# Cast lead-polystyrene spaghetti type calorimeter for LHCb ECAL Upgrade II

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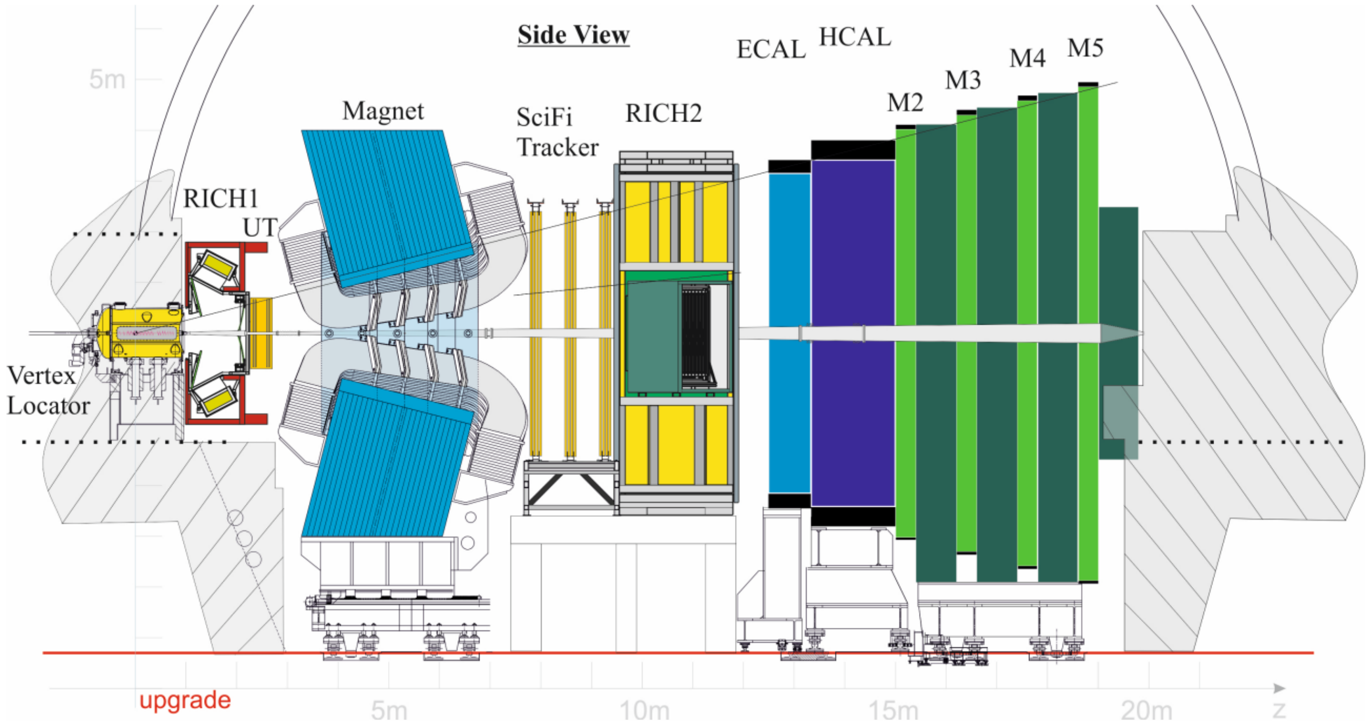
# LHCb collaboration and detector

LHCb physics program:

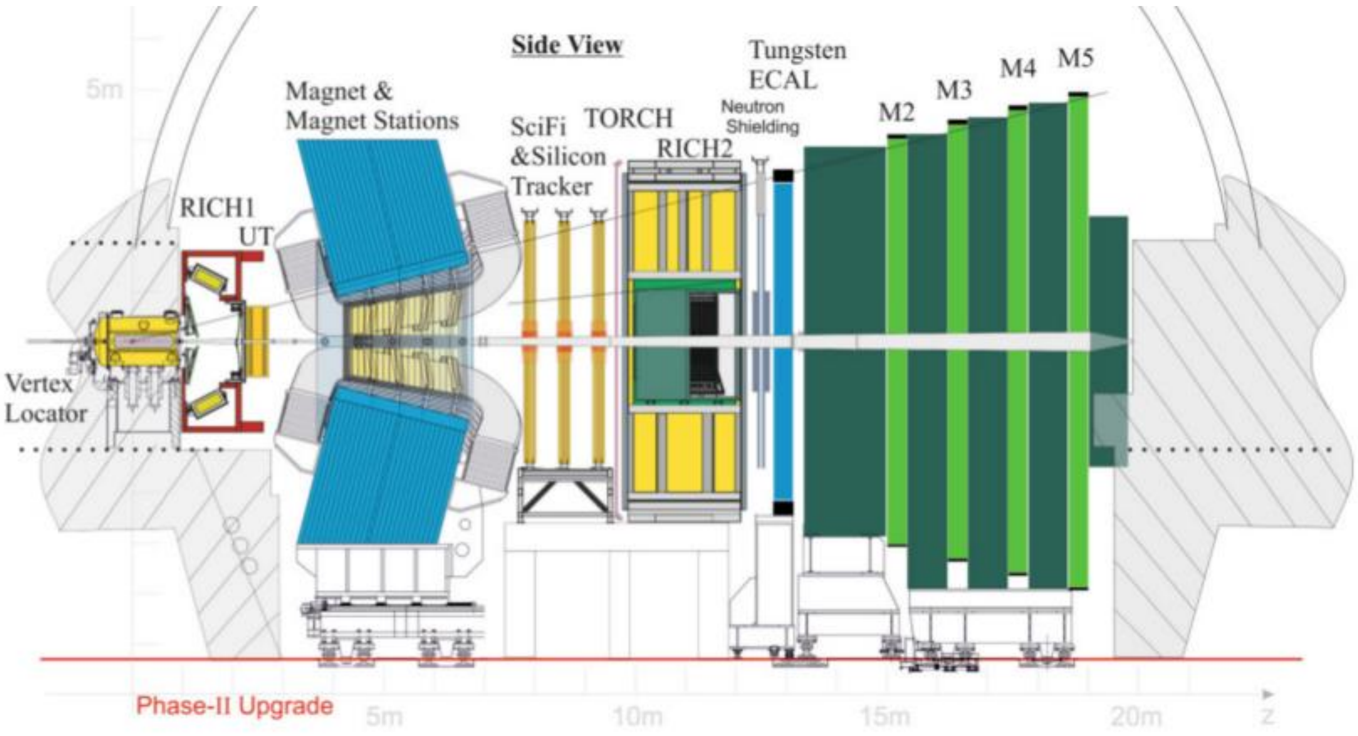
- Flavour physics
- CP violation
- Rare decays of  B and charm hadrons
- Electroweak and QCD processes



# LHCb collaboration and detector

<u>LHCb physics program:</u>
- Flavour physics
- CP violation
- Rare decays of B and charm hadrons
- Electroweak and QCD processes

