# SpaCal modules with Pb absorber: prototype performance

## Review of ECAL LS3 consolidation

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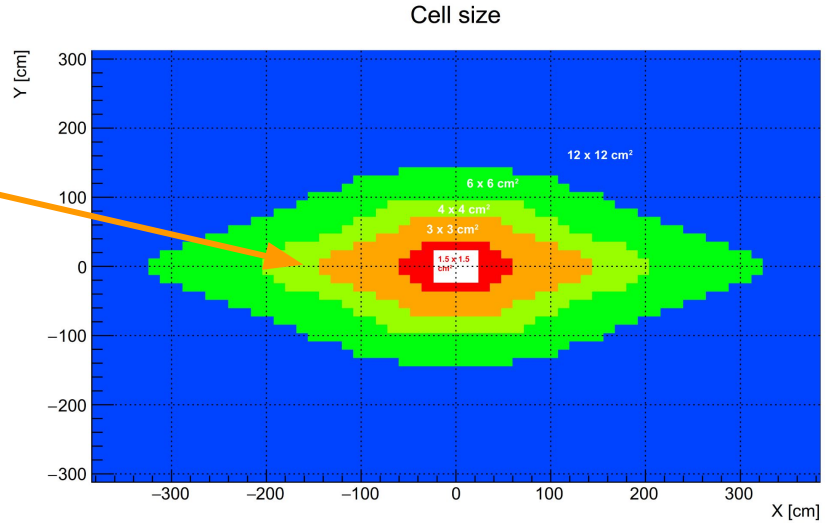
# SpaCal Pb polystyrene technology overview (144 modules) :

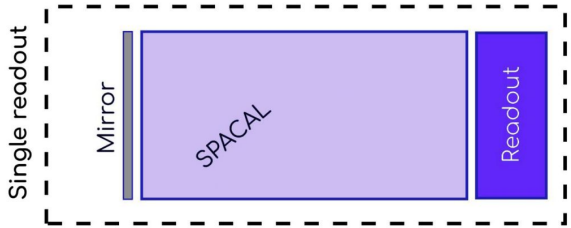
★ This talk is about the orange region.

★ SpaCal with Pb absorber and polystyrene scintillating fibres in the inner ECAL region. Advantages wrt shashlik and features:

- Radiation tolerant up to 40 kGy (current shashlik significantly degraded)
- Higher granularity (from 4x4 to 3x3 $cm^2$)
- Compatible with longitudinal segmentation and run 5 configuration (double-sided readout)
- Tilted modules (needed by SpaCal technology)

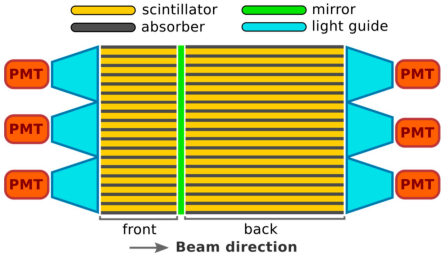


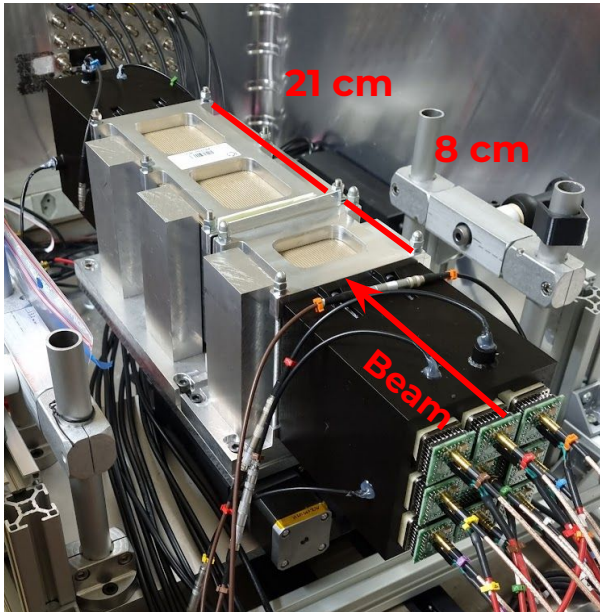

Proposed Run 4 configuration ->




Part of the results show double-sided readout configuration, made in view of run 5.

