The LS3 enhancement of the LHCb electromagnetic calorimeter

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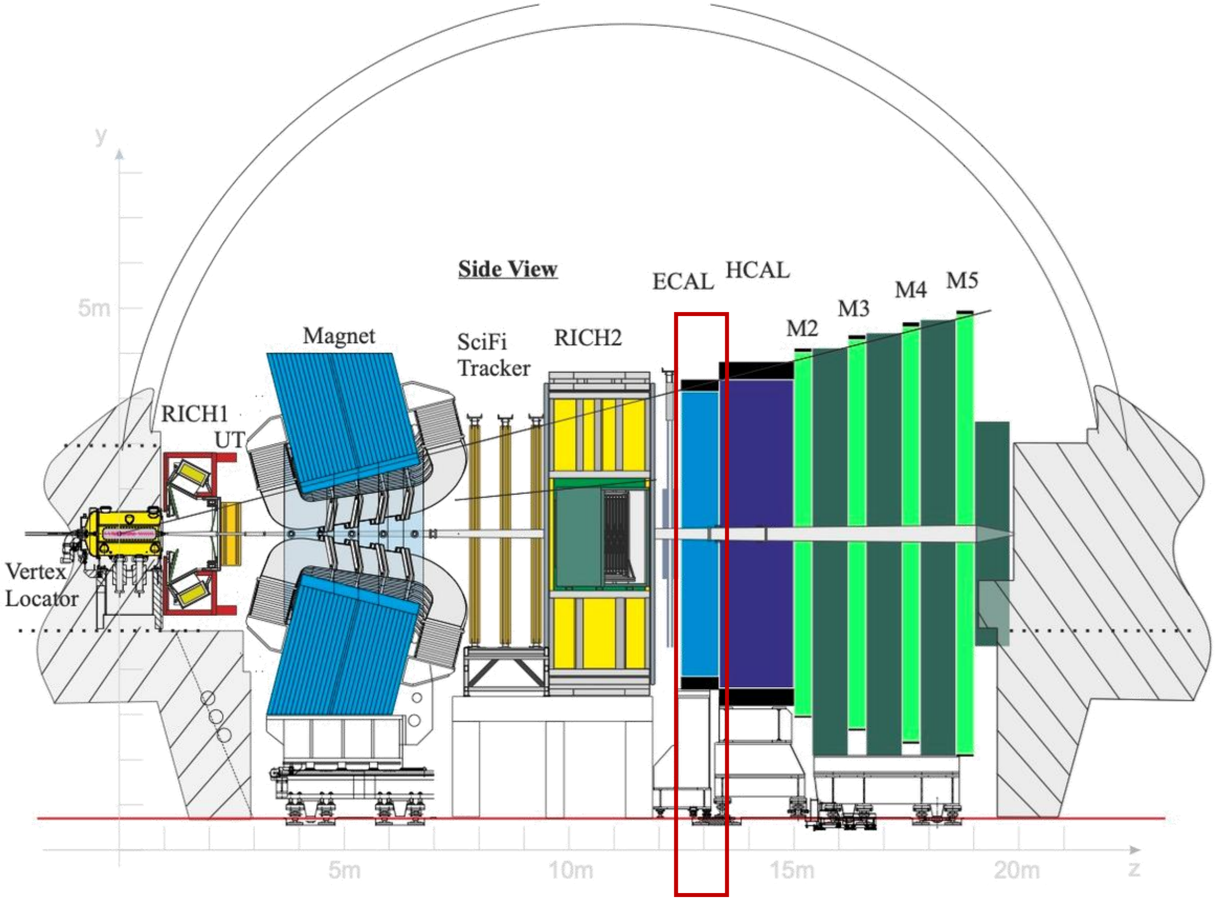
Introduction

