Channeling 2010

Deflection of high-energy negative particles in a bent crystal through axial channeling and multiple volume reflection stimulated by doughnut scattering

E. Bagli, V. Guidi, **A. Mazzolari**, W. Scandale and A.M. Taratin
On behalf of UA9 collaboration

Ferrara, October 5, 2010

Sensor and Semiconductor Laboratory

INFN Istituto Nazionale di Fisica Nucleare

Outlook

- Deflection of high energy negative particles through interaction with crystalline axis
- Doughnut scattering of particles in straight crystal
- Doughnut scattering of particles in bent crystal
- Experimental apparatus
- Deflection in DSB regime for perfect alignment with axis
- Interesting peculiarity – vertical beam deflection
- Deflection for orientations far from a perfect alignment

Deflection of particle beams through interaction with crystalline axis

We observed deflection of 150 GeV π^- by the <111> axis of a bent silicon crystal through different mechanisms

1. multiple scattering of π^- mesons by bent atomic strings:

   Doughnut Scattering Bound (DSB) → quasi-bound states, particles follows the bent axis

   Doughnut Scattering UnBound (DSUB) → particles don't follow the bend

2. Volume capture by crystal axis

3. Multiple volume reflection in one crystal, assisted by DSUB

Doughnut scattering of particles in straight crystal

Multiple scatterings by atomic strings particles with orientation angle ψ are distributed along a circle with the radius ψ around the axis direction. Therefore this scattering was called “doughnut scattering” (DS)

Crystal length required to obtain a full randomization of the transverse momentums of particles (equalization length) was suggested by Lindhard

$$\psi_1 = \sqrt{\frac{4Z_1Z_2e^2}{pvd}}, \qquad \lambda_1 = \lambda(\psi_1) = \frac{4}{\pi^2 N d a \psi_1},$$

For 150 GeV π^- mesons in Si crystal along <111> axis ψ_1=33.8 μrad and λ_1=26.3 μm

Doughnut scattering of particles in bent crystal

A) Deflection condition of particles by a bent crystal through DS regime was formulated by Shulga and Greenenko

If this condition is satisfied, particles have time to “finish” the momentum randomization around the changing angular position of axis – quasi-bound states (DSB)

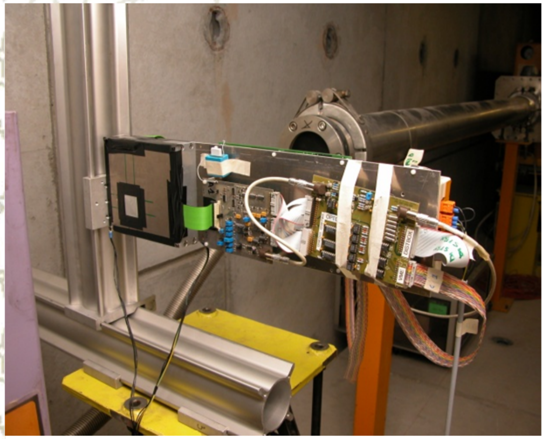
$$\overline{\psi^2} = \frac{\lambda L}{R^2} \le \psi_1^2$$

Randomization center of particle momentums is in the angular position of axis, it shifts with the penetration of a particle into a bent crystal

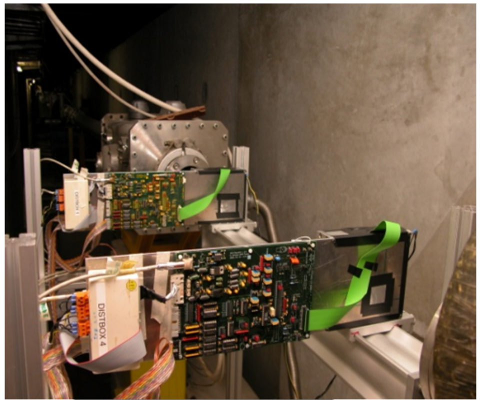
B) For unbound states of doughnut scattering (DSUB) randomization radius, determined by transverse particle momentum, changes with changing the angular position of axis

