e+BOOST
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Bando PRIN 2022

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Ministero dell'Università e della Ricerca

The e+BOOST Project

intense e+ source Based On Oriented crySTals

EPS-HEP 2025

Marseille, France, 9 July 2025

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On behalf of the e+BOOST collaboration
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Talk Outlook

- Positron source state of the art
- Coherent interactions in crystals
- Crystal based positron source
- Last beam test experimental results

FCC-ee state of the art

- EUSPP is giving a clear input for the construction of a new powerful accelerator for future HEP: muon collider, FCC, CLIC, ILC.

- Within the CHART project the FCC-ee injector is proposed.

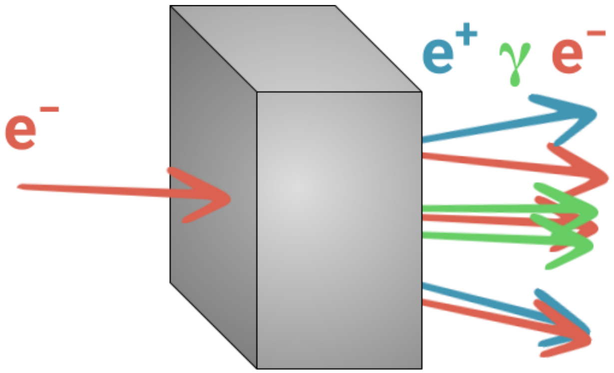
Eur. Phys. J. Special Topics 228, 261623 (2019)

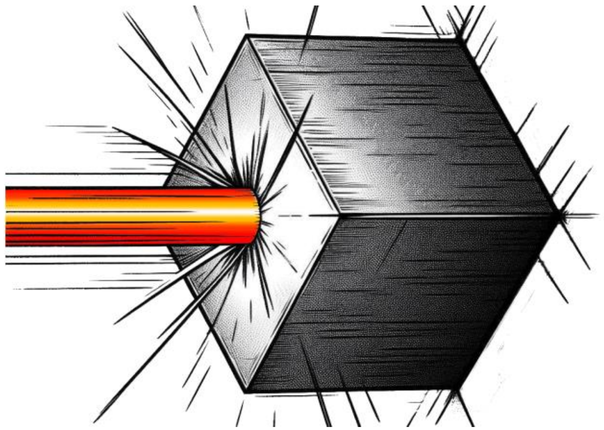
https://www.psi.ch/en/cas/fcc-ee-injector-design-and-psi-positron-source-pss-project

European Strategy Update

Swiss Accelerator Research and Technology

Conventional Positron source





Conventional scheme

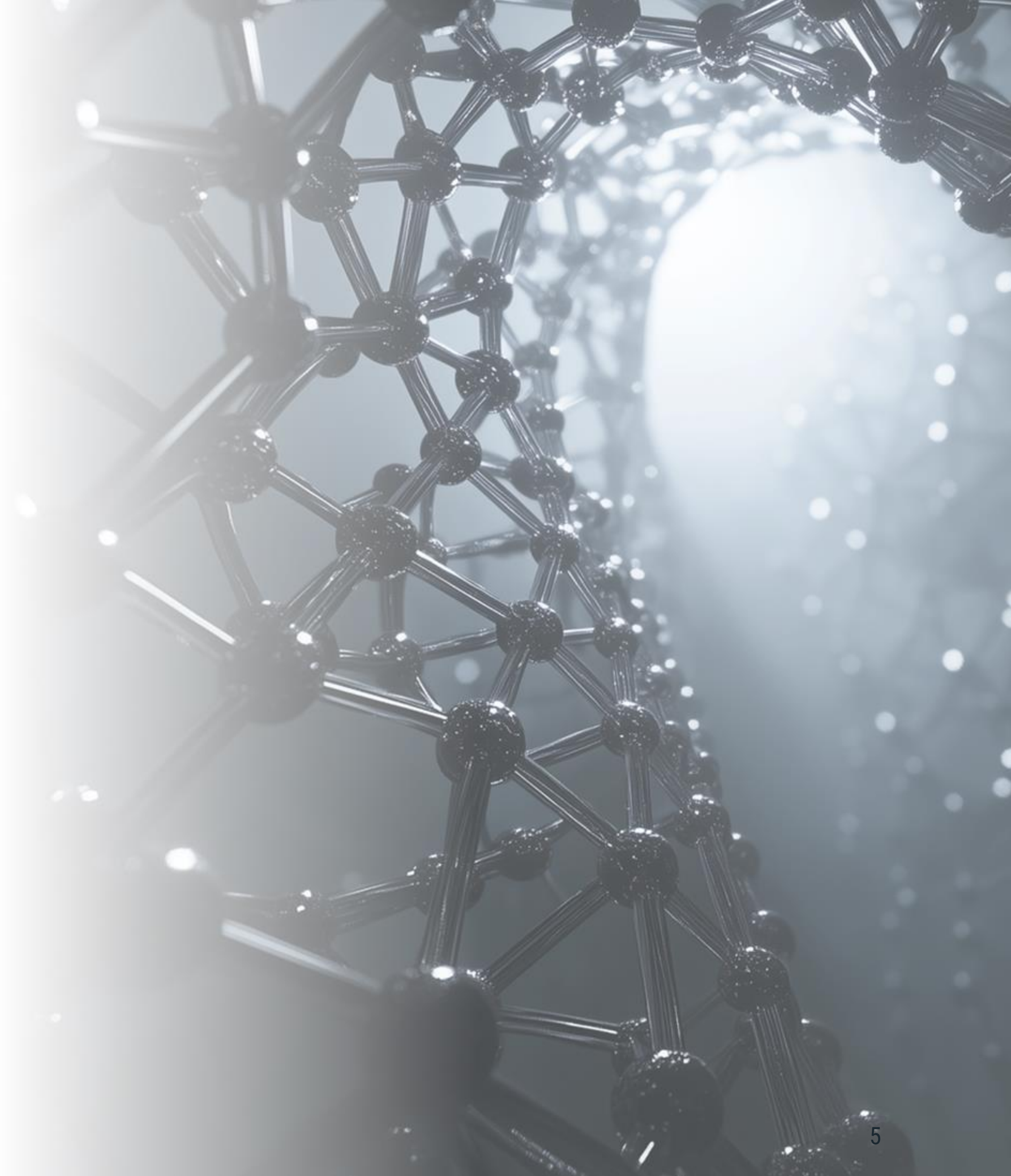
a high-energy primary electron (e^-) beam impinges on an amorphous tungsten (W) target.

