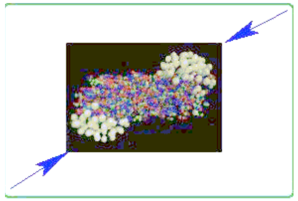
Crystal experiment to test collimation in the SPS



Walter Scandale

CERN

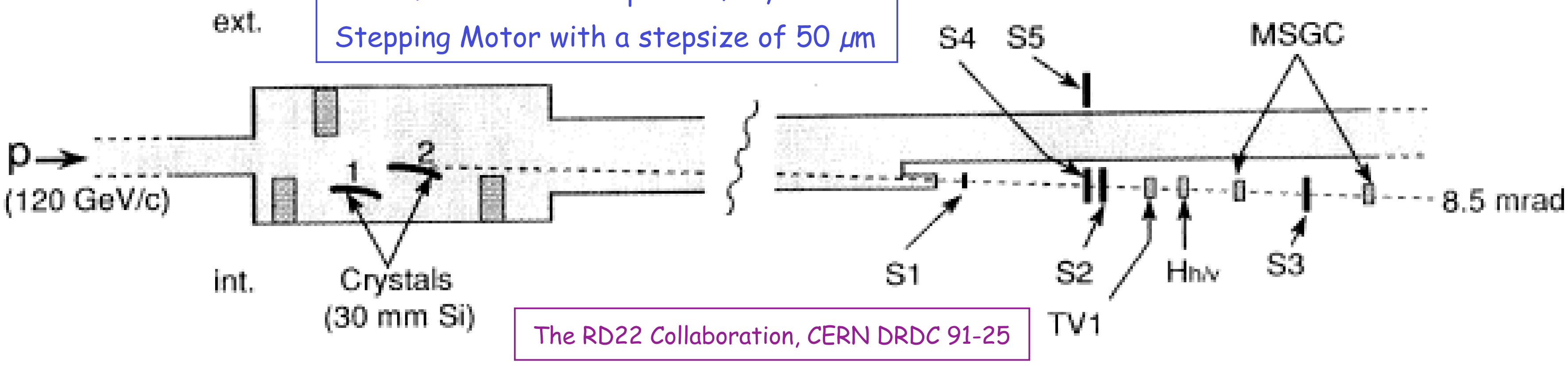
Geneva, 08 July 2005

Collimation WG

The experimental set-up

Goniometer with a stepsize of 2 μrad

Stepping Motor with a stepsize of 50 μm

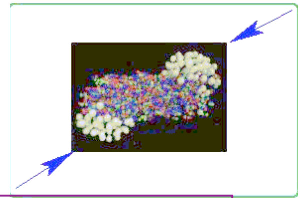


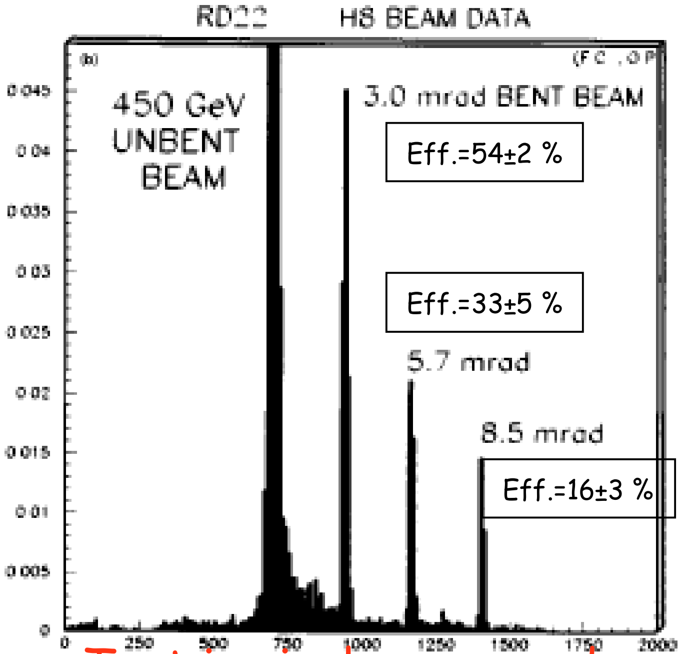
The RD22 Collaboration, CERN DRDC 91-25

Special tank located the upstream empty half-cell of the long straight section # 5 in the SPS - total length of the set-up about 20 m

- Two Si crystals 3 cm long, bent by about 8.5 mrad, mounted on goniometers
- 3 scrapers (2 horizontal and 1 vertical) to find the beam position and horizontal angle
- Laser monitoring system for the alignment of the crystals
- Scintillators to estimate extracted beam intensity
- Scintillator hodoscope to estimate horizontal and vertical extracted beam profile
- Miscrostrip gas chamber 0.1·0.1 mm^2 pixel size
- CsI scintillating screens 0.2·0.2 mm^2 pixel size
- (later) a scintillator horizontal fisc to measure the extracted beam profile; thickness initially 1 mm, later 0,2 mm.

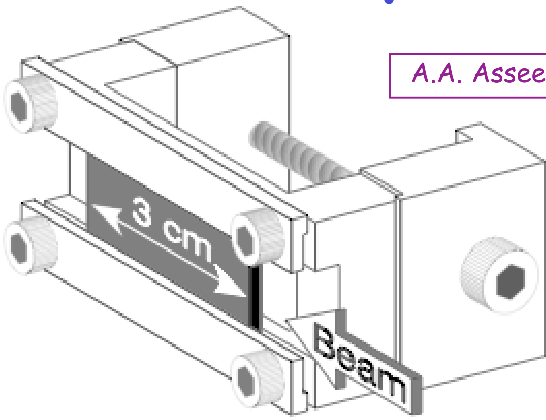
The basic crystal





Test in single pass mode

F. Costantini, Nucl.Inst.Meth. A333 (1993) p125

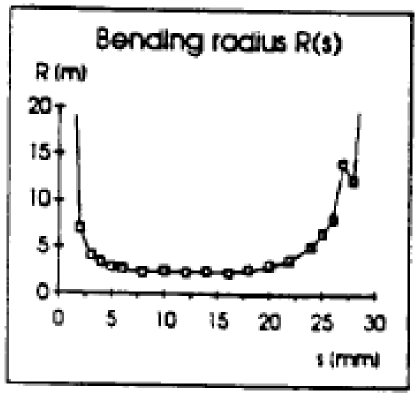


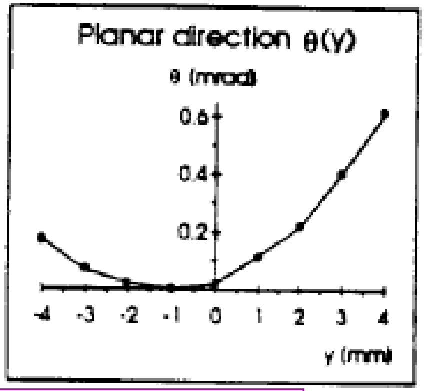
A.A. Asseev et al, Nucl.Inst.Meth. A330 (1993) p39

Silicon crystal

- 30 mm long,
- Serpukov style holder

	This proposal	H8 Beam Ref. [8]	LHC
p (GeV/c)	120	450	8000
Bent length (cm)	3	3	5
Bending angle (mrad)	10-20	7.5	0.7
Bending radius (cm)	300-150	400	7100
p/R (GeV/cm)	0.4-0.8	1.1	1.1
L_d (cm)	9	35	620



