Development of Single- and Double-sided Ladders for the ILD Vertex Detector

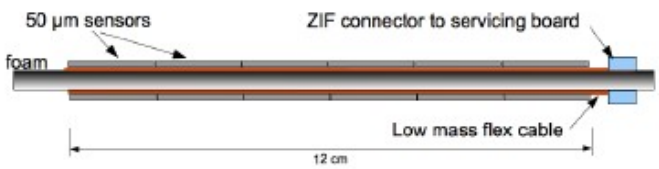
J. Baudot on behalf of the PLUME coll.

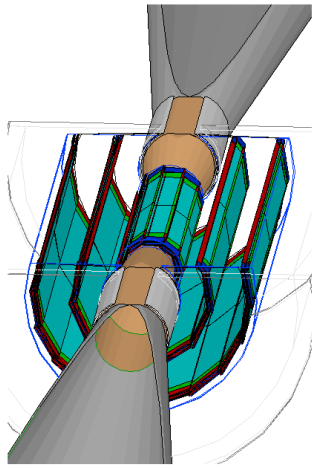
LCWS/Granada – 29 Septembre 2011

Contents

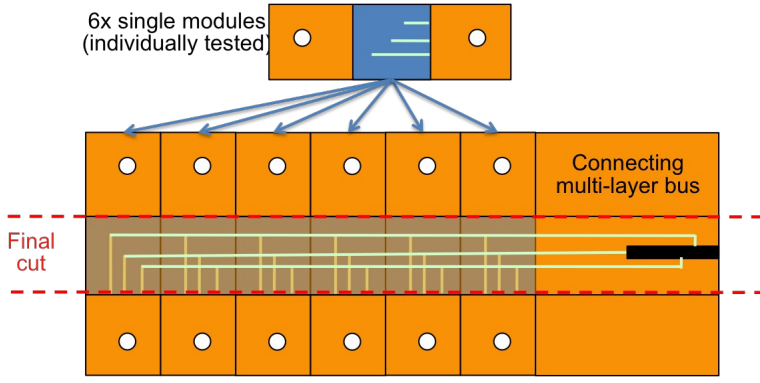
R&D lines of CPS based ladders

- **Ultra-light double-sided ladder : PLUME project**
  - ✗ Pixelised Ladder using Ultra-light Material Embedding
  - ✗ Objectives :
    - ➔ demonstrate feasibility of 2-sided ladder (0.3 % X0) for the ILD vertex detector by 2012 (DBD)
    - ➔ evaluate benefits of 2-sided concept : σ_{sp}, redundancy, alignment, shallow angle pointing, elongated⊕square pixels
  - ✗ Collaboration : Bristol - DESY - Oxford – Strasbourg



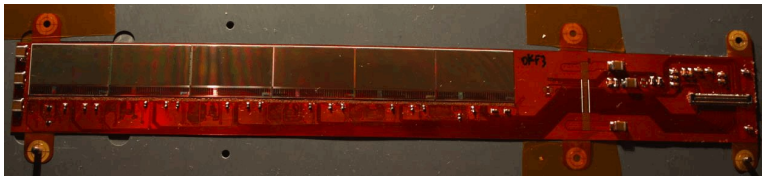


- **Unsupported single-sided ladder : SERNWIETE project**
  - ✗ SEnsor Row Neatly Wrapped In an Extra-Thin Envelope
  - ✗ Objectives :
    - ➔ demonstrate feasibility of unsupported concept (≤0.15 % X0)
    - ➔ for the ILD vertex detector by 2012 (DBD)
    - ➔ evaluate thermo-mechanical properties : system integration, curved supports
  - ✗ Context : EU project Had. Phys. 2 (coll. with Univ. Frankfurt & CERN)

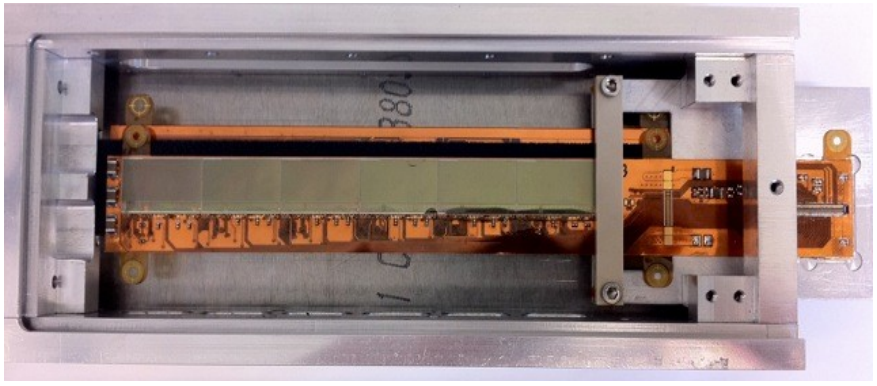


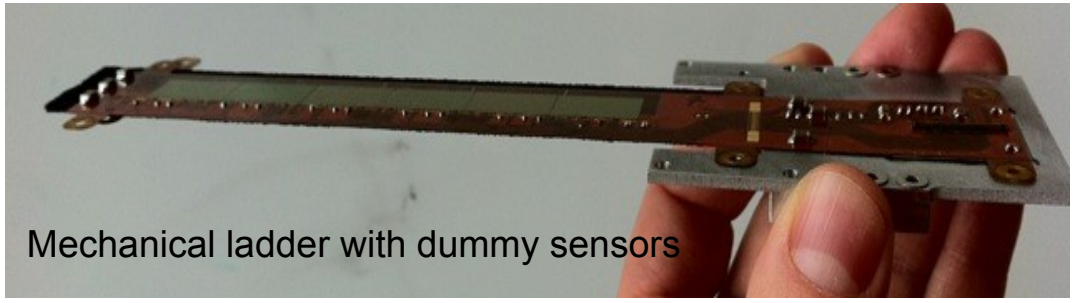
PLUME-2010 design

- Goals for 1st design
  - ✗ ensure electrical functionality with 6 MIMOSA 26
  - ✗ address the full fabrication & assembly chain
  - ✗ validate concept with electrical+mechanical+thermal tests
    - ➔ Note: MIMOSA 26 not designed for power pulsing



- Key features
  - ✗ sensors thinned down to 50 µm
  - ✗ low mass cable = 140 µm thick with 2x20 µm copper
    - ➔ much wider (24 mm) than sensor (14 mm) for electrical “safety”
  - ✗ spacer = SiC foam at 8% density
  - ✗ 1 ladder = 8M pixels, 10g, 0.6 % X_0 (cross section)
    sensitive surface ~ 12.7 x 1.1 cm^2 on two sides



