Test beam results for neutron and proton irradiated MuPix7 prototypes

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Physikalisches Institut Heidelberg
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INTERNATIONAL MAX PLANCK RESEARCH SCHOOL PTFS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

Motivation

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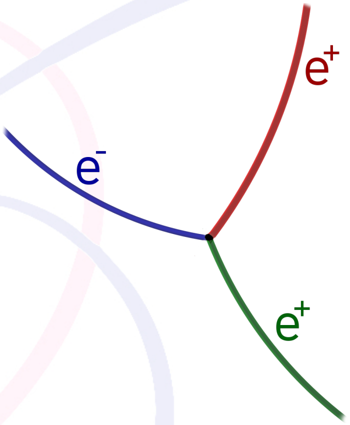
- new physics searches at low momenta and high rates require thin and fast pixel sensors
  e.g. Mu3e: search for $\mu^+ \rightarrow e^+ e^- e^+$
- Mu3e pushes HV-MAPS development
- AMS H18 process itself is radiation hard
- Radiation damage is not an issue for Mu3e
  $\rightarrow$ Design not optimized for radiation hardness
- Are HV-MAPS potentially useful for LHC-like experiments?
  $\rightarrow$ Perform measurements with irradiated MuPix7 prototypes



signal

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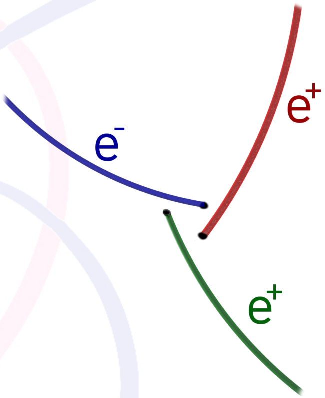
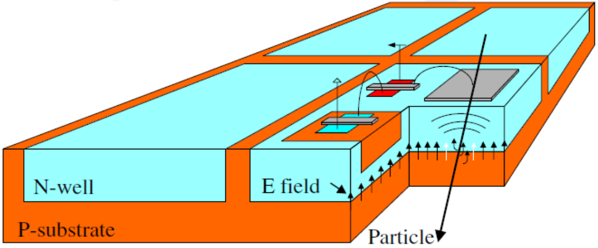


background

The MuPix7

HighVoltage - MonolithicActivePixelSensors (HV-MAPS)

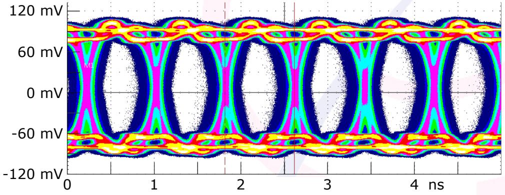
(I.Peric, P. Fischer et al., NIM A 582 (2007) 876)



- digital position and time read out
- 80 x 80 µm^2 pixel size
- 256 x 256 pixel
- 2 x 2 cm^2 active size
- $\sigma_t < 14.3$ ns measured
- efficiency > 99.5 % measured
- 50 µm thin $\approx$ 0.05% radiation length

MuPix7

- full self-triggered zero-suppressed readout running in on-chip state machine
- 1.25 GBit/s serial data output
- 125 MHz external reference clock
- 32 pixel $\times$ 40 pixel with size of 103 x 80 μm^2
- active area: 3.3 mm^2 $\times$ 3.2 mm^2



