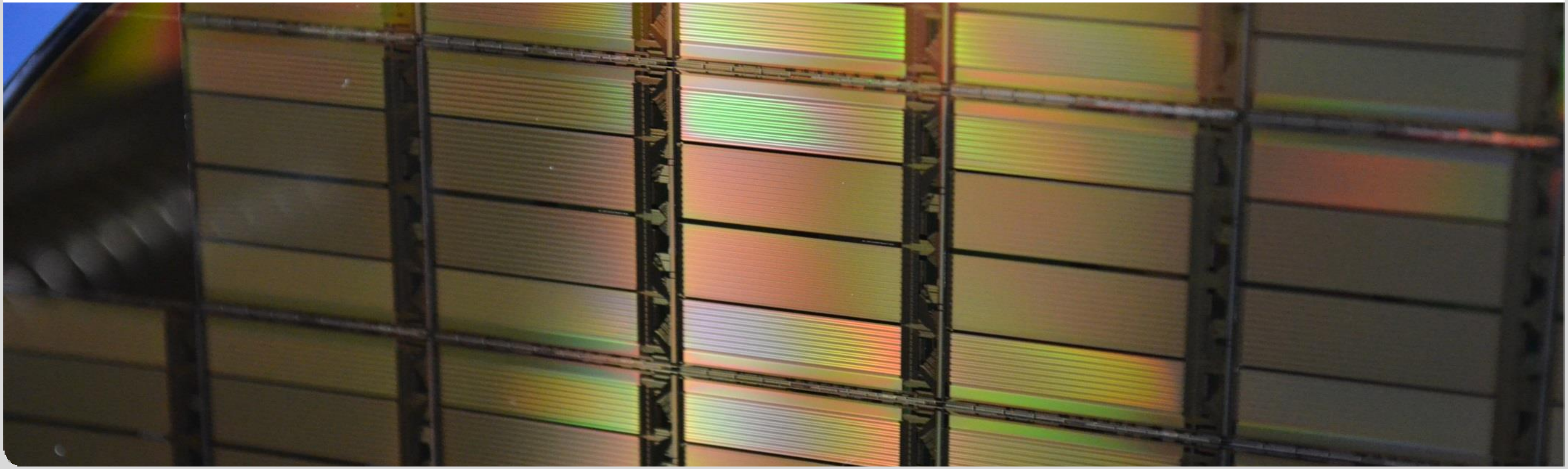
Characterization of HVCMOS Sensors

Felix Ehrler

ASIC and Detector Laboratory (ADL), Institute for Data Processing and Electronics (IPE)

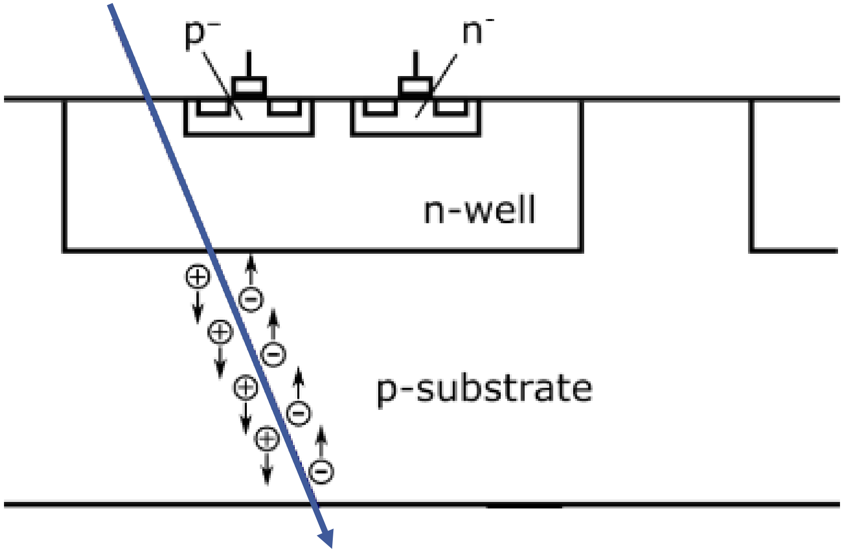


- What is HVCMOS?
- Sensor Characterization
- Some Example Measurement Results

What is HVCMOS?

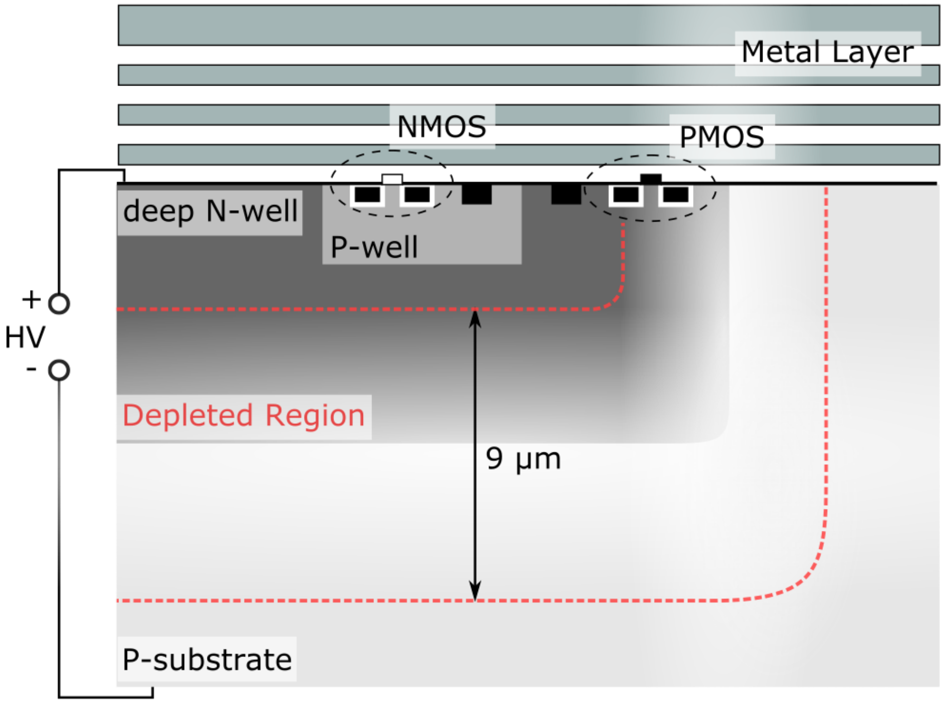
HVCMOS for High Energy Physics

- HV CMOS = High voltage complementary metal oxide semiconductor
- Large depletion depth (= signal strength)
  - High depletion voltage (up to 250 V)
  - High resistive substrate (up to 1kΩcm or more)
- Electronics placed inside the pixels:
  - Monolithic active pixel sensor (MAPS)



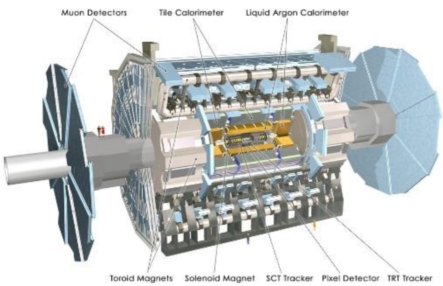
HVCMOS for High Energy Physics

- Fast and efficient charge collection by drift
- Sensor and electronics on the same die
- Low material budget (≤ 50 µm)
- Simple assembly (no bump bonding)
- Low cost
- Radiation tolerant technology, further increased by special design

