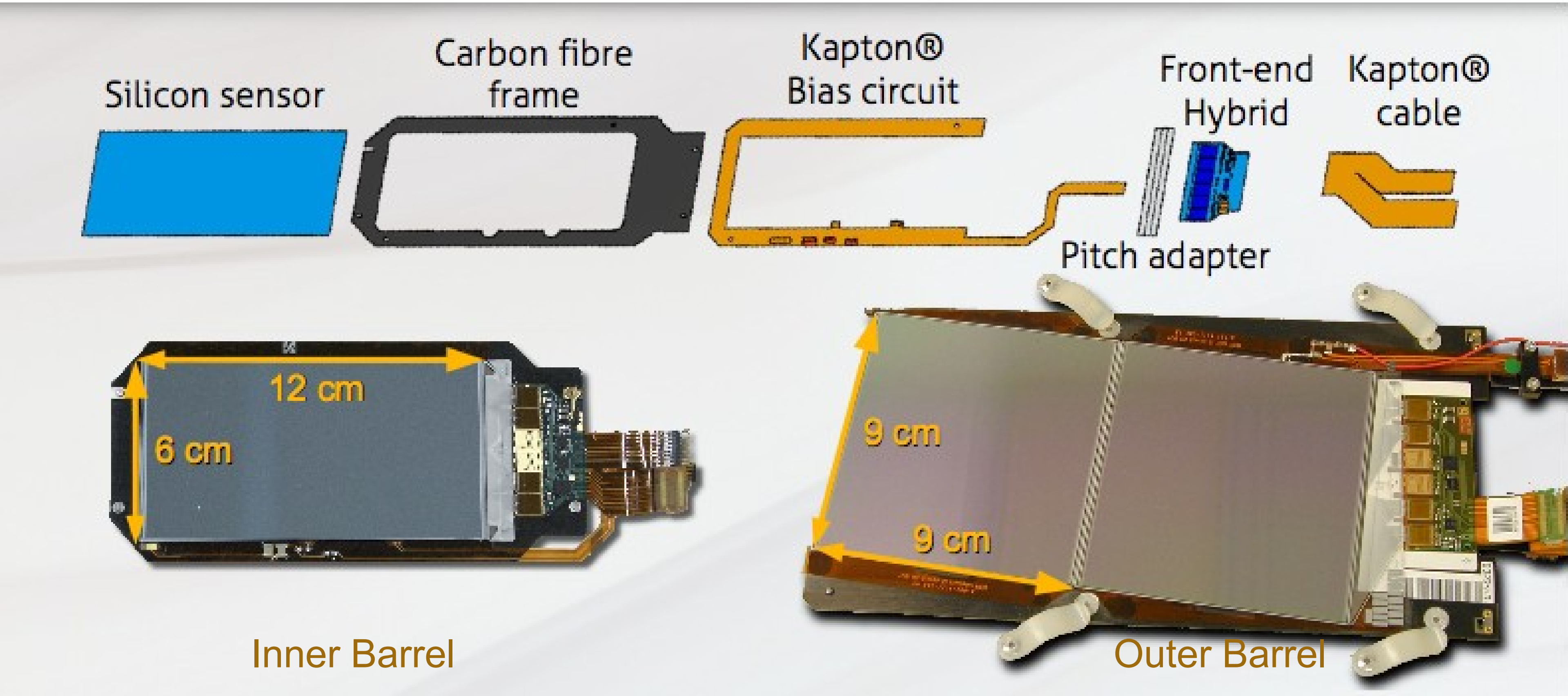
MODULE DESIGN

Some thoughts towards possible module (and system) designs for the CMS Tracker Upgrade

Outline

- Modules in the present tracker
  - Integration in the system
- New requirements for HL-LHC
  - Higher granularity
  - Trigger
- Implications for module design
  - Examples of concepts considered so far
  - Outlook for developments needed

Barrel modules



- Wedge-shaped endcap modules follow the same concept

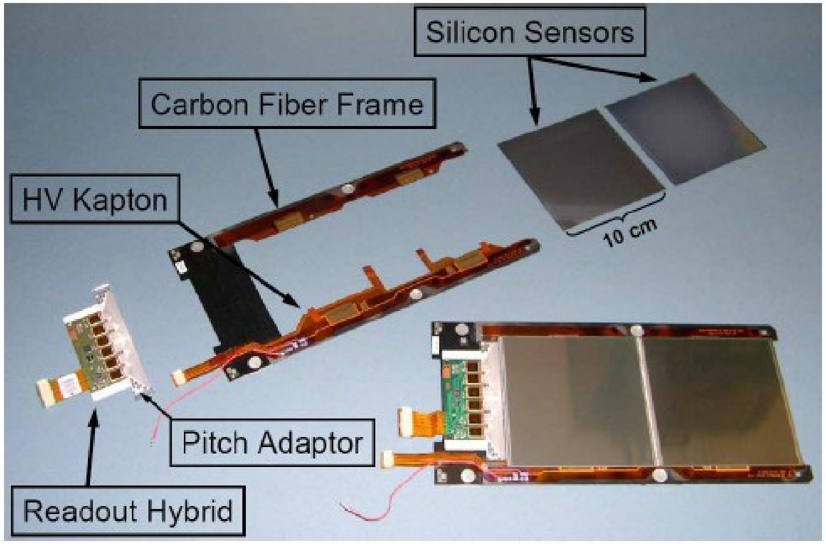
Modules – main features

- Strip length 10÷20 cm; pitch 80÷180 μm
- Connections through wirebonds
  - Sensor to pitch adapter
  - Pitch adapter to readout chip
  - Sensor to sensor (where applicable)
- 9.3 M channels ➔ 24 M bonds!

