulation of crystals for halo cleaning
Parameters of bent silicon crystals as orientation, sizes, bending angles, thickness of damaged layer, and so on in dependence on problems to be solved in channeling experiment at SPS.

Result, milestones :
Bent silicon crystals of different types checked optically and with X-rays before measurements with high energy proton beams.

4.2.5 Task Title : Surface treatment of silicon samples for the SPS

Task coordinator : Vincenzo Guidi, belonging to team: Ferrara

Objectives :
Fabrication of a crystal for channeling does demand many operations to be carried out such as slicing, dicing, polishing and so on. Each step involves a mechanical action onto the sample that causes imperfections into the crystal (scratches, deformations, dislocations, vacancies) that perturb the performance for channeling.
A recent study demonstrated that the quality of a crystal positively affects its performance. Aim of the work is to perfect the already established methodology for application to the crystal for channeling.

Methodology :
A specifically conceived wet-chemical etching was developed for planar erosion of silicon atoms. Etching consists of a sequence of chemical treatments to the surfaces of the sample. Erosion is pursued until the superficial amorphous layer

has been removed. The planar etching is rather a slow process that allows precise trimming of the portions to be removed, in close connection with the information determined through structural characterization (e.g. RBS-channeling in task 6). An equipped facility for chemical etching is available at the Sensors and Semiconductors group at the University of Ferrara.

Task Input:

The task is depending on : Crystal fabrication
The task is depending on crystal manufacturer and structural characterization.

Result, milestones :
Achievement of crystals with optimal crystalline quality.

4.2.6 Task Title : New crystalline materials for channeling in the SPS

Task coordinator : Vincenzo Guidi, belonging to team: Ferrara

Objectives :
Study of zeolites (and zeotypes) for channeling in the SPS.

Methodology :
Zeolites (and zeotypes) are a class of crystalline oxides built up from corner shared tetrahedra TO4 (T = typically Si and Al, but also Ga and P), whose structures may contain 1-, 2-, or 3-dimensional systems of linear internal channels of infinite length and aperture size ranging from 0.1 to 1 nm, depending on the specific framework topology. Zeolites sometimes occur in large crystals (crystal thickness of 0.1-2.0 mm orthogonal to a channel system and length up to 10-20 mm along the channels) as natural materials (alumino-silicate minerals) and can be produced as synthetic materials. In zeolites, the extremely regular and periodic channel systems act as potential wells in a very similar way of nanotubes. Such a property might be exploited for steering of high energy particles by channelling effects.

Task Input:

The task is depending on : Morphological and structural characterizations of crystals and their surfaces
Results of characterization.

Result, milestones :
Feasibility study of samples from new materials for channeling in the SPS.

4.2.7 Task Title : Morphological and structural characterizations of crystals and their surfaces

Task coordinator : Alberto Vomiero, belonging to team: LNL Legnaro

Objectives :
Provide a quality control for crystal samples to be used for channeling experiment at SPS.
According to the experience gained in recent years, special attention is needed to the fabrication of crystals with high surface quality (see also task 5), to minimize the effects of possible surface amorphous layers, which can disturb proton channeling affecting the overall channeling efficiency.
Major objective is thereby the morphological and structural characterization of the

samples prior to the installation into the accelerator.
Characterization will compare the results gained by different preparation methods, and will be useful for fine tuning of the parameters of preparation methodologies.

Methodology :
Using a set of solid state techniques (X-ray diffraction, electron microscopy, atomic force microscopy, ion-beam analysis) to measure critical bulk and surface properties of crystal samples during whole production process.
In particular the XRD facility with the low-size blanked X-ray probe at PNPI will be dedicated to structural characterization of crystals before and after bending.
Ion beam analysis will be performed at LNL to gain information about the crystalline perfection of the surface layers of the crystal and to evaluate the crystalline disorder induced by preparation methodologies.
Surface morphology will be investigated by the means of electron microscopy (LNL and Ferrara University) and AFM to obtain qualitative and quantitative information about surface roughness and presence of extended defects as a consequence of surface handling during preparation.

Task Input:

The task is depending on : Crystal fabrication
Initial crystalline materials and crystal samples on different production stages.
The task is depending on crystal manufacturers and will feed back information to them.

