CRILIN: Crystal Calorimeter with Longitudinal Information

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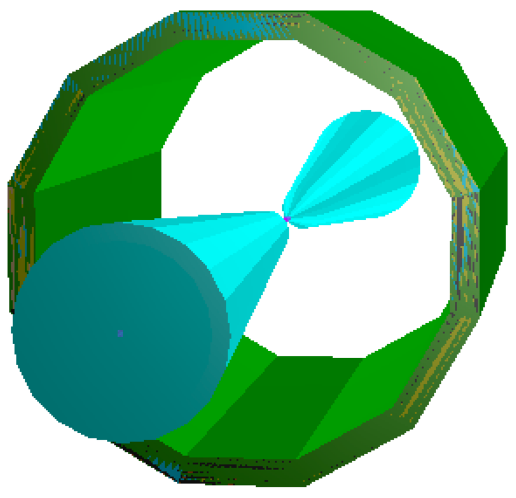
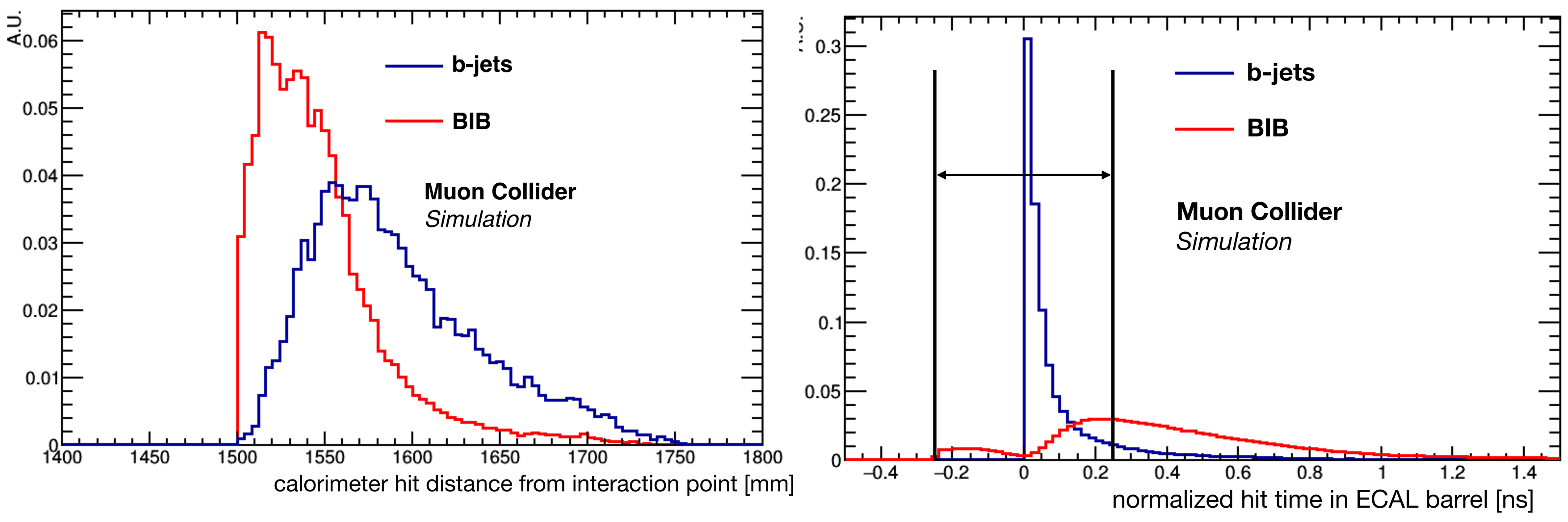
Introduction



