FERMILAB-PROPOSAL-0980

Fermilab

Directorate

Memorandum of Understanding
for the test beam program

T-980

A Crystal Collimation Experiment (CCE) at the Tevatron

June 9, 2008

This Memorandum of Understanding is intended between Fermi National Accelerator Laboratory and the following Institutions of the CCE Collaboration:

CERN

Institute of High Energy Physics (IHEP), Russia

Istituto Nazionale di Fisica Nucleare (INFN), Sezioni di Ferrara, Milano-Bicocca, Roma, Italy

Joint Institute for Nuclear Research (JINR), Russia

Petersburg Nuclear Physics Institute (PNPI), Russia

U.S. LARP, USA

This memorandum is intended solely for the purpose of providing a work allocation for Fermi National Accelerator Laboratory and the participating universities and institutions. It reflects an arrangement that is currently satisfactory to the parties involved. It is recognized, however, that changing circumstances of the evolving research program may necessitate revisions. The parties agree to negotiate amendments to this memorandum to reflect such revisions.

The general obligations of the experimenters while at FNAL are contained in the Special Considerations in Appendix 1.

1. Introduction

1.1. The CCE leadership roles and participants are outlined in Appendix 2.

1.2. The motivations and the goals of the experiment agreed to in this MOU are described in Appendix 3.

1.3. The status of the studies already performed at the Tevatron is described in Appendix 4.

2. Outline of fronts of activity

2.1. The CCE is organized in 3 stages: preparatory stage described in Appendix 5 (part for stage 1 essentially complete by June 2008); stage 1 consisting of Configuration 1 and 2 (to be completed by Spring 2009 shutdown); and stage 2 consisting of Configurations 3 and 4 (starting middle of 2009, with plans and beam time request subject to approval by FNAL Director Review).

2.2. The CCE is organized in 4 experimental phases (identified as "configurations"), as described in Appendix 6 together with the expected goals for the 3 year duration of the experiment.

2.3. Activities shall be organized in working groups with each group reporting every 2 weeks to the person responsible for the activity in a phone (video) conference. The person responsible for each activity shall produce a written report once a month on the progress of the activity itself.

2.4. Collaboration meetings shall be organized before each milestone.

3. Manpower and financial considerations

3.1. The number of physicists from each Institution participating in the Experiment is currently as follows (with names given in Appendix 2):

BNL	5
CERN	5
Chicago Univ.	1
FNAL	15
Hiroshima Univ.	2
IHEP	~~5~~ 4
INFN	11
JINR	2
KEK	1
PNPI	~~1~~ 3
RINP-BSU	1
SLAC	13

3.2. The responsibilities for each institute in the CCE are described in Appendix 7.

3.3. The overall cost of the project is $1207k. Appendix 8 presents the cost contribution of each Party.

3.4. All financial responsibilities are subject to approval by the relevant Funding Agencies. Each Institution is expected to provide enough technical manpower to cover the design, construction, commissioning, operation and maintenance of the equipment for which it is responsible.

4. Time schedule and Deliverables

4.1. The time schedule is presented in Appendix 8 together with each institute's responsibilities.

SIGNATURES

This MoU is produced in 7 original documents, each dated and signed by FNAL and Collaborating Institutions.

____________________ 6/14/2008
Nikolai Mokhov,
Spokesperson, APC, FNAL

____________________ / /2008
Walter Scandale,
Spokesperson, CERN

____________________ 6/25/2008
Steve Peggs,
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Ralph Assmann,
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Steve Myers,
AB Department, CERN

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Robert Aymar,
Director General, CERN

____________________ / /2008
Sergio Bertolucci,
Vice-President, INFN

____________________ / /2008
Vladimir Kekelidze,
Director, LHE, JINR

____________________ / /2008 15.07.09.
Nikolai Tyurin,
Director, IHEP

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Director, HEPD PNPI

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Vladimir Shiltsev,
Accelerator Physics Center, FNAL

____________________ 6/19/2008
Roger Dixon, Accelerator Division, FNAL

____________________ 6/19/2008
James Strait, Particle Physics Division, FNAL

____________________ 6/16/2008
William Griffing, ES&H Section, FNAL

____________________ 6/19/2008
Hugh Montgomery,
Associate Director, FNAL

____________________ 6/19/2008
Stephen Holmes,
Associate Director, FNAL

APPENDIX 1: Special considerations

In all the phases of the experimental work outlined in this MoU, the experimenters will abide by the Fermilab Environmental Safety and Health Manual (FESHM) as prescribed and guided by the laboratory's safety staff.

1 The responsibilities of the Spokespersons and procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Experimenters" (http://www.fnal.gov/directorate/documents/index.html). The Spokepersons agree to those responsibilities and to follow the described procedures.