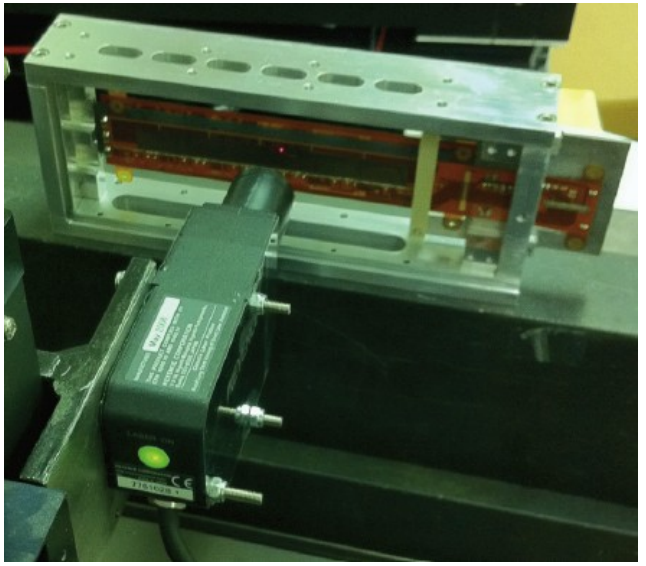


Mechanical ladder with dummy sensors

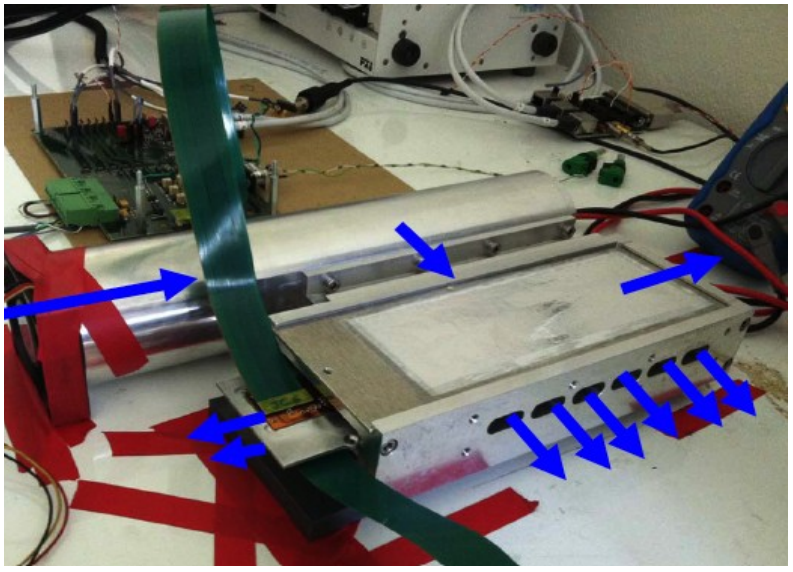
→ 2 functional ladders produced

PLUME-2010 tests

- Cooling
  - ✗ ambient air flow between 2 to 3 m/s (limited by fan power so far)
  - ✗ enough to maintain temperatures below 50 °C on sensors
    - ➔ stronger flow under design
- Mechanical
  - ✗ surface survey on mechanical prototype ►►►►►
    - ➔ Height RMS ~ 20 µm
  - ✗ vibration monitoring still to be done



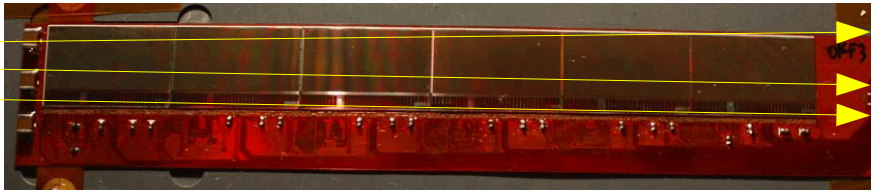
- Electrical (all 12 sensors operating)
  - ✗ Fixed Pattern Noise ~ 0.3-0.4 mV
  - ✗ Thermal noise ~ 0.9-1.0 mV
  - ✗ Fake rate < 10^{-4} hits/pixel/frame for threshold = 6x noise
  - ✗ Fake rate < 10^{-5} hits/pixel/frame for threshold = 8x noise
  - ✗ Ladder operation is similar to individual sensor operation

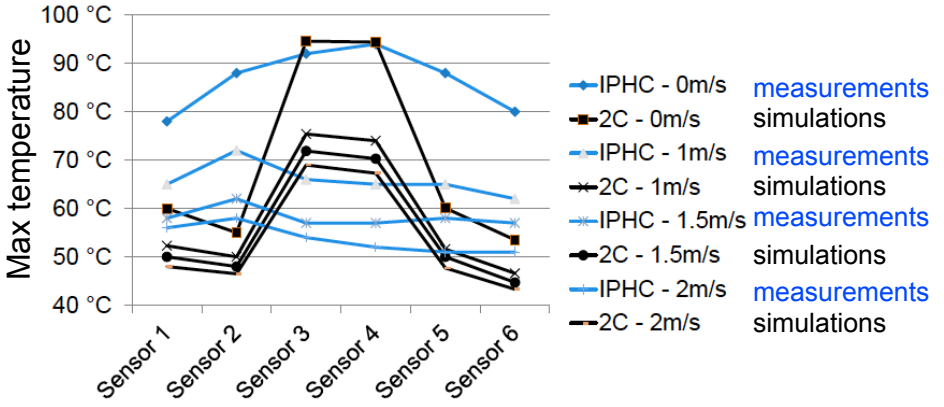


- Test beam
  - ✗ Foreseen early November @ CERN-SPS, 120 GeV π-

PLUME-2010 simulations

- Cooling
  - ✗ Difficulties to reproduce measurements
    - ➔ Average T well reproduced
    - ➔ Distribution of T depends crucially on material modeling (ex. metal lines)
  - ✗ Impact of heat conductivity between sensors
    - ➔ mechanical stitching between sensors could reduce T by ~ 5 °C





- Mechanical
  - ✗ Importance of sandwich effect
    - ➔ foam much less stiff possible
  - ✗ predicted vibration frequency to be measured soon
  - ✗ Investigation of single-sided ladder to be done

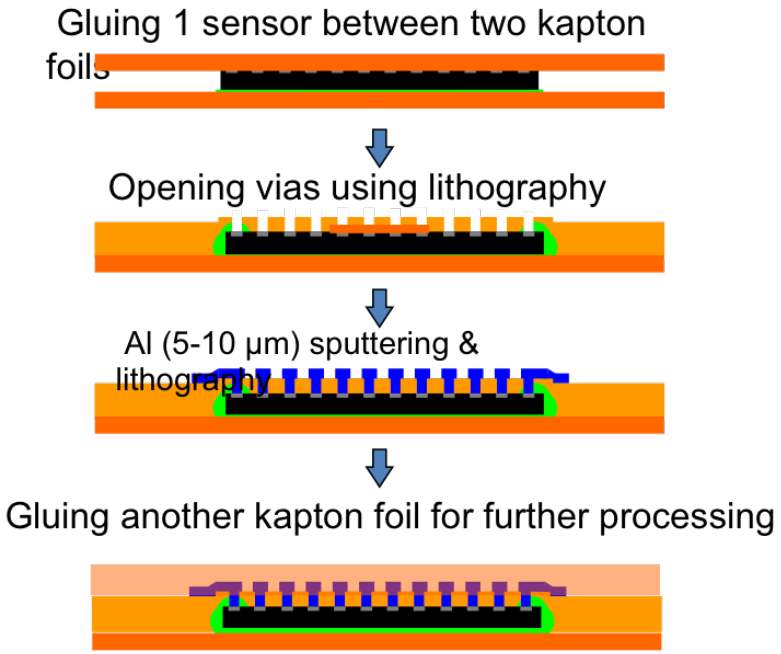
support mat. Budget (X0)	SiC foam 8% 0.18 %	SiC foam 4% 0.09 %	RVC 0.03 %
1st vibration mode (Hz)	260	270	230
2nd vibration mode (Hz)	990	980	450
3rd vibration mode (Hz)	1280	1110	670
static sagging (μm)	4	5	6