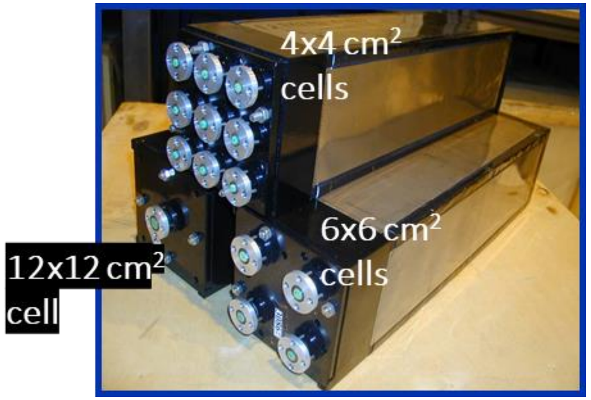
<u>Upgrade challenges:</u>
- High radiation
- High occupancy and pile-up
- Timing requirements

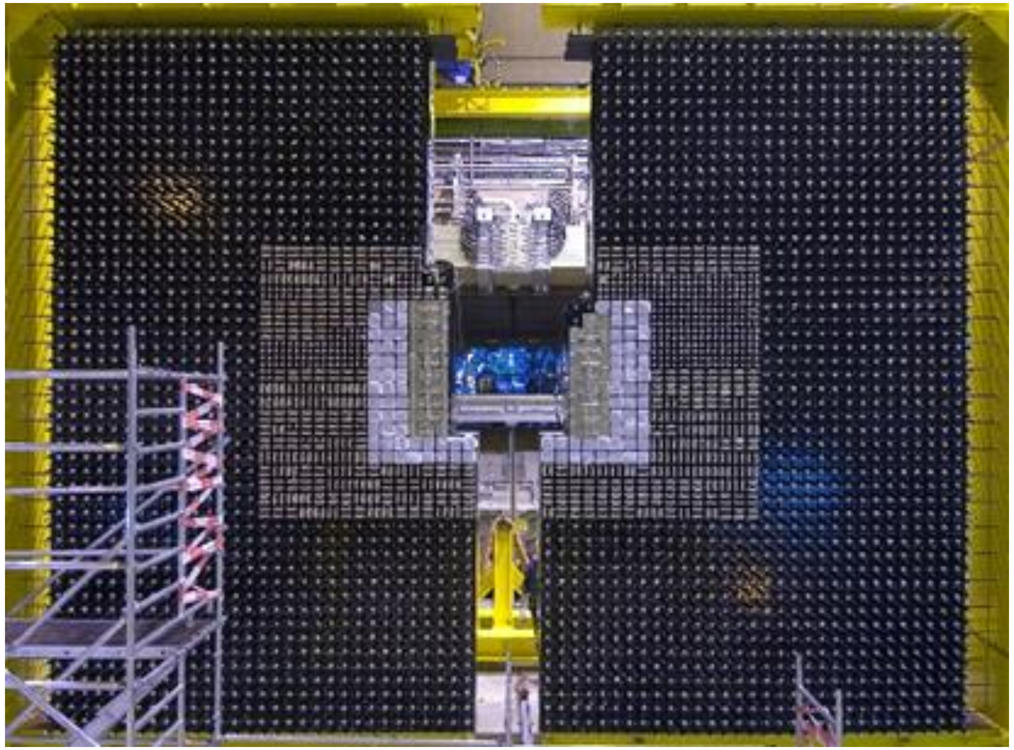


# R&D in view of the LHCb ECAL Upgrade II

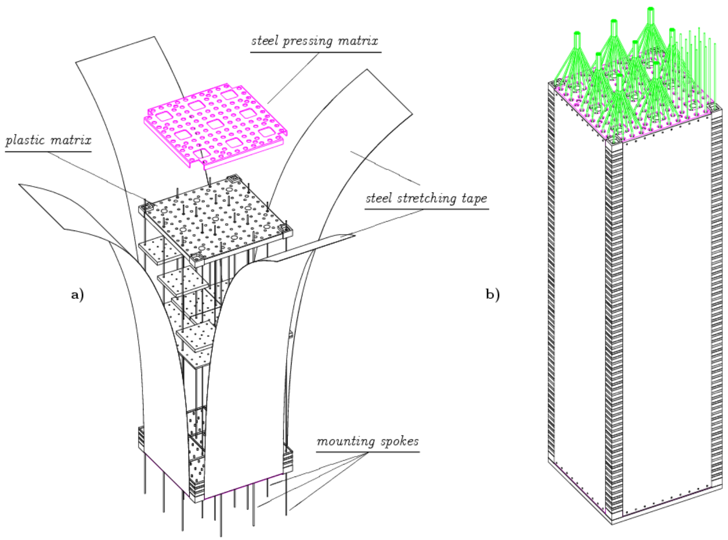
Current LHCb ECAL:

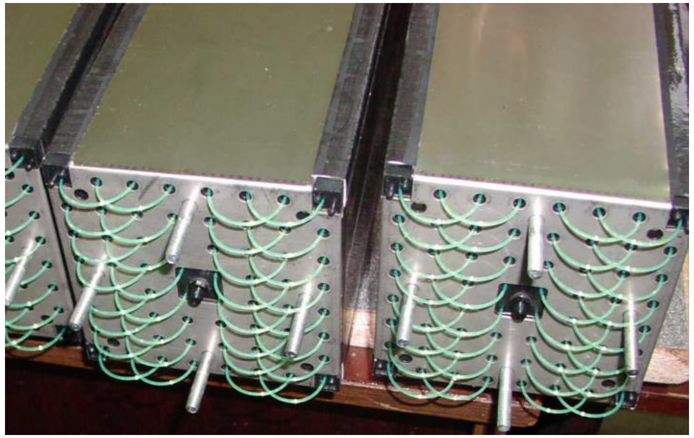
- Large array (8 x 7 $m^2$) with 3312 modules and 6016 channels
- Shashlik technology: 4x4 / 6x6 / 12x12 $cm^2$ cell size
- Optimised for $\pi^0$ and $\gamma$ reconstruction in the few GeV to 100 GeV region at $2 \times 10^{32}$ $cm^{-2}s^{-1}$
- Radiation hard up to 40 kGy
- Energy resolution: $\sigma(E) / E \approx 10\% / \sqrt{E} \oplus 1\%$



