Module assembly and metrology for the Phase-2 Upgrade of the Strip tracking detector of the ATLAS experiment

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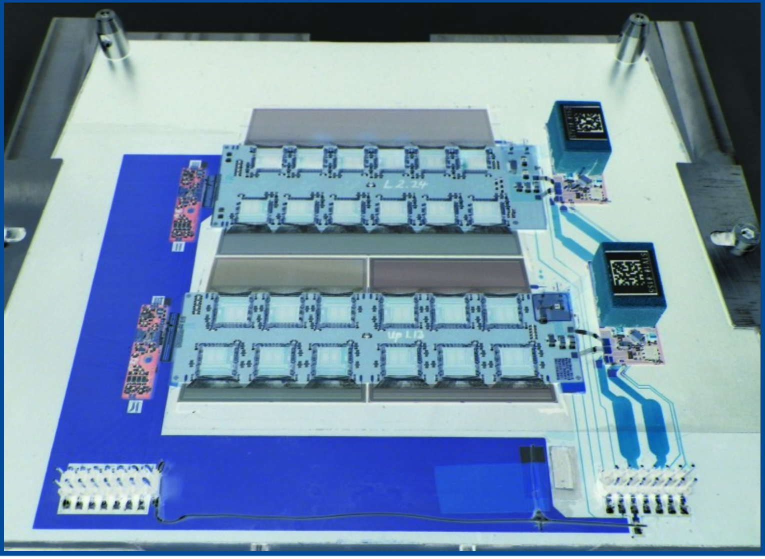
(University of Freiburg)

on behalf of the endcap and the barrel strip community



Forum on Tracking Detector Mechanics

July 2nd 2014

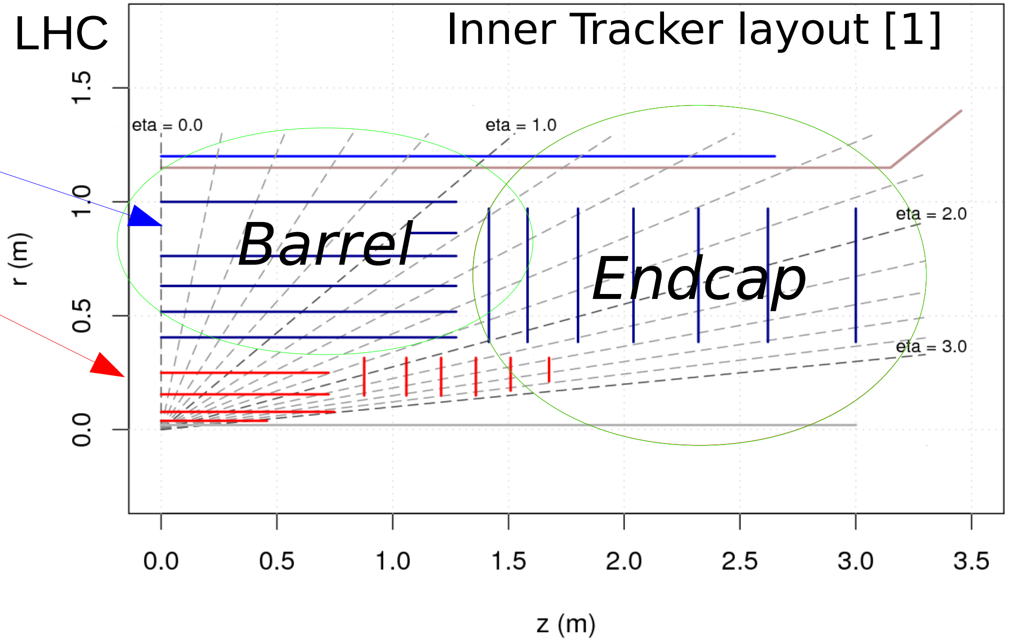
DESY, Hamburg

Outline

- Phase-2 Upgrade of the ATLAS experiment
  - Layout of the upgrade strip tracker
  - Barrel and Endcap Strip Tracker – Prototyping of Stave and Petalet Modules
- Module Assembly – Metrology – Mechanical and Electrical Results
  - Barrel – Stave – Stavelets
  - Endcap – Petalet
- Summary of Stave and Petalet Assembly Program
- Outlook

Upgrade of the Silicon Tracker

- Towards High Luminosity (HL) LHC



Inner Tracker layout [1]

strip detectors

pixel detectors

- Requirements:
  - Luminosity of 5x10^{34} cm^{-2}s^{-1} leeds to high rates → high granularity
  - high fluences lead to radiation up to 2*10^{15} n_{eq}/cm^2
    → radiation hard sensors and electronics
  - low material budget to improve tracking
    → use “light” mechanics
  - implementation in the existing detector, partial reuse of old services

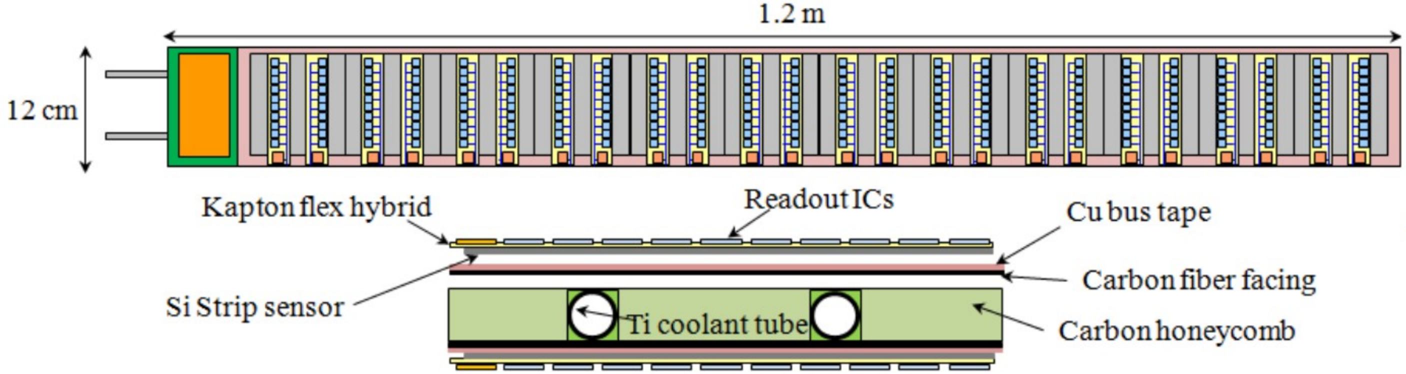
Detector	Silicon area [m^2]	Channels [10^6]
Pixel total	8.2	638
Strip barrel	122	47
Strip endcap	71	27
Present Pixel	20%	12%
Present SCT	30%	8%

[1] ATLAS Collaboration, 2012, Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment.

Requirements/Plans for the Detectors

- double-sided modules with up to 6-inch n-in-p silicon strip sensors and readout electronics (placed directly on top of the sensors)
- save mass and low amount of material
- rigidity and stability for an easy integration of the big structures
- simplified assembly for a large scale production, which makes it possible to produce hybrids and modules in several places/institutes
- precision and glue height not critical for first steps of hybrid and module glueing, but for the placement of modules (actually sensors) onto the bigger structures! Position of the sensor should be determined by a proper survey to achieve a good alignment with the software
- use of CO_2 cooling planned, cooling tubes located in the support structures (cores) in between the front and backside modules

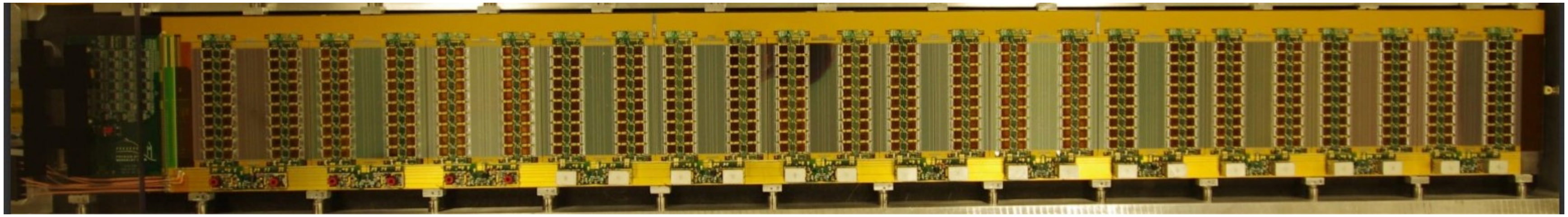
Stave



- Idea:
  - easy to build
  - small amount of material (for the stave X/X_0 ~1.8%)
  - but, stiff structure made out of carbon to hold several modules (1.2m long)
  - titanium tubes integrated into the core for cooling with CO_2
  - bustape for supplying the modules with power and readout data placed ontop of the carbon facings
  - easier to integrate bigger structures into the detector

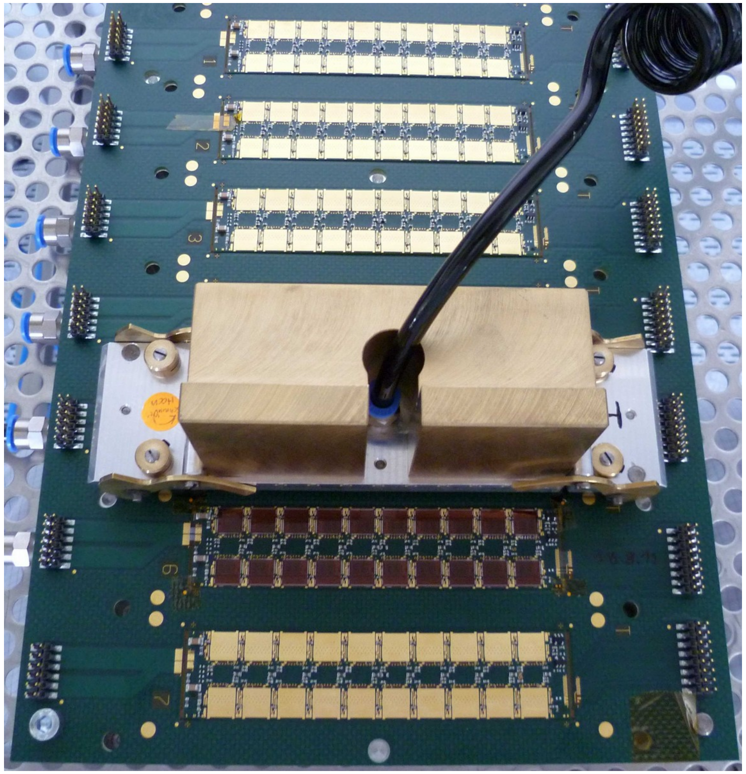
→ hybrid will be directly glued onto sensor surface and sensor will be glued on stave!

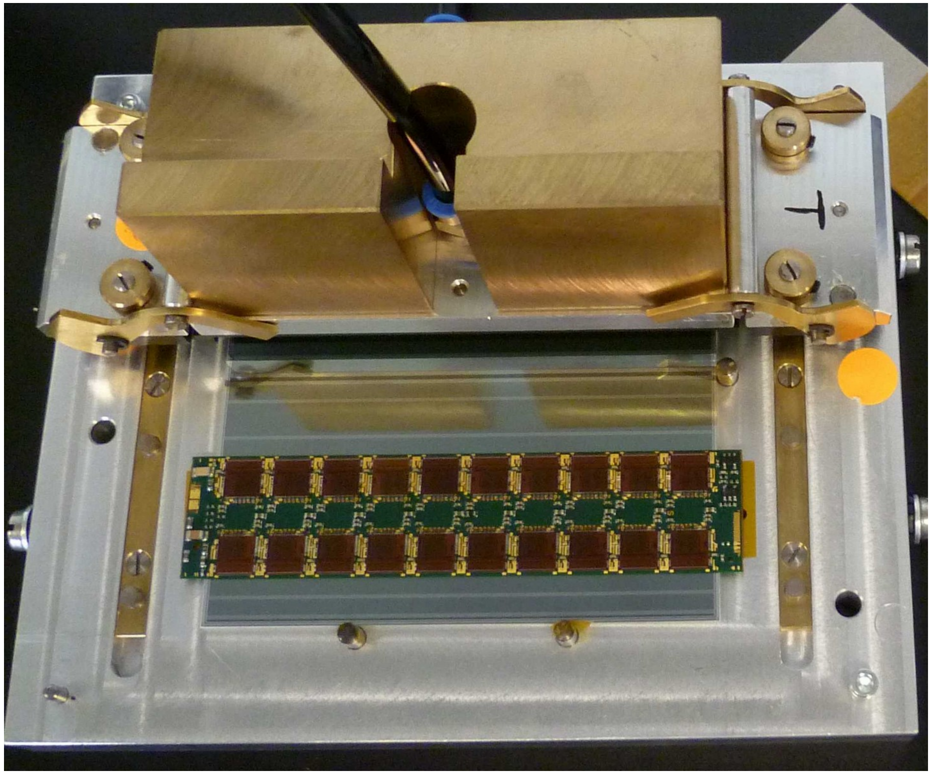
- A fully loaded side of the DC-DC powered Stave containing 12 working modules (24 hybrids)



Stave Hybrids and Modules

- Stave hybrids come in panels, containing 8 hybrids
  → can be easily tested after glueing and bonding
  → improvements on the tabs to hold the hybrids in their place (gave some bowing of hybrids during reflow)

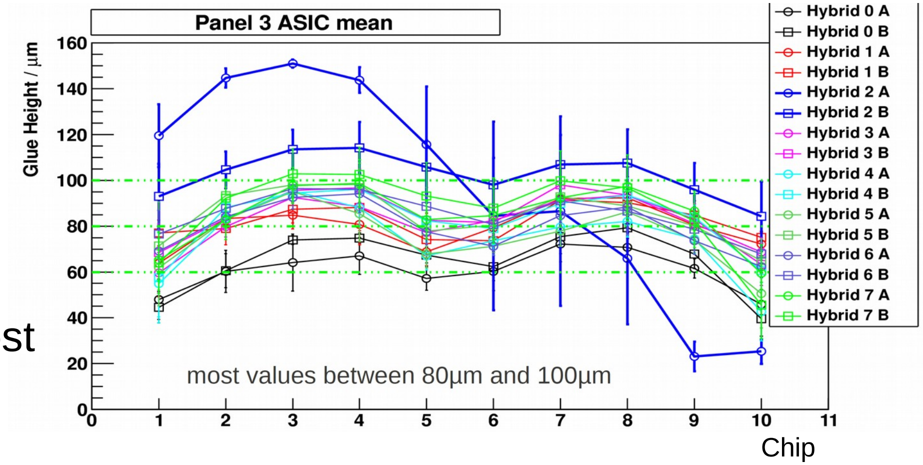




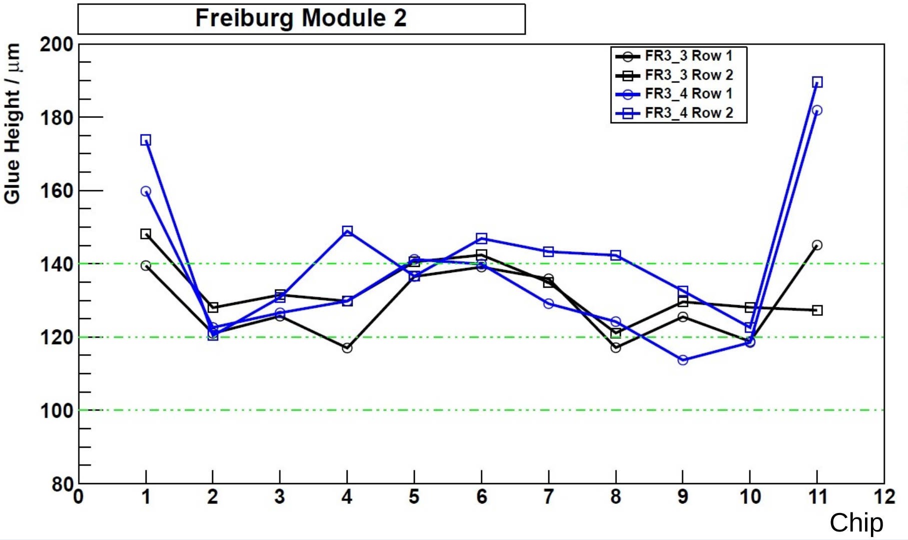
- 250nm stave modules are made of a sensors with four strip rows and two hybrids (with each having two rows of 12 ASICs and 128 channels/ASIC)

