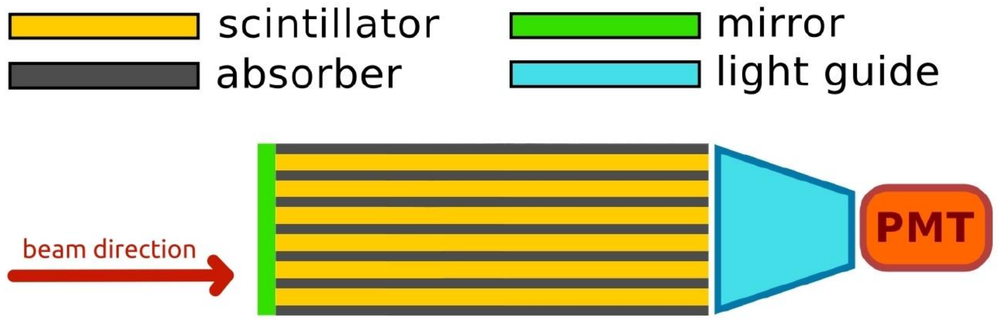
Performance studies and design optimization of Spaghetti Calorimeter prototypes

Aleksandar Bordelius, on behalf of WP 3.2.0 (R&D group on SpaCal technology)

1. Introduction to SpaCal Technology

A Spaghetti Calorimeter (SpaCal) is a sampling calorimeter in which scintillating fibers (inorganic or organic) are inserted into a dense absorber (tungsten or lead).

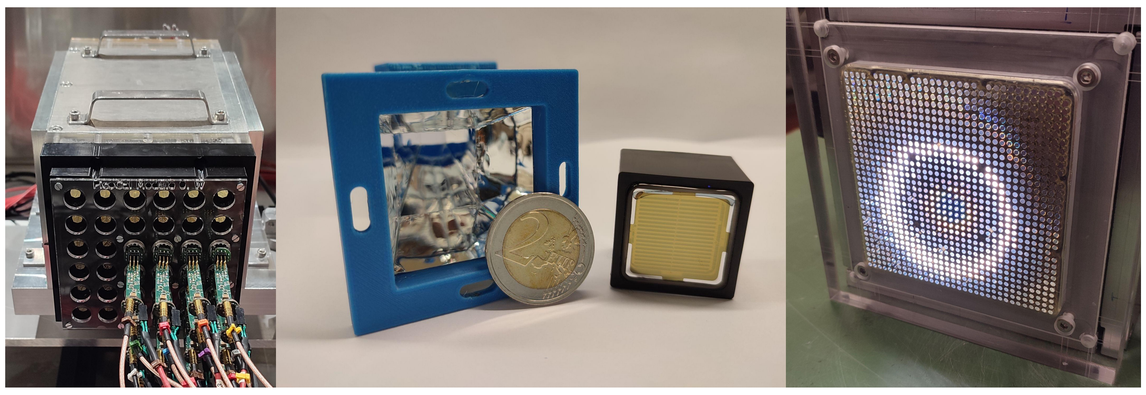


Photomultiplier tubes with a metal channel dynode type (MCD-PMTs) are one photodetector option for the SpaCal technology. They are a good candidate considering the requirements:

- Can be made compact (to fit a cell size of down to 15 × 15 mm^2).
- Are radiation-hard for applications in experiments at hadron colliders.
- Have good timing capabilities (small photoelectron transit time spread).

2. SpaCal Prototypes

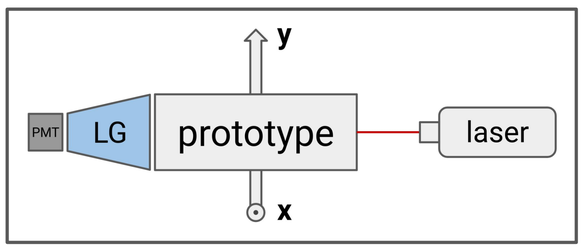
The first module-size SpaCal prototype with tungsten absorber and plastic scintillating fibers was assembled at CERN in 2023 and evaluated during test beam campaigns. This year, we expect two new module-size SpaCal prototypes, one with tungsten absorber and crystal (GAGG) fibers, and the other with lead absorber and plastic scintillator fibers.

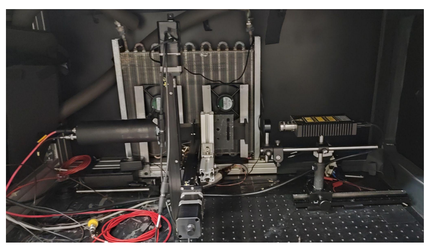


Hollow light guides offer a cost-effective and radiation-tolerant alternative to traditional PMMA light guides and have similar performance. Different models of MCD-PMTs were tested with the prototypes but not yet equipped in a double-sided readout configuration.

