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G.A. 101046458

# TECHNO-CLS EXPERIMENT WITH 6 GEV ELECTRONS AT CERN


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Sezione di Ferrara


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TECHNO-CLS Workshop, Ferrara

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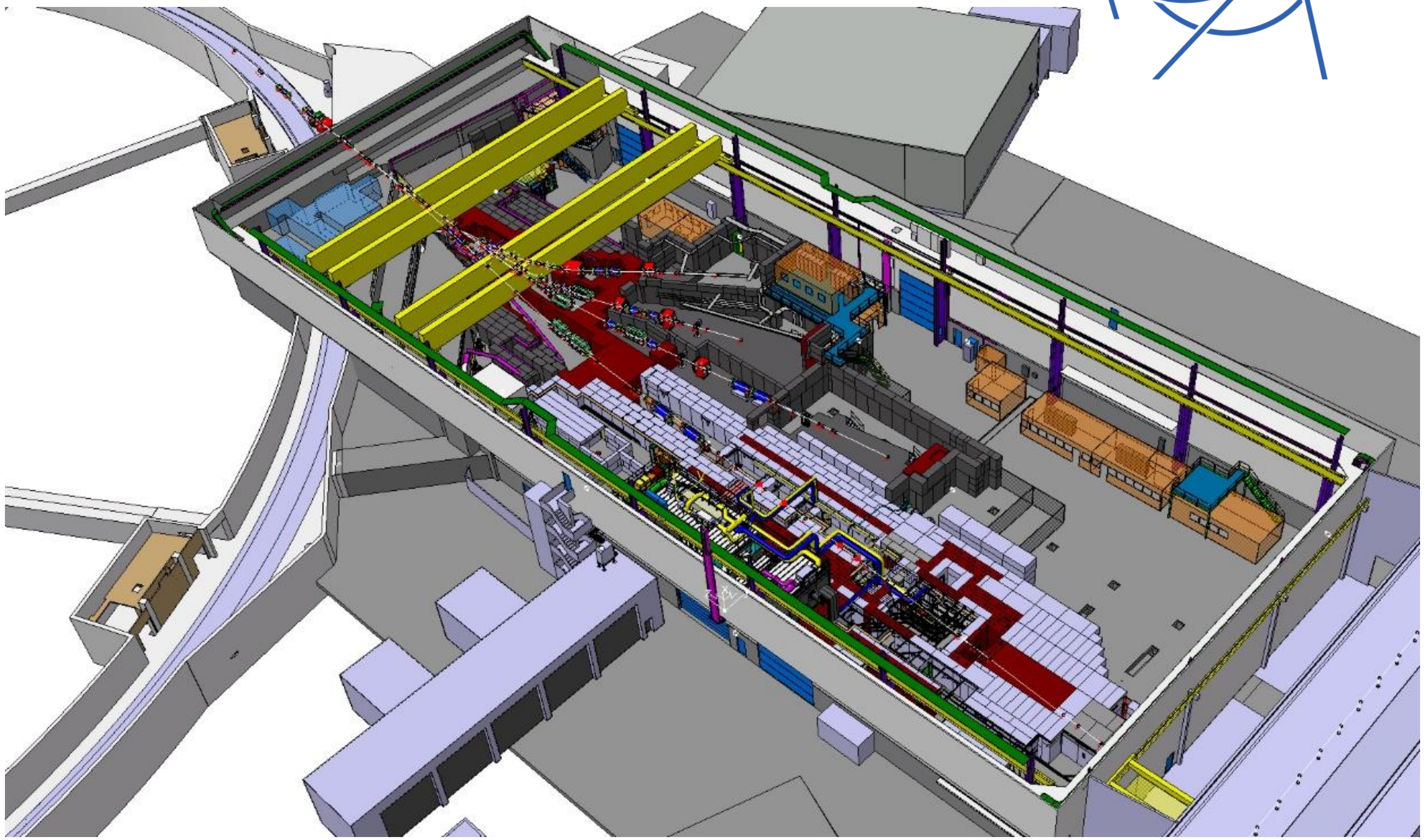
# Why experiments at CERN Proton Synchrotron?

1-15 GeV electrons and positrons available: currently (together with CERN SPS) the only available facility with positrons at energy > 10 GeV*.

Multi-GeV positrons would permit to test Large Period Large Amplitude Undulators realized within TECHNO-CLS



*see N. Charitonidis (CERN) talk this afternoon

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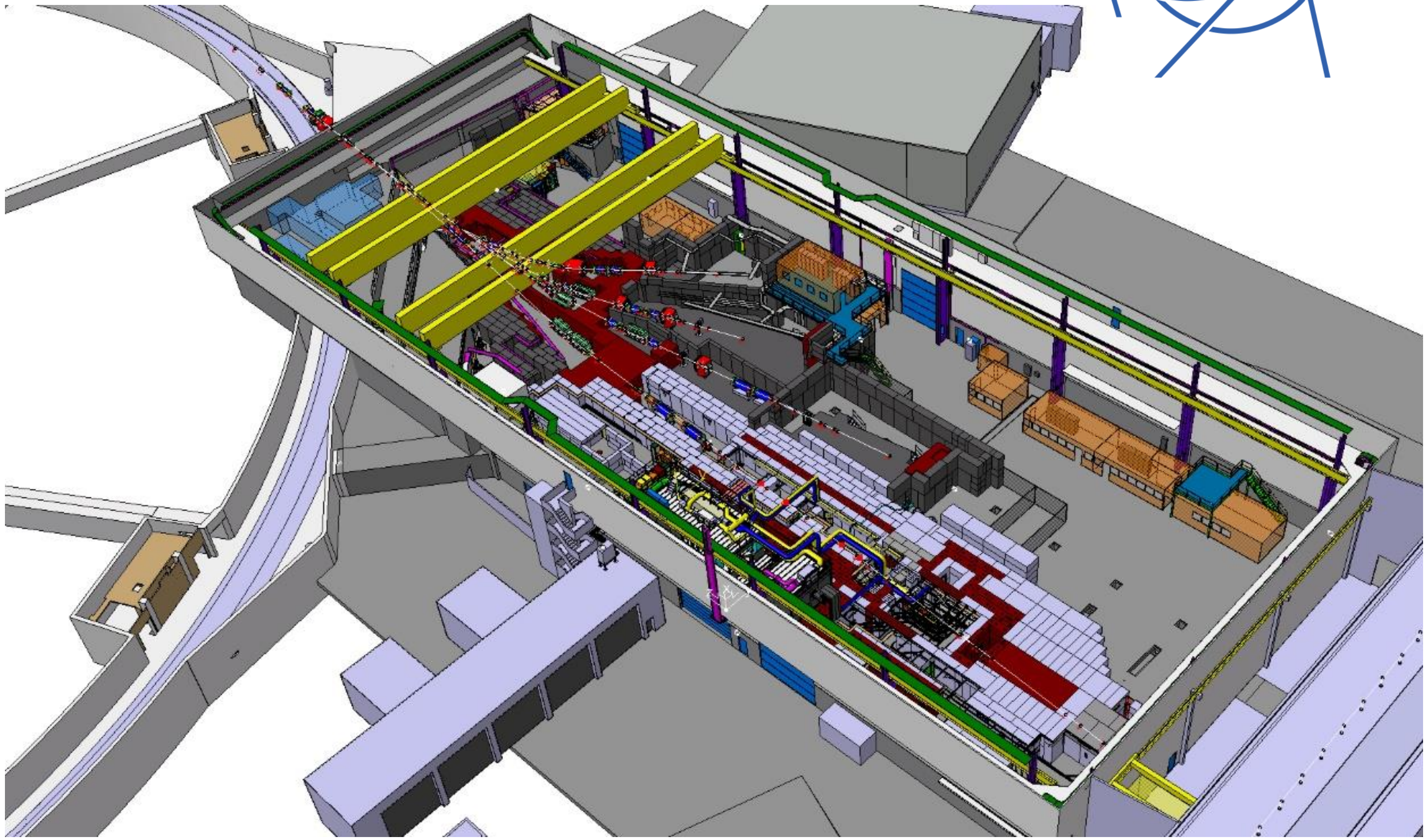
# Why experiments at CERN Proton Synchrotron?

1-15 GeV electrons and positrons available: currently (together with CERN SPS) the only available facility with positrons at energy > 10 GeV*.

The beams are secondary and tertiary with parameters not ideal to test crystalline undulators



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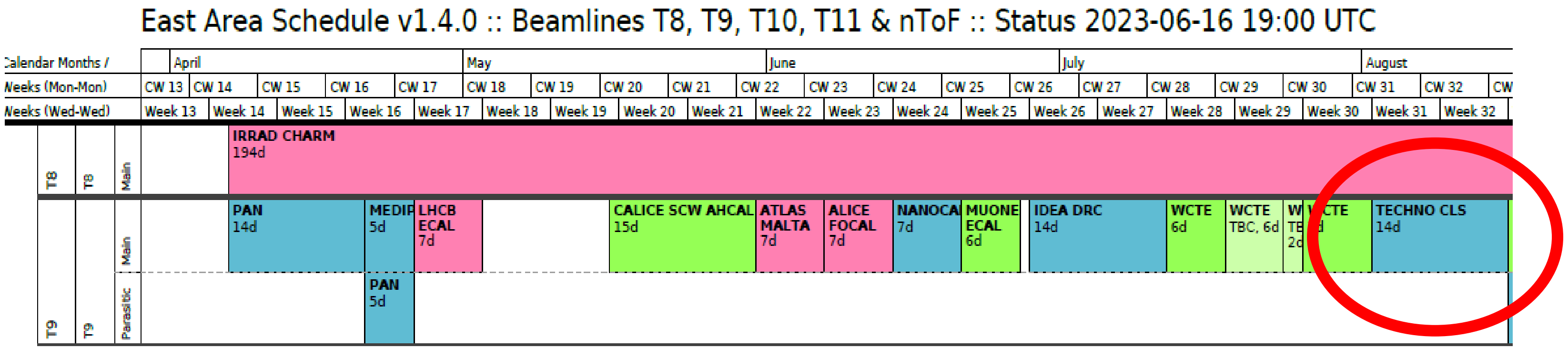
# Experiment at CERN PS T9 in August 2023

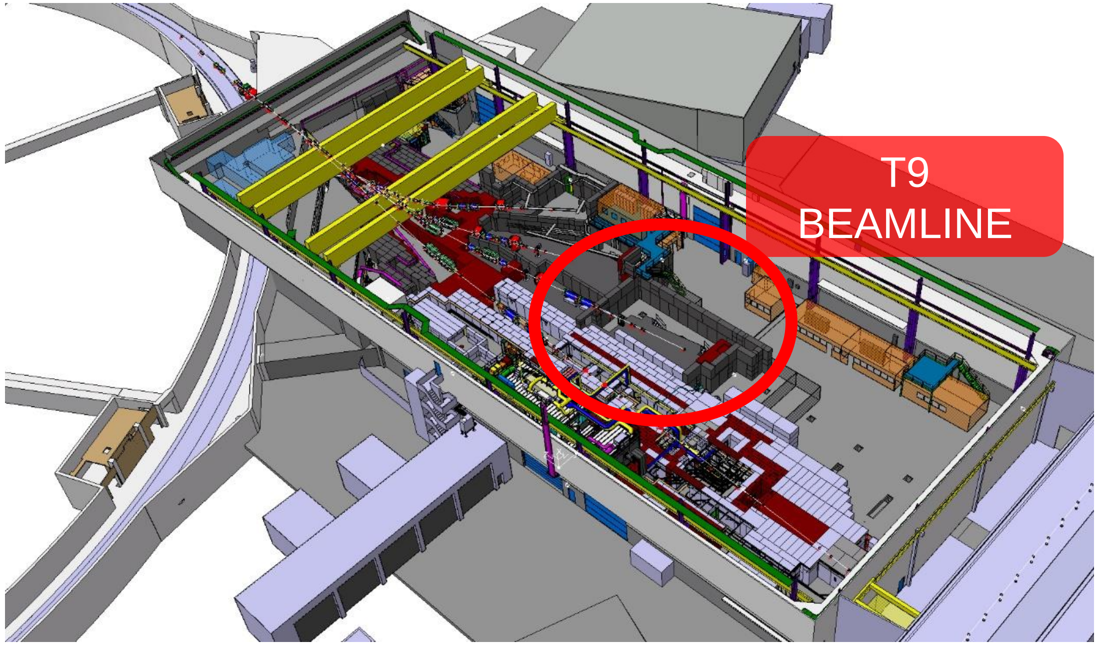



Participation to the December 2022 call:

- requested 2 weeks with 5-10 GeV secondary electrons/positrons

Highly competitive call – we succeeded!!

