Channeling Experiments with Sub-GeV Electrons in Flat and Periodically Bent Silicon Single Crystals

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Institute for Nuclear Physics
University of Mainz, Germany

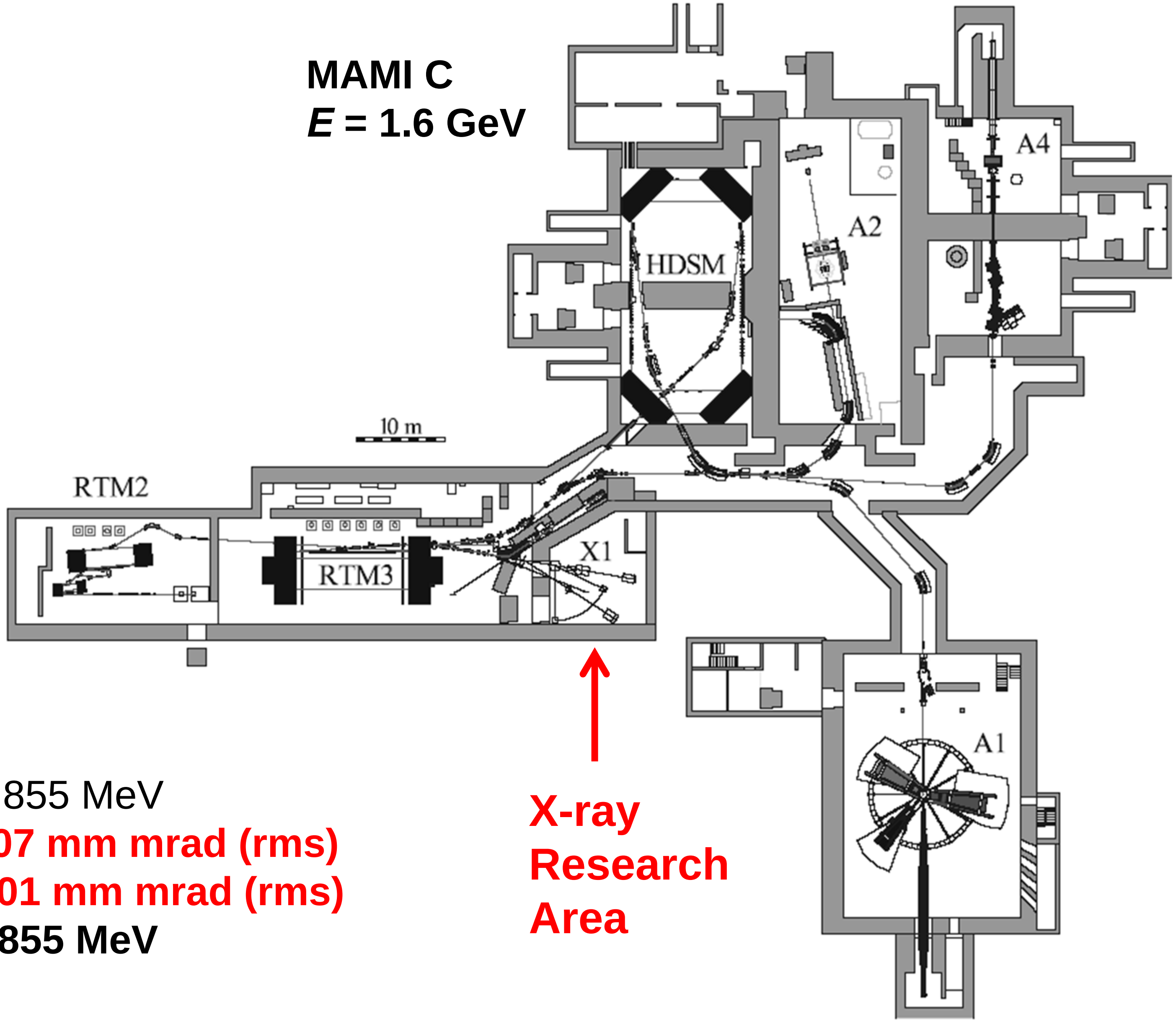
The 6th International Conference
Channeling 2014 - Charged & Neutral Particles Channeling Phenomena
Capri (NA), Italy, October 5-10, 2014

Outline

1. Introduction
2. Dechanneling length measurements for plane silicon crystals in (110) orientation - Reanalysis
3. Experiments with a graded composition strained layer $Si_{1-x}Ge_x$ large amplitude undulator
4. Outlook
5. Conclusions

Floor Plan of the Mainz Microtron MAMI Facility

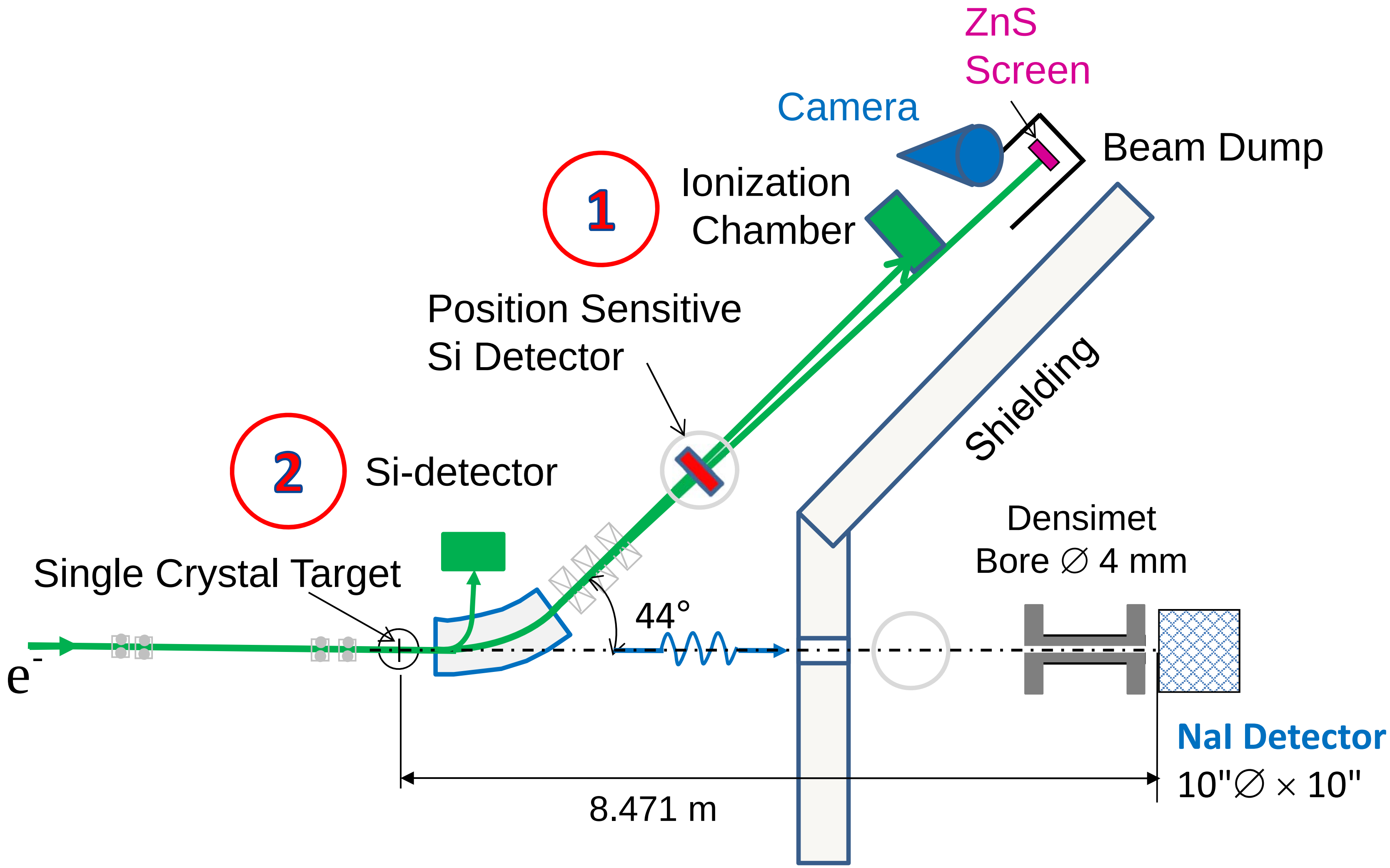
MAMI C
***E* = 1.6 GeV**



E = 180 - 855 MeV
$\varepsilon_{hor} \cong$ 0.007 mm mrad (rms)
$\varepsilon_{vert} \cong$ 0.001 mm mrad (rms)
at 855 MeV

X-ray Research Area

Basic Setup for the Experiments with Electrons at MAMI



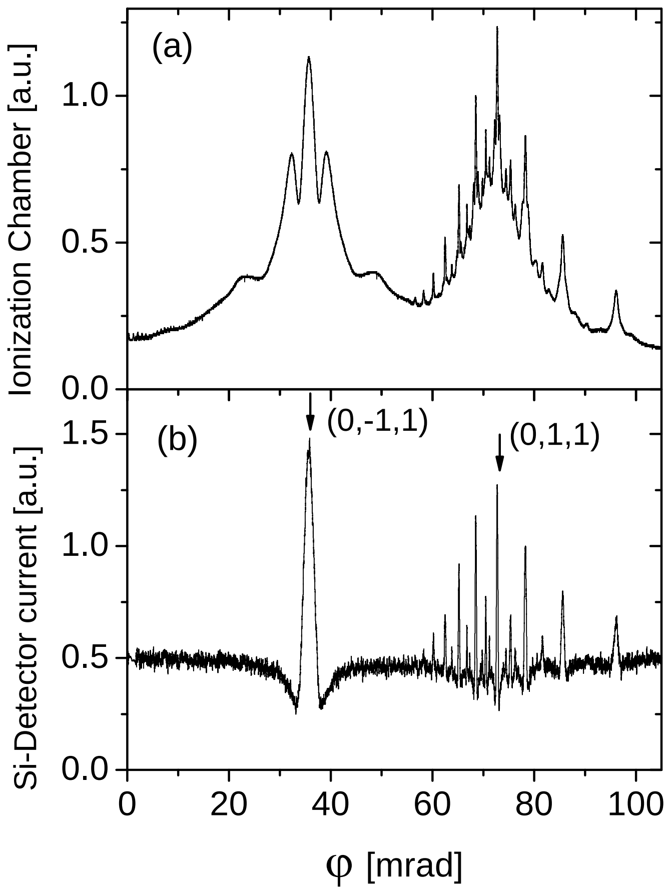
2. Dechanneling length measurements for plane silicon crystals in (110) orientation

Reanalysis of published measurements

W. Lauth, H. Backe, P. Kunz, A. Rueda,
Int. Jour. Mod. Phys. **A 25** (2010) 136

Measurement of signal hight as function of the silicon single crystal thickness

Angular scans at 600 MeV
thickness 14.6 μm



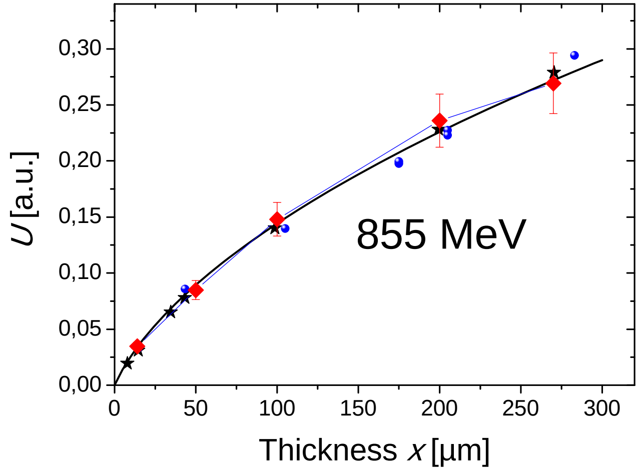
1

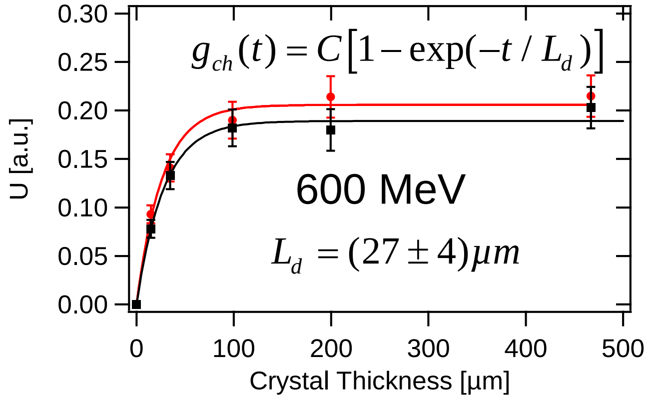
Low
energy loss
signal

2

High
energy loss
signal

Signal as function of thickness





Analysis with rate equation

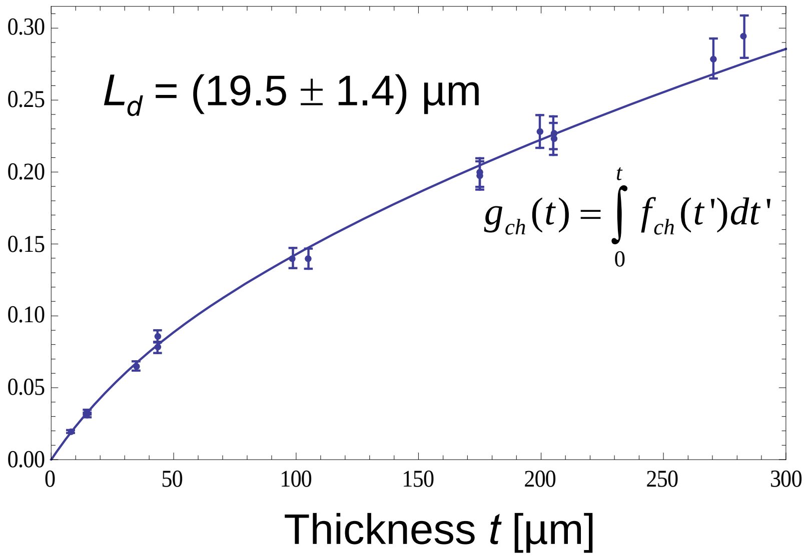
Solve $$\frac{df_{ch}(t)}{dt} + \frac{f_{ch}(t)}{L_d} = 0$$

Occupation function $f_{ch}(t)$

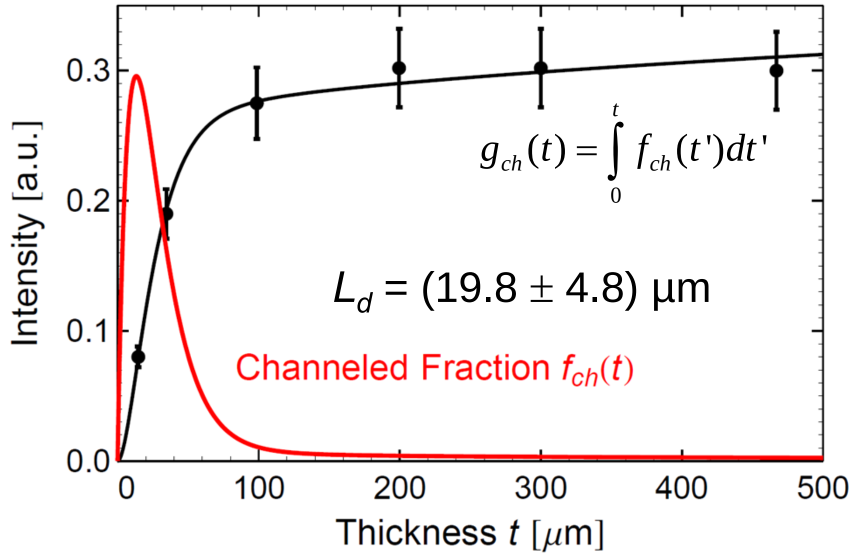
Fit function $g_{ch}(t) = C\int_0^t f_{ch}(t')dt'$

E_e =855 MeV

1 Low energy loss signal

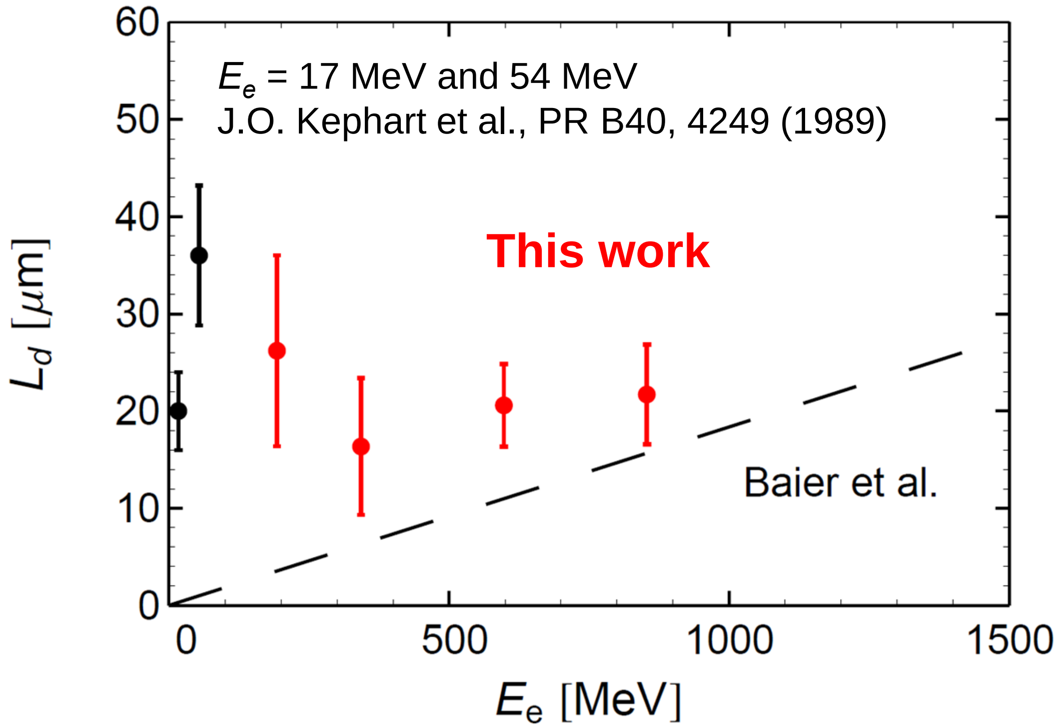


2 High energy loss signal



Results for Dechanneling-Length Measurements for Electrons

(110) Plane of Si Single Crystals



Theory of Baier et al.

$$L_d = 18.8\,\mu\text{m}\,\frac{E_e}{1000\,\text{MeV}}$$

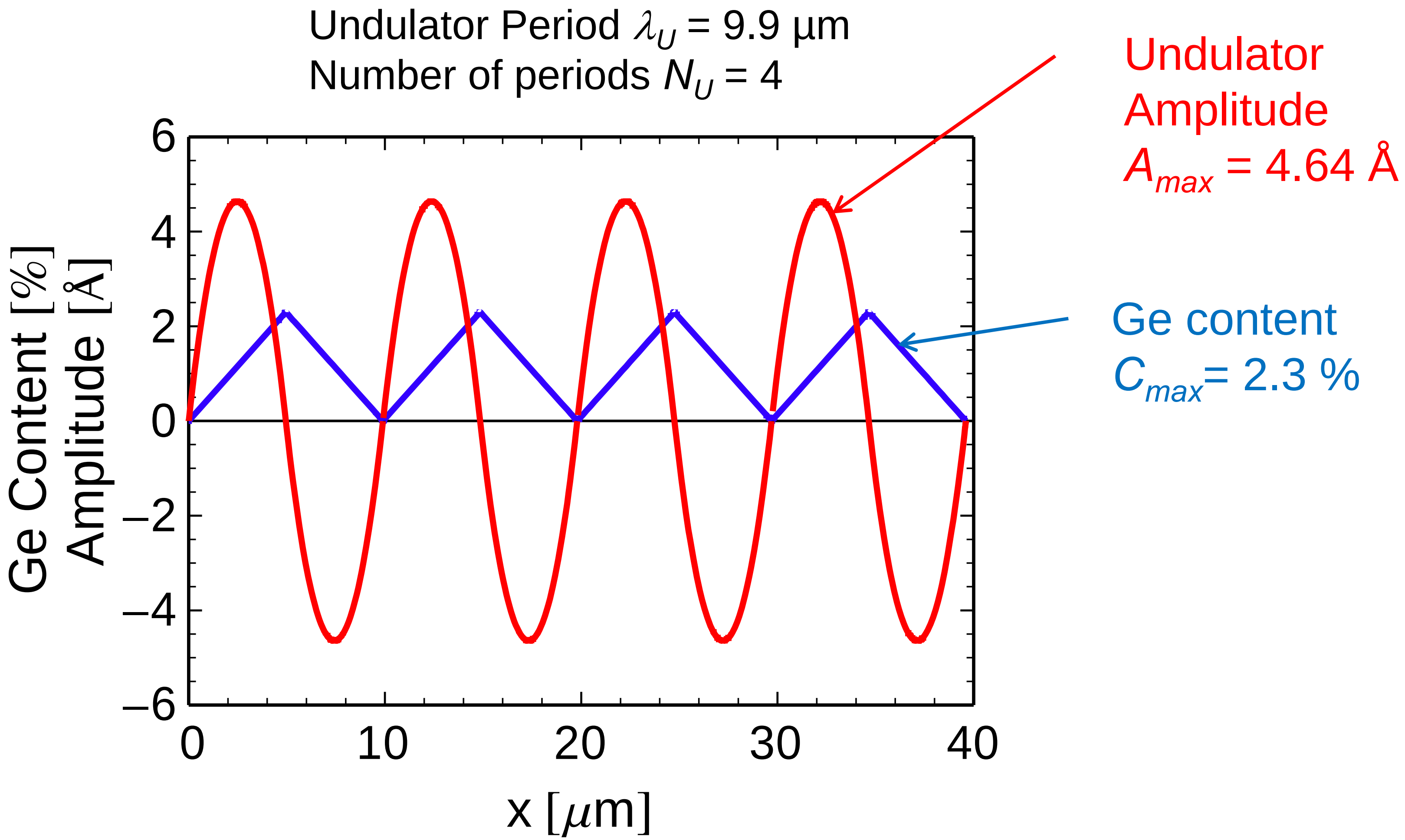
"Quantum State" Dechanneling Regime

"Classical" Dechanneling Regime

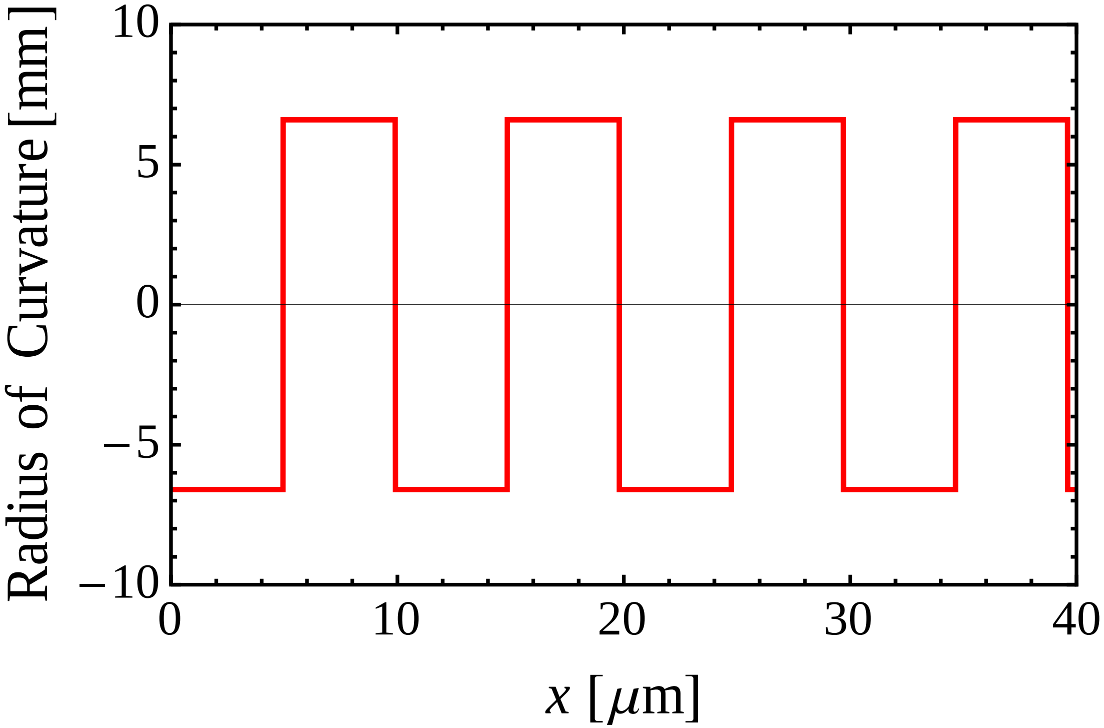
3. Experiments with a graded composition strained layer $Si_{1-x}Ge_x$ large amplitude undulator

John Lundsgaard Hansen, Arne Nylandsted,
Ulrik I. Uggerhøj
(Molecular Beam Epitaxy) MBE-Group
Department of Physics and Astronomy
University of Aarhus

Germanium Content and Amplitude Distribution
(110) plane



Radius of curvature



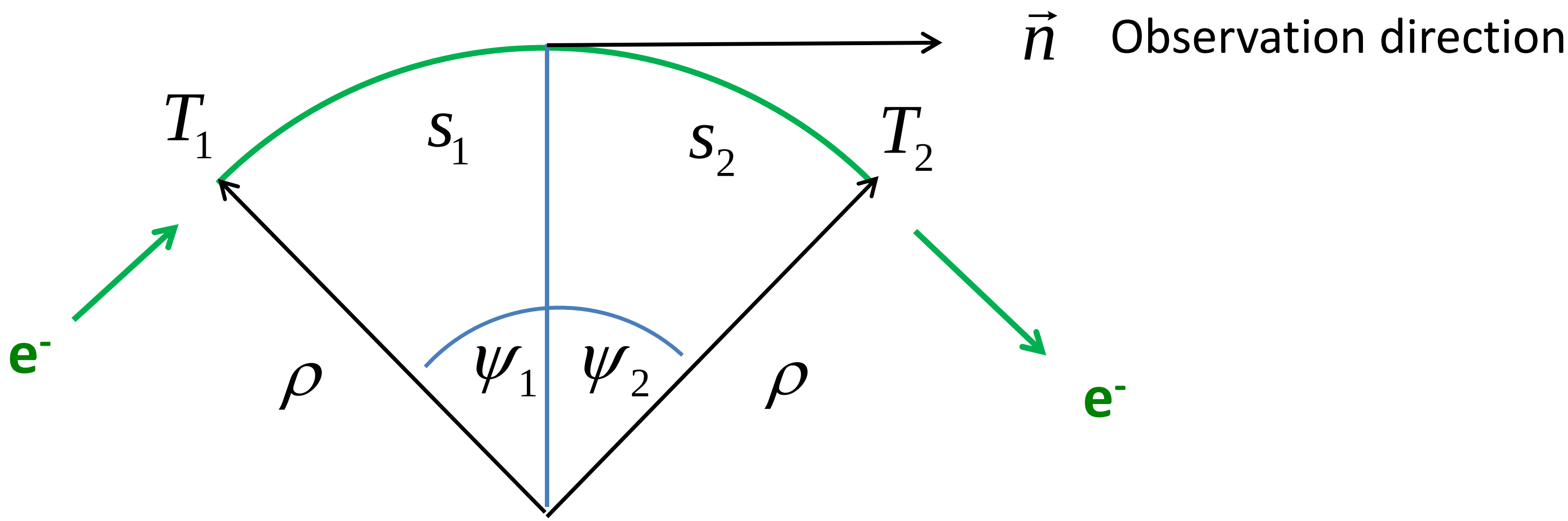
$$\rho = \frac{\left(\sqrt{1+(dy/dx)^2}\right)^3}{d^2y/dx^2}$$

$$\simeq \left(\frac{d^2y}{dx^2}\right)^{-1} = 6.60\,\text{mm}$$

$$pc = 855\ \text{MeV}$$

$$B_{equiv} = \frac{pc}{e\,\rho\,c} = 432\ \text{Tesla}$$

Synchrotron-like Radiation Emission
from Finite Arc Element of Undulator

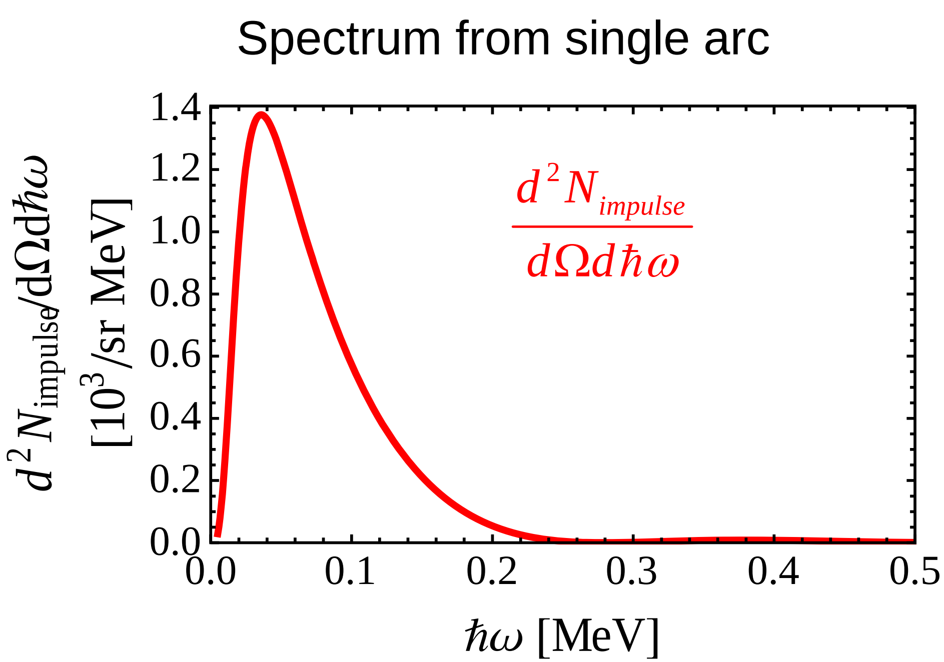


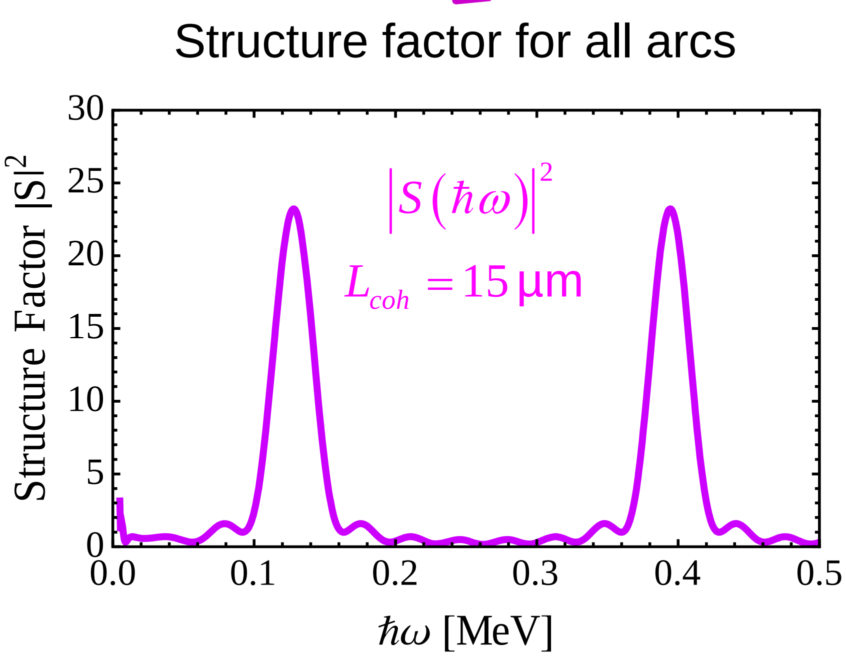
$$\psi_1 = \psi_2 = 0.375\ \text{mrad}$$

Schwinger's approach $\quad T_1 \to -\infty, \quad T_2 \to \infty$

Calculations at E_{beam} = 375 MeV
4-Period Undulator with λ_U = 9.9 μm and A_{max} = 4.64 Å

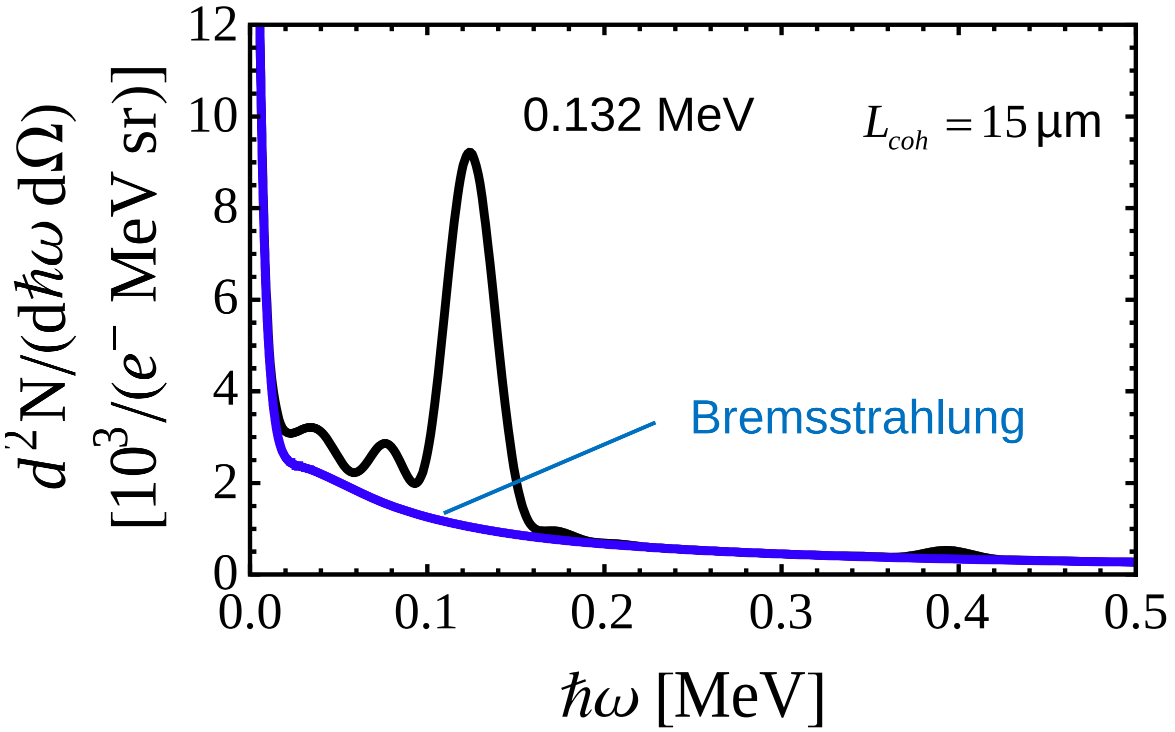
$$\frac{d^2 N_{train}}{d\Omega d\hbar\omega} = \frac{d^2 N_{impulse}}{d\Omega d\hbar\omega} \left| S(\hbar\omega) \right|^2$$





Expected Spectrum at E_{beam} = 375 MeV
4-Period Undulator with λ_U = 9.9 µm and A_{max} = 4.64 Å

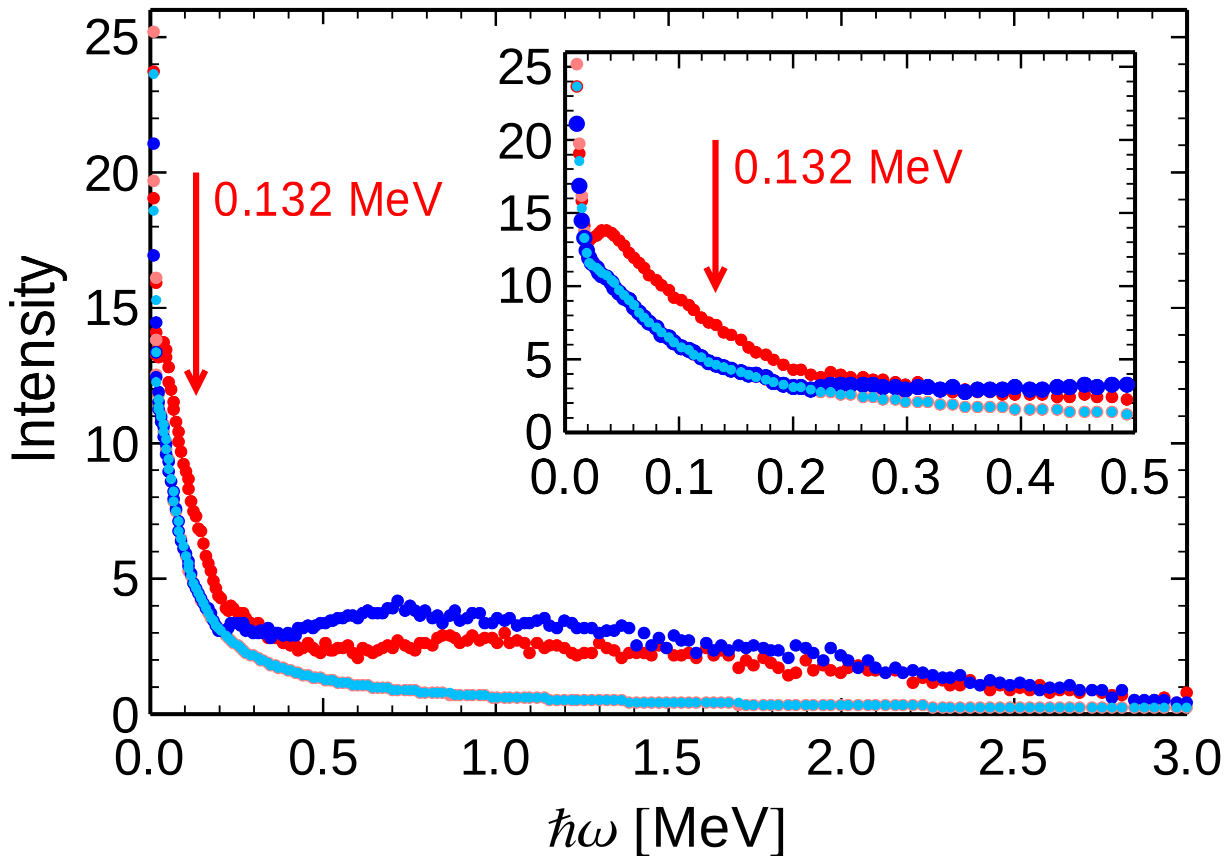
$$\frac{d^2N}{d\Omega d\hbar\omega} = \frac{d^2N_{impulse}}{d\Omega d\hbar\omega}\left|S(\hbar\omega)\right|^2 + \frac{d^2N_{brems}}{d\Omega d\hbar\omega}$$



Deconvoluted Photon Spectra at (110) Planar Channeling for Plane and Undulator Crystals

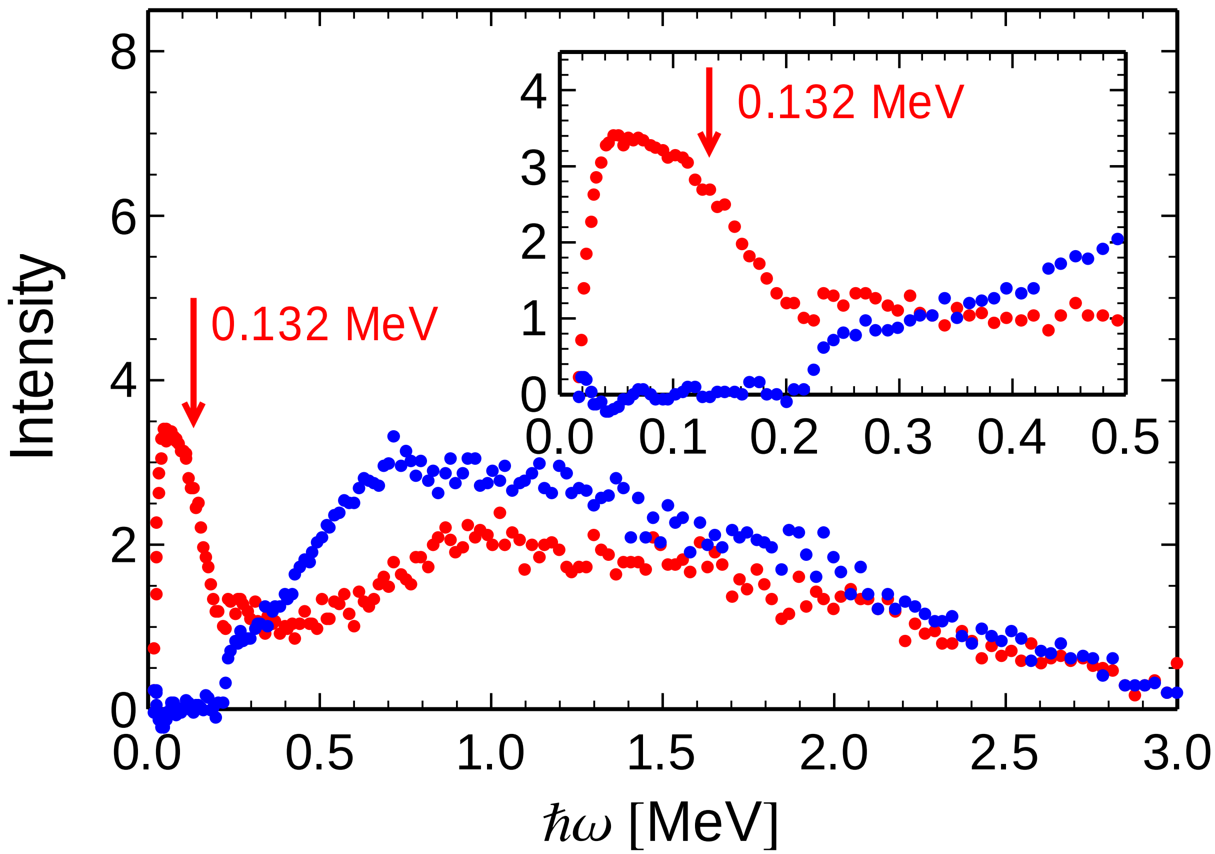
Beam Energy 375 MeV

Crystal Thickness 50 µm resp. 39.6 µm



Deconvoluted Difference Spectra (Off-Channeling Contribution Subtracted)

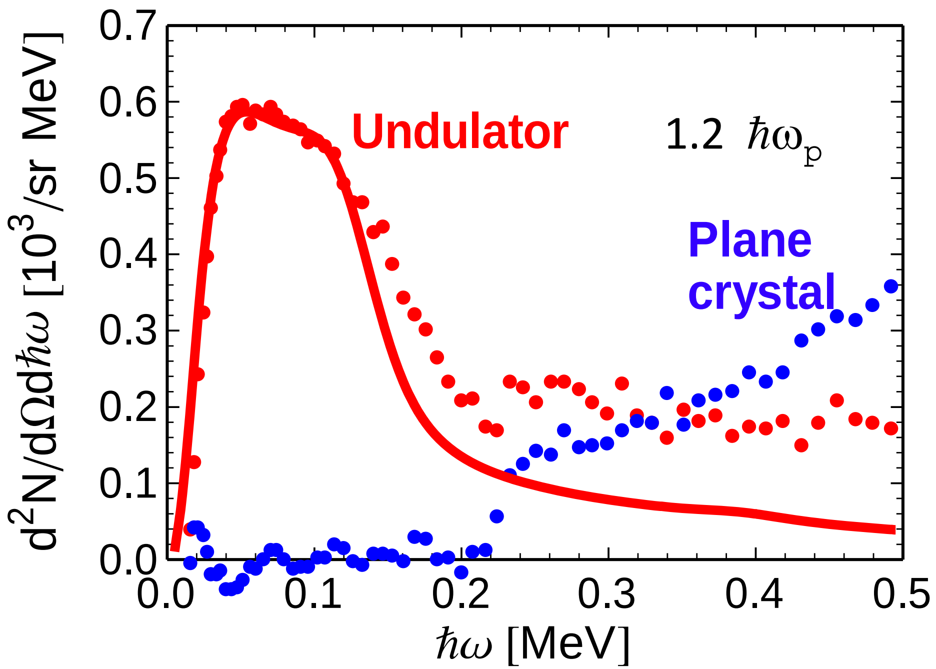
Beam Energy 375 MeV



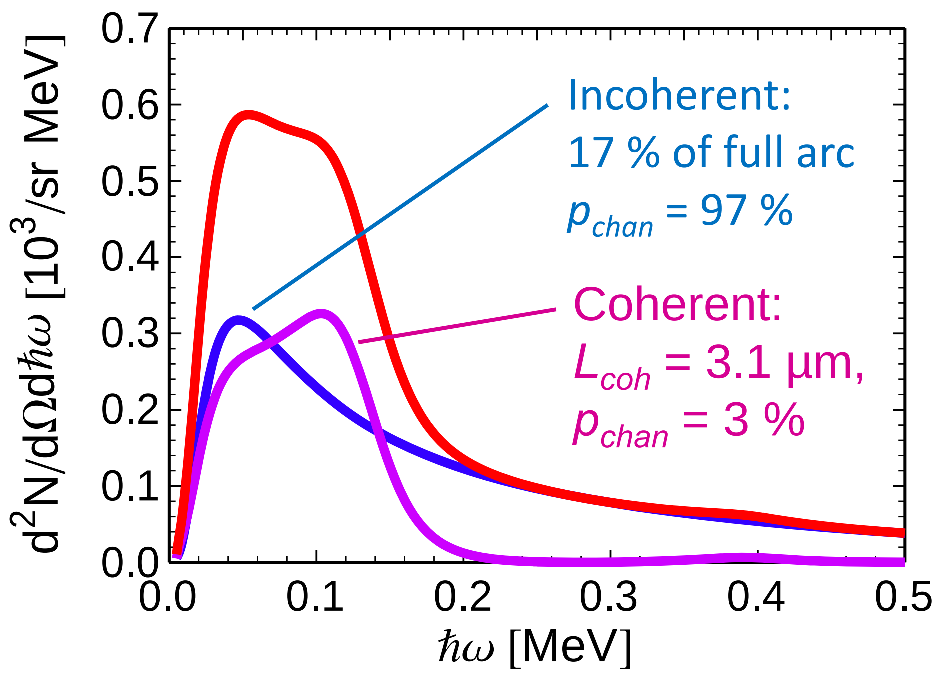
Some indication of a peak at the right energy. However, line shape is strongly asymmetric.

Evidence for Undulator Radiation
Simulation Results at E_{beam} = 375 MeV

Comparison with experiment

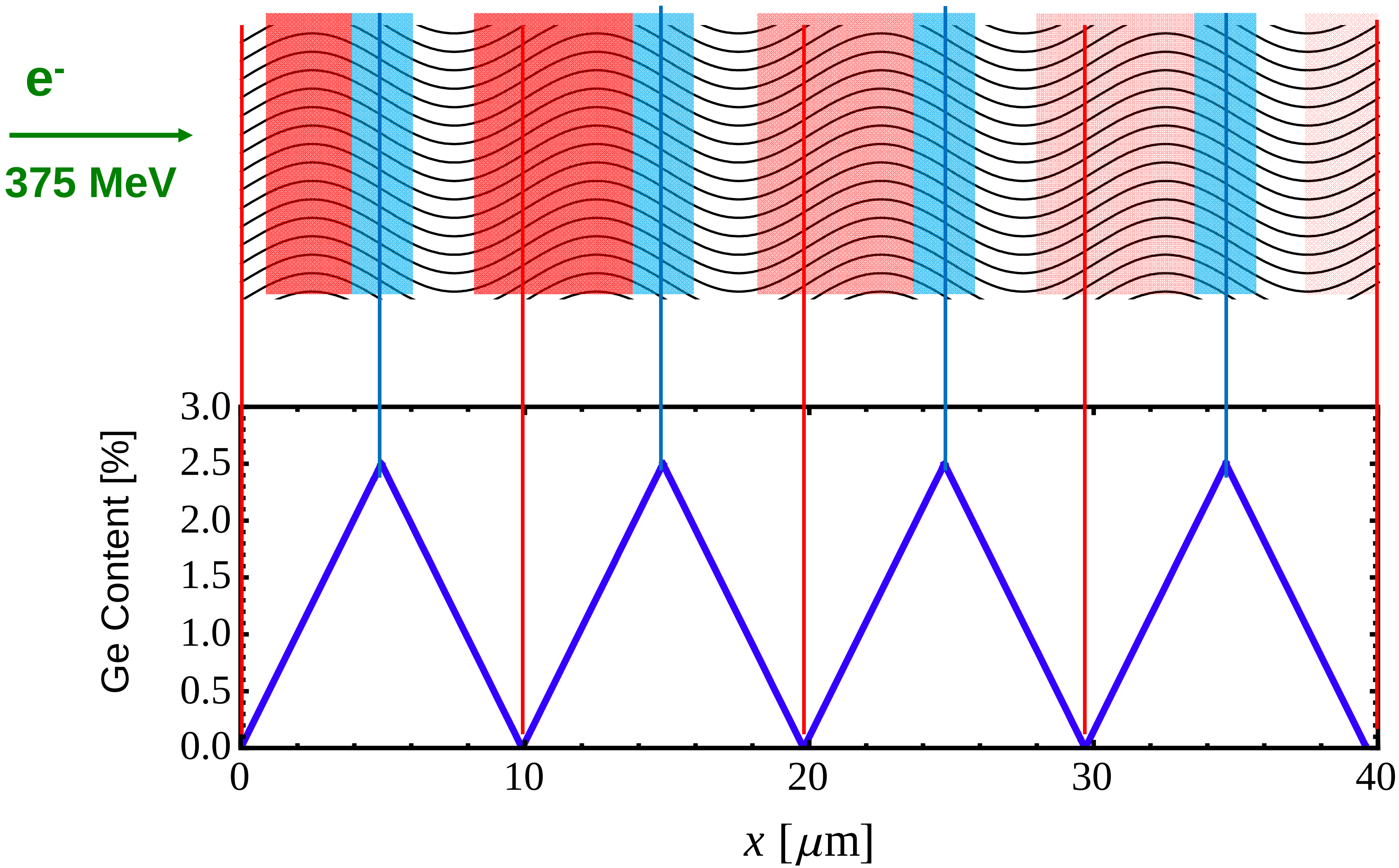


Decomposition of calculation



Why is the coherent contribution so small?

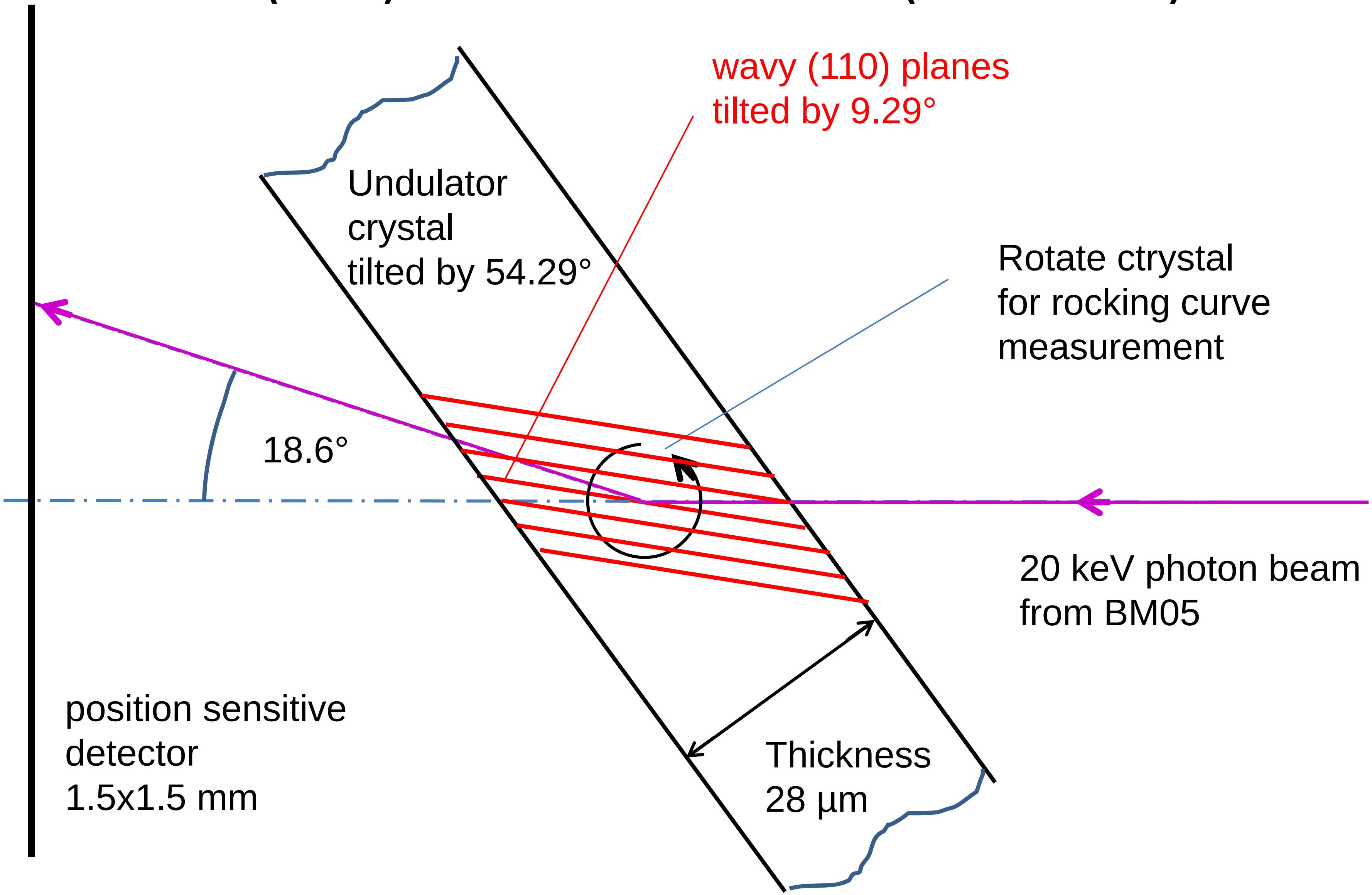
Red: Channeling Domains
Blue: Dechanneling Domains
White: Rechanneling Domains



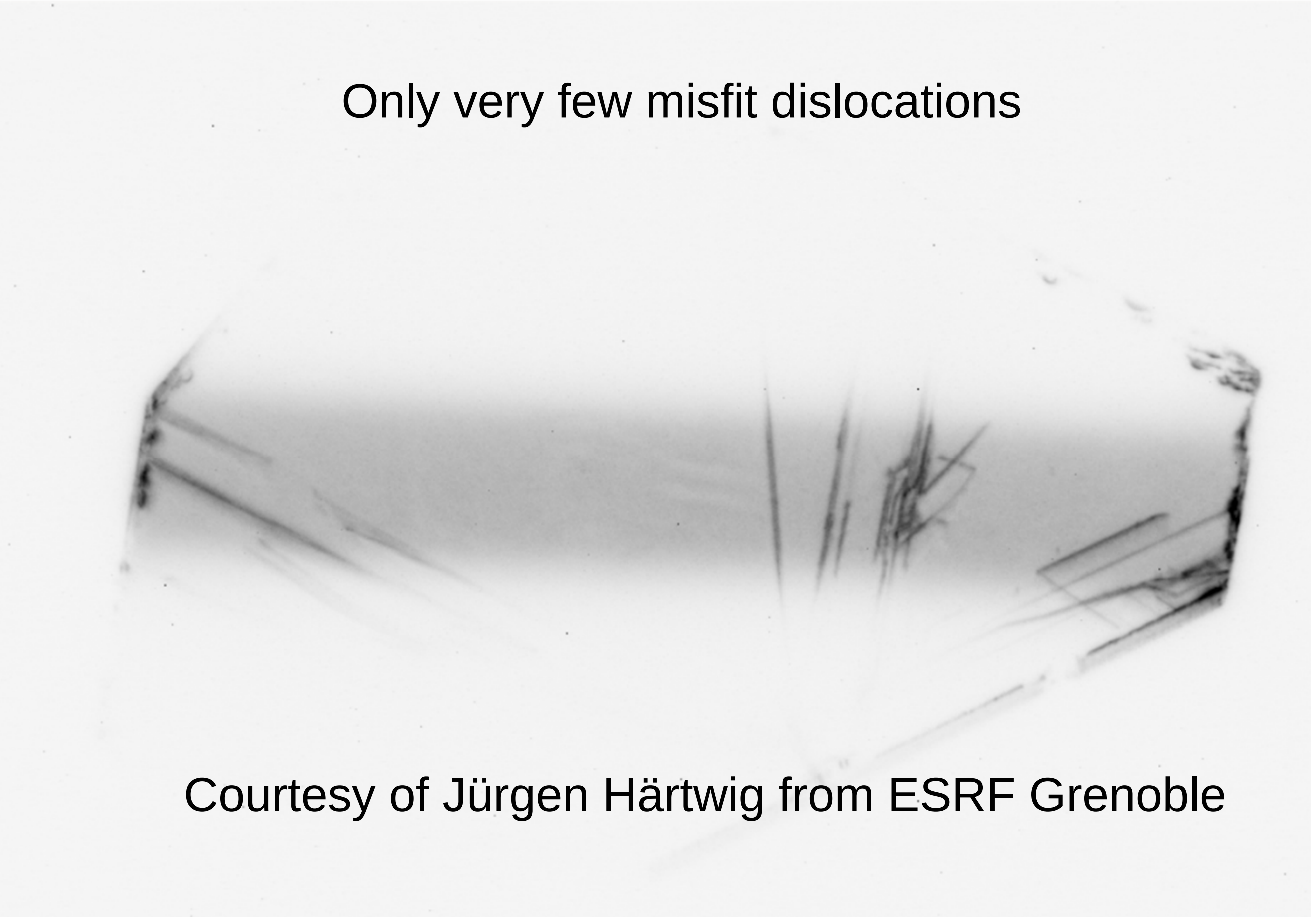
4. Outlook

Investigation of the undulator with the method of X-ray topography at the ESRF in Grenoble

X-ray topography of the Si_xGe_{1-x} undulator with (220) reflection at ESRF (Grenoble)



Snap-shot at a fixed rocking position
Nearly perfect crystal



Snap-shot at a fixed rocking position
$Si_{1-x}Ge_x$ undulator crystal

? Not allowed to show results ?

Preliminary results of measurements at ESRF
indicate a very dense networks of misfit dislocations

Courtesy of Jürgen Härtwig and Thu Nhi Tran Thi

5. Conclusions

- Experimental results at MAMI energies below 855 MeV for (110) planar channeling exhibit quantum state phenomena
- The same may be true for (111) channeling in a bent crystal still at 855 MeV
- Experiments with a 4-period λ_U = 9.9 µm strained layer $Si_{1-x}Ge_x$ crystal undulator at MAMI reveal evidence for emission of undulator radiation
- Detailed investigation of undulator quality with X-ray topography at synchrotron radiation facility ESRF (Grenoble) is in progress

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