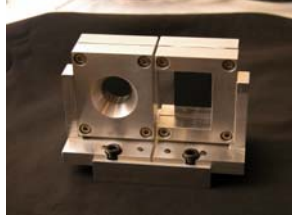


OBSERVATION OF PROTON REFLECTION ON BENT SILICON CRYSTALS AT THE CERN-SPS

Walter Scandale *CERN*

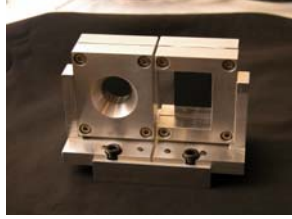
For the H8-RD22 collaboration

(CERN, FNAL, INFN, IHEP, JINR, PNPI)

PAC07

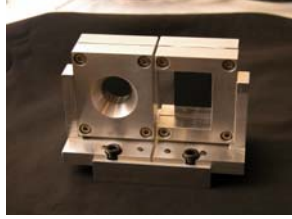
26 June 2007

Outlook



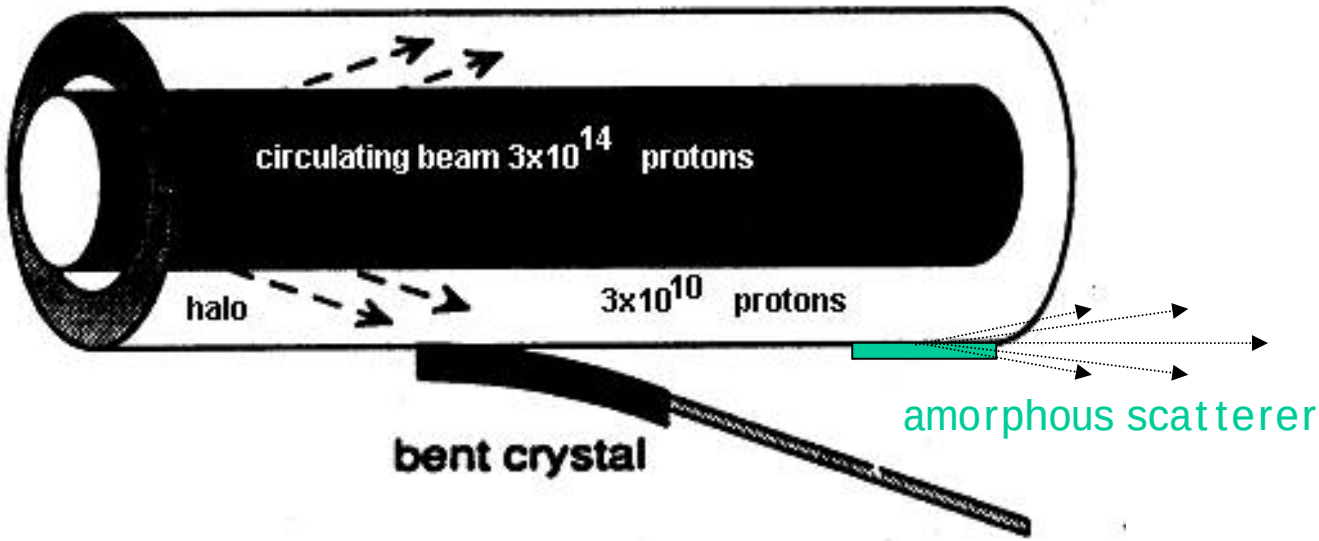
- Why using crystals in hadron colliders
- The H8-RD22 experiment at CERN
  - Experimental layout
  - High precision goniometric system
  - Tracking detectors
  - Silicon crystals
- The results of the 2006 run
  - Crystal Angular Scans (Strip and Quasi-Mosaic Crystals)
  - deflection
  - Efficiency
- Breaking news from the 2007 run

Why using crystals in hadron colliders



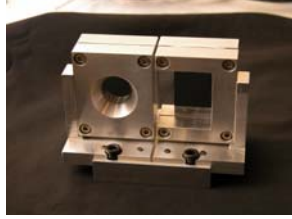
Crystal collimation: a smart approach for primary collimation

- A bent crystal deflects halo particles toward a downstream absorber:
  - the selective and coherent scattering on atomic planes of an aligned Si-crystal may replace more efficiently
  - the random scattering process on single atoms of an amorphous scatterer.



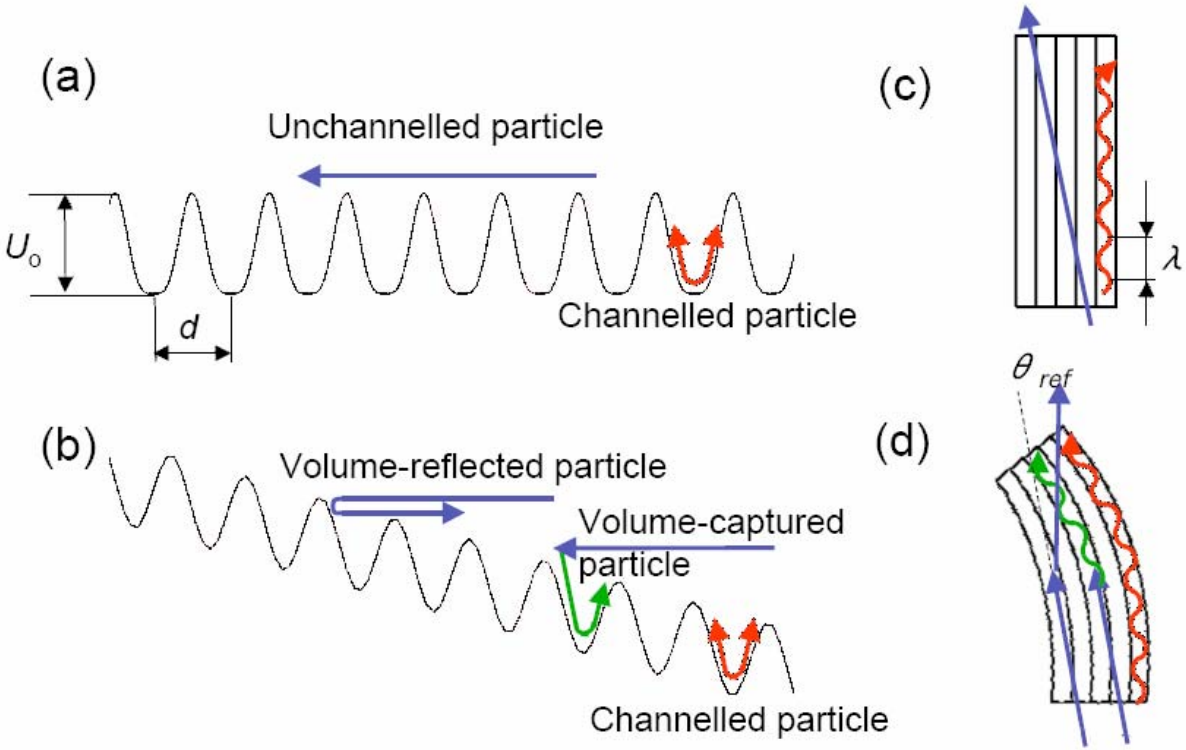
E. Tsyganov & A. Taratin (1991)

Particle-crystal interaction



Possible processes:

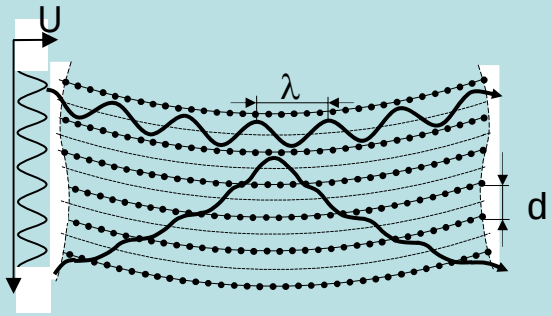
- multiple scattering
- channeling
- volume capture
- de-channeling
- *volume reflection*



