CRYSTAL-BASED TECHNOLOGIES FOR THE MUON COLLIDER

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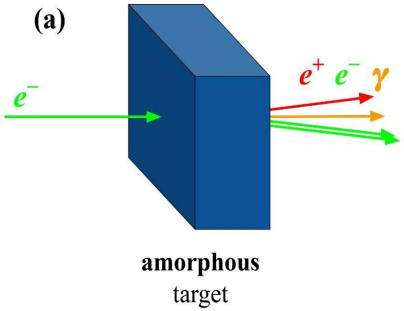
Crystals ongoing activity: Hybrid crystal-based positron source for future e+e- colliders

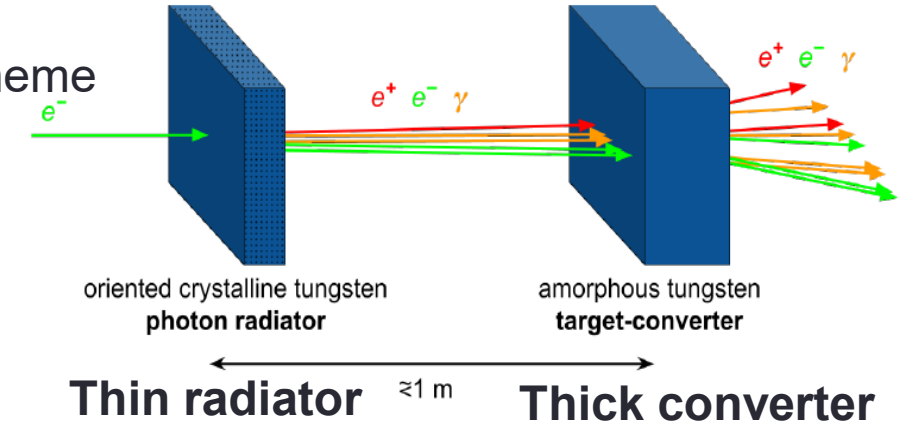
Main advantages of the hybrid source:

- **Enhancement of photon generation** in crystals in channeling conditions ➔ **enhancement of pair production in the converter target!**
- **High rate of soft photons** ➔ creation of **soft e^+ easily captured** in matching systems
- **Decrease of the deposited energy and Peak Energy Deposition Density (PEDD) in the converter target!**

Conventional



Hybrid scheme



Geant4 simulation improving the hybrid scheme…

Scheme	conv.	hybrid						
L_{crys} [mm]	–				2			
D [m]	–	0.6		1			2	
L [mm]	17.6				11.6			
Collimator?	no	no	no	yes	no	no	yes	no
Magnet?	no	no	no	no	yes	no	no	yes
E_{dep} [GeV/e^-]	1.46	1.34	1.32	1.13	1.32	1.27	1.11	1.27
PEDD [MeV/(mm³ · e^-)]	38.3	12.8	8.4	8.2	8.4	4.1	3.8	3.9
Out. e^+/e^-	13.7	15.1	15.1	13.6	15	14.9	13.7	14.9
Out. e^+ beam size [mm]	0.7	1	1.2	1.2	1.2	1.5	1.5	1.5
Out. e^+ beam div. [mrad]	25.9	27.4	26.8	27.7	28.9	29.2	25.6	27.1
Out. e^+ mean energy [MeV]	48.7	46.2	45.6	47.4	45.9	46.1	47.7	46.3
Out. n/e^-	0.37	0.31	0.31	0.27	0.29	0.29	0.26	0.3
Out. γ/e^-	299	310	308	270	307	301	268	301

conventional (amorphous)
collimator
magnet

Huge reduction of PEDD in the converter! Same or even higher rate of positrons!

