Fast Readout of the Pixel Detector at the Mu3e Experiment

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on behalf of the Mu3e Collaboration

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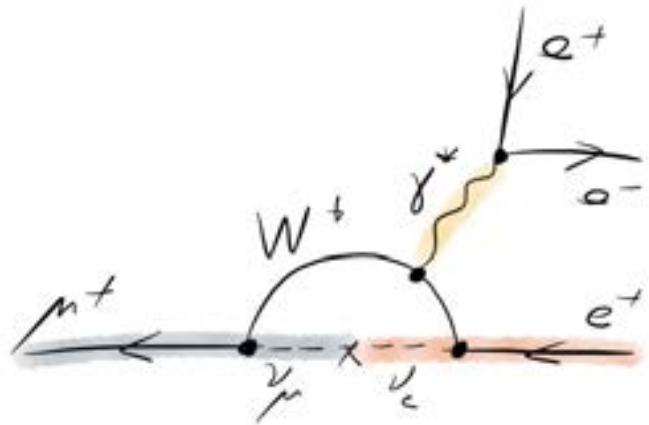
SEIT 1386

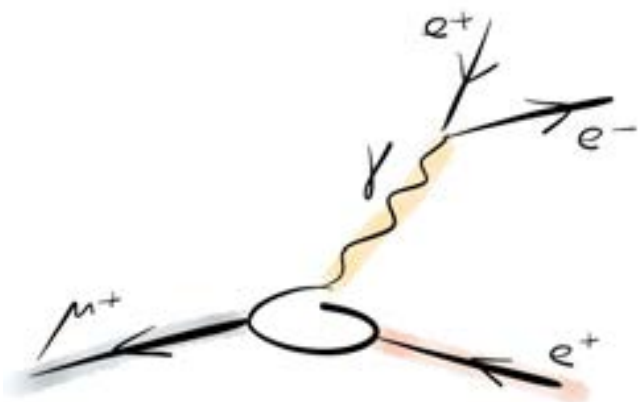
The Mu3e Experiment

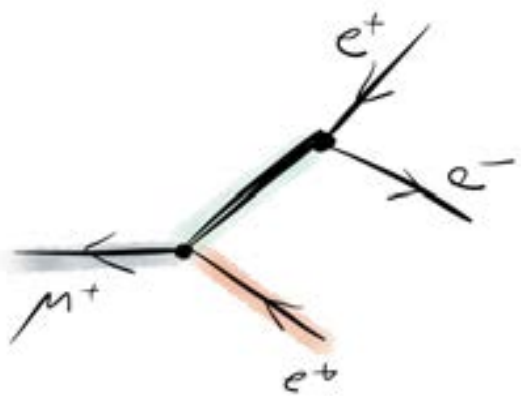
Charged lepton flavour violating decay: $\mu^+ \to e^+e^-e^+$



In SM via ν mixing: BR $< 10^{-54}$

Observation of $\mu \to eee$ is a clear sign for New Physics
SUSY, GUTs, left-right symmetric models, ...





The Mu3e Experiment

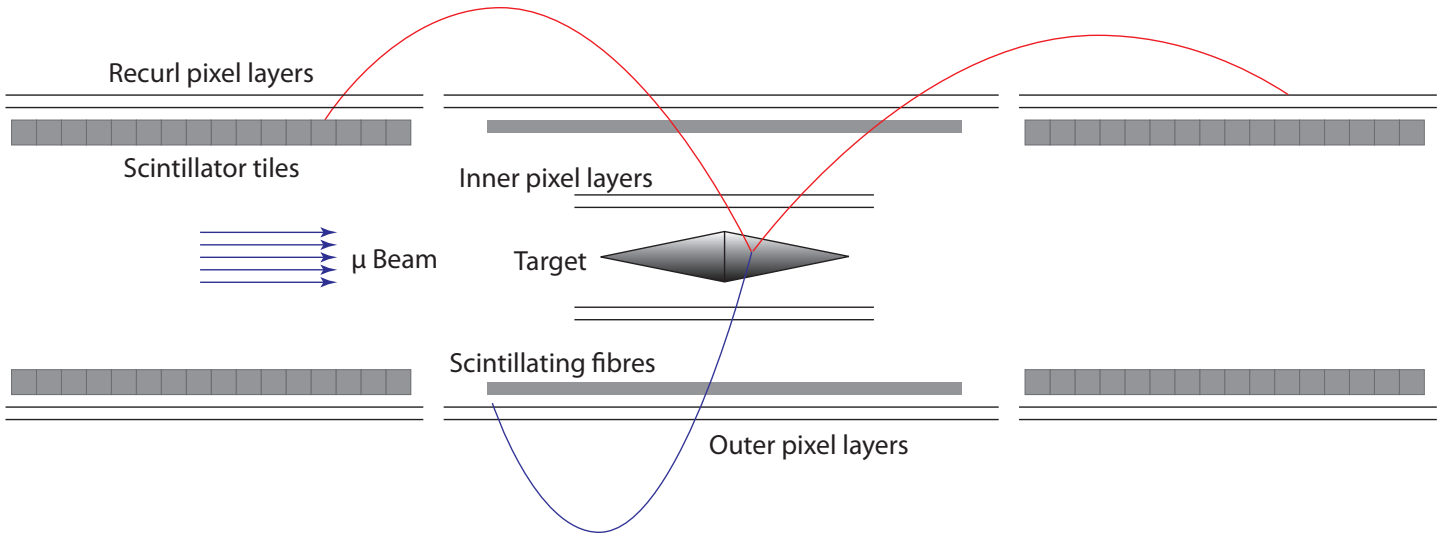
Mu3e: Search for $\mu \to eee$ down to BR $< 10^{-16}$ (90% CL)
Probe mass scale for new physics $\mathcal{O}(10^3\,\text{TeV})$