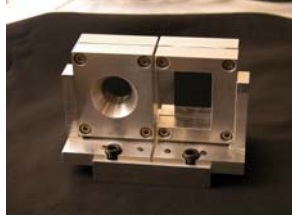
Volume reflection

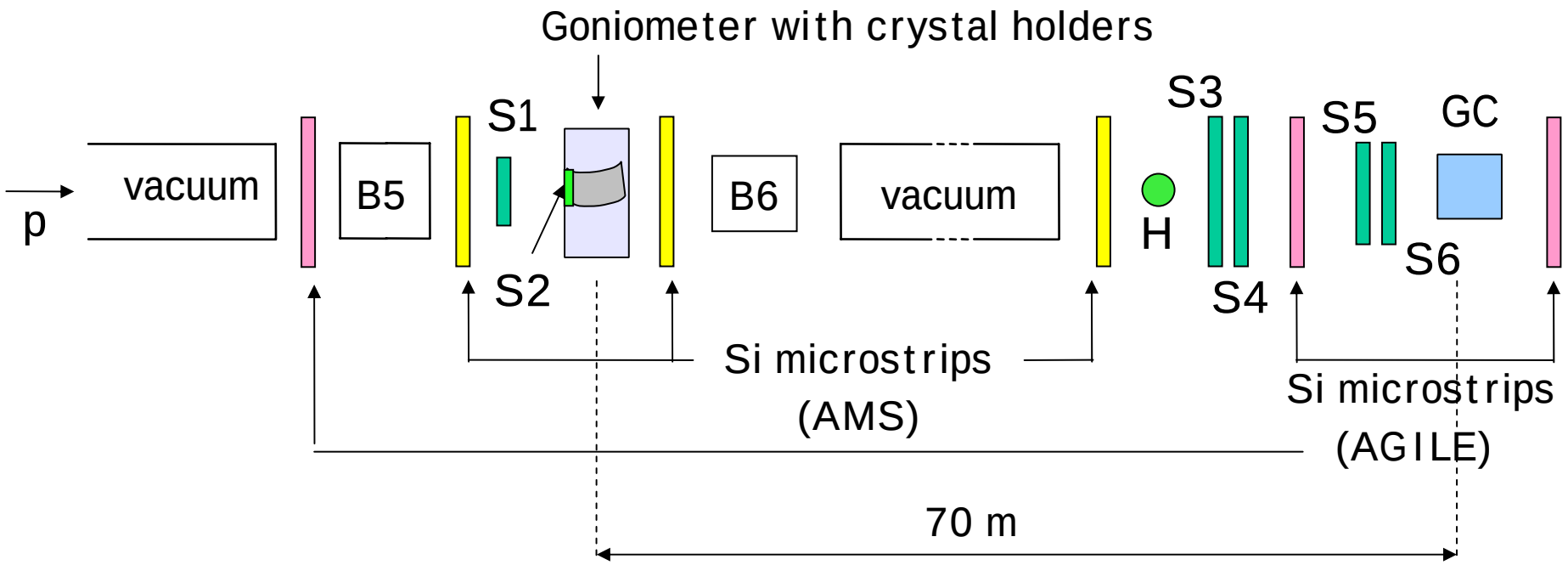
Prediction in 1985-'87 by
A.M.Taratin and S.A.Vorobiev,

First observation 2006 (IHEP - PNPI - CERN)



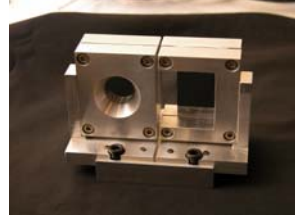
The H8RD22 apparatus



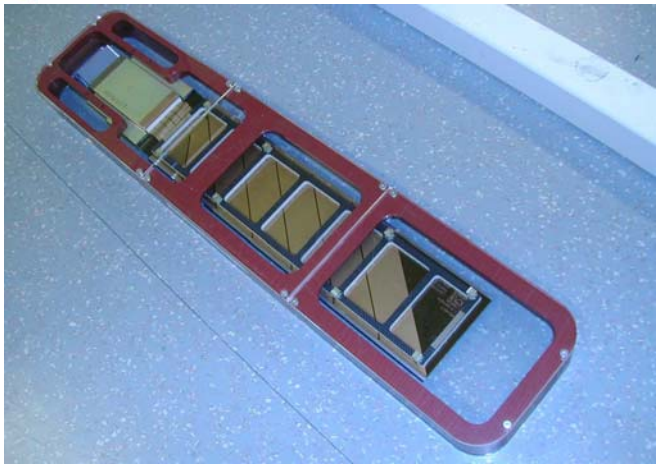


- The scintillators S1-S6 produce the trigger
- The Si microstrips (AMS & AGILE) give the particle tracks
- The gas chamber (GS) and the hodoscope (H) provide a fast beam profile
- The goniometer orients the crystal respect to the incoming beam direction