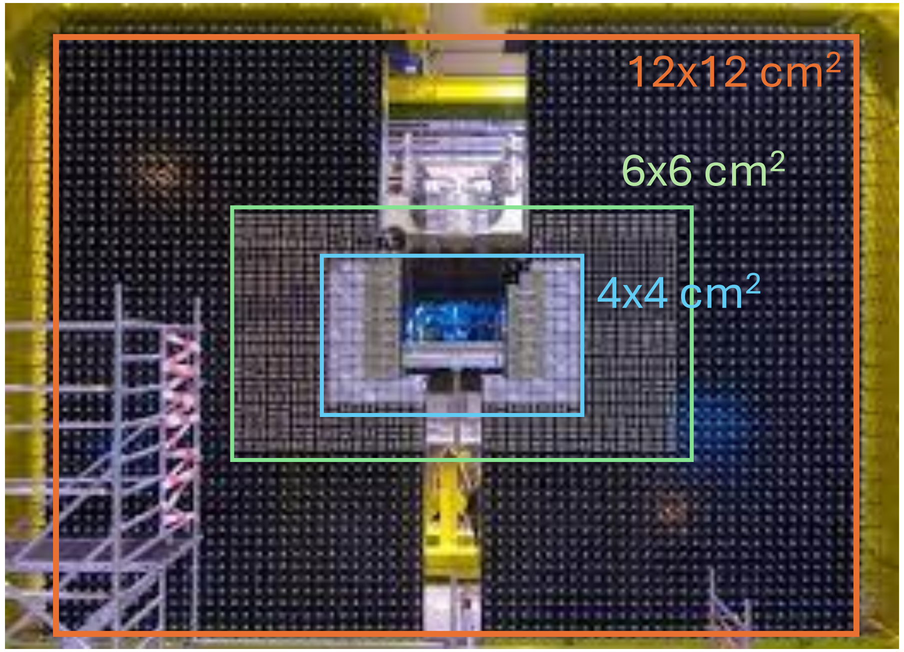
Upgrade I of LHCb has already brought improvements in:

- Trackers: VELO, Tracking chambers
- Fully software trigger

The second part of Upgrade I (U1b) will require modifications of the Electromagnetic Calorimeter (ECAL) in order to keep its performances



The current LHCb ECAL

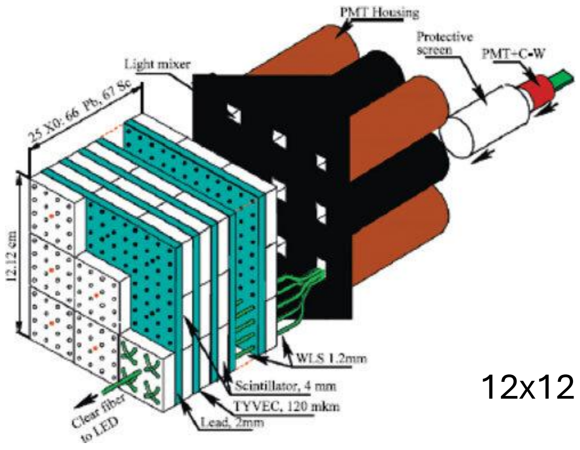


Optimised for π^0 and γ identification in the few GeV to 100 GeV region

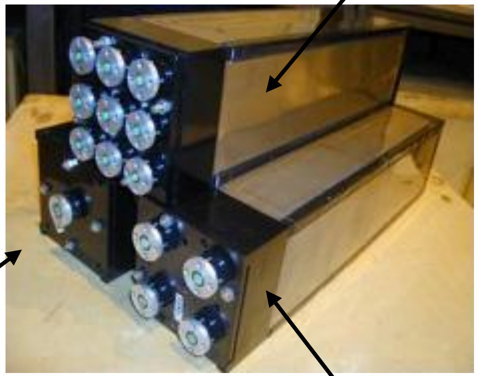
- Large array of ~50 m^2 with 3312 modules and 6016 channels
- 12x12 cm^2 modules divided in 3 regions with different cell dimension

- **Shashlik** technology → sampling calorimeter with lead and polystyrene layers
- Radiation hard up to 40 kGy
- Energy resolution:

$$\sigma(E)/E \sim 10\%/\sqrt{E(\mathrm{GeV})} \oplus 1\%$$



4x4 cm^2

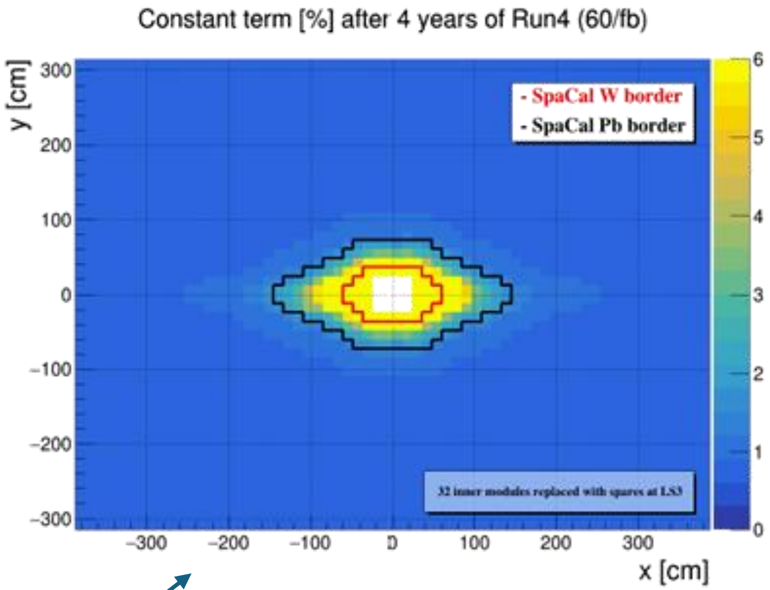


12x12 cm^2

6x6 cm^2

Motivation for LS3 enhancement

LHCB-TDR-024



Challenges in Run3:

1. Accumulated radiation dose
2. Event occupancy

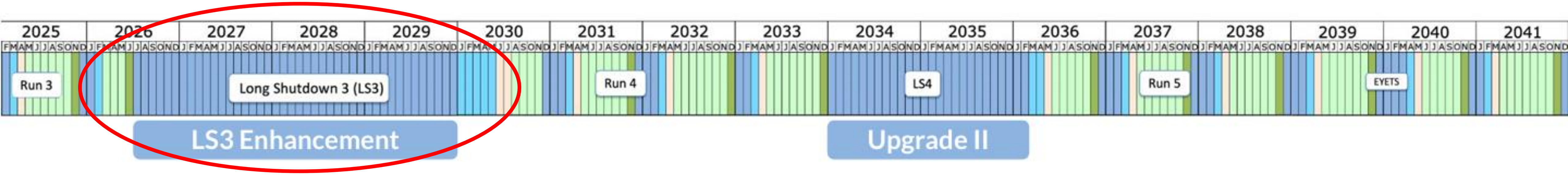
First enhancement in preparation for Upgrade II:

- New module arrangement → now possible because of fully software trigger
- New technology in inner region: Spaghetti Calorimeter (SpaCal)

Maintain current energy resolution of $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$

Without LS3 enhancement → <u>no more</u> contribution to physics!

LS3 upgrade strategy



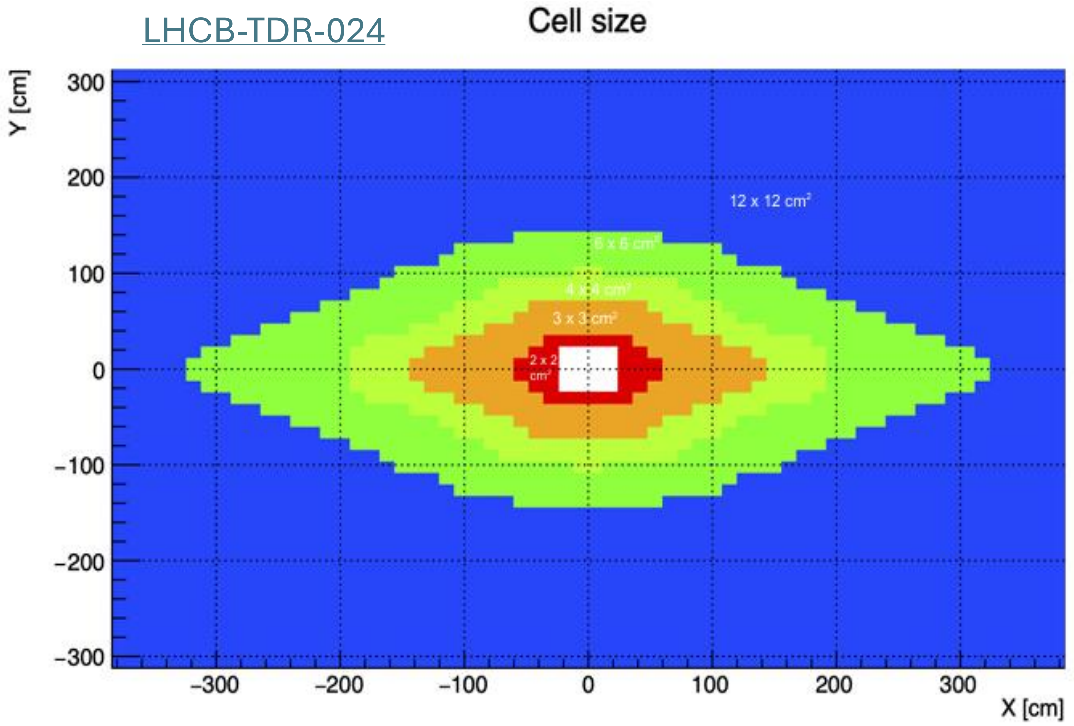
LS3 Enhancement from July 2026 to end of 2029:

- Introduce radiation-tolerant SpaCal with single-sided readout in the inner regions
  - 32 SpaCal-W (2×2 cm^2 cells) & 144 SpaCal-Pb (3×3 cm^2 cells) modules
  - plastic scintillating fibers compliant with Upgrade II conditions

- Rebuild ECAL in rhombic shape to improve performance at $L = 2\times10^{33}$ cm^{-2} s^{-1}

