A 530 MeV positron beam for channeling experiments at the Mainz Microtron MAMI

1. Introduction to MAMI

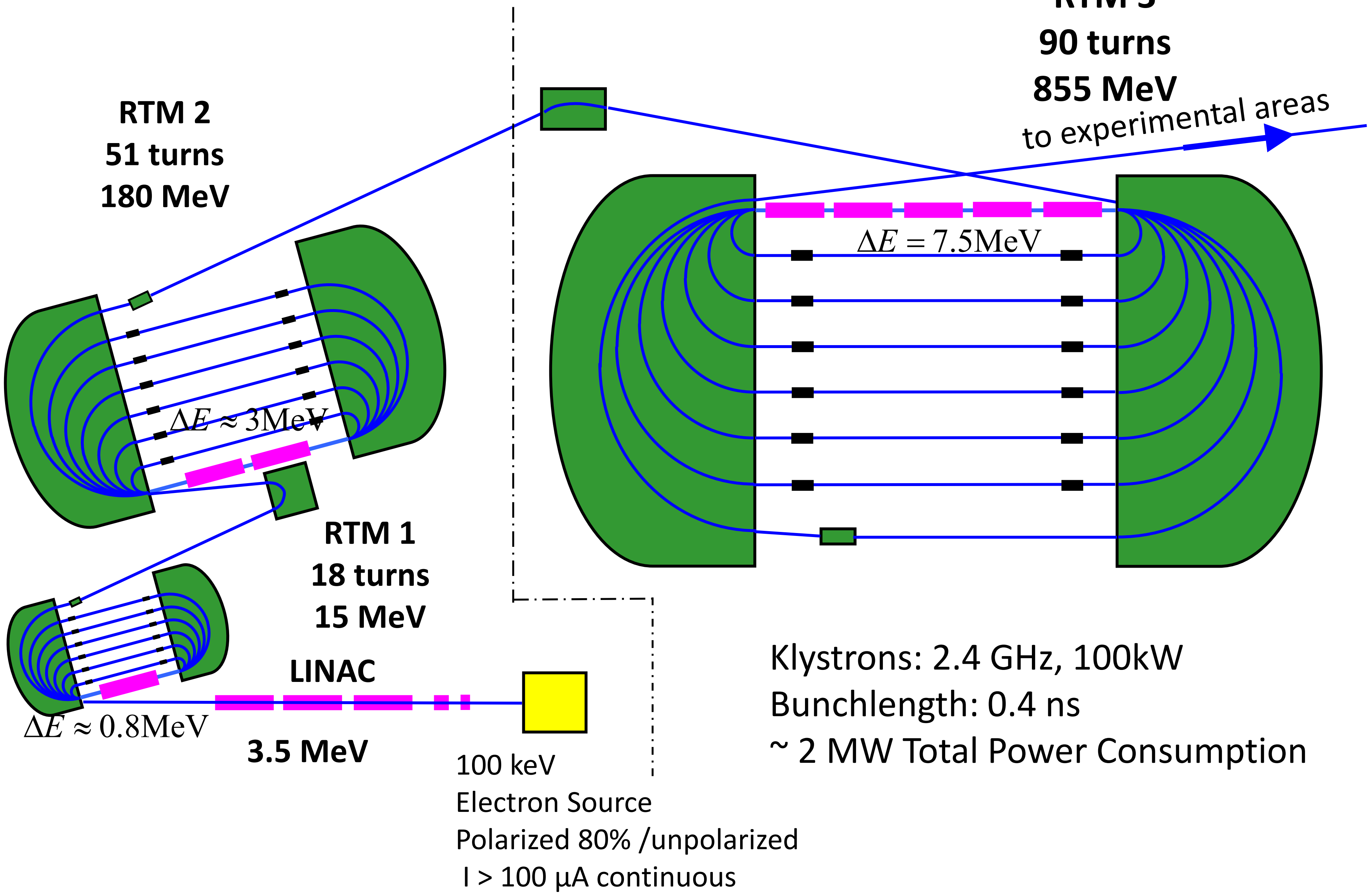
2. Why Positrons

3. Positron beamline @ MAMI with low Emittance

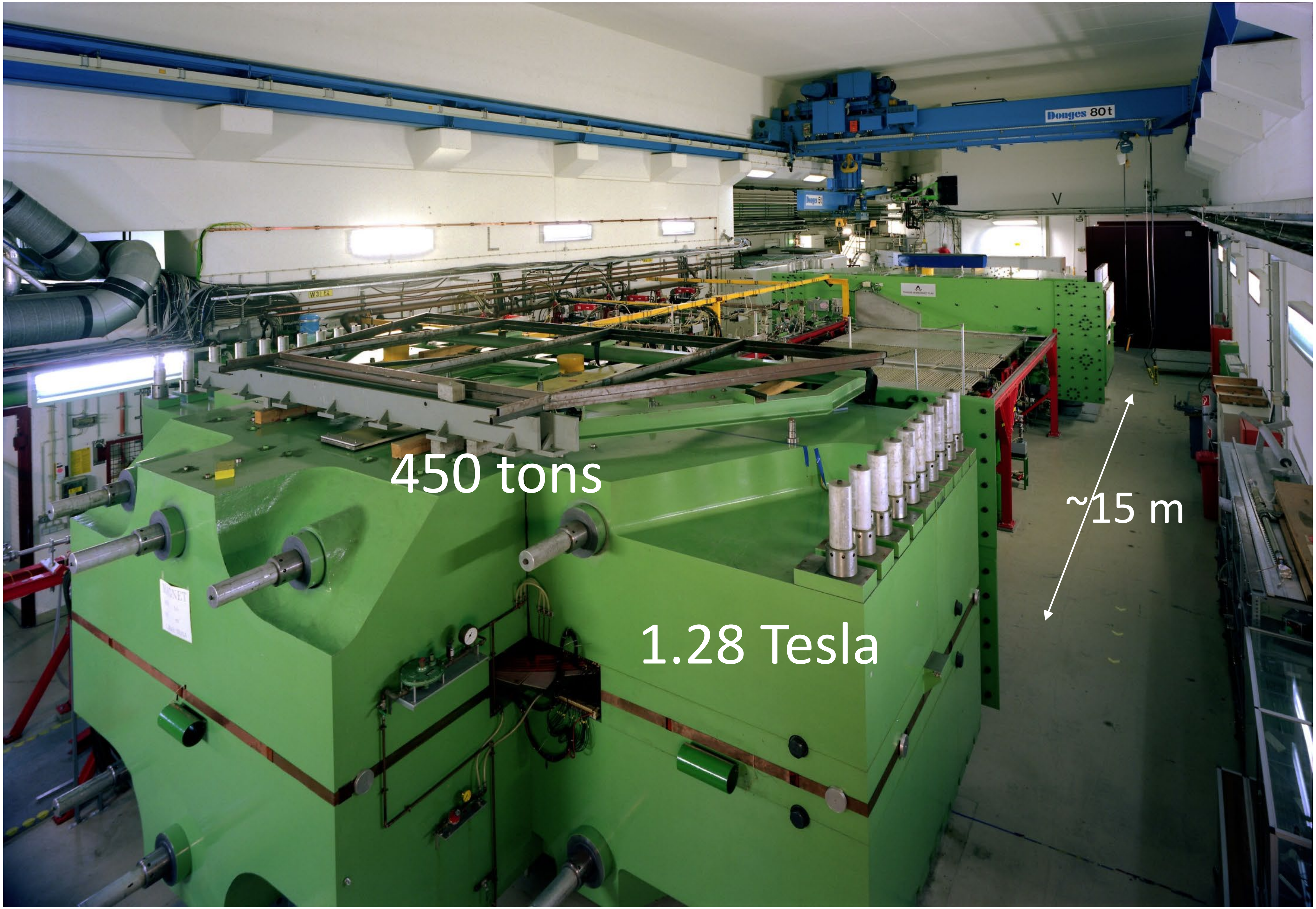
4. Status and future experiments with Positrons

DESY-KIPT Seminar, W. Lauth, 2024

Mainzer Mikrotron MAMI B



Klystrons: 2.4 GHz, 100kW
Bunchlength: 0.4 ns
~ 2 MW Total Power Consumption


Donges 80 t
450 tons
1.28 Tesla
~15 m

Ground plan of MAMI

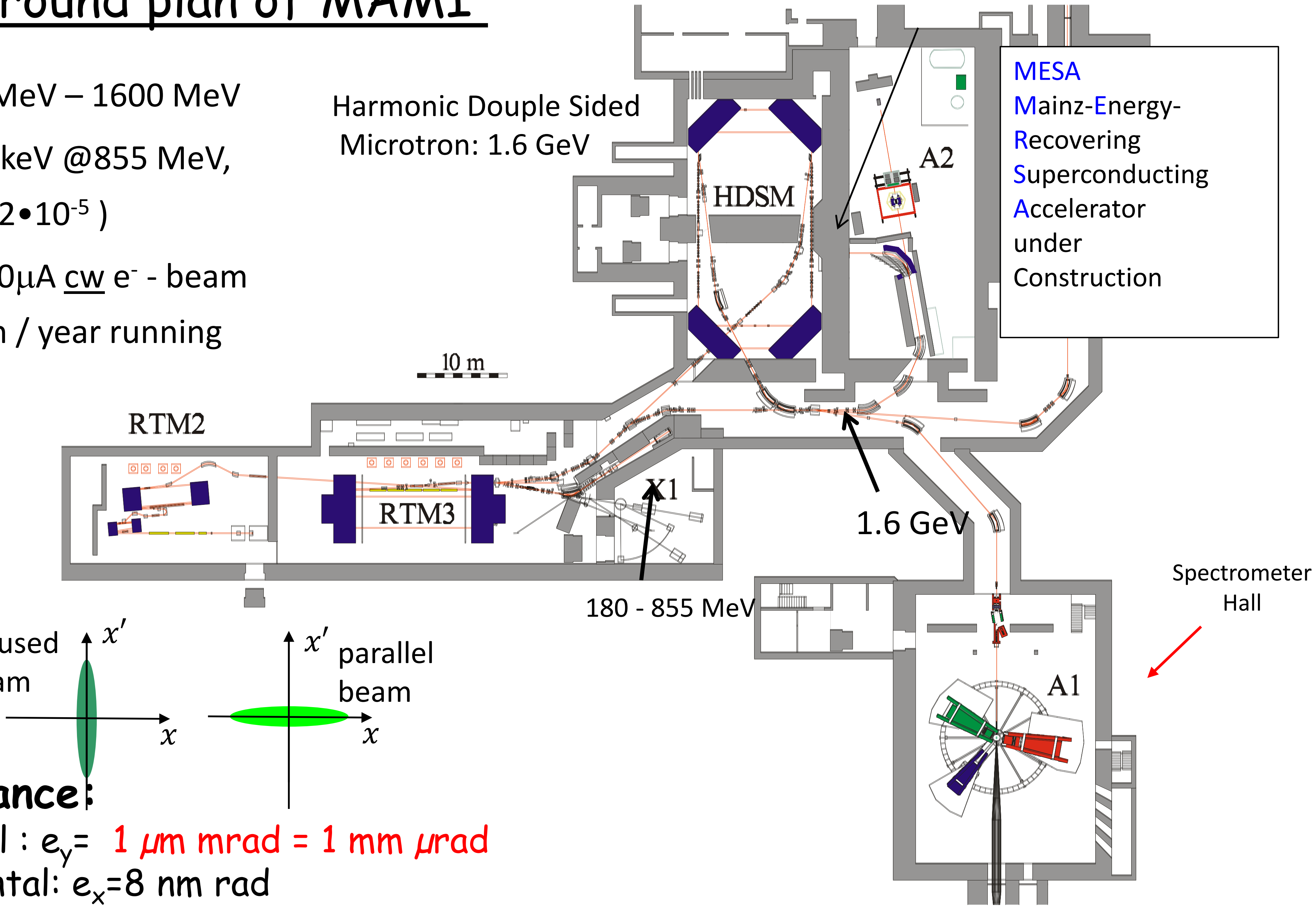
E= 180 MeV – 1600 MeV

ΔE = 13 keV @855 MeV,

$\Delta E/E = (2 \bullet 10^{-5})$

max. 100µA <u>cw</u> e^- - beam

~ 7000 h / year running

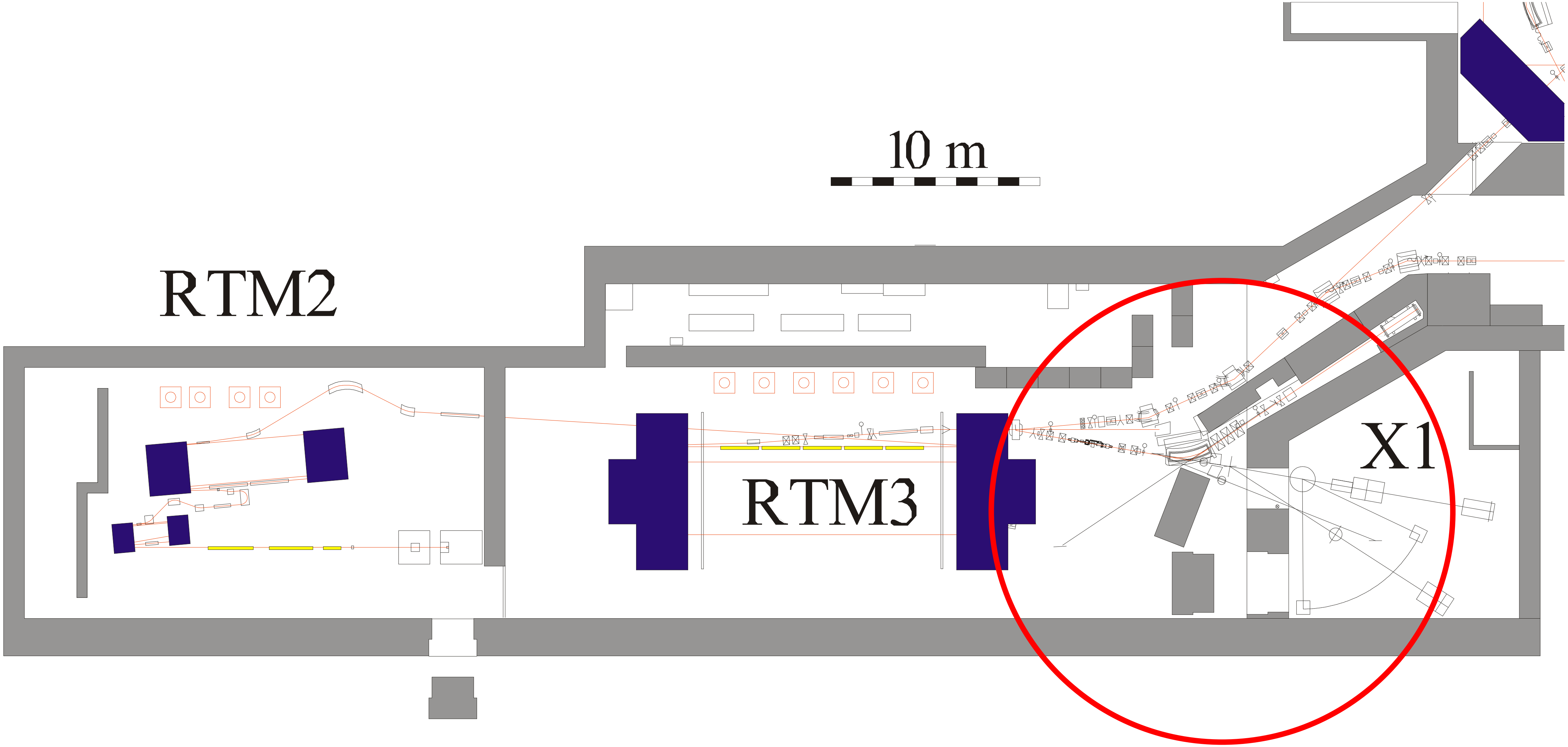


Emittance:

