The Tangerine Project

TowArds Next GEneRation SIlicoN DEtectors

Manuel Alejandro Del Rio Viera on behalf of the Tangerine Project

PIER Detector Workshop

June 1st 2023

HELMHOLTZ UNIVERSITÄT BONN

DESY.

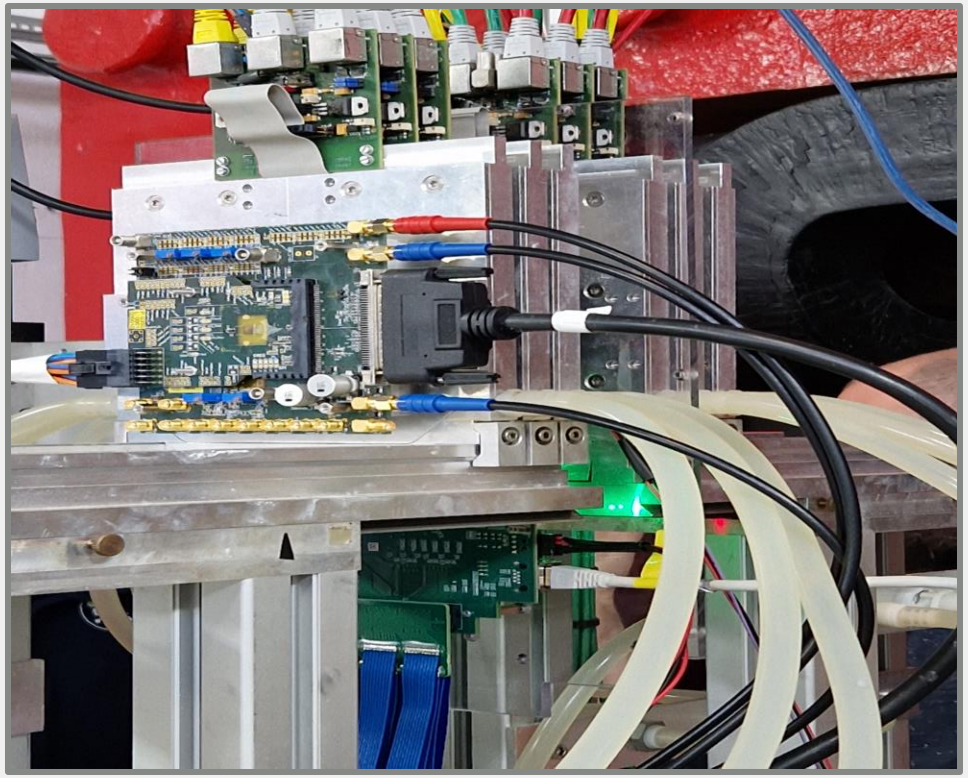
The Tangerine Project

TowArds Next GEneRation SIlicoN DEtectors

Goal: Develop the next generation of monolithic silicon pixel detectors using a 65 nm CMOS imaging process

- **Trackers for future e^+e^- Colliders**
- **Reference detector at DESY-II test beam upgrade**

