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Design and construction of electromagnetic calorimeter for LHCb experiment

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Abstract

Discussed are constructive features of the design of individual modules, calorimeter wall, support structures and the related questions, as foreseen to build electromagnetic calorimeter of the LHCb experiment at CERN.

1 Introduction

"Shashlik" calorimeter technology, implying a sampling scintillator/lead structure read out by plastic WLS fibers, has been accepted for electromagnetic calorimeter construction in the LHCb experiment [1]. This decision was made taking into account good energy resolution, fast response time and reliability of the "shashlik" technology, as well as the experience accumulated at other experiments [2, 3, 4].

Paper addresses the design and construction of electromagnetic calorimeter for LHCb experiment. Discussed are the design of individual modules, calorimeter wall, support

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structures and the scope of related questions. Also considered are mass production and quality control of calorimeter modules, their transportation to CERN and acceptance tests, and installation into LHCb detector. Requirements to calorimeter design in order to provide possibility of access, maintenance and proper operation of ECAL are briefly mentioned.

2 ECAL overview

LHCb experiment is aimed at the precision studies of CP asymmetries and rare B-decays, exploiting copious B meson production at LHC. The experiment will operate with an average luminosity of $2 \times 10^{32}\ cm^{-2}s^{-1}$, corresponding to the production rate of $10^{12}\ b\bar{b}$ pairs per year of data taking.

Efficient π^0's reconstruction in the wide range of momentum spectrum, discrimination between electrons, and charged hadrons with overlapping photons, the reconstruction of electrons and high energy γ's make up the ECAL contribution to the LHCb detector potential.

Electromagnetic calorimeter is a part of LHCb calorimeter system, which also comprises the preshower detector and the hadron calorimeter. Electromagnetic calorimeter will be placed starting at 12490 mm from the interaction point (Figure 1).

The outer dimensions of ECAL are matched projectively to those of the tracking system, $\theta_x < 300\ mrad$ and $\theta_y < 250\ mrad$. Due to the substantial radiation dose level around the beam pipe, the active calorimeter volume has a central square hole of $65 \times 65\ cm^2$ [1].

Main parameters of LHCb electromagnetic calorimeter are listed in Table 1.

[1]Since the hole size is not multiple to that of module, the innermost modules will be partly instrumented, thus giving a hole of quoted size in the active calorimeter volume.

Table 1: *Main parameters of LHCb electromagnetic calorimeter*

	Inner section	Middle section	Outer section
Inner size	$65cm \times 65cm$ [1]	$194cm \times 145cm$	$388cm \times 242cm$
Outer size	$194cm \times 145cm$	$388cm \times 242cm$	$776cm \times 630cm$
Cell size	$4.04cm \times 4.04cm$	$6.06cm \times 6.06cm$	$12.12cm \times 12.12cm$
Technology	Shashlik		
Volume ratio	$Pb : Sc = 2 : 4$		
Moliere radius	3.5 cm		
Radiation length	1.64 cm		
Absorber	Lead		
Scintillator	$PSM - 115 \oplus 2.5\% \; p - terphenyl \oplus 0.01\% \; POPOP$		
Depth	42 cm (25 X_0)		
# of modules	176	448	2688
# of cells per module	9	4	1
# of fibers per module	144	144	64
# of channels	1472	1792	2688
WLS fiber type	$Y11(200)MS$		$BCF - 92A(DC)$
WLS fiber length	17.4 km	44.1 km	118 km

3 Engineering design

3.1 Module design

The isometric view of LHCb calorimeter is shown in Figure 2. Inner, middle and outer section modules have similar basic design features differing by the number of cells per module and by the fiber density. There are 9, 4 and 1 cells per calorimeter module and 16, 36 and 64 fibers [5] per cell for the inner, middle and outer sections respectively

(see Figure 3), so that fiber density for inner and middle sections is 144 fibers per module, while for outer section fiber density is decreased and equal to 64 fibers per module.

Transverse cell dimensions are fixed from HCAL cell size, the ECAL-HCAL projectivity requirements, and typical shower maximum z-position in ECAL and HCAL. A total of 835 mm space in z-coordinate is occupied by electromagnetic calorimeter. The assembled Pb/Sc stack, comprising also the related mechanics, has its length of 432 mm.

The front (monitoring) side of electromagnetic calorimeter includes plastic covers to provide light isolation and prevent fiber loops (for middle and outer section modules, see section 3.1.2) from being damaged, and the monitoring system (section 3.5) – clear transport fibers, splitters and optical connectors – for modules of all three ECAL sections.

At the rear (read-out) side, space is allocated for fibers to form a bundle (section 3.1.2), for the light mixer (section 3.1.3), for the PM and PM base (section 3.1.4), and for related mechanics.

The read-out system is followed by the cooling system (section 3.4).

Additional 60 mm space is reserved for cabling. Each channel requires 1 cable for signal read-out, and 4 cables supplying high voltage and 3 extra feeds, to the PM. Cable $RG178BU$ of $KX21A$ type with seven 0.10 mm diameter wires and external diameter $\oslash = 1.80$ mm is considered as the option for signal cable.

3.1.1 Pb/Sc stack structure

Each module is constructed from alternating layers of 2 mm thick lead, white reflecting 120 μ thickness paper (TYVEK) and 4 mm thick scintillator tiles. In sum, there are 66 Pb/Sc layers resulting in a total depth of 25 X_0.

The tile is produced of polystyrene-based PSM-115 scintillator with the 2.5% p-ter-phenyl and 0.01% $POPOP$ admixtures. The concentration of scintillating dopants is chosen so, that the scintillator light is almost saturated, and is tuned for the scintillator emission spectrum to match the absorption spectrum of WLS fiber. Scintillator tile production employs the high pressure injection moulding technique.

Tile edges are chemically mat (thus providing the diffusive reflection) in order to improve light collection efficiency, transverse uniformity [5] and prevent tile-to-tile light crosstalk. Alternatively the tile edges could be aluminized (HERA-B solution) with the technique of Al evaporation in vacuum by HV-induced explosion. With this latter method one obtains $\sim 10\%$ worse reflection efficiency, compared to the mat coating.

The Pb plates are produced with sheet-metal stamping.

3.1.2 Fiber routing

The light from scintillator tile, is re-emitted and transported by 1.2 mm diameter WLS fibers penetrating the entire module, and is then read out with PM. The fibers belonging to each calorimeter cell are bundled at the end of the module and polished. The number of fibers per bundle as well as the size of fiber bundle is shown in Table 2. We are planning to use more radiation hard [6] $Y11-200(MS)$ [2] fibers for the inner

Table 2: *Number of fibers per bundle (1 fiber in the bundle is a clear fiber for monitoring) and fiber bundle size*

	# of fibers in bundle	Bundle diameter, ⊘, [mm]
Inner section	$1+16$	6.0
Middle section	$1+36$	8.4
Outer section	$1+64$	10.8

[2] $Y11-200(MS)$ denotes multi-cladding (M) S-type (S) $Y11$ Kuraray fibers with the concentration of WLS dye of 200 ppm. S-type fiber core has molecular orientation along drawing direction,

and middle section modules and $BCF-92A(DC)$ [3] fibers for the modules belonging to the outer section.

WLS fibers penetrating the Pb/Sc stack, are bended at different curvature in front of the stack, where fiber loops are made, and behind the stack, where the fibers are bundled.

Bending of the fiber at small curvature radii, leads to the light losses both due to mechanical degradation because of fiber cracking, and due to the change of light reflection angles, governed by the geometrical optics. The latter effect dependence on the bending radius, has been simulated with Monte Carlo for 1.2 mm diameter fibers. Simulation results are plotted in Figure 4.

In the front part of the module fibers form a loop for large cell sizes, where loop is possible without significant light losses. Fiber "pairing" becomes complicated for small cell sizes (small curvature radii of fibers), i.e. for inner section modules. In this latter case, the fibers are cut, polished, and aluminium mirror is made on the fiber front edge. Even for middle and outer section modules, the straightforward fiber bending with the radius as small as 15 mm, would lead to mechanical fiber damage. In order to avoid mechanical fiber damage, special technique of fiber bending under high temperature [4], has been elaborated, and successfully applied for HERA-B and PHENIX electromagnetic calorimeter modules. Presently this technique is proved to provide fiber performance long-term stability. At the same time, radii of fiber bending at the read-out side are not as small (Table 3), so that no special efforts are needed.