To be tested at PSI in 2025

PAUL SCHERRER INSTITUT PSI

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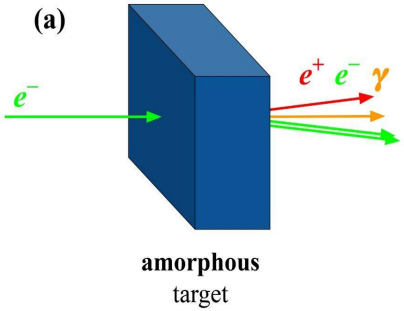

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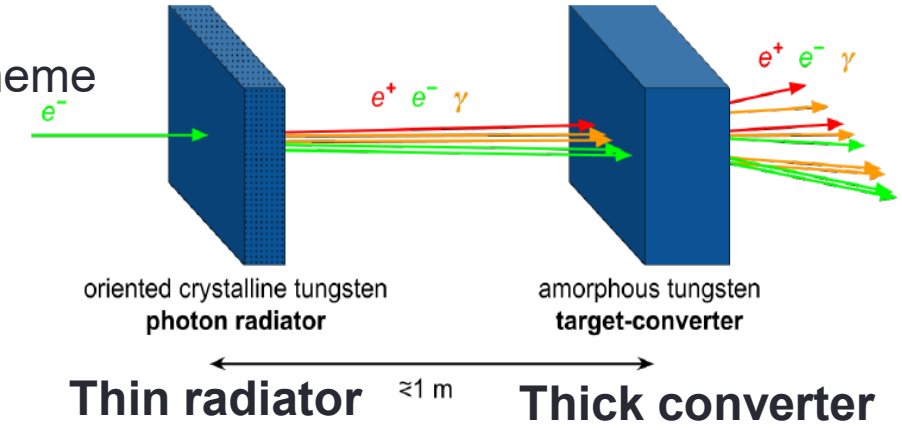


Ongoing activity

Experiment

Radiation and irradiation tests as a route to select the final configuration for the crystal radiator and amorphous converter.

Simulation

Implementation of the hybrid-source in the full FCC-ee pre-injector MC simulation

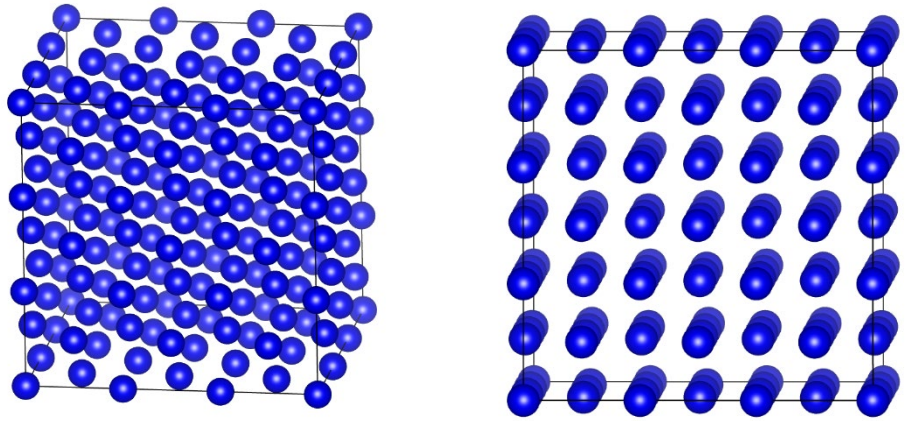
The final goal is to be ready with a full hybrid source dosing to be directly compared with the conventional one and to be tested at PAUL SCHERRER INSTITUT PSI within the CHART project in 2025 (?)

CHART Swiss Accelerator Research and Technology

This activity will be moved to RD-FCC in 2024, since it will be dedicated to the FCC-ee positron source studies within the full Injector design!

2024 Activity: Bent crystals and particle beams

- Atoms in crystals appears aligned along planes/rows of atoms
- In case of bent crystals, particles impinging within a critical angle acceptance are forced to follow lattice planes or axis
- These effects feature very strong angular kick comparable to **10^2 T** magnetic dipole
- Only particle impacting on crystal are affected: easy to intercept only precise portion of beam with micrometric precision
- The deflection angle is controlled with precision, depending on geometry and bending of crystal