- 2416 modules will be dismantled and stored in dedicated areas in the cavern

LHCB-TDR-024



New ECAL layout

176 SpaCal modules with scintillating plastic fibres:

- W absorber for innermost modules
- Pb absorber for intermediate region
- single-sided readout
- all modules tilted by 3°+3°

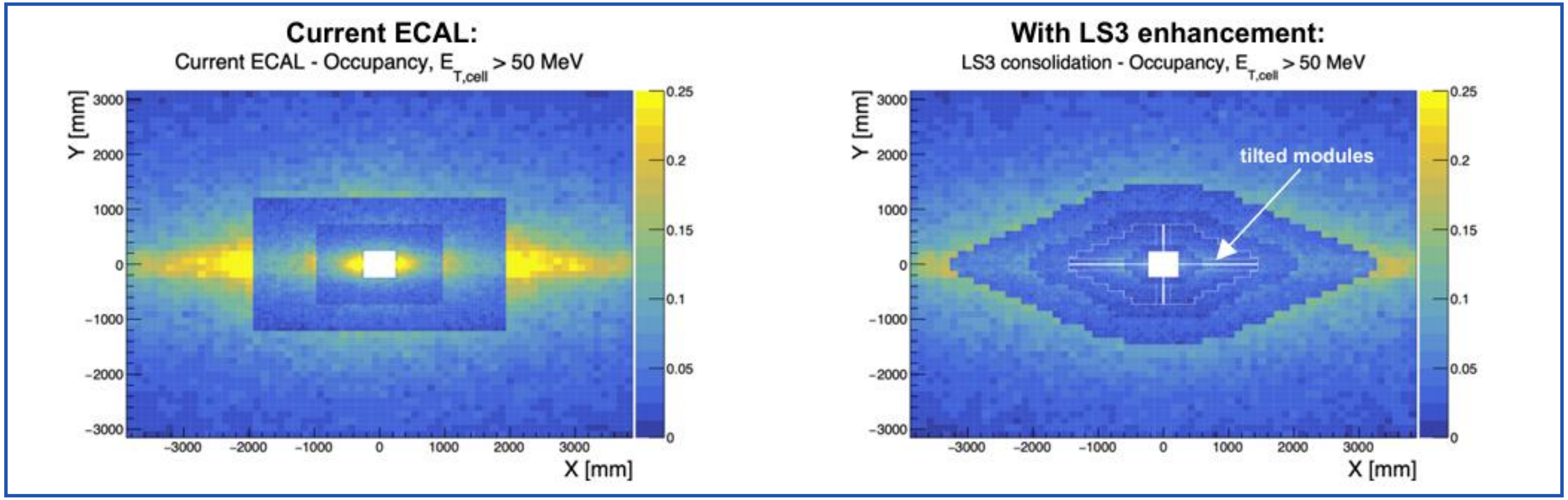
Outer Shashlik modules retained

Cell size:	Modules:
2 x 2 cm^2	32 *new* SpaCal-W modules
3 x 3 cm^2	144 *new* SpaCal-Pb modules
4 x 4 cm^2	176 existing modules in rhombic configuration
6 x 6 cm^2	448 existing modules in rhombic configuration
12 x 12 cm^2	2’512 existing modules in rhombic configuration

Occupancy performance

- Occupancies from detailed simulation, including the hadronic component
- Assumed luminosity: L = 2×10^{33} cm^{-2} s^{-1}

LHCB-TDR-024

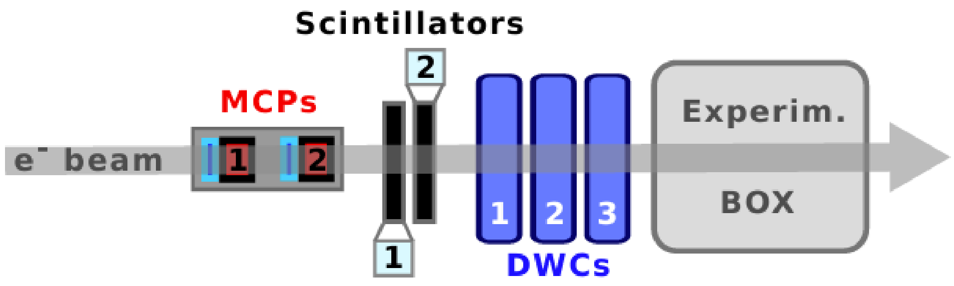


- Sizeable occupancy in large regions before LS3 enhancement (e.g. challenge for π^0 reconstruction)
- Occupancy map after LS3 enhancement is reasonably flat