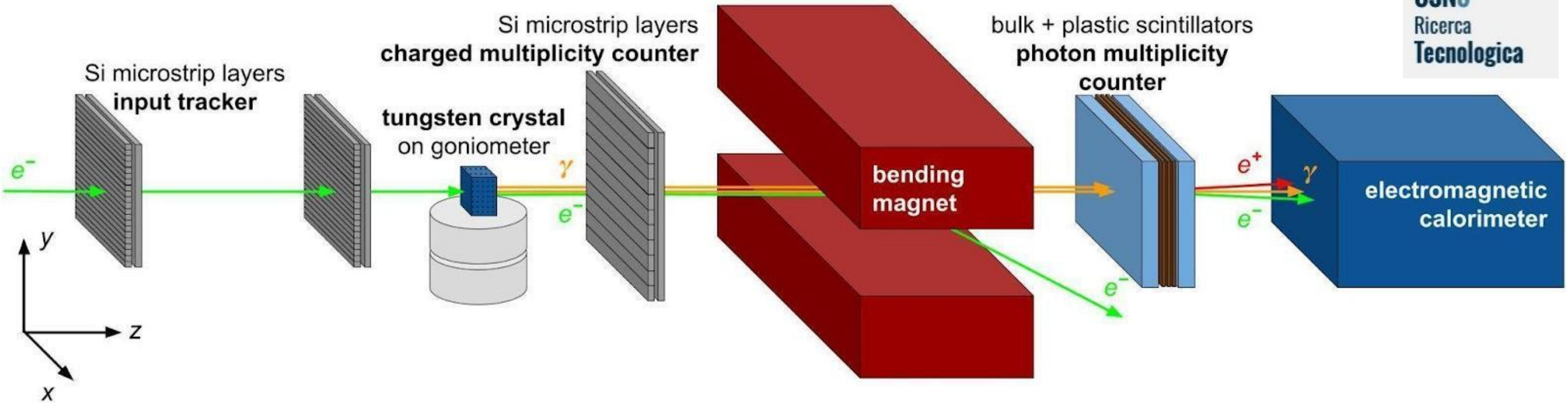
**Leader of the experimental RUN: E. Vallazza (INFN MiB) and L. Bandiera (INFN Ferrara)**



# Experimental setup @CERN PS T9

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

**Electron** at ***6* GeV/*c***




**The setup is versatile and has already been used also at CERN SPS and at DESY Test Beam Facility**

# the setup   input stage

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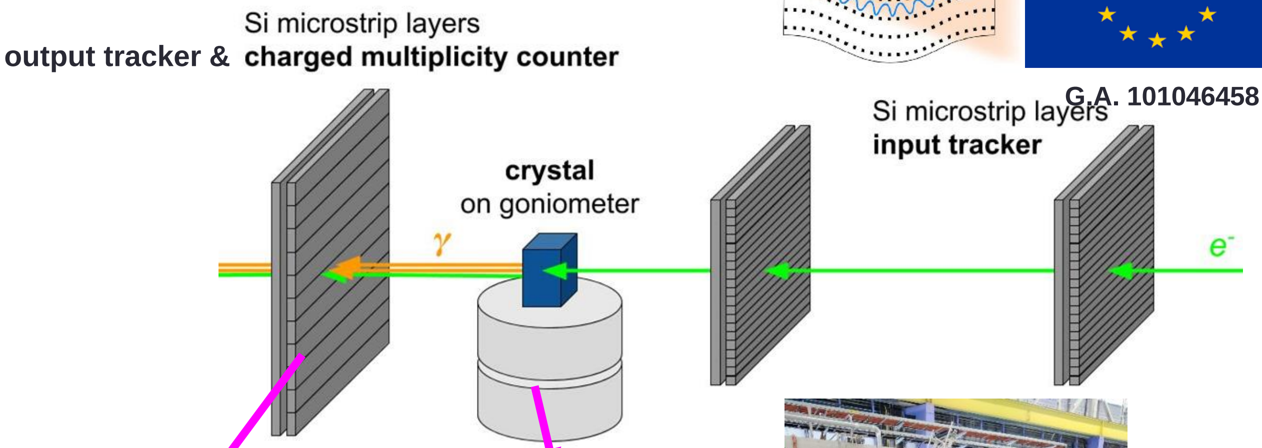
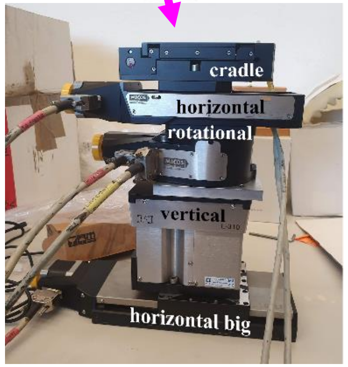



**input tracker**
~2×2 cm² *xy* double-sided Si microstrip sensors, with an overall ~10 μm single-hit resolution




**output tracker & charged multiplicity counter**
pair of ~10×10 cm² single-sided Si microstrip sensors, with an overall ~35 μm single-hit resolution


**Goniometer @LNL &UNIPD**
fine-grained, remote-controlled movements along $x$, $y$, $\theta_x$ and $\theta_y$ with ~5 μm/μrad resolution

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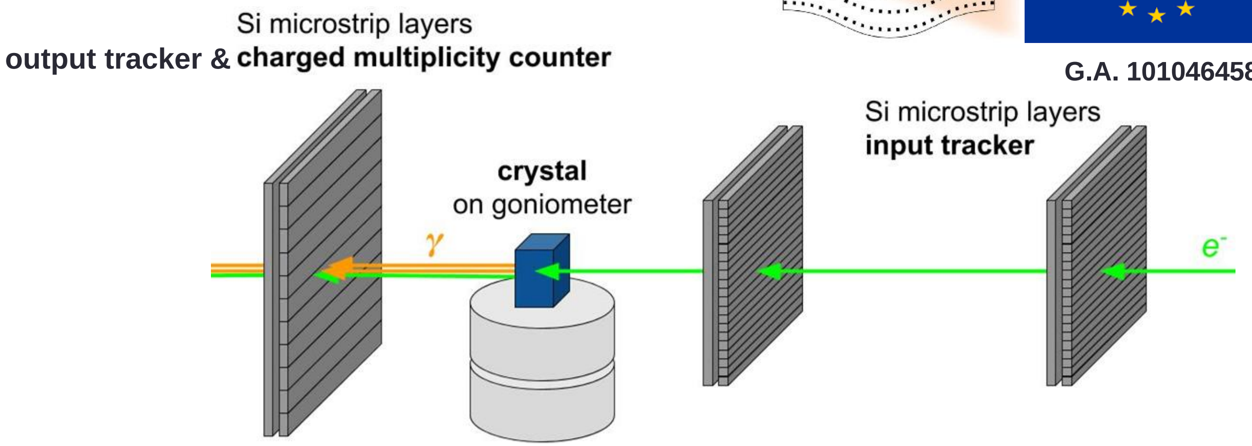
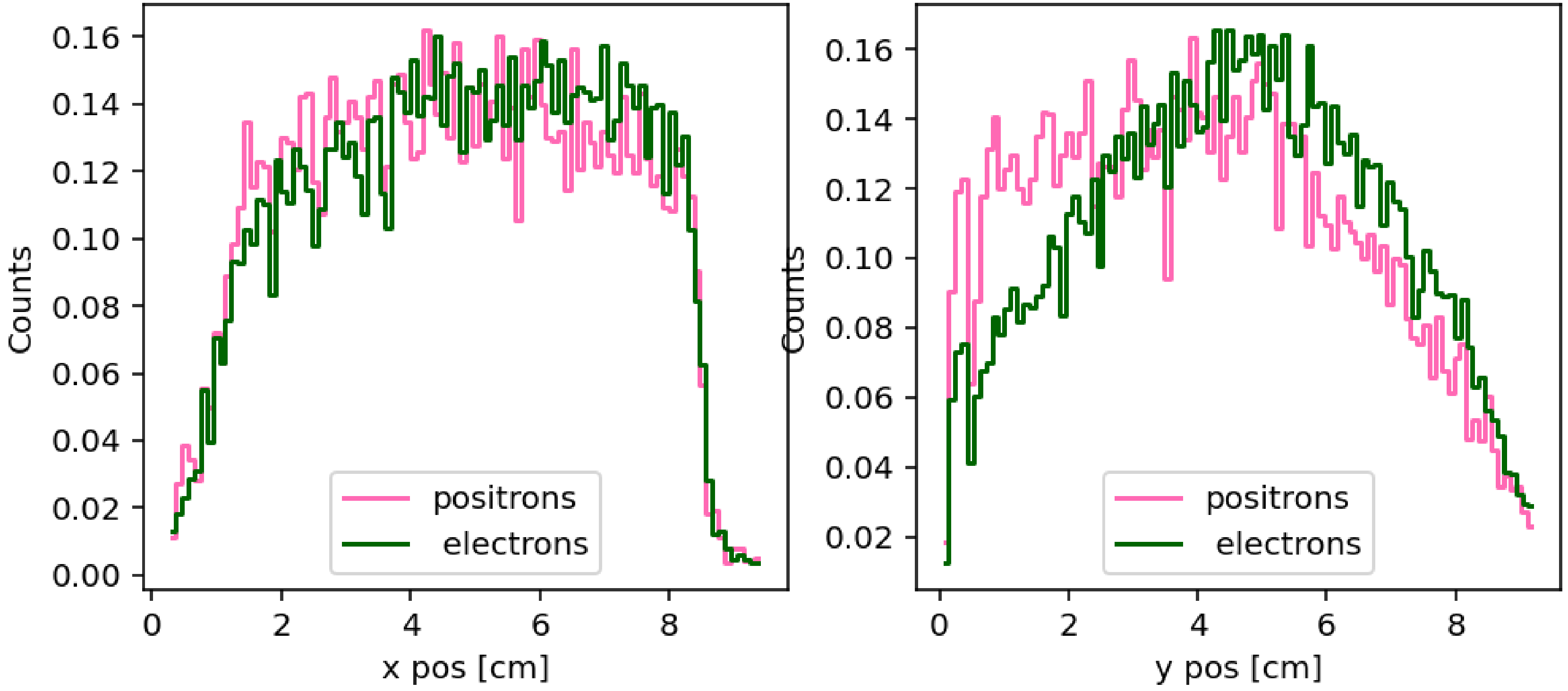
# the setup **the beams**