★ 500 μm thick sensors

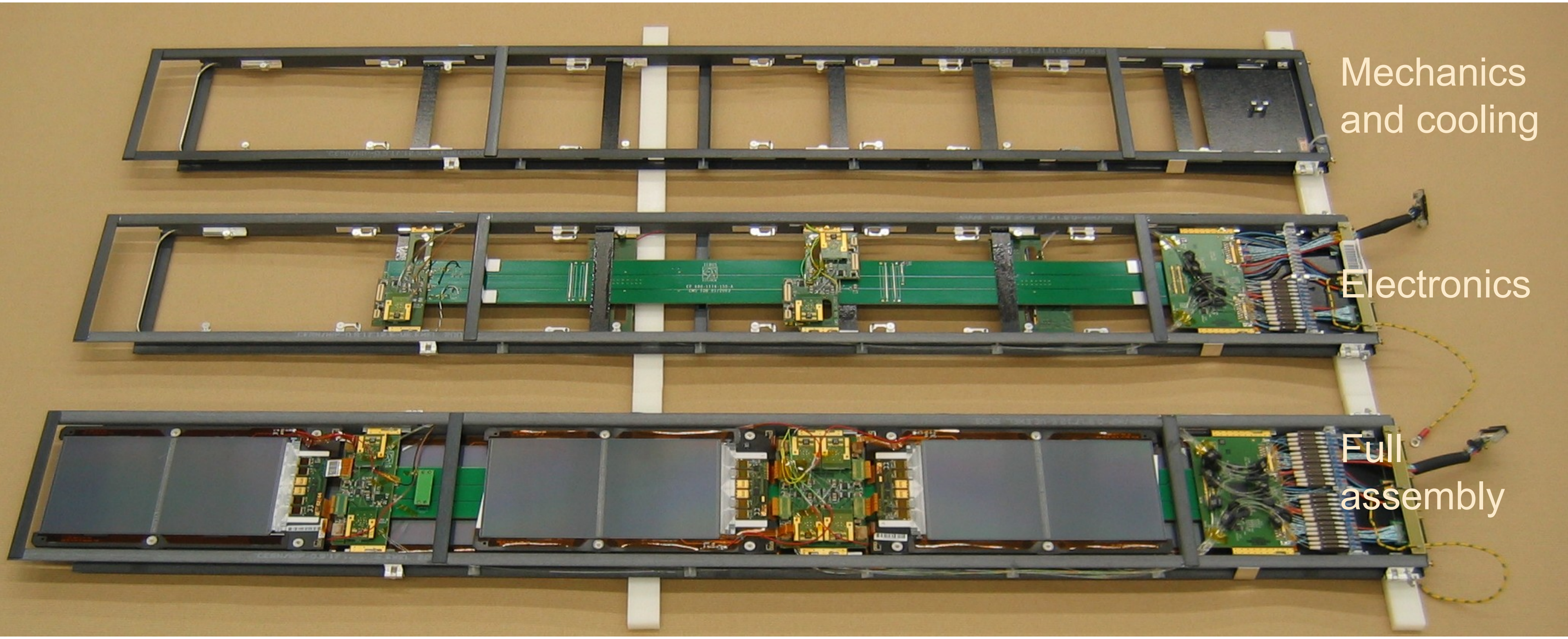
★ Largest sensor surface
- Ratio silicon/rest less favourable for other flavours

Outer Barrel module			**Mass (g)**	**Int length**	**Rad length**
			49.99	**0.22%**	**0.95%**
Silicon sensors		21.22	42%	39%	51%
Hybrid		1.95	4%	3%	6%
Copper	1.29				
Rest	0.66				
Pitch adapter		2.77	6%	5%	7%
Ceramic support		4.27	9%	9%	7%
CF frame		12.91	26%	29%	16%
Plate	5.16				
Legs	7.74				
Cooling (Alu + SS)		0.94	2%	2%	2%
HV		1.08	2%	2%	4%
Encapsulant		2.47	5%	5%	4%
Rest		2.38	5%	5%	4%

