

TCAD Simulation of the MuPix7 Sensor for the Mu3e Pixel Tracker

Annie Meneses Gonzalez

Physikalisches Institut Heidelberg



DPG Spring Meeting
March 19, 2018



UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

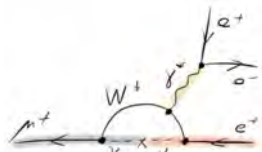


Outline

- The Mu3e Experiment
 - * Goal
 - * Challenges
- TCAD Simulation
 - * Motivation
 - * Synopsis Sentaurus Software
 - * Device Structure (MuPix7)
 - * Simulation of quasi-stationary characteristics
 - * Transient simulation of MIP
- Summary



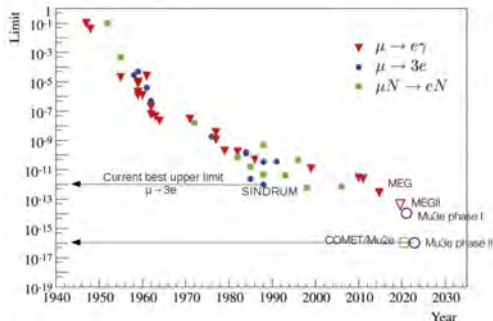
The Mu3e Experiment



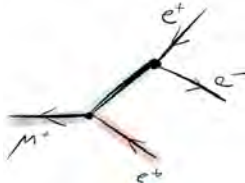
Decay $\mu \rightarrow e e e$ mediated by neutrino mixing

$BR(\mu^+ \rightarrow e^+ e^- e^+) \ll 10^{-54} \rightarrow$ Standard Model

- Too small to access experimentally
- An experimental observation: a clear signature of new Physics



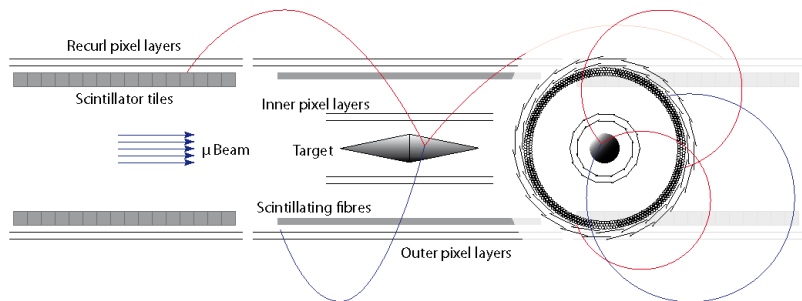
Search for Physics Beyond SM via the Charged Lepton Flavor Violation decay



Challenges of the Experiment

1. High decay rate of muon

- $\pi E5$ at PSI $\Rightarrow 10^8$ Hz Phase I $\Rightarrow 290$ days of data taking
- 10^9 Hz Phase II (possibility under investigation at PSI)

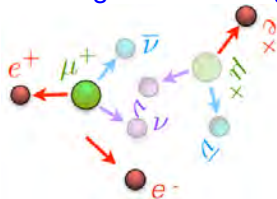


Challenges of the Experiment

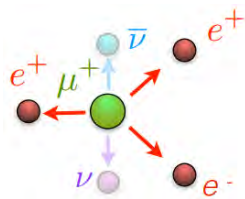
1. High decay rate of muon

- $\pi E5$ at PSI $\Rightarrow 10^8$ Hz Phase I $\Rightarrow 290$ days of data taking
- 10^9 Hz Phase II (possibility under investigation at PSI)

Two categories of background



Accidental Background



Irreducible Background

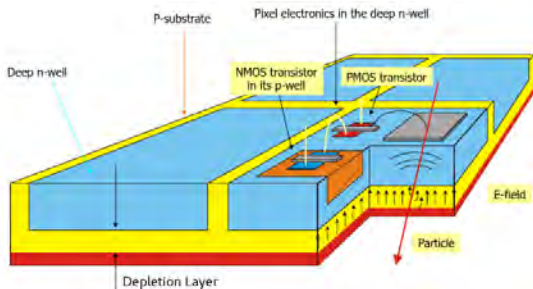
- ## 2. Good vertex and timing resolution
- $\Rightarrow 100 \mu m$ and $500 ps$

- ## 3. Excellent momentum resolution
- $\Rightarrow 0.5 MeV$

High Voltage Monolithic Active Pixel Sensors

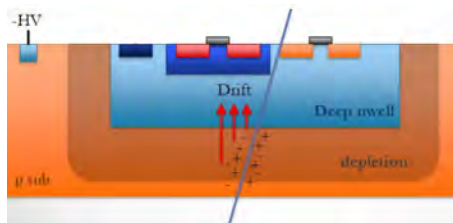
- Low momenta decay electrons \Rightarrow up to 53 MeV
- Multiple Coulomb scattering

Pixel tracker based on $50 \mu\text{m}$ thin HV-MAPS



- * Integration of sensor and readout functionalities
 \Rightarrow Reduce material budget

