H2020 MSCA RISE N-LIGHT
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Study of the influence of the curvature radius and the beam energy on beam steering and radiation by sub-GeV electrons

Riccardo Negrello
PhD Student at UniFE, Ferrara
INFN Ferrara section
riccardo.negrello@unife.it

Channeling2023 – Conference
Riccione, 05/06/2023

Channeling 23

Motivations:

- A lot of attention is devoted to channeling effects of electrons around GeV :
  - Interest for alternatives x-ray sources
  - Relatively large availability of accelerators

- Study of the influence of the curvature on Channeling Radiation. This experimental knowledge may be exploited to:
  - **Determine with more accuracy the Channeling Radiation contribution to crystalline undulators**

  - Radiative losses during **extraction from electron and positrons accelerators**

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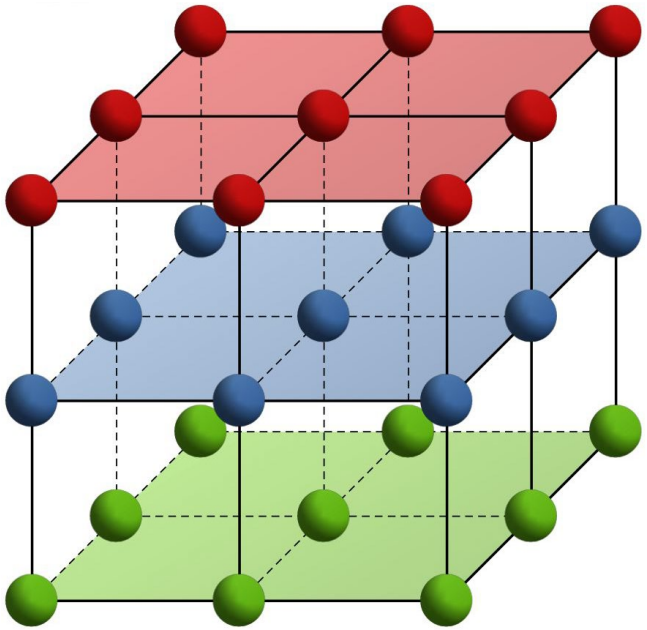
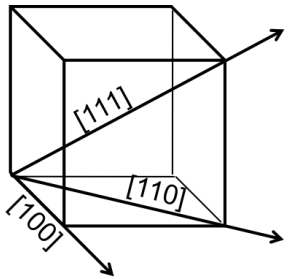
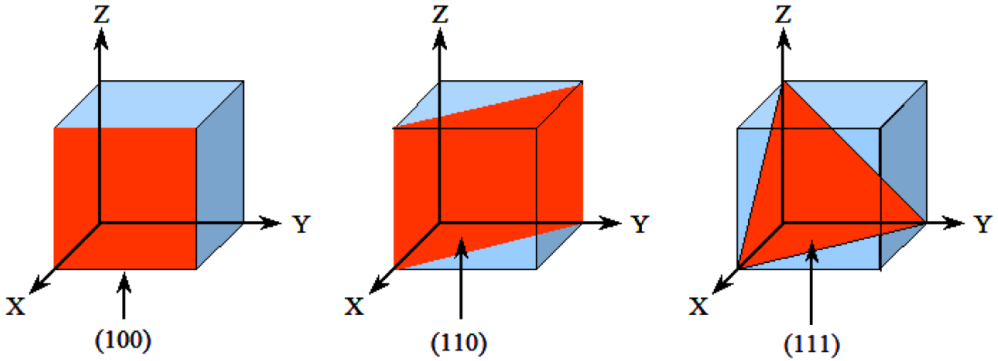
Crystalline solids:

A crystal is a solid structure consisting of atoms, molecules or ions having a geometrically regular arrangement, which is repeated indefinitely in the three spatial dimensions, called the **crystal lattice.**

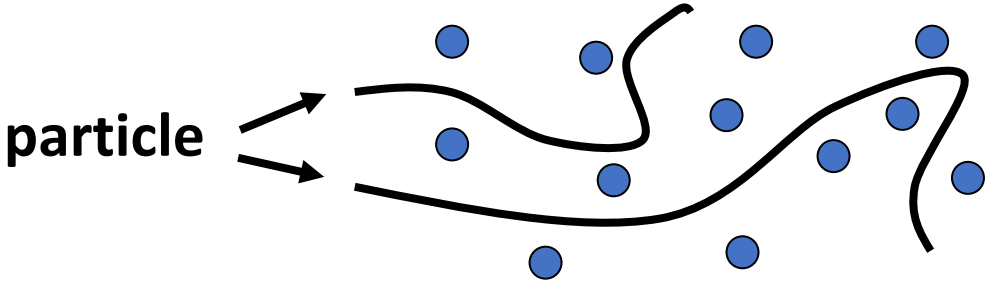


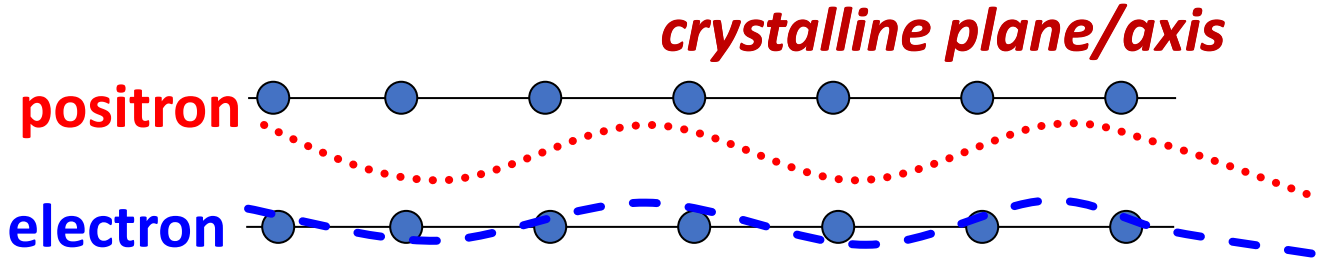
Simmetry: Axes and planes

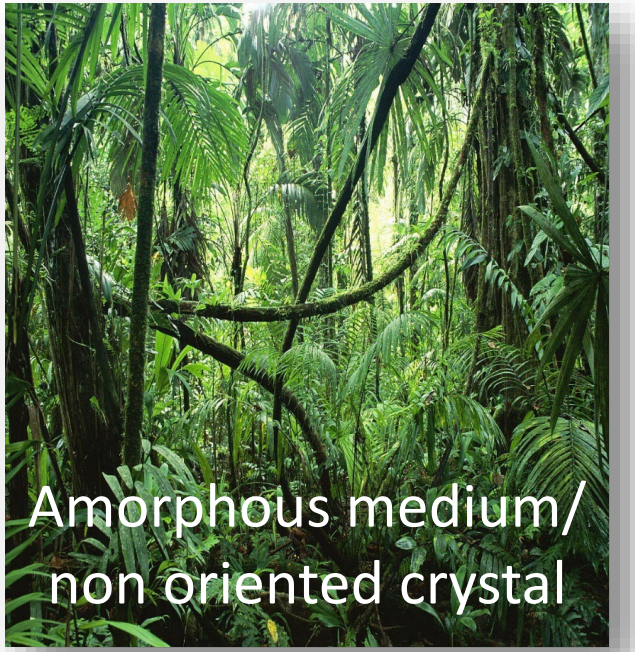




Multiple scattering & Channeling:







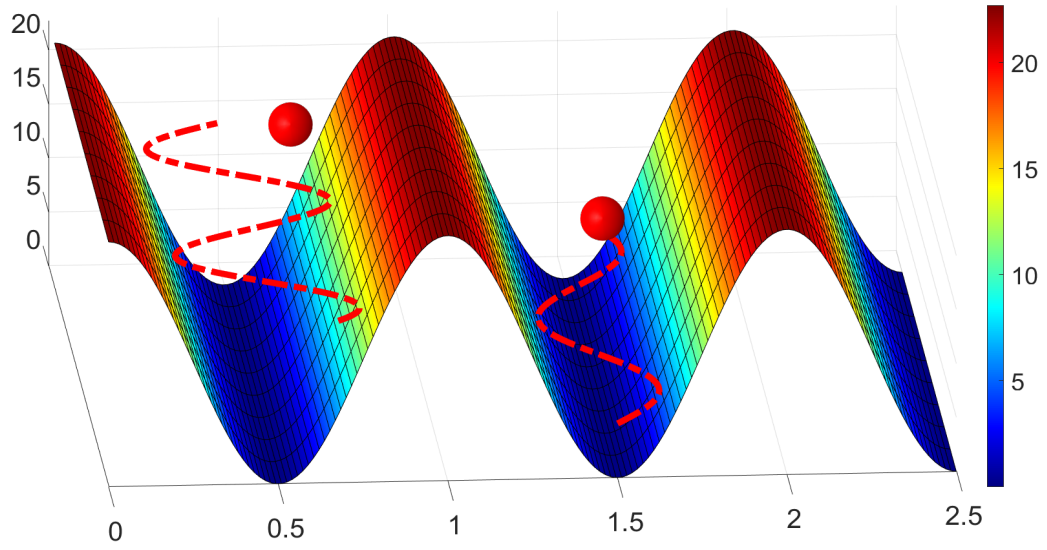
Planar Channeling

$$U_{pl}(x) = N d_p \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} V(x,y,z)\, dy\, dz$$