2 To carry out the experiment, a number of Environmental, Safety and Health (ES&H) reviews are necessary. This includes creating a Partial Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The Spokespersons will follow those procedures in a timely manner, as well as any other requirements put forth by the division's safety officer.

3 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ES&H Section.

4 All items in the Fermilab Policy on Computing will be followed by experimenters (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

5 The Spokespersons will undertake to ensure that no PREP and computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Computing Division management. They also undertake to ensure that no modifications of PREP equipment take place without the knowledge and consent of the Computing Division management.

6 Each institution will be responsible for maintaining and repairing both the electronics and the computing hardware supplied by them for the experiment. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

7 If the experiment brings to Fermilab on-line data acquisition or data communications equipment to be integrated with Fermilab owned equipment, early consultation with the Computing Division is advised.

8 At the completion of the experiment:

8.1 The Spokespersons are responsible for the return of all PREP equipment, Computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of three months after the end of running the Spokespersons will be required to furnish, in writing, an explanation for any non-return.

8.2 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously (in 30 days) and in compliance with all ES&H requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters.

8.3 The experimenters will assist the Fermilab Divisions and Sections with the disposition of any articles left in the offices they occupied.

8.4 An experimenter will be available report on progress at a Fermilab All Experimenters Meeting.

APPENDIX 2: Organization of the experiment and current participants

Co-spokespersons:

N.V. Mokhov	FNAL
W. Scandale	CERN

Coordinators:

Yu.A. Chesnokov (IHEP)	Russia
V. Guidi (INFN)	Italy
W. Scandale (CERN)	CERN

Participants:

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Genova University and INFN, Italy
M. Bozzo, M. Macri

Hiroshima University, Japan
S.A. Strokov, **T. Takahashi**

Insubria University and INFN, Italy
D. Bolognini, S. Hasan, D. Lietti, **M. Prest**

Institute for High Energy Physics, Protvino, Russia
A.G. Afonin, **Yu.A. Chesnokov**, ~~V.I. Kotov,~~ V.A. Maisheev, I.A. Yazynin

Joint Institute for Nuclear Research, Dubna, Russia

A. Kovalenko, **A. Taratin**

High Energy Accelerator Research Organization (KEK), Japan
S. Sawada

RINP-BSU, Minsk, Belarus
V. Tikhomirov

Petersburg Nuclear Physics Institute, Gatchina, Russia
Yu.M. Ivanov, V.V. Skorobogatov, A.S.Denisov

Roma – La Sapienza and INFN, Italy
R. Santacesaria

Stanford Linear Accelerator Center
J. Amann, A. Chao, L. Keller, T.W. Markiewicz, R. Noble, M. Oriunno, Shilun Pei, **A. Seryi**, J. Smith, C. Spencer, J. Spencer, G. Stupakov, U. Wienands

The names in bold are the contact persons of each group.

APPENDIX 3: Motivations of the experiment

Beam collimation is mandatory at any collider and high-power accelerator in order to protect components against excessive irradiation, to minimize backgrounds in the experiments, to maintain operational reliability over the life of the machine and to reduce the impact of radiation on the environment. At the LHC, the super-conducting magnets must be protected against direct beam losses in order to prevent quenches. A standard approach is a two-stage collimation system in which a primary collimator (target) is used to increase the betatron oscillation amplitudes of the halo particles, thereby increasing their impact parameters on secondary collimators during subsequent turns. The LHC implements a system with 3 to 4 cleaning stages (depending on the energy and on the considered magnets).

Conventional primary collimators are amorphous. For example, the Tevatron uses a 5 mm long piece of tungsten, while the LHC uses a 0.6 m long piece of fiber-reinforced graphite. Such a collimator gives a random angular kick to the incident particles in all directions due to ordinary multiple Coulomb scattering, and "sprays" the losses downstream. The overall collimation efficiency of the Tevatron two-stage collimation system is 99.9%. This is adequate for the machine and detector performance, but the situation at the LHC – with 2 or 3 orders of magnitude larger stored beam energy - is more stringent, requiring a higher collimation efficiency. The LHC multi-stage "conventional" cleaning has a predicted efficiency of ≥99.995% per m of superconducting magnets.

In contrast, bent crystal primary collimators can coherently direct channeled halo particles deeper into a nearby secondary absorber. This results in a reduction of out-scattering from the system, thereby reducing beam losses in critical locations and radiation loads to the downstream superconducting magnets.

