On the History of High Energy Channeling

Edward Tsyganov
UTSW MC at Dallas

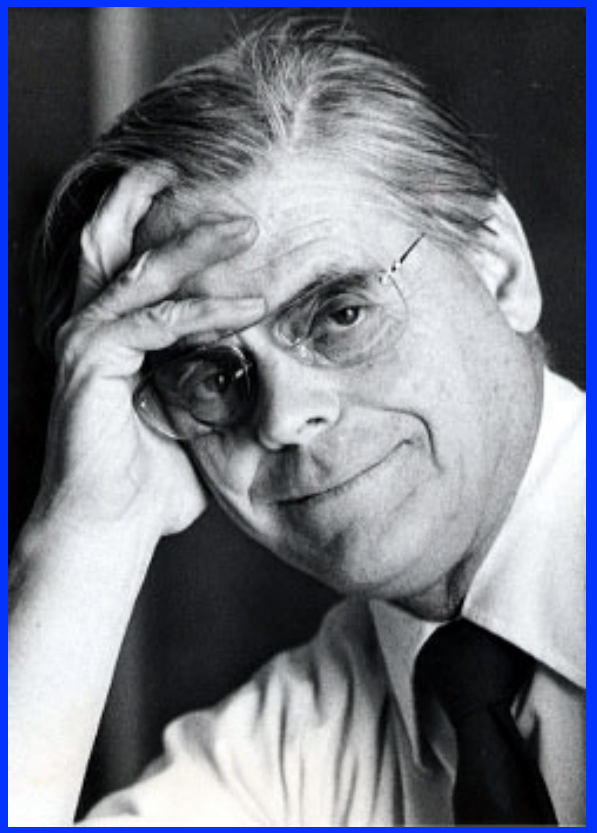
Richard Carrigan
Fermilab

Channeling 2012, September 23-28, 2012 Alghero (SS), Italy

Outline of the talk:

- Bent crystals for beam deflection
- Bent crystals for beam extraction
- Bent crystal scrapers on colliders
- Channeling radiation of high energy electrons and positrons
- High energy experiments using bent crystal
- Full beam reflection in bent crystals

Fermilab, 1975



Robert R. Wilson

Dick Carrigan and family

Channeling 2012, September 23-28, 2012 Alghero (SS), Italy

FERMILAB-Proposal-0507

PROPOSAL TO STUDY CHANNELING AT FERMILAB

W. Gibson (Spokesman), State University of New York at Albany

Z. Guzik, E. Tsyganov (Spokesman), T. Nigmanov, A. Vodopianov,
Joint Institute for Nuclear Research, Dubna

M. Atac, R. Carrigan, B. Chrisman, T. Toohig, Fermilab

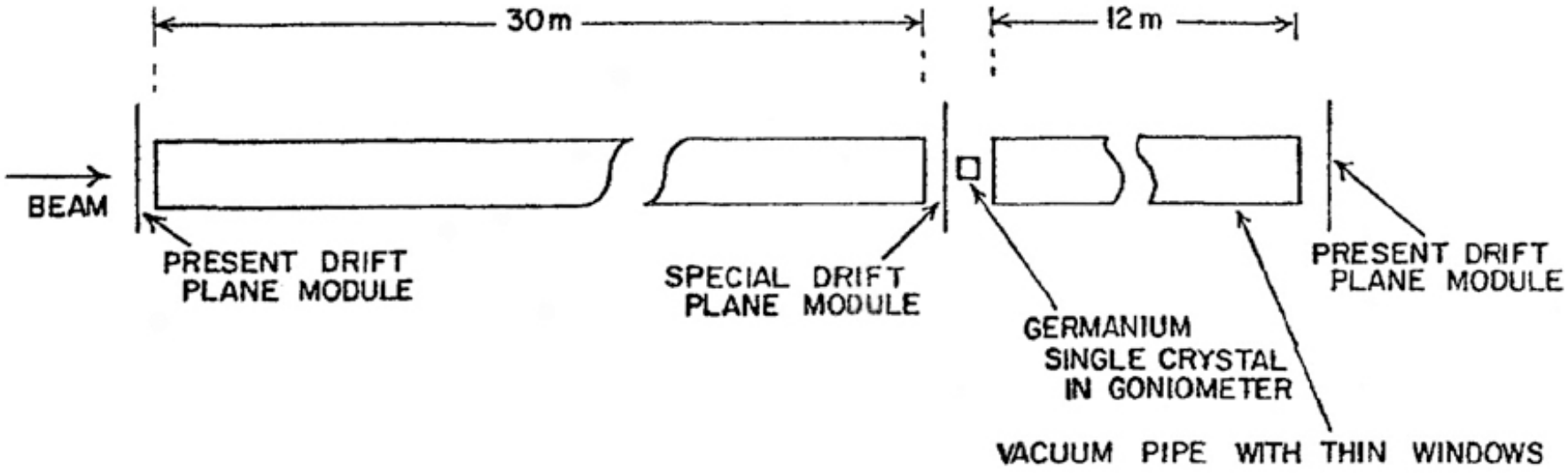
A. Kanofsky, G. Lazo, Lehigh University

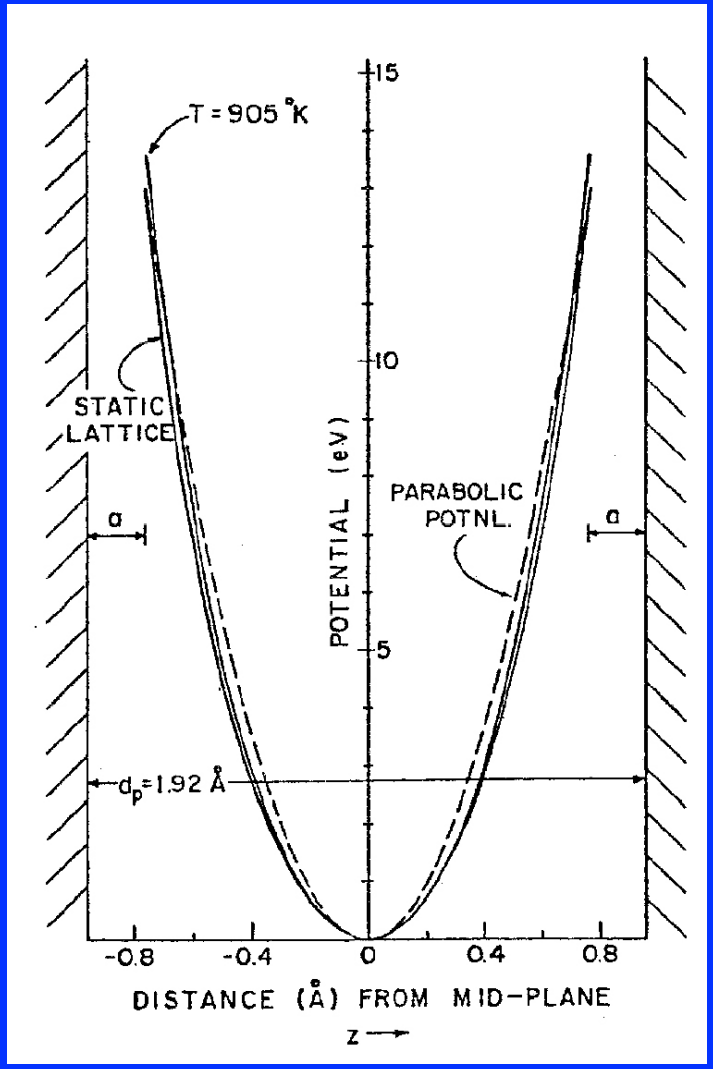
D. Stork, B. Watson, UCLA.

September 8, 1976

Channeling at Fermilab, 1977

PROPOSED SYSTEM FOR CHANNELING STUDIES USING
THE KAON FORM FACTOR APPARATUS

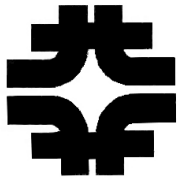




Continuum potential energy for protons channeled in the (110) planes of Si. D.S. Gemmel, Reviews of Modern Physics, 46 (1974) 129.

6 - member Scientific Panel held at Fermilab including Prof. D.S. Gemmel from Argonne National Laboratory *rejected* proposal to deflect high energy beam using bent crystal. *"No chance".*

The paper was rejected by Phys. Rev. Lett.
Prof. Alexis A. Maraddudin of UC Irving declared that the paper is *scientific absurd*, senseless, unintelligent, bizarre proposal.



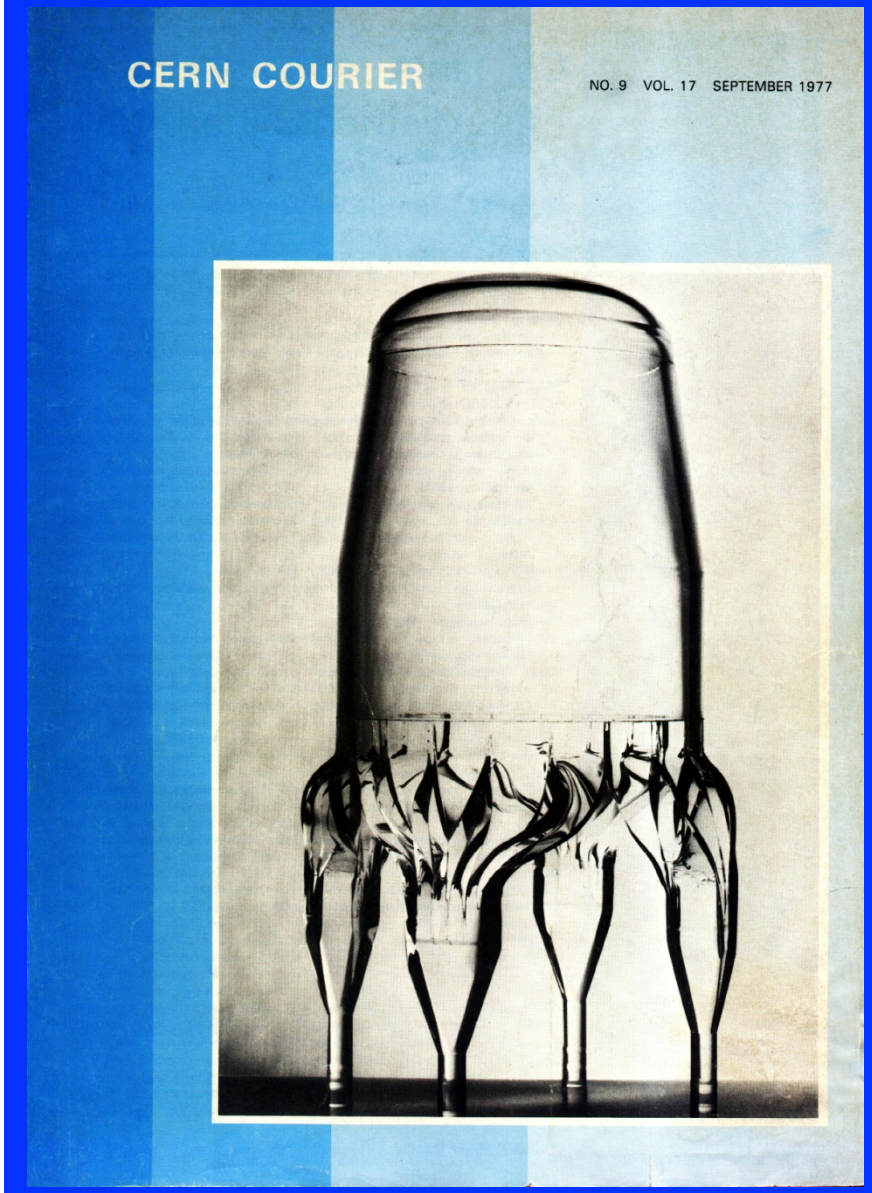
Fermilab

TM-682
2042.000

SOME ASPECTS OF THE MECHANISM OF A CHARGE PARTICLE PENETRATION THROUGH A MONOCRYSTAL

Edouard N. Tsyganov*
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

August 1976



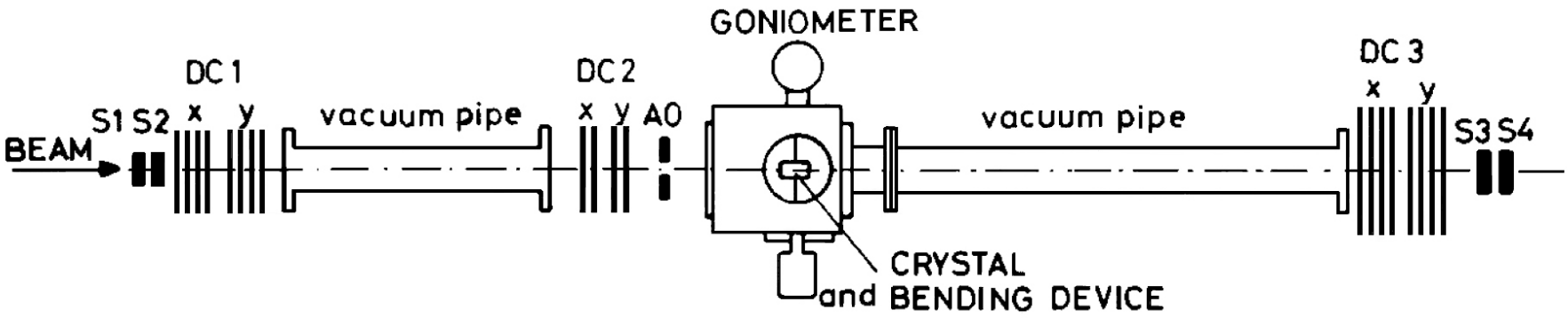
CERN COURIER, September 1977:

A common misunderstanding in channelling is that particles may be trapped in a tube, for example, between four strings in a cubic lattice. This has led some people to hope that channelling could be exploited to bend high energy beams by transmission through a bent crystal.

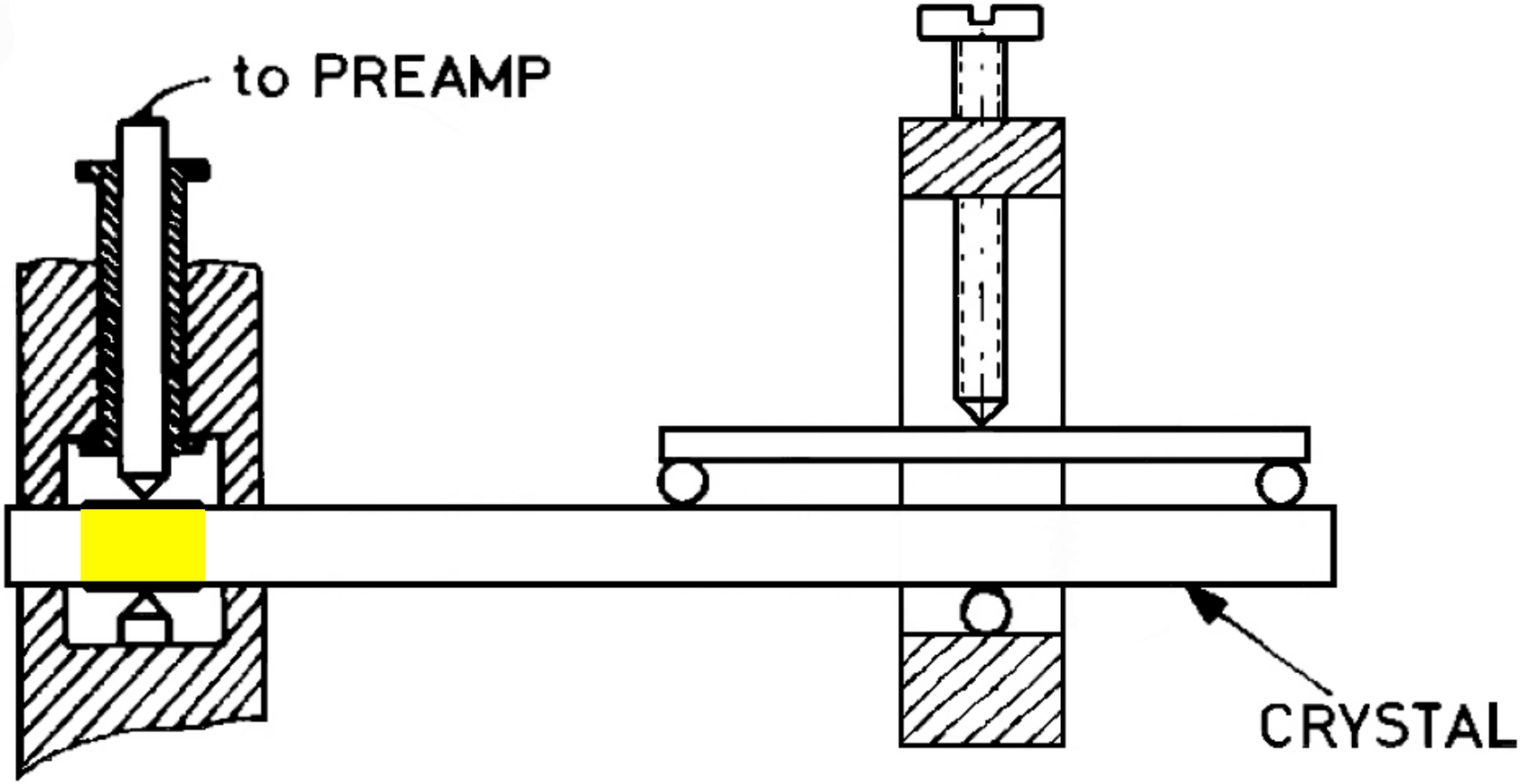
In June 1979 the group of prominent channelists including J. Lindhard and E. Uggerhoy visited Dubna after Tulinov' conference in Moscow.
I presented our plans for the experiment.
J. Lindhard and E. Uggerhoy were quite skeptical on possible success of the experiment. "No chance".

Joint Institute for Nuclear Research at Dubna under the leadership of Prof. N. Bogolyubov decided to go on with the experimental proof of the hypothesis.

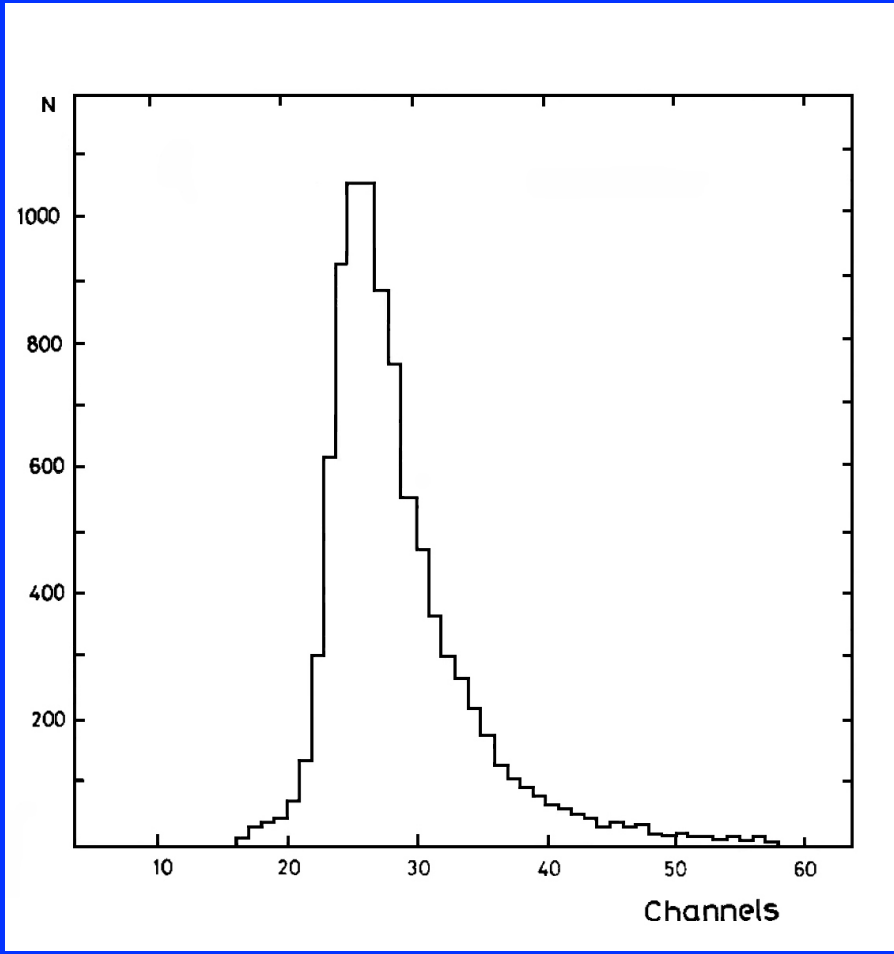
Channeling 8.4 GeV protons in single crystals of Si and Ge at Dubna synchrophasotron

