University of Padova

Insubria University

INFN-Lab. Naz. di Legnaro

University of Ferrara

High energy protons channeling and volume reflection effects through a bent germanium crystal

Oleksiy Lytovchenko

for the COHERENT experiment

D. De Salvador, A. Carnera, S. Carturan, O. Lytovchenko, N.Argiolas, M. Bazzan, G. Della Mea, A. Mazzolari, D. Vincenzi, E. Bagli, P. Dal Piaz, S. Baricordi, V. Guidi, A. Berra, D. Bolognini, S. Hasan, M. Prest and E.Vallazza

Channeling 2010, Ferrara, October 3-8

Ge for beam deflection: theoretical considerations

✓**Crystal perfection is mandatory**: **dislocations free (or at least Etch Pits Density < $10^2/cm^2$) materials must be acquired.**

⇒ Si fulfils the requirement. Until a decade ago, Si was by far the best choice...

⇒ Thanks to the renewed interest towards Ge (multijuction solar cells, MOSFET, graded Si-Ge alloys) now Ge crystals with EPD ≅ $0/cm^2$ are available.

✓**Ge potential benefits...(in theory)**

Higher Z as compared with Si (32 vs 14) implies

⇒ stronger equivalent magnetic field (scales with Z)

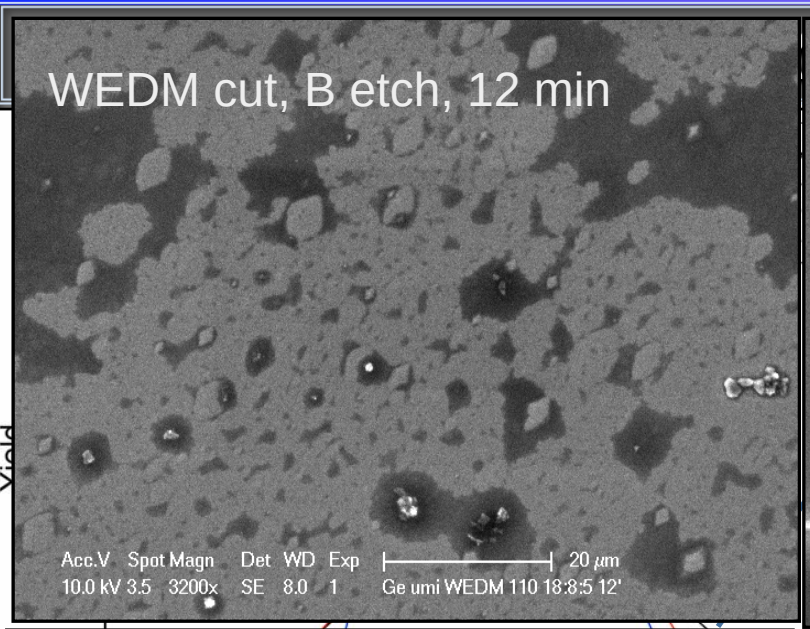
⇒ higher critical angle for both axial and planar channeling (scales with √Z)

