A HV-MAPS Pixel Tracker for the Mu3e Experiment

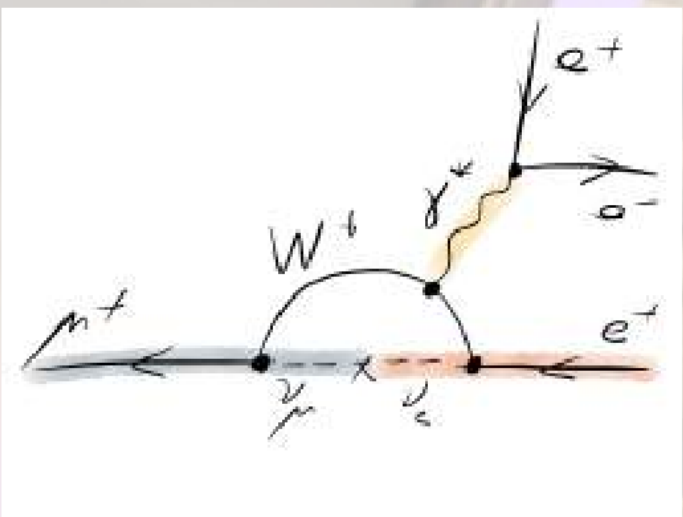
Heiko Augustin

Physikalisches Institut Heidelberg

DPG Spring Meeting
T72.1
02. March 2016

Mu3e

The Physics Goal



- $\mu^+ \rightarrow e^+e^-e^+$ suppressed to a BR below 10^{-54} in the Standard Model
- Any observed signal is a sign for new physics
- Current limit BR $< 10^{-12}$ (SINDRUM)
- Aiming for sensitivity of 1 in 10^{16} decays

SINDRUM: "Search for the decay muto3e" Nucl. Phys.,B299 1, 1988

Mu3e

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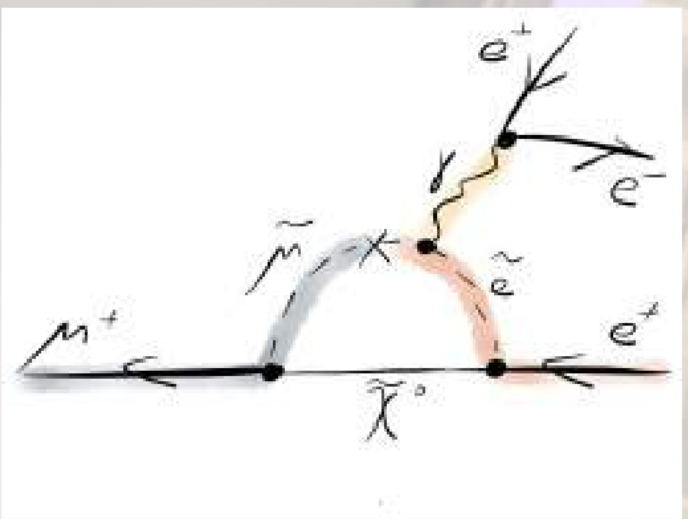

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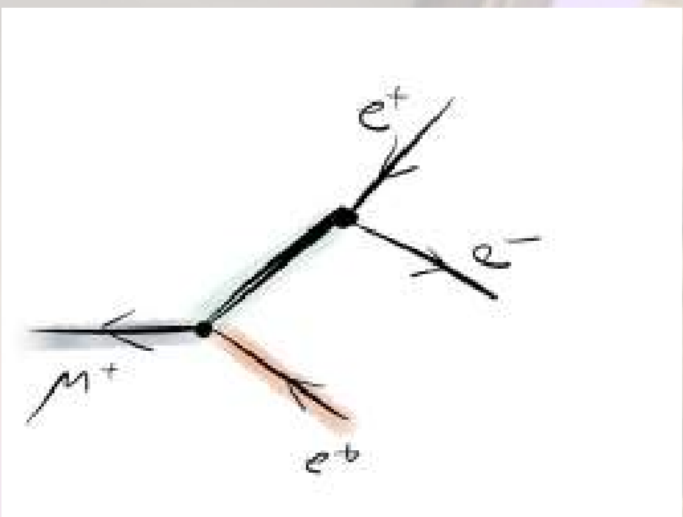

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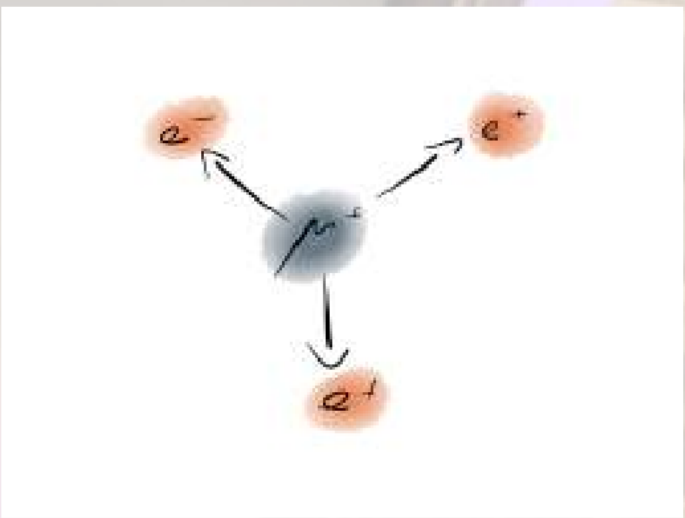
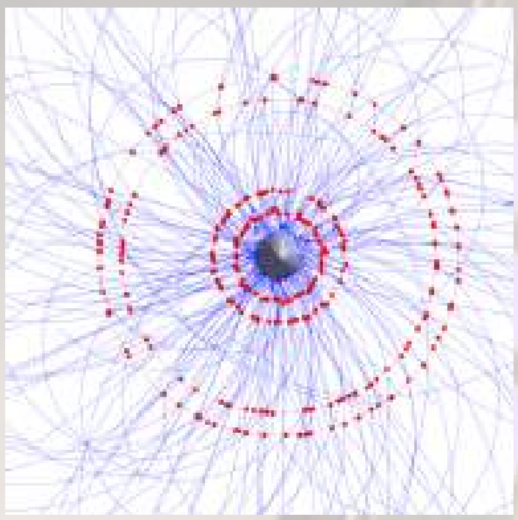
The Signal Decay

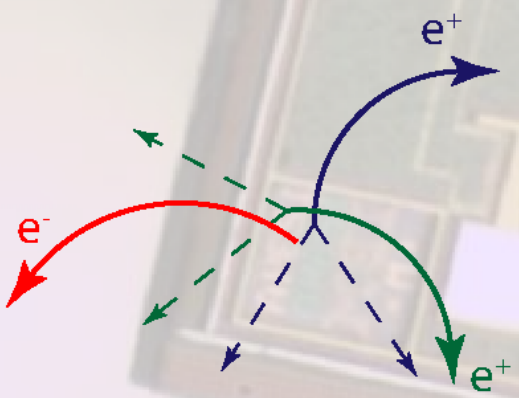


- Muons decay at rest: $\Sigma \vec{p} = 0$
- Common vertex and coincident in time
- Maximal momentum 53 MeV/c
- Reconstruct invariant mass from charged particle tracks ($E_{tot} = m_{\mu}$)

The Background

Accidental & Combinatorial

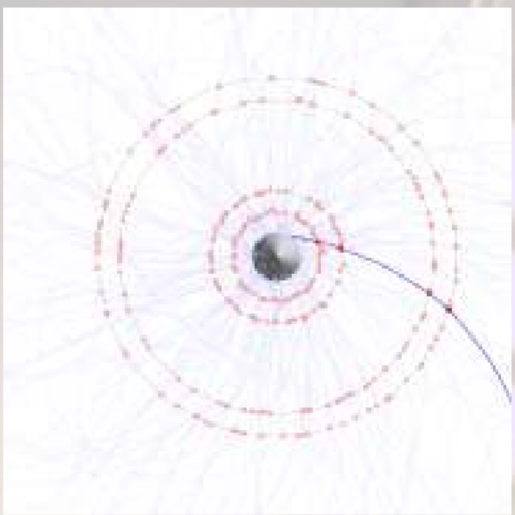


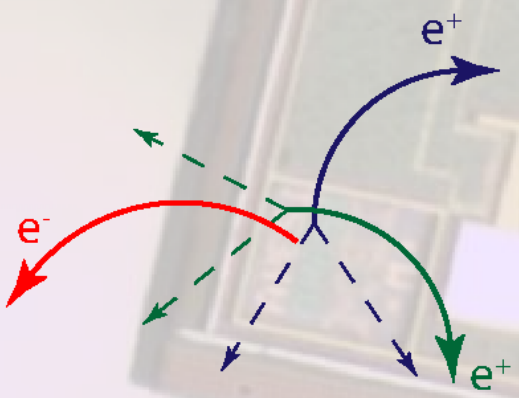


- 10^9 decays per second
- Gives rise to accidental & combinatorial background
- Good time and vertex resolution needed

The Background

Accidental & Combinatorial





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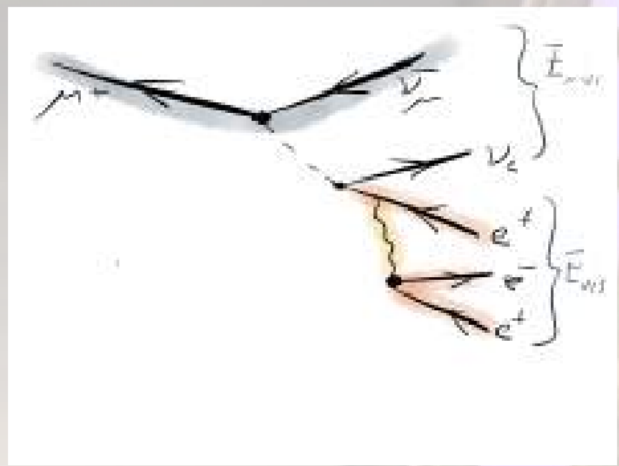
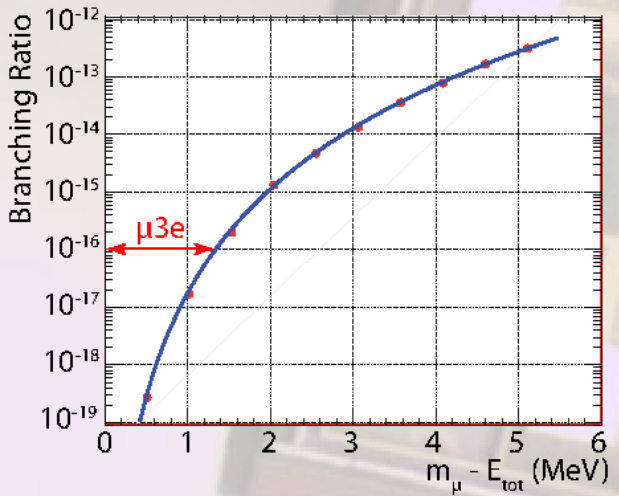
The Background

Irreducible





R.M.Djilkibaev and R.V.Konoplich, Phys.Rev., D79 073004, 2009

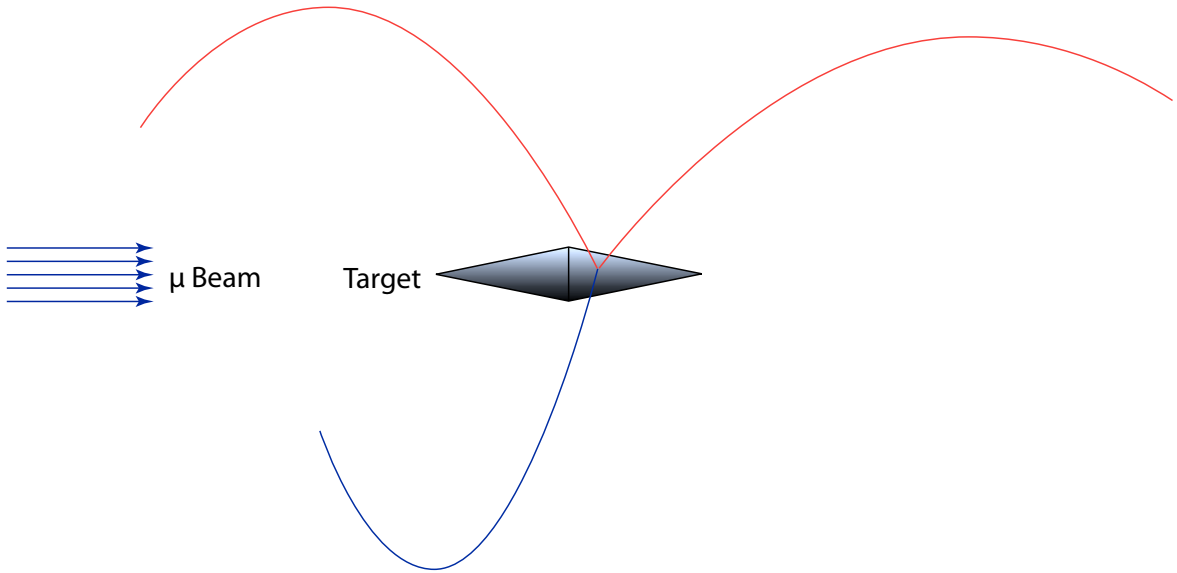
- Irreducible background from radiative decays with internal conversion: $\mu^+ \to e^+e^-e^+\bar{\nu}_\mu\nu_e$
- Good momentum resolution needed to suppress SM background
- Momentum resolution is dominated by multiple scattering $\propto \sqrt{x}/p$