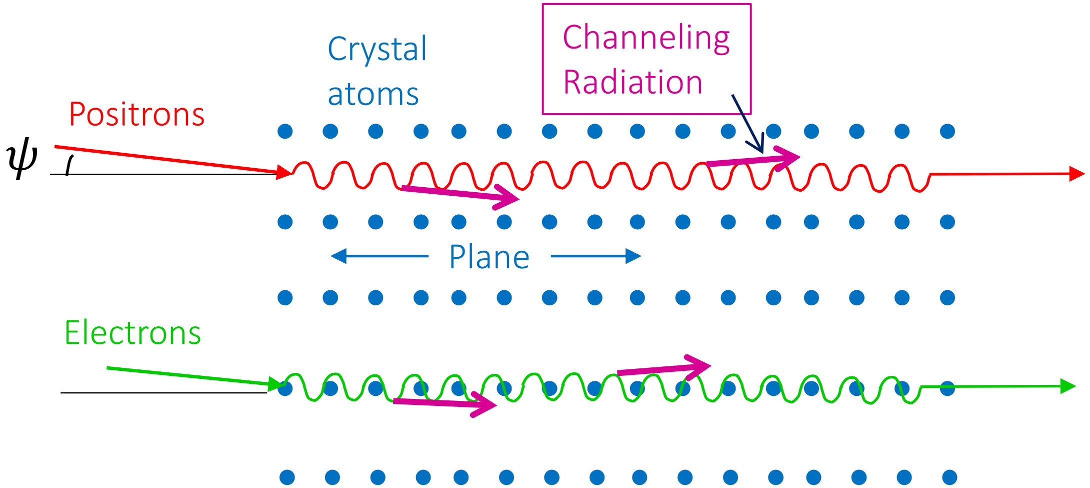
Vertical : e_y= 1 µm mrad = 1 mm µrad

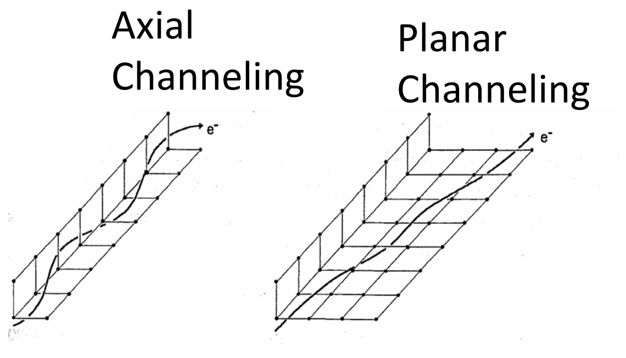
Horizontal: e_x=8 nm rad

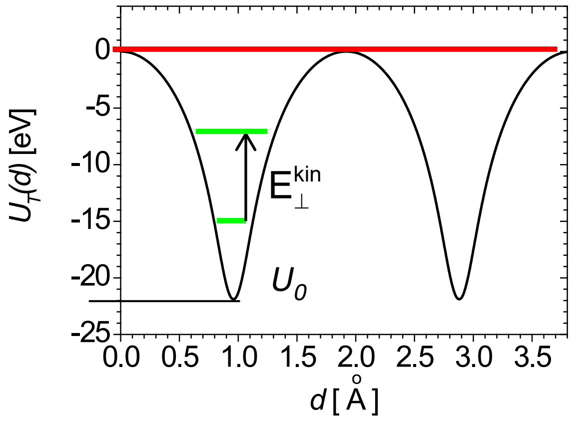
Production of high-energy positrons



Channeling Radiation







$$E_\perp^{kin} = \frac{p_\perp^2 c^2}{2mc^2} \approx \frac{E\psi^2}{2}$$

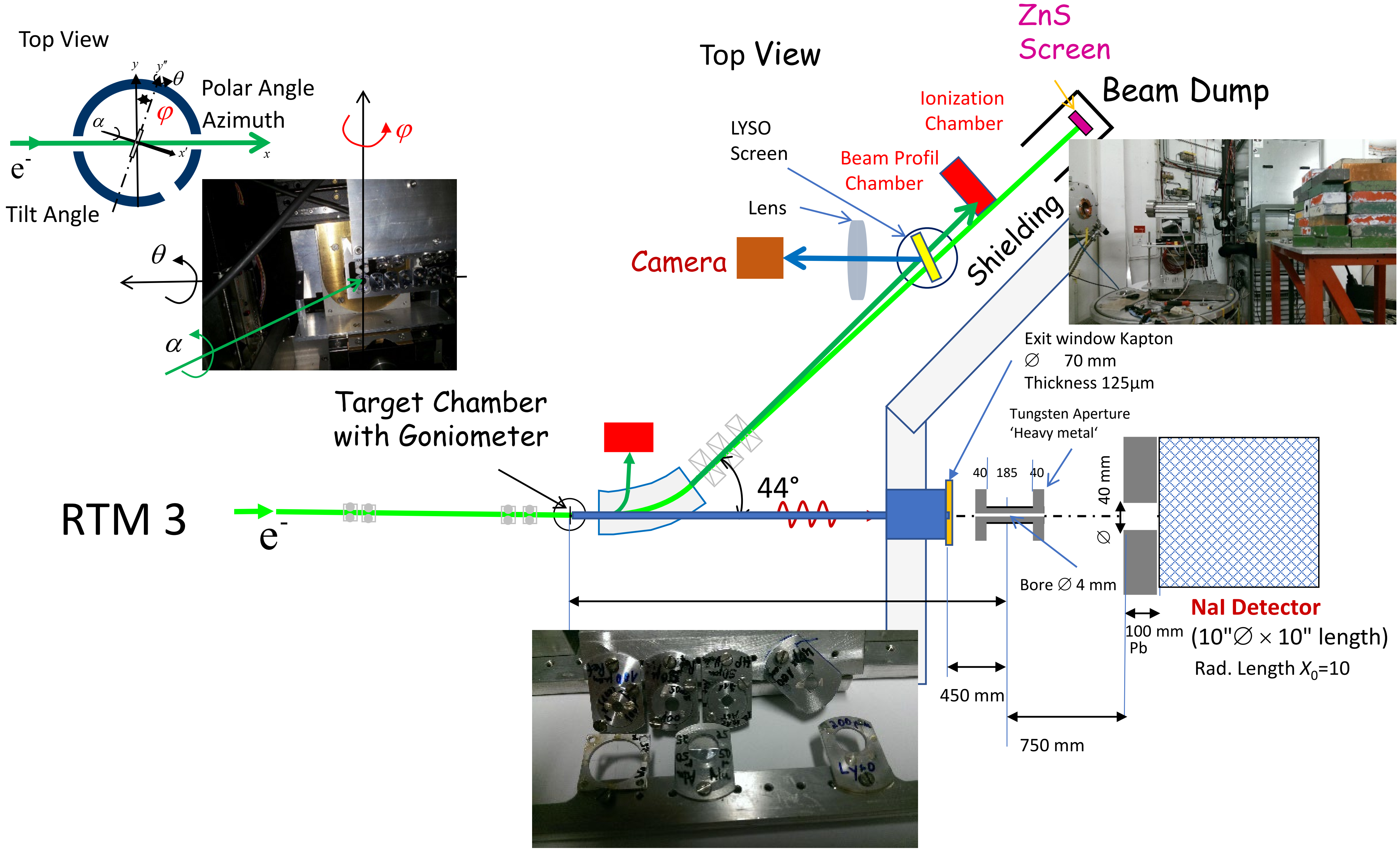
$$E_\perp^{kin} < U_0 \rightarrow$$

Lindhard critical angle

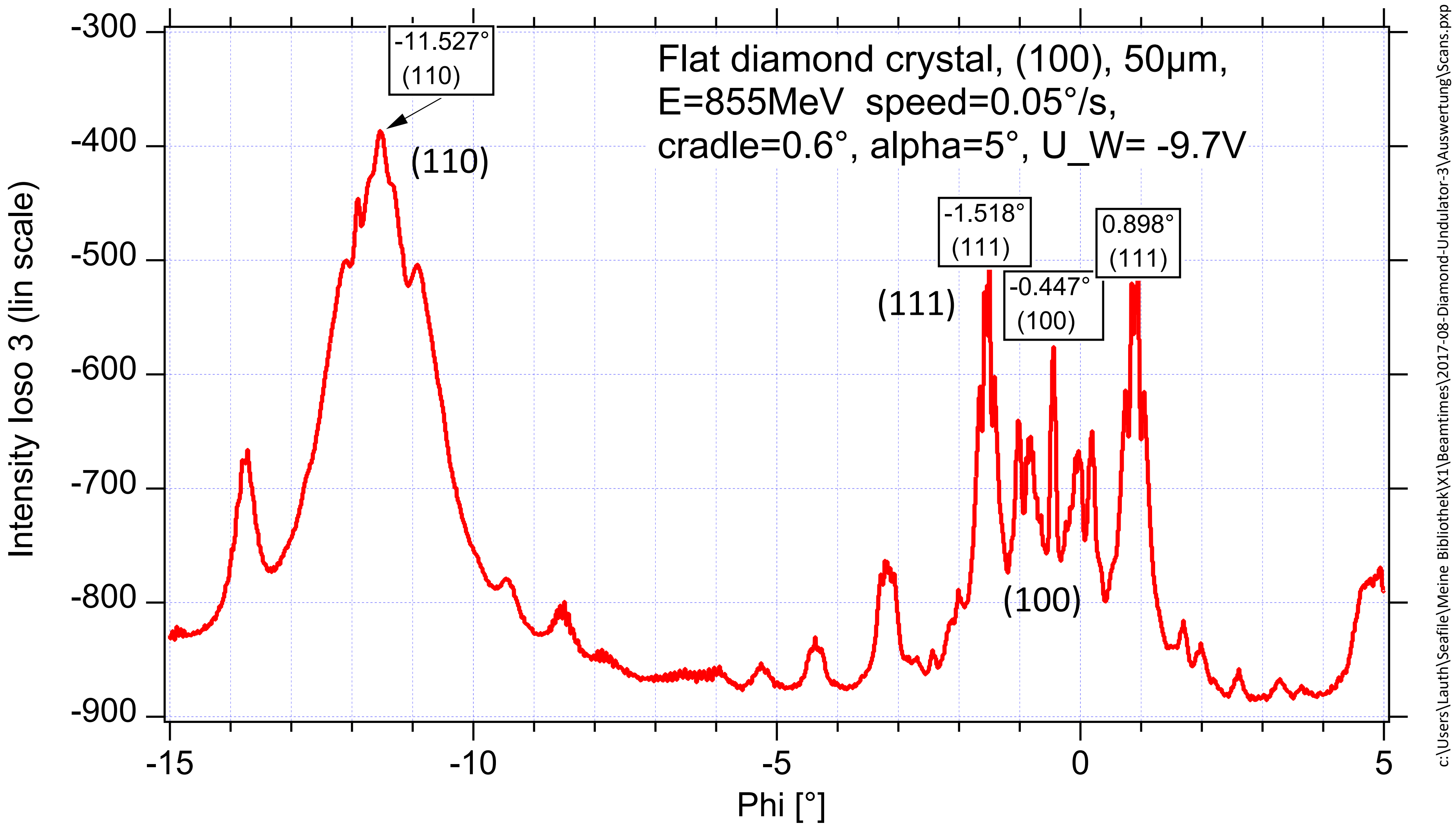
$$\psi < \sqrt{\frac{2U_0}{E}} \approx \sqrt{\frac{2 \cdot 20eV}{1\ GeV}}$$

