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IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis
anr GA No ANR-21-CE31-0007
cnrs

Experiments on crystal radiators at DESY TB and CERN PS

2nd FCC-France&Italy workshop – Venice

Nicola Canale

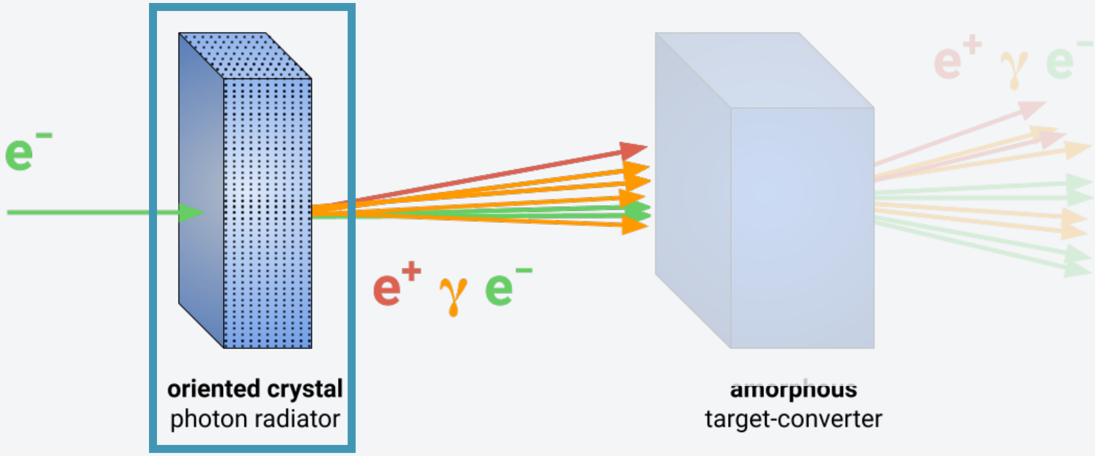
on behalf of F. Alharthi, A. Bacci, L. Bandiera, D. Boccanfuso, S. Carsi, I. Chaikovska, R. Chehab, D. De Salvador, P. Fedeli, V. Guidi, V. Haurylavets, O. Iorio, G. Lezzani, L. Malagutti, S. Mangiacavalli, A. Mazzolari, P. Monti Guarnieri, V. Mytrochenko, R. Negrello, G. Paternò, M. Prest, M. Romagnoni, M. Rossetti Conti, A. Selmi, F. Sgarbossa, M. Soldani, A. Sytov, V. Tikhomirov, E. Vallazza

INFN Ferrara
ncanale@fe.infn.it

Outlook

As presented in talks by **A. Sytov and G. Paternò**, **crystal-based positron sources** offer promising potential for future colliders.

Here, we will see the **test beam results** on **crystal radiators**, which serve as a crucial **benchmark for simulation code** validation.



Outlook

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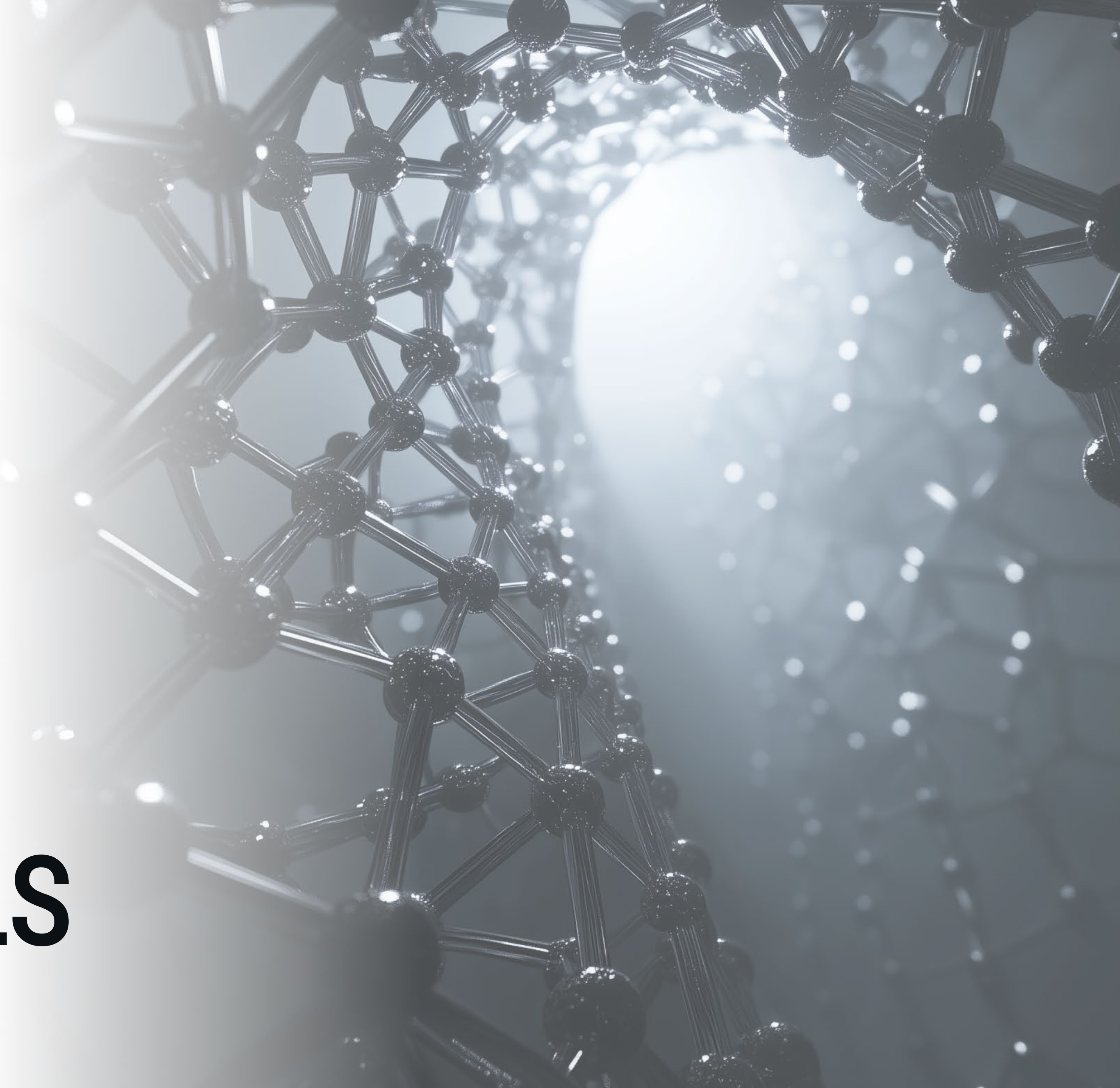
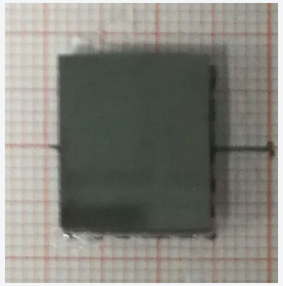
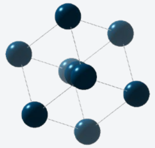
Here, we will see the **test beam results** on crystal radiators, which serve as a crucial **benchmark for simulation code** validation.

- **THE CRYSTALS**
- EXPERIMENTAL **SETUP**
- TESTBEAM **RESULTS**

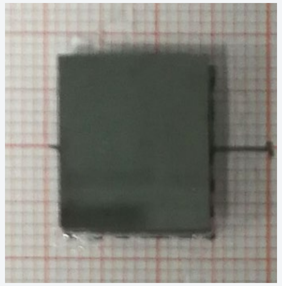
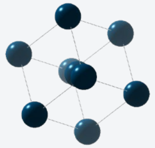
THE CRYSTALS



Crystal radiators

Material: Tungsten (W)
channelling Axis: <100>
$\theta_C \approx 0.5\, mrad$
Thickness: 2.25 mm (0.64 X0)
(research center manufactured crystal)

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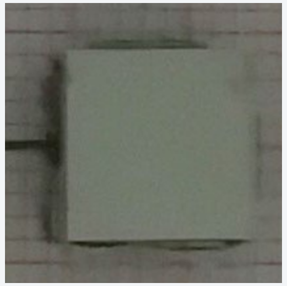
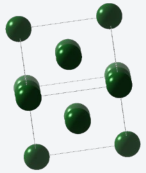

Material: Iridium (Ir)
channelling Axis: <110> (most efficient)
$\theta_C \approx 0.6$
Thickness: 1 -2 mm (0.34 – 0.68 X0)
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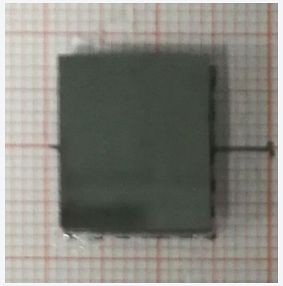
Tested at DESY T21 beamline with 5.6 GeV/c electrons

Tested at CERN PS T9 beamline with 6 GeV/c electrons

Crystal radiators

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Research Center quality crystal

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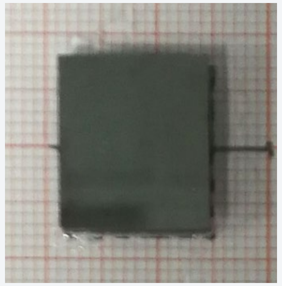
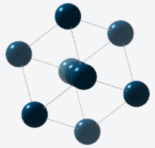

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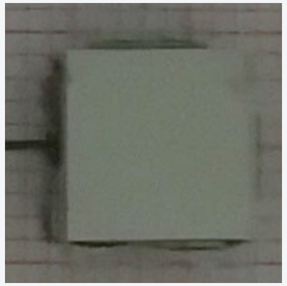
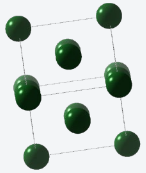

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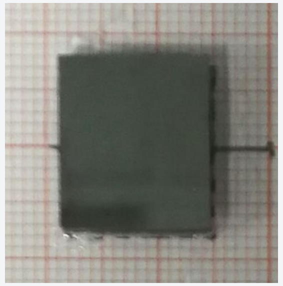
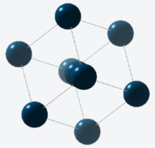
Crystal radiators

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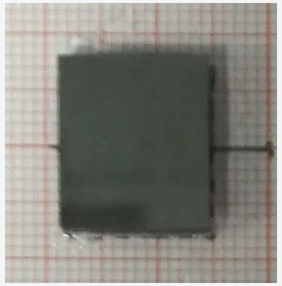
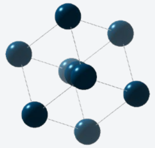

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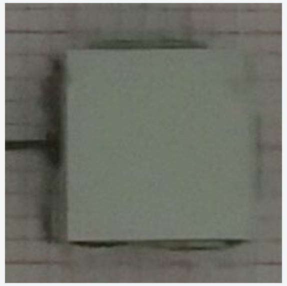
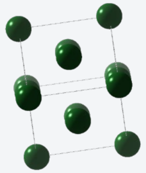

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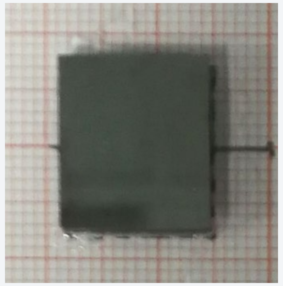
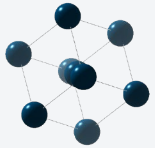
Research Center quality crystal

W 2mm baseline for Hybrid source radiator - 1.5mm for optimization studies

Tested at DESY T21 beamline with 5.6 GeV/c electrons

Tested at CERN PS T9 beamline with 6 GeV/c electrons

Crystal radiators

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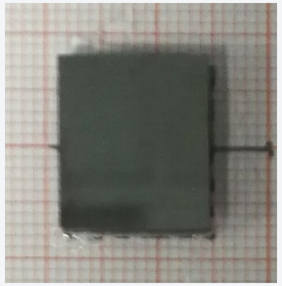
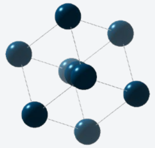

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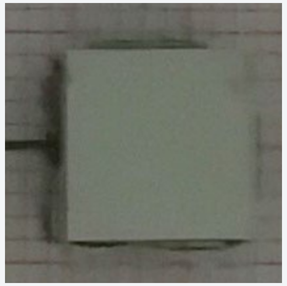
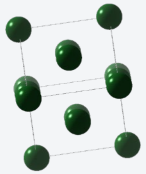

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Higher potential, interesting alternative

Tested at DESY T21 beamline with 5.6 GeV/c electrons

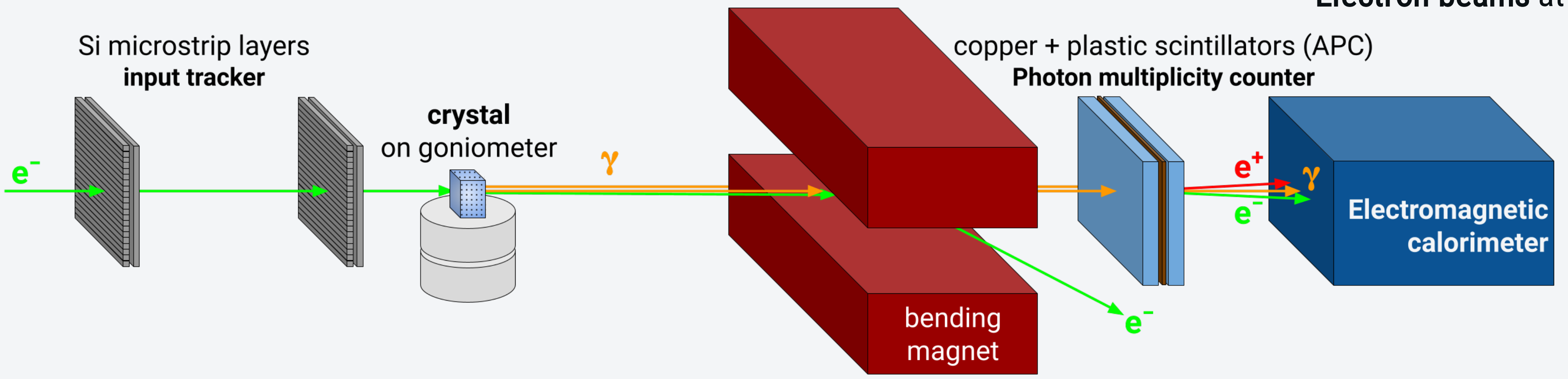
Tested at CERN PS T9 beamline with 6 GeV/c electrons

EXPERIMENTAL SETUP

The setup

CERN setup configuration

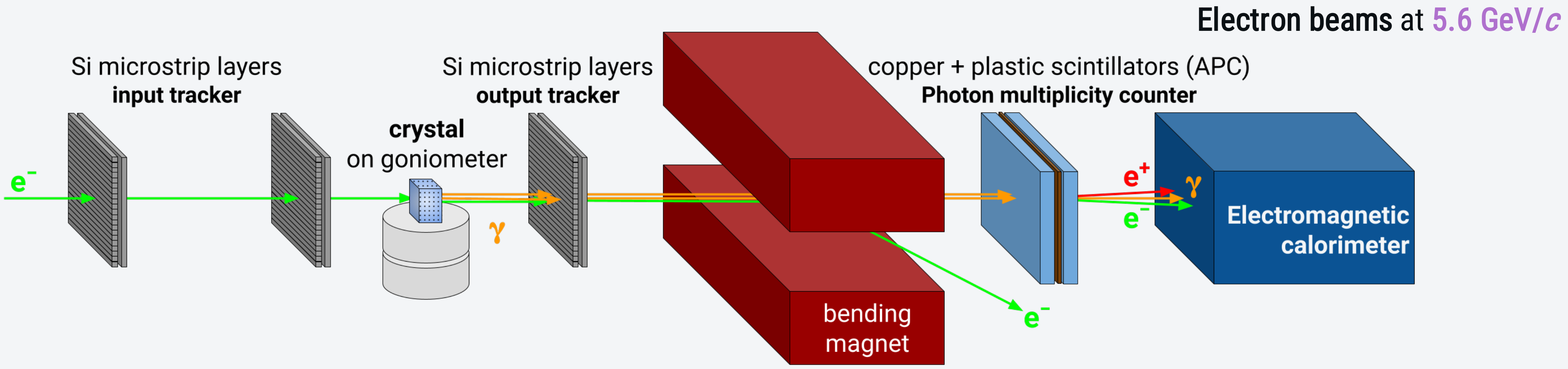
Electron beams at 6 GeV/*c*



Provided by INFN Milano Bicocca team – Erik Vallazza & Michela Prest

The setup

DESY setup configuration



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CERN configuration

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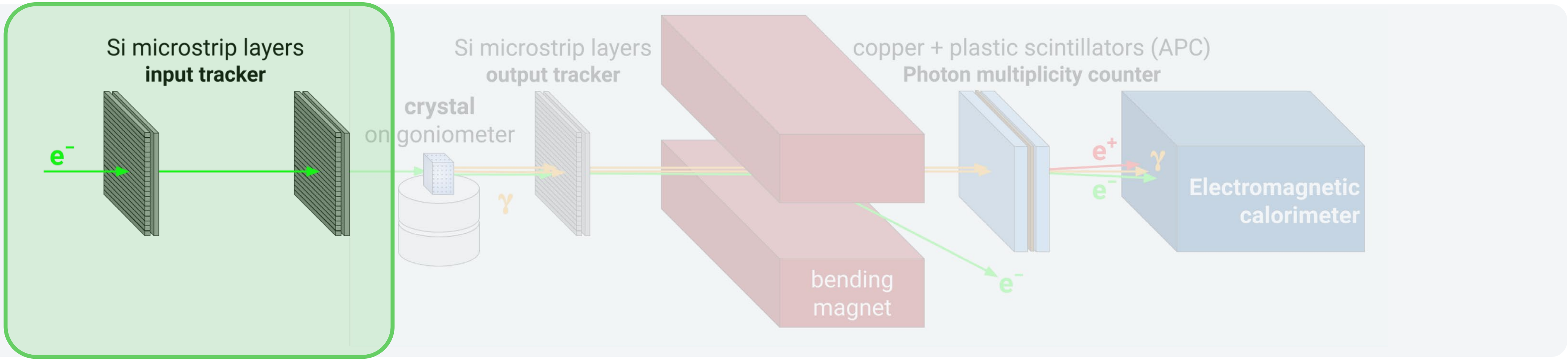