# Shashlik: present LHCb ECAL



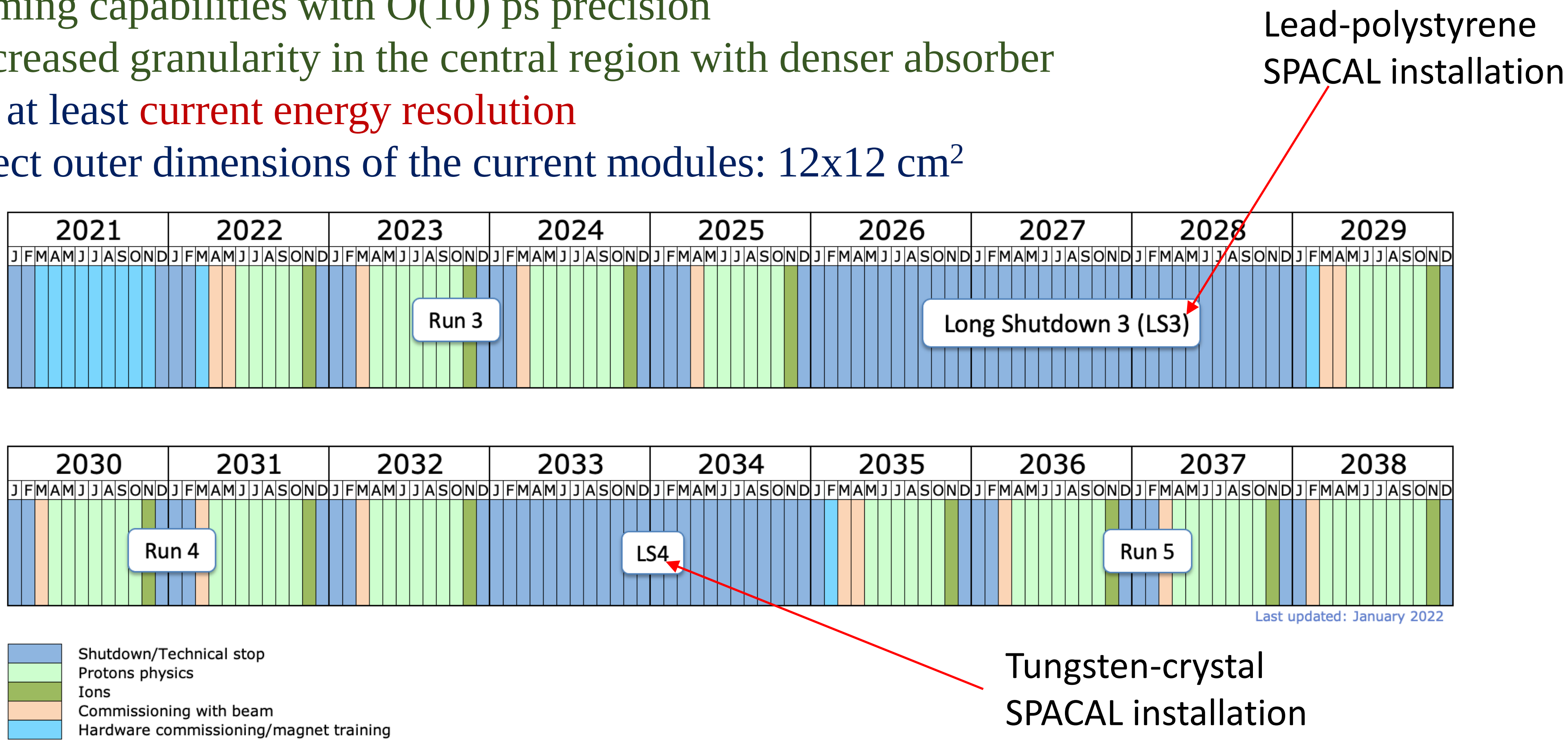



- 4 mm thick scintillator tiles and 2 mm thick lead plates
- 66 lead plates and 67 scintillator layers, ≈ 40 cm deep, ~25 $X_0$ (1.1 $\lambda_I$)
- Molière radius: ≈ 35 mm
- Module size: 12 x 12 $cm^2$
- Segmentation performed by splitting the scintillator layer into 9 or 4 tiles
- Light readout through WLS fibres: KURARAY Y11, Ø1.2 mm
  - ✓ distance between fibres: 15 mm (Outer), 10 mm (Middle, Inner)
- In order to improve the light yield and longitudinal non-uniformity, fibres are bent into U-shape loops, such that they pass through each cell twice
- Special heating & bending procedure
  - ✓ light loss in the bend measured: only ≈ 5.5 ± 2.2%

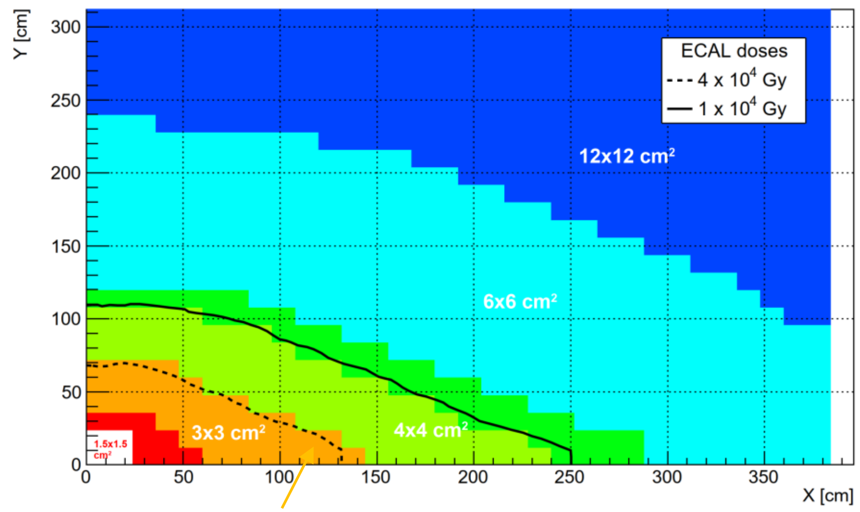
# Motivation for the Upgrade II of the LHCb ECAL

Requirements for the Upgrade II: operation at L = 1-2 x $10^{34}$ $cm^{-2}s^{-1}$

- Sustain radiation doses up to 1 MGy at 300 $fb^{-1}$
- Pile-up mitigation crucial
  - ✓ Timing capabilities with O(10) ps precision
  - ✓ Increased granularity in the central region with denser absorber
- Keep at least current energy resolution
- Respect outer dimensions of the current modules: 12x12 $cm^2$



# R&D strategy for the ECAL Upgrade II




Radiation limit of current Shashlik technology

<u>SPACAL technology for inner region:</u>

- ➢ 32 innermost modules with scintillating crystal fibres and W absorber
  - ✓ Development of radiation-hard scintillating crystals
  - ✓ 1.5x1.5 $cm^2$ cell size
- ➢ 144 modules with scintillating plastic fibres and Pb absorber
  - ✓ Need radiation-tolerant organic scintillators
  - ✓ 3x3 $cm^2$ cell size

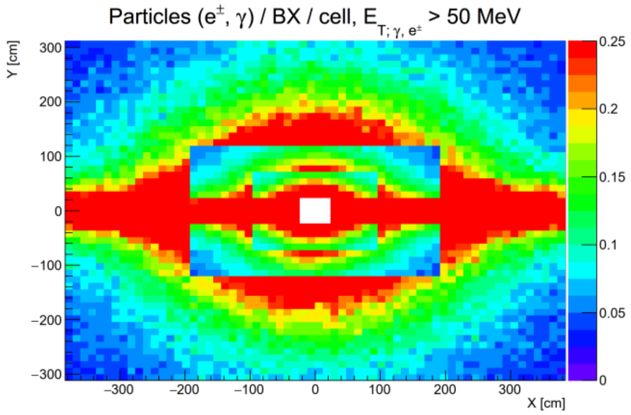
<u>Shashlik technology:</u>

- ➢ Timing with new WLS fibres, long. segmentation (double-sided readout)
  - ✓ Cost optimisation by refurbishing ≈ 2000 existing modules for timing
  - ✓ Adapt to the required cell sizes by adding ≈ 1300 new modules

