Report on the Engineering Design Review for the LHCb Scintillator-Pad and Preshower Detector

Present: A.Ereditato (referee), E.Gouchtchine, J.Lefrançois, T.Nakada, A.Schopper, W.Witzeling

1. Introduction

The engineering design of the Scintillator-Pad and Preshower Detector has been successfully reviewed Thursday, March 14, 2002 by an external referee, Antonio Ereditato, INFN/NAPOLI. Based on the supporting note (LHCb 2001-138, CALO, 12/11/2001) a number of questions have been raised concerning details of the design of the scintillator-pads, the fibers, the module boxes, the modules support system, the lead converter and the overall integration of the detector. Many details of the detector dimensions and there tolerances, as well as the manufacturing techniques and the related manpower needs have been discussed. The questions have been answered to the satisfaction of the referee, and are listed together with the answers in section 3. As a matter of fact, a few questions (Q2, Q5) were pointing to delicate issues that will have to be addressed in a critical way in the future calorimeter integration EDR.

2. Overview

The Scintillator-Pad/Preshower Detector consists of a lead converter that is sandwiched between two almost identical planes of rectangular scintillator pads of high granularity with a total of 11904 detection channels. It uses scintillator pad readout by wavelength-shifting fibers that are coupled to 64 channels multi-anode photomultiplier tubes via clear plastic fibers. The sensitive area of the detector is 7.6 m in width and 6.2 m in height. The detector planes are divided into two parts, each of them can slide independently on horizontal rails to the left and right side in order to allow service and maintenance works. The lead converter in between the SPD and PS detector planes has a thickness of ~2 X0 (12 mm), and is not movable. The scintillator thickness is 15 mm. The distance along the beam axis between the centers of the PS and the SPD scintillator planes is 56 mm. The arrangement of cells is a one to one projective correspondence with the Electromagnetic Calorimeter segmentation. Therefore, each PS and SPD plane is subdivided into inner, middle and outer sections with approximately 4x4, 6x6 and 12x12 square cm cell dimensions. The cells are packed in ~48x48 square cm boxes (detector units) that are joined into super modules. Each super module has a width of ~96 cm, a height of ~6.5 m and consists of detector units that form 13 rows and 2 columns. The space reserved for the SPD/PS detector between the first muon chamber and the electromagnetic calorimeter is 180 mm.

A dedicated engineering design review on the overall integration of the calorimeter system and on its support structures is foreseen at a later stage and is not part of this review. However, questions related to these items were also addressed as far as they could affect the design of scintillator pads, the module boxes and the super-modules.

3. Questions and Answers

Q1) Justify the choice of an "immovable" lead converter.

A1) The total weight of Lead is about 8 tons. The rest of the detector adds another 2 tons. The ``mobility" of the converter demands a much more complex and heavy support.

Q2) Does the clearance preshower-M1 and preshower-ECAL quantitatively account for tolerances in the dimensions of the three detectors?

A2) The movable detector parts slide by the rails on the top and in the guide
t the bottom. Therefore the position at the top and the bottom is fixed along Z. The gaps between detector super modules and converter as well as between detector and the ECAL and MU1 is 1 cm. The side of the detector close to the Lead is the bottom of the module boxes, and it is flat and continuous. There are no problems expected here. The other side of the detector looking outside on ECAL and MU1 are the side of fragile cable area. To avoid the possible intervention from neighbors it will be enclosed with thin plastic film. At present, not all the design details of the ECAL and MU1 surface are known.

Q3) Comment on the choice of Aluminum vs. plastic for the box cover material.

A3) Aluminum cover provides better mechanical stability. Al is better for machining. Effects of material budget and cost are negligible.

Q4) How precise must be the screw adjustment of the detector needed to correct for the deformation of the support beam?

A4) The primary deflection of the main support beam under the load of the 8 tons of Lead is expected to be small (<2 mm). The screw adjustment will correct the deformation with a tolerance of better than 0.5 mm.

