Note on the preliminary organisation for the design, fabrication and test of a prototype double-sided ladder equipped with MAPS

J.Baudot[a], J.Goldstein[b], A.Nomerotski[c], M.Winter[a]

[a] IPHC - Université de Strasbourg,
[b] University of Bristol,
[c] University of Oxford

updated 2009, June 11
updated 2009, May 18
updated 2009, March 9
created 2009, February 21

Contents

1 Introduction

This document describes a project initiated by several laboratories (Bristol, Oxford, Strasbourg) aiming to design, fabricate and test a demonstrator ladder featuring minimal material budget and equipped with CMOS sensors on its both sides. Though we shall give some details on the short and long-term goals and on the task list, the document is mainly a internal note for self-organisation for the team starting the job in the first semester of 2009.

We propose to give the following acronym to the project:

- **PLUME**: a Pixel Ladder with Ultra-low Material budgEt, (with a possible extension iPLUME for Ilc-Plume or double-sIded-PLUME).

The identified participants as today are listed below.

- Bristol University,
- DESY Hamburg,
- IPHC Strasbourg,
- Oxford University,

DESY has agreed recently to join the project. It will investigate temperature and power cycling effects. The following institutes are potential partners

- IKF & Goethe University of Frankfurt,
- FNAL Chicago,
- IRFU Saclay.

The CBM group from IKF and Goethe University in Frankfurt, though pursuing its own goal (a ladder demonstrator for CBM), is contributing to the project by providing essential elements (flex, proximity board) and exchanging information.

1.1 Goals

The 2-3 years goal is to obtain a prototype ladder equipped with CMOS pixel sensors, matching reasonably well the ILC requirements for the vertex detector. Though the sensors themselves may not reach all the desired specifications, the geometry, stiffness, material budget and thermal properties of the ladder should be addressed aggressively. A factor of at most two, in the performances reached with respect to those expected, would be acceptable. Additionally, this ladder has to carry sensors on its two sides (double-sided or double-layer ladder).

A shorter term and first goal for the project is to demonstrate the feasibility and estimate the performance improvement for tracking with a double-sided ladder. Hence, this document is divided in two parts; the first one is devoted to the final ladder while the second one to the so-called "first ladder'.'

1.2 Communication

This document and other information on the project are available on the web page `http://iphc.cnrs.fr/plume.html`. We intend to use the EDMS system as the central document repository. Consult the above mentioned page for updates and links to EDMS (minutes of meetings, notes & reports, talks...).

2 Final ladder

2.1 Specifications

Our design is based on the ILC requirements for double-layer ladders [?], among which the most prominent figure is the material budget of 0.16 %. A list of other specifications for one ladder follows:

- the single point resolution of individual sensors is expected to be slightly 3 μm, double-layer ladder provide an additional pointing accuracy which have to be estimated,
- active ladder width is 10 mm,
- active ladder length is 125 mm (considering that butting two ladders produce the 250 mm length), so the ladder have to support 6 sensors of about 200 mm length each,
- inactive area (for instance between two adjacent sensors) should be as low as possible,
- sensor thickness is 50 μm,
- one ended double-sided readout with only one cable outgoing from the ladder to the servicing board,
- compliance with passive cooling (individual sensors are expected to dissipate power below 200 mW/cm^2),
- compliance with power cycling in a 3 T magnetic field,
- the mechanical stability should allow to benefit without degradation from the sensor single point resolution ($\lesssim 3$ μm),
- the relative initial mechanical position of the sensors on the ladder should be known to a precision which allow an efficient alignment.

A basic hypothesis is that the CMOS sensors vertex detector at ILC will operate in a power cycling mode and at room temperature so that air flow cooling should be enough. Hence we always assume the sensor to be on top of all elements of a ladder.

For this final ladder, we foresee to demonstrate the compliance to all these requirements with experimental tests in the expected operational conditions including power-cycling mode in a strong (4 T) magnetic field and air cooling. They should include beam tests to evaluate the pointing accuracy. These tests should also be complemented by mechanical stress simulations.

2.2 Notes on timing

The goal is to reach a functional ladder by 2012. The detailed design has to wait for the results of the first ladder concept trial. Nevertheless, two key elements require considerable time for design and fabrication:

- the flex on which the sensors are connected,
- the ladder structure wich supports directly the flex with the sensors.

The design phase and identification of potential provider could start in 2009 before knowing the output of the first ladder trial, so as to make these elements available in 2010 whenever needed.

2.3 Guidelines for the design

We do not know which sensor will be used for the final ladder. However this "final" sensor will look like the current MIMOSA-26 sensor [2, 3] which provide zero-suppressed data in digital format for a 576×1152 pixel matrix. The pixel area is 18.4×18.4 μm^2 and the whole sensor dimensions are 13.7×21.5 mm^2.

