Crystals Deflectors for High Energy Ion Beams

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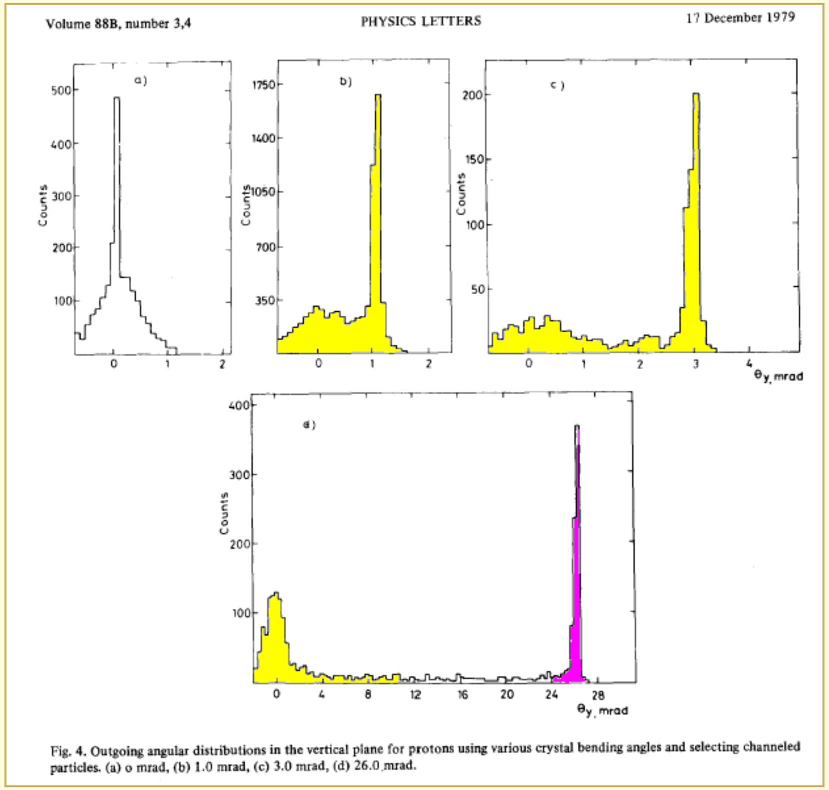
• **1979: The experiment initiated and leading by Eduward Tsyganov at LHE JINR synchrophasotron proved possibility of high energy proton beam deflection by bent crystal**

The first observation of particle deflection by



Application of Si bent crystal Channeling (for proton beams)

- In 1984 bent crystal was used for the first time to extract protons from the synchrophasotron;
- Experimental studies of channeling in bent crystals were made then in IHEP(Protvino), PNPI, CERN and FNAL;
- Beam extraction with bent crystals was studied at U70 (IHEP), CERN SPS and Tevatron;
- Bent crystals are regularly used in IHEP for the beam extraction from U70 and for splitting the extracted beam.

Bent crystal application for ion beams
(1992-2012)

Brief summary:

- The experiments performed at JINR, CERN and BNL showed that multi-charged ions are also successfully deflected by bent crystal.

- However, electromagnetic dissociation (ED) becomes possible for heavy nuclei of the LHC energies even for well channeled particles, which should be taken into account.

Studies of crystal applications at JINR in the 90's

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CRYSTAL DEFLECTOR
FOR RELATIVISTIC ION COLLIDERS

Submitted of "NIM"

1992

It would be interesting to r
beam extraction for fixed target
colliders RHIC and LHC which are
tional opportunity to extend an e
tant for the other high energy co
GSI(Darmstadt)[9] and LHE(Dubna)
Our calculations of the effi
by bent crystals and main questio
problem are presented below.

2. Efficiency of Ion Beam Deflec

Let us consider the variatio
channeling in crystals in going
charged ions ($Z=2$, $E=AE_1$, A-atom
dependencies of channeling param
Assume that the ion energy per n
proton case (i.e. the velocity
remain the same as for the proto
energy of channeling particle ar
High energy charged particl
tals if the radius of their curv
critical quantity R_c, which value
electric field averaged over the

$R_c(Z, AE_1) = \omega R_c^1 (E_1$

$\omega = \frac{A}{Z}$, $R_c^1(E_1) =$

2

is 10 x 10 cm^2 [16]. Taking into account that the cross section of the deflector is about 0.1 cm^2 and the extracted beam divergence is also small (θ_c), one can use the corresponding step by step movement of a detector unit or beam scanning to provide quasi-uniform irradiation of the detector area under above mentioned particle density.