Si microstrips

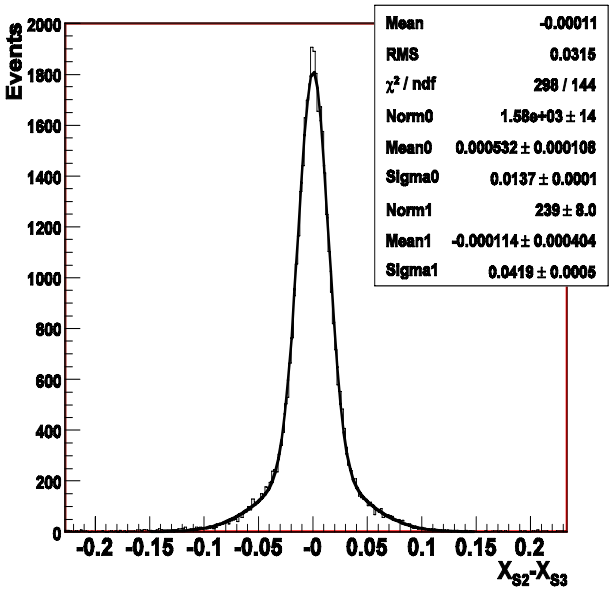


AMS

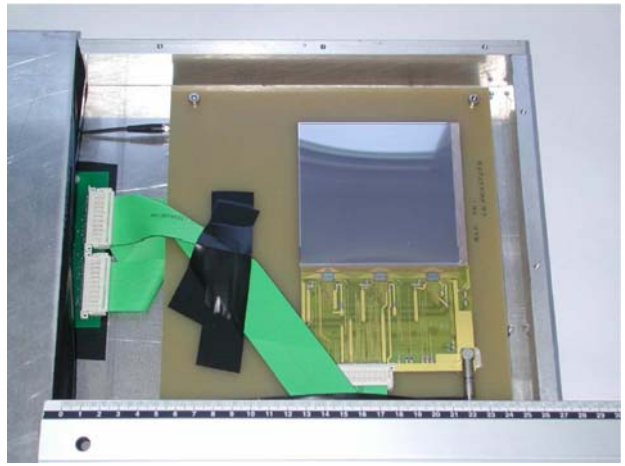


Built at INFN - Perugia

pitch 110 μm, σ =14μm

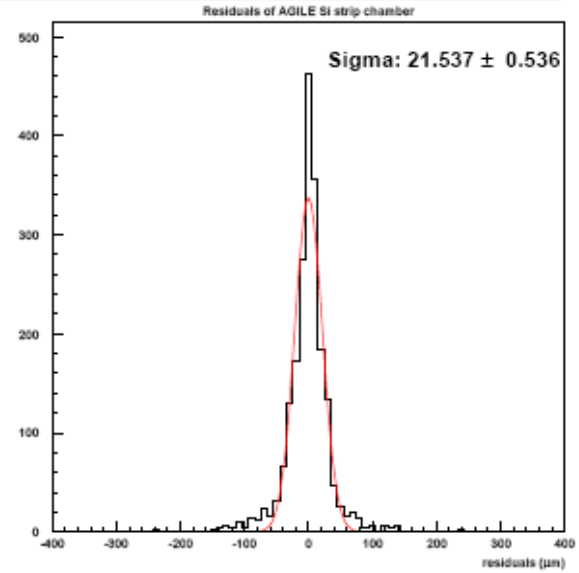


AGILE



Built at INFN - Como & Trieste

pitch 242 μm, σ =22μm

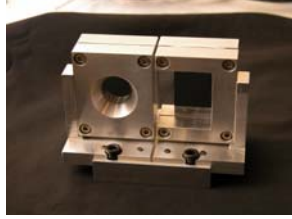


ion on bent cr

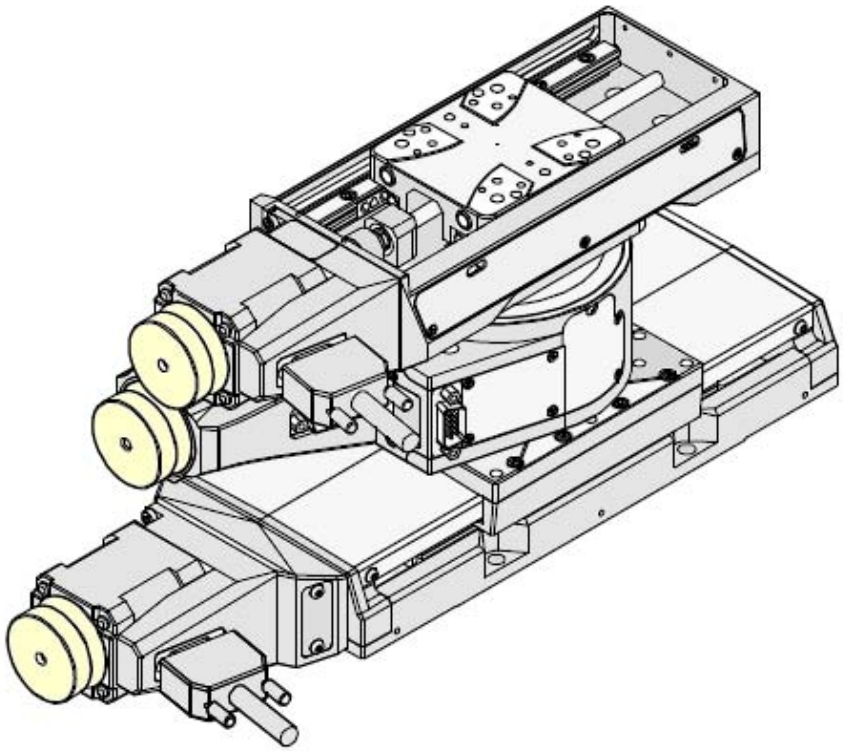
2

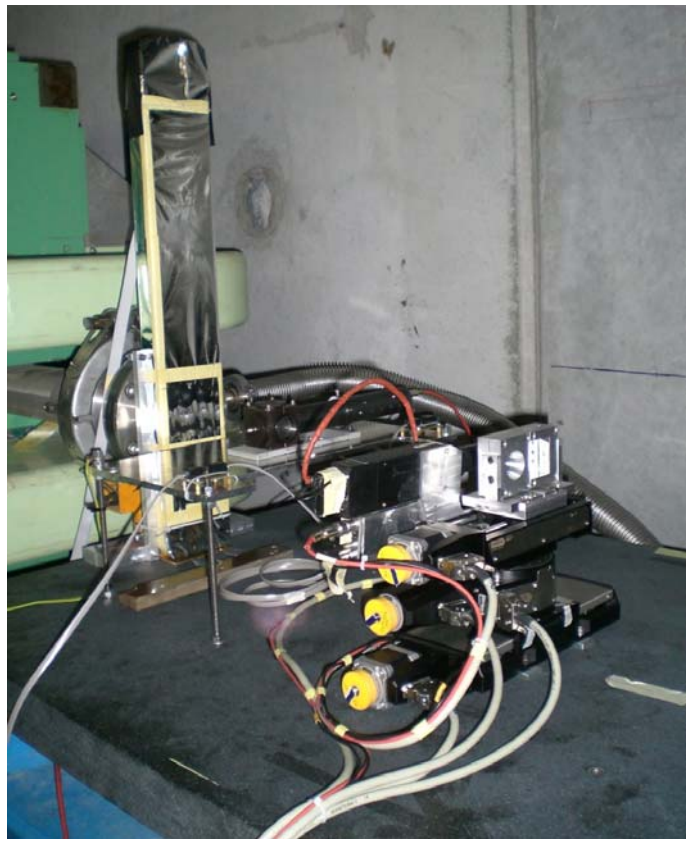
Goniometer

Assembled at INFN - Legnaro

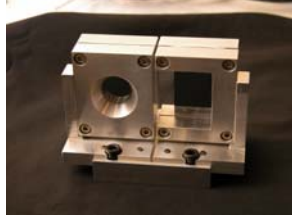


- Two motors for translations
  - 2 μm repeatability
  - 102 mm range (upper stage)
  - 52 mm range (lower stage)
- One motor for rotations
  - 360° range
  - 1.5 μrad precision
  - 1 μrad repeatability



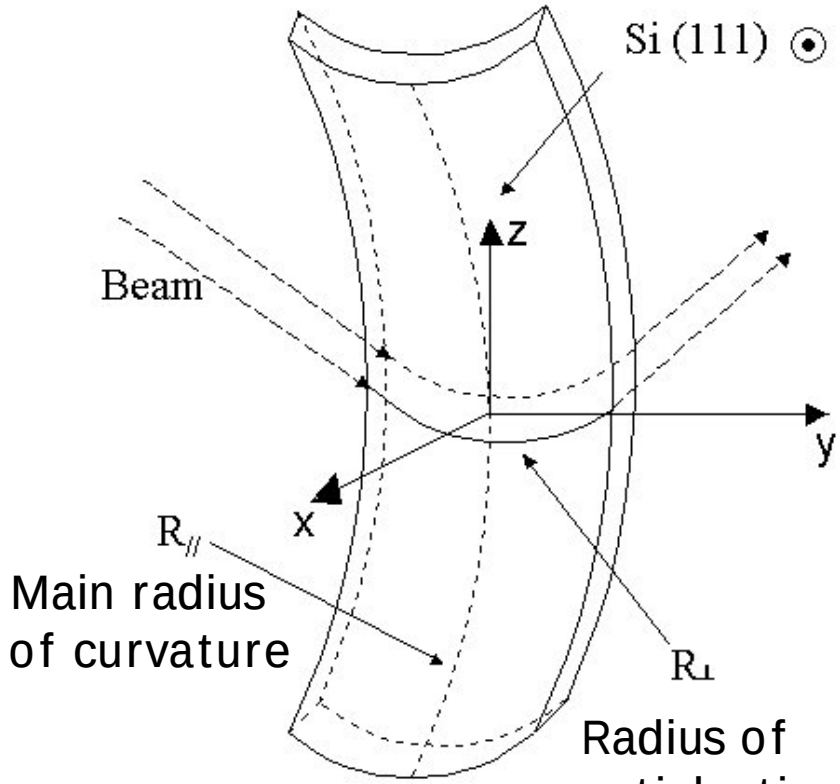


Strip crystals



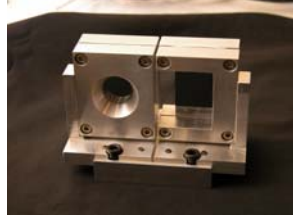
Built at IHEP - Protvino and at INFN - Ferrara

The main curvature due to external forces induces the anticlastic curvature seen by the beam

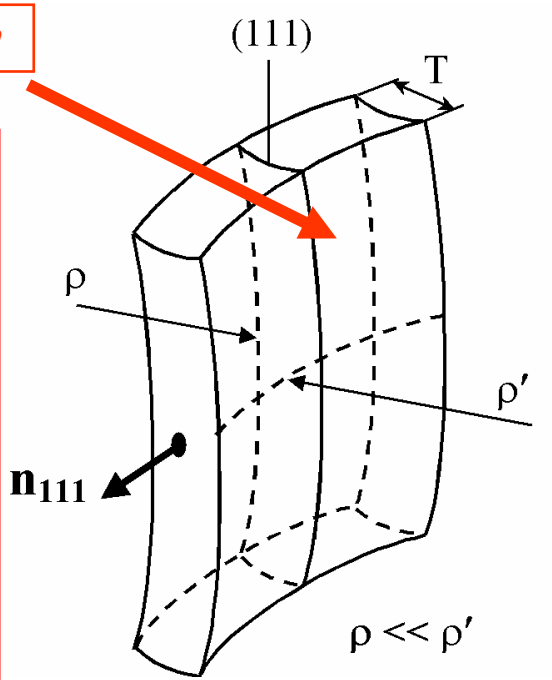


Quasimosaic crystals

Built at PNPI - Gatchina

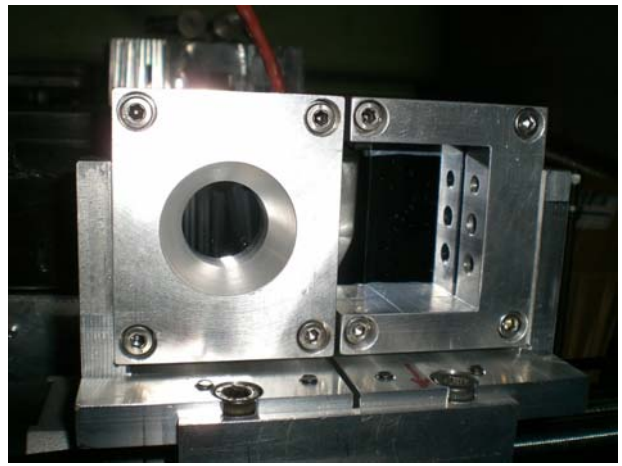


Beam direction



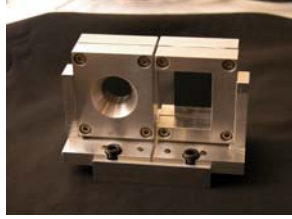
Quasi-Mosaic effect (Sumbaev , 1957)

- The crystal is cut parallel to the planes (111).
- An external force induce the main curvature.
- The anticlastic effect produces a secondary curvature
- The anisotropy of the elastic tensor induces a curvature of the crystal planes parallel to the small face.



