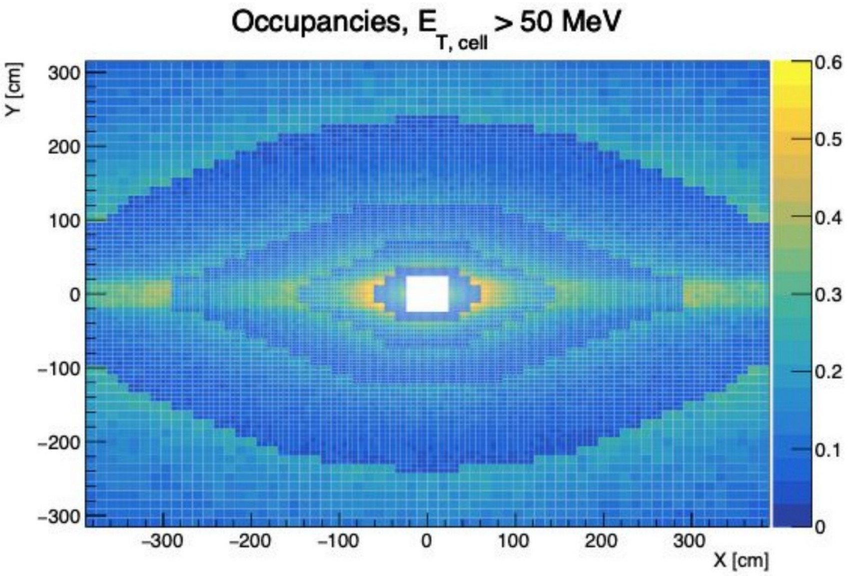
Poly SPACAL-Pb performance

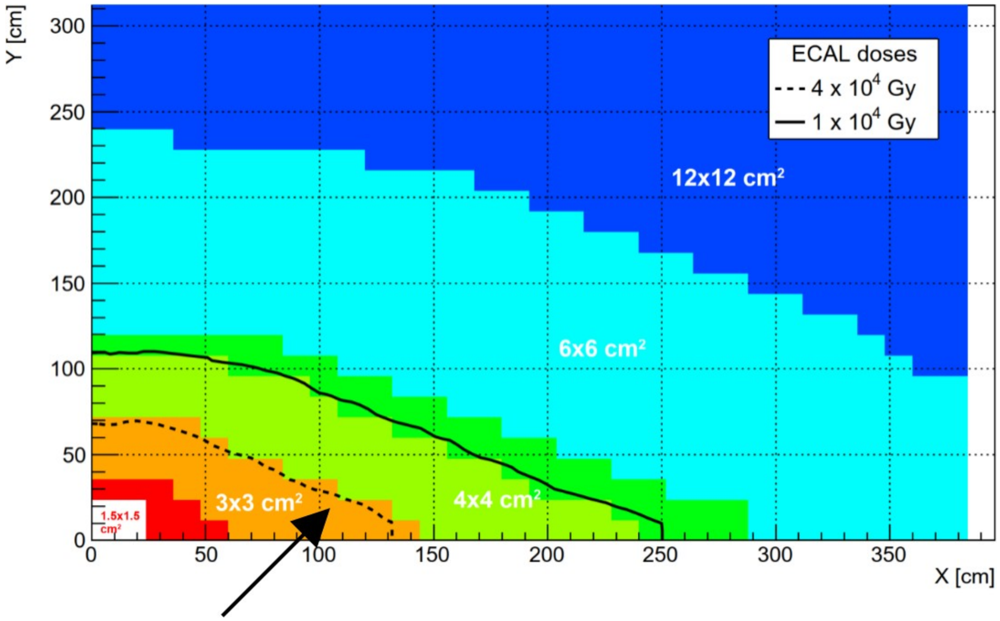
S. Kholodenko

Outline:
- Classic spaghetti type module
- Cast Lead/Poly Spaghetti (two prototypes)
- Future plans

R&D strategy for the ECAL Upgrade II

Two technologies, 6 zones with different granularity





Radiation limit of current Shashlik technology

SPACAL technology for inner region:

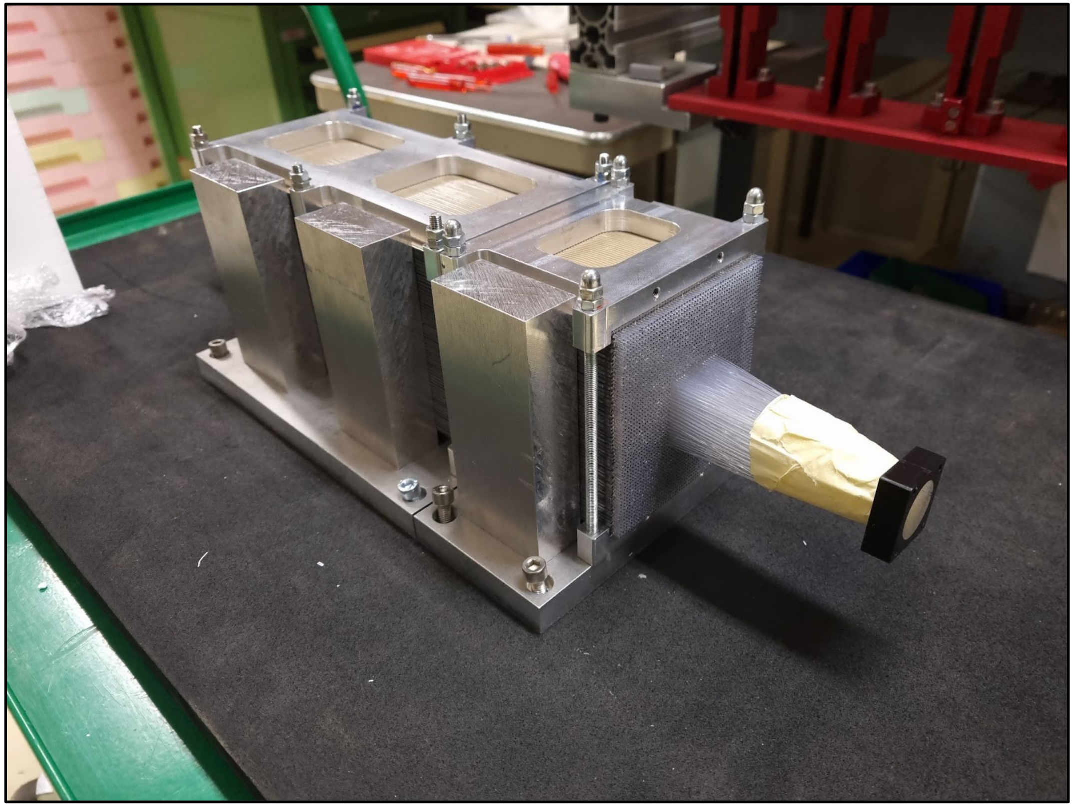
- 32 modules with cell size 15 x 15 mm² (innermost): radiation hard scintillating crystal fibres and W absorber.
- 144 modules with cell size 30 x 30 mm² with scintillating plastic fibres and Lead absorber.

This talk is about the region marked in orange

Shashlik technology (Outer regions):

- Improved time resolution with new fast WLS fibres (Kuraray YS2/YS4);
- Double-sided readout;
- Required cell sizes → adding 1300 new modules.

Lead/Polystyrene spaghetti module



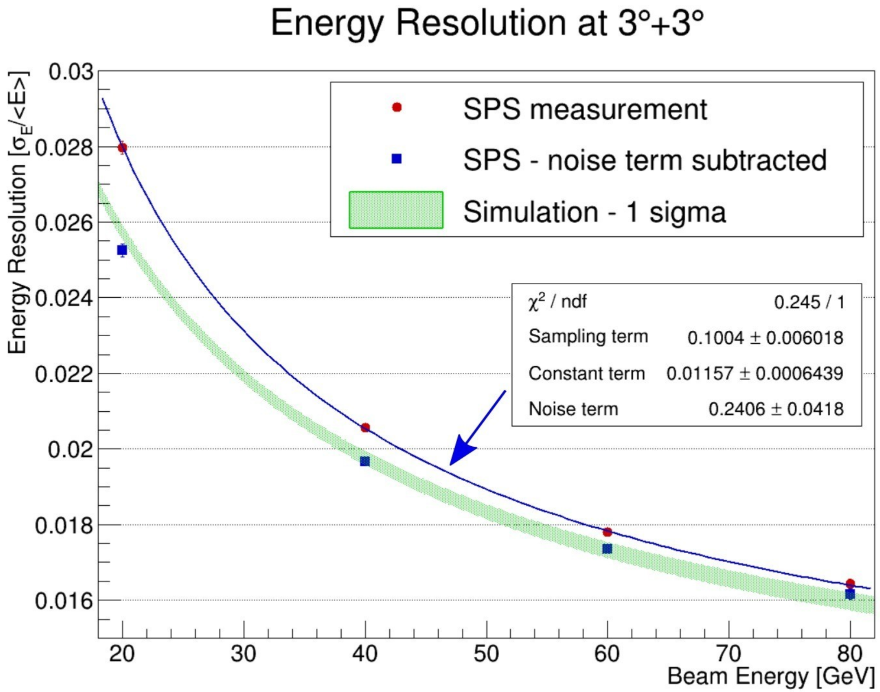
Module details:

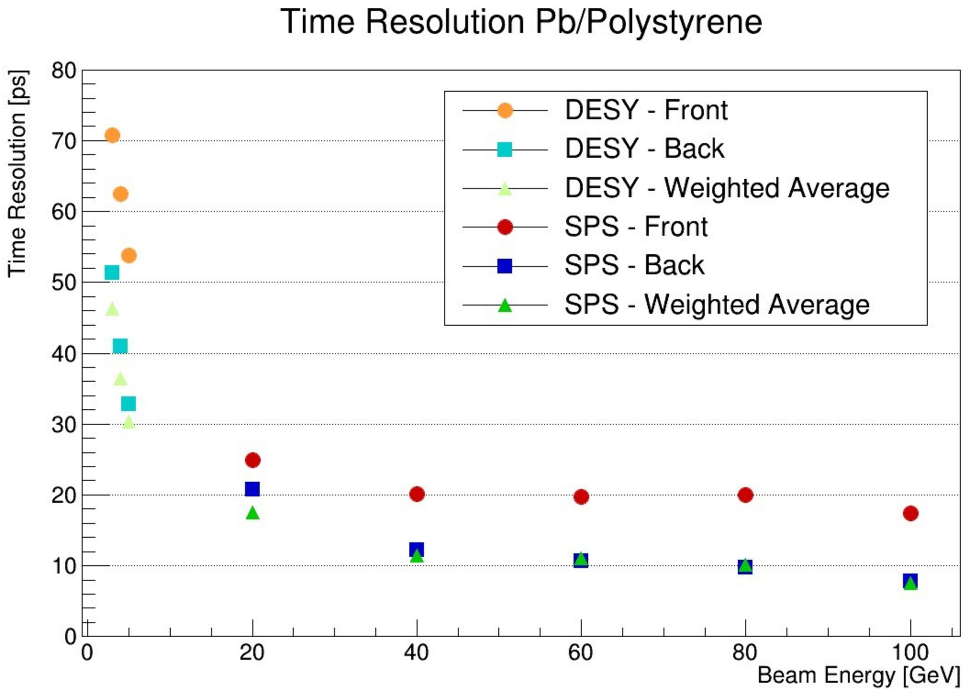
- 9 cells of 3x3 cm2 (RM ~ 3 cm)
- 8+21 cm long (7+18 X0)
- Reflective mirror between sections
- Kuraray SCSF-78 round fibres ∅ = 1.0 mm
- Light guides 10 cm long

Different PMTs for different measurements:

- Energy resolution: R7899-20 (current ECAL)
- Time resolution: R11187 (TileCal) MCD PMT

Lead/Polystyrene spaghetti module (1)





Sampling term: (10.0 ± 0.6)%

Constant term: (1.2 ± 0.1)%

Time resolution below 30 ps for energies above 10 GeV

Motivation for CAST prototype (1)

Scheel, C.V. (Dec 1994).
The spaghetti calorimeter
Research, development, application.
Available from INIS

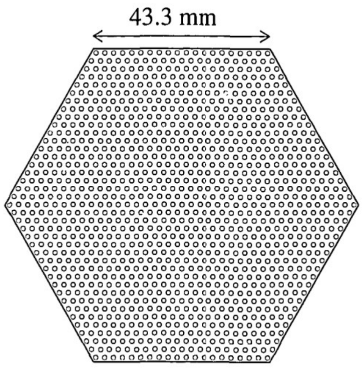


Figure 3.3: *The cross-section of one spaghetti calorimeter module. The fiber diameter is 1.0 mm and the distance between each is 2.2 mm, for a total of 1141 fibers.*

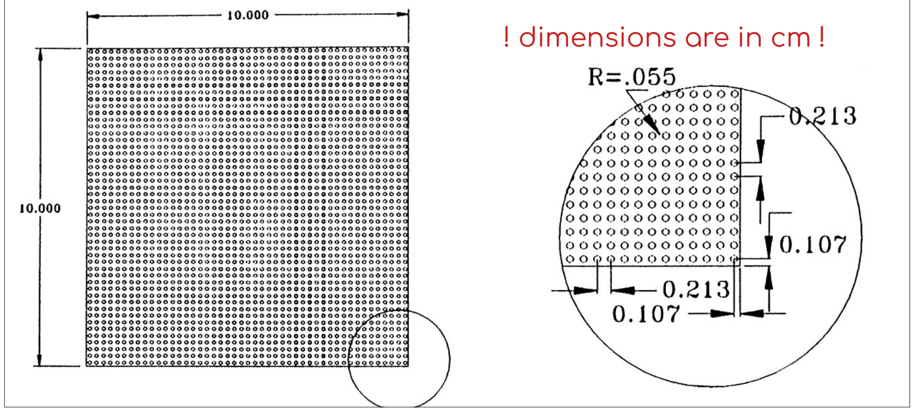
Historically spaghetti type calorimeters are pretty much the same:

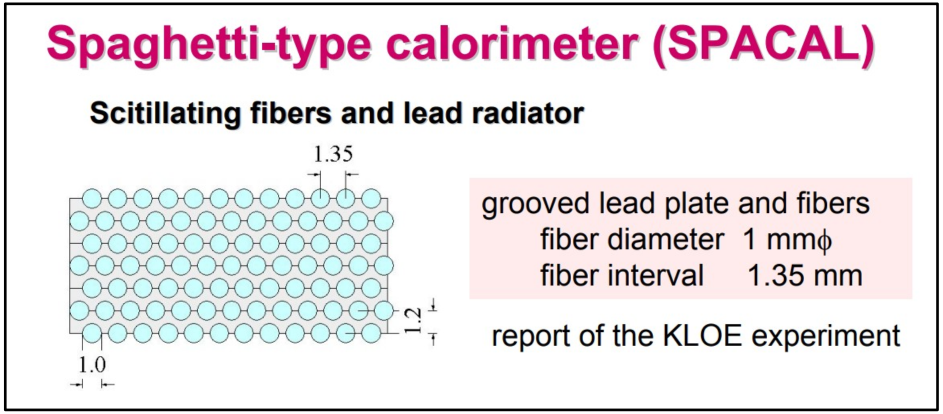
- small fibres diameters (diam. 1 mm)
- thin layers of lead plates with the `grooves`

This design leads to some questions:

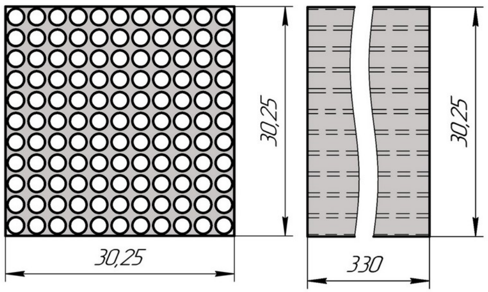
- not a simple assembly procedure
- no guarantee of mechanical stability
- no guarantee of possibility for fibres being extracted

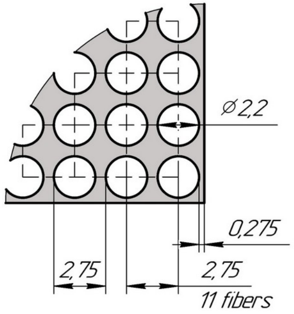
T.A. Armstrong et al., NIM A 406 (1998) 227—258

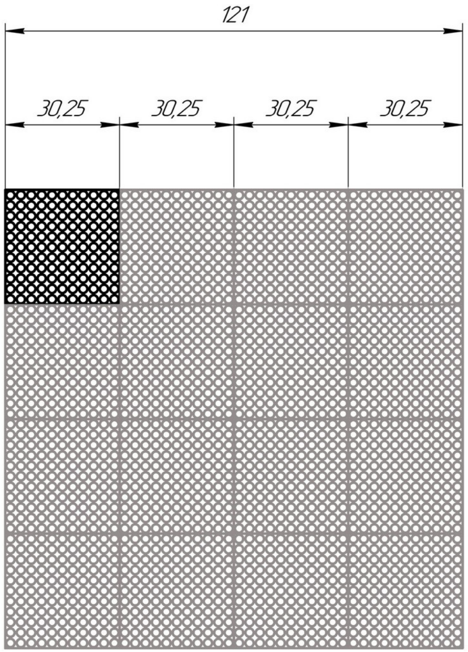




Motivation (2): CAST Lead/Polystyrene

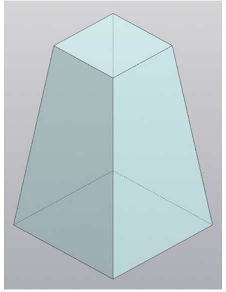


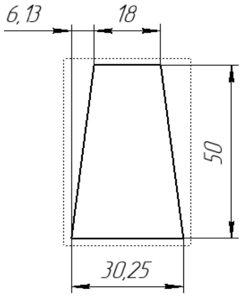




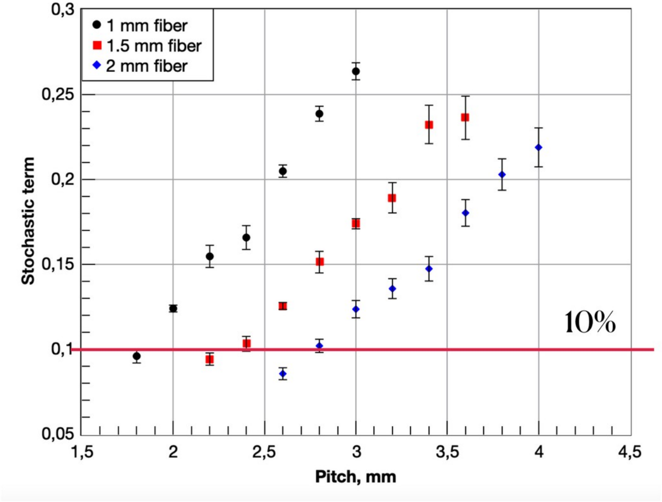
- CAST absorber production
- High Pb alloy
  + dopants for mechanical stability (loads ~ 1 ton)
- Large fibres diameter

  necessary to simplify assembly
  + possible fibres changing procedure





MC: Energy resolution (sampling term)