The Detector

1T magnetic field

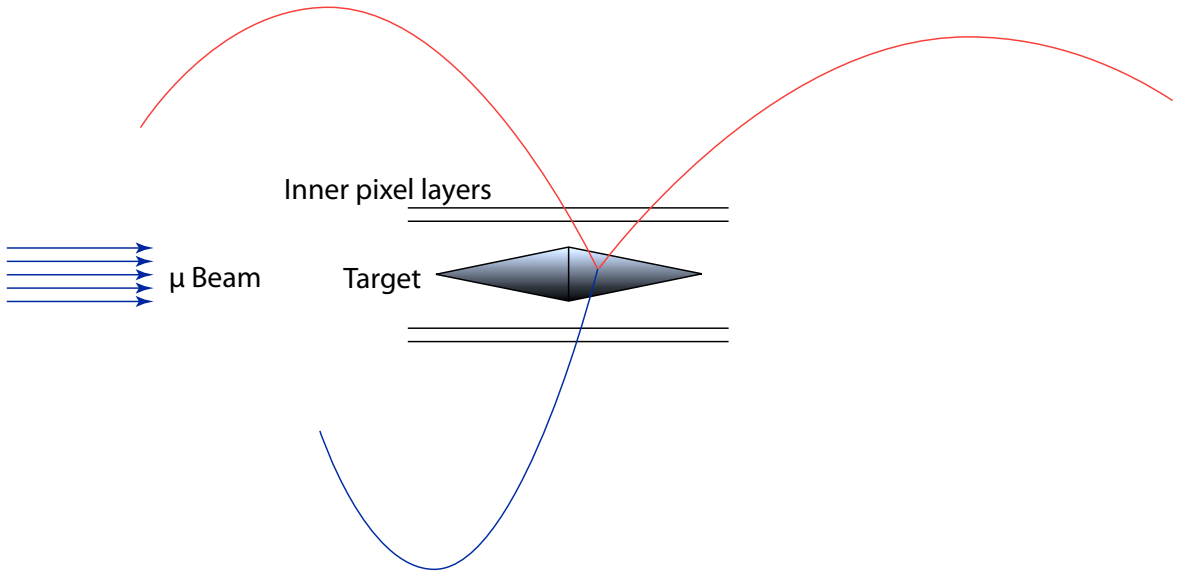
The Detector

1T magnetic field



The Detector

1T magnetic field



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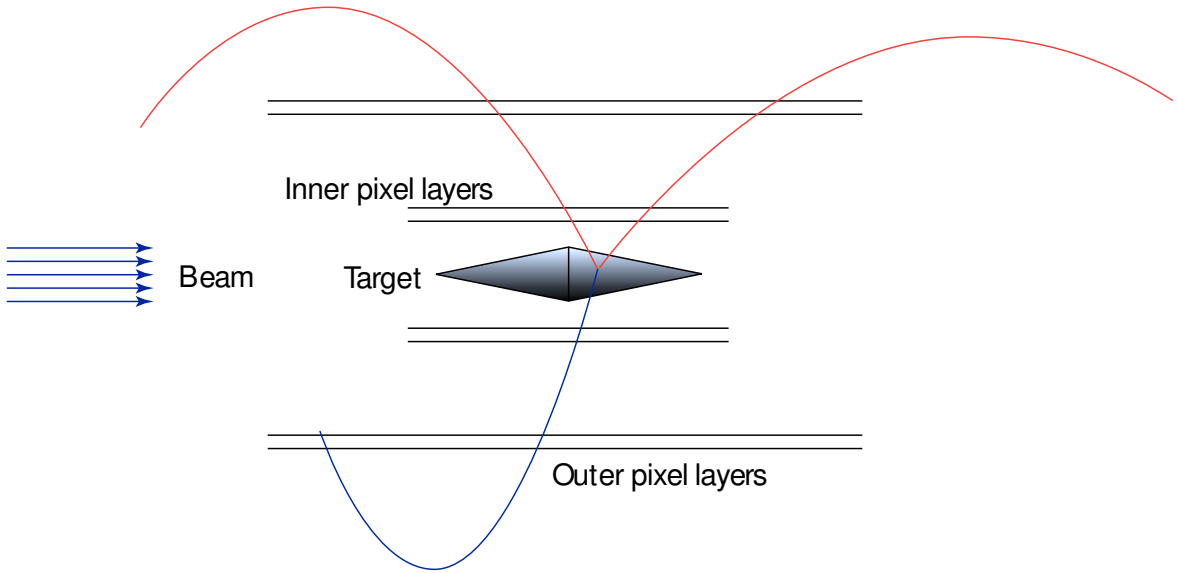
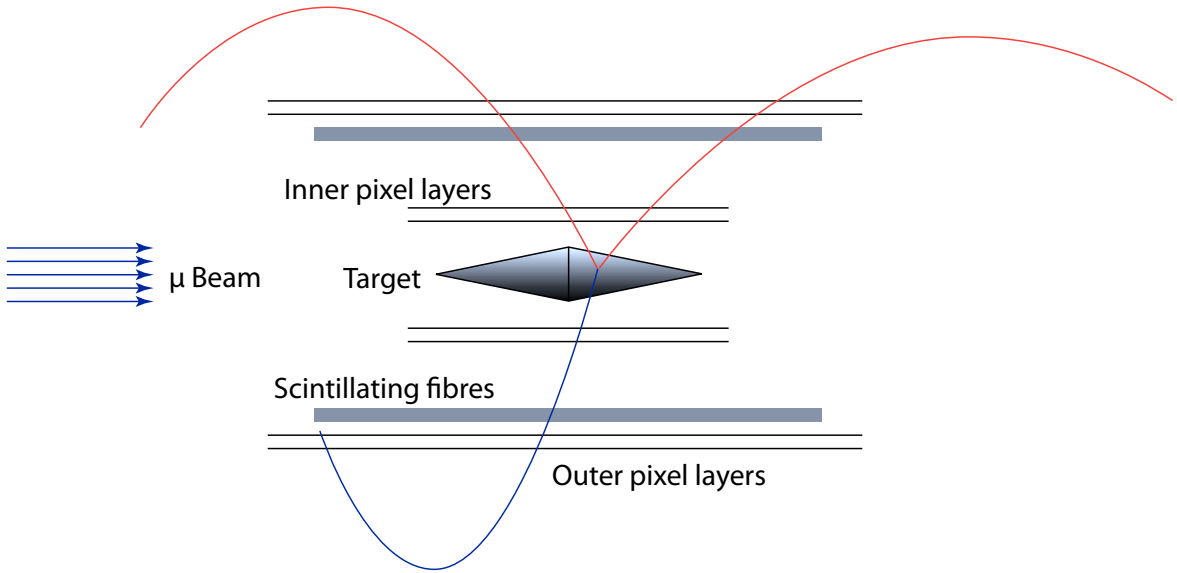


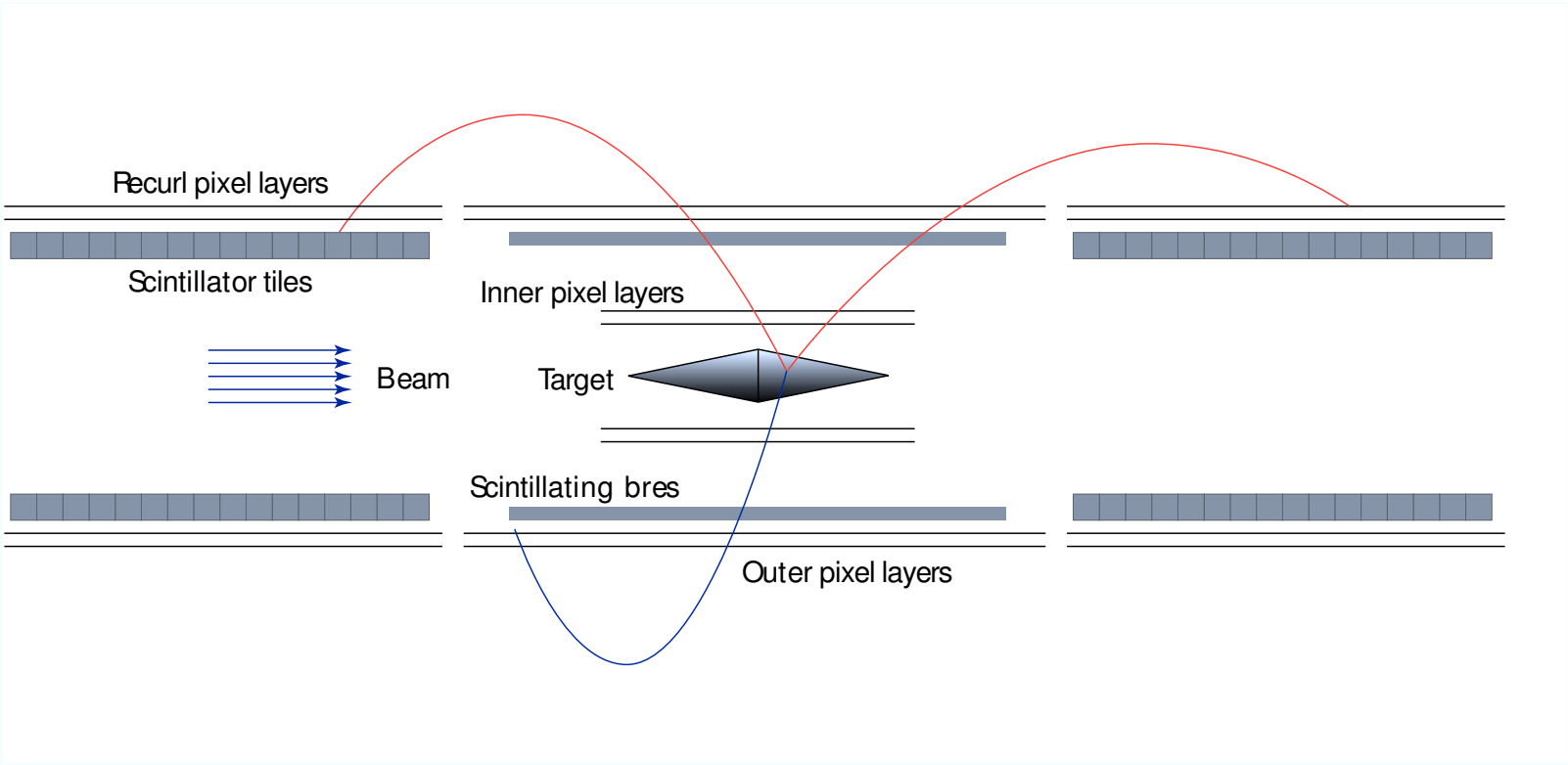
The Detector

1T magnetic field

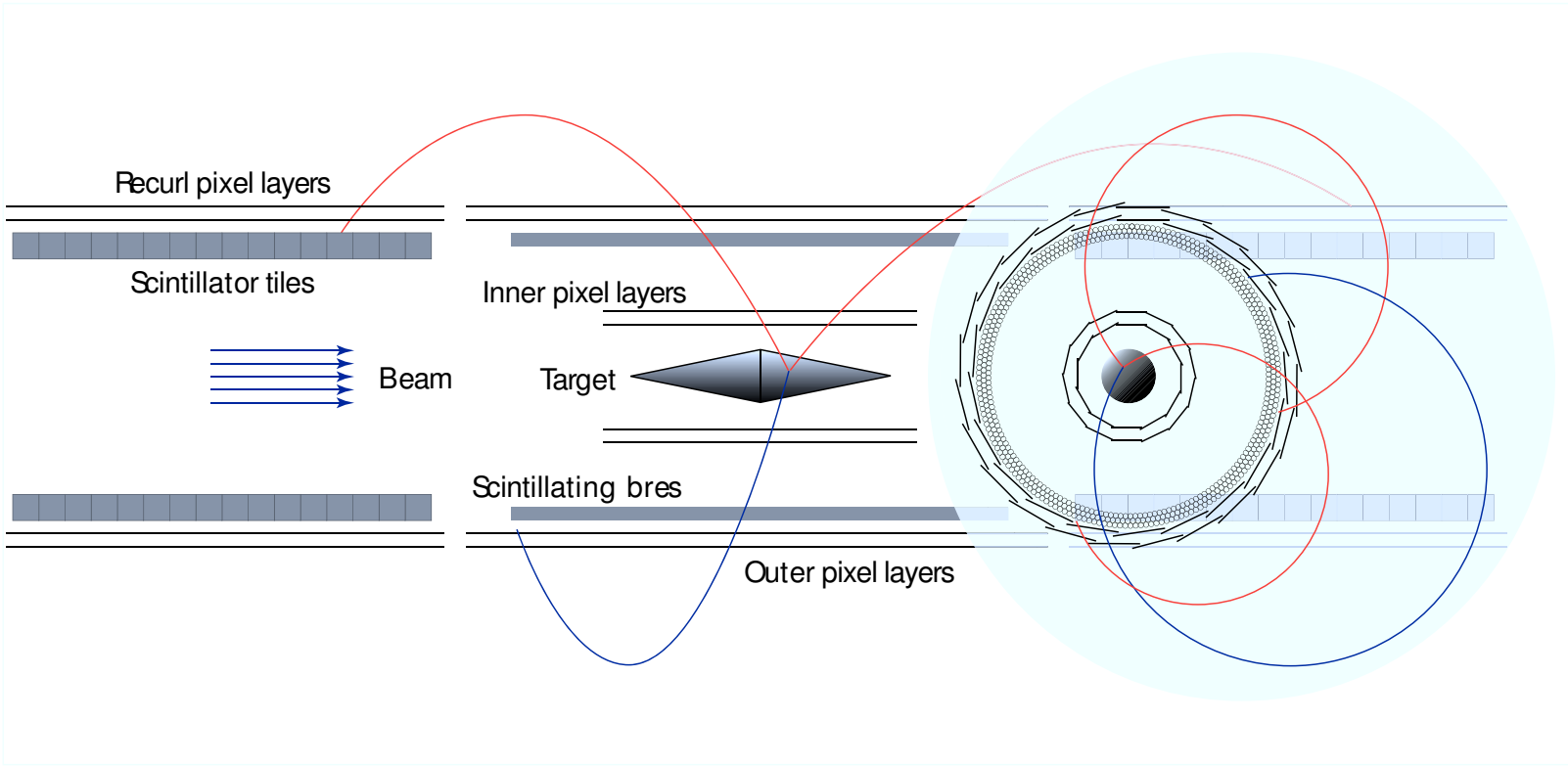


The Detector

1T magnetic field



The Requirements for the Silicon Pixel Tracker



- Good vertex resolution
- Good time resolution & low dead time
  $\rightarrow$ fast signal generation & shaping
- Good momentum resolution $\rightarrow$ low material budget

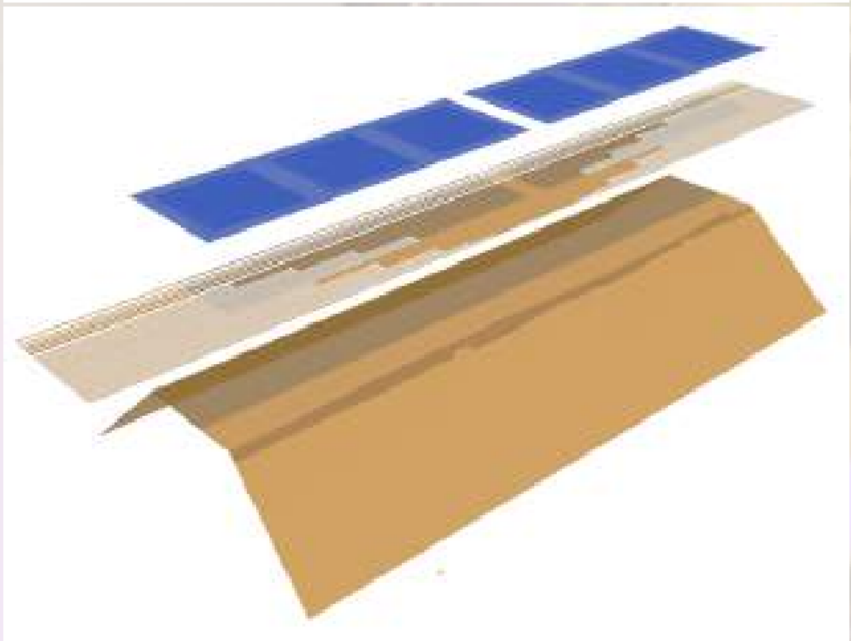
The Requirements for the Silicon Pixel Tracker

