Bent Crystal Extraction from a 100 TeV Proton Collider

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Channeling 2014, October 5-10, 2014, Capri, Italy

- The work is motivated by the FCC design proposal at CERN
- The JINR has expressed the interest of participation in the FCC

The two topics:

- high energy accelerators

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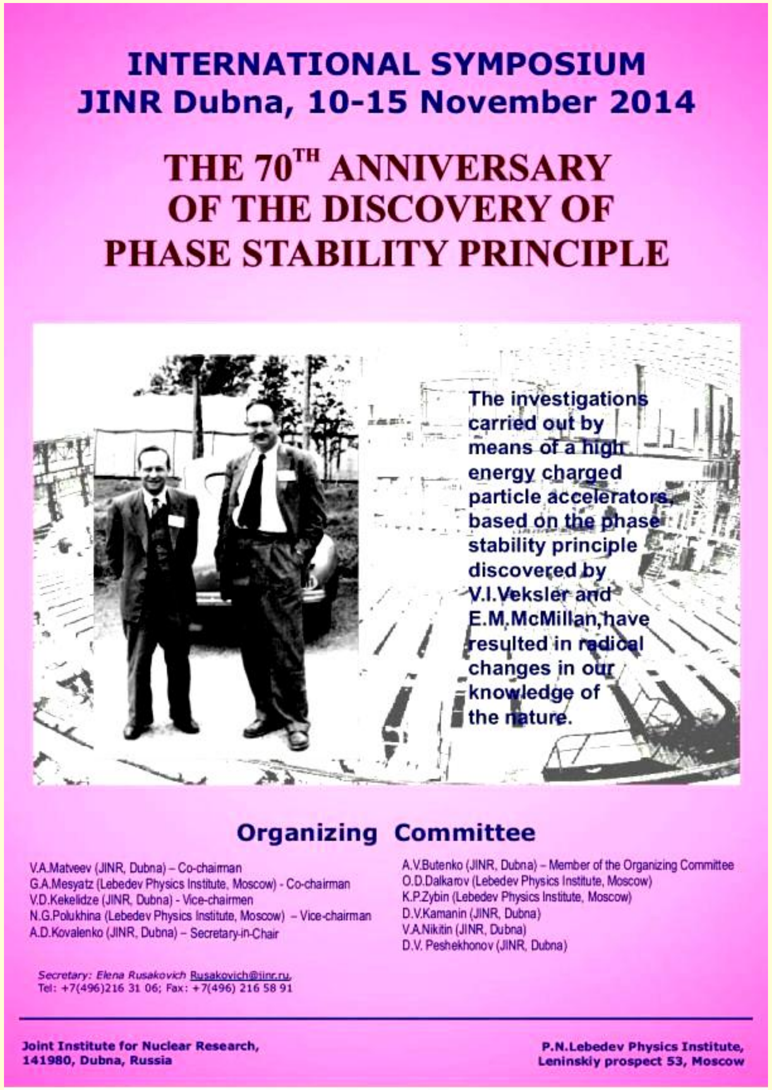
- crystals applications

are combined naturally in FCC

Crystal assisted extraction and colimation of protons over energy range from 0.450 to 50 (100) TeV is presented .



- In the 30's of the last century search for new phenomena in cosmic space, which are resulting in the observables at the men-made detectors, was the main point of V.Veksler's interests.

- **Veksler's proposal (1944):**

how to overcome "relativistic barrier " at resonant acceleration of charged particles was really outstanding.

The auto-phasing (phase stability) effect make it possible operation of all high energy particle accelerator.

10-GeV proton accelerator at JINR–Synchrophasotron (1957) – was really the first base for the world high energy physics research

• **1979: The experiment initiated and leading by Edward Tsyganov at LHE JINR synchrophasotron proved possibility of high energy proton beam deflection by bent crystal**

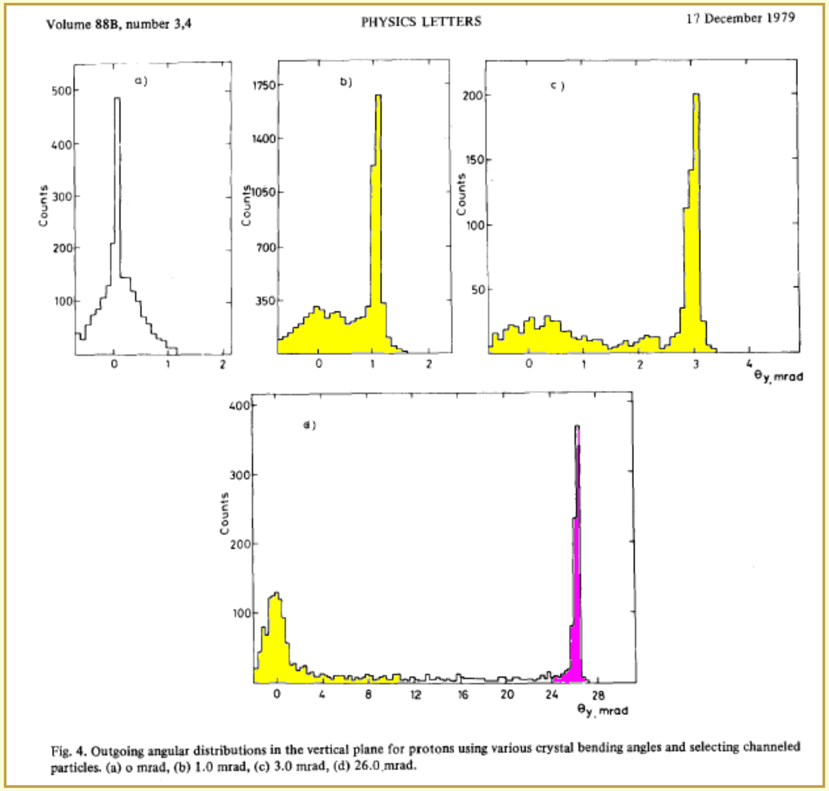
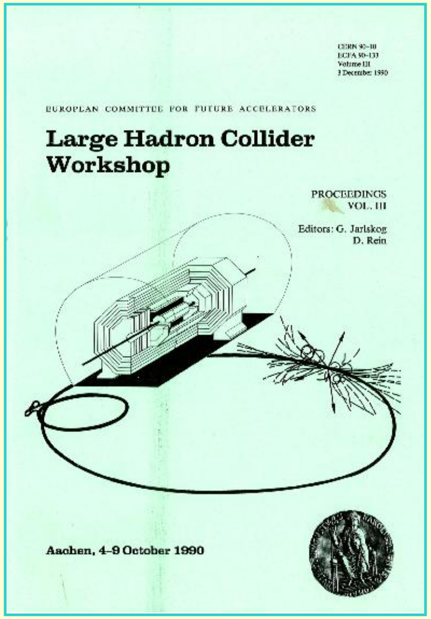


