The MuPix Telescope - Working Principle, Performance and MuPix Test Beam Results

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

Motivation

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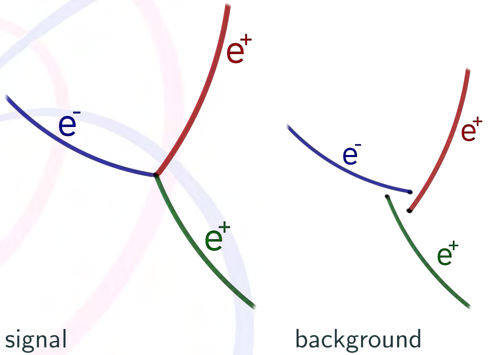
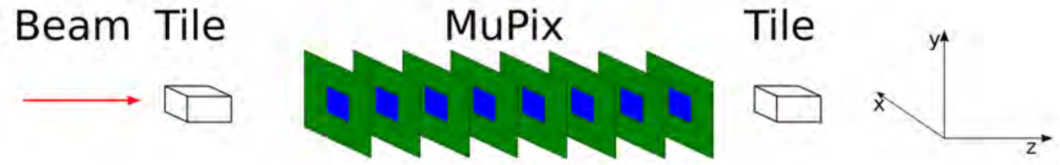
- new physics searches at low momenta require thin and fast pixel sensors e.g. Mu3e: search for $\mu^+ \rightarrow e^+ e^- e^+$
- Mu3e pushes HV-MAPS development $\rightarrow$ requires a lot of test beams and integration studies
- we need a test setup, that combines multiple aspects of the Mu3e detector



The MuPix Telescope

Concept

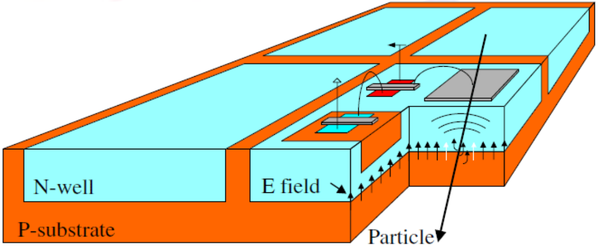
Idea: Build a tracking telescope from Mu3e detector components to test read out, synchronization and carry out test beams



Use one pixel layer as device under test (dut)

HighVoltage - MonolithicActivePixelSensors (HV-MAPS)

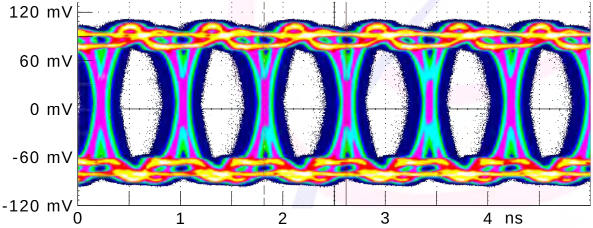
(I.Peric, P. Fischer et al., NIM A 582 (2007) 876)

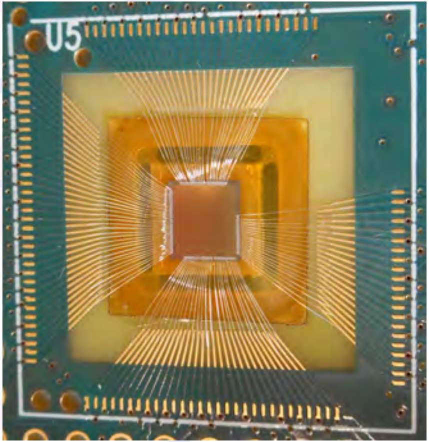


- digital position and time read out
- 80 x 80 µm^2 pixel size
- 256 x 256 pixel
- 2 x 2 cm^2 total size
- $\sigma_t < 11$ ns measured
- efficiency > 99.5 % measured
- 50 µm thin $\approx 0.05\%$ radiation length

