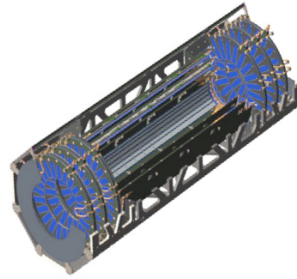


The ATLAS Pixel Detector - Overview and Present Status -



Reiner Klingenberg

University of Dortmund, Germany

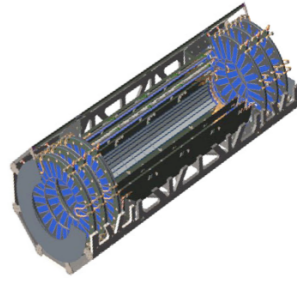
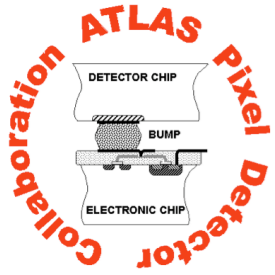
on behalf of the ATLAS Pixel Collaboration

-
- Basic Design Ideas: Radiation Tolerance
 - Modules - Assembly and Tests
 - Present Work: Detector Integration and Tests

STD6 6th International Hiroshima Symposium
on the Development and Application of Semiconductor Tracking Detectors

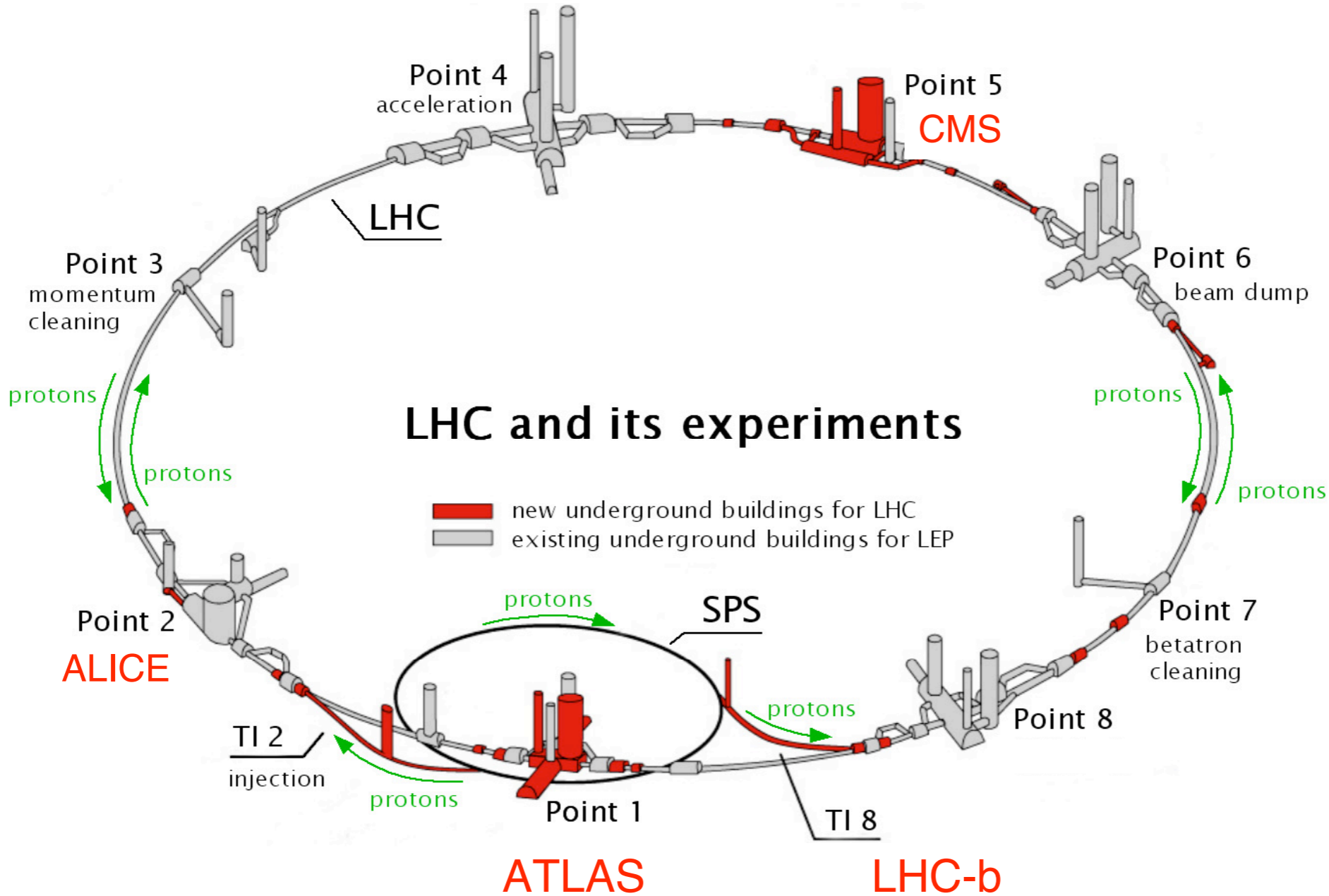
Carmel CA USA, September 2006

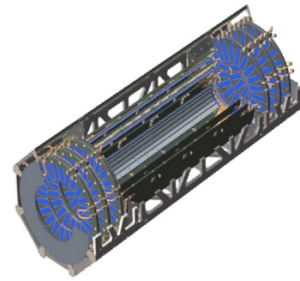
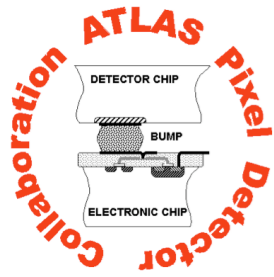




The Large Hadron Collider at CERN

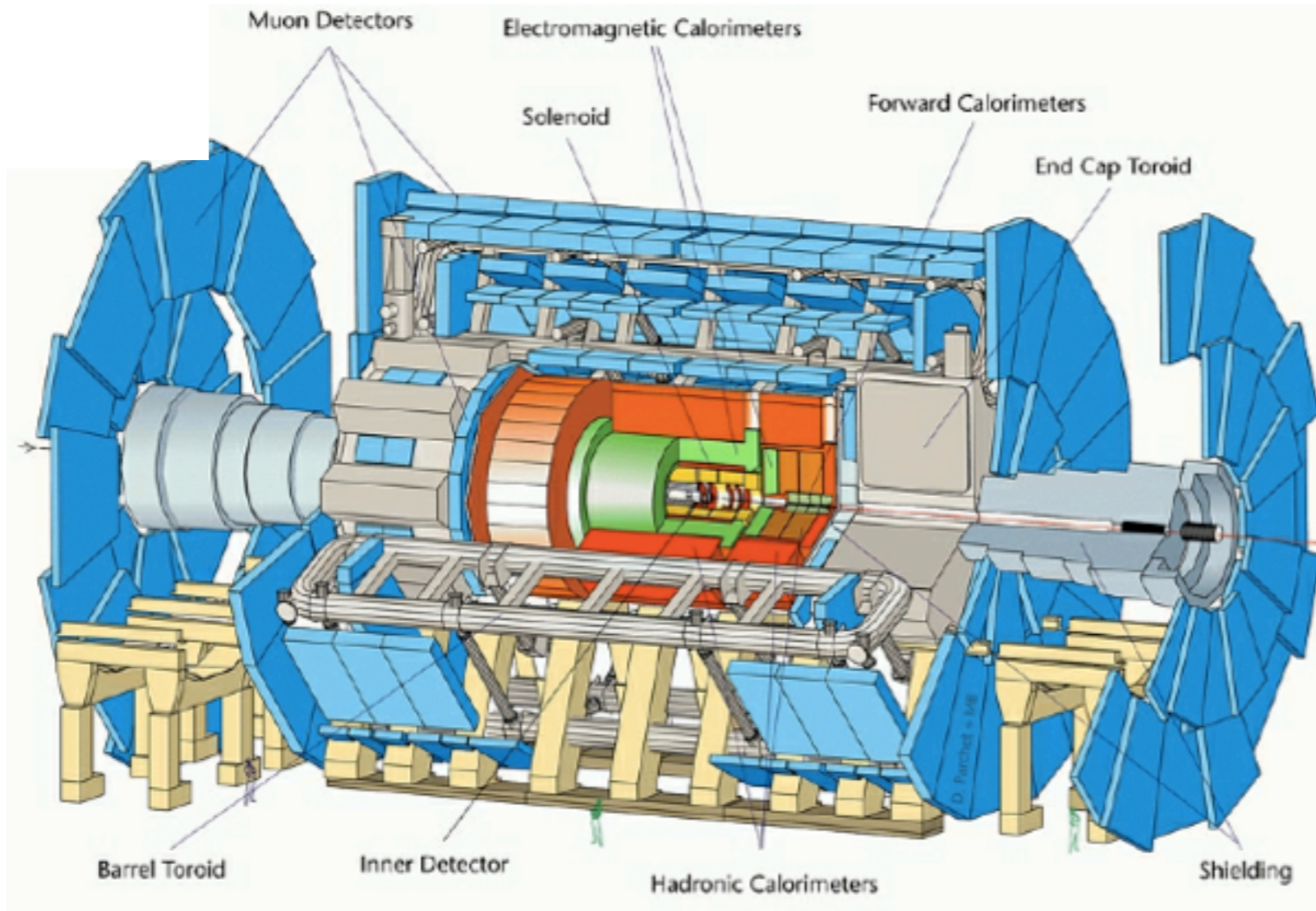
p-p collisions @ $\sqrt{s} = 14$ TeV





The ATLAS Experiment at the LHC

$\varnothing = 25$
 $L_{\text{toroid}} = 26 \text{ m}$
 $L_{\text{EC-span}} = 46 \text{ m}$
 $\text{weight} = 7000 \text{ t}$



Calorimetry:

$$\frac{\sigma_E}{E}(e, \gamma) = \frac{10\%}{\sqrt{E/\text{GeV}}} \oplus 0.3\%$$

$$\sigma_e = \frac{60 \text{ mrad}}{\sqrt{E/\text{GeV}}}$$

$$\sigma_t = \frac{4 \text{ ns}}{E/\text{GeV}}$$

$$\frac{\sigma_E}{E}(\pi^\pm) = \frac{50\%}{\sqrt{E/\text{GeV}}} \oplus 3\%$$

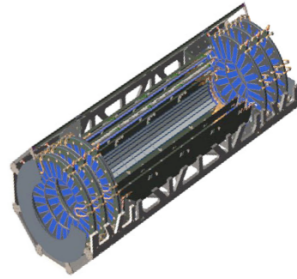
$$\frac{\sigma_E}{E}(\text{jet}) = \frac{50\%}{\sqrt{E/\text{GeV}}} \oplus 2\%$$

Tracking:

$$\frac{\sigma}{p_T}(\text{Inner Det}) \approx (0.03 p_T / \text{GeV} + 1.2)\%$$

$$\frac{\sigma}{p_T}(\text{IDet} + \mu) \approx (0.009 p_T / \text{GeV} + 1.4)\%$$

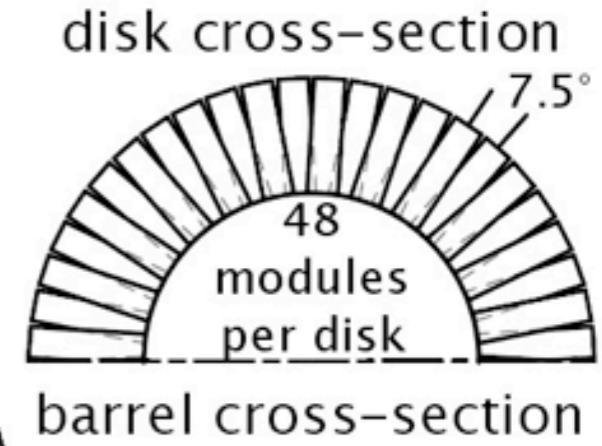
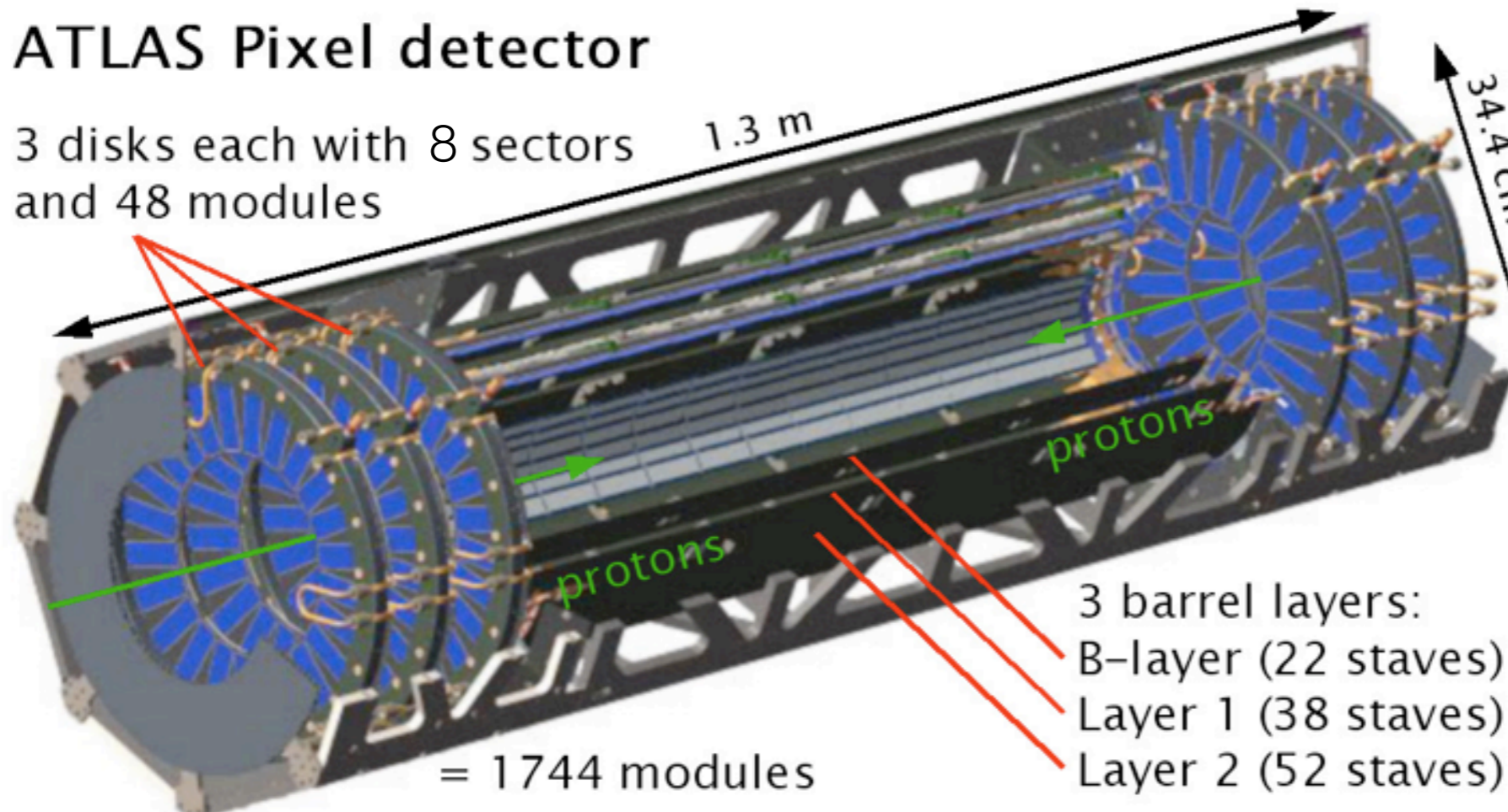




The ATLAS Pixel Detector

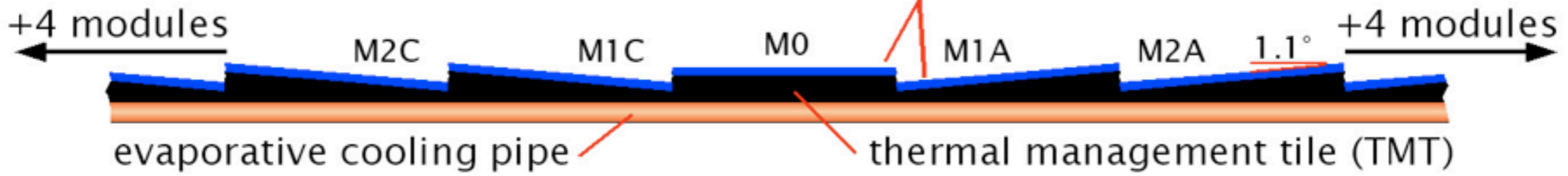
ATLAS Pixel detector

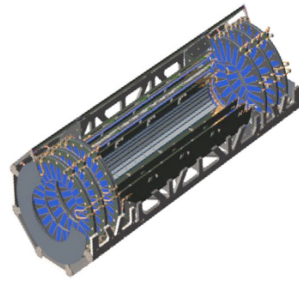
3 disks each with 8 sectors and 48 modules



- 3 barrel layers:
- B-layer (22 staves)
- Layer 1 (38 staves)
- Layer 2 (52 staves)

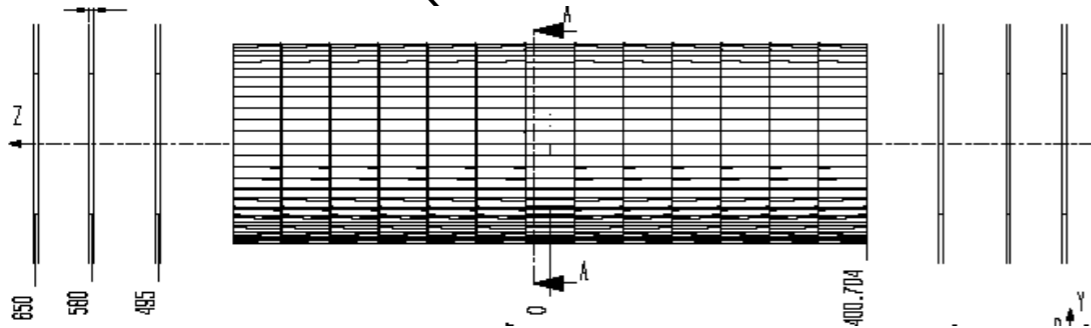
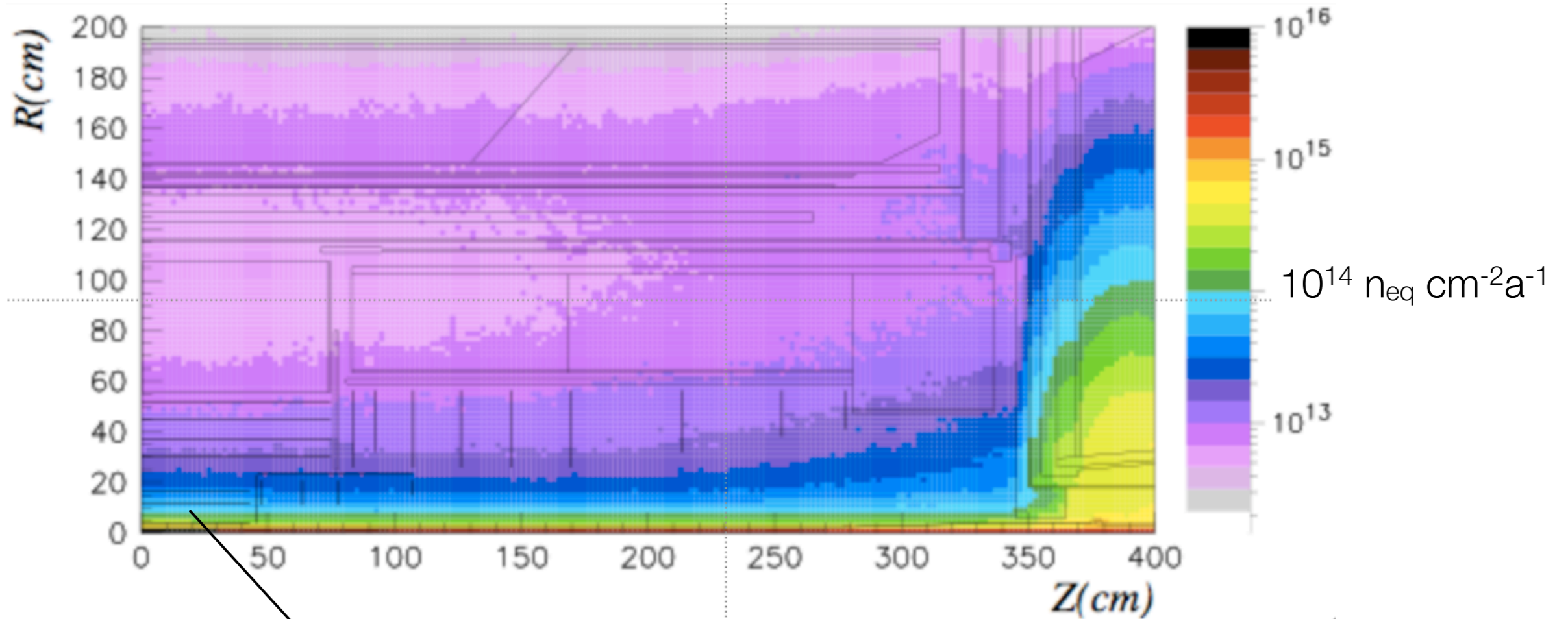
stave cross-section (with 13 modules)





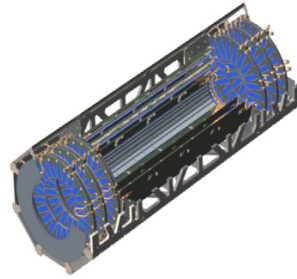
Issue: Radiation Tolerance @ $10^{34} \text{cm}^{-2} \text{s}^{-1}$

- Radiation map of the inner detector:



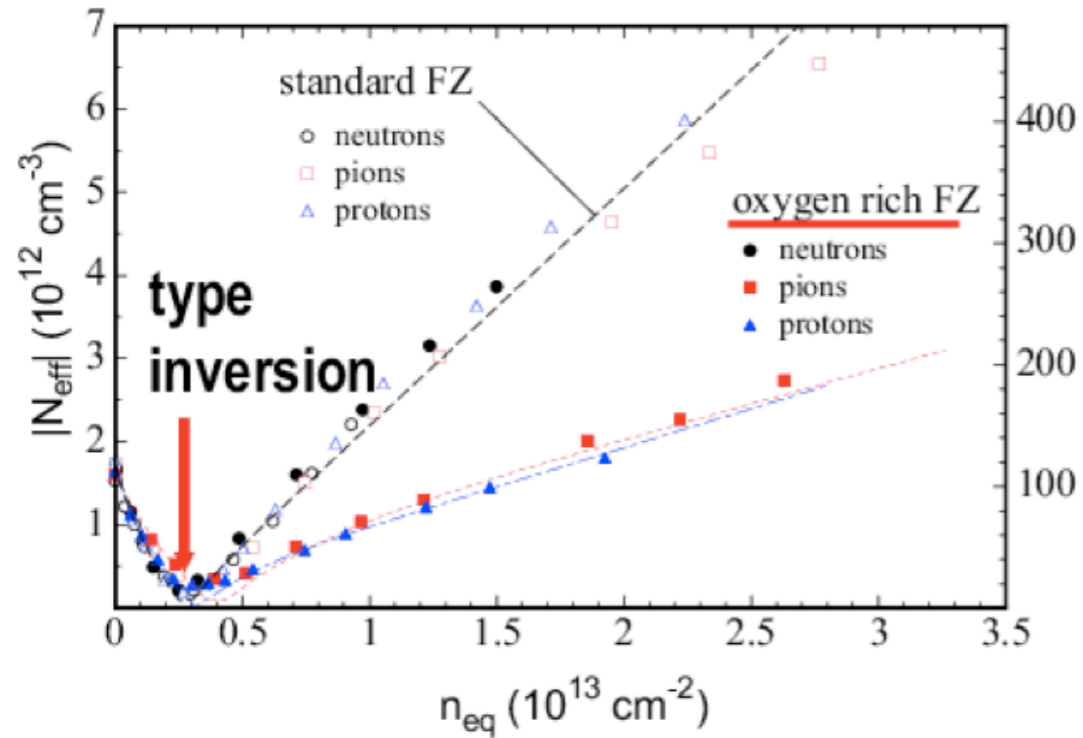
$10^{15} \text{ neq cm}^{-2}$ during 10 years of operation

