

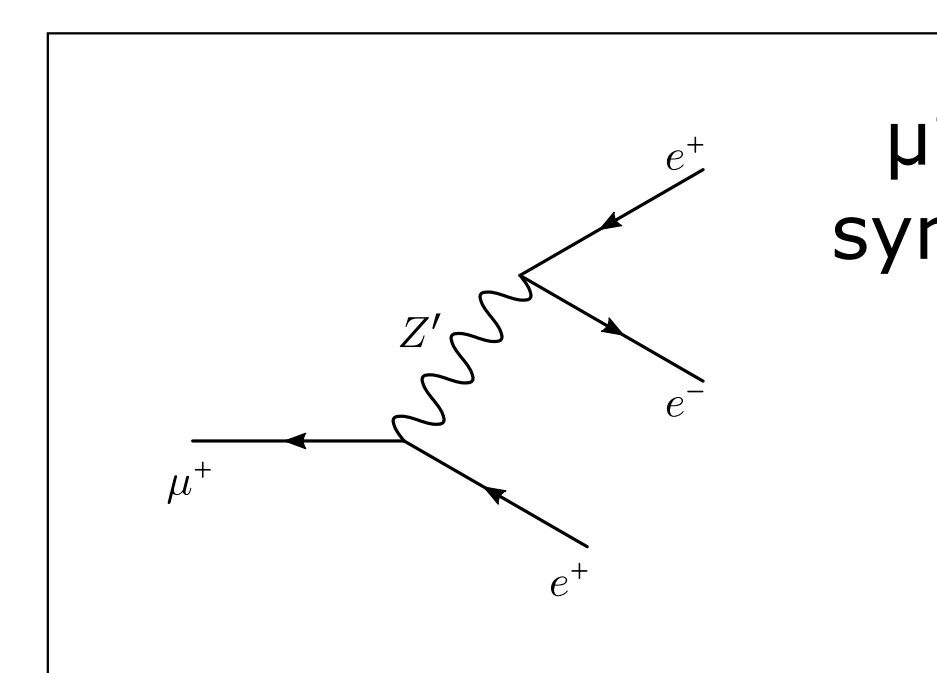
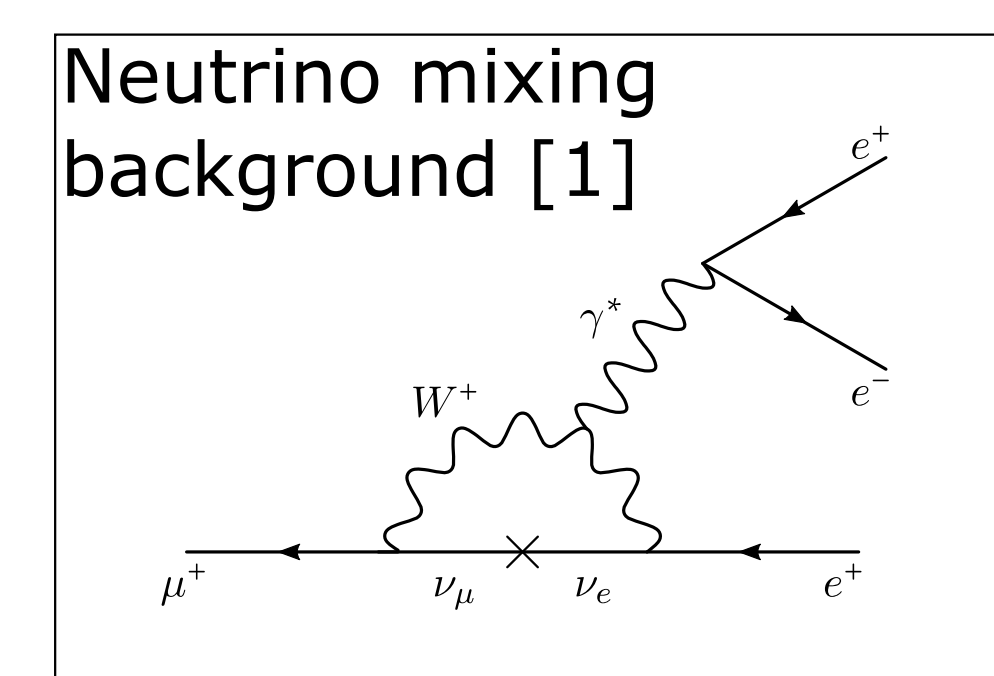
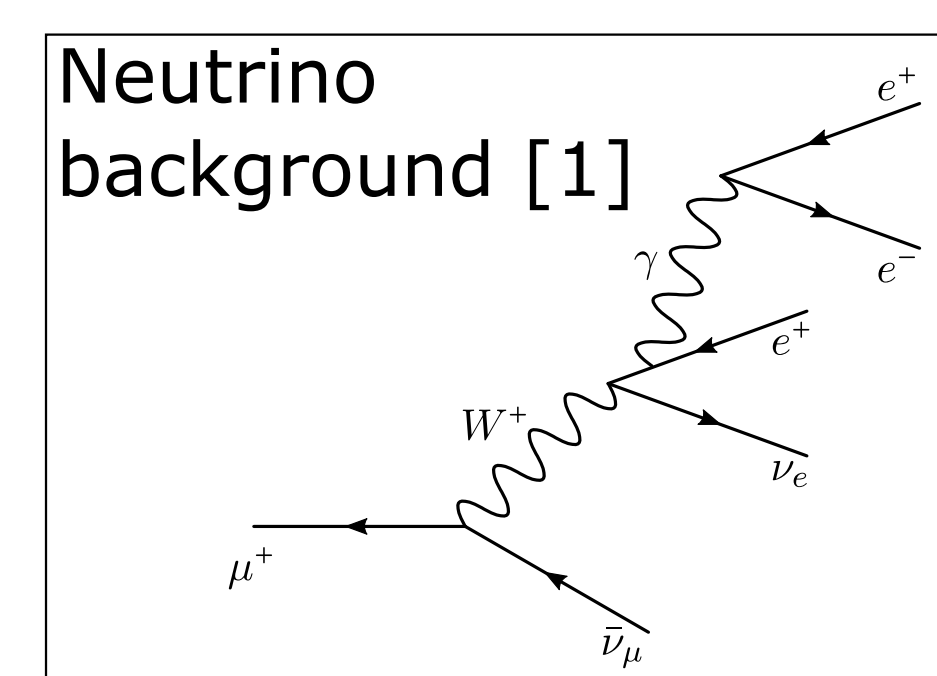
HV-CMOS Sensors for the Mu3e Experiment searching for Lepton-Flavor Violation