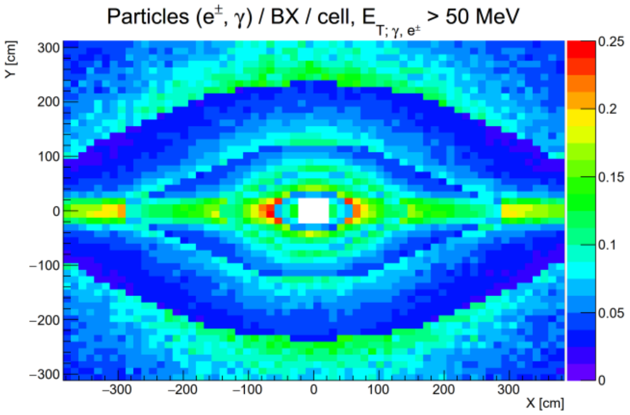
<u>Comparison of current and Upgrade II calorimeter layouts at L = 1.5 x $10^{34}$ $cm^{-2}s^{-1}$</u>

- ➢ Occupancies manageable in Upgrade II configuration
- ➢ Further pile-up mitigation from timing

**Current ECAL**

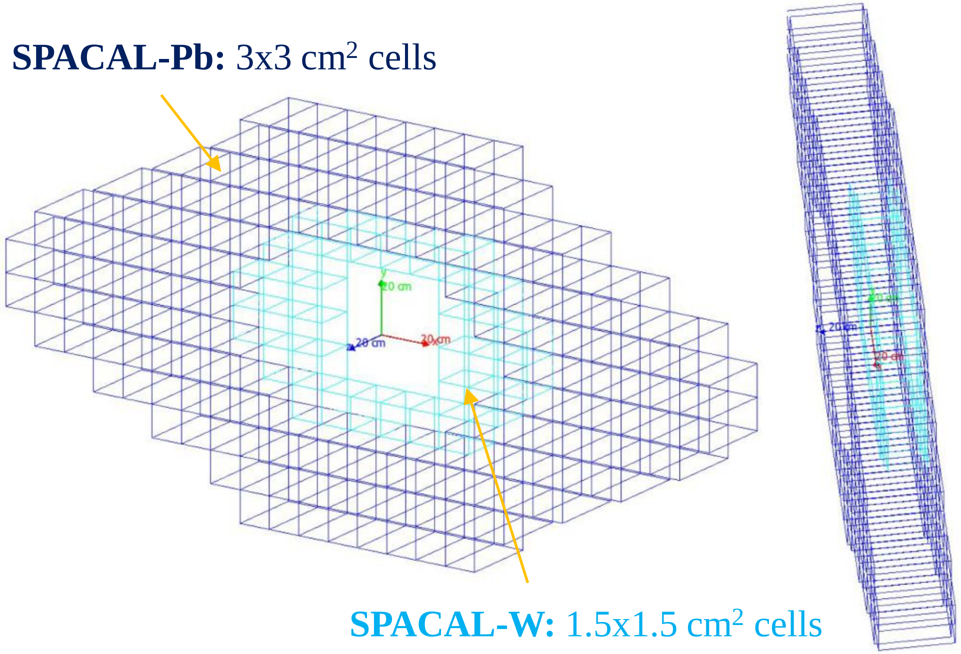


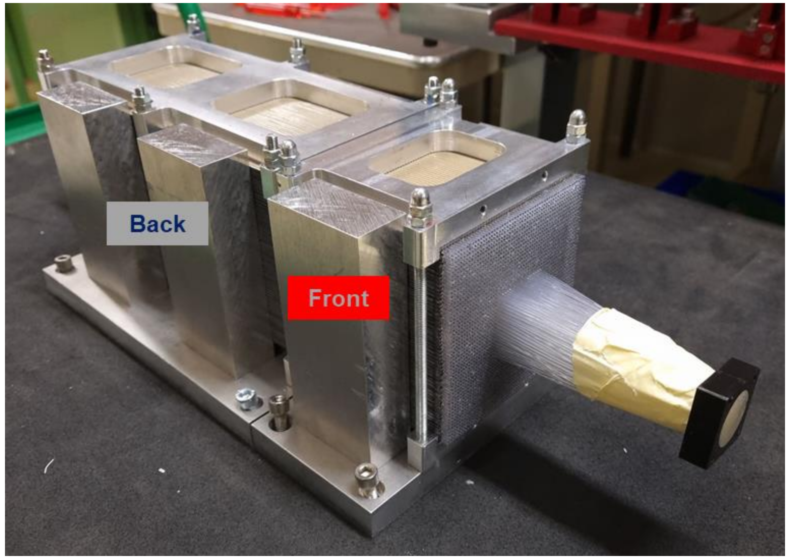

**Upgrade II configuration**



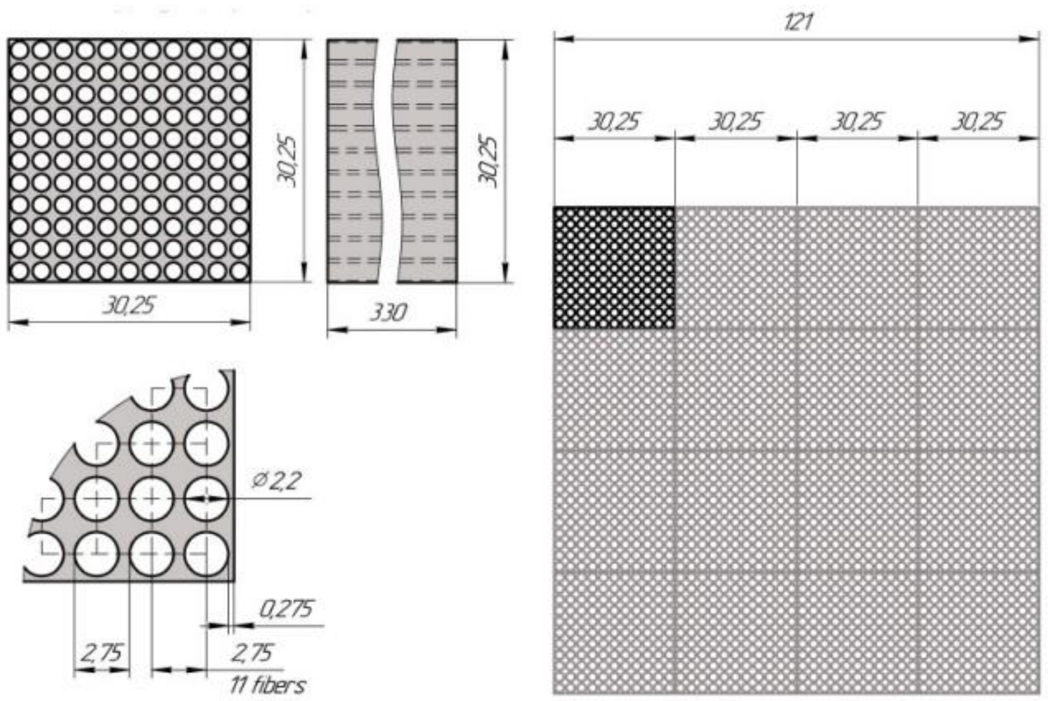
# Lead-polystyrene spaghetti type calorimeter

