Compact calorimeter based on oriented crystals

Speaker:

Alessia Selmi

On behalf of the **INFN STORM/OREO Collaboration**

IDF2022- INFN workshop on Future Detectors

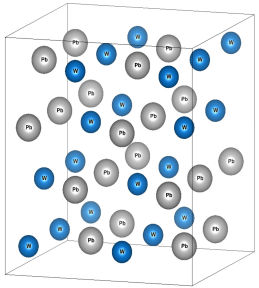
Oct 17 – 19, 2022

Bari

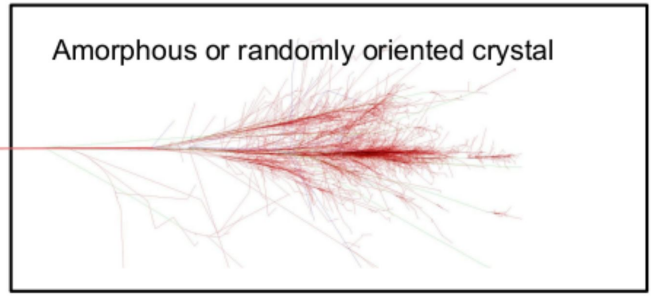
Acknowledgement to

UNIVERSITÀ DEGLI STUDI DELL'INSUBRIA

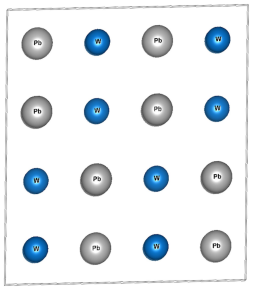
Randomly oriented crystal



Particle



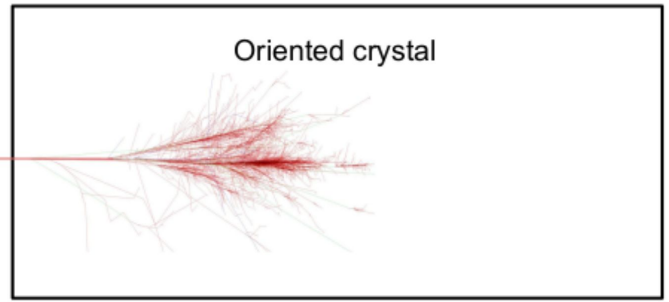
Oriented crystals



Axial orientation

Strong Field

Particle



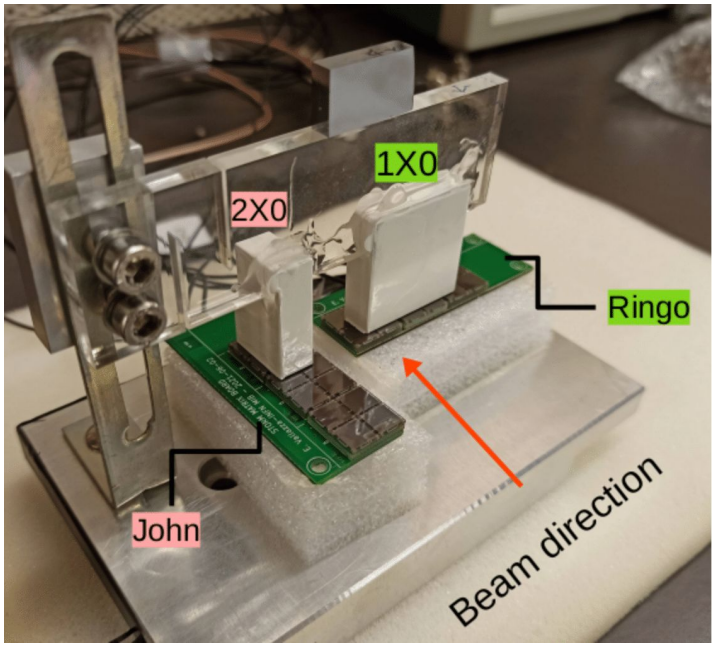
Reduction of the radiation length X_0
in comparison with amorphous media

Compact calorimeter!

STORM (STrOng cRistalline electroMagnetic field)

beamtest on the H2 line at the CERN SPS, North Area, CERN

with 120 GeV electrons



PWO crystals

	$1\ X_0$	$2\ X_0$
axis	<001>	<100>
interatomic pitch	12.020 Å	5.456 Å
U_0	∼600 eV	∼700 eV
Θ_0	∼1 mrad	∼1 mrad
strong field ($\chi = 1$)	∼ 30 GeV	∼ 30 GeV

$1\ X_0$ 0.9 x 3 x 3 cm^3

Produced by The Institute for Nuclear Problems, Belarusian State University, Minsk