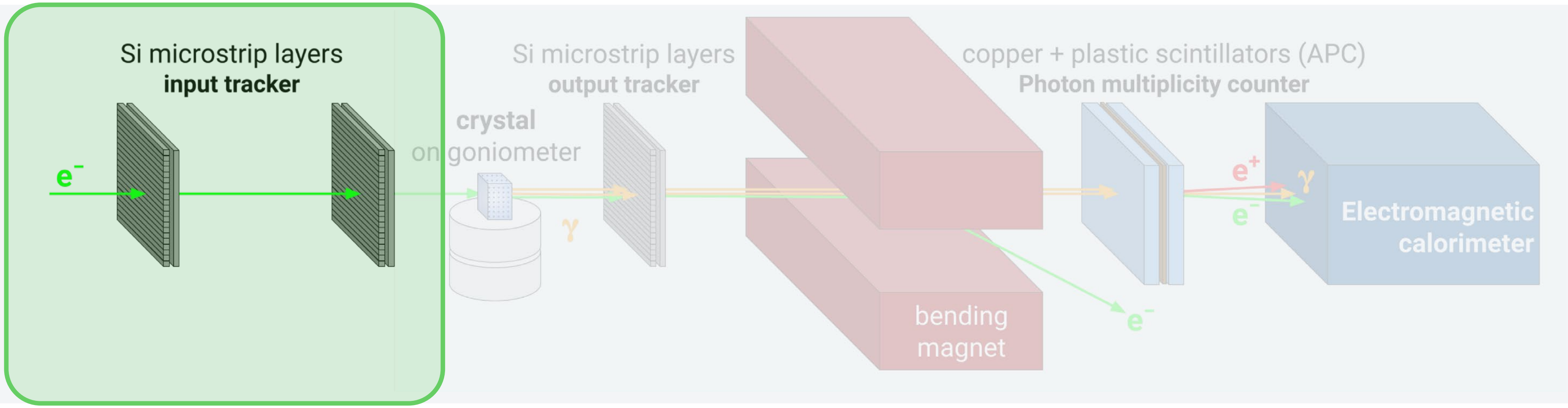
Input stage

Reconstruct track and impinging angle on the crystal

The setup

CERN configuration

DESY configuration



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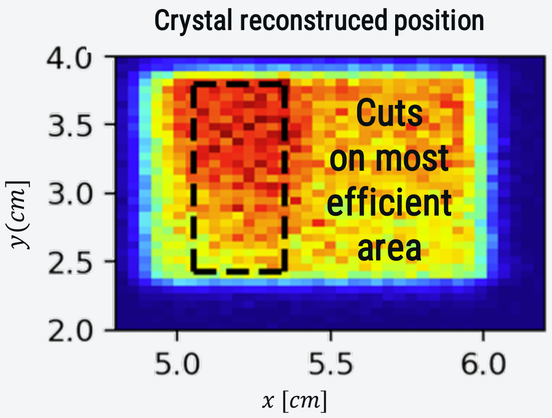
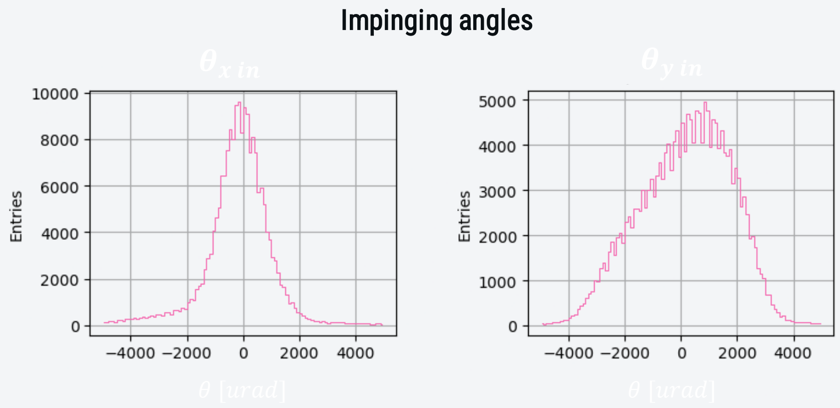


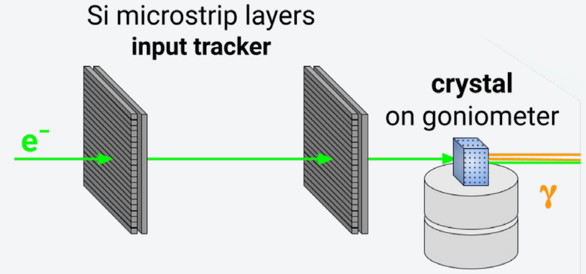


The setup - input stage

Input tracker

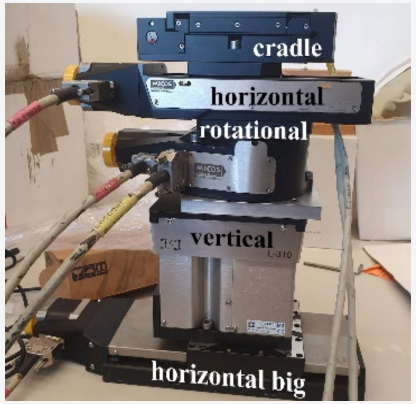
~ 2×2 cm^2 *xy* double-sided Si microstrip sensors, with an overall **~10 µm** single-hit resolution.

~ **9.5×9.5 cm^2** *xy* double-sided Si microstrip sensors, with an overall **~40 µm** single-hit resolution.



Goniometer from LNL & UNIPD

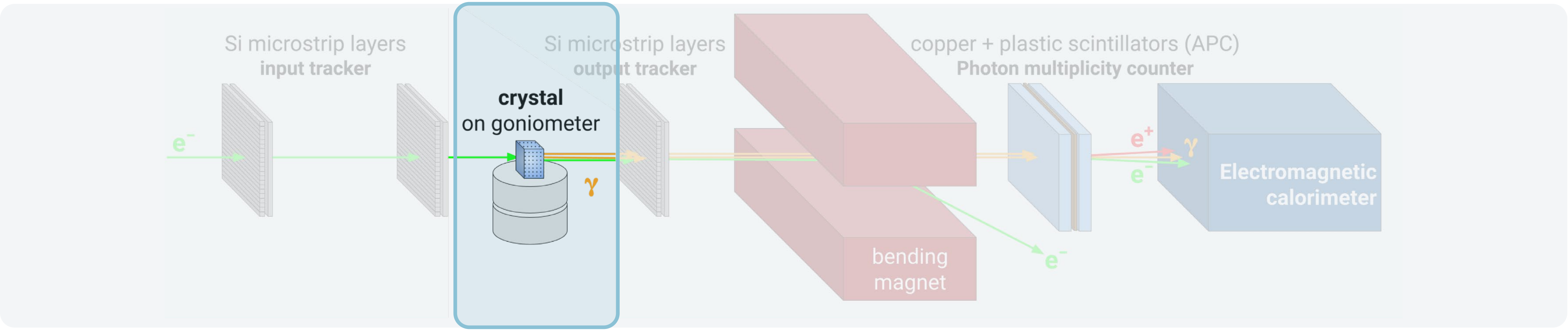
Fine-grained, remote-controlled movements along x, y, θ_x and θ_y with ~5 µm, 1µrad resolution.



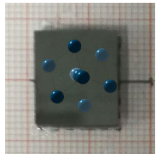
The setup - the crystal

CERN configuration

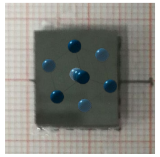
DESY configuration



Material: Tungsten (2.25 mm)
channelling Axis: <100>
Axial potential: 1 keV
$\theta_C \approx 0.5\ mrad$-



Material: Tungsten (1.5-2 mm)
channelling Axis: <111>
Axial potential: 1 keV
$\theta_C \approx 0.6\ mrad$



Material: Iridium (1-2 mm)
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Axial potential: 1 keV
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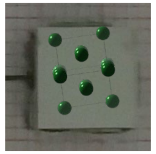
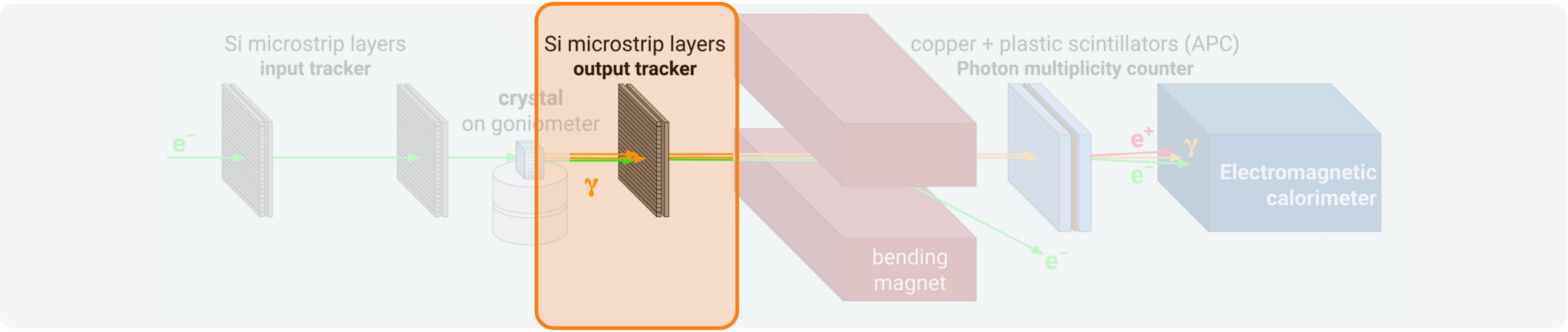


The setup - output tracker

DESY setup configuration



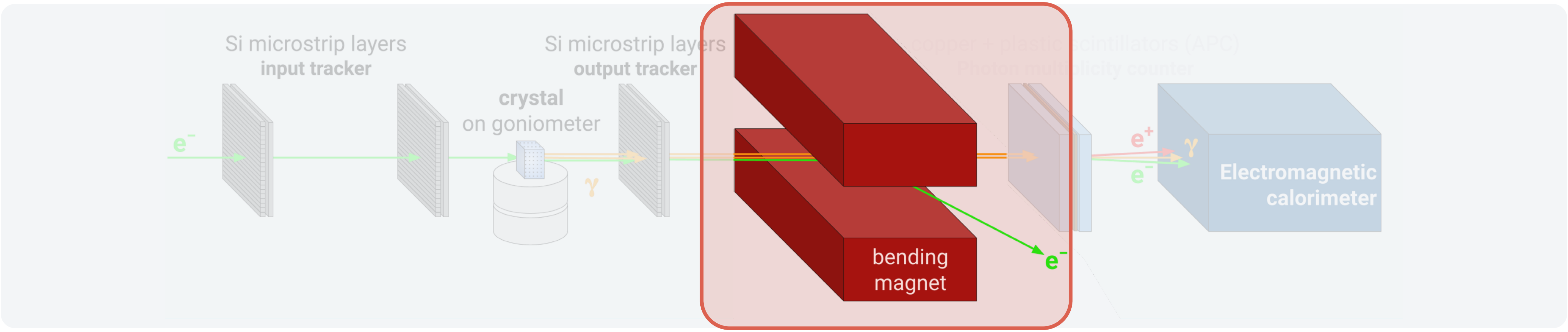
output tracker

As multilpicity counter to align the crystal

The setup - magnet

CERN configuration

DESY configuration



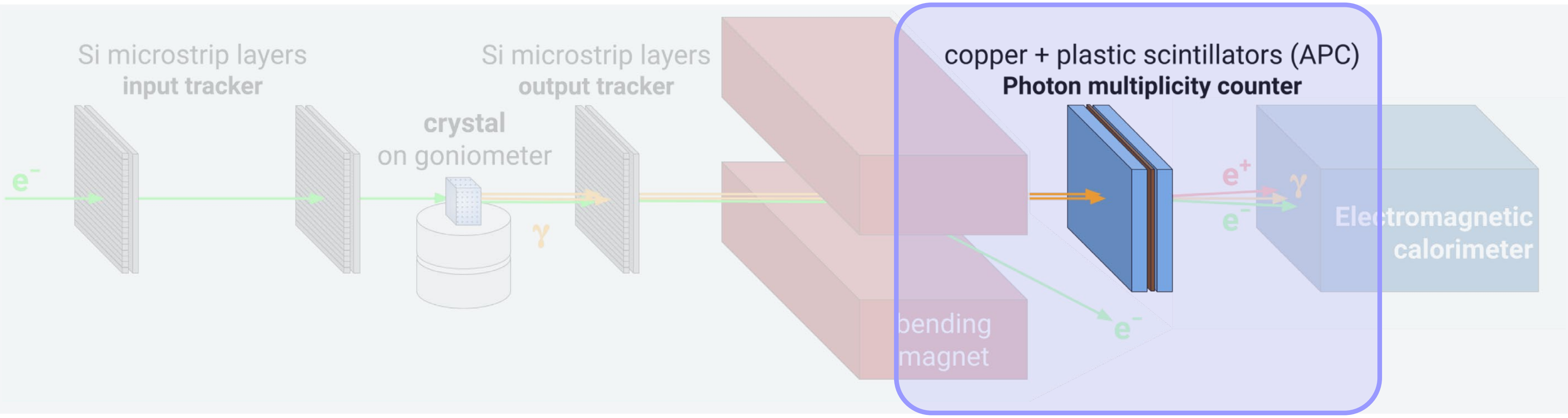
Magnet

Select only the photons

The setup - output stage

CERN configuration

DESY configuration



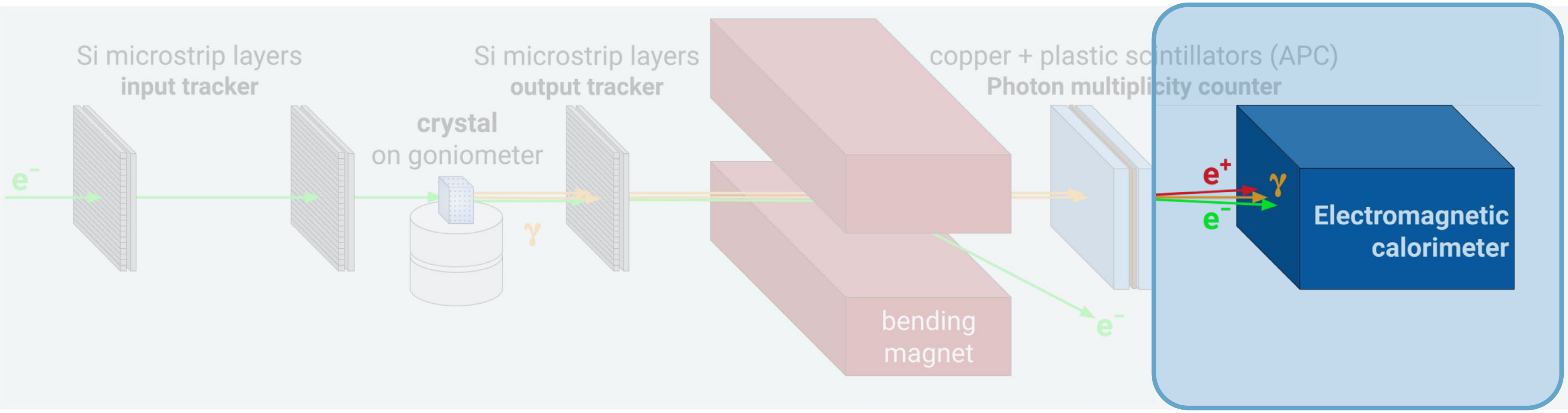
APC + Cu converter

Photon mutiplicity counter

The setup - output stage

CERN configuration

DESY configuration



Radiated energy loss

calorimeter signal

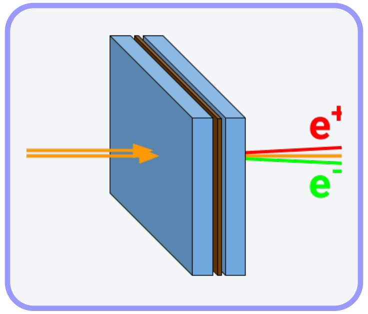
The setup - output stage

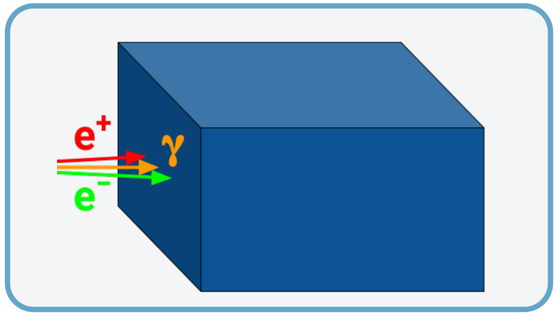
An Active Photon Converter (APC) based on plastic scintillators and thin layers of copper ($0.2X_0$) for photo conversion

Calorimeters consists in

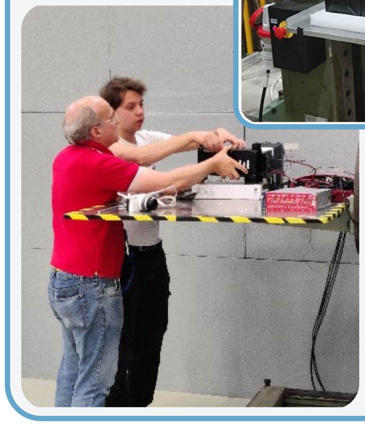
- 3×3 matrix of BGO blocks, PMT-based readout
- (OPAL) Lead glass blocks read out by PMTs

Active Photon Converter (APC)

