Subtask 3.1.4

The OREO Calorimeter

Status and Prospect

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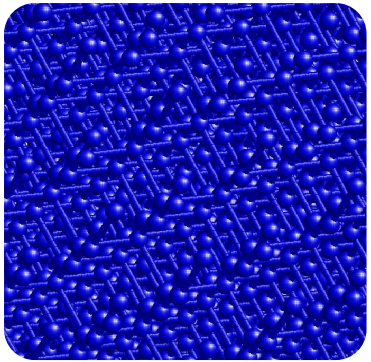
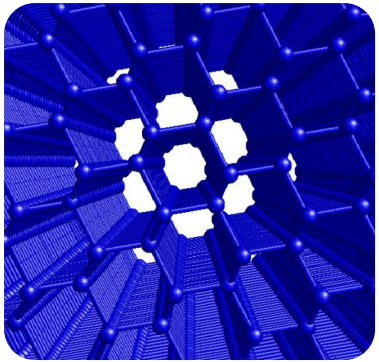
International Conference on Technology & Instrumentation in Particle Physics

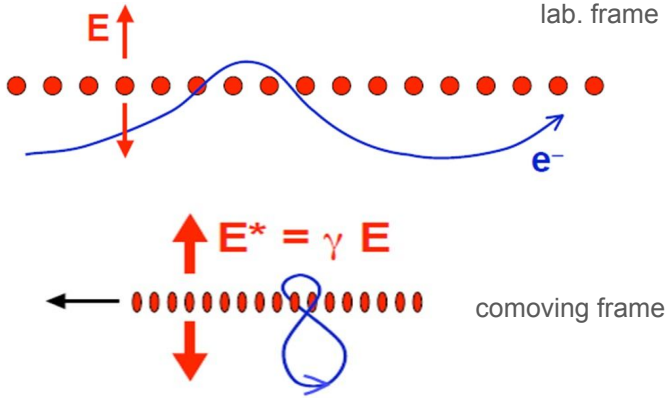
Electromagnetic interactions in oriented crystals



Amorphous



Oriented



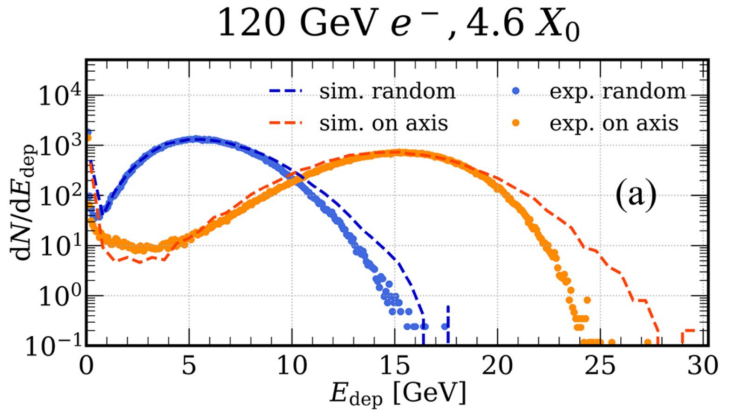
Standard
Bethe-Heitler
processes
Bremsstrahlung
Pair-production

In High Z crystals, E* can reach the Swinger Critical Field
1.32×10^{16} V/cm → Strong Field (SF) regime

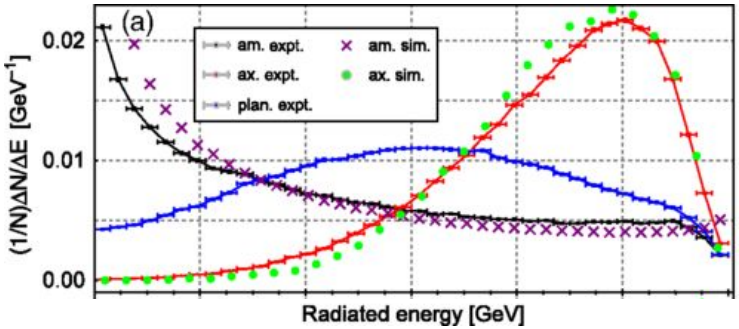
- **Harder radiation emission**
- **Enhanced probability of pair production**