3.1.3 Light mixer

To reduce the contribution from the PM cathode non-uniformity to the constant term, a quadrangular prism light mixer as made from polystyrene, will be used. Light mixer application was studied with Monte Carlo. Simulated was the response to MIP, where

that makes the fiber mechanically stronger against cracking.

[3] $BCF-92A(DC)$ stands for double cladding (DC) $BCF-92A$ Bicron fibers.

[4] Fibers are heated with the dry air up to the temperature $t = 85^oC$.

Table 3: *Fiber bending at the stack rear side. Δz stands for z-distance, where fibers are bended in order to form a bundle. Δr is the corresponding maximum shift in $r\phi$-plane, i.e. the distance between the corner fiber and the outer bundle surface. In brackets shown is the total z-distance between the end of Pb/Sc stack and the end of fiber bundle*

Monitoring side		
Middle/Outer section	$R = 15\ mm$	
Read-out side		
	$\Delta r,\ [mm]$	$\Delta z,\ [mm]$
Inner section	19	55 (75.5)
Middle section	32	60 (80.5)
Outer section	70	60 (80.5)

the light as produced in scintillator was absorbed, re-emitted and transported by WLS fibers. Fiber bundle was followed by the light mixer, and next by the window of PM.

Conclusive is the distribution of the response non-uniformity versus the length of light mixer, as shown in Figure 5. The non-uniformity of response is the non-uniformity at the mixer end, convoluted with PM cathode non-uniformity [5]. Critical is to have non-uniformity small with respect to the constant term of the design energy resolution, 0.8%, which does not look as a challenge.

3.1.4 Photomultiplier

The size of fiber bundle (Table 2, section 3.1.2) and the light mixer parameters (section 3.1.3) determine the requirements to PM window size and photocathode

[5] For the case illustrated in Figure 5 photocathode non-uniformity was taken to be 20%. The light produced in the scintillator tile by MIP, produces a green light distributed over all the WLS fibers. Typically contribution of the closest fiber is only about 15% of total light. Therefore the response non-uniformity to MIP signal is as small as $\sim 2\%$ already without the use of light mixer.

uniformity.

Different PMs are being presently considered to be used for ECAL. As an example of space needed and of PM characteristics required, the specifications of $FEU-115M$ photomultiplier [2, 7] are given in Table 4. The laboratory test results of FEU-115M

Table 4: *Specifications of FEU-115M*

Manufacturer	MELS, Moscow
Light sensitivity range	$300 \div 820\ nm$
Photocathode diameter	$25\ mm$
External PM diameter	$30\ mm$
PM length	$90\ mm$ / $72\ mm$
Number of stages	12 / 10
Cathode sensitivity	$\geq 80\mu A/lm$
Anode sensitivity	$100A/lm$
Operating voltage	$1.8\ kV$
Rise time	$\leq 5ns$

are shown in Table 5. Resistive divider is the presently considered solution for the PM

Table 5: *Laboratory test results of FEU-115M*

QE at WLS fiber emission spectrum	13%
Cathode uniformity over the central area	$\oslash 10mm$ $rms = 5\%$
Linearity at 2% level	$> 50mA$ (100%) $> 100mA$ (50%)
Gain (HV [kV])	5×10^5 (1.8) 10^6 (2.0)

base [6].

[6] Back-up solution is the Cockroft-Walton base, ideologically similar to what is successfully used at

3.2 Calorimeter wall design

Electromagnetic calorimeter wall design is shown in Figure 2 (isometric view), Figure 6 (front view) and Figure 7 (side view). Calorimeter is positioned on two platforms, $+x$ and $-x$, that are movable along x-direction (transverse to the beam axis). The rail guide on the top ensures stability of ECAL. Quality requirements (see Figure 6) to the platform design are:

- local deviations from the plane surface should not exceed 0.5 mm;
- plane surface deviations from the horizontal surface should not exceed 0.5 mm over the platform length.

Modules of each platform are grouped in two-row module structures, by being constricted with the stainless steel tape of 0.25 mm thickness, and then pulled to the frame bar. With special mechanical tooling, each group is stretched to ensure a dense packing, and precisely positioned in x-coordinate. For effective module shape to remain quadrangular, technological spacers in-between modules in each row, will be foreseen. Thus physical module size is 122×122 mm^2. Enlarged drawing of mechanical structure of this tooling is exported to the right in Figure 6. Hatched insert serves as a stop between the modules and the frame bar, ensures a uniform load distribution throughout all the modules, and significantly simplifies tensioning system. Additionally, a pressing plate provides the uniformly distributed load from the top. Such a technique gives (x, y) module positioning with a precision of better than 1 mm. This precision has been achieved with the HERA-B ECAL.

Exception is the 4 module upper columns closest to the center ($x = 0$), that are grouped in double-column structures and suspended to the frame with the stainless steel tapes. This makes possible the replacing of the innermost modules, suffering from the highest radiation dose [7].

HERA-B calorimeter. Compared to the HERA-B solution, the main difference will be considerably reduced z-size by using 2-3 level plate with SMD components.

[7] For details, see [6].

On the left of Figure 6 drawn is a movable pipe scaffold. It allows to access calorimeter modules at different height.

Electronics platform is positioned at the top of calorimeter wall. On each side ($+x$ and $-x$) platform placed are 4 racks of 2.0 m height, carrying the electronics for ECAL and preshower detector. The rack height corresponds to four $9U$ crates interlayered with a fan cooling system.

3.3 Support structure design

Electromagnetic calorimeter is fixed on two ($+x$ and $-x$) main platforms. Platforms are placed on the rails, and can be moved out, in order to allow calorimeter maintenance, and access the beam pipe.

The weight of individual module roughly equals to 30 kG, from which the Pb/Sc stack weights of about 27.5 kG, and the read-out part (PM, resistive divider, etc.) plus housing contribute 2 kG more.

Module structure of each half a platform is pressed from the top with 1.4 *tonnes* load distributed over the surface with the pressing plate.

Electronics platform load will be driven by the calorimeter wall and partially by the side columns. The main platform should be stable against adding of this load in either way.

Thus, the integrated load on each main platform is as much as 51 *tonnes*. The static load distribution is illustrated in Figures 6 and 7.

3.4 Cooling system

Choice of resistive divider as a PM base, assumes high power consumption by the read-out system. For the innermost calorimeter modules power makes up as much as ~ 1 W

per module, and is dissipated inside the closed volume of read-out system. In order to keep the temperature inside the system acceptable, one should replace the single open side of the plastic cover with the aluminium radiator. Read-out system covers are designed to give additional way to the air in-between them (see Figure 3). In addition to that, 0.5 m^3 of air per second will be pumped through the system in a gap between the module covers and hadron calorimeter wall. Conditioning air will be supplied to the region around the beam pipe. For that purpose holes in the steel ribbons of the inner frame are required. The estimates show [8] all the above precautions taken will allow to keep the temperature inside the read-out system not exceeding 20 degrees with respect to the outside temperature. The quoted temperature difference should be proved with the experimental tests.

In the inner – the most power-consuming – section, the space of 41 mm is foreseen for cooling system. The space for cooling in middle and outer sections is equal to 21 mm.

Alternative Cockroft-Walton solution for PM base does not require dedicated cooling system.

3.5 Calibration and monitoring of ECAL

Calibration and monitoring of electromagnetic calorimeter will mainly be based on the data. Nonetheless, in order to "initialize" the calibration and factorize module and electronics contributions, a dedicated calibration signal is foreseen to be delivered directly to PM. In this way calibrated is the read-out chain.

Calibration signal will be initialized either by laser, producing $\sim 10\,ns$ pulses of $\sim 1\,mJ$ each, or by a system of ~ 180 green LEDs, which will be placed on the top of ECAL wall. The initial signal will be distributed at the front side of ECAL with a system of splitters similar to that described in detail in [8]. LED based system will require one-level 1 : 40 signal splitting with ~ 180 splitting units. Thus, one LED serves 4 modules for inner section, 9 modules for middle section, and 32 modules for outer

[8] A factor of 2 safety margin is taken for the estimates.

section. Alternative laser based solution requires 3-level splitting (see [8]), and ~ 160 splitters of 3 different types.