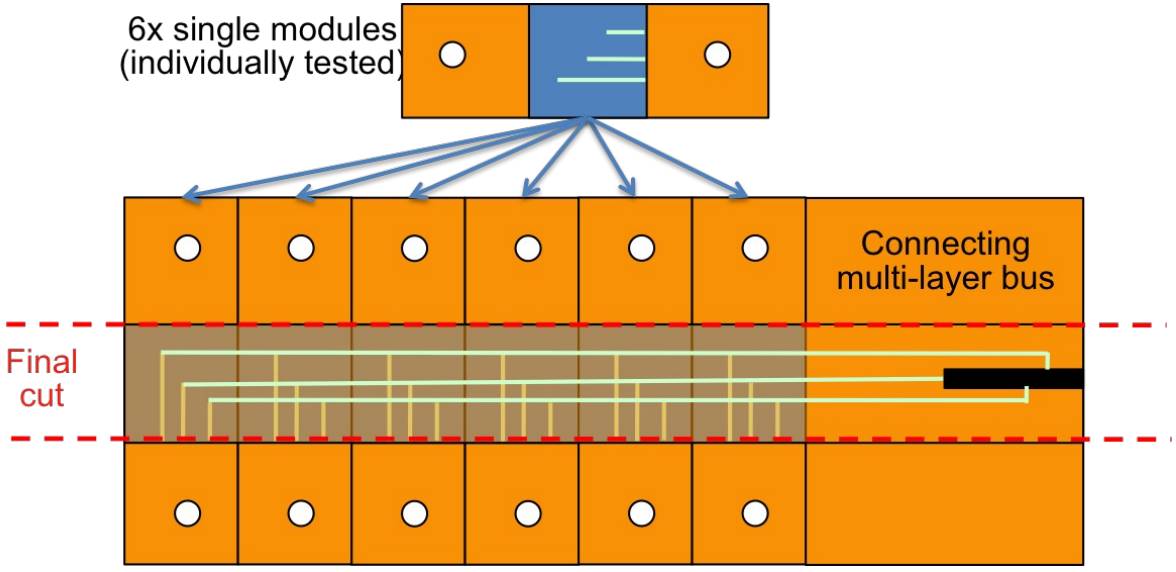
PLUME-2011 design

- Modification wrt 2010 design
  - ✗ priority to material budget
  - ✗ reduced cable width ►►►►
    - ➔ only 4 additional mm / sensor width
    - ➔ metal density higher → helps heat transfer
  - ✗ low-mass cable with aluminum
    - ➔ provided by CERN
  - ✗ SiC foam (spacer) lower density ~ 4%
- Preliminary material budget
  - ✗ transverse cross-section
    - ➔ 0.344 % X0 = 2x0.053(sensors) + 2x0.058(Al flex) + 0.092(SiC4%) + 0.030(SMD)
  - ✗ weighted budget accounting for overlaps (MIMOSA 26 sensitive layer=10 mm wide)
    - ➔ 0.502 % X0 = 2x0.069 (sensor) + 2x0.098 (Al flex) + 0.138 (SiC4%) + 0.030 (SMD)
- Schedule
  - ✗ copper cable version fabricated, 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 → "VXD sector" test in AIDA

SERNWIETE

- Design features
  - ✗ realisation by R. De Oliveira team @ CERN
  - ✗ embed sensor one by one
    - ➔ alleviates traces-pad alignment difficulty
    - ➔ allows individual testing before assembly
  - ✗ processing of further metal layers decoupled from sensor embedding
    - ➔ 3 additional metal layers
  - ✗ metal is aluminum
- sensor embedded → stand higher mechanical stress
  - ➔ allows deeper thinning (~30 µm)
  - ➔ allows bending
- Material budget
  - ✗ sensor ~ 0.03 % X0
  - ✗ Metal ≤ 0.02 % X0
  - ✗ polyimide ≤ 0.1 % X0
  - ✗ Overall ≤ 0.15 % X0



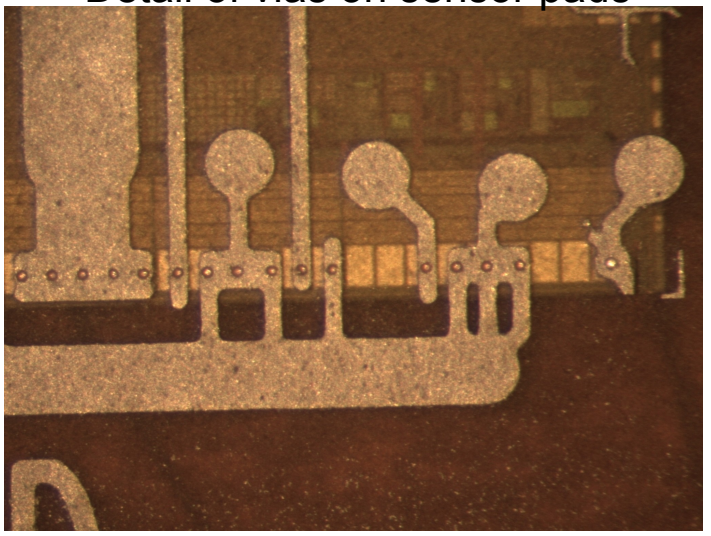


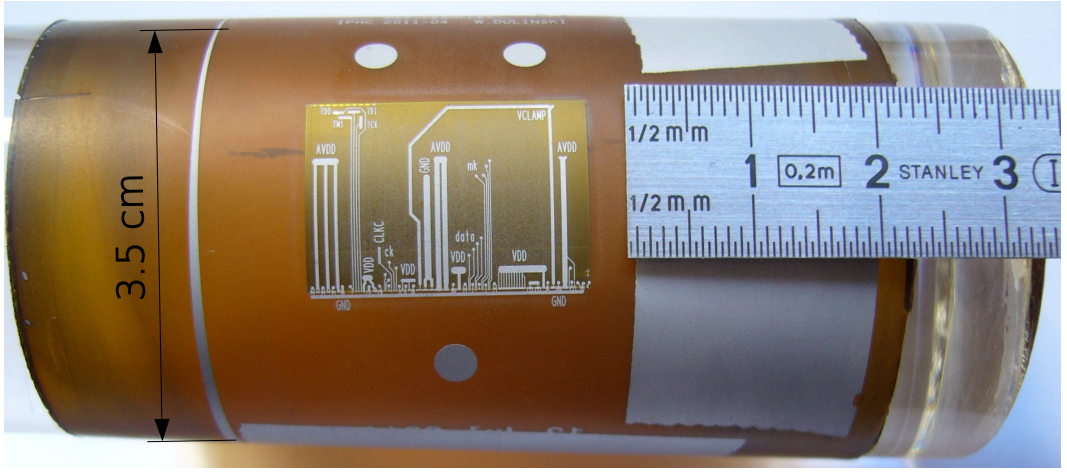
SERNWIETE

- Status
  - ✗ first single sensor (MIMOSA 26) embedded, August 2011
  - ✗ not functional due to shallow Vias

- Further steps
  - ✗ new trial this Fall
  - ✗ 2-sensors cable in December 2011
  - ✗ thermo-mechanical studies for 2012
  - ✗ 6-sensors cable < Summer 2012

Detail of vias on sensor pads





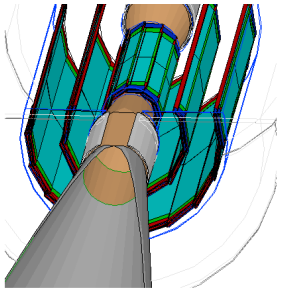
Mechanical sample embedded and bent
→ No cracks visible on the silicon,
still await electrical confirmation

Summary

- Double-sided ladder (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

- Unsupported Single-sided ladder (SERNWIETE)
  - ✗ 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 schedule)

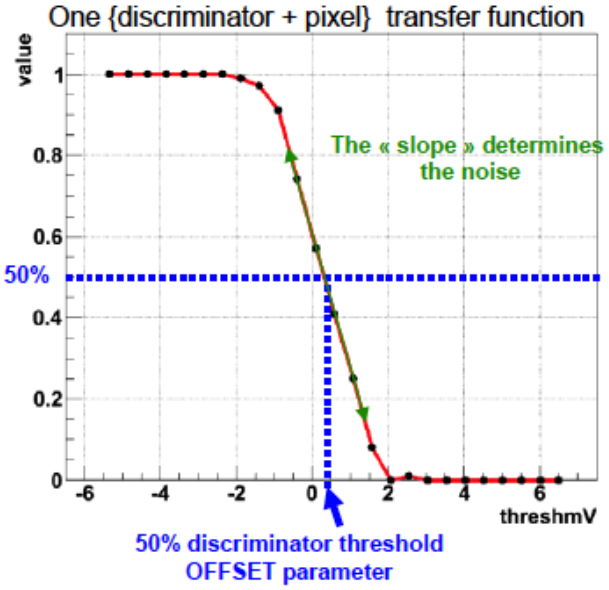
- Applications
  - ✗ PLUME beam tests will be an important milestone for the ILD
  - ✗ 6 to 8 ladders (12 x MIMOSA 26 each) will run during long beam periods in the framework of the FP7-AIDA project
    - ➔ Complementary experience wrt STAR-PXL (start of run: FY2012)



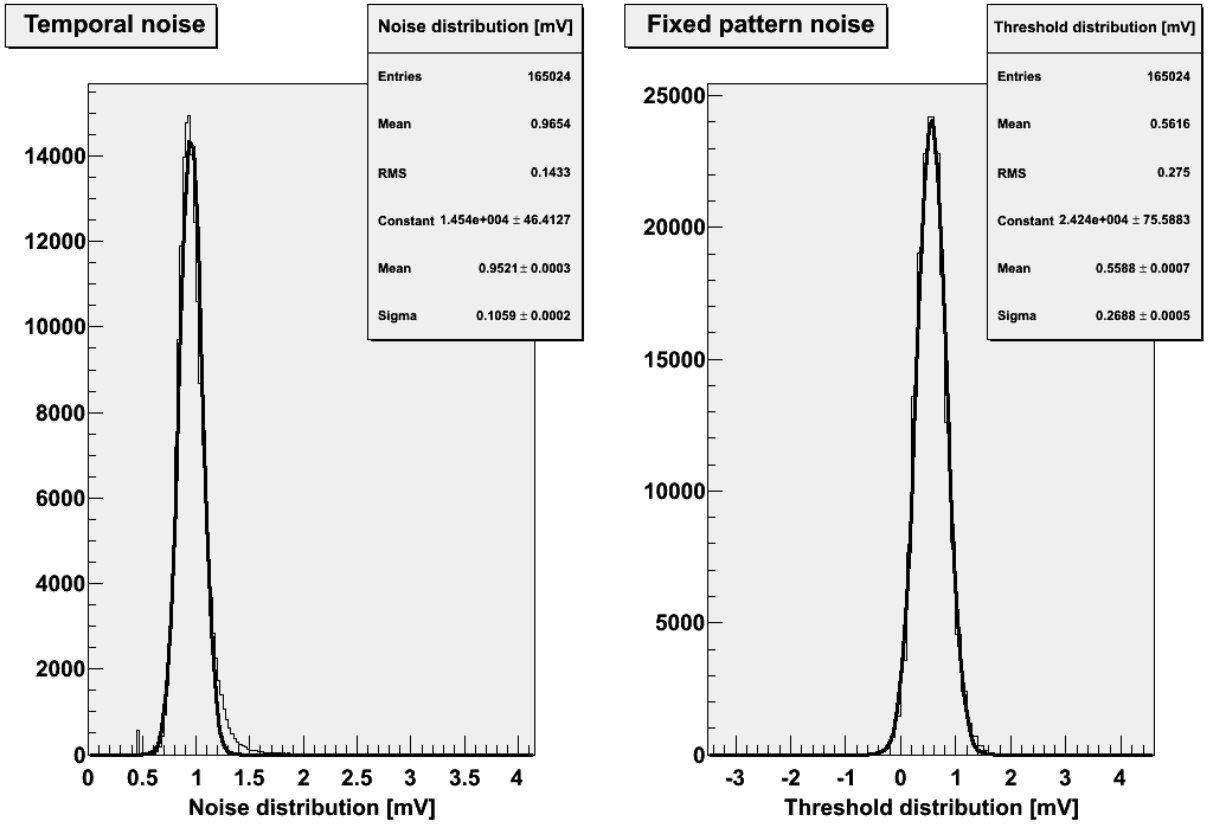
- Additional slides
  - ✗

PLUME-2010 electrical tests

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

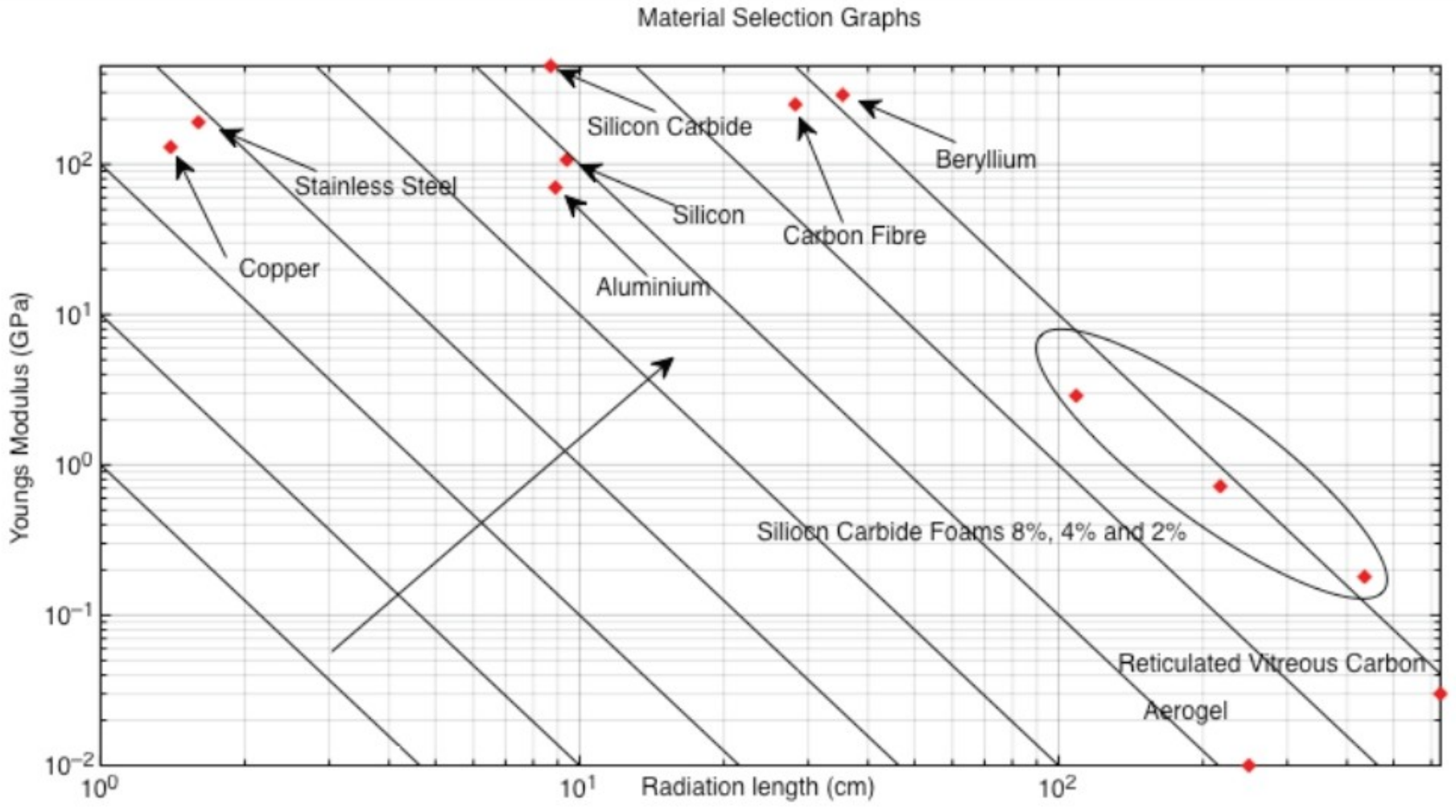


Current consumption/sensor ~230 mA @ low threshold



Temporal noise at mV level as expected from single sensor measurements

Materials for stiffener/spacer

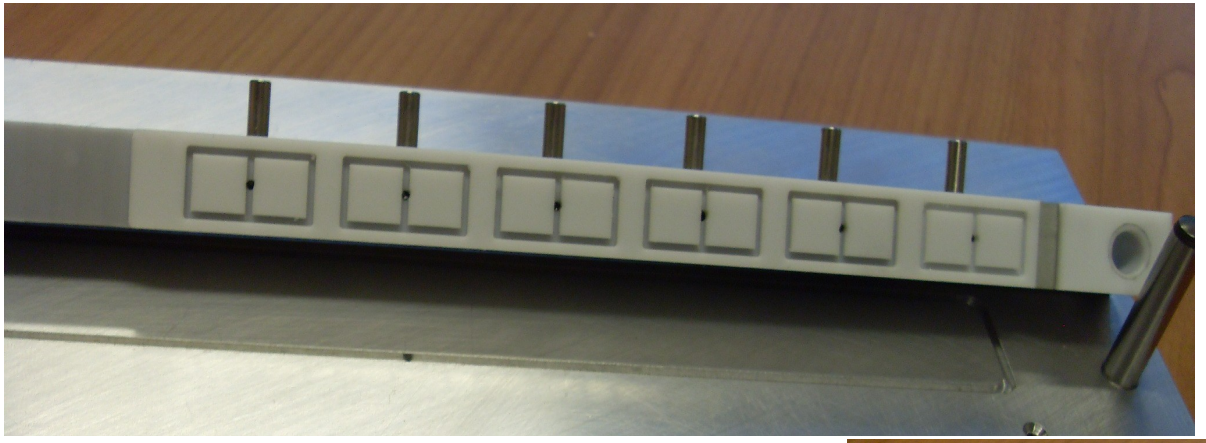


From Joel Goldstein, Brisol U.

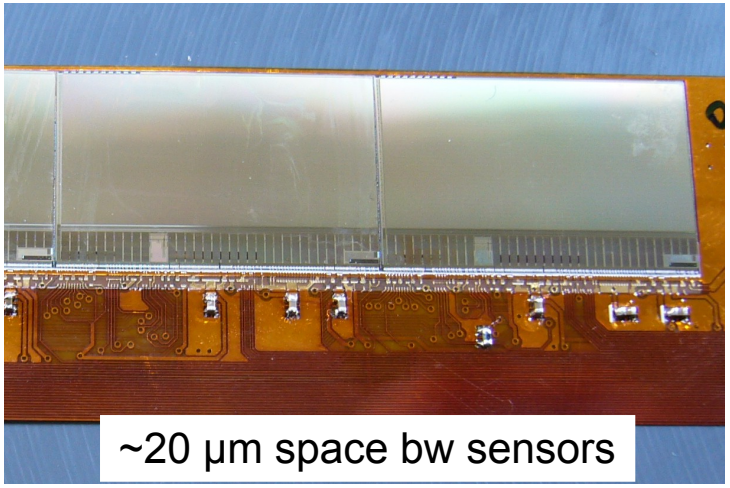
PLUME-2010 module assembly

MIMOSA 26
50 µm thick

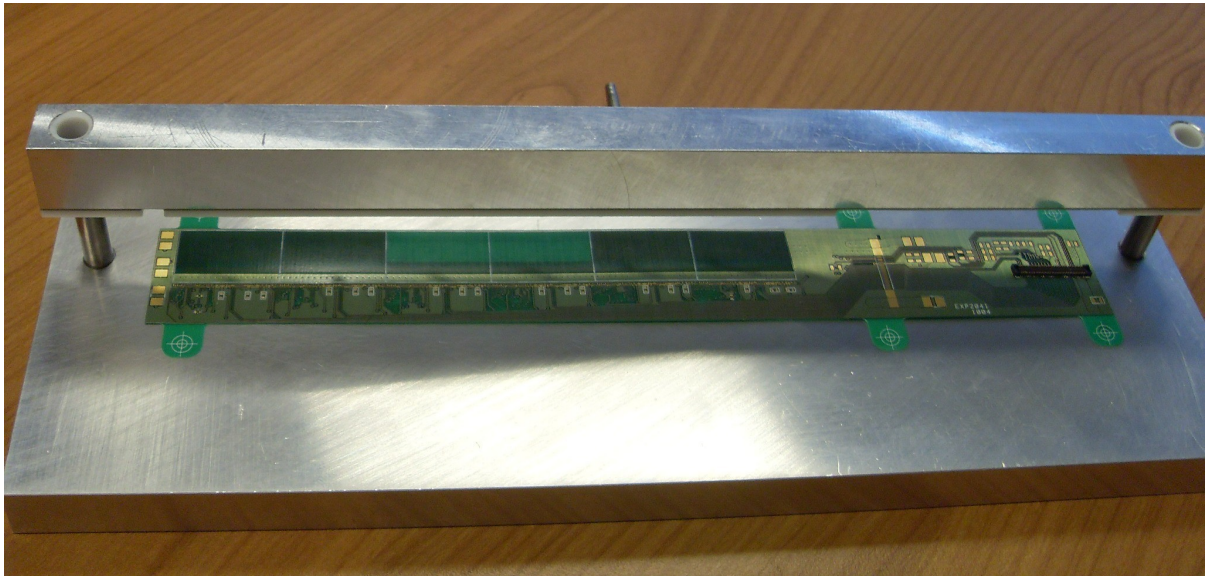
x6, manual positioning,
vacuum fixed



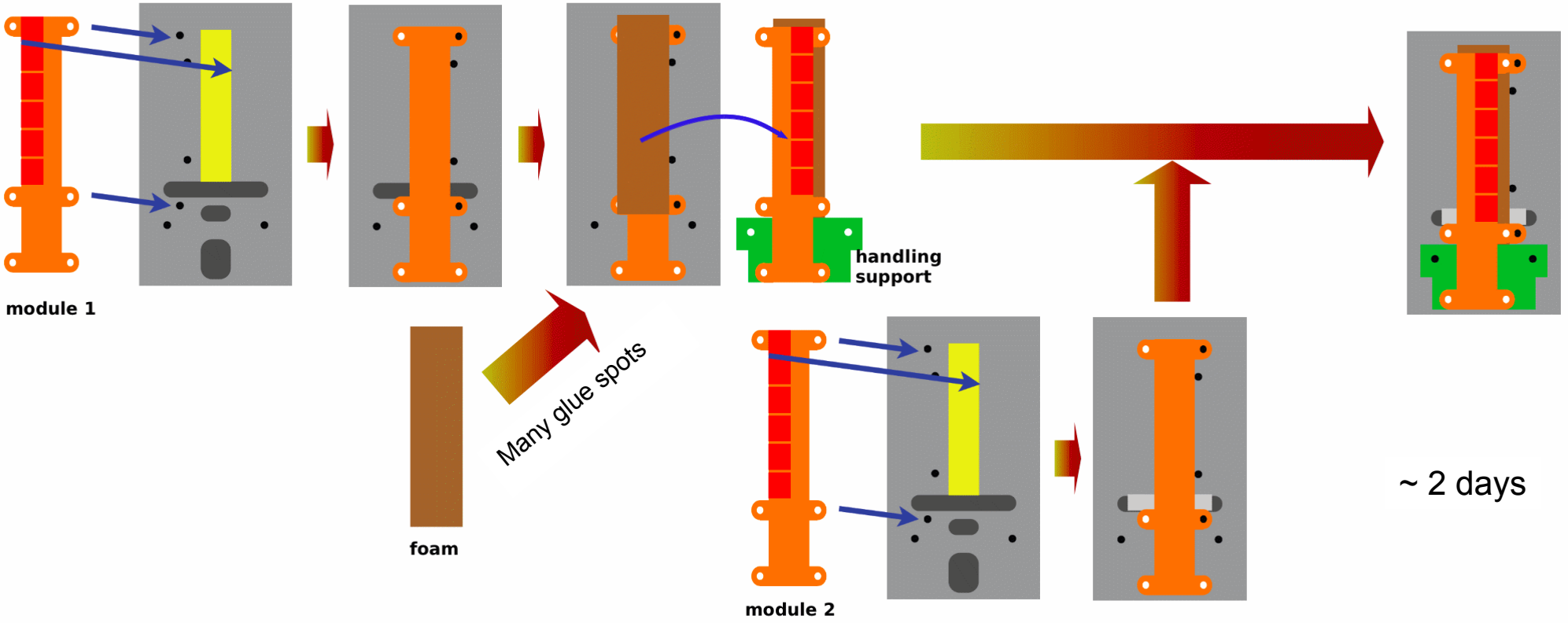
Controlled glue dispensing
small pressure while curing
Then wire bonding



~20 µm space bw sensors



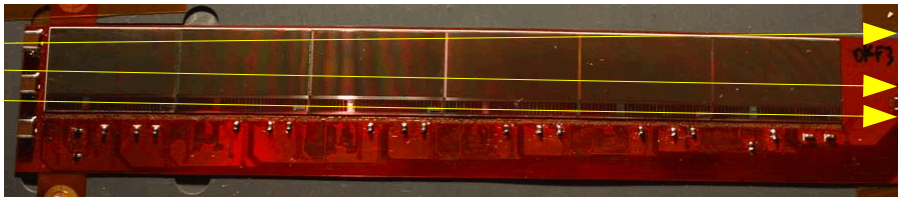
PLUME-2010 ladder assembly



- 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 tests

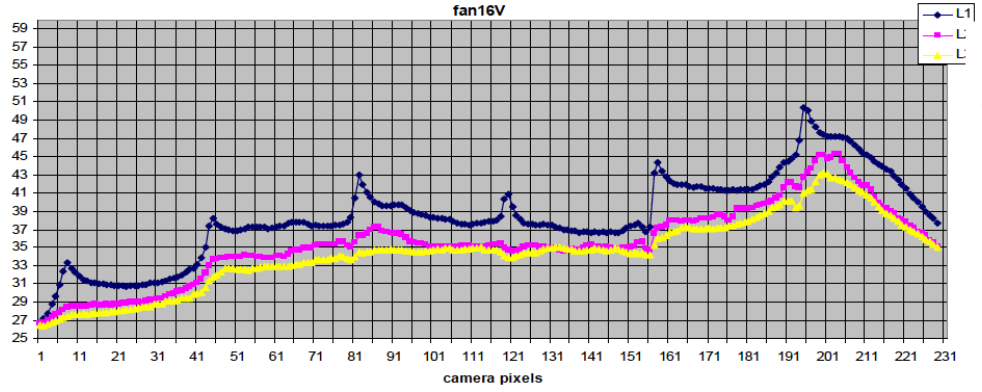
IR camera thermal measurement on a single module



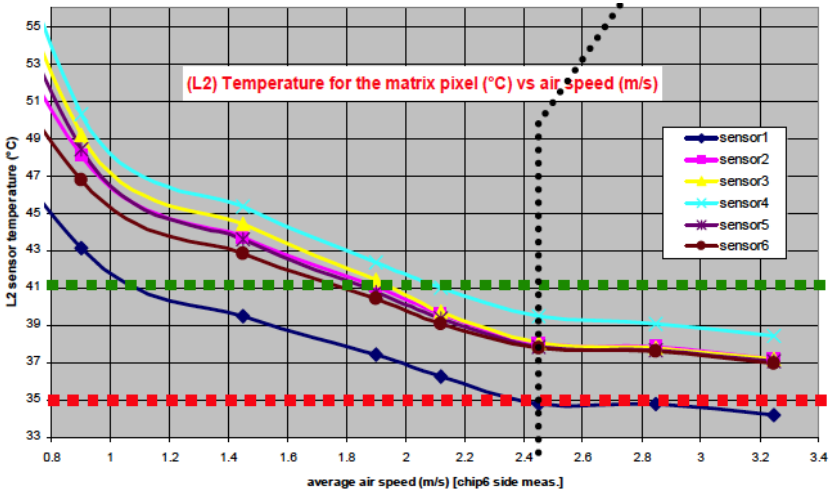
MIMOSA 26 internal (diode) temp. measurement on ladder