Oriented Scintillating Crystals

- Scintillation/Čerenkov crystals are widely used to build compact Electromagnetic calorimeters (ECAL) but their **lattice effects are usually neglected**
- Strong Field (SF) Threshold for PWO at 25 GeV and 1 mrad, **effects visible already at few GeV and up to 1º**
- In the strong field (SF) regime, the electromagnetic shower development **is accelerated** being much more **compact**



Eur. Phys. J. C (2025) 85: 1239



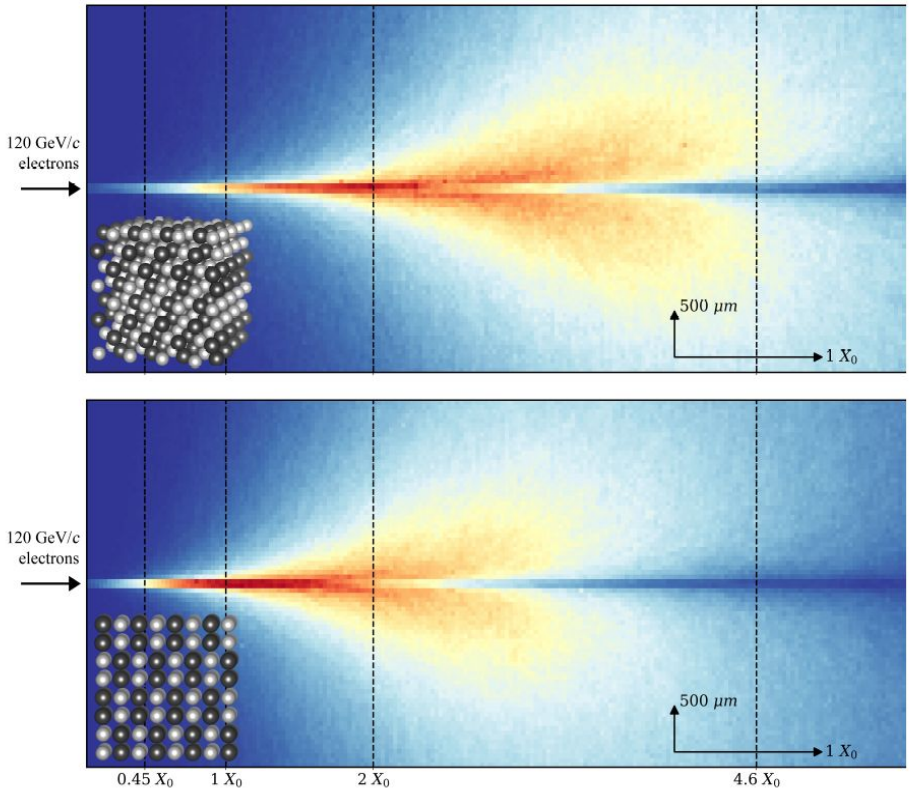
Phys. Rev. Lett. 121 (2018) 021603

The ORiEnted CalOrimeter (OREO)

Idea: exploit the SF to develop an ultra-compact ECAL made of oriented PWO-UF

OREO's Strength

- Reduced effective radiation length ⟶ more compactness & less longitudinal leakage
- Enhanced pair production probability ⟶ Higher γ-detection efficiency
- SF has no effect on hadrons ⟶improved PID and higher γ/hadron discrimination