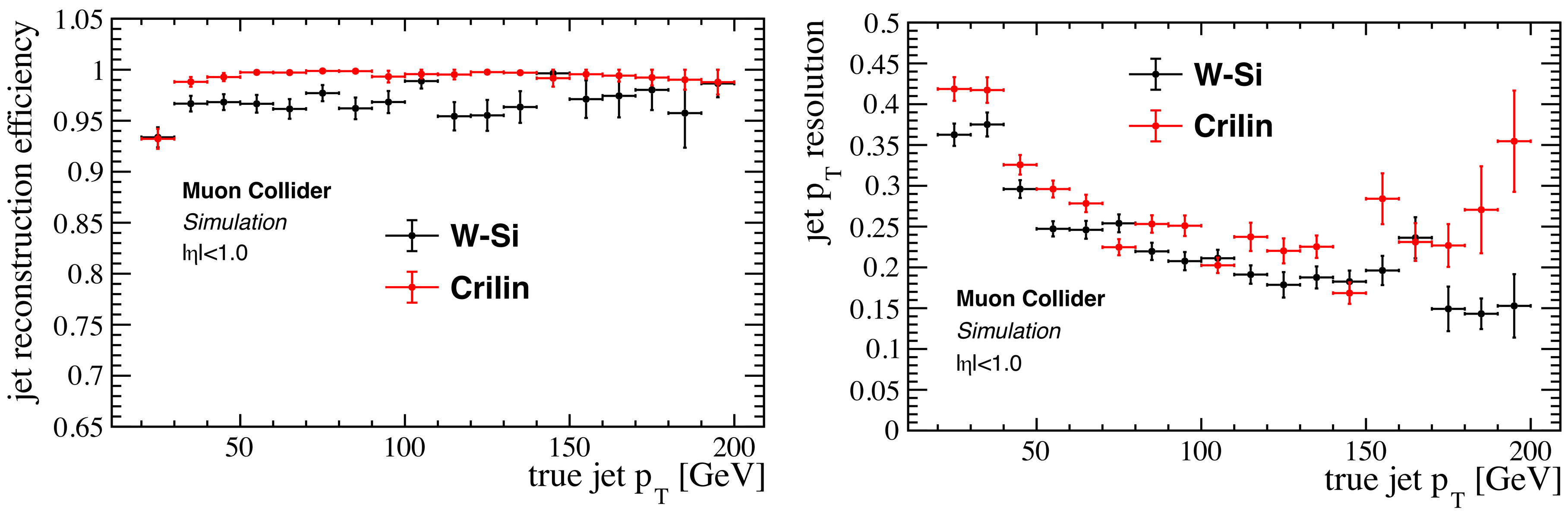
Crilin barrel design for a Muon Collider

In a future Muon Collider (MC), a major challenge for detector design and event reconstruction is represented by beam-induced background (BIB) due to muons decay and subsequent interactions, characterized by particles with low momentum (~ 1.8 MeV), displaced origin, and asynchronous time of arrival.

Crilin - a semi-homogeneous, longitudinally segmented electromagnetic calorimeter based on Cherenkov PbF_2 crystals with UV-extended SiPM readout - features fine granularity, excellent timing, good pileup capability and energy resolution, along with improved radiation resistance. Its modular architecture, featuring stackable and interchangeable sub-modules, allows crystals granularity, transversal and longitudinal dimensions scaling to maximize performance.



Simulated energy-weighted longitudinal hit profile (left) and hit time distribution wrt prompt photons arrival