Pixel Sensor Requirements

Pixel Size	Time Resolution	Material Budget	Efficiency
$80 \times 80\,\mu m^2$	$< 20\,ns$	$< 1‰\ X_0$/layer	$> 99\%$

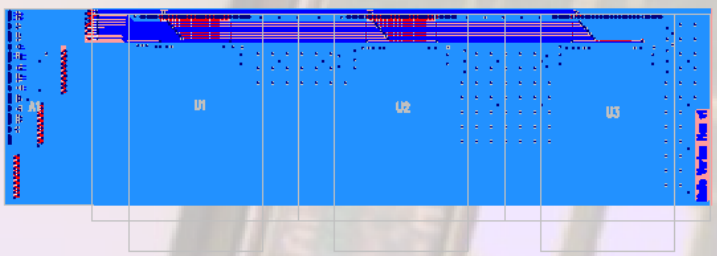
- Good vertex resolution
- Good time resolution & low dead time
  $\rightarrow$ fast signal generation & shaping
- Good momentum resolution $\rightarrow$ low material budget

The Pixel Tracker



- Readout & Powering via Flexprints: T42.7
- Cooling in Helium atmosphere: T75.2

The Pixel Tracker



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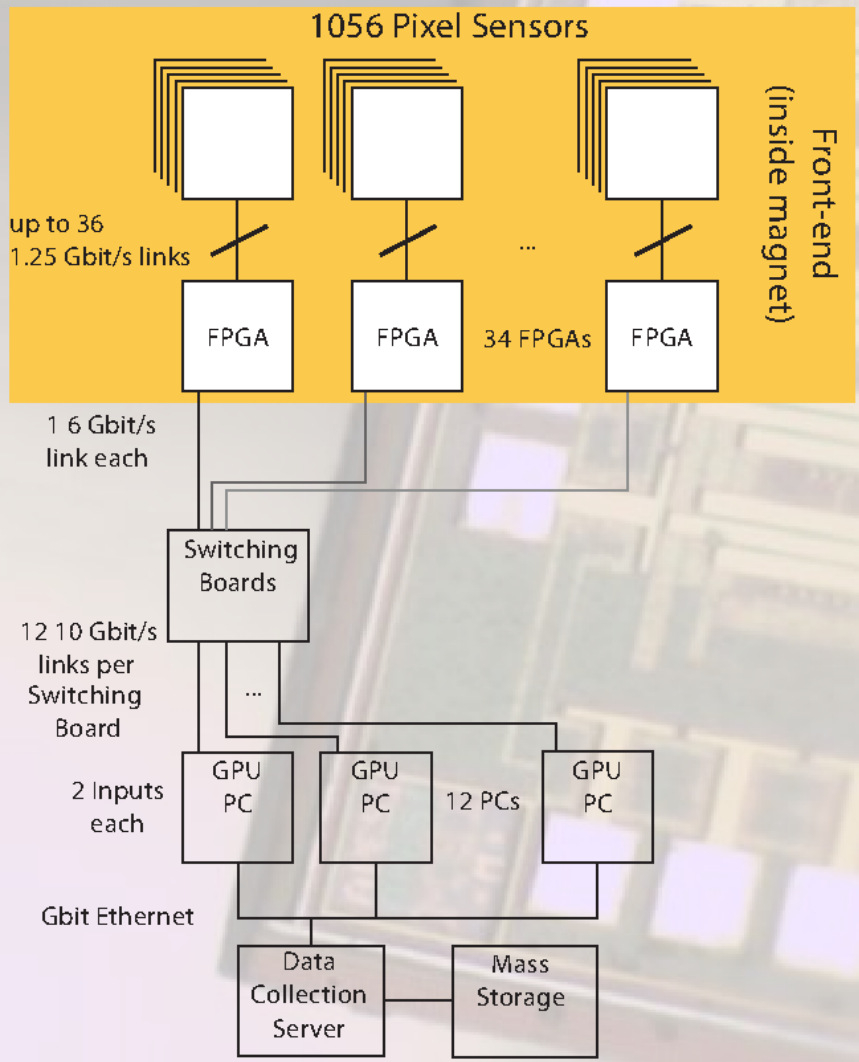
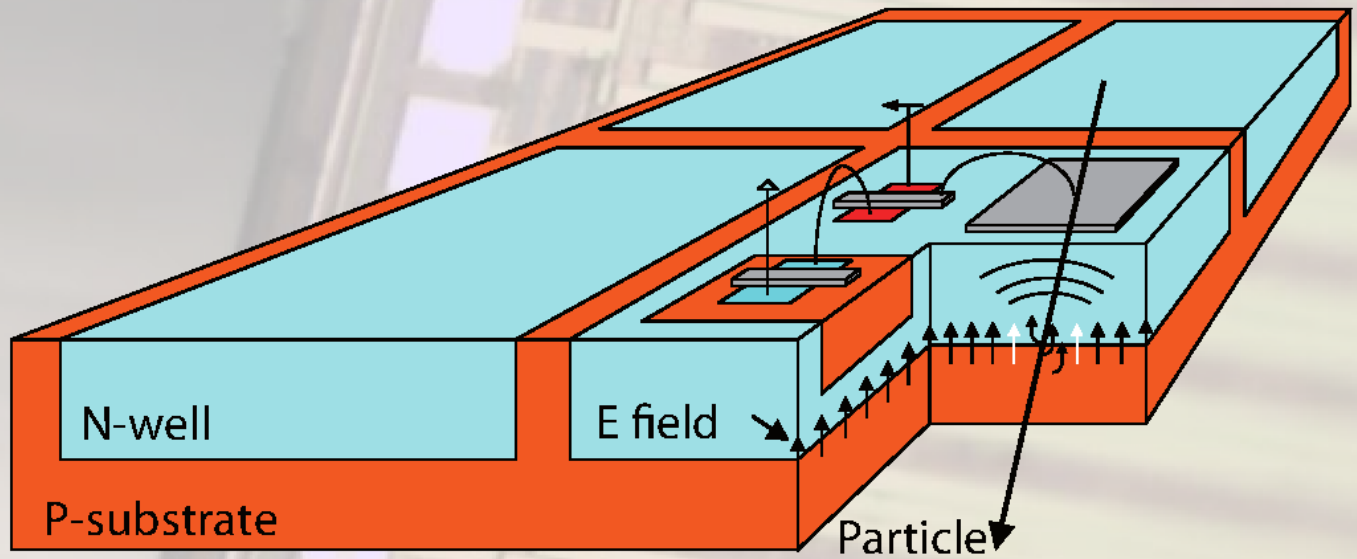
The Pixel Tracker

Readout



- Untriggered readout
- 1 Tbit/s raw data rate
- GPU based online reconstruction
- Sessions:
  T42.5, T42.6, T22.5, T22.4, T98.1, T98.5

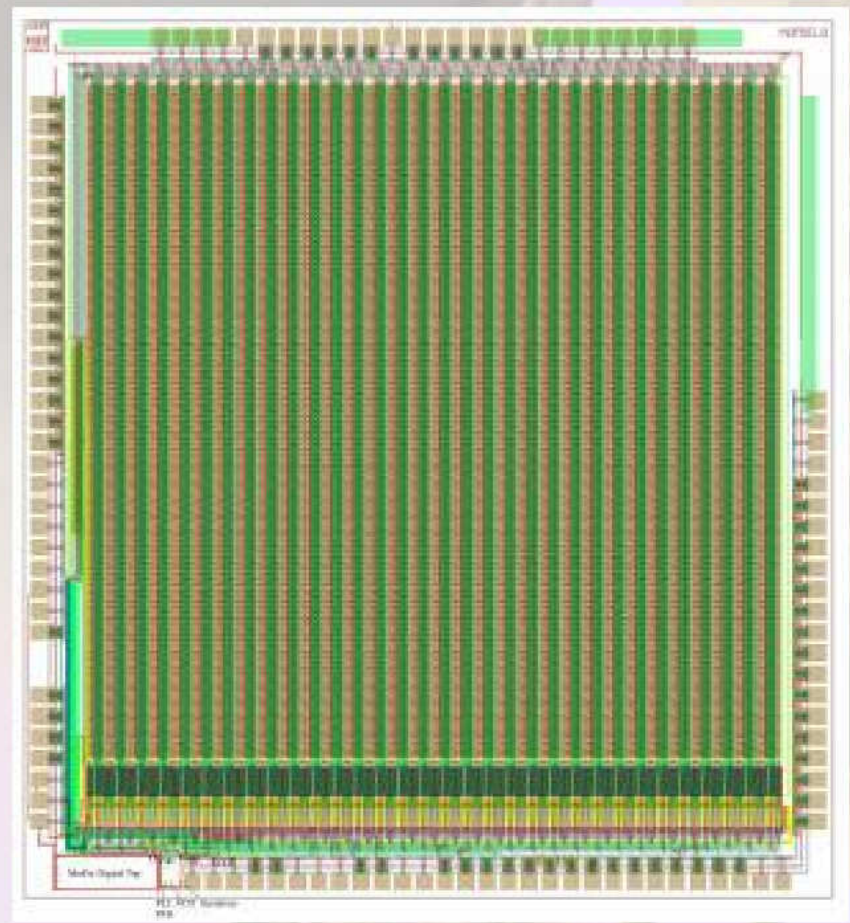
High Voltage Monolithic Active Pixel Sensors



I.Peric, P. Fischer et al., NIM A 582 (2007) 87

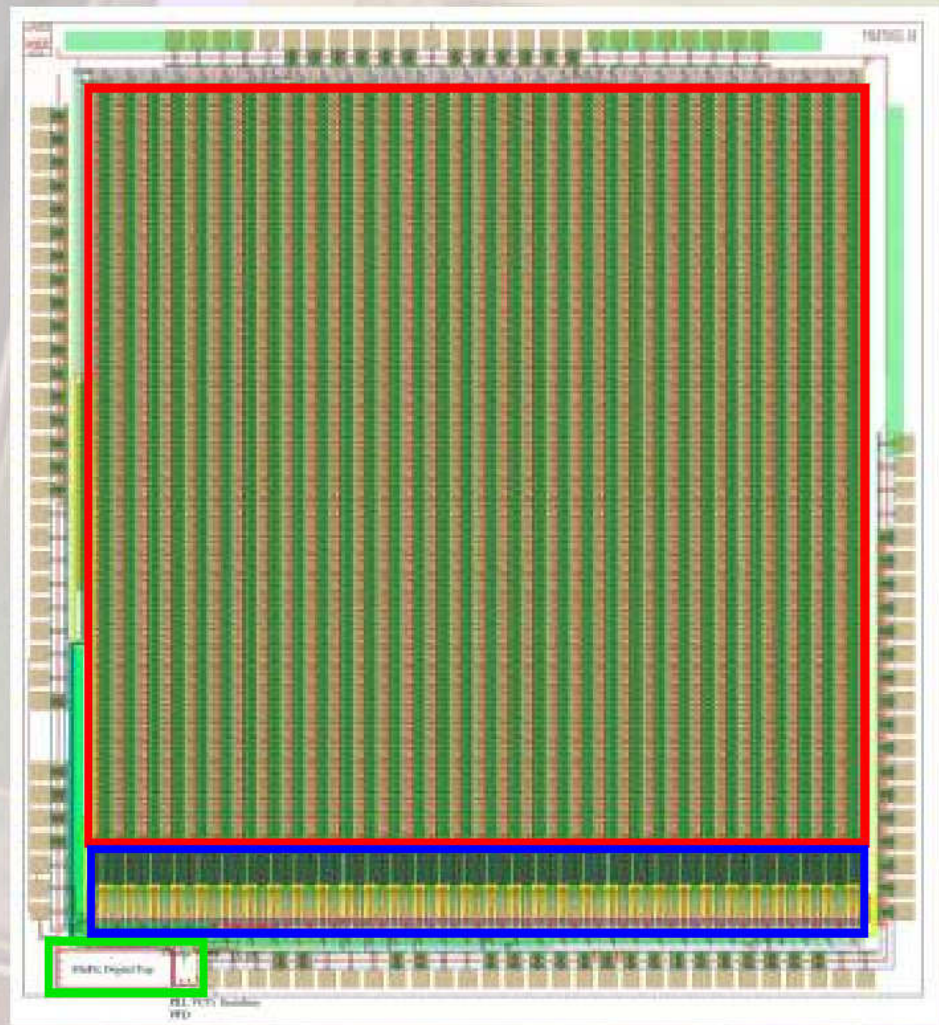
- Deep n-well in p-doped substrate
- Depleted area is the active detector volume $\approx 15\,\mu m$
- Fast charge collection via drift
- Sensor can be thinned to $< 50\,\mu m$

