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Design and Production of the LHCb Silicon Tracker

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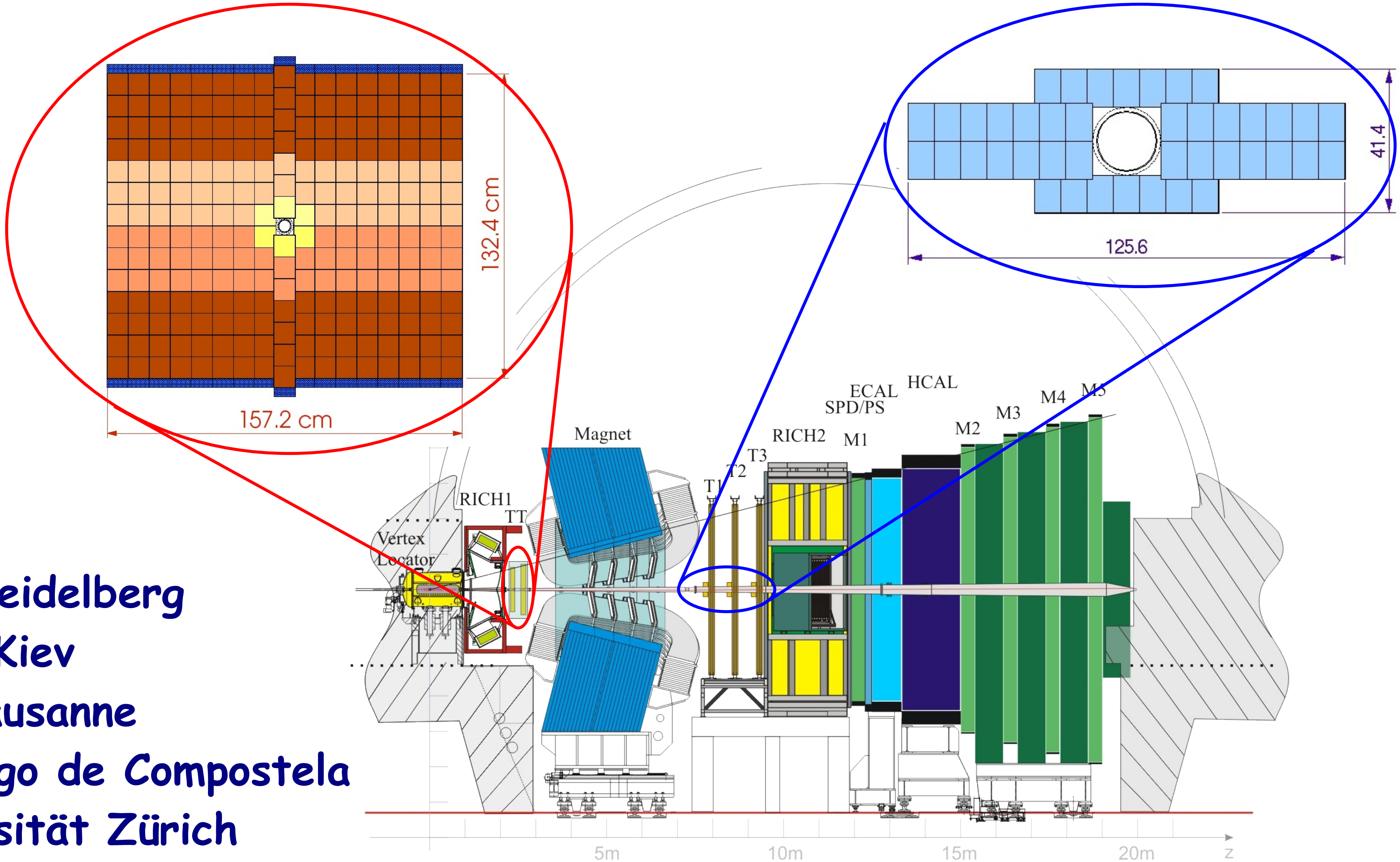
LHCb Silicon Tracker

Trigger Tracker (TT)

Inner Tracker (IT 1-3)



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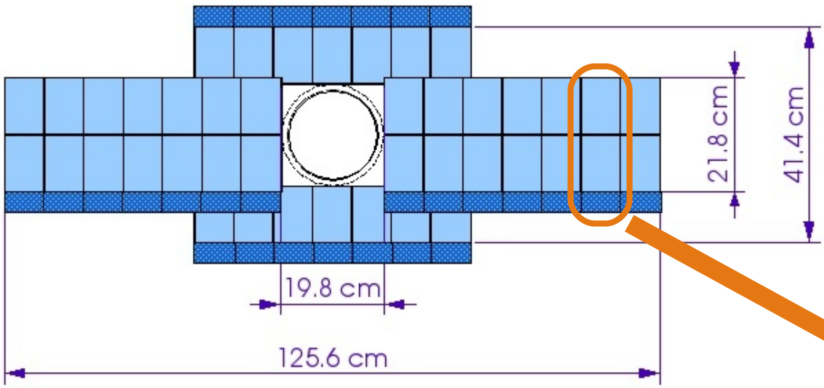
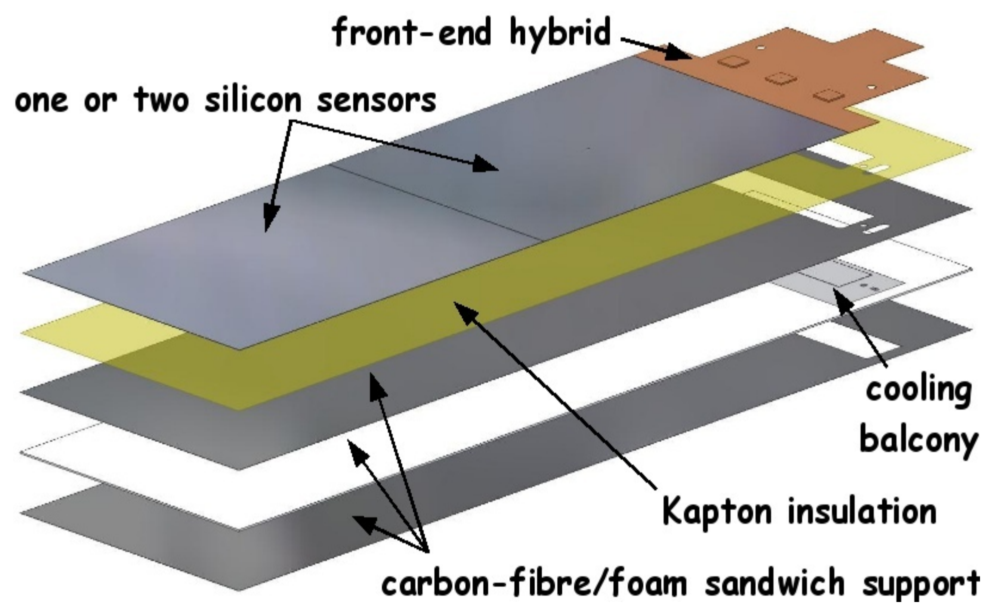
Inner Tracker



