Scalability of Detector Technologies

ATLAS
High Granularity Timing Detector

Lucia Masetti
Johannes Gutenberg University Mainz
PRISMA Cluster of Excellence

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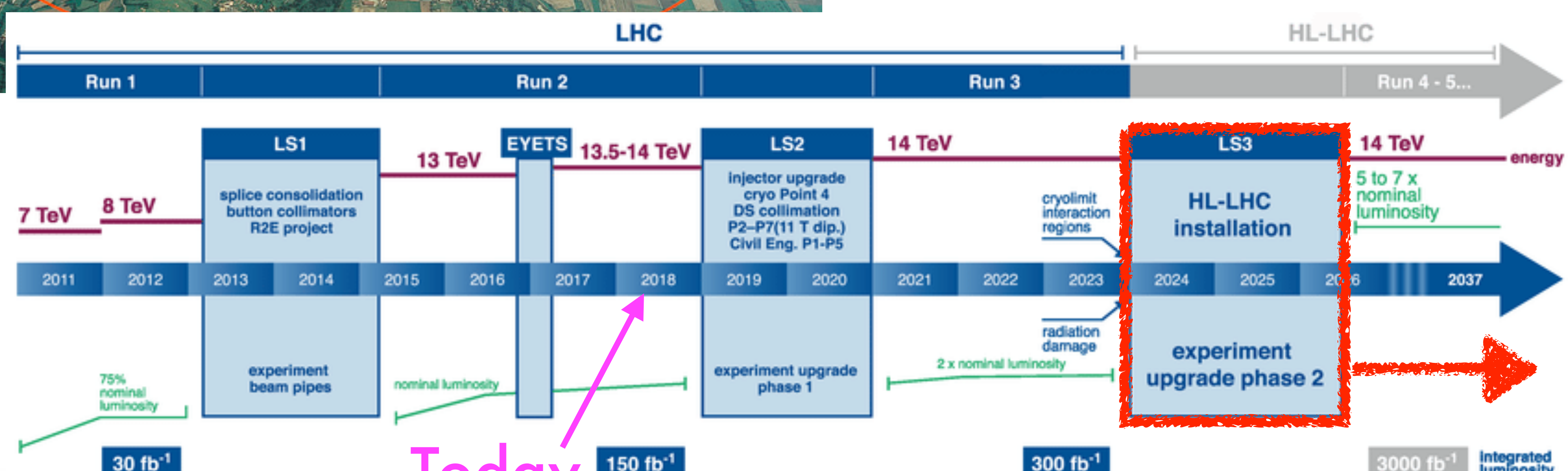
Outline

- Introduction
  - Challenge → task → required performance
- Overall design
  - Constraints + (vs.) requirements → design choices
- Some more details
  - Electronics, assembly, mechanics, cooling
- Conclusion

Introduction

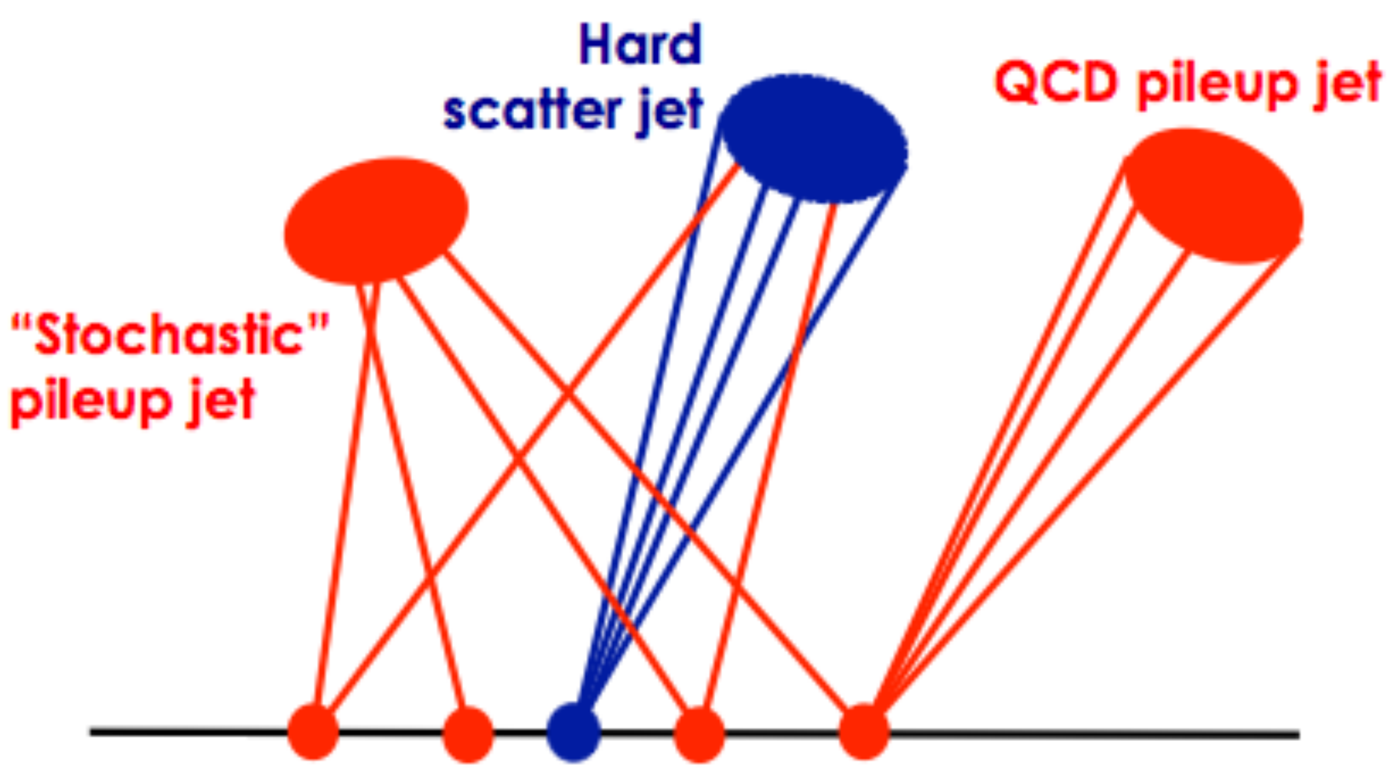
High Luminosity LHC

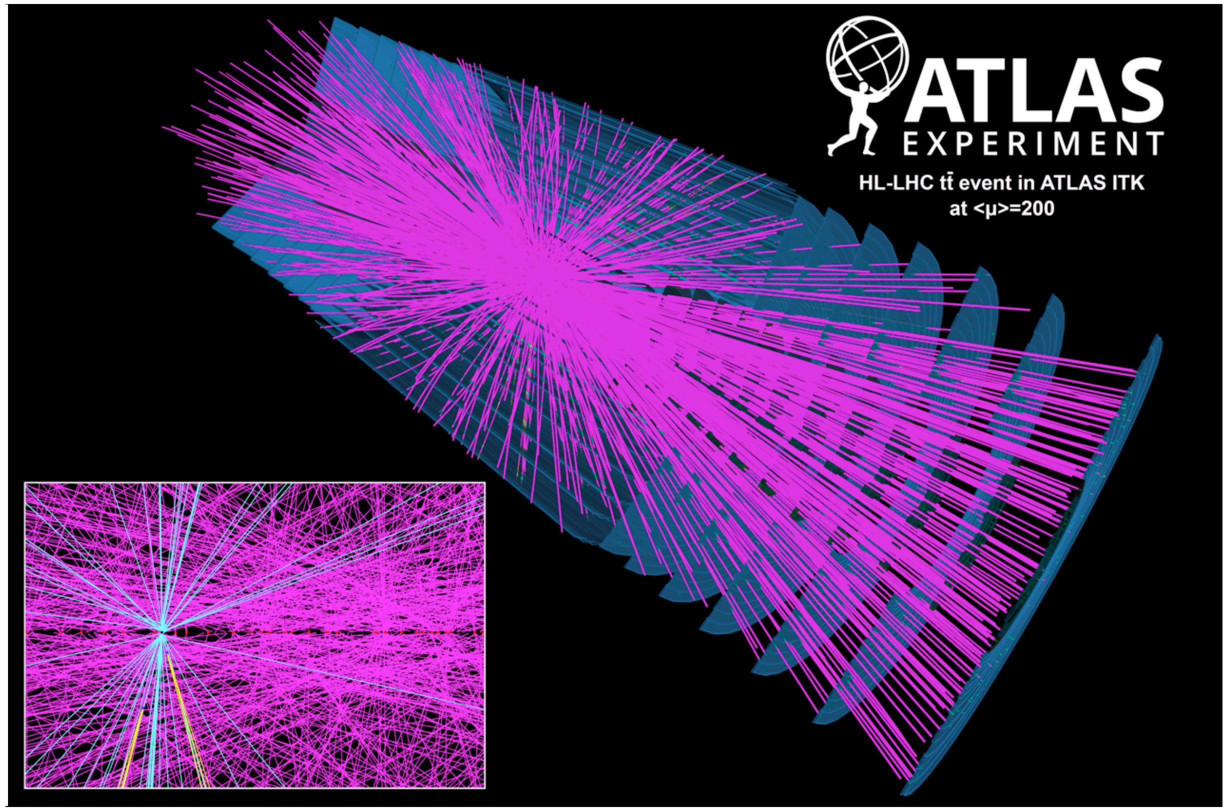
- Run 3
  - instantaneous luminosity $2 \times 10^{34} cm^{-2} s^{-1}$
  - integrated luminosity 300/fb
- Run 4
  - instantaneous luminosity $7.5 \times 10^{34} cm^{-2} s^{-1}$
  - integrated luminosity 3000/fb