Fig. 4. Outgoing angular distributions in the vertical plane for protons using various crystal bending angles and selecting channeled particles. (a) o mrad, (b) 1.0 mrad, (c) 3.0 mrad, (d) 26.0 mrad.

The first observation of particle deflection by



EXPERIMENTAL INSERTIONS FOR THE LHC

by

Walter Scandale,
CERN, div SL, Geneva.

Luminosity and number of interactions.

In a hadron collider the most important parameters are the luminosity and the beam energy.

For round beams and head-on collisions, the luminosity L is given by:

$$L = \frac{kN_b^2 f_0 \gamma}{4\pi\varepsilon^* \beta^*}$$

where k is the number of bunches in each beam,
N_b is the number of particles per bunch,
f_0 is the revolution frequency,
γ is the energy divided by the rest mass of the particles,
$\varepsilon^* = \gamma\sigma^2/\beta^*$ is invariant emittance,
β^* is the betatron function at the crossing point.

The most fundamental limitation to the performances of the LHC comes from the beam-beam interaction, which has two components, the head-on interaction which occurs at the wanted interaction points, and the long range interactions, which occur on either side of the interaction region in the portion of the beam pipe which is common to both beam. The importance of these effects is determined by the beam-beam tune shift parameter ξ

$$\xi = \frac{N_b r_p}{4\pi\varepsilon^*}$$

where r_p is classical radius of the proton.

The studies of the CERN SppbarS and at the Fermilab Tevatron have shown that the total tune spread due to the beam-beam interaction and to the magnetic imperfections has to be limited to below 0.02.

By assuming a contribution of the lattice non-linearities to the tune-spread smaller than 0.005, as assured by the lattice design, the permissible total beam-beam tune spread ΔQ is 0.015. This quantity has to be shared by the different interaction regions, and it determines the ultimate performance of the collider.

The total beam current might be limited by the increasing difficulties of controlling the particle losses in the superconducting magnets and of dumping the beams, as well as by the heat load on the cryogenic system due to the synchrotron radiation.

Using the parameters of Table 1, the LHC has been optimized for three simultaneous pp collision with a maximum luminosity of 1.65 10^{34} cm^{-2} s^{-1}, and a total energy in the center of mass of 14.4 TeV.