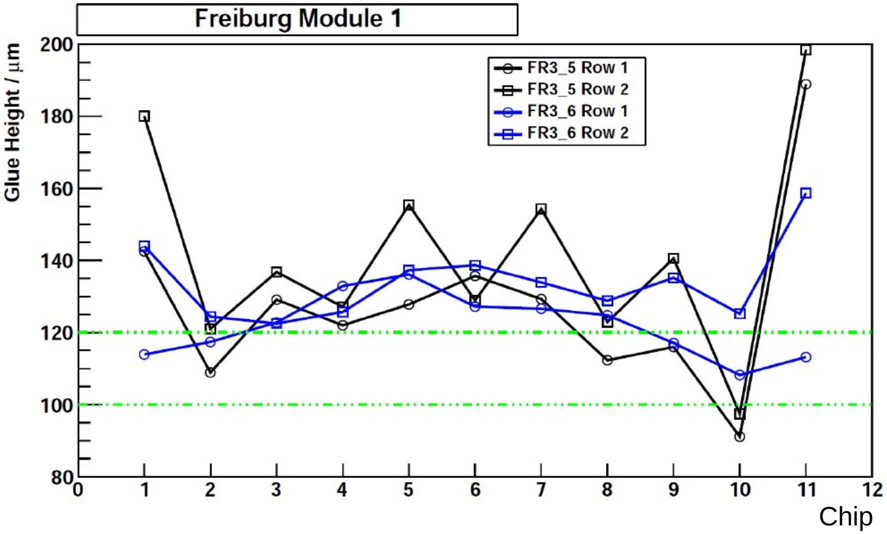
Stave – Module Height Measurements

- Glue height is measured as difference between pads in all four corners of the ASIC and nearby pads on the hybrid with a measurement microscope (using autofocus)
  → height is under control (80-100μm) (see right for results of one full panel)
  → height differences only critical for bonding and later pick-up with the tool
- Glue Height of several Modules is measured in a similar way and as expected (>100μm, mostly flat in the middle part, while the outermost points are higher due to bending of the hybrid parts with no sensor underneath)

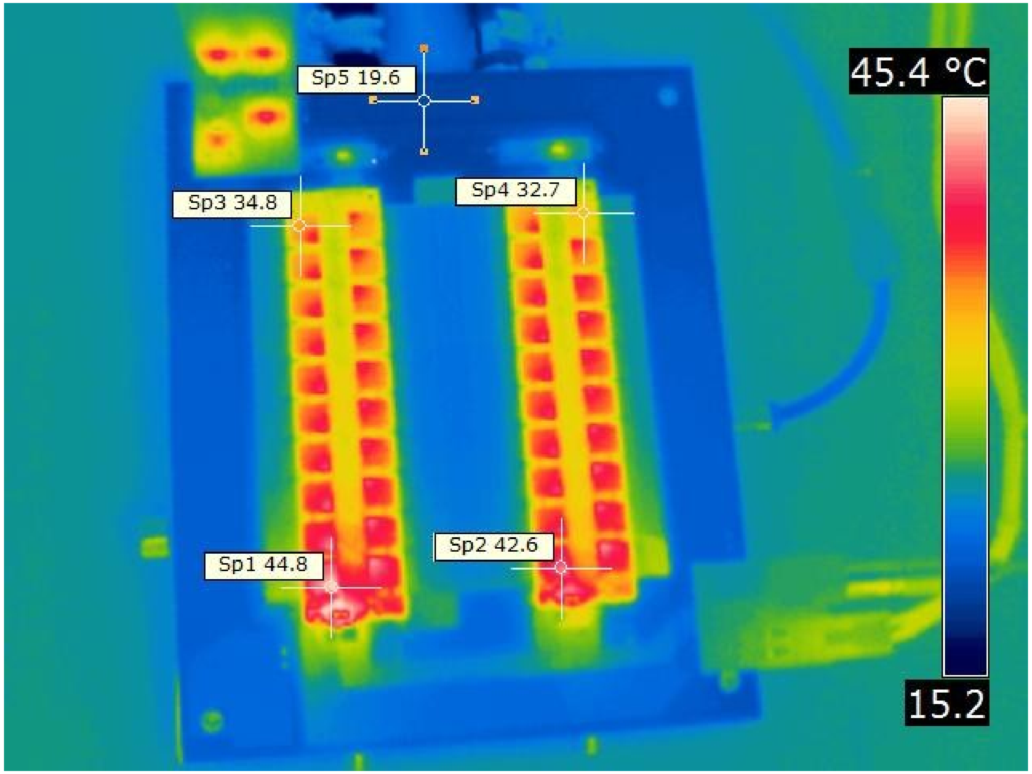


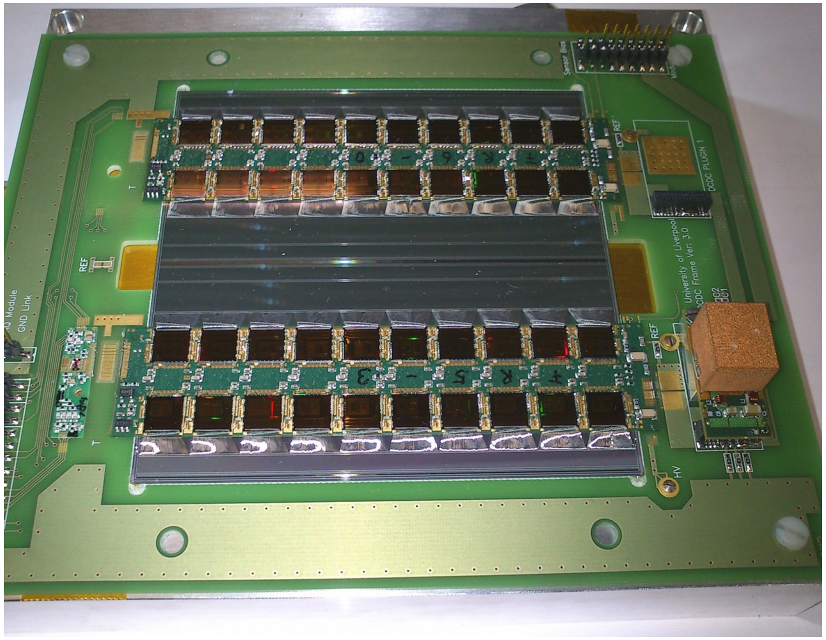
most values between 80μm and 100μm





Thermal Map of Stave Module

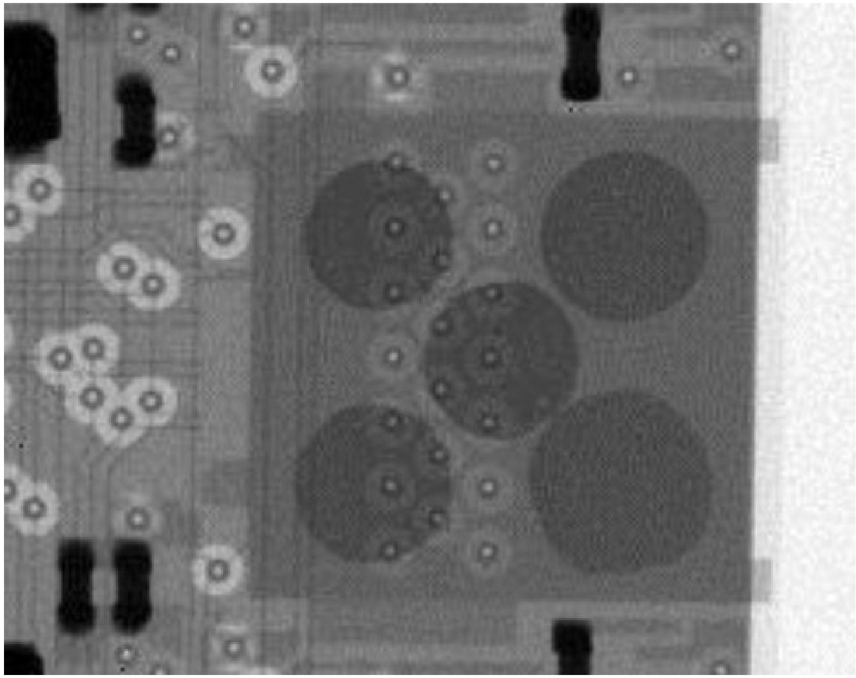




- Check the thermal distribution over a full module (measured in Freiburg)
  - ASICs are quite hot,
  - but no hot spots on the sensor,
  - cooling works fine, heat is distributed uniformly through the hybrid to the sensor (backside)

Hybrid ASIC Glue Coverage

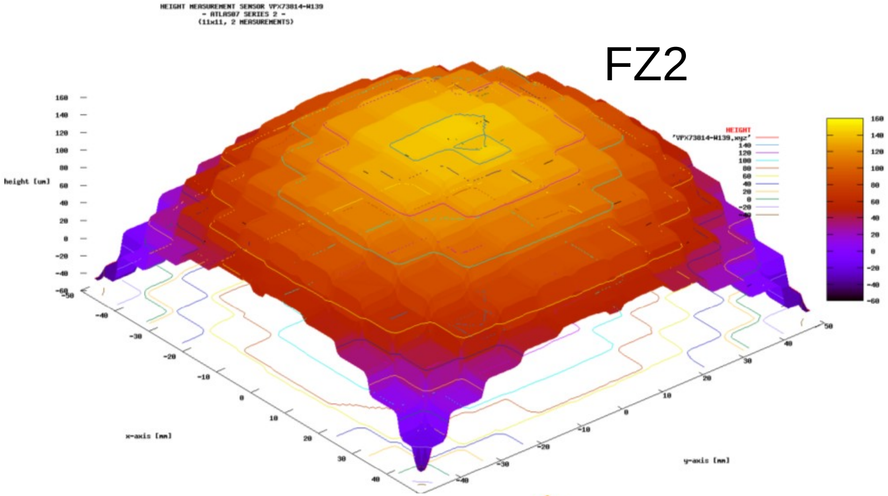
- X-ray imaging of the assembled hybrid with the Medipix detector done in Cambridge/Glasgow allows to easily check
    - spread of glue and amount of covered area
    - uniformity of the single glue dots (pattern)
- Picture shows ~40% coverage
- Could be used to define the glue masks (stencil thickness, pattern?) for the new 130nm ASICs to attach a proper amount of glue in terms of good heat transfer



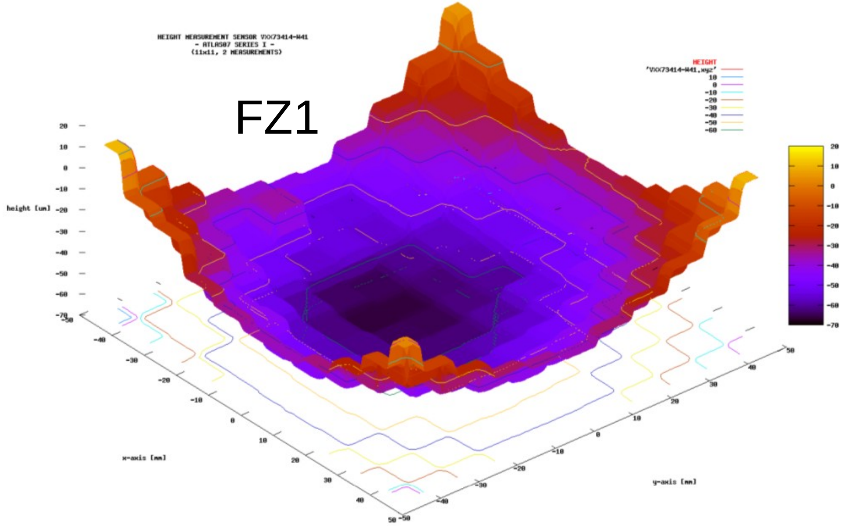
A. Blue at AUW 2014 - Overview of all other activities & Summary from Valencia

Sensor Survey

- The survey of the sensors (several series of ATLAS07 sensors for the Stave modules, measured in several institutes) showed different height results for the two FZ types available
  - Bow differs in sign and magnitude
    - FZ1 negative ~80µm
    - FZ2 positive ~200µm
  - No issues when glueing modules due to vacuum fixation on jig
  - Can still be glued on staves, if the maximum of the bow is <400µm

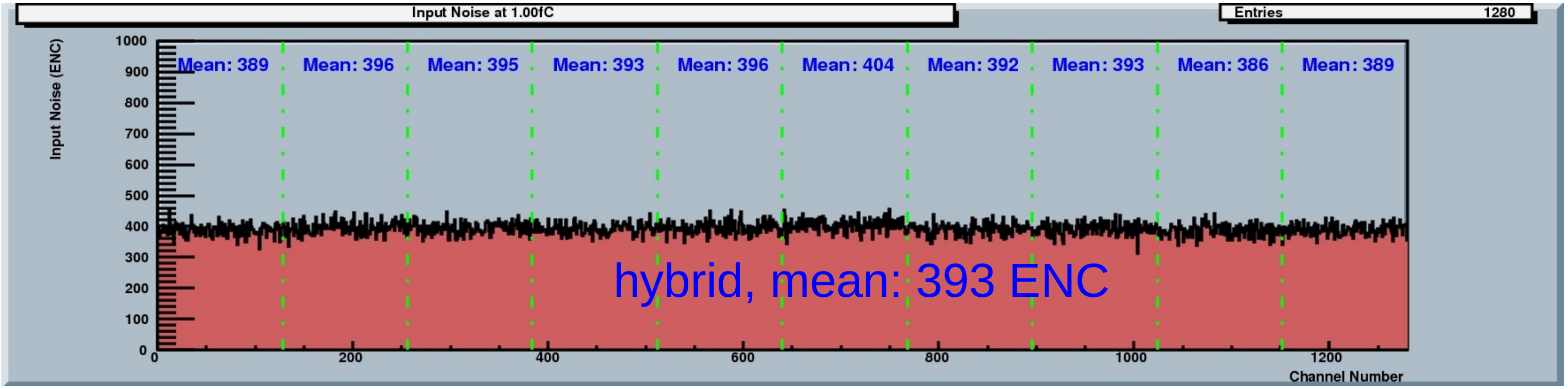


SERIES	SENSOR	EDGES (AVG) [um]	CENTER (MAX) [um]	HEIGHT DIFFERENCE [um]
1	VXX73414-W40 (FZ1*)	8,6	-68,5	-77,1
1	VXX73414-W41(FZ1*)	7,4	-68,0	-75,4
2	VPX73812-FZ1-Pstop-W52	6,4	-66,8	-73,2
2	VPX73814-FZ2-Pstop-W139	-27,0	146,7	173,7
2	VPX73816-FZ2-Pstop-W191	-39,0	173,2	212,2
3	VPX76331-FZ1-Pstop-W295	12,4	-96,3	-108,7

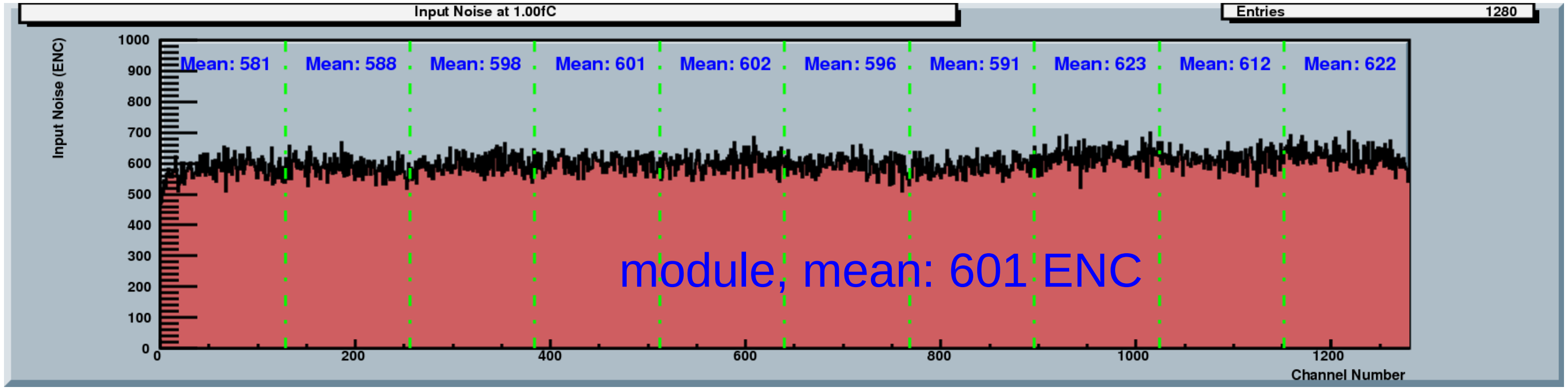


Stave Hybrids and Modules - Electrical Results

- Exemplary results of an electrical characterization test with the HSIO
  → all stave hybrids show similar, good performance
  → mean noise of ~400 **E**quivalent **N**oise **C**harge = electrons



→ mean noise of a stave module is ~600ENC (tested in DC-DC frame at 200V, ~20°C)



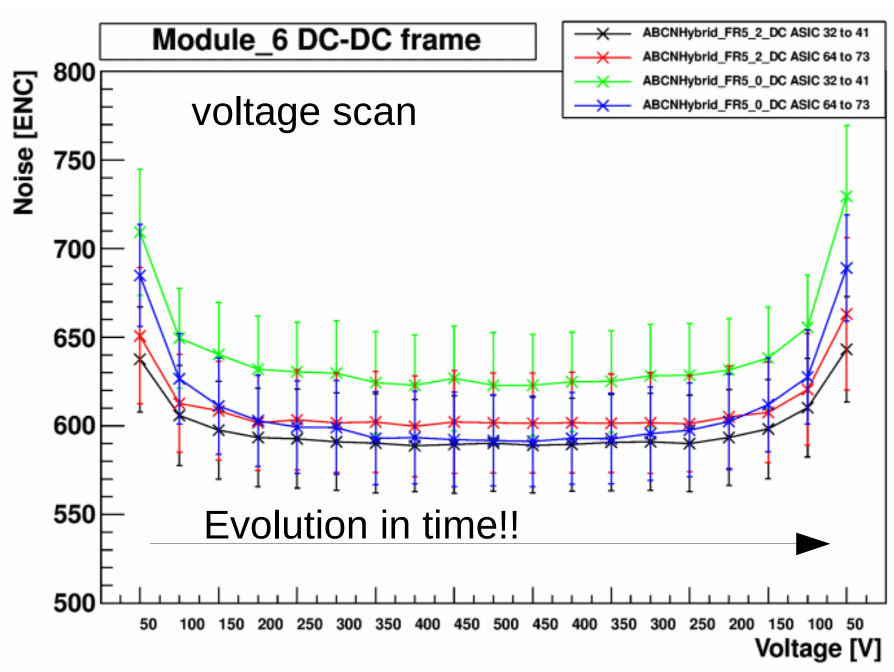
only one of four streams shown!

Stave Modules – More Electrical Results

- Exemplary results of a noise vs. voltage scan (going from 0V→500V→0V, ~20°C) and a longterm noise measurement (200V, 20°C)

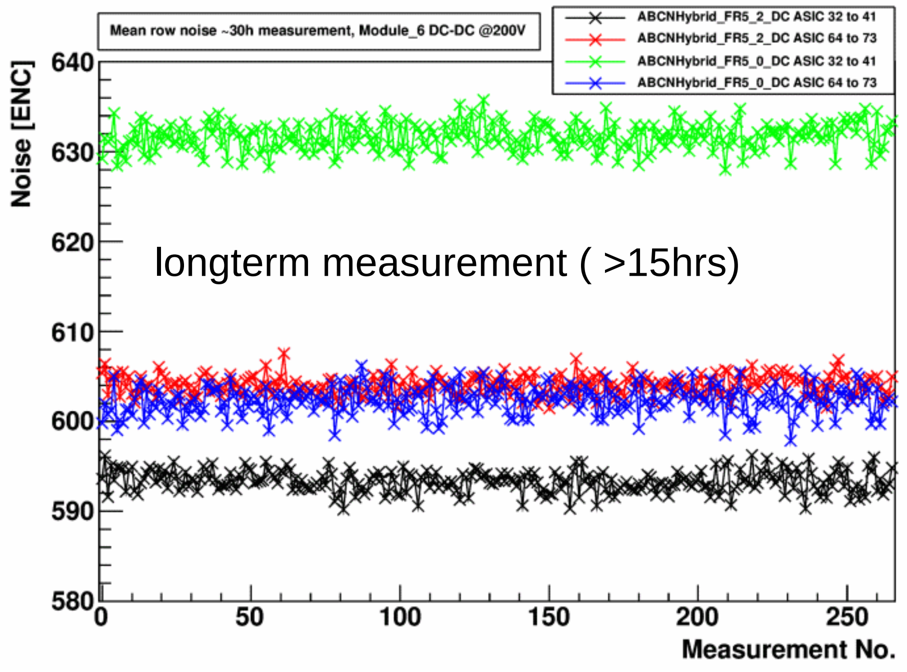
→ obtain a plateau of minimal noise at ~150V (after reaching full depletion voltage!)

→ stable in noise over a long time (variation between measurements < 5ENC)



voltage scan

Evolution in time!!



longterm measurement (>15hrs)

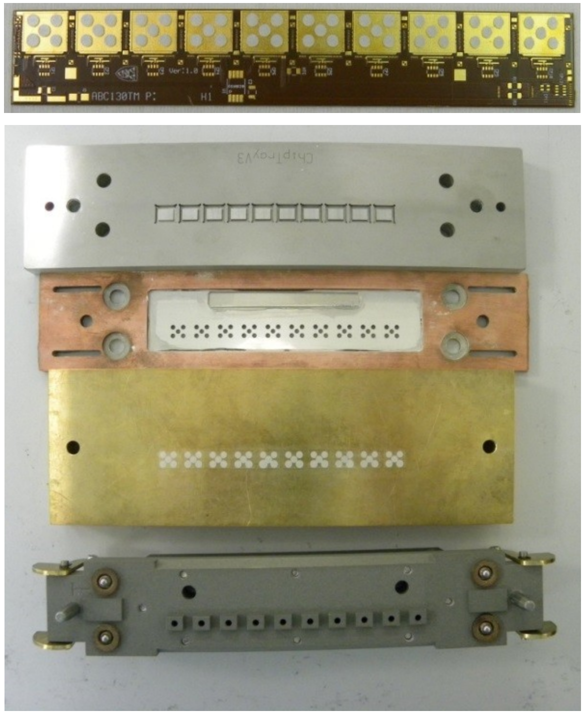
Stave Module Production

- Stave 250nm program is almost finished:

  7 Institutes (Liverpool, Cambridge, Glasgow, Berkeley, SantaCruz, DESY Zeuthen, Freiburg) have very successfully built ~85 modules (~200 hybrids)

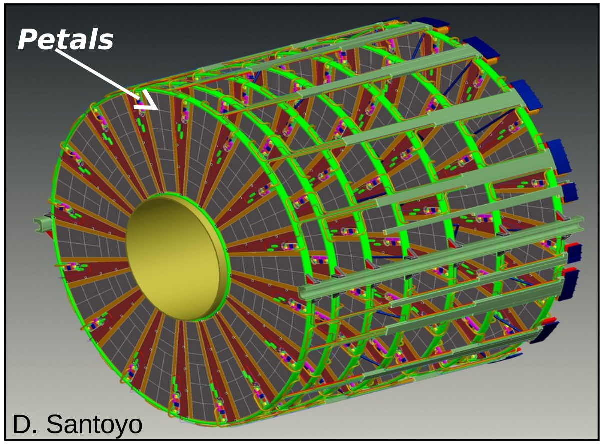
- Modules have been successfully and with the planned precision (~15μm) mounted on Stavelets and Staves (one serial and one DC-DC powered) in the UK and US
  → showing good results and performance!

- Design of the new hybrids and tooling is finished, successfully tested and now awaiting ABCN130 and HCC chips to build and test the first 130nm hybrids and modules

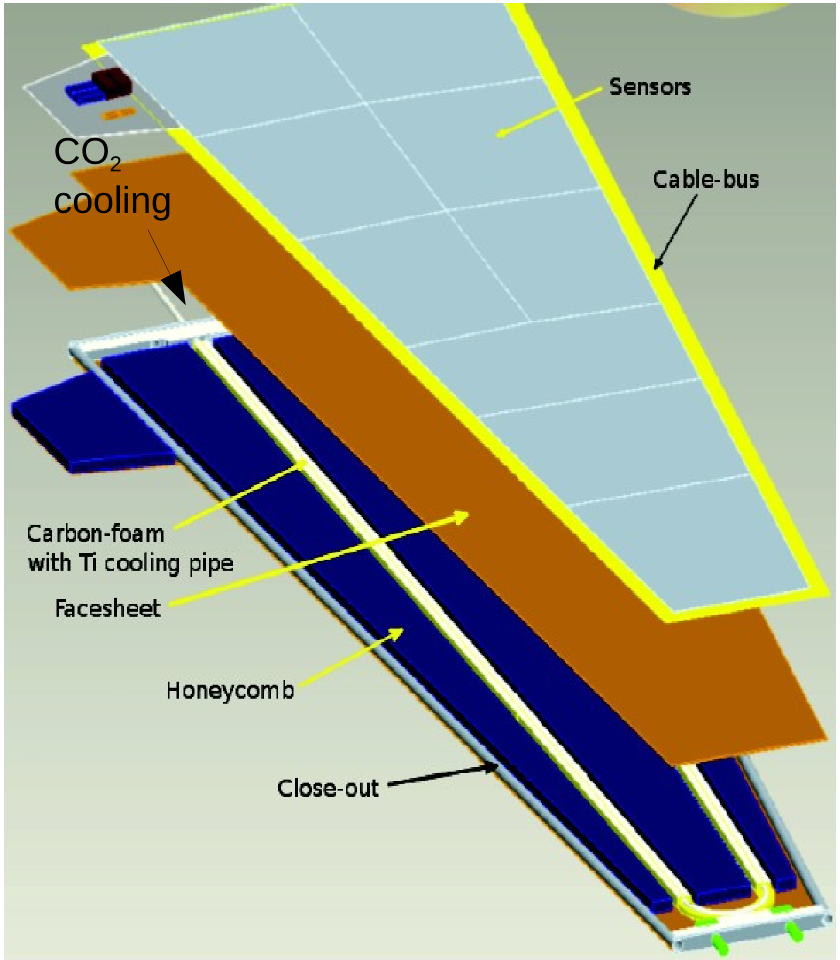


The Endcap, the Petal and the Petalet

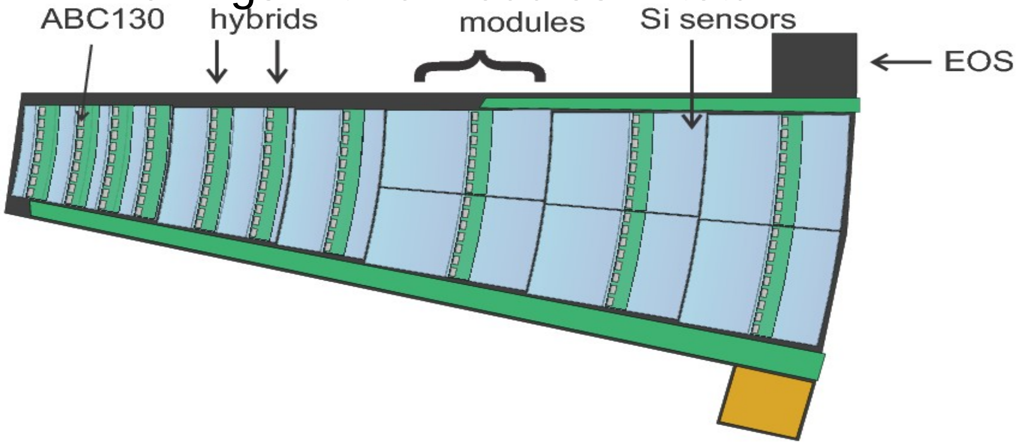
- **Endcap**
  - 7 disks (each) with 32 Petals per disk (→ in total 446 Petals and ~9000 modules)



D. Santoyo

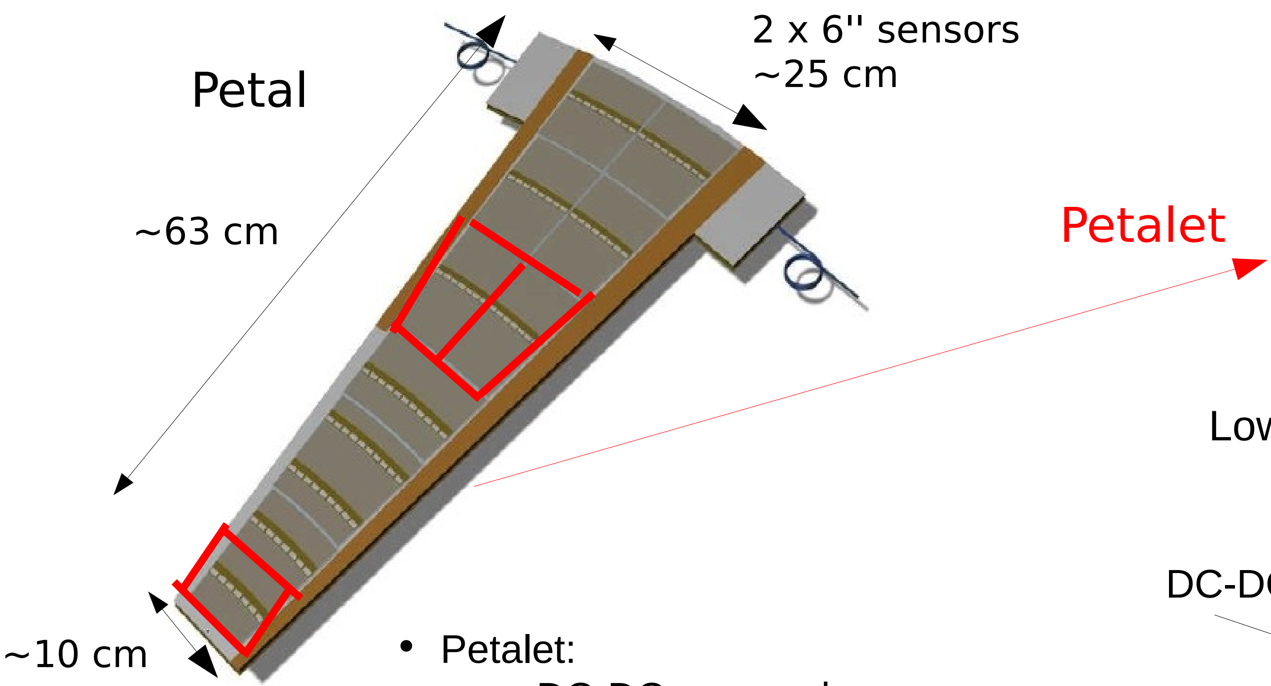


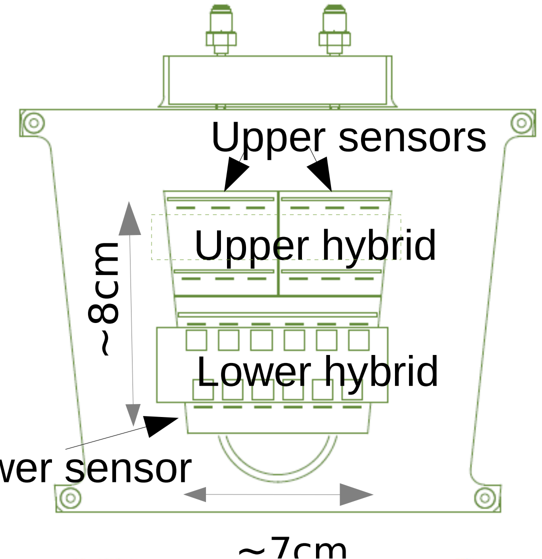
- **Petal**
  - 6 rings with 9 modules in total



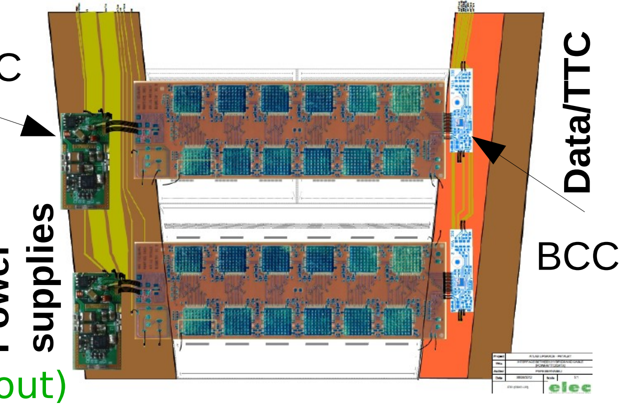
The Endcap, the Petal and the Petalet

- Idea: test the assembly and hybrid design/production on innermost radius with smallest strip pitch and region where petal splits in 2 sensor columns



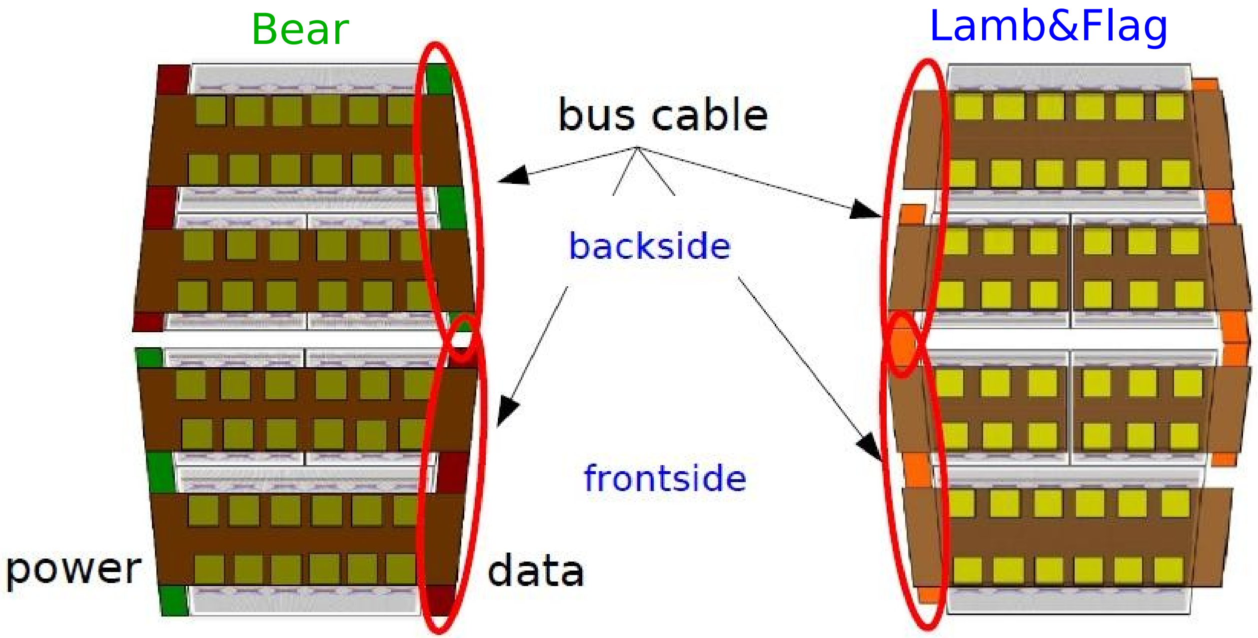


- Petalet:
  - DC-DC powered.
  - two-sided.
  - for each side: 3 sensors, 24 ASICs and 2 (or 3) hybrids.



(bear layout)

Different Layout Options for the Petalet



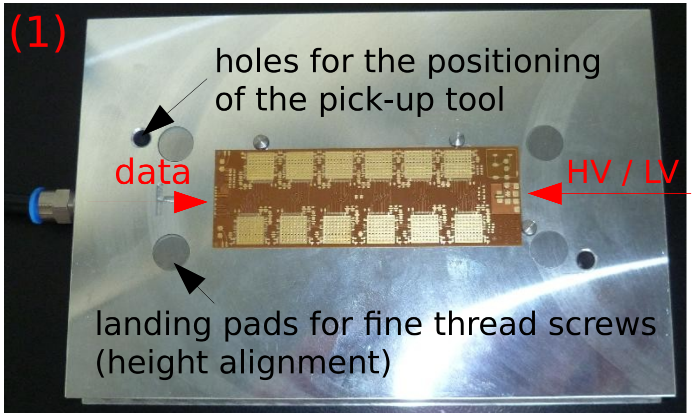
Bear layout
(one single top hybrid bridged over both sensors with data and power on different sides
+ simple routing, simple hybrids
- mechanically challenging,
- needs to control top sensor positions to each other
- electrical connection required

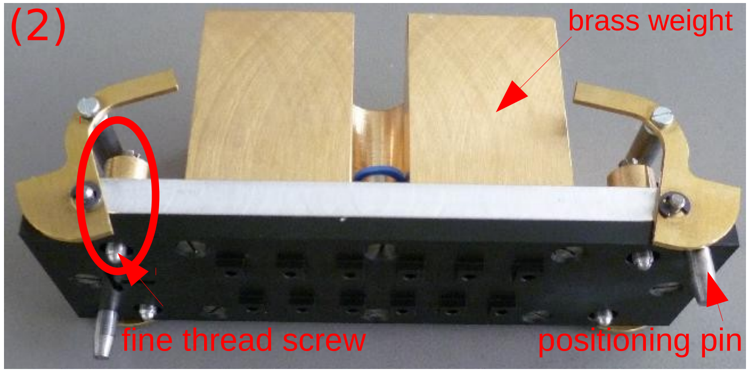
Lamb&Flag layout
(each top sensor has own hybrid with data/power/TTC from one side)
+ testing simple
- routing complex, both data/power from each side
- needs left/right hybrid design

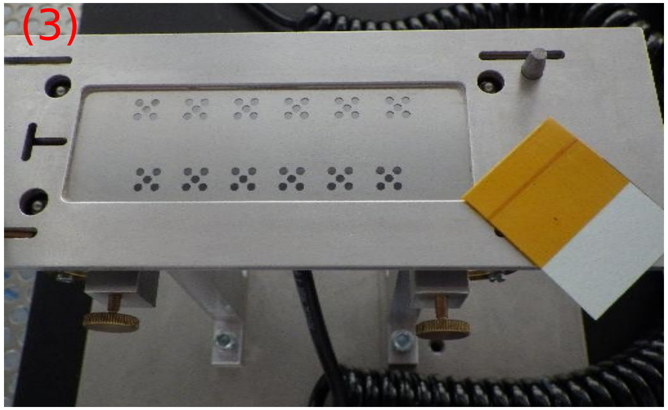
SemiCafe de la Place layout
(like Lamb&Flag but only one upper hybrid)

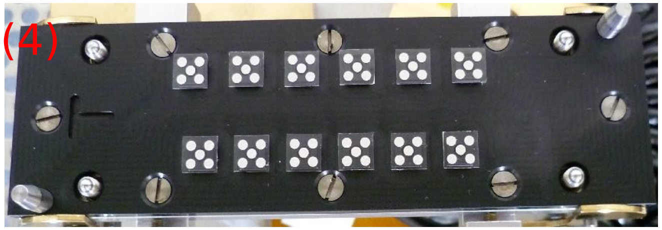
Hybrid - Tooling and Building

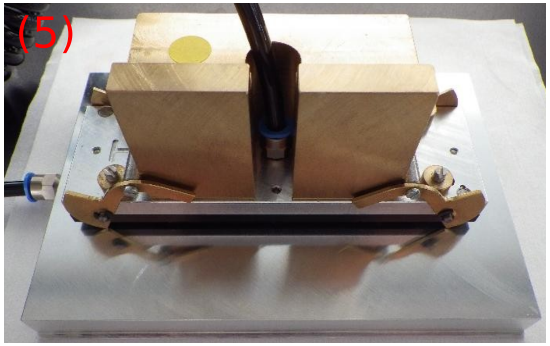
- (1) Hybrid attached on vacuum jig.
- (2) ASICs placed in chip tray and picked-up with tool.
- (3, 4) Silver-epoxy glue (Traduct) spread with a stencil on to their backside.
- (5) Pick-up tool with the ASICs placed on the hybrid.
    - Glue height is defined by the fine thread screws of pick-up tool.









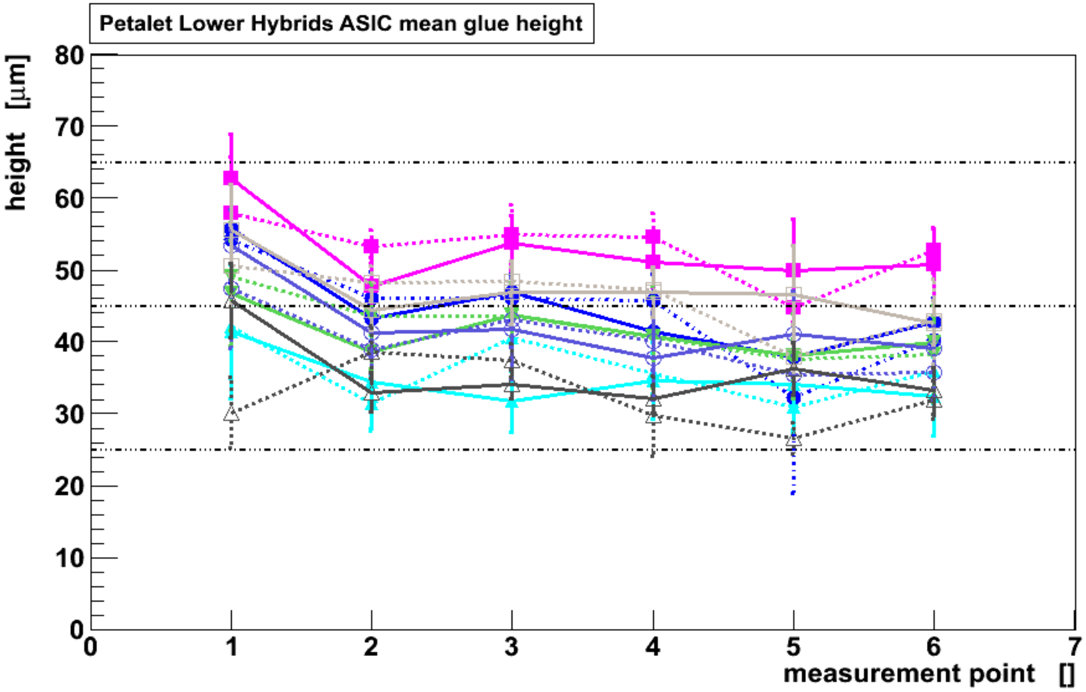


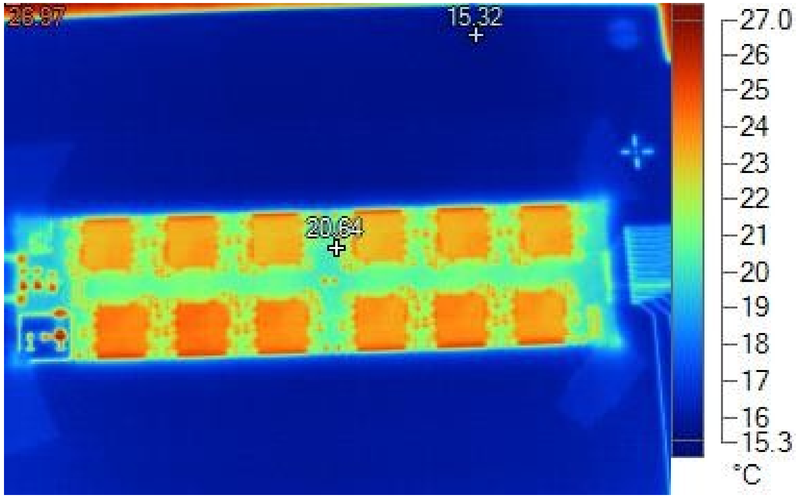
- time to glue a hybrid ~15min, ~8hrs for curing the glue and ~1hour for the bonding

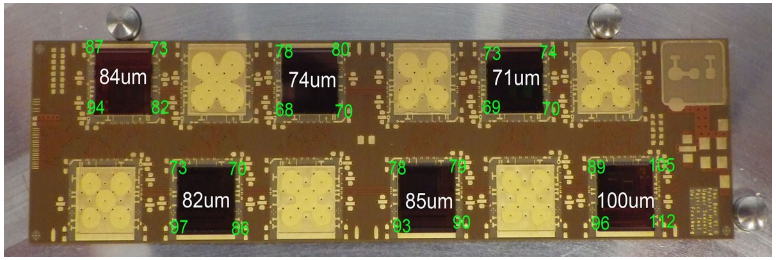
Petalet Lower Hybrids – Glue height

- Check glue height (by measuring the height difference between pads on the ASIC and Hybrid in all four corners, see right bottom picture)
  - → under control (see left picture), important for the bonding and heat dissipation!
- Check hybrid temperature during readout of the Chips
  - → uniform (see temperature map top right)

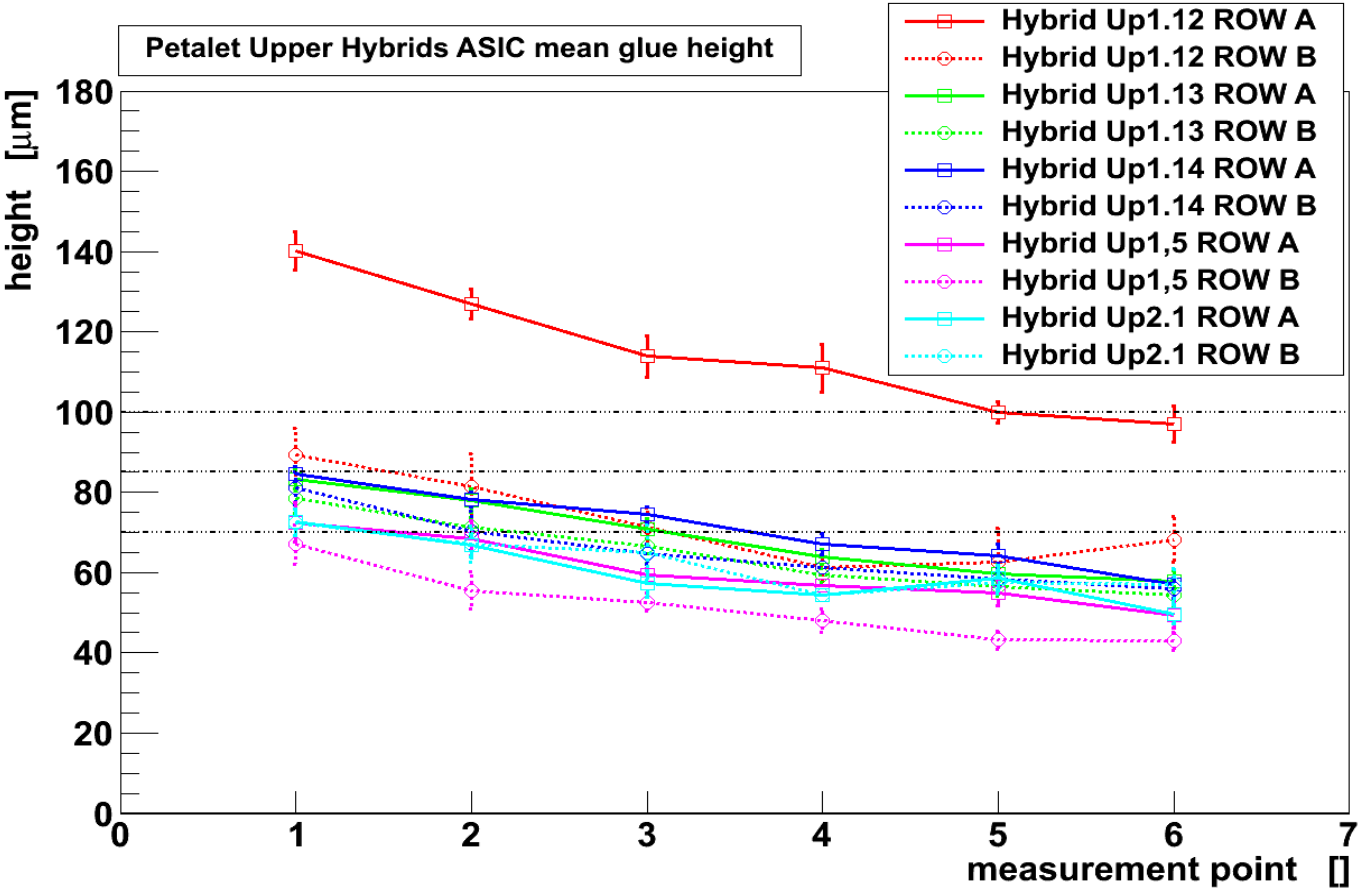
→ Good thermal conductivity, uniformity in height and adhesion achieved!







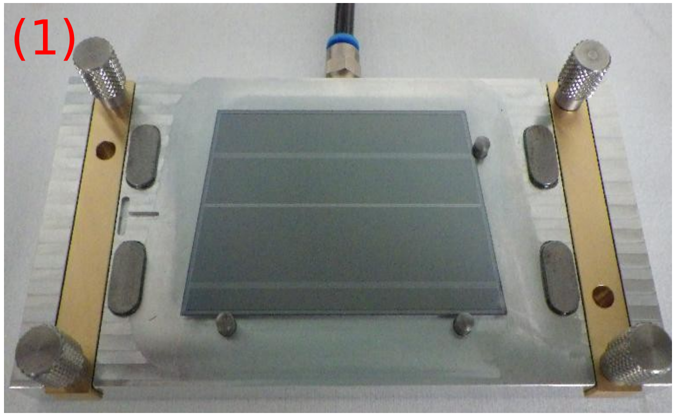
Petalet Upper Hybrids – Glue Height

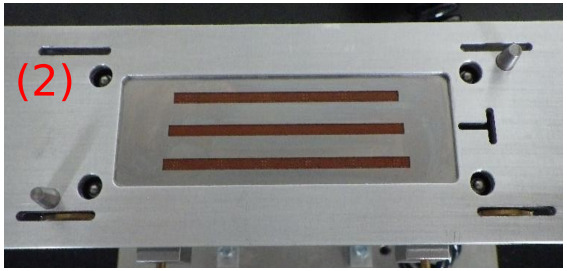


- Glue height (of one batch) of the upper hybrids is well controlled (some adjustments on the jig after glueing hybrid Up1.12)
- Height needs to be controlled, due to wearing out of 'landing' pads for the fine thread screws, which define the height of the ASICs

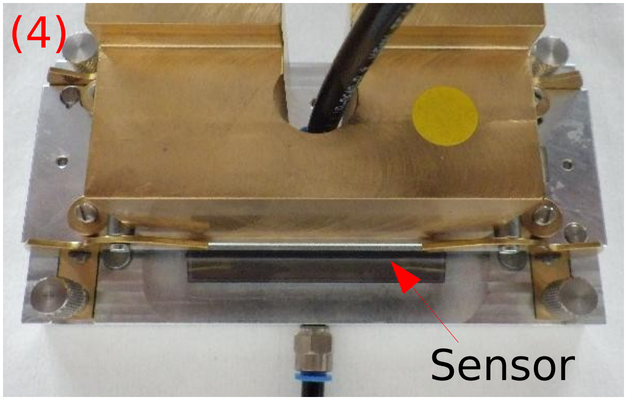
Petalet Modules – Tools and Glueing

- (1) Place and fix a (big) sensor on the module building jig.
- (2,3) Lift the hybrid using the pick-up tool and spread non-conductive epoxy (Epolite) on backside of hybrid using the 125µm thick metal hybrid glue stencil.
- (4) Attach hybrid to the sensor and let it cure for some hours.
  → Glue height is defined by jig design and is aimed for >100µm.
  (Set by height difference between sensor backside and fine thread screws.)
- (5) Bonding all the channels (~2hrs).

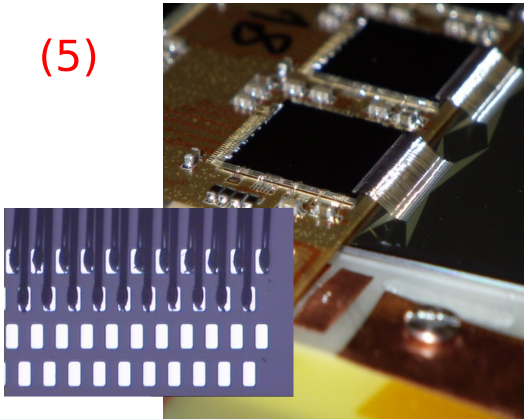

(1)


(2)


(3)
Glue profile on backside of hybrid.

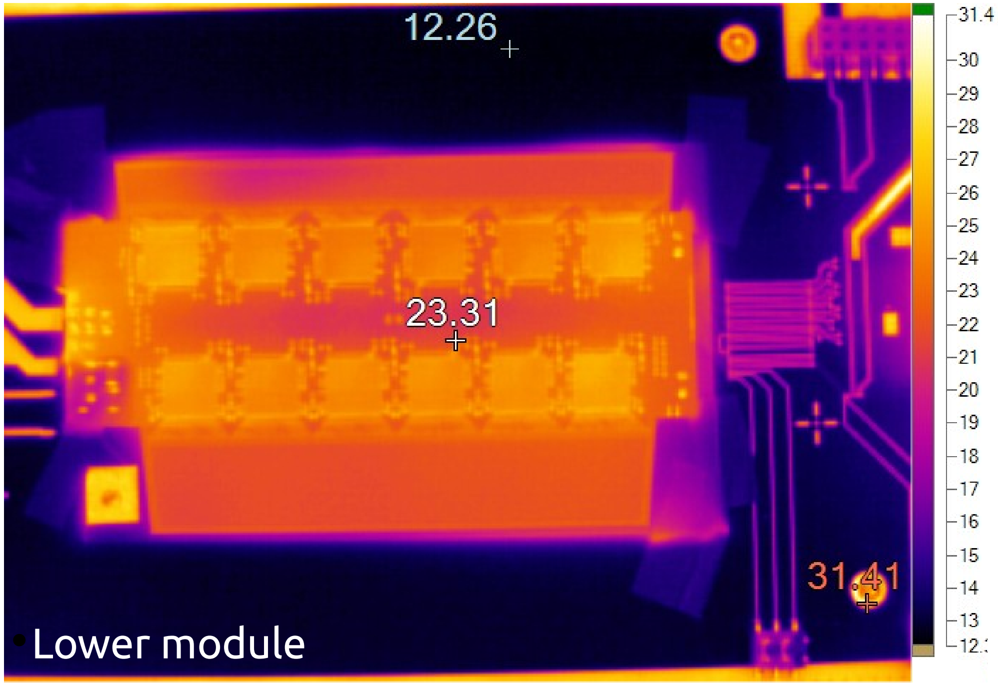

(4)

(5)

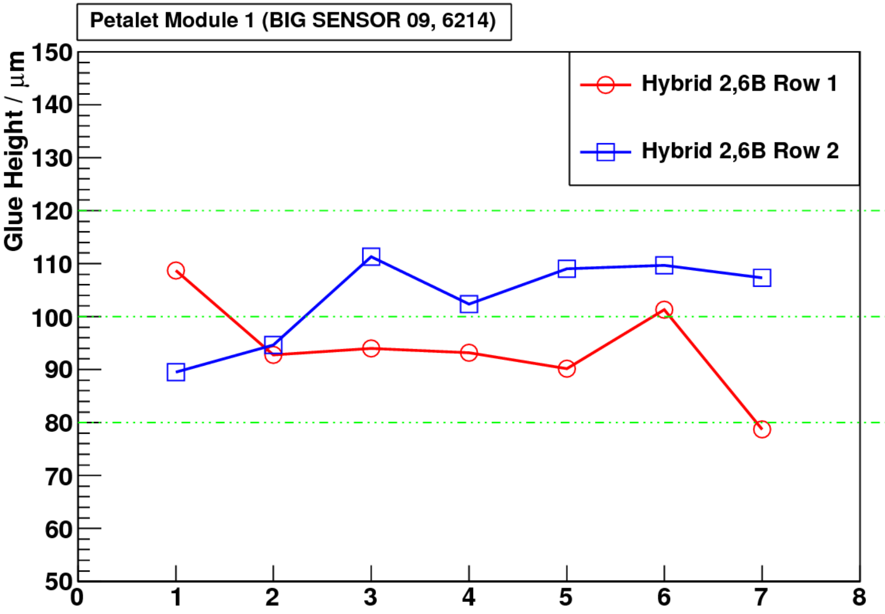


Petalet Module – Temperature Map

- Uniform glue height and spread needed for a good thermal conductivity
  → ASICs need to be cooled through the whole sensor
  (from the backside and inner part of the core)

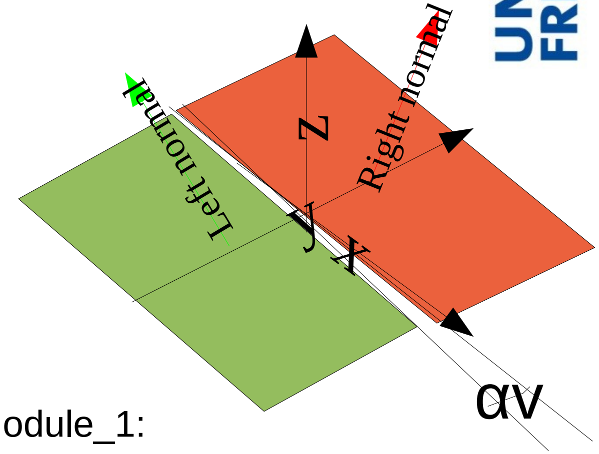


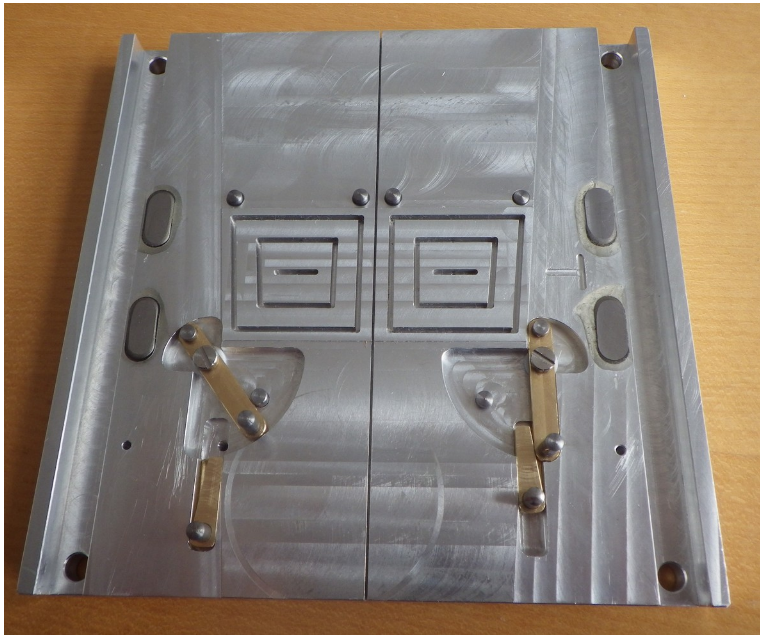
- Lower module



Petalet - Upper Module Assembly

- First attempt of an easy version of the assembly jig
  - using sensor cut edges for alignement
  - gives high precision and control over the glue height and good alignment between normals
  - **but** there remains a tilt between two upper sensors of ~1mrad (in conflict with the sensors built-in 20mrad stereo angle)

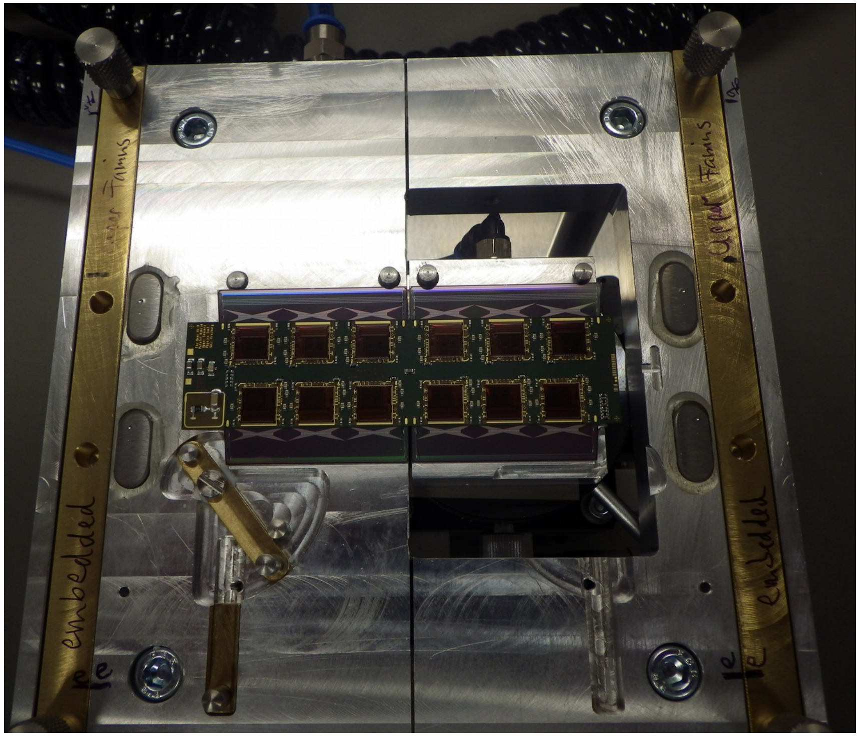




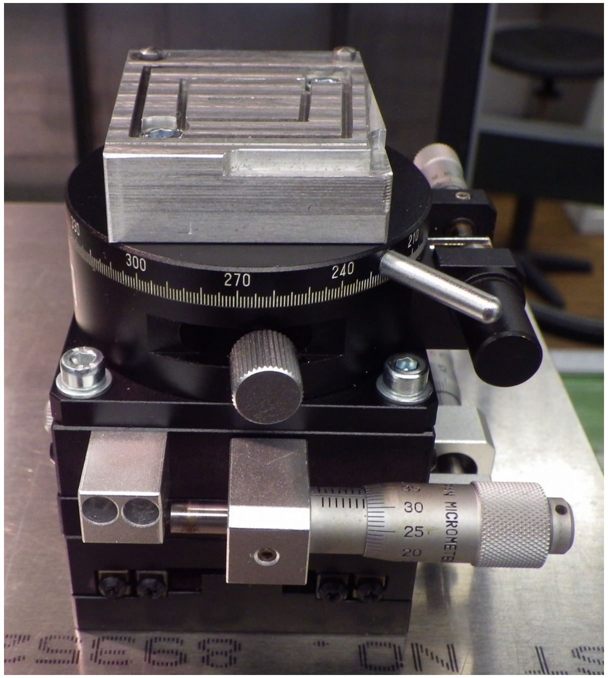
- Upper Embd Module_1:
  - $\beta(x,z)=0.090$ mrad
  - $\gamma(y,z)=0.370$ mrad
  - $\alpha v(x,y)=0.870\pm0.185$ mrad
- Upper Std Module_1:
  - $\beta(x,z)=0.119$ mrad
  - $\gamma(y,z)=0.460$ mrad
  - $\alpha v(x,y)=1.253\pm0.185$ mrad
- Upper Std Module_2:
  - $\beta(x,z)=-1.073$ mrad
  - $\gamma(y,z)=0.113$ mrad
  - $\alpha v(x,y)=0.850\pm0.185$ mrad

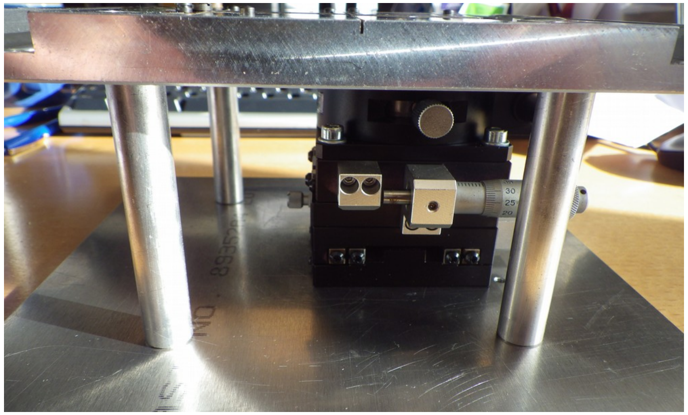
→ Sensor edges not cut precise enough (variation of ~50µm per edge, with the current CNM Petalet prototype sensors) → Modification of assembly tool needed!

Improvements on the Upper Module assembly

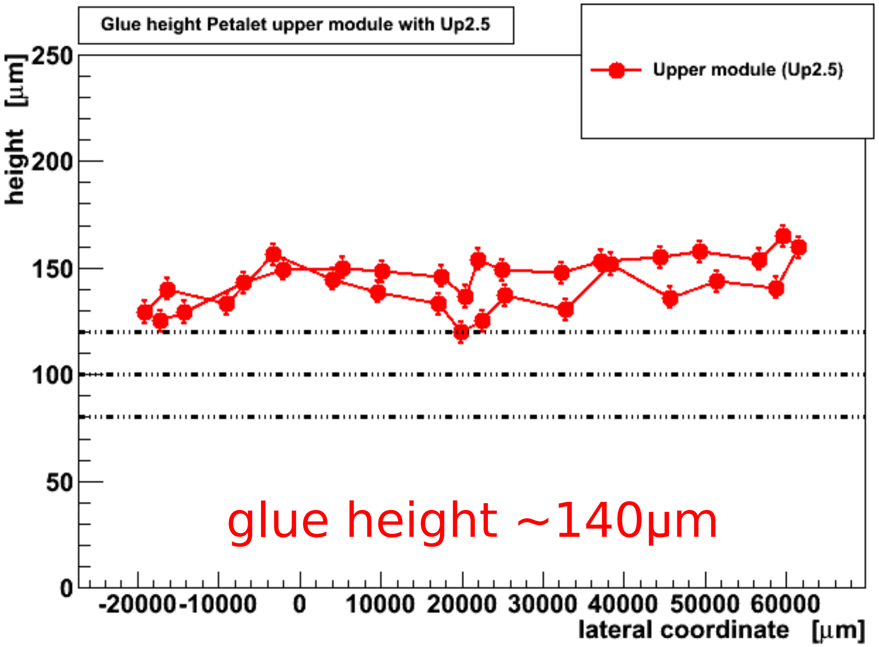


- using x,y and phi-stage with precision of ~1µm for placing the right sensor with respect to the left one
- use (distance between) the sensor fiducials to align under measurement microscope with specific program (less than 15min for positioning, mostly due to old measurement microscope)





Petalet - Upper Module Assembly



glue height ~140µm

Results using the new tool:

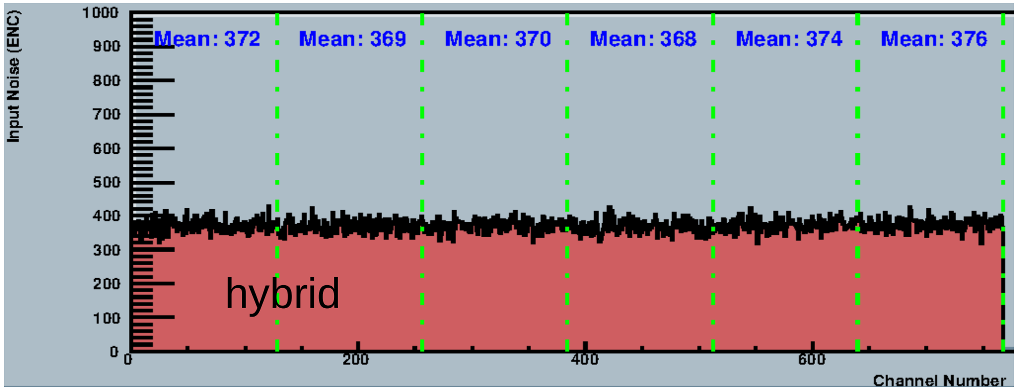
- Upper Module Up2.3:
  - αv(x,y)=0.01 mrad
  - distance between sensors (top) = 954±5µm
  - d(bottom)= 954±5µm
- Upper Module Up2.5:
  - αv(x,y)=-0.02 mrad
  - distance between sensors (top) = 962±5µm
  - d(bottom)= 961±5µm

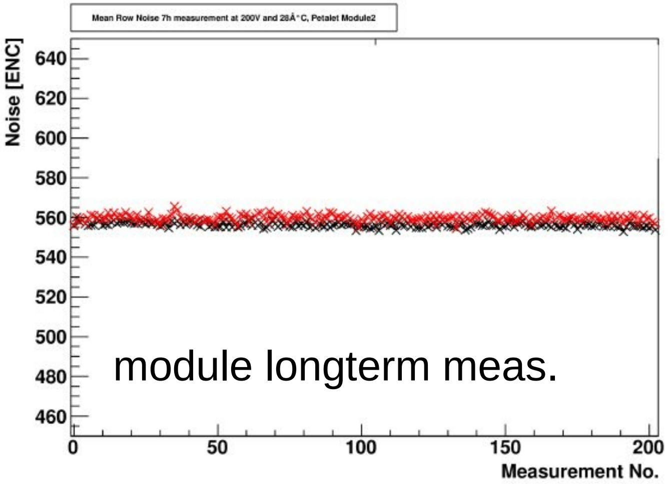
- Achieved a negligible tilt between sensors!
  - → two sensors can be connected by one hybrid with a precise alignment!
  - → same procedure also could be used to later place modules on core (alignment of sensor fiducial to some fiducial on core or – similar to the staves – in a frame holding the core!)
- Therefore fiducials need to be placed into the core or a well defined frame respectively (should be visible from both sides of the core to allow a proper front- to-backside module alignment)

Petalet Hybrids and Modules - Electrical Results

→ all petalet hybrids show good performance (mean noise ~380ENC)

→ results are comparable with the stave programme

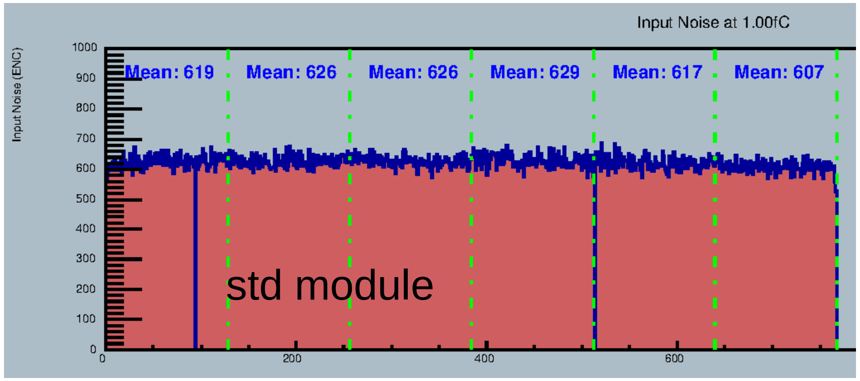


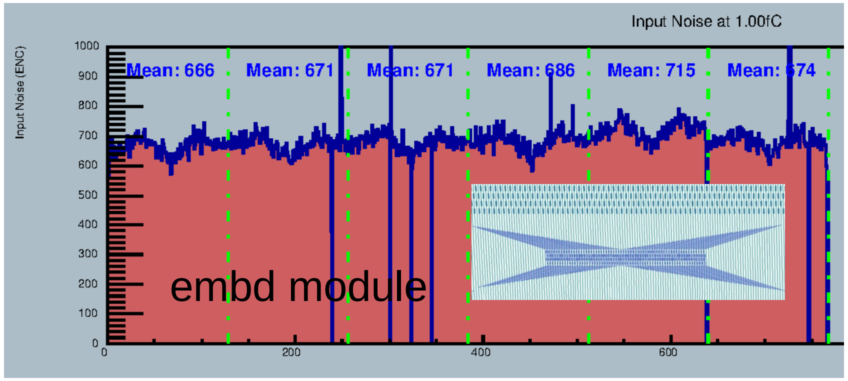


→ noise of the modules differs for the standard and embedded modules (tested at 200V, 20°C)

→ mean noise of the a-grade std modules is ~560ENC and pretty stable over time (see above)

→ the embedded modules show a slightly higher noise and this 'zigzag' trend over the ASICs (which follows somehow the pitch-adaptors)





Endcap - Summary

- So far Freiburg and DESY Zeuthen built (all in bear layout)
  ~ 30 working lower hybrids and 12 lower modules
  ~ 20 working upper hybrids and 8 upper modules

- these modules are built with two different sensor options, one 'standard' type and one having a 2nd metal layer to have an embedded pitch adaptor for an easier bonding (same pitch as for the ASICs)
  → some effect on the resulting noise (further investigation needed!)

- Valencia has hybrids built and working and is now on the way to produce their first module in the alternative Lamb&Flag layout

- one double-sided dummy petalet (with aluminium core) and one side of Core6 were successfully loaded with modules by hand,
  → no (final) precision in placing the modules (aimed <100μm)

- tools for placing modules onto the core are designed and undergoing first trials

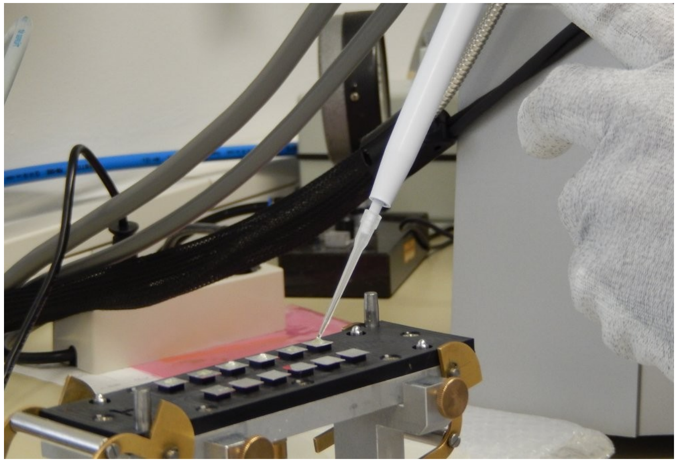
Glue Studies

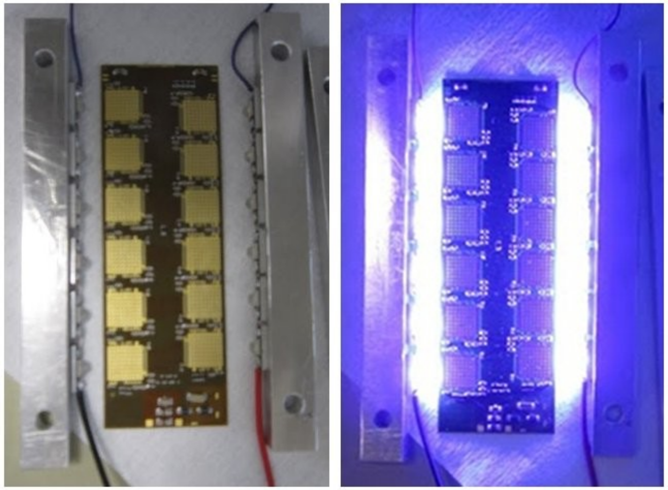
- Glue Studies to find faster curing glues (e.g. UV-curable) for both glueing steps (ASICs to hybrid and hybrid onto sensor) are ongoing (in Zeuthen and Birmingham)

- First results show that using UV-curable glues could be used and a drop in time for the ASIC to hybrid glueing from ~8hrs (mostly curing time) to 15min is possible
  → less critical if there are instabilities in the vacuum supply

- Bonding could be done successfully
  → electrical behaviour and noise of the hybrids so far similar to the current ones (<400ENC)

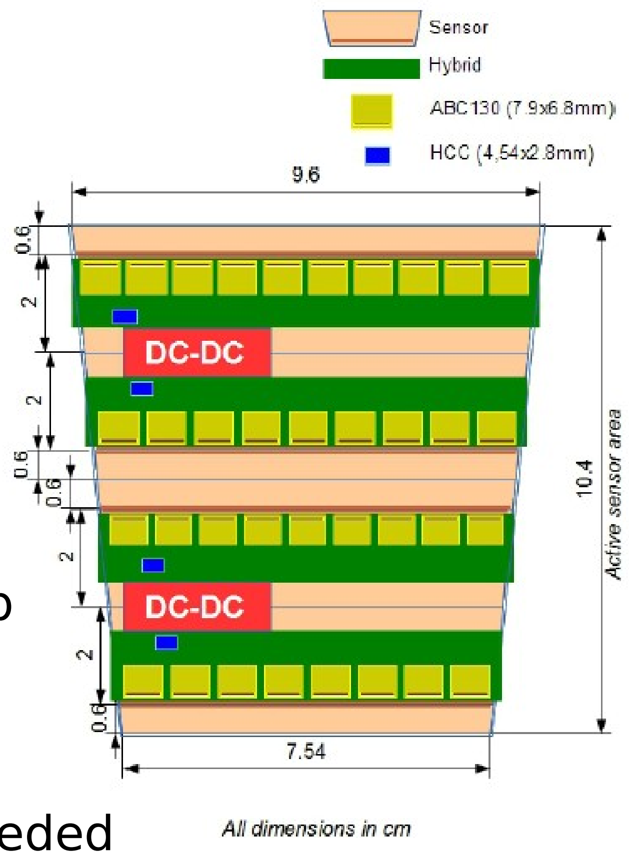
- Plan: Build and test also modules with those hybrids





Petal – 130nm Plans

- New ABCN-130nm ASICs have 4 rows of bondpads (256 channels)
  - Decrease in power consumption per channel
  - Smaller hybrids → less material
  - New Multiplexing Chip (HCC) on hybrid
  - But more challenging for the bonding
- Hybrids will have the same width as the sensors
  → makes later bonding to bustape easier,
  when hybrid does not bend over the edge!
- Up to 4 hybrids on one module for the innermost ring will make it quite crowded and hard to pick-up and place on core (see drawing)
- DC-DC for powering could be also placed on the module → compact, less space on the bus tape needed



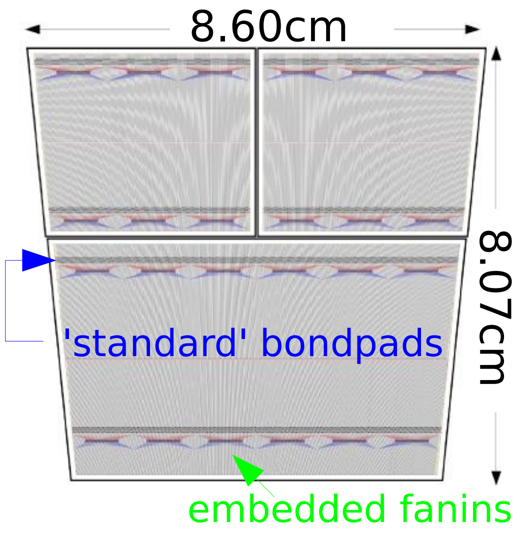
Summary

- stave-250nm program is almost finished and a lot of effort is already put on the upcoming 130nm parts
- a lot of good and working modules could be built and are used for the stavelets, staves and going to used on petalets
- a module built of two sensors connected by one hybrid is a possible option
- transfer of gained experience onto 130nm module assembly is in full swing

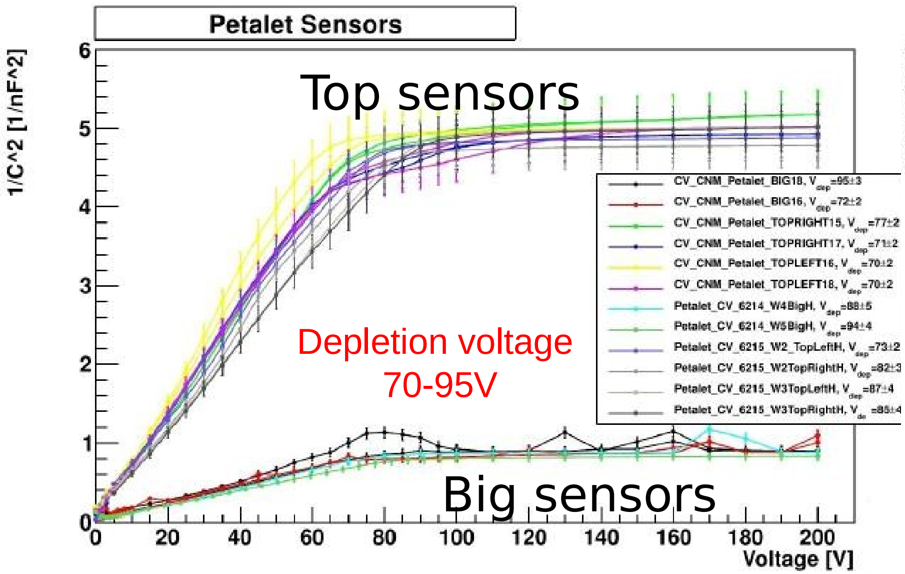
Thank you for your attention!

Backup

Petalet Sensors



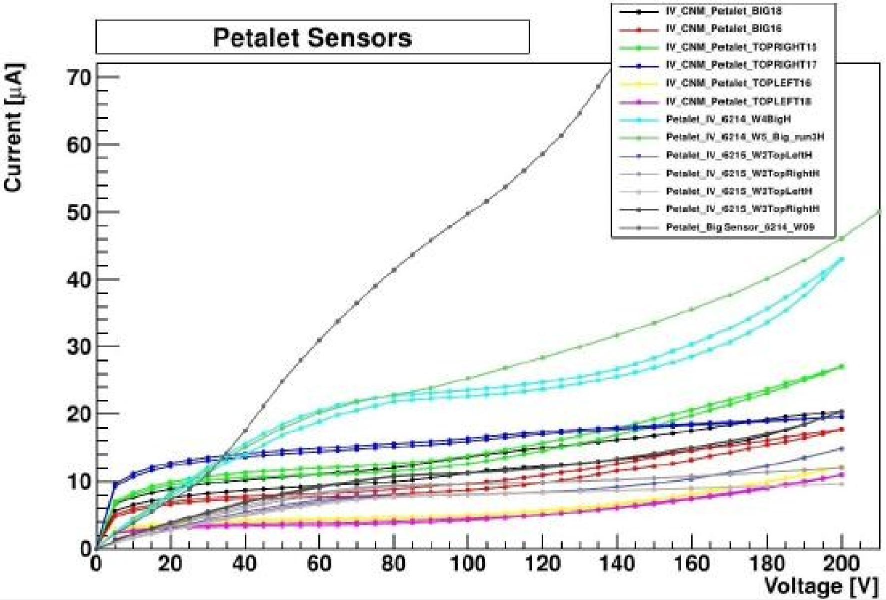
- 4'' silicium n-in-p strip sensors with p-stop produced by CNM, Barcelona
  - Varying strip pitch
  - Implemented stereo angle (20mrad)
  - With double-metal layer to implement embedded fanins (to match the bondpads of the readout chips avoiding large bond angles)
- Capacitance and current as functions of voltage for all sensors (two full *petalets)* measured in Freiburg
  → good agreement with results from CNM



Top sensors

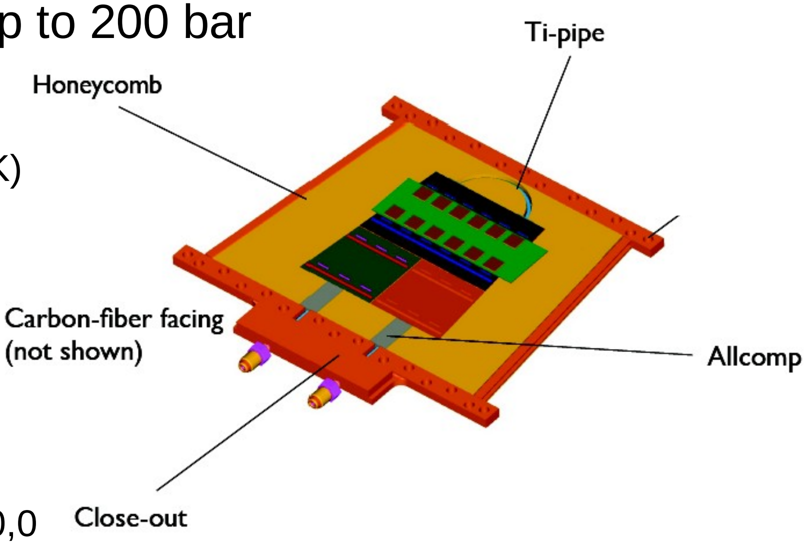
Depletion voltage
70-95V

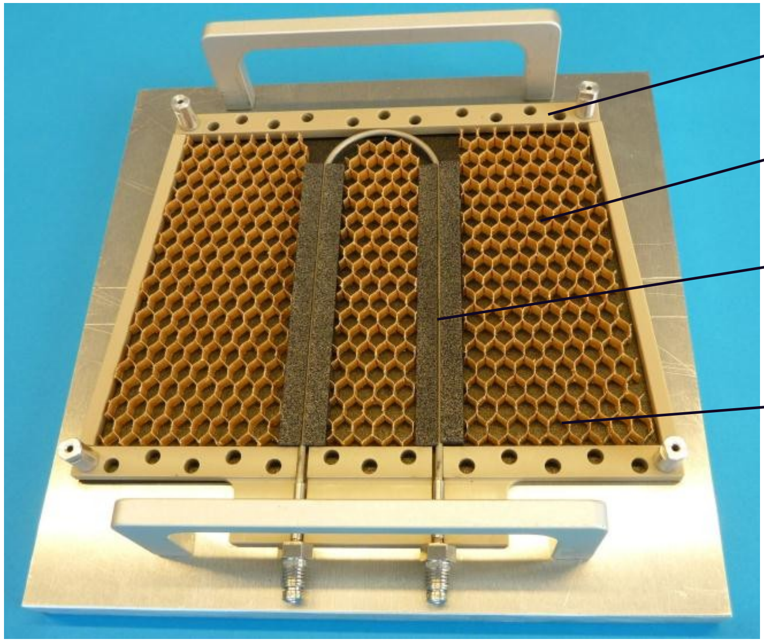
Big sensors



Petalet Core Design

- Petalet core designed and several cores produced, with improved flatness of the carbon facings (height differences <100µm)
- Stainless steel fittings brazed to Ti-pipe, tested up to 200 bar



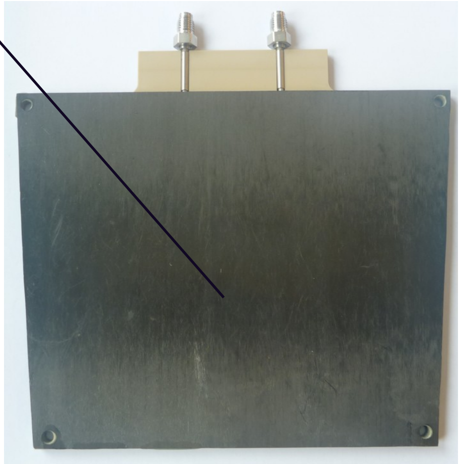


Closeouts (PEEK)

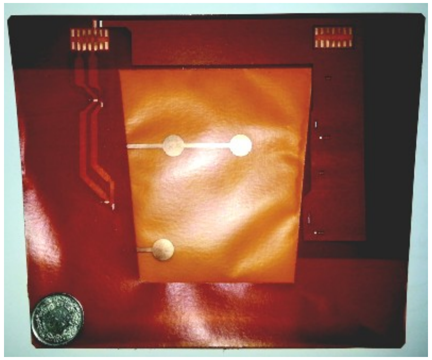
Honeycomb

Cooling, Ti-tube /
Pocofoam

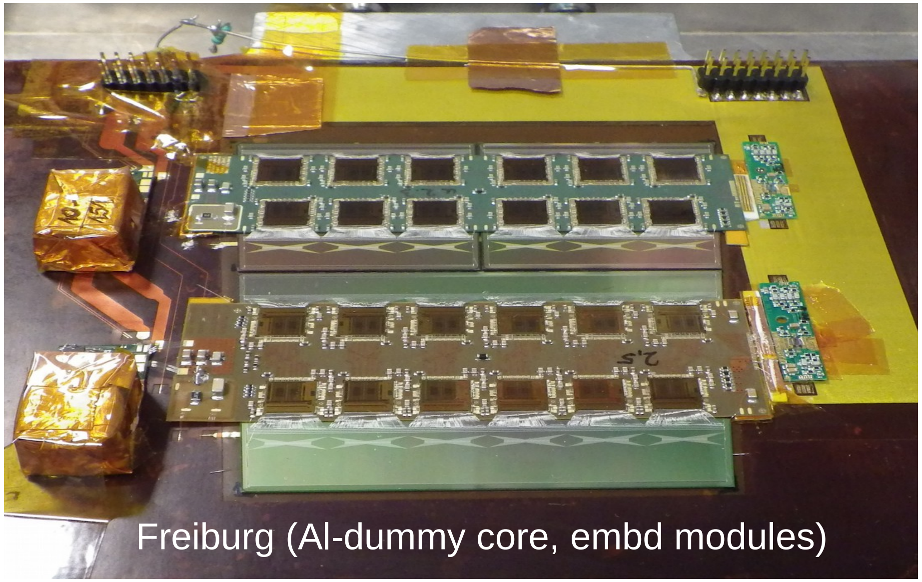
Facing 3Layer 0,90,0



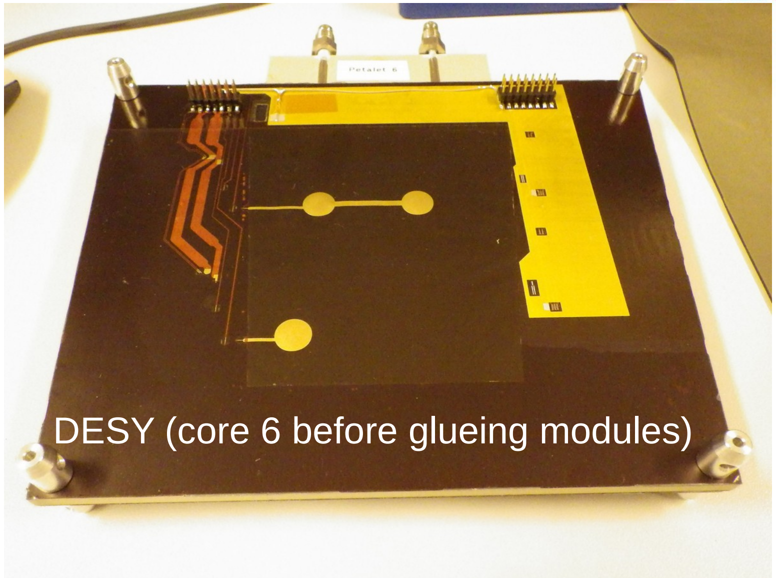
Bus tape (bear layout)



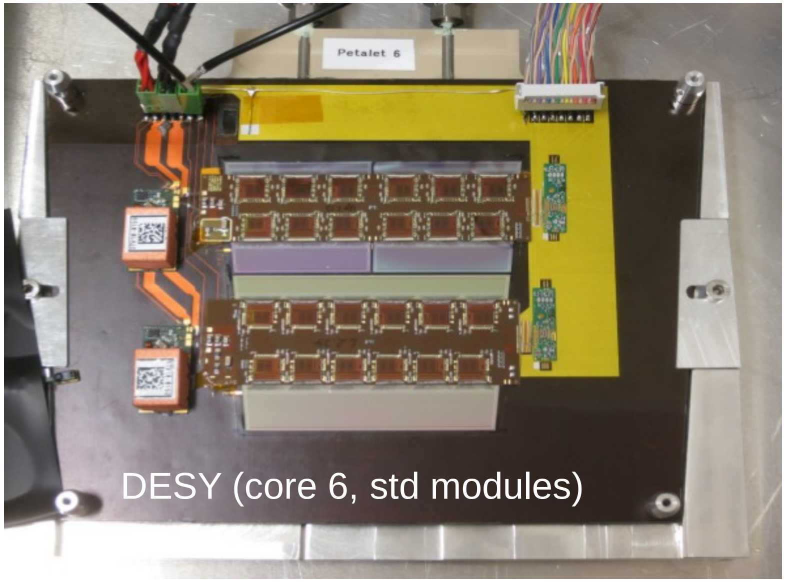
Assembled Petalets



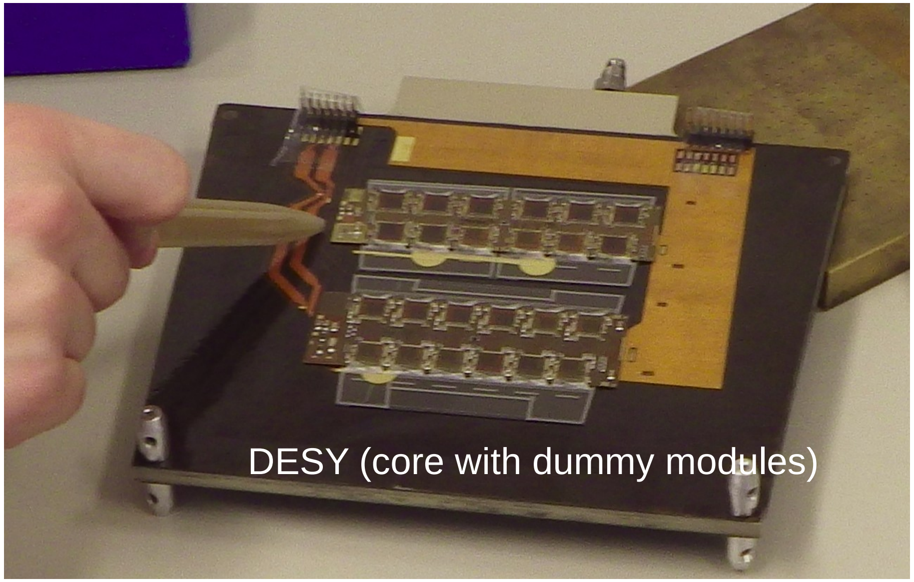
Freiburg (Al-dummy core, embd modules)



DESY (core 6 before glueing modules)



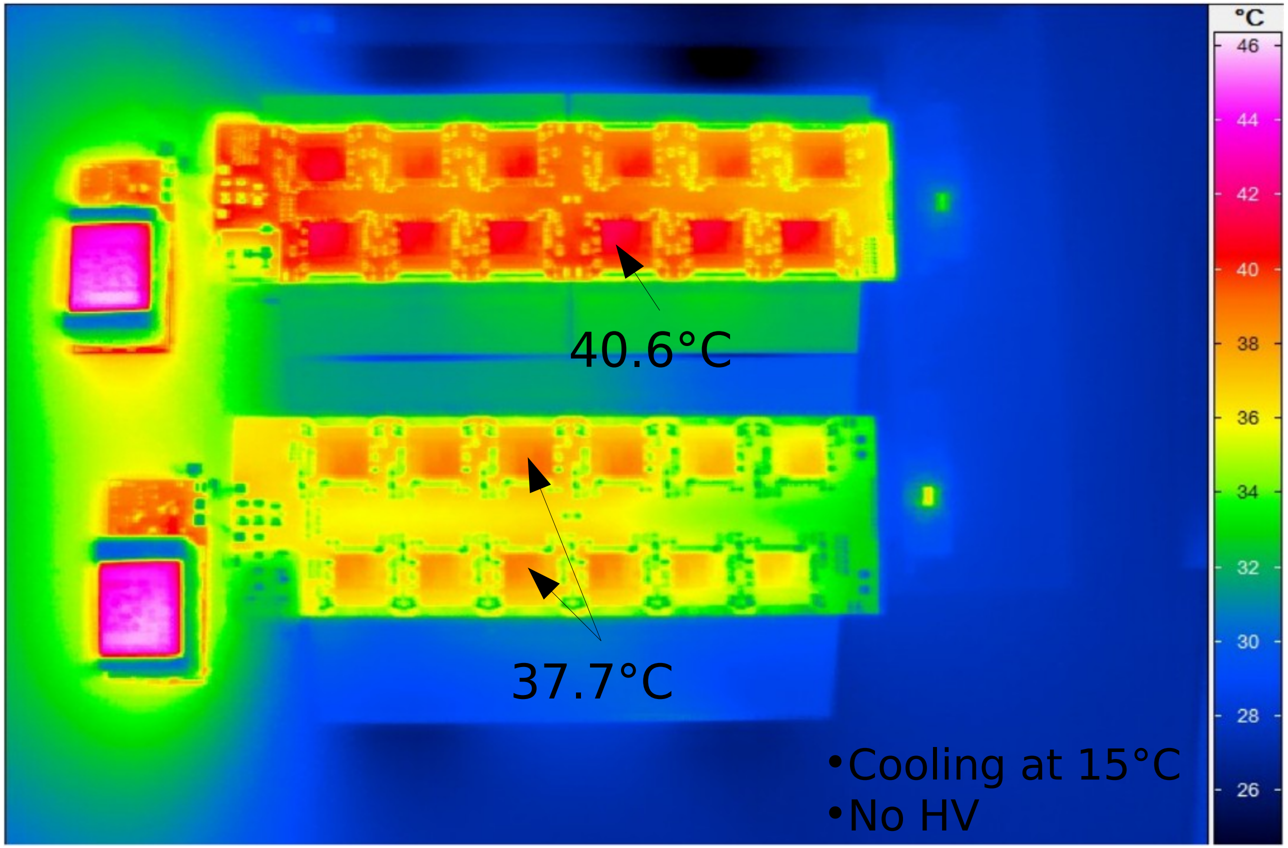
DESY (core 6, std modules)



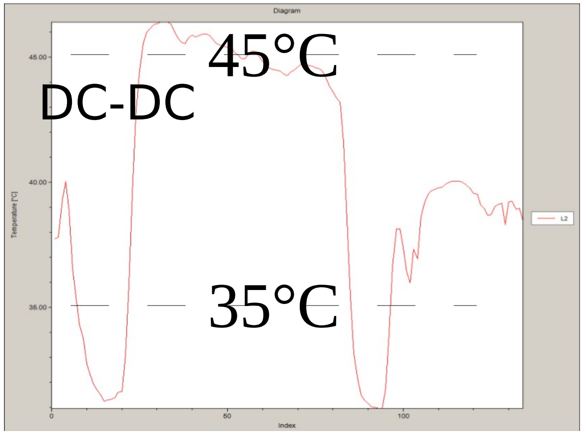
DESY (core with dummy modules)

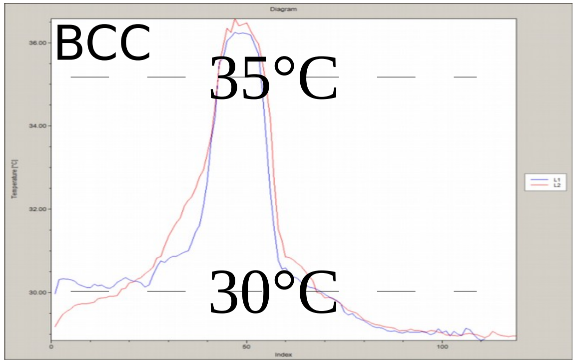
Thermal Results of the Petalet

- Temperature distribution of the Petalet at DESY

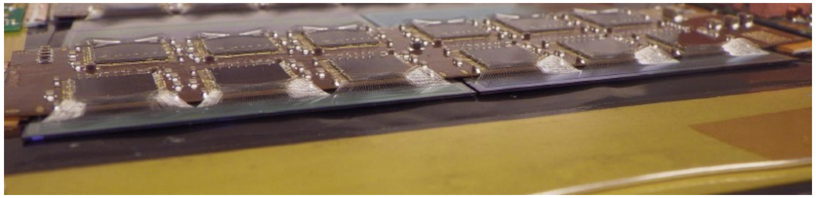


- Cooling at 15°C
- No HV



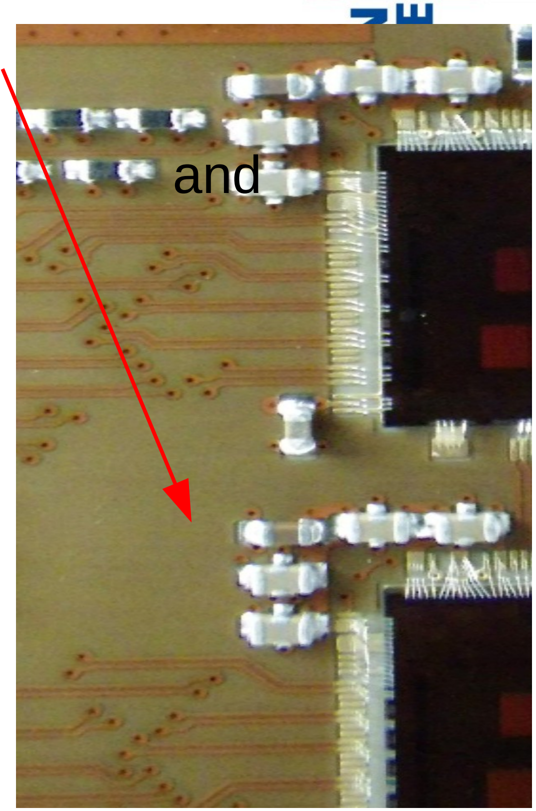


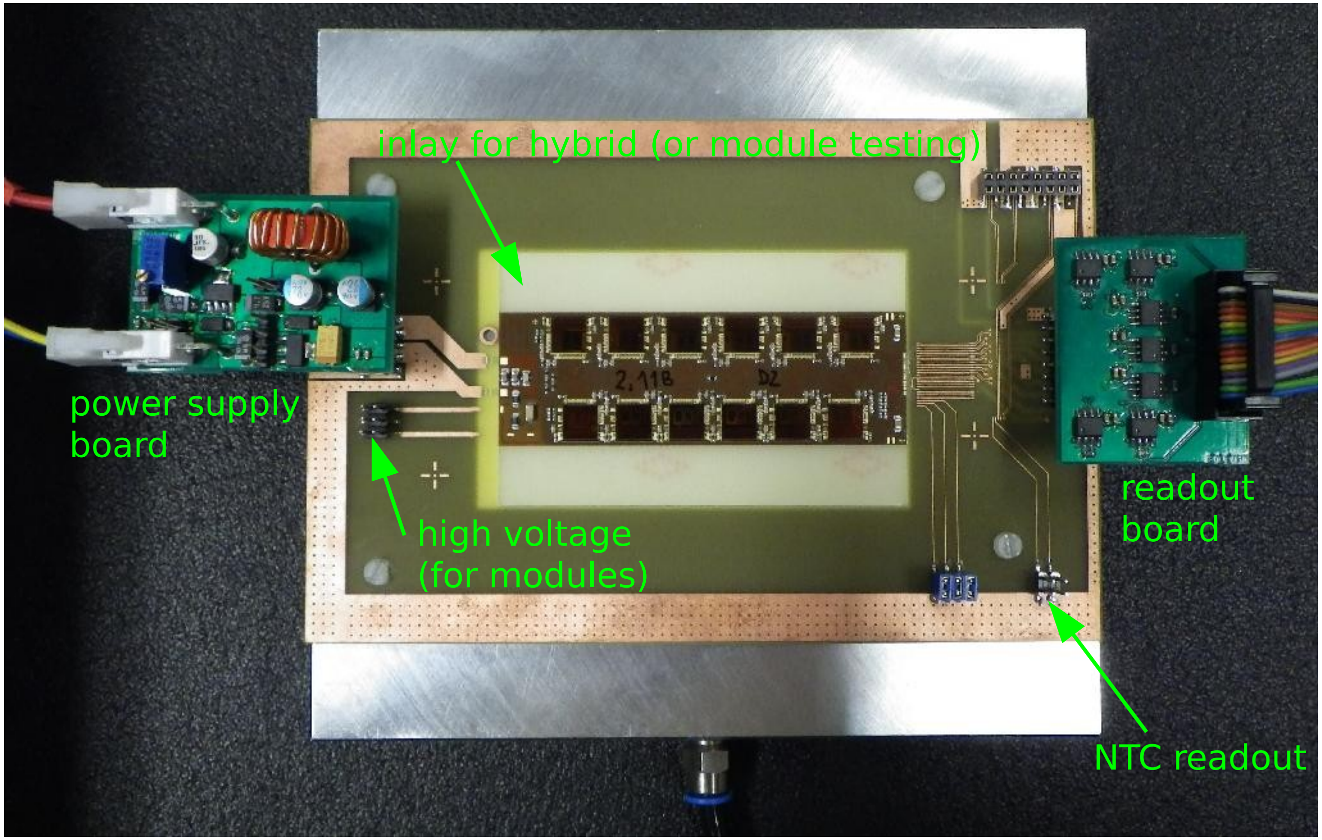
- Upper hybrid (and sensor!) significantly warmer (much higher glue height due to wavy bustape surface)
- thermal studies of petalets as soon as fully assembled (both sides!) → to check if cooling is sufficient enough!!



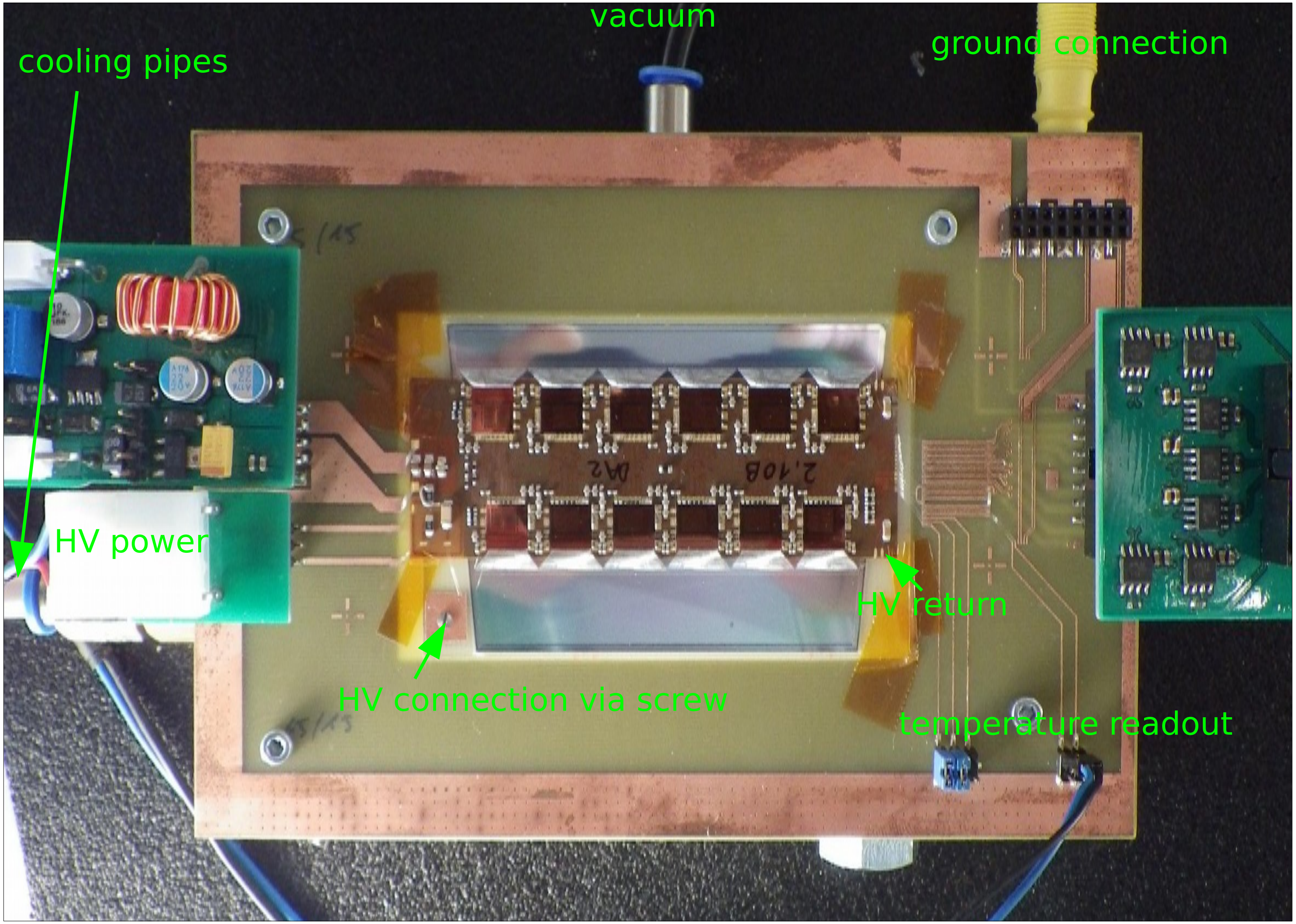
Petalet Hybrid Testframe

- Wirebond all connections between ASICs and hybrid
- Place hybrid in the test frame (designed at Freiburg) and bond Low Voltage and data connections





TestFrame Petalet Modules



Freiburg HSIO TestSetup

Albert-Ludwigs-Universität Freiburg

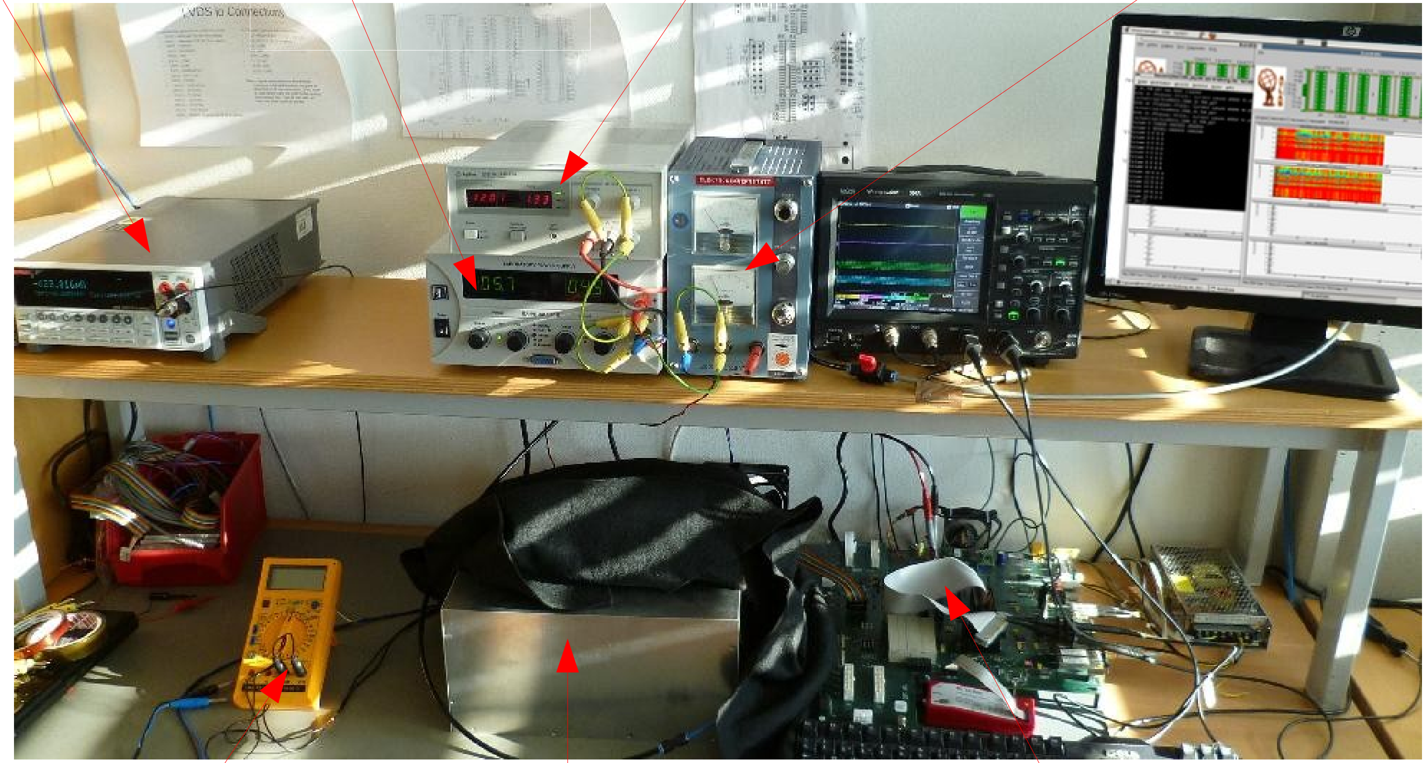
- Test device in light tight box, flushed with nitrogen and mounted on a cooled test jig (8°C)
- HSIO High Speed I/O with Virtex FPGA (integrated circuit) and binary readout

HV power supply

LV power supply

HSIO power supply

readout board power supply



thermistor measures temperature on hybrid

light tight box with test device

HSIO board