TEST AND CHARACTERISATION OF BENT CRYSTAL PROTOTYPES

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Outline

Introduction
- Needs for MDM and EDM measurement
- Channeling in very long crystals

CRYSTALRAD simulation code & Geant4

Experimental and simulation results
- Experimental setup
- Experimental setup implemented in Geant4
- Measured and simulated deflection angle distributions
What we want:
- To measure MDM and EDM

What we have:
- Very divergent beam of short living particles
- Very short lifetime

What we need:
- The bent crystal attached to the target
- Low crystal thickness
- High deflection angle

Crystal thickness must be comparable with the lifedistance of the particle

Critical channeling angle (Lindhard angle)
\[ \theta_L = \sqrt{\frac{2U_0}{pu}} \]

Critical channeling radius
\[ R_{cr} = \frac{pu}{E_0} \]

Peculiarities of bent crystal in SELDOM experiment:
- Very thick bent crystals \(~\text{several cm}\)
- Very high deflection angle \(~15 \text{ mrad}\)
- Low deflection efficiency
- No channeling data either for 180 GeV or for 1 TeV for such crystals

*E.N. Tsyganov, Fermilab TM-682 (1976)

Main conception – tracking of charged particles in a crystal in averaged atomic potential

Program modes:

1D model – particle motion in an interplanar potential
2D model – particle motion in an interaxial potential

Simulation of the different physical processes:

- Multiple and single Coulomb scattering on nuclei and electrons.
- Nuclear scattering
- Ionization energy losses
- Crystal geometry

New: unification of CRYSTAL** and RADCHARM++*** simulation codes into the CRYSTALRAD code to simulate the radiation spectra by Baier-Katkov formula

Advantages:

- High calculation speed
- MPI parallelization for high performance computing

What have we been granted by (2016-2019)?

- FERMI: 200 kh
- GALILEO: 100 kh
- MARCONI: 900 kh

Project VELoce special for SEDDOM simulations. MARCONI: 320 kh


Insertion of CRYSTAL routing inside Geant4: validation on channeling of 855 MeV electrons at Mainz Mikrotron MAMI

SELDOM setup in experiment at CERN SPS H8

Beam $p, \pi^+$
180 GeV
SELDOM setup: the bent crystals

**Si**
- length: 8 cm
- bending angle: 16 mrad
- planes: (111)

**Ge**
- length: 5.5 cm
- bending angle: 14.7 mrad
- planes: (110)

*Ge is shorter with a factor 1.5 than Si*

Every crystal was mounted on high precision goniometer

Characterized with XRD in Ferrara

Made in Ferrara
Beam:
- r.m.s. size: 1 mm
- angular divergence: 24 μrad
- protons 180 GeV: 2/3
- pions π⁺ 180 GeV: 1/3

tele1 & tele2:
- Si 0.3 mm thick
- 2 layers of Al: each 0.1 mm thick

World material: G4_AIR

BC1 & BC2:
- 2 layers of Si: each 0.41 mm thick
- 2 layers of Al: each 0.1 mm thick

Definition of angles:
\[ \theta_{in} = \frac{(z_2 - z_1)}{L_{12}} \]
\[ \theta_{out} = \frac{(z_4 - z_3)}{L_{34}} \]
\[ \theta_{defl} = \theta_{out} - \theta_{in} \]
Visualization of Geant4 simulations: secondary particles

bent crystal

tele2

beam

tele1

tele2

bent crystal

BC1

BC2
In each silicon layer for each particle we score:
- X, Y positions
- $\theta_x, \theta_y$ angles
- deposited energy
- particle type

We consider: deposited energy $\sim$ charge collected

We calculate the initial and deflection angle distribution $\theta_{in}$ and $\theta_{defl}$

We distinguish single and multiple events

We keep only single events (At all the strip detectors)
Tracker to measure the incidence angle

Angular uncertainty of initial angle estimated by Geant4 simulations: \(~7 \mu\text{rad}\)

Non zero resolution reasons:
- Scattering on Si and Al
- Scattering on air in and after the tracker
- Space charge distribution and strip size
- Multiple events

These factors were considered in simulations
Experimental vs simulation results for Si bent crystal

Initial angle cut: \( \pm 20 \mu \text{rad} \)

Deflection efficiency (in agreement with analysis by Milano group):
- Experiment: \( 11 \pm 2 \) %
- Simulations: \( 13 \pm 1 \) %
Experimental vs simulation results for Ge bent crystal

Initial angle cut: \( \pm 20 \mu \text{rad} \)

Deflection efficiency (in agreement with analysis by Milano group):
- Experiment: \( 13 \pm 2 \% \)
- Simulations: \( 15 \pm 1 \% \)

Ge is thinner but more efficient than Si
Experimental vs simulation results for Si bent crystal: effect of strips of the tracker on the deflection of the outgoing angle.

**Peaks** in the deflection angle distribution are connected with:
- Strip size
- The distance between strip detectors

Angular **uncertainty** of the outgoing angle $\approx 50 \, \mu$rad
Important contribution into experimental and simulation results of INFN Milano Group

Deflection angle vs $\theta_{out}$ in xz plane
- non-channelled particles
Conclusions

Channeling of 180 GeV protons and pions in very long Si and Ge bent crystals was observed.

Ge crystal is more efficient than the Si one and thinner which is very important for the MDM and EDM measurements.

All the experimental results were reproduced by simulations using Geant4 with CRystal routine and complete experimental setup implemented.

Channeling of 1 TeV exotic baryons will be less efficient but still possible in SELDOM experiment.
Thank you for attention!