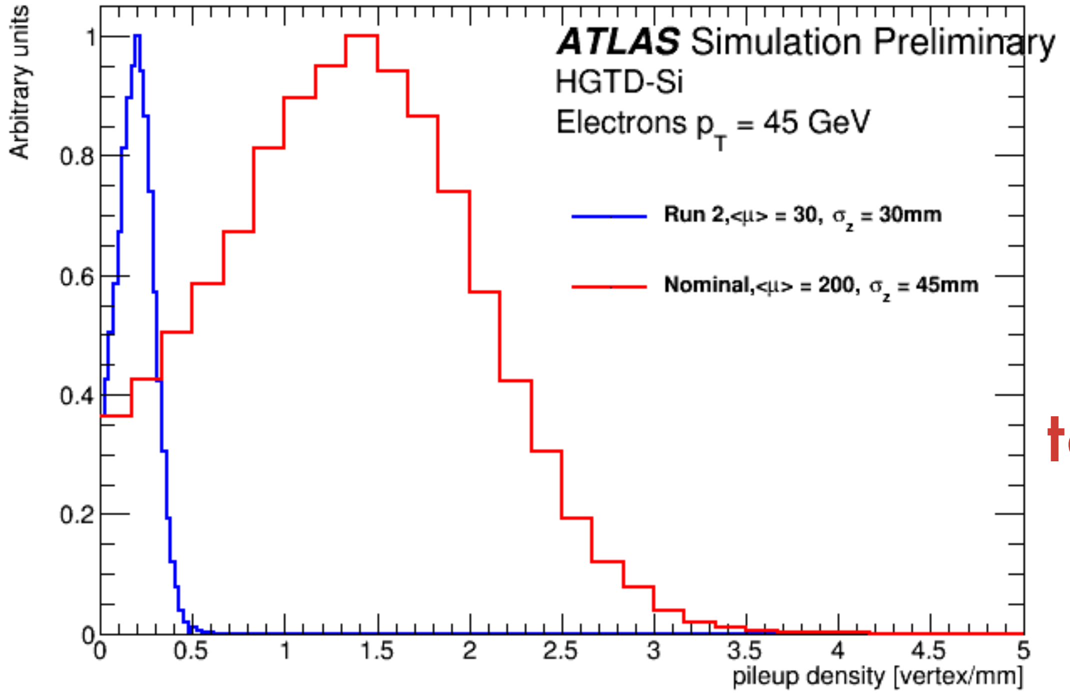
The challenge

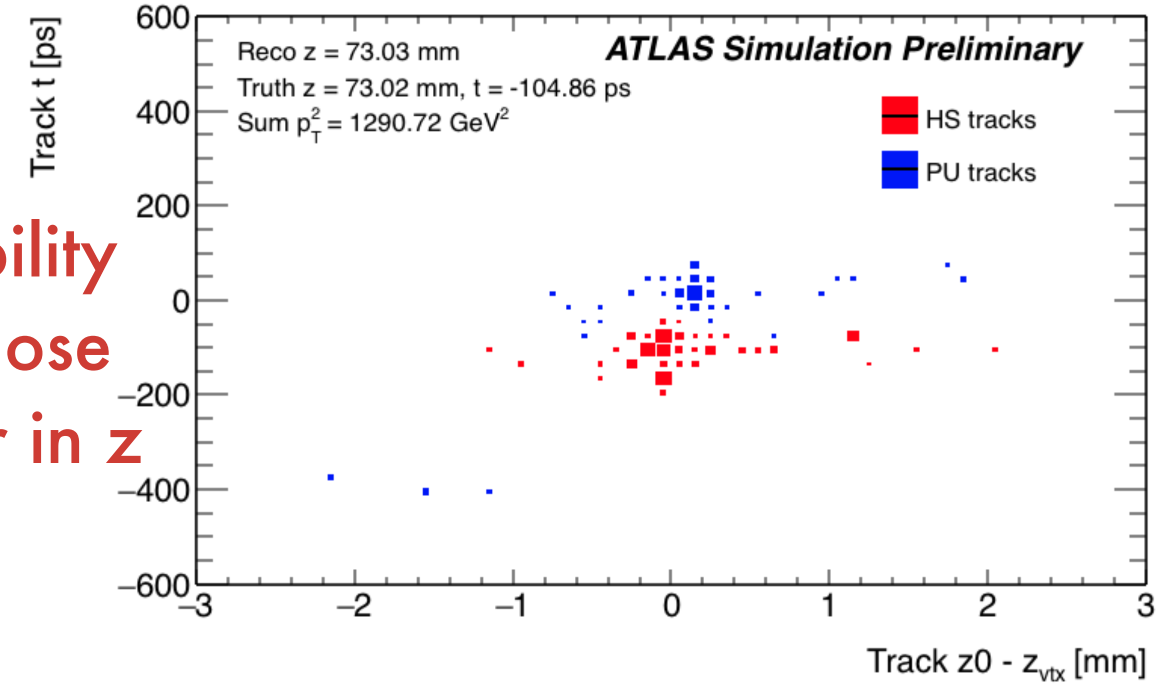
- The price for higher instantaneous luminosity is higher pile-up
  - About 200 collisions per bunch crossing (150 ps, 50 mm)
  - Overlapping vertices, high noise in calorimeter endcaps and forward region



