The ATLAS Pixel Detector

ATLAS Pixel Detector Collaboration

Bonn, Dortmund, Genova, LBL, Marseille, Milano, New Mexico, Ohio, Oklahoma, Praha, Siegen, Udine, Wuppertal

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VERTEX06

SI LAB

Silizium Labor Bonn

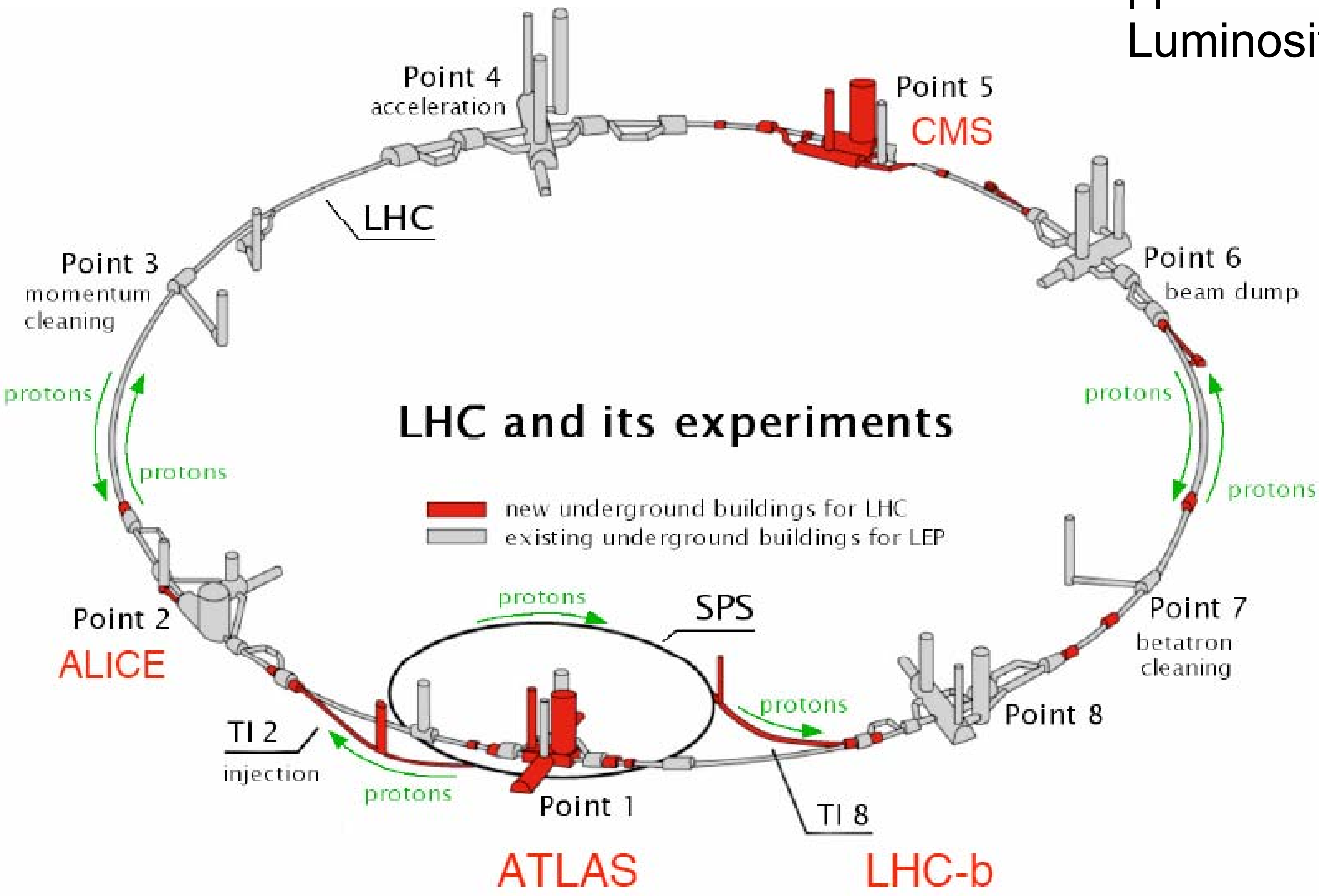
Contents

- The Atlas Pixel detector
  - Requirements, design, choices
- Module tests and detector integration
- Some issues
  - Potting, delamination, pipe corrosion, cables
- Present status and schedule

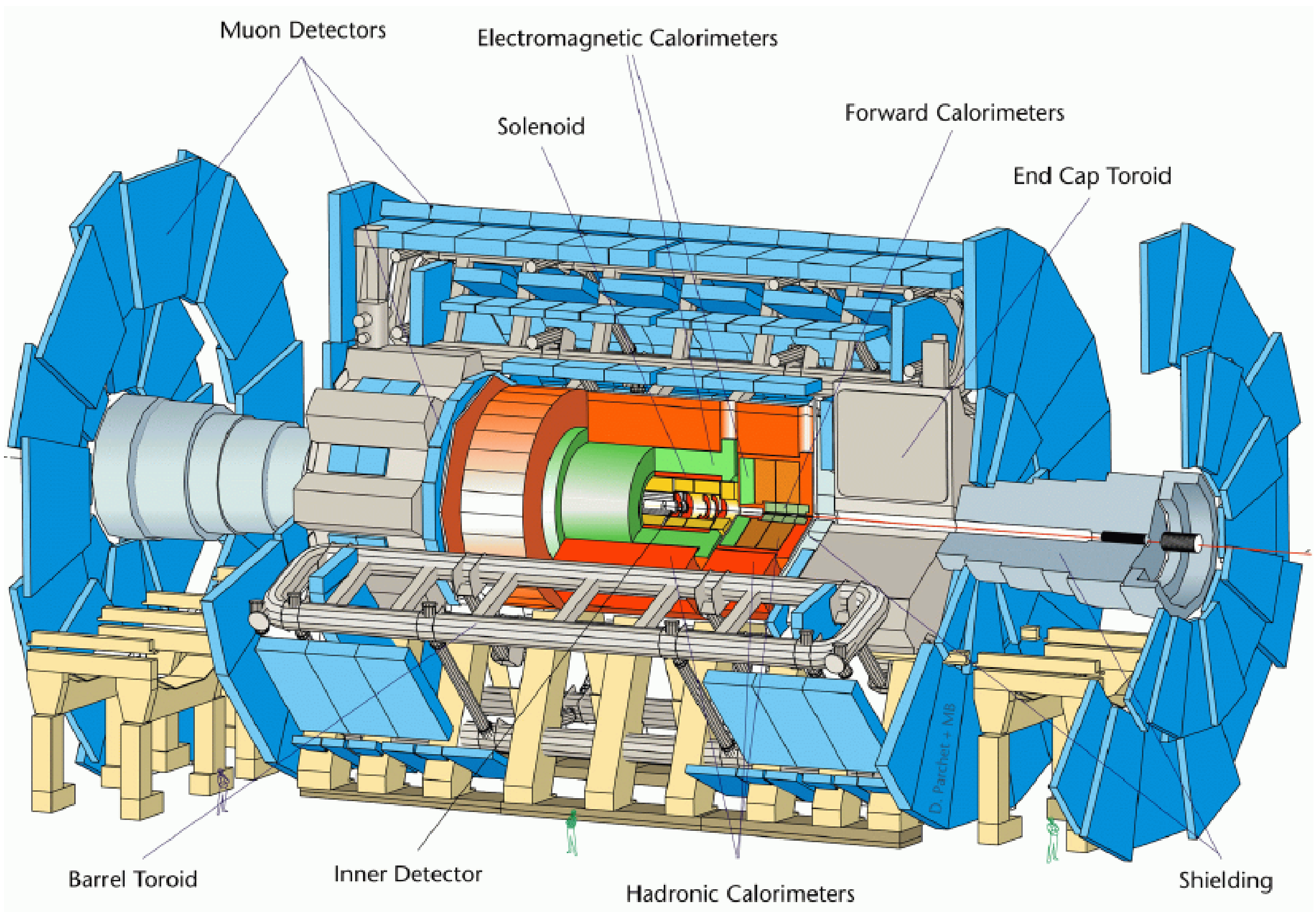
LHC and ATLAS

pp collisions $\sqrt{s} = 14\text{TeV}$

Luminosity 10^{34} cm^{-2} sec^{-1}

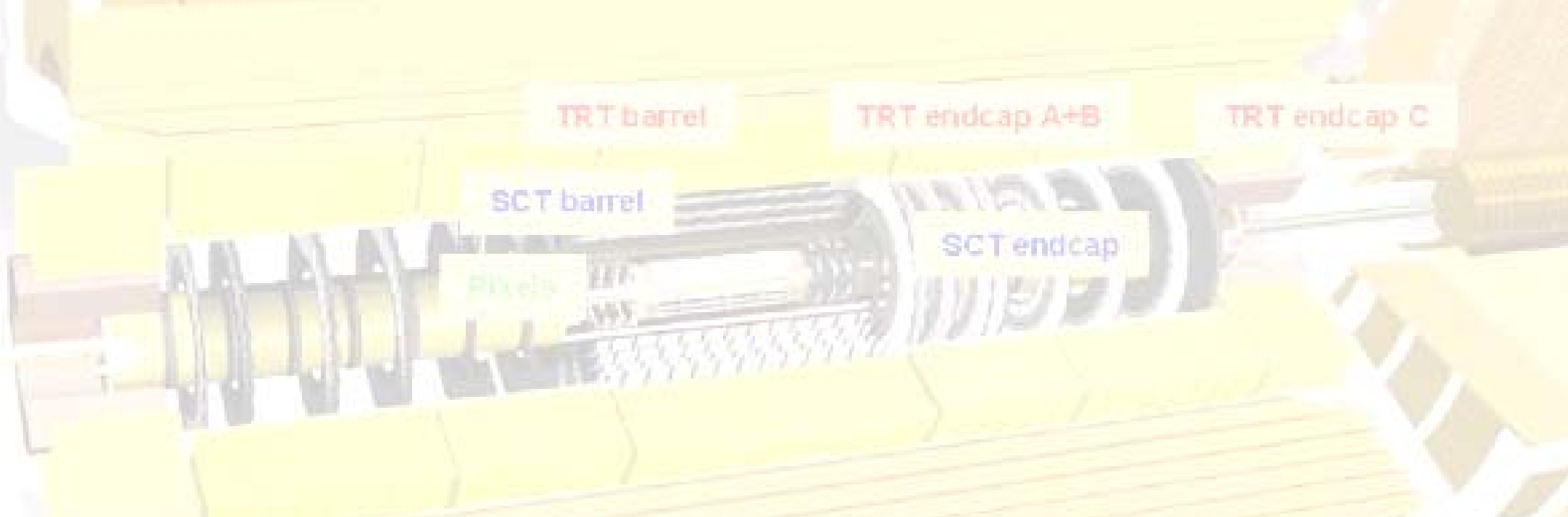


LHC and ATLAS



Inner detector tracking system

- Outermost system uses gas-filled 4mm straws
  - Contains 420k electronic channels. Transition radiation (TRT) gives particle ID