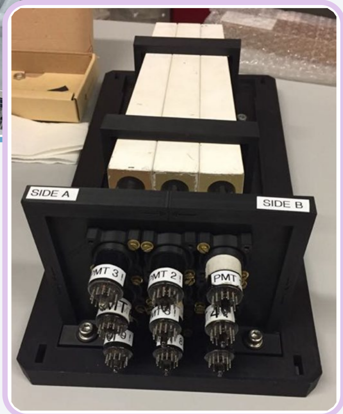




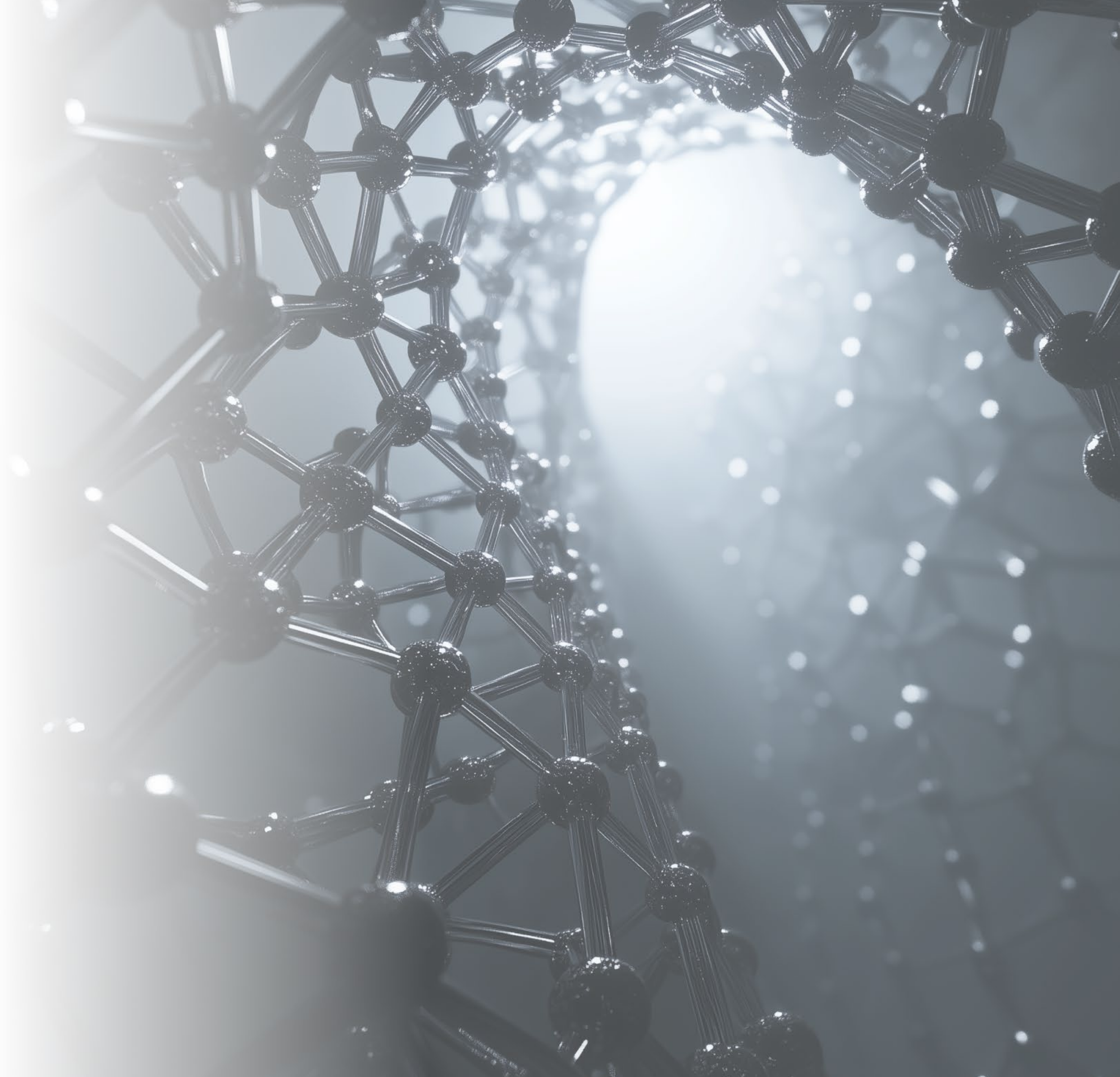
Pb glass calorimeter



BGO calorimeter



TESTBEAM **RESULTS**



DESY T21 line

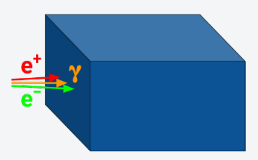
Electron beams at 5.6 GeV/c

W of 2.25 mm (0.64 X0) aligned along <100> axis.

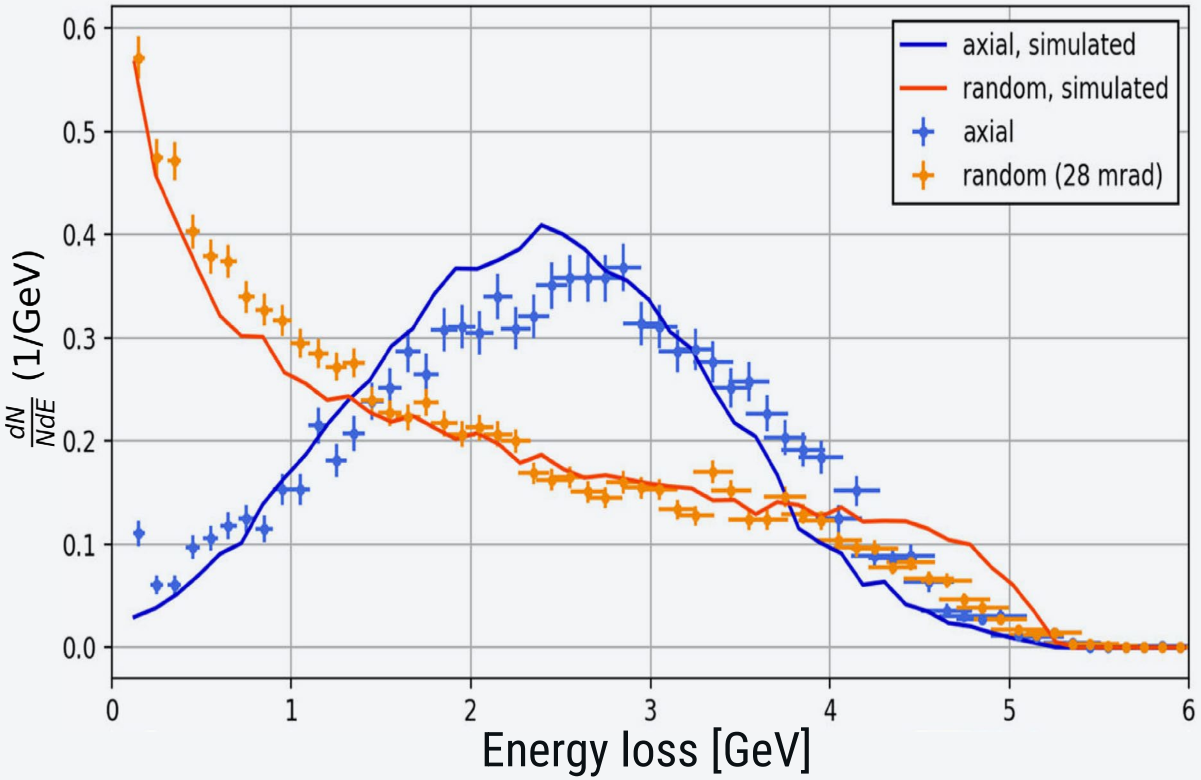
(research center manufactured crystal)

Radiated energy loss

DESY setup configuration



Calorimeter Signal – Energy loss of
W 2.25mm (~0.65X_0) <001>

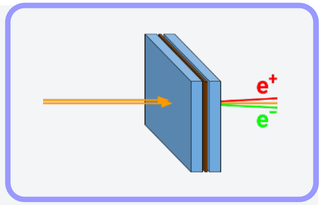


Clear difference in energy loss distribution.
In axial orientation : **peaks above 2.5 GeV**,
In amorphous orientation **it vanishes** as typical for Bremsstrahlung

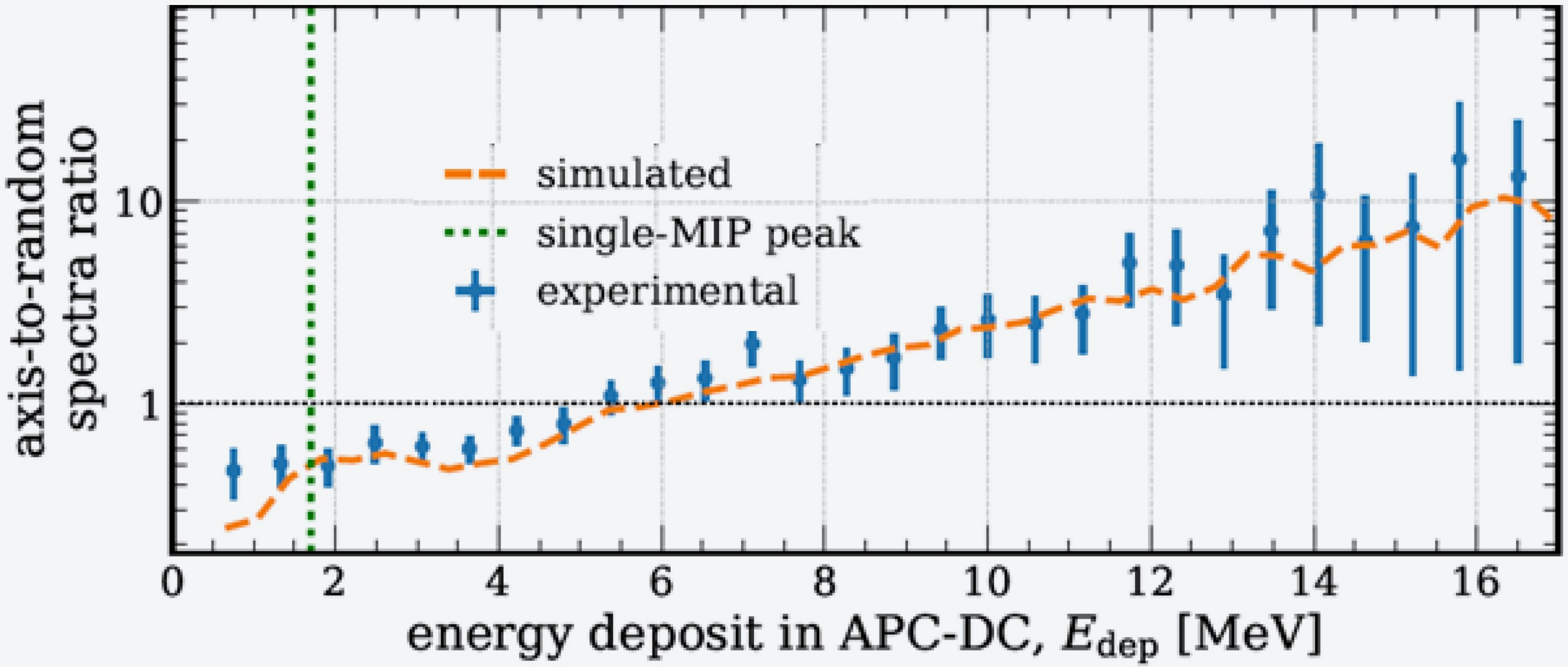
Bandiera et al. [4]

Active Photon Converter (APC)

DESY setup configuration



Active **P**hoton **C**onverter (Photon multiplicity counter)
axial to amorphous signal of W 2.25mm (~0.65X_0) <001>



Clear enhancement of photon production in axial orientation case

Bandiera et al. [4]

CERN PS

Electron beams at 6 GeV/*c*

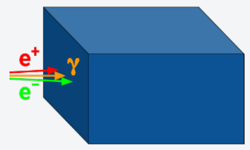
W of 1.5 - 2 mm (0.43 – 0.57 X0) aligned along <111> axis. (industrial manufactured crystals)

Ir of 1 -2 mm (0.34 – 0.68 X0) aligned along <110> axis. (industrial manufactured crystals)

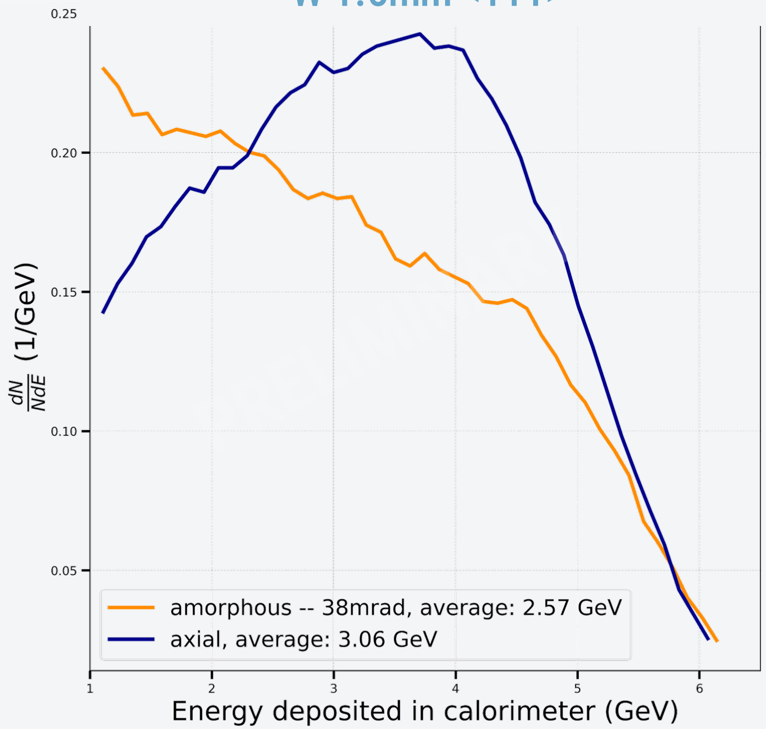
Radiated energy loss

CERN setup configuration

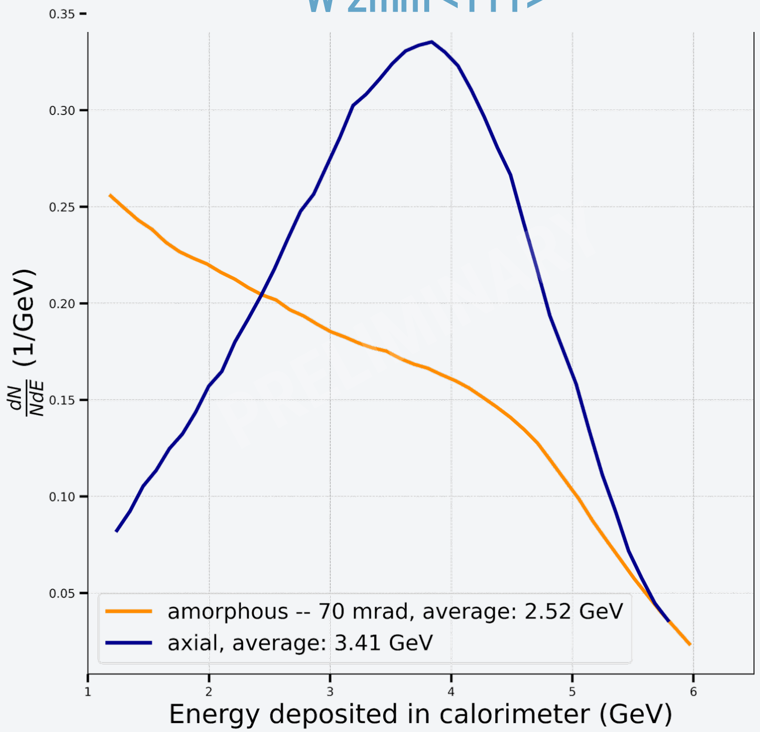
For both the W and Ir aligned along the <111> axes and the <110> axes, respectively, the radiative energy loss distribution **peaks above 3.5 GeV**, while for **amorphous orientation it vanishes** as typical for Bremsstrahlung



Calorimeter Signal
W 1.5mm <111>



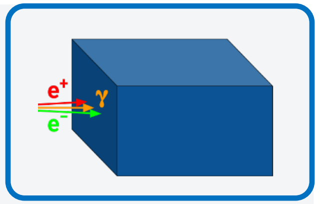
Calorimeter Signal
W 2mm <111>



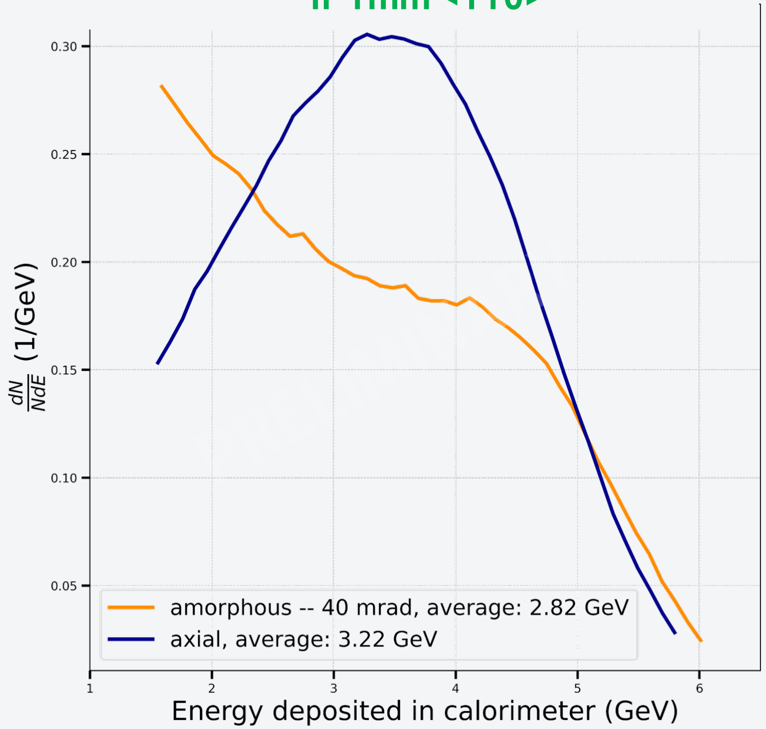
Radiated energy loss

CERN setup configuration

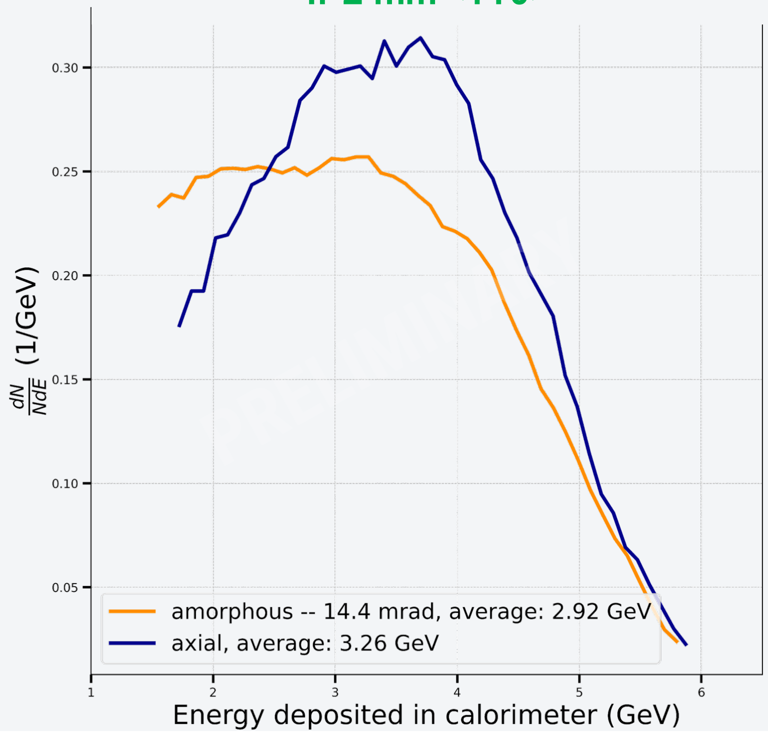
For both the W and Ir aligned along the <111> axes and the <110> axes, respectively, the radiative energy loss distribution **peaks above 3.5 GeV**, while for **amorphous orientation it vanishes** as typical for Bremsstrahlung