Calibration signal is delivered with the clear optical fibers of $\oslash = 1.0\ mm$ (or more radiation hard quartz fibers) to the front side of module [9]. The light is transmitted from the transport fiber to the clear $\oslash = 1.2\ mm$ fiber, which penetrates each cell at the cell center, via optical connector. Due to the fiber cross section difference, the light loss becomes minimal. The 1.2 mm diameter clear fiber is bundled in front of PM together with WLS fibers.

Optical splitters are fixed at the front side of the calorimeter. In order to provide space for the splitters, optical connectors should be deepened into the covers hiding WLS fiber loops. In addition, deepening optical connectors decreases the probability of transport fibers to be damaged. This makes no problem for the inner section, where no WLS fiber loops is foreseen, and for outer section, where the interfiber distance is large enough (15.25 mm). Dedicated tooling to attach the connector in the middle section modules, also makes the connectors deepening possible.

4 Manufacture of ECAL

4.1 Module construction and assembly

Calorimeter modules will be manufactured basing on the facility in Vladimir, where the HERA-B and PHENIX calorimeter modules have been produced. Accumulated is the wide spectrum of technologies on many plastic species and plastic details production.

After the production is well ongoing as many as 10 modules per day could be produced. Though the production rate is twice lower for small cell size inner modules, their amount of 176 is small, compared to the total number of 3312 modules.

[9] Complicated access and other design considerations make it impossible to deliver calibration signal from the rear side to PM.

Module assembly is illustrated by Figures 8 and 9 for the most complicated case of inner module assembly. It starts from the Pb/Sc stack assembly in the vertical position using well-like tooling (Figure 8a).

Then the assembled stack is pressed with 500 kG force. This procedure is repeated 5 times, which makes possible structure deformations stable, and after that the stainless steel side tapes of 100 μ thickness are welded to the steel matrix plate.

Next WLS and calibration fibers are inserted into the stack structure (Figure 8b). At this stage fibers for outer and middle section modules that are to form a loop, are already prepared with the thermo-technique.

In order to form a fiber bundle, fiber housing is mounted, and fibers are fixed with the tongs (Figure 9a). Flay-cut of fiber ends ensures fibers to be collinear and perpendicular to the cut.

Then mounting of the read-out system follows (Figure 9b). PM is placed in the housing with insertion of 2.5 mm thick steel screen and 3 to 5 layers of 0.05 mm thick permalloy protection [10]. The PM base plate is not shown in the figure. Finally mounted is the module end-cup cover, which guarantees the light isolation. The Al inclusion in the plastic cover improves thermoconduction from the read-out system (section 3.4).

4.2 Quality control

Powerful facility has been developed by ITEP/IHEP/UNIPLAST group [9] to build electromagnetic calorimeters for HERA-B and PHENIX experiments and to control their performance. With some modifications it can efficiently be applied to control the quality of electromagnetic calorimeter module production for LHCb experiment.

The final goal of all the test measurements is to manufacture the calorimeter modules with similar response and designed performance. This implies a detailed control at

[10] The length of this screening is determined by the longitudinal component of the magnetic field. The required screen length and its implementation in the design will be separately studied.

each step of module production, starting from the input control of raw material and up to characteristics studies of the assembled module.

An extensive test procedure has been elaborated to prove the technique, and to monitor material and module performance. The most attention has been paid to

- monitor the scintillator composite and response;
- control module performance.

The idea of all control measurements is to compare the result of measurement to that obtained for the working standard, which performance has been proved by the extensive studies from spectroscopy analysis and up to the beam tests.

The raw material quality control mainly covers the control of polystyrene -based PSM-115 plastic and p-terphenyl . The facility for careful studies of material composition, as well as the "on-line" test program to be used for module mass production, has been established. IR-spectroscopy methods, studies of transparency for blue (420 nm) light with spectrophotometer, gas and liquid chromatography methods and other chemical methods have been developed to control the raw materials quality.

In order to measure the scintillator tile quality, along with transparency measurements with spectrophotometer, a special "hedgehog" test is extensively used. This test implies studies of tile response to the signal induced by the radioactive source. Signal is read out via WLS fibers in ordinary way with PM. The "hedgehog" test allows also to control the quality of tile edge coating.

Control of the assembled module with cosmic particles along with the Pb/Sc stack control, covers the test of fibers, bundle quality etc. Cosmic test of horizontally positioned modules with the same calibrated PM is now proved to be possible for as many as 10 modules per day per one test set-up, so that all the produced modules could be subjected to it. Selected module samples could be tested with electron or MIP beam to measure response, uniformity and energy/spatial resolution. Each module obtains the individual data block with all measurement results.

Detailed description of quality control program could be found in [9].

5 Transportation and acceptance tests

Modules produced and tested at Vladimir, will be packed in wooden boxes and transported to CERN by truck, in a way it was done for HERA-B electromagnetic calorimeter. Then the manufactured modules will be stored at CERN, and subjected to the acceptance tests.

Acceptance test program includes the test with cosmic particles and the beam test of selected modules. The test set-up with cosmic particles is similar to quality control test at Vladimir with trigger organized with the hodoscope planes of scintillator.

6 Detector installation

6.1 Assembly of the calorimeter wall

Main aspects of the assembly procedure had been proven with HERA-B calorimeter. Calorimeter module wall should be assembled on each, $-x$ and $+x$, platform separately in the moved out position. For assembly of the calorimeter wall, two movable pipe scaffolds are needed.

Having quite moderate mass of 30 kg, calorimeter modules can be positioned manually, and do not instantly require dedicated mounting tools. Exceptions for each platform are the innermost region block – inner frame around the beam pipe (see Figure 10), and the ECAL modules around the frame that could have to be replaced after some years of irradiation – and two upper double-column blocks on the top of it.

After the half-wall installation, the pressing plate will be mounted on the top.

An important task is to move both platforms in their working positions. Each platform should be moved to the precisely adjusted position, slowly in tiny steps, so that no hit can happen.

6.2 Access, maintenance and operation

Access possibility for maintenance of the rear (read-out) side of the ECAL wall, is important. The access is possible, when the ECAL or HCAL platform is pulled out. Normally access to the front (monitoring) side of ECAL is not required. Nonetheless it is also possible when the ECAL platform is pulled out.

Special attention is given to the possibility of replacing the 32 innermost modules. This can be realized when the platform is pulled out, and the two movable double-columns of modules are shifted upwards to the one of allowed positions. The double-column structures can be fixed at different height level, to allow operations with the innermost modules.

References

[1] LHCb Collaboration, LHCb Technical Proposal, CERN LHCC 98-4 LHCC/P4 20 February 1998.

[2] HERA-B Collaboration, HERA-B Proposal, DESY-PRC 94/02 May 1994; HERA-B Collaboration, HERA-B Design Report, DESY-PRC 95/01 January 1995.

[3] Bazilevsky A. *et al*, IEEE Transactions on Nuclear Science v.43, No.3 (1996).

[4] J.Badier *et al*, "Shashlik Calorimeter: Beam Test Results", Nucl.Instrum.Meth. A348 (1994) 74-86.

[5] S.Barsuk *et al*, "Fiber density and uniformity of response of LHCb electromagnetic calorimeter", LHCb 2000-034, CALO.

[6] S.Barsuk *et al*, "Radiation damage of LHCb electromagnetic calorimeter", LHCb 2000-033, CALO.

[7] V.Rykalin, "The new version of PMT FEU-115M 10 stage FEU115M10", *presented at* LHCb calorimeter meeting, November 1999.

[8] G.David *et al*, IEEE Transactions on Nuclear Science 45 (1998) 705.

[9] S.Barsuk *et al*, "The facility to control the production of shashlik type electromagnetic calorimeter", LHCb 2000-044, CALO.