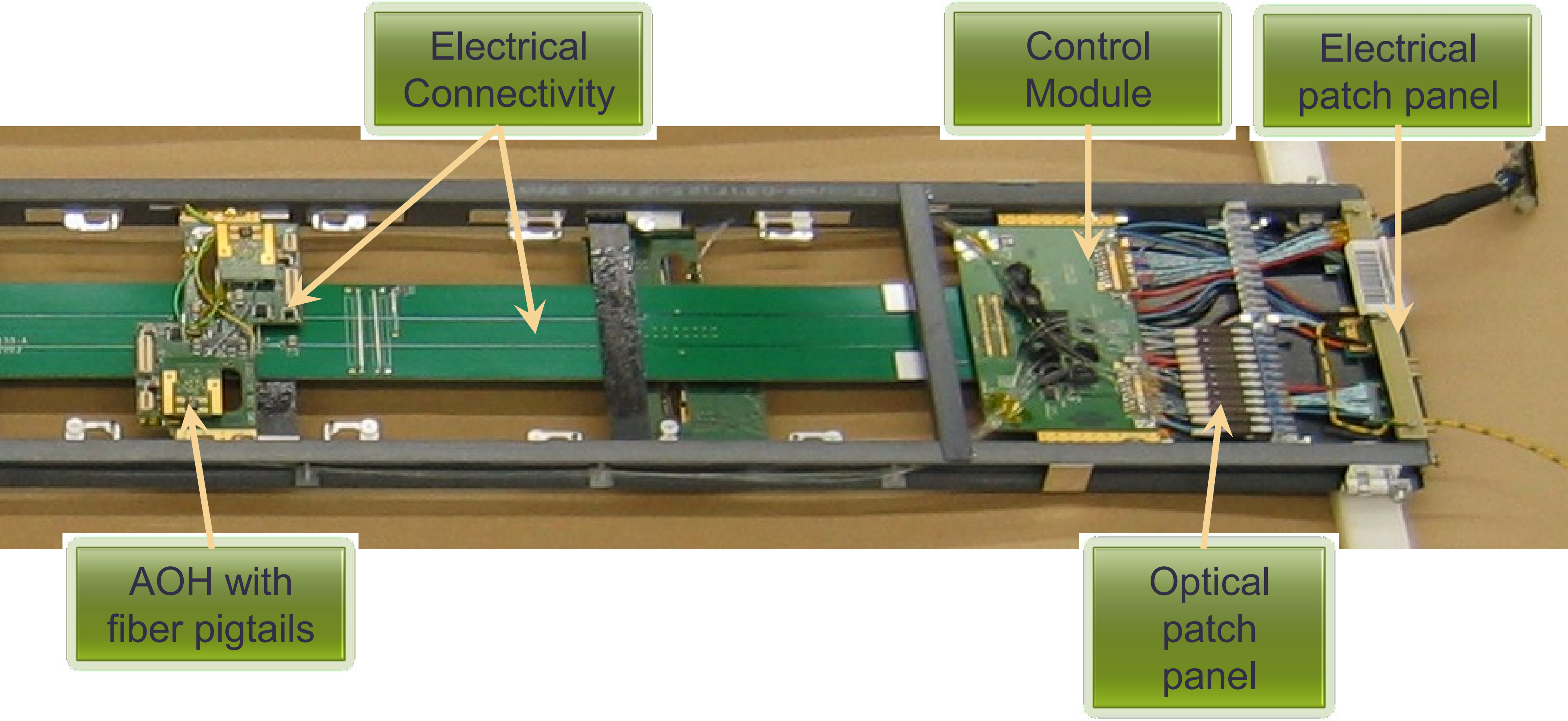


Modules in sub-assemblies

- Example: Outer Barrel
  - Implementation details different in other subsystems, but similar concept

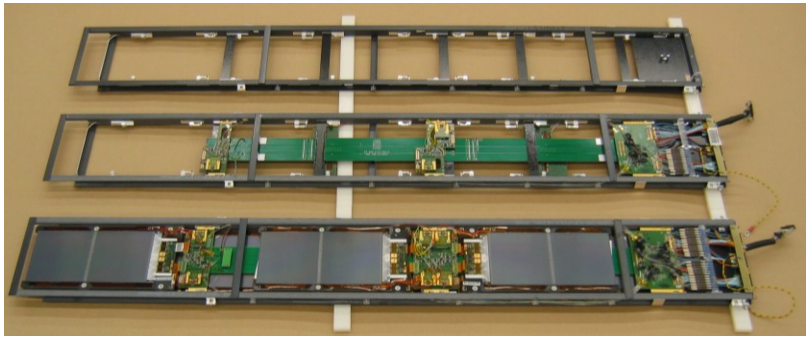


Electronics: closer look



Weight analysis

Outer Barrel "Single-sided Rod"				Mass (g)
				804.6
Modules			**299.9**	**37%**
	Sensors	127.30		
	Electronics	89.58		
	Mech & cool	83.06		
Cooling			**94.3**	**12%**
	Cooling blocks	68.83		
	Cooling pipes	12.73		
	Cooling fluid	12.74		
Electronics			**277.4**	**34%**
	Cu	60.88		
	FR4	133.04		
	Insulators	12.98		
	Optical	30.78		
	Other	39.70		
Mechanics			**132.5**	**16%**
	Side profiles	114.62		
	End-ribs	12.89		
	Spheres	5.00		



- Electrical connectivity is the dominant contribution
  - N.B. these are 500 μm thick sensors
- If we had to redo the same TK, we should invest in connectivity
- Better power distribution is a key

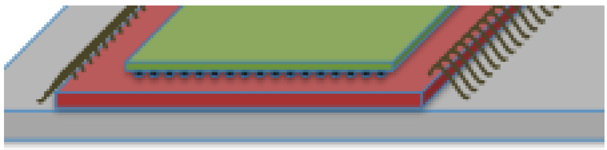
Upgrade: higher granularity

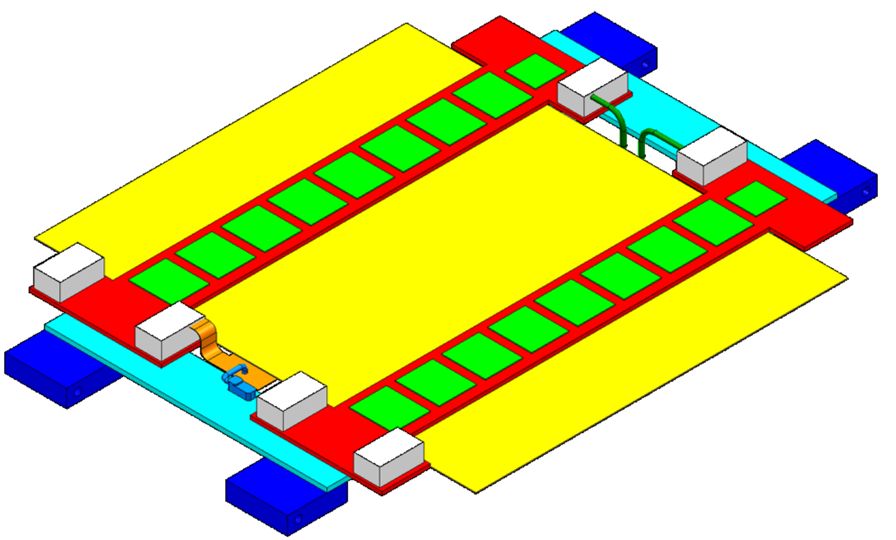
- At least ×5 increase in granularity: implications
- Strip length goes from 10÷20 cm to 2.5÷5 cm
- Pitch ≤ present Tracker (≈ 90µm)
- Channel count ≈ 50 million
  - Would imply ≈ 100 M wirebonds using "old" design
  - A factor of 2 reduction is obviously welcome
- Density of pitch adapters ×5
  - Mass of pitch adapters would become comparable to the silicon sensors!!

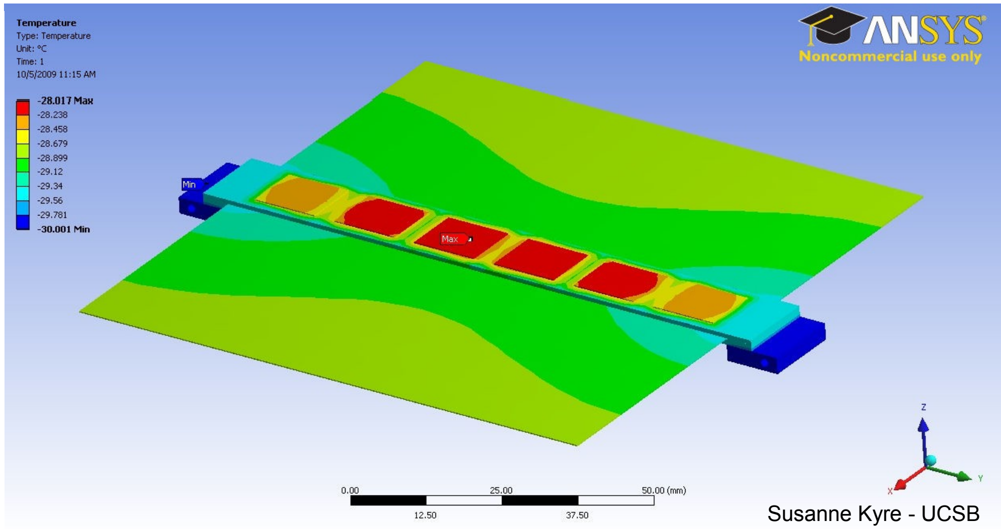
- Conclusion:
- More advanced interconnections are mandatory!

A new module

- “High density” hybrid integrates pitch adapter
  - Pitch adapter integrated in sensor pursued as backup
- Hybrid wirebonded to sensor
- Chips bump-bonded (C4) on hybrid
  - Saves 50% of the wirebonds
- No experience with these types of substrates!
  - Stringent requirements e.g. on CTE, rad hardness, reliability…
- Cooling seems OK, but possibly issues with deformations in cold







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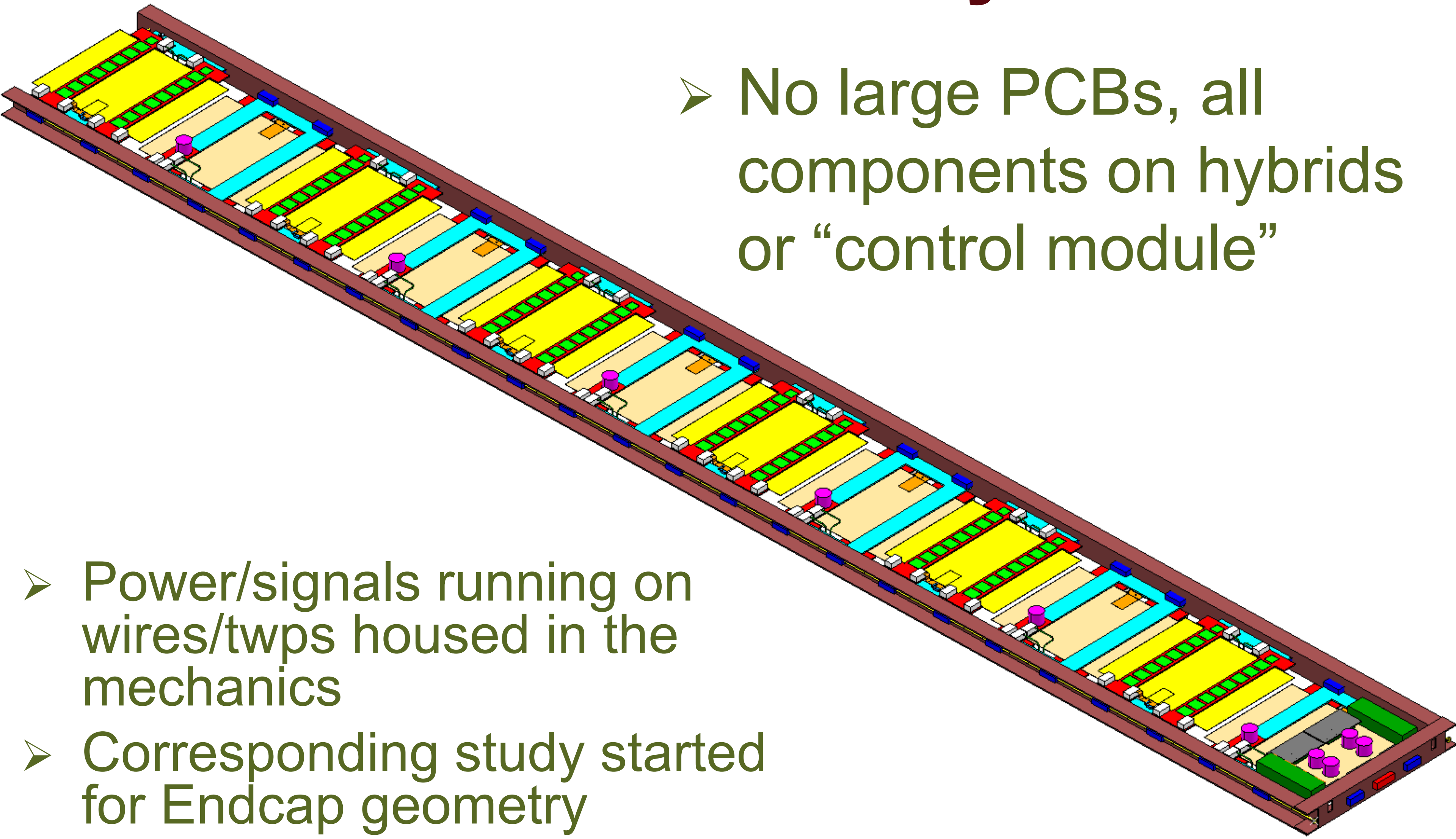
The modules in the system

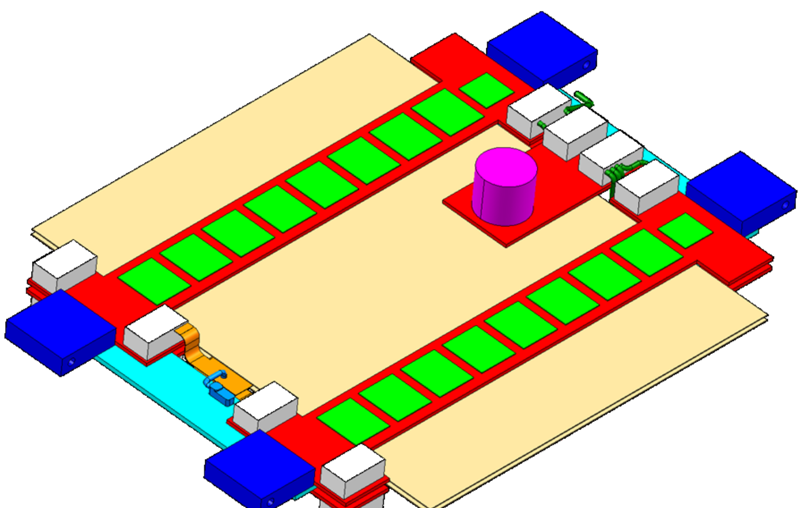


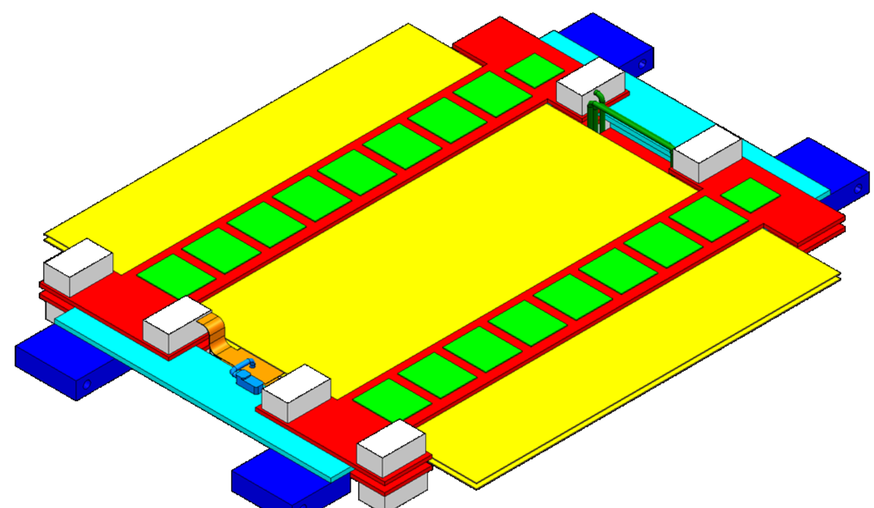
- No large PCBs, all components on hybrids or “control module”

- Power/signals running on wires/twps housed in the mechanics
- Corresponding study started for Endcap geometry
  - Looks very promising

Stereo modules

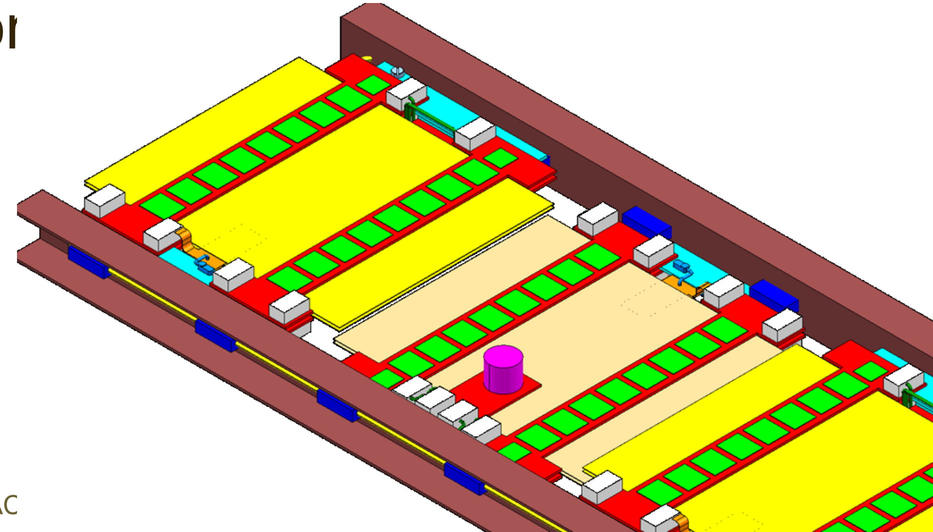
- Example with 2.5 cm strip length
- Thermal/deformation analysis to be started
  - More channels/power density
    - Probably cooling still OK
  - More symmetric assembly
    - Possibly solves problem of deformation





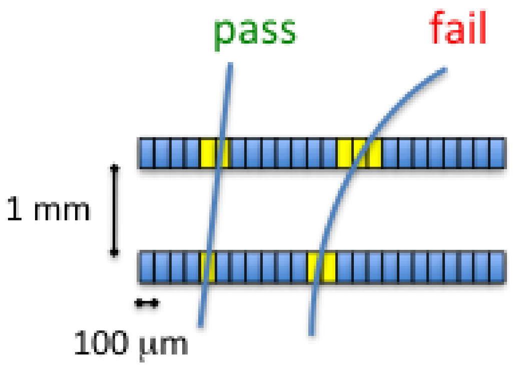
Stereo module assembly

- Power converter relocated
- More channels ➔ 5 (or 6) GBTs / rod
  - If readout based on CBC
- Serious integration problem
  - Optical transmitter too bulky
  - No straightforward solutio

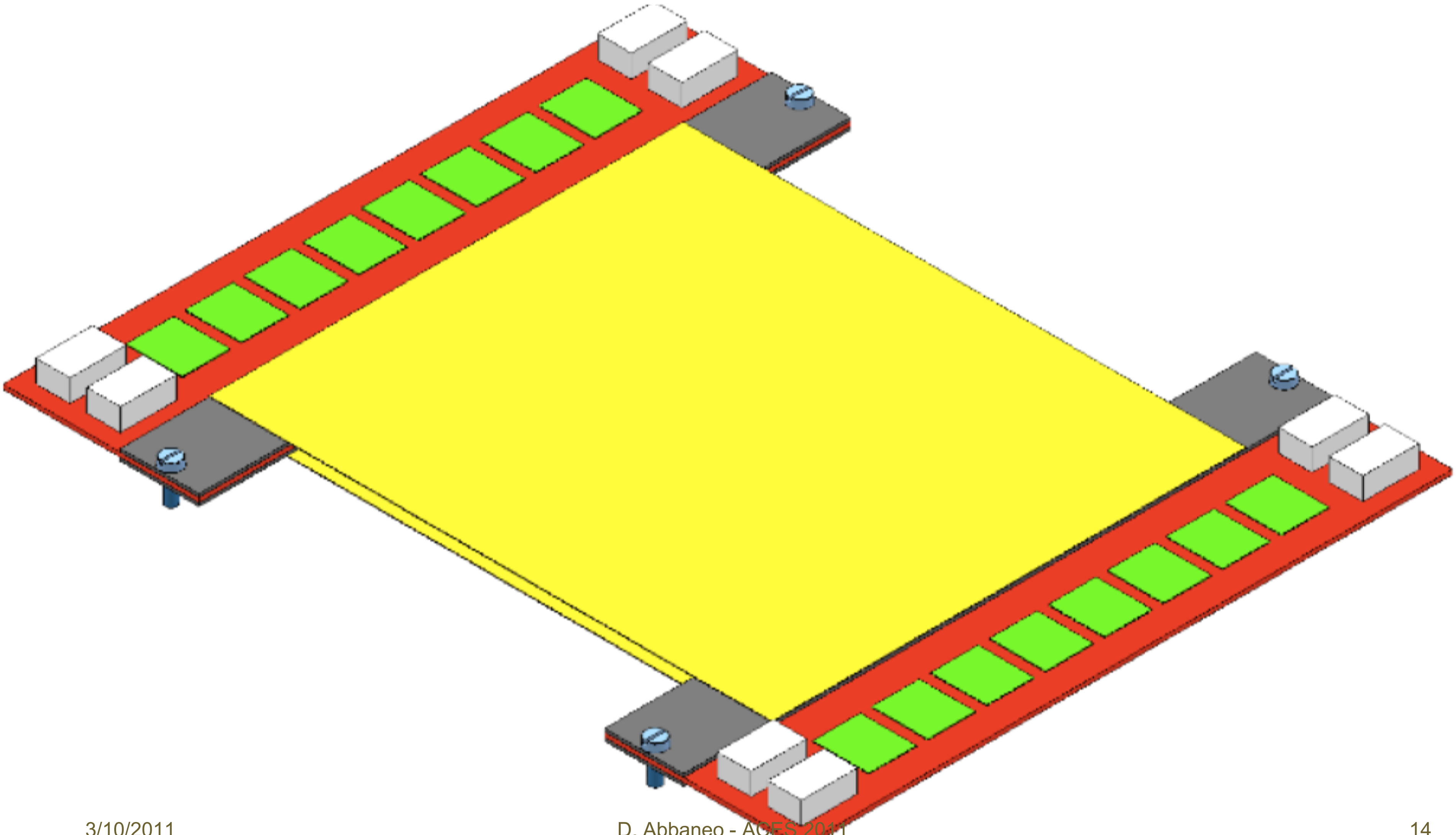


Trigger modules

- Select locally hits from particle above a P_T threshold ("P_T module")
  - Threshold 1 to a few GeV → data reduction of one order of magnitude or more
- Correlate signals in two closely-spaced sensors
- Two families of sensors:
  - Strip based
    - ★ Outer layers
    - ★ No information in the z view @ L1
  - Pixellated
    - ★ Suitable for inner layers
    - ★ Some precision also in the z coordinate

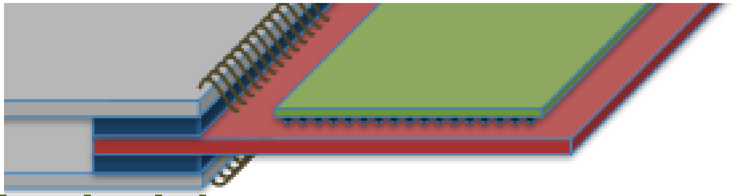


Trigger module for outer layers

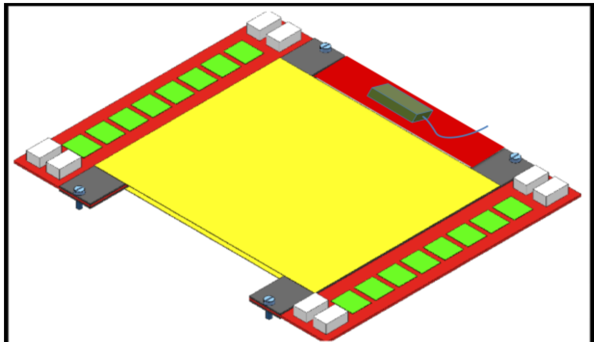


Trigger module for outer layers: features

- ≈ 5 cm long strips, ≈ 90 μm pitch
- Wirebonds from the sensors to the hybrid **<u>on the two sides</u>**
  - 2048 channels on each hybrid!!

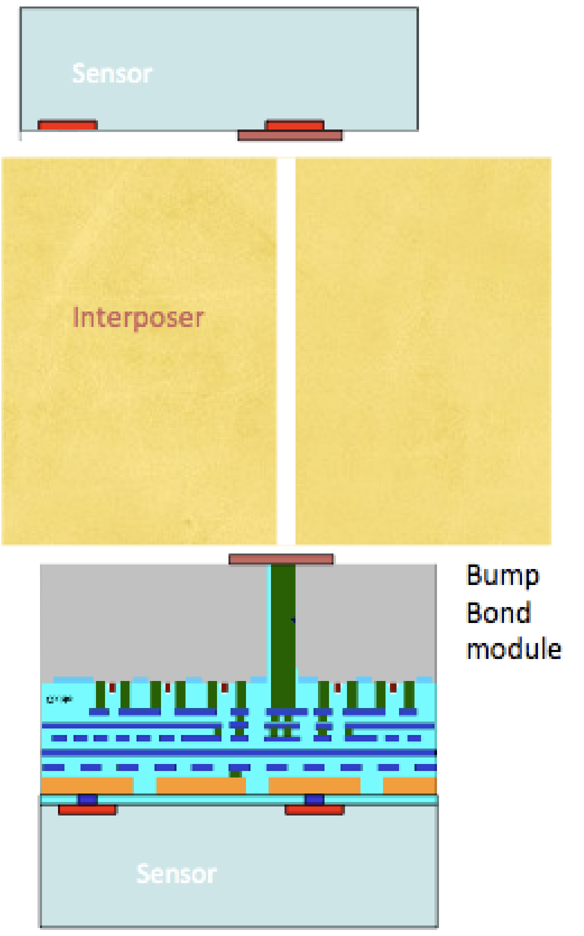


- Chips bump-bonded onto the hybrid
- Neat and lightweight design
- Possibly need 1 GBT / module
  - Depends on the choice for the readout
  - Ideally to be integrated in the module itself, to avoid cumbersome connectivity
    - ★ Rather impossible with current dimensions
    - ★ No solution at present



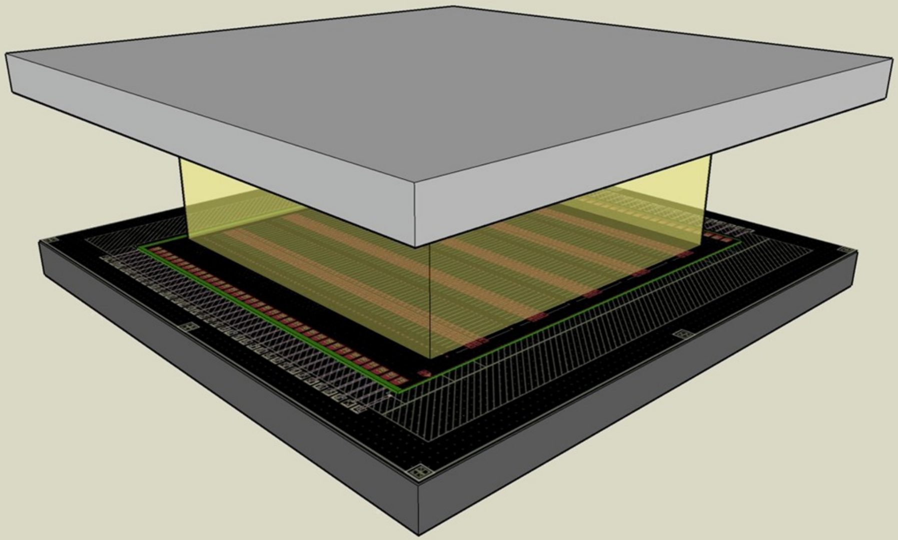
Pixellated P_T modules based on 3d electronics