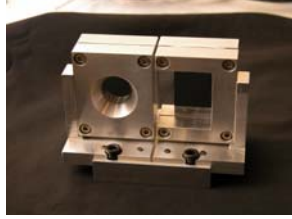
Crystal size: 0.7 x 30 x 30 mm³

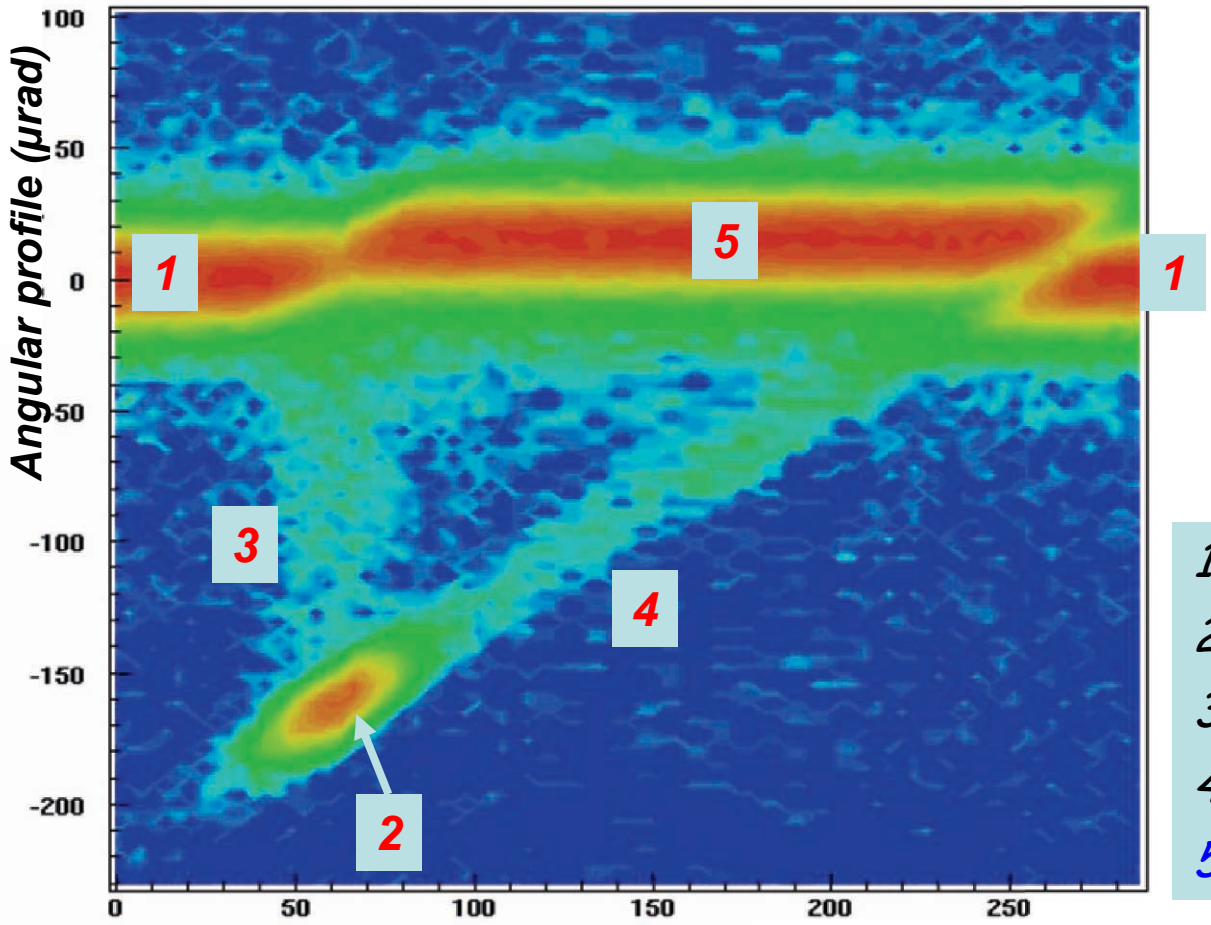
Data taking



- Pre-alignment of the crystal respect to the beam line using optical methods
- Fast alignment of the crystal to the beam direction through the hodoscope (pitch 2 mm): the channeling peak is well visible at about 1 cm from the non-deflected beam
- Fast angular scan using the gas chamber (pitch 200 μm) and a high intensity beam (10^8 proton per SPS pulse): the reflection region is well visible.
- High statistics scan with the Si microstrip, in the range predefined by the fast angular scan (10^4 protons per SPS pulse)