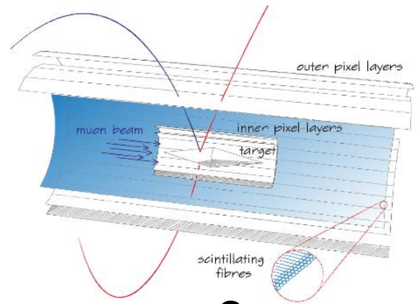


High Energy Physics Experiment

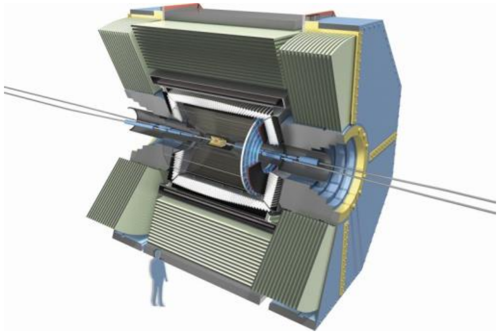
Karlsruhe Institute of Technology



ATLAS

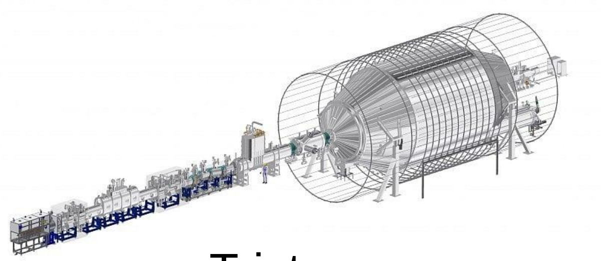


mu3e

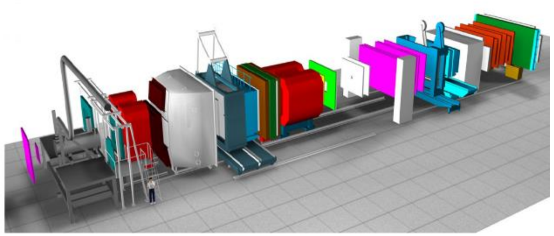


Belle II

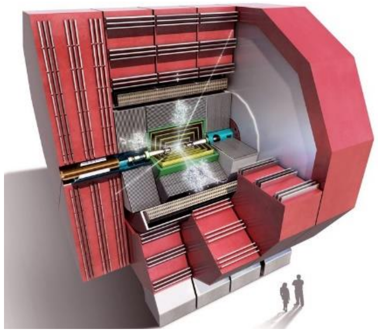
KIT ASIC and Detector Laboratory



Tristan



Compass



CLIC

Requirements of HEP

- Tracker: Particle identification or decay reconstruction

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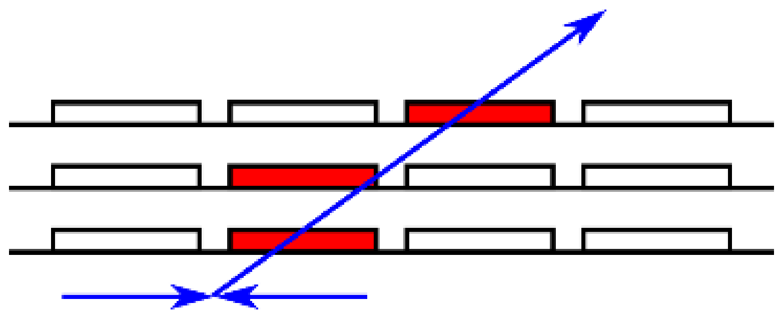
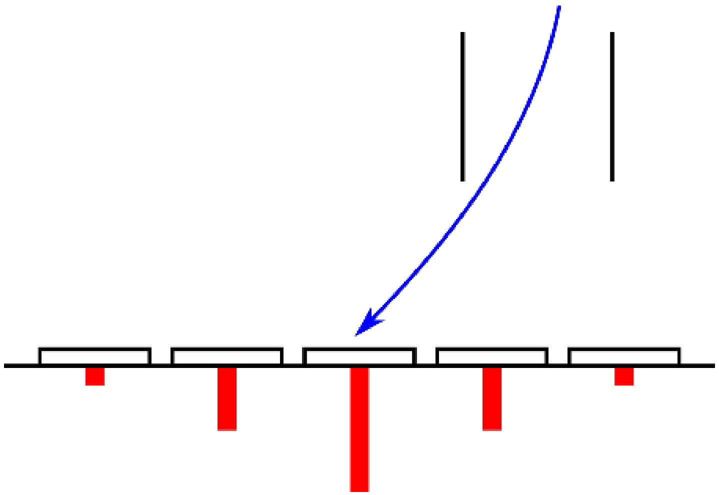
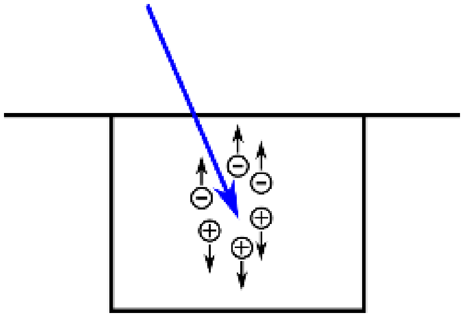
- Particle trajectory
- Energy measurement
- Rate measurement







Requirements of HEP

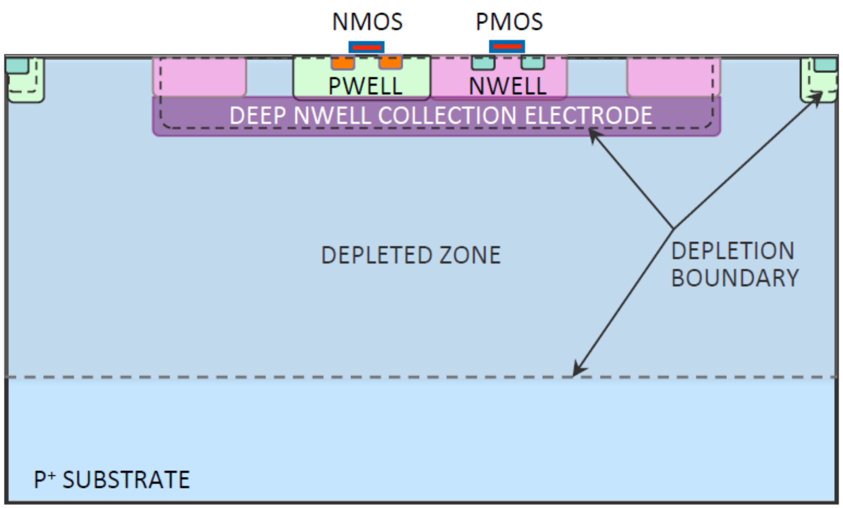
- Tracker: Particle identification or decay reconstruction

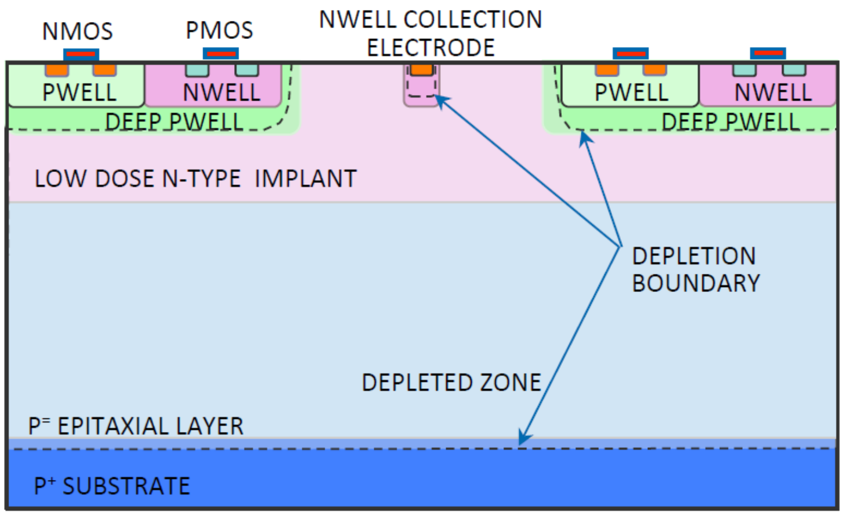
- Particle trajectory
- Energy measurement
- Rate measurement

- Spacial resolution (pixel size between 30x30 µm² and 50x250 µm²)
- Time resolution (10-50 ns)
- High efficiency (>99%)
- Energy Resolution
- Signal-to-noise-ratio
- Harsh measurement environment: radiation hardness

Variants of HVCMOS

- Small fill-factor
  - Small collection electrode without electronics (not yet radiation hard)
- Large fill-factor
  - Larger collection electrode with pixel electronics inside





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- HRCMOS
  - Focus on high resistive substrate (not radiation hard)
- HVCMOS
  - Focus on high depletion voltage

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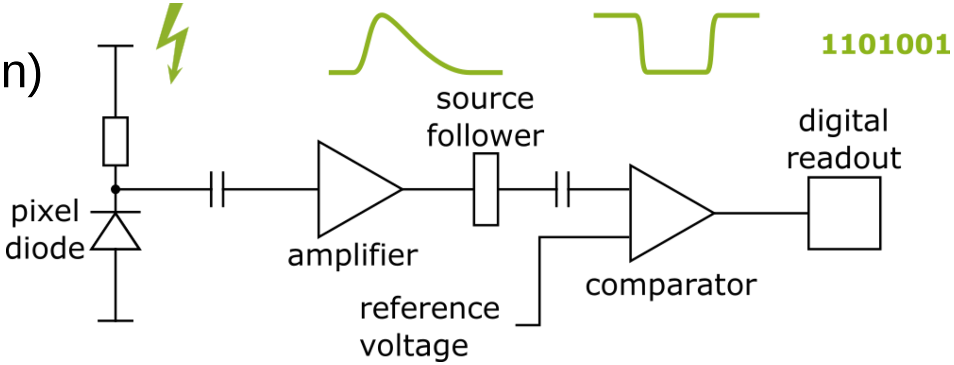
- HV-Monolithic Active Pixel Sensor
- Capacitvly Coupled Pixel Detector
  - Intermediate concept between Hybrid Sensor and Monolithic Active Pixel Sensor

