INFN
FERRARA


Ministero dell'Università e della Ricerca

Bando PRIN 2022

UNIVERSITÀ RICERCA

Intense positron source Based On Oriented crySTals - e+BOOST
(PI L. Bandiera)
PRIN2022-2022Y87K7X
Financed by Italian Ministry of University and Research - PRIN project

Experimental results of the CERN PS Test beam

Hybrid crystal-based positron source for FCC

Ferrara 16 October 2023

Nicola Canale
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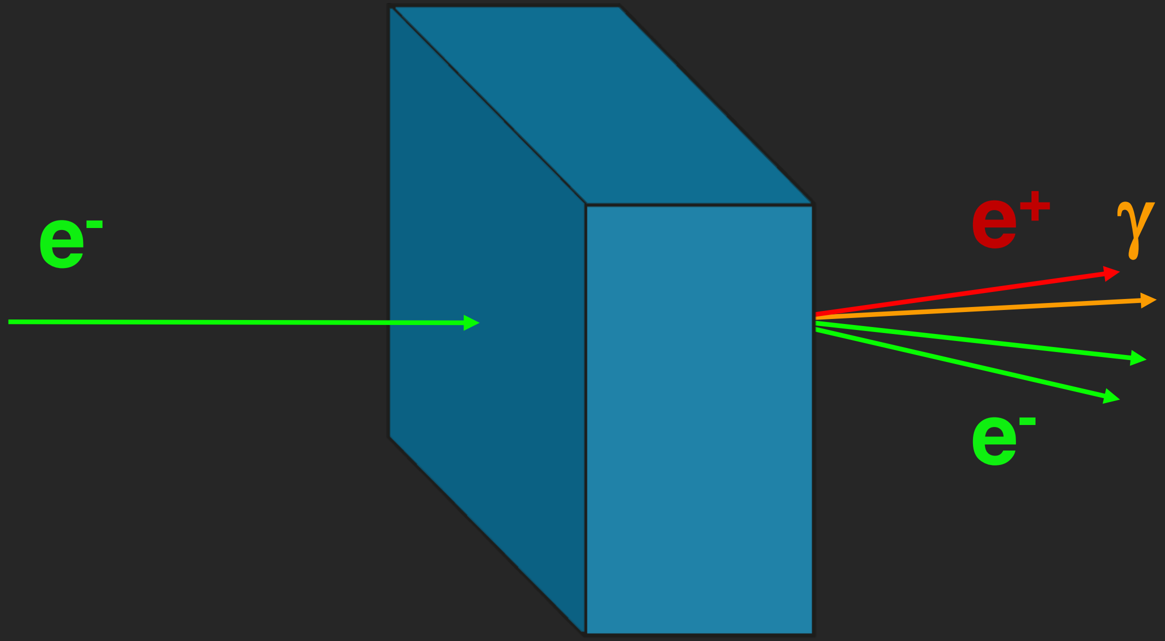
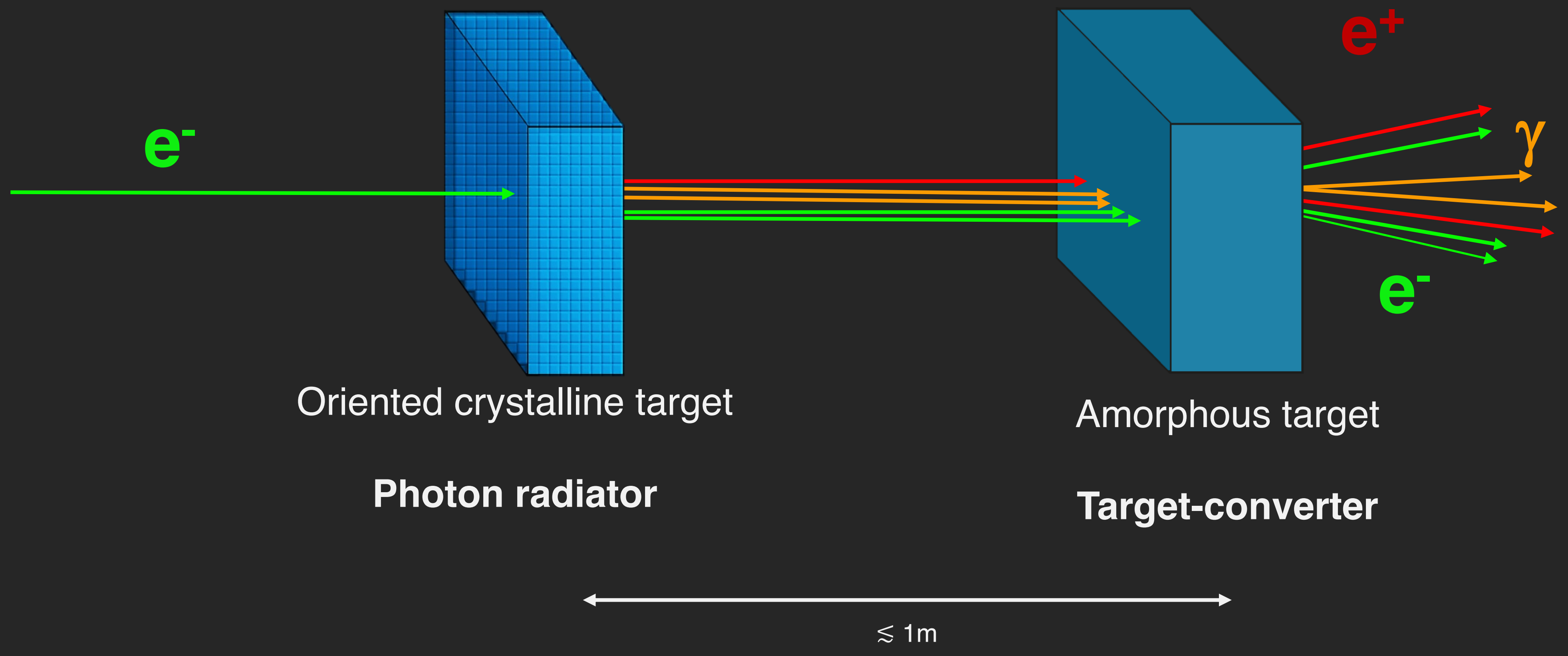
Conventional e^+ source

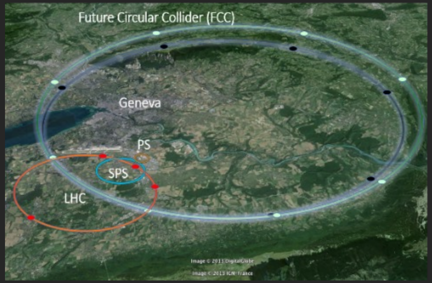


Amorphous target
usually made of high-Z material (W, Pb,..)

Hybrid crystal-based e^+ source



Option for FCCee, ILC, CLIC.

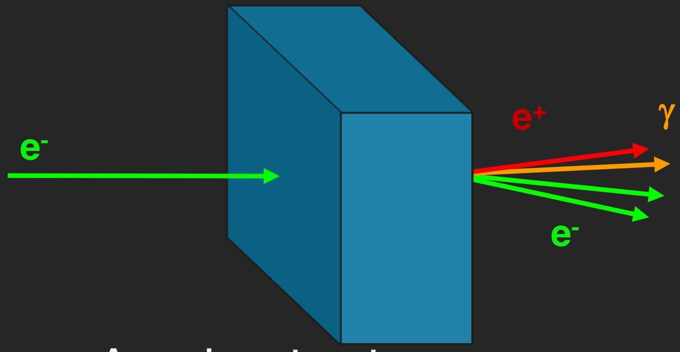


- **Intense gamma-ray source** exploiting the strong crystalline potential of a high-Z material;

- **Crystal radiator for intense e^+ sources** in current (SuperKEKB, FACET II, etc..) and future accelerators/colliders, such as the Future Circular Collider **FCCee @CERN**):

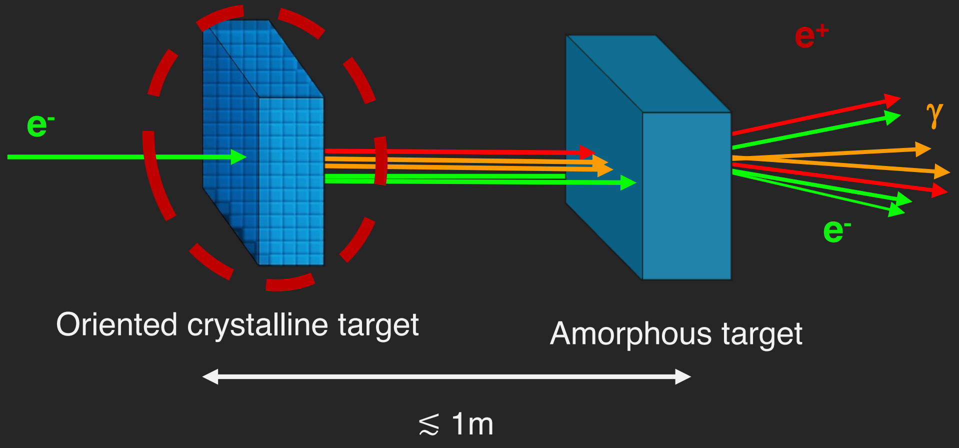
  - Enhancement of photon generation in crystals ➔ enhancement of pair production in the converter target
  - High rate of soft photons ➔ creation of soft e^+ easily captured in matching systems
  - Decrease of the energy deposited in the converter target