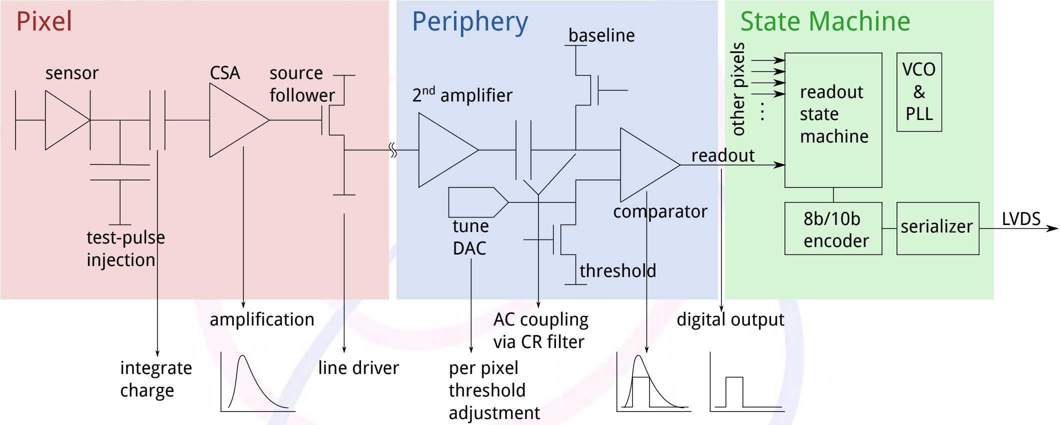
MuPix 7

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

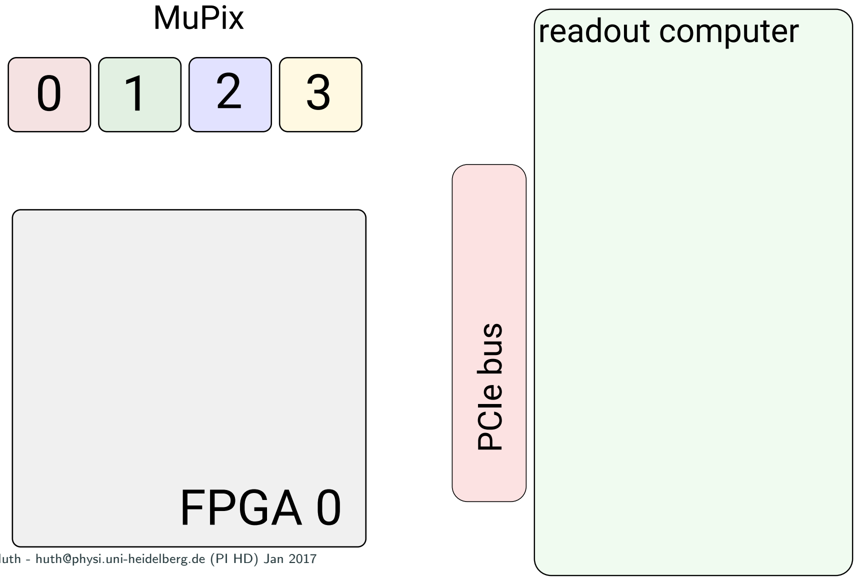




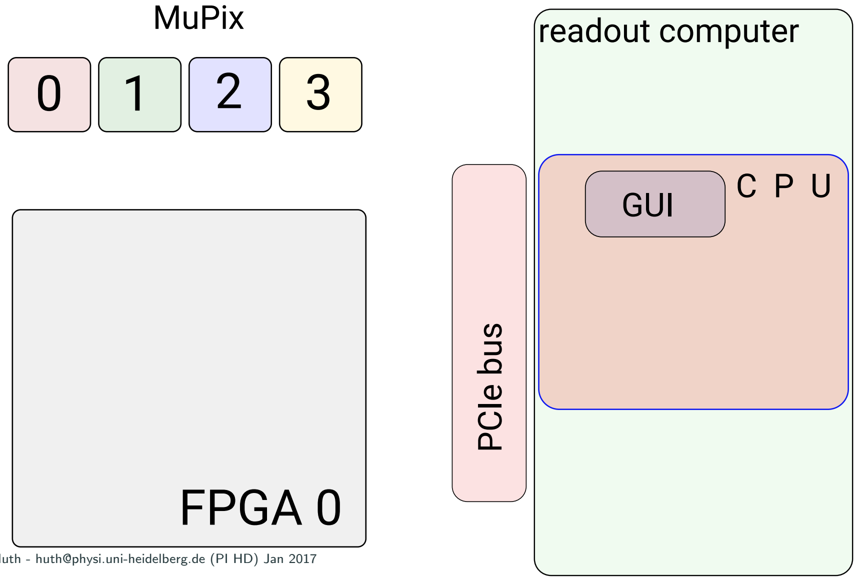
MuPix7 II


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

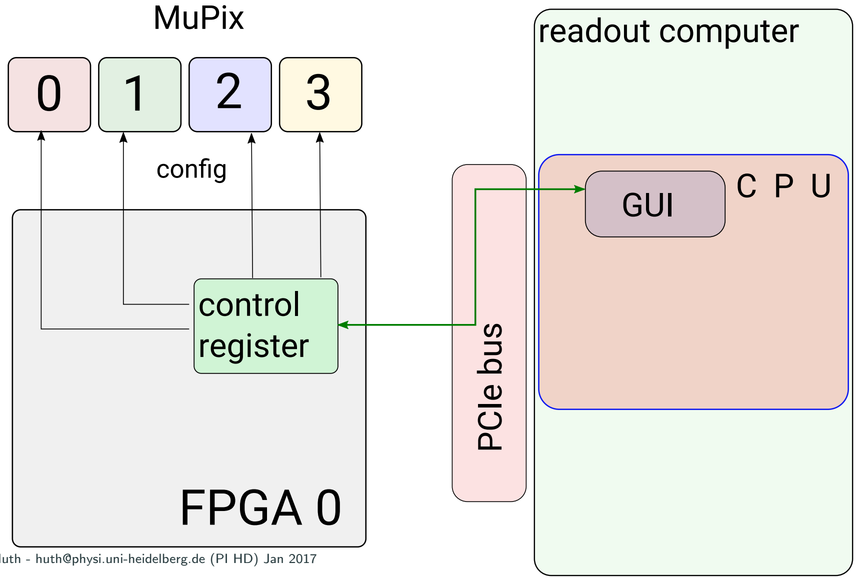
Readout and Control Scheme



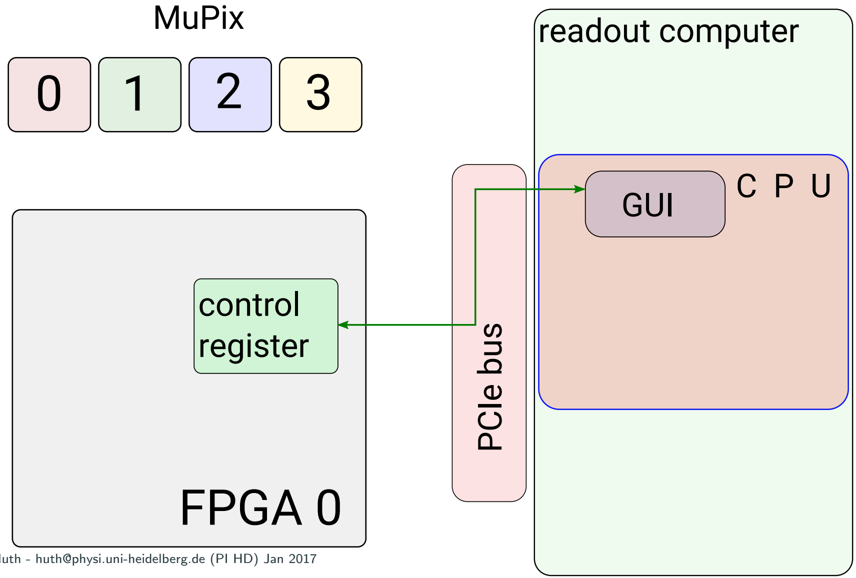
Readout and Control Scheme