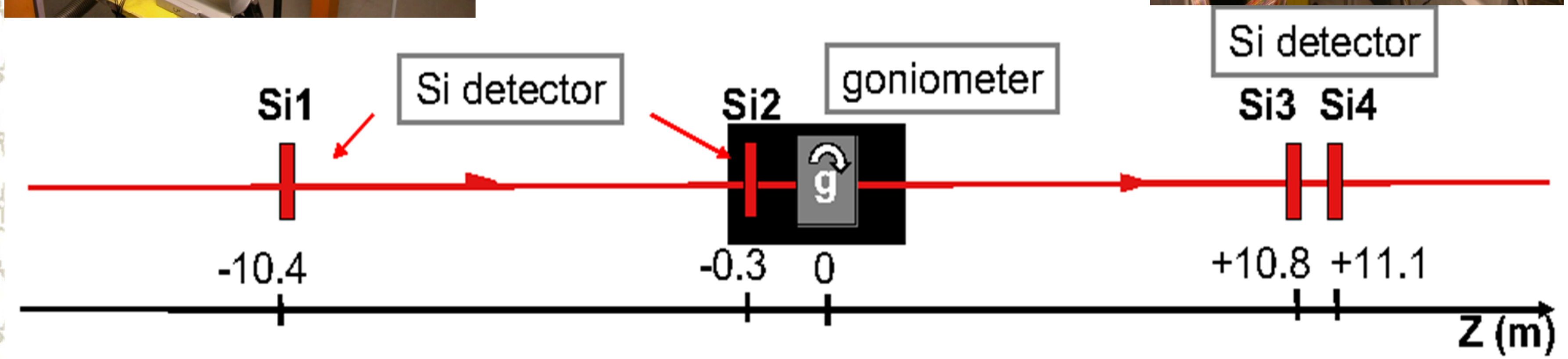
Experimental apparatus

Four microstrip silicon detectors, two upstream and two downstream of the crystal were used to measure the particle angles with resolution of σ_a=3 μrad



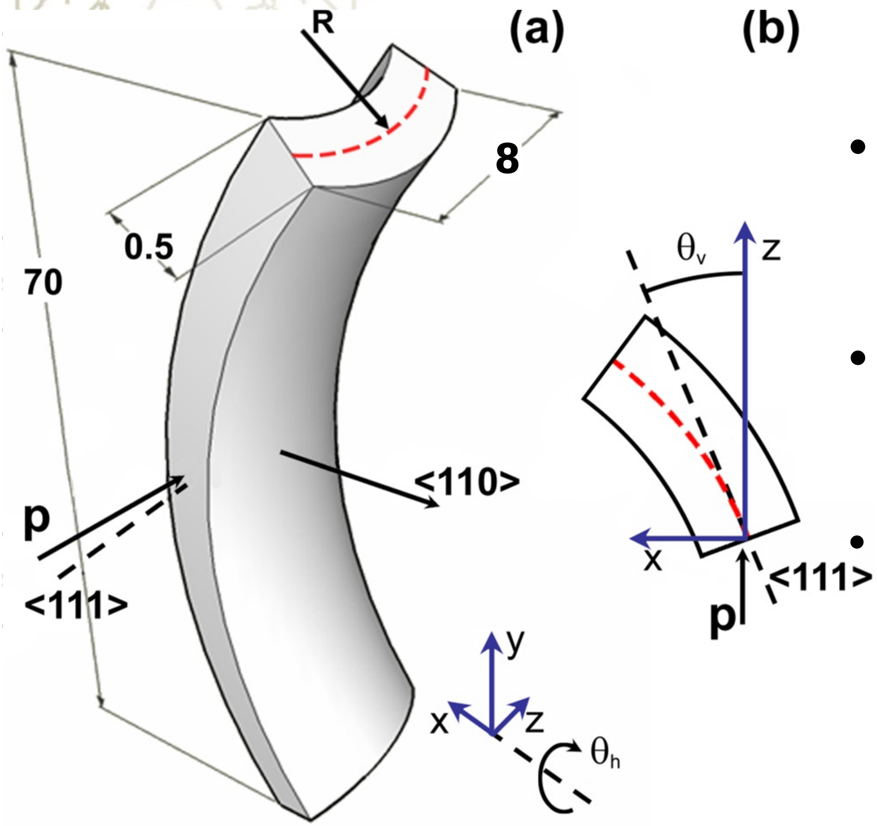
- 1.92×1.92 cm^2 telescopes with reading steps 50 μm
- Spatial resolution:5 μm
- DAQ rate = 2.1 kHz