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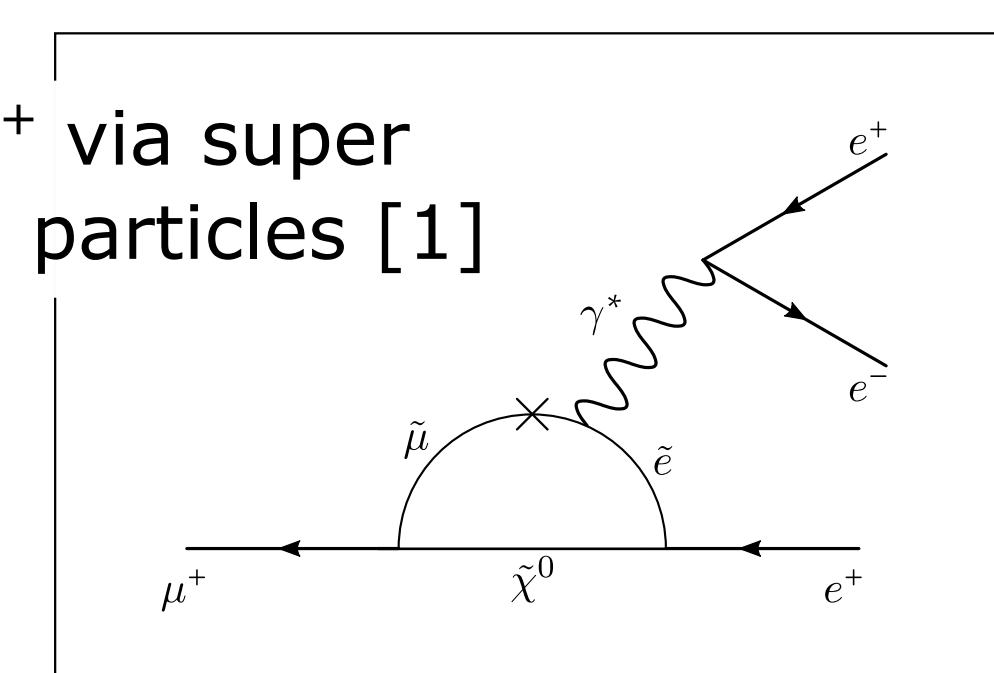


Physics beyond the Standard Model of particle physics?

- Lepton flavor is conserved in Standard Model
- The decay channel $\mu^+ \rightarrow e^+e^-e^+$ is only possible due to neutrino oscillations, with very small branching ratio ($<10^{-50}$). This is not observable.
- Any observation of this process is a proof for physics beyond the SM
- Mu3e detector is constructed to identify $\mu^+ \rightarrow e^+e^-e^+$ decay and to filter out all other events, especially neutrino background is challenging



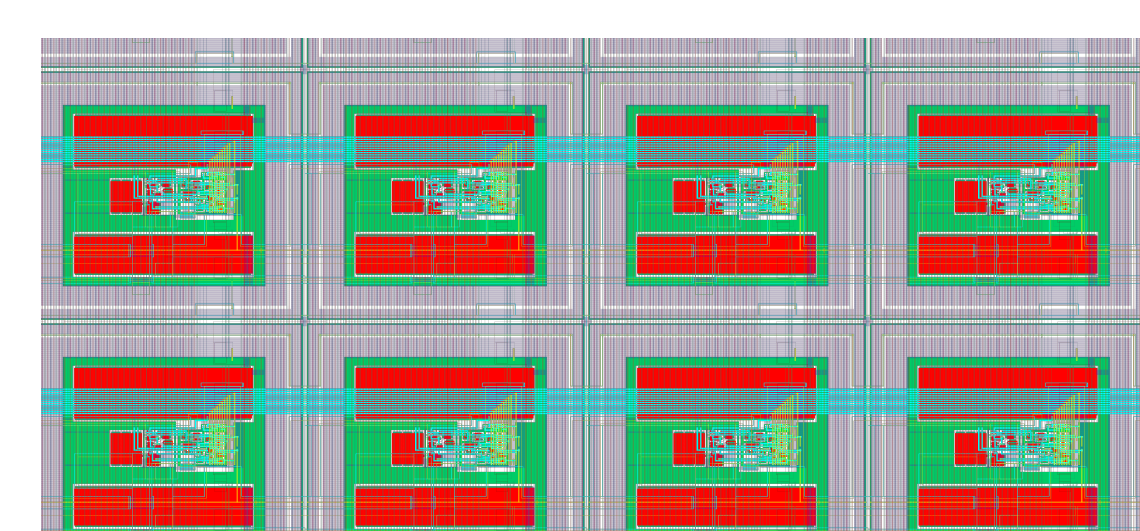
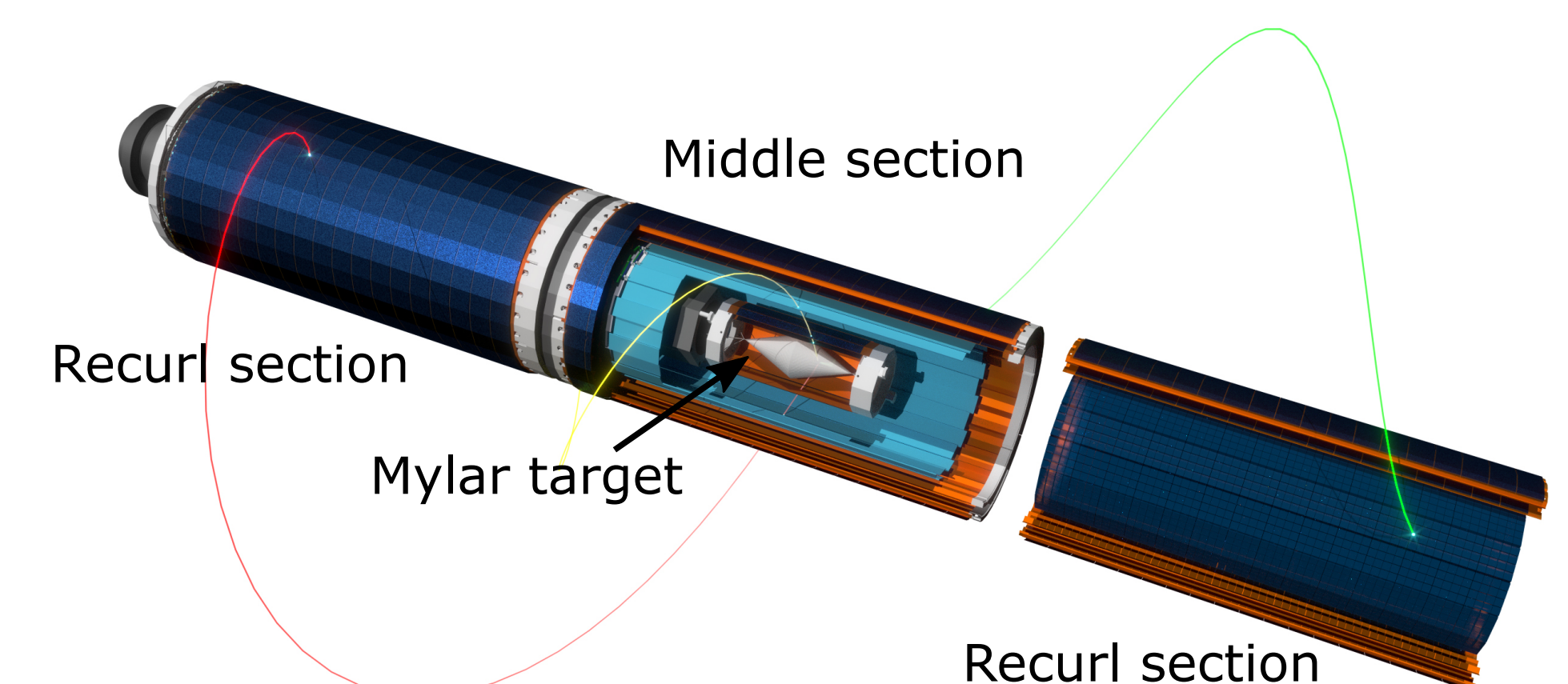
$\mu^+ \rightarrow e^+e^-e^+$ via super symmetrical particles [1]



