The OREO (ORiEnted calOrimeter) project

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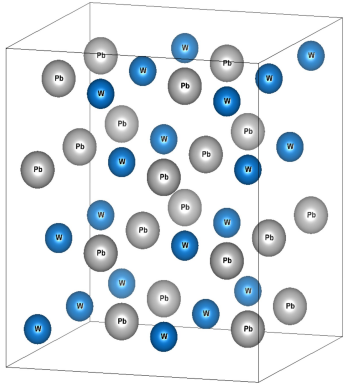
EPS-HEP CONFERENCE
July. 07-11, 2025

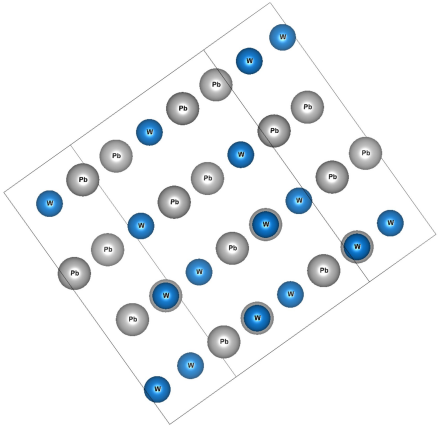
MiB - Ferrara
LNL - LNF

DRD6 - Detector Research and Development
WP3 subtask 3.1.4

Oriented crystals

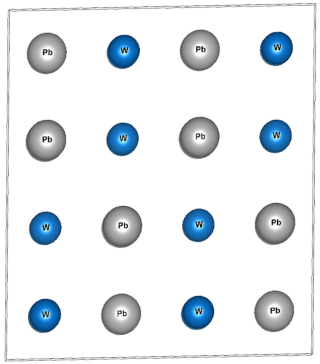


Randomly oriented crystal



Planar orientation

Oriented crystals



Axial orientation

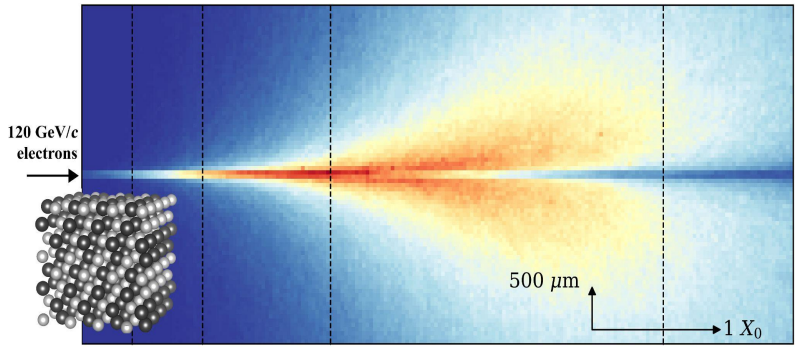
Bethe-Heitler bremsstrahlung and standard pair production

Coherent mechanisms →

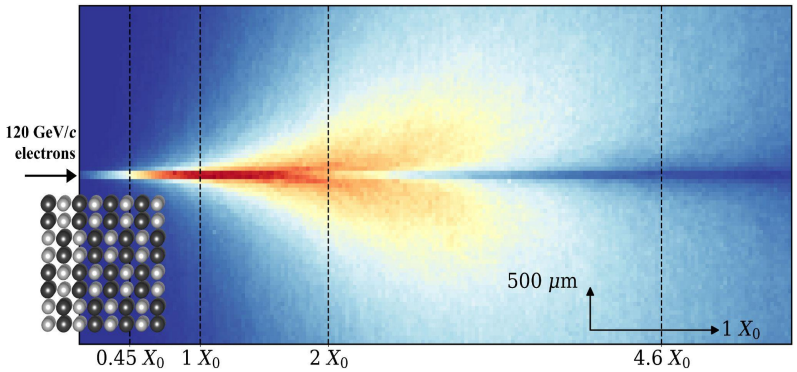
Modification of the electromagnetic processes

Orienting an electromagnetic calorimeter!

Random orientation



Axial orientation



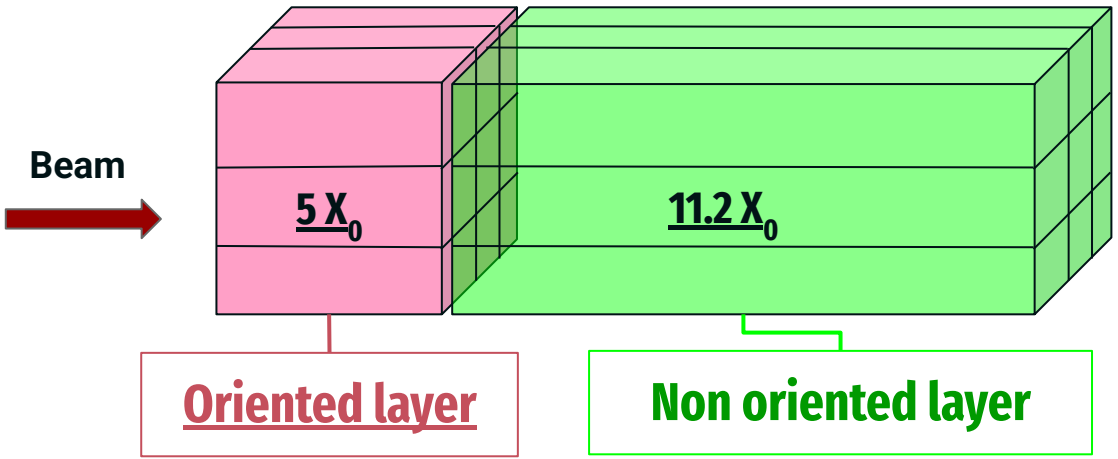
Acceleration of the electromagnetic shower development

Reduction of the effective radiation length X_0, whereas λ_{int} (hadronic interaction length) is unaffected