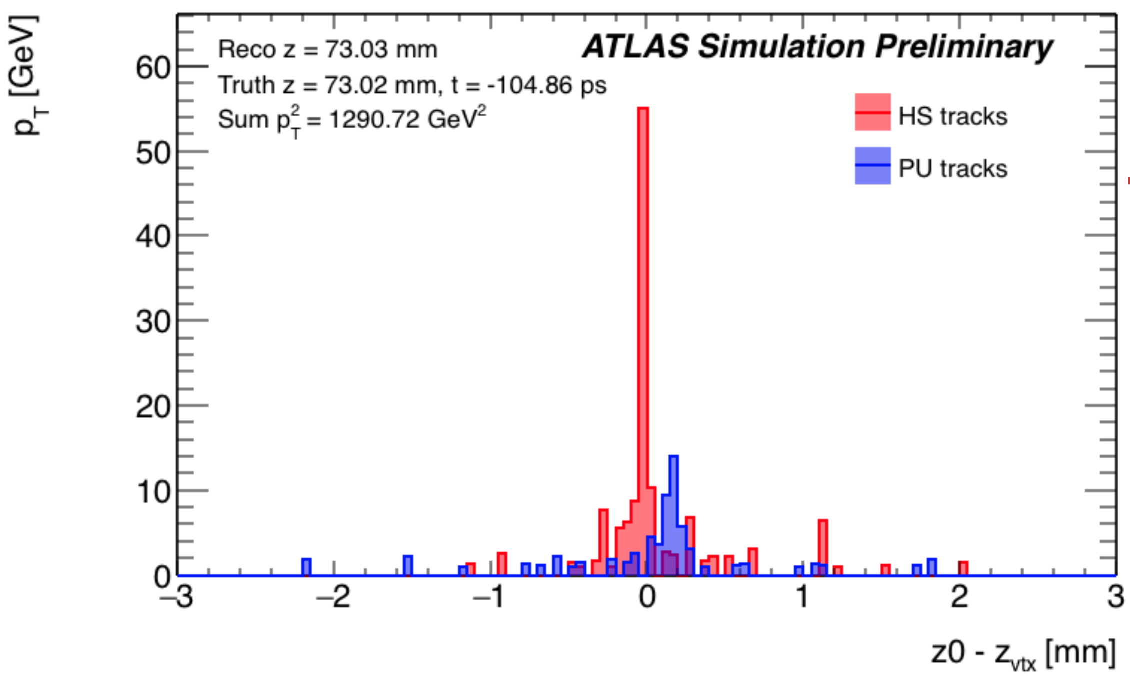


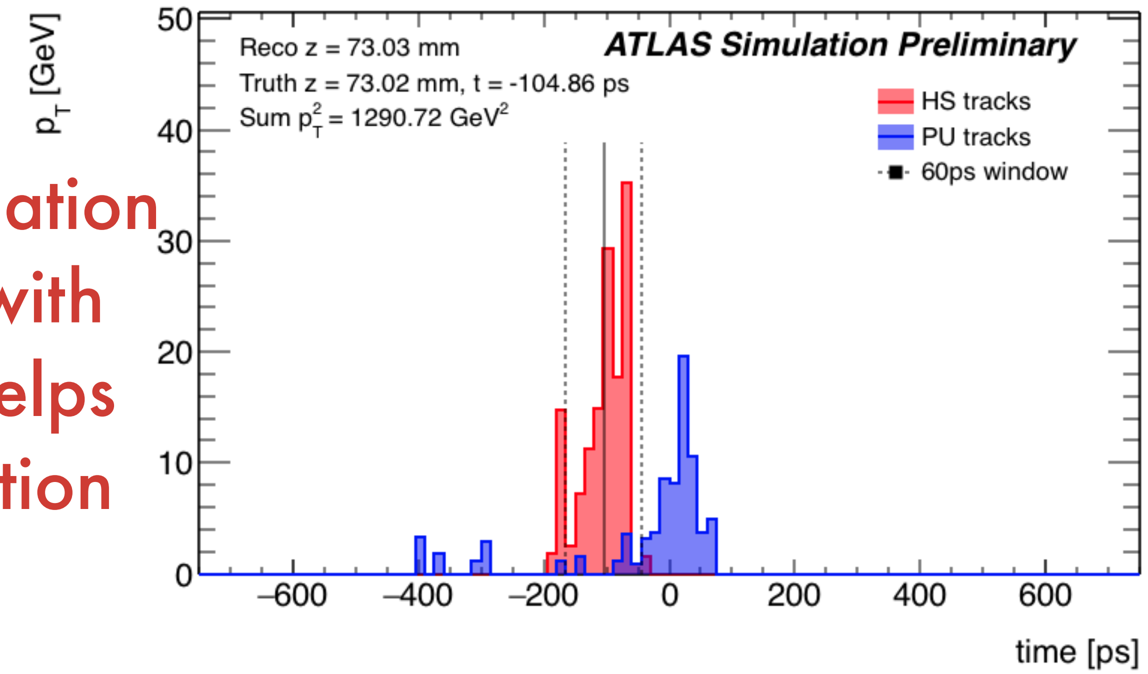
One of the tasks





High probability of vertices close to each other in z

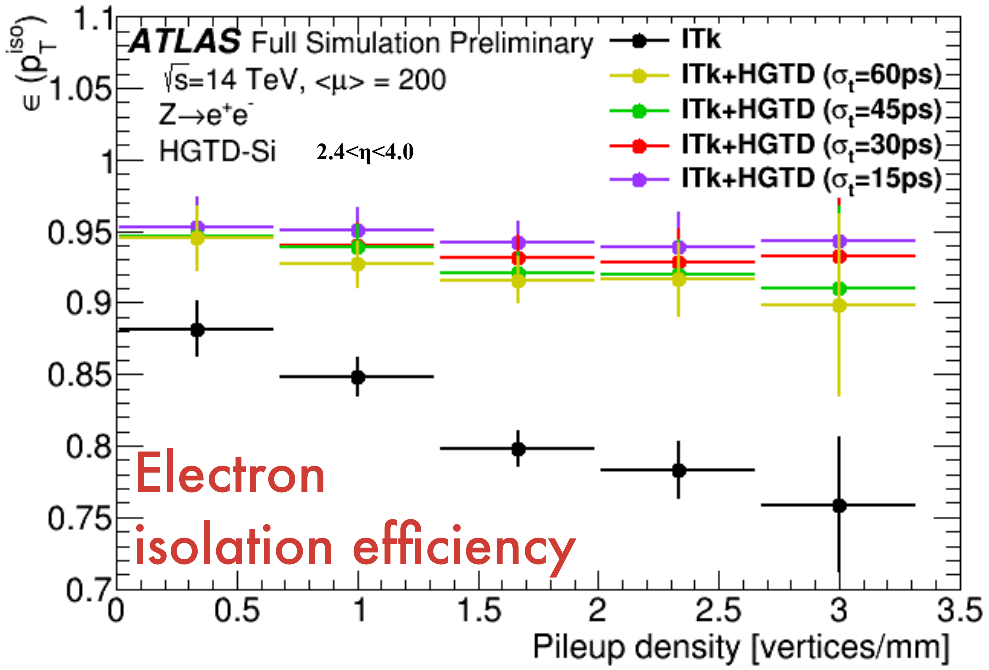




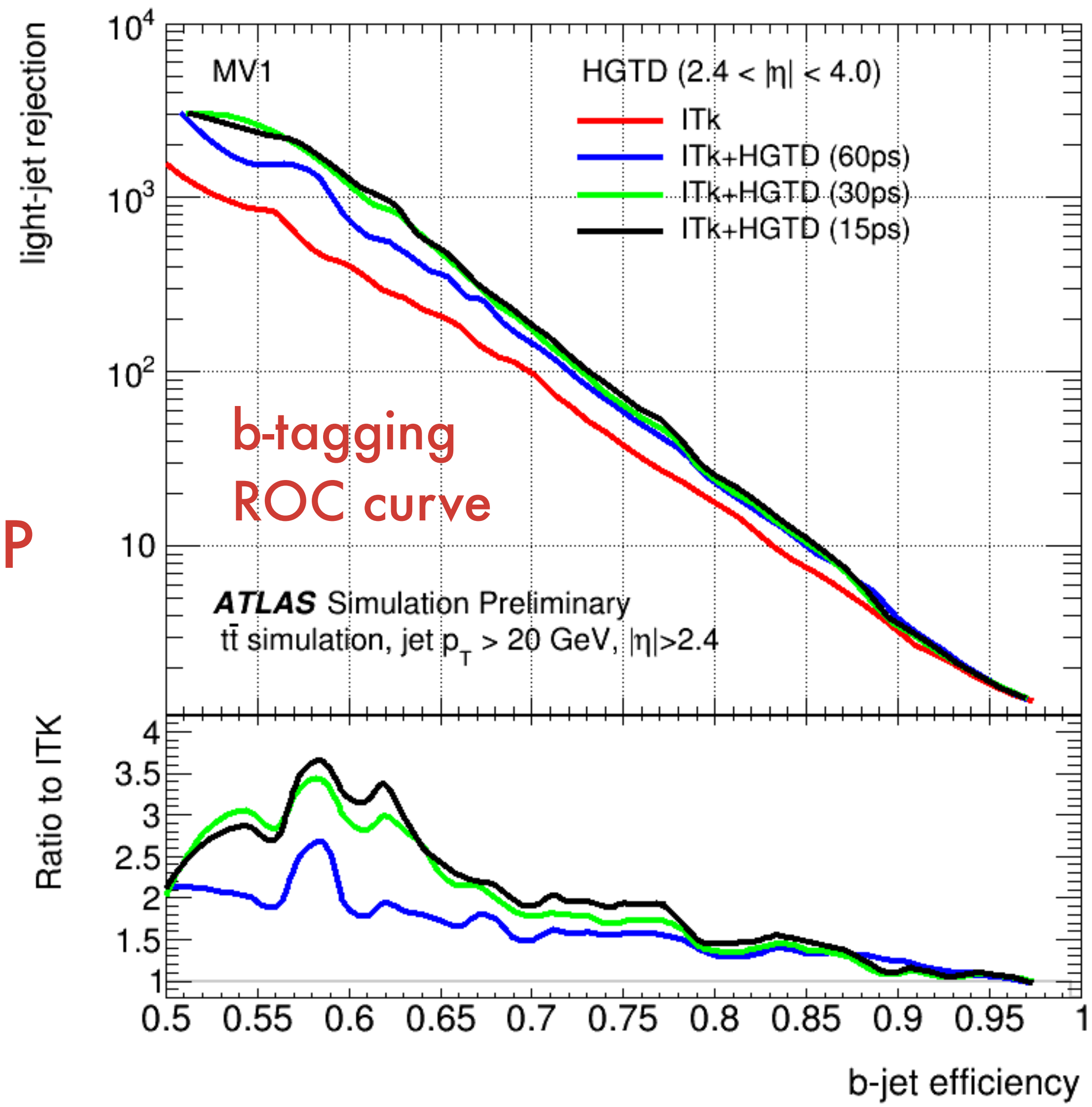
Time information together with tracking helps discrimination

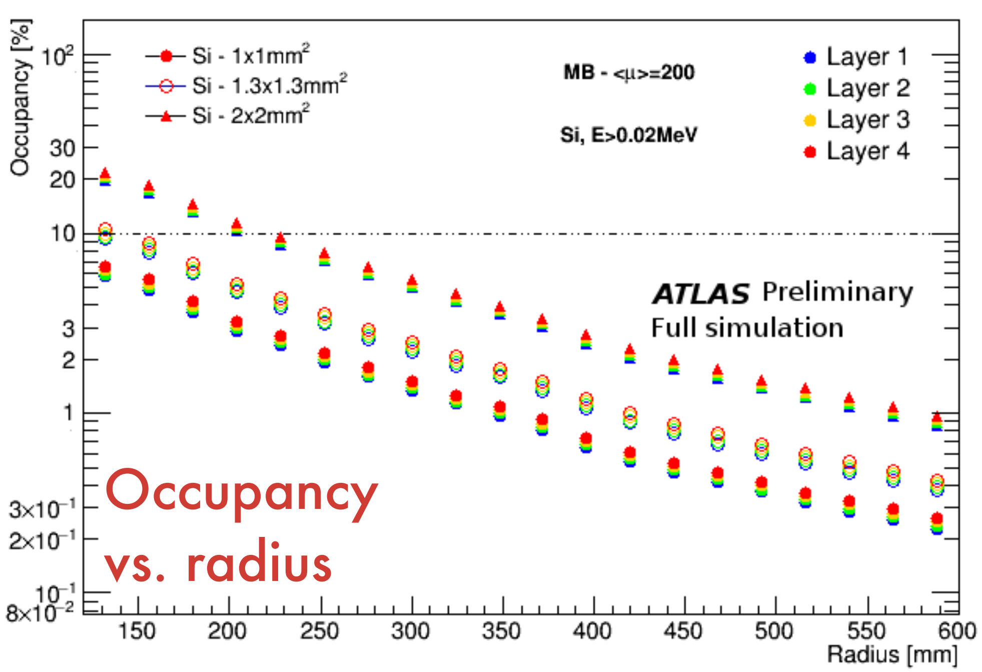
Required performance

a.k.a. what is good enough?



No large improvement for σ_t < 30 ps for a single MIP



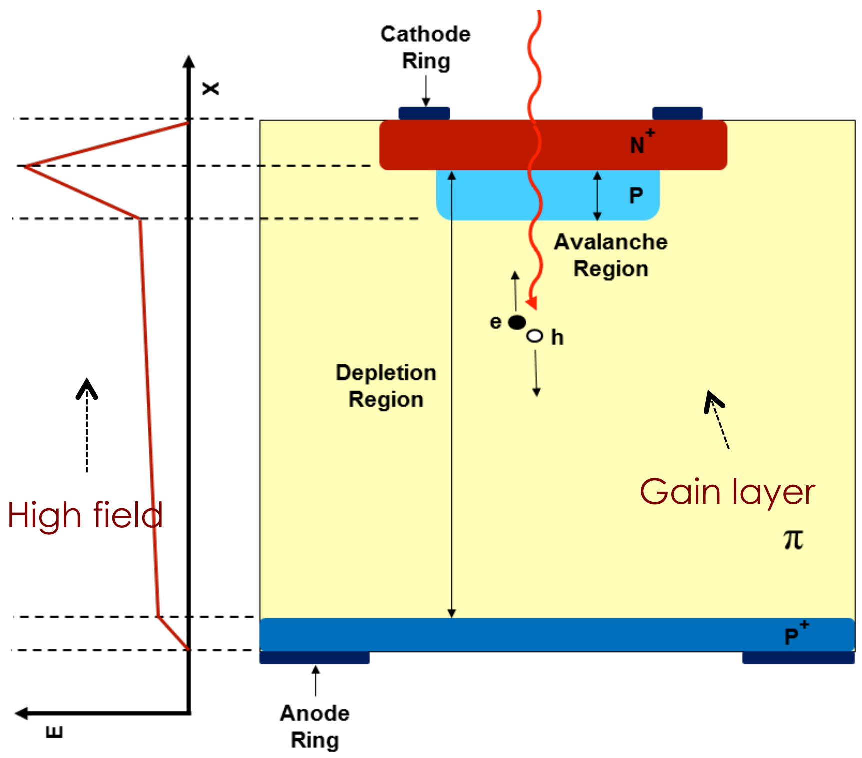


Granularity of 1.3x1.3 mm² keeps occupancy < 10% at all radii

Overall design

Choice of technology

see yesterday's talk by J. Lange



- Detectors with 30-50 ps time resolution and 1.3x1.3 mm^2 granularity?
  - Low Gain Avalanche Detectors
- Known for a few years: excellent performance before irradiation when read out by oscilloscope with high sampling rate
  - What else is needed to make a detector out of these sensors?

Available space

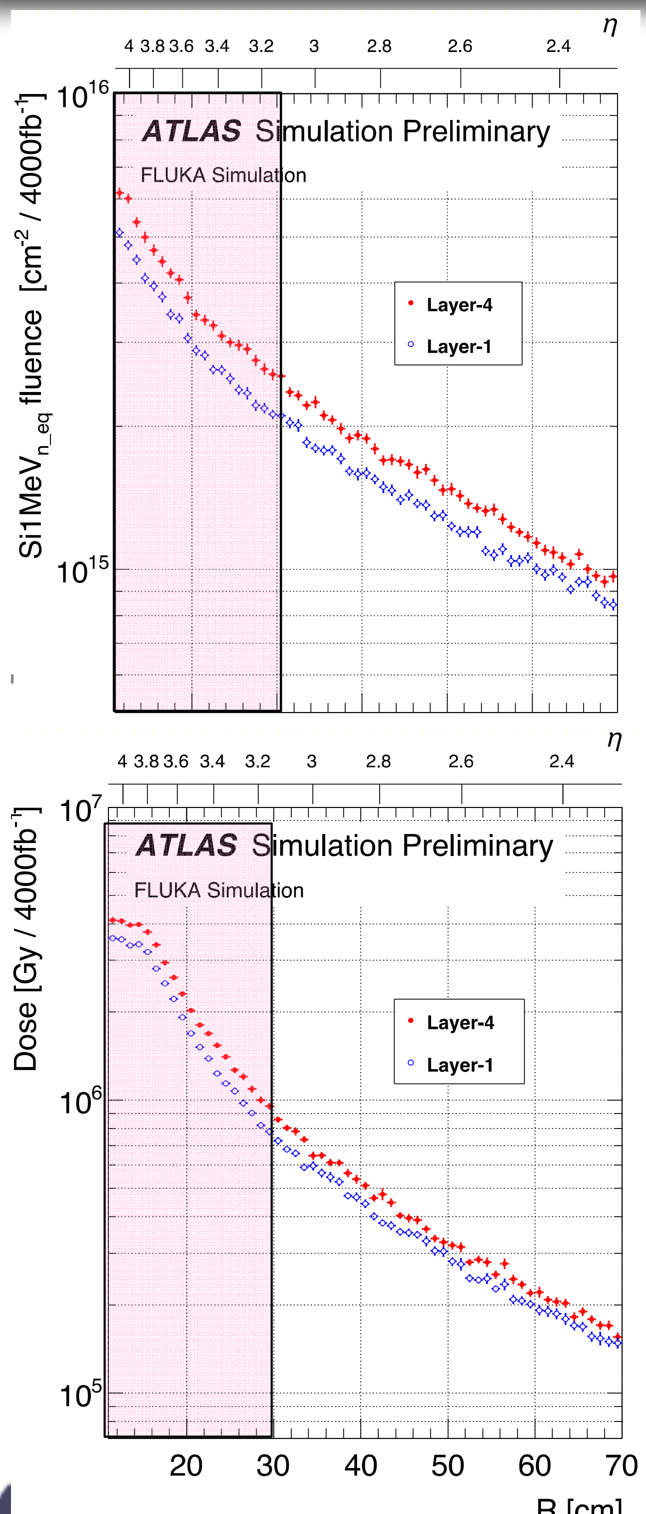
Minimum Bias Trigger Scintillators to be removed → space can be used by HGTD

Radially constrained by ITk services (64cm) and beam pipe (12cm)

Corresponding to $2.4 < \eta < 4.0$

Thickness constrained to $\Delta z = 7.5$ cm (+ 5 cm moderator)

Radiation hardness

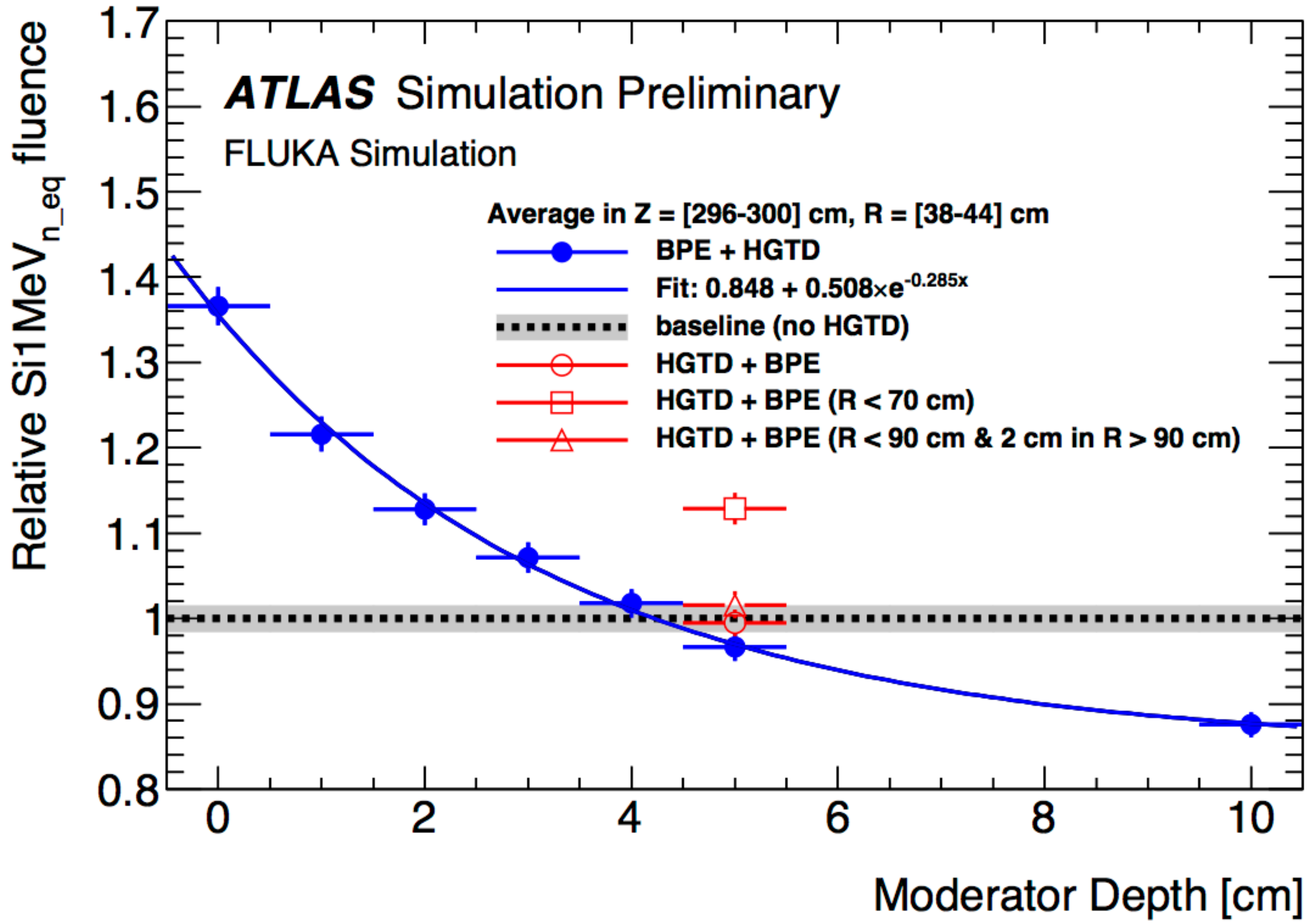


- Max neutron fluence and dose after 4 ab^{-1}, including safety factors (not in the plots):
  - At r = 12 cm: 9×10^{15} n_{eq}/cm^2 and 9 MGy
  - 20% of sensors and ASICs (r < 30 cm) need replacement at half lifetime of HL-LHC
- To reduce radiation damage:
  - Operation of silicon detectors at -30°C using CO_2 cooling from inner detector

Moderator for tracker

Radiation level on ITk must not be increased by inserting the HGTD

Moderator (borated polyethylene) needed to shield tracker from back-scattered neutrons

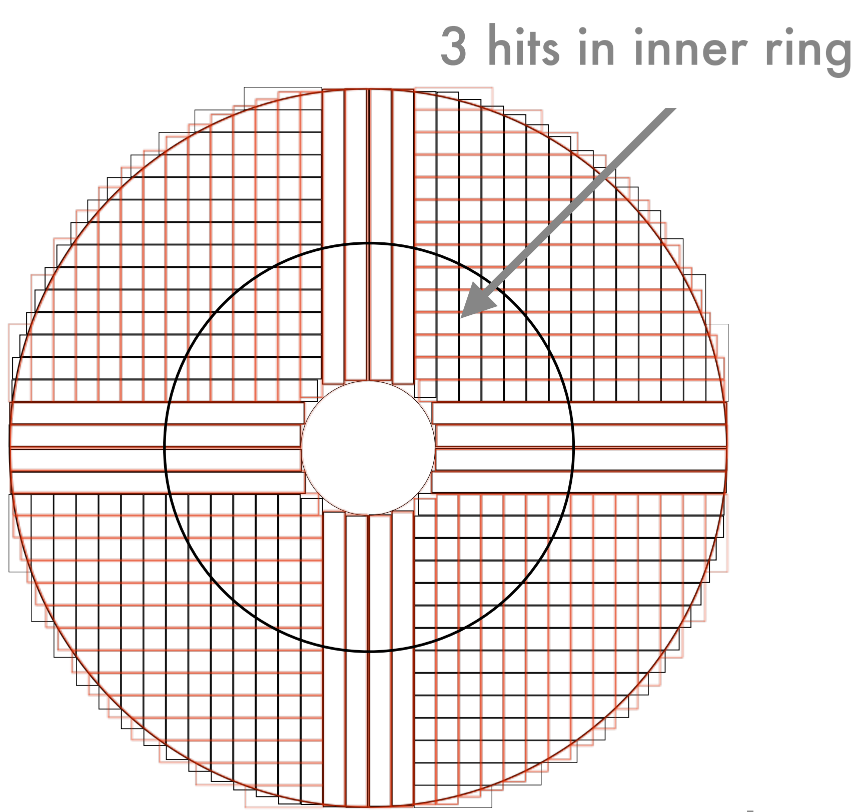


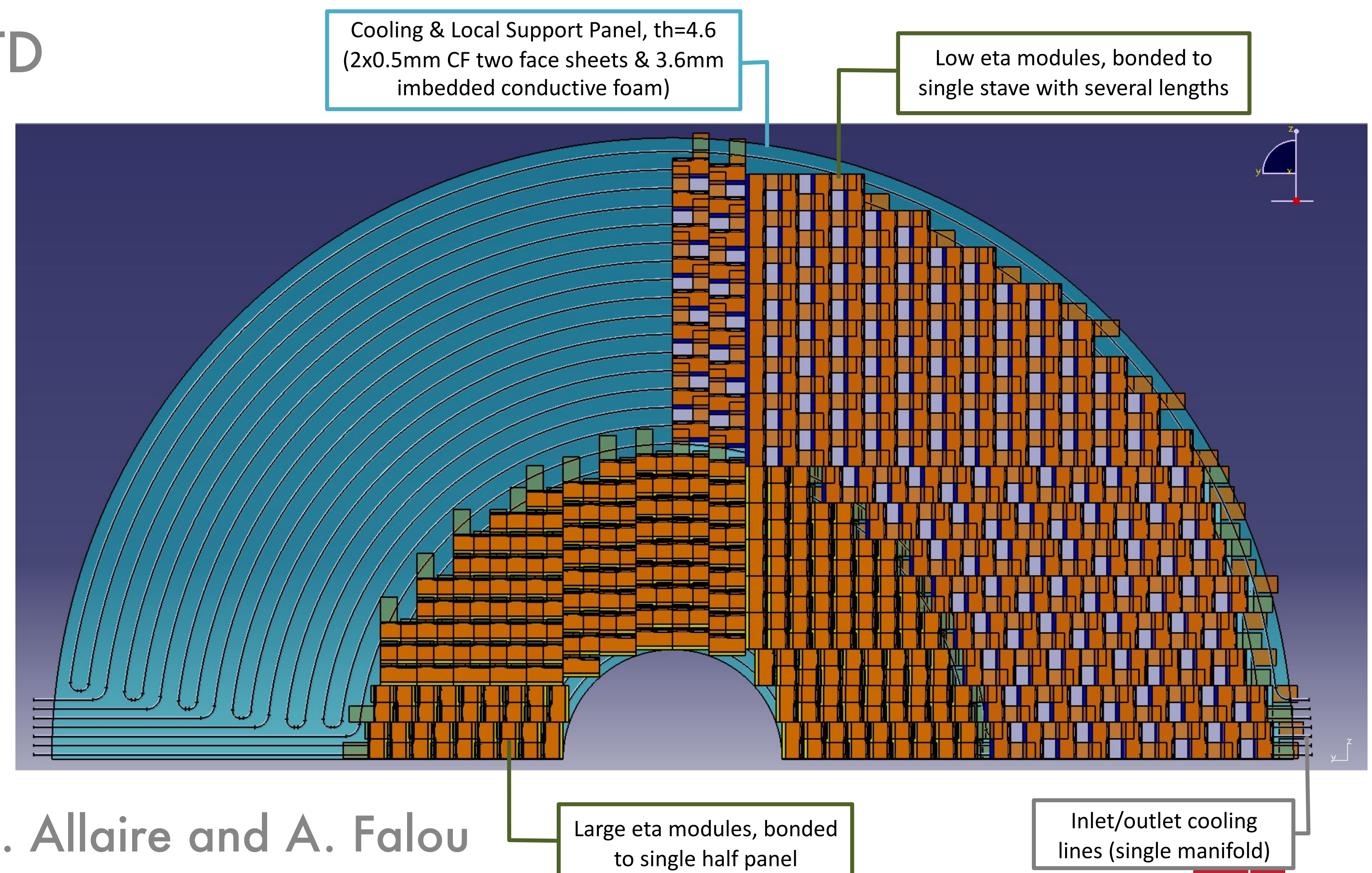
Reducing the cost

- Sensors are the most expensive single component
- But, reducing number of hits per track (number of layers) degrades time resolution
- Make use of different radiation levels at different radii and pileup dependence on η
  Time resolution per layer is less affected at high radius and there is less pileup to get rid of
- Currently proposed solution
  - More hits per track at small radii by increasing overlap between sensors
  - Total decrease in number of layers
  - Saves both on sensors and on services and mechanics

Current design

- **Two layers** per endcap with sensors on both sides and higher overlap at low radii to ensure 3 hits per track
- **Inner ring** separated from outer staves to allow for easier replacement at half lifetime
- 5 cm **moderator** “after” HGTD





Drawings by C. Allaire and A. Falou

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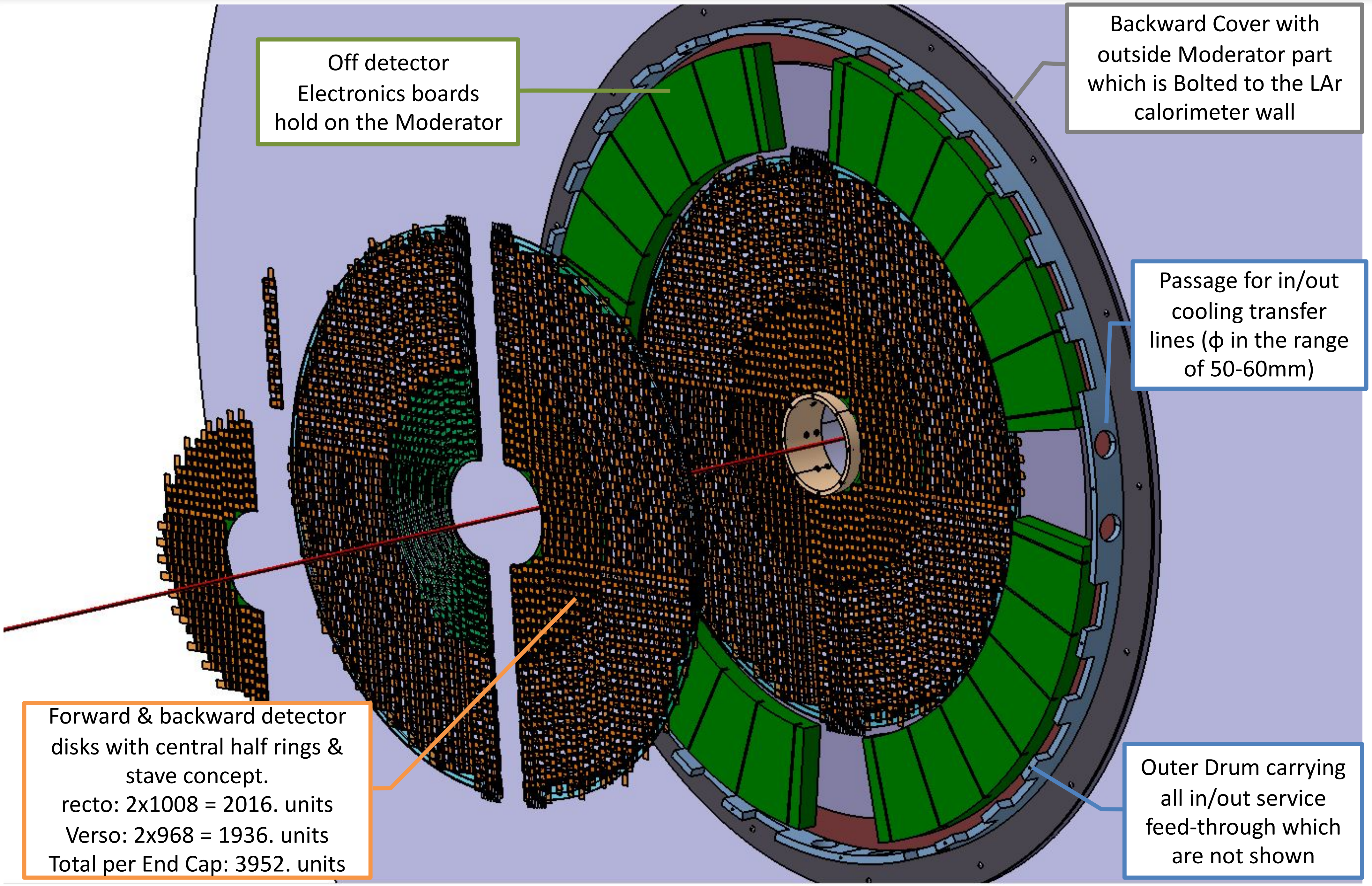
Putting it all together



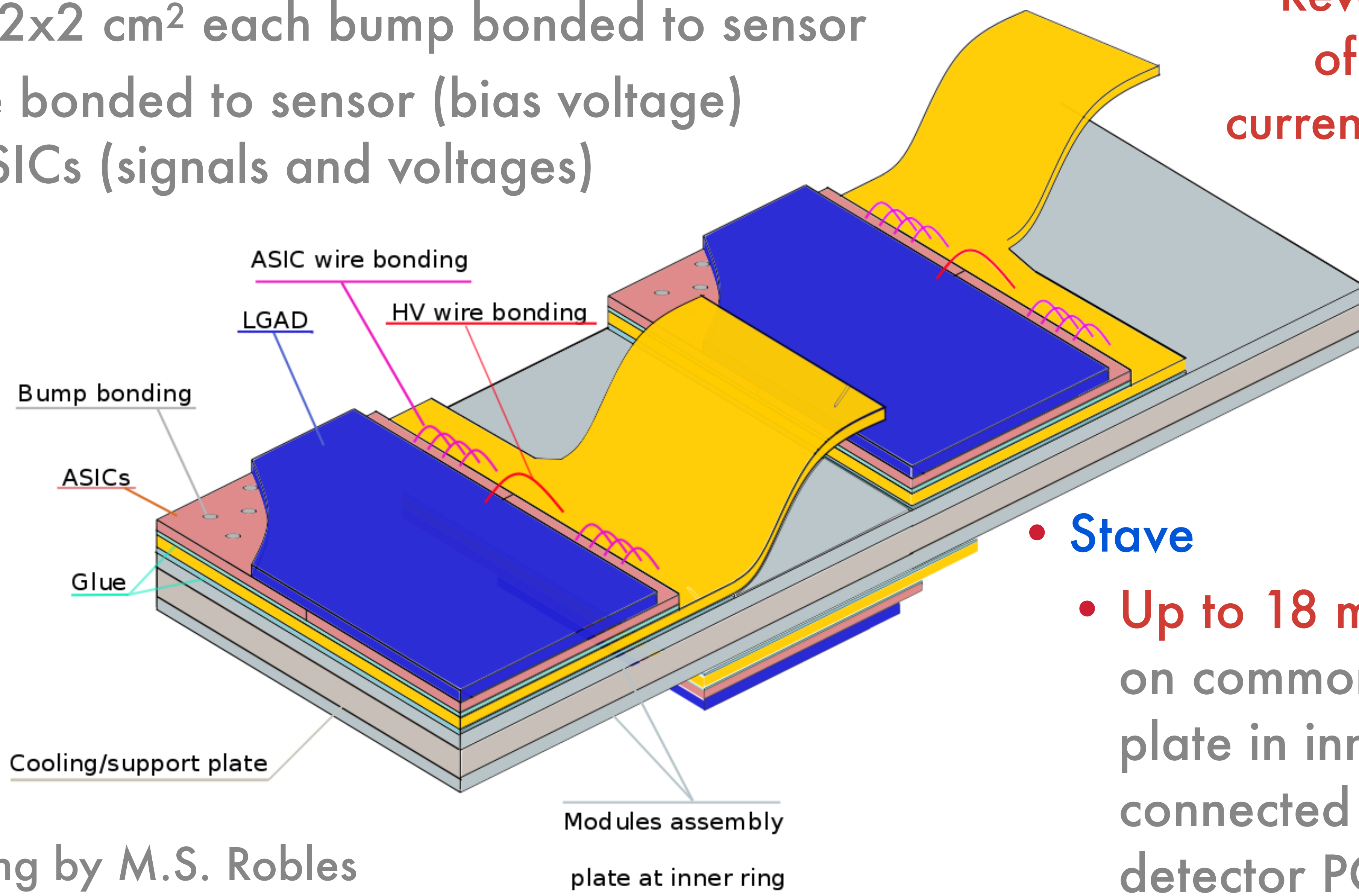
Slide by A. Falou

Some more details

Modules and staves

- Module
  - Sensor: 4x2 cm² with 1.3x1.3 mm² pads
  - 2 ASICs: 2x2 cm² each bump bonded to sensor
  - Flex: wire bonded to sensor (bias voltage) and to ASICs (signals and voltages)

