Overview on the Tangerine MLR1 Chip

First 65nm CMOS Pixel Detector developed at DESY

Gianpiero Vignola & Tangerine group
Hamburg, 02 Mar 2022

HELMHOLTZ

DESY.

Tangerine MLR1 Timeline

2020 - to date

Start
Founding Procedure and Design started
1st half of 2020

Tangerine Born
The project begins
September 2020

MLR1 Submission
Chip sent to the factory
December 2020

MLR1 at CERN
Wafer with many prototypes
June 2021

MLR1 Chip at DESY
Several samples bonded for testing
October 2021

DESY Test Beam
DESY II, few events
18 Oct - 01 Nov 2021

CERN Test Beam
At SPS, few events
10 Nov - 15 Nov 2021

MAINZ Test Beam
At MAMI, 500k events
02 Dec - 06 Dec 2021

Fe55 Studies

Data analysis
Root and Corryvreckan
Oct 2021 - to date

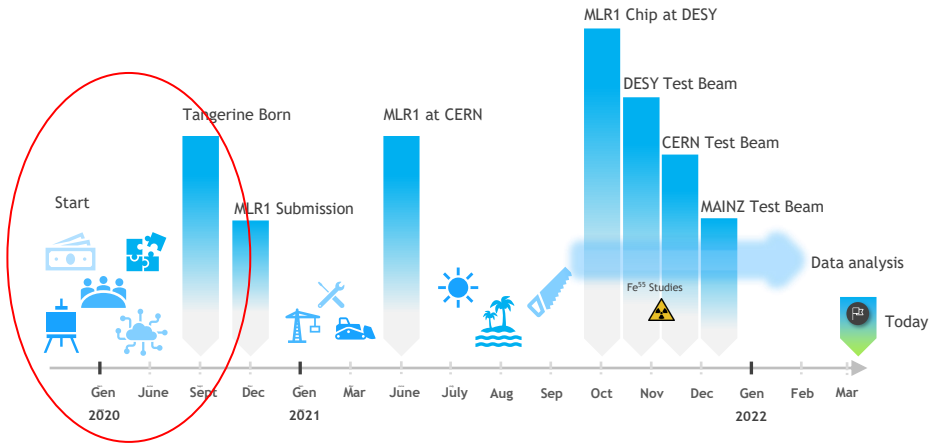
Today
Presentation
02 Mar 2022

Gen 2020 | June | Sept | Dec | Gen 2021 | Mar | June | July | Aug | Sep | Oct | Nov | Dec | Gen 2022 | Feb | Mar

Tangerine Project overview

First half of 2020

- **Goal**: Design a monolithic pixel detector in 65nm CMOS imaging technology
  - **Main application**: beam telescope
  - **Potential applications**: linear collider experiments, etc.
- Requirements:
  - **Position resolution**: ~ 3µm
  - **Rate capabilities**: 1 MHz particle rate
  - **Time resolution**: ~ 1-10 ns
  - **Low material budget**: < 0.05% X/X_0
  - **Energy measurement** via ToT
- Founded By InnoPool & DESY
- Tangerine project start in Sep. 2020

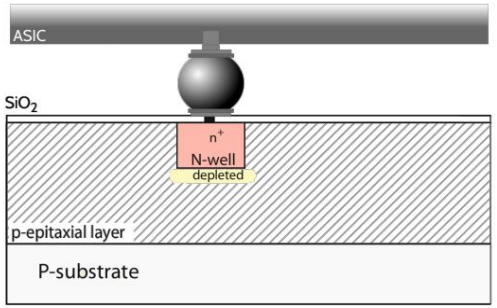


Why Monolitic Active Pixel Sensor?

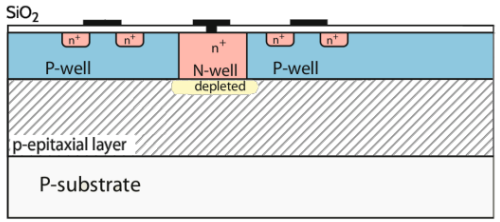
In 65 nm CMOS imaging process

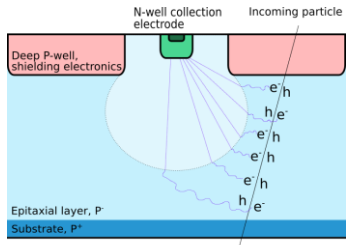
- Reduce: Material budjet, Production cost & Complexity
- Recent improvements thanks ALICE ITS:
  - Small collection electrode (reduce noise and power consumprion order ~ 40 mW cm^{-2})
  - Spatial resolution ~ 5 µm
  - 180 nm CMOS process
- 65 nm process allow:
  - Higher logic density → small pixel pitch and/or increase in-pixel functionality
  - further decrease in power consumption
- Three processes available for the sensitive volume design: Standard, Modified, Modified with N-gap

Hybrid sensor sketch

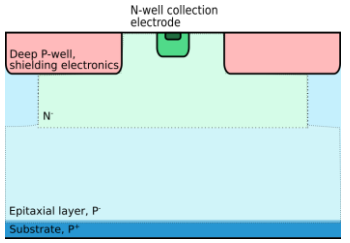


Monolithic sensor sketch

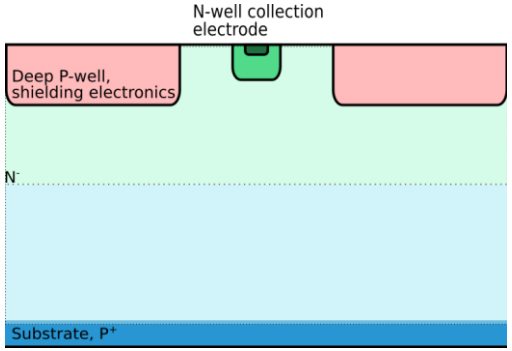




Standard ALPIDE-like



Modified with N-gap



Modified (MLR1)

@ H. Wennlöf

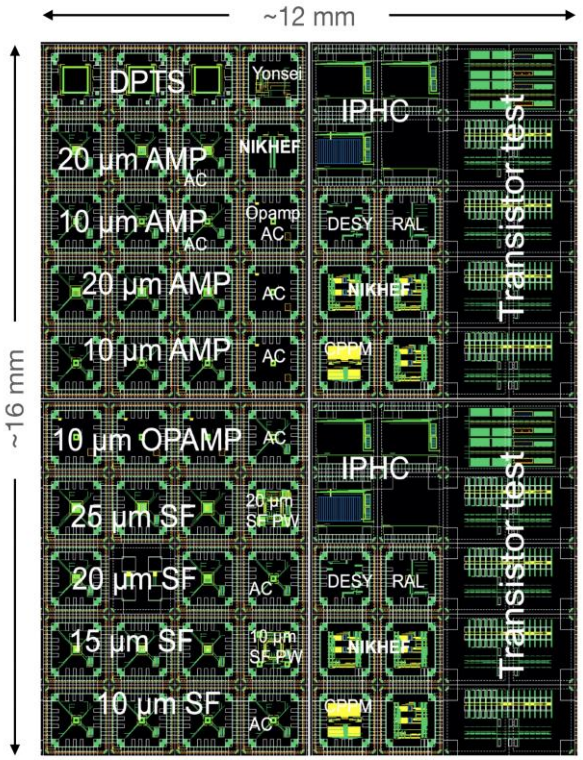
MLR1 production

Second half of 2020, first half of 2021

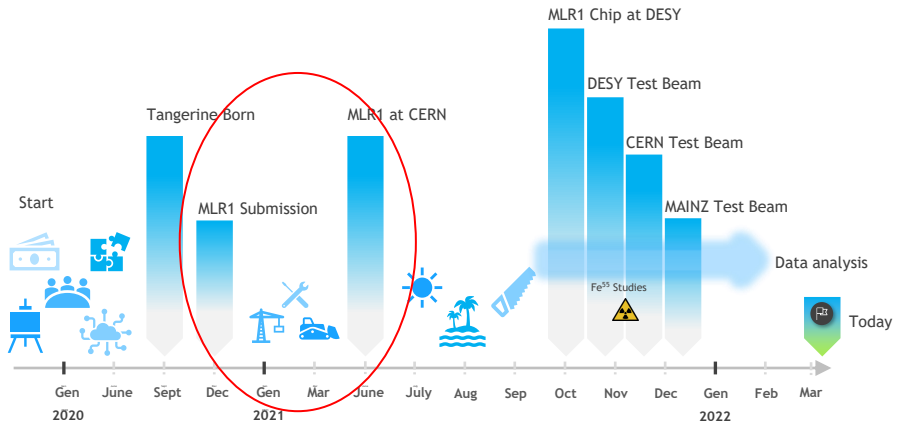
- Multi Layer Reticle 1 divided up into “sites” of 1410x1410 µm for different test chips shared between DESY, CERN, RAL, Nikhef, etc.