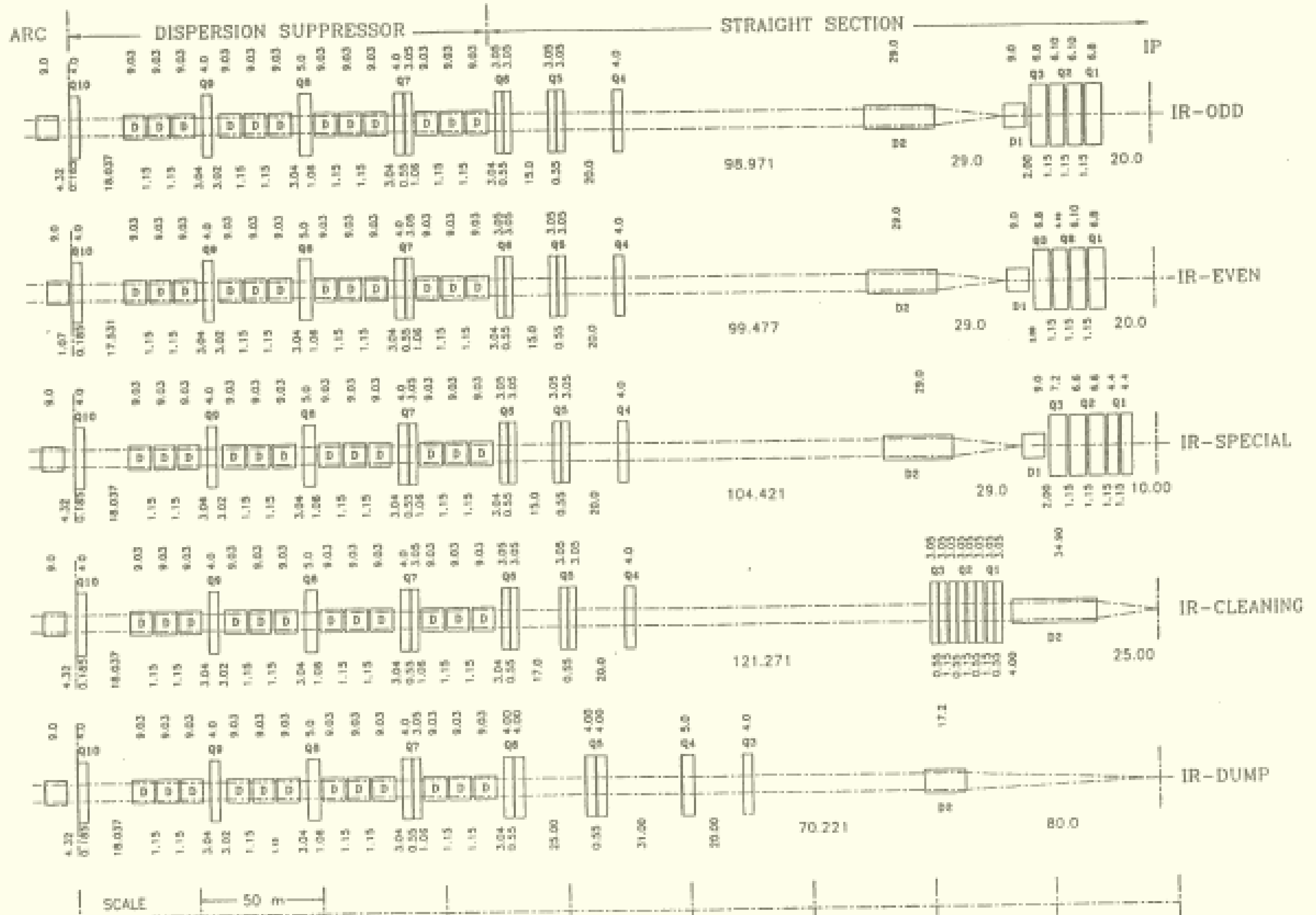
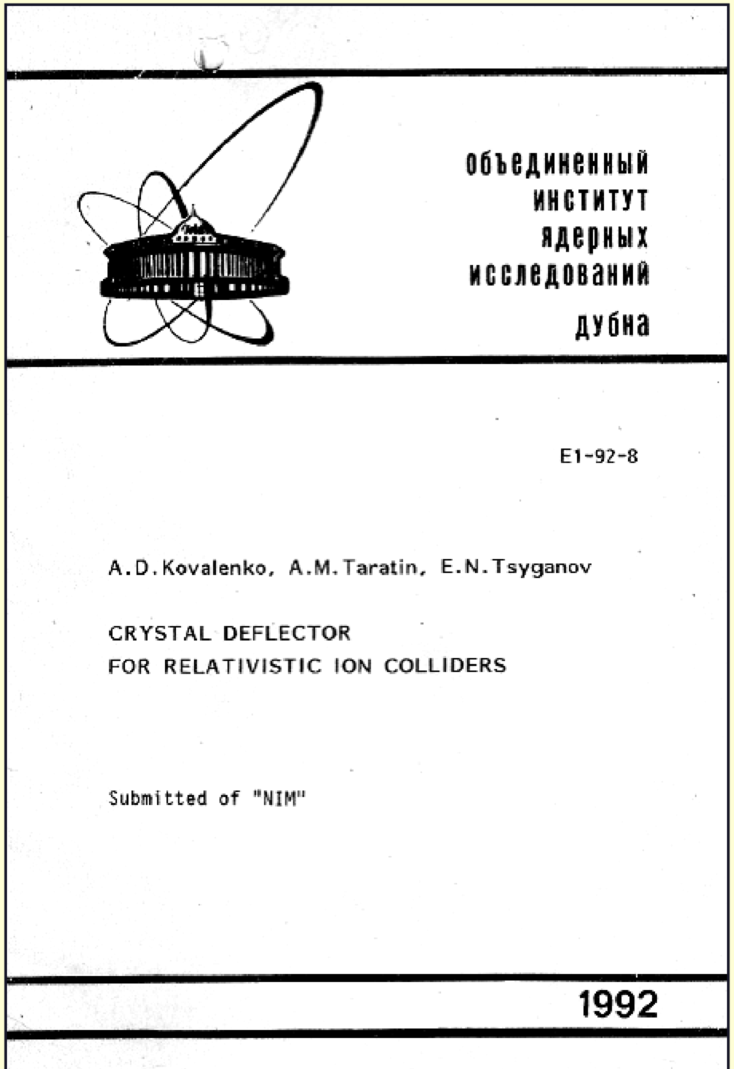


Fig.1. LHC Lattice version 1 – experimental and machine insertions

The studies of crystal applications at JINR in the 90's


объединенный
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исследований
дубна