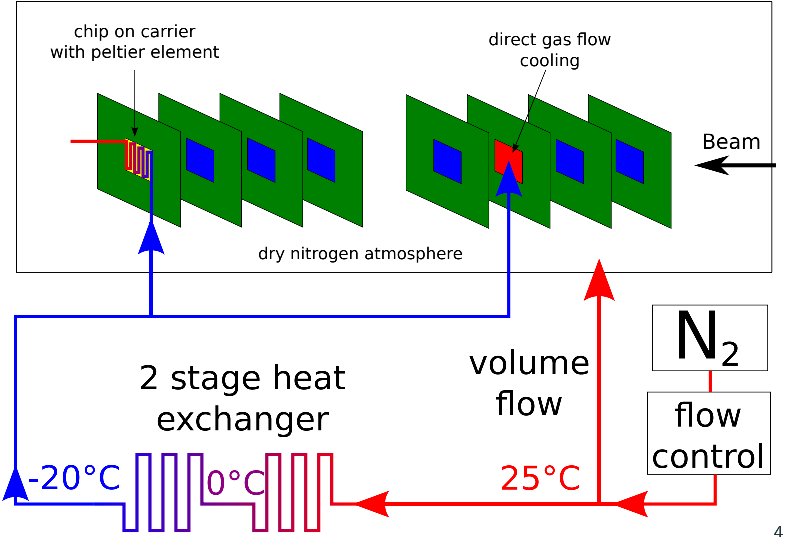
Questions addressed in the talk

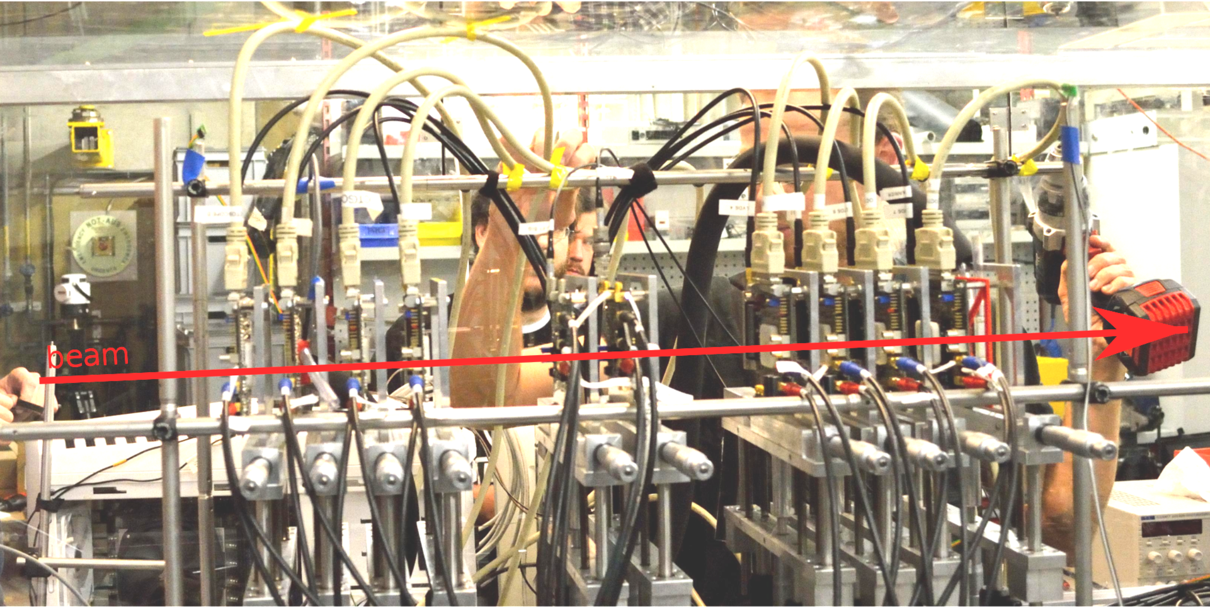
- how does the test beam setup look?
- can we operate the MuPix after irradiation?
- do we see a temperature influence?
- how performs the irradiated MuPix compared to the non irradiated MuPix?
- how is efficiency, noise and time resolution changing with the dose?

Setup and Samples

Setup

- dry N_2 volume box
- gaseous nitrogen cooling
- up to 2 duts in parallel
- gas cooled down to $-20\,^{\circ}C$




beam

Samples

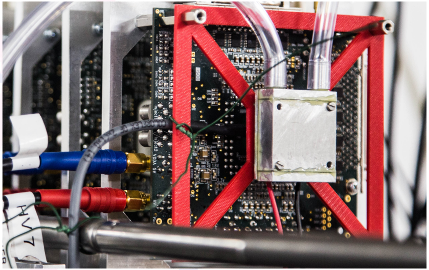
CERN PS proton irradiated

- 28 MeV/c protons
- 7.8×10^{15} p/cm^2 $\approx 4.7 \times 10^{15}$ n/cm^2
- 1.5×10^{15} p/cm^2 $\approx 0.9 \times 10^{15}$ n/cm^2
- directly glued to a thinned PCB
- cooled with gas flow

Ljubljana neutron irradiated

- 5.0×10^{15} n/cm^2
- 1.0×10^{15} n/cm^2
- 5.0×10^{14} n/cm^2
- mounted on carrier
- cooled with peltier element

All sensors tested after 1 year of annealing at room temperature

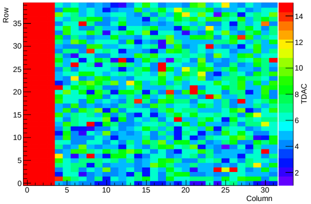


Irradiated sensors need to be cooled to $< 10\,^\circ$C to be operated (we used $\approx$ 0-4 $^\circ$C)

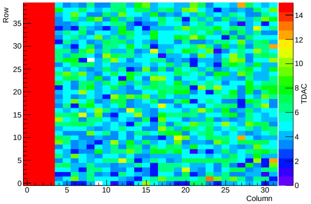
Observations & Results

Noise based tuning - 70 V

$0.0\,n/cm^2$



$1.5 \times 10^{15}\,n/cm^2$



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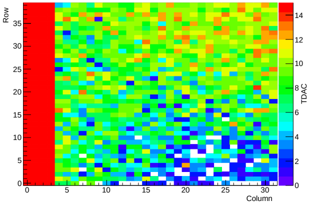
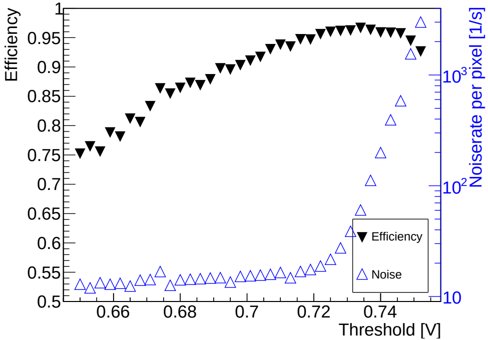


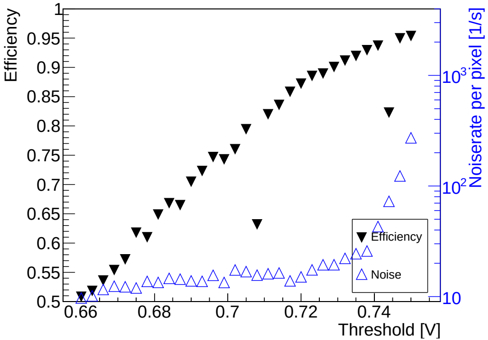
- all sensors tuned to 1 Hz noise per pixel
- over tuned pixels corrected
- flat distribution for non irradiated
- clear structure in proton irradiated
- increased pixel to pixel variations
- only 95 % of the pixels tuned!

Efficiency and noise at HV = -60 V

Non irradiated

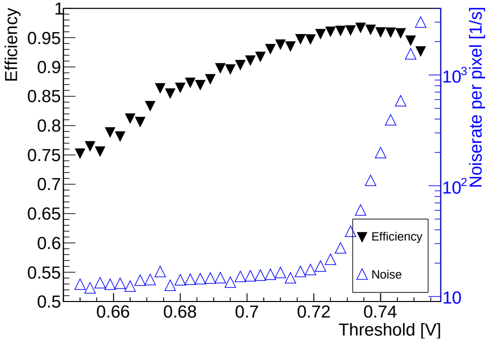


Ljubljana neutron irradiated 5.0×10^{14} n/cm^2

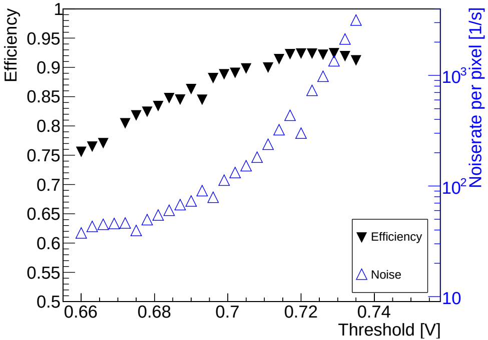


Efficiency and noise at HV = -60 V

Non irradiated

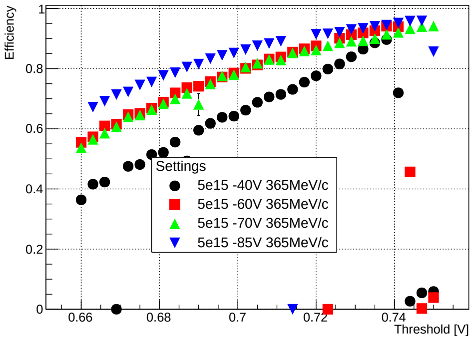


PS proton irradiated 1.5×10^{15} p/cm^2

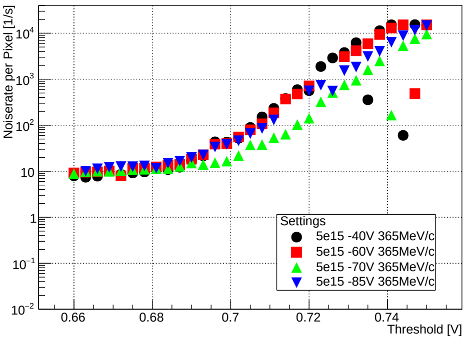


Effect of the HV $5.0 \times 10^{15}\ n/cm^2$

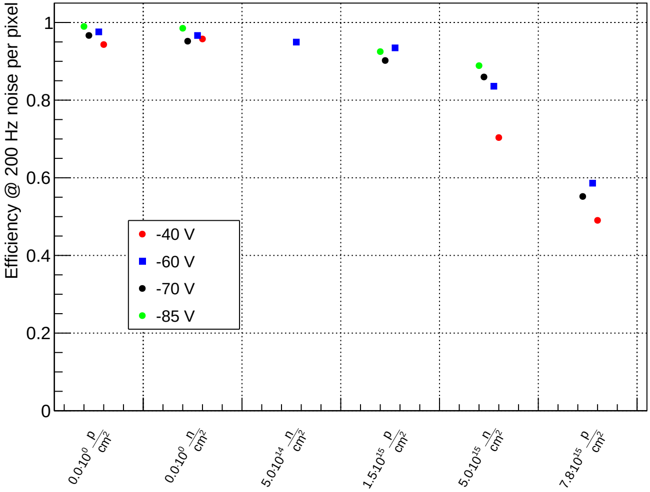
201611_psi_carrier_5e15_eff_hpRemoved.pdf



201611_psi_carrier_5e15_noise_hpRemoved.pdf

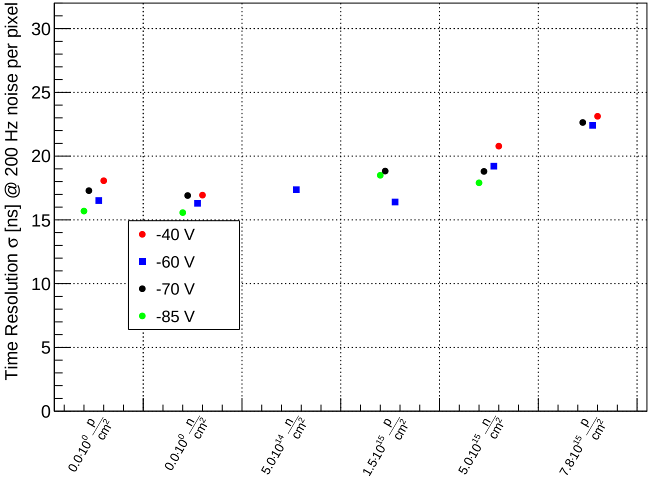


Comparison of the different irradiation doses



- per pixel noise rate 200 Hz
- no significant difference between carrier and direct mount
- only small decrease in efficiency up to doses of 5×10^{15} n/p/cm^2
- 1.0×10^{15} n/cm^2 sensor broken (likely bonding issue)