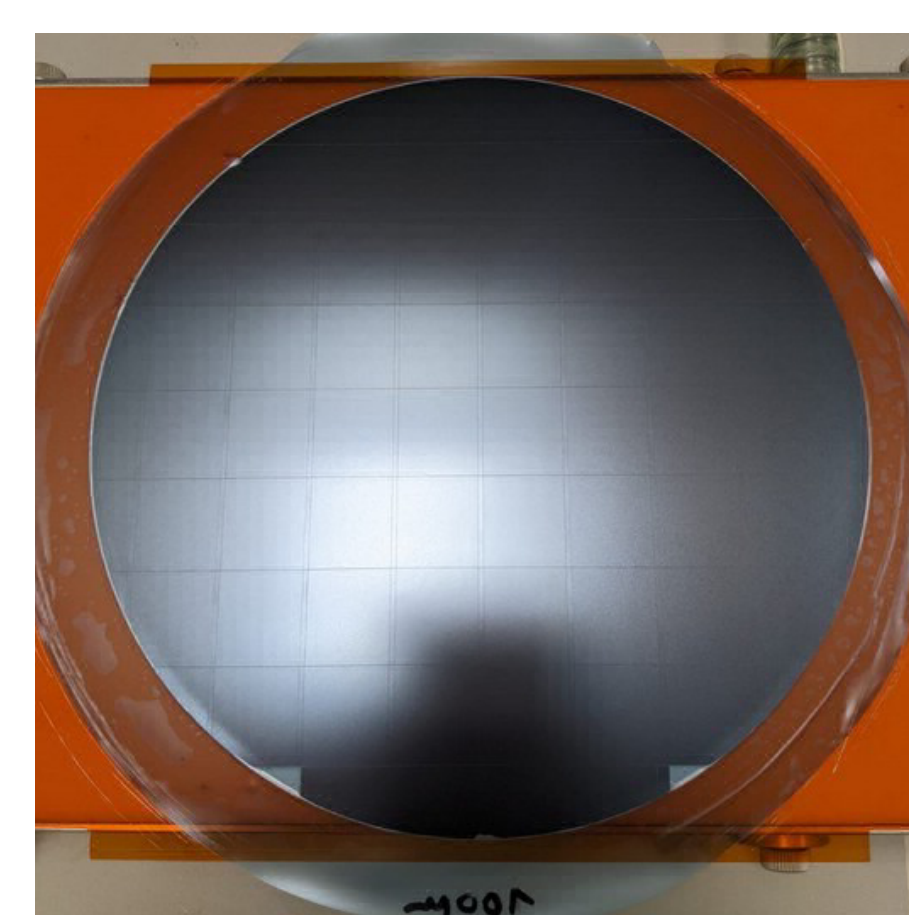
The Mu3e experiment

- At Paul-Scherrer-Institute (Switzerland)
- Muons are created by an accelerator with a high rate of up to 10^9 per second
- They are stopped in a Mylar target and decay
- The decay products are tracked and analyzed
- For background exclusion high precision measurement is required:
 - Vertex resolution $\sim 100 \mu\text{m}$
 - Time resolution 20 ns (pile-up)
 - Low material budget 0.1% of X_0 /layer (multiple-scattering)
 - High noise suppression

Schematic drawing of the Mu3e detector [2]



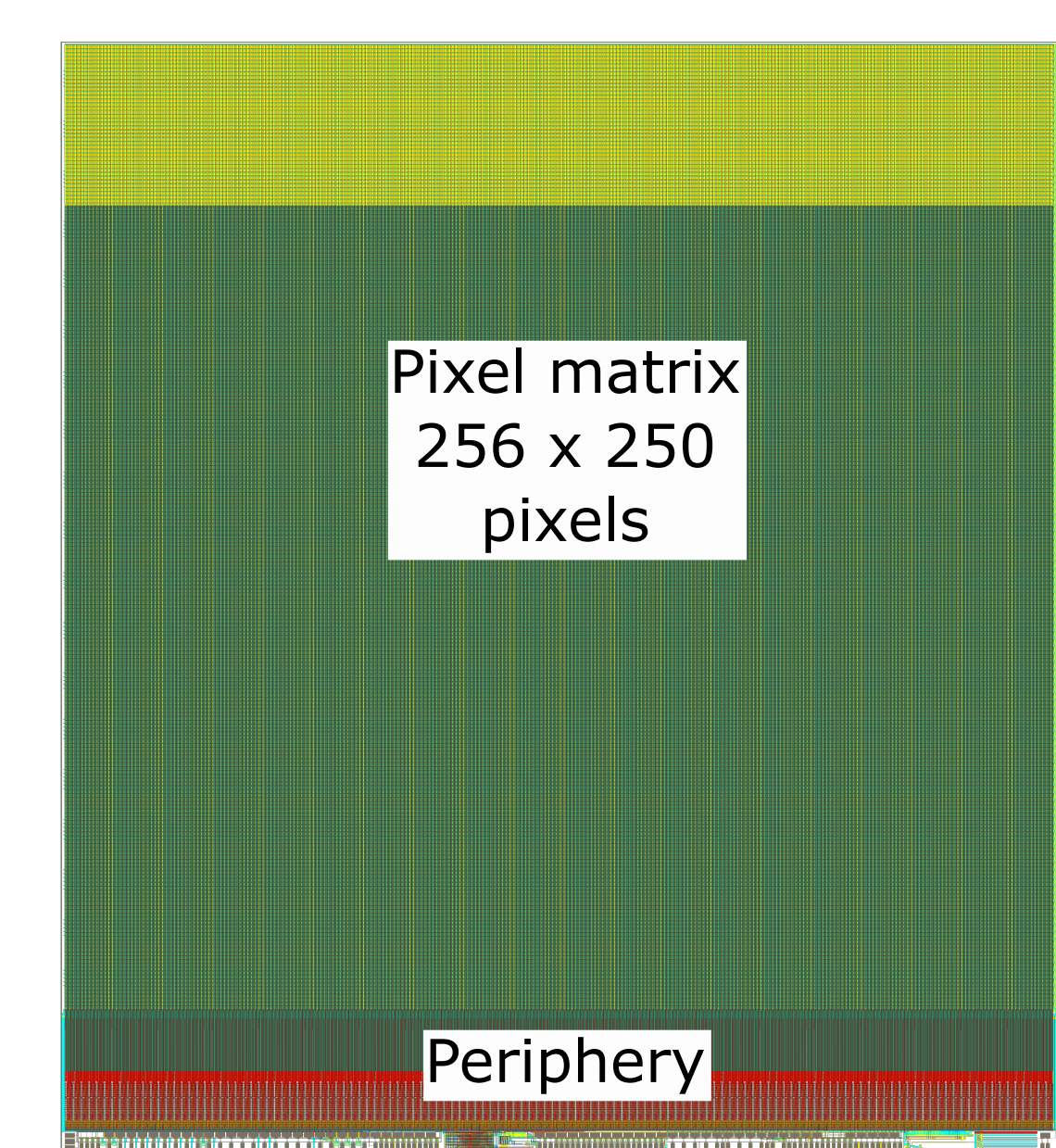
Layout of eight MuPix11 pixels



Thinned sensor chips on a wafer [3]

The MuPix sensor chip

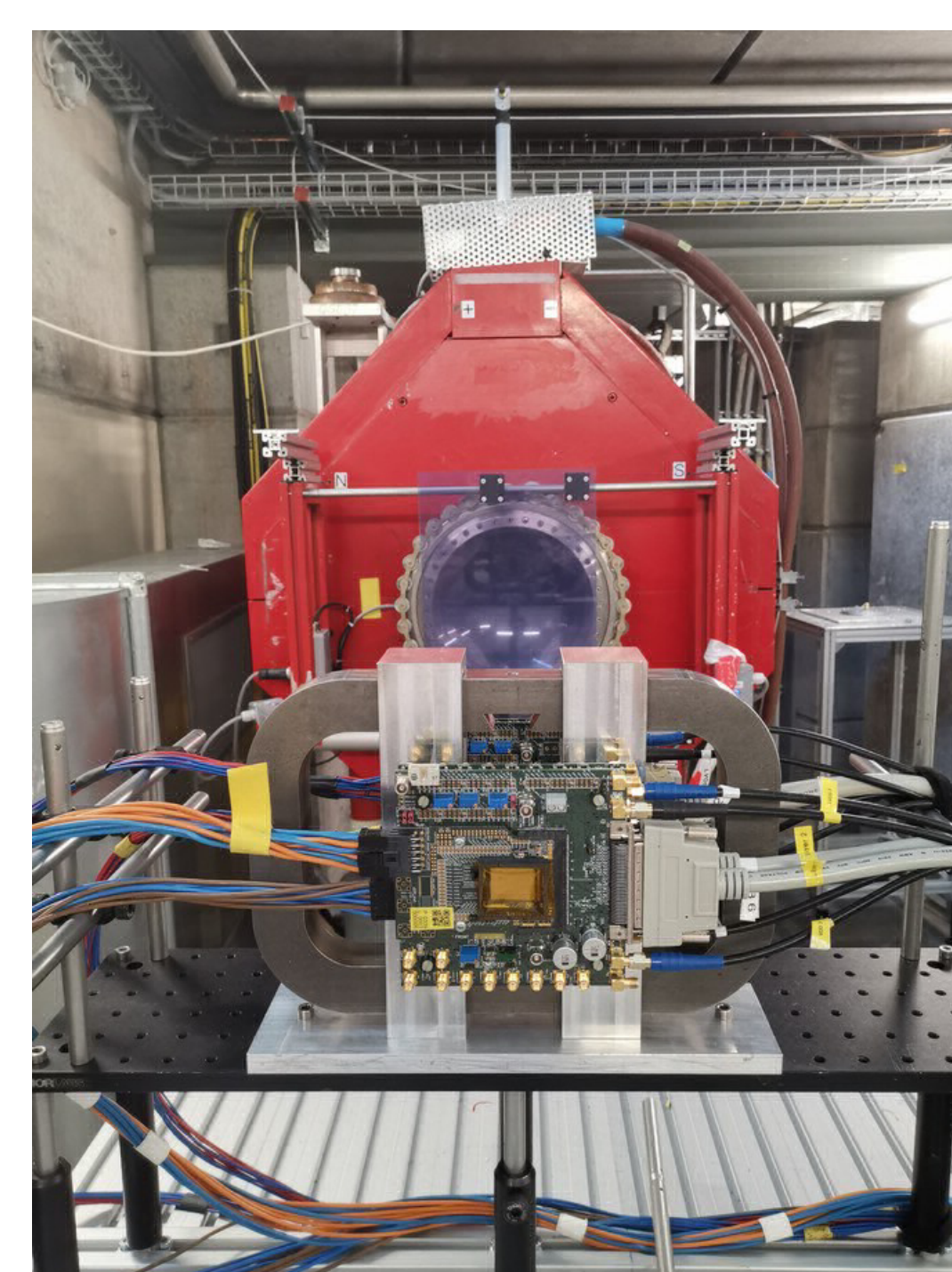
- Monolithic HV-CMOS pixel sensor $(2 \text{ cm})^2$
- High spatial resolution: $(80 \mu\text{m})^2$ pixels
- Time resolution better than 10ns
- Thickness $\sim 50 \mu\text{m}$
- He-gas cooling \rightarrow low energy consumption
- Minimal support: Kapton foil with aluminum traces
- Mu3e pixel tracker consists of central tracker (4 layers) and 2 recurl stations (2 layers each)
- The total number of sensorchips is 2844 with a total area of larger than 1.1 m^2