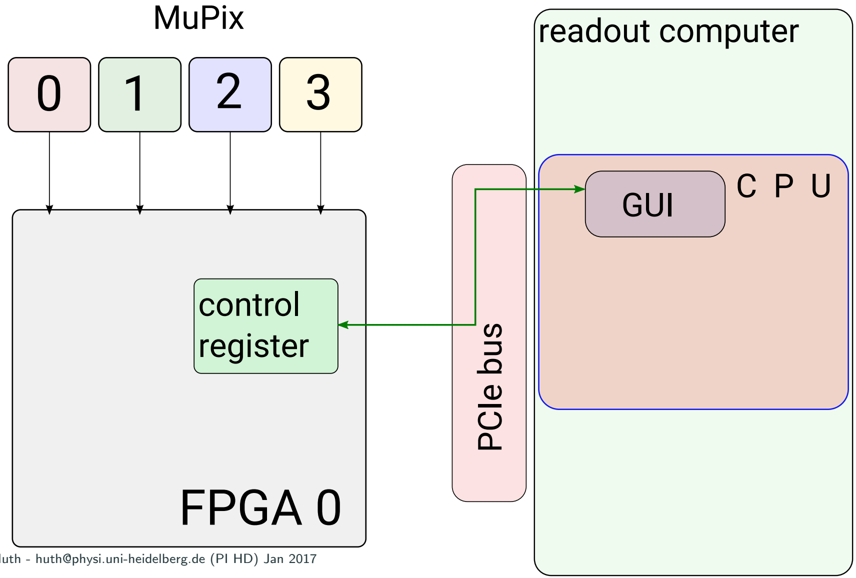
Readout and Control Scheme



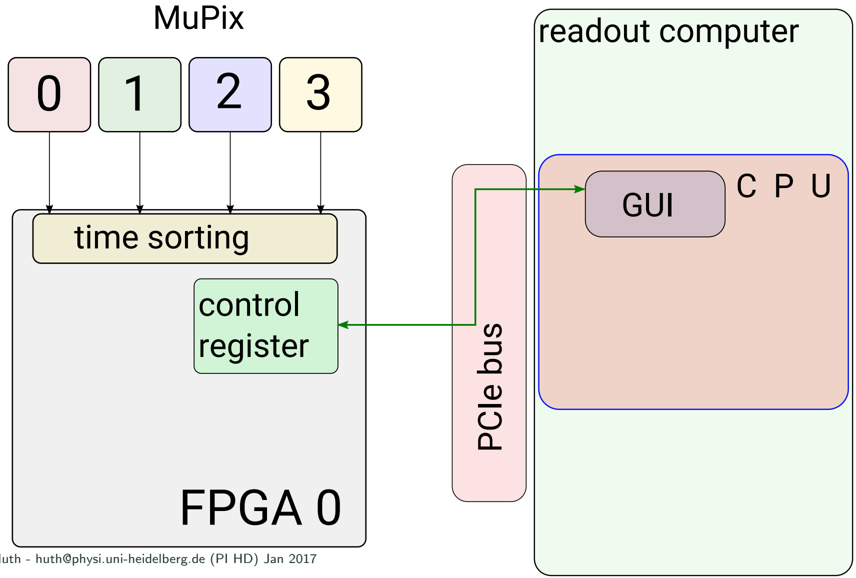
Readout and Control Scheme



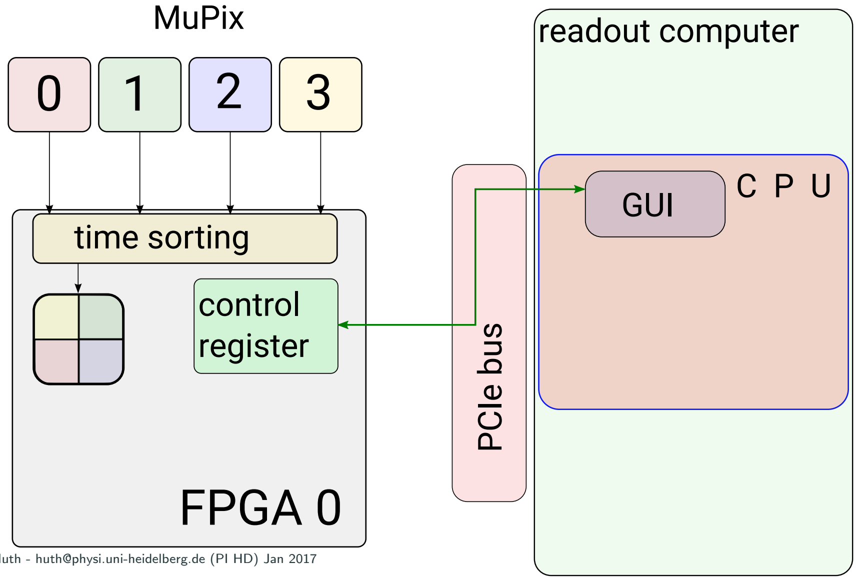
Readout and Control Scheme



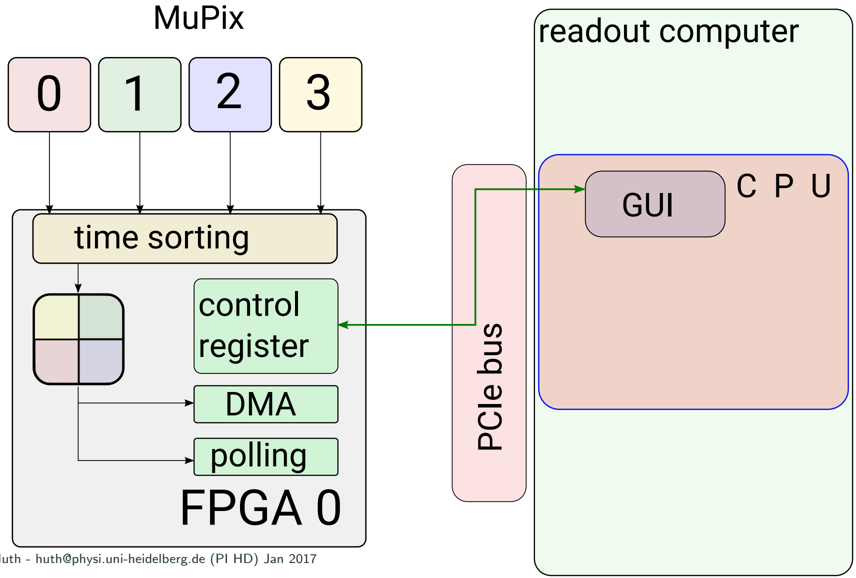
Readout and Control Scheme



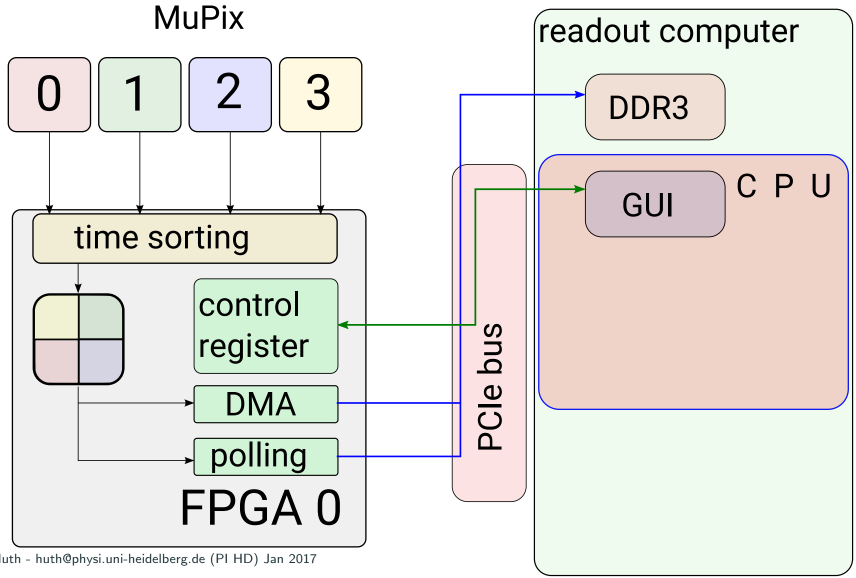
Readout and Control Scheme



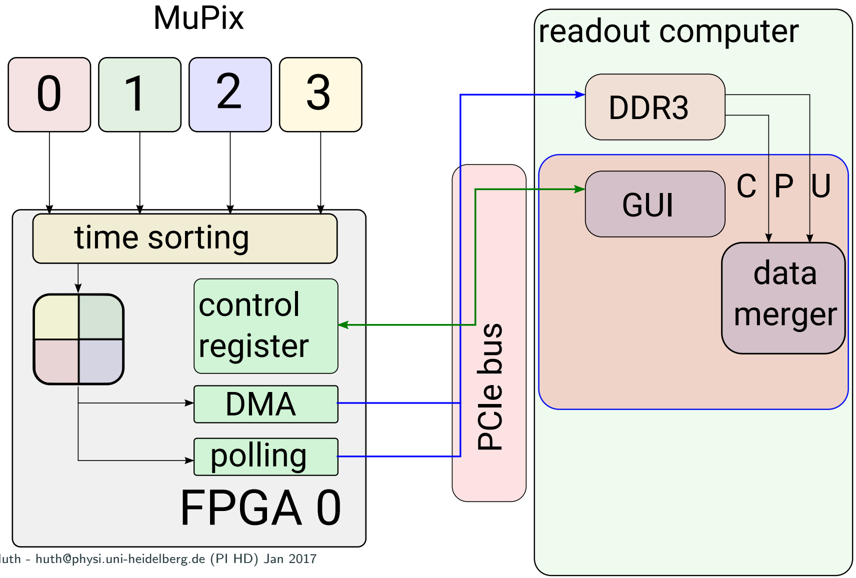
Readout and Control Scheme