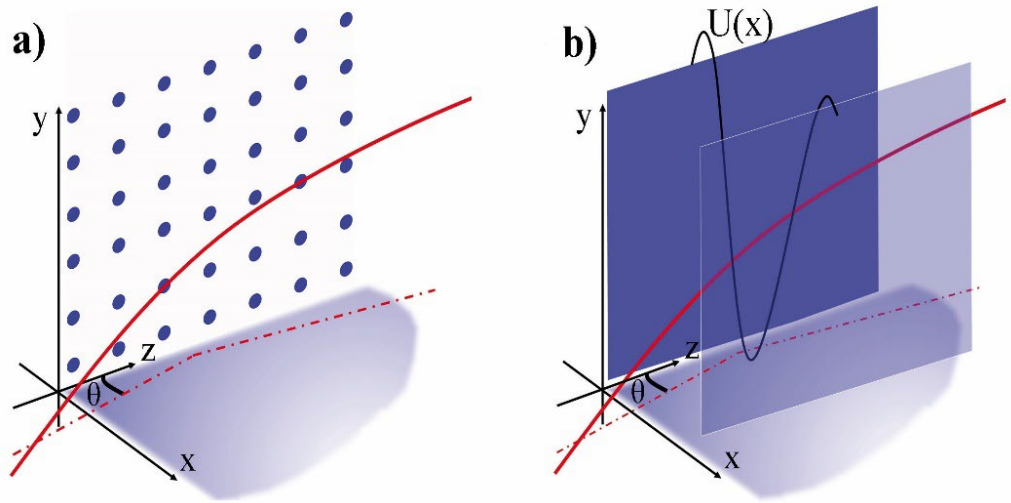
where

$$V_{TF}(r) = \frac{Z_i Z e^2}{r}\Phi\left(\frac{r}{a_{TF}}\right)$$

is the particle-atom screened Coulomb potential



J. Lindhard, K. Dan. Vidensk. Selsk. Mat. Fys. Medd. 34 (1965) 14.



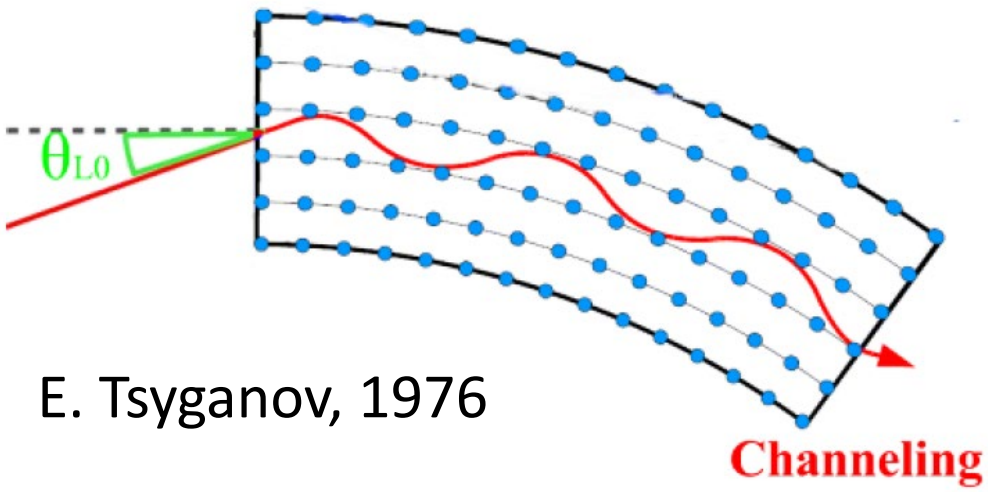
Critical angle for channeling:

$$\theta_c = \sqrt{\frac{2U_0}{pv}}$$

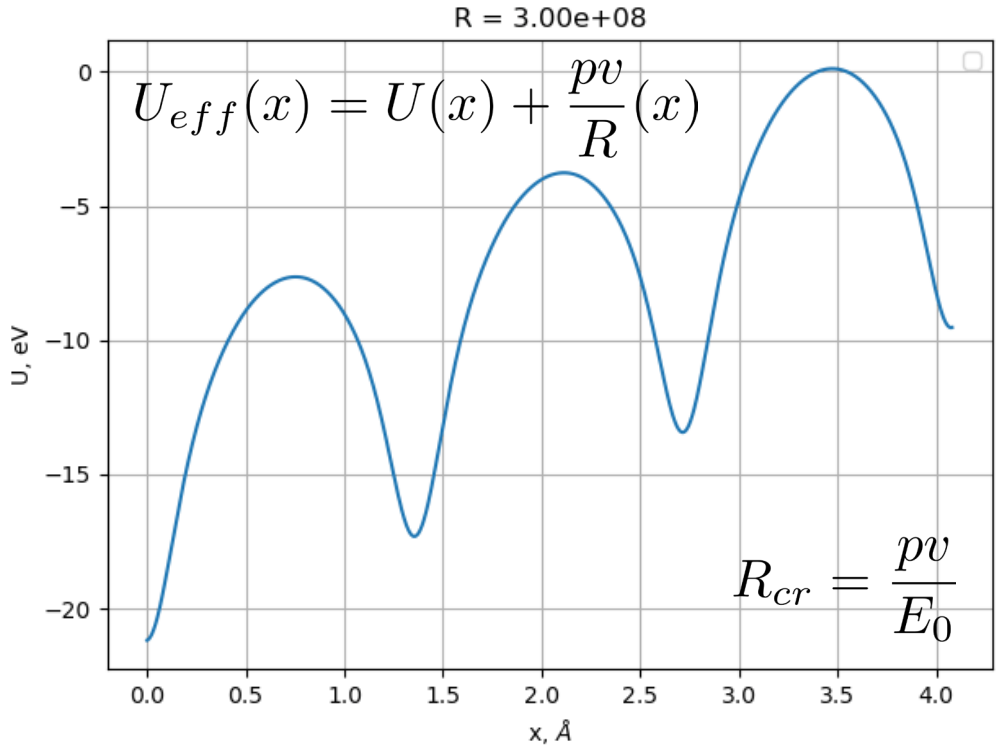
U_0 = *19* eV for Si (111)
ϑ_c ≈ 216 µ*rad* at *E ~ 1* GeV

Channeling in a bent crystal

- Bending the crystal lattice planes is equivalent to adding a centrifugal force
  - Curvature radius *R*
- Particles can be trapped in channeling and bent!
- Like in a **magnetic** field



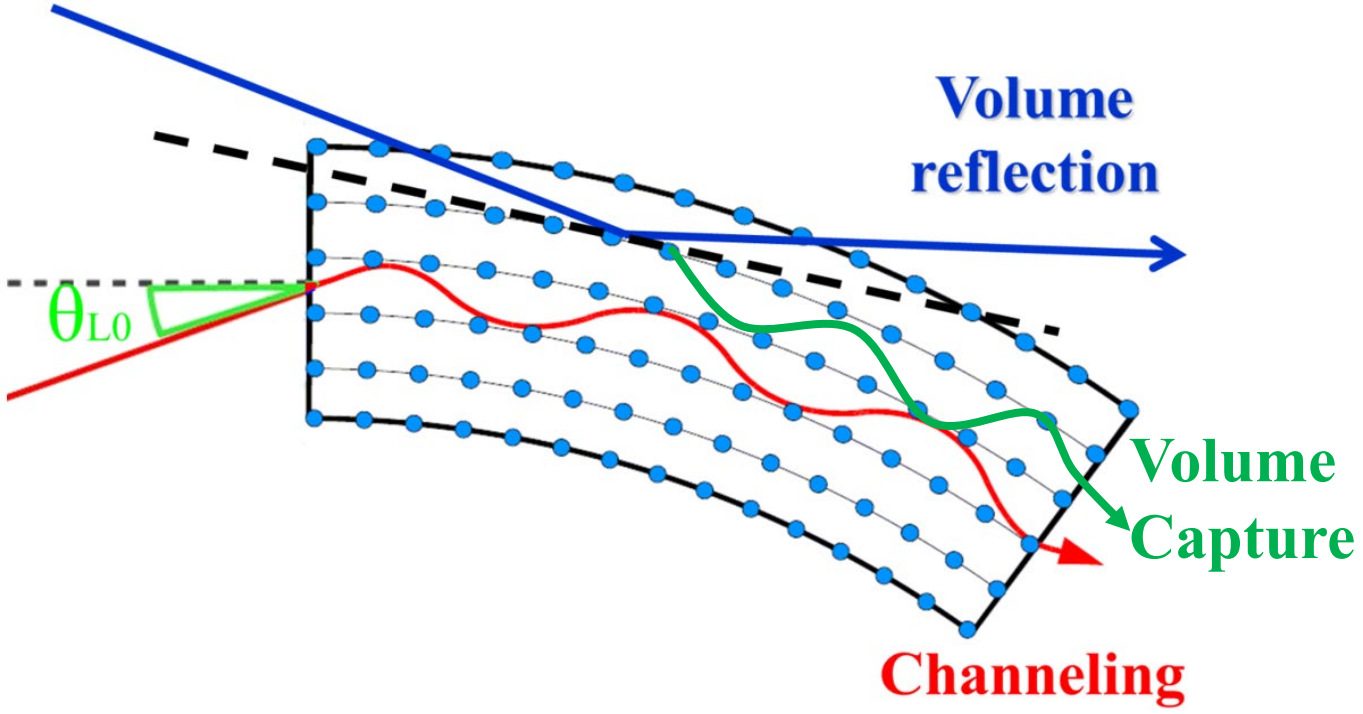
E. Tsyganov, 1976



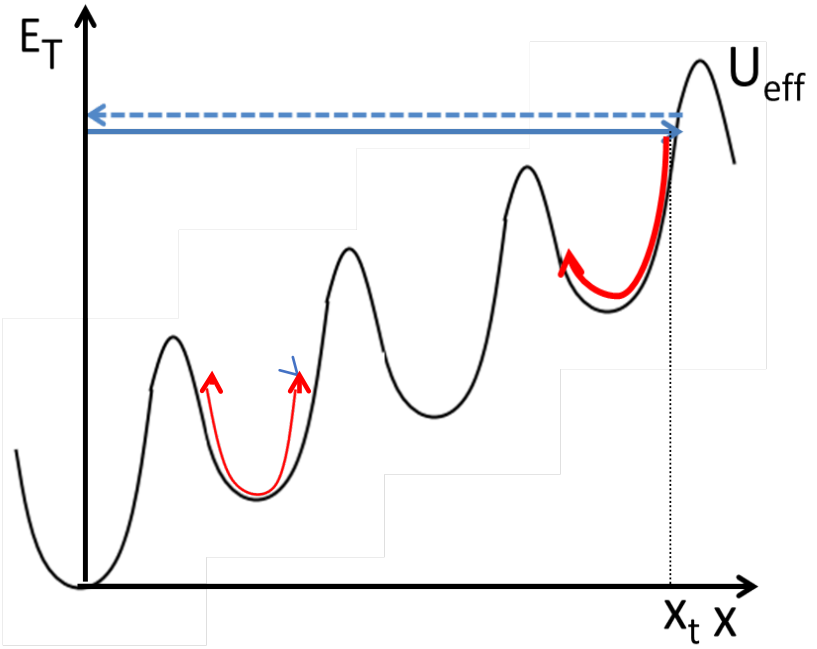
Bent crystals can be used in particle accelerators as elements for collimation or extraction

Volume Reflection in a bent crystal

- If crystal is bent, over-barrier particles can be deflected in a direction opposite to crystal bending;
- Angular acceptance equal to the crystal bending angle;
- Deflection angle of the order of the critical angle.
- Radiation comparable with CR

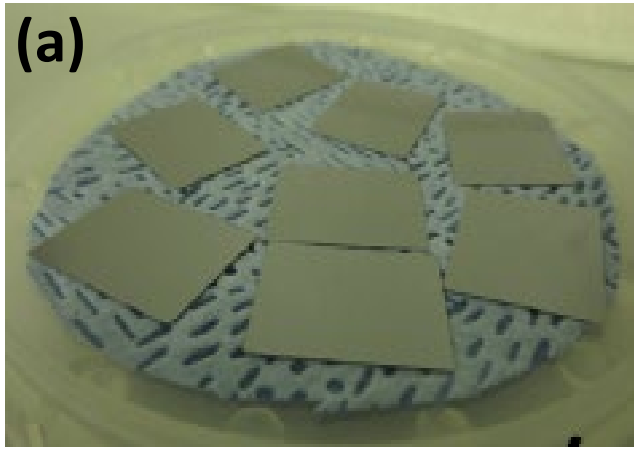


$$U_{eff}(x) = U(x) + \frac{pv}{R}x$$



Theory: Taratin and Vorobiov (1987)
Observed @CERN: H8RD22 (2007-2008)

Fabrication and characterization of crystals:

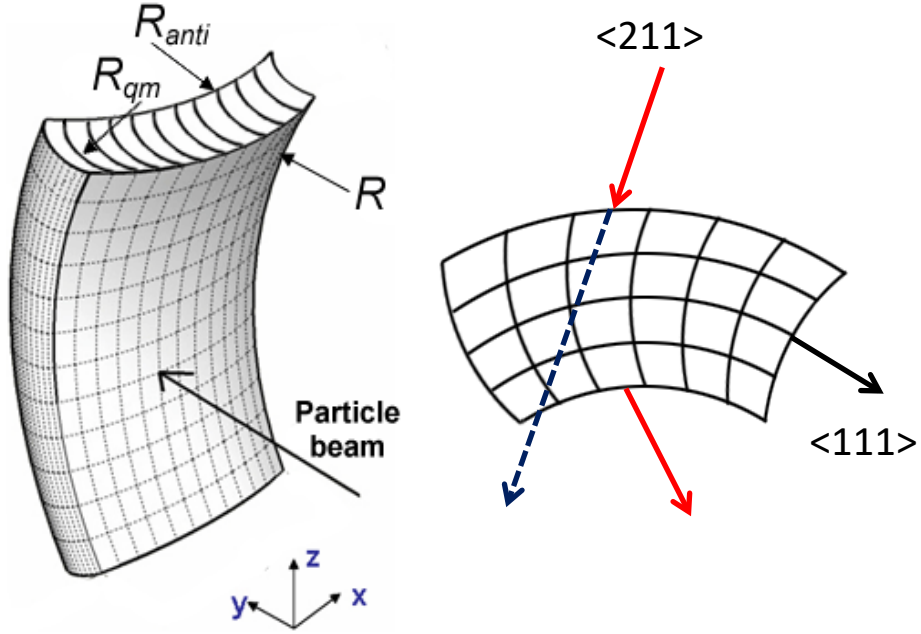


Realization of **tens micron Si membranes(a)** and their **bending(b)**:

- determine the **dechanneling length** and deflection capability
- study **channeling radiation** in the **sub-GeV energy range**

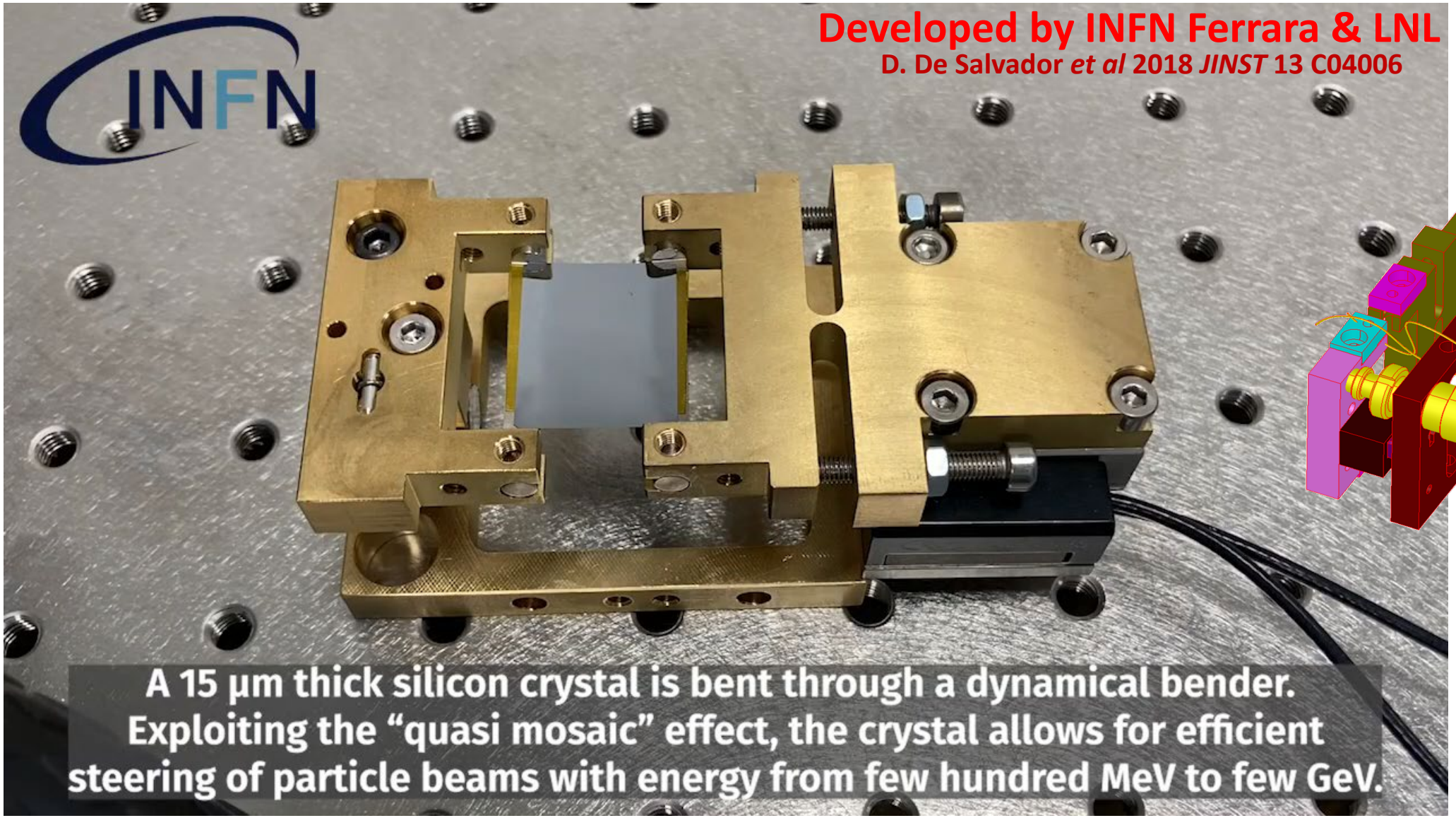
Experiments with **0.855 GeV electrons** at the MAMI B line

Quasimosaic effect (Ivanov et al., 2005)



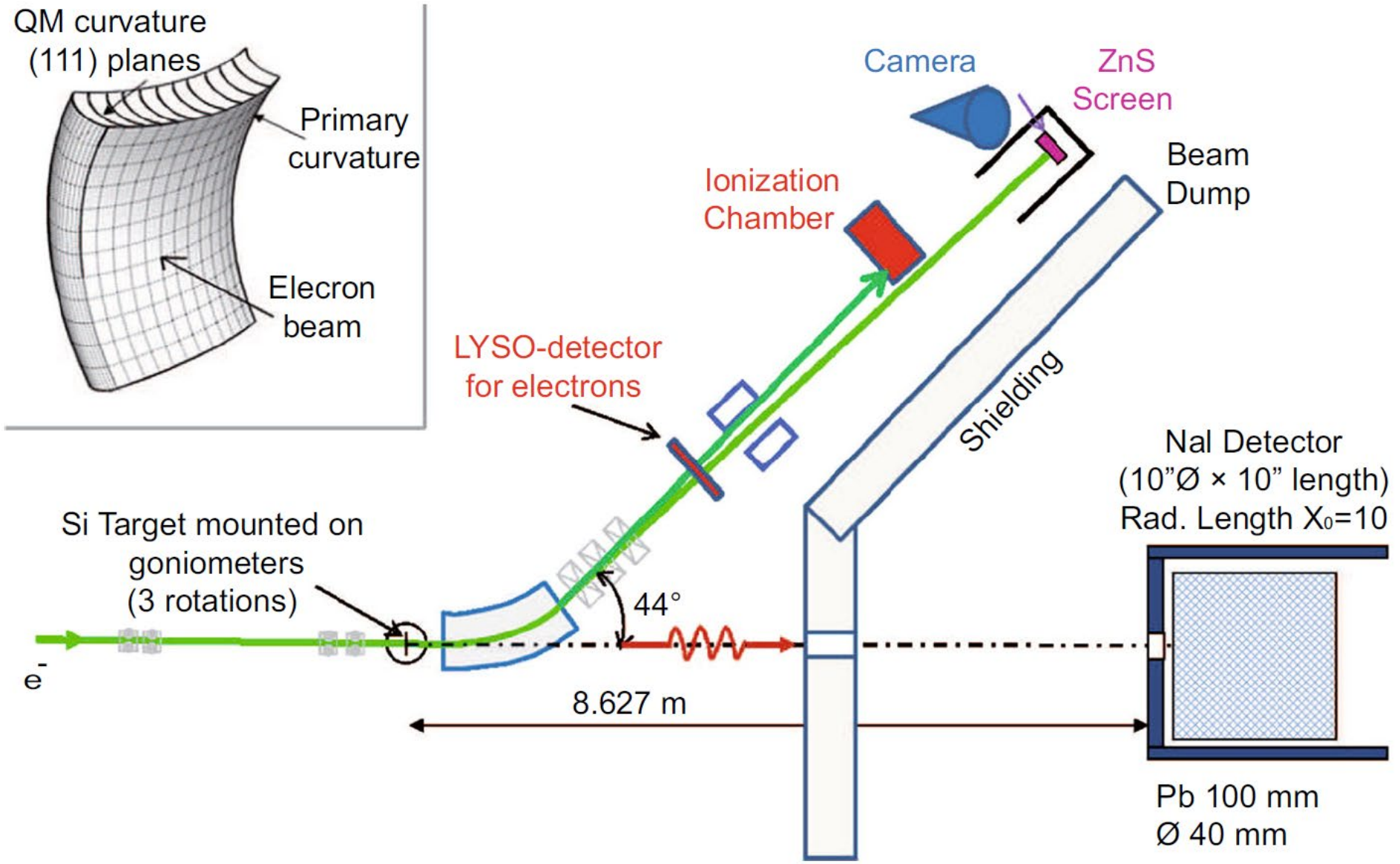
INFN Ferrara &LNL

Dynamical holder:



co-financed by INFN LNF/SHERPA e INFN Ferrara/Unife

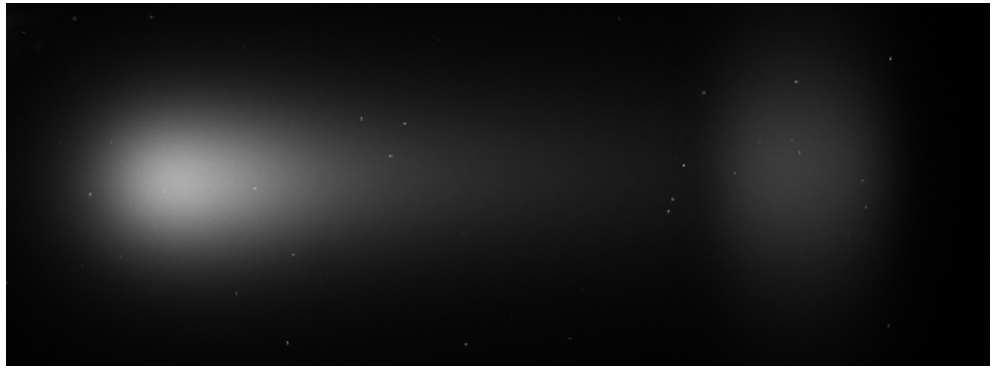
Experimental setup:

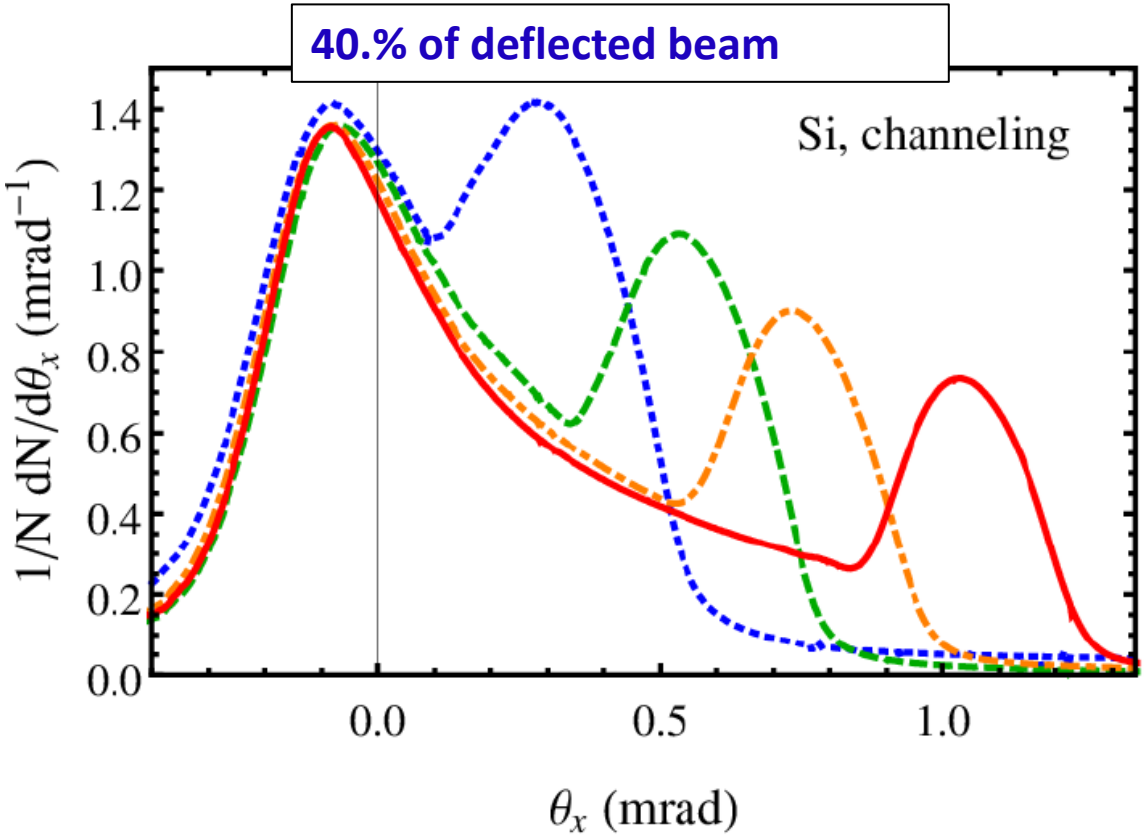


Results with bent crystals: deflection

Direct Beam

Beam angular divergence: **21.4 µrad**





A.I. Sytov, L. Bandiera et al. Eur. Phys. J. C 77, 901 (2017)

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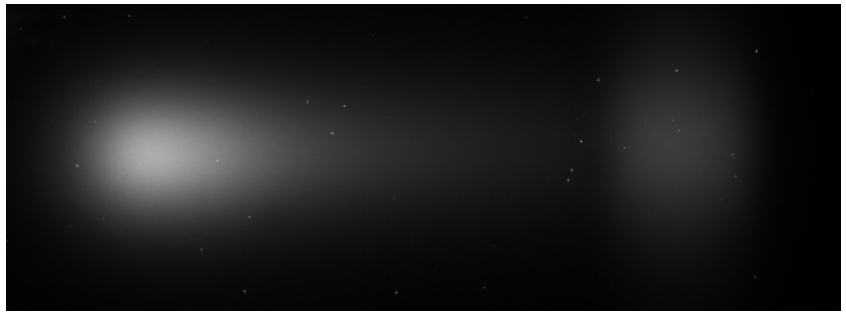

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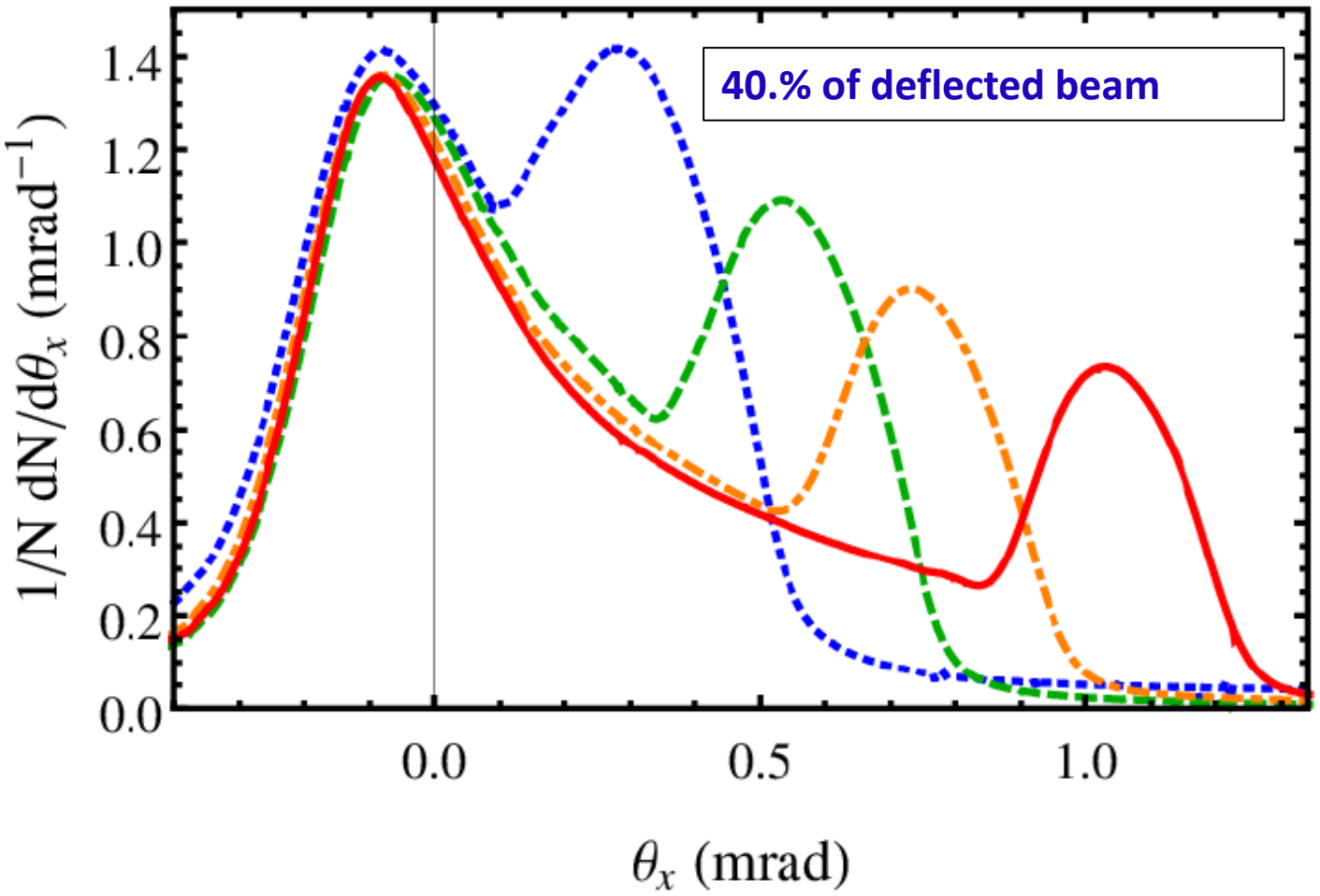
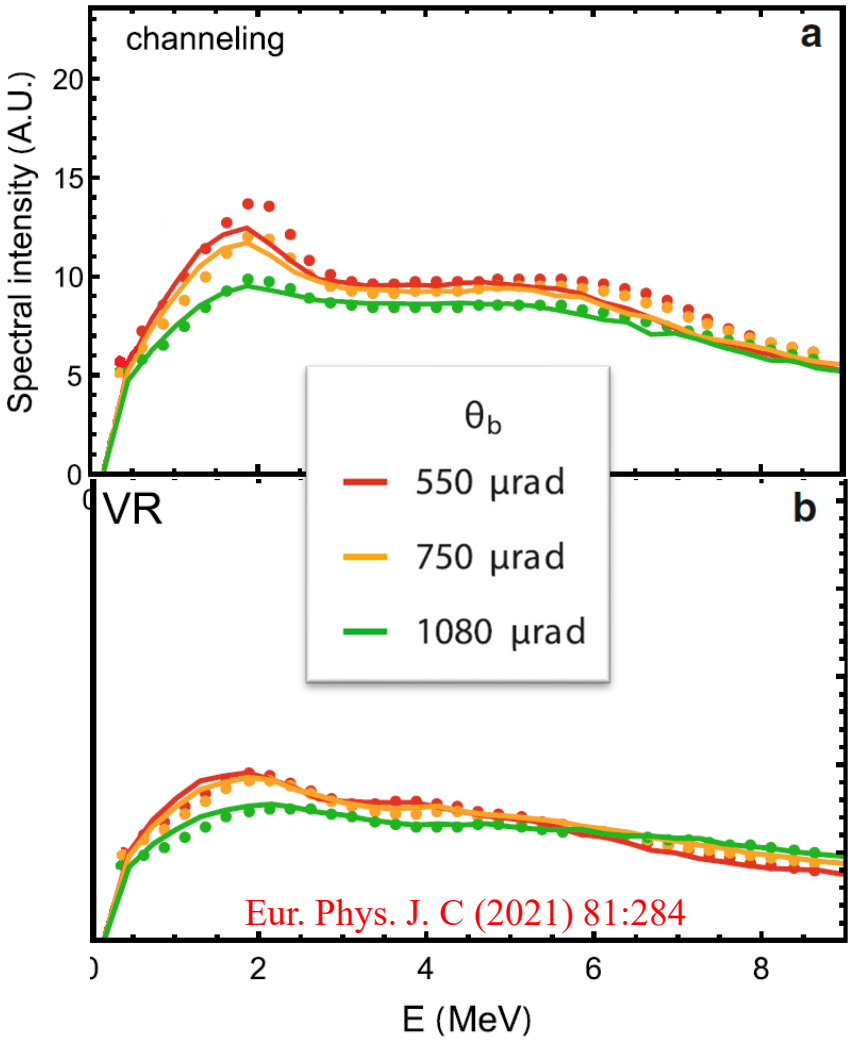


Increasing bending angle →lowering the potential well depth →higher dechanneling probability