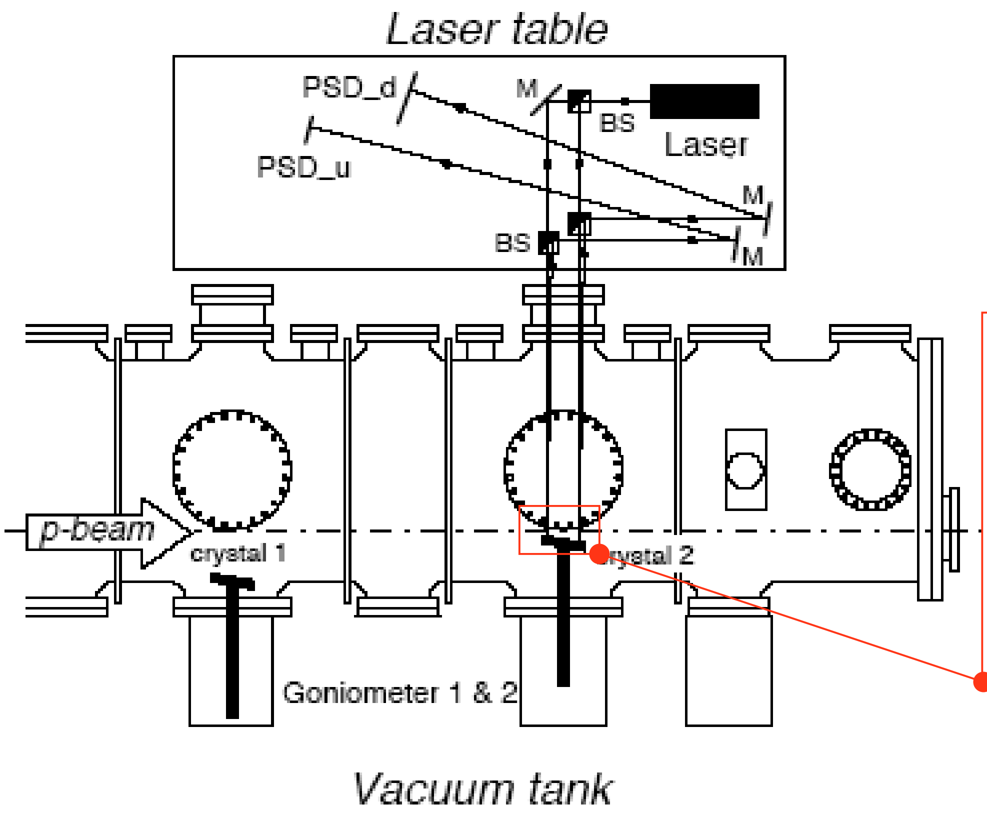


Main drawbacks

- Varying radius of curvature
- Anticlastic vertical bending

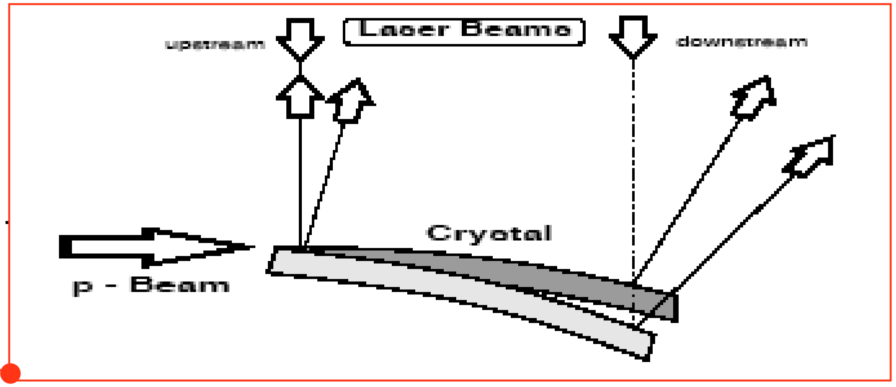
The RD22 Collaboration, CERN DRDC 94-11

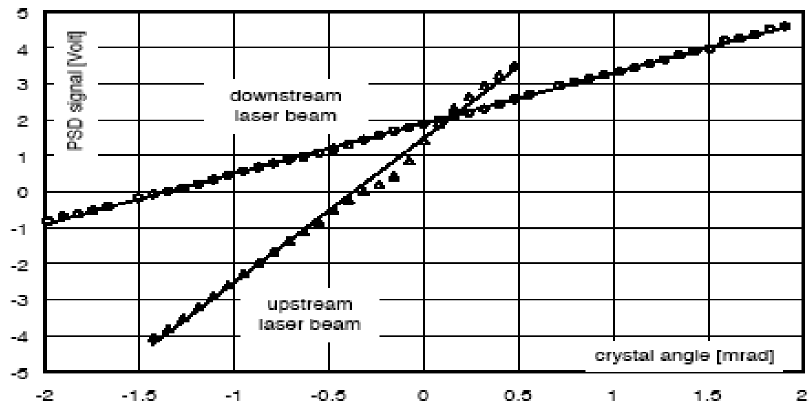
The goniometer and the laser



Use of the laser table

- Crystal pre-aligned
- Continuous monitor of the crystal alignment

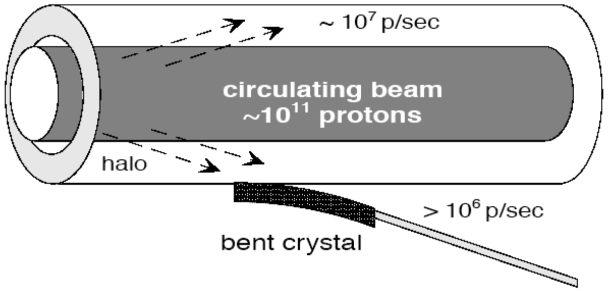