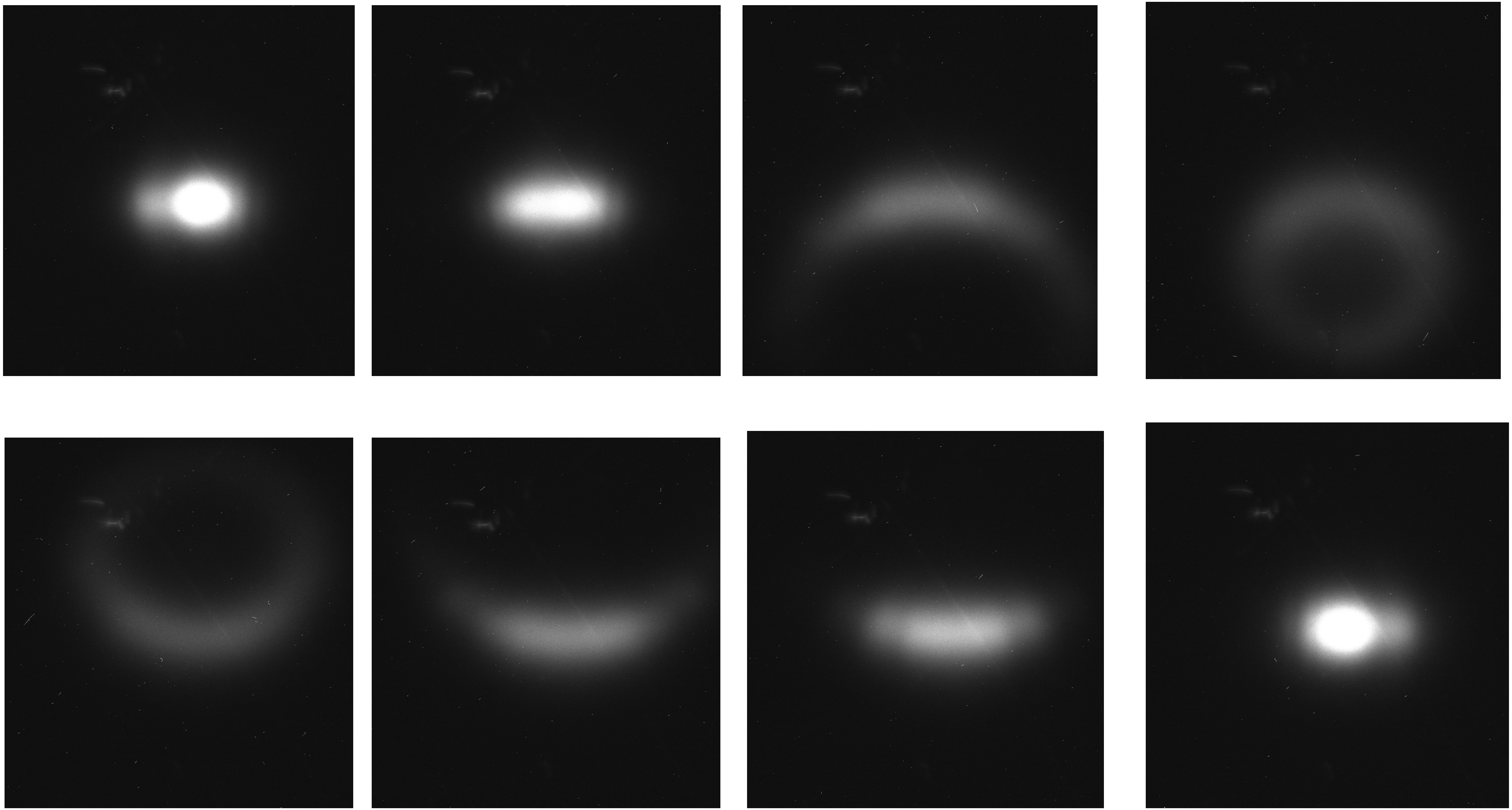
$$\psi < 0.2\ mrad$$

Experimental Setup (855) MeV e⁻

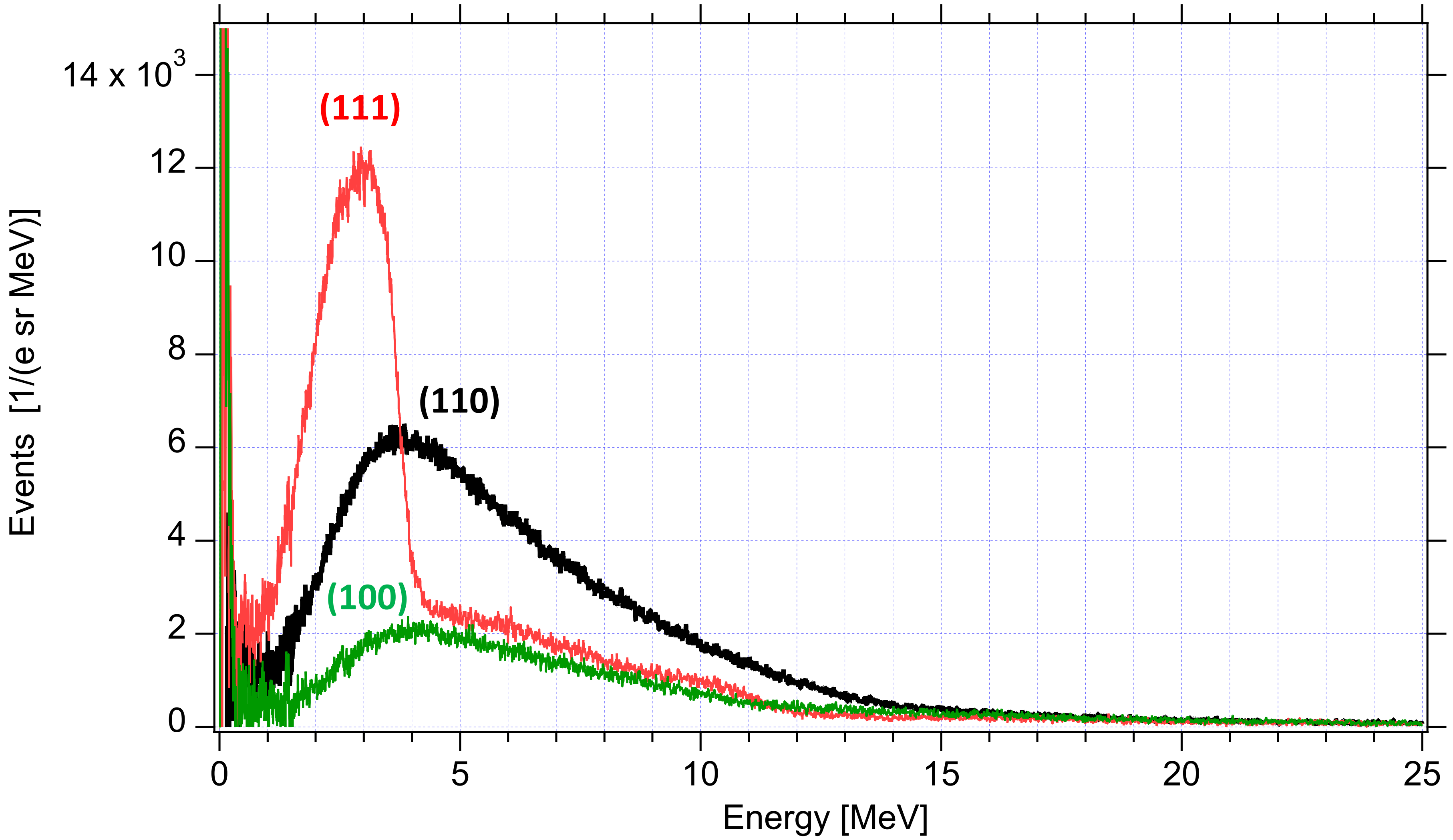


Scan around the vertical axis Φ
Diamond, flat 50 μm crystal
855 MeV e-beam



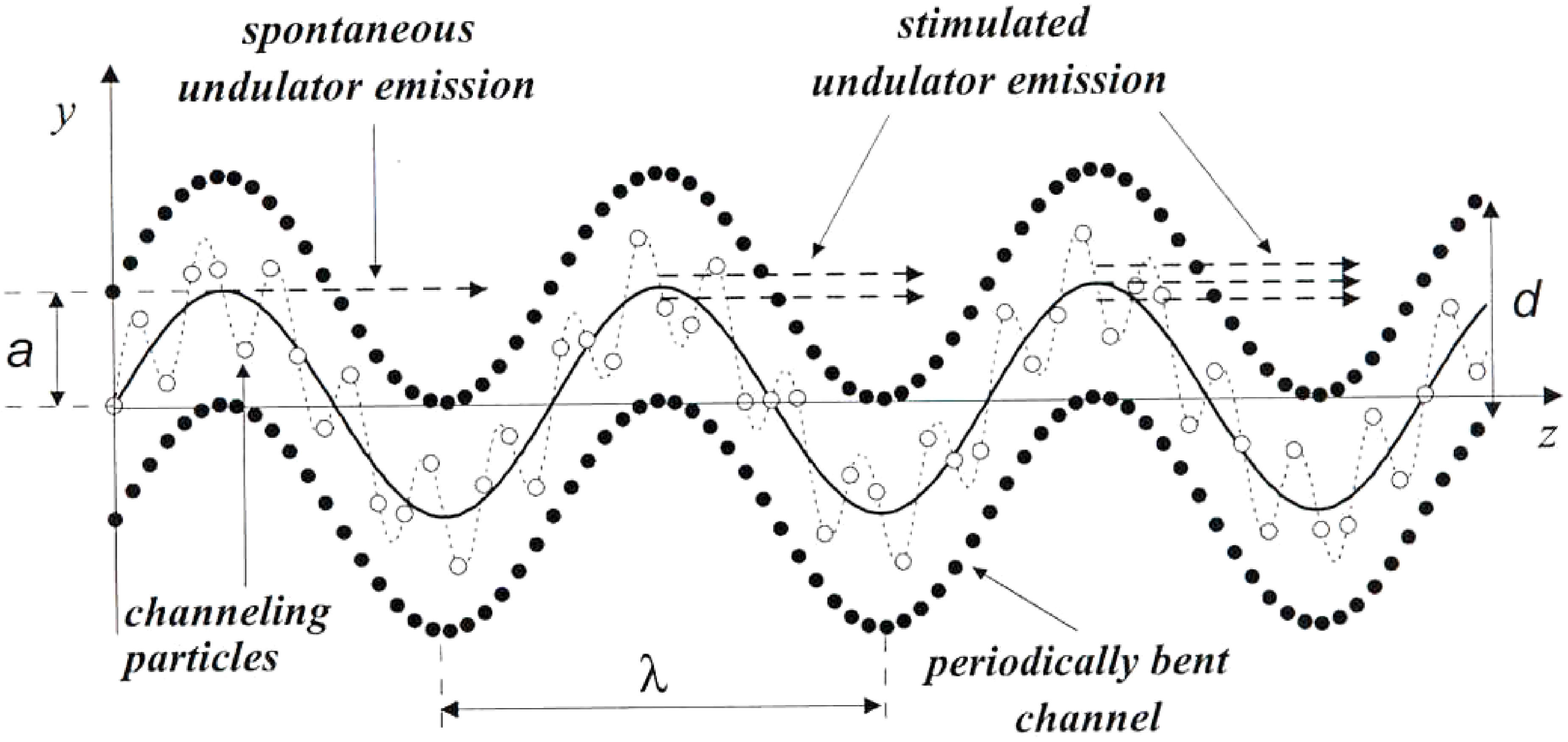


Channeling radiation of a flat diamond crystal



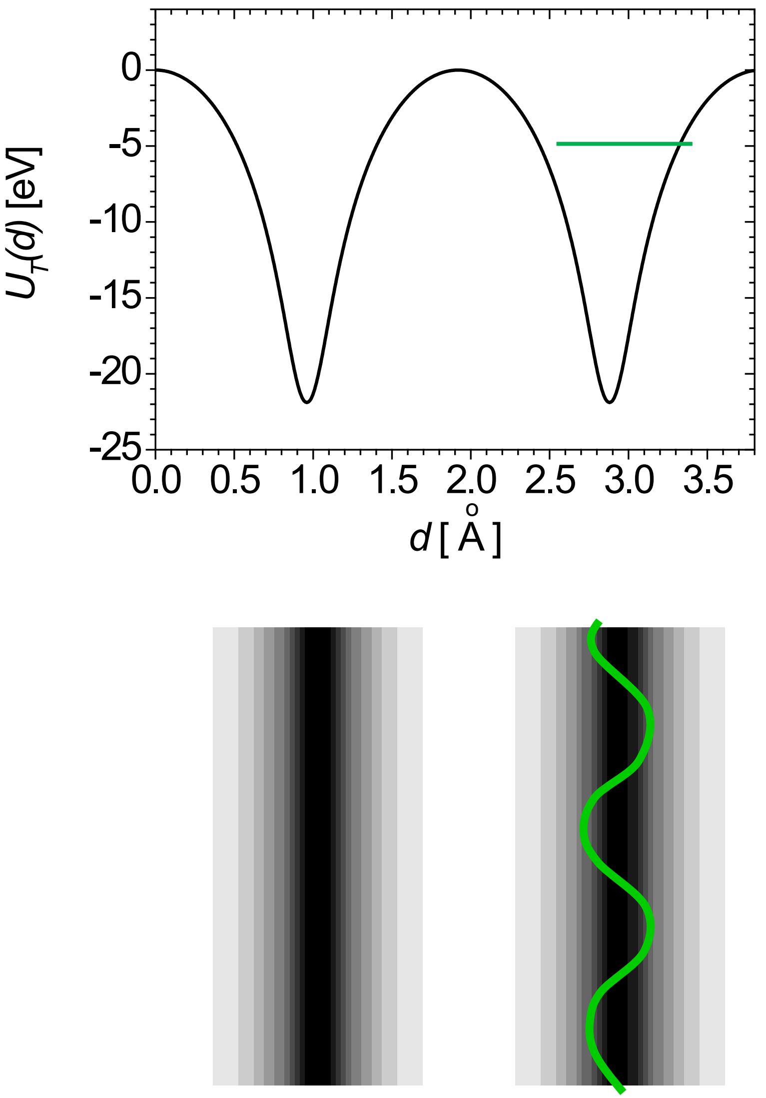
Undulator Radiation at Positron/Electron Channeling in a Single Crystal

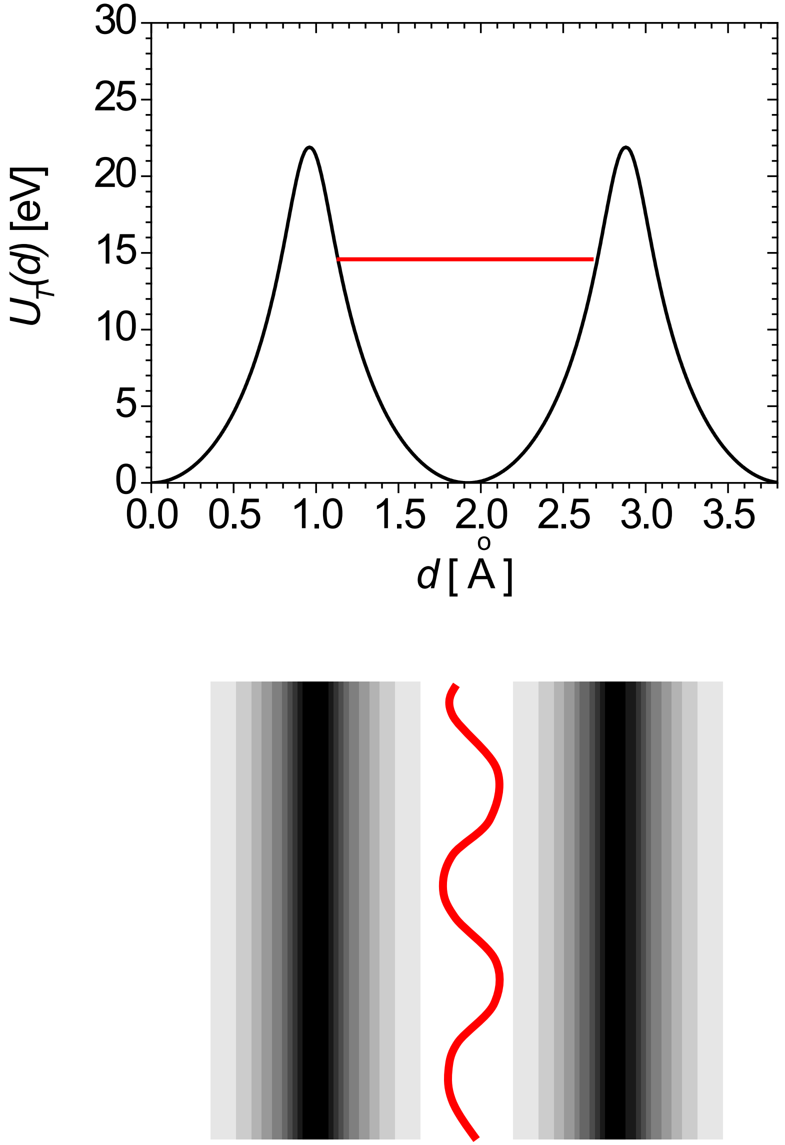
A. Solov'yov, A. Korol, W. Greiner *et al.*