Three stations with four layers each:

- 1-sensor ladders above/below beam pipe
- 2-sensor ladders left/right of beam pipe

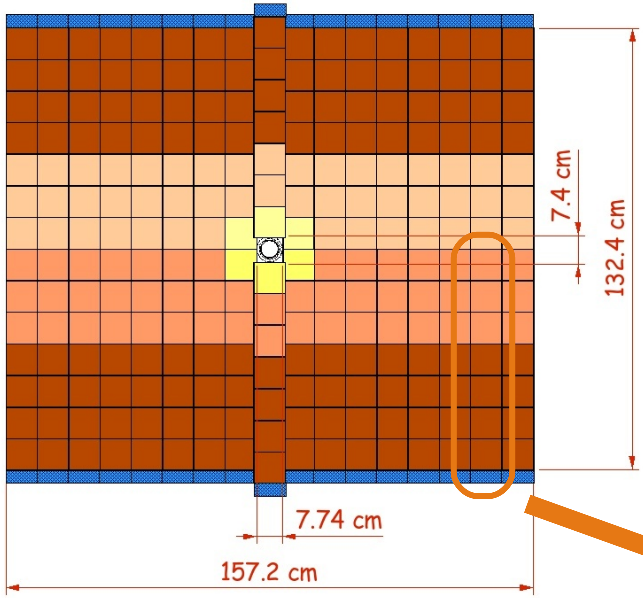


Main concerns in design phase:

- material budget
  - sensors as thin as possible
    320 μm for 1-sensor ladders
    410 μm for 2-sensor ladders
  - supports / cooling etc.
- cost (number of r/o channels)
  - large pitch (197 μm)

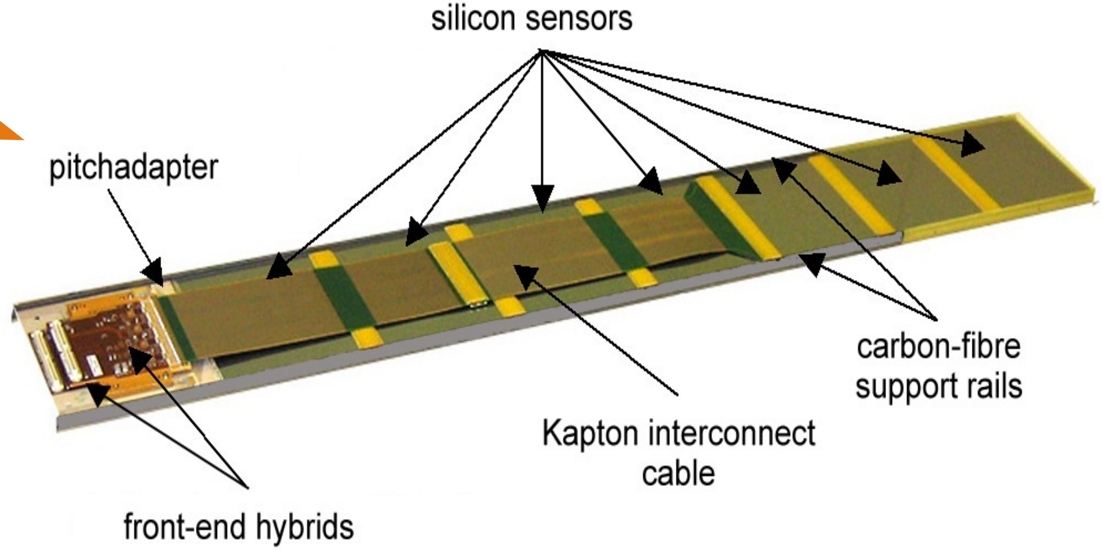
~ 4.2 m², 504 silicon sensors,
336 modules, 130k readout strips

Trigger Tracker



<u>One station with four detection layers</u>:

- 7-sensor long modules
- up to 4-sensor long readout sectors
- all r/o hybrids at one end of the module
- “inner” r/o sectors: Kapton interconnects



<u>Main concerns in design phase</u>:

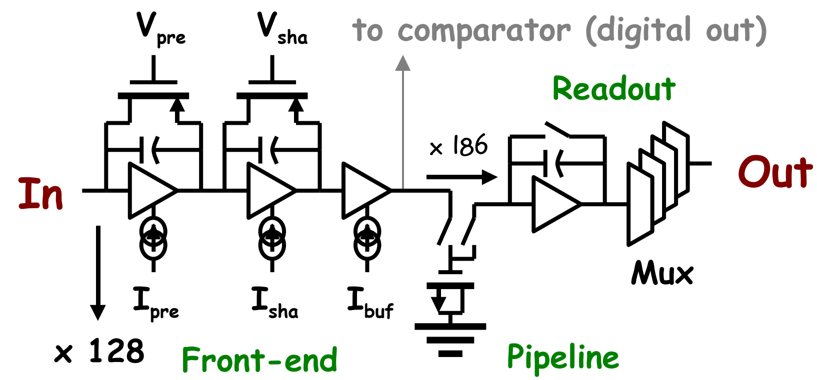
- material budget:
  - r/o hybrids outside acceptance
- cost (number of r/o channels)
  - large pitch (183 μm)
  - long strips (up to 37 cm)
- S/N for very long readout strips

~ 8.2 m^2, 896 silicon sensors,
280 r/o sectors, 143k r/o strips

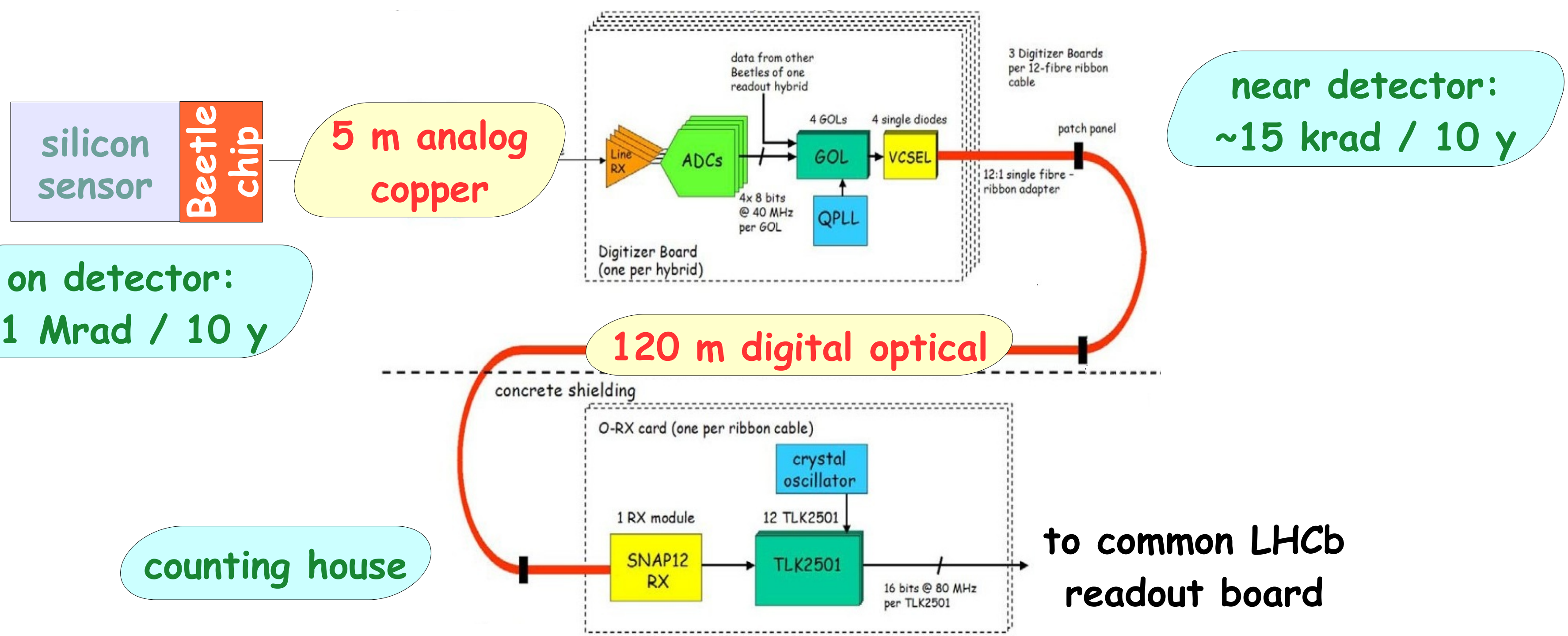
Silicon Tracker Readout

"Beetle" front-end readout chip:

- radiation-hard design in 0.25 μm CMOS
- analog pipeline, multiplexed analog readout
- adjustable shaping time of ~ 25 ns



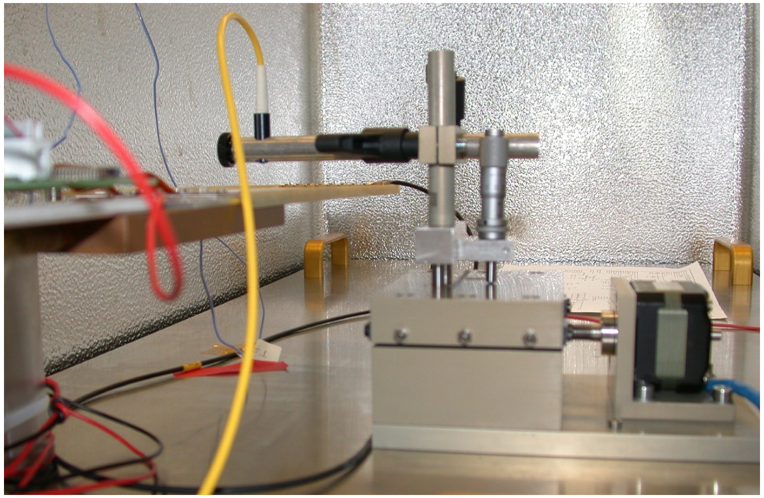
Digital optical readout link:



Detector R&D

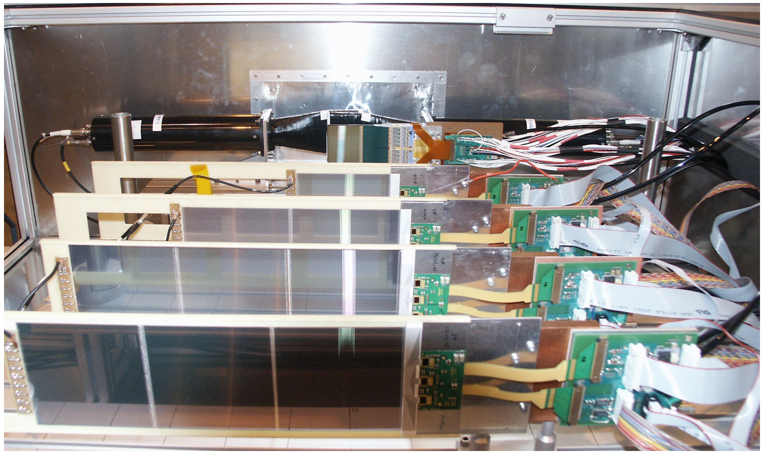
Main concerns:

- required sensor thickness for Inner Tracker
- S/N for long r/o strips of Trigger Tracker
  (37 cm long strips read out at 25 ns !)
- signal integrity for readout sectors
  with Kapton interconnect



Various prototypes tested:

- different sensor thicknesses, strip lengths,
  strip geometries (pitch, implant width)
- with and without Kapton interconnects
- all read out with Beetle front-end chip
- test beams and IR-laser test stand



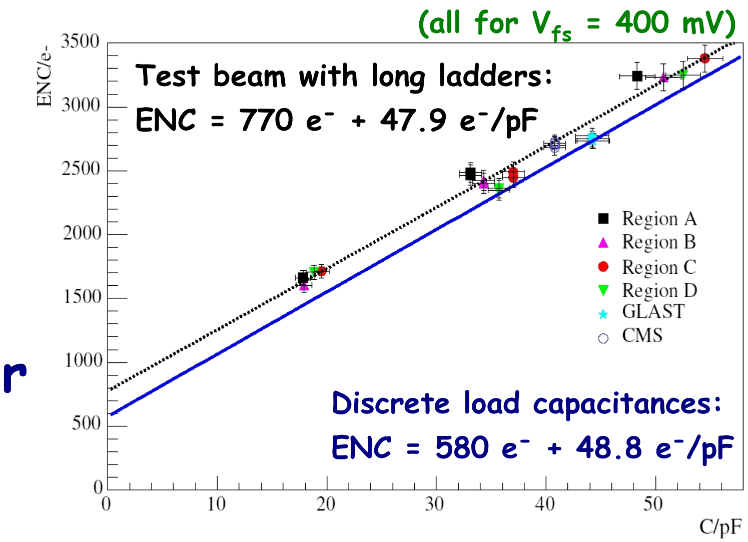
Main Findings from R&D

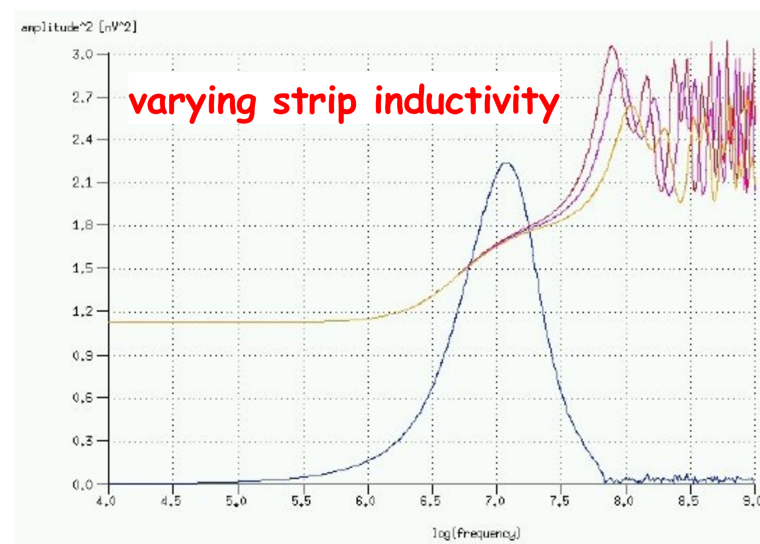
Noise proportional to detector capacitance:

- observed no significant noise contribution from strip resistance (up to 33 cm strip length)
- confirmed by SPICE simulation of r/o strips (as LCR network) and Beetle front-end amplifier
- careful: convolution of detector noise spectrum with frequency response function of amplifier

-> do not use simple recipes

to estimate this noise contribution





Also: no deterioration of signal integrity due to the Kapton interconnects

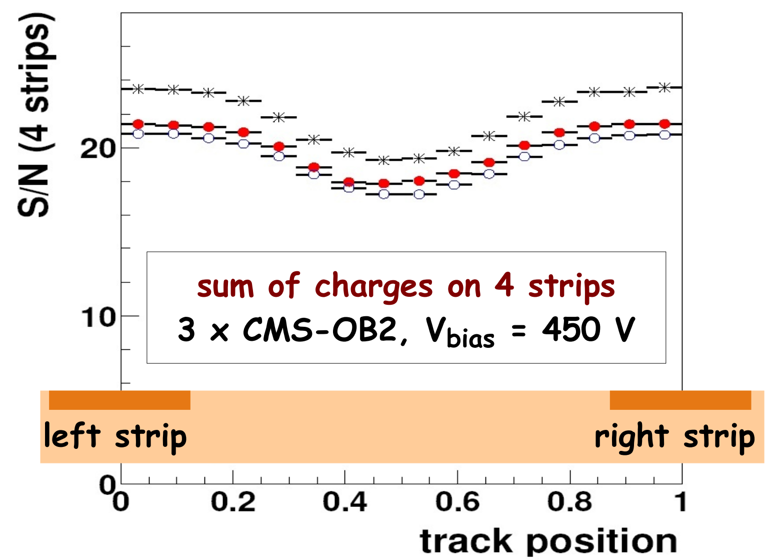
- behave just as an additional capacitive load
- again, confirmed in the SPICE simulation

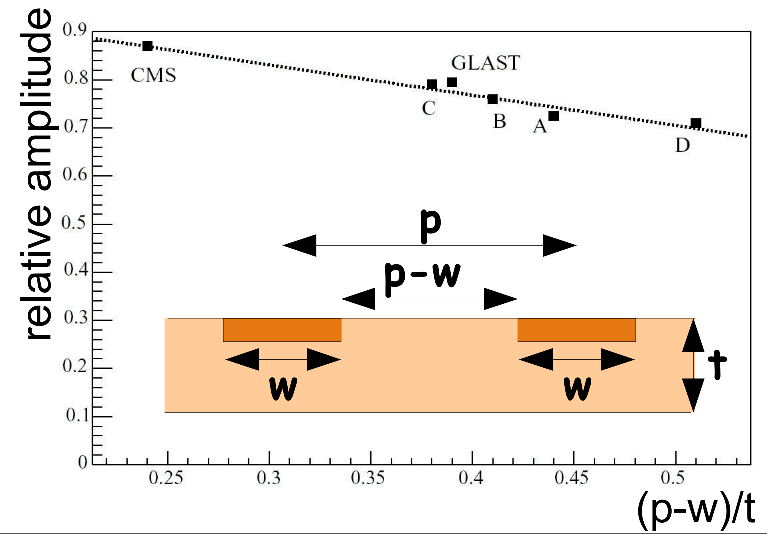
Main Findings from R&D

Significant loss of CCE in between readout strips:

- observed on all tested detectors
- not an artefact from clustering
- size of charge loss is independent of strip length, overbiasing, shaping time
- but seems to depend roughly linearly on the ratio (pitch-width) / thickness
- attributed to charge trapping at silicon bulk – oxide interface in between the strip implants
- unfortunately never found the time to do a proper simulation ...

sensor thicknesses chosen such that S/N > 12 in between strips

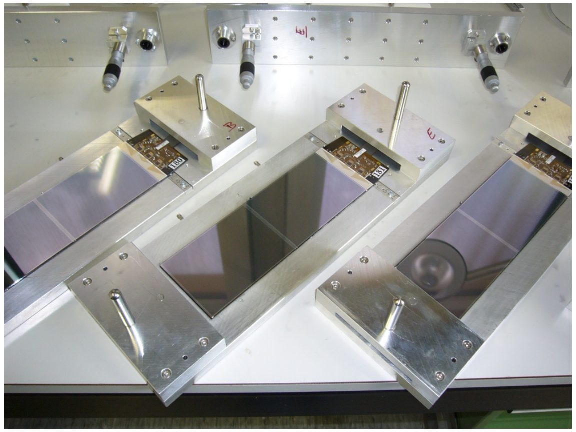


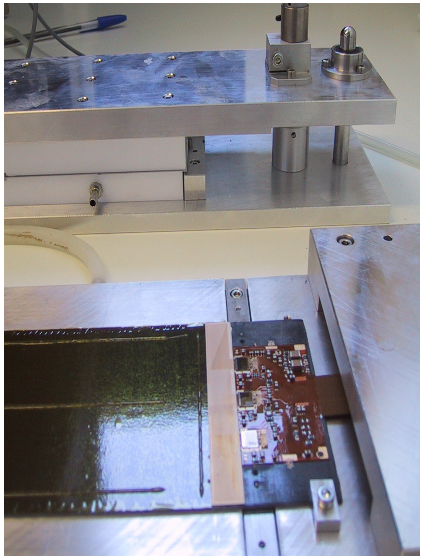


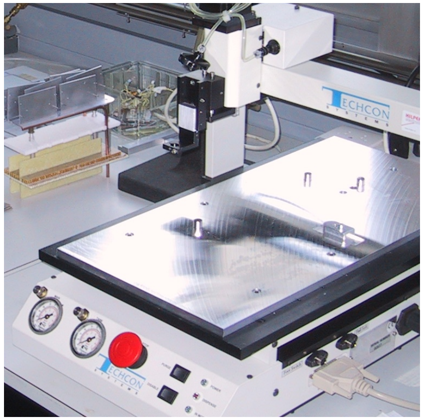
IT Module Production

Main production steps:

- position hybrid & pitch adaptor, glue them onto the sandwich support
- r/o functionality test
- position and glue silicon sensor(s)
- measure sensor alignment
- bond hybrid and pitch adaptor, bond bias and GND to the sensor(s)
- r/o functionality and HV test
- bond all readout strips
- 48h burn-in test:
  - 34 temperature cycles between +40°C and -5°C
  - detectors continuously biased at 500 V
  - readout tests at different temperatures



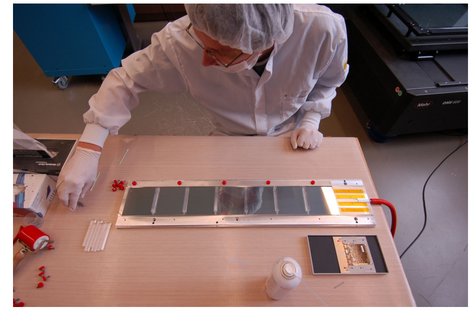


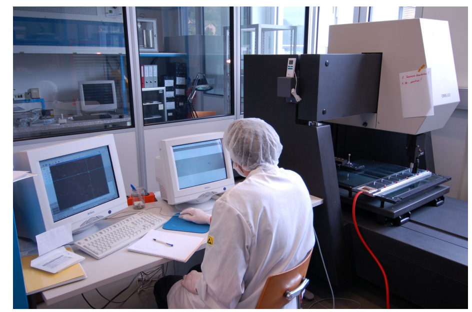


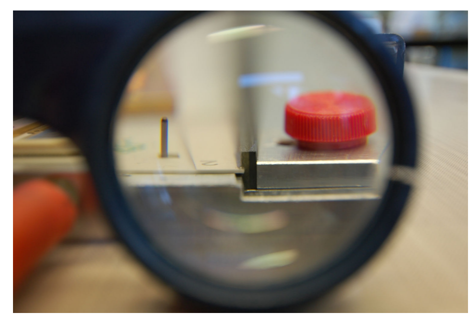
Trigger Tracker Production

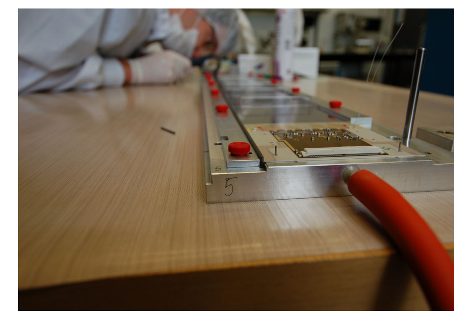
"Stage I" production steps:

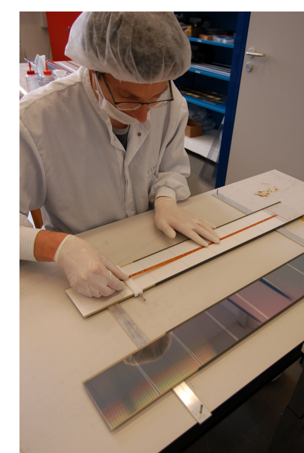
- place seven sensors and lower hybrid (use sensor edges for positioning)
- measure and correct alignment (CMM)
- glue support rails along the edges
- measure final sensor alignment
- glue bias voltage cable along back of module, connect GND and bias voltage (soldering / bonding)
- bond sensors and pitch adaptor
- 36 h burn-in test:
  - several temperature cycles between 25°C and 5°C
  - detectors biased at 500 V, currents monitored
  - IV curves and readout tests at different temperatures











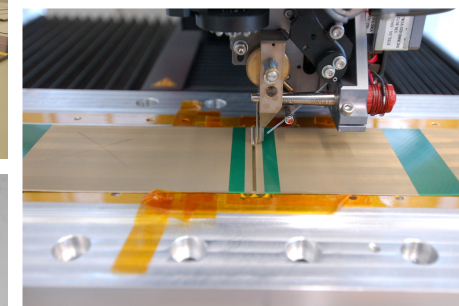
Trigger Tracker Production

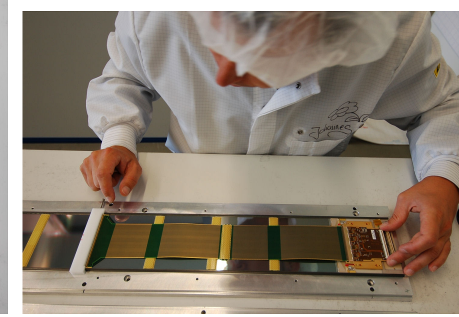
"Stage II" production steps:

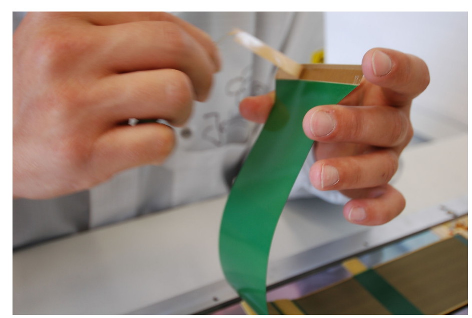
- glue Kevlar protection caps over bonds
- assemble, bond and mount Kapton interconnect cable and upper hybrid onto the detector module
- solder GND connections to lower hybrid
- 36h burn-in test

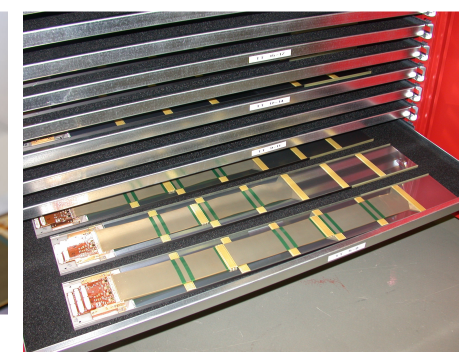
"Stage III" production steps:

- for "4-2-1" modules repeat stage-II steps for the 3rd readout sector
- 36h burn-in test





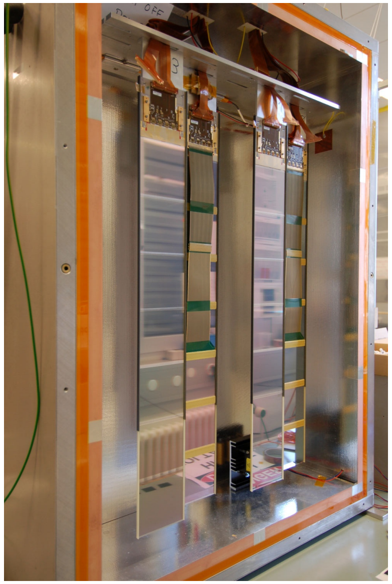


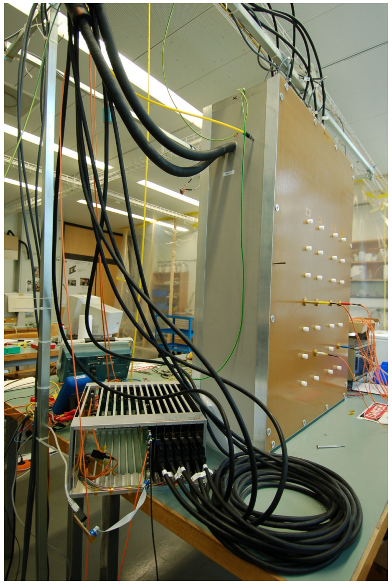


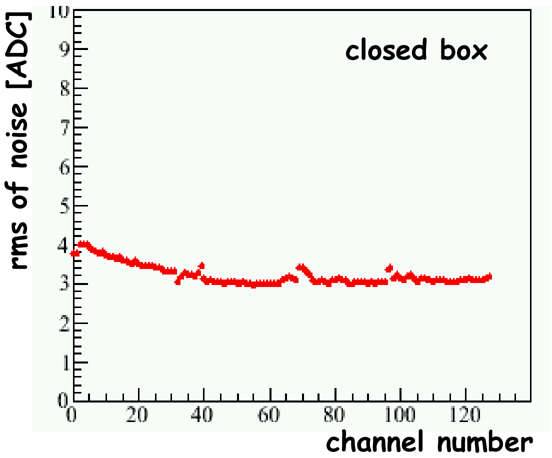
Burn-In Tests

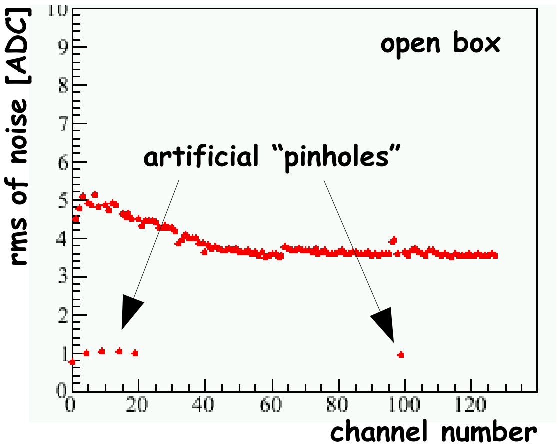
Thermal cycling with readout tests at different temperatures

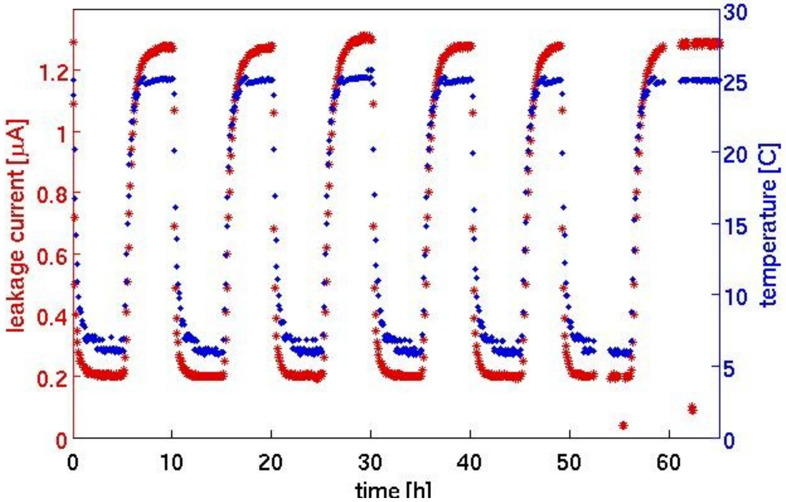
- pedestal and noise measurements
- pulse-shape and charge-collection scans
  - IR laser to inject signals in sensors (TT)
  - internal test pulse on Beetle chip (TT and IT)
- identify bad strips (open, short, pinhole) from analysis of noise and test-pulse data











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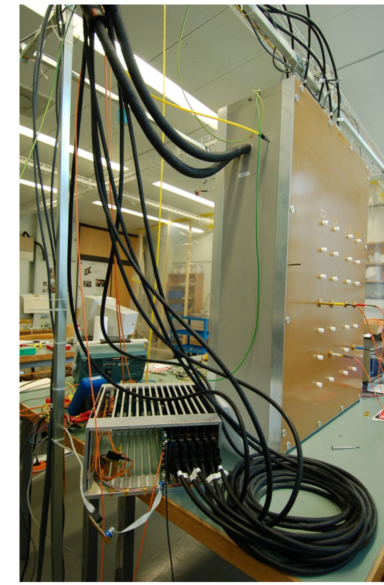
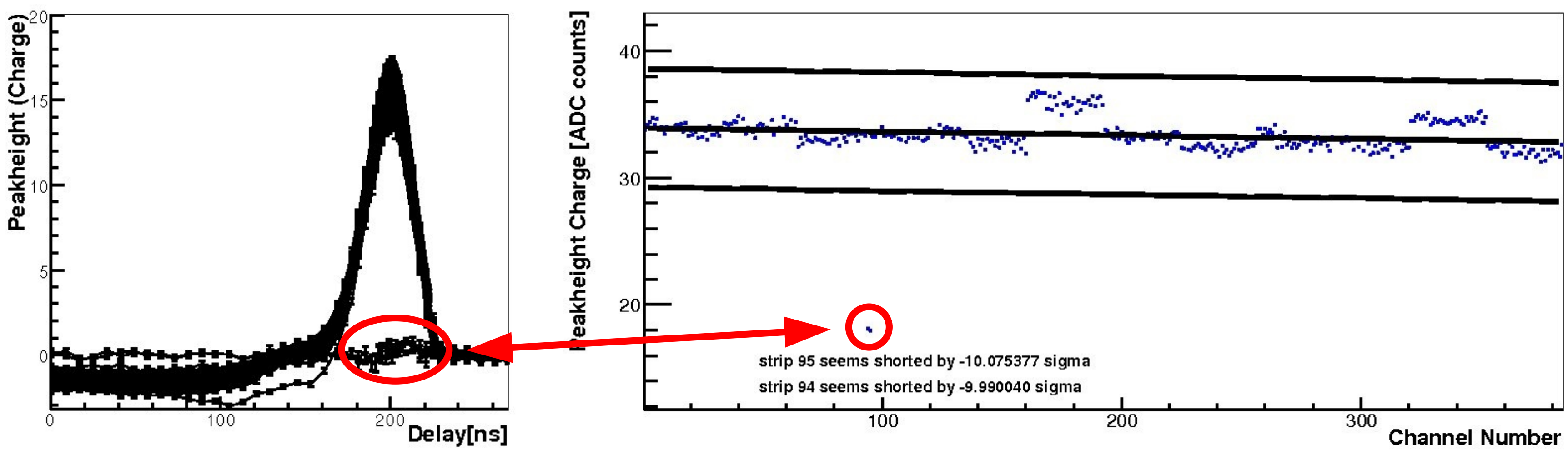
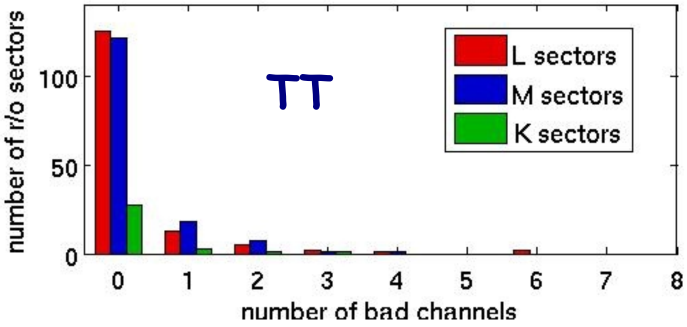


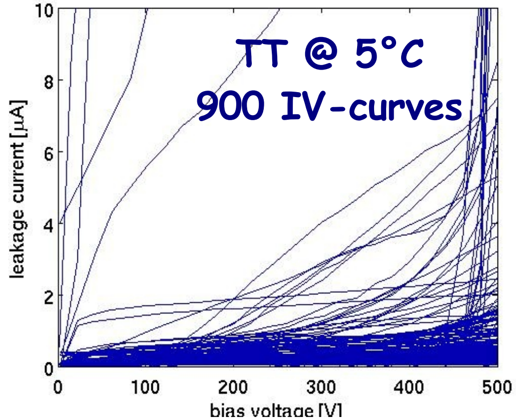


Module Quality



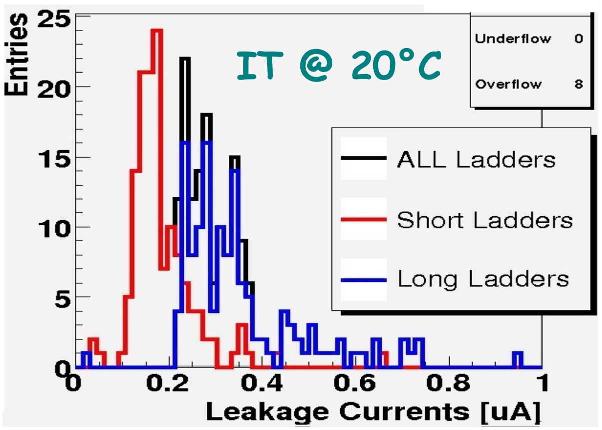
TT module production finished

- 147 modules produced (= 15% spares)
- three modules "lost" during production
- three modules had to go through "major" repair cycle (e.g. replace sensor)
- found 109 bad strips out of ~ 158 k tested
- leakage currents typically < 500 nA per sensor



IT production ongoing, expect to finish in March

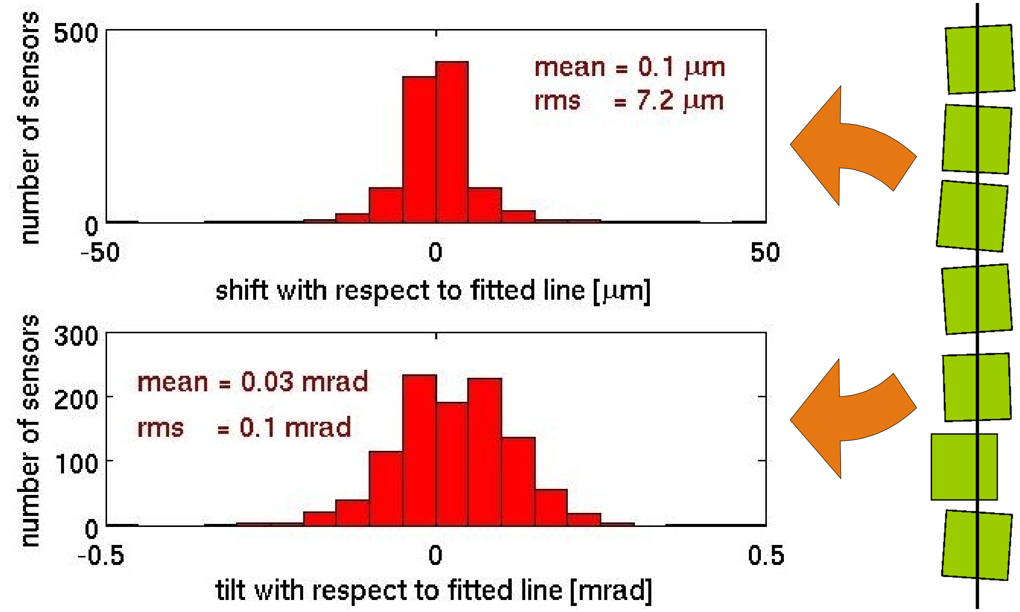
- currently ~ 300 modules produced and fully tested
- some 15 of these show unstable HV behaviour between 350 V and 500 V, under investigation
- fraction of bad strips « 1 %
- leakage currents typically < 400 nA per sensor