Conventional e+ source

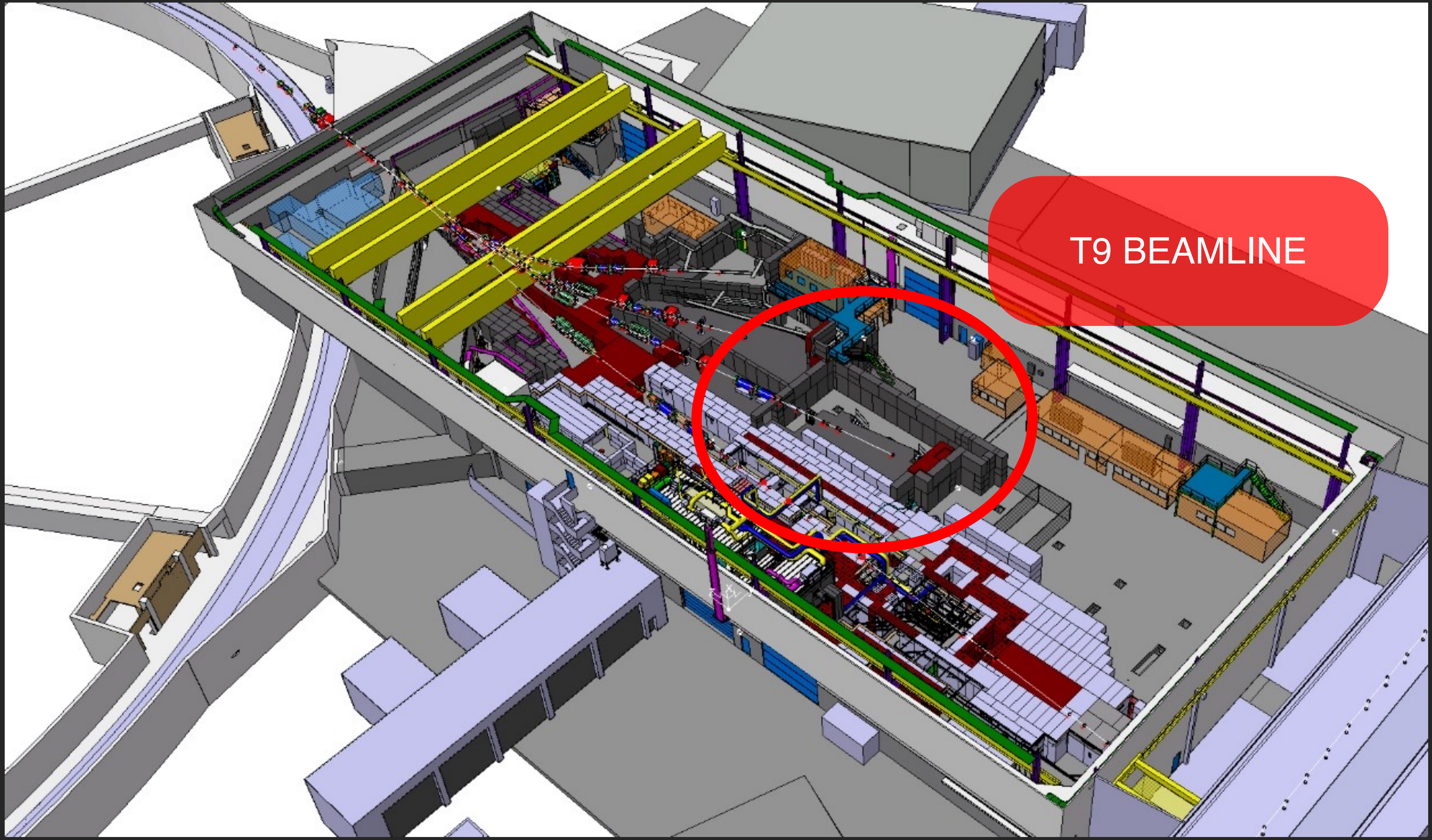


Amorphous target

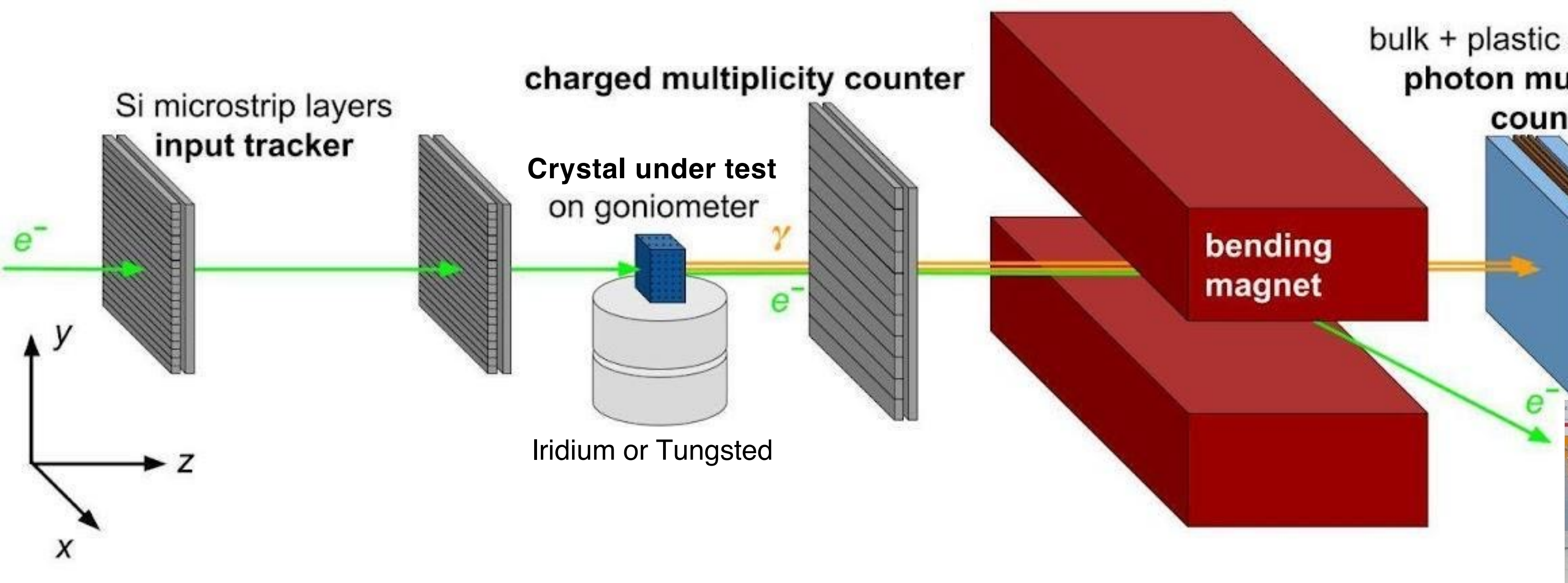
Hybrid crystal-based e+ source



Experiment at CERN PS T9 in 2022 and 2023



Experiment at CERN PS T9 in 2022 and 2023



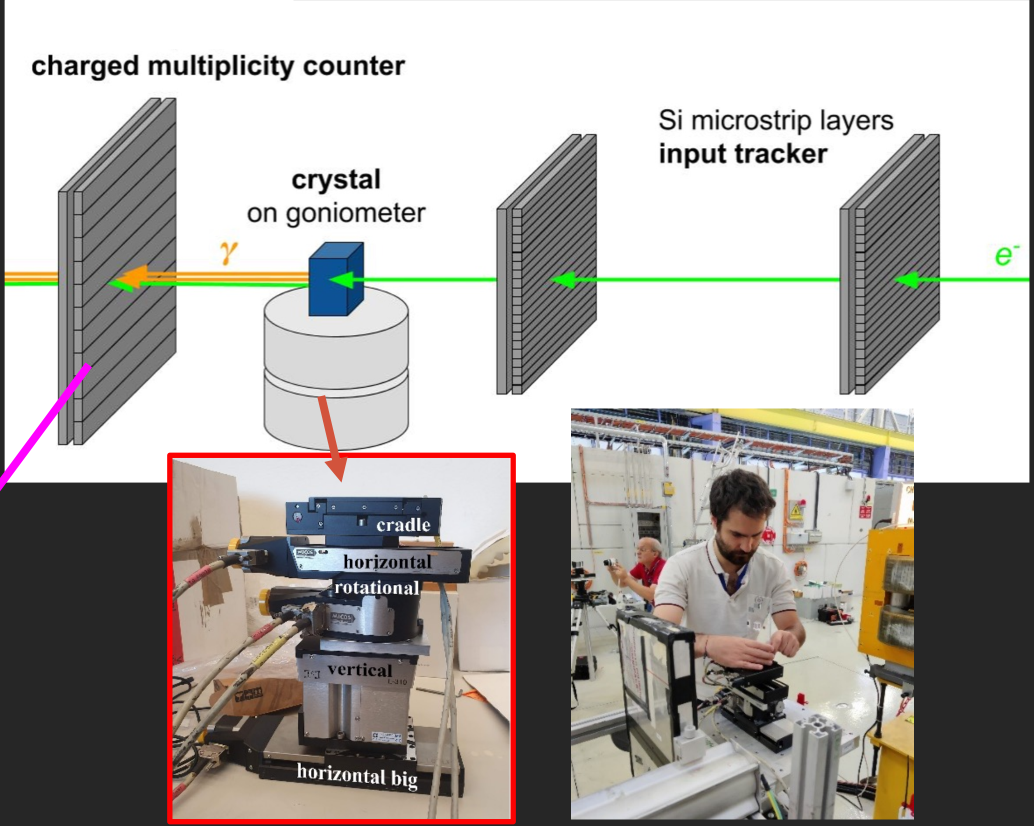
Provided by the INFN Milano Bicocca team – Erik Vallazza & Michela Prest

the setup input stage

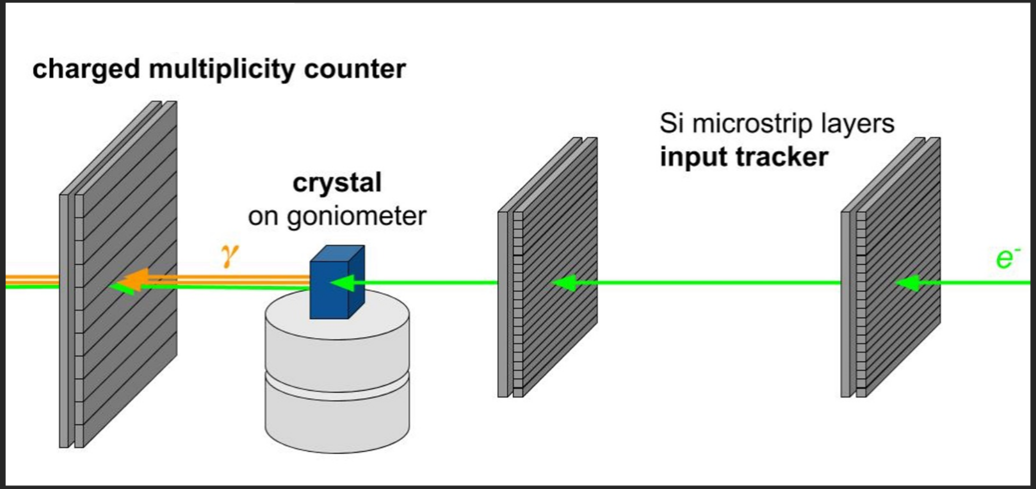
input tracker
~10×10 cm^2 *xy* double-sided Si microstrip sensors, with an overall ~10 µm single-hit resolution

Charged multiplicity counter

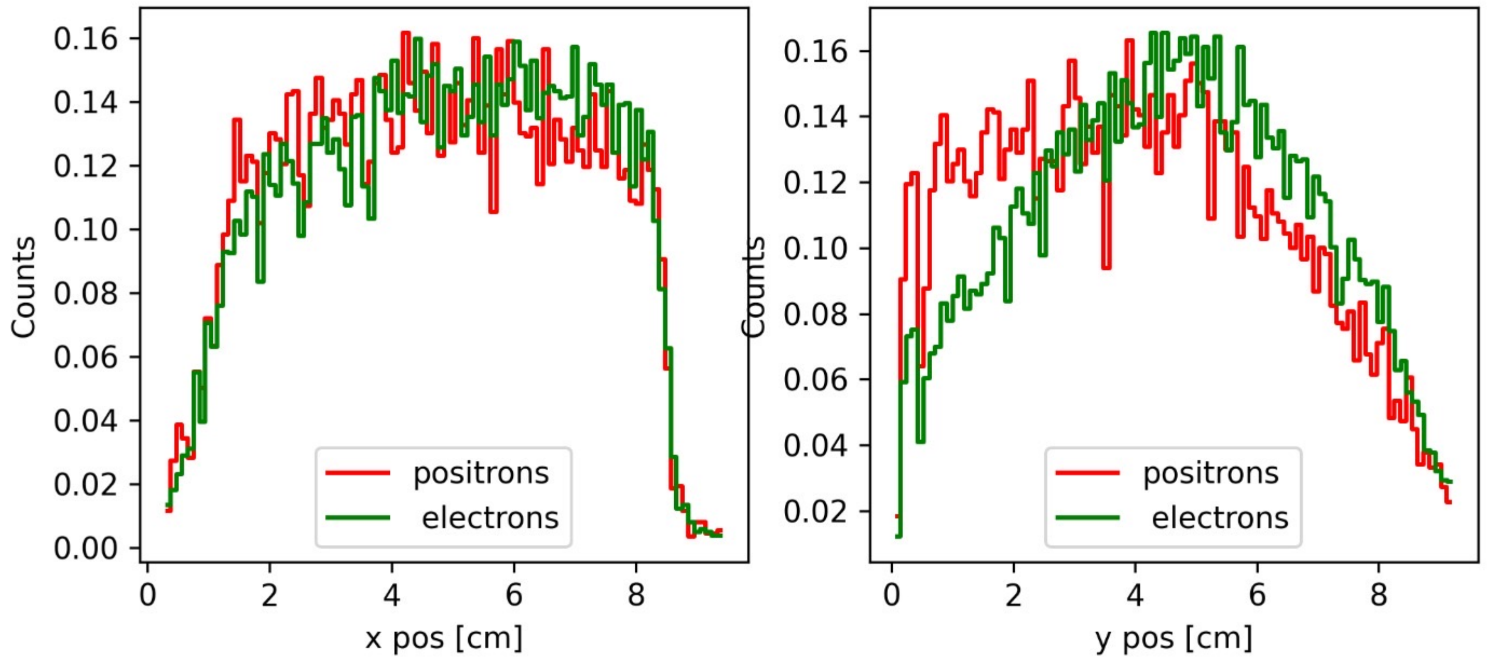
Goniometer @LNL &UNIPD
fine-grained, remote-controlled movements along x, y, θ_x and θ_y with ~5 µm/µrad resolution



