Readout Electronics for the First Large HV-MAPS Chip for Mu3e

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Abstract:

Mu3e is an upcoming experiment searching for charged lepton flavour violation in the rare decay μ→eee. A silicon pixel tracker based on 50 μm thin high voltage monolithic active pixel sensors (HV-MAPS) in a 1T magnetic field will deliver precise vertex and momentum information. The MuPix HV-MAPS chip combines pixel sensor cells with integrated analogue electronics and a complete digital readout. For the characterization of the first large MuPix system-on-chip a dedicated readout system was developed. The dedicated readout chain and the first results from the characterization of the large scale MuPix prototype are presented.

Mu3e Challenges:

- **High rates**
- **Good vertex resolution**
- **Precise timing**
- **Excellent momentum resolution**
- **Extremely low material budget**
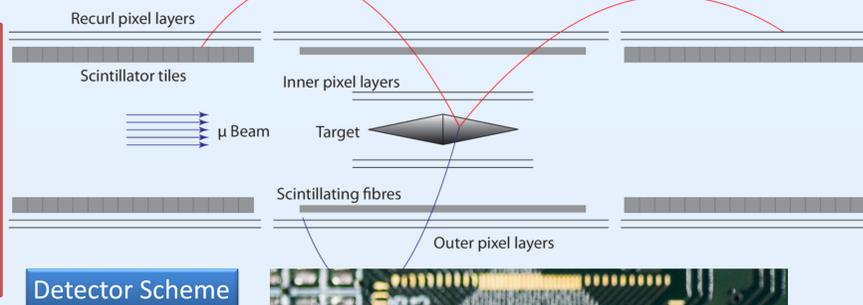
Detector Scheme

HV-MAPS:

- **H**igh **V**oltage **M**onolithic **A**ctive **P**ixel **S**ensors combine advantages of:
  - Fast hybrid pixel detectors
  - Thin monolithic active pixel sensors (MAPS)
- Analog and digital electronics integrated
- First stage amplifier inside the pixel
- ➤ Good signal to noise ratio of 20 achievable

- Compact digital readout logic placed below the pixel matrix
- Reduced digital crosstalk
- High voltage (≈ -85 V)
  - ➤ Small depletion zone (≈10 μm)
  - ➤ Fast charge collection within 1 ns
- Most of substrate passive
  - ➤ Wafer can be thinned to < 50 μm

N-well   E field
P-substrate   Particle
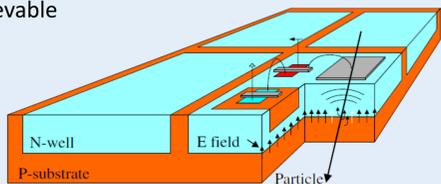
Ref.: I. Peric, A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology Nucl.Instrum.Meth., 2007, A582, 876

Test Beams:

Test beam campaigns for the MuPix7 prototypes:
- 170 GeV SPS π-beam at CERN
- 5 GeV electron beam at DESY
- 224 MeV mixed π[+], μ[+], e[+] beam at at PSI
- 1 GeV electron beam at MAMI Johannes Gutenberg University Mainz

DESY test beam setup based on:
- One MuPix7 chip
- Track information given by Aconite beam telescope based on MIMOSA chips

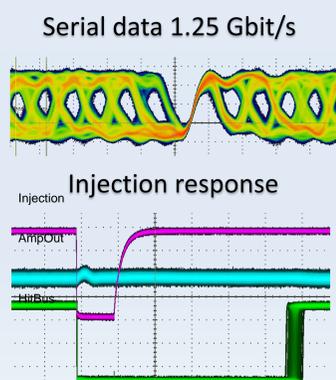**MuPix Telescope** based on 4 or 8 MuPix7 chips used for test beam measurements with high rates

MuPix Setup at DESY

MuPix Telescope

MuPix8 first results:

- ✓ **First large prototype 1x2cm²**
- ✓ **Power on test ok (<1A)**
- ✓ **Serial data output @ 1.25 Gbit/s**
- ✓ **8/10 Bit encoding**
- ✓ **Injection to single pixel**
- ✓ **⁹⁰Sr source signal detected**

Serial data 1.25 Gbit/s

Injection response

Injection
AmpOUT
HitBus

MuPix8 Prototype

MuPix readout electronics:

MuPix8 PCB:

- Chip on board or chip on Insert PCB
- Clean low voltage based on LT1763, LT1764 power regulators
- Four LVDS links for serial data output at 1.25 Gbit/s
- LVDS for chip and board control via SCSI3 cable
- Test-pulse circuit
- Threshold DAC
- Temperature ADC

STRATIX IV PCB:

- Altera Stratix IV PCIe development kit
- Data acquisition
- Chip control
- MuPix PCB board control
- 4 MuPix per STRATIX IV PCB

HSMC SCSI Control Adapter:

- Daughter card of STRATIX IV PCB
- Two SCSI3 connectors for MuPix PCBs
- LVDS converters for MuPix control and MuPix PCB control
- NIM inputs for external trigger i.e. beam scintillator triggers.

MuPix PCB
↕ SCSI3 cable
HSMC-SCSI Adapter
↕ HSMC
STRATIX PCIe PCB → PC
PCIe

MuPix8 PCB

MuPix:

- High voltage monolithic active pixel sensor for Mu3e
- 80 x 80 μm² pixel size
- Active area of 2 × 2 cm²
- Sensors thinned to 50 μm
- Full analog and digital readout electronics integrated
- Each hit is converted on-chip into pixel address and time-stamp
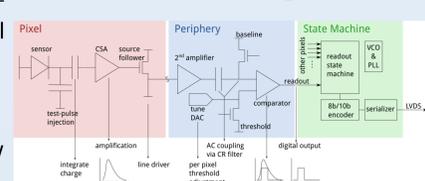- Zero suppressed data sent through 1-3 serial LVDS output links at 1.25 Gbit/s

MuPix8 chip prototype has
- 200 x 128 pixels of size 80 x 81 μm²
- Single stage amplifier for each pixel
- Digital readout at 3 x 1.25 Gbit/s
- Readout state machine integrated

MuPix9 submitted:
- Test structures for I²C inspired slow control
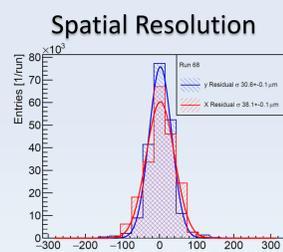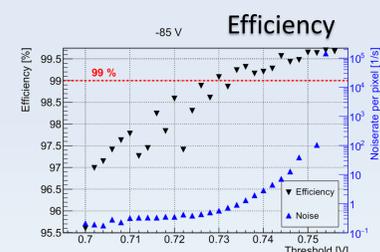- Serial powering test structures

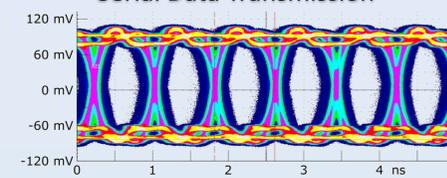

MuPix Block Diagram

MuPix7 Performance:

MuPix7 is a first full system on chip prototype. Performance studies at 4 GeV electrons @ DESY 90° impact angle Individual pixel thresholds:
- Efficiency above 99%
- Spatial resolution given by pixel cell size
- Pixel hit **time resolution** below **15 ns**
- Serial data transmission flawless

Serial Data Transmission

Efficiency

Spatial Resolution

Time Resolution

σ = 14.3 ns