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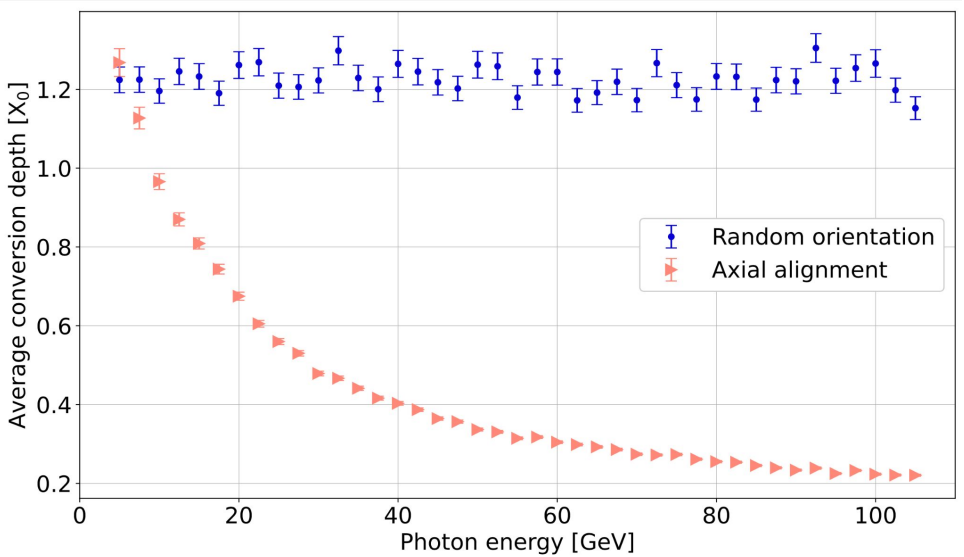

arXiv:2601.04129

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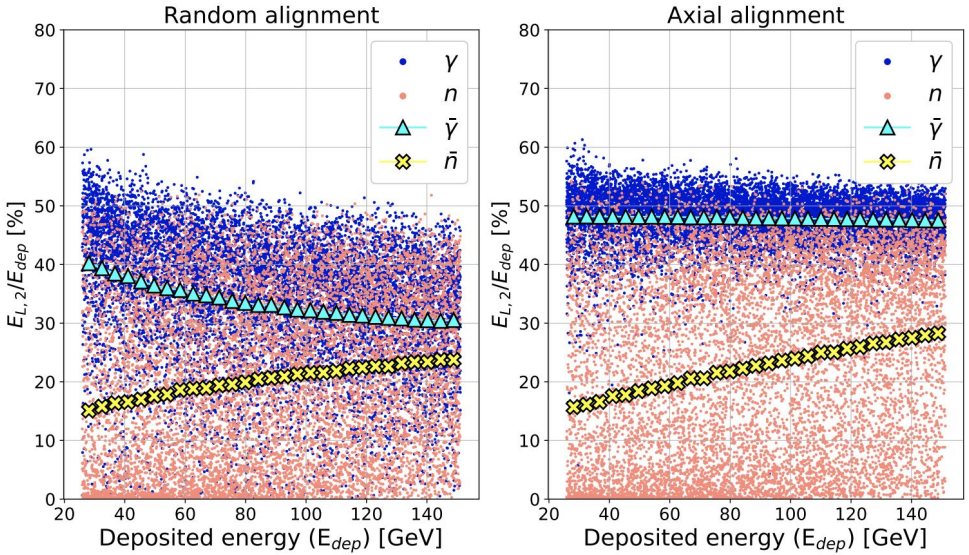
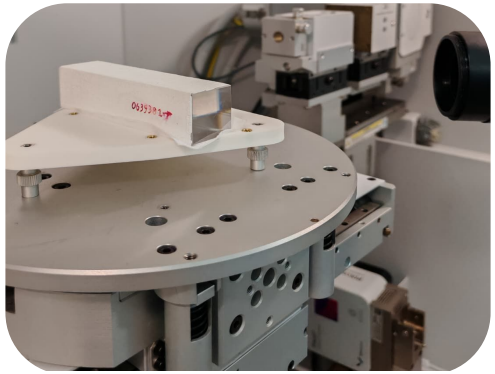
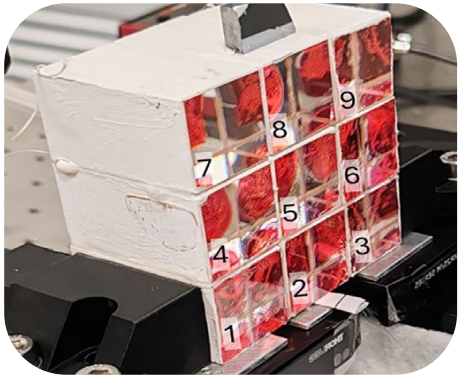