Experimental apparatus

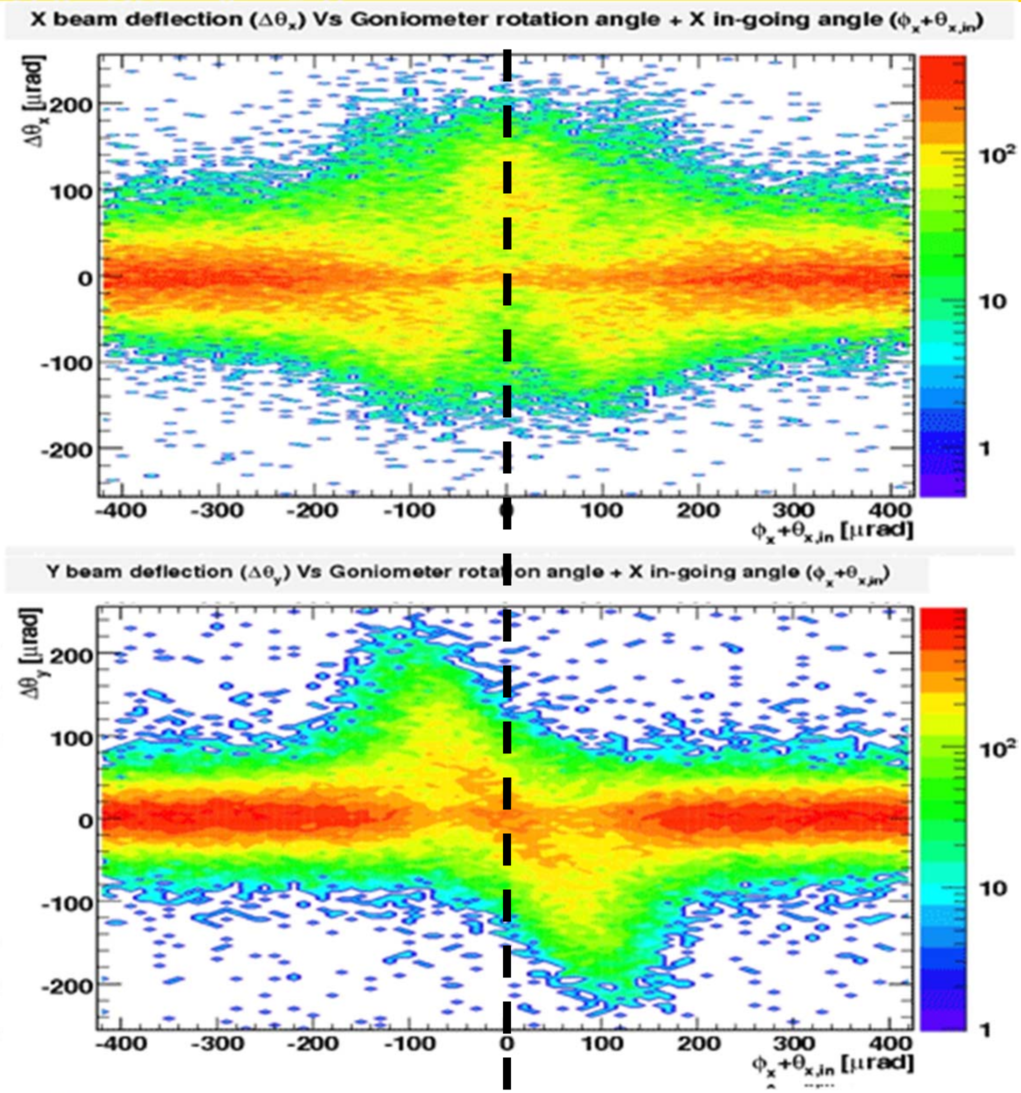
Silicon strip crystal, anticlastic bending



- $70 \times 8 \times 0.3$ mm^3 silicon strip was bent along its length
- Bend angle was measured with 400 GeV/c proton beam, α=185 μrad.
- Condition for particle deflection in DSB regime was fulfilled

$$\overline{\psi^2} = 0.098\psi_1^2$$

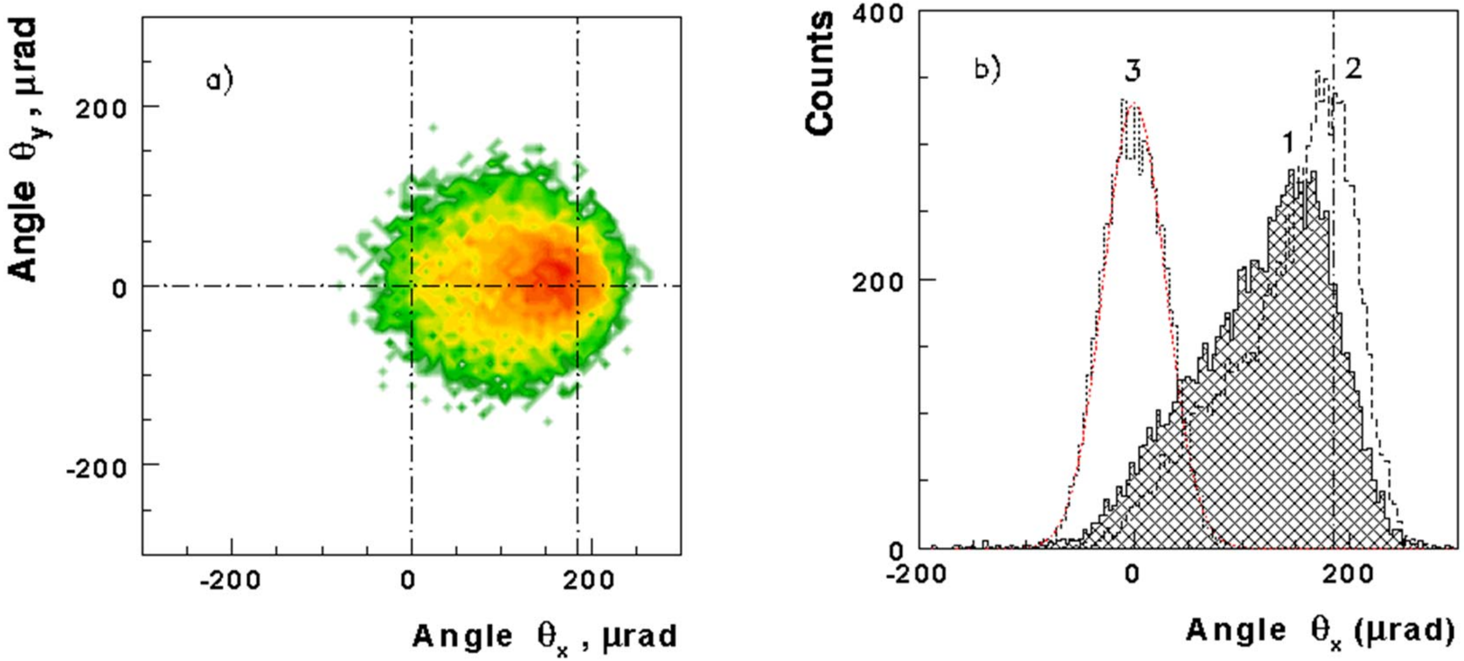
Searching for <111> axis



- Cradle scan
- Deflection in horizontal direction
- Deflection in vertical direction