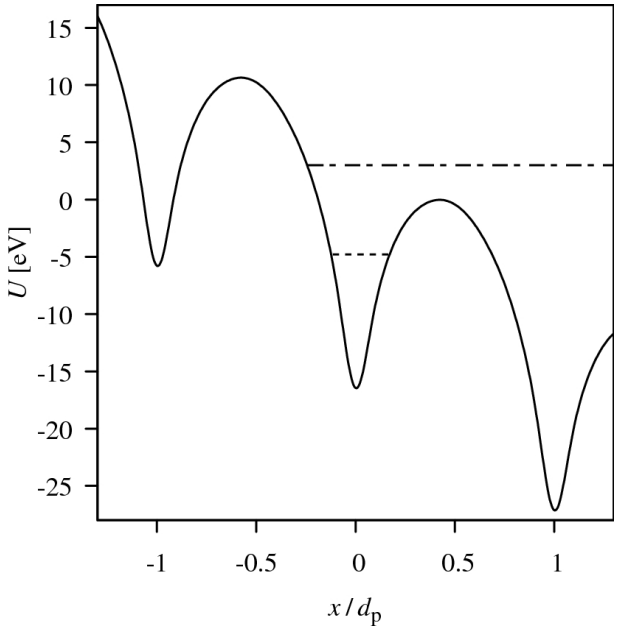
Previous Experiments:



MAIN TRENDS:

- **CR intensity decreases as ϑ_B increases**
  because dechanneling becomes stronger

- **Same trend for VR**
  radiation because the more the crystal is bent, greater is the contribution of gamma emitted by electron crossing the crystal at more misaligned trajectories



Harder radiation but less intense

Higher bending means lower critical angle, meaning less volume captured particles and fast dechanneling

Experiment at different energies

Investigate deflection and radiation properties as a function of the energy

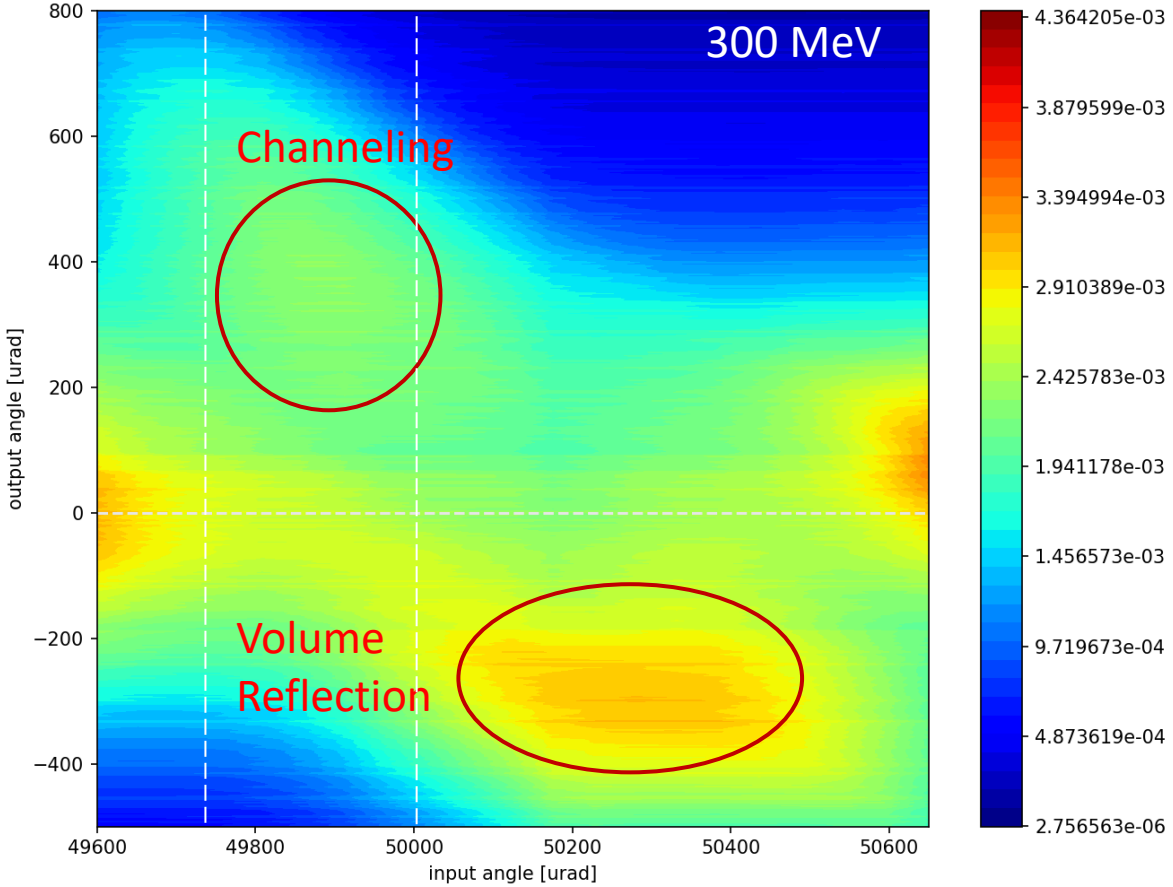
Silicon crystal 15 µm Fixed bending angle

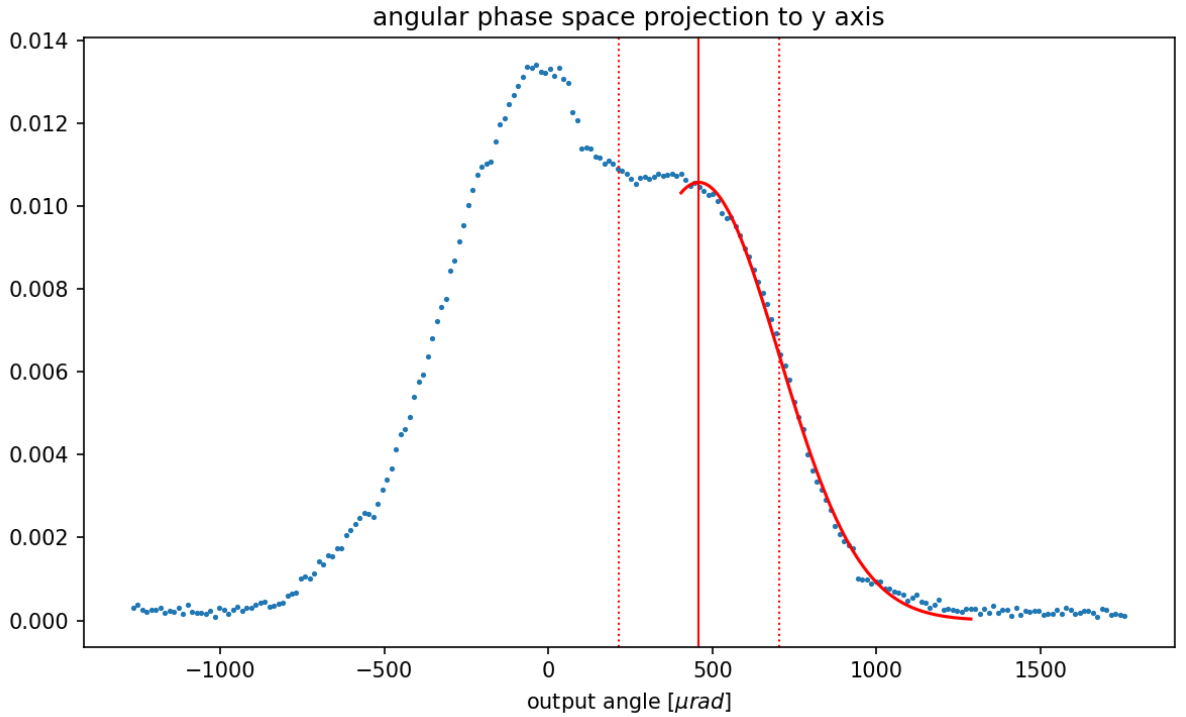
855 MeV
600 MeV
300 MeV

Beam size: 105 µm
Angular divergence: 21 µrad
in the plane of the crystal bending

Results: Deflection

Distribution of the beam particles after the interaction with the crystal vs crystal to beam orientation:

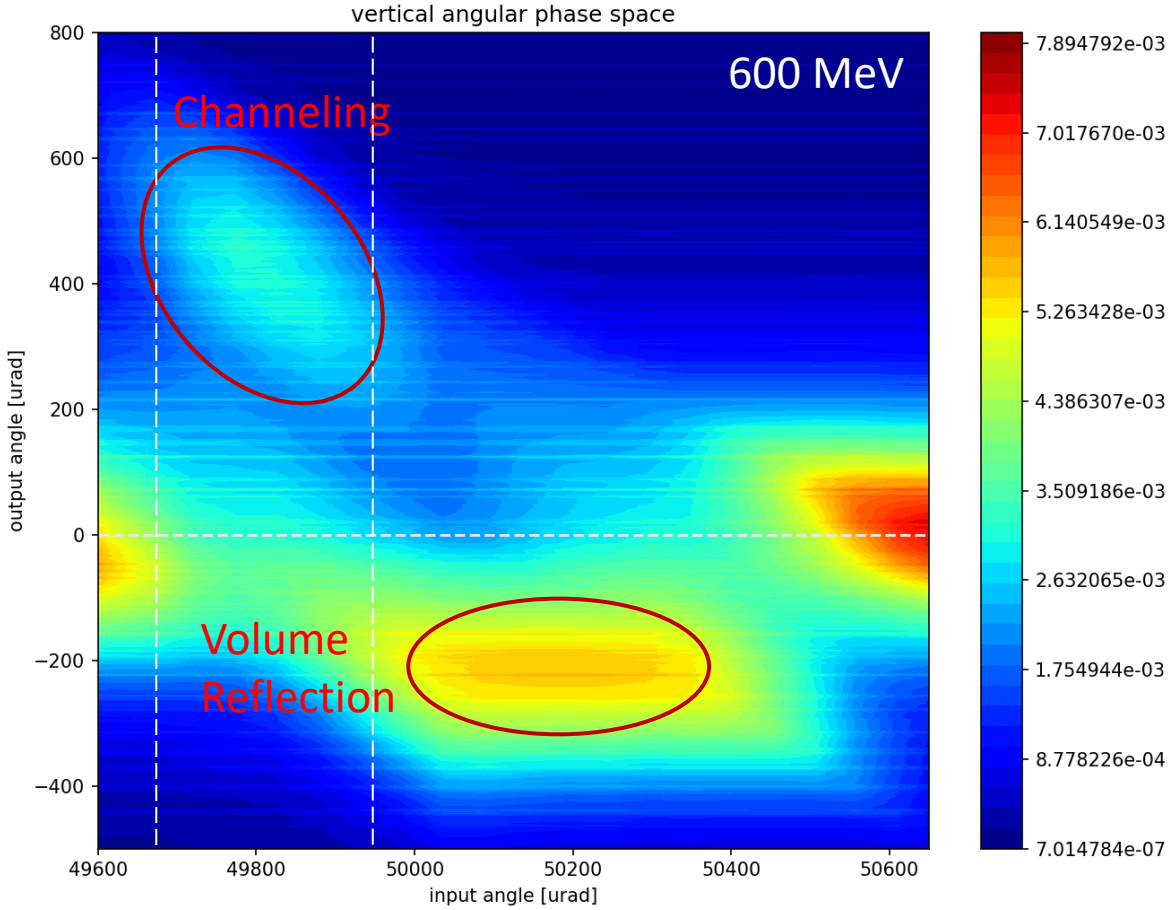


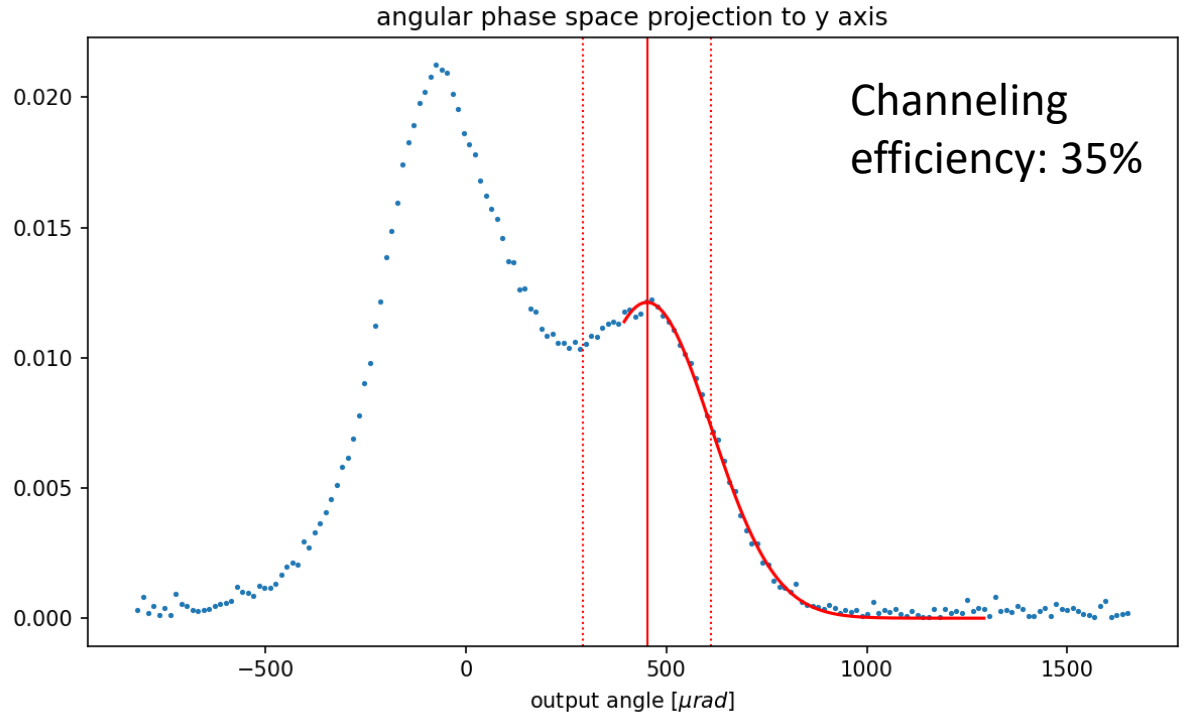


$$\theta_{sc} = \frac{13.6\text{MeV}}{pv}\sqrt{l_{cr}/X_{rad}}[1 + 0.038\ln(l_{cr}/X_{rad})]$$

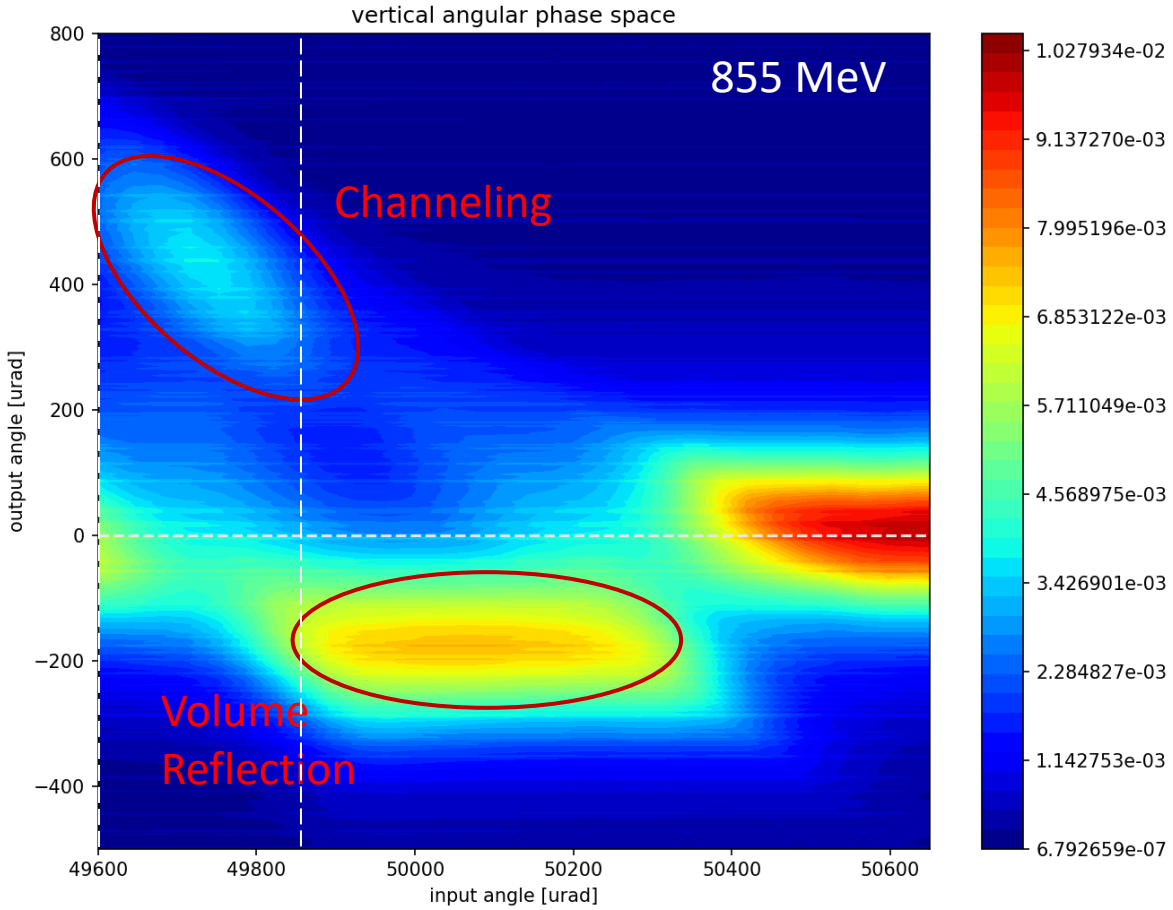
The presence of particles outside the channeling peak is given by a large amount of dechanneled particles due to the multiple scattering emphasized by the low energy

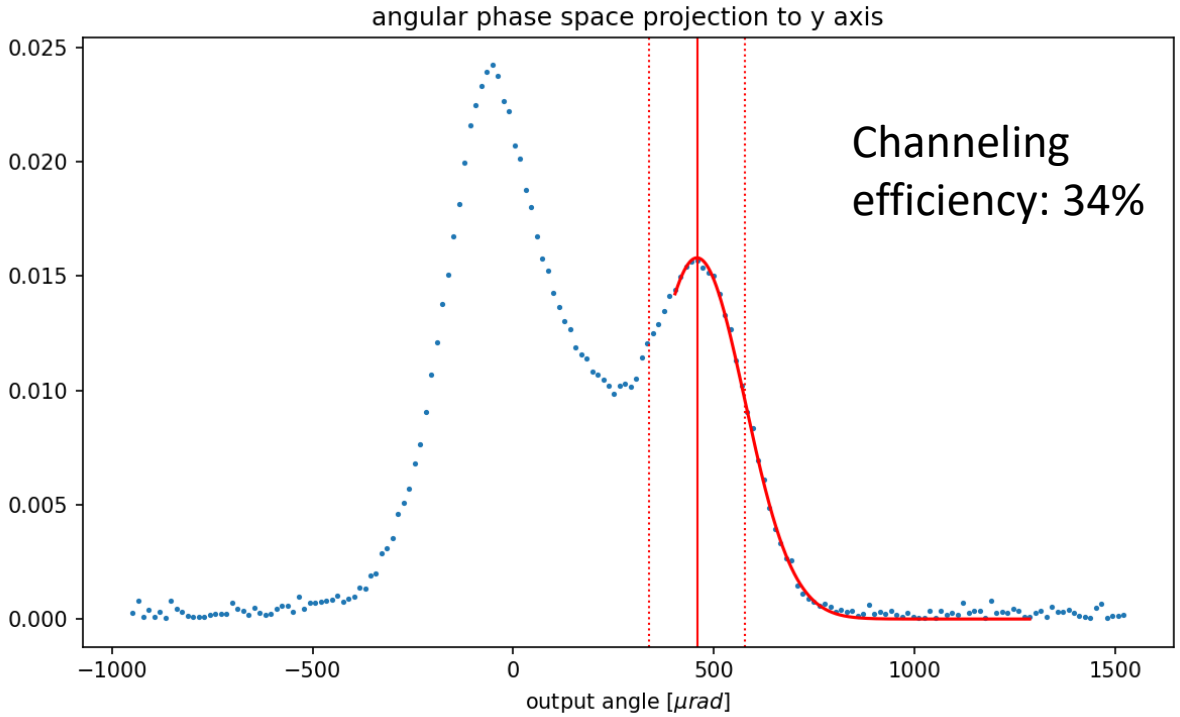
Results: Deflection





Results: Deflection





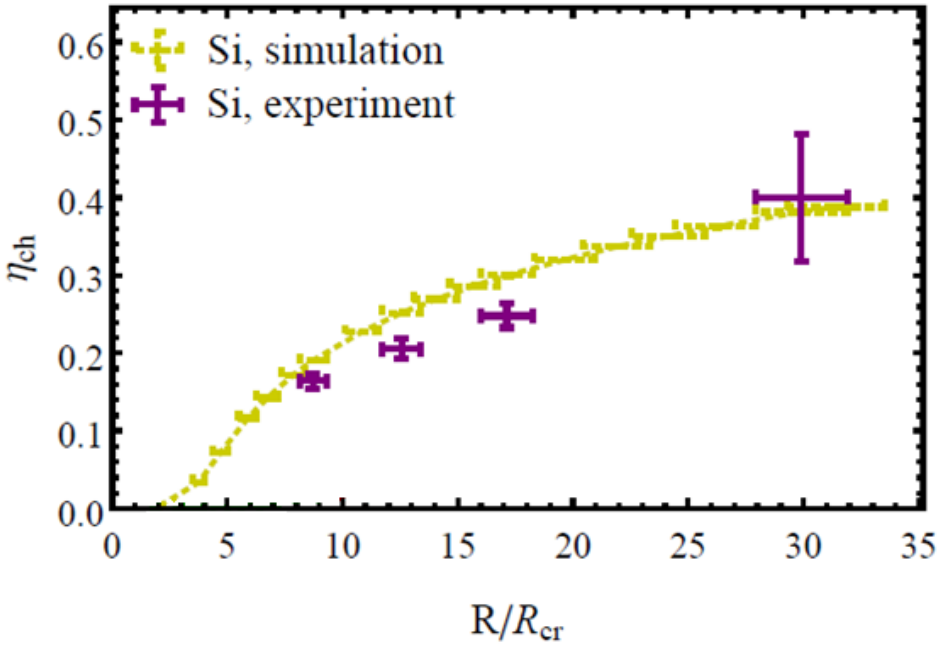
More define Channeling and Volume Reflection peak