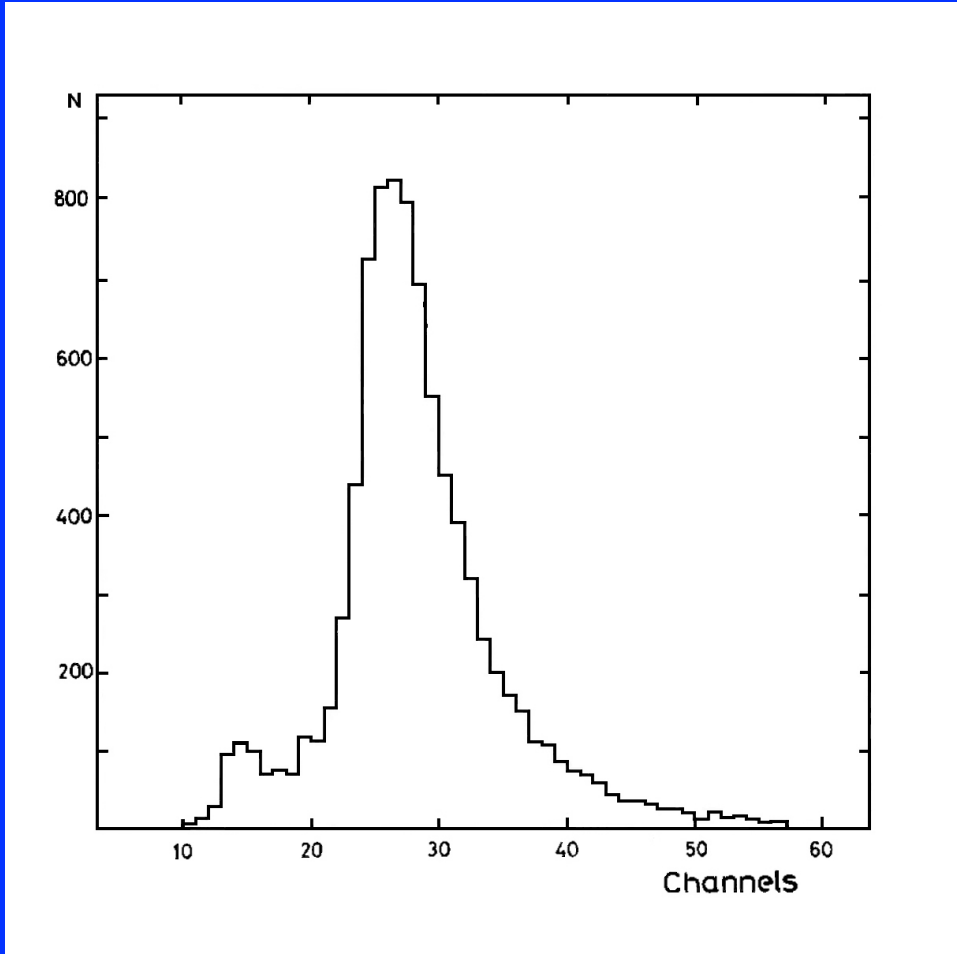


Si crystal, semiconductor detector and bending device



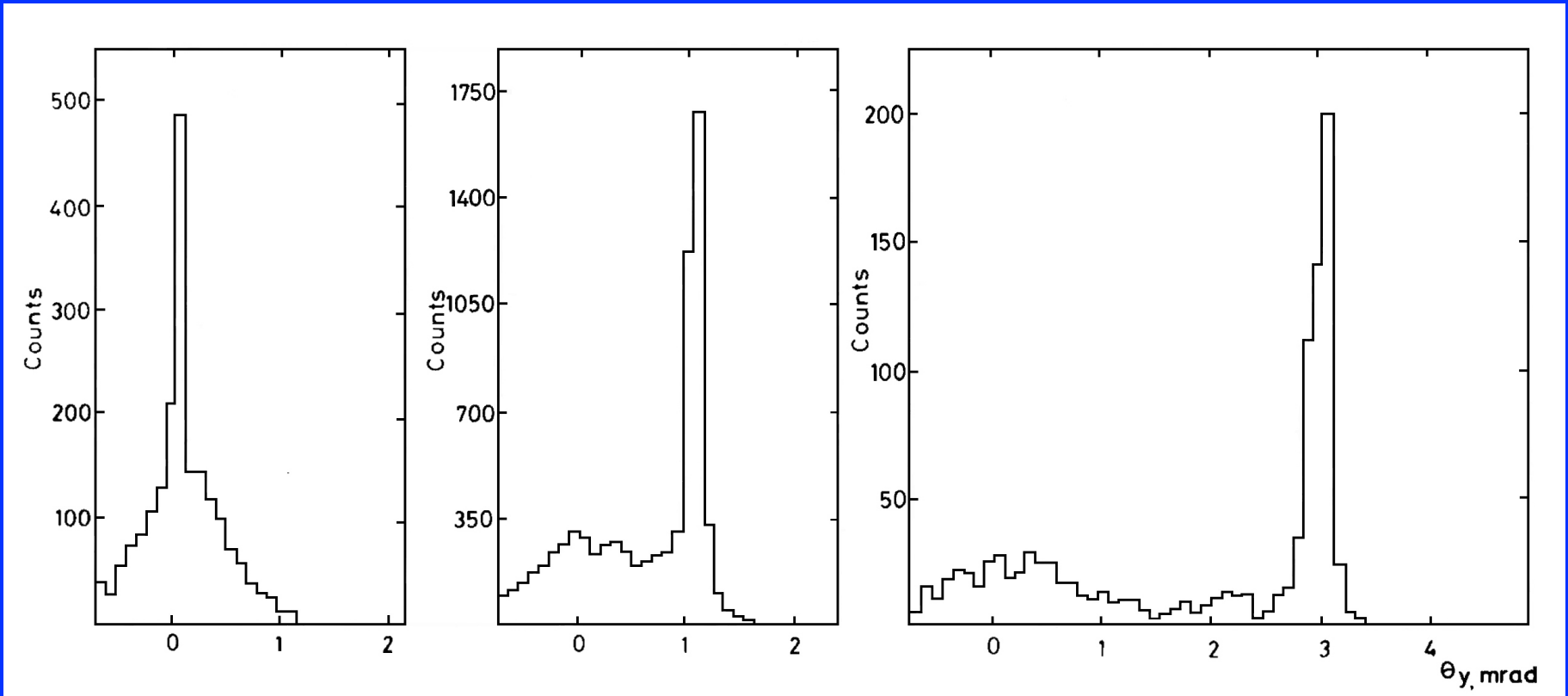
Ionization losses in Si crystal



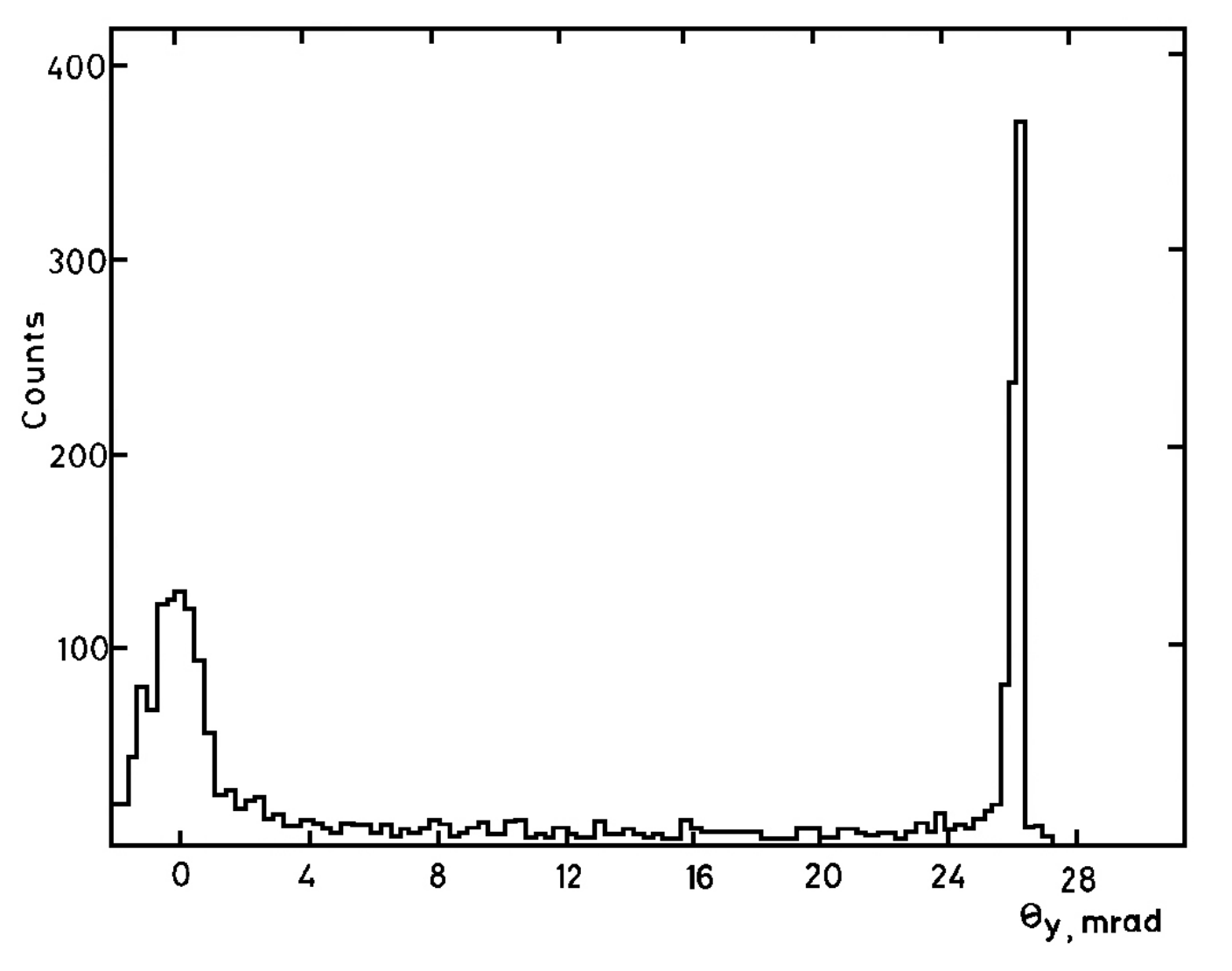


random direction **(110) plane aligned**

Beam deflection in bent silicon crystal



Beam deflection in bent silicon crystal



Channeling 2012, September 23-28, 2012 Alghero (SS), Italy

Volume 88B, number 3,4 PHYSICS LETTERS 17 December 1979

STEERING OF CHARGED PARTICLE TRAJECTORIES BY A BENT CRYSTAL

A.F. ELISHEV, N.A. FILATOVA, V.M. GOLOVATYUK, I.M. IVANCHENKO, R.B. KADYROV, N.N. KARPENKO, V.V. KORENKOV, T.S. NIGMANOV, V.D. RIABTSOV, M.D. SHAFRANOV, B. SITAR, A.E. SENNER, B.M. STARCHENKO, V.A. SUTULIN, I.A. TYAPKIN, E.N. TSYGANOV, D.V. URALSKY and A.S. VODOPIANOV
Joint Institute for Nuclear Research, Dubna, USSR

A. FORYCKI, Z. GUZIK, J. WOJTKOWSKA and R. ZELAZNY
Institute for Nuclear Research, Swierk, Poland

I.A. GRISHAEV, G.D. KOVALENKO and B.I. SHRAMENKO
Physical-Technical Institute of the Academy of Sciences of the Ukrainian SSR, Kharkov, USSR

M.D. BAVIZHEV and N.K. BULGAKOV
Institute for Nuclear Physics at the Tomsk Polytechnical Institute, Tomsk, USSR

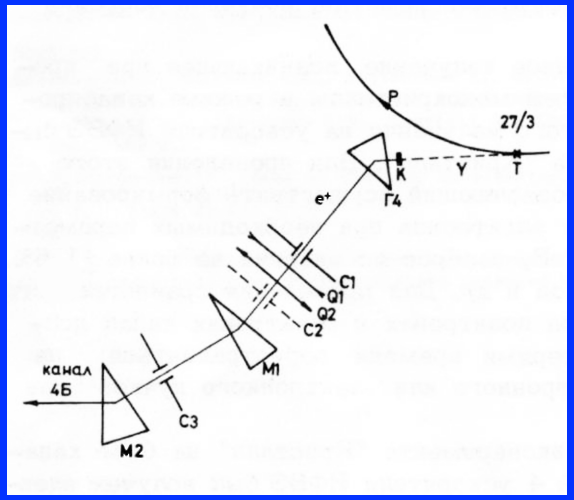
V.V. AVDEICHIKOV
Radium Institute, Leningrad, USSR

R.A. CARRIGAN Jr. and T.E. TOOHIG
Fermi National Accelerator Laboratory [1], *Batavia, IL, USA*

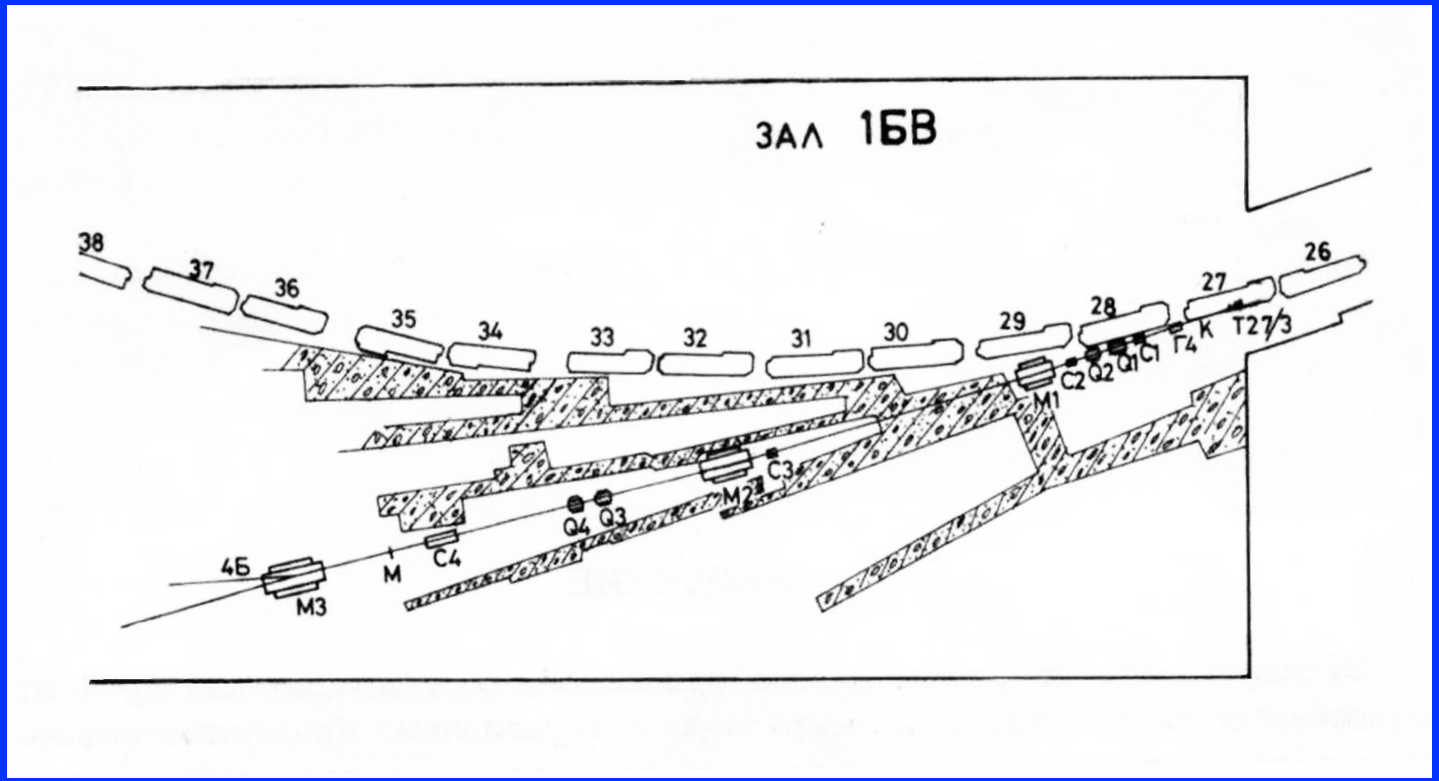
W.M. GIBSON, Ick-Joh KIM, J. PHELPS and C.R. SUN
State University of New York at Albany [2], *NY, USA*

Received 30 August 1979

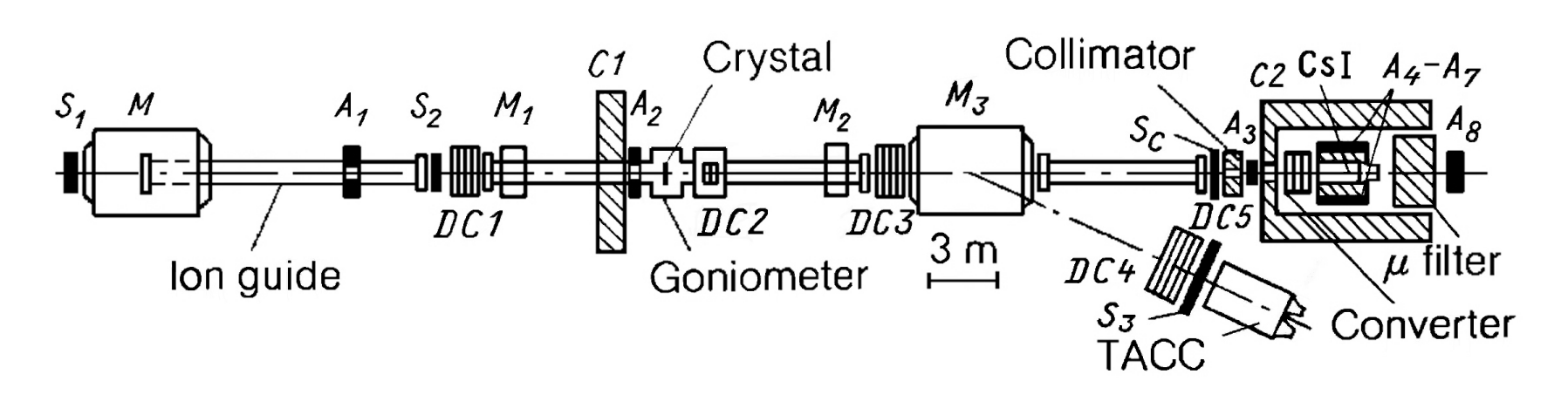
Channeling radiation experiments at Serpukhov

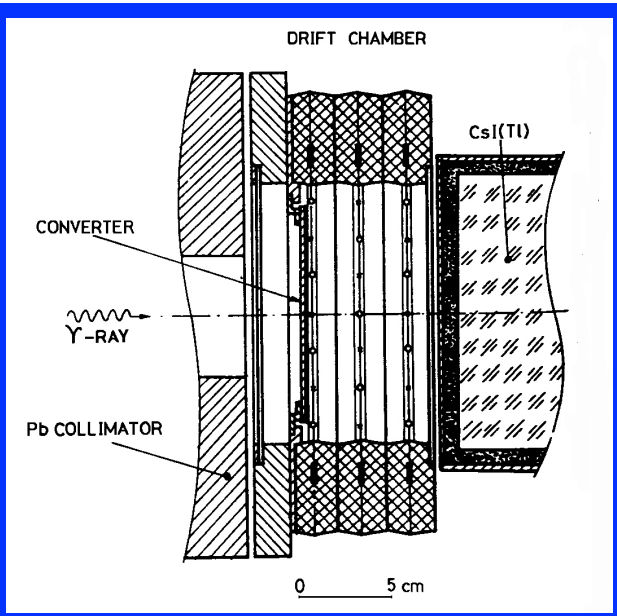


Beam line of 10 GeV electrons and positrons at IHEP, Serpukhov



Channeling of 10 GeV electrons and positrons in Si and Ge





Nuclear Instruments and Methods 194 (1982) 239–241
North-Holland Publishing Company

RADIATION FROM 10 GeV POSITRONS CHANNELED IN SILICON CRYSTALS

N.A. FILATOVA, V.M. GOLOVATYUK, A.N. ISKAKOV, I.M. IVANCHENKO, R.B. KADYROV, N.N. KARPENKO, T.S. NIGMANOV, V.V. PALCHIK, V.D. RIABTSOV, M.D. SHAFRANOV, E.N. TSYGANOV, I.A. TYAPKIN, D.V. URALSKI
Joint Institute for Nuclear Research, Dubna, U.S.S.R.

A. FORYCKI, Z. GUZIK, J. WOJTKOWSKA
Institute for Nuclear Research, Swierk, Poland

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State University of New York at Albany, Albany, N.Y., U.S.A.

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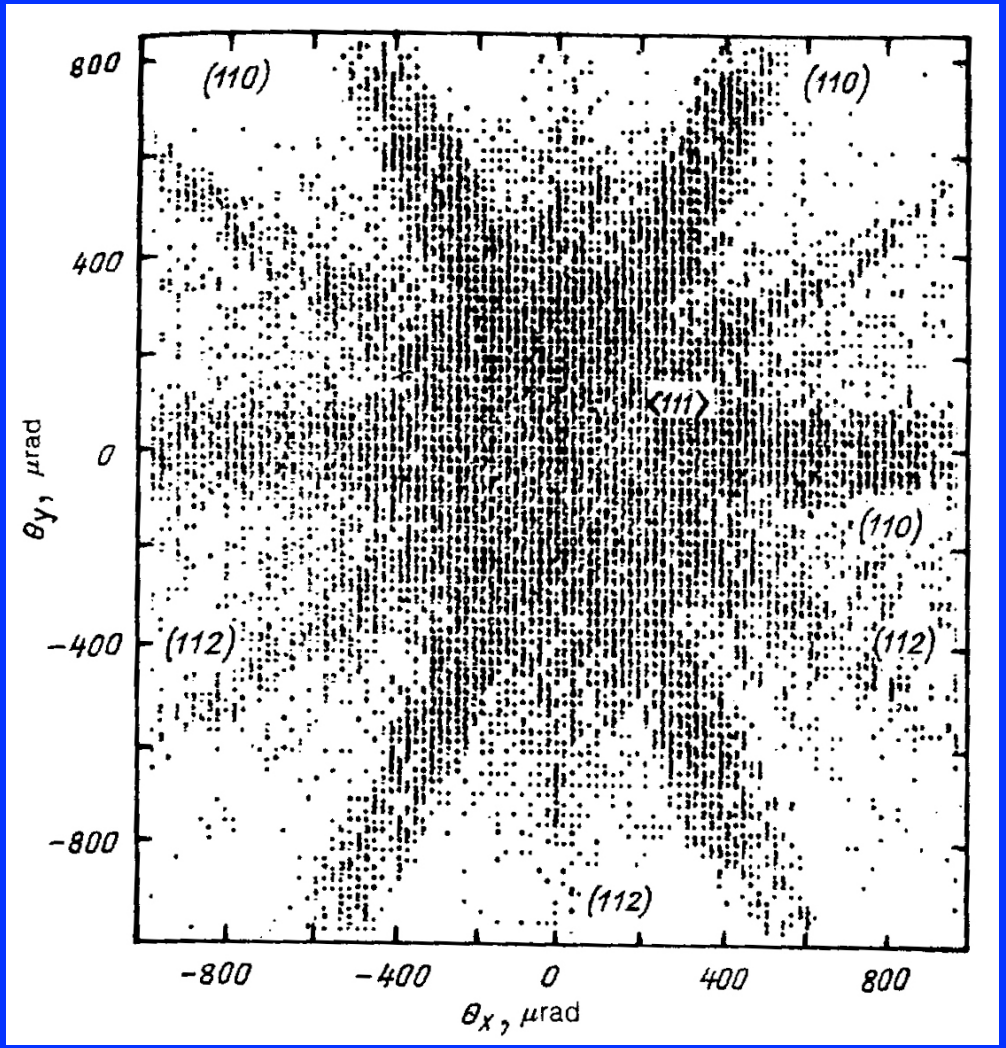
E.I. DENISOV, V.I. GLEBOV
Kurchatov Institute of Atomic Energy, Moscow, U.S.S.R.

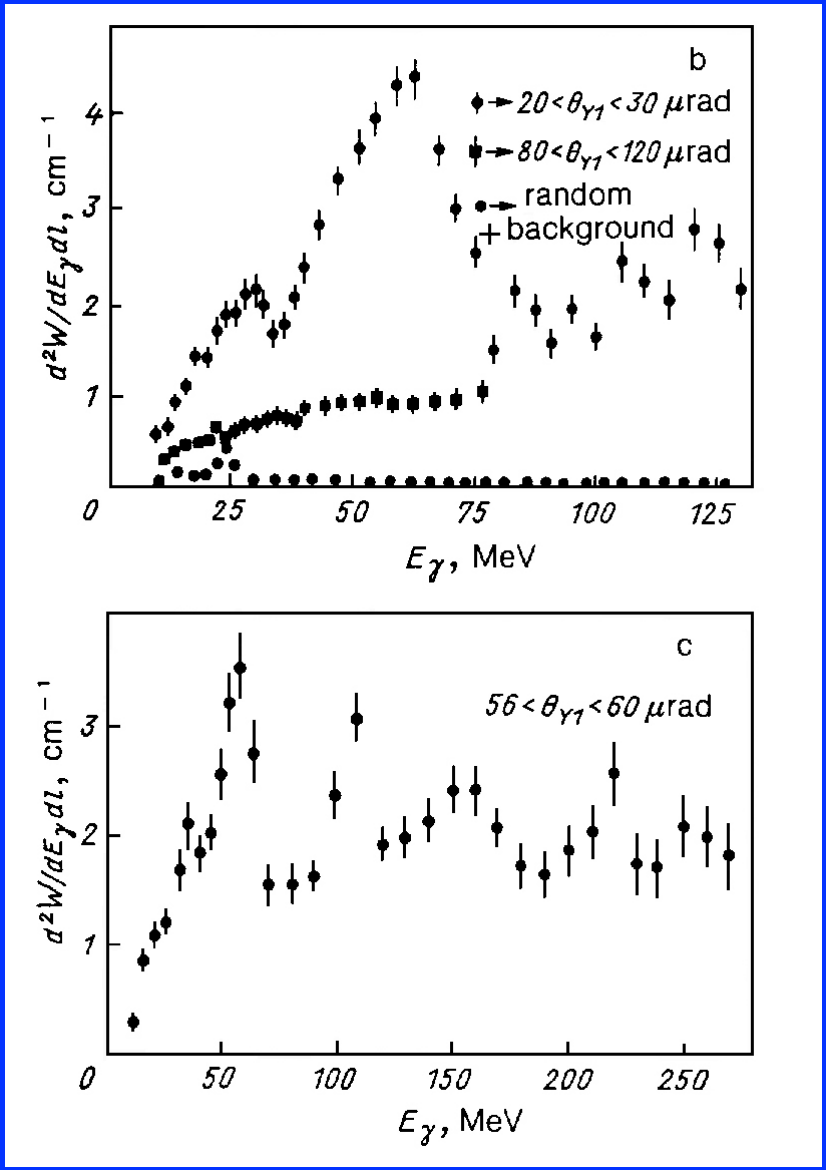
and

V.V. AVDEICHIKOV
V.G. Khlopin Radium Institute, Leningrad, U.S.S.R.

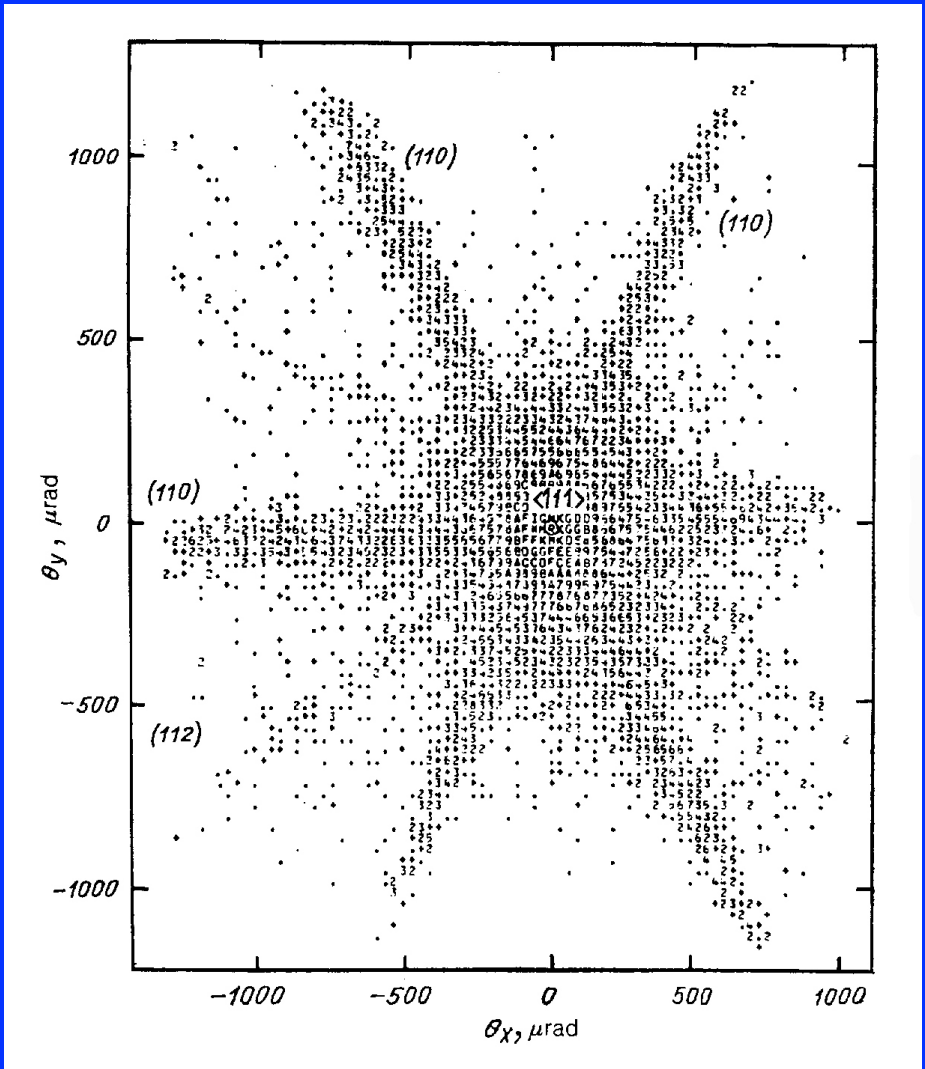
Axial channeling of 10 GeV positrons in Si



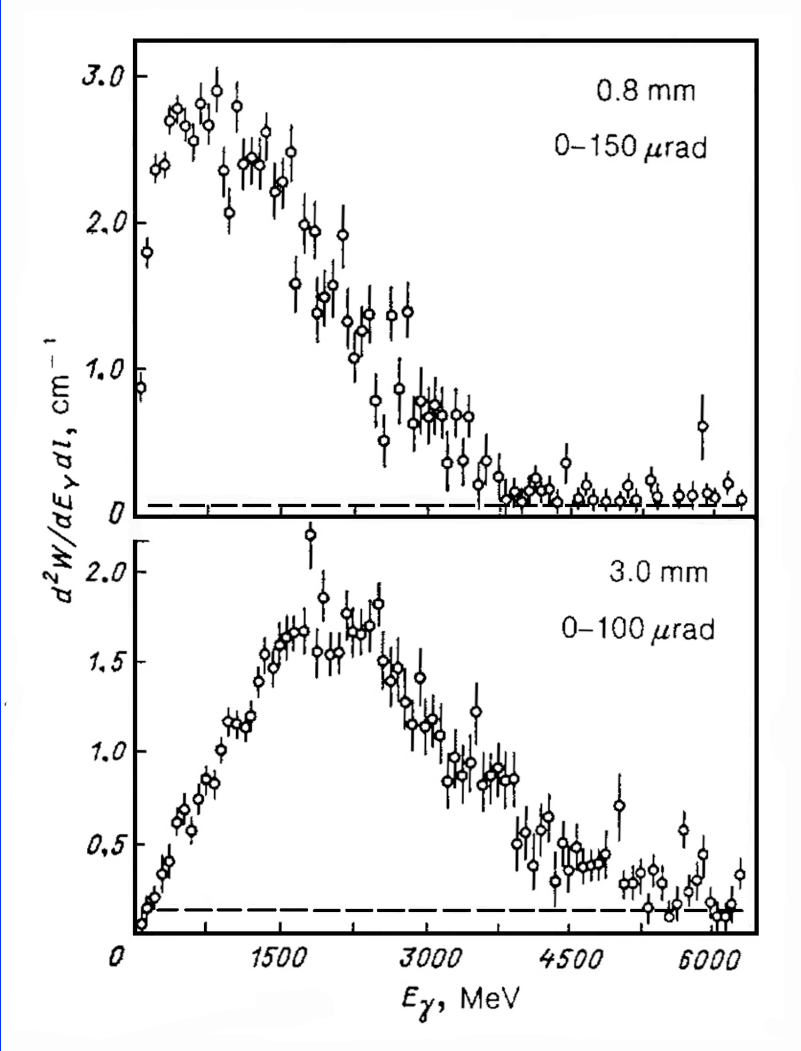
Gamma spectra for 10 GeV positron planar (110) channeling in Si

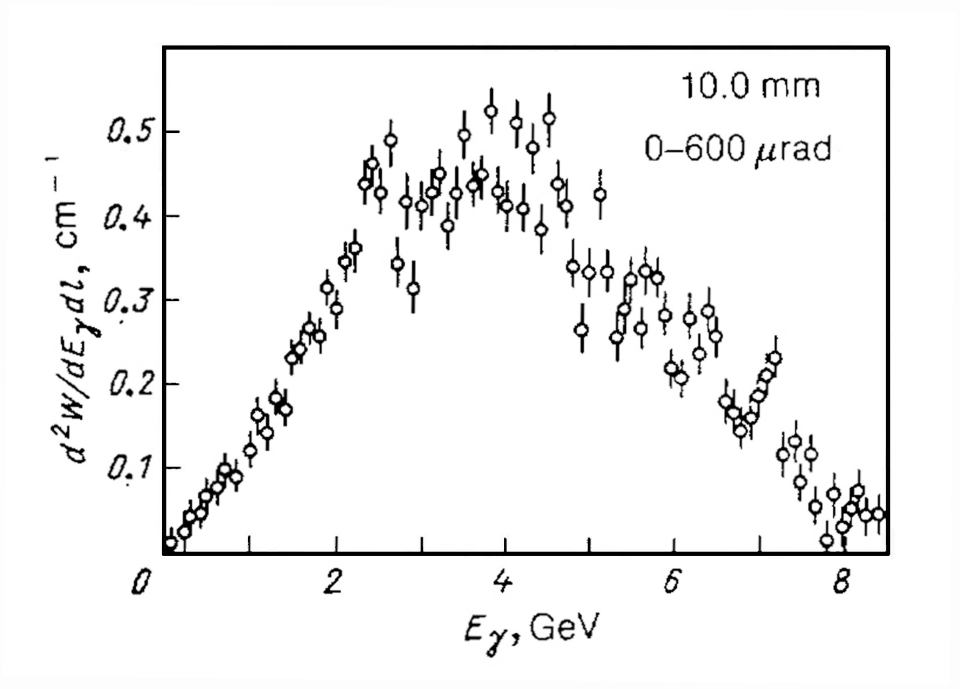


Axial channeling of 10 GeV electrons in Si



Gamma conversion efficiency for 10 GeV electrons for the axial oriented <111> thick Si single crystal.