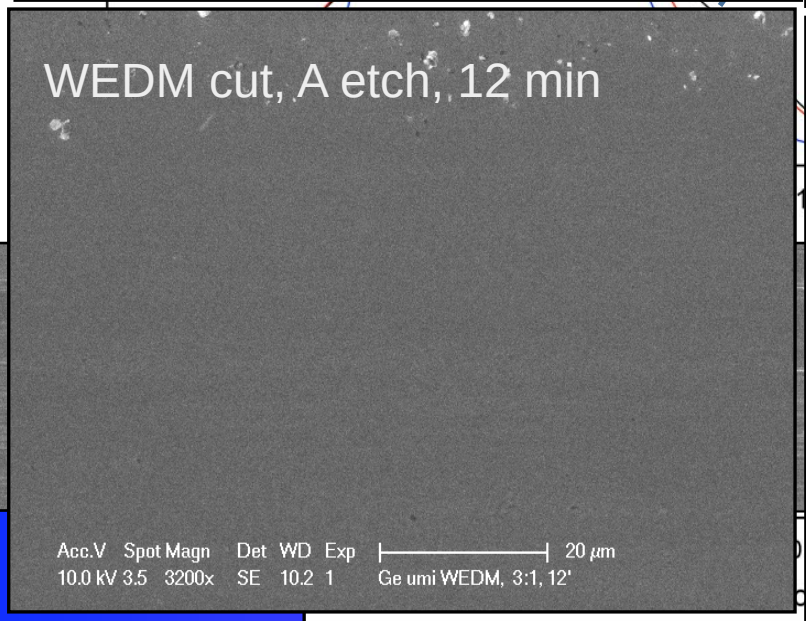
✓**Ge drawbacks....(in practice)**

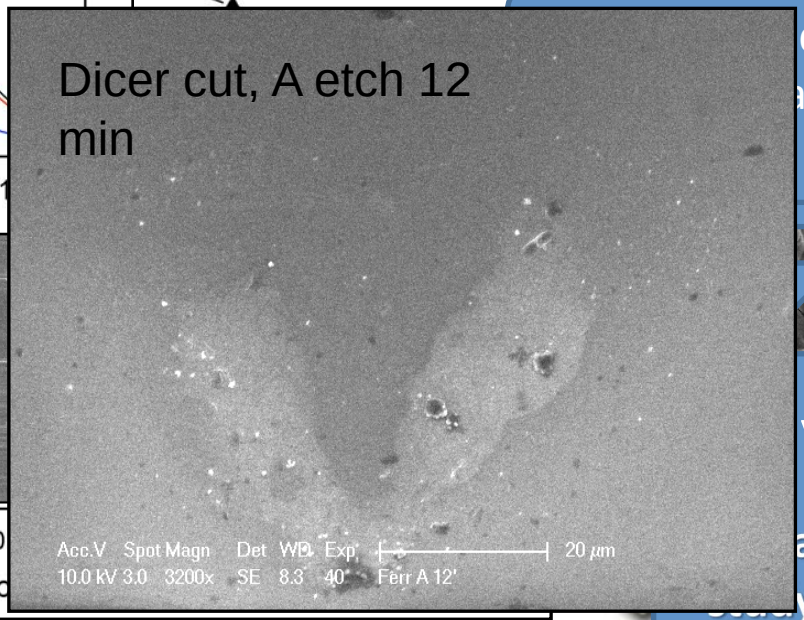
⇒ extremely brittle! (crystal damage inflicted by cutting can propagate deeply)

⇒ lower reactivity as compared to silicon (ΔH_{GeO2} -132 vs ΔH_{SiO2} -217 Kcal/mol)... Etching must contains always an oxidant and a complexing agent....