Improved γ/hadron discrimination

OREO - ORiEnted calOrimeter

Prototype of compact inorganic scintillator calorimeter



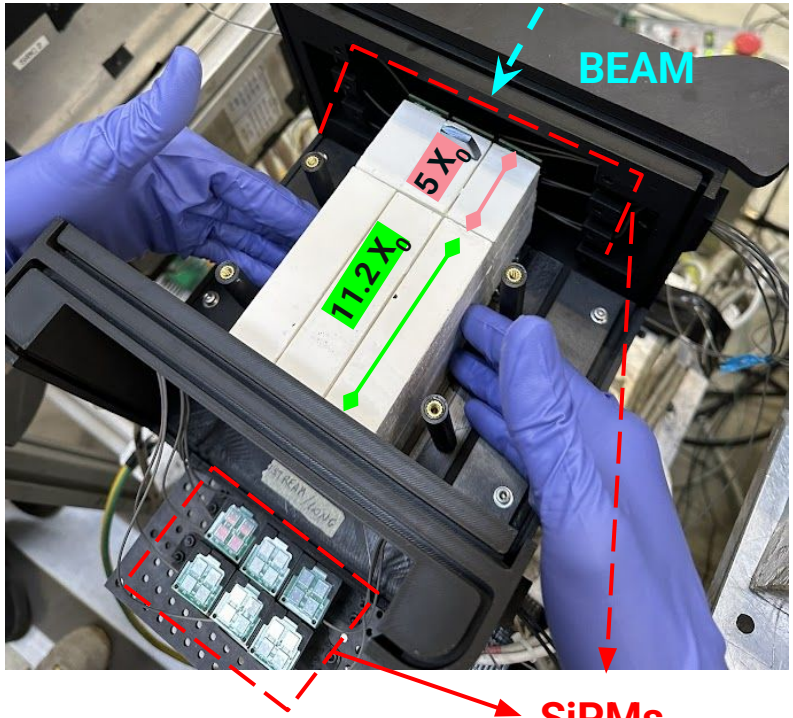
3x3 matrix of **oriented**
$PbWO_4$ - UF crystals
readout by SiPMs

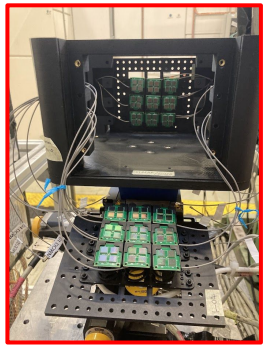
$1X_0$ = 0.89 cm

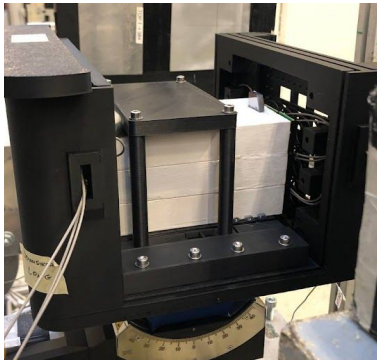
CERN

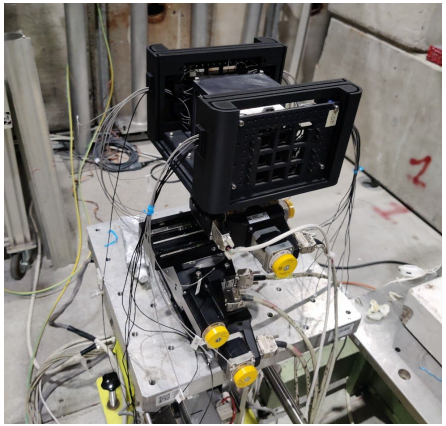
DRD6 - Detector Research and Development
WP3 subtask 3.1.4