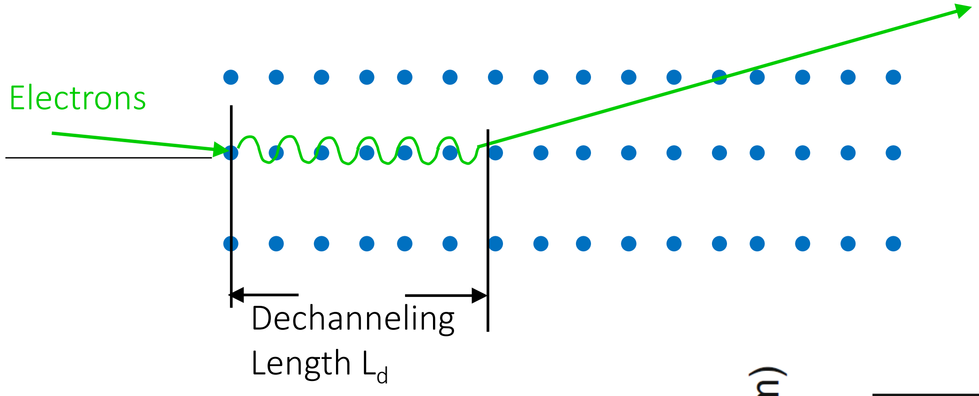
Why Positrons

Electrons versus Positrons



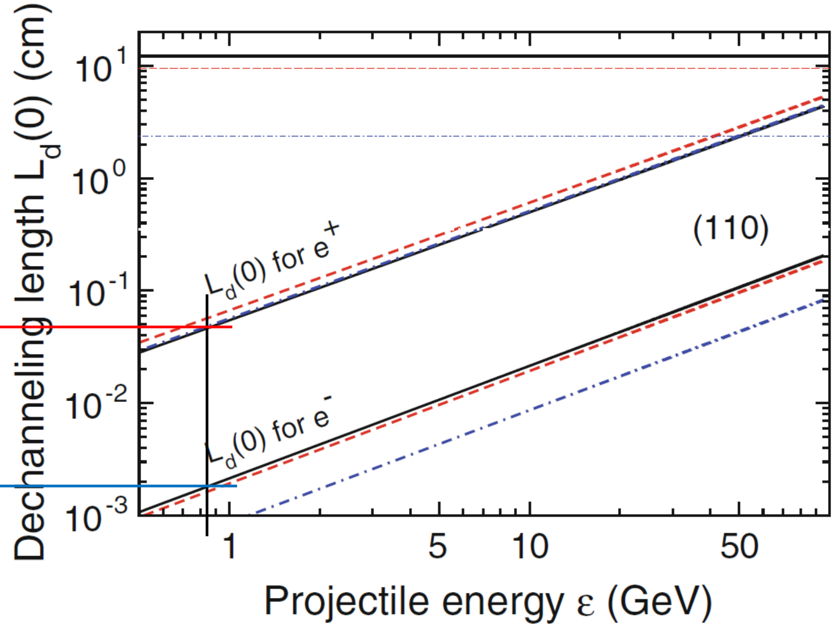


Dechanneling length

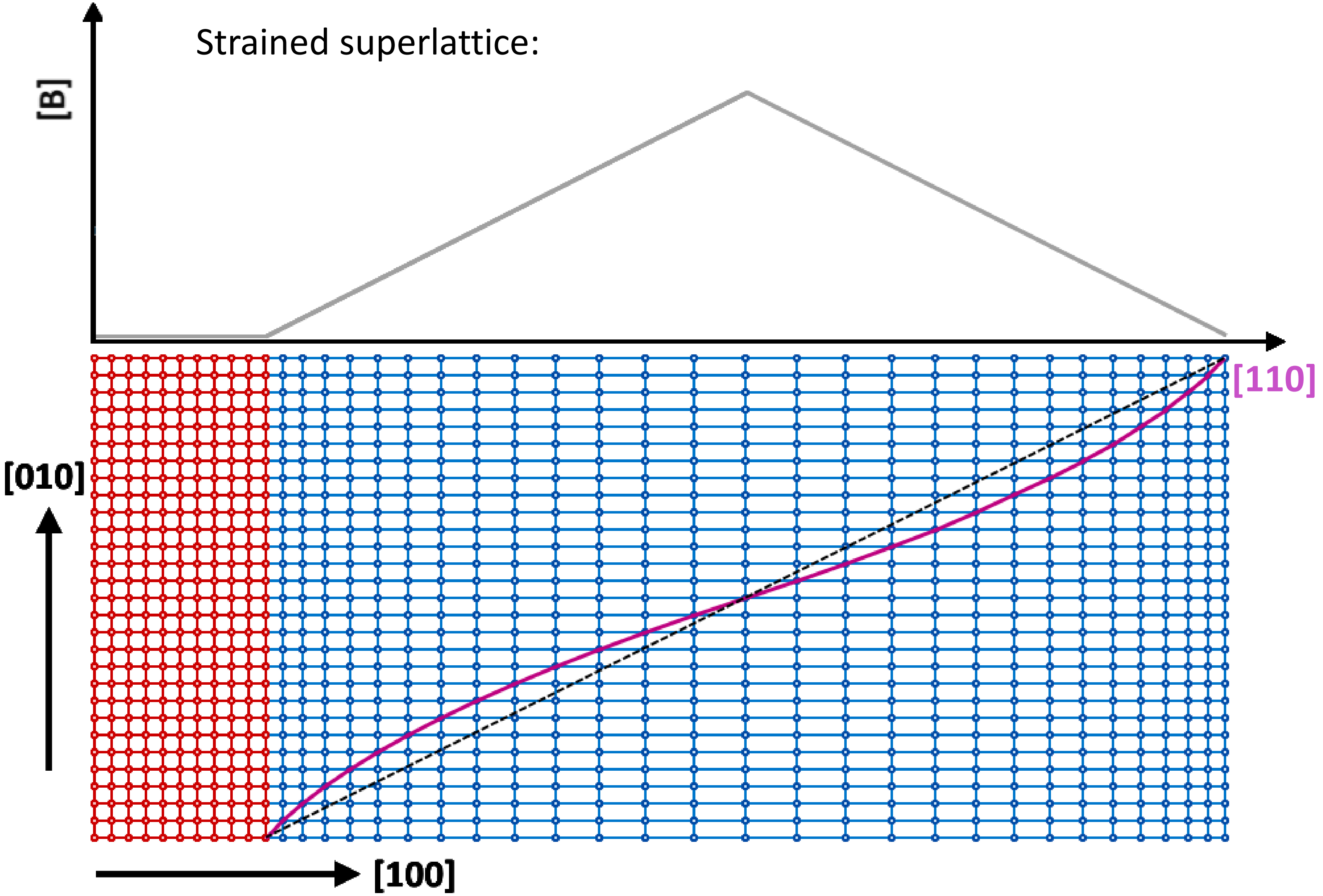


Positrons
~ 300µm

Electrons
~ 20µm
@ 855 MeV



Superlattice principles



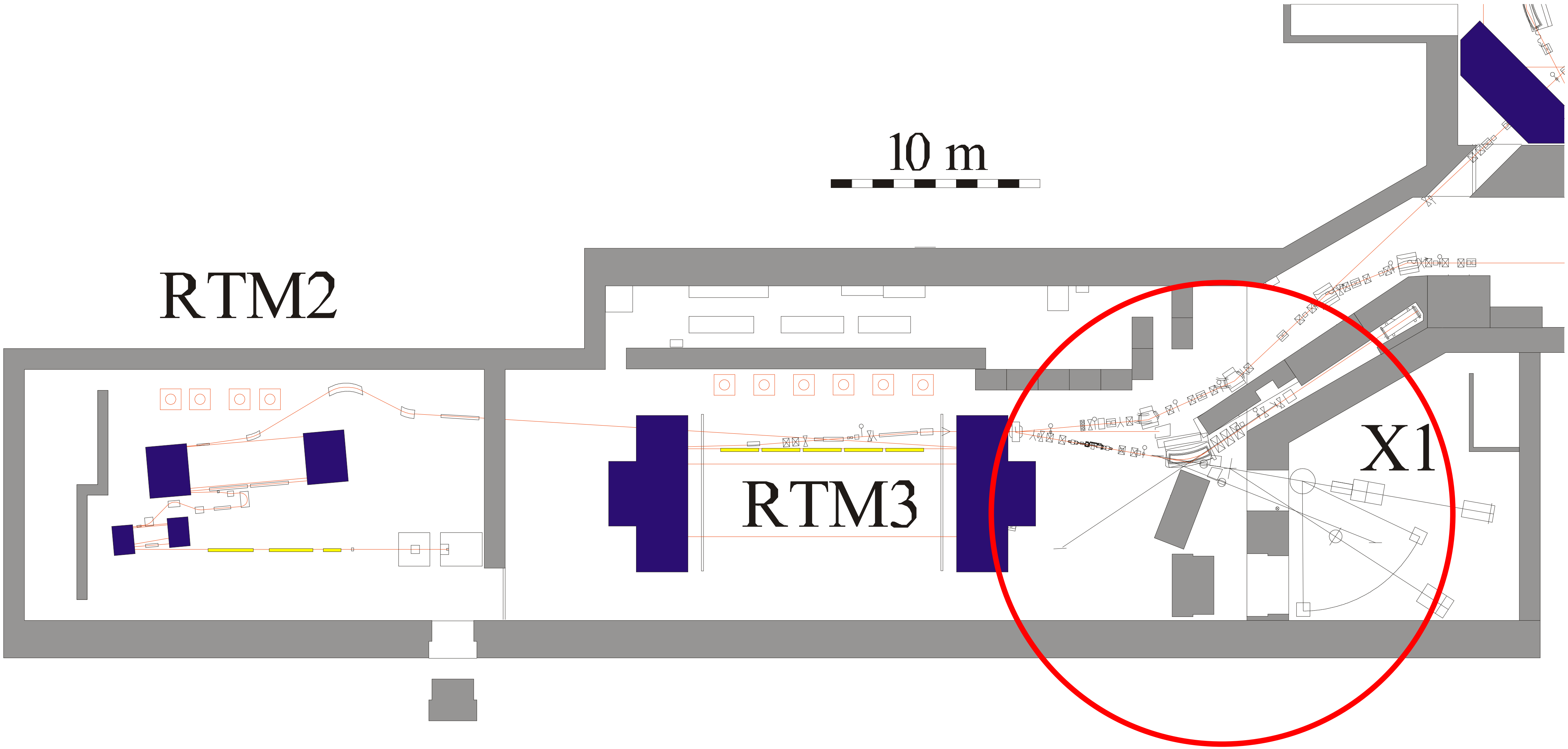
Undoped substrate

Growth with increasing doping
= increase in crystal parameter along [100].

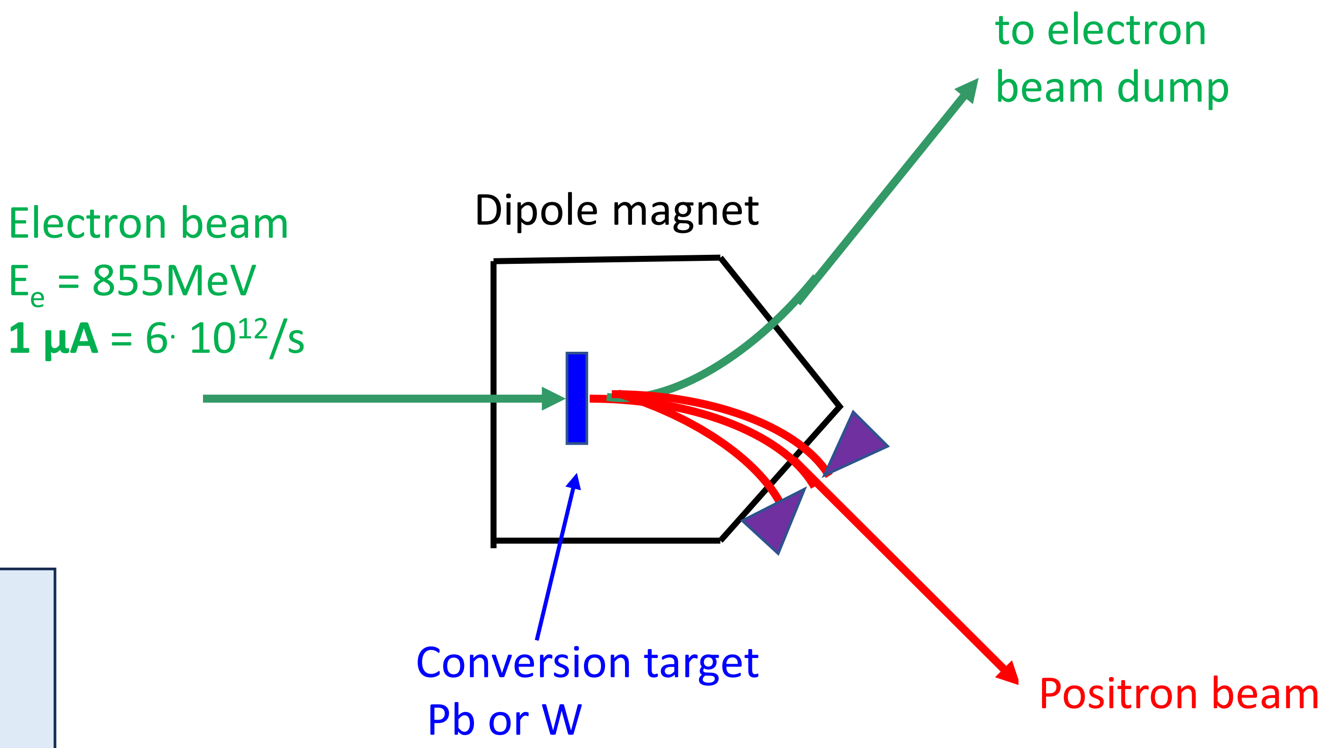
Growth with decreasing doping
= decrease in crystal parameter along [100]

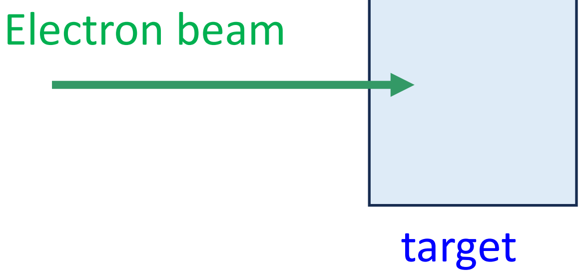
Channeling along [110]: undulation

Production of high-energy positrons

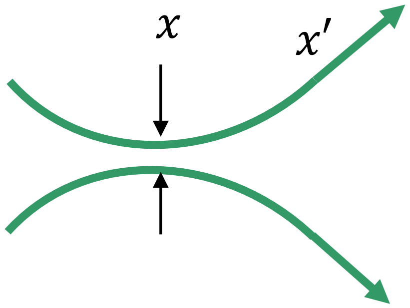


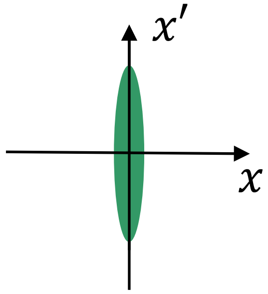
Pair production with the MAMI beam in combination with a monochromator





High quality Positron beam @ MAMI





vertical

MAMI: $\varepsilon_x = x \cdot x'$

$= 1\, mm \cdot \mu rad$

$= 10\, \mu m \cdot 0.1 mrad$

Emittance $\varepsilon_x = x \cdot x' = \frac{F}{\pi} = const$

Thin target for Positron production

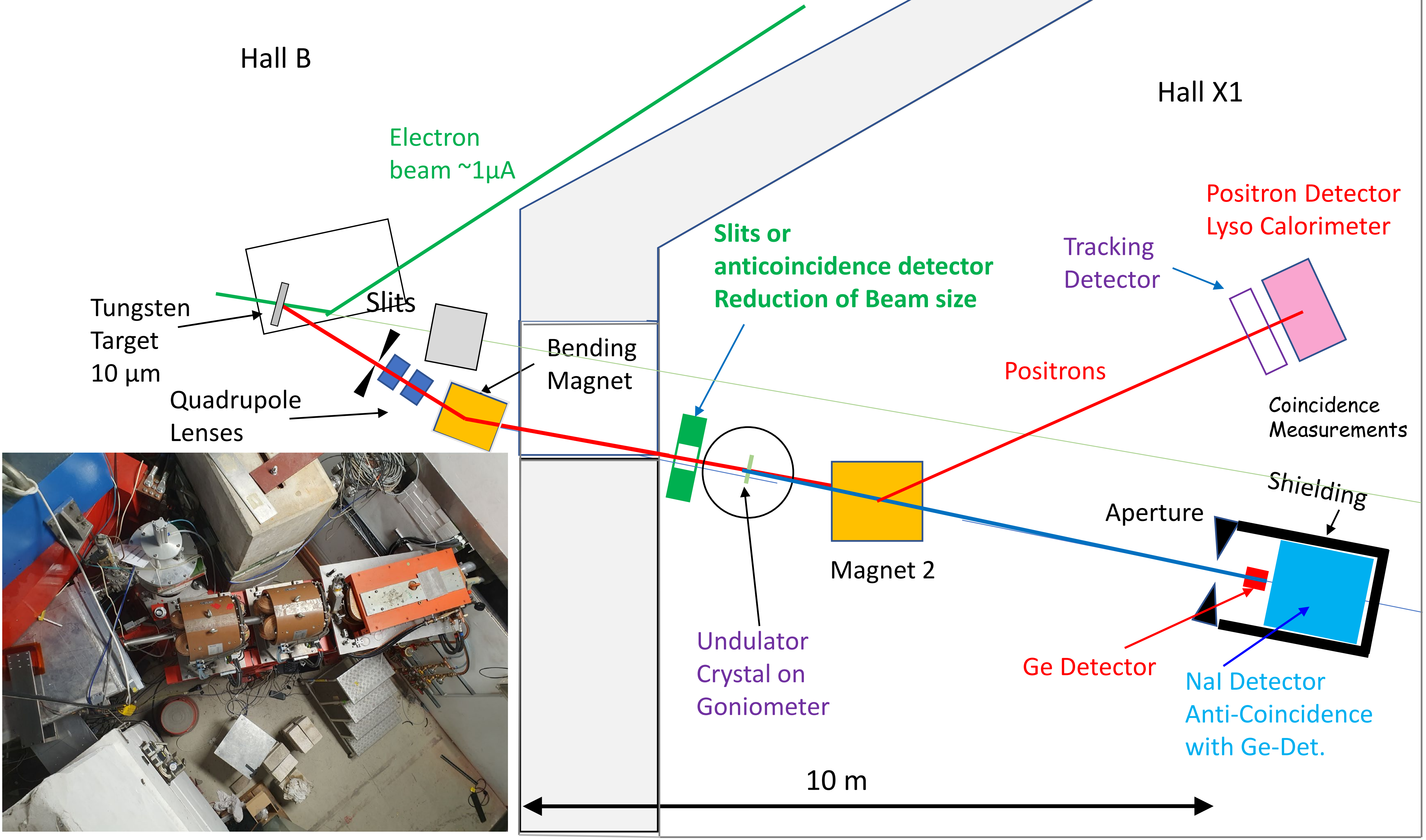
$10\ \mu m\ \ W \ \rightarrow Scattering\ \sigma_S = 0.94\ \mathrm{mrad}$

$\sigma_p = \cong \frac{1}{\gamma} = 1\ \mathrm{mrad}\ @500\mathrm{MeV}$

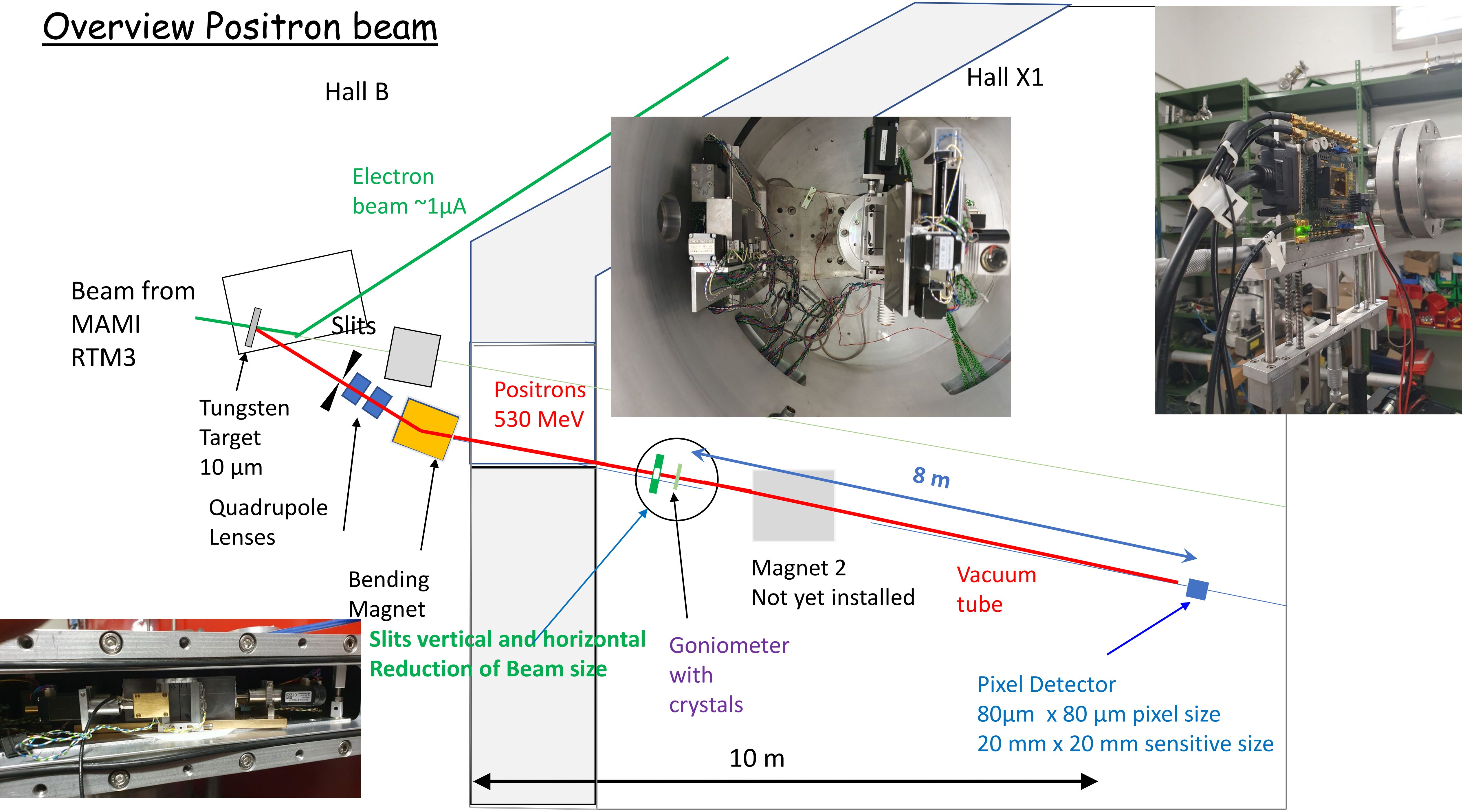
Emittance of Positrons: $\varepsilon_{e+} = 10\ \mu m\ \cdot\ 1.4\, mrad$