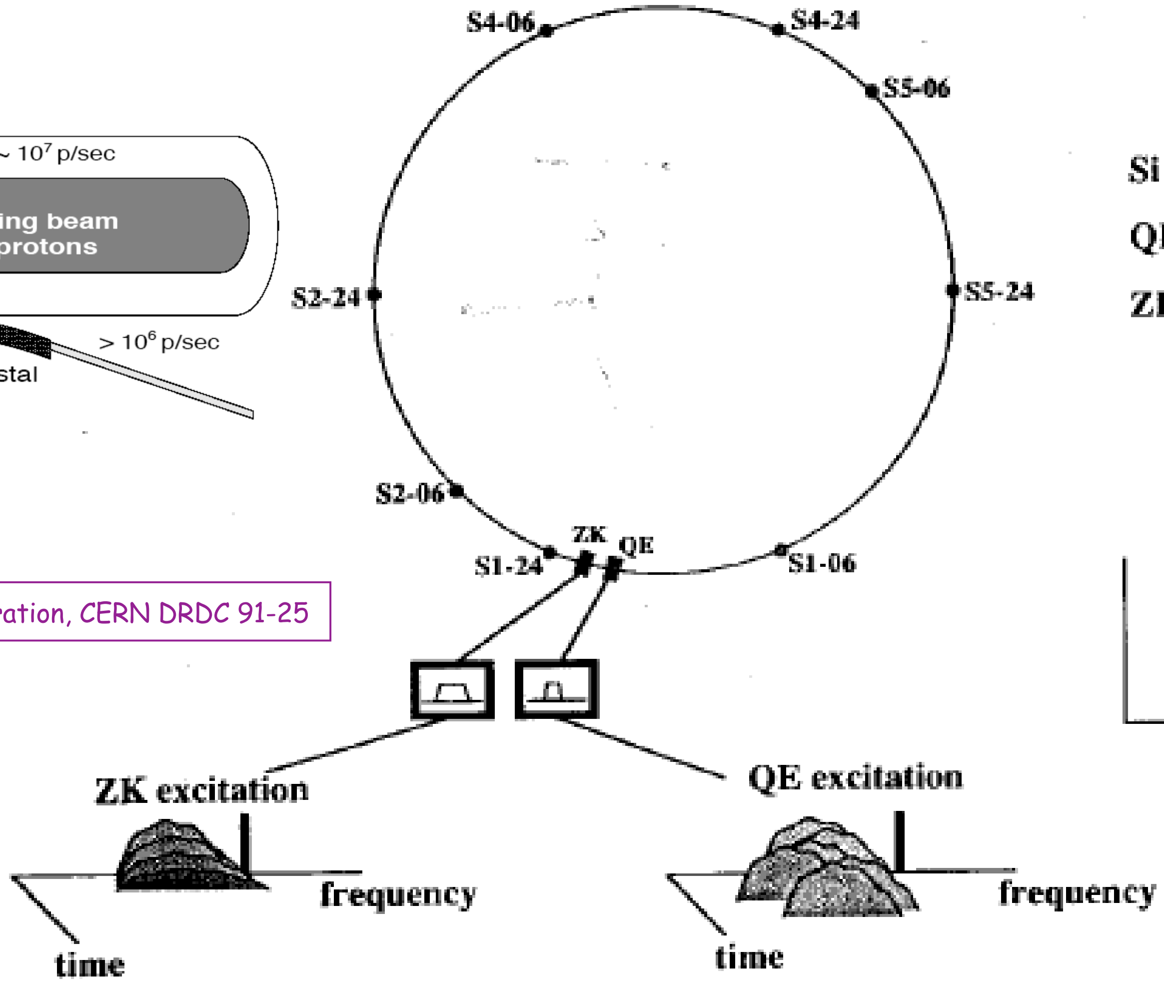


Goniometer with a stepsize of 2 μrad
Stepping Motor with a stepsize of 50 μm

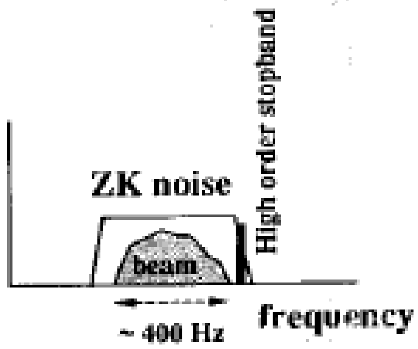
The RD22 Collaboration, CERN SL-95-088

The halo formation set-up



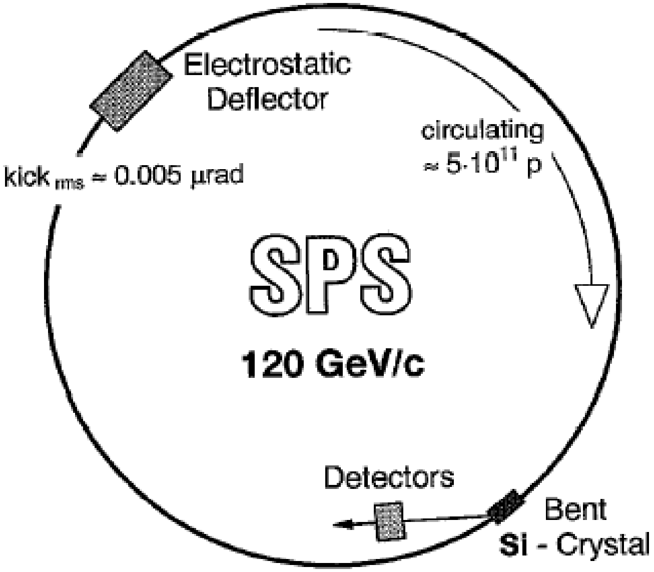


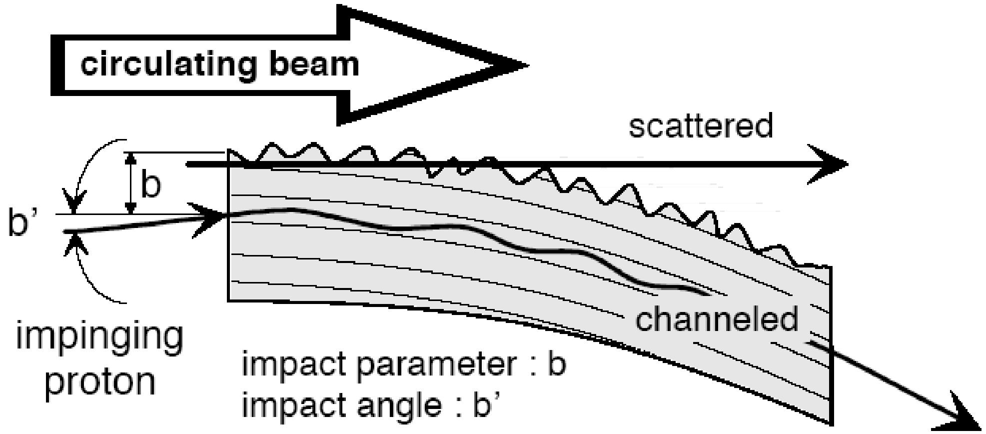
Si = sextupoles
QE = quadrupole
ZK = e.m. deflector



