# Toward HL-LHC: Advancing the ATLAS Inner Tracker (ITk) for the High-Luminosity Era

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@BrookhavenLab

Who am I?

- Mounia Laassiri
- 2011: B.Sc. in Physics
- 2013: M.Sc. in Security of Computer Networks and Embedded Systems
- 2019: Ph.D. in Physics and Nuclear Instrumentation
- 2022: Post-Doc at HIP
  - POSEIDON– Position-sensitive detectors for nuclear fuel imaging
- 2024: Post-Doc at BNL
  - ATLAS Experiment and African School of Physics
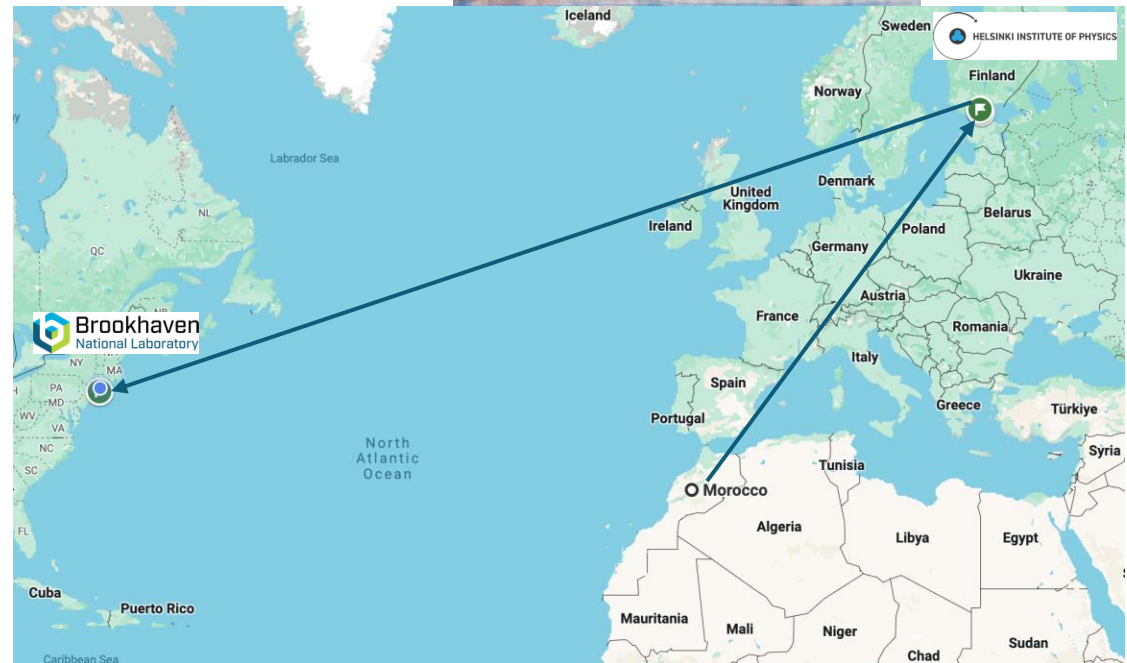
Particle physics: what we know!

- **The Standard Model (SM)** of particle physics:
  - Defines elementary **particles**, and their **interactions**
- **ATLAS** and **CMS** experiments discovered the Higgs boson in **2012**
  - Proved the existence of the last piece of the **Standard Model**
  - Made expected splash in the **scientific community**
  - Also made **international** news!

Standard Model of Elementary Particles

The New York Times

Physicists Find Elusive Particle Seen as Key to Universe

Share full article   122

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson. Pool photo by Denis Balibouse

By **Dennis Overbye**
July 4, 2012

ELSEVIER

Observati
with the
ATLAS Colla
This paper is de
contributions to

The Large Hadron Collider (LHC)

Need a **machine** capable of producing the particles we want to study...

- World's largest particle accelerator with 27 km circumference
- Collides **protons**, heavy ions. pp collisions at 7, 8, 13, now **13.6 TeV**
- Has **four detectors** stationed: (ALICE, ATLAS, CMS, LHCb)
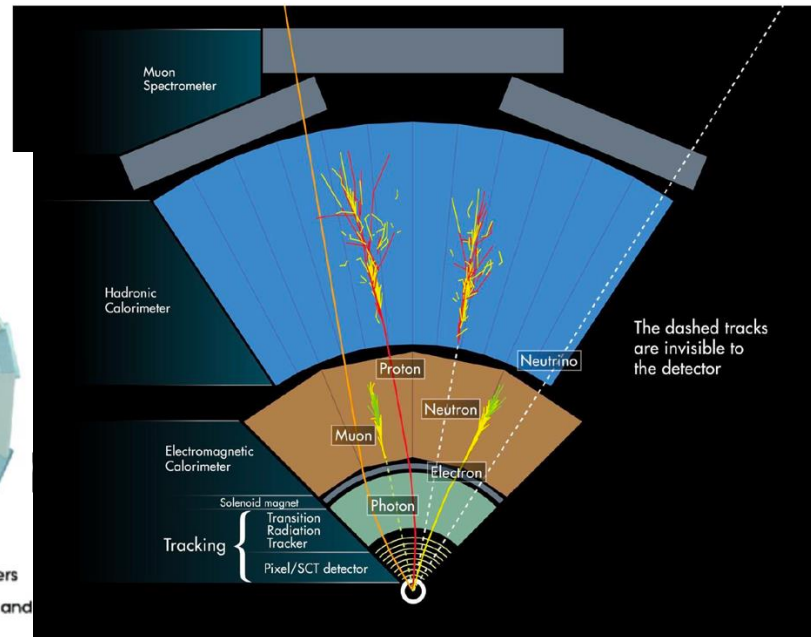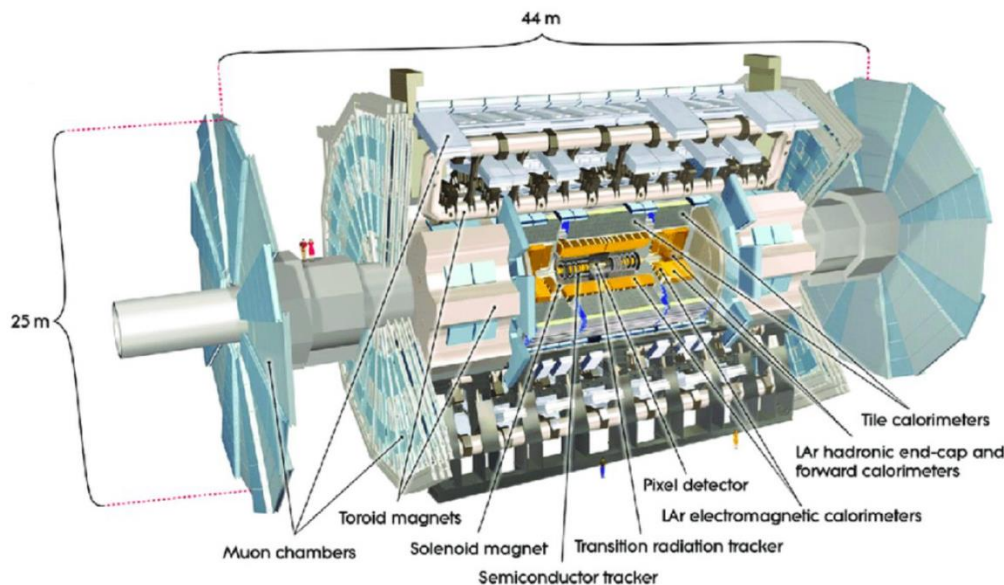- It's BIG
- It's EXPENSIVE
- What's it good for?
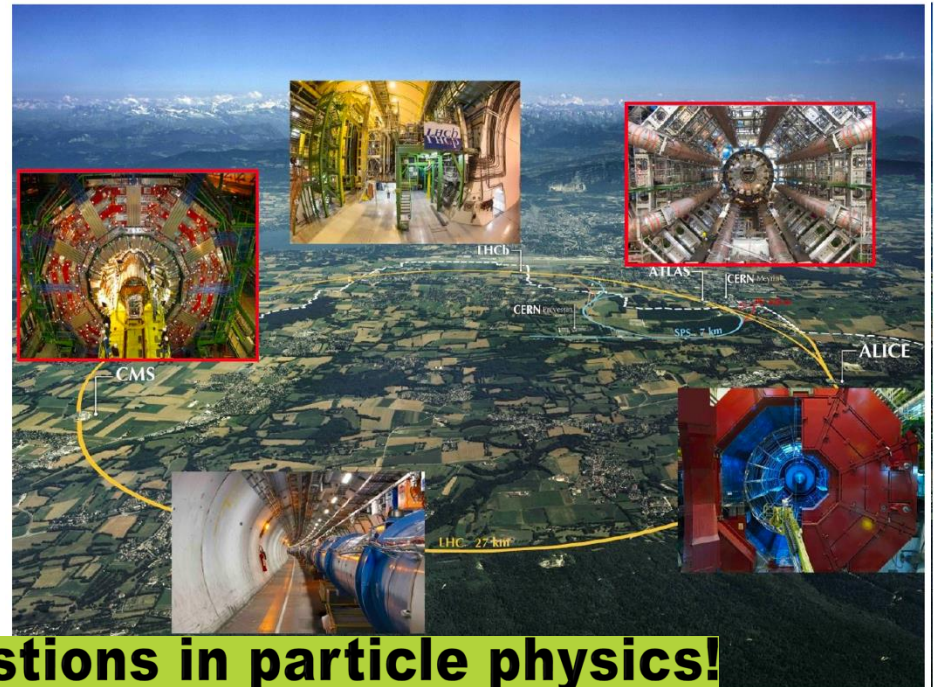
Answering the big questions in particle physics!