Publications on channeling of 10 GeV electrons and positrons in Si and Ge

[3]V. M. Golovatyuk, I. M. Ivanchenko, R. B. Kadyrov *et al.*, Preprint D1-81-592 [in Russian], JINR, Dubna (1981); FERMILAB Pub-81/34-Exp, Batavia (1981); Phys. Rev. Lett. **48**, 488 (1982); Nucl. Instrum. Methods **194**, 239 (1982).

[4]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-83-731 [in Russian], JINR, Dubna (1983).

[5]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-83-603 [in Russian], JINR, Dubna (1983); Pis'ma Zh. Eksp. Teor. Fiz. **38**, 462 (1983) JETP Lett. **38**, 561 (1983)].

[6]N. K. Buigakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-83-621 [in Russian], JINR, Dubna (1983).

[7]N. K. Bulgakov, A. S. Vodop'yanov, V. M. Golovatyuk *et al.*, Preprint 1-83-640 [in Russian], JINR, Dubna (1983).

[8]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint R1-85-27 [in Russian], JINR, Dubna (1985).

[9]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint R1-85-28 [in Russian], JINR, Dubna (1985).

[10]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Zh. Eksp. Teor. Fiz. **90**, 1527 (1986) Sov. Phys. JETP **63**, 898 (1986)].

[11]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-84-630 [in Russian], JINR, Dubna (1984).

[12]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-84-639 [in Russian], JINR, Dubna (1984).

[13]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint 1-84-372 [in Russian], JINR, Dubna (1984).

[14]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint R1-85-670 [in Russian], JINR, Dubna (1985).

[15]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint R1-85-671 [in Russian], JINR, Dubna (1985).

[16]N. K. Bulgakov, A. S. Vodop'yanov, I. Voĭtkovska *et al.*, Preprint R1-85-672 [in Russian], JINR, Dubna (1985).

[17]A. S. Vodop'yanov, I. Voĭtpovska, and V. M. Golovatyuk *et al.*, Preprint R13-82-547 [in Russian], JINR, Dubna (1982); Nucl. Instrum. Methods **211**, 353 (1983).

[18]M. D. Bavizhev, N. K. Bulgakov, A. S. Vodop'yanov *et al.*, Preprint R13-81-644 in [Russian], JINR, Dubna (1981); Nucl. Instrum. Methods **206**, 379 (1983).

[19]I. Voĭtkovska, V. M. Golovatyuk, Z. Guzik *et al.*, Preprint R13-82-374 [in Russian], JINR, Dubna (1982); Nucl. Instrum. Methods **215**, 135 (1983).

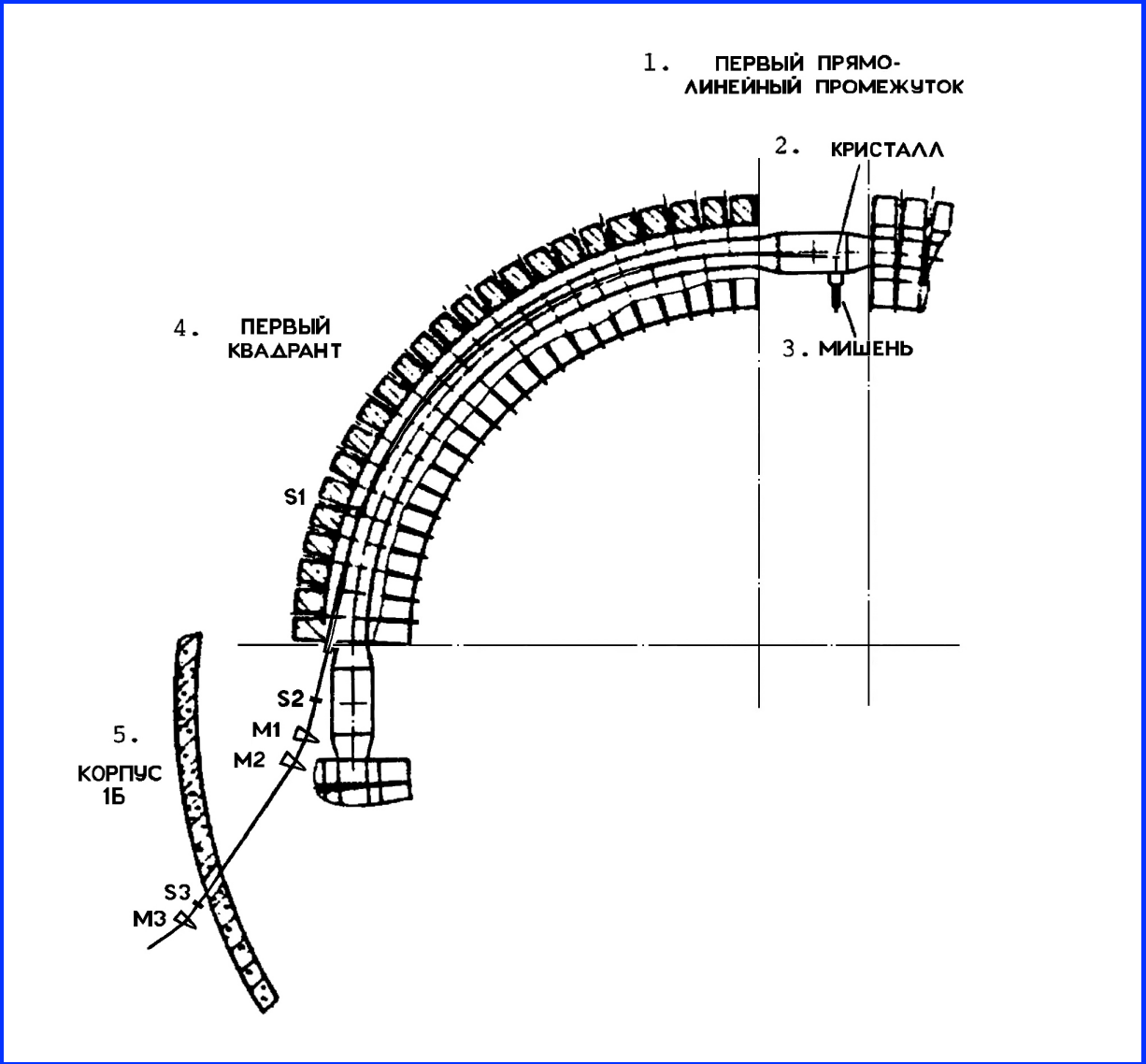
[20]M. D. Bavizhev, N. K. Bulgakov, I. Voĭtkovska *et al.*, Preprint 82-74 OP [in Russian], Institute of High Energy Physics, Serpukhov (1982).

[21]N. K. Bulgakov. I. Voĭtkovska, V. M. Golovatyuk *et al.*, Prib. Tekh. Eksp. **4**, 53 (1986).

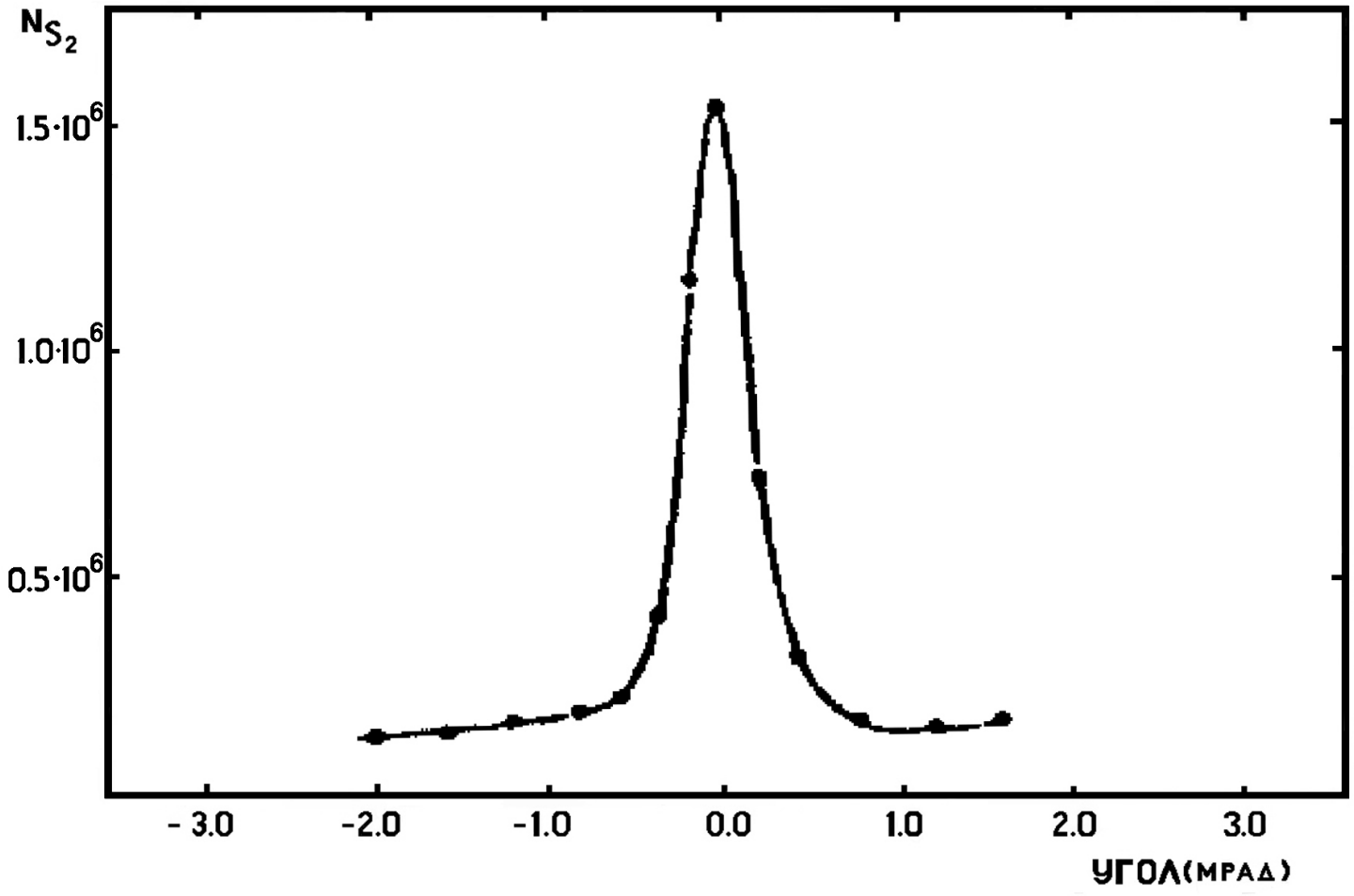
[22]N. K. Bulgakov, I. Voĭtkovska, V. M. Golovatyuk *et al.*, Preprint 13-84-676 [in Russian], JINR, Dubna (1986).

Beam extraction using bent crystals

Schematics of beam extraction from Dubna synchrophasotron



7.5 GeV *First bent crystal extraction (1984)*



Краткие сообщения ОИЯИ №1-84.

УДК539.1.03

ВЫВОД УСКОРЕННОГО ПУЧКА ИЗ СИНХРОФАЗОТРОНА ОИЯИ С ПОМОЩЬЮ ИЗОГНУТОГО МОНОКРИСТАЛЛА

В.В.Авдейчиков, В.Н.Булдаковский, А.В.Бычков, А.С.Водопьянов, И.Войтковска,В.М.Головатюк, В.П.Григорьев, З.Гузик, В.П.Заболотин, Н.И.Зимин, И.Б.Иссинский, Р.Б.Кадыров, Б.К.Курятников, Л.Г.Макаров, Е.А.Матюшевский, В.А.Мончинский, Т.С.Нигманов, С.А.Новиков, В.Г.Перфеев, В.Д.Рябцов, А.Б.Садовский, В.Г.Тимофеев, И.А.Тяпкин, Н.А.Филатова, Э.Н.Цыганов, М.Д.Шафранов, Д.И.Шерстянов, Д.Яворска

Fermi National Accelerator Laboratory

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0100.000

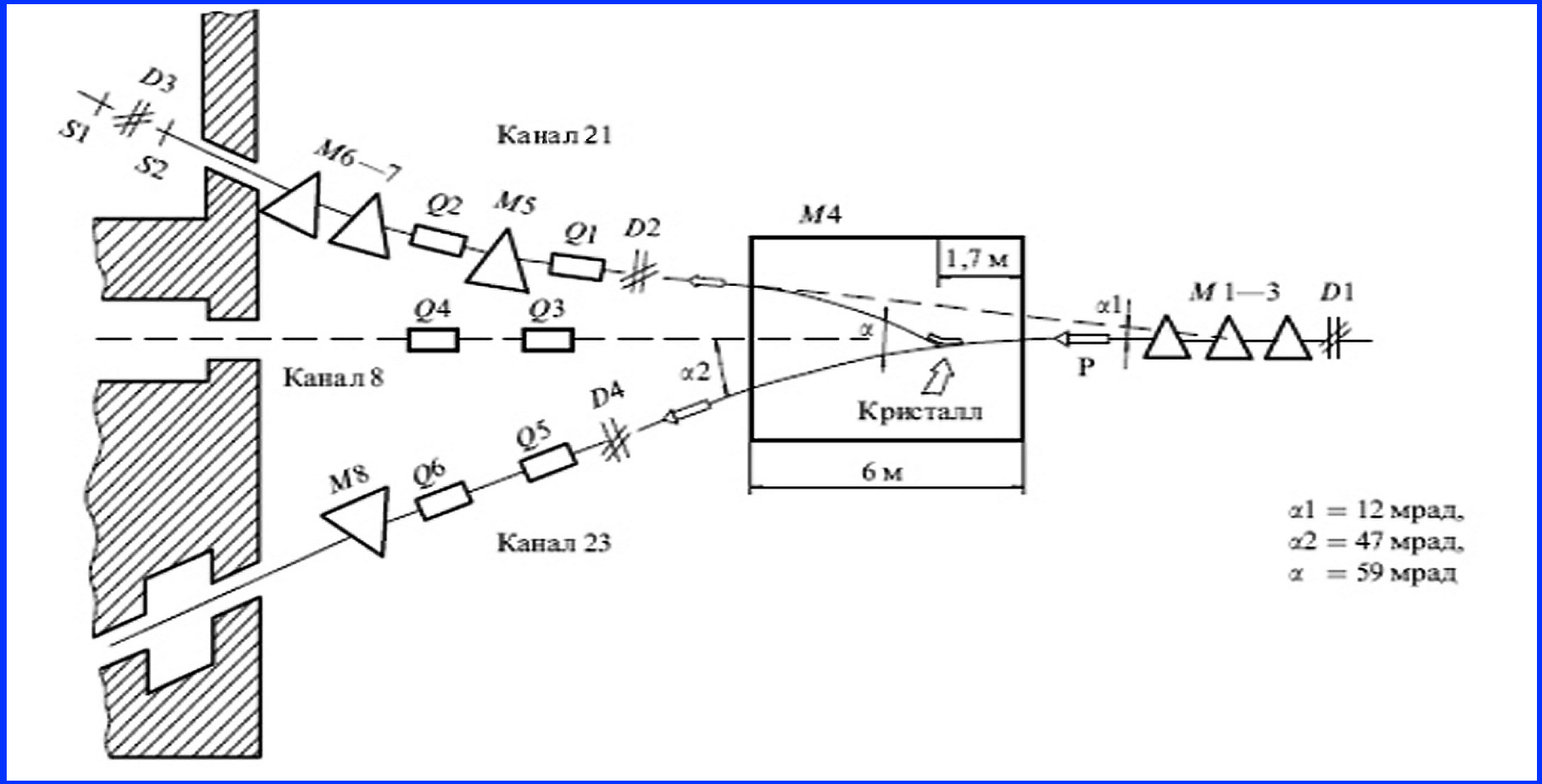
ACCELERATED BEAM EXTRACTION BY MEANS OF A BENT SINGLE CRYSTAL AT THE JINR SYNCHROPHASOTRON

V. V. Avdeichikov, V. N. Buldakovskii, A. V. Bychkov,
A. S. Vodop'yanov, I. Voitkovska, V. M. Golovatyuk,
V. P. Grigor'yev, Z. Guzik, V. P. Zabolotyn, N. I. Zimin,
I. B. Issinskii, R. B. Kadyrov, B. K. Kuryatnikov,
L. G. Makarov, E. A. Matyushevskii, V. A. Monchinskii,
T. S. Nigmanov, S. A. Novikov, V. G. Perfeev, V. D. Ryabtsov,
A. B. Sadovskii, V. G. Timofeev, I. A. Tyapkin, N. A. Filatova,
E. N. Tsyganov, M. D. Shafranov, D. I. Sherstyanov,
and D. Yavorska
Joint Institute for Nuclear Research
Dubna, USSR

January 1984
(Translated in February of 1986)

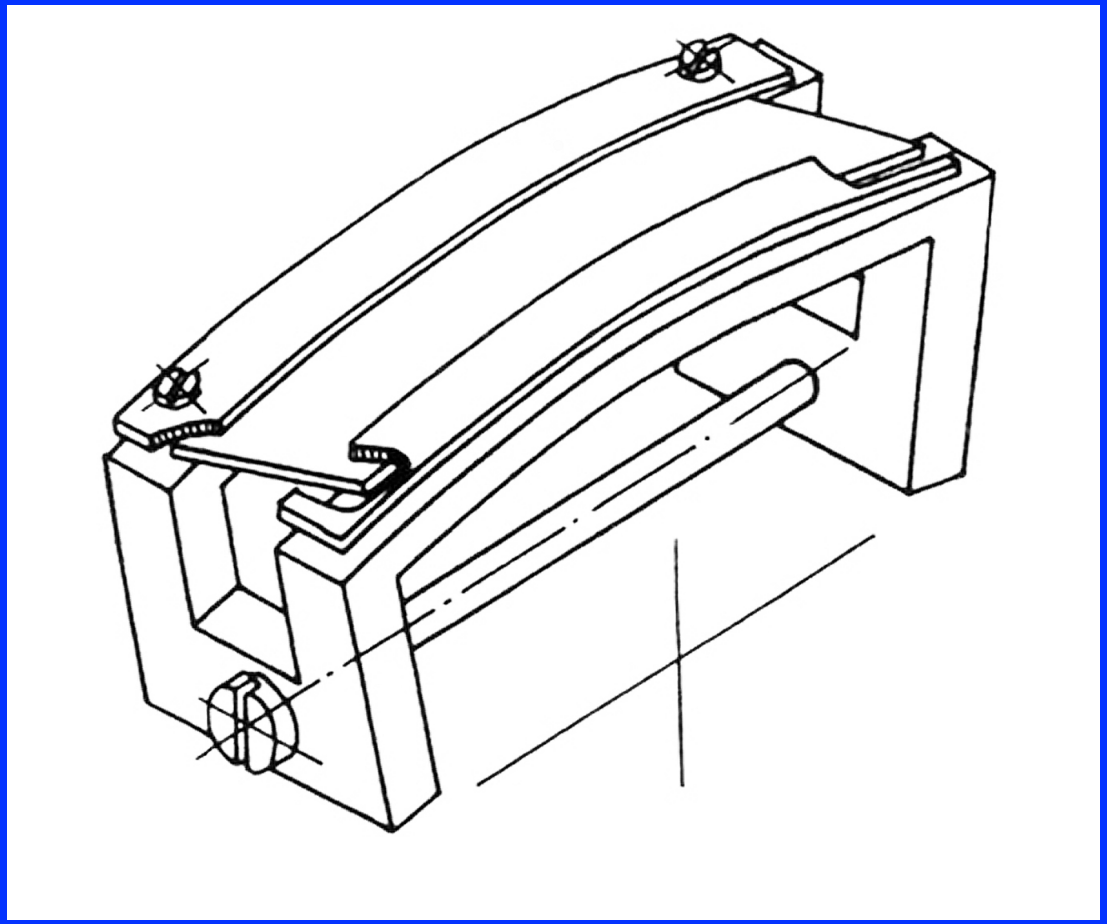
Institute of High Energy Physics at Serpukhov

The diagram of beam-split station



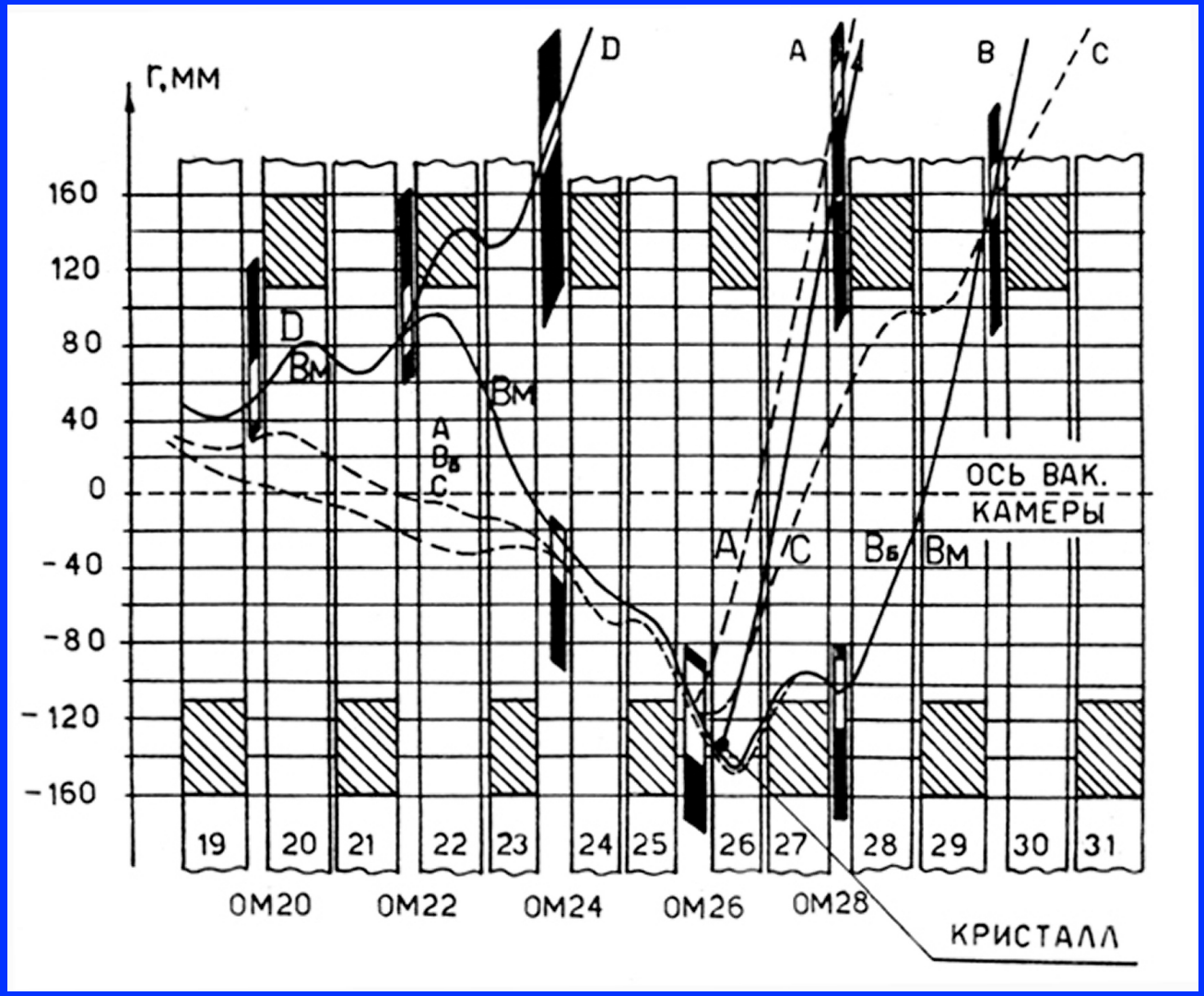
Straight line – beam for neutrino experiments, channel 23 – experiment “ГИПЕРОН”, channel 21 – experiment “СФИНКС”.