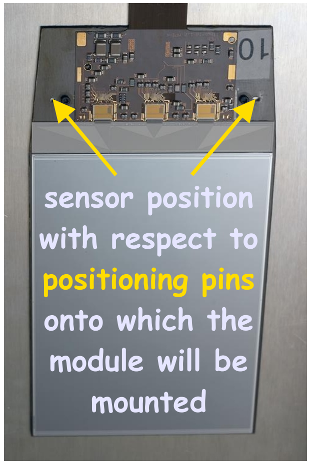


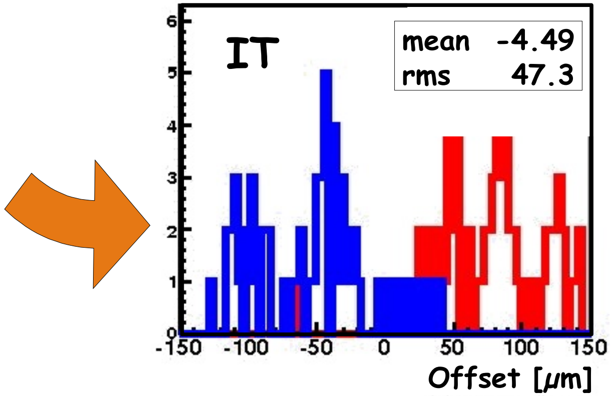
Module Quality

Positioning precision (benchmark: expected spatial resolution of ~ 50 μm)

- excellent relative positioning of the sensors on a module
- each module can be treated as one unit in software alignment, no need to align individual sensors
- positioning of sensors on supports worse than what we had hoped for (for IT, not measured for TT)
- mainly due to worse than expected tolerances on production templates
- no problem: software alignment of individual modules was always foreseen



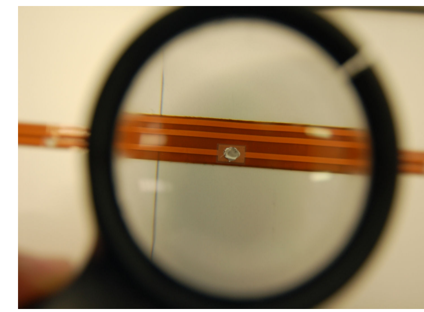




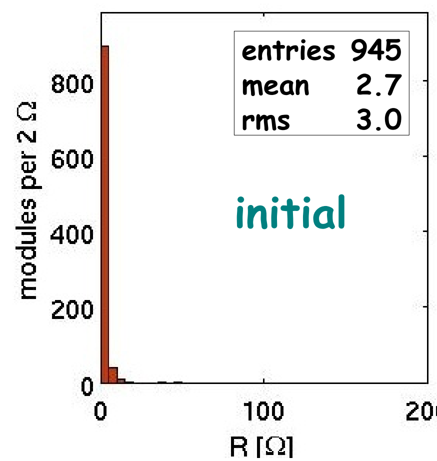
Silver Glue

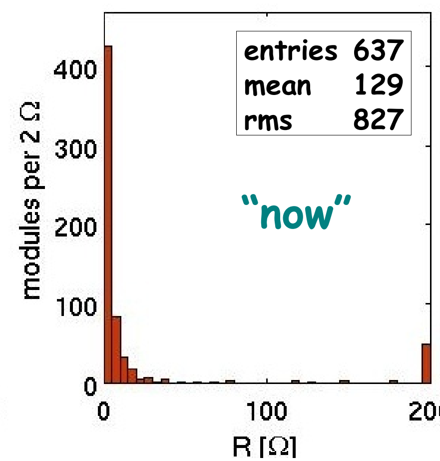
<u>Silver glue on aluminium is a bad idea</u> (similar effects reported by CMS)

- TT: use Kapton cable to connect bias voltage to sensor backplane
- electrical connection initially done with silver glue
  - TT9-75: Elecolit 340 (one-component "silver paint")
  - TT76-155: Elecolit 325 (two-component epoxy)



- measured resistance of all connections
  - shortly after module production
  - again after a few weeks / months
- find significant increase of resistance
  - for both types of silver glue
  - typically a few hundred Ohms now



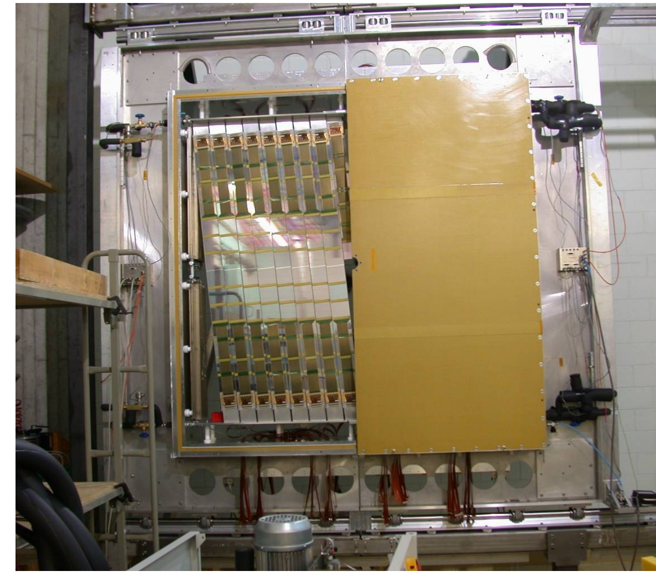


- added bond connections on all sensors to avoid long-term problems
- also: some GND connections on IT done with silver glue -> add bond wires

Installation / Commissioning

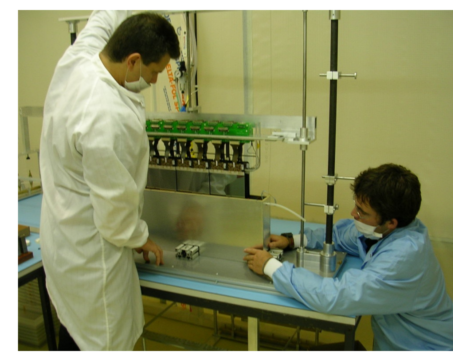
<u>TT</u> (one large detector box):

- test assembly of detector box in the lab
  - included one half-layer of modules
  - extensive mechanical and thermal tests
- detector box now installed in the experiment
- modules will be installed layer by layer
  - HV / readout tests in between any two layers
  - first modules foreseen for March



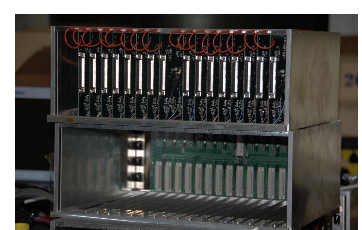
<u>IT</u> (12 individual detector boxes):

- first box assembled and being debugged
- commissioning of each box in the lab
  - installation of first box foreseen for March



<u>Readout electronics</u> (24+24 “Service Boxes”):

- assembly and burn-in tests underway
- valuable experience from module burn-in stands



Summary

Production of detector modules approaching completion

- "115%" of TT modules and ~90% of IT modules produced and tested
- number of "lost" modules so far quite small

Quality of modules very satisfactory

- number of bad channels low (< 0.1%)
- leakage currents small (< 500 nA / sensor at 500 V)
- sensor-sensor alignment good (rms < 10 μm)
- noise / pulse shape distributions as expected

What to do different / better next time ?

- build "final" modules much earlier on
- reserve more time for transition from prototyping to series production