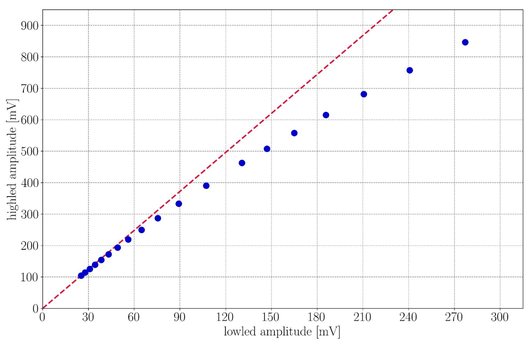
4. Laboratory measurements

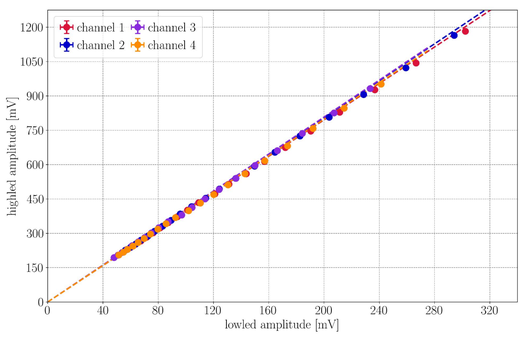
A laboratory bench was set up at CERN to study the response linearity of photodetectors and light collection uniformity of hollow light guides. A linear response of a photodetector over an entire relevant dynamic range is essential for good energy resolution. Light guides introduce non-uniformities in response and affect the constant term of energy resolution.