$= \ 1mm \cdot 0.014\, mrad$

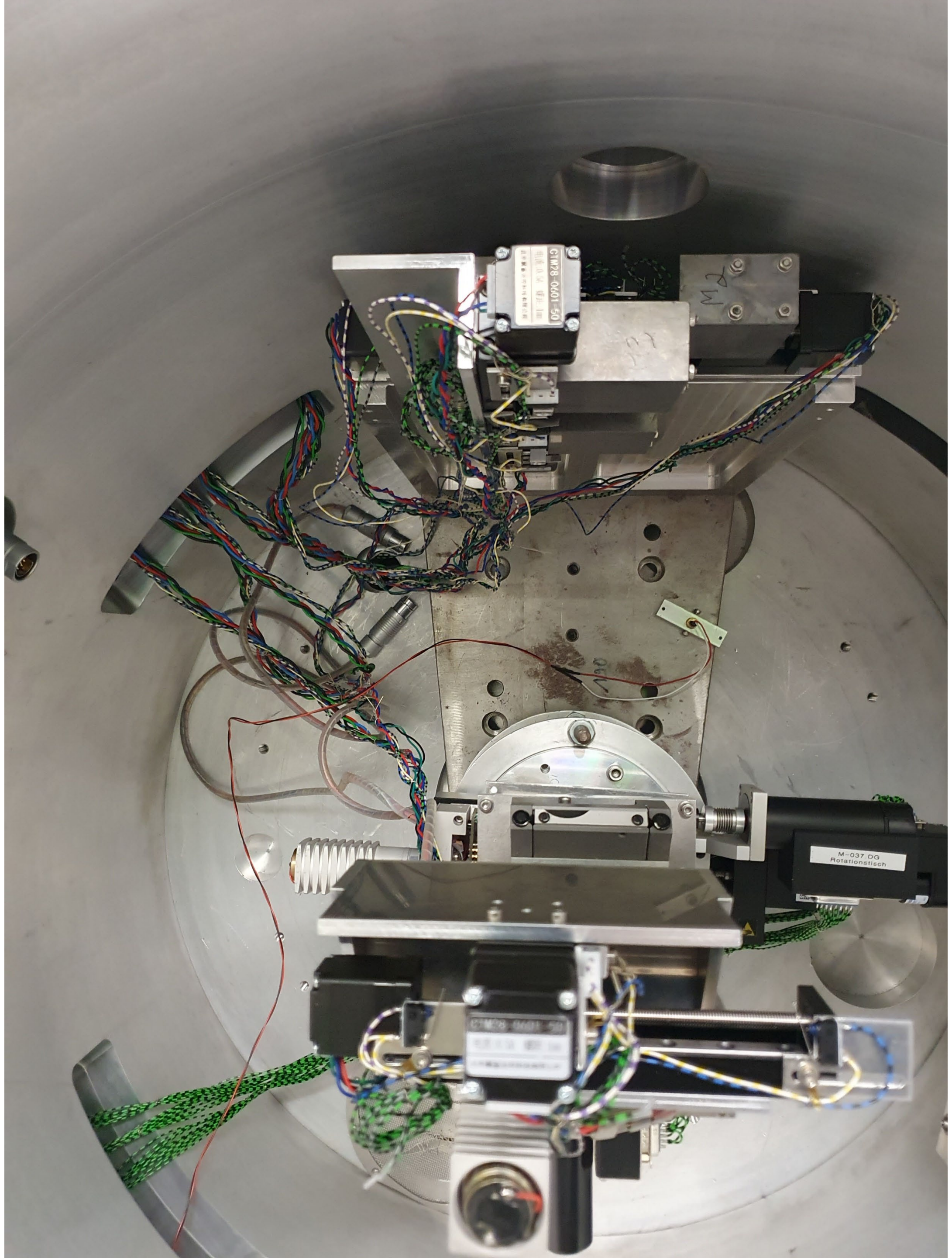
Positron beam line



Overview Positron beam

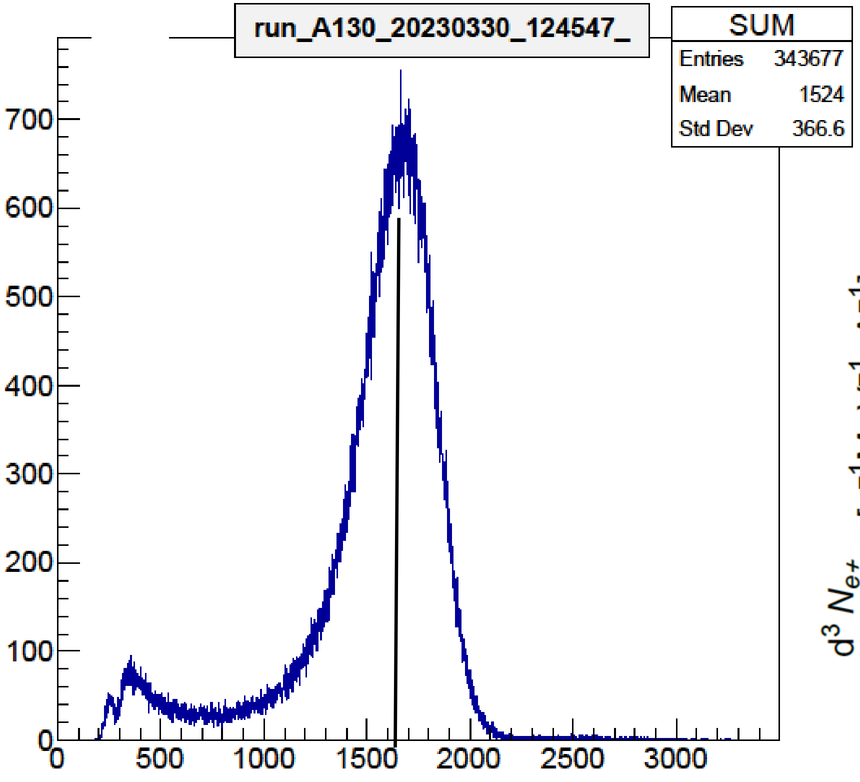



X1

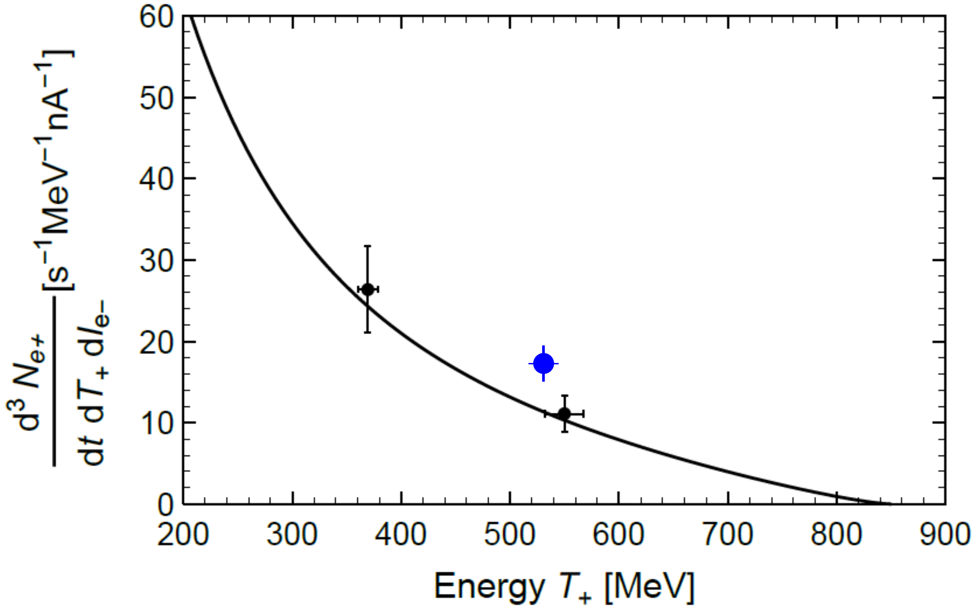

M-037.DG
Rotationstisch

Production Rate

10 μm W Target
Slit width 3mm
~4.5 MeV



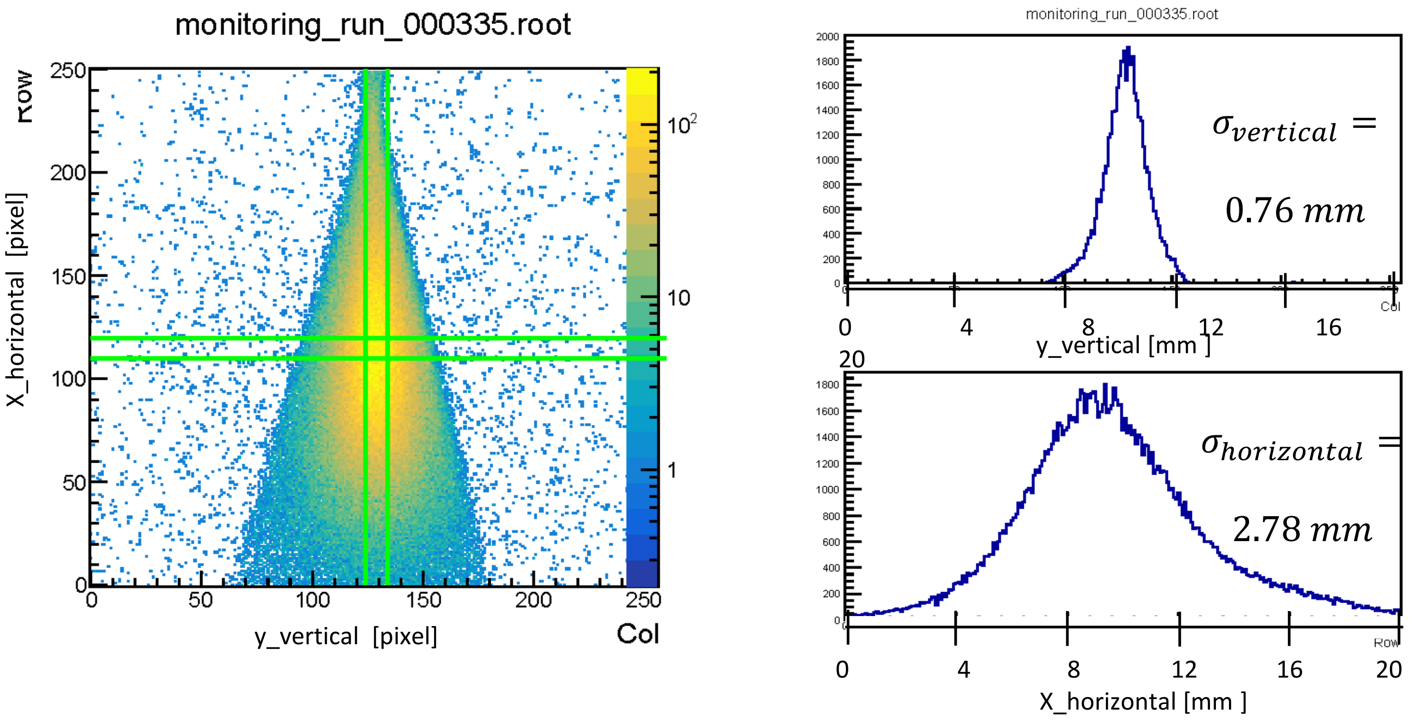
530 MeV



$$17.3 \frac{1}{s \cdot nA \cdot MeV}$$

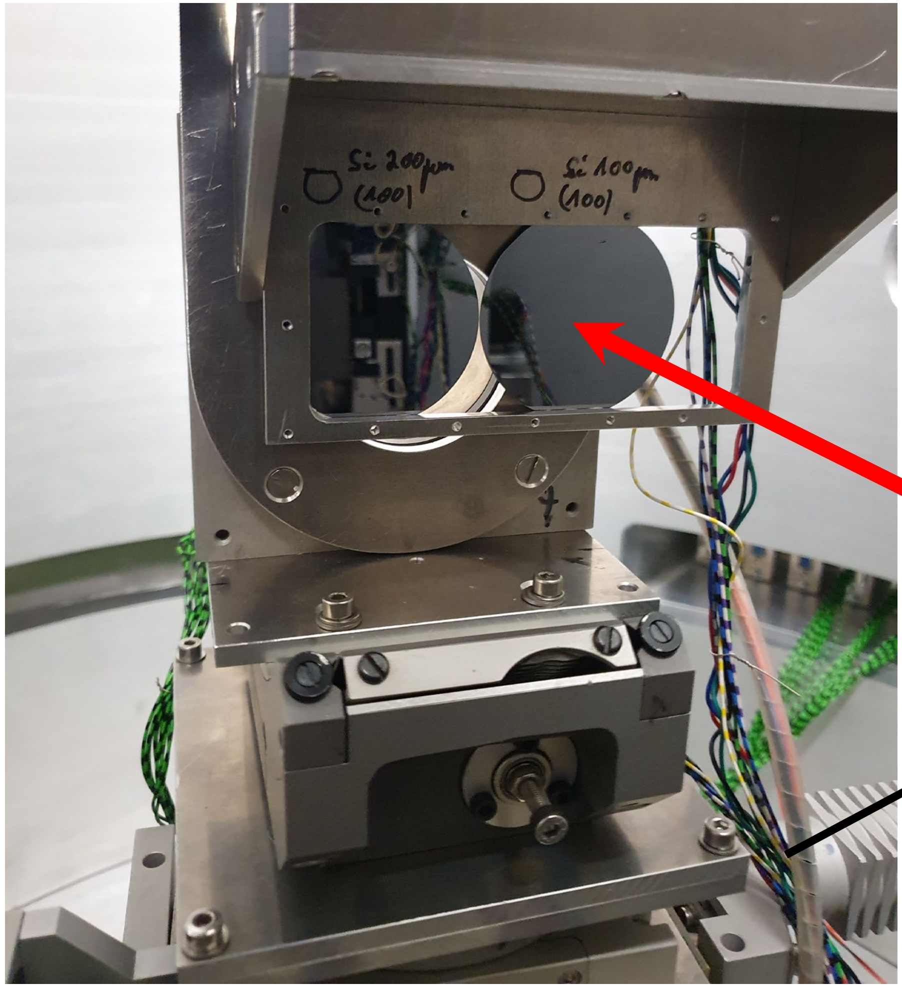
Max. e-current (without shielding) ~1 µA ->
Max. positron rate **20 kHz**