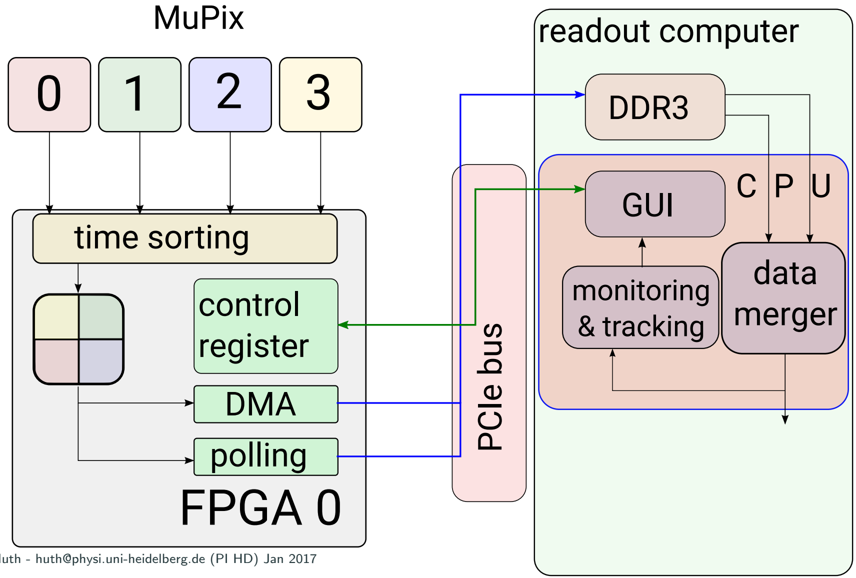
Readout and Control Scheme



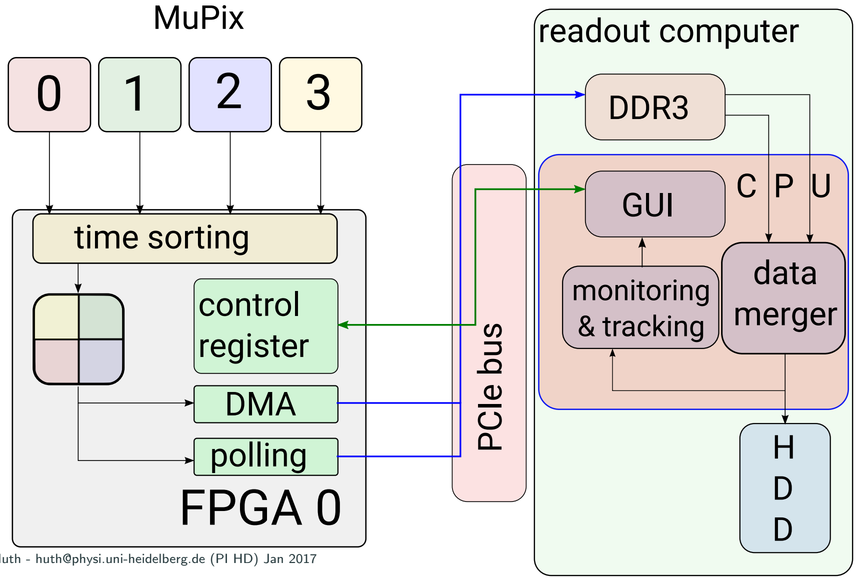
Readout and Control Scheme



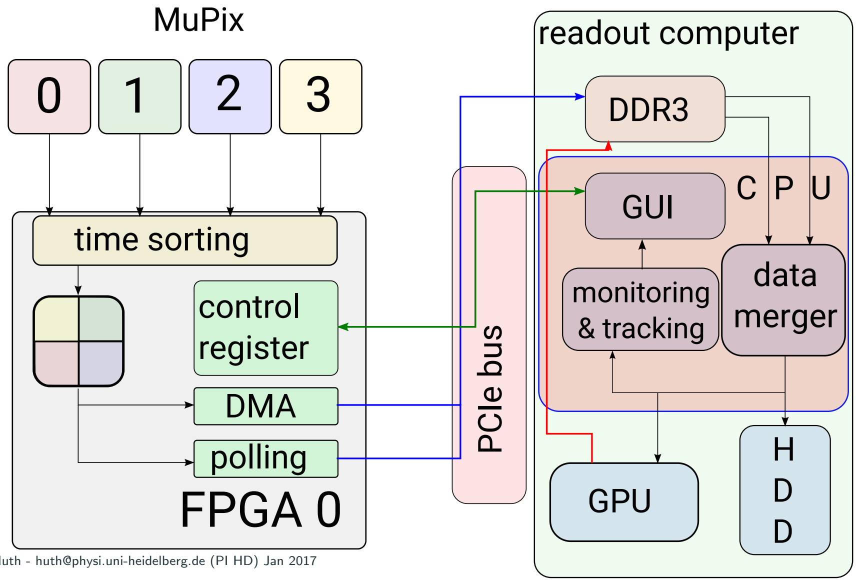
Readout and Control Scheme



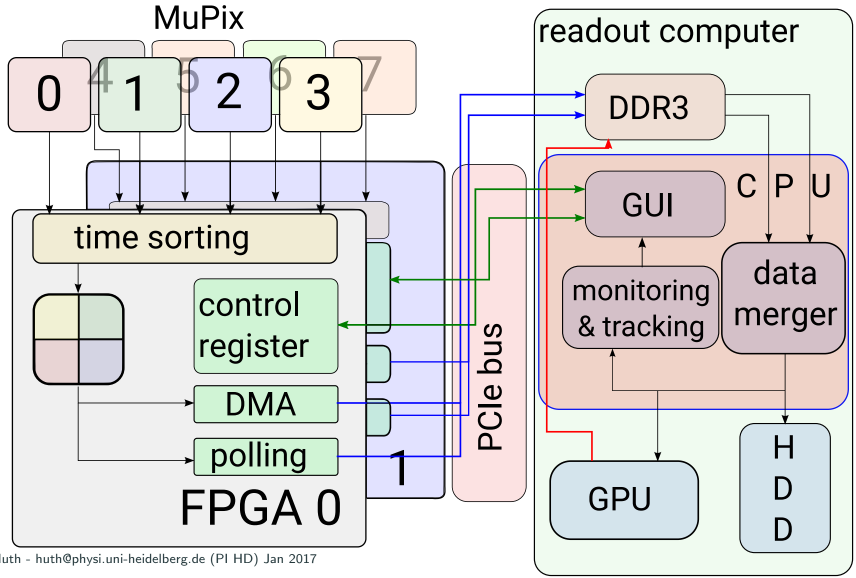
Readout and Control Scheme



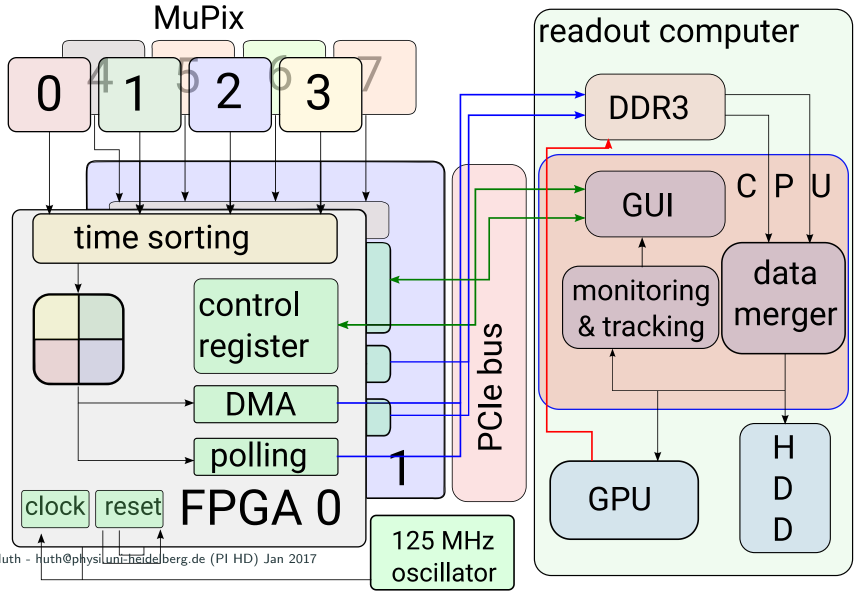
Readout and Control Scheme



Readout and Control Scheme