For the flex design, the main input parameter is the number of signal lines it should convey. We base our estimate on the number of signals required to operate the MIMOSA-26 chip which are listed in table 1.

signal description	**# pads per line**	**# lines**	**shared with other sensors**	**current**	**frequency**
Analogue power & ground	25	2	yes	180 mA	
Digital power & ground	35	2	yes	60 mA	
Data outputs	1	8°	no	-	80 MHz
Digital controller (JTAG)	1	5	yes	-	100 kHz
Digital controls	1	1	yes	-	-
Analog controls	5	1	no	2.2 mA	-
Clock	1	2	yes	-	80* MHz
Temperature sensor	1	1	no	-	-
TOTAL	**142+**	**22**	**12**		

Table 1: Detail of the signals and the corresponding pads for the MIMOSA-26 sensor.

° Future version will only need two lines for the data output.

*The sensor maximal frequency is 100 MHz.

+The sensor features in fact 240 pads, the difference is due to test pads.

3 First ladder (2009 goal)

The first ladder should demonstrate that a low material budget ladder, equipped on both sides, can provide the adequate resolution on the track parameters for a particle crossing the two sensors. Other constraints are not addressed at this stage, like the thermal dissipation...nevertheless every feature of the first design matching or nearing the final expectation is welcome.
It is expected that two ladders will be assembled with at least one fully functional. For this first trial, tests will be conducted after each of the process steps, if possible. The latter requires that electrical and data acquisition test facility shall be available to several participants.
The final test of the ladder will occur in beam tests at the CERN-SPS. The IPHC group will provide the telescope setup (TAPI [4]), for reconstructing reference tracks, and the data acquisition system. Data will naturally be shared among participants, the IPHC group can provide an analysis framework.

3.1 Initial concept

The initial concept is based on an existing large size sensor, MIMOSA-20 [5], having an area of 1×2 cm^2. The chips will be thinned down to 50 μm.
Flex cables developed for the CBM ladder demonstrator by IK-Frankfurt are also readily available. This re-use of an existing flex avoids the time-consuming design and fabrication of a specific one in 2009. The flex cable is a 300 μm thick polyimide slab with several metal (copper) layers which allow for the side by side connection of 2 sensors of the MIMOSA 20 type.
The mechanical structure which supports the two flex, on each side, is expected to be the silicon carbide (SiC) foam (8% density to be confirmed) already experienced by the LCFI collaboration.
Finally, concerning the front-end board servicing the sensors, again, due to time constraints, the re-use of the PCB developed for CBM is under consideration.

Picture 1 sketches a possible arrangement of the different parts within an aluminium frame which holds the whole ladder and can be easily handle and positioned in the telescope setup. Fixtures and connections have to be understood as follows:

- sensors are glued on flex,
- flexes are glued on silicon carbide foam,
- SiC foam is glued at both ends on aluminium frame,
- PCBs are screwed on aluminium frame,
- sensor-flex are connected to PCB-flex through a ZIF connector,
- PCBs are connected to the data acquisition system through a 50-pins flat cable containing all the lines (analog signals, powers, controls).