the setup **the beam**



Beam distributions
(electron/positron beam, 6 GeV)

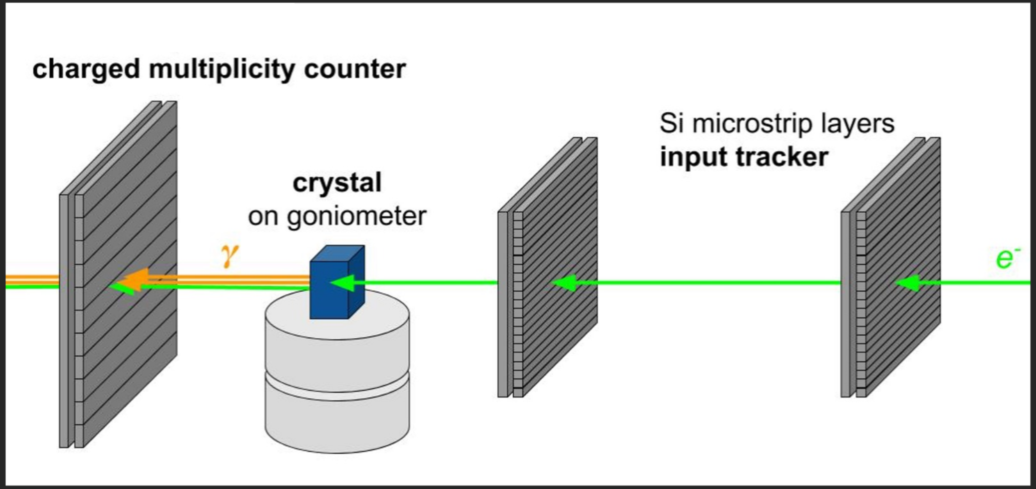


Rate

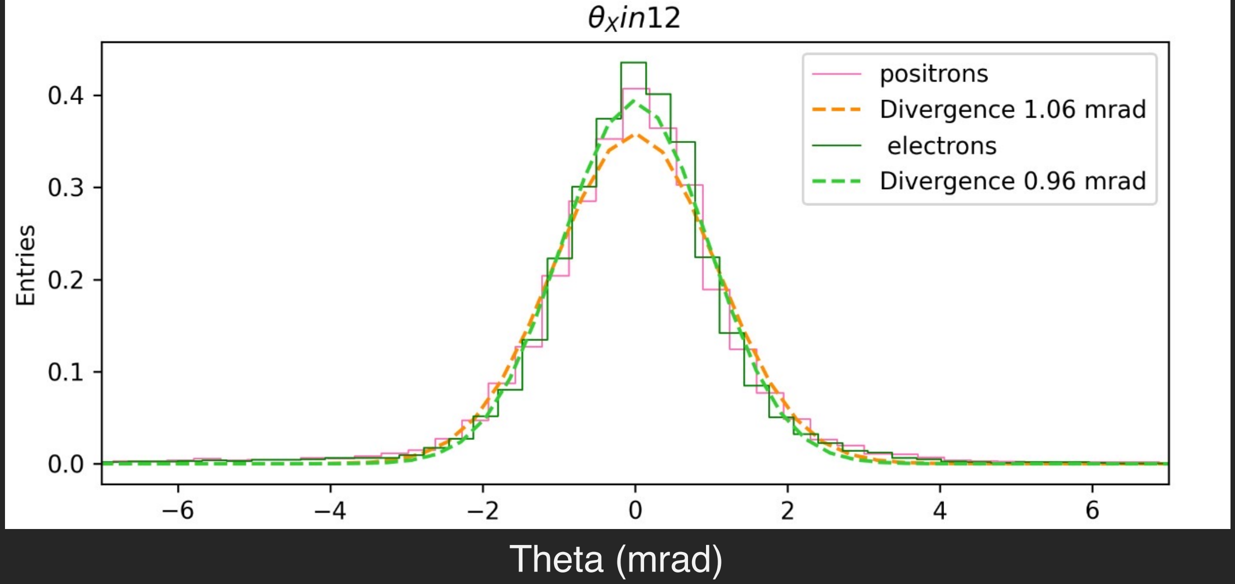
- 10^2-10^3 particles/spill
- Spill duration 400 ms
- 4-6 spills per minute

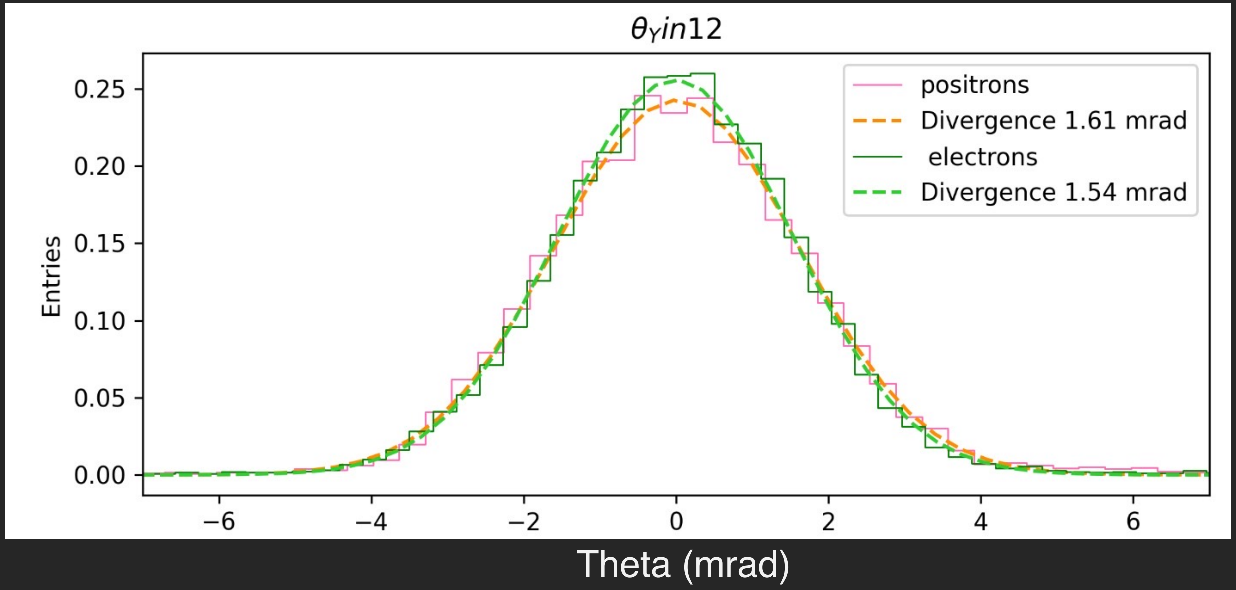
The quality of the beam can be improved removing the upstream Cerenkov detectors and working in vacuum

the setup **the beam**



Input angle distributions (electron/positron beam, 6 GeV)





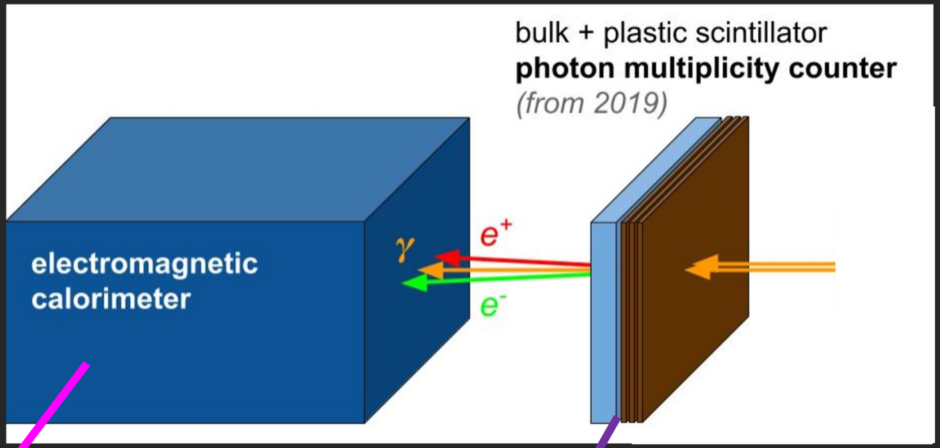
The quality of the beam can be improved removing the upstream Cerenkov detectors and working in vacuum

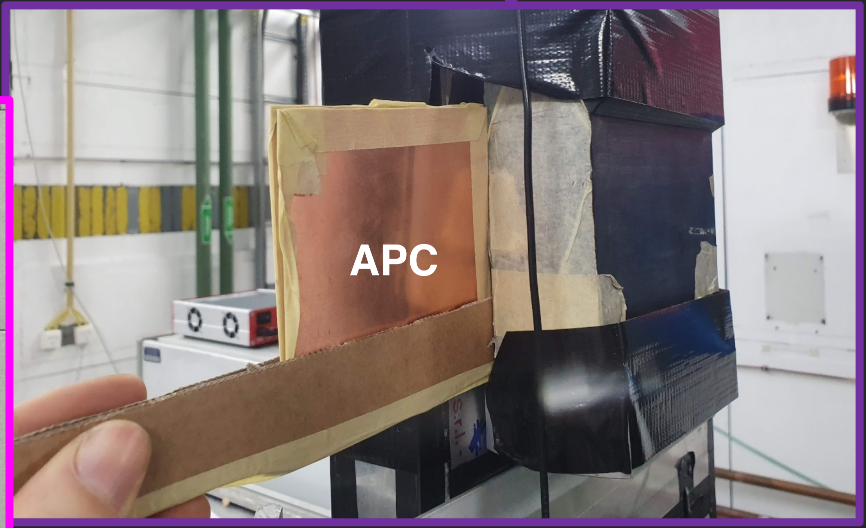
the setup   output stage

Different **calorimeters** can be exploited:

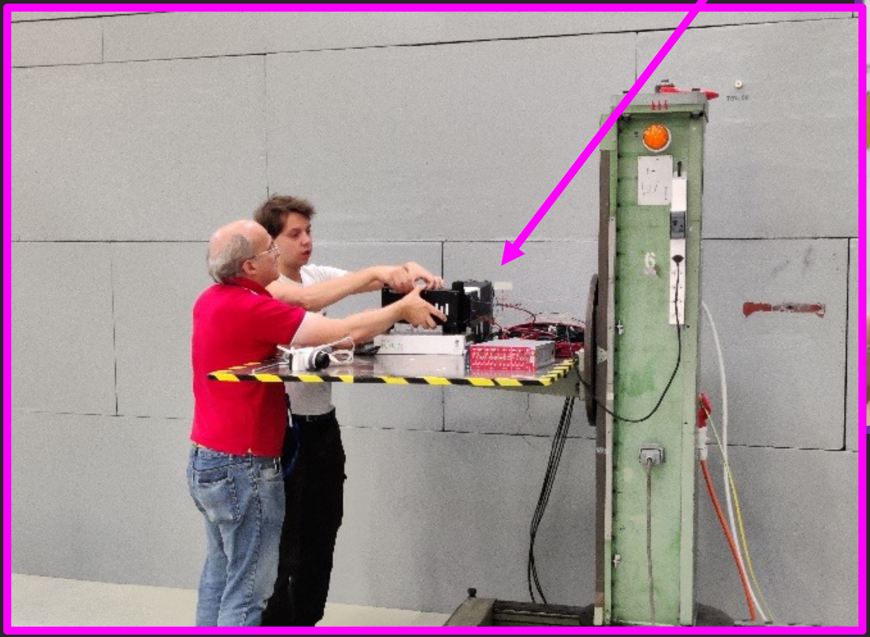
- 3×3 matrix of PWO blocks from the CMS endcap, SiPM-based readout
- 3×3 matrix of BGO blocks, PMT-based readout
- **(OPAL) Pb glass blocks read out by PMTs**

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



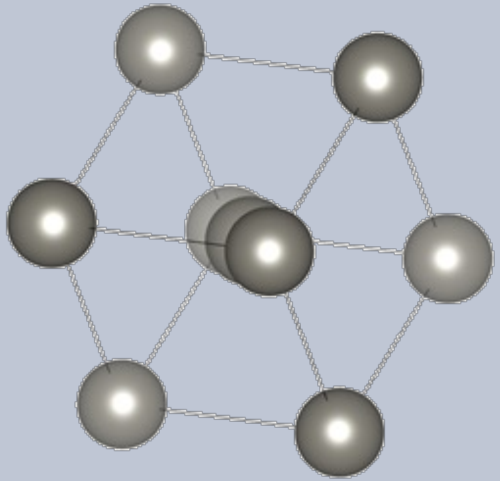


Lead glass

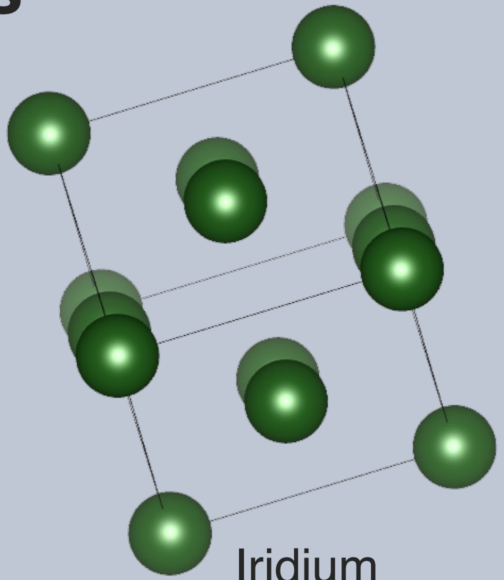


Channeling radiation in **high-Z MATERIALS**

High Z- atoms



Tungsten
(111 axis)



Iridium
(110 axis)

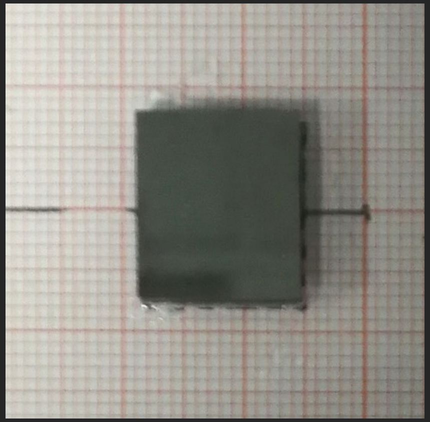
Strong axial potential (10 times Si <110>)

Huge radiation enhancement in axial channeling!

Very high-density material!

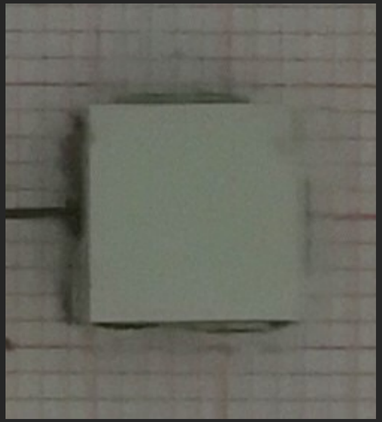
Channeling radiation in **high-Z MATERIALS**

1.



Material: Tungsten
Channeling Axis: <111> (most efficient)
Axial potential: 1 keV
$\theta_c \approx 0.6$ mrad → of the order of beam divergence
Lattice structure: Body Centered Cubic
(BBC, space group #229)
Thickness: 1.5 & 2 mm

2.

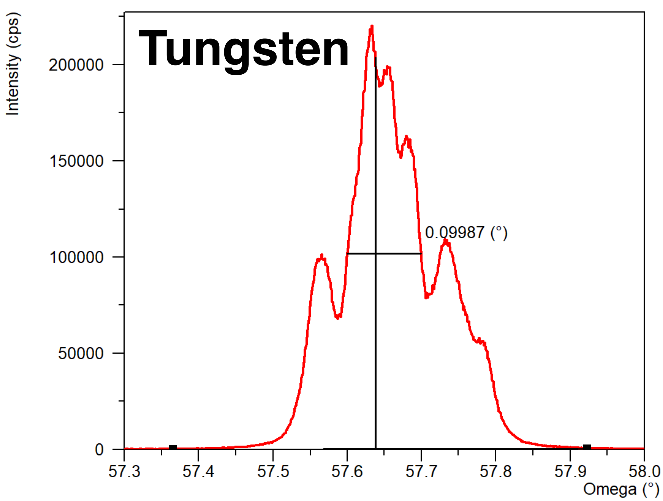


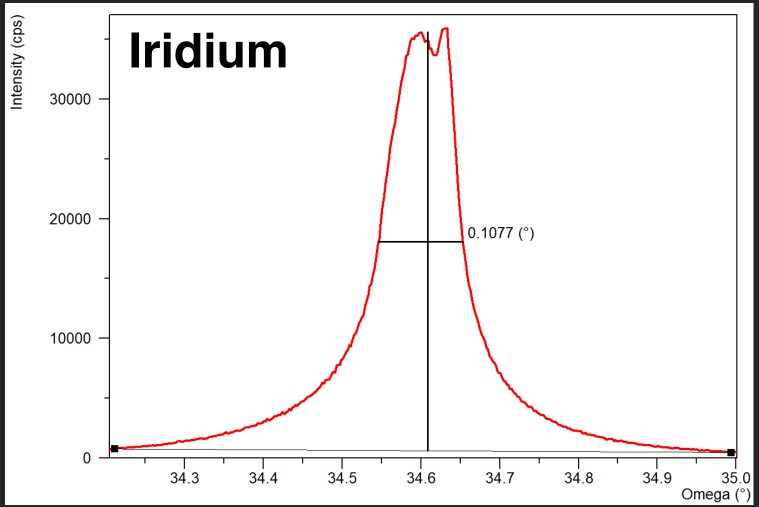
Material: Iridium
Channeling Axis: <110> (most efficient)
Axial potential: 1 keV
$\theta_c \approx 0.6$ mrad → of the order of beam divergence
Lattice structure: Face Centered Cubic
(FCC, space group # 225)
Thickness: 1 & 2 mm

Very high-density material!

Samples Characterization

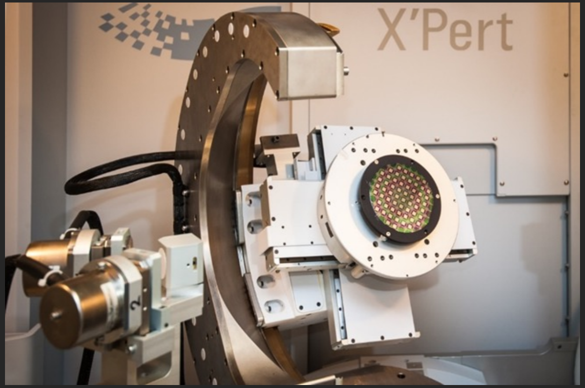
X-ray diffraction Rocking Curve

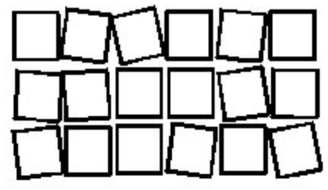




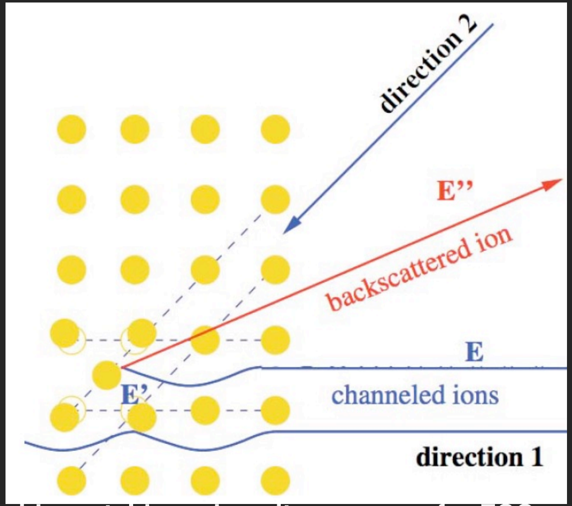
Characterization of superficial mosaicity performed with **High Resolution XRD at Ferrara lab (@8.04 keV)**

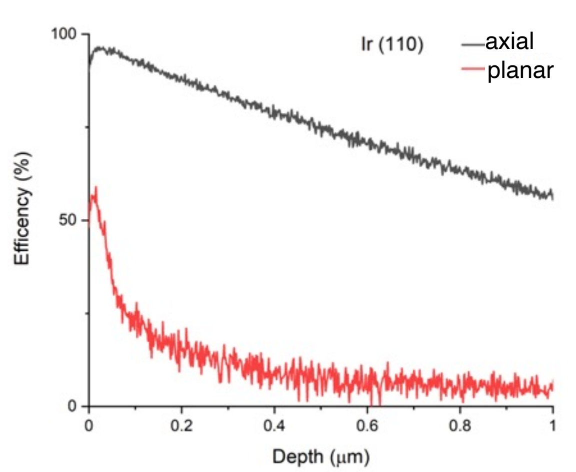
FWHM ≤ 2 mrad – larger than Channeling Angle → big contribution of quasi-channeled particles in radiation (low monochromaticity!)