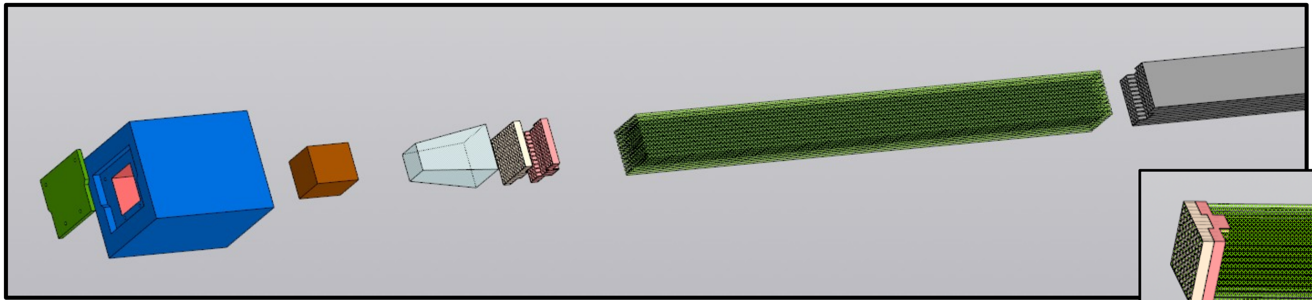


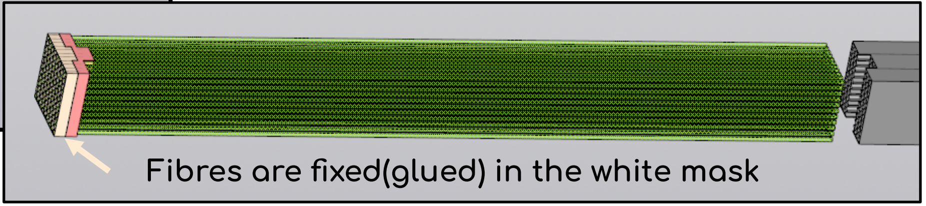
To maintain a competitive environment the fibres size fixed to the largest available in the market – 2 mm in diameter.

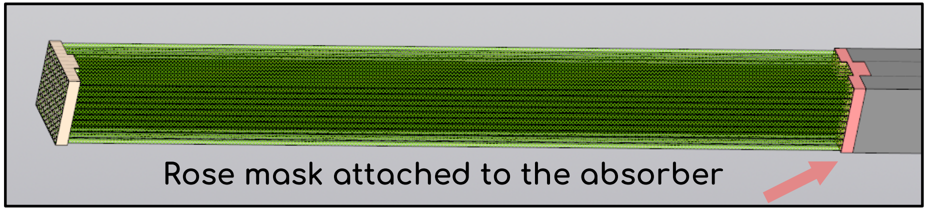
- Kuraray SCSF-78 ø2mm
- Protvino (R&D on fibres production)

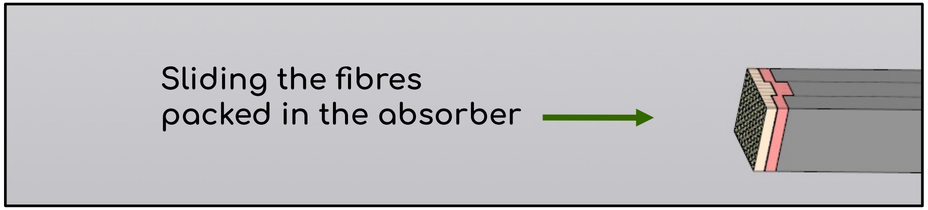
CAST Lead/Polystyrene: General prototype design

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!

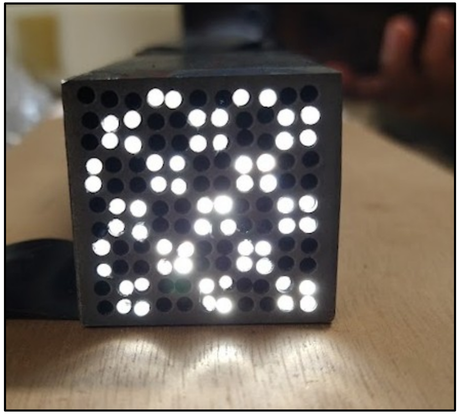
The general idea well described in this presentation:
https://indico.cern.ch/event/1033286/contributions/4339326/attachments/2237072/3792152/Lead%20SPACAL%20MISiS%20R%26D%20Dadabaev%20Shakhzod.pdf

CAST Lead/Polystyrene: first prototype

Some details were presented:
https://indico.cern.ch/event/1050676/contributions/4414407/attachments/2271405/3857622/25.06.2021.pdf

1st CAST Lead/Poly prototype

fibres “type A” installed



Garth’s typographic alloy (84% of Lead + Sb + Sn)

Single-cell prototype produced, assembled in July 2021.

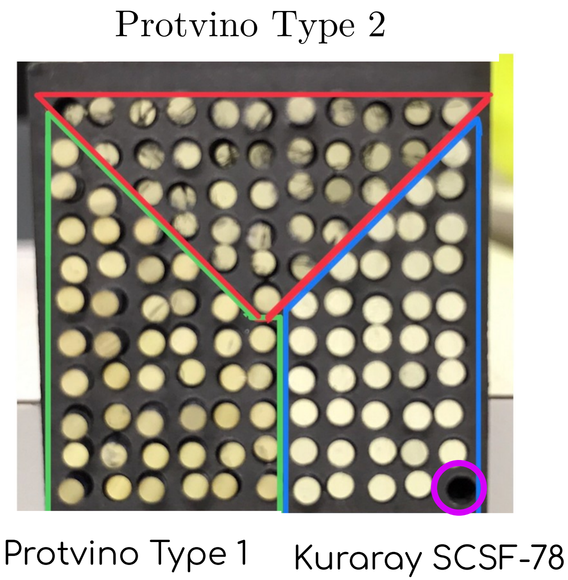
Cell size: 30.25 x 30.25 mm^2

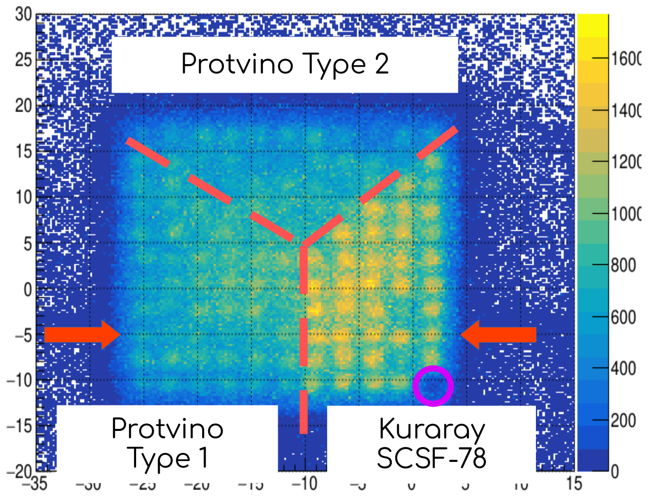
11 x 11 matrix of 2 mm diameter fibres

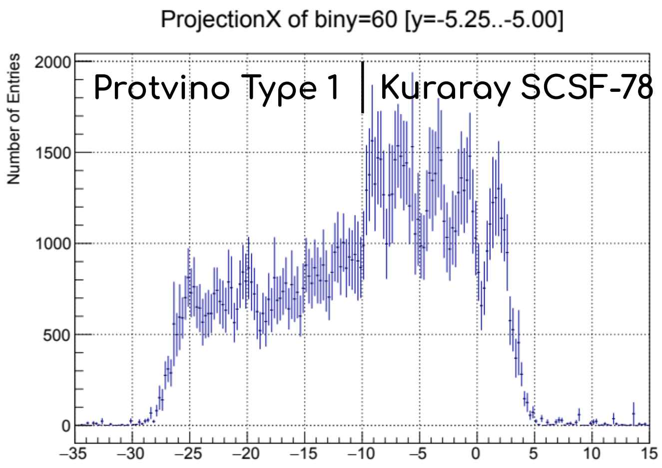
Double-sided readout with R11187 PMTs through 50 mm long lightguide

Tested at CERN during July`21 - October`22

1st CAST Lead/Poly prototype (muonography)







Muonography tests (in 2021) were aimed to compare scintillating fibres (and improve).