OREO - ORiEnted calOrimeter

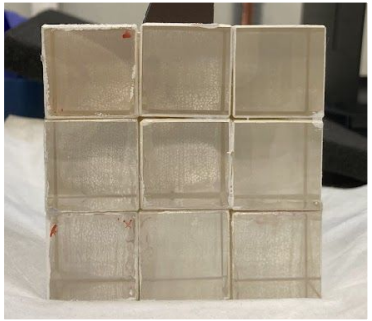




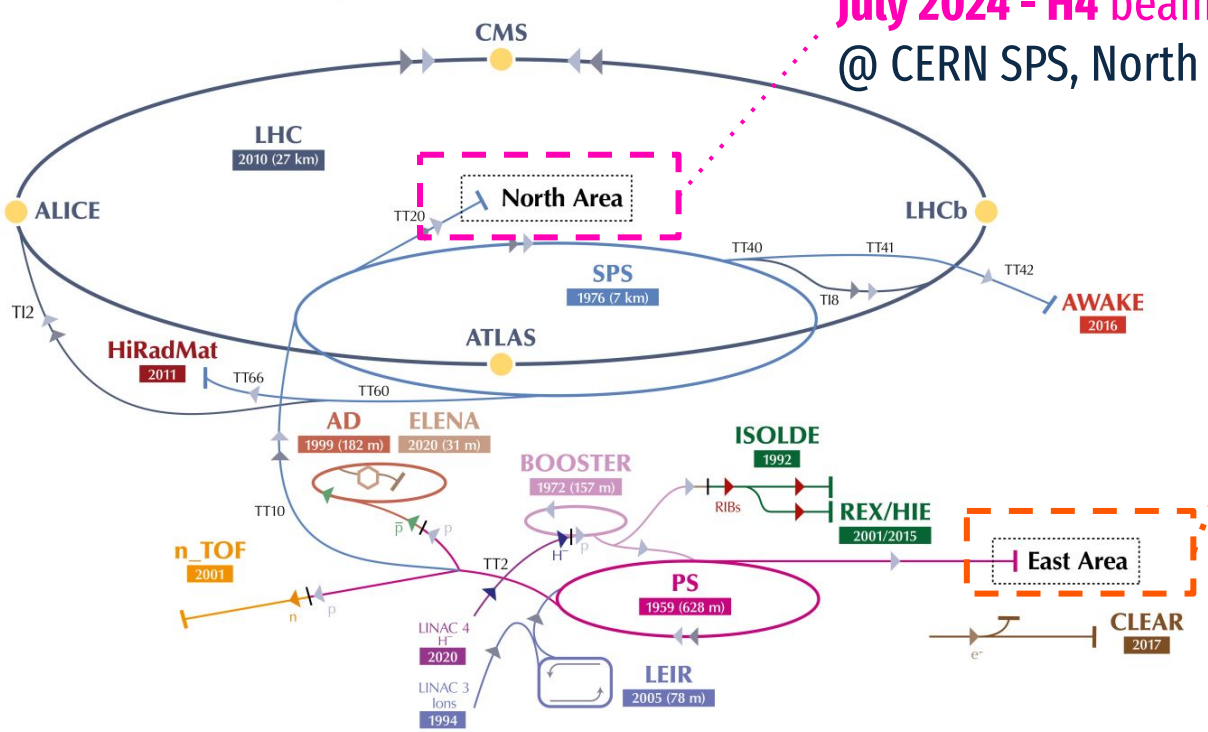




Front face



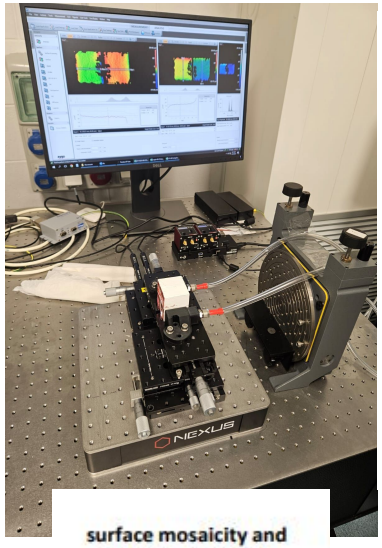
July 2024 - H4 beam line
@ CERN SPS, North Area



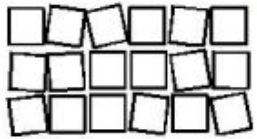
June 2024 - T9 beam line
@ CERN PS, East Area

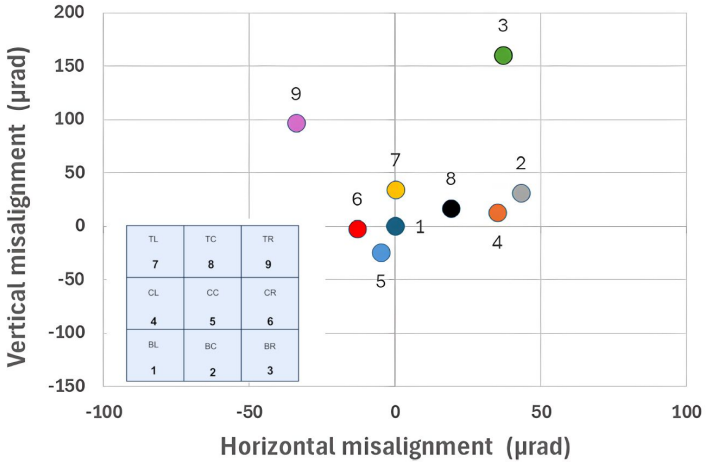
Tested with different energies:
from 1 GeV to 200 GeV

Crystal characterization



surface mosaicity and crystal orientation





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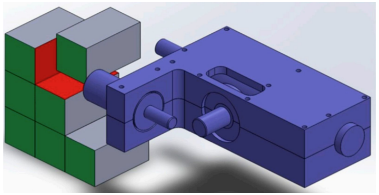
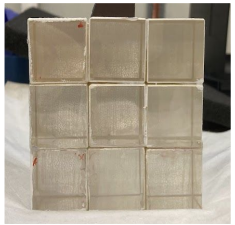
Istituto Nazionale di Fisica Nucleare
Sezione di Ferrara



Front face



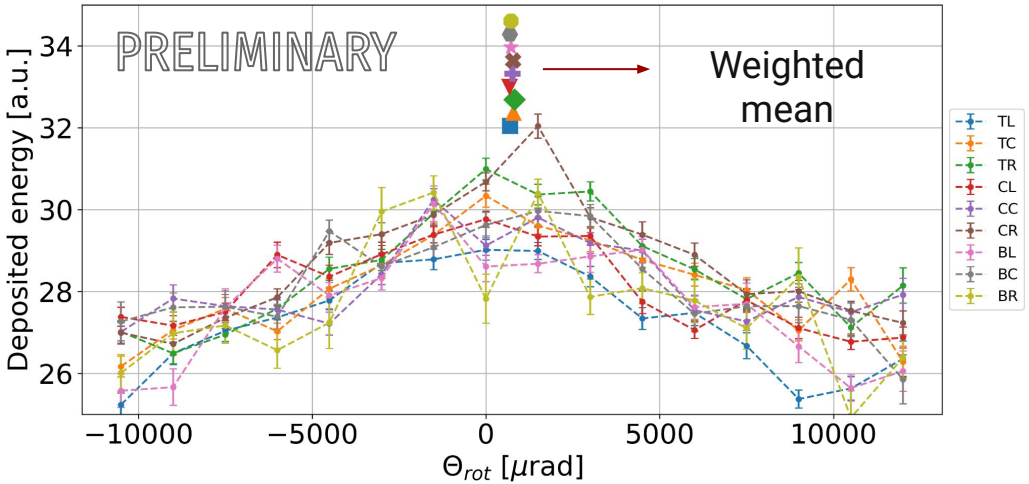
5 X_0 oriented layer

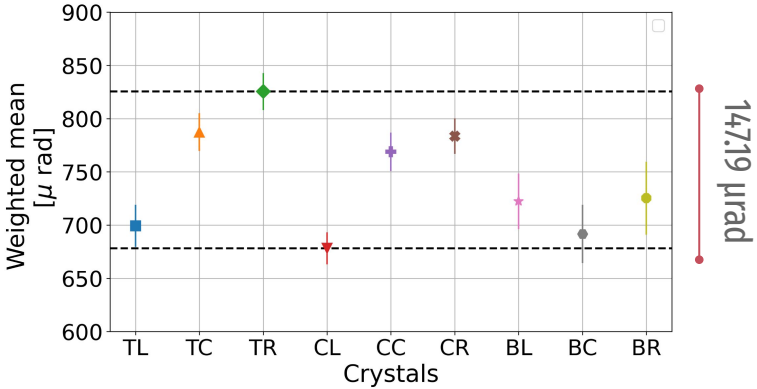
Gluing procedure:

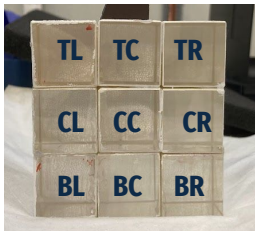
- preliminary lattice characterisation with laser
- autocollimator and High_resolution X-Rays Diffractometer
- real-time corrections of relative miscut
- Fizeau interferometer for real-time check

Preliminary results @ CERN PS

6 GeV
electrons beam







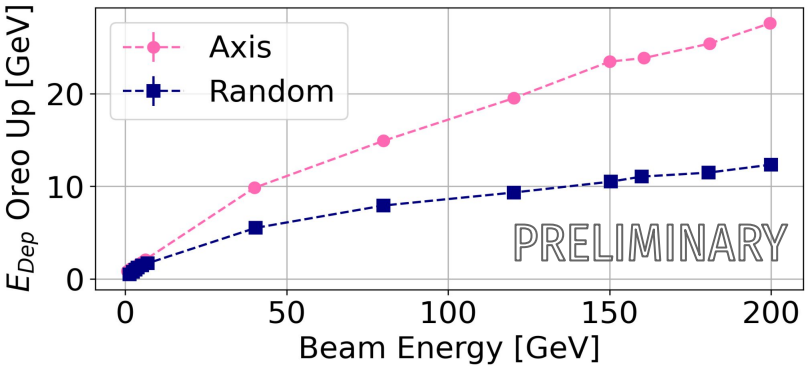
The largest observed deviation is **147.19 μrad**

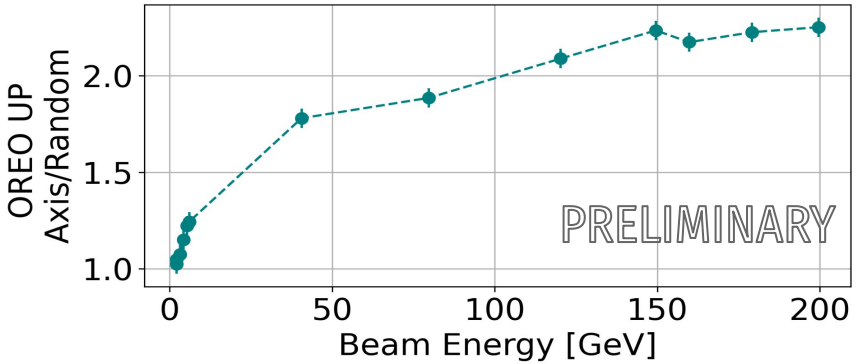
Acceleration in the e.m. shower development is visible **for an incident angle Θ up to 1°**

The crystals are well inter-aligned!

Preliminary results @ CERN PS and CERN SPS

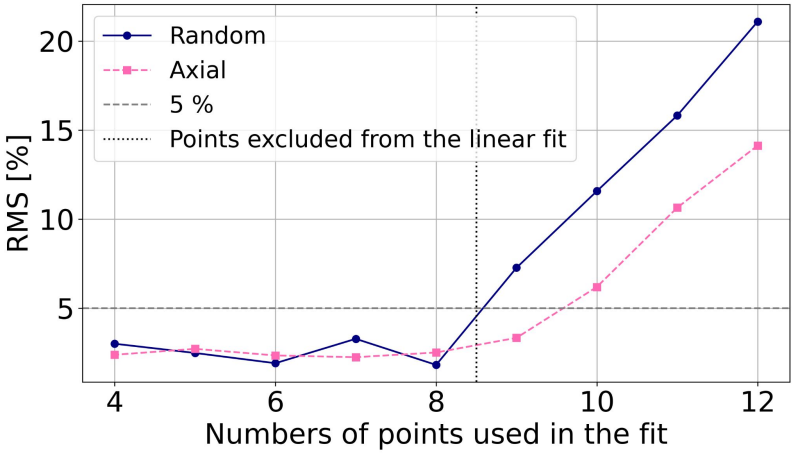
from 1 GeV to 200 GeV

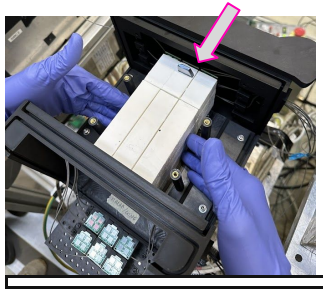




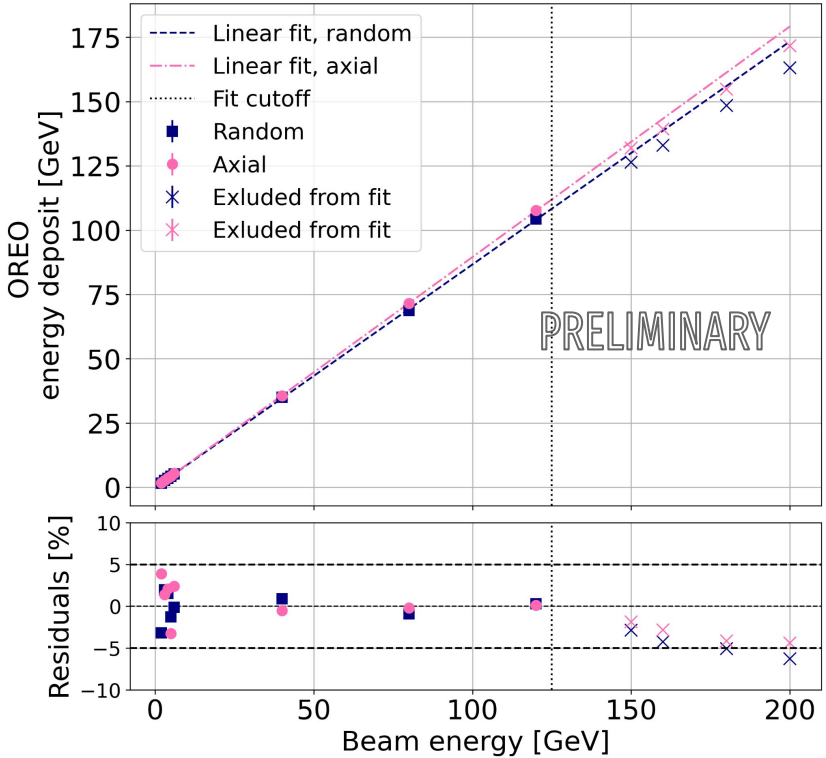
Acceleration of the electromagnetic shower development