Experimental conditions for an exposure of emulsion stacks are similar, but the particle track density can be increased up to $2\cdot10^4 cm^{-2}$.

The extracted beam intensity can increase substantially (up to 10^4-10^5 s^{-1}) using a special mechanism of beam halo particles shifting at the deflector.

External low intensity ion beams provided as a "by-product" at unique high energy ion colliders can be also used for the calibration of experimental instrumentation and even for some applied investigations (local radiation damage of different materials or, e.g., electronics components).

So the addition of crystal deflectors to the lattice of relativistic ion colliders with energies of tens GeV and higher will open up new possibilities for experiments and involve more users in their scientific programs.

References

[1] A.F.Elishev et al. Phys.Lett., v.B88, p.387, 1979.
V.V.Avdeichikov et al. JINR Rapid Communication 1-84, Dubna (1984).
[2] A.A.Assev, M.D.Bavizhev et al. Preprint IHEP 89-57, Serpukhov 1989.
[3] "An Expression of Interest in a Super Fixed Target Beauty Facility (SFT) at the Superconducting Super Collider", SSC-EOI # 14 (1990).

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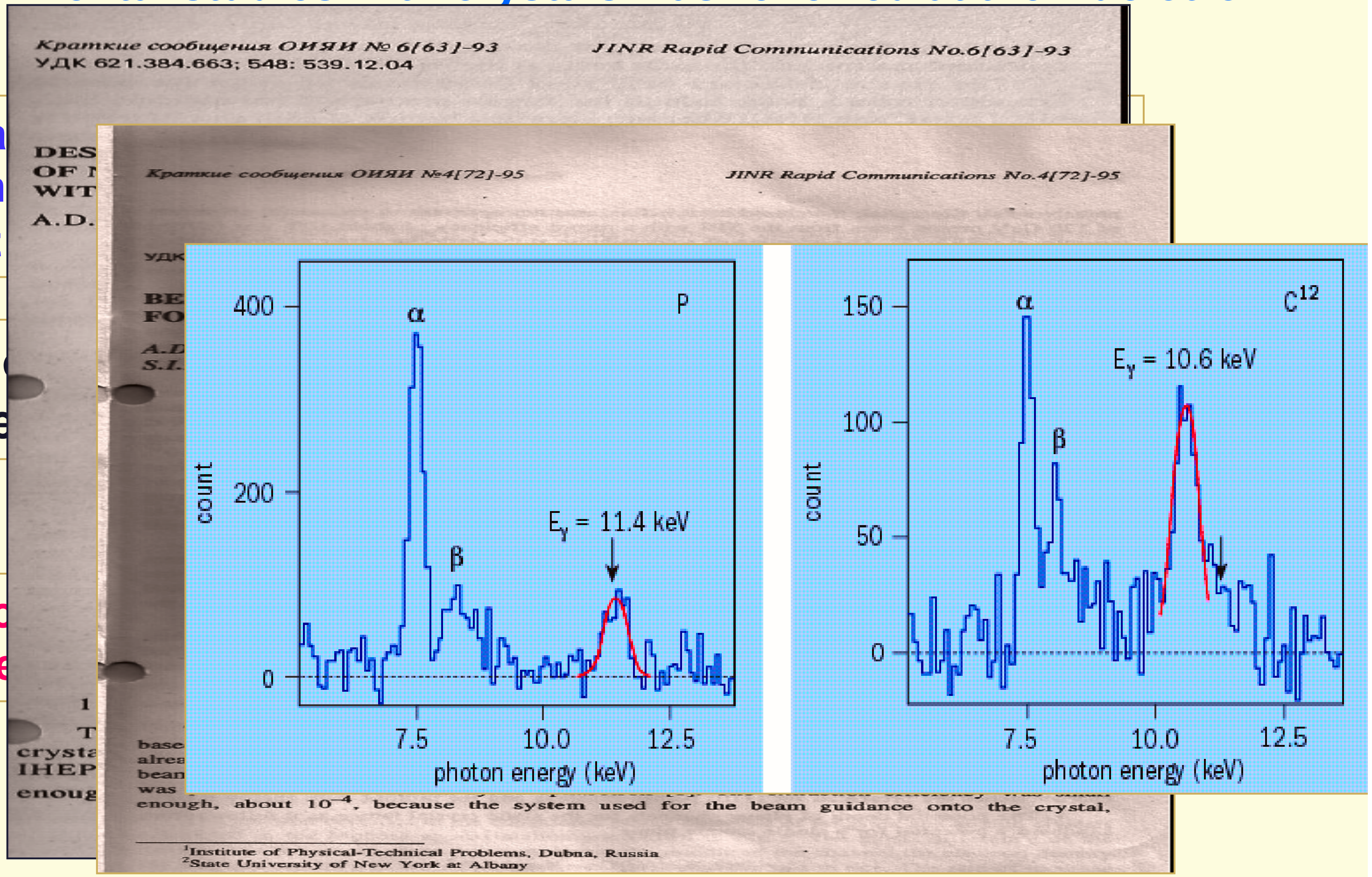
Studies of crystal applications at JINR in the 90’s