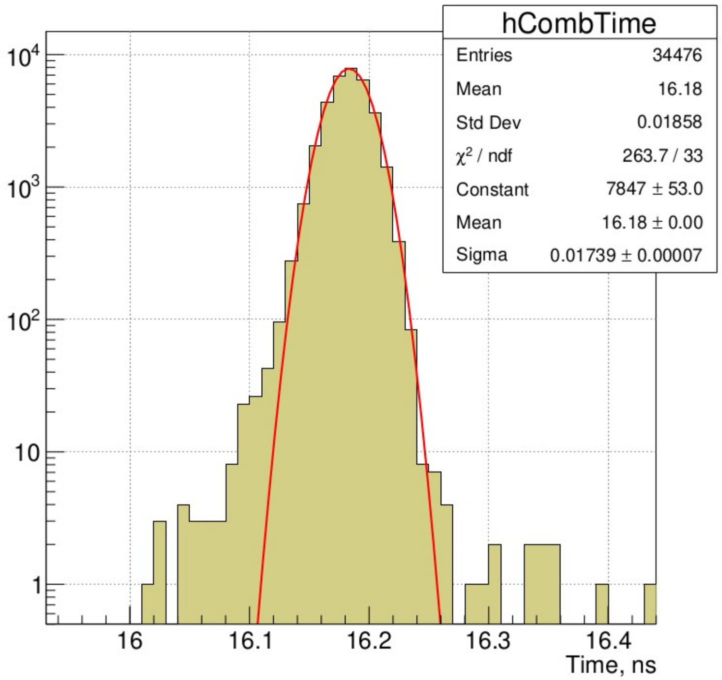
First batch of fibres from Protvino was giving factor ~2 less LY wrt SCSF-78, since 2021 quality gradually improves

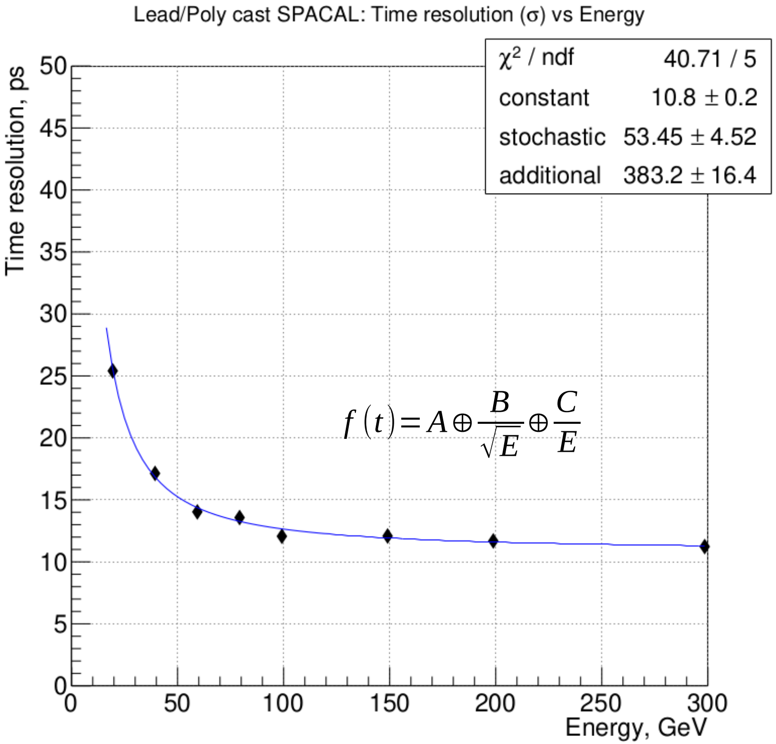
https://indico.cern.ch/event/1127741/contributions/4733262/attachments/2389907/4085340/SPACAL_LeadPoly_studies_option2021.pdf

Test setup + some other details are described in the supplementary slides

1st CAST Lead/Poly prototype: time resolution (Oct-2022)

Dual readout, 100 GeV e^- beam





Last tests with prototype version #1 performed in October`22 @ SPS H2 beamline.

Note:
HV tuned to have maximum amplitude in the acceptable range of a digitizer @ 300 GeV e^- beam

Test setup + some other details are described in the supplementary slides

Towards the 2nd CAST Lead/Poly prototype

Prototype version #1: points to improve

- material: Garth's typographic alloy contains Pb-84%, Sb-12%, Sn-4%

  have to minimize Antimony (and other `easily activated` dopants)
- issues with steel rods (extracting after molding)
- holes alignment (fibres damaging during assembly)

General idea for the prototype v2:

- holes to be made by calibrated stainless-steel capillaries (ideally inner Ø2.1 mm)
- Base Lead alloy to be changed to minimize antimony

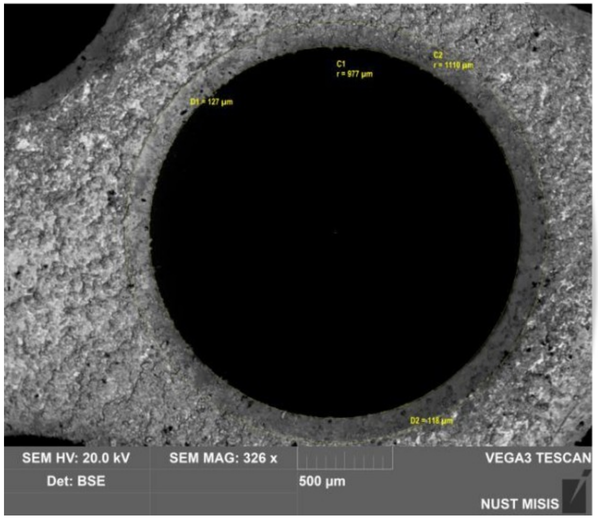
2nd CAST Lead/Poly prototype

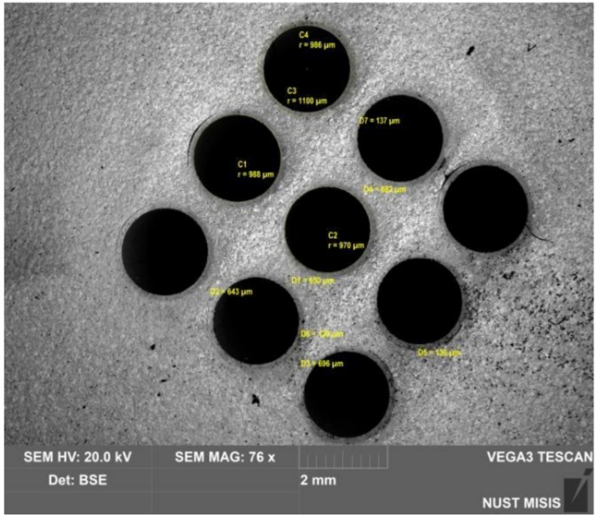
Dimensions:

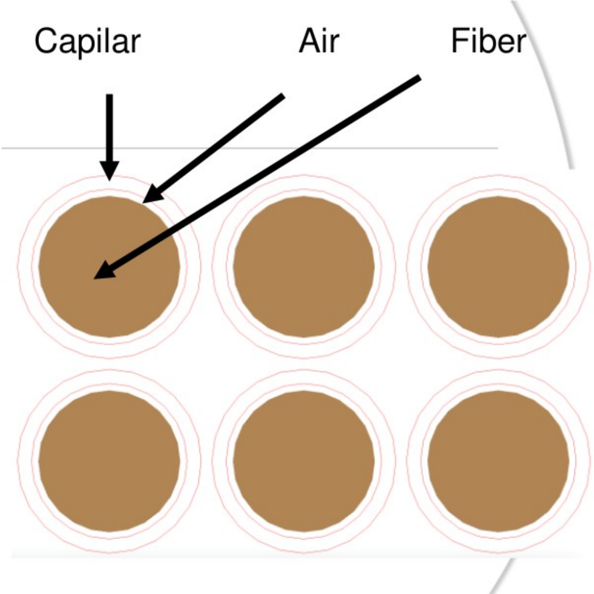
Fiber diameter: 2 mm
Capillary inner diameter: 2.2 mm
Capillary wall thickness: 0.1 mm

Advantages:

1. The use of non-removable capillary tubes will significantly simplify the absorber production.
2. Capillary tubes will reinforce the mechanical properties of the whole absorbers.



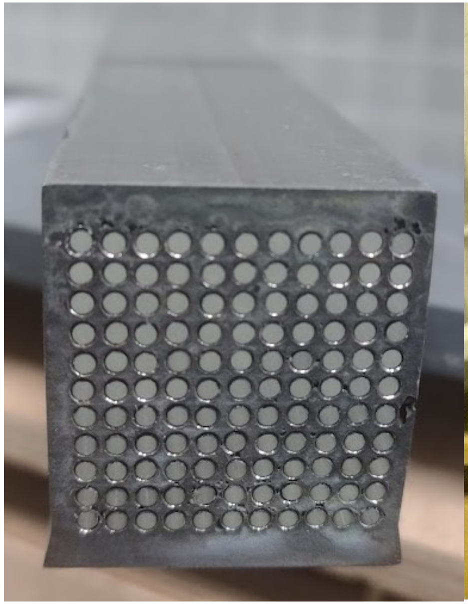


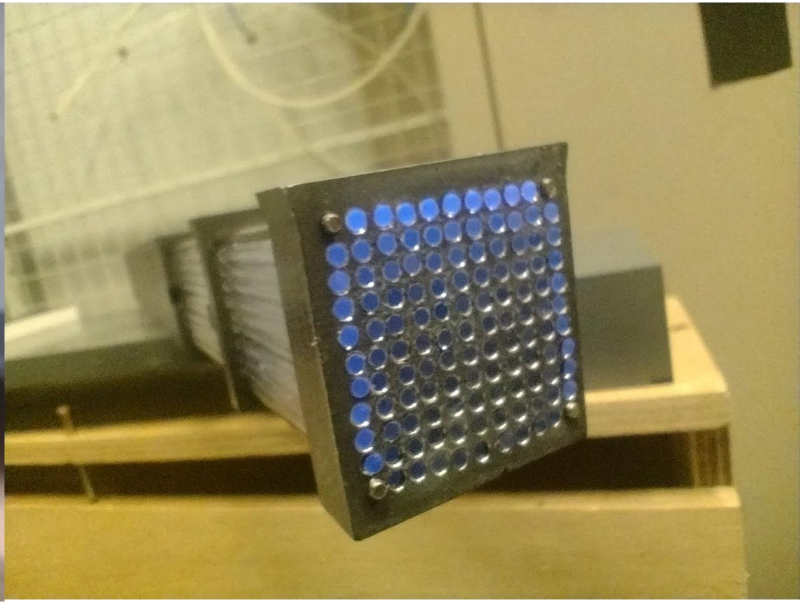


Plans for the second prototype were presented 25th of February 2022
https://indico.cern.ch/event/1131540/contributions/4748187/attachments/2398016/4100488/25.02.2022.pdf

Last update presented by Hubert:
https://indico.cern.ch/event/1212877/contributions/5101680/attachments/2541751/4376136/LHCb_fridaymeeting%20_4Nov2022.pdf