JINST 19 P10014 (2024)

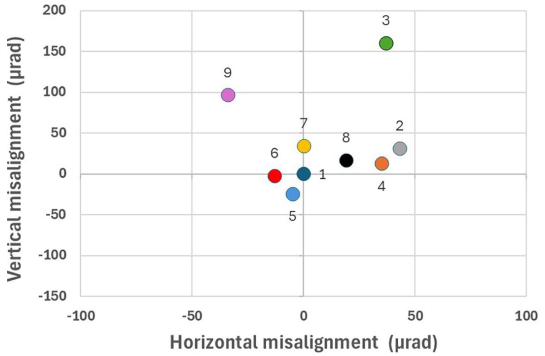
Upstream Oriented Layer construction



PWO-UF crystals grown with Czochralski method by Crytur Spol S RO **with a decay constant of 670ps.** Each crystal was characterized with **XRD diffractometer** at university of Ferrara.



realization of a $5X_0$ matrix of crystals glued to each other and aligned to its main crystallographic axis

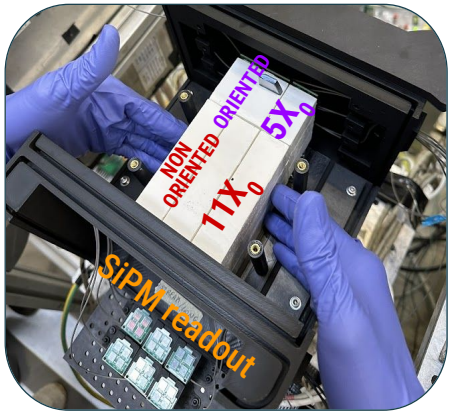


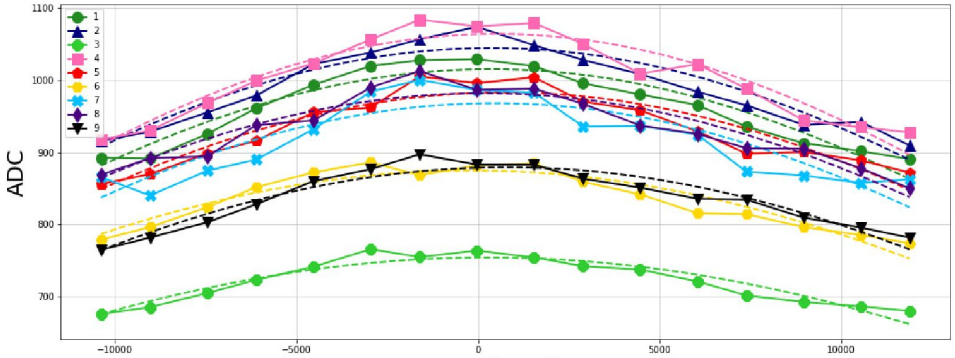
Mutual crystal alignment measured less than 200μrad, well within the SF acceptance (Θ_0~1mrad)

NIMA, 1069 (2024) 169869

OREO first prototype test

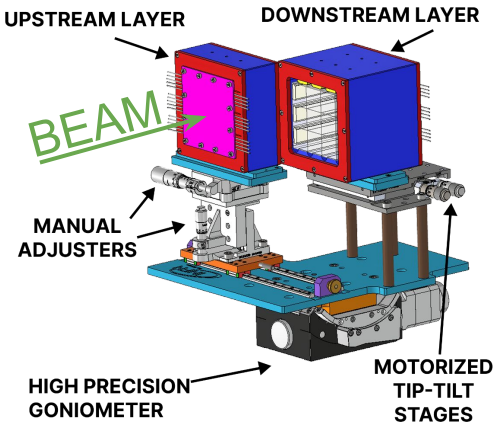
- OREO prototype consists of the oriented layer of $5X_0$ followed by a non-oriented layer of $11X_0$
- Each crystal is read out by a 2x2 SiPM matrix
- First beam tests @CERN PS with 1-6 GeV e-
- Success: all the crystals are aligned! We are able to build an oriented calorimeter