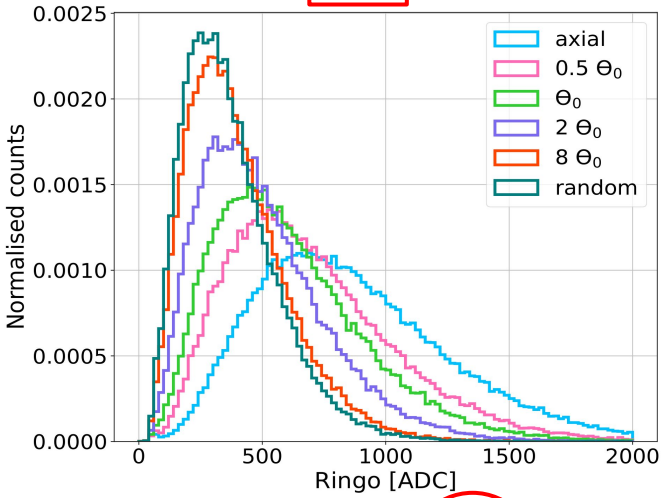
$2\ X_0$ 1.8 x 0.9 x 2.7 cm^3

Produced by Molecular Technology GmbH (Moltech), Berlin

Energy deposited in crystals (ADC units)

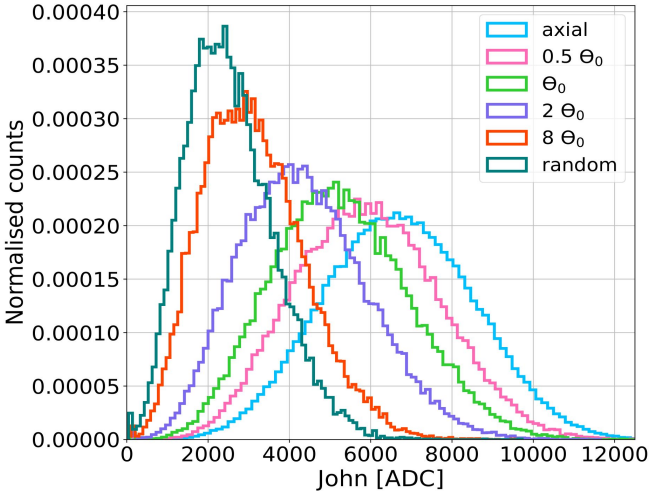
$$\Theta_0 = \frac{U_0}{mc^2} \sim \text{mrad}$$

1X$_0$



$$E_{Ax} \sim 2.5\, E_{Rn}$$

2X$_0$

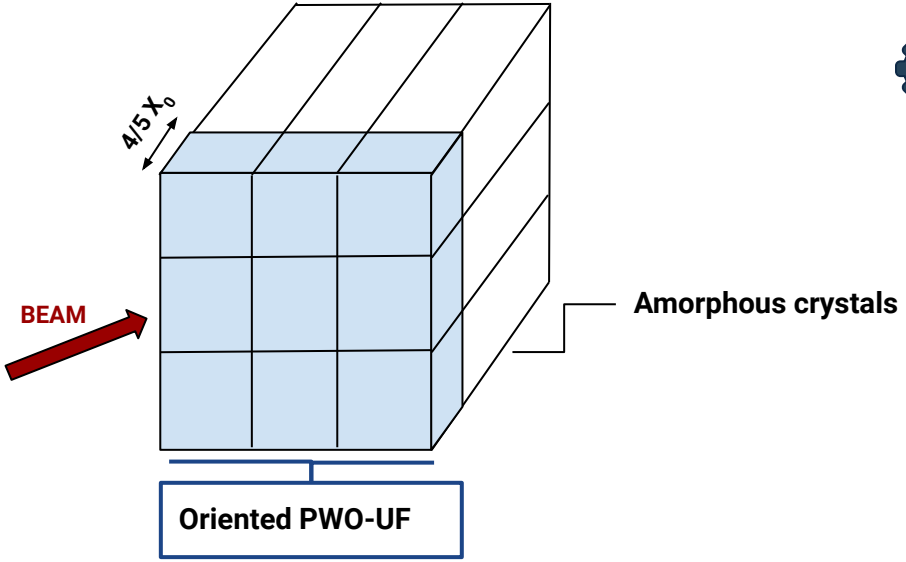


$$E_{Ax} \sim 3\, E_{Rn}$$

Decrease of **X$_0$** of around 30%

OREO - ORiEnted calOrimeter

National Coordinator
Laura Bandiera, INFN FE



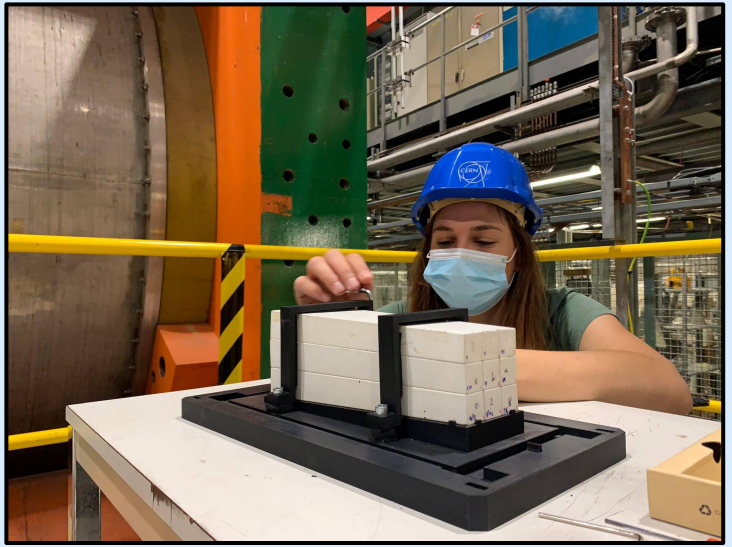
Prototype of compact crystal based calorimeter