The first suggestion to use a bent crystal for beam halo collimation was made for the SSC [1]. Studies investigating crystals for 1 to 70 GeV proton beam collimation have been performed at IHEP [2]. A serious and interesting early attempt at crystal collimation was made at RHIC [3]. This was followed by a study at the Fermilab Tevatron [4], using some of the BNL equipment. Experiments on beam extraction from accelerators using bent crystal channeling were successfully performed at JINR, IHEP, CERN and Fermilab from 1984 to 1997. The optics implementation of crystal-enhanced collimation for the LHC has been preliminarily analyzed at CERN [5]. There are also recent interesting developments on further increase of channeling efficiency [6].

Volume Reflection has recently emerged as an exciting new possibility for oriented crystal collimation. The Volume Reflection (VR) phenomenon was demonstrated in crystal experiments with external proton beam energies of 1 GeV and 70 GeV at PNPI and IHEP [7]. VR is a coherent effect in a bent crystal predicted two decades ago [8]. It occurs when the momentum vector of a particle becomes tangent with one of the bent crystallographic planes. A particle with a relative angle that is locally larger than the critical channeling angle θ_c, but which cannot penetrate into the neighboring plane has its relative transverse momentum reversed. The VR deflection angle is on average 1.5 θ_c (plus a relatively small statistical spread), no matter where along the length of the crystal the reflection occurs.

The efficiency of volume reflection for 400 GeV/c protons in short bent silicon crystals was measured to be 97% in the recent H8RD22 experiment at the CERN SPS H8 beam line [9]. The VR acceptance angle was confirmed to be the crystal bending angle - much larger than the angular acceptance for channelling. The requirements on crystal alignment are therefore substantially reduced for operation in the VR mode. In addition, the H8RD22 experiment demonstrated the possibility of using multiple volume reflections in a ganged sequence of short bent crystals, with high efficiency and with a total deflection angle that is proportional to the number of crystals.

Goals of the experiment

The primary goals of CCE are to:

1. Measure channeled, volume-reflected and scattered beams as well as beam losses (radiation levels) downstream of the crystal setup in comparison with simulations.
2. Demonstrate reproducible beam loss reduction in the B0 and D0 in comparison with simulations, aiming at a routine use of the crystal based collimation in the Tevatron stores.
3. Test and confirm fundamental models of single-turn and multi-turn dynamics with crystals.
4. Develop optimal crystal/goniometer/instrumentation system for one- and two-plane collimation exploring and exploiting novel crystal technologies and newly understood phenomenon, volume reflection.
5. All of the above in conjunction with the CRYSTAL experiment at CERN SPS, aiming at a Phase II crystal-based collimation system for the LHC (improved performance, reduced impedance and heavy-ion option).

An unambiguous confirmation that the physics of multi-turn cleaning dynamics is understood – quantitatively and fundamentally - is a necessary first step in being able to evaluate an engineering implementation of this technique in the LHC. If proven, this understanding could lead to enhancements in the performance of the LHC collimation system with protons and (perhaps) with heavy-ions. Enhanced understanding would also have implications for other future accelerators such as the ILC and the Muon Collider. The Tevatron is a unique test bed for testing and improving the present understanding of crystal-enhanced collimation with stored beams. Recently approved, the crystal test program CRYSTAL at the CERN SPS strengthens the physics reach of the Tevatron experiment.

Impact on the CDF/D0 collider detectors

- Benefit to CDF/D0: at least a factor of 2 reduction in proton beam loss (as already shown in the 2005 data). There can be a more substantial reduction with new crystals and other hardware of Configurations 3 and 4 (> June 2009). There is a possibility to reduce antiproton losses in CDF/D0 with another crystal at F49.
- Maximum possible luminosity loss in Configurations 1 and 2 (May 2008 – March 2009): 20 hrs → 4.3 pb-1 out of 1300 pb-1/yr →0.33% (compared to 0.68% difference in CDF and D0 luminosities).
- Nothing happens if the crystal doesn't channel (Dec. 2007 results).
- Minimal risk to the silicon: only the target at E0 is retracted, nothing else moves.
- Effect or risk to CDF/D0 with crystal collimator for full store (beginning of store):
  (i) crystal works: losses reduced via efficient scraping;
  (ii) crystal doesn't work: re-insert tungsten target, loose small amount of luminosity at beginning of store, beam losses the same.