Rutherford BackScattering with 2 MeV alpha particles in channeling

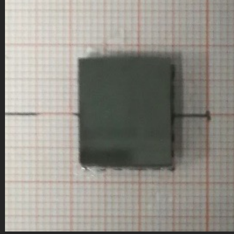


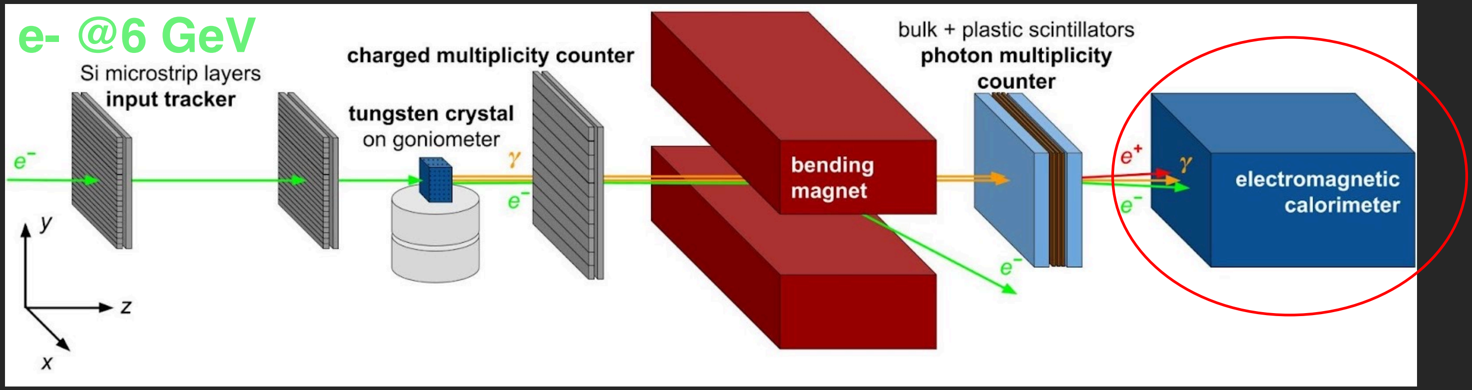


2022 data

1. Radiated energy loss: calorimeter signal

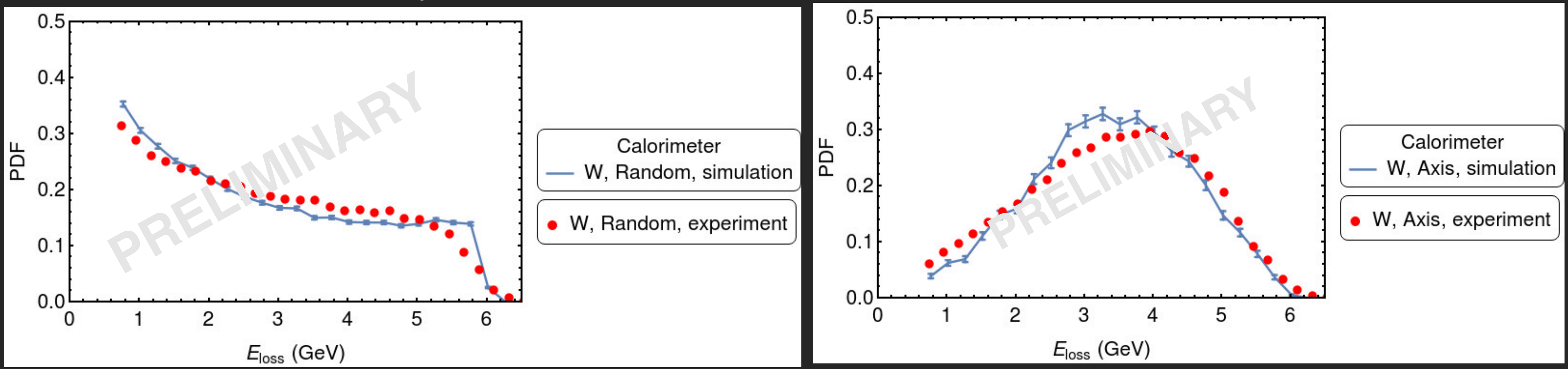
W <111>
2 mm





For the **2 mm long W** aligned along the **<110> axes** the radiative energy loss distribution **is peaked at 3.6 GeV**, while for the **random orientation is close to 0** as typical for Bremsstrahlung.

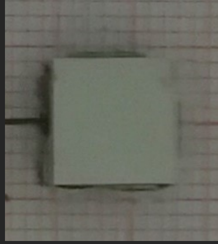
electromagnetic radiation in the Lead Glass calorimeter

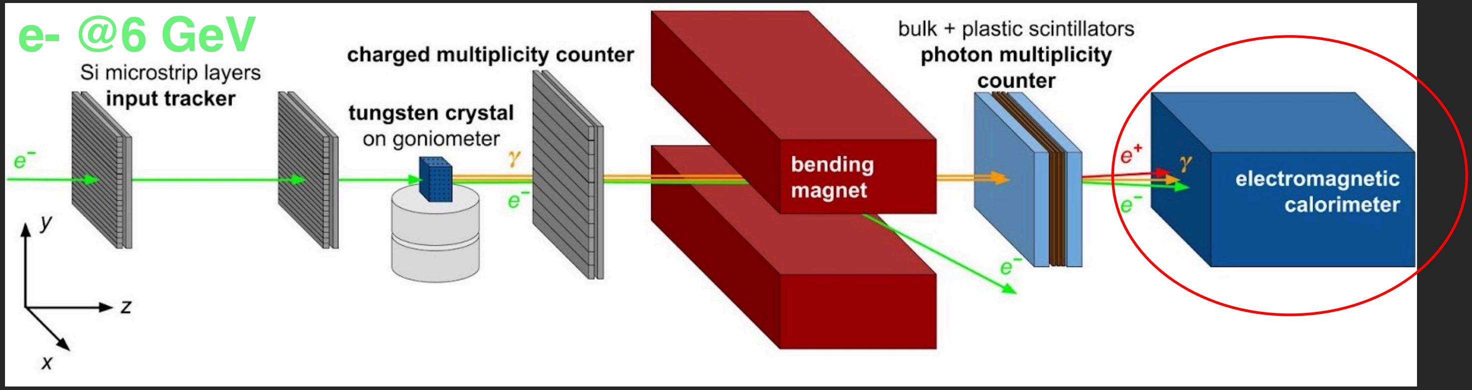


East Area T9 line

2. Radiated energy loss: calorimeter signal

Ir <110>
1 mm

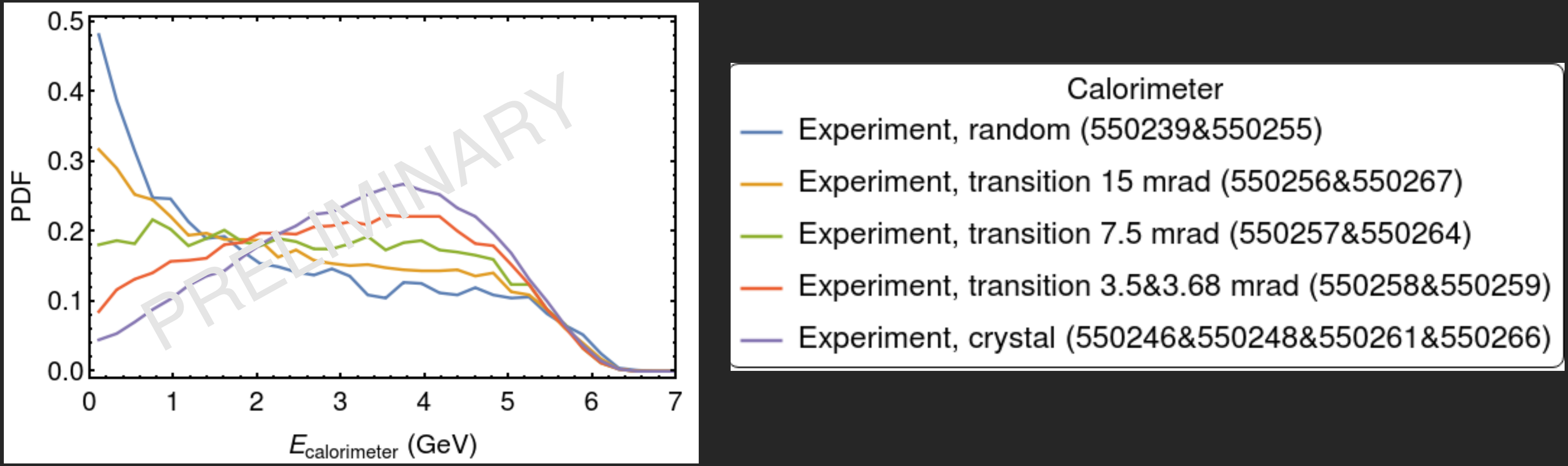




electromagnetic radiation in the Lead Glass calorimeter

For the **1 mm long Ir** aligned along the **<110> axes** the radiative energy loss distribution **is peaked at** 3.8 GeV, while for the **random orientation is close to 0** as typical for Bremsstrahlung.

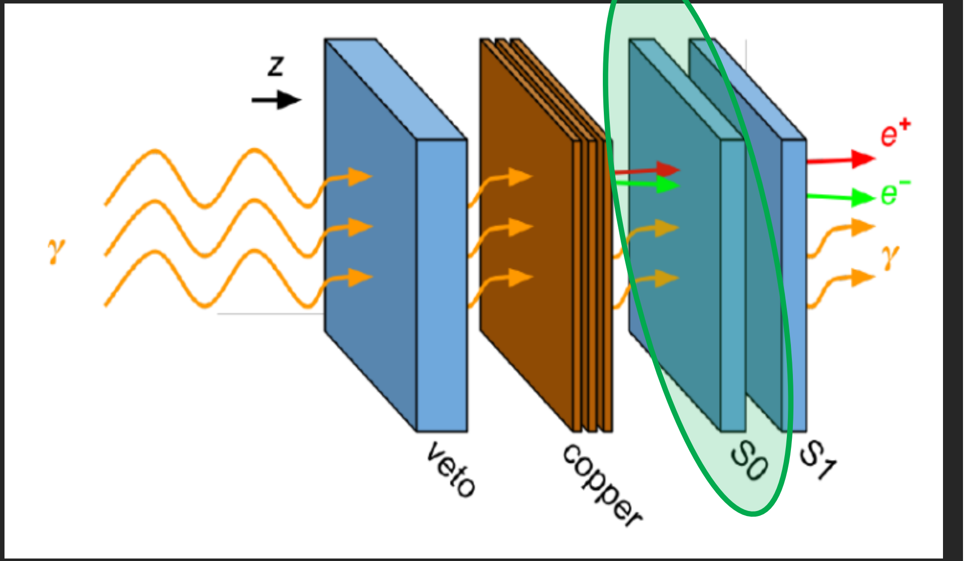
We also see an effect up to 15 mrad from the axes!