Angular beam profile as a function of the crystal orientation





The **angular profile** is the change of beam direction induced by the crystal

The **rotation angle** is angle of the crystal respect to beam direction

The **particle density** decreases from red to blue

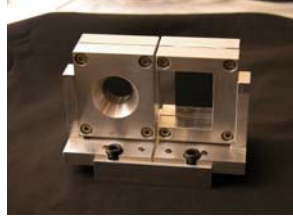
1 - "amorphous" orientation

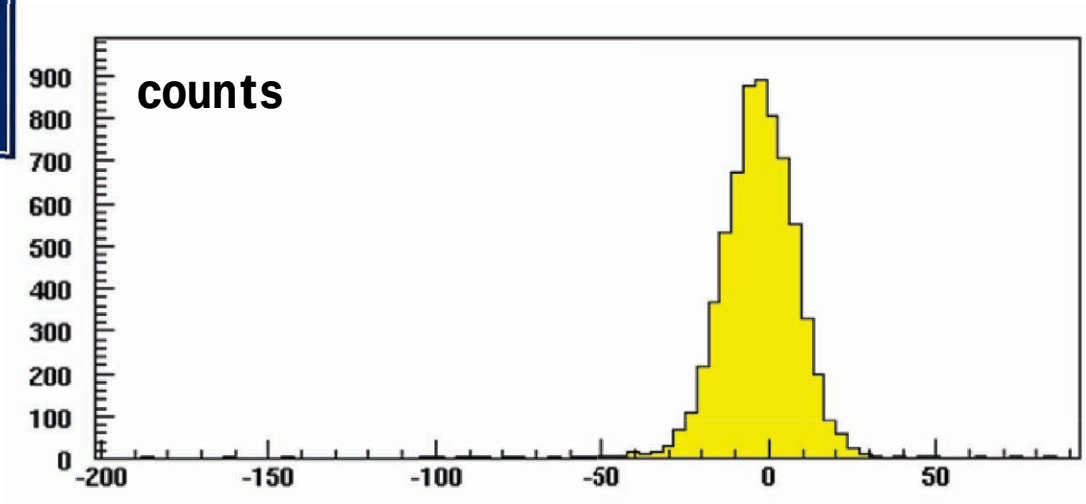
2 - channeling

3 - de-channeling

4 - volume capture

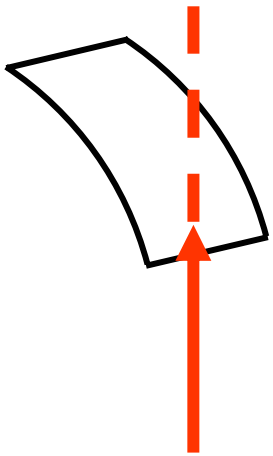
5 - volume reflection

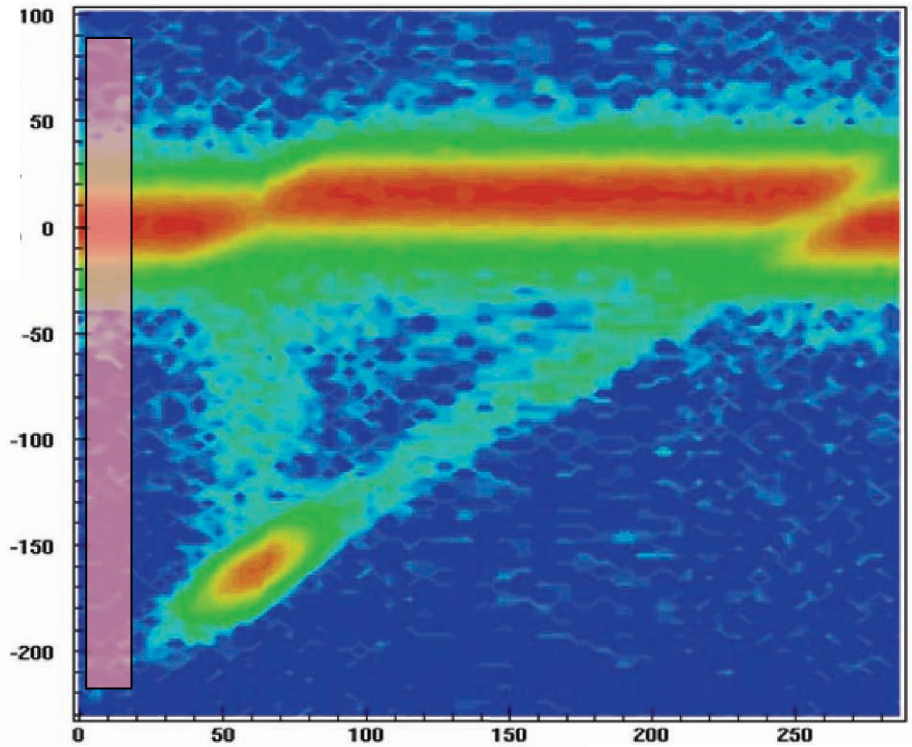




Angular profile μrad

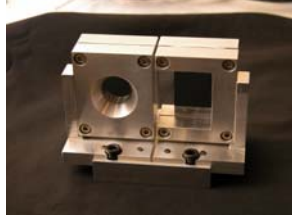
Amorphous

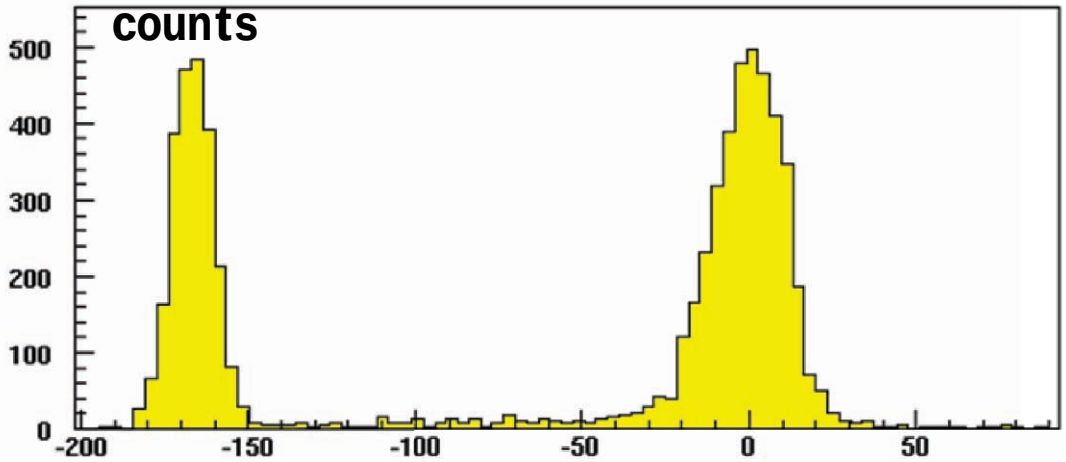




Rotation angle (μrad)

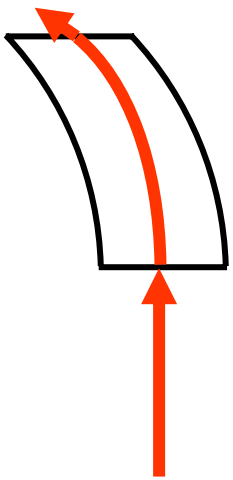
Angular profile (μrad)

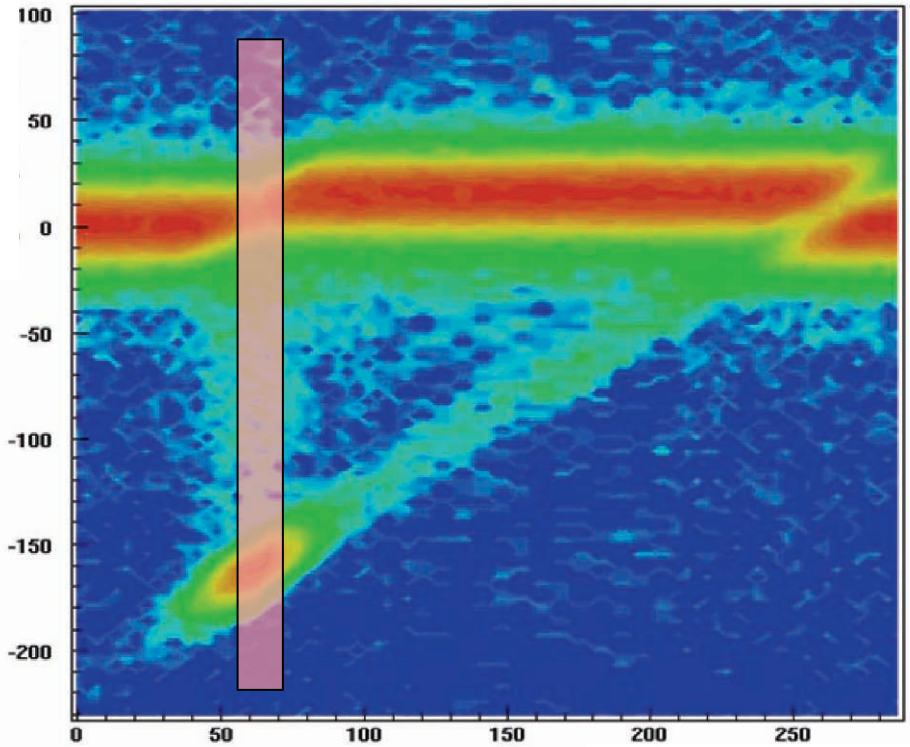




Angular profile µrad

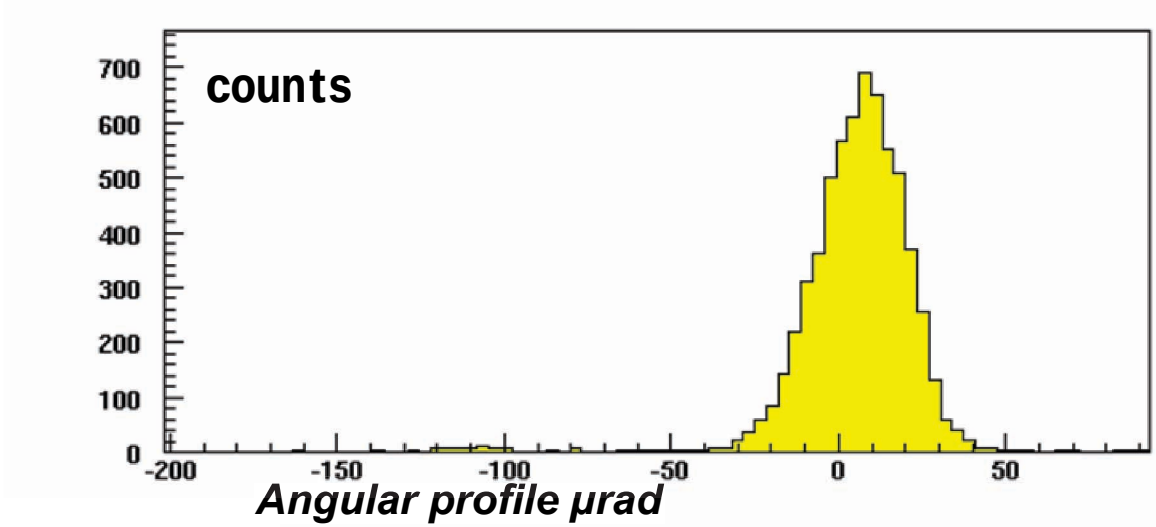
Channeling

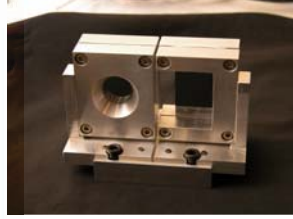




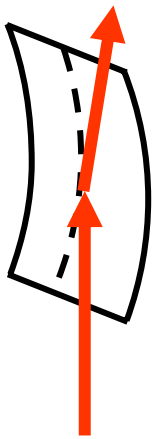
Angular profile (µrad)