E1-92-8

A.D.Kovalenko, A.M.Taratin, E.N.Tsyganov

CRYSTAL DEFLECTOR
FOR RELATIVISTIC ION COLLIDERS

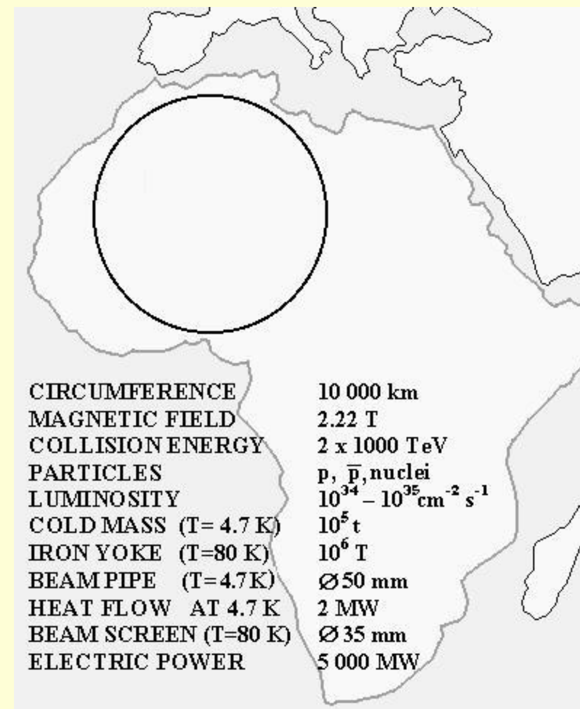
Submitted of "NIM"

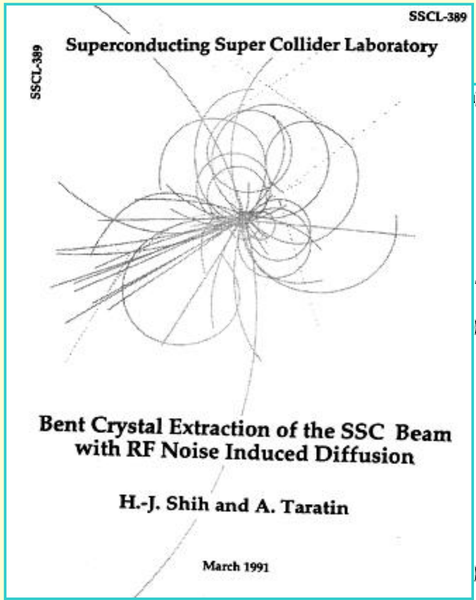
1992

The studies of 100 TeV range accelerators at JINR in the 90's

- A.M.Baldin & A.D. Kovalenko, " How a 100 TeV synchrotron/ collider based on Nuclotron-type cryomagnetic system would look" *(1995), JINR Rapid communications, also at APS meeting (Indianapolic, May, 1995).*

- A.D. Kovalenko, "VLHC based on cooled iron intermediate temperature field superconducting magnets " *(2001),Intern. Conference on High Energy Accelerators, March, 2001, Tsukuba, Japan.*





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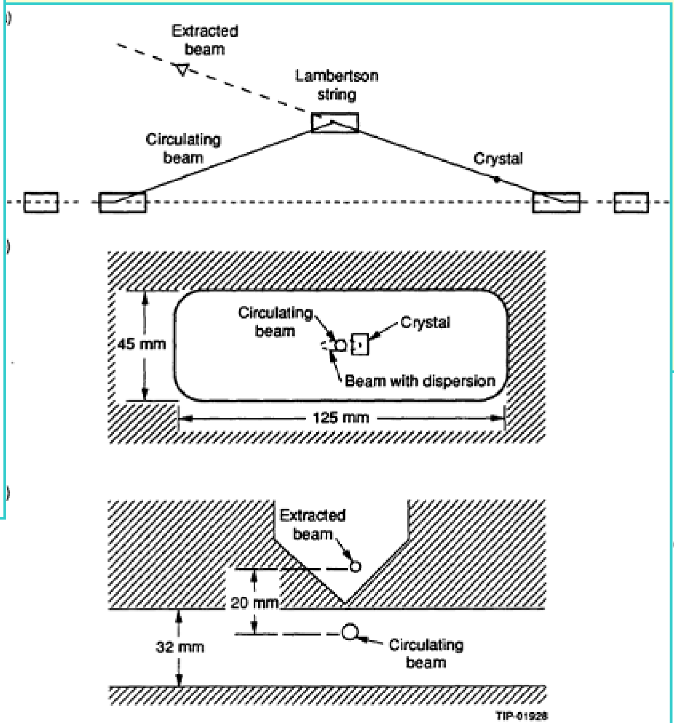
Superconducting Super Collider Laboratory

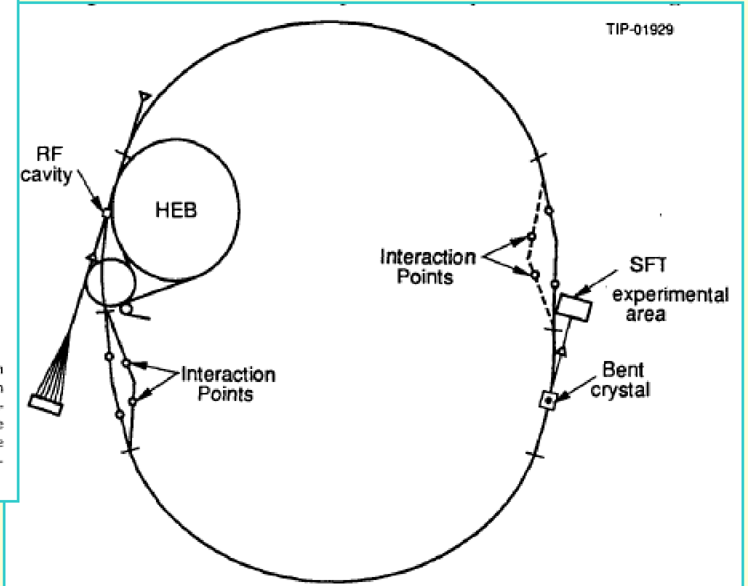
Bent Crystal Extraction of the SSC Beam with RF Noise Induced Diffusion