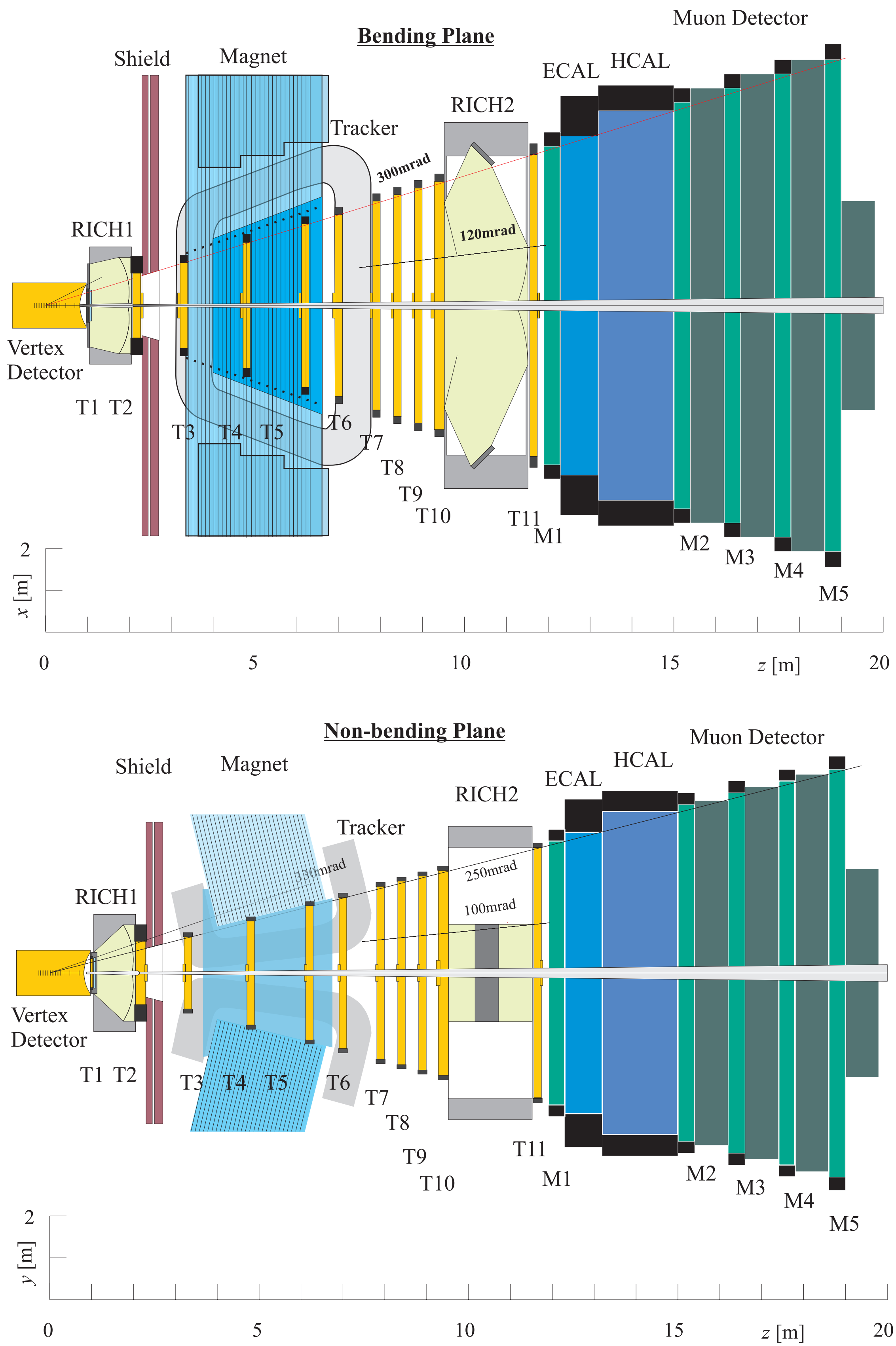

Figure 1: *LHCb detector*

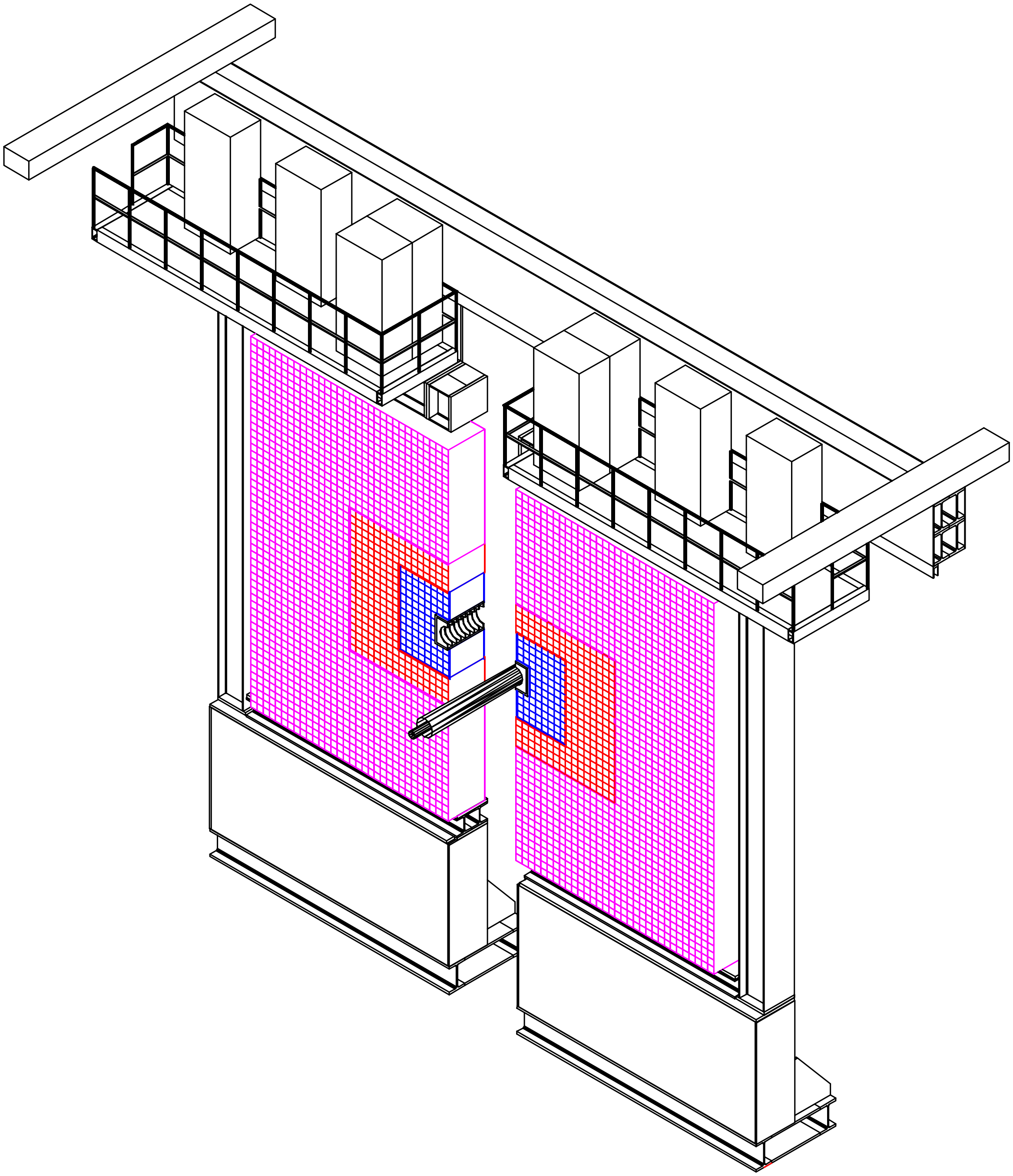

Figure 2: *Electromagnetic calorimeter* 3d*-view from behind of ECAL towards the interaction point. Shown are three sections of calorimeter, ECAL main platforms and electronics platform with the racks on the top of the calorimeter wall. Around the beam pipe drawn is the inner supporting frame. One of two ECAL platforms is partially moved out*