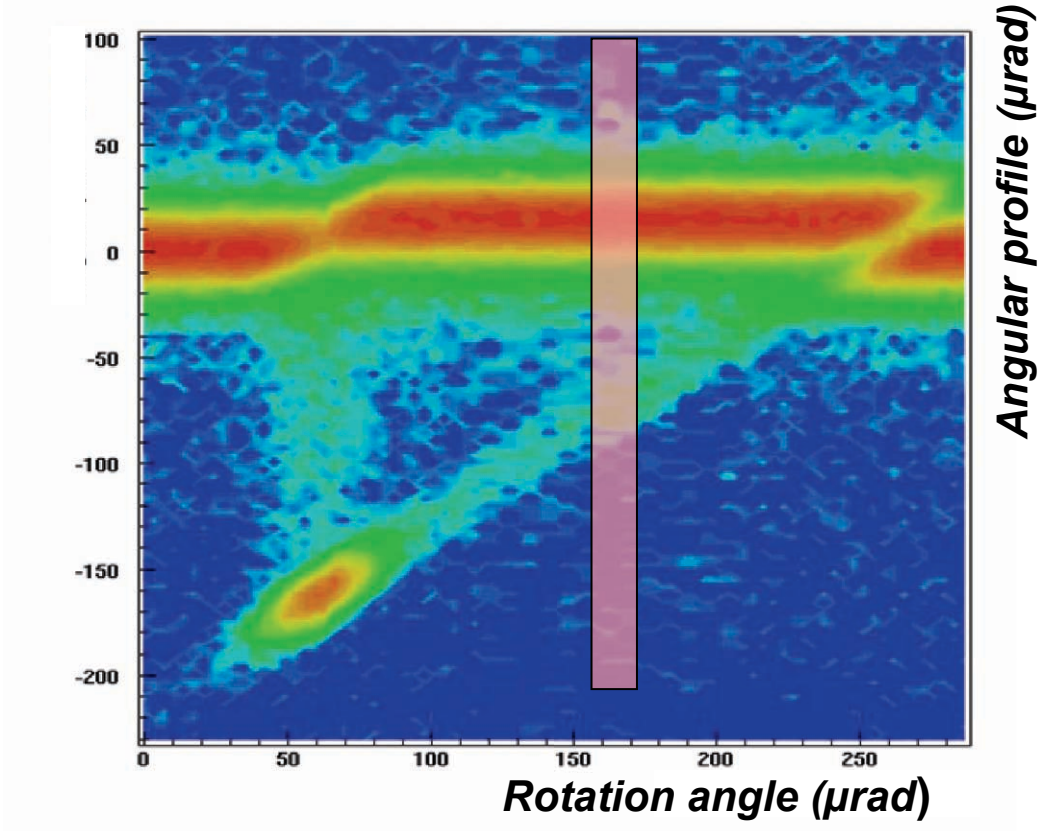
Rotation angle (µrad)



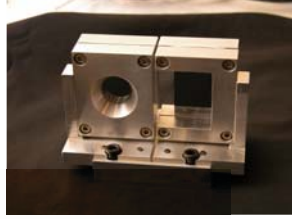


Volume Reflection

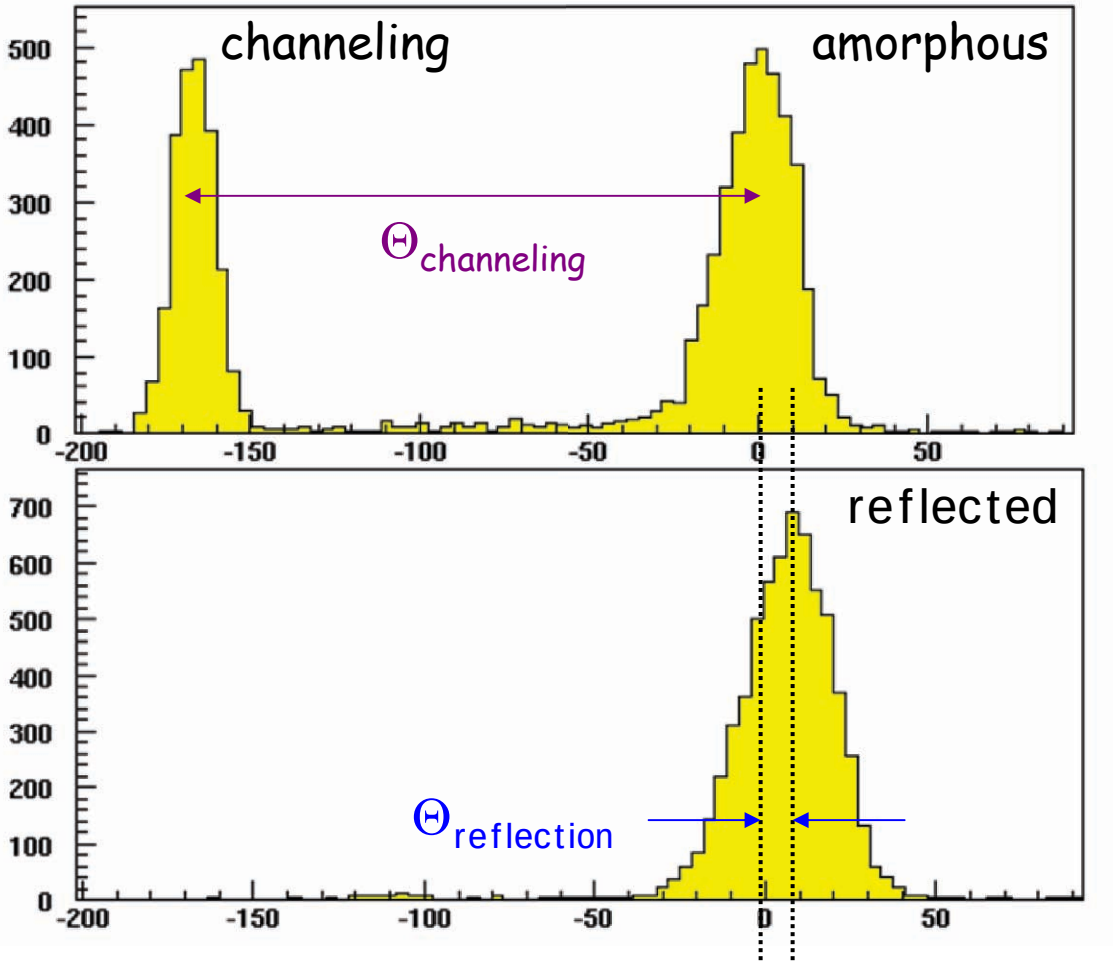




Deflection

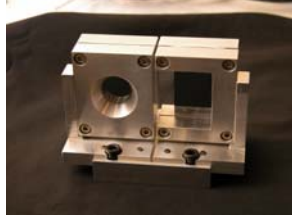


- Identify channeling, reflection and amorphous peaks of the angular profile distribution
- Compute the angular shift -> ***deflections***
- (underlying hypothesis: the incoming beam follows a stable direction)



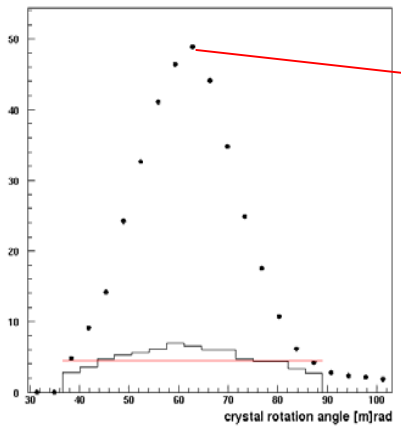
Angular profile μrad

Efficiency



- Integral of the events within $\pm 3\sigma$ around amorphous, channeling and reflected peaks
- Normalize the integrals to the incoming flux
- Ratios of channeling or deflection over amorphous normalized peak integrals -> ***efficiencies***
- (underlying hypothesis: the incoming beam flux is stable)