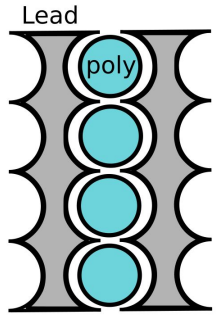
# 9 cell prototype double-sided readout: SpaCal Pb with 1 mm ∅ organic fibres



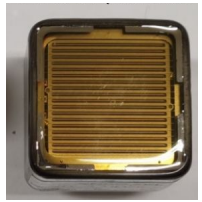




**Module assembly details:**

- Grooved lead
- 3x3 cm$^2$ cells (16 cells would fit in a full 'module-0')
- Kuraray polystyrene scintillating fibres SCSF-78, single cladding, round section
- fibres dimension: 1 mm
- Pitch between fibres: 1.67 mm
- Total length: 29 cm (8 front section + 21 back section




**Readout**
10 cm light guides
Hamamatsu R11187 (matches the 3x3 cell)
metal channel dynode (MCD) PMT



# SpaCal Pb with 1 mm ∅ organic fibres: Energy resolution and simulations comparison

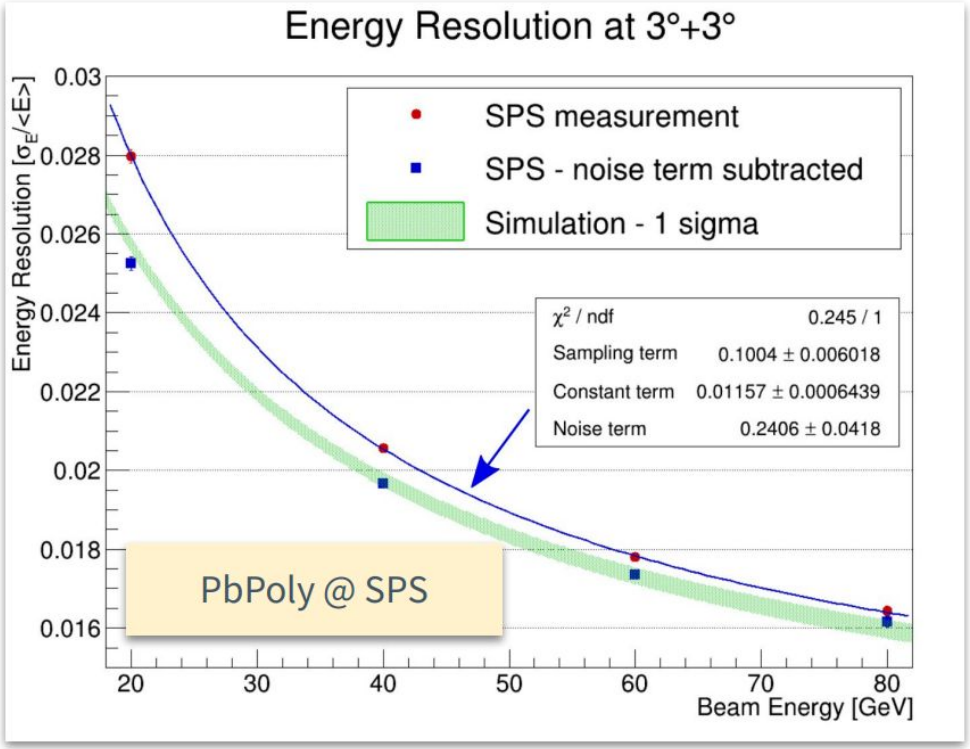
Baseline performance.
Measured at high energy electrons in SPS CERN:

- 3°+3° incidence angle
- best fit to data adding noise term

Same E resolution as current ECAL:

★ Sampling term: 10.0±0.6%
★ Constant term: 1.2±0.1%

Simulations reproduces the measurements with noise term subtracted!



