AFP tracker production and testing

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LHC Forward Working Group
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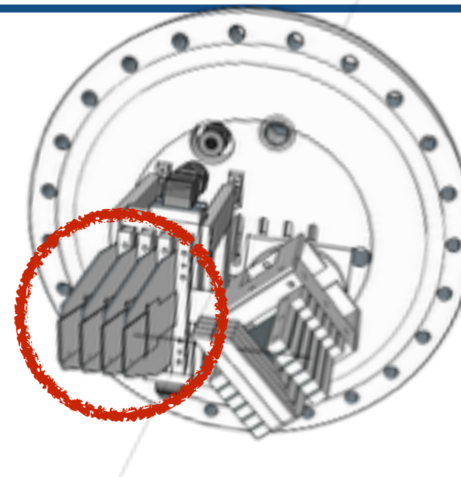
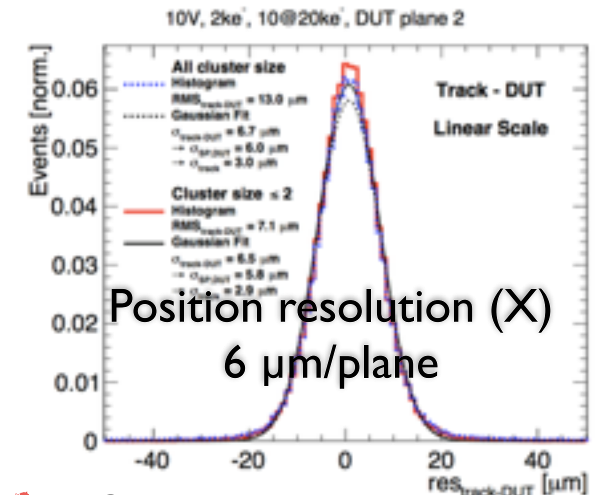
The AFP Tracker Module

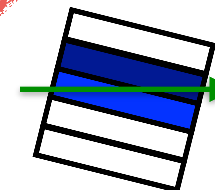
- **Requirements**
  - Radiation hardness
  - Slim-edge for acceptance
  - Position resolution for pT and t reconstruction resolution
- **Chip: FE-I4 chip**
  - Radiation hard electronics: 250 Mrad
  - 50x250 μm^2 pixels
    + Charge collection information (4-bit ToT)
    + Maximum charge sharing in X (along 50 μm pitch)
  - FE-I4 signal (HitOr) as trigger in initial one-arm phase
- **Sensor: 3D Silicon sensor**
  - Column-like electrodes -> Radiation hard
    - Fluence: >5x10^{15} n_{eq}/cm^2
  - Slim-edged down to ~180 μm
  - 2nd use of 3D technology in HEP (1st IBL)