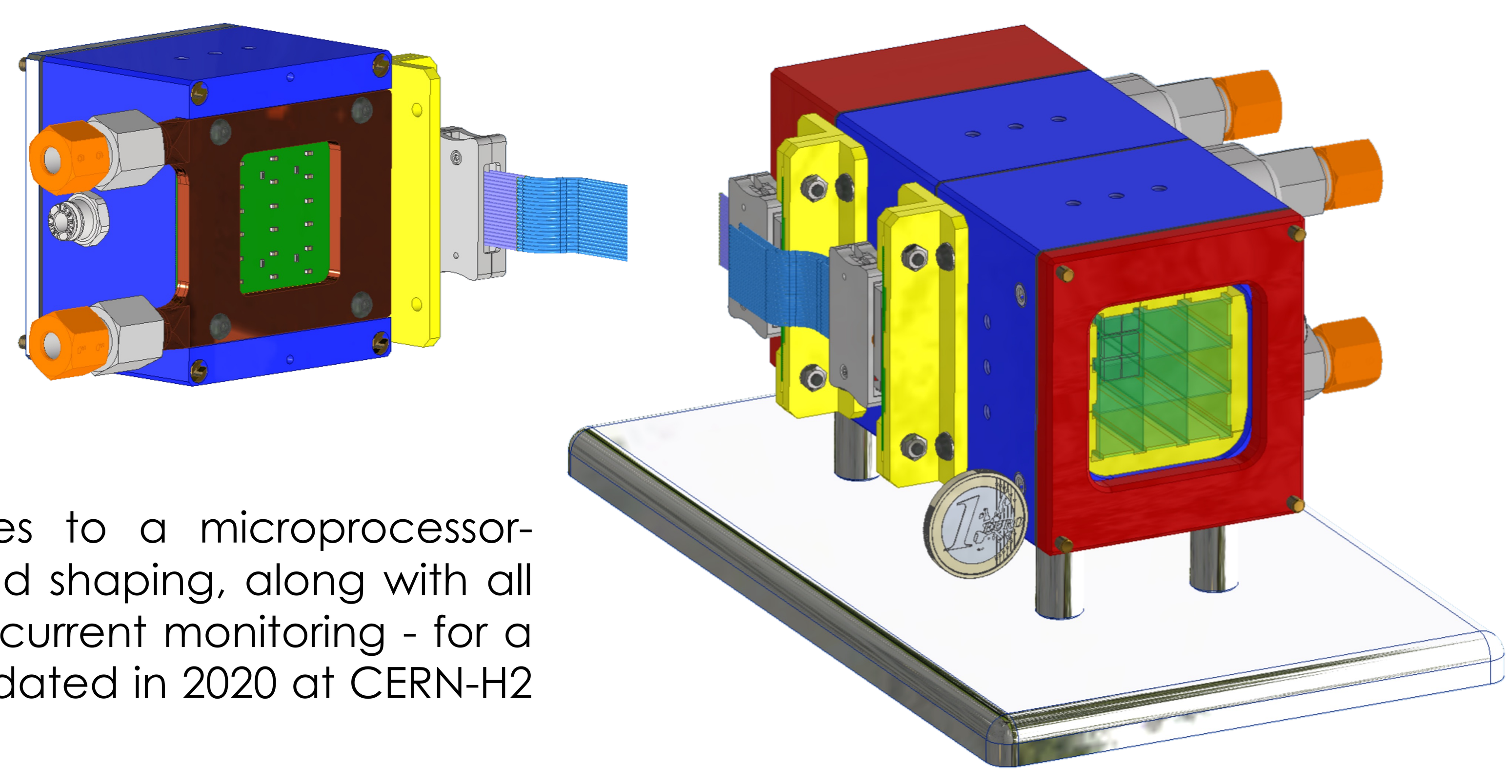


Crilin simulated b-jet reconstruction performance and comparison with W-Si calorimeter

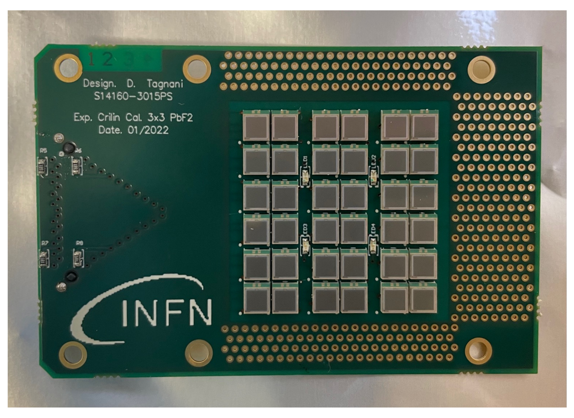
Excellent background rejection and particle flow performance can be achieved through the following design requirements: **1)** high granularity to reduce BIB overlap and identify jet substructures **2)** excellent timing ($\sigma_t < 100\ ps$) to exclude BIB components **3)** longitudinal segmentation to separate signal showers from BIB fakes and assign jets vertexes **4)** good energy resolution (< 10/sqrt(E)). The Crilin ECAL barrel design for the MC with 5 layers of 10x10x40 mm^3 crystals was evaluated in the International MC framework for the reconstruction of hadronic jets from $\mathrm{H} \to \mathrm{b\bar{b}}$ decays (at $\sqrt{s} = 1.5\ \mathrm{TeV}$) against the expected (300 γ/cm^2 per BX) BIB using particle-flow methods: good separation is achieved with O(5 GeV) energy deposit per crystal.