Time Resolution



- per pixel noise rate 200 Hz
- time difference relative to reference track hits time stamps
- plotted resolution corresponds to σ of a Gaussian fit
- similar behaviour as efficiency: time resolution reduced due to dose

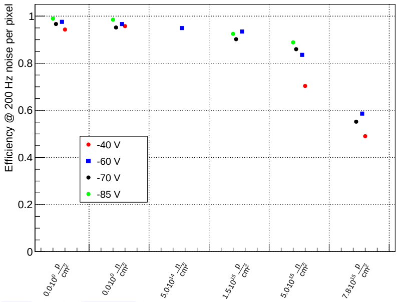
Conclusion & Outlook

Conclusion

- up to 7.8×10^{15} p/cm^2 irradiated samples
- 1 year annealing at room temperature
- design NOT rad. hard, but
  - efficiency $> 90\,\%$
  - time resolution < 25 ns
- increased leakage $\rightarrow$ need cooling to $< \; 10\,°C$
- same DACs as for non irradiated at room temperature used
- results show intrinsic AMS H18 radiation hardness!

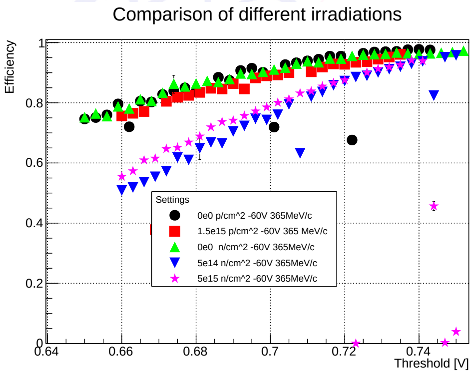
Outlook

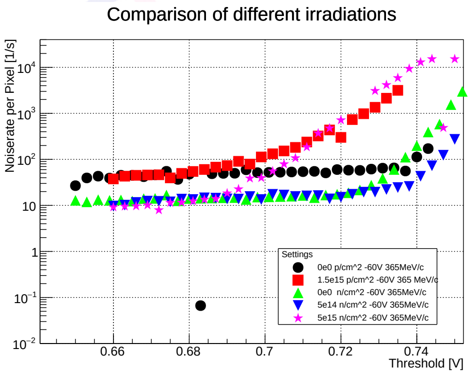
- new MuPix8 has circular transistors
- perform similar tests
- improve cooling setup
- optimize DAC settings for irradiated samples