# SpaCal Pb with 1 mm ∅ organic fibres: Time resolution

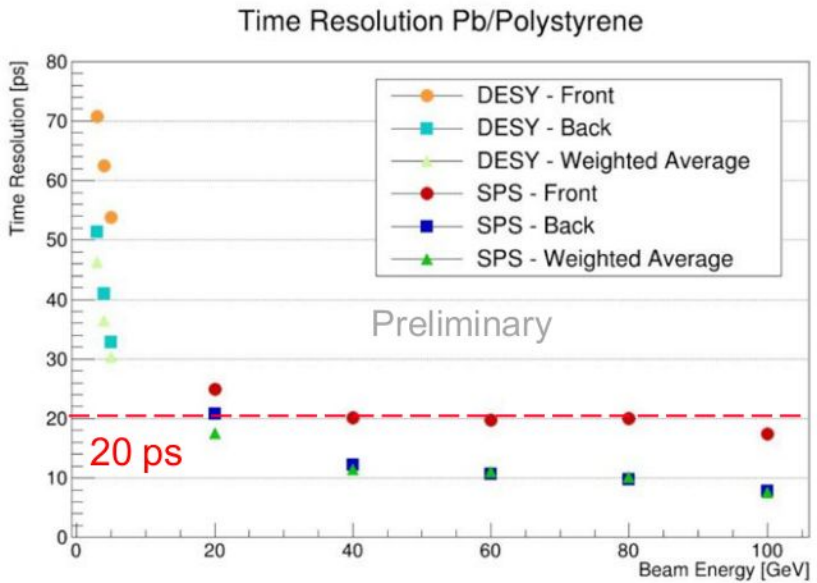
Measured between 1 to 100 GeV:

- 3°+3° incidence angle
- timestamps front/back sections with CFD

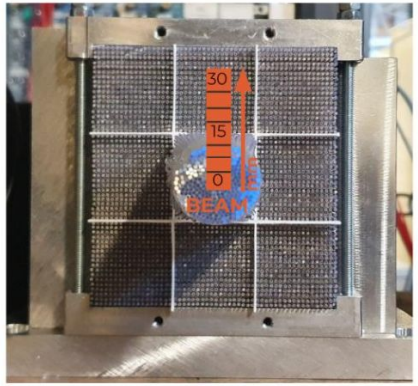
Time resolution:

★ < 20 ps @ > 20 GeV

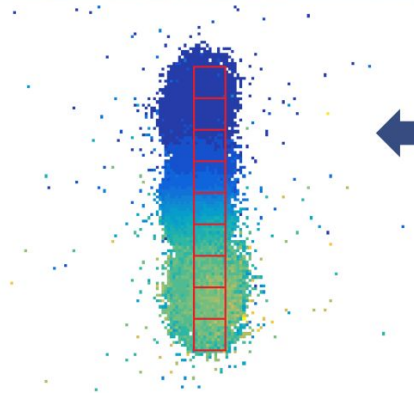
★ ~ 10 ps @ 100 GeV



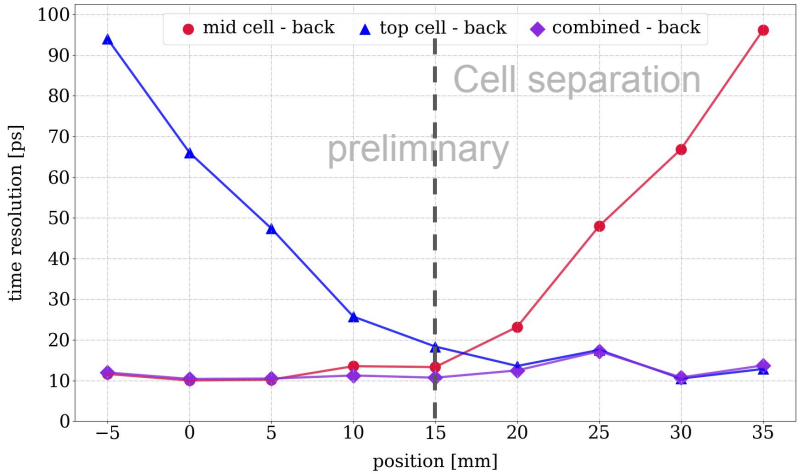
# SpaCal Pb with 1 mm ∅ organic fibres: Time resolution moving between cells




PbPoly prototype



Events are grouped by hit position




Time res can be recovered using the information of two cells.
Better than 20 ps even using only the seed cell information.
Study to be completed with new prototypes.