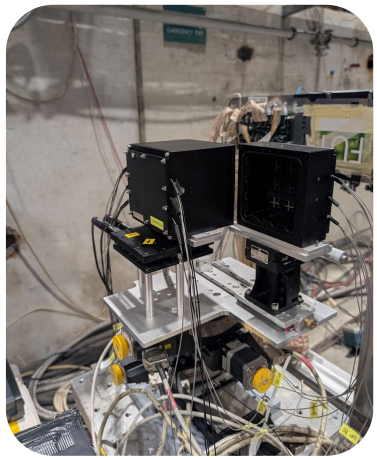


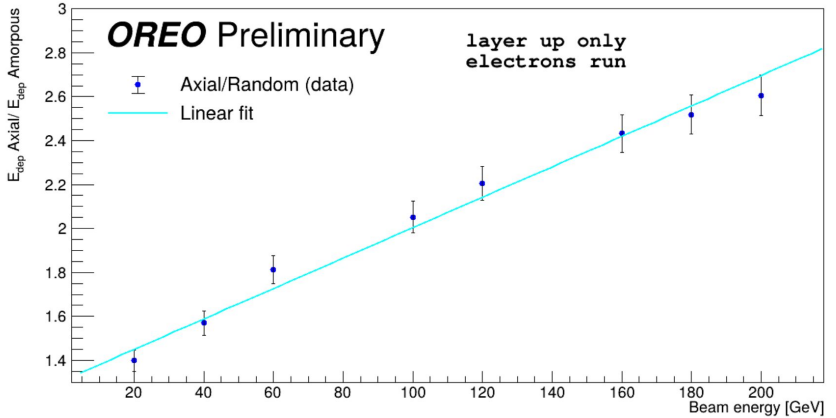


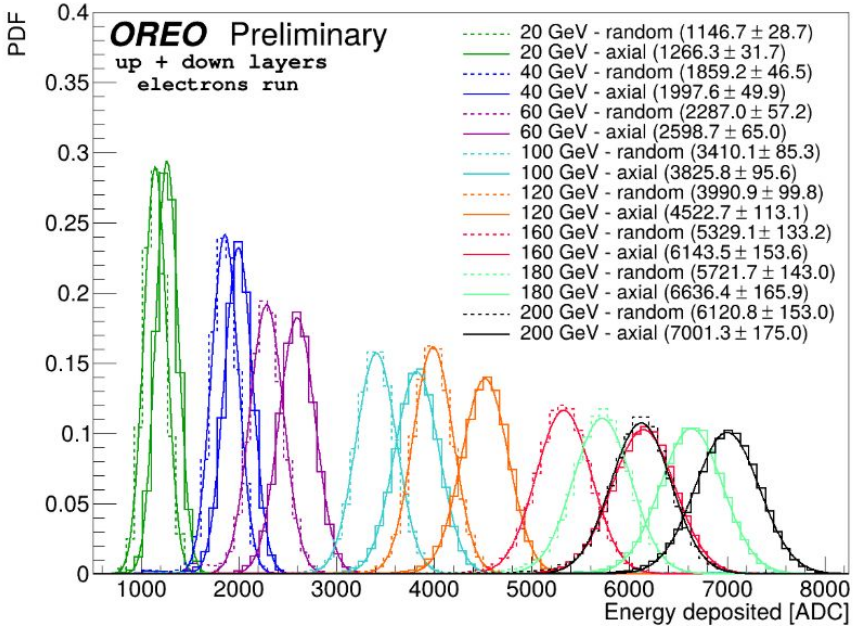
Enhancement of Energy deposition

- Second beam test, 2 weeks at CERN SPS 20-200 GeV e^-, exploring the full SF regime
- Strong enhancement of energy deposition in the first $5X_0$ **up to +150% with respect to amorphous, strong adaptability for preshower layers**
- Enhancement scales with energy up to a plateau at the TeV scale