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The Large Hadron Collider

The ATLAS detector

Particles produced at the LHC need to be reconstructed!

- *Trackers + Calorimeters + Muon Spectrometer*
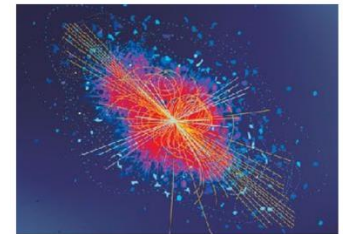- Different **layers** detect different **particles** (needed for different final states!)

LHC future looks bright

- All experimental measurements agree with **Standard Model predictions**
- We still have *many questions to answer!*

Dark Matter 26.8%

Ordinary Matter 4.9%

Dark Energy 68.3%
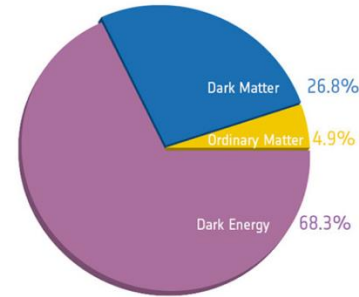
What is dark matter?

What new particles and forces are out there?

+ more!

We need more data	To increase the precision of our measurements
	To increase the probability of seeing rare events

Upgrading to the High Luminosity LHC (HL-LHC), with 10x more proton-proton collisions!

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High-Luminosity LHC

- 2029: LHC will finish upgrade to

High Luminosity LHC

- **Pro**: Will increase ATLAS + CMS datasets by ~ factor of 10
- **Con**: Extremely challenging data-taking environment
 - Extensive **detector upgrades** in progress to handle this
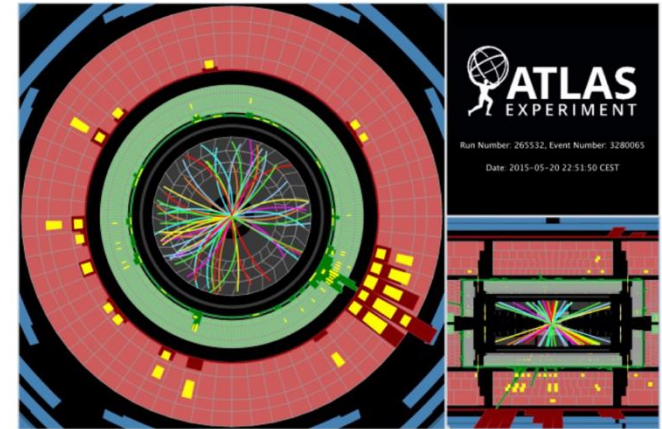
Current LHC: 20-30 collisions each time we cross beams
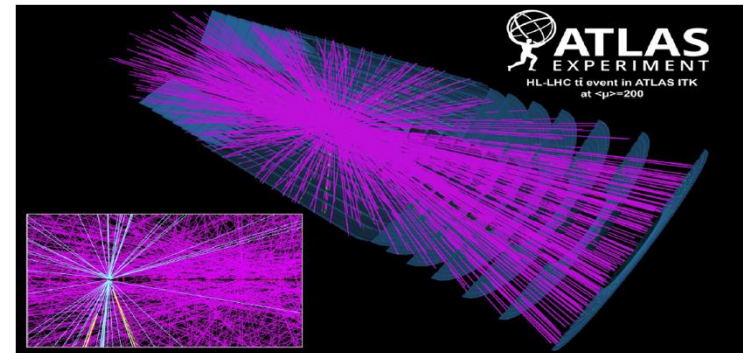
HL-LHC: up to 200 collisions each time we cross beams

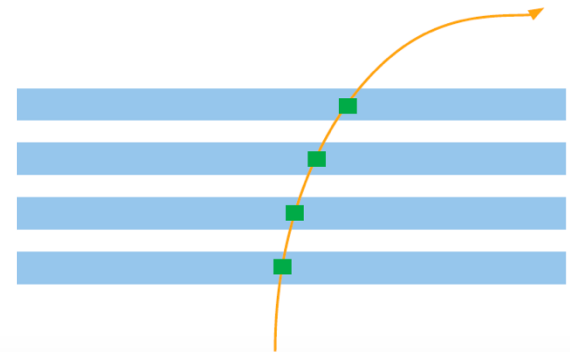Brookhaven
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Silicon based tracking

- Particle hits silicon
- Electric signal read out
- Series of hits forms a **track**
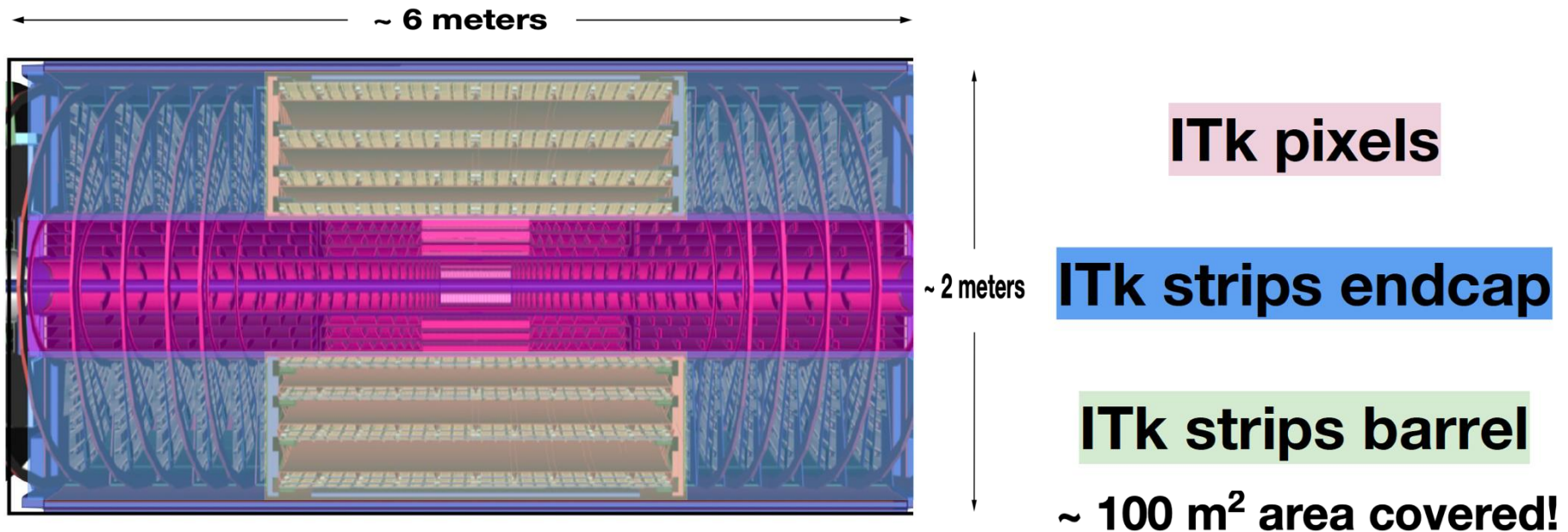- Use radius to measure **particle momentum**

Silicon trackers actively used by ATLAS and CMS!
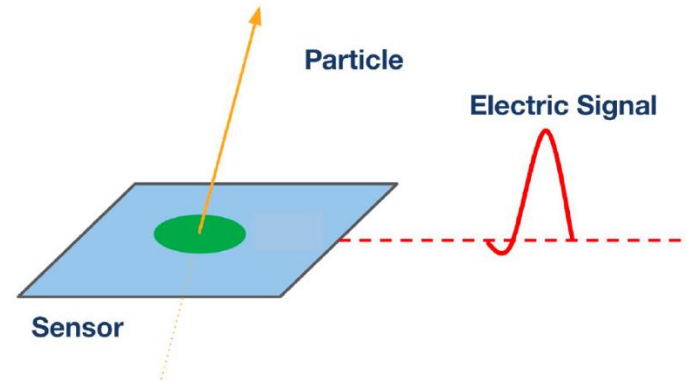
G. D'amen - BNL physics seminar series

New ATLAS Inner Tracker (ITk)

- Part of ATLAS **upgrade**: Replace tracker with **full silicon pixel** and **strip** sub-detectors - **The ITk** (Inner Tracker):
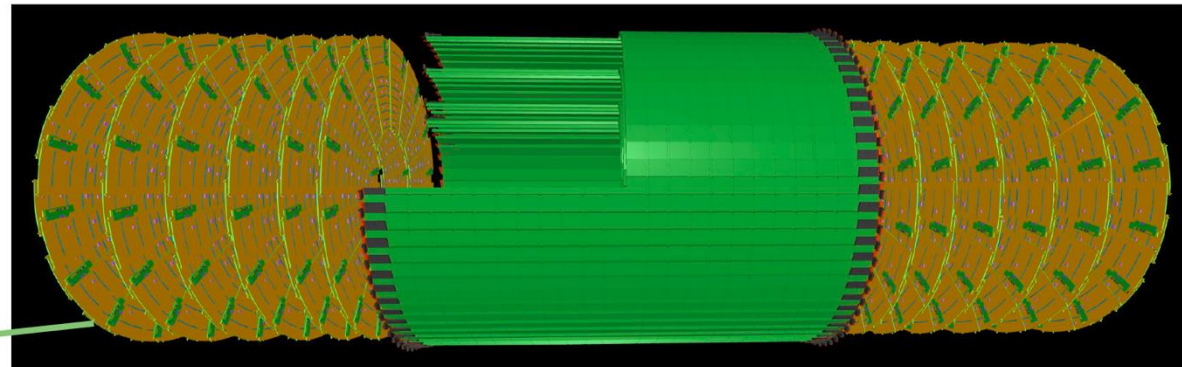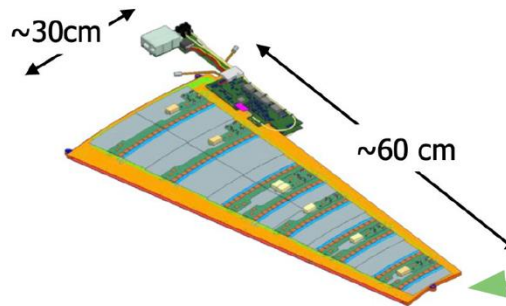

~ 6 meters

~ 2 meters

ITk pixels

ITk strips endcap

ITk strips barrel

~ 100 m² area covered!

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ITK strips layout

1 Disk = 32 **Petals**

~30cm

~60 cm

Endcap
6 disks

Barrel
4 layers

Endcap
6 disks

ITk viewer

1 Barrel layer = 56-144
Staves

1400 mm

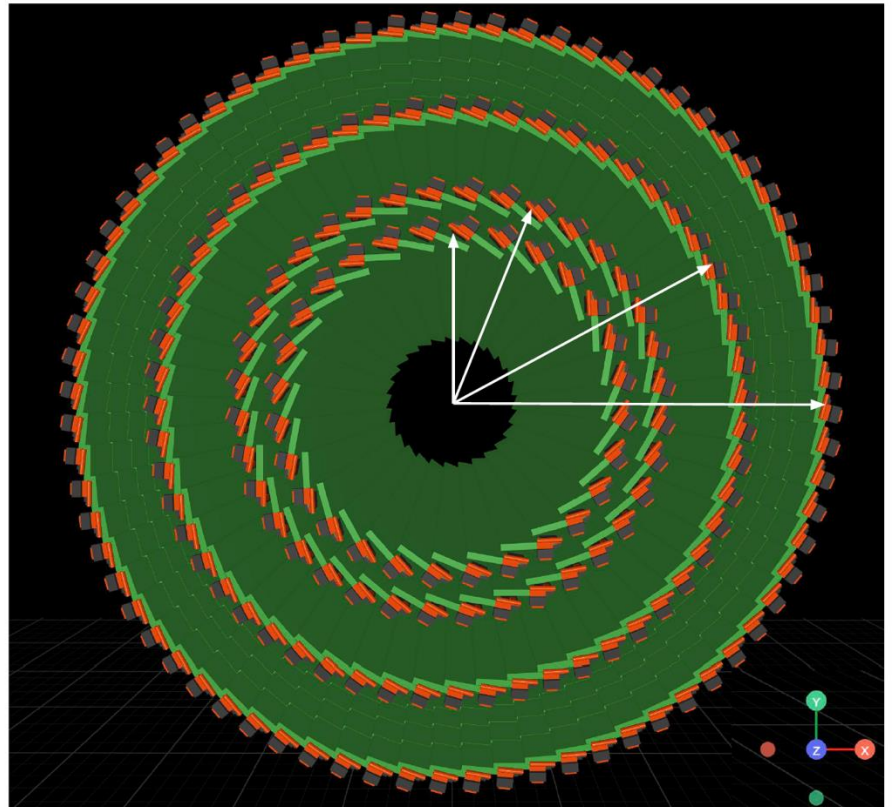**Brookhaven**
National Laboratory
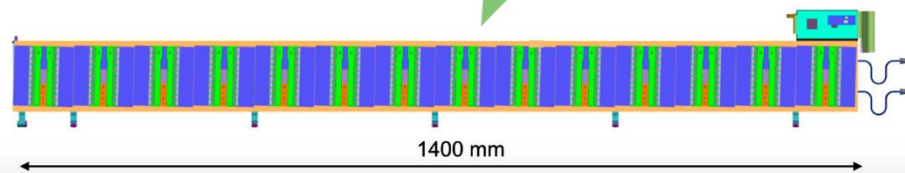
ITK strips barrel layout

- The **ITk strips barrel** will be made of **four layers**
- Inner two layers: **Higher granularity sensors**
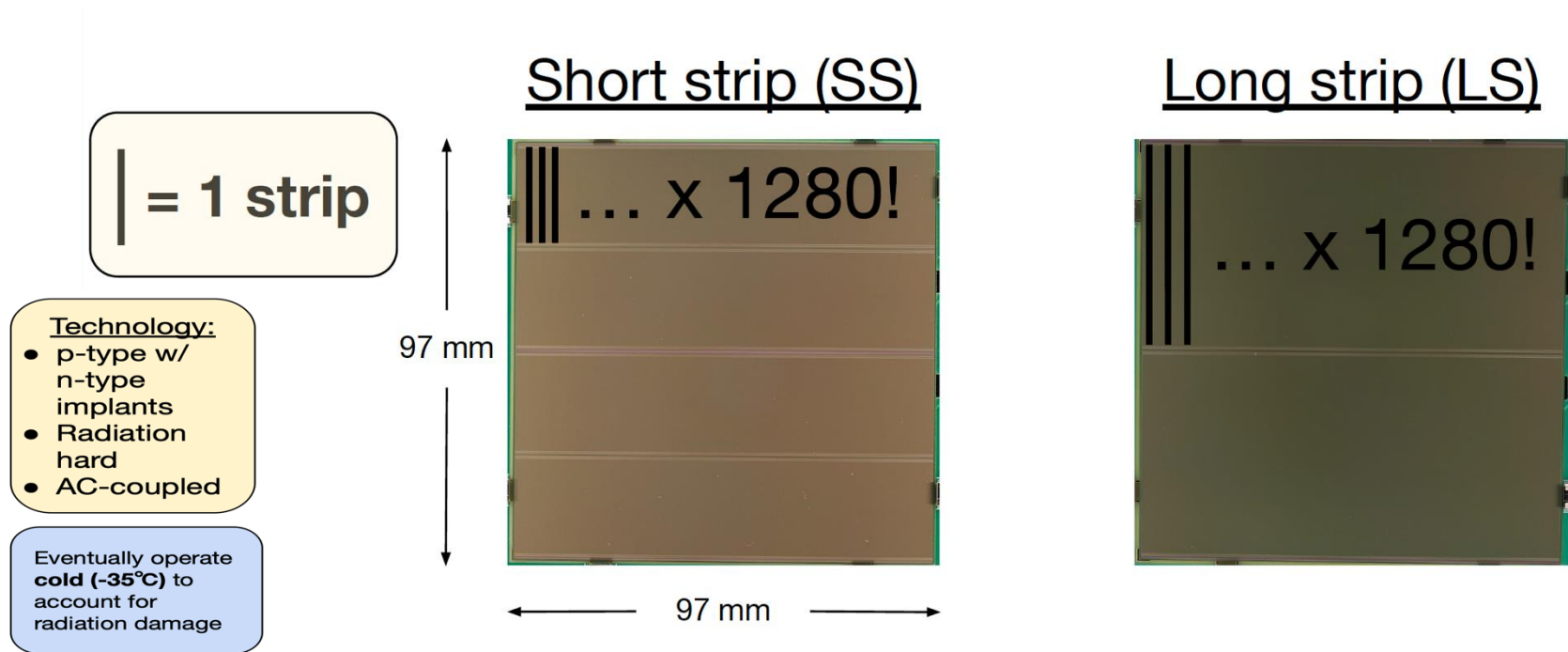- Outer two layers: **Lower granularity sensors**

Layer	Radius [mm]	Channels in ϕ	Strip Pitch [μm]	Strip Length [mm]
0	405	28×1280	75.5	24.1
1	562	40×1280	75.5	24.1
2	762	56×1280	75.5	48.2
3	1000	72×1280	75.5	48.2

ATLAS-TDR-025

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Sensors

- Detect particles at the **strip level.** Two flavors of **barrel** sensors:

| = 1 strip

Technology:
- p-type w/ n-type implants
- Radiation hard
- AC-coupled

Eventually operate **cold (-35℃)** to account for radiation damage

Short strip (SS)

||| … x 1280!

97 mm

97 mm

Long strip (LS)

||| … x 1280!

- SS/LS: 4/2 rows of 1280 strips in same amount of area.

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Hybrids

- Need to **read out each strip**

- Hybrid**: Flex PCB** glued onto
sensors

- **Hosts ASICs**, called the **ABCStar**
  - Hybrid hosts 7-12 ABCStars, depending on hybrid/sensor flavor
- Wire-bonded to strips for **individual readout!**

ABCStar chip
(x10 for this type)
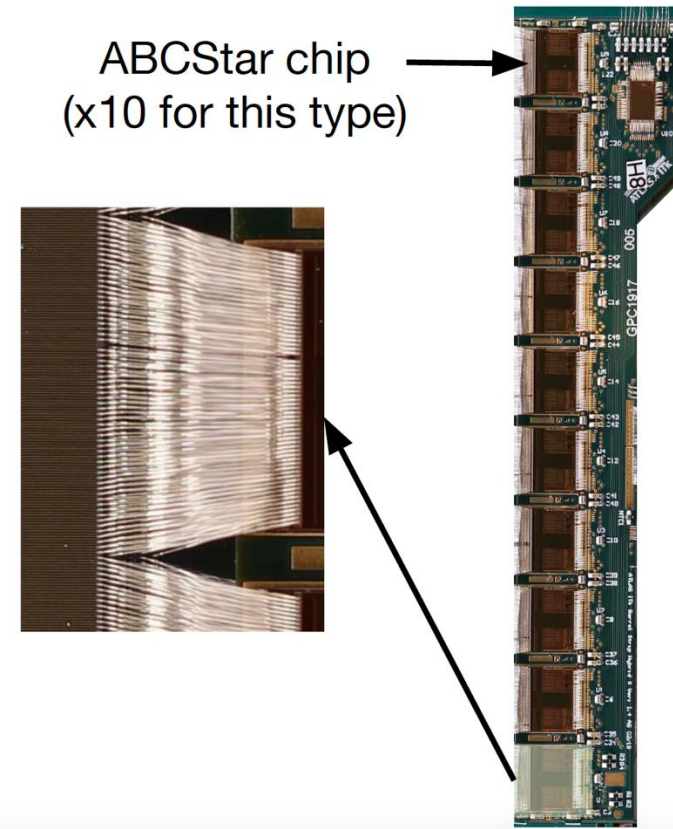
Powerboards

- Need to power ASICs on hybrid
- Accomplished via a **powerboard** PCB housing various components:

DC-DC converter
- 11V input, 1.5V output
- 110 μm Al shield to prevent EM noise leakage

Measurement and control
- Linear regulator for 11V → 1.4/3.3 V
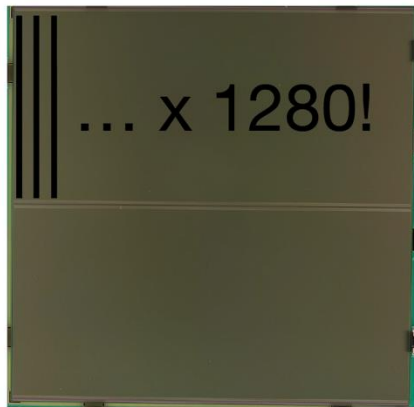- Enable/Disable DCDC
- Measure volage, current, temperature

HV filter
- Includes a GanFET (Gallium Nitride Front End Transistor)
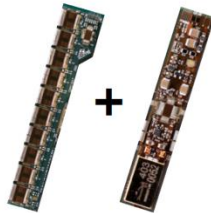- Allows **isolation** of failed sensor in breakdown connected to the same HV line
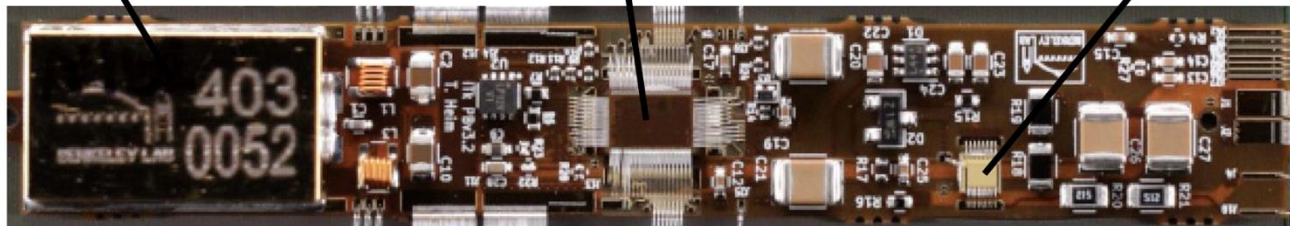
Modules

- Let's put all it together!
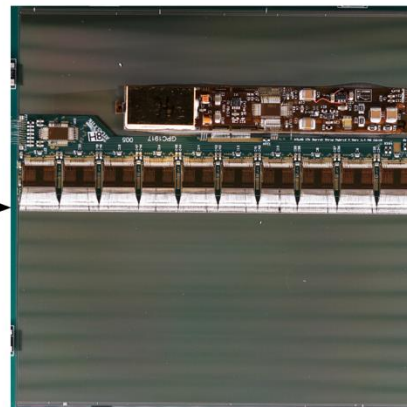 - Define this as a **module**:
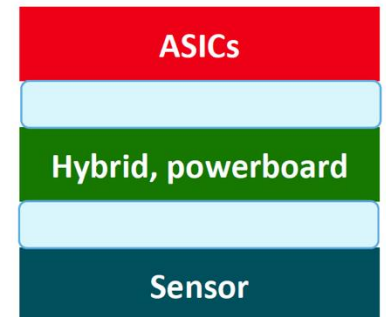

Long strip **sensor** ... x 1280! + + = Long strip **module**

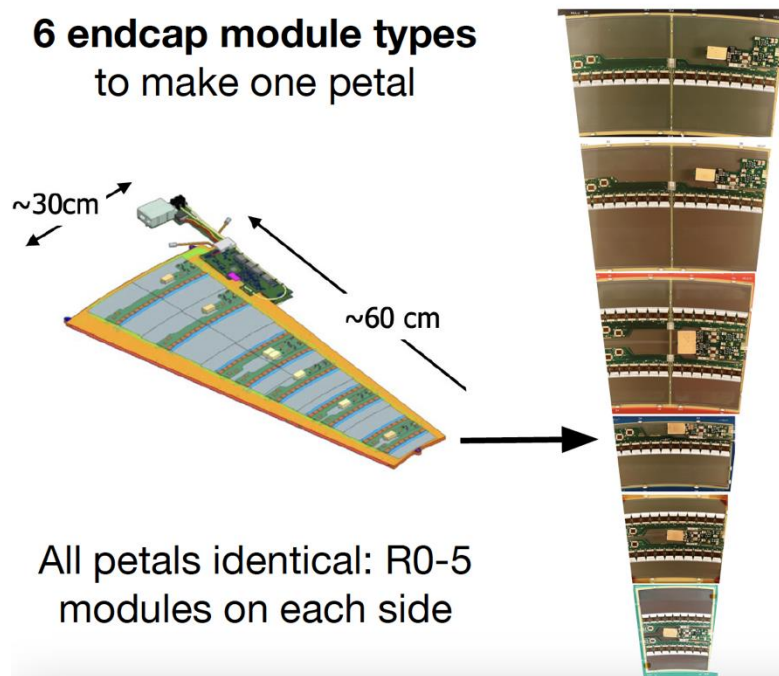Birds-eye view

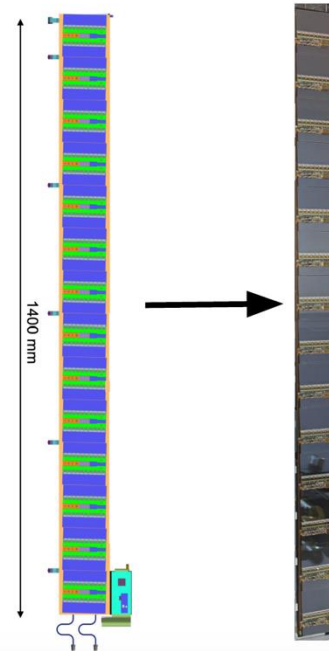Side view: ASICs, Hybrid, powerboard, Sensor

All module flavors

Need appropriate module geometries to make up **petals** (endcap) and **staves** (barrel):

6 endcap module types to make one petal

~30cm

~60 cm

All petals identical: R0-5 modules on each side

1400 mm

Each stave has **14 modules per side**

Long strip stave: **14 long strip modules per side**

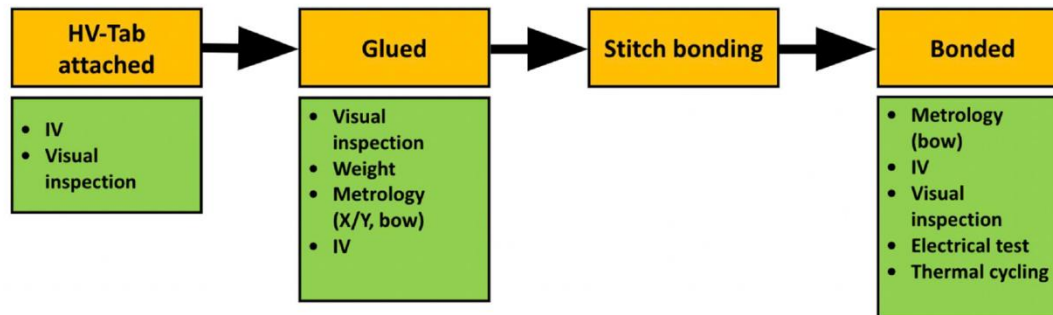Short strip stave: 14 short strip modules per side

ITK at BNL

- At BNL, we **assemble** and **test** <u>modules</u> and <u>staves</u>
- **50%** of strip barrel staves will be produced at BNL
- I work on module and stave testing—and investigating problems discovered during testing!
- Developing **interlock systems** to ensure safe thermal cycling of silicon strip modules, enhancing operational safety and reliability
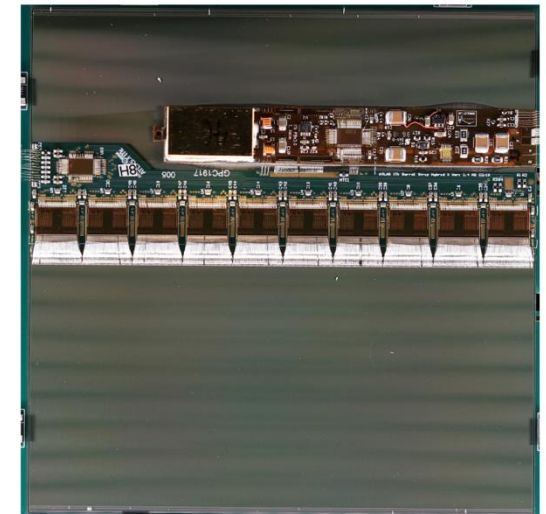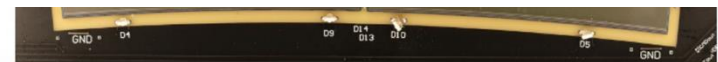- Serving as US contact of **the coldjig software**.

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Module QC

- Module QC tests are performed after each **assembly step**:

| HV-Tab attached | → | Glued | → | Stitch bonding | → | Bonded |

- **HV-Tab attached**
  - IV
  - Visual inspection
- **Glued**
  - Visual inspection
  - Weight
  - Metrology (X/Y, bow)
  - IV
- **Bonded**
  - Metrology (bow)
  - IV
  - Visual inspection
  - Electrical test
  - Thermal cycling

2024 JINST 15 P09004 [arXiv:2401.17054]
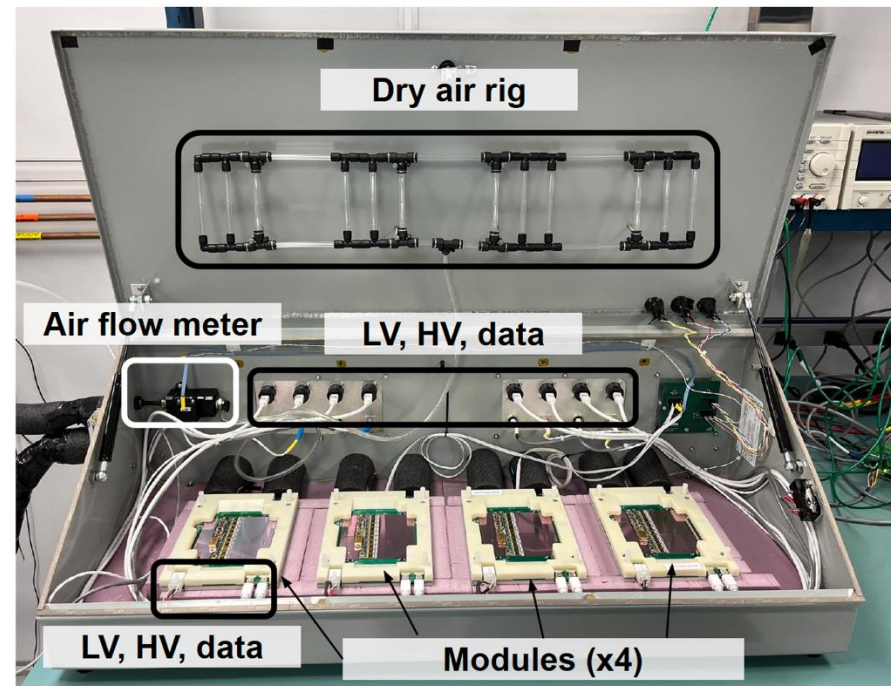

Completed module!

Module QC setup

- To perform these steps, need a robust and complete setup!

- **Module testing at BNL**
  - Coldbox (Modules go in here)
  - Chiller (temp control)
  - Dry air flow (humidity control)
  - Power supplies to power electronics, bias sensors
  - FPGA + PC for DAQ
  - Raspberry pi: Environment monitoring

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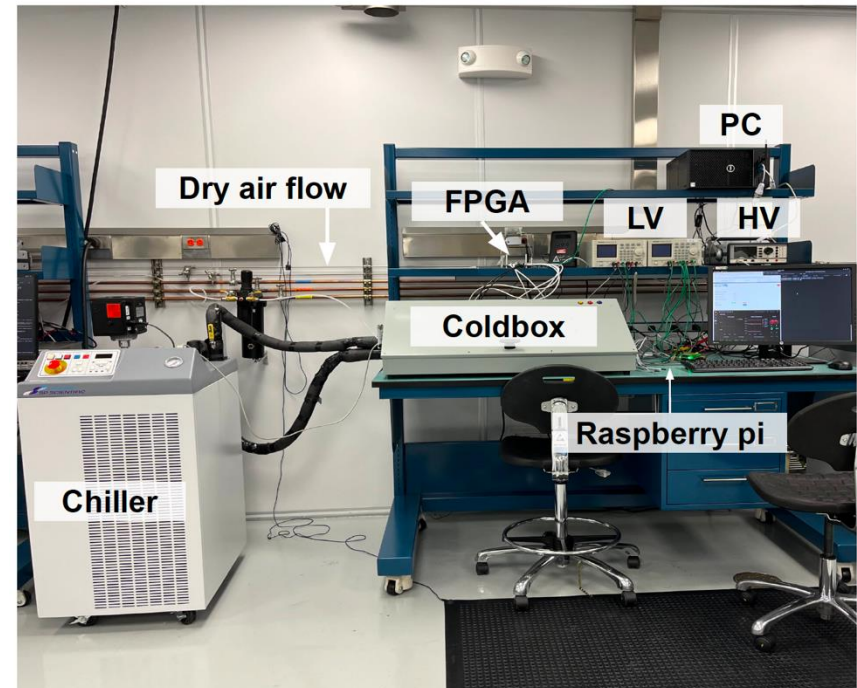
Module QC coldbox

- **Inside the coldbox**
  - Up to four modules
  - Dry air rig (minimize humidity)
  - Air flow meter (monitor)
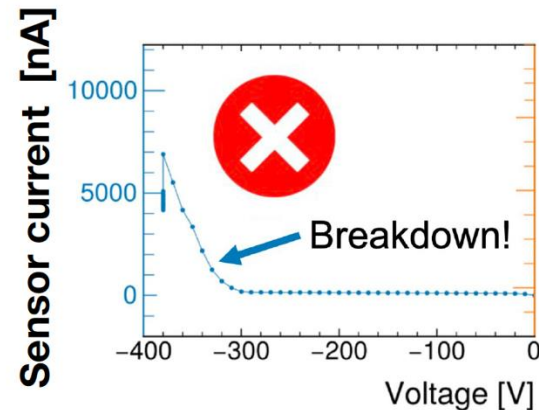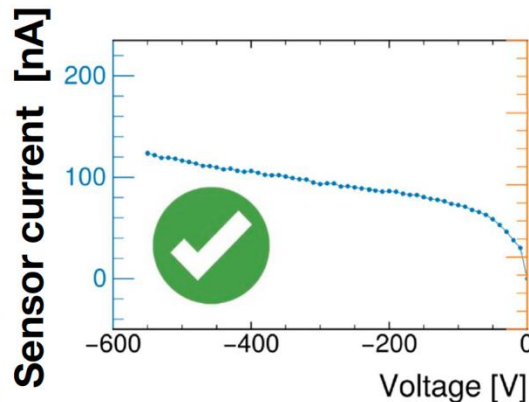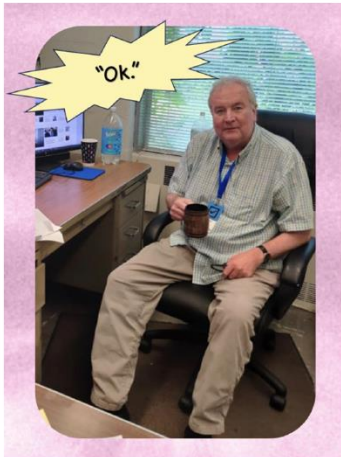 - Module side LV, HV, data lines
  - Box side LV, HV, data lines

Dry air rig

Air flow meter

LV, HV, data

LV, HV, data

Modules (x4)

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Module IV

- Modules must be operational up to **-500 volts**

- First electrical test of a module: **IV curve**
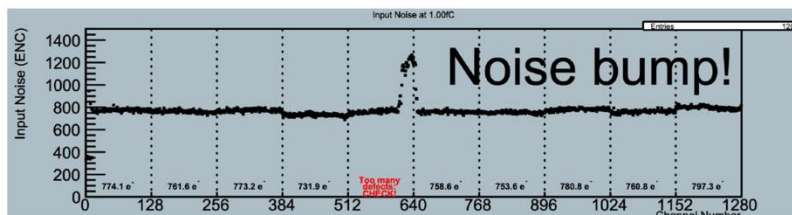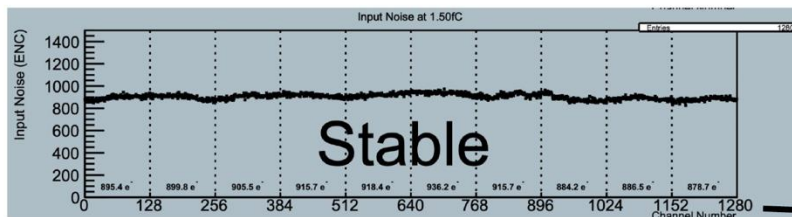 - Increase voltage in steps of -10V, measure sensor current

Module electrical test

- Modules must exhibit **acceptable noise**
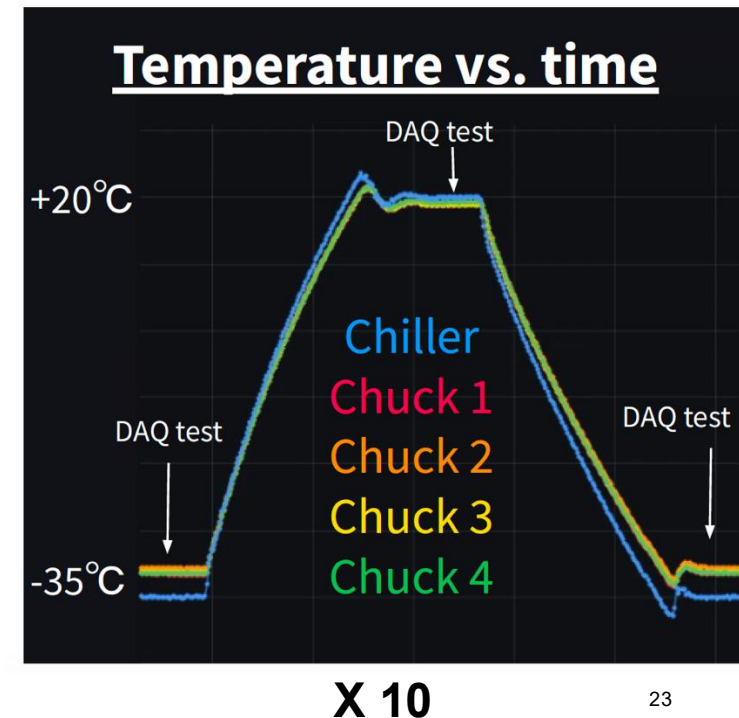- Bias sensor at **-350V**, inject **test charges**, measure gain, noise

Stable

Noise bump!

… x 1280!

Module thermal cycling

- Expect modules to experience **temperature changes** during operation (~ 1 expected time per year from **year end shutdown**)

- Emulate this effect with **thermal cycling**

- Define one thermal cycle as:
  - Start cold
  - Take noise measurement
  - Go warm
  - Take noise measurement
  - Go cold
  - Take noise measurement

- Module must undergo 10 thermal cycles and have passing noise and IV afterwards
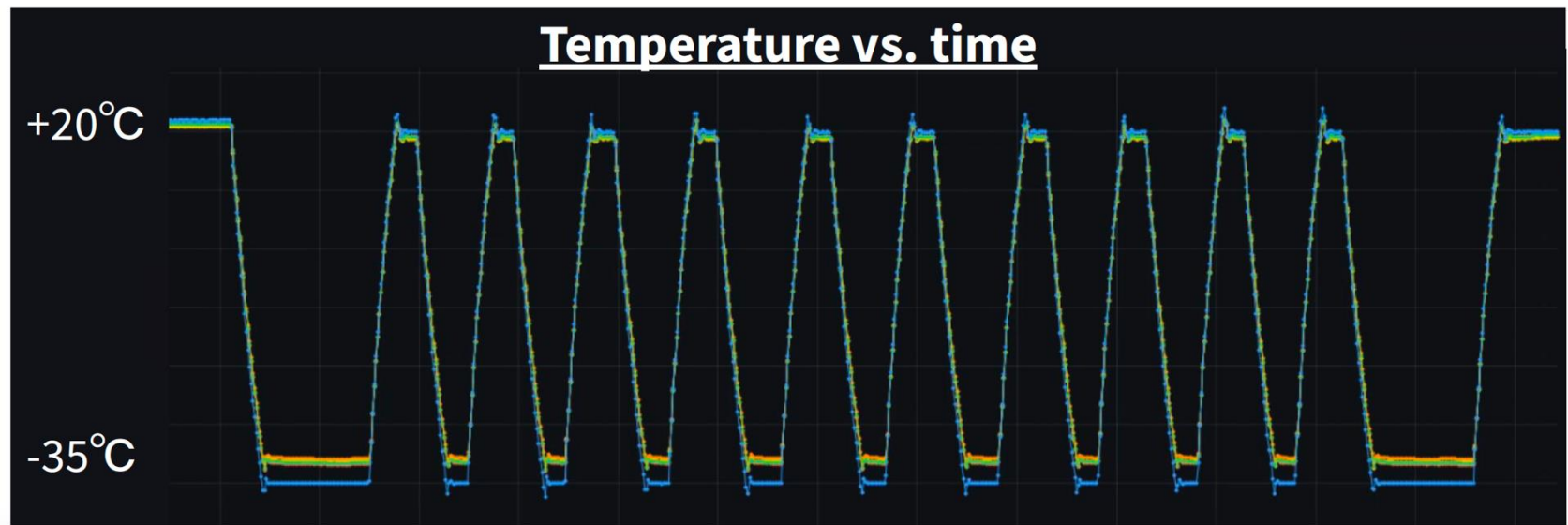
Temperature vs. time

DAQ test

+20°C

Chiller
Chuck 1
Chuck 2
Chuck 3
Chuck 4

DAQ test

DAQ test

-35°C

X 10

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Module thermal cycling example

- Example set of ten thermal cycles
- Cycled four modules simultaneously
- Noise and IVs after TC looked good

**Temperature vs. time**

+20°C

-35°C

Stave testing setup

- If modules **pass** all steps, **load** them onto **stave/petal**
- Need to ensure modules **not affected** during this step!
- No well-defined **stave/petal QC procedure** yet, but have testing setup:
- **Example stave testing setup**
  - Coldbox (Stave inside)
  - Chiller (temp control)
  - Dry air (humidity control)
  - Power supplies to power electronics, bias sensors
  - FPGA for DAQ
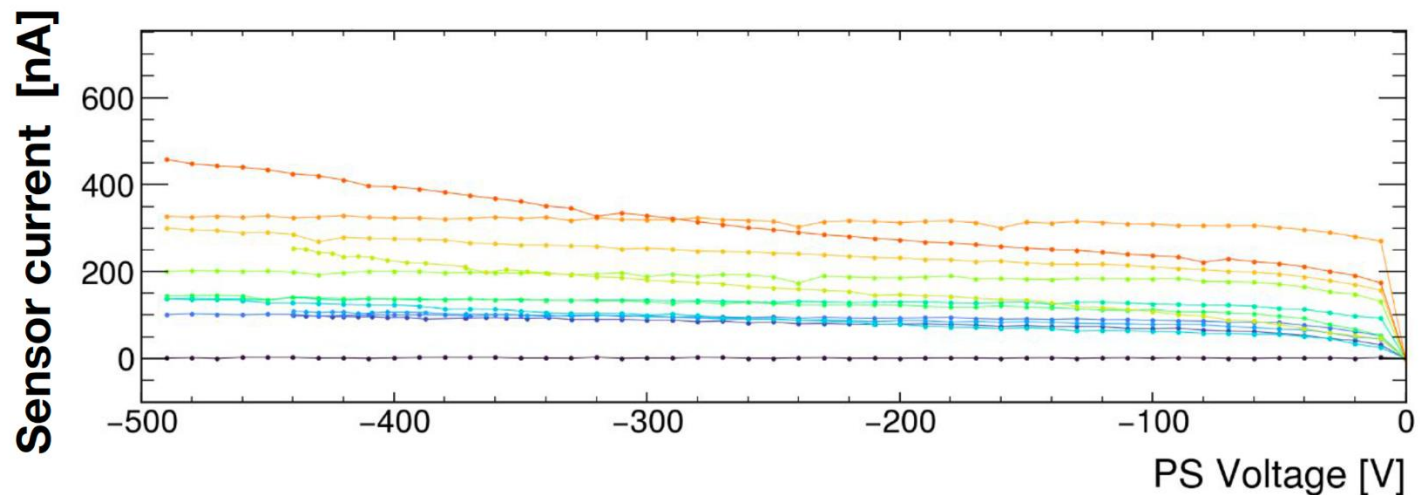 - Raspberry pi: Environment monitoring
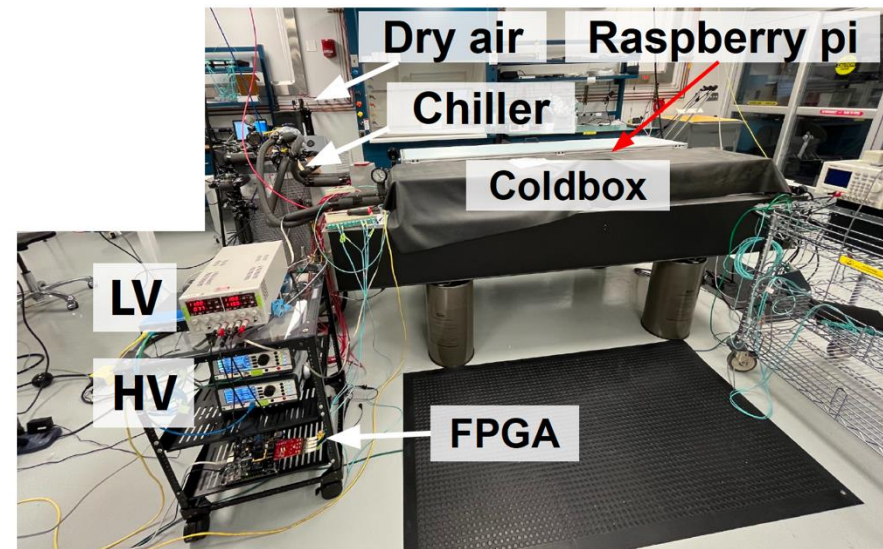
Stave coldbox

- **Inside the coldbox**
  - One stave
  - Dry air flow (minimize humidity)
  - Coolant inlet/outlet (temperature control)
  - LV/HV connector
  - **End Of Substructure** (EOS) card for data readout
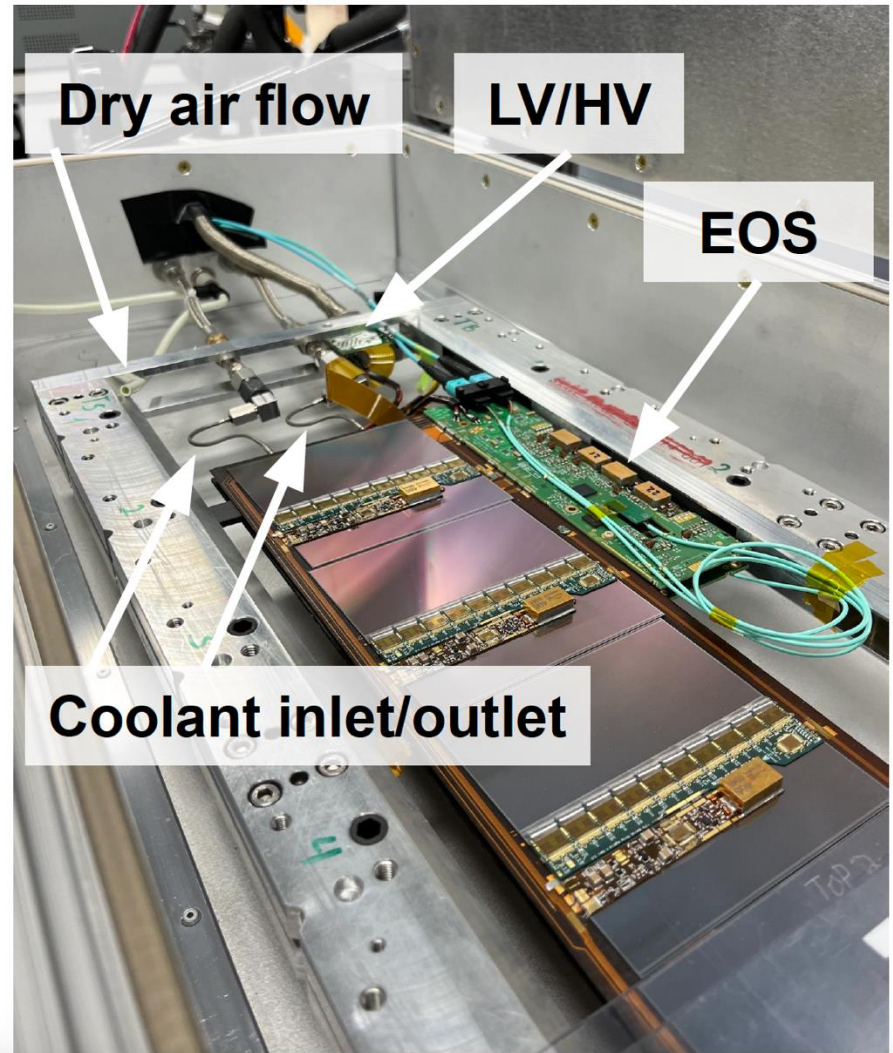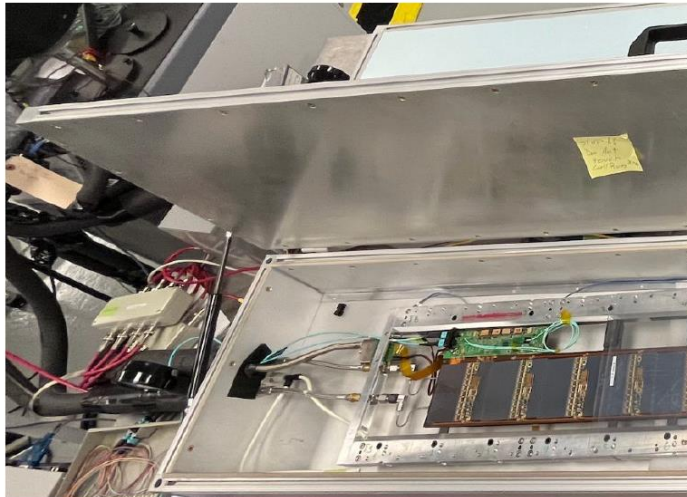
Stave IV

- Can take IV of **all modules simultaneously**

- In this case, **no modules in breakdown**
- Varied current magnitudes among modules, partially expected from **light leakage**

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Stave electrical test

- Can take noise measurement of **all modules simultaneously**
- Example noise measurement for **one stave side** (14 modules)
- X-axis ranges: 300-1100 ENC
- Expected shape near **DCDC coil**
- Flat, ~ 900 ENC. Considered **healthy noise** for **Long Strip stave**
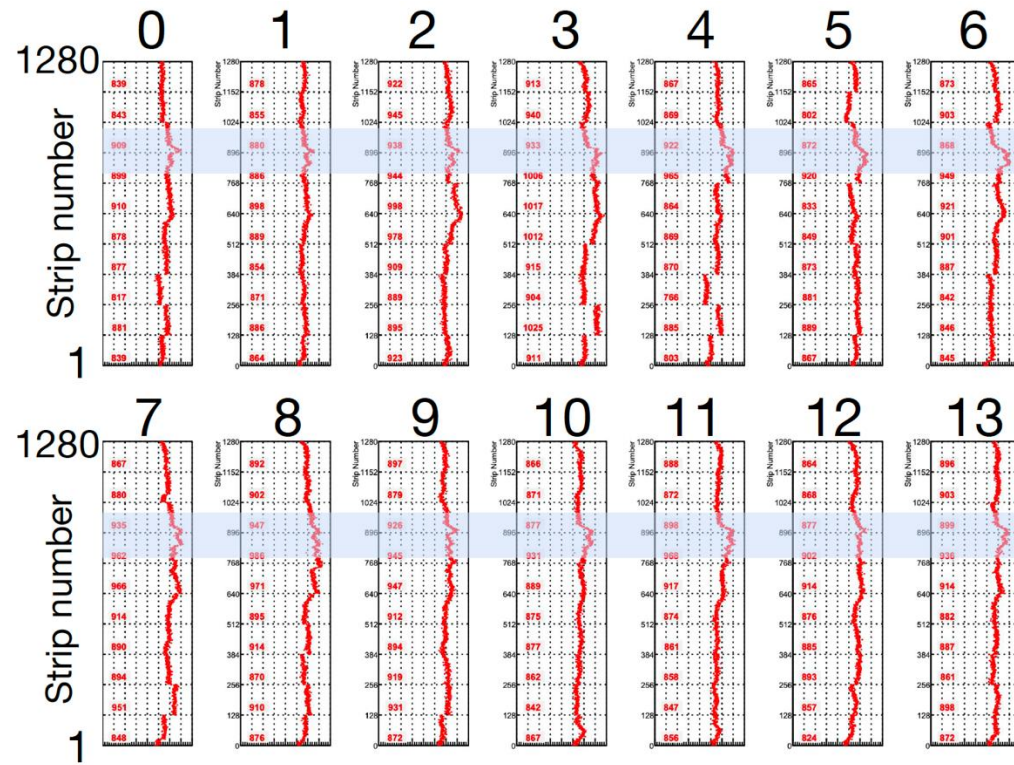
Noise [ENC] xmin/max of each: **300/1100**

35

Stave TC

- Also plan to **thermal cycle** staves a number of times (number undefined, at least **5 times**)
- Will compare noise **before** and **after** thermal cycling, just like for module TC
- In this example, TCd stave to inlet/outlet avg. temperature = -35℃ **5 times**
- Noise looks **very similar** before/after
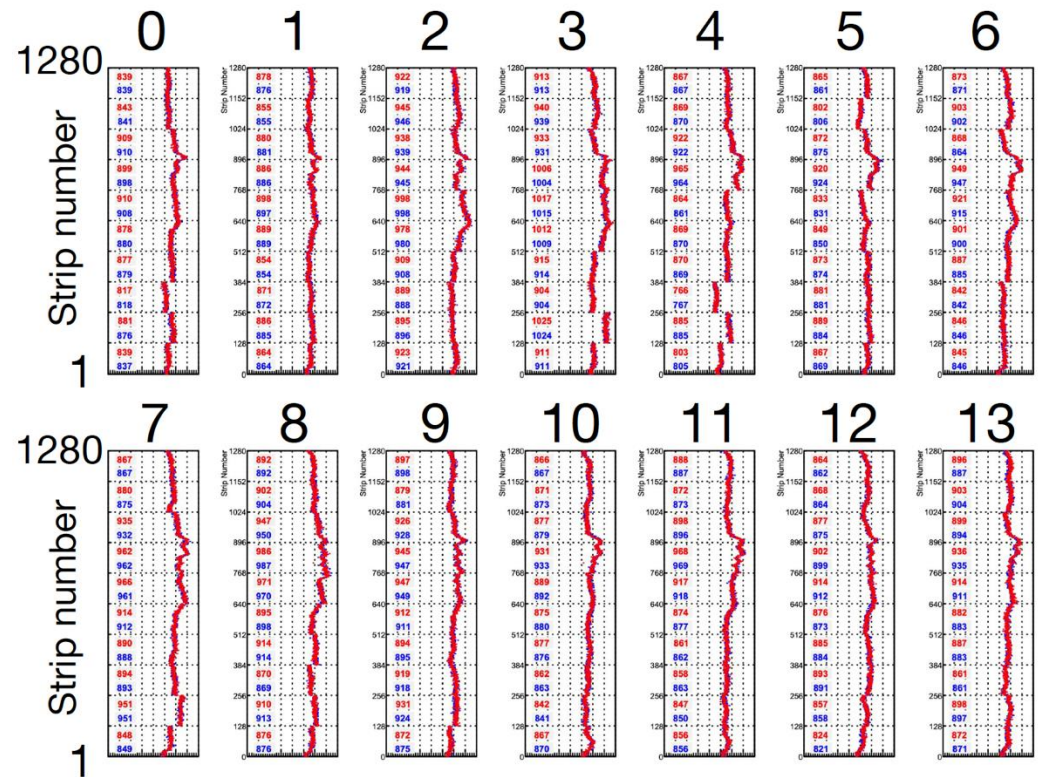
Noise [ENC] xmin/max of each: **300/1100**

Summary and the future of ATLAS

- BNL does critical work in assembly and testing of ITk Strips

- I am heavily involved in testing of ITk strip modules and staves at BNL & Developing interlock systems

- ITk should be installed and HL-LHC fully operational by the end of the decade

The more **robust** the **ITk**, the better the chance for **new physics discoveries**!

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Thank you!

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