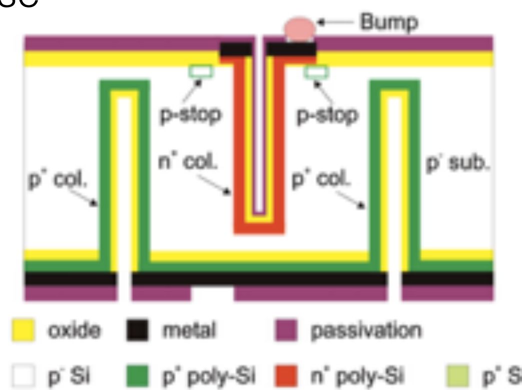


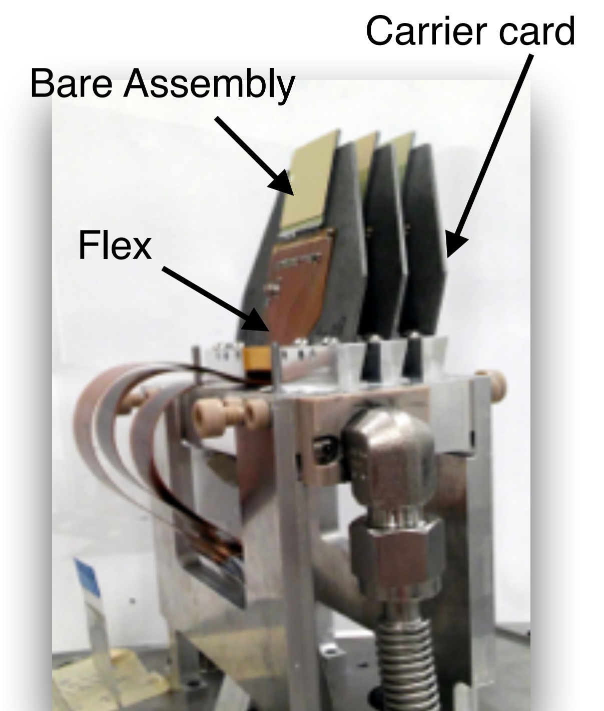


See J. Lange's talk

Charge-weighted interpolation

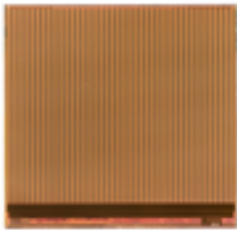






AFP Tracker Module Production

Chip

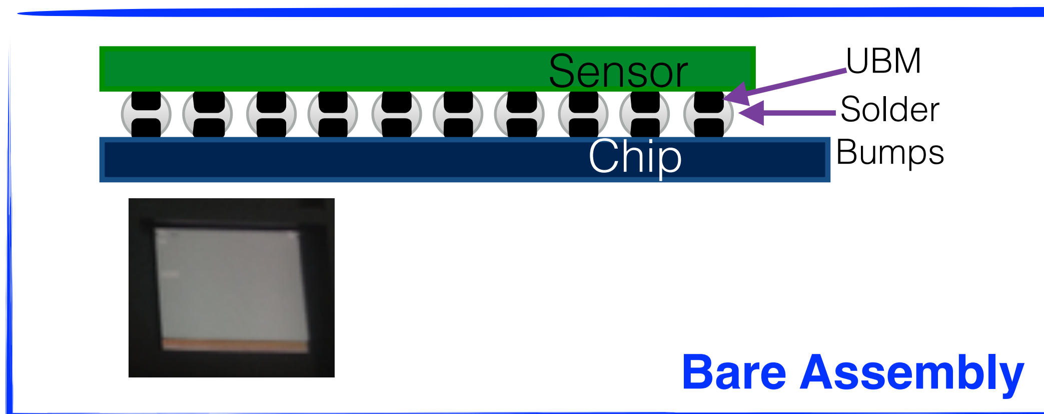


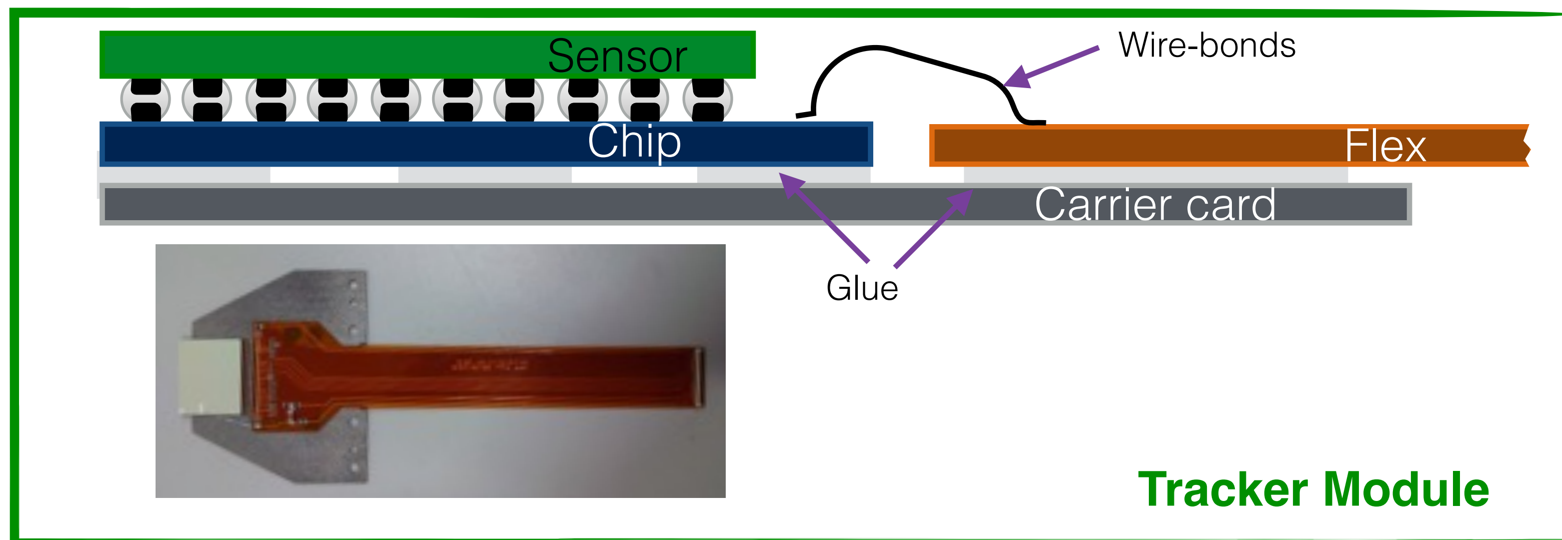
Sensor

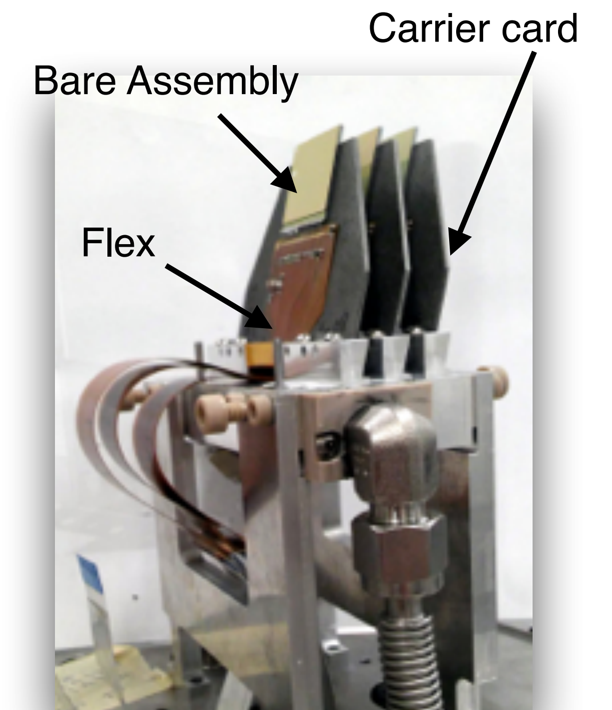
Carrier card

Flex

Flip-Chip

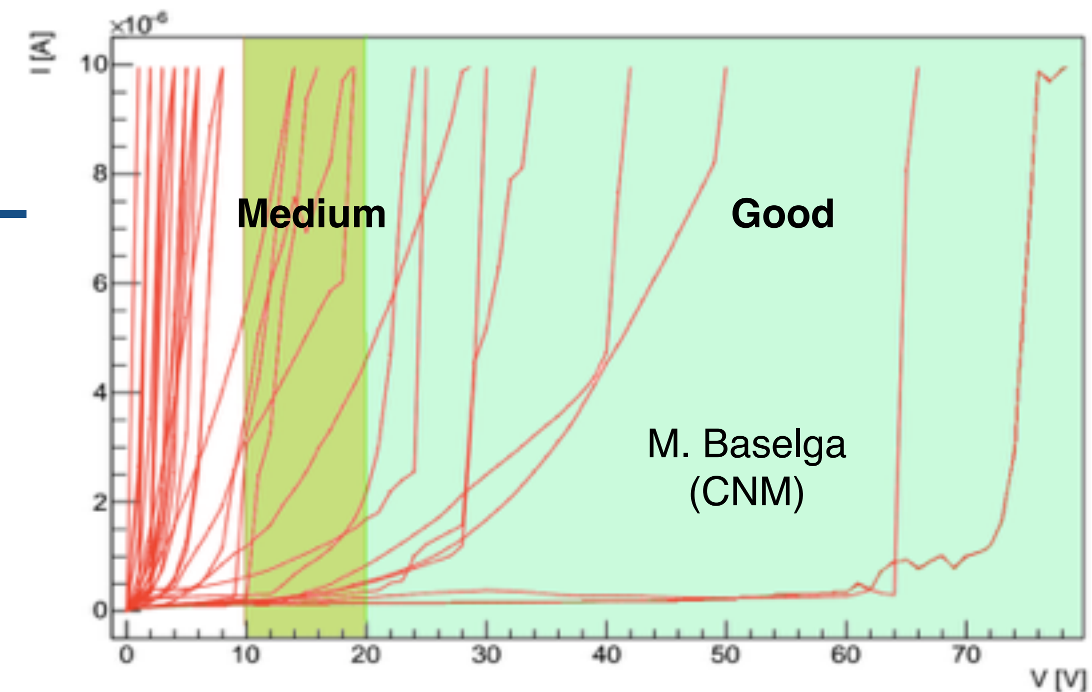


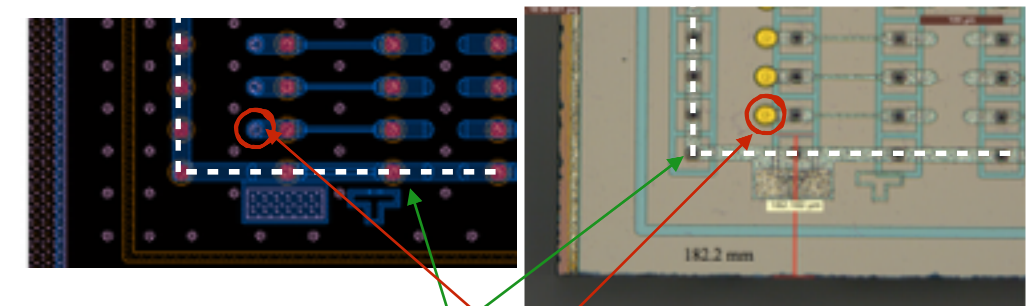


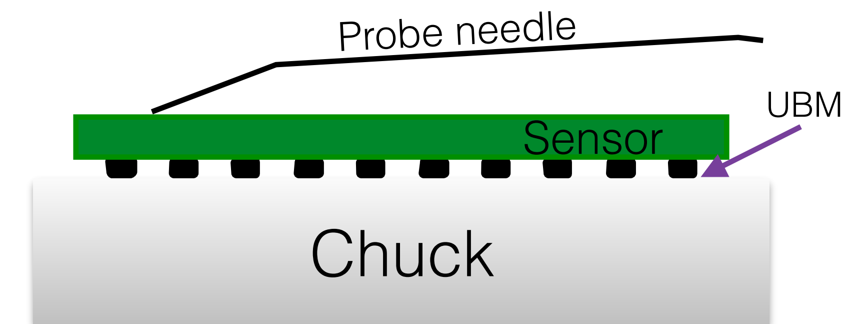


Sensor Production (I)

- **CNM 3D Silicon sensor**
  - First CNM production (January 2015) for AFP had low yield:
    - 40 sensors produced in total (5 wafers)
      - 5 broken sensors
      - 19 bad quality IV: $V_{BD} < 10$ V
      - 7 medium quality IV: 10 V < V_{BD} < 20 V
      - 9 good quality IV: $V_{BD} > 20$ V
  - Second production soon to be finished (~1 month)
- **Sensor qualification (at CNM)**
  - 3D Guard-Ring IV measurement:
    - Proven not to be reliable, probes a small fraction of total pixels
  - Under Bump Metallization (UBM) contact
    - Contact UBM in chuck, more reliable than 3D G-R
  - For 2nd production will use temporary metallization for sensor qualification

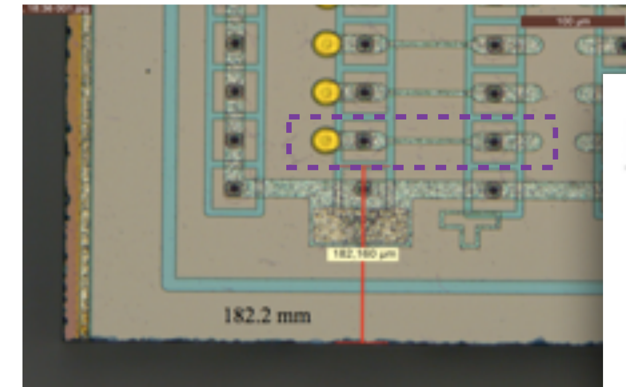


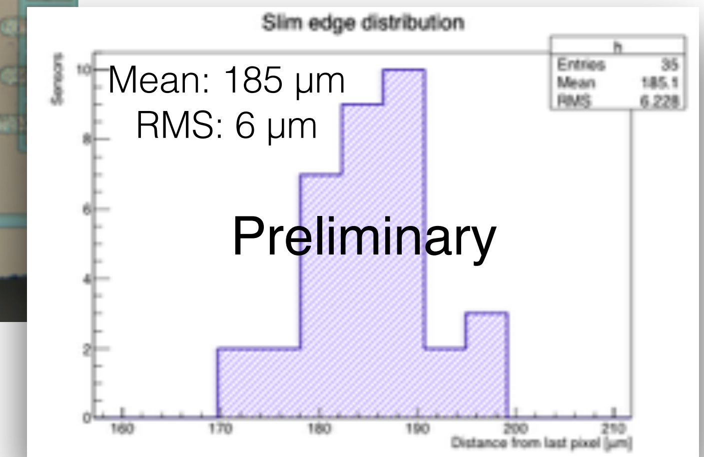


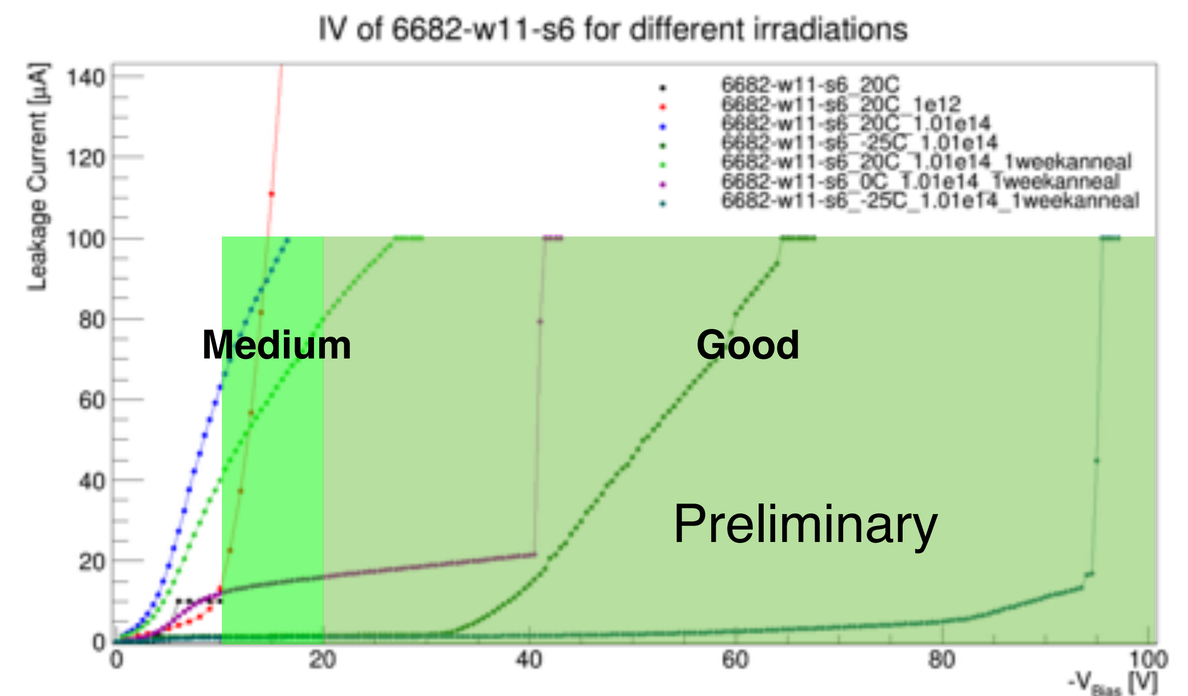


Sensor Production (II)

- **Slim-edge measurement**
  - Edge slimming at CNM: standard diamond saw
  - Check edge extension after slim-edge
- **Irradiation campaign**
  - Try to recover bad quality IV sensors
  - Irradiate sensors at Ljubljana with neutrons up to moderate fluences (10^{14} n_{eq}/cm^2)
    - Low dose thought to improve inter-pixel isolation (p-stop)
  - Recovered 5 sensors out of 11
    - 4 Good quality
      - 1 already installed in Far Station
    - 1 Medium quality

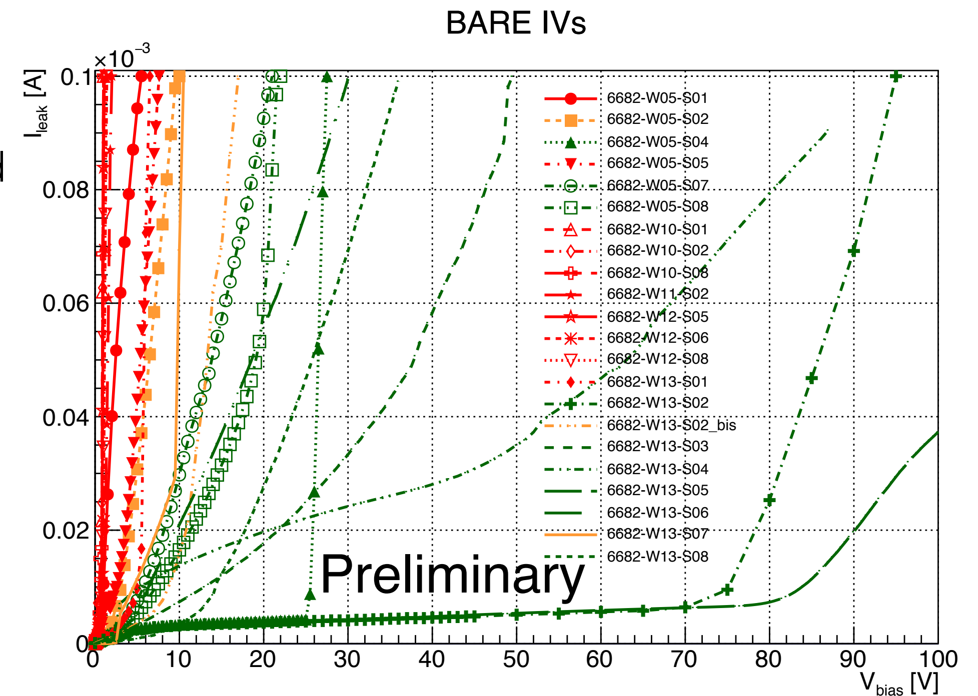






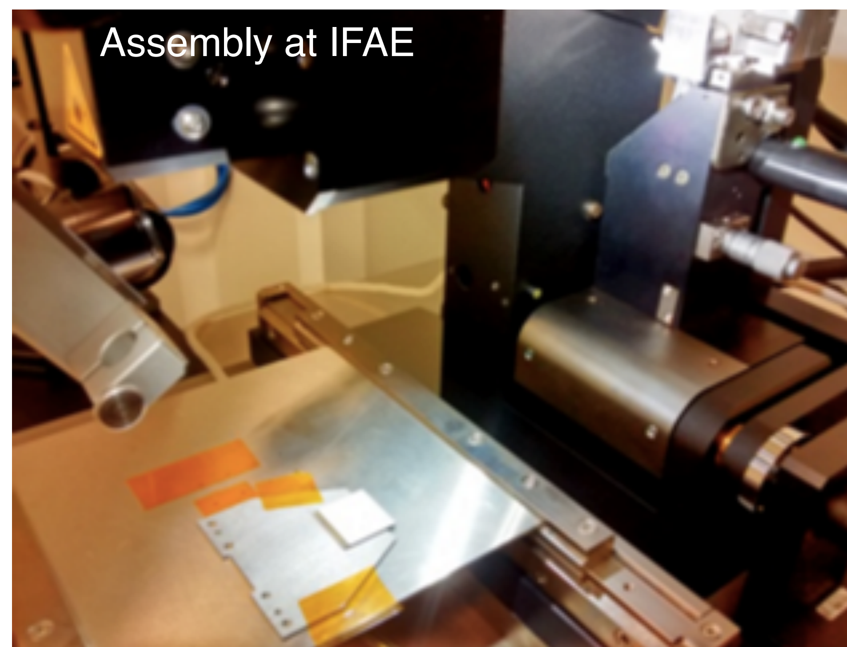
Bare Assembly and Tracker Module Production

- **Bare Assembly:** Sensor flip-chipped to FE-I4 chip
  - Select sensor based on IV behavior at “wafer” level to be flip-chipped
  - Flip-chip done “in-house” at IFAE
- **Tracker Module:** Bare Assembly + carrier card + Flex (at IFAE)
  - Bare Assembly is glued onto the carrier card with alignment marks
  - Flex also glued onto carrier card
  - Chip is wire-bonded to Flex

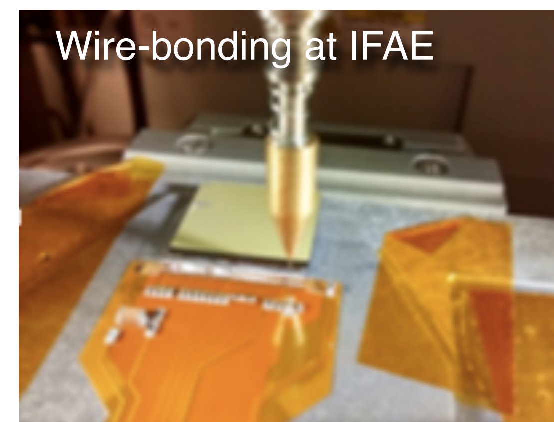


Carrier card

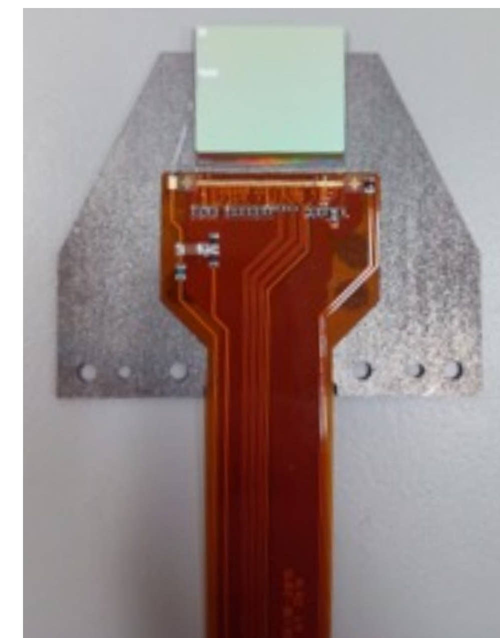
Flex



Pick and Place machine

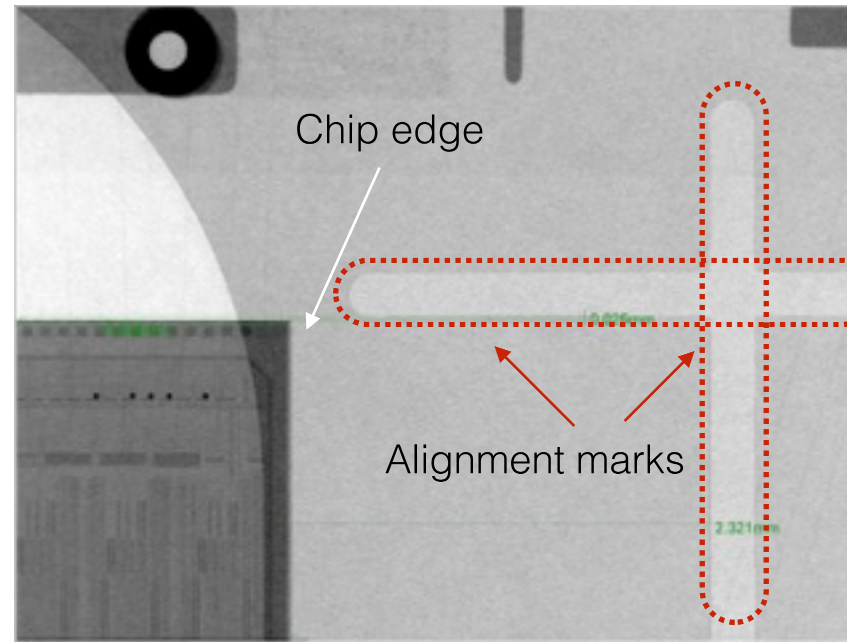


Wire-bond machine


Tracker module

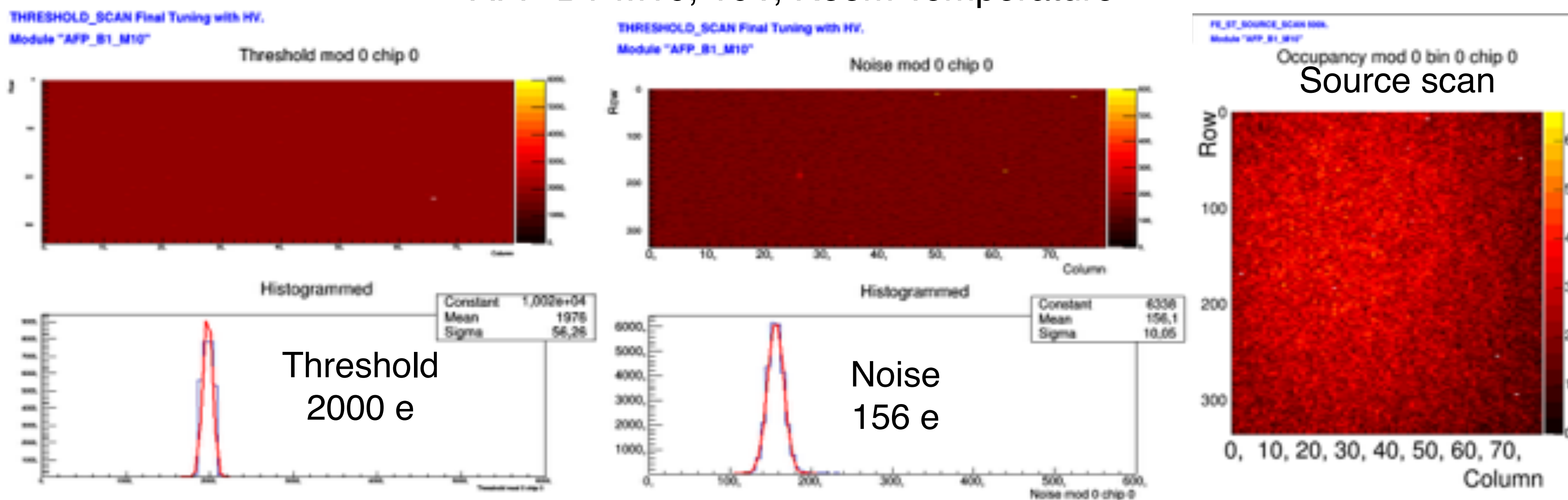
Tracker Module Testing

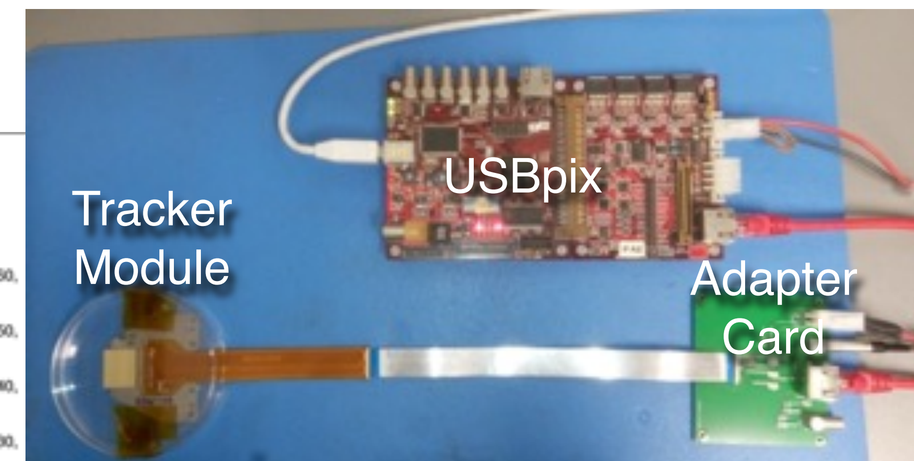
- Alignment measurement with X-ray microscope
- Module testing
  - First calibration measurements performed
  - Tuning of device to standard values
    - Threshold: 2000 e; ToT: 10 ToT at 20 ke
  - Source scan (Sr90)
    - Look for disconnected pixels
- Modules are sent to CERN



Within ~100 μm due to not optimal alignment marks (to be improved)

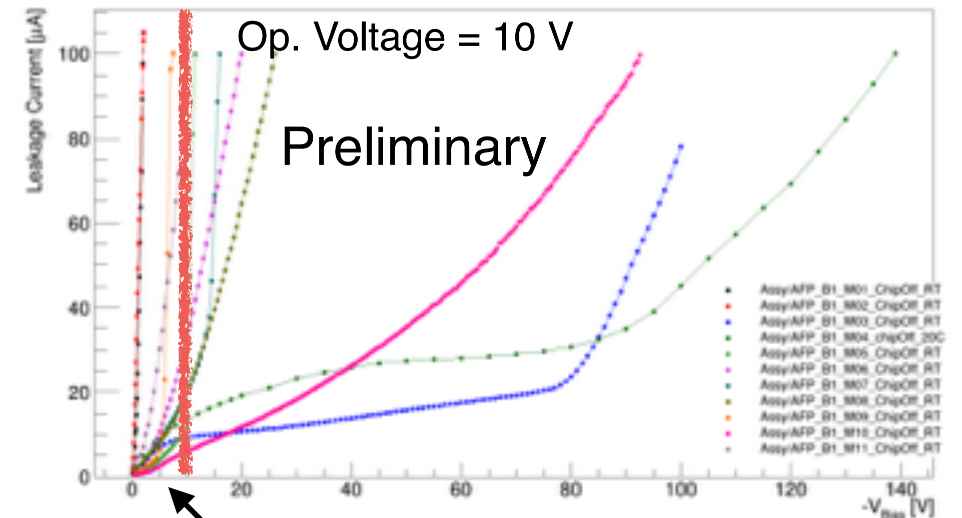
AFP-B1-M10, 10V, Room Temperature



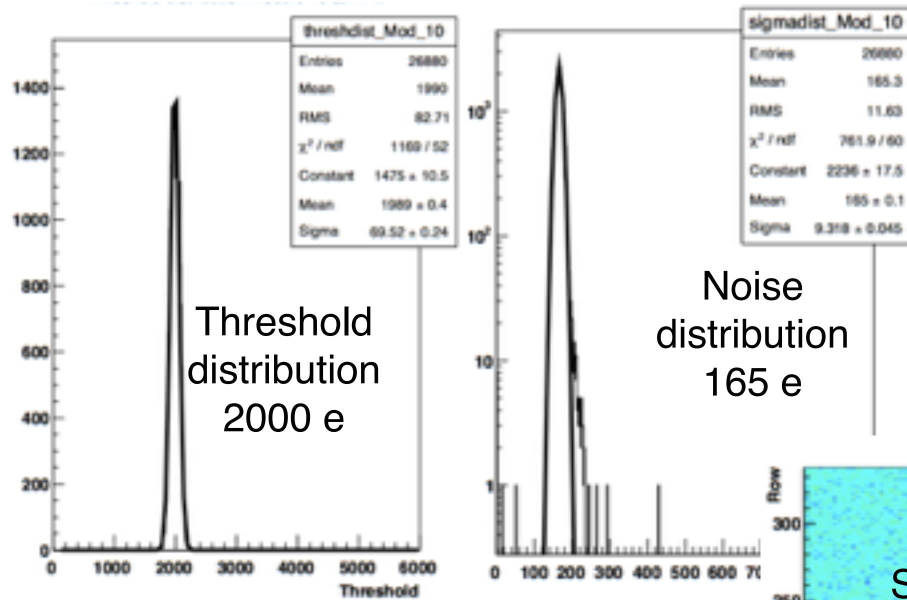


Tracker Module Quality Assurance

- Visual inspection at arrival to CERN
  - Check for broken/shorted wire-bonds due to transport
- IV measurement
- Standard tuning, calibration and source scan (Sr90/Am241)



Assembled worst devices first to debug process

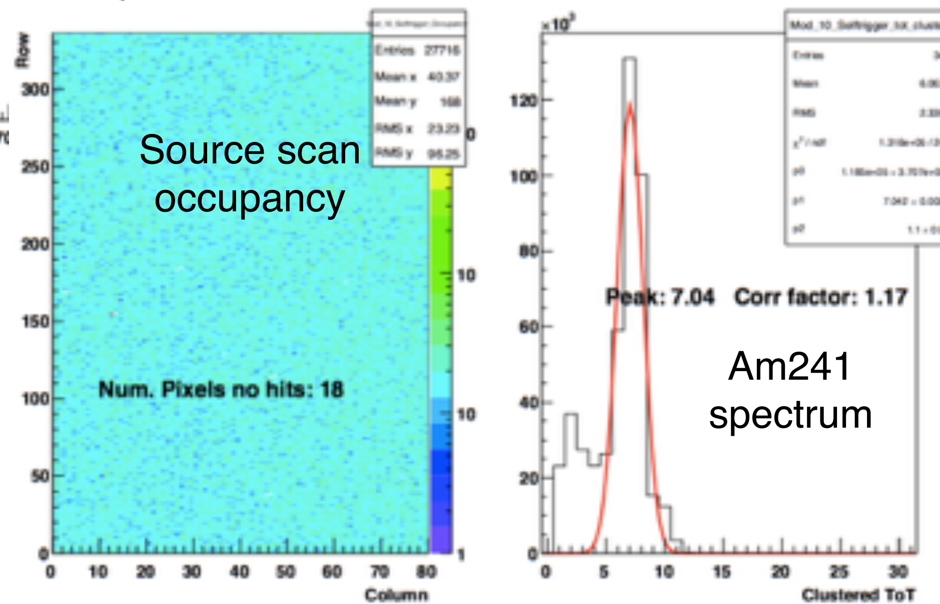


Threshold distribution 2000 e

Noise distribution 165 e

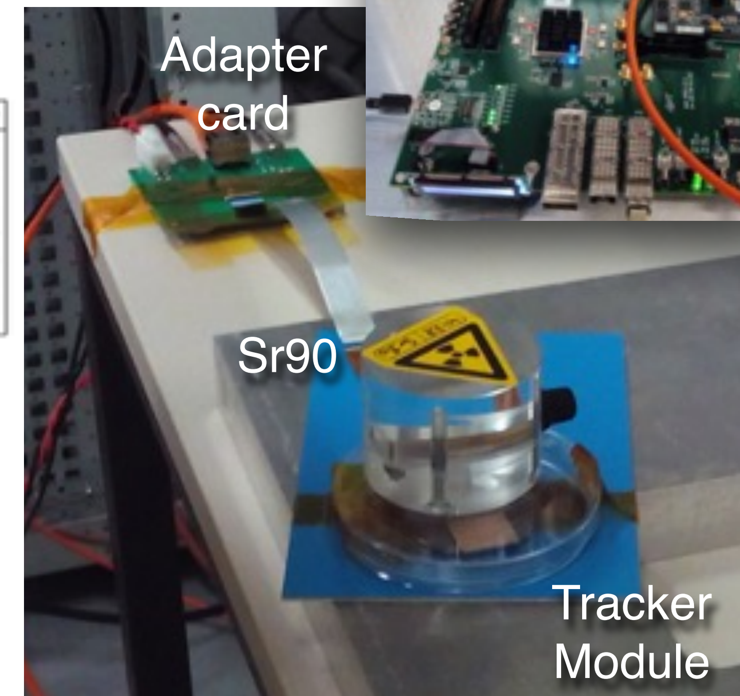
AFP-B1-M10, 10V, Room Temperature

Thanks to Martin Kocian for his help with the HSIO!