1. This interaction generates bremsstrahlung radiation, which then converts into e^+e^- pairs. **Several problems with the conventional scheme.**
2. The Peak Energy Deposition Density (PEDD) in the target can also cause localized energy that can **generate thermal stresses** that may result in **target failure** [limit found experimentally at SLC: **35 J/g** for **W**]

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

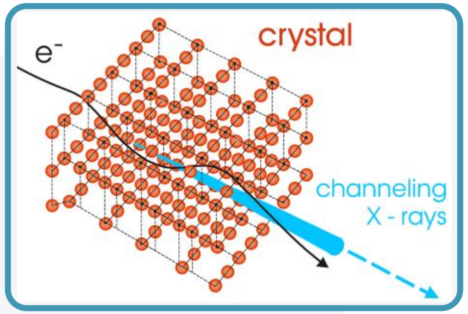
S. Maloy et al., Slc target analysis. LANL LA UR-01-1913 72 (2001)

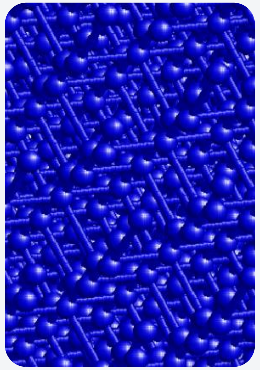
Why a CRYSTAL BASED POSITRON SOURCE



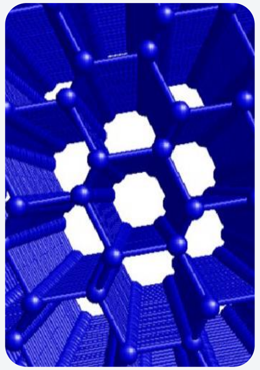
Coherent effects in crystals - Channeling

- When a charged particle impinges on a crystallographic axis or plane within a critical incidence angle, it is trapped within the atomic potential well and it said to be in the **channelling state.**
- A channelled particle is forced to an **oscillatory motion** resulting in **Channeling Radiation emission.**
- **Enhanced radiation emission.**

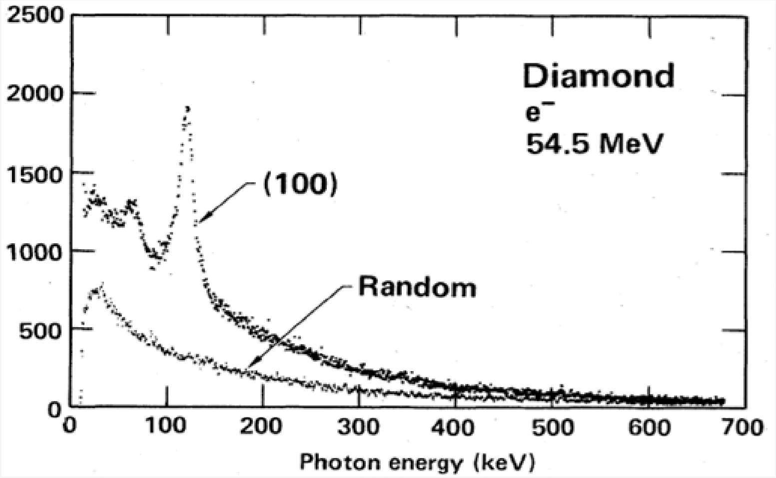




Amorphous



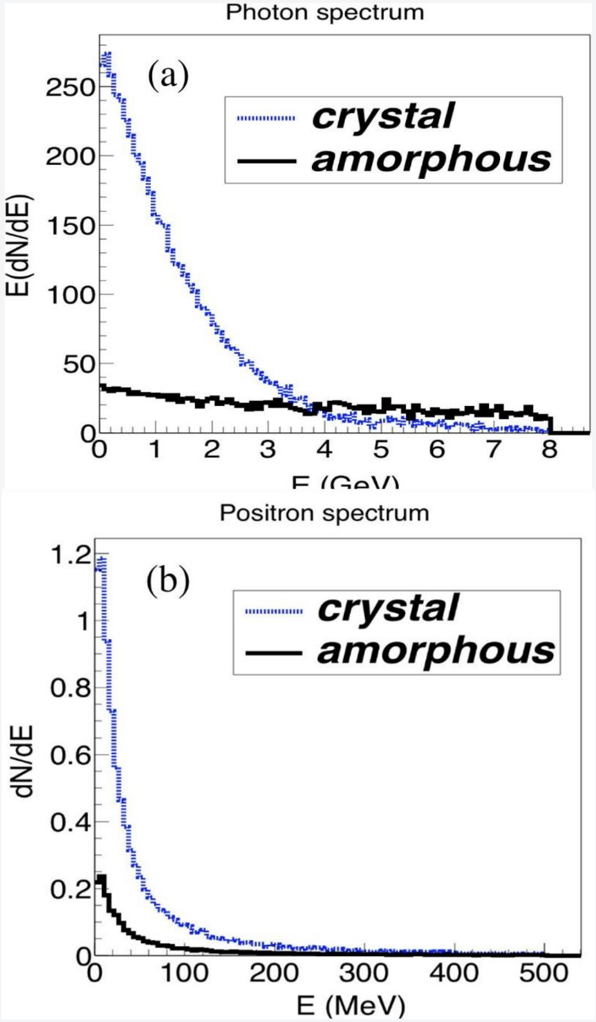
Oriented



Coherent effects in crystals

- **Coherent Interactions** significantly enhance radiation emission, especially in the **soft** part of the spectrum.
- These photons can convert into **electron–positron pairs**, leading to a larger yield of **secondary particles**.
- Using **crystalline targets** in positron sources is advantageous, and aligning them properly comes at **virtually no cost**.

X. Artru, I. Chaikovska, R.Chehab et al. NIM B 355 (2015) 60



Crystal-based positron source: single crystal

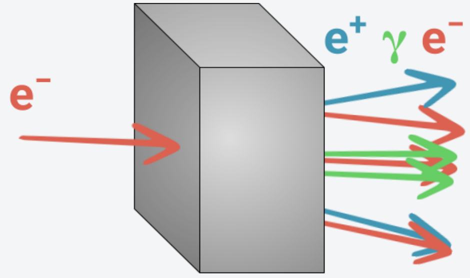
Idea of using oriented crystal for positron sources was proposed by R. Chehab, et al., in 1989 and validated at CERN in 2000 and KEK in 2002

R. Chehab, CERN-1989-005.105

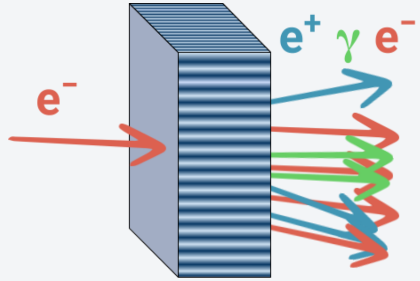
R. Chehab et al., Phys. Lett. B, 525 (2002) 41-48

I. Chaikovska et al., In: 10th IPAC, p. 003 (2019)

From conventional scheme → Crystalline positron source



Amorphous



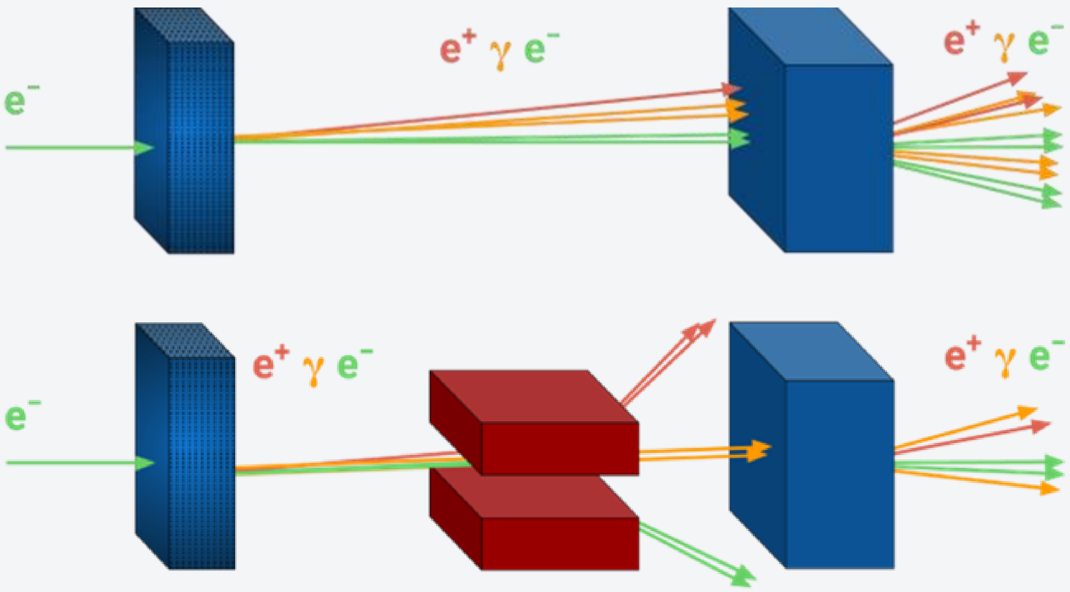
Oriented

Main advantages:

- **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
- **We can decrease the primary e- current (more sustainable) to obtain the same number of positrons!**
- **Shorter crystal compared to amorphous converter can also reduce the total deposited energy**

Crystal-based positron source: hybrid scheme

Hybrid positron source



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

For even higher intensity positron source (e.g. for linear collider, as CLIC):

- We need to decrease the deposited energy and Peak Energy Deposition Density (PEDD) in the converter target!
- Total energy deposited is **split between two stages** results in overall lower energy density
- Very low energy deposit and PEDD in thin radiator (<X0) **very low heating and thermo-mechanical stress**

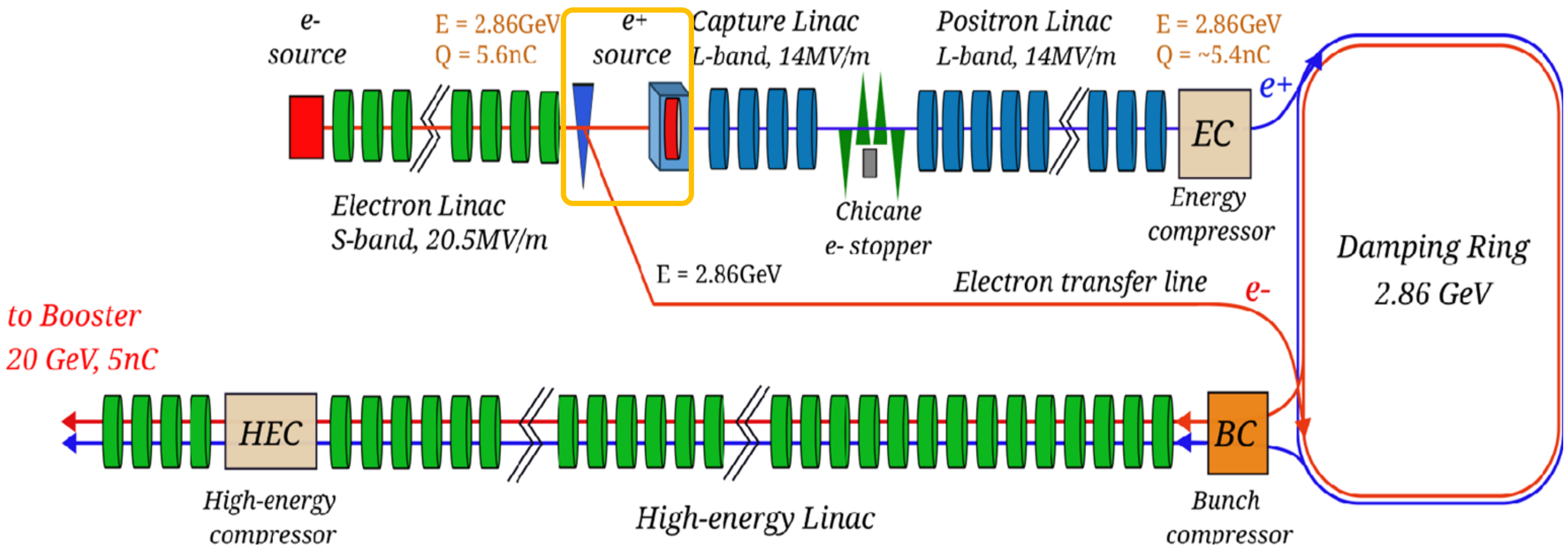
FCC-ee CRYSTAL-BASED SOURCE OPTIMIZATION VIA **SIMULATIONS**

FCC-ee Injector design

The *e*+ source at FCC-ee relies on the conventional scheme

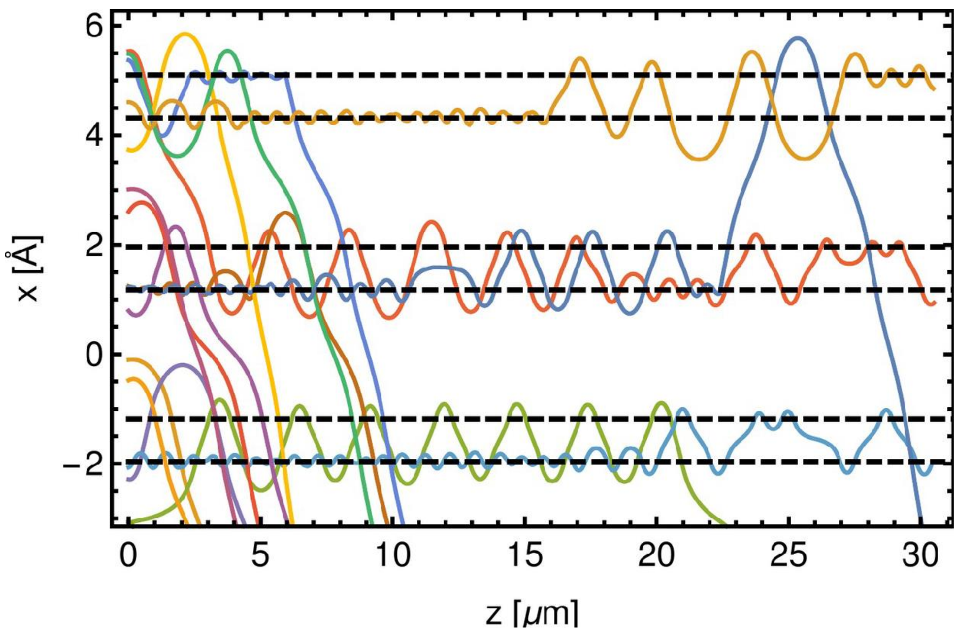
Operation Mode	Final Energy [GeV]	Beam Current [mA]
Z	45	1270
W	80	137
H	120	26.7
ttbar	182.5	4.9

Frank Zimmermann, FCCWeek2024



Simulation of oriented crystals

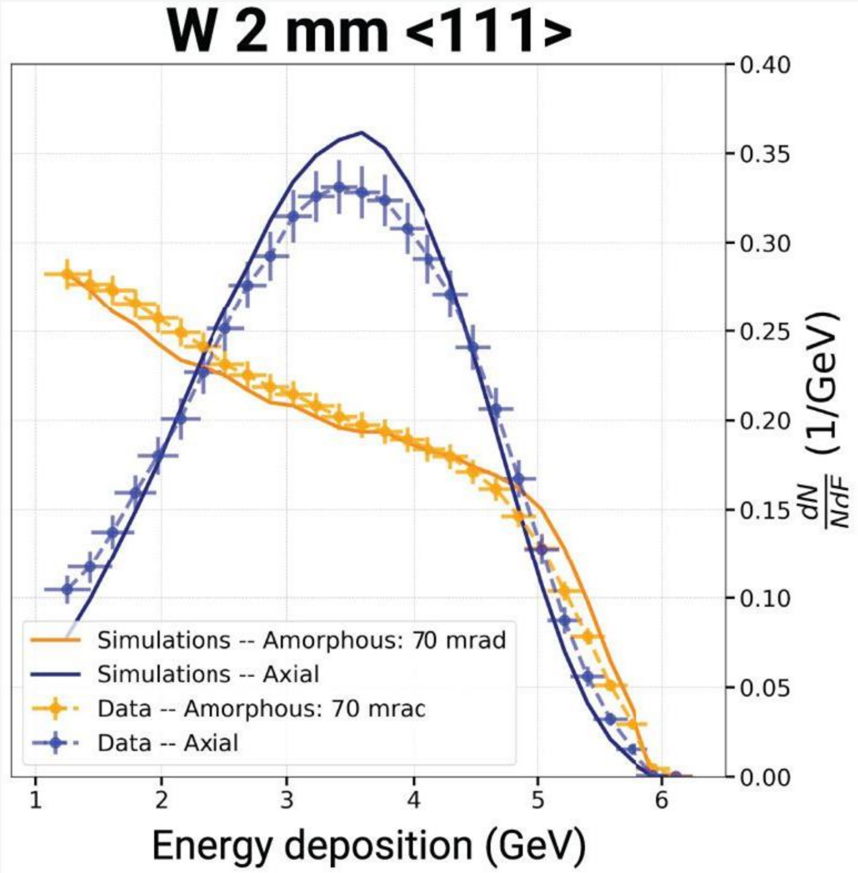
- Simulations to optimize the crystal-based positron source based on *G4ChannelingFastSimModel*.
- Integrated in Geant4, the model simulates coherent interactions in crystalline media.
- Simulated an oriented tungsten along the <111> axis



A.I. Sytov, V.V. Tikhomirov. NIM B 355 (2015) 383–386.
L. Bandiera, et al., Nucl. Instrum. Methods Phys. Res., Sect. B 355, 44 (2015)
A. I. Sytov, V. V. Tikhomirov, and L. Bandiera. PRAB 22, 064601 (2019)
A. Sytov et al. Journal of the Korean Physical Society 83, 132–139 (2023)

Geant4 Crystal Radiator Simulation validation of thin radiator

- Simulation model for **Crystal Radiator** already **validated at Desy and CERN with 6 GeV electrons**
- Energy deposited at the ECAL by the emitted photons
- Typical Bremmstrahlung sprectrum for amorphous crystal
- Suppression at low-energy and enhancement at higher energies that reaches a maximum at approximately 3.5 GeV
- Enhancement is connected with the increased number of photons



N. Canale, et al., NIMA 1075 (2025), 170342

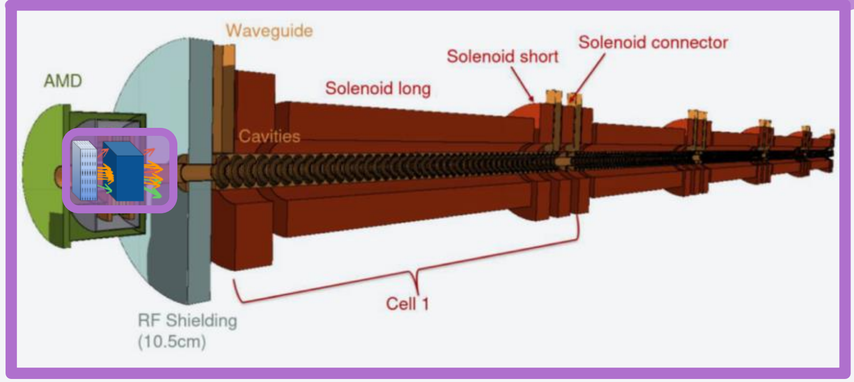
L. Bandiera et al., Eur. Phys. J. C 82 (2022)

Simulate the following stages after the positron source

FCC-ee Injection Group - positron source task Leader I. Chaikovska and F. Alarthi (IJCLab)

After the positron source, the pair is captured in the injector system.
The simulation stages are simulated with the framework *RF-Tracking*.

Primary electrons at 2.86 GeV



- Adiabatic Matching Device (AMD)
- RF cavity
- Positron Linac

We measure the performances of e^+ sources **before the damping ring** where the cooling occurs

Simulation of oriented crystals

In collaboration with
I. Chaikovska and F. Alarthi
(IJCLab)

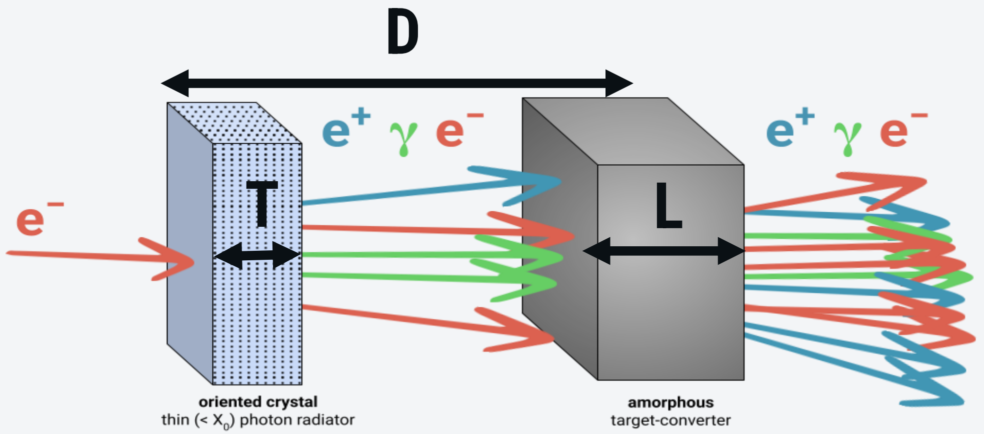
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

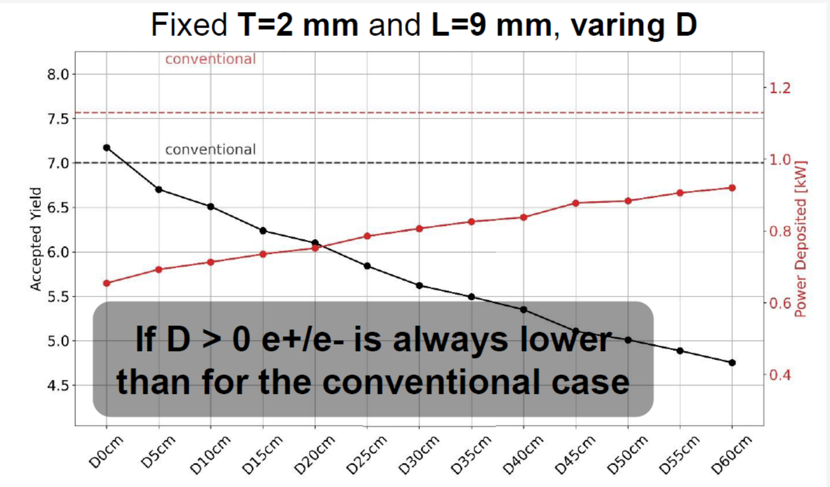
CDR of FCC-ee positron source: e- @2.86 GeV on W target at 15 mm

Positron yield, energy deposit and PEDD can be modified by tuning radiator *thickness* (***T***), *amorphous thickness* (***L***) and the distance between them (***D***).

- Simulation studies converge to a total W thickness of about **12 mm (~3.4X_0) {T~1.5 mm + L~10.5 mm}**
- **D~0 cm**
- We can think about a **single thick crystal**
- The Single Crystal **PEDD** is **acceptable** considering FCC-ee parameters.
- The **performances** are very **similar** to the hybrid source.

L. Bandiera et al., Eur. Phys. J. C 82 (2022)





Simulation of oriented crystals

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I. Chaikovska and F. Alarthi
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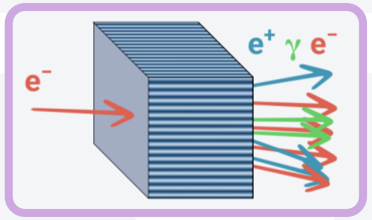


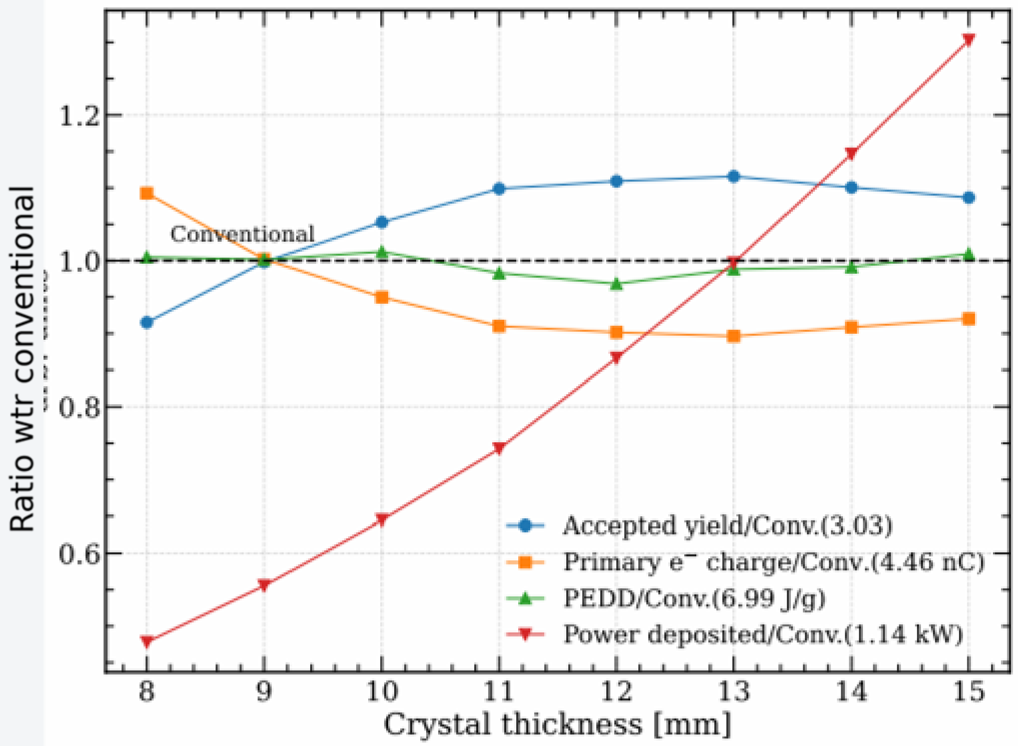
Optimizing the single crystal thickness:

a) Maximizing acceptance yield by the damping ring
b) Minimizing primary electron bunch charge
c) Minimizing deposited power

12mm is the best compromise

Table 3: Summary of the FCC-ee e^+ source optimization results.

Parameter	Conventional	Crystal-based
Target thickness [mm]	15	12
e^+ production rate	7.1	7.6
Accepted yield at the DR	3.03	3.36
Primary e^- bunch charge [nC]	4.46	4.0
Deposited power in the target [kW]	1.14	0.98
PEDD in the target [J/g]	6.99	6.76

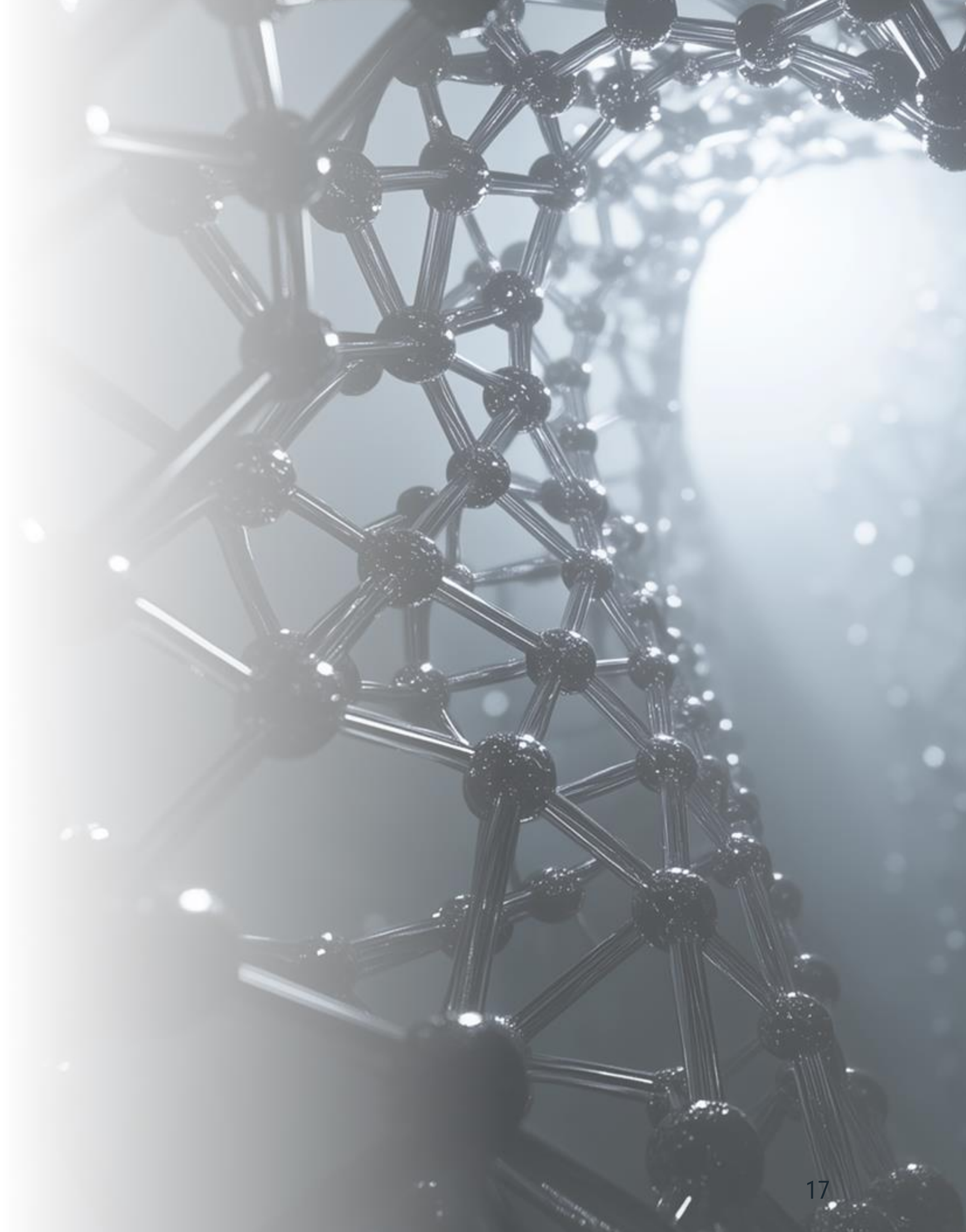


Adapted from F. Alharthi, et al., NIMA 1705 (2025) 170412

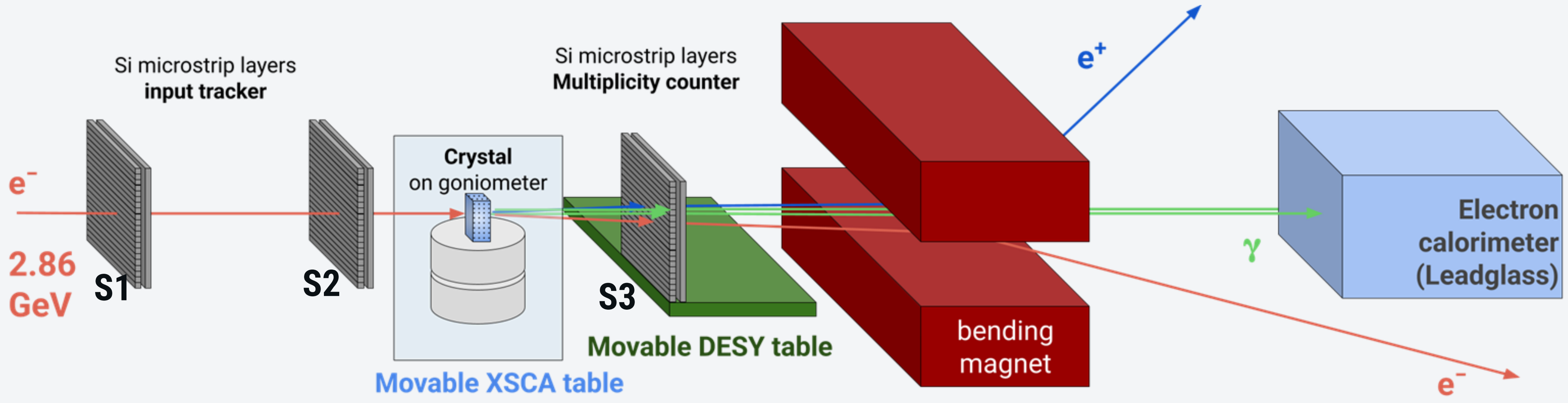
BEAM TEST

To benchmark simulation for the thick crystal converters (single and hybrid) from 2.86GeV electron

Hybrid vs **12mm crystal** vs **15mm conventional**/amorphous



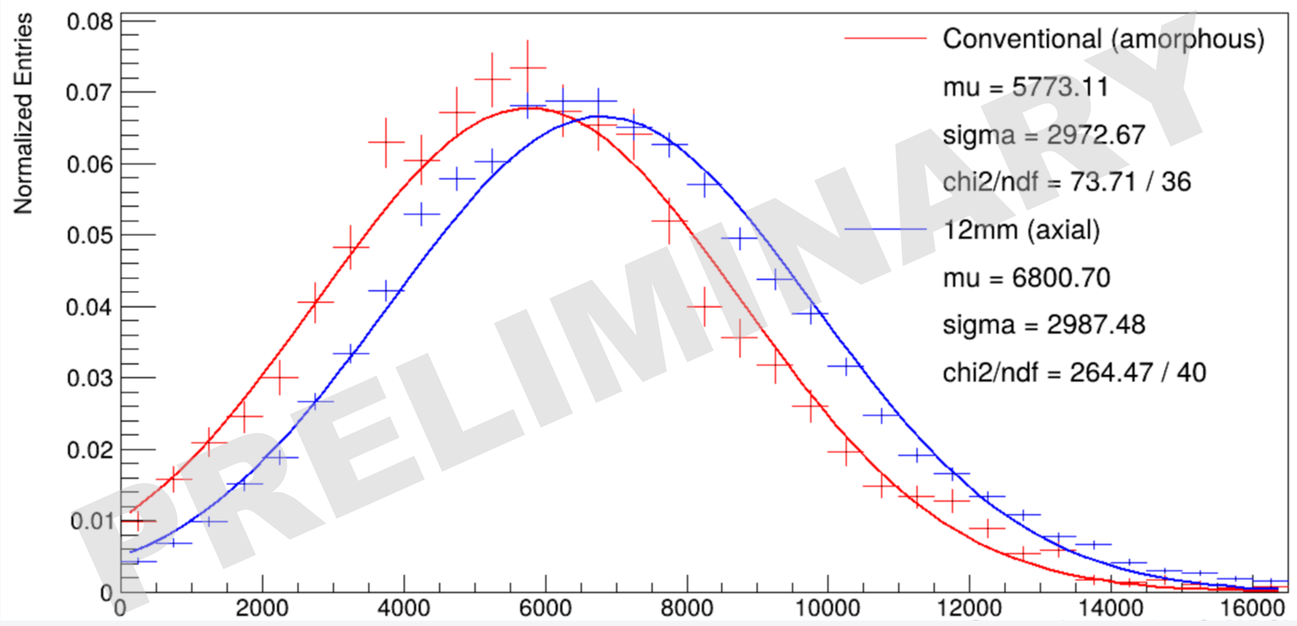
Beam Test setup



- We had a beam test in **June 2025 at CERN PS T9** with electrons of **2.86GeV/c** (nominal FCC-ee injector baseline energy) where we have tested commercial crystal converters
- **Goal**: verify an **enhancement of the total collected charge** (proportional to energy deposited, which is connected to the number of secondaries) w.r.t. conventional W amorphous on the Silicon Detector 3 (**S3**)

Beam Test very preliminary results June 2025

12mm Thick oriented W radiator and converter
(Single thick crystal scheme)
Enhancement of secondaries measured at silicon detector positioned after the crystal sample
Blue 12mm thick oriented radiator
Red 15mm conventional CDR FCC-ee



Collected charge on S3[ADC]

Mean collected charge on S3 at 2.86 GeV electrons

Net gain on S3 collected charge **+17.8% w.r.t. conventional scheme**
Simulations to be integrated

Conclusions and Next steps

- The preliminary design of a crystal-based positron source for the FCC-ee at 2.86 GeV **has been developed**, considering both a single-oriented crystal and a hybrid configuration.
- Both configurations have been tested at the CERN PS T9 beamline, using beam energies of 2.86 GeV (nominal FCC-ee injector energy.
- **At 2.86 GeV**, both configurations show an enhancement in secondary particle charge of approximately **16% (Hybrid) and 17.8% (Single Crystal)**, relative to the conventional setup.
- Although the results are slightly below the expectations from simulation, they are based on **preliminary analyses** with non-optimized fits and selection cuts.
- Next steps: 1) Including Simulations
- Next steps: 2) include measuring the energy and counting the yield of outgoing positrons. **Integration into the P3 project within CHART3 is foreseen**.

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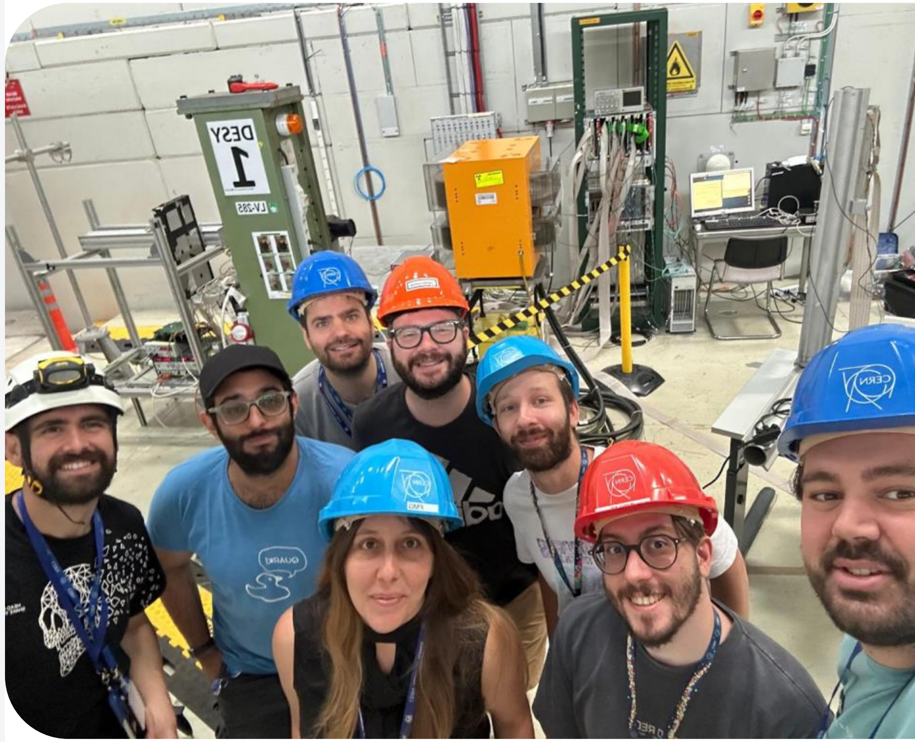
F. Alharthi, I. Chaikovska, R. Chehab, V. Mytrochenko, Y. Wang (IJCLab)
V. Tikhomirov, V. Haurylavets



Acknowledgments

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2022Y877X

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