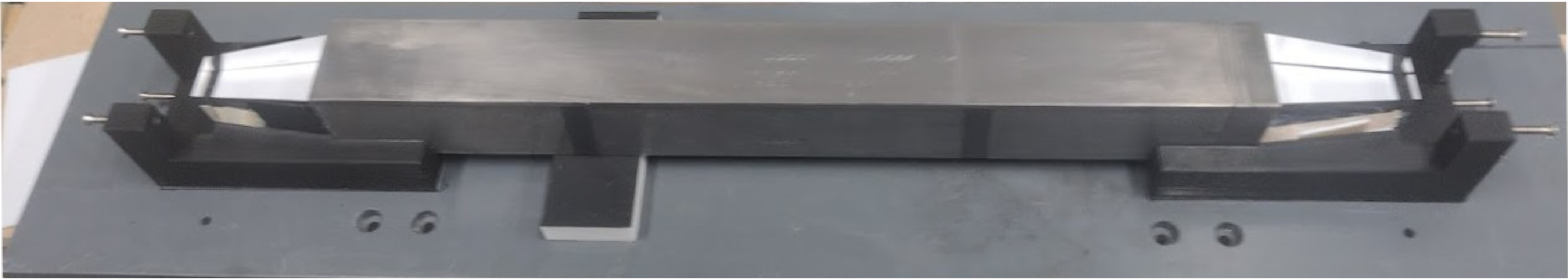
2^{nd} CAST Lead/Poly prototype



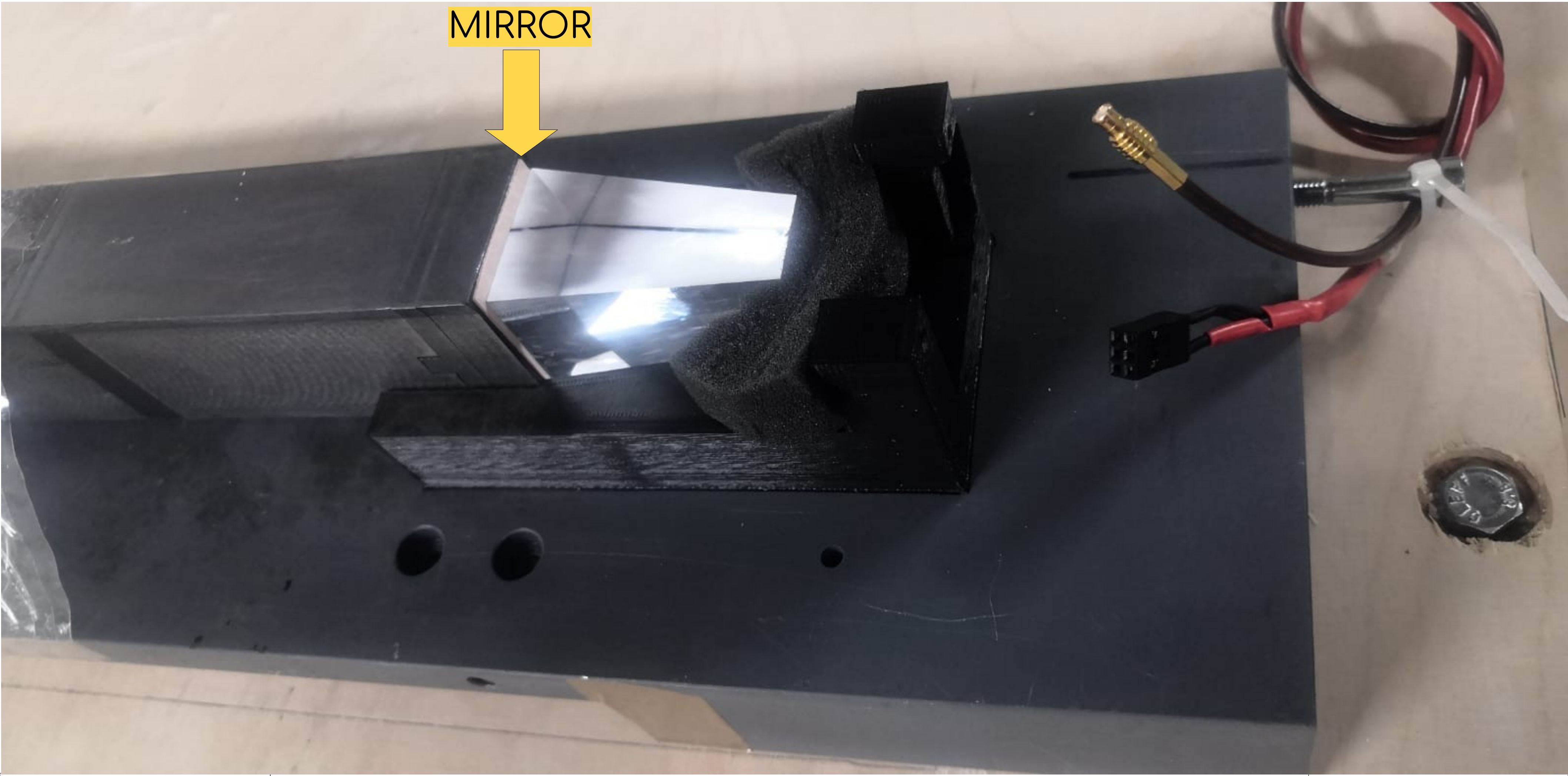


Proof of concept for capillaries-based cast SPACAL design.

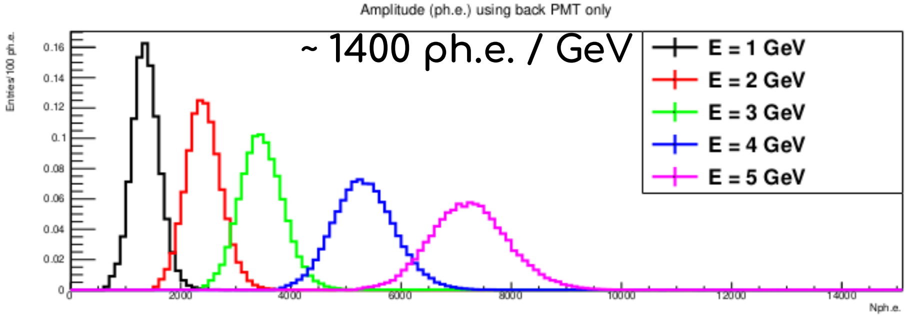
Single cell prototype:
No longitudinal segmentation
Total length: 337 mm
Transverse 30.5 x 30.5 mm^2



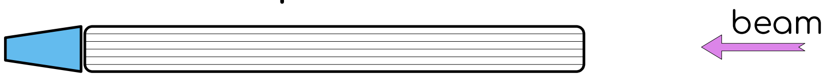
Time measurements with single PMT @ back + mirror

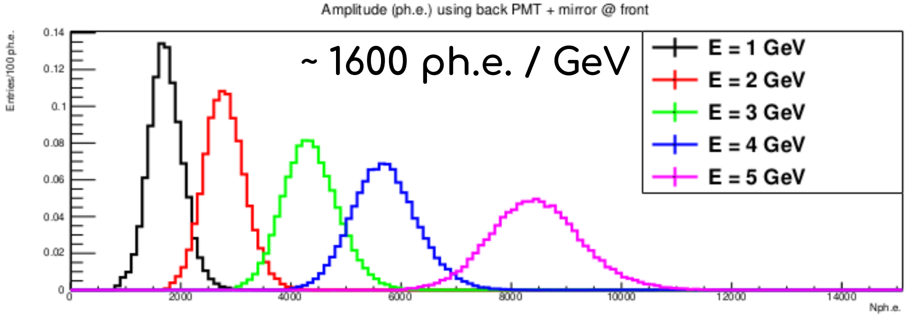


2nd CAST Lead/Poly prototype: Light-Yield

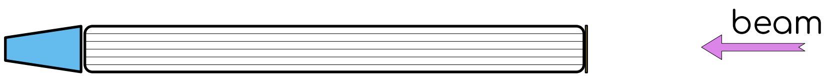


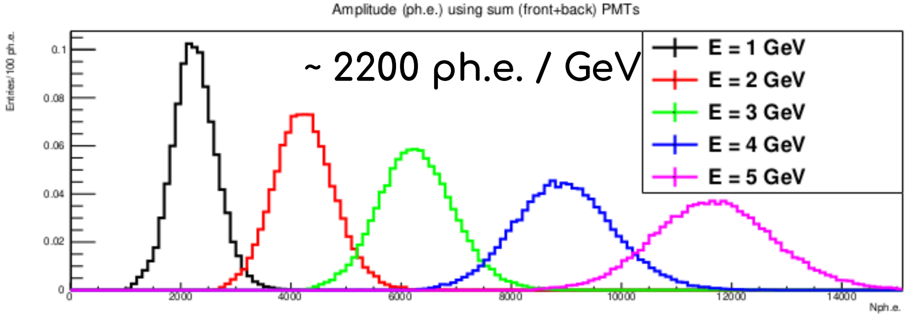
Using information from
the BACK pmt ONLY