Q5) How often the two detector halves are expected to move apart and how well the nominal relative position can be reproduced? Do you expect interference with other detectors?

A5) With the current design the estimation of time necessary to move the detector in/out of the position of operation is a few hours. Our goal for the relative SPD vs. PS position precision is 1 mm. A position measurement device will exist to check the position after opening and closing. The grand service/reparation can be done during the main yearly shutdown. For small interventions on the detector, a 1-2 day access seems sufficient.
It is difficult now to make a precise estimation of the interference with other detectors. This needs more work on whole LHCb detector integration. Presumably, some service work on electronics can be done with detector at the operation position.

Q6) You correctly aim at reducing the total detector weight (support structure). What are your realistic goal and the proposed strategy?

A6) The super-module support structure has about 3% of X0, that is comparable with the material budget of scintillator pads themselves (4%). Further reduction of material is not essential and mechanical stability and tolerance of the support should have a preference.

Q7) Where will scintillator pads be eventually produced and according to what schedule?

A7) It will be defined. Basic option considered is ISC,Kharkov. The full production schedule can be within 12 months.

Q8) What is the experimental probability of making cracks (even micro-cracks) in bending the fibers? Is it acceptable?

A8) Our experimental experience in bending the fibers is based on the manufacturing of about hundred pads and shows no evidence of cracks. We did not study in details the experimental probability of cracks in bent fibers considering it to be small. Here we can also refer to the experience of other groups. The mechanical stability of bent fibers was studied by K.Hara et al. (NIMA v.411, 1998, p.31). Their results with clear fibers (S-40 type, 0.8 mm diameter, KURARAY) show a substantial durability over 1 cm bending radius. In the case of PS/SPD the fiber diameter is 1 mm and the minimal bending radius is 1.8 cm, that can be considered as conditions with smaller bending stress. Moreover, we choose the S-type (S-70) for PS/SPD for even better mechanical properties, than S-40 type. In addition, the manufacturer (KURARAY) proposes us recently developed J-type, which is an S-type with improved transparency and aging properties. We can also refer to the similar experience in LHCb ECAL, where the selection criteria is a loss of transparency smaller than 5% with 1.2 mm diameter fiber bent at 5.5 cm diameter, that is close to our requirements.

Q9) Can you give more details on the design of the machine for fiber winding and gluing, and on its operation?

A9) See description of the machine design, drawings and photos (Appendix 1).

Q10) What is the adopted scheme for LED monitoring? It has certainly impact on the module technical design and construction.

A10) The present idea is to control all the optical connection from the pad to the PMT. For this purpose, each pad will be equipped with an individual LED. The blue LED will be glued at the middle of the pad inside the plastic holder. The LED is connected with a 1 mm diameter and 1-3 m long coaxial cable to the LED driver situated on the site of PMTs. The prototype of LED monitoring system was successfully tested last summer.

Q11) What is the required tolerance on the CFRE wall thickness? Is it actually achieved?

A11) The CFRE is now to be replaced with Fiberglas for better mechanical tolerance under possible temperature variation (mainly during transportation). The tolerance of outer dimension of the box is defined by manufacturing technique and depends on the mold tolerance (+- 0.2 mm). The thickness of the wall is 0.35+-0.03mm. Therefore, the tolerance on the wall thickness is not a critical parameter.

Q12) Are you still considering the possibility of clear fibers spliced to WLS fibers inside the boxes?

A12) No, we are not.

Q13) Comment on the (important!) quality control tests on pads after fiber gluing. How will the test proceed and with what manpower?

A13) The goal is to have a simple, reliable and fast procedure to control the quality of fiber gluing into the pad. The use of a collimated radioactive source is more time consuming than using a blue LED. The light signal from the LED will be measured in a few (5) predefined positions over the pad as a response from PMT connected to the fiber ends. It will be compared with one of the reference tile pre-calibrated with a radioactive source. The facility includes a light tight box with four LEDs mounted on four sides and one LED in the center. The PMT operates in a charge integration mode. The estimated manpower is one person working synchronously with fiber gluing. In total 2 man*years.