Measurement of the beam size of the focused positron beam with the pixel detector



distance of 1.04 m from the centre of the crystal chamber

Channeling of Positrons in Si crystals

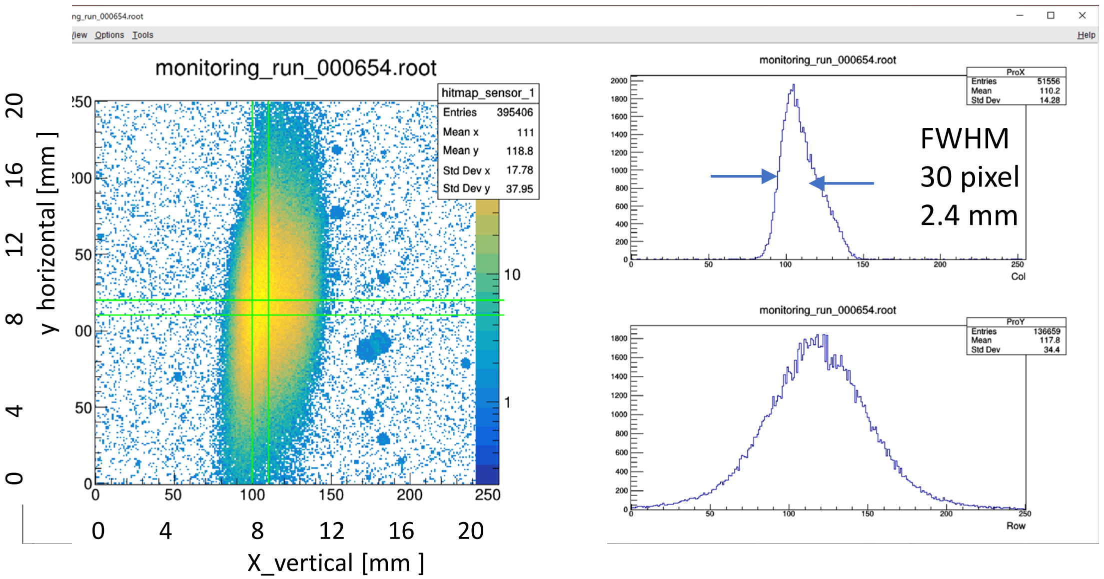


e^+

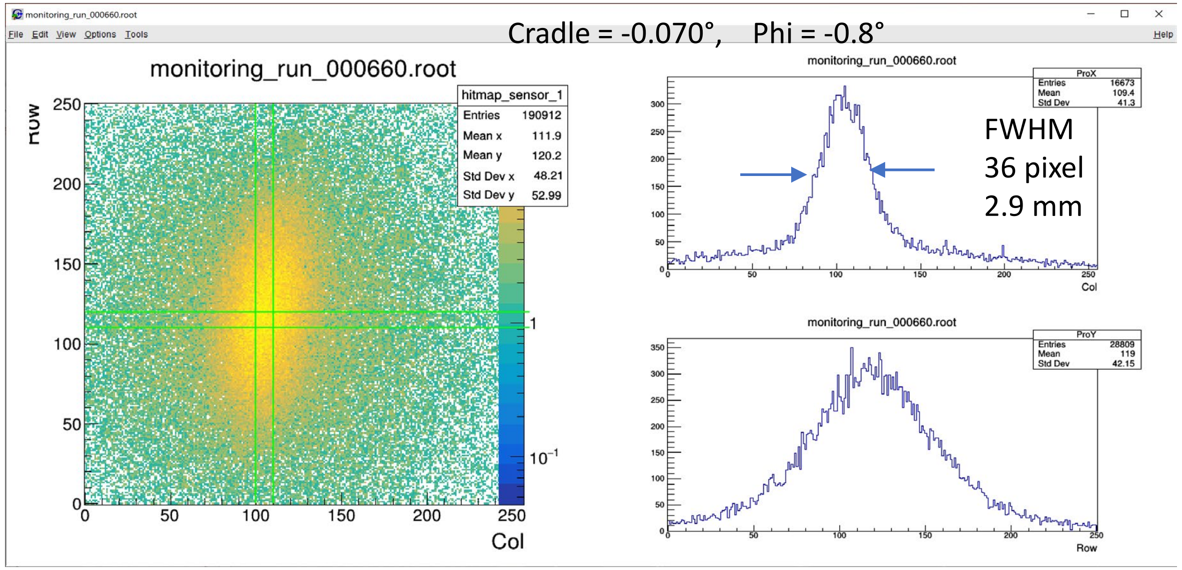
Detection of Positrons with pixel detector

200 µm (100) Si crystal

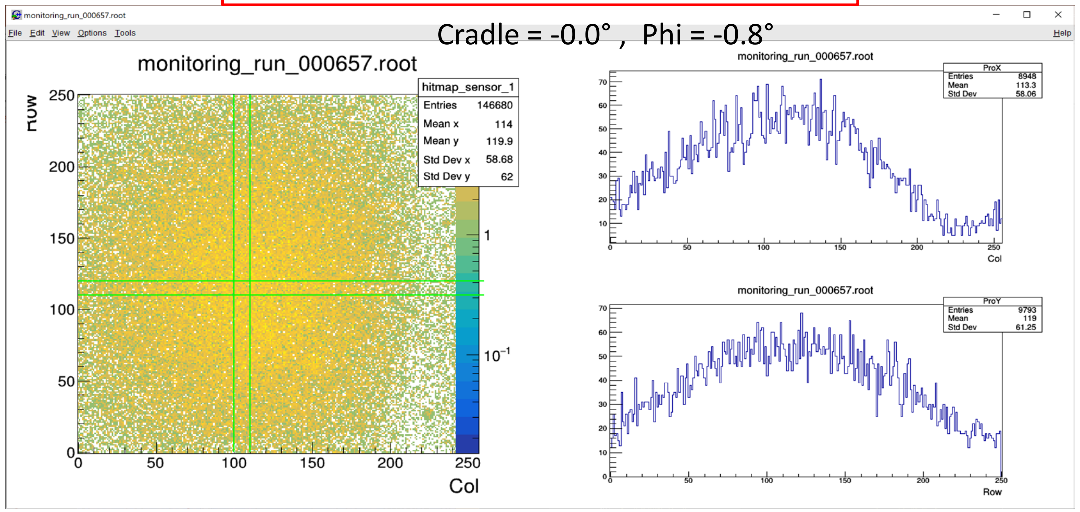
Without crystal

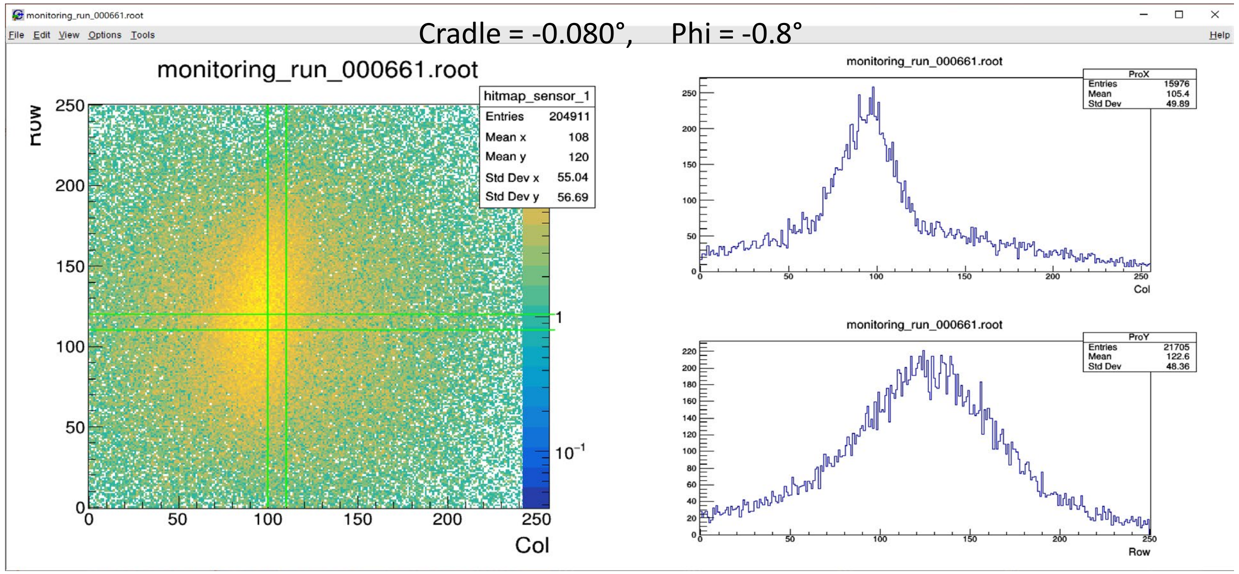


With oriented crystal



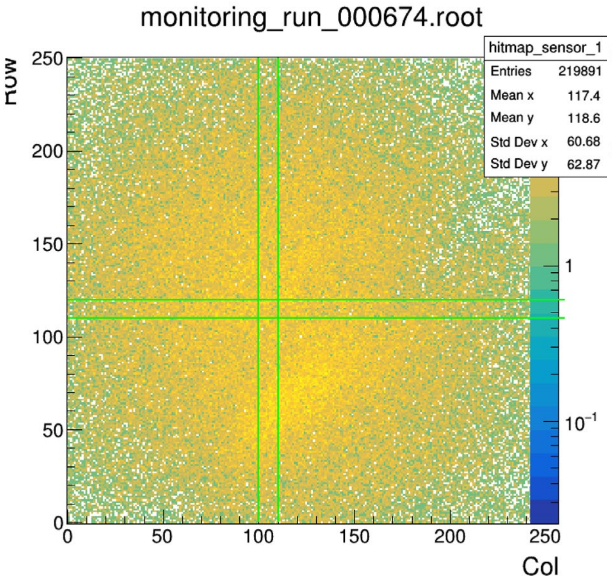
Random orientation of crystal



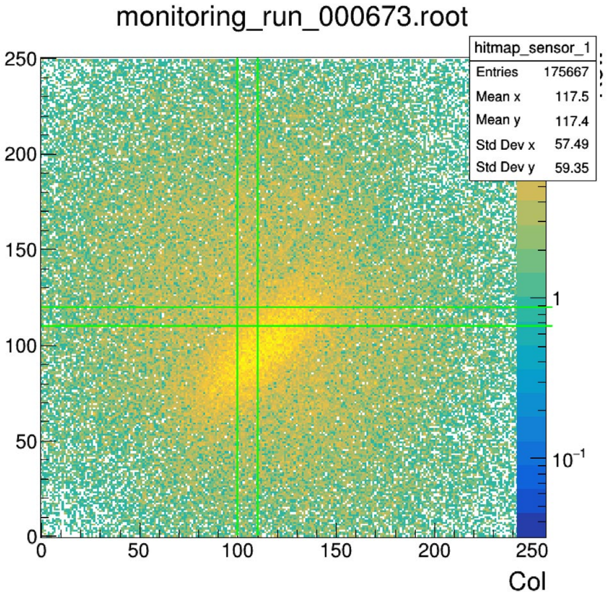


200 µm (100) Si crystal

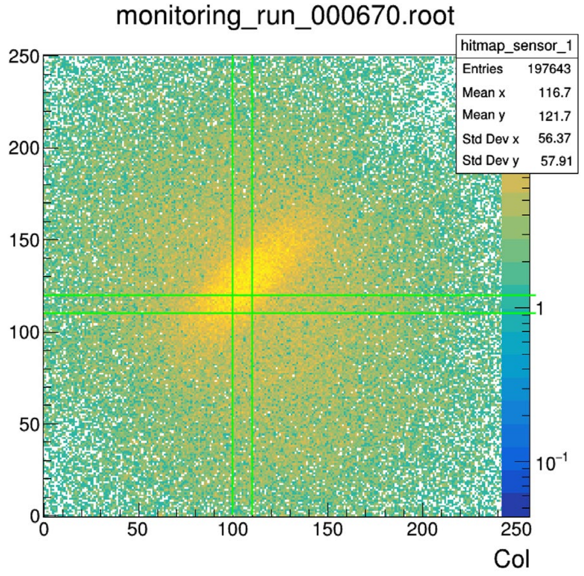
110 Plane
Rotation arround vertical axis



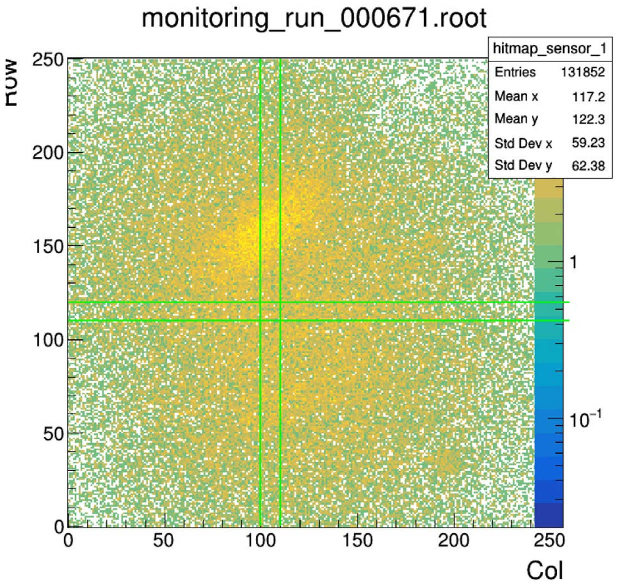
Cradle = -0.2°
Phi = -0.11°



Cradle = -0.2°
Phi = -0.13°

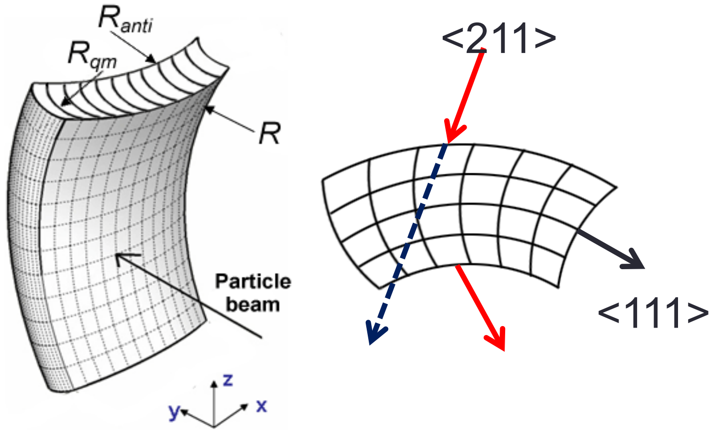


Cradle = -0.2°
Phi = -0.15°

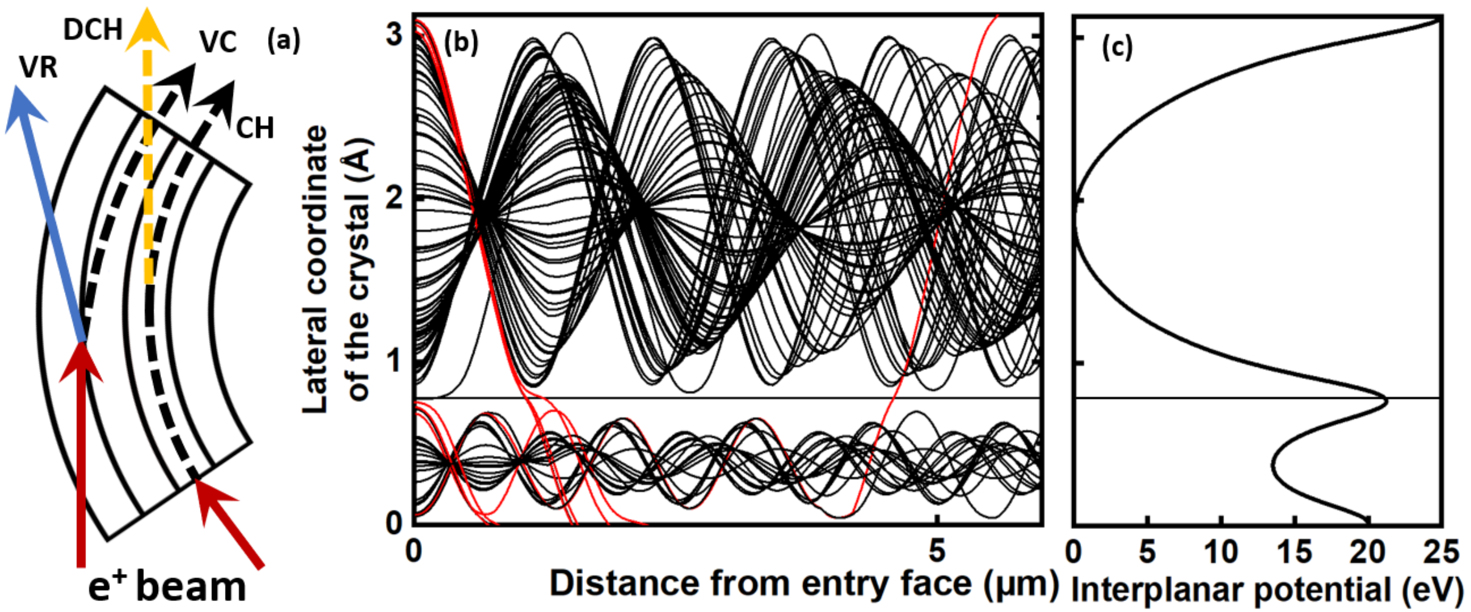


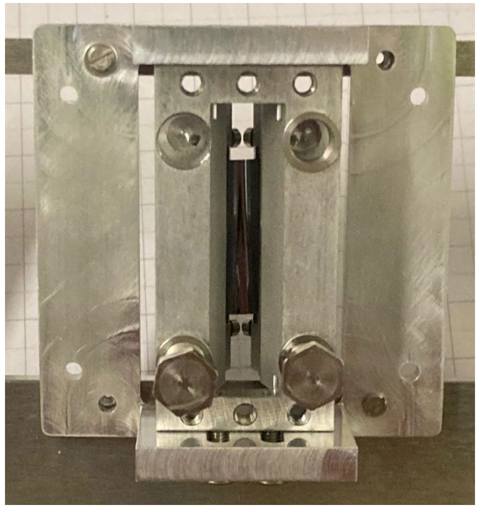
Cradle = -0.2°
Phi = -0.17°

Mechanically bent Si crystal test with 530 MeV positrons



Guidi, V., et al.,, 2009. Journal of Physics D Applied Physics42(18).
Germogli, G.,NIM B, 2015. 355: p. 81-85