In 1995 experimental studies with crystals was renewed at the Nuclotron

- Slow extra
It could be n
efficiency at

- Samples
were studie

- Parametric
energy nucle



Crystal deflectors at SPS CERN lead beam

- The extraction of Pb nuclei with 270 GeV/c·u from the CERN SPS has been made using 4 cm long Si crystal bent along the (110) planes by the angle 8.5 mrad. (1997)

- The extraction efficiency was ~ 10%, *(~ 2 times less than for the the SPS proton beam with the same crystal).* The width of the measured orientation dependence (~50 μrad was also considerably smaller than for the protons.

- These were caused by the reduction of the contribution of multiple passages of nuclei through the crystal due to increase of the losses caused by nuclear interactions for particles do not captured into the channeling regime.

Studies of crystal collimation (1)

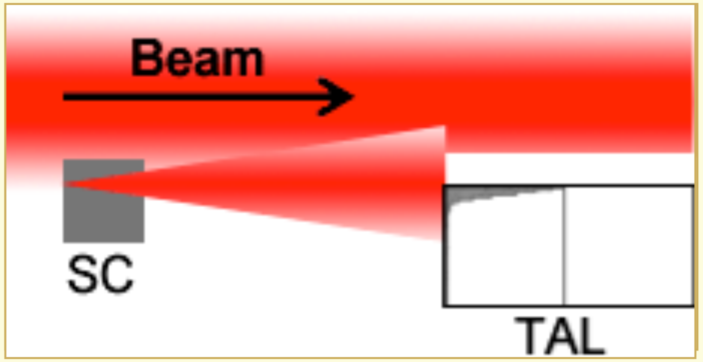
- at SPS CERN lead ion beam

UA9 Collaboration,
Leader: W. Scandale

UA9 collaboration: CERN, INFN (Italy), IHEP, JINR and PNPI (Russia), BNL, FNAL and SLAC (USA), Imperial College, London

UA9 Main research goal:
Test a bent crystal as a primary collimator

Bent crystal can deflect the collider beam halo protons/ions in channeling state directing them onto the absorber.



Number of diffracted protons /ions from crystal primary collimator and the secondary collimator-absorber should be significantly reduced

What does it mean “significantly reduced” and what have been obtained up to now?

Studies of crystal collimation (2)

• at RHIC BNL gold ion beam

• The first experiment on the nuclei collimation has been realized at Au-beam p = 250 GeV/c. (RHIC, BNL)

The 5 mm long Si crystal bent along the (110) planes by the angle 440 μrad was used. The yield of secondary particles generated by the beam halo nuclei in the crystal was measured by the beam loss monitors downstream the crystal.

The beam losses in the crystal were reduced by 25% for the crystal orientation provided the deflection of channeled nuclei.

Studies of crystal collimation (1a)

- In the UA9 experiment one of the 2 mm long Si crystals with the bend angle ~170 μrad was used as a primary collimator.