Technology Computer Aided Design



- MAPS reversely biased to **high voltages**
- Thick **depleted area**
⇒ $15 \mu\text{m}$ for $20 \Omega\text{cm}$
- Fast **time collection** via drift
⇒ time resolution better than 15 ns

TCAD

Use of computer simulations to develop and optimize semiconductor processing technologies and devices

Synopsys Sentaurus TCAD

SYNOPSYS[®]

Select DB Tool

SENTAURUS PROCESS SIMULATION, STRUCTURE GENERATION, INTERCONNECT SIMULATION, LITHOGRAPHY

SENTAURUS GRID GENERATION

SENTAURUS DEVICE SIMULATION

SENTAURUS VISUALIZATION

Fabrication process

Mesh

Electrical Operation

Visualization

Fabrication process

Workbench

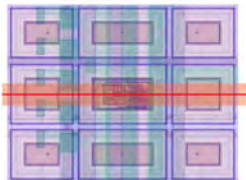
	Voltage	Location
1		53
2		56
3		59
4		61
5		65
6		65
7		71
8		74
9		77
10	40	83
11		83
12		96
13		89
14		82
15		55
16		55
17		55
18		55
19		55

Edit mode: none, colored, mesh, scenario, structure, tools, view, variables, pcm, system, extensions, help

MuPix7

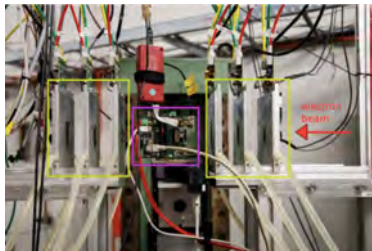
- First HV-MAPS prototype which include all the functionalities required for the Mu3e experiment

Pixel size [μm^2]	103 x 80
Bulk resistance [Ωcm]	20
Active area [mm^2]	10.6
Thickness [μm]	50



Layout of the MuPix7 pixel unit with nine charge collecting diodes and the in-pixel circuitry

Experimental results:

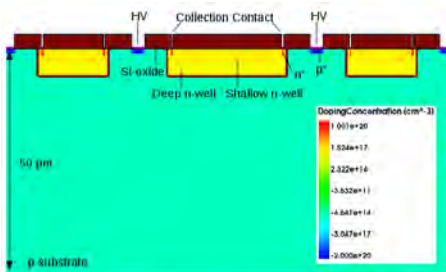


- * DESY-II beam test facility
- * EUDET Telescope
⇒ MAPS MIMOSA-26
- * 4 GeV electron beam

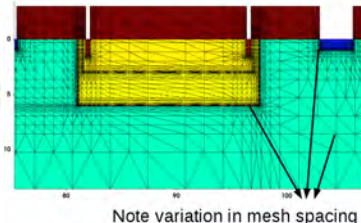
<https://arxiv.org/abs/1803.01581>

Creation of the Structure

1. Accurate prediction of the geometry and doping distribution



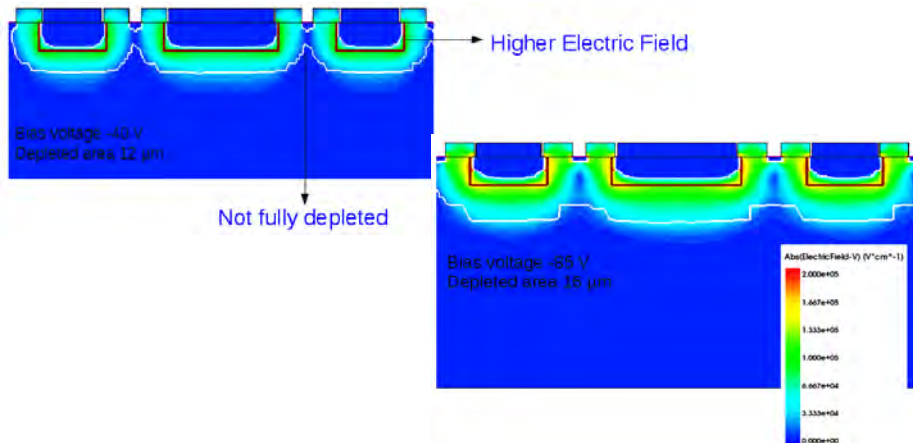
Build mesh distribution



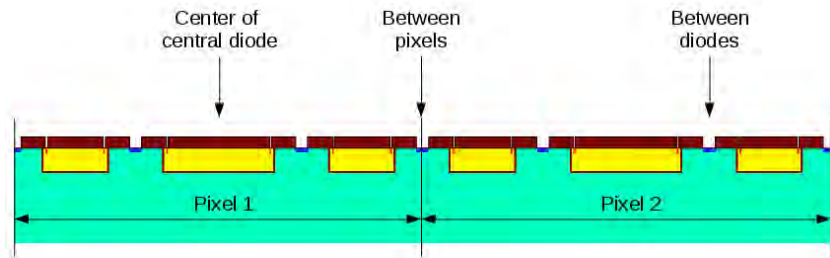
2. Simulation of quasi-stationary characteristics