Deflection in DSB regime for perfect alignment with axis

Only particles with divergence less than 10 μrad are selected



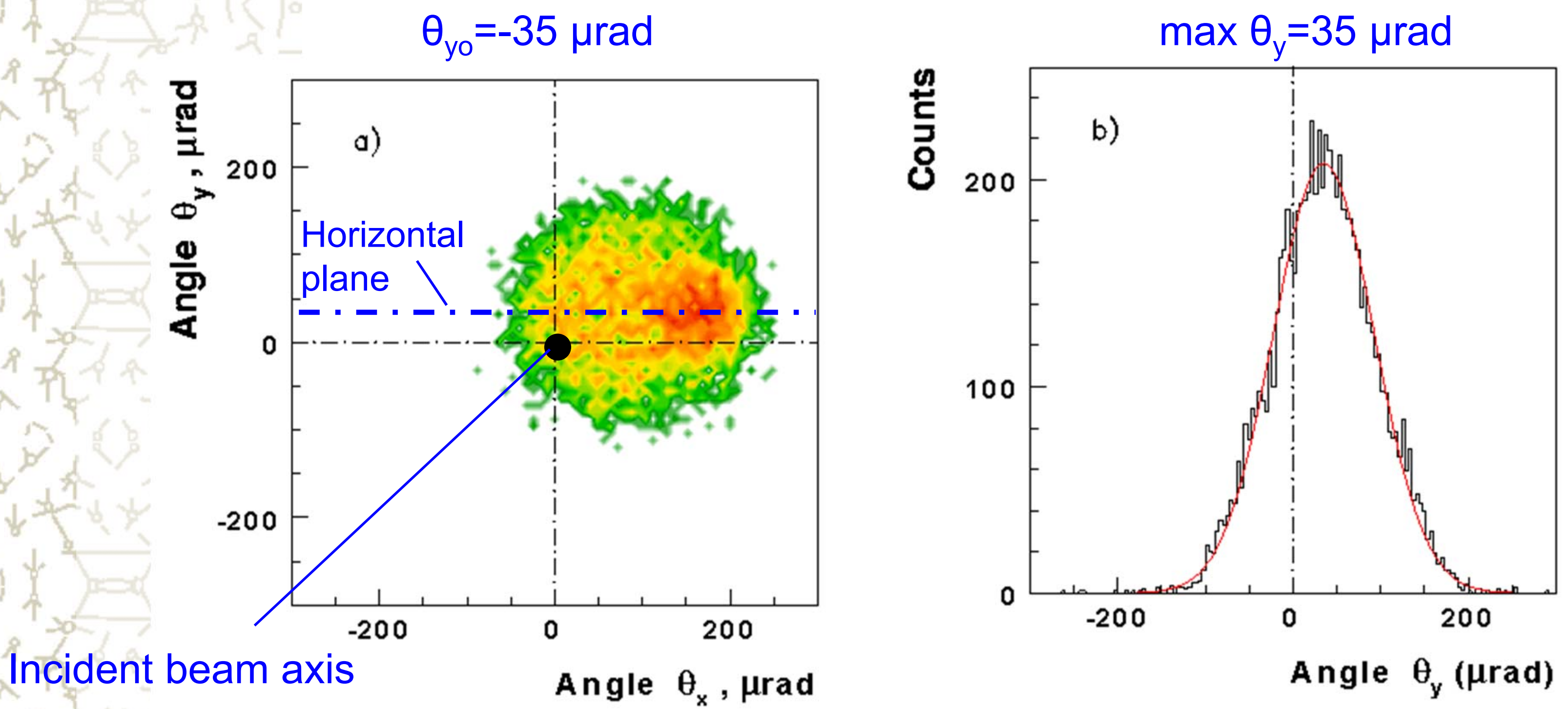
Distribution maximum at $\theta_x < \alpha$ because of the crystal torsion

Deflection efficiency $P_d(\theta_x > 0) = 95.4$ %

2, 3 – simulation results 3 – for straight crystal

Interesting peculiarity – vertical beam deflection

Beam incident with $\theta_{yo} \leq \psi_1$ is deflected to the vertical direction