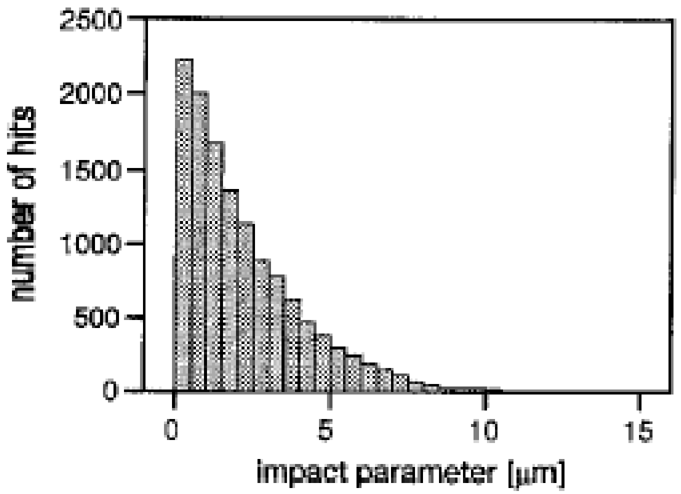
The RD22 Collaboration, CERN DRDC 91-25

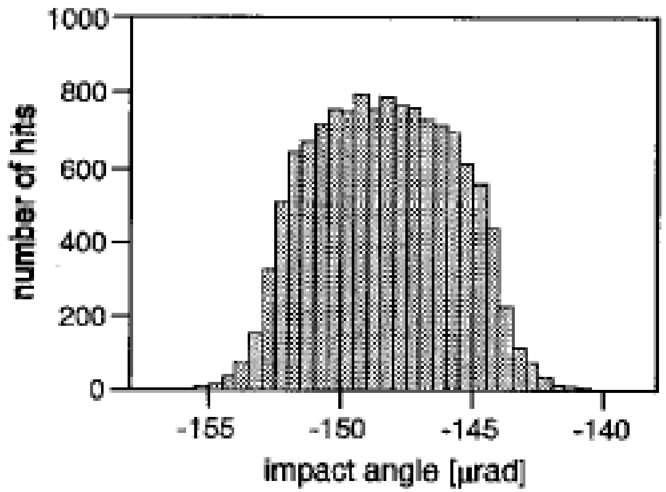
The impact parameter





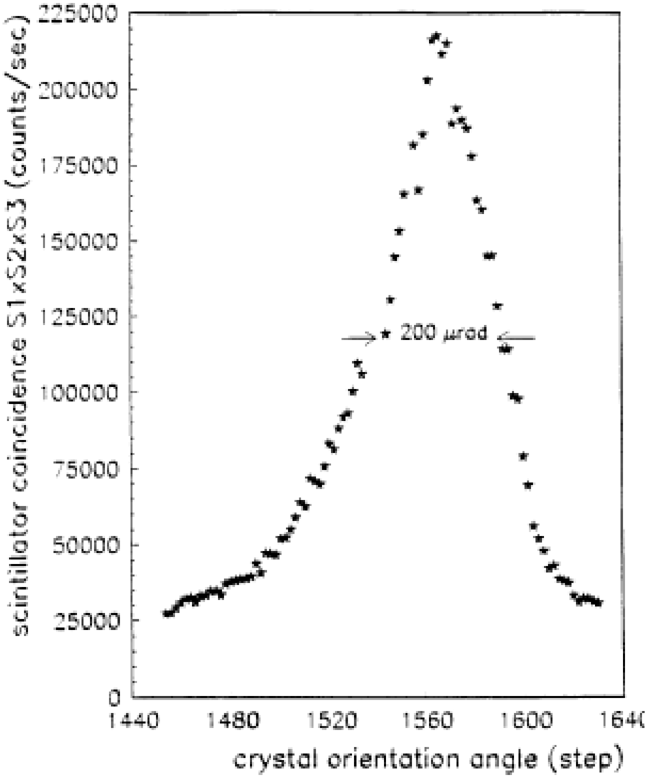
The RD22 Collaboration, Phys. Lett. B 357 (1995) 671-677





Extraction efficiency

The basic crystals

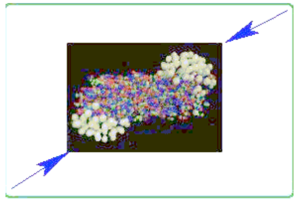


	Crystal 1	Crystal 2
beam intensity (protons)	$(7.0 \pm 0.1) \cdot 10^{11}$	$(3.7 \pm 0.1) \cdot 10^{11}$
beam lifetime (hrs)	20 ± 2	12 ± 1
protons lost per second	$(6.7 \pm 0.6) \cdot 10^{6}$	$(8.9 \pm 0.7) \cdot 10^{6}$
protons detected per second	$5.6 \cdot 10^{5}$	$6.6 \cdot 10^{5}$
background (%)	5	2
detection efficiency (%)	78 ± 12	78 ± 12
extraction efficiency (%)	$\mathbf{10.2 \pm 1.7}$	$\mathbf{9.3 \pm 1.6}$

The RD22 Collaboration, CERN DRDC 94-11

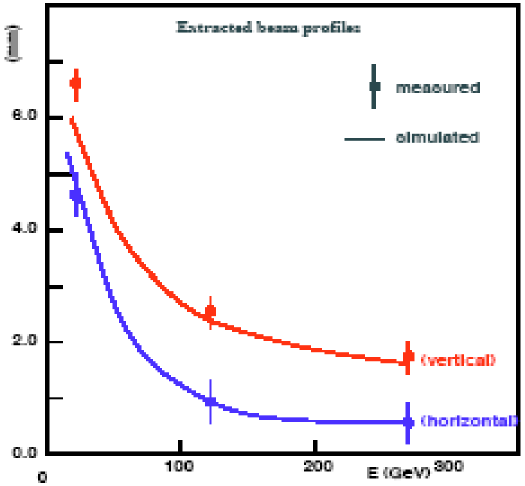
- Large channeling efficiency measured
- Consistent with simulation expectation
- Large angular response related to multi-turn effect

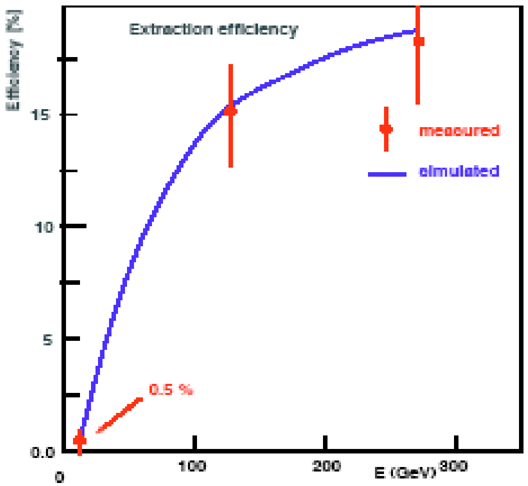
Energy dependence



G. Arduini et al., CERN SL 97-031 and SL 97-055

Beam energy (GeV)	Extraction efficiency (%)	Prediction simulation (%)
14	0.55±0.3	0.46
120	15.1±1.2	15.1*
270	18.6±2.7	17.7





Dechanneling vs beam energy

- Critical angle $\psi_c \propto p^{-1/2}$
- Dechanneling due to hits on e^- and dechanneling due to bending
  --> $L_D \propto p$
  --> $L_B = L_D (1-F)^2$

Channeling probability

$$P_c = (1-F)e^{-l_s/L_D} e^{-l_b/L_B}$$

Scattering angle

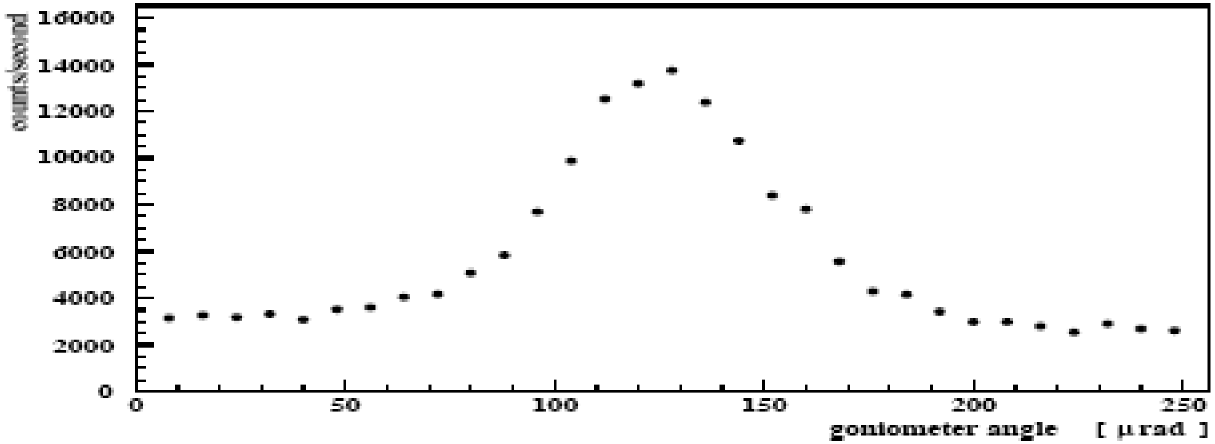
- Gaussian distribution
- $\langle\theta\rangle = 0$

$$\theta_{rms} = \frac{13.6\,MeV}{\beta c p}\sqrt{\frac{L_{eff}}{X_0}}\left(1 + 0.038\ln\left(\frac{L_{eff}}{X_0}\right)\right)$$

- Multiple scattering and dechanneling determine the energy dependence of the extraction efficiency
- For a given beam energy and crystal bending angle there is an optimal crystal length
- Extrapolations of crystal efficiency to the LHC beam energy are reliable (but they depend to some extent on the assumed size of the amorphous layer, which is not known)

Ion extraction efficiency

G. Arduini et al., CERN SL 97-036 and SL 97-043



- *Angular scan smaller than with protons*
- *Electromagnetic breakup cross section large*
- *Multiturn effect smaller than with protons*

Table 2: Extraction efficiences for Pb ions at 22 TeV/c.