- TJ 65nm ISC Process limitations in MLR1:
  - Only 3+1 metal layer
  - 10µm epitaxial layer

- MLR1 timetable:
  - Design submitted 01-Dec-2020
  - GDS files approved 15-Dec-2020
  - MLR1 at CERN June 2021



expect O(500) dies per wafer



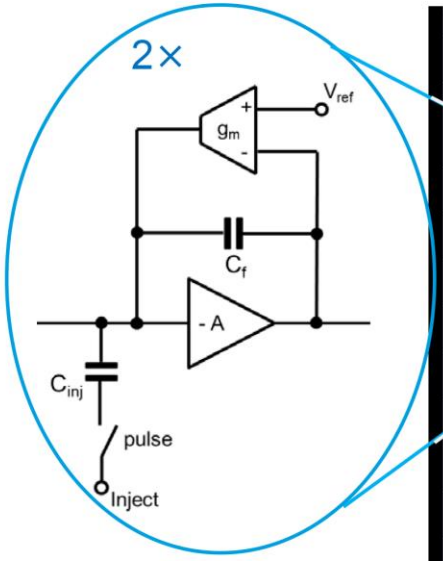
Tangerine MLR1 Chip Details

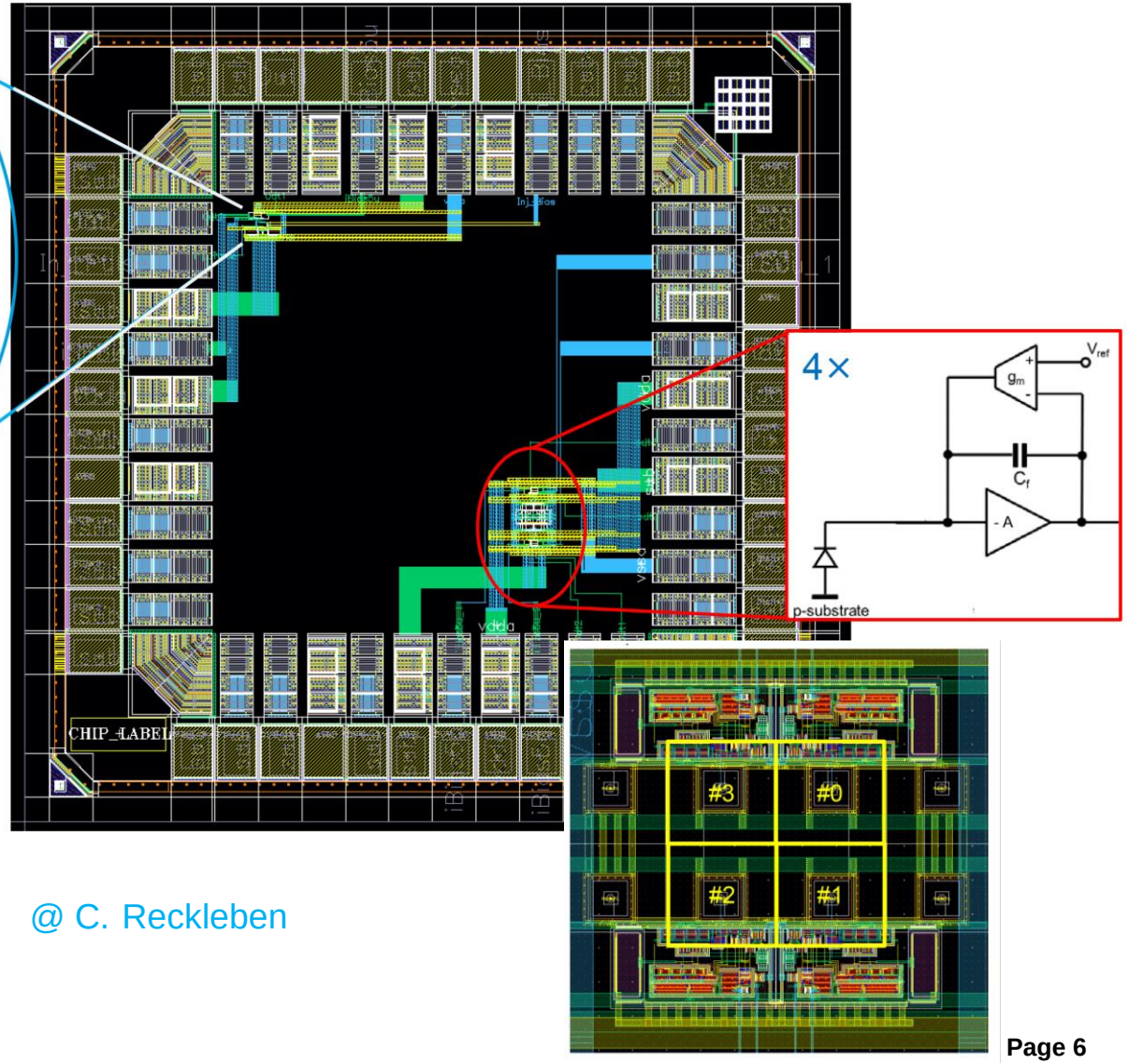
Become familiar with the 65 nm process

2 CSAs with different gains

a) feedback cap 1.5fF → 107µV/e
b) feedback cap 2.0fF → 80 µV/e-

- Use Charge injection as stimulus
- No Pixel diode
- **Aim**: Evaluation of CSA performance





@ C. Reckleben

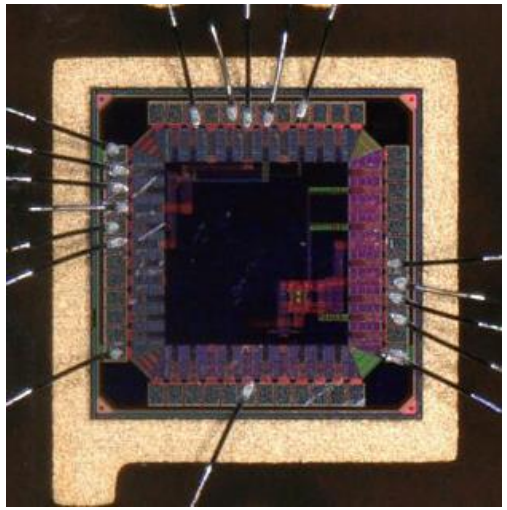
Block of 2x2 pixel with CSA

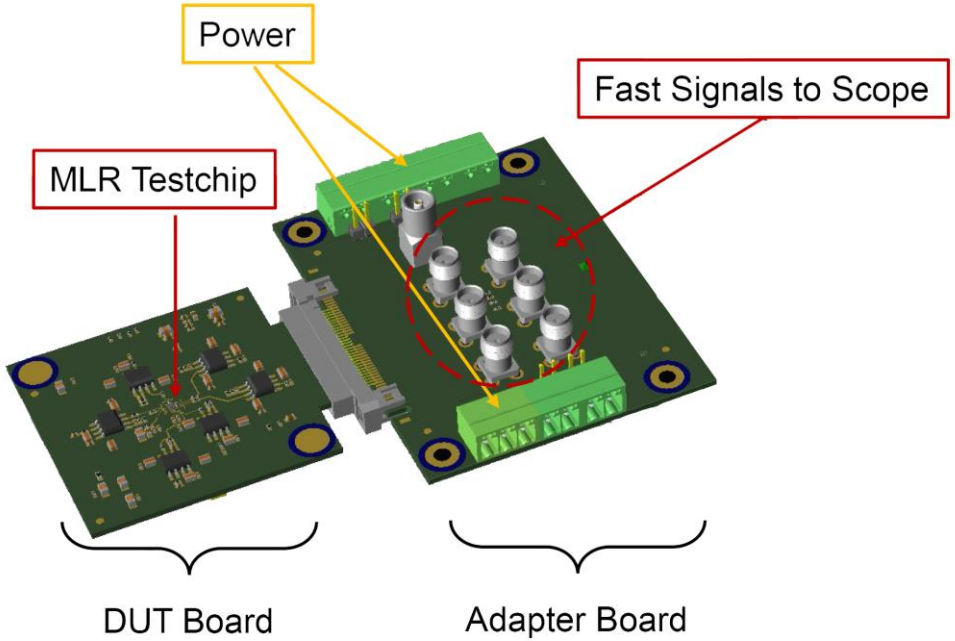
- **Gain**: 80 µV/e- , Cf = 2fF (typ)
- **Sensing node**: nwell hexagon 1.2µm diameter
- **Pitch**: 16 µm
- **outputs**: 4 analog read-out
- **Aim**: Pixel characterization