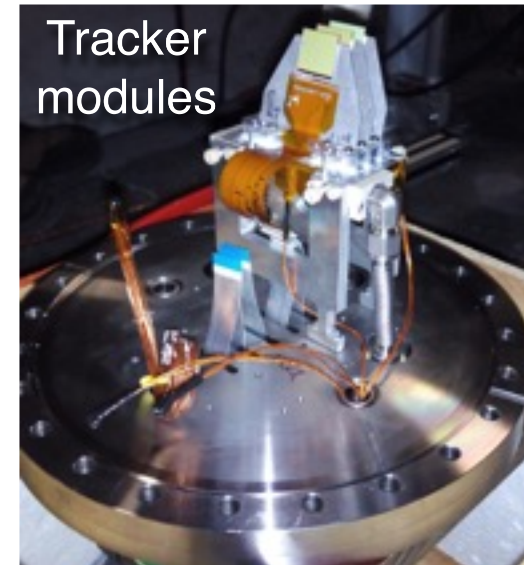
Source scan occupancy

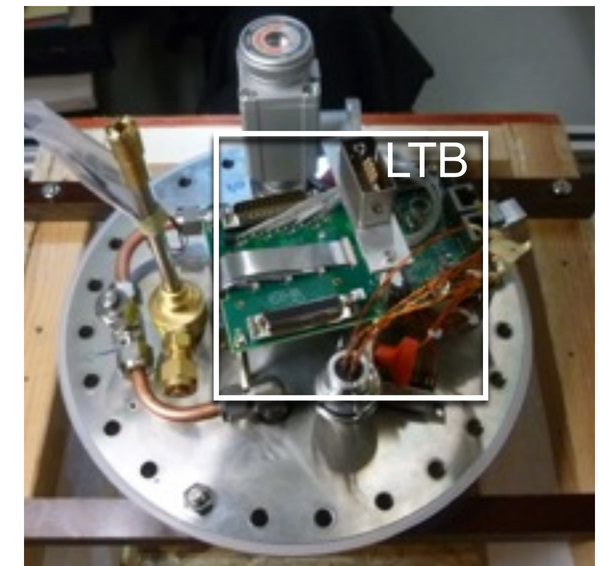
Am241 spectrum

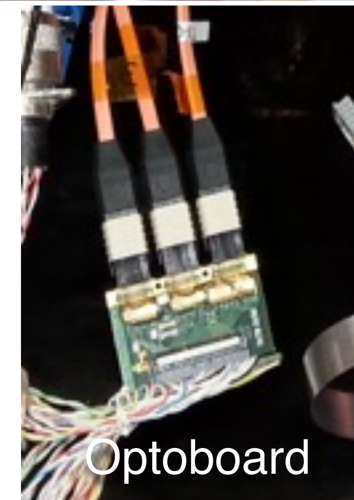


Full Readout Chain Testing

- Full readout chain tested before/after installation:
  - **Tracker module/s**
  - **Local Trigger Board (LTB)**
    - Routes Low and High Voltage, I/O and clock to the modules
    - Gets the HitOr signal from the modules and sends a trigger signal via HitBus chip
  - **Optoboard**
    - Intermediate stage between LTB and DAQ (HSIO)
    - Gets/Sends I/O/clock from HSIO via optical fibre
    - Sends/Gets I/O/clock to LTB via electrical cable
  - **High Speed Input/Output (HSIO)**
    - Calibrates modules/Runs data acquisition



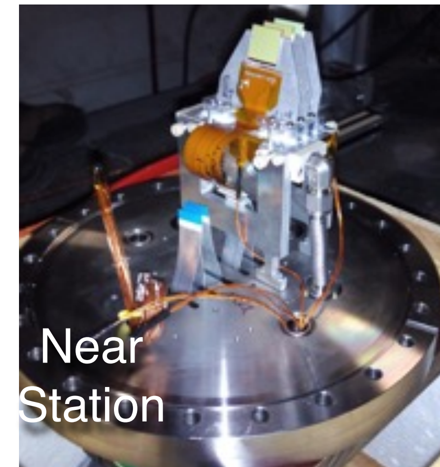


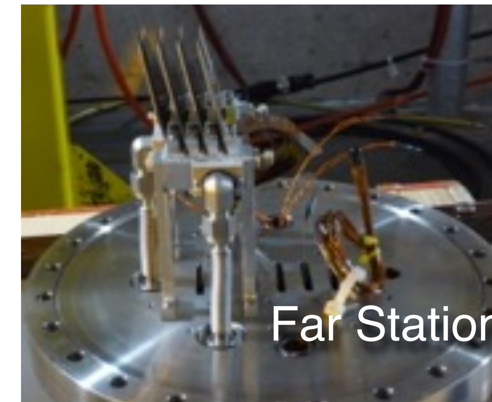


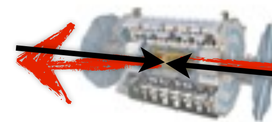
Status after early installation

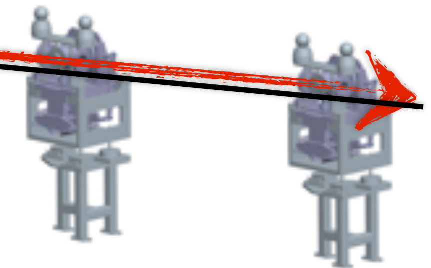
- A total of 11 tracker modules were produced
  - 1 broken due to wire-bond short
  - 2 non-responsive chips
  - 1 module with wide area of disconnected pixels
  - 7 Medium-Good quality modules -> **Installed**
    - 3 in Near Station
    - 4 in Far Station
      - One module in Far Station has a short in the High Voltage line
        - Inside the pot, so not accessible until TS1 (June)
        - Use plane without HV, but 3D detectors are still functional with no bias
- Worst modules can be replaced in short accesses
- Read-out of trackers functional after installation

INSTALLED









BACK-UP