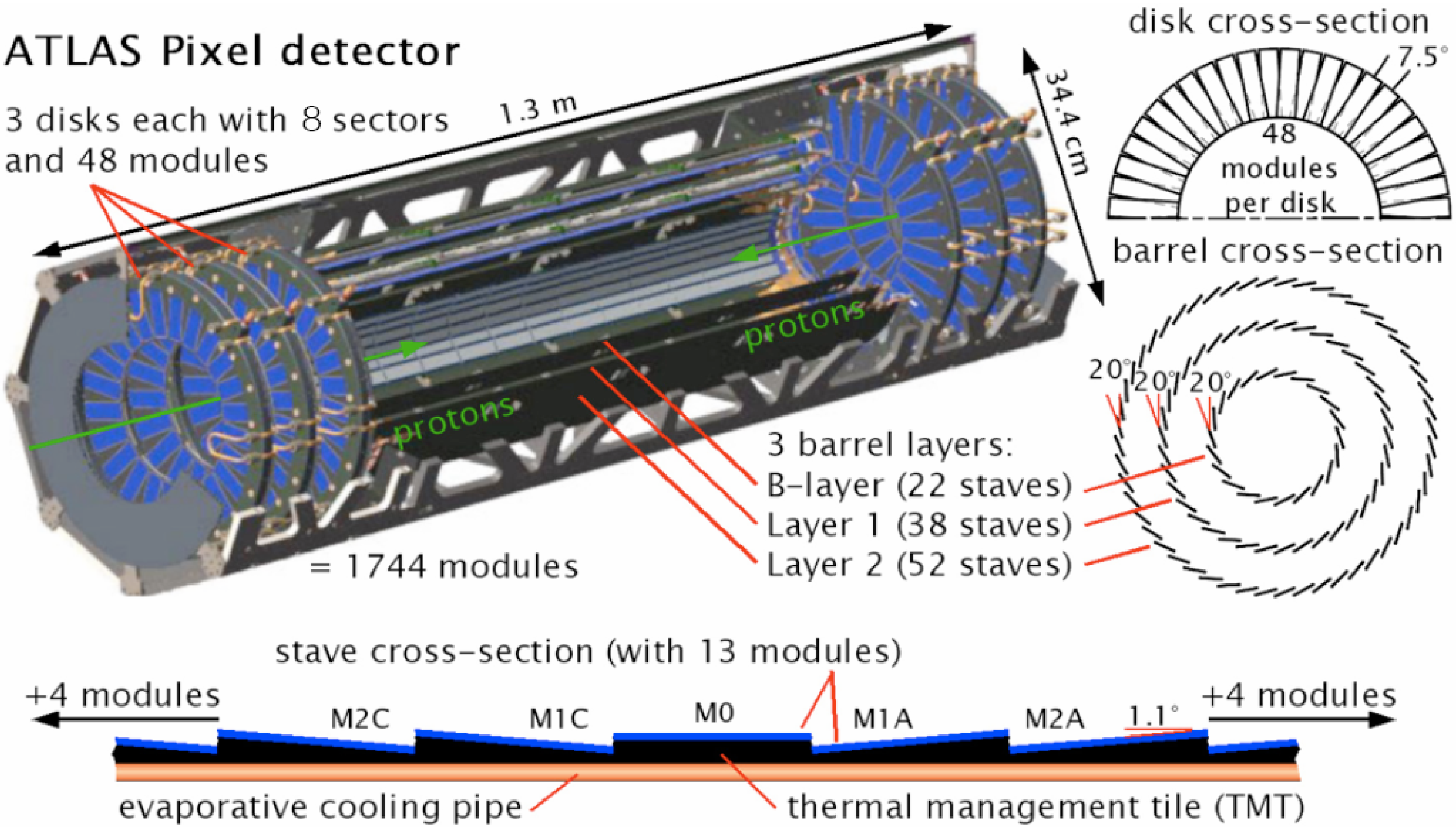


- Intermediate system is a large silicon strip tracker (SCT)
  - Four barrel layers and 9 disk layers with 61 m^2 silicon and 6.2M channels
- Innermost system is a silicon pixel tracker

Requirements

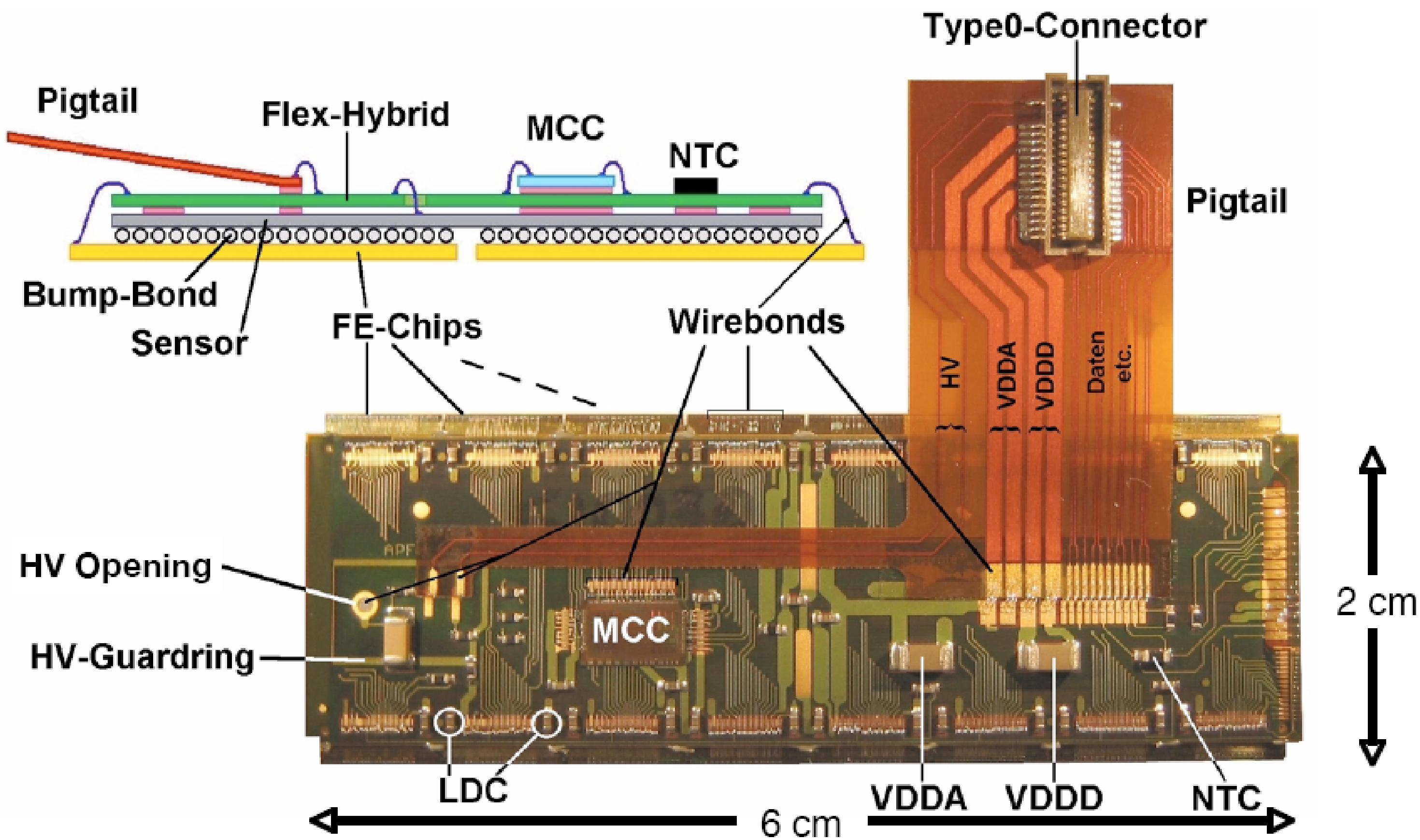
- Radiation hardness
  - sensor dose of 10^{15} neutron eq/cm^2
  - electronics 50 Mrad
- Technical Design Report specification
  - $r\varphi$ resolution of 13 μm
  - efficiency better than 97% at end of lifetime
  - provide modest resolution (6 bits) analog charge measurement (ToT)
- Given the 25 ns beam crossing rate at the LHC
  - must be able to assign each hit to the proper bunch crossing
  - must be able to store the hit information during the trigger latency time of ~100 beam crossings
- Advantages of a pixel detector
  - Pattern recognition due to very low occupancy
  - Low noise through reduced capacitance

Pixel detector



Pixel module

- Basic building block glued on a support/cooling structure
  - Sensor, 16 FE chips, controller chip, flex hybrid, services pigtail

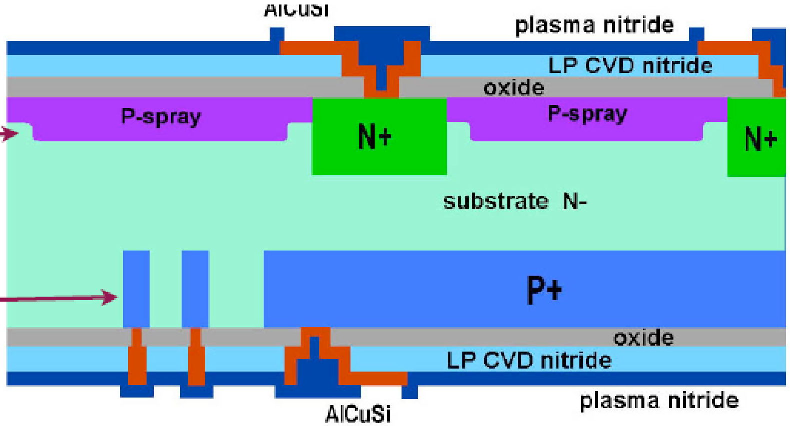


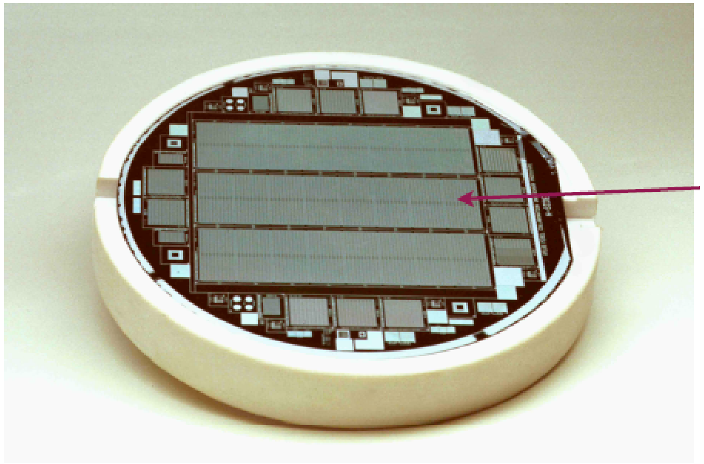
Sensor

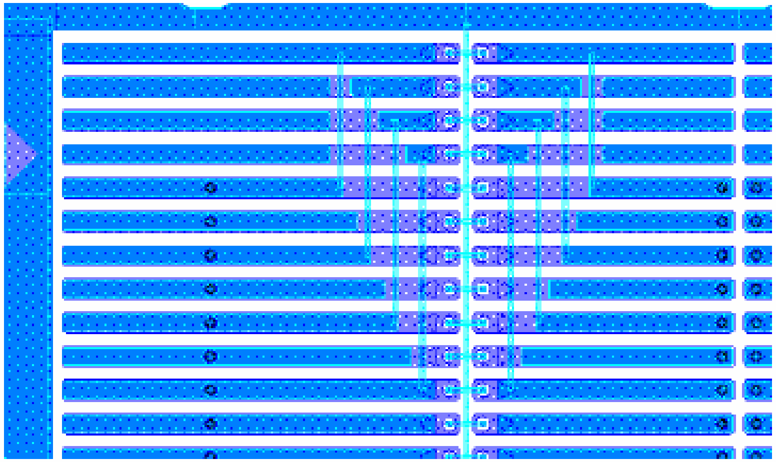
- Design driven by radiation hardness requirement
  - n^+ pixels in n-bulk (oxygenated Si) with moderate p-spray
  - 16.4 mm x 60.8 mm x 280μm , 46080 pixels (50x400 μm^2)

isolation of n+ implantations: moderated p-spray

multi guard ring on the p-side



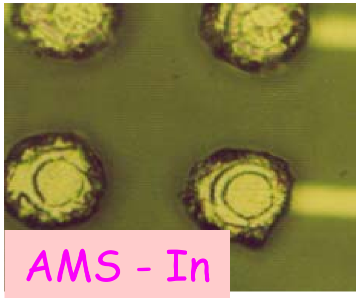


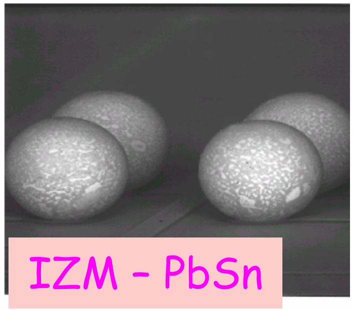


Special pixels in inter-chip region

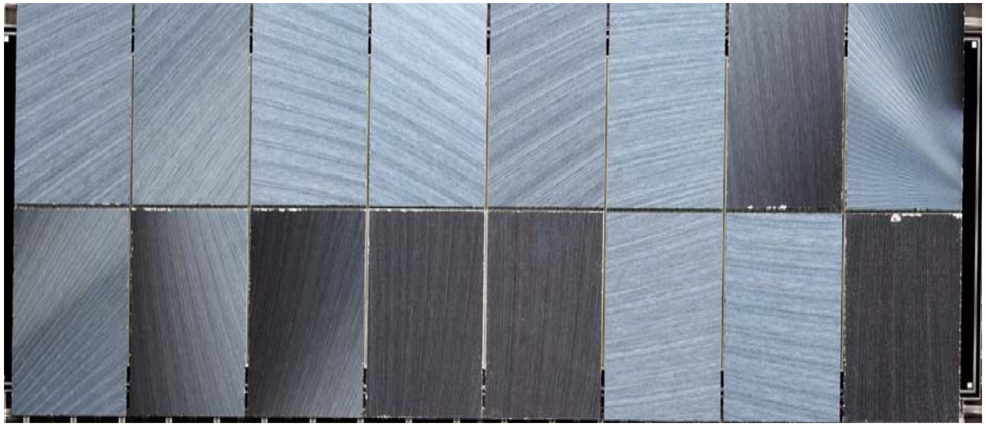
“long”,”ganged”

Bump bonding

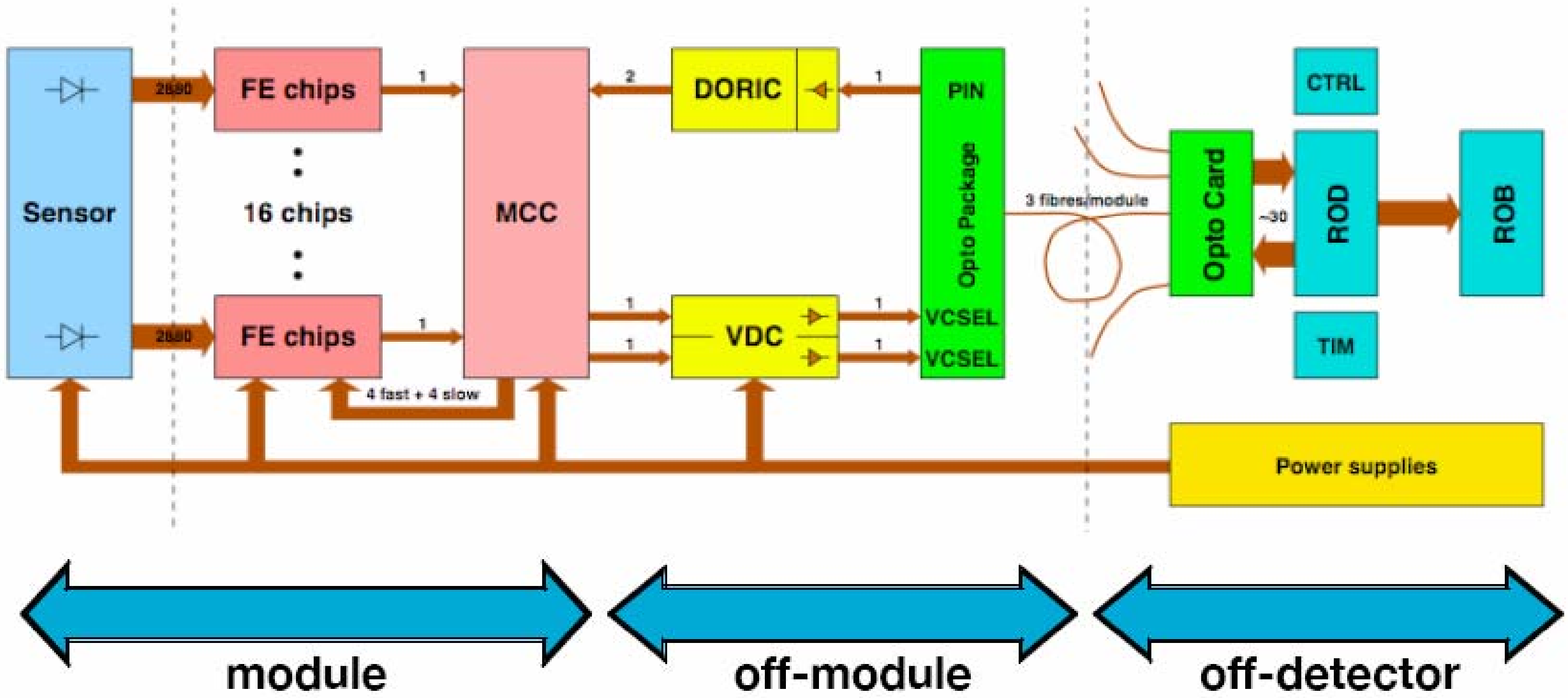




- Bump bonds connect FE pre-amplifier to sensor pixel
- Two techniques, from different manufacturers :
  - **In** bumps by Selex (ex Alenia-Marconi Systems), Rome
  - **PbSn** bumps by Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration, Berlin
- Bumping defects can be found before module assembly
  - production contract fixes a rejection at 0.3% faulty bumps
  - reworking techniques in place to recover FE
  - global yield after reworking is 94%



Read-out scheme



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	

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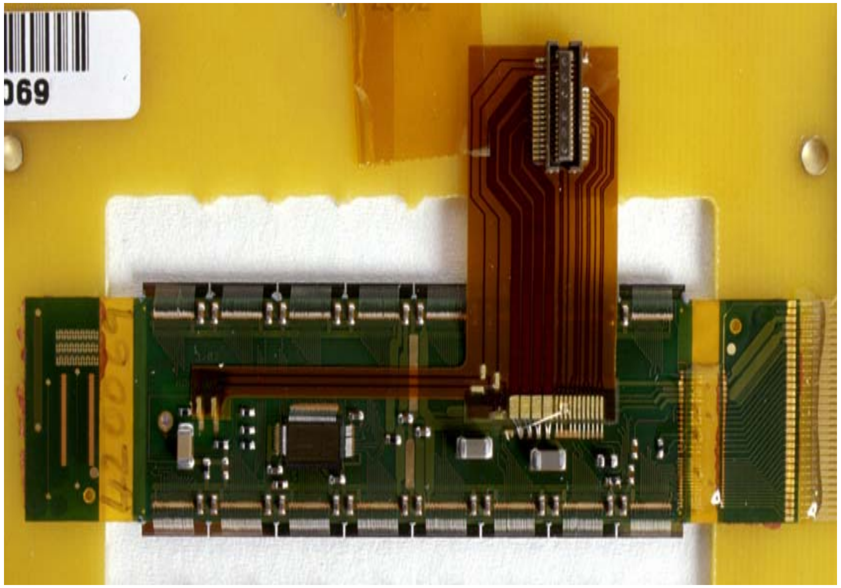
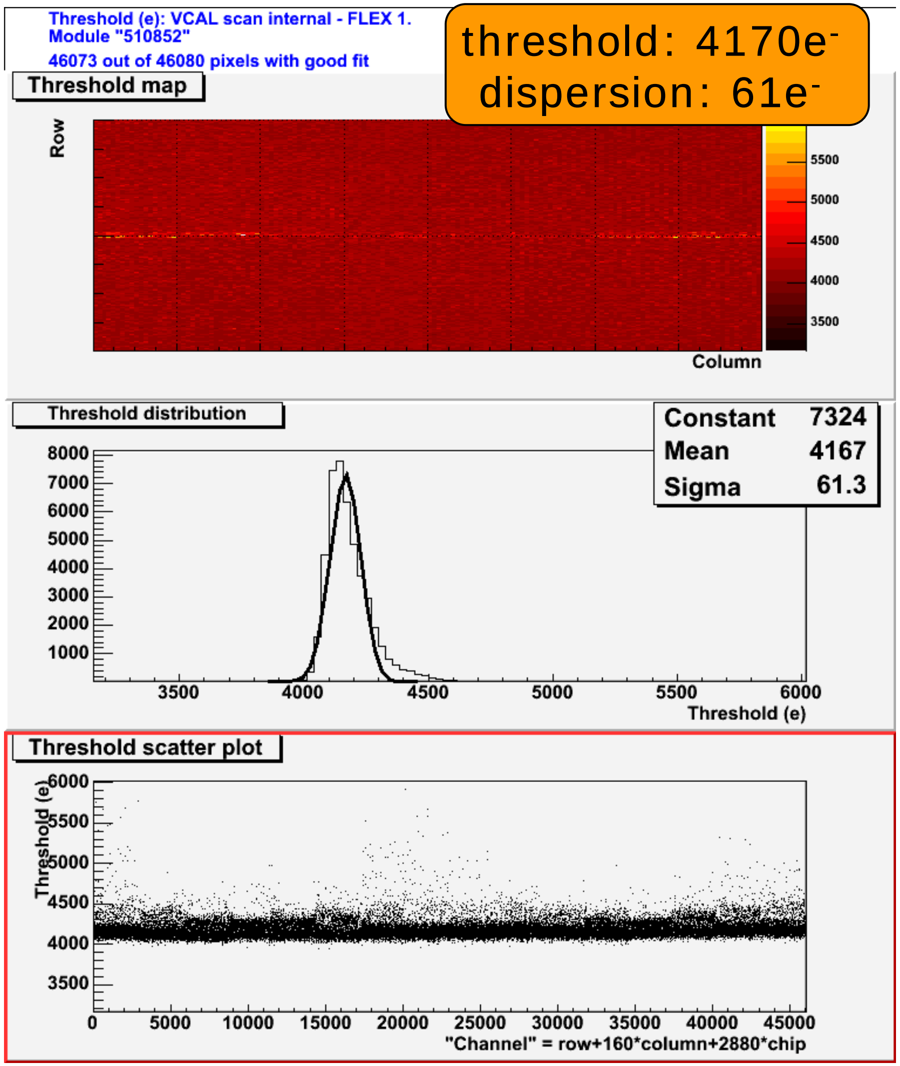
Module tests

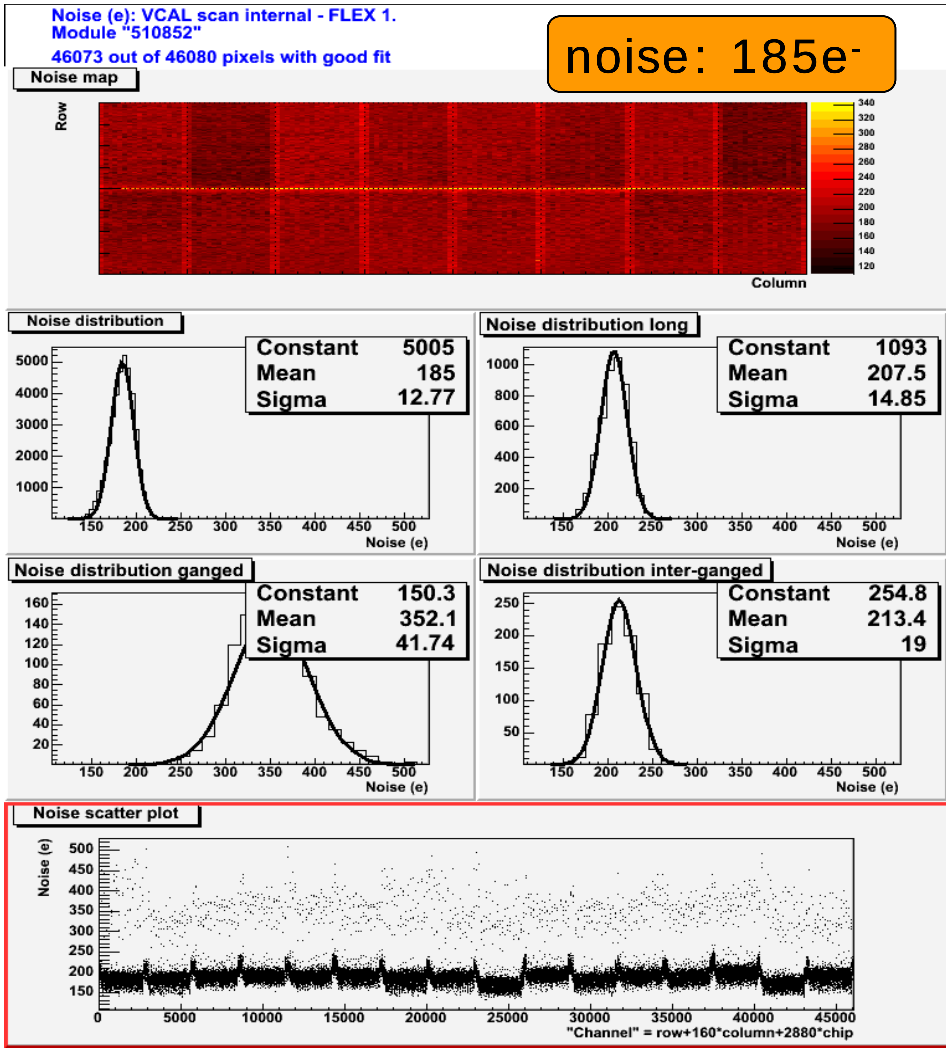
- After assembly each module is tested extensively
  - includes thermal cycling and tests at -10°C (operation temperature)



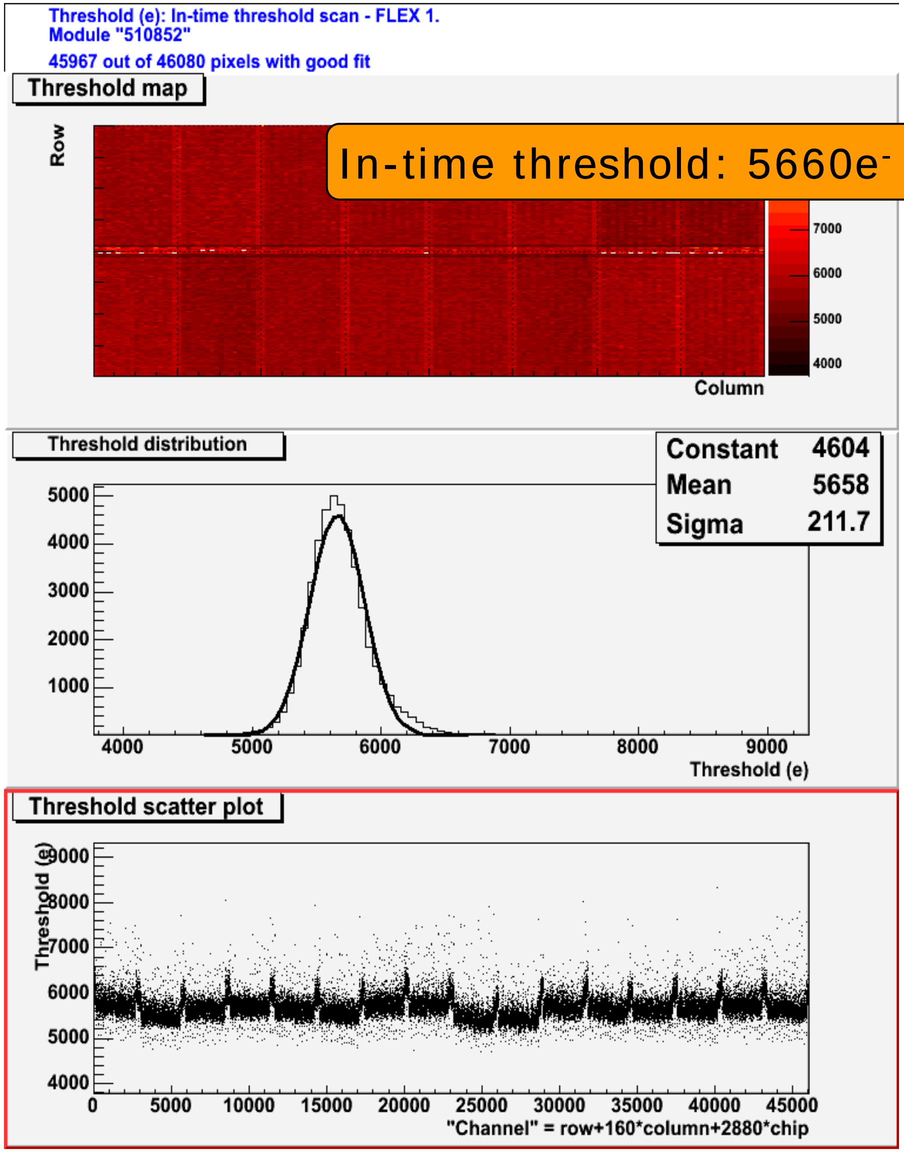
  - basic tests are
    - threshold and noise after threshold tuning
    - in-time threshold (charge which exceed the discriminator threshold within 20ns)
    - data taking with ^{241}Am: check if channels work, charge information obtained by time-over-threshold (ToT)

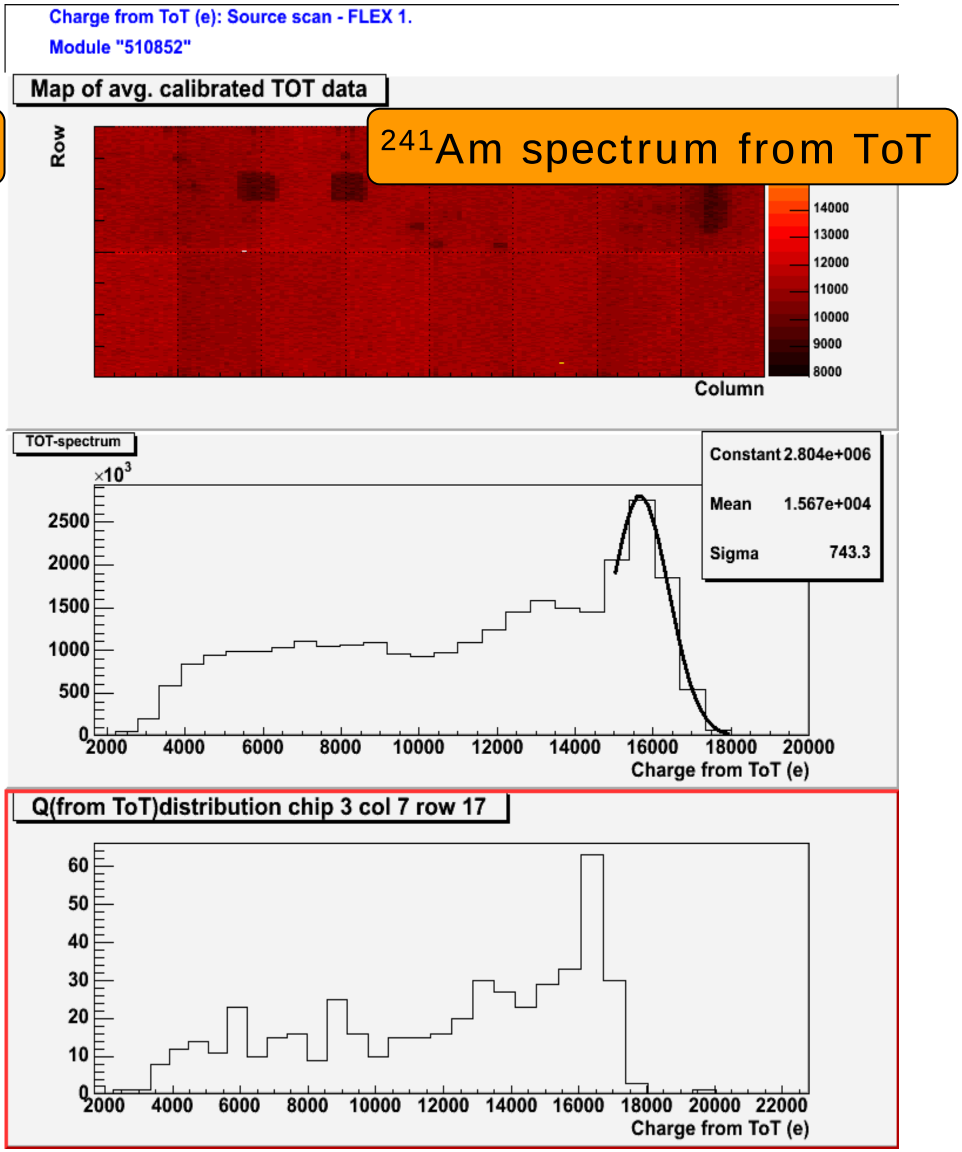
Lab measurements I





Lab measurements II

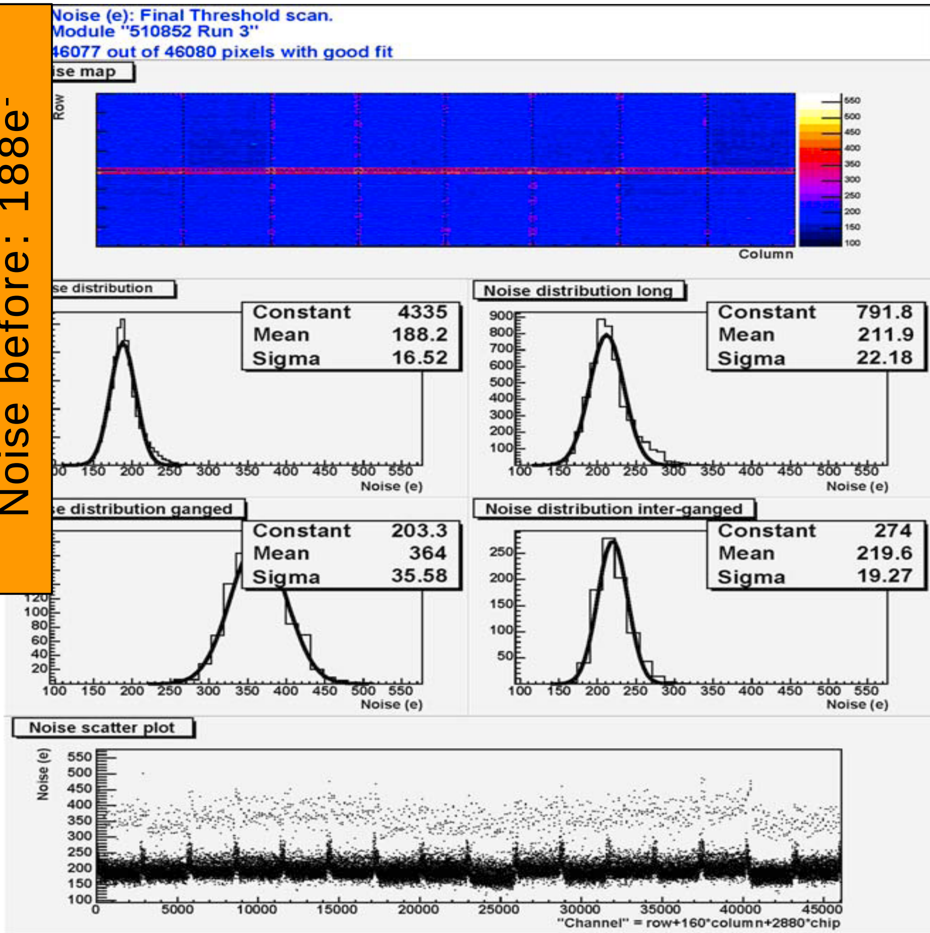




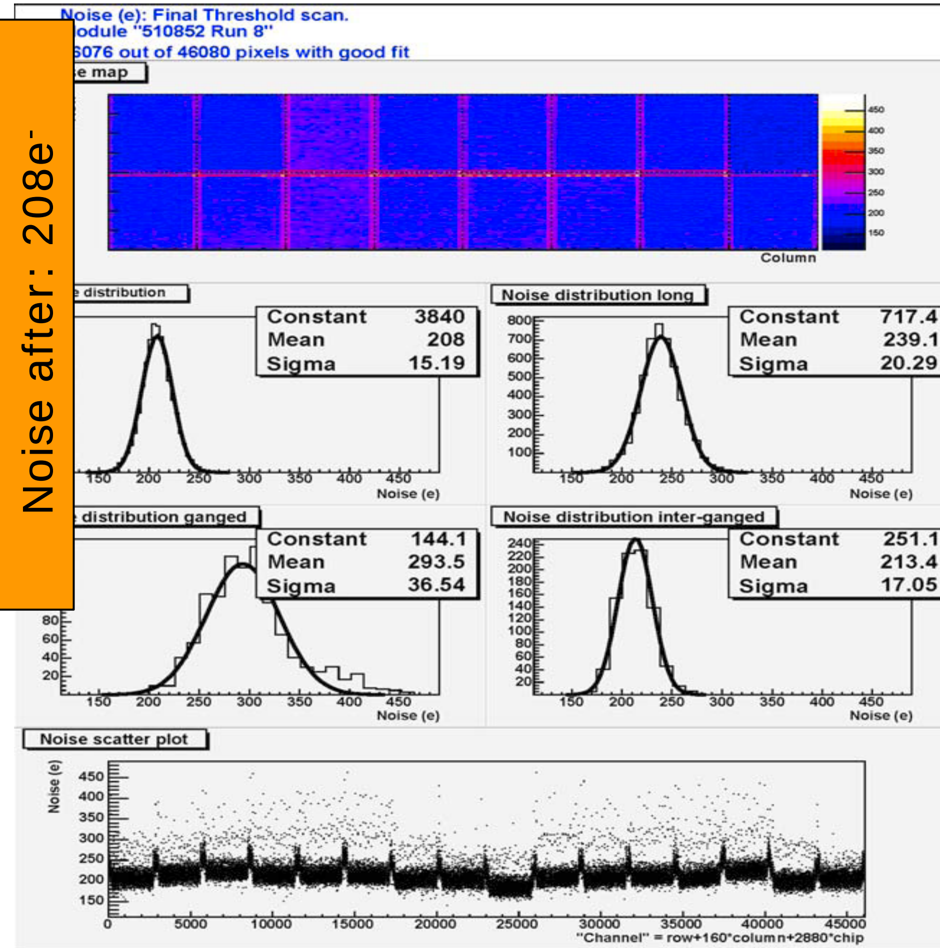
Tests after irradiation

Extensive radiation studies at CERN PS, irradiation of 7 production modules to ATLAS lifetime dose ($2x10^{15}$ p/cm^2 ≈ 50MRad).

Noise before: $188e^-$

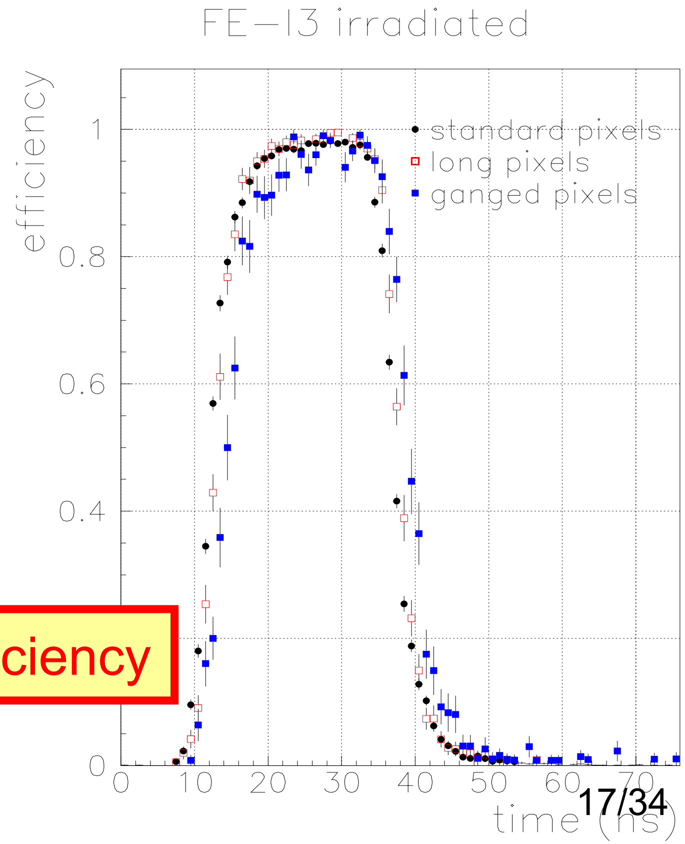


Noise after: $208e^-$



Test beam results

- Test beam 2004 to characterize production modules
- Radiation hardness
  - Sensors almost fully depleted after 3 yrs high lumi with 600V bias
  - Charge collection efficiency reduced to 80% (trapping)
  - Lorentz angle decreases with increasing bias voltage ($15^o \rightarrow 5^o$)

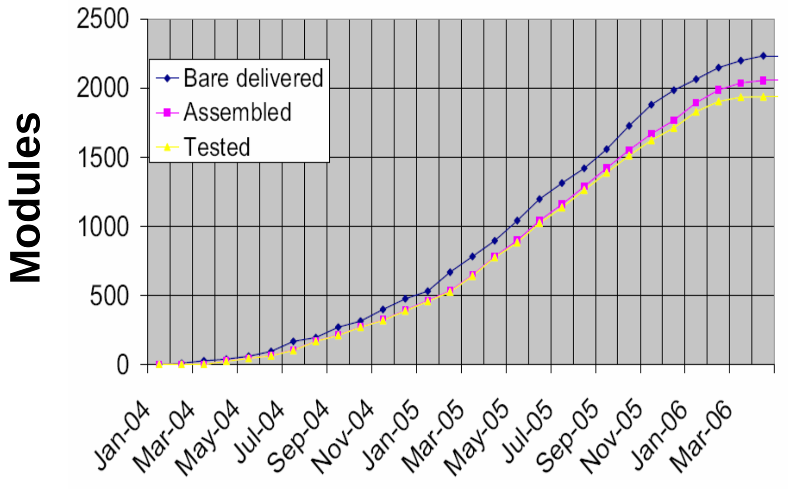


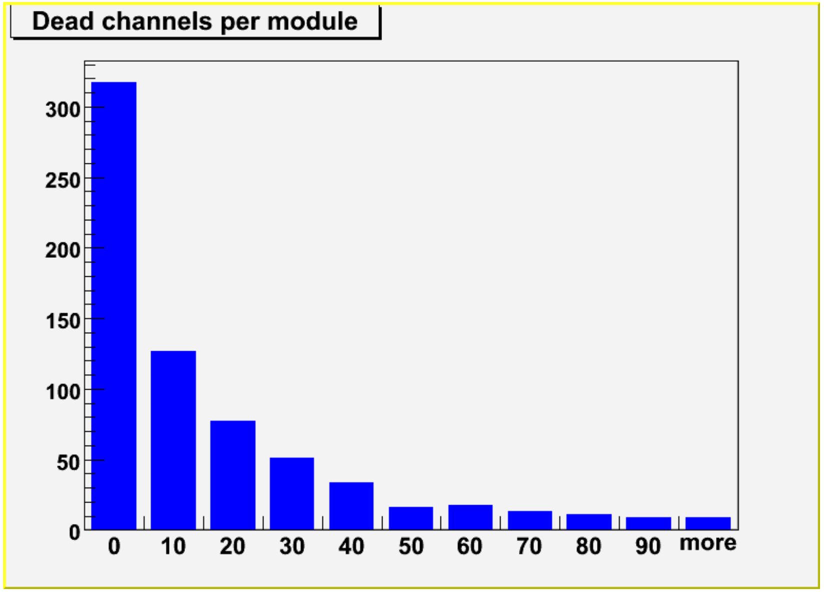
- Detector performance
  - In rφ direction 7μm (no irradiation) to 10 μm (after irradiation)
  - Efficiency: 99.9% → 98.2% after irradiation (at 500V)
  - Pixel geometry slightly affects efficiency
  - High rate tests passed

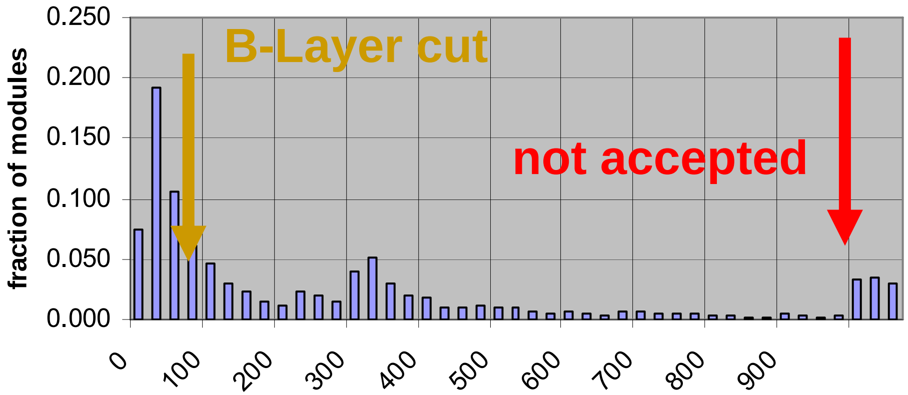
In-time efficiency

Module ranking

- All modules assembled and tested at production sites
  - 1744 needed for detector
  - Electrical tests establish ranking penalty



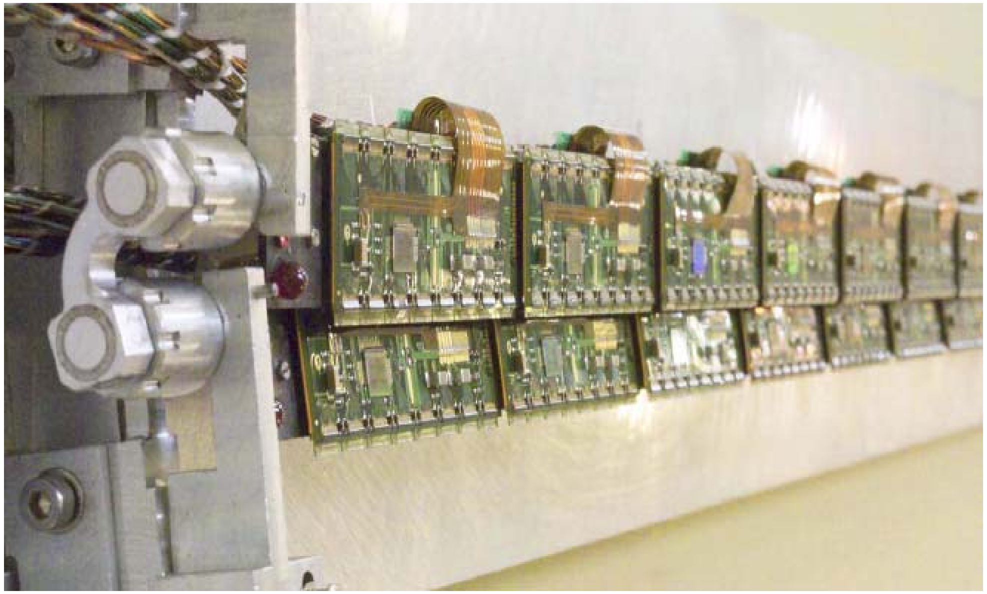


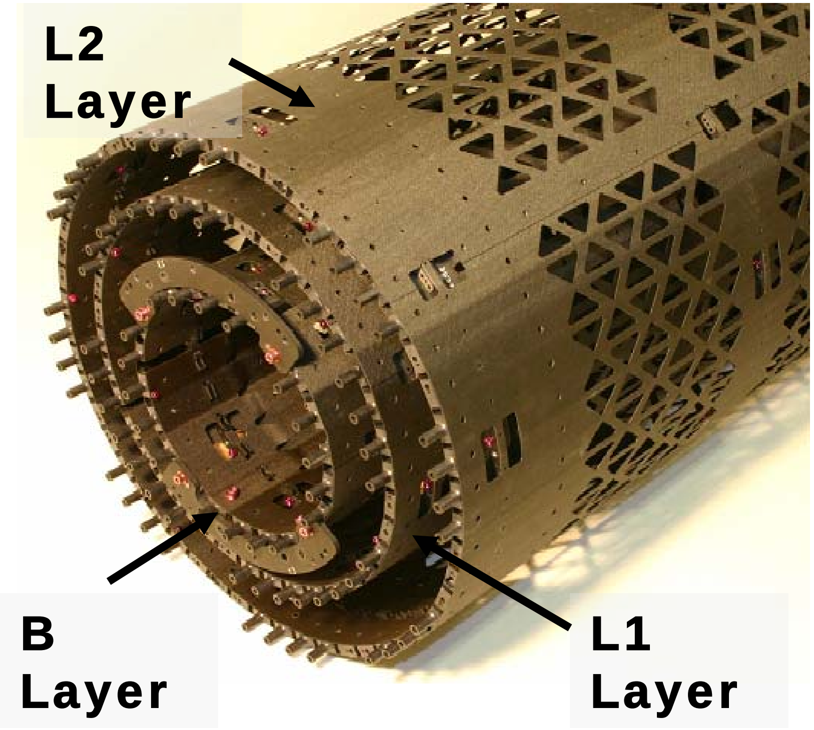


Excellent modules available for the critical innermost layer

Pixel Barrel

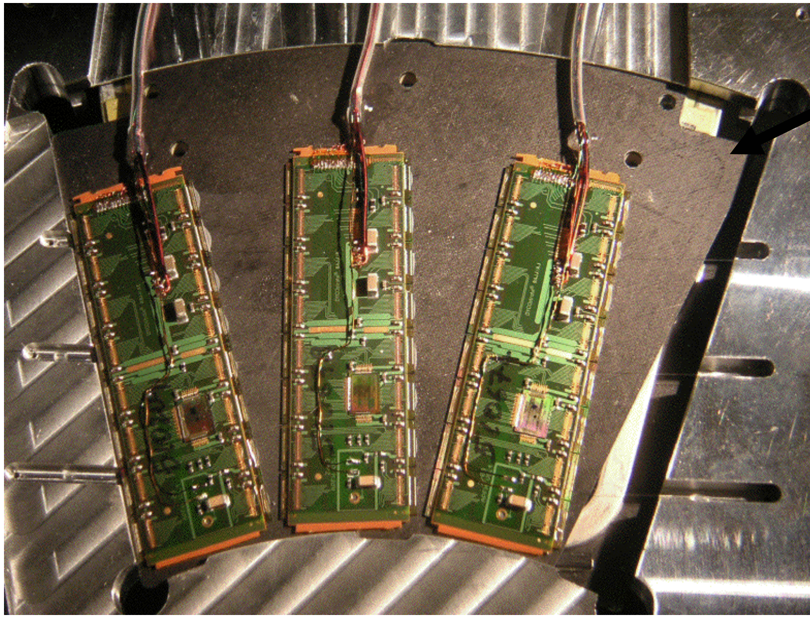
- Barrel composed of
  - barrel frame (carbon fiber laminate)
  - staves
    - 13 modules
    - Shingled carbon-carbon support
    - All identical (except cabling)



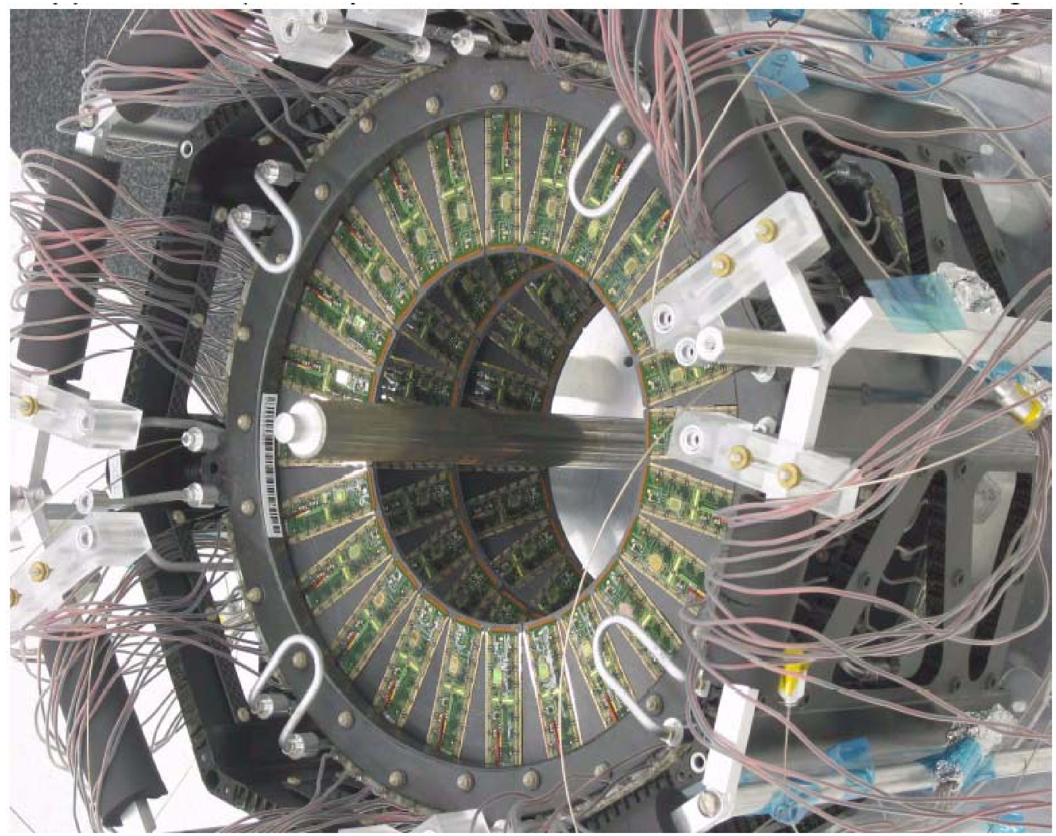


- For integration two staves are linked by a unique cooling tube (bi-stave)

Pixel End Cap



Sector assembly (1/8 of a disk):
6 modules are mounted on
carbon-carbon plates,
sandwiching the cooling pipe.



Assembled at LBL
and shipped to CERN
for integration

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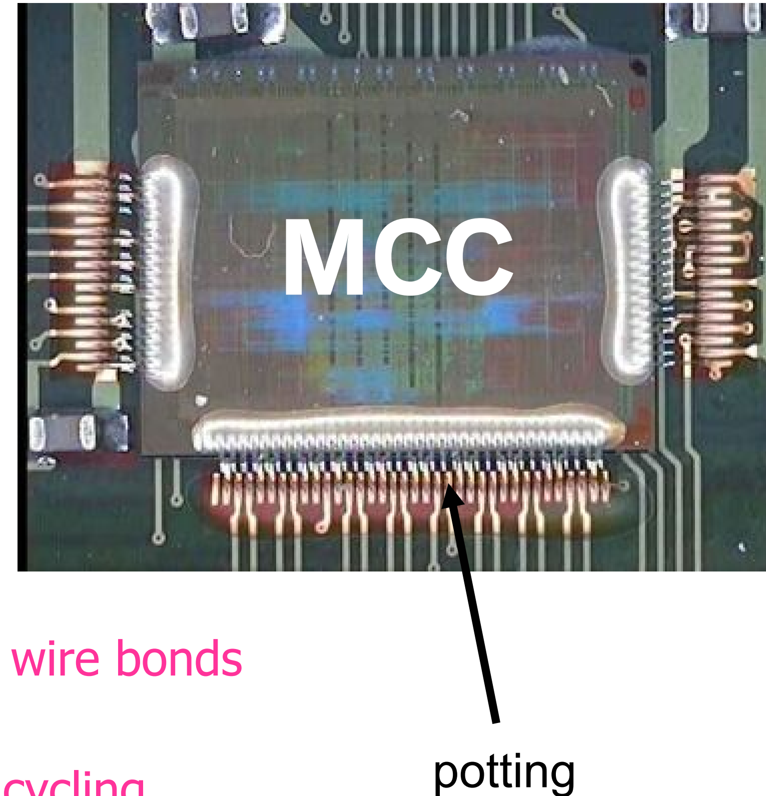
MCC Potting

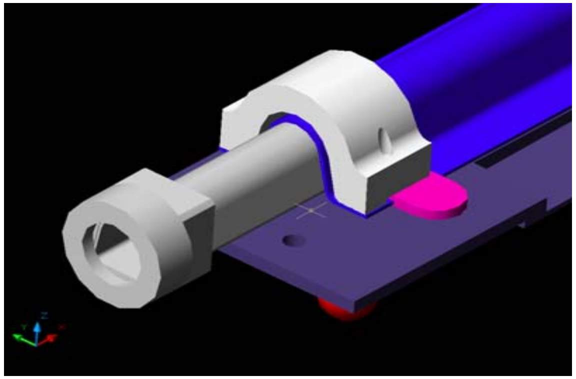
- Wirebonds on front-end chips are potted
  - avoid resonant breaking of wires
- Also MCC potted as handling precaution
- Problems appeared during "burn in"
  - infant mortality
  - 10 cycles [-30°C;+30°C]
  - Observed MCC potting detaching, breaking wire bonds
    - Related to geometry, component surface
  - No problem on FE chips after long thermal cycling
- Action: stop potting MCCs and repair
  - Anyway not critical
  - Remove potting and re-bond modules in Bonn

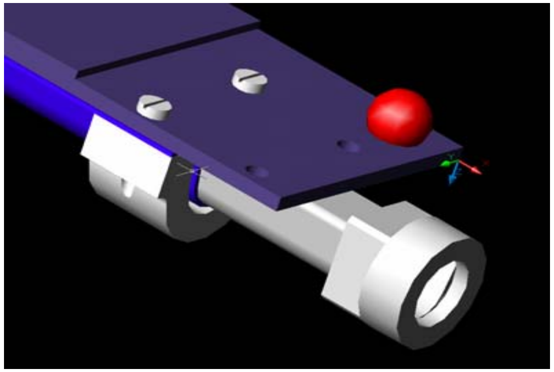


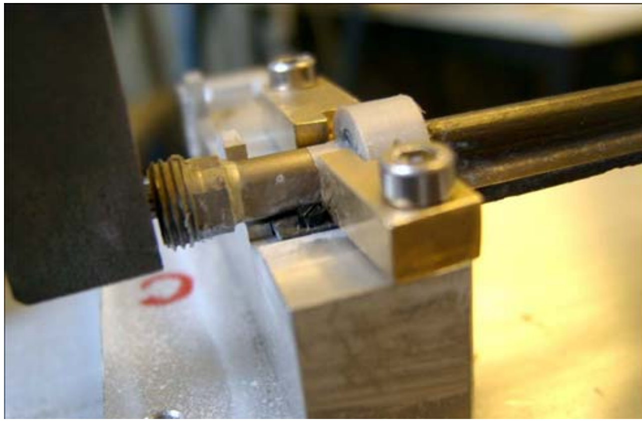
Stave delamination

- Delamination observed between CC Thermal Management Tile and Ω-shaped carbon fiber
  - Gluing scheme
  - Ω-shaped cooling tube favors delamination by deformation and torque
  - increase of thermal impedance between tube and pixel module

- Solution: reinforcement by adding a peek collar



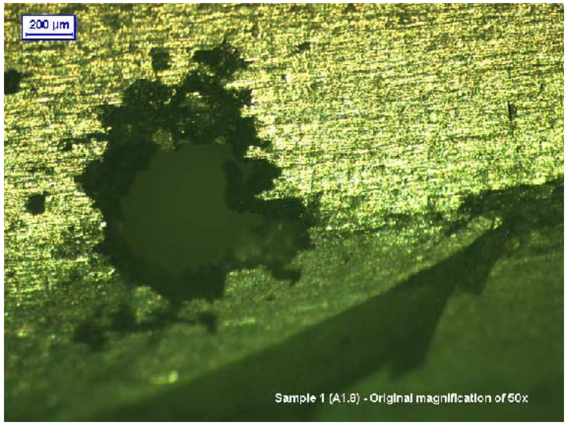




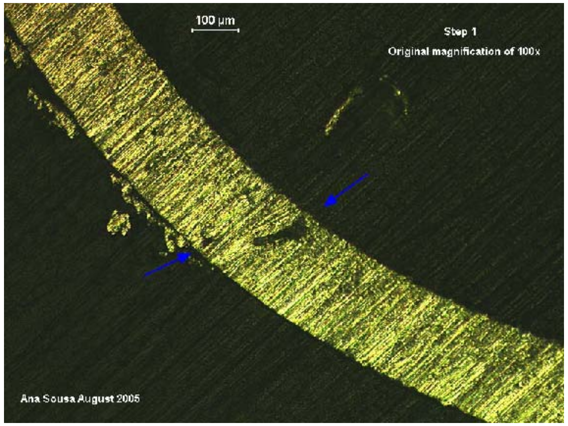
- Thermal performance is satisfactory after this modification

Pipe corrosion

- Serious concern (July 2005): corrosion of stave cooling pipes
  - Ni-Al galvanic pair and moisture
    - bare pipe material (Al)
    - Ni plating used to allow for brazing of the pipe fittings
    - no proper drying procedure → water
  - already ~15% of pipes leaky
  - experts consulted agreed on the need to change **<u>all</u>** the pipes

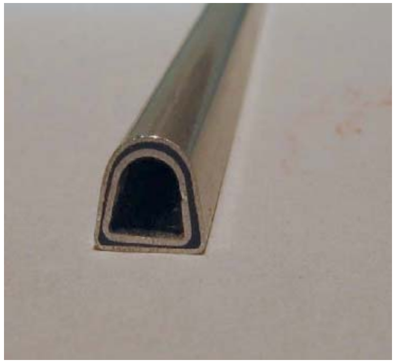


- Six months delay in schedule
  - repair the 43 (30%) loaded staves with a pipe-inside-the-pipe
  - production of new staves with new Al compound and laser welding
  - repair of bare staves (~100)



Insertion fix

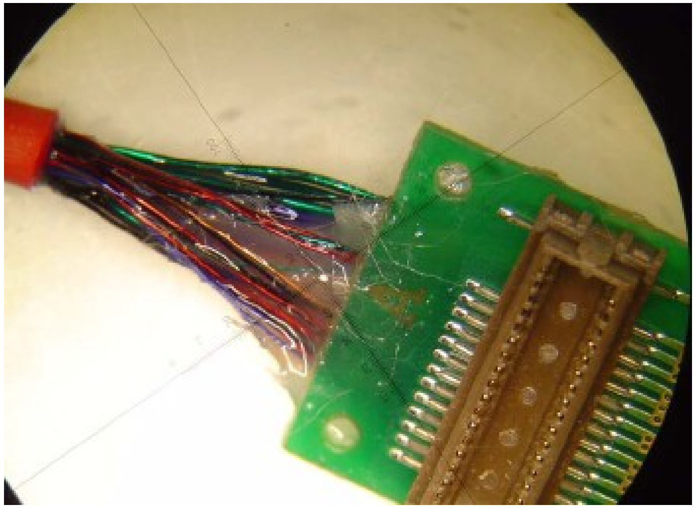
- Pipe insertion fix to avoid corrosion of inner pipe
  - D-shaped pipe inserted, stycast adhesive, fittings glued
  - additional thermal impedance (~10%)
  - smaller hydraulic diameter of cooling circuit
  - extensive studies performed



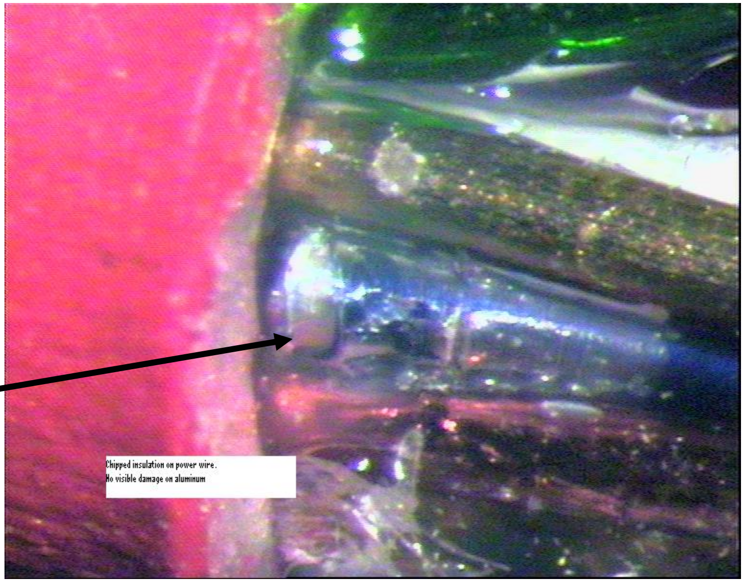
- Staves are paired (bi-staves) and served by one cooling circuit. Tests with evaporative cooling indicate that:
  - (1 repaired + 1 new) stave can be cooled when dissipating 190W, i.e. can reach end-of-lifetime
  - Only outer barrel layer consists of these kind of bi-staves (~half dose than intermediate layer).

The low mass cable problem

- Barrel aluminum signal and power cables
  - 100 μm wire for signal
  - 300 μm for power
  - 21 wires in a bundle
  - wire-bonded on a small PCB

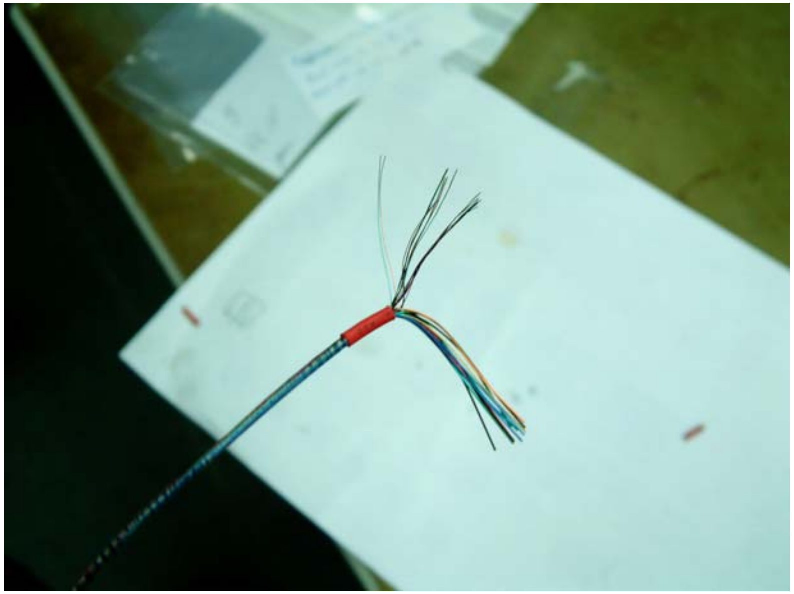


- Defective cables discovered during integration
  - cable stressed during manipulation?
    → strain relief
  - systematic check (visual inspection and electrical tests):
    ~50% of the 2000 cables affected
  - cracks in insulation
    cause signal wire breaking



Cable problem solution

- Production process in Taiwan inspected
  - Wires are bent and immersed in 400°C NaOH for stripping
  - Excessive bend and high T can damage the insulator



- Problem caused ~3 months delay in already dense schedule
- Procedure corrected: now cable yield ~90%
- Expect all cables produced by October 1st

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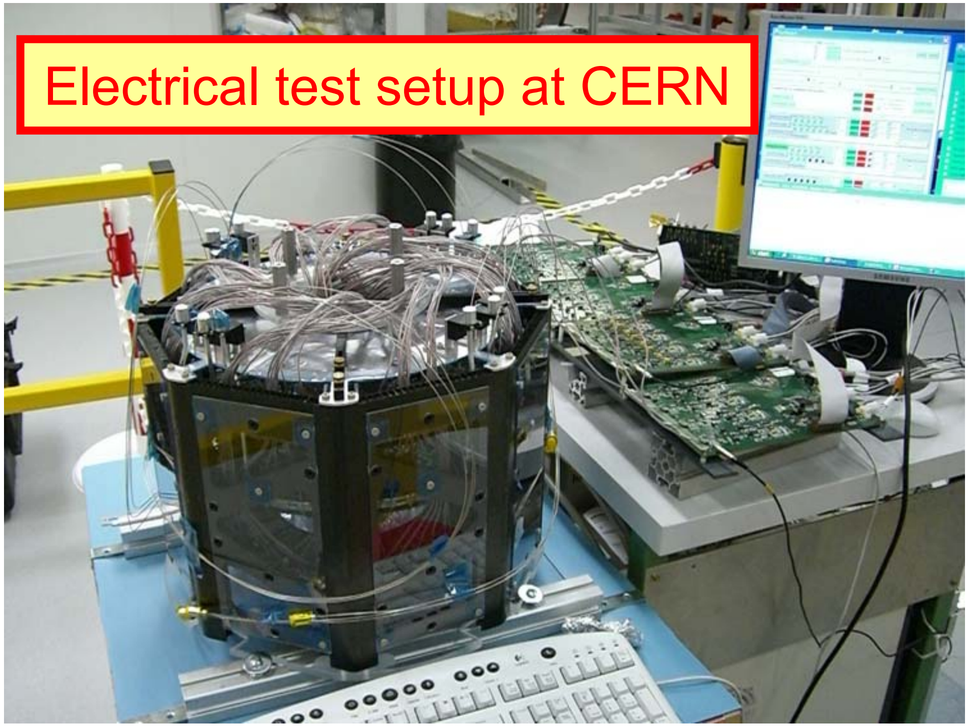
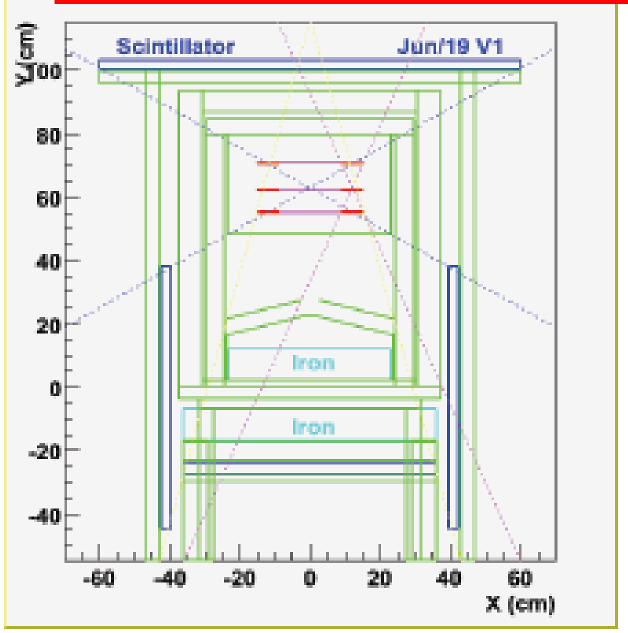
End cap status

- Both Pixel End Caps are not at CERN
  - Were fully assembled in LBL
  - dead channels at few per mil level
- Preparing for cosmic tests in November
  - test DAQ chain, services and software