Circulating beam intensity (10^7 ions)	Beam lifetime (hrs)	Extraction efficiency (%)
13.0	2.2	4.0±1.5
10.0	0.3	10.0±3.5
6.7	1.2	9.0±3.0
5.0	0.04	11.0±4.0
5.0	0.23	5.0±2.0

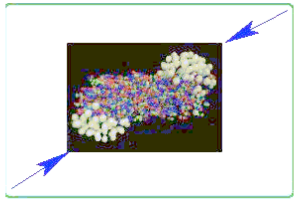
Outcomes of RD22

Primae of RD 22:

- ♦ Channelling efficiency consistently of the order of 10 % (more than an order on magnitude larger than in previous experiments)
- ♦ Experimental evidence of multiturn effect in extraction mode
- ♦ Robust method to evaluate the extraction efficiency
- ♦ Experimental validation of simulation code at high energy
- ♦ Extraction of Led ions

- ♦ All these results were never exploited for collimation
- ♦ neither for HEP in collider mode

Deliverables



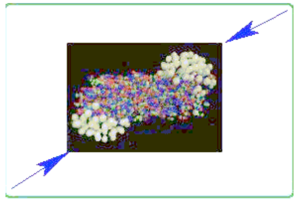
Why a new experiment ?

- The experience at U70 is very promising
- There is a strong incentive to propose collimation upgrade (we need however guidance from RHIC ad FNAL experiences) and to exploit crystal in LHC experiments
- Considerable improvement were made in crystal production
  - More homogeneous bending radius using strip crystals with anticlastic curvature (the Russian way)
  - "perfect" surface with no amorphous layer using chemical hatching (the Italian way)

Goals

- Propose sound ways to check the collimation efficiency
- Check if the collimation efficiency is high enough at .2 mrad
- Check if the collimation efficiency is high enough at 4 mrad
- Propose sound ways to align the crystal

Crystal Technique for Halo Cleaning in the LHC
INTAS-CERN Project 2000-132



Scientific coordinator: Walter Scandale, CERN

IHEP Protvino:

A.G.Afonin - tuning the accelerator settings
A.A.Arkhipenko - data taking
V.T.Baranov - data taking and analysis
V.M.Biryukov - computer simulations and coordination
M.K.Bulgakov - support of external beam line
V.N.Chepegin - collimator settings and data taking
Yu.A.Chesnokov - major crystal expert; design, realisation, installation and tests of crystals
Yu.S.Fedotov - accelerator settings
V.A.Gavrilushkin - participation in the shifts
V.N.Gorlov - data taking
V.N.Gres - diagnostics guy
V.I.Kotov - support of accelerator experiments
V.A.Maisheev - data taking, external beam line tuning
A.V.Minchenko - accelerator settings
V.I.Terekhov - chief of diagnostics
E.F.Troyanov - accelerator coordination
M.Y.Vrazhnov - participation in the shifts
V.A.Zelenov - participation in the shifts

Ferrara University:

M. Butturi – laboratory experimentalist
M. Ferroni – structural characterization
V. Guidi – structural characterization and local coordinator
C. Malagù – dicing-machine esperimentalist
G. Martinelli – head of laboratory
M. Stefancich – micromachining esperimentalist
D. Vincenzi – micromachining esperimentalist

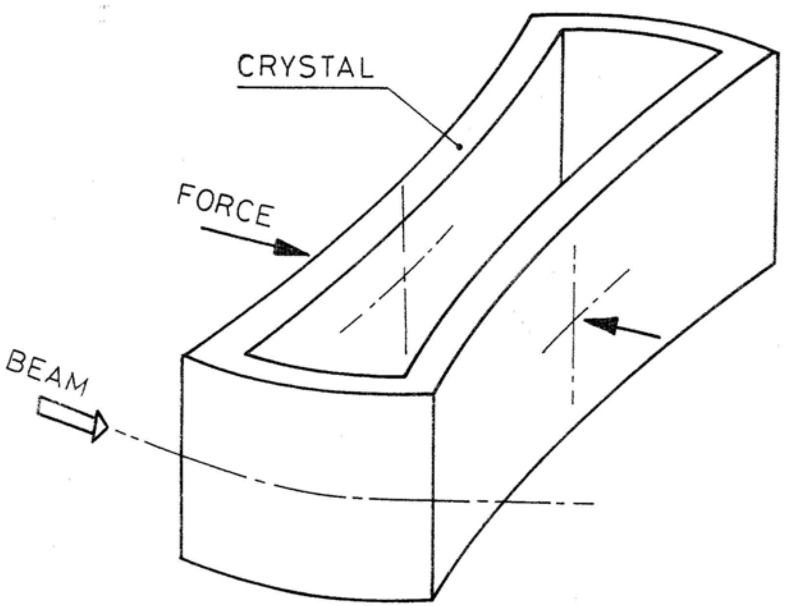
PNPI Saint Petersbourg :

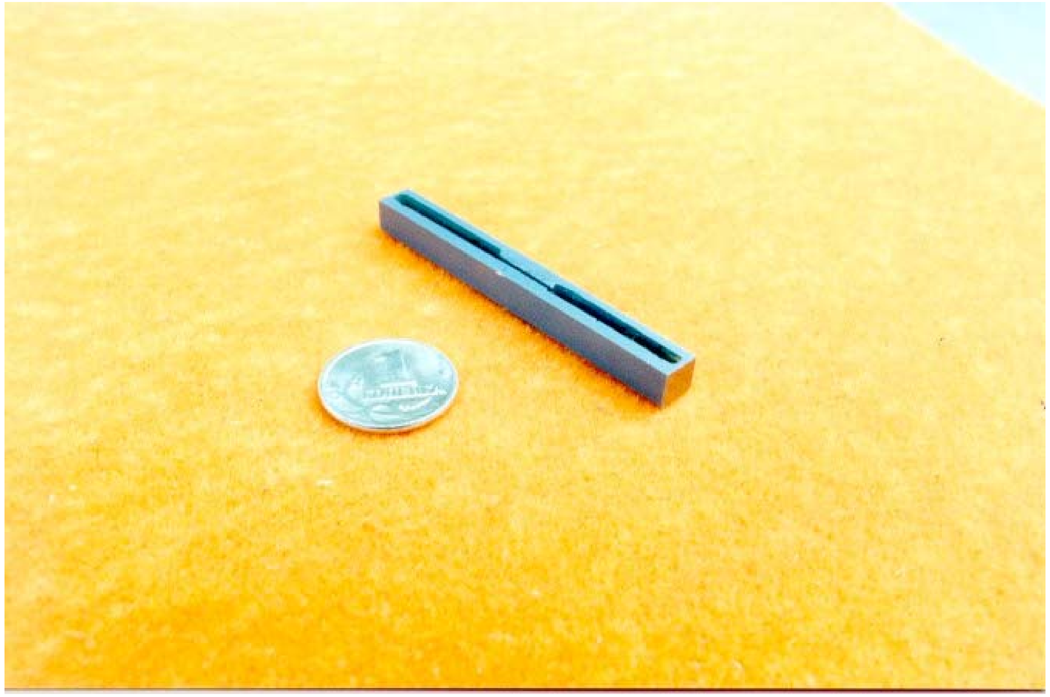
B.A.Chunin – optical measurements
A.S.Denisov – electronics
V.V.Ivanov – mechanical design
Yu.M.Ivanov – head of lab, coordination, crystal design, data analysis
M.A.Koznov – optical surface preparation
L.P.Lapina – calculations and data handling
A.A. Petrunin – X-ray diffraction measurements
V.V.Skorobogatov – crystal orientation, cutting and treatment
V.V.Vavilov – data acquisition