- High muon stopping rates $\sim 2 \cdot 10^9$ muons/s
- Momentum of decay electrons:
  $\sim$ 15 – 53 MeV/c
- Background from SM decay $\mu \to eee\nu\overline{\nu}$ and accidental combinations

- Excellent momentum and vertex resolution
- Precise timing
- Low material budget

The Mu3e Experiment

Mu3e: Search for $\mu \to eee$ down to BR $< 10^{-16}$ (90% CL)



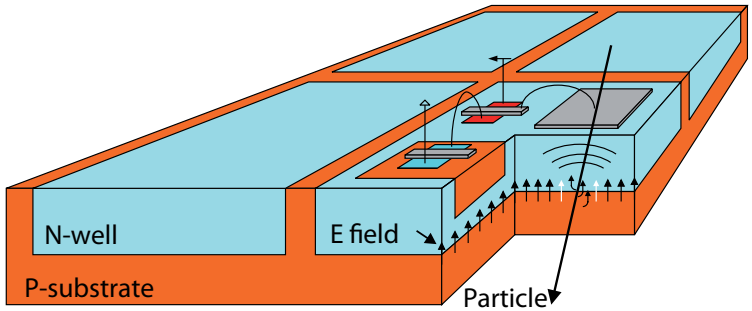
Tracking detector:
Thinned Si pixel sensors
(HV-MAPS)

+ Timing detector:
Scintillating fibres and tiles

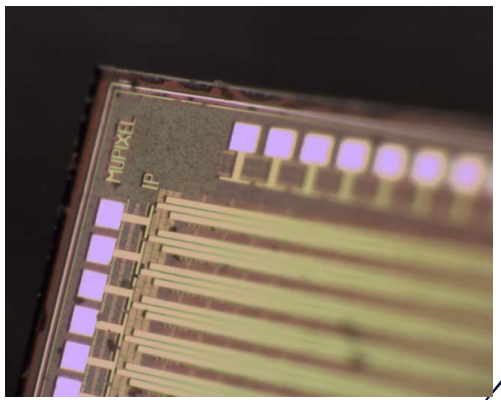
HV-MAPS

High Voltage Monolithic Active Pixel Sensors

- 180 nm HV-CMOS process
- N-well in p-substrate
- Reversely biased by $> 50\,\mathrm{V}$
  - Fast charge collection via drift
  - Depletion zone of $\sim 10\,\mu\mathrm{m}$
    Thinning possible ($\lesssim 50\,\mu\mathrm{m}$)
    $\rightarrow$ $\sim 1\,‰$ X_0 per layer including flexprint and mechanical support
- Integrated readout electronics