OREO linearity

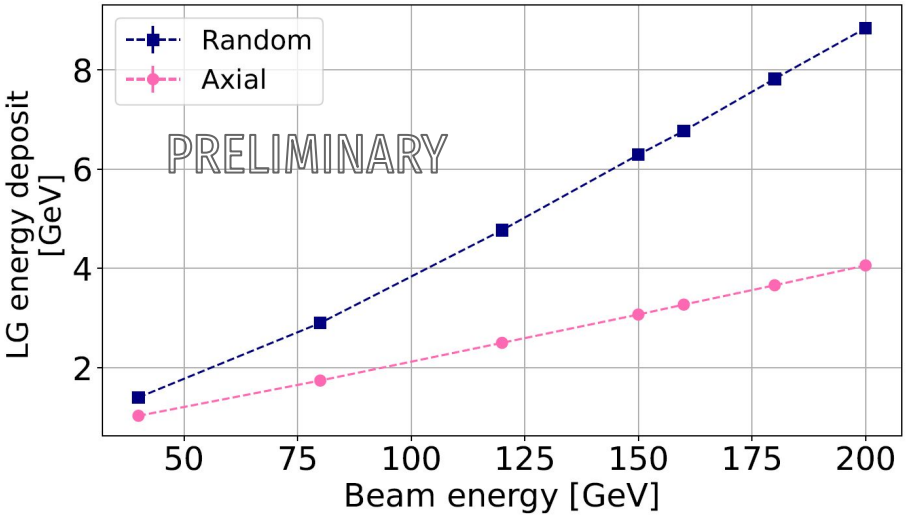


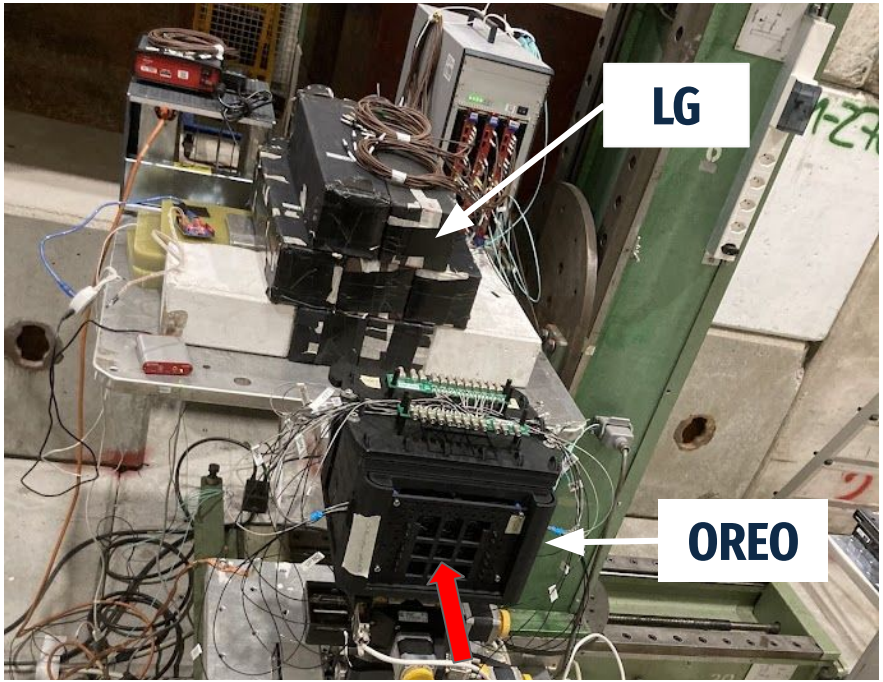


$$\mathrm{RMS}[\%] = \sqrt{\frac{1}{\mathrm{ndof}} \sum_i (\mathrm{Residual}_i)^2}$$