Discussion and Conclusions:

E(MeV)	ϑ_c(μrad)	$\Delta\vartheta_b$(μrad)	R_{cr}(mm)	R_{ben}(mm)	R_{ben}/R_{cr}	η_{ch}
855	216	~455	1.6	~33	21	0.34
600	258	~455	1.1	~33	30	0.35
300	365	~455	0.55	~33	59	--

$$R_{cr} = \frac{pv}{E_0}$$

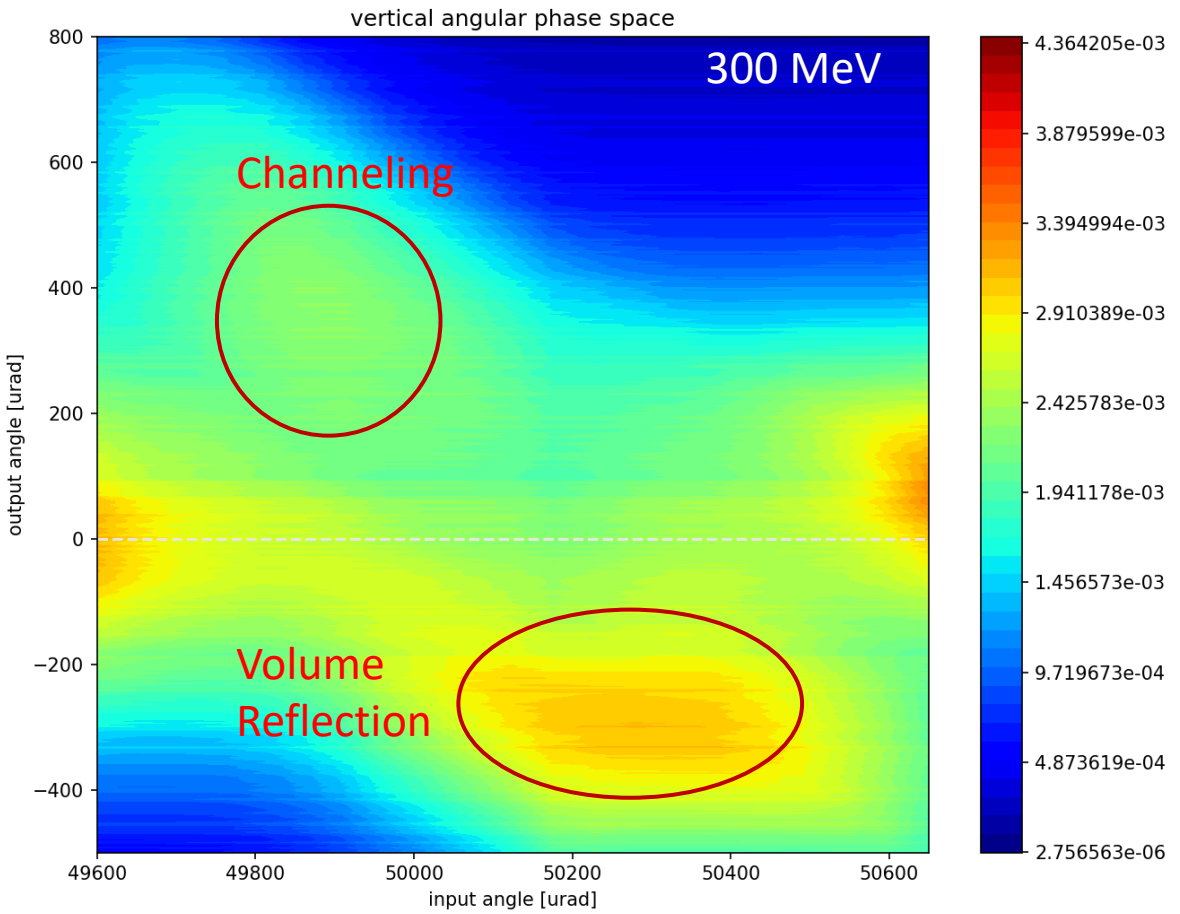
$$E_0 \approx 5.4 GeV/cm$$

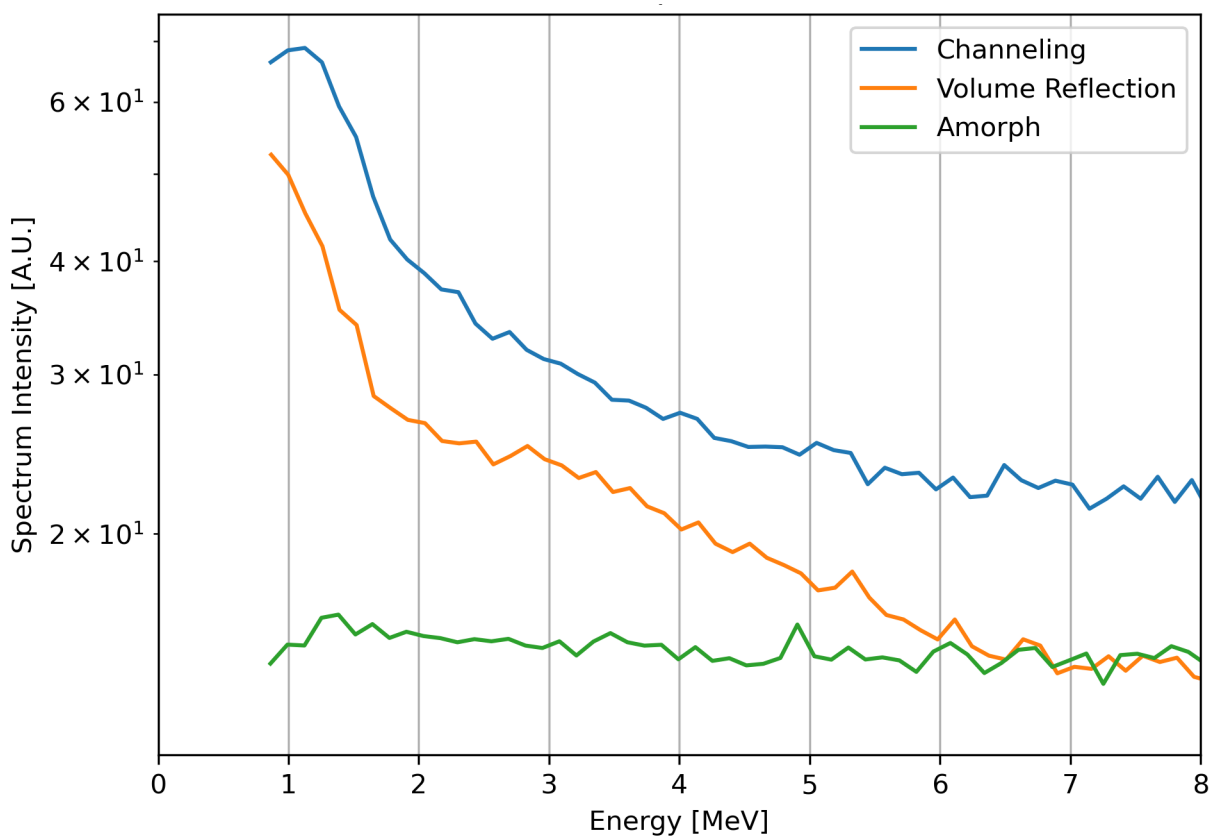


For 855 and 600 MeV the efficiency follow the trend obtained from the previous simulations, and **are very close!**

At 300 MeV, ϑ_c is higher, more channeled particles but higher ϑ_{SC} this causes a greater dispersion of the particles in the channeling leading to a lower resolution of the channeling peak and a lower reliability in the efficiency value