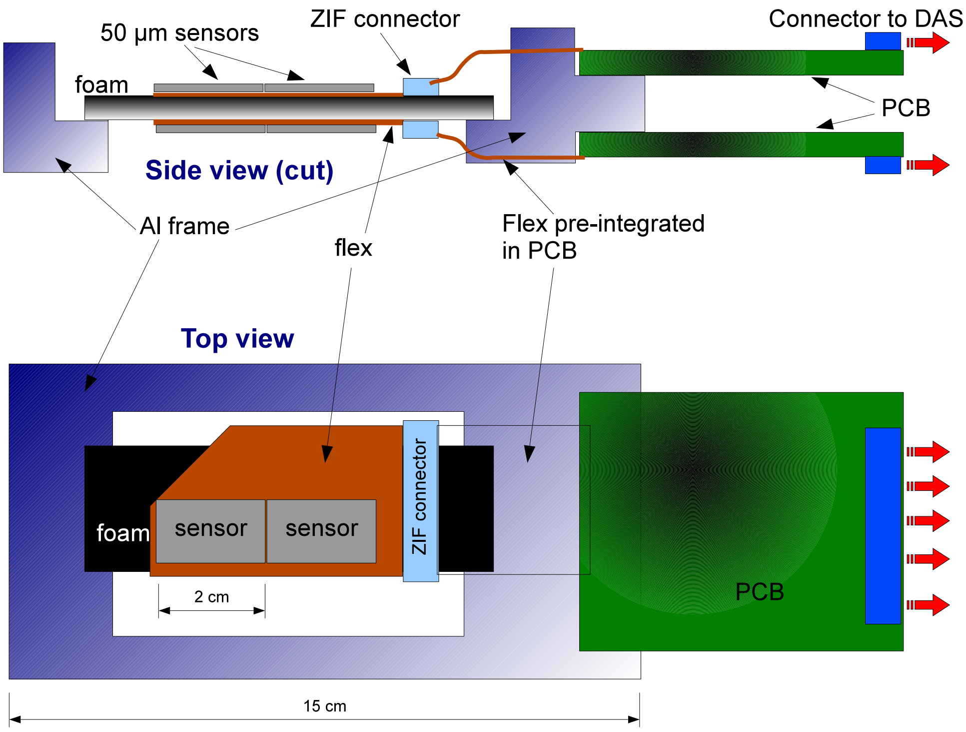

Figure 1: Possible design of the first ladder in two views.

One benefit of this design is the mechanical separation between the ladder itself and the two PCBs. The part which links them is a flex pre-integrated in the PCB which is *a priori* easy to bend (which is not the case of the flex supporting directly the sensors).

A final constraint comes from the room available inside the TAPI telescope, see drawing 2. Indeed the frame handling the ladder should be able to rotate inside TAPI to study the hits correlation on the two sides at different incident angles.

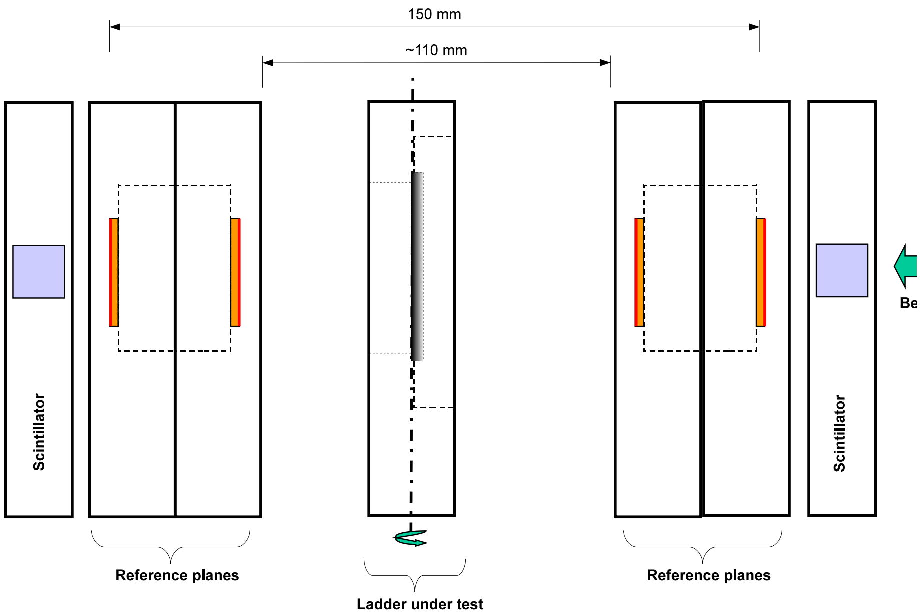

Figure 2: Arrangement of reference planes and ladder under test in the TAPI telescope.

3.2 Components required

Table 3.2 provides a list of all major components required to fabricate two ladders in 2009.

Adhesives used to bond the sensors on the flex, the flex on the foam and the foam on the frame do not appear as element. Nevertheless, the potential different glues have currently not been chosen and their characteristics have to be identified. There is no connector taken into account on the flex as well because, the connector is sold to the proximity board servicing one flex.

To specify the terminology, we name **module** a flex equiped with sensors and a connector and **ladder** a mechanical support structure holding modules on its both sides. For the numeration, the ladder number n is propagated to the module number with the addition of an A or B.

It has to be noted that data can be acquired with a single module which can hence be tested and validated.

part	description	quantity for one ladder	minimal quantity	total quantity available	provider
sensor	MIMOSA 20	4	8	many	IPHC
flex	multi-layer polyimide	2	4	6+1	IKF
mechanical support	silicon carbide foam	1	2	enough	Bristol/Oxford
proximity board	PCB with flex	2	4	?	IKF or IPHC
support frame	Al frame	1	2	?	IPHC

Table 2: List of components required for the 2009 ladder with availability.

3.3 Material budget estimate

In table 3.3 below, we simply consider the material budget along a path crossing two sensors. The flex budget is a sum of the three component thicknesses weighted by their respective radiation length, taking into account a conservative fill factor for the copper lines of 25 %. The computation goes as follow:

layer	thickness (μm)	X_0 (cm)
polymide	150	28
adhesive	100	35
copper	36×0.25	14.3
AVERAGE	300	20.5

We take into account that sensors are glued to flex and both flex to foam, so an adhesive layer appears 4 times. Its thickness of 20 μm and $X_0 = 35$‘cm (acrylat adhesive) are first very preliminary hypothesis.

material	X_0 **(cm)**	**thickness (**μ**m)**	**budget (**$\%X_0$**)**
SiC foam	8.7 $\times 8\%$	2000	0.18
sensor	9.36	50$\times$2	0.11
adhesive	35	20$\times$4	0.02
flex average	20.5	300 $\times$ 2	0.29
		TOTAL	**0.60**

Table 3: Material budget estimate for the 2009 ladder.

3.4 Tentative schedule and tasks organisation

The 2009 ladder project aims at validating the different tasks necessary to build such types of ladder. Hence it is important to specify each assembly step (components are considered as already available), which we do in table 3.4.

task	**tool required**	**location**
thinning sensors	-	IPHC sub-contractor
module assembly mounting and connecting pairs of sensors on flex cable	placement jig	IPHC
modules are shipped from IPHC to Oxford.U. (dedicated box required)		
testing module : electronics, 55Fe source, beta source	Acquisition system, source module support	IPHC, Oxford.U.
modules are shipped from Oxford.U. to Bristol.U.		
ladder assembly mounting modules on SiC foam	?	Bristol.U,
mounting a ladder on Al support frame	Al support frame	Bristol.U.
ladder is shipped from Bristol.U. to Oxford.U. in their support frame		
mounting of boards on support frame	-	Oxford.U. ?
testing ladder : electronics, 55Fe or/and beta source	Acquisition system, source	IPHC, Oxford.U.
ladder is shipped from Oxford.U. to IPHC		
mounting the device on a beam telescope	TAPI	IPHC

Table 4: Assembly steps for the 2009 ladder

The tentative schedule for year 2009 follows in table 5:

		General tasks	**Ladder-0**	**Ladder-1**
May	2^{nd}	ordering MIMOSA-20 sensor thinning		
June	1^{st}		assemble module-0A (IPHC)	
	2^{nd}	tool module box (IPHC)	characterise module-0A (IPHC / IKF) *module-0A* → *Bristol*	
July	1^{st}	Reception of thinned MIMOSA-20 (IPHC) Reception of servicing boards (IPHC) **validate module concept**	mount module-0A on foam (Bristol) assemble module-0B (IPHC) characterise module-0B (IPHC) *module-0B* → *Bristol*	assemble modules-1A, 1B (IPHC)
	2^{nd}	*Acquisition system* → *Oxford* tool ladder support frame (IPHC)	characterise module-0B (IPHC) *module-0B* → *Oxford*	characterise modules-1A, 1B (IPHC) *modules-1A, 1B* → *Oxford*
August	1^{st}	**validate ladder concept**	test module-0B (Oxford) *module-0B* → *Bristol*	test modules-1A, 1B (Oxford) *modules-1A, 1B* → *Bristol*
	2^{nd}		mount module-0B on foam (Bristol) *ladder-0* → *Oxford*	mount mod.-1A, 1B on foam (Bristol) *ladder-1* → *Oxford*
September	1^{st}		characterise ladder-0 (Oxford) *ladder-0* → *IPHC*	
	2^{nd}		test ladder-0 (IPHC)	characterise ladder-1 (Oxford) *ladder-1* → *IPHC*
October	1^{st}	finalise beam telescope (IPHC)		test ladder-1 (IPHC) ladder-1 into telescope (IPHC)
	2^{nd}	prepare beam telescope con't (IPHC)	start final ladder developments: flex, module tools, ladder tools, testing setups	
November	1^{st}	bring telescope with ladder-1 to CERN start commissionning on Nov. 5th resume data taking by Nov. 12th late	final ladder developments con't	
	2^{nd}	start analysis of beam test data	final ladder developments con't	
December		beam test data analysis cont'd	final ladder developments con't	

Table 5: Tentative calendar for the 2009 project.

References

[1] The ILD Concept group, *The International Large Detector: Letter Of Intent*, March 2009 (available at http://www.ilcild.org/documents/ild-letter-of-intent).

[2] C.Hu-Guo *et al*, *Development of MAPS for charged particle tracking: A fast readout architecture and its applications*, presented at the 7th International Meeting on Front-End Electronics, Montauk, May 2009 (available at http://iphc.cnrs.fr/Presentations.html).

[3] A. Himmi *et al*, *Mimosa26 User Manual*, 2009 (available at http://iphc.cnrs.fr/List-of-MIMOSA-chips.html).

[4] W.Dulinski *et al.*, *Beam telescope for medium energy particles based on thin submicron precision MAPS*, IEEE Nuclear Science Symposium 2007, Hawai (available at http://iphc.cnrs.fr/Proceedings.html).

[5] C.Colledani *et al.*, *MIMOSA 20 User Manual*, 2007 (available at http://iphc.cnrs.fr/List-of-MIMOSA-chips.html).