Interplay of the Tevatron and SPS experiments

A recently approved crystal test program at the CERN SPS provides a good chance to strengthen the physics reach of the Tevatron experiment, certainly for Configurations III and IV. The focus of the SPS experiment is to test crystal collimation in a single beam with artificially produced halo to gather information on the optimal crystal material, optimal mode of operation (reflection *versus* channeling and many crystals/single-turn *versus* fewer crystals/multi-turn), and optimal single-particle near-beam detector. This is complementary to the scope of CCE at the Tevatron: single particle in beam-beam mode; high flux with a halo structure closer to the one expected for the LHC; the background reduction in an operational experimental apparatus; the background reduction along a SC ring using the Tevatron BLM and the operational procedure to set-up the crystal collimation in parasitic mode and later in exclusive mode in a collider similar to the LHC. At the SPS, one can have a good insight to the single particle multi-turn effect at a faster time; this should allow the best selection of 1) the crystal among the different possible variants, 2) the detector technology and 3) of the layout configuration. The relevant benefits offered by the SPS experiment to the CCE at the Tevatron are the following:

- the crystal collimation layout can be optimized in time for Configurations III and IV;
- the crystal and detectors will be fully tested prior the installation in the Tevatron tunnel;
- some of the SPS components can be reused in the Tevatron during the 2010 run;
- all these will make it possible to perform the CCE in less time, possibly in only one year.

References

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4. R.A. Carrigan, A.I. Drozhdin, R.P. Fliller, N.V. Mokhov, V.D. Shiltsev, D.A. Still, Fermilab-Conf-309-AD (2006).
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6. V.V. Tikhomirov, JINST **2**, P08006 (2007).
   V.V. Tikhomirov, Phys. Lett. **B655**, 217 (2007).
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APPENDIX 4: First studies of crystal collimation at the Tevatron

Studies in 2005

It was proposed [1] to implement a bent crystal in the Tevatron collimation system. Calculations indicated that one could improve the Tevatron collimation system efficiency and reduce beam loss rate immediately upstream of the CDF and D0 collider detectors by a factor of:

(1) two with one (horizontal) amorphous primary collimator replaced by a crystal, and with contributions from beam-gas scattering unsuppressed;
(2) three with one (horizontal) amorphous primary replaced, and with contributions from beam-gas scattering suppressed;
(3) four to six for the two-plane collimation.

The modified BNL assembly with a 5 mm long silicon crystal was installed in the Tevatron in the dog-leg of the E0 straight section downstream of the horizontal 5 mm long tungsten primary collimator (target) D49. Fig. 1 shows a schematic of the arrangement. An amorphous primary collimator and the crystal could be alternatively inserted into the beam halo. The horizontal betatron phase advances to the secondary collimator (at E03) from the amorphous primary (at D49) and the crystal in E0 were 40° and 18°, respectively - equally good for the two-stage collimation. The scattered or deflected beam was intercepted by a 1.5 m long steel secondary collimator E03H, 23.8 m downstream from the crystal. At E0 the proton helical orbit was on the inside of the accelerator central orbit.

Beam studies were first performed at 150 GeV and then at 980 GeV in the summer and fall of 2005. The crystal was typically 5.5 σ_b from the beam, while the secondary collimator was at 6 σ_b, where σ_b, the horizontal rms spread of the beam, was 0.45 mm. Typical results are shown in Fig. 2. A channeling dip is present at 0 μrad with a width of 22 ± 4 μrad (rms). The width of the channeling dip is a convolution of the beam divergence, the channeling critical angle, and multipass channeling effects. The distribution of the dip is consistent with the beam divergence and the 5 μrad channeling critical angle at 980 GeV.

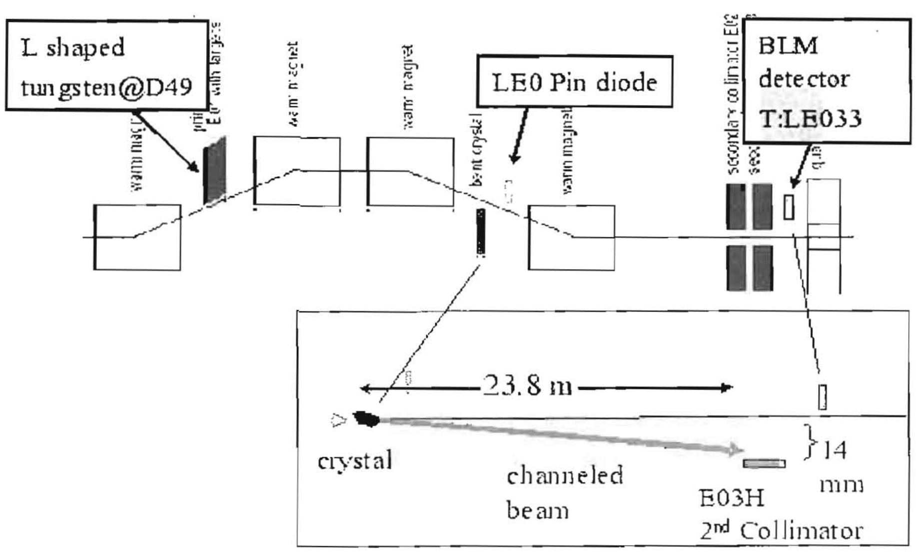

Figure 1 Schematic of the 2005 experimental setup at E0.

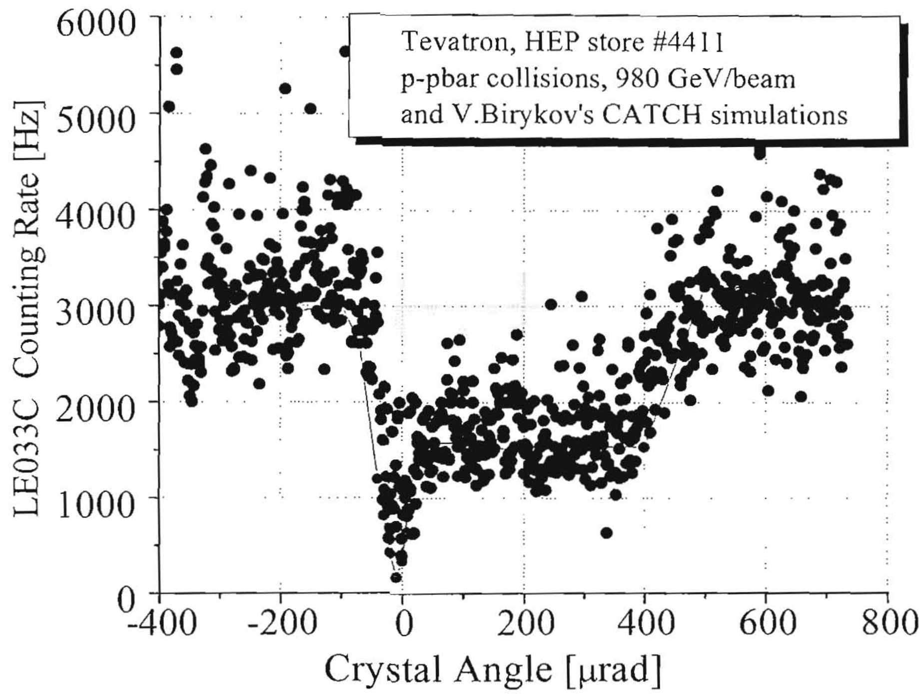

Figure 2 Crystal angle scan in 2005 configuration. CATCH [1] simulation results are shown by the solid line.

When using the crystal, the secondary collimator achieved almost a factor of two reduction of CDF losses a half a ring or three kilometers downstream (in agreement with modeling). Moreover, the secondary collimator could remain 1 mm or so further away from the beam, thus reducing the beam impedance. The nuclear interaction rate in the crystal was a factor of 2 to 3 lower than in the amorphous primary target, proportionally reducing the irradiation of downstream components.

While the beam halo loss at a critical location was shown to be reduced, losses at other areas of the collider were not measured, and so it is not possible to draw a conclusion about the overall collimation efficiency. Such an assessment of overall efficiency must compare losses outside of the collimation region to the total losses. The proposed experiment aims at showing reduced losses all around the ring, except in the collimation region (where most particles are stopped).

Studies in 2007

Calculations at IHEP with the simulation code CATCH [2] showed that the collimation efficiency for the Tevatron conditions could be improved by replacing the original 5 mm long crystal with a shorter one with a smaller angle, based on a strip–technology that was developed to improve the crystal performance. The original O-shaped crystal was therefore replaced with a new one designed, fabricated and mechanically bent in collaboration between IHEP (Protvino) and the University of Ferrara-INFN. The chemically etched crystal – 3 mm long with a 0.15 mrad bending angle - was installed in the Tevatron in late 2006. No clear channeling signal was detected during a series of End-of-Store (EOS) studies in 2007. In all the cases the amplitude of the noise in the PIN and BLM detectors was unacceptably high. During the fall 2007 shutdown, laser scans in the tunnel revealed a quite large wobbling of the crystal holder. As a result, the positioning of the crystal with respect to the beam was unstable and the results of the angle scans were irreproducible. It was concluded that the crystal must be replaced, the goniometer must be modified and additional beam diagnostics must be installed.

References

1. V.M. Biryukov, A.I. Drozhdin, N.V. Mokhov, 1999 PAC Proc., 1234 (1999).
2. V.M. Biryukov, CATCH 1.4 User's Guide, SL / Note 93-74 (AP), Geneva CERN, 1993. arxiv.org/abs/hep-ex/0110046.

APPENDIX 5: Preparatory phase

The preparation for the experiment will move forward on two fronts:

Hardware:

- *Crystals*: A new set of fully tested crystals has to be prepared for installation.
- *Beam diagnostics*: Major beam diagnostics changes are not foreseen in 2008. Feasibility studies need to be performed in order to determine adequate beam diagnostics to characterize the effects of crystal collimation and to test and confirm fundamental models of single-turn and multi-turn dynamics. These studies must be undertaken quickly, to allow a decision to be made well before the end of 2008 concerning the potential construction of new diagnostics (like Roman Pots) in order for them to be ready for installation in early 2009. Initial results from preliminary beam tests with the new crystals, and the prototyping results of a beam profile system on a circulating beam, will both be included in the discussions leading to this decision.
- *Beam loss detection*: Beam loss will be measured all around the Tevatron ring, in order to permit the measurement of the overall collimation efficiency. More PIN diodes will be added to increase the acceptance for measurements of the nuclear interaction rate in the crystal, and to reduce statistical uncertainties in measurement rates. Further improvements in channeling measurements will be made by deploying a gated counter system similar to that used to measure losses near CDF. A gated system allows loss backgrounds from the antiproton beam and from DC components of the beam to be suppressed. These modifications require no access to the Tevatron vacuum and little or no modification to the existing infrastructure, and so will be deployed at the earliest possible time.
- *Goniometer*: Modifications of the present goniometer will be studied, for possible implementation at an earliest occasion after May 2008. The possibility of developing a complete new goniometer will also be evaluated, considering design, procurement and assembly times.
- *Second plane*: A feasibility study will be performed and hardware developed for a two-plane collimation system to be installed for the 2009 collider run.
- *Roman Pots*: A feasibility study will be performed and hardware developed for single particle detection experiments in the 2010 collider run (if it occurs).

Modeling:

- *Simulation network*: The activities of simulation experts at the different CCE institutions will be coordinated within a simulation network.
- *Beam simulations*: Benchmark the simulation package against established data. Complex modeling simulations will be performed in advance of full beam testing in 2009, in order to predict the performance and efficiency of the new configuration, and in order to perform sensitivity analyses under variations of the crystal and the collimation parameters.
- *Single particle simulations*: Single-hit and multi-hit simulations of experimental studies with Roman Pot detectors will be performed, to study their feasibility and their performance limits.
- *Theoretical modeling*: Other modeling – non-simulation or toy-model simulation – will be performed as necessary, to help in achieving the primary goals of the experiment.

APPENDIX 6: Experimental configurations of the CCE

Four experimental phases (called configurations in the following) have been identified through the 2008 to 2010. In this Appendix, the four configurations are analyzed in terms of hardware and software to be developed and expected results. First two configurations comprise Stage 1 of CCE and are well defined. Configurations 3 and 4 comprise Stage 2 of CCE, with exact scope and beam request to be defined on the basis of the Stage 1 results and are subject to approval by the Fermilab Director review. The final part of the Appendix is dedicated to the expected goals of the experiment in its 3 year duration. The required resources in terms of shifts and time of End-of-Store (EOS) studies are shown.

Configuration I: ***May – September 2008, two shifts for installation, 4 End-of-Store Studies (8 hrs)***

The crystal and goniometer were removed from the tunnel, the work to improve the goniometer has started and the original O-shaped crystal was sent to INFN and PNPI for its characterization. The crystal is back at Fermilab in April 2008. The beam diagnostics were enhanced by scintillating counters installed in the crystal region and already tested flying/crawling wires to measure the channeled beam profile at E11. The main goal of this Configuration is to tune the re-installed system and perform:

Beam studies:

- The halo structure.
- The transverse diffusion rate and possibility to improve the orbit stabilization.
- The behavior of the existing enhanced detectors when the beam hits the crystal (beam loss pattern, profiles with flying/crawling wires).
- The stability of beam halo losses versus time (loss jitter), for different collimation depths and materials intercepting the halo (primary collimator, crystal).
- Tests of performance of the upgraded installation.

Simulations: to study the expected behavior of the beam losses and of the beam profile in the presence of multi-turn channeling and small impact parameters:

- Study of the most efficient crystal technologies (strip *vs* O-shaped) and parameters (length, etc.) for collimation in the collider environment.
- Calculation of channeled, reflected and scattered beam profiles at the critical locations: collimators, beam instrumentation and upstream of CDF and D0.
- Analysis of the influence of an amorphous layer on the crystal surface.

Configuration II: ***October 2008 – March 2009, 12 hrs of beam studies***

Configuration II is aimed at thorough studies of beam dynamics and collimation efficiency of the upgraded and tuned setup, aiming at reproducibility and – after one or two Beginning-of-Store tests - routine use of crystals in the Tevatron stores. In the same period, manufacturing of the new crystals, hardware and electronics for the measurements in Configuration III will be performed to be ready for installation in the tunnel during the March 2009 shutdown.
The following goals are assumed in this Configuration:

Beam studies: the following items are going to be studied:

- Systematic measurements of the channeled and reflected beams, and the consequent effects on beam losses and beam profile monitors.

- The consistent reduction of beam losses upstream of the CDF with the crystal during beam collisions.
- Reproducible changes of beam losses around the Tevatron ring when amorphous collimators and bent crystals are interchanged.

Simulations:

- The expected multi-turn beam dynamics with the new crystal, including a quantitative investigation of the expected reduction of beam losses near the CDF, of the expected beam loss regime around the ring and of the expected horizontal and vertical beam profiles.
- Impact of diffusion speed and impact parameters on crystal efficiency.
- Designs and plans for implementation and measurements of an enhanced collimation system for Configuration III.

<u>Configuration III</u>: ***April 2009 – December 2009, non-shutdown installations and beam studies (subject to approval by the Fermilab Director Review)***

This configuration assumes operations with

1) a new mono-crystal
2) a new goniometer
3) the existing beam instrumentation

The following goals are assumed in this Configuration:

Beam studies: the following items will be studied:

- The channeled and the reflected beams, in both planes, and the consequent effects on beam losses and horizontal and vertical beam profile monitors.
- The reduction of beam losses upstream of the CDF during beam collisions - at least a factor of four is expected.
- Changes of beam losses around the Tevatron ring when amorphous collimators or bent crystals are used

Simulations: the following items will be studied:

- The expected multi-turn beam dynamics with the new crystals and 2-D collimation.
- The impact of diffusion speed and impact parameters on efficiency of the new crystals.
- The designs and plans for the implementation of single-particle detectors mounted inside Roman Pots, to be installed in Configuration IV
- The single particle measurement capabilities with single particle detectors

<u>Configuration IV</u>: ***January 2010 – end of Run II, non-shutdown installations and beam studies (subject to approval by the Fermilab Director Review)***

This configuration assumes operation with:

1) the same new mono-crystal and/or new multi-crystal prototype, mounted on
2) a new push-pull goniometer system used in Configuration III, that allows the exchange of two crystals without breaking the vacuum, plus upgraded beam instrumentation enabling single-particle near-beam detection.

The multi-crystal prototype (a series of volume reflection crystals) will be fully optimized in the H8 line of the SPS at CERN, prior to installation in the Tevatron. Configuration IV also includes two-plane collimation capability.

Single particle detection requires the Roman Pots – provided by CERN/SLAC or those used in the CDF - to be installed at C0 as currently thought. Both issues – which Roman Pots and their location are to be determined in the preparatory phase. At this point two alternate layout options are considered to provide the largest possible lever-arm for identifying particles that interact with the crystal [1]. These near-beam detectors can be brought close to the beam halo, and may require Tevatron operation in a proton-only mode at a reduced intensity. It may also require some beam set-up time and procedures to produce a diffusive halo in a single beam similar to that produced by beam-beam collisions. The installation of Roman Pots also requires some control system upgrades.

The following goals are assumed in this Configuration:

Beam studies: the following items are going to be studied:

- The channeled and the reflected beams, particle-by-particle, including trajectory reconstruction for each particle that hits the crystal
- The precise measurement of beam losses at critical locations in the ring (the collimation region and the collider experiments CDF and D0)
- Measurement of the overall collimation efficiency assisted by crystals.

Simulations: the following items will be studied:

- The expected multi-hit beam dynamics with indications of the position and angular distributions of the channeled and reflected particles
- The impact of diffusion speed and impact parameters on crystal efficiency in channeling and reflection mode.
- The expected losses around the ring.

References

1. B. Parker, presentation to the Single Particle Working Group, available via URL: http://indico.fnal.gov/materialDisplay.py?contribId=0&materialId=slides&confId=1691 ,26 March (2008).

APPENDIX 7: Parties Responsibilities and Time schedule of the different Configurations

This Appendix reports for every Configuration the schedule from T0 and the Institute responsible of the activity both for the hardware and the software point of view. The activities have been divided in two blocks, 2008-2009 and 2010 (if a Tevatron run is going to be performed).

Table 1: Hardware timeline for 2008 and 2009

Item	*Start Time from T0 (months)*	*Institution*
Test with the present crystal	2	FNAL
Beam diagnostics: detailed description of the feasibility study and organization of working groups	4	FNAL/CERN
Start of the beam diagnostic activity	5	All
Development of an in situ alignment setup	5	FNAL/CERN
Analysis of the present goniometer and of its possible modifications	4	FNAL/INFN/IHEP
Goniometer modifications	4 to 7	FNAL/INFN/IHEP
MILESTONE - 1: - change the crystal - modify the goniometer - confirm decreased losses at CDF	9	All
Test the new crystal	10 to 12	All
Report on the beam diagnostic working groups activity	11	All
MILESTONE - 2:		All
- analysis of the results with the new crystal	12-24	
- plans for the final upgrade of the goniometer and of the beam diagnostic system	18	All