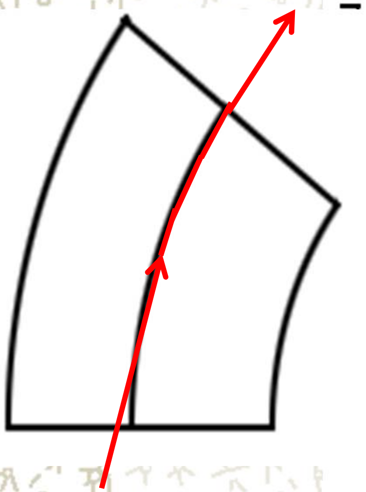


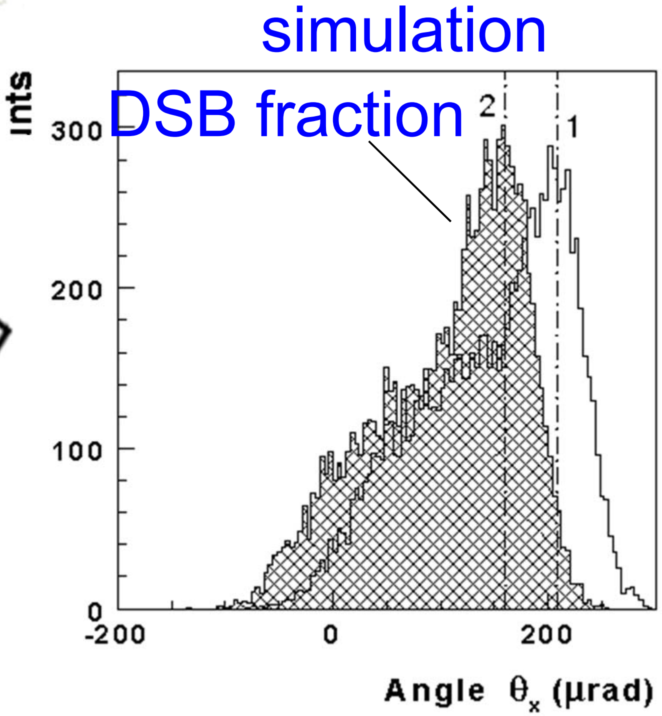
- For narrow beam fraction deflected in DSB regime maximum position of the vertical deflection angles is at $\theta_y = -\theta_{y0}$
- In DSUB regime vertical deflection occurs also but its value is smaller than θ_{y0}

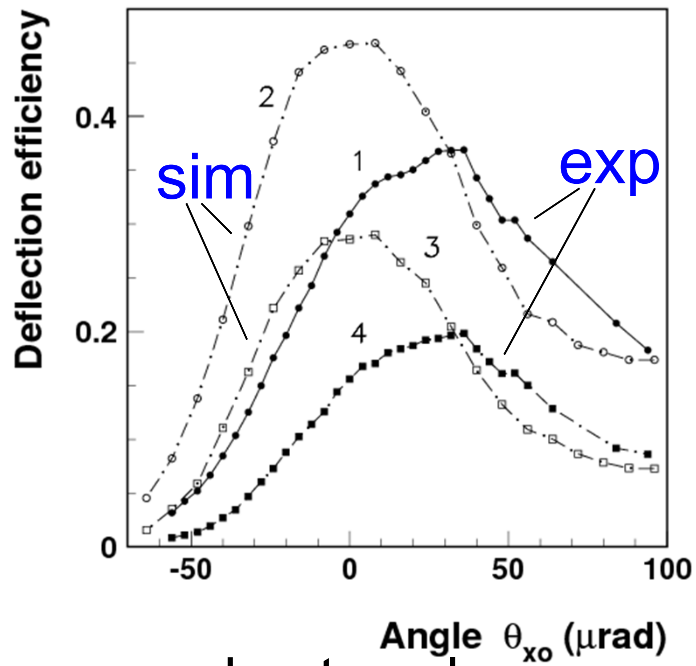
Observation of volume capture of particles in DSB regime

Deflection angle distributions for θ_{xo}=-24 μrad (1) and 24 μrad (2)

DSB fractions (3) and (4) vs θ_{xo} and fractions deflected with $|\theta_x-\theta_{xd}|$ < 32 μrad (1) and (2)