# Technology optimization: SpaCal Pb with 2 mm ∅ organic fibres

**2mm diameter fibres : why?**

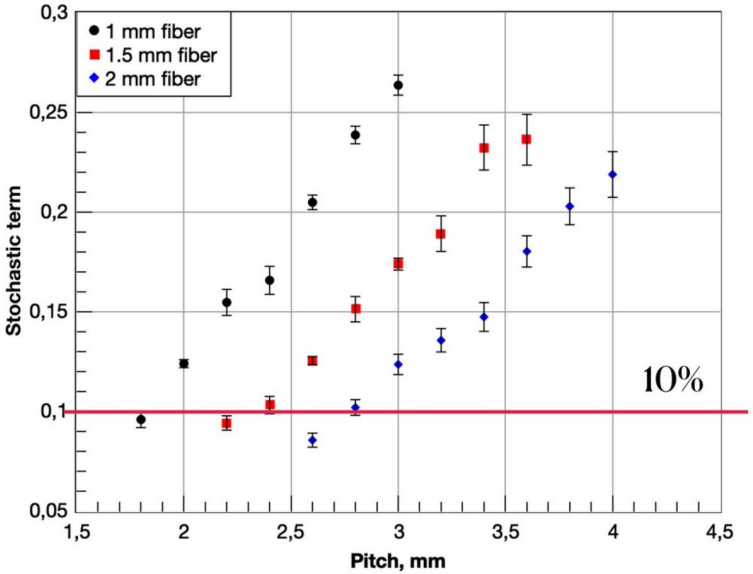
Production of 1 mm ∅ and 1.67 mm in lead is complicated by the material properties. Increasing the diameter would make production easier.

Even with 2 mm ∅ fibers, rolling technique used for the first prototype not viable for 144 modules production (handling the different planes too complicated even with external mechanics)

**Performance compensation in the design:**

**Example: decrease the pitch to preserve the 10% sampling term**

There is a combination of Pitch and ∅ that provides the required stochas term. Fibre size fixed to the largest available in the market – 2 mm in diar Kuraray SCSF-78 ∅ 2mm | Protvino (R&D on fibre production)

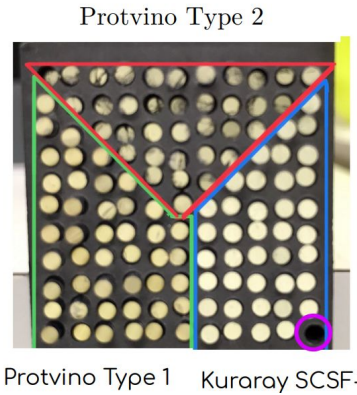


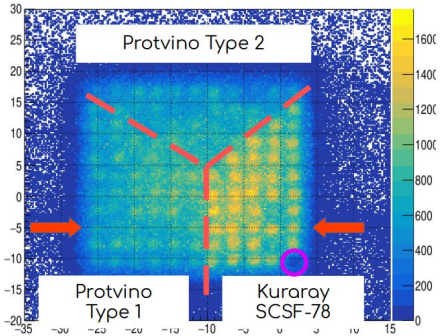

**Technology under development, 2 cells produced, 1 module under production.**

# Single-sided readout SpaCal Pb with 2 mm ∅ poly: two single cell prototypes

## With steel rods, to be removed after casting:

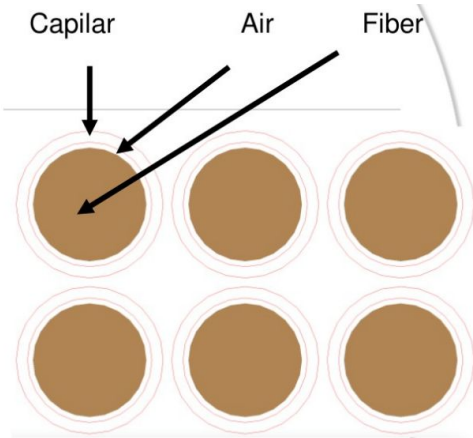
Difficult to remove tubes after molding!
Material: Garth's typographic alloy contains Pb-84%, **Sb-12%**, Sn-4%