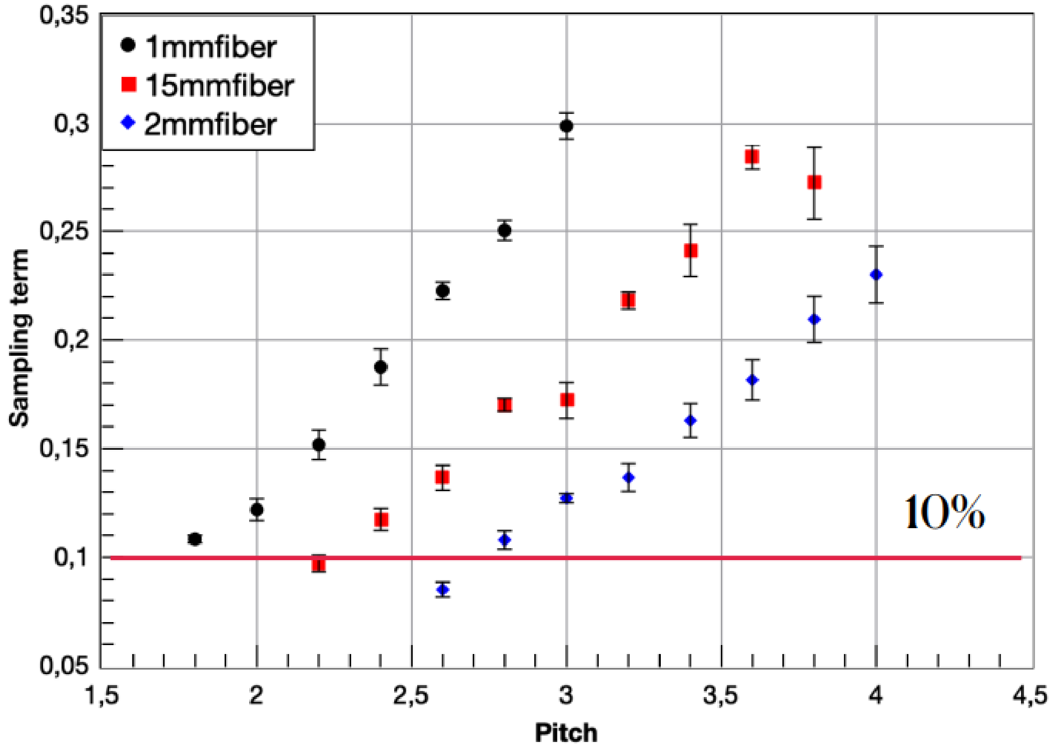
- Inner ECAL region implemented in SPACAL technology
  - ✓ Allows to study reconstruction and physics performance
- 32 SPACAL-W modules: 4.5+10.5 cm long, 1.5x1.5 cm$^2$ cell size
- 144 SPACAL-Pb modules: 8+21 cm long, 3x3 cm$^2$ cell size




# Cast SPACAL prototype




- Cast absorber made of Garth's typography alloy (GTA) in MISiS
- 84% Pb + Tin & antimony for mechanical stability (loads ~ 1 ton)
- Large fibres diameter necessary for fibres changing procedure

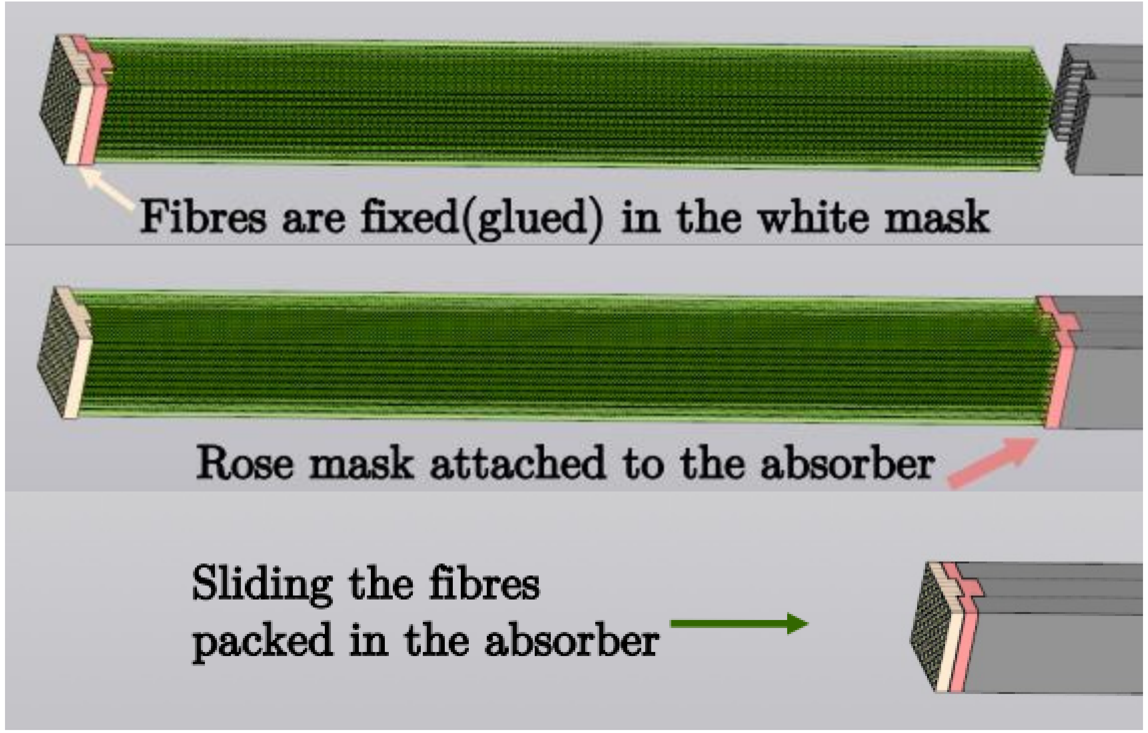
- Constant term of energy resolution was monitored. Constant term in range of ~ 1-2%
- For pitch in range 2 and 3 mm Stochastic term of energy resolution is good enough for LHCb purposes

