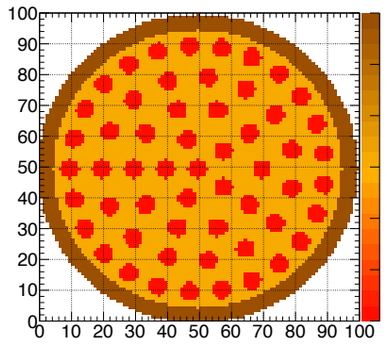
# AFP: A new LHC detector made in Barcelona

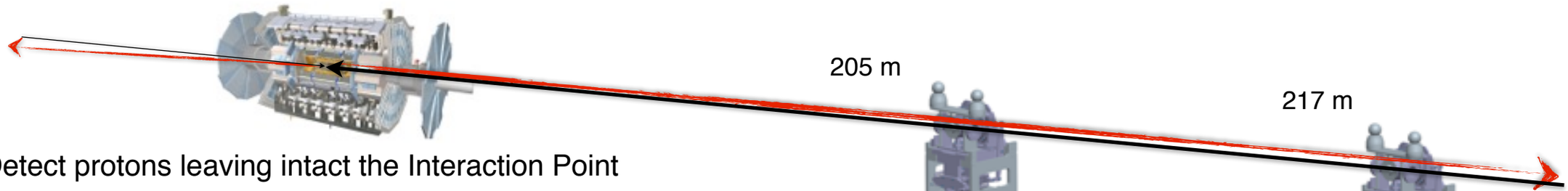
I. López Paz



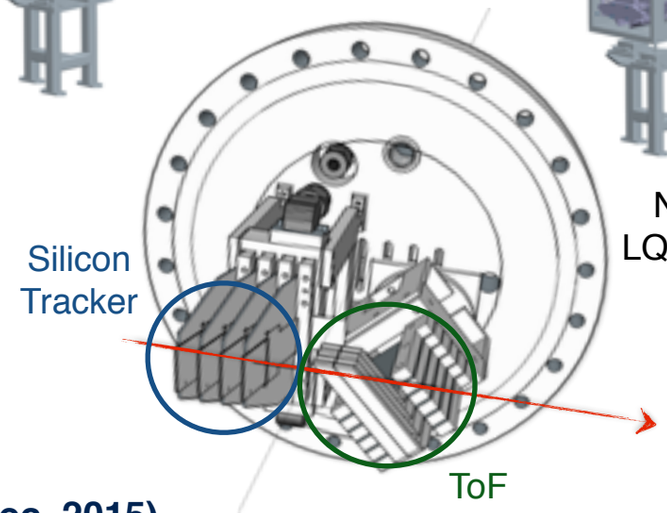

***IFAE*** Pizza Seminar

EXCELENCIA SEVERO OCHOA
BIST Barcelona Institute of Science and Technology
UAB Universitat Autònoma de Barcelona

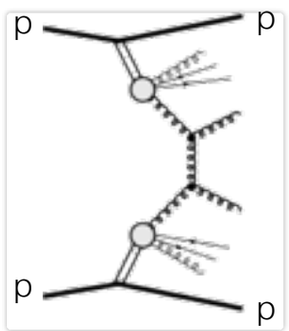
# ~~Astonishingly Fast Project (AFP)~~
# ATLAS Forward Protons (AFP)

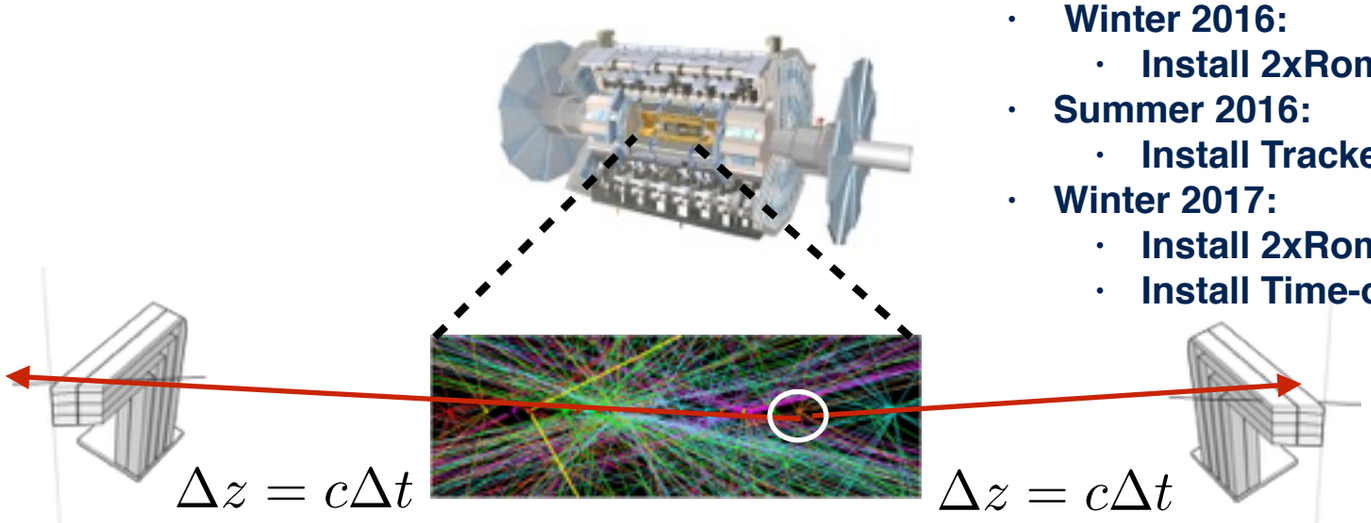



- **Motivation:** Detect protons leaving intact the Interaction Point
- **Detectors in AFP**
  - **3D Silicon Tracker:** 4 planes per station in all stations
    - Reconstruct transverse momentum and proton energy loss
  - **Time-Of-Flight:** 16 L-shaped Quartz bars (LQbars) per side
    - Determine position of primary vertex of the proton (pile-up removal)
- **Roman Pots:** Move detectors ~3 mm from the beam



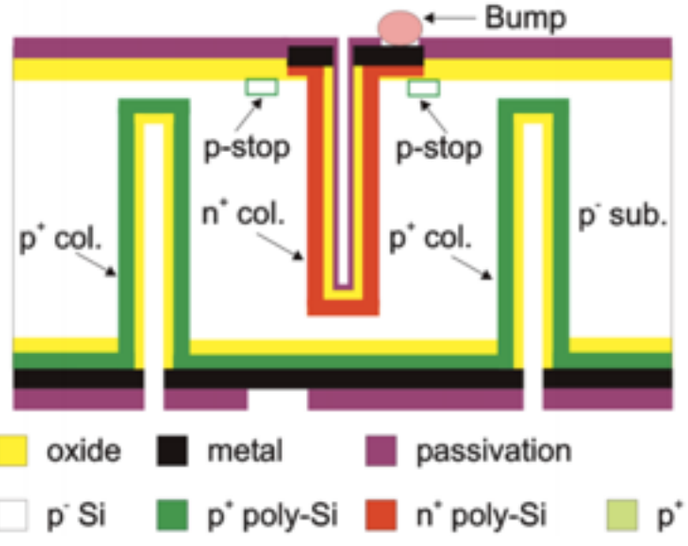

**AFP schedule (Dec. 2015)**
- **Winter 2016:**
  - **Install 2xRoman Pots in one side of ATLAS**
- **Summer 2016:**
  - **Install Tracker in Roman Pots**
- **Winter 2017:**
  - **Install 2xRoman Pots in other side of ATLAS with tracker**
  - **Install Time-of-Flight detectors**



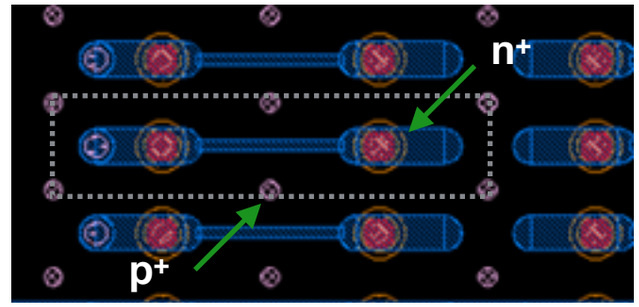



# AFP 3D silicon detectors

- **Column-like electrodes**
  - Inter-electrode distance (~67 $\mu$m) de-coupled from detector thickness (230 $\mu$m)
    - **Lower voltage** for full efficiency (<10 V) before irradiation
    - Shorter drift distance -> Low trapping probability -> **Radiation hard**
- **2nd use of 3D detectors in HEP**
  - First use in ATLAS Insertable B-Layer (IBL, 2014)
  - Profit from previous experience with IBL sensors (FE-I4)




**IFAE was the 3D detector expert in IBL**

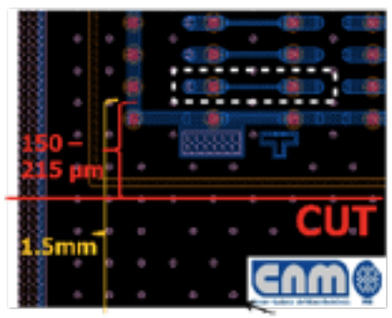


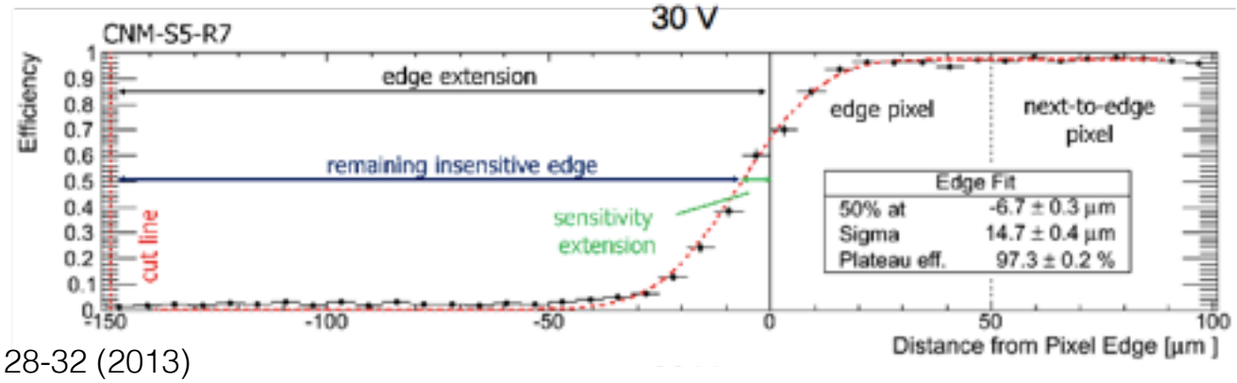

**Characterize slim-edged 3D sensors with FE-I4 chip for AFP in testbeams**

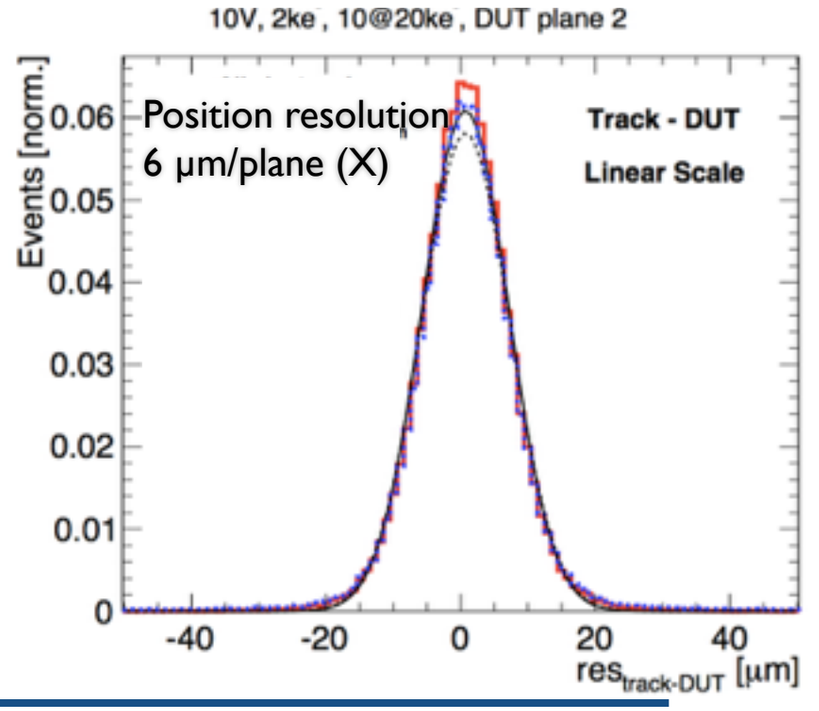
# Test-beam characterization for AFP (2012-2014)

- **Radiation hardness**
  - High efficiency after non-uniform irradiation
- **Slim-edge efficiency**
  - Slim-edged sensors down to ~180 $\mu$m
  - Efficient up to the last active pixel
- **Measured position resolution**
  - 6 $\mu$m resolution per plane



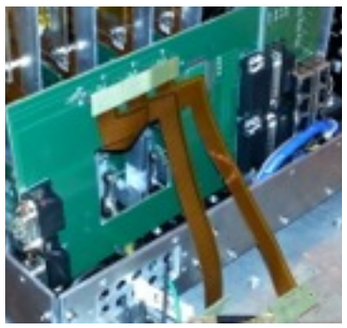

S. Grinstein et al, NIMA 730 28-32 (2013)
J. Lange et al, JINST 10 C03031 (2015)
I. Lopez et al, IEEE ANIMA2015 Conf. Proc.

**3D FE-I4 detectors proven suitable for AFP**

# Tracker and ToF integration test-beamS (2014-2016)

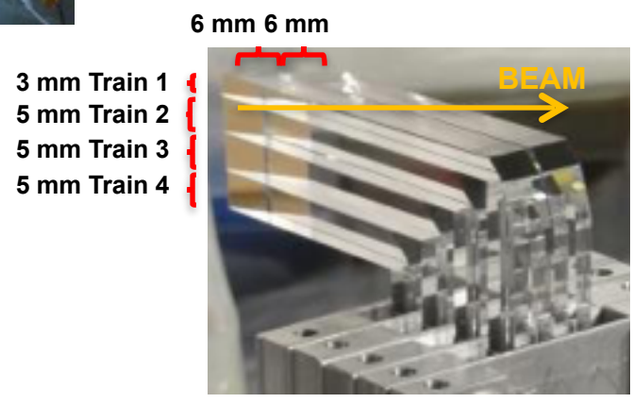
**TRACKING: 5 FE-I4 3D Pixel Detectors**
• IBL style (by CNM/FBK), IBL spares (not best quality)

**Trigger: Pixel Plane Coincidence**
• Logic by HitBus chip developed for ATLAS-DBM

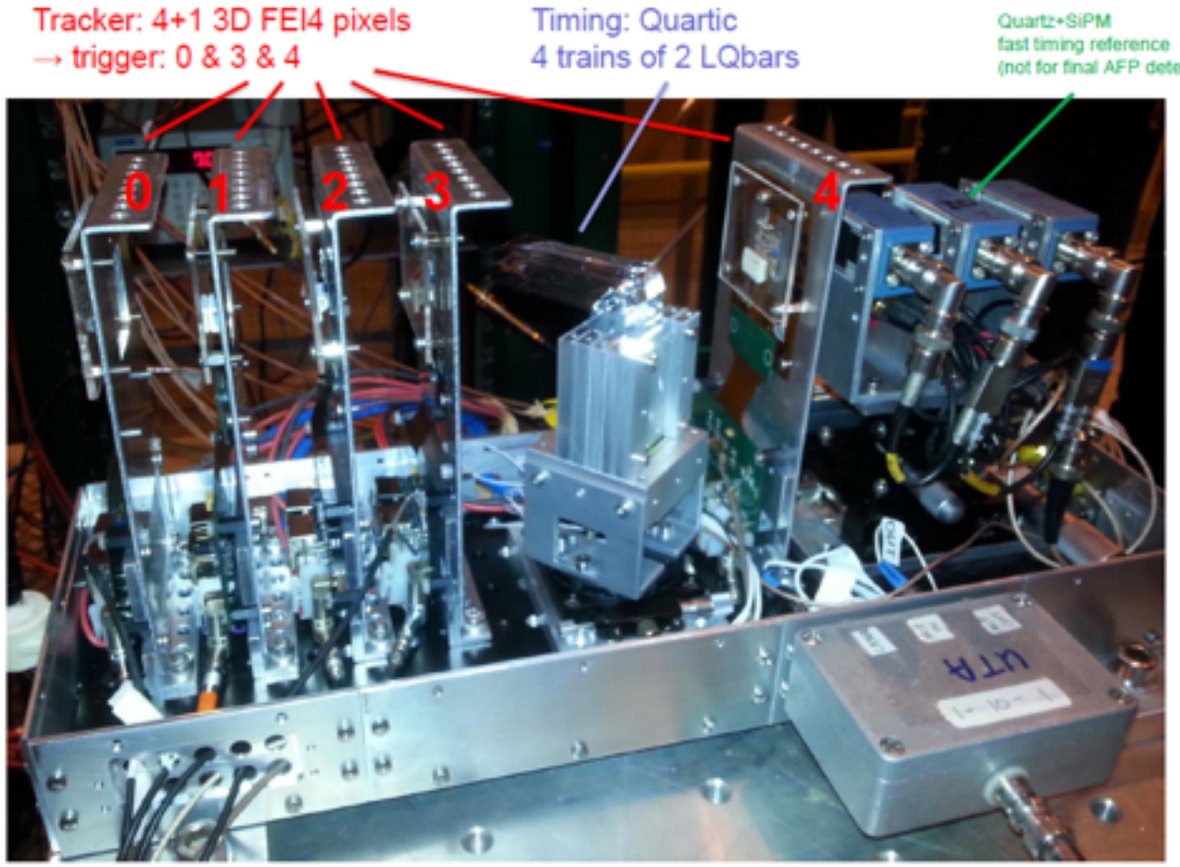


**READOUT: RCE**

**TIMING: 4 rows of trains of 2 LQbars**
• Oriented at Cherenkov angle of 48°




Signal chain
→ 4x4-pixel MCP-PMT
→ PreAmp
→ Constant Fraction Discriminators (CFD)
→ High-Precision Time-to-Digital (HPTDC )



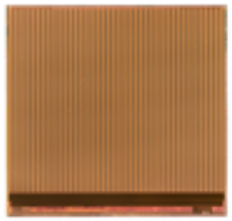

**Strong participation of IFAE:**
**— Testbeam experts**
**— Tracker experts**
**— Testbeam coord. (J. Lange)**

**Successful integration test beam**
**-> AFP approved for installation (Summer 2015)**

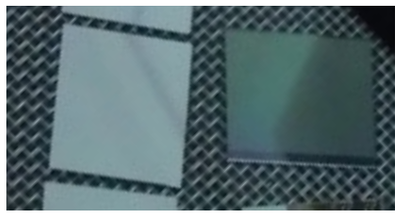
Presented in ATLAS weekly (J. Lange) ATL-COM-UPGRADE-2015-010
https://indico.cern.ch/event/286492/ Submitted to JINST

# AFP tracker module production: Overview

Chip



Sensor



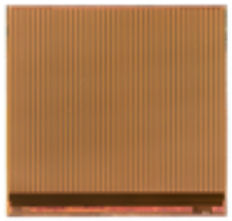
Carrier card

Flex (~Cable)

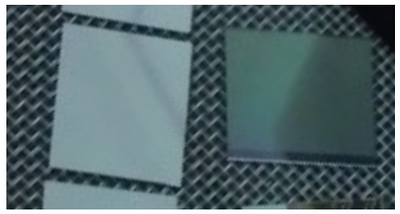
**Full module production at IFAE**

# AFP tracker module production: Overview

Chip



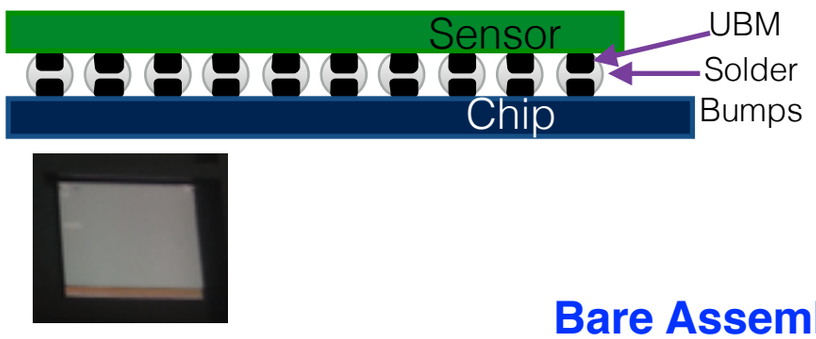
Sensor



Carrier card

Flex (~Cable)

Flip-Chip

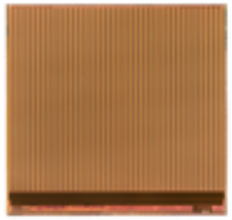



**Bare Assembly**

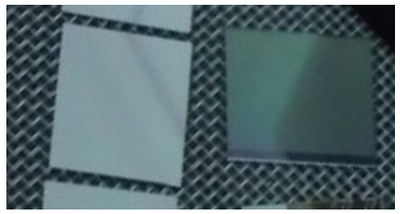
**Full module production at IFAE**

# AFP tracker module production: Overview

Chip



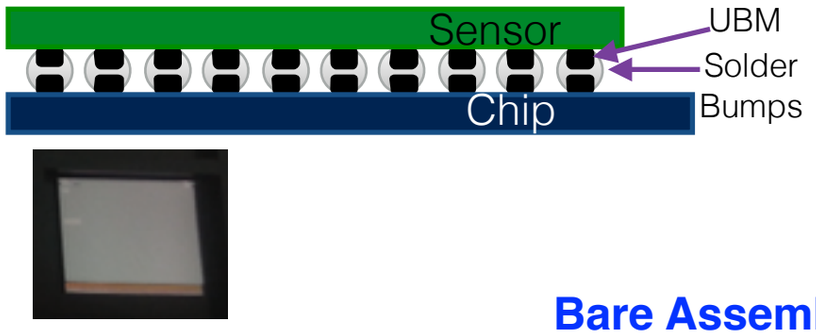
Sensor



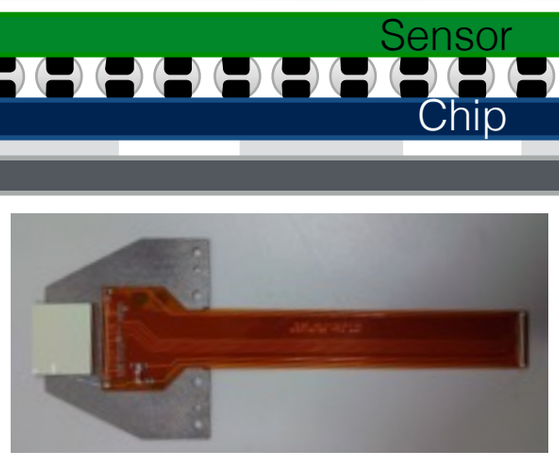
Carrier card

Flex (~Cable)

Flip-Chip

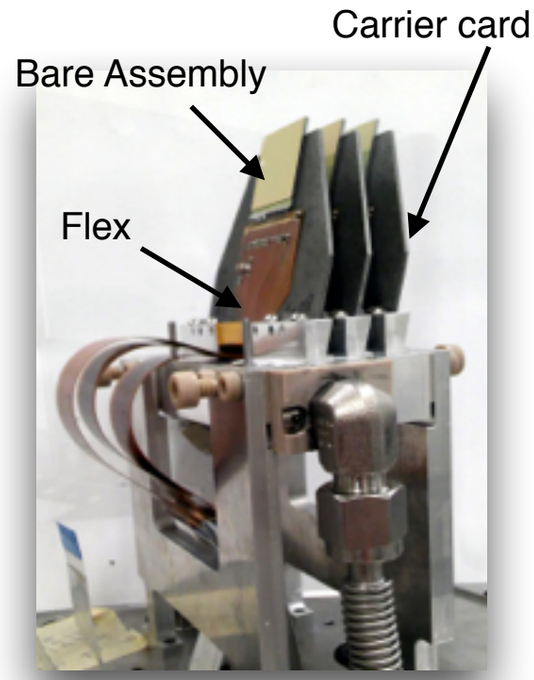



**Bare Assembly**




**Tracker Module**

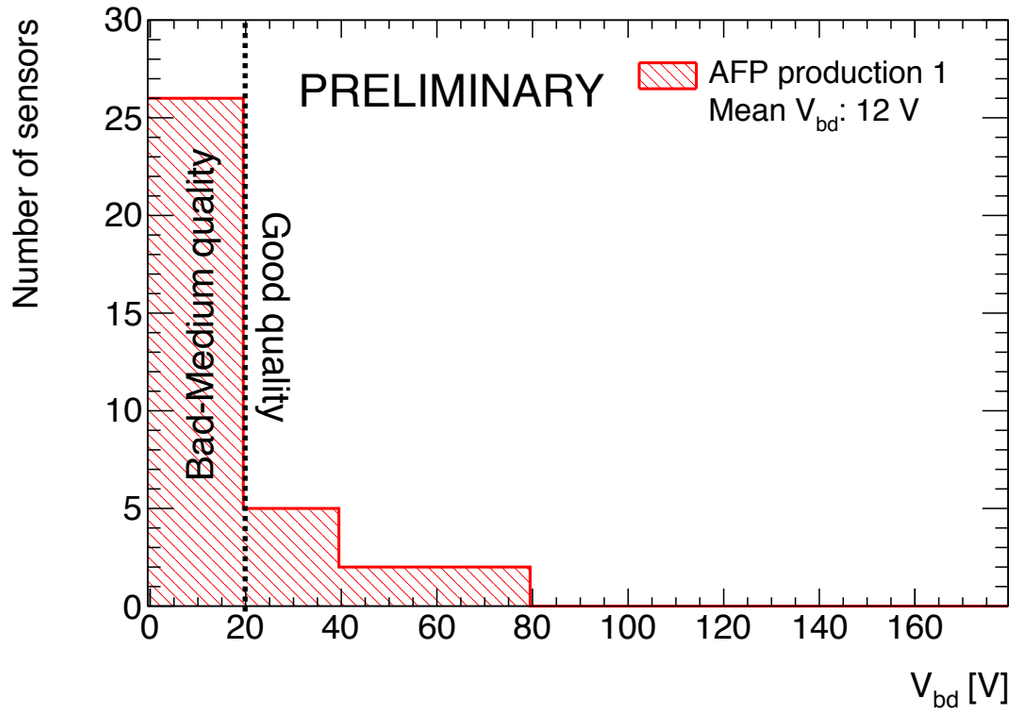
## Full module production at IFAE



# Sensor Production

- **First CNM production** (January 2015) for AFP had low yield:
  - 40 sensors produced in total (5 wafers)
    - 5 broken sensors
    - 19+7 bad-medium quality IV: $V_{BD} < 20$ V
    - 9 good quality IV: $V_{BD} > 20$ V

**Sufficient for first installation (YETS 2015-2016)**

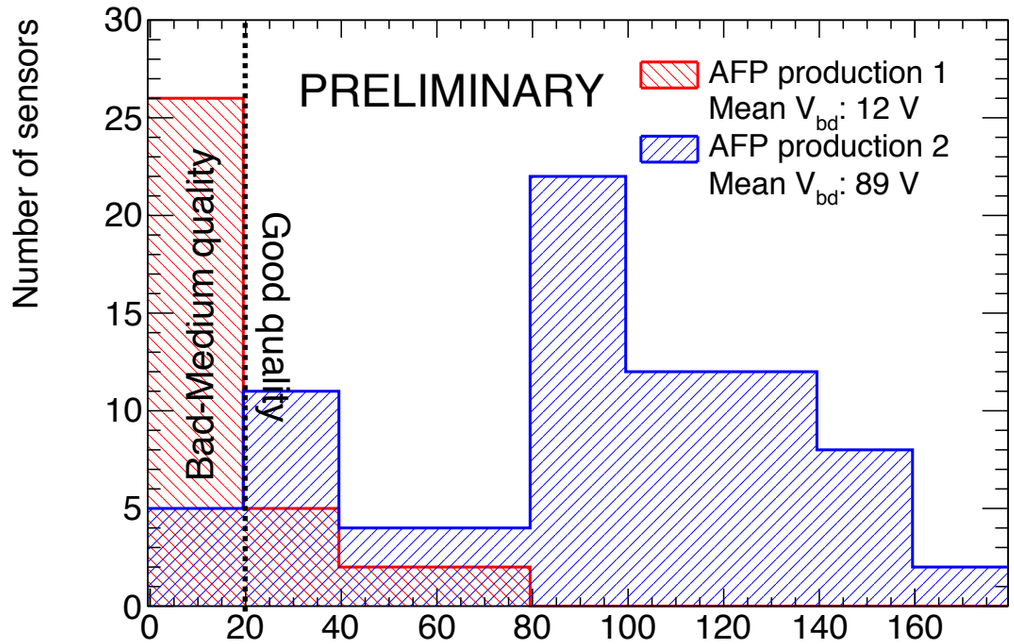



| Production run | Wafer Yield | Good Wafers | Sensor Yield | Good Sensors |
|---|---|---|---|---|
| AFP 1 | 38 % | 5 | 23 % | 9 |

# Sensor Production

- **First CNM production** (January 2015) for AFP had low yield:
  - 40 sensors produced in total (5 wafers)
    - 5 broken sensors
    - 19+7 bad-medium quality IV: $V_{BD} < 20$ V
    - 9 good quality IV: $V_{BD} > 20$ V

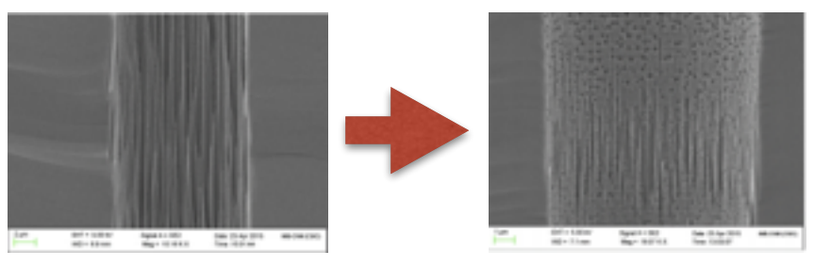
**Sufficient for first installation (one ATLAS side)**




- **Second CNM production** (April 2016)**:**
  - 80 sensors produced in total (10 wafers)
    - 5 bad quality: $V_{BD} < 20$ V
    - 75 good quality: $V_{BD} > 20$ V

**Optimization of column-etching process at CNM**

| Production run | Wafer Yield | Good Wafers | Sensor Yield | Good Sensors |
|---|---|---|---|---|
| AFP 1 | 38 % | 5 | 23 % | 9 |
| AFP 2 | 83 % | 10 | 94 % | 75 |



**Side-walls damage reduced of columns**

**Second production for winter 2016-2017 installation**

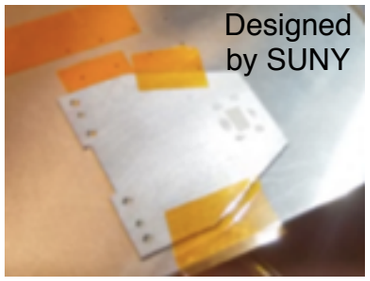
# Bare Assembly and Tracker Module Production

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

| Production Step | Total | Good | Yield |
|---|---|---|---|
| Bump Bonding | 22 | 21 | 95 % |
| Assembly | 17 | 17 | 100 % |

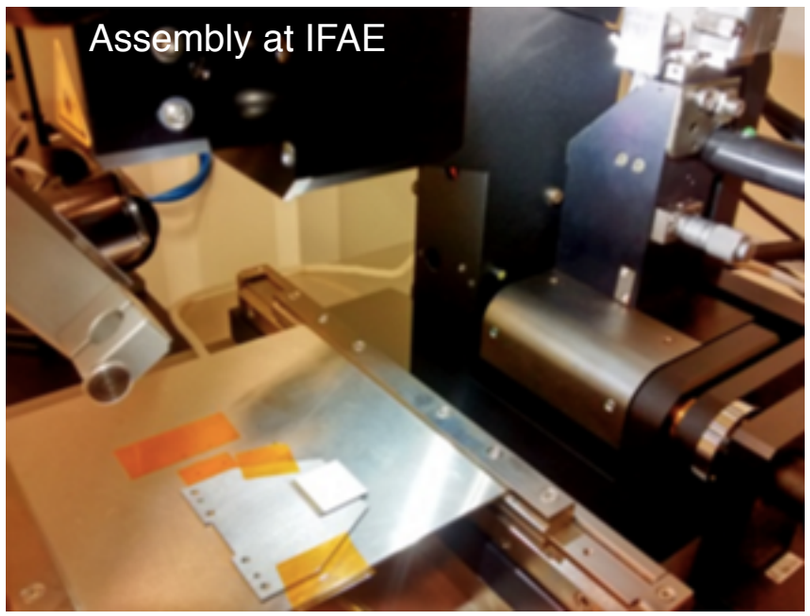
Note: includes modules produced after installation

**Bump-bonding and Assembly at IFAE (Mokhtar, Jorge G. Eric P.)**

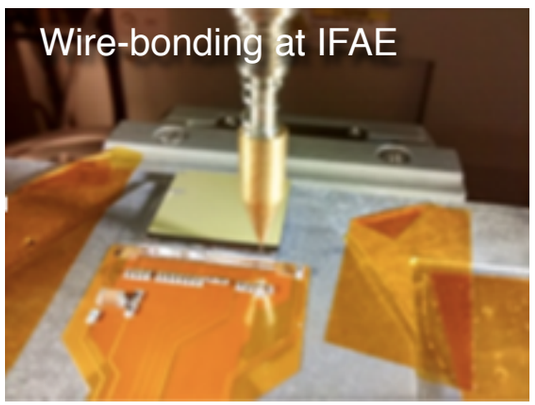


Carrier card

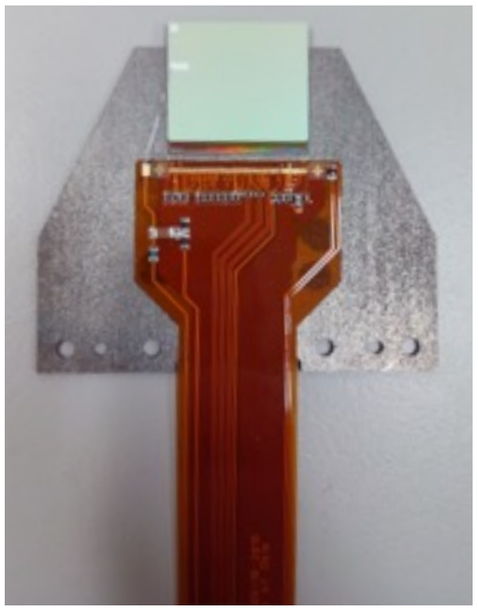
Flex



Pick and Place machine

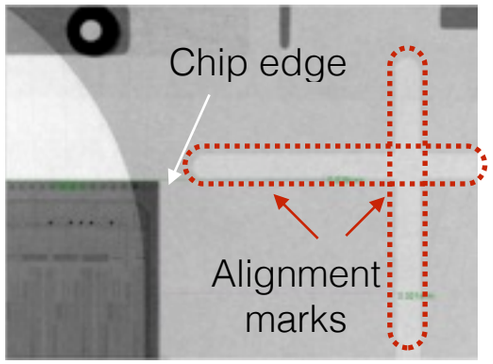


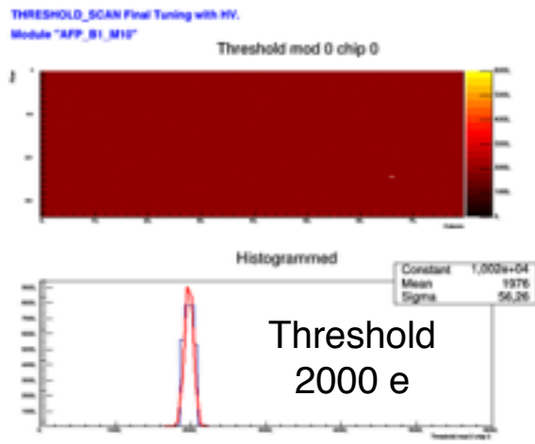
Wire-bond machine

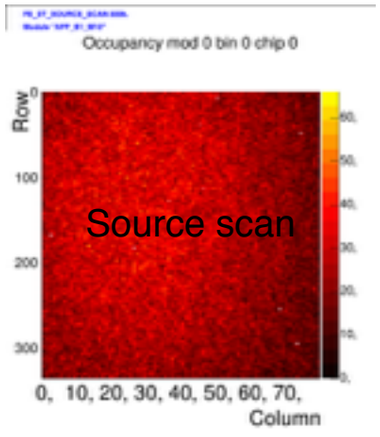

Tracker module

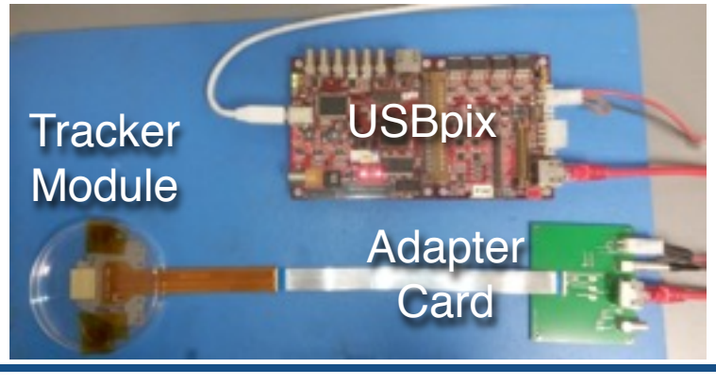
# Tracker Module Quality Assurance

- **At IFAE-Barcelona**
  - Alignment measurement with X-ray microscope
  - Module testing
    - First tuning and tests with radioactive source to look for disconnected pixels
  - Modules are sent to CERN

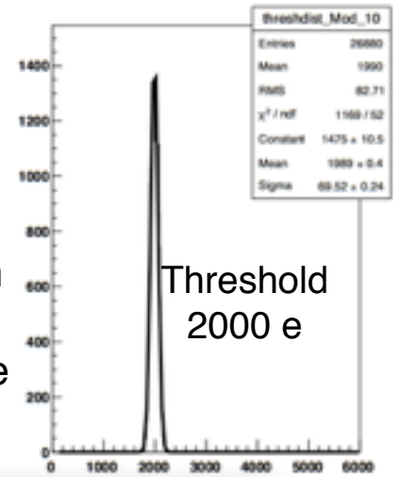


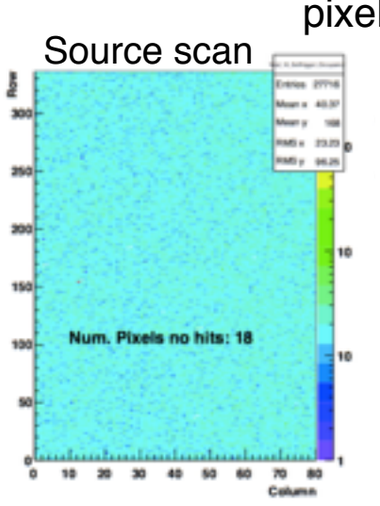



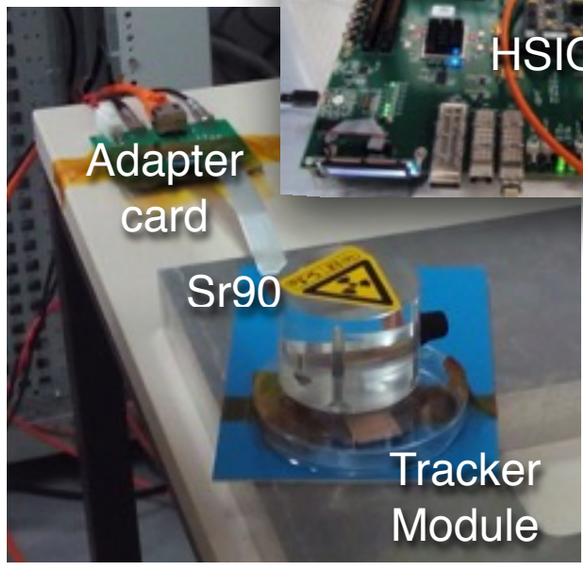




- **At CERN (by IFAE)**
  - Visual inspection
  - Module testing with final DAQ system
    - Tuning and tests with radioactive source to look for disconnected pixels





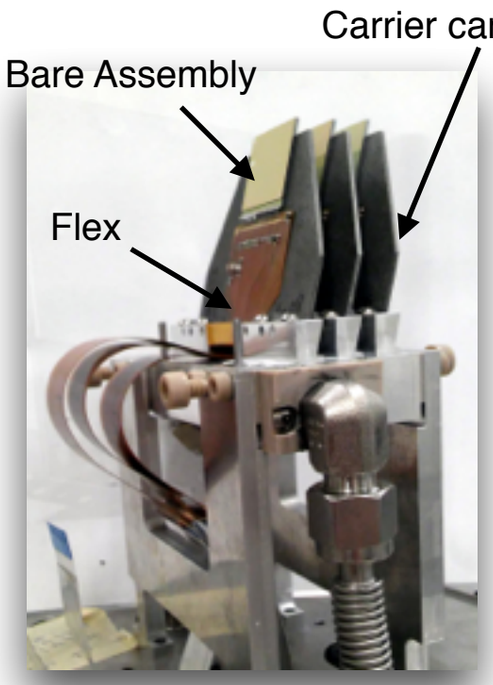


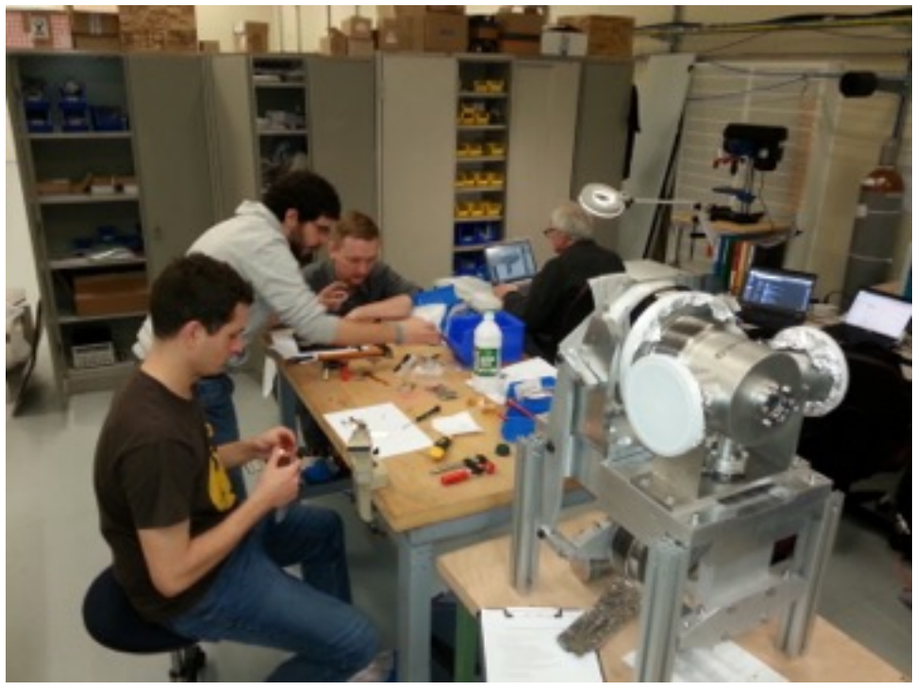

| Production Step | Total | Good | Yield |
|---|---|---|---|
| QA | 17 | 14 | 82 % |

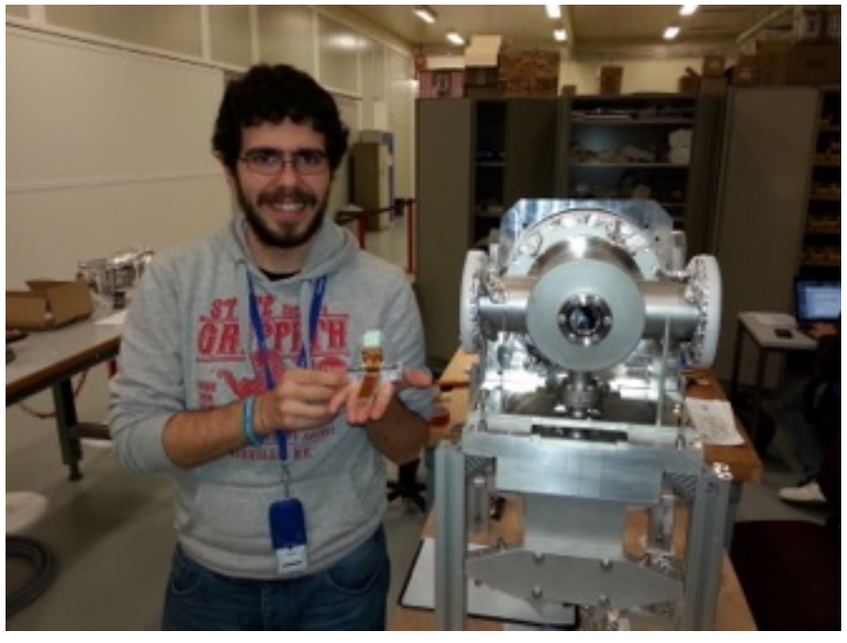
Note: includes modules produced after installation

# Silicon tracker installation (AFP0+2)

- By December 2015 the installation of the silicon tracker on one side of ATLAS was foreseen for summer 2016
  - Still, were **able to produce 7 working modules ahead of time for installation** (26th of February 2016)

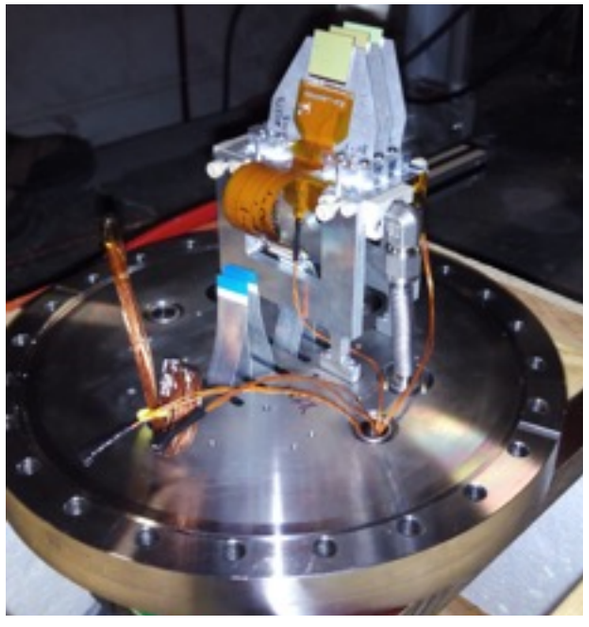


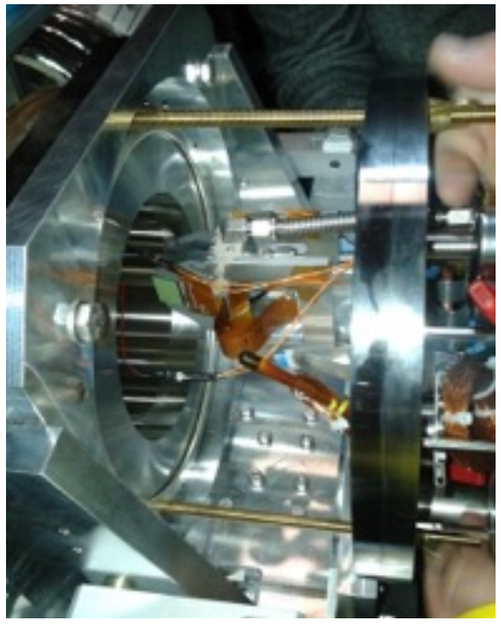





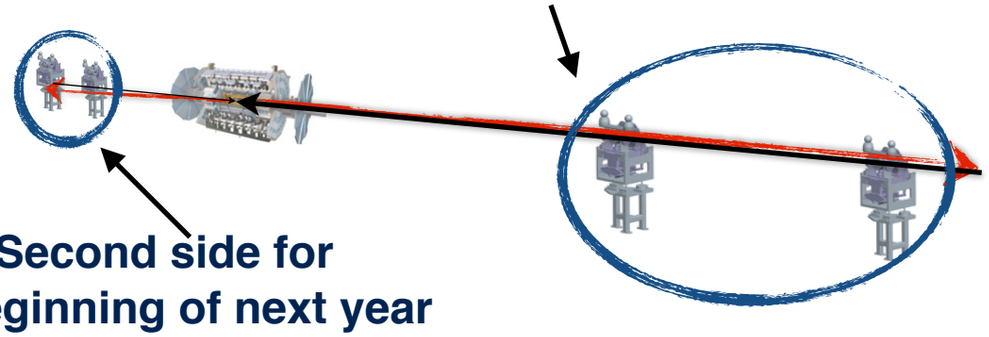
# Silicon tracker installation (AFP0+2)

- By December 2015 the installation of the silicon tracker on one side of ATLAS was foreseen for summer 2016
  - Still, were **able to produce 7 working modules ahead of time for installation** (26th of February 2016)
    - 4 (3) modules in C side FAR (NEAR) station
    - Short in HV line of one FAR station module prevents it from being biased
      - Still usable at 0 V: just with lower efficiency



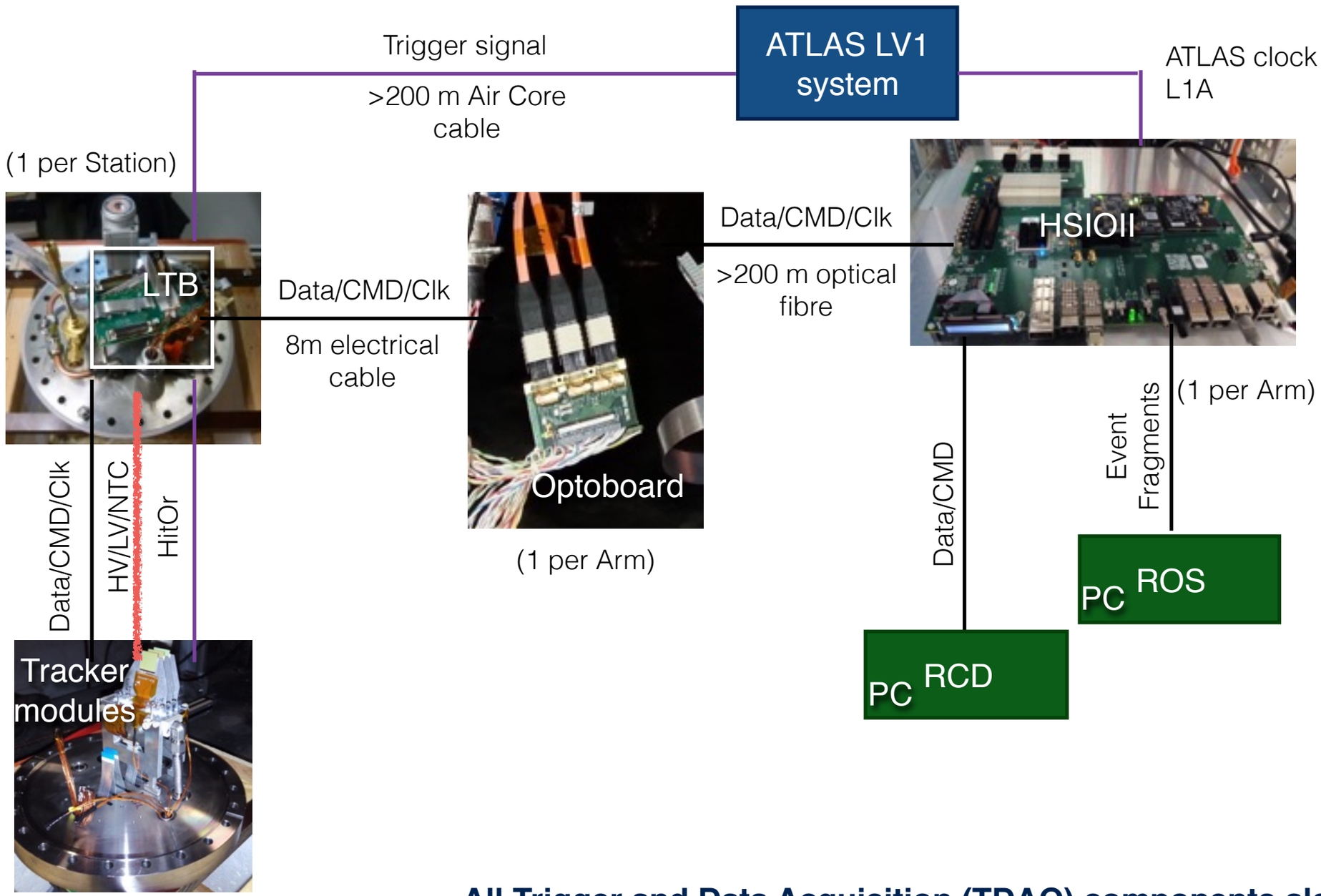


**Overall successful (and fast!) tracker installation on one side of ATLAS!**



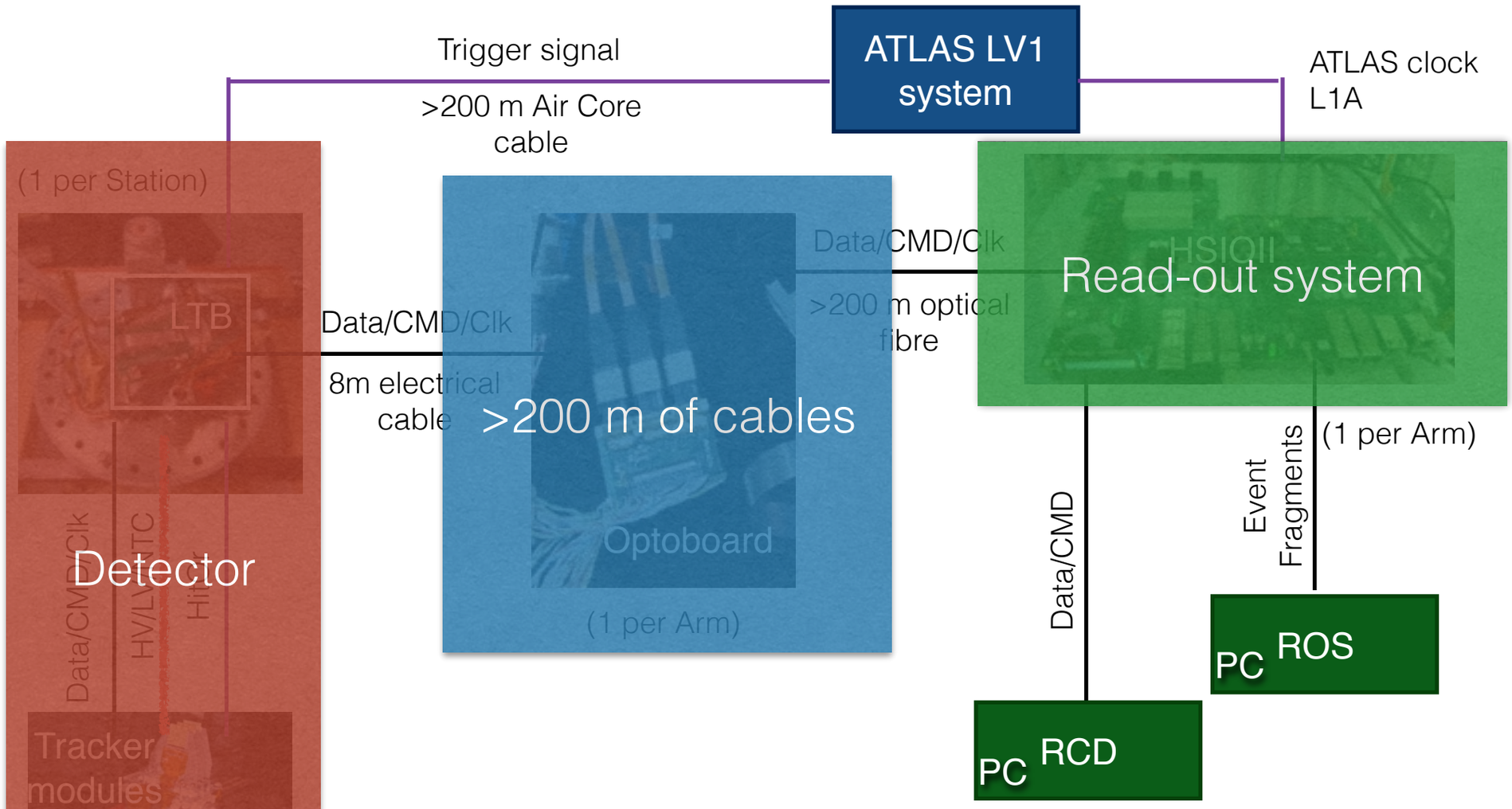
**Second side for beginning of next year**

# Read-out and trigger chain (AFP0+2)




**All Trigger and Data Acquisition (TDAQ) components also installed**

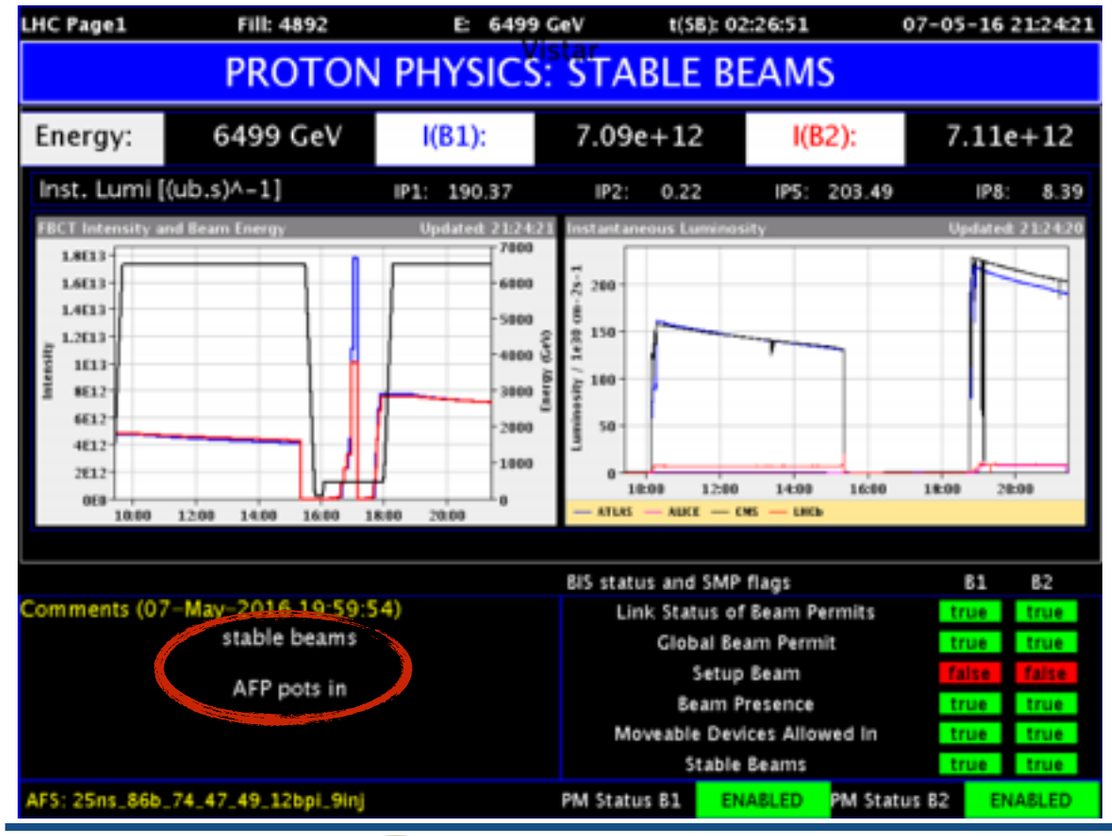
# Read-out and trigger chain (AFP0+2)




**All Trigger and Data Acquisition (TDAQ) components also installed**

# AFP0+2 running:
# First insertion & intensity ramp-up (part 1)

| Date | Fills with AFP inserted | TDAQ Mode |
|---|---|---|
| 19-22 April | Alignment and Loss Maps | AFP only |
| 23 April | 3 bunches | AFP only |
| 24-25 April | 12 bunches | AFP only |




Vistar

## IFAE Internal Newsletter #30

**Wednesday, 27th of April 2016**

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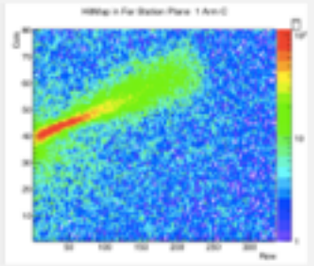
**AFP commissioning work at CERN: hit map of the first data taking in the beam**

The AFP detector was recently installed in the LHC beam line. The sensors installed inside the Roman Pots were produced at CNM-Barcelona and assembled and qualified at IFAE. The 18th of April, the AFP detector was inserted into the LHC beam for the first time, during its beam-based alignment and loss maps tests. I. Lopez and J. Lange are leading the AFP commissioning work at CERN.



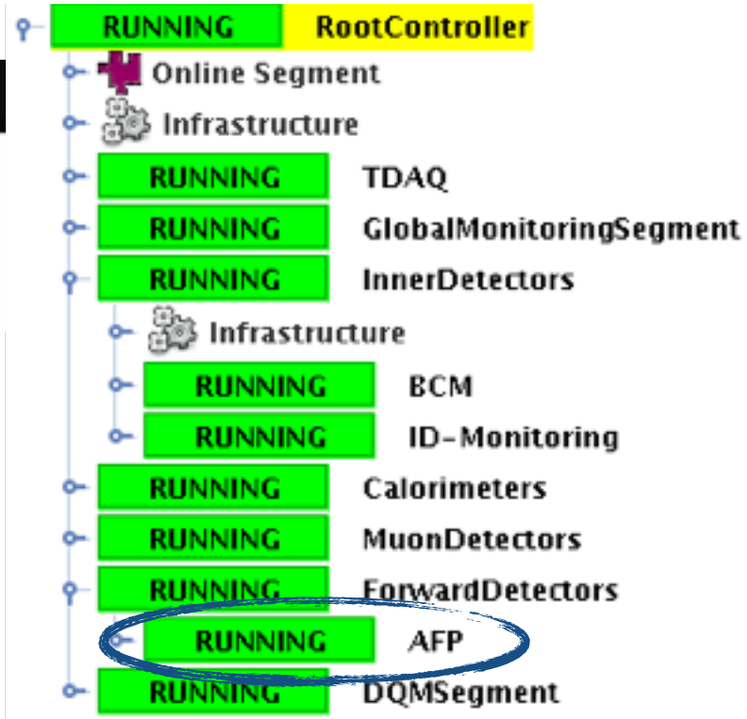
**First time AFP was inserted in beam position**

**LHC needs AFP to be inserted for validation during the intensity ramp-up after YETS**

# AFP0+2 running: Weasel break and integration

| Date | Fills with AFP inserted | TDAQ Mode |
|---|---|---|
| 19-22 April | Alignment and Loss Maps | AFP only |
| 23 April | 3 bunches | AFP only |
| 24-25 April | 12 bunches | AFP only |
| 29 April – 5 May | LHC power cut -> TDAQ integration | |

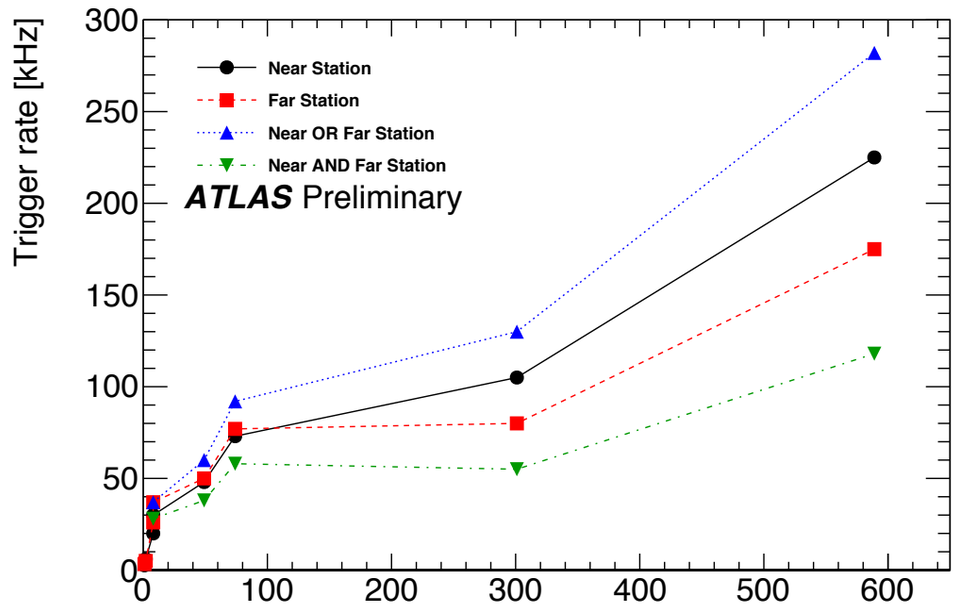

Weasel knocks out CERN's powerful particle accelerator




**Integrated AFP Data Acquisition into ATLAS**
**—> Can take data combined together with ATLAS**

# AFP0+2 running: Intensity ramp-up (part 2)

| Date | Fills with AFP inserted | TDAQ Mode |
|---|---|---|
| 19-22 April | Alignment and Loss Maps | AFP only |
| 23 April | 3 bunches | AFP only |
| 24-25 April | 12 bunches | AFP only |
| 29 April – 5 May | LHC power cut -> TDAQ integration | |
| 7 May | 49/86 bunches | with ATLAS |
| 9 May | 300 bunches | with ATLAS |
| 13 May | 600 bunches | with ATLAS |

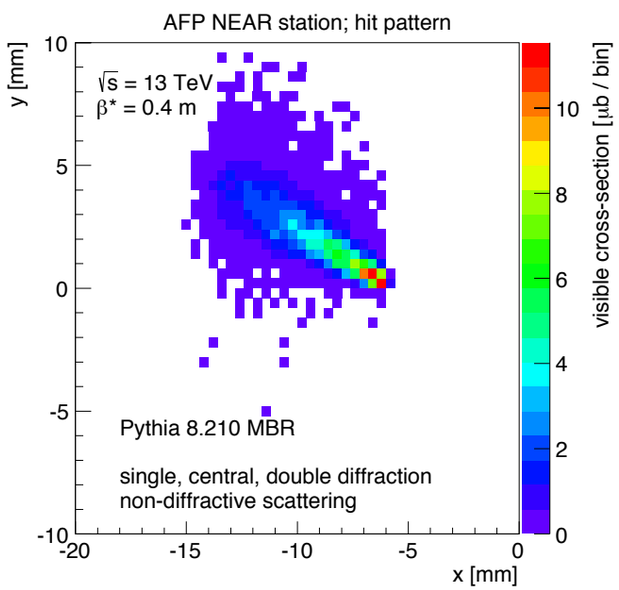


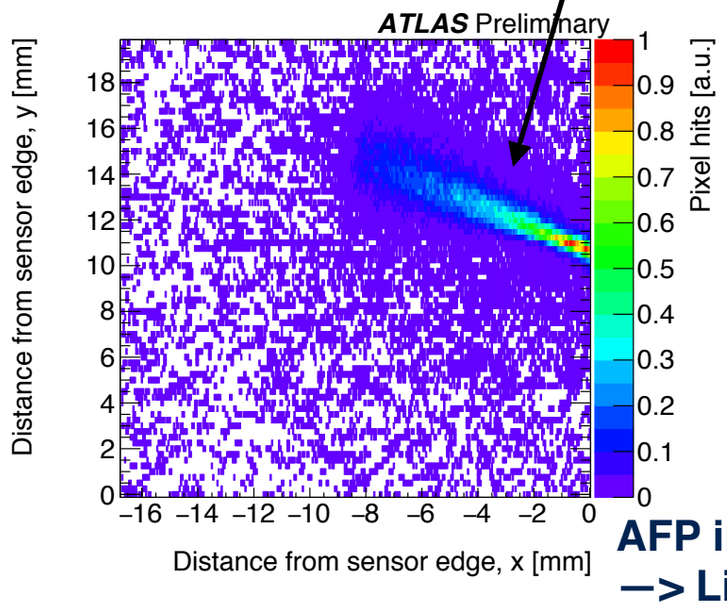

SIMULATION

$20\sigma$ nom.
$\beta$=0.40 m
$\sqrt{s}$ = 13 TeV

DATA

Diffractive protons



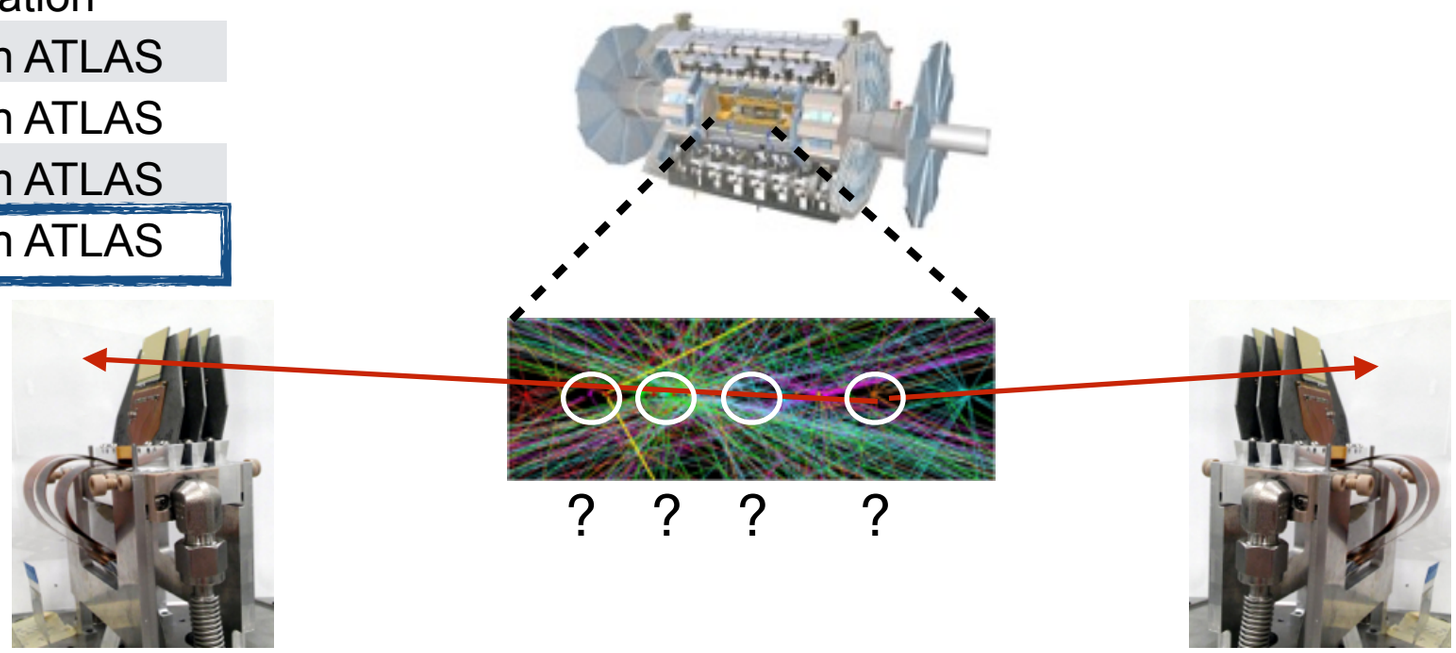




**AFP increases radiation intake on other forward detector**
**—> Limited in-beam time before AFP destroys it**

# AFP0+2 running: Low pile-up physics run

| Date | Fills with AFP inserted | TDAQ Mode |
|---|---|---|
| 19-22 April | Alignment and Loss Maps | AFP only |
| 23 April | 3 bunches | AFP only |
| 24-25 April | 12 bunches | AFP only |
| 29 April – 5 May | LHC power cut -> TDAQ integration | |
| 7 May | 49/86 bunches | with ATLAS |
| 9 May | 300 bunches | with ATLAS |
| 13 May | 600 bunches | with ATLAS |
| 31 July | 600 b. low-μ physics run | with ATLAS |

## Now the physics!

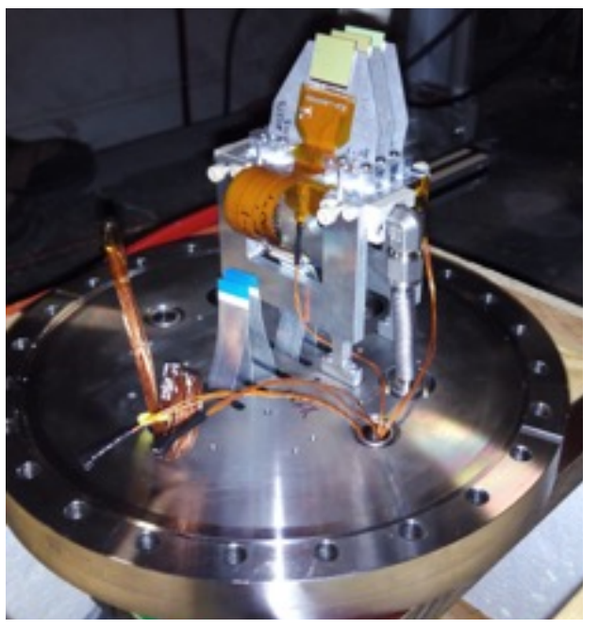



**Without Time-of-Flight can't cope with pile-up -> beam separation to reduce pile-up**

**—> AFP's special run at low pile-up coming the 31st of July for physics**

# Conclusions and Outlook

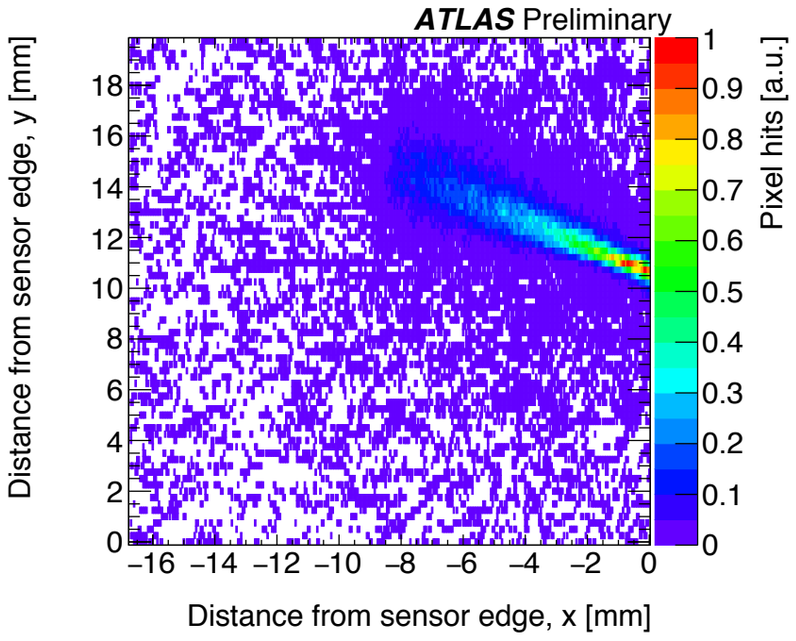
- **Conclusions**
  - 3D FE-I4 sensors were proven to be suitable for AFP:
    - Radiation hardness, small inactive area and good position resolution
    - Successful integration test beams with Time-of-Flight detector
  - 7 silicon tracker planes were successfully assembled, qualified and installed in AFP0+2 Roman Pots (in a very short time-scale!)
  - AFP has been successfully integrated with ATLAS TDAQ and took data during LHC's intensity ramp-up



**IFAE crucial for tracker production, beam test coordination, operation and TDAQ integration**

- **Outlook**
  - New silicon tracker production on-going -> Better quality than first production
  - Plan to replace installed modules with new production sensors during EYETS 2016-2017 and install the second AFP arm (AFP2+2)

**Low pile-up for physics run scheduled for this Sunday**
**Plan to have a first look at the data**



# Back-up