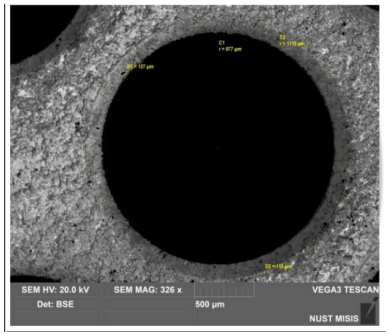



## With calibrated capillary tubes (steel, copper), part of the final assembly:

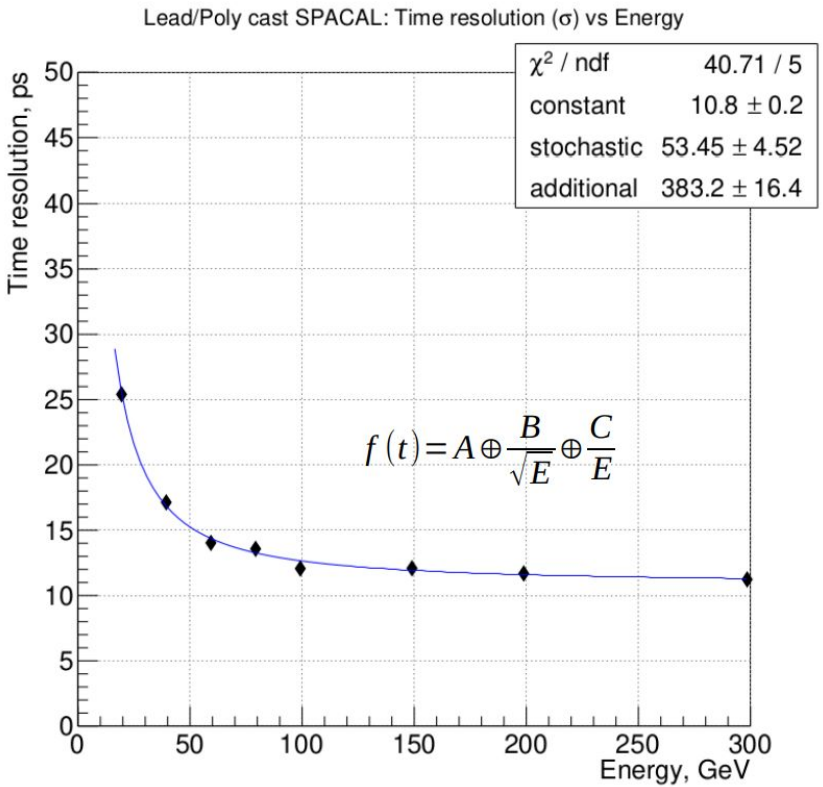
Tubes are not removed.
Antimony content minimized -> (lower activation)