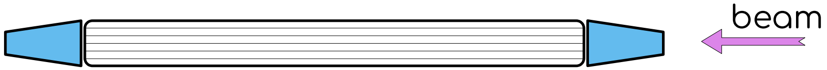


Using information from
BACK pmt + Mirror in front

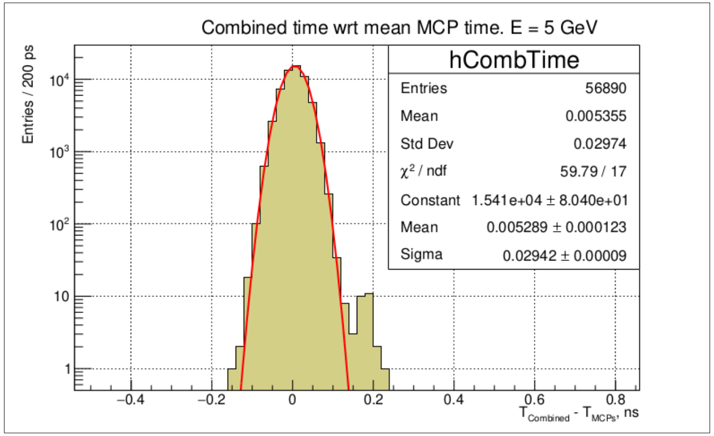


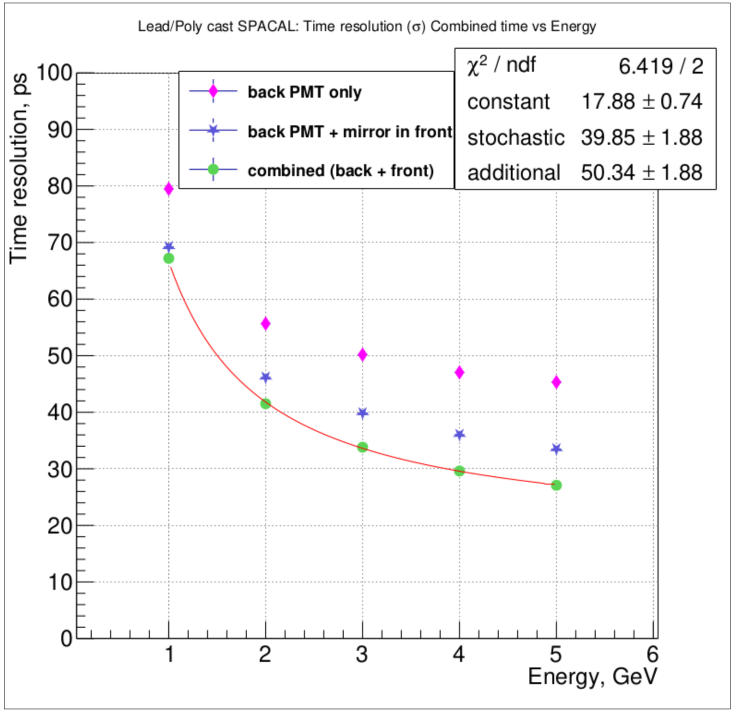


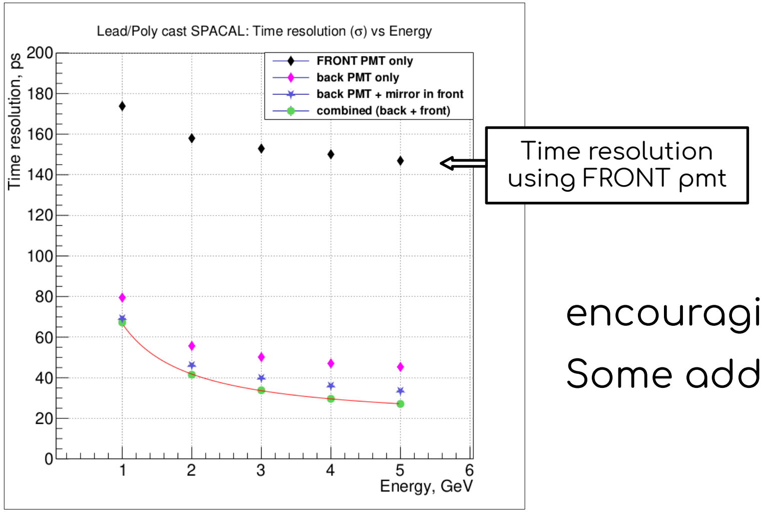
Using information from
both BACK pmt + FRONT pmt



2nd CAST Lead/Poly prototype: Time resolution







encouraging performance of the prototype with Back PMT + mirror in FRONT

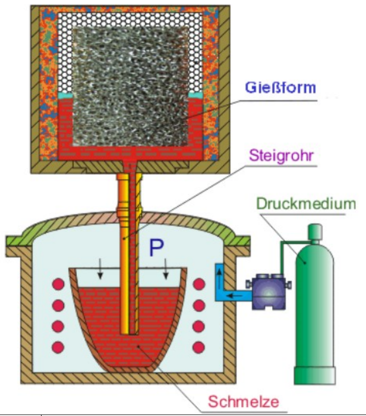
Some additional studies to be performed.

Summary and future plans

- Lead/Poly SPACAL shows adequate performance
- The CAST absorber technology with stainless steel capillaries looks promising and suitable for the mass production.
- For the Cast prototype most part of the work was done in Russia in 2021-22 (MISiS, Protvino).
- Due to the war initiated by the Russian government in Ukraine further studies in Russia could face some problems. Final detector production in Russia looks impossible today → effecting work efficiency
- Nevertheless the new prototype with stainless tubes has been produced.
- Knowledge sharing meeting with ICM in Sep`22 (https://icm-chemnitz.de/)
- R&D for a full scale module production with low pressure molding is ongoing ICM. + MISiS (?)
- Full scale module 121x121 mm2 is in preparation. Aiming to have tests in 2023.

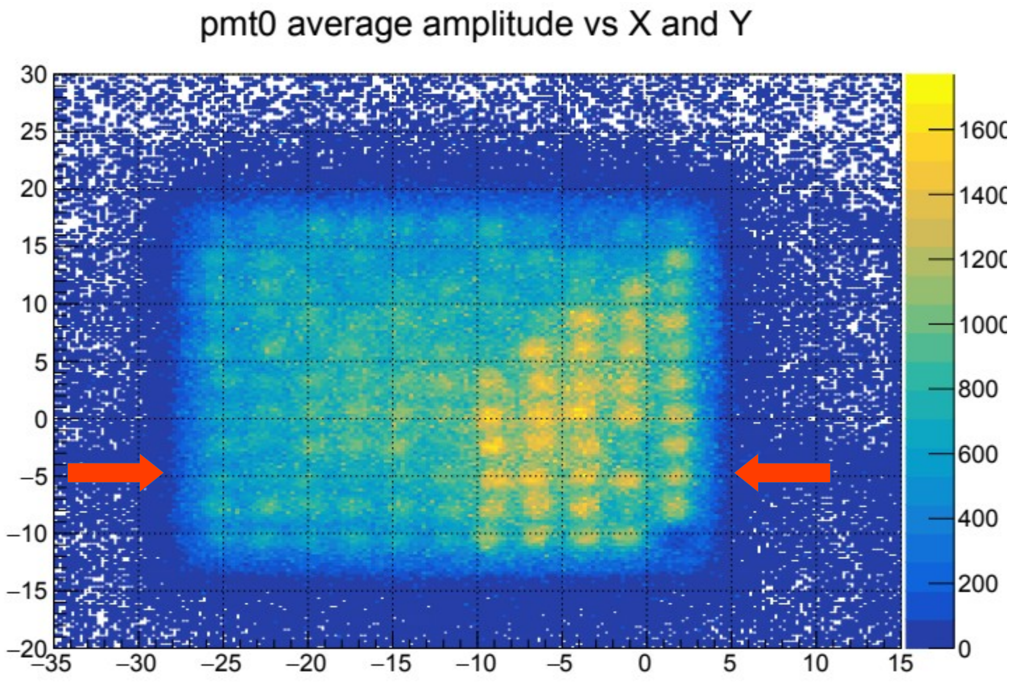
from **spaghettini** to **bockwurst calorimeter**

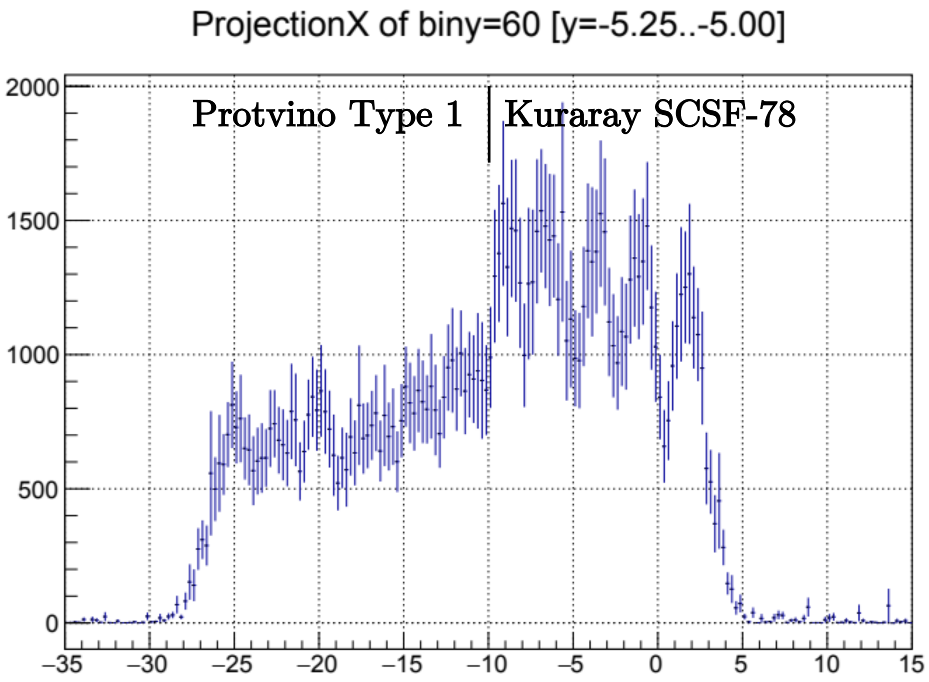
ICM
Institut Chemnitzer Maschinen- und Anlagenbau e.V.