## 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***

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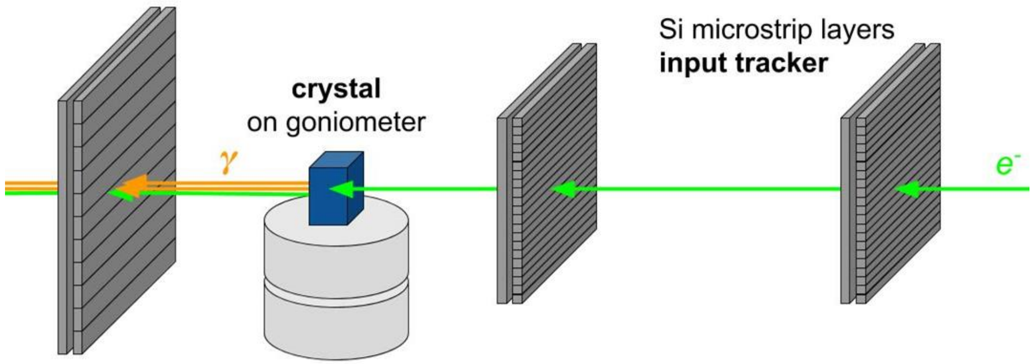
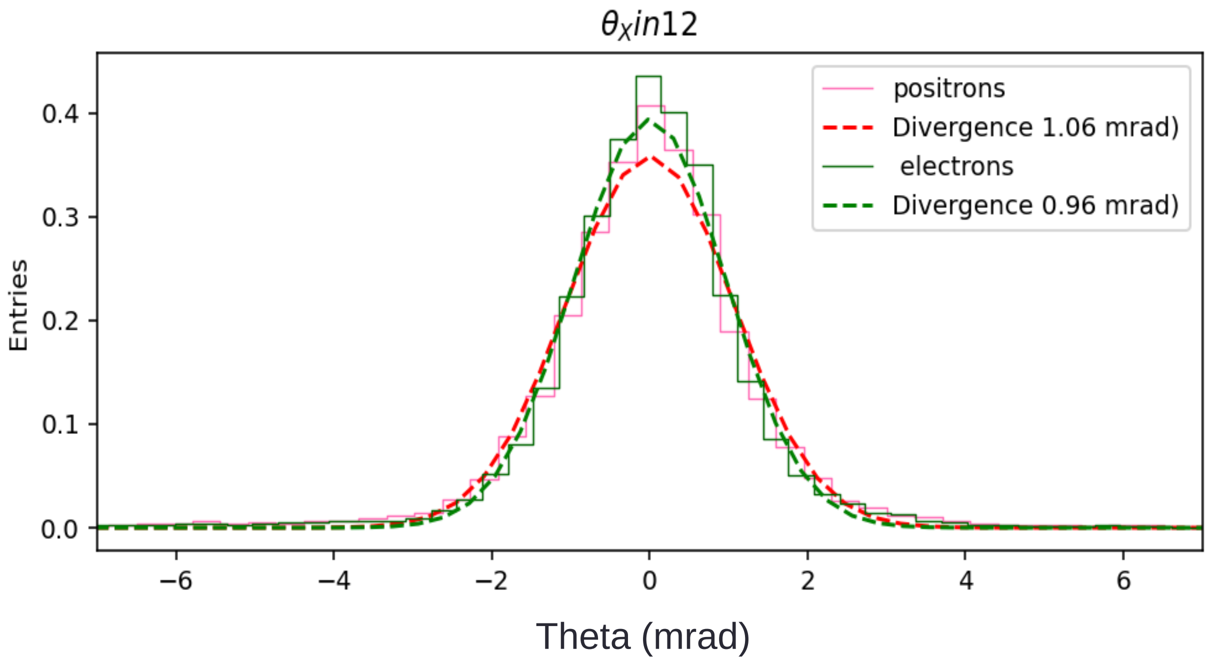
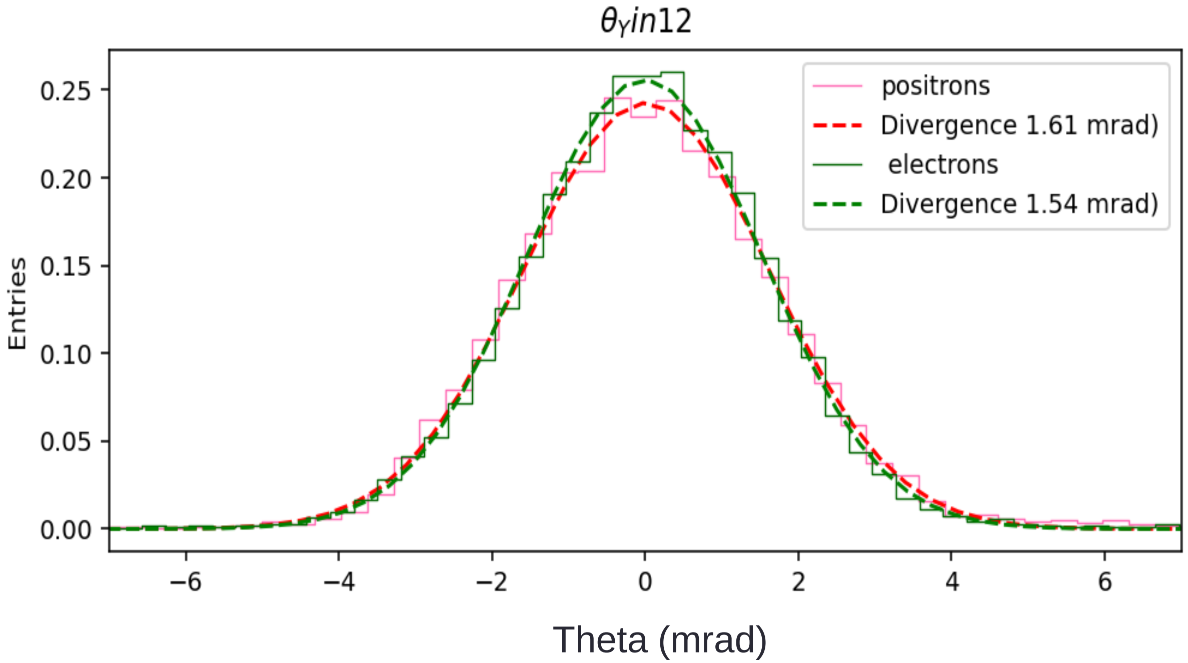
# the setup **the beams**




## 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***

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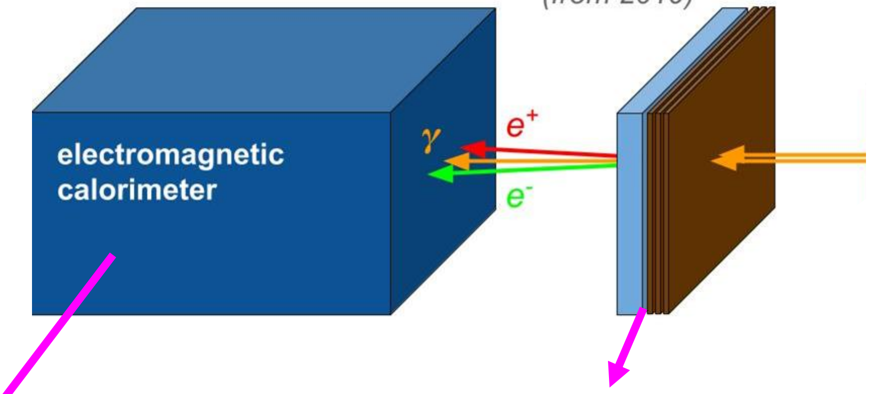
# the setup output stage

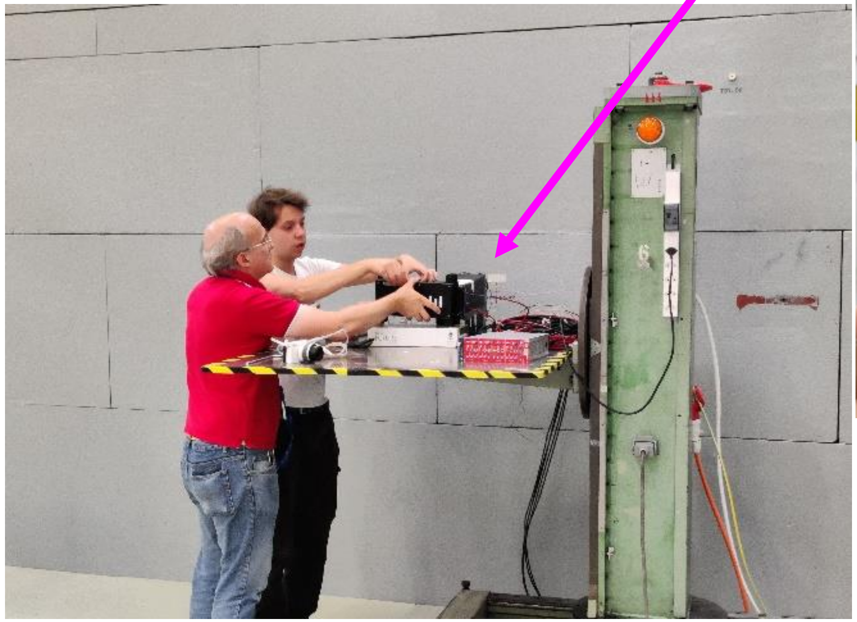
different **calorimeters** can been exploited:

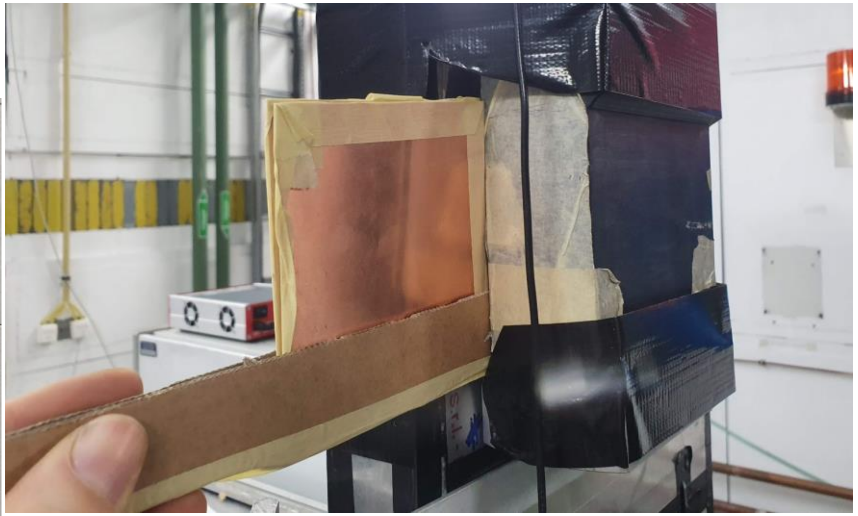
- 3×3 matrix of PWO blocks from the CMS endcap, SiPM-based readout
- **(OPAL) Pb glass blocks read out by PMTs**
- 3×3 matrix of BGO blocks, PMT-based readout