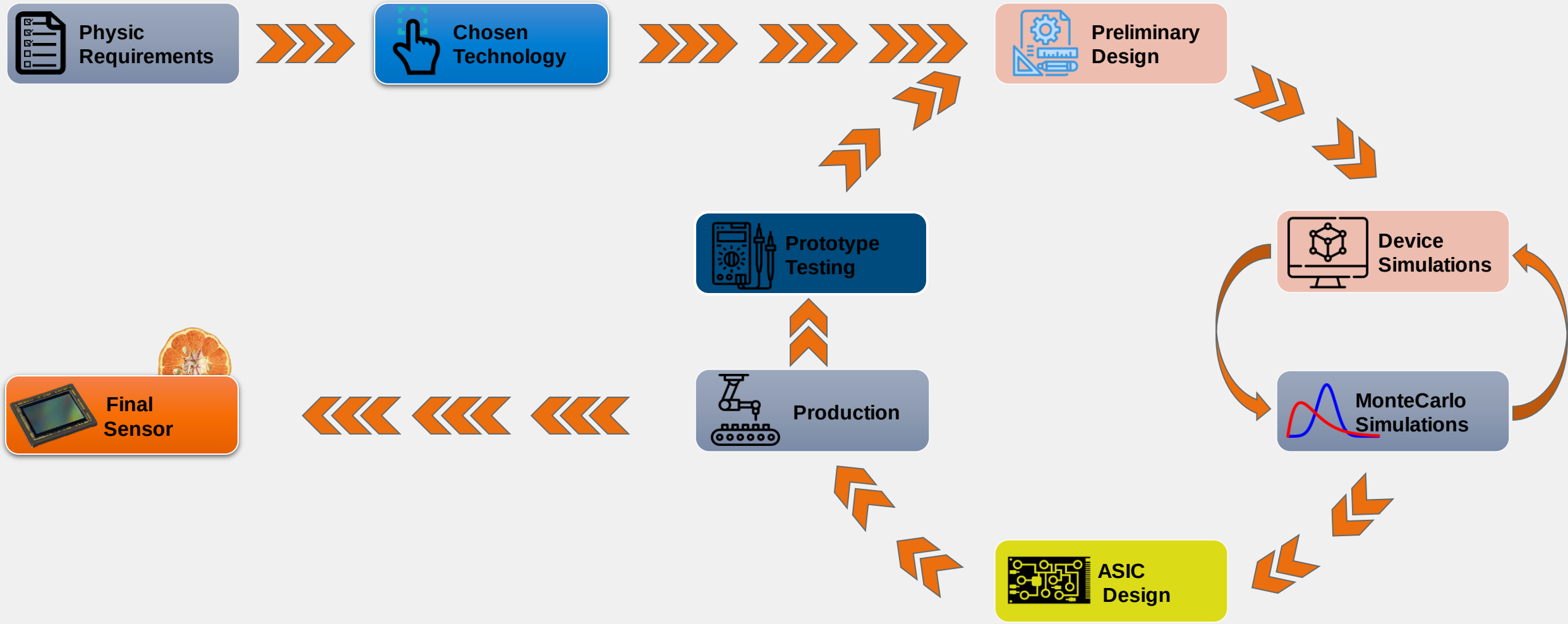
- A Helmholtz Innovation Pool and DESY project
- The project started in 2020
- Part of the **Work Package 1 (WP1):** Monolithic pixel detectors in novel CMOS imaging technology
- Supported by **CERN EP R&D**



MIMOSA Telescope at the DESY II Facility

Our Tangerine Workflow

Involved in all steps of developing a Silicon Detector

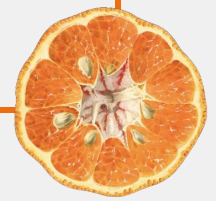


Physic Requirements

in a 65 nm CMOS technology

Tangerine Chip Requirements:

- Material budget **< 0.05% X/X_0 ~ 50 µm silicon**
- Single-point resolution **~ 3µm**
- Time resolution **~ 1-10 ns**
- Rate capabilities: **1 MHz particle rate**
- Granularity **< 25 µm x 25 µm**



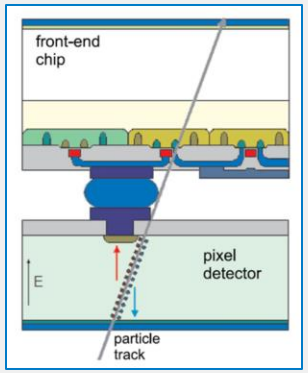
	(HL-) LHC (ATLAS/CMS)	Lepton Colliders
Material budget	10% X_0	< 1% X_0
Single-point resolution	~ 15 µm	≤ 3 µm
Time resolution	25 ns	~ ps – ns
Granularity	50 µm x 50 µm	≤ 25 µm x 25 µm
Radiation tolerance	O(10^{16} n_{eq} / cm^2)	< 10^{11} n_{eq} / cm^2

Simon Spannagel 93rd PRC

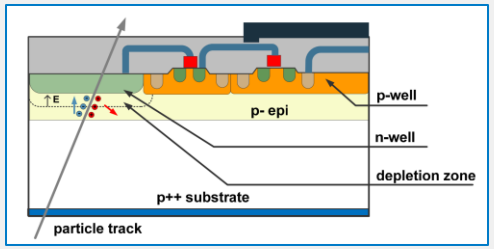
Monolithic Active Pixel Sensors (MAPS)