Calorimeter Signal
Ir 1mm <110>



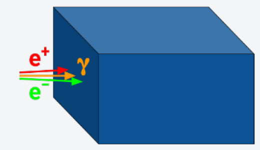
Calorimeter Signal
Ir 2 mm <110>



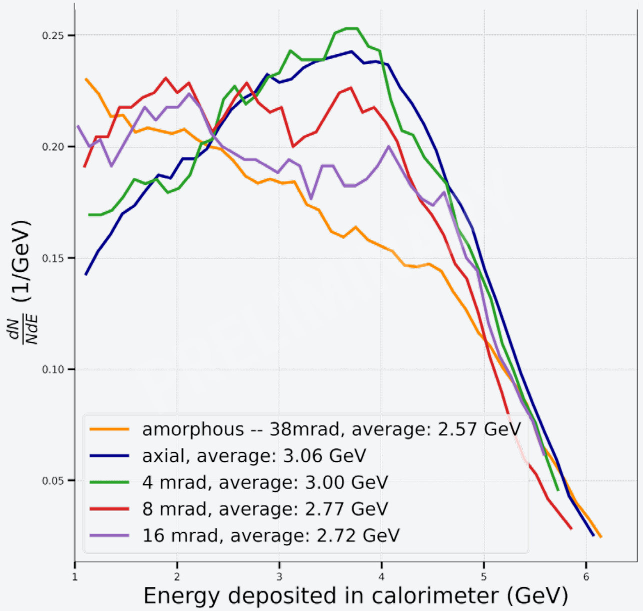
Radiated energy loss - Transition

CERN setup configuration

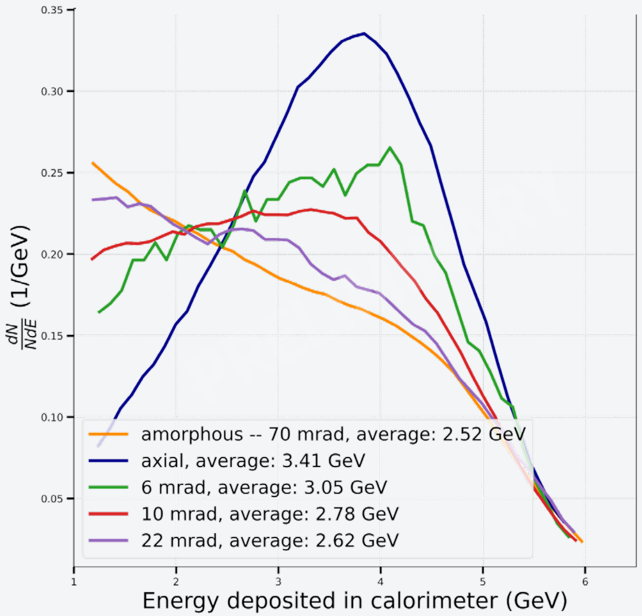
For both the W and Ir aligned along the <111> axes and the <110> axes, respectively, the radiative energy loss distribution **peaks above 3.5 GeV**, while for **amorphous orientation it vanishes** as typical for Bremsstrahlung



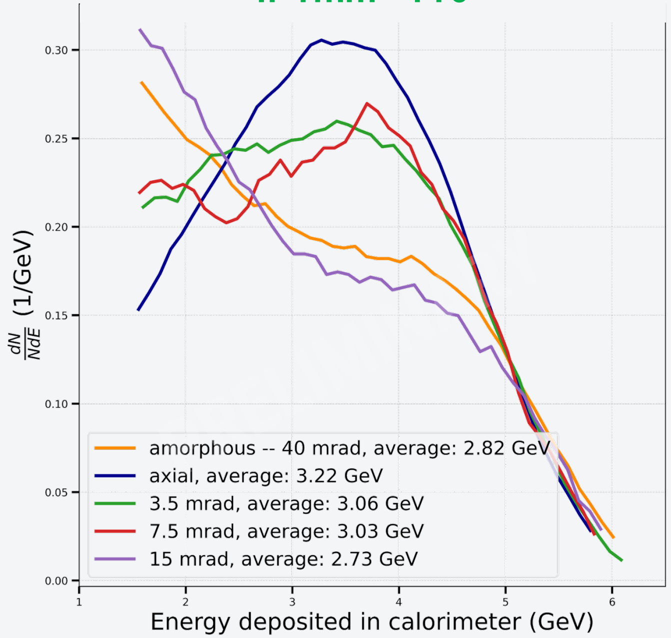
Calorimeter Signal
W 1.5mm <111>



Calorimeter Signal
W 2mm <111>



Calorimeter Signal
Ir 1mm <110>

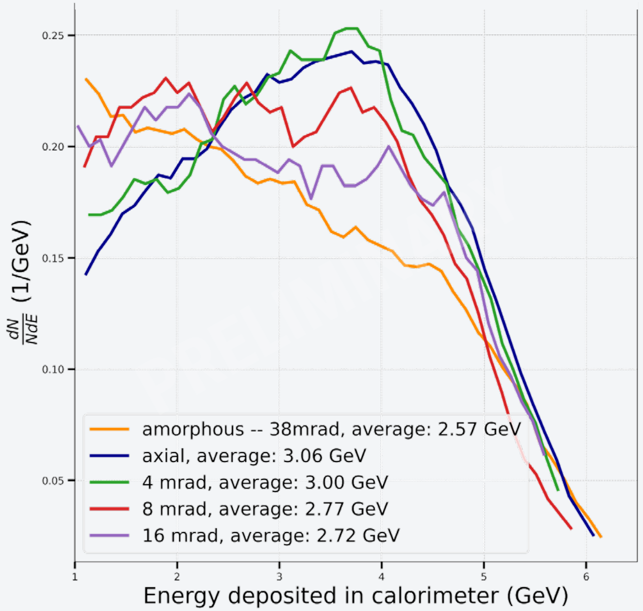


Radiated energy loss - Transition

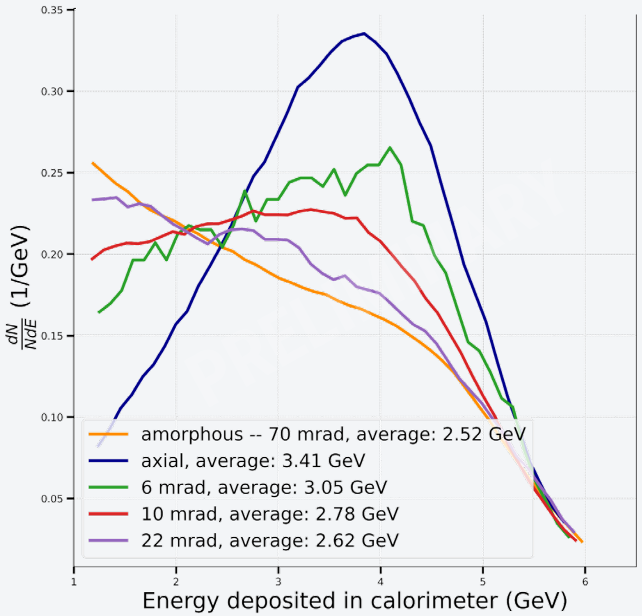
CERN setup configuration

We observed continuous transition from amorphous to aligned mode with the axis, extending 15 mrad, *i.e.* much wider the critical angle (~0.6 mrad).

Calorimeter Signal
W 1.5mm <111>



Calorimeter Signal
W 2mm <111>



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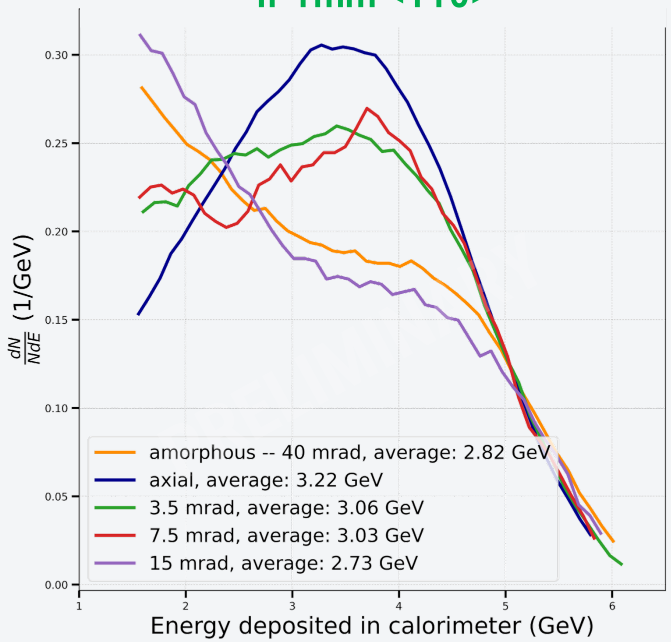
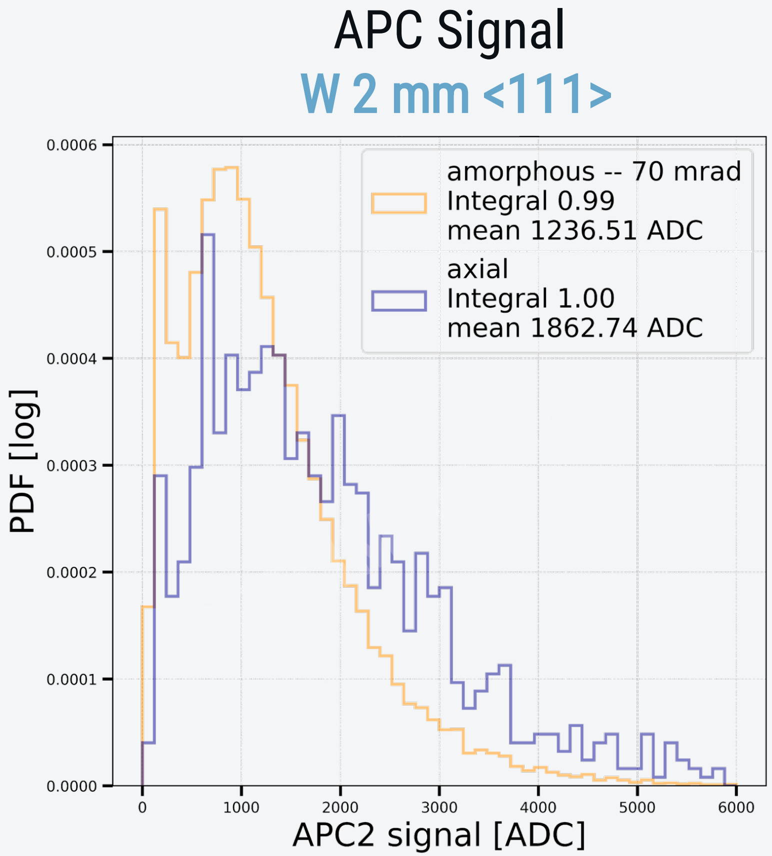
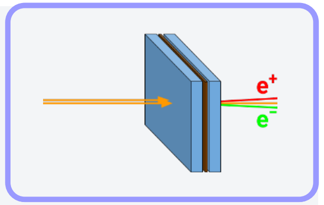


Active Photon Converter (APC)

CERN setup configuration





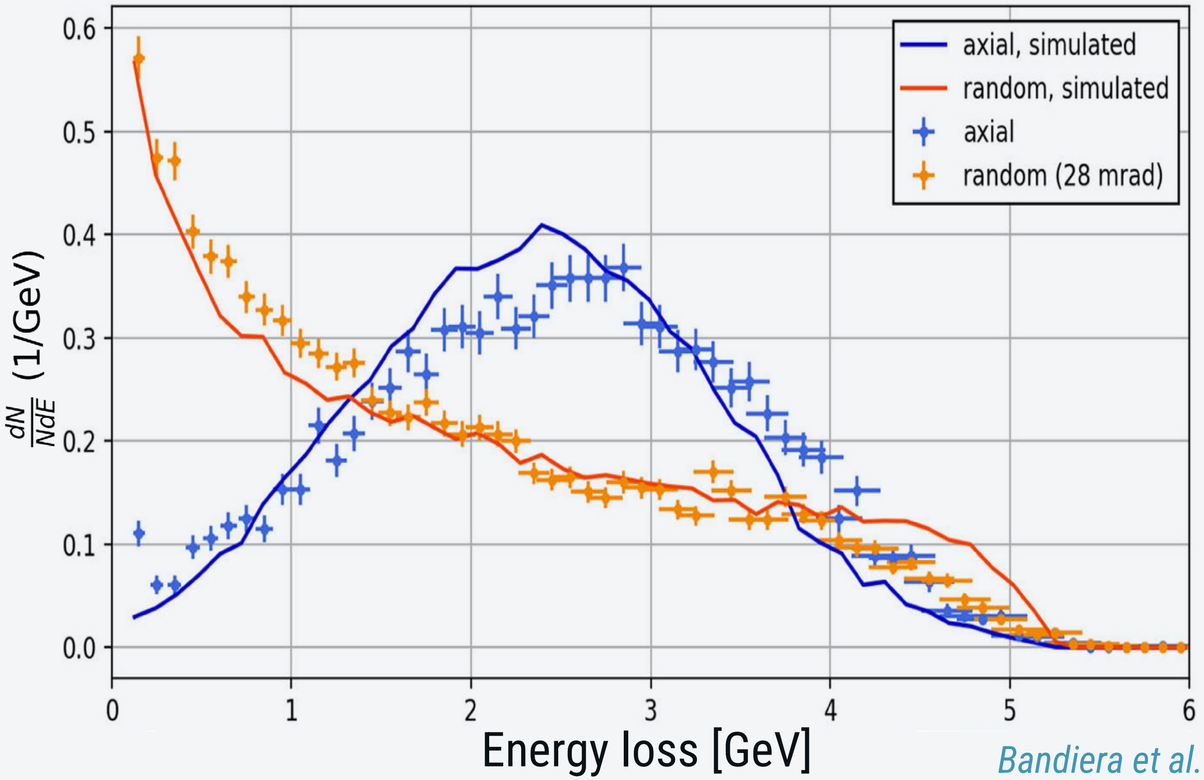
Clear enhancement of the energy deposited in the second scintillator, thus **more photon production** in axial orientation case

SIMULATION CODE **VALIDATION**

Our simulation code **WORKS !**

DESY setup configuration

Calorimeter Signal – Energy loss of
W 2.25mm (~0.65X_0) <001>



Bandiera et al. [4]

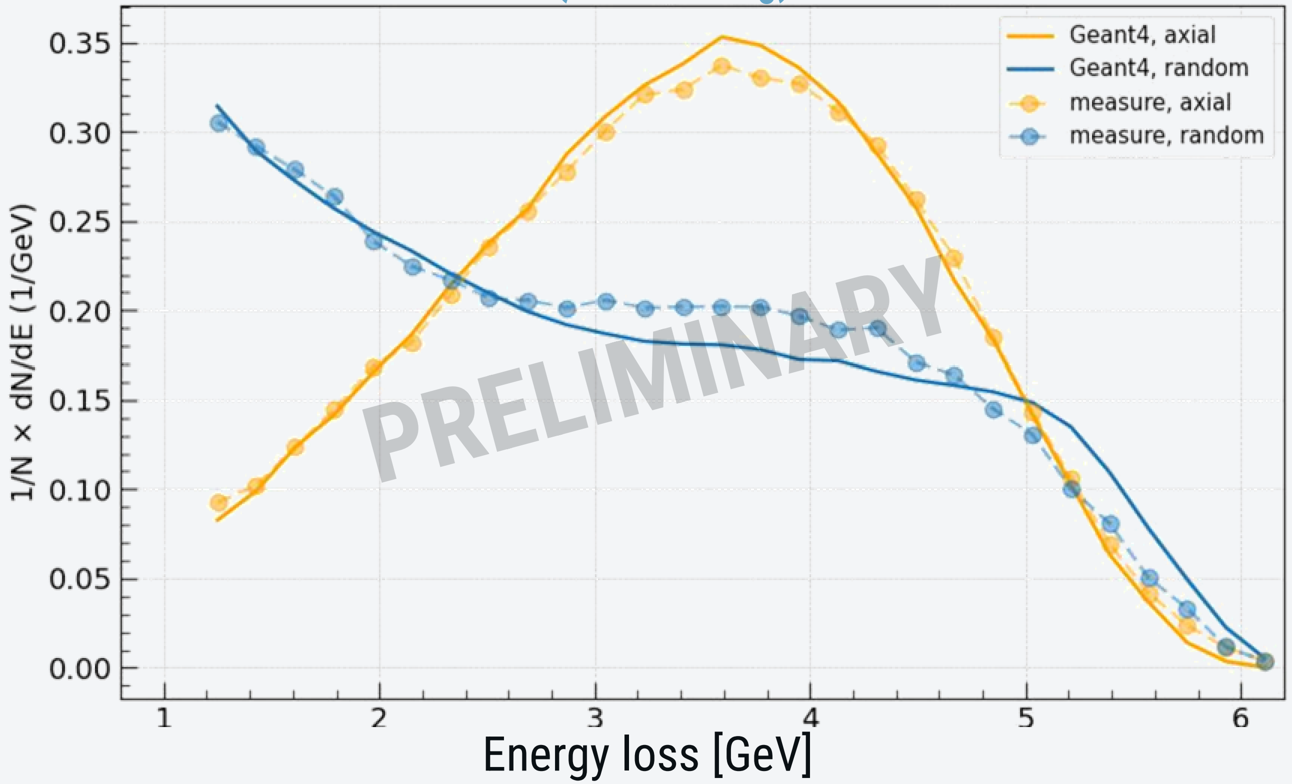
The results from beam tests conducted at DESY and CERN PS **agrees** with the Monte Carlo simulation:

- The whole setup was simulated using the Geant4 toolkit with the new *G4ChannelingFastSim* library *A. Sytov et al. [5 – 6]*
- The output file encompassing all secondary γ and $e^{\pm}$ particles considers the interactions within the entire experimental setup. *Bandiera et al. [4]*

Our simulation code **WORKS !**

CERN setup configuration

Calorimeter Signal – Energy loss of W 2mm (~$0.57X_0$) <111>



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CERN setup configuration

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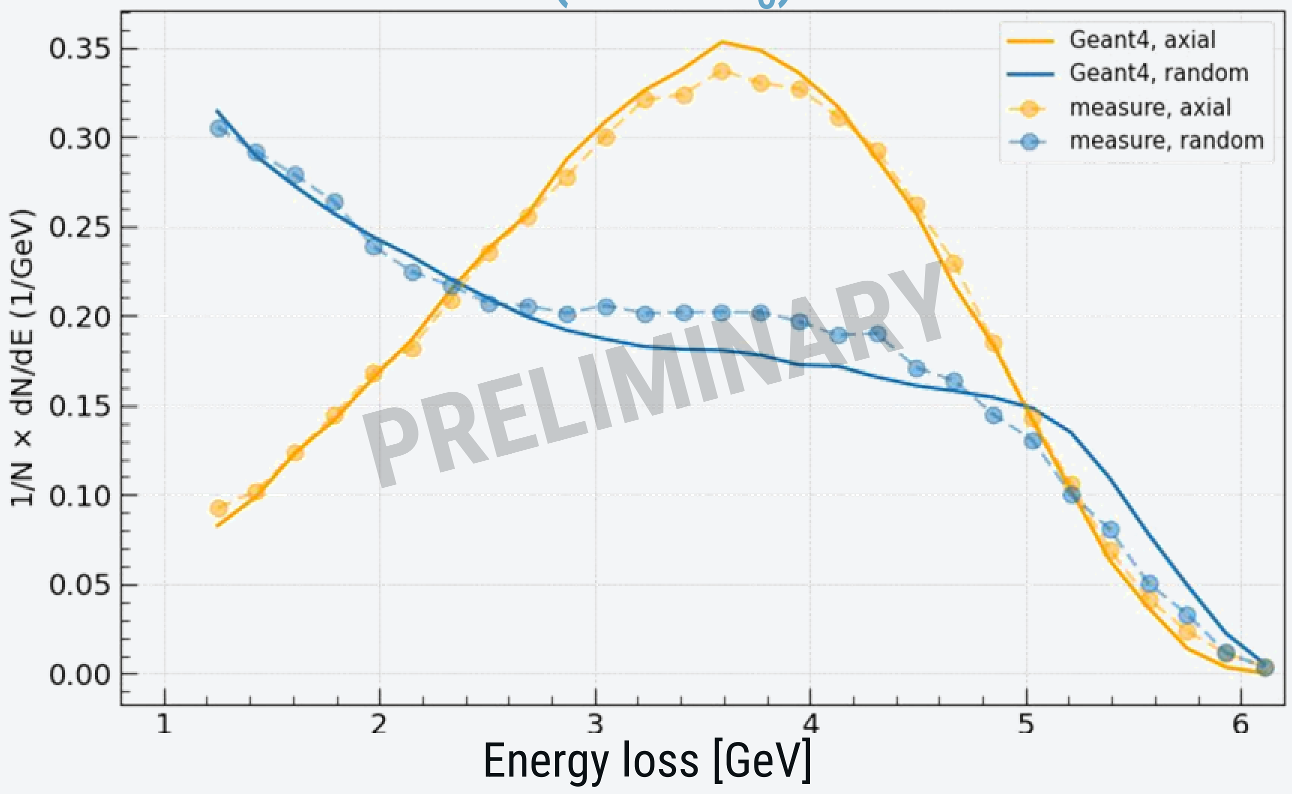

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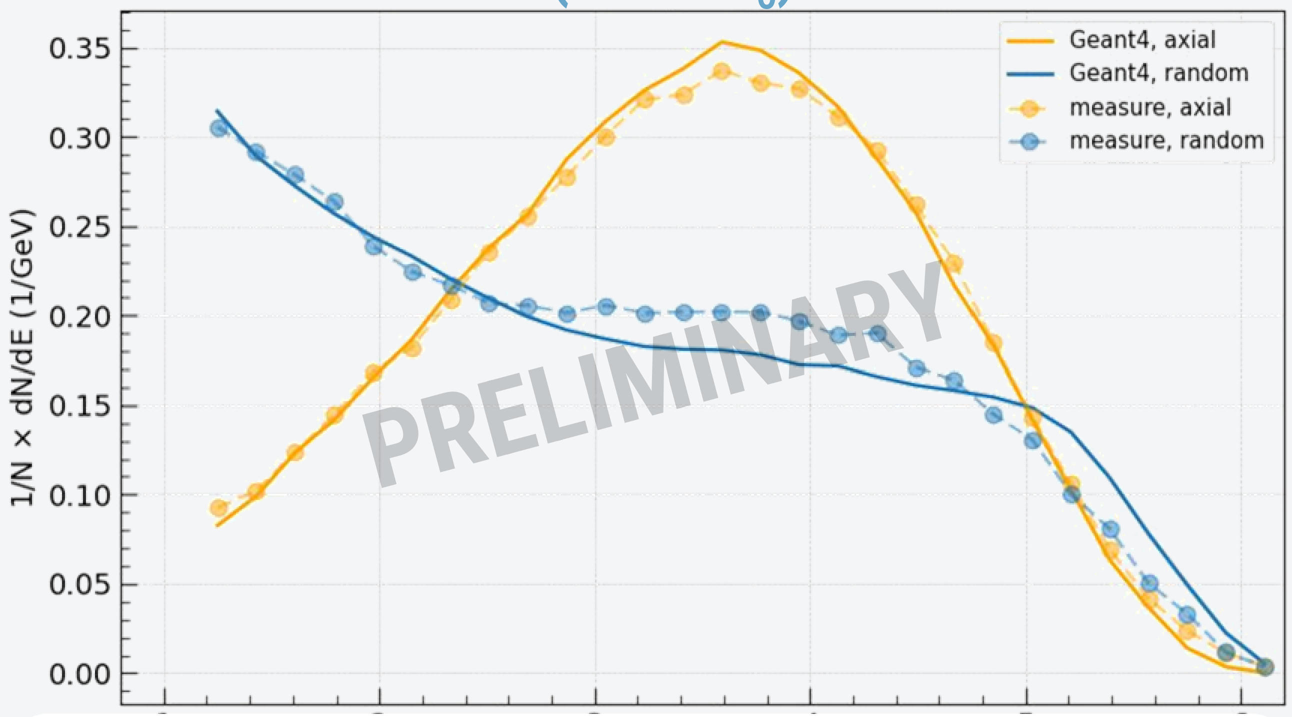
Once the **simulation environment was validated** against experimental findings, efforts were directed towards optimizing the FCC-ee positron source scheme.

Parameters chosen for the FCC-ee positron source optimization via Geant4

Our simulation code **WORKS !**

CERN setup configuration

Calorimeter Signal – Energy loss of W 2mm ($\sim 0.57X_0$) <111>



As seen in A. Sytov and G.Paternò talks of 05/11/2024

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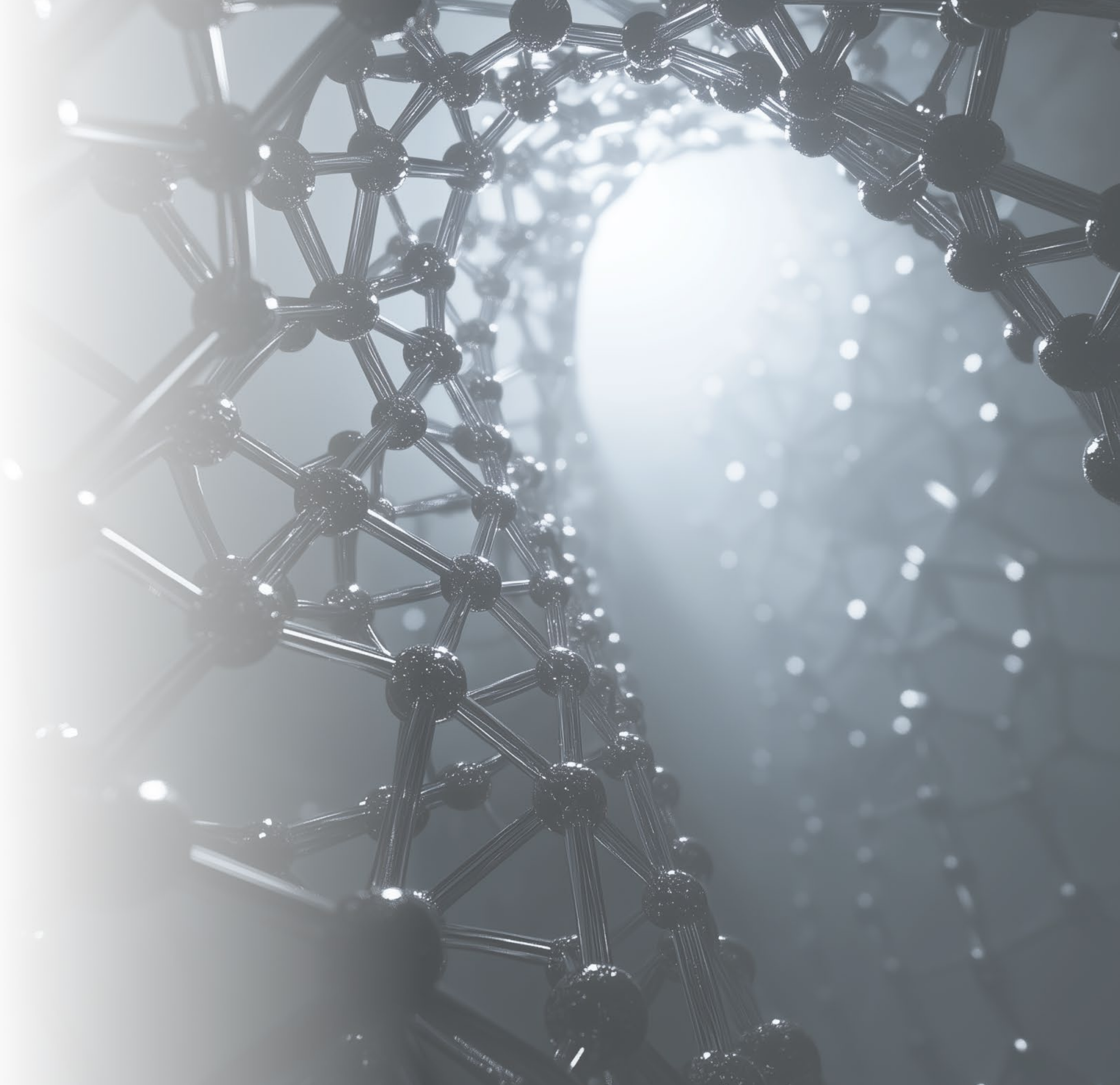
FUTURE PERSPECTIVE



Future Perspective

- Comparison with simulations:
  - W 1.5 mm
  - Ir
- Optimization of the hybrid source for 2.86 GeV/c

- Future test at CERN PS
  - New energy baseline (e^- 2.86GeV/c)
  - Single crystal

Future Perspective

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  - W 1.5 mm
  - Ir
- Optimization of the hybrid source for 2.86 GeV/c

- Future test at CERN PS
  - New energy baseline (e^- 2.86GeV/c)
  - Single crystal

Optimization of hybrid and single crystal including test of radiator converter for CHART P3 project

ncanale@fe.infn.it

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Iryna Chaikovska (IJCLab)
iryna.chaikovska@ijclab.in2p3.fr

References and Aknowledgment

References:

[1] Frank Zimmermann, FCC Week 2024 10-14 June

[2] R. Chehab et al., NIM B 266 (2008)

[3] X. Artru, I. Chaikovska, R.Chehab *et al*. NIM B 355 (2015)

[4] L. Bandiera *et al*., Eur. Phys. J. C 82 (2022)

[5] A. Sytov *et al.* Phys. Rev. Accel. Beams 22 (2019)

[6] A. Sytov *et al.* JKPS 83 (2023)

Acknowledgement:

We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Call for tender No. 104 published on 02.02.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU – Project Title : "*Intense positron source Based On Oriented crySTals - e+BOOST*" 2022Y87K7X– CUP I53D23001510006

e+BOOST PRIN2022- 2022Y87K7X

Bando PRIN 2022

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

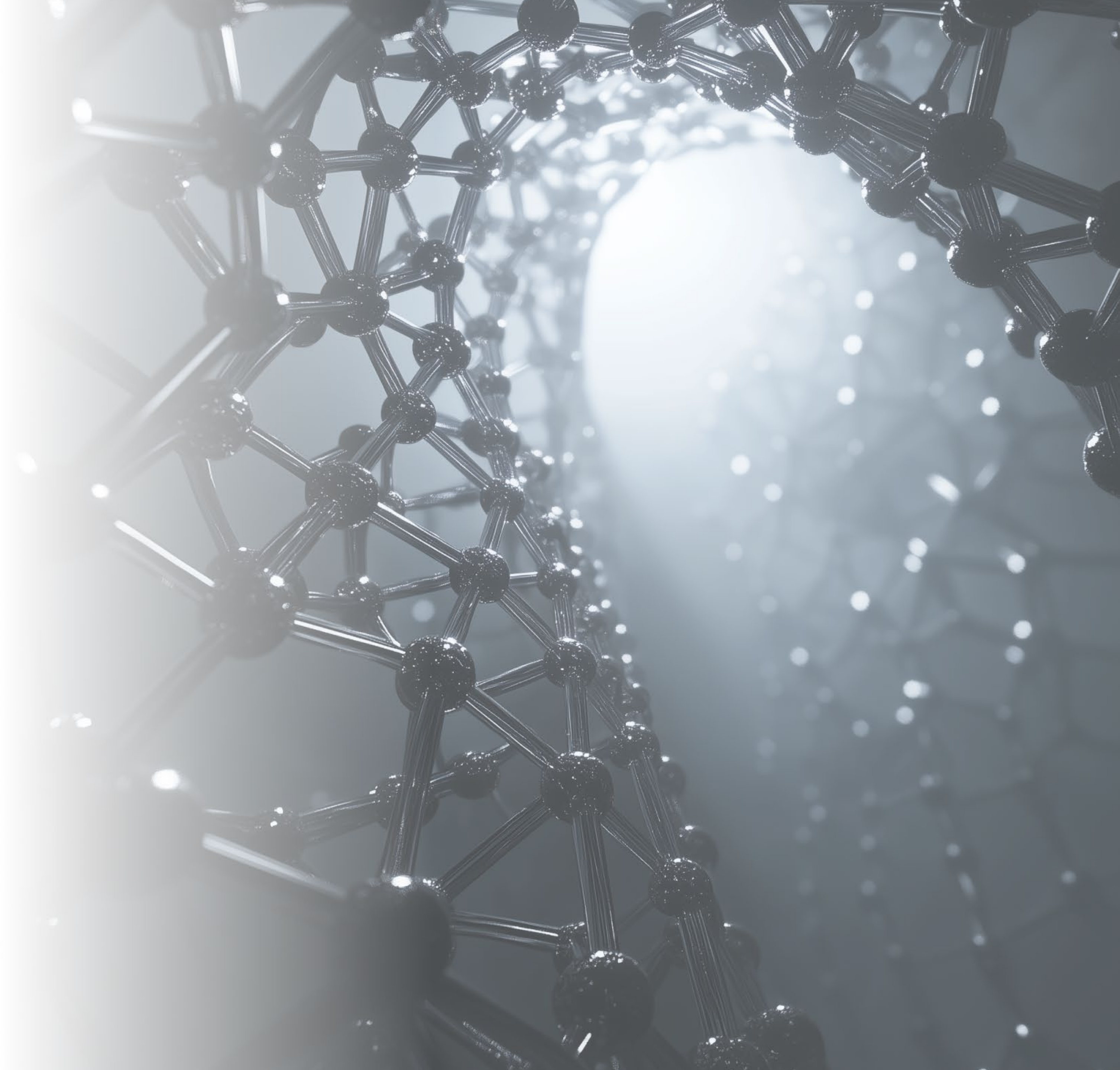
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

EIC-PATHFINDER-OPEN TECHNO-CLS (GA 101046458)

Marie Curie Global Fellowships, Project TRILLION GA n. 101032975

GA No ANR-21-CE31-0007

BACKUP

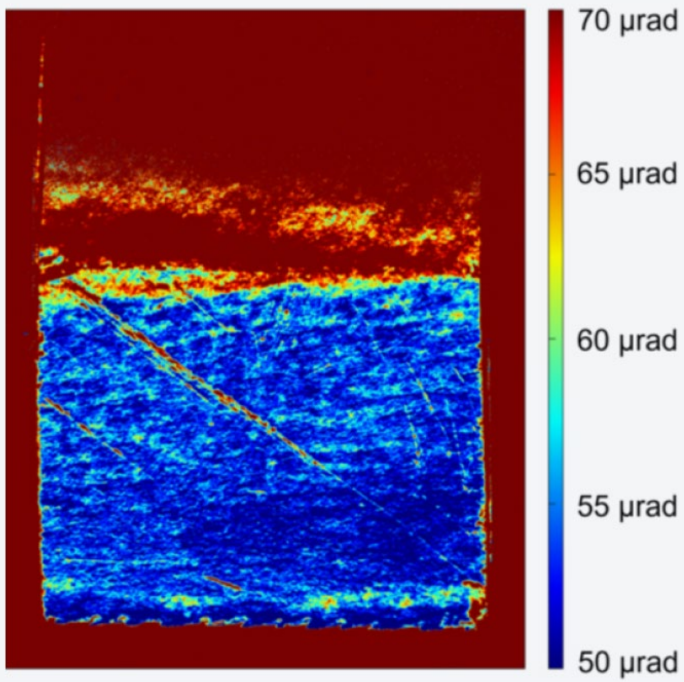


CRYSTAL
CHARACTERIZATION

Research center crystals quality check

ESRF
The European Synchrotron

W 2.25mm
(~0.65X_0)
<001>



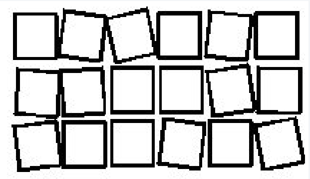
Imaging of the sample mosaicity measured at BM05 beamline of ESRF.