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

bulk + plastic scintillator
**photon multiplicity counter**
*(from 2019)*

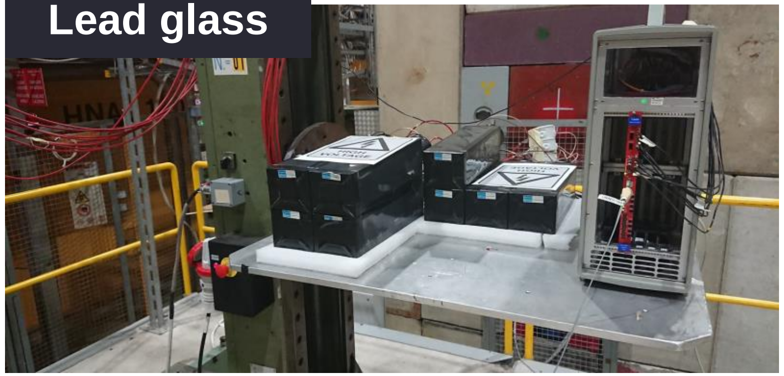




APC

Lead glass



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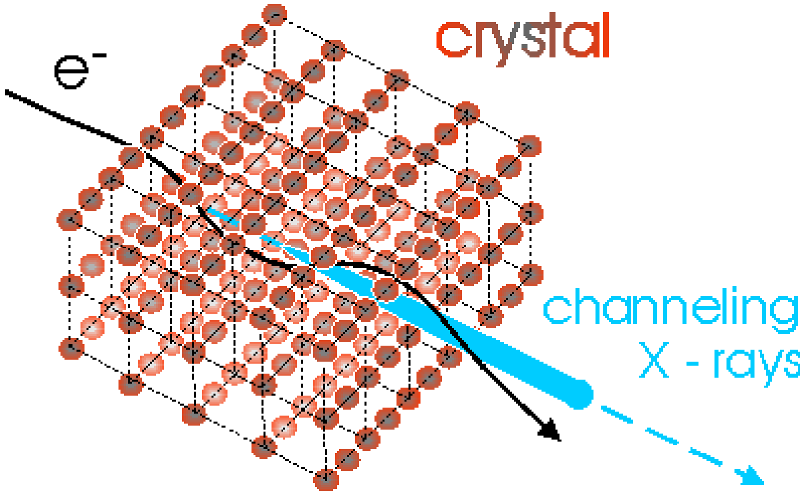
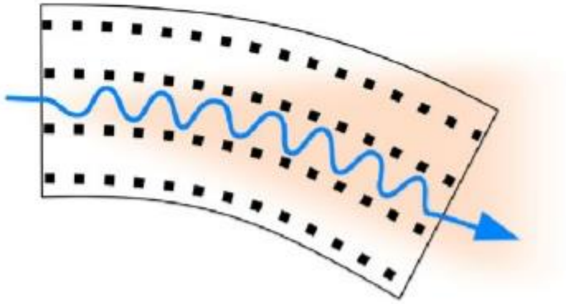
# Which Crystal Light Source to test?

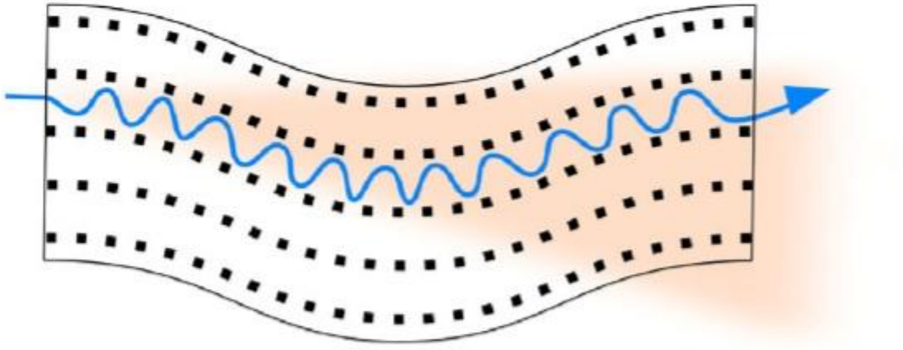
## Linear




## bent



## periodically bent



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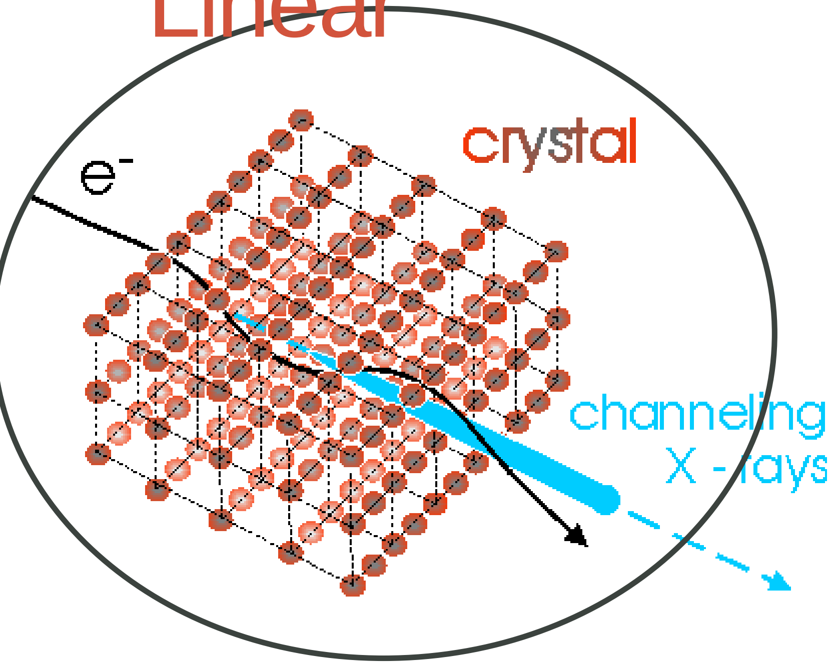
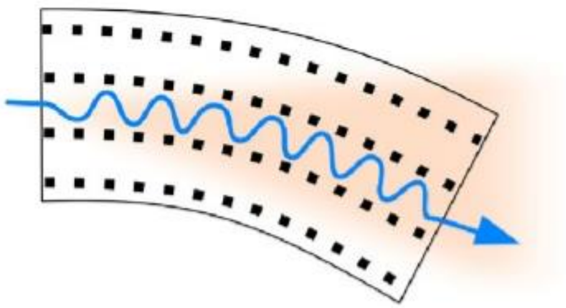
# Which Crystal Light Source to test?

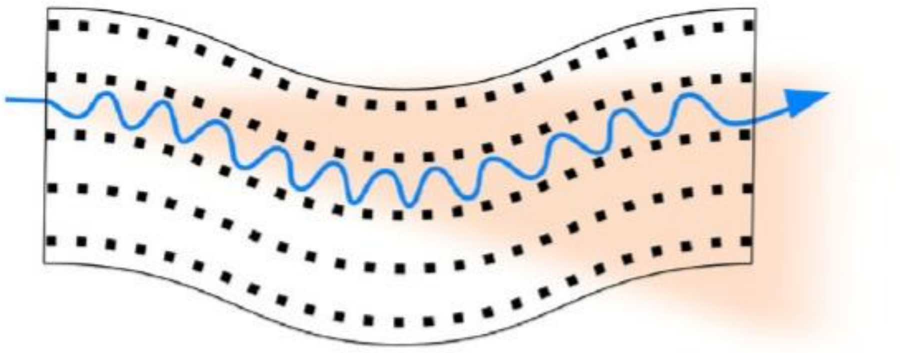
## Linear




## bent

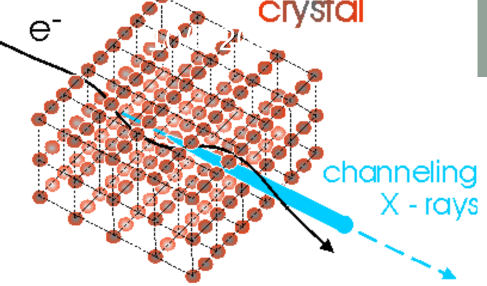


## periodically bent



For the first test we focused on linear crystals:

- ❑Already available experimental setup;
- ❑Samples ready to be tested;




# Channeling in linear crystals

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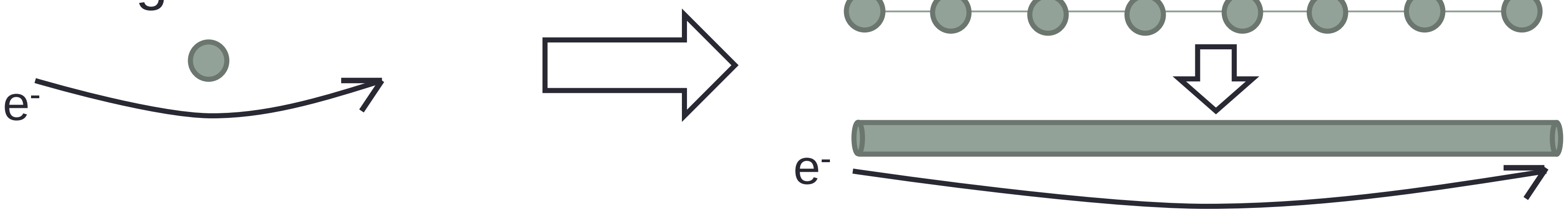
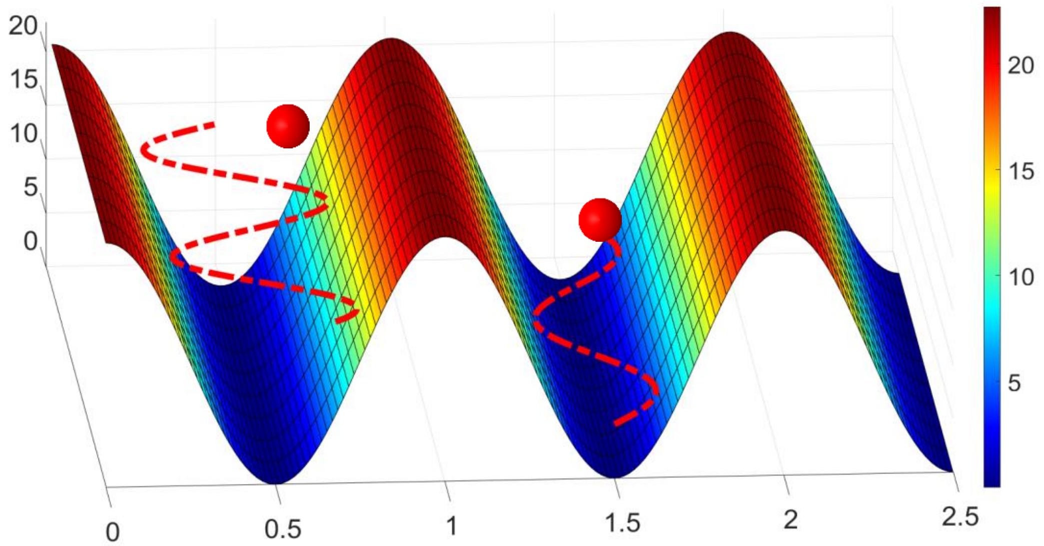
Single atom

String of atoms



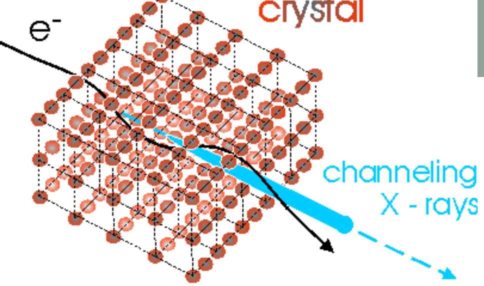

J. Lindhard, K. Dan. Vidensk. Selsk. Mat. Fys. Medd. 34 (1965) 14.

**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

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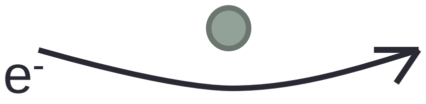
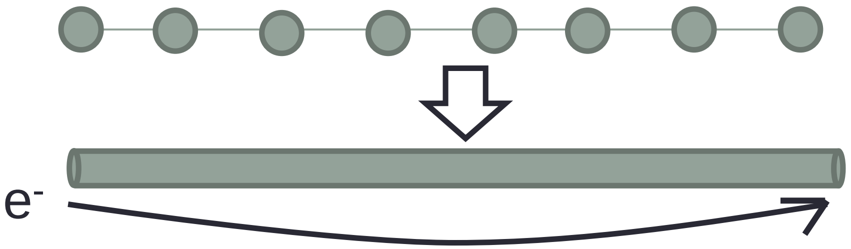
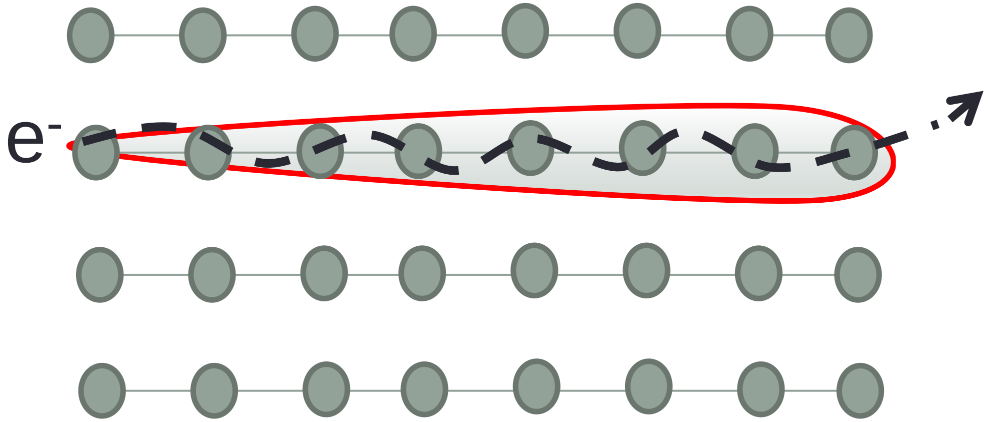
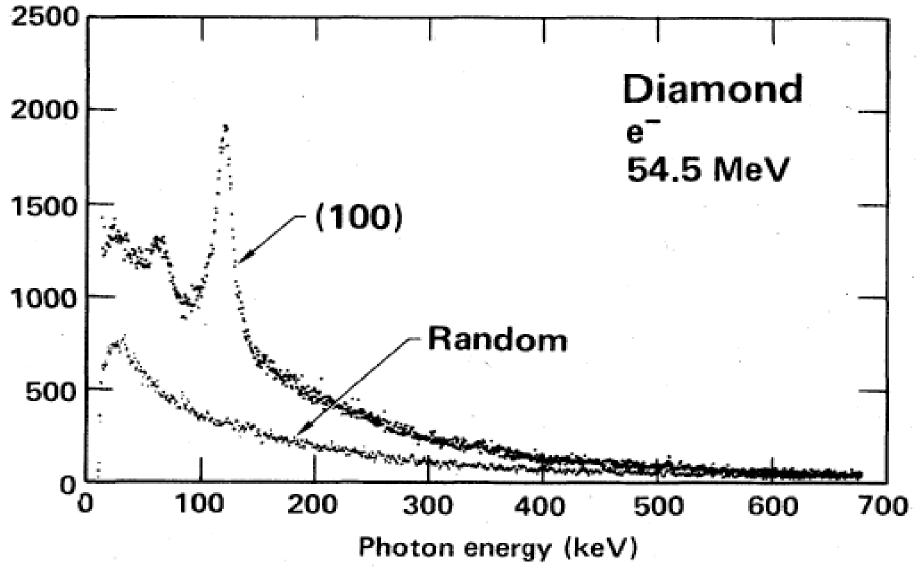



## Channeling Radiation (1976, Kumakhov)



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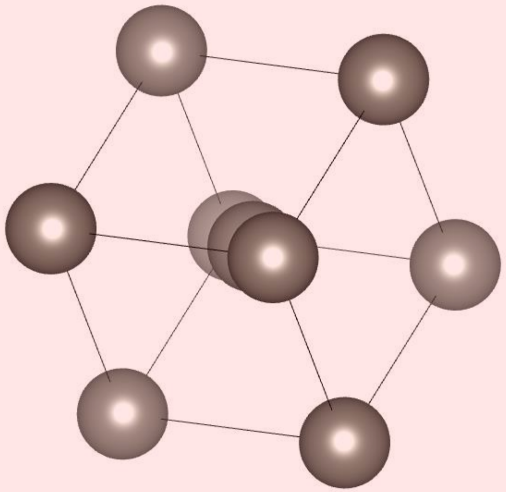
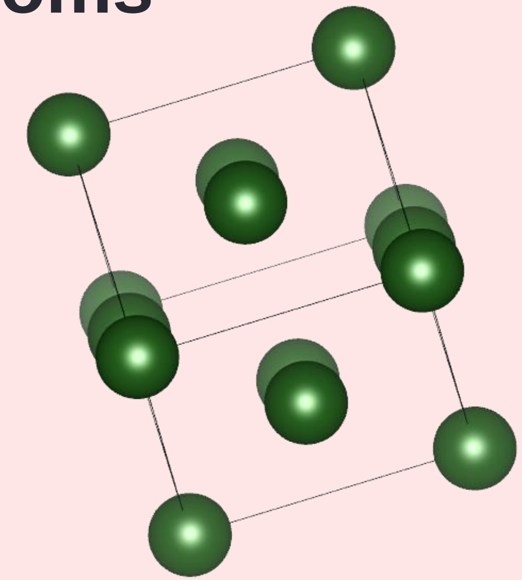
# Exploration of **NEW MATERIALS** beside Silicon and Germanium

## 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!***

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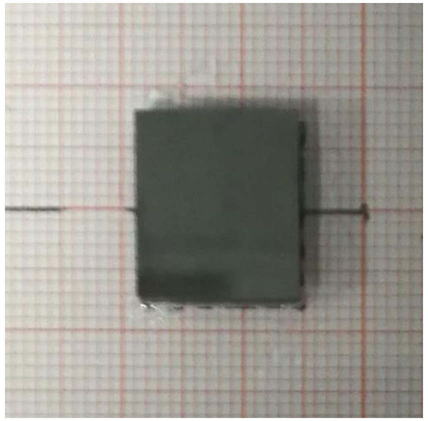
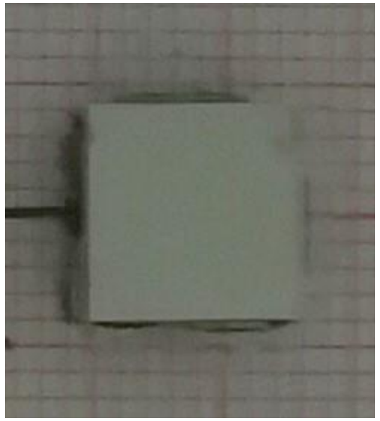
# Exploration of **NEW MATERIALS** beside Silicon and Germanium

**1.**



**2.**



**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**: 2 mm (0.6 of W Radiation Lenght)

**Material**: Iridium (1x7x8 mm)
**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 mm (0.3 of Ir Radiation Lenght)

***Very high-density material!***

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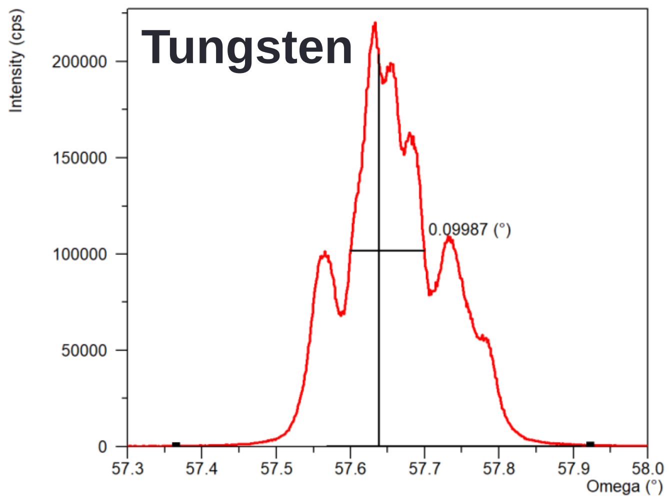
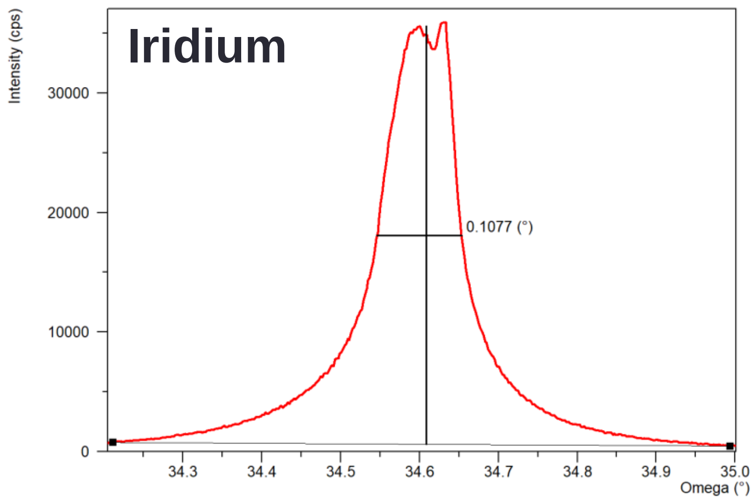
# Samples Characterization

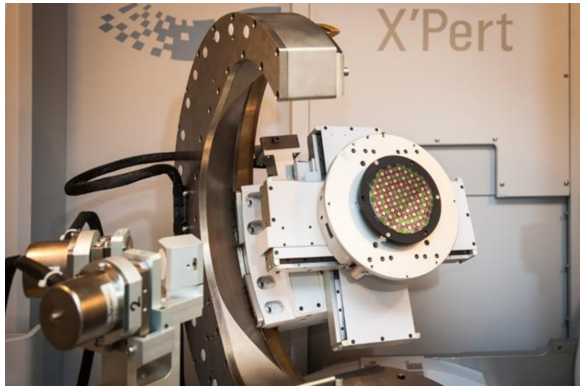
## X-ray diffraction Rocking Curve

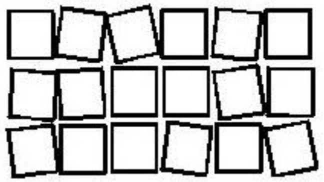


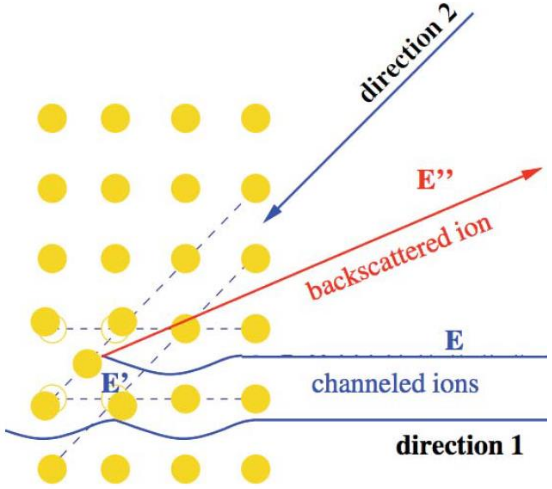

Characterization of superficial mosaicity performed with **High Resolution XRD at Ferrara lab (@8.04 keV)**

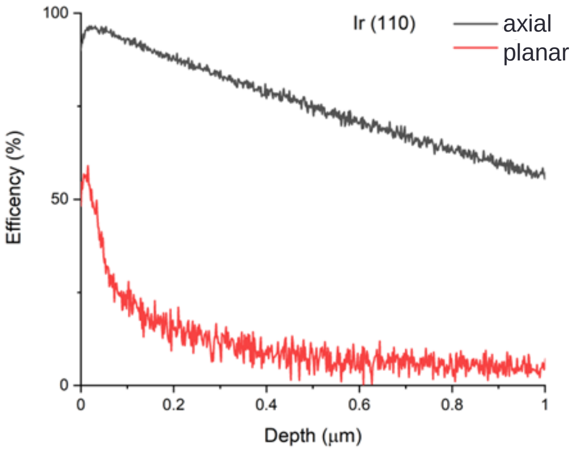
**FWHM ≤ 2 mrad – larger than Channeling Angle -> big contribution of quasi-channeled particles in radiation (low monochromaticity!)**



## Rutherford BackScattering with 2 MeV alpha particles in channeling



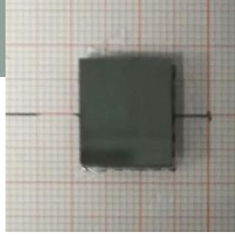



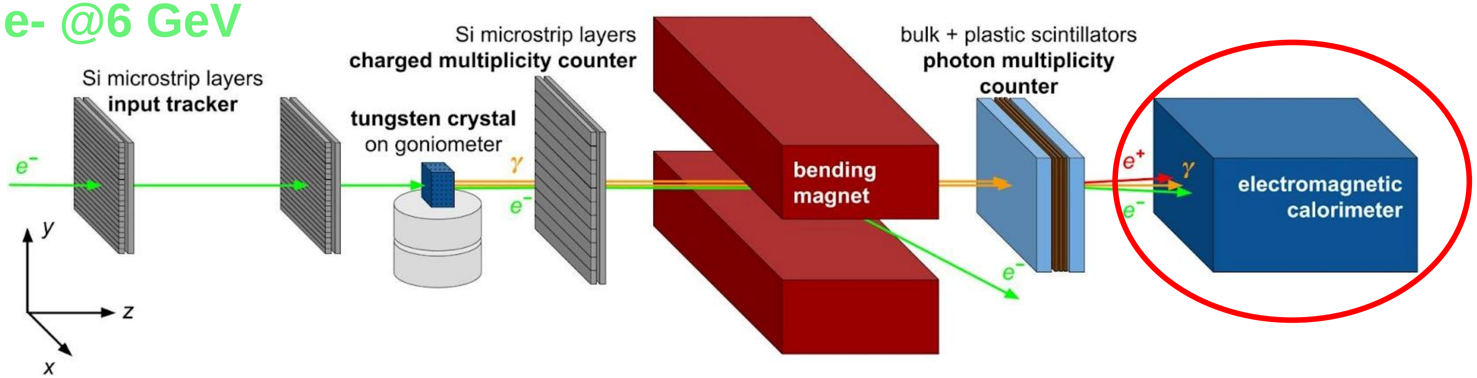


Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

# 1. Radiated energy loss: calorimeter signal

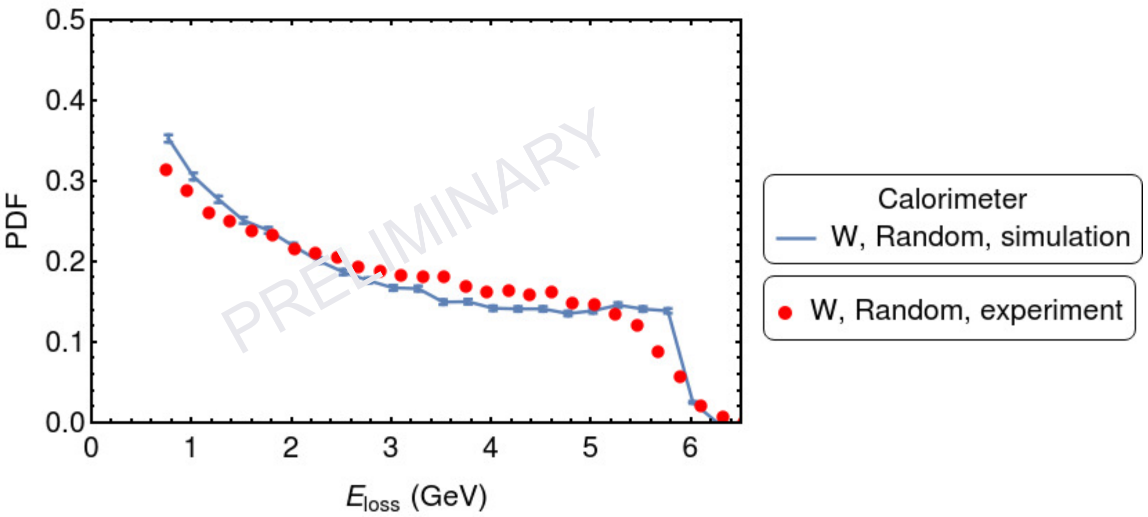
**W <111>**
**2 mm**

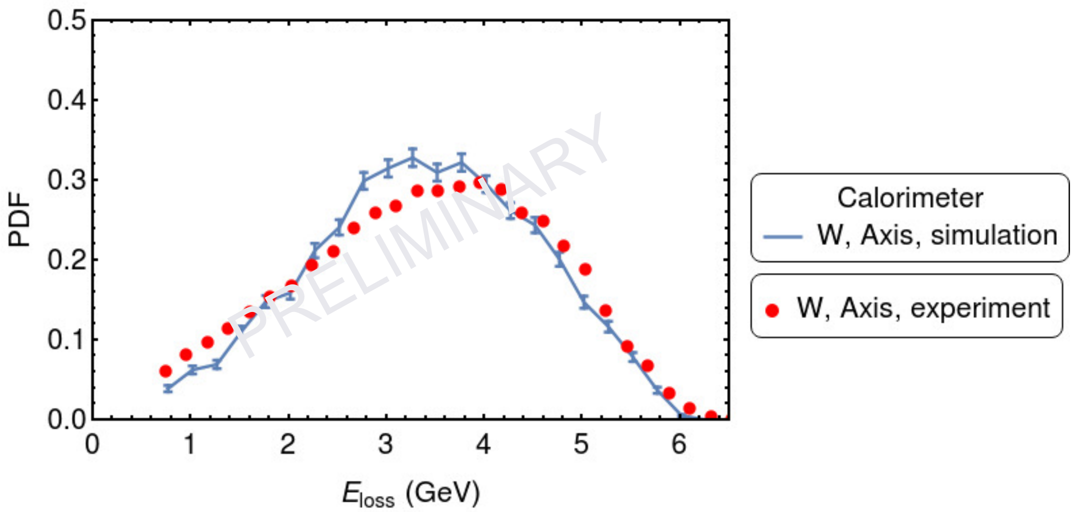





For the **2 mm long W** aligned along the **<111> axes** the radiative energy loss distribution **is peaked at 3.6 GeV**, while for the **random orientation is close to 0** as typical for Bremsstrahlung.

electromagnetic radiation in the Lead Glass calorimeter

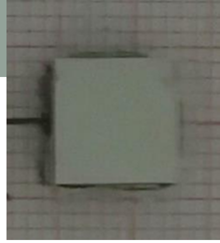


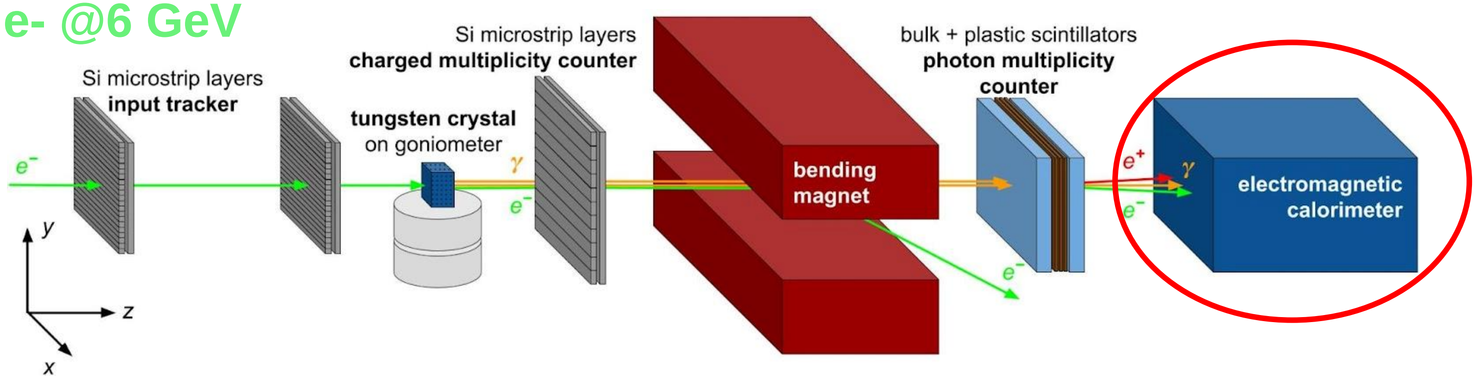

**East Area T9 line**

# 2. Radiated energy loss: calorimeter signal

**Ir <110>**
**1 mm**

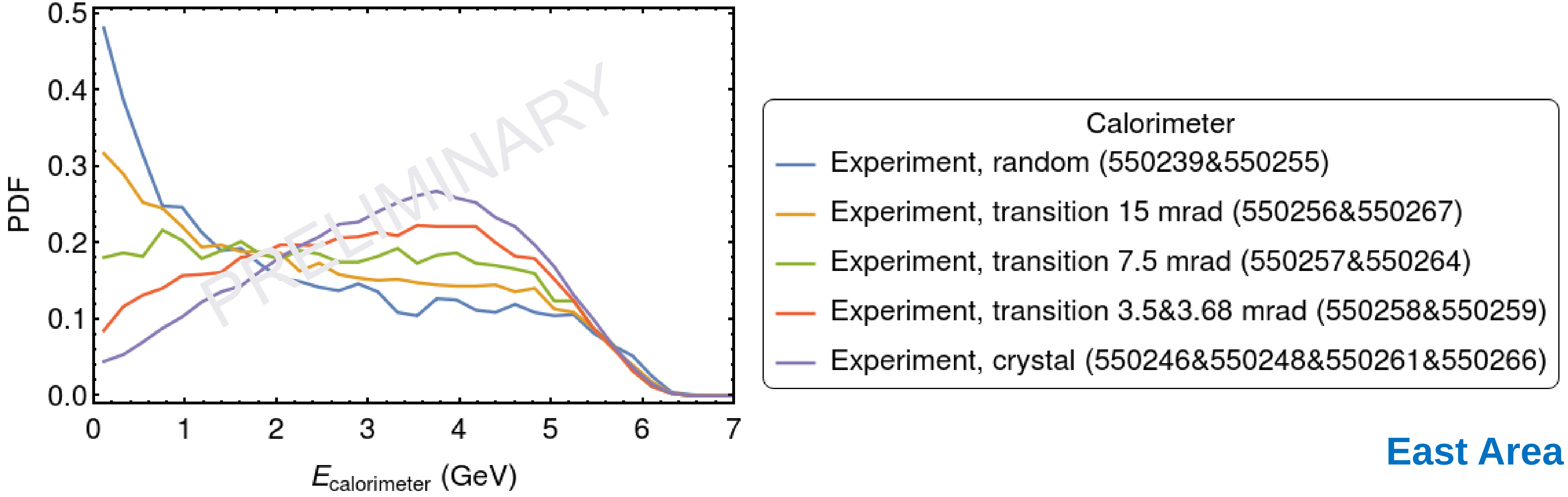


e- @6 GeV




For the **1 mm long W** 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!

electromagnetic radiation in the Lead Glass calorimeter




**East Area T9 line**

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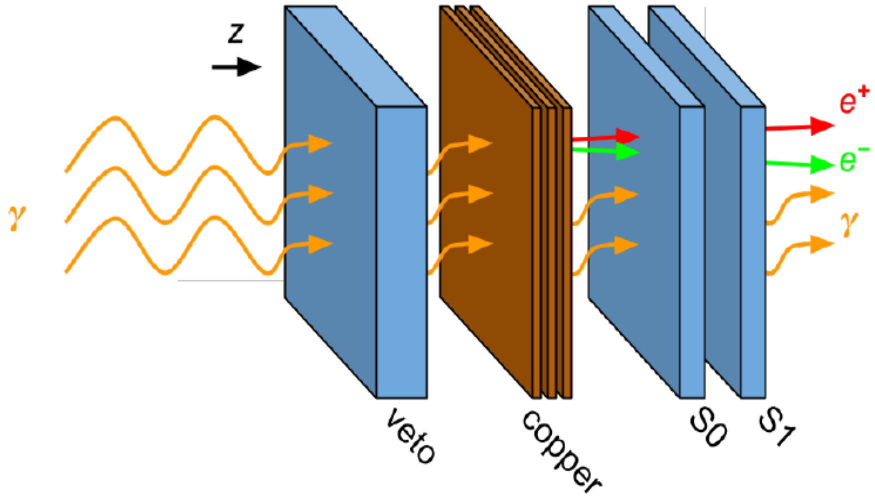
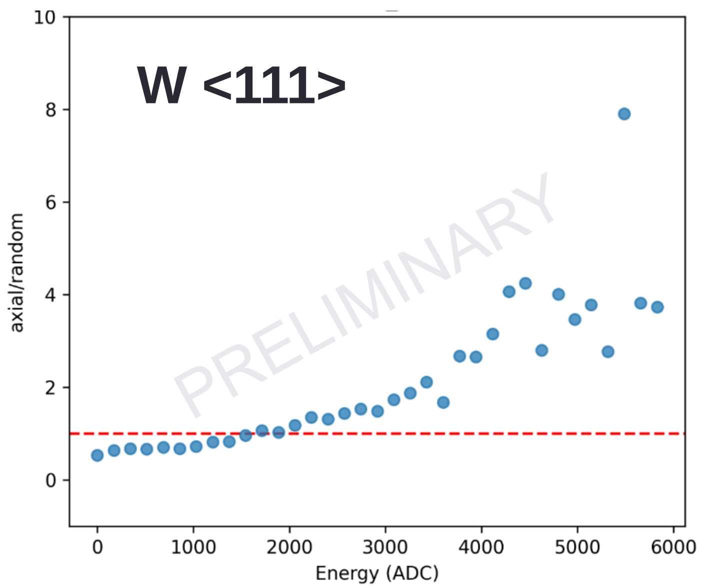
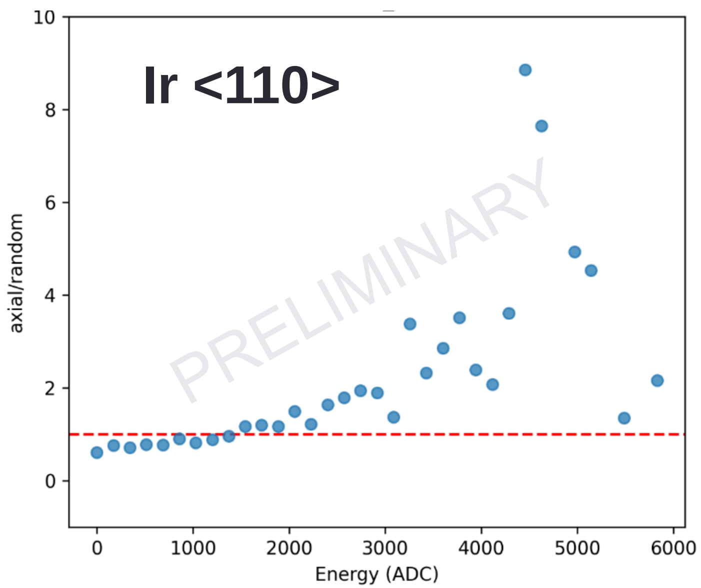
# "Counting" the number of photons

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



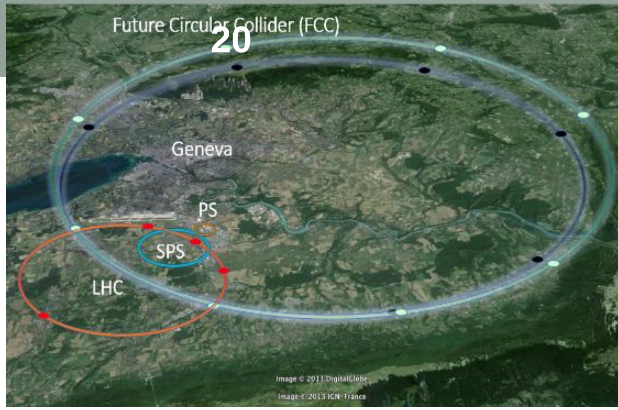




- An **estimate of the number of photons that emerge from the crystal was obtained via an Active Photon Converter**, which consisted of plastic scintillators placed upstream (for photon veto) and downstream (for electron-positron pair multiplicity measurement) with respect to a converter layer (0.2-0.4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

# Possible applications

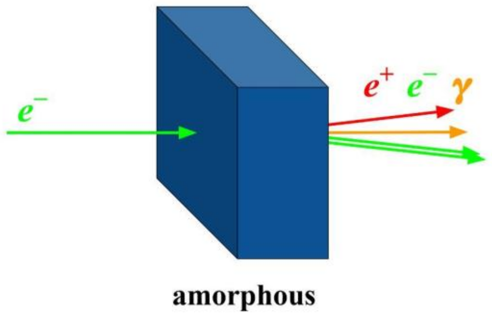



- **Intense gamma-ray source** exploiting the strong crystalline potential of a high-Z material;

- **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 ➔ enhanchement 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

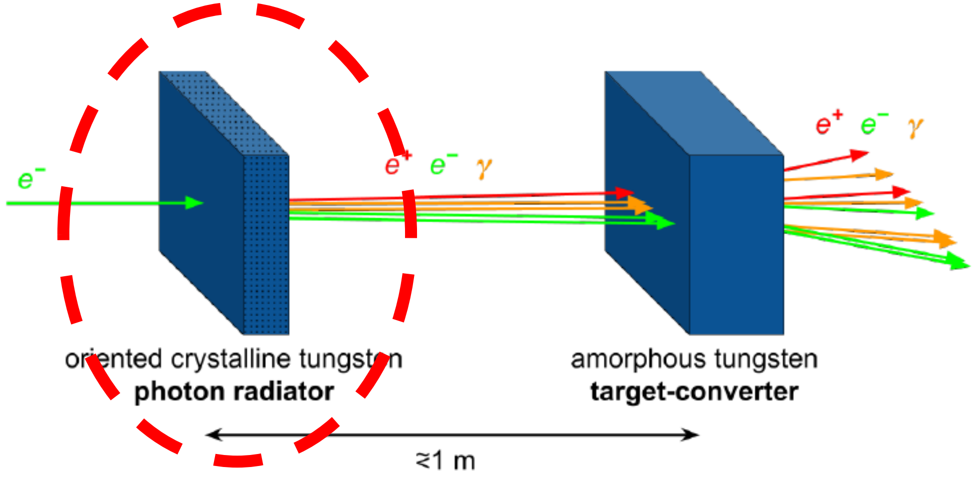
**L. Bandiera et al., Eur. Phys. J. C 82 (2022) 699**

**Conventional e+ source**



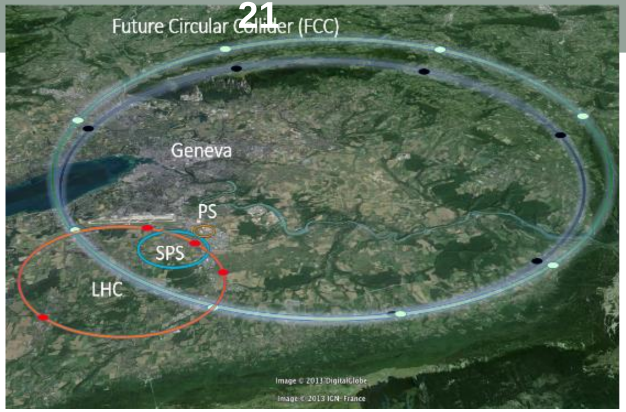

usually made of high-Z material (W, Pb,..)

**Hybrid crystal-based e+ source**

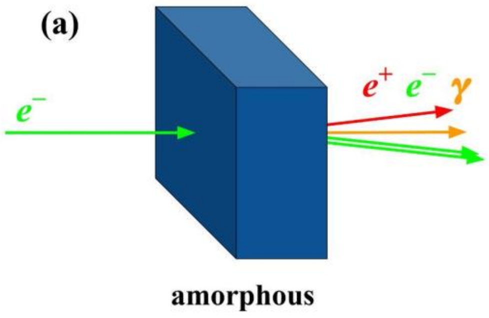



**Option for FCCee, ILC, CLIC..**

# And with a crystalline undulator?




**Conventional e+ source**



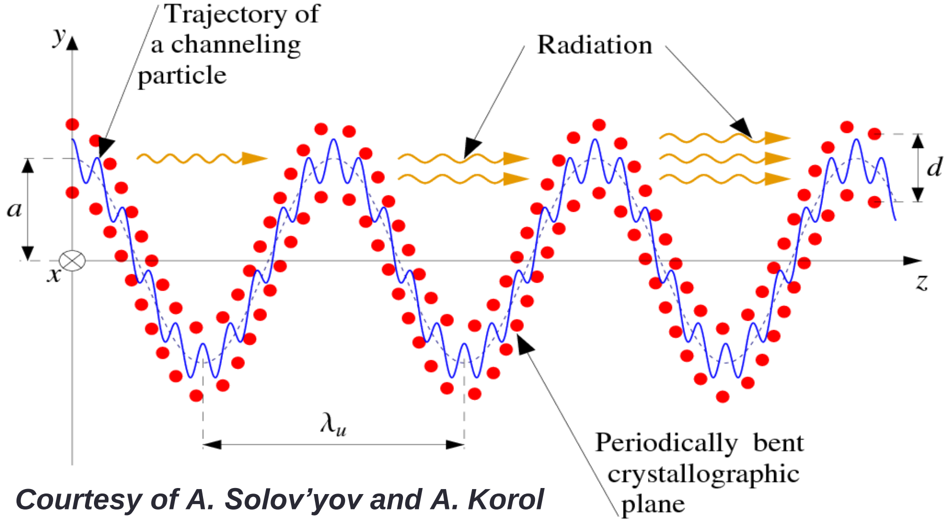

usually made of high-Z material (W, Pb,..)

**Crystalline undulator**

**Hard X-rays and gamma rays**

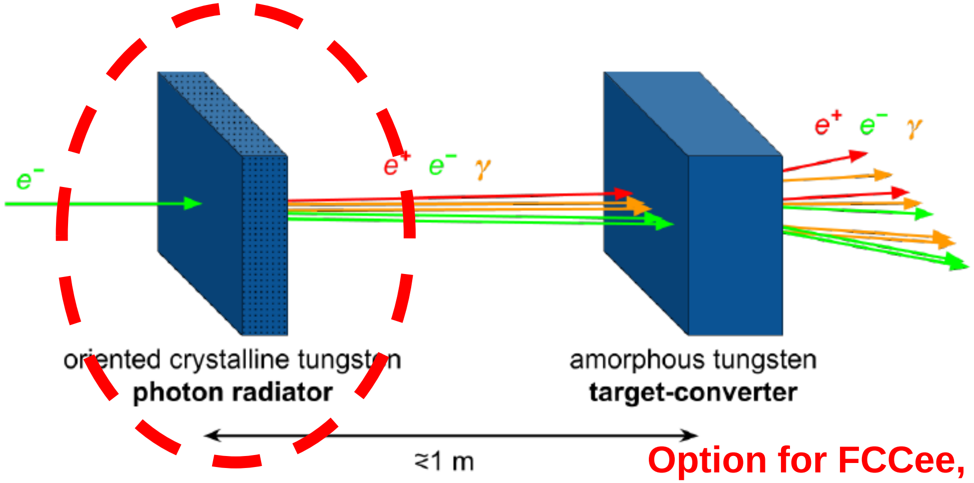
Exploiting a crystalline undulator as radiator may result in some advantages in terms of enhancement of soft photons

**Interesting to be investigated**




*Courtesy of A. Solov'yov and A. Korol*

**Hybrid crystal-based e+ source**




**Option for FCCee, ILC, CLIC..**

*Idea of R. Chehab, V. Strakhovenko and A. Variola, NIM B 266 (2008) 3868*

# Summarizing

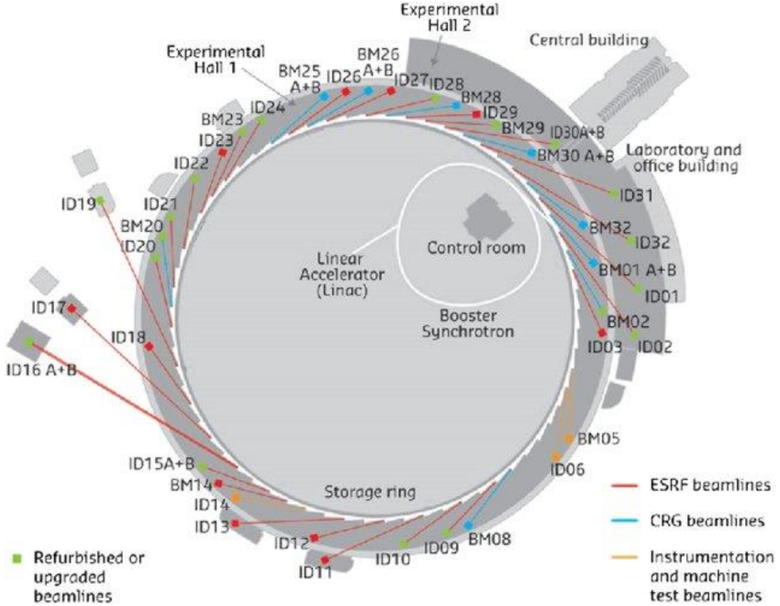
G.A. 101046458

- An **experiment on radiation emitted by 6 GeV electrons interacting with linear W and Ir crystals** was carried out at CERN PS
  - Radiation emission in axial potential (1 keV) is quite intense, but the quality of the crystals is low -> thereby decreasing its monochromaticity
  - Monte Carlo simulation are necessary to extrapolate the Single Photon Spectrum
  - Interesting for **hard gamma-ray sources (10-100 MeV)** and as radiators in a crystal-based **positron source for future collider** (e.g. the Future Circular Collider at CERN)

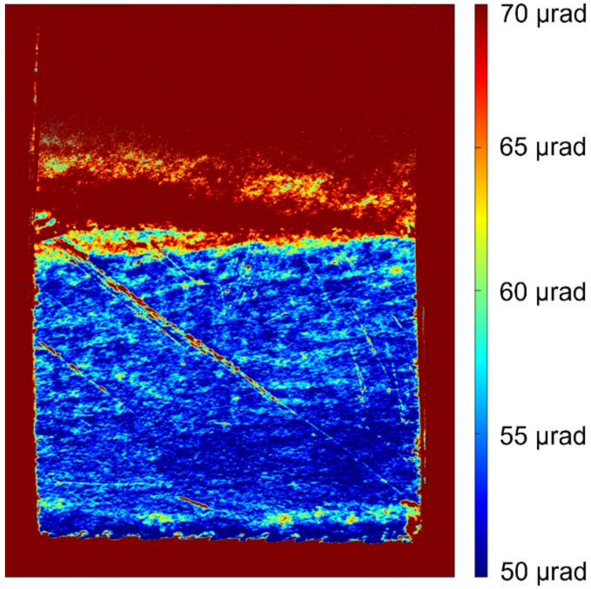
- We **characterized the 6 GeV positron beam**, which is similar to the electron beam one (as expected). We checked that the **energy can be increased up to 15 GeV**, but the fraction of electrons/positrons in the beam is highly decreased.

# Future plans… complete the characterization

Maybe, topography can be performed at the synchrotron facility ESRF (beamline BM05). The facility allowed both high spatial (≈5μm) and angular (≈1μrad) resolution thanks to the high intensity and energy of the diffracting photons (20 keV).




*Example of topography on a W sample*




**X-ray topography @BM05**
**Courtesy of Thu Nhi Tran CALISTE**

**L. Bandiera et al., Eur. Phys. J. C 82 (2022) 699**

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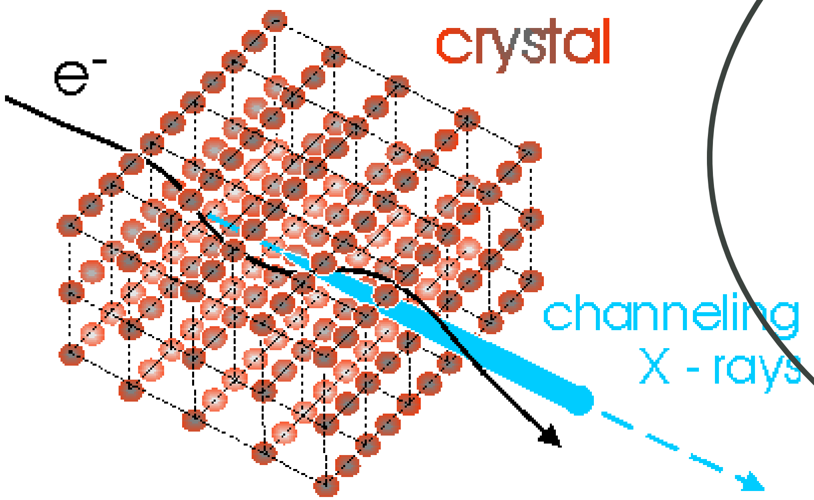
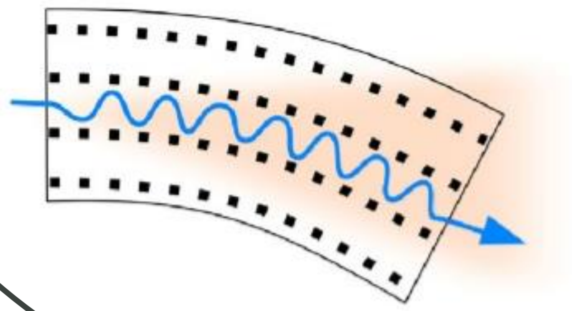
# Future plans… new experiment

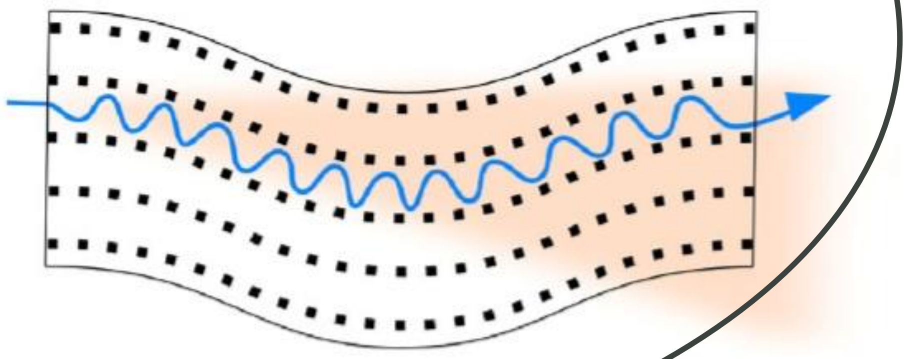
## Linear



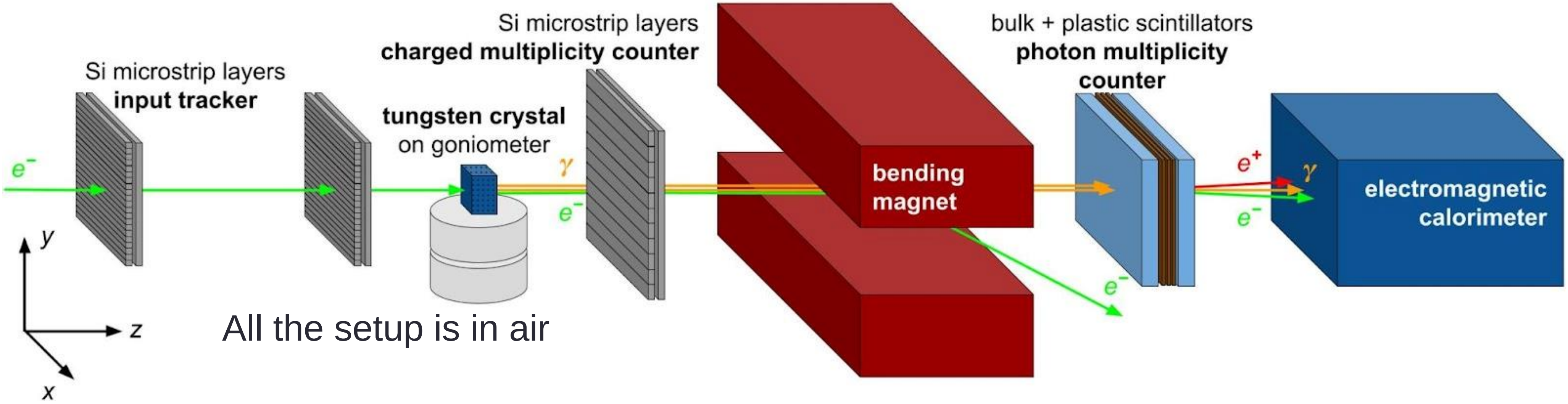

## bent



## periodically bent



# Future plans…. The Challenge!




**Challenge 1. Work in vacuum?**
Investigate with beam physicists in charge of the PS&SPS beamlines the possibility to work in vacuum or with He bag (to reduce MS in air), which is necessary to test thinner Bent Crystals and Periodically Bent Crystals of low-Z material;

**Challenge 2. Is the rate and quality of the beam sufficient to test small samples?**
We can trigger on the Si detectors to select only particles impinging on a small size crystal (BC or PBC).. Nevertheless it is fundamental to evaluate how many photons we can get in two weeks of data taking.

**Challenge 3. Which detector for CU peak?**
Plan: perform a Geant4 simulation of the experimental setup to understand if and which detector could be used to measure the gamma-ray peak of CU without being blinded by the harder channeling/bremsstrahlung radiation spectrum,

# Thank you for the attention!

The PS T9 line area from above during the night shift