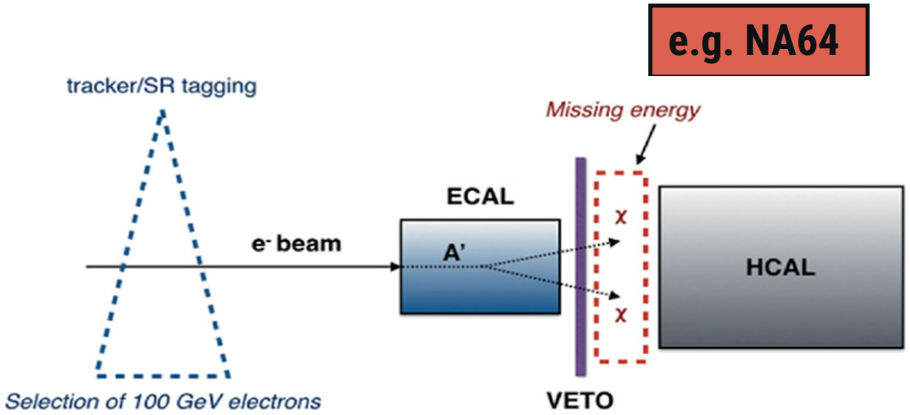


Applications - Fixed target, beam dump and forward region of colliders

Compact electromagnetic calorimeter in forward geometry

Example: Light Dark Matter search

1. A FIP produced in the calorimeter can only be detected if it survives for the overall length before decaying visibly: **the shorter the length, the higher the sensitivity** while ensuring a sufficient number of effective X_0 to absorb the shower
2. Higher γ-detection efficiency ⟶ **reduce the background** of highly penetrating photons



Credits to:
L. Marsicano and A. Celentano INFN Genova
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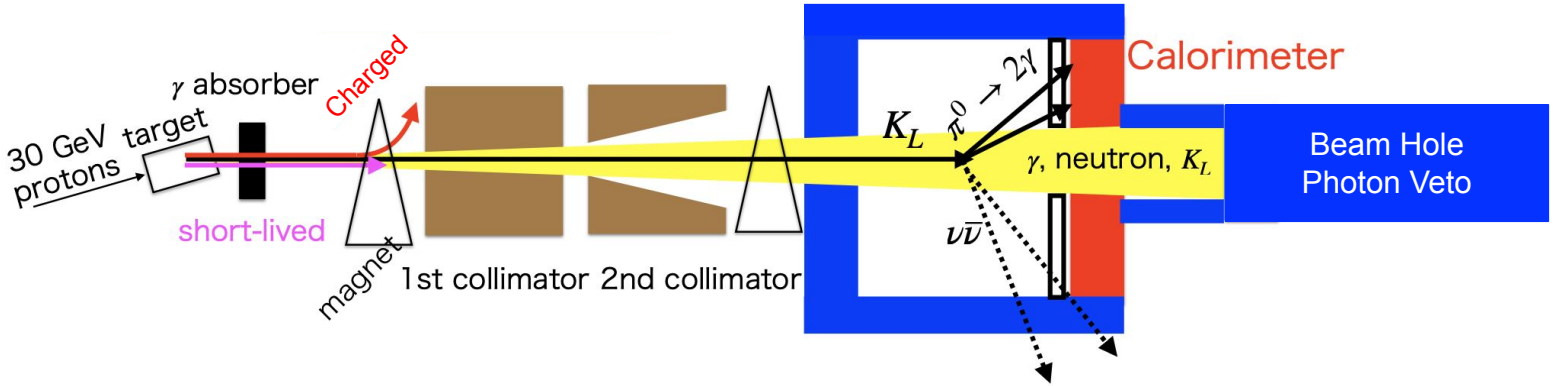
Applications - Fixed target, beam dump and forward region of colliders