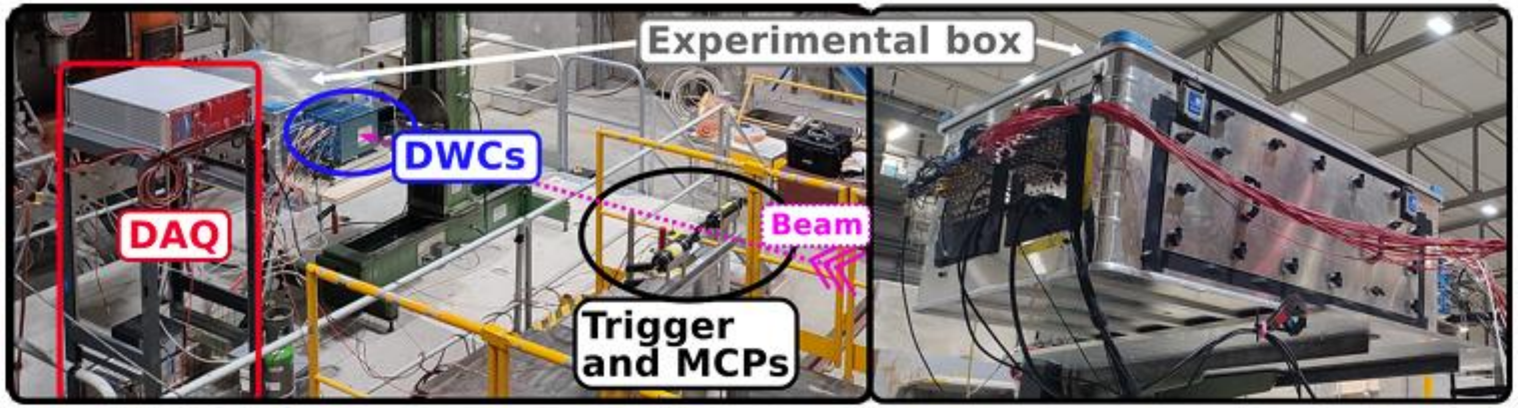
R&D and beamtest results

Beamtest campaigns at DESY and CERN SPS

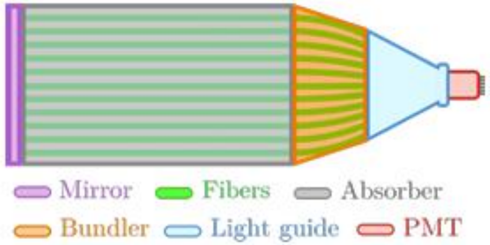
Energy and time resolution



- SpaCal with tungsten absorber:
  - SpaCal-W prototypes with plastic scintillating fibers
- SpaCal with lead absorber:
  - SpaCal-Pb prototypes with single-sided readout

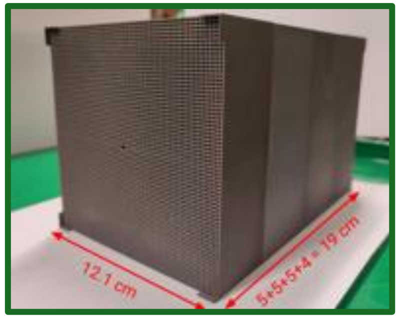


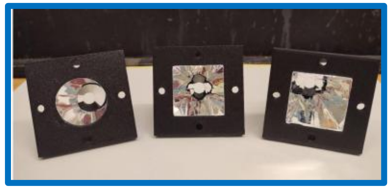
The SpaCal prototypes

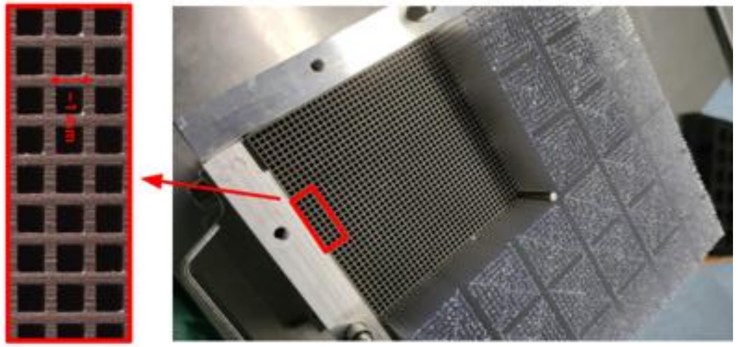


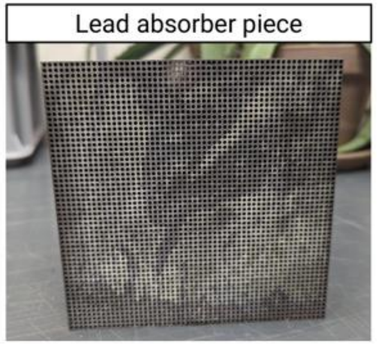
SpaCal-W

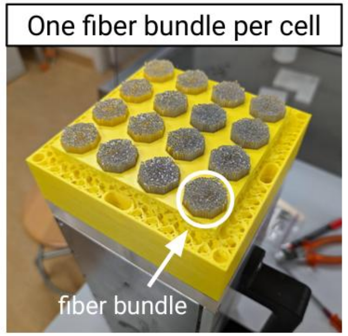
- 3D-printed **tungsten absorber**:
- Plastic scintillating *square* fibers (1.0x1.0 mm^2)
- 3D printed "hollow" **light guides** to match the cell sizes of the module to the size of the PMT