Location of the pixel detector

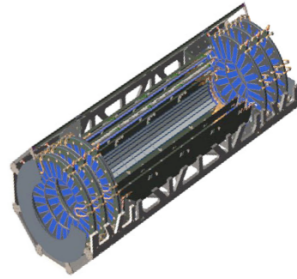


Sensor Strategies (I)

- Usage of DOFZ: diffusion oxygenated float zone silicon

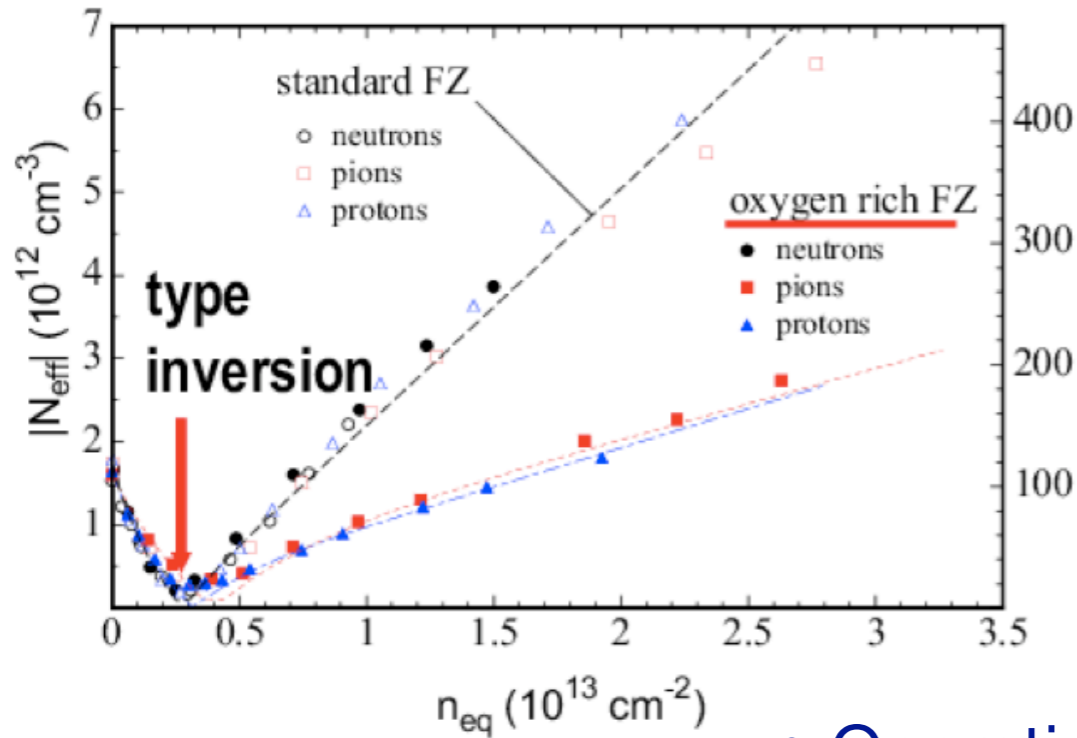


(RD48/ROSE)



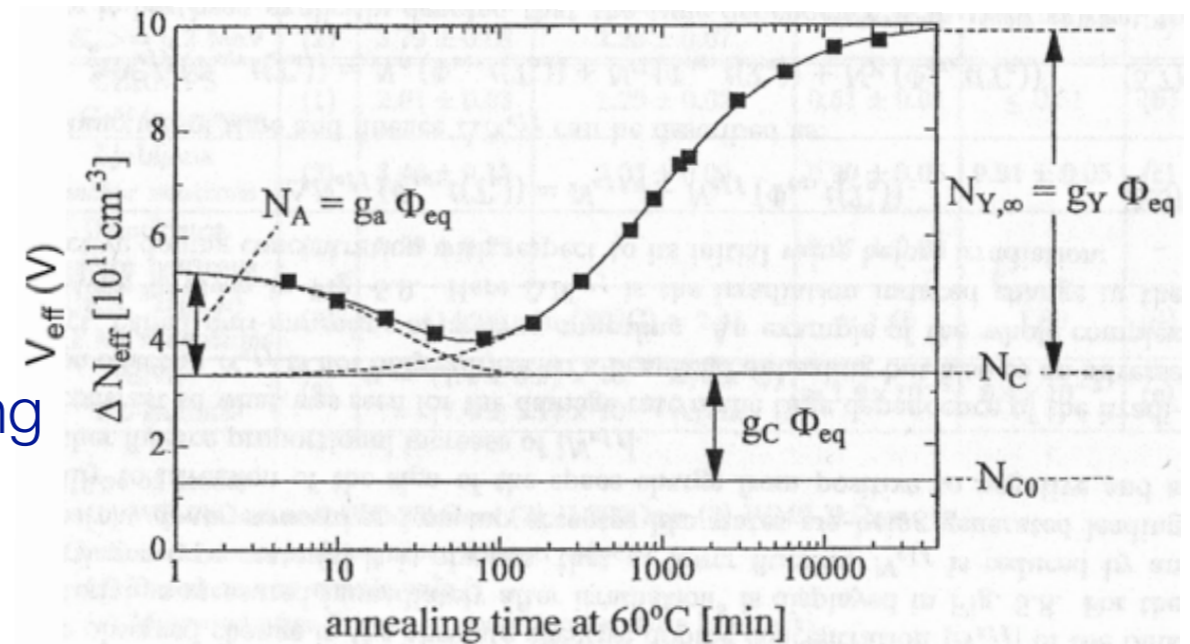
Sensor Strategies (I)

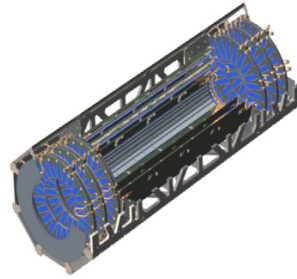
- Usage of DOFZ: diffusion oxygenated float zone silicon



- Operation conditions avoid reverse annealing

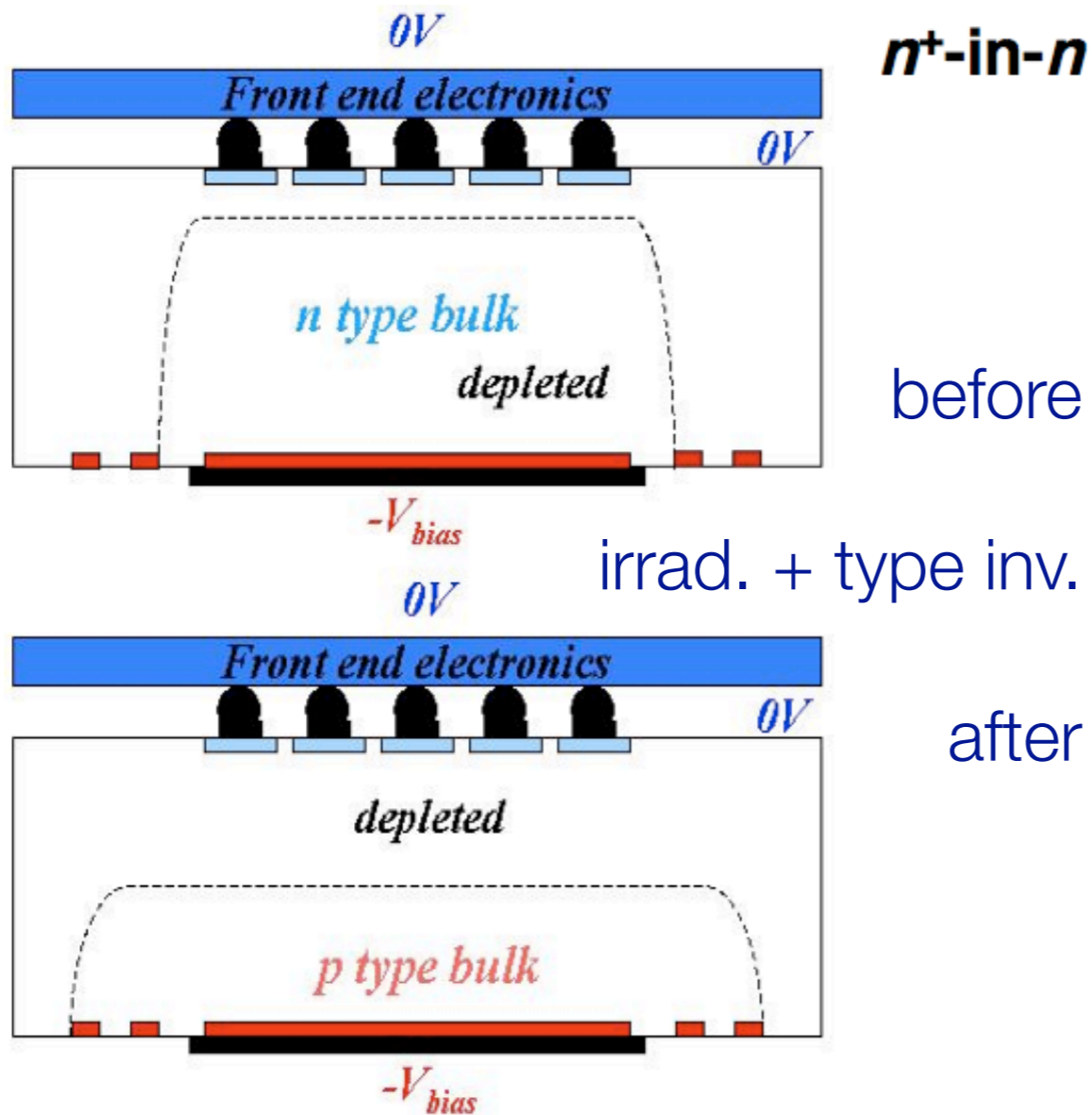
short time (beneficial) annealing
+ constant damage + reverse annealing
(Hamburg model)

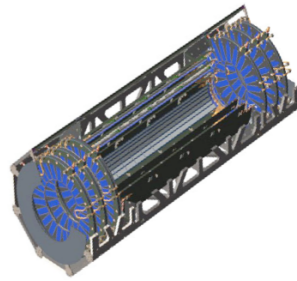




Sensor Strategies (II)

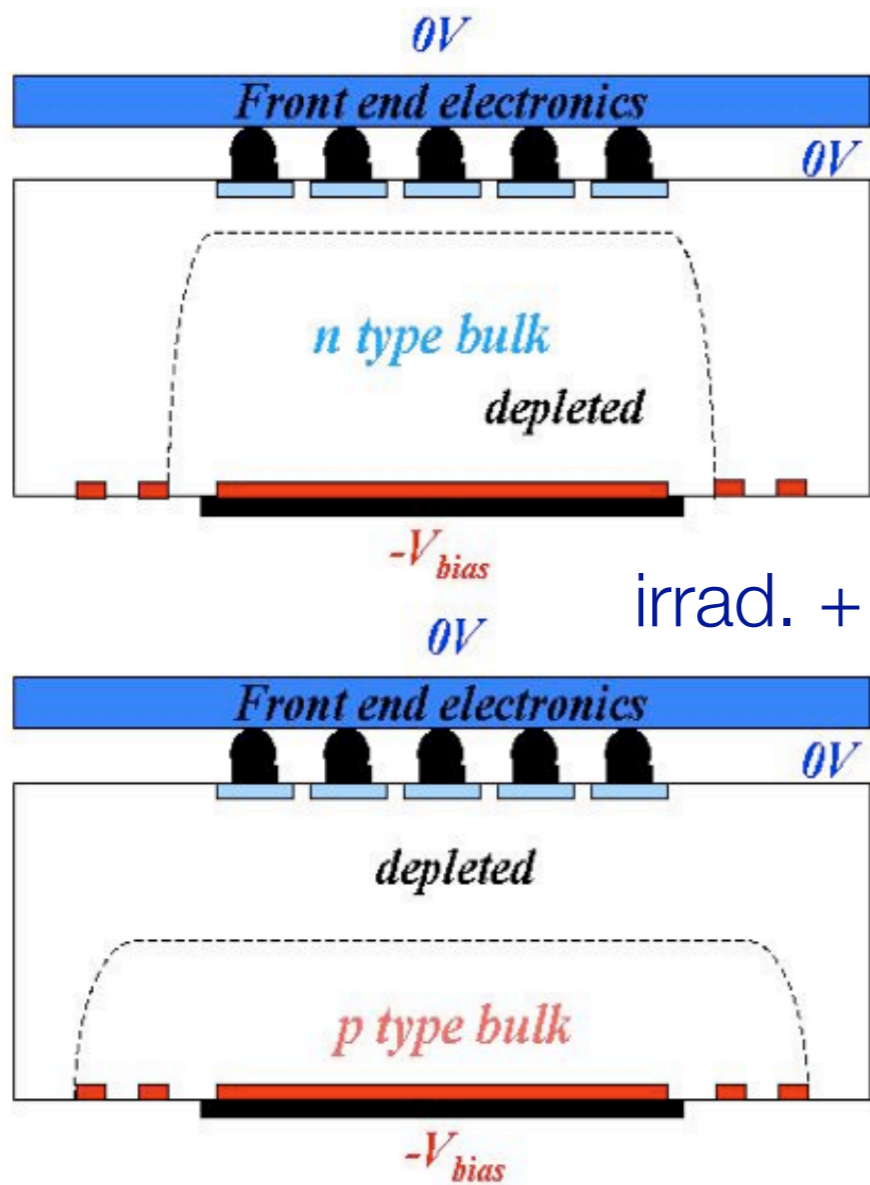
- design of bulk





Sensor Strategies (II)

- design of bulk and surface

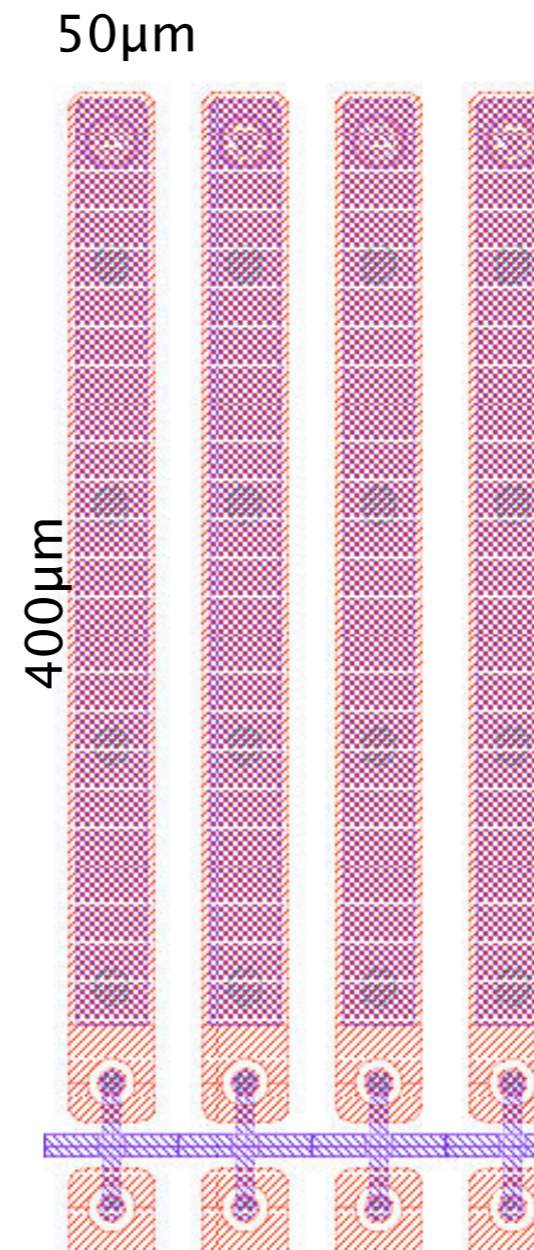


n^+ -in- n

before

irrad. + type inv.

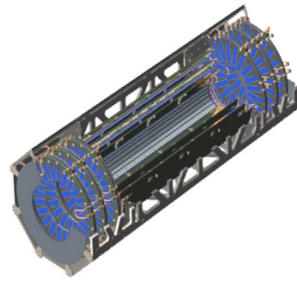
after



bias grid



Sensor Strategies (II)

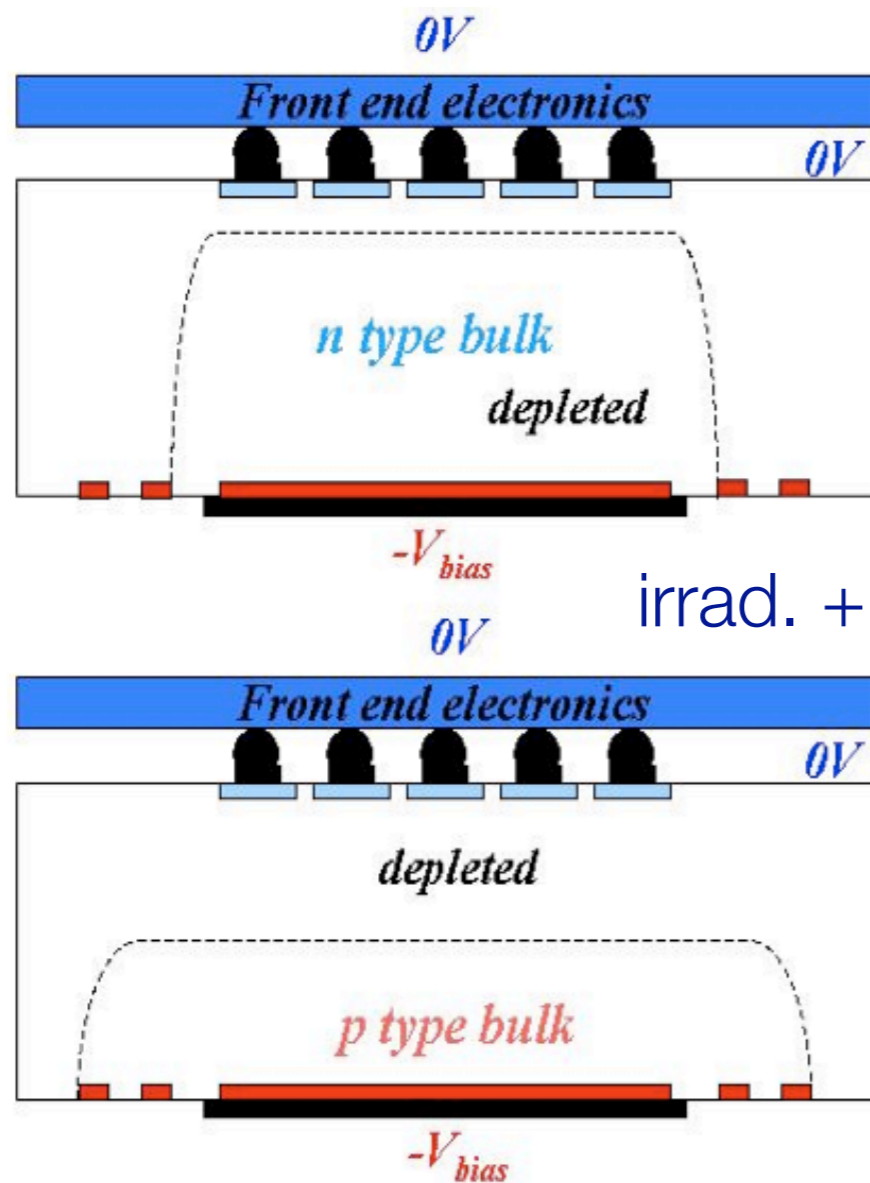


- design of bulk

and

surface

Indium or SnPb

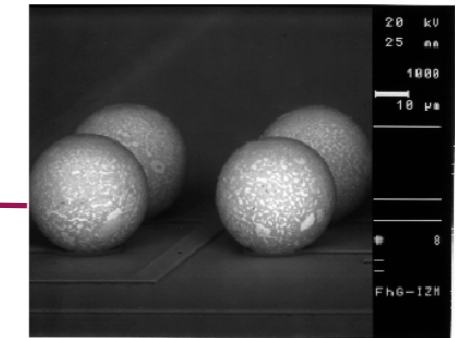
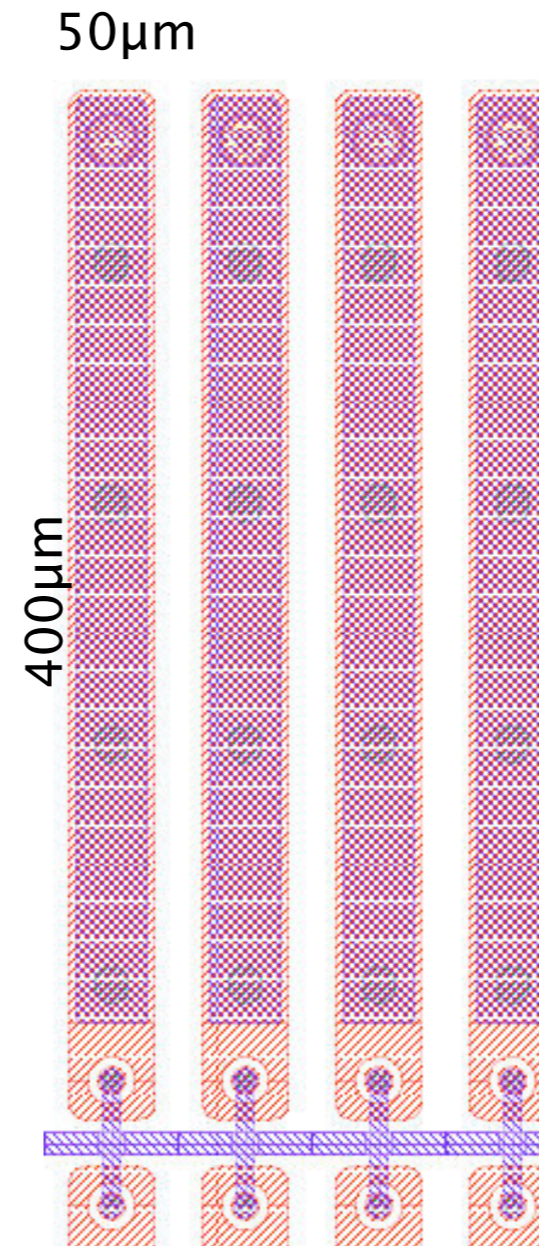


n^+ -in- n

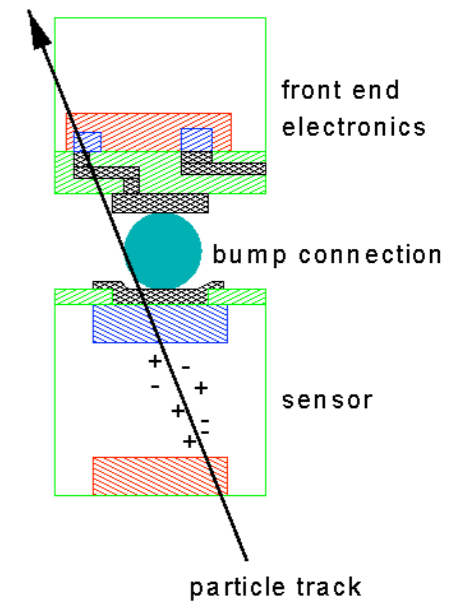
before

irrad. + type inv.

after

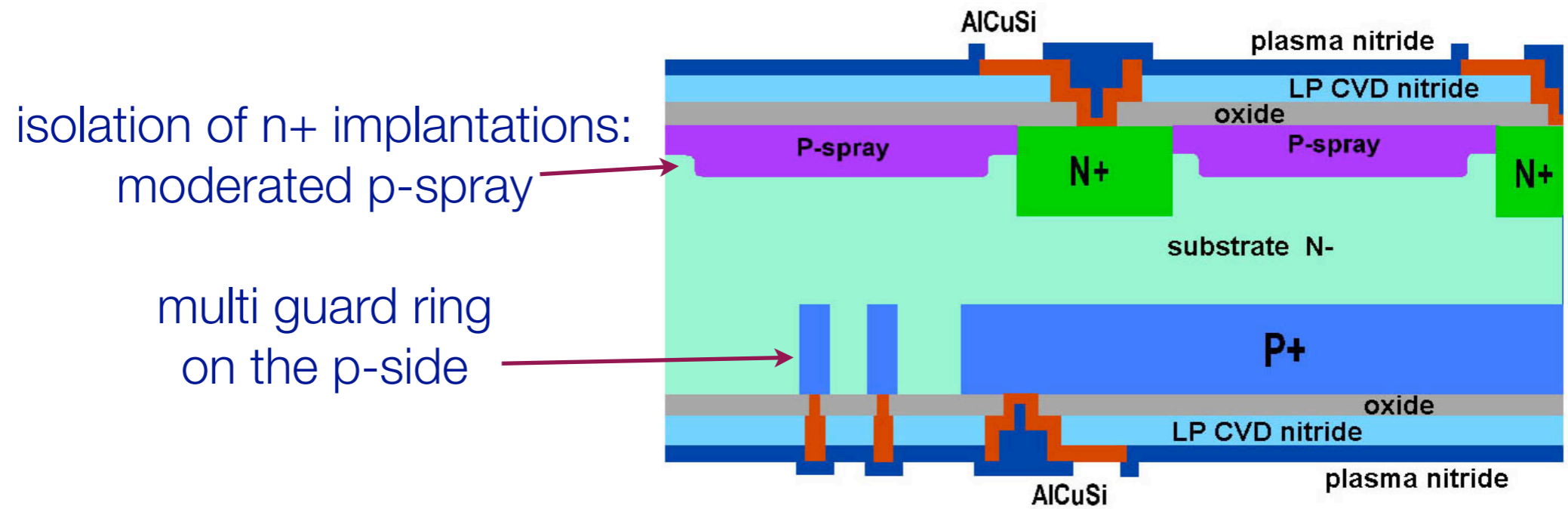
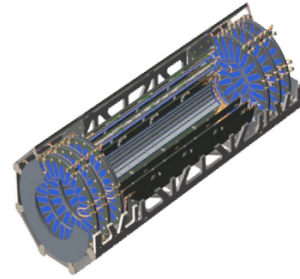


connection of FE electronics

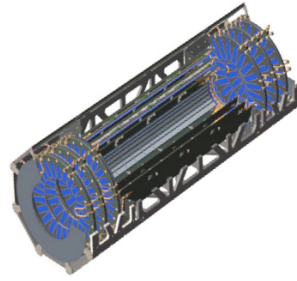


bias grid

Sensor Layout

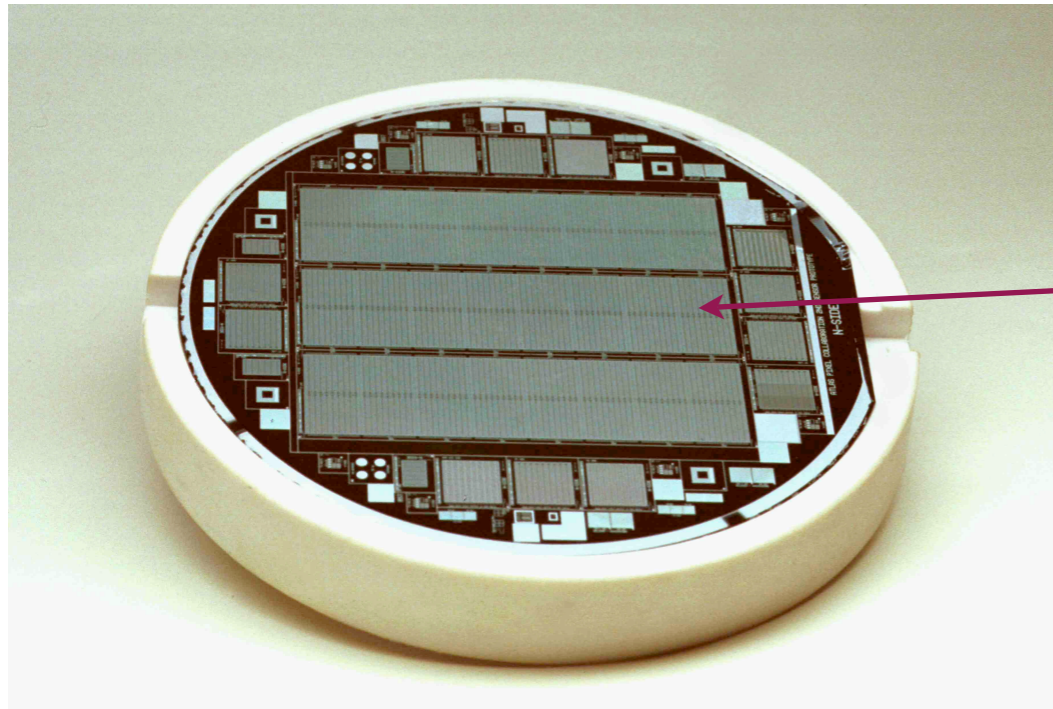
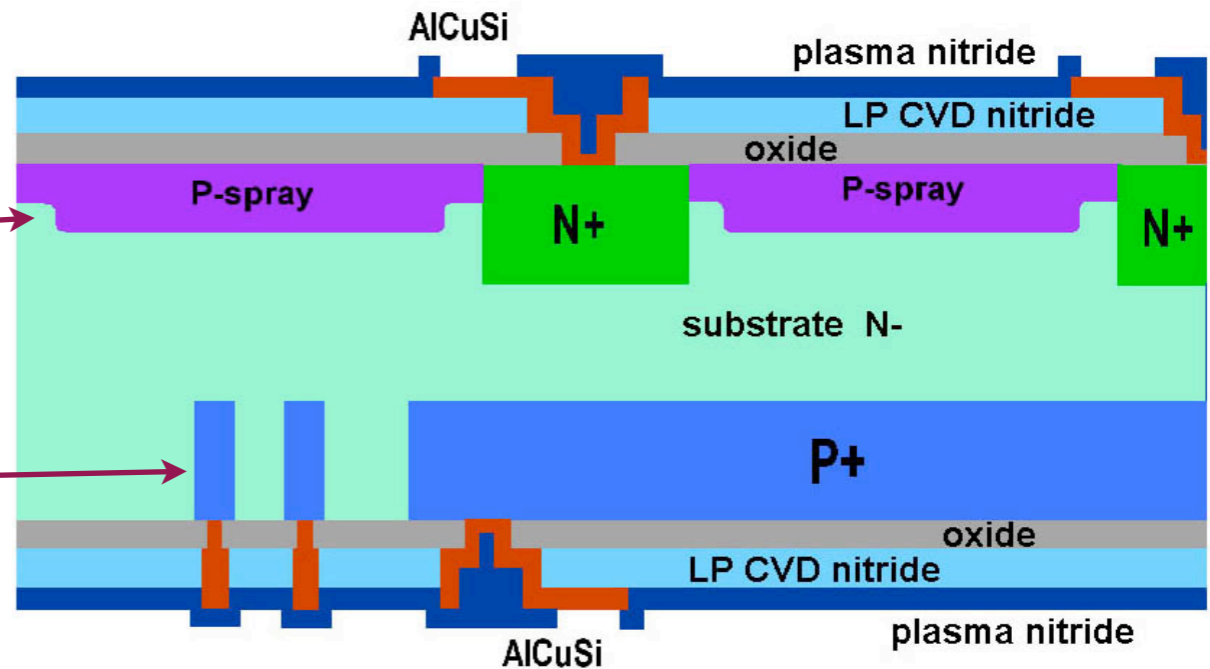


Sensor Layout



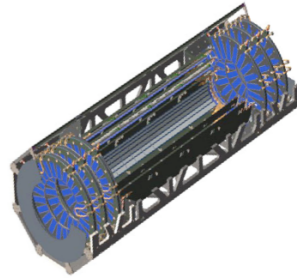
isolation of n+ implantations:
 moderated p-spray

multi guard ring
 on the p-side

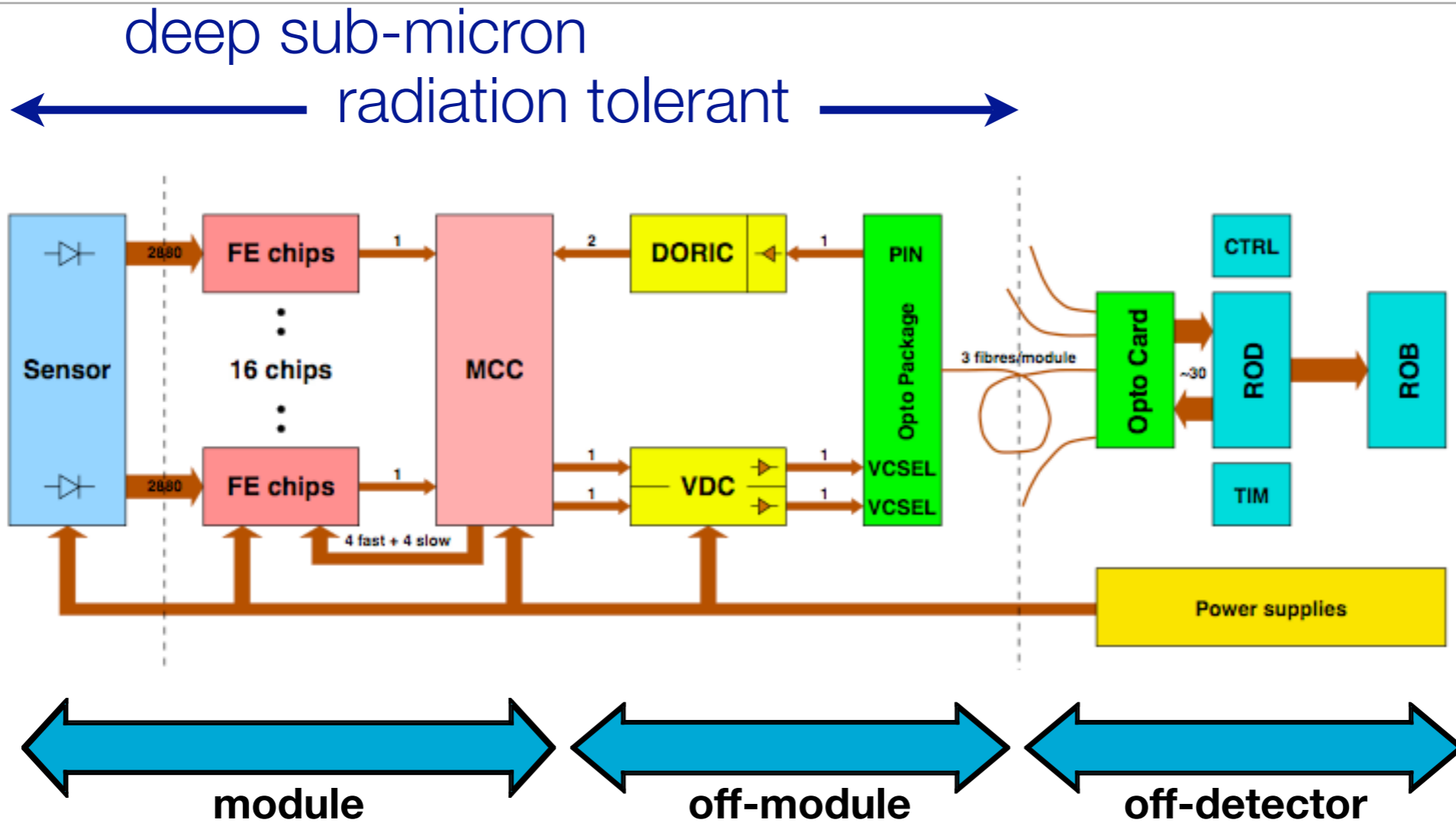


46000 pixel cells
 à 50x400(600) μm^2

- Production and full testing of 1000 wafers (2500 tiles) finished

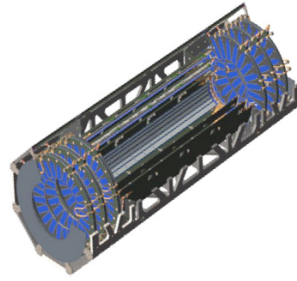


Read-out Electronics

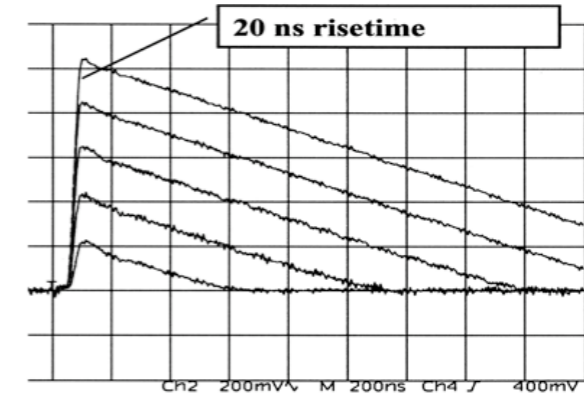


- 1 Sensor
- 16 front end chips (FE)
- 1 module controller chip (MCC)

- Optical receivers (BOC)
- Readout Drivers (ROD)
- Readout Buffers (ROB)
- Timing Control (TIM)
- Slow Control, Supplies



One of 80 Million FE Cells

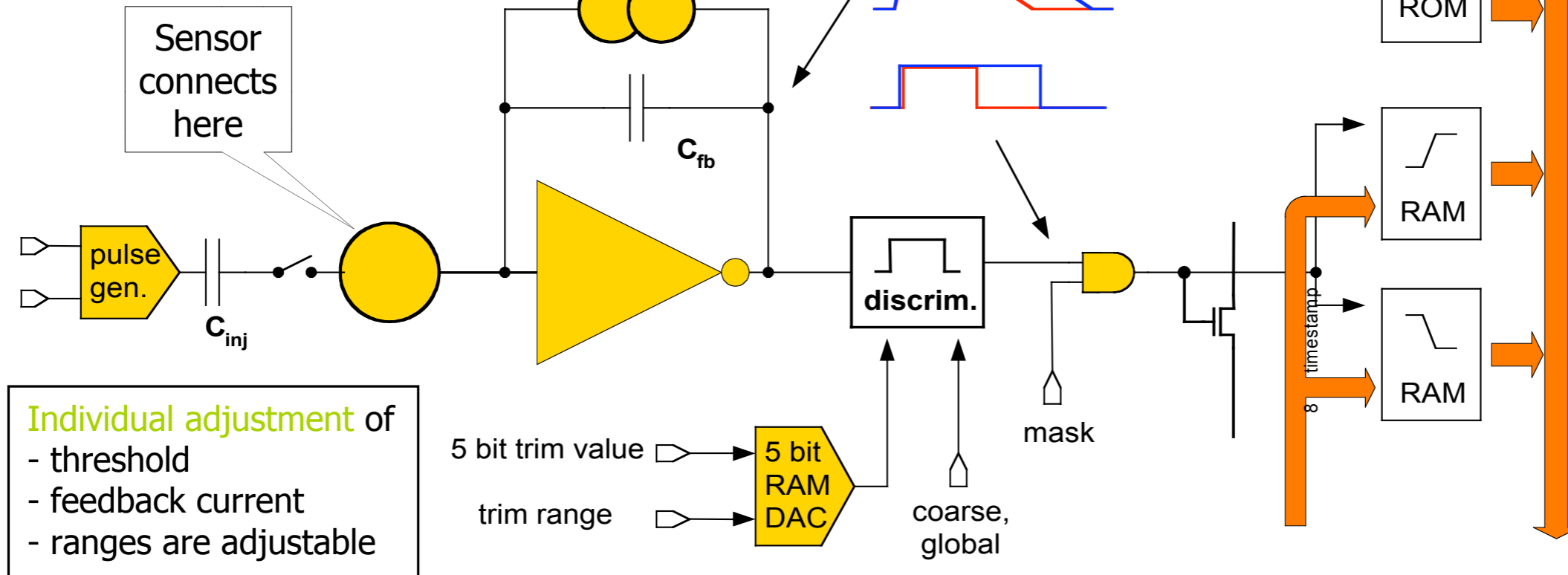


feedback uses constant current

- high stability for fast shaping
- tolerates > 100 nA leakage
- linear decay

Analog information

- measure width of hit
- works nicely due to linear discharge



Inject

Bump pad

Preamplifier

Tune

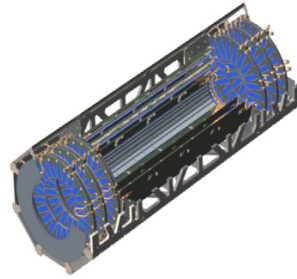
Discriminator

Mask

Fast-OR

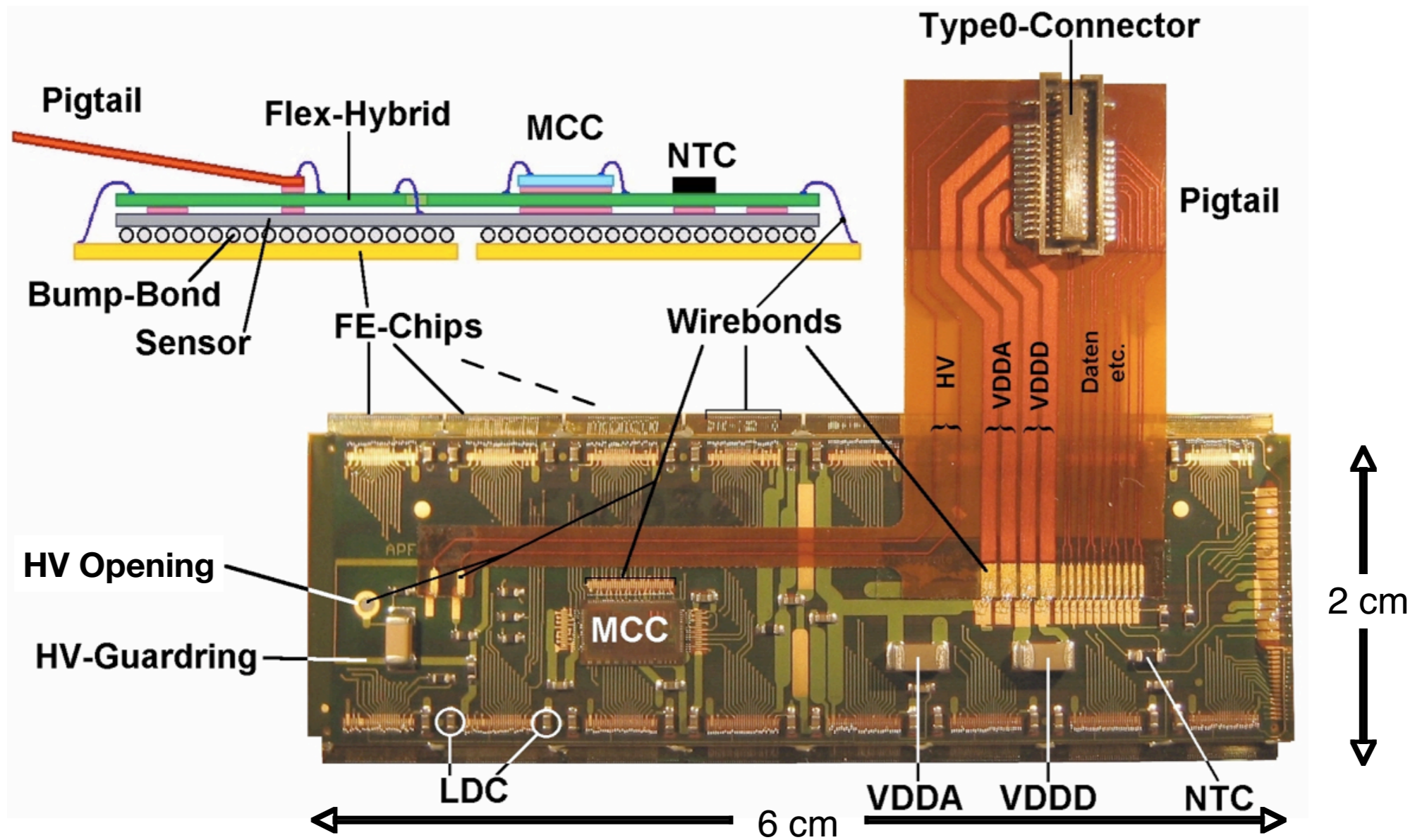
Readout

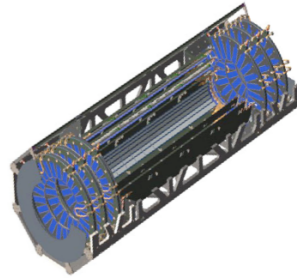




The ATLAS Pixel Module

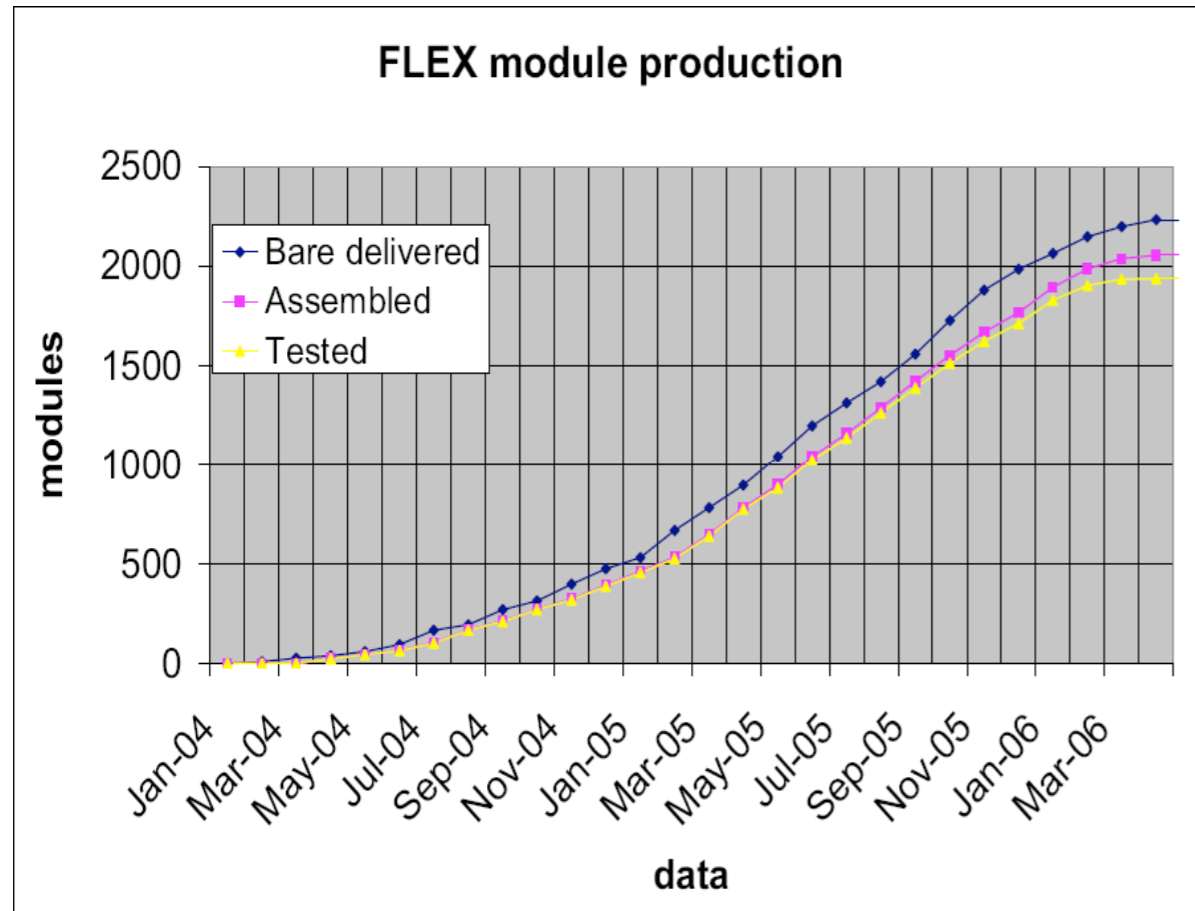
= sensor + FE electronics + loaded flex hybrid

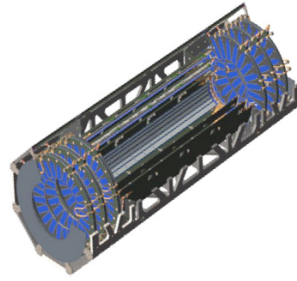




Module production & tests

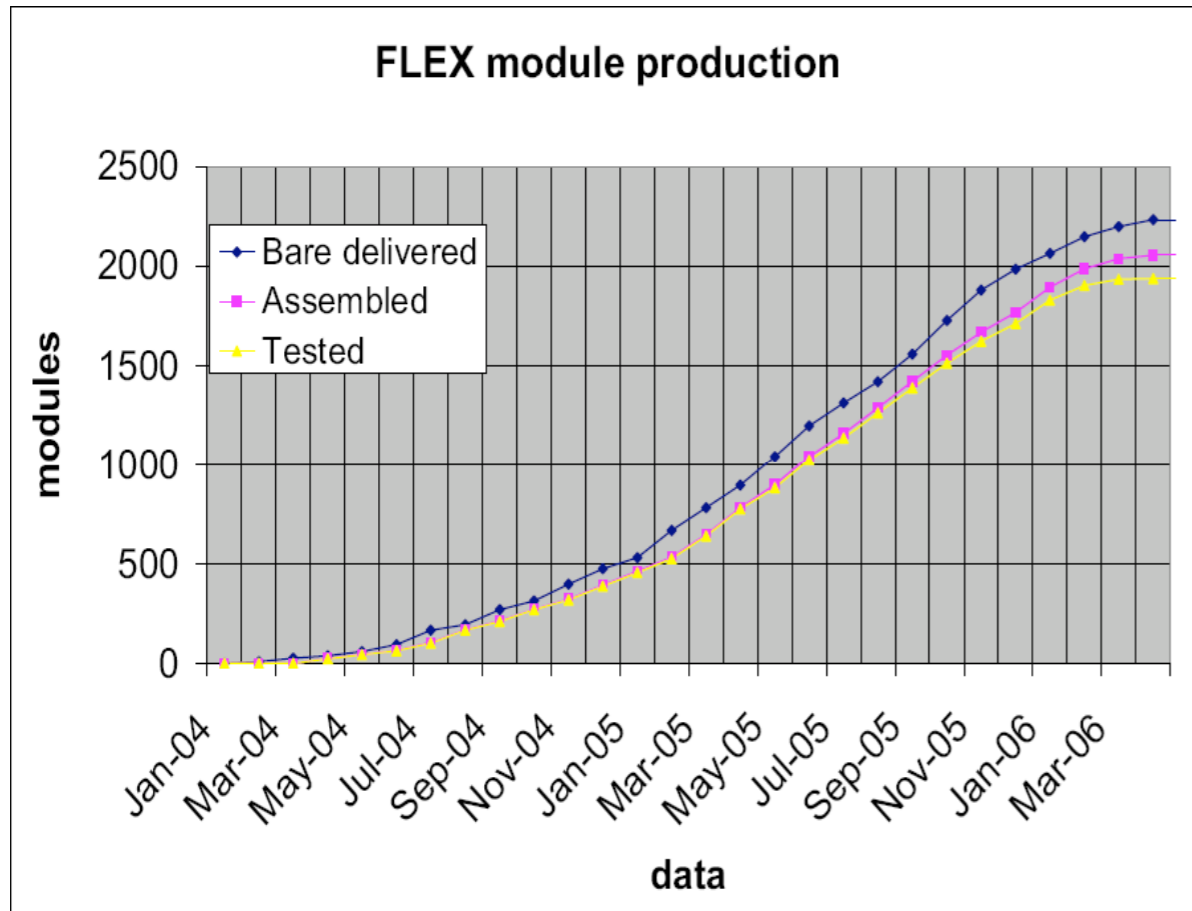
- 1744 pixel modules are needed for the full pixel detector



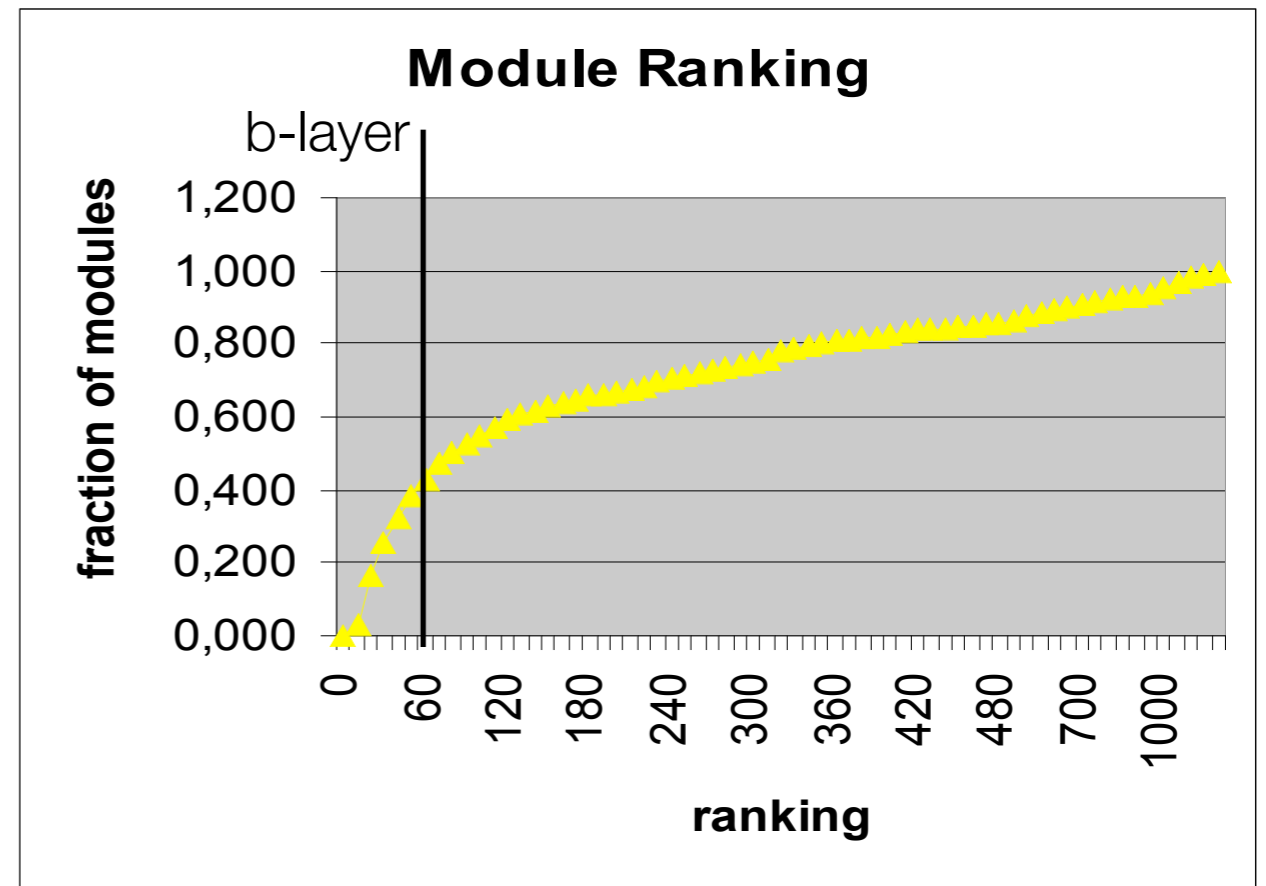


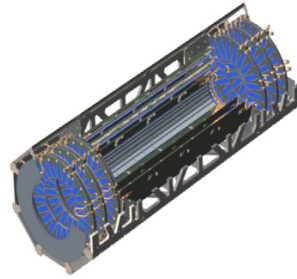
Module production & tests

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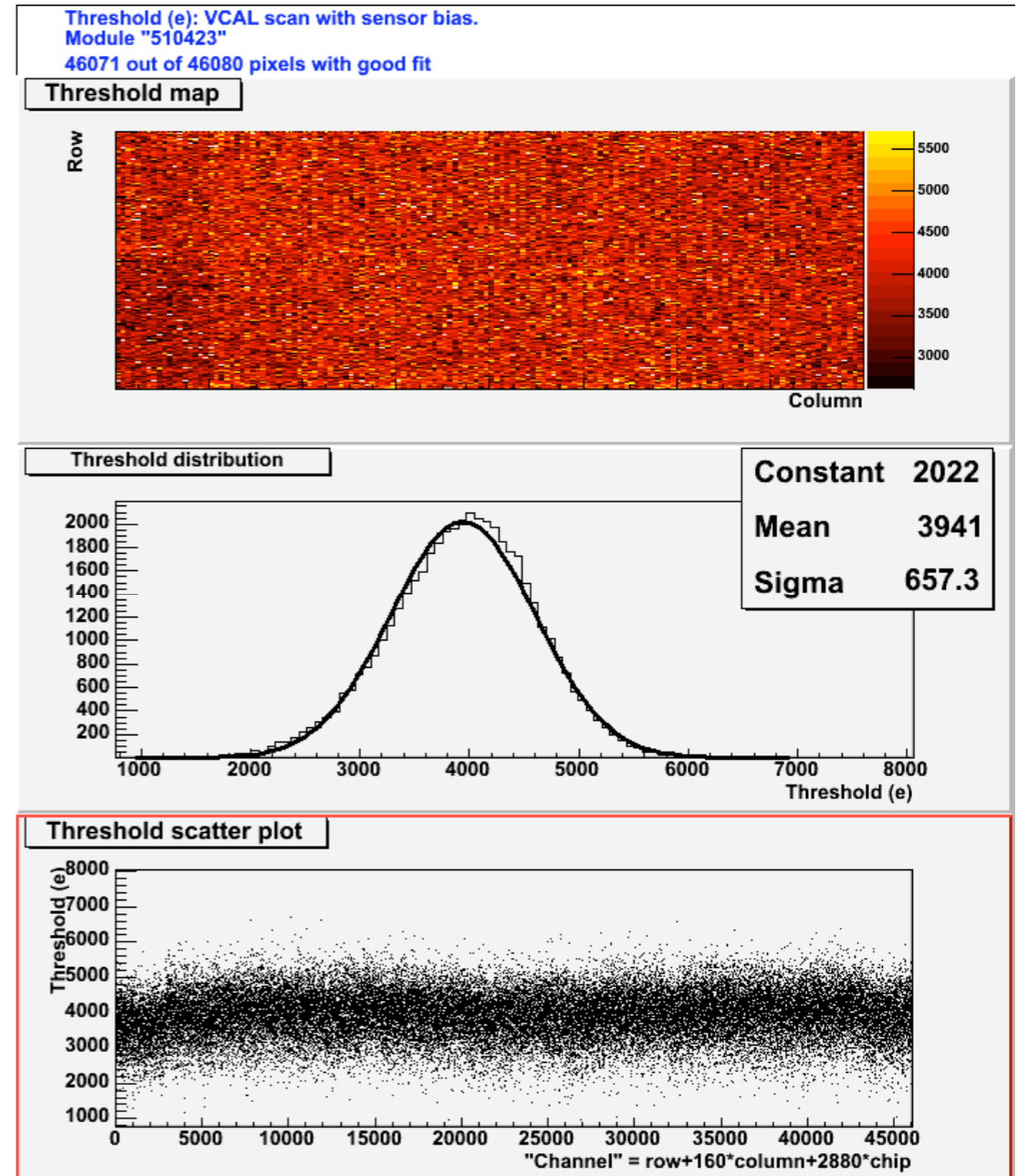
- Quality of modules has been verified

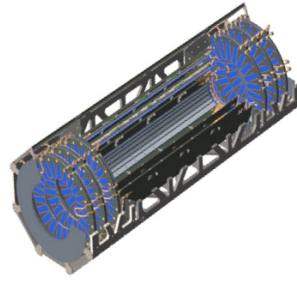




Example of module tests

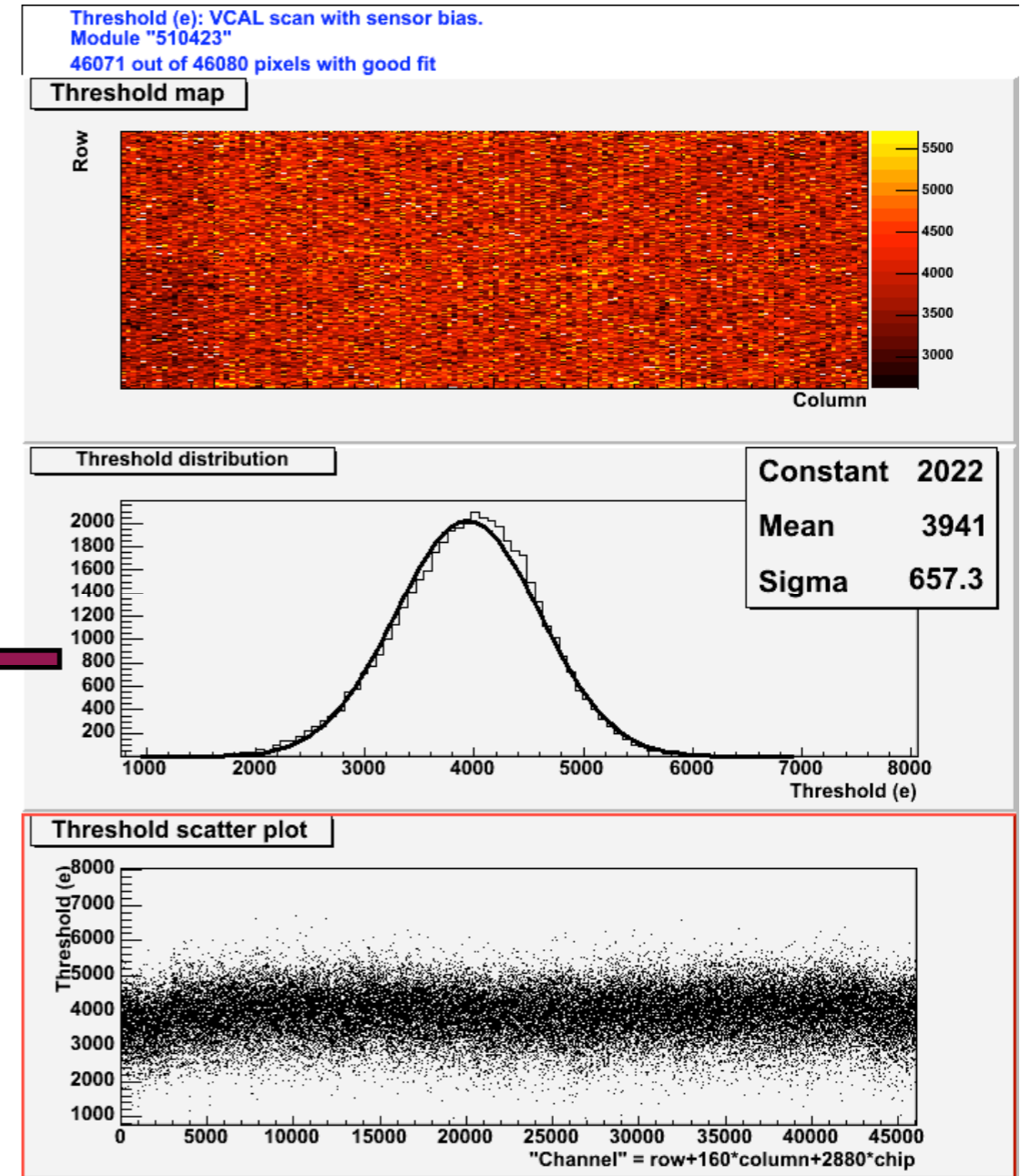
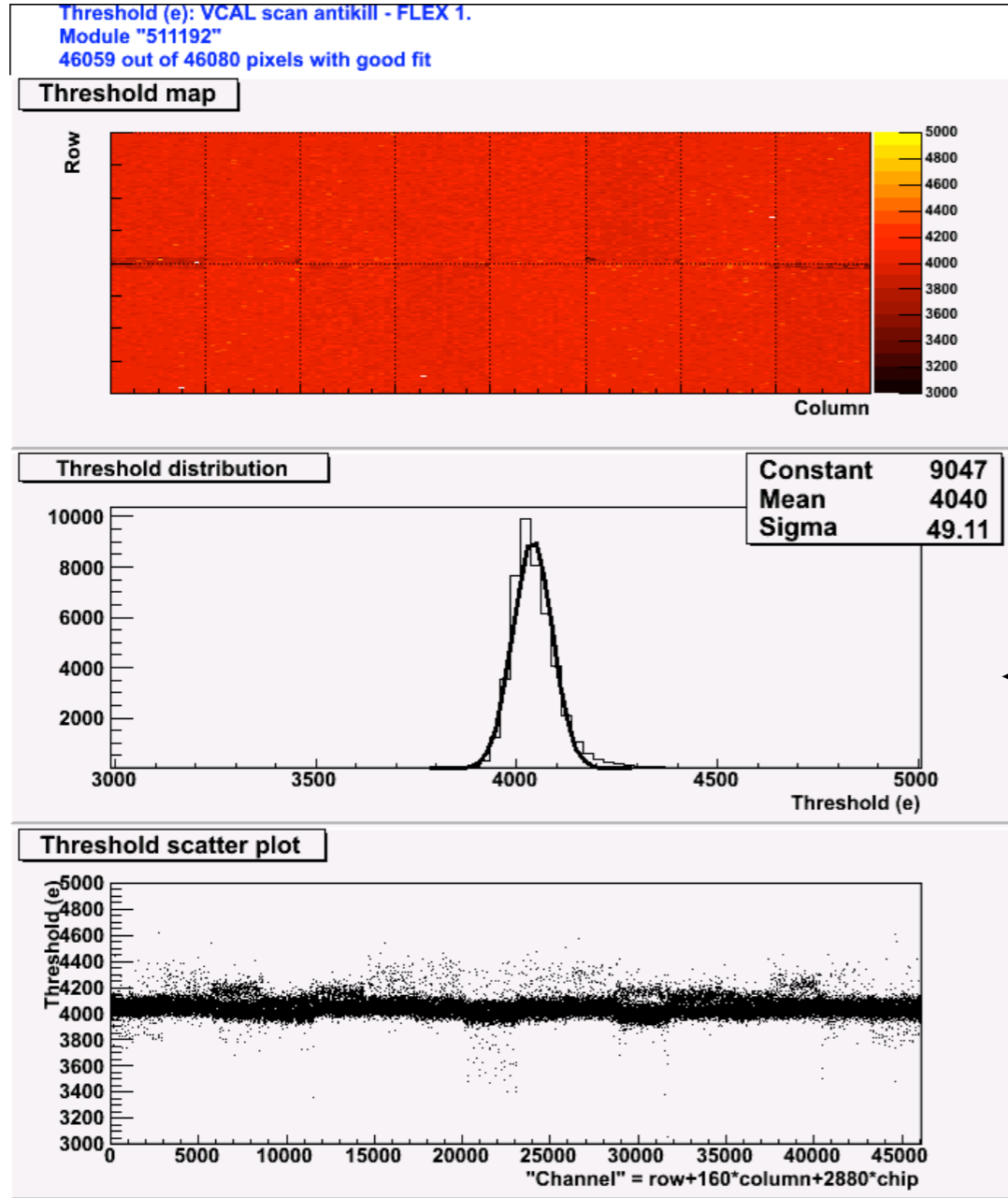
Tuning of FE cell thresholds

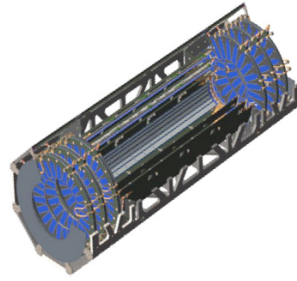




Example of module tests

Tuning of FE cell thresholds

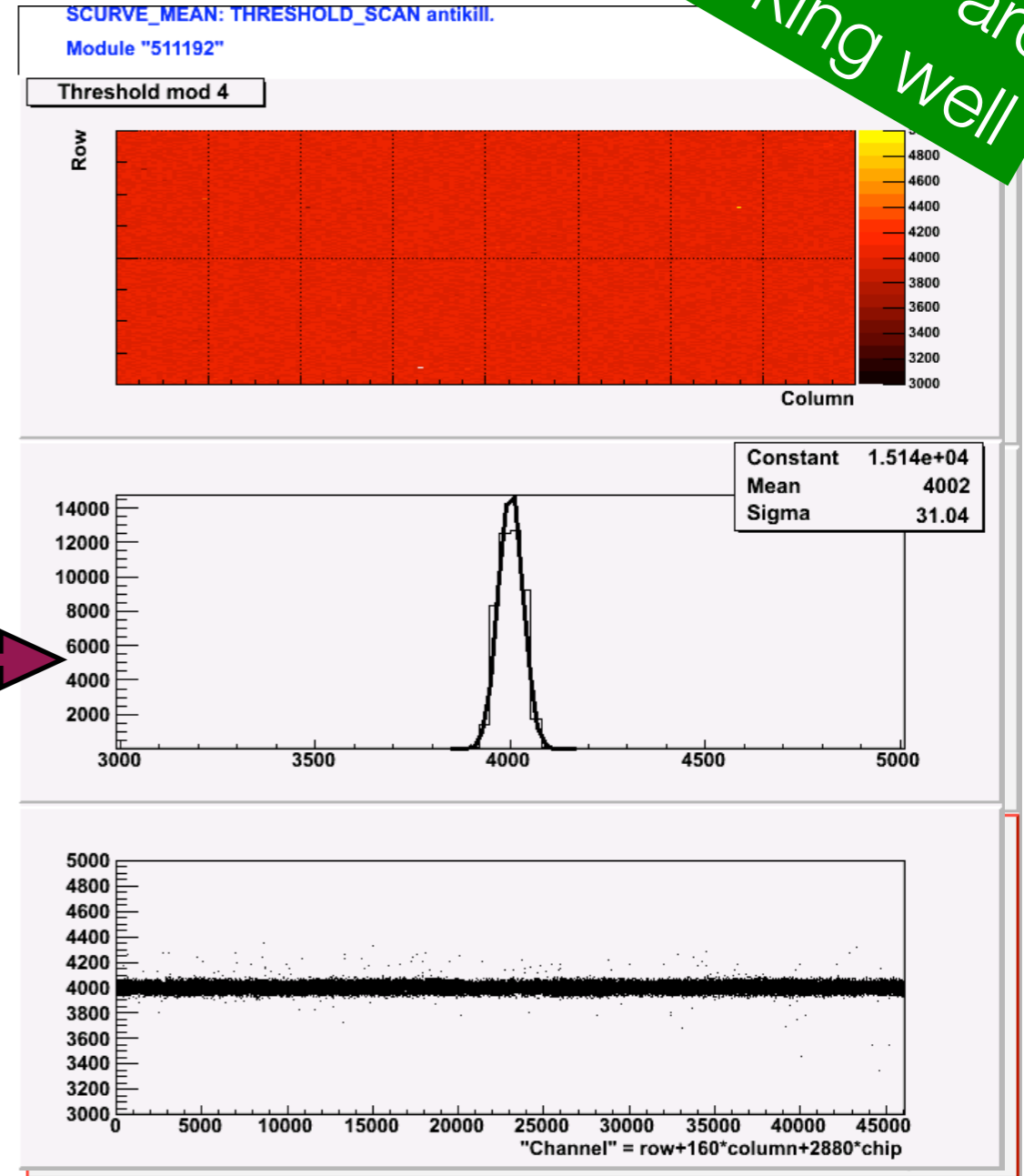
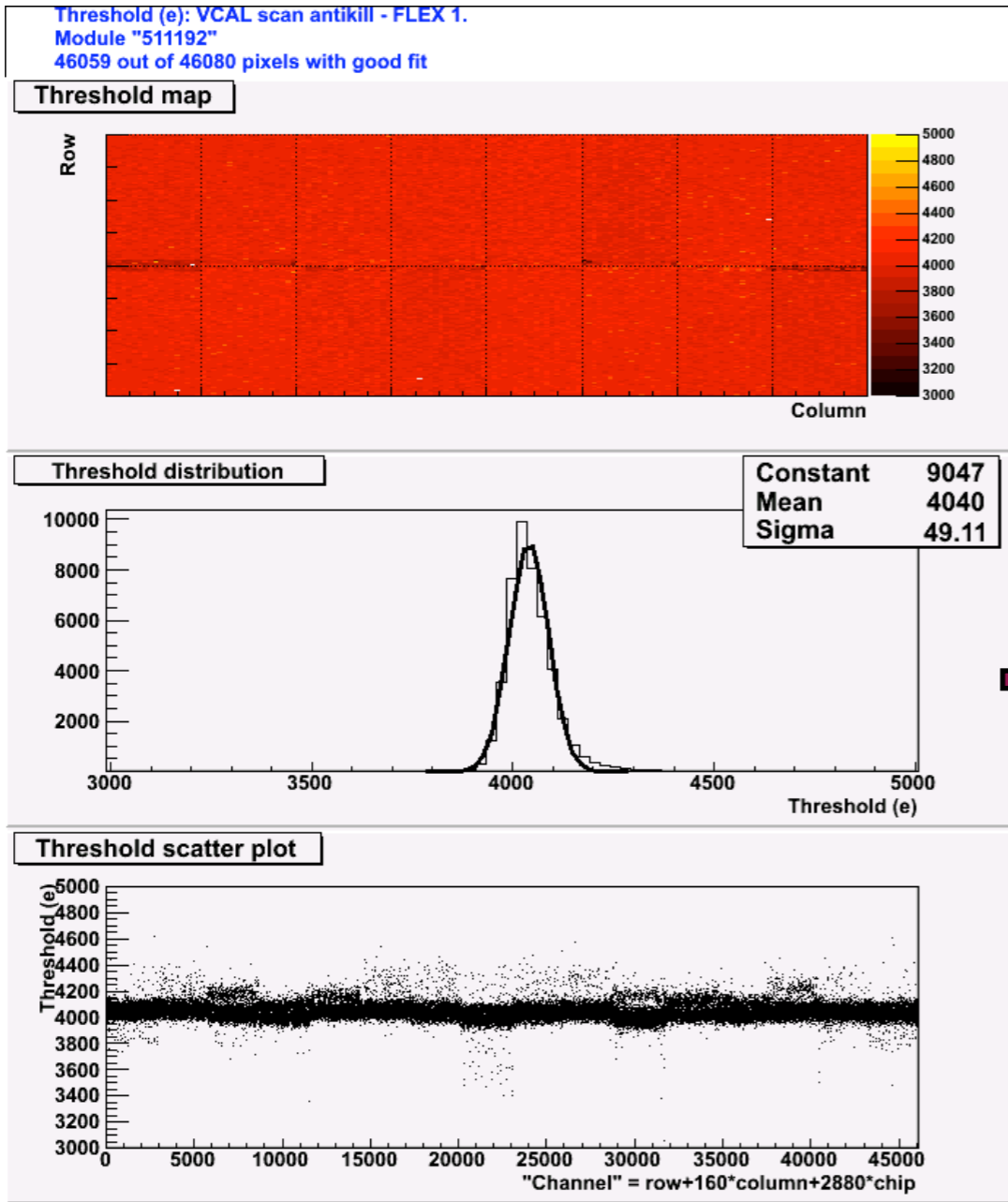




Example of module tests

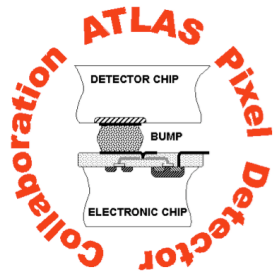
Modules are working well

Tuning of FE cell thresholds

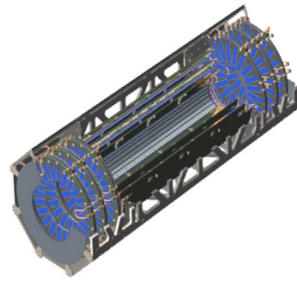


single module lab read-out vs. final full detector read-out



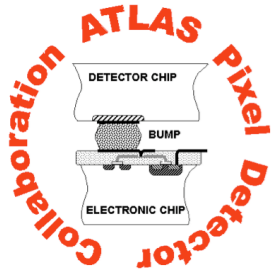


Test Beam Results

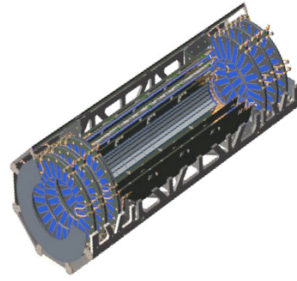


- Production modules have been tested after irradiation $10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$ (NIEL) and 500 kGy (ionisation)



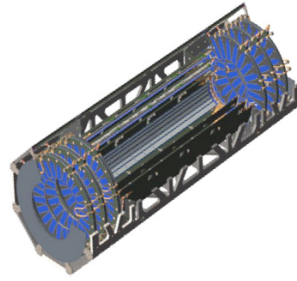


Test Beam Results



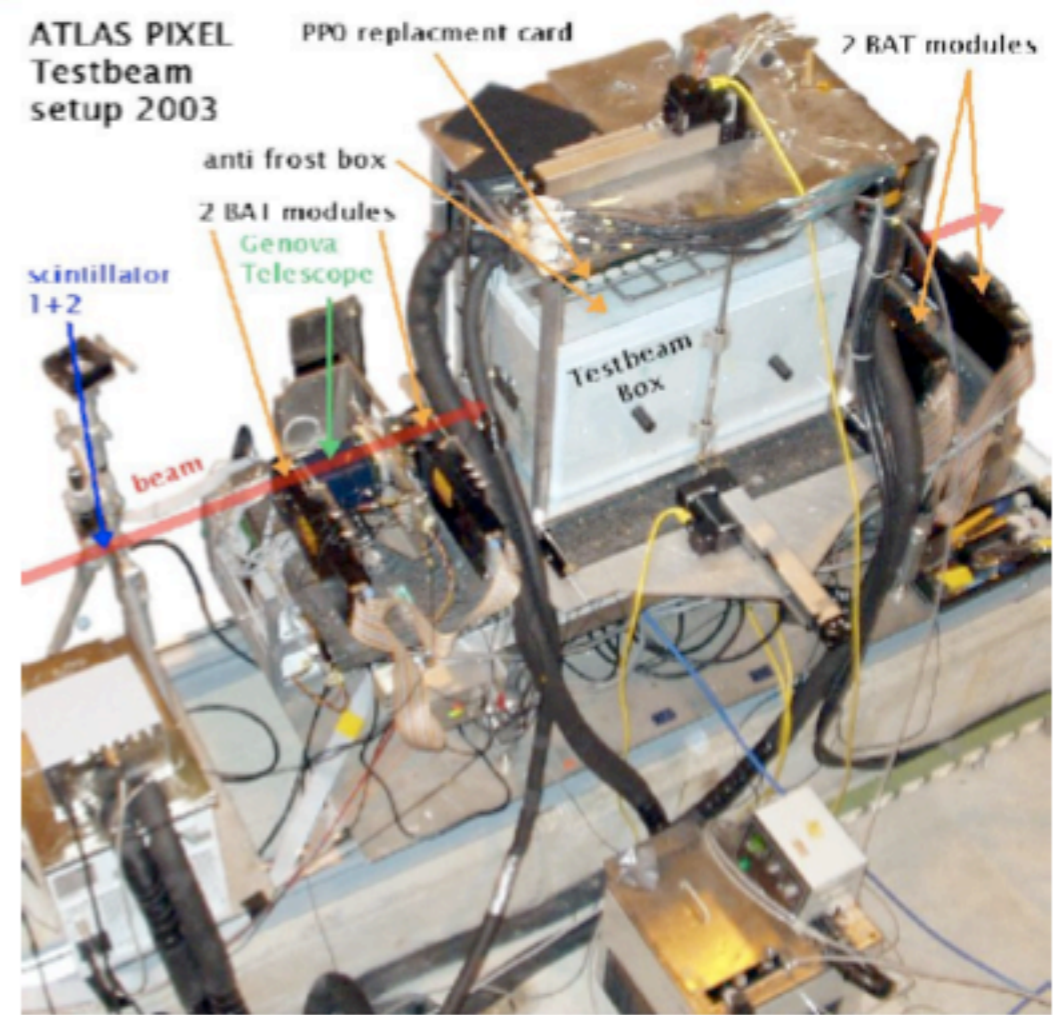
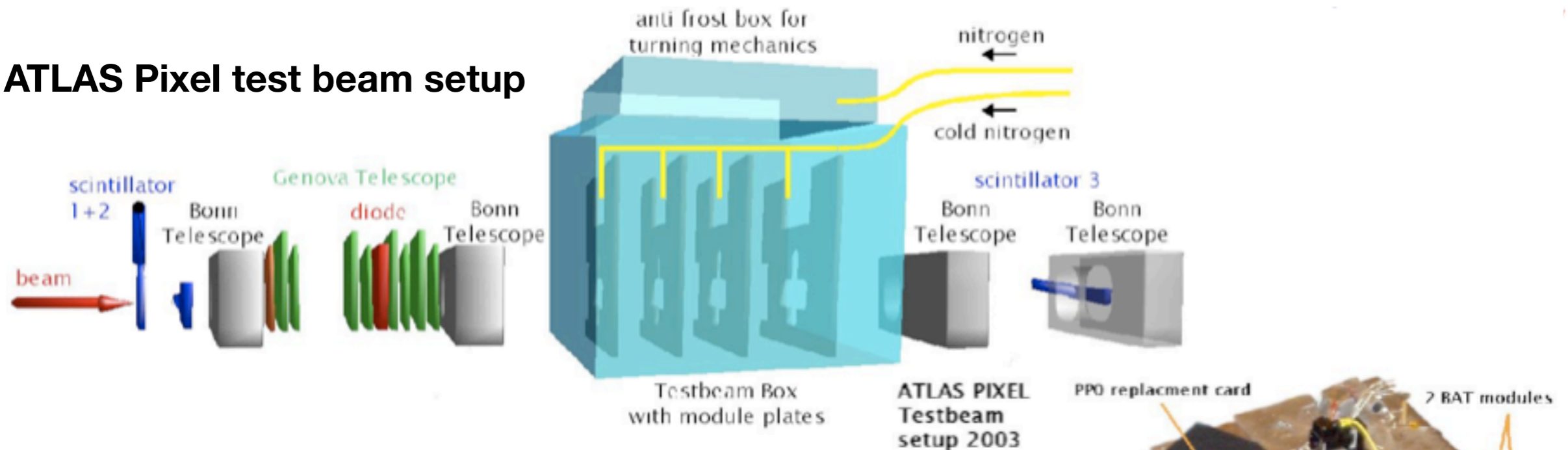
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 - efficiency (TDR > 97%)
 - 99.9 % before irradiation
 - 97.8 % after irradiation (500V bias, fully depleted)

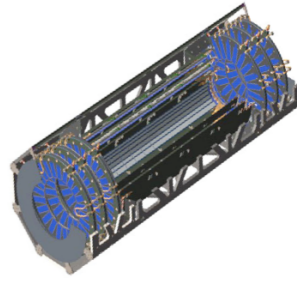




Test Beam Results

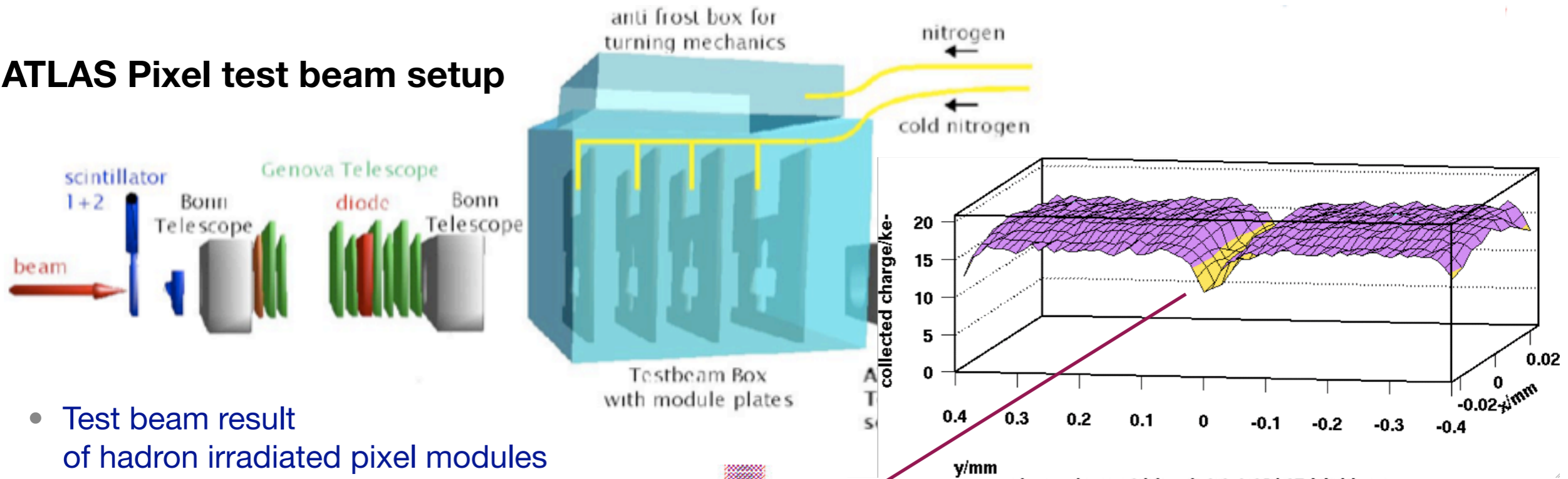
ATLAS Pixel test beam setup



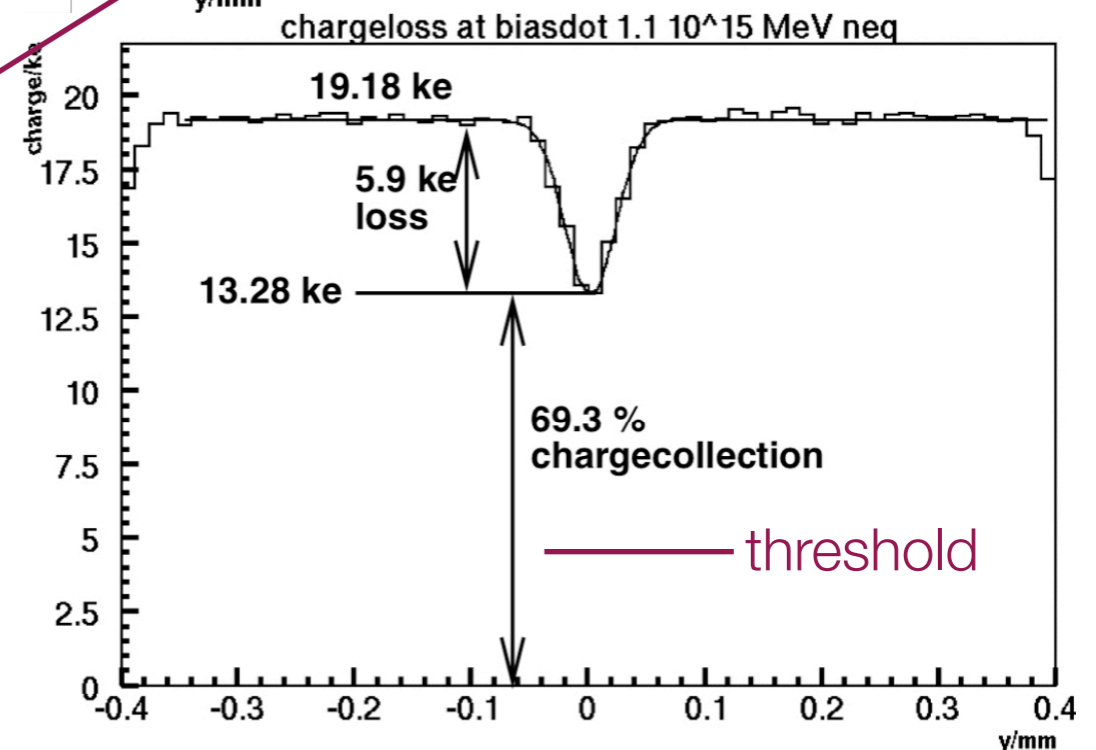


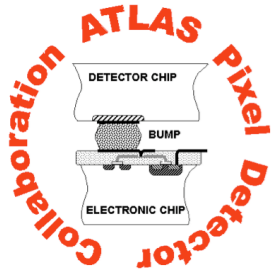
Test Beam Results

ATLAS Pixel test beam setup

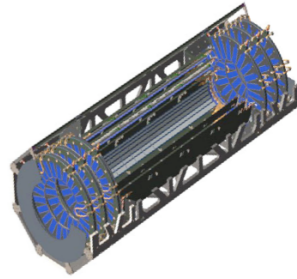


- Test beam result of hadron irradiated pixel modules @ $10^{15} \text{ neq cm}^{-2}$
- there is homogenous charge collection
- small deviation near the bias dot (15% unirradiated, 30% after end of lifetime dosis)
- values stay well above the threshold



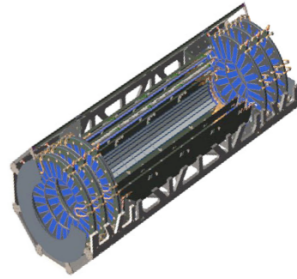


Test Beam Results



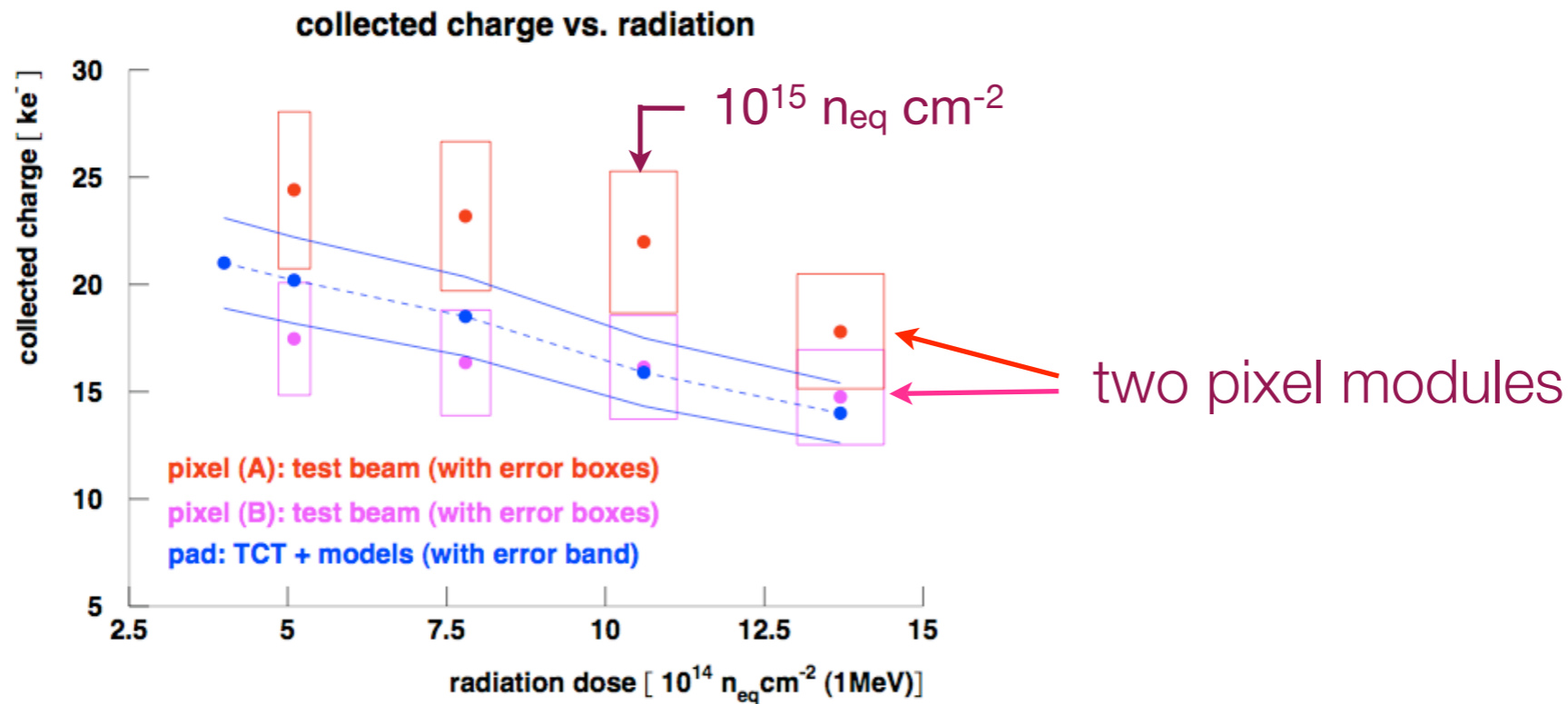
- Production modules have been tested after irradiation $10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$ (NIEL) and 500 kGy (ionisation)
 - efficiency (TDR > 97%)
 - 99.9 % before irradiation
 - 97.8 % after irradiation (500V bias, fully depleted)
 - charge collection after irradiation
 - 87 % (± 14 %) if controlled annealing is performed during LHC breaks

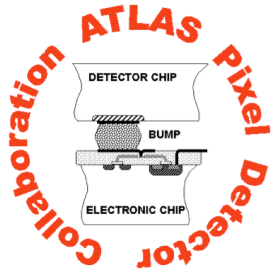




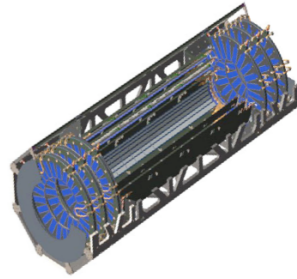
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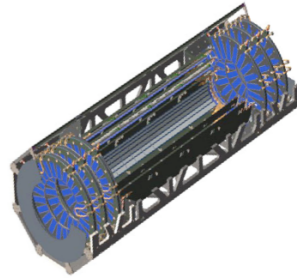


Test Beam Results



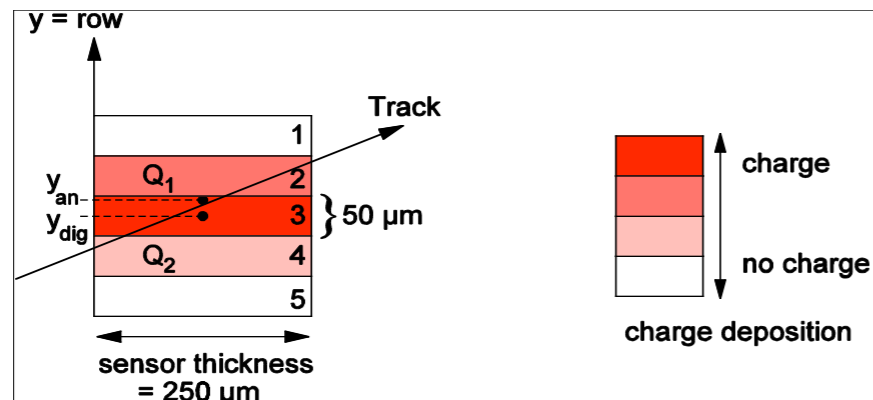
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 - efficiency (TDR > 97%)
 - 99.9 % before irradiation
 - 97.8 % after irradiation (500V bias, fully depleted)
 - charge collection after irradiation
 - 87 % (± 14 %) if controlled annealing is performed during LHC breaks
 - spatial resolutions (TDR < 13 μm)
 - 7.5 μm before irradiation (at incidence angle 10°)
 - 9.7 μm after irradiation (at incidence angle 15°)



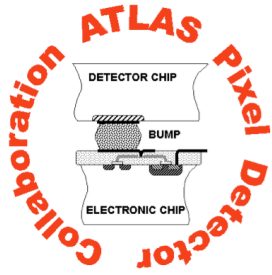


Test Beam Results

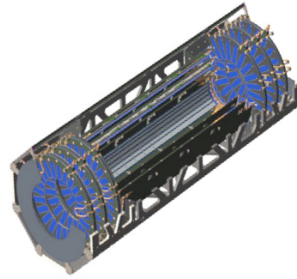
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 - efficiency (TDR > 97%)
 - 99.9 % before irradiation
 - 97.8 % after irradiation (500V bias, fully depleted)
 - charge collection after irradiation
 - 87 % (± 14 %) if controlled annealing is performed during LHC breaks
 - spatial resolutions (TDR < $13 \mu\text{m}$)
 - $7.5 \mu\text{m}$ before irradiation (at incidence angle 10°)
 - $9.7 \mu\text{m}$ after irradiation (at incidence angle 15°)



- these studies are being verified under combined test beam conditions

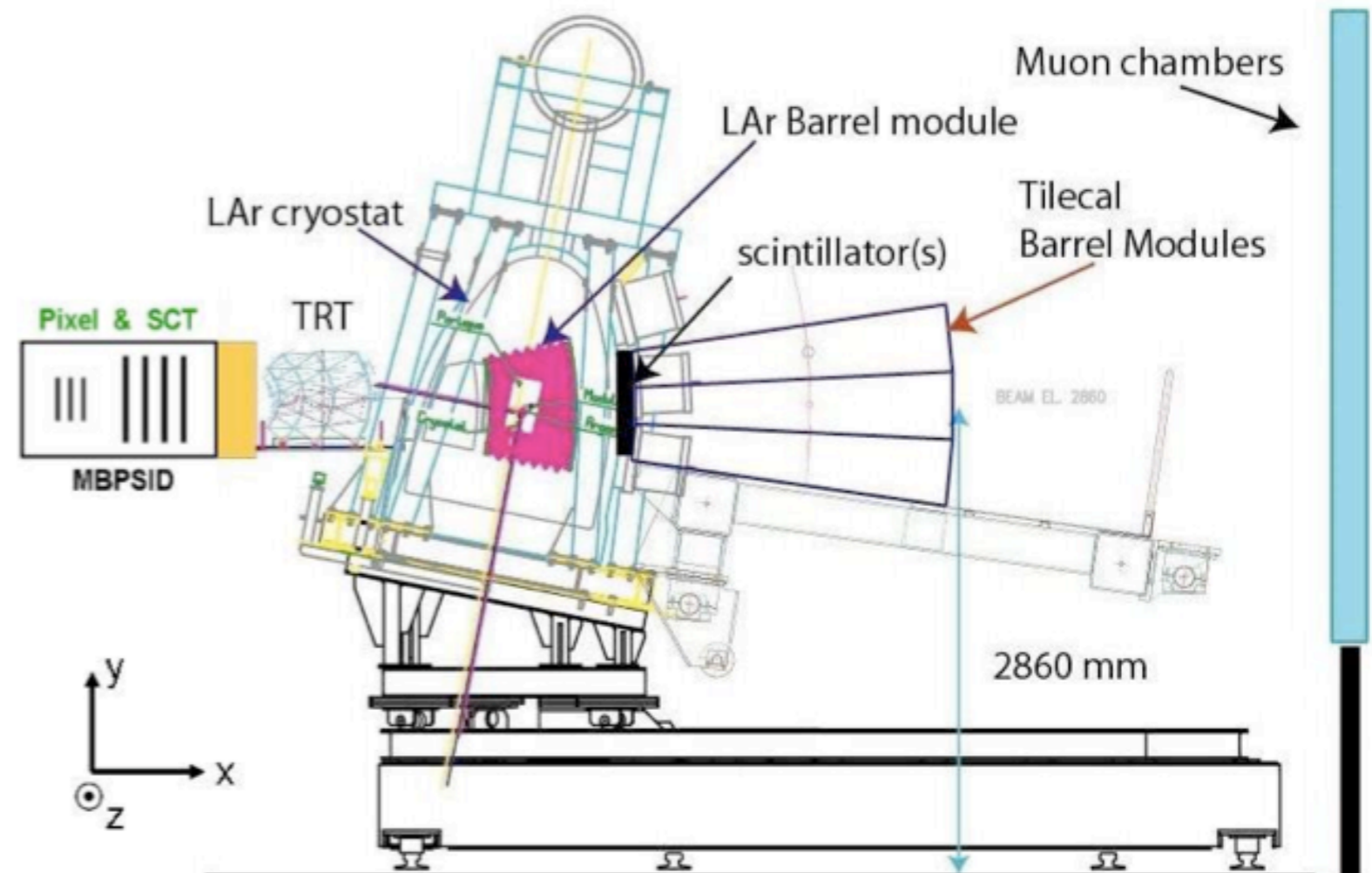


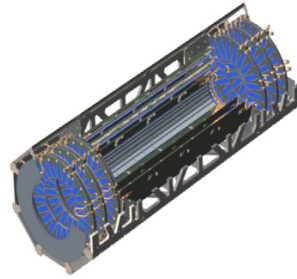
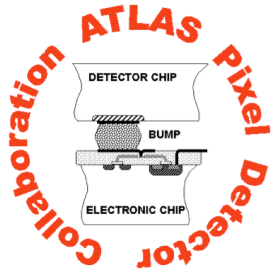
Test Beam Results



- a sector of the ATLAS barrel part has been used for detector performance studies
- this emulates transversely (high p_{\perp}) emitted particles passing through the barrel

ATLAS Combined Test Beam

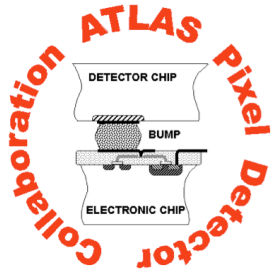




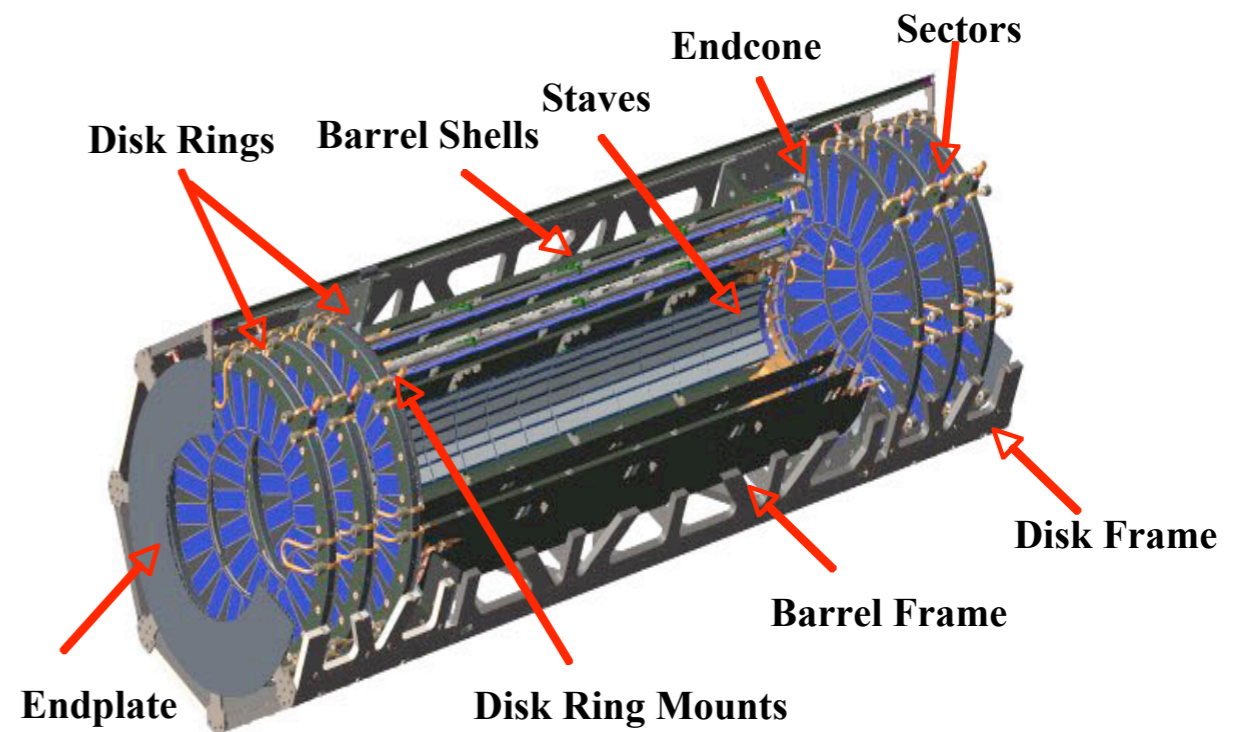
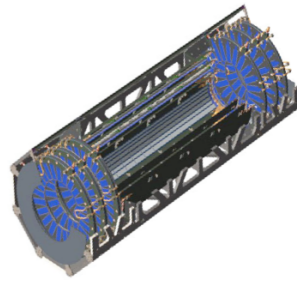
Test Beam Results

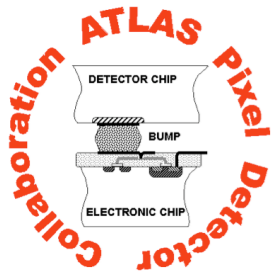
- Production modules have been tested after irradiation $10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$ (NIEL) and 500 kGy (ionisation)
 - efficiency (TDR > 97%)
 - 99.9 % before irradiation
 - 97.8 % after irradiation (500V bias, fully depleted)
 - charge collection after irradiation
 - 87 % (± 14 %) if controlled annealing is performed during LHC breaks
 - spatial resolutions (TDR < 13 μm)
 - 7.5 μm before irradiation (at incidence angle 10°)
 - 9.7 μm after irradiation (at incidence angle 15°)
- efficiency of irradiated detectors under high intensity conditions, LHC-like particle flux
 - read-out electronics is verified
 - efficiency is not affected by occupancy @ b-layer rate including safety margin (+ 23 %)
 - onset of inefficiencies is gradual, < 3 % @ b-layer rate + 65%



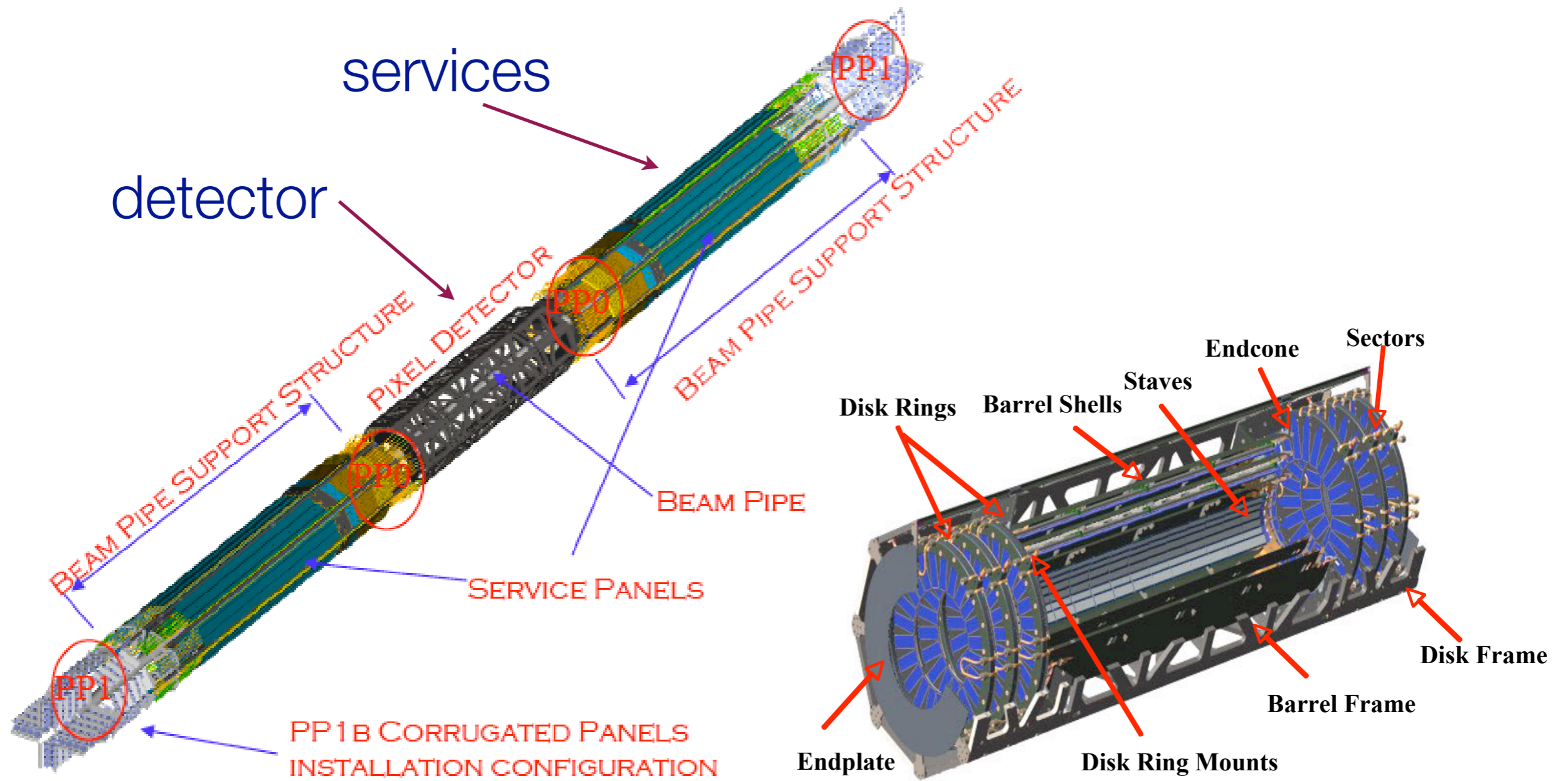
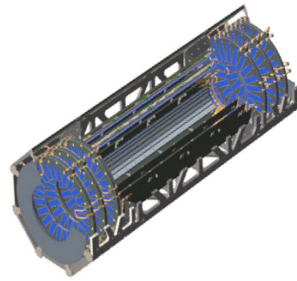


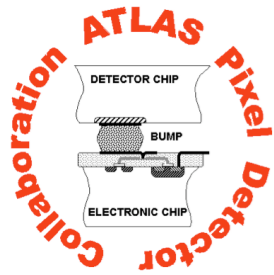
Present Work: Pixel Detector Assembly and Integration



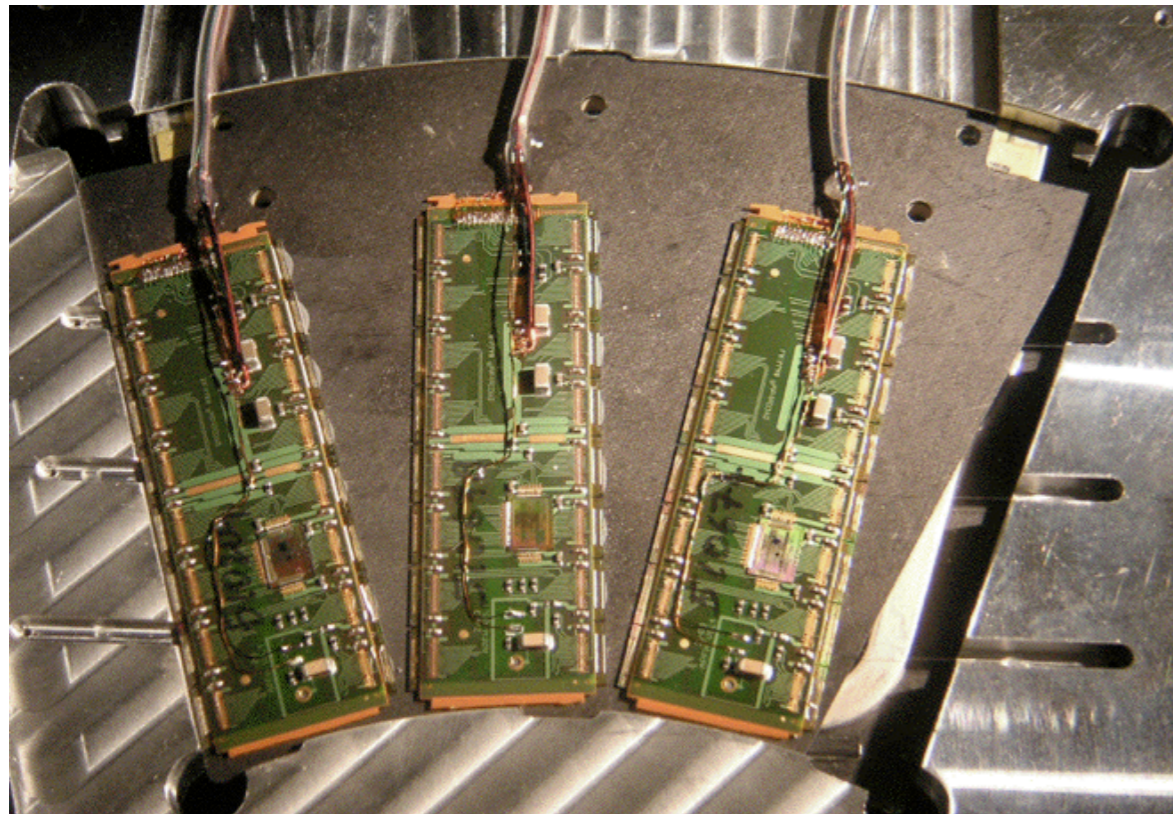
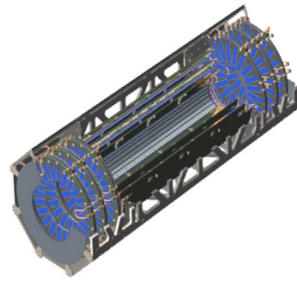


Present Work: Pixel Detector Assembly and Integration





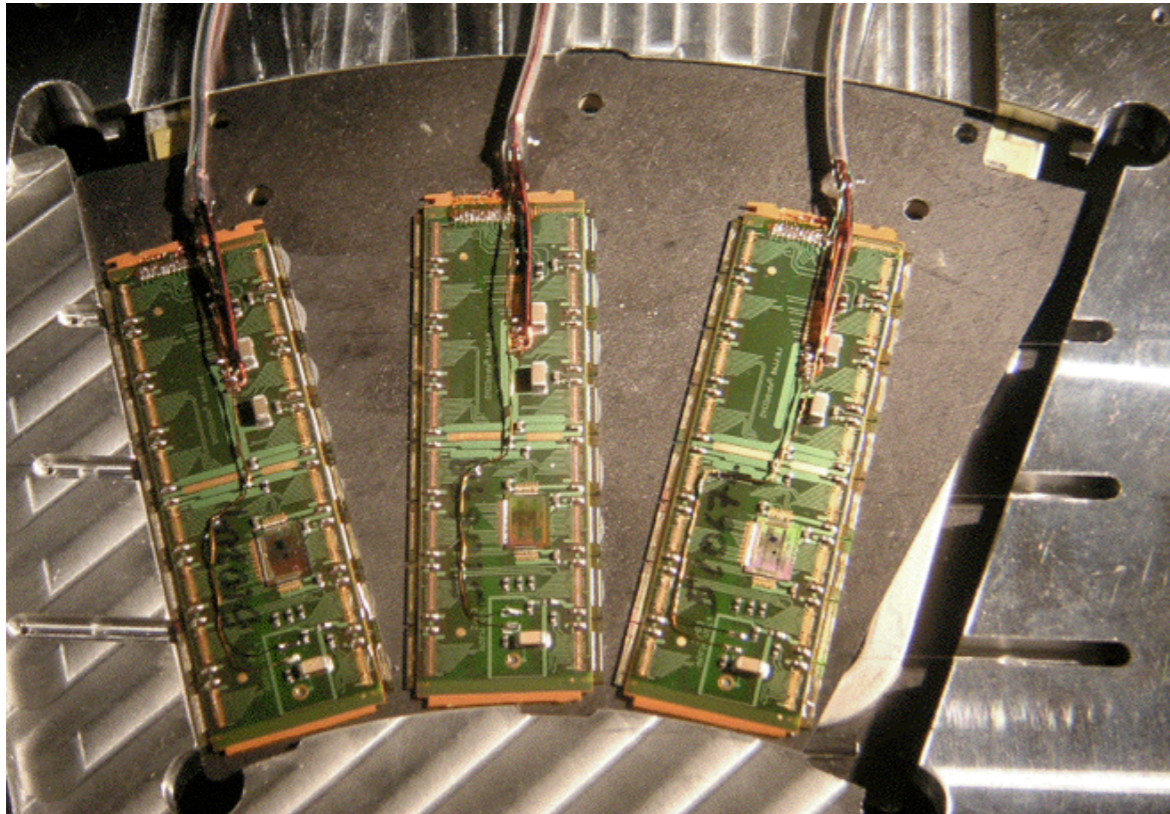
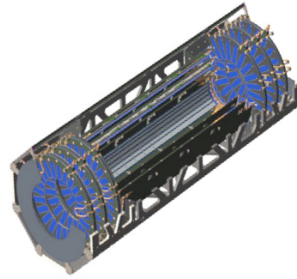
Pixel End Cap



assembly of disks in sectors = 1/8 of a disk
2x3 modules on C-C plates,
sandwiching the cooling

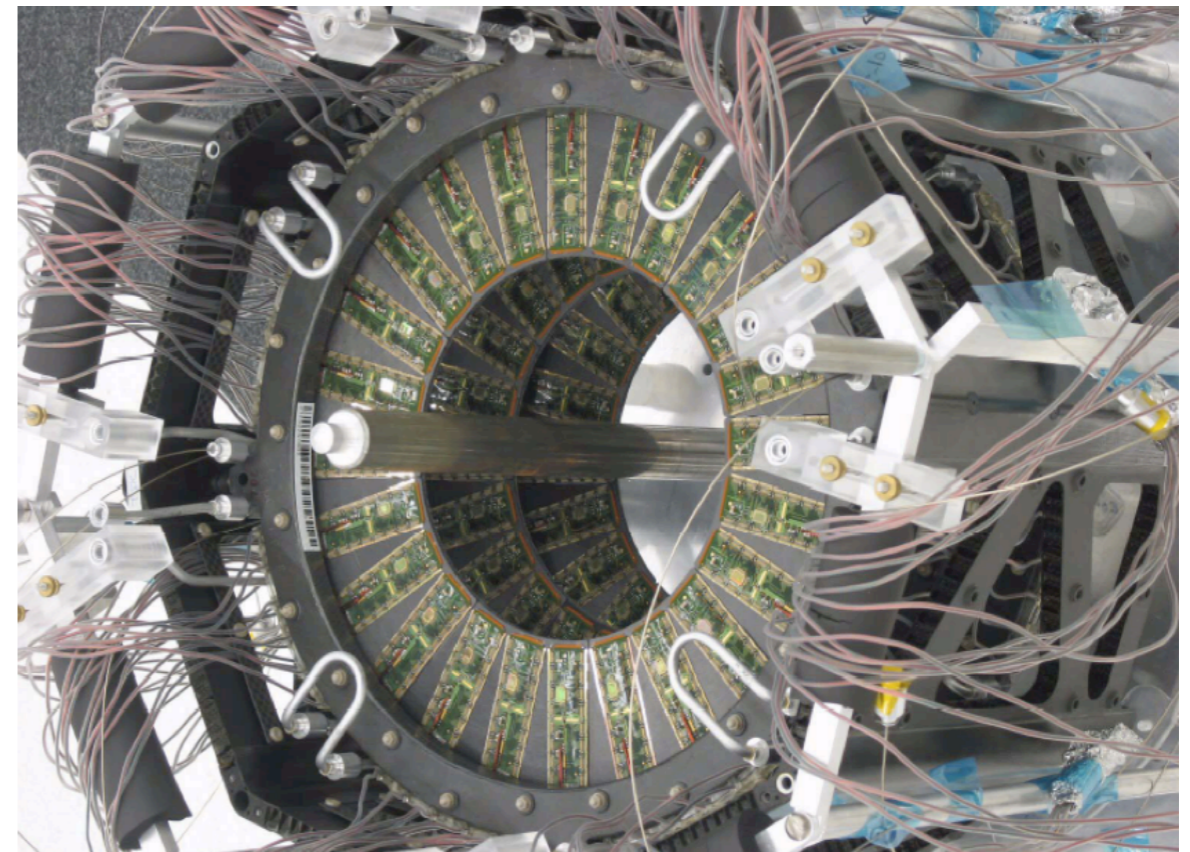


Pixel End Cap



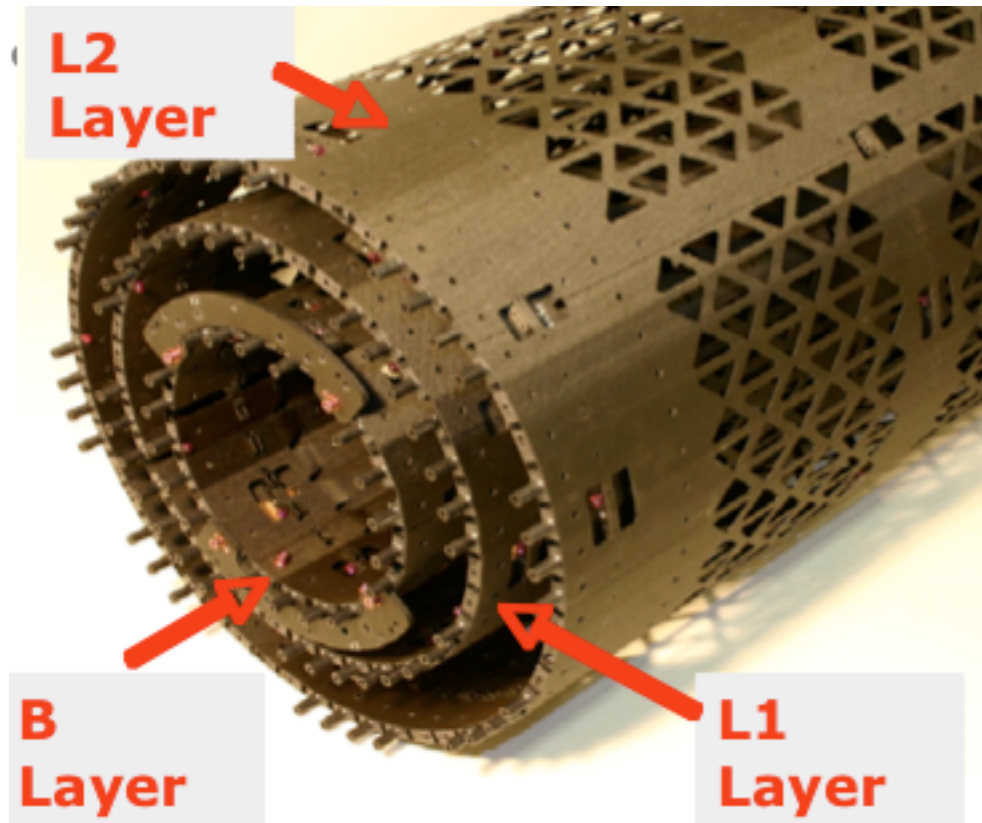
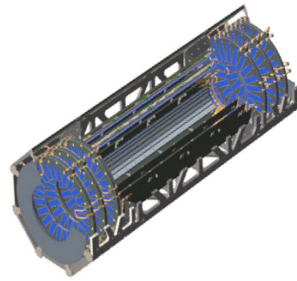
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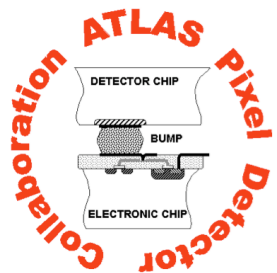
one of the end caps
3 disks à 2x24 modules



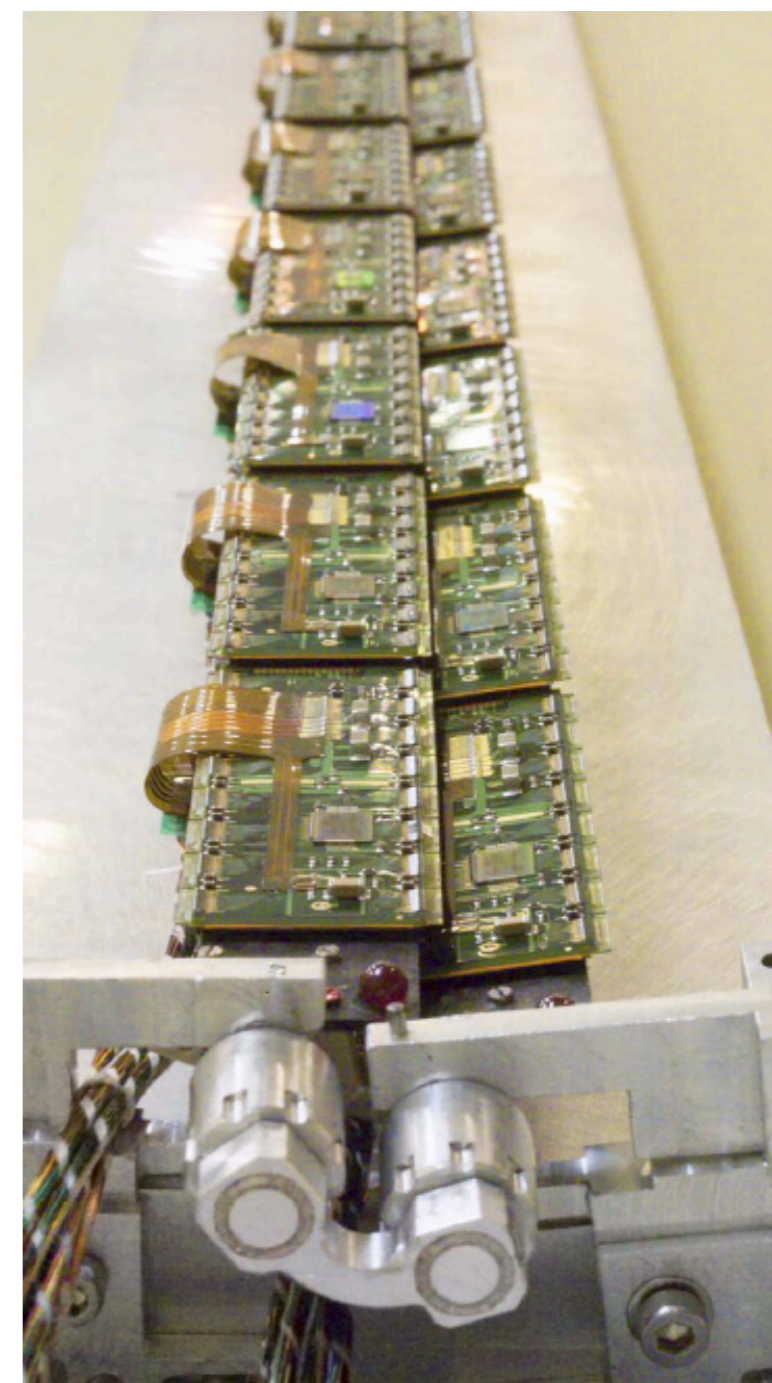
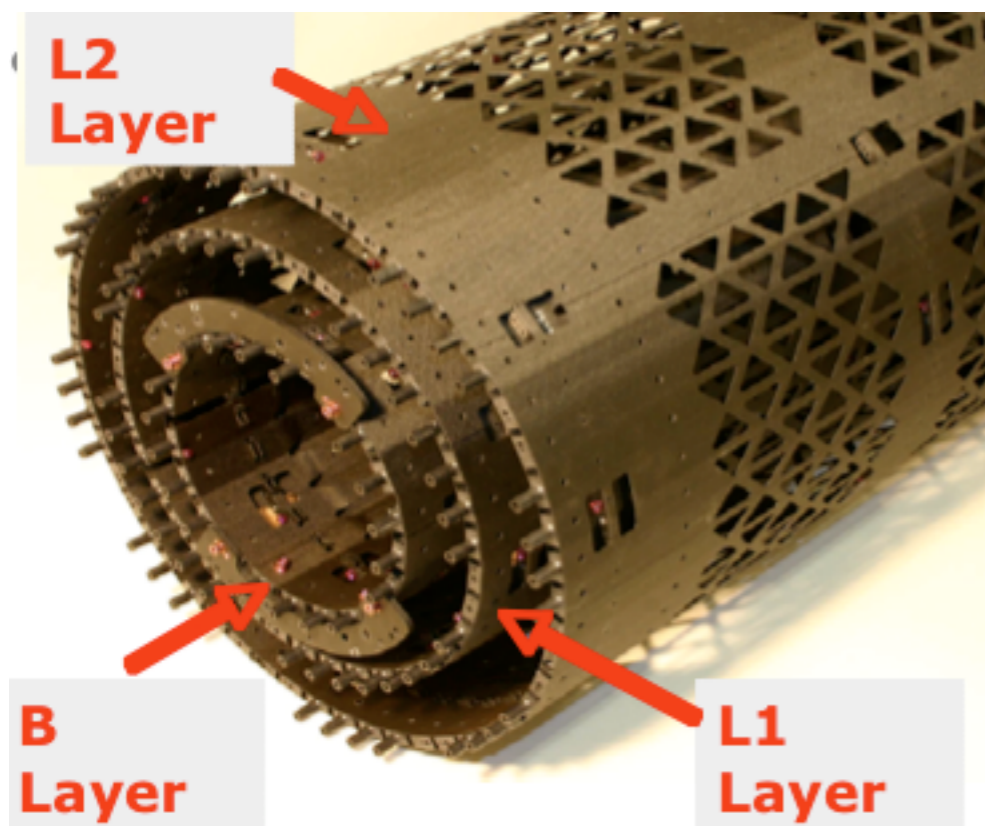
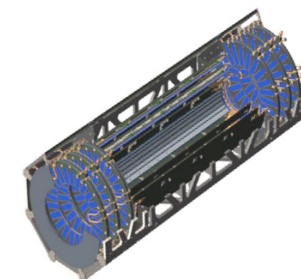


Pixel Barrel





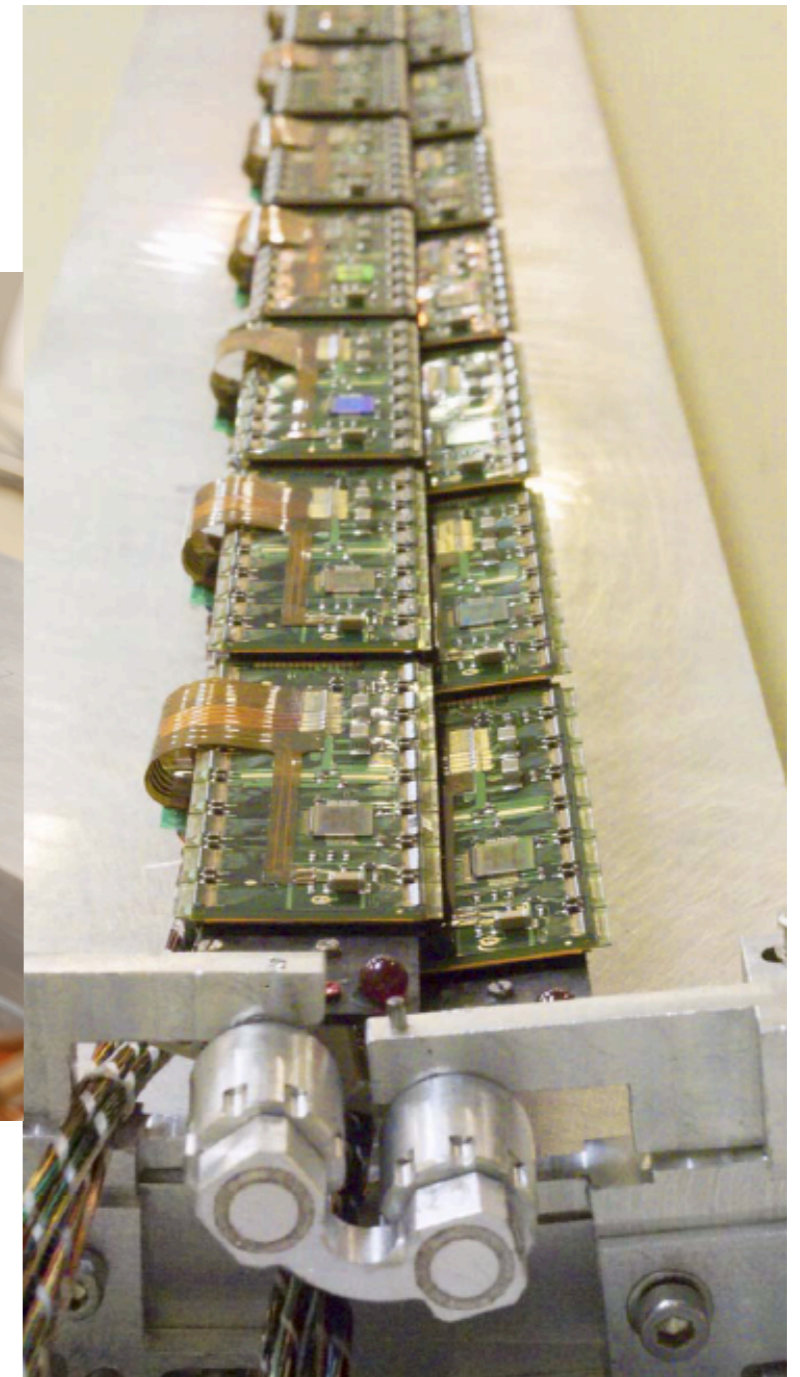
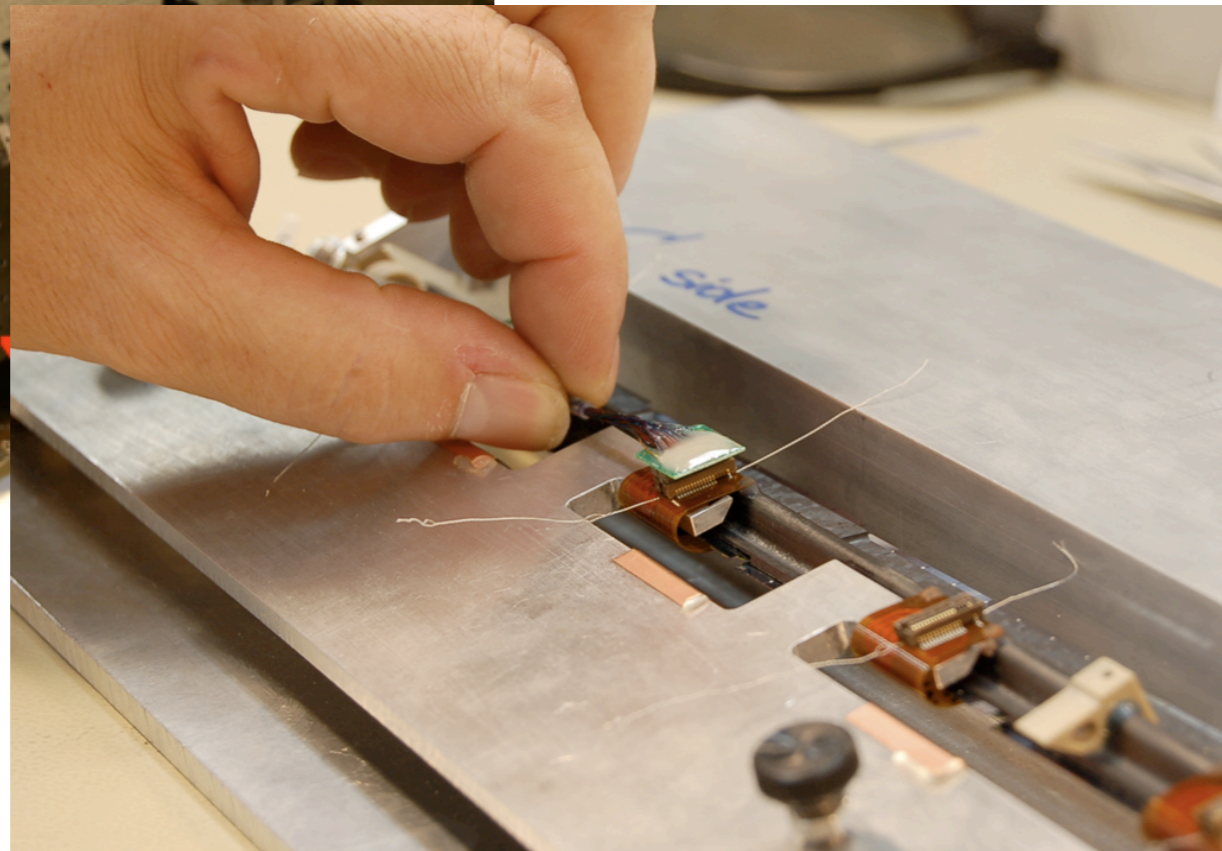
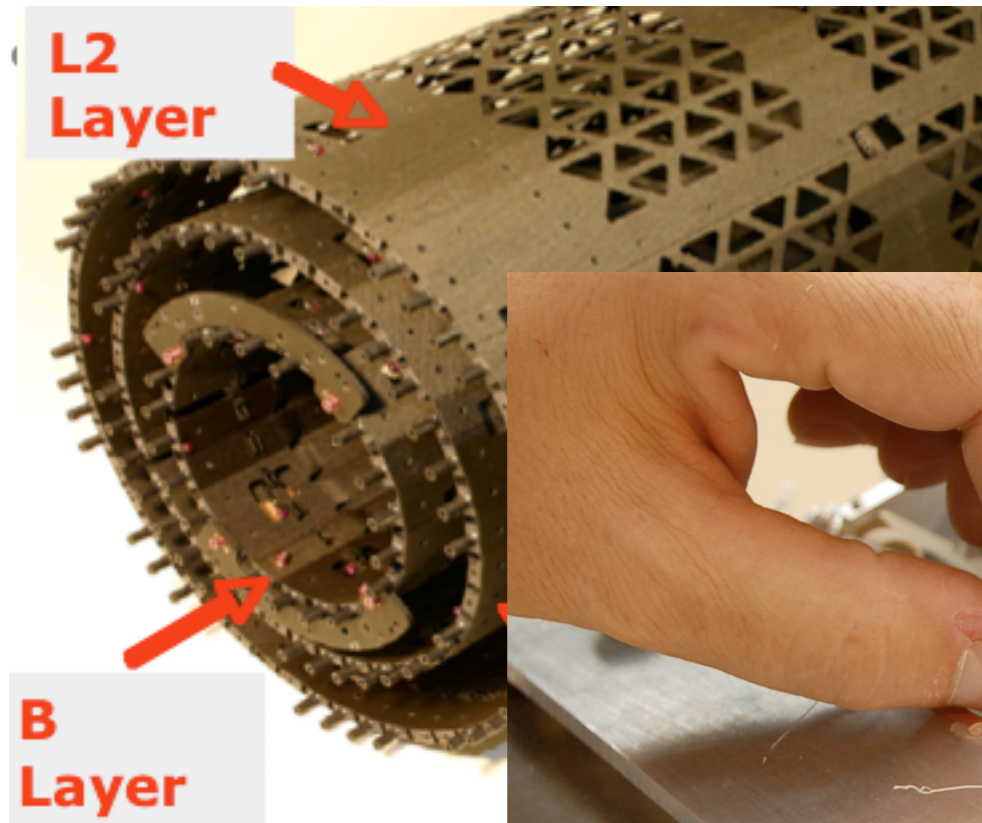
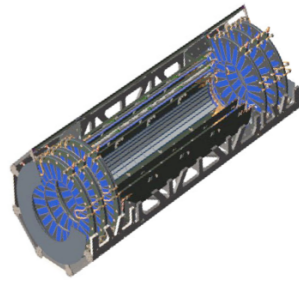
Pixel Barrel



bi-stave w/ U-link

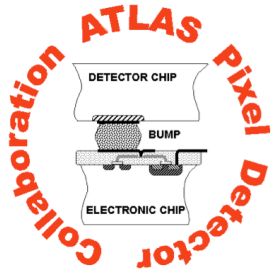


Pixel Barrel

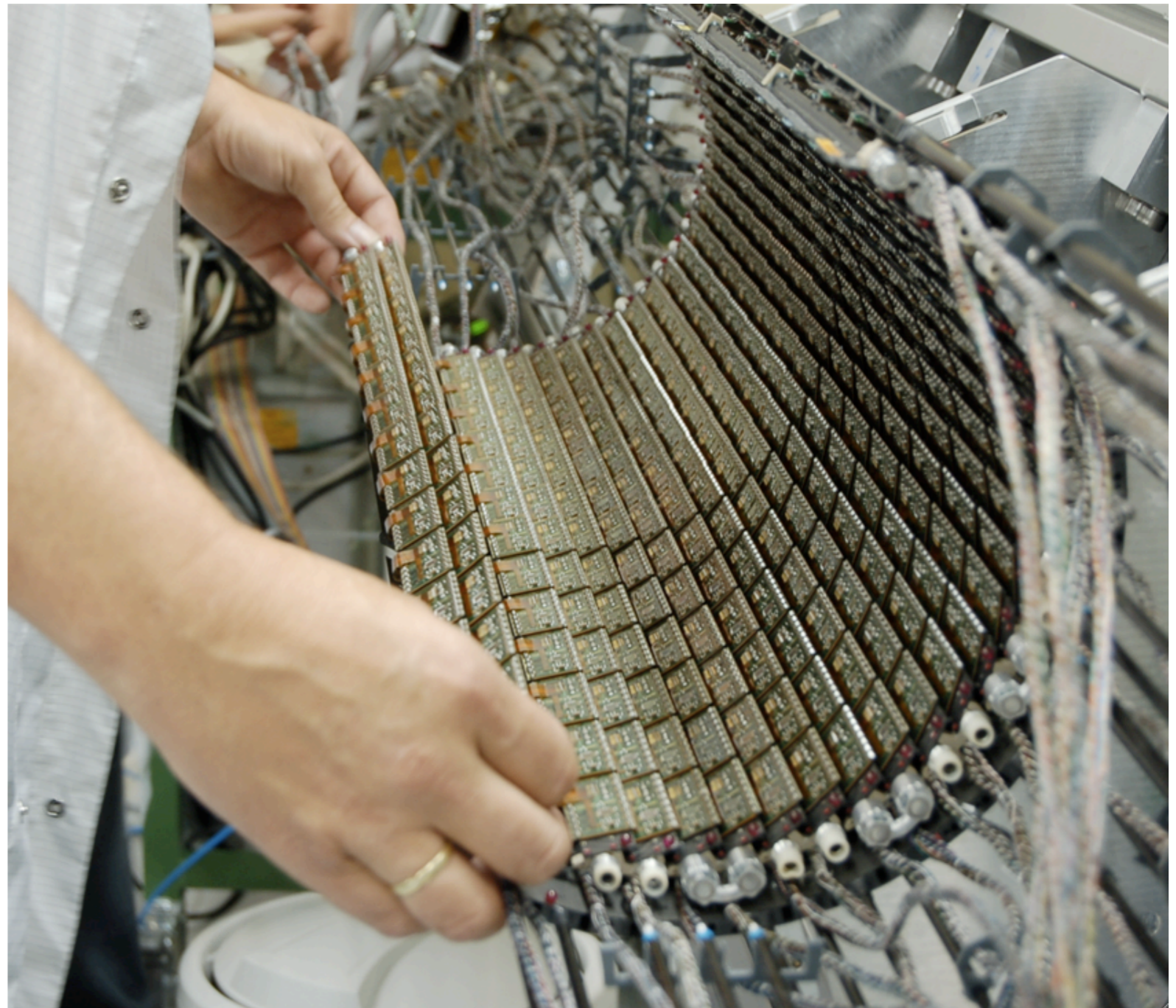
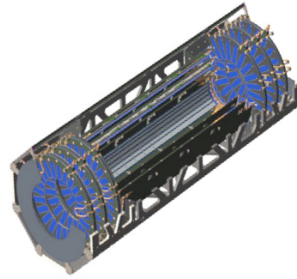