Result, milestones :
Measured bulk and surface properties of crystals used in channeling experiment at SPS.
Optimization of crystal fabrication and quality control of the crystals to be used in the SPS for operation under reproducible conditions.

4.2.8 Task Title : Proton beam characterization at IHEP

Task coordinator : Yuri Chesnokov, belonging to team: IHEP Protvino

Objectives :
First characterization of crystals in the U70 facility at 70 GeV/c. For the experiment in the main ring (multipass mode), with a small angle of bending (about 200 microradiant), a beam scraper is foreseen for removal of deflected beam from circulation. In testing in one-pass mode setup in external beam line will be used.

Methodology :
The U70 accelerator at IHEP is an ideal facility to probe the crystals. Additional test for particle detectors produced at JINR may be carried out before transportation to CERN. The U70 accelerator is equipped with more than one station for measurements of channeling efficiency, including main ring stations and external beam lines.

Task Input:

The task is depending on : New crystalline materials for channeling in the SPS
Crystals provided by the manufacturers that show good structural characterization are used for pre-test with 70 GeV/c protons.

Result, milestones :

This task will provide a pre-test for crystal performance prior to be installed into the SPS.

4.2.9 Task Title : Experiment construction and implementation at the SPS

Task coordinator : Massimiliano Fiorini, belonging to team: Ferrara

Objectives :

Preparation of the experimental setup for crystal channeling measurements at the SPS: crystal holders, goniometers, particle detectors and data acquisition.

Design and construction of the experimental setup for channeling measurements.

Methodology :

Two crystal stations have to be set up, each of which equipped with goniometer and sample holder to be mounted in a new tank in the SPS.
The JINR group will be in charge of tank construction. Based on the experience gained at IHEP, design and construction of the crystal holders will be possible for both of stations. Regarding goniometers we will first consider the adaptation of previously used instruments in the RD22 experiment, which will be endorsed by PNPI and LNL.
The first crystal station is an assembly of 2 vertical Roman pot, to detect the particles bent by the first crystal at low angles (200 mrad). Roman pots have to be equipped with either silicon microstrips or scintillating-fiber detectors. Here, a beam scraper is needed for removal of the deflected beam from circulation. Additional detectors – beam loss monitors near the crystal and the scraper are useful for fine tuning of the system.
The second station is an external telescope to detect the protons extracted from the SPS through a crystal bent with an angle of some mrad. The telescope will be a structure similar to the one used in the RD22 experiment. A scintillating hodoscope and GEM, provided detectors by existing CERN experiments, could be added to achieve the beam profile.
The Ferrara team will be in charge of construction of the external telescope detectors and related electronics. Detectors from JINR will also be implemented. The data acquisition system will be jointly developed by JINR and PNPI.

Task Input:

The task is depending on : SPS lattice study
The task is depending on the SPS lattice calculations and on the geometry of the experiment. Moreover, provision of crystals is due on the strength of the studies developed in task 4.

Result, milestones :

Measurement of crystal channeling efficiency at low and large bending angles.
This task can be subdivided into three periods:
• procurement and assembly of the needed components (mechanics, detectors, electronics, DAQ)
• construction and setting up of the experimental apparatus
• data taking and measurements

4.2.10 Task Title : Runs of crystal channeling experiments at SPS

Task coordinator : Walter Scandale, belonging to team: CERN

Objectives :

Perform data taking runs of crystals channeling experiment in the values conditions.

Methodology :
As soon as the two crystal stations will be implemented data taking with run shifts will be carried out. Data analysis will follow to determine the performance of the method of crystal channeling.

Task Input:

The task is depending on : Experiment construction and implementation at the SPS
Constrution of the experimental setup is needed.

Result, milestones :
Data about crystal channeling will be an important basis for comparison with simulations and for a critical analysis of the method.

4.2.11 Task Title : Extrapolation of SPS results to the LHC energies

Task coordinator : Valery Biryukov, belonging to team: IHEP Protvino

Objectives :
Assessment of crystal channeling technique as potential beam instrument at the LHC energies, in particular for the use at LHC in diffractive physics and halo cleaning.