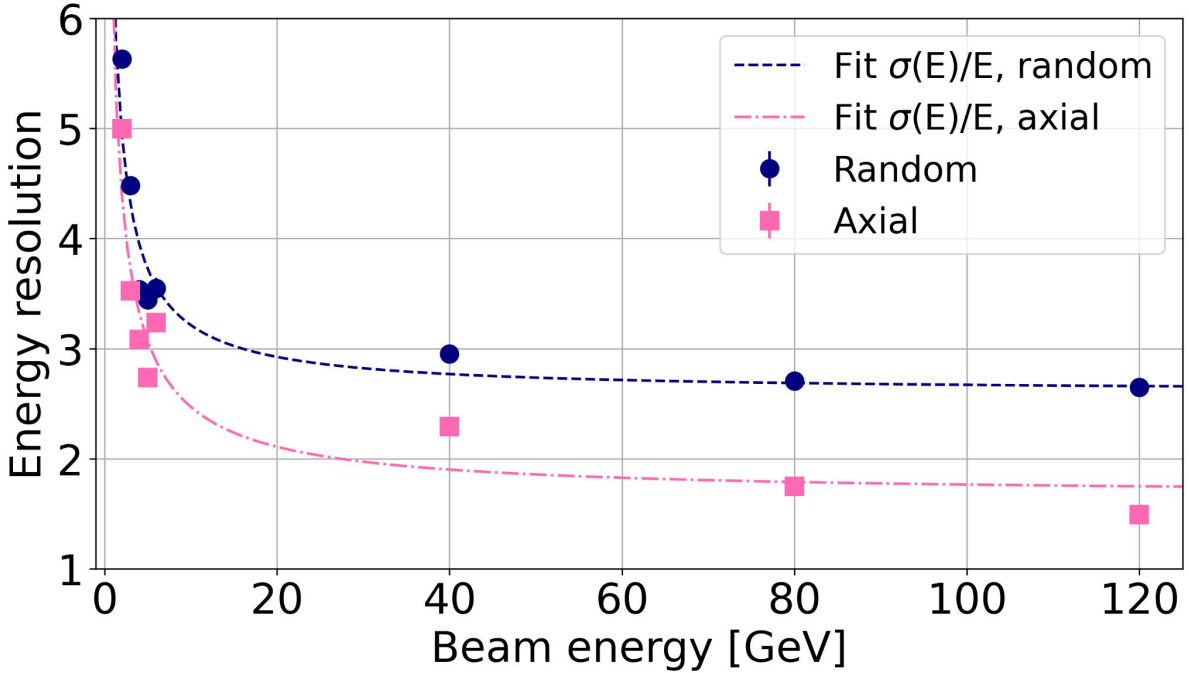


Longitudinal leakage





Energy resolution → $R = \sigma_E/E$

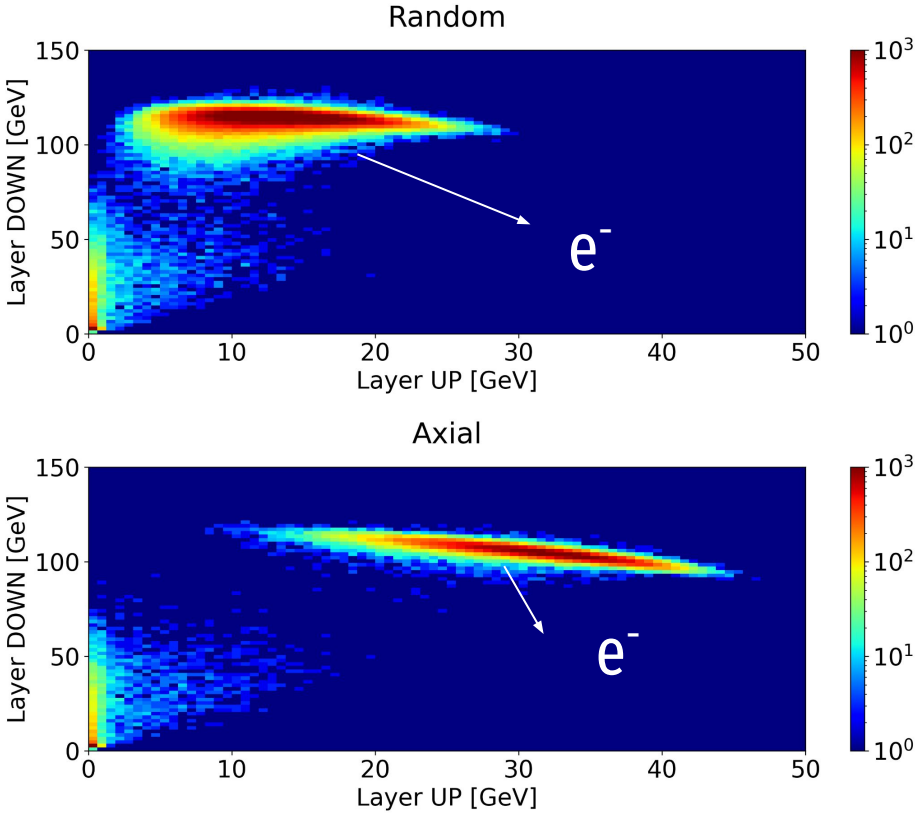


$$R(E) = \frac{a}{\sqrt{E}} \oplus c$$

Orientation	a [% $\sqrt{\text{GeV}}$]	c [%]
Random	5.95 ± 0.48	2.60 ± 0.18
Axial	5.76 ± 0.52	1.66 ± 0.20

electrons/hadrons discrimination

150 GeV
Hadron beam



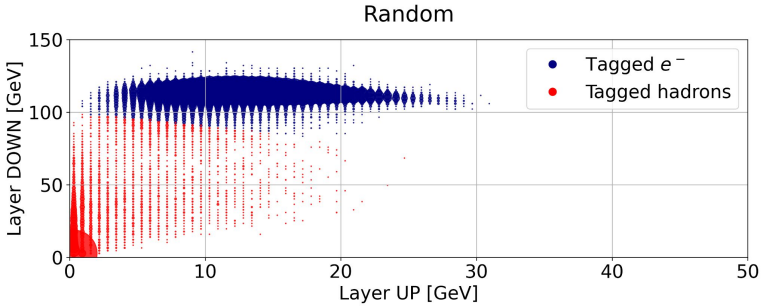
Significant **enhancement** in the energy deposited by electrons, resulting in a clear shift toward higher values

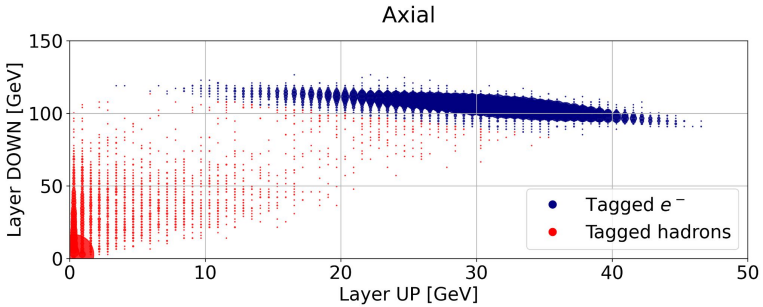
The axial strong field modifies **only the electromagnetic processes**

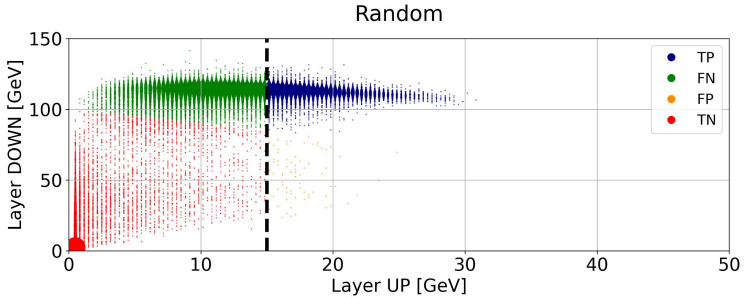
The hadrons are unaffected by the lattice orientation