Crystal deflector design

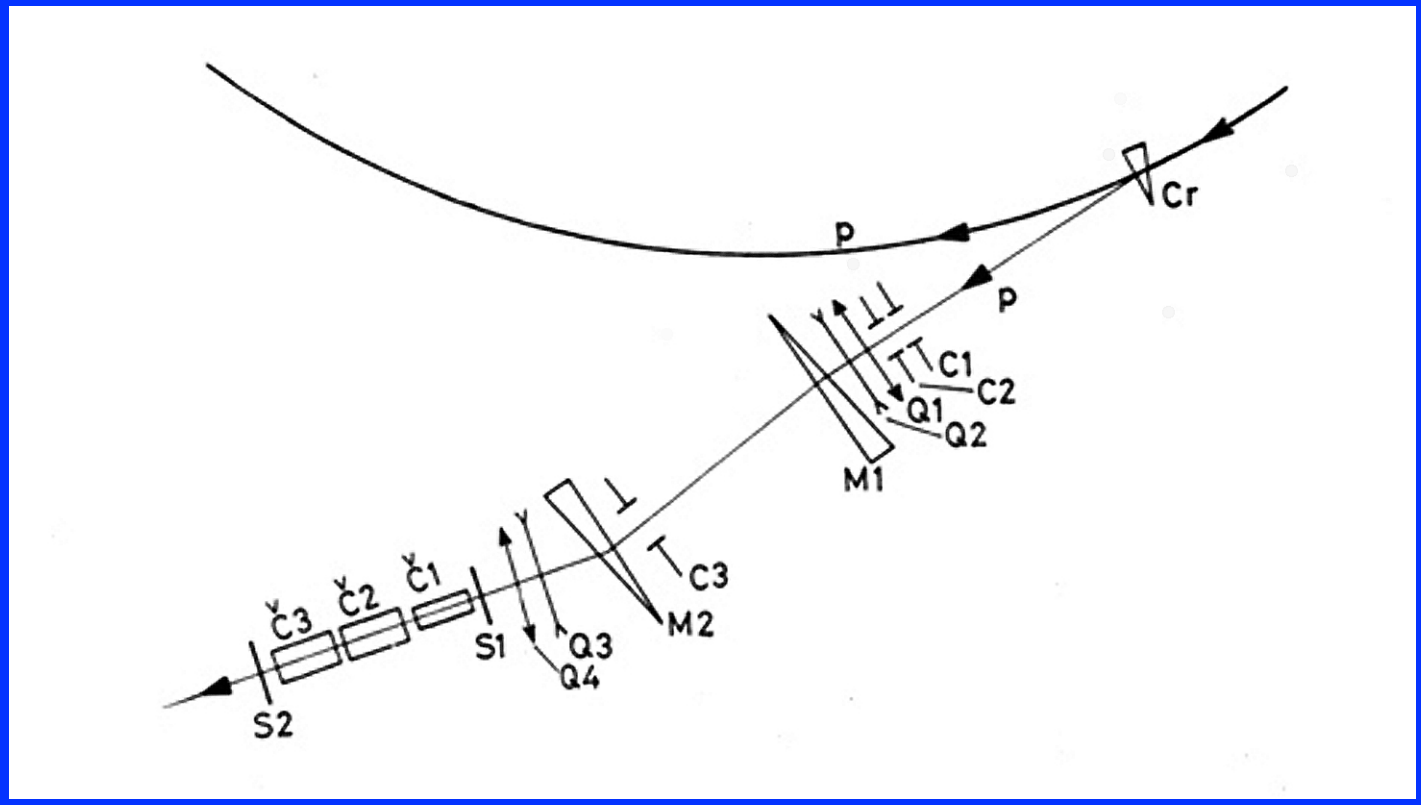


Crystal with skew cat edges had channeling acceptance ±5 mrad, depending on vertical position, and was bent by 80 mrad.

The diagram of slow beam extraction from У-70

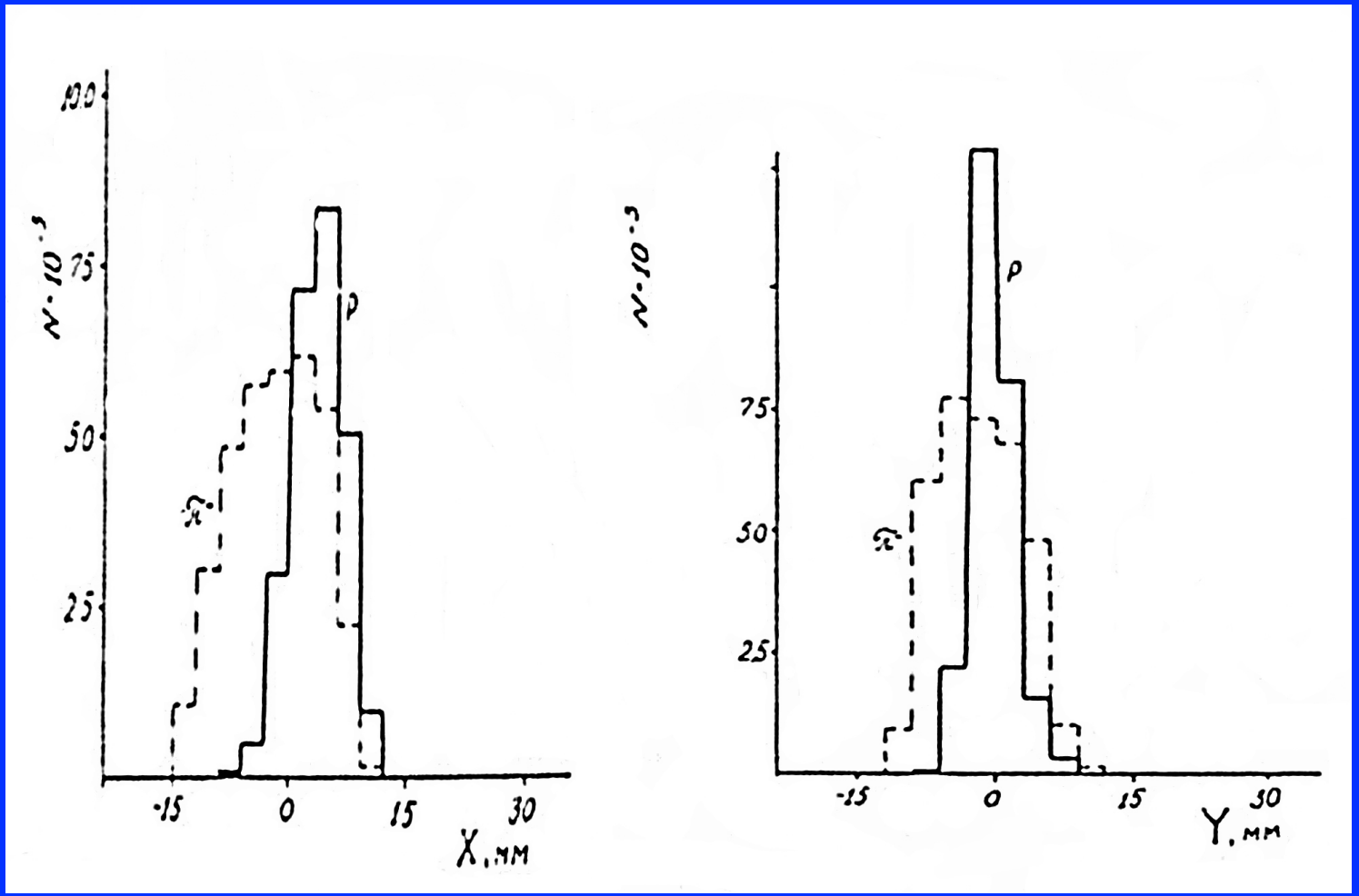


First beam slow extraction at Serpukhov using bent crystal (1986)



Primary beam extraction for experiment “ПРОЗА”, channel 14

Profiles of primary 70 GeV beam extracted for experiment “ПРОЗА”. Profiles of 40 GeV pion beam also shown for comparison.



Bending experiment at CERN

Volume 93B, number 4 PHYSICS LETTERS 30 June 1980

BENDING OF HIGH ENERGY BEAMS USING AXIAL AND PLANAR CHANNELING

J. BAK, G. MELCHART and E. UGGERHØJ [1]
CERN, Geneva, Switzerland

J.S. FORSTER [2], P.R. JENSEN, H. MADSBØLL, S.P. MØLLER,
H. NIELSEN, G. PETERSEN and H. SCHIØTT
Institute of Physics, University of Aarhus, Aarhus, Denmark

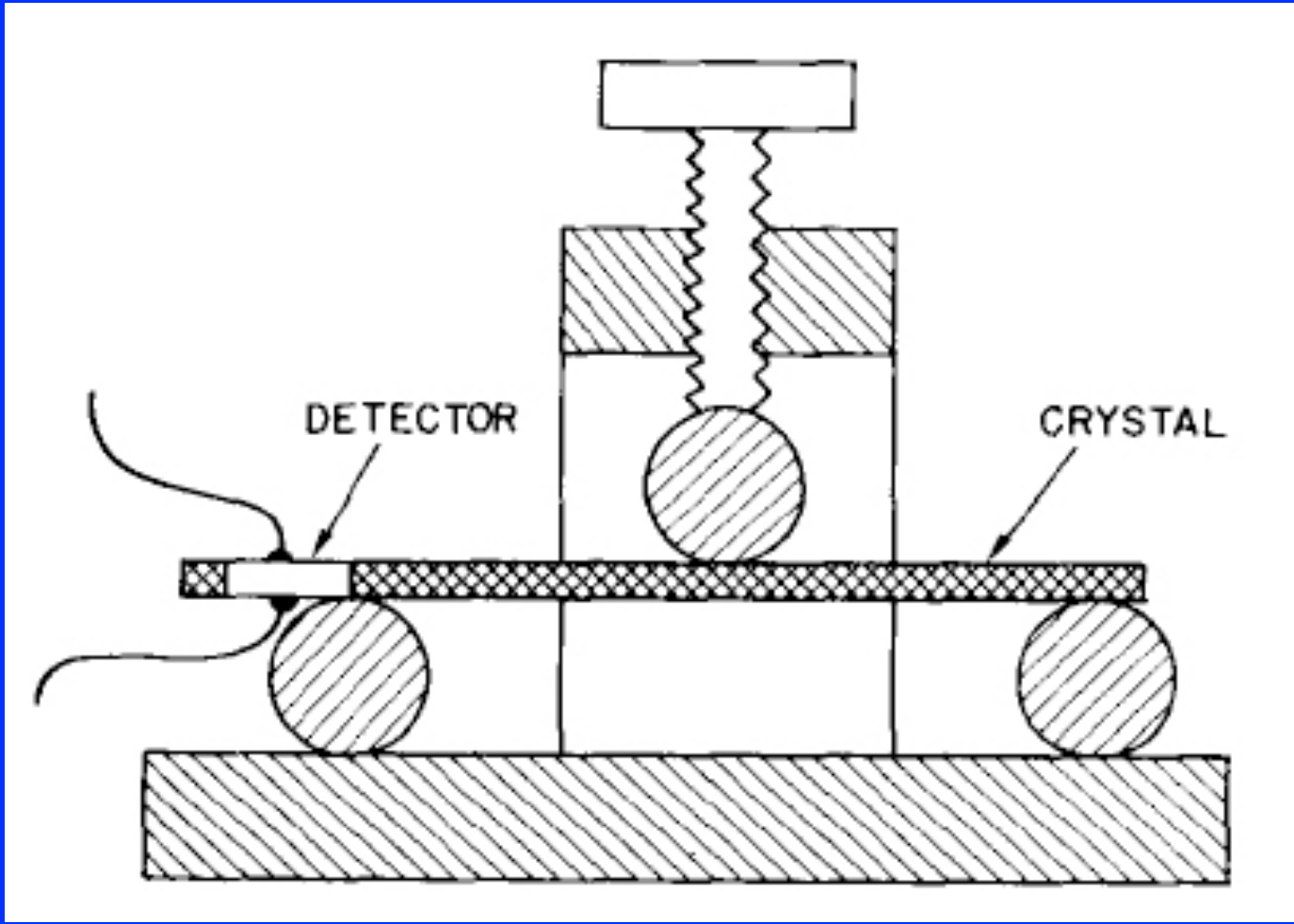
and

J.J. GROB and P. SIFFERT
Centre de Recherches Nucléaires, Strasbourg, France

Received 3 April 1980

A very strong and dramatic bending effect has been found for 12 GeV/*c* positive particles channeled along crystal axes and planes. For a combination of axial and planar channeling the bending efficiency is 5--10%. The maximum bending angle was 52 mrad obtained over a 20 mm long ⟨111⟩ Si-crystal. The axial channeling is also able to bend negative particles.

Bending device at CERN



Scatter plots

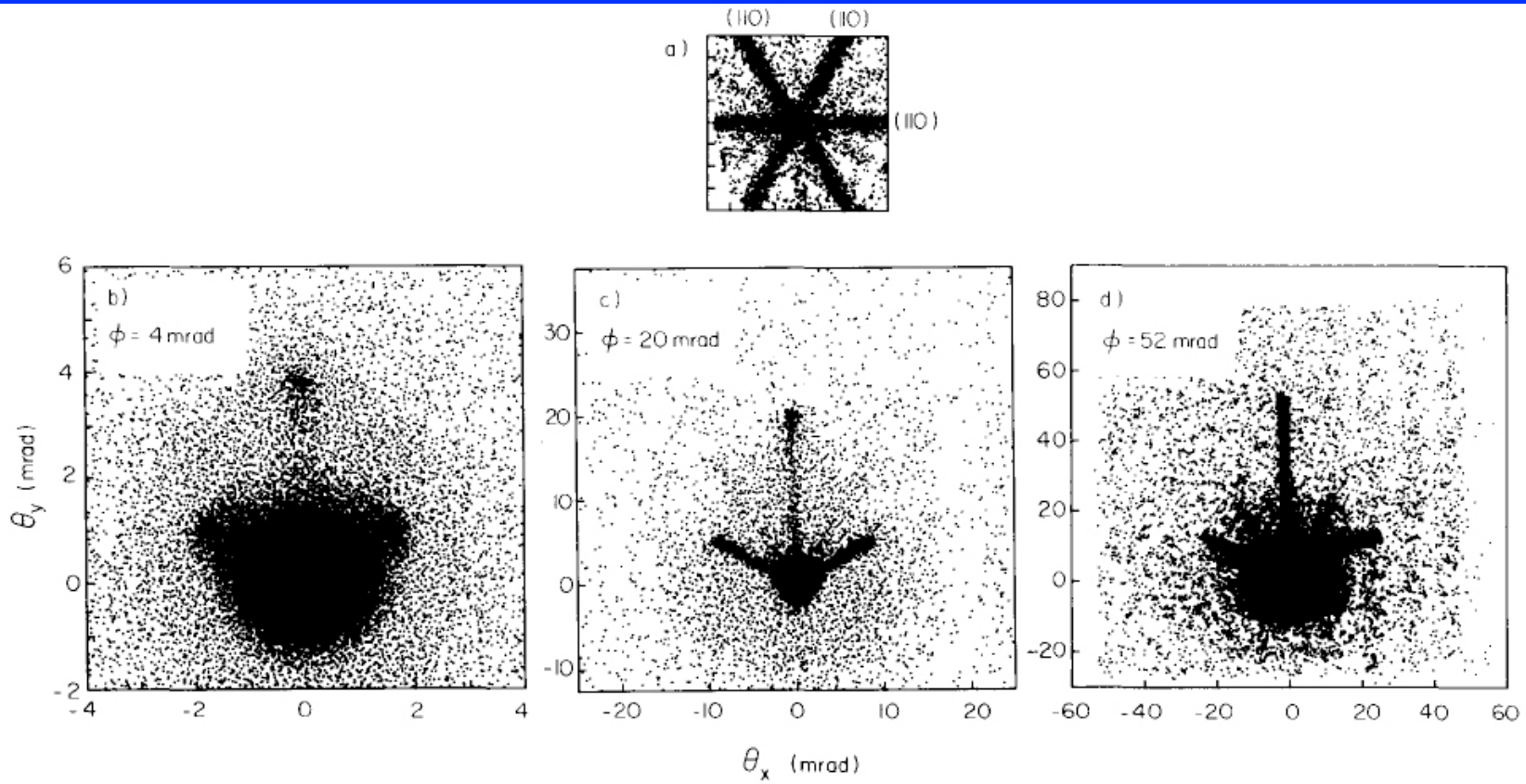
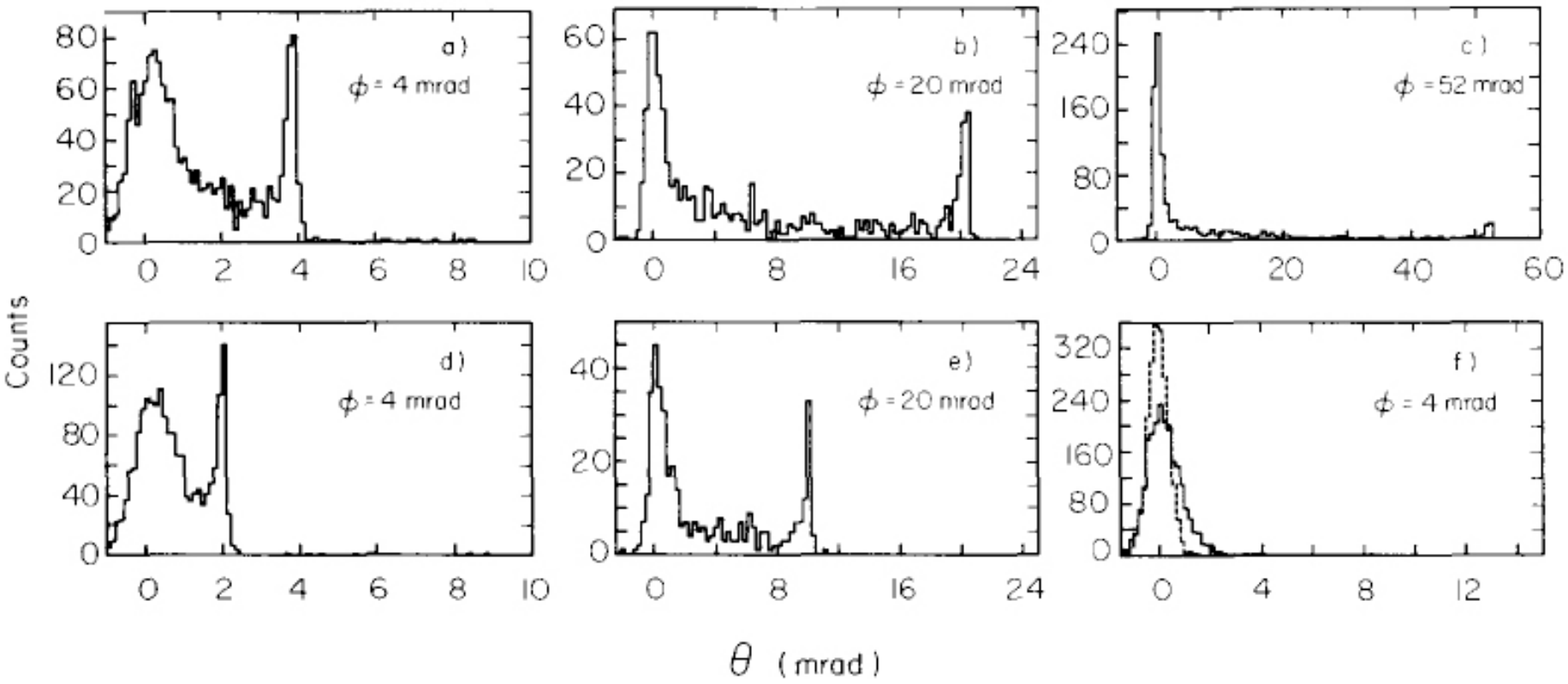


Fig. 2. (a) Normalized intensity distribution in incident angle space of positive projectiles with small energy loss, showing the (110)-planes and the ⟨111⟩-axis; (b)–(d) Two-dimensional intensity distribution of scattering angles, for a bending of 4 mrad, 20 mrad and 52 mrad, respectively.

First bending results at CERN



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

European Laboratory for Particle Physics

CERN - SL DIVISION

CERN SL/94-26 (EA)

DEFLECTION OF HIGH ENERGY BEAMS BY CHANNELING IN BENT SILICON CRYSTALS

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Abstract

Experimental results on the deflection of a high energy positive beam by means of planar and axial channeling in a bent silicon crystal are presented. The primary 450 GeV/c H8 proton "microbeam" in the CERN SPS North Area as well as secondary 200 GeV/c positive hadrons in the H8 beamline were used in the present investigations. A silicon crystal was bent to deflect the beam horizontally in a classical 3-point bender. Deflection efficiencies of up to 50 % were observed for planar (111) channeling at 450 GeV/c, in agreement with theoretical calculations.

Paper presented at the Fourth European Particle Accelerator Conference (EPAC'94),
London, United Kingdom, 27.6.-1.7.1994

Experimental set-up

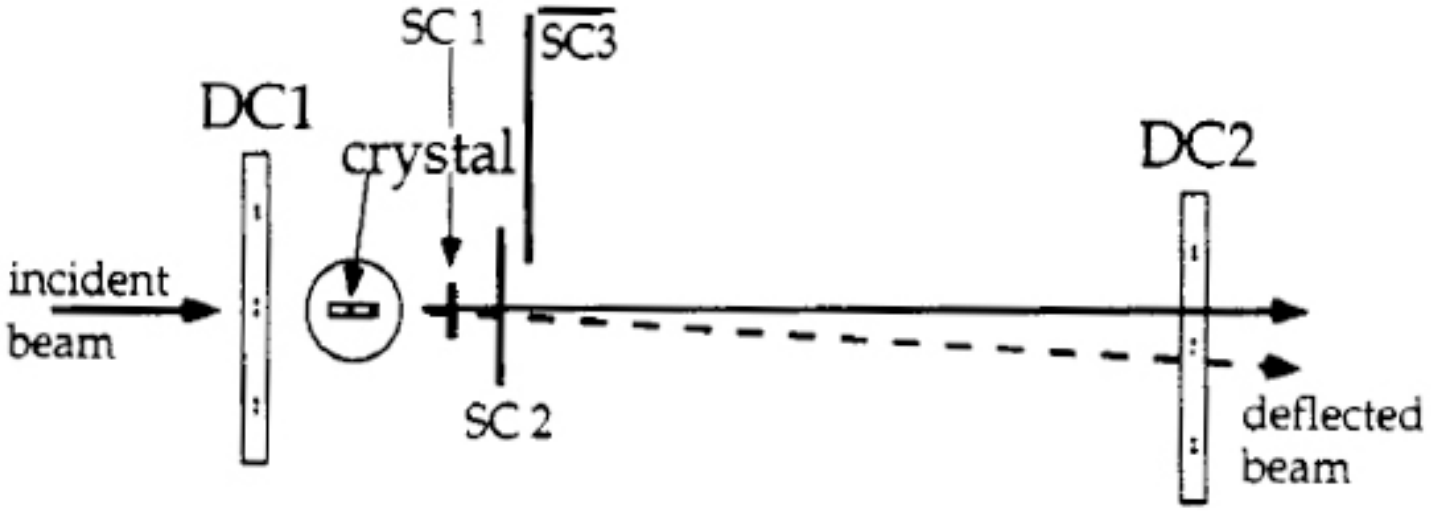
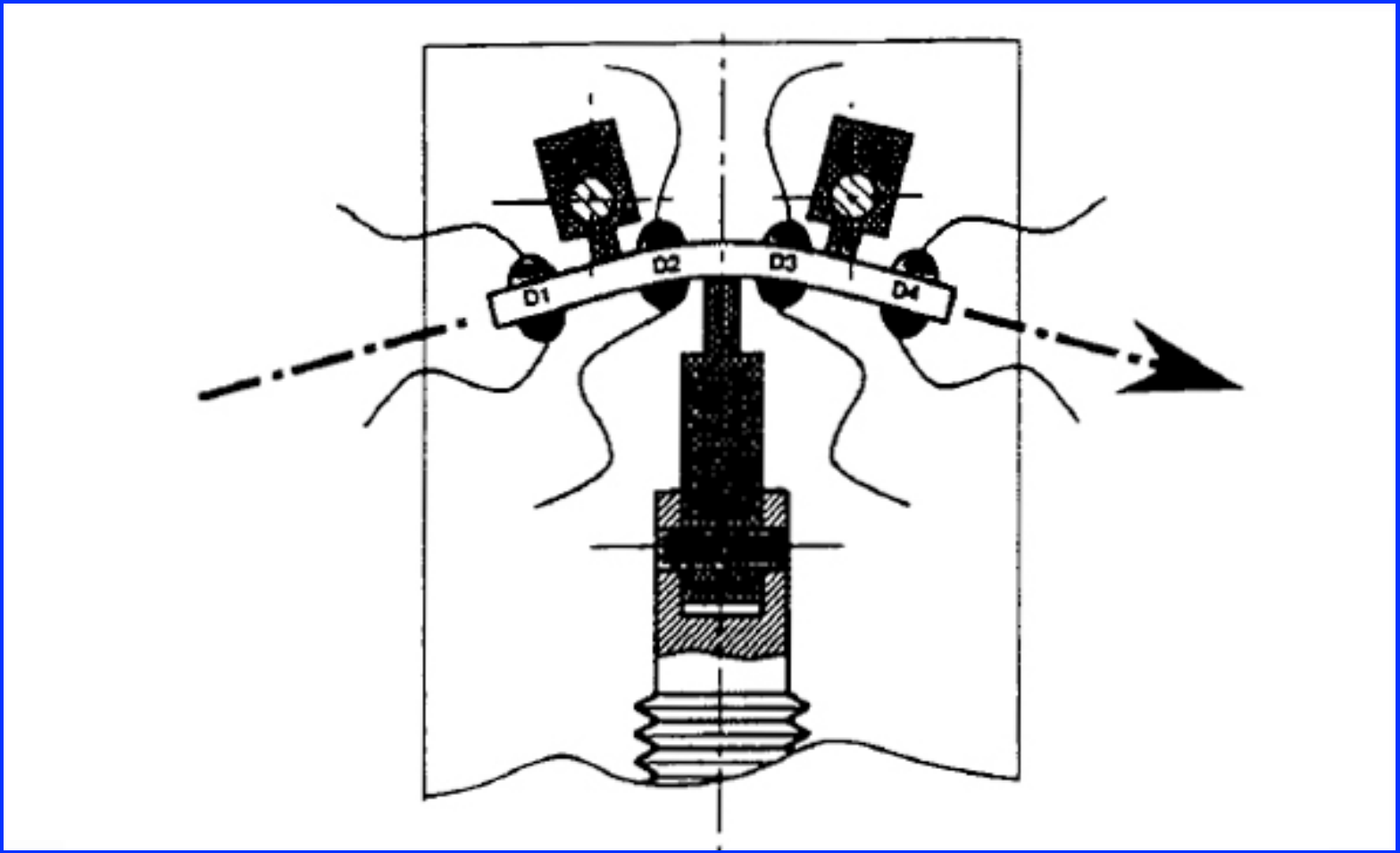


Figure. 1: Schematic view of the experimental set-up for the bent crystal experiment. Two driftchambers (DC) are used to track the protons. The scintillation counters SC1,2, serve as trigger counters, SC3 is a veto counter.