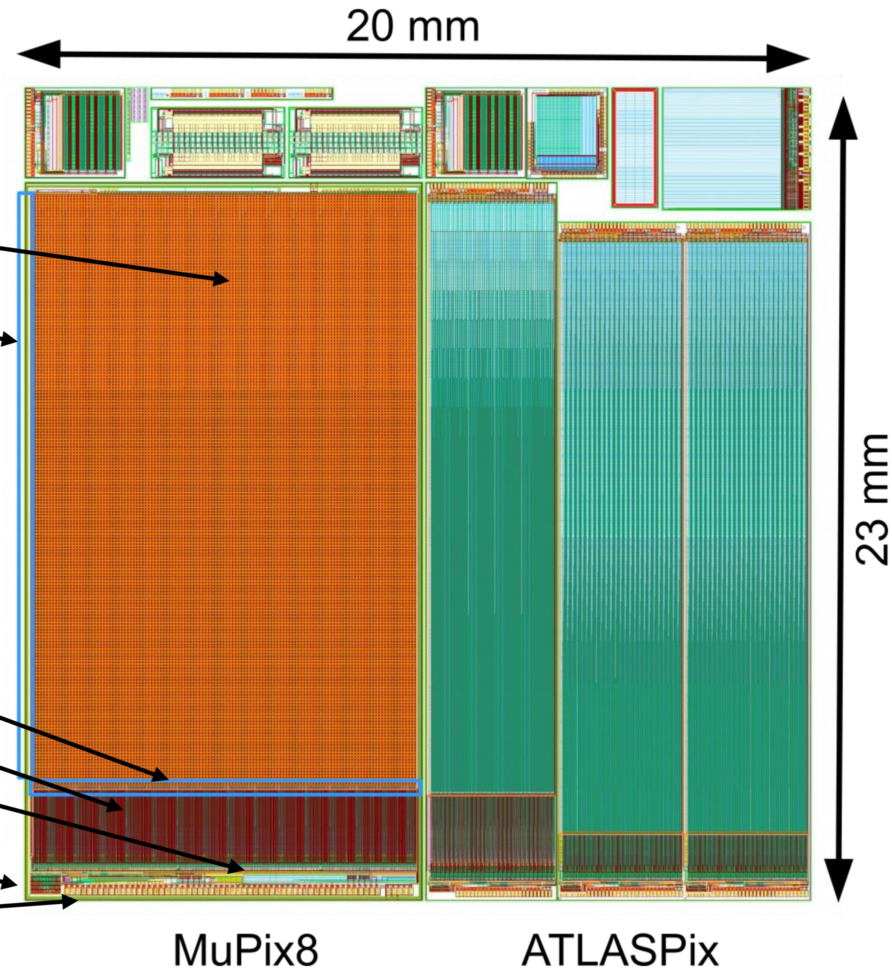
Components of MAPS

- Signal path
  - Pixel diode
  - In-pixel amplifier
  - Comparator (in pixel or periphery)
  - Readout (buffer, timestamp generation, encoder, serializer)
- Configuration
  - Shift register (matrix configuration)
  - RAM (pixel configuration)
- Bias block
- Derivation of several clocks from reference clock (PLL)



Components of MAPS

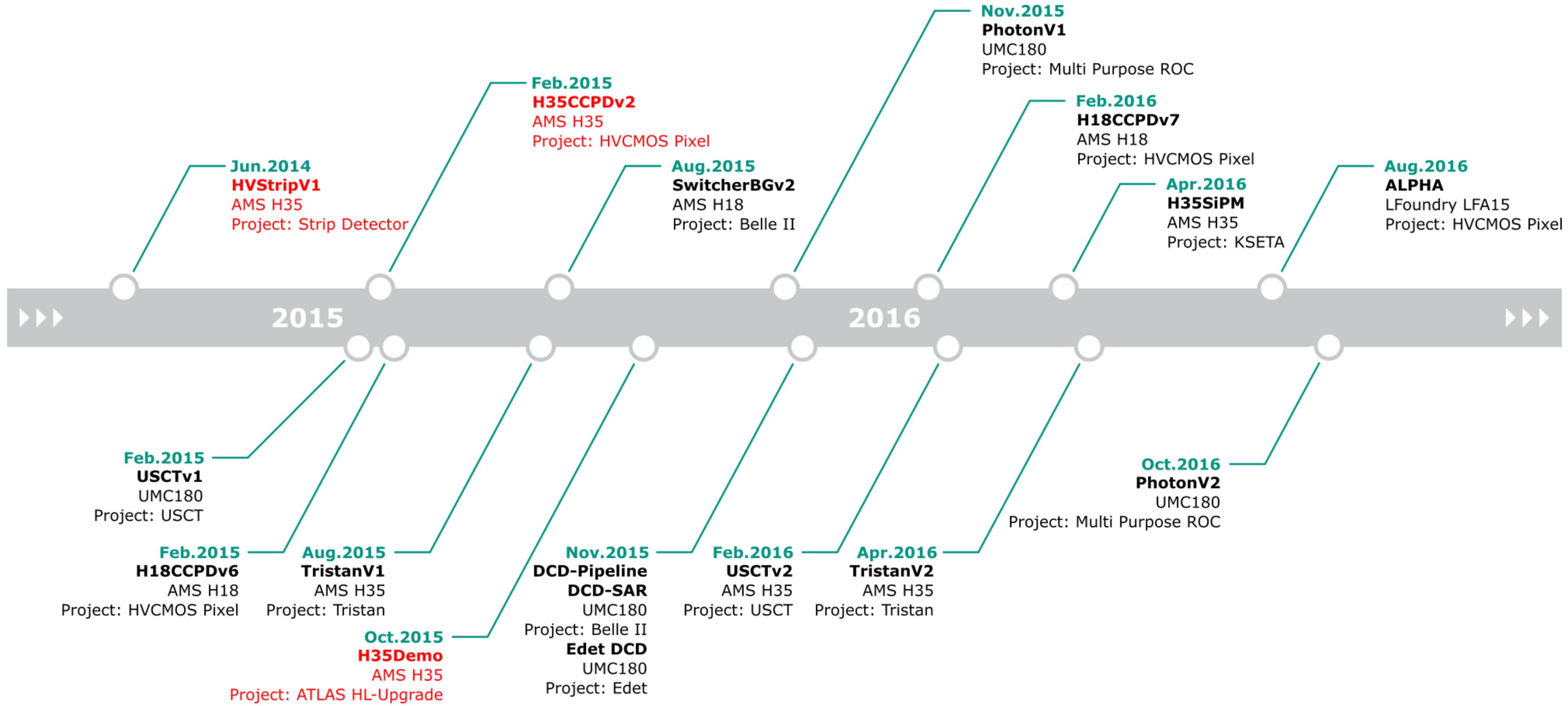
- Pixel Matrix
- Row register
- Column register
- Column readout
- Readout / Serializer
- DACs / Biasing
- Bond pads



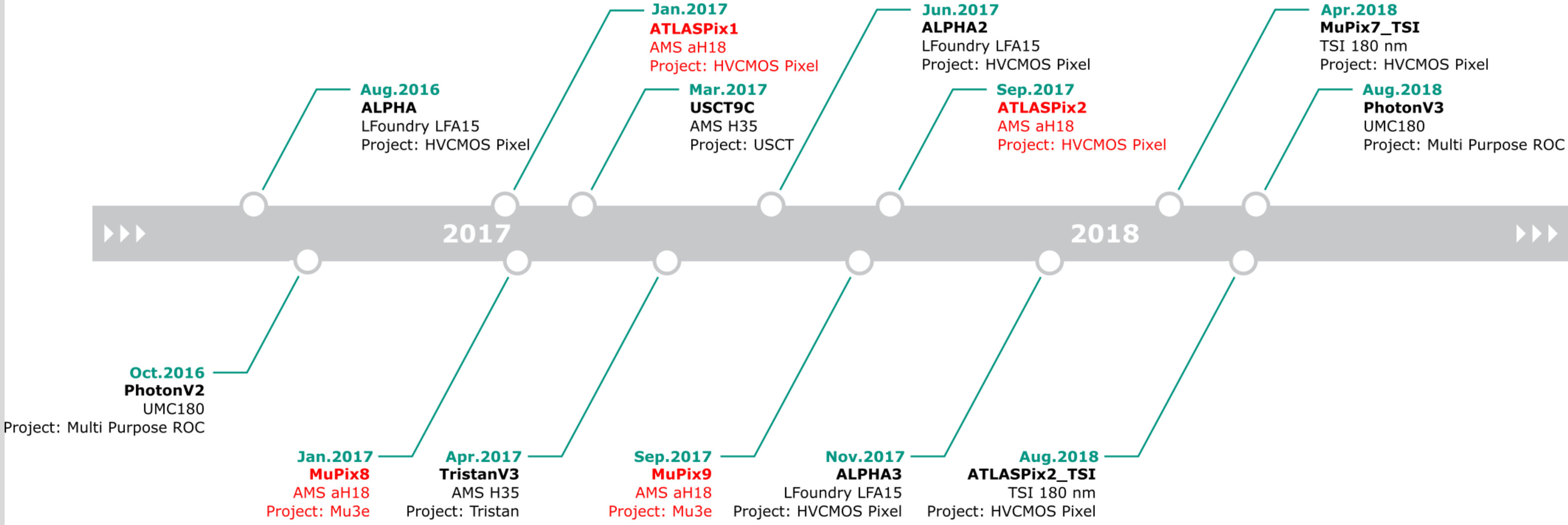
Readout

- Zero supressed (and triggered) readout
- One or more differential output lines for serial data transmission
- Transmitted information:
  - Spacial information (e.g. column number, row number)
  - Timestamp
  - Additional information
    - time over threshold
    - signal height
    - waveform sample points
    - 2nd timestamp
    - cluster information