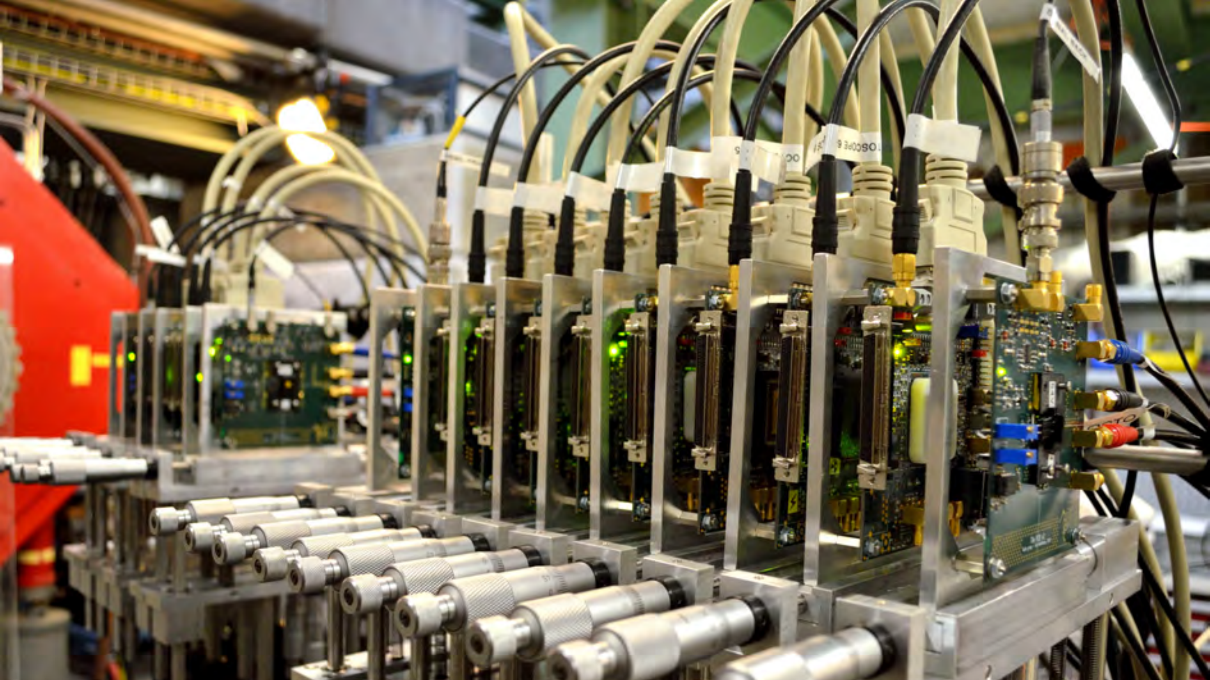
Readout and Control Scheme



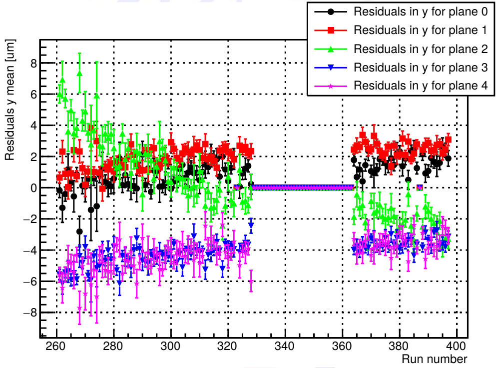
Telescope Design Goals

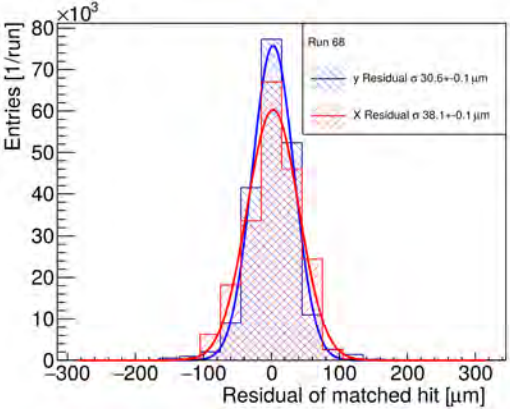
	target	current status
pixel size [μm]	80x80	103x80
# layers	4	8
track rate [MHz]	20	1
material budget per layer	50 μm sensor	50 μm sensor
	25 μm support	100 μm support
radiation length ‰	0.6	0.9
time resolution σ [ns]	17	1 (tiles)
		14 (mupix)