Color indicates the mosaicity of the sample

Characterization of mosaicity of the lattice performed at **ESR Syncrothron** (Grenoble, France)
(20 keV X rays)

Mosaicity **≤ 60 µrad**.

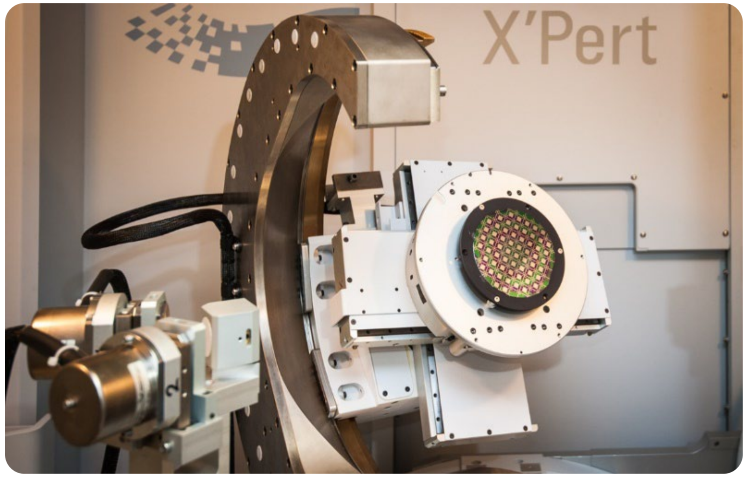
largest mosacity are still below 150 µrad near the scraches

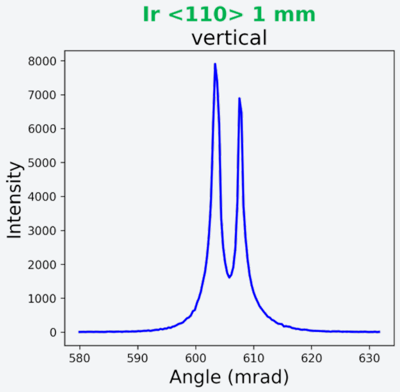


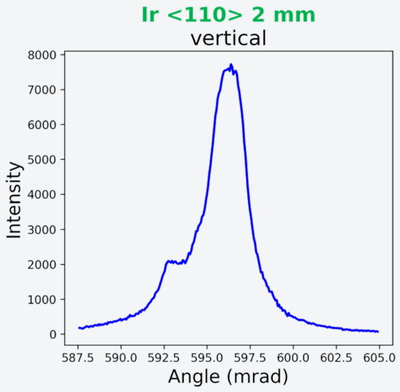
*In crystallography, the **mosaicity** is a measure of the spread of crystal plane orientations*

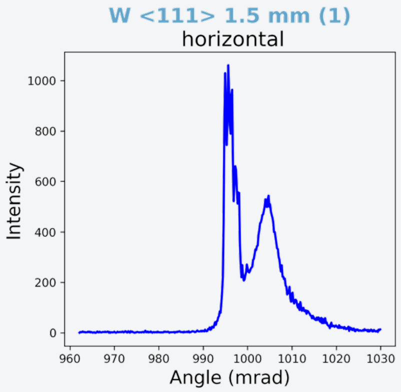
Industrial crystals quality check

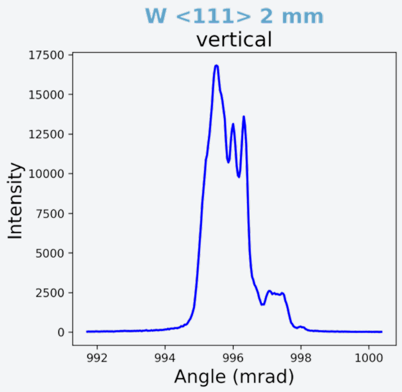
Characterization of superficial mosaicity of the lattice performed with High Resolution XRD at laboratories of Ferrara (@ 8.04 keV)











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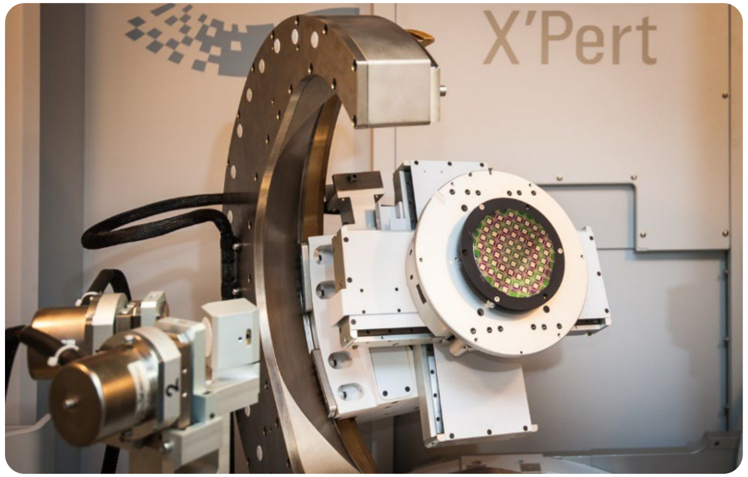
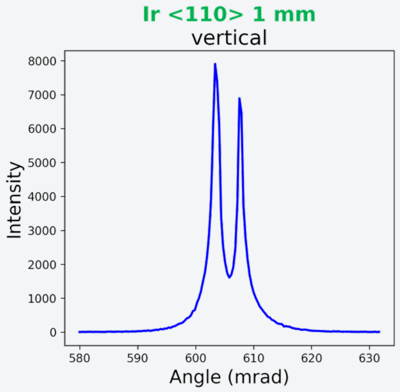
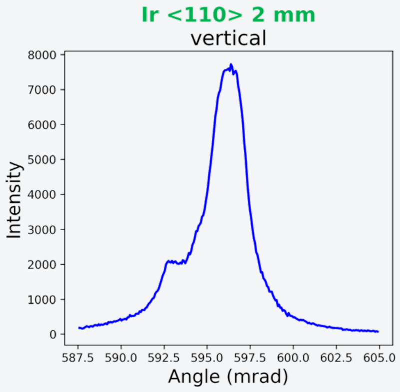
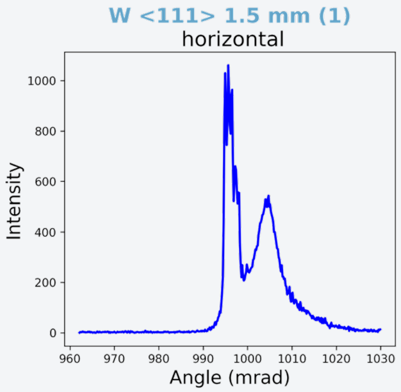
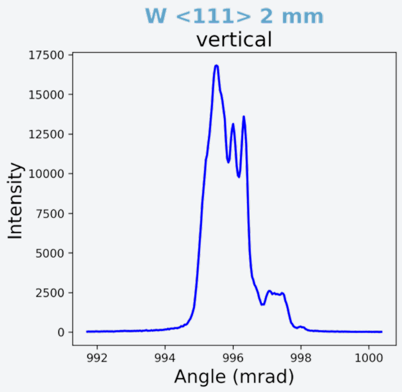


FWHM of industrial crystal is wider than the critical angle, **the coherent effects are still available?**

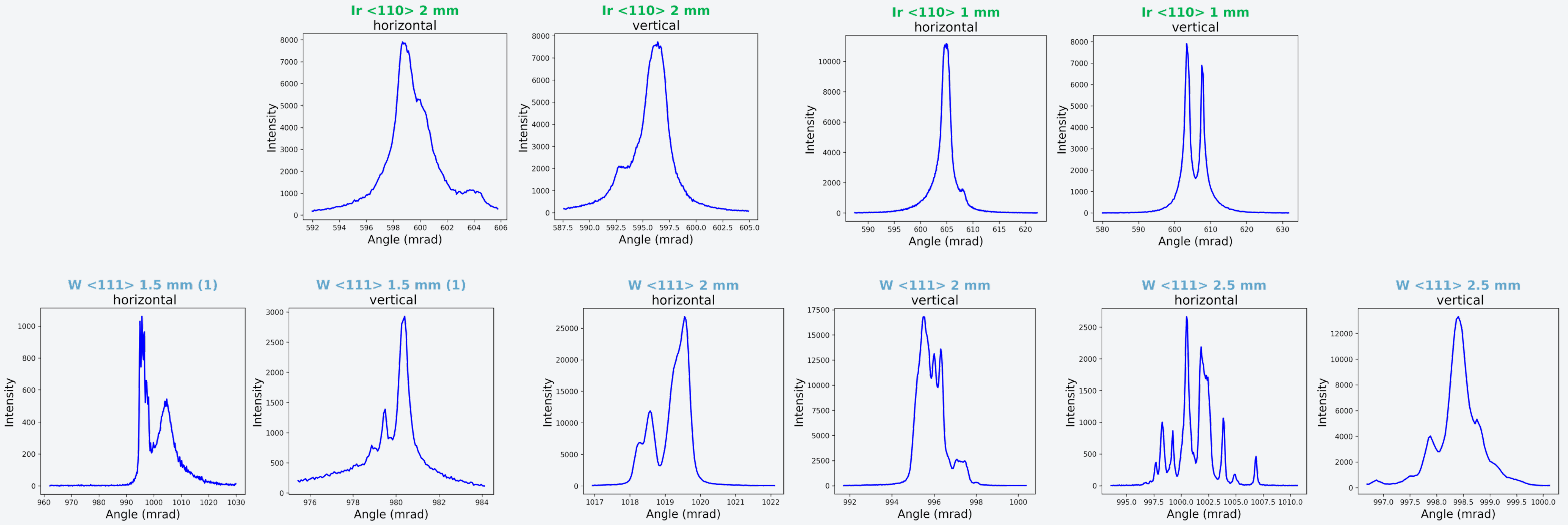


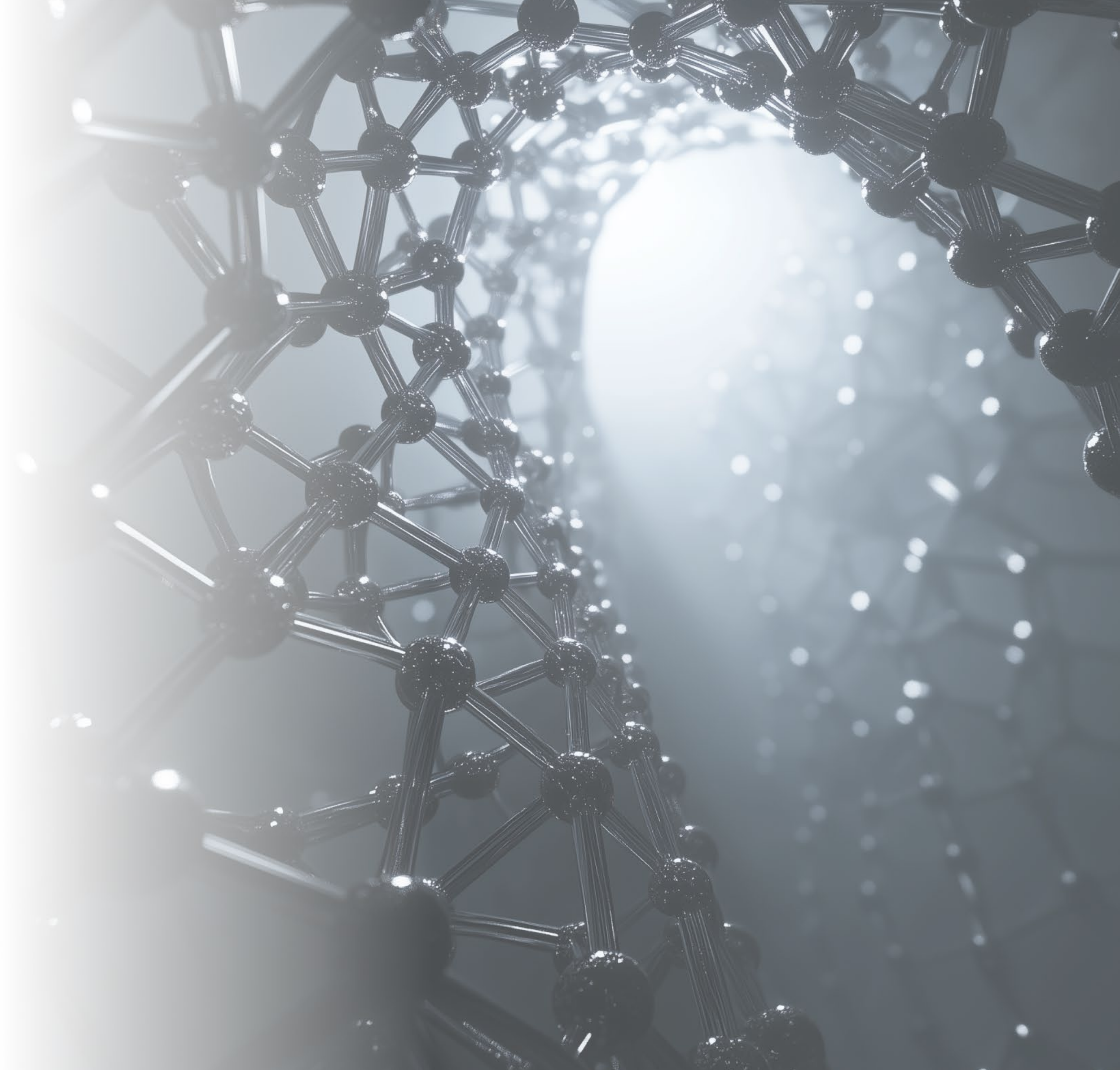






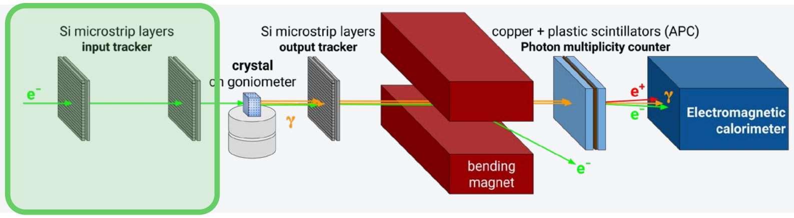
Summary of HRXRD test for CERN samples





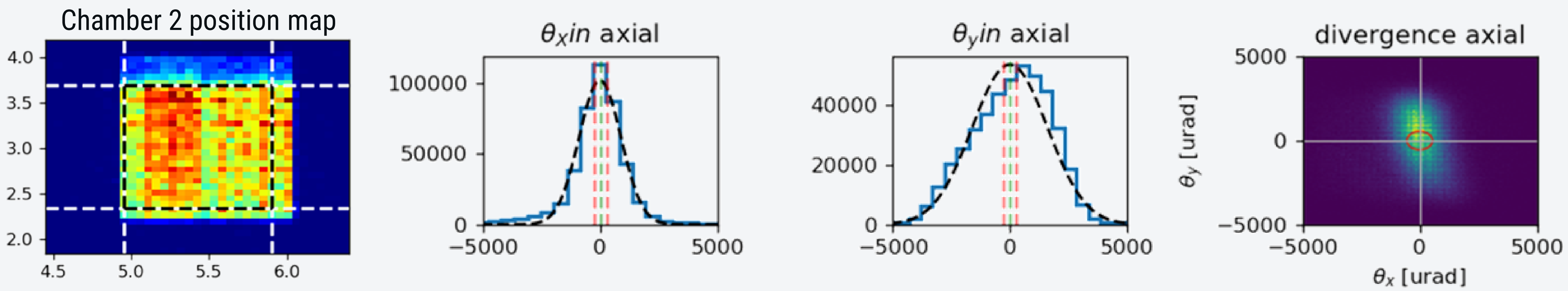
INPUT
TRACKERS

The setup



Input stage

Reconstruct track and impinging angle on the crystal

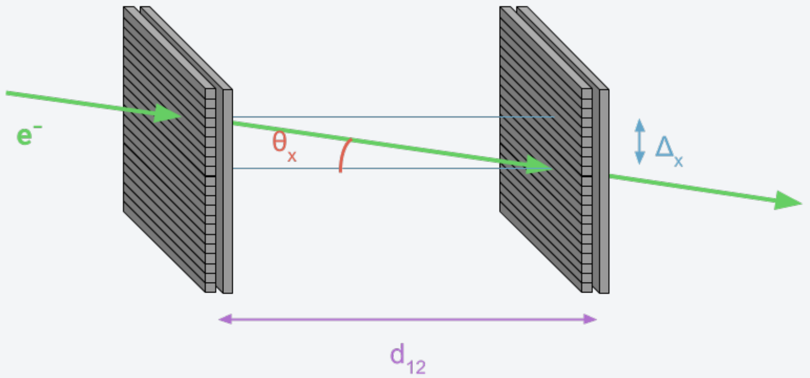


Hit position on Chamber weighted by Calo signal

input tracker

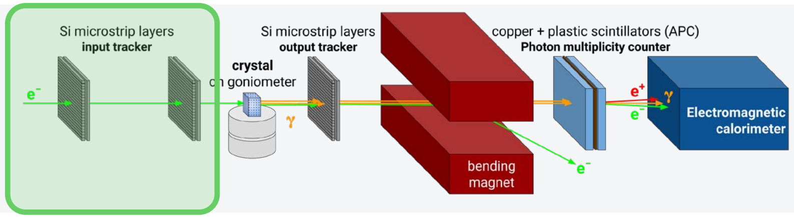
~2 × 2 or 9.5 × 9.5 cm² *xy* double-sided Si microstrip sensors, with an overall ~10 μm single-hit resolution self-triggering on strip to select the proper area