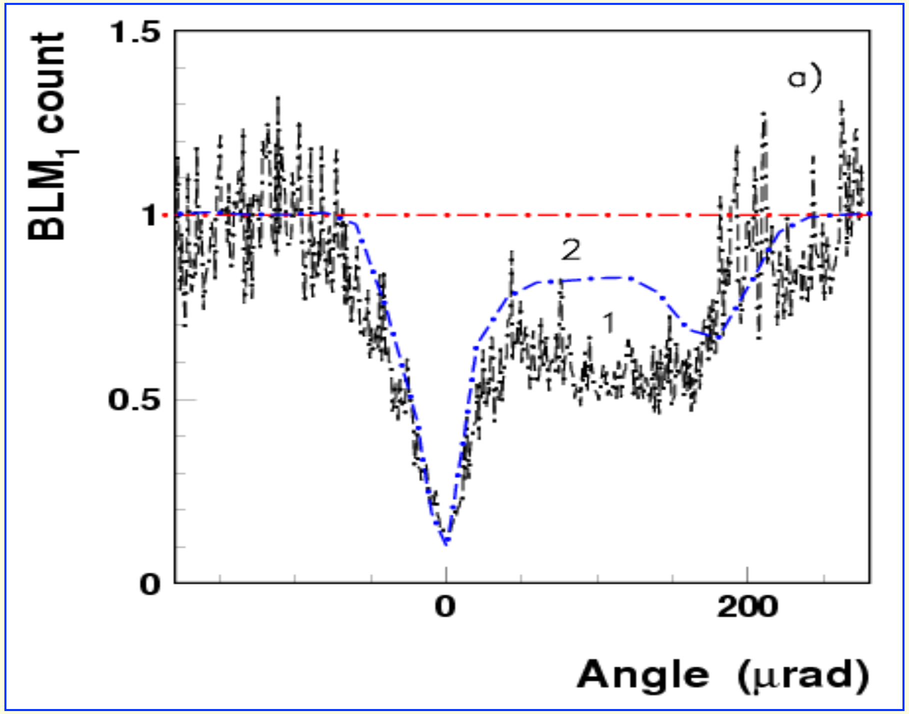
- The studies were performed both with protons and Pb nuclei with p = 120 GeV/c and 270 GeV/c

Crystal collimation of the SPS Pb-beam
(the particle momentum p = 270 GeV/c·u)

The measured and simulated dependences of Pb nuclei losses in the crystal on its orientation.

1 - the beam losses observed in the crystal normalized to the value for the amorphous orientation of the crystal (dot-dashed line).

2 - the simulated number of inelastic nuclear interactions of nuclei in the crystal.



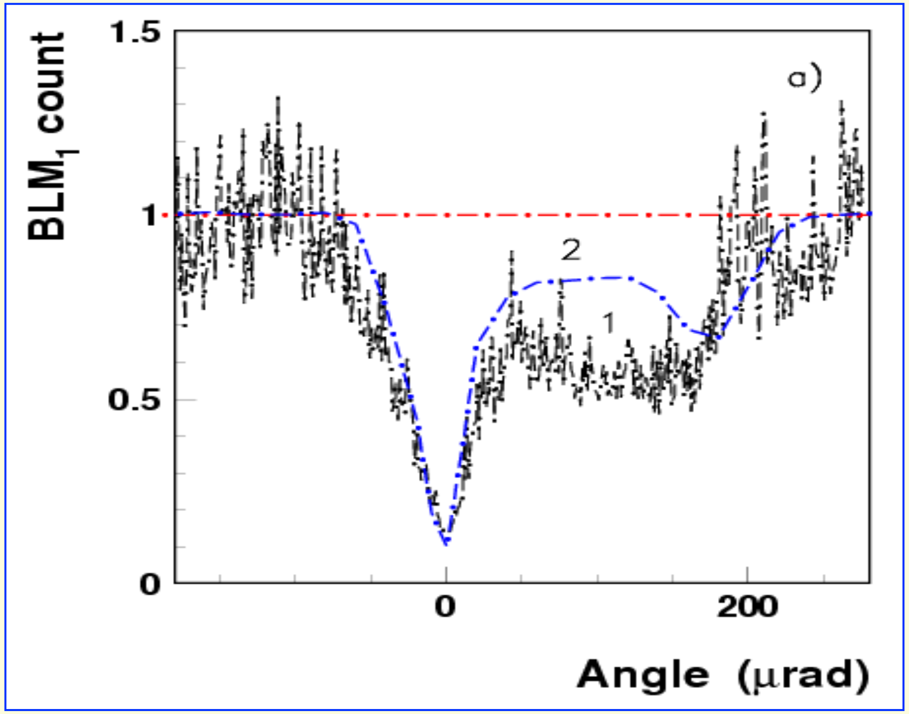
The losses were reduced more than 7 times in the aligned case (a deep minimum near zero).

Crystal collimation of the SPS Pb-beam
(the particle momentum p = 270 GeV/c·u)

The simulation well describe this reduction in the aligned crystal.