Test Beam Results

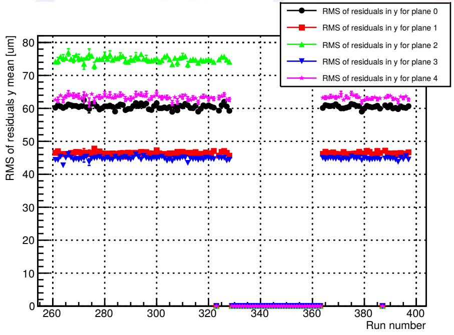


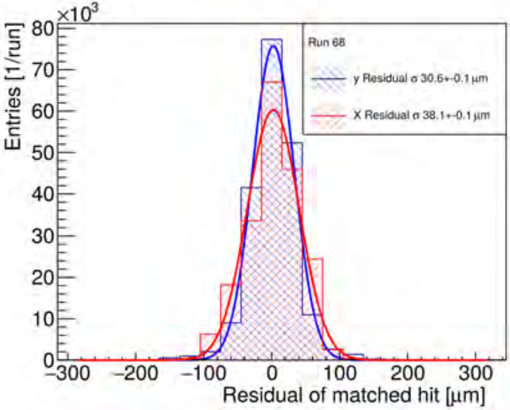
Alignment & Resolution



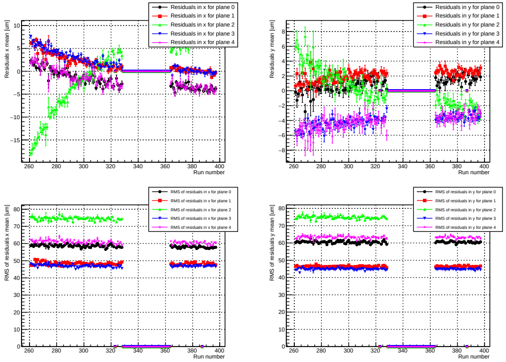


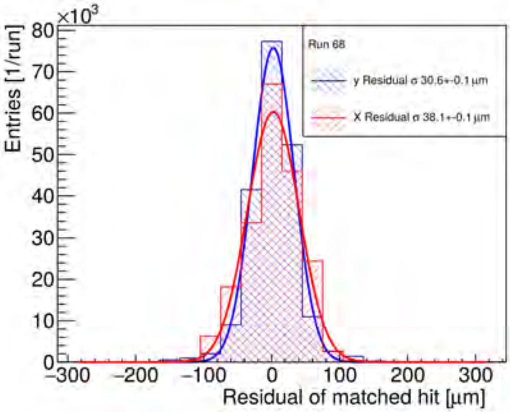
Alignment & Resolution



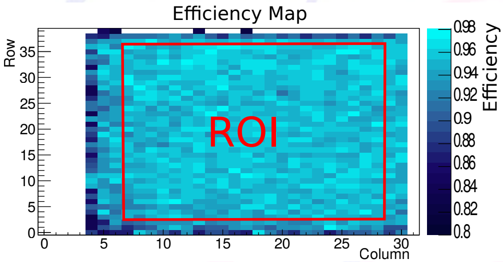


Alignment & Resolution

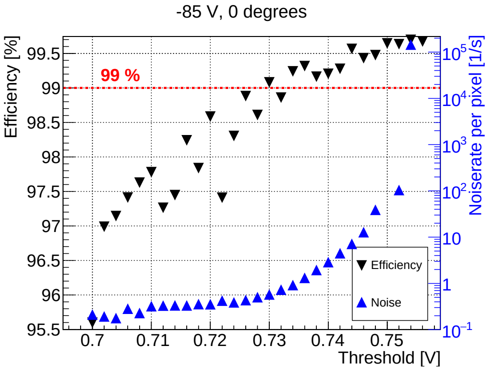




Efficiency Studies using the MuPix Telescope

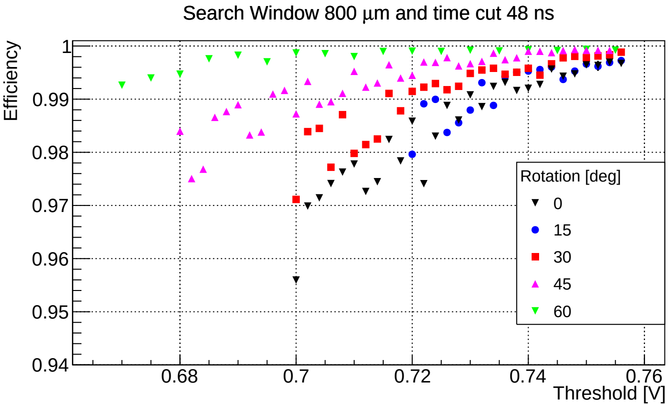


define ROI to eliminate sensor edge effects

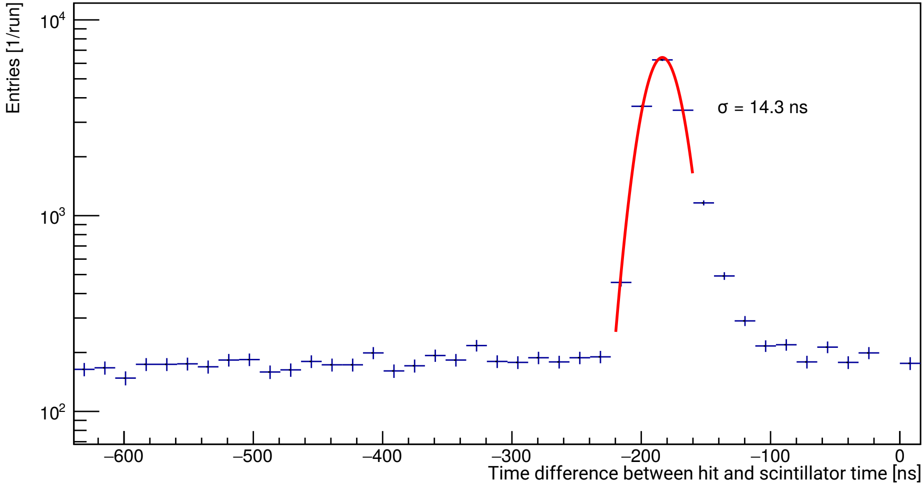


Efficiency Studies using the MuPix Telescope II

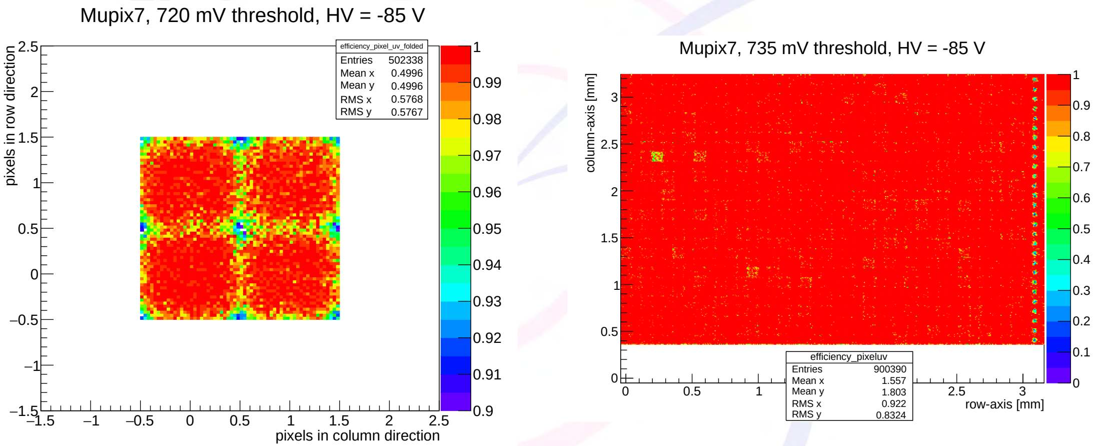
- dut rotated
- thicker effective depletion zone
  higher signal - more efficient
- similar effect with higher
  substrate resistivity
- new prototype!