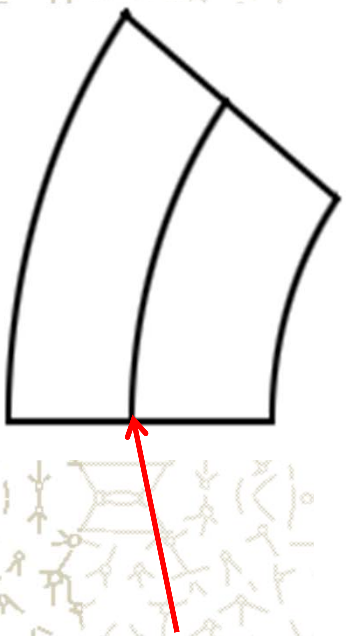


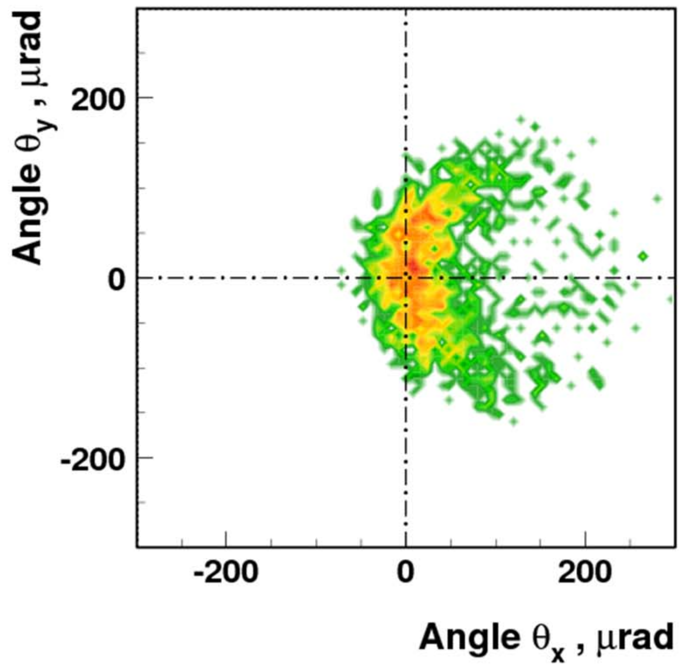


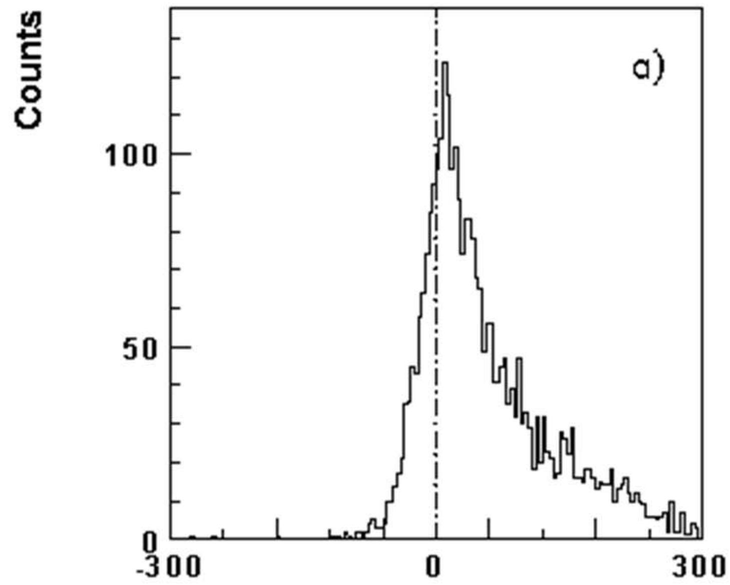
For incident angles $|\theta_{xo}|>\psi_1$ DSB fraction appears due to volume capture (VC). VC of particles in DSB regime exists along the whole arc of crystal bend Its probability equals about 7%

Deflection for orientations far from a perfect alignment

Beam incident angle θ_{xo}=-50 μrad – direction opposite to the bending direction



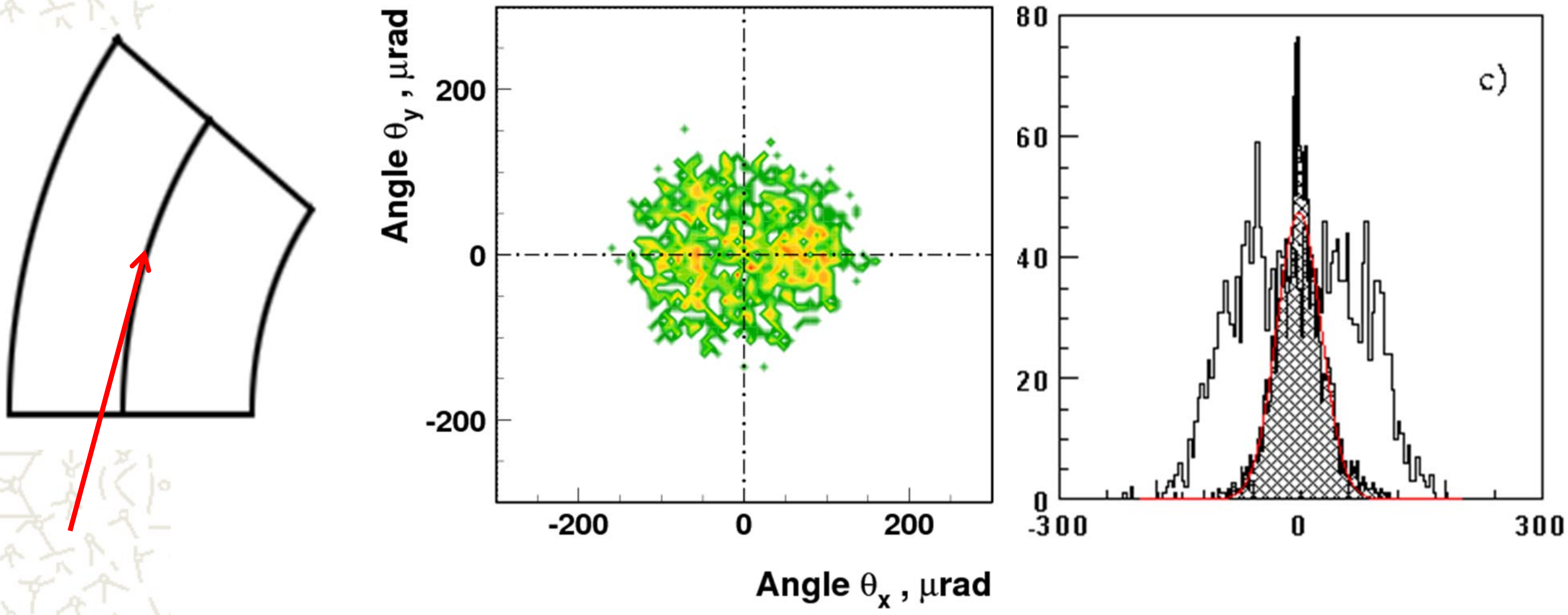




- Unbound states (DSUB) forms an arc distribution
- Maximum in deflection angles is about zero