EU budget for 02/03: 60 Keuro

O-shaped crystal used during INTAS 132 experiments

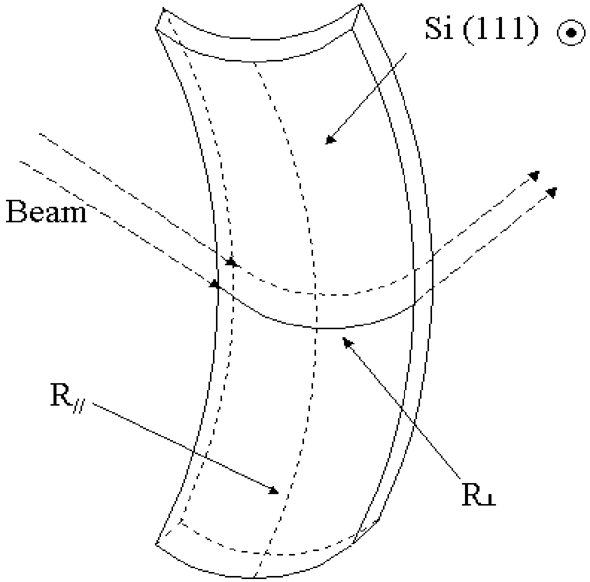
Crystal is 3 to 5 mm along the beam



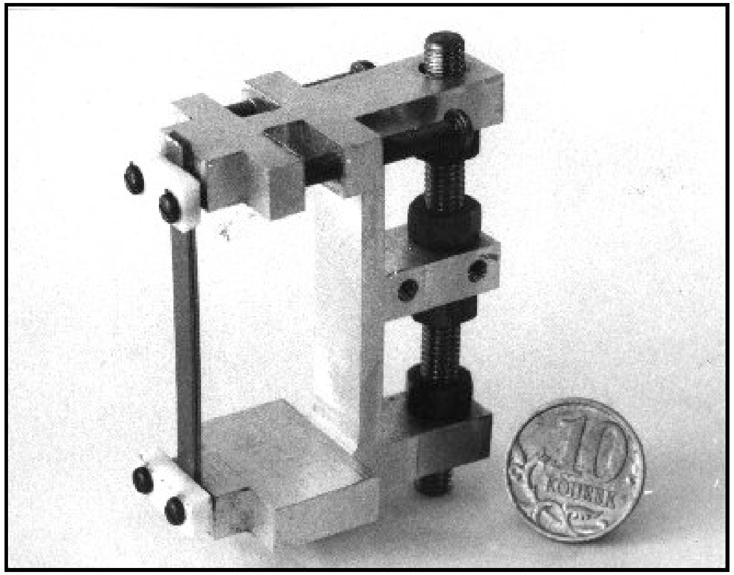


Strip-type crystal used during INTAS 132 experiments

Bending exploits anticlastic effects due to anisotropy of cristalline Si.
For the (111) direction the sample takes the shape of a saddle



Scheme of the crystal (not in scale)

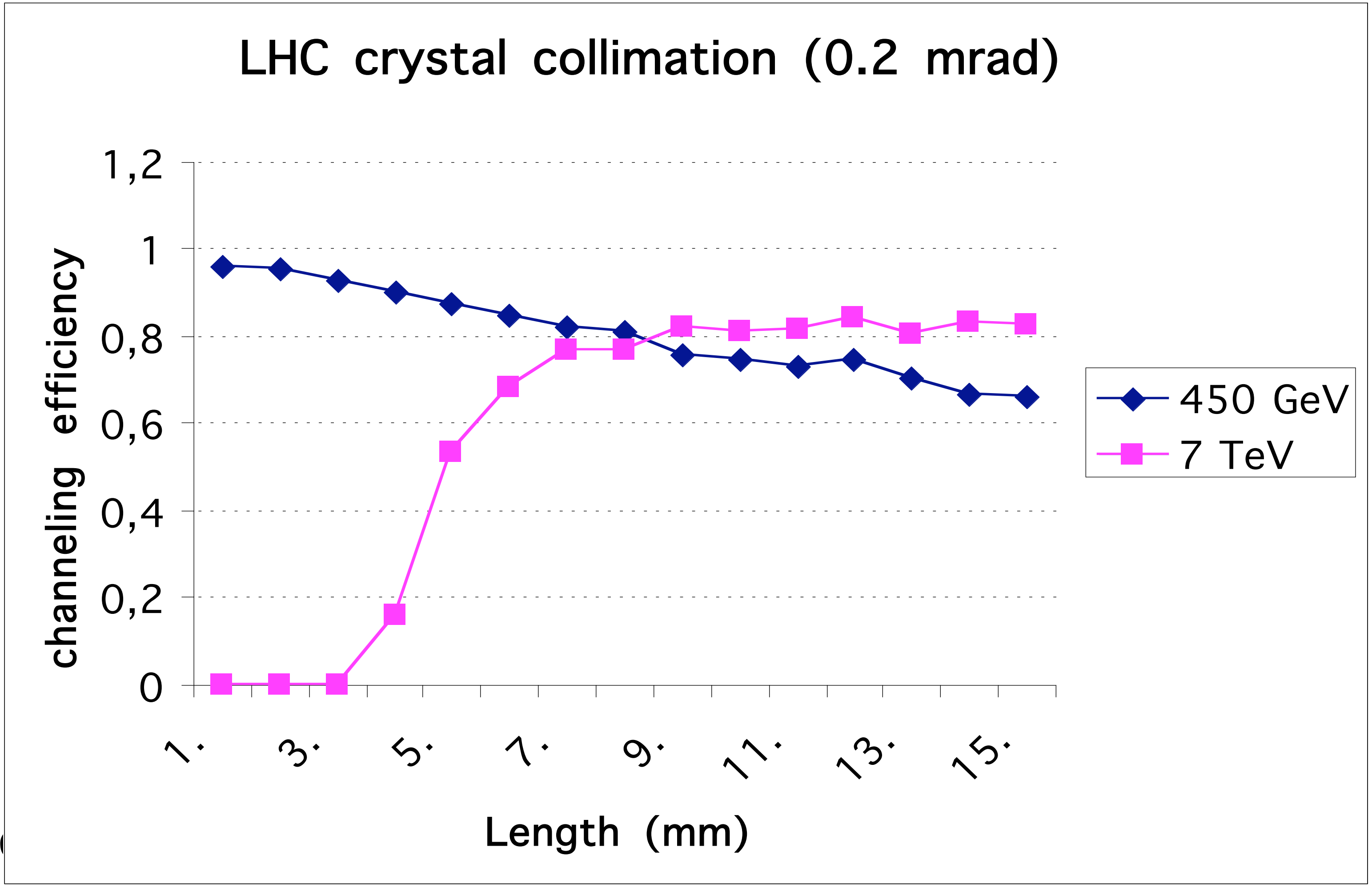


Example of crystal with bending device

- **Dimensions 0.5×2×50mm^3**
- **1/$R_\perp$ is the curvature experienced by channelled particles**