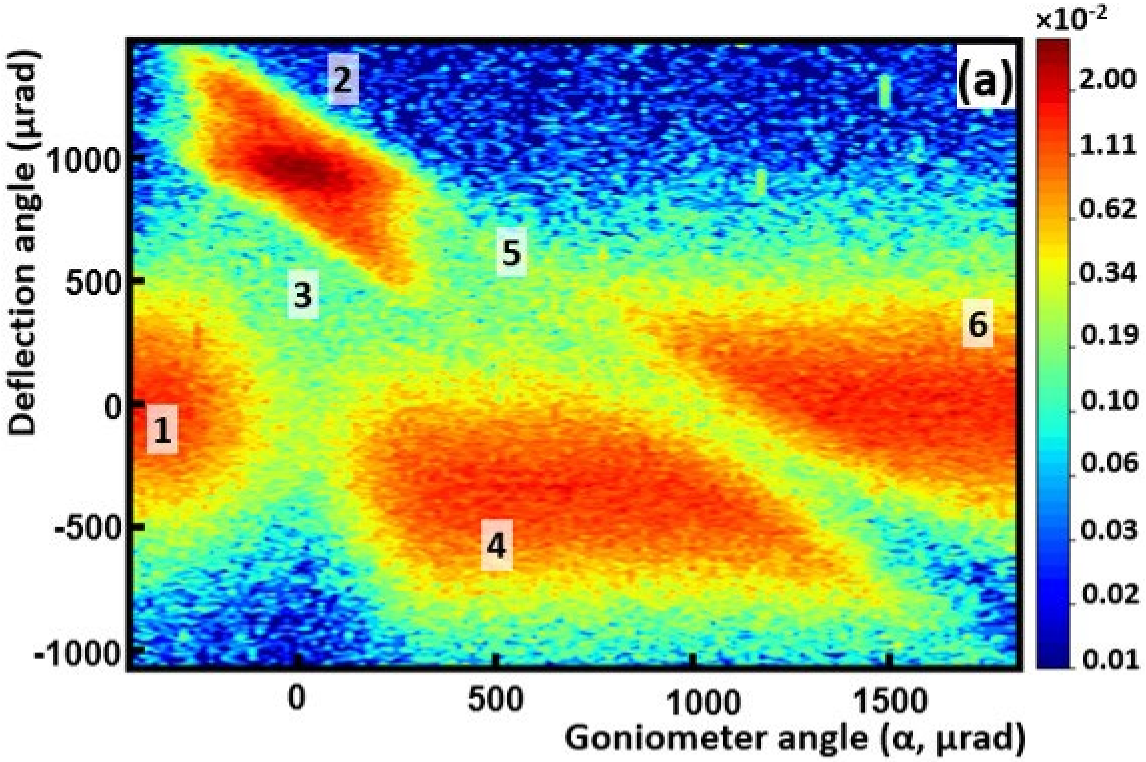




Crystal label: BC-Si-QMO*
Thickness along the beam: 29.9±0.1 μm Bent planes, exploiting quasimosaic effect (111)
Bending angle: 970±10 μrad

Crystal available from a previous project @

Experimental results on beam steering of 530 MeV positrons



Mazzolari, A., Backe, H., Bandiera, L., et al., (2024)
arXiv:2404.08459

TECHNO-CLS MILESTONE:
First high-efficient deflection of sub-GeV positron worldwide !!!

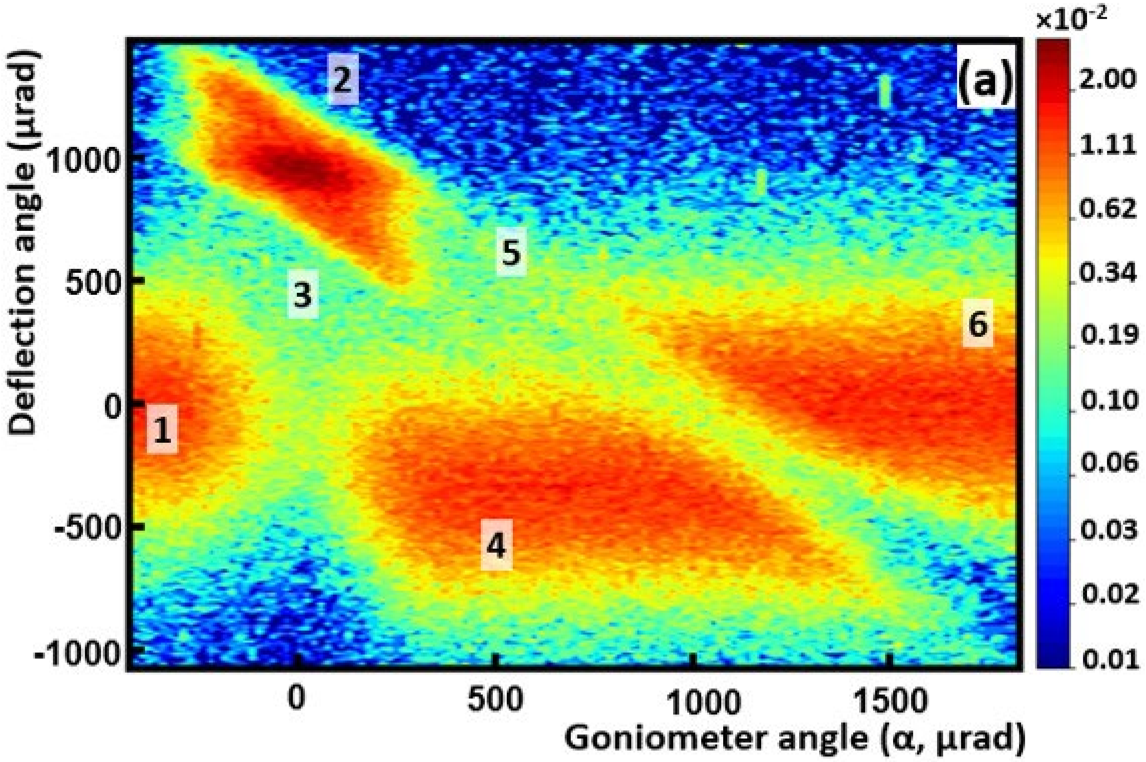
Fallout in :

- ❑ Crystal-Light-Source
- ❑ Channeling based technologies
- ❑ Accelerator technologies: for beam steering, extraction, focusing..

Open access paper on arXiv
Submitted to Phys. Rev. Lett.

530 MeV positrons* vs 855 MeV electrons**

Angular scan for deflected beam distribution: (1) and (6) nonchanneling regime; (2) channeling; (3) dechanneling; (4) volume reflection; and (5) volume capture.



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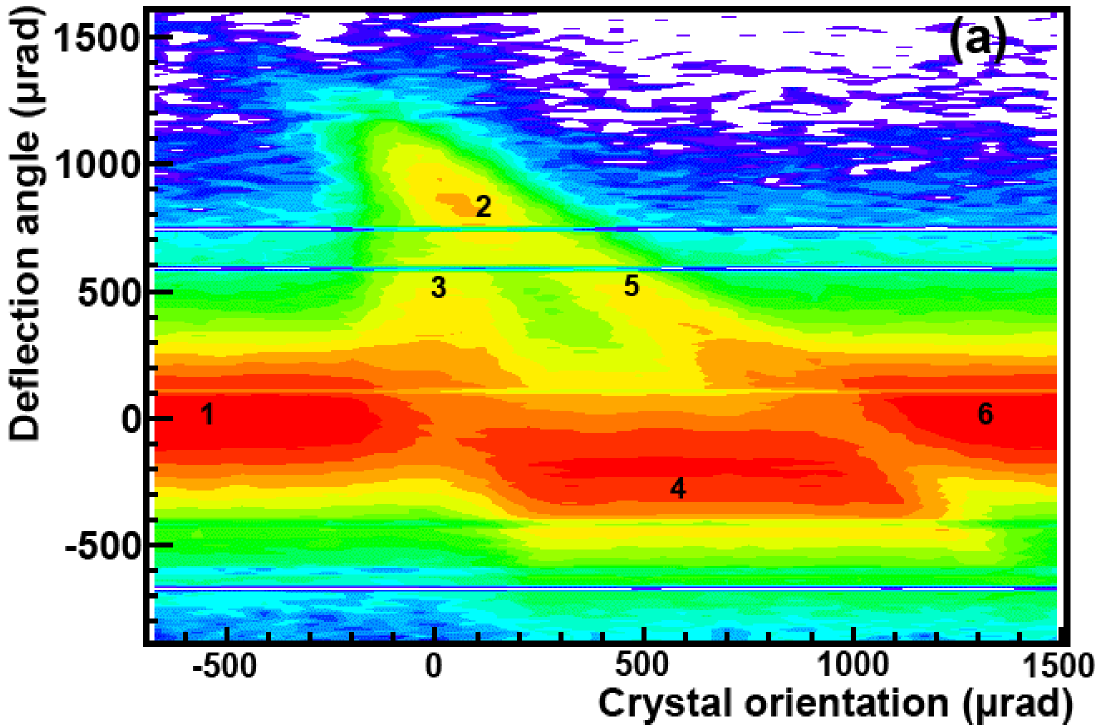


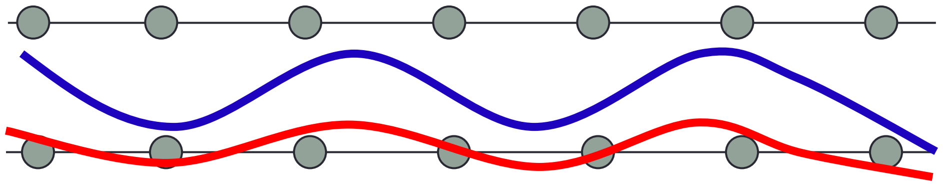
**Mazzolari A., Bagli E., Bandiera L., et al., Phys. Rev. Lett. 112 (2014) 135503

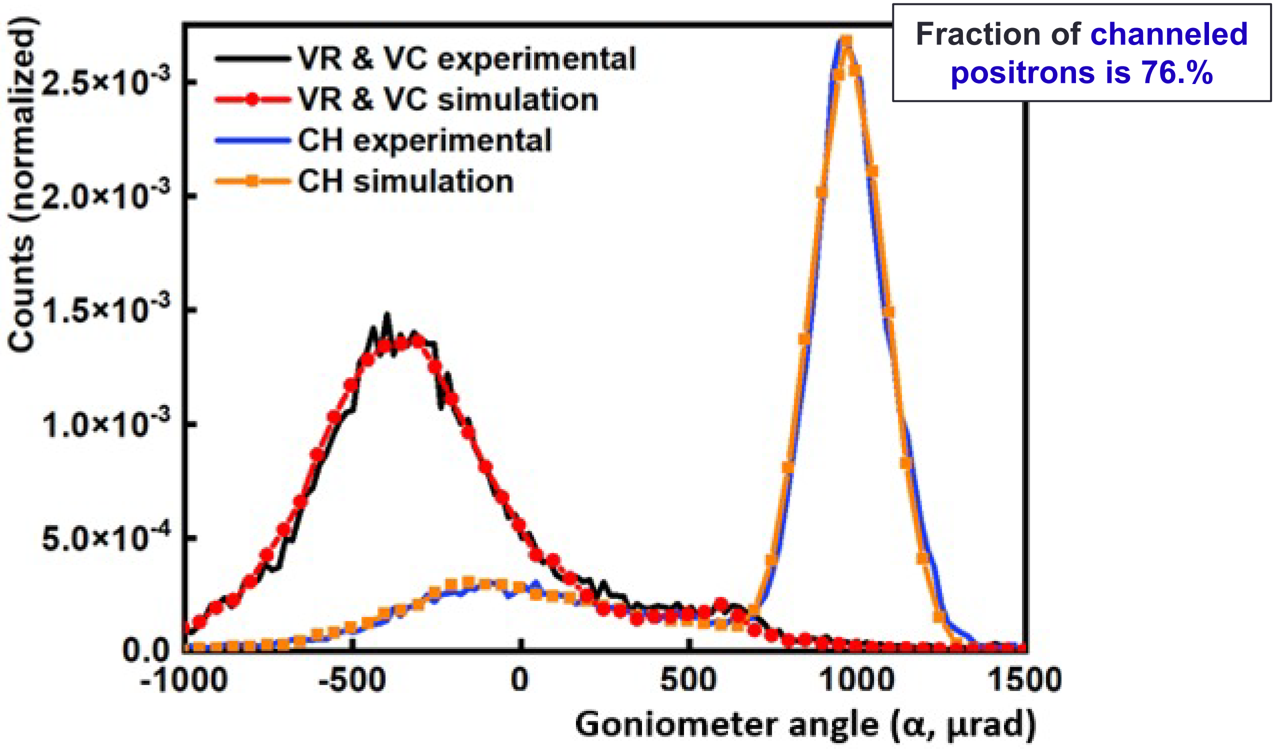
Channeling efficiency e+ vs e-

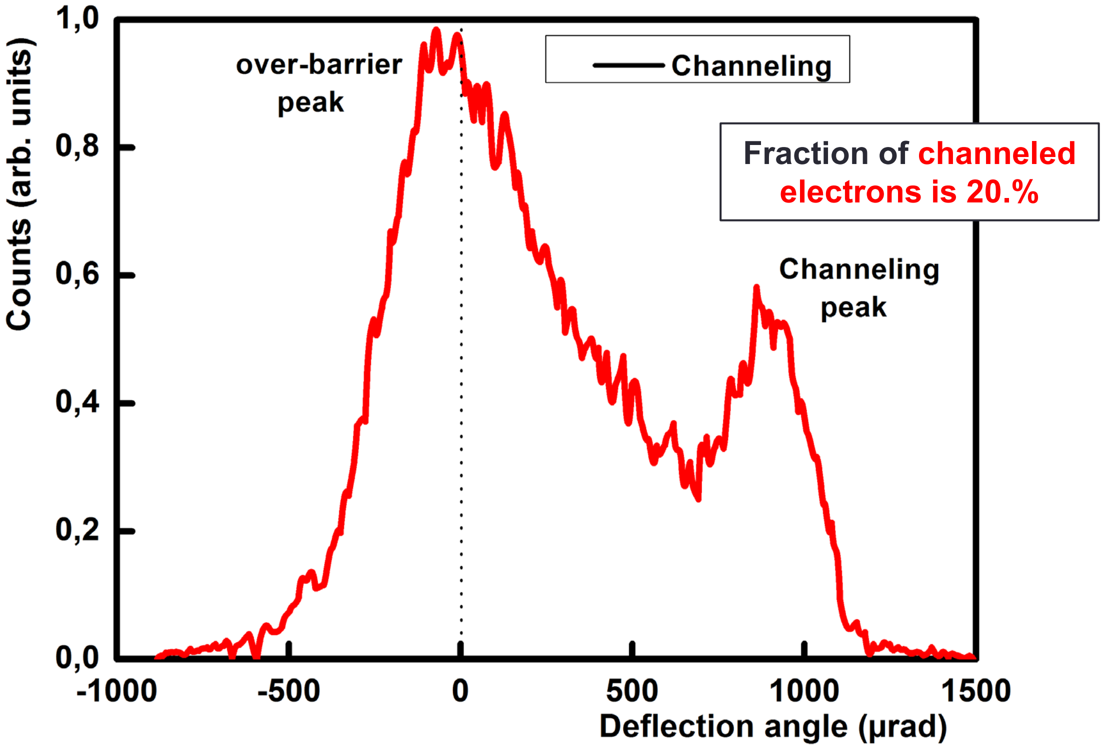
Advantage of positrons for CLS –> higher channeling efficiency!

positron

electron







*Mazzolari, A., Backe, H., Bandiera, L., et al., (2024) arXiv:2404.08459

**Mazzolari A., Bagli E., Bandiera L., et al., Phys. Rev. Lett. 112 (2014) 135503

Future experiments with the Positron beam line

- Deflection of positrons (√)
- Channeling radiation with positrons /Tagging of channeling radiation
- Characterization of Undulator crystals
- Dechanneling length measurements
- Undulator radiation with periodically bent crystals

Thanks for your attention

TECHNO-CLS

Horizon Europe EIC-Pathfinder Project TECHNO-CLS: "Emerging technologies for crystal-based gamma-ray light sources"