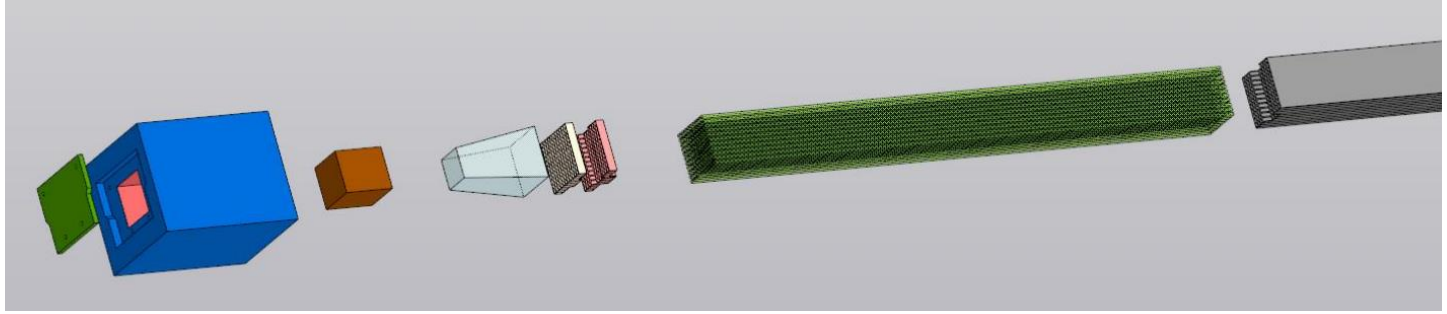
# Easy fibre-changing method

Due to the high expected radiation doses in the central region, the procedure for ‘fast’ fibres changing (during annual stop) has been implemented in the design.

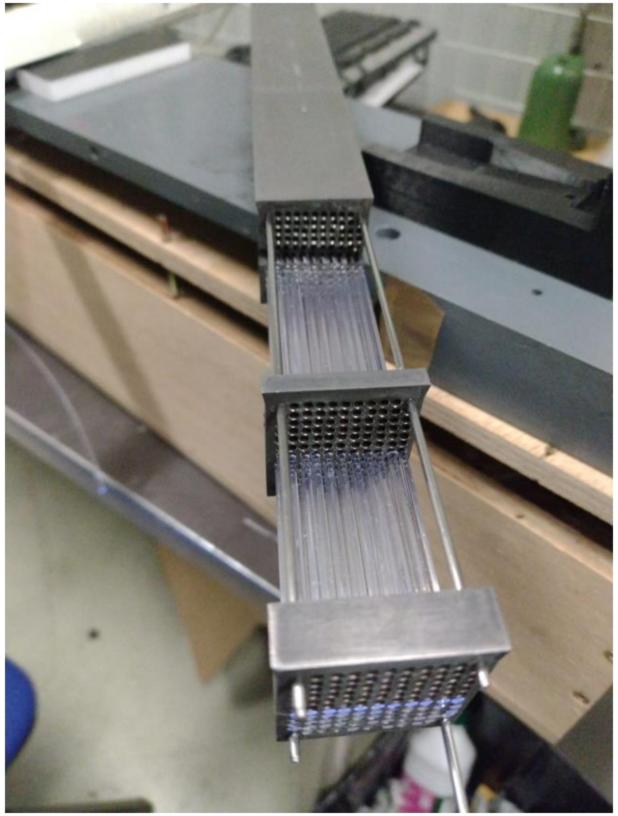
<u>Advantages:</u>

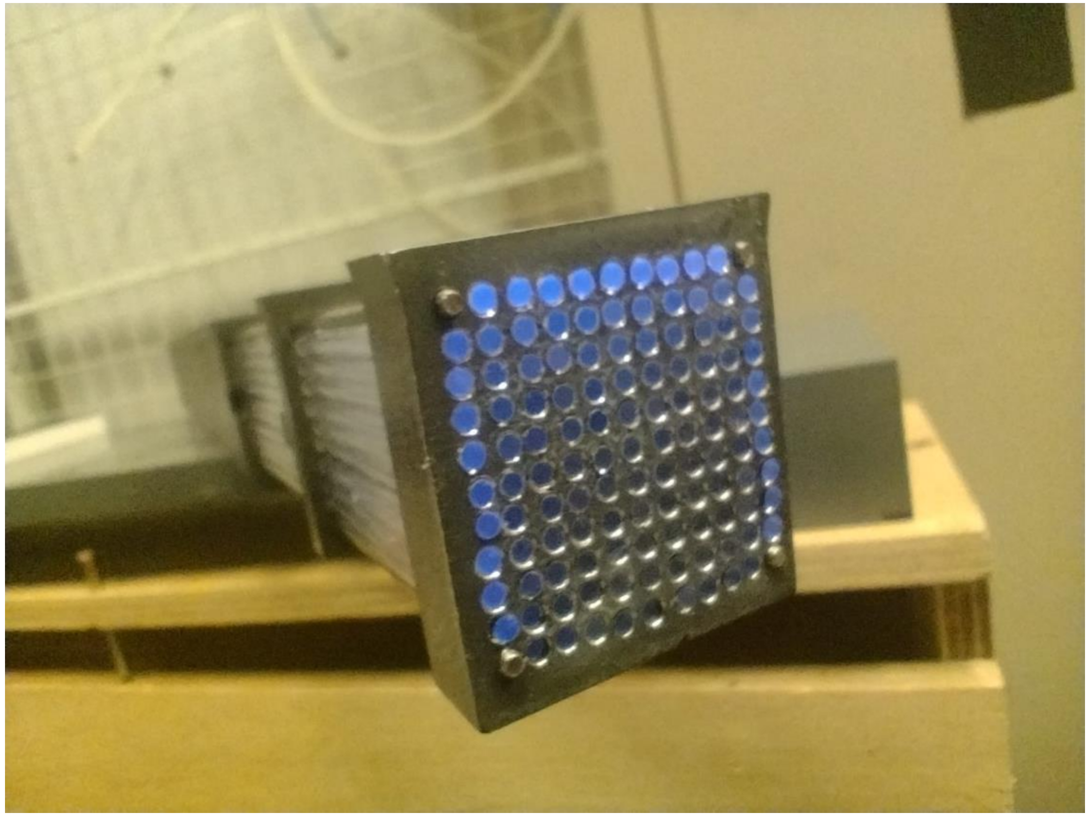
- Possibility to change fibres in one turn per cell
- Changing fibres → polystyrene lightguide instead of a bundle
- Using masks to fix all 121 fibres and guide them into absorber
- Adjustable granularity