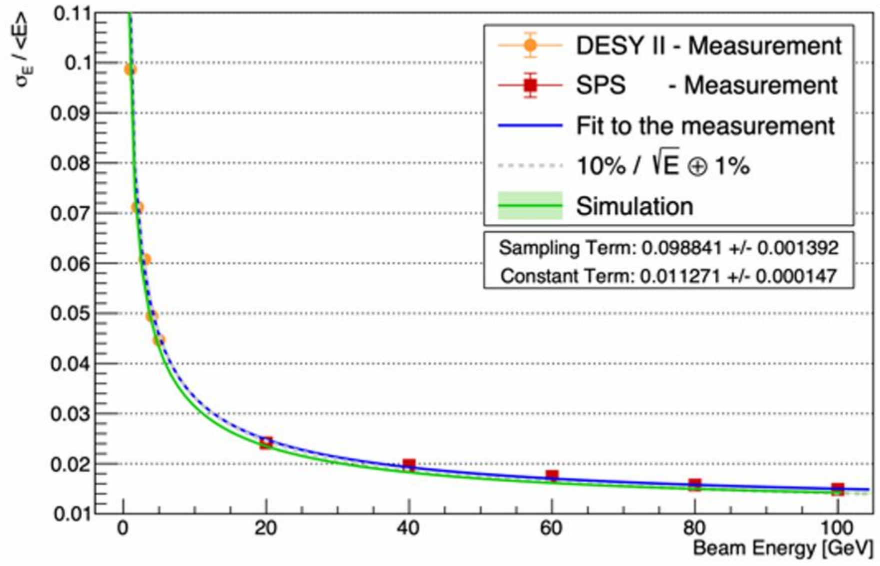
SpaCal-Pb

- Cast-lead absorber with stainless steel capillary tubes
- Plastic scintillating *round* fibers (d=1.5mm)

SpaCal-W

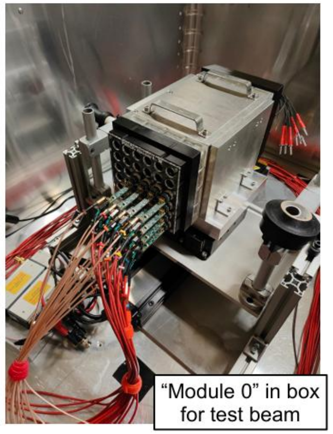
Full size Module 0 assembled at CERN

Electron beam incidence angle: 3°+3°

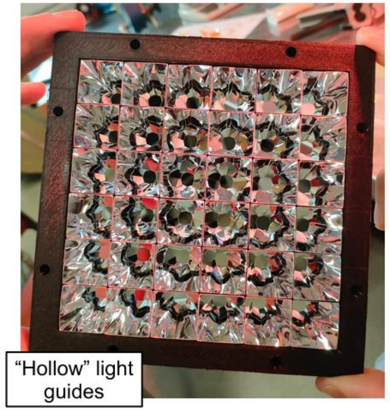


Energy resolution

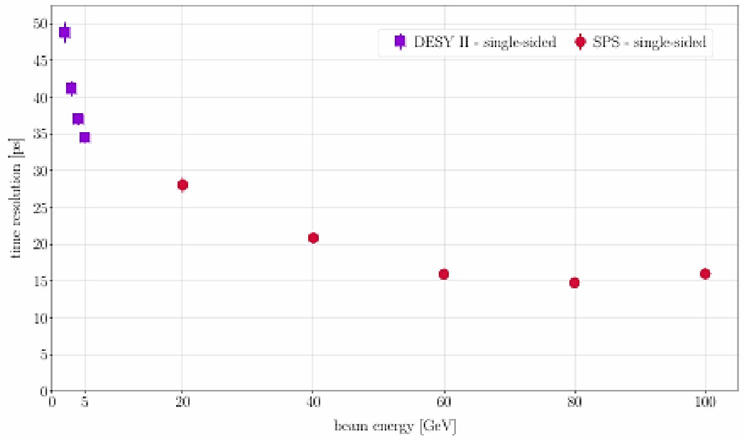
- Single-sided readout & Hamamatsu R14755U-100
- Sampling term: 9.9%, constant term: 1.1%
- Good agreement with simulations