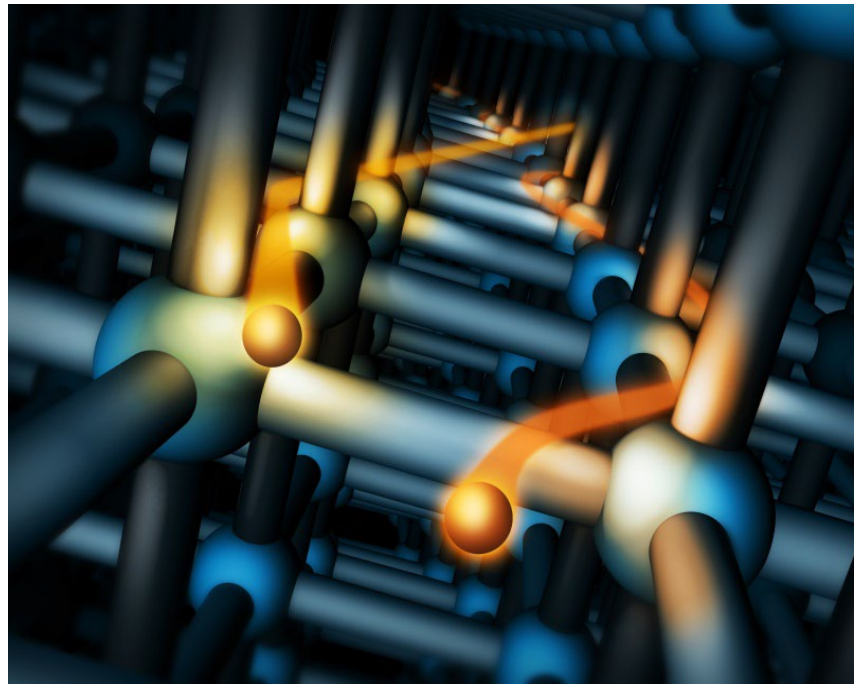
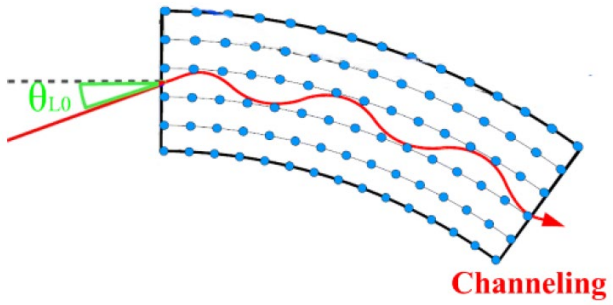
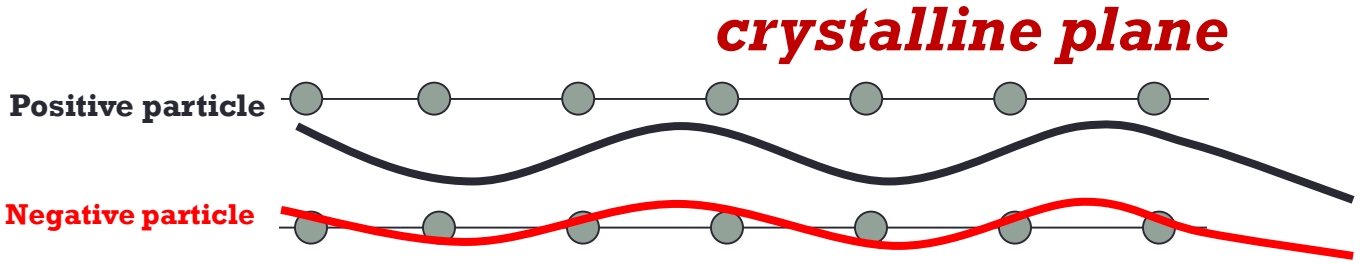
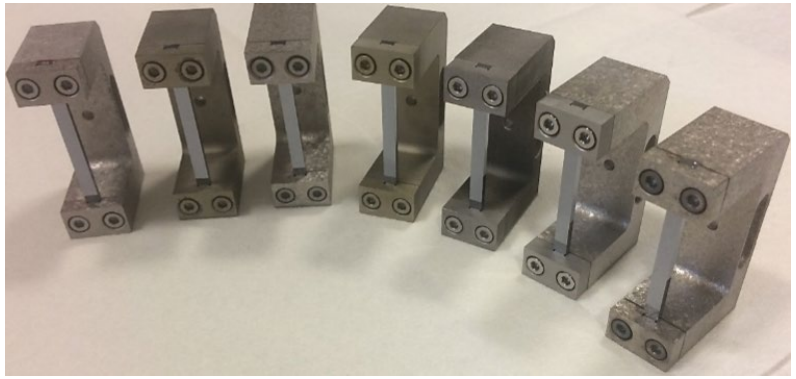