Crilin prototype

In its current design, the Crilin prototype (Proto-1) consists of two sub-modules, each composed of a 3-by-3 crystals matrix, housed in a light-tight case which allows their optical coupling to the SiPM boards. The latter is coupled to an additively manufactured micro-channel heat exchanger used to thermalize the SiPM matrix. Each SiPM board houses a layer of 36 photo-sensors, so that each crystal in the matrix is equipped with two separate and independent readout channels, each consisting in a series of two 15 μm pixel-size SMD SiPMs from Hamamatsu (part no. S14160-3015PS), selected for their high-speed response, short pulse width and to better cope with the expected TNID.



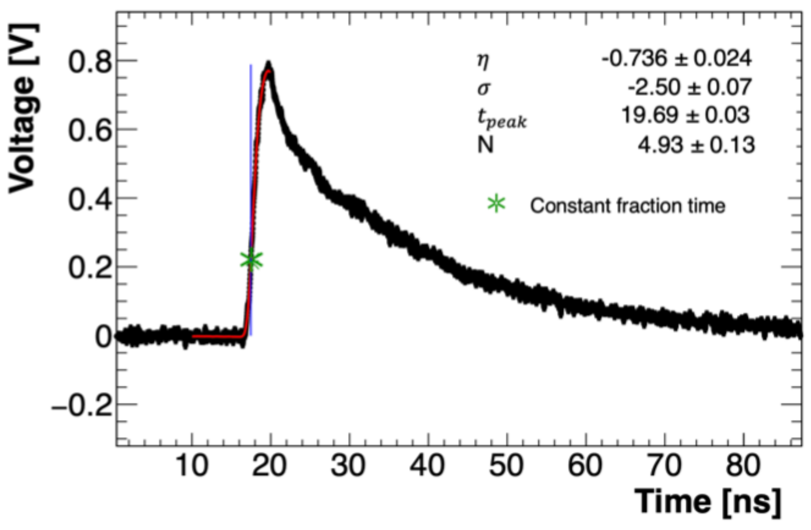
Crilin Proto-1 rendering (right). SiPM board and cooling system detail (top left)



Crilin SiPM board for the 3x3 crystal matrix

SiPMs are connected via 50-ohm micro-coaxial transmission lines to a microprocessor-controlled Mezzanine Board, which provides signal amplification and shaping, along with all slow control functions - individual bias regulation, temperature and current monitoring - for a total of 18 readout channels. A 2-crystal prototype, Proto-0, was validated in 2020 at CERN-H2 with an e^- and γ test beam.