Table 2: Software timeline for 2008 and 2009

Item	*Start Time from T0 (months)*	*Institution*
Organization of the simulation working group	1	FNAL/BNL/CERN/IHEP/RINP-BSU/JINR/SLAC
Comparison of the simulation codes	2	Same
Detailed simulation of the present setup and comparison with experimental results	3 to 6	Same
MILESTONE - 1: Simulation working group reports concerning Configurations 1 and 2	8	Same
Work on the after-shutdown layout	10	All
MILESTONE - 2: Final report	12	

Table 3: Hardware timeline for 2010

Item	*Time after T1 (months)*	*Institution*
Build a second goniometer	10	INFN/IHEP
Integrate the new goniometer	10	FNAL
Procurement and test of new mono- and multi- crystals	10	CERN/INFN/PNPI/IHEP
Build 3 Roman Pots	10	CERN/INFN/SLAC
Build 3 near-beam detectors Integrate the Roman Pot assemblies	10 10	INFN FNAL/SLAC
Install goniometer and crystals	11 (2009 shutdown)	FNAL
Install Roman Pots & detectors	11 (2009 shutdown)	FNAL/SLAC
MILESTONE – 1: - Change the crystal - Modify the goniometer - Installation of Roman Pots and single particle detectors. - Confirm decreased losses in CDF	11 (2009 shutdown)	All
Test the new crystals	14 to 18	All
MILESTONE – 2: - Analyze the results - Confirm decreased losses at CDF	14 to 20	All

Table 4: Software timeline for 2010

Item	*Time after T1 (months)*	*Institution*
Detailed simulation of the new setup and comparison with experimental results	0 to 6	FNAL/BNL/CERN/IHEP/RINP-BSU/JINR/SLAC
MILESTONE - 1: - Simulation working group reports concerning Configurations 3 & 4	6	same
Compare simulations with experimental data	14	same
MILESTONE - 2: - Final report	18	same

APPENDIX 8: Cost contribution of each Party

This Appendix presents an overall table for the costs of each institution, a detailed breakdown of the overall costs and a detailed breakdown for the FNAL contribution. Note that the FNAL, BNL and SLAC costs shown in Table 1 and 2 are those provided by LARP. Remaining labor contributions (salary), covered by corresponding Divisions, are not shown for BNL and SLAC, while listed for Fermilab in Table 3.

The costs are computed considering a 3-year duration of the experiment. The cost numbers for IHEP and PNPI are in fact man month equivalent (that is the Institution has given a certain amount of man months which have been transformed in cost equivalent).

Table 1: Cost contribution of each Party

Institution	*Cost contribution (k$)*
BNL (LARP)	150
CERN	81
FNAL (LARP)	222
IHEP	75
INFN	460
JINR	9
PNPI	60
RINP-BSU	
SLAC (LARP)	150
TOTAL	**1207**

Table 2: Breakdown of the cost contribution

ITEM	BNL (LARP)	CERN	FNAL (LARP)	IHEP	INFN	JINR	PNPI	RINP-BSU	SLAC (LARP)	TOTAL
CRYSTALS				**20**	**52**		**50**			**122**
Preparation of a new crystal for Conf. ½				10	26					
Preparation of a multistrip for Conf. ¾				10	26					
Preparation of a new quasimosaic crystal							50			
GONIOMETER			**160**	**20**	**143**					**323**
Design, assembly and test for Conf . ¾			160	20	143					
NEAR BEAM DETECTORS	**50**				**150**				**50**	**250**
Design, assembly and test for Conf . ¾	50				110					
Data acquisition					40					
BEAM INSTRUMENTATION			**54**							**54**
SIMULATION	**50**	**49**	**8**	**15**		**5**			**50**	**177**
DATA TAKING and ANALYSIS	**50**	**32**		**20**	**115**	**4**	**10**		**50**	**281**
TOTAL	**150**	**81**	**222**	**75**	**460**	**9**	**60**		**150**	**1207**

The costs are expressed in k$ for an integrated period of 3 years.

Table 3: FNAL costs ($222k is LARP contribution over 3 years)

DIVISION/ITEM	*Equipment (k$)*	*Operating (k$)*	*Personnel (person-weeks)*
Accelerator Division	**188**	**20**	**133**
Goniometer design	140	20	70
Beam Instrumentation	48		23
Access to accelerator tunnel			5
Experimental network support			2
Accelerator safety reviews			1
Data taking and analysis			32
Accelerator Physics Center			**95**
Simulations (**$8k from LARP**)			55
Planning			30
Data analysis			10
ES&H Section			**1**
Safety review			1
TOTAL	**188**	**20**	**229**