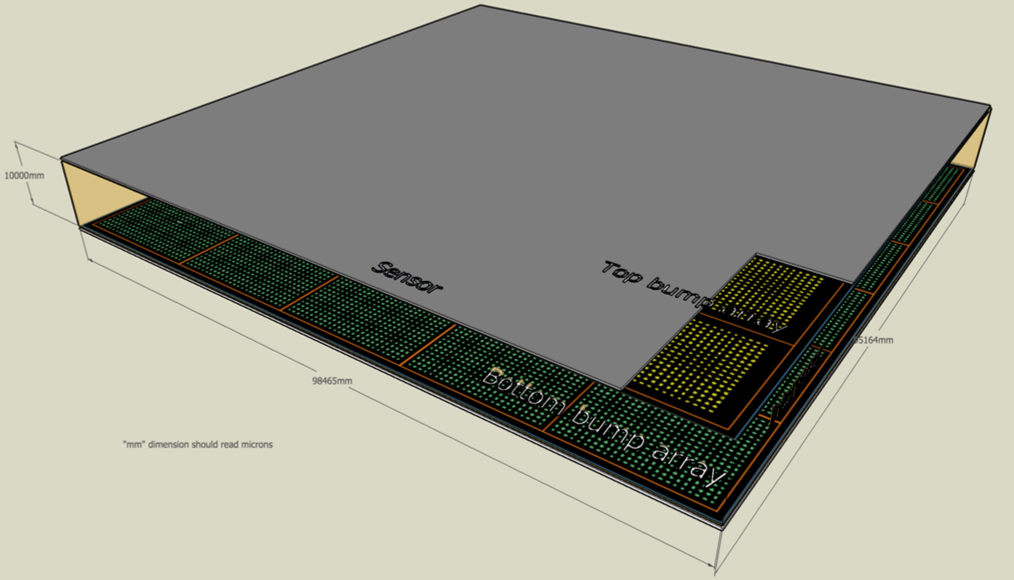
- A single chip connected to top and bottom sensors
- Analogue paths through interposer from top sensor, segmented in ~ cm long strips
- Bottom sensor provides z precision (~ mm long pixels)
- Electronics and connectivity (interposer) are technological challenges (yield, robustness, mass, large–size module)



Development in steps

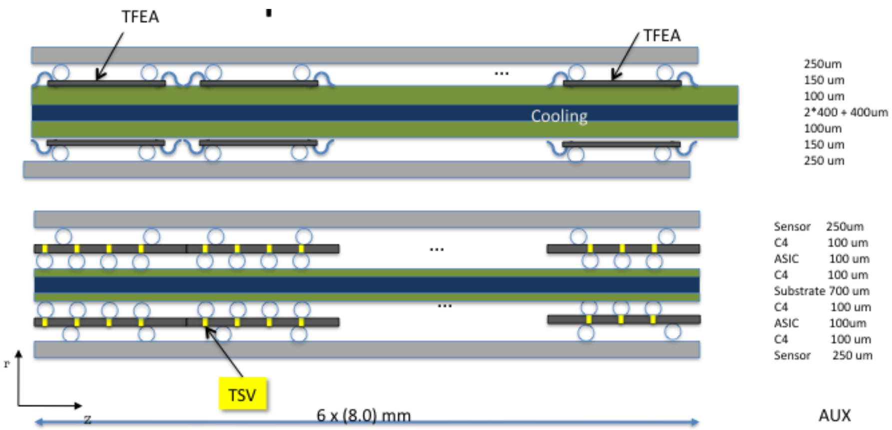
- Demonstrator 5×5 → module 100×100?

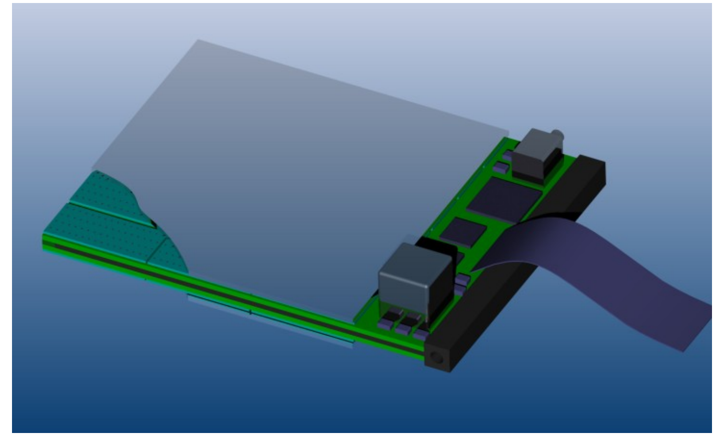




- A long way to go for large surface, and volume production

Pixellated P_T modules – other approach





- ⊙ Interconnection with or w/out TSVs, symmetric assembly
- ⊙ Low-distance digital lines from top to bottom (through edge of substrate)
- ⊙ Auxiliary electronics integrated in module
  - ★ But the sketch is an "artistic view", not a realistic model!

➢ Based on application of existing (advanced) technologies

- ⊙ Concept developed in cooperation with two packaging companies
  - ★ The substrate is a commercial product
  - ★ Interconnection techniques used in commercial devices
- ⊙ Realistic (?) goal 48x48 mm^2

➢ Interconnection is nevertheless the challenge

- ⊙ Large assembly combined with our requirements (yield, low T operation, reliability, rad hardness….) is exotic

➢ Substantial penalty in mass and power

Conclusions and outlook

- Studies of a few module designs started
  - Several ideas considered…
    - … and possibly more to come!
- Hybrid technology is a key
  - Start exploring technological options in parallel with design of active components
    - Stringent requirements on CTE, rad hardness, reliability
  - Interconnection technology is even more crucial for pixellated P_T modules
- Integration of optical links is an issue
  - Notably for trigger modules
  - A much smaller packaging for the optical transmitter seems mandatory