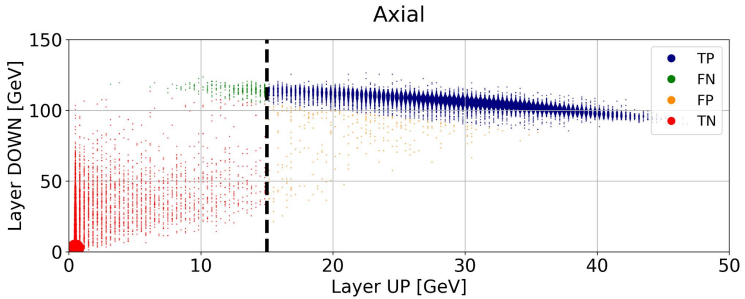
electrons/hadrons discrimination

150 GeV
mixed beam





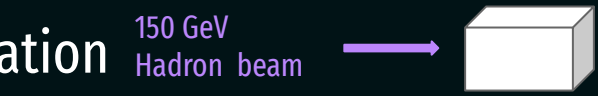




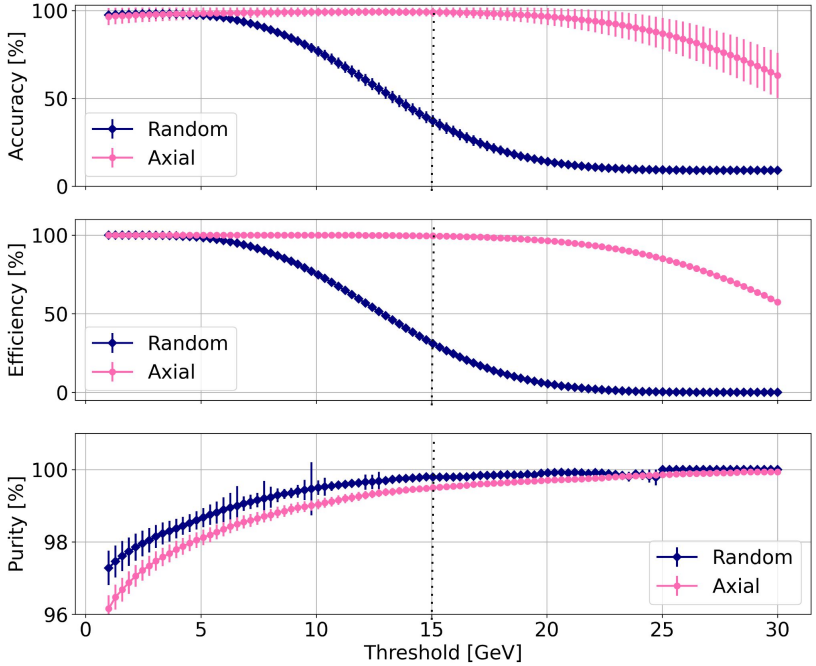
	Actual Positive	**Actual Negative**
Predicted Positive	True Positive (TP)	False Positive (FP)
Predicted Negative	False Negative (FN)	True Negative (TN)

electrons/hadrons discrimination

150 GeV
Hadron beam



- **Accuracy**: percentage of correctly classified events (both true positives and true negatives) out of all the events $\Rightarrow \frac{TP + TN}{TP + FP + TN + FN}$
- **Efficiency**: proportion of true electrons (true positives) correctly identified by the system out of the total number of true electrons $\Rightarrow \frac{TP}{TP + FN}$
- **Purity**: proportion of correctly identified electrons (true positives) out of all the events identified as electrons by the system $\Rightarrow \frac{TP}{TP + FP}$



15 GeV threshold

Metric	Random / Axial	Δ (Axial - Random)
Accuracy [%]	37.52 ± 3.34 / 99.09 ± 2.53	+61.56 ± 4.16
Efficiency [%]	31.44 ± 1.02 / 99.45 ± 0.10	+67.99 ± 2.50
Purity [%]	99.80 ± 0.02 / 99.50 ± 0.09	-0.30 ± 0.09

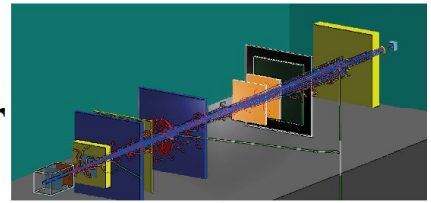
OREO - More work on...

- 2025→ **orient the central crystal of the downstream layer** → beam tests and data analysis
- Monte Carlo simulation: implementation of the **physics of oriented crystals into Geant4**

European Commission

Marie Skłodowska-Curie Actions Individual Global Fellowships
GA 101032975

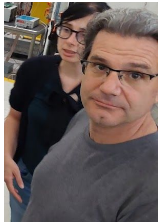
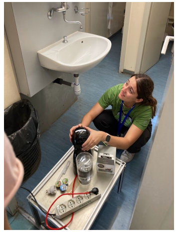
Steering and radiation effects in oriented crystals and their applications implementation into Geant4



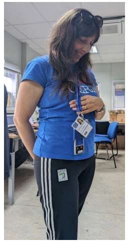
The OREO team: R&D, DAQ, electronics and mechanics





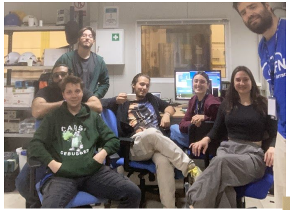




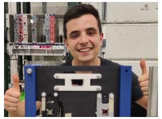
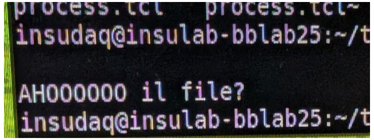