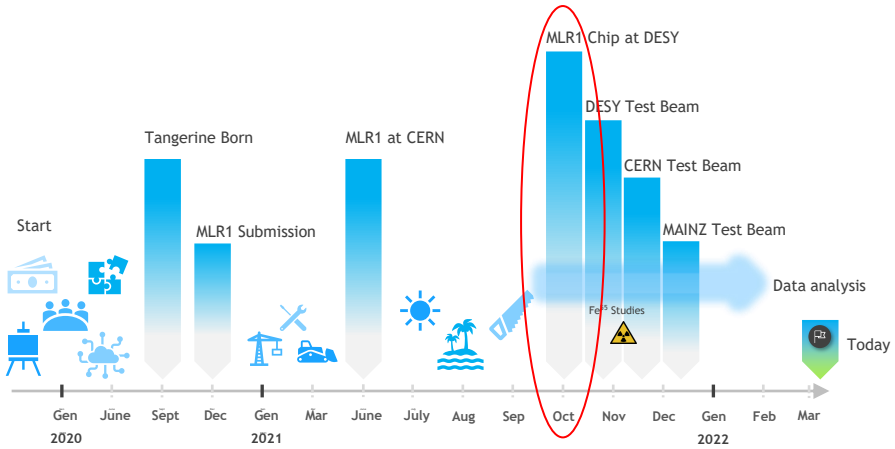
Tangerine MLR1 Chip at DESY

October 2021

- MLR1 Chip arrived at DESY in early October
- different samples, same structure with slightly different doping profiles (details not known)
- In the meantime, the Tangerine group has grown
- Chip glued and bonded on DUT board (designed and ready at DESY)
- ASIC designers carry out the first tests on CSAs comparing them with simulations Evaluation of: Gain, Delay, Rise Time, Falling edge
- First waveforms obtained with Fe^{55} source

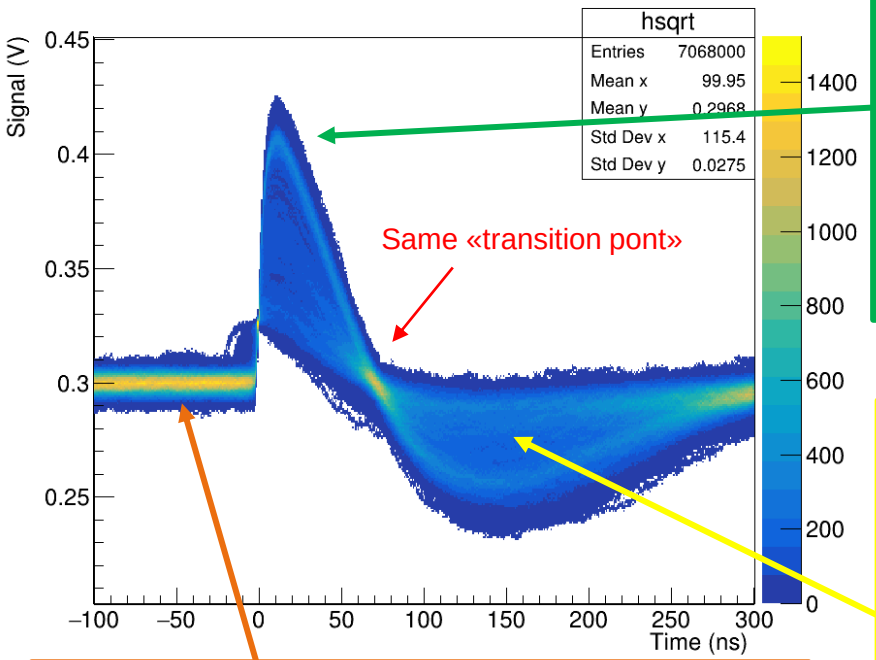


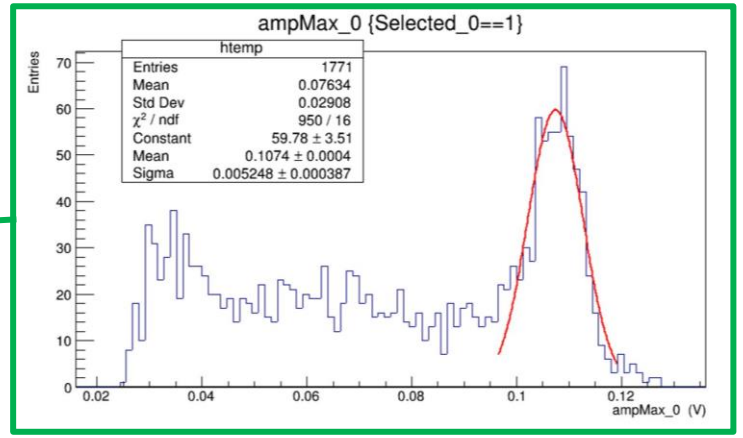


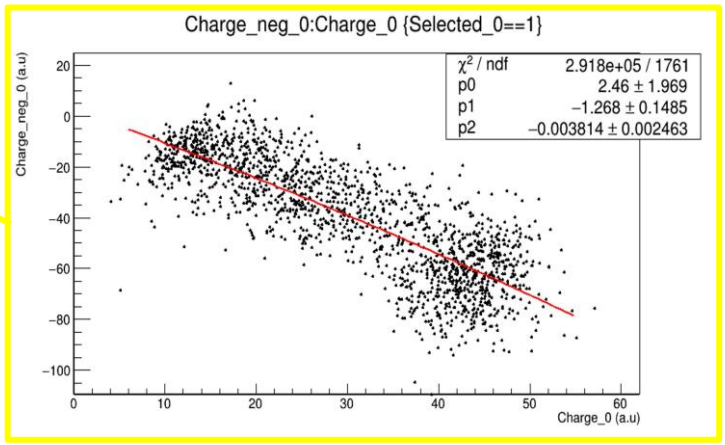


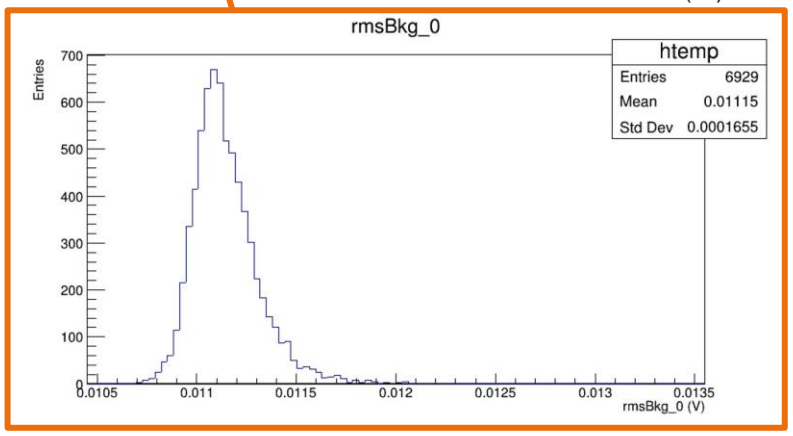
Fe^{55} source studies

October-November 2021









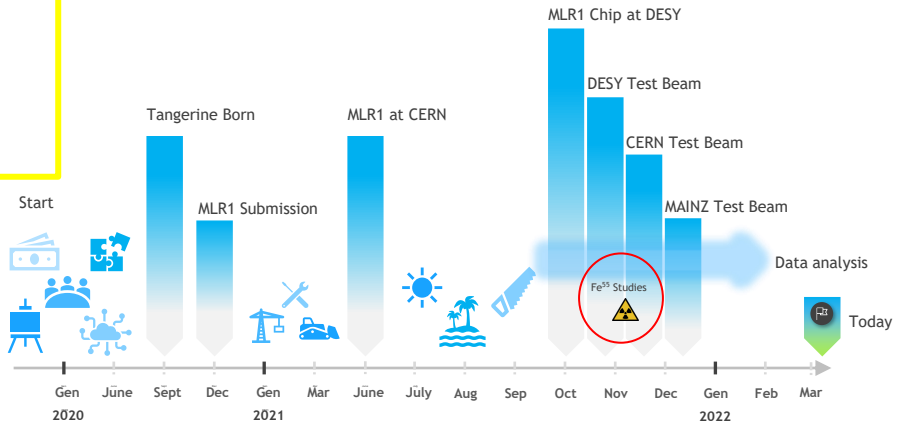
Example reported:

- Sample ID: 4 pixel 0
- Exposure time: ~ 1 night
- # Trigger: 6929 (all 4 channels)
- Thresholds: 20 mV over noise

Signal amplitude Expected:

(@ Christian Reckleben)

- K_α: 5.8 keV → ~ 1590 e-
- @ Cf = 2fF ±10% → ~ 127 mV
- Gain 1.33 → ~ 168 mV ±10%



DESY Test Beam

18 Oct – 01 Nov 2021

Setup / Data taking

- Oscilloscope based Read-out of 4 pixels
- Few event per hour expected
- Two data taking used