The MuPix7 Prototype



- Commercial 180 nm HV-CMOS process
- Thinned to 50 µm

The MuPix7 Prototype



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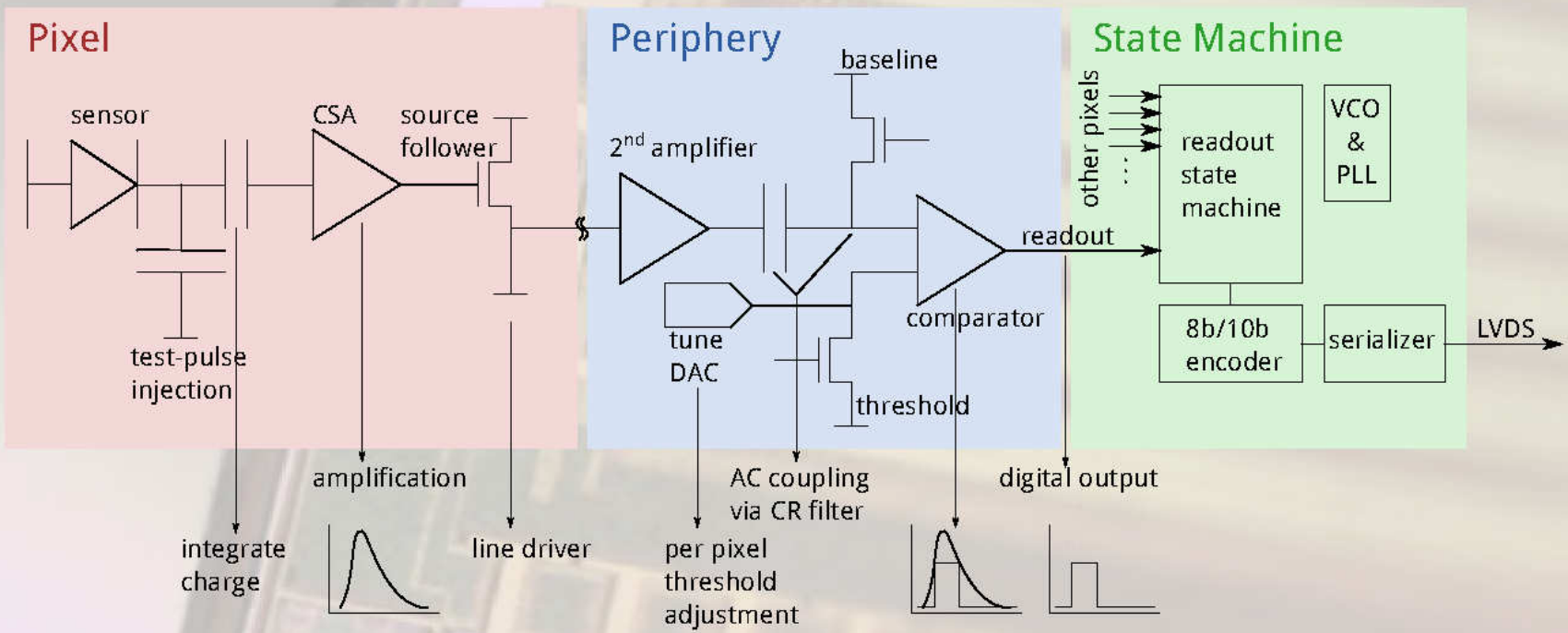
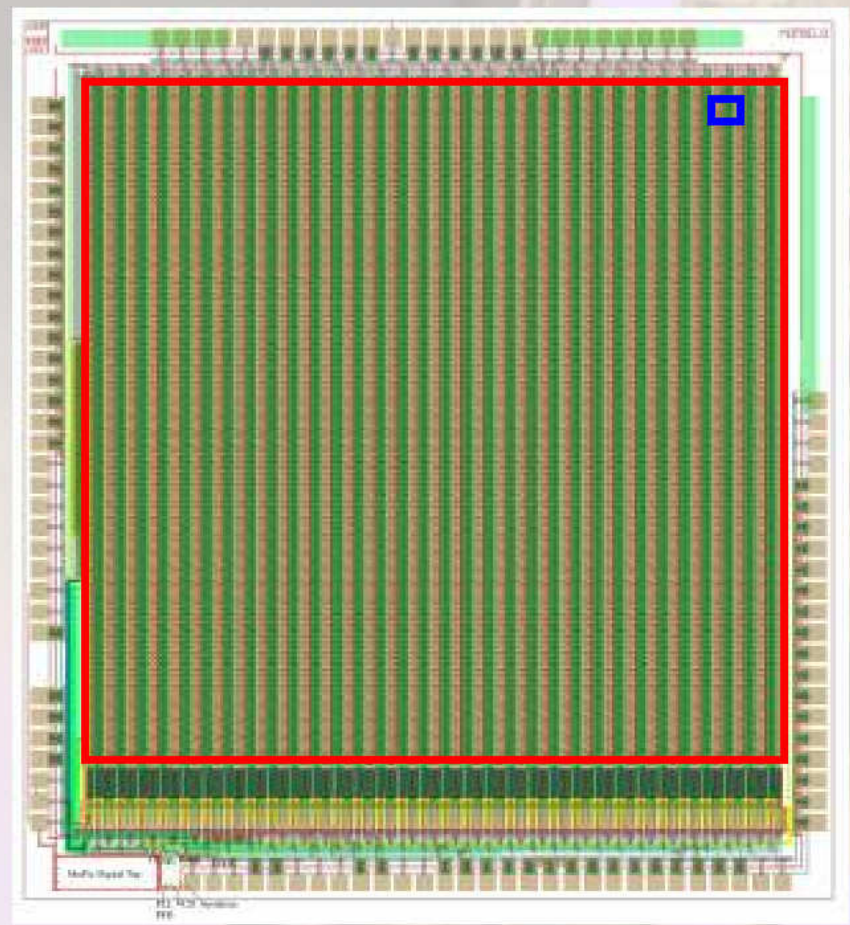
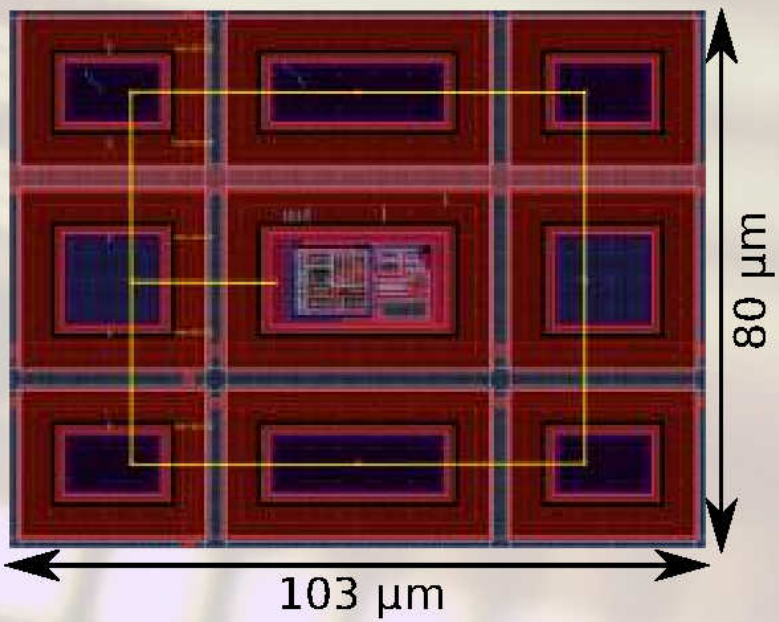


The Pixel



- $3.2 \times 3.2\,\mathrm{mm}^2$ active area
- 32×40 pixels
- 3×3 diode structure
- In-pixel amplifier



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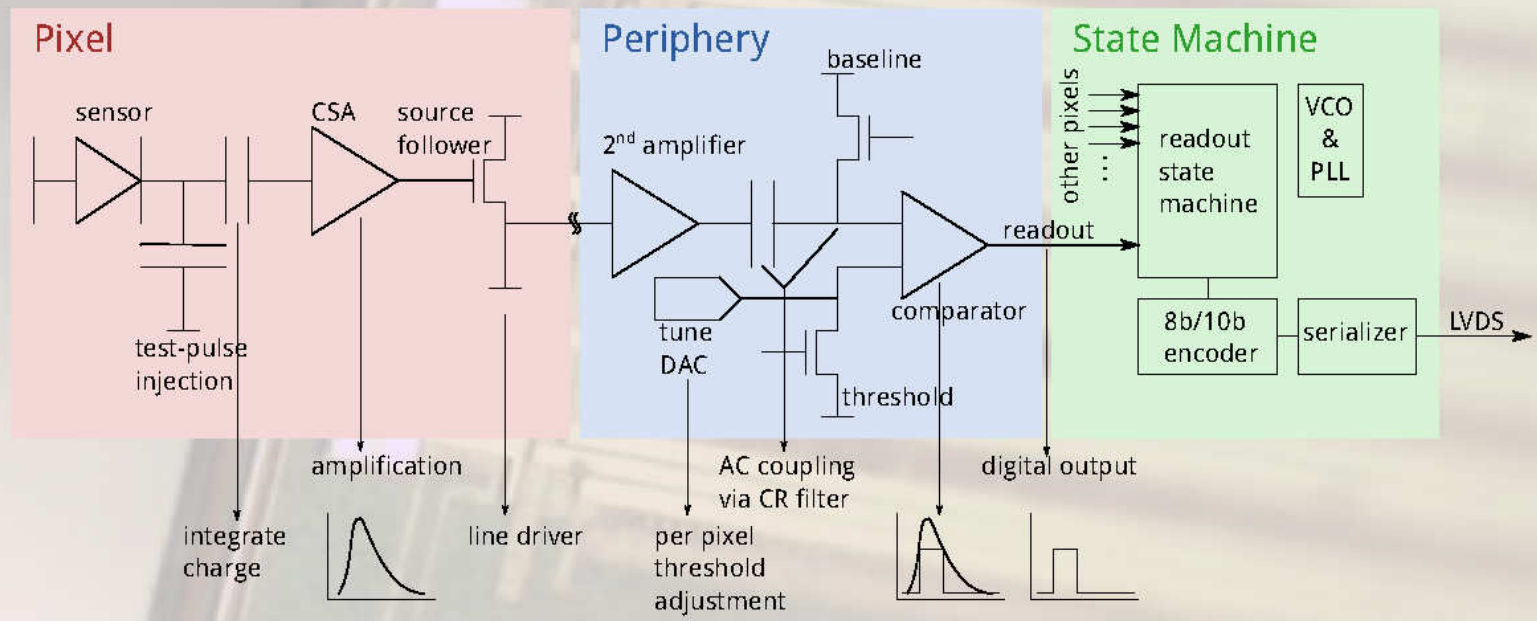
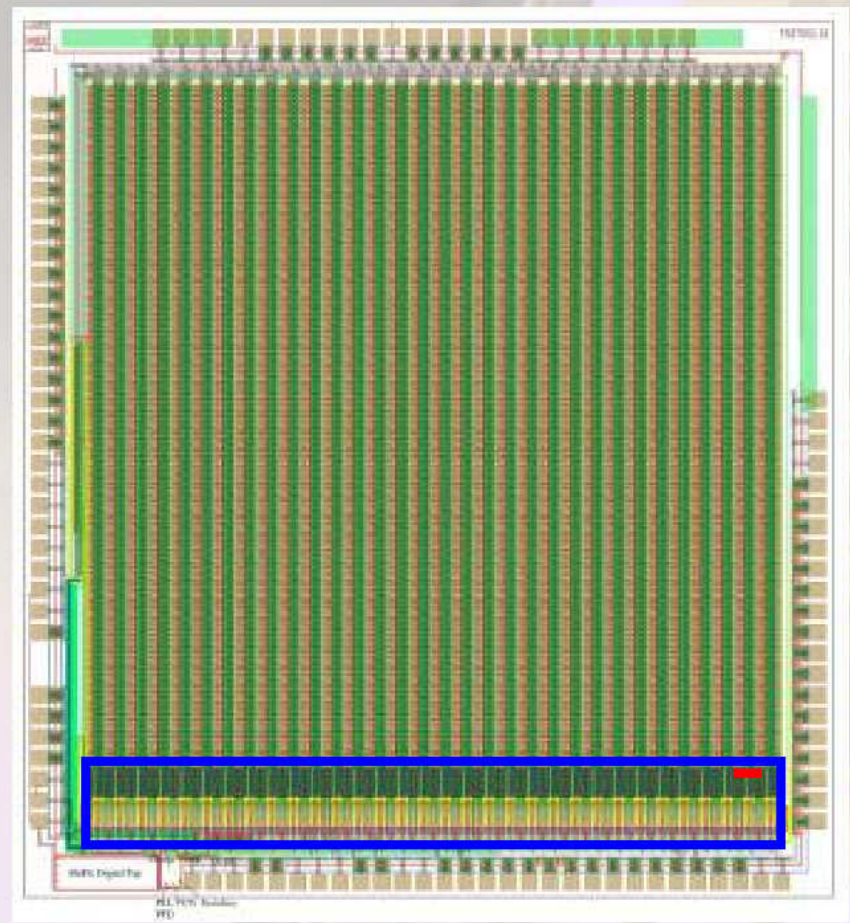


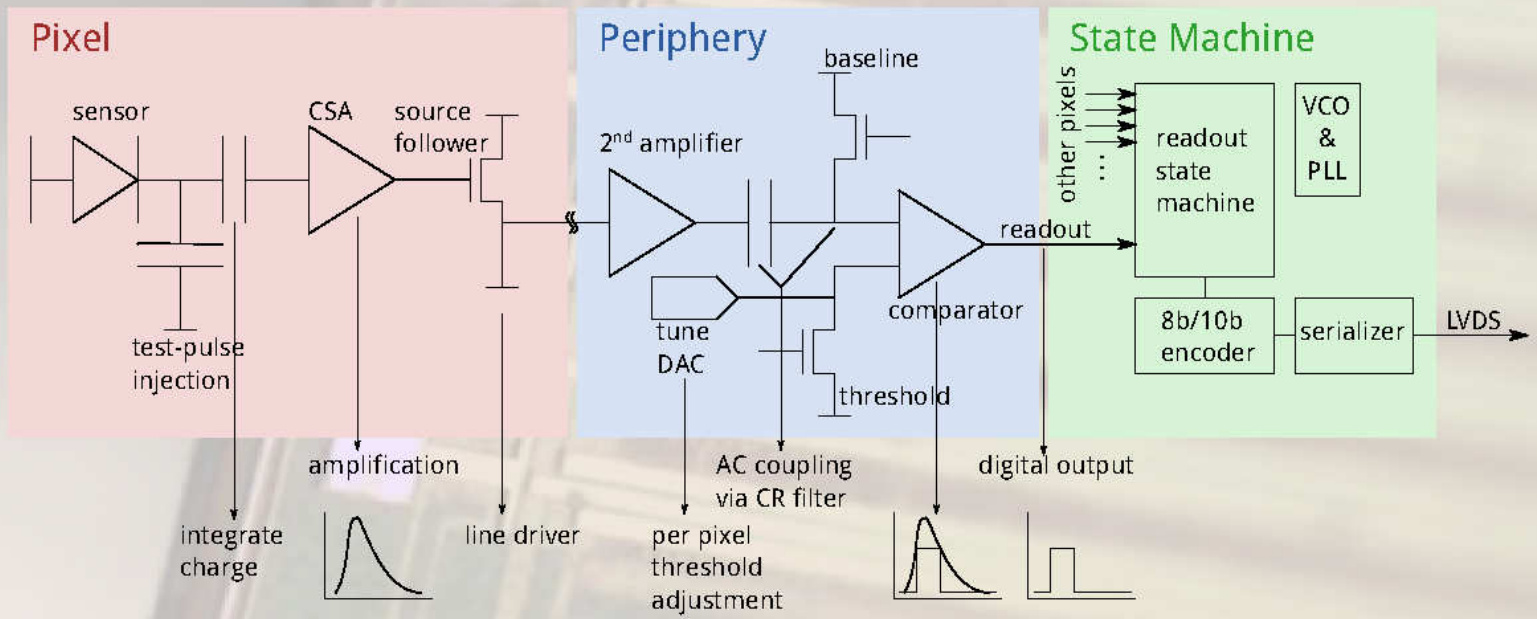
- In-pixel amplifier
- Point-to-point connection to periphery