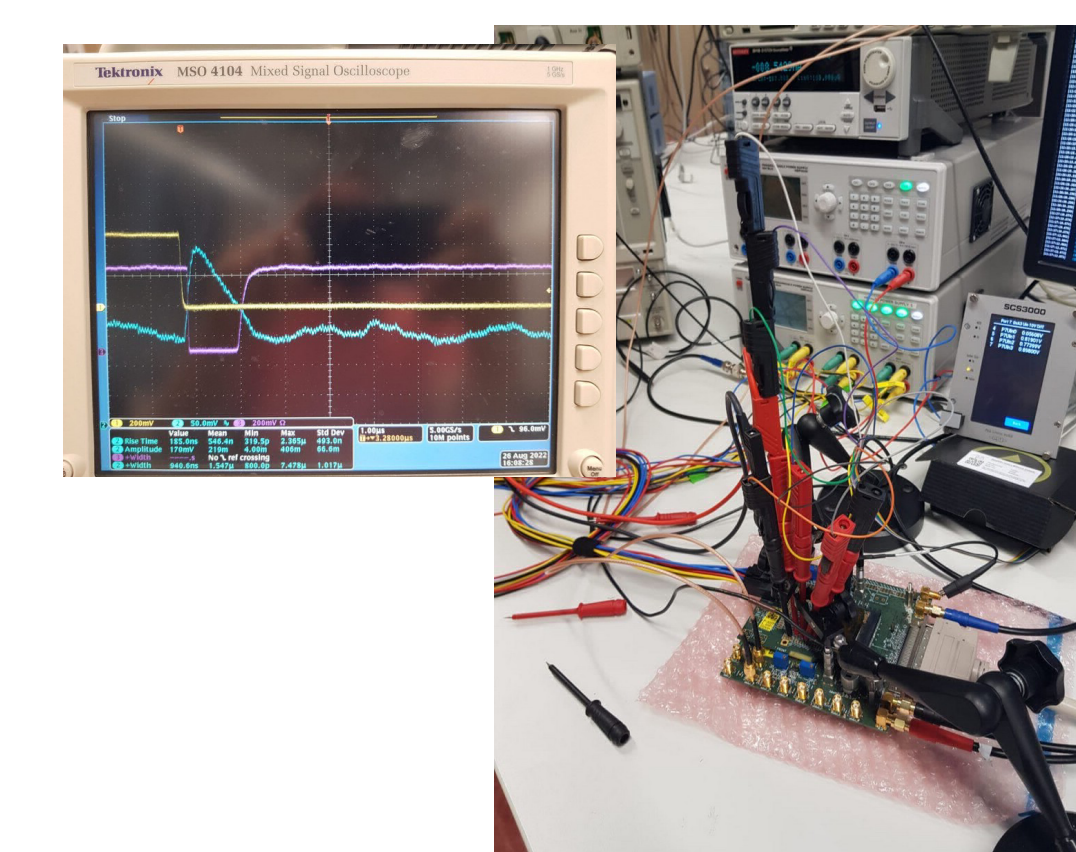
Layout of MuPix11

Our Mu3e research group

- Funded by DFG
- Development of pixel sensor chip
- Production of sensor chips
- Test and calibration of chips
- MuPix11 is the production version of the sensor chip
- Tests are ongoing, the first results are very good
- Development of sensor chips with improved time resolution for Mu3e upgrade
- Start of muon data taking is planned in 2024

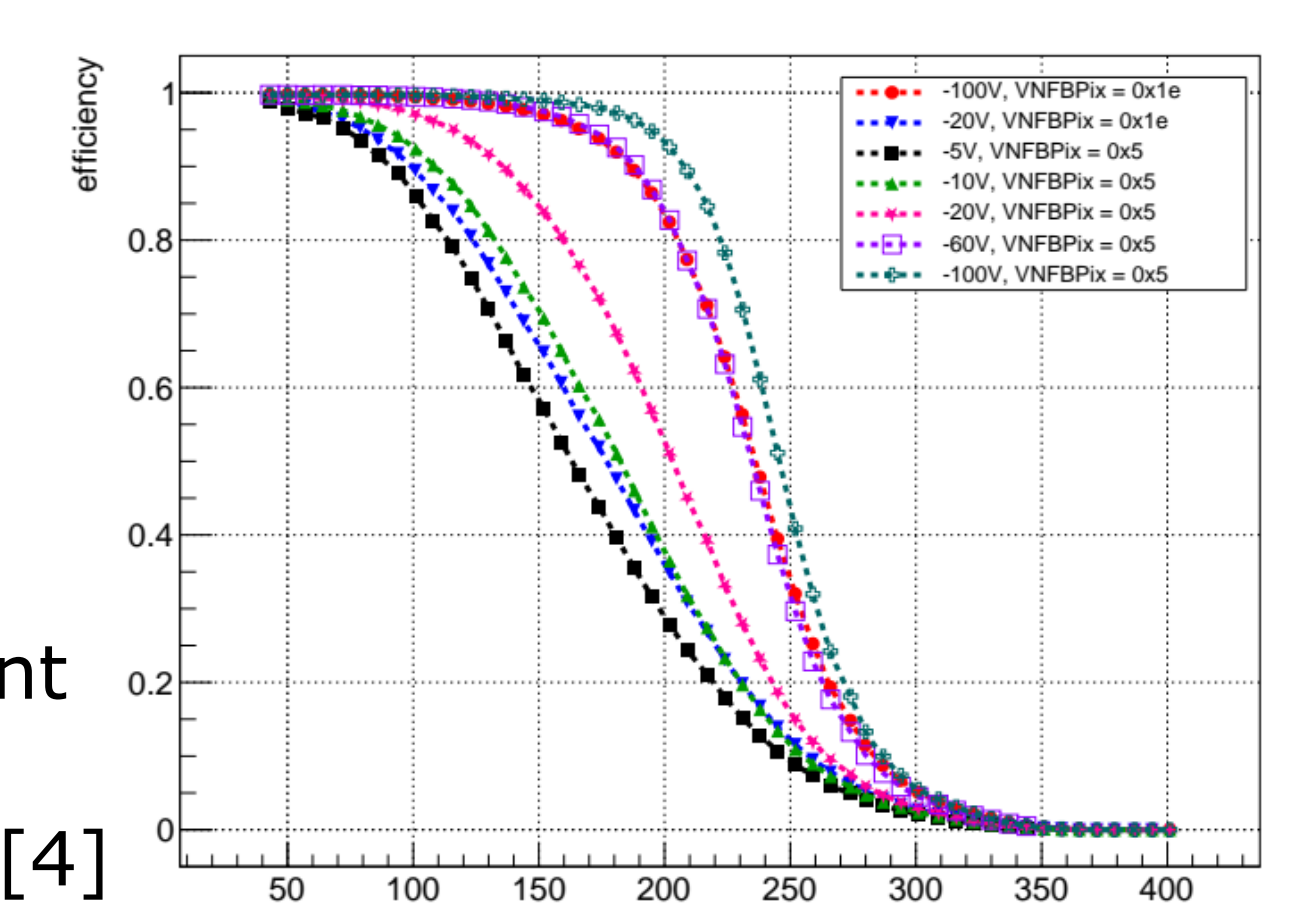


Beam test site at PSI with a MuPix11 [4]



Laboratory test setup. The oscilloscope shows the chips response to a test signal (yellow) at amplifier output (blue) and comparator output (magenta) [4]

Efficiency measurement in PSI beam test at different chip settings [4]



- [1] A. Blondel et al., "Research Proposal for an Experiment to Search for the Decay $\mu \rightarrow eee$ ", Jan. 2012.
 [2] K. Arndt, et al., "Technical design of the phase I Mu3e experiment", 2020.
 [3] Picture by David Immig
 [4] H. Augustin, Mu3e collaboration meeting Sept. 2022