Image from https://www6.slac.stanford.edu/news/2015-02-25-slac-led-research-team-bends-highly-energetic-electron-beam-crystal.aspx

Crystals in 2024: Investigation of channeling in bent crystals for the Muon Collider Collimation System*







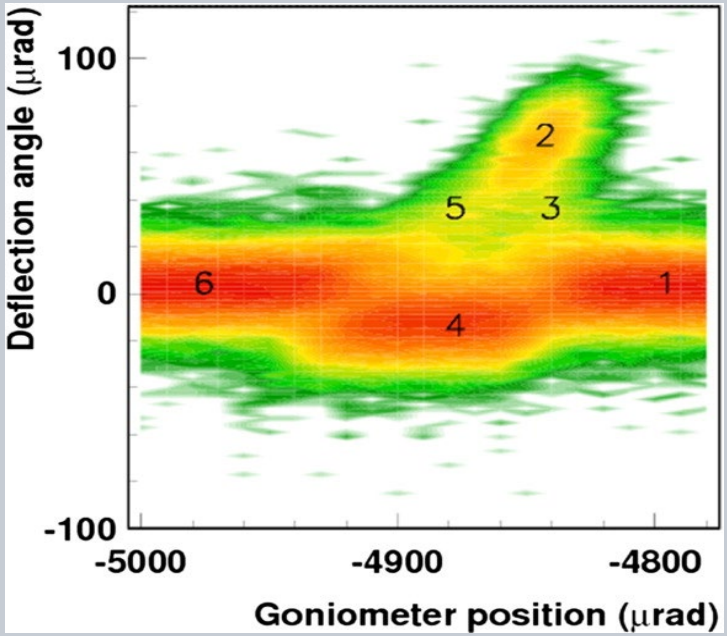
Bent Si crystals for LHC proton/ion beam collimation @INFN FE

- The technique is well established for positively charged particle beams
  - 70 GeV proton extracted beamline at IHEP for ~10 years (1989-1999)
  - Study of Σ+ spin precession at Tevatron (E761)
  - Crystal collimation for the HL-LHC upgrade baseline program
- **The challenge for Muon collider is the deflection of the negative muon beam!**

*D, Schulte et. al, Muon Collider. A Path to the Future? POS 2019

Crystals in 2024: Investigation of channeling in bent crystals for the Muon Collider Collimation System