"Module 0" in box for test beam



"Hollow" light guides

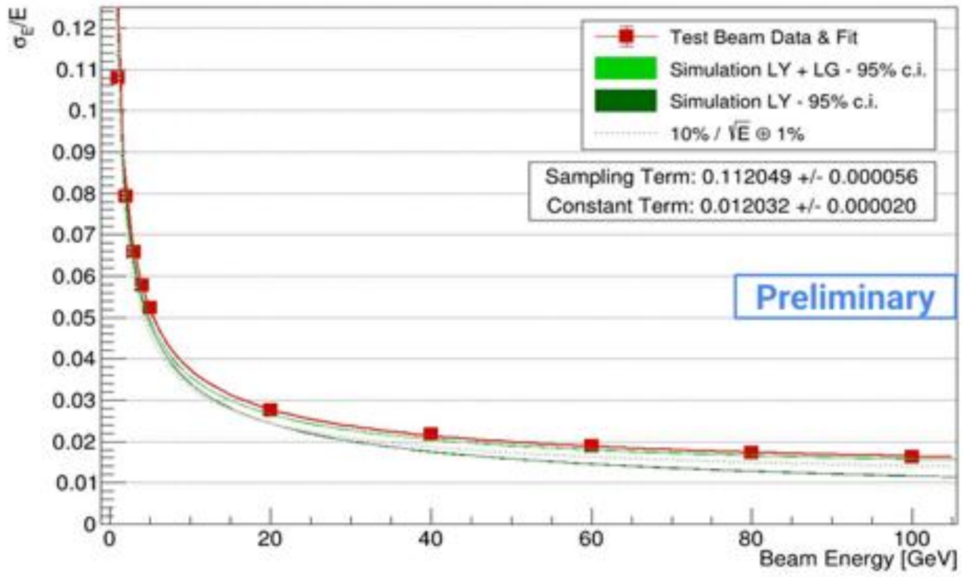


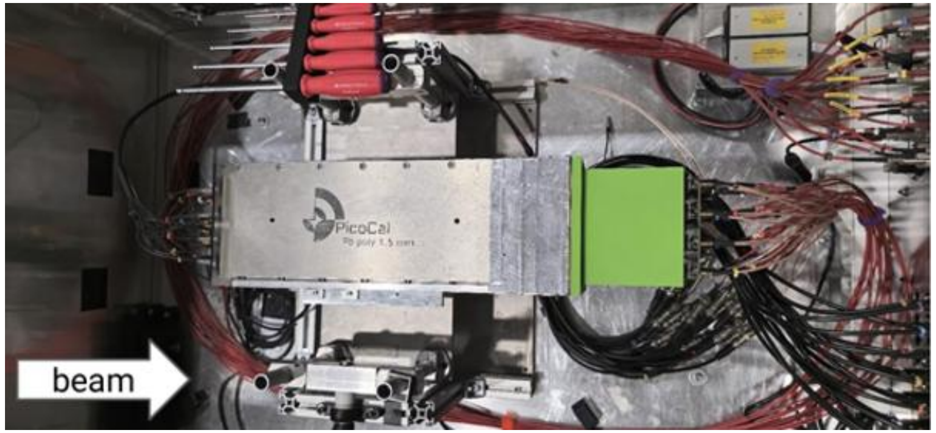
Time resolution

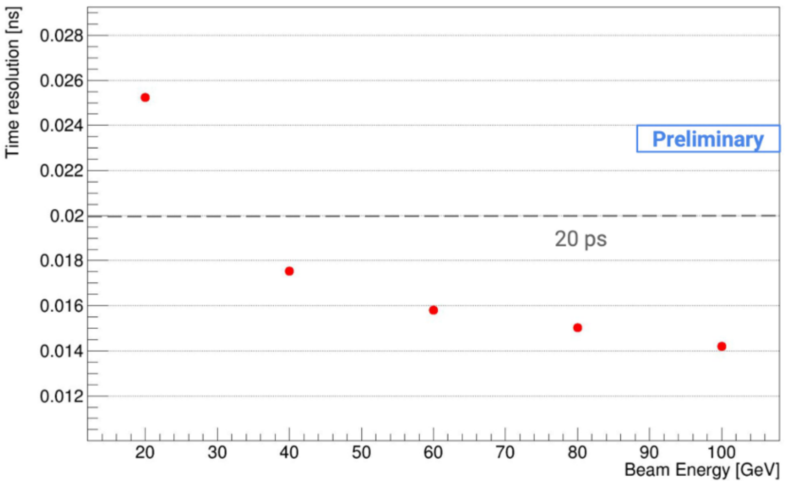
- Single-sided readout & Hamamatsu R7600U-M4
- Time resolution ~20 ps above 40 GeV

