Motivation

Despite high-Z scintillators are largely used to build e.m. calorimeters, the influence of their crystal lattice on the e.m. shower formation is usually completely ignored both in the detector design and simulations. Nevertheless, it has been known since decades that the lattice structure of a crystal may strongly influence the e.m. processes, which may result in a strong decrease of the shower length. The usage of oriented scintillator crystals in e.m. calorimeters would permit thus to reduce the amount of material necessary to build the detector, a possibility from which HEP and astrophysics experiments could benefit from.

Strong electromagnetic field in crystals

For small angle between charged particle trajectory and crystal axes/planes direction, it is possible to replace the Coulomb potential of each atom with an average continuous potential of the whole plane/string (see Fig. 1), corresponding to a strong electrostatic field \( E \sim 10^{10} \text{ V/cm} \) [1].

At energies of some GeV, the continuous axial field felt by a particle in its rest frame is enhanced by a factor \( y \) because of the Lorentz contraction, thus becoming comparable to the Schwinger critical field of QED, \( E_0 = m^2 c^3/e \hbar = 1.32 \cdot 10^4 \text{ V/cm} \), which can be reached for instance in pulsar atmosphere.

The interaction with the strong field of a crystal axis leads to enhancement of pair production and bremsstrahlung, thus reducing \( X_0 \) and thereby the e.m. shower length as compared to a randomly oriented crystal or amorphous material.

GEANT4 modified simulation for a PWO crystal with \( X_0 \) reduced vs E beam

The electromagnetic shower is simulated using the Geant4 toolkit in which the cross sections for bremsstrahlung and pair production are rescaled [3] in agreement with full Monte Carlo experiment with axially oriented PWO [1].

Possible Applications

X_0 reduction is possible if the crystal axes are aligned with the beam direction within 1°. Thereby, elective application can be in:

**HIGH-ENERGY PHYSICS:**
1. Fixed-target Experiments: forward e.m. calorimeters/preshower with reduced volume.
2. Beam Dump: compact active beam dump with an increased sensitivity to dark photons.

**ASTROPARTICLE PHYSICS:**
1. Satellite borne gamma-ray telescopes: With a gamma module (see Fig. 8) made of oriented crystals, one may point the telescope towards the source and the shower of gamma rays with energy larger than 100 GeV can be completely contained in a quite restrained volume.

References


Radiation Length Reduction in an axially oriented PWO crystal

L. Bandiera et al, ArXiv: 1803.10005

Figure 2

PbWO₃ scintillator crystal lattice: Schmelleite type structure (tetragonal, \( a=b=5.456, c=12.020 \) Å).

X₀ standard = 8.9 mm

Experiment at CERN SPS H4 beamline with 120 GeV/c electrons

Figure 3

Orientation of the crystal with respect to the 120 GeV/c electron beam. The used crystal was 4 mm (0.45 \( X_0 \)) along the beam direction and parallel to [001] axes.

Figure 4

(a) The experimental [1] and simulated radiated energy distributions under axial alignment within some mrad (ax. exp. and sim.) and when the beam is misaligned (am. exp. and sim.) with respect to the [001] axes, i.e. as for an amorphous material. The radiated energy is much harder for axial than for random orientation.

(b) Simulation [2] for pure bremsstrahlung in amorphous (purple) and axial (green) orientation. In axial case, \( X_0 \) is decreased from 8.9 to 1.6 mm.