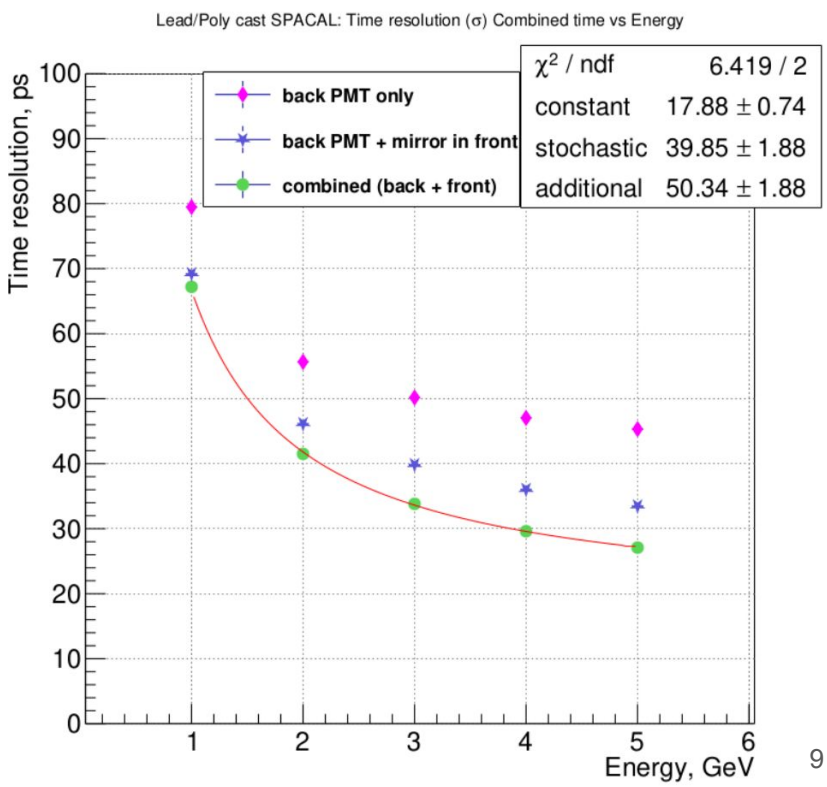



# SpaCal Pb with 2 mm ∅ poly single cell: time resolution

**Without capillary**

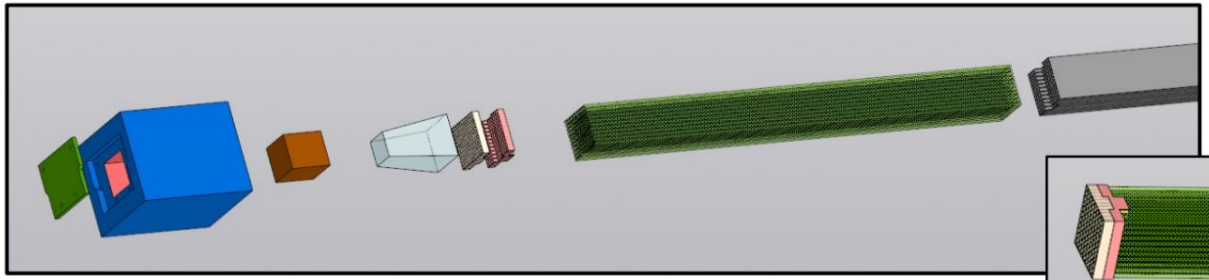


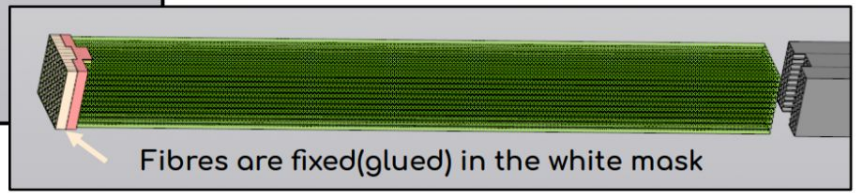

**With capillary (only up tp 5 GeV)**

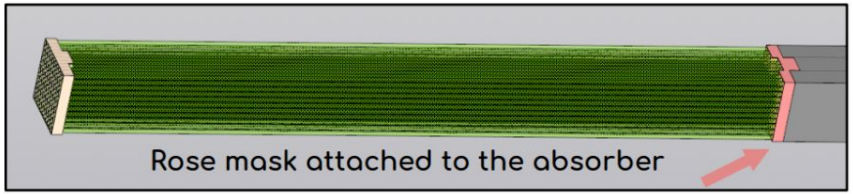


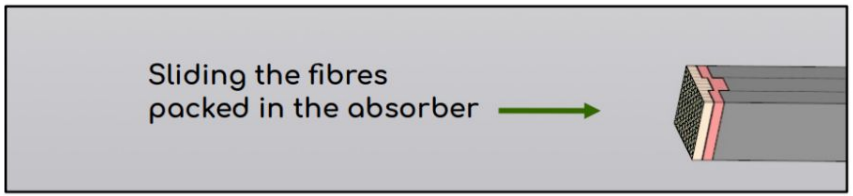
# 2 mm ∅ prototype developed with efficient fiber insertion mechanism

Fibres assembly/changing procedure has been implemented in the design.