H.-J. Shih and A. Taratin

March 1991



Proposed Extraction Scheme. (a) The horizontal doglet with a bent crystal inserted about 200 m upstream of the Lambertson string. The dashed line with an arrow indicates the extracted beam line. (b) The cross-sectional view at the position of the crystal. Using large dispersion in combination with rf noise induced diffusion, a small fraction of the beam intercepts the crystal. (c) The cross-sectional view in the Lambertson string. The extracted beam, which is the portion of the beam that the bent crystal intercepts and deflects vertically, has been separated from the circulating beam by 2 cm and passes the field-free region.

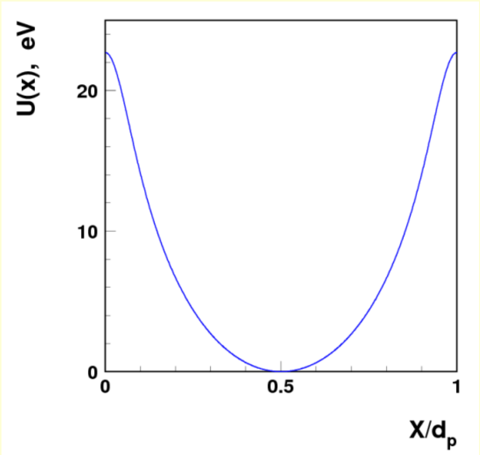


Layout of the SSC with the Extraction Elements: RF System in the West Utility Straight, Bent Crystal in the East Utility Straight, External Beam Line for Extraction and SFT Experimental Area.

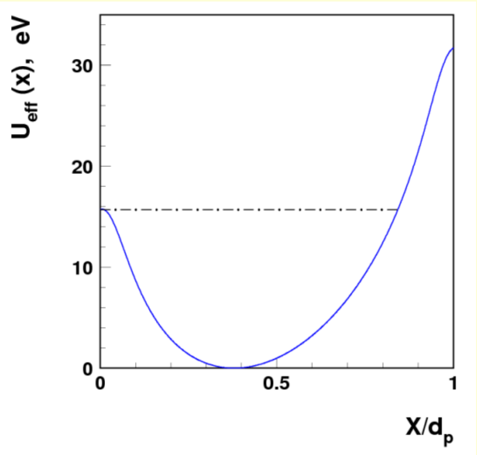
Channeling parameters: **protons, 50 TeV, Si crystal**

- Dechanneling length due to scattering by crystal electrons, **$S_{1/e}$ ~ E, 10 cm, p 200 GeV (FNAL) → S1/e = 50 m**
- Critical channeling angle **$\theta_c=(2U_o/pc)^{1/2}$ → θ_c=1 μrad**
- Critical radius of crystal bending **$R_c=pc/eE_m$ → R_c=85 m**

- Effective potential **$U_{eff}(x,R)=U(x)+xpc/R$**



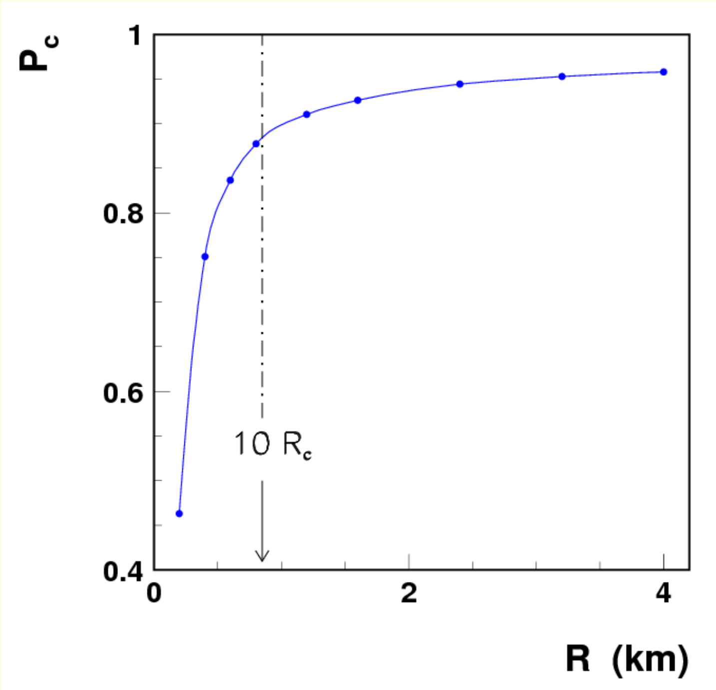
Potential well decreases and shifts



straight

$R=7R_c$

Capture efficiency:



Capture efficiency decreases because of well depth reduction

Crystal bend radius should be R > Rc

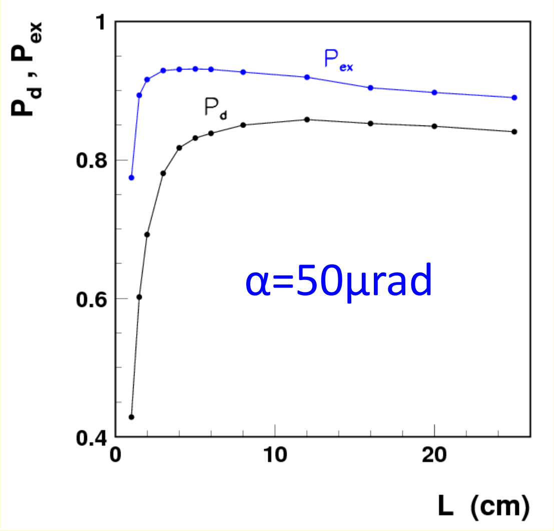
Deflection efficiency by fixed angle - dependence on R

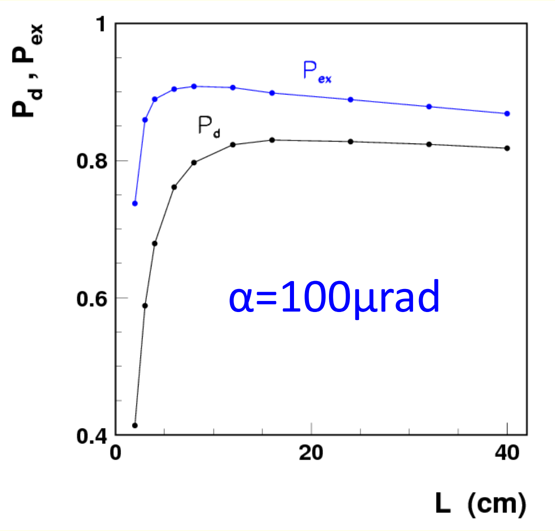
For single passage through a crystal

Deflection efficiency is maximal P_{dm} at some radius R_m , crystal length L_{dm}

P_{dm}=85%, L_{dm}=12 cm

P_{dm}=83%, L_{dm}=16 cm





P_{exm}=93%, L_{exm}=3 cm

P_{exm}=91%, L_{exm}=6 cm

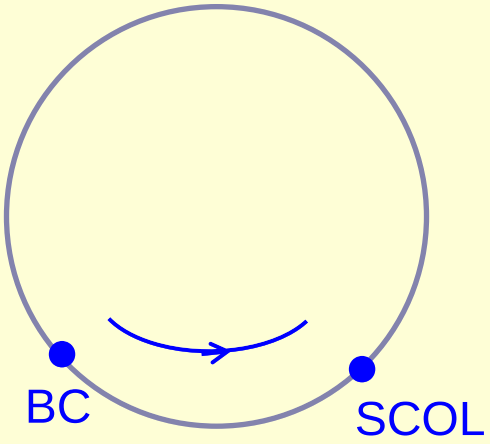
There are many passages through a crystal in collimation and extraction process they increase deflection efficiency

Collimation, extraction efficiency has maximum P_{exm} at smaller length L_{exm}

Simulation of beam halo extraction

Halo is generated by the amplitude increase of betaron oscillations

$$P(\Delta x_m) = \exp(-\Delta x_m / \lambda) \, ,$$



Two points along the ring were considered:

- BC - crystal
- SCOL – collimator-absorber

β_x=500 m and $\Delta\mu_x$=0.25

Distances from the orbit $X_{BC}=6\sigma_x$ and $X_{SCOL}=7\sigma_x$

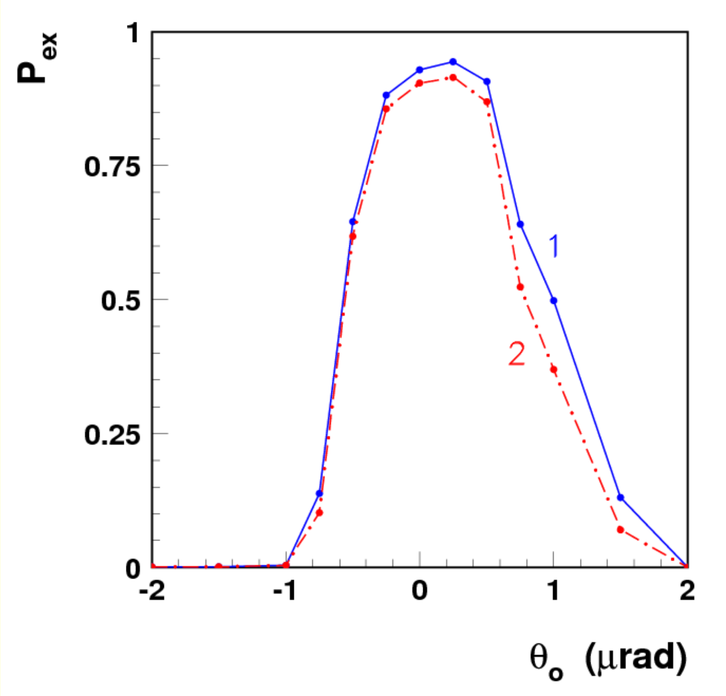
Two linear 6-D transfer matrices M(6,6) were used to transport particles between

