DEVELOPMENT AND EVALUATION OF PROTOTYPES FOR THE ATLAS ITK PIXEL DETECTOR

FLORIAN HINTERKEUSER ON BEHALF OF THE ATLAS COLLABORATION
New all-silicon ATLAS inner detector for HL-LHC: ITk

- Same volume as current tracking detector
- Pixel and Strips
- Pixel detector consists of multi-chip modules
  - Quad modules (4 chips on 1 large sensor) and pseudo triplets (3 single chip modules on shared flex PCB)
- One design goal: Excellent performance with minimal material budget
- Use a serial powering scheme
  - Modules powered by constant current, voltage generated by on-chip voltage regulator (Shunt-LDO)
  - New powering scheme: requires extensive prototyping
ITK PIXEL PROTOTYPING

- Prototypes for the different subsystems Inner System (IS), Endcaps (EC) and Outer Barrel (OB) to cover mechanics, electronics and integration

- Prototyping with FE-I4b modules yielded valuable input for system design, integration and further developments of the new readout chip generation (RD53A)
  - Chain length of up to 16 modules prototyped
  - Large scale prototypes with RD53A modules are in early development stages

Populated half cooling line during OB demonstrator integration

Ring-0 prototype for the EC, fully loaded quadrant on a half ring

R0/1 coupled ring for the inner endcaps. First prototype to be loaded with RD53A modules

Integration concept for the inner endcaps.
SERIAL POWERING PROTOTYPING

- Requirements to **further develop Shunt-LDO** voltage regulator based of ITk pixel prototyping

  - **New features added**: Input voltage clamps, overload protection and a low power mode for testing during integration without cooling

  - **Design and features verified**, radiation hardness proven in several X-ray campaigns

- Studying of low-level system aspects in **serial powering chains** with current generation readout chips (RD53A)

  - One of several existing setups: serial powering chain for **up to 16 quad modules** in Bonn

  - First results very promising, RD53A module **performance as expected**
Test Beam Studies of Barrel and End-Cap Modules for the ATLAS ITk Strip Detector before and after Irradiation

Arturo Rodríguez Rodríguez
On behalf of the ATLAS ITk Strip Community
ATLAS Upgrade

- HL-LHC: ~ 4000 fb⁻¹
  - Requires increased radiation hardness
- Pile-up from ~50 to ~200
  - Requires increased granularity

New tracker for the HL-LHC has to maintain the performance of the present Inner Detector under more difficult conditions. **New all-silicon Inner Tracker (ITk)**

**ITk Strip Module:**
- One planar Si n⁺-in-p sensor
- Low mass PCBs (hybrids)
- Power board with DC-DC conversion
- ABCStar and HCCStar as readout chips
Test Beam

- Five test beam campaigns since 2018; two for irradiated modules
- 4 - 5.8 GeV electron beam @DESY
- 120 GeV pion beam @CERN SPS
- EUDET beam telescope
- Time tag of tracks from telescope with USBPix system with FE-I4 chip.
- Dry ice foam cooling box @DESY and MPI cooling box @CERN used for irradiated modules

Double-sided R0 module (innermost Endcap module):
- Carbon honeycomb core including services
- Two fully populated R0 modules are positioned by hand on each side of the core
  - Stereo angle of 31 mrad (target 40 mrad)
- Using unirradiated sensors
Efficiency and tracking resolution for Double-Sided R0

- Tracking resolutions along the strips and transversal to them agree with expectation
- ITk requirements:
  - Efficiency higher than 99 %
  - Noise occupancy smaller than 0.1 %
  - Equivalent S/N > 10
  - Easily satisfied for a large range of thresholds for unirradiated modules
- Unirradiated R0 module S/N = 29.3
- Unirradiated Long Strip module S/N = 23.8
- Irradiated R0 module @ 500 V S/N = 14.8
- Irradiated Long Strip module @ 500 V S/N = 15.9

More details can be found:

- ATLAS ITk Strip TDR, HSTD12, INSTR20
Radiation-Hard Silicon Strip Sensors for the ATLAS Phase-2 Upgrade

Věra Latoňová
(IoP CAS, CU Prague)
on behalf of ATLAS Collaboration

ICHEP 2020

30th July 2020
ATLAS Inner Tracker (ITk) strip sensors:

- Single-sided n$^+$-in-p manufactured on 6” wafers,
- Thickness (300 - 320) μm,
- Al strips AC-coupled to n$^+$ implants grounded via polysilicon bias resistors,
- Strip isolation by common p-stop,
- 8 different designs: Barrel region (Short strips (SS) and Long strips (LS)) and End-cap region (R0-R5).

Expected maximal radiation fluences (incl. safety factor 1.5):

- Short strip barrel: $1.1 \cdot 10^{15} \text{n}_{eq}\text{cm}^{-2}$,
- Strip end-cap: $1.6 \cdot 10^{15} \text{n}_{eq}\text{cm}^{-2}$.

Radiation damage:

- **Bulk damage** – Increase in leakage current, increase in full-depletion voltage and reduction in charge collection efficiency (CCE).
- **Surface damage** – Cause for early break-down voltages, decrease of interstrip resistance, reduced channel isolation.
Evaluation Program

- **Program consists of:**
  - **QC:** Tests on MAIN Sensors to be assembled in modules:
    - Tests on every sensor: Visual inspection, IV, CV, metrology.
    - Tests on sample sensors: Leakage current stability, full strip tests, detailed strip tests.
  - **QA:** Sample tests performed on miniature sensors and test structures:
    - Tests before irradiation.
    - Irradiation.
    - Tests after irradiation

- **Irradiation sites:**

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<th>Particle type</th>
<th>Site</th>
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<td>Protons</td>
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<td>Birmingham (28 MeV)</td>
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<tr>
<td>Neutrons</td>
<td>Ljubljana TRIGA reactor</td>
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<tr>
<td>Gammas</td>
<td>UJP Praha (^{60}Co)</td>
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- **Institutions & tests:**

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<th>QA (TC)</th>
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Effect of irradiation on measured sensor characteristics

**Leakage current** [3]

- Irradiated sensors were measured at cold.
- Non-irr. sensors were measured at 20 °C.

**Effective PTP resistance vs $V_{\text{test}}$** [3]

- ATLAS17LS mini sensor irr. by gammas to different TID.

**Interstrip resistance vs TID** [3]

Comparison for sensor prototypes ATLAS17LS, ATLAS12EC, ATLAS07 and ATLAS12.

**Charge collection vs bias voltage**

Compared results for proton irr. at CERN-PS, CYRIC and Birmingham.
MIRAM Miniaturized Radiation Monitor
ACQP TPX3 ASIC

Carlos Granja, Pavel Soukup, Jan Jakubek, Daniel Turecek, Cristina Oancea, Lukas Marek, Martin Jakubek

ADVACAM, Prague, Czech Republic

*Start-up of the Medipix Collaboration/IEAP CTU Prague

M. Malich, S. Gohl, B. Bergmann, S. Pospisil, A. Smetana,
Institute of Experimental and Applied Physics, Czech TU, Prague, Czech Republic

MIRAM ESA Project 4000122160/17/UK/ND

www.advacam.com

in cooperation with

C. Granja, ADVACAM

ICHEP, Prague, July 2020
MIRAM ACQP TPX3 Bread Board

**ACQP BB:**
- Mass = 30 g
- PCB 4 layers
- Timepix3 + semicond sensors:
  - Si 100, 300, 500 µm
  - CdTe 1000 µm
- FPGA
- Micro-processor ARM CORTEX M7
  - SRAM 0.5 MB
  - Flash memory 16 MB
- Sensor bias: ± 500 V
- Data rate
  - 2.5 Mpx/s
  - 16 fps
- SPI (MIRAM/LCP)
- USB 2.0 (service, calibration)
- Readout, I/O ports:
  - SPI (MIRAM/LCP)
  - USB 2.0 (service, calibration)

**Power consumption:**
- 1.2 W continuous operation
  - TPX3 ASIC: 700-800 mW
  - microprocessor: 100-150 mW
  - FPGA: 100 mW
  - bias source: 100 mW
- 0.4-0.7 W duty cycle, low-power mode

**Spectrometry, timing**
- Energy threshold 3.5 keV
- Energy resolution ≈ 5-8%
- Time resolution 1.6 ns

**Notes:**
P. Soukup (HW,FW), D. Turecek (FW,SW)
ADVACAM Prague, April 2019

TPX3 ASIC
Si 500 µm

Passive cooling

Spectrometry, timing
- Energy threshold 3.5 keV
- Energy resolution ≈ 5-8%
- Time resolution 1.6 ns

**ACQP BB TPX3 500 µm Si**

**Timepix3 Chipboard (TCB)**

**Readout electronics board (REB)**


\textbf{MiniPIX-Timepix + Heavy charged particles: protons, ions}

\textit{Quantum imaging detection and track visualization of energetic protons, alpha particles, ions}

\textbf{Light ion U-120 cyclotron, Rez-Prague Synchrotron HIT, Heidelberg, Germany Synchrotron, HIMAC, Chiba, Japan}
Angular distributions of energetic light charged particles
Single layer TPX + MiniPIX-Timepix camera + 1D angular distributions + wide FoV sky map

Angular distribution of a 12 MeV electrons beam incident at $\beta = 60^\circ$ and $\alpha = 45^\circ$. By single layer MiniPIX-Timepix camera.

Angular distribution of a 31 MeV proton beam along the (a) elevation and (b) polar angles for four incident geometries (collected separately) by a single layer MiniPIX-Timepix camera (sensor 300 $\mu$m silicon).

Electron beam 12 MeV – 1x direction
Microtron NPI-CAS Prague

Proton beam 31 MeV – 4x directions
Cyclotron NPI-CAS Prague Rez

Angular flux [cnt x cm$^{-2}$ x min$^{-1}$ x sr$^{-1}$]

C. Granja, K. Kudela, et al., Directional detection of charged particles/cosmic rays with radiation camera MiniPIX Timepix, NIM A 911 (2018) 142-152
Study of a MAPS detector prototype for the upgrade of the BESIII inner tracker

Mingyi Dong

Institute of High Energy Physics, CAS
State Key Laboratory of Nuclear Detection and Electronics
on behalf of the working group (IHEP, IPHC, SDU)
• Three layers CPS detector prototype designed for BESIII inner tracker upgrade
• 1/10 coverage of the inner tracker (~720cm² → 180 chips)
• In φ direction: 2, 3 and 4 ladders for layer1-layer3 respectively
• In Z direction: 2 sets of ladders each layer

Ladder:
• 10 Mimosa28 chips (thinned to 50 µm)
• Flex cable
• Carbon fiber mechanical support
Setup of the test (T24 test beam in DESY)

- **Five detector ladders arranged in parallel**
  - Telescope system, DUT plane
  - Spacing: 20mm
- **Two scintillators provide trigger signals**
  - Size: $15\text{mm} \times 15\text{mm}$
- **Fans for air cooling**
- **A temperature sensor monitors the environment temperature**
Test Results

- Spatial resolution: about 5 $\mu$m. Maximum of tracking efficiency: 96%
- Loss of $\sim$4% of the efficiency is due to the readout and DAQ system. Already updated for next test.

- The average gap between neighboring chips is better than 10 $\mu$m.
- The material budget is about $0.37\% X_0 /$ ladder (based on Highland formula).