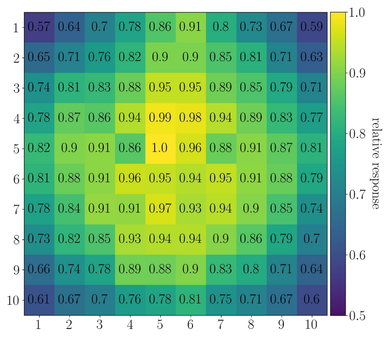


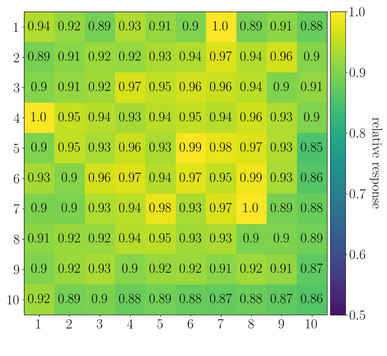
4.1 Response linearity





4.2 Response uniformity

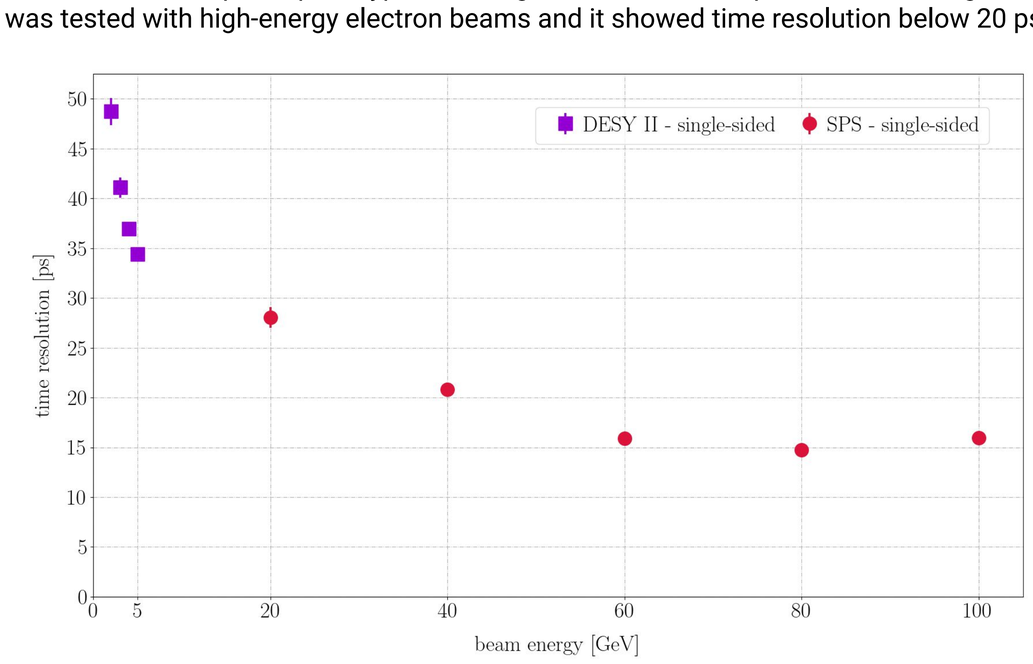




3. Test beam results

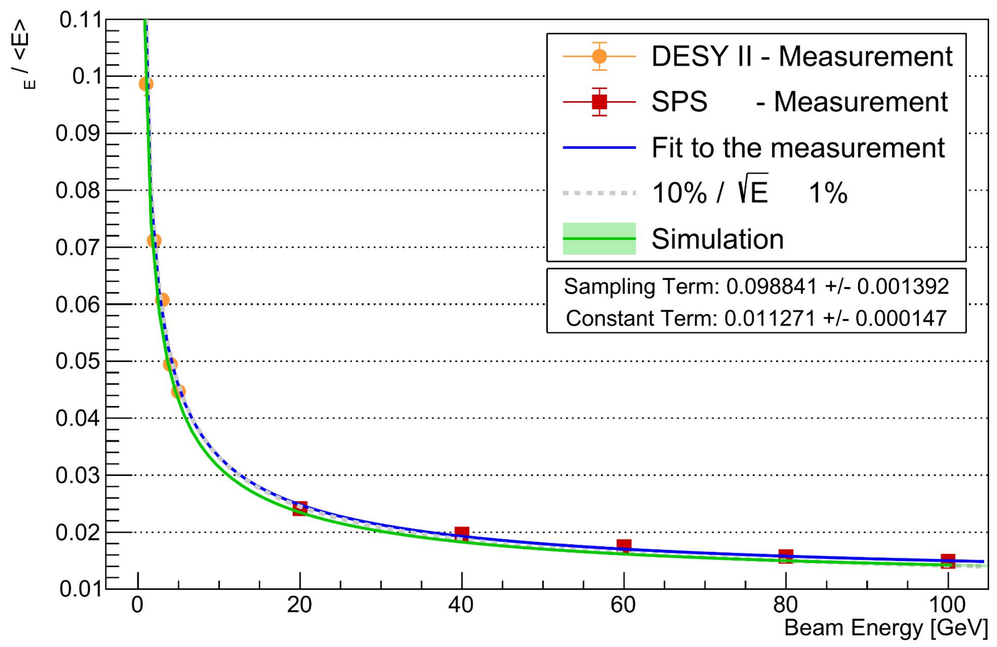
3.1 Time resolution

The module-size SpaCal prototype with tungsten absorber and plastic scintillating fibers was tested with high-energy electron beams and it showed time resolution below 20 ps.



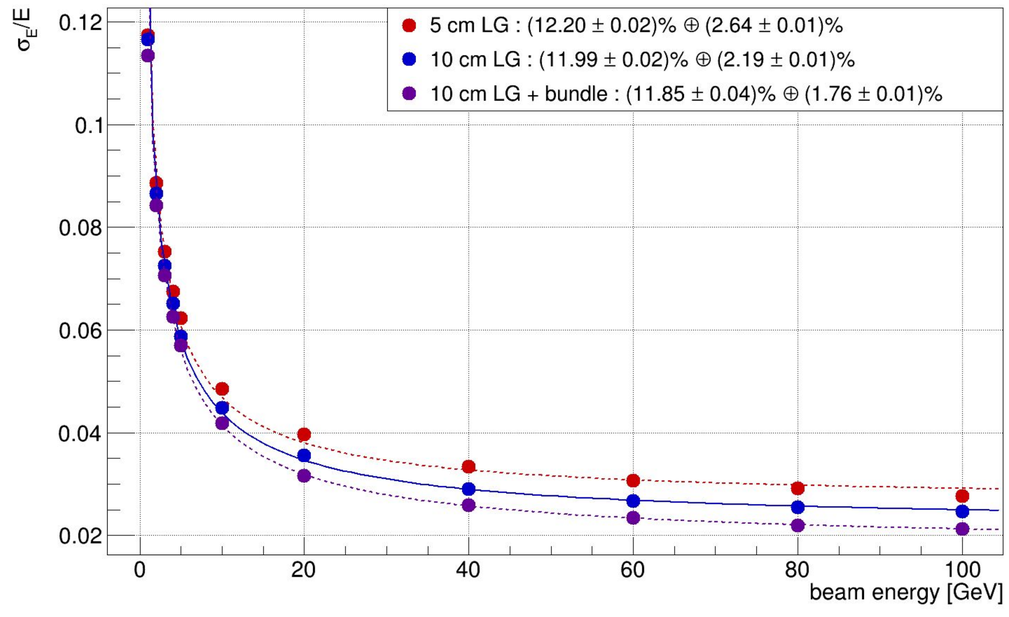
3.2 Energy resolution

By selecting events in the center of a cell, energy resolution has around 10% sampling and 1% constant term, which agrees with Monte-Carlo simulations.



4.3 Monte-Carlo simulations

Laboratory measurements were used as input for Monte-Carlo simulations to study the effect of light guides on energy resolution for SpaCal with lead absorber and 3 cm cells.



With longer light guides, the light collection uniformity is improved. Additional gain can be achieved by bundling the fibers and reducing the entrance surface of the light guide to the size of the bundle. The following also increases absolute light collection.

References

[1] LHCb Particle Identification Enhancement Technical Design Report, https://cds.cern.ch/record/2866493
[2] Test beam studies of SpaCal prototype calorimeter module with tungsten absorber, https://cds.cern.ch/record/2878818