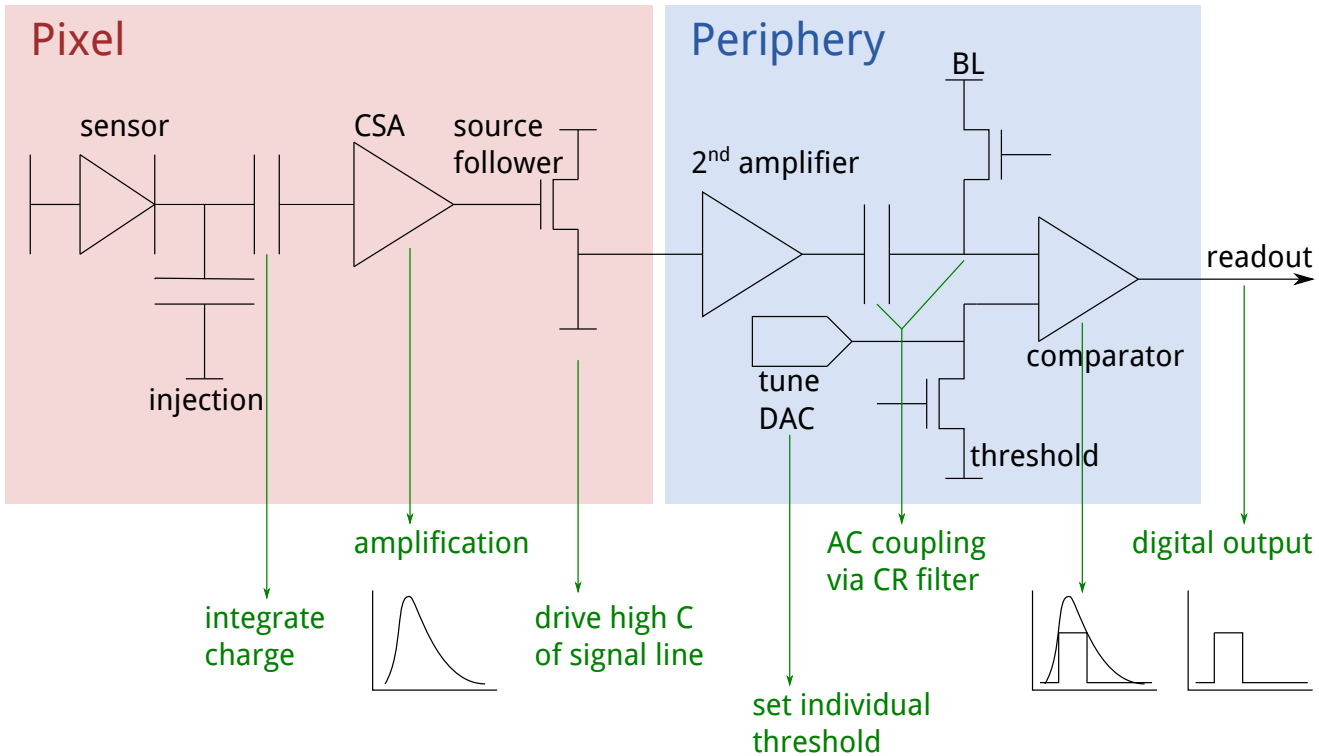


I. Perić, NIM A 582 (2007)



HV-MAPS

Analog Part



Inside N-well:

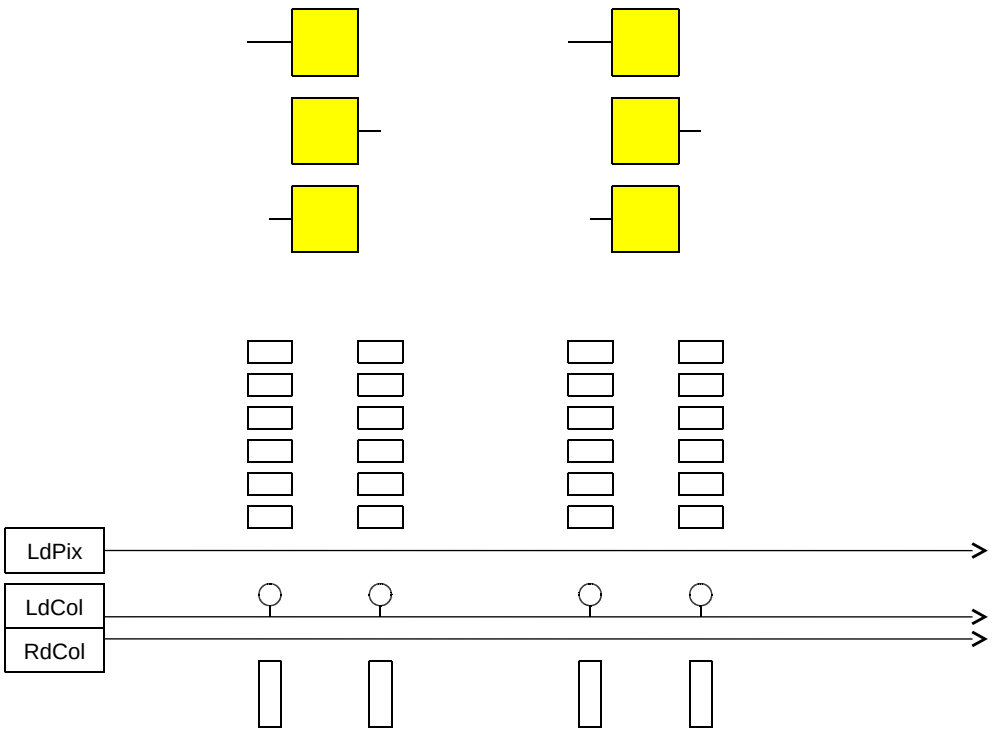
- Sensor diode
- CSA and source follower