Reverse order of stack-up currently preferred



Drawing by M.S. Robles

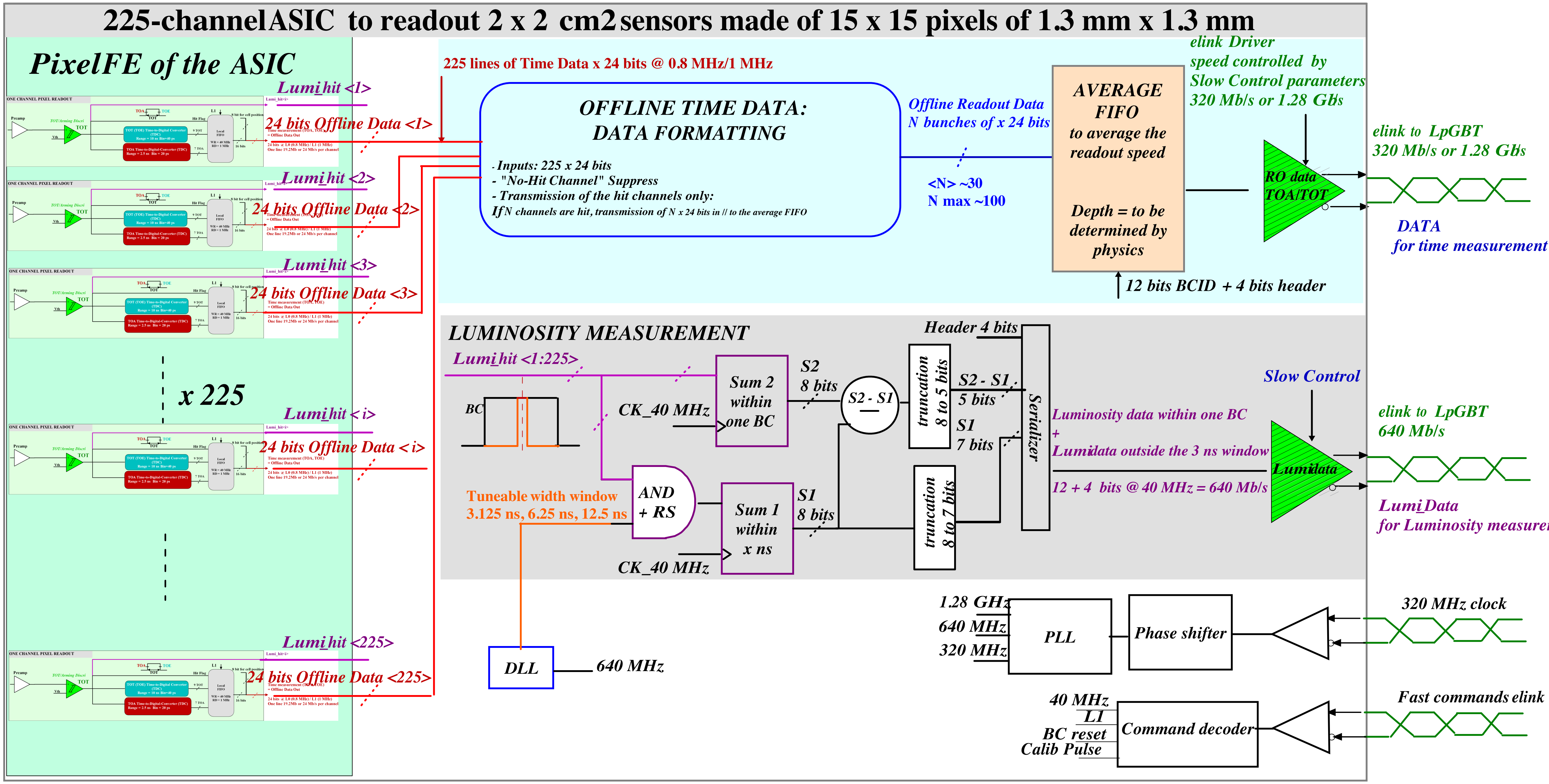
- Stave
  - Up to 18 modules glued on common assembly plate in inner ring and connected to same off detector PCB

Front end ASIC

- Functionalities
  - Amplifier, discriminator, time walk correction, time-to-digital converters
- Requirements

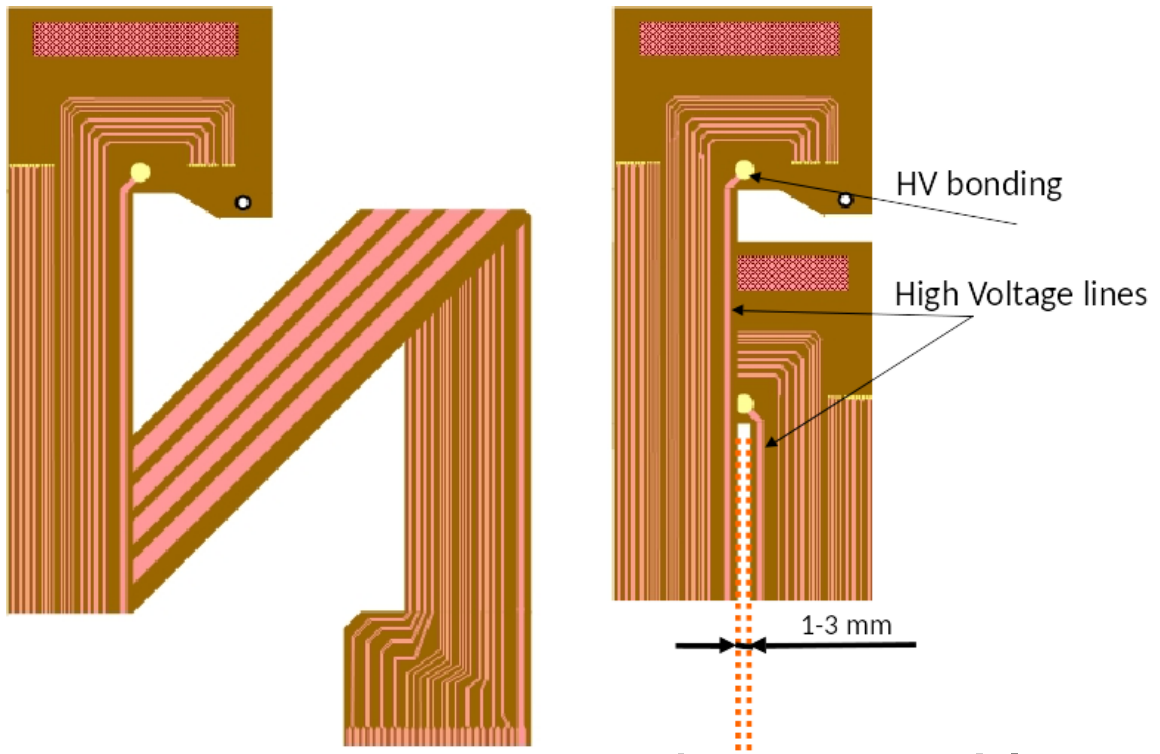
Pad size	1.3×1.3 mm^2
Detector capacitance	3.4 pF
TID and neutron fluence	Inner region: 4.5 MGy, 4.5×10^{15} n_{eq}/cm^2 Outer region: 2.1 MGy, 4.0×10^{15} n_{eq}/cm^2
Number of channels/ASIC	225
Collected charge (1 MIP) at gain=20	9.2 fC
Dynamic range	1-20 MIPs
(preamplifier+discr.) jitter at gain = 20	< 20 ps
Time walk contribution	< 10 ps
TDC binning	20 ps (TOA) and 40 ps (TOT)
TDC range	2.5 ns (TOA) and 10 ns (TOT)
Number of bits / hit	7 for TOA and 9 for TOT
Luminosity counters per ASIC	7 bits (sum) + 5 bits (outside window)
Total power per area (ASIC)	<200 mW/cm^2 (<800 mW)
e-link driver bandwidth	320 Mb/s, 640 Mb/s or 1.28 Gb/s

Front end ASIC



Kapton Flex

- Functionalities
  - Connect electrical signals between sensors/ASICs and off-detector electronics
- Mechanical requirements
  - Limited total thickness per stave allows for 300 µm per flex
  - No damage to wire bonds
- Electrical requirements