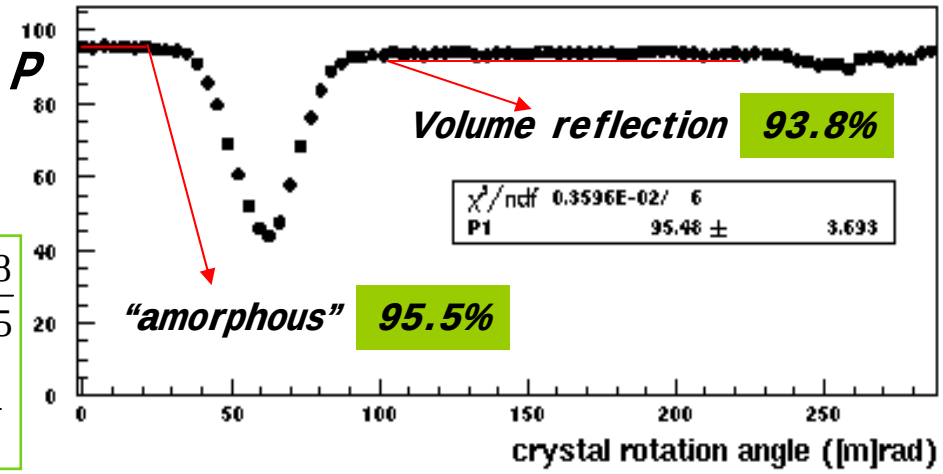
Example of efficiency estimate



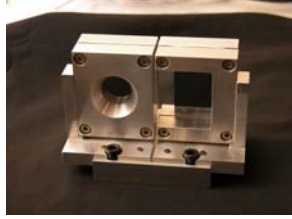
Channeling

49.9%

$$\begin{cases} \varepsilon_{refl} = \dfrac{P_{refl}}{P_{amor}} = \dfrac{93.8}{95.5} \\ \varepsilon_{ch} = \dfrac{P_{ch}}{P_{amor}} = \dfrac{49.9}{95.5} \end{cases}$$



Typical results



QM2 quasimosaic crystal

ε (reflection) = 98.2 %

ε (channeling) = 52.7 %

$\Theta_{channeling}$ = 73 μrad

$\Theta_{reflection}$ = 12 μrad

ST4 strip crystal

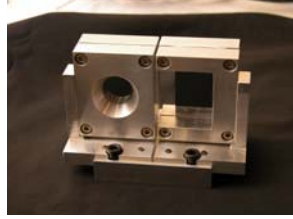
ε (reflection) = 98.2 %

ε (channeling) = 51.2 %

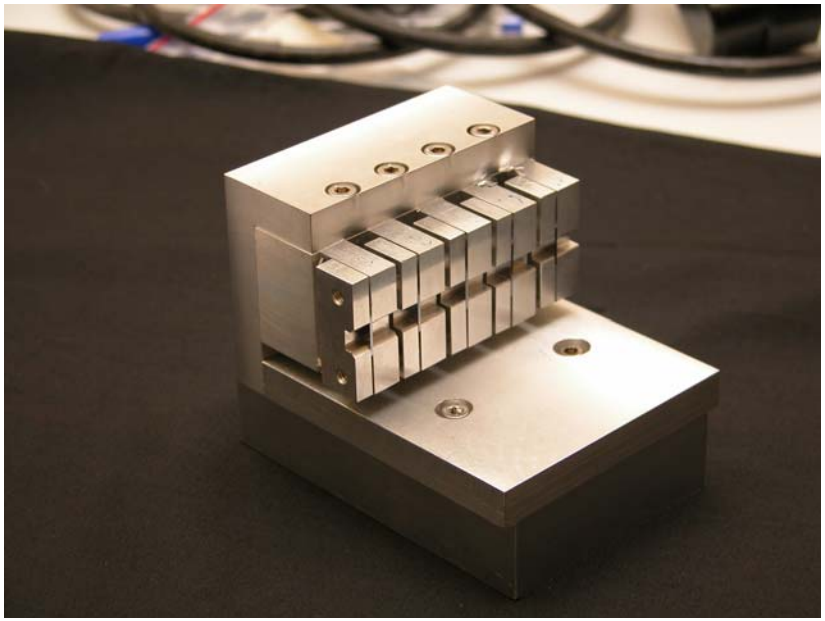
$\Theta_{channeling}$ = 163 μrad

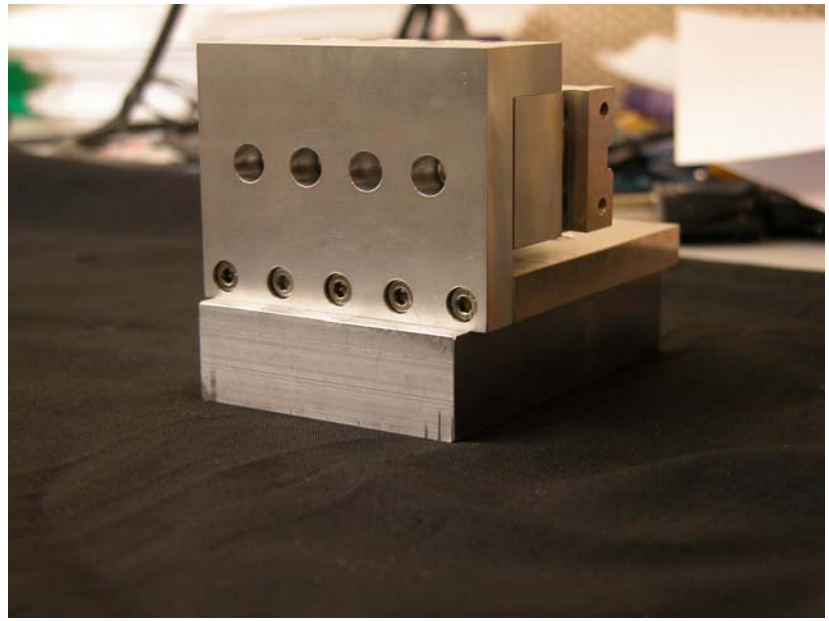
$\Theta_{reflection}$ = 14 μrad

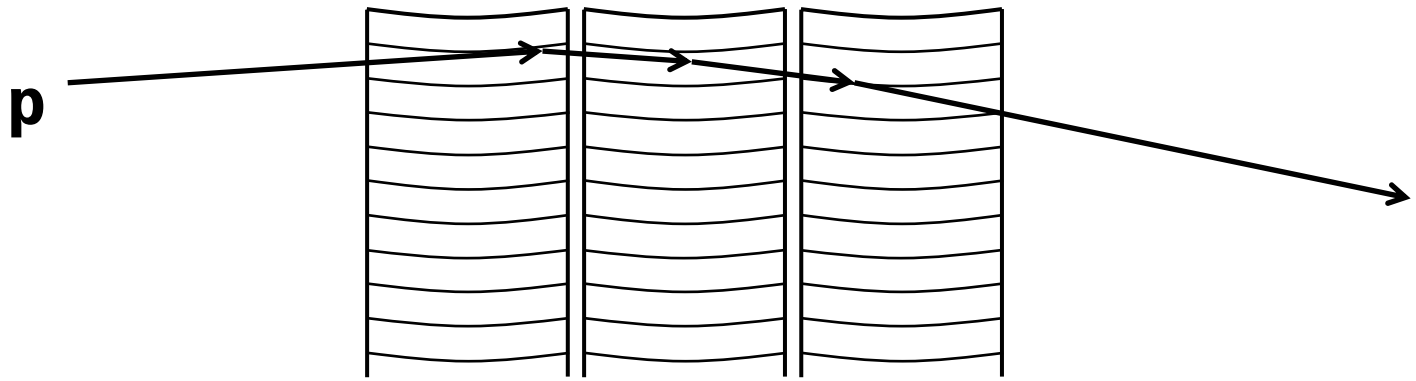
2007 run breaking news



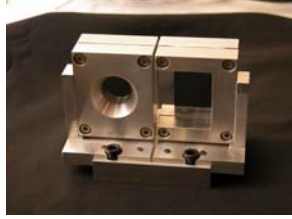
5 heads multicrystal crystal (PNPI)



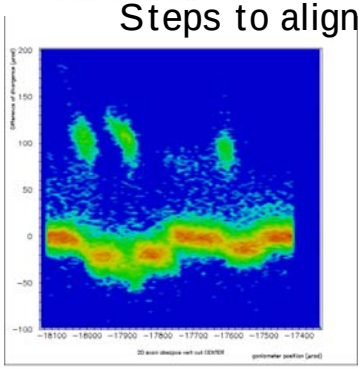


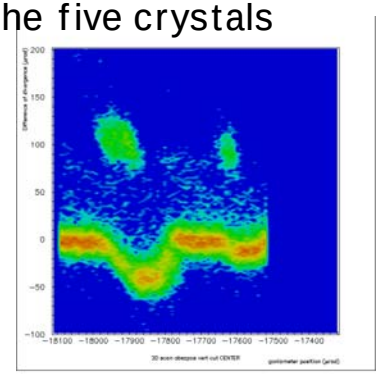


- Beam profile in multiple VR condition in the Q5M5 crystal
- Active area for best results: 400x800 mm^2