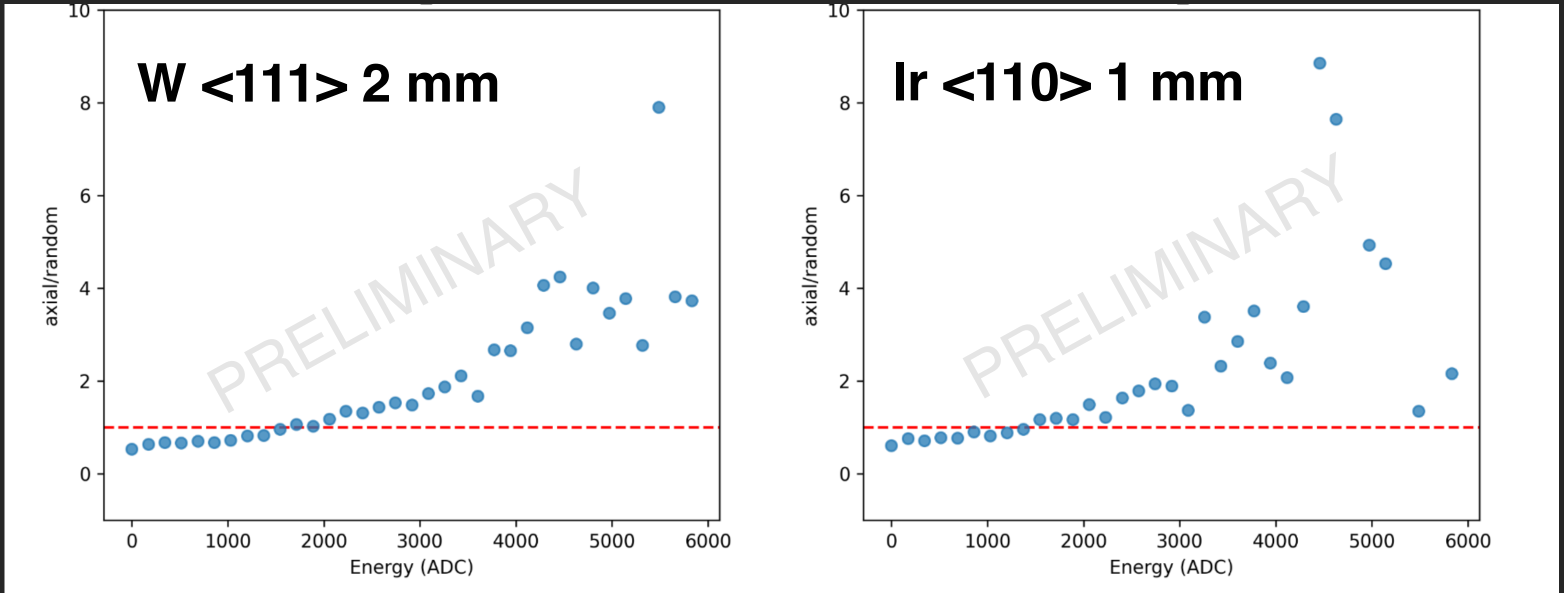


East Area T9 line

“Counting” the number of photons

Enhancement of energy deposited in downstream scintillator S0 in case of axial orientation of the crystal related to the random orientation





- An estimate of the number of photons that emerge from the crystal was obtained via an Active Photon Converter, which consisted of plastic scintillators placed upstream (for photon veto) and downstream (for electron-positron pair multiplicity measurement) with respect to a converter layer (0.2-0.4 radiation lengths of copper).

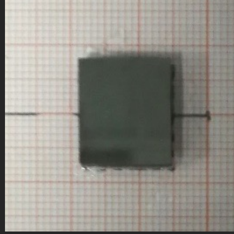
- **Increase** in the average number of high-energy deposit events (i.e. in the average number of events featuring many output photons **— more than 2) in case of** axial alignment if compared to random.

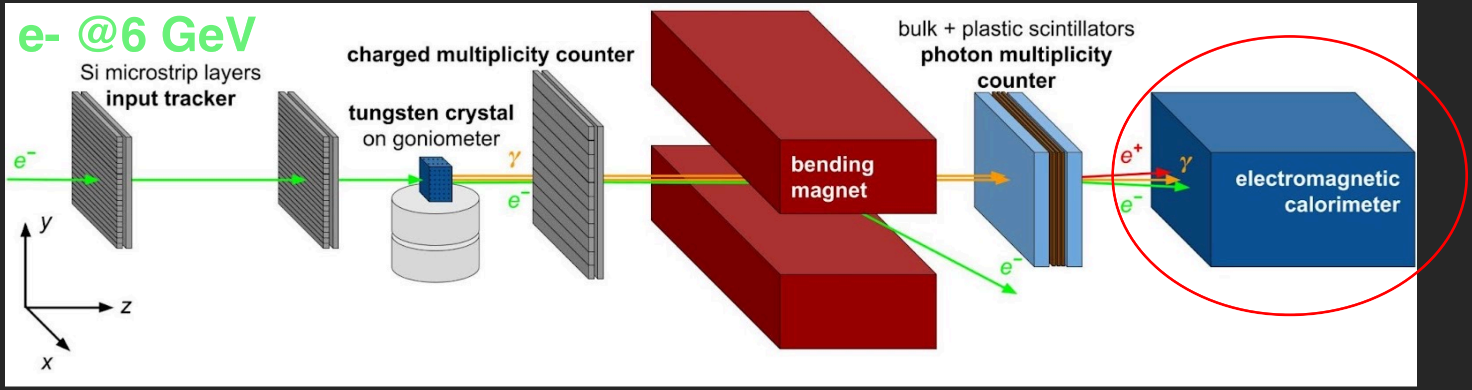
- The **Single Photon spectrum can be extrapolated via simulation (we expect peak @ 10-100 MeV)** -> will be carried out in the next future!

2023 data

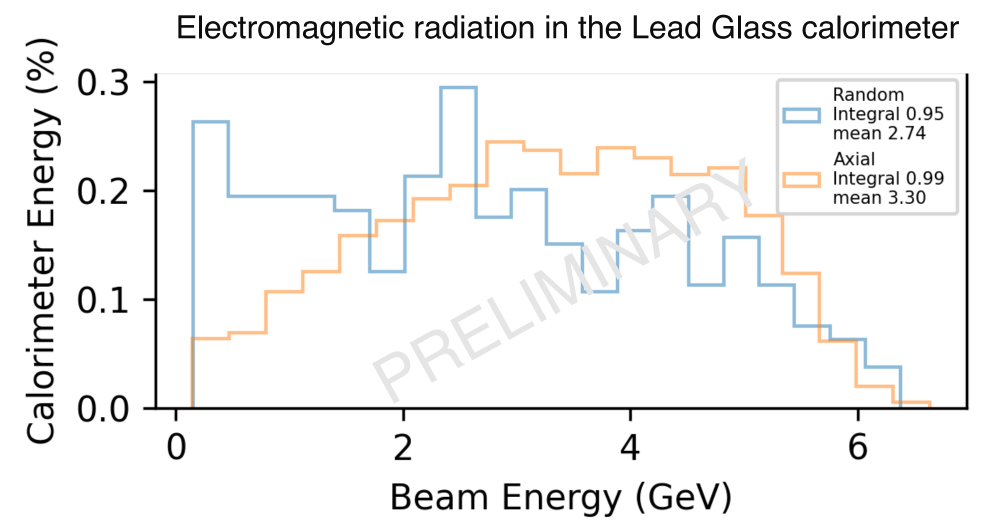
1. Radiated energy loss: calorimeter signal

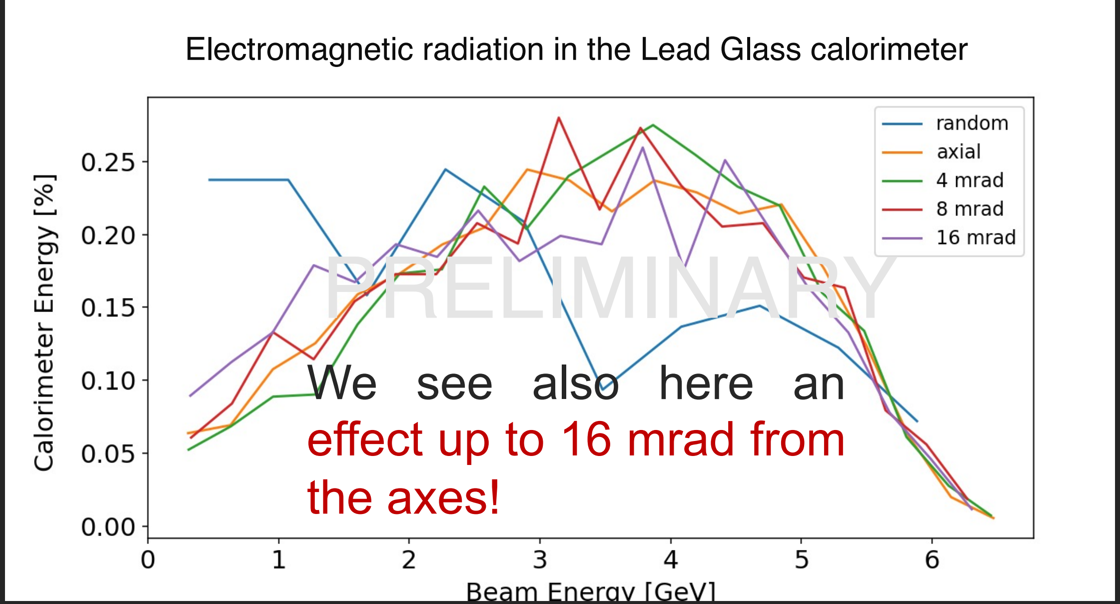
W <111>
1.5 mm





For the **1.5 mm long W** aligned along the **<111> axes** the radiative energy loss distribution **is peaked at 3.3 GeV**, while for the **random orientation is close to 0** as typical for Bremsstrahlung.

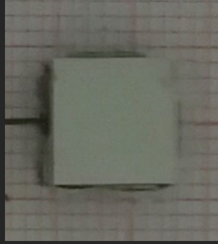

Electromagnetic radiation in the Lead Glass calorimeter

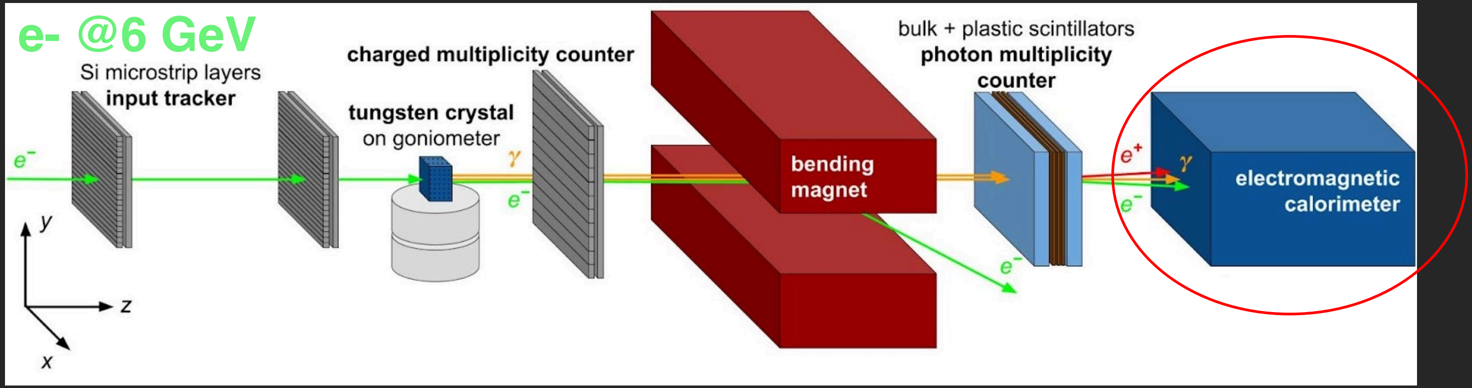

Electromagnetic radiation in the Lead Glass calorimeter

We see also here an effect up to 16 mrad from the axes!