SUPPLEMENTARY SLIDES

1st CAST Lead/Poly prototype

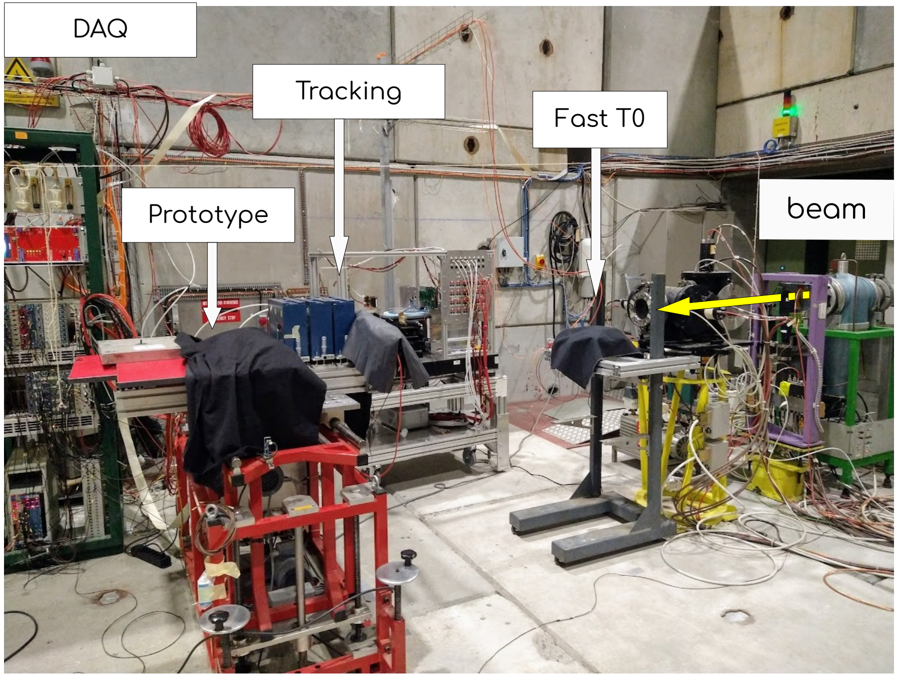


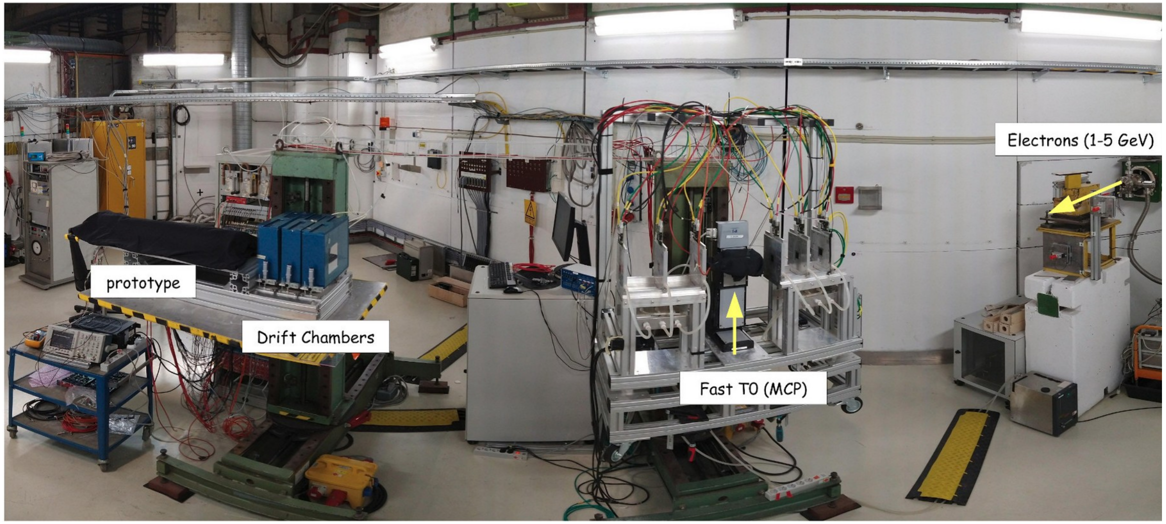


Average number of photoelectrons/muon

Roughly factor of two difference between Kuraray SCSF78 and Protvino type 1 (silicone-based cladding)

Beamtests: CERN H4 / H8 and DESY T24





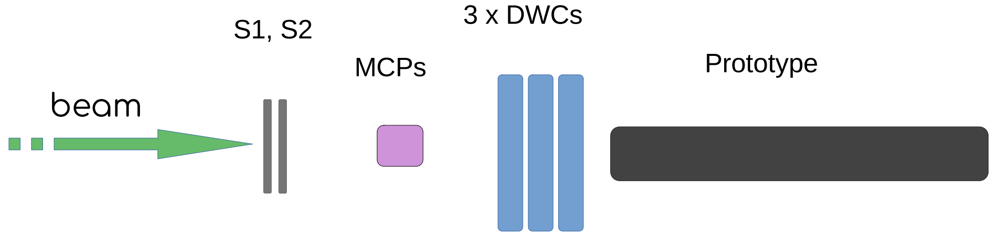
CERN H4: electrons with E = 20 – 300 GeV

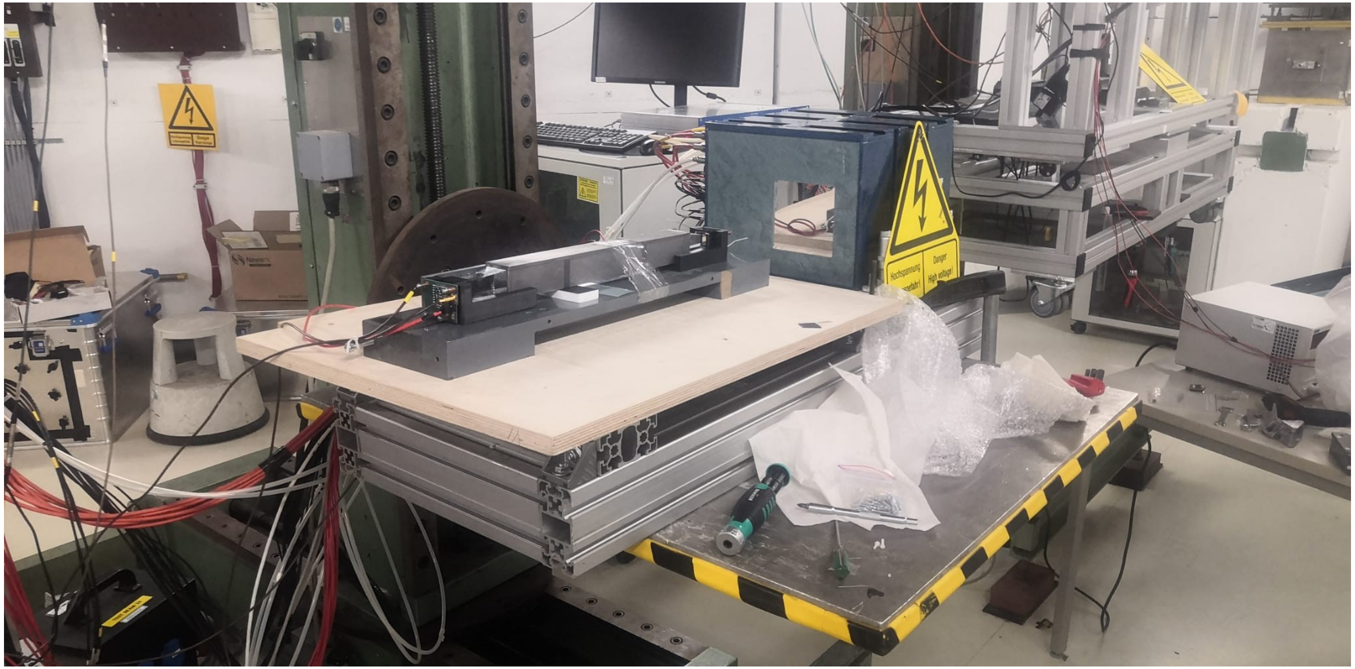
CERN H8: muons and hadrons (p = 150 GeV/c)