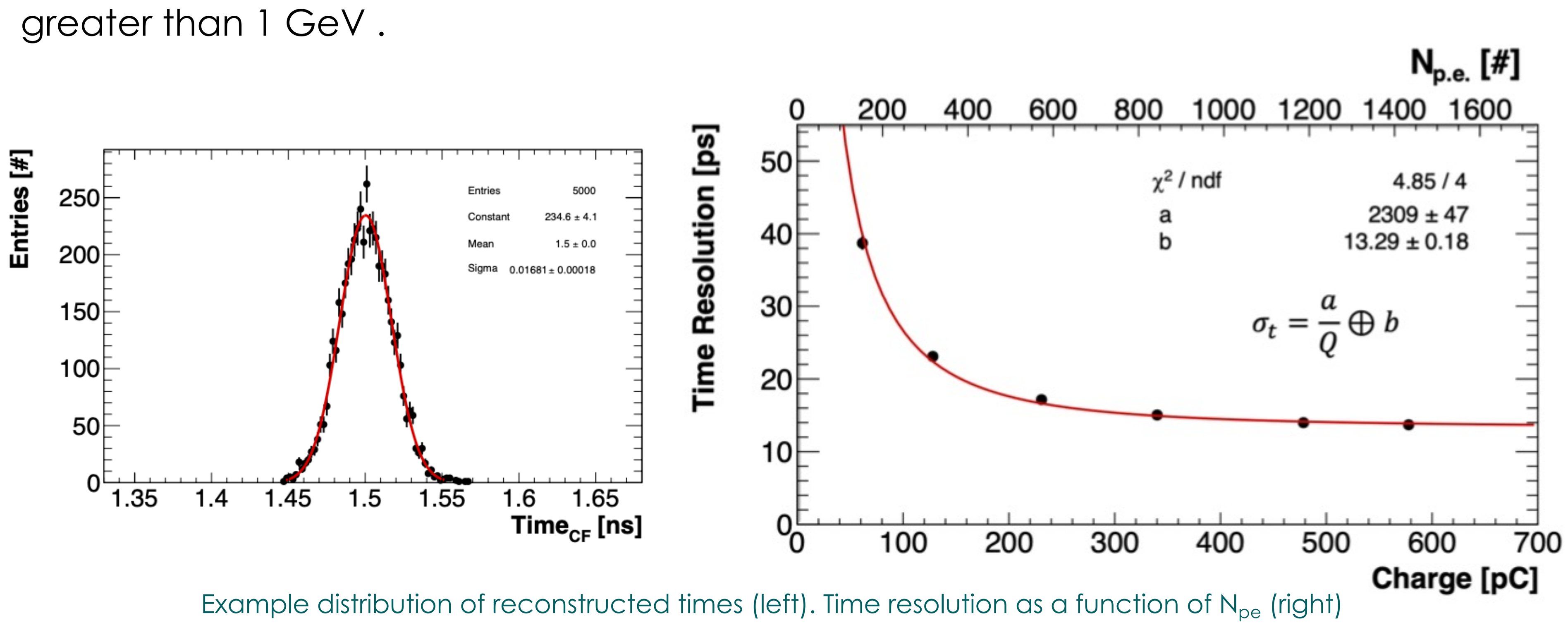
SiPM and FEE timing resolution studies



SiPM waveform with overlayed log-n fit

A first prototype of the front-end electronics was tested by exposing two SiPMs to a picosecond UV laser source with variable intensity. SiPM signals were digitised at 40 Gsps. Timing was reconstructed by means of a log-normal fit applied to SiPM pulse rising edges and constant fraction technique.

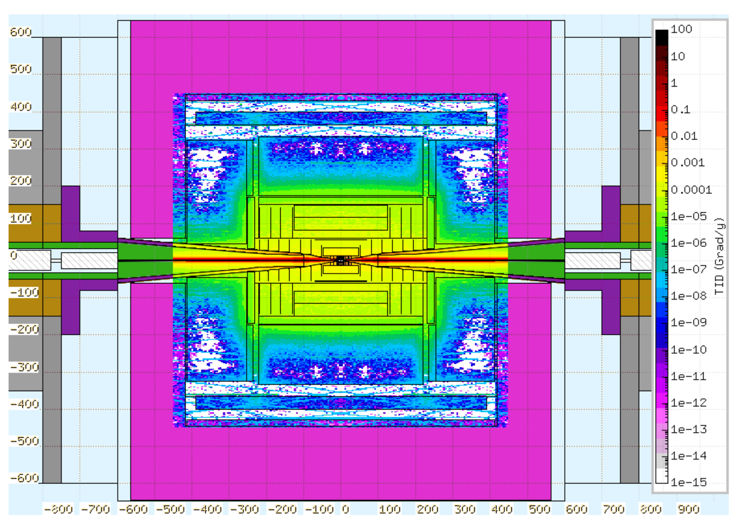
The time resolution and its dependence on N_{pe} was evaluated. A resulting 13 ps constant term contribution to timing resolution was evaluated on fitted data. Using the 1 p.e. per deposited MeV light yield evaluated with the previous (Proto-0) test beam, a timing resolution better than 100 ps can be expected for energy deposits greater than 1 GeV .