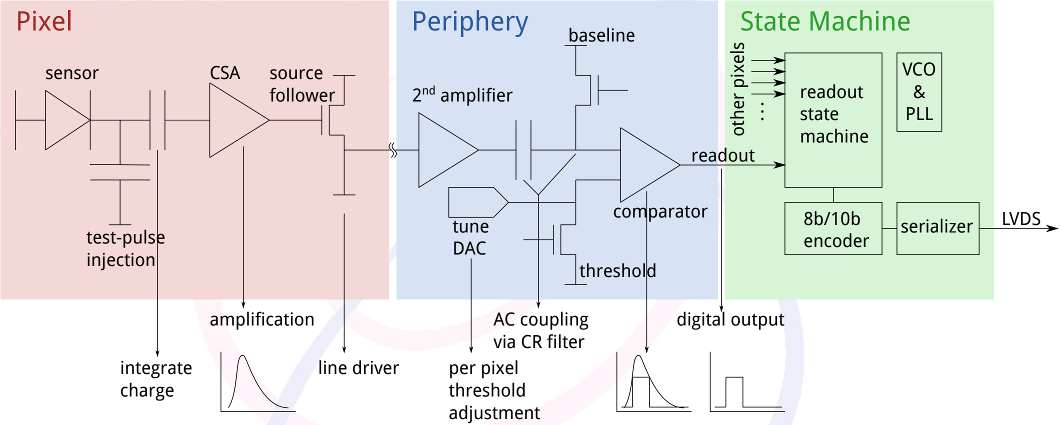
BACKUP

Comparison of different doses at $-60\,V$





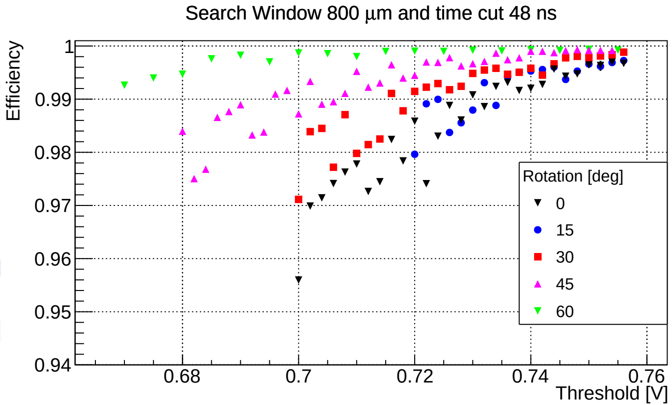
MuPix7 II



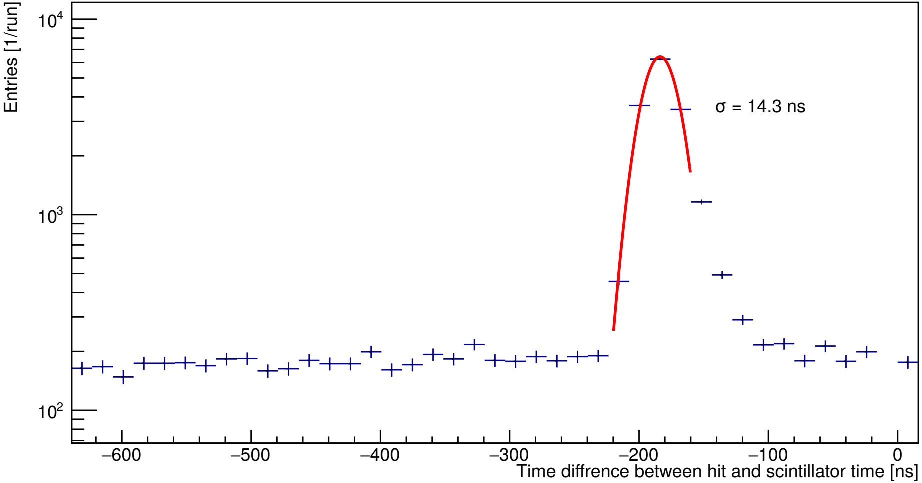
Pixel
sensor
CSA
source
follower
test-pulse
injection
Periphery
baseline
2nd amplifier
tune
DAC
comparator
threshold
readout
State Machine
other pixels
readout
state
machine
VCO
&
PLL
8b/10b
encoder
serializer
LVDS
amplification
integrate
charge
line driver
per pixel
threshold
adjustment
AC coupling
via CR filter
digital output

Efficiency Studies using the MuPix Telescope II

- dut rotated
- thicker effective depletion zone higher signal - more efficient
- similar effect with higher substrate resistivity
- new prototype!

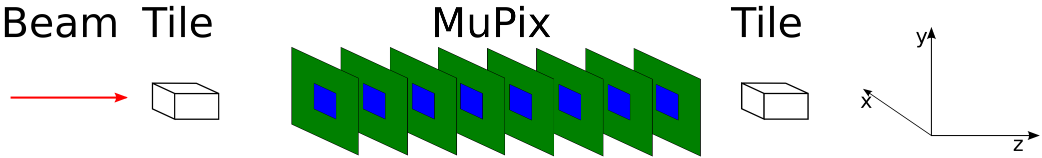


Time Resolution



Concept

Idea: Build a tracking telescope from Mu3e detector components to test read out, synchronization and carry out test beams



Use one pixel layer as device under test (dut)