only 1 over the 2 modules switched on

High air flow
+1.5 m/s

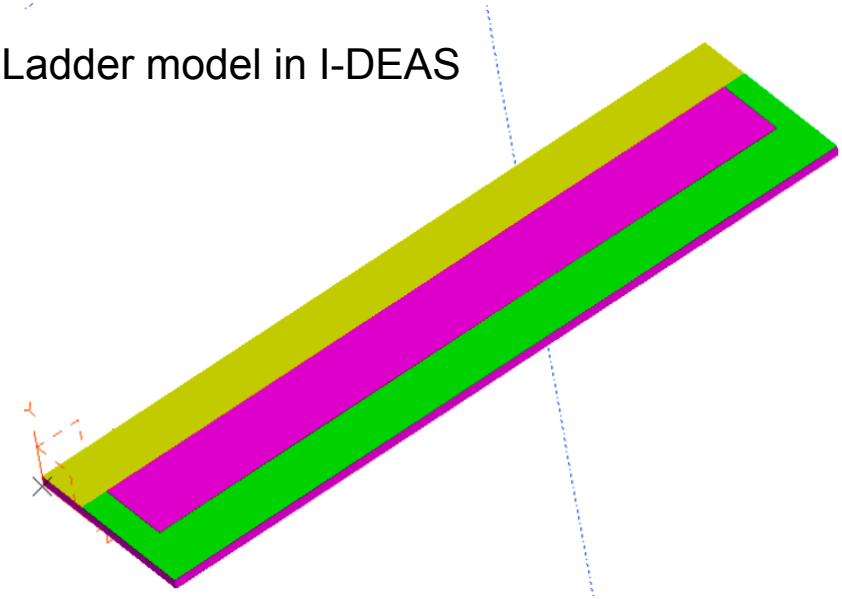


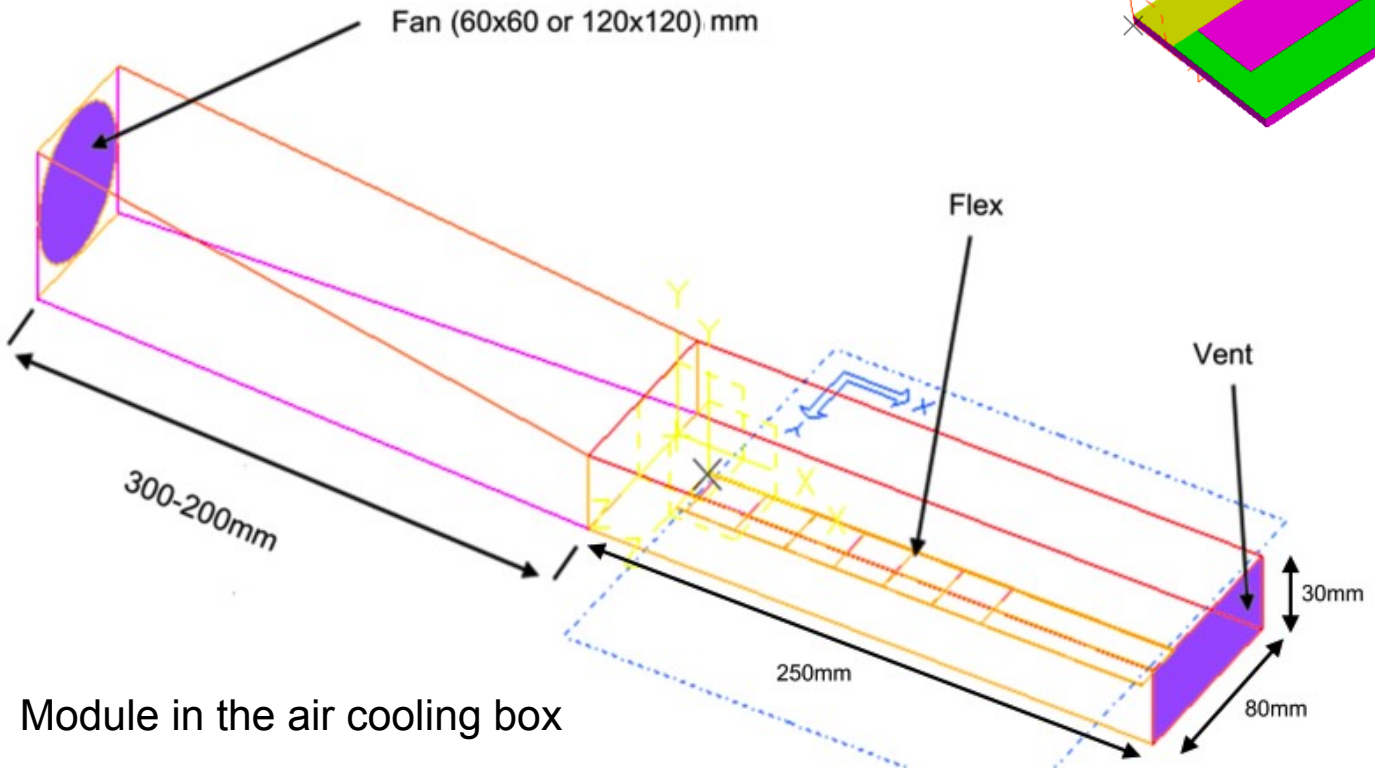
Low air flow



PLUME-2010 simulations

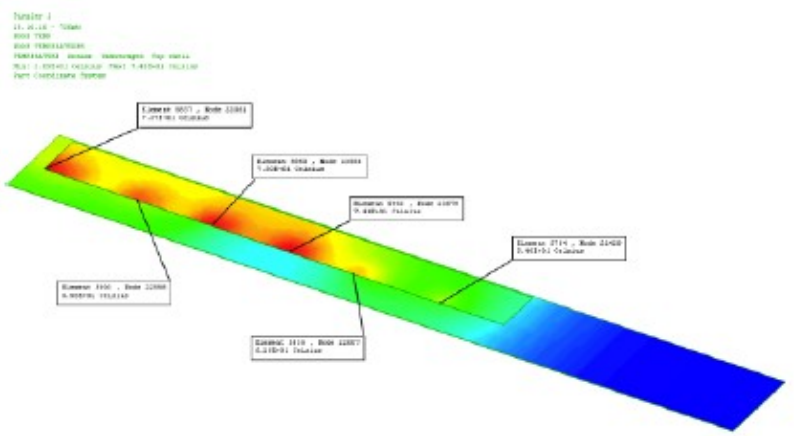
Ladder model in I-DEAS



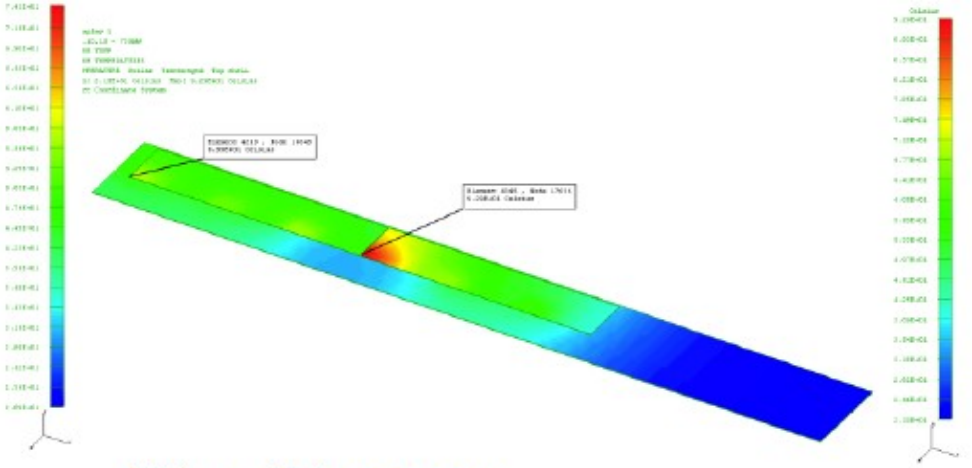


Module in the air cooling box

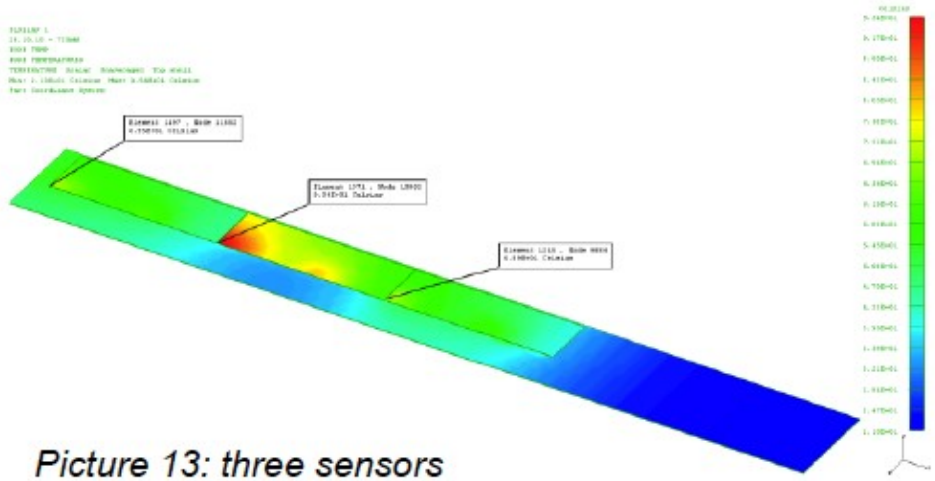
PLUME-2010 simulations



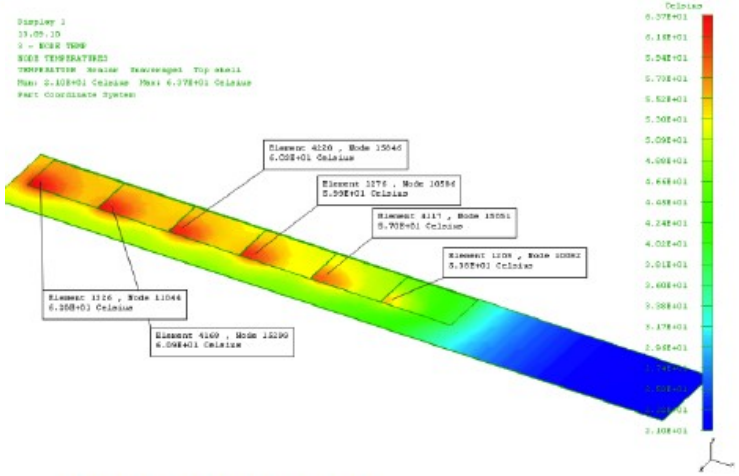
Picture 11: one sensor



Picture 12: two sensors



Picture 13: three sensors

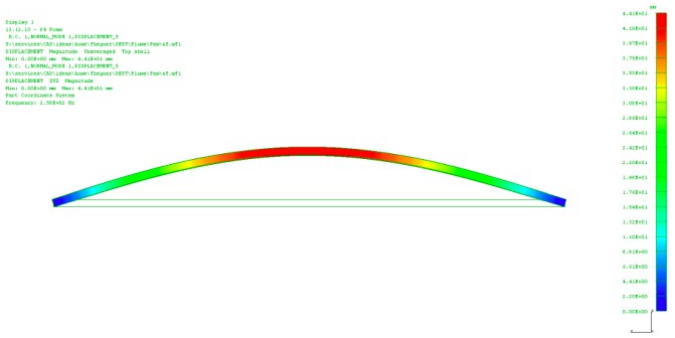


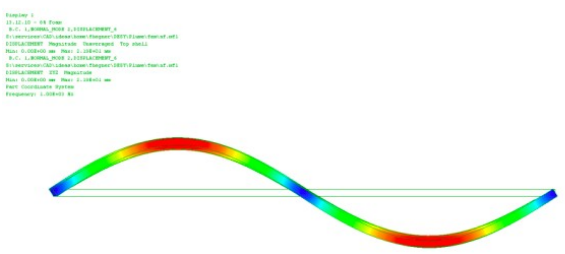
Picture 10: all sensors

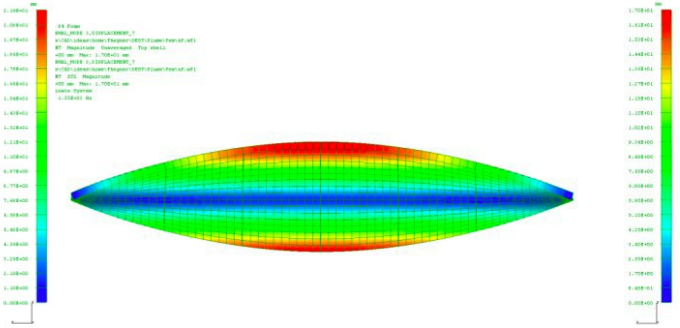
→ importance of heat conductivity among sensors for efficient cooling by air

PLUME-2010 simulations

Ladder supported at both ends







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2nd vibration mode (Hz)	990	980	450
3rd vibration mode (Hz)	1280	1110	670
static sagging (μm)	4	5	6

PLUME-2011 simulations

- Improved T homogeneity ← higher metal layer density