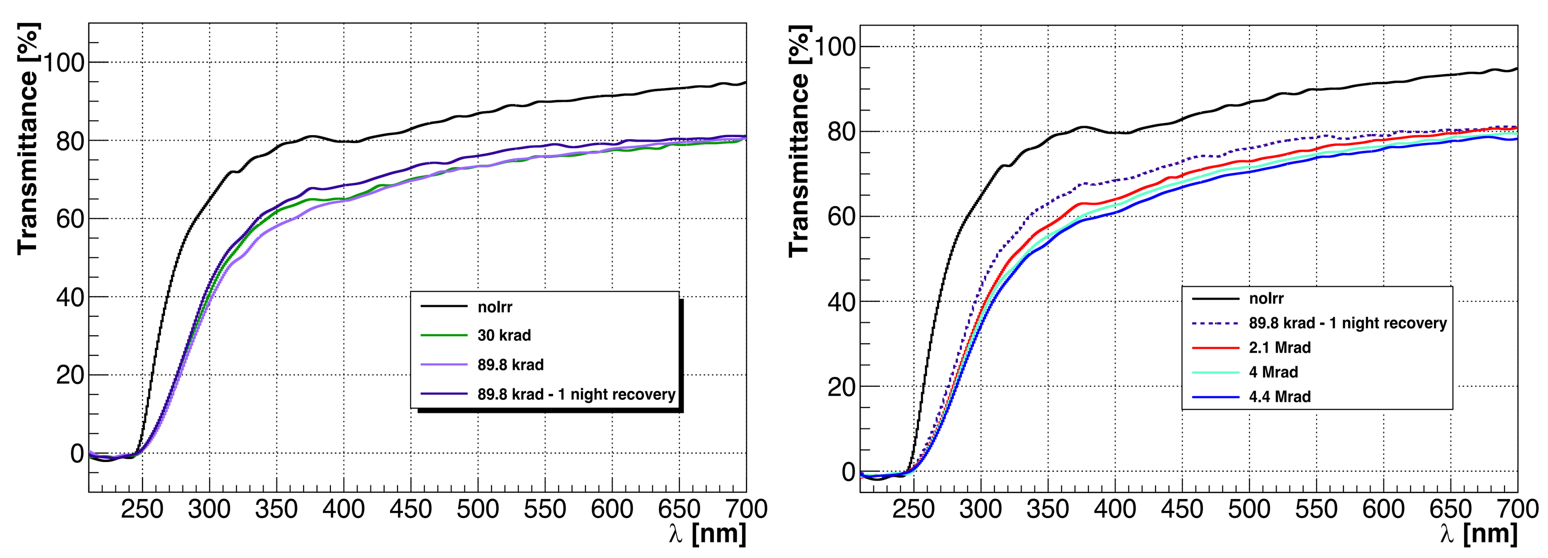
Example distribution of reconstructed times (left). Time resolution as a function of N_{pe} (right)

Radiation hardness

FLUKA simulations implementing the BIB yielded were carried out at $\sqrt{s} = 1.5\ \mathrm{TeV}$, yielding a 10^{14} 1/cm/y expected 1-MeV-neq fluence, along with a 10^{-4} Grad/y total ionising dose (TID) on the EMC. A radiation characterization campaign was started in February 2021 on β-PbF2 crystals from SICCAS, with different wrapping configurations.



TID map from FLUKA simulation



Crystal transmission spectra deterioration at different irradiation steps

A first TID test up to 4 Mrad was carried out at ENEA-Calliope using photons from 60Co, showing a worst case 40 % decrease in transmittance for all specimens. A subsequent NIEL test carried out at ENEA-FNG with 14 MeV neutrons up to a 10^{13} n_{1MeV}/cm^2 fluence showed no effect on transmittance.

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