On chip periphery

- 2nd stage amplifier
- Comparator

HV-MAPS

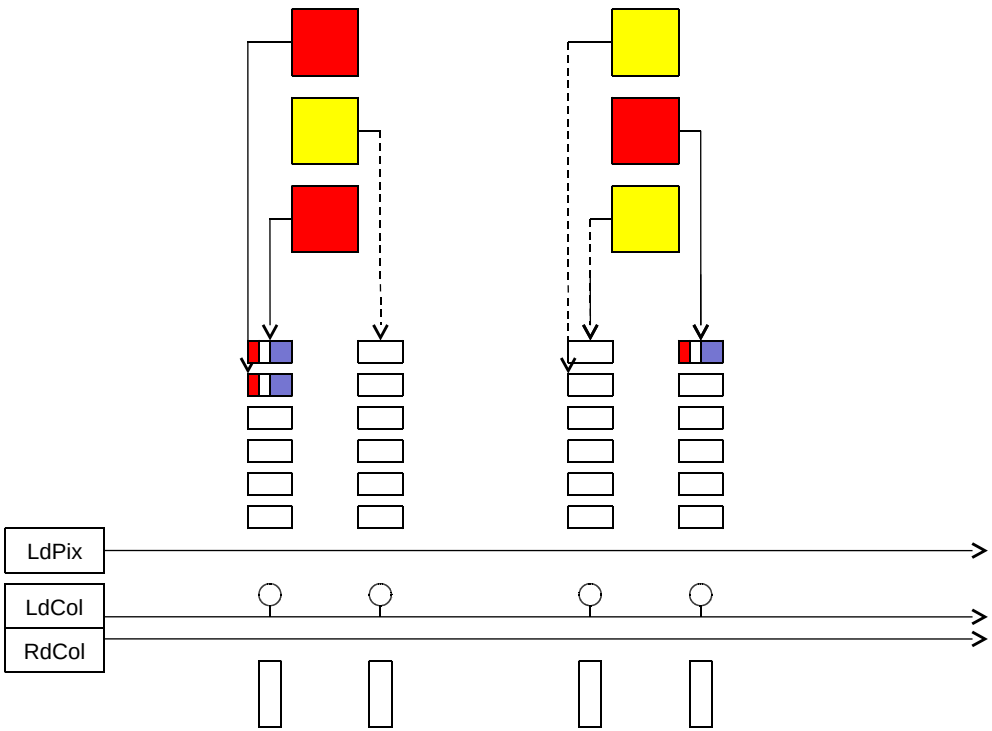
Digital Part



Priority-based, zero-suppressed readout

HV-MAPS

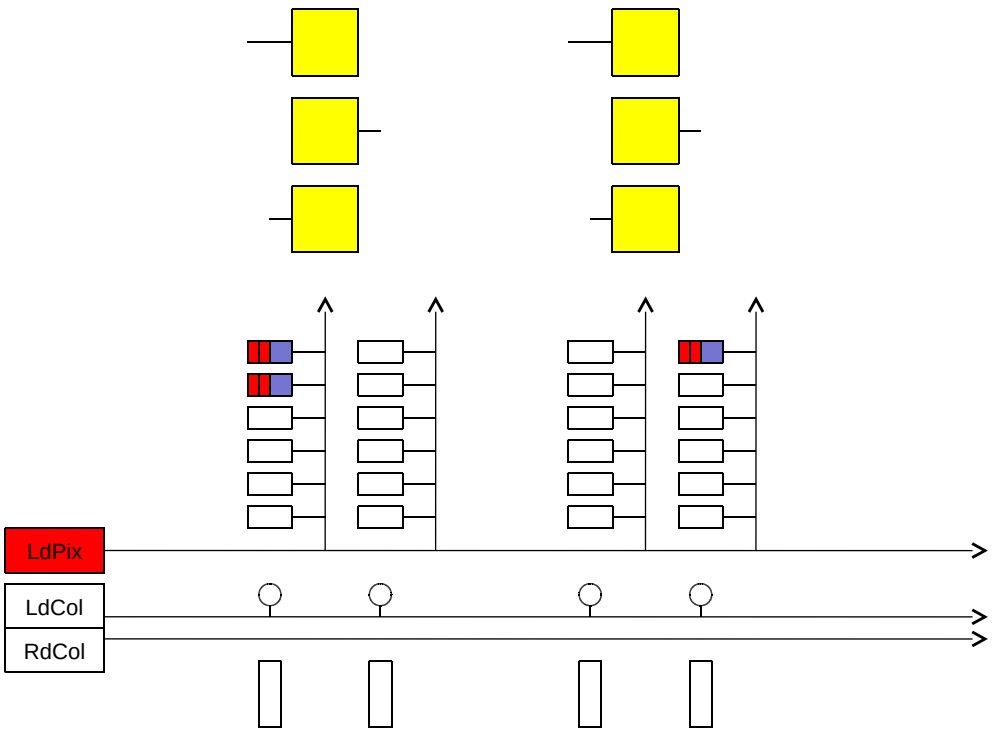
Digital Part



Comparator issues hit signal
Set hit flag
Store time stamp into RAM of readout-cell