ϑ_{IN} reconstructed at crystal entrance



$$\vartheta_x = \arctan(^{\Delta x}/_{d_{12}})$$

The setup



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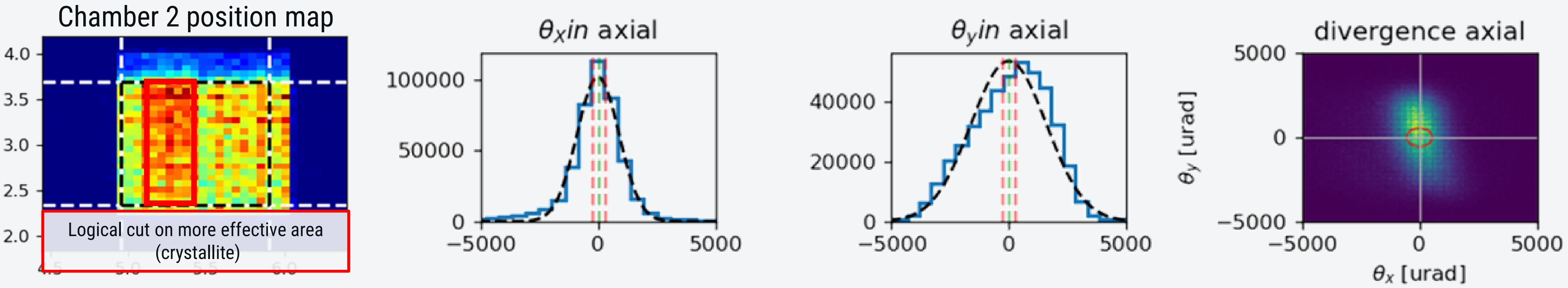

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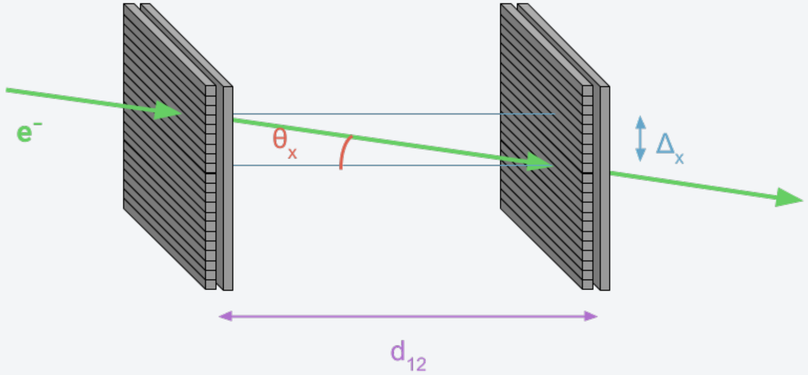

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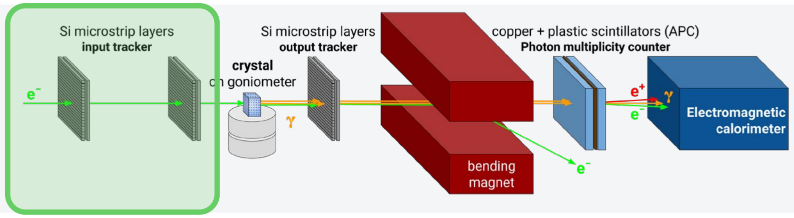

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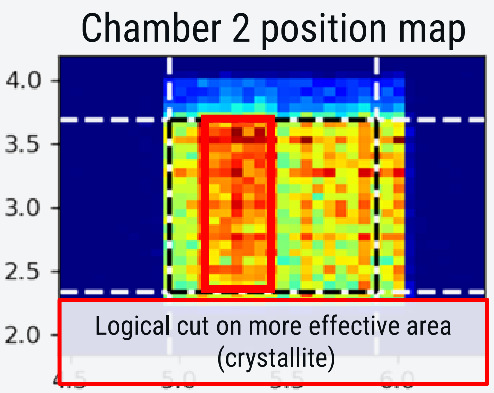

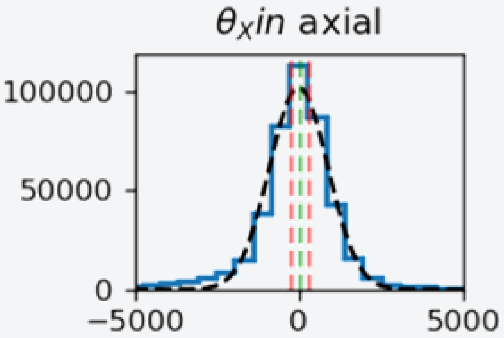

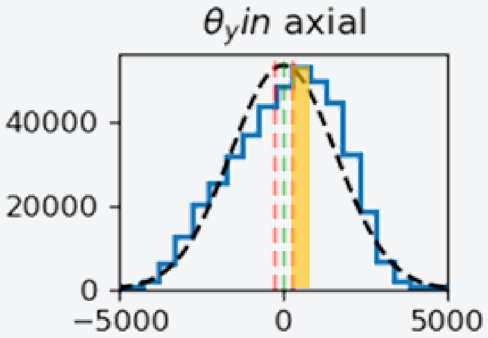

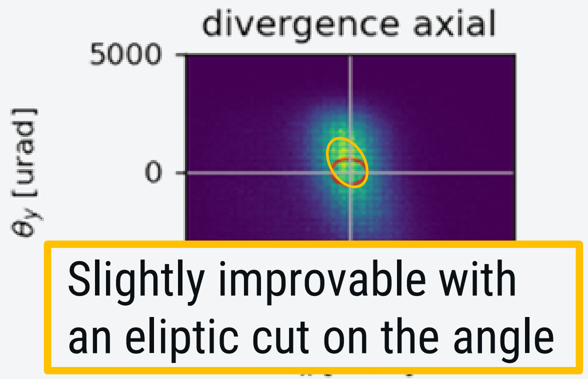

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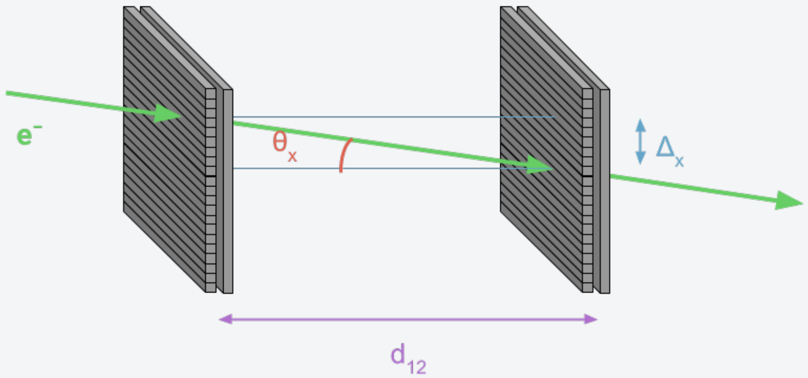
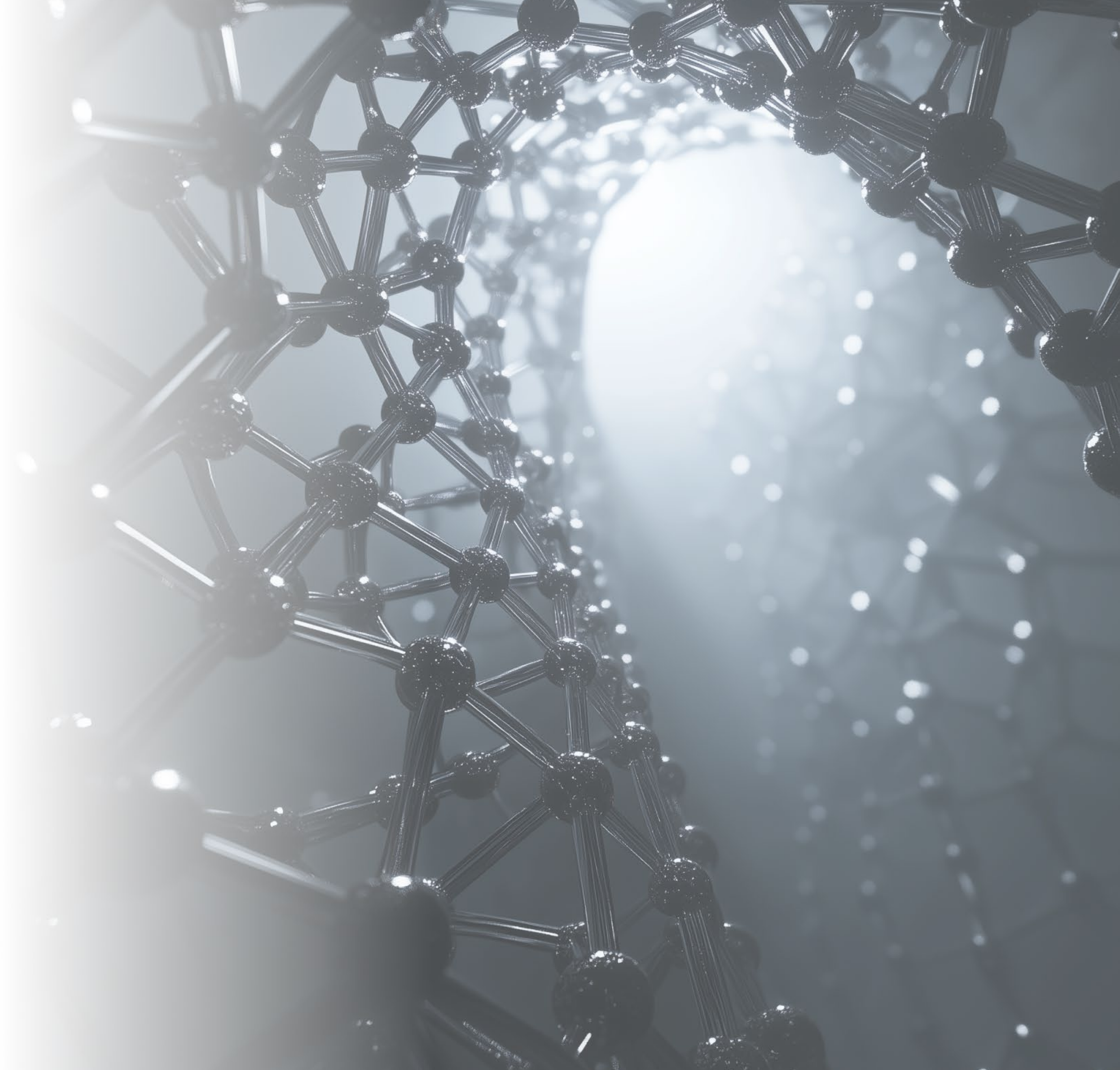
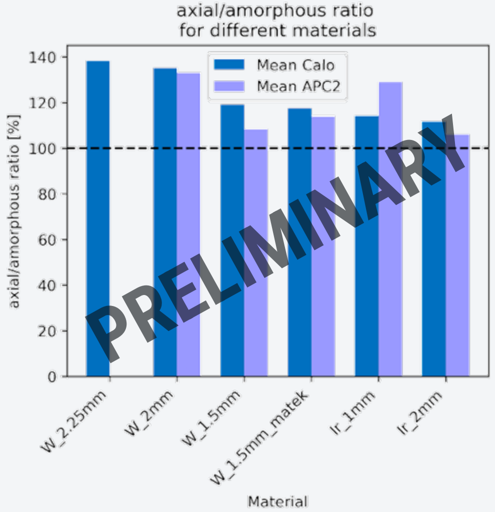


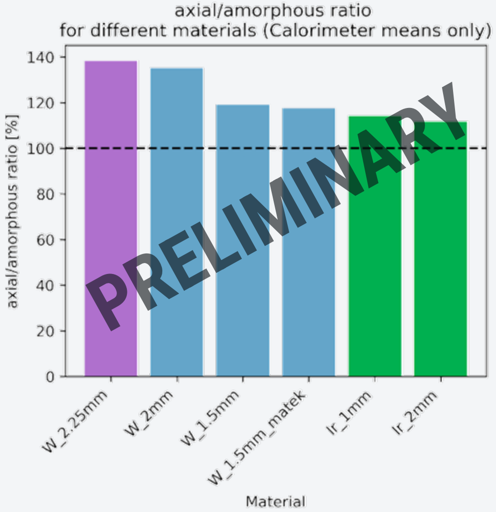
$$\vartheta_x = \arctan({}^{\Delta x}/_{d_{12}})$$

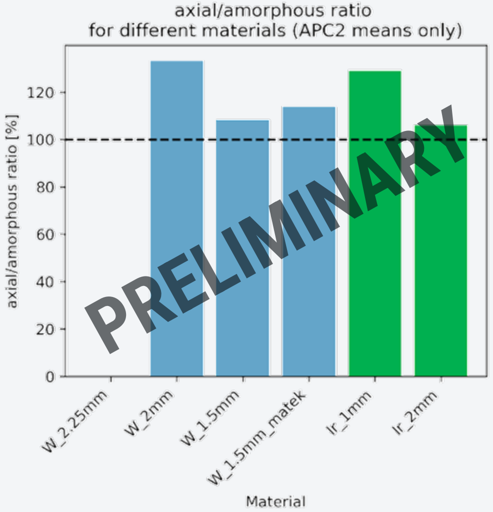
RESULTS **SUMMARY**



Summary







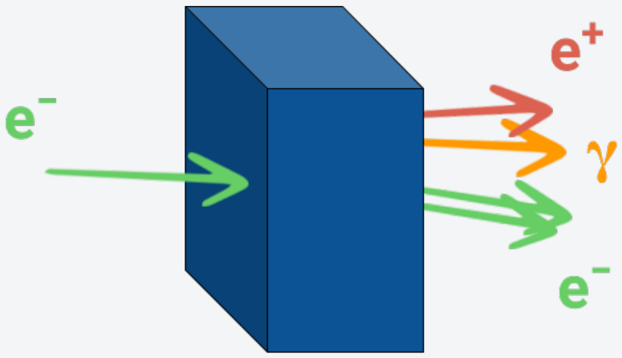
Material	Axial/amorph Calo	Axial/amorph APC2
Ir_1mm <110>	~114 %	~129 %
Ir_2mm <110>	~112 %	~106 %
W_1.5 mm <111>	~119 %	~108 %
W_2mm <111>	~ 135 %	~133%
W_2.25 <100>	~138%	Not calculated

CONVENTIONAL
e^+ SOURCE PROBLEMS

Conventional scheme limitations

As seen
in A.Sytov and
G.Paternò talks

Conventional scheme

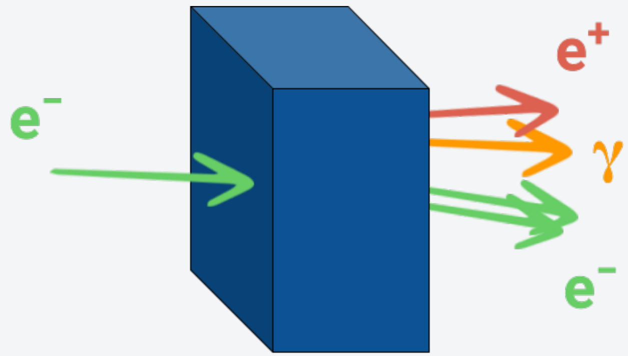


Thick amorphous
target

Conventional scheme limitations

As seen in A.Sytov and G.Paternò talks

Conventional scheme



Thick amorphous
target

Current (Limited by the target)

- Average energy deposition
  → target heating/melting

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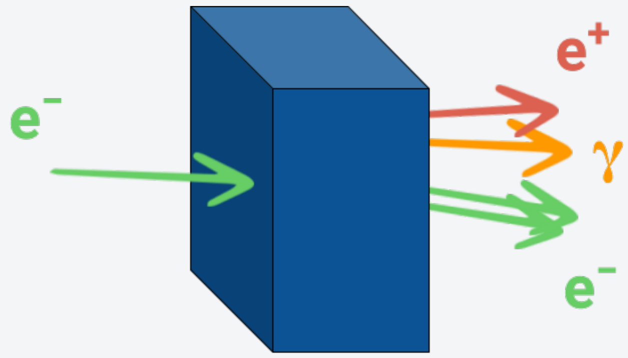
As seen in A.Sytov and G.Paternò talks

Conventional scheme



Thick amorphous target

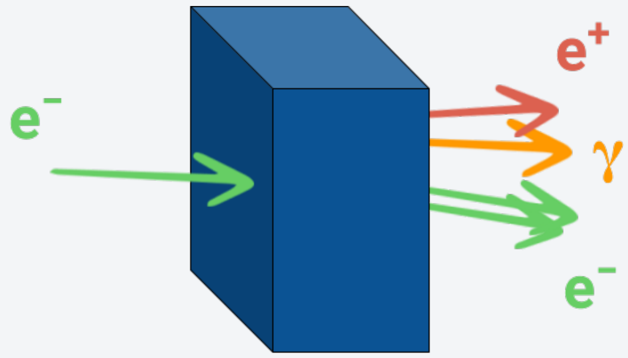
Current (Limited by the target)