Quasi-stationary characteristics

- Electric Field profile



Signal generation from Minimum Ionizing Particles



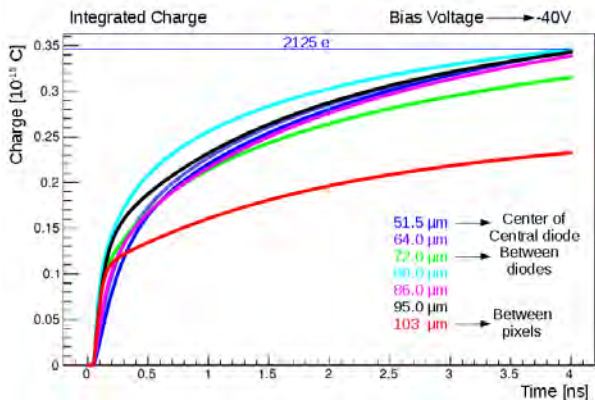
- Energy loss $\Rightarrow 5 \text{ MeV/cm}$
- Electron beam $\Rightarrow 4 \text{ GeV}$
- Ionization Energy
 $\Rightarrow \text{Silicon } 3.6 \text{ eV}$

Linear Energy Transfer

$$\Rightarrow 2 \times 10^{-5} \text{ pC}/\mu\text{m}$$

$$\Rightarrow 130 \text{ e} - h/\mu\text{m}$$

Signal generation from Minimum Ionizing Particles



- Fit function

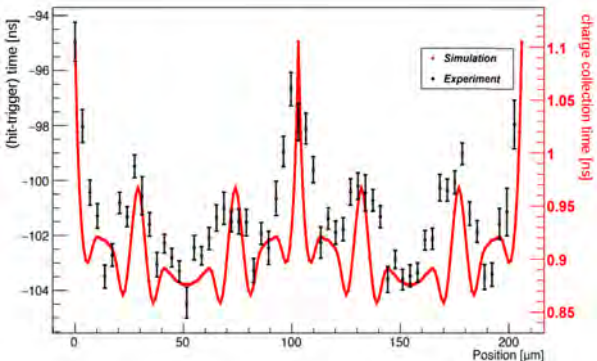
$$\Rightarrow A \times e^{-\frac{x-x_0}{\tau}}$$

How much charge is collected

How fast is the charge collected

Charge collection time

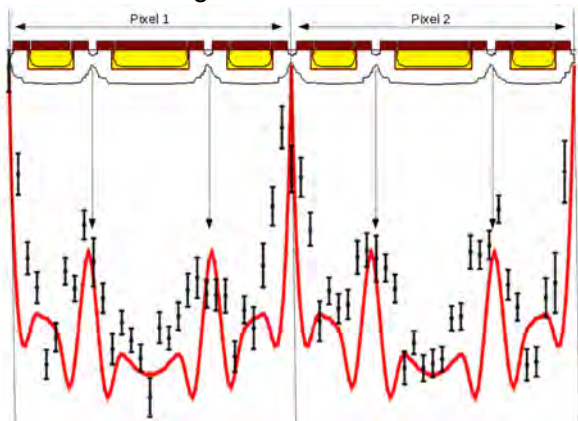
Bias Voltage \Rightarrow -40 V



- Edge of the pixel
 \Rightarrow Charge sharing
- Between diodes
 \Rightarrow Not fully depleted
 \Rightarrow Lost by recombination
 \Rightarrow Collected via diffusion

Charge collection time

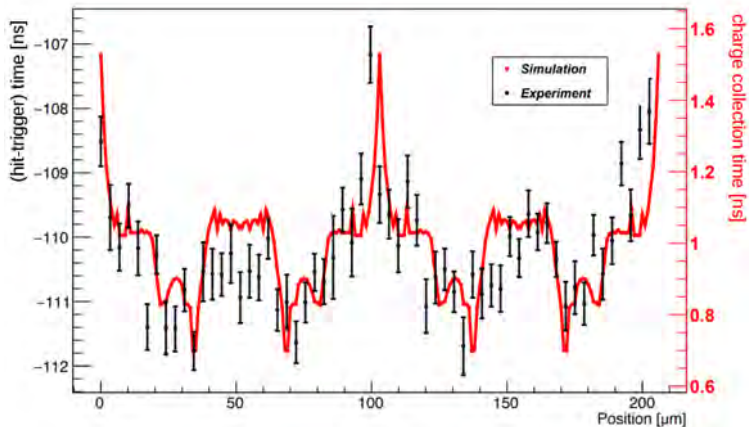
Bias Voltage \Rightarrow -40 V



- Edge of the pixel
 \Rightarrow Charge sharing
- Between diodes
 \Rightarrow Not fully depleted
 \Rightarrow Lost by recombination
 \Rightarrow Collected via diffusion

Charge collection time

Bias Voltage \Rightarrow -85 V



Summary

- The structure and collection process of MuPix7 was reproduced.
- Taking into account the limited position resolution of the measurement, all major features are reproduced by the simulation.
- Simulation can be used to further optimize the charge collection process and timing behavior in future devices.