BC → SCOL
SCOL → BC

Dependence of extraction efficiency on crystal orientation

For a bend angle 1) **α=50 μrad** with crystal length **L=3 cm**

and 2) **α=100 μrad** with **L=6 cm**

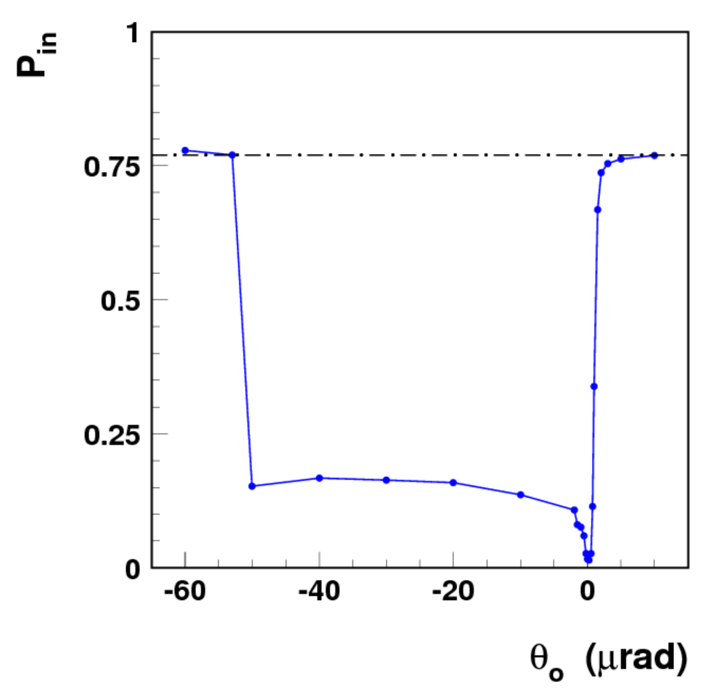


Efficiency more than 90% is possible in angular range, $\Delta\theta_o \approx 1$ μrad

Goniometer should has a step smaller than 1 μrad

Observation of volume reflection during crystal orientation

Beam losses observed by BLMs are smaller for VR crystal orientations



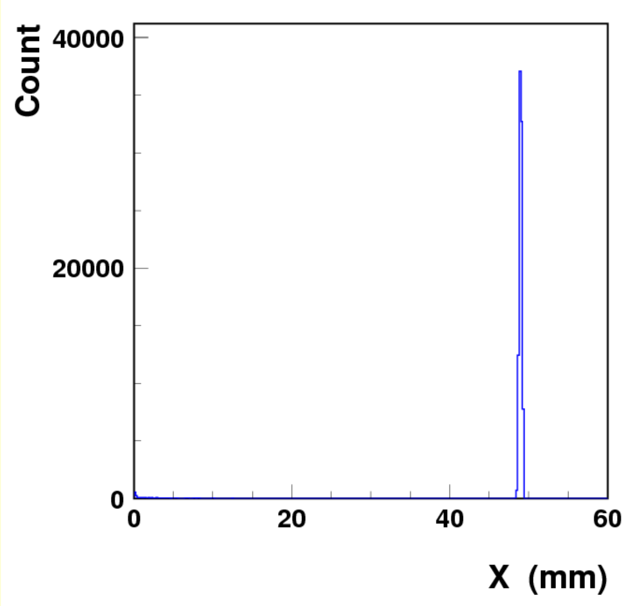
VR exists in wide angular range determined by bend angle

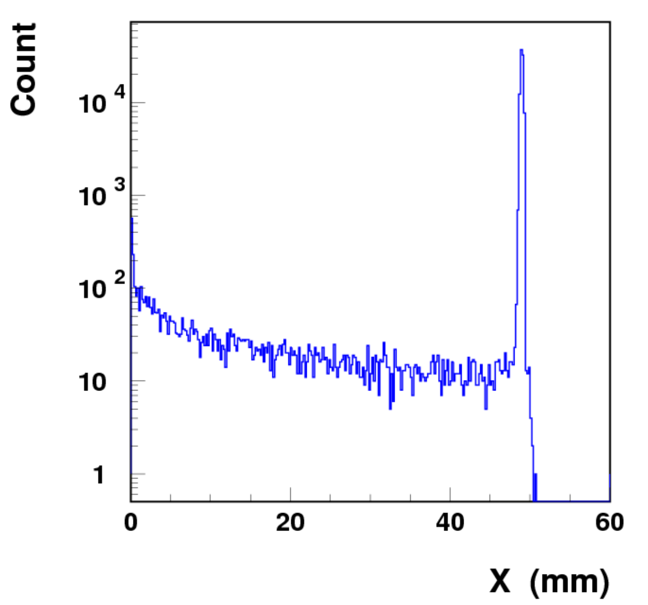
Observation of small losses in VR region considerably simplifies finding of crystal channeling orientation