Submission Timeline – Projects of KIT ADL



Submission Timeline – Projects of KIT ADL



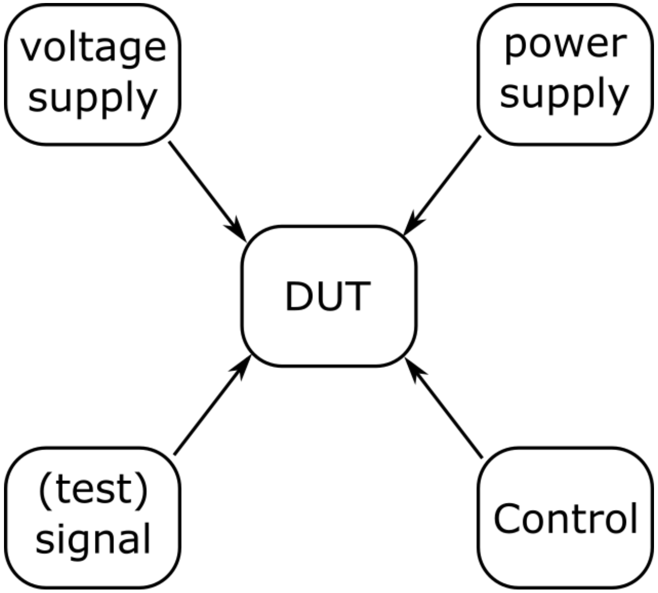
Sensor Characterization

What is to be Characterized?

- Functionality
- Energy Resolution
- Time resolution
- Spacial resolution
- Detection efficiency
- Radiation hardness

Components of Characterization Setups

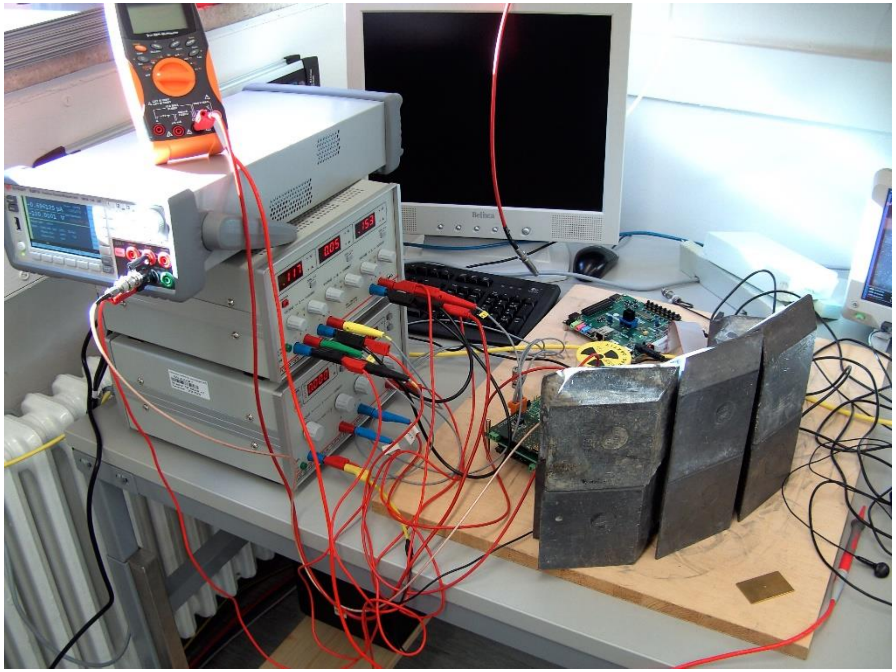
- The Device Under Test (DUT) needs:
  - Power supply
  - Bias voltages
  - Configuration
  - Data connections
  - Signal source (particles or electrical pulses)

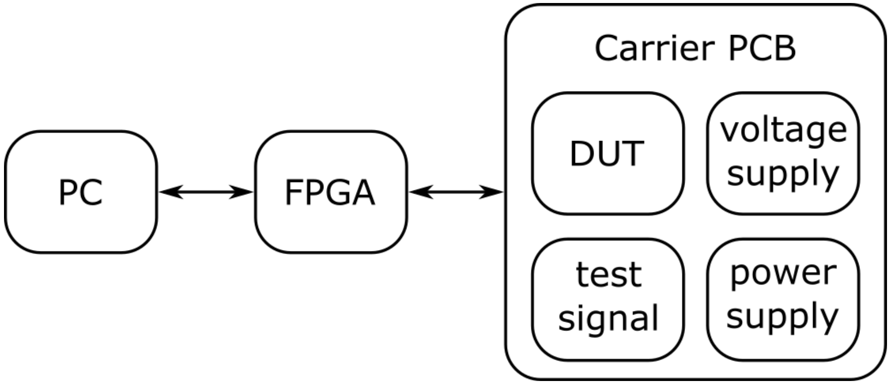


DUT-Specific Setup

- PCB
- Software
- Firmware

- Big effort required
- Cheap for few tested sensors



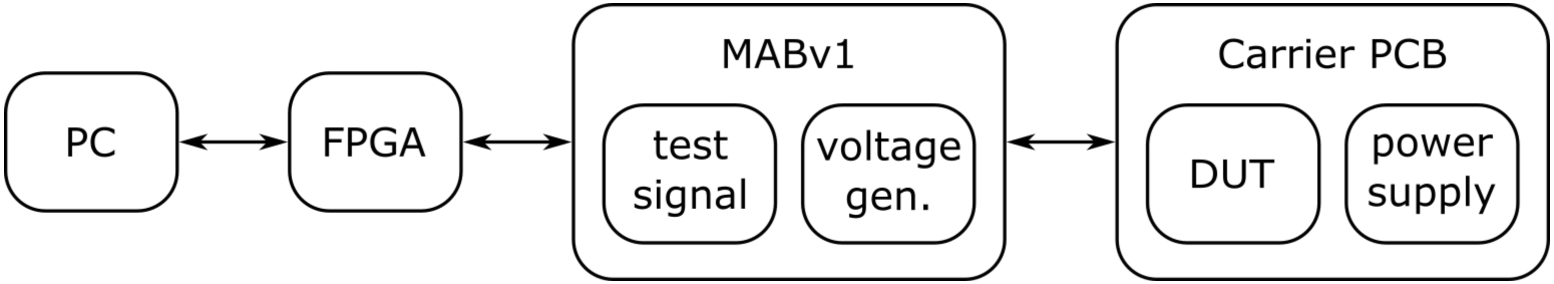


Measured Chips

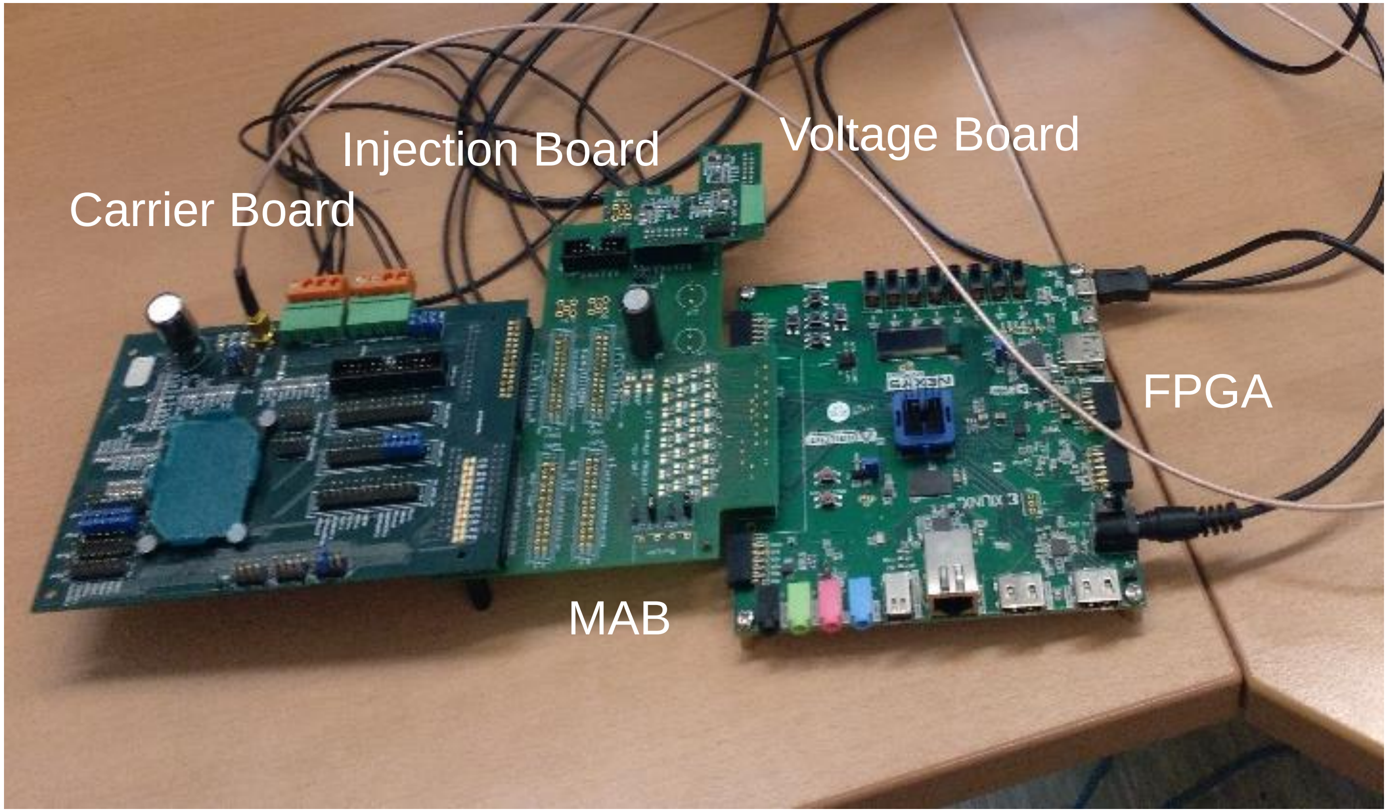
- HVStripV1
- CCPDv1
- CCPDv2
- H35Demo

Multipurpose Adapter Board v1 (MAB)

- Interconnection beween FPGA and carrier
- Modular: daughter boards
  - Voltage board
  - Injection board
- Outsourcing of some functionality (expensive compontents)
- Reusable for new projects
- No FMC connector

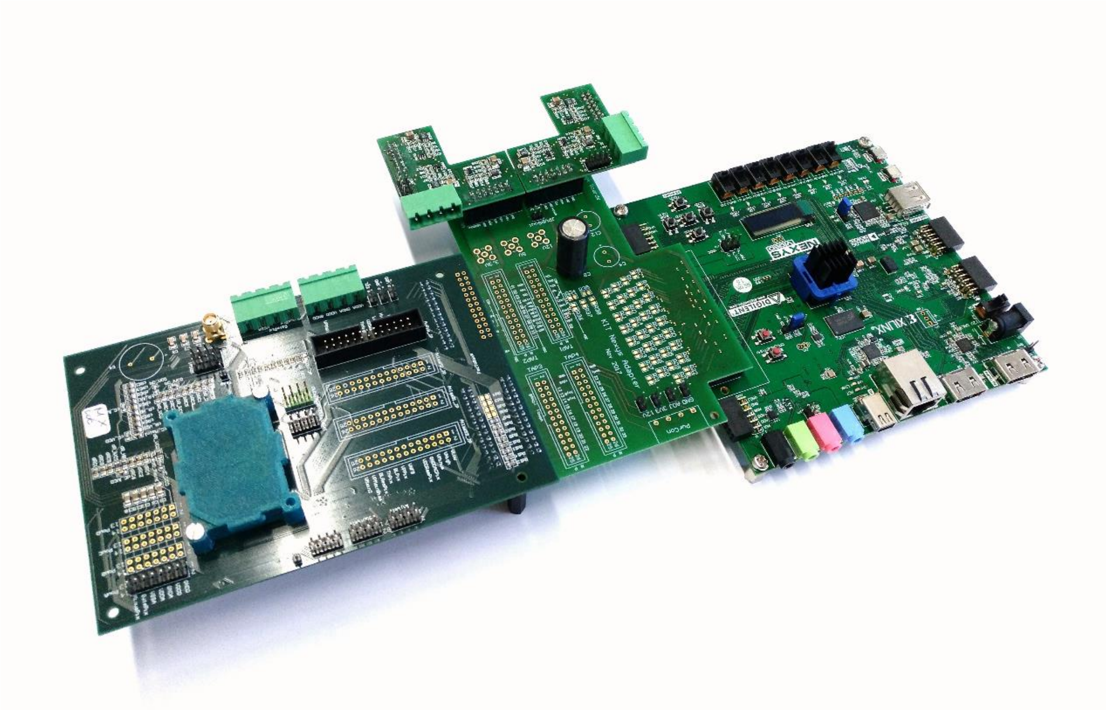


Multipurpose Adapter Board v1



Multipurpose Adapter Board v1

- NexysVideo (Artix7)
- modular
- 10 arbitrary voltages
- 2 testsignal generators

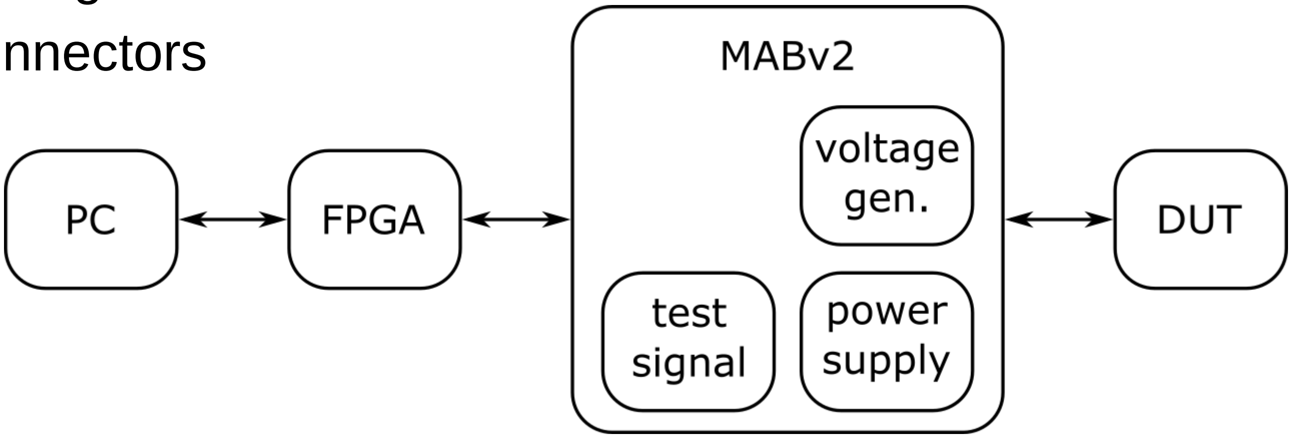


MAB v1 has been used in the characterization of:

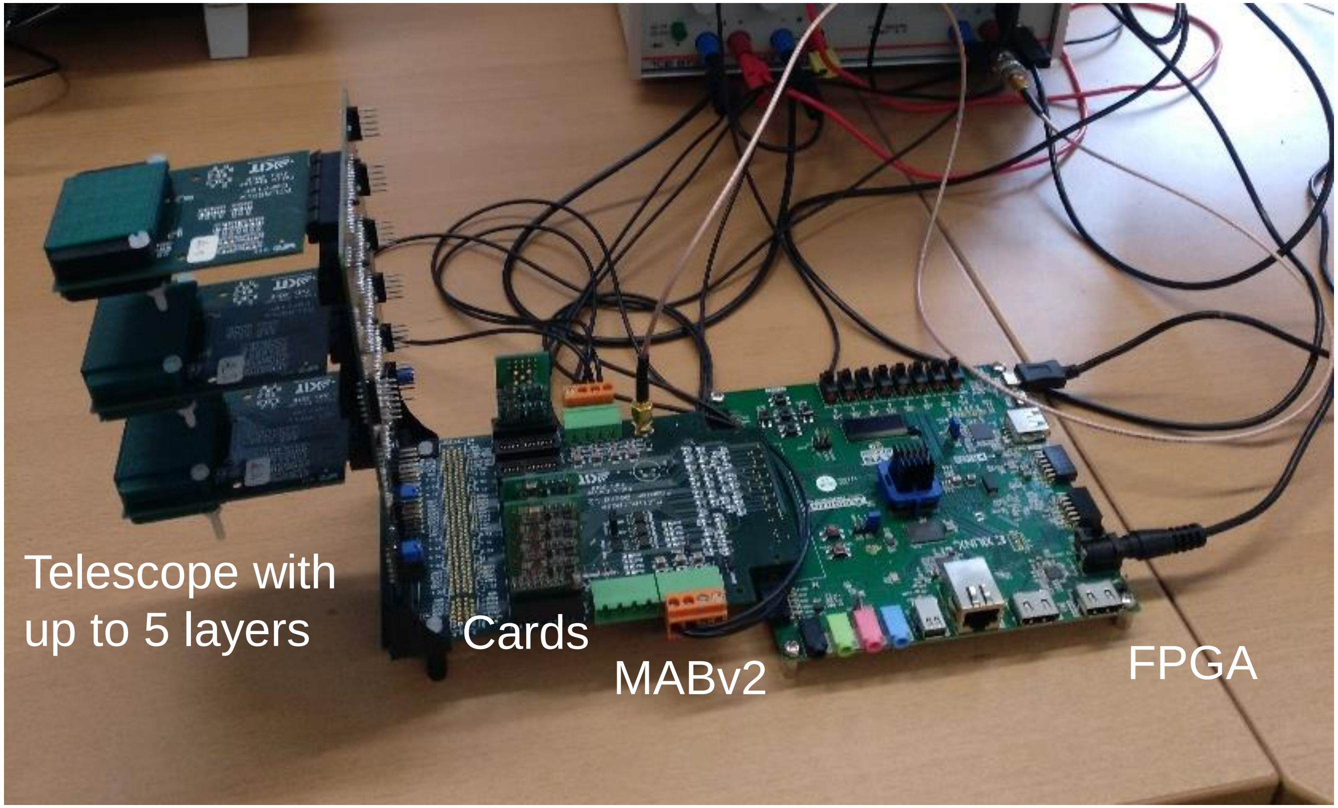
- MuPix8
- ATLASpix_M2
- ATLASpix_Simple
- ATLASpix_Isosimple
- 2 LFoundry ATLAS chips (PPtB, Waveform sampling)
- MuPix9
- CCPD
- ATLASpix2

Multipurpose Adapter Board v2

- One large board for routing and configuration of the …
- … up to eight configurable function cards. Depending on the DUT, a function card can be plugged in an arbitrary slot:
  - Voltage card (8 voltages)
  - Injection card (2 test signal generators)
  - Configuration card
  - Others possible/planned: Deserializer card, Trigger card …
- Power supply
- Separated ground
- PCIe connectors



Multipurpose Adapter Board v2



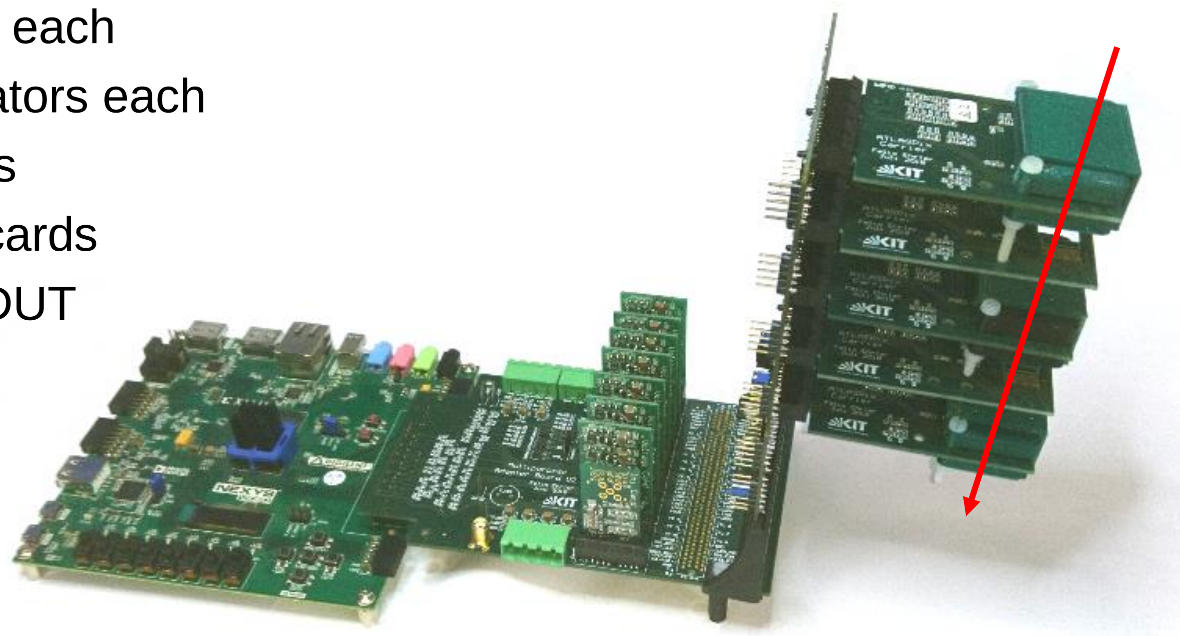
Multipurpose Adapter Board v2

New Properties

- PCIe connectors
- No common ground needed
- Highly modular
- 8 function card slots
  - 8 arbitrary voltages each
  - 2 test signal generators each
  - 4 configuration lines
- Small and simple DUT cards
- No wires connected to DUT

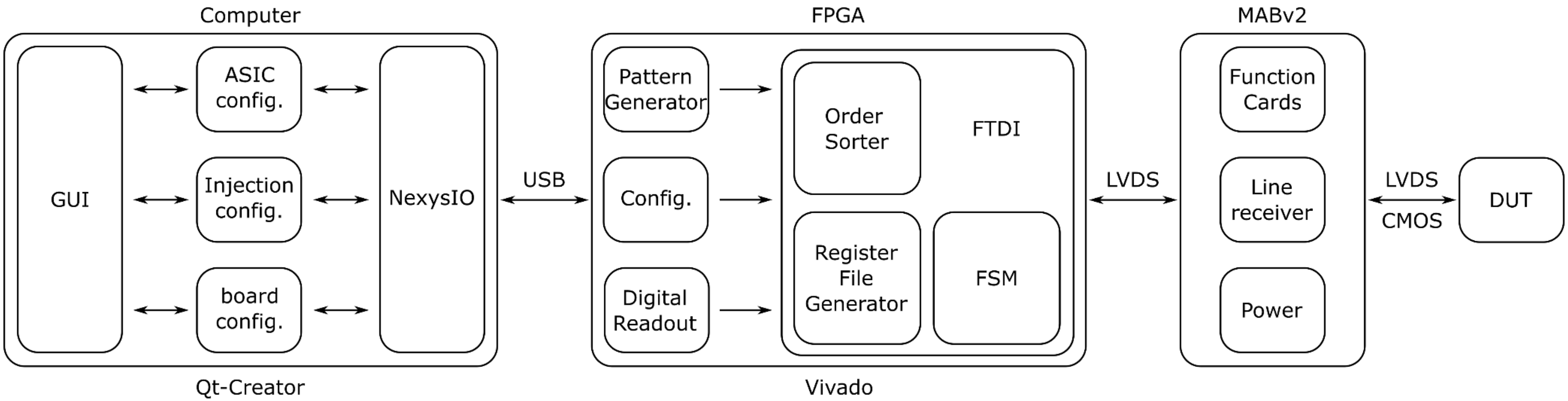
Multipurpose Adapter Board v2 with beam telescope

- Currently 5 AtlasS1 layers
- MuPix8 layers under construction

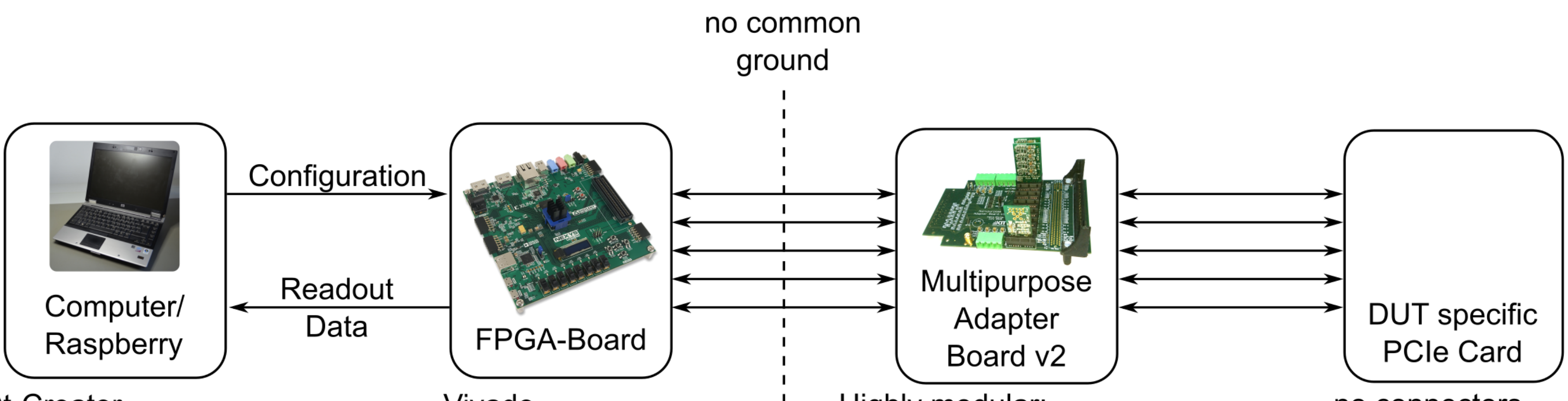


Modular Soft- and Firmware

- Simple to adapt existing Firmware modules to new ASIC
  - Universal Modules in FPGA Firmware
  - Automated register file generation
  - Versatile communication with computer
- C++ classes for rapid development
  - Communication class
  - Capsuled configuration classes: Bit manipulation? – Never again!
  - MAB classes



Characterization Setup Summary



- Qt-Creator
- Generic classes for rapid development
  - Communication class
  - Configuration classes
  - Test signal class
  - Labtool classes
  - Lasersetup class

- Vivado
- Sensor configuration
- MAB configuration
- Data collection/buffering
- Data reduction
- Data transmission

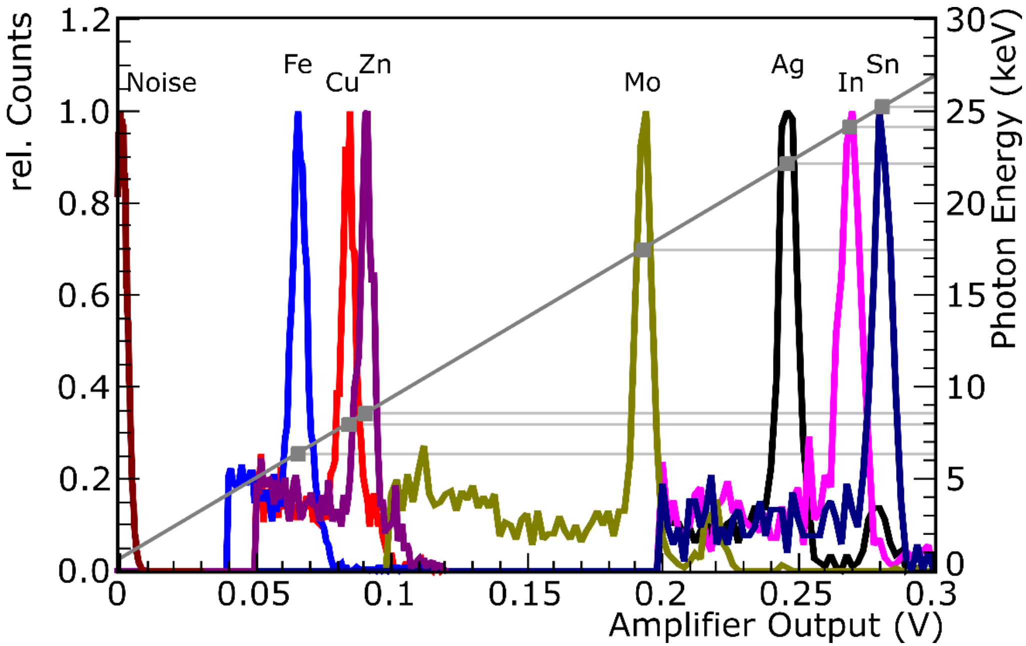
Highly modular:
- 10 power connectors
- 1 high voltage connector
- 4 differential line receivers
- 25 free differential lines
- 8 arbitrary function cards
  per card:
  - 8 arbitrary voltages
  - 2 test signal generators
  - 4 configuration lines

- no connectors
- easy to handle
- small
- cheap
- simple components

Some Example Measurement Results

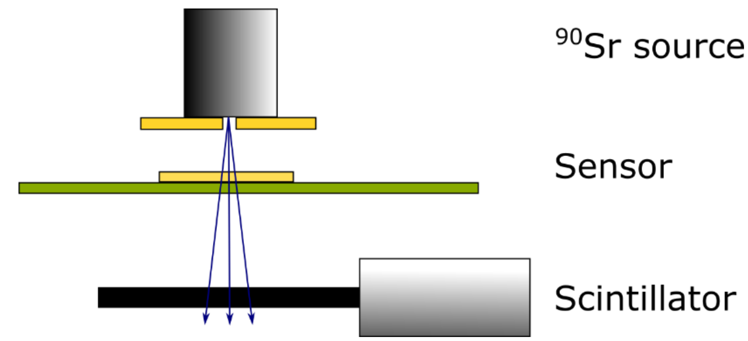
X-ray Spectrum – Energy Resolution

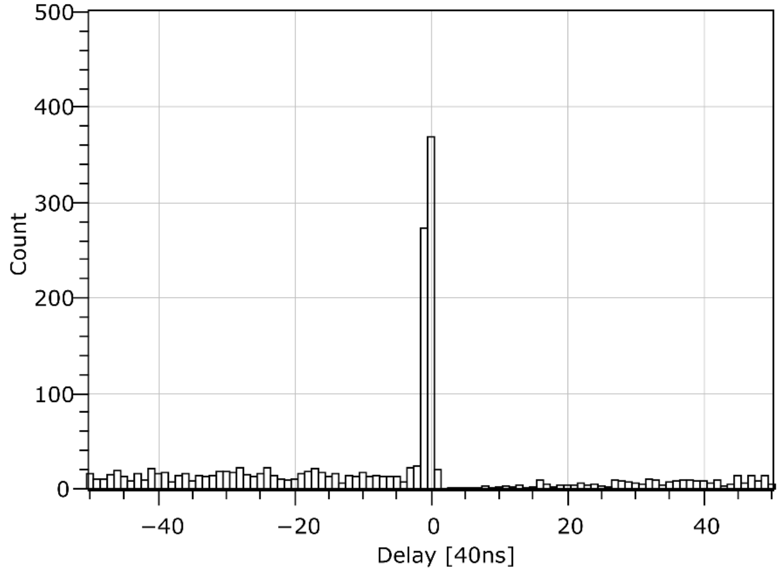
- X-rays from an X-ray tube are sent to targets of different elements to generate monochromatic X-ray radiation
- X-ray energy corresponds to a certain charge generated in silicon
- Used to show linearity of amplifier



Time Resolution Measurement

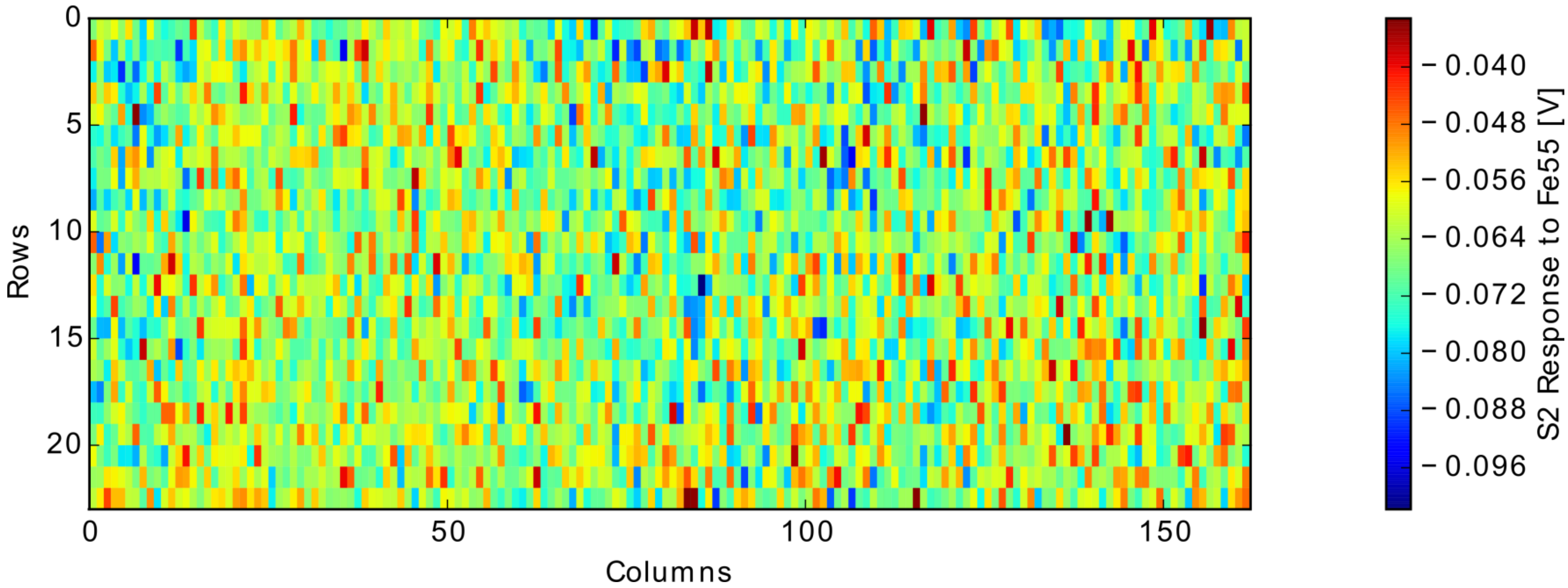
- Strontium-90 source is placed above sensor and scintillator
- The variation of the difference of the timestamps generated by both is the time resolution