Bending device



Deflection 200 GeV AND 450 GeV proton beams

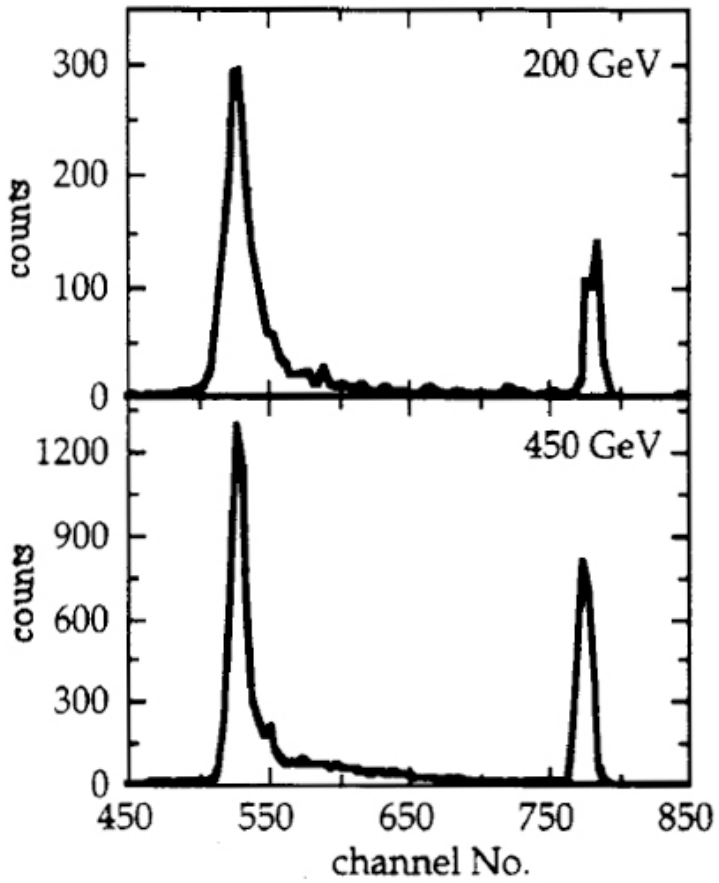


Figure 5: Comparison of 200 GeV/c and 450 GeV/c data on planar bending of positive particles. The horizontal profiles recorded in DC2 are shown. The peak on the right represents particles deflected by 3 mrad.

First extraction from SPS

Physics Letters B 313 (1993) 491–497
North-Holland

PHYSICS LETTERS B

First results on proton extraction from the CERN-SPS with a bent crystal

H. Akbari [b], X. Altuna [b], S. Bardin [b,1], R. Bellazzini [f], V. Biryukov [b,2], A. Brez [f], M.P. Bussa [h], L. Busso [h], A. Calcaterra [d], G. Carboni [f], F. Costantini [f], R. De Sangro [d], K. Elsener [b], F. Ferioli [b], A. Ferrari [b], G.P. Ferri [b], F. Ferroni [g], G. Fidecaro [b], A. Freund [c], R. Guinand [b], M. Gyr [b], W. Herr [b], A. Hilaire [b], B.N. Jensen [a], J. Klem [b], L. Lanceri [i], K. Maier [j], M.M. Massai [f], V. Mertens [b], S.P. Møller [a], S. Morganti [g], O. Palamara [e], S. Peraire [b], S. Petrera [e], M. Placidi [b], R. Santacesaria [g], W. Scandale [b], R. Schmidt [b], A.M. Taratin [b,3], F. Tosello [h], E. Uggerhøj [a,b], B. Vettermann [b,4], P.F. Vita [f], G. Vuagnin [i], E. Weisse [b] and S. Weisz [b]

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[c] *ESRF, Grenoble, France*
[d] *Laboratori Nazionali di Frascati, Frascati, Italy*
[e] *Università di Lecce and INFN, Lecce, Italy*
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Received 30 June 1993

Extraction from SPS

ELSEVIER

Nuclear Instruments and Methods in Physics Research B 119 (1996) 215-230

NIM B
Beam Interactions with Materials & Atoms

Proton extraction from the CERN SPS using bent silicon crystals ★

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Received 25 October 1995; revised form received 8 March 1996

Abstract

The extraction of high energy particles from a circular accelerator by means of channeling in bent crystals is an attractive alternative to classical extraction schemes, in particular for high energy proton colliders where a classical scheme becomes expensive and incompatible with normal operation. This paper reviews the ongoing extraction experiments at the CERN-SPS with bent silicon crystals. It describes the principles of beam extraction by means of a bent crystal and the different extraction schemes used: first- and multi-pass extraction and the methods to create diffusion. The limitations in tuning the accelerator to the desired impact parameters and crucial items concerning crystal preparation, bending and pre-alignment are discussed. The experimental procedures including an overview of the detection of circulating and extracted beam are given. Finally, the paper summarizes the results of these experiments together with ideas for future developments.

Extraction scheme

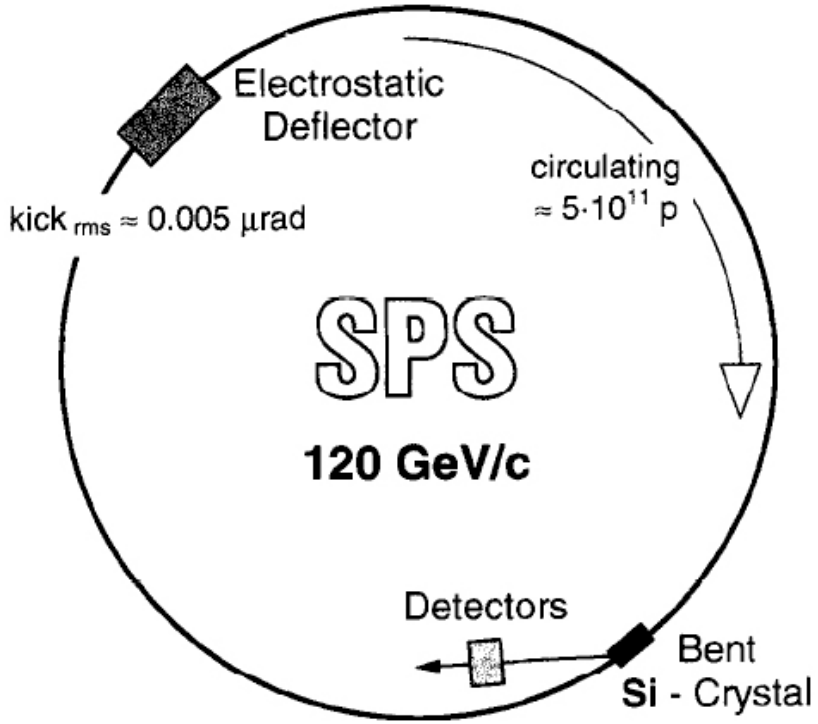


Fig. 5. The principle of the SPS extraction experiments with a bent crystal.

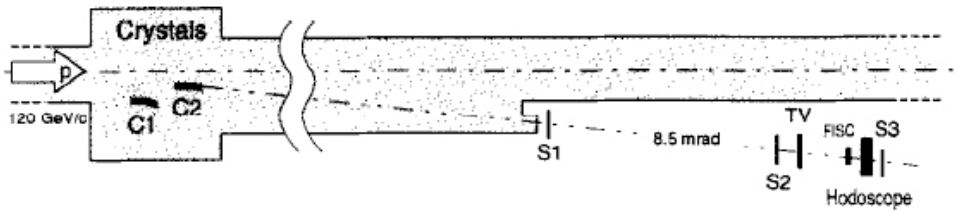
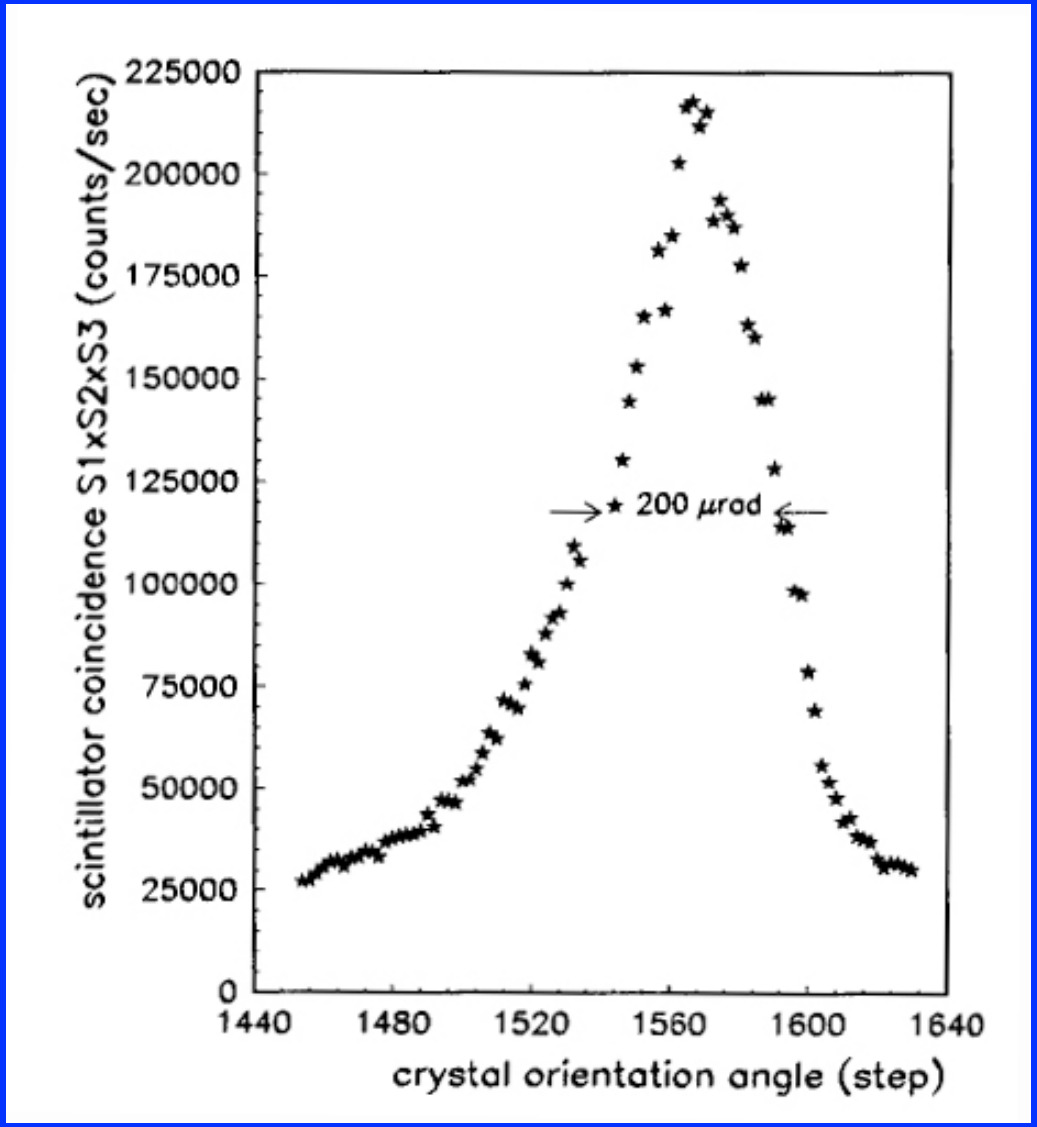
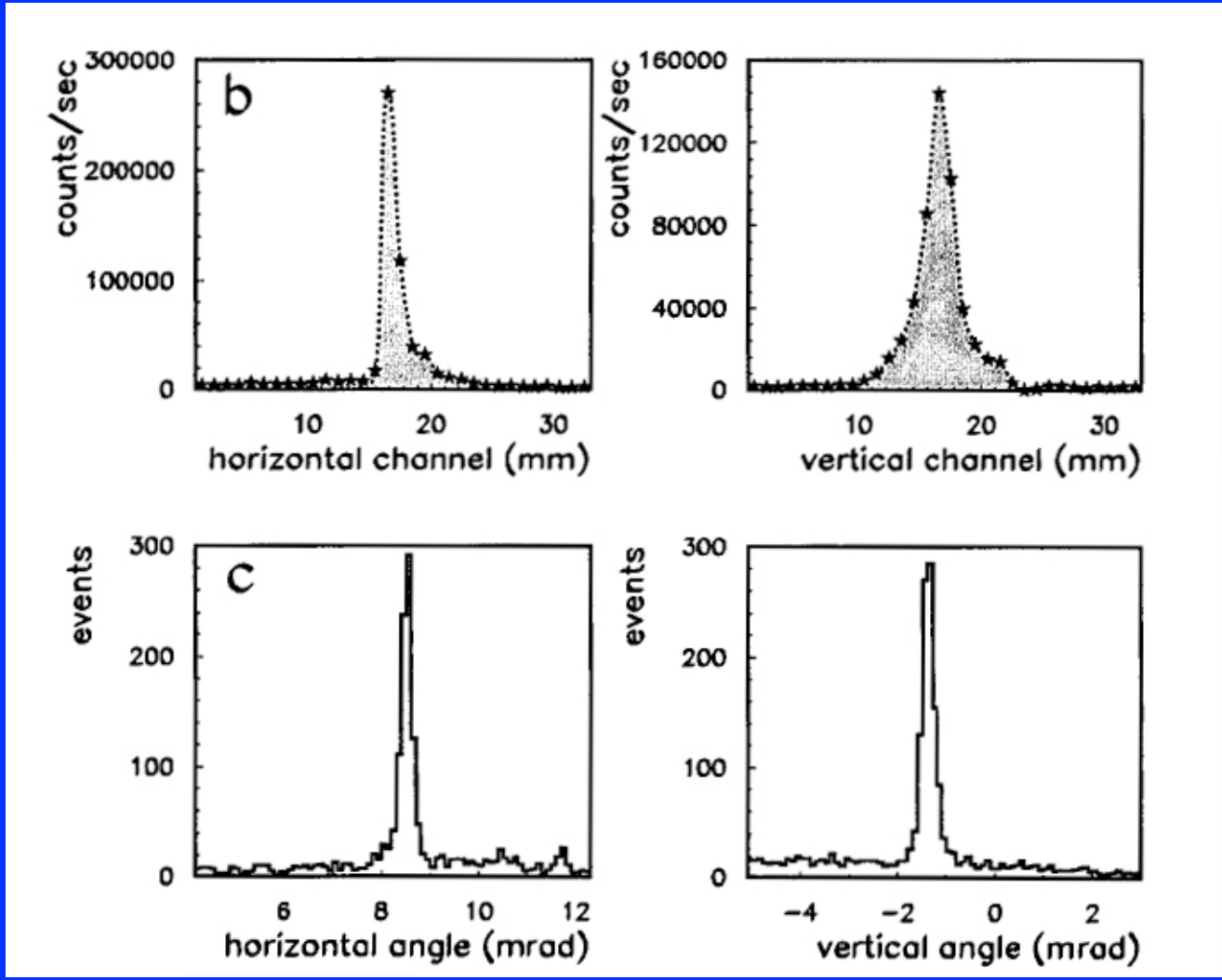


Fig. 6. Schematic view of the crystal and detector arrangement to measure the extracted proton beam at the SPS.

Angular scan at firs extraction from SPS



Extracted 120 GeV beam parameters



Extraction efficiency

Table 1
Results obtained during the first measurements using crystals a shown in Fig. 8

	Crystal 1	Crystal 2
Beam intensity [protons]	$(7.0 \pm 0.1) \times 10^{11}$	$(3.7 \pm 0.1) \times 10^{11}$
Beam lifetime [hrs]	20 ± 2	12 ± 1
Protons lost [s^{-1}]	$(6.7 \pm 0.6) \times 10^{6}$	$(8.9 \pm 0.7) \times 10^{6}$
Protons detected [s^{-1}]	5.6×10^{5}	6.6×10^{5}
Background [%]	5	2
Detection efficiency [%]	78 ± 12	78 ± 12
Extraction efficiency [%]	10.2 ± 1.7	9.3 ± 1.6

VOLUME 79, NUMBER 21 PHYSICAL REVIEW LETTERS 24 NOVEMBER 1997

Deflection and Extraction of Pb Ions up to 33 TeV/c by a Bent Silicon Crystal

G. Arduini, C. Biino, M. Clément, K. Cornelis, N. Doble, K. Elsener, G. Ferioli, G. Fidecaro, L. Gatignon, P. Grafström, M. Gyr, W. Herr, J. Klem,* U. Mikkelsen,† and E. Weisse
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(Received 15 July 1997)

The first results from an experiment to deflect a beam of fully stripped, ultrarelativistic Pb^{82+} ions of 400 GeV/c per unit of charge, equivalent to 33 TeV/c, by means of a bent crystal are reported. Deflection efficiencies are as high as 14%, in agreement with theoretical estimates. In a second experiment a bent crystal was used to extract 270 GeV/c-per-charge Pb^{82+} (22 TeV/c) ions from a coasting beam in the CERN-SPS, and a high extraction efficiency of up to 10% was found. These represent the first measurements to demonstrate applications of bent crystals in high energy heavy ion beams. [S0031-9007(97)04627-9]

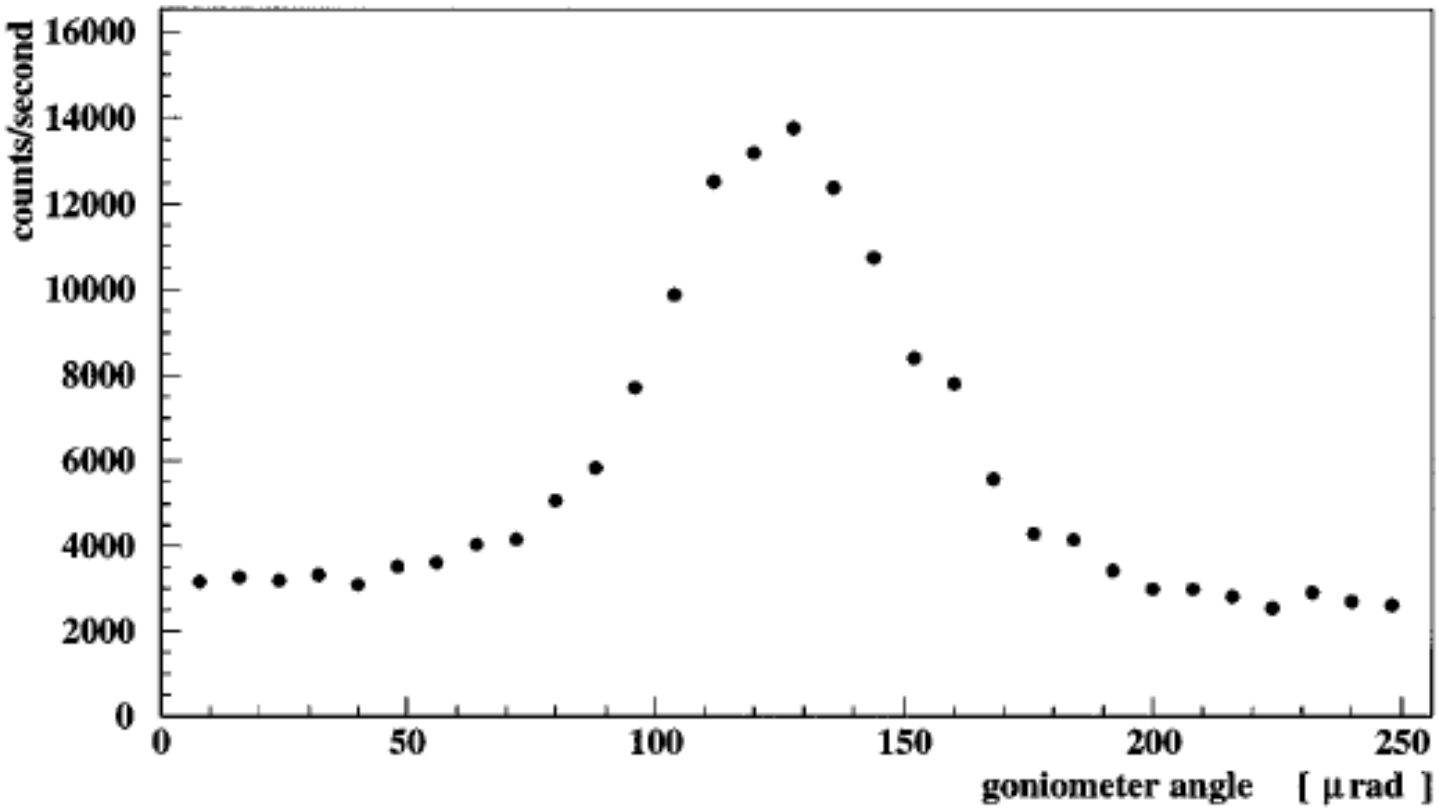

FIG. 5. Angular scan for extracted Pb ions from a stored SPS beam, 270 GeV/c per charge (22 TeV/c).

Beam deflection by bent crystal at Fermilab

54

Nuclear Instruments and Methods in Physics Research B2 (1984) 54–59
North-Holland, Amsterdam

DEFLECTION OF HIGH ENERGY CHANNELED CHARGED PARTICLES BY ELASTICALLY BENT SILICON SINGLE CRYSTALS *

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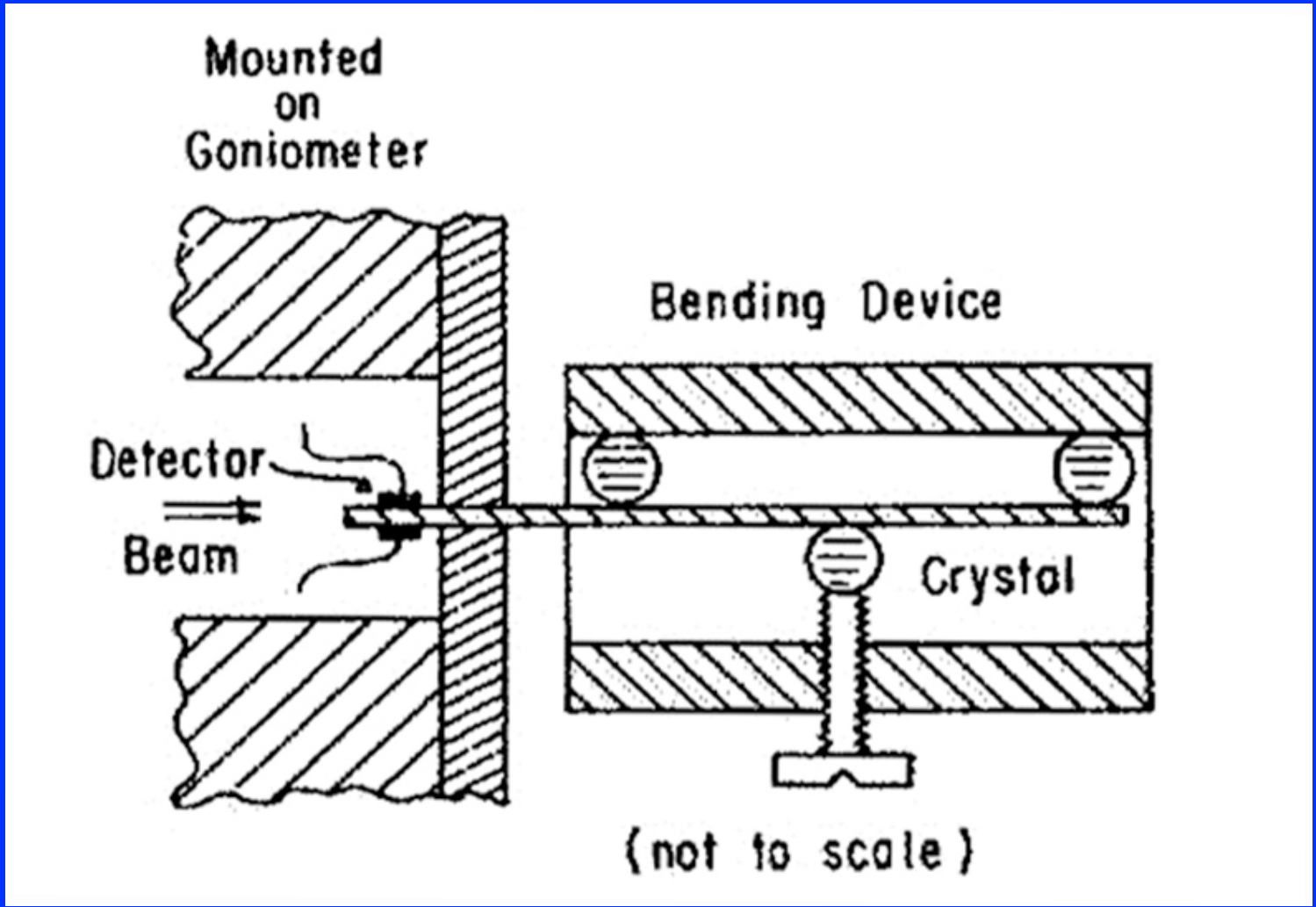
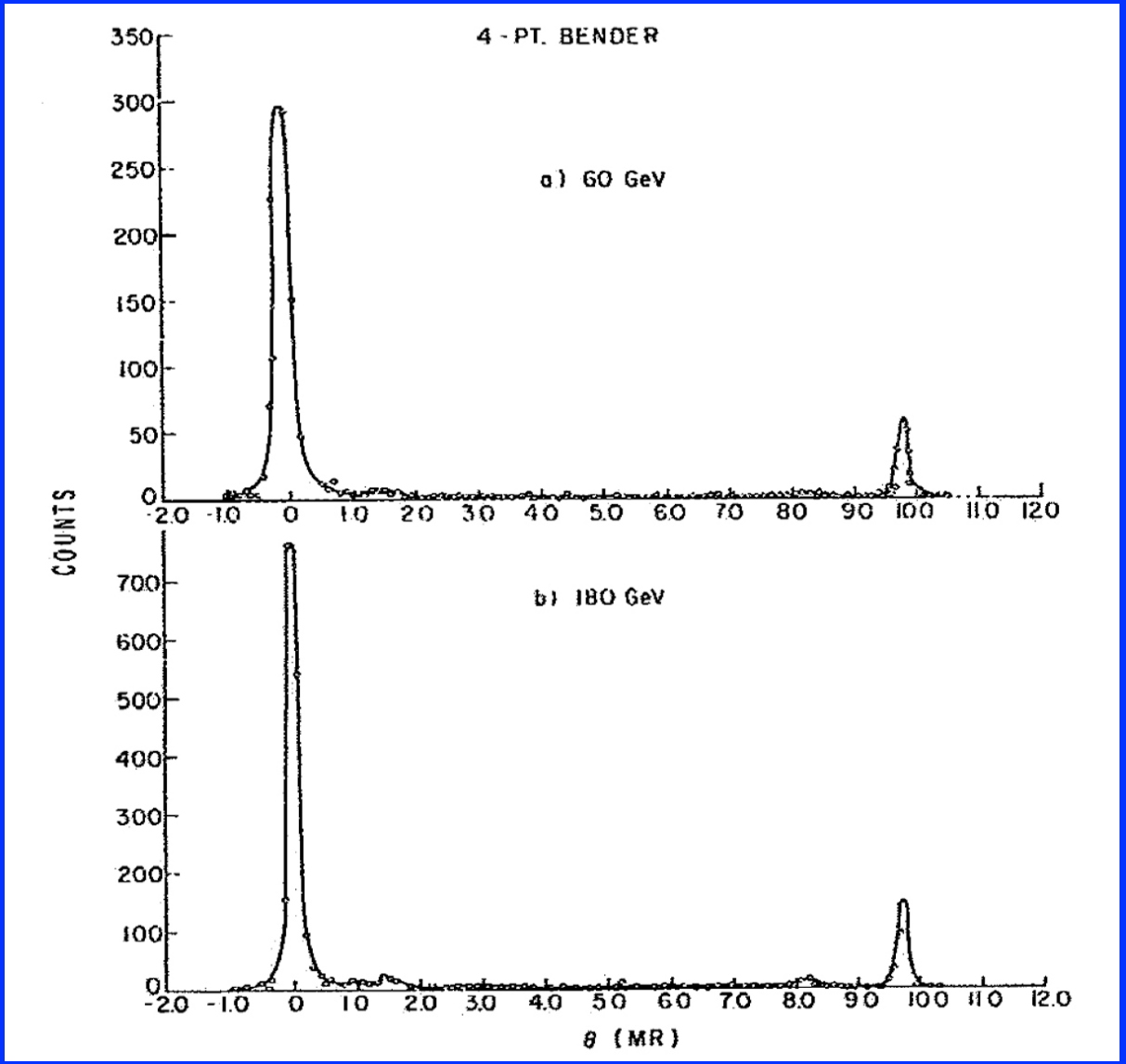
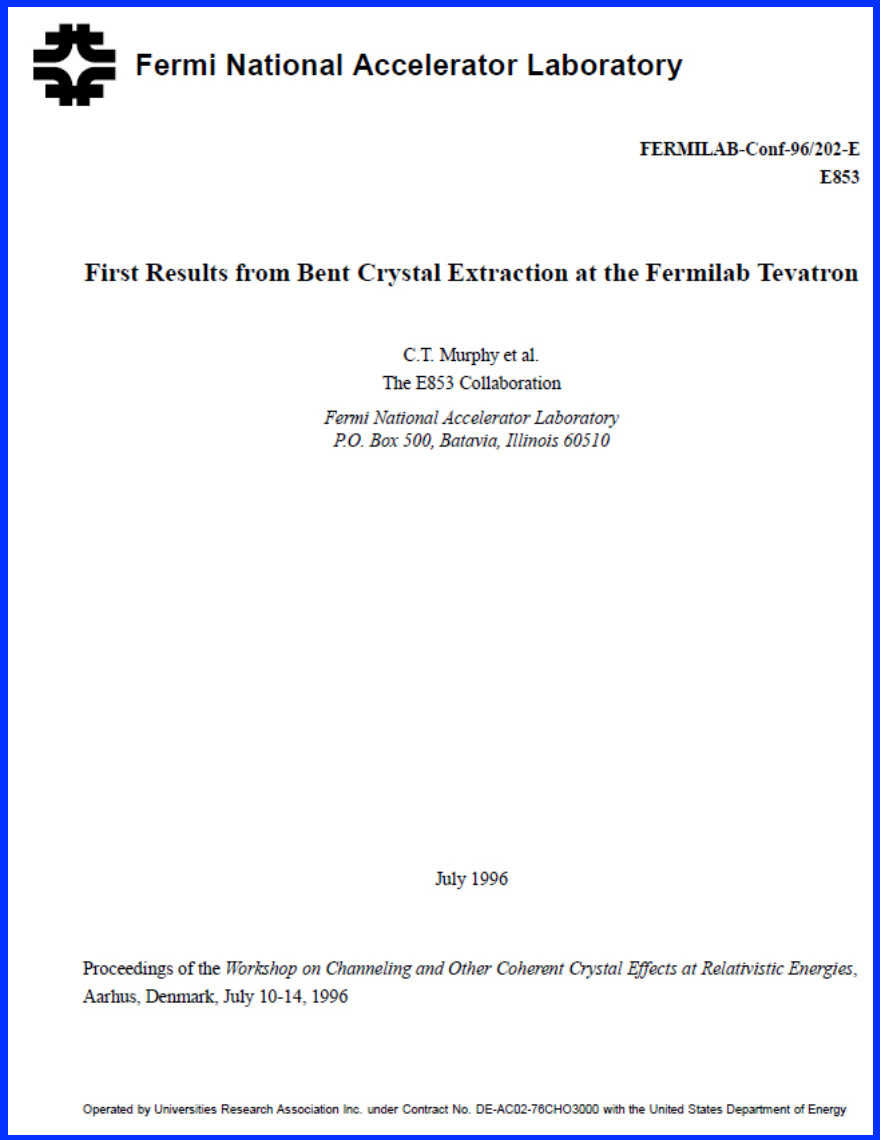
Three point bending device