Q14) What are the advantages and disadvantages of the three variants for PMT layout. When will you decide upon?

A14) The choice should be based on the final dimension of the electronic PCB taking into account cooling and magnetic field shielding, at the end of 2002. The choice of layout does not affect the module or support design.

Q15) Is your actual experience reassuring about the 0.1 mm tolerance on the thickness of the lead converter all over its surface?

A15) We have a statement from the firm offering such product.

Q16) How precisely you have to synchronize the different detector channels? Is that precision achievable with the envisaged LED system?

A16) We expect the necessary synchronization precision of 1 nsec to be achievable. The signal is integrated over 25ns, and ~15% of a sample is subtracted digitally from the following one. With a 1 nsec shift in integration time this fraction changes by less than 2%.

Q17) How labor intense and reliable is the cell wrapping procedure?

A17) As the TYVEK paper will be preliminary cut into the pad dimension, the wrapping procedure itself will take about 5 minute/pad.

Q18) Do you have experience with prototypes of the inner detector parts?

A18) In 2000 we have built and tested two prototypes of modules with 3x3 matrix of pads of the inner detector region. We also tested the assembly procedure and fibers layout in the inner module with special full size module prototype with pads made of conventional plastic. The result of this test validates the layout of fibers shown on Fig.4 in the note on the design and construction of module-0.

Q19) Is the present quality of the optical connectors adequate in relation to the required mechanical tolerances?

A19) The improved version of connectors is expected to come up in this month.
We consider that the fiber holes' matching is to be better than 0.04 mm (<5% of light loss).

Q20) The mechanical properties of the fibers and of the other materials can be affected by radiation. Are the presently available data reassuring?

A20) The only irradiation test was done in October 2001. There were 4 inner pads and 4 outer pads irradiated to 100 krad with 24 GeV protons. The mechanical properties were observed not to change considerably (there was no evidence of visible cracks).

Q21) A general comment: you should provide a scheme of the required installation phases and show that it is compatible with the available resources and with the general experiment schedule, also taking into account safety margins for unexpected failures.

A21) See the manpower estimation for QC, fiber gluing, module assembly in Appendix 2.

Appendix 1

WLS Fibre/Scintillator Pad Gluing Machine
==

Design and Operation.
----

1. The Fibre Gluing Machine (FGM) places WLS fibre into the ring groove milled in the scintillator pad and uniformly injects the optical glue (BC-600 "BICRON") inside the groove over the fibre.
The cross-section of the groove has dimensions of 4.5 mm in depth and 1.05 mm in width. The bottom of the groove has a semi-round shape fitting the fibre.
In total there will be 3.5 loops of WLS fibre placed inside the groove.

Table 1.

Region	SPD cell (mm)	PRS cell (mm)	Groove dia (mm)	Total number
Outer	39.66	39.84	37.0	2944
Middle	59.50	59.76	56.0	3584
Inner	119.00	119.50	110.0	5376

2. The FGM consists of 4 functional modules: a glue dispenser, rotating table, fibre packer (three sizes) and a control block operating the stepper motors.
3. The FGM is push-button operated by one technician.

* The glue is prepared for the batch of 10-20 pads, depending on the pad size.
* Each scintillator pad from a batch is fixed on the individual round plate
* Then the plate with the pad is installed on the rotating table.
* The syringe is put down to the bottom of the groove
* First rotation of the table is to cover the bottom of the groove by the first portion of the glue
* Stop.
* Insert the fibre in the groove for 1/4 of cycle and fix the fibre end on the plate clamp. Put down the wheel of the fibre packer on the fibre.
* Rotate the table for next 3.25 cycles packing the fibre into the groove and glue feeding
* Stop.
* Lift up the syringe.
* Clamp the second fibre end and lift up the fibre packer.
* Take away the plate with the pad