The Periphery



- Additional amplification stage
- Signal digitisation
- 8-bit time stamps
- Zero-suppressed readout

The Periphery



- Individual pixel tuning
- Characterise analogue behaviour

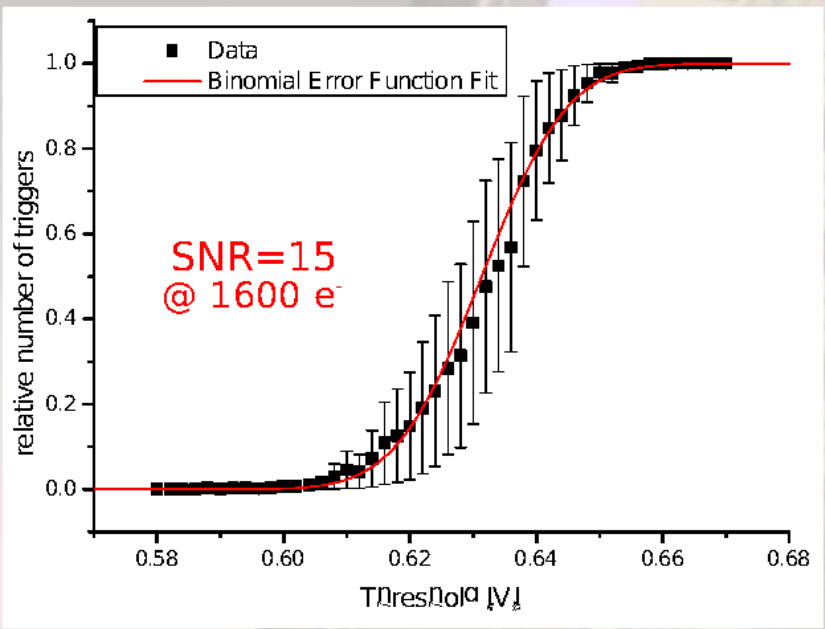
→ T72.2 & 3

The Analogue Behaviour

- Test of general functionality
- HV-dependence
- Analogue performance
- Pulse shape reconstruction
- SNR determination

More Details: T72.2, T72.3

The Analogue Behaviour



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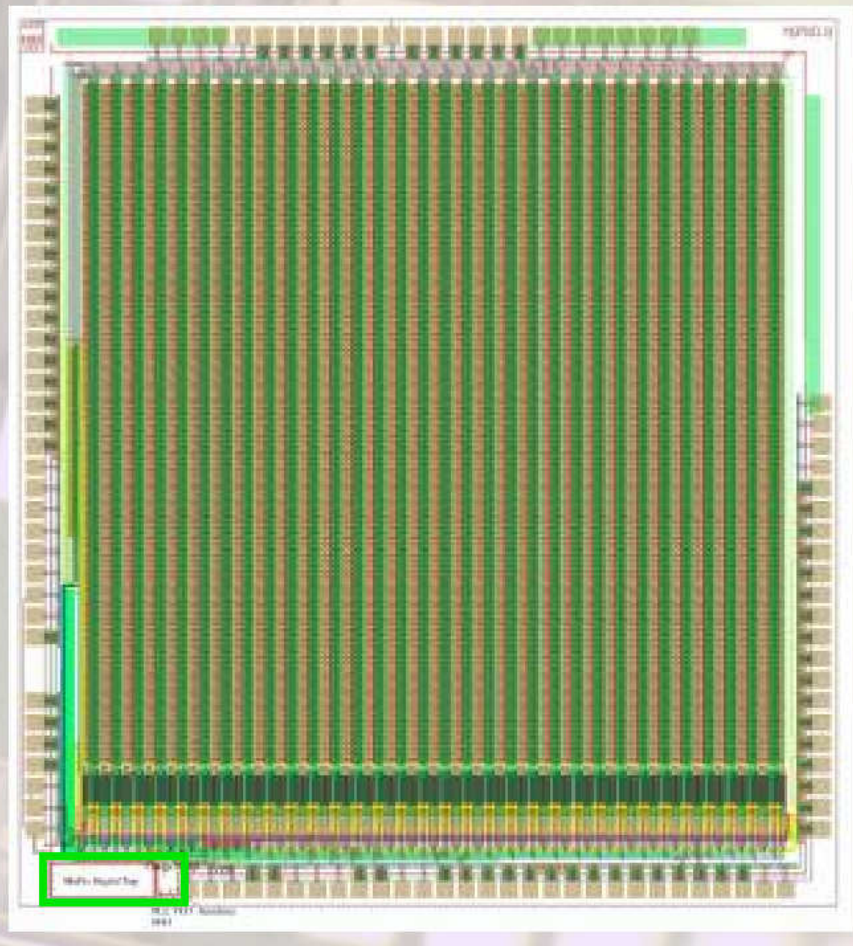
More Details: T72.2, T72.3

The MuPix State Machine



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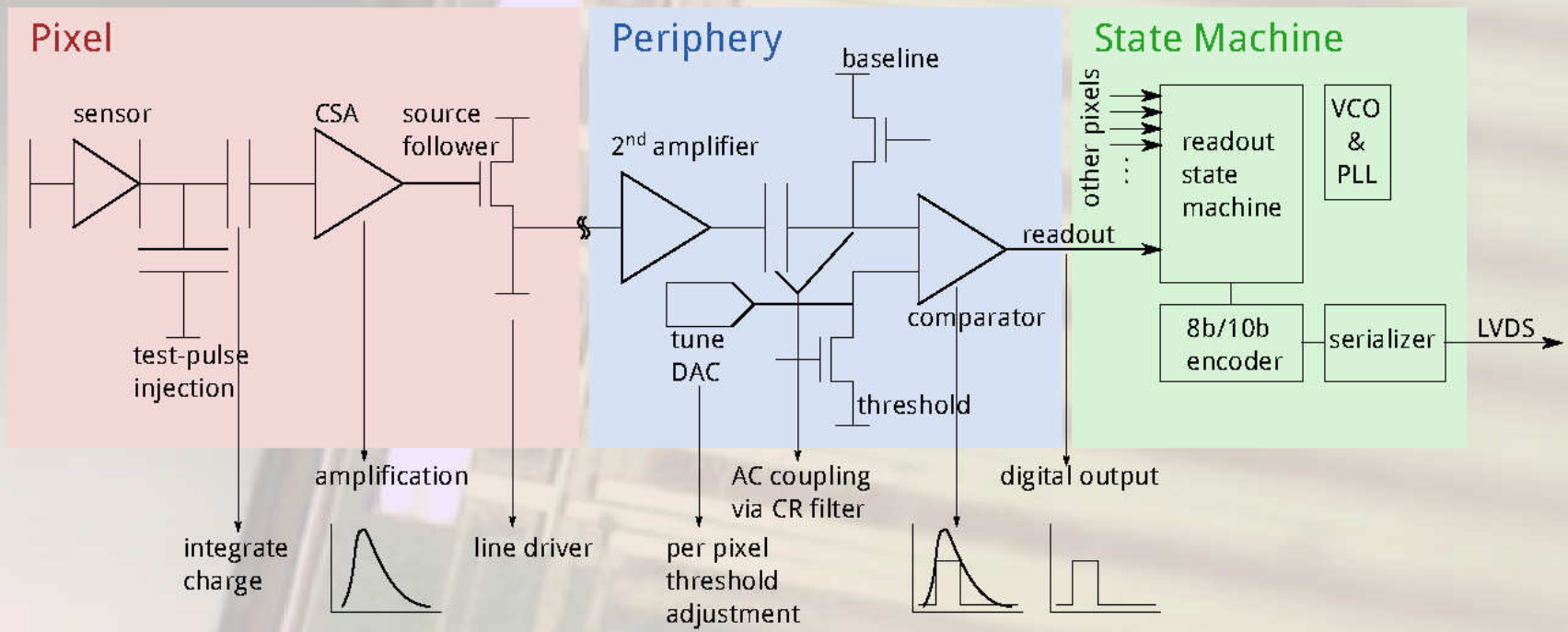
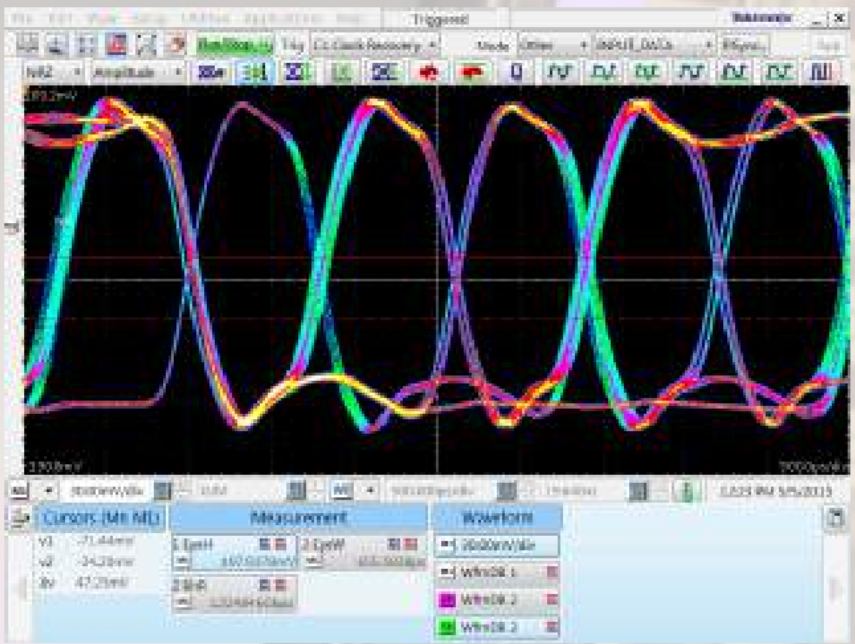


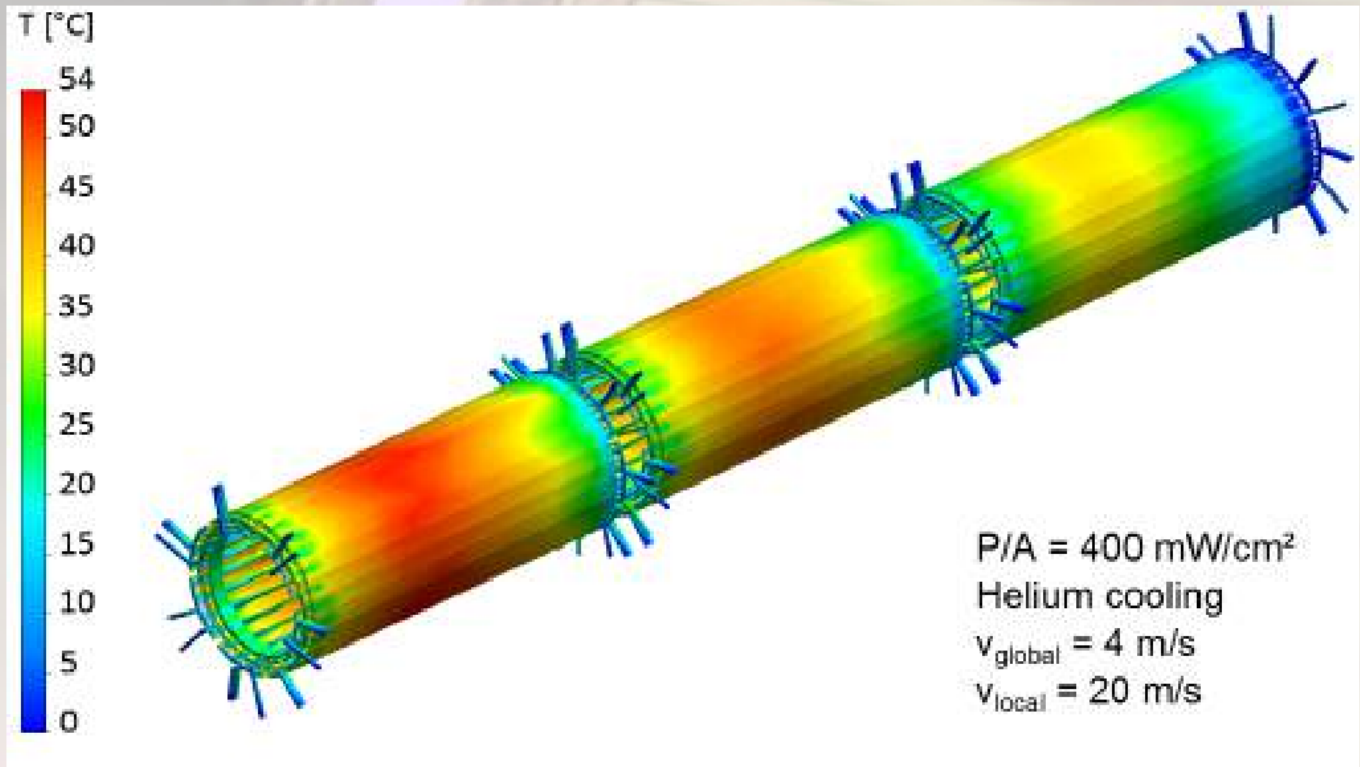
- On-chip readout state machine
- VCO & PLL
- LVDS Gbit data link