Results with four point bending device



Fermilab beam extraction using bent crystal



Fermi National Accelerator Laboratory

FERMILAB-Conf-96/202-E
E853

First Results from Bent Crystal Extraction at the Fermilab Tevatron

C.T. Murphy et al.
The E853 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

July 1996

Proceedings of the *Workshop on Channeling and Other Coherent Crystal Effects at Relativistic Energies*, Aarhus, Denmark, July 10-14, 1996

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PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **1**, 022801 (1998)

First observation of luminosity-driven extraction using channeling with a bent crystal

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(Received 2 September 1997; published 26 June 1998)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **5**, 043501 (2002)

Beam extraction studies at 900 GeV using a channeling crystal

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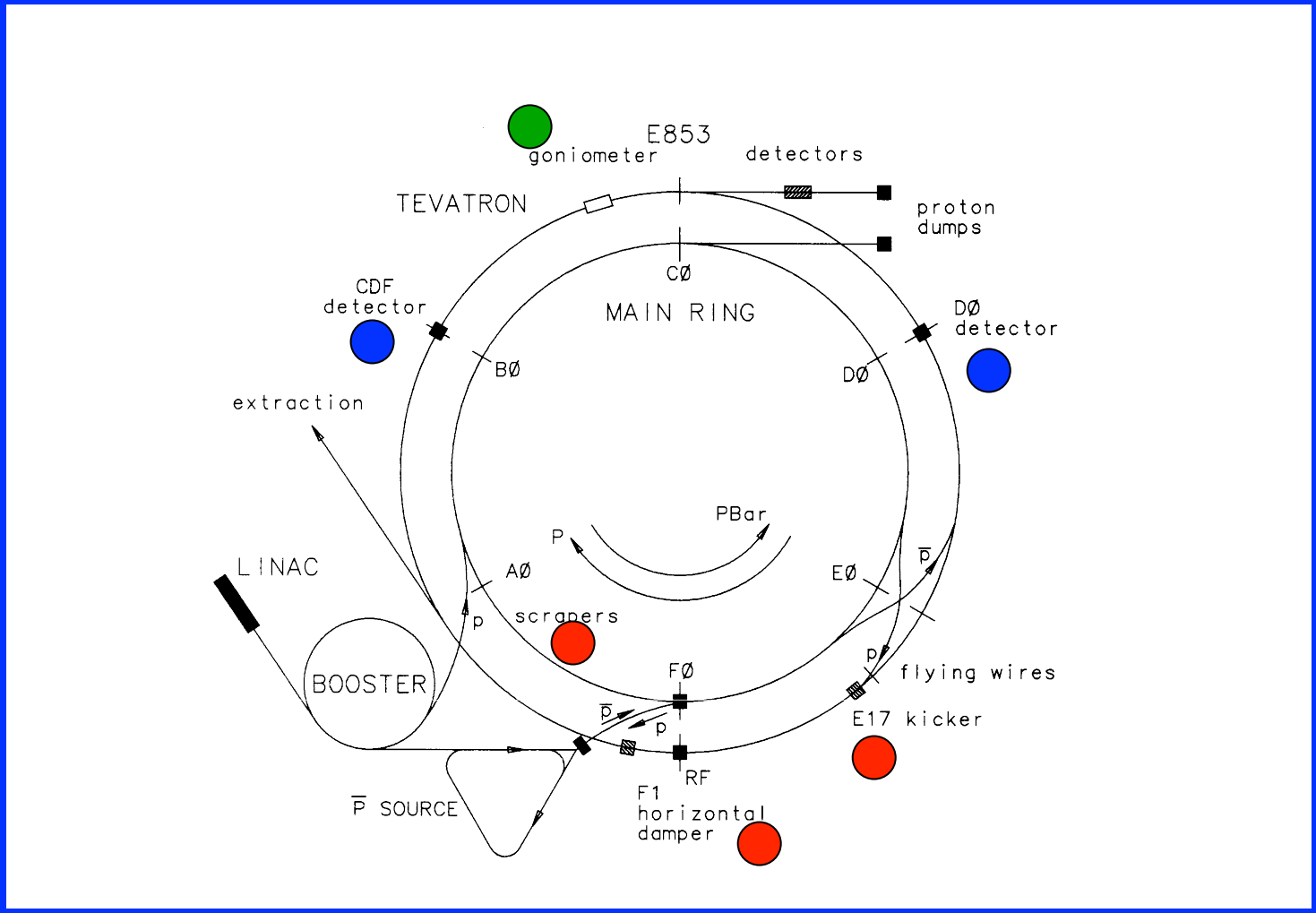
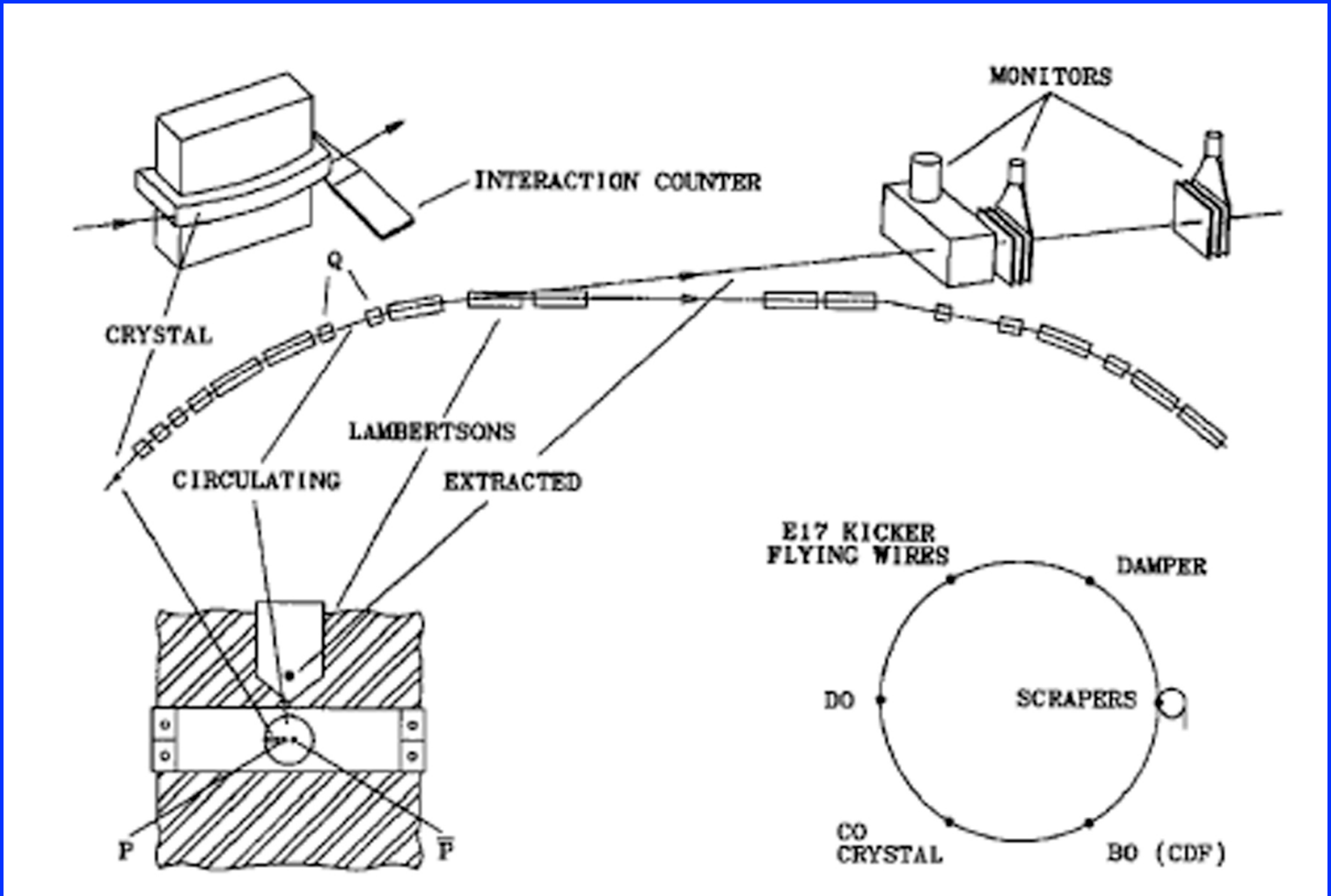
(Received 4 October 1999; revised manuscript received 26 February 2002; published 30 April 2002)

Luminosity-driven channeling extraction has been observed for the first time in a 900 GeV study at the Fermilab Tevatron. This experiment, Fermilab E853, demonstrated that useful TeV level beams can be extracted from a superconducting accelerator during high luminosity collider operations without unduly affecting the background at the collider detectors. Multipass extraction was found to increase the efficiency of the process significantly. The beam extraction efficiency was about 25%. Studies of time dependent effects found that the turn-to-turn structure was governed mainly by accelerator beam dynamics. Based on the results of this experiment, it is feasible to construct a parasitic 5–10 MHz proton beam from the Tevatron collider.