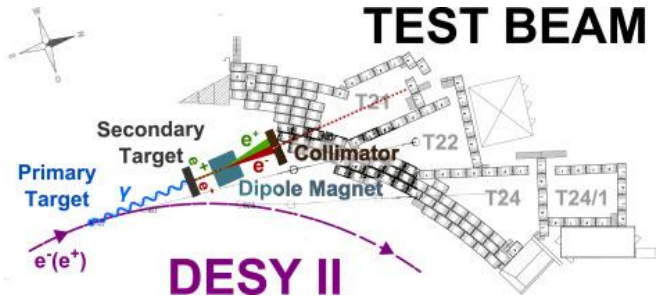
Veto Scintillator Mode

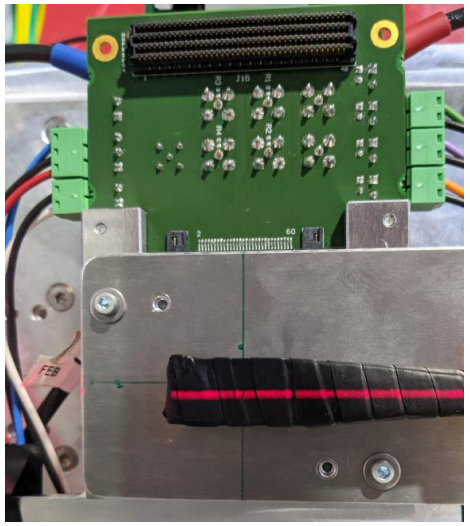
- 3 scintillator used (one with hole) combined with NIM logic
- Trigger rate few Hz (>99% of junk data)
- Efficiency studies possible

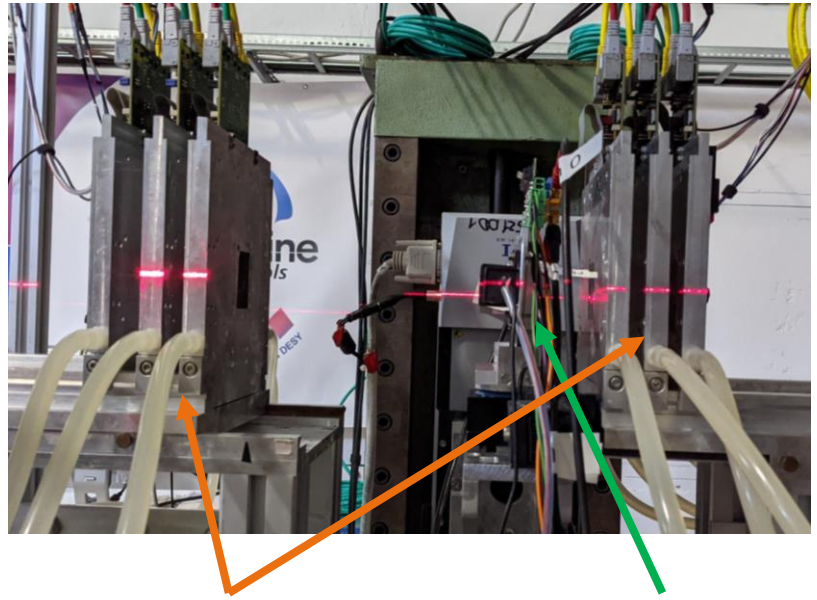
Scope used to trigger the telescope

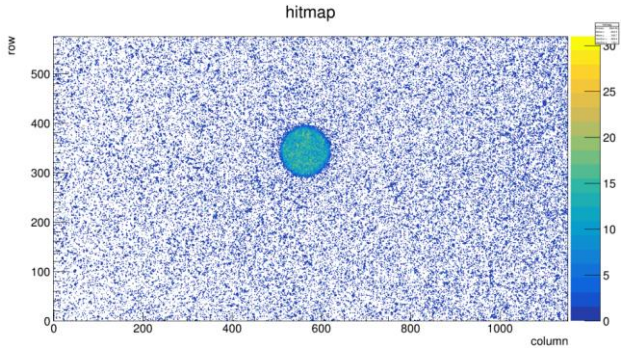
- Scope trigger delay not relevant for mimosa
- Event rate 1 event every 5-15 minutes

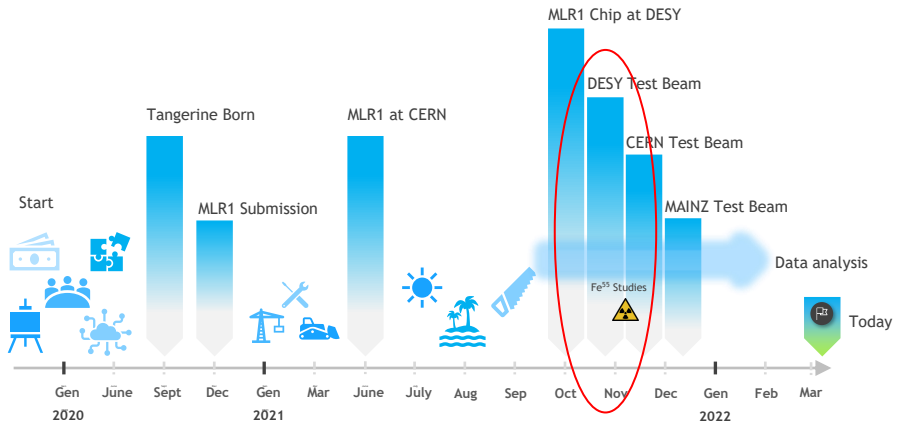
@ L. Huth







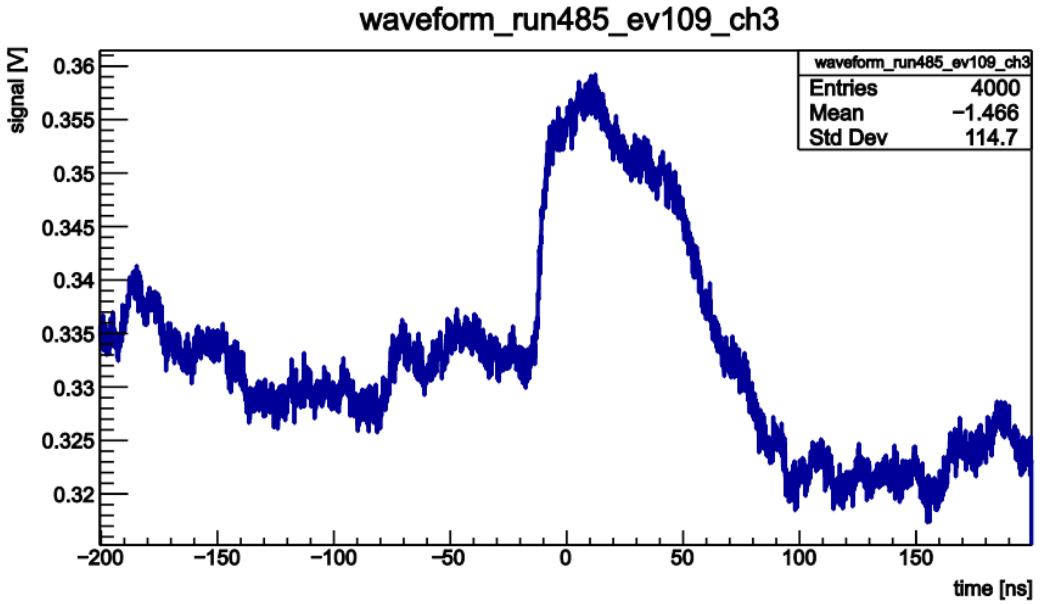


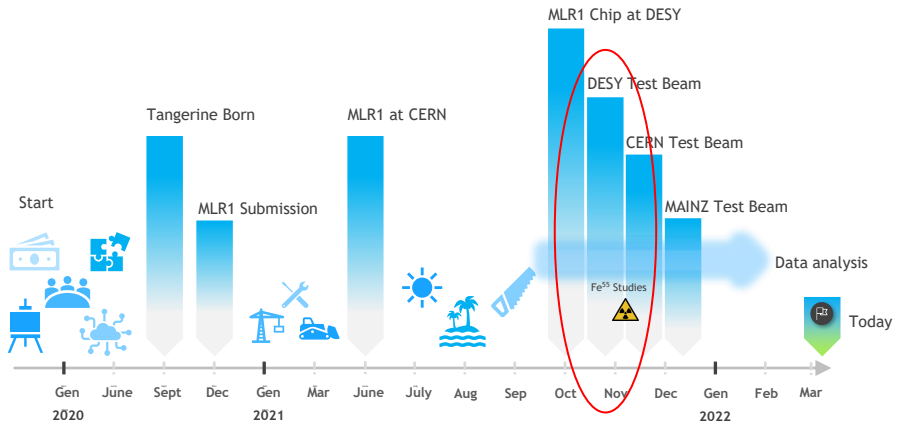


DESY Test Beam: Results

18 Oct – 01 Nov 2021

- Most populated run in 2 weeks: **110 events**
- only low statistic preliminary results:
  - MIP response order of 50 mV
  - Rise time 5-10 ns
  - Slew rate on the order of mV/ns
  - Noise fluctuations
- Main outcomes:
  - gained confidence with the Chip
  - **rate too low at DESY Facility**