**Advantages:**

- Simplify the assembly procedure
- Possibility to **load fibers in one turn** per cell
- Changing fibers → **polystyrene lightguide** instead of a bundle
- Using masks to fix all **121 fibers** and guide them into absorber
- Adjustable granularity!

**-> Investigating the use of green fibres for both run 4 and 5.**

**Polystyrene scintillating fibres currently in use:**

Kuraray SCSF-78 1-2 mm ø:

- 440 nm emission
- 2.8 ns decay time
- ~10000 photons/MeV

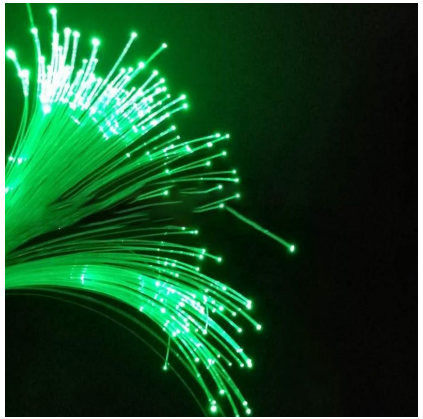
From the SciFi experience: green is better for radiation hardness!

**530 nm from Kuraray:**

SCSF-3HF(1500):

- 530 nm emission
- 7 ns decay time
- ~10000 photons/MeV

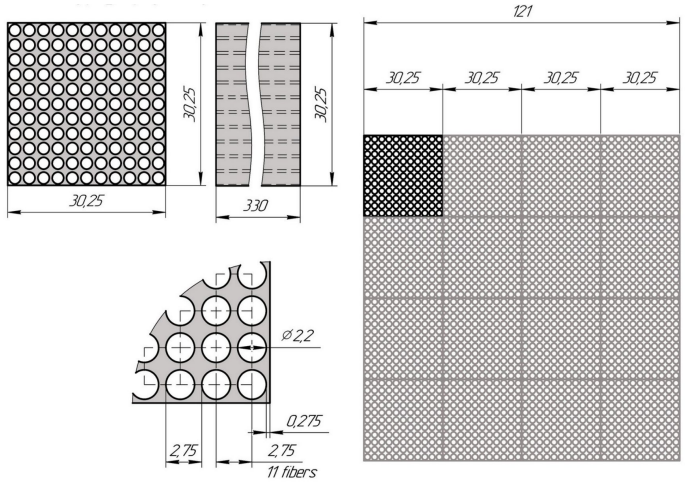
-> Ordered fibres for single cell tests.



# SpaCal Pb with 2 mm ∅ poly: new module late 2023/early 2024

**New Pb poly SpaCal:**

- should be ready for assembly by this summer
- 121x121x30 $mm^3$
- 9 cells (-> energy resolution)
- 3x3 $cm^2$ cell
- Kuraray polystyrene scintillating fibres SCSF-78, single cladding, round section
- Total length: 30 cm (10 front section + 20 back section