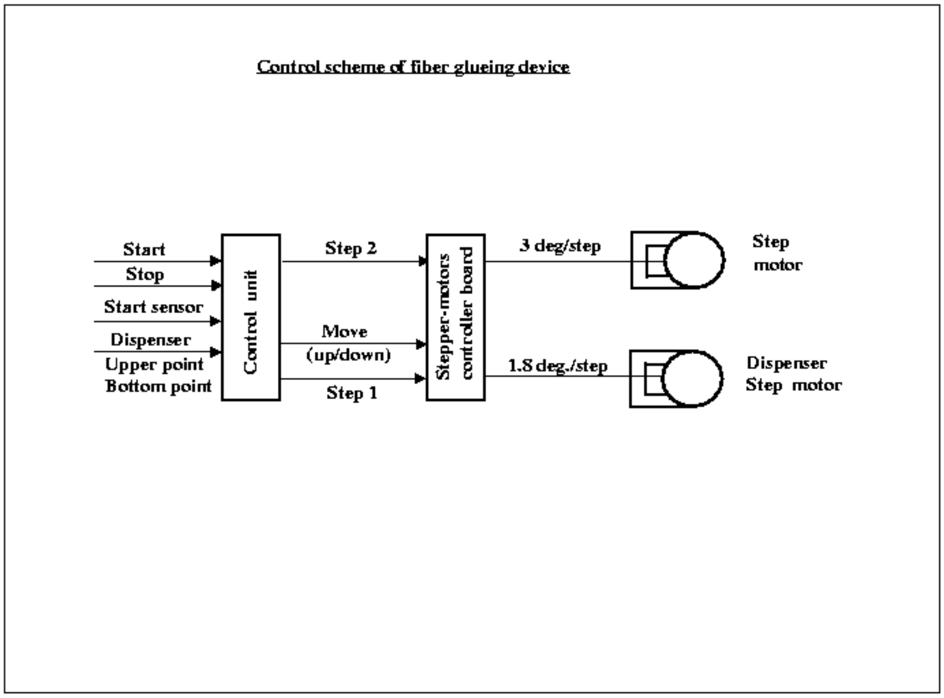
4. Glue expense is 0.11-0.32 cm^3 per pad. One syringe is sufficient for 10-20 pads, depending on the pad size.