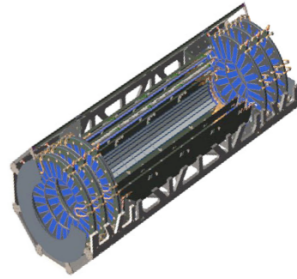
1456 modules need individual cabling & testing

bi-stave w/ U-link



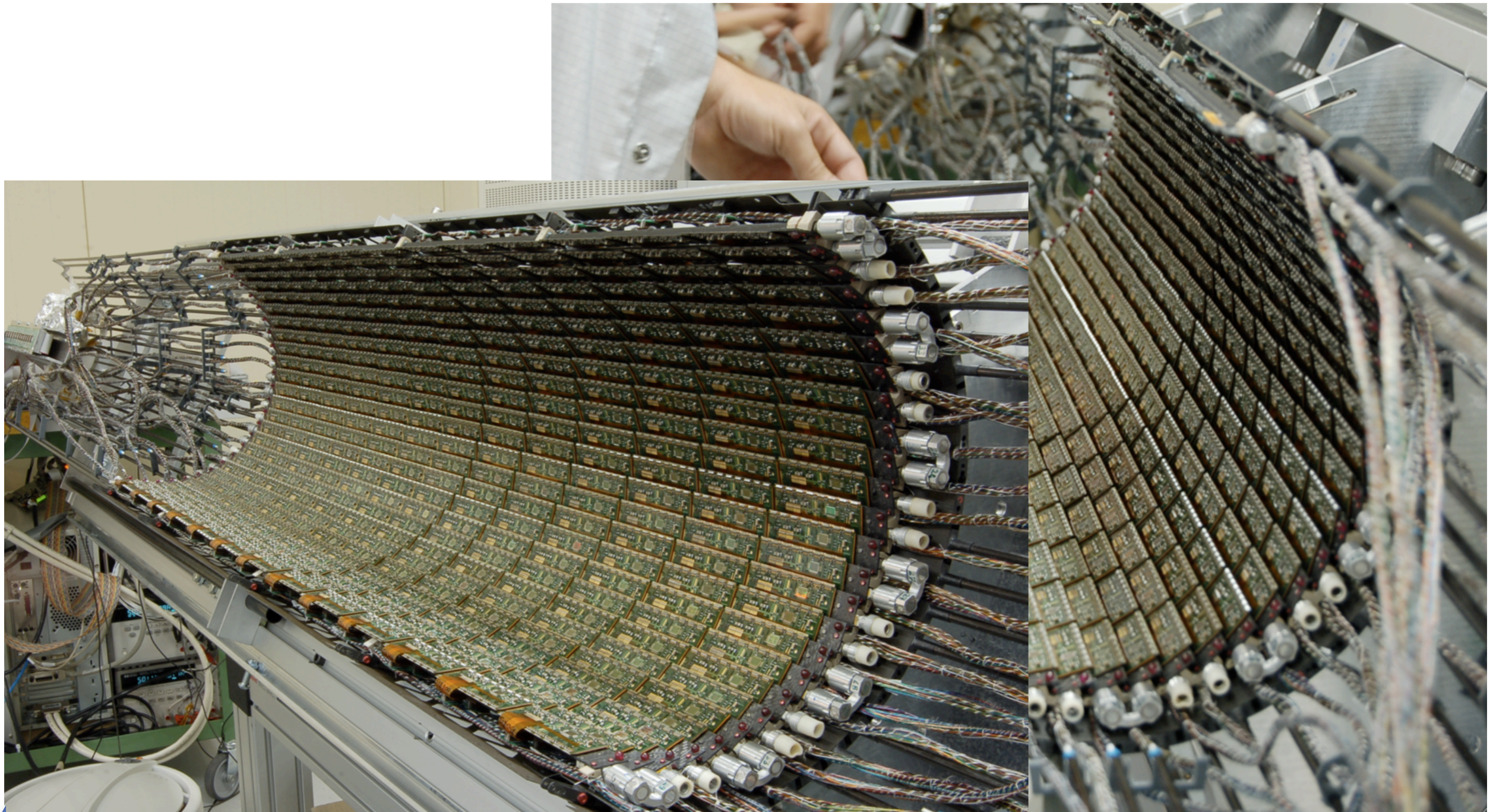
Pixel Integration as of September 2006

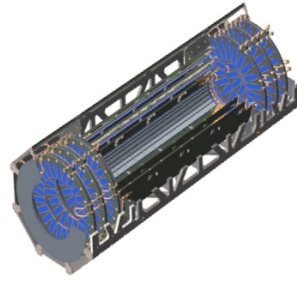




Pixel Integration as of September 2006

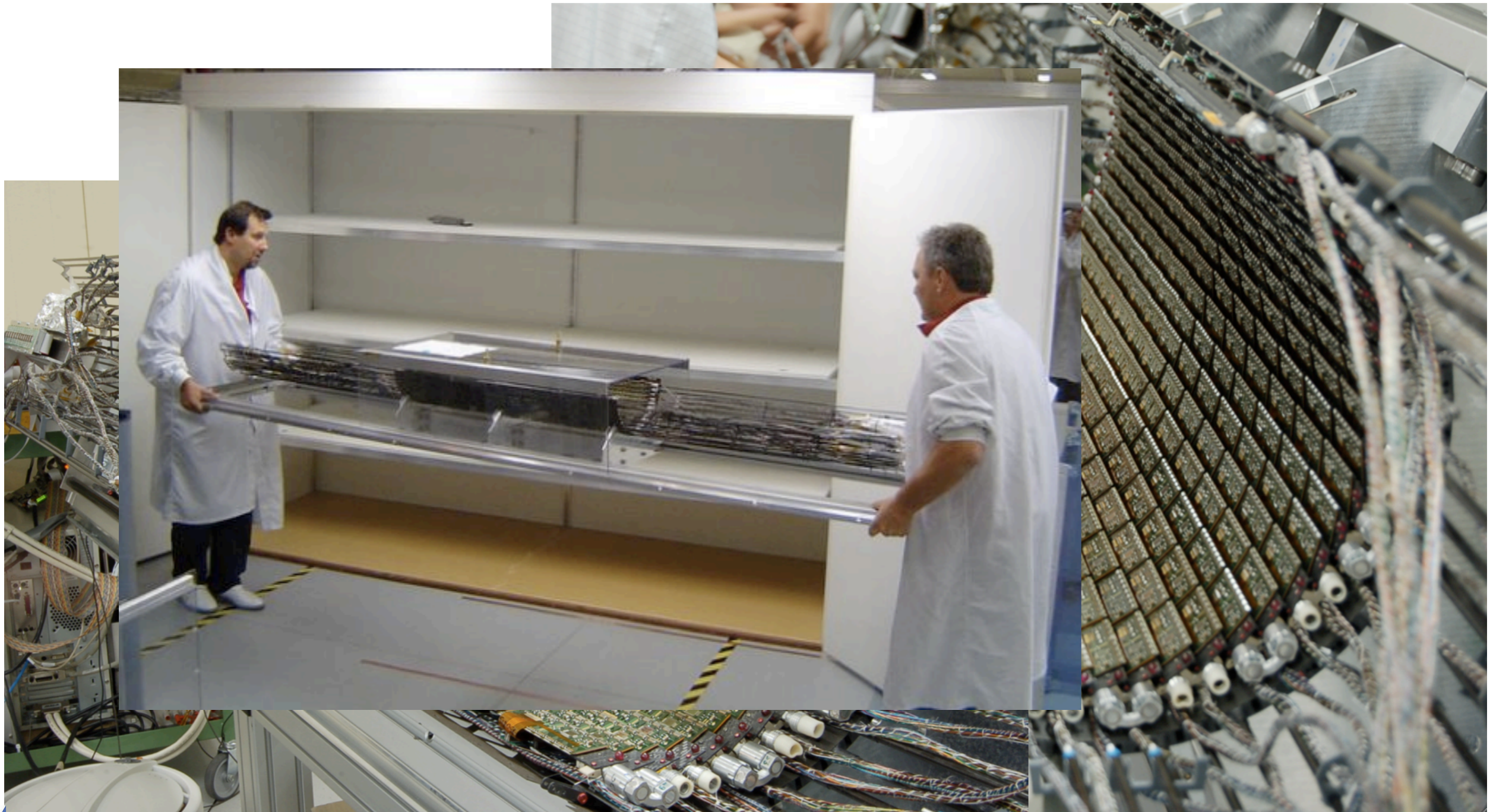
- both half shells of layer 2 are completely filled

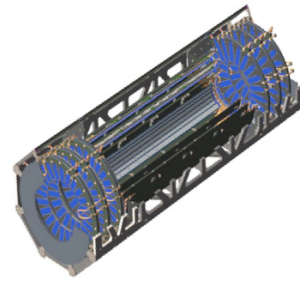
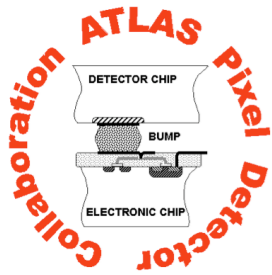




Pixel Integration as of September 2006

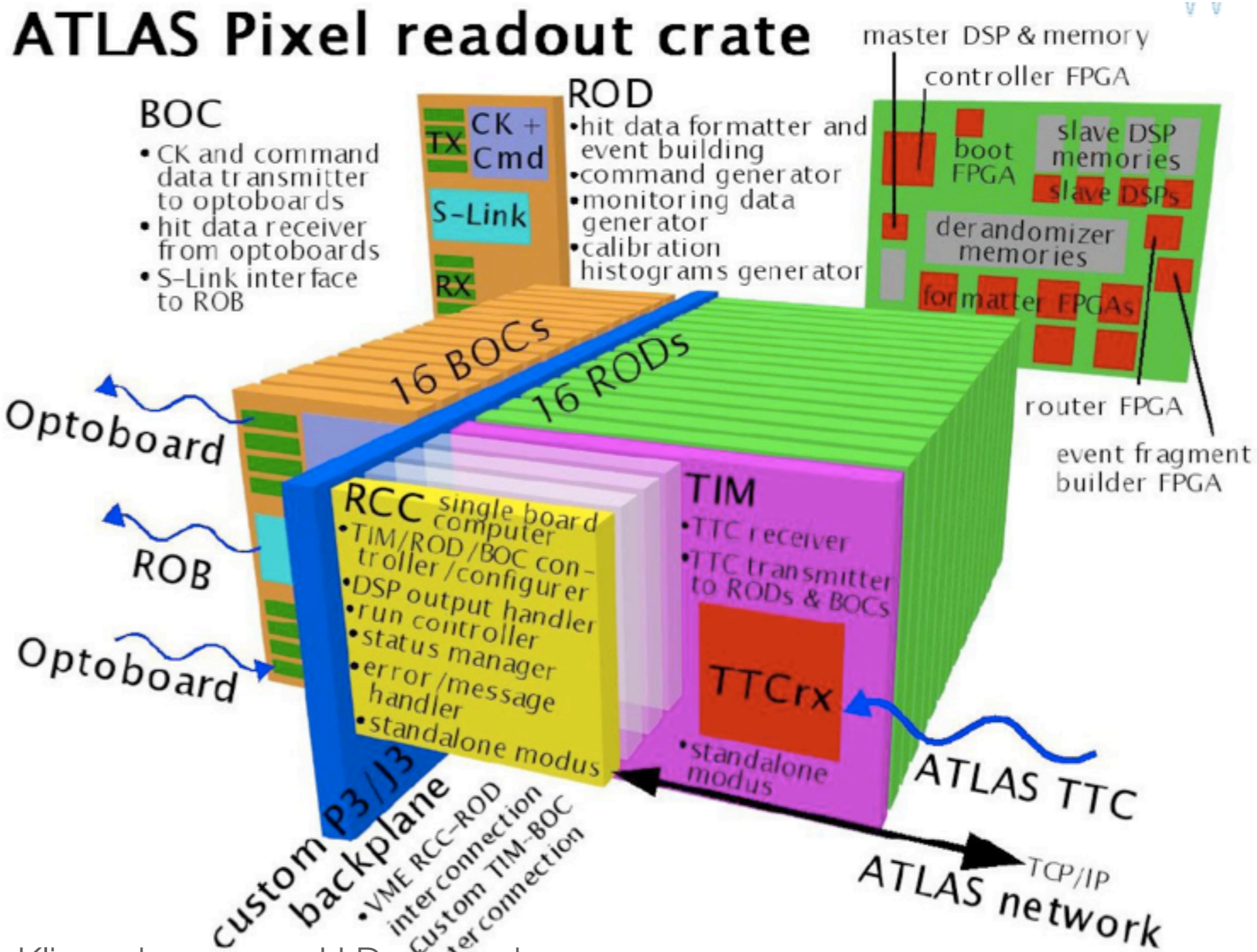
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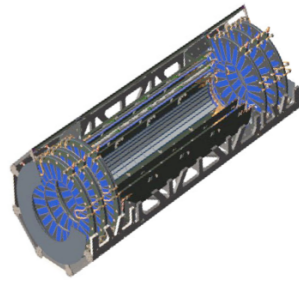
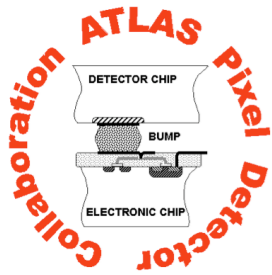




Dedicated System Tests

- to set-up the full chain of services and read-out for large parts of the detector





Dedicated System Tests

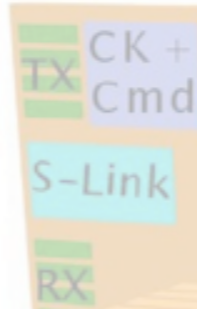
- to set-up the full chain of services and read-out for large parts of the detector

ATLAS Pixel readout crate

PP0 and
opto board

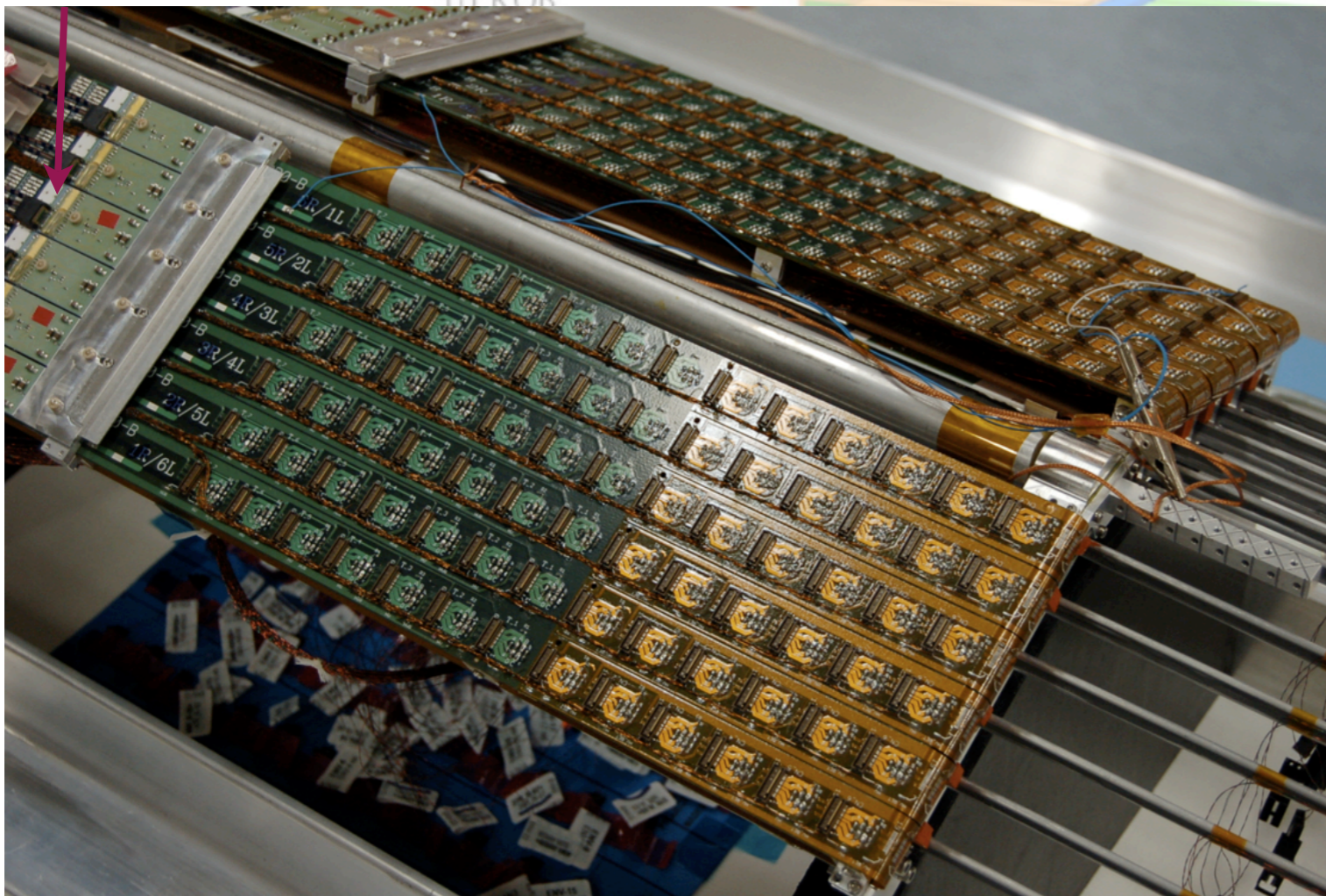
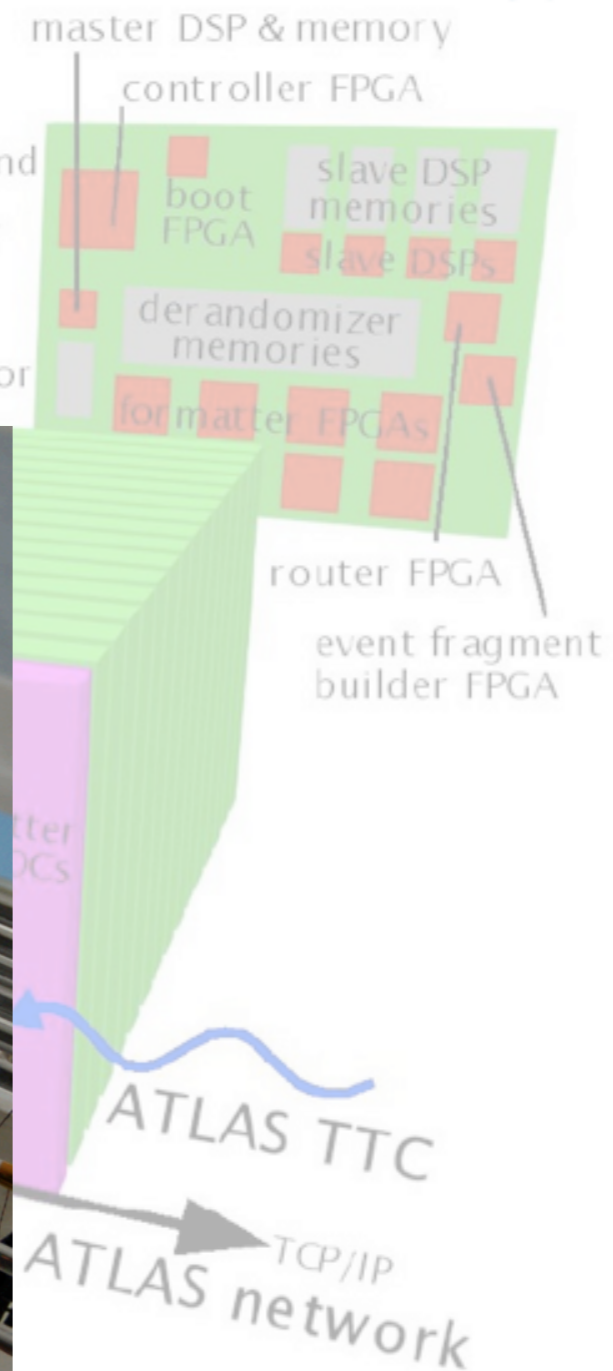
BOC

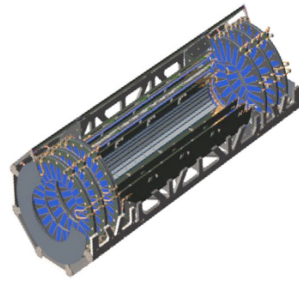
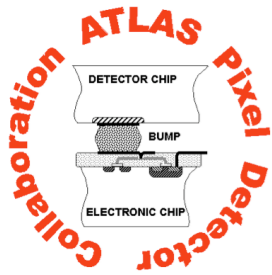
- CK and command data transmitter to optoboards
- hit data receiver from optoboards
- S-Link interface to ROB



ROD

- hit data formatter and event building
- command generator
- monitoring data generator
- calibration histograms generator





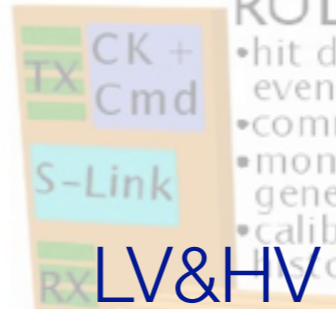
Dedicated System Tests

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ATLAS Pixel readout

BOC

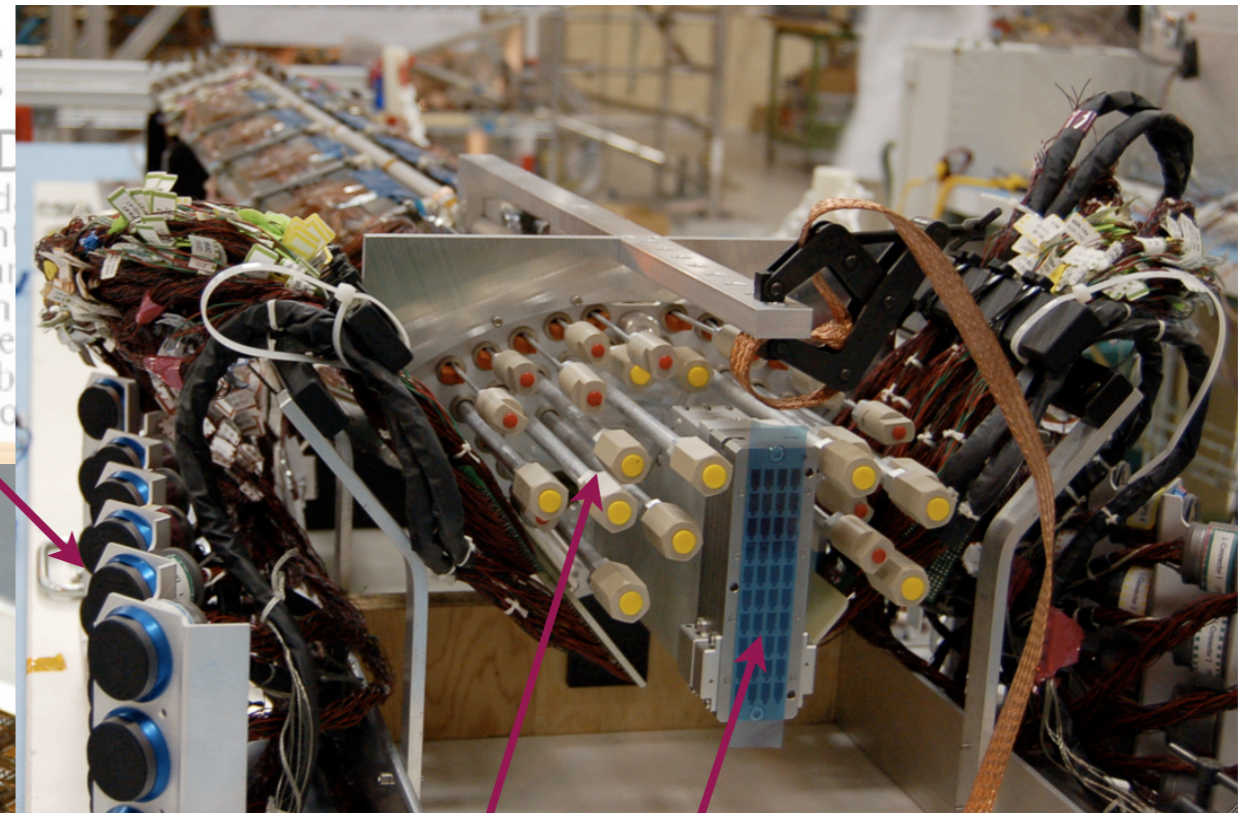
- CK and command data transmitter to optoboards
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ROB

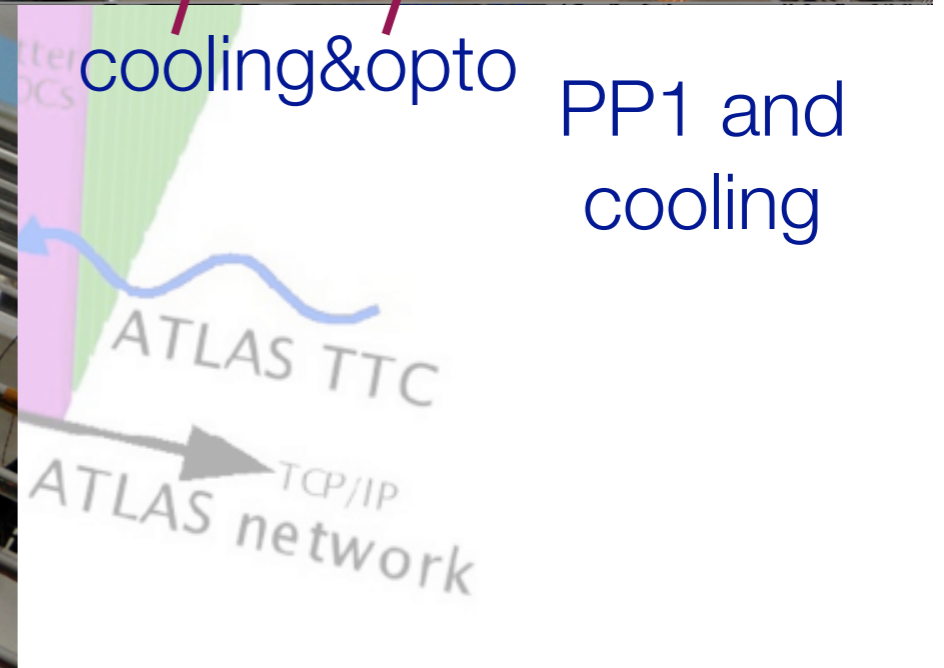
- hit data event
- command
- monitoring
- generator
- calibration
- test

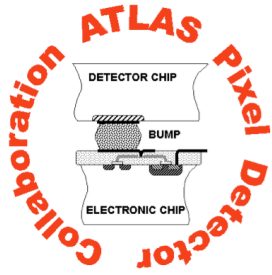
PP0 and opto board



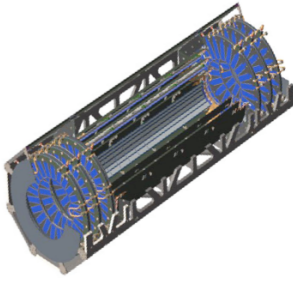
cooling&opto

PP1 and cooling



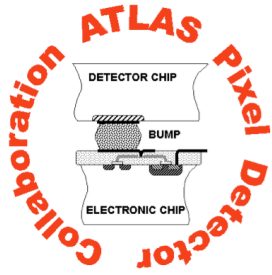


ATLAS Pixel: Conclusion and Outlook

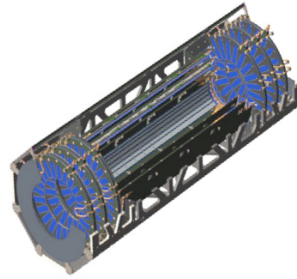


- radiation tolerant design of sensor, FE and mechanics
- performance of detector has been verified under test beam conditions
- both half shells of layer 2 are completely filled
layer 1 started to be assembled
- infrastructure for services & read-out is installed in surface building
- continue with system tests including staves & disks





ATLAS Pixel: Conclusion and Outlook



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• a three hit pixel detector is on its way for CERN-LHC