in a 65 nm CMOS technology

Hybrid



Monolithic

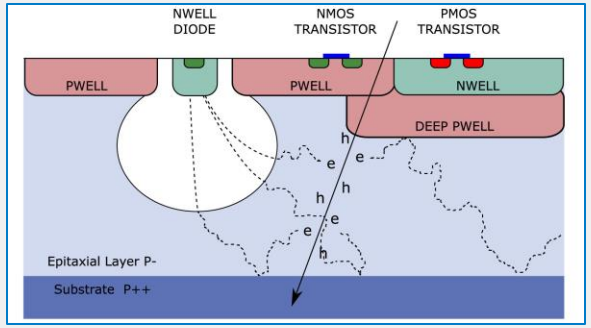


N. Wermes/Univ. of Bonn

From Hybrid to Monolithic

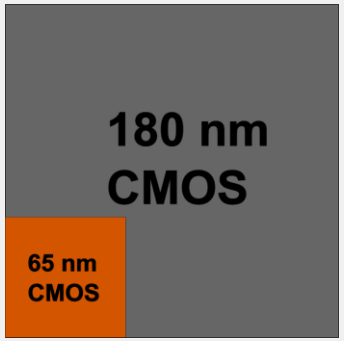
- Reduced material budget
- Reduced complexity
- Reduced production cost
- Smaller pixels

ALPIDE ALICE ITS Upgrade



Small Collection Electrode

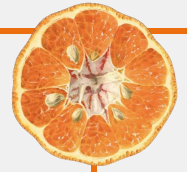
- Reduce noise and power consumption (~40 mW/cm^2)
- Better spatial resolution ~ 5 µm



180 nm to 65 nm

- Higher logic density
  - ✓ Smaller pixels
  - ✓ Better in pixel functionality
- Further decrease in power consumption

Device Simulations

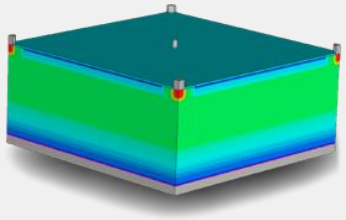


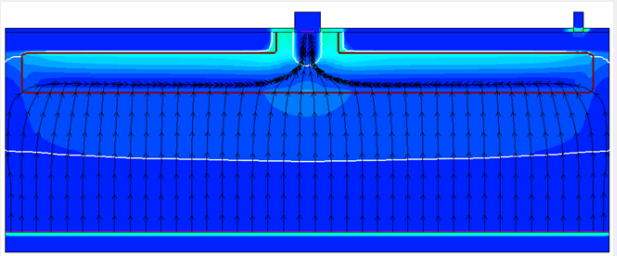
Simulations provide important insight into performance parameters of the sensor.

- **Standard layout**:
  - Small depleted volume
    - Collection by drift and diffusion
      - Lower efficiency but better spatial resolution due to charge sharing

- **N-blanket layout**:
  - Larger depleted region
    - Collection mostly by drift
      - Higher efficiency

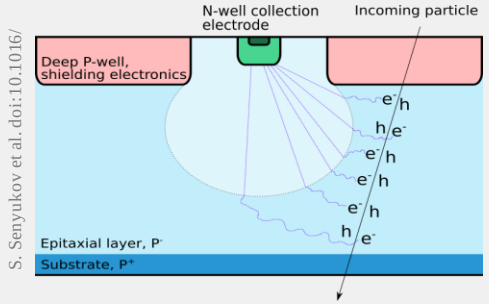
- **N-gap layout:**
  - Lateral component of electric field
    - Even better efficiency and collection time





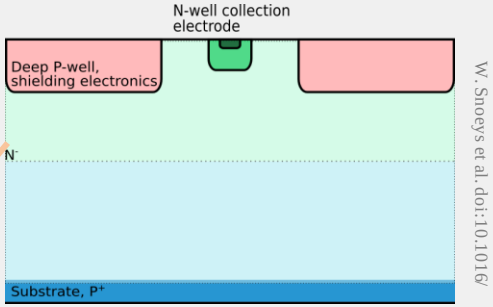
Monolithic Active Pixel Sensors (MAPS)

Standard



Small Collection Electrode

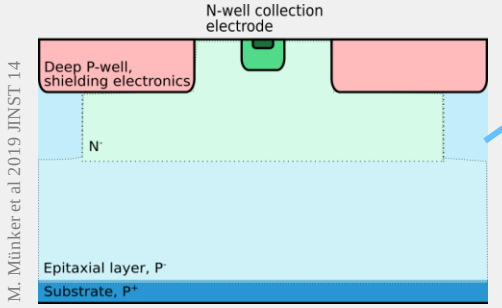
N-Blanket



Continuous N-type Implant

Increase the depleted region

N-Gap



Gap in Continuous N-type Implant

Speed up charge collection

Monte Carlo Simulations

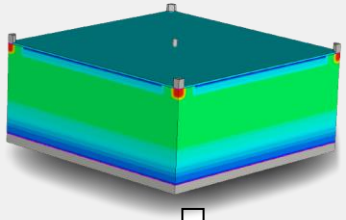
Transient Simulations - Full Detector Response