Voltage Controlled Oscillator & Phase Locked Loop



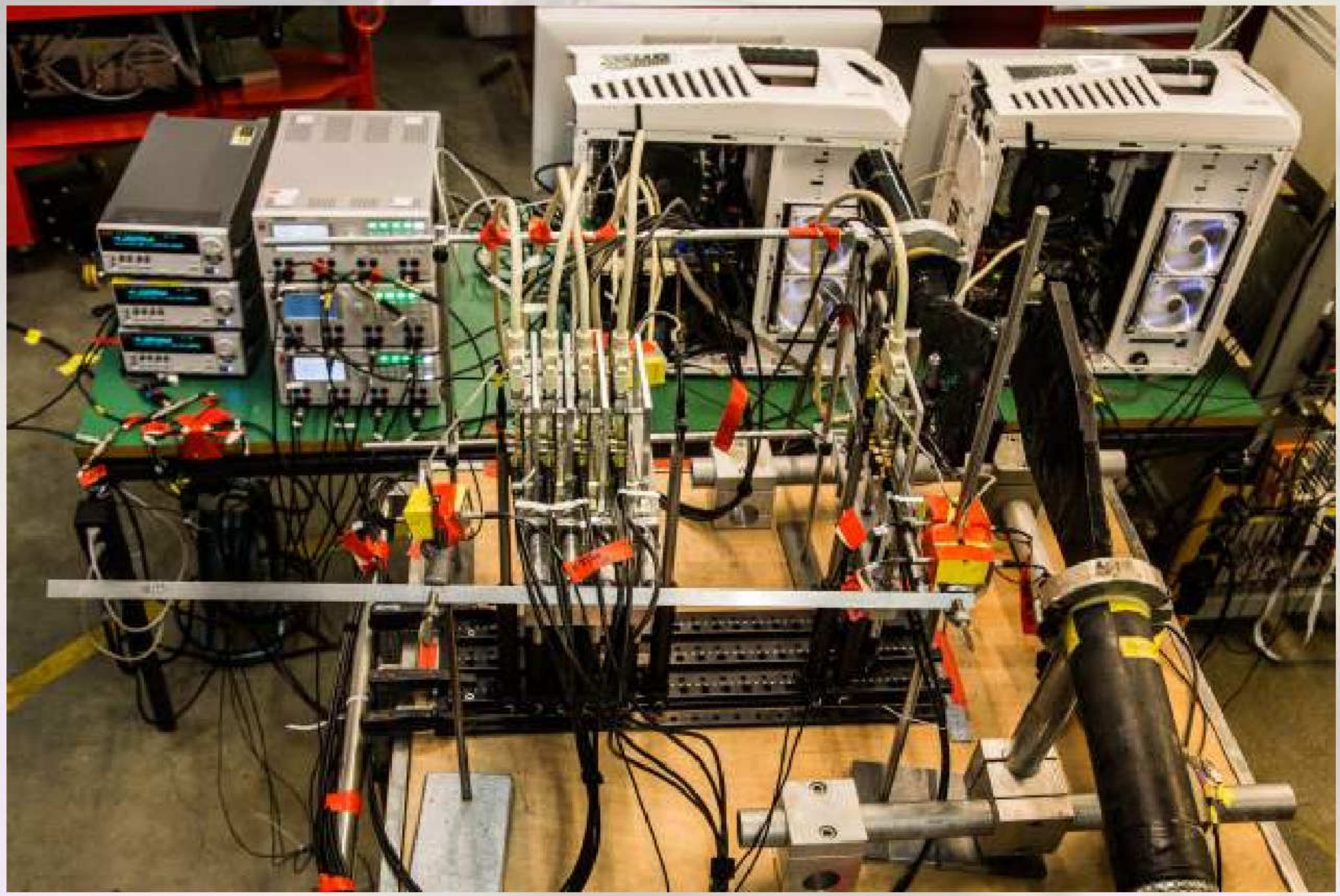
- Stable working point
- Chip as line driver
- Jitter <100 ps ($\rightarrow$ T72.2)
- 1.25 Gbit/s 8b10b encoded data
- Up to 30 MHits/s possible

Power Consumption



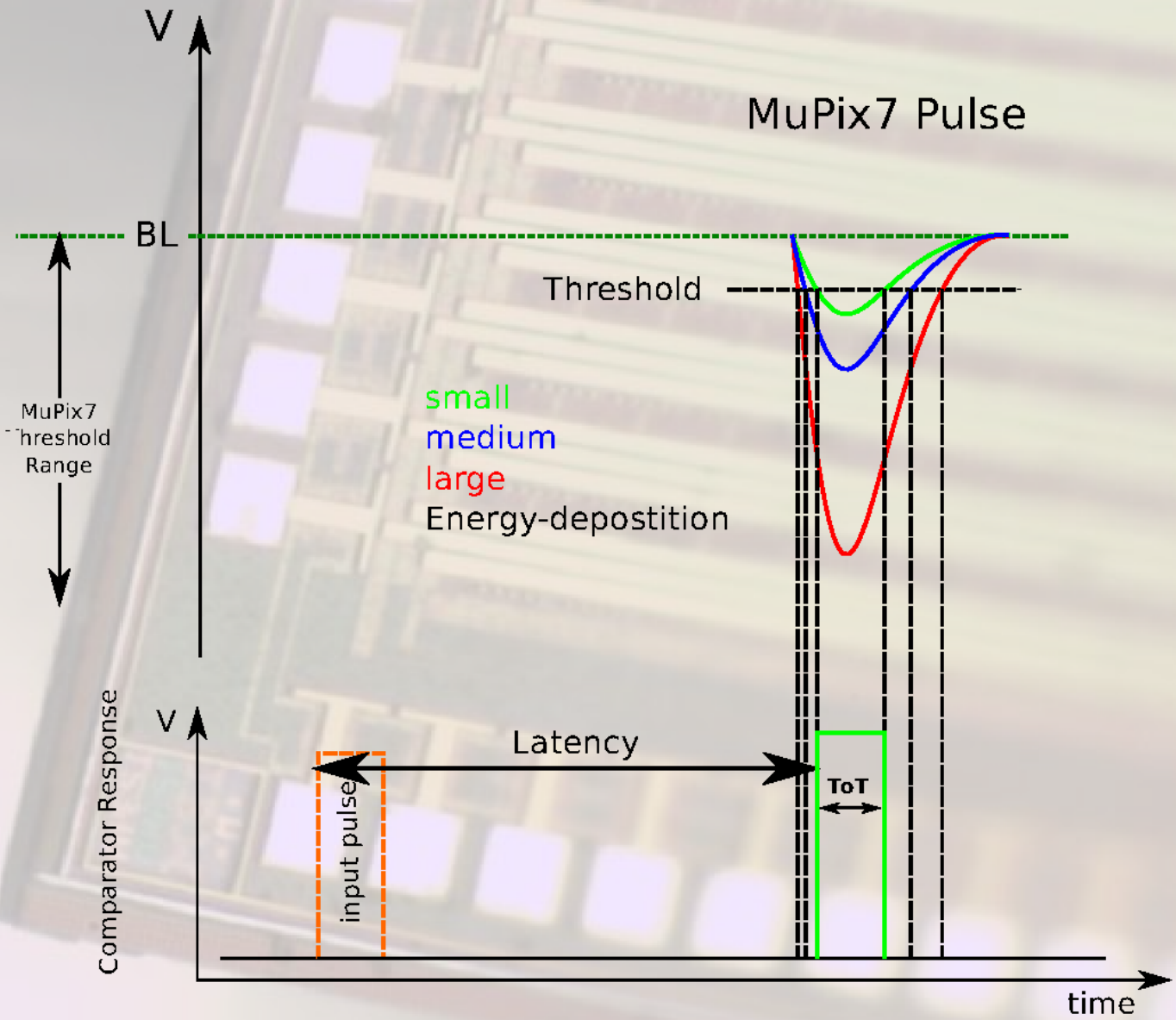
- Upper limit of 400 mW cm^{-2}
- Temperature gradient of 50 K ($\rightarrow$ T75.7)
- Investigation of temperature dependence ($\rightarrow$ T72.2)

Testbeam Measurements



Time Resolution

Time Resolution



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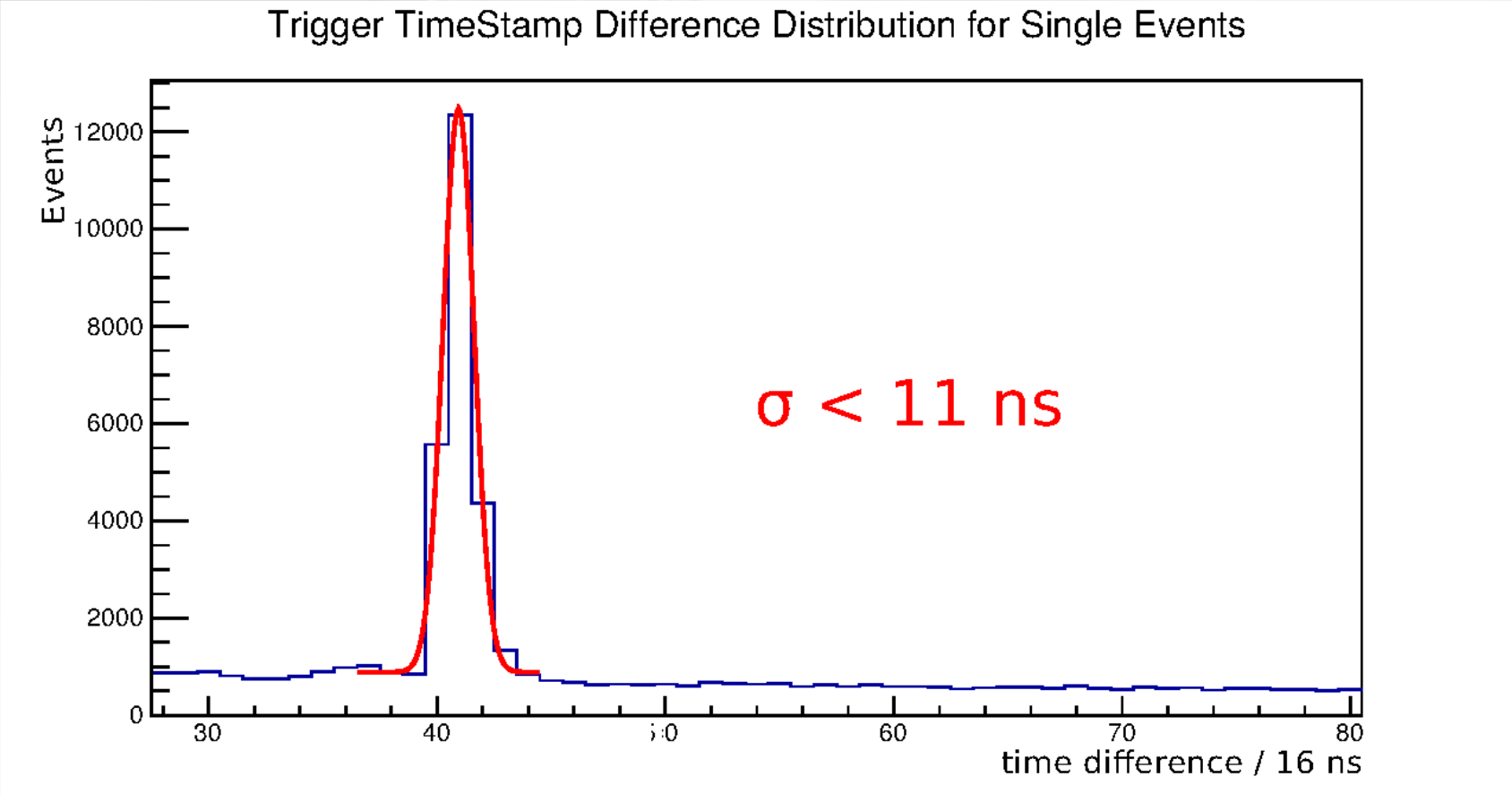
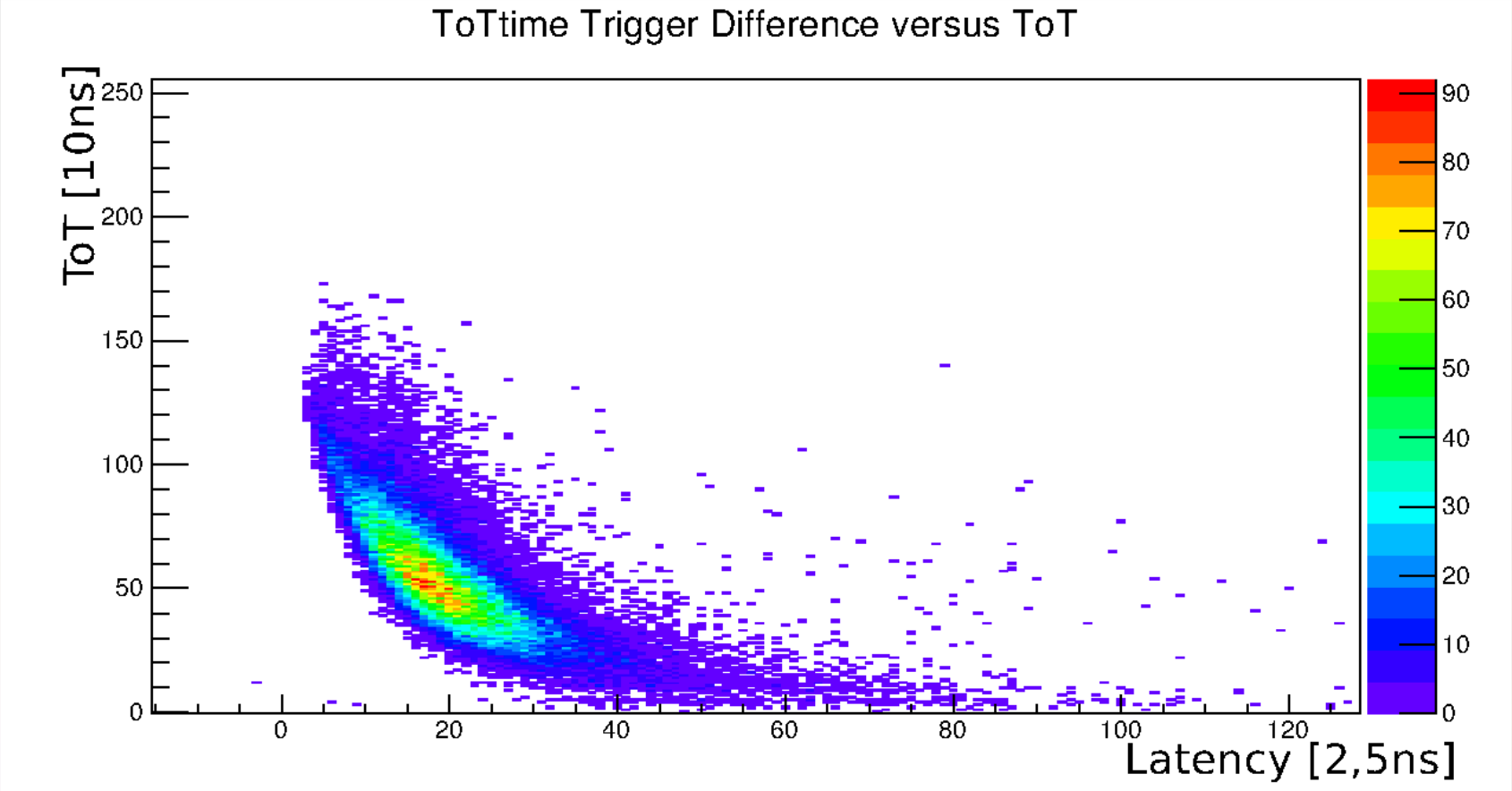