Deflection for orientations far from a perfect alignment

- Beam incident angle $\theta_{xo} \approx \alpha/2$



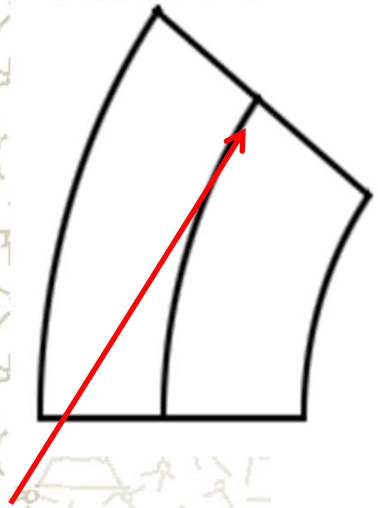
Hatched histogram is a distribution for amorphous orientation

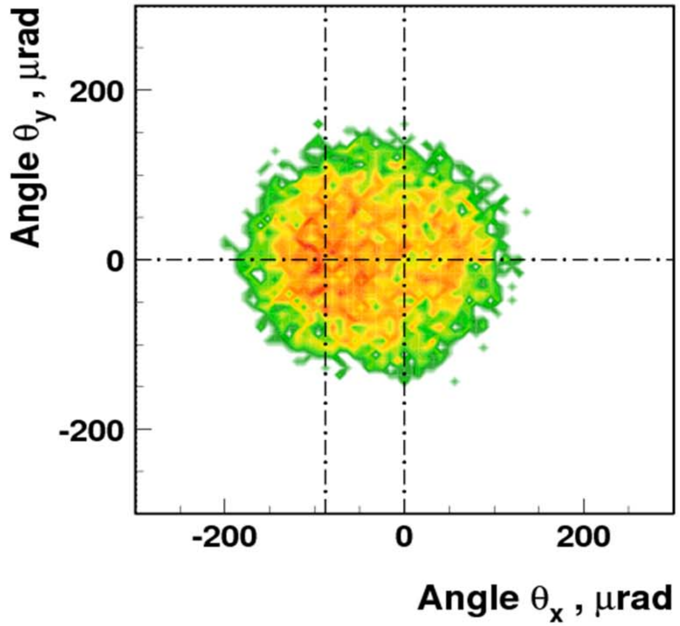
Deflection angle distribution is broadened three times with respect to amorphous alignment and centered at $\theta_x=0$

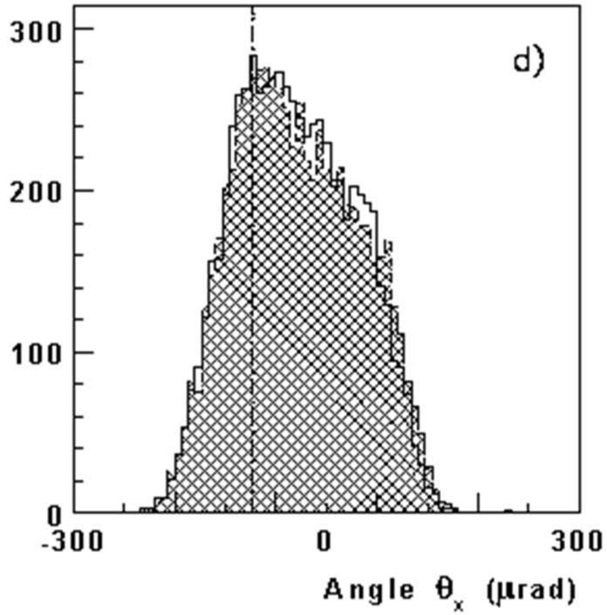
Deflection for orientations far from a perfect alignment