- 3x3 matrix of oriented PWO-UF readout by SiPMs

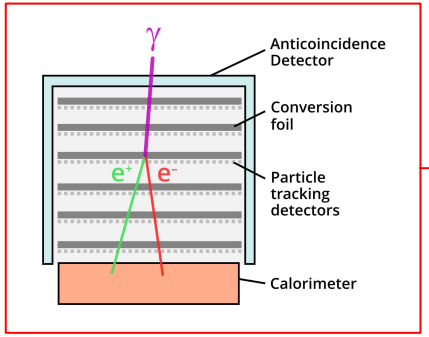
GOAL

Prove that it's possible **to contain e.m.** showers **in a reduced volume/weight** and cost

Thanks for the attention

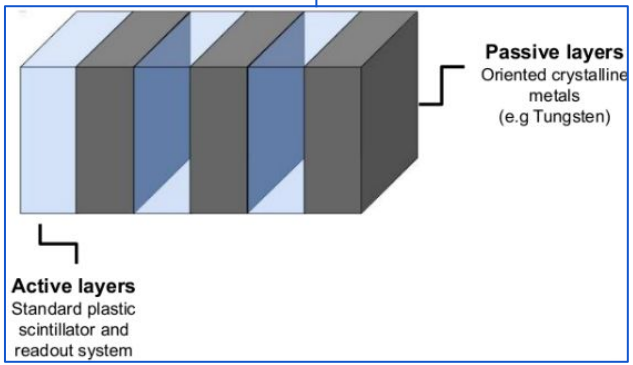


Possible applications

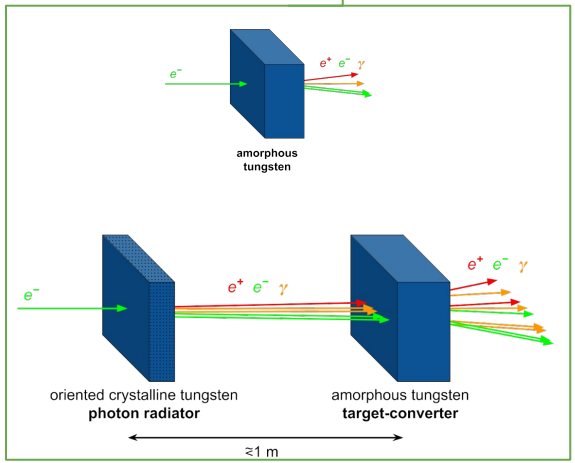


Source-pointing γ-ray telescope

Sampling and homogeneous calorimeter for fixed-target experiments



Intense positron source



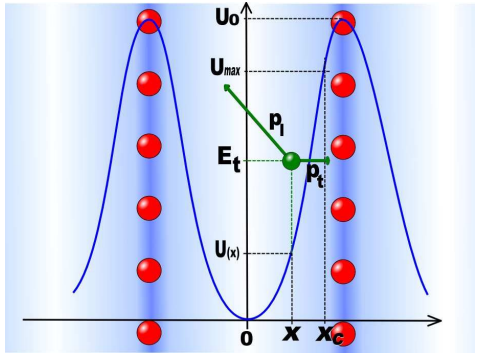
Light particles interaction with oriented crystals

Misalignment crystal → e^+/e^- → incoherent bremsstrahlung

But what happens if the crystal is oriented?

1912 → J.Stark introduced the idea that the crystalline lattice may modify the motion of charged particles

1965 → J.Lindhard → **axial / planar channeling**



e+ planar channeling

Critical angle → $\theta_c = \sqrt{\frac{U_0}{pv}}$ →

It depends on:
- the input energy
- the material

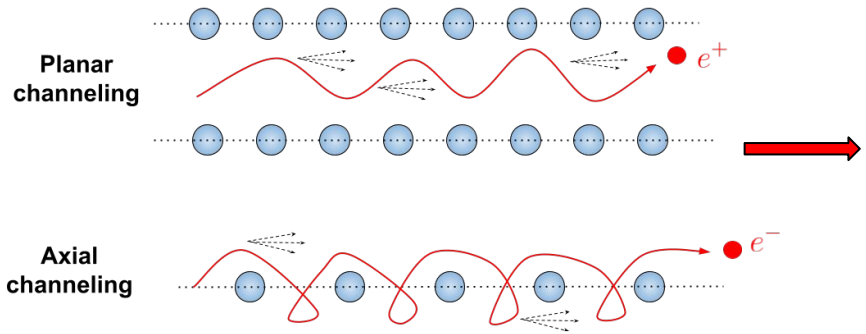
At 120 GeV for Tungsten →

Planar : $\theta_c = 31\ \mu\text{rad}$

Axial : $\theta_c = 110\ \mu\text{rad}$

1976 → M.Kumakhov demonstrated that the crystalline lattice modifies the features of the electromagnetic processes inside the crystal