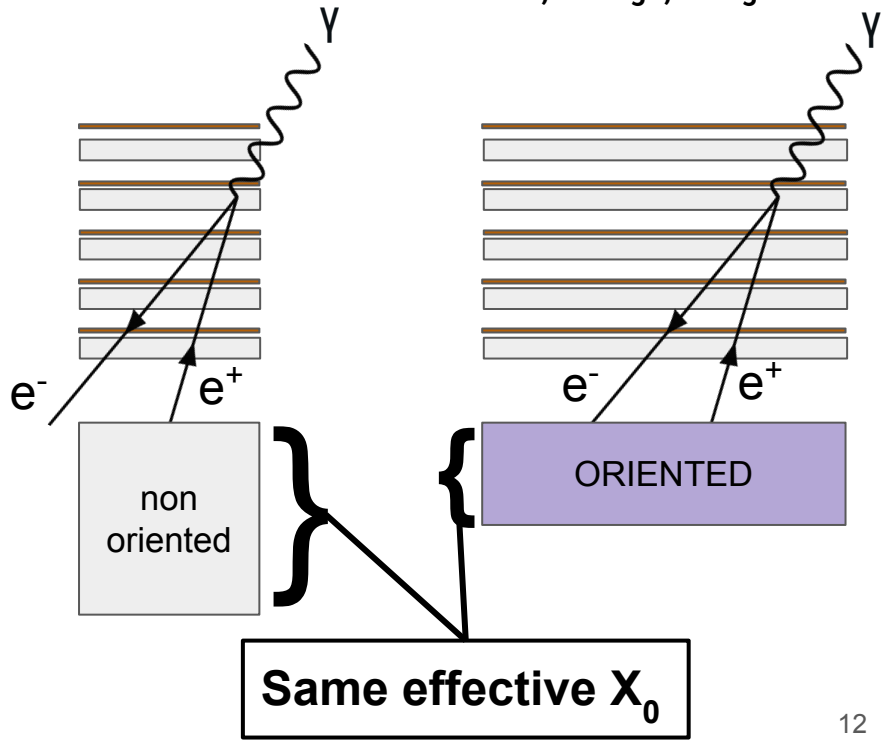
- Fixed-target setups are **intrinsically forward** → ideal for oriented-crystal operation
- **Improved photon detection** in neutral-hadron beams: reduced sensitivity to hadronic interactions prevents "blinding" from the beam
- PWO-UF advantages: fast decay time → excellent timing, strong radiation hardness → suitable for beam veto calorimetry
- Physics driver: ultra-rare $K_L \to \pi^0\nu\bar{\nu}$ searches (SM ~ 3 x 10^{-11}) with dominant background $K_L \to \pi^0\pi^0$. Very-forward SAC-like veto inside the neutral beam: **intercepts escaping photons while tolerating >500 MHz neutral-hadron rates**

Applications - Space-borne High-Energy γ-ray detector with pointing system

Unidentified High Energy γ-ray sources from the galactic center

- The better containment of the shower allows for reduced thickness ⇒ more payload available for transverse size increase ⇒ better acceptance
- Directional enhancement suppresses isotropic background ⟶ improved source detection
- Dual operation: standard mode without pointing; enhanced mode with pointing

Collaboration with Fermi team
E.Cavazzuti, L.Costamante,S.Cutini,
M.Duranti, F.Longo, V.Vagelli



Conclusions

- OREO project investigated coherent effects in calorimetry by developing an ECAL based on oriented scintillating crystals with accelerated EM shower development, better γ-detection efficiency, improved γ/hadron discrimination.
- CERN beam tests validated the oriented calorimeter concept, showing up to a +150% increase in energy deposition at 200 GeV in a $5X_0$ section with respect to amorphous configuration.
- Scintillating crystals presents a crystal structure and are grown with a defined orientation, coherent effects should be considered in granular ECAL design and operation.
- Oriented calorimeters are especially promising for forward collider regions, fixed-target and beam-dump experiments, and space missions for VHE γ-ray source detection and localization.

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