- Average energy deposition
  → target heating/melting
- Peak Energy Deposition Density (**PEDD**)
  → Inhomogeneous and instantaneous energy deposition, that cause thermomechanical stresses due to temperature gradient

Conventional scheme limitations

As seen in A.Sytov and G.Paternò talks

Conventional scheme



Thick amorphous target

Current (Limited by the target)

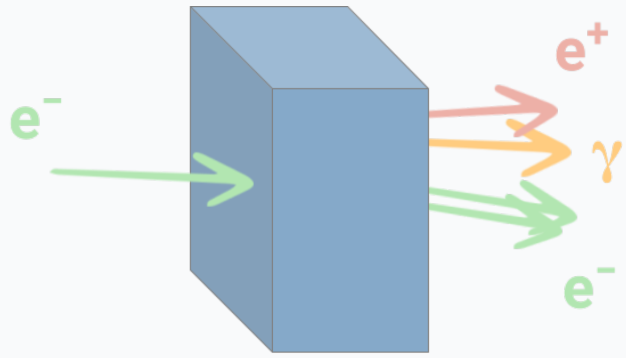
- Average energy deposition
  → target heating/melting
- Peak Energy Deposition Density (**PEDD**)
  → Inhomogeneous and instantaneous energy deposition, that cause thermomechanical stresses due to temperature gradient

e^+ source set a critical constraint for the peak and average current → **Luminosity Constraint!**
Expecially for future Linacs

Hybrid crystal based positron source for e^-e^+colliders

Idea of R. Chehab, A. Variola, V. Strakhovenko and X. Artru [3]

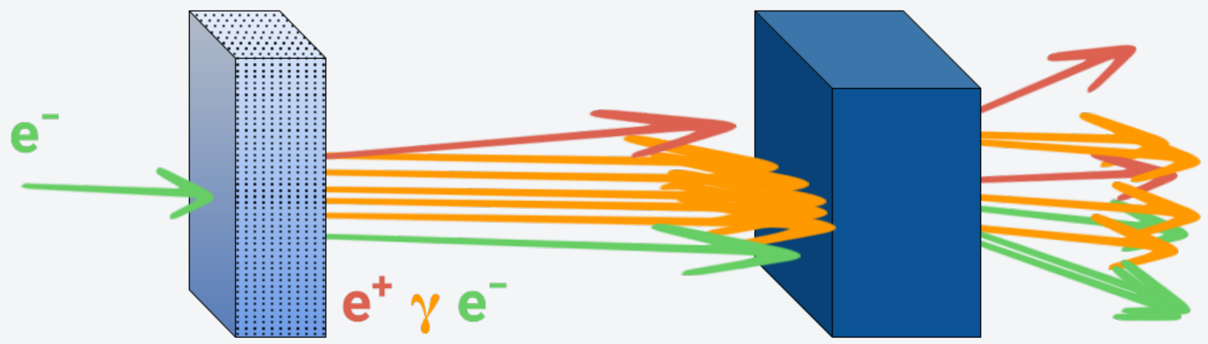
Conventional scheme



Thick amorphous
target

Problem in future Linacs

Hybrid positron source



“Thin” oriented crystalline target (< X_0)
photon radiator

Amorphous
target-converter

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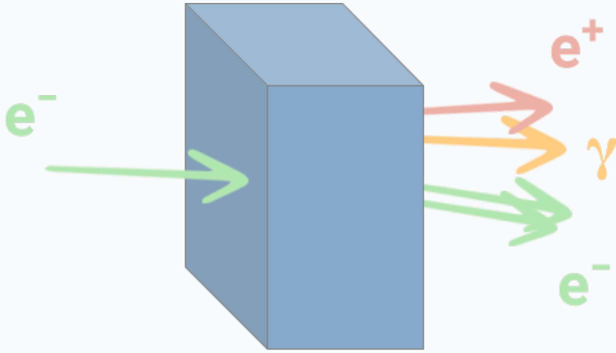

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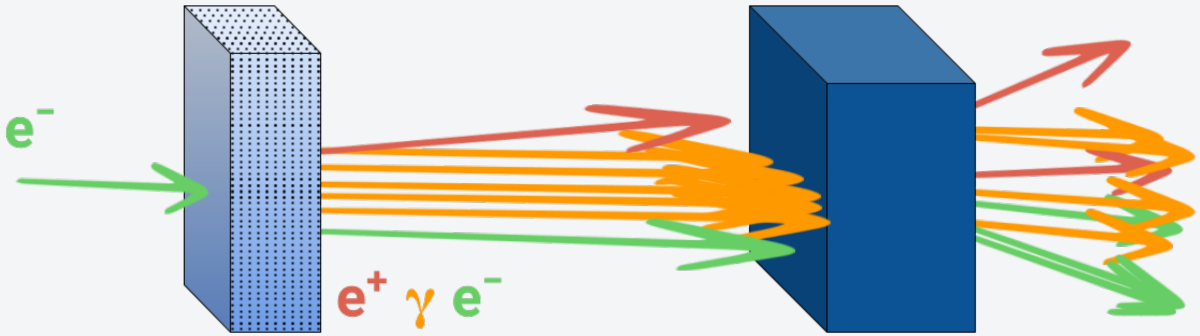


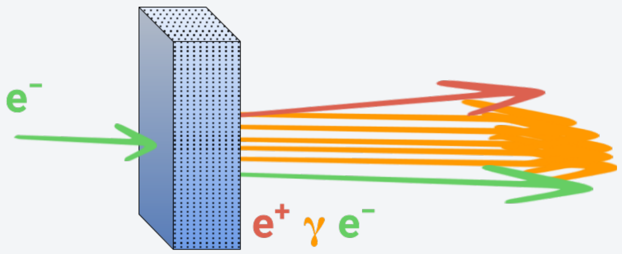
"Thin" oriented crystalline target (< X_0)
photon radiator

Amorphous
target-converter

"Thin" crystal radiator, with thickness < X_0 will limit the heating, enhance the radiation and thus increase the target reliability

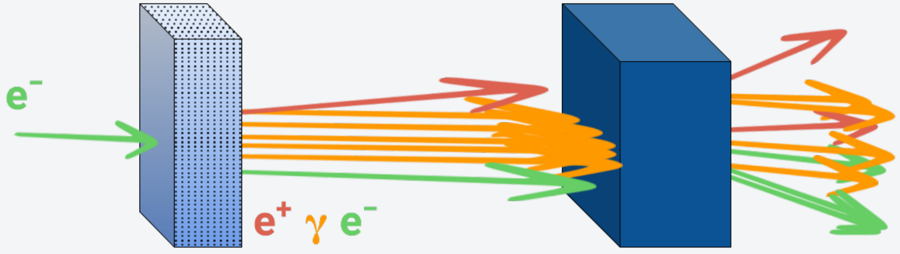
Coherent effects for crystal-based positron sources

Crystalline photon radiator



"Thin" oriented crystalline target (< X_0)
photon radiator

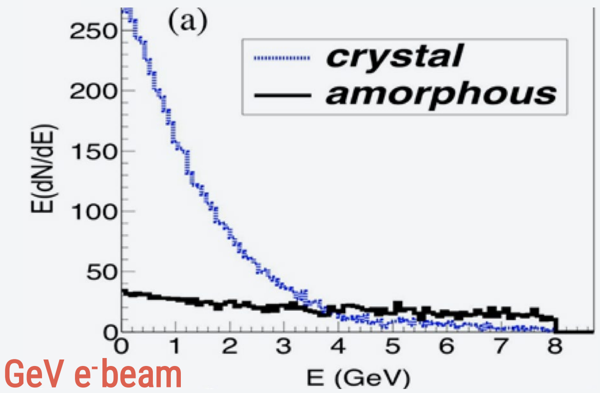
Hybrid positron source



"Thin" crystal (< X_0)
photon radiator

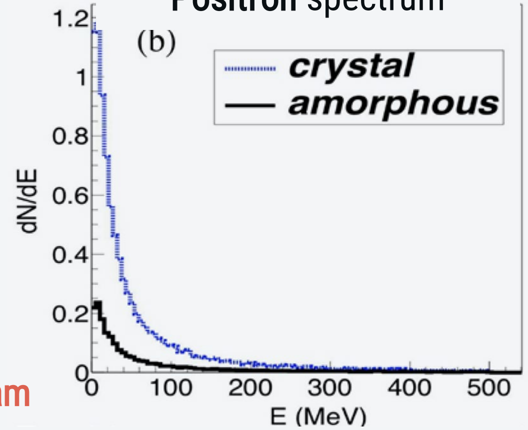
Amorphous
target-converter

Photon spectrum *X. Artru et al. [3]*



8 GeV e⁻ beam

Positron spectrum *X. Artru et al. [3]*

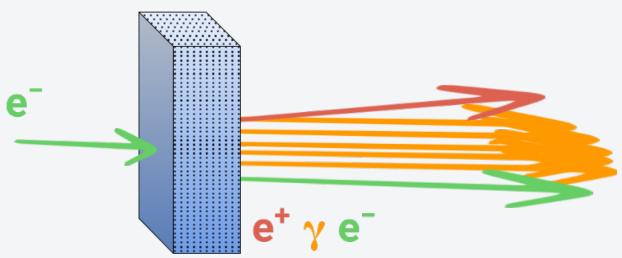


8 GeV e⁻ beam

1. **Enhancement of photon generation** in crystals in coherent conditions → **enhancement of pair production** in the converter target

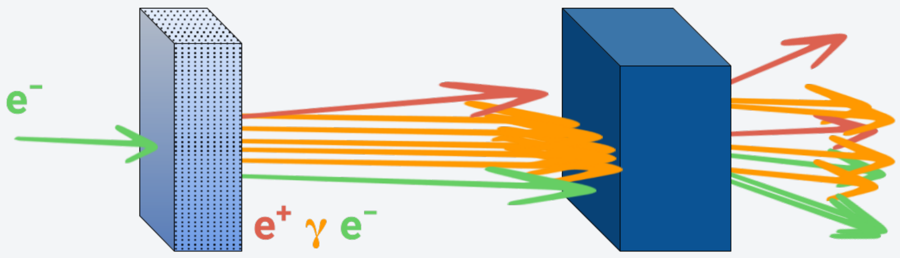
Coherent effects for crystal-based positron sources

Crystalline photon radiator



“Thin” oriented crystalline target (< X_0)
photon radiator

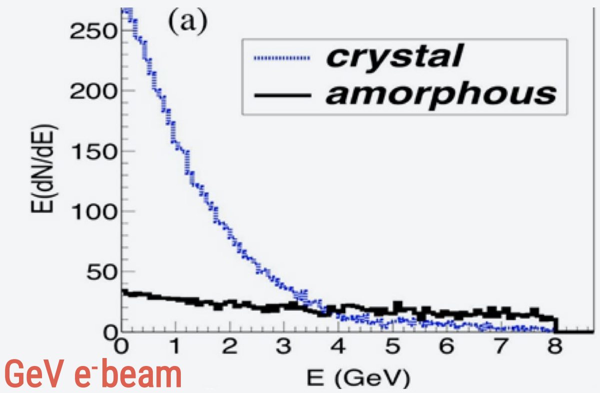
Hybrid positron source



“Thin” crystal (< X_0)
photon radiator

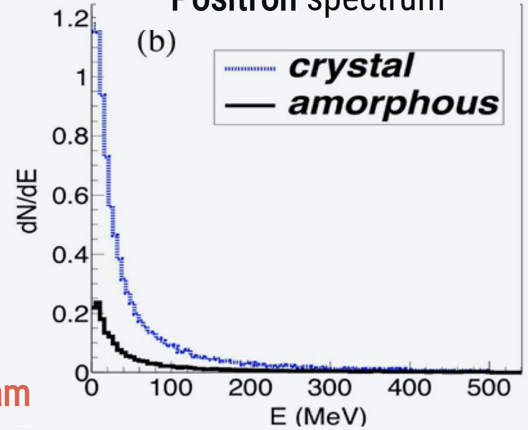
Amorphous
target-converter

Photon spectrum *X. Artru et al. [3]*



8 GeV e⁻ beam

Positron spectrum *X. Artru et al. [3]*

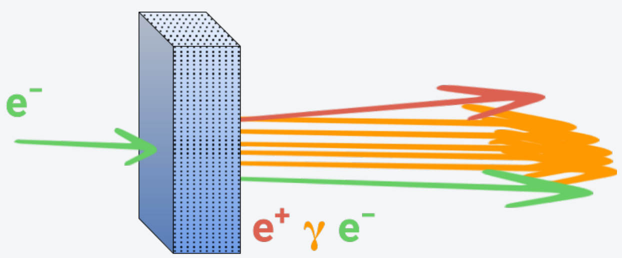


8 GeV e⁻ beam

1. **Enhancement of photon generation** in crystals in coherent conditions → **enhancement of pair production** in the converter target
2. High rate of soft photons → creation of soft e⁺ easily captured in matching systems

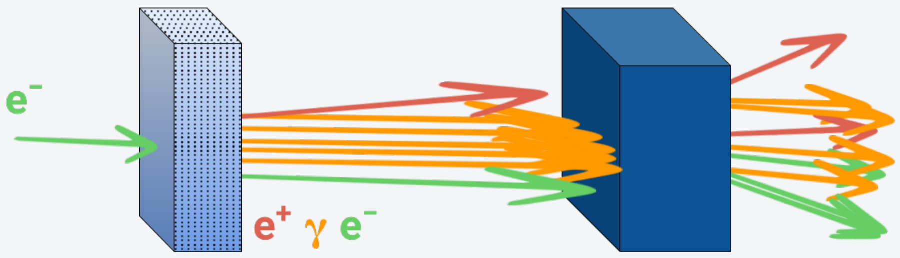
Coherent effects for crystal-based positron sources

Crystalline photon radiator



"Thin" oriented crystalline target (< X_0)
photon radiator

Hybrid positron source



"Thin" crystal (< X_0)
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Amorphous
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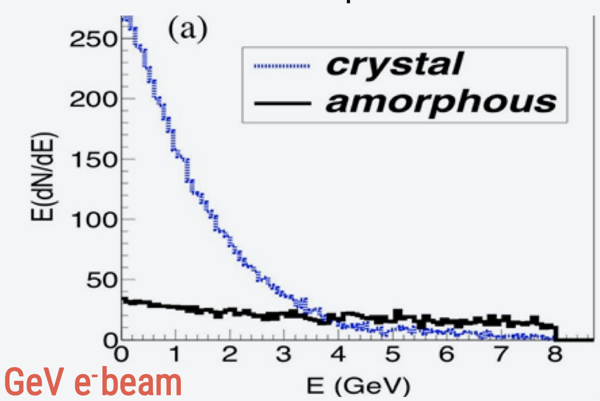
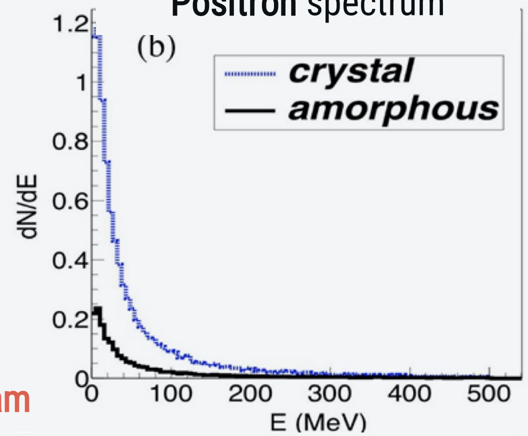


8 GeV e⁻ beam

Positron spectrum *X. Artru et al. [3]*



8 GeV e⁻ beam

1. **Enhancement of photon generation** in crystals in coherent conditions → **enhancement of pair production** in the converter target
2. **High rate of soft photons** → creation of soft **e⁺ easily captured** in matching systems
3. Decrease of the PEDD in the converter

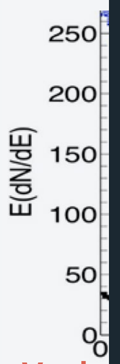
Bandiera et al. [4]

Coherent effects for crystal-based positron sources

Cryst

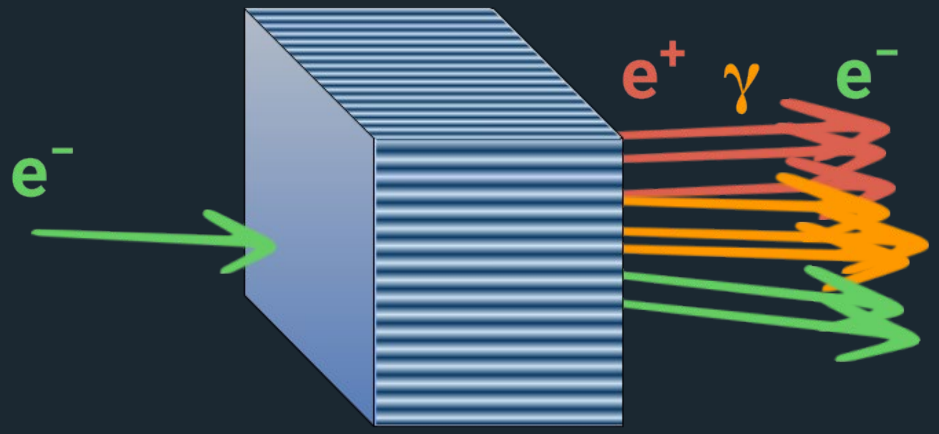
e⁻

"Thin"



8 GeV e⁻ be

Or a Single Thick Crystal



The **performances** are very **similar** to the hybrid source.

We can use **just one device** to optimize the positron source of FCC-ee

ancement of **oton generation** in stals in coherent nditions → **ancement of pair duction** in the nverter target

As seen in G.Paternò talk

crease of the PEDD he converter

Bandiera et al. [4]