Distribution of deflected halo particles at collimator-absorber

Channeling peak is very narrow, its position is determined by beta-function β_x

Here, for β_x=500 m and α=100 μrad → X_m=50 mm

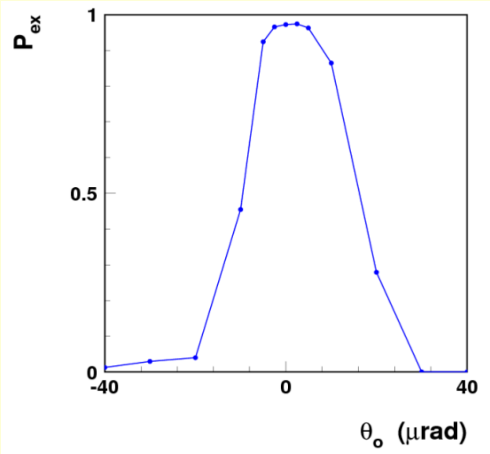


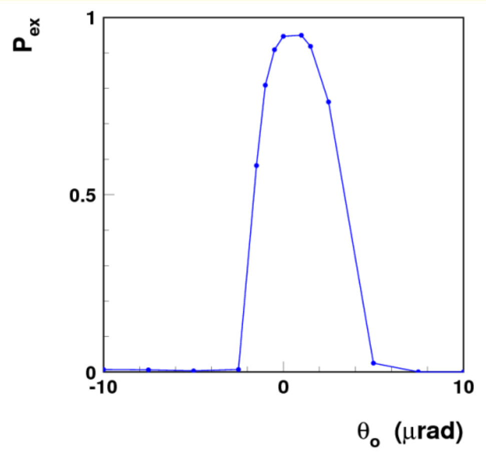


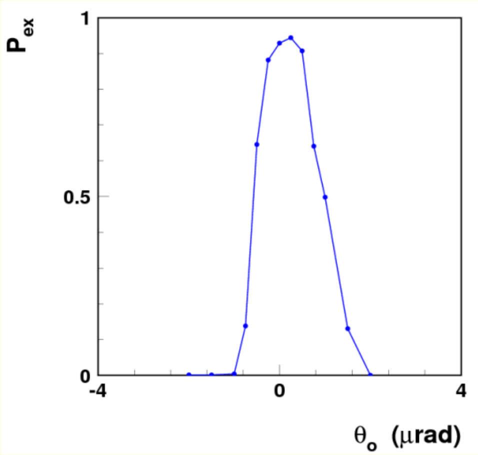
Dependence of extraction efficiency on particle energy

For deflection angle α=50 μrad – angular scans for optimal crystal length L_m

0.45 TeV	7 TeV	50 TeV







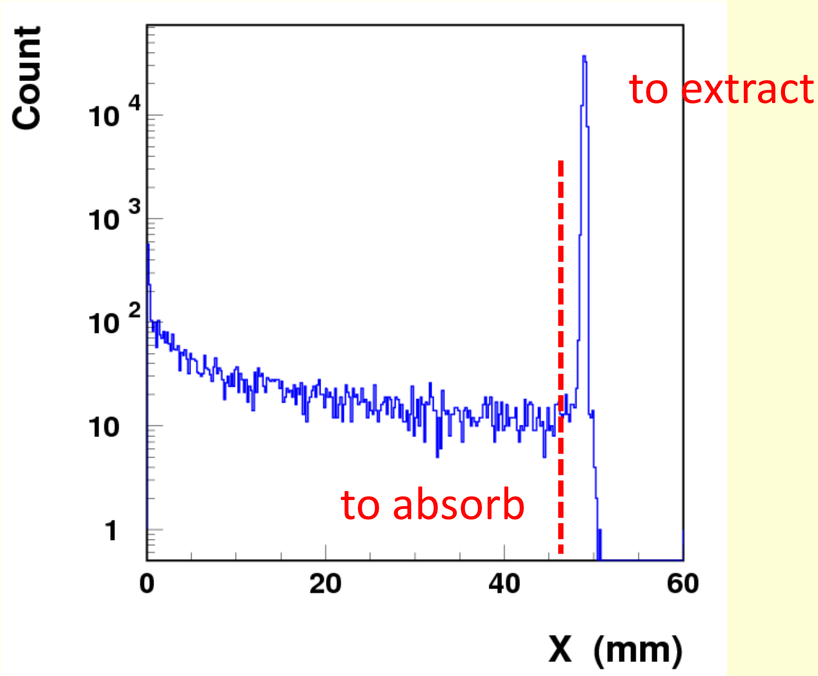
P_{exm}=97.5%, L_{exm}=0.03 cm	P_{exm}=95%, L_{exm}=0.4 cm	P_{exm}=94%, L_{exm}=3 cm

Dependencies are similar when angles and crystal radii are measured by relative units, θ_o/θ_c and R/R_c

Maximal efficiency and scan width decreases because of nuclear losses increase

To have both halo collimation and extraction:

- **Collimator-absorber straight before Lambertson magnet to absorb tail of deflected particles;**
- **SCOL horizontal size is a few cm, its vertical size should be sufficient to cool it;**
- **Channeled particles are extracted passing through passive Lambertson magnet aperture.**



SUMMARY

- The use of Si crystal for 50 TeV proton beam deflection is considered; conceptual scheme of the particle extraction from the ring is presented; it is suggested to produce a horisontal dogleg with the Lambertson magnet (LM) in a straight section of the collider ring. In this case the deflection angle of about 100 μrad or even smaller may be sufficient for the collider beam halo extraction.

- The critical bend radius *Rc* of the (110) silicon channels for channeling of 50 TeV/c protons is about 85 m; the crystal bend radius should be 5...10 *Rc* (the maximal extraction efficiency); the crystal length should be 4...8 cm to obtain the required deflection of 100 μrad for channeled particles.

- The extraction efficiency of the collider beam halo can reach to about 90%. The extraction of a natural halo provides both the collider beam collimation and the external beam of 50 TeV protons for experiments at fixed targets.

THANK YOU

FOR YOUR ATTENTION