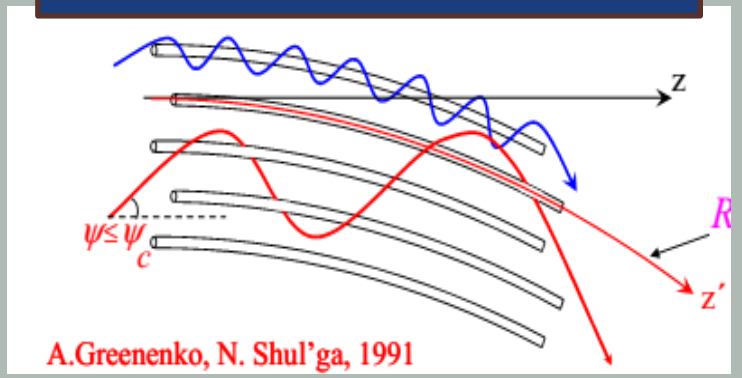
PLANAR EFFECTS



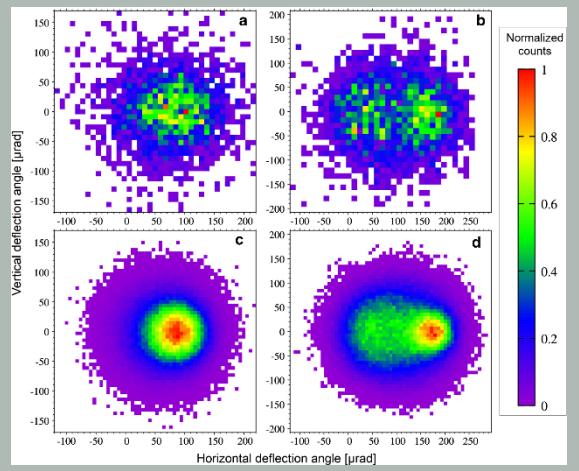
Channeling(2): First result obtained at CERN within H8RD22/UA9 (150 GeV π^-) **with INFN crystals** shows high potentialities also for negative particles!

Volume reflection(4): high efficiency for both positive and negative particles

AXIAL EFFECTS



Deflection of more than 90% of the electron beam.



L. Bandiera, I. V. Kyryllin et al. Eur. Phys. J. C 81 (2021) 238

Crystals in 2024: Attività e Richieste

- Progettazione di un cristallo ottimizzato per operazioni a 5 TeV (**sia per particelle positive che negative**) compatibile col CDR del Muon Collider mediante simulazioni MC in Geant4
- Partecipazione test beam con CRILIN per sviluppo calorimetro elettromagnetico (sinergia con OREO-CSNV ed NA62-CSNI).
- Personale coinvolto: L. Bandiera (10%), V. Guidi (20%), M. Romagnoni (20%). Totale: 0.5 FTE
- **Richieste di missioni**:
  - Visita al CERN per collaborazione nell'ottimizzazione della simulazione in Geant4 dei cristalli curvi per Muon Collider. 15 giorni per 1 persona – **3 keuro**
  - Metabolismo (0.5 FTE) – **1 keuro**

BACK UP

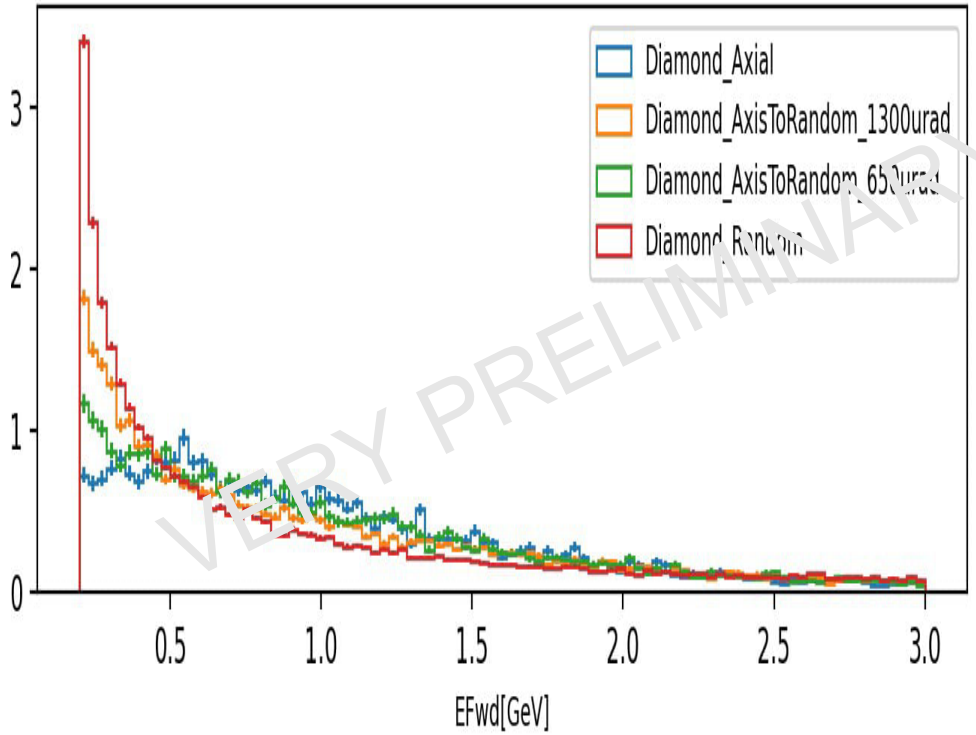
INFN Ferrara activity ongoing – 2023

Currently on RD-MUCOL

Experimental activities

- Characterization and **test on different material than W (Ir and diamond)** as a route the final configuration for the crystal radiator and amorphous converter
- Optimized irradiation tests on crystal and converter targets (planned @MAMI for November 2023): we are planning to irradiate a crystal sample already characterized by X-ray and tested on e-beam - **Joint effort between IJCLab and INFN-FE**

Energy loss spectra of 5.6 GeV electrons in a diamond crystal (2 mm, <110>) in different crystal-to-beam orientation.



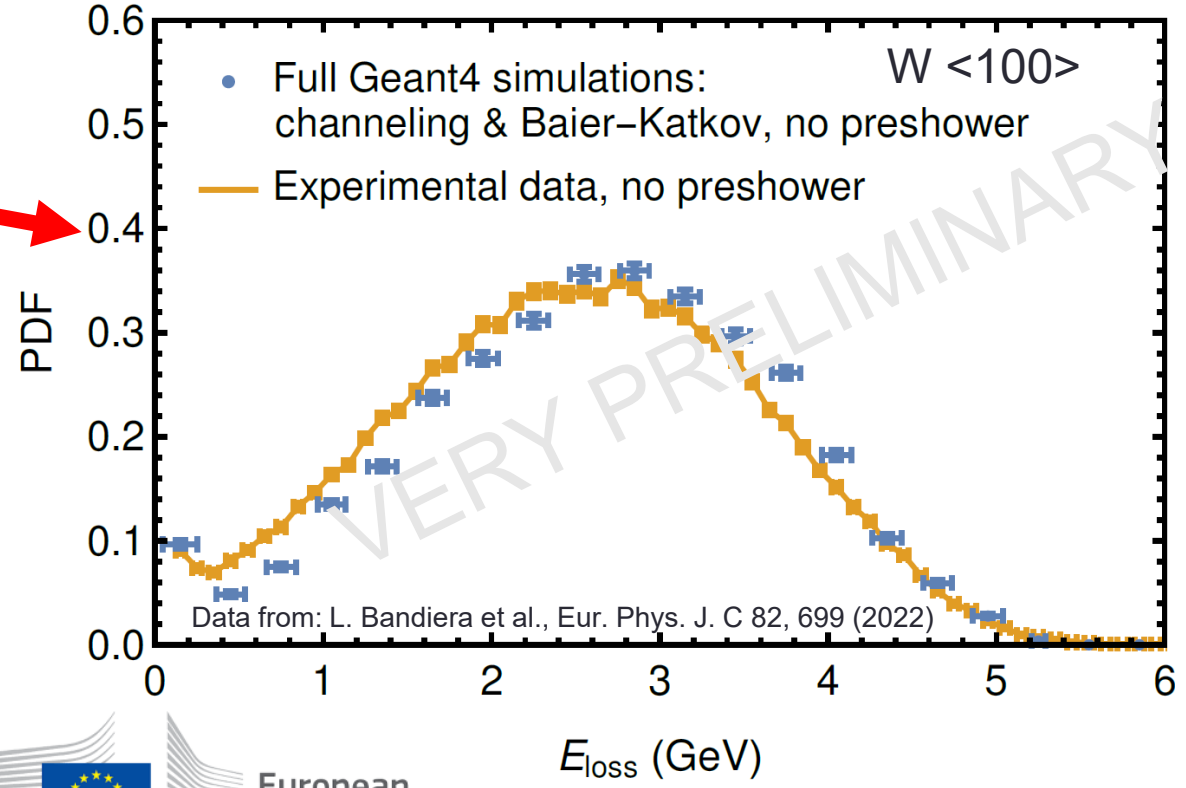
The analysis of increase of photon number is ongoing

INFN Ferrara activity ongoing – 2023

Currently on RD-MUCOL

Monte Carlo activities

- Validate the new G4 model for **crystal radiator simulation <u>inside</u> Geant4** -> possibility to change crystal parameters inside Geant4
- We are goint to use the current MC setup in Geant4 for the implementation of the hybrid-source in the full pre-injector -> collaboration with people involved in this task (from the CHART project) - **Joint effort between IJCLab and INFN-FE**