@ F. Feindt

CERN Test Beam

SPS 10 – 15 Nov 2021

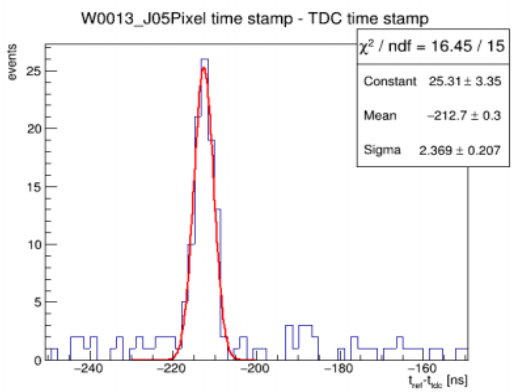
Setup / Data taking

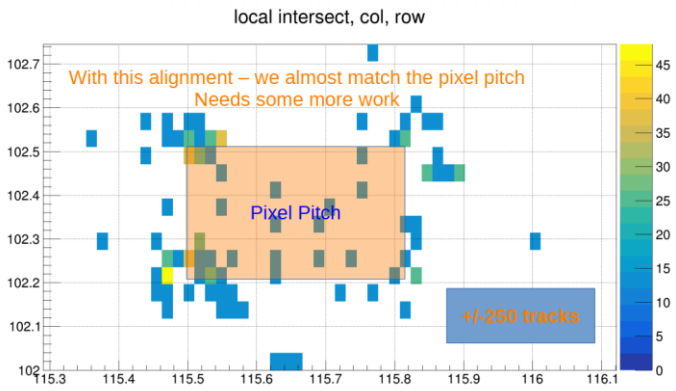
- Oscilloscope based readout
- Timepix3 reference telescopes
- Trigger as input to SPIDR DAQ + offline sync
- 120 Gev pions, High intensity 1e6 per spill

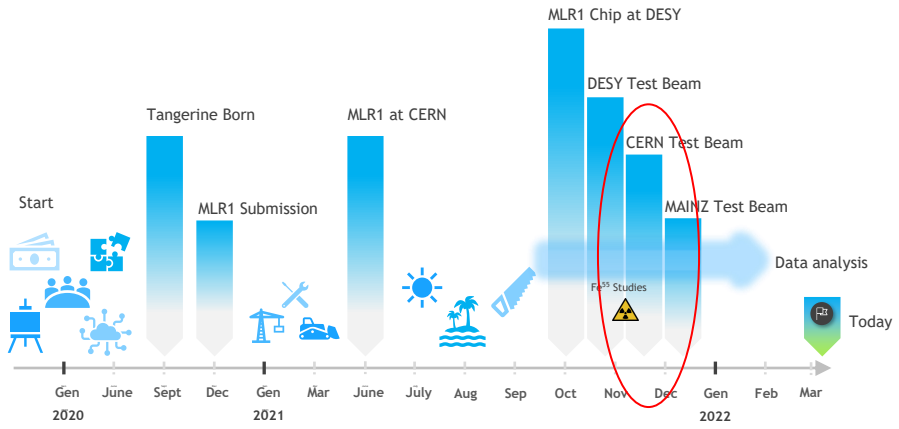
Results

- Scope trigger correlate nicely in time → time resolution ~ **2.4 ns**
- Thanks to the excellent spatial resolution of the telescope, the pixel structure is recognizable
- Also in this case few events for hour, **event rate extremely lower than expected**!

@ L. Huth & A. Simancas







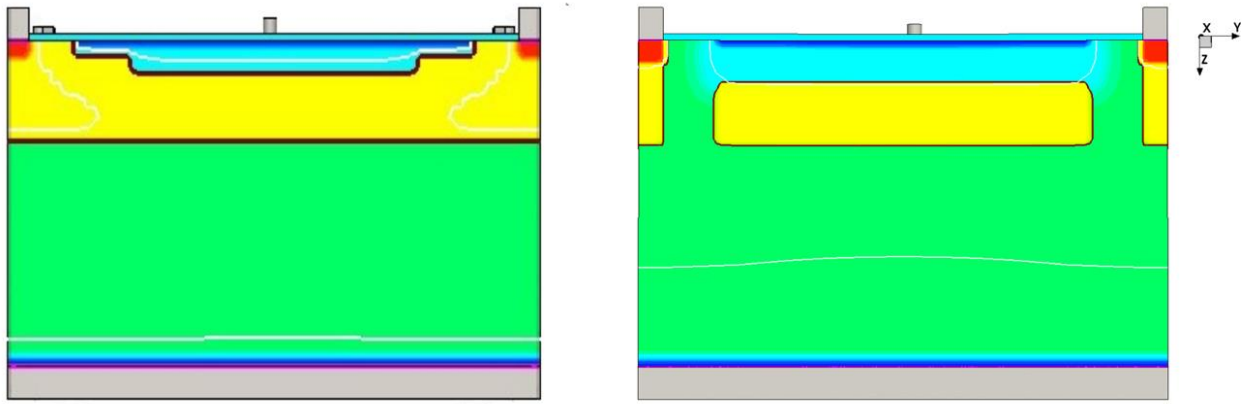
MLR1 Real Chip

Explanation for the low efficiency of the chip

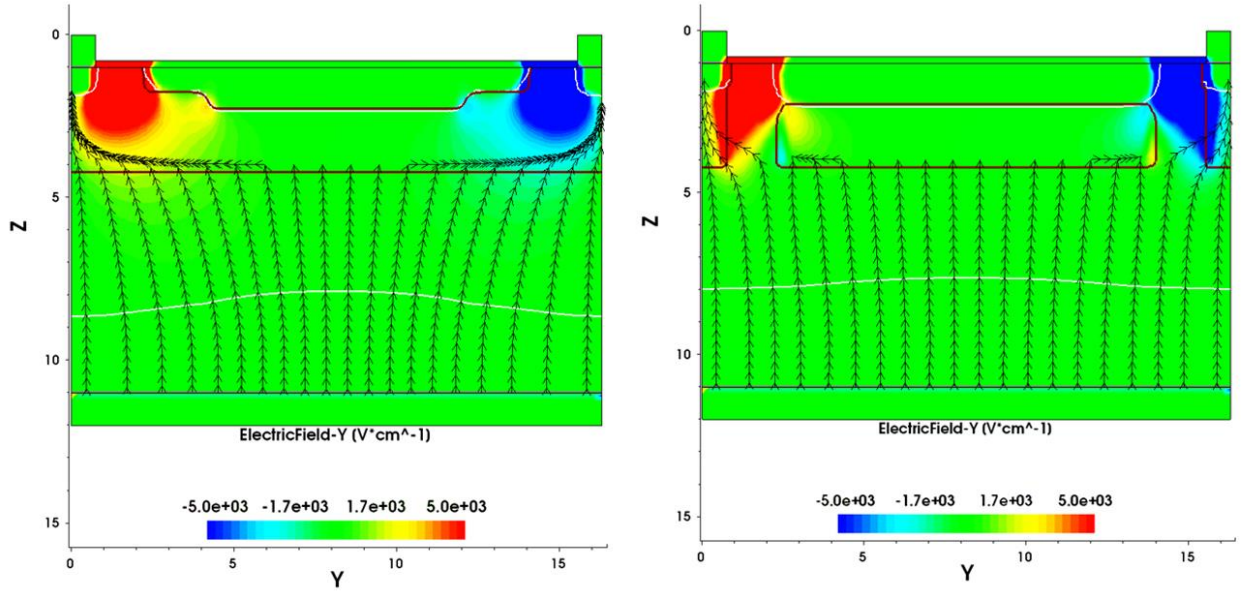
- The very low rate at DESY and CERN prompted an in-depth analysis of the MLR1 chip
- After Interactions with CERN people involved in MLR1 production, a sensor layout issue in DESY MLR1 Chip was found
- TCAD simulations confirmed that the chip cannot perform as expected
- The **expected efficiency is now ~ 0.5%**
- The observed rates now make sense but there was not enough beam time to collect sufficient statistics

@ A. Simancas

Doping Concentration



Lateral Electric Field

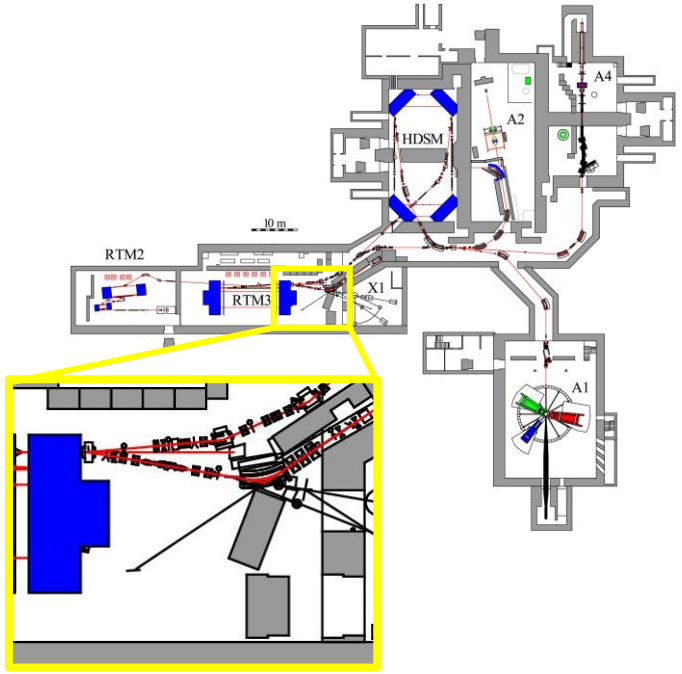


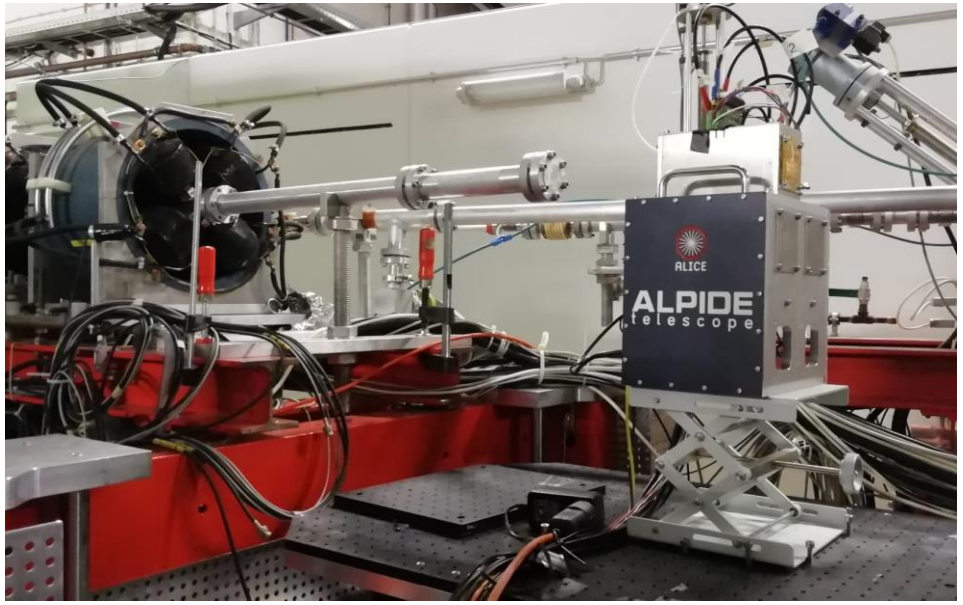
Expected MLR1 Pixel **Real MLR1 Pixel**

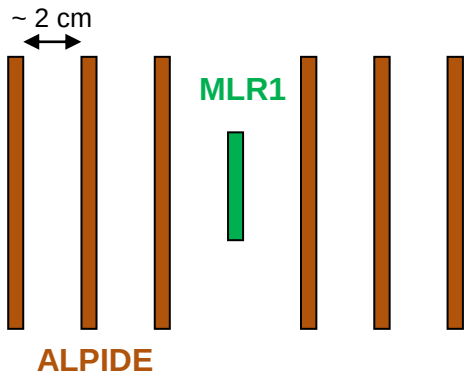
Mainz Test Beam

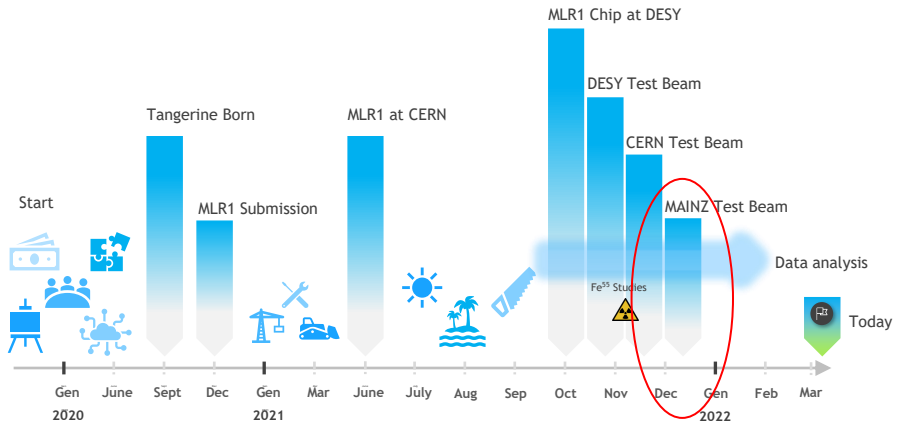
MAMI Microtron 02 – 06 Dec 2021

- Electron energy: 855 MeV
- Beam Imax: ~ 100 µA
- Beam size: ~ 1mm^2
- Trigger: provided by MLR1 (scope)
- Tigger rate: Few Hz
- Recorded events: > 500k





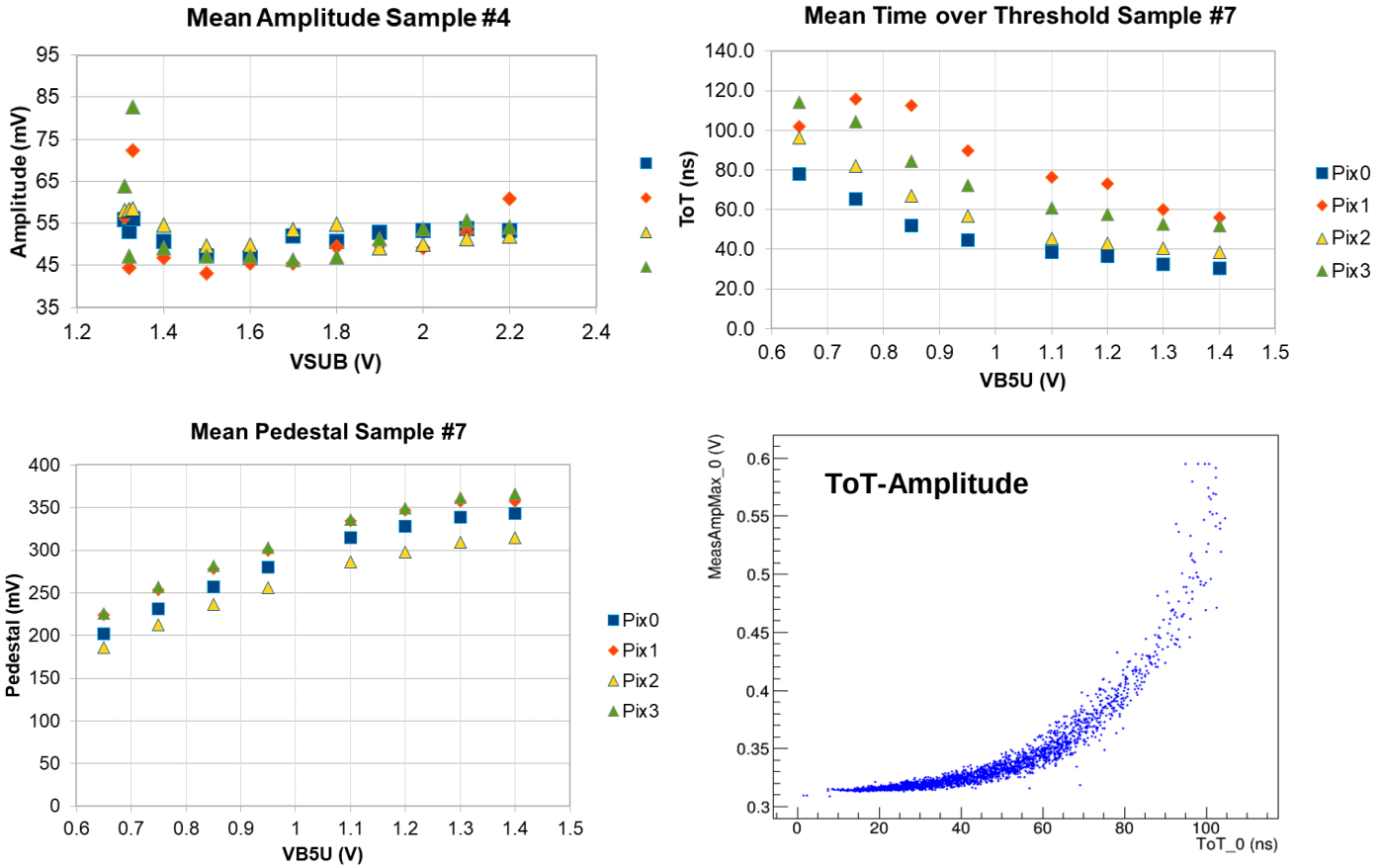


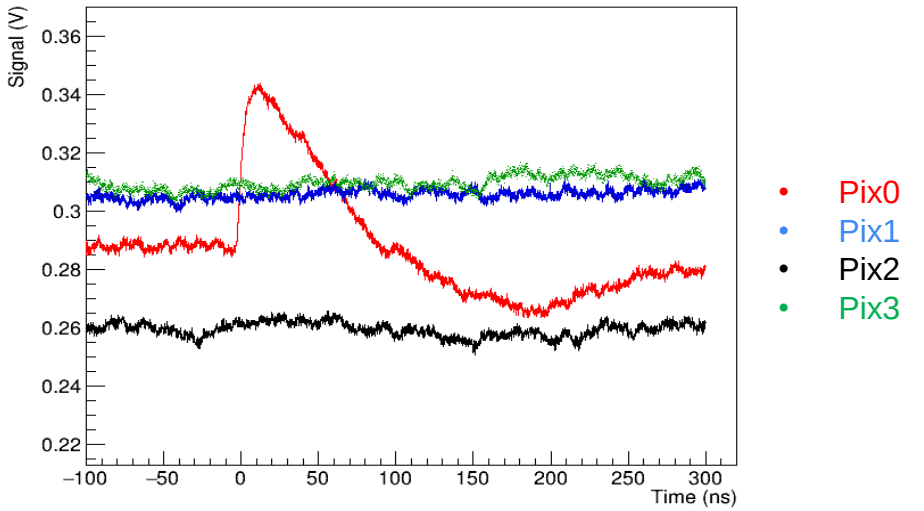


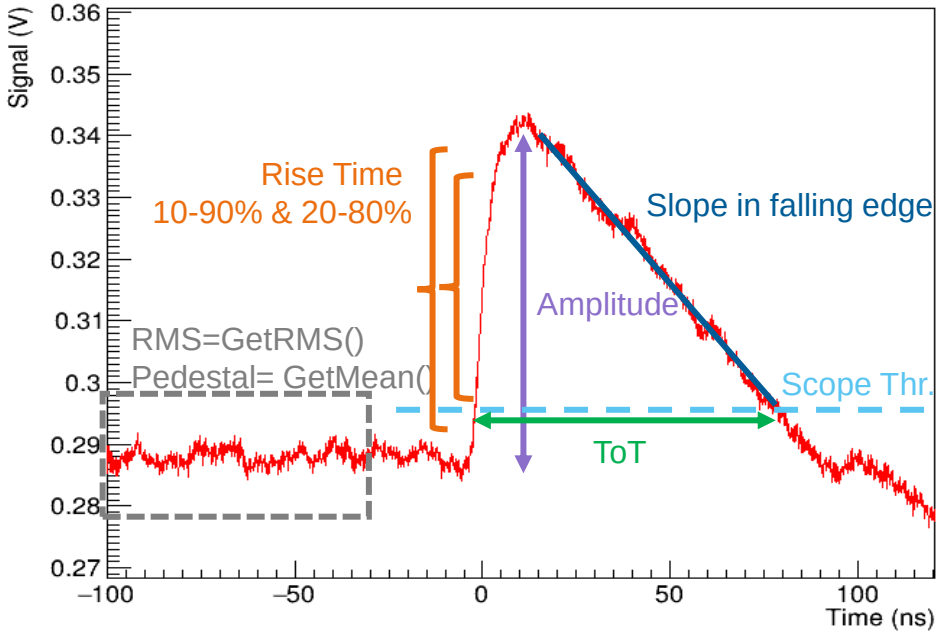
Mainz Test Beam: Results

Waveform Analysis with ROOT

- Tested Sample #4 & sample #7
- IB5U scan (amps bias current) 4-14 µA (VB5U 0.65 - 1.4 V)
- VSUB scan (pwell sub voltage, sensor cathode) 1.25 - 2.2 V

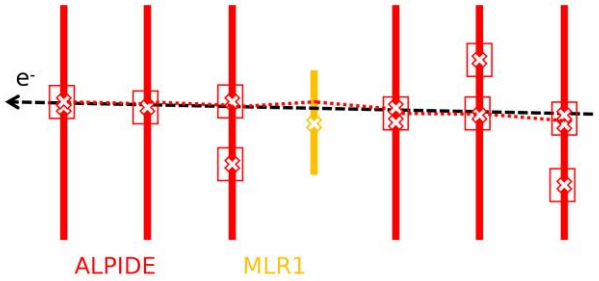




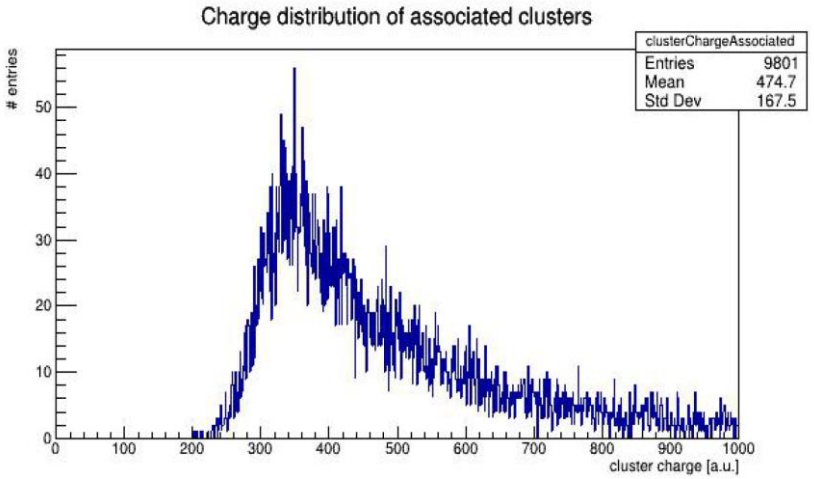


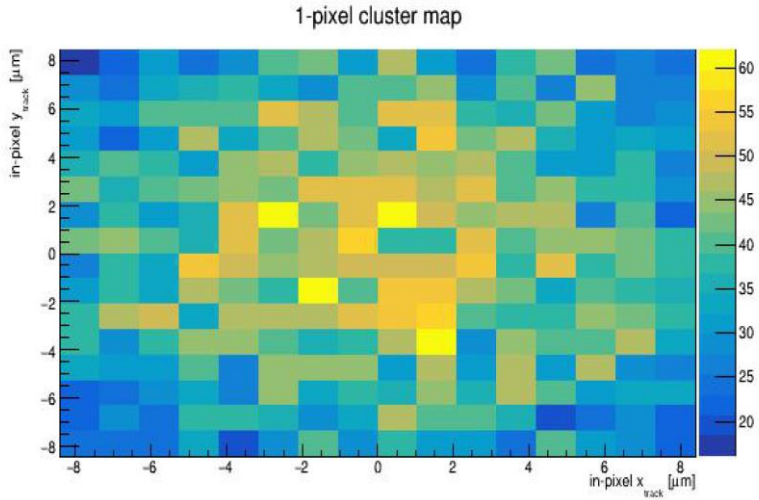
Mainz Test Beam: Results

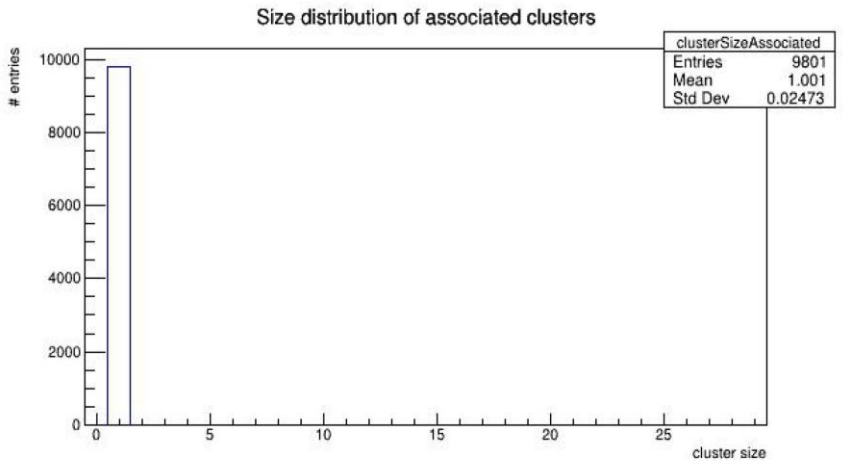
Corryvreckan Analysis

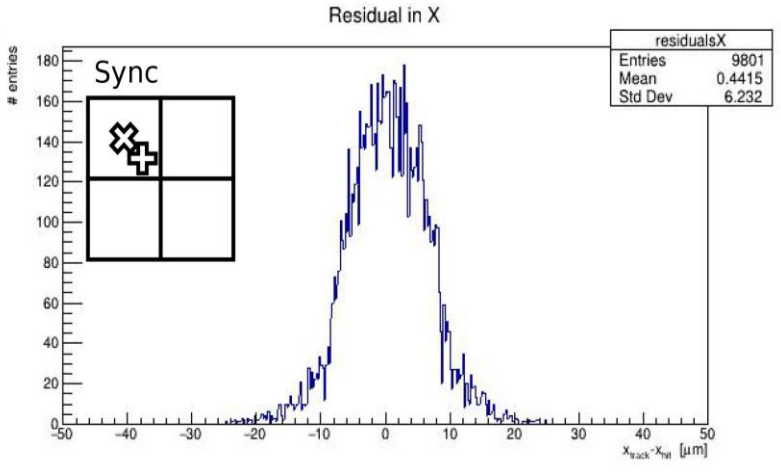


- Corryvreckan use hit ⊠ (pixels above threshold) and Clusters ▯ (groups of adjacent hits) to recontruct particles trajectories ····
- ALPIDE busy time caused misalignment between telescope and MLR1 data and made resynchronization necessary
- **Residuals** (Difference between positions from track interpolation and DUT meas) **~ 6µm** is dominated by ALPIDE resolution and low beam momentum







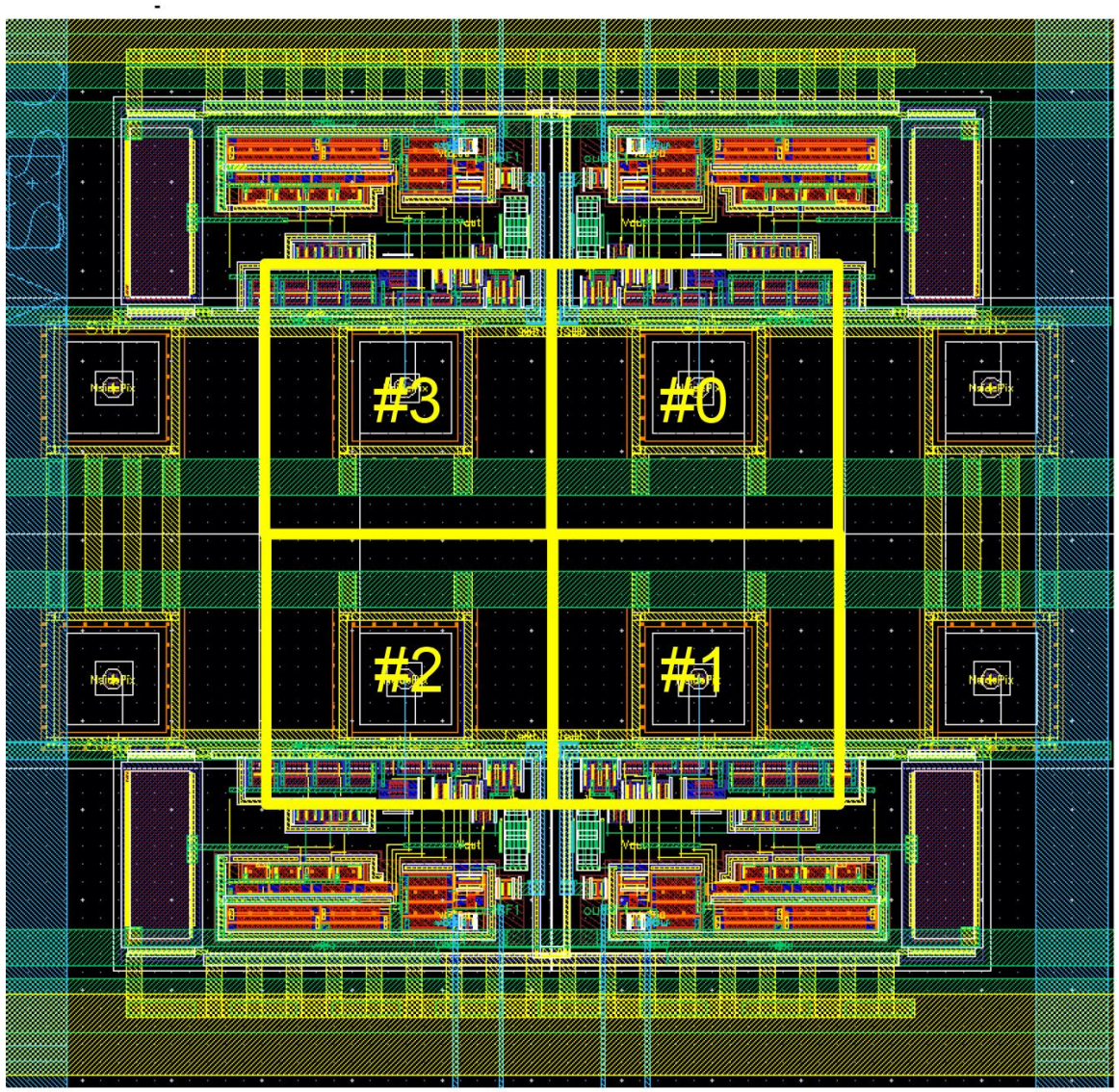


@ F. Feindt

Conclusions

Results with the tangerine MLR1 Chip

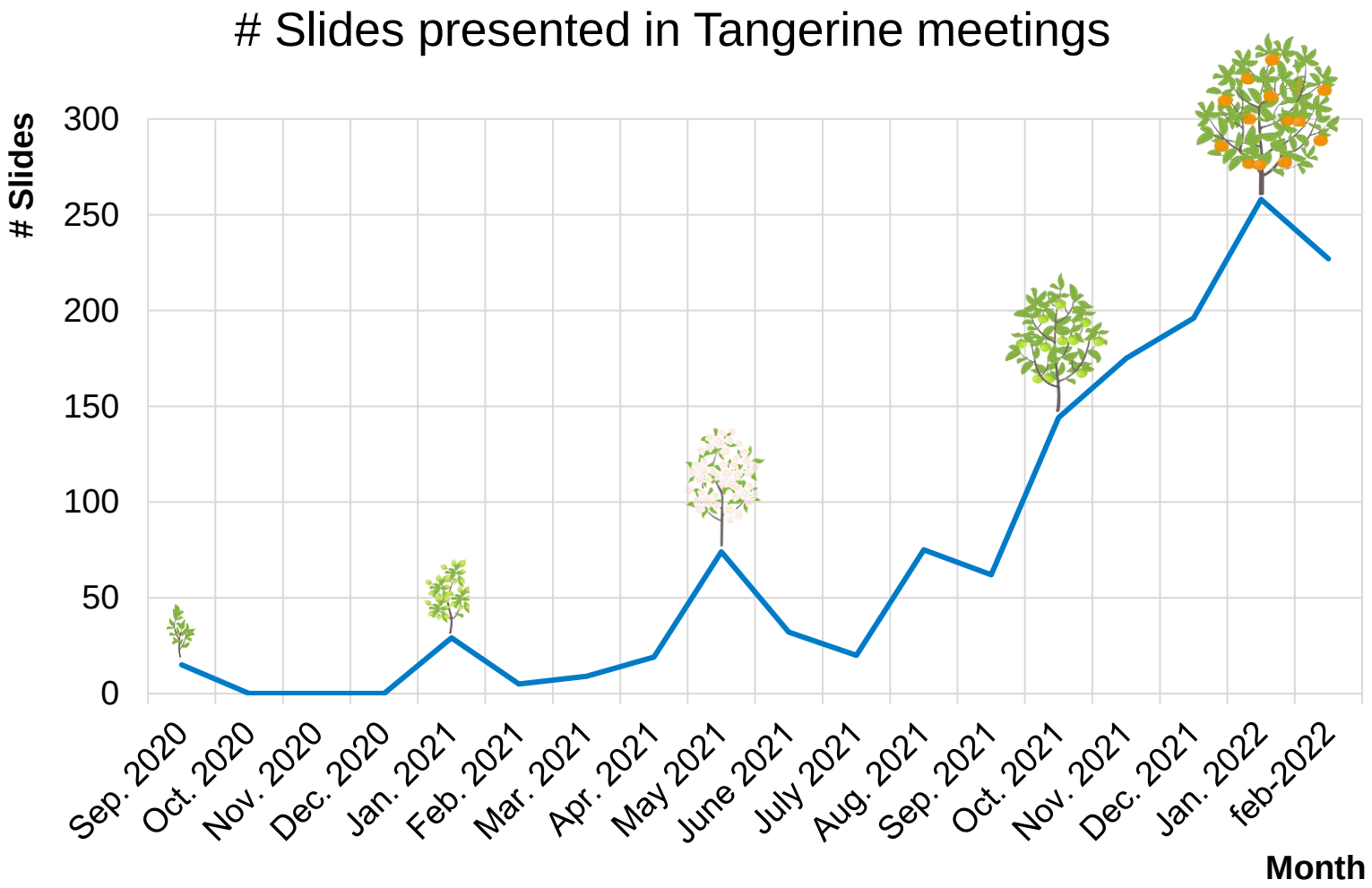
- A 65 nm CMOS pixel detector was for the **first time** developed & investigated at DESY
- DESY MLR1 Chip allowed the **first tests on designed CSAs** with the direct study of the waveforms
- The Chip shows **a time resolution of 2-3 ns** with MIPs (preliminary)
- **Spatial resolution of a few µm** for MLR1 (considering the sensor layout issue and the small pitch)
- Results of the studies on MLR1 will allow improvements in the **next prototype**



Tangerine project present & future

Towards the next prototype

- MLR1 is just the beginning of the story
- The Tangerine group is now focused on TCAD and Allpix^2 simulations
- The ASIC design of the next prototype(s) is in the final stages of preparation for submission
- The next Chip with larger matrix and digital read-out is expected at DESY by the end of 2022



Thank you

Contact

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Synchrotron DESY

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