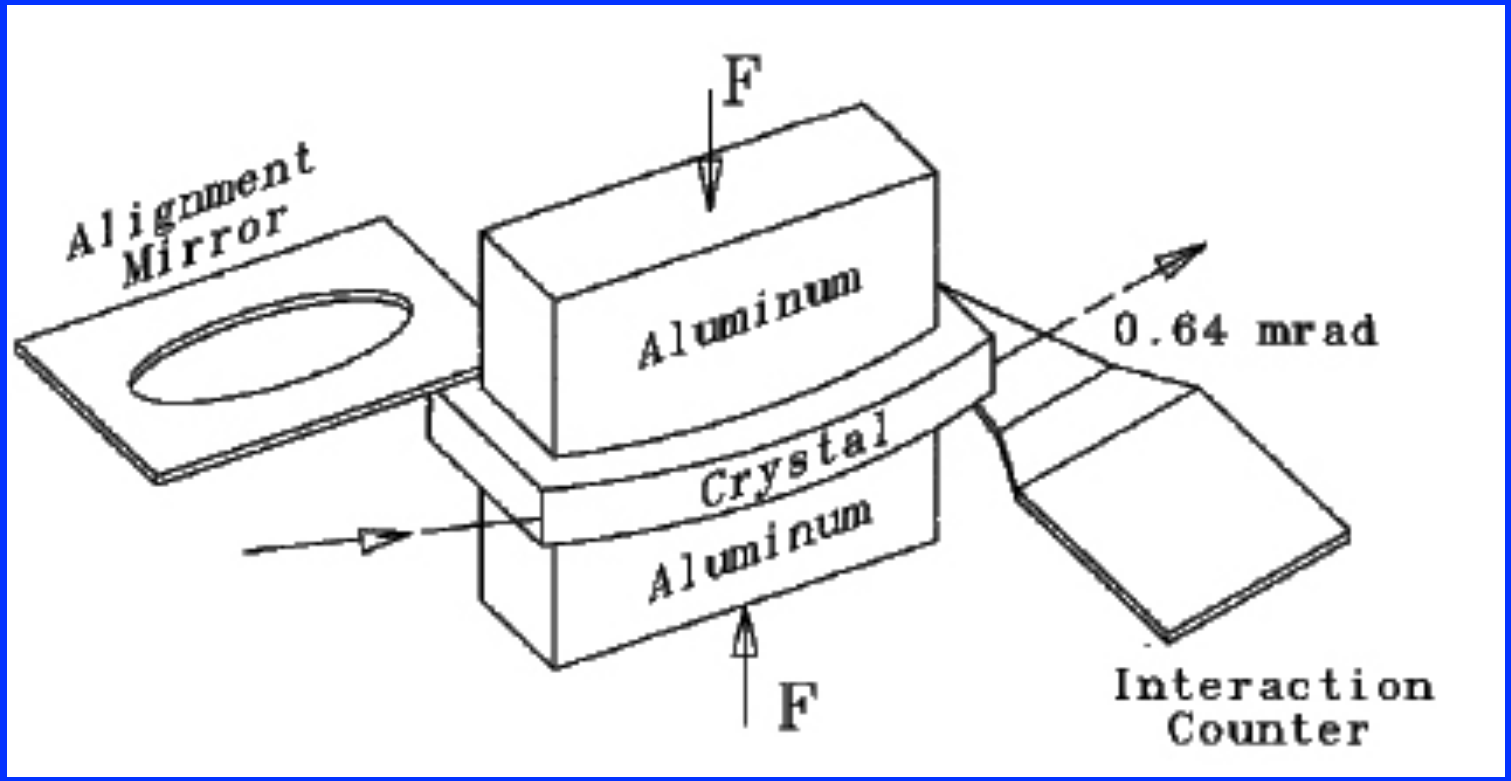
Fermilab beam extraction schematics



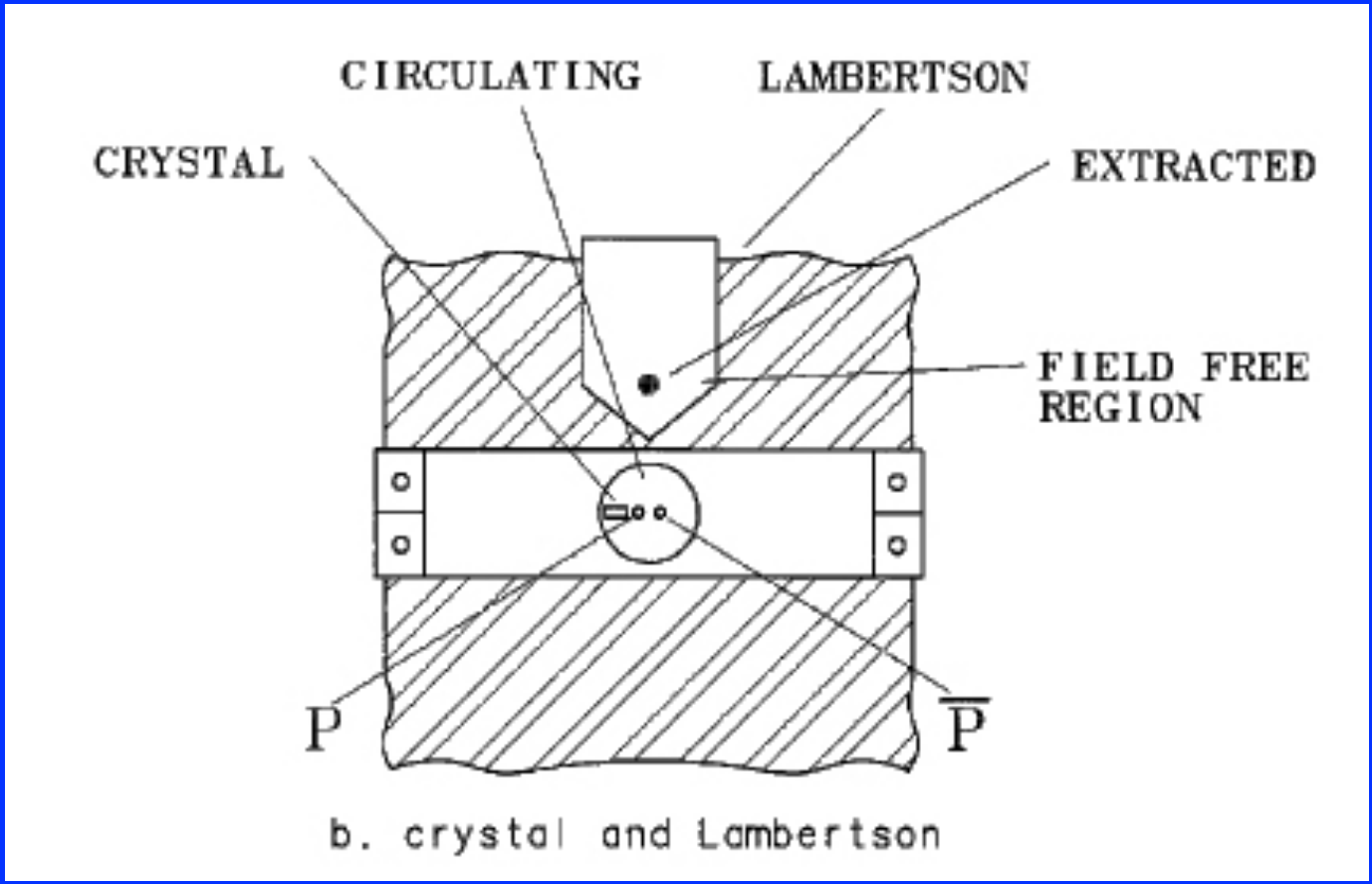
Fermilab beam extraction schematics



Bent crystal at Fermilab beam extraction

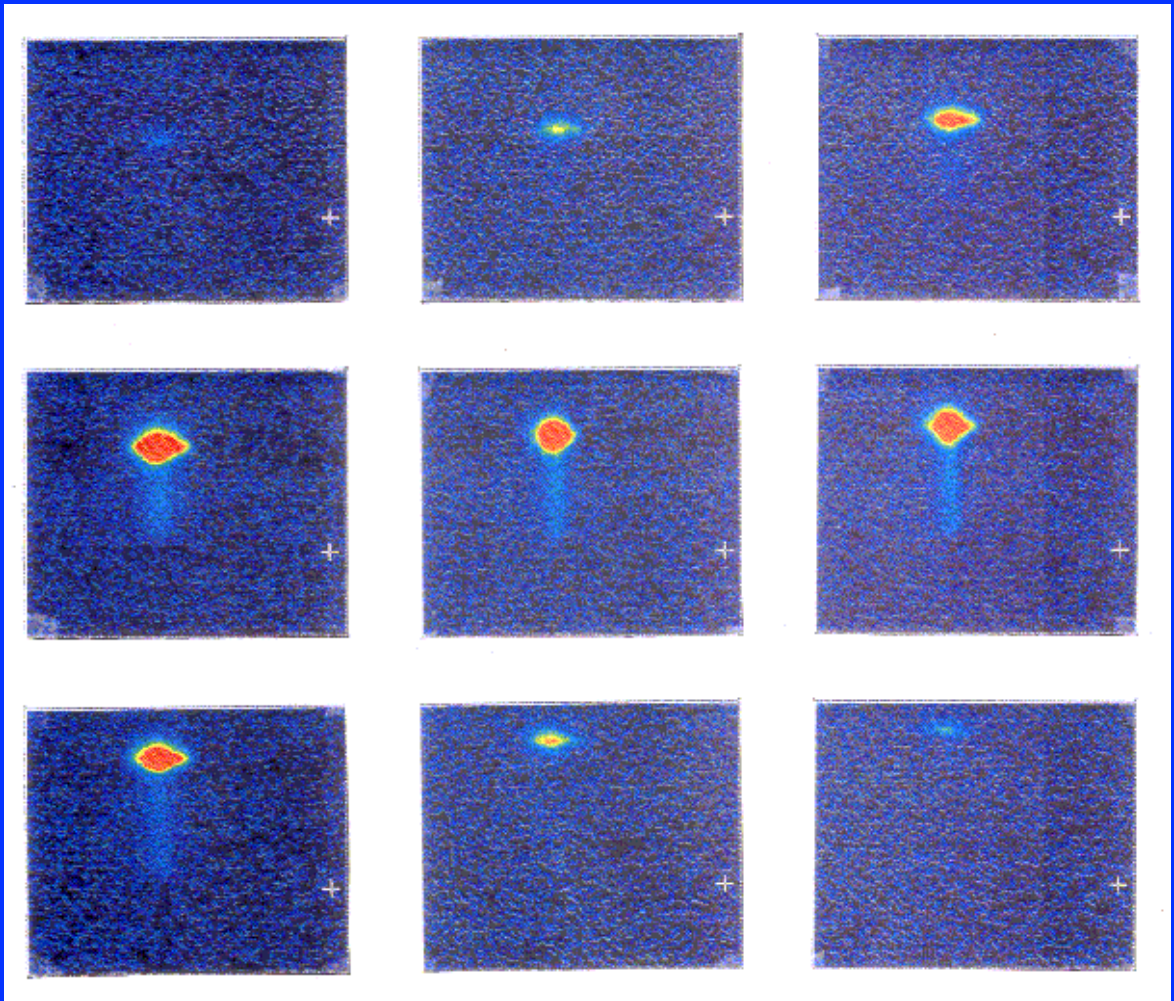


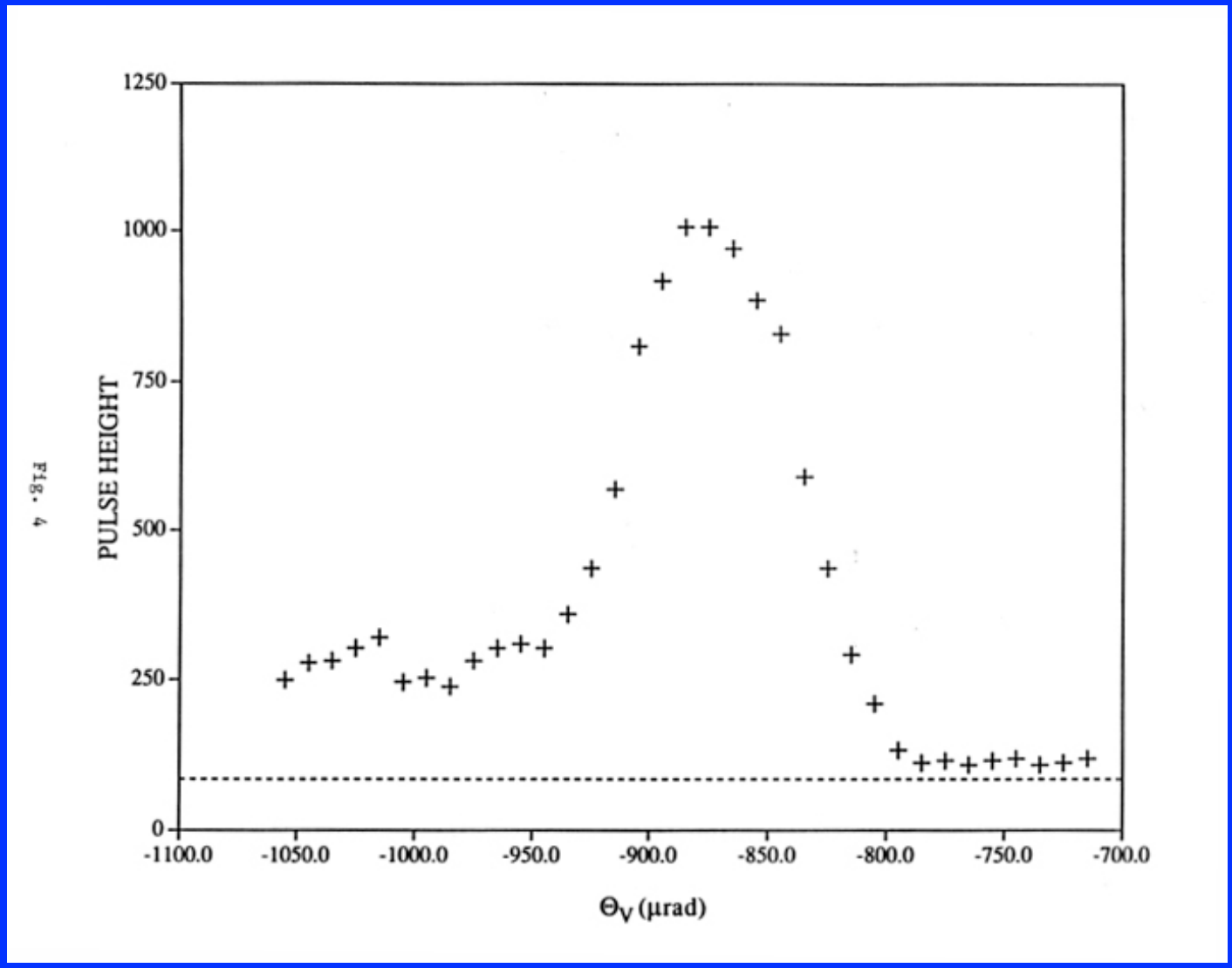
Lambertson



b. crystal and Lambertson

Very first results on beam extraction from Tevatron using bent crystal




1250
1000
750
500
250
0
PULSE HEIGHT
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-950.0
-900.0
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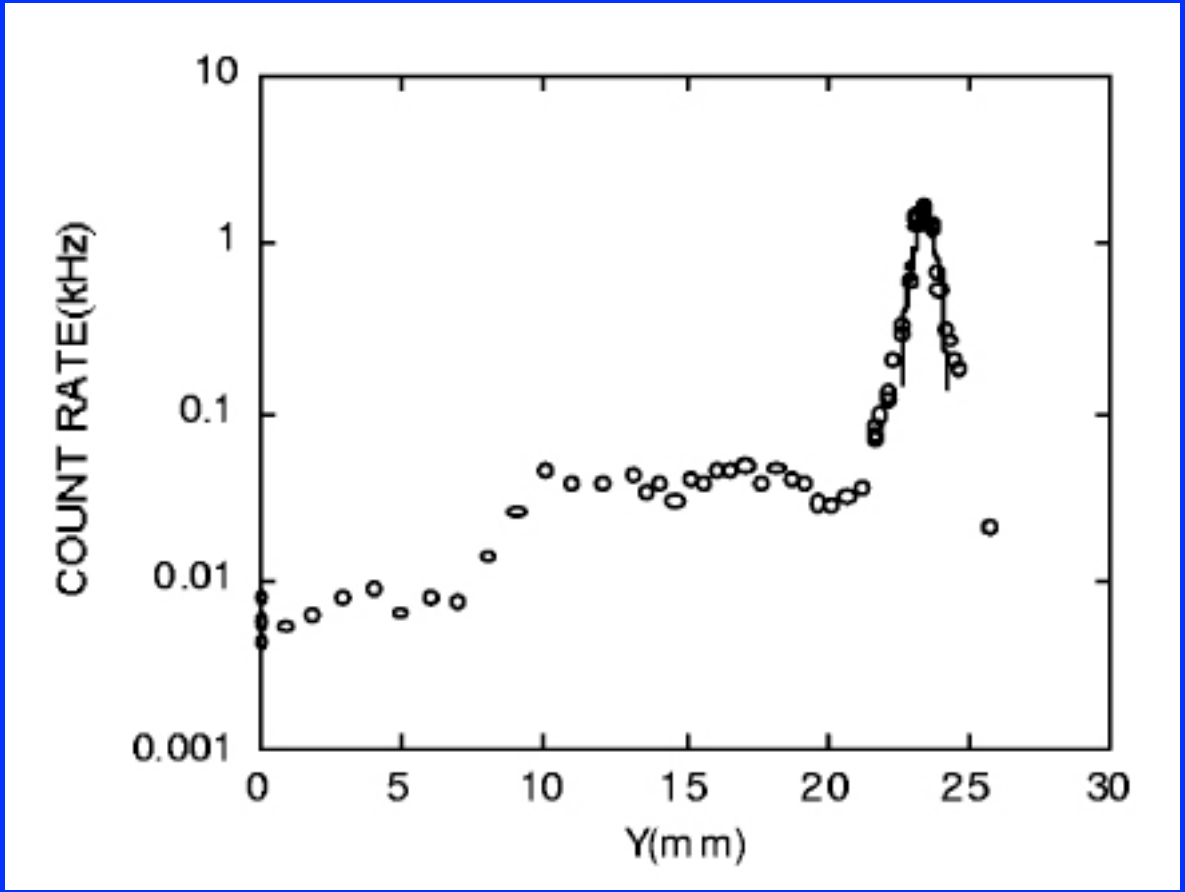
-800.0
-750.0
-700.0
Θv (μrad)


COUNT RATE(kHz)
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0.01
0.001
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5
10
15
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25
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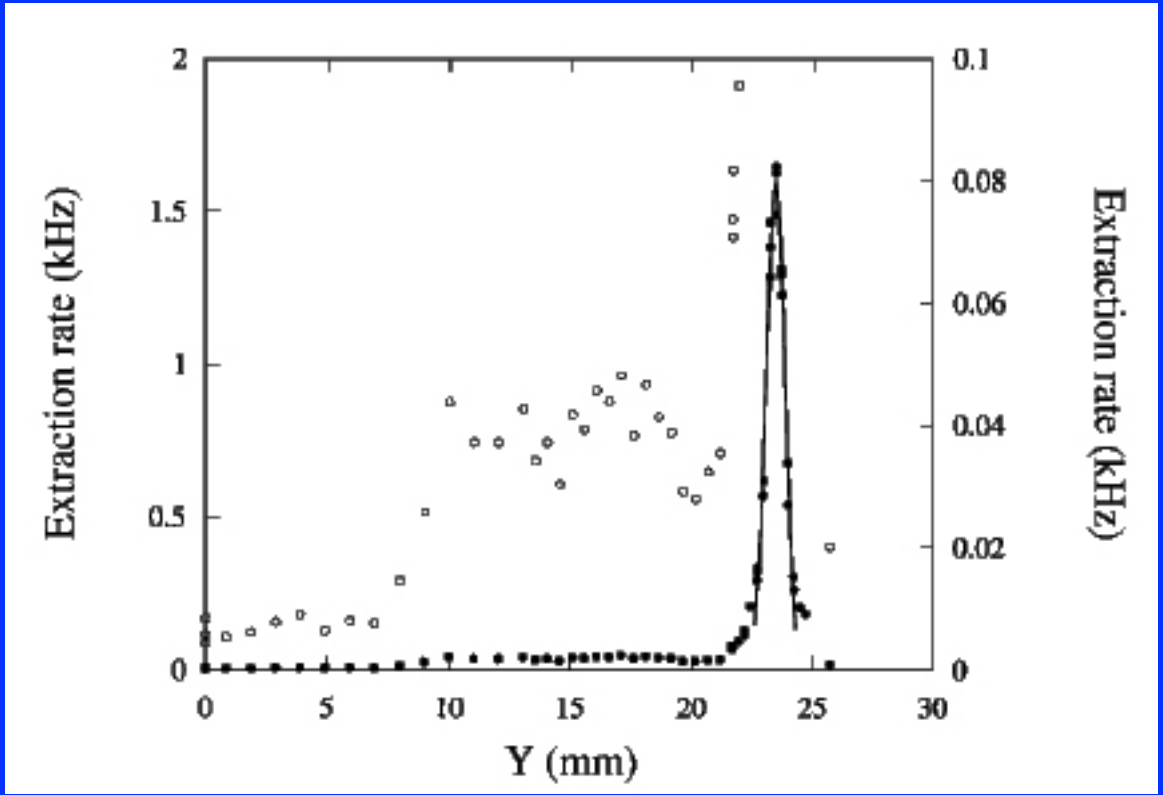
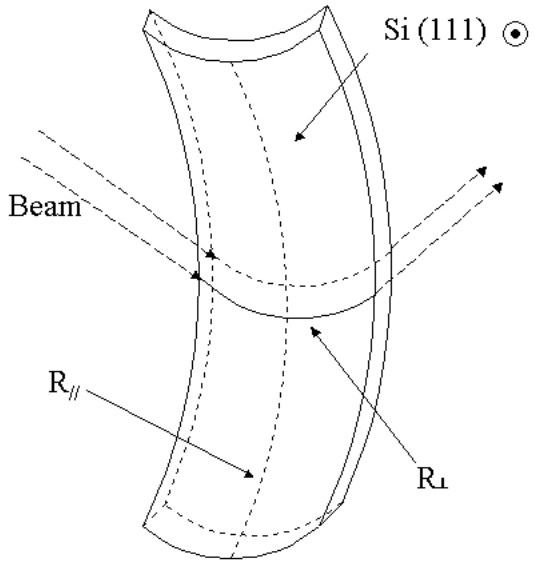
Y(mm)


Extraction rate (kHz)
Extraction rate (kHz)
Y (mm)
0
0.5
1
1.5
2
0.02
0.04
0.06
0.08
0.1
5
10
15
20
25
30

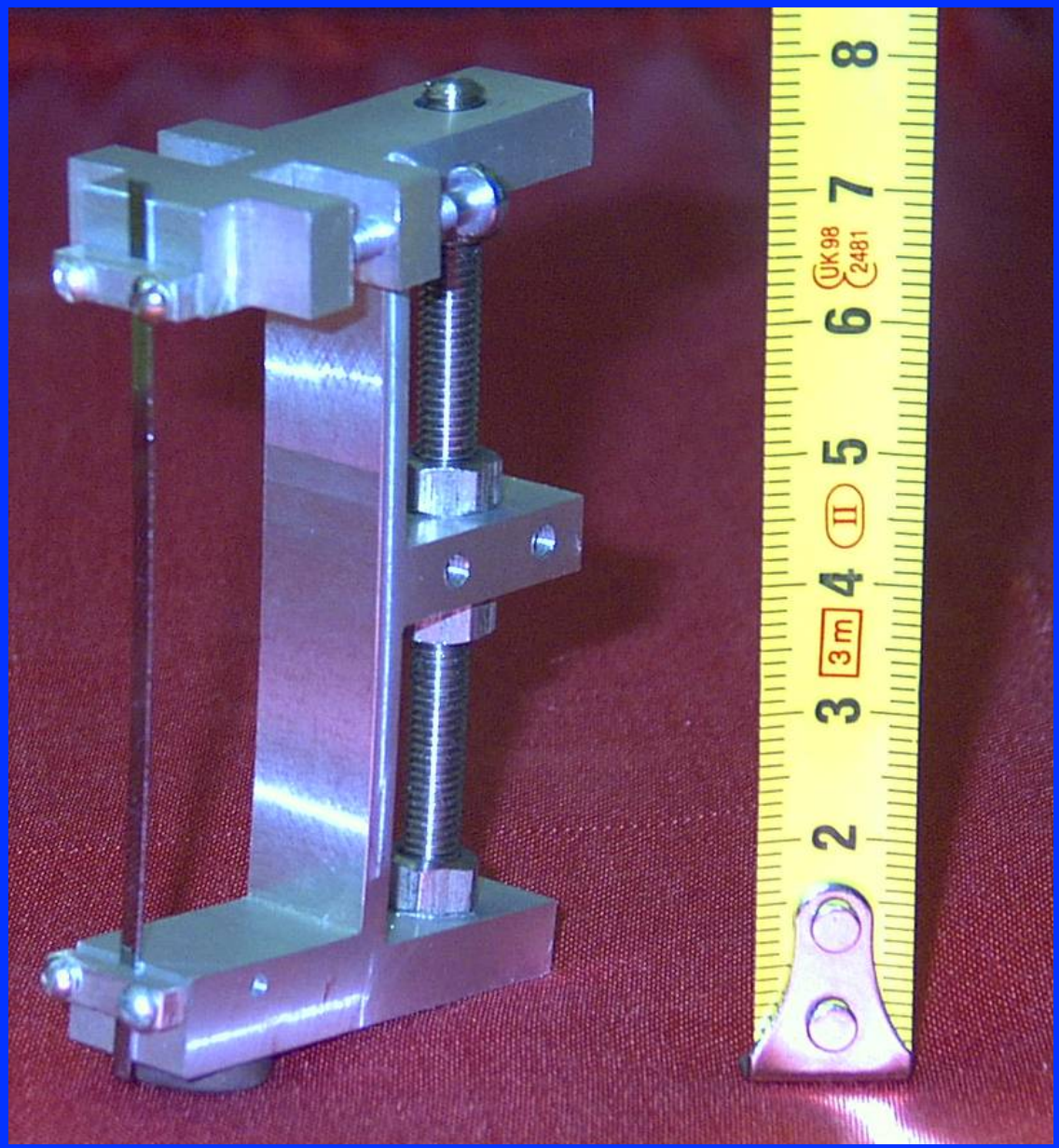
Extraction of the Proton Beam from the 70 GeV IHEP Accelerator.

A.G. Afonin*, V.T. Baranov*, V.M. Biryukov*,
Yu. M. Ivanov, A.A. Kardash*,V.I.Kotov*,**
V.A.Maisheev*, V.I.Terekhov*, E.F. Troyanov*,
Yu.S. Fedotov*, V.N. Chepegin*, Yu.A. Chesnokov*.

* IHEP, Protvino, Moscow reg., 142280 Russia
** INPh, Gatchina, St. Petersburg, 188350 Russia



Strip-shaped crystals, ~2 mm length along the beam and subjected to special chemical polishing, showed the best beam extraction efficiency: ~85%. A general view of the bending device, with a strip-shaped crystal, is shown in next figure


8
7
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2481
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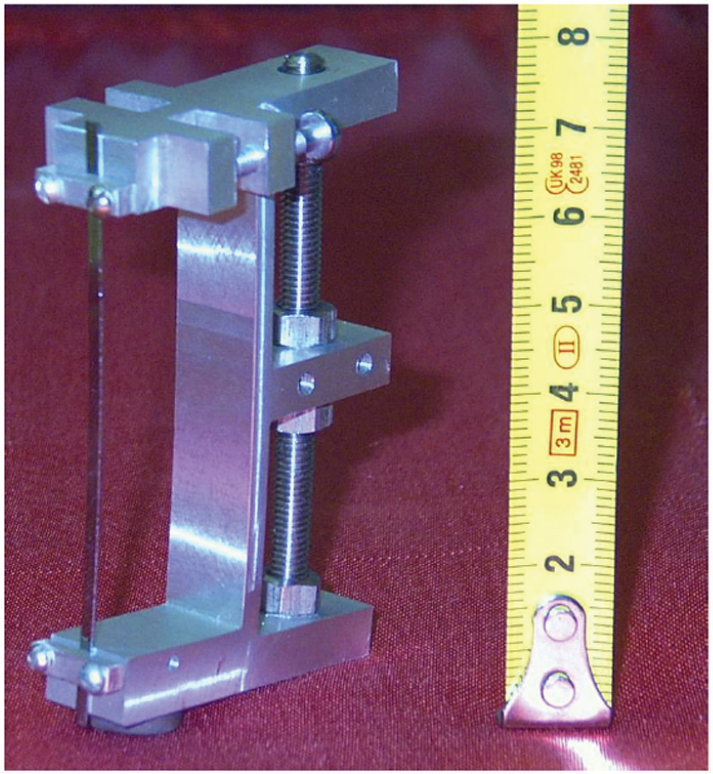
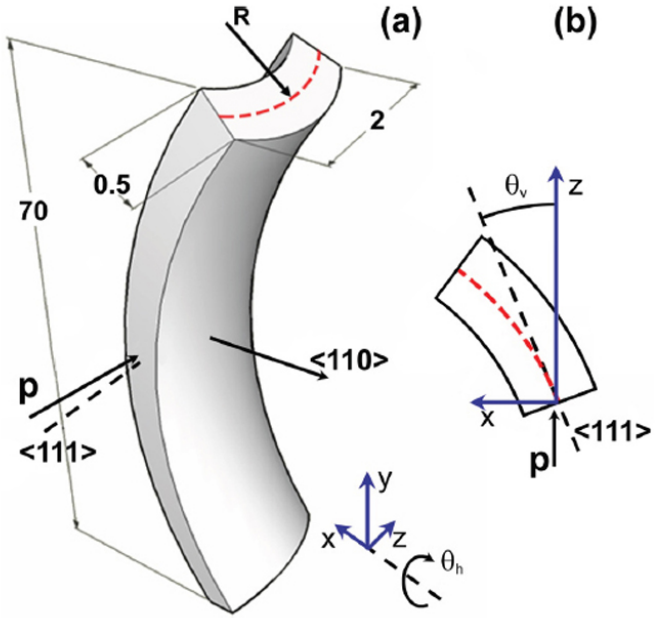
3m

What is *bent crystal*?





Crystal bending is accomplished through *anticlastic* deformation

№	Position	Type	Bend angle mrad	Sizes l×h×R, mm	Efficiency, %	Energy GeV	Extraction scheme
1	SS-106	S	1.0	2.0·35·0.5	85 80	70 70	106-24-26 106-20-22-26
2	SS-106	O	0.7	3.5·5·0·0.7	60	70	106-24-26
3	SS-19	S	2.0	5.0·45·0.5	67	70	20-22-26
4	SS-19	O	2.1	5.0·5.0·0.7	65	70	20-22-26
5	Unit 22	S	0.8	1.9·45·0.5	85	70	24-26
6	Unit 22	S	0.9	1.8·45·0.5	80	50	24-26

CONCLUSION

At once after the first experiment of extraction by the bent crystal we began to use proton beam for physical needs. That was urgent necessity because the only crystal channeling gave us the possibility to have 70 GeV proton beam at the experimental facility which worked before with the secodaries. The need to have intensity in the range 10^9 – 10^{11} proton per spill led us to utilization of short crystals with the help of bending extraction magnets. Resonant slow extraction system dos not work well in such range of intensity. And it dos not work in parallel with the internal targets. We have fulfilled such extraction system. Every accelerator run some experimental set-up works using the proton beam extracted by the bent crystal.

First Observation of Magnetic Moment Precession of Channeled Particles in Bent Crystals

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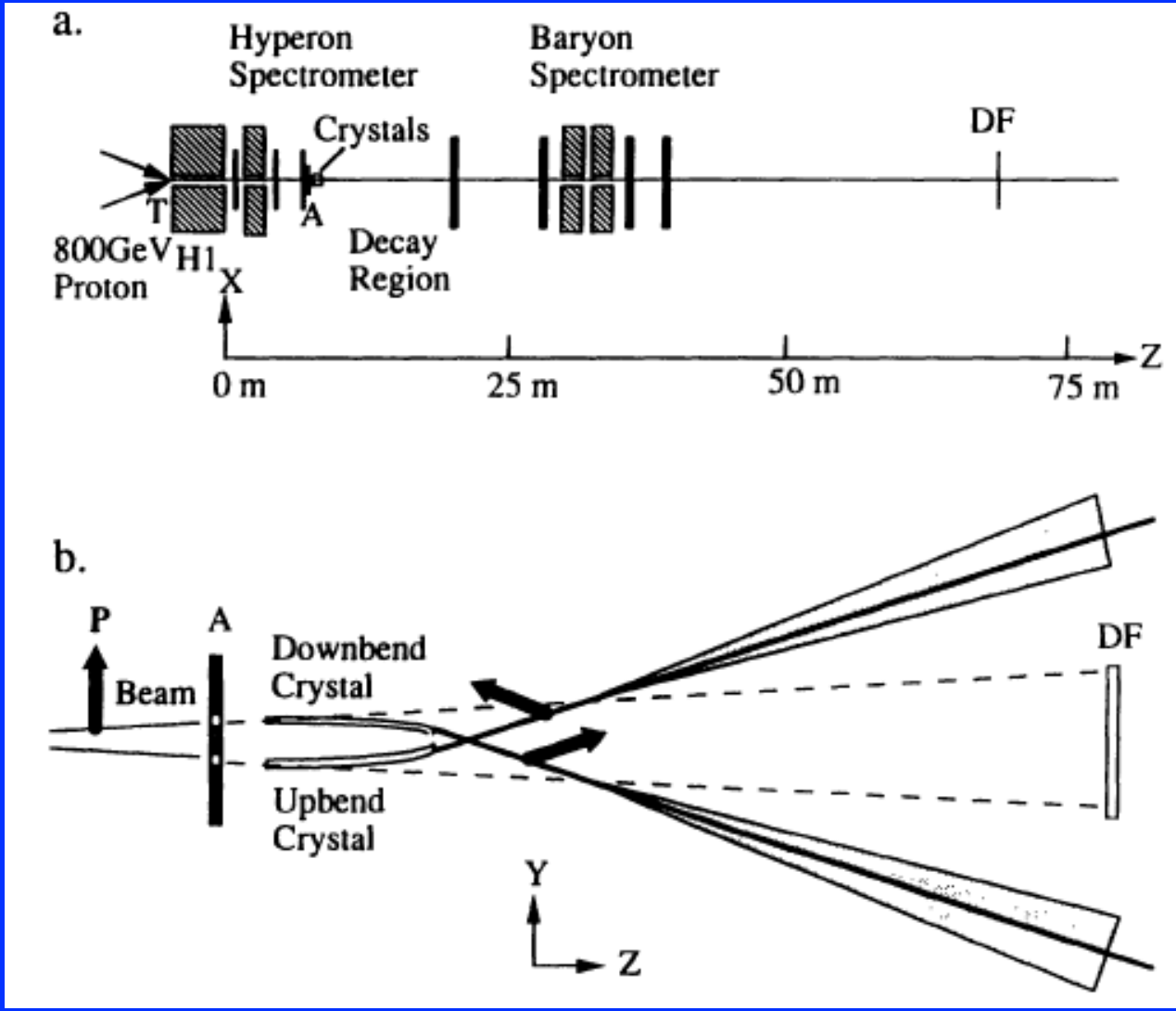
(Received 8 September 1992)

Spin precession of channeled particles in bent crystals has been observed for the first time. Polarized Σ^+ were channeled using bent Si crystals. These crystals provided an effective magnetic field of 45 T which resulted in a measured spin precession of $60° \pm 17°$. This agrees with the prediction of $62° \pm 2°$ using the world average of Σ^+ magnetic moment measurements. This new technique gives a Σ^+ magnetic moment of $(2.40 \pm 0.46 \pm 0.40)\mu_N$, where the quoted uncertainties are statistical and systematic, respectively. We see no evidence of depolarization in the channeling process.