The periodicity of the planar/axial channeling motion leads to the coherent emission of photons



This leads to an enhancement in the radiation emission with respect to the case of amorphous medium (incoherent bremsstrahlung)

Intense radiation source!

At high energies (about tens of GeV) → **STRONG FIELD REGIME**

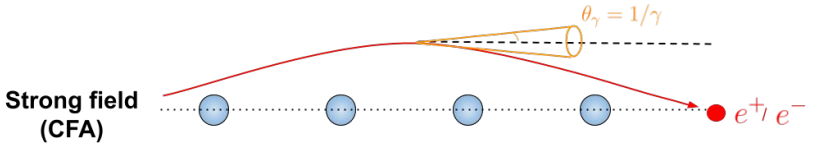
Lorentz factor

$$\chi = \frac{\gamma E}{E_0} > 1$$

Field experienced by the electron in its rest frame

QED critical electric field $\sim 1.3 \cdot 10^{18} \frac{V}{m}$

The particle experiences a field that can be considered constant along the string → **Constant Field Approximation (CFA)**



→ Large enhancement of radiation emission and pair-production

Angular range

$$\Theta_0 = \frac{U_0}{mc^2}$$

→ Does not depend on particle energy

For Tungsten 120 GeV

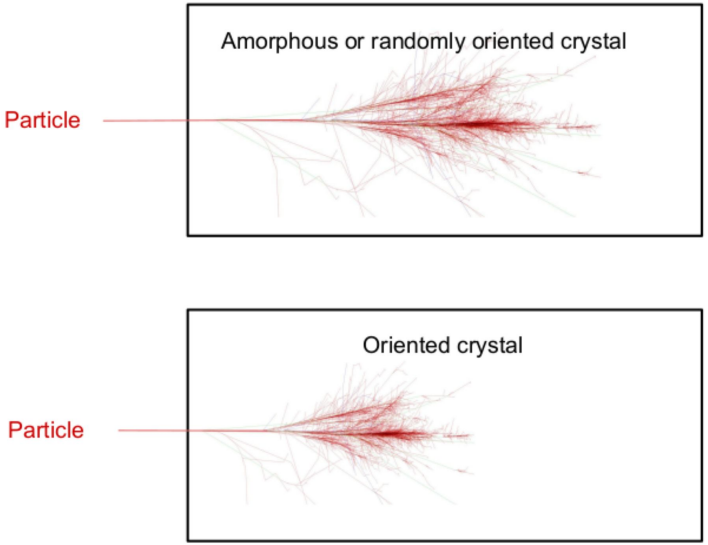
$$\Theta_0 = 1.2 \text{ mrad}$$

vs

$$\theta_c = 110 \ \mu\text{rad}$$

Large enhancement of radiation emission and pair-production → **acceleration of the electromagnetic shower** → Described in terms of the radiation length X_0:

X_0 is the mean distance over which a high energy electron loses all but 1/e of its energy via bremsstrahlung.

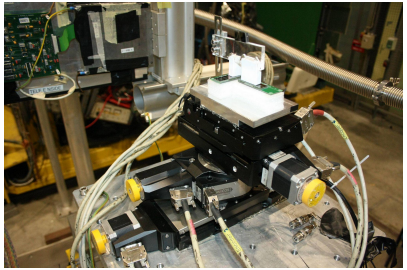


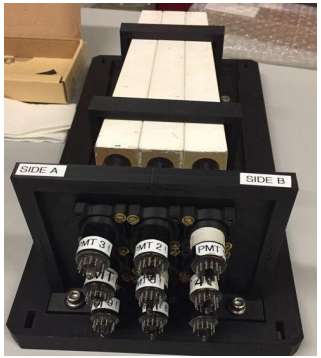
reduction of the radiation length in comparison with amorphous media

Compact calorimeter!

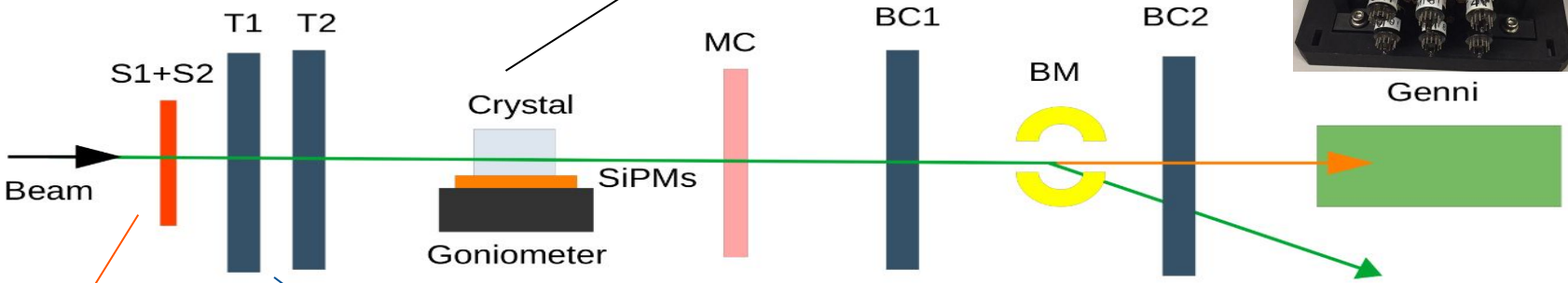
The electromagnetic shower starts before in the oriented crystal!

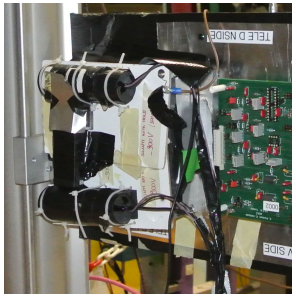
The experimental setup



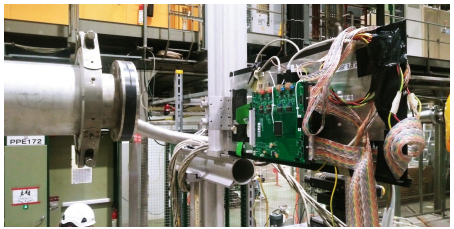


Genni

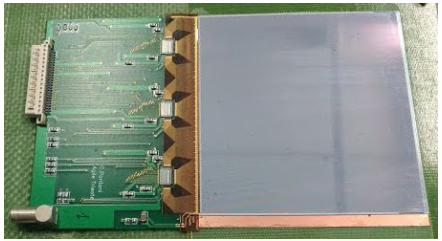




Trigger system



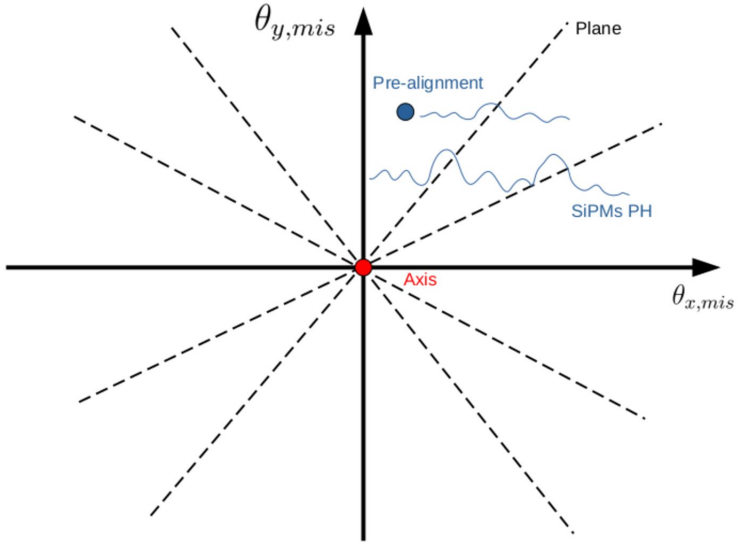
Tracking system



Tracking system

The fine alignment

The stereogram

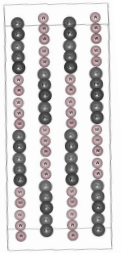


The stereogram has been reconstructed with the experimental data using the output signal of the Ringo ($1X_0$ crystal) and John ($2X_0$ crystal) SiPMs and of the multiplicity counter

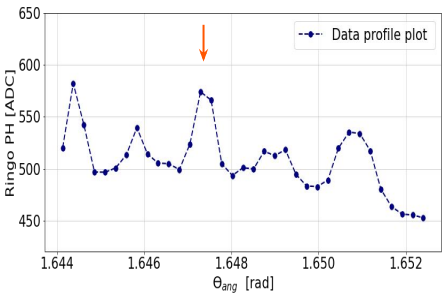
The PH of the SiPMs and the one of the multiplicity counter are expected to be larger when the beam is aligned with respect to the axis; a smaller enhancement is expected when it is aligned with planes

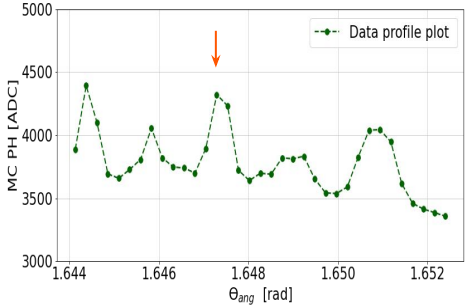
θ_{mis} → the angle between the particle trajectory and the crystalline sample

The stereogram reconstruction → Ringo (1X0 crystal) and MC

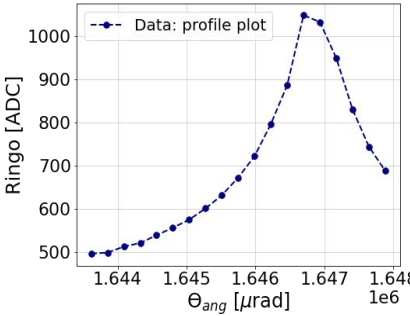


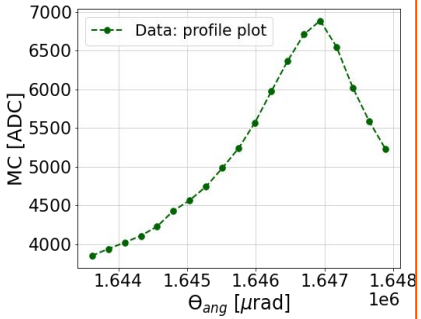
1° angular scan

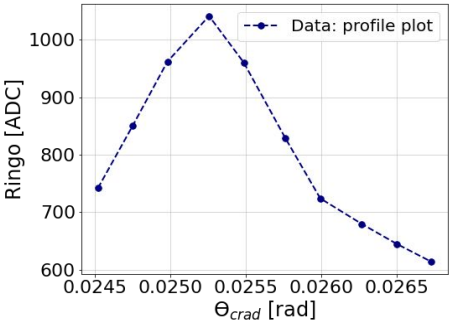


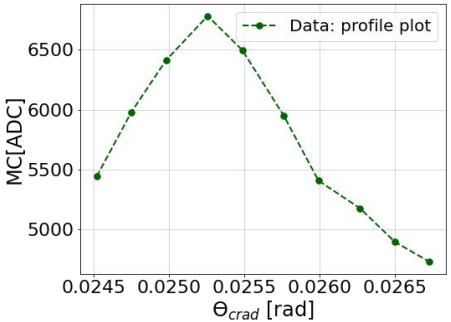


2° angular scan

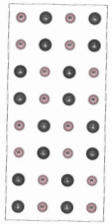






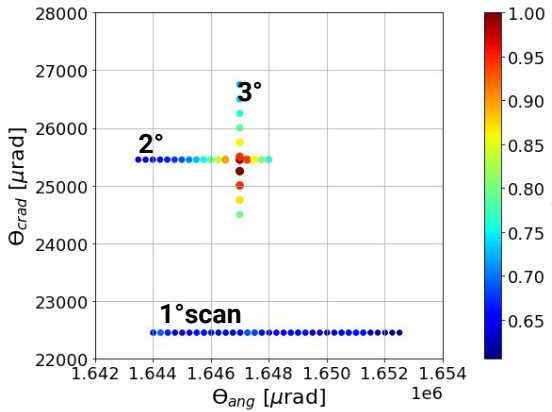


3° cradle scan

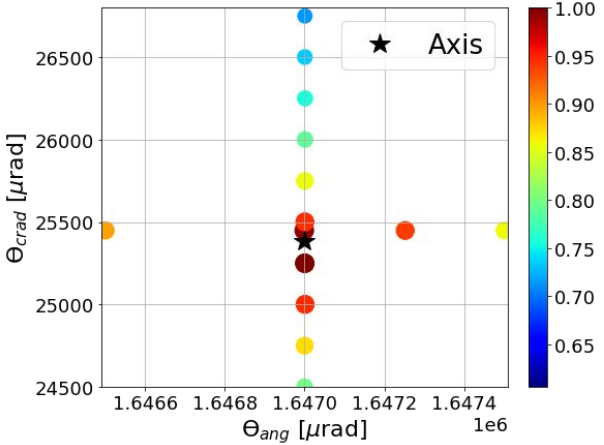


The complete stereogram

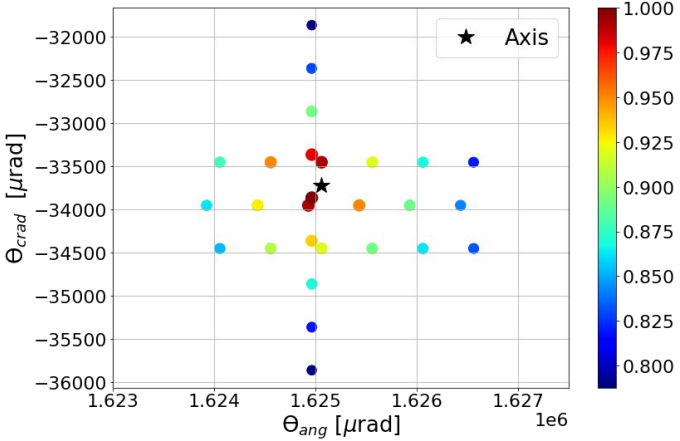
Ringo
($1X_0$ crystal)



Zoom

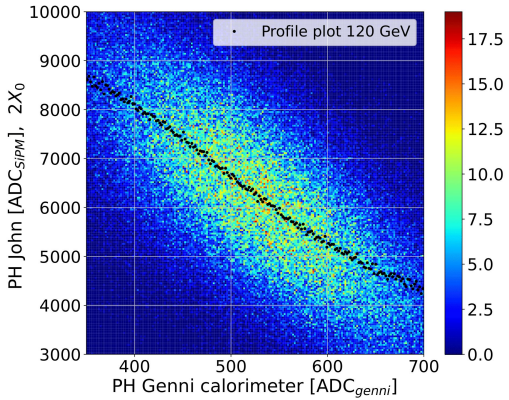


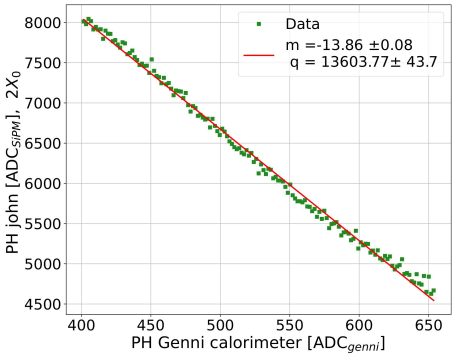
John
($2X_0$ crystal)



Each dot represents the normalized mean value of the PH of Ringo and John.
The axis has been chosen between the two points with the higher PH values

SiPMs PH correlation with calorimeter signal



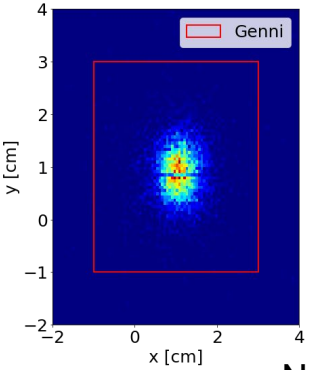


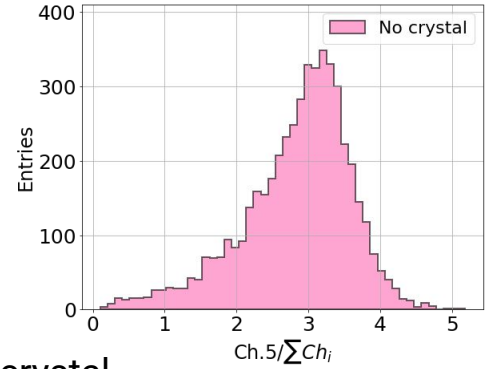
The two signals are anti-correlated

$$E_{TOT} = E_{SiPM} + E_{Genni}$$

Can I calibrate the SiPMs?

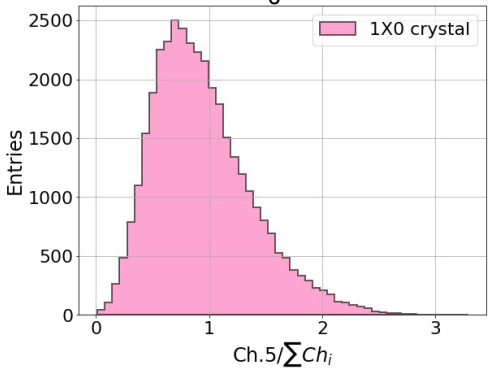
NOT SO EASY



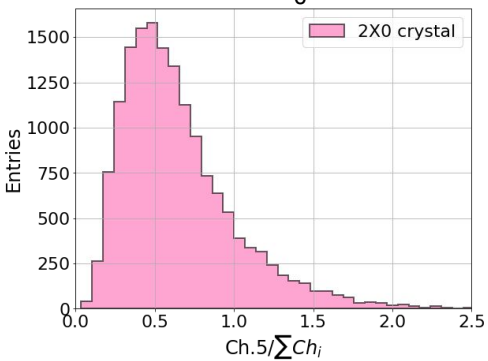


No crystal

1X_0

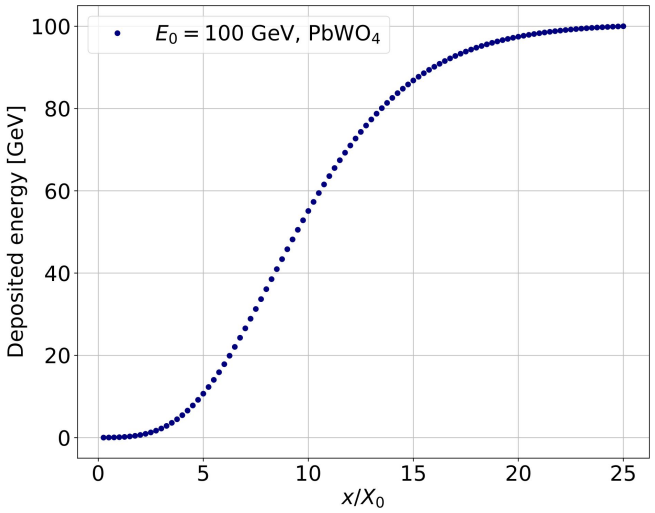


2X_0



A Monte Carlo simulation is needed

Evaluation of the radiation length reduction



Cumulative deposited energy as a function of the thickness of the detector in units of X_0 for a 100 GeV electron beam impinging on a PWO crystal

Extrapolated from the curve

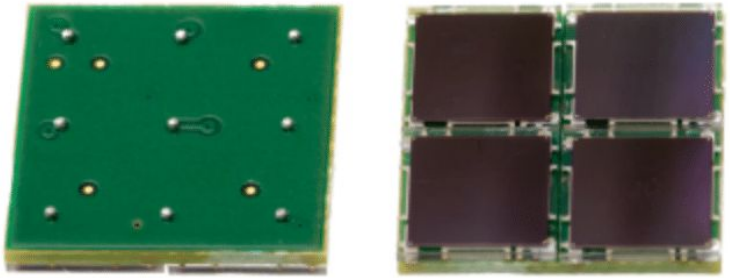
	Deposited energy random	Deposited energy axial	Thickness in X_0 in axial	Thickness increase
1 X_0	100 MeV	250 MeV	1.41	41%
2 X_0	650 MeV	1.9 GeV	2.87	43%

Decrease of $\mathbf{X_0}$ of around 30%

- It depends on the input energy
- Compact calorimeter
- Particle ID in the calorimeter itself

Features of ARRAYC-60035-4P-BGA

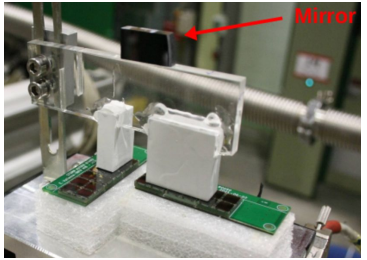
Array size	Sensor type	Readout	Board Size	Sensor pitch	Nr. of connections
2	60035	Sensor	14.3×14.2 mm^2	7.2 mm	3×3 BGA

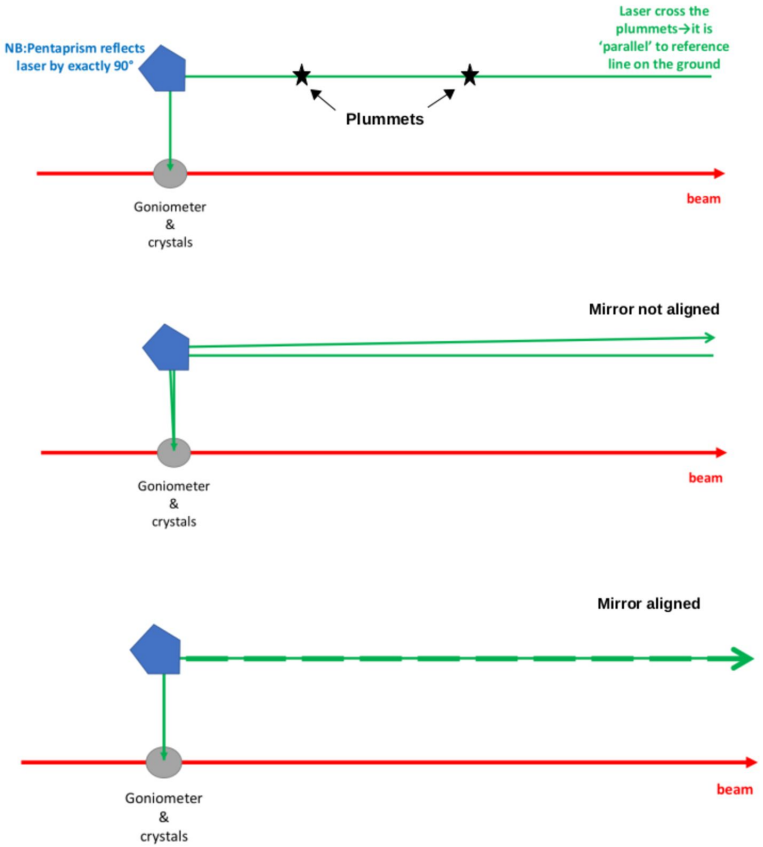


squared pixel dimensions = 35×35 μm^2
C-series dimensions = 6x6 mm^2

Pixel n° ~ 116000

The pre-alignment procedure → performed using a laser and several mirrors





1. Crystalline sample + holder and mirror are placed on the goniometer on the beamline
2. Two plummets, set on a reference line drawn parallel with respect to the beam, are used to align the laser
3. A pentaprism, positioned in front of the crystal, reflects the laser light of exactly 90° on the reference mirror on the holder
4. The mirror is aligned using the goniometer so that the laser returns along the same path
5. The mirror is aligned with the beam by rotating the holder of 90°
6. The crystalline sample is aligned with the beam using an offset measured previously in the laboratory