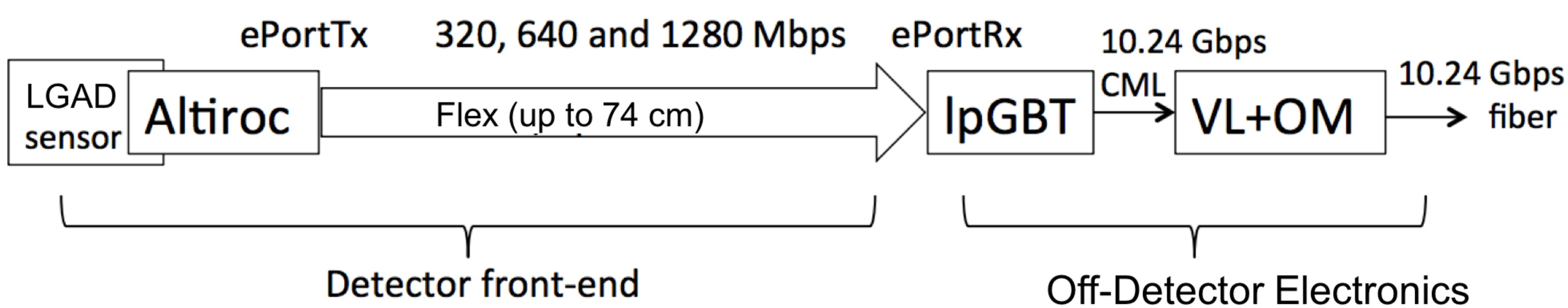


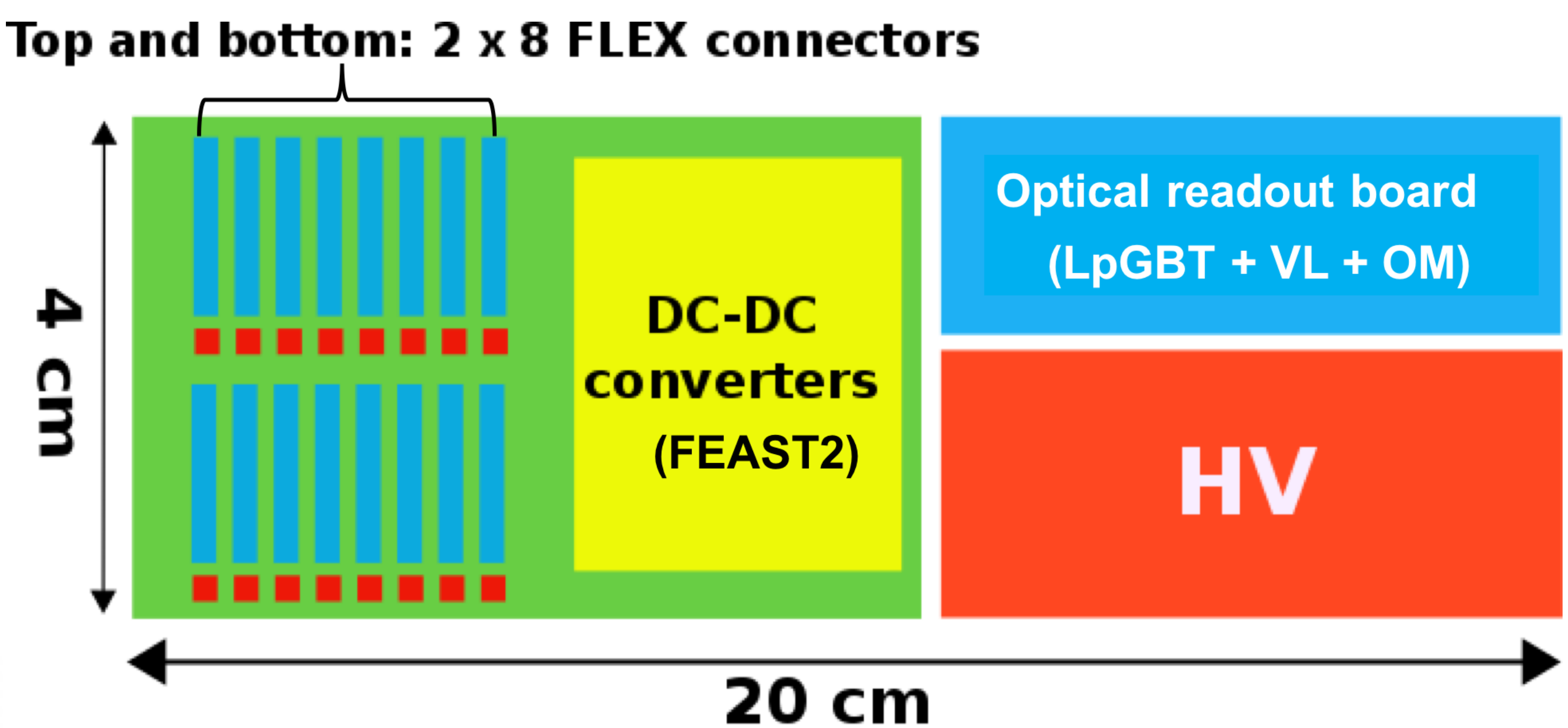
Drawings by M.S. Robles

Signal type	Signal name	Number of wires	Comments
HV	1 kV max.	2	Clearance
POWER	1x V_{vdda}, 1x V_{vddd}	2	Minimize voltage drop
GROUND		1 plane	Dedicated layer
Slow control	Data, ck, (opt. +rst, error)	2 to 4	I2C link
Input clocks	320 MHz, Fast command e-link, (opt. 40 MHz(L1))	6 or 8	LVDS
Data out lines	Readout data (TOT,TOA,Lumi)	4 pairs	4 e-links differential SLVS.
ASIC reset	ASIC_rst	1	Digital

Off-detector electronics

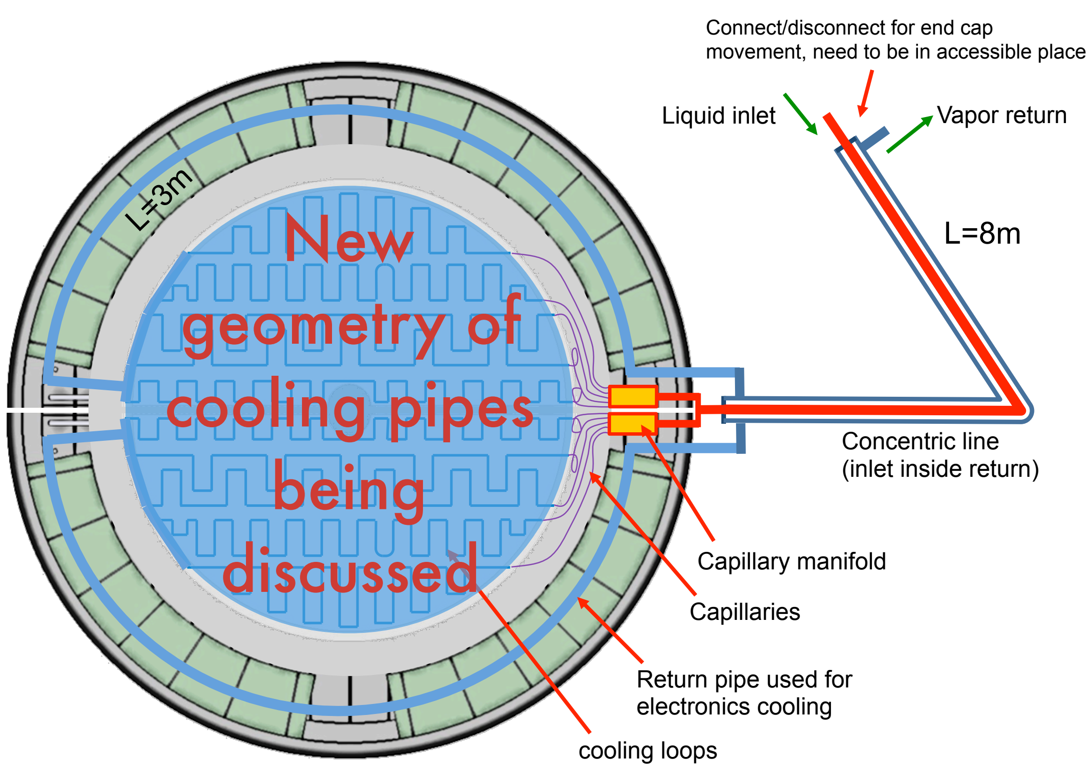
- Functionalities
  - DC/DC converters for LV, HV distribution, data serialisation, transceivers/transmitters for optical links

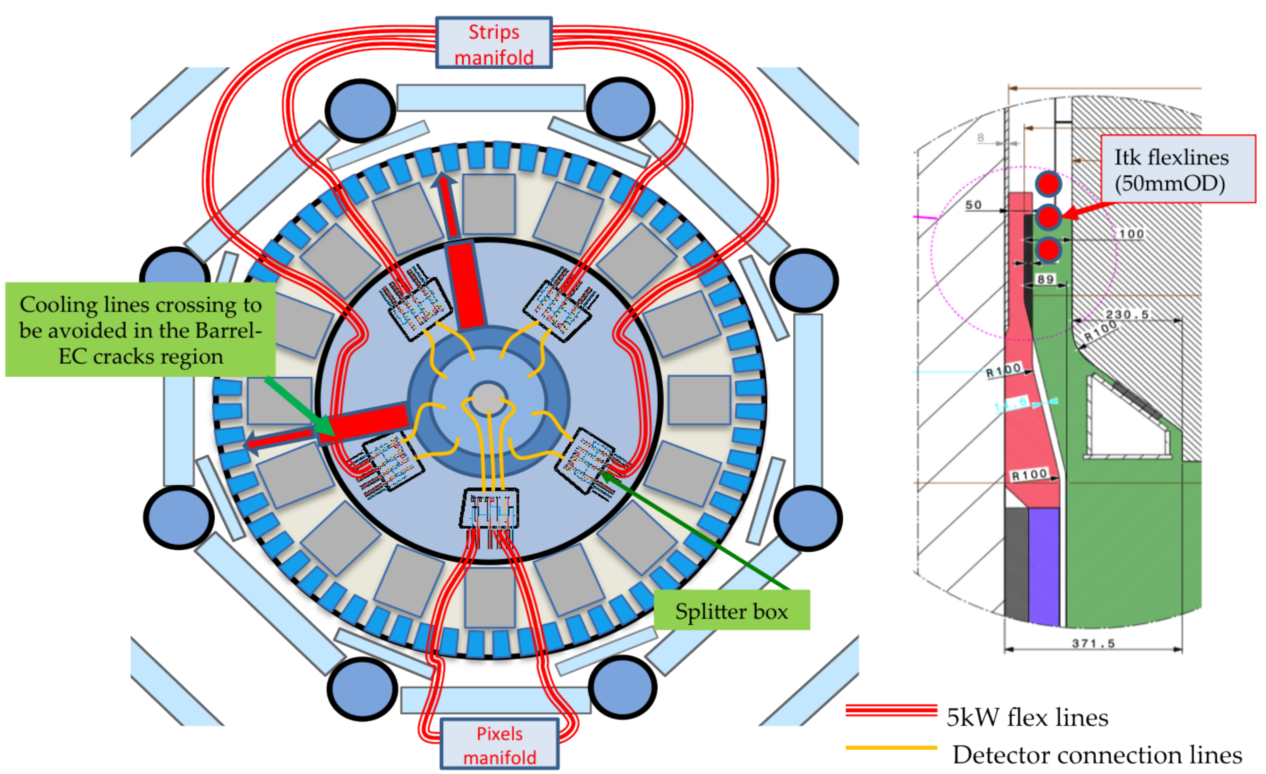




Cooling

- **Requirements**
  - To be integrated with ITk cooling system
  - Operation of sensors at -30°C with stability of few degrees
  - Operation of off-detector electronics at about +18°C
  - Total cooling power of 20 kW