Spin precession of Σ^+ in bent crystal



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Nuclear Instruments and Methods in Physics Research A 363 (1995) 511–519

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Beam halo crystal extraction from the Tevatron during collider runs

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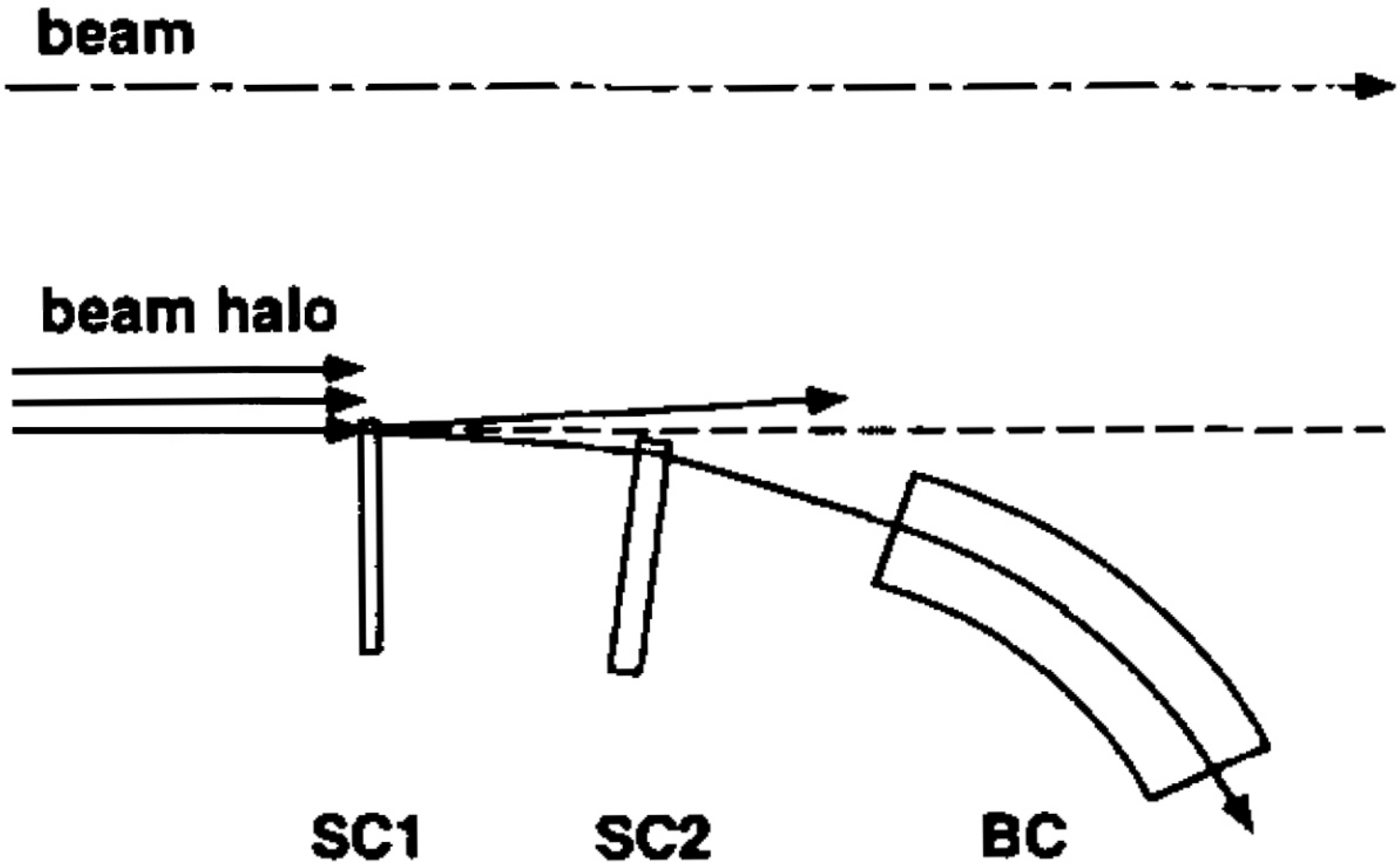
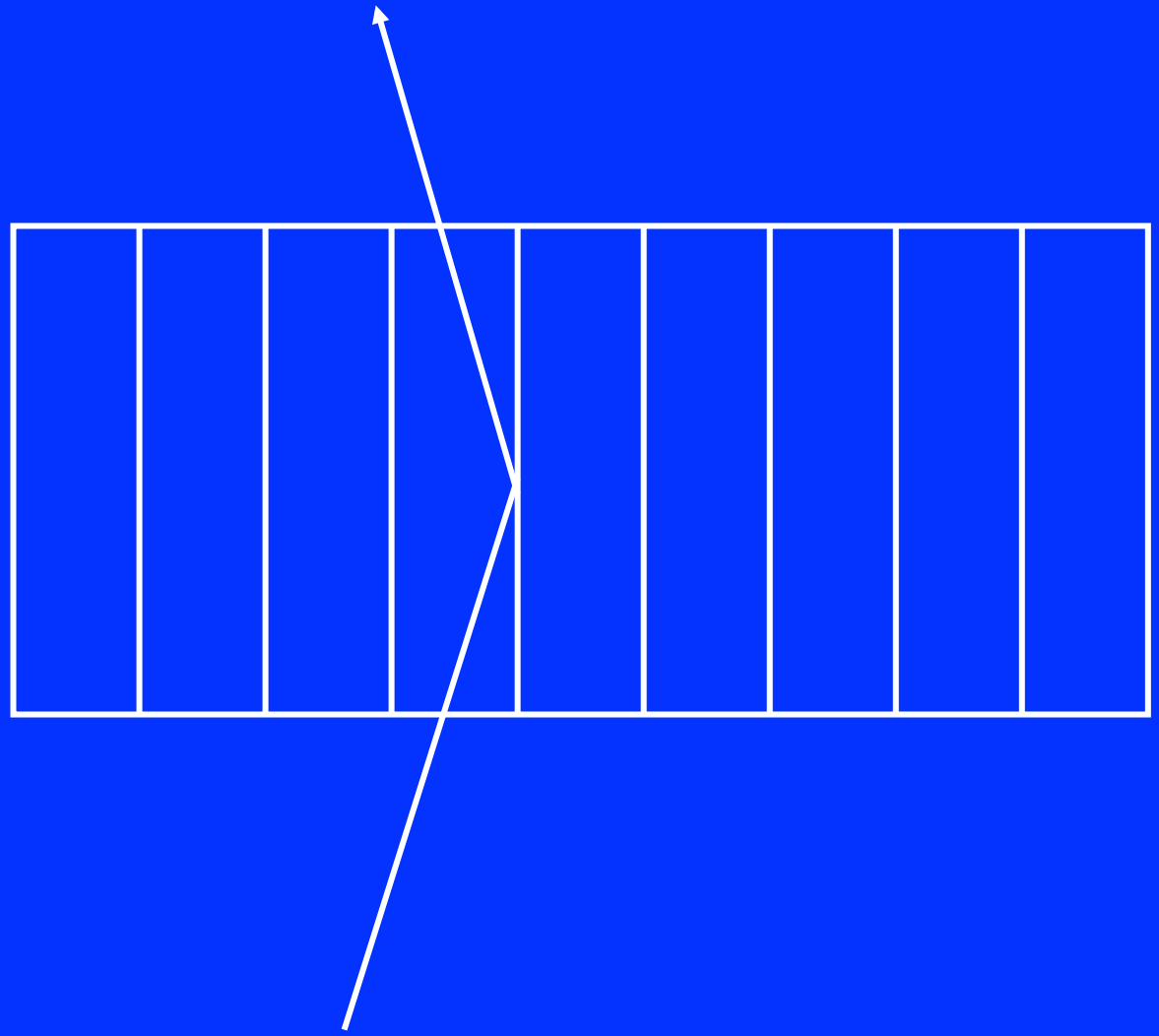
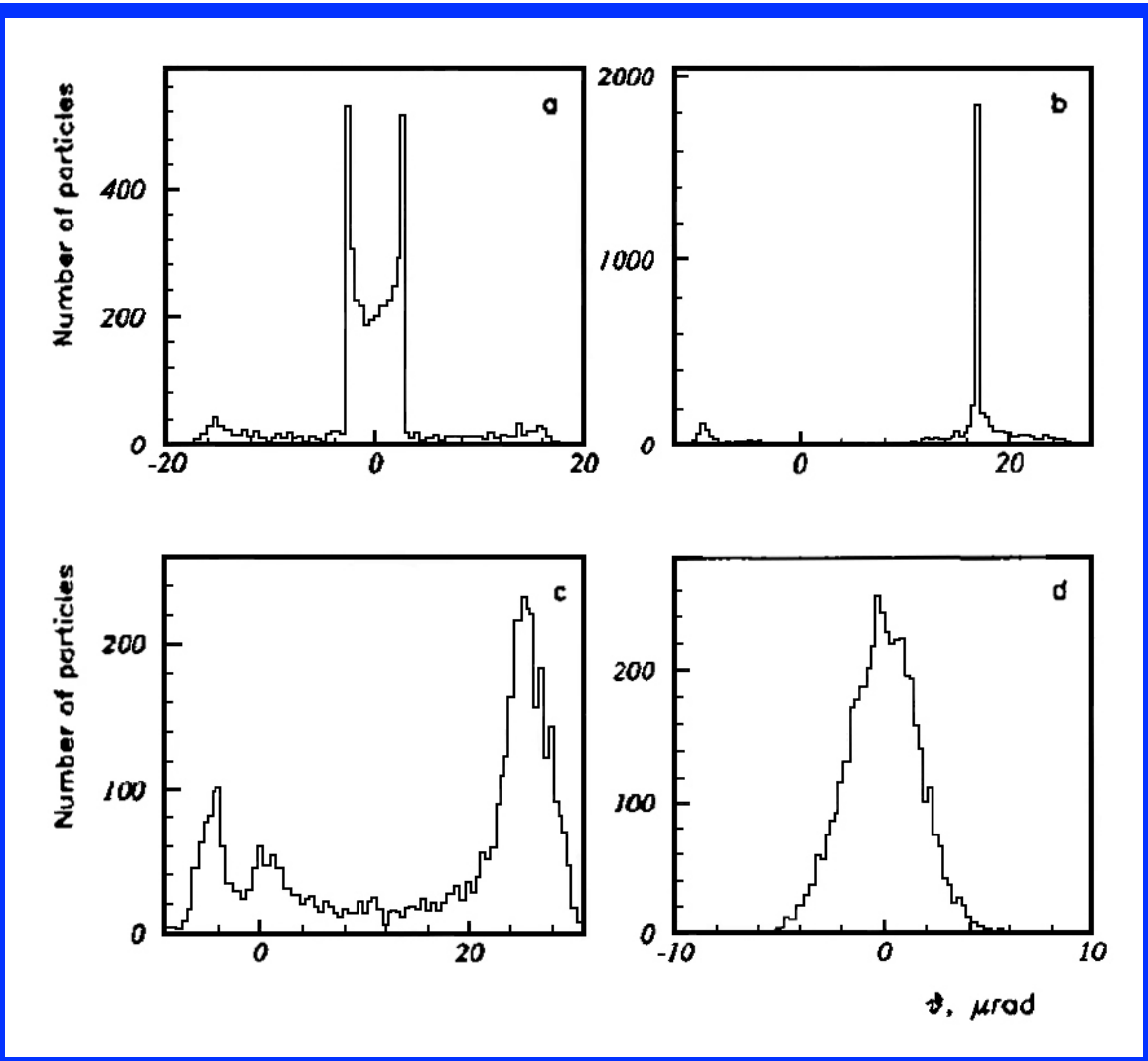
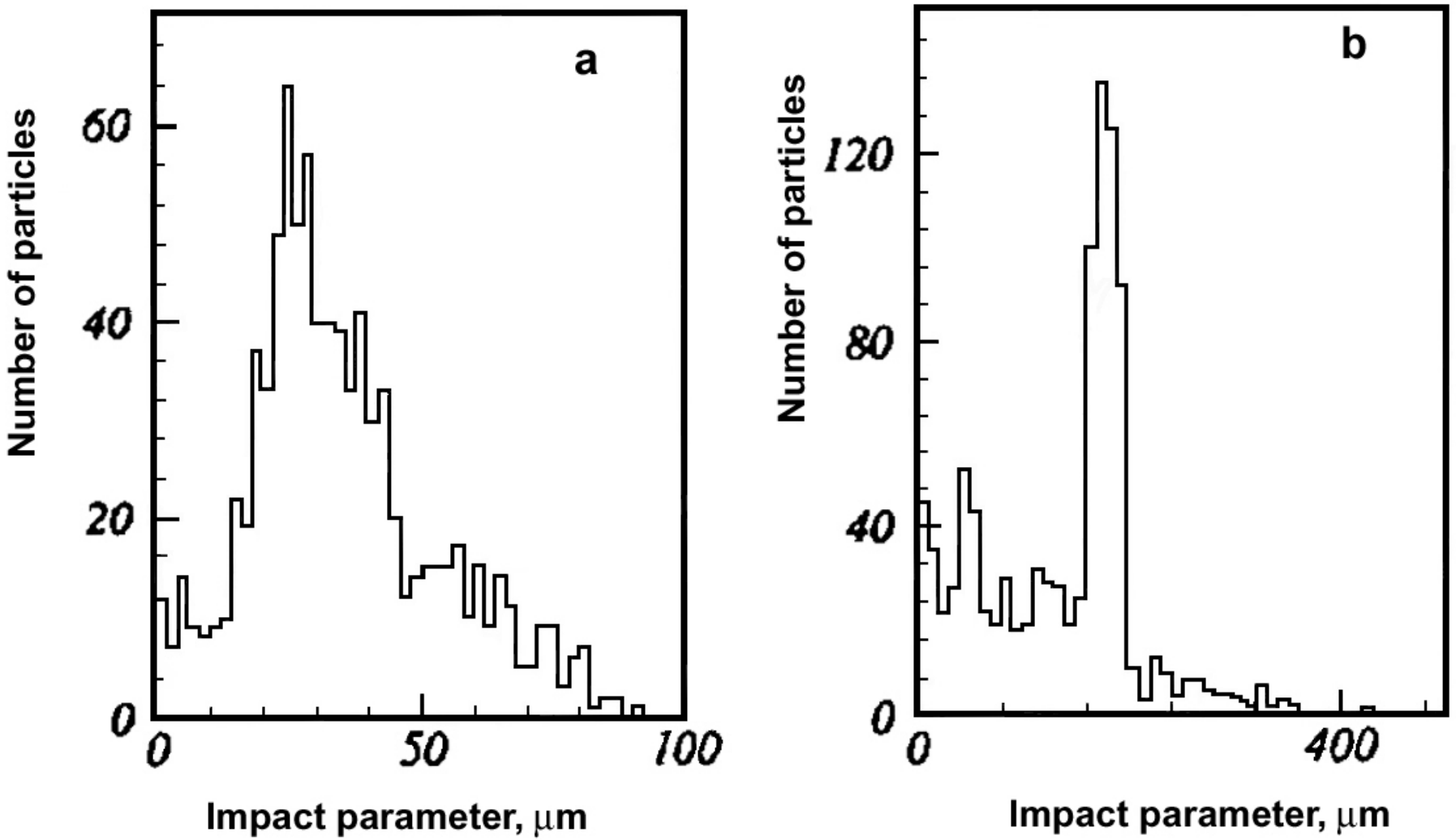

beam
beam halo
SC1
SC2
BC

Crystal mirror concept





Angular distributions of outgoing particles for the cases when the tungsten crystal planes (110) are tilted (a) by 0 μrad, (b) by 8.5 μrad, (c) by 12.75 μrad, and (d) by 68 μrad relative to the direction of an incident 900 GeV-protons.

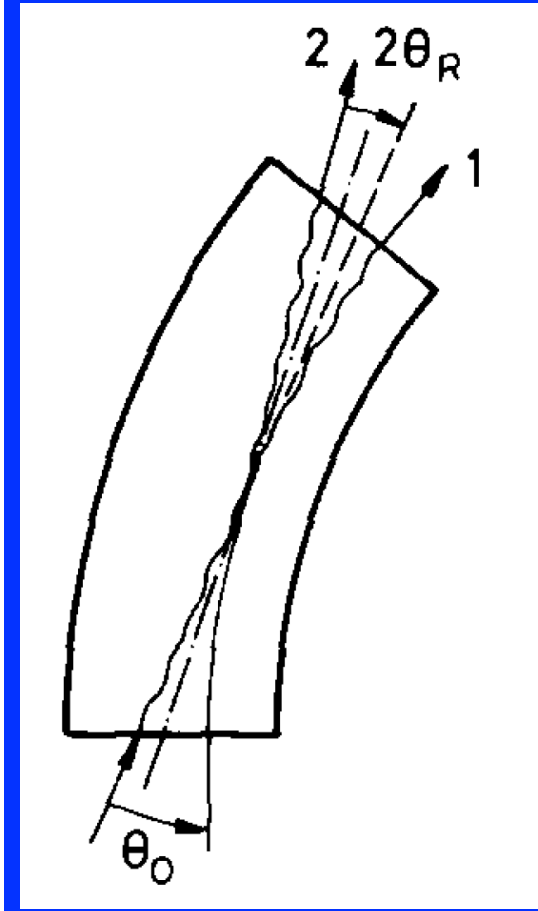


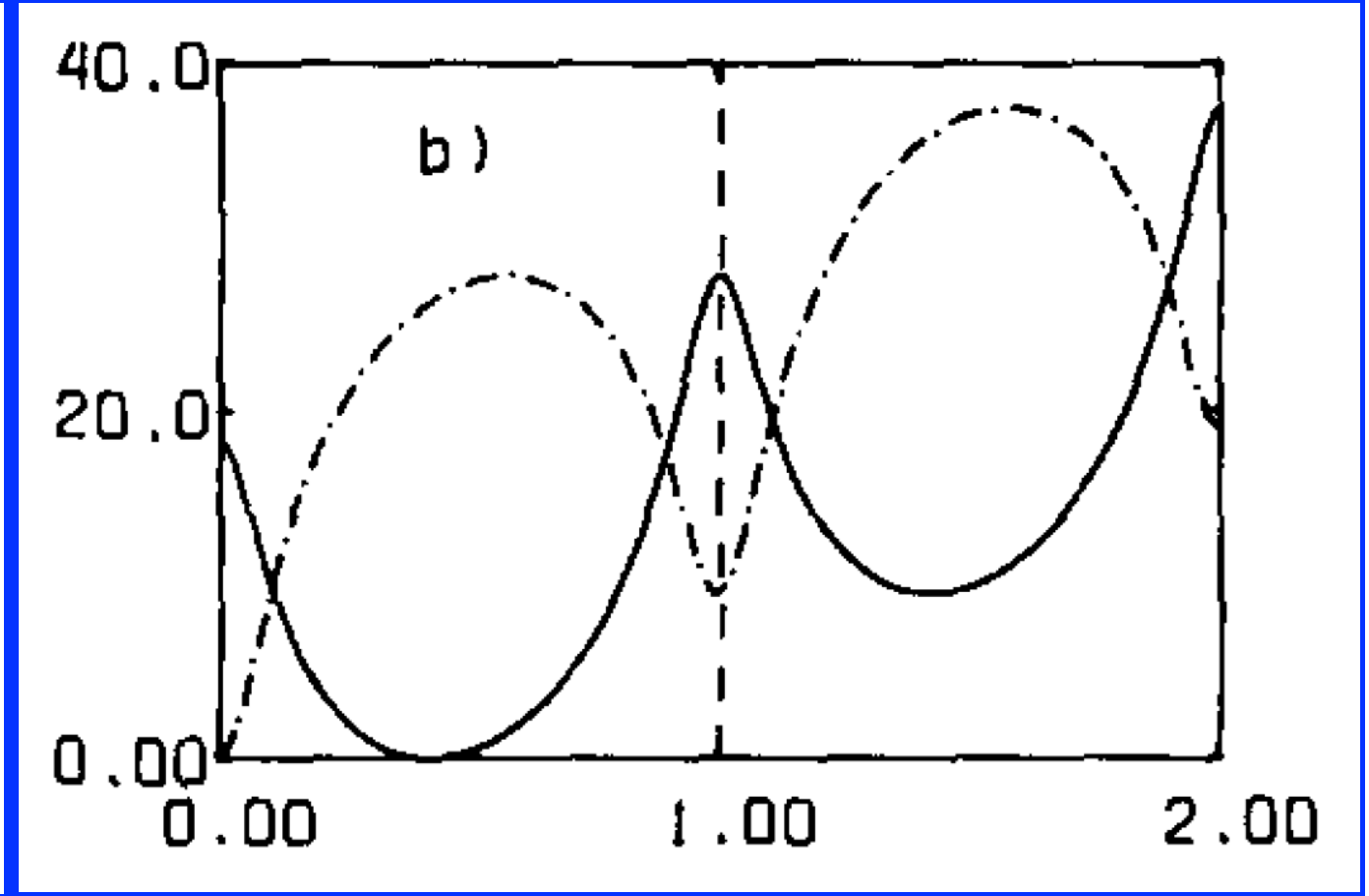
Impact parameter for different crystal mirrors SC2: a - silicon, b - tungsten.

"The device is suitable for cleaning up the proton beam halo (a clean crystal scraper), or for useful extraction of the proton beam halo particles with a 99% efficiency. When it is used as a clean scraper, it could work as an efficient clean radiation drain preventing radiation due to a proton beam loss that now is spreading around the Tevatron.

The device is suitable to be used at the LHC collider for both circulating proton beams. It could reduce the background radiation due to a beam halo loss by a factor of about 100."

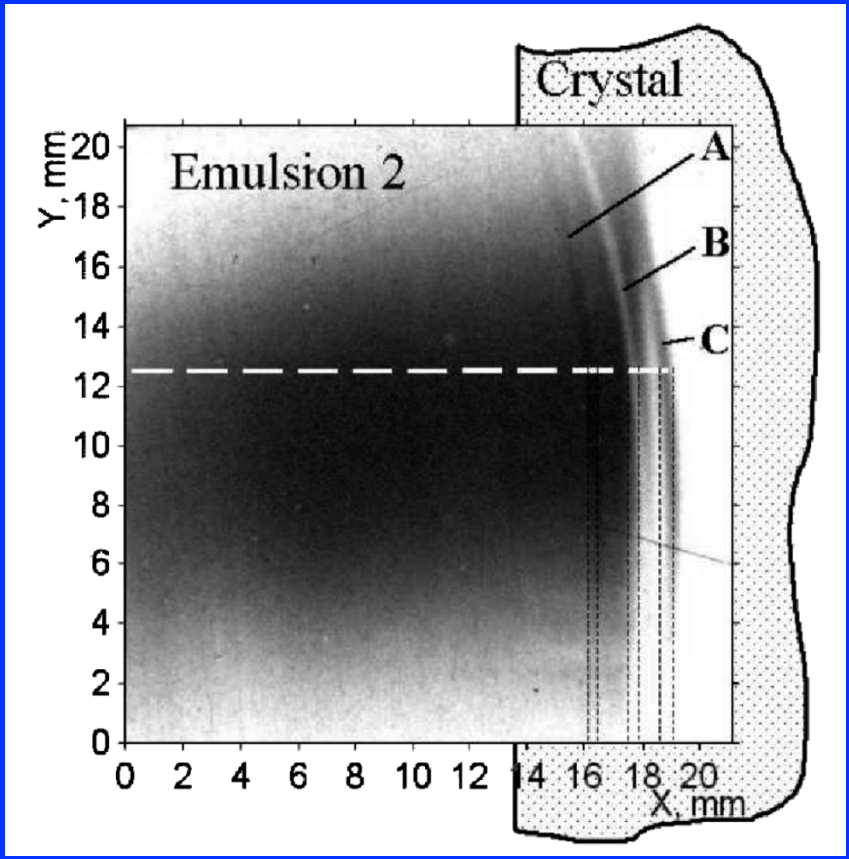
A.M. Taratin, S.A. Vorobiev, "Deflection of High-Energy Charged Particles In Quasi-Channeling States in Bent Crystals", Nuclear Instruments and Methods in Physics Research B26 (1987) 512-521

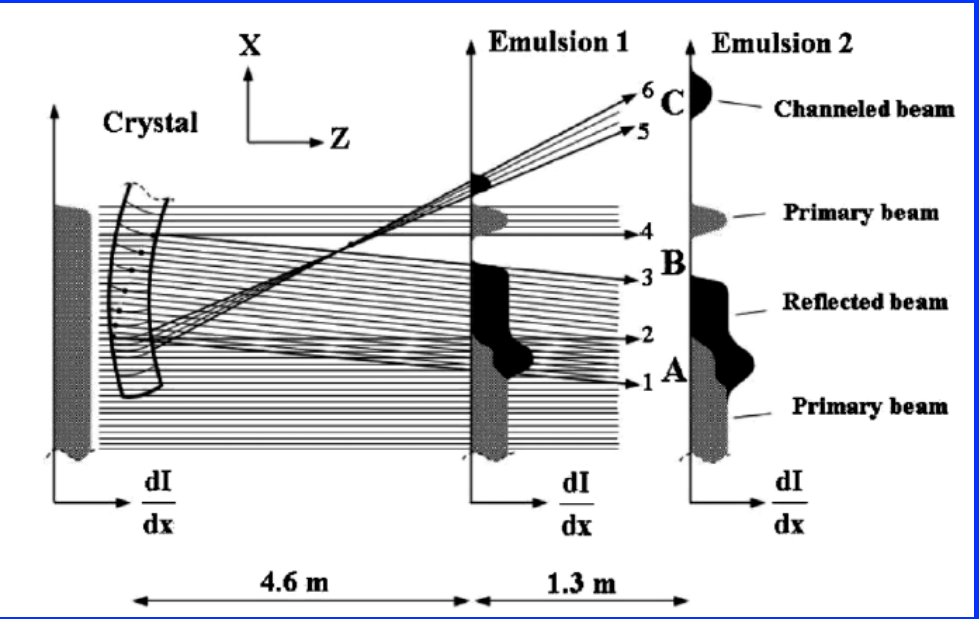




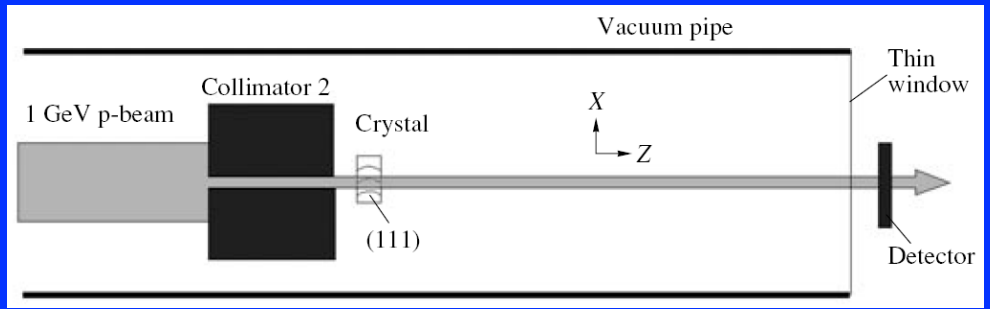
Yu.M. Ivanov, A. A. Petrunin, V.V. Skorobogatov, Yu.A. Gavrikov, A.V. Gelamkov, L. P. Lapina, A. I. Schetkovsky, S. A. Vavilov, V. I. Baranov, Yu.A. Chesnokov,2 A. G. Afonin, V. T. Baranov, V. N. Chepegin, V. Guidi, W. Scandale, and A. Vomiero, "Volume Reflection of a Proton Beam in a Bent Crystal", PRL 97, 144801 (2006)

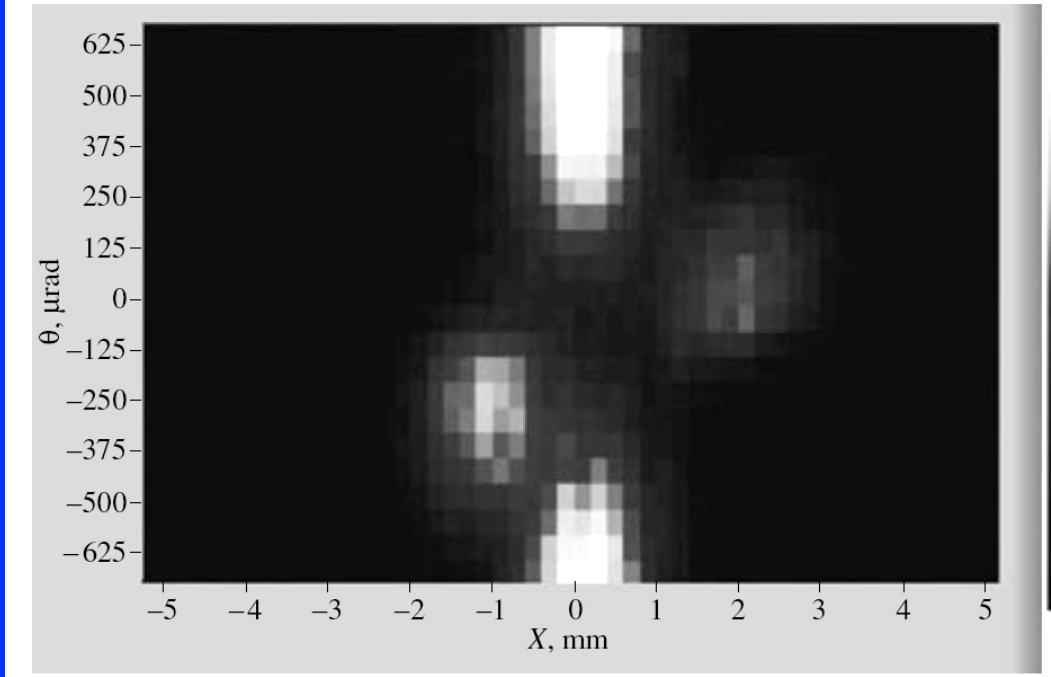
Protvino, 70 GeV





Yu.M. Ivanov, N.F. Bondar', Yu.A. Gavrikov, A.S. Denisov, A.V. Zhelamkov, V.G. Ivochkin, S.V. Kos'yanenko, L.P. Lapina, A.A. Petrunin, V.V. Skorobogatov, V.M. Suvorov, A.I. Shchetkovsky, A.M. Taratin, W. Scandale, "Volume Reflection of 1-GeV Protons by a Bent Silicon Crystal" *JETP Letters, 2006, Vol. 84, No. 7, pp. 372–376.*





The right and left peaks are easily identified as the regions of the channeling effect and reflection effect, respectively.


thanks for your attention!
grazie per la vostra attenzione!