The **static** Electric Field, Doping Concentration and Electrostatic Potential Profiles are converted and imported into **Allpix Squared (APSQ):**

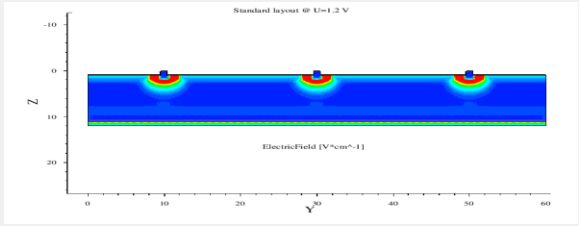
- **Combining the best of both :** **High statistics** and **accurate field modeling**
- **Same conditions** as lab and test beam setup are simulated
- Simulation results are **compared with measurements** of prototypes

SYNOPSYS®

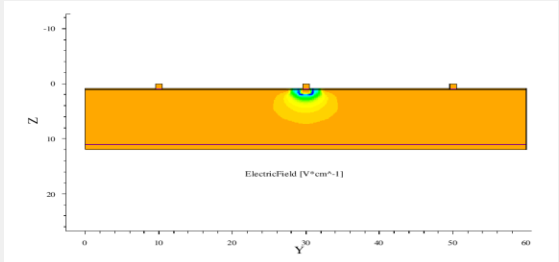
Generic Doping Profiles

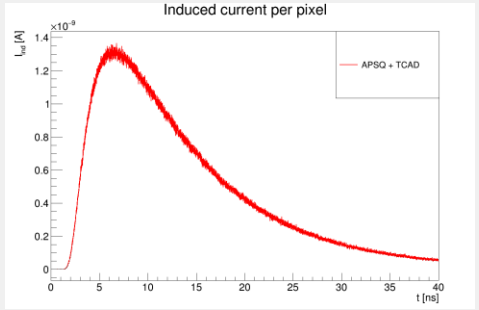


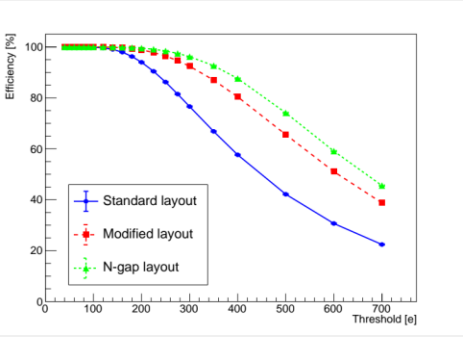
Electric Field



Weighting Potential



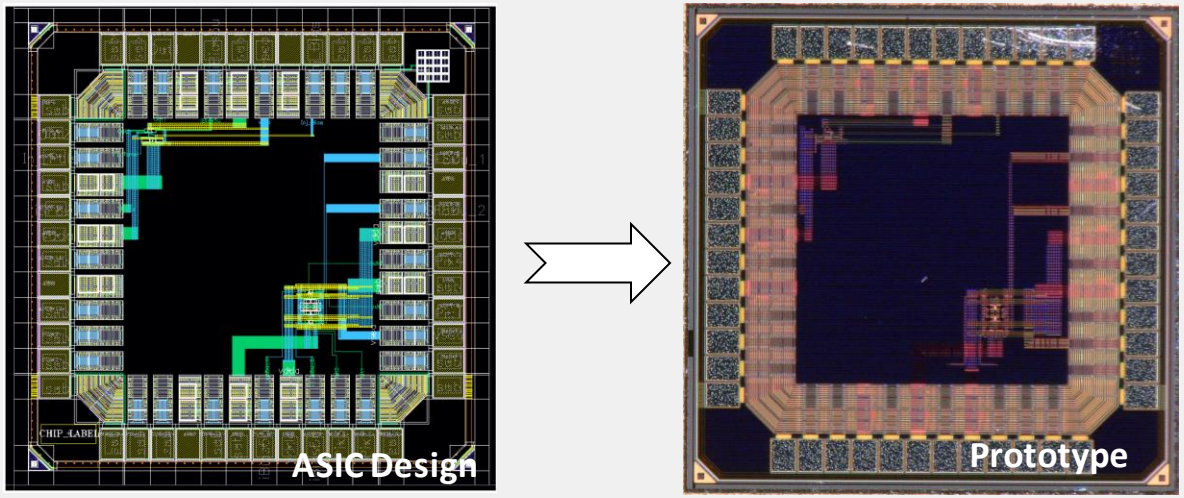




ap² allpix squared

First Prototype

Multi-Layer Reticle 1 (MLR1) production

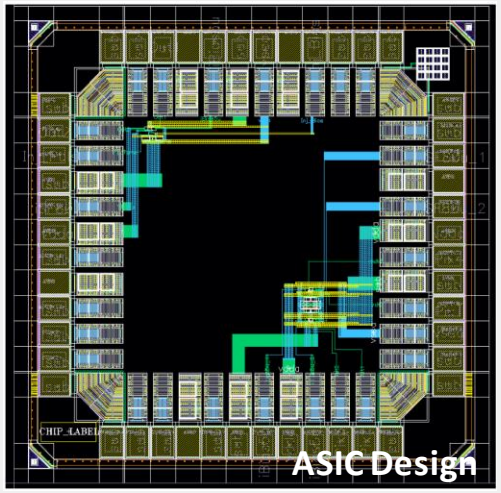


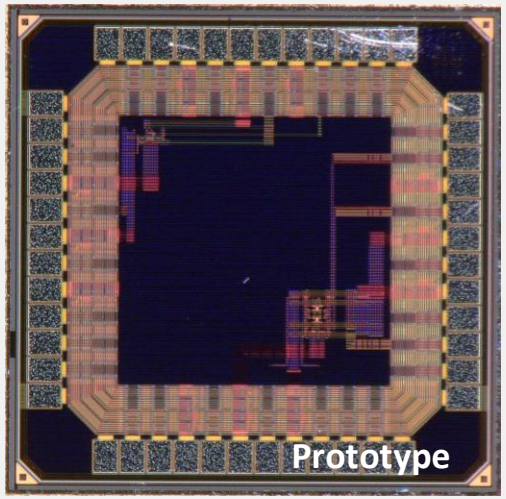
DESY MLR1:

- Entirely developed at DESY
- Test structures for Charge Sensitive Amplifier (CSA) characterization developed at DESY
- Block of 2x2 16 µm pixels with an analogue readout for pixel characterization

Second sensor under study

Multi-Layer Reticle 1 (MLR1) production





DESY MLR1:

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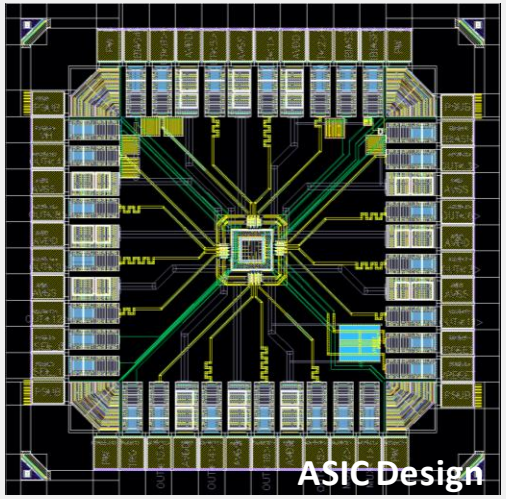
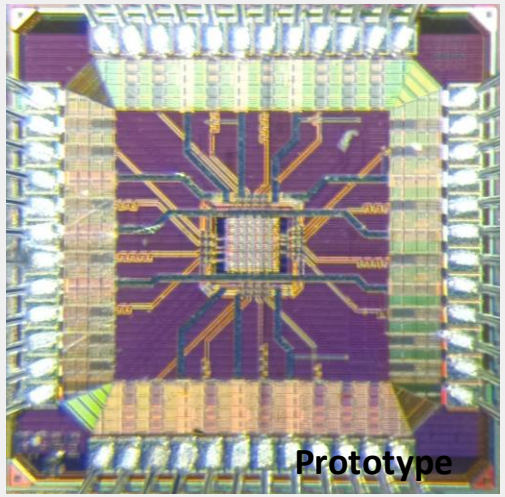
Analogue Pixel Test Structures (APTS)



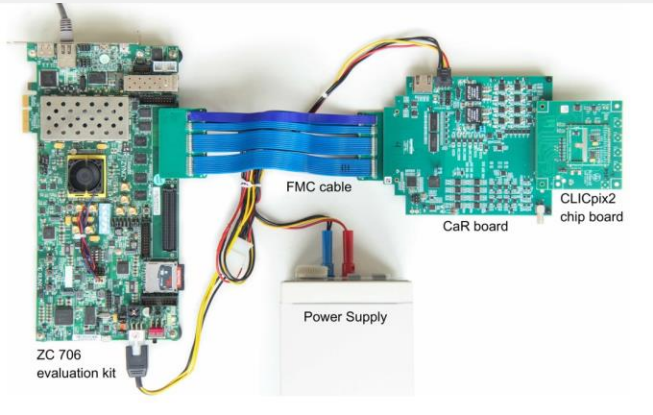


Analogue Pixel Test Structures (APTS):

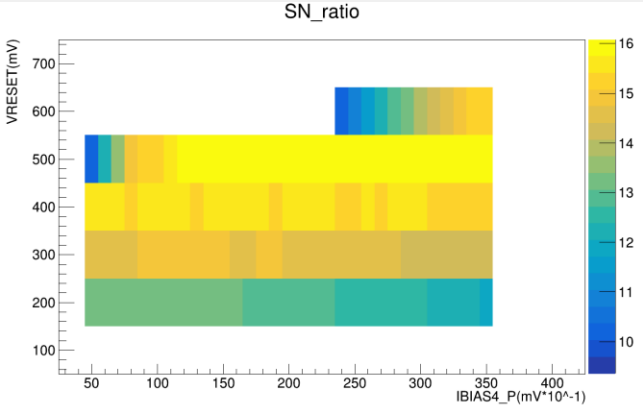
- Designed at CERN (DESY involved in the lab and TB characterization)
- 4x4 pixels structure with analogue output
- Different sensor pitches and layouts

Laboratory Activities

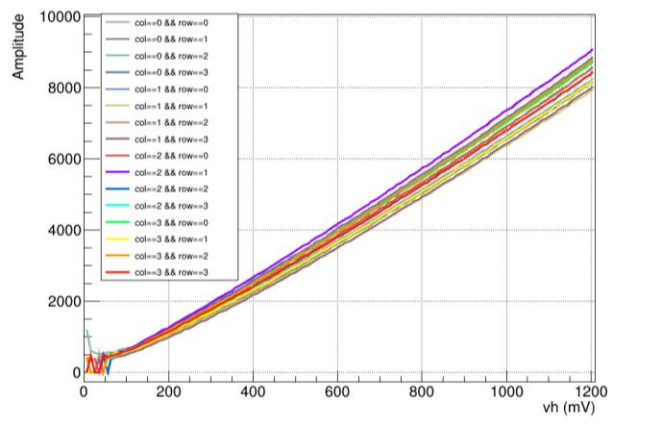
DAQ development, TB preparation, Calibration



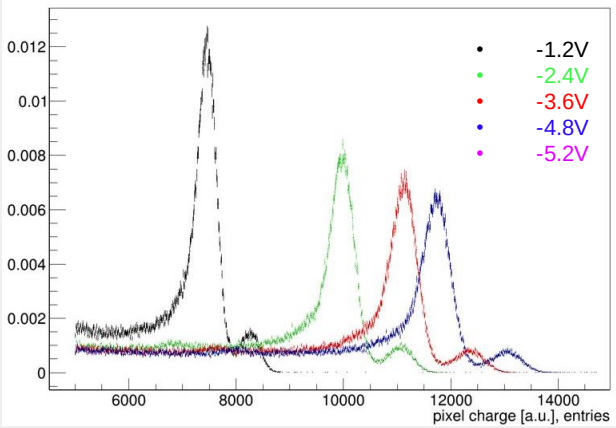
Caribou DAQ System



Example of parameters scan



Charge injection study

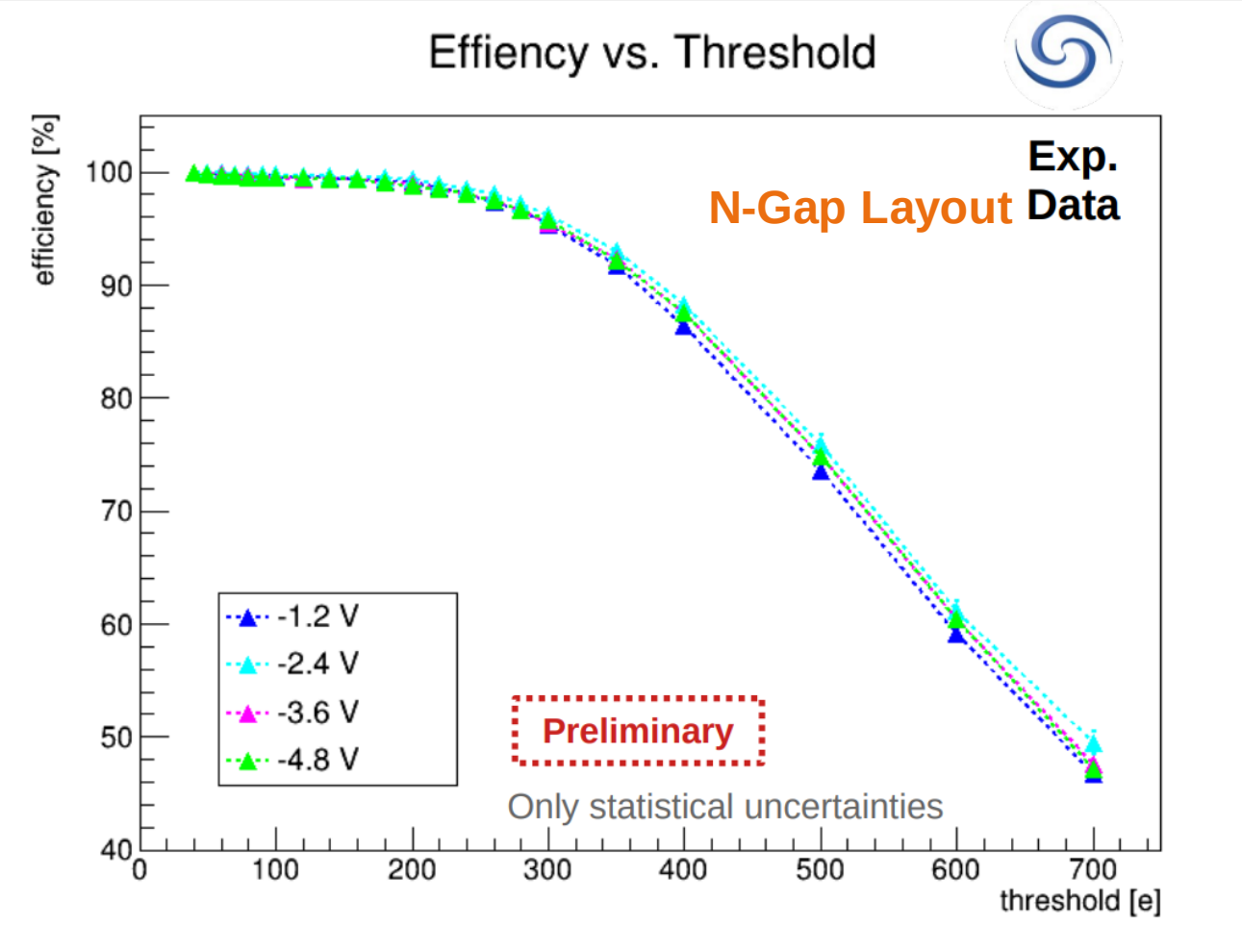


Fe-55 studies on APTS

- Development and testing of **data acquisition system**
- Optimization of front-end **operation parameters**
- Studies with charge injection and radioactive sources for **gain calibration**
- **Integration and testing** in preparation for Test Beam campaigns

Test Beam Results

N-Gap Layout



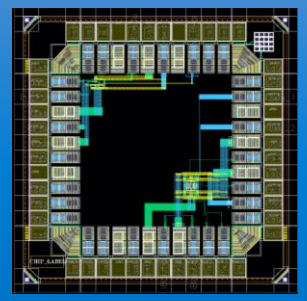
@Adriana Simancas

- ✓ No significant impact between voltages
- ✓ Similar trend between different voltages
- ✓ Valuable set of measurements to validate our simulations