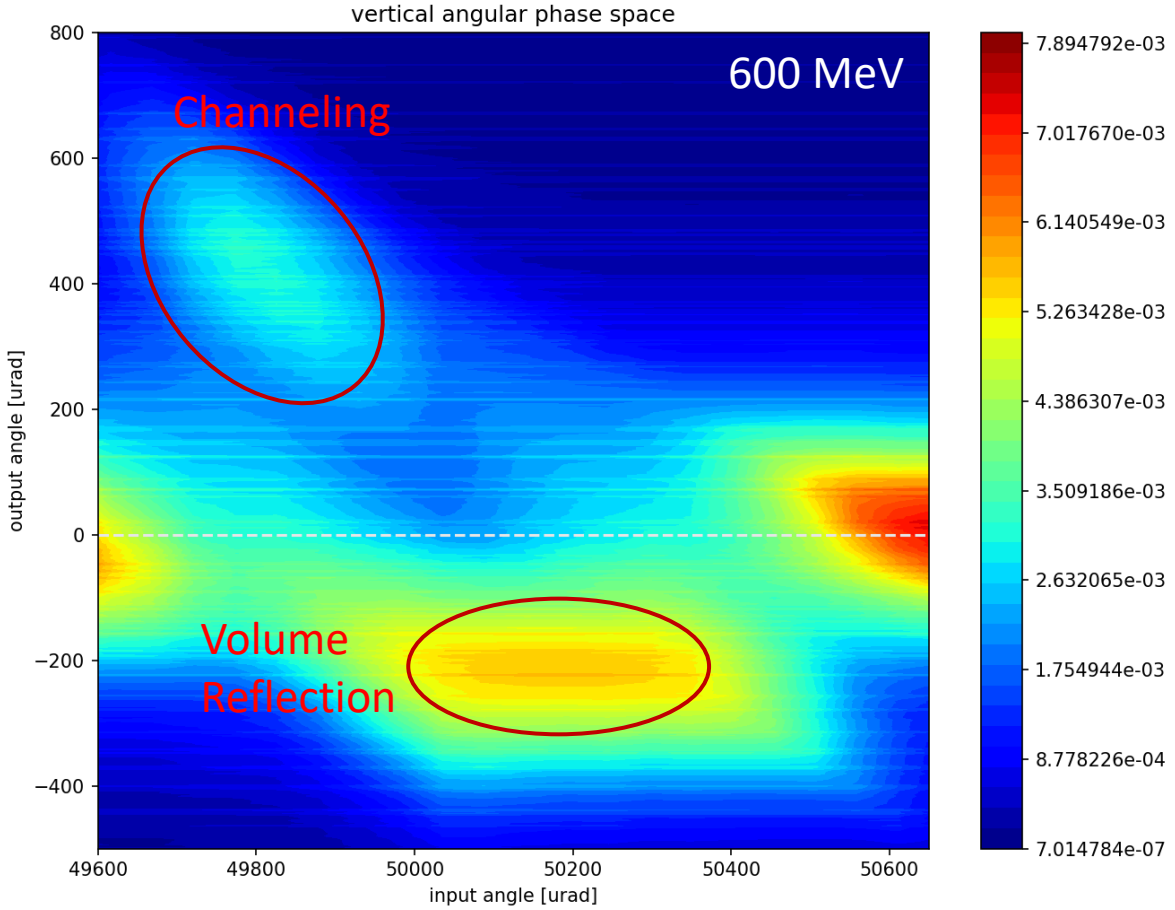
Results: Radiation

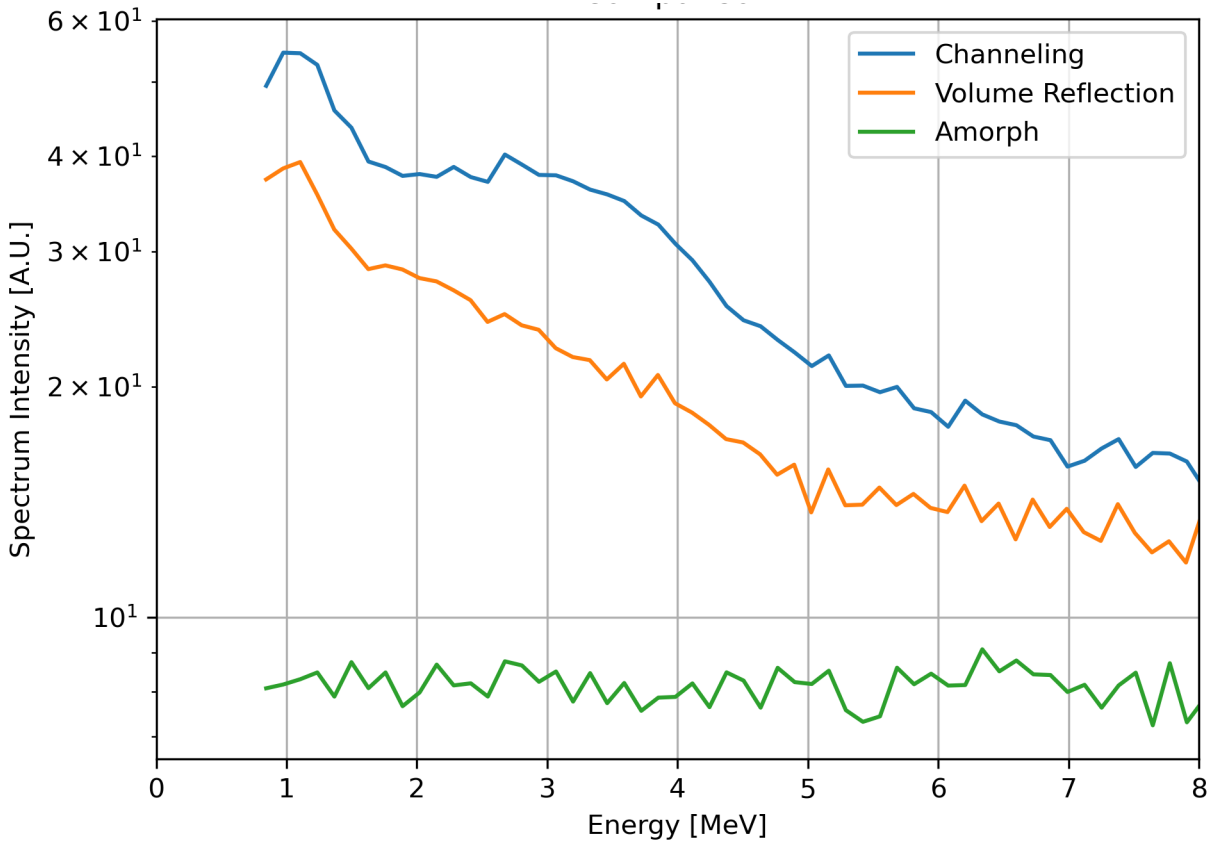




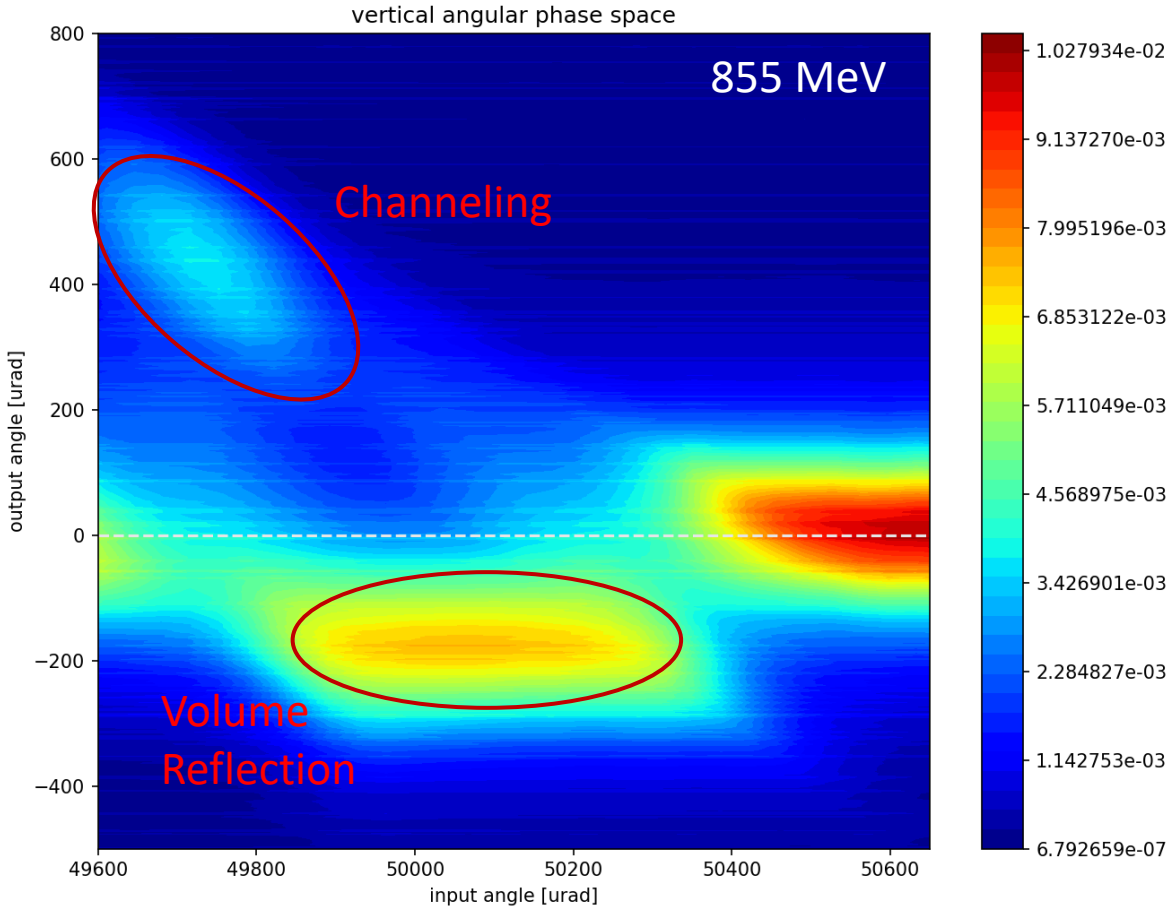
VR allows to generate intense radiation not far from the CR one, without the very strict requirement on the beam crystal alignment because the angular acceptance is equal to the bending angle

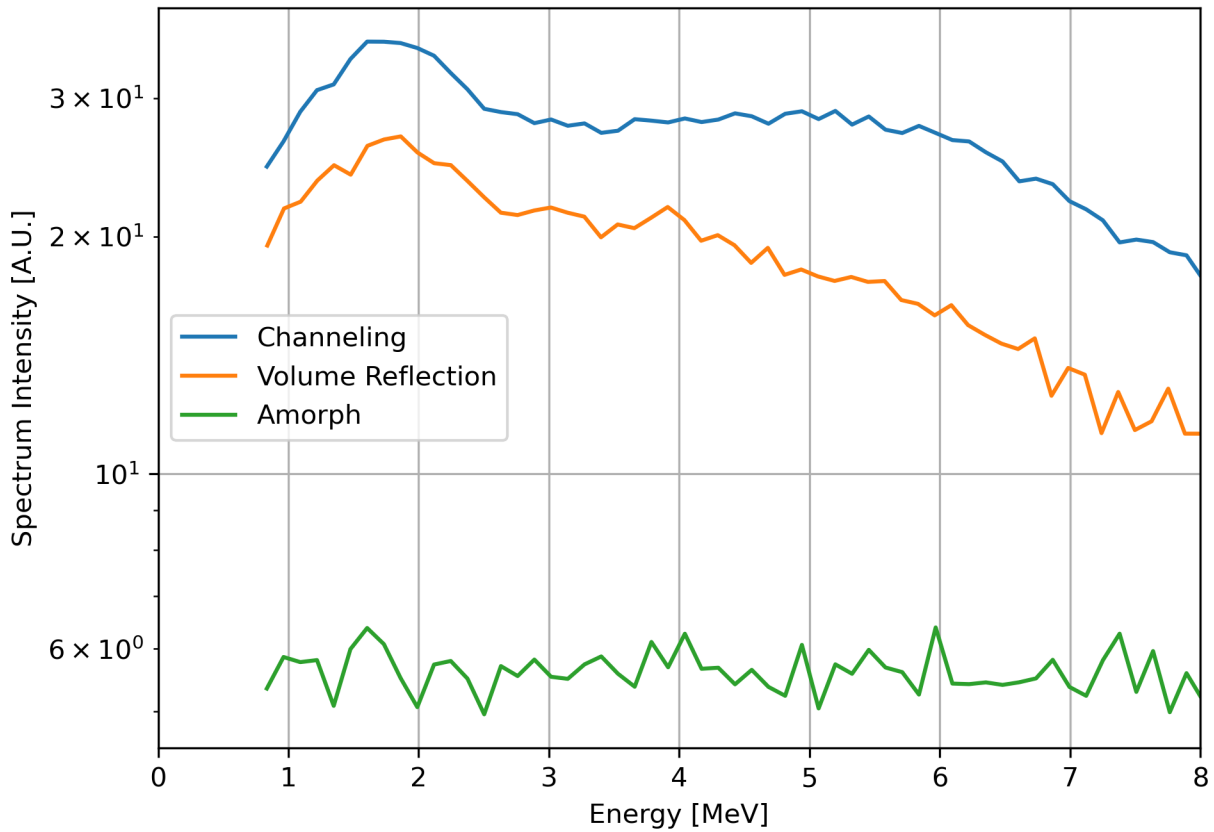
Results: Radiation





Results: Radiation





Conclusions and prospects:

We studied defletion and radiation for bent silicon crystals:

- Increasing the bending angle at fixed energy (855 MeV) we observed:
  - Decrese in channeling deflection efficiency because of the dechanneling, but there is still deflection after 1 mrad
  - CR intensity decreases as ϑ_B increases because dechanneling becomes stronger and same trend for VR but the acceptance increase thanks to VR

- Increasing the energy at fixed bending angle(455 mrad):
  - deflection efficiency do not change much between 600 and 855 MeV (the role of dechanneling and critical radius nearly compensate each other)
  - as expected channeling and VR radiation are harder and the enhancement is more evident at higher energies

Data still preliminary: make and exploit simulations to understand better the physics processes, the main parameter: the **Dechanneling length** and optimizing them for the possible application

Possible exploitation to extract sub-GeV / GeV electron and positron beams or for intense gamma sources

Thank you for the attention!

If you have any question, please contact me at
riccardo.negrello@unife.it