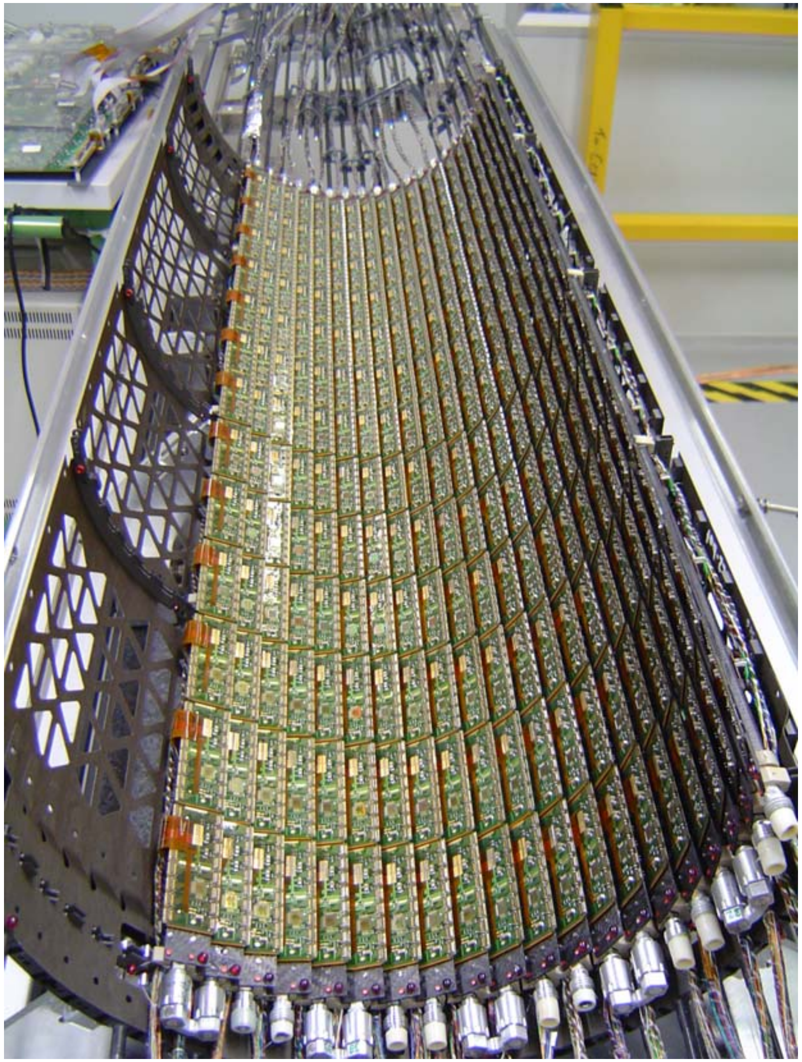

Transport box

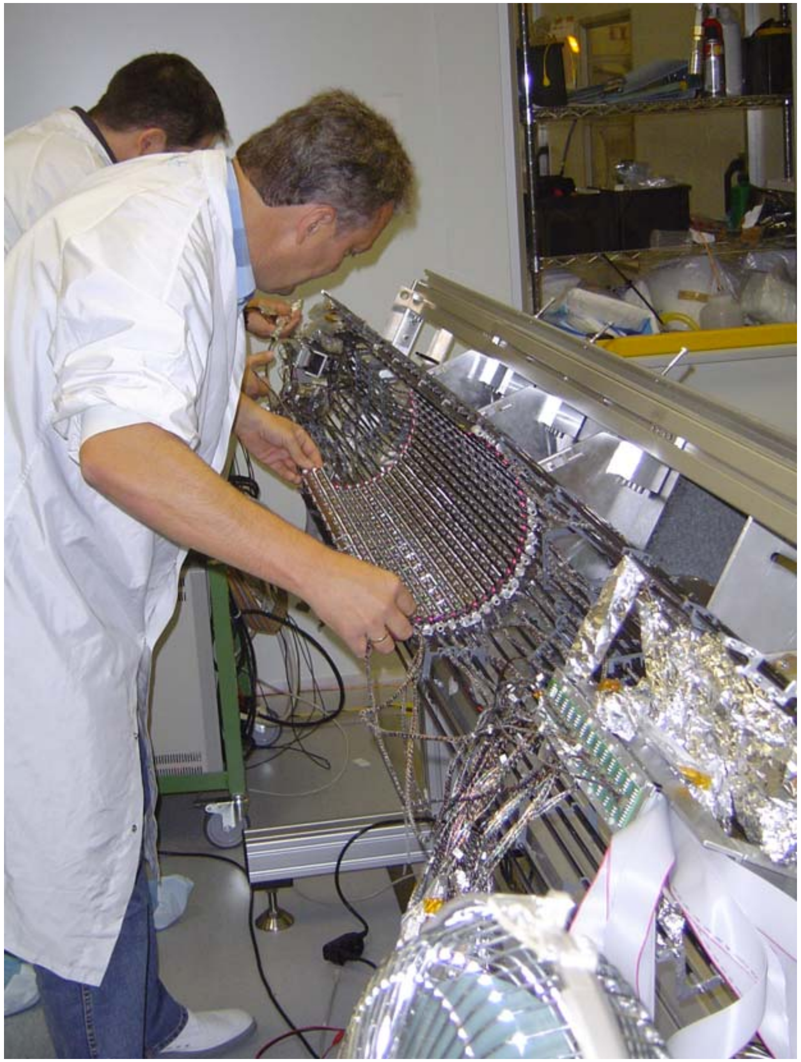

Electrical test setup at CERN

Planned cosmics stand


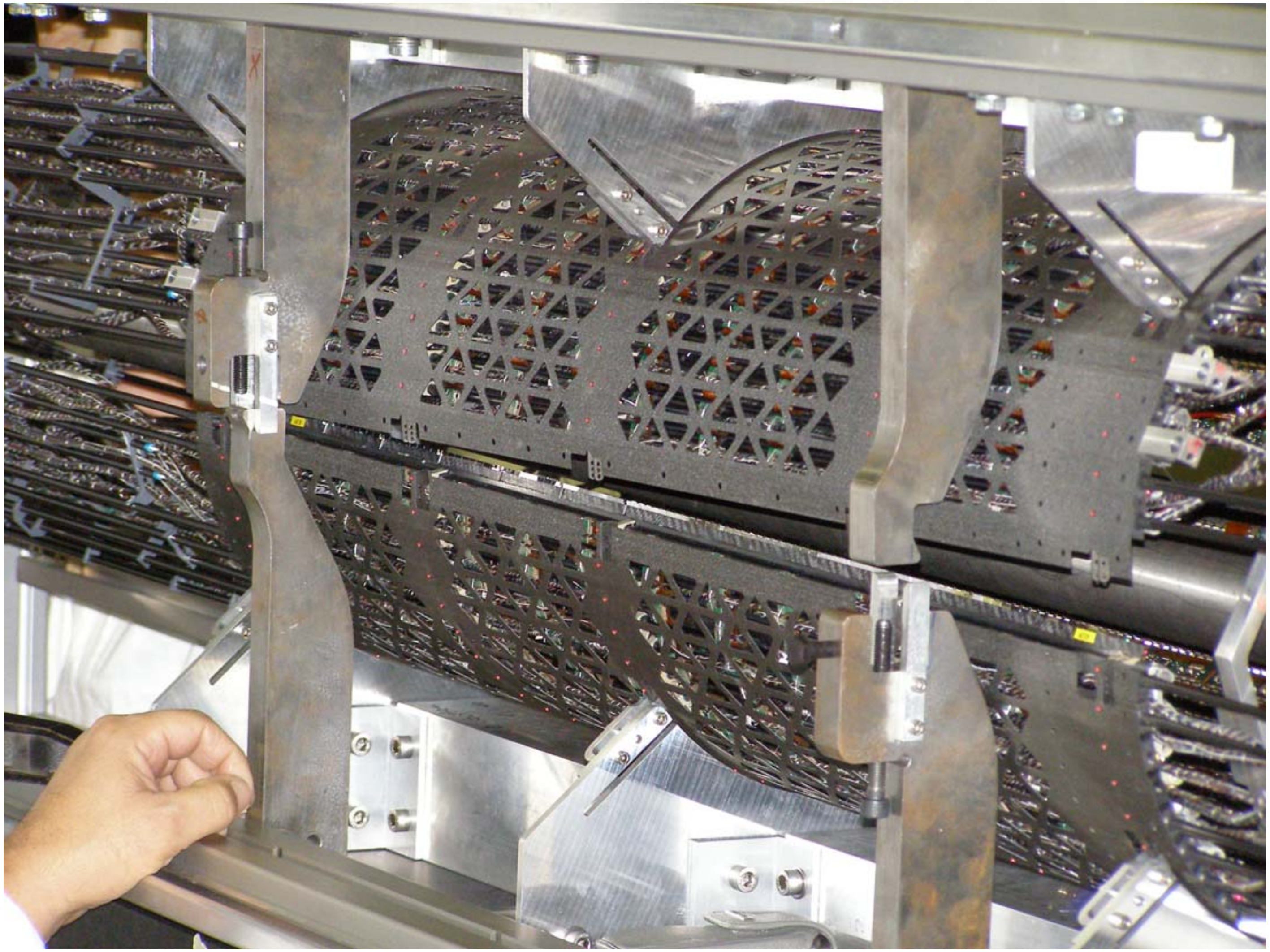
Barrel integration

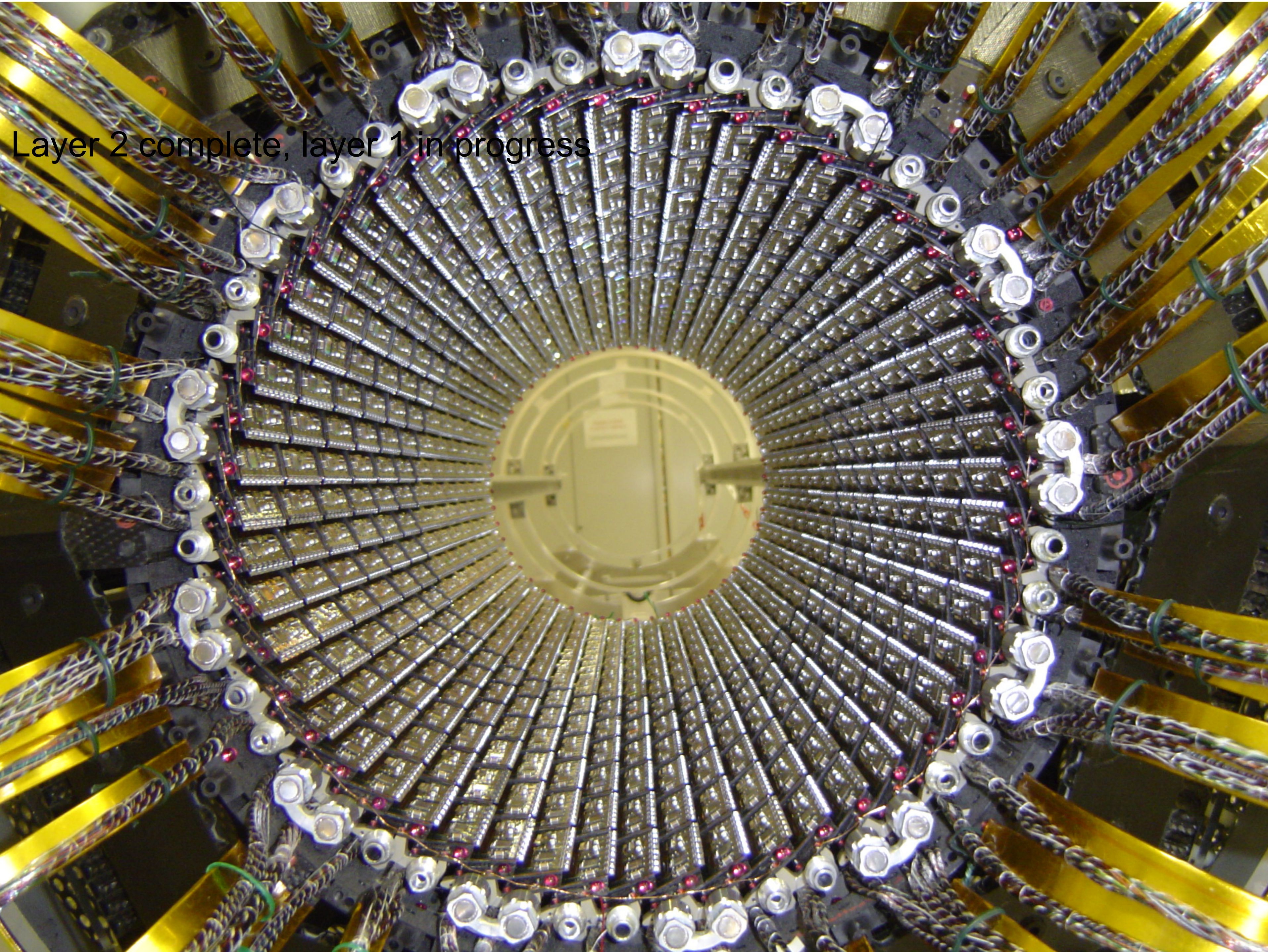
Layer 2 complete, layer 1 in progress





Barrel integration





Layer 2 complete, layer 1 in progress

Schedule

- Pixel detector is well on track !
  - end caps are at CERN ready to be integrated
  - Layer2 fully equipped and clamped

- Present schedule foresees pixel ready on April 1st (no joke!)
  - Layer1 6 staves to go, clamping beginning of November
  - B-Layer clamping end of November

ATLAS will have a complete 3 hit pixel system, when recording the first LHC collisions

Summary

- After ~10years R&D the ATLAS pixel detector is nearly completed
- Test beam results and an extensive QC program makes us confident that the system will perform within specs

- A number of problems were tackled in a collaboration wide effort and solutions appear adequate
- Pixel will be integrated into ATLAS this April