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

Karol Krizka

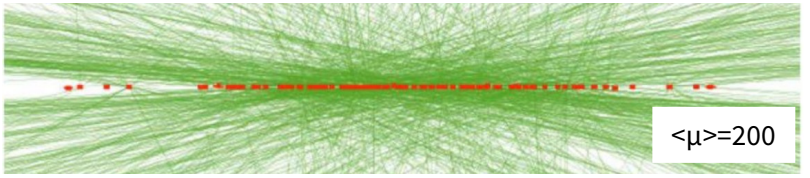
on behalf of the ITk Strips Collaboration

July 14, 2021

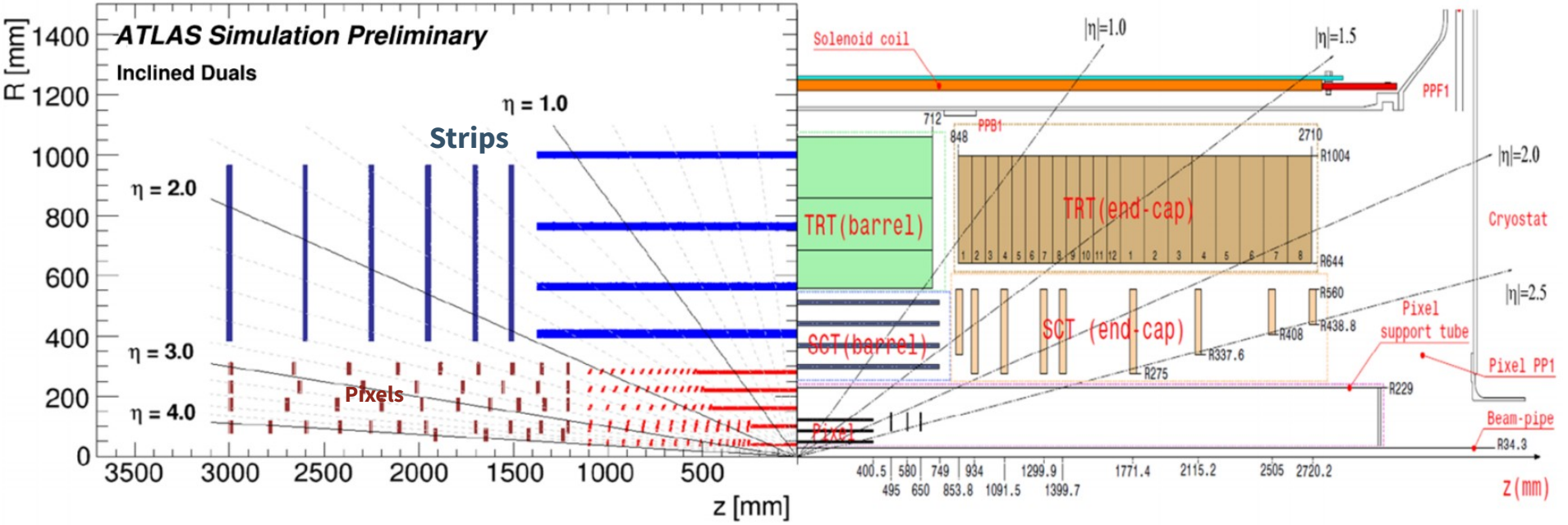
DPF2021

ITk Detector Overview

The **I**nner **T**rac**k**er (HL-LHC ATLAS)



The current detector



- **All silicon replacement for current tracker**
  - Higher granularity, larger radiation tolerance
  - Extends |η| coverage from 2.5 → 4.0

ITk Strips Detector Overview

	Module Count
SCT	4088
ITk Strips	17888

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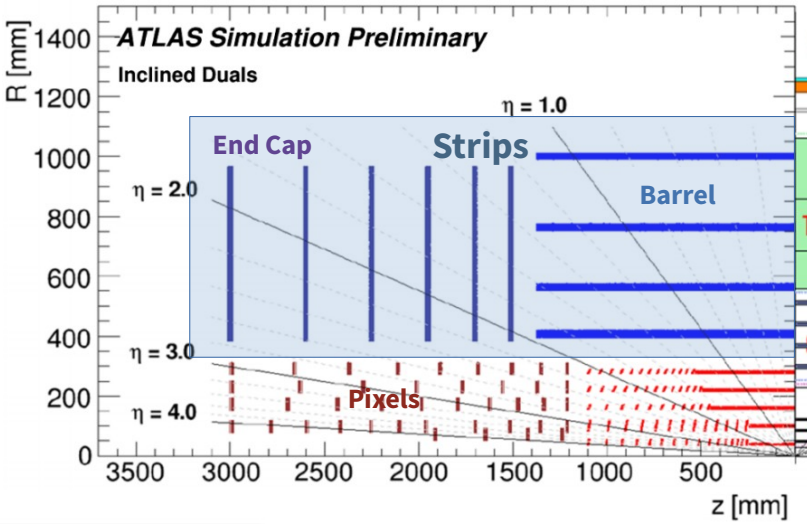

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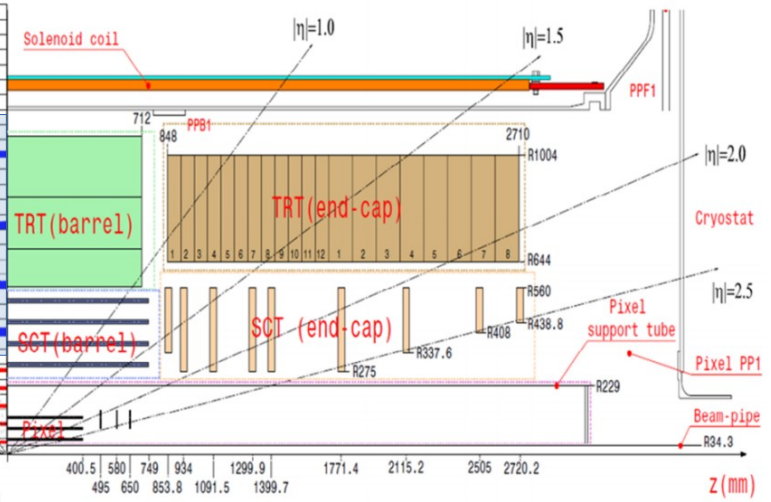
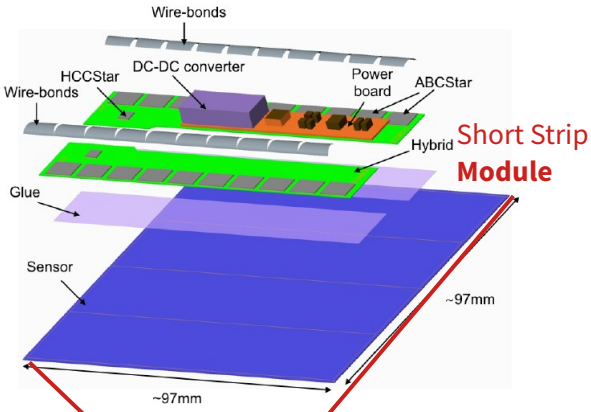
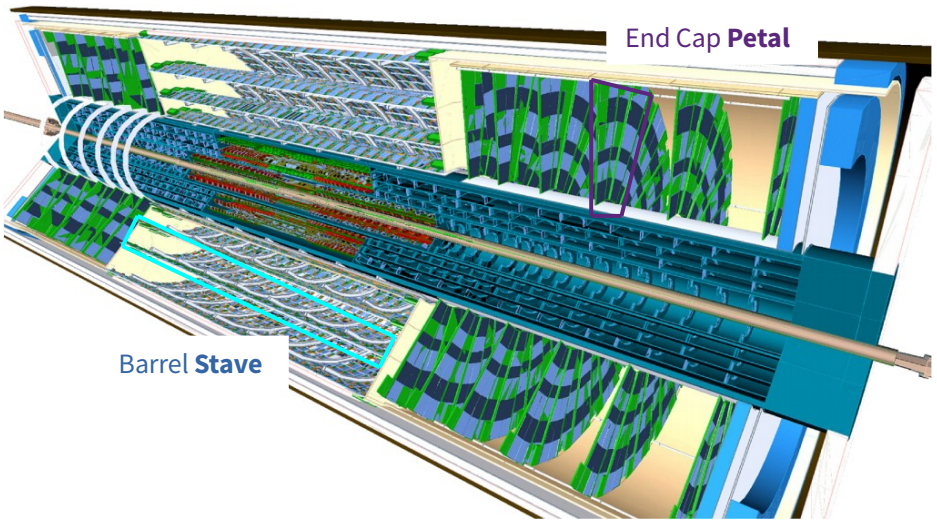




Short Strip **Module**



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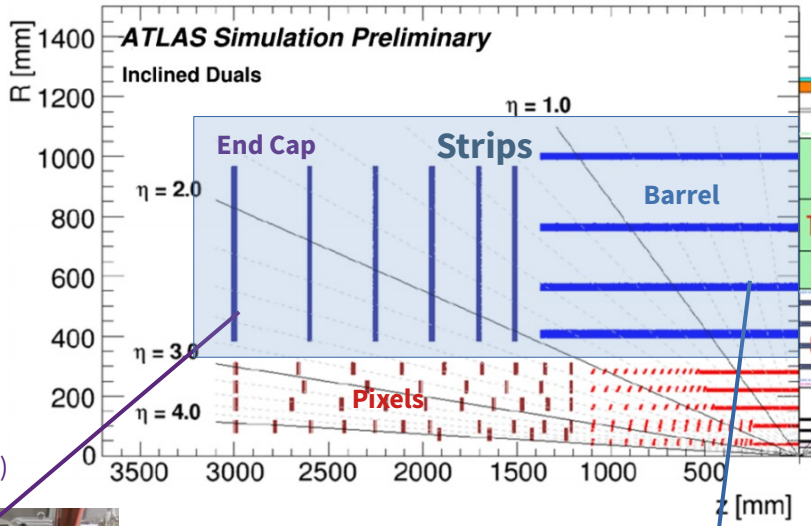
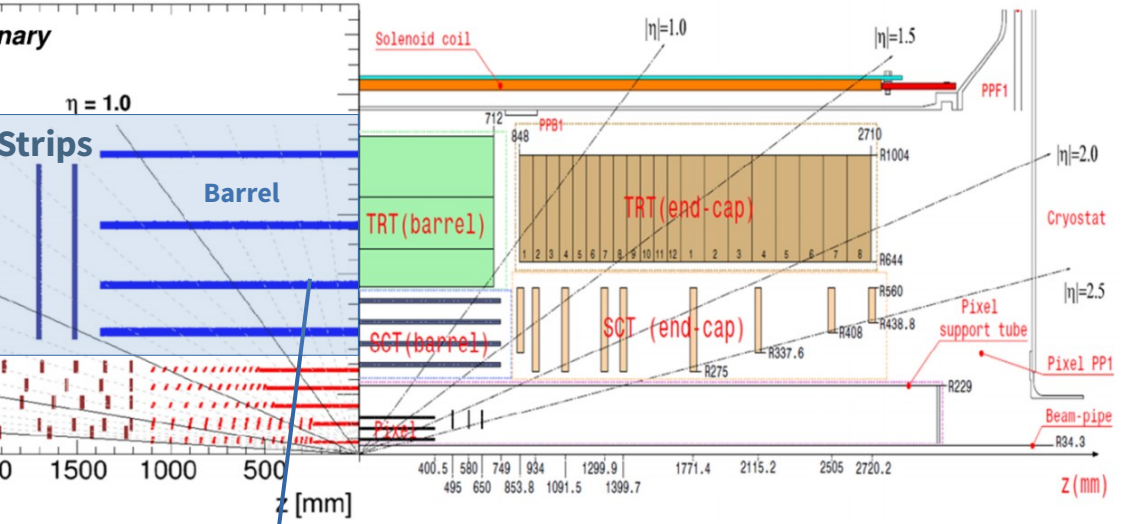
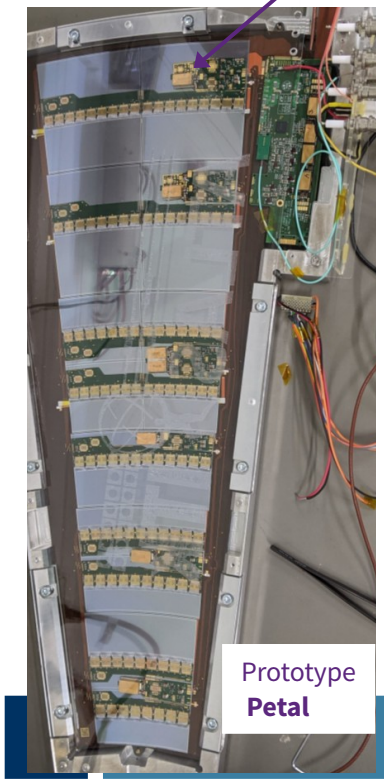


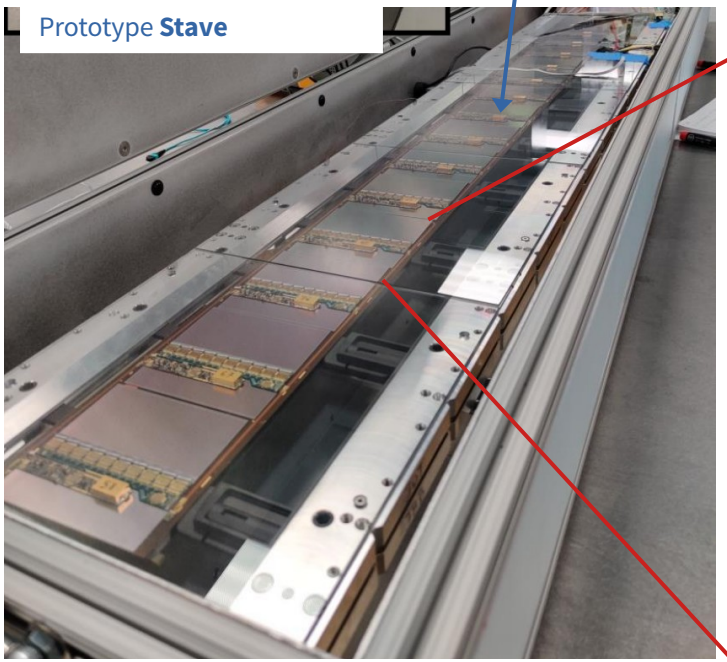


End Cap
(ring geometry)

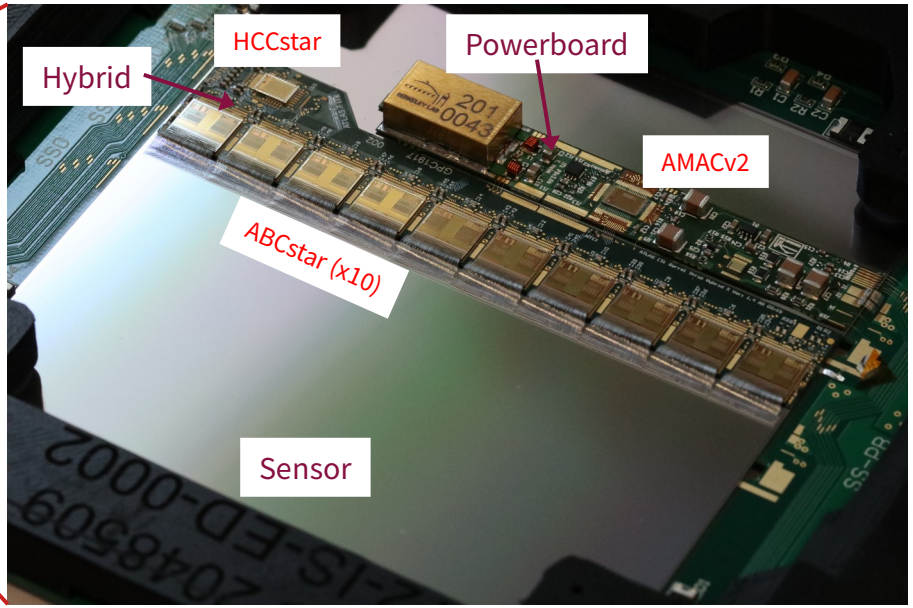


Prototype **Petal**

Prototype **Stave**

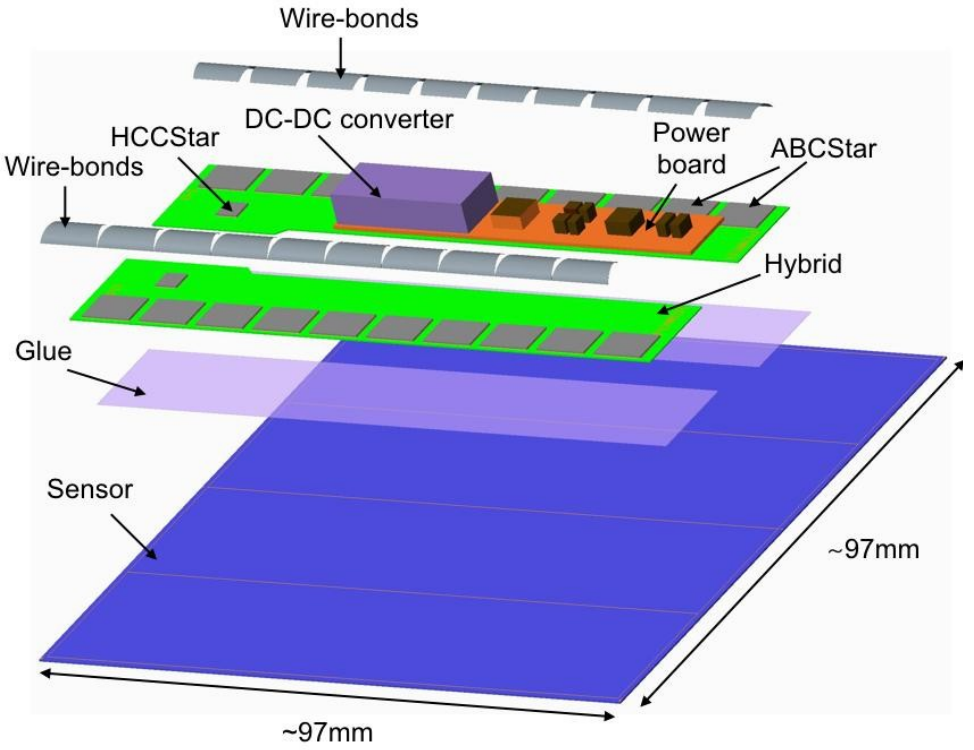


Prototype **Module**



ITk Strips Module

- **Basic building block**
  - Variations based on sensor geometry
  - Barrel/endcap difference is shape
- **2560 or 5120 channels/module**
- **Parallel powering scheme**
  - ~14 modules per LV channel
    - 11V → 1.5V on-module DC/DC conversion
  - ≤4 modules per HV channel
  - On-module power control and monitoring



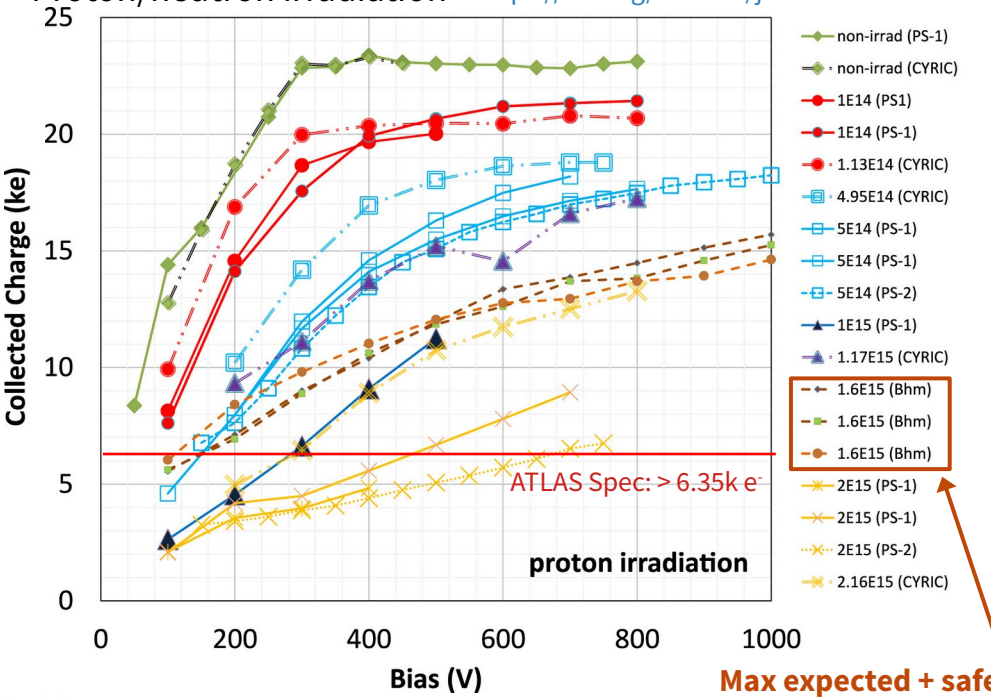
Assembly includes:

- Precision placement and gluing of ASIC-to-PCB and PCB-to-sensor
- Wirebonding: each FE ASIC has 256 bonds in four rows (x10/20 FE's per module)

Sensors

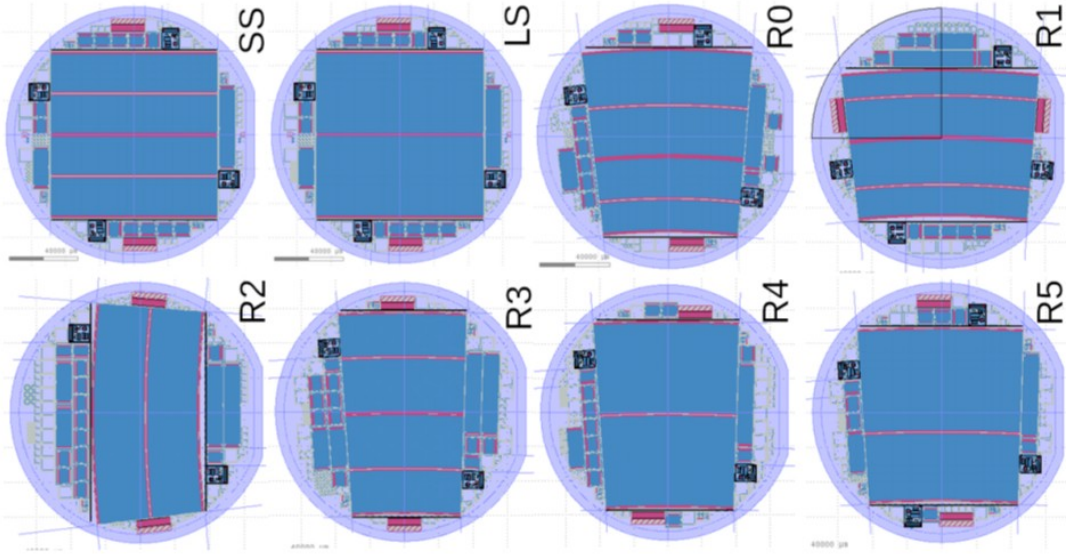
- 320µm thick silicon, n^+-in-p doped
- 75.5 µm strip pitch
- One sensor / wafer
  - Surrounded by mini-sensors for R&D
- bias voltage: -100V to -500V

Proton/neutron irradiation https://doi.org/10.1016/j.nima.2020.164422



Max expected + safety:
1.6×10^{15} n_{eq}/cm^2

SS, LS are barrel, R# are end-cap



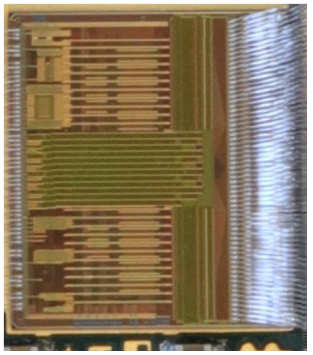
ATLAS reviews passed.

Production order made!

Status of ITk Strips ASIC's

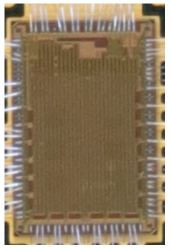
HCCstar design and verficatio by B. Rosser
HCCstar irradiation testing by J. Heinlein
AMAC design and verification by S. Lu
AMAC wafer probing by L. Zagazeta

ABCstar (Front End Chip)



- Binary readout
- v1 (pre-production) available

HCCstar (FE Interface Chip)



- Connects 10x ABC to stave
- v0 (prototype) available
- v1 (pre-production) design being finalized

AMACstar (Power Control and Monitoring)

- v2a (prototype) available
- star (pre-production) design done
  - Tied to HCCstar production: same wafer

- **All chips made in 130 nm at Global Foundry**
- **Functionality of chips validated up to stave/petal system level**
- **Extensive testing in simulation for all chips**
  - Includes SEE-injection testing and "module" level tests

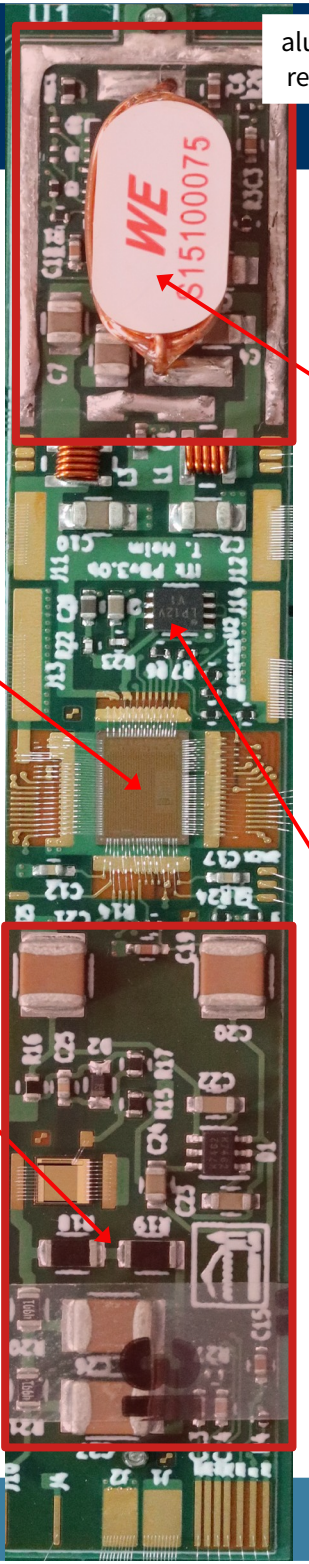
Powerboard

AMAC (The Brain)

- Control/measurement
- Run-time calibration
- Interlock functionality
- Custom ITK Strips ASIC

HV Switch

- GaNFET with source at -500V
- Enabled using 100 kHz clock connected to a charge pump
- Commercial chip



bPOL12V (The Heart)

- Rad-hard Buck converter
- We use an air-core coil
- 0.1mm Al shield-box to prevent EM noise leakage to sensor
- ASIC designed at CERN

linPOL12V

- Rad-hard linear regulator
- 1.4V for AMAC digital logic
- 3.3V for HV switch enable
- Low output current
- ASIC designed at CERN

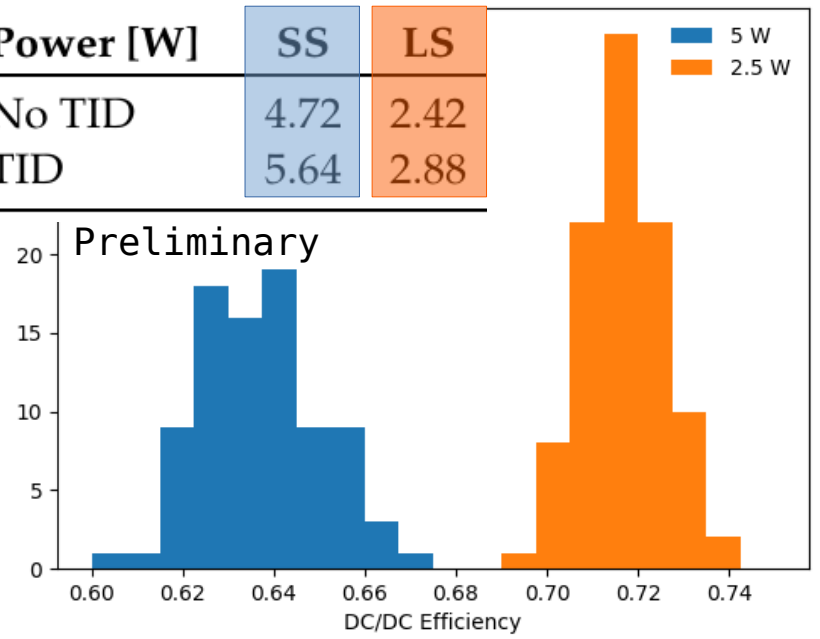
Powerboard Results

Details @ TWEPP2019

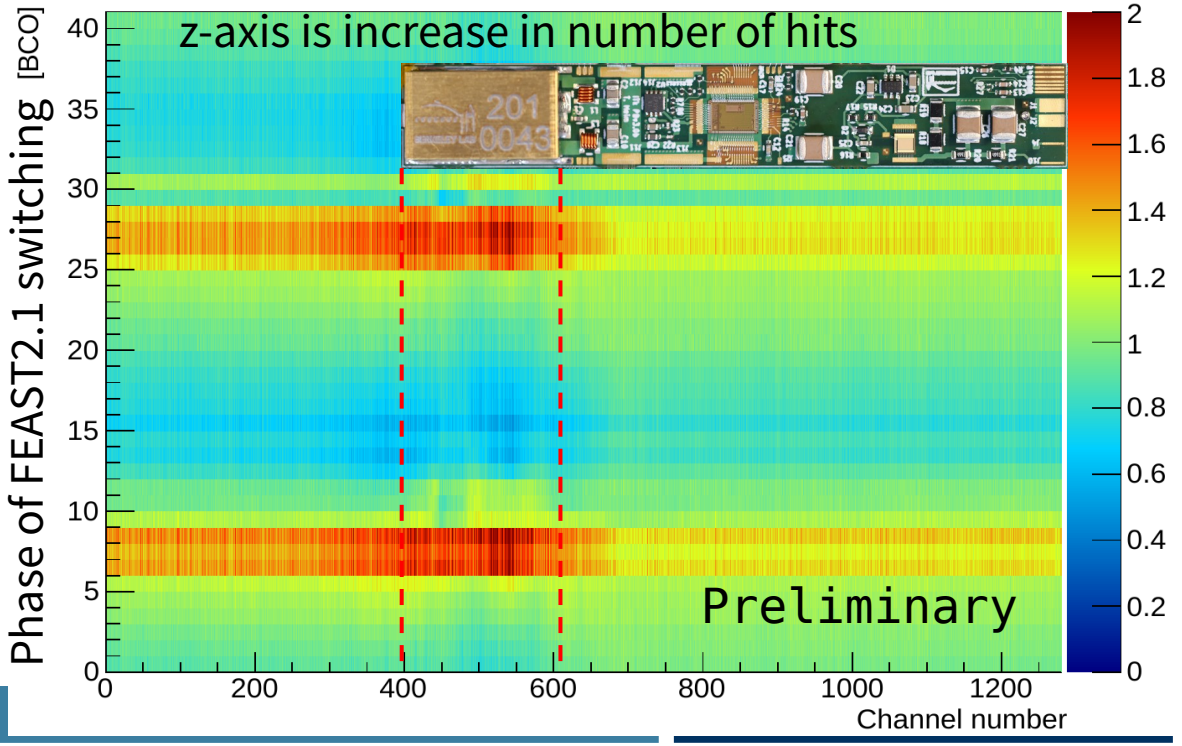
- **Extensive testing for reliability → can be a single point of failure**
  - Follow closely the development and testing of bPOL12V at CERN

Data for 87 PBv3's

Power [W]	SS	LS
No TID	4.72	2.42
TID	5.64	2.88

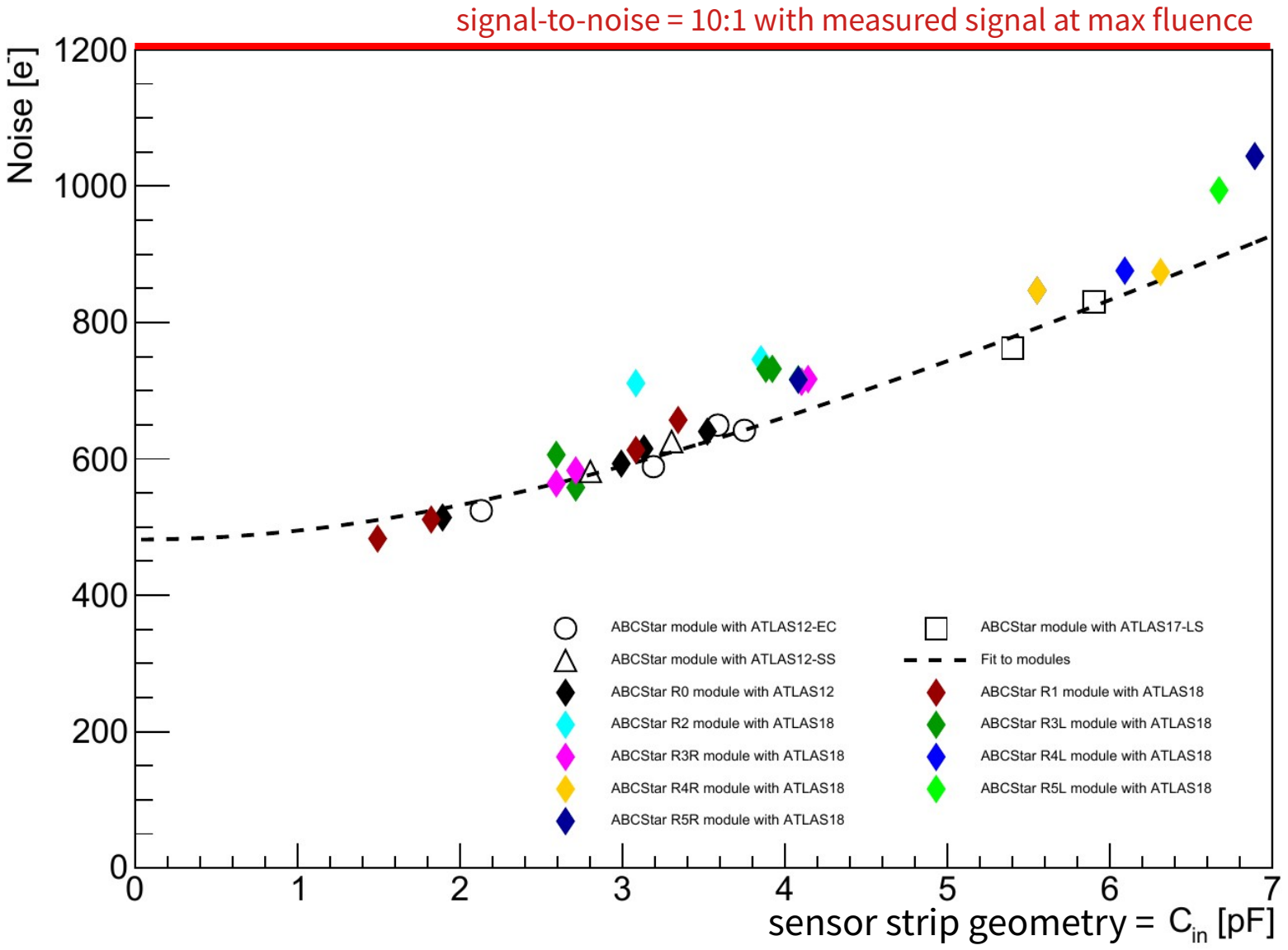


- **Can trigger on emitted EM-field phase to study effect of EMI radiation**
  - Mainly a tool, EMI not an operational issue



Module Results

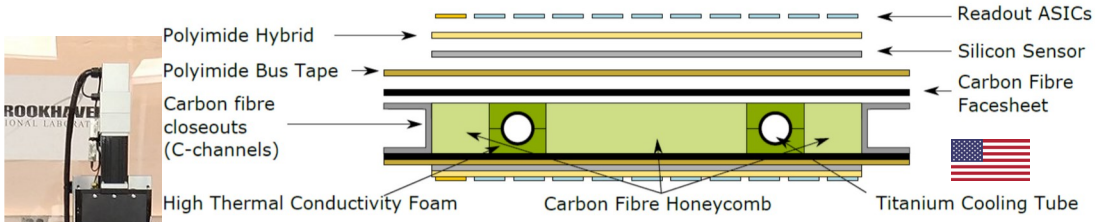
Module results by P. Sharma

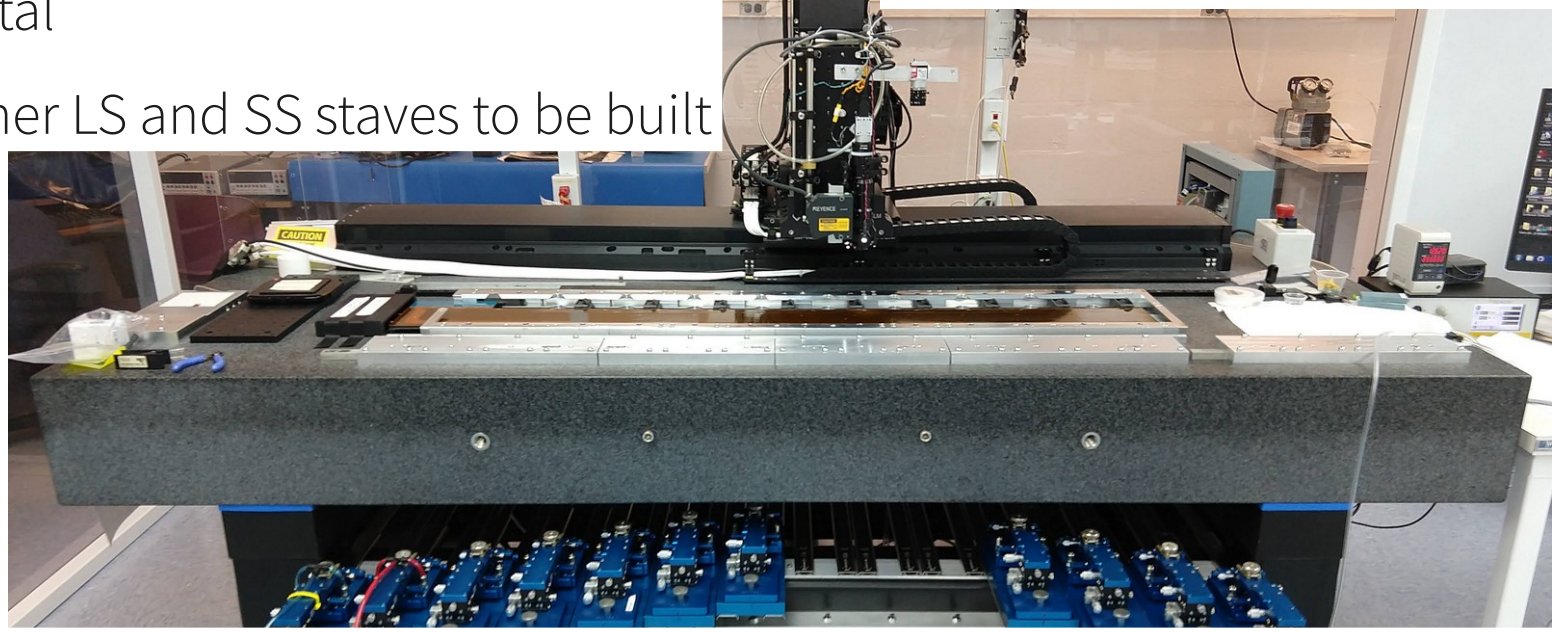


Staves and Petals

Stave results by F. Capocasa

- **Existing prototypes:**
  - 1x LS stave, 1x SS half-stave
  - 1x petal
  - another LS and SS staves to be built





- **Assembly automated via a custom robot**
  - Image recognition used for precise placement of modules

Petal Assembly on YouTube

- **Very useful for understanding and fixing system level issues**

Quality Control Systems

Hybrid Burn-in Crate

Powerboard Burn-in
+ Thermal Cycling Crate

Module Thermal Cycling Box

All systems for large scale testing being commissioned.

Module Pre-Production

- **Pre-production will demonstrate we can produce 18000 modules**
  - Pre-production: Defined 10% of the actual production
  - A global effort: ~20 assembly sites across 4 continents
- **Two stage process due to part availability**
  - Pre-production A: ~20% of pre-pro
  - Pre-production B: use final components
- **Currently starting Site Qualification**
  - Detailed procedure documents written
  - Videos and measurements to demonstrate build quality
  - Complicated by COVID travel restrictions

	pre-pro A	pre-pro B
Sensors		
ABCstar		
HCCstar	v0	v1
Hybrid		
AMAC	v2a	star
bPOL12V	v4	750 x v4, 100 x v6
linPOL		
Powerboard	Prototype ASIC's	

Conclusion

Completed: No show stoppers found when testing prototypes

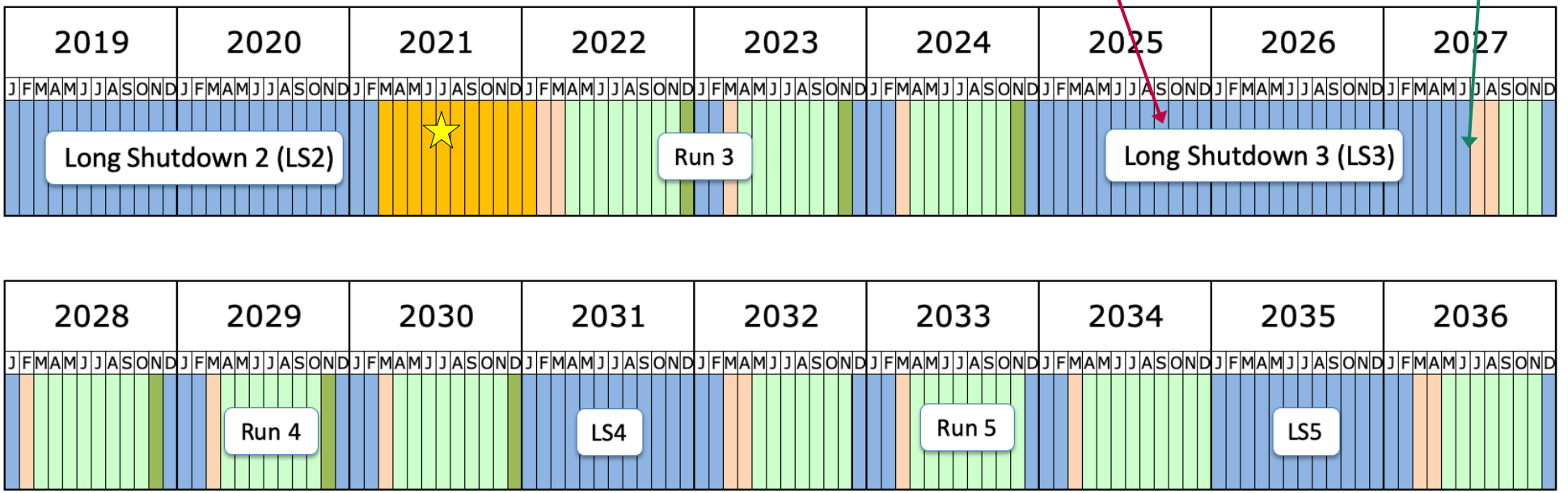
Next Step: Prove we can build entire detector (pre-production)

BACKUP

High Luminosity LHC

Installation of **major upgrades** to accelerator and detectors.

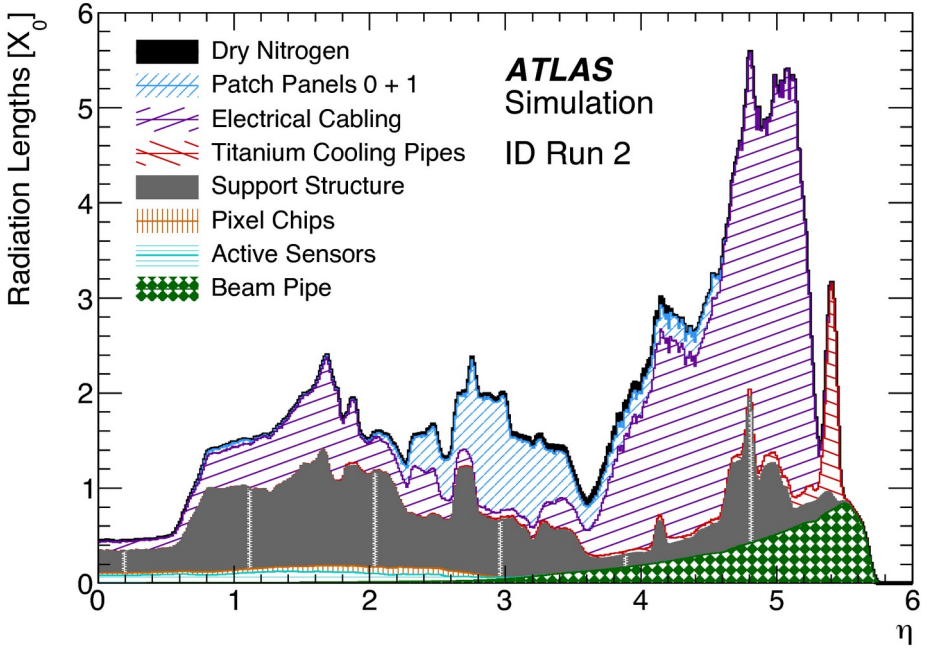
Start of **HL-LHC**



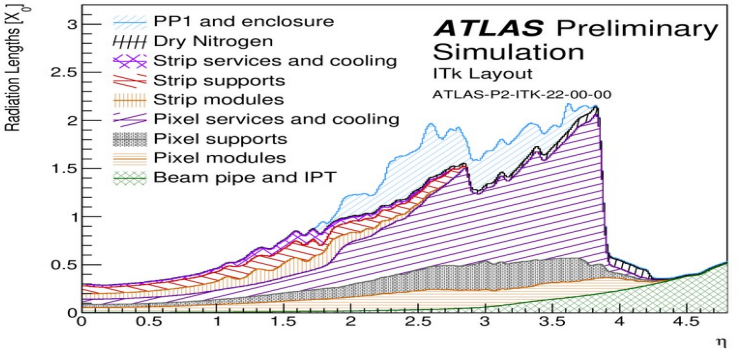
Shutdown/Technical stop
Protons physics
Ions
Commissioning with beam
Hardware commissioning/magnet training

	LHC (Run 2+3)	HL-LHC
Integrated Luminosity	300 fb^{-1}	4000 fb^{-1}
Instantaneous Luminosity	2 x 10^{34} cm^{-2} s^{-1}	up to 7.5 x 10^{34} cm^{-2} s^{-1}
Average # of Interactions Per Bunch Crossing	**50**	**200**

Material Budget

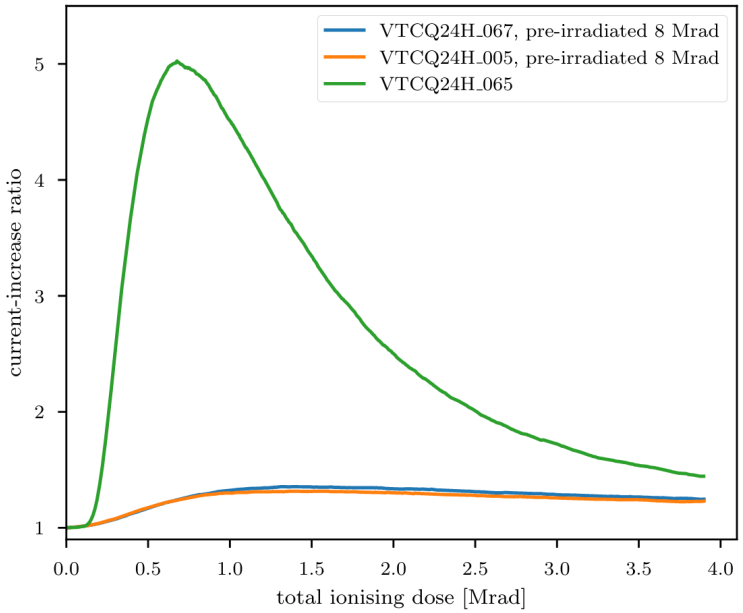


ITK-2019-001



ITk Strips ASIC Radiation Hardness

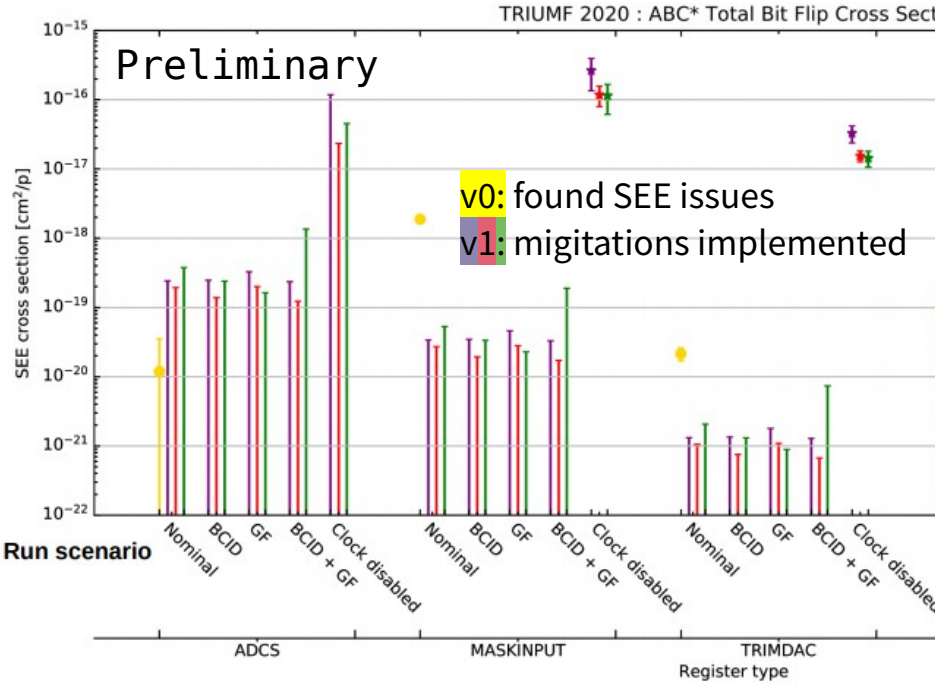
ABCstar TID Peak (Details)



- Power usage increase vs ionizing dose known feature of 130nm chips
- Current design can handle the expected "peak"
- Pre-irradiating the ASIC's removes the peak
  - Will do a passive irradiation at a Co60 facility

Single Event Error Mitigations

- Effect of SEE's on operation
  - FE chips: data corruption
  - AMAC: power switching of module ← bad
- Tested in all chip versions with proton and heavy ion irradiation



COVID Related Impacts

- **Limited access to laboratories**
  - General delay in getting everything setup
- **Virtual collaboration meetings**
  - No informal interaction, split across timezones
- **No site-visits for Site Qualification**
  - Replaced by videos, but those can always miss something
- **Limited travel for test beams**
  - Means limited person power available and remote experts
- **The Great Silicon Shortage**
  - Test boards have to be redesigned as parts go out of stock
  - Purchasing production quantities of certain components now
  - FlexPCB material also impacted
  - Currently no impact on manufacturing of ASIC's