Incident angle $\theta_{xo} > \alpha/2$

Maximum is on the side opposite to the bend at θ_x=-88 μrad





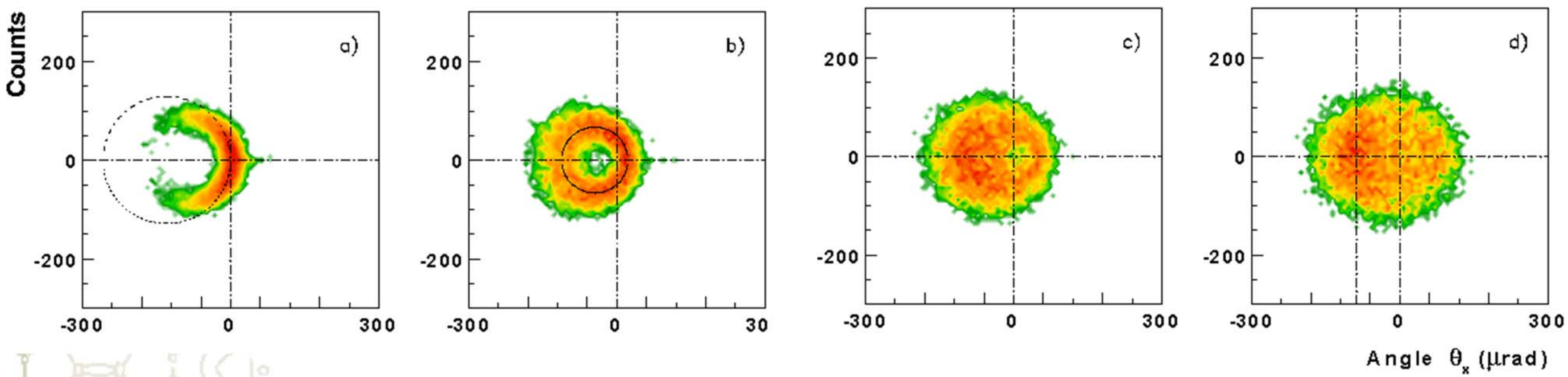


Effect MVR OC occurs when $\alpha:\theta_{xo}:\theta_{yo}=4:2:1$ and $\theta_{yo} >> \psi_1$

θ_{yo} is about zero → MVR OC cannot occur near the crystal entrance

Analysis with depth penetration (simulation)

Particles obtain large vertical momentums and some negative deflections
This leads to the realization of the MVR OC for a large part of the beam

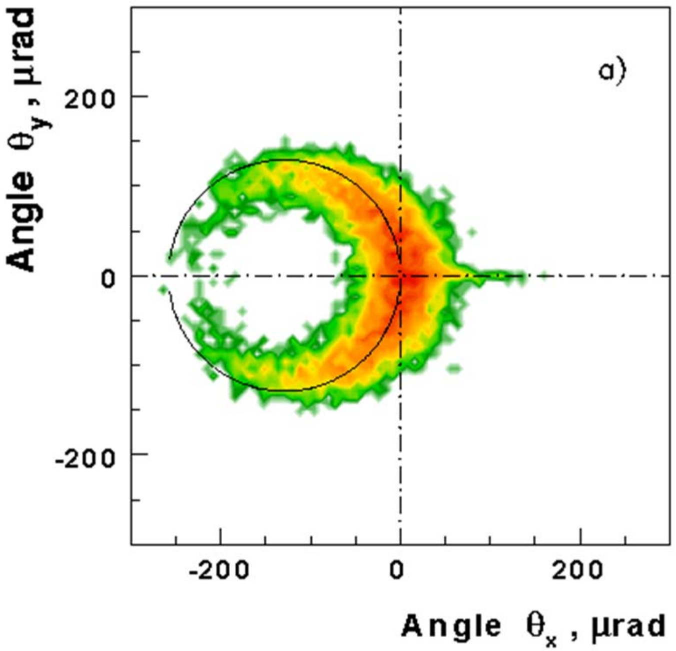


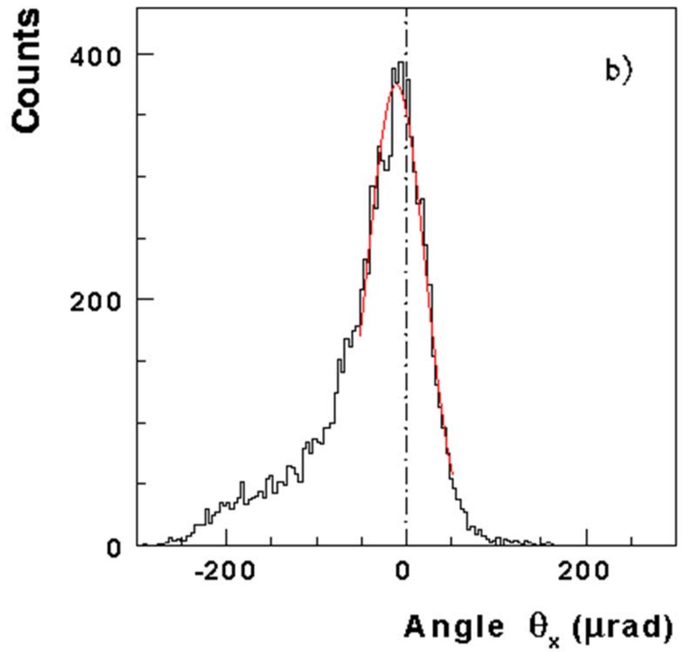
2 mm 4 mm 6 mm 8 mm

So, due to doughnut scattering in unbound regime near the entrance particles perform MVR OC in the following layers of the crystal

Comparison with a straight crystal for the same orientation

For the same incident angle of the beam with <111> axis of a straight crystal of the same length (simulation)





Randomization around the axis direction with radius about θ_{xo}

The distribution maximum remains about zero

Thank you

Thank you