DESY T24: electrons with E = 1 – 5 GeV

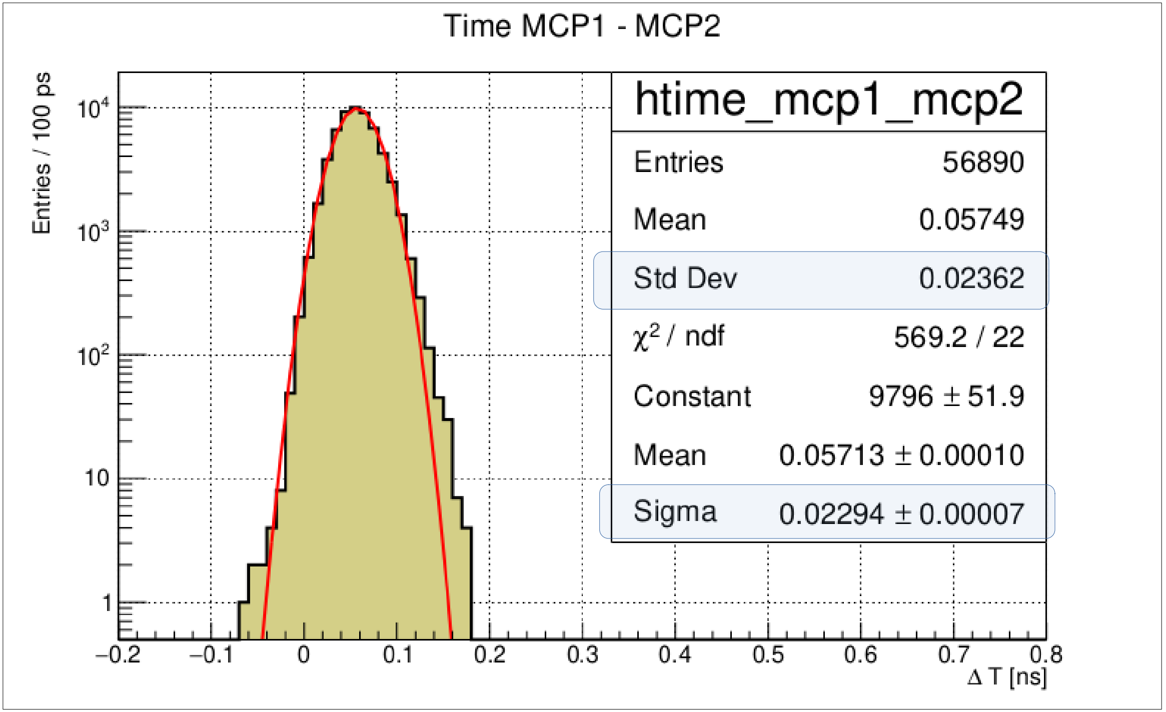
Setup:
- tracking system (3 stations of DWC)
- Two scintillation counters for triggering
- Two Fast T0 counters (next slide)
- CAEN digitizers: DT5742 / V1742 (custom calibration)
- TDCs(V1290N), ADCs

Setup





Time reference: MCP1 – MCP2 time



Finally the RMS (or sigma if you want) of the time difference MCP1 – MCP2 is **σ ~ 24 ps.**

Intrinsic time resolution of a single MCP

$\sigma_{1,2}$ ~ 24 / √2 ps

Taking average MCP time as a time reference:

σ_{mean} ~ 24 ps / 2 = 12 ps

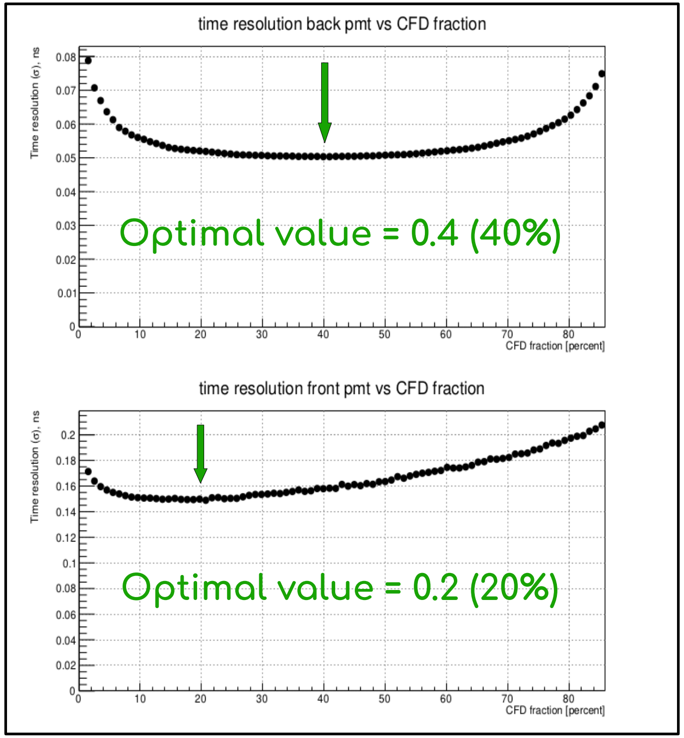
Combined time determined as $T_{comb} = \frac{T_{Back} + \beta \cdot T_{Front}}{1+\beta}$

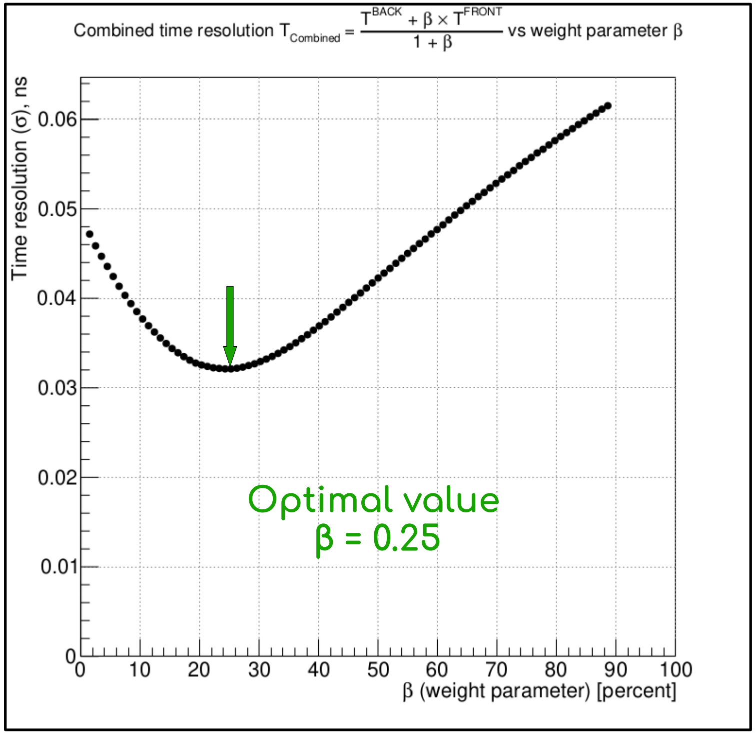
Where

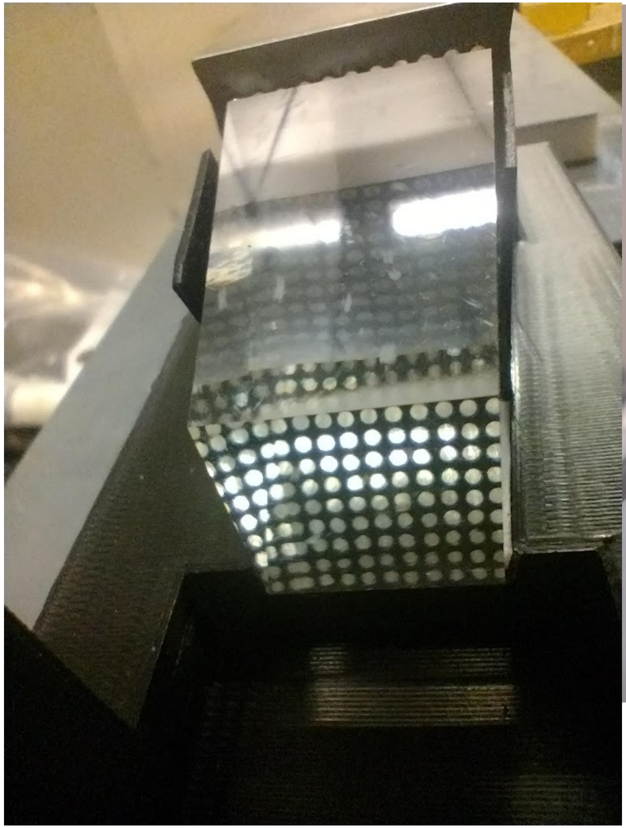
T_{BACK} and T_{FRONT} – time of signal arrival to the BACK and FRONT PMT respectively

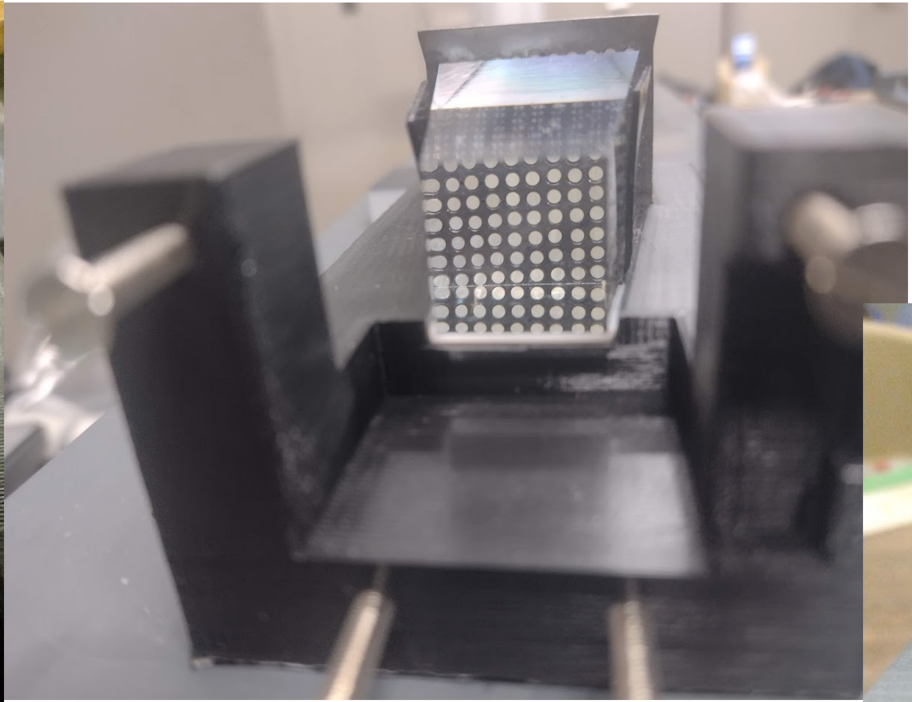
(taking as time of the signal arrival a moment of pulse crossing 0.4 and 0.2 of the pulse height (for back and front respectively)

β = 0.25 – optimal weight parameter (bottom right plot)









Fibres were polished with diamond mill in bundles off 70 pcs