SpaCal-Pb

Electron beam incidence angle: 3°+3°







Energy resolution

- Single-sided readout & Hamamatsu R11187
- Sampling term: 11.2%, constant term: 1.2%
- Good agreement with simulations

Time resolution

- Single-sided readout & Hamamatsu R11187
- Time resolution < 20 ps above 20 GeV

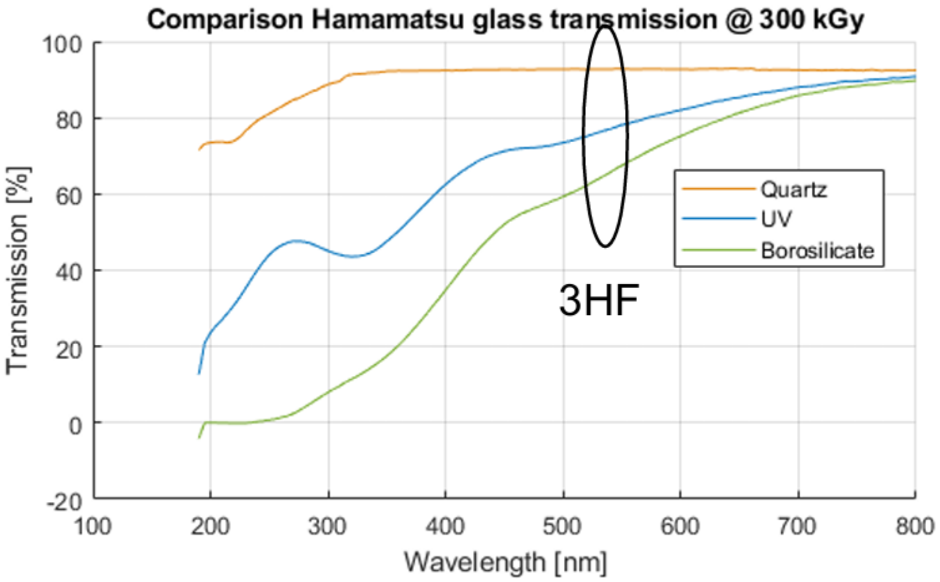
Photon sensors

For SpaCal-W modules:

- candidate under study: Hamamatsu R9880U MCD PMT
- sufficient linearity (2%) at low gain achieved with dedicated voltage divider

For SpaCal-Pb modules:

- candidates under study: Hamamatsu R9800, NNVT N2014
- larger model needed to maximise light collection

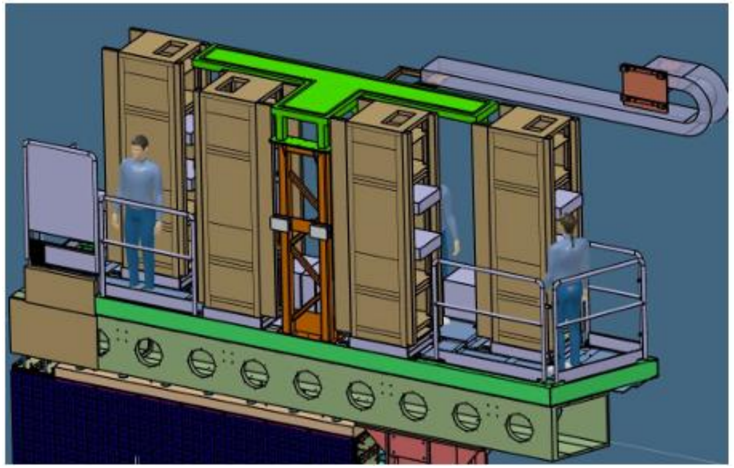


- 300 kGy is the expected dose for the innermost PMTs at the end of Run 5
- Moderate difference between different window materials at 530 nm (scintillation photons from 3HF)

Integration and installation plan

- Production and Quality Assessment before LS3
  - SpaCal modules are produced in phases to ensure timely delivery
- Mechanical compatibility and Installation logistics
  - precise design an testing to ensure smooth installation in the existing ECAL structure
- Installation during LS3
  - dismantling of ECAL wall
  - reinstallation of modules
- Commissioning before Run 4

Modified infrastructure on top of the calorimeter



Conclusions

- LS3 enhancement extends ECAL performance into Run4 operations:
    - 176 modules will be replaced with new SpaCal technology
    - new arrangement of modules improves occupancy
- New SpaCal technology validated in beam tests at DESY and SPS
    - both SpaCal-W and SpaCal-Pb meet the requirements on energy resolution and radiation hardness
    - good results also in time resolution
- Strategic step towards Upgrade II (PicoCal)

Thank you !