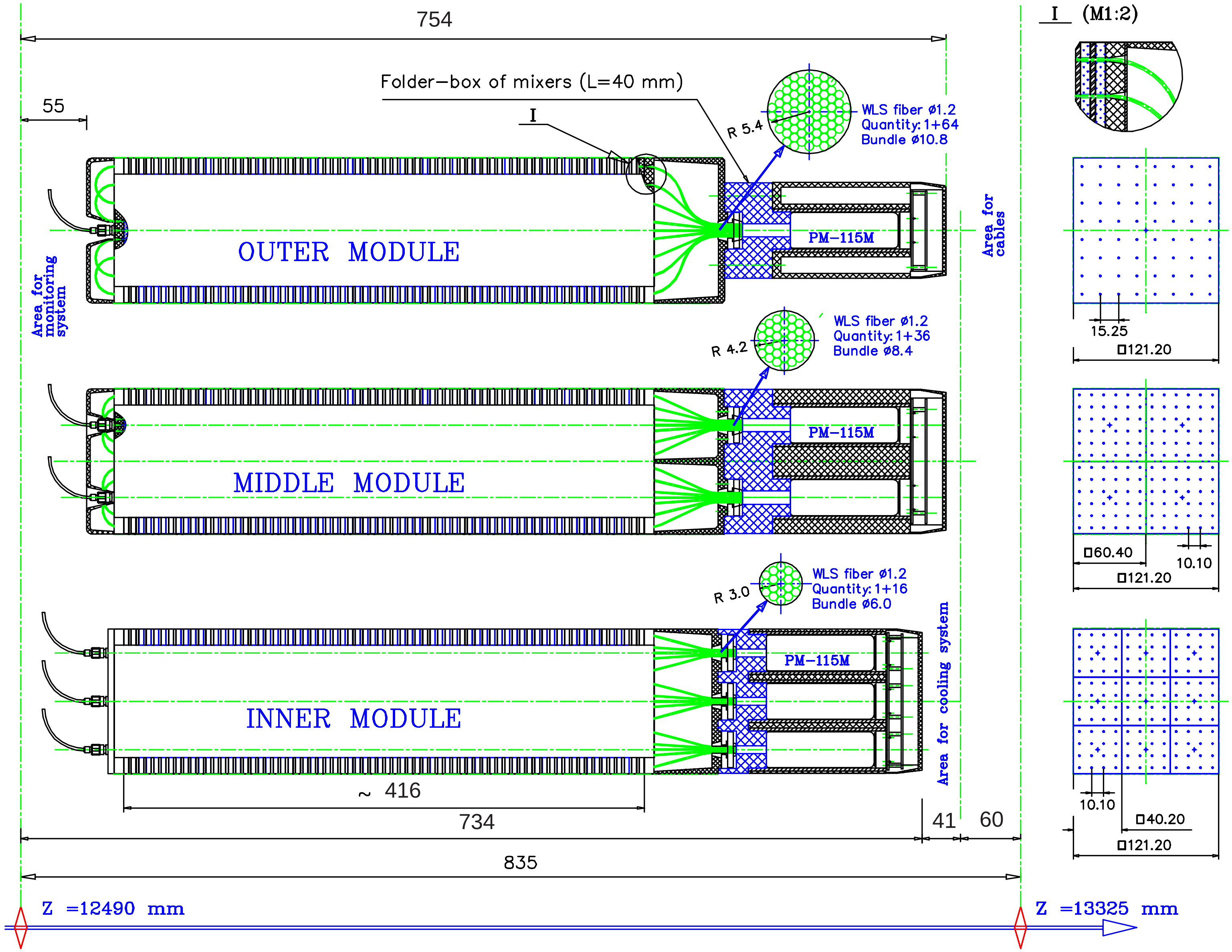

Figure 3: *Electromagnetic calorimeter modules for inner, middle and outer sections. At the monitoring side shown are transport fibers, connectors, fiber loops (if any) and plastic covers. At the read-out side shown are fiber bundles, light mixers, PMs and their bases. $PM - 115M$ is shown as an example of PM. Also shown are area for splitters, space for cooling system and for cabling, and the related mechanics. For more details see the text*

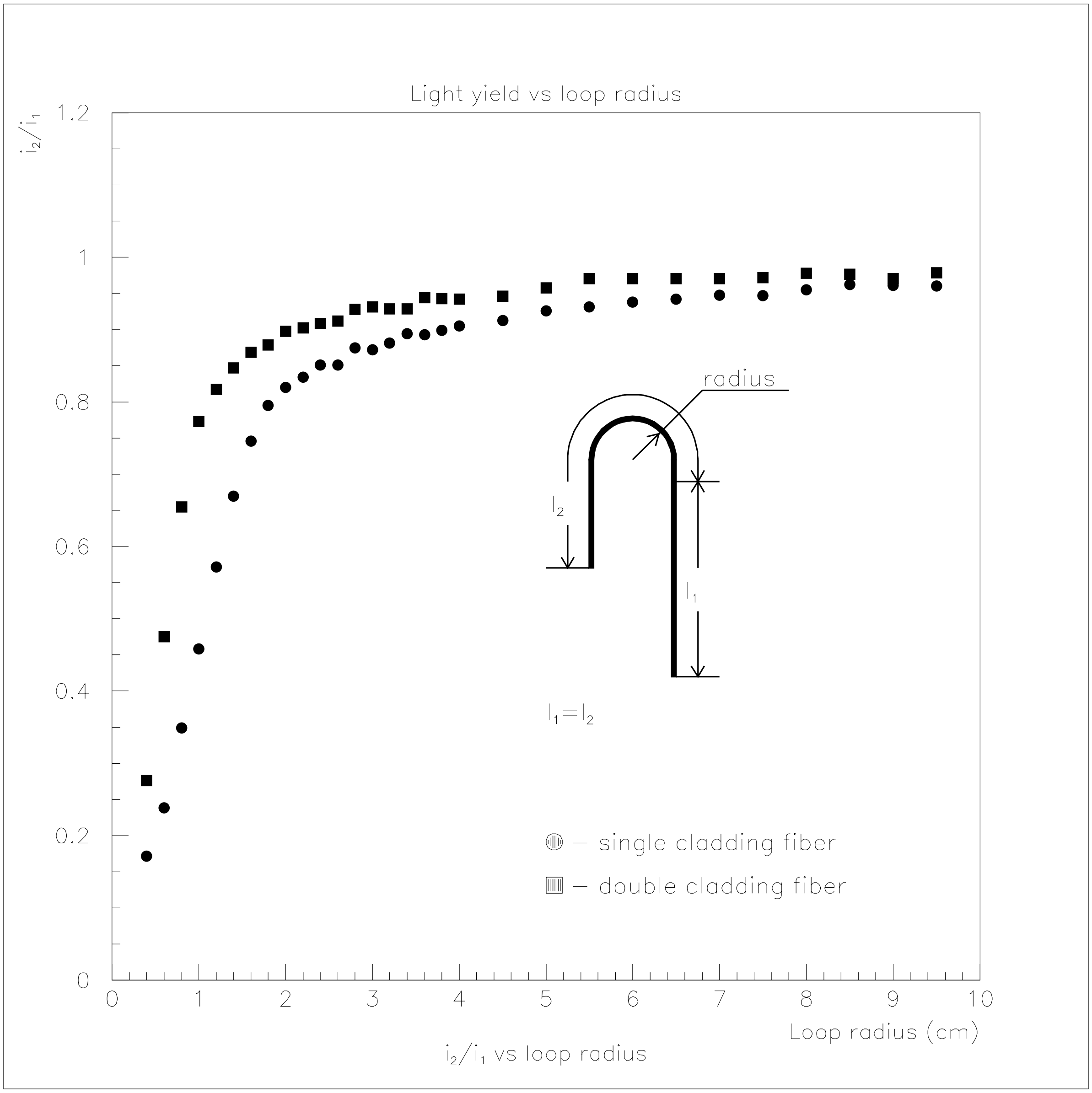

Figure 4: *Light yield efficiency versus fiber bending radius, as simulated with Monte Carlo.* i_1 *and* i_2 *are light intensities from straight and looped ends correspondingly. For more details see the text*