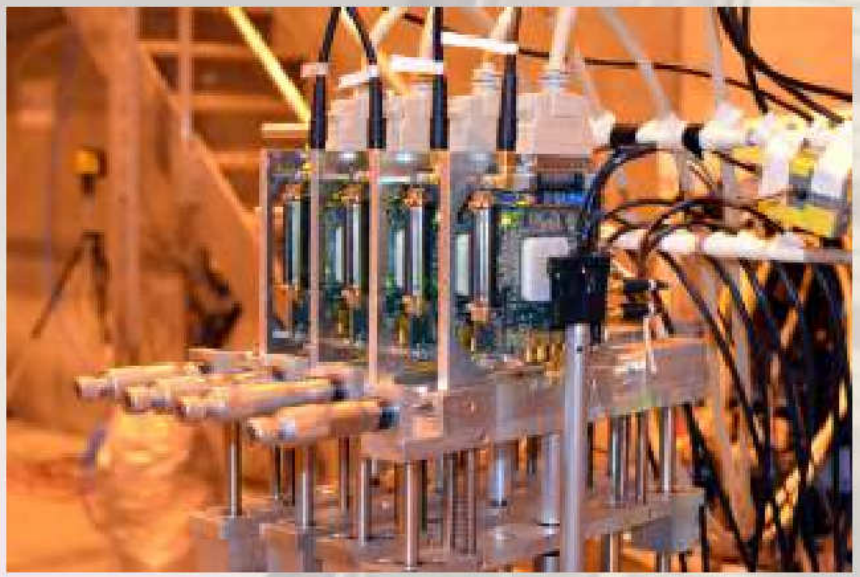
- Sandwich scintillator setup
- Time resolution measured to <11 ns

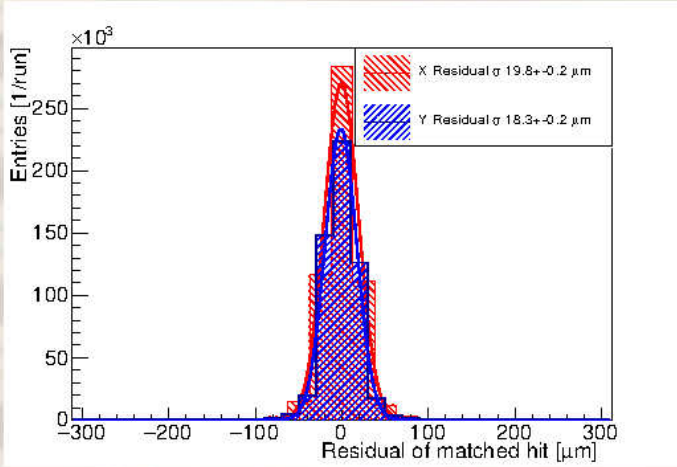
Time Resolution



- Sandwich scintillator setup
- Time resolution measured to <11 ns
- Time walk observed for pixel analogue behaviour

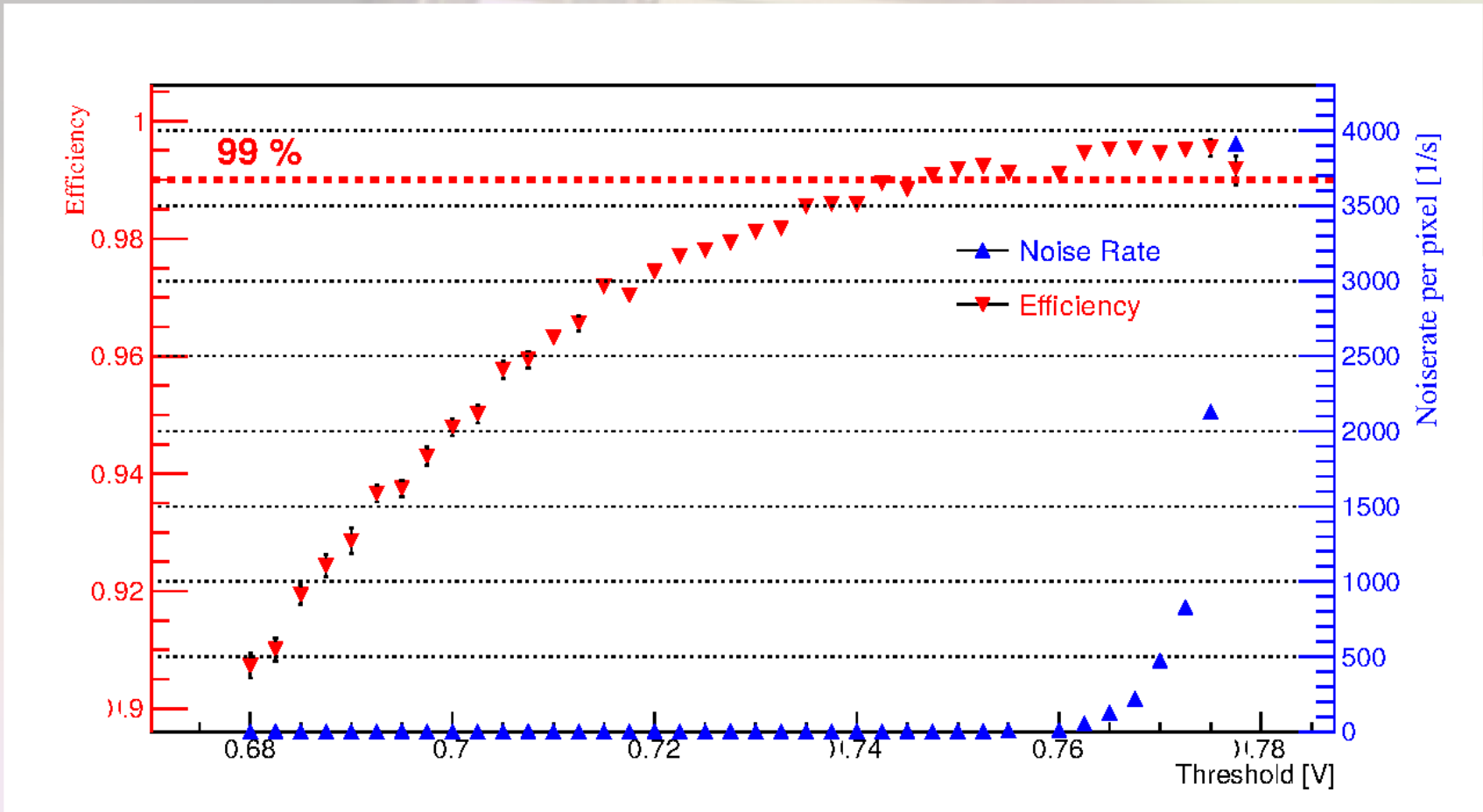
The MuPix Telescope (T99.5)





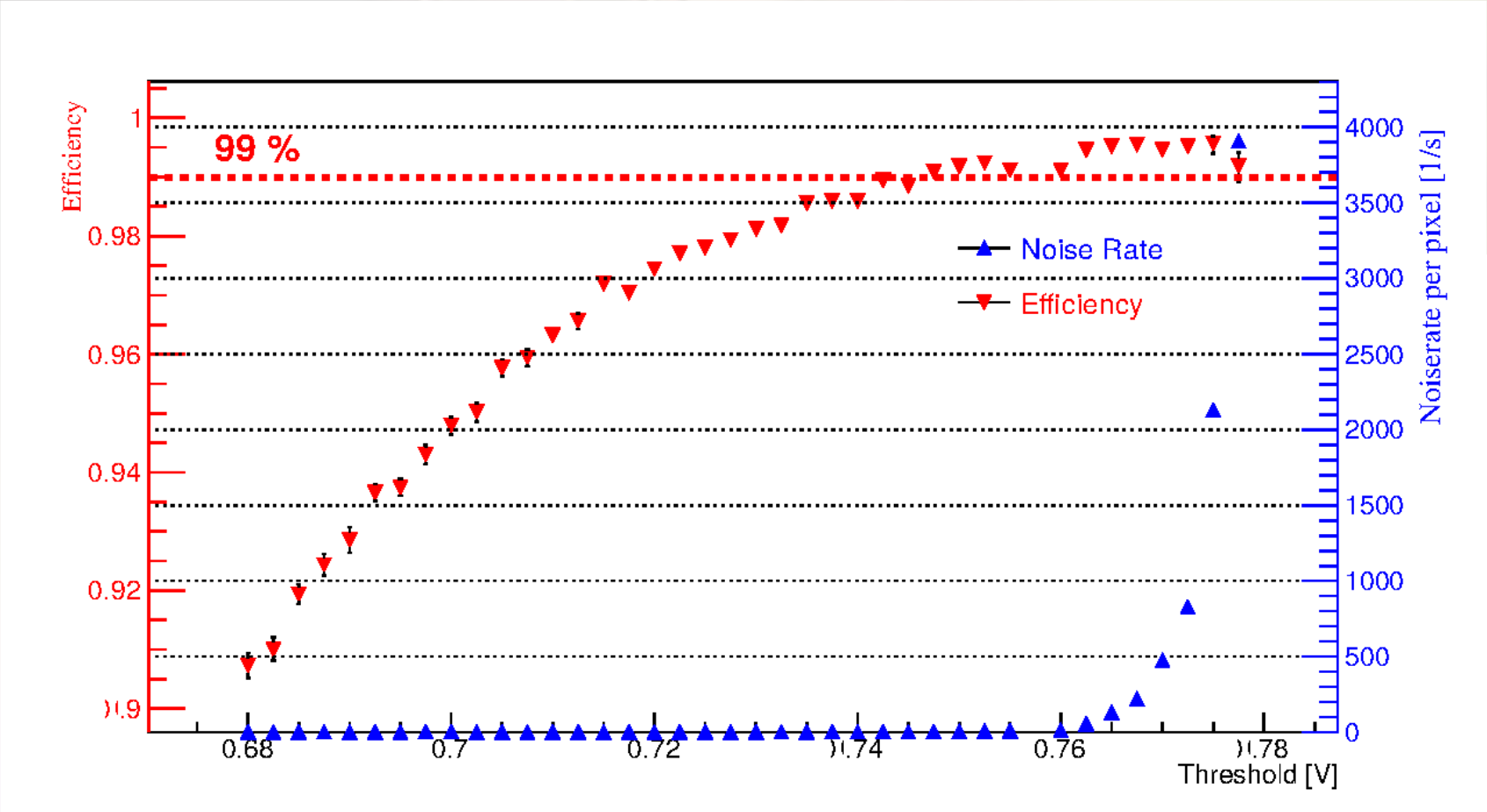
- 4 layers MuPix7
- Use one as DUT
- Time sorted data (T22.4)
- Resolution <30 µm
- Position resolved analysis

Efficiency Measurements



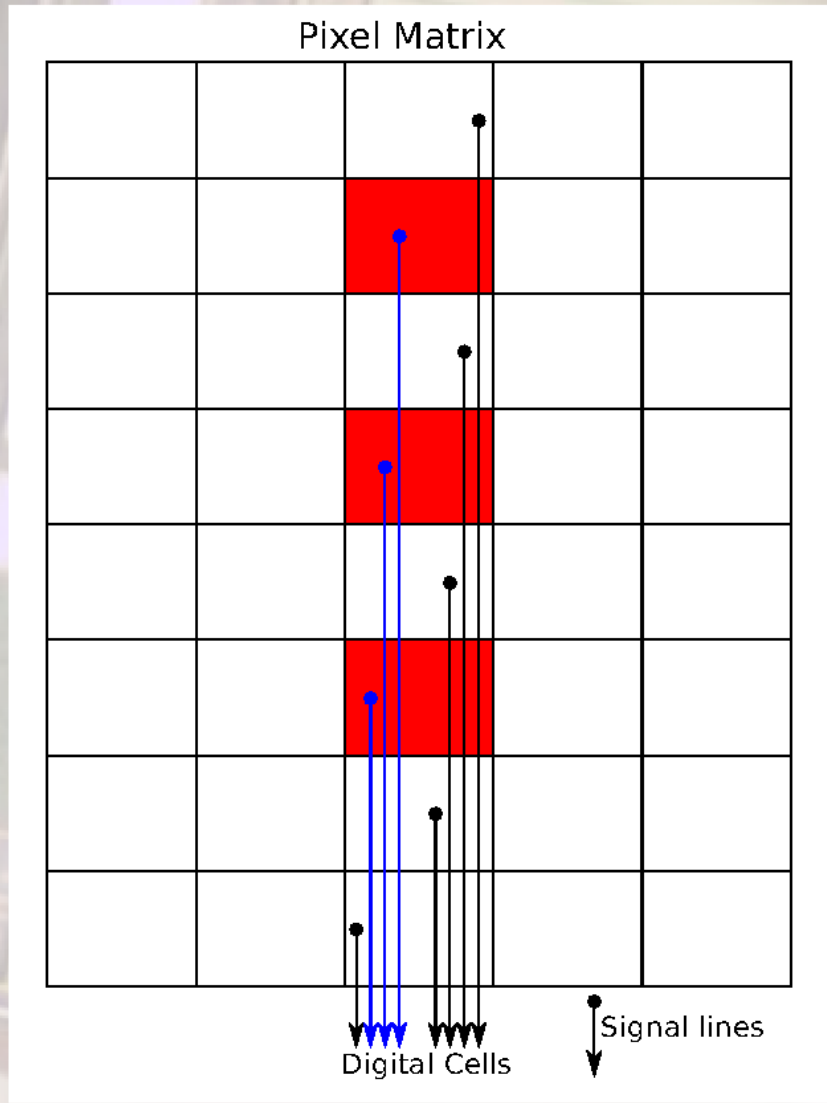
- Use telescope setup
- 220 MeV mixed pion beam provided by PSI