Methodology :
We will apply Monte Carlo code CATCH [1] successfully verified in all crystal extraction and collimation experiments of recent decade: at CERN SPS, Tevatron, IHEP, and RHIC [2-5] in order to evaluate the potential effect of crystal channeling at the LHC energies [6-8]. CATCH will be extensively used for understanding of the results of the new SPS experiment and extrapolation of SPS results to the LHC.
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[8] V.M. Biryukov, V.N. Chepegin, Yu.A. Chesnokov, V. Guidi and W. Scandale. Nucl. Instr. Meth. B 234 (2005) 23

Task Input:

The task is depending on : Proton beam characterization at IHEP
The task requires detailed input from the SPS crystal collimation and extraction experiment encompassing the measured data and details of the setup for accelerator, crystal hardware and possibly diagnostics resolution in order to assess data and evaluate theory. Input from the LHC accelerator and collimation experts is essential as well for a sound extrapolation from the SPS to the LHC case.

Result, milestones :
Predictions for the crystal collimation and extraction performance at the LHC

energies, in particular for the crystal collimator insertion into the designed classic collimation system for the LHC, basing on the experimental data received in the course of CERN SPS experiment on crystal extraction and collimation and using the computer model verified in the experiments.

4.2.12 Task Title : Result analysis

Task coordinator : Walter Scandale, belonging to team: CERN

Objectives :
Comparison of experimental results achieved in the SPS measurements with current theories of beam multipass steering by short crystals in a broad range of energies.

Methodology :
Dedicated workshops will be organized to report and discuss experimental results with the international scientific community.

Task Input:

The task is depending on : Experiment construction and implementation at the SPS
This task will receive inputs from all the other tasks with particular reference from task 10 and 11.

Result, milestones :
Experimental results and computer simulations will be critically analized. The aim is to provide useful inforamation to the LHC.

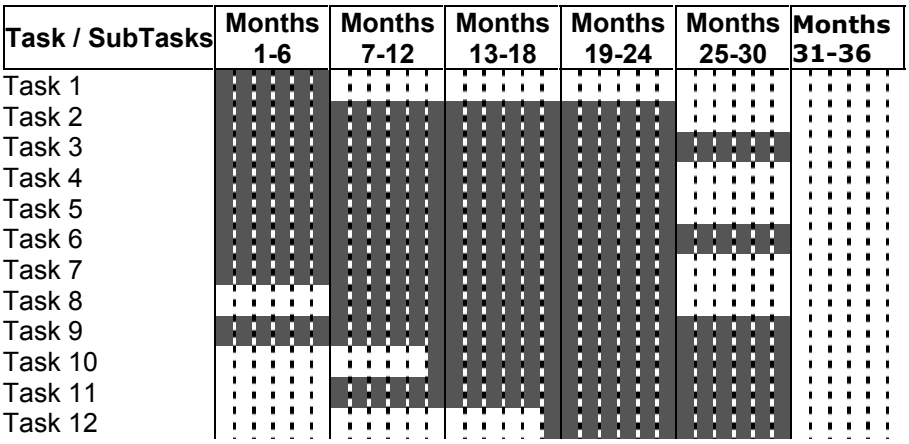
4.3 Project Management

4.3.1 Planning & Task allocation

4.3.1.1 List of Task Titles

1. SPS lattice study
2. Simulation of crystals for halo cleaning
3. Simulation of crystals for diffraction physics
4. Crystal fabrication
5. Surface treatment of silicon samples for the SPS
6. New crystalline materials for channeling in the SPS
7. Morphological and structural characterizations of crystals and their surfaces
8. Proton beam characterization at IHEP
9. Experiment construction and implementation at the SPS
10. Runs of crystal channeling experiments at SPS
11. Extrapolation of SPS results to the LHC energies
12. Result analysis

4.3.1.2 The project will last 30 months with the activities as indicated in the diagram below



4.3.1.3 Team involvement

Teams	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7
CERN							
Ferrara							
IHEP Protvino							
PNPI Gatchina							
INFN Pisa							
LNL Legnaro							
JINR Dubna							

Teams	Task 8	Task 9	Task 10	Task 11	Task 12
CERN					
Ferrara					
IHEP Protvino					
PNPI Gatchina					
INFN Pisa					
LNL Legnaro					
JINR Dubna					

4.3.2 Project Management Description

Based on the experience from the previous successful INTAS-CERN projects, the management of the present proposal and the co-operation between the participants will be carried out by e-mail, regular telephone audiconferences and collaboration meetings. We foresee a regular exchange of scientists between the teams in order to facilitate the development of new technologies, to jointly participate in the accelerator runs and data handling and analysis, and to discuss the results and to plan further directions in the activities. All visits will be scheduled so as to ensure timely progress of the project.