HV-MAPS

Digital Part

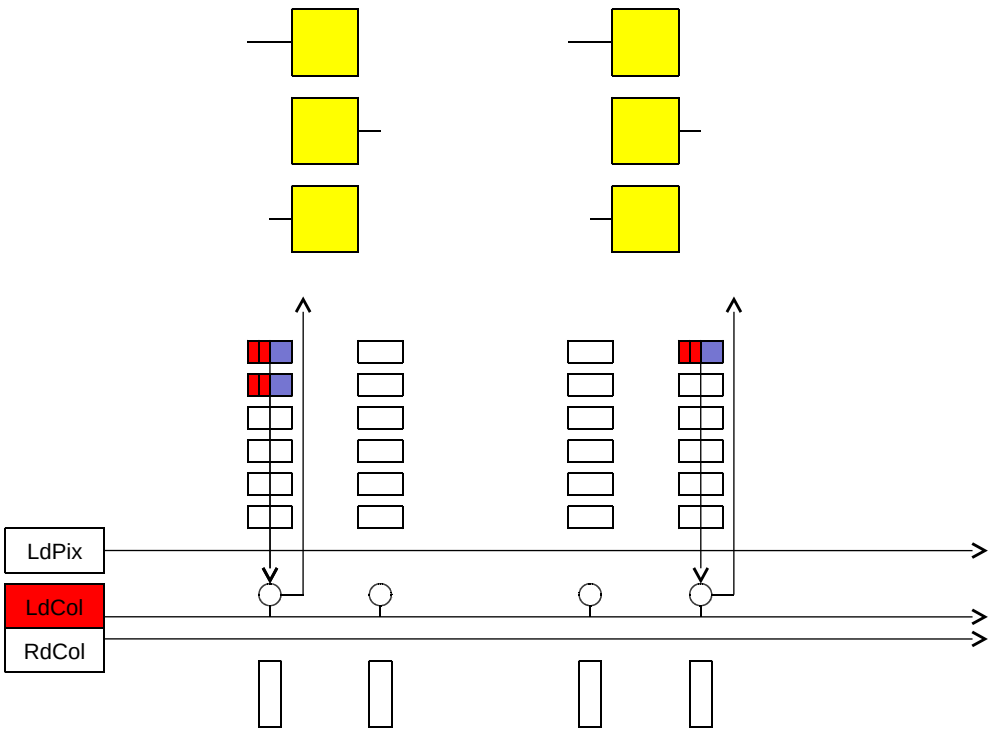


Confirm hits

→ store into memory cell

HV-MAPS

Digital Part

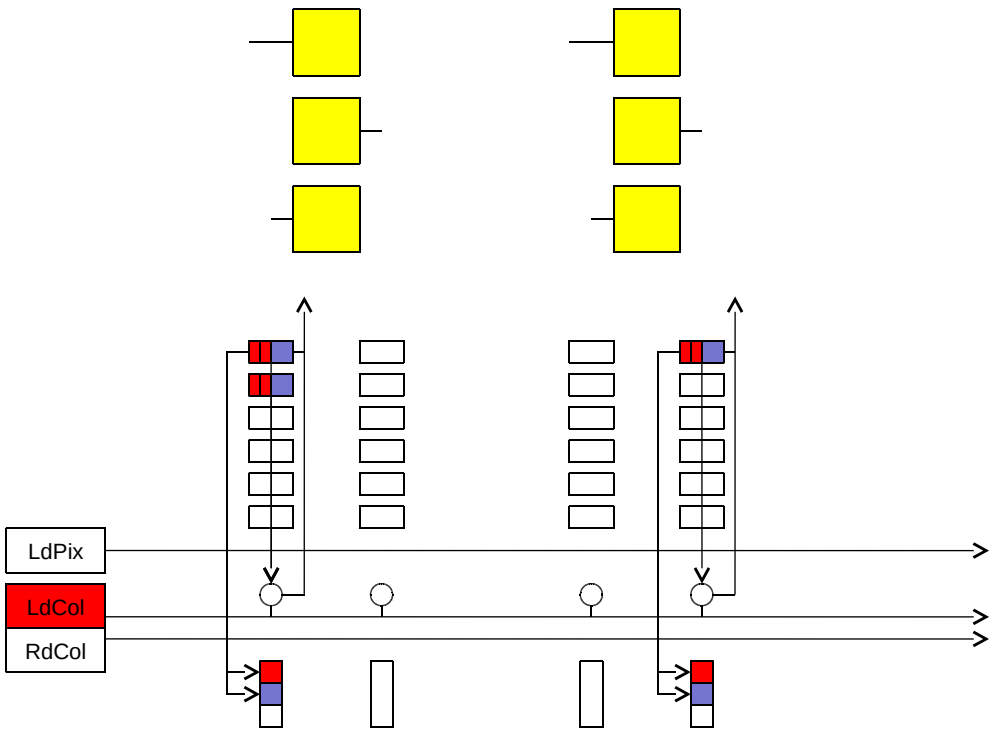


Store time stamp
and row address