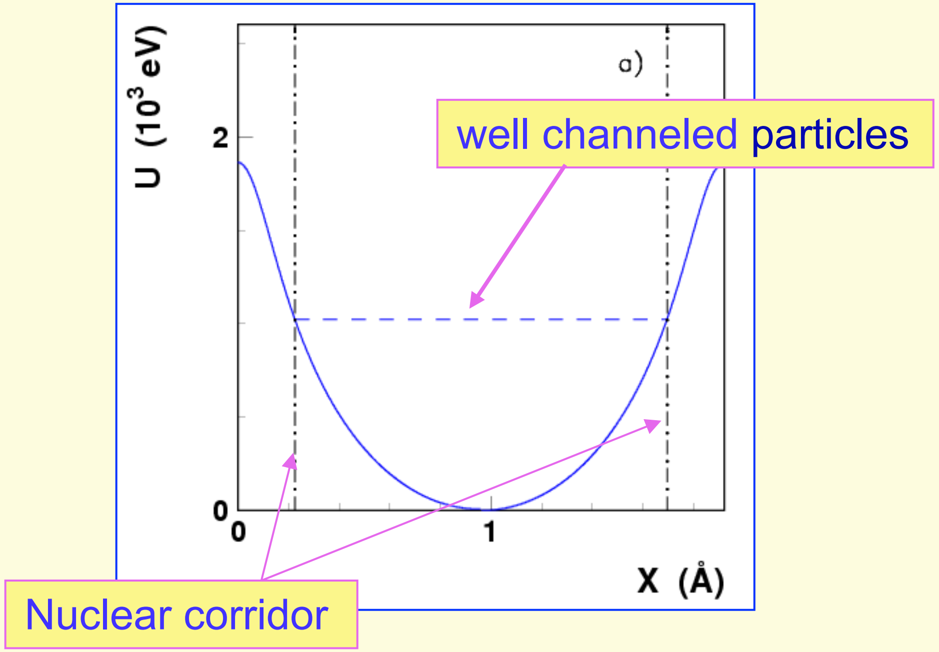
The simulation shows that this reduction value can be provided only when about 90% of particles hitting the crystal are deflected in channeling regime by the bend angle (channeling efficiency).

On the right of the minimum there is the angular region with reduced losses caused by the volume reflection of particles in the crystal.

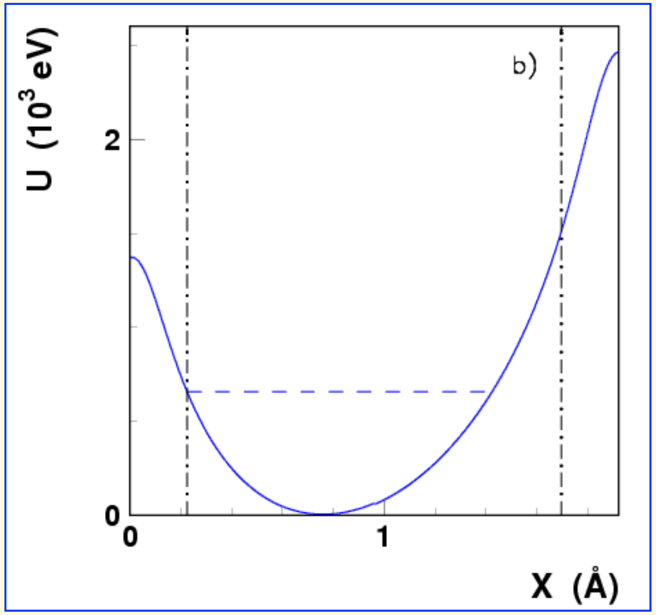


The studies of radiation resistance of the crystals are required.

Crystal collimation of the SPS Pb-beam
(the particle momentum p = 270 GeV/c·u)



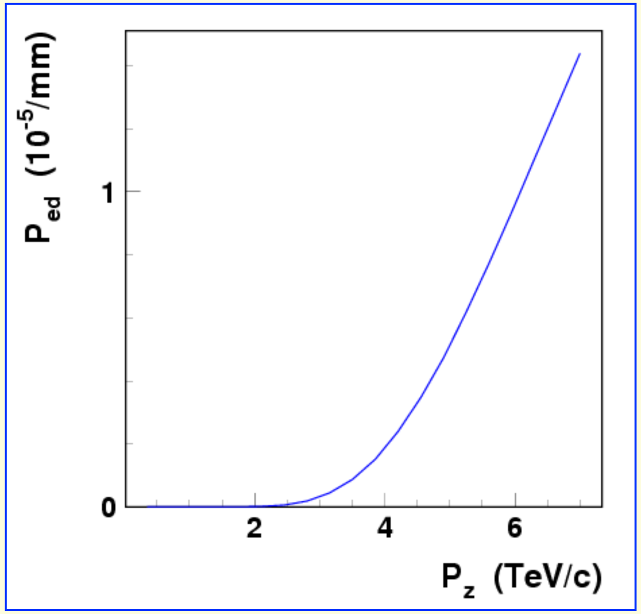
The potential of the (110) planar channel in a silicon crystal for Pb nuclei.

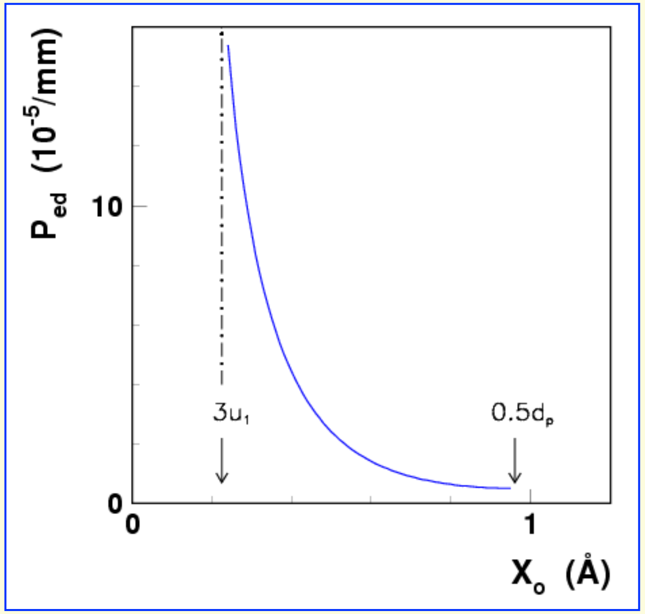


The effective potential of the (110) planar channel bent with R=100 m for Pb nuclei with p = 7 TeV/c.

ED probability for channeled nuclei

(the results of analysis performed by A.Taratin)





•The Si crystals 3-5 mm long are planned to be used for the LHC beam collimation. The losses of the well channeled fraction due to ED is estimated to about 0.01%.

(110) silicon channel.

Bent crystal application for ion beams
(1992-2012)

Brief summary:

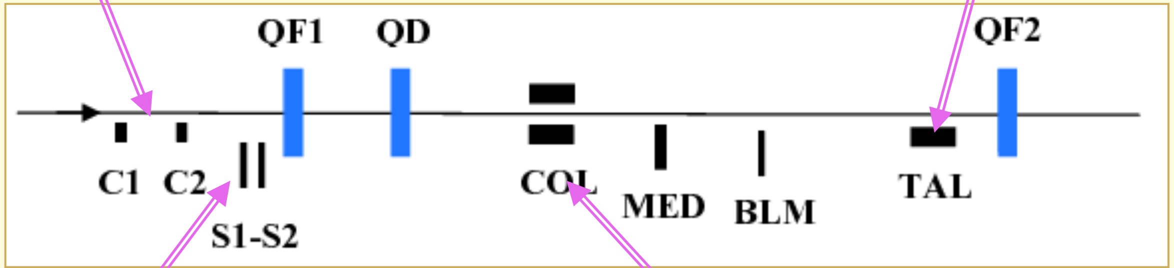
- The experiments performed at JINR, CERN and BNL showed that multi-charged ions are also successfully deflected by bent crystal.
- Collimation efficiency of 90% have been demonstrated at SPS lead beam
- Electromagnetic dissociation (ED) for well channeled Pb-ions in Si crystal at 7 TeV is estimated to about 0.01%
- Radiation hardness of the Si crystals should be tested

THANK YOU
FOR YOUR ATTENTION

UA9 experiment layout

Two crystals C1 and C2 alternatively used as a primary collimator are placed upstream quadrupoles (QF1)

60 cm long tungsten absorber (TAL) used as a secondary collimator



Telescope S1-S2 installed downstream the tank registers the inelastic nuclear interactions of protons with the crystals

Two sided collimator (COL) was used to fix the beam orbit Its inner jaw can be moved to intercept the deflected beam

- The deflected beam was directly observed with a pixel detector MEDIPIX (MED).
- Beam loss monitor (BLM)