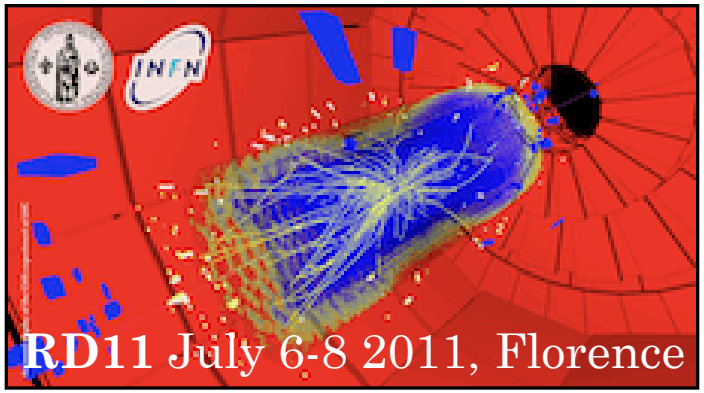
# SILICON STRIP DETECTORS FOR THE ATLAS HL-LHC UPGRADE

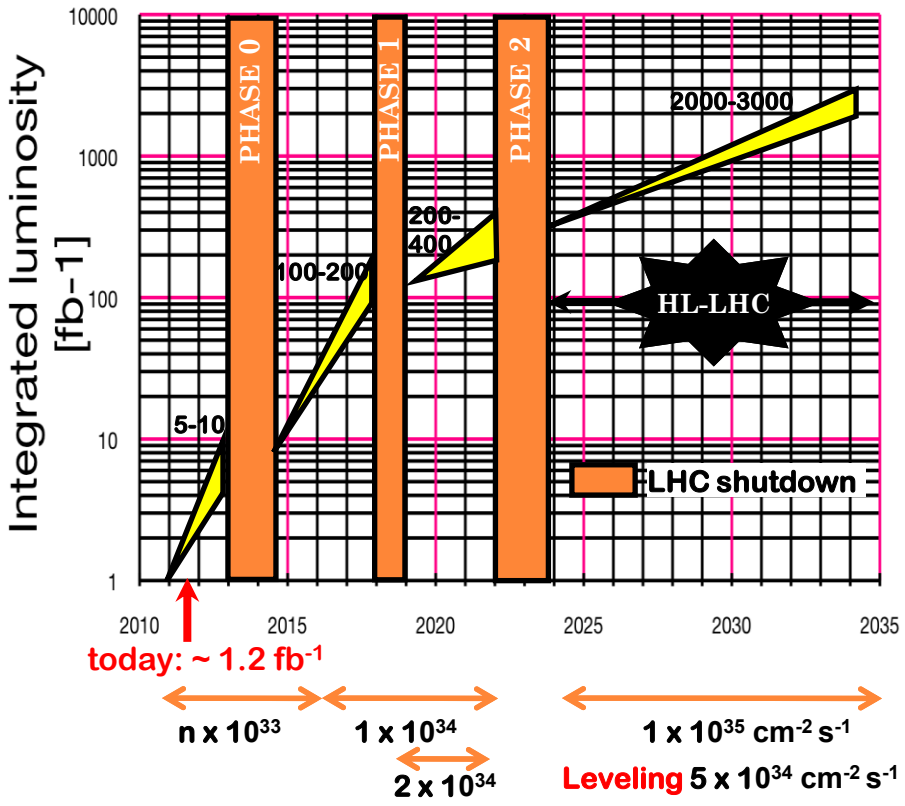
Jose Bernabeu (IFIC)

on behalf of the ATLAS Upgrade Community




RD11 July 6-8 2011, Florence

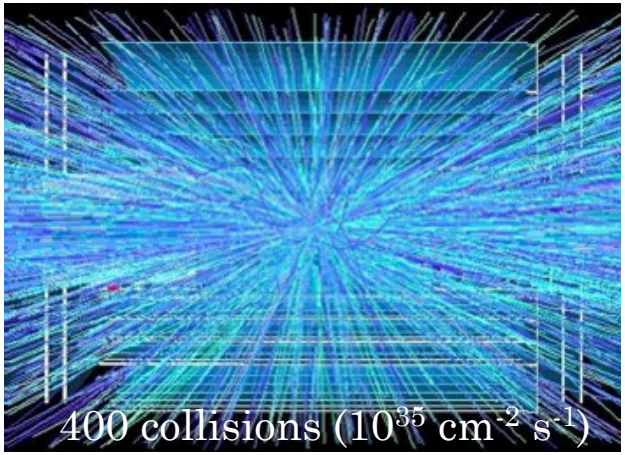
# LHC Luminosity and Inner Tracker Upgrades



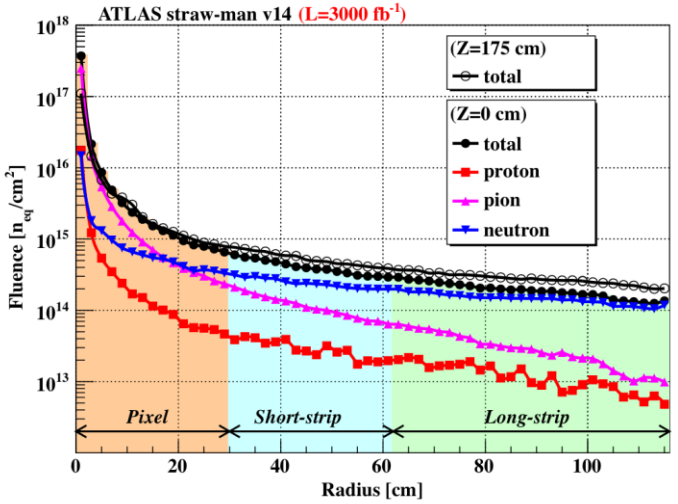

- Phase 0
  - New beam pipe with additional pixel layer (IBL)
- Phase 1
  - Possible pixel replacement under study
- Phase 2
  - Replace inner tracker
  - All silicon, pixel + strips

# New ATLAS Inner Tracker

- Higher Occupancy
  - Higher granularity




- Higher Radiation
  - Better radiation hardness




SHORT STRIP (2.4 cm) μ-strips:

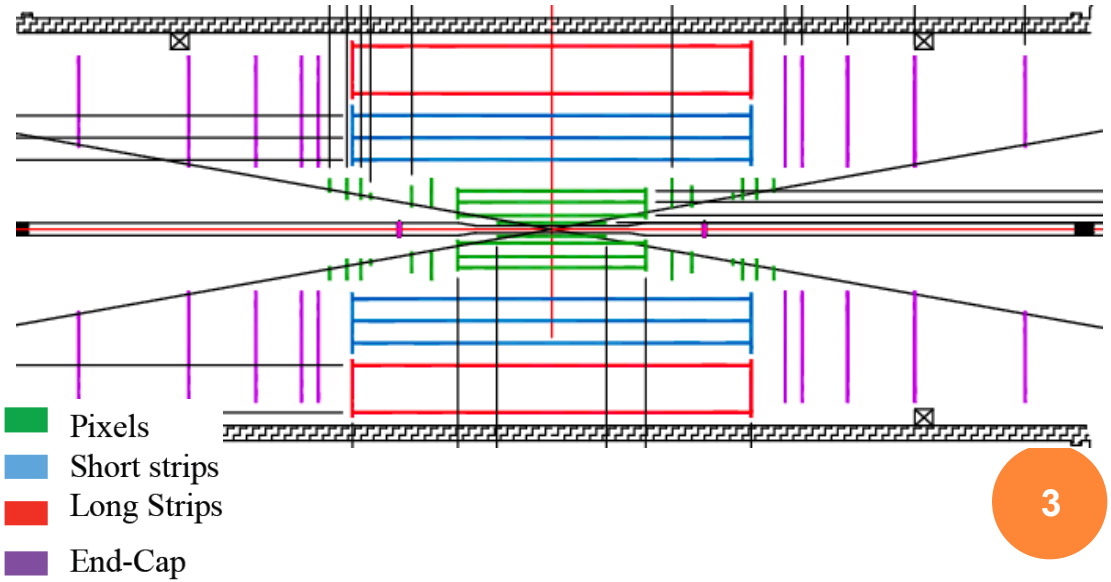
r = 38, 50, 62 cm

Up to 1.2 x $10^{15}$ 1MeV $n_{eq}/cm^2$

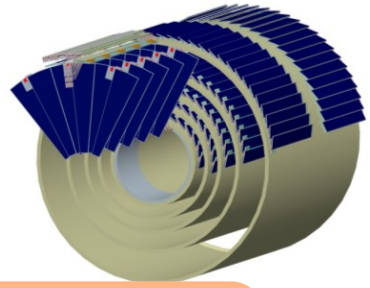
LONG STRIP (4.8 cm) μ-strips :

r = 74, 100 cm

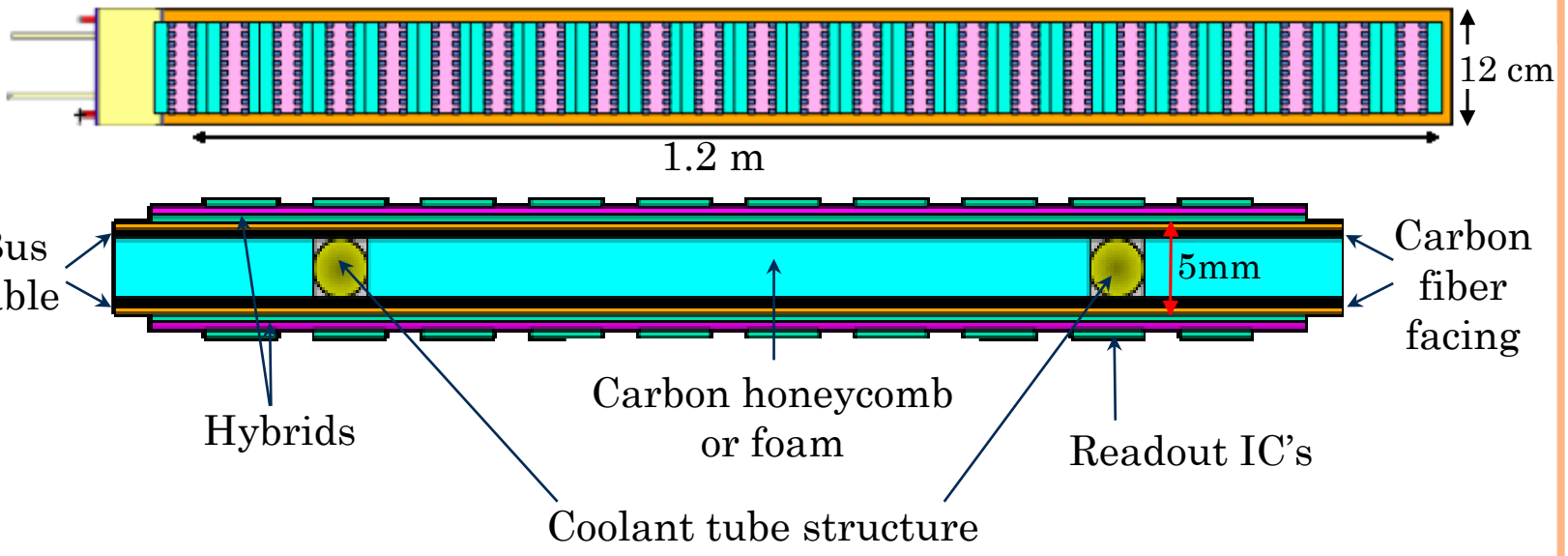
Up to 5.6 x $10^{14}$ 1MeV $n_{eq}/cm^2$

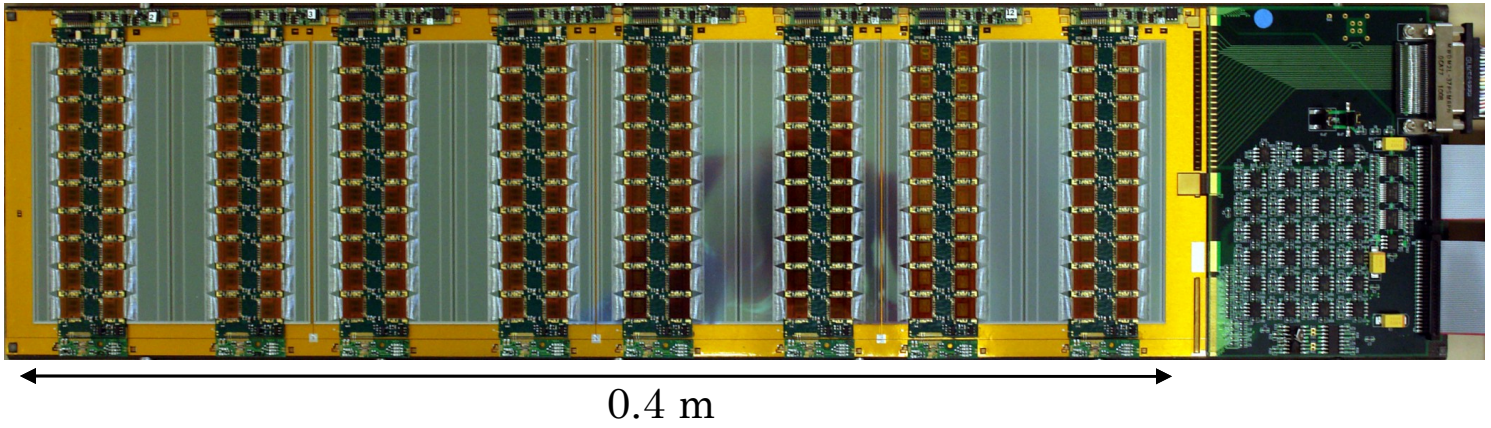


# BARREL STRIP INTEGRATION



**STAVE (baseline design)**



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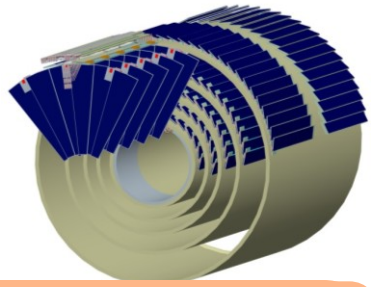
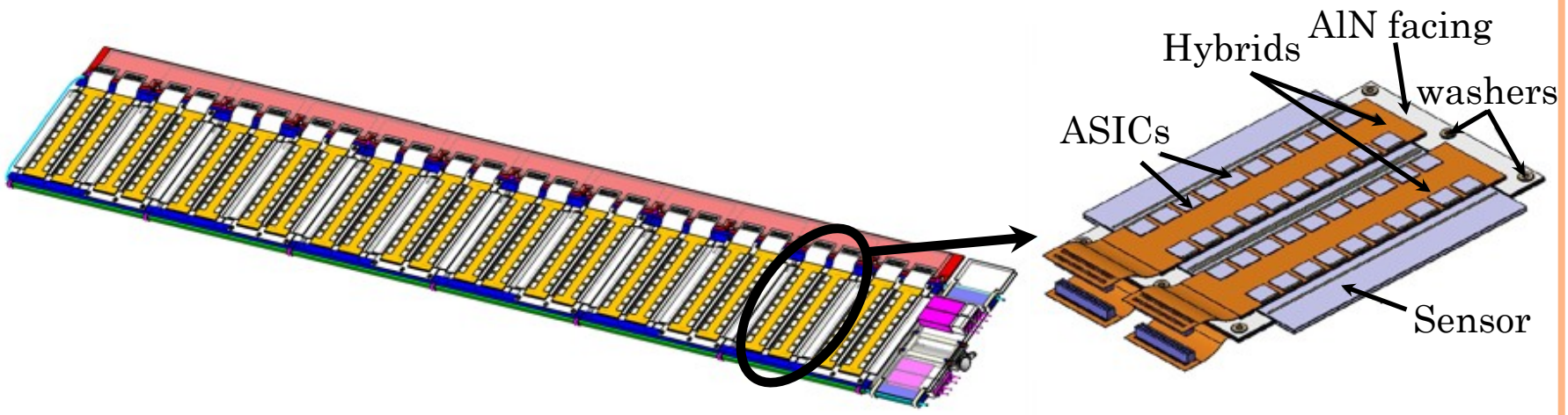
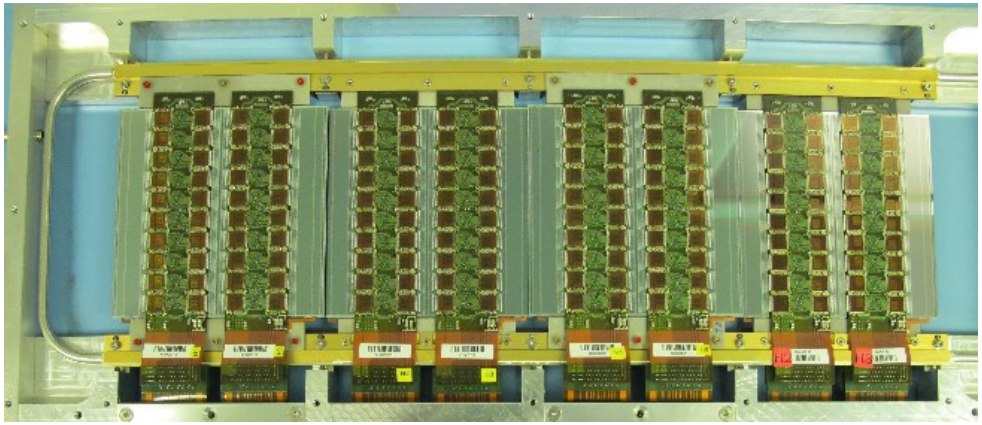


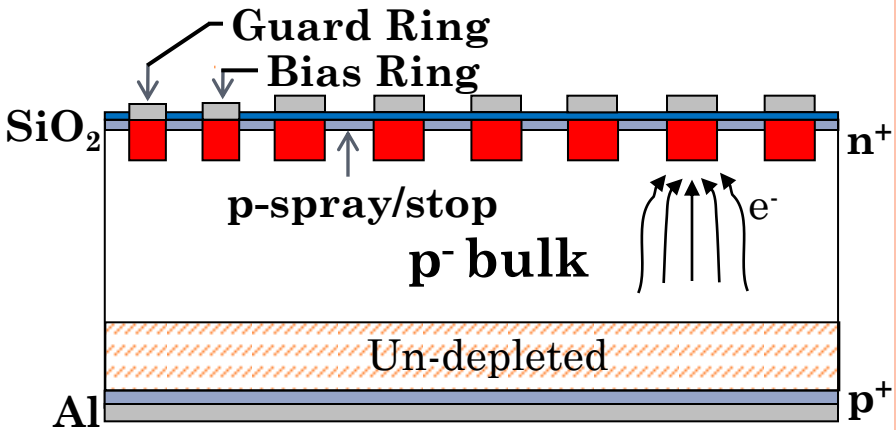
**SUPERMODULE (fallback design)**

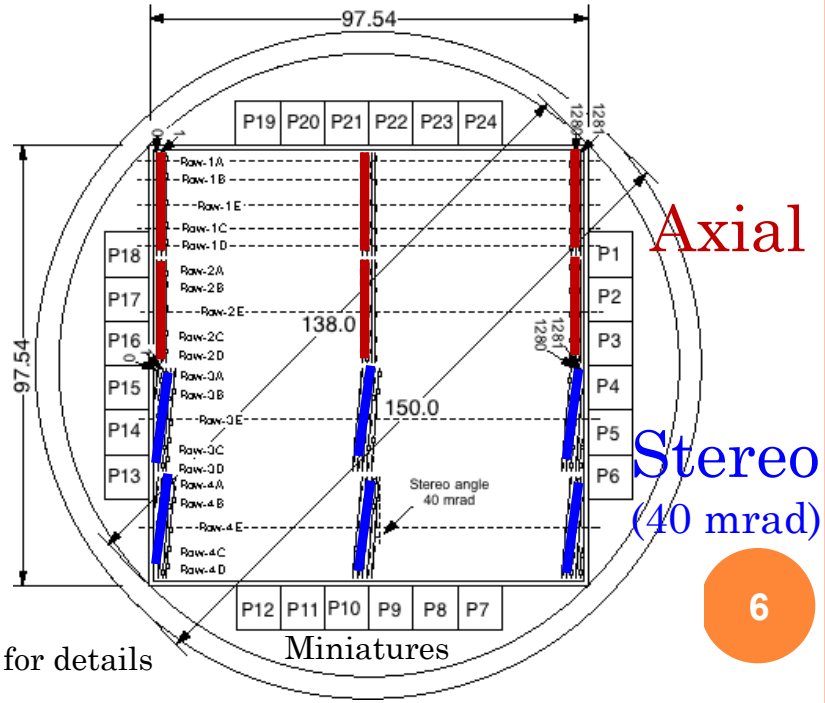


# Barrel Silicon Sensor

- **$n^+$ strips in p substrate**
  - Electrons collected
    - Faster signal, less trapping
  - Depleting from strip side
    - Signal under depleted
  - Single-sided process
    - Cheaper (in opposition to $n^+n$)
- **6" FZ wafer <1 0 0>**
  - Hamamatsu Photonics (HPK)
  - Big sensor: 9.75 x 9.75 $cm^2$, 320 μm
  - 4 segments, 2.39 cm each
  - 1280 channels, 74.5 μm pitch
  - Miniature sensors (1 x 1 $cm^2$) for irradiation studies

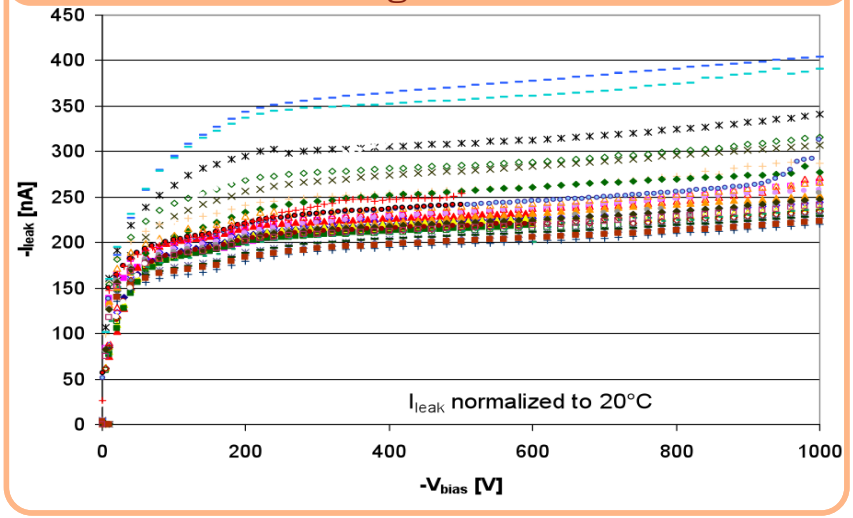


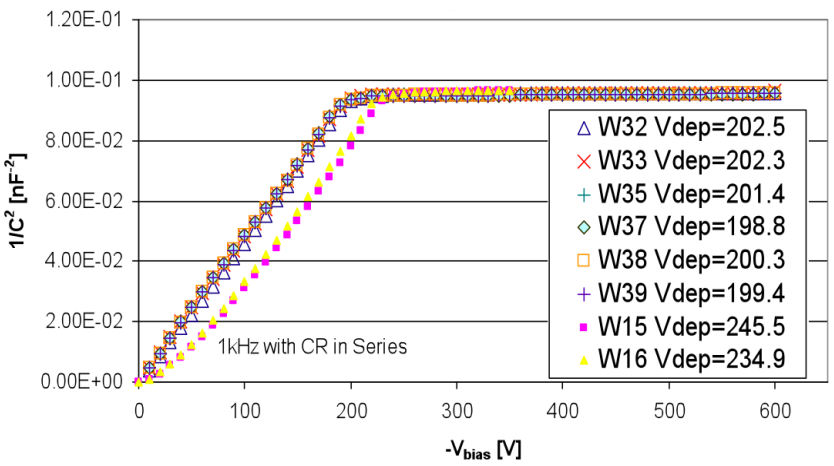

See N. Unno, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S24-S30 for details

# Full Size Sensor Measurements (pre-rad)

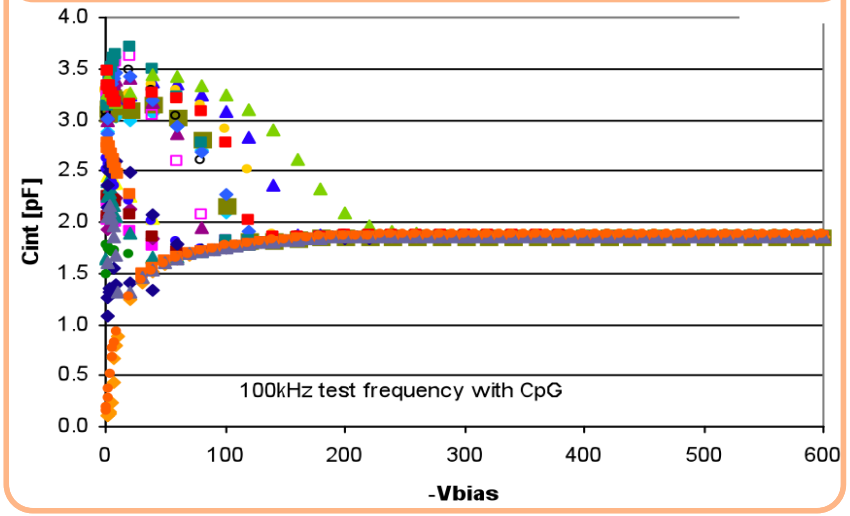
## Leakage current




## Depletion voltage




## Interstrip Capacitance

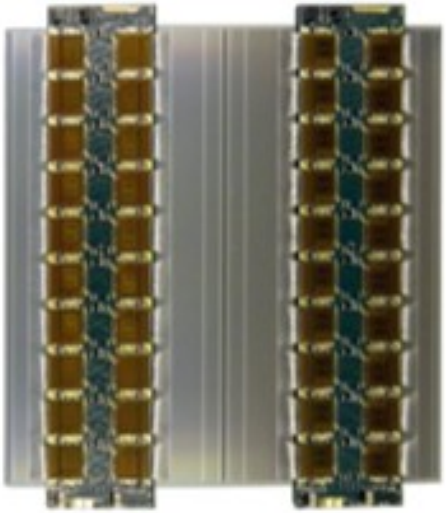


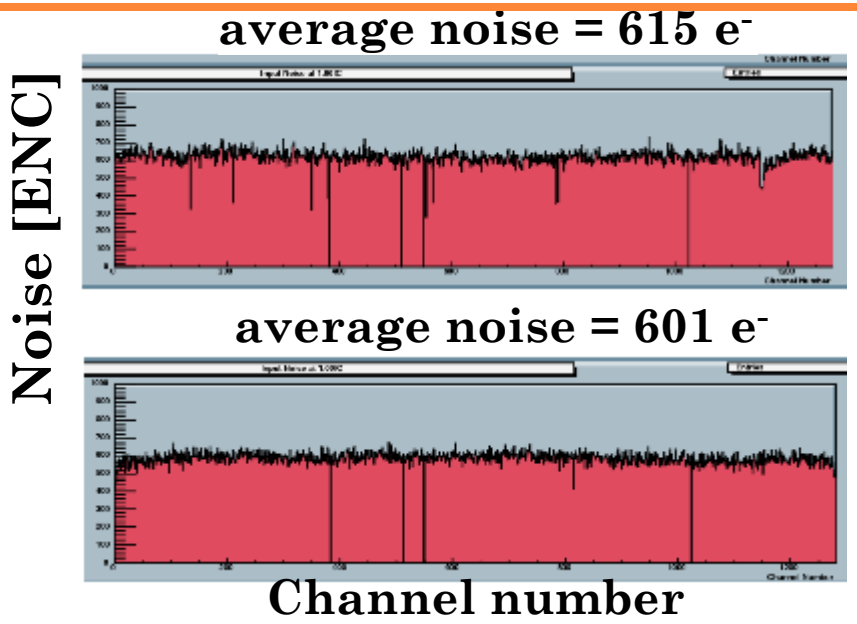

| Parameter | Specification | Measurement |
|---|---|---|
| Leakage Current | <200μA@600V | 200nA – 370nA |
| Depletion Voltage | <500V | 190V – 245V |
| Interstrip Capacitance | <1.1pF/cm (3probes) | 0.7pF/cm |
| Coupling Capacitance | >20pF/cm | 24 – 30pF/cm |
| Polysilicon Resistance | 1.5±0.5MΩ | 1.3 – 1.6MΩ |
| Interstrip Resistance | >10xRbias≈15MΩ | >19GΩ |

See J. Bohm, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S104-S110 for details

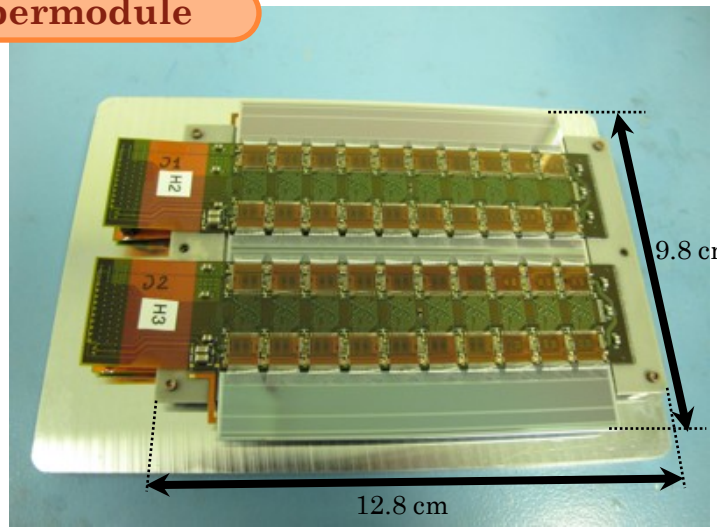
# MODULES AND STAVELETS WITH SENSORS

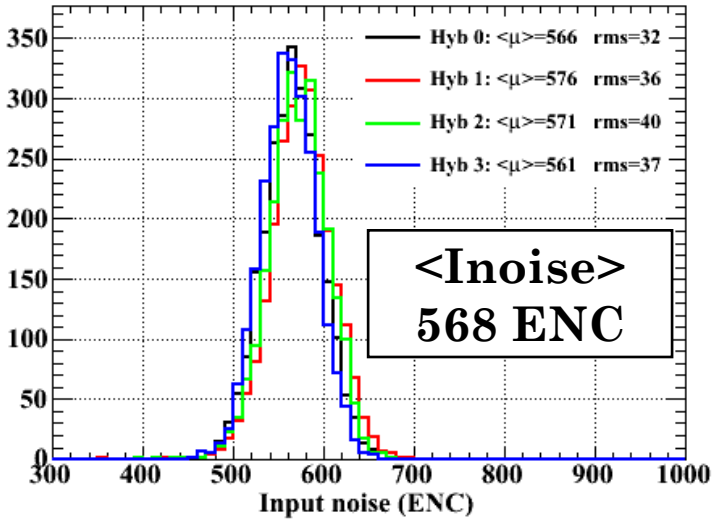
**stave module**





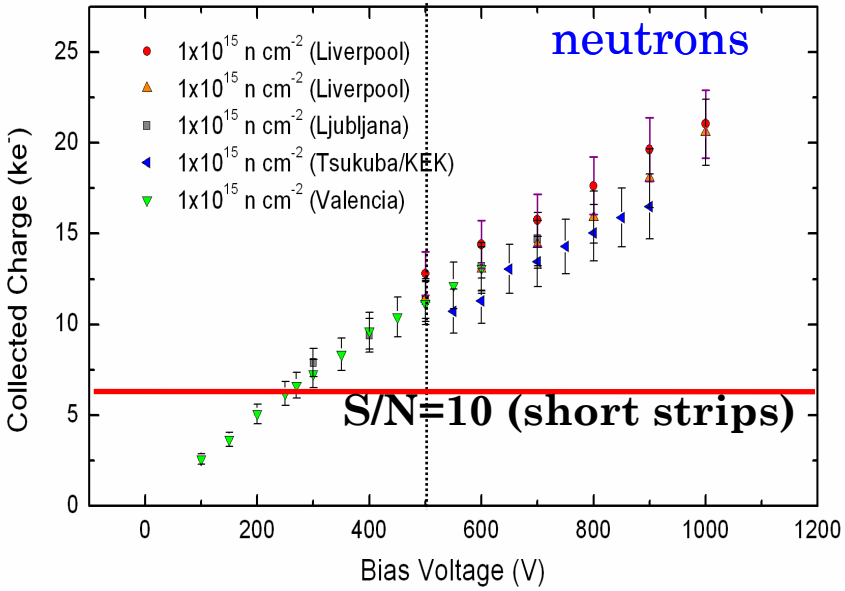

**supermodule**

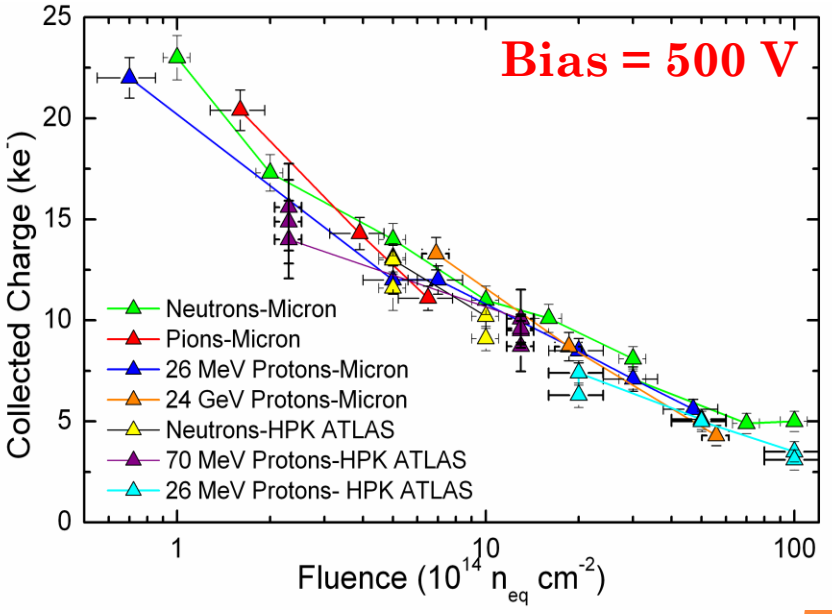


# Miniature Sensor Measurements (post-rad)

- Different irradiations
  - Protons, pions, neutrons
- Charge Collection measured in different locations (setups)
- S/N > 15 @ 500V, $10^{15}$ $n_{eq}/cm^2$
- Very good agreement to $10^{16}$ $n_{eq}/cm^2$
  - NIEL equivalences verified

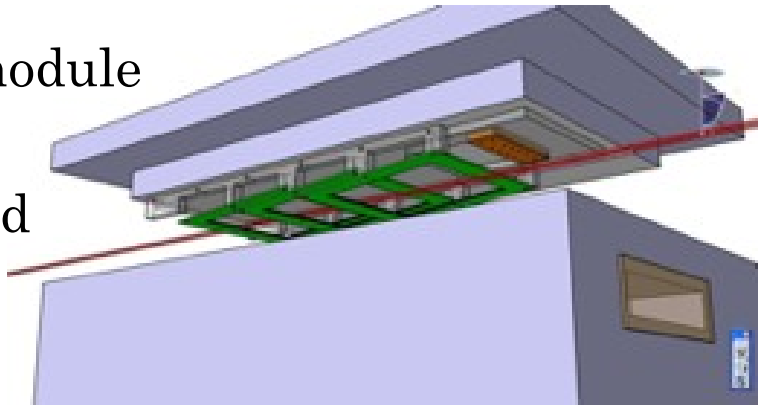


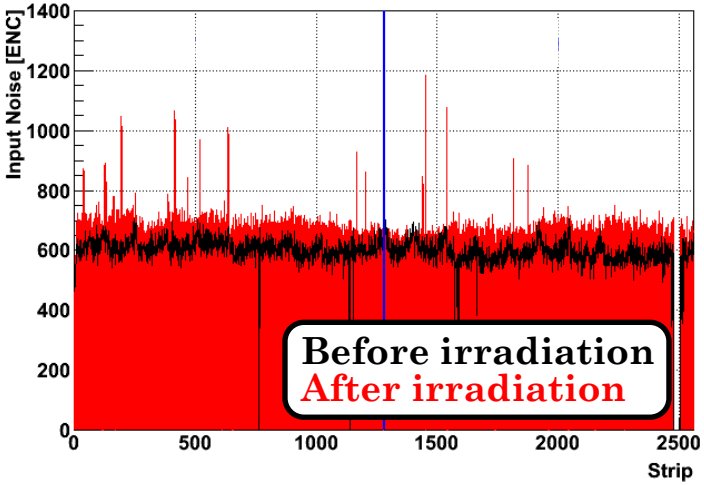




See K. Hara, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S83-S89 for details

# IRRADIATED MODULE

- Irradiated at CERN-PS
  - 24 GeV protons scanning the full module
    - Motorized table (x,y,θ), cooled box
  - Module biased, powered and clocked during irradiation
  - Dose: 1.9 x $10^{15}$ $n_{eq}/cm^2$
- Sensor and module:
  - Noise as expected from $I_{shot}$ increase
  - Fully functional module

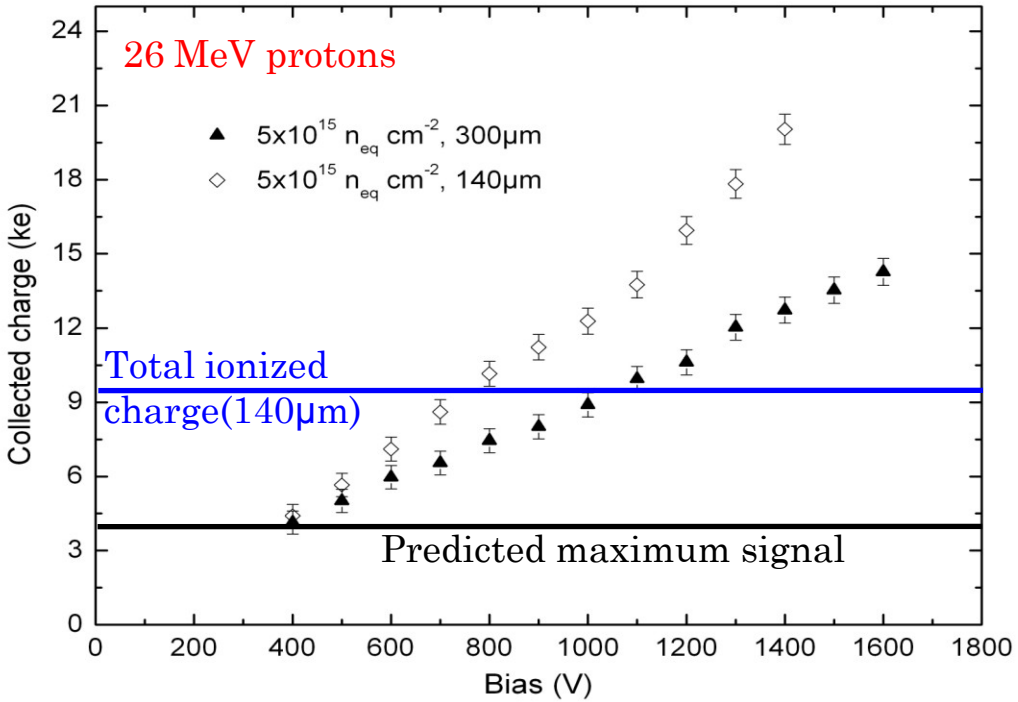





| | Column 0 | Column 1 |
|---|---|---|
| Pre-irrad | 610 | 589 |
| Post-irrad | 675 | 650 |
| Difference | 65 | 61 |
| Expected | 670 | 640 |

# Charge Multiplication

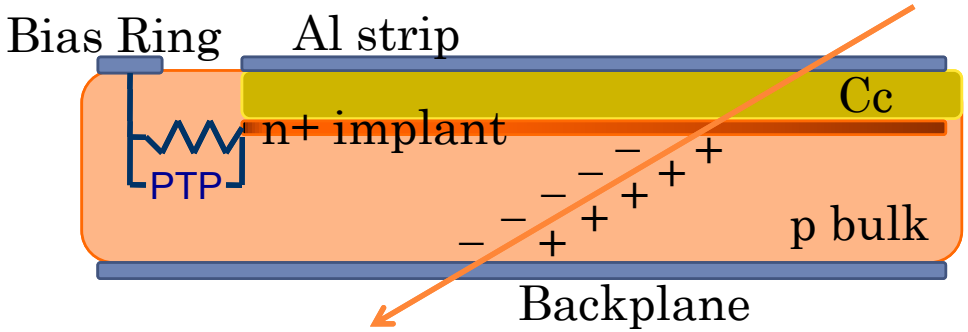
- For heavily irradiated $n^+p$ sensors (>5 x $10^{15}$ $n_{eq}/cm^2$)
  - Increased signal charge with high bias voltage
  - Charge multiplication
- Very high local electric fields
  - Likely due to impact ionisation
  - Thin sensor (140μm) has higher fields and higher multiplication
  - Sensors could be used for higher fluences



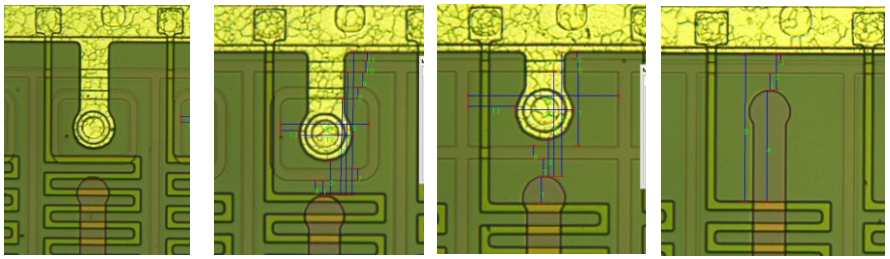

Micron (1x1cm²)
80μm, AC, $n^+p$

See G. Casse, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S156-S61 for details

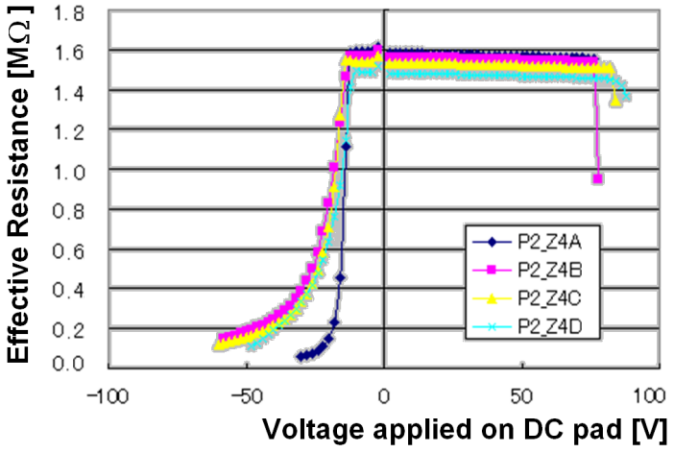
# PUNCH THROUGH PROTECTION (PTP)




- In case of beam loss
  - Enormous charge
  - Electric field collapses
  - Large voltage on the implant strip. Al strip grounded by electronics
    - Risk of breaking the coupling capacitor



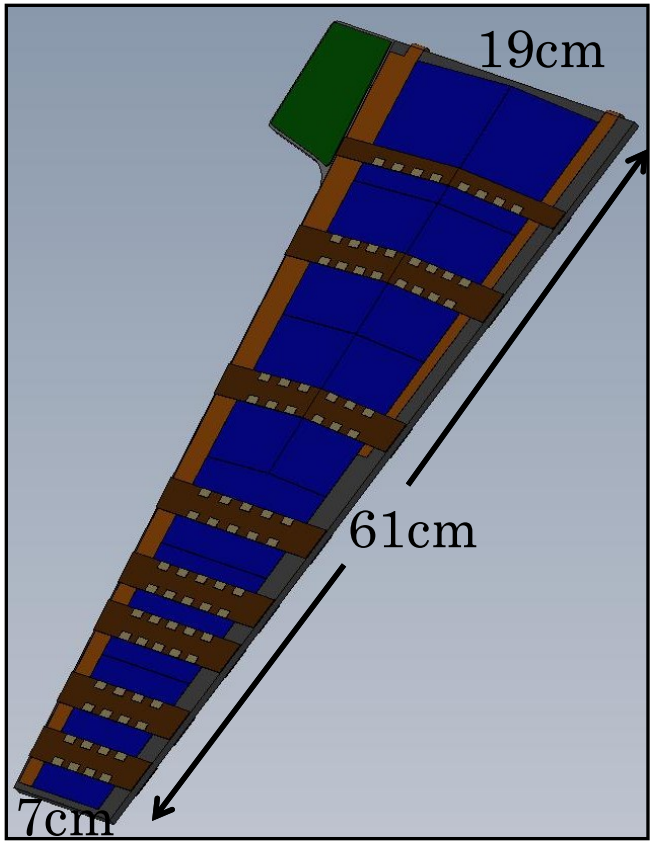
- Studies on PTP
  - PTP structures included in miniature sensors (HPK)
  - If $V_{implant} > V_{PTP}$, protection active
  - No degradation after radiation
  - Effectiveness depends on beam position along the strip
  - More studies ongoing

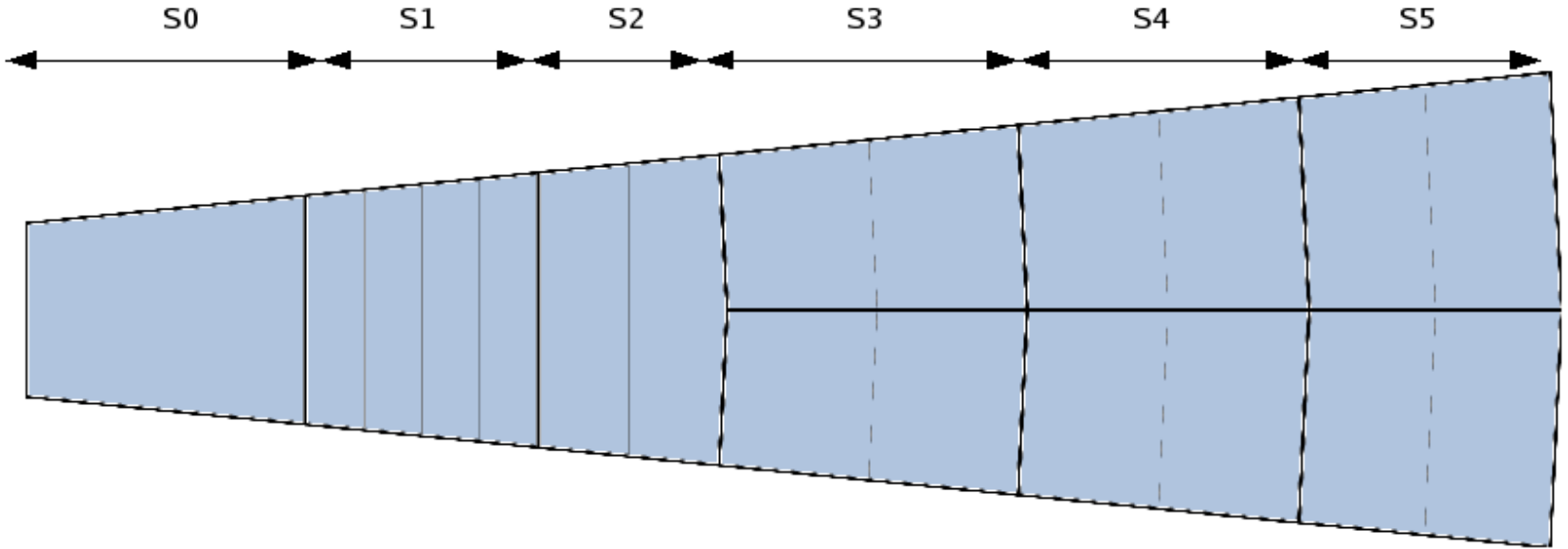



See S. Lindgren, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S111-S117 for details

# Endcap Strip Integration

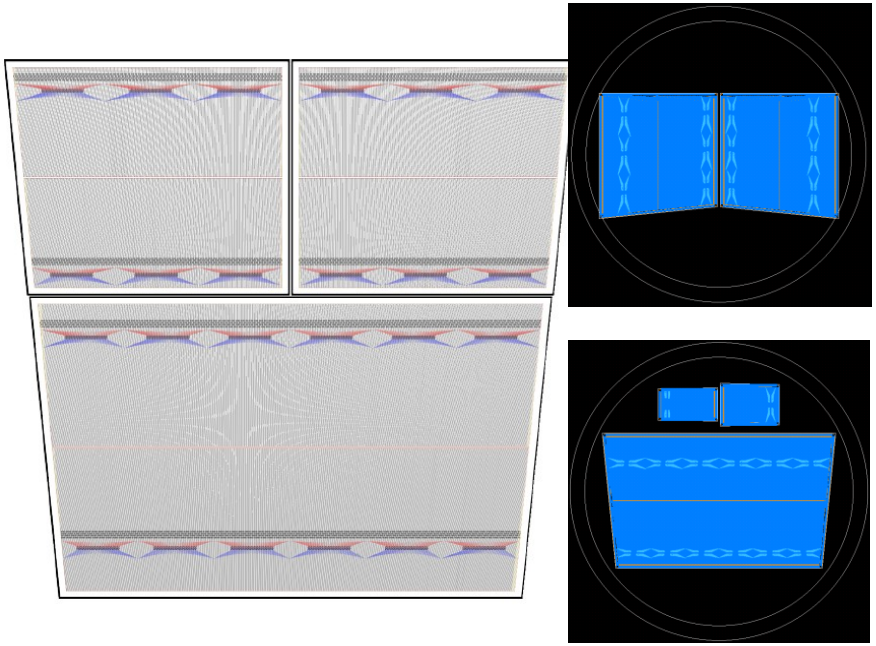
- Development program based on adapting barrel stave
- 6 rings, 6 different Si sensors !
- Sensors will use same technology as barrel
- Varying pitch (67-106μm)
  - High bonding angles

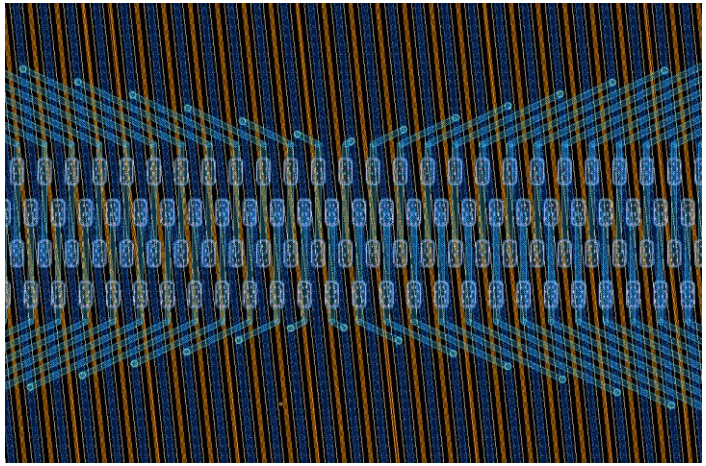


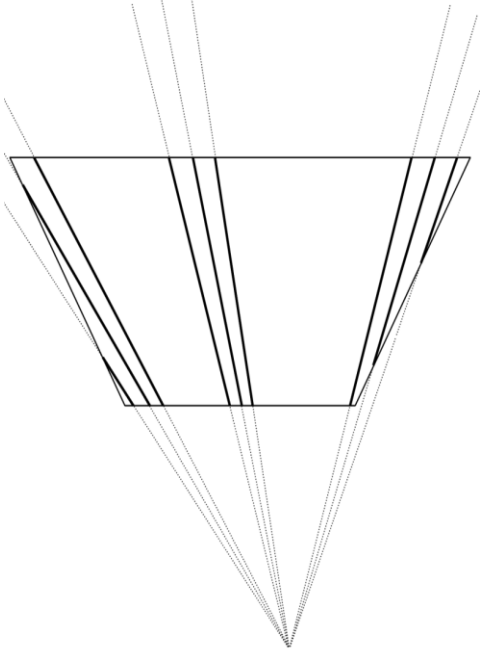



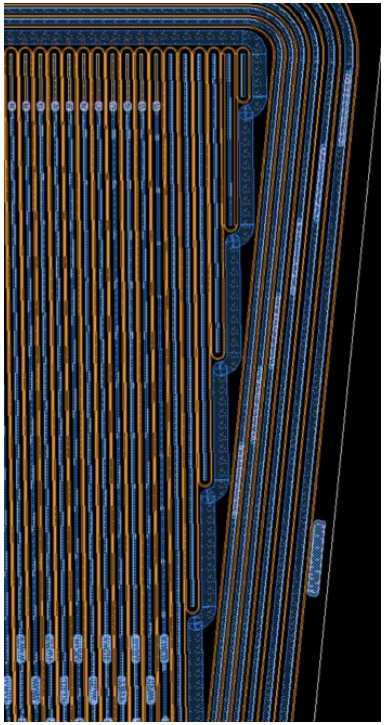
# ENDCAP STRIP PETAL-LET

- Design and fabrication
  - IFIC and CNM
- 4” wafers, integrated half stereo
  - Truncated strips
  - Bias ring at the same distance from the strips
- Double metal for embedded fanins
- Samples ready in October







# SUMMARY

- Present ATLAS tracker will be replaced by a new all-silicon tracker.
- Module and stave concepts are progressing well.
- Prototype full size barrel strip detectors have been fabricated (HPK):
  - Final specifications are already met.
  - Modules performing very well.
  - Sensors and modules fully functional after irradiation.
- Miniature sensors:
  - Test of Punch Through Protection (PTP) structures.
  - Charge multiplication observed.
- Endcap strip sensors to be designed.
  - Prototype fabrication ongoing.