of 1st hit in column
in end-of-column cell

Delete hit flag

HV-MAPS

Digital Part



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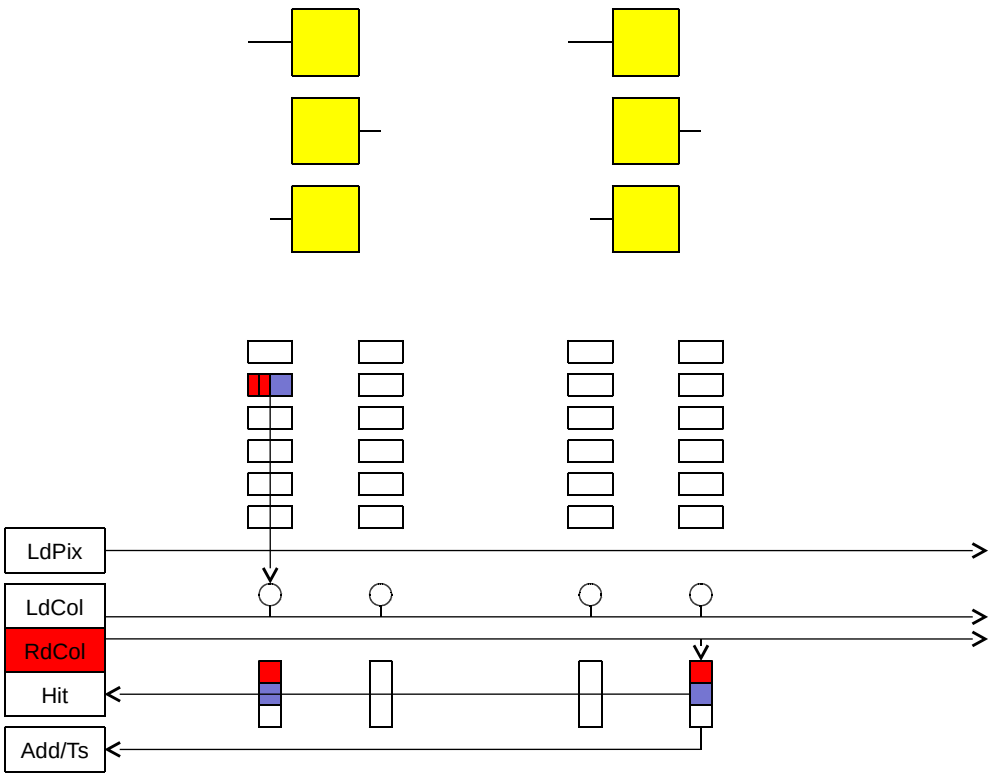
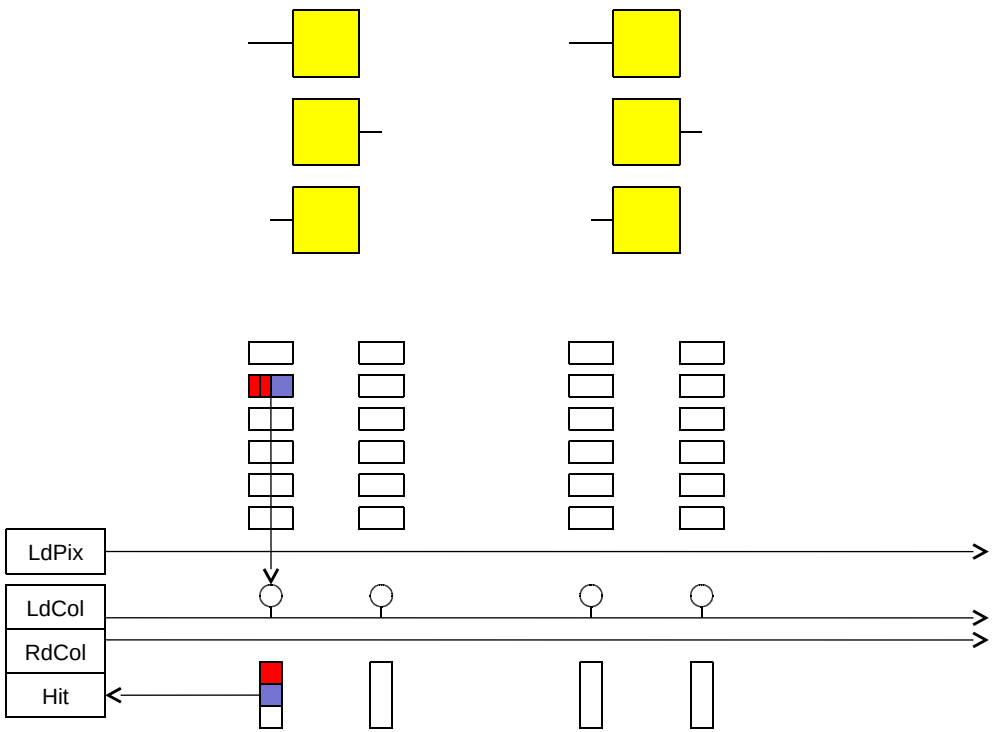