Efficiency Measurements

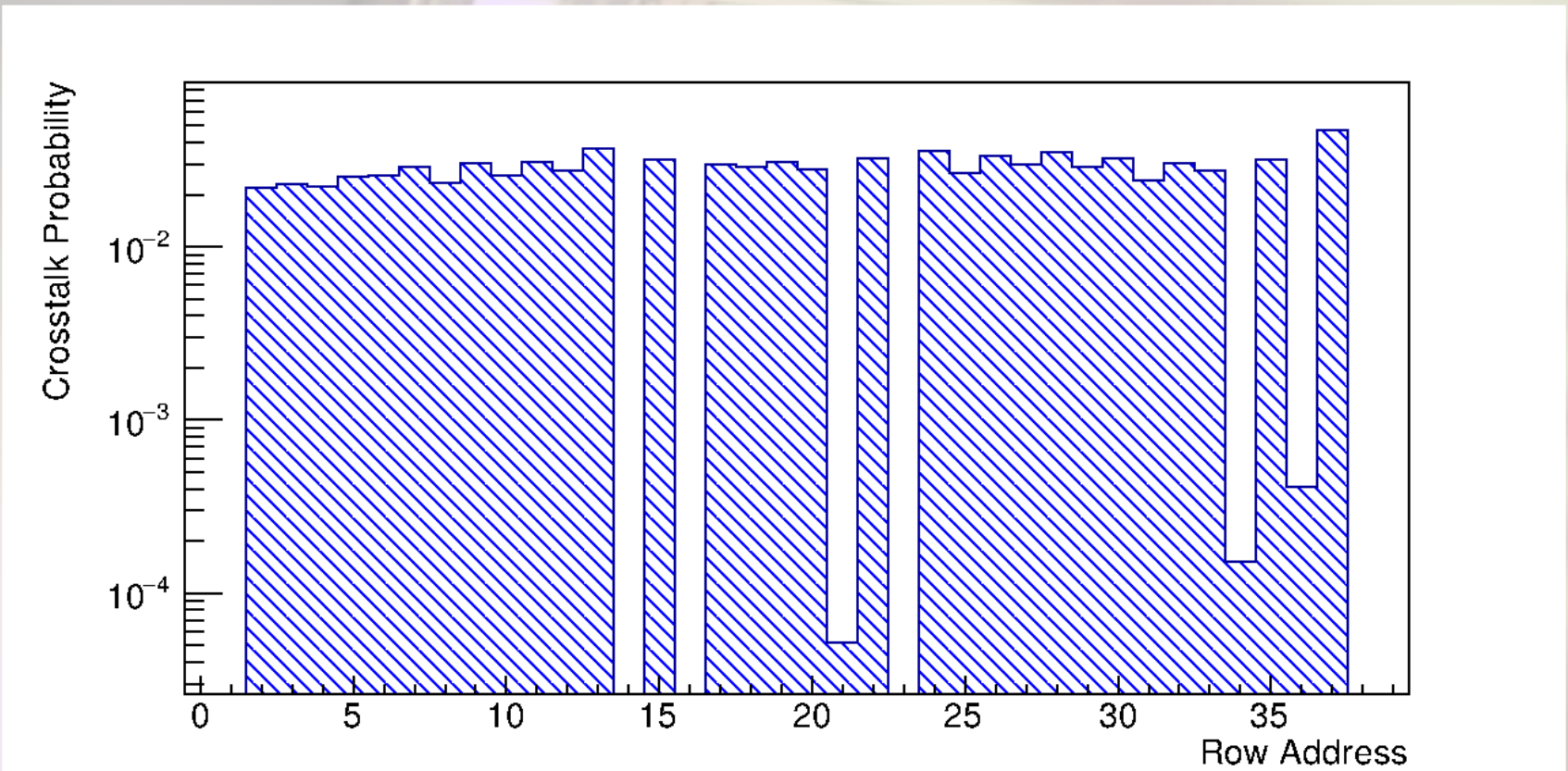


- Efficiencies above 99 % observed
- Tuning results in sharp noise edge
- Power consumption: $\approx 300\,\mathrm{mW\,cm^{-2}}$

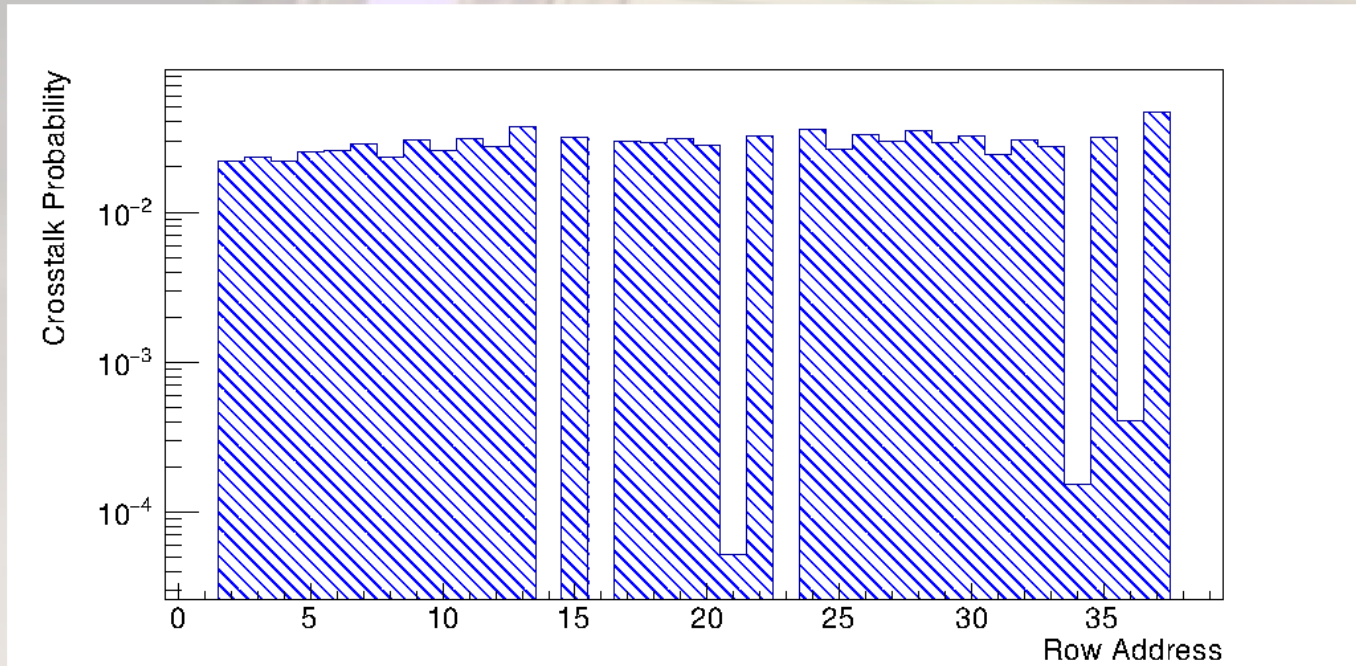
Crosstalk



Crosstalk


Crosstalk Probability
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
30
35
Row Address

Crosstalk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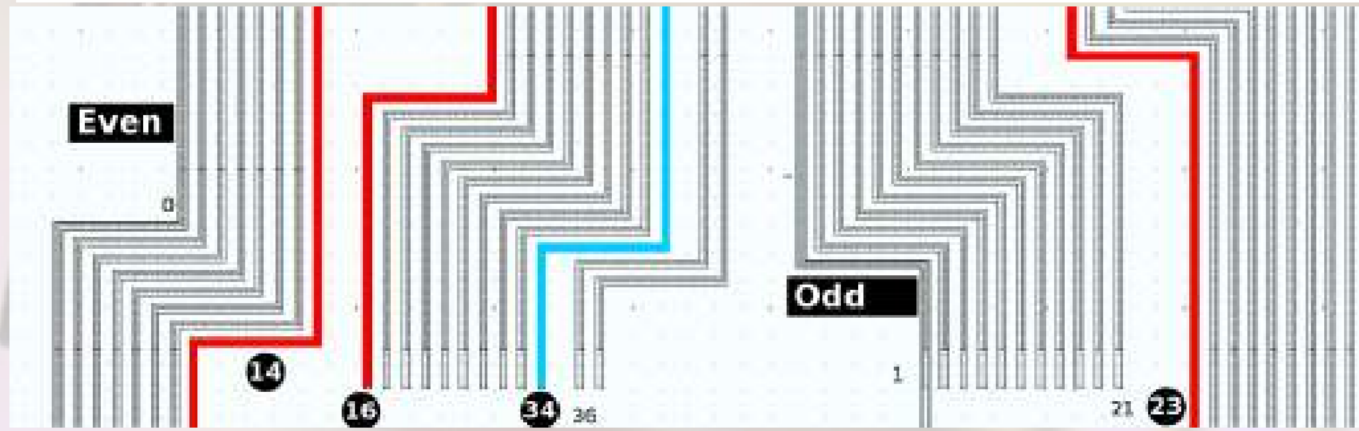
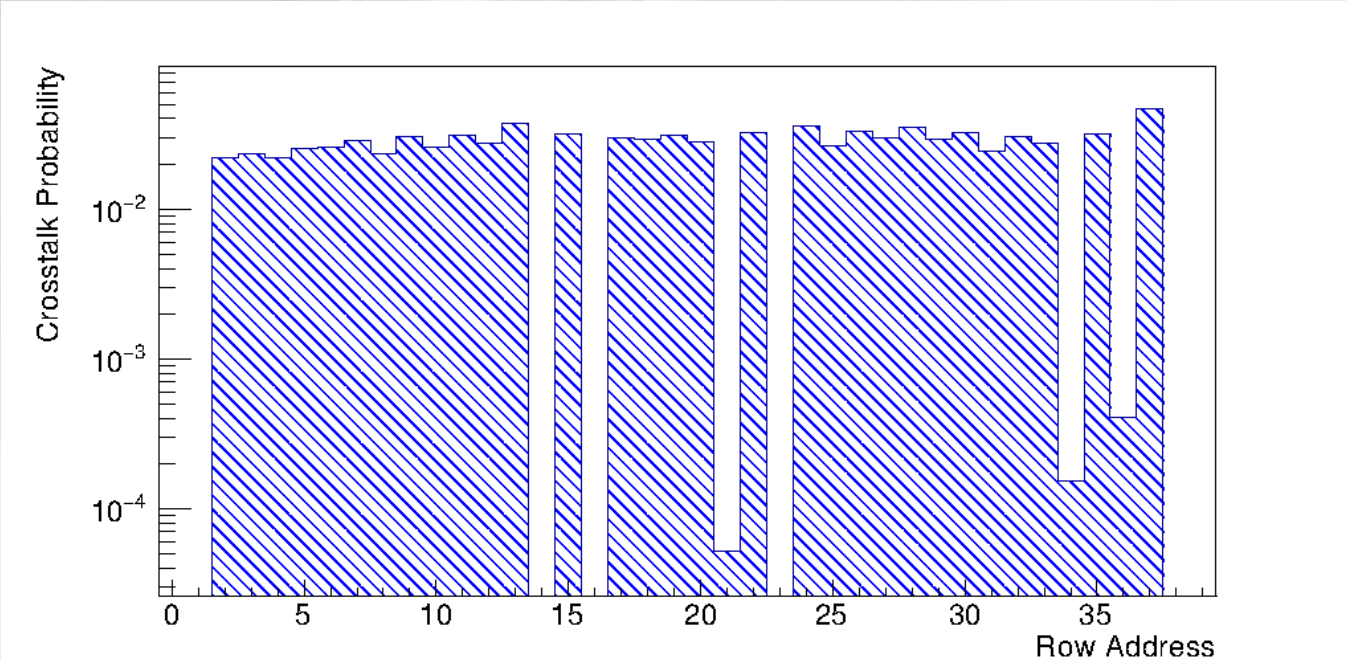
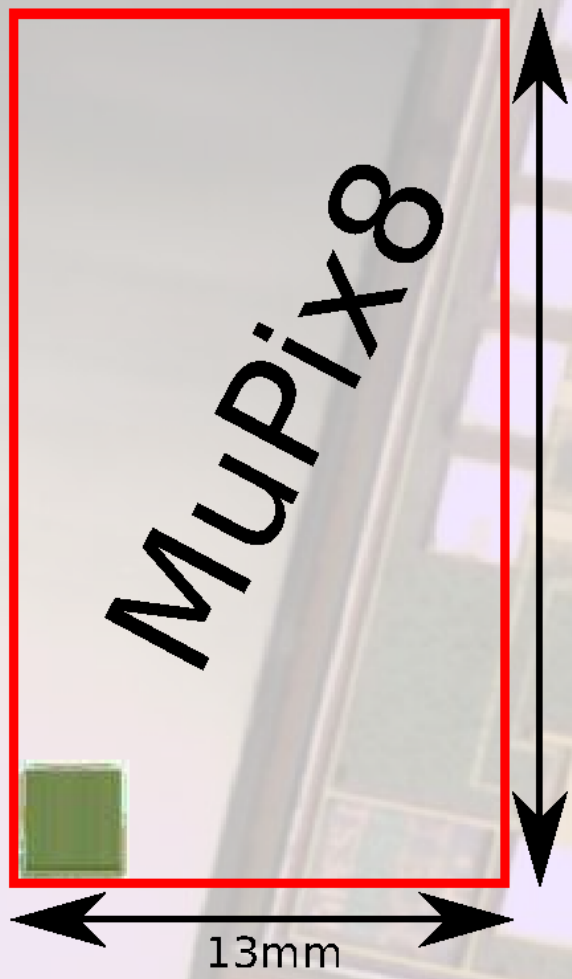

Even
0
14
16
34
36
Odd
1
21
23

Crosstalk



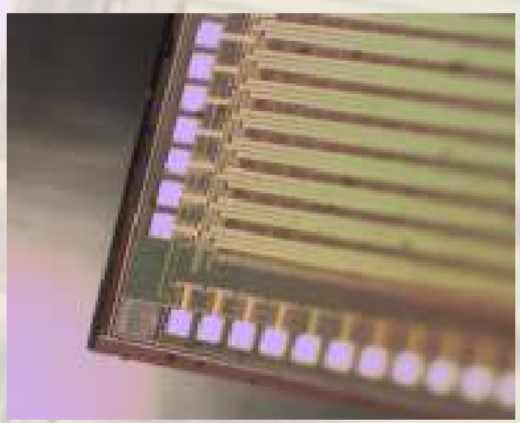
- Crosstalk observed
- Matches signal routing

MuPix8 Prototype



- Submission planned for June 2016
- First big chip $2.3 \times 1.3\,\mathrm{cm}^2$
- Pixel size $80 \times 80\,\mu\mathrm{m}^2$
- Higher resistivity substrate
- First module prototypes

Summary



- Reliable characterisation setup & frame work
- Very well performing chip technology
- First HV-MAPS prototype with integrated readout
- Many design goals already satisfied

Acknowledgments

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Mu3e Talks

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