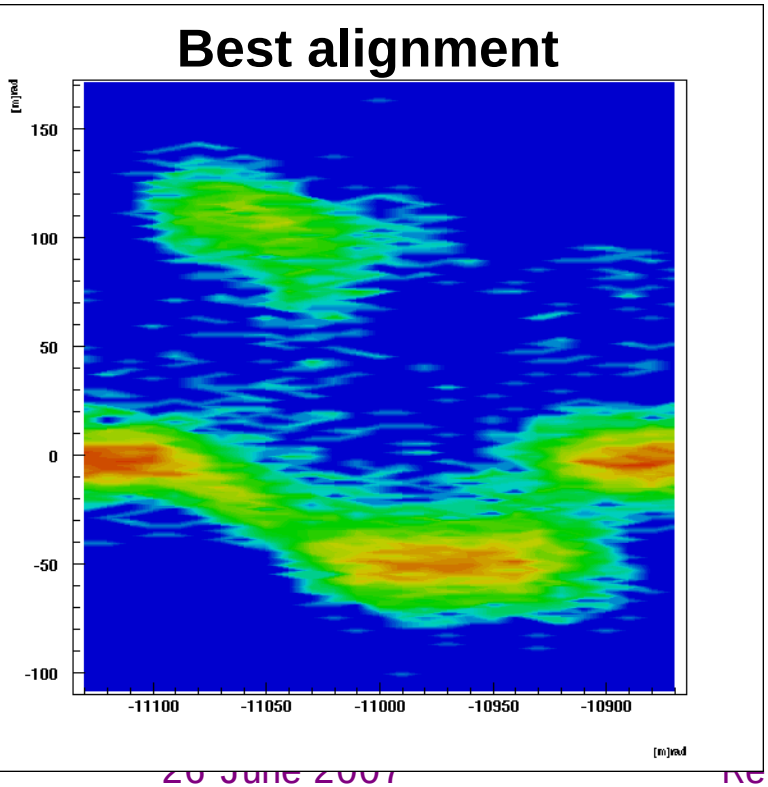
Steps to align the five crystals



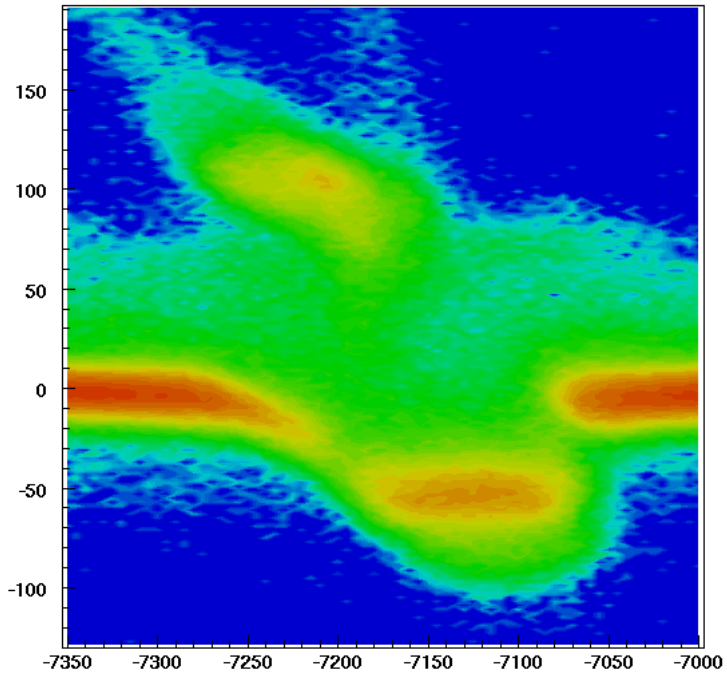


- Volume reflection angle 53 μrad
- Efficiency ≥ 90 %

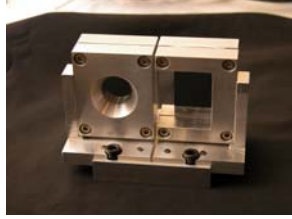
Best alignment



High statistics

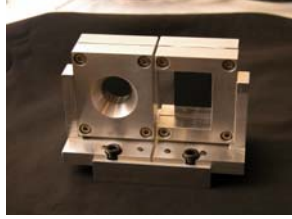


Conclusion



- High efficient reflection (and channeling) observed in single pass interaction of high-energy protons with bent crystals (0.5 to 10 mm long)
- Single reflection on a Si bent crystal deflects > 98 % of the incoming beam by an angle $12 \div 14$ μrad
- Very promising for application in crystal collimation
- Possible development consists in multi-reflections on a sequence of aligned crystals to enhance the reflection angle (successfully tested in the 2007 run).

Acknowledgments



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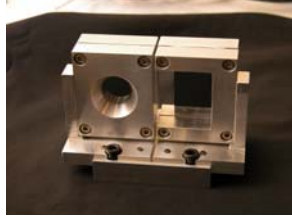
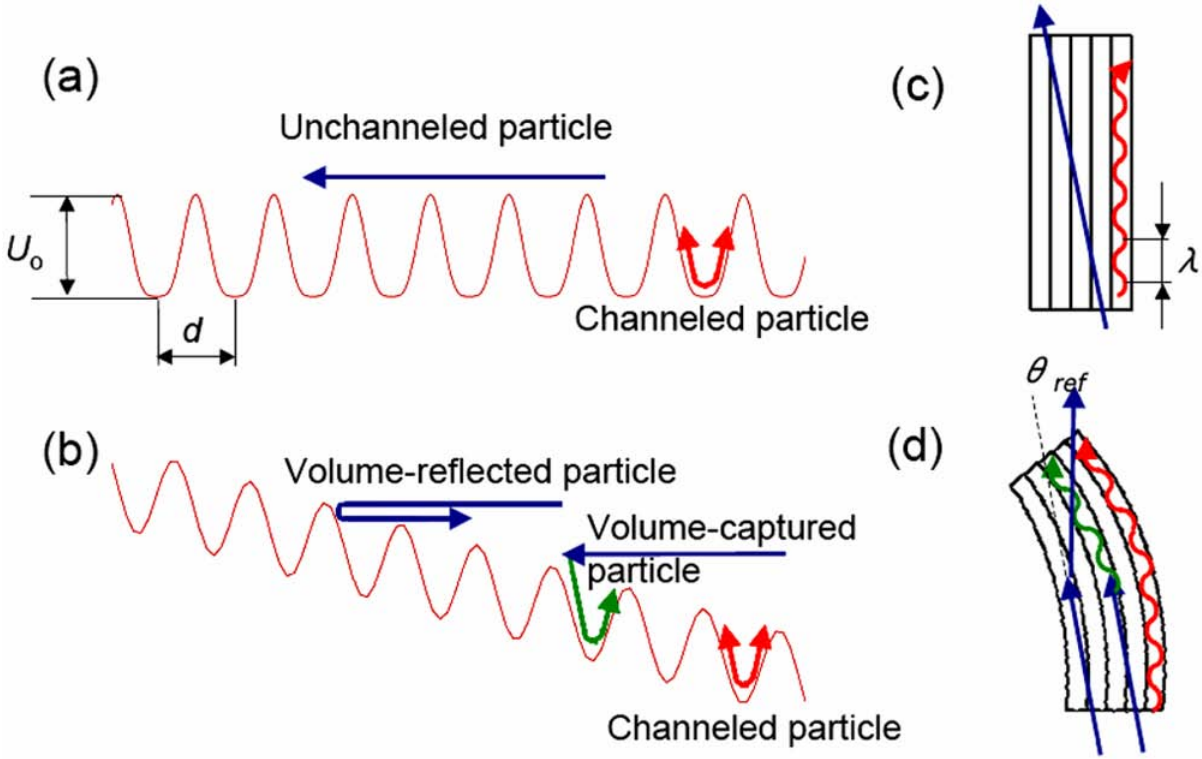
- The Council of the President of the Russian Federation grant NSh-3057.2006.2,
- The Program "Physics of Elementary Particles and Fundamental Nuclear Physics" of Russian Academy of Sciences.

Particle-crystal interaction



Possible processes:

- multiple scattering
- channeling
- volume capture
- de-channeling
- *volume reflection*



Volume reflection

Prediction in 1985-'87 by
A.M.Taratin and S.A.Vorobiev,

First observation 2006 (IHEP - PNPI - CERN)