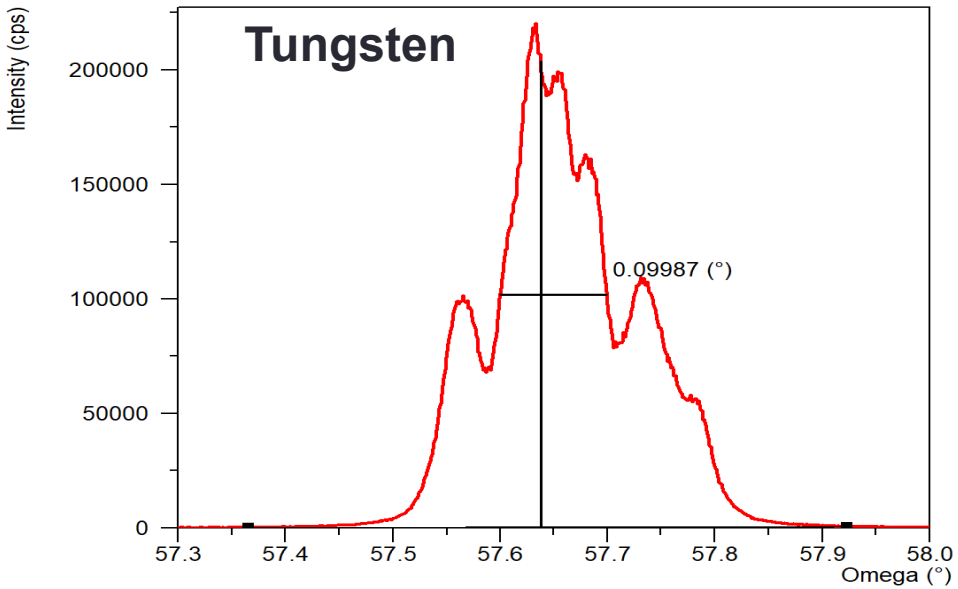


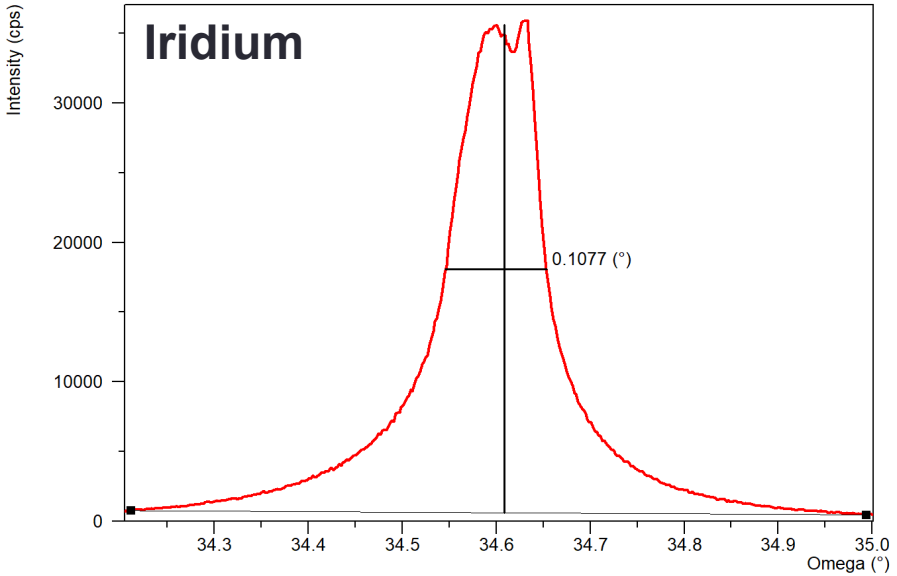
European Commission

Trillion

A. Sytov (MSCA Individual Fellow)

XRD characterizationof crystal radiator





Characterization of superficial mosaicity of the lattice performed with High Resolution XRD at laboratories of Ferrara (@

FWHM ≤ 2 mrad for Ir and W

≈ 0.4-0.7 mrad for SiC