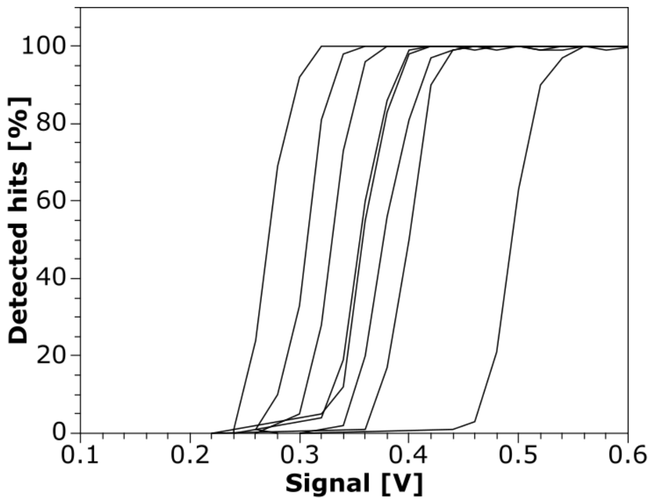


Uniformity

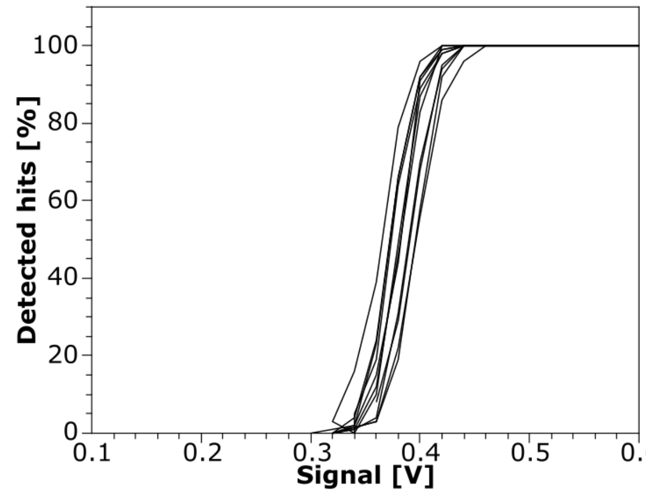
- Small production differences lead to non-uniform behavior
- Solution: Adjust the local threshold of each pixel



Tuning



Before tuning, the S-curves are widly spread. After tuning they are close together.



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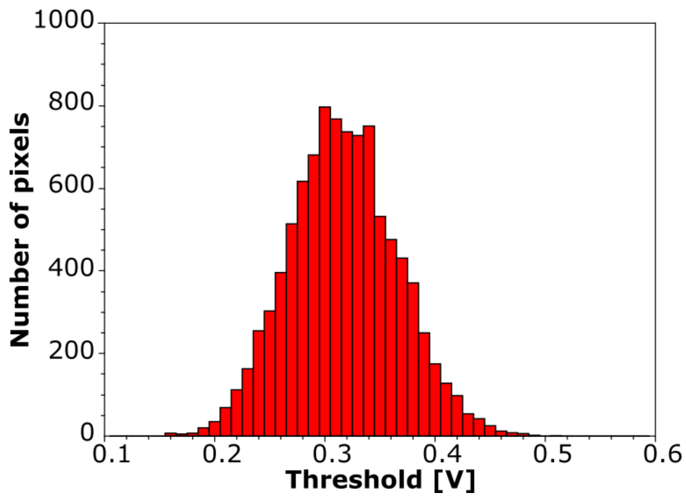
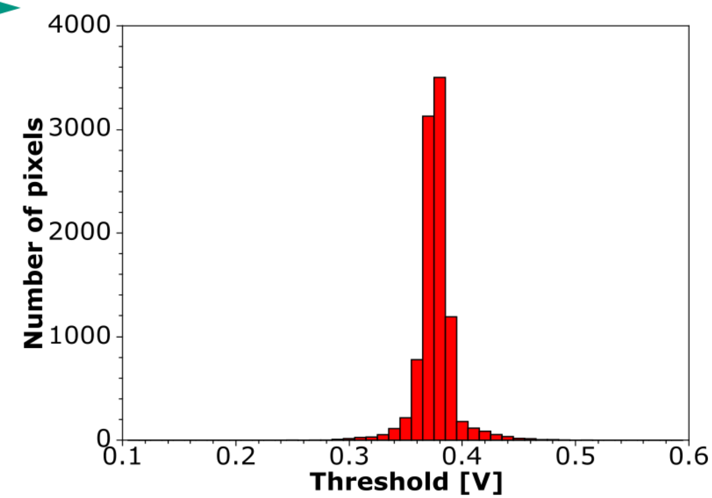


Tuning reduces the spread of threshold by a factor of 5. The threshold is defined as the point at 50% detection efficiency.



Conclusion

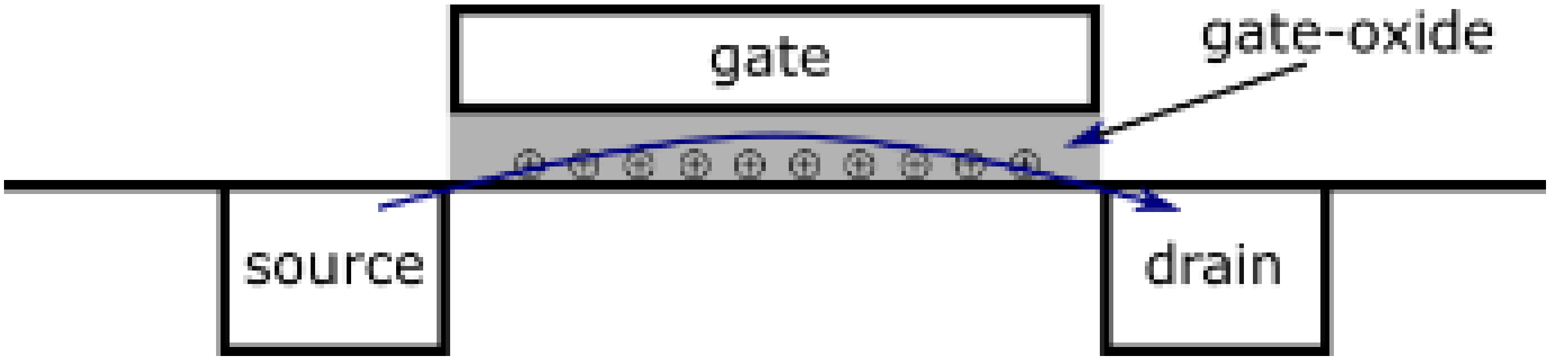
- HVCMOS is a versatile technology
- A lot of research is going on in the HVCMOS collaborations
- In some years, most trackers might be based on HVCMOS sensors
- Some effects not yet fully understood
- A lot of characterization to be done!

Many thanks to
Alena, Ivan, Rudolf,
and all other people at
IPE and ETP

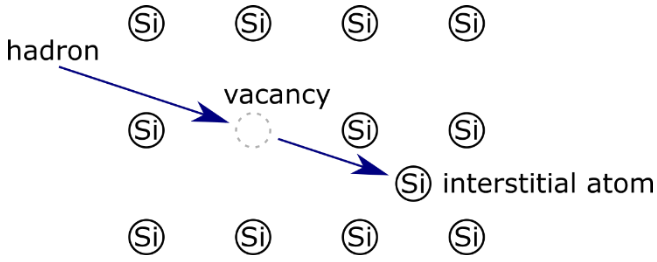
Thank you for your attention!

Backup

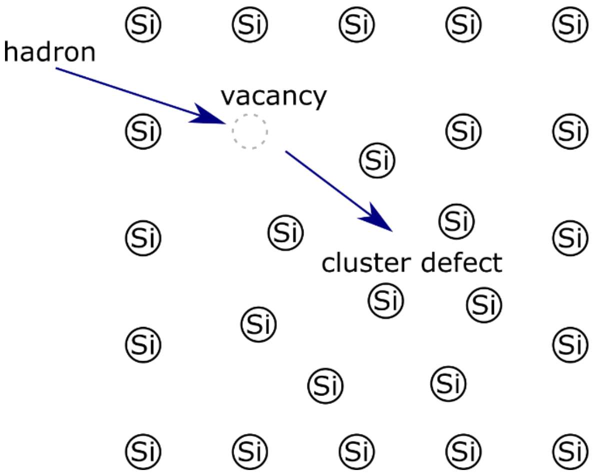
Oxide Charge



Bulk damage



Si
hadron
vacancy
interstitial atom



Si
hadron
vacancy
cluster defect