From Ge wafers to the final strip…







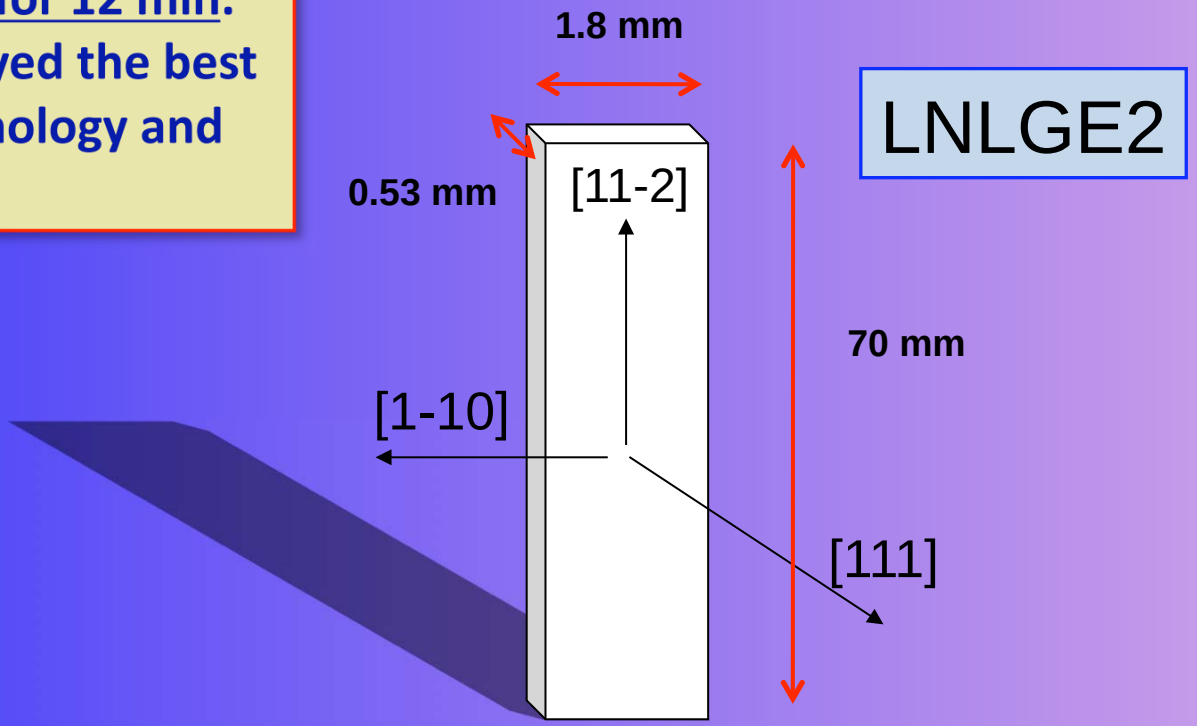
A few points concerning the processing route…

✓ You had only a quick glance… About 120 strips were cut, etched and analyzed...

✓ The EPD claimed by the factory (0 /cm2) was also tested by applying anisotropic chemical etching (Superoxol, H2O2 : HF : H2O, 1 : 1 : 4), followed by inspection with optical microscopy and Etch Pits count….

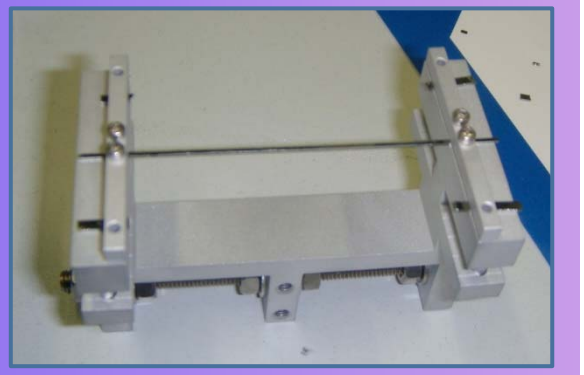
✓It was confirmed that EPD in the bulk is really 0/cm2 !

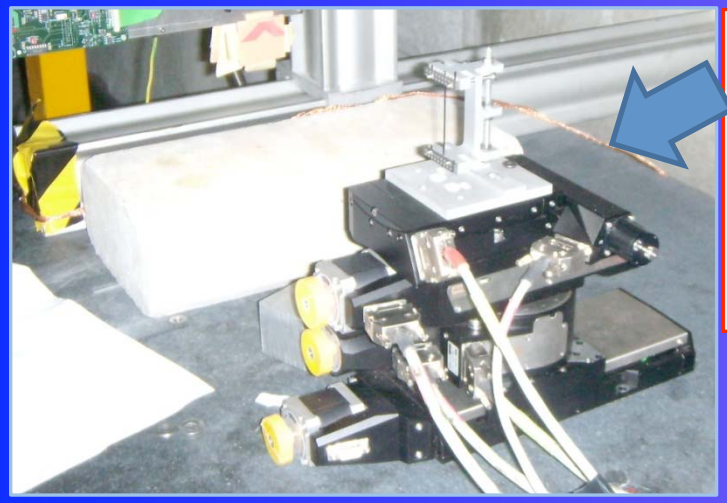
✓The chosen strip was dicer cut, etched with B composition for 12 min. It was selected since displayed the best results as for surface morphology and crystal quality



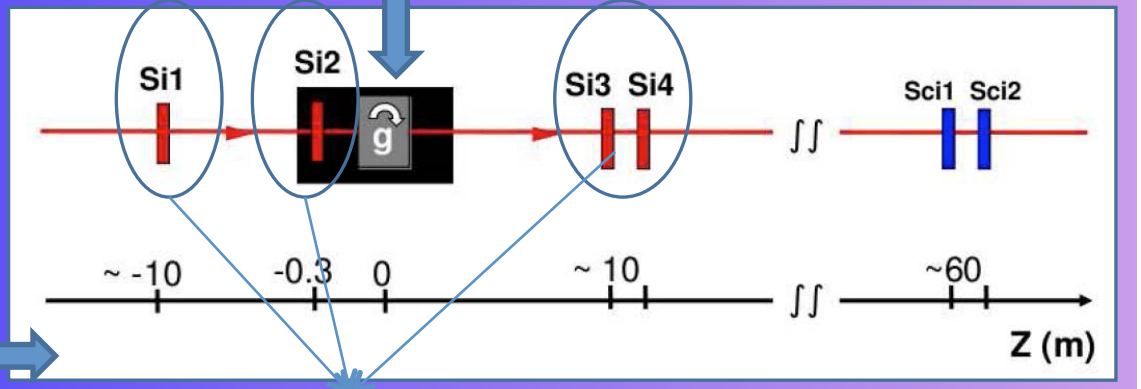
Tests with High Energy Protons CERN SPS H8 400 GeV: June 2010

Ge strip mounted on the strip holder (Ferrara University) for bending





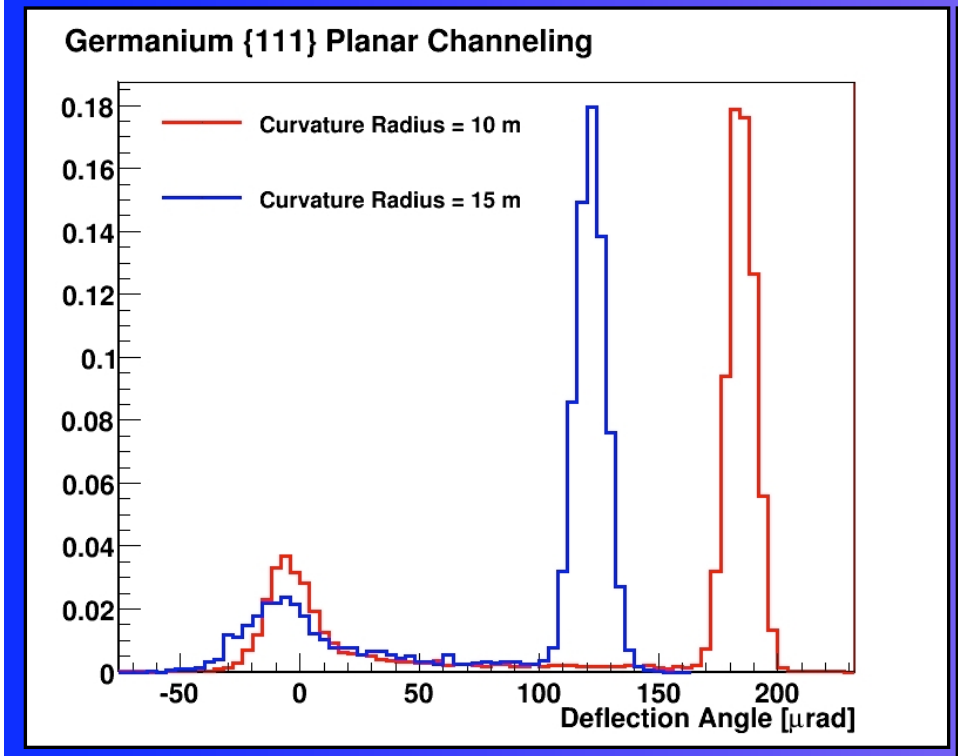
High precision goniometer (INFN-LNL)
2 translation stages
2 rotation stages (1 μrad accuracy)

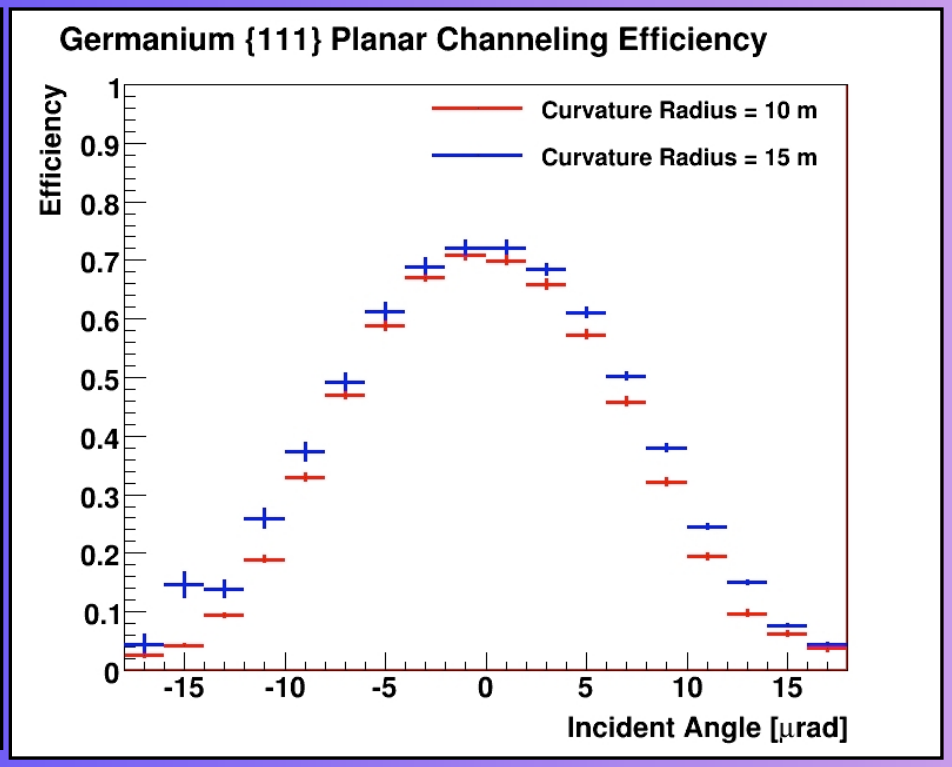


Sketch of the experimental set-up (Coherent experiment)

Particle trajectory reconstruction

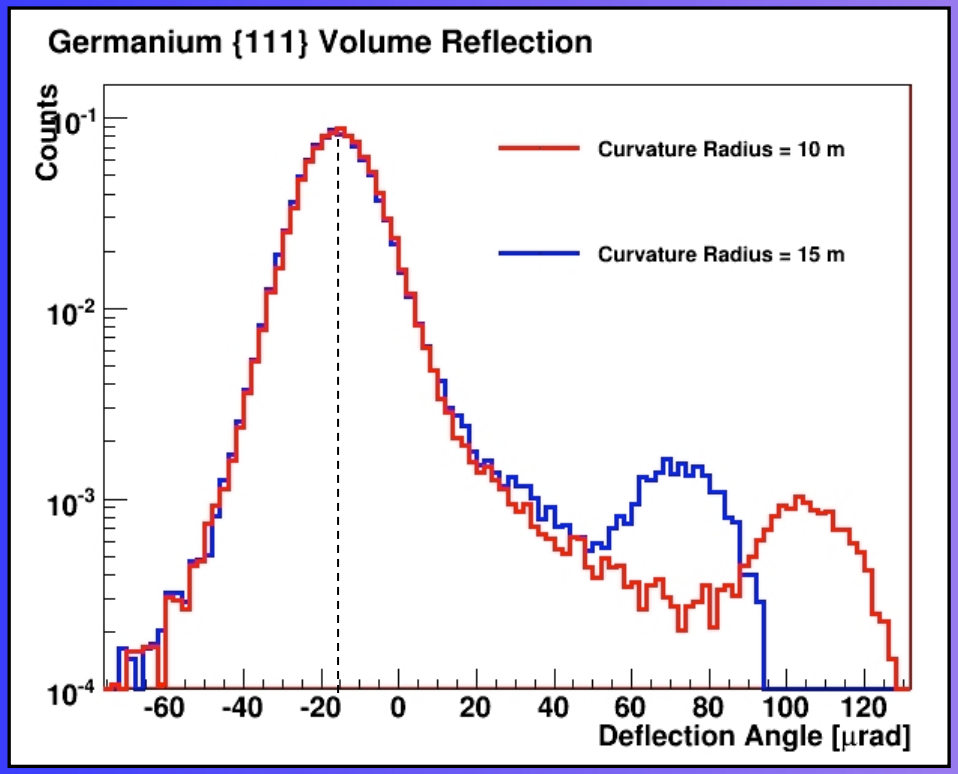
Planar channeling with 2 curvatures





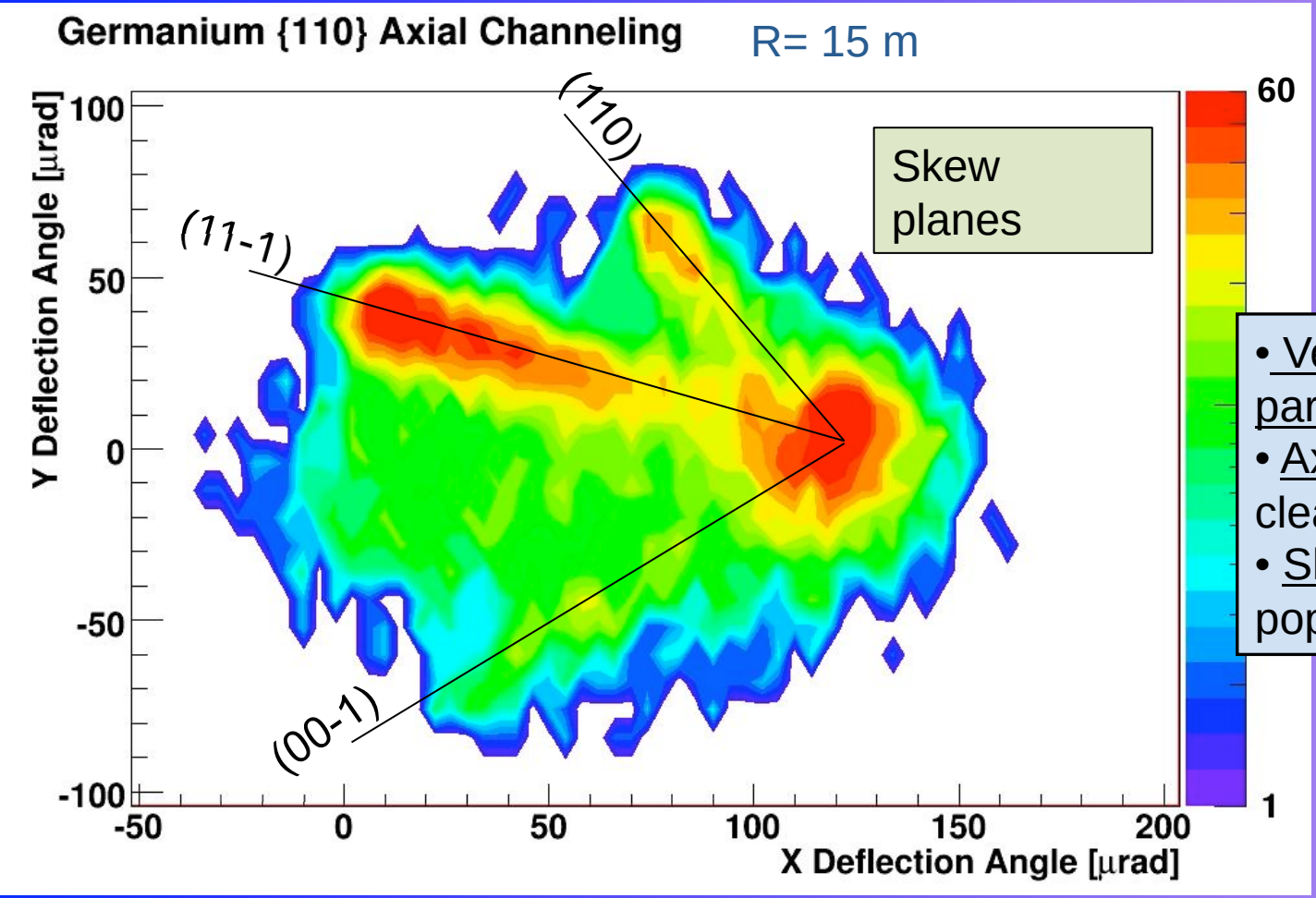
Curvature radius R (m)	10	15
Deflection (μrad)	185 ± 2	122 ± 2
Maximum Efficiency (%)	70.5 ± 1.0	72.5 ± 1.0
FWHM/2 (μrad)	8.6 ± 0.1	9.2 ± 0.1

Volume reflection with 2 curvatures



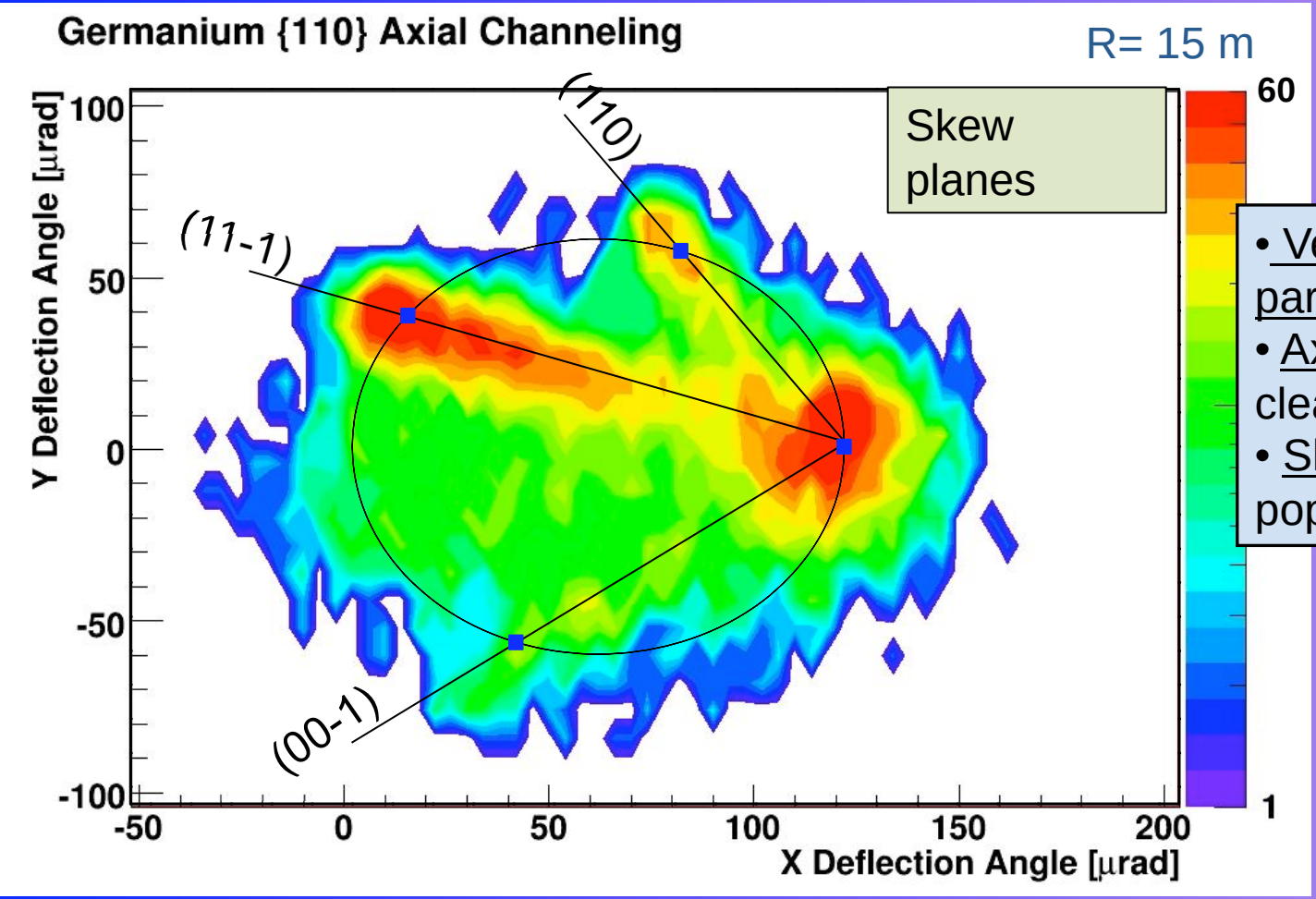
Curvature radius R (m)	10	15
Deflection (μrad)	15.3 ± 0.2	15.9 ± 0.2
Efficiency [-∞,+3σ] (%)	95.9 ± 0.4	95.3 ± 0.4

[110] axial channeling: preliminary analysis



- Very few undeflected particles
- Axial deflection is clearly visible
- Skew planes are also populated

[110] axial channeling: preliminary analysis



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A (not straightforward) comparison...

We cannot compare directly with previous results, neither Si or Ge…
- **different orientation or**
- **different curvature radius or**
- **different beam path**

1994, S.P. Moller et al., Si (111),R=35.7 m strip 50x10x0.9 mm, protons 450 GeV, Beam Div. 3 μrad — 50

1998, C. Biino et al., Ge (110),R=60 m strip 50x10x1 mm, protons 450 GeV, BD 3 μrad — 60

2008, W. Scandale et al., Si (111), R = 8.6 m, strip 1.85x70x0.5 mm, protons 400 GeV, max eff — 44

2009, W. Scandale et al., Si (110), R = 38 m, strip 1.94x70x0.5 mm, protons 400 GeV, max eff — 83.4

This work, Ge (111), R = 15 m, strip 1.8x70x0.5 mm, protons 400 GeV, max eff — 72.5

Planar channeling efficiency (%)

Concluding remarks and future planning

- Two different cut techniques were tested (WEDM and dicer). Dicer was more reproducible (though a deeper study of WEDM cut is in progress).
- Wet etching was used for the damaged layer removal Ge strip displaying the best crystal quality (HRXRD) was selected (B etch, 12 min)
- The chosen strip proved to deflect a 400 GeV proton beam with high efficiency by both planar channeling and volume reflection
- To the best of our knowledge, for the first time axial channeling in this energy regime was observed for germanium
- In order to improve crystal quality of the beam entry surface, mechanical polishing prior to etching will be our next issue.
- Ge crystals <110> oriented will be searched for.... (higher interplanar distance ....)

Thank you ....