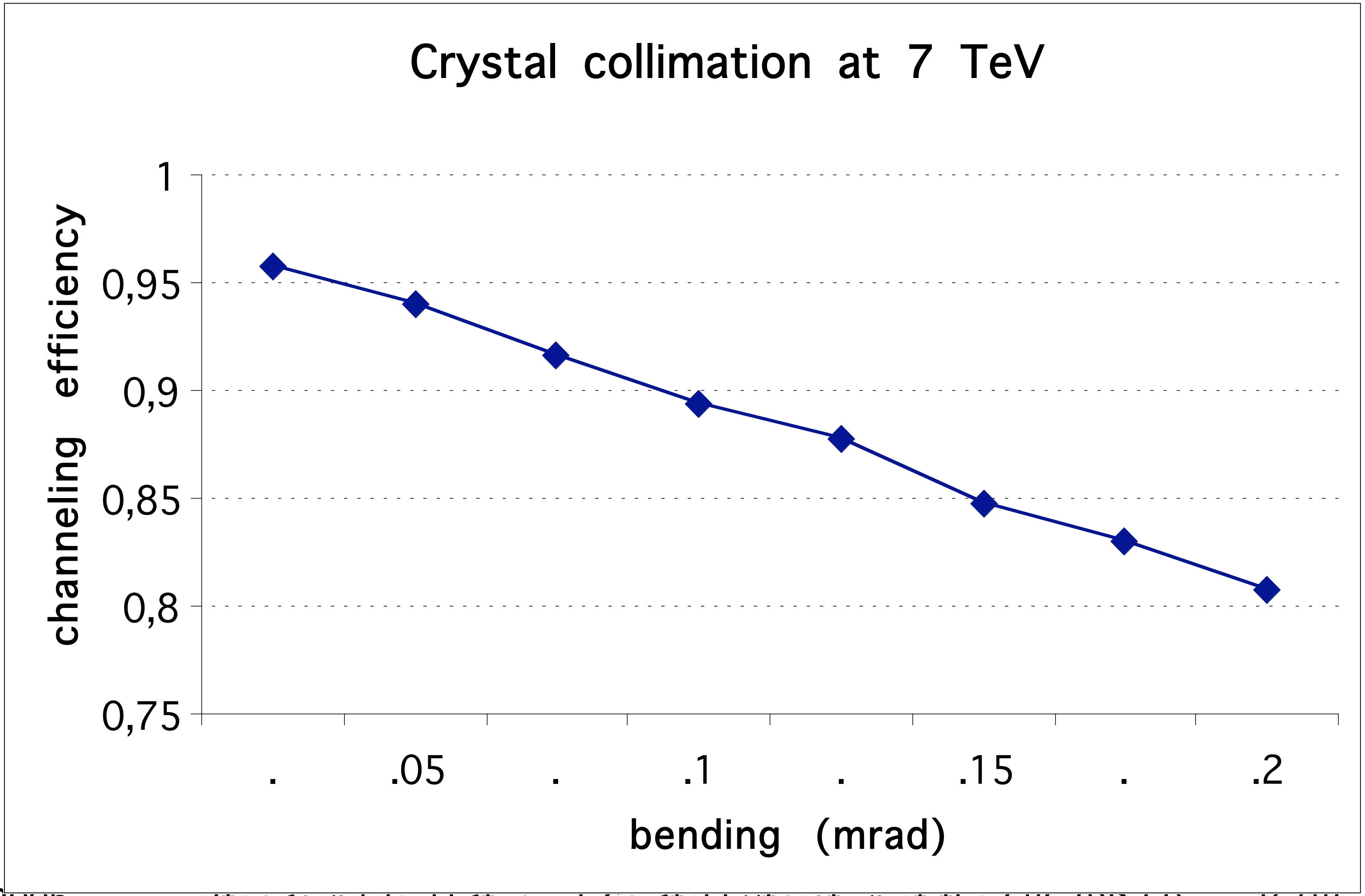
LHC:CHANNELING EFFICIENCY (0.2mrad)

The channeling efficiency as a function of the crystal length along the LHC beam for two cases:at flattop 7TeV and at injection 450GeV
The bending angle was 0.2mrad



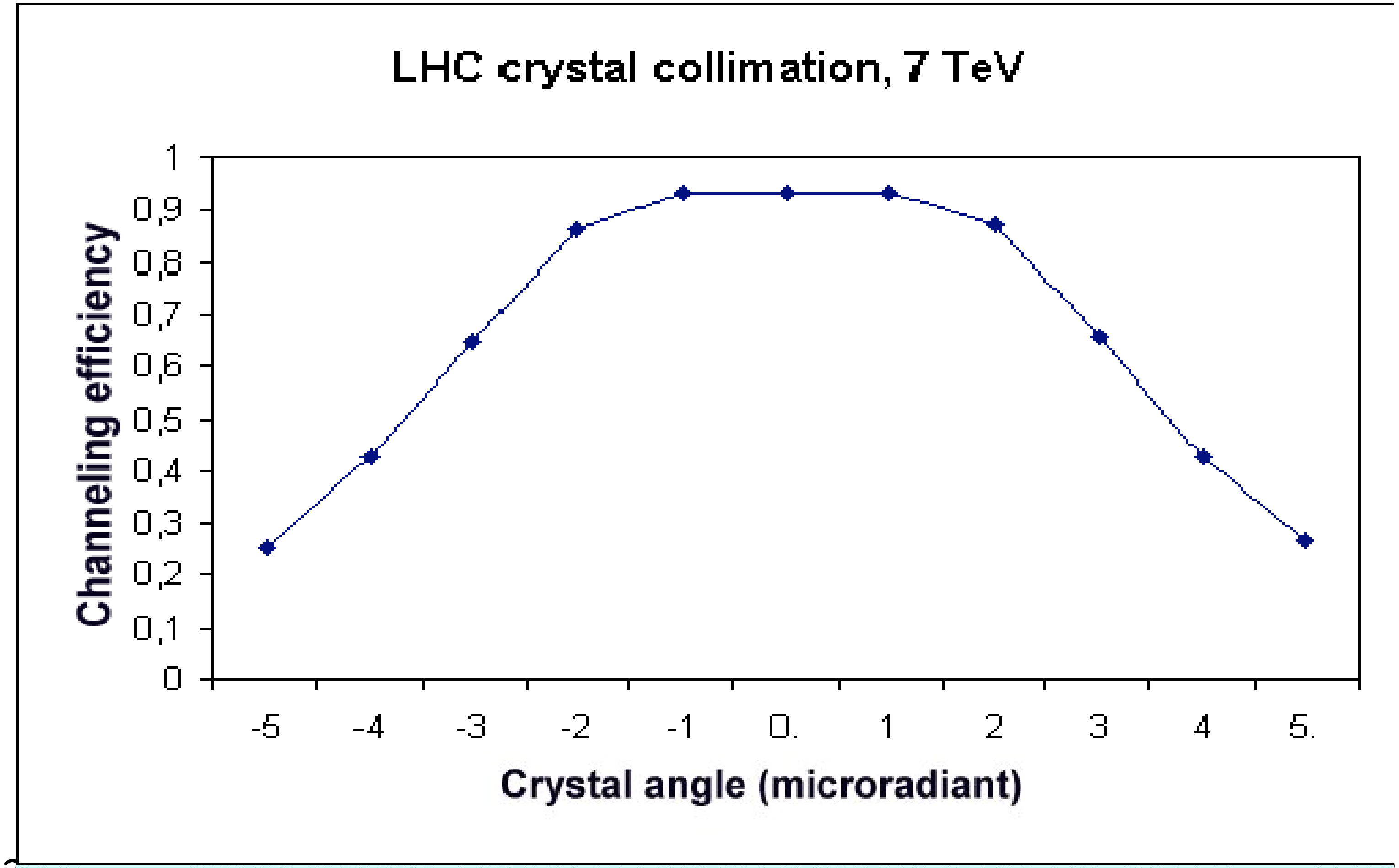
LHC:CHANNELING EFFICIENCY vs angle

The channeling efficiency F as a function of the crystal bending angle.
Silicon (110) with a rough (1μm) surface