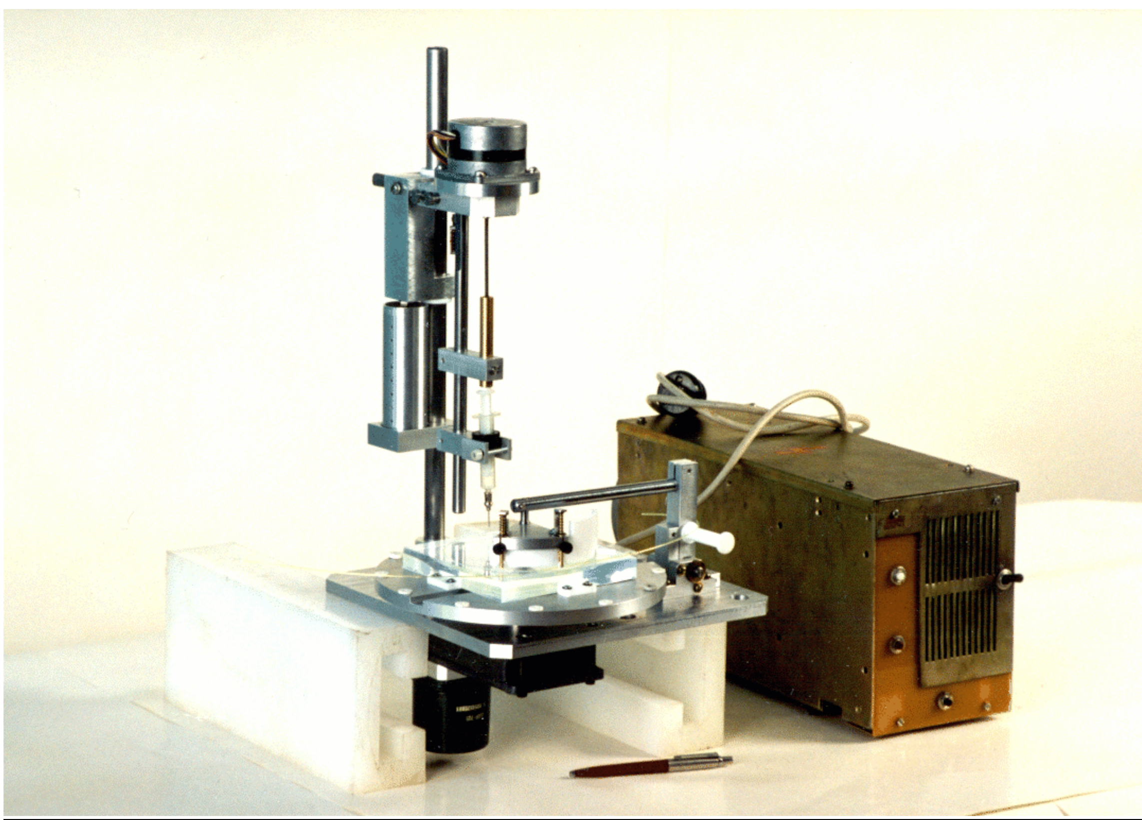
Time for gluing is about 2 hours/20 pads.
5. The glue dispenser and table stepper motors must run in the synchronous mode because of the speed of glue feeding is directly connected with the speed of the table rotation.
The motor steps chosen are 1.8 deg/step for the glue dispenser and 3 deg/step for the table motor.
The scheme for the motors control is shown on a scheme on the Fig.1.
The control groups of step pulses are produced by an electronic control unit. The control signals for the stepper motors are "STEP1" and "UP/DOWN" for the glue dispenser and "STEP2" for the rotation of the table.
The 3 modes of the gluing processing corresponding to the groove diameter are shown in the Table 2.

Table 2.

Groove D(mm)	ND	Nt/ND	L(mm)
37	0.77	38.8	1.4
56	1.18	25.5	2.1
110	2.32	12.9	4.1

ND - glue dispenser rotation number per one table rotation
Nt - rotation frequency of the table stepper motor
Nd - rotation frequency of the dispenser stepper motor
L - glue expence for one pad (the diameter of the syringe is 10 mm)


Control scheme of fiber glueing device
Start
Stop
Start sensor
Dispenser
Upper point
Bottom point
Control unit
Step 2
Move
(up/down)
Step 1
Stepper-motors controller board
3 deg/step
1.8 deg./step
Step motor
Dispenser Step motor



Appendix 2

Optical cables processing

Op. N.	Operations for one cable (four optical connectors, one PM coupler)	Time (min)
1	Cut fibers and move to the working area (128 fibers up to 2.6 m)	64
2	**QC:** Visual inspection of fibers	32
3	Wipe the fibers with the water-spirit mixture	40
4	Insert fibers into light-tight black pipes	40
5	Insert fiber ends into the holes of PM coupler	60
6	Insert fiber ends into the proper holes of light connectors	60
7	**QC:** Check fibers layout with light source	30
8	Glue preparation	15
9	Glueing fibers into the PM coupler	20
10	Glueing fibers into the connectors	20
11	Cutting and polishing machine (CPM) maintenance	20
12	Mount connectors on CPM	15
13	Process connectors	10
14	Mount PM coupler on CPM	15
15	Process coupler	10
16	**QC:** check connectors' and coupler' surface quality with microscope	30
17	**QC:**check light transmission through the cable with light source	20
18	Maintenance of CPM	30
	Time (hrs):	**8.85**

LEDs and LED cables preparation

Op. N.	Operations for one cable (16 tles)	Time (min)
1	Prepare cables	32
2	Soldering of LED connectors	32
3	Soldering of multipin connetor	16
4	Prepare LEDs	16
5	Soldering of LEDs	16
	Time (hrs):	**1.87**

Tiles processing preparation

Op. N.	Operations for 16 tiles	Time (min)
1	Cut fibers and move to the working area	30
2	**QC**: Visual inspection of fibers	30
3	Wipe the fibers with the water-spirit mixture	15
4	Unpack scintillator tiles and move to the working area	15
5	**QC**: Visual inspection of tiles	15
6	Wipe the grooves of tiles with the water-spirit mixture	20
	Time (hrs):	**2.08**

Tiles processing

Op. N.	Operations for 16 tiles	Time (min)
1	Mounting all tiles onto individual cradles	10
2	Glue preparation	20
	a. weighting the resin and the hardener	
	b. mixing and vacuumization	
	c. filling the syringe with the glue	
	d. mount the syringe to the gluing machine	
3	Mount the cradle with a tile on the turn-table of the gluing machine (GM)	15
4	Put down the syringe	5
5	Make one rotation of the GM and fill the groove up with the glue	15
6	Insert the fiber in the groove on • of ring and clamp one fiber on the plate	15
7	Working motion - 3• rotation of the turn-table with glue feeding.	30
8	Lift up the syringe	5
9	Clamp the second fiber end on the plate and lift up the fiber packer	20
10	Take away the cradle with the tile.	10
11	Move tiles out for glue hardening	10
11	Maintenance of GM	60
	Time (hrs):	**3.58**

Op. N.	QC for 16 tiles (24 hours after)	Time (min)
1	Mount tile in the light tight box	15
2	Insert fiber' ends into optical connector	30
3	Measure light response with LEDs (5 points x 16 tiles)	240
4	Take away fibers from optical connectors and get tile back from the box	15
5	Maintenance of test facility	30
	Time (hrs):	**5.50**

BOX ASSEMBLING

Op. N.	Operations for buch of 16 tiles (G16)	Time (min)
1	Wrap scintillator tiles with TYVEK	32
2	Glue LEDs on each tile	32
3	Mark ends of fibers	15
4	Place the tiles into the box	20
5	Distribute the fibers inside of box and make a bundle	10
6	Connect LED cables	20
7	Insert fibers into light-tight black pipes	3
8	Insert fiber ends into the proper holes of light connector	15
9	**QC**: Check fibers layout with light source	30
10	Assemble the outlet port with fibers' bundle and LEDs' cables	15
11	Close the box with the cover and fix ports on it	5
12	Install the box and fix connectors for the glueing	5
13	Preparation of the glue	15
14	Glueing fibers into the connectors	10
15	Mount the bunch on cutting and polishing machine	10
16	Process connector	10
17	Remove the bunch from cutting and polishing machine	5
18	Maintenance of the cutting and polishing machine	10
	Total (hrs):	**4.37**

Op. N.	QC for modules (per 16 tiles)	Time (min)
1	Mount box on stand	10
2	Connect optical cable to PM	5
3	Measure light response with radioactive source	160
4	Remove fibers from optical connectors and get tile back from the box	5
5	Maintenance of test facility	30
	Time (hrs):	**3.50**

Total time per 16 tiles (hrs): 23.11

SPD+PRS	Boxes	Spare boxes	G16	Hours	Days	Months
Outer section	336	10	346	7997	1000	41.7
Middle section	56	10	264	6102	763	31.8
Inner section	21	10	279	6448	806	33.6
Totals*:	**413.00**	**30.00**	**889**	**20547**	**2568**	**107.0**

***Spoilage in production is not included.**

Start	End	Duration (m)	W. days	% of boxes	Outer	Middle	Inner	G16	Rate/day
Apr-02	Sep-02	6	144	9.5	42			42	0.29
Oct-02	Dec-02	3	72	24.8	110			110	1.53
Jan-03	May-03	5	120	43.8	194			194	1.62
Jun-03	Dec-03	7	168	14.9		66		264	1.57
Jan-04	Jun-04	6	147	7.0			31	279	1.90
Totals:		27	651	100.0				889