Readout of end-of-column cells works similar

Write col + row addr and time stamp to bus

HV-MAPS

Digital Part



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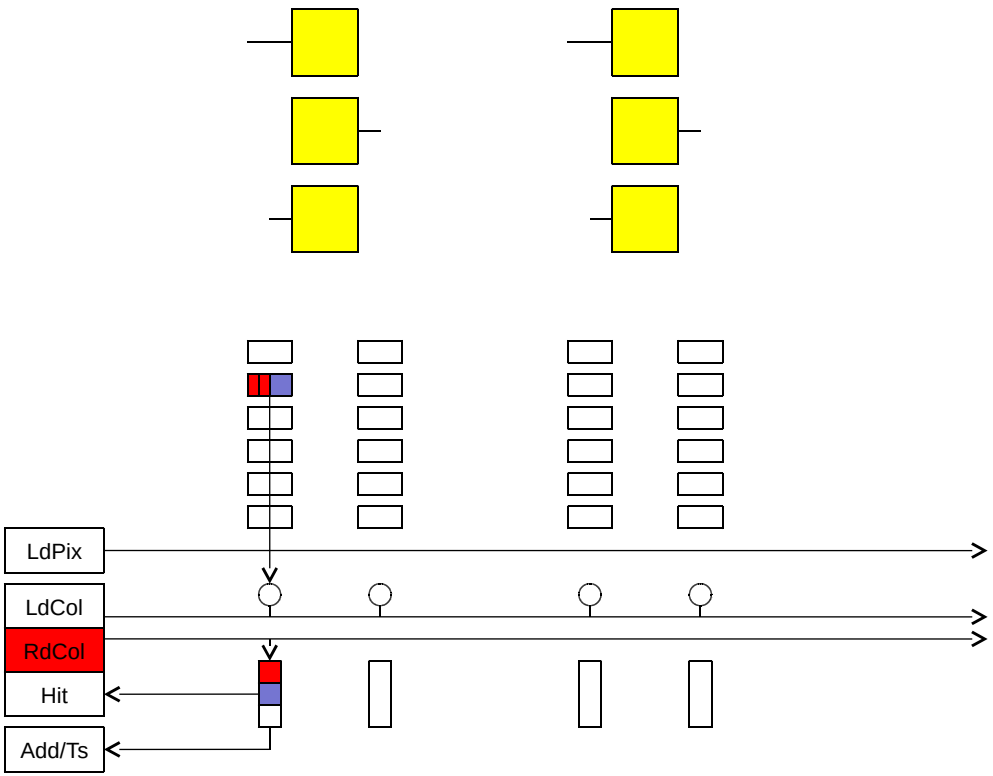

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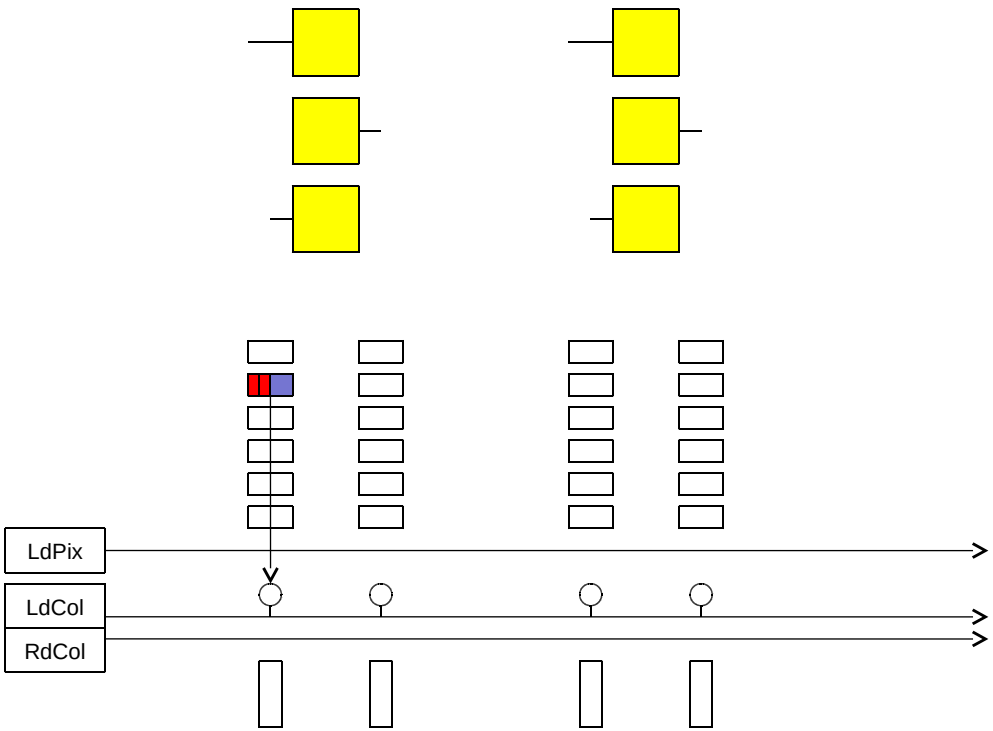
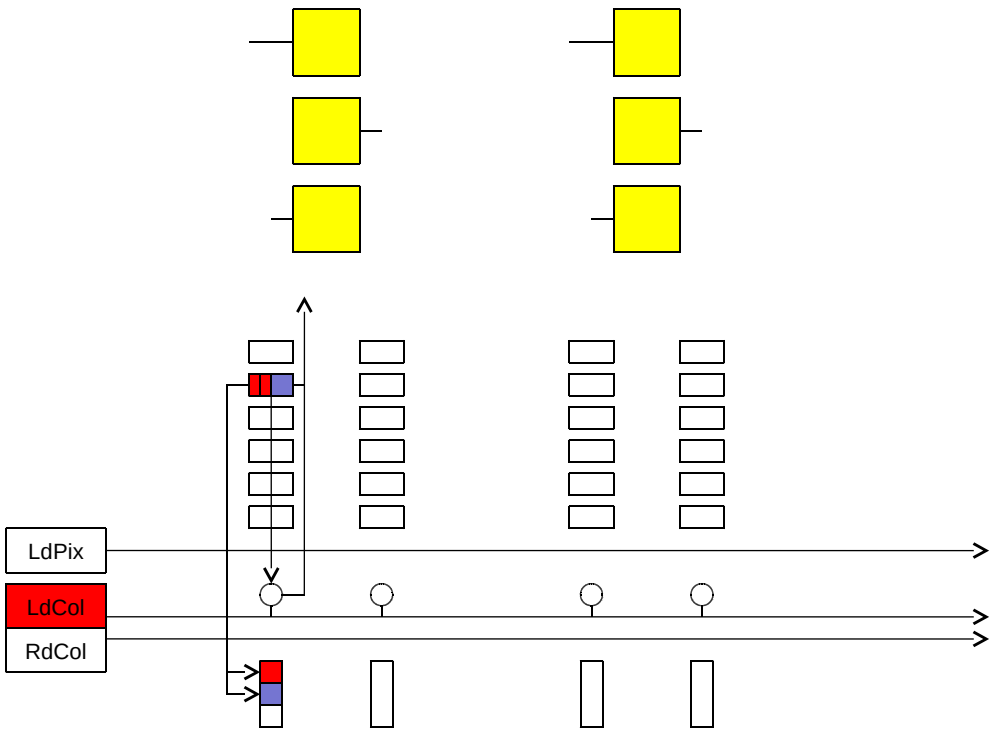


Copy hit data from readout-cell to end-of-column cell

Write data from end-of-column to bus

HV-MAPS

Digital Part



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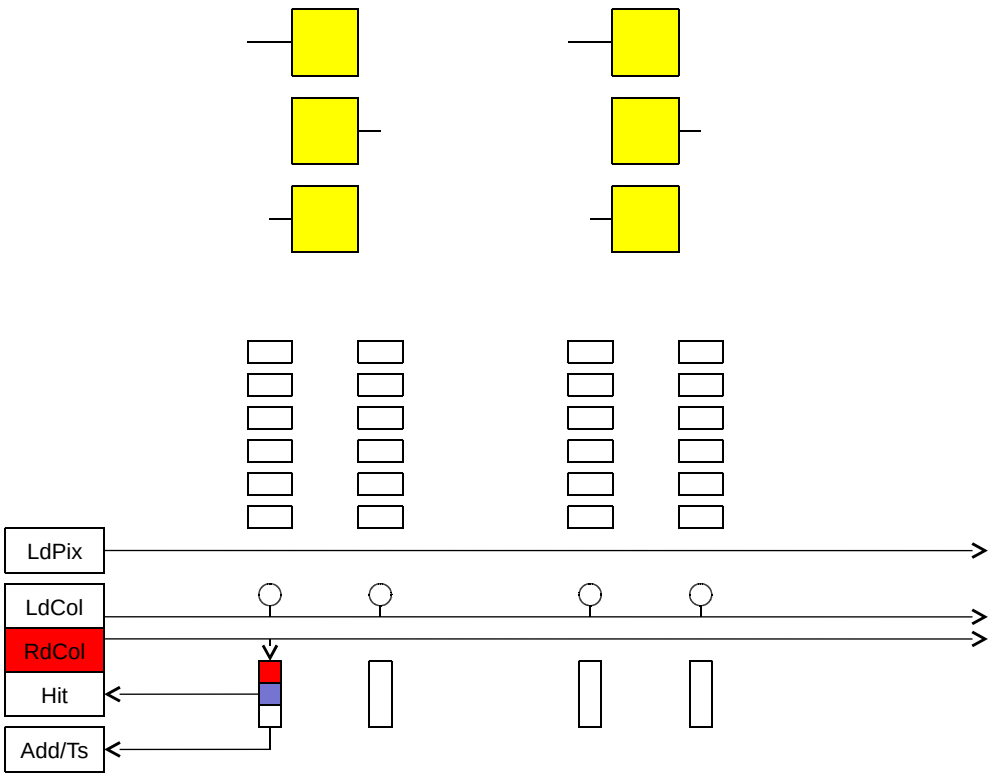

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