## Tentative TB plan for DESY + SPS (using R11187 PMT)

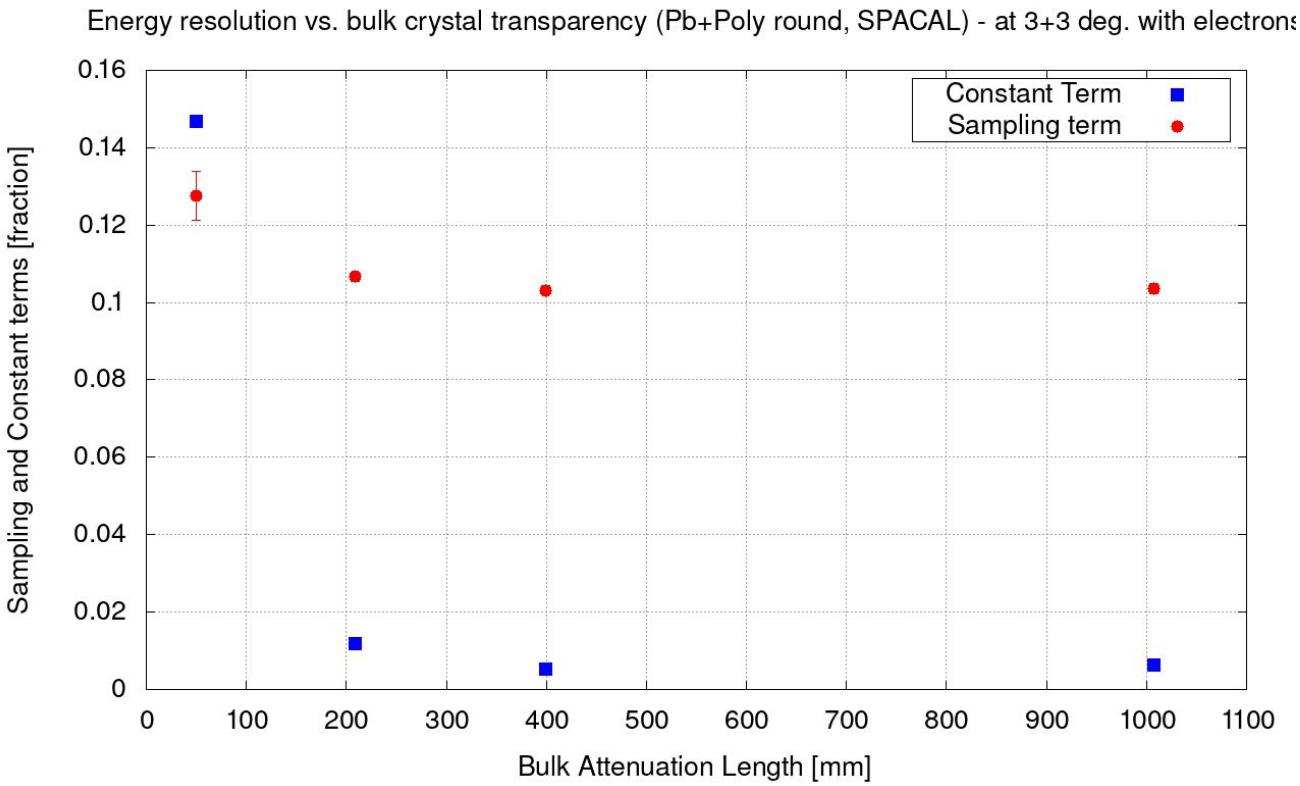
1. Calibration: cell by cell
2. Energy and time resolution: V1742 digitizer @ 5 GHz and ADC (no time res), 3+3, 1-100 GeV.
3. Energy and time resolution at different angles (fastest config or ADC): V1742 @ 5 GHz, 1-5-20-60-100 GeV, 1+1, 3+3, 6+6, -6 -6)
4. Best time resolution with 12 m long cable
5. Position scan: position resolution, time resolution

# Conclusions

- Spacal Pb poly technology can provide energy resolution for run 4 at the level of $10\%/\sqrt{E} \oplus 1\%$, with higher granularity.
- Absorber and PMTs can be reused in run 5 (LS3 consolidation compatible with with LS4).
- Time resolution < 20 ps above 20 GeV.
- Single cell with 2 mm fibres tested.
- Module 0 construction in progress, ready late 2023/early 2024

# Backup

# Pb+Polystyrene - round fibres




- Energy resolution against **bulk attenuation length**
- Stable behaviour until about **2-300 mm** bulk absorption length (about 10% of nominal value)

# Inner region with LS3 consolidation: