Ultra-light pixellated systems

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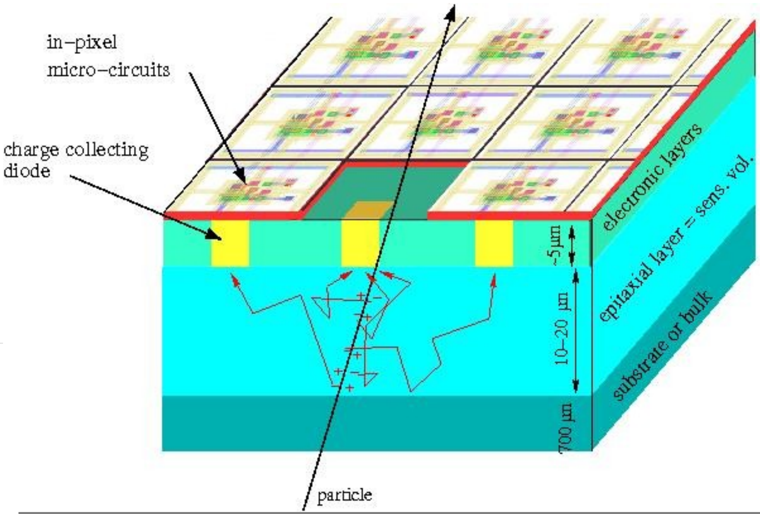
Mont Sainte Odile, 2011 September 8

- ✗ Motivations
- ✗ The PLUME collaboration
- ✗ PLUME-2010
- ✗ PLUME-2011
- ✗ Sensor embedding
- ✗ Summary

Motivations

CMOS pixel sensors

- ✗ Potentially extremely thin ~ 25 µm ~0.027 % X_0



Questions

- ✗ How much can CMOS pixel sensors be thinned down for integration?
- ✗ Can we provide support structures & services which are not “much more thick” than the sensors?
- ✗ Any new ideas opened by such thin sensors?
- ✗ How do we benefit from industry rapid technology advances?
- ✗ Do we have the necessary skills/equipments in our laboratories?
- ✗ Do integration studies bring some feedback to the design of the sensors themselves?

The PLUME R&D

- ✗ “classical” approach
- ✗ double-sided ladders
- ✗ design ILC oriented

Sensor embedding

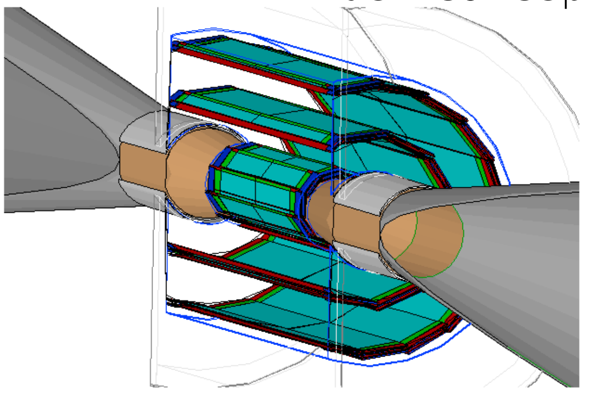
- ✗ Exploratory approach
- ✗ Exploit monolithic aspect of sensors
- ✗ R&D partly supported by FP7 Hadron-Physics2-ULISI

The PLUME collaboration

ILC-oriented

- ✗ Double-sided ladders
- ✗ Air cooled
- ✗ Power pulsed @ T=200ms
- ✗ 125 mm long
- ✗ Material budget goal ~ 0.3 % X_0
- ✗ Results expected for mid-2012

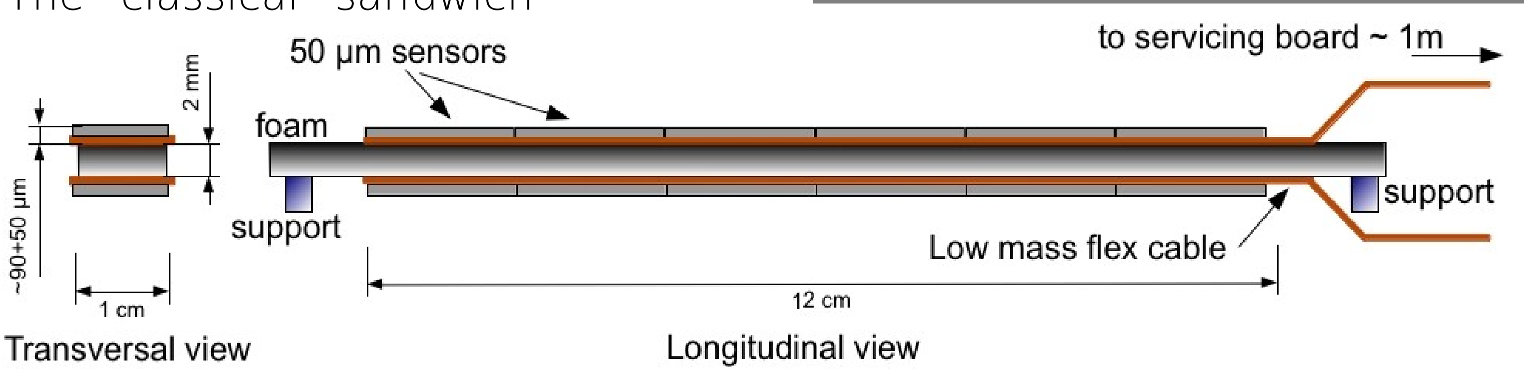
ILD vtx det. concept



Double-sided ladders benefits

- ✗ Redundancy
- ✗ Alignment: faster and/or more robust
- ✗ Track finding boosted by mini-vectors
- ✗ <u>Note:</u> material budget increase ~ few 0.1% X0 between single- and double-sided options

The "classical" sandwich



The PLUME collaboration

University of BRISTOL

- Mechanical design
  stiffener, supports
- Stability measurements
- Modules mounting on ladders

DESY

- Simulations (FEA)
- Ladder mock-up & thermal measurement
- Power pulsing tests

IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

- Sensors mounting on modules
- Electrical tests
- Readout & DAQ
- Cooling system
- Test beam infrastructure & analysis

UNIVERSITY OF OXFORD

- Low-mass cable
  design & test
- Test beam analysis

Synergy with

- ✗ IKF – Frankfurt, CBM group
- ✗ LBNL – Berkeley, STAR-HFT group

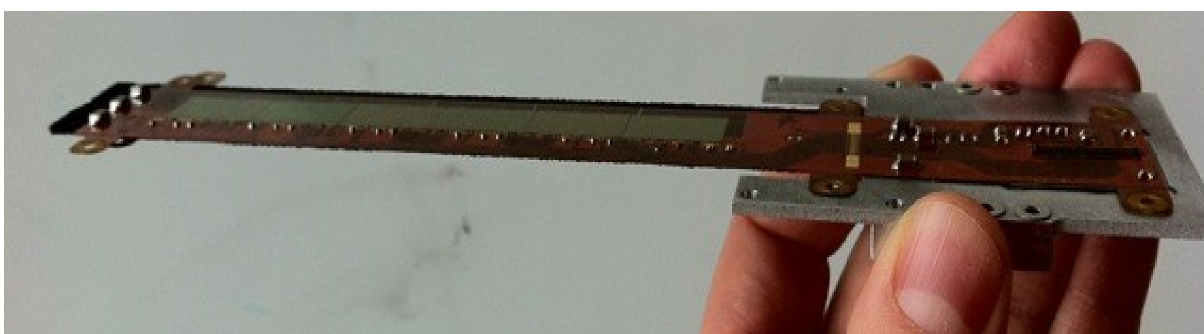
PLUME-2010 design

Goals

- Electrical functionality
  with 6 MIMOSA 26 (see M.Winter's talk)
- Address the full fabrication, assembly & test chains
- Note: MIMOSA 26 not designed for power pulsing

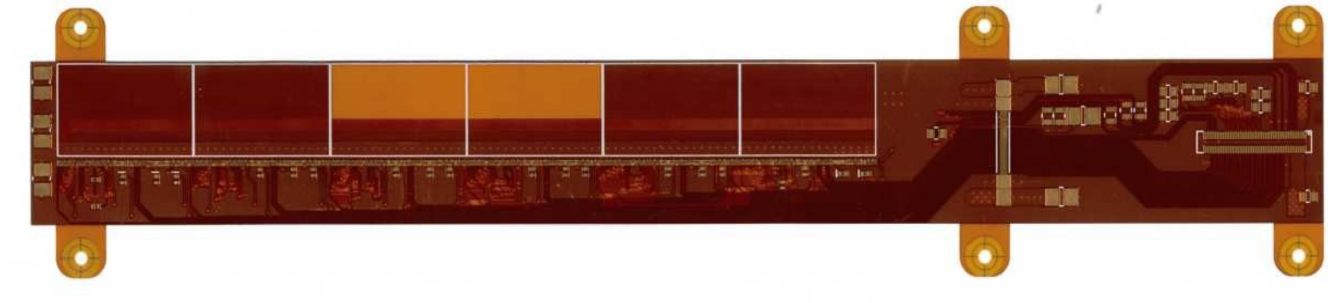
Key features

- 6x MIMOSA 26 thinned down to 50 µm
- Low mass cable = 140 µm thick with 2x20 µm copper
- Spacer = SiC foam at 8% density
- 1 ladder = 8M pixels, 10g, 0.6 % X_0 (cross section)

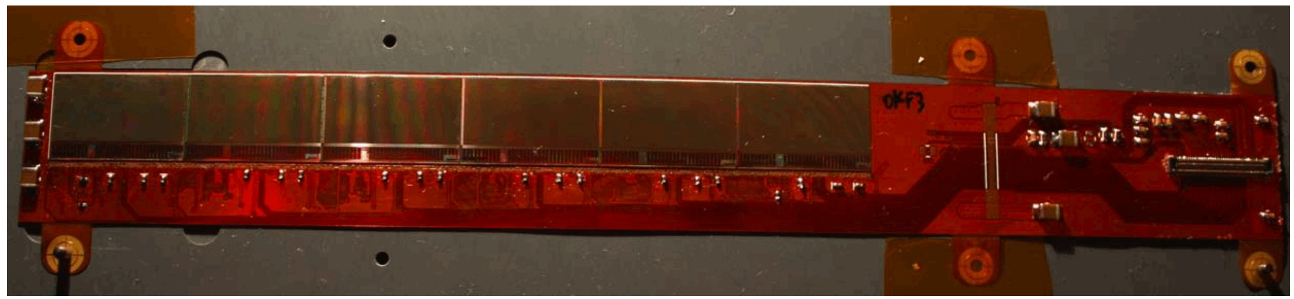


PLUME-2010 design

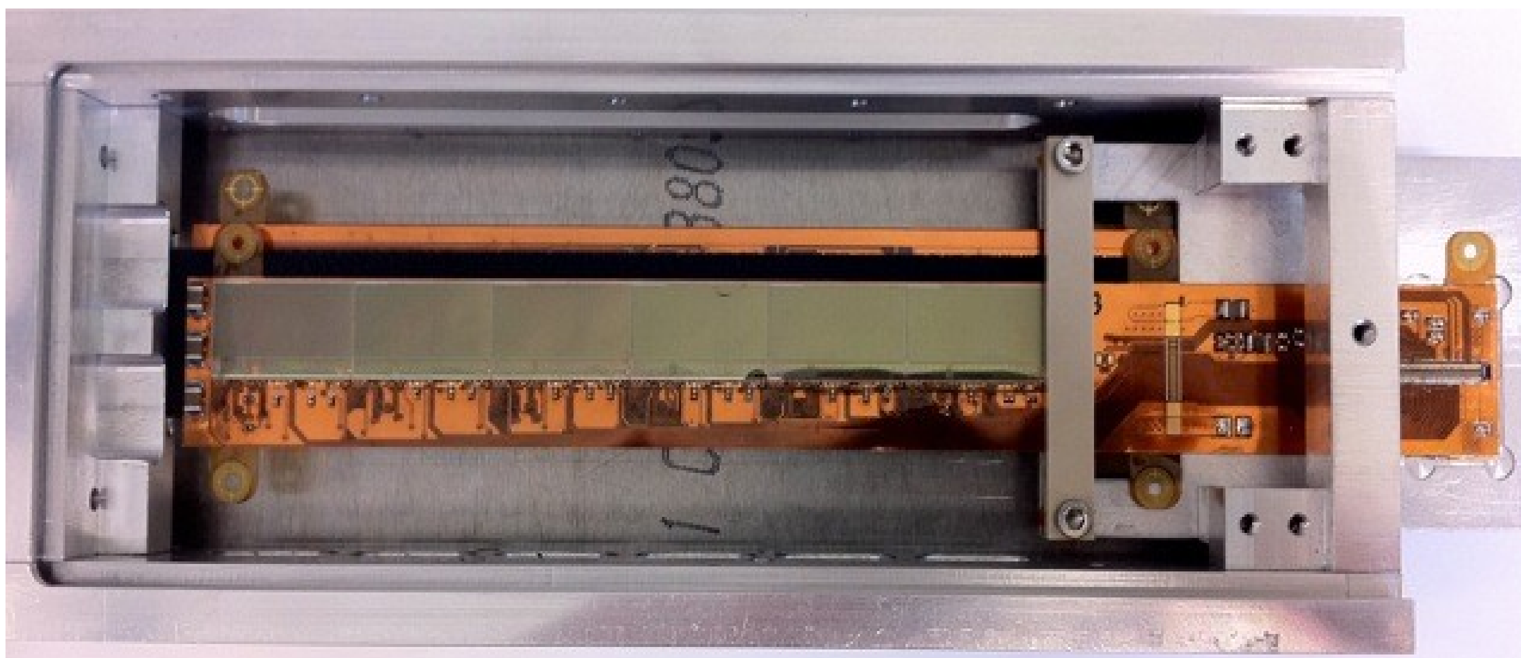
bare low mass cable



module with 6 sensors

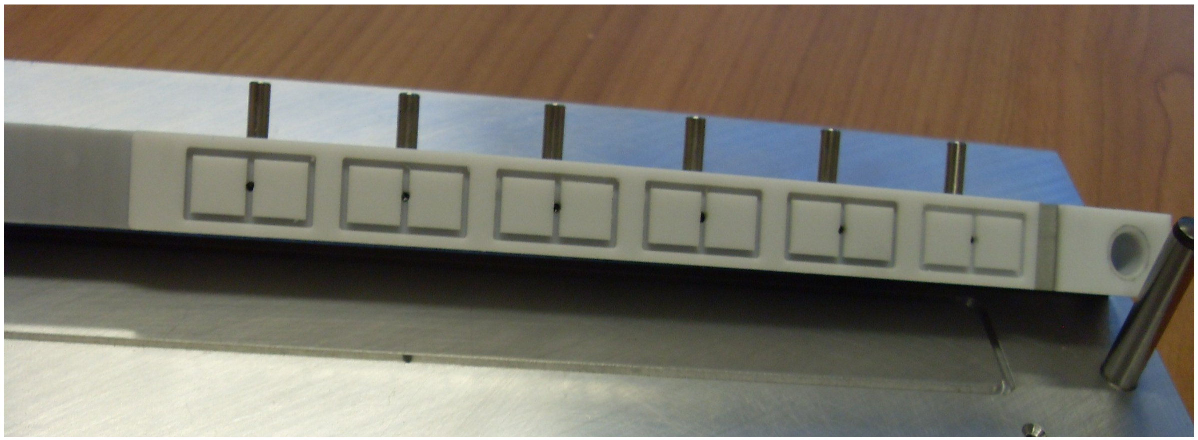


complete ladder
(2 modules)

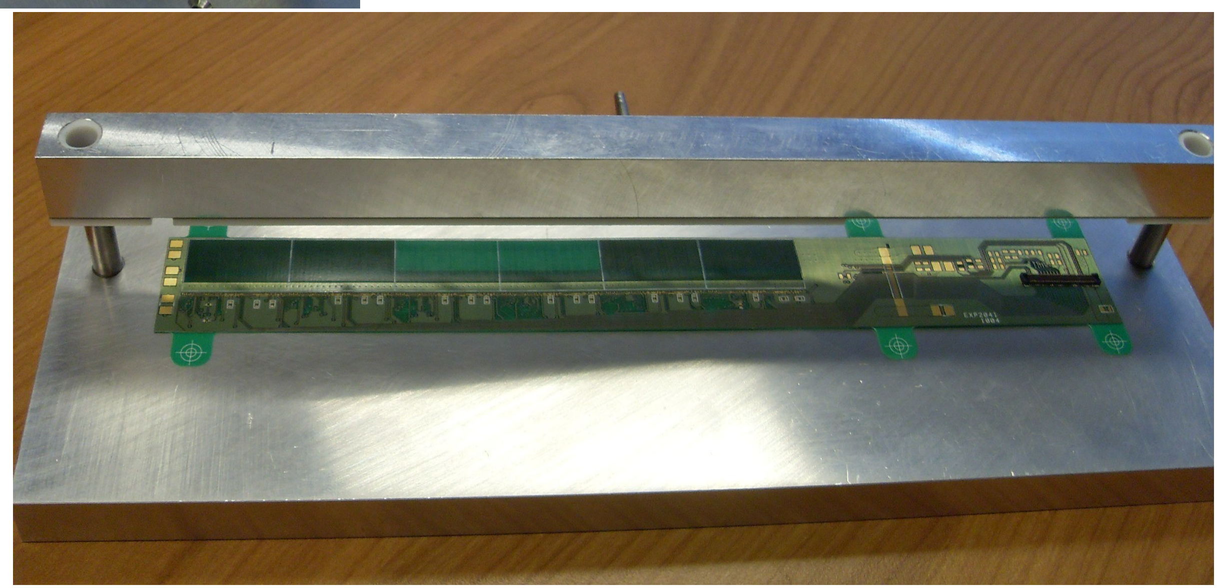


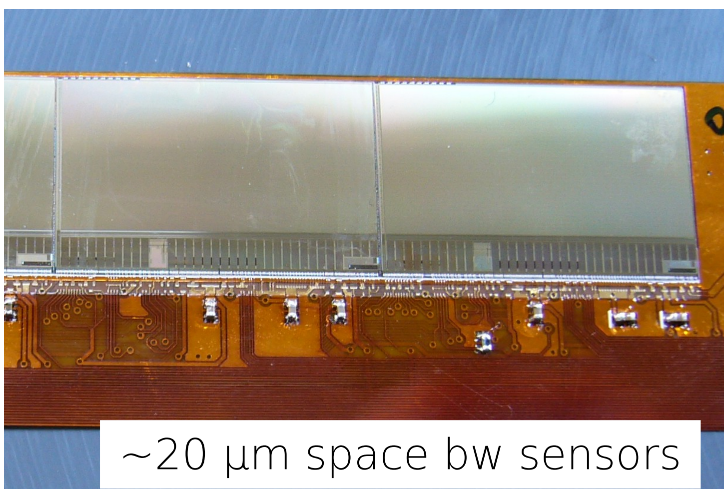
PLUME-2010 module assembly

x6, manual positioning,
vacuum fixed

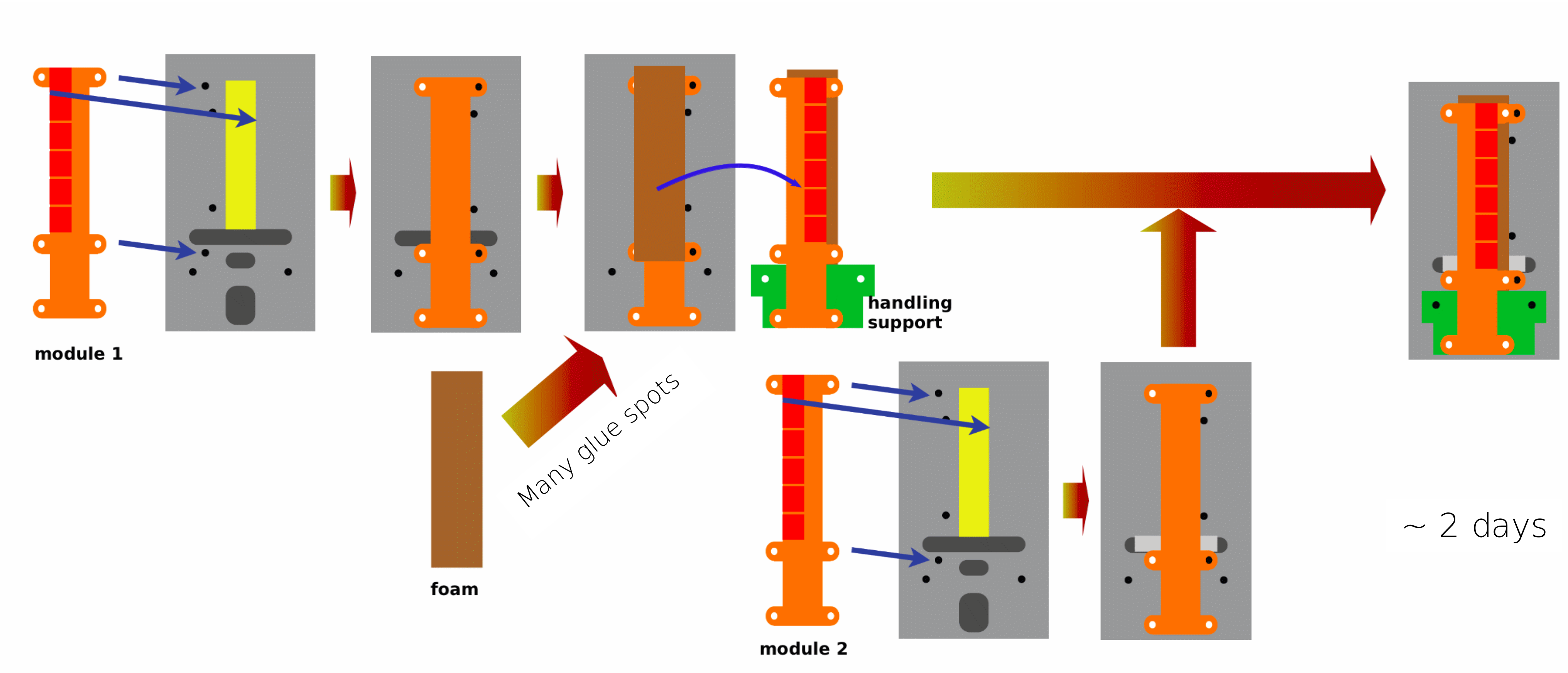


Controlled glue dispensing
small pressure while curing
Then wire bonding





PLUME-2010 ladder assembly



Modules

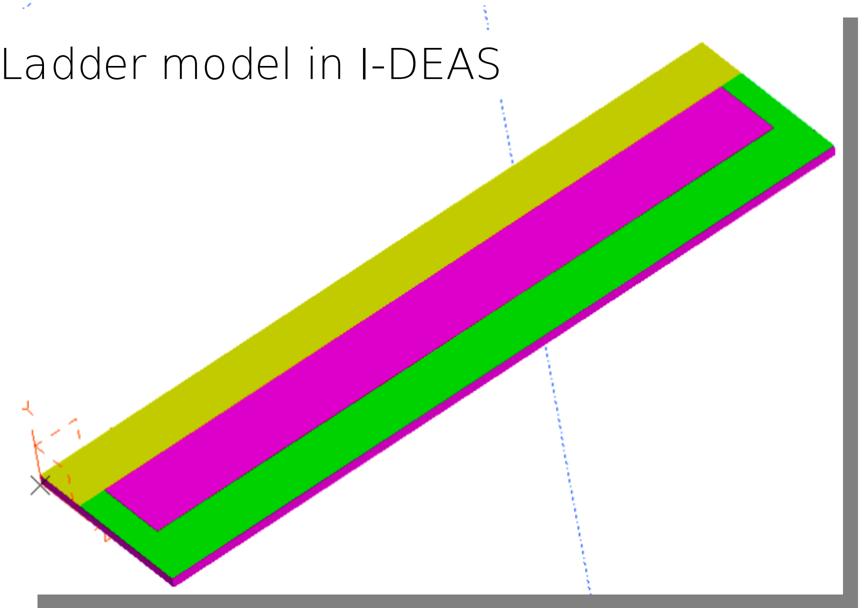
- ✗ ~30 low mass cables produced (all copper)
- ✗ 5 equipped with 6 MIMOSA26
  - ➔ All electrically functional
  - ➔ 3 with 1 or 2 non-functional sensors

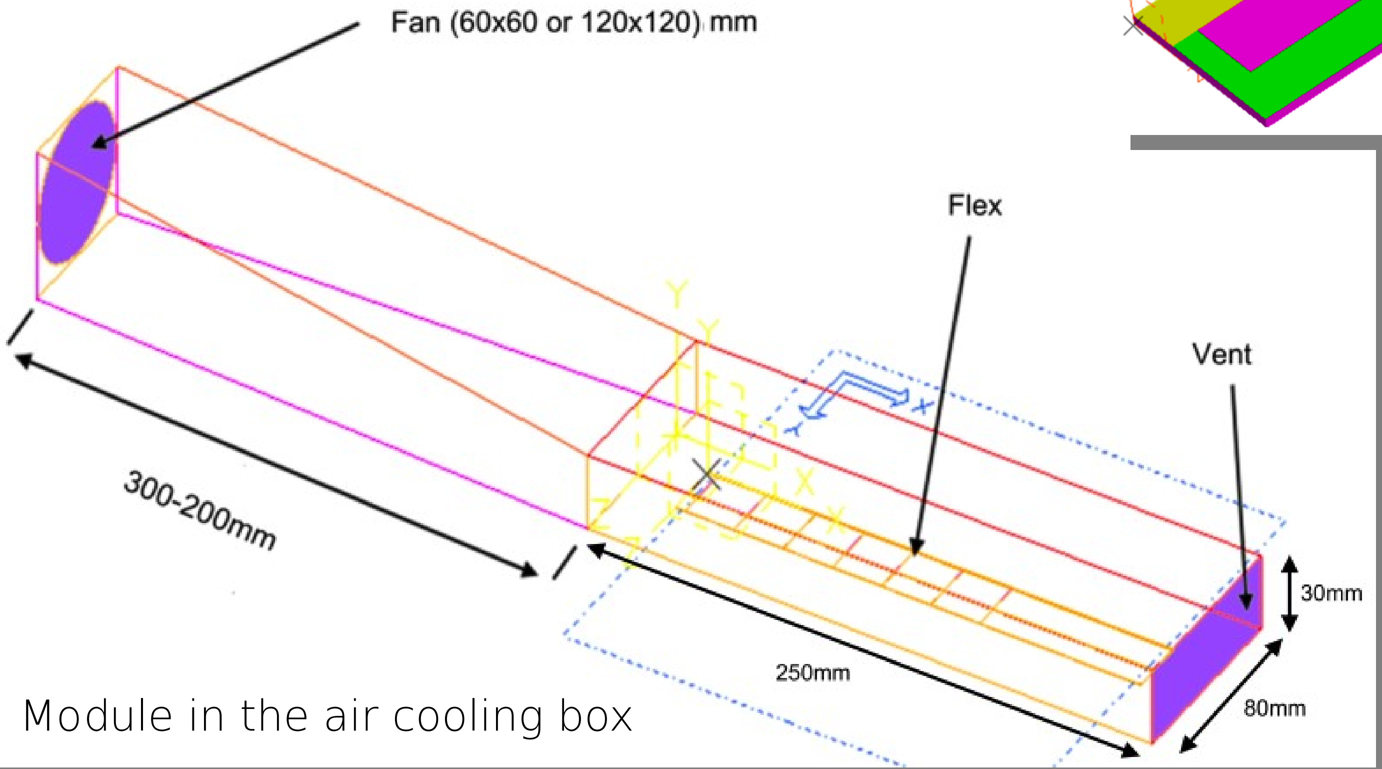
Ladders

- ✗ 3 assembled
  - ➔ 1 with dummy sensors
  - ➔ 1 electrically functional
  - ➔ 1 still curing

PLUME-2010 simulations

Ladder model in I-DEAS

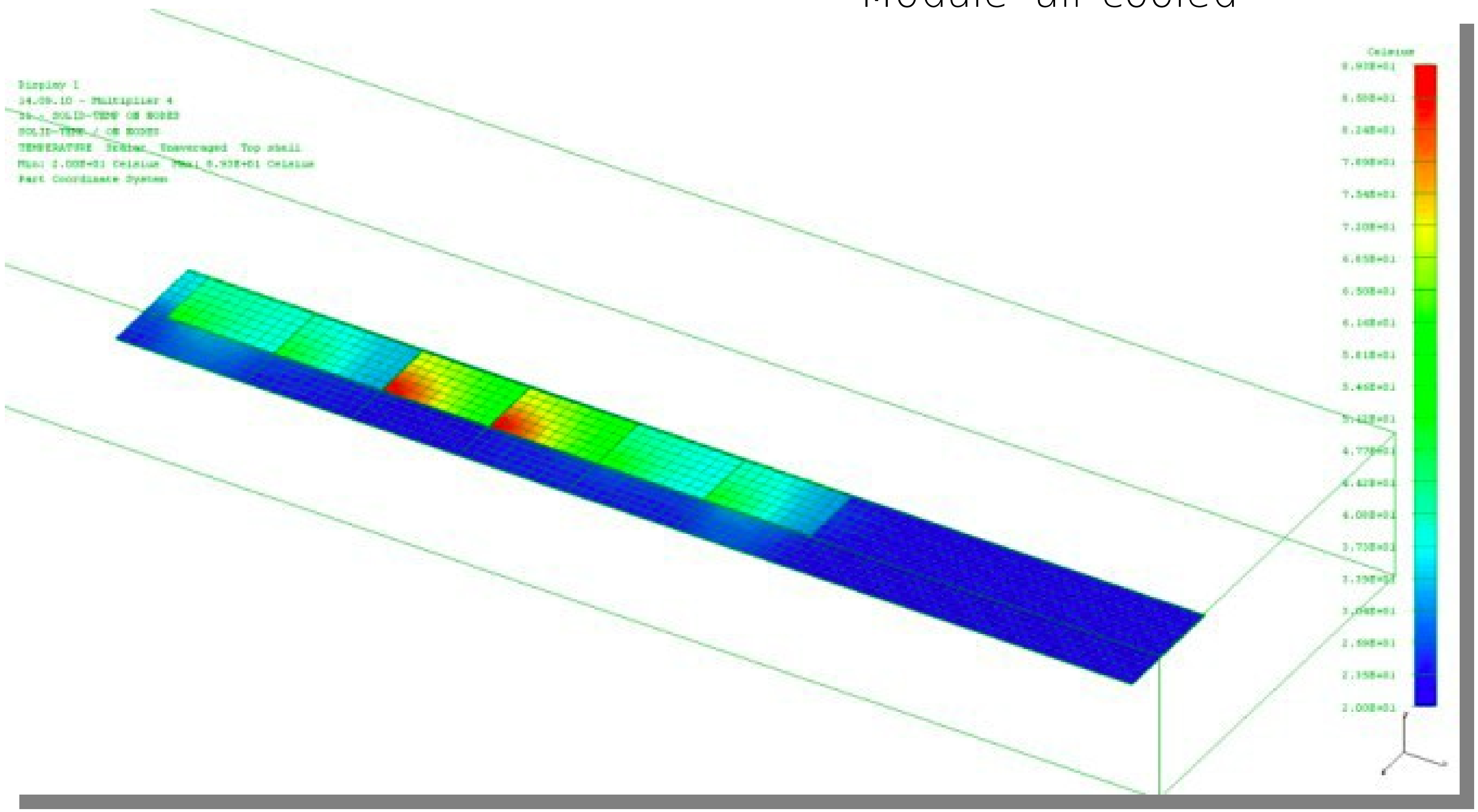




Module in the air cooling box

PLUME-2010 simulations

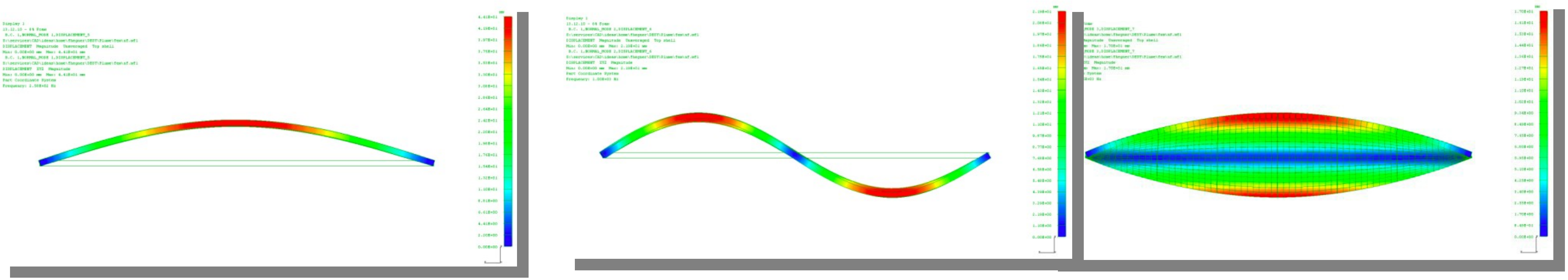
Module air cooled



→ importance of heat conductivity among sensors for efficient cooling by air

PLUME-2010 simulations

Ladder supported at both ends

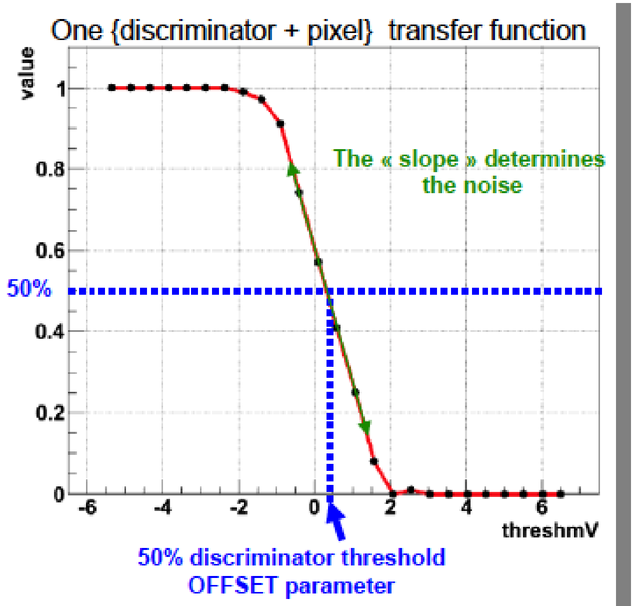


2C - Mode		SiC foam 8% in Hz	SiC foam 4% in Hz	RVC in Hz
One sensor/ Two sensors/ Three sensors	1	255	265	235
	2	990	981	453
	3	1281	1117	674

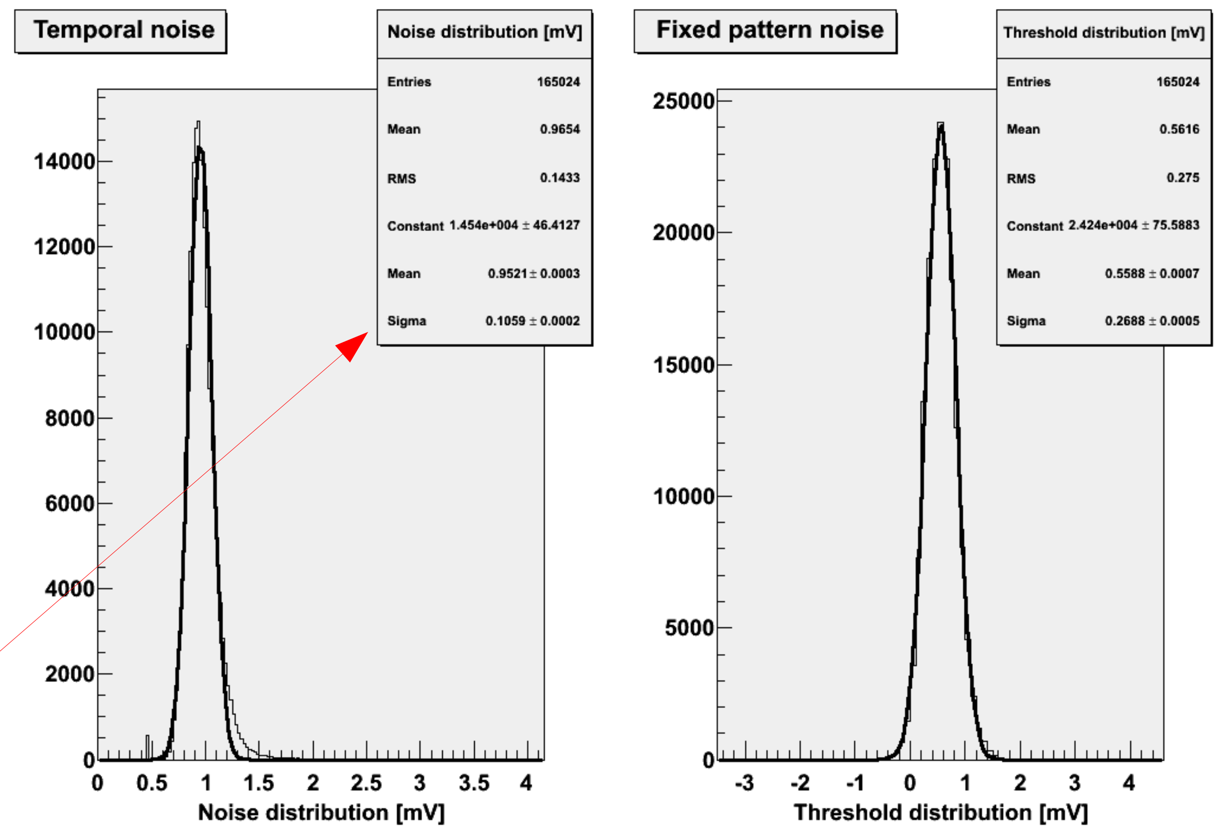
→ importance of sandwich effect for stiffness

PLUME-2010 electrical tests

Scan of the discriminator thresholds with all 6 sensors switched on (5 tuned for 1% occupancy)



Current consumption/sensor ~230 mA @ low threshold

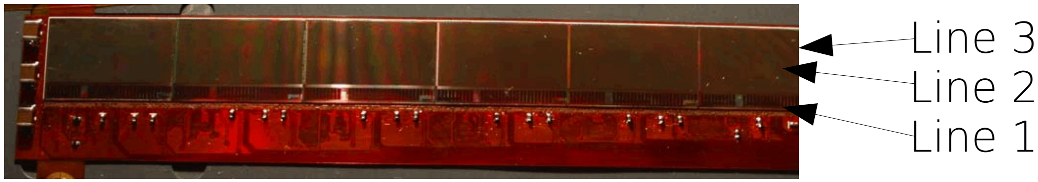


Temporal noise at mV level as expected from single sensor measurements

→ Waiting for quantitative measurement of fake hit rate with threshold (very soon)

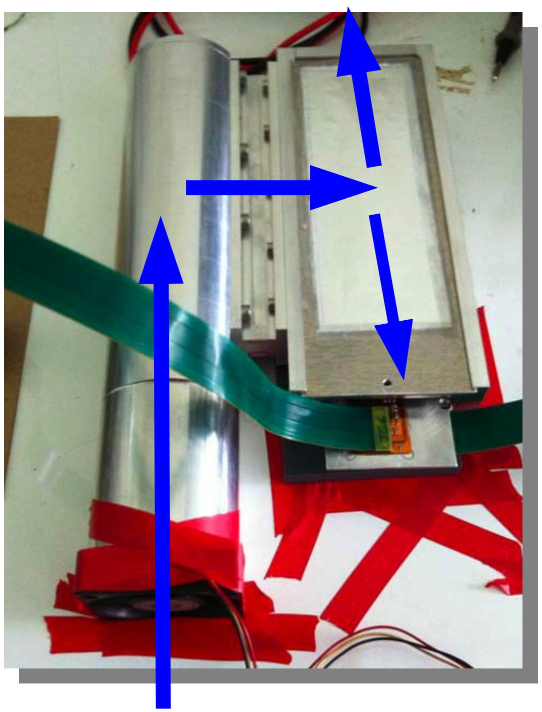
PLUME-2010 thermal tests

IR camera thermal measurement on a single module



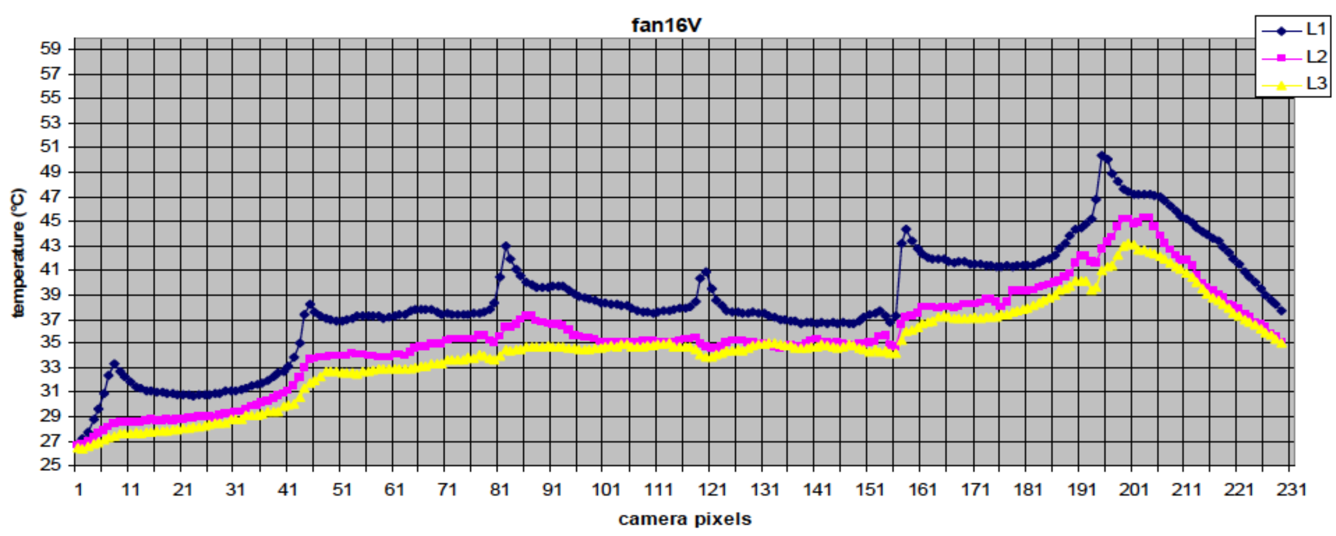
MIMOSA 26 internal (diode) temp. measurement on ladder

only 1 over the 2 modules switched on



ambient air

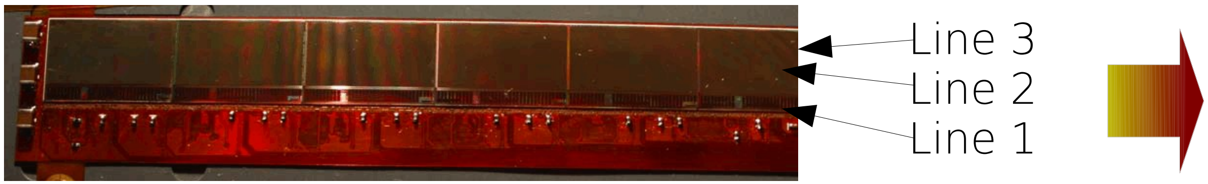
Low air flow

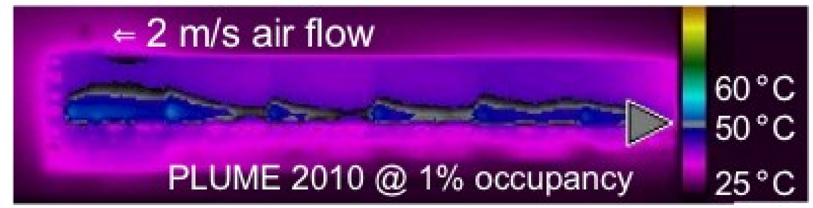


High air flow +1.5 m/s

PLUME-2010 thermal tests

IR camera thermal measurement on a single module





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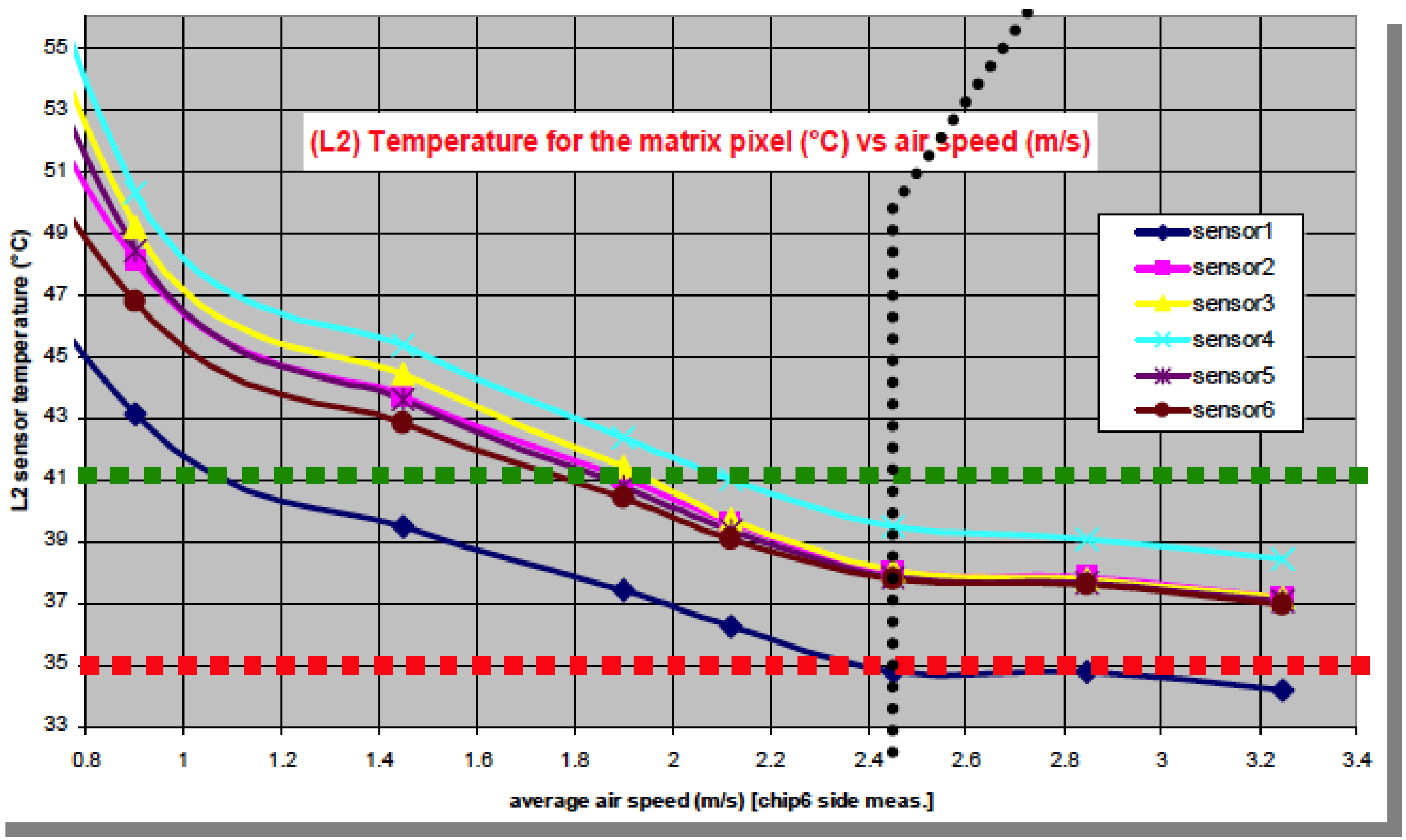
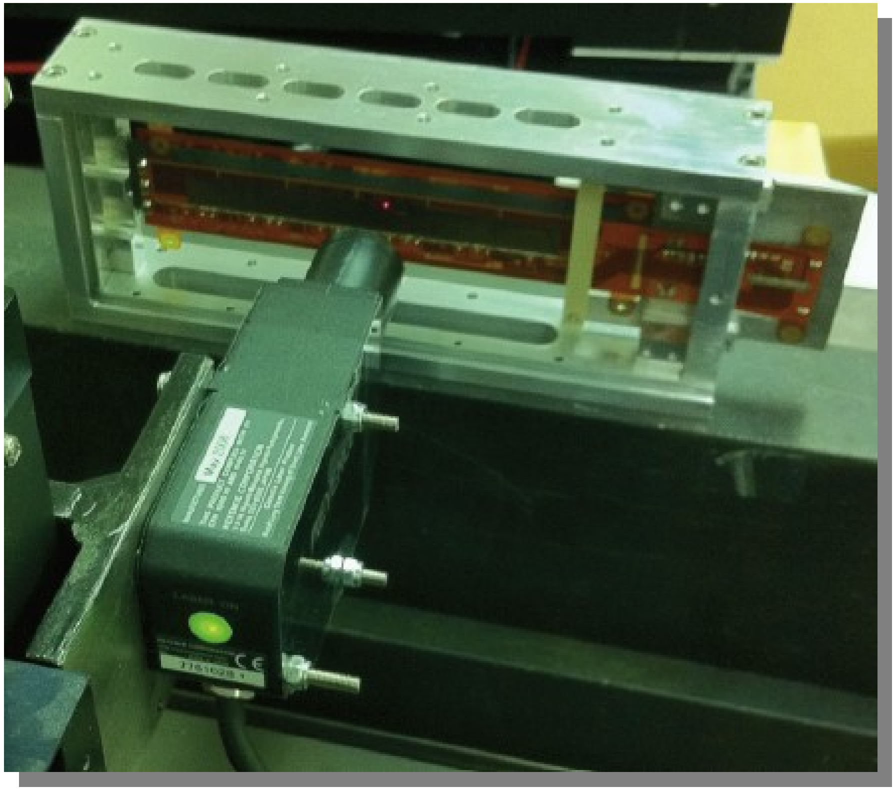
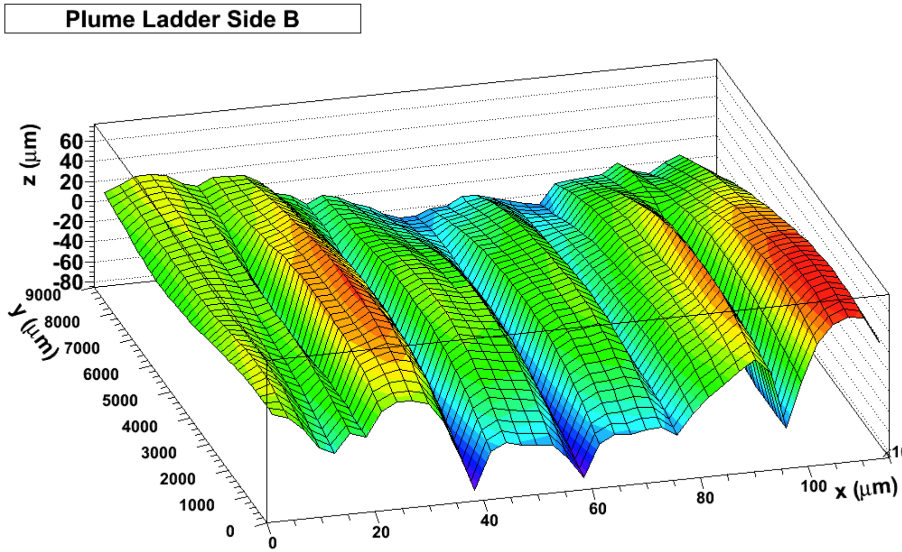


PLUME-2010 mechanical tests

Surface survey of ladder with dummy sensors





With the help of Ryan Page & setup from RAL

<u>Functional ladder air cooled</u>
→ Waiting for survey and vibration measurements for quantitative conclusion (end of September 2011)
→ Waiting for test beam at CERN-SPS with 120 GeV π (november 2011)

PLUME-2011 design

Why is the 2010 design so thick ?

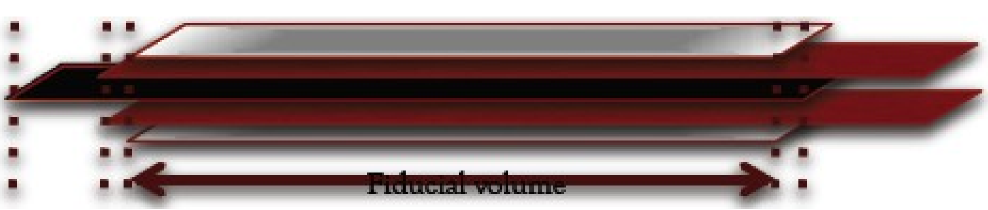
- ✗ cable width ~ 2 x sensor width
- ✗ metal ~ copper
- ✗ SiC foam (spacer) density ~ 8%

New (2011) design

- ✗ cable width ~ sensor width + 4 mm (wire bonds+SMD comp.)
- ✗ metal ~ aluminum (CERN) (still copper from industry)
- ✗ SiC foam (spacer) density ~ 4%

New (PRELIMINARY) material budget

- ✗ transverse cross-section
  - ➔ 0.344 % X0 = 2x0.053(sensors) + 2x0.058(flex) + 0.092(SiC4%) + 0.030(SMD)
- ✗ average (weighted / 10 mm wide MIMOSA 26 sensitive layer)
  - ➔ 0.502 % X0 = 2x0.069 (sensor) + 2x0.098 (flex) + 0.138 (SiC4%) + 0.030 (SMD)



Schedule

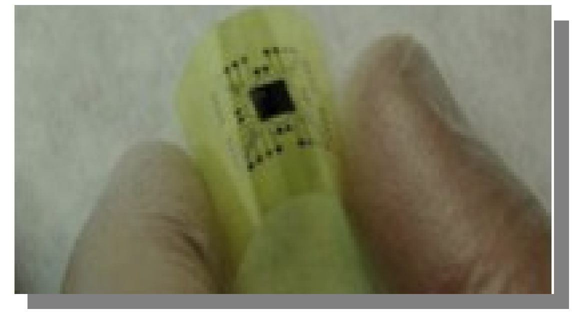
- ✗ copper cable version in test
- ✗ Aluminum cable version expected in Oct.
- ✗ semi-automatic positioning machine for module assembly available in Nov.
- ✗ First ladder in 2012-Q1
- ✗ Ladder small prod. (~10) » mid-2012

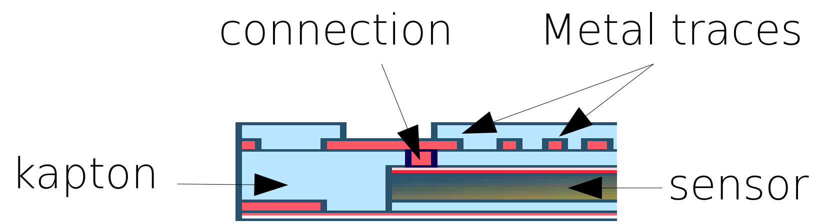
Sensor embedding

Rationale

- Get rid of the wire bonds (less material)
- Provide a mechanical protection to sensors
  - allows thinner sensors
  - Allows more mechanical stress by evening it
- Possibilities
  - Lower material budget (average ~ cross section)
  - Supportless
  - cover non planar surface

SEnsor Row Wrapped In
Extra-Thin Envelope = SERWIETE





profile view

Difficulty

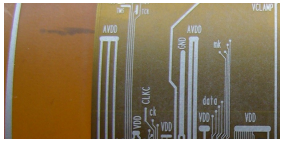
- Alignment of the narrow pad rings of several sensors over a long distance (~ladder length)
- Add metal layers over the embedded sensors

IMEC-CFRM process

- SERWIETE

CERN process

- CERNWIETE



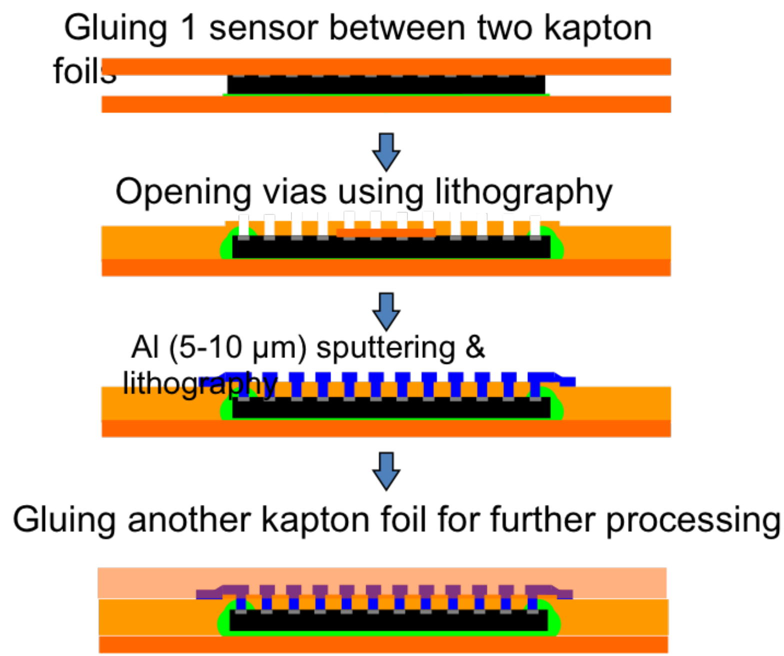
Sensor embedding: CERN

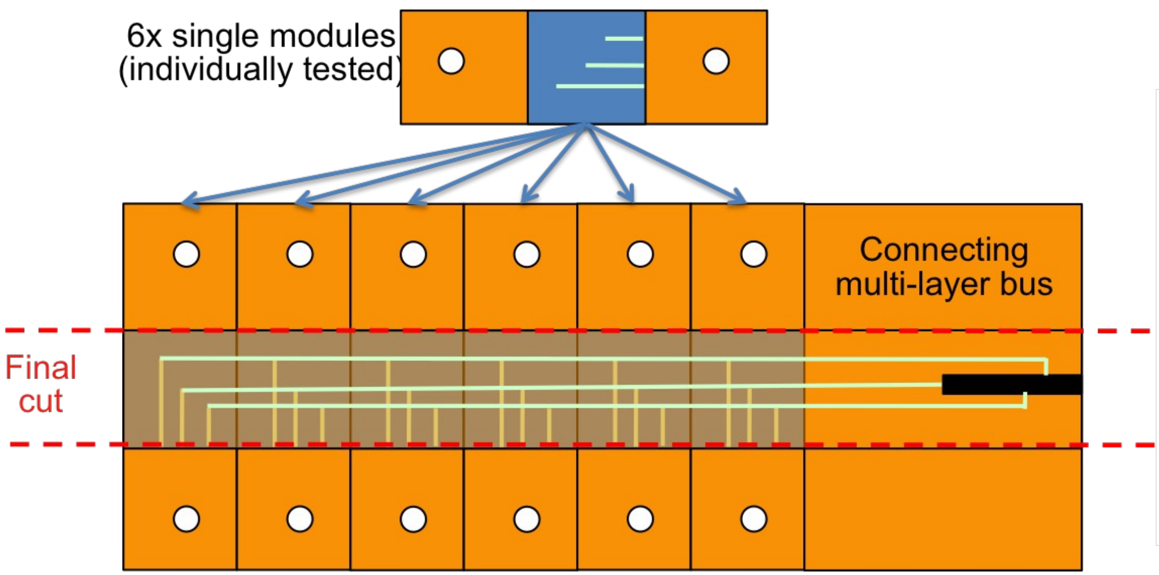
Idea from R. De Oliveira, W.Dulinski

- ✗ Embed sensor one at time
  - ➔ Alleviate alignment difficulty
  - ➔ Allow individual testing before assembly (yield)
- ✗ Processing of further metal layers decoupled from sensor embedding

Questions

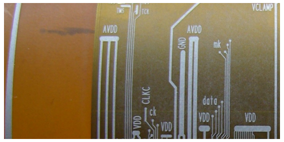
- ✗ Insensitive area in-between sensors?
  - ➔ Possibility to overlay embedded sensors





Material budget

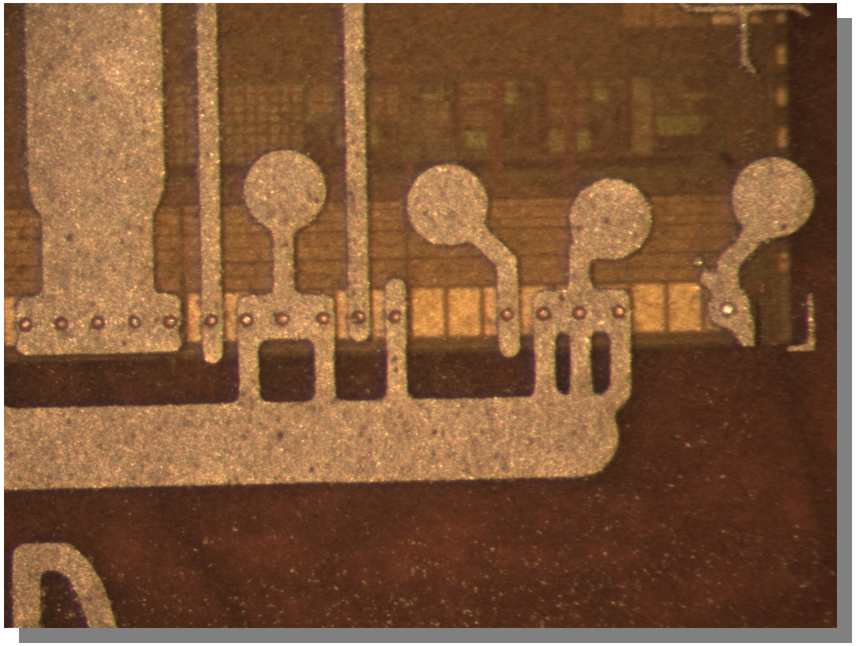
- ✗ Embed sensor one at time
  - ➔ Alleviate alignment difficulty
  - ➔ Allow individual testing before assembly (yield)
- ✗ Processing of further metal layers decoupled from sensor embedding

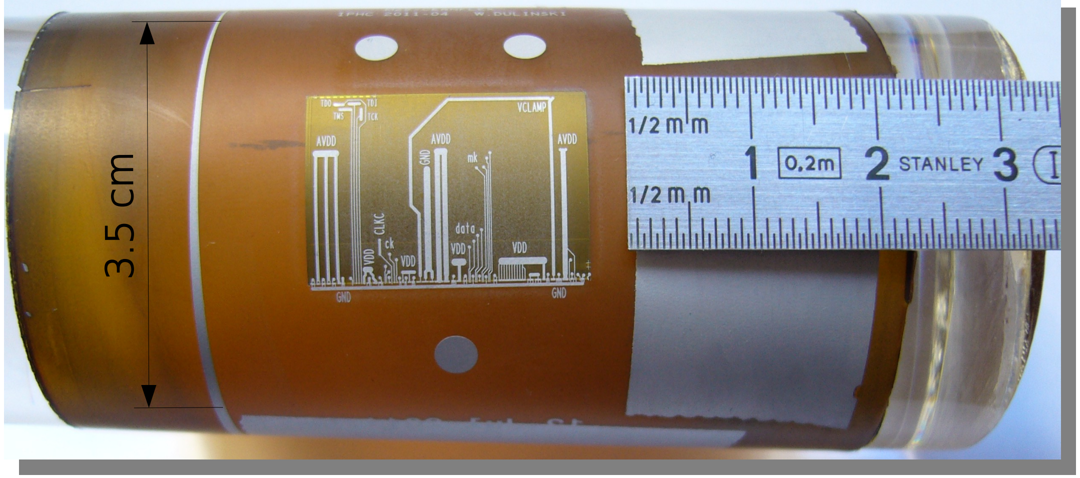


Sensor embedding: CERN

- **Status**
  - ✗ First single sensor embedded,
  - ✗ Not functional because connection problem
    - ➔ Vias under microscope investigation
    - ➔ Used for stress test
  - ✗ Interconnecting bus design ready
    - ➔ 3 metal layers (guarantee impedance)
  - ✗ Further processing this Fall

Detail of vias on sensor pads

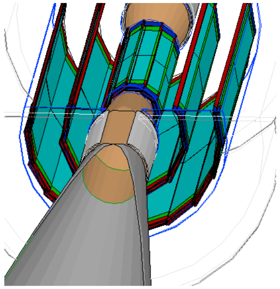




→ No cracks visible on the silicon, still await electrical confirmation
→ Thermal behavior?

Summary

- PLUME
  - ✗ A first (functionally) successful design in 2010 to be fully validated in Nov. 2011
  - ✗ New design in 2011 to reach material budget of (cross sect.) $O(0.03)$ % X_0
  - ✗ Simulation effort to validate models to predict new designs performances
  - ✗ “infrastructures” in place for further designs and/or other sensors
- Sensor embedding (SERWIETE & CERNWIETE)
  - ✗ Quite promising, probably 1st manifestation of new integrations methods/technics within the reach of CMOS pixel sensors
  - ✗ Still expecting a first functional prototype (<2012 according to plan)
- Applications ?
  - ✗ PLUME beam tests will be an important milestones for the ILD available in 2012 (to be compared with DEPFET-based Belle II-VXD & STAR-PXL)
  - ✗ 6 to 8 ladders (12 x MIMOSA 26 each) will run during long beam periods in the framework of the FP7-AIDA project
    - ➔ Complementary experience wrt STAR-PXL

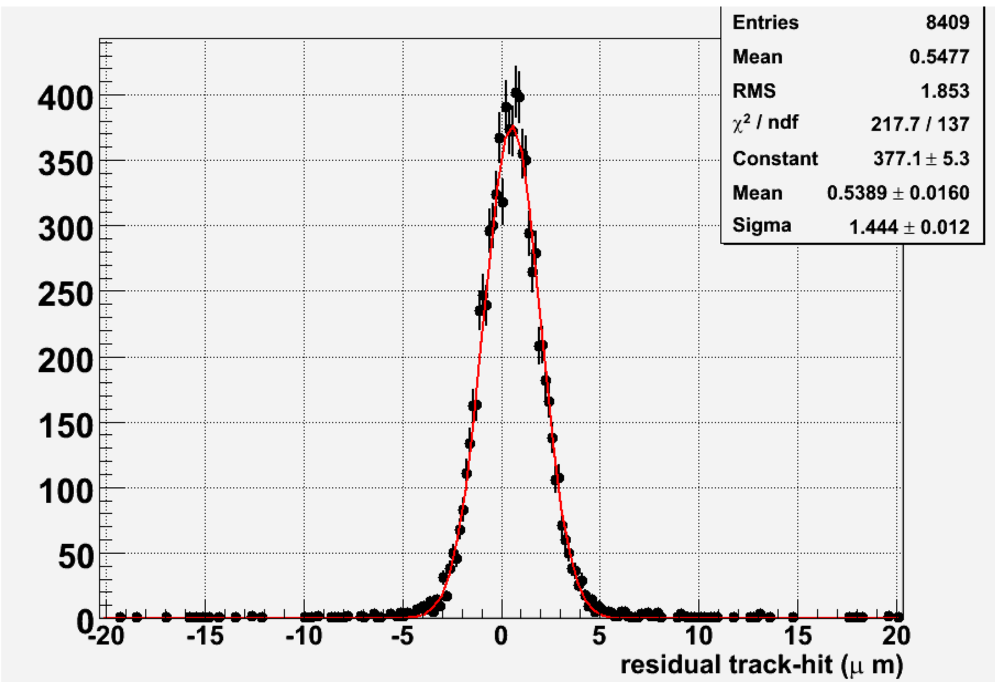


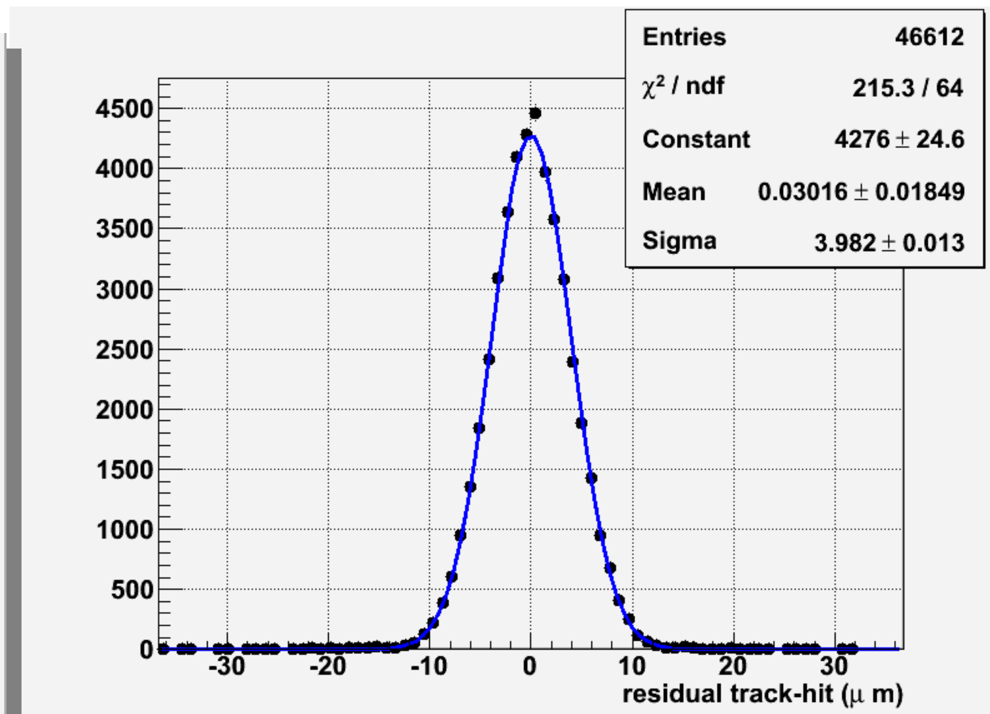
- Additional slides

  ✗

Defining the spatial resolution

- **From the residual resolution**
  - ✗ Fit with a single gaussian
  - ✗ Spatial resolution = single gaussian std. deviation



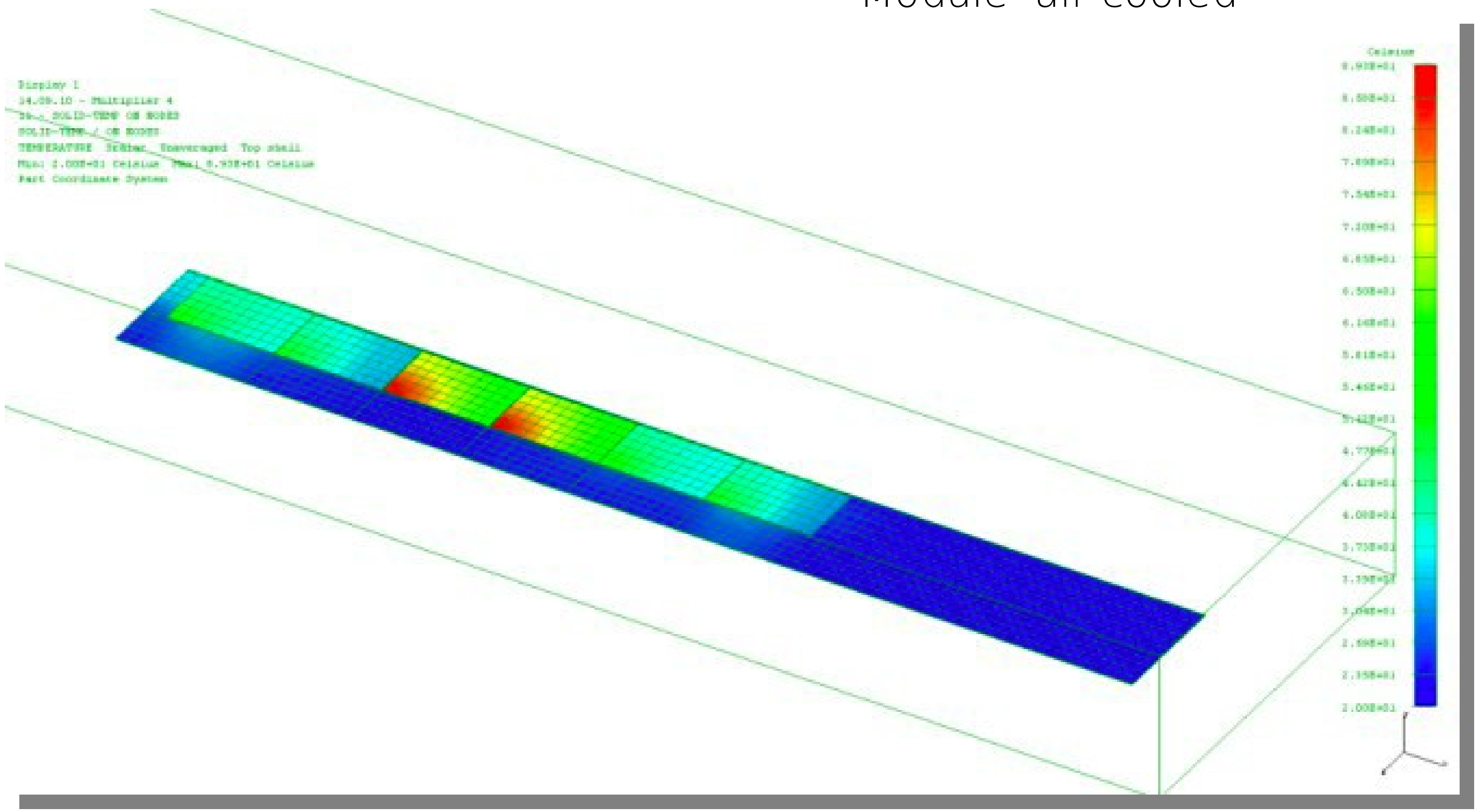


Analog sensor case:
MIMOSA 18, pitch 10 μm

Binary sensor case:
MIMOSA 26, pitch 18.4 μm

PLUME-2010 simulations

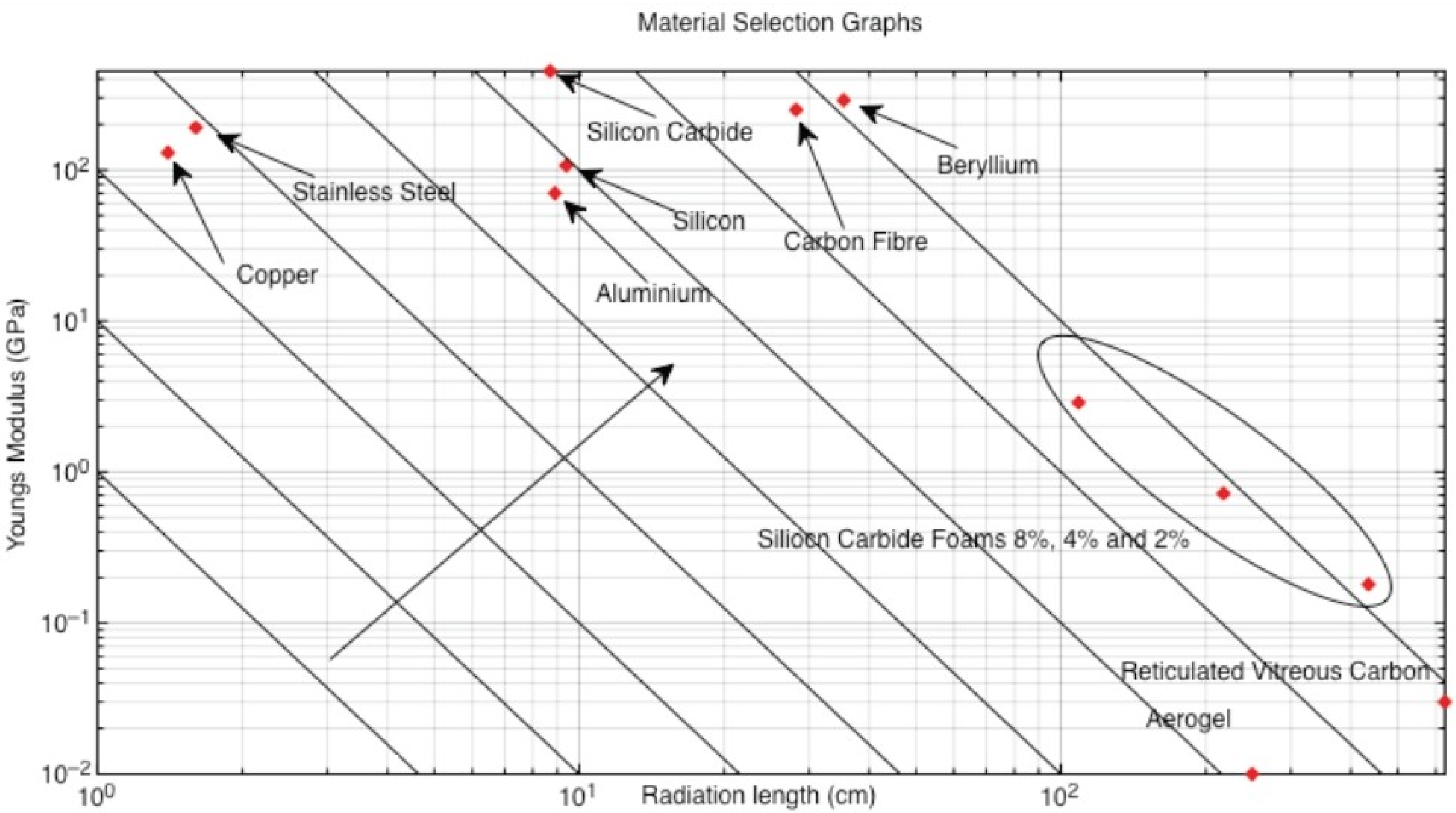
Module air cooled



PLUME-2010 simulations

Module air cooled

Materials for stiffener/spacer



From Joel Goldstein, Brisol U.

Parameter space for a VXD