ATLAS strip detector upgrade for HL-LHC

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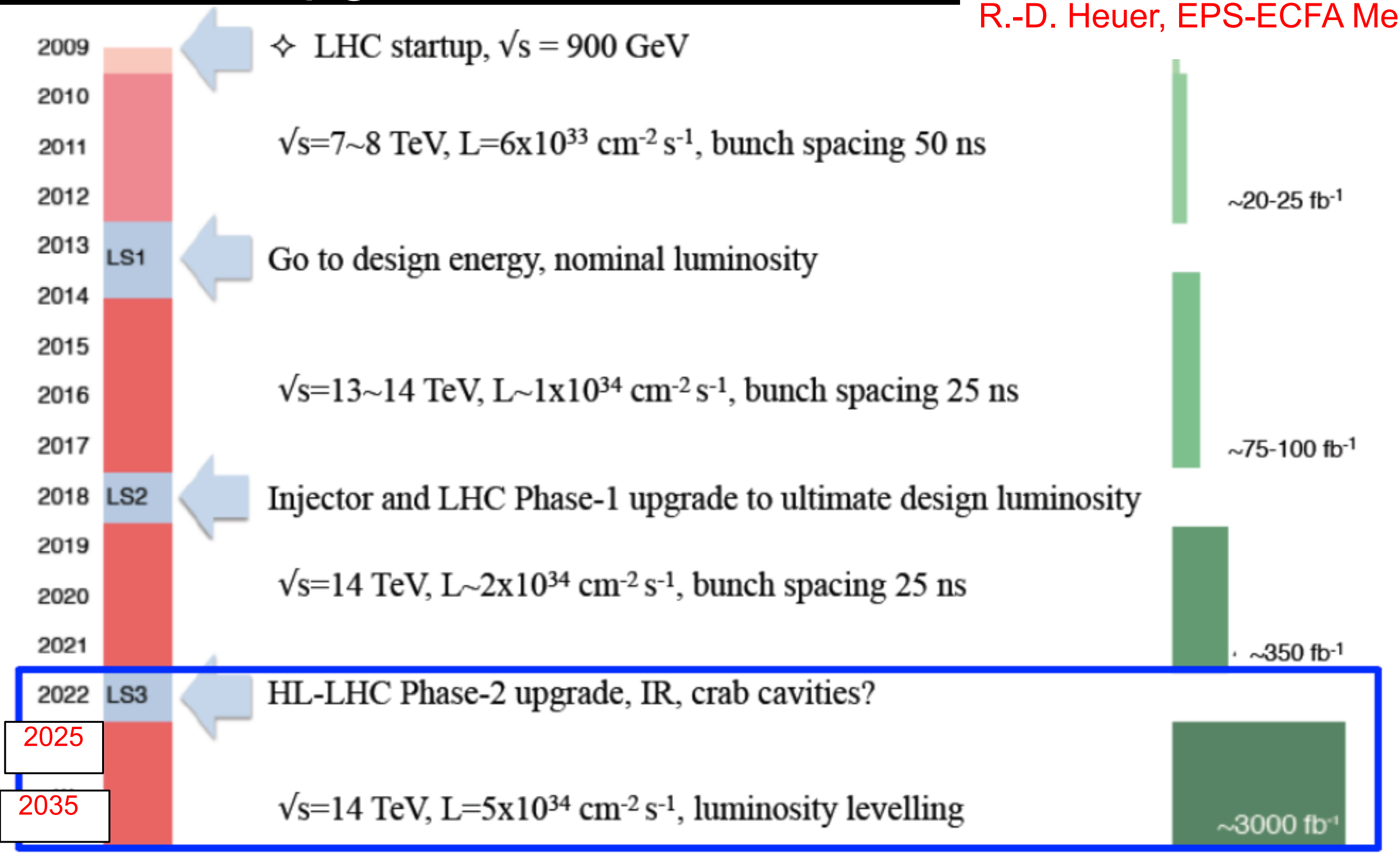
on behalf of ATLAS Collaboration

ATLAS upgrade : From LHC to HL-LHC

R.-D. Heuer, EPS-ECFA Meeting, July 2013



2009 ✧ LHC startup, √s = 900 GeV

2010

2011 √s=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

2012 ~20-25 fb^{-1}

2013 LS1 Go to design energy, nominal luminosity

2014

2015

2016 √s=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

2017 ~75-100 fb^{-1}

2018 LS2 Injector and LHC Phase-1 upgrade to ultimate design luminosity

2019

2020 √s=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

2021 ~350 fb^{-1}

2022 LS3 HL-LHC Phase-2 upgrade, IR, crab cavities?

2025

2035 √s=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity levelling ~3000 fb^{-1}

Phase 0 upgrade during LS1

- ❑ New beam pipe with additional pixel layer (IBL)

Phase 1 upgrade during LS2

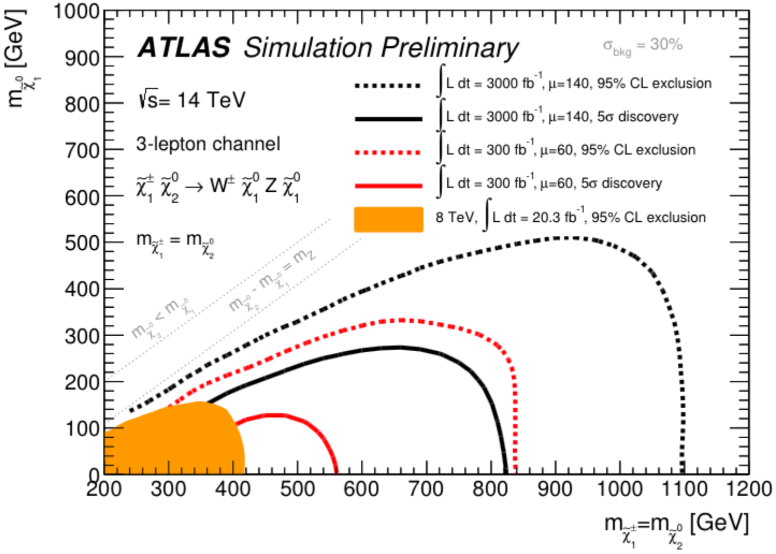
- ❑ new muon small wheels, Fast track trigger

Phase 2 upgrade during LS3

- ❑ replacement of inner detector ,calo/muon upgrade , L1 track trigger

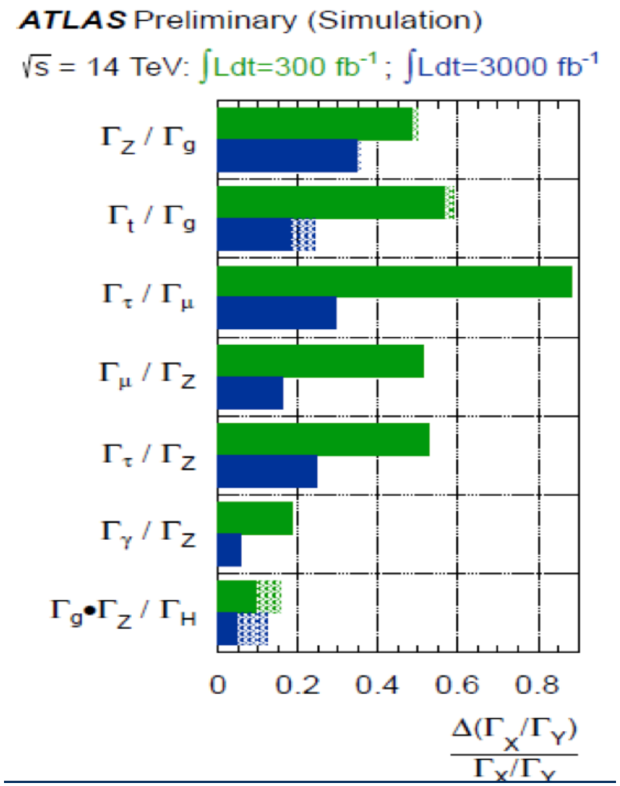
Motivation for the upgrade

SUSY particles at HL-LHC
3 TeV for squarks
~ 2.5 TeV for gluinos
400 GeV rise in sensitivity wrt the L=300 fb^{-1} case



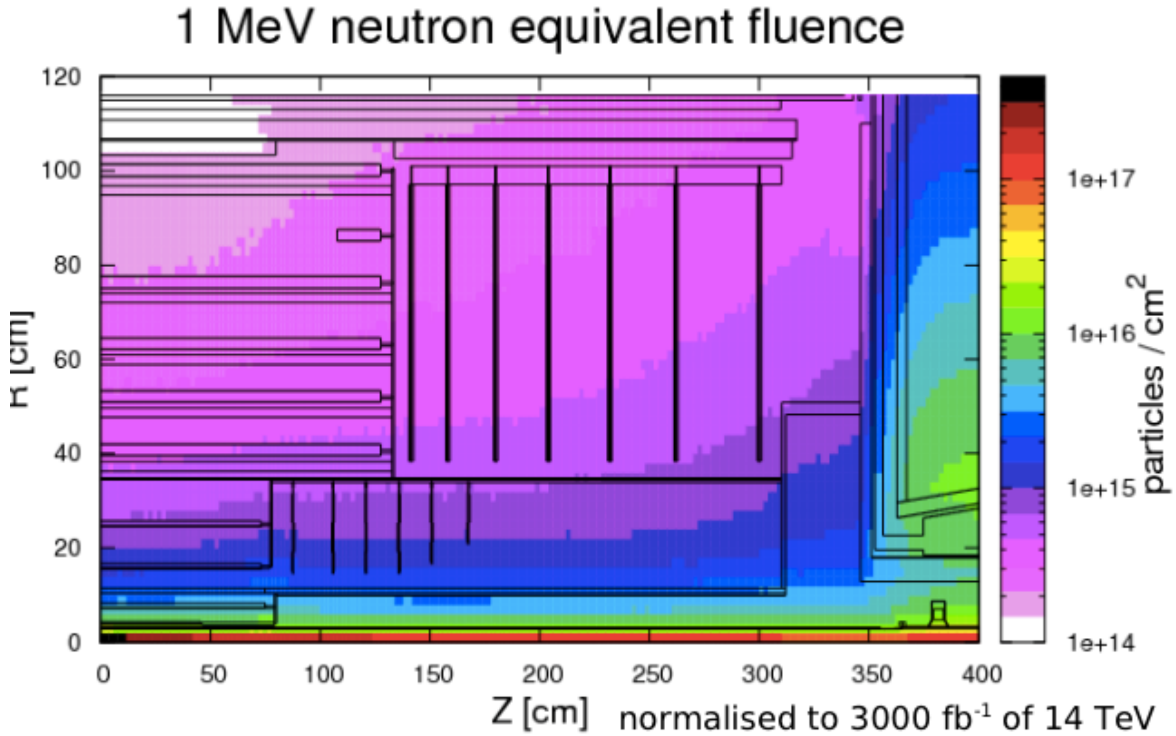
Higgs measurement

Expect significance improvements in the Higgs precision measurement in HL-LHC upgrade



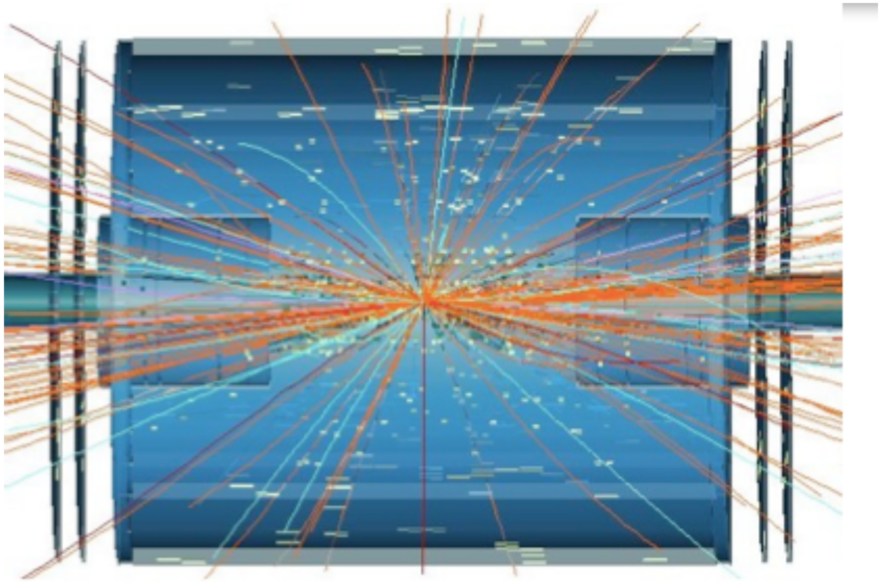
Why to upgrade ATLAS detector (2)

- High particle fluences
  - Present ATLAS silicon detector is designed only up to 2*10^{14} Neq/cm^2
  - Radiation hardness for strip detector upgrade is up to 2*10^{15} Neq/cm^2
  - Activation of material
  - → Need a new detector to survive in such high fluences

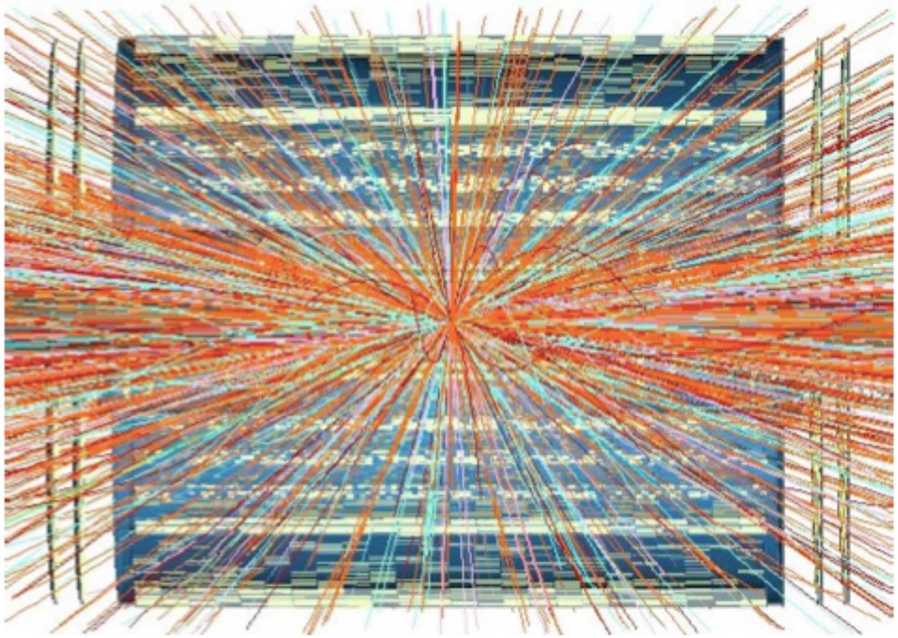


Why to upgrade ATLAS detector

- To keep ATLAS running in HL-LHC requires tracker replacements
- Major difficulties in new tracker design
  - 10 times higher dose
  - Much higher occupancy (200 collisions per beam crossing)
  - -->Motivate to use all silicon tracker at HL-LHC

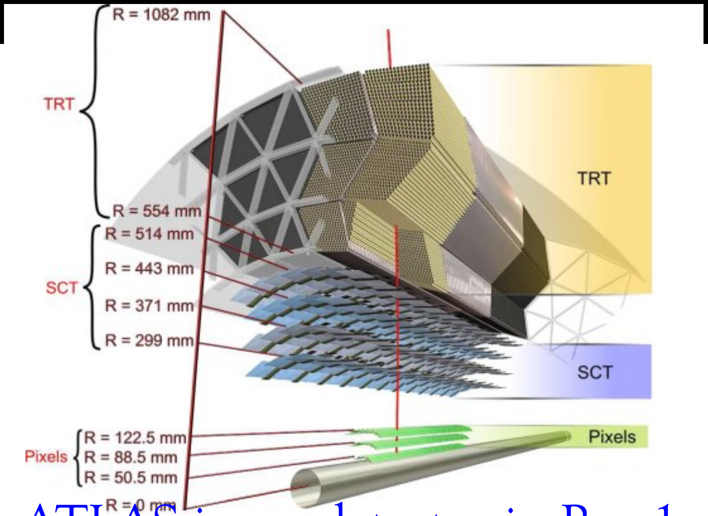


LHC

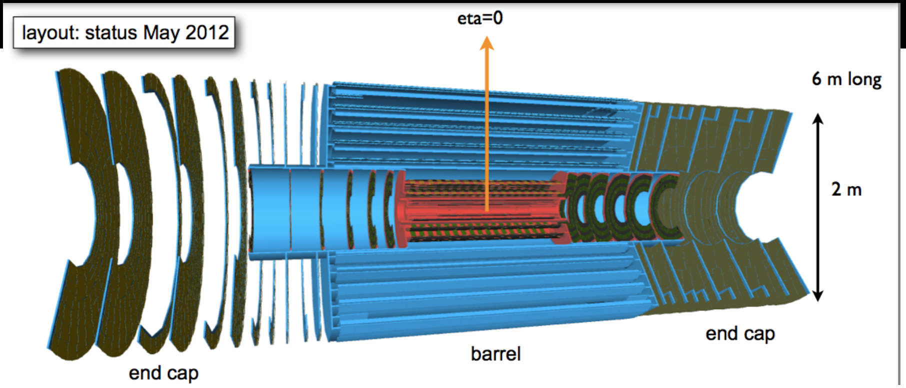


HL-LHC

The new Tracker for ATLAS



ATLAS inner detector in Run1



ATLAS inner detector in phase two upgrade

Pixel detector	**ATLAS run 1**	**ATLAS phase 2**
Radial distance	50-150mm	About 40-150mm
Channels	80.4 M	638 M (X8 times more)
Modules	47k	About 400k (X8 more)

Strip detector	**ATLAS run 1**	**ATLAS phase 2**
Radial distance	300-560mm	About 350-1000mm
Channels	80.4 M	638 M
Modules	4k	20k~30k (190m^2 silicon)

This talk will focus on strip detector upgrade

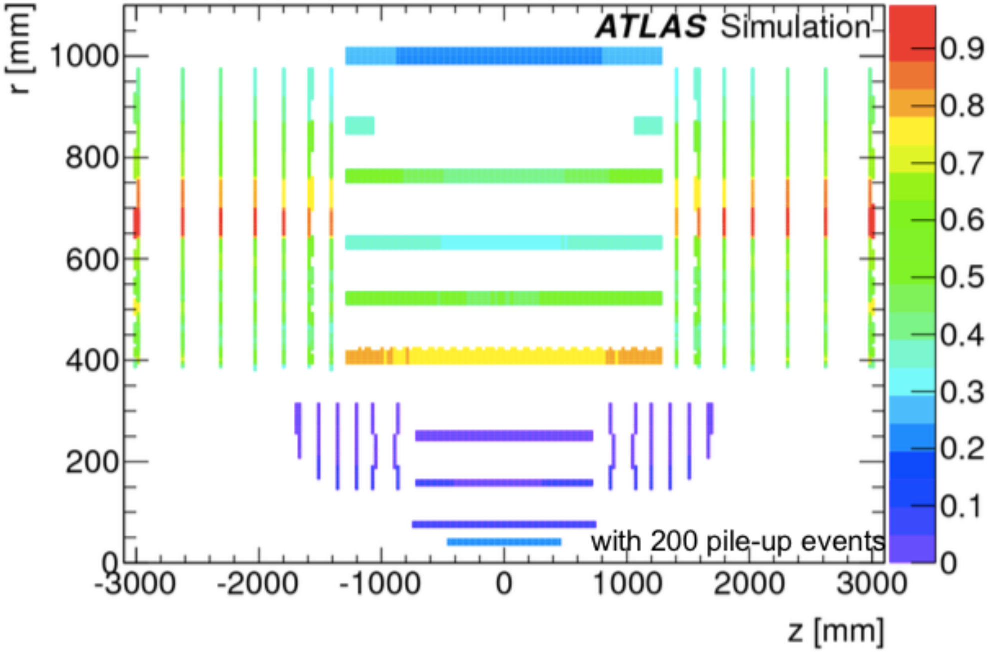
Why we need more channels?

- Motivation 1
- Need to keep hit occupancy <1% for strip region.

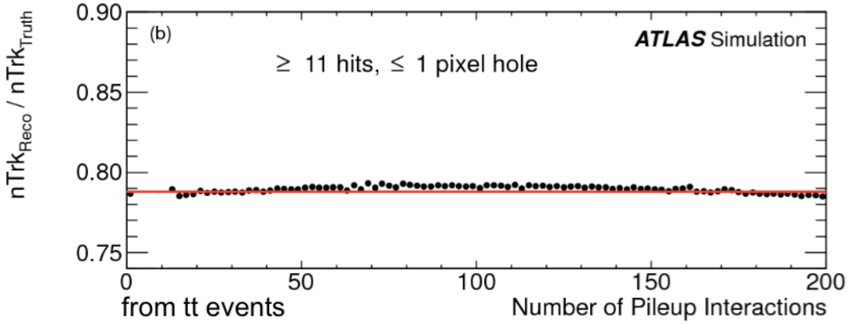
- Motivation 2
  - To keep high tracking efficiency in high pileup Environments

High granularity and high number channels are needed

Occupancy of ATLAS Inner detector for HL-LHC

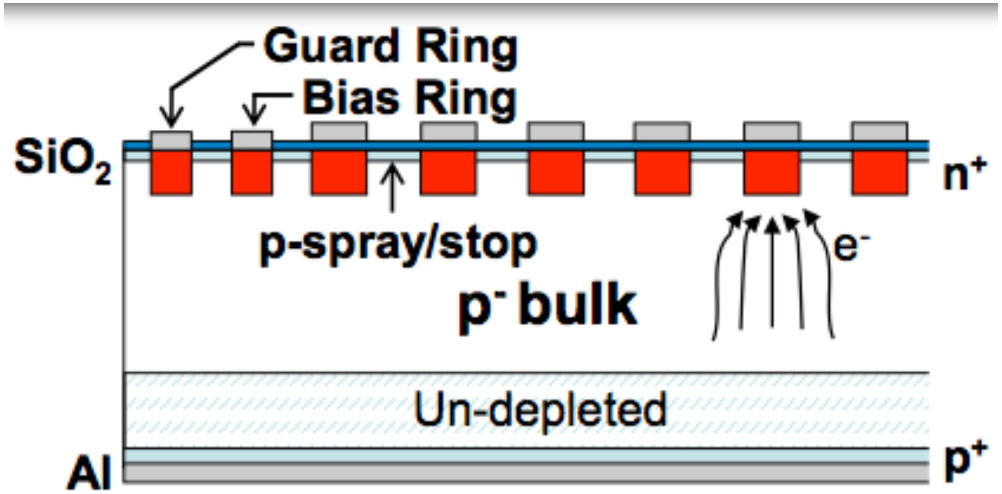


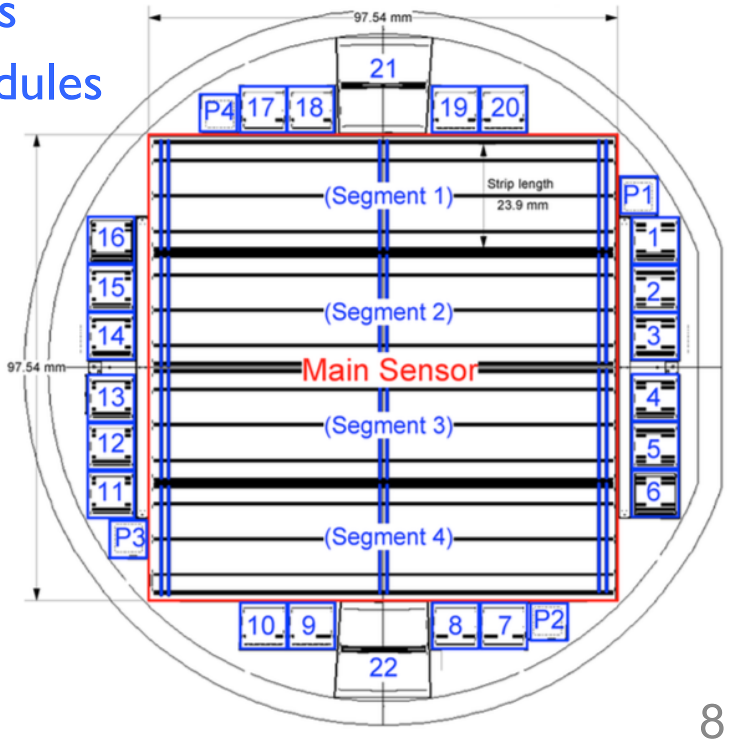
Hit efficiency Vs Number of pileup



Radiation Hard Sensors for strip detector upgrade

- **Sensors**: 98 x 98 mm^2 for Barrel .
  - **n+-strip in p-type substrate (n-in-p) sensors**
  - Collects electrons like current n-in-n pixels
  - Faster signal, reduced charge trapping
  - Long strips (98mm) and short strip designs (25mm),
  - We have two round of prototyping
- The study of planar sensors are quite advanced
  - Many studies have been done for radiation hardness
  - Full size sensors have been studied and used in modules

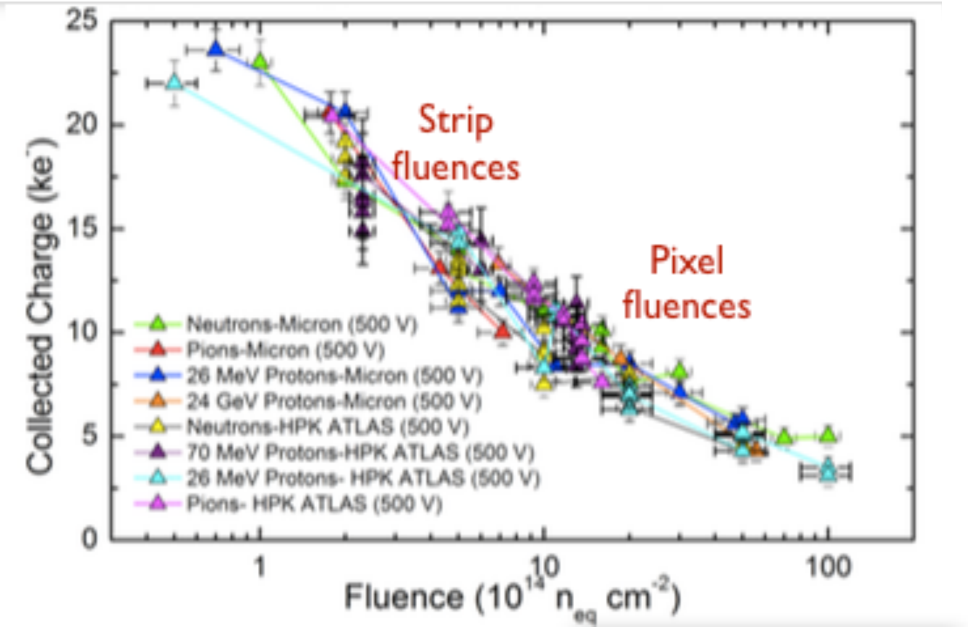


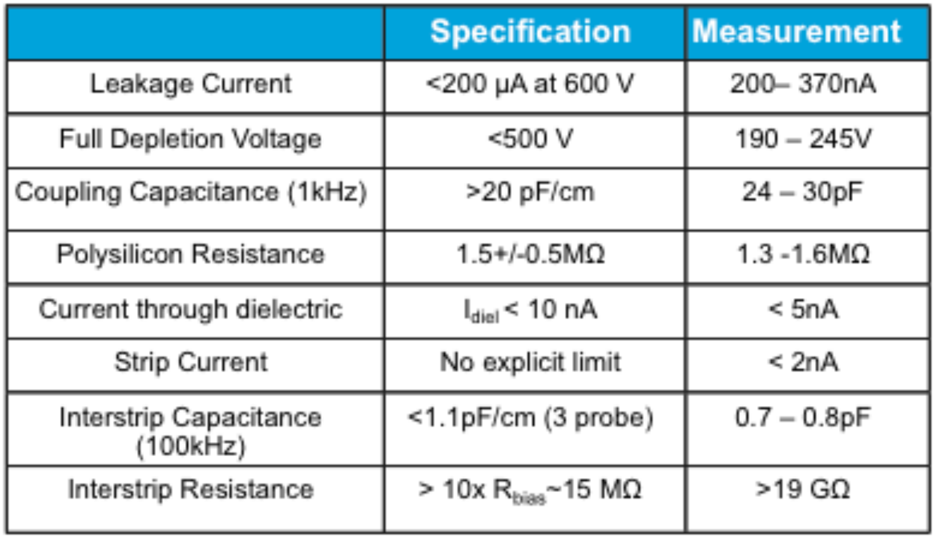


short strip designs of full size Sensor.
4 rows of short strips

Sensor Irradiation Tests

- Miniature devices irradiated to strip barrel radiation level with neutrons, pions, and protons
- Consistent results between different groups/ equipment
- S/N is greater than 10 for strip sensor
  - Noise : 600-800 e^- noise



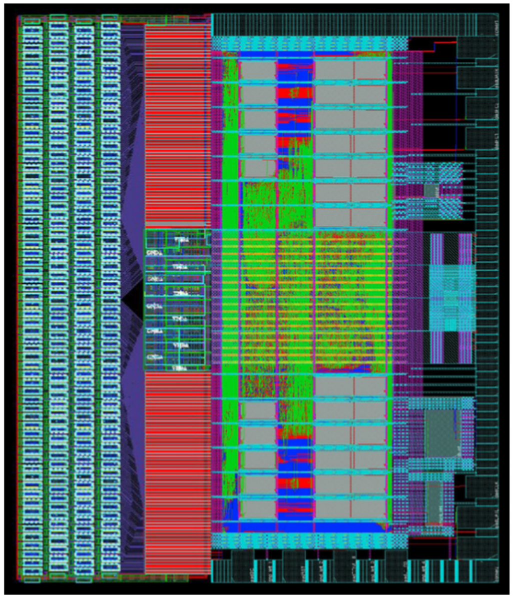


	Specification	Measurement
Leakage Current	<200 μA at 600 V	200– 370nA
Full Depletion Voltage	<500 V	190 – 245V
Coupling Capacitance (1kHz)	>20 pF/cm	24 – 30pF
Polysilicon Resistance	1.5+/-0.5MΩ	1.3 -1.6MΩ
Current through dielectric	I_{diel} < 10 nA	< 5nA
Strip Current	No explicit limit	< 2nA
Interstrip Capacitance (100kHz)	<1.1pF/cm (3 probe)	0.7 – 0.8pF
Interstrip Resistance	> 10x R_{bias}~15 MΩ	>19 GΩ

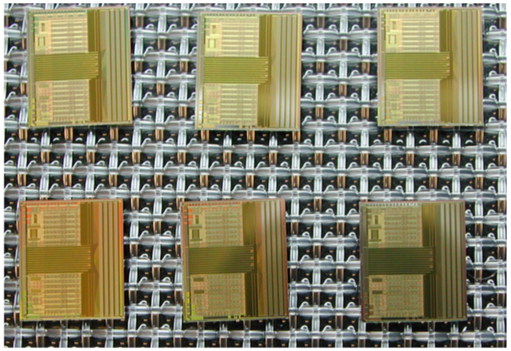
Frontend Readout ASIC for strip upgrade

- Readout chip (two round of prototyping)
  - ABCN25 chip: IBM 250nm technology
  - ABC130 chip: IBM 130nm technology
- ATLAS binary architecture
  - 128 channels of preamplifier/shaper/comparator
  - Memory banks for trigger latency and derandomizer
- Timing requirement
  - Shaper designed for 25ns peaking peak

- Radiation tolerance
  - TID all NMOS transistors in enclosed geometry
- Recent development :
  - Switched from IBM 250nm to IBM 130nm technology
  - Benefit of power
    - ❑ 20W for 250nm technology
    - ❑ 3W at 1.5V for 10-chip hybrid in 130nm technology
  - Benefit of material budget
  - Reduce the hybrid and chip area (less material)

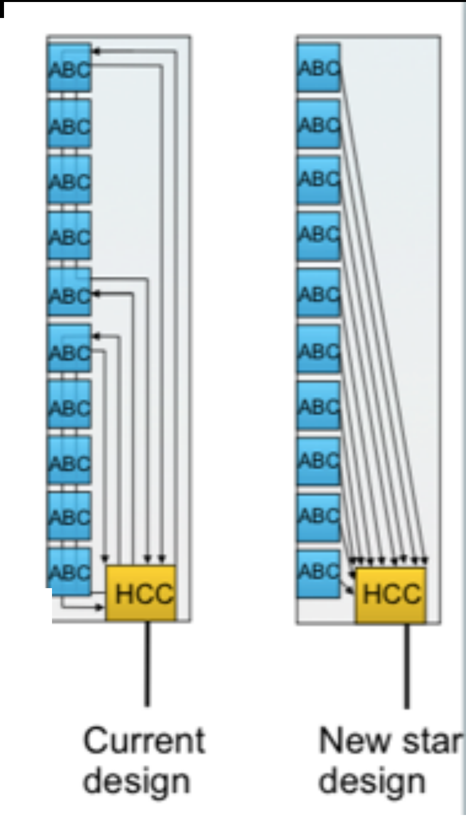


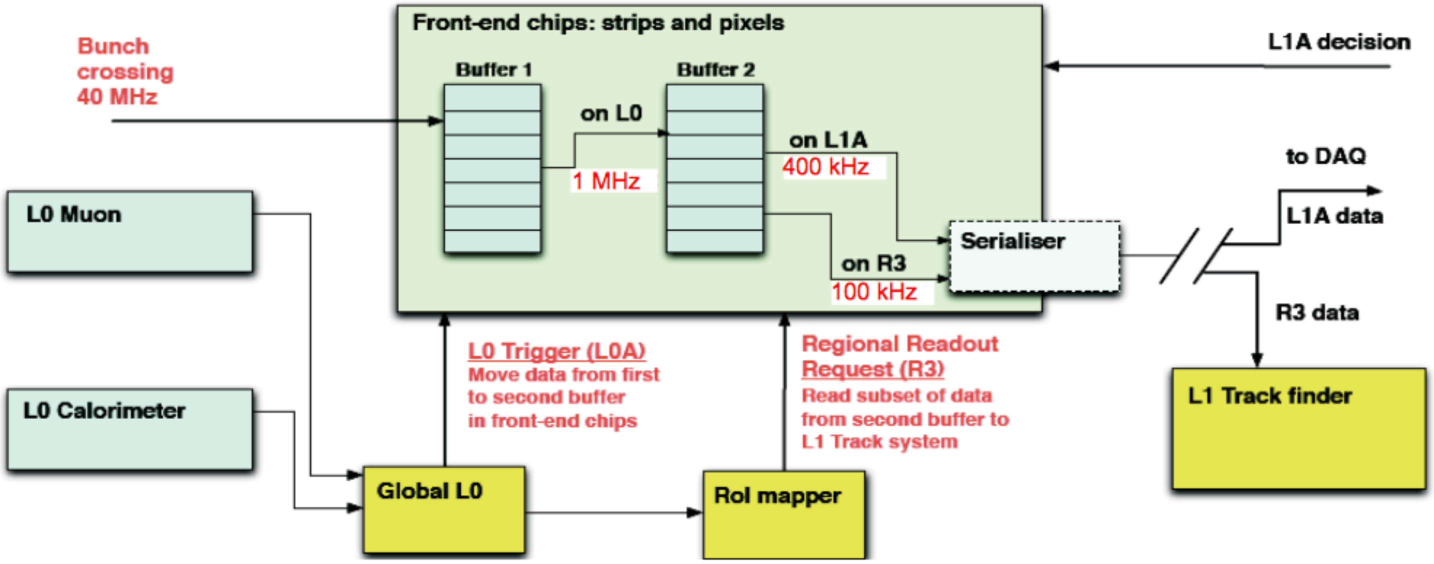
Chip size 7900 um x 6700 um



Hybrid and Hybrid control chip (HCC)

- Hybrid : Kapton flex with frontend chip
- Trigger group raise a higher requirement for readout speed
  - L0 :1MHz , L1: 400kHz
- The new Star architecture is in development, it allows us to
  - Reduce size of packet
  - Use full readout bandwidth of front end chip
  - Build events in HCC to reduce latency

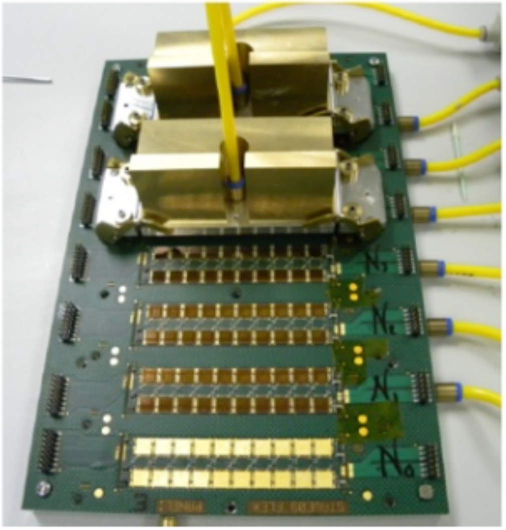




ECFA HL-LHC 2014 trigger presentation

Strip detector Module building

Hybrids



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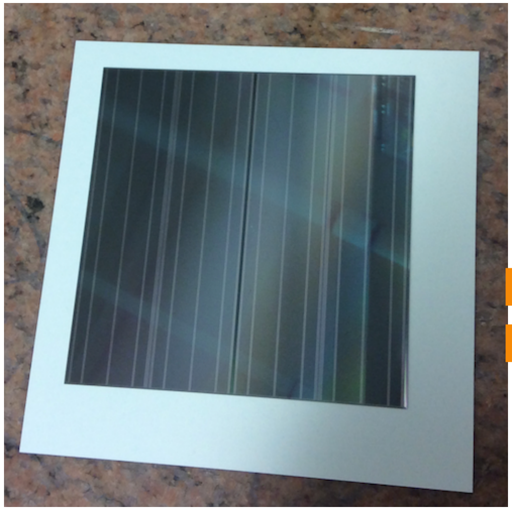
sensor



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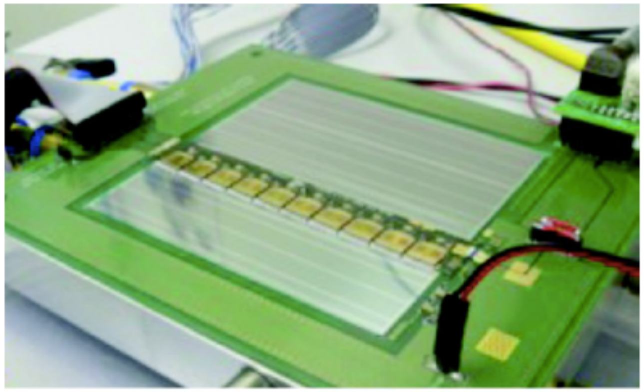
Module



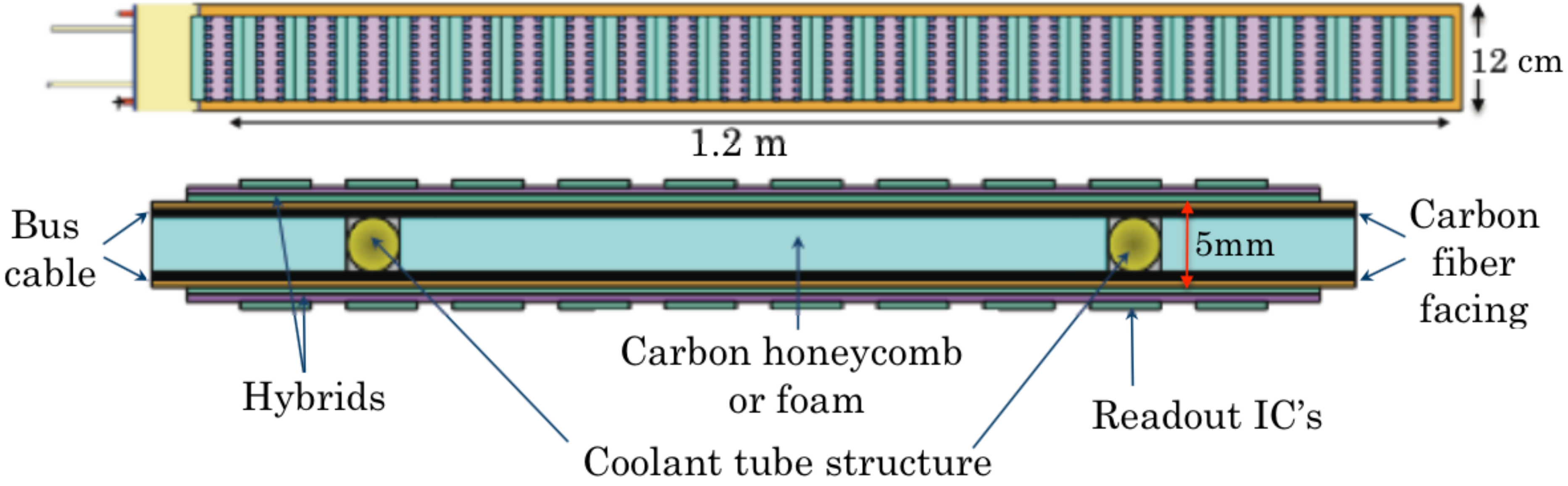
- Module
  - Silicon sensor with readout hybrid
- 250nm version of readout chips used for prototyping.
- Seven different sites were involved in module production
  - 5 barrel sites and 2 end-cap sites
  - Strong community in module productions
- 200 hybrids and >85 modules were produced (250nm)
- First 130nm modules have been made.

Stave concept in Barrel

Stave= stave core structure + cooling + electrical services (power, data, TTC) + modules

Modules (12~14 per sided) glued on on top of readout tape
which is on top of the carbon composite structure (stave core structure)

Designed to minimize material, for large scale assembly and replaceable



Stave core is a sandwich construction for high structural rigidity with low mass.
Services integrated into plate including power control and data transmission:
bus-tape co-cured to carbon fibre facings.
Design optimized to minimize cooling path between heat sources and cooling pipes.

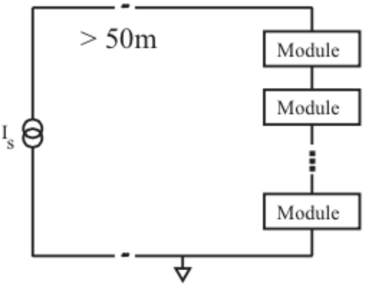
POWERING OPTIONS for stave

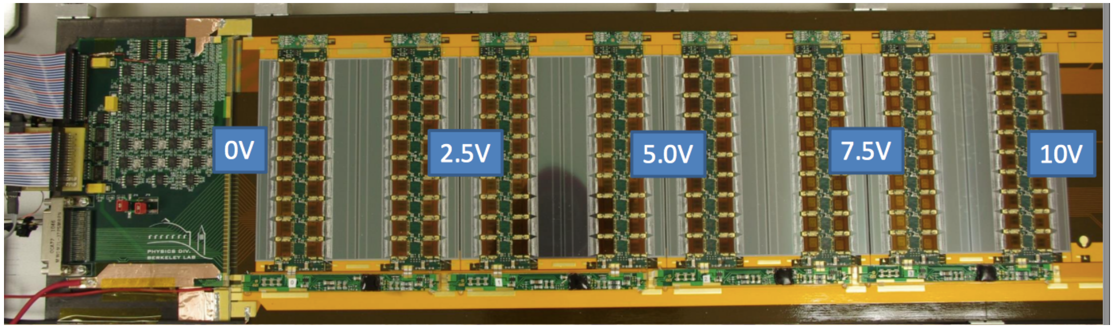
Both full size DC-DC powered stave and serial powered stave has been built

- Contributions from many institutes
- 12 modules on this stave
- Good noise performance (input noise level is about 600 ENC)

Serial powering Stave 250

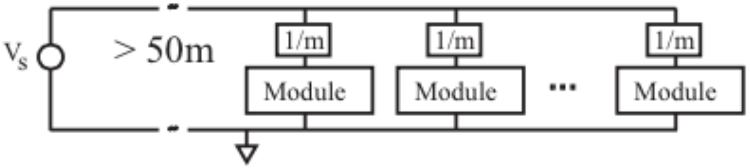
Serial Powering

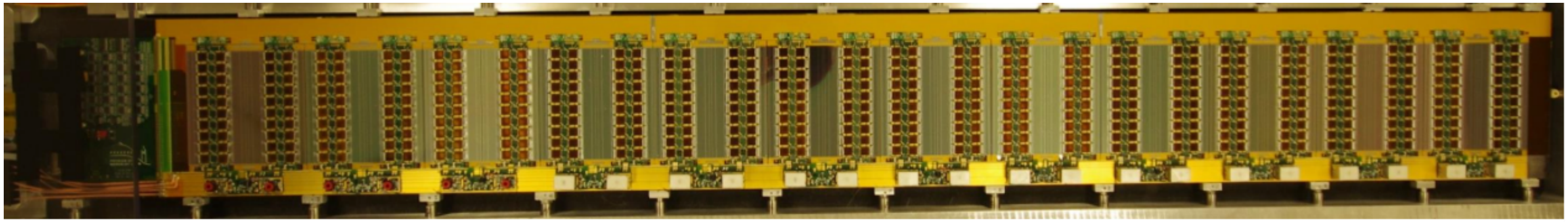




DC-DC

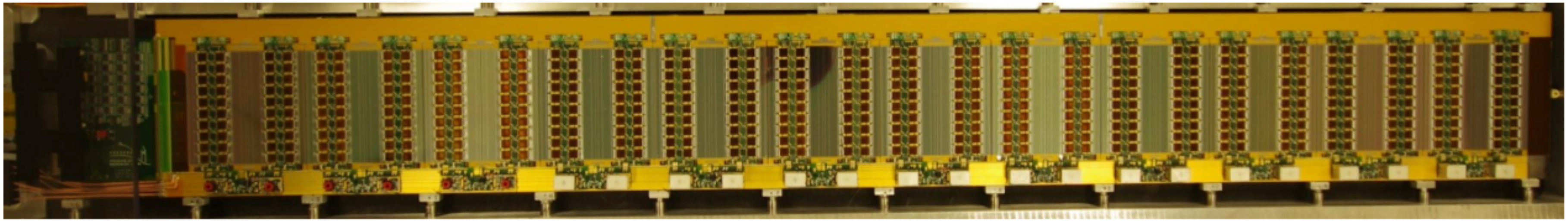
DC-DC powering stave 250





The development of stave

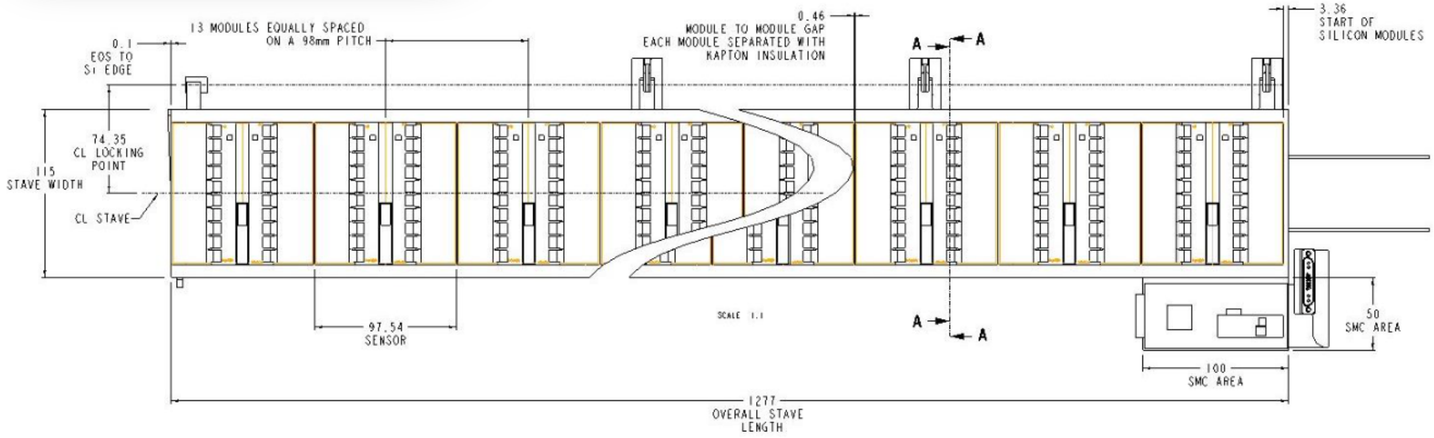
DC-DC powering stave 250 (with ABCN25 chip)

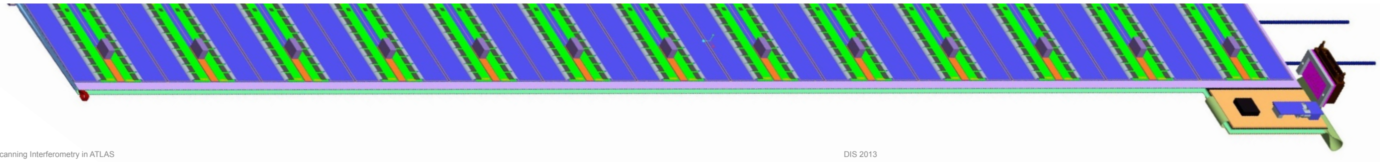


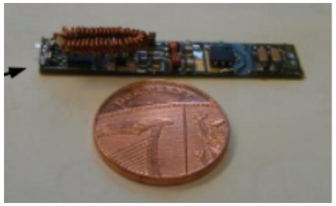
DC-DC stave 130 design development highlight

1. novel design of the on sensor DC-DC converter
2. Reduce number of hybrid in each module by using ABC130 chip

Drawing of DC-DC powering stave 130 (with ABC130 chip)



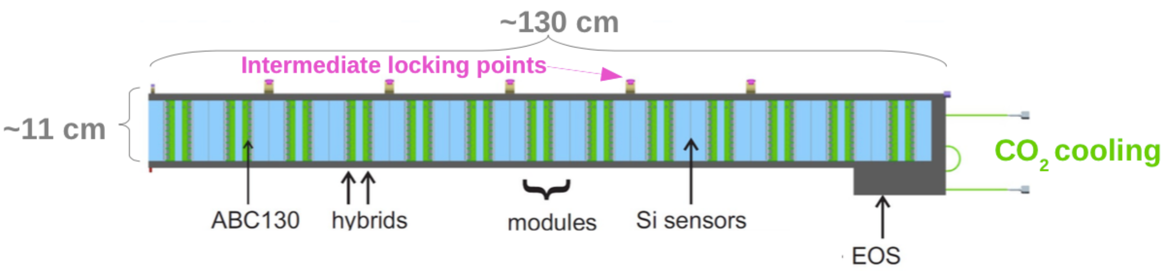


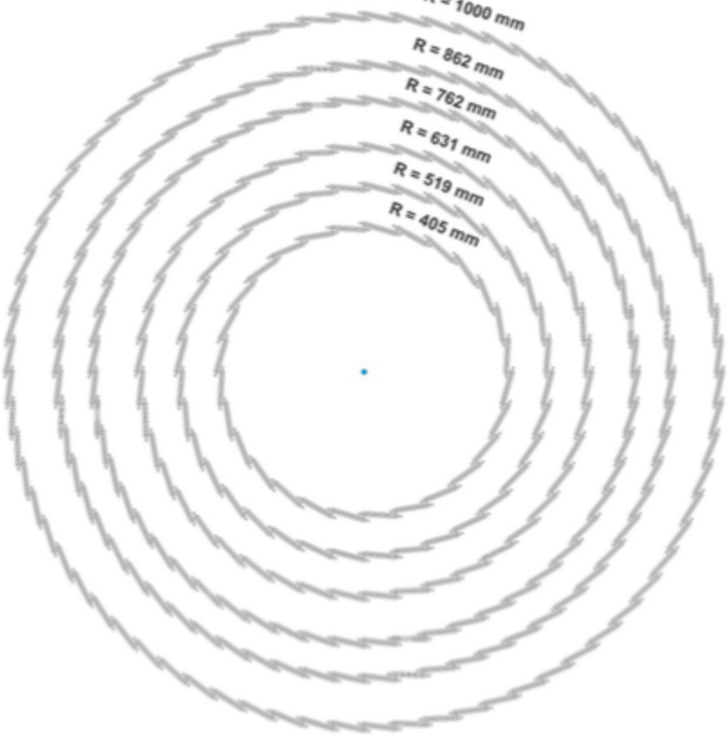


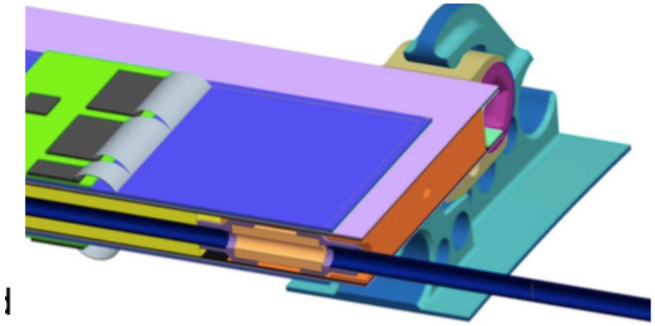
Strip Barrel design of the new strip detector

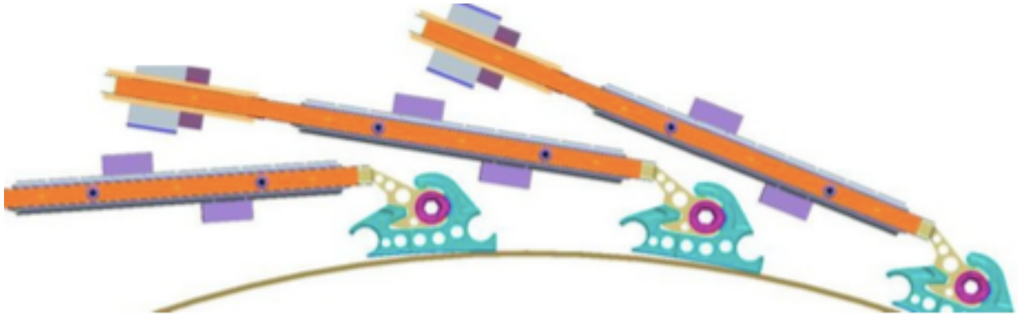
- Barrel detector composed of staves

Modules (12~16 per side) glued on carbon composite structure (stave core structure)



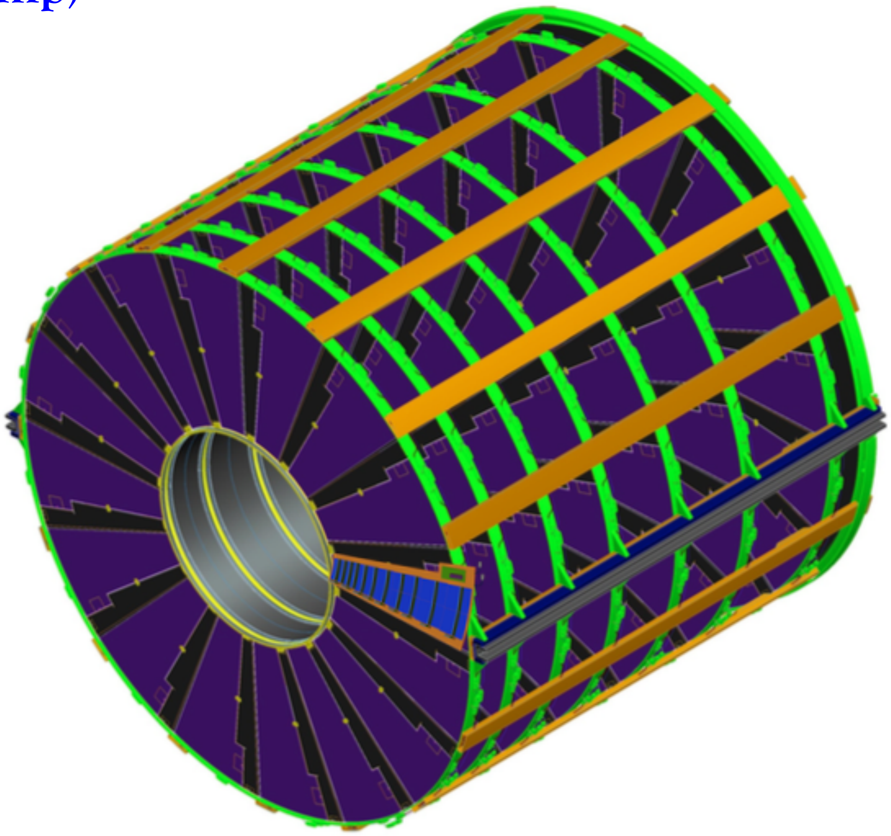


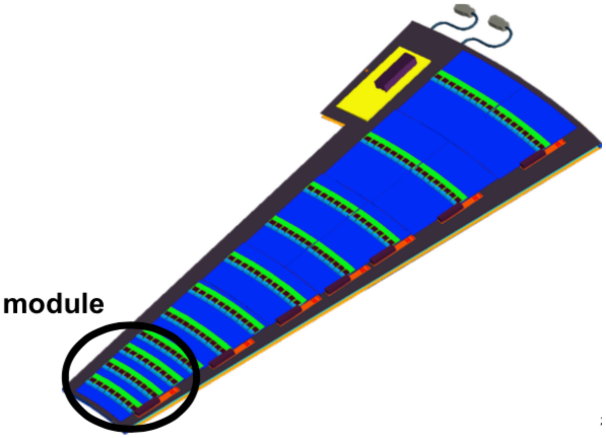




Endcap design of the new strip detector

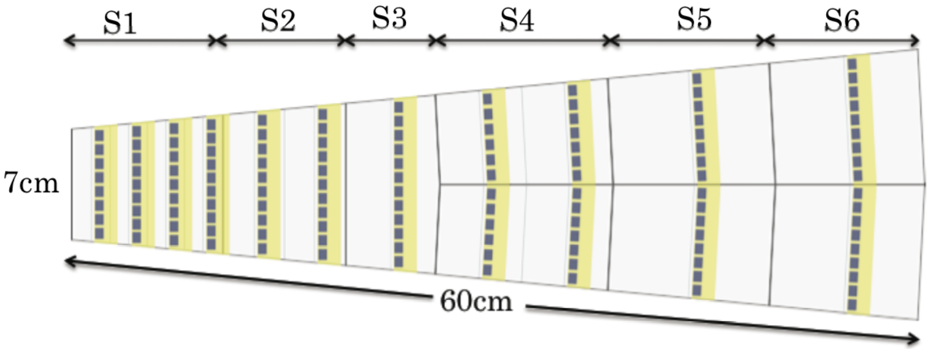
- Endcap detector composed of petals
  - Following the stave concept in Barrel
  - Kapton flex with frontend chip(ABCN chip)
- Endcap design
  - 7 wheels per endcap
  - 32 petals per wheel
  - 18 modules per petal



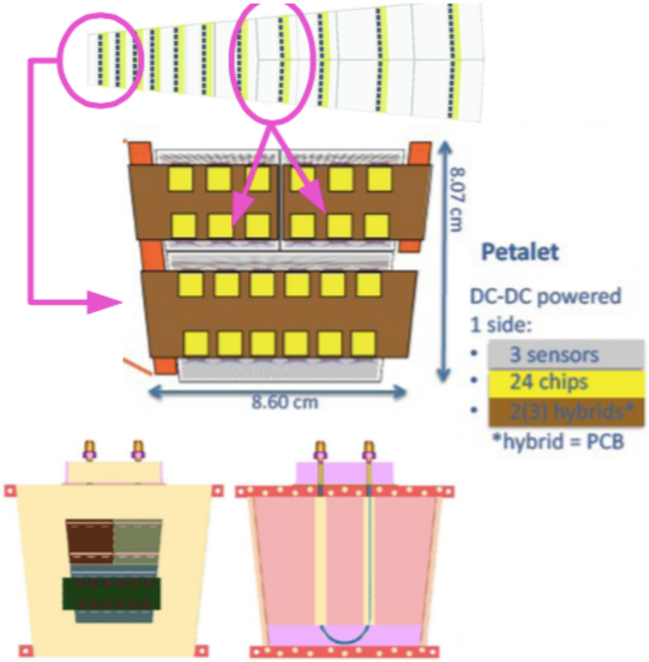


Petal and petalets

- **Petal:**
  - 6 different sensor designs needed due to complex shape
  - Up to 15 different hybrids
  - 6 rings

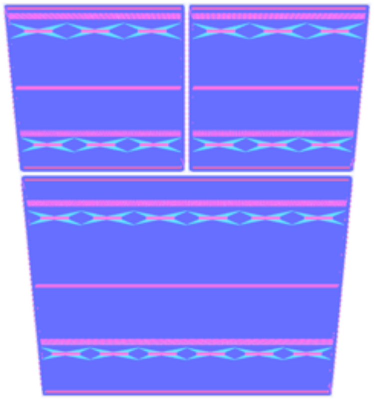


- **Petalet**
  - Test small scale of prototypes
  - Cost efficient, valuable insights: construction, gluing, tooling



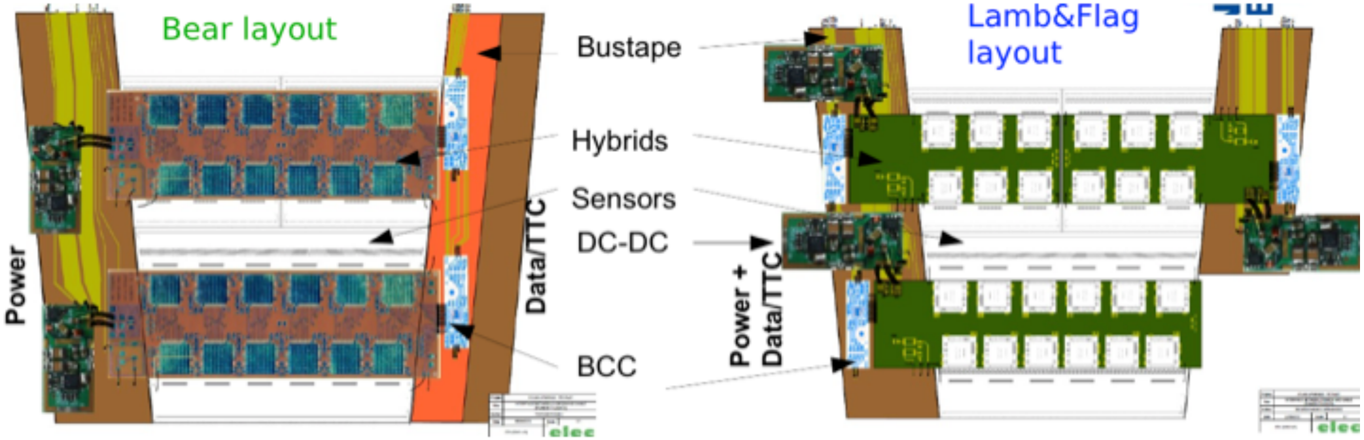
Sensor for petalet:

Built-in stereo angle (40 mrad for stereangle)
Radial strips to get r-Φ
Fan-ins to bridge different strip pitch
Align chip-sensor pads



Petal and petalets (2)

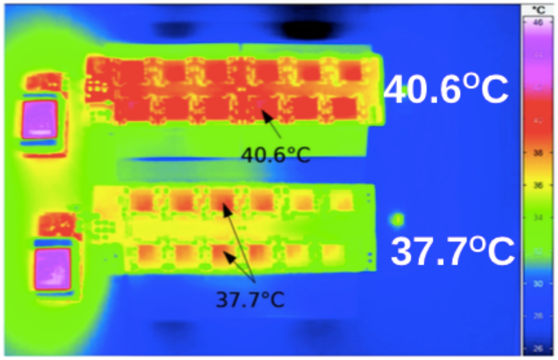
Two design for petalets: Lamb & Flag Versus The Bear

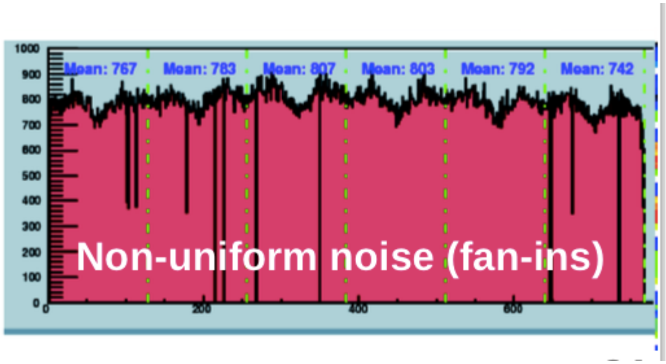


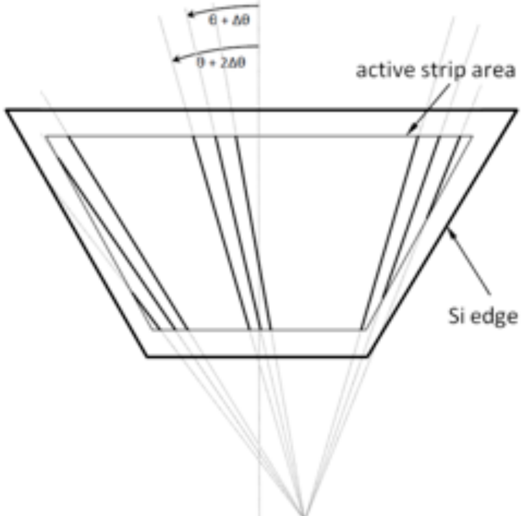
- ☐ one hybrid for two sensors
- ☐ Data/power lines from two sides
- ☐ simple routing, simple hybrids
- ☐ mechanically challenging,

- ☐ Split hybrids
- ☐ Data/power lines from same end
- ☐ Make it simple for testing
- ☐ routing complex

Non-uniform noise due to Fan-ins in sensors design



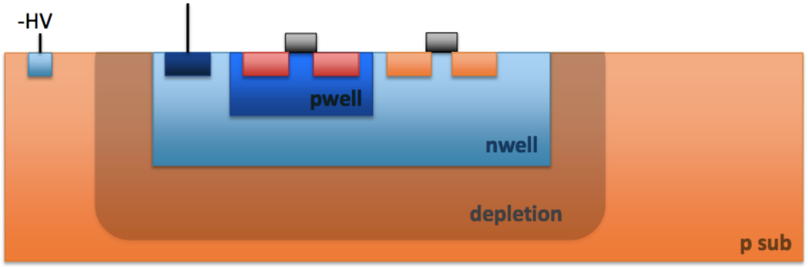




alternative sensor solution for strip detector upgrade: CMOS sensors developments

- ATLAS agreed to explore the possible use of the technology for silicon strip detector upgrade.

- Implemented in commercial CMOS (HV/HR) technologies (350nm, 180nm)
  - Collection electrode is a large n-well/p-substrate diode
- Advantage:
  - High granularity: pitch can be reduced to below 50um
  - low material budget : Can be thinned down to 50um
  - Monolithic: Front-end electronics and sensor can be built in the same chip
  - Low cost
- Drawback:
  - Low MIP signal : 1000~2000 e
  - Need low noise readout electronics readout chip
  - so far not proven to be radiation hard for our detector



- Three year plan for CMOS sensor development in ATLAS ITK strip:
  - Year 1 :Characterization of basic sensor/electronics properties and architecture
  - Year 2: Fabricating and evaluating a large-scale device.
  - Year 3: Full prototypes of sensors and ABCN'

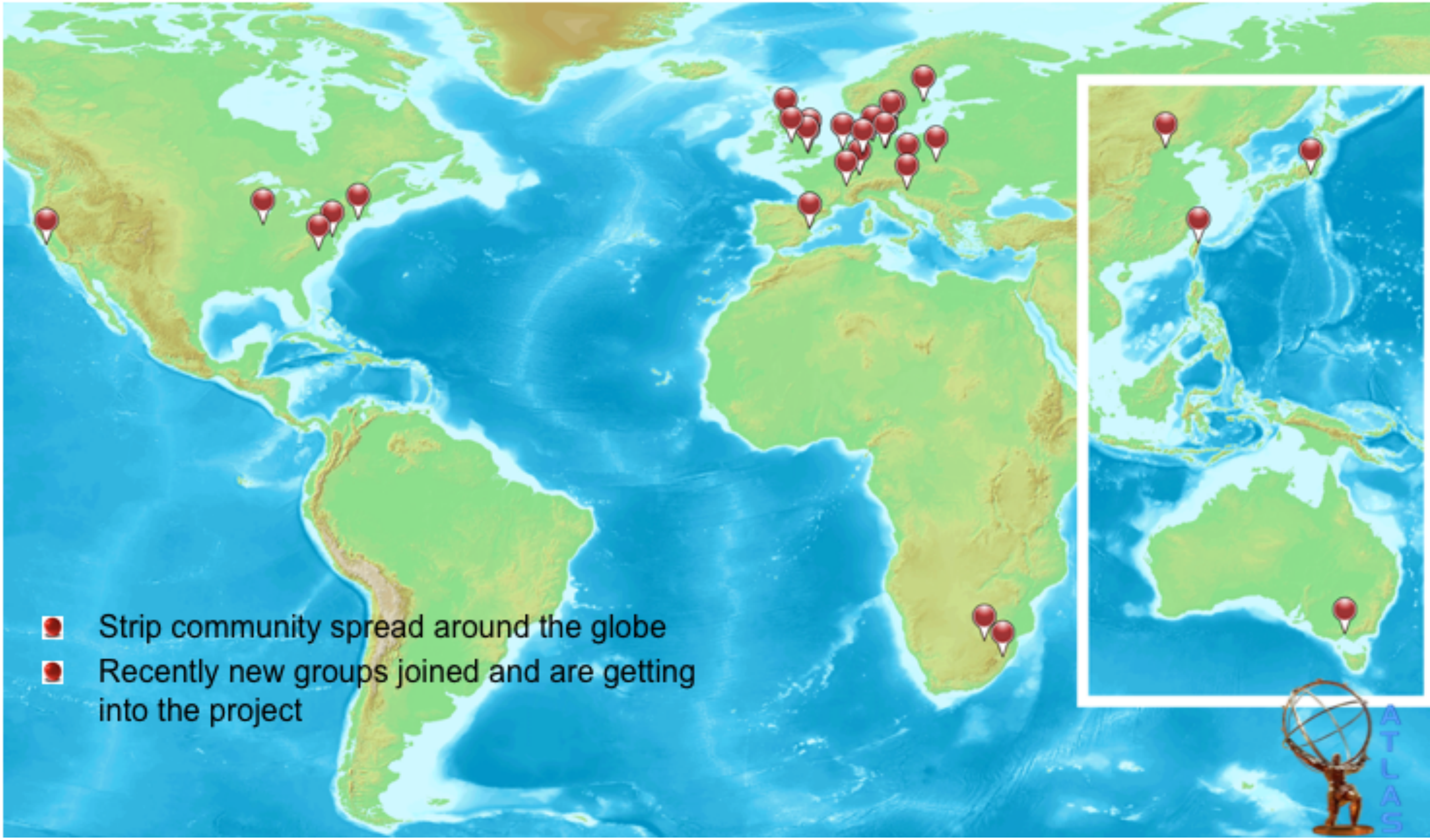
Summary

- ATLAS ITK strip detector with 190m^2 silicon and 21000 modules needs to be ready to go into ATLAS in ~10 years

- Significant progress have been made for strip detector upgrade
  - Baseline sensors evaluations are very advanced.
  - Stave/petal prototyping is in good shape

- Roadmap
  - Last year: Initial design report (IDR)
  - Next year: technical design report (TDR)
  - One or two years after TDR: modules pre-productions
  - After one or two years : modules and stave/petal productions
  - In 2024: detector integrations

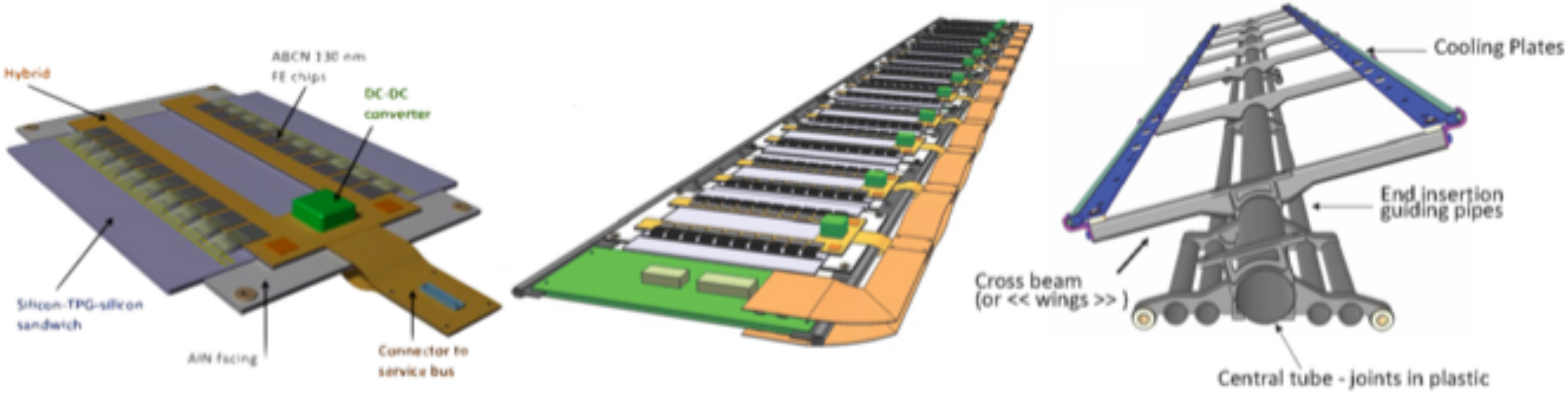
Institutions in ATLAS ITK strip upgrade activity



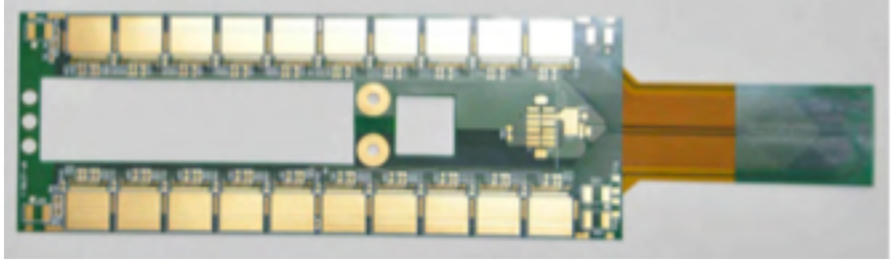
- Strip community spread around the globe
- Recently new groups joined and are getting into the project

Alternative solution to stave/petal : super modules

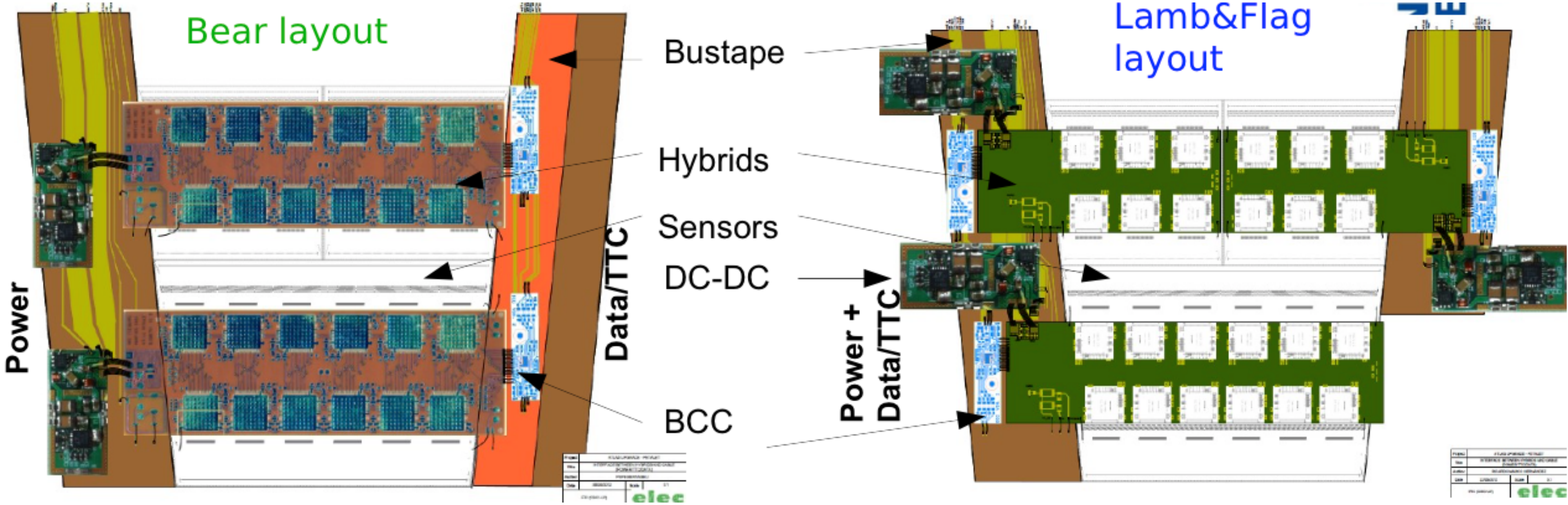
- Alternative solution for stave design
- Double-sided modules are attached to a carbon fibre local support
  - End inserted into the overall tracker support structure
-



☐ Full prototype of 250nm ASICs built
☐ Preparting system for 130nm



Two design for petalets: Lamb & Flag Versus The Bear

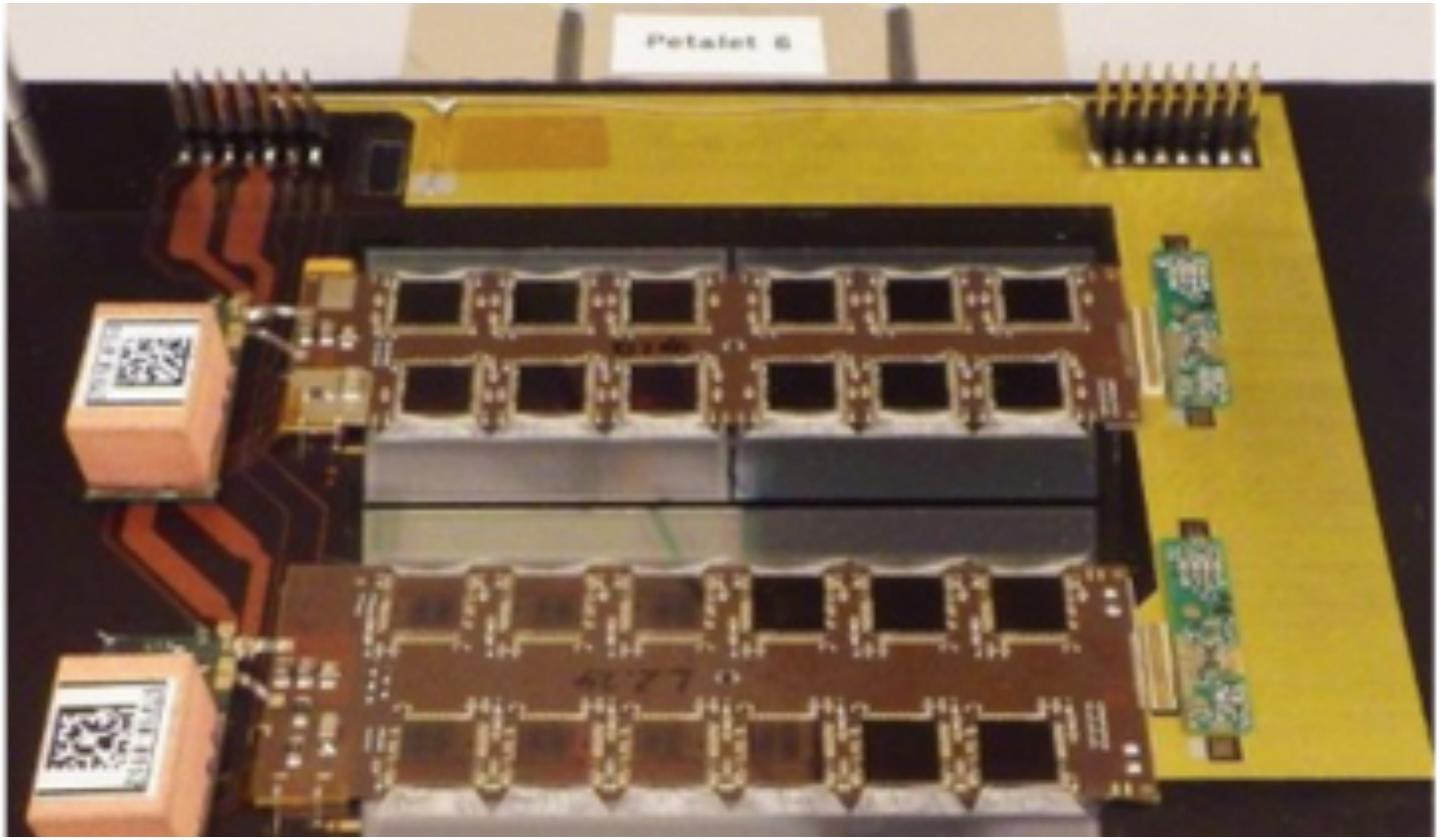


- one hybrid for two sensors
- Data/power lines from two sides

- simple routing, simple hybrids
- mechanically challenging,
- needs to reference detector positions to each other, carbon supports
- electrical connection required

- Split hybrids
- Data/power lines from same end

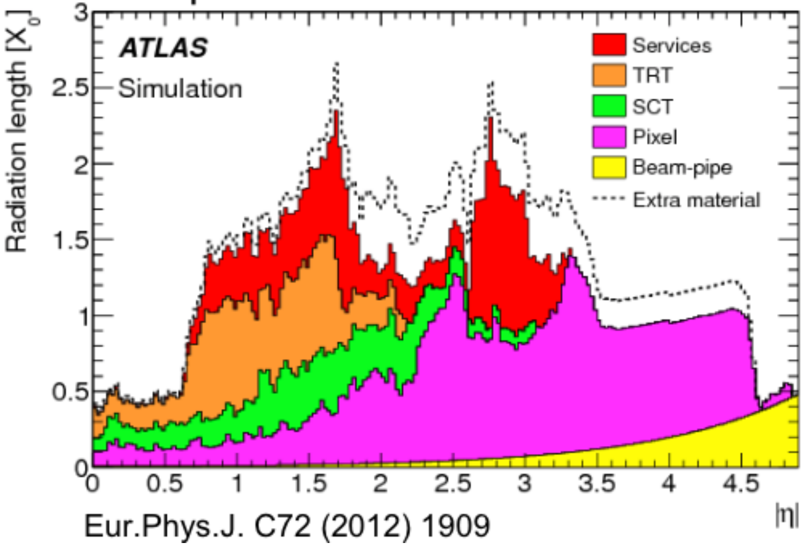
- testing simple
- routing complex, both data/power from each si
- needs left/right hybrid design


Petalet 6
4277

Material budget

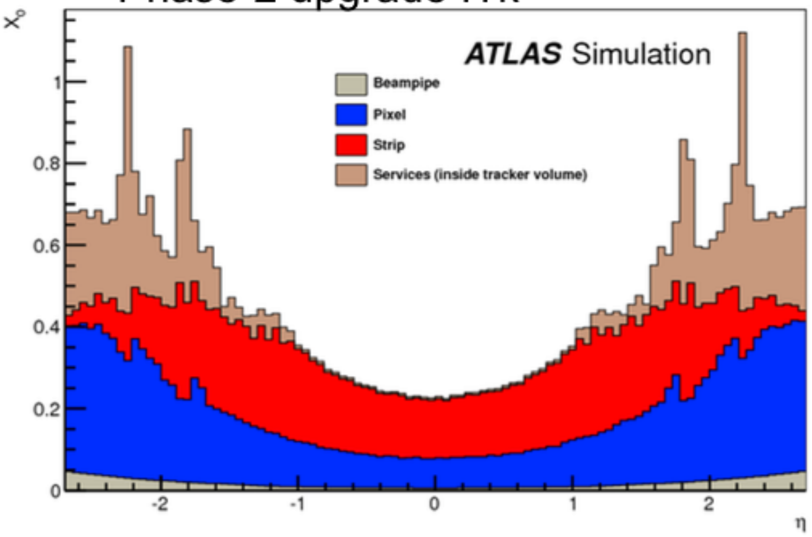
- The design of stave and petal help a lot in reducing material
  - About a factor of 2 less material than present detector
- Impact on performance
  - Less tracking inefficiencies
  - Momentum resolution improved

present inner detector



Eur.Phys.J. C72 (2012) 1909

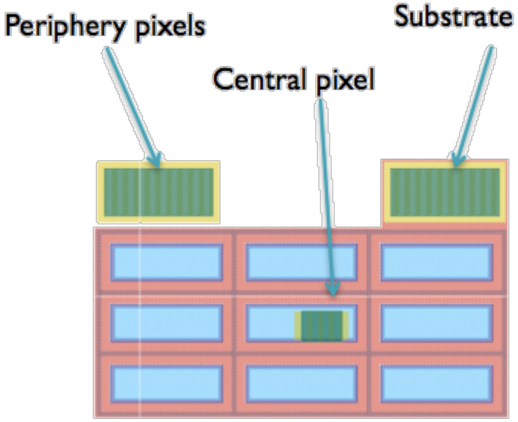
Phase-2 upgrade ITk

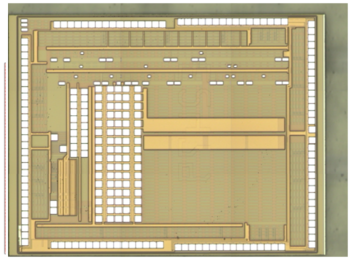


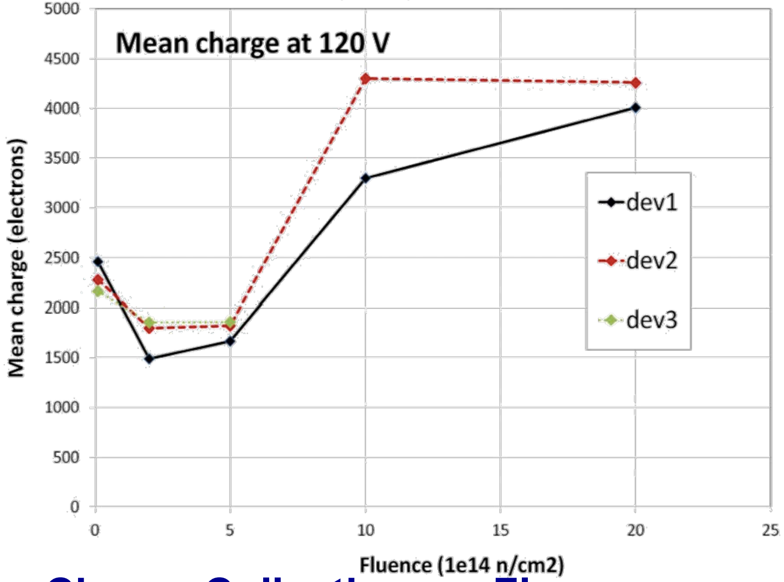
alternative sensor solution for strip detector upgrade: CMOS sensors developments (2)

from Igor Mandic
JSI Ljubljana

We first designed and fabricated a simple test chip to evaluate basic characteristics of the technology.





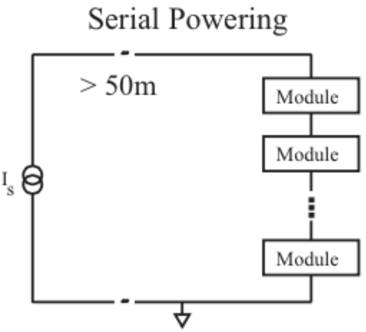


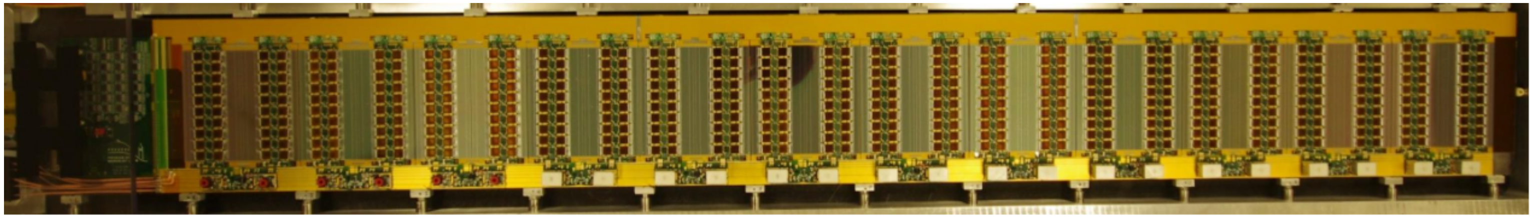
Charge Collection vs. Fluence for Three Devices

- **Charge decreases after initial radiation as expected, the diffusion contribution is disappearing.**
- **Charge increases with more irradiation – believe this is due to increase in depletion region due to acceptor removal.**
- **Based upon other E-TCT results we may expect that the collected charge will start to decrease again at yet higher fliuences.**

POWERING OPTIONS for stave

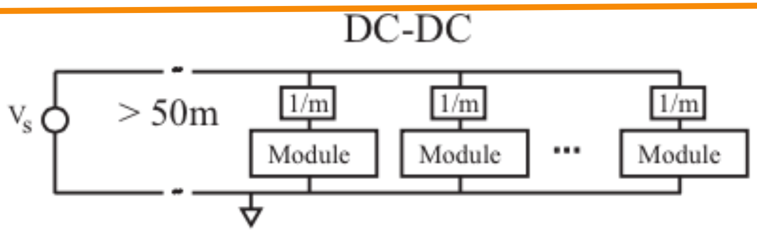
Serial powering

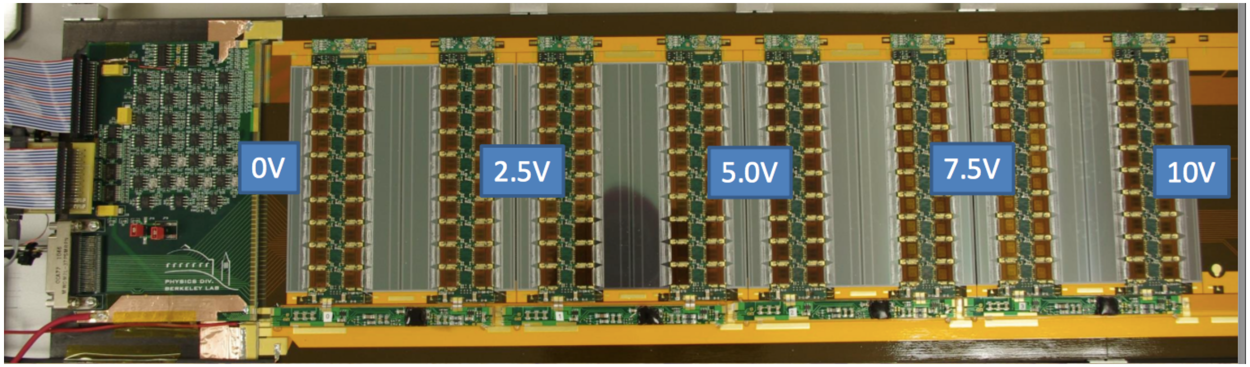




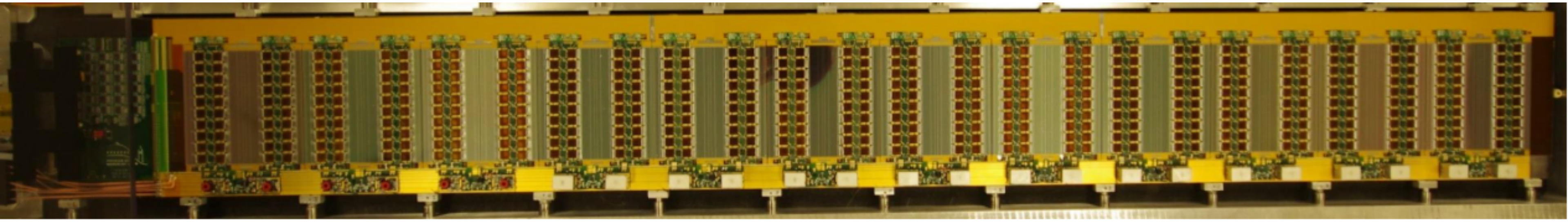
DC-DC powering

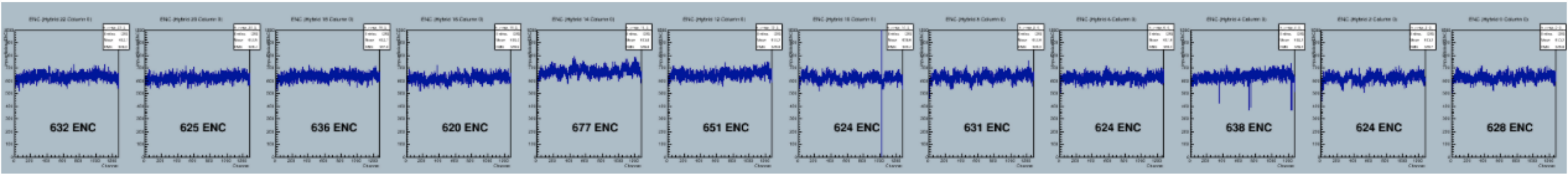
Power and DC-DC converters!





Stave testing





- Full DC-DC powered Stave has been built
  - Contributions from many institutes
  - 12 modules on this stave
  - Good noise performance -> 600-677 ENC (equivalent noise charge)
- Full scale serial powered stave is in progress