MBN Research Center

Università degli Studi di Ferrara
- Ex Labore Fructus -

University of Kent

Hellenic Mediterranean University

ESRF

INFN
Istituto Nazionale di Fisica Nucleare

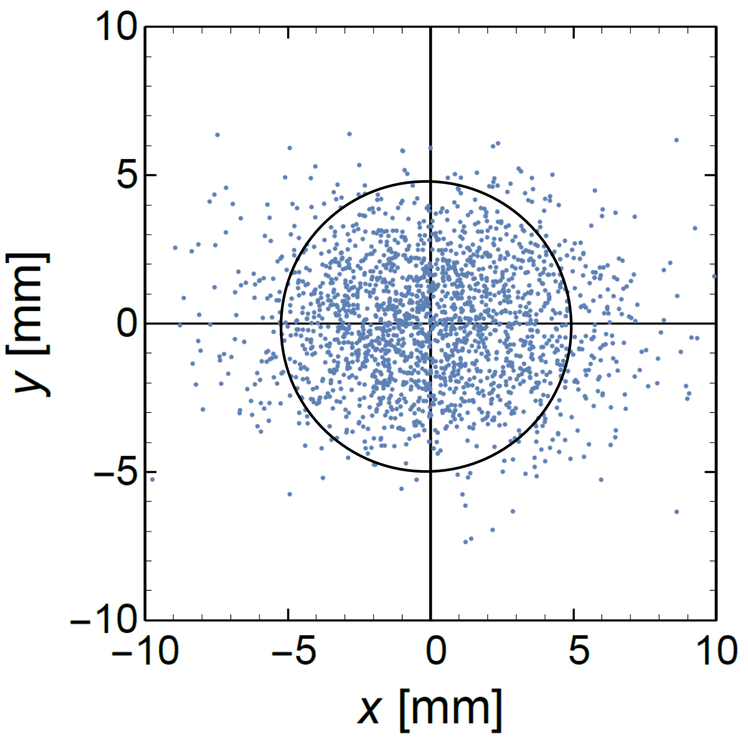
Università degli Studi di Padova

Johannes Gutenberg Universität Mainz
JG|U

Beam spot size and divergence @crystal chamber

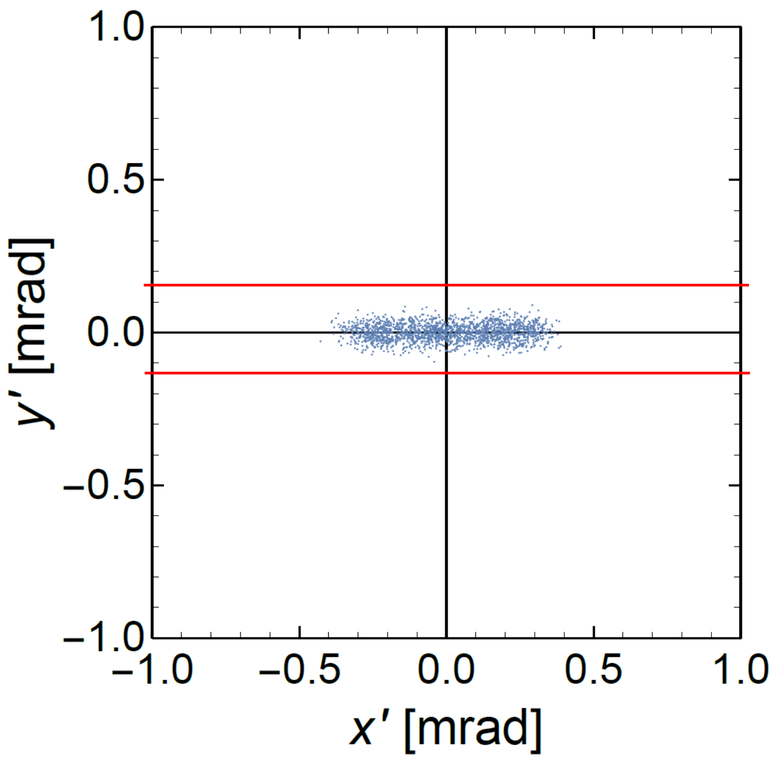
$\Delta^p/_p = \pm 1 \cdot 10^{-3} \quad \langle=\rangle \; ^{1MeV}/_{500\text{MeV}}$ $\theta_{Positrons} \sim {}^{0.8}/_{\gamma}$ $\frac{\theta_{Scat}}{2} = 0.56 mrad$ 10 µm W

Beam spot size



85% accepted in a diameter of 10 mm

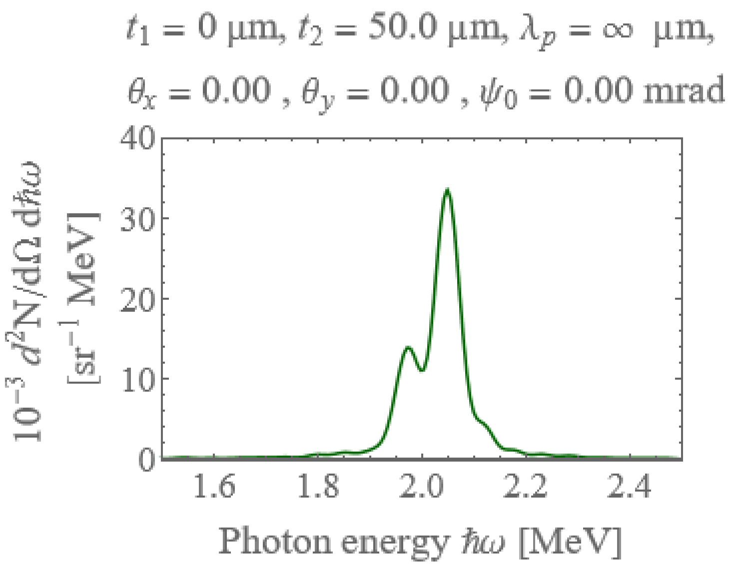
Divergence



Count rate estimation for channeling radiation

Calculation H. Backe et al., arXiv:2404.15376

- Positron rate: ~$2 \cdot 10^4$ Positrons/s
- Reduction of beam spot size 2mm
  -> 5000 Positrons/s
- Solid angle $3 \cdot 10^{-7}$ sr
  (d=4mm, Distance 6m)
- Integral Channeling photons~ $3000/$ (e^+ sr)

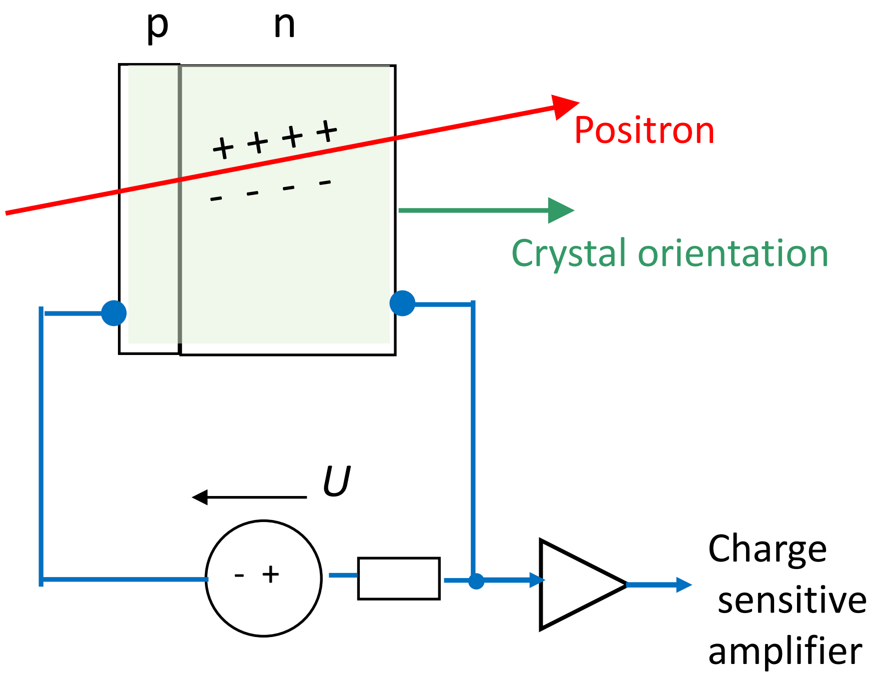


Total Count Rate = Photons/(e^+ sr) · Solid angle · Positrons/s

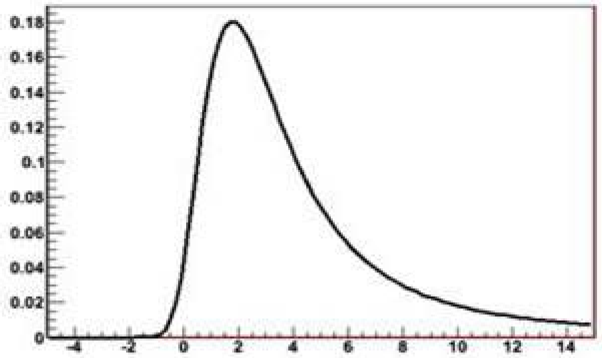
= $3000/$ (e^+ sr) · $3 \cdot 10^{-7}$ sr · $5000\ e^+$/s

~ 5/s

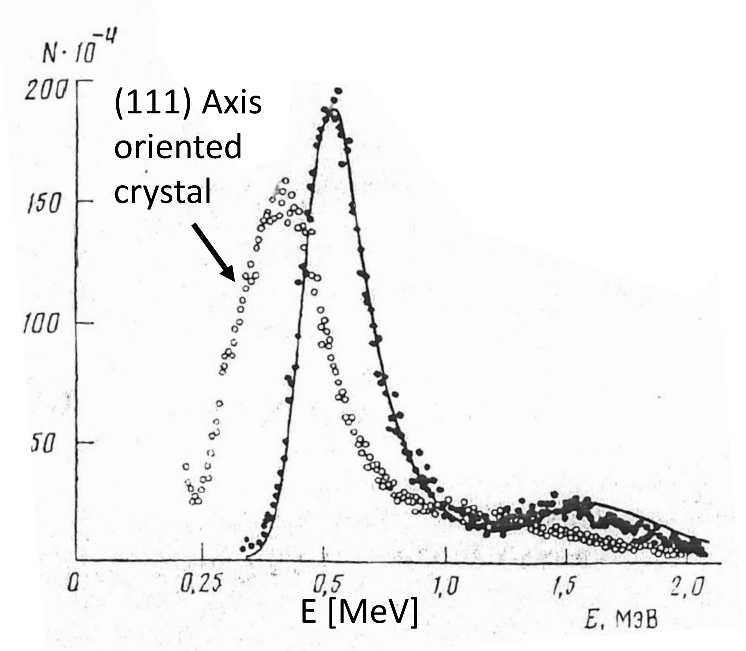
Dechanneling length measurement with Si-crystal-detector



Landau Spectrum



Ionization loss is different for channeled and non channeled particle

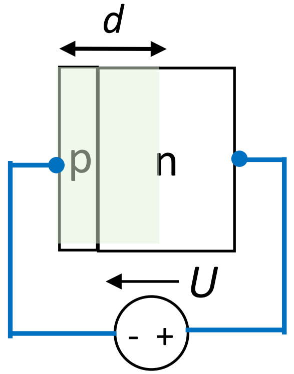


Ionization loss of 1200 MeV positrons in 160µm Si

D.I. Adeishvili, et al.
Journal of Nuclear Physics 48 (1988) 38.

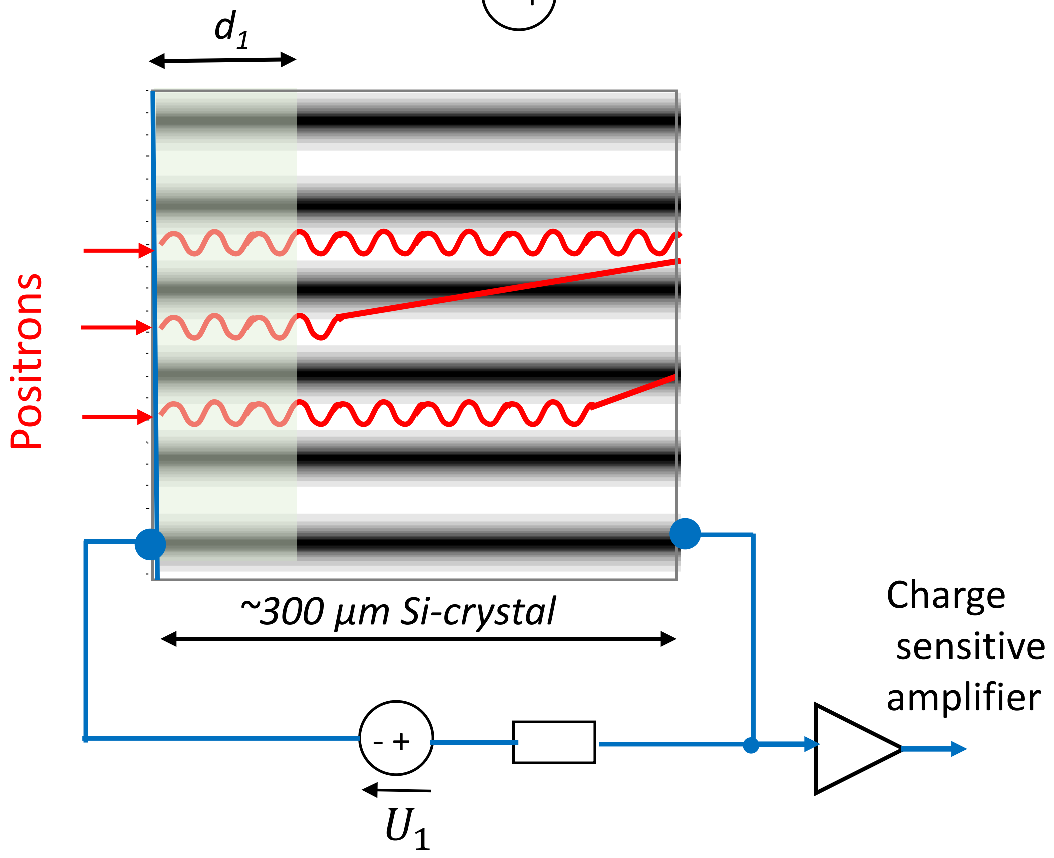
Ionization loss measurements for different detector voltages

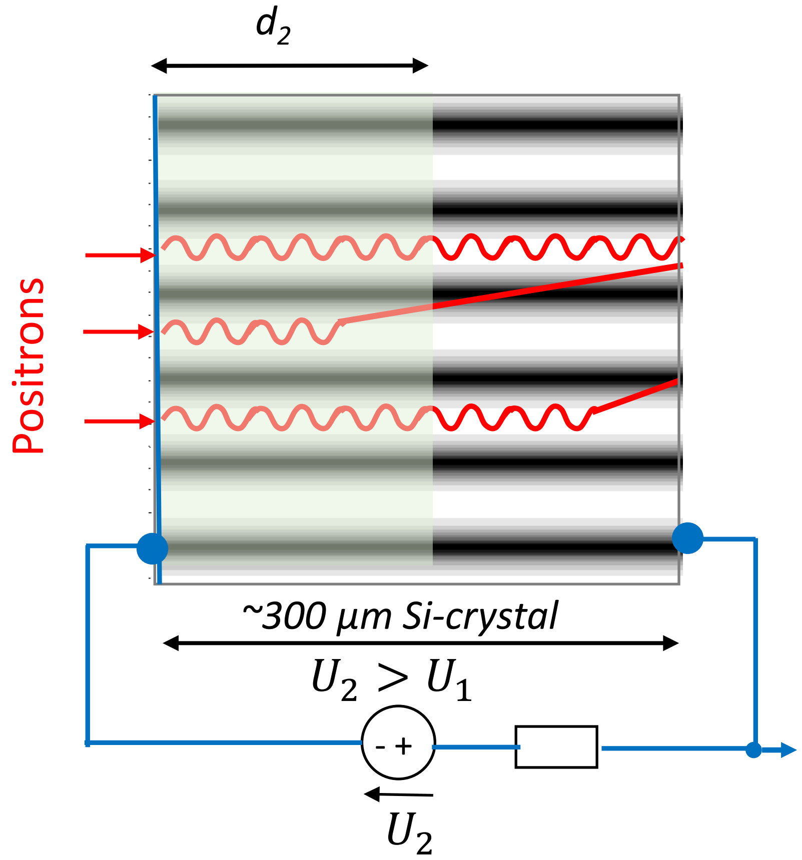
A.V. Shchagin et al,
arXiv:2211.01913



$$d = \sqrt{(U+V)\frac{2\varepsilon\varepsilon_0}{eN}}$$

d: depletion width
U: external voltage
N: doping concentration
V: junction potential ~0.6V





Signal height of detector ~ produced charge in depletion layer