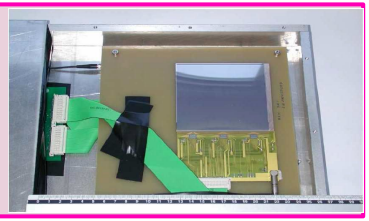




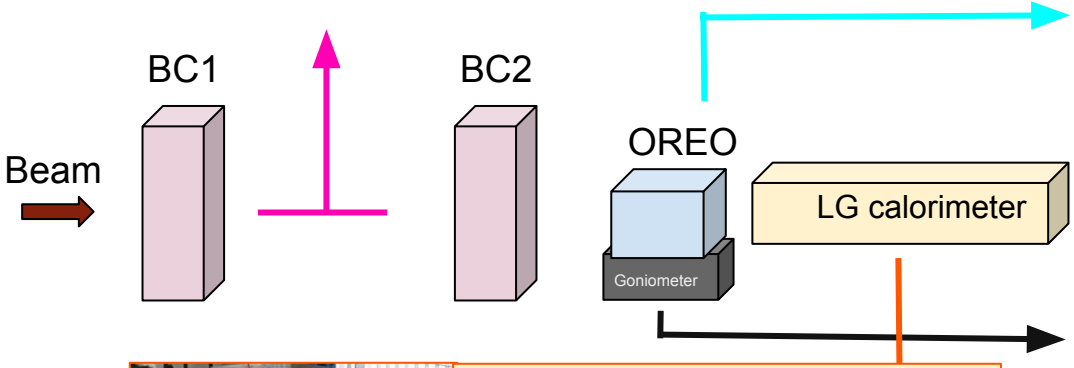

References

[1] L. Bandiera et al. , Phys.Rev.Lett. (2018)
[2] L. Bandiera, V.V.Haurylavets, V. Tikhomirov NIMA 936 (2019)
[3] L. Bandiera et al.,Front. Phys. (2023)
[4] M. Soldani, P. Monti-Guarnieri, A. Selmi et al.,arXiv:2404.12016v1
[5] P. Monti-Guarnieri et al., *JINST* 19 P10014 (2024)
[6] L. Malagutti et al., NIMA (2024)

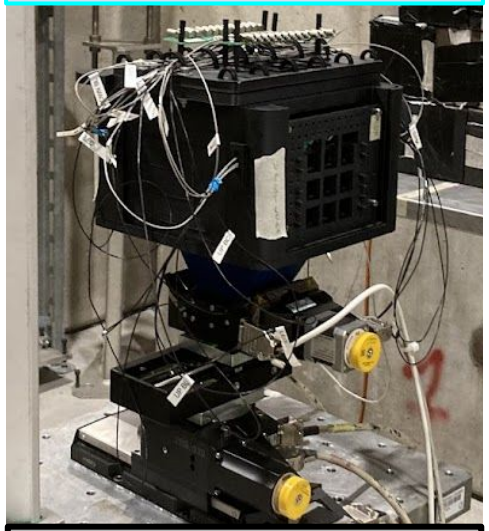
The experimental setup

Tracking system: two single side silicon microstrip detectors with a spatial resolution of ~ 30 μm in both x and y direction

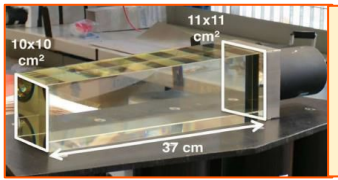




OREO PROTOTYPE



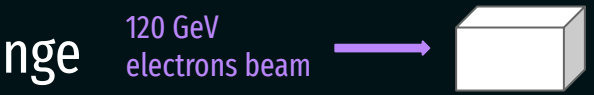
Multi stage goniometer

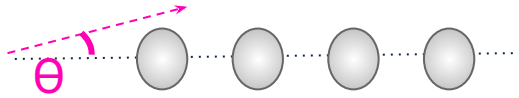


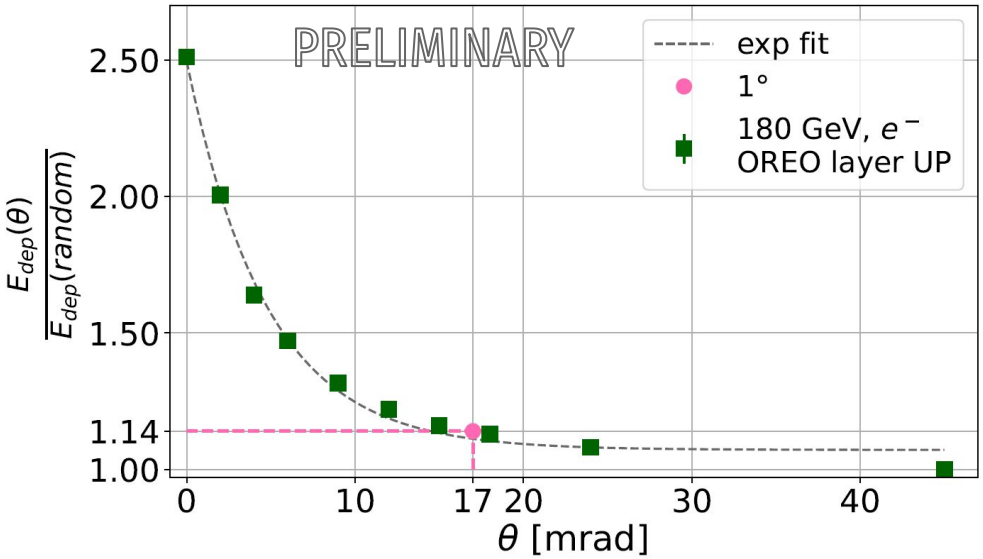
Lead Glass electromagnetic calorimeter

Preliminary results: angular range

120 GeV electrons beam







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

For $PbWO_4$ axis <001>
Θ_0 ~ 0.82 mrad

Acceleration in the e.m. shower development is visible **for an incident angle Θ up to 1°** (17 mrad)

Application: HIKE Small Angle Calorimeter SAC

GOAL → measure the Branching Ratio of a very rare neutral decay:

$$K_L \rightarrow \pi^0 \nu\bar{\nu}$$

BACKGROUND:

- $K_L \rightarrow \pi^0\pi^0$ with only two photons detected
- 500 MHz of hadrons

Reject the hadrons while improving the photons detection efficiency

Oriented Calorimeter!