Time Resolution



Studies using the Duranta Telescope



Conclusion & Outlook

Conclusion

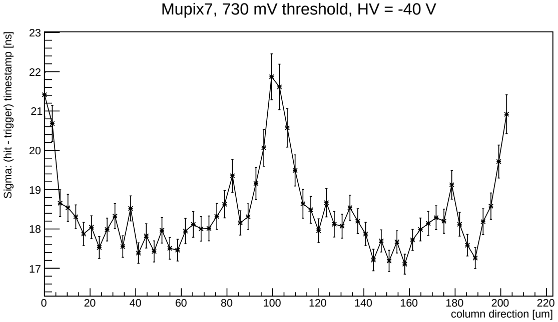
- MuPix Telescope is a crucial tool for system integration and test beam studies
- thin and fast telescope: 0.9 ‰ X/X_0 per layer and 1 MHz track rate
- intensively used to study MuPix7:
  99.5% efficiency
  14 ns time resolution
- will also be used with next prototype generation

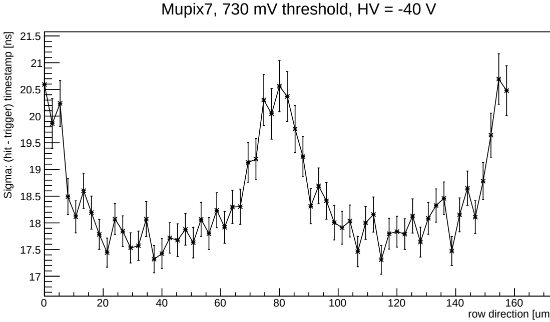
Outlook

- integrate the MuPix8
- improve user friendliness

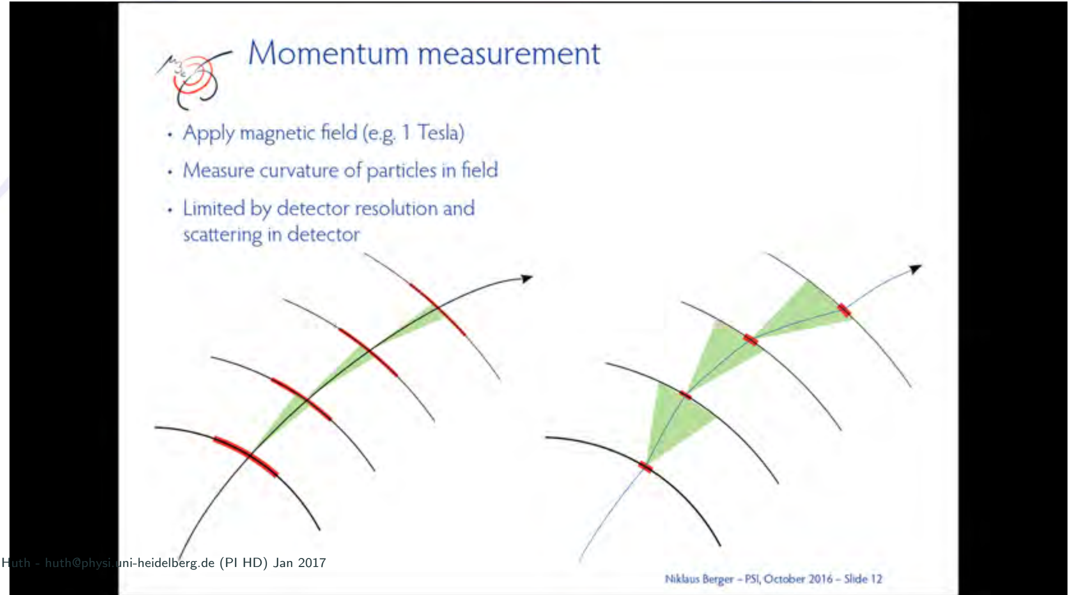
BACKUP

Time Resolution with DURANTA





Tracking in MS regime



Track Model

Trackmodel: Straight track without scattering

$$\vec{x}(z) = \vec{x_0} + \vec{a} \cdot z$$

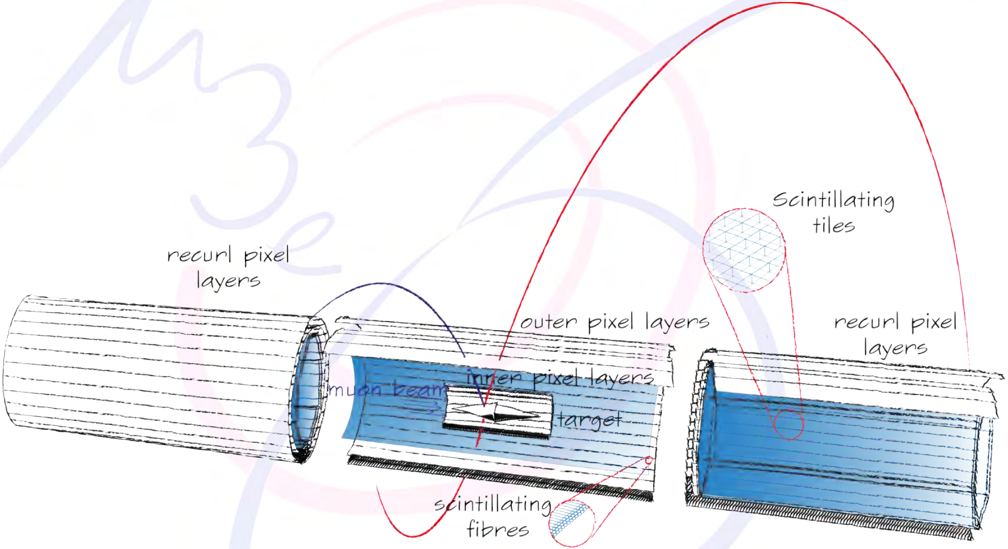
$\rightarrow \mathcal{X}^2$ can be analytically minimized

$$\mathcal{X}^2 = \sum_{i=1}^{n} \left(\frac{(x_i - (x_0 + a_x \cdot z_i))^2}{\sigma_{x_{m_i}}^2} + \frac{(y_i - (y_0 + a_y \cdot z_i))^2}{\sigma_{y_{m_i}}^2} \right)$$

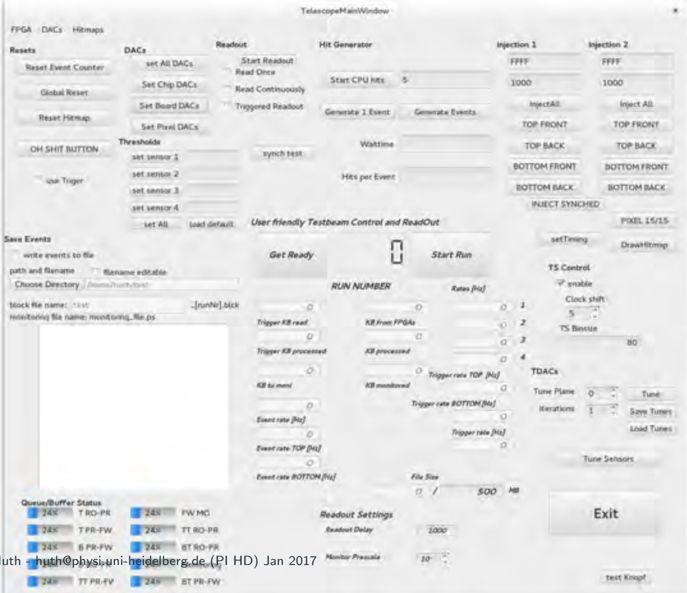
assuming $\sigma_{x/y_{m_i}} = \text{pixel resolution} = \frac{\text{pixel size}}{\sqrt{12}}$

$\rightarrow$ Fast and robust track model!

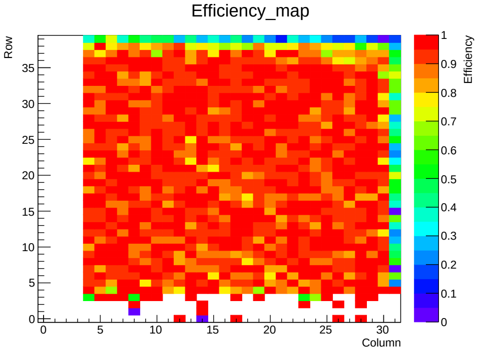
Mu3e Detector

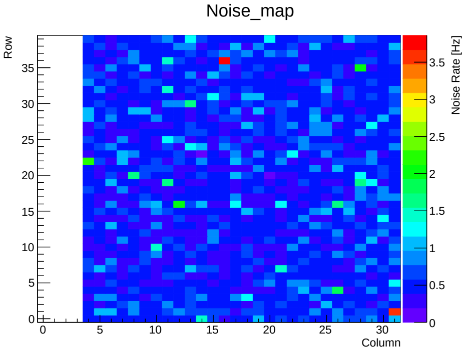


GUI

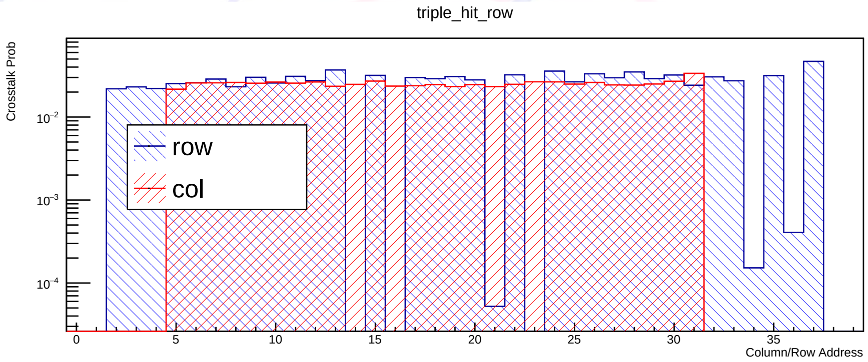

TelescopeMainWindow
FPGA
DACs
Hitmaps
Resets
Reset Event Counter
Global Reset
Reset Hitmap
OH SHIT BUTTON
use Triger
DACs
set All DACs
Set Chip DACs
Set Board DACs
Set Pixel DACs
Thresholds
set sensor 1
set sensor 2
set sensor 3
set sensor 4
set All
load default
Readout
Start Readout
Read Once
Read Continuously
Triggered Readout
synch test
Hit Generator
Start CPU hits
5
Generate 1 Event
Generate Events
Waittime
Hits per Event
Injection 1
Injection 2
FFFF
1000
InjectAll
Inject All
TOP FRONT
TOP BACK
BOTTOM FRONT
BOTTOM BACK
INJECT SYNCHED
PIXEL 15/15
setTiming
DrawHitmap
User friendly Testbeam Control and ReadOut
Get Ready
Start Run
RUN NUMBER
Rates [Hz]
Save Events
write events to file
path and filename
filename editable
Choose Directory
block file name:
_[runNr].blck
monitoring file name: monitoring_file.ps
Trigger KB read
Trigger KB processed
KB from FPGAs
KB processed
KB monitored
Event rate [Hz]
Event rate TOP [Hz]
Event rate BOTTOM [Hz]
Trigger rate TOP [Hz]
Trigger rate BOTTOM [Hz]
Trigger rate [Hz]
File Size
500
MB
TS Control
enable
Clock shift
TS Binsize
80
TDACs
Tune Plane
Iterations
Tune
Save Tunes
Load Tunes
Tune Sensors
Exit
Queue/Buffer Status
T RO-PR
T PR-FW
B PR-FW
TT PR-FW
FW MO
TT RO-PR
BT RO-PR
BT PR-FW
Readout Settings
Readout Delay
1000
Monitor Prescale
10
test Knopf

Efficiency/Noise map



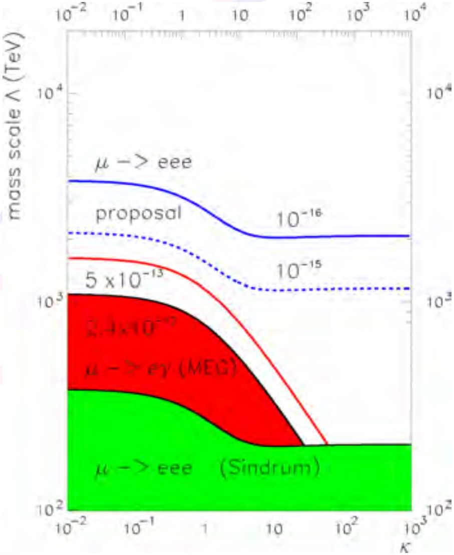


Crosstalk

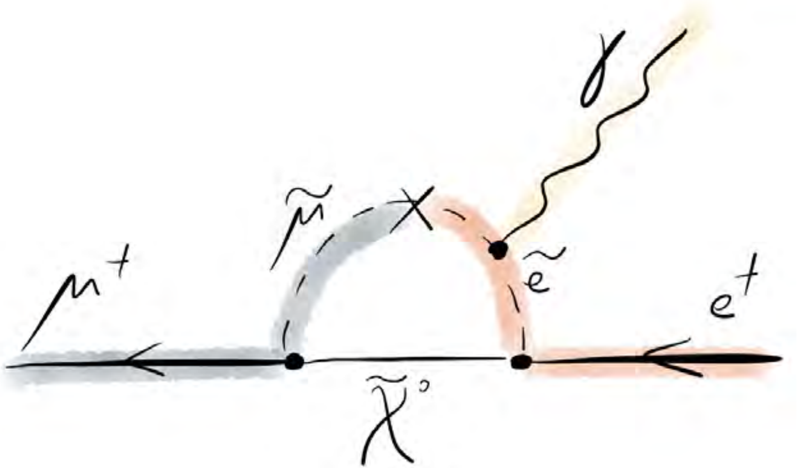


triple_hit_row
Crosstalk Prob
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
30
35
Column/Row Address
row
col

Mass Scale Sensitivity



$\mu \to e\,\gamma$



Muon decays history