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	0	0	3000	7000	5000	0	15000
3	INFN Pisa	0	0	0	0	0	0	0
4	LNL Legnaro	0	0	3000	4000	8000	0	15000
SUBTOTAL	(EURO)	0	0	6000	11000	13000	0	30000

NIS TEAMS								
	Team name	Cost categories						TOTAL
		Labour Costs	Overheads	Travel & subs.	Consumables	Equipment	Other	(EURO)
5	IHEP Protvino...	31800	0	5000	3200	0	0	40000
6	PNPI Gatchina...	30000	0	5000	5000	0	0	40000
7	JINR Dubna	35000	0	5000	0	0	0	40000
SUBTOTAL	(EURO)	96800	0	15000	8200	0	0	120000

TOTAL	(EURO)	96800	0	21000	19200	13000	0	150000

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	300	12	3600
Senior Researcher	6	200	120	24000
Scientist/Engineer	3	150	28	4200
Technical or Other	1	0	0	0
TOTAL				31800

Team name: PNPI Gatchina

Number of individual grants		Cost per month	Total number of man months	Total cost (EURO)
Team Leader	1	300	20	6000
Senior Researcher	4	200	65	13000
Scientist/Engineer	3	150	60	9000
Technical or Other	2	100	20	2000
TOTAL				30000

Team name: JINR Dubna

Number of individual grants		Cost per month	Total number of man months	Total cost (EURO)
Team Leader	1	300	20	6000
Senior Researcher	4	300	80	24000
Scientist/Engineer	2	200	25	5000
Technical or Other	0	0	0	0
TOTAL				35000

4.4.2.2 Travel and subsistence

Team 1 (CERN)

Team 2 (Ferrara)
*

Team 3 (INFN Pisa)
*

Team 4 (LNL Legnaro)
*

Team 5 (IHEP Protvino)
*

Team 6 (PNPI Gatchina)
*

Team 7 (JINR Dubna)
*

4.4.2.3 Consumables

Team 1 (CERN)

Team 2 (Ferrara)
Travel expenses: it partly covers travel expenses for collaboration meeting.
Consumables: silicon wafers 2000; chemical reagents 3000; photolitographic masks 2000; part of the expenses for construction/re-arrangement of the hodoscope and pertaining infrastructures 5000.

Team 3 (INFN Pisa)
*

Team 4 (LNL Legnaro)
3000 euros as a contribution to expenses for collaboration meetings

Team 5 (IHEP Protvino)
*

Team 6 (PNPI Gatchina)
*

Team 7 (JINR Dubna)
*

4.4.2.3 Equipment

Team 1 (CERN)

Team 2 (Ferrara)
*

Team 3 (INFN Pisa)
*

Team 4 (LNL Legnaro)
2000 Atomic force microscopy tips and accessories;
2000 Scanning electron microscopy filaments and accessories; 8000 kE Stepping motors for sample holders and electronic remote controls

Team 5 (IHEP Protvino)
*

Team 6 (PNPI Gatchina)
*

Team 7 (JINR Dubna)
*

4.4.2.4 Other Costs

Team 1 (CERN)

Team 2 (Ferrara)
Financial contribution by national institution will be provided upon acceptance of the present project. Most of the necessary equipment is currently available.

Team 3 (INFN Pisa)
No financial request is demanded for the simulations endorsed by Pisa; travel expenses for collaboration will be found within currently operating TOTEM experiment.

Team 4 (LNL Legnaro)

Team 5 (IHEP Protvino)
*

Team 6 (PNPI Gatchina)
*

Team 7 (JINR Dubna)
*

4.5 Project innovation potential and dissemination of results

Project innovation potential and dissemination of results

The first direct consequence of the validation of the channeling process will result in an order of magnitude reduction of the accelerator-related backgrounds in collider detectors, respective reduction of the irradiation of superconducting elements in the machine. The second result will be an enlargement of the actual program for proton-proton diffractive physics in two directions increase the minimum angle of a final state particle and in the mass range for the diffractively produced system.