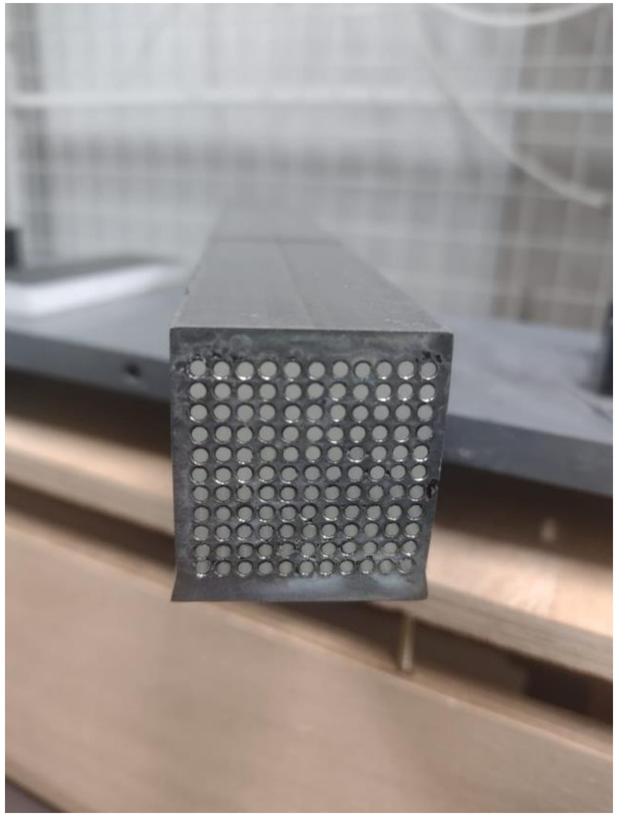


# Easy fibre-changing method

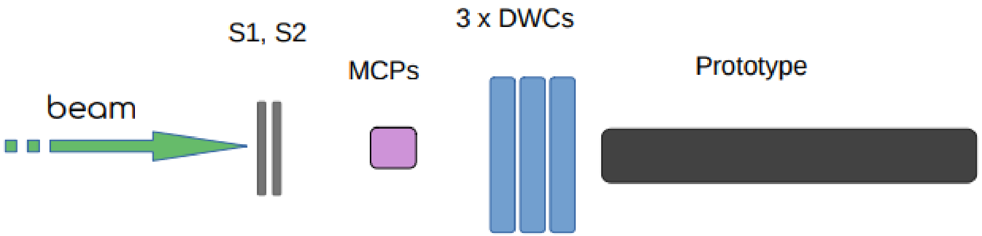


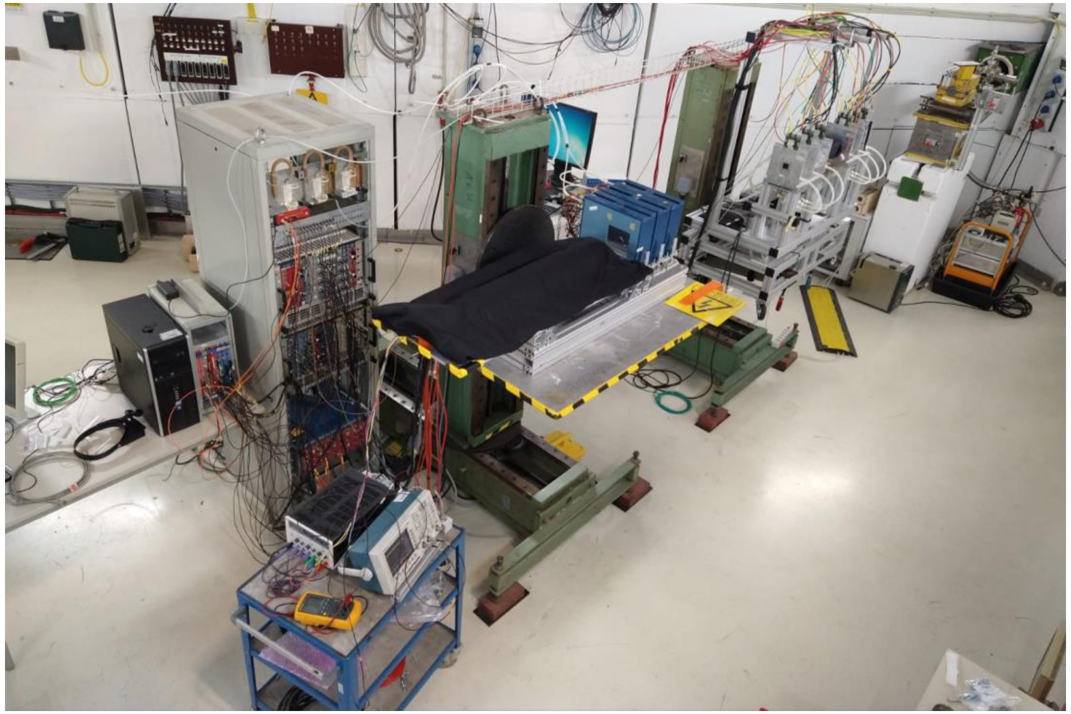




The process of fibre installation

# Test beam studies



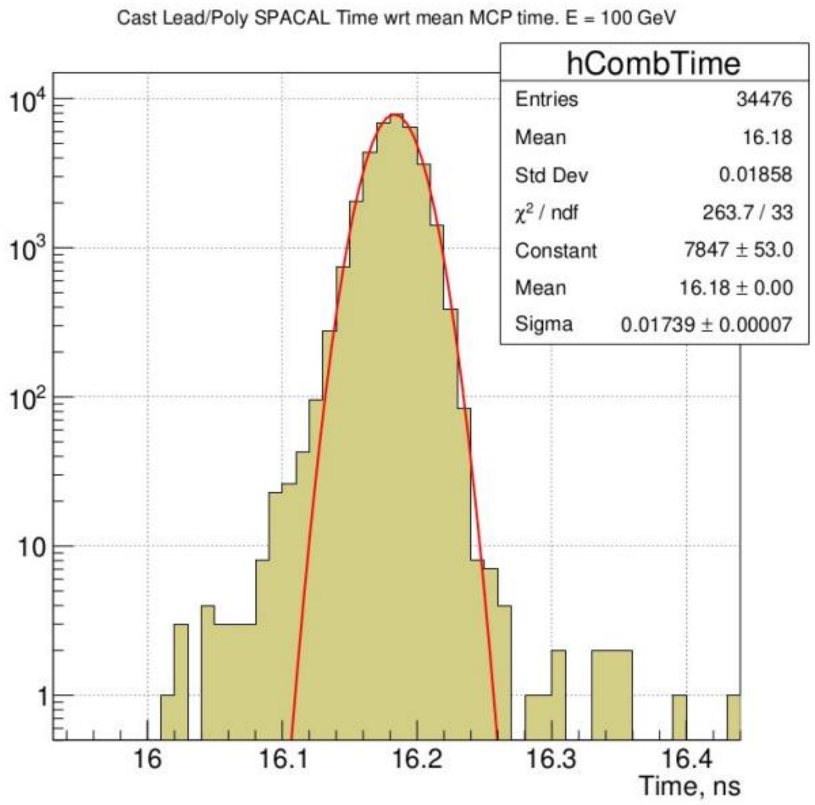



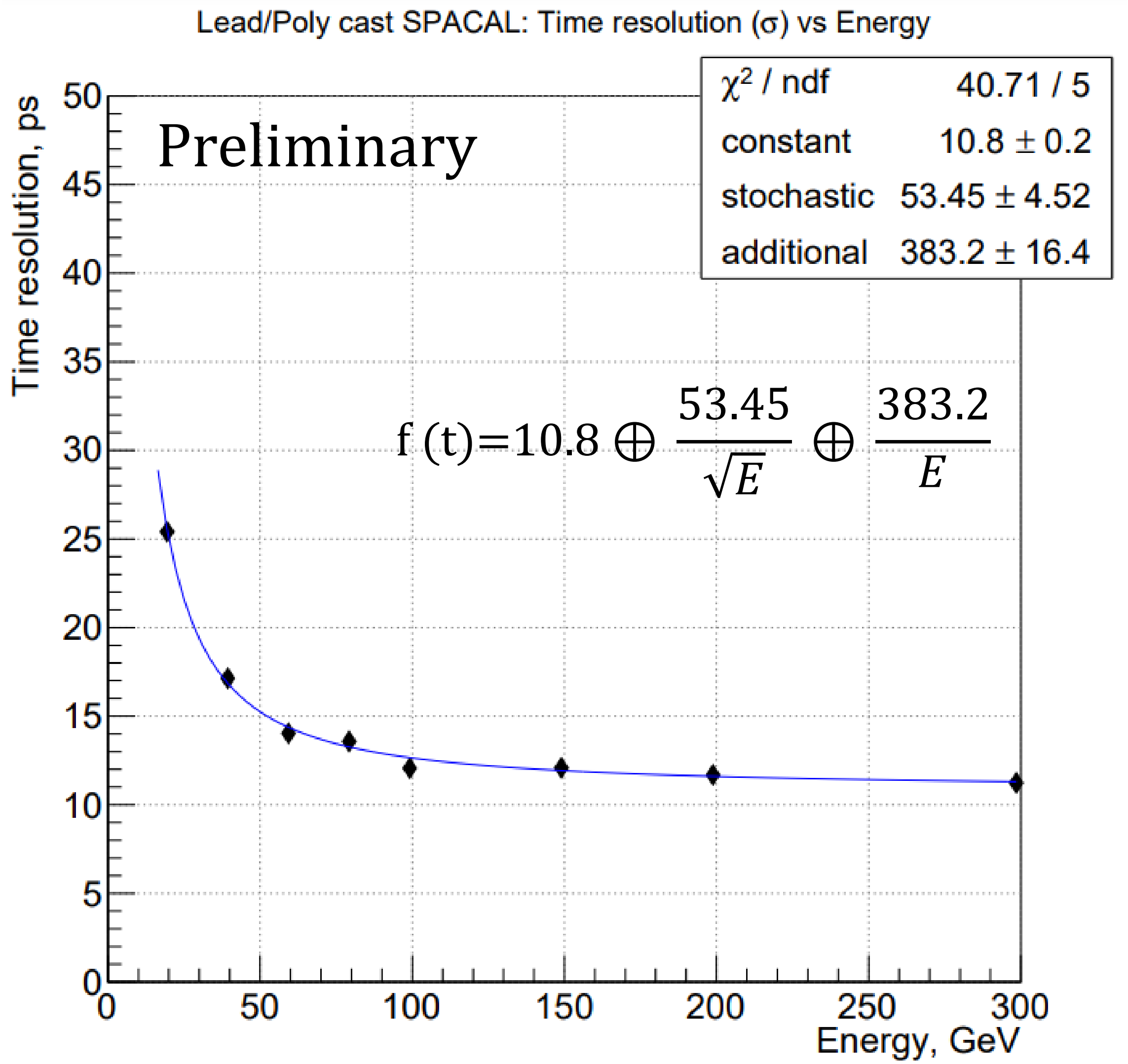
Test beam setup:
- S1, S2 – scintillator pads
- MCPs – Micro-Chip plate detectors
- DWCs – Delay wire chambers
- SPACAL prototype:

SPS test beams October 2022
- H8 beam line
- Electrons with energies 20 to 300 GeV

DESY test beams December 2022
- T24 beam line
- Electrons with energies 1 to 5 GeV

# Time resolution of SPACAL prototype

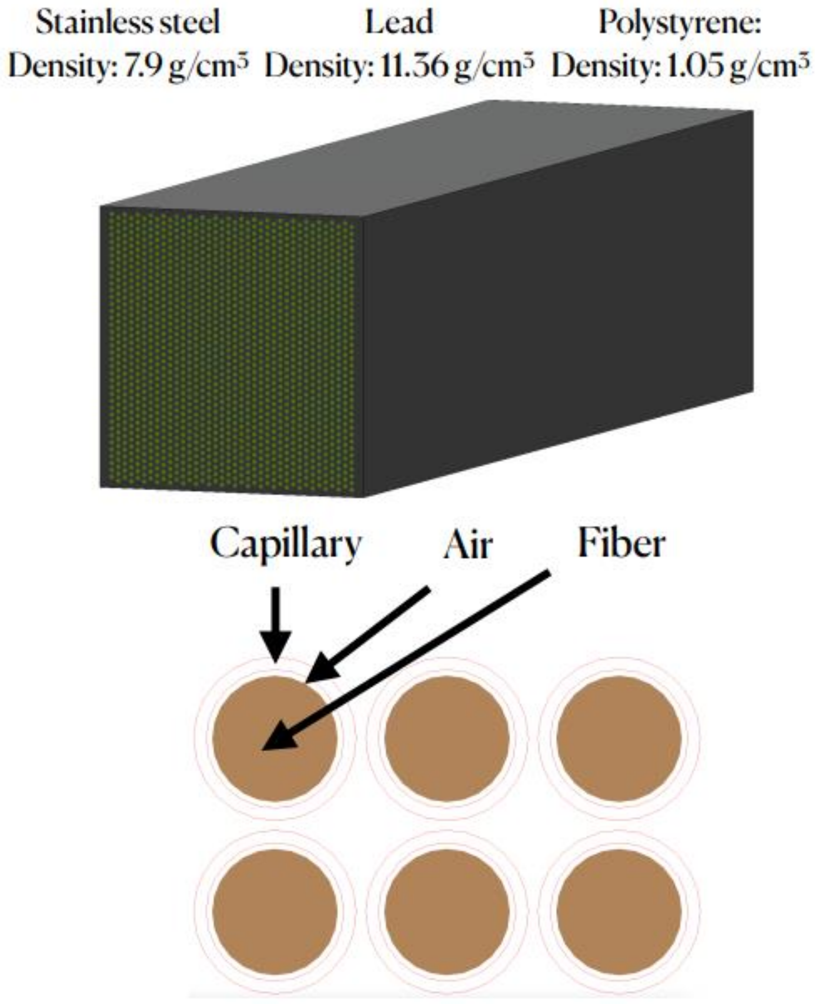



- Measured time resolution is satisfactory
- Tests at lower energies ongoing

# SPACAL prototype with capillary tubes

- Garth's typography alloy could be not the best solution for absorber purposes due to antimony activation by hadrons
- Stainless steel capillary tubes with a combination of Babbit BK2 alloy can be used as a better solution (similar average density, predefined inner diameter)
- 2 mm round (diameter) fibres, 2.2 mm inner diameter, 100 µm capillary tube wall thickness
- Distance between centers of fibres: 2.75 , 2.95 mm
- Produced in MISiS and being tested



# Conclusion & Future plans

- Cast Lead/Poly SPACAL technology developed
- Two prototypes were produced and tested at the SPS test beam facility (20-300 GeV)
- Tests with lower energies (DESY T24, 1-5 GeV) ongoing
- Cast SPACAL based on Babbitt BK2 with stainless steel capillary tubes meets all the requirements.
- Full-scale 12x12 $cm^2$ module is expected next summer