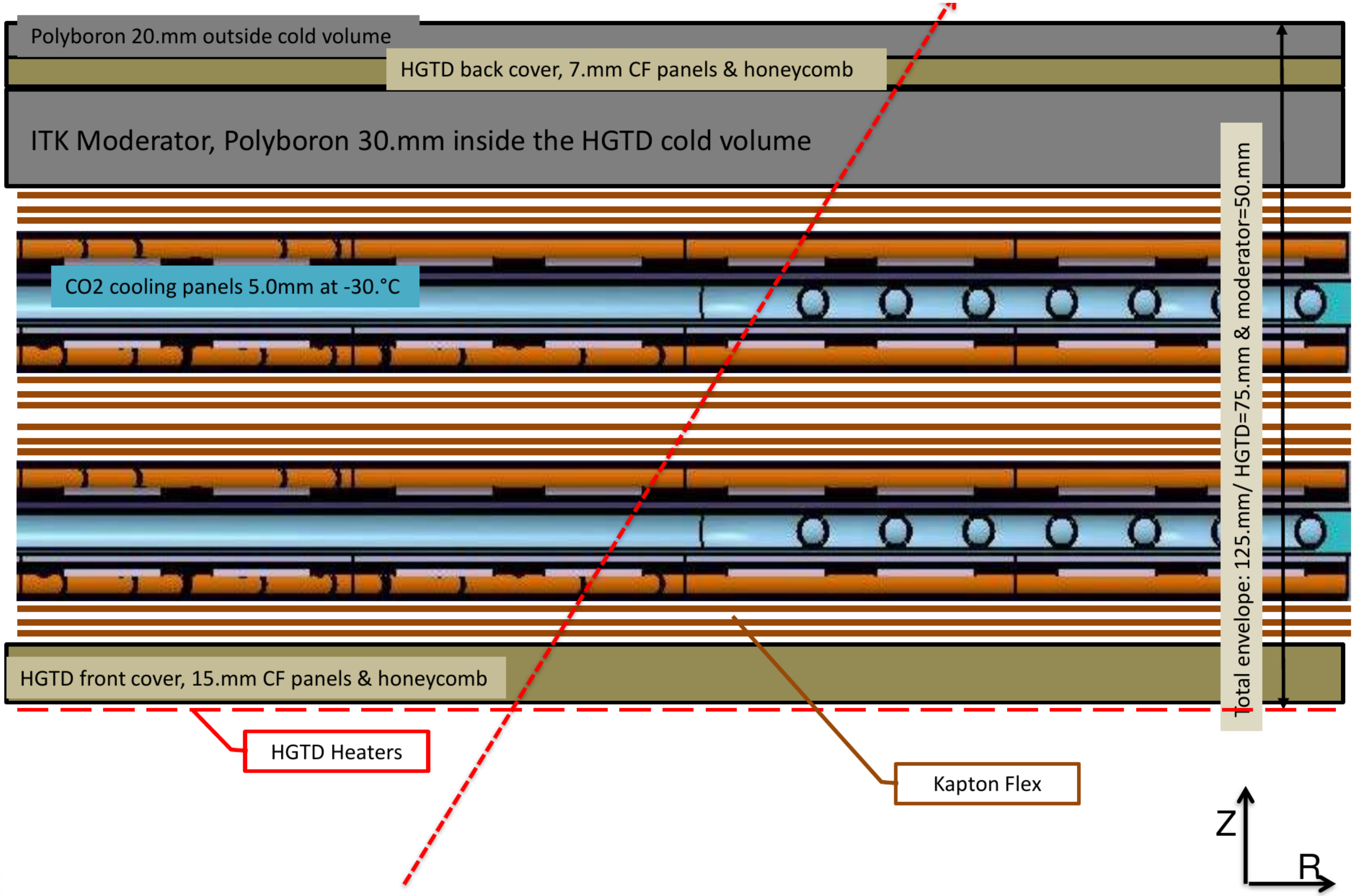




Drawings by A. Falou

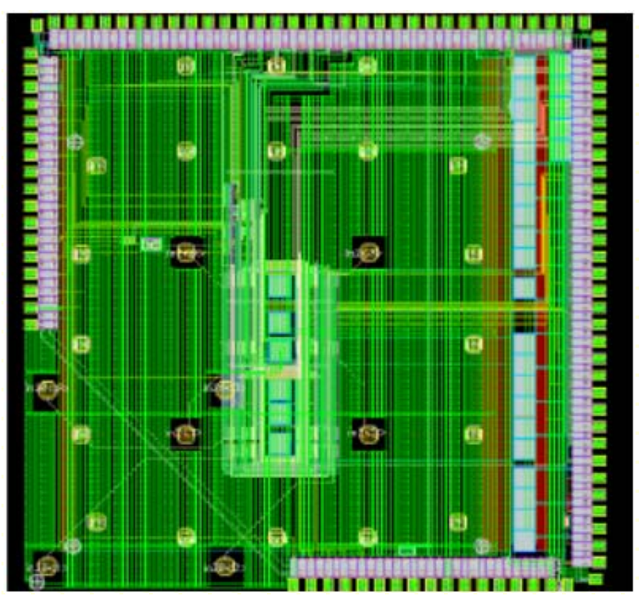
Mechanical integration

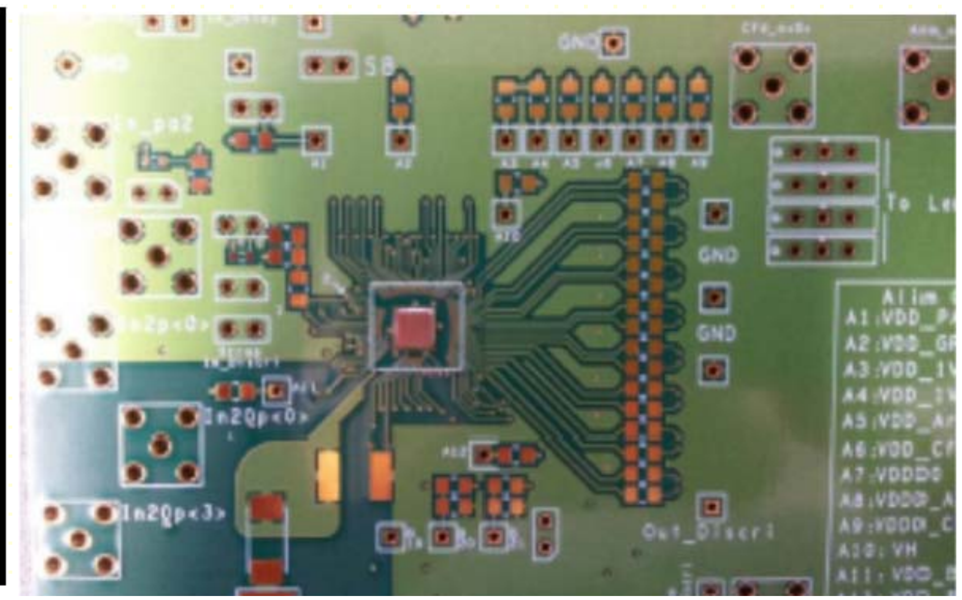
Need exact drawing of all components and plan of steps needed for installation



R&D status

- Sensor
  - Very active community also beyond HGTD: LGAD tests and sensor improvements in time resolution, active area, radiation hardness → yesterday's talk by J. Lange
- Front end ASIC
  - ALTIROC0 prototype in TSMC 130 nm technology with 4 channels bump bonded to LGAD array and tested with beam in Summer 2017. Only analog part, no TDC and FIFO. Good performance, but improvements in noise level and bandwidth needed





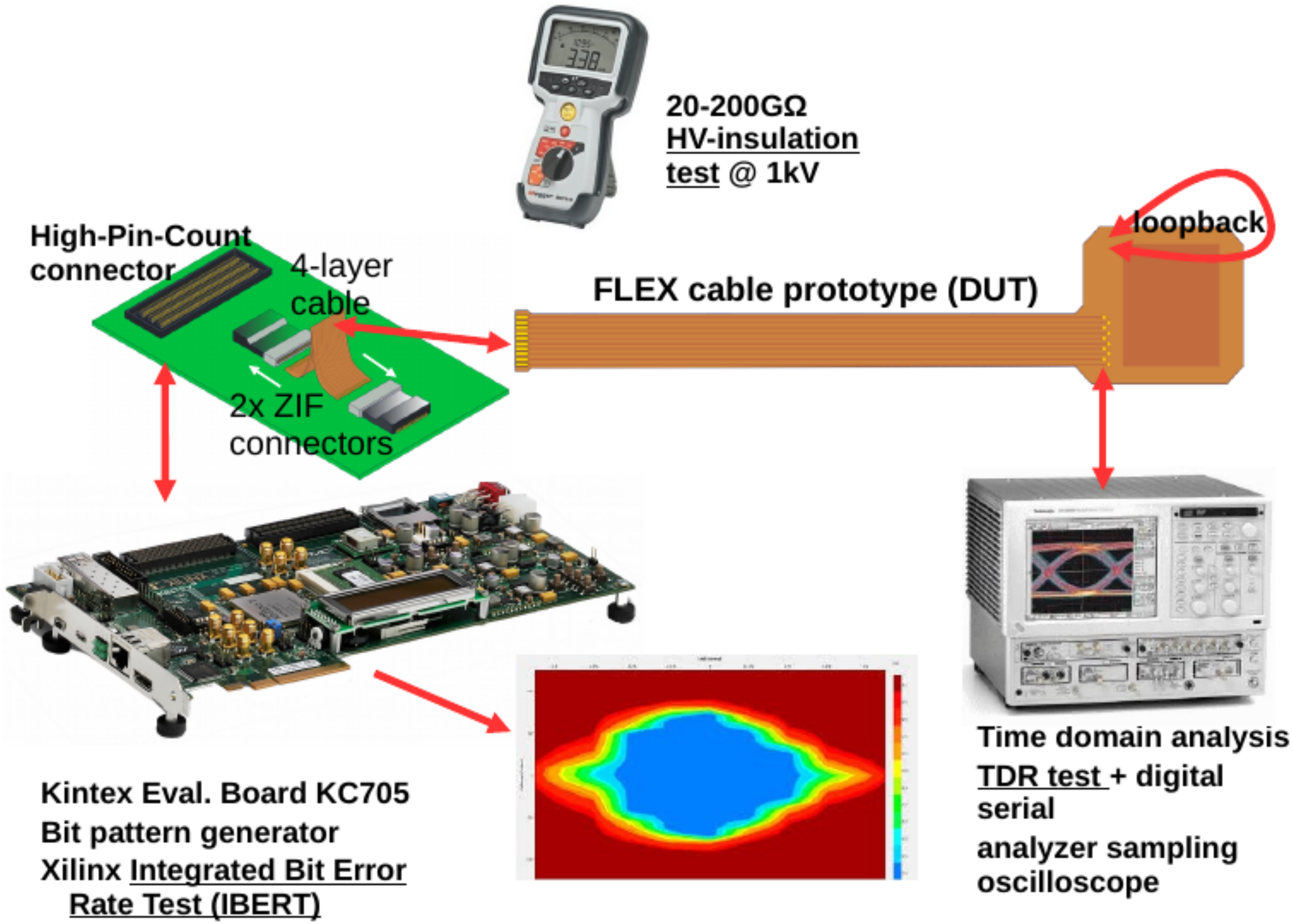
R&D status

- Flex
  - Prototype design to test signal transmission and isolation of HV line being finalised
  - Optimisation of design for full detector ongoing
- Module stack up
  - Identified possible materials and glues
- Services and off-detector electronics
  - Design and optimisation of distribution ongoing
- Mechanics and cooling
  - Optimisation ongoing within task-force together with ITk and ATLAS technical coordination

Next steps

- Sensor
  - More tests with newest technologies
  - Arrays with larger surface and more pads
- Front end ASIC
  - ALTIROC1 prototype with 25 channels and full single pixel readout (analog+TDC+FIFO) to be tested after bump bonding to sensor in Fall 2018
- Flex
  - Production and test of first prototype with few lines over longest expected distance in the next months
- Module stack up
  - "Dummy" (no electrical functionalities) mechanical prototype of few modules in a stave in the next months

Next task in Mainz



Conclusion

Summary and outlook

- Many steps from identification of problem and possible solution to design (and construction) of a full detector
- ATLAS HGTD has to cope with very tight mechanical and radiation hardness constraints together with challenging performance requirements
- All tests done so far look promising, but a lot of work is still needed in all components
- Start in 2015 → tighter schedule than for other ATLAS phase II projects
- Prolonged R&D phase will help improving technology, but challenging for qualification of production sites and production itself
- There is room for more collaborators to join the fun!