The ATLAS ITk Strip Detector for the Phase-II LHC Upgrade

6 September 2023

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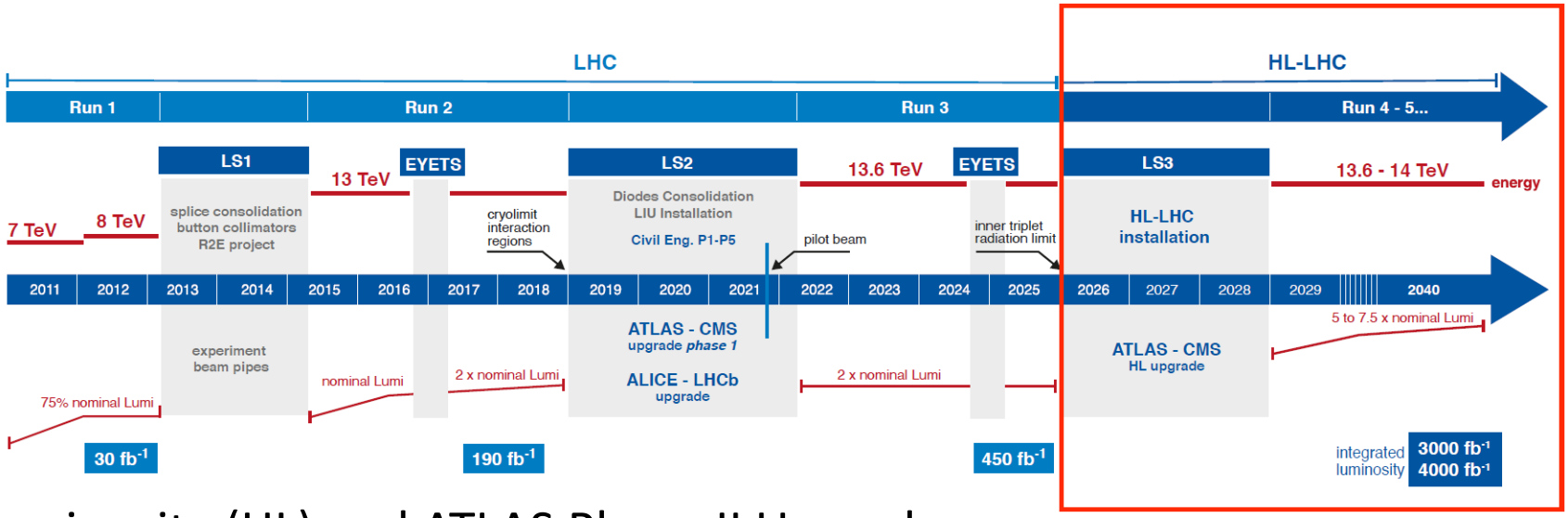
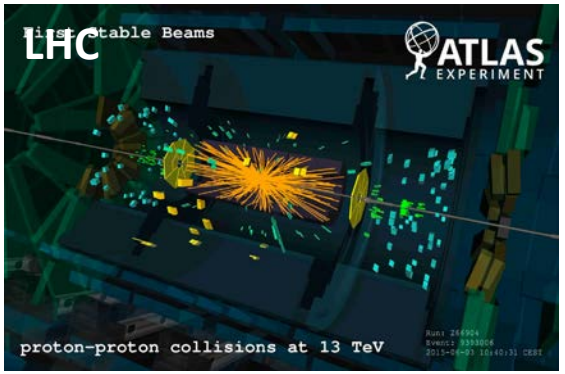
On belhalf on the ATLAS ITk Strip community

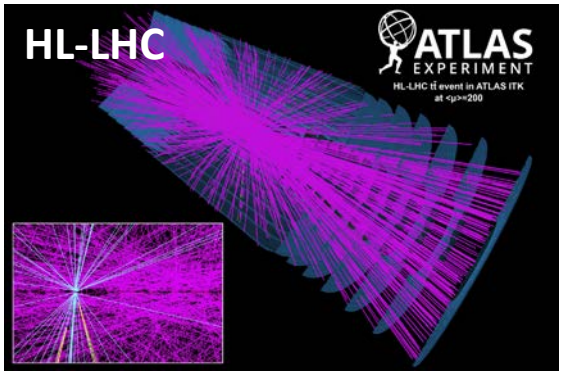
HL-LHC and ATLAS Phase-II



High Luminosity (HL) and ATLAS Phase-II Upgrade

- Increase accelerator luminosity (L_{peak}=7.5x10^{34} $cm^{-2}s^{-1}$)
- Increase pile-up: 200 interactions/bunch crossing
- More radiation damage
- Produce 10 times the amount of data



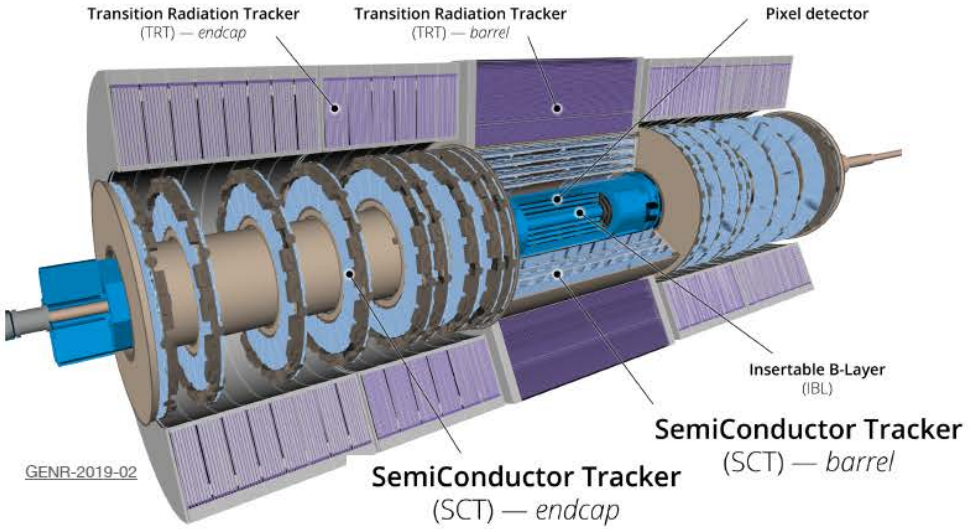


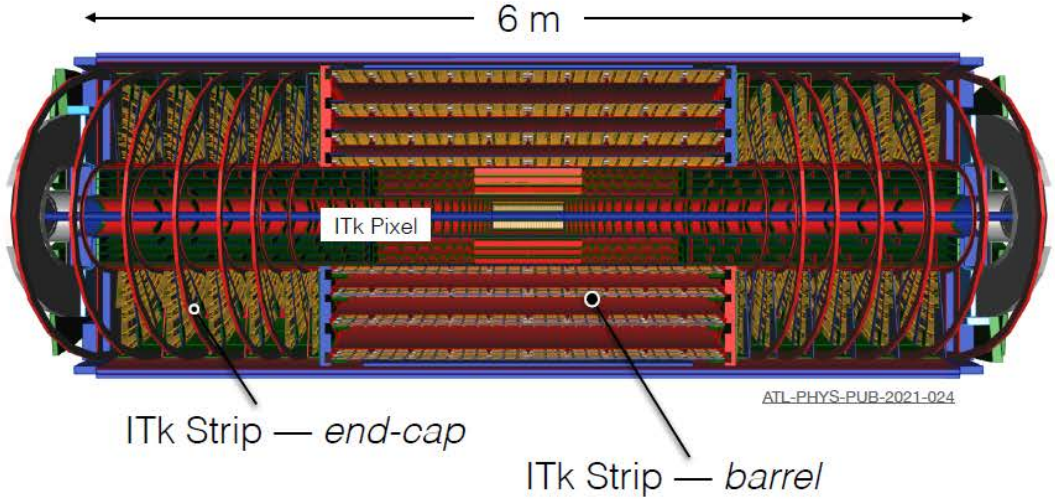
C. Gemme “The ATLAS HL-LHC Upgrade Program”

ITk – New ATLAS Inner Tracker

- Full replacement of the present ATLAS Inner Detector with Inner Tracker (ITk)
- ITk is full silicon: strips and pixels
  - Better spatial resolution
  - More readout channels
  - Higher radiation tolerance
  - More coverage a low angle
  - Higher trigger rate

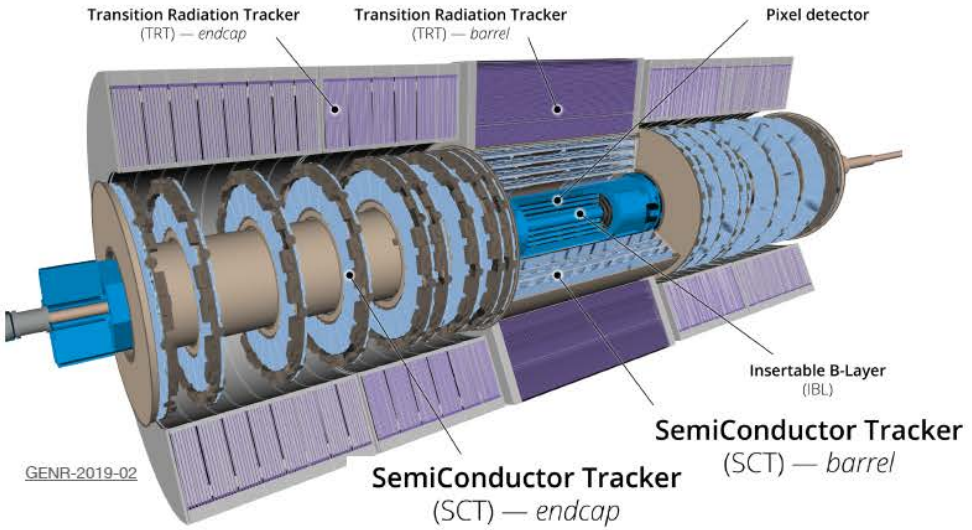
	Present Inner Detector	New ITk for HL-LHC
Sub-detectors	Si (pixels+strips) & gas tracker	Si (pixels+strips)
Coverage |η|	<2.5 (Si) < 2.0 (gas tracker)	<4.0 (pixels) <2.7 (strips)
Trigger rate	100 kHz	1 MHz

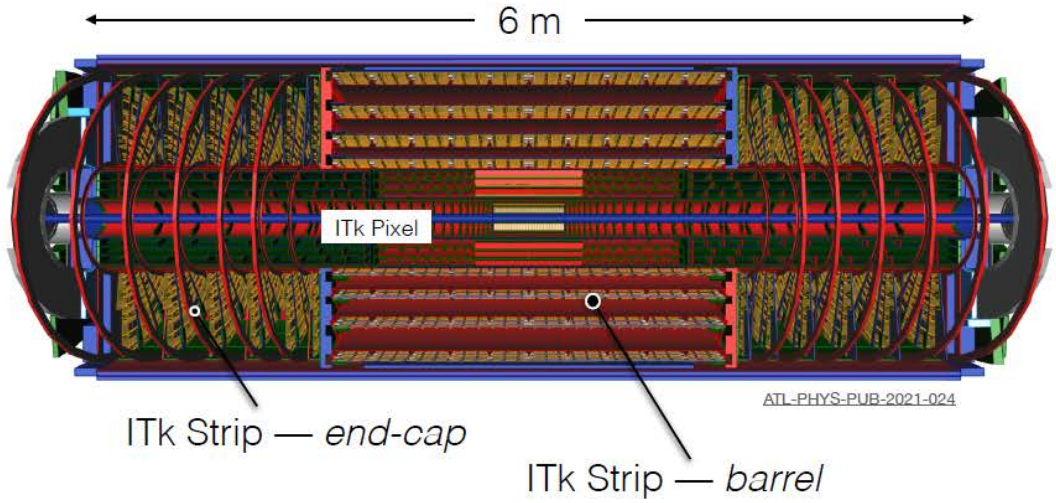




ITk Strips

K. Nakamura “ATLAS ITk Pixel Detector Overview”

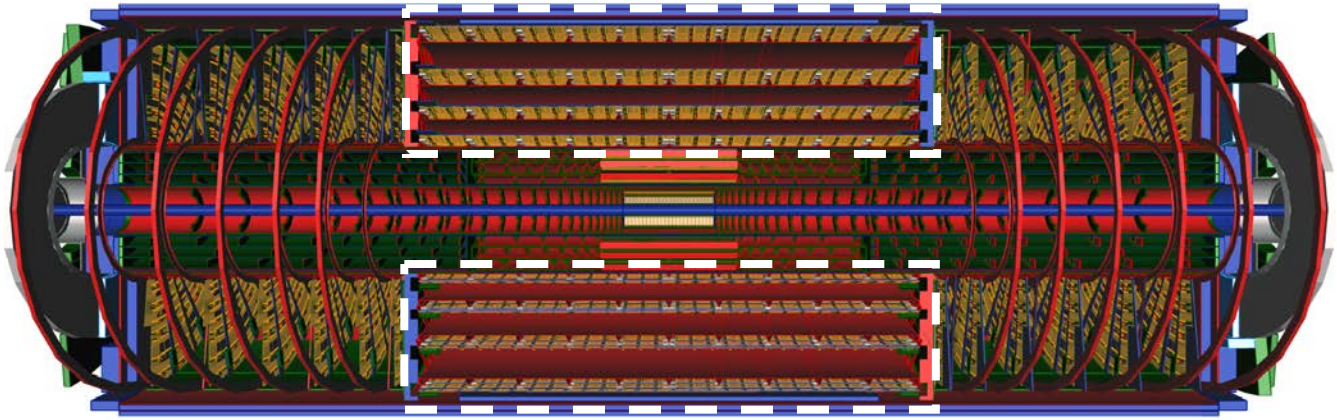




- Inner Detector SCT (Strips)
  - 4088 sensors
  - 61 m^2 of silicon
  - Strip length: 12.8 cm
  - 6 million strips
  - Dose: up to 3.8 Mrad

- ITk Strips
  - 17,888 sensors
  - 165 m^2 of silicon
  - Strip length: 1.4 – 6 cm
  - 60 million strips
  - Dose: up to 50 Mrad

ITk Strips - Barrel



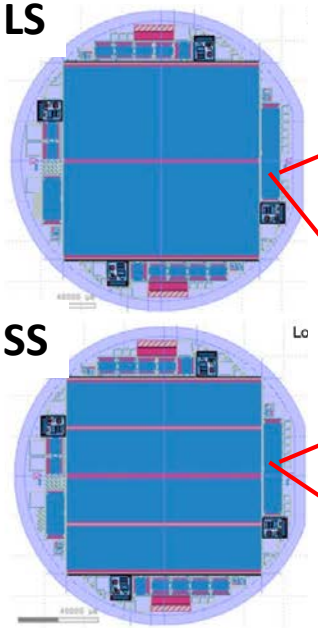
- 10,976 modules
- 392 staves

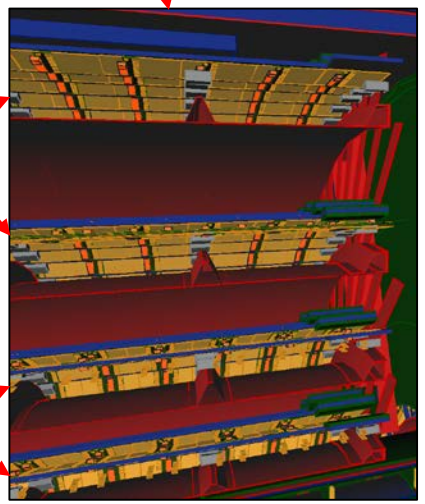
(14 modules/stave/side)

- 4 barrel layers

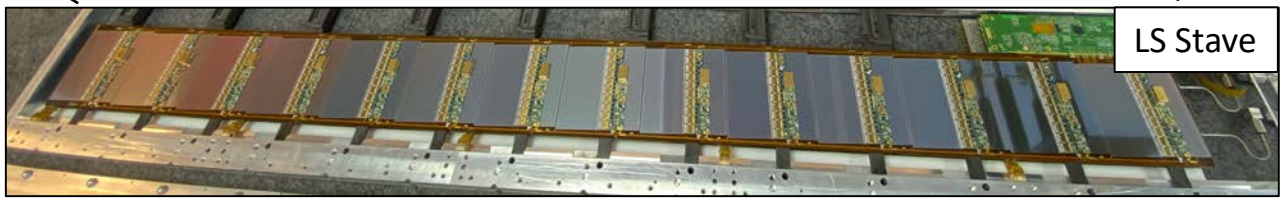
10cm

- Single-sided micro-strips
  - Sensor pitch: 75.5 um
  - Shorts Strips (**SS**): 24.1 mm
  - Long Strips (**LS**): 48.3 mm
- Electronics glued on top on the sensor
  - Amplifying, buffering, control, readout circuit with developed ASIC
  - Power circuit, also with ASIC and DCDC converter

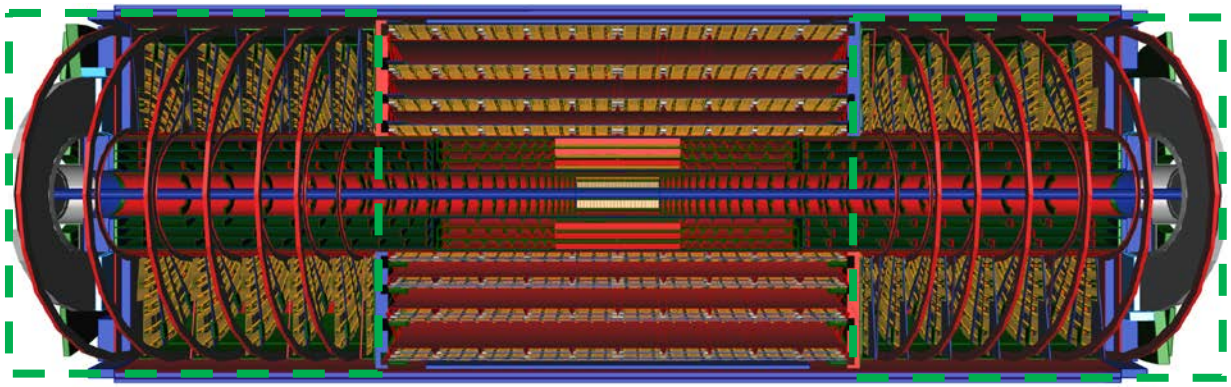




1.4m



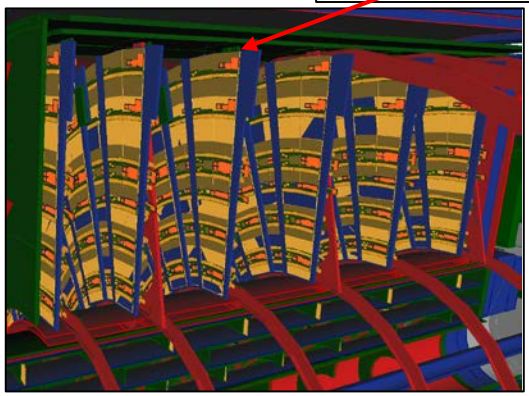
ITk Strips – 2 Endcaps



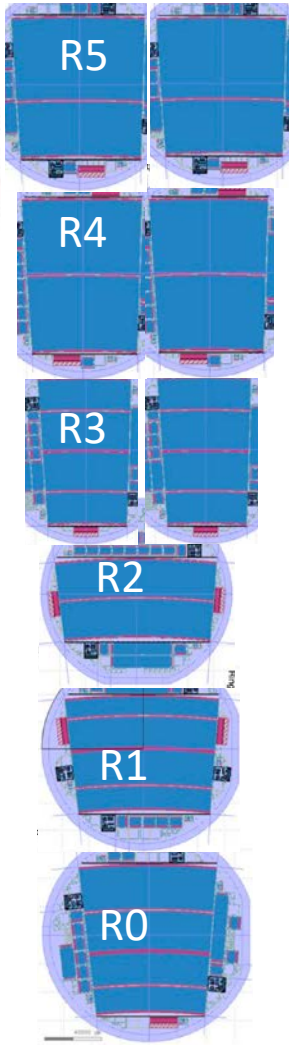
- 4,608 modules
- 384 petals

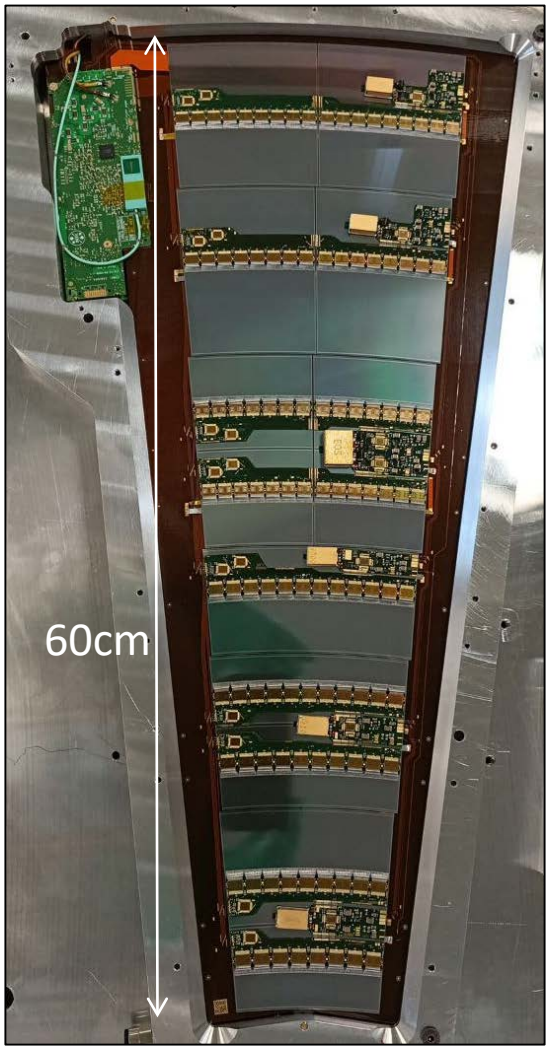
(6 modules/petal/side)

- 6 disks/endcap



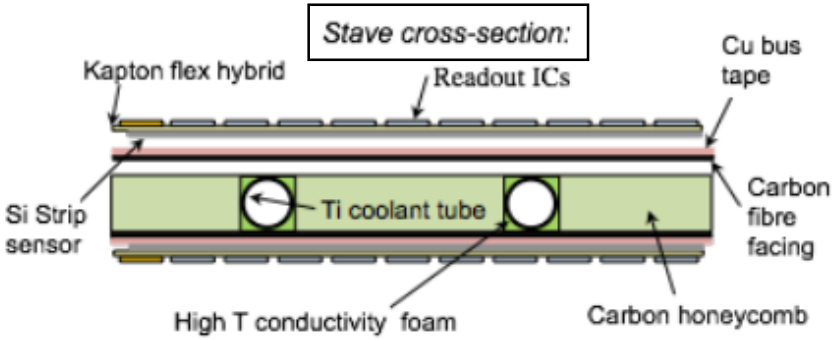
- 6 sensor geometries
- Single-sided micro-strips
- Sensor pitch: 70-80 um
- Strip Length: 1.4 – 6 cm

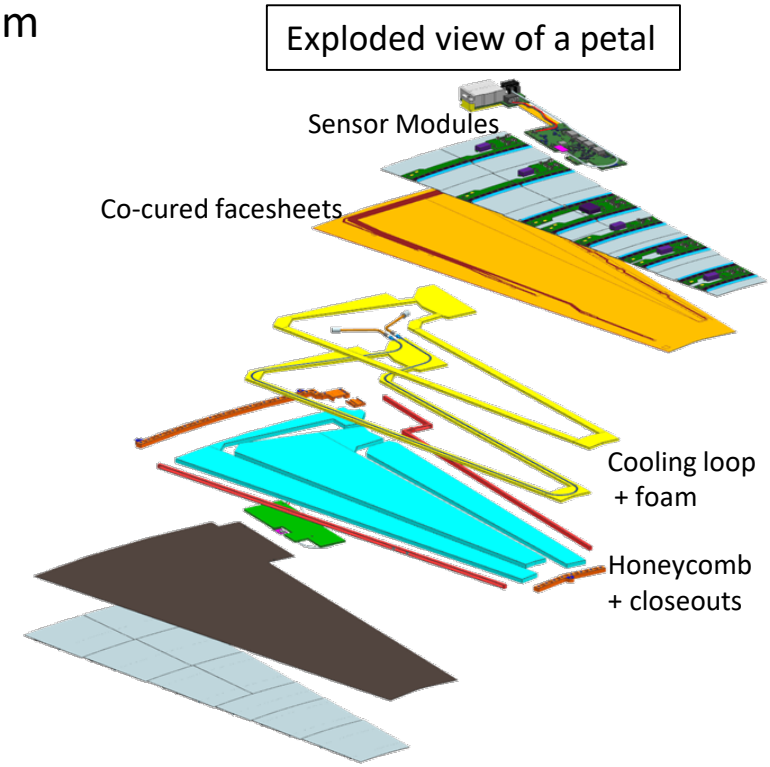




ITk Strips – Stave/petal core

- Important effort to integrate all these sensors
- Minimising support material in global structures: all carbon fibre.
- Integrating modules in sub-structures (staves and petals)
  - Low mass: Carbon fibre honeycomb, carbon fibre facings
  - Includes cooling: Ti pipes, high T conductivity foam



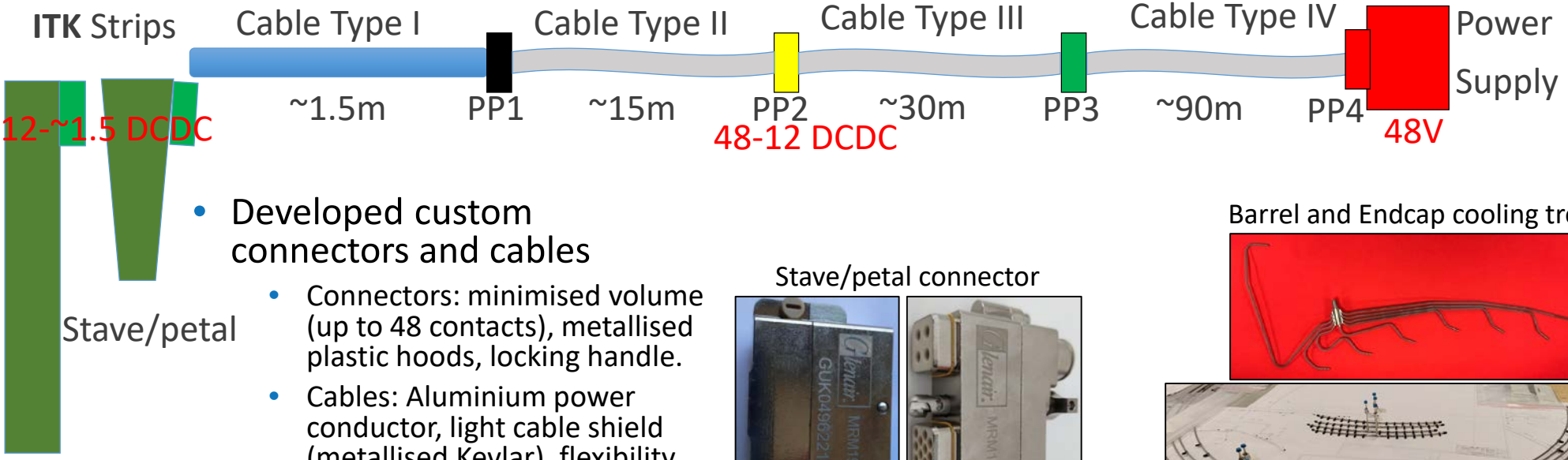


ITk Strips – Power Scheme

- Minimising services

M. Stanitzki"The ATLAS ITk Strip End-of-Substructure Card - From design to production"

  - Single electrical cable per sub-structure (both sides)
    - One LV channel per sub-structure (stave/petal) side (14 barrel modules, 6 endcap modules)
    - DCDC scheme to reduce voltage drop: PS=48V, PP2=11V to the stave/petal, Module=1.5V
    - Shared Parallel Powering for HV (bigger share for Outer Barrel and Endcap)
  - Sharing cooling loops for several sub-structures (8/9 staves, 16 petals)



- Developed custom connectors and cables
  - Connectors: minimised volume (up to 48 contacts), metallised plastic hoods, locking handle.
  - Cables: Aluminium power conductor, light cable shield (metallised Kevlar), flexibility.

Stave/petal connector

Barrel and Endcap cooling tree

ITk Strips – Project Schedule Needs

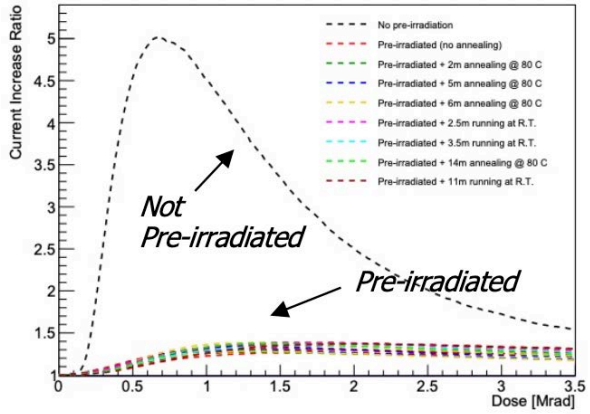
- Beginning 2028: full ITk (Strips and Pixels) installation in ATLAS.
- Beginning 2027: Barrel and the 2 Endcaps need to be finished and ready to integrate with the Pixels.
- For this, the installation of the first staves and petals in the detector and their commissioning need to start early 2024. Activity for more than 2 years until late 2026.
- So, module production to build staves/petals is about to start now.
- All of the activities of the project are either in:
  - Pre-production: final items that validate the production (staves, petals, services, power supplies)
  - Production (sensor, ASICs, modules, global structures).
- All activity statuses are reviewed twice a year by ATLAS management and by the LHC Committee

ITk Strips – Sensor Production

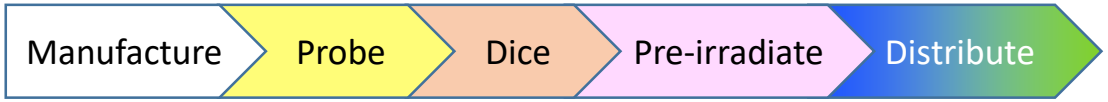
- Production in HPK (Hamamatsu) started 2 years ago
- 54% of the sensors already received:
  - 6519 Barrel LS sensors (SS are needed later in the project – 2 barrel inner layers)
  - 4449 EC sensors (all flavours are needed from the beginning to produce petals)
- Delivery as planned in schedule.
- Low rejection rate (2%). Please note that:
  - The contract spells out the delivery of "good sensors" (Not all sensors produced. But rather the ones that pass the vendor tests and selection procedures.).
  - There is a process of information exchange with the company about the rejections after ATLAS-side tests are performed.
  - Once we agree to reject (from both sides), this means that such sensors will be re-delivered at a later day. That is, this is NOT a "production loss" for our side.

ITk Strips – ASICs Production

- All custom ASICS (ABCstar, HCCstar, AMACstar) made by Global Foundry using 130nm technology
- Pre-irradiation to avoid TID bump
- Extensive simulation to prevent issues due to working in high-radiation environment
- Triplication of logic to improve SEE protection
- Final design validated in several test beams



ASICs production flow

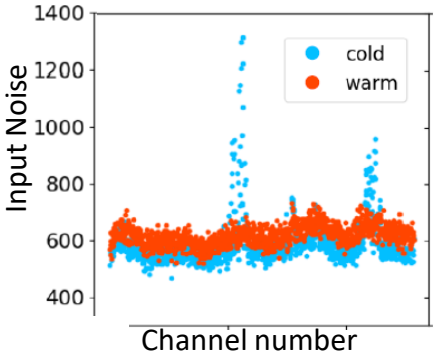


ASIC		Manufactured	Probed	Diced	Pre-Irradiated	Distributed
ABCStar (amplifier, dig. & buffering)	Number	330,880	172,020	90,360	8,243	4,982
	%	**94.6%**	**49.2%**	**30.2%**	**2.8%**	**1.7%**
HCCStar (Control and Comm.)	Number	32,306	32,306	23,191	6,981	576
	%	**93.4%**	**93.4%**	**70.7%**	**21.3%**	**1.7%**
AMACStar (Power Monit.)	Number	28,246	24,350	19,535	5,906	5,262
	%	**117%**	**100.5%**	**87.8%**	**26.5%**	**23.6%**

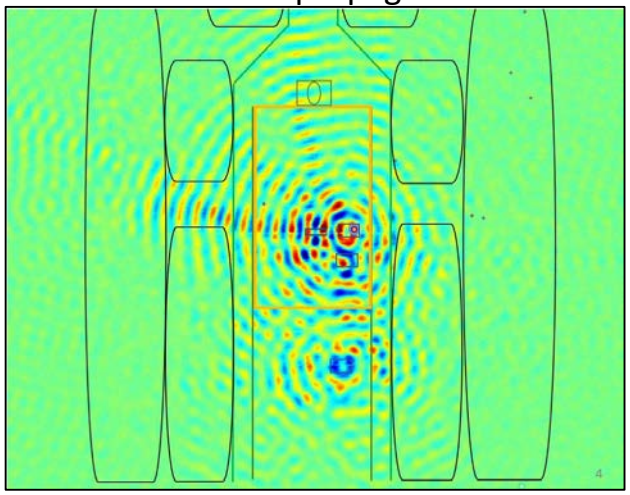
ASIC	Probing Yield
ABCStar	87.5%
HCCStar	96.8%
AMACStar	93.3%

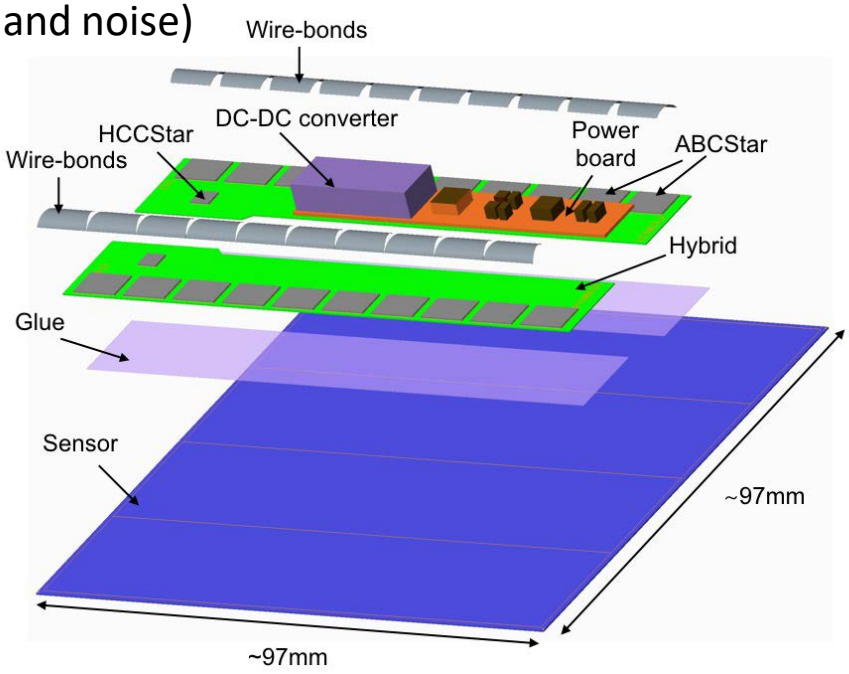
ITk Strips – Module Production

- Just entered in production for Barrel LS and Endcap modules.
- During quality checking of pre-production modules at low temperatures (<-20º)
  - Excess noise, we called Cold Noise
  - More than one year of investigation. Accepted that the source of the noise is mechanical vibrations in the powerboard.
  - The mechanism by which vibration couples back into the front-end remains unknown.
- Barrel LS modules can use a glue that prevents the noise.
- Endcap modules do not show the noise, different circuit material and layout.
- Need a solution for SS modules (higher current → vibrations and noise)
  - New powerboard? Thicker glue?
  - Solution needed by summer 2024



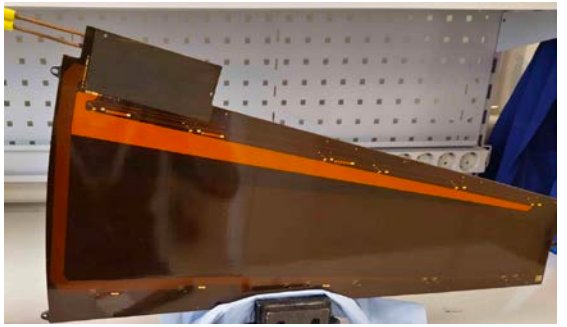
Vibration propagation

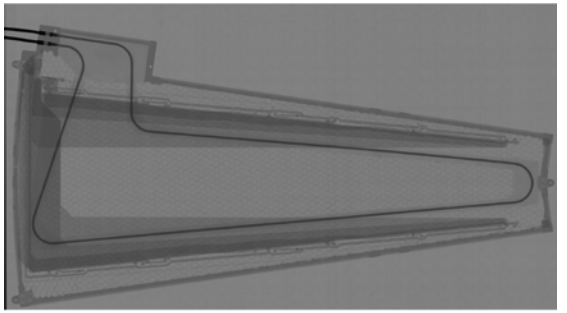


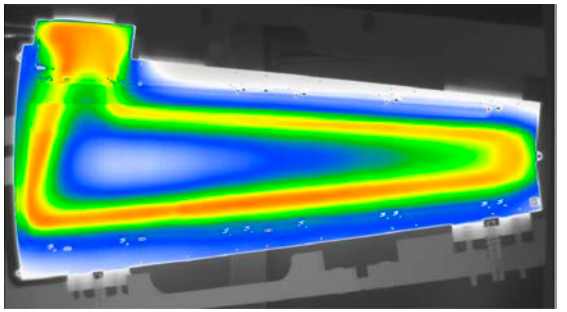


ITk Strips – Stave and Petal Pre-Production

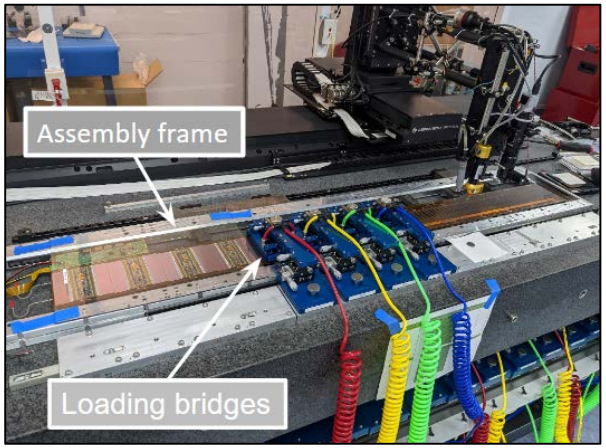
- Core: structure + thin flexible circuit co-cured (bustape)
  - Endcap: manufactured in industry, 16 pre-production cores finished and validated.
    - Production of bustapes ongoing. About to start production of cores.
  - Barrel: delays on the bustape due to adjustments on the nickel gold plating of small pads over a long object (1.4m), control of the etching (impedances for the high speed lines)
    - 20 pre-production bustapes. Results encouraging, towards production.
- Module loading
  - Developed precision tooling and camera mounted on XYZ stage, for both barrel and endcap.



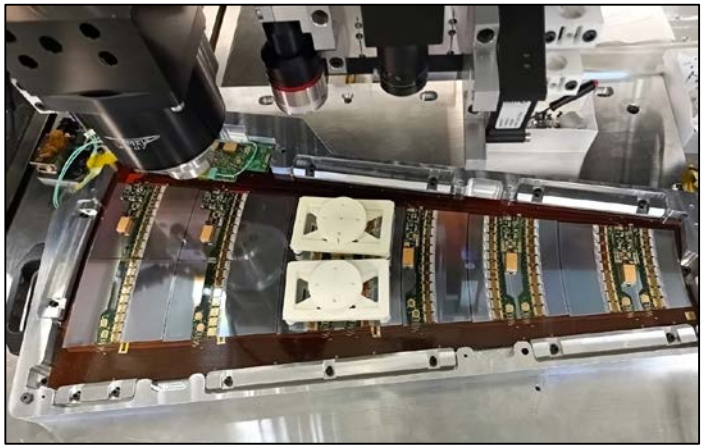




Barrel Loading System



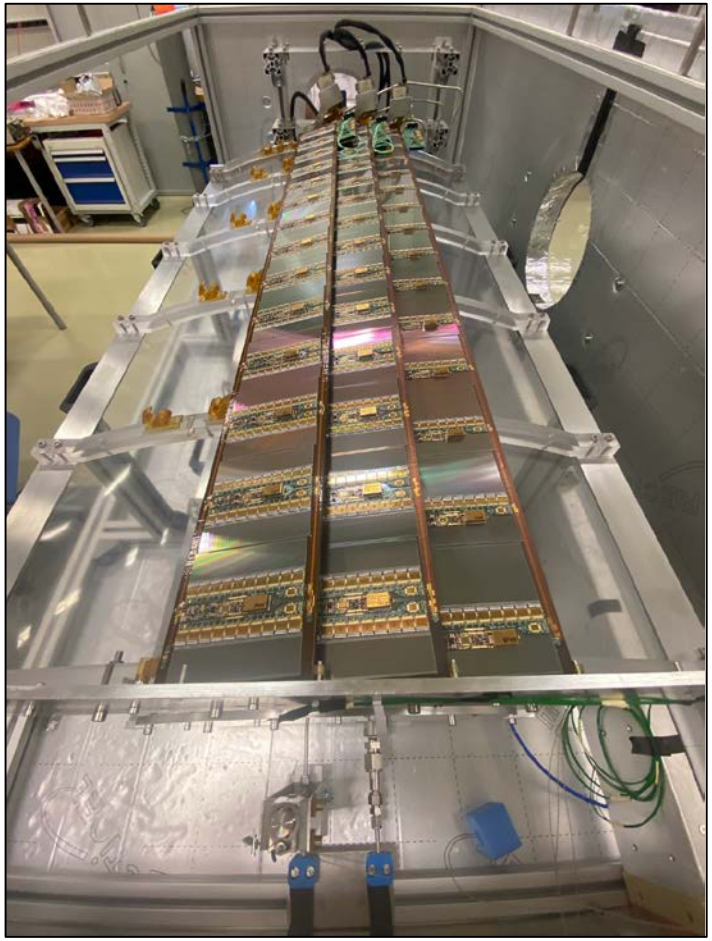
Endcap Loading System



ITk Strips – System Test

- Multi stave/petal setup
- Barrel System Test for up to 8 staves
- Endcap System Test for up to 12 petals
- Test of:
  - Pre-production staves/petals
  - Services and power supply
  - Develop Data Acquisition, Monitoring, Interlock.

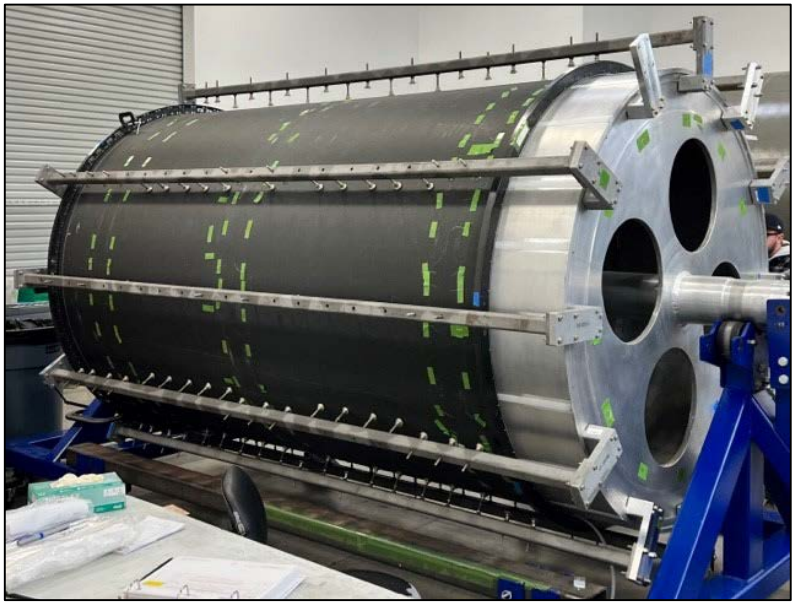
Barrel System Test @ CERN

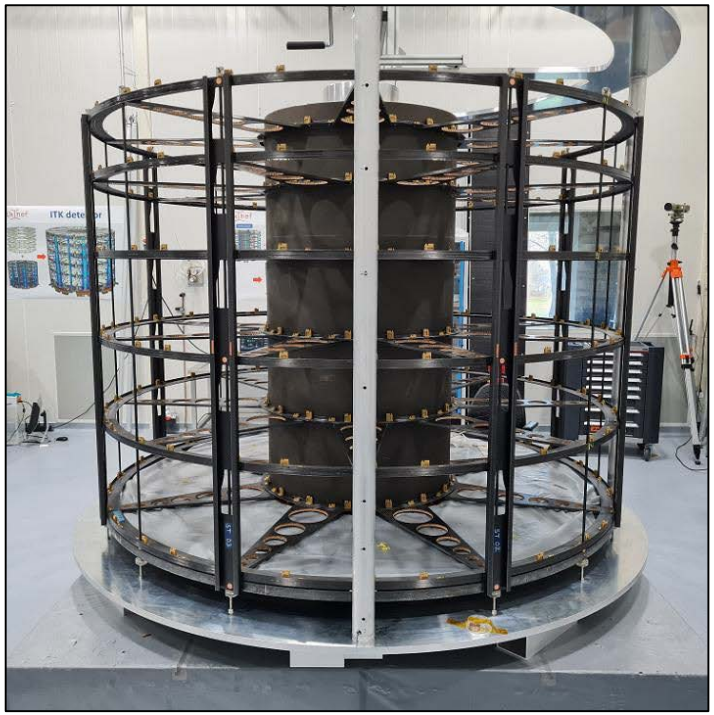


Endcap System Test @ DESY

ITk Strips – Global Structures Production

- First Endcap structures finished!
- Second Endcap Structure in production
- The structure for the 4 barrel layers in production
- Outer barrel layer (L3) finished and being dressed with stave clamps



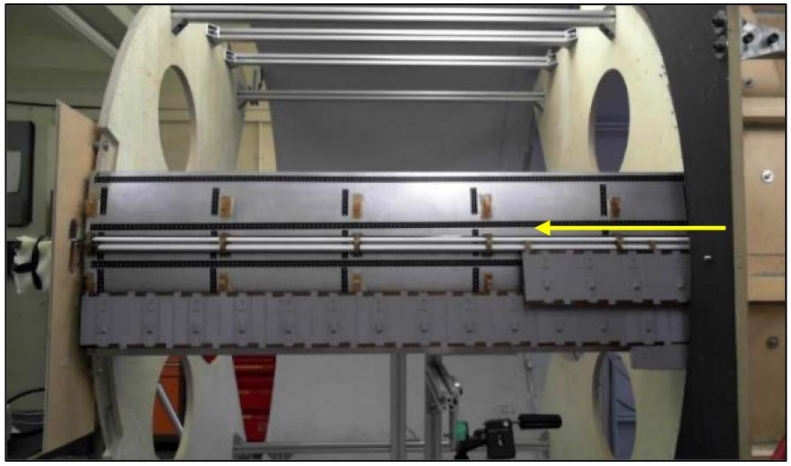


ITk Strips – Integration (stave/petal installation)

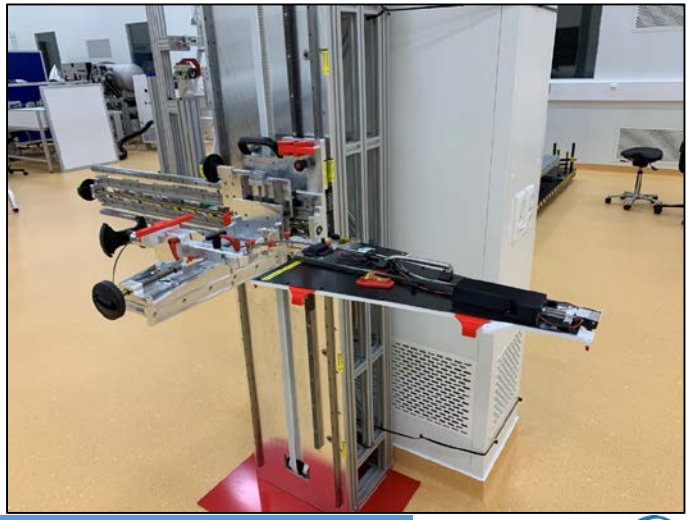
- Being prepared to install staves and petals
  - Barrel @ CERN, Endcap at DESY and NIKHEF
- Pre-production of Services and Power Supplies will be used to equip integration sites

Barrel (and later ITk) integration area @ CERN

Stave insertion tool



Petal insertion tool

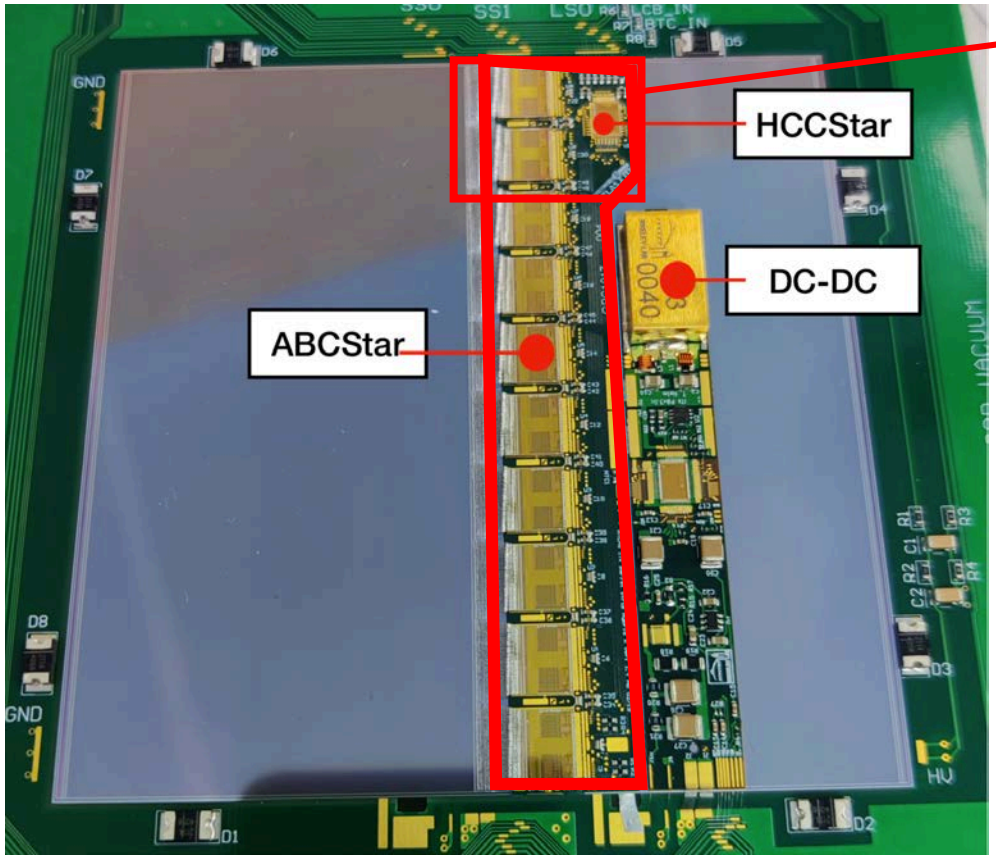


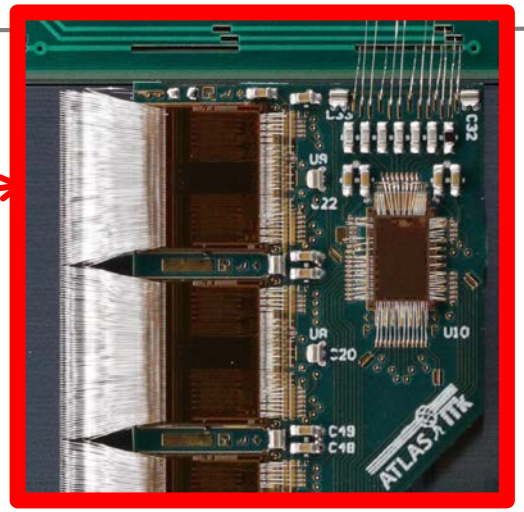
Summary

- Building a tracker detector for operation at the high luminosity LHC is challenging
  - Radiation hardness, increased granularity, low mass
- The ITk Strip detector is progressing through production and integration
  - Sensors, ASICs, modules, staves, petals, global structures, services, power supplies
- Not an easy path
  - Faced issues, like the Cold Noise
- Important effort of project coordination
  - 57 institutes from 14 countries
  - Developed tools for production database, logistics, project scheduling.
- The ITk Strips Collaboration is starting with enthusiasm the production of modules, staves and petals
  - It will take the next 3 years

Thank you

LS Module





Each FE ASIC has 256 Al wirebonds in 4 rows

Flexible PC boards each carrying:

- 10 FE readout chips (ABCstar)
  - 256 channels/chip
    - → 2560/5160 channels per LS(SS) module
- 1 Hybrid Controller Chip (HCCstar)
  - Interface between FE chips and electrical signal on bus tapes

ASICs backup

- SRAM problem:
  - Problem is data loss in a few channels due to a setup timing problem in the memory blocks that shows up at lower voltage and lower duty cycle. We have worked to mitigate the conditions that cause the problem by running at slightly higher voltage and inverting the clock going to the ABCStars to improved the duty cycle.
- ABCStar lower yield:
  - The SRAM problem and difficulties in the ASIC manufacturing process that lead to poor analog matching within individual ASICs.
- Pre-irradiation at Ruđer Bošković Institute (RBI) (Croatia)