First testbeam results of prototype modules for the upgrade of the ATLAS strip tracking detector

ICHEP
Chicago, USA
4th August, 2016

Susanne Kuehn on behalf of the ATLAS Collaboration

Albert-Ludwigs-Universität Freiburg

38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

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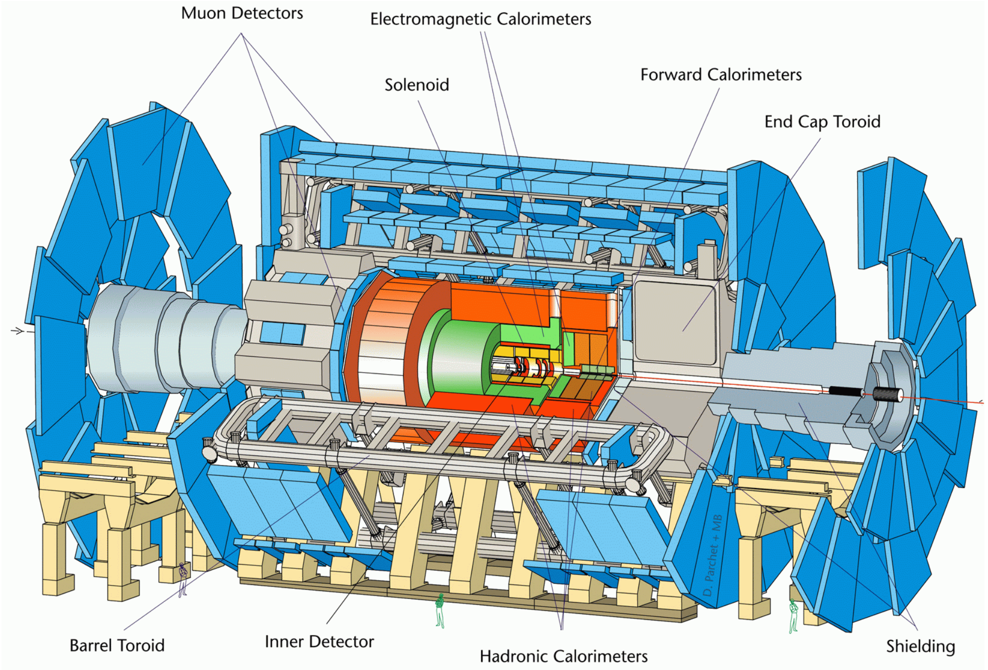
CHICAGO

Outline

- Introduction to Phase-II Upgrade of the Silicon Strip Tracker of the ATLAS experiment for the High-Luminosity LHC
- Concept and details of prototyping of the Silicon Strip Tracker
- Detector modules and testbeam setups
- Results for various detector prototypes
- Summary



Challenges for Tracking Detector at HL-LHC

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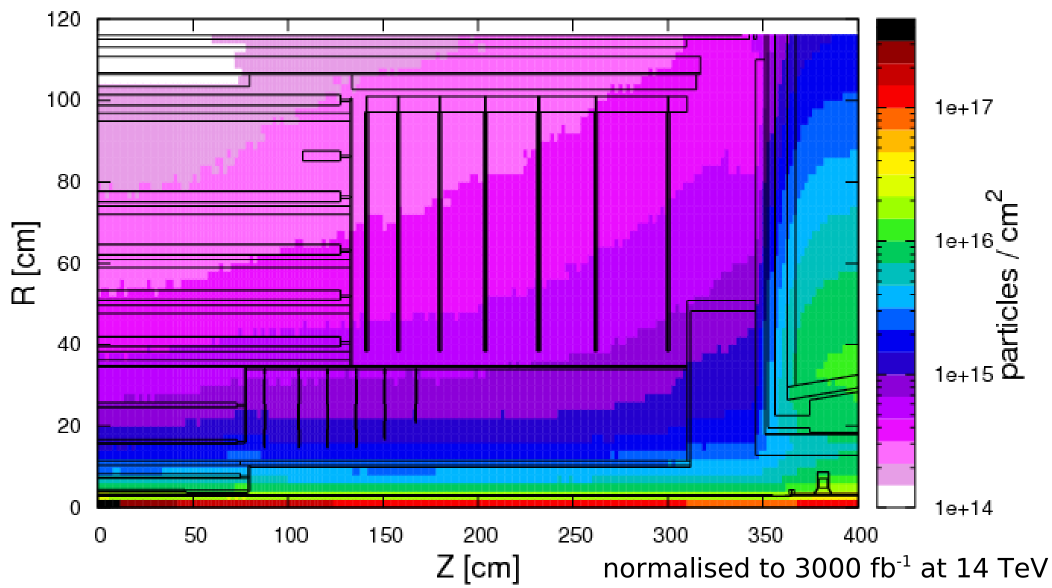
Upgrade of LHC to High-Luminosity LHC forseen in 2025

This morning: Guido Volpi, "ATLAS Upgrades for the next Decades"

- Luminosity of up to $7.5 \cdot 10^{34}$ cm^{-2}s^{-1}
  - Triggering with high rate and large event sizes
- Up to 200 simultaneous interactions per bunch crossing
  - High occupancy → keep at 1% level with higher granularity
- High particle fluences
  - Radiation hardness of up to $2 \cdot 10^{15}$ n_{eq}/cm^2 (strips)
  - Activation of material
- Low material budget



→ New tracker at the HL-LHC has to maintain the performance of the present Inner Detector under more difficult conditions
→ Decision to build new all-silicon tracker

New All-Silicon Tracker Layout

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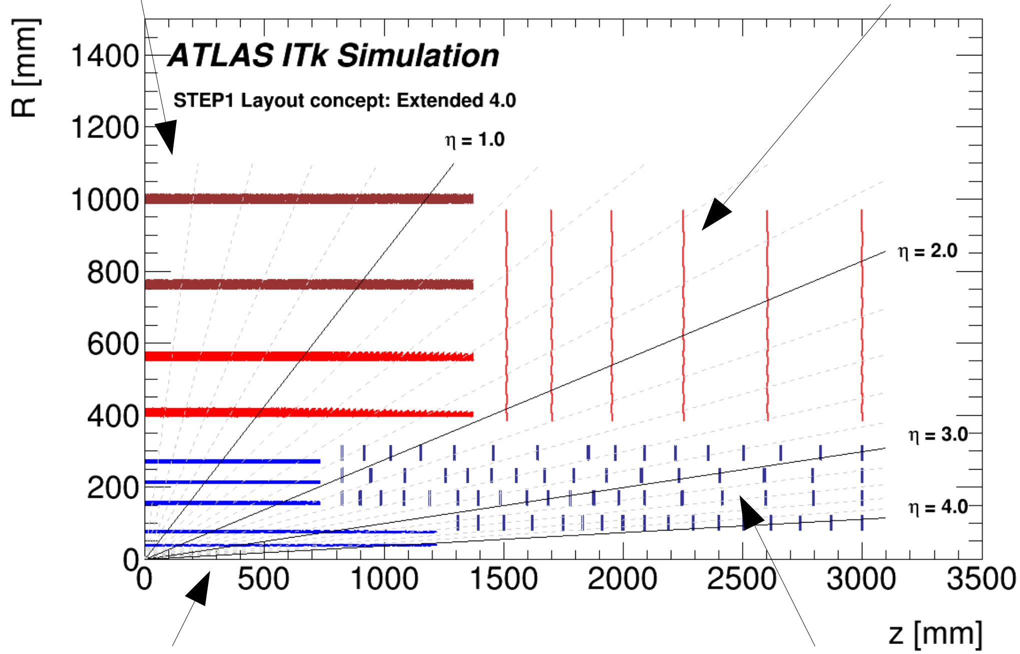
4 central strip layers

6 forward strip layers



5 central pixel layers

Multiple forward pixel layers

- In 2 T magnetic field
- ~6 m long, ~1 m radius
- Full coverage up to |η| = 4
- CO_2 cooling

Layout under finalization (1 out of 4 candidate layouts shown (vary in |η|-coverage and layout of forward pixel layers)

Poster session: Simon Viel, "Expected Performance of the ATLAS Inner Tracker Upgrade"

Technical Design Reports end of 2016 (strips) and 2017 (pixels)

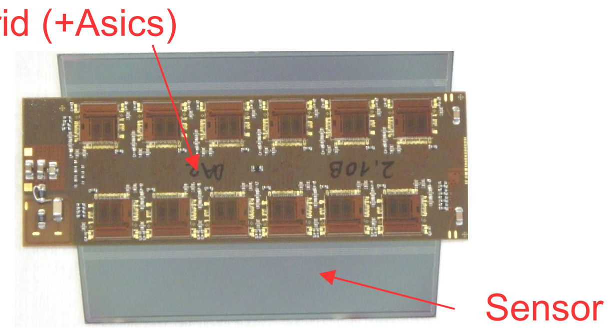
Detector	Area [m²]	Channels	Maximum dose [1MeV n_{eq}/cm²]
Pixel	> 8.2	> 638 M	up to $2*10^{16}$
Strips	up to 163	~ 50 M	up to $2*10^{15}$

CERN-LHCC-2015-020
CERN-LHCC-2012-022
ITK-2016-001

ATLAS

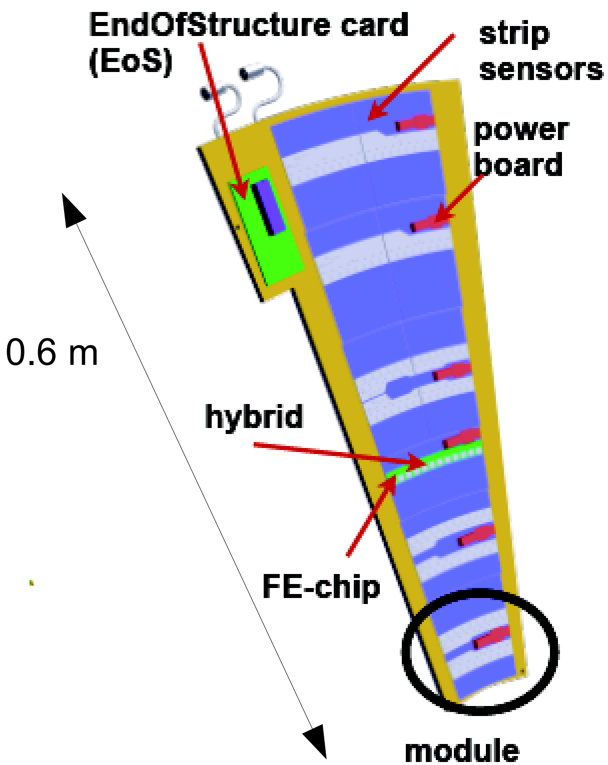
- Modularity for easier final assembly, multiple site production, early system tests

Module (6"): ~ 20,000

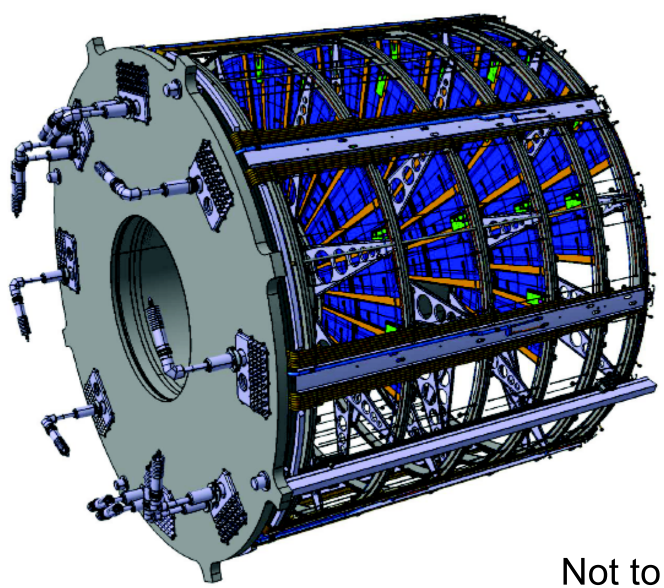


For central (barrel) region: Same concept with modules and staves

Carbon core with double-sided modules (sketch: **petal**), ~ 384



End cap with petals: radius ~1 m, 2 end caps



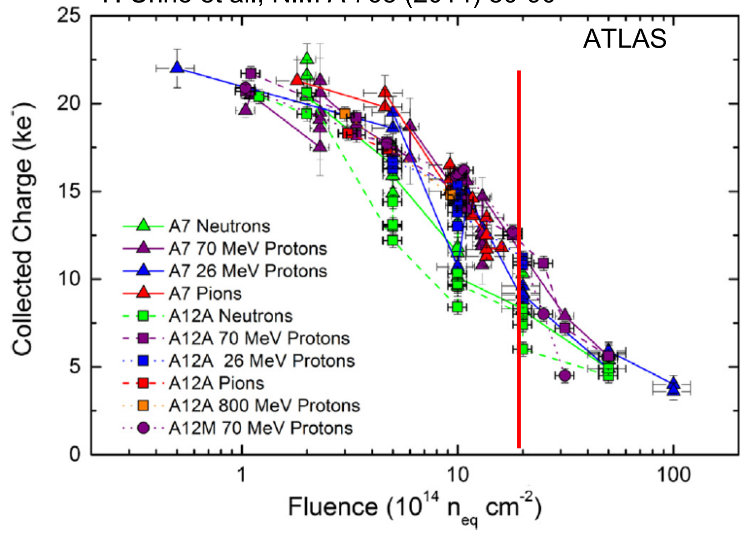
Not to scale

Sensor Design and Readout Electronics

Silicon sensors

- n-in-p float-zone strip sensors with p-stop isolation
- ~320 μm thick
- Covering 97x97 mm^2 (in barrel region)
- Strip length 14-58 mm

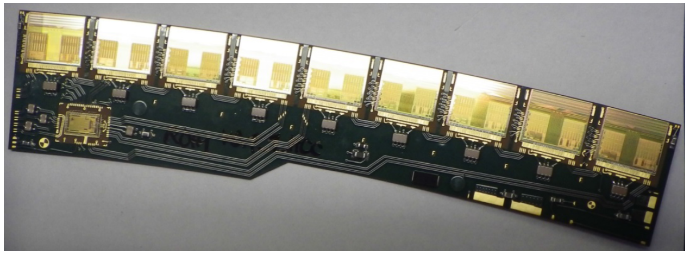
K. Hara et al., NIM A DOI:10.1016/j.nima.2016.04.035
Y. Unno et al., NIM A 765 (2014) 80-90



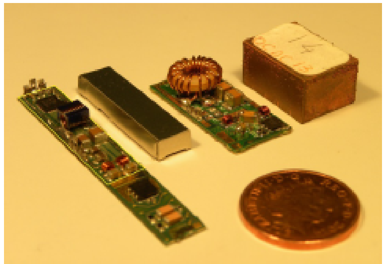
Collected charge after proton, neutron and gamma irradiation, β-source tests after 80 min annealing at 60°C

Readout electronics

- Binary readout chip (130 nm CMOS) and hybrid controller chip (~3 W per module with 20 Asics)
- Data transfer on hybrid at 320 Mbit/s and on bus tape with up to 640 Mbit/s
- DC-DC powering for increased power efficiency
- HV multiplexing



End cap hybrid with ABC130 chips



DC-DC converter

Module prototypes with binary readout

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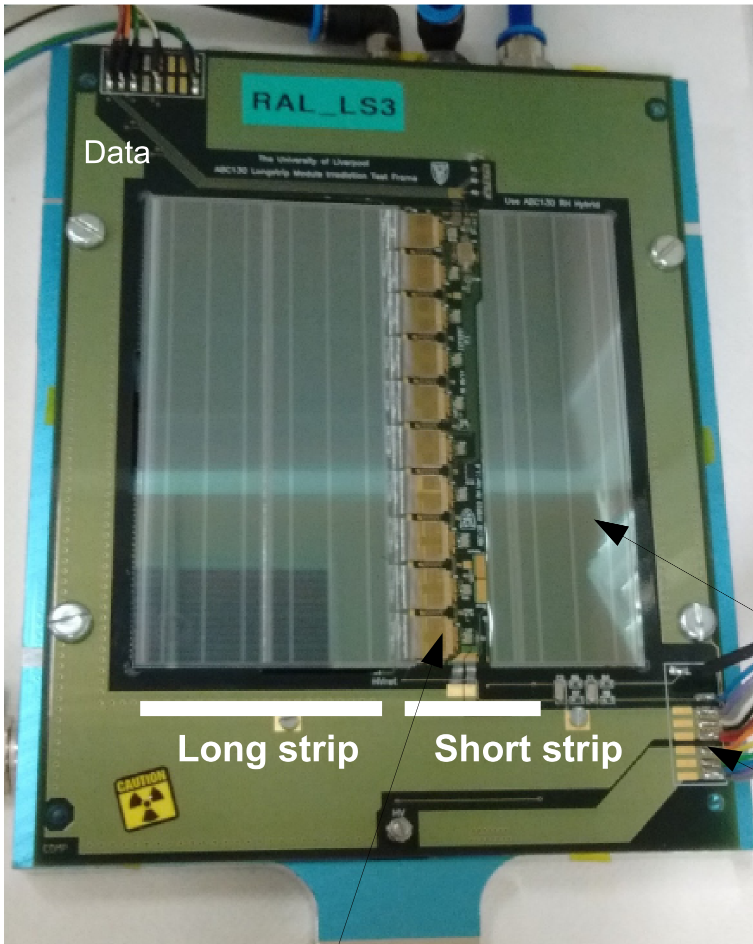
Module for barrel region

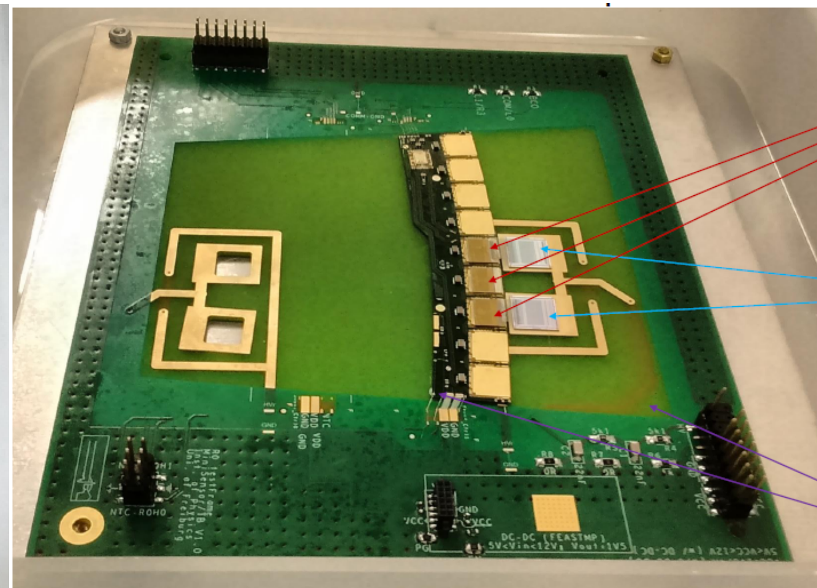


Hybrid with 10 ABC130 chips bonded to a region of long strips (two segments stitched) and of short strips

10 x 10 cm² sensor with 4 strip segments of 24 mm

LV / HV

Mini module for end cap region



3 ASICS ; 2 of which are connected to sensors, 1 which completes the chain but is not connected to anything (can be ignored).

2 Mini Sensors (1cm x 1cm)

R0H0 Frame and Hybrid

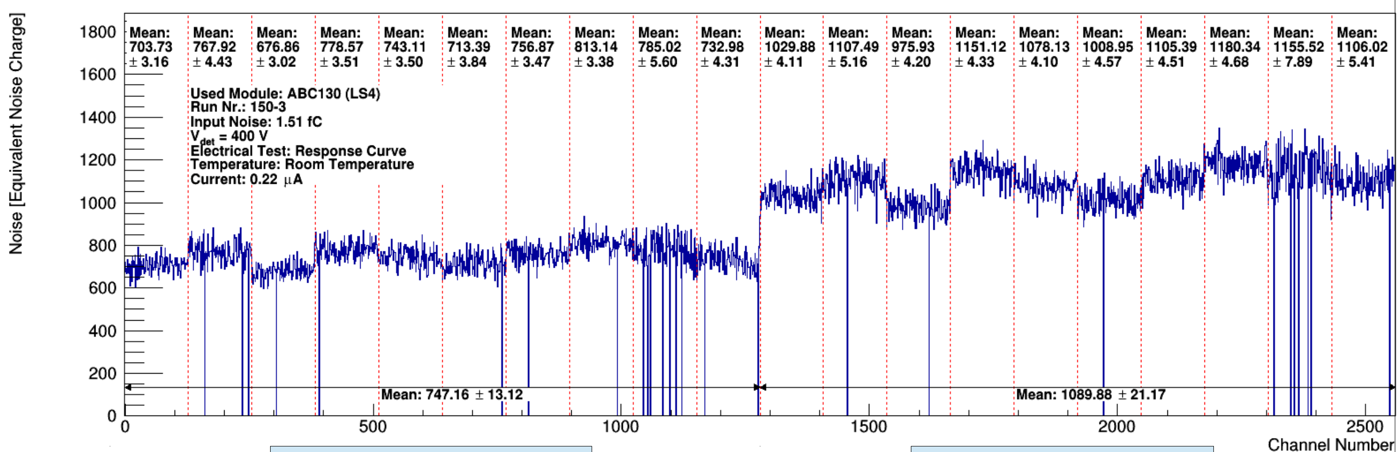
Both types unirradiated and irradiated tested

Tests of modules: unirradiated

Electrical tests with binary readout

- IV curves, threshold scans (noise and gain measurements)

Noise for barrel module (fully depleted, I_l= 0.2 µA at 400 V)



Short strips

Long strips

Noise 747±13 ENC

Noise 1090±21 ENC

Gain varying 75 – 85 mV/fC

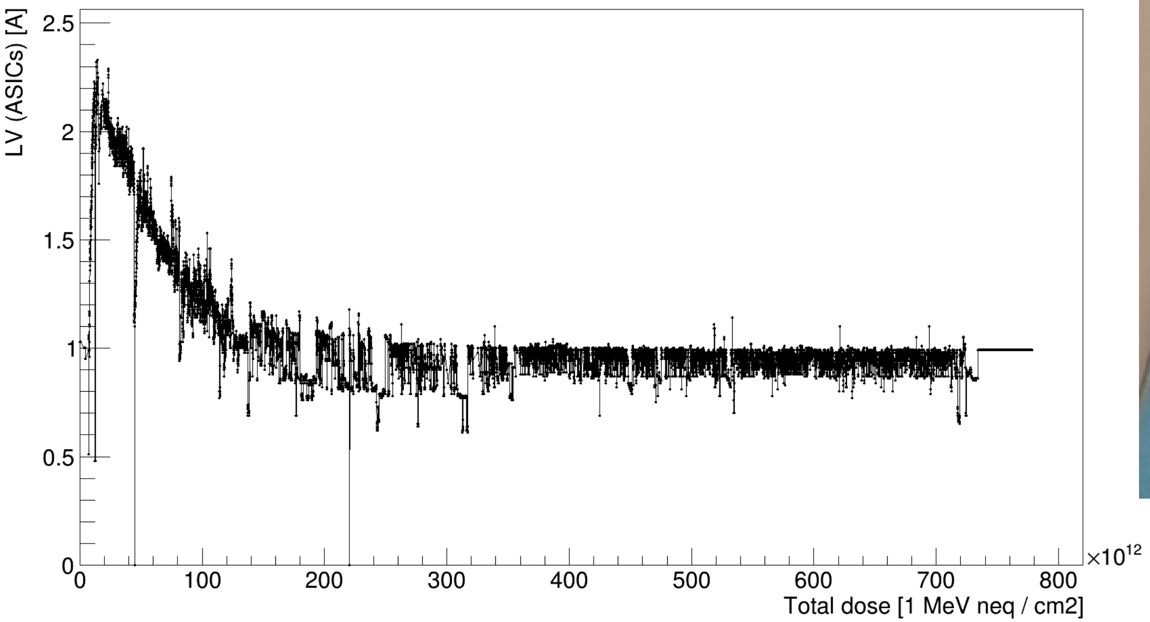
Noise for end cap module

- Unbonded channels ~440 ENC
- Bonded channels ~540 ENC
- After neutron irradiation of sensor to 2×10^{15} n_{eq}/cm² and ASIC to 4 Mrad with x-rays: Bonded channels ~640 ENC (at 400 V)

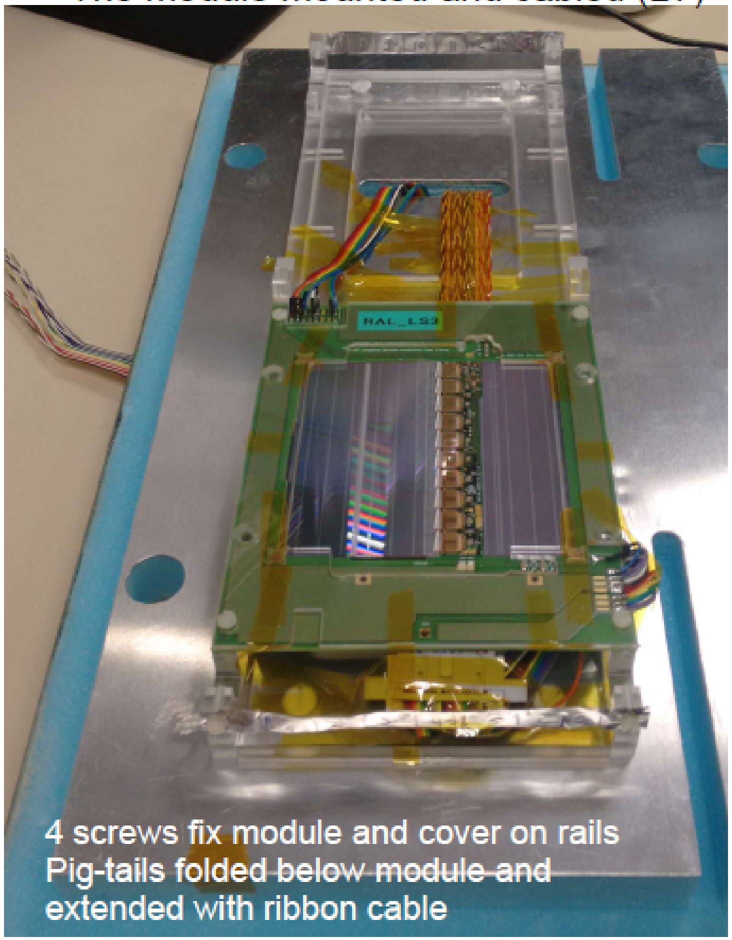
Results for unirradiated end cap and barrel devices with mini sensors similar

Irradiation of full-size barrel module

- Full-size module irradiated in PS at CERN with protons to 7×10^{14} n_{eq}/cm^2 ~ 37 Mrad
- Irradiated cold (~ -20°C) and Asics powered
- Radiation induced change of low voltage of Asics observed during irradiation



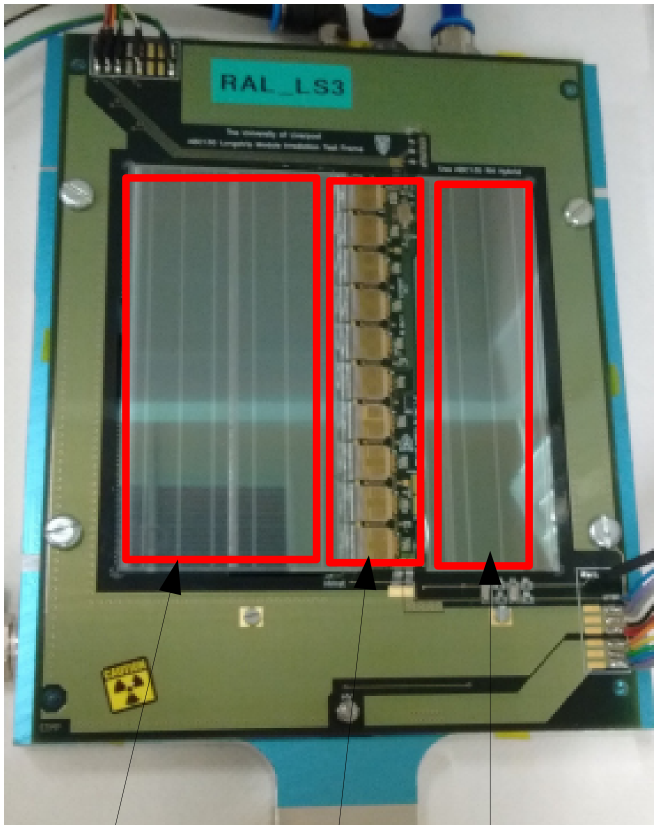
The module mounted and cabled (LV)



Tests of irradiated module

Electrical tests

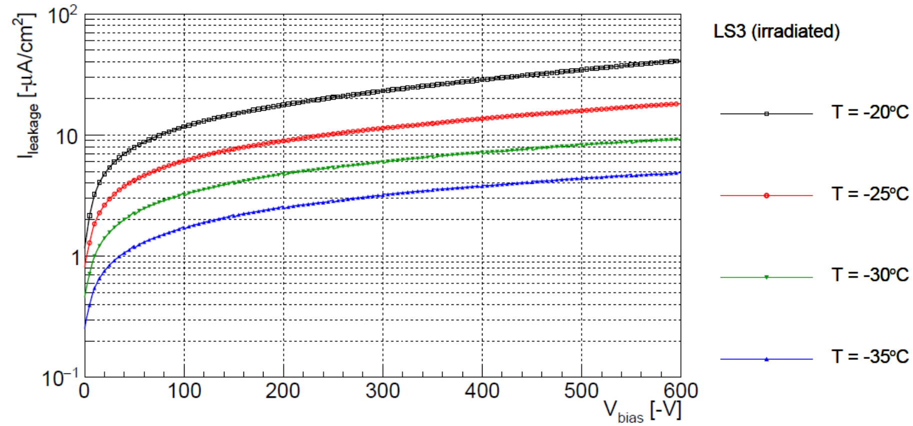
Module functional after irradiation



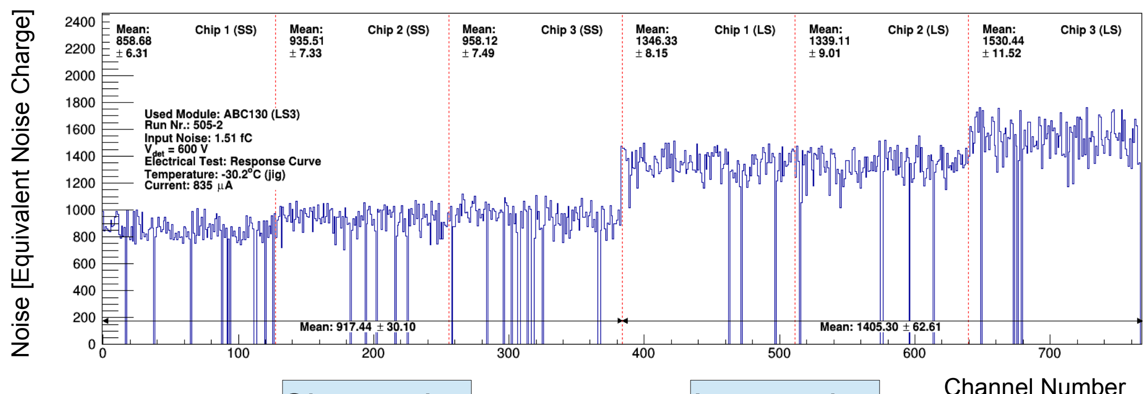
Long strip Asic 1-10

Short strip Asic 1-10

Not bonded



Noise at 600 V (max. voltage, I_l= 835 µA) (detailed analysis still ongoing)



Short strips → Noise ~920 ENC

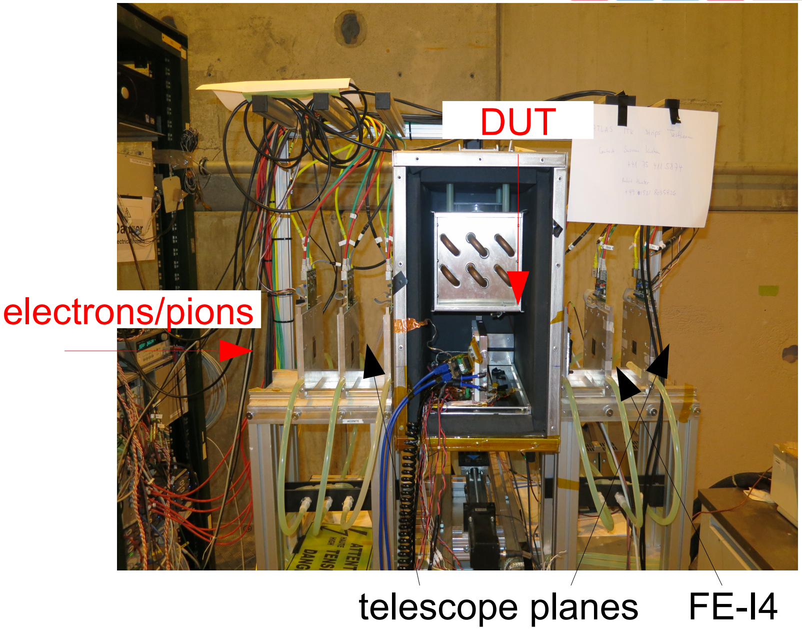
Long strips → Noise ~1410 ENC

Testbeam measurements

- Several conducted during last years at SLAC with 10 GeV electrons, at DESY with 4.8 GeV electrons and at CERN with 120 GeV pions

- Use of EUDET style telescopes (6 planes) for tracking and FE-I4 pixel detector for timing (rolling shutter readout of telescope sensors)

- Different DUTs in box on x-y-stages allow investigation of behaviour of Asics and sensors, separately and before and after irradiation
  - **Unirradiated barrel and end cap mini modules, full-size barrel module (May and Oct. 2015)**
  - 11 positions on unirradiated full-size barrel module and irradiated end cap mini module (May 2016)
  - 3 positions on irradiated full-size barrel module (July 2016)



Testbeam results: general

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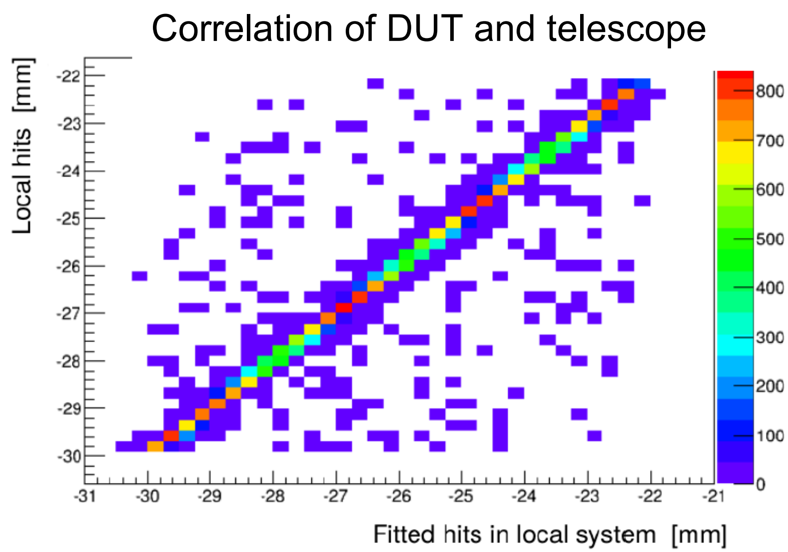
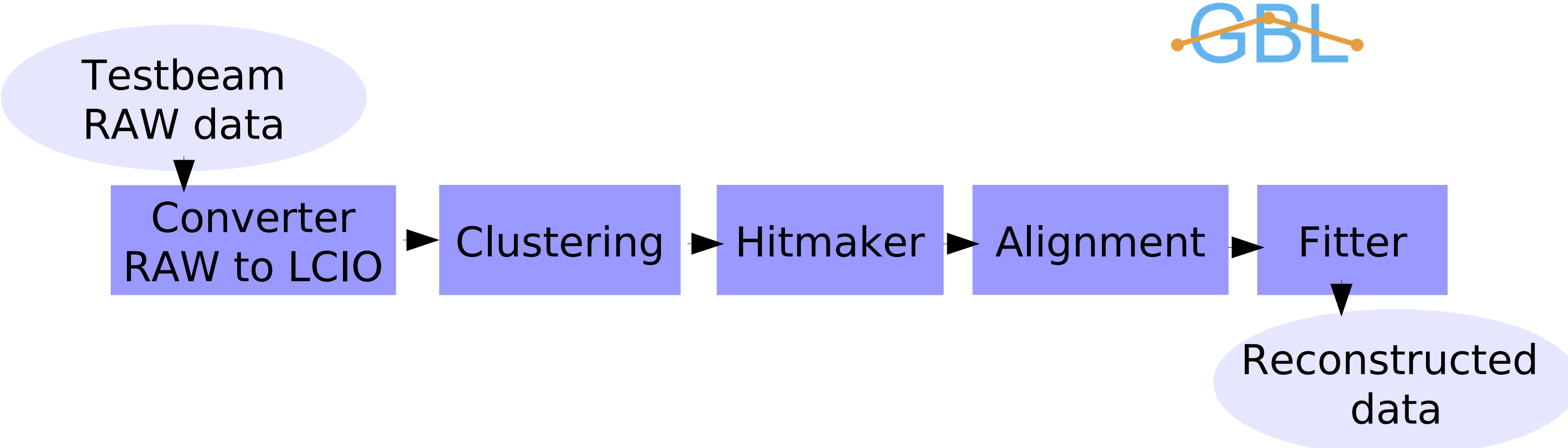
- Testbeams allowed stable running of full hybrids with binary Asics in testbeam infrastructure (after debugging by DAQ experts, desynchronisation in time occuring which is treated offline)
- Characterization of DUTs with externally triggered binary readout, rate 200 – 300 Hz
- Deploy General Broken Lines algorithm* for tracking and EUTelescope software for reconstruction



GBL



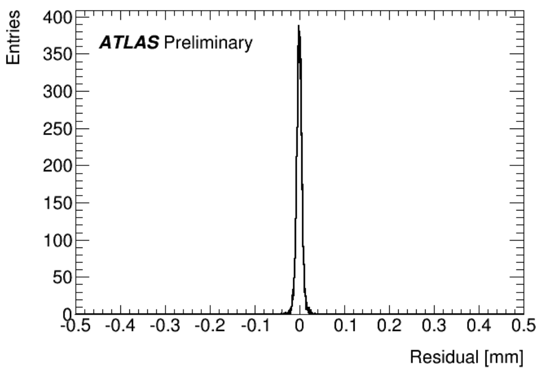
* Nelson et al., Track reconstruction and alignment for ATLAS Devices Under Test, DESY note, 2014

Mini modules for end cap region

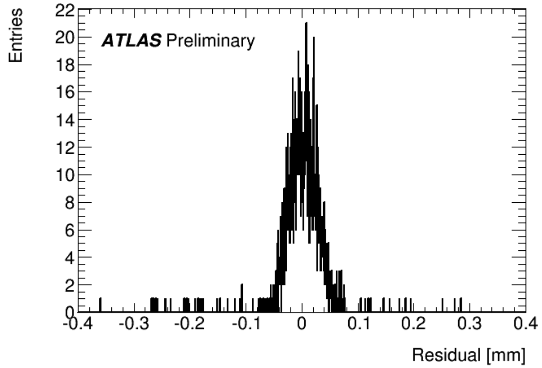
Analysers: Marc Hauser Freiburg, Riccardo Mori Freiburg

- Residuals <6 μm for telescope, ~35 μm for DUT

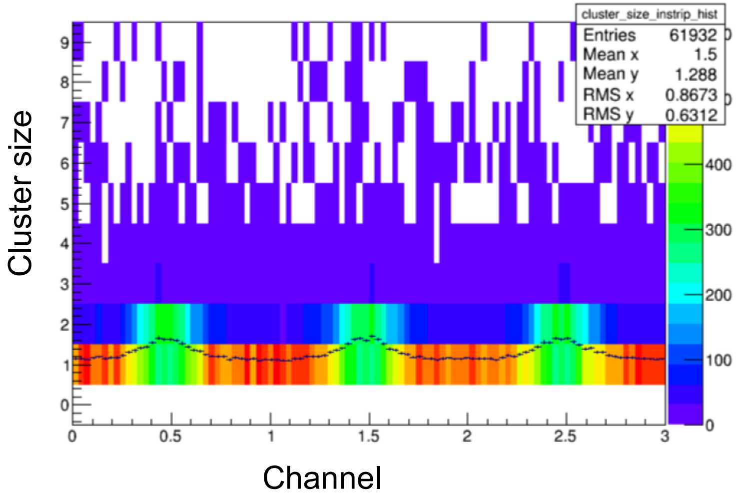
Telescope planes



DUT (HV = 450 V, threshold 303 mV)



- Average cluster size at low thresholds around 1.5 between strips



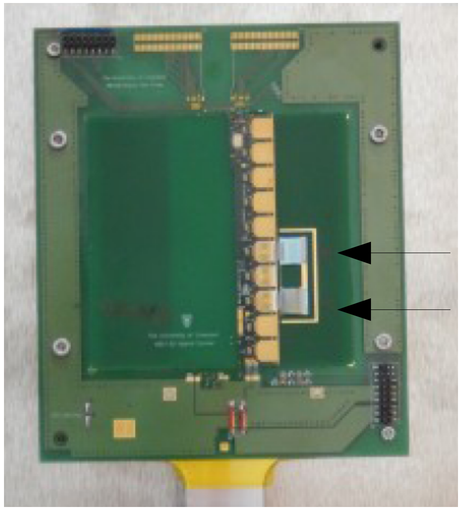
Clustersize (modulo 3 strips)

DUT (HV = 350 V, threshold 67 mV < MPV)

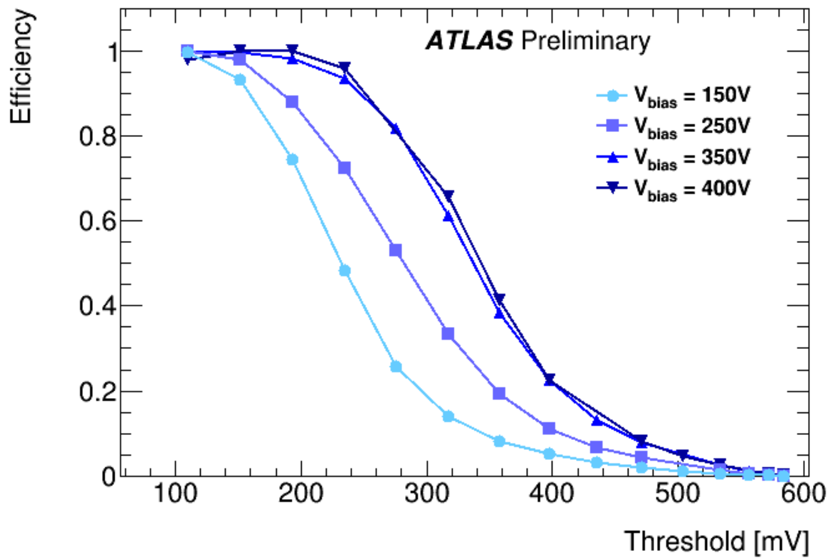
Testbeam results: mini barrel module

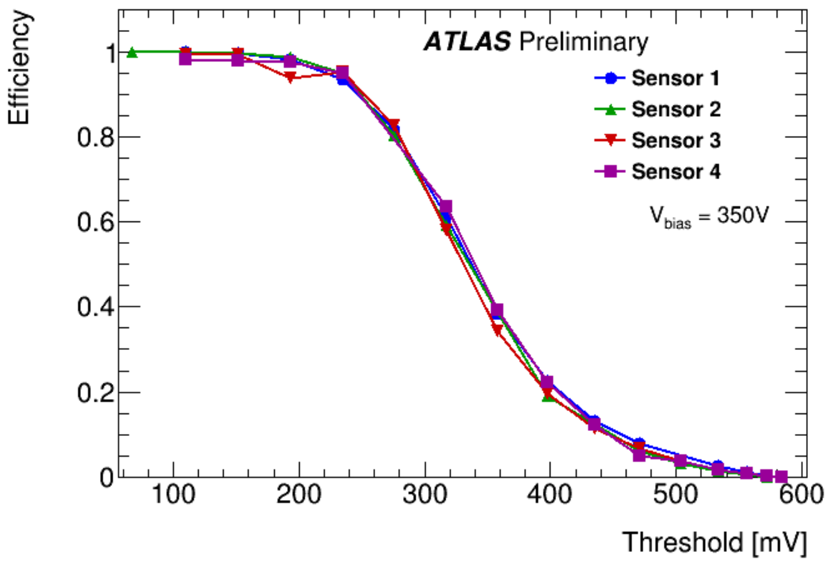
Two mini modules for barrel region

- Investigation of signal and efficiency
- Efficiency for various bias voltages: #hits(DUT)/#hits(track&FE-I4 hit)
- Similar amount of collected charge for all mini modules (absolute charge calculation ongoing)



Analysers: Lucrezia Bruni Nikhef, John Keller DESY, Richard Peschke DESY

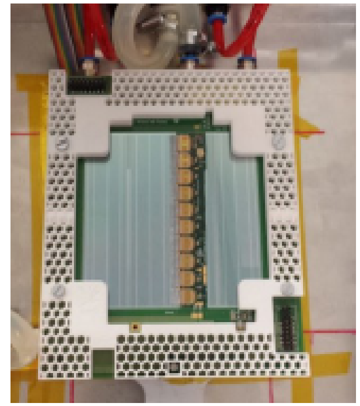


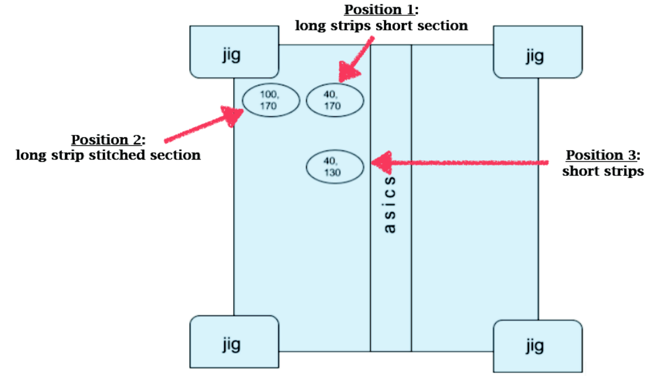


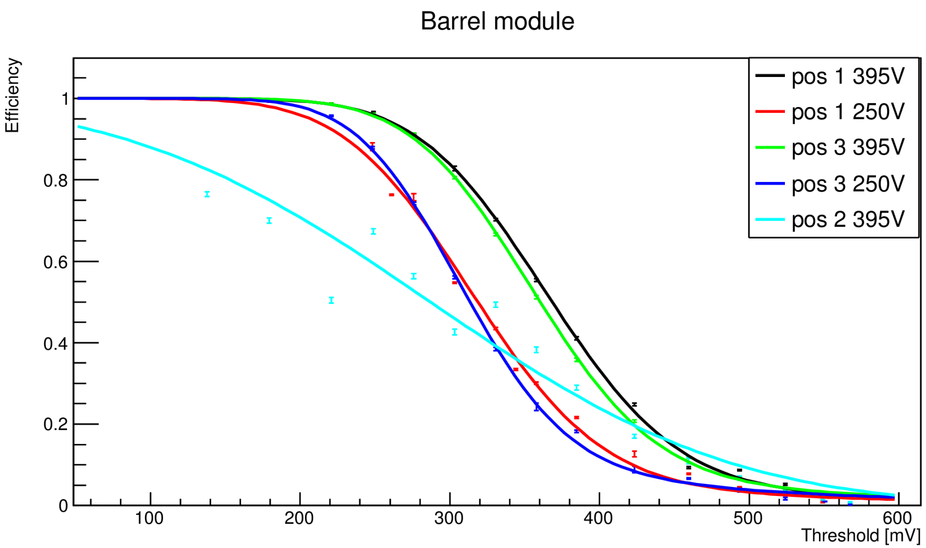
Testbeam results: full-size module

Full-size module for barrel region

- Investigation of signal and efficiency
- Residuals 5 μm for telescope, 35-45 μm for DUT
- Efficiency: #hits(DUT)/#hits(track&FE-I4 hit)







Analysers: Lucrezia Bruni Nikhef, John Keller DESY, Richard Peschke DESY

- Gain calculation and determination of absolute amount of signal ongoing
- Similar behaviour in signal collection for short and long strip region
- Estimate of signal/noise with (MPV – pedestal) / noise
  - Long strips @395V ~ 29
  - Short strips @395V ~ 50

Summary

- All-silicon tracker for HL-LHC for the ATLAS experiment foreseen
- Strip tracker has modular concept
- Prototyping and measurements of modules in Inner Tracker Upgrade Collaboration heavily pursued
  - Several test beams successfully conducted
  - Tests before and after irradiation to expected fluences at the HL-LHC
  - Mini modules for central and end cap region show similar behaviour
  - Measurements show high efficiency and high signal to noise ratio before irradiation, analysis after irradiation ongoing
  - Performance in noise as expected
- Started to prepare comparisons to simulation data and measurements with a beta source
- Results will be collected in Technical Design Report
- Results with x-ray testbeam taken in parallel (http://arxiv.org/abs/1603.04846)

Acknowledgment

Thank you !

Thank you to all collaborators contributing to the testbeams

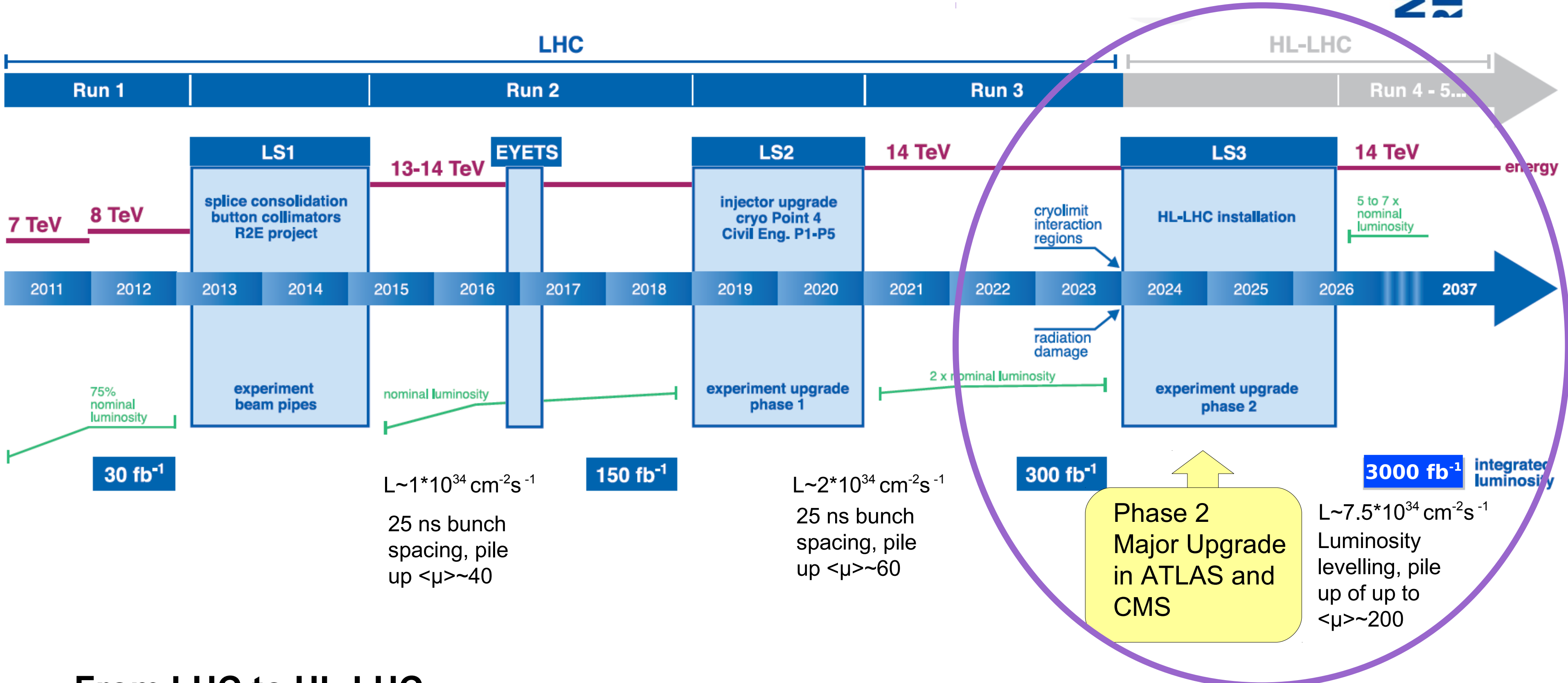
This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

Spares

From LHC to HL-LHC

LHC/ HL-LHC Plan (last update Oct. 2015)



From LHC to HL-LHC

Instantaneous luminosity x5 → Particle densities x5

Integrated luminosity x10 → Radiation damage x10

Increase of overlap of proton-proton events (pile up x5)

From LHC to HL-LHC

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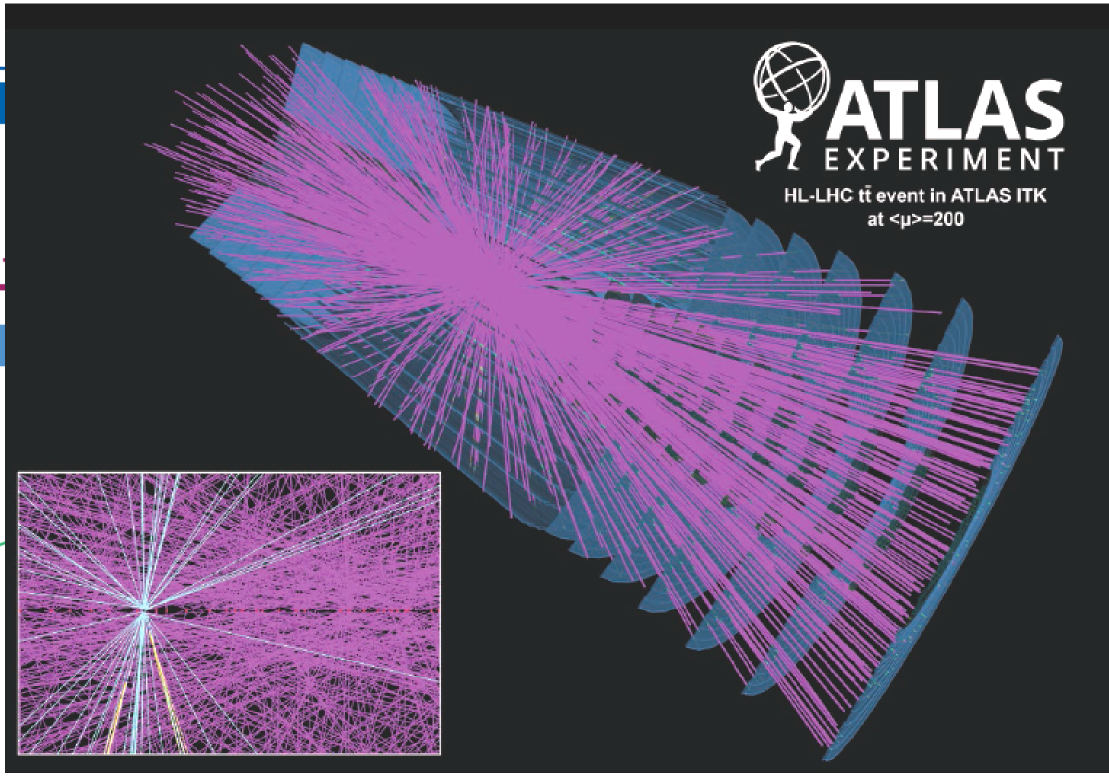
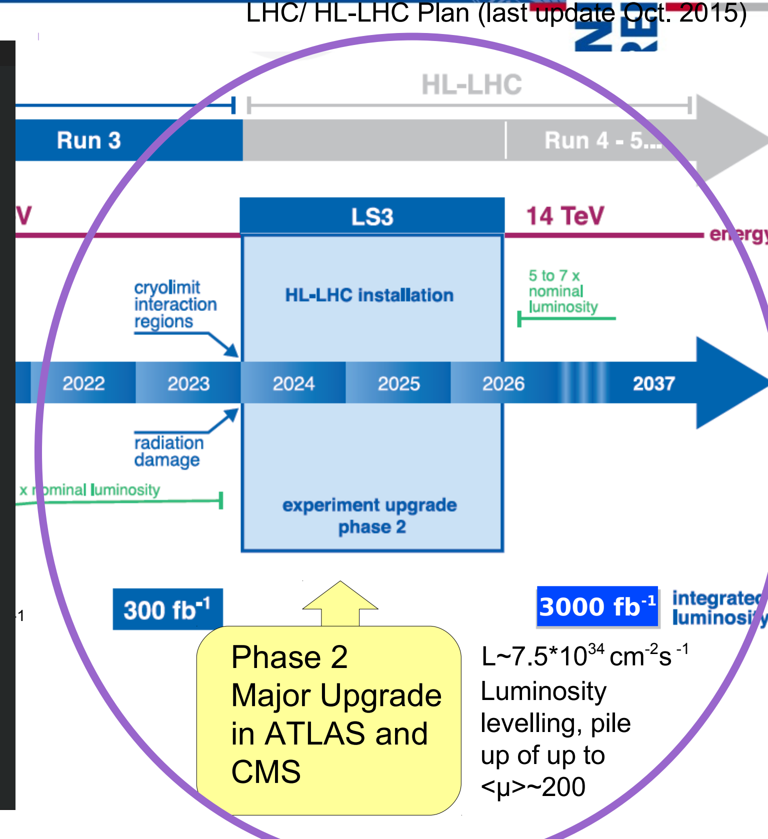




Phase 2
Major Upgrade in ATLAS and CMS

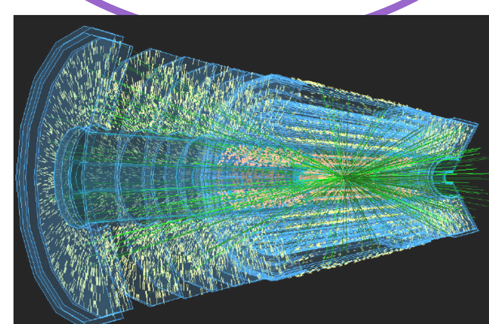
$L \sim 7.5 \cdot 10^{34}\,cm^{-2}s^{-1}$
Luminosity levelling, pile up of up to $\langle\mu\rangle \sim 200$

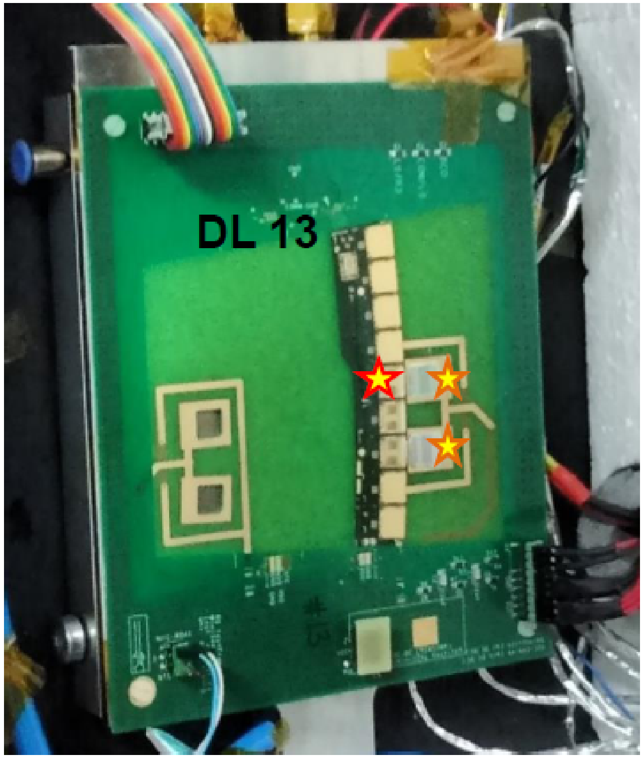
From LHC to HL-LHC

Instantaneous luminosity x5 → Particle densities x5

Integrated luminosity x10 → Radiation damage x10

Increase of overlap of proton-proton events (pile up x5)


Simulated event with muons and average pile up of 140 collisions per bunch crossing



DL 13

Irradiated Sensors (Both)
neutron irradiated to $2E15 neq/cm^2$, annealed at 60C for 80min
One Irradiated ASIC
xray irradiated to 4MRad (over TID peak), 0.85Mrad/hr at -5C

4

DL 14

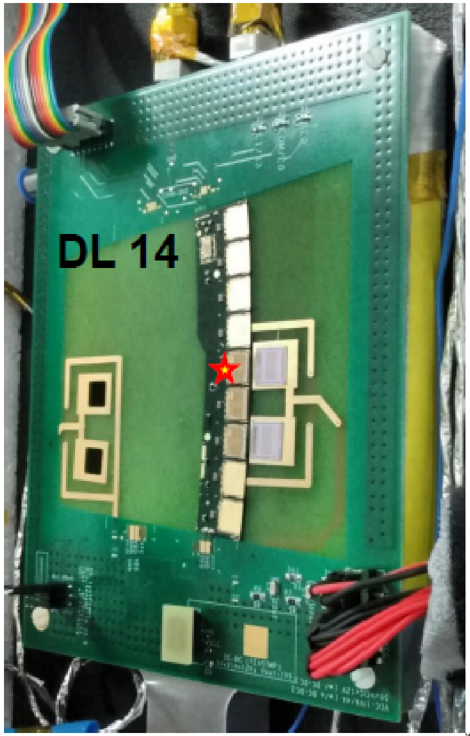
UN-Irradiated Sensors (Both)
One Irradiated ASIC
xray irradiated to 1.45MRad (at the TID peak), 0.85Mrad/hr at -5C

Legend:

★ : x ray irradiation
(size gives rough dose info)

★ : neutron irradiation

Thus, have all four possible combinations of unirradiated and irradiated sensor and ASIC.



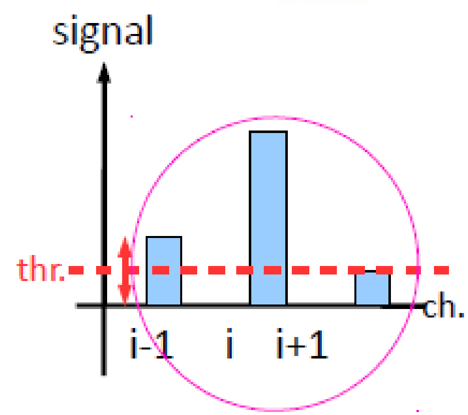
Robert Hunter

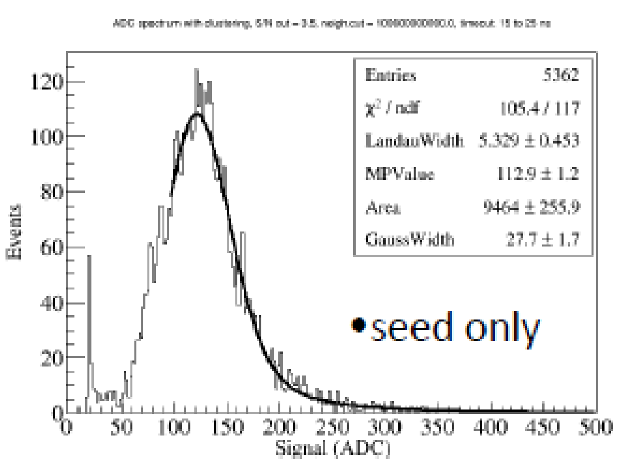
Consideration for binary readout

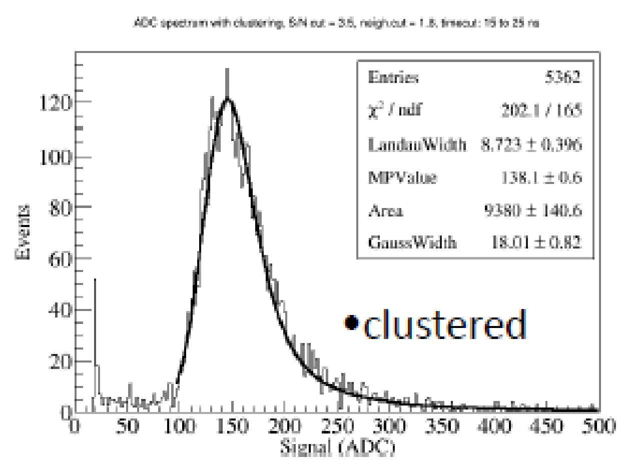
- Binary system takes only the occupancy from threshold scans:
  - Clustering procedure is not directly possible.
    → no directly measure of full charge
    (only charge of seed available.)

- Analogue system with beta source:
  - doesn't give position information, but clustering is possible.
    → full charge (and also on seed only).

  - Charge distribution from seed only is not Landau-shaped:
    => no direct comparison between MPVs.







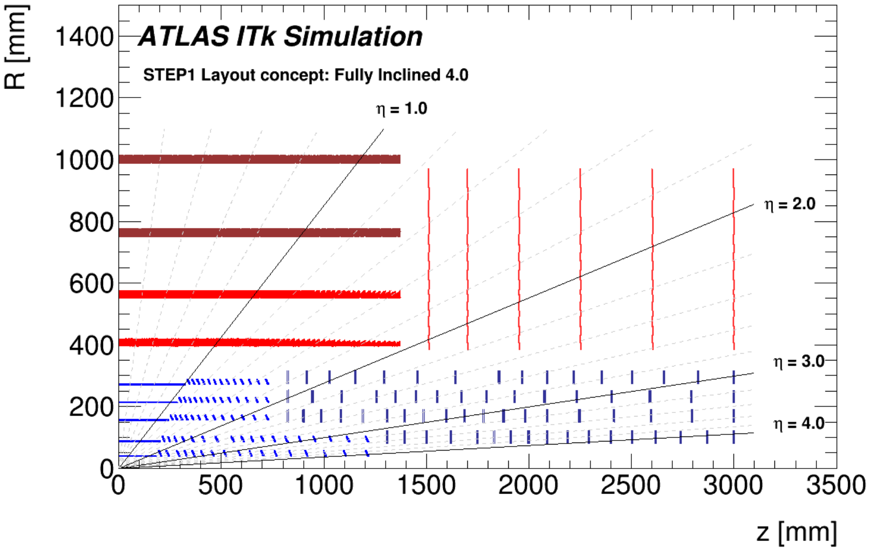
[4] Testbeam crew, AUW, 11.2015.

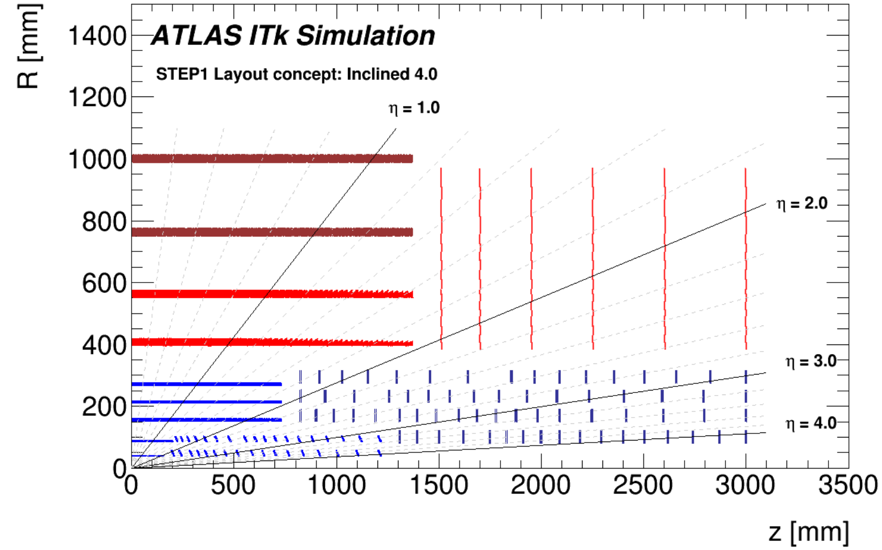
From Riccardo Mori, Freiburg

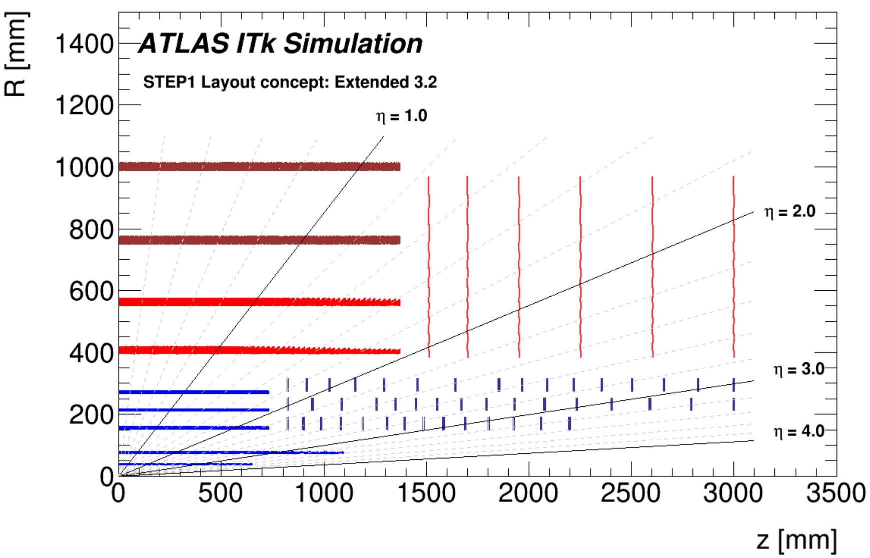
Further optimization of layout

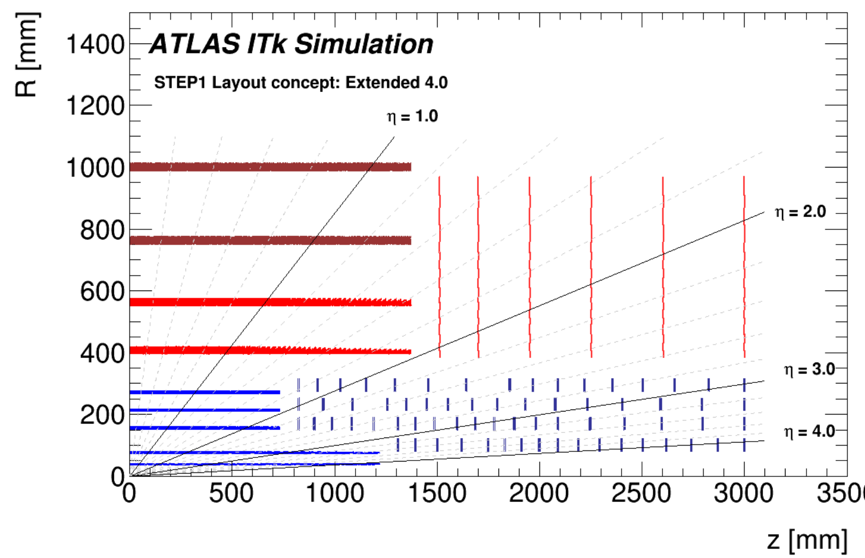
ITK-2016-01

ITK-2016-01





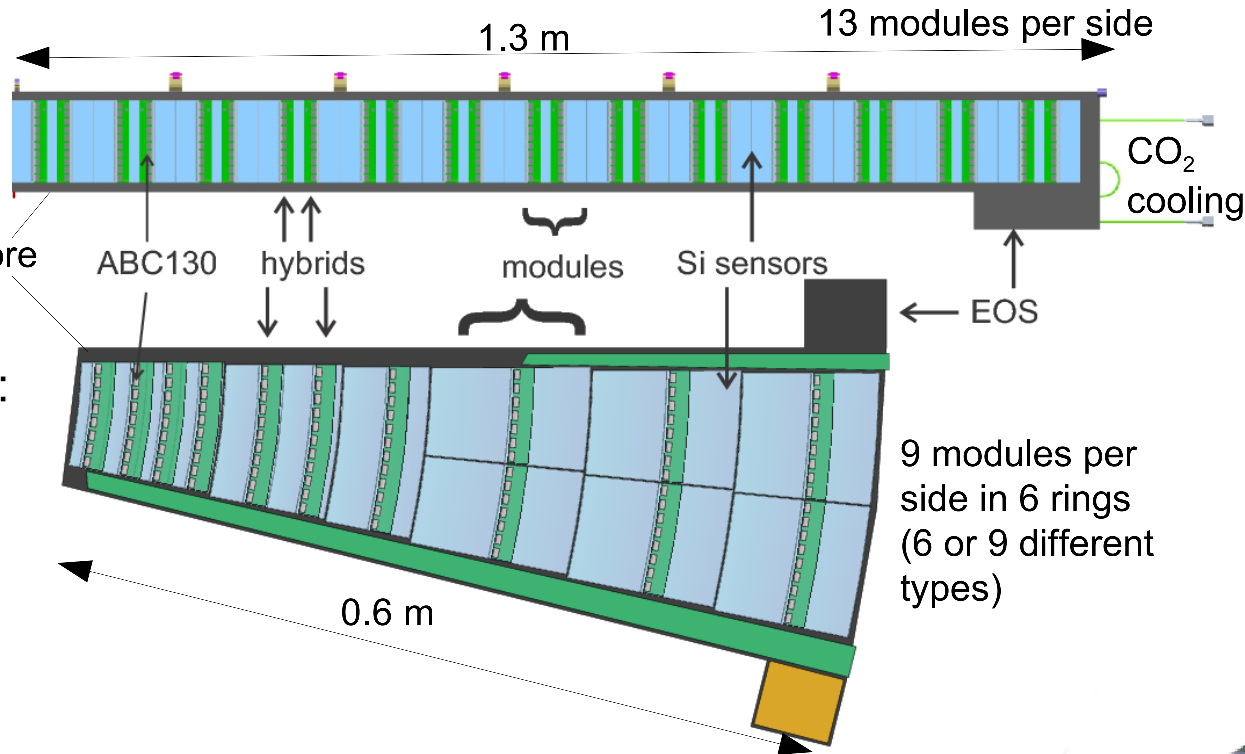




Layout of staves/petals and modules

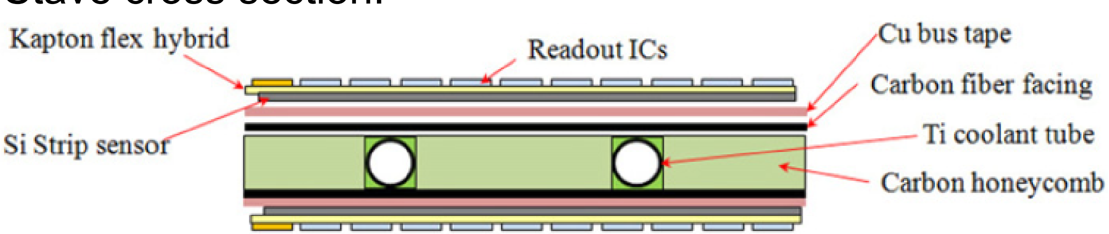
Barrel: Staves

Endcap: Petals

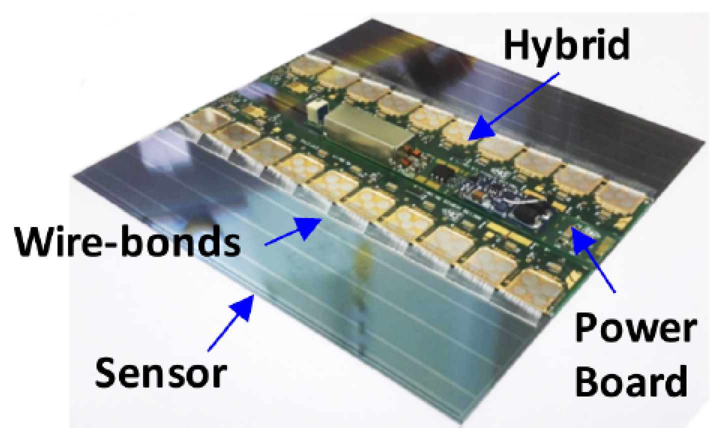


- double-sided
- low material
- rigidity
- simplify assembly for large scale production

Stave cross section:



NIM A 699(2013)93–96



Design of Central Strip Detector

- Assembly of pre-built support structures, end insertable including cabling and cooling

Staves: 10° tilted, in total 472 staves (~13,000 modules)