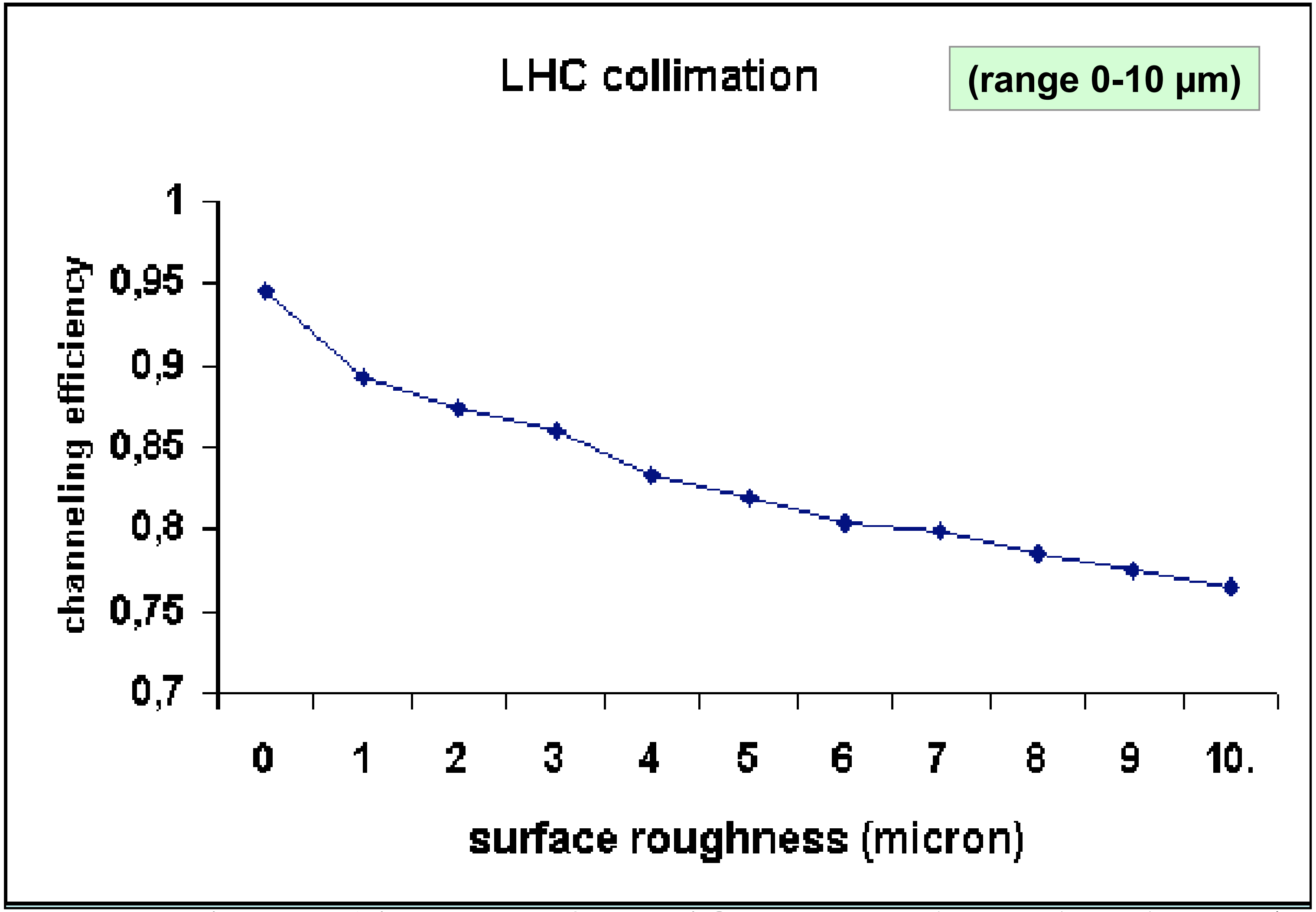
LHC:EFFECT OF CRYSTAL MISALIGNMENT

Channeling efficiency as a function of the crystal orietation angle w.r.t. the beam envelope.The orientation curve has FWHM 7µrad at top energy

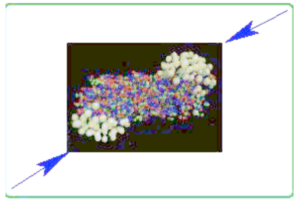


LHC: Requirement on crystal surface

Channeling efficiency as a function of the crystal surface roughness ('septum width')



PHYSICAL PROPERTIES CHARACTERIZATION



A complete charaterization of the crystal sample has been made on AN2000 and CN accelerator LNL through:

IonBeamAnalyses: the crystal sample defects were investigated by 4He+ protons channeling with energy range 1-7MeV,In particular analysis of:
- **Mechanical slicing**
- **Mechanical bending**
- **Chemical treatment to the surface**
- **Low and hight protons channeling irradiation**
- **Thermal treatment damage recovery to irradiation)**

Thermal treatment:crystal sample annealing in vacuum (10^{-6} Torr) and atmosphere controlled (Ar or He)

Microscopy AFM e HRTEM:

Analyses of crystal lattice imperfections (by means of TEM and HRTEM)

Analyses surface morphology of samples (by means of ATM)

Optical measurements of the bending angle through the : Surface-Stress Induced Optical Deflection:

HCCC

Halo Collimation through Channeling in Crystals

PARTECIPANTS:

Ferrara	**LNL (Laboratori Nazionali Legnaro)**
Andrea Antonini	Gianantonio Della Mea
Mariangela Butturi	Alberto Quaranta
Vincenzo Guidi	Alberto Vomiero
Francesco Logallo	Fabiana Gramegna
Cesare Malagù	Valentino Rigato
Giuliano Martinelli	Alessandro Patelli
Emiliano Milan	Enrico Boscolo Marchi
Marco Stefancich	Marco Bonafini
Donato Vincenzi	Enrico Negro

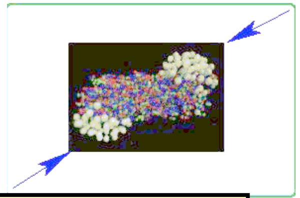
Collaborations :

CERN, Geneva, Switzerland

Institute for High Energy Physics (Protvino)

Petersburg Nuclear Physics Institute (Gatchina)

Outcomes



Monte Carlo model successfully predicts the particles channeling in the crystal

Crystal can be very efficient in the LHC environment,the expected efficiency figure is about 90%. This should make the LHC 10 times cleaner.

Crystal works efficiently at very high intensity (~10^{12}) with a lifetime of many years as required for LHC collimation

Crystal survives at the abnormal dump of the LHC beam with same `safety margin

The same crystal scraper may work efficiently over full energy range,from injection through ramping up to top energy.

Bent crystal of low-Z and high-Z material are avaible with efficiency similar to silicon

The crystal can be used directly as scraper in a system collimation or as precision alignment system for traditional collimator

It is not necessary to redesign the collimator system; it is enough to replace the "amorphous" primary element with a channeling crystal

Some Literature

- W. Scandale, Proc. LHC Workshop, eds G. Jarlskog and D. Rein, Aachen, 1990, vol. III p. 760.
- The RD22 Collaboration, CERN DRDC 91-25
- The RD22 Collaboration, CERN DRDC 92-51
- A.A. Asseev et al, Nucl.Inst.Meth. A330 (1993) p39
- The RD22 Collaboration, CERN DRDC 94-11
- The RD22 Collaboration, CERN SL-95-088
- The RD22 Collaboration, Phys. Lett. B 357 (1995) 671-677
- G. Arduini et al., CERN SL 97-031 and SL 97-055
- G. Arduini et al., CERN SL 97-036 and SL 97-043