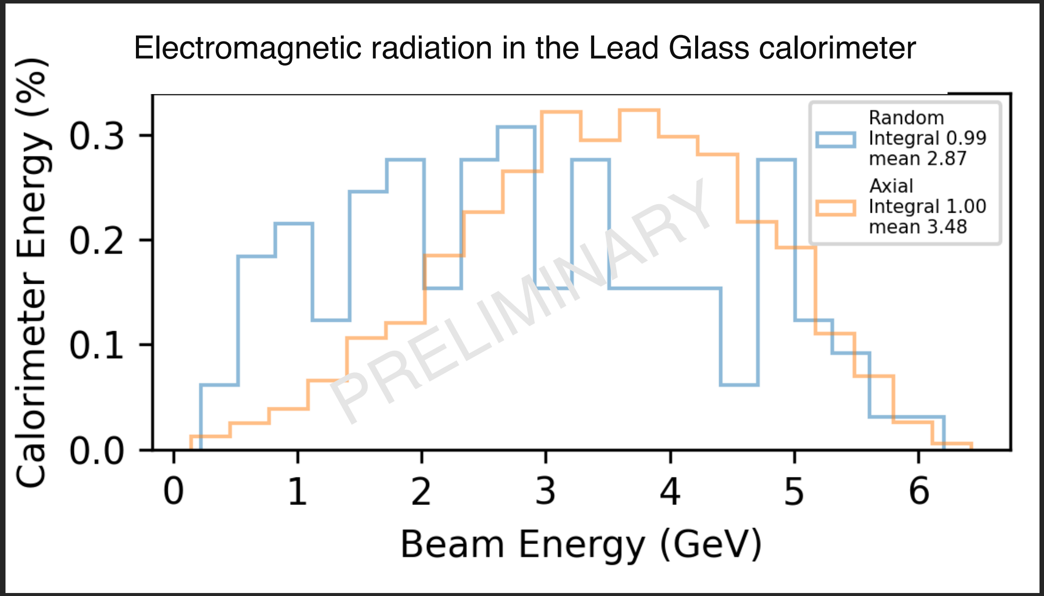
2. Radiated energy loss: calorimeter signal

Ir <110>
2 mm





For the **2 mm long Ir** aligned along the **<111> axes** the radiative energy loss distribution **is peaked at 3.5 GeV**, while for the **random orientation is close to 0** as typical for Bremsstrahlung.

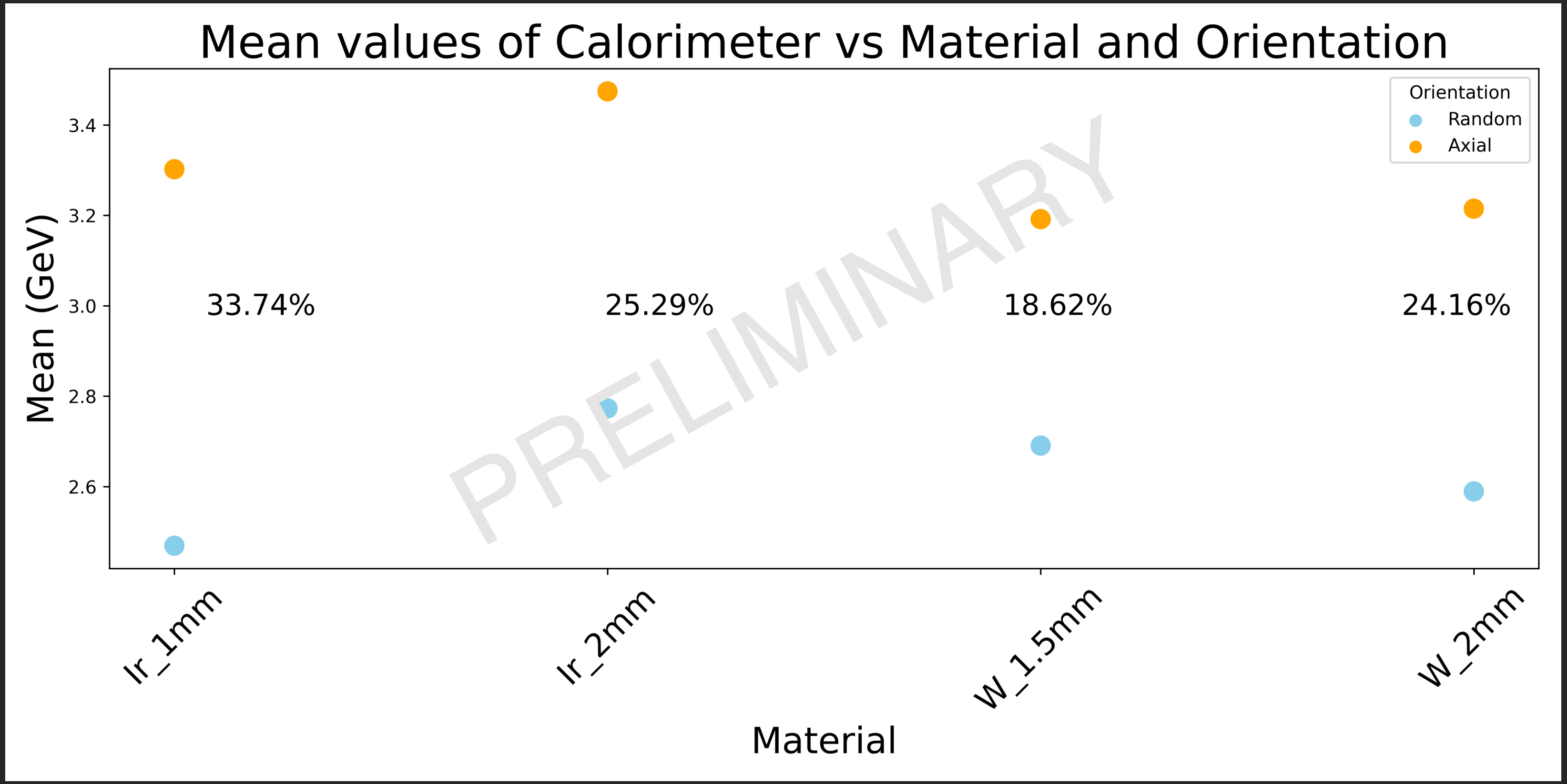


East Area T9 line

Summary table

Mean values of Calorimeter Signal (in GeV)

	Ir 1 mm	Ir 2mm	W 1.5 mm	W 2 mm
Axial	3.3	3.5	3.2	3.2
Random	2.5	2.8	2.7	2.6



Summarizing

Experimental test on radiation emitted by 6 GeV electrons interacting with W and Ir crystals in axial alignment were carried out at the external line T9 of CERN PS

- ☐ Different thicknesses were selected: W 1.5 and 2 mm; Ir 1 and 2 mm.
- ☐ The surface crystal quality was measured via x-ray diffraction.
- ☐ The experimental data can be used to validate MC simulation in Geant4.
- ☐ Some of these crystals can be chosen for the upcoming MAMI irradiation test.

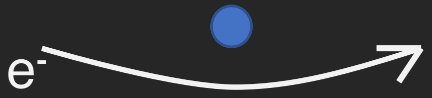
Thank you

The PS T9 line area from above during the night shift

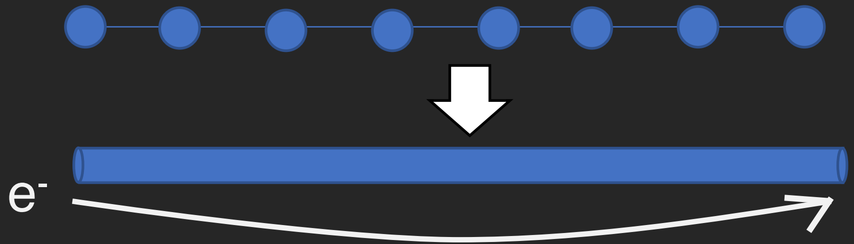
Small backup

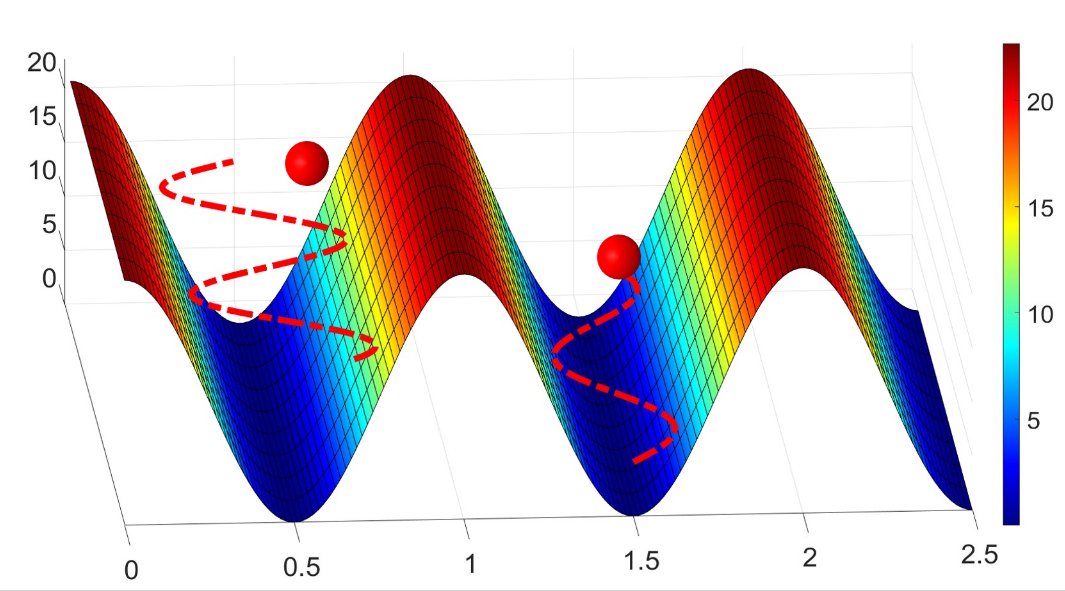
Channeling in linear crystals

Single atom



String of atoms





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

Critical angle for channeling:

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

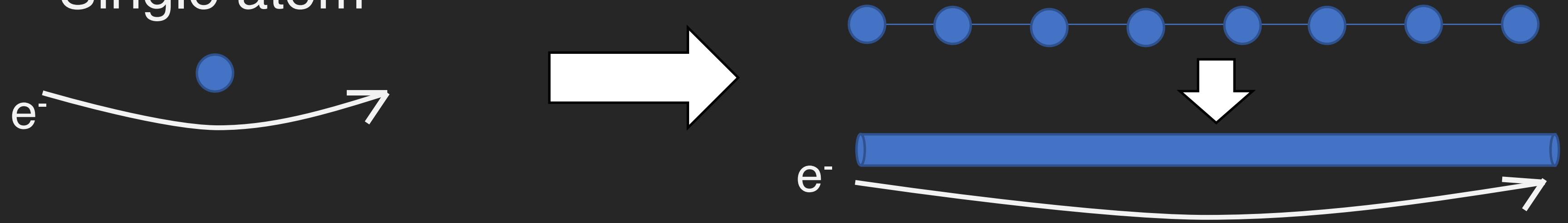
max of the potential well, U(x)

momentum*velocity

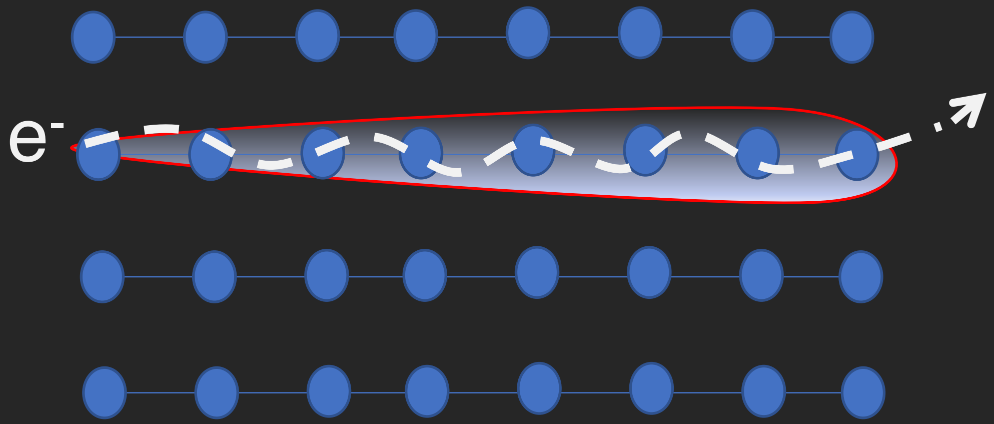
Channeling radiation in linear crystals

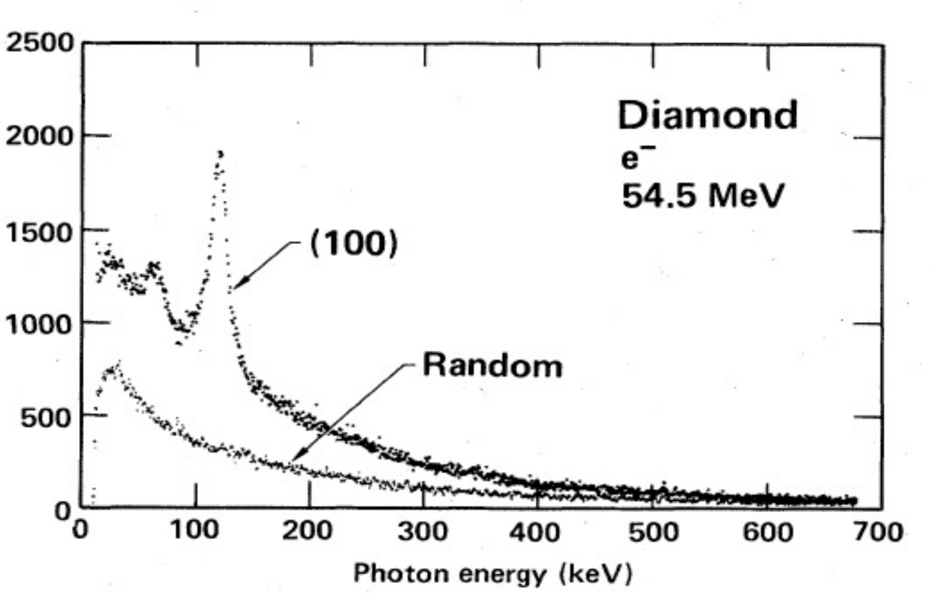
Single atom

String of atoms



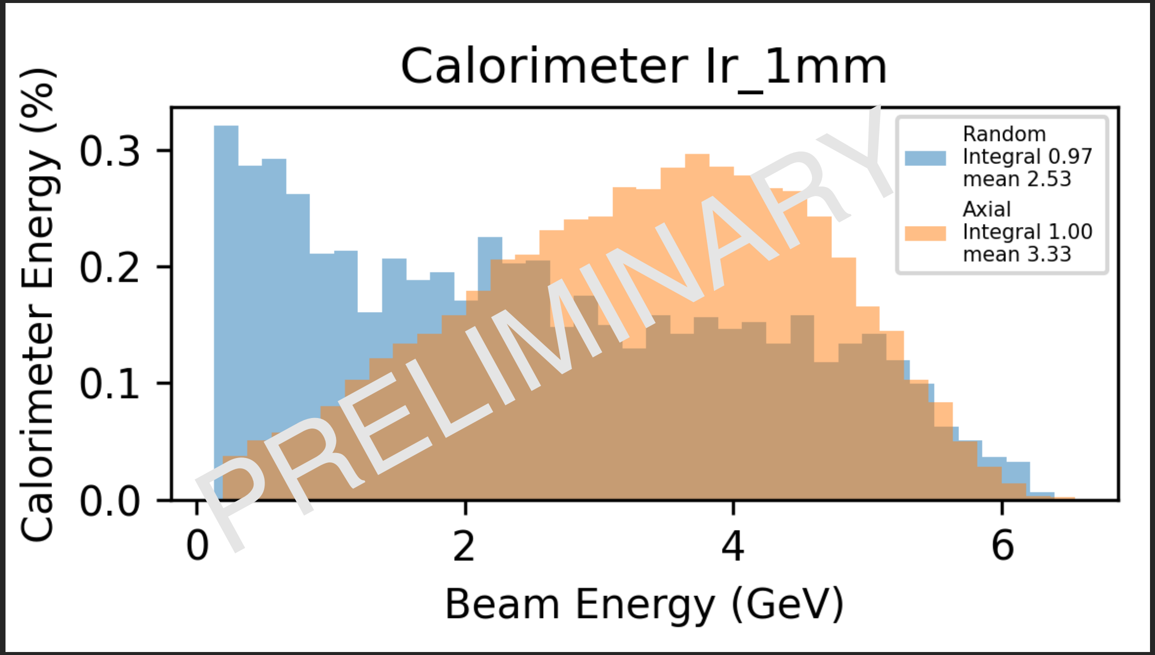
Channeling Radiation (1976, Kumakhov)



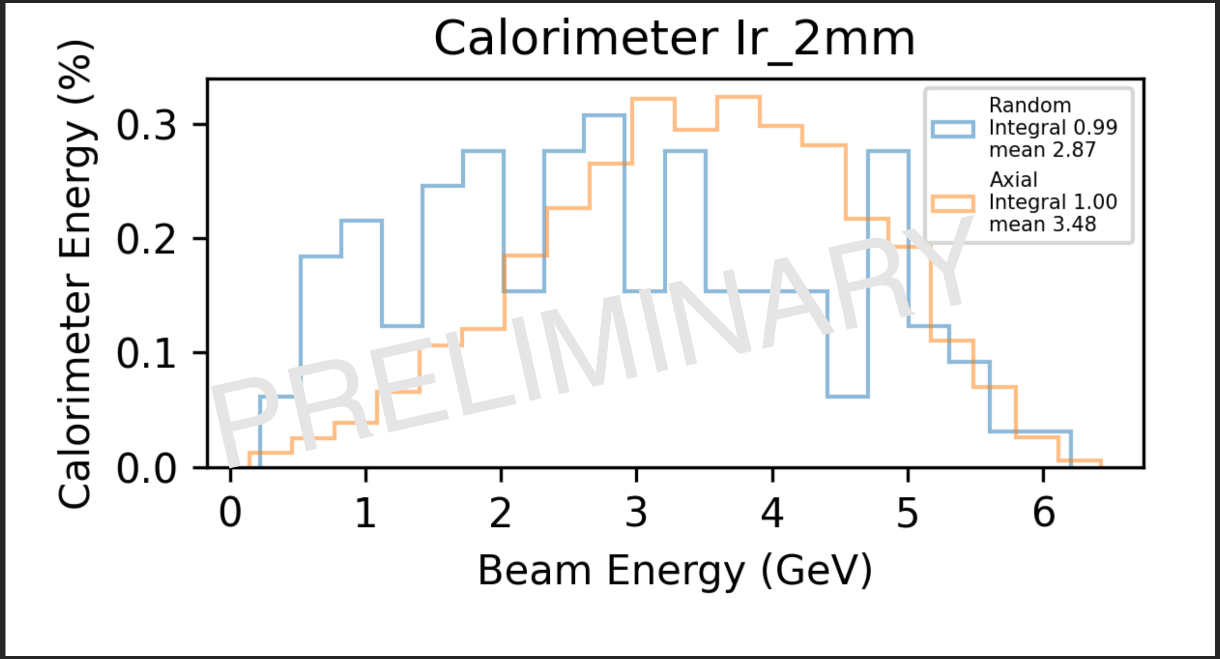


Iridium

2022

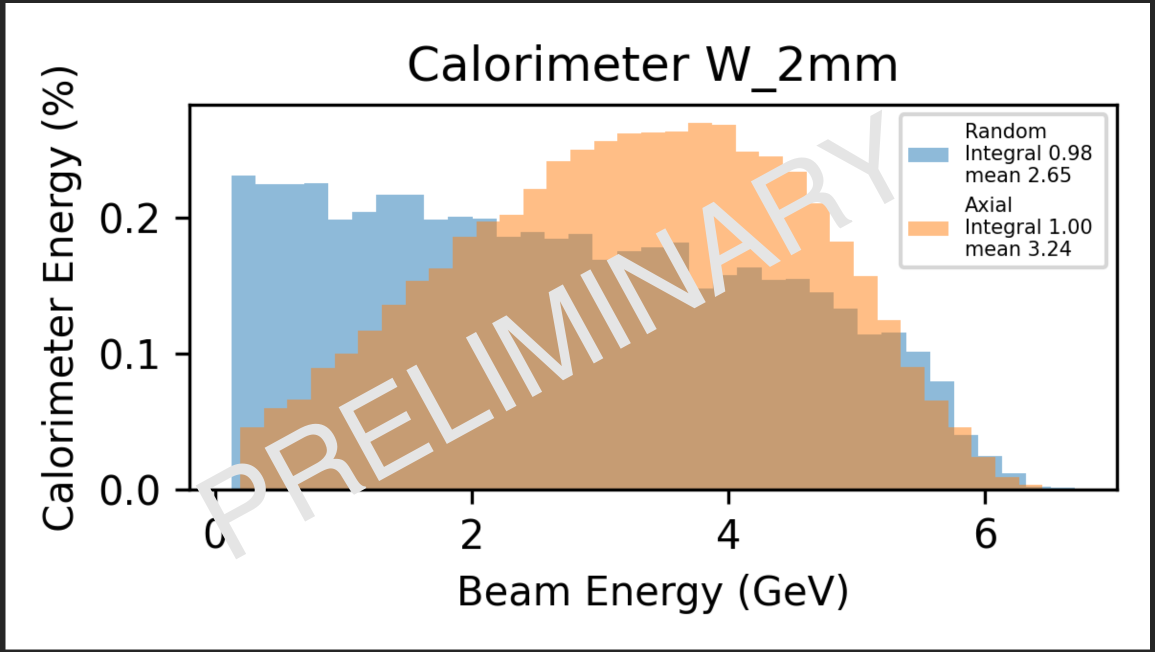


2023



Tungsten

2022



2023