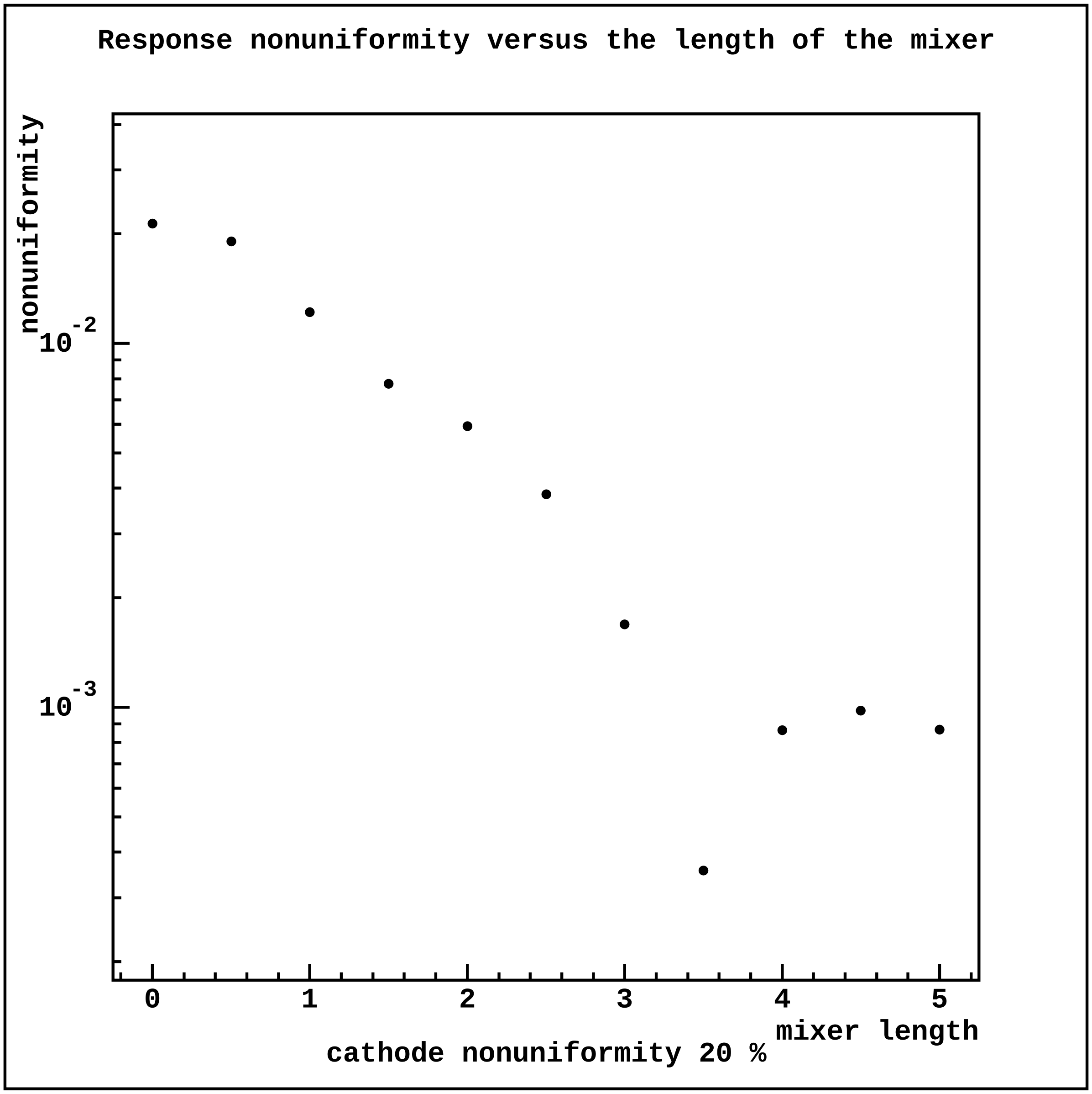

Figure 5: *Monte Carlo simulation results of the quadrangular light mixer. Shown is the non-uniformity of response versus the length of light mixer. The photocathode non-uniformity was taken to be* 20%

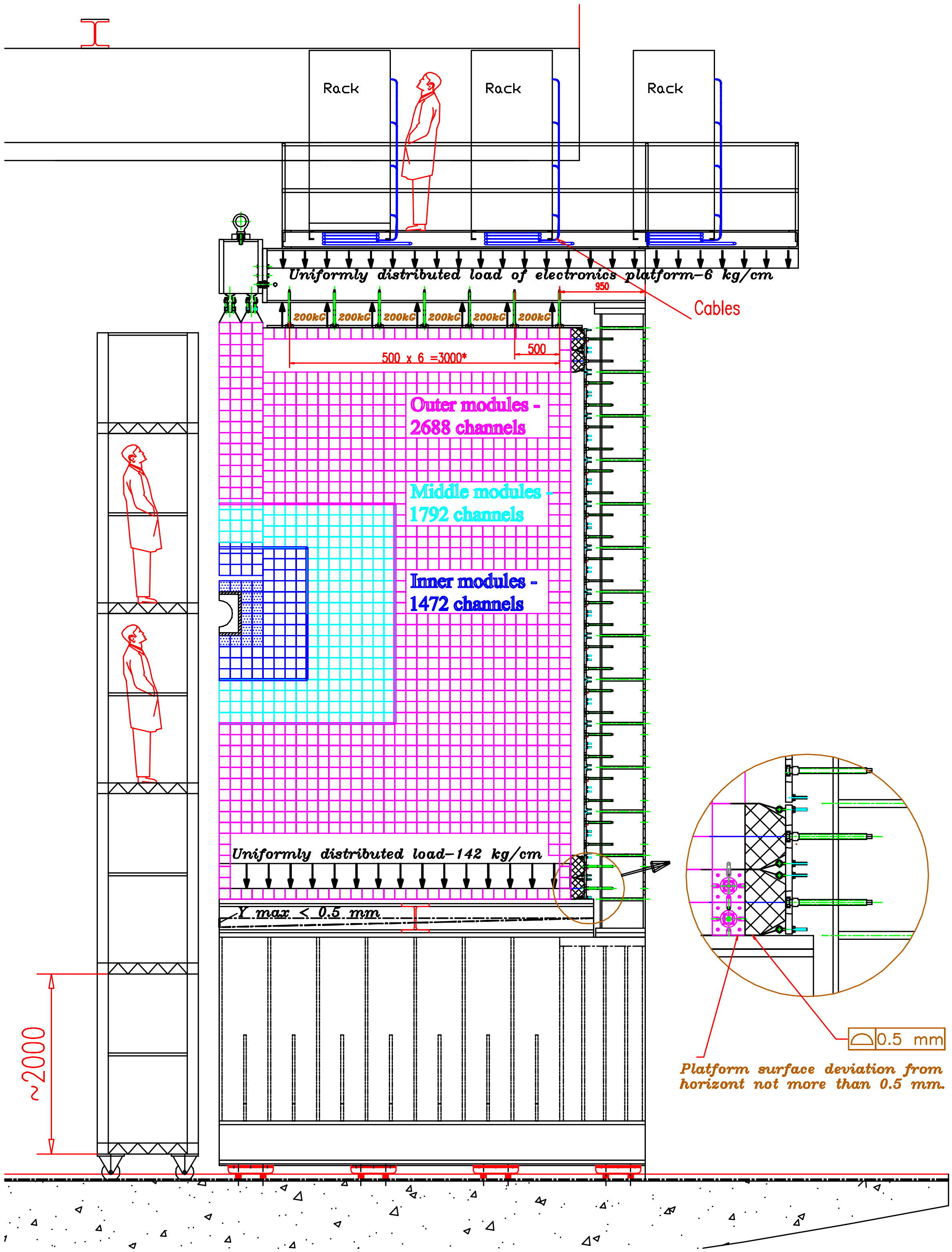

Figure 6: *One of two platforms of electromagnetic calorimeter in moved out position, front view. Shown are the three sections of calorimeter modules, main platform, main and small inner frames, electronics platform on the top of calorimeter wall, and movable pipe scaffold. Exported is the enlarged drawing of mechanics used to tension and precisely position double-row module structures. Arrows indicate the static load. For more details see the text*

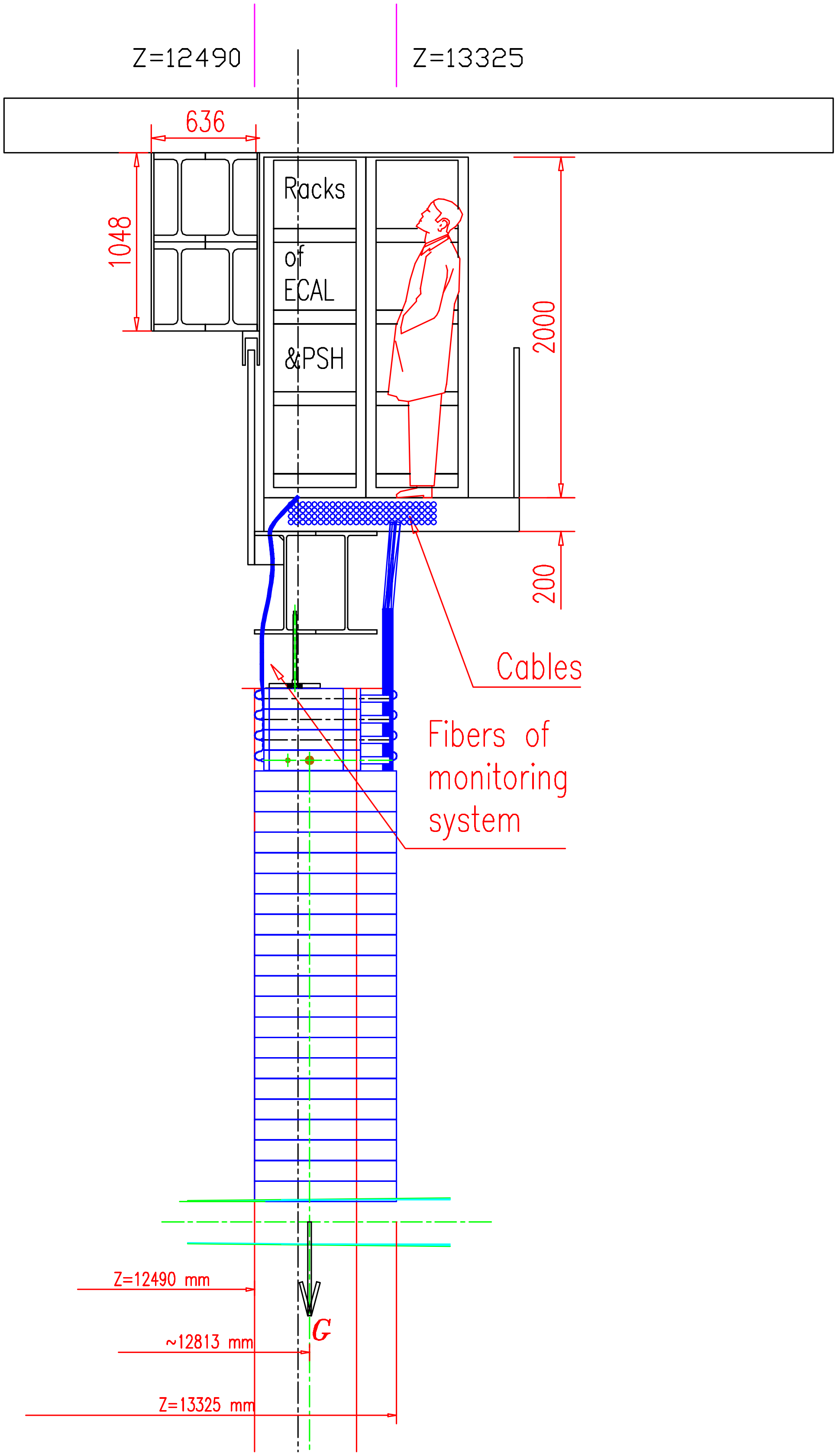

Figure 7: *Electromagnetic calorimeter, side view. Shown are the calorimeter wall, electronics platform on the top of it and the rail guide to ensure platform main platform stability. Arrow indicates the center-of-gravity position. For more details see the text*

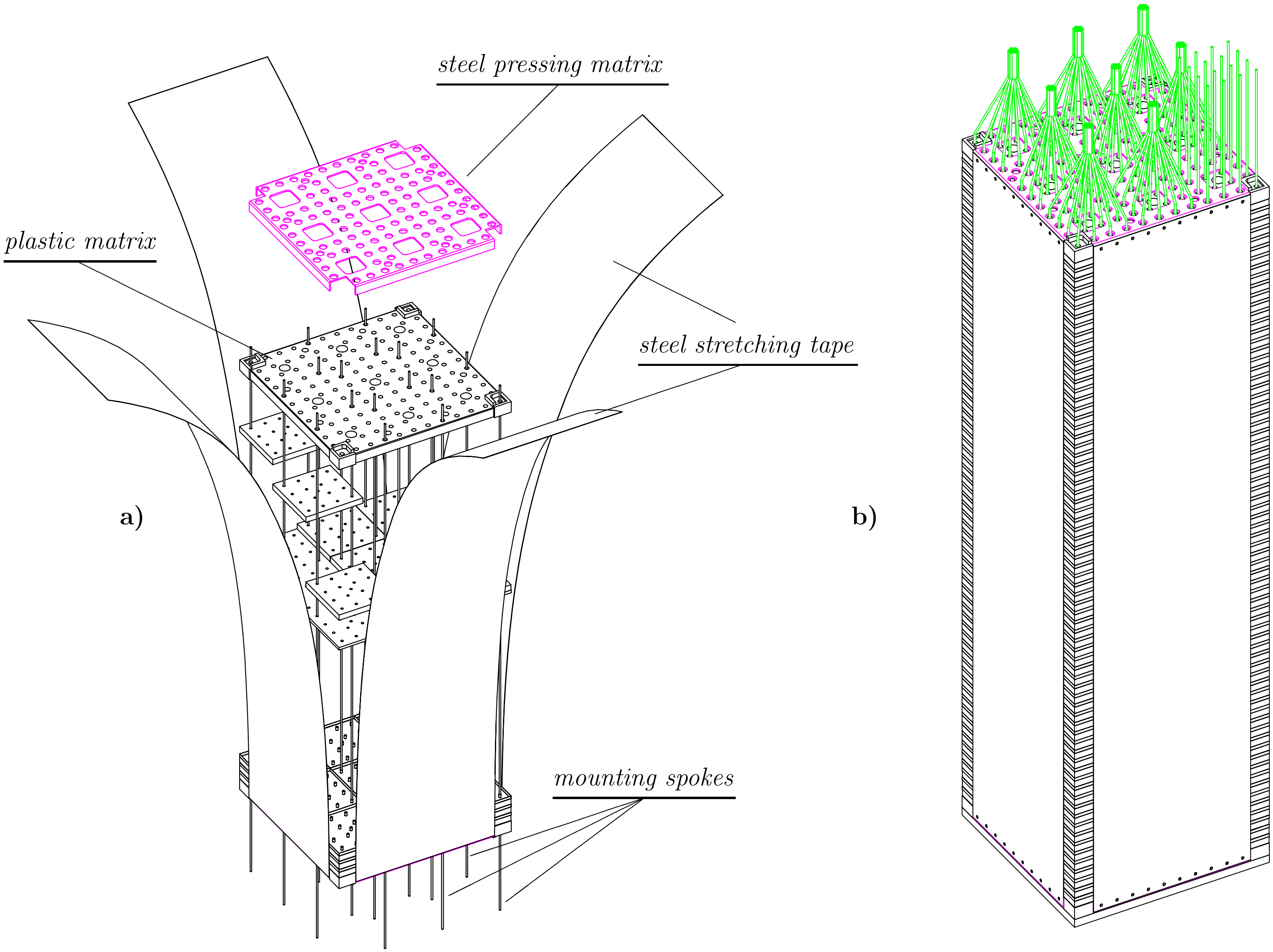

Figure 8: *Assembly of the inner section module. Shown are* **a)** *the Pb/Sc stack during assembly, and* **b)** *the assembled stack with welded tape and inserted fibers. For more details see the text*

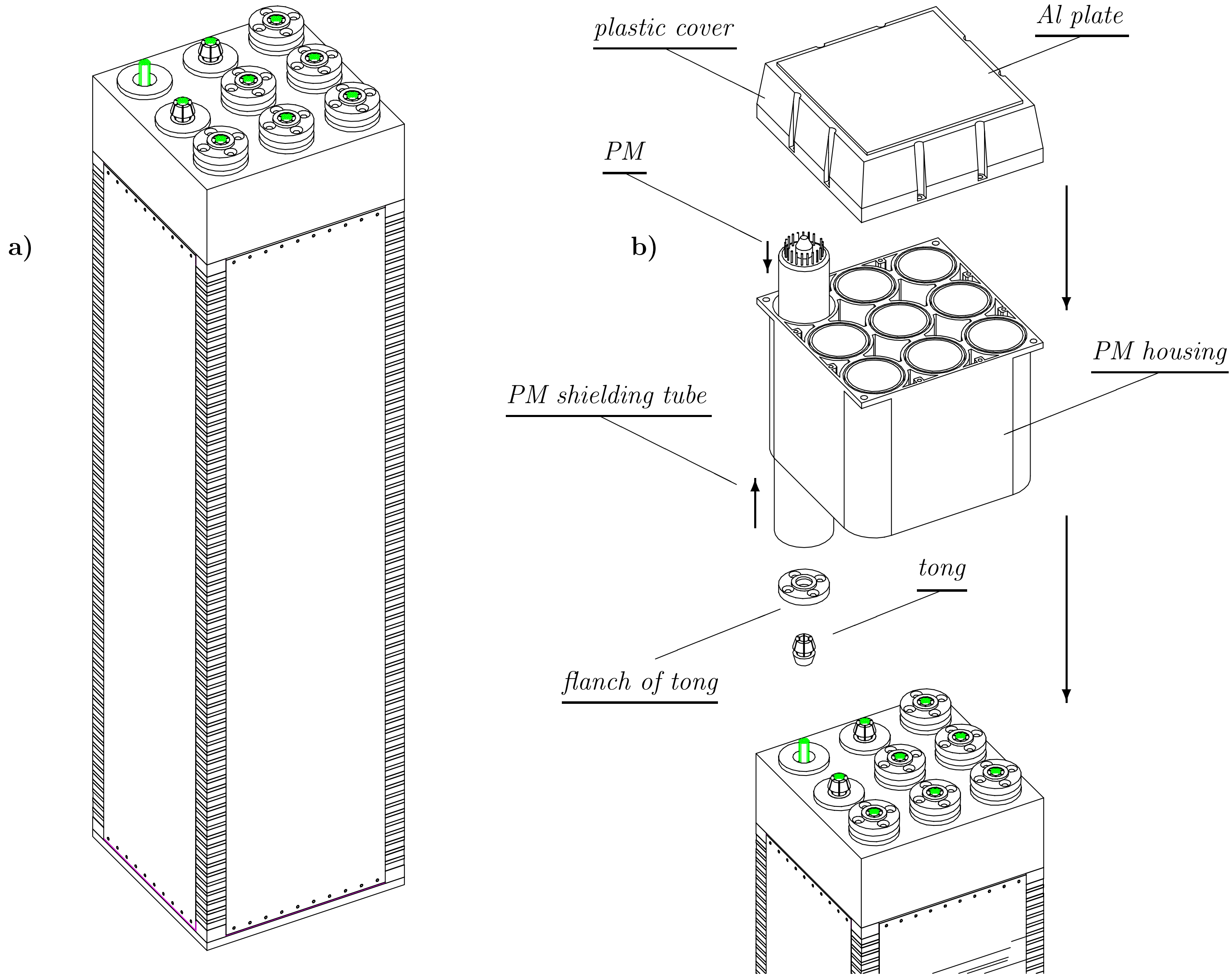

Figure 9: *Assembly of the inner section module. Shown are* **a)** *the assembled stack with 6 from 9 formed fiber bundles, and* **b)** *the read-out part assembly. For more details see the text*

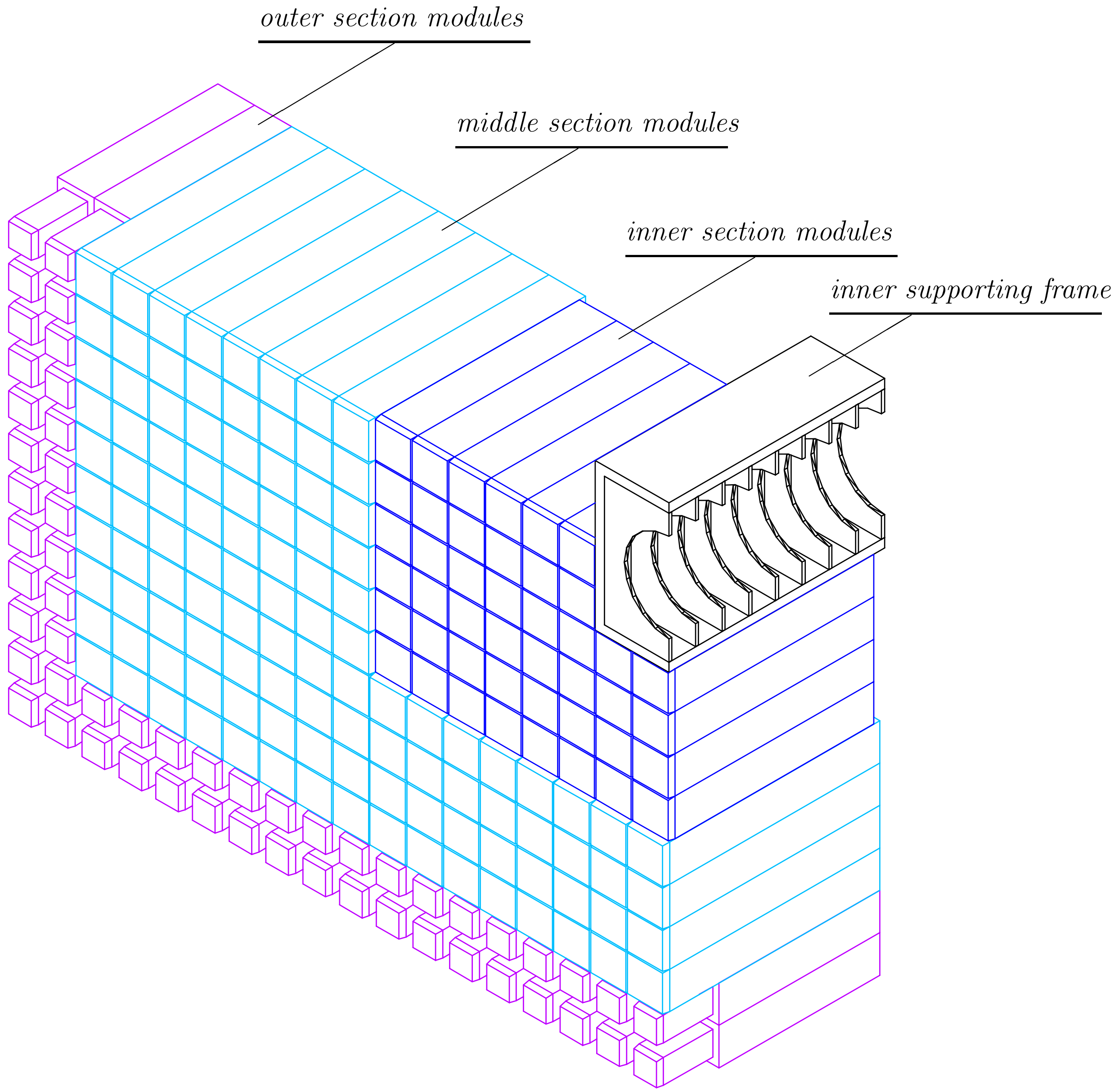

Figure 10: *Inner part fragment of the ECAL quarter. View from behind of ECAL towards the interaction point. Shown are the three section modules and the inner supporting frame*