Timeline and next to come

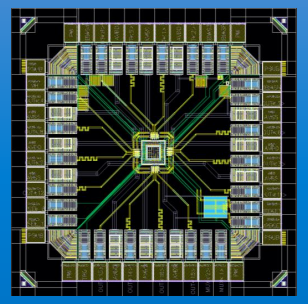
From MLR1 to ER1

MLR1 reticle



DESY Chip V1

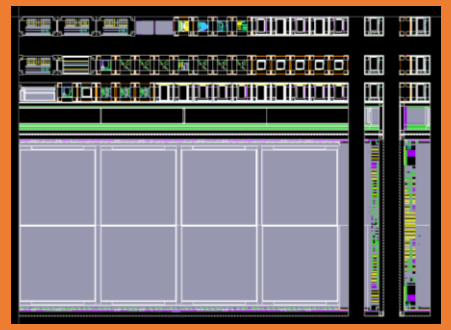
2021



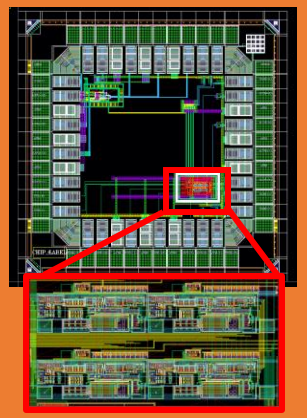
APTS

2022

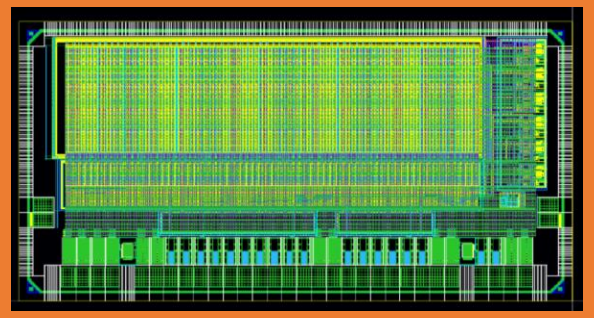
Engineering Run 1 (ER1) in Production



ER1 reticle



DESY Chip V2



H2M Chip

2023

DESY Chip V2

- 2x2 pixel (35x25 µm^2) with all-in-pixel functionality
- External access to CSA and discriminator output
- N-gap layout with 2.5 µm and 4 µm gap
- Single Front-End with charge Injection

H2M (Hybrid-To-Monolithic)

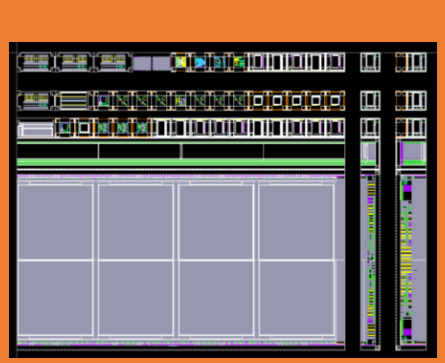
- Collaboration of DESY, CERN and IFAE
- 3 x 1.5 mm^2 , 64 x 16 square pixel, 35 µm pitch
- 8-bit counter per pixel
- 4 acquisition modes (ToA, ToT, counting, binary RO)

Conclusions

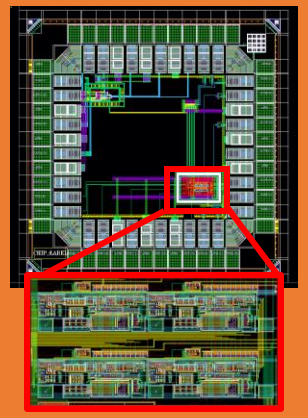
Go Tangerine!

- The Tangerine group investigates the **65 nm CMOS imaging** technology
- **Upgrading our DESY II MIMOSA Telescope** is the primary goal of the project
- We are involved in **all stages of development and testing** of the prototypes
- Device and Monte Carlo simulations reduce **production iterations** (and costs)
- Simulation results are **compared with data** from TB and laboratory measurements
- The **next prototypes** are expected at DESY in Summer-Fall 2023

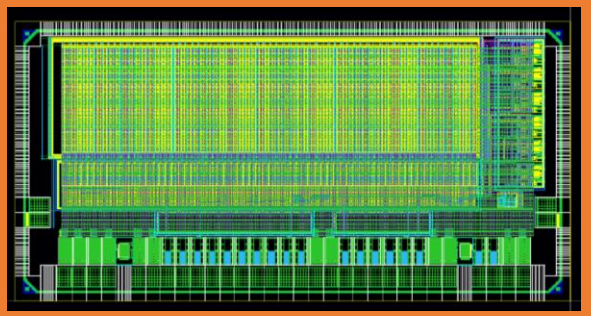
Coming in Q2-Q3 2023



ER1 reticle



DESY Chip V2



H2M Chip

2023

Thank you for your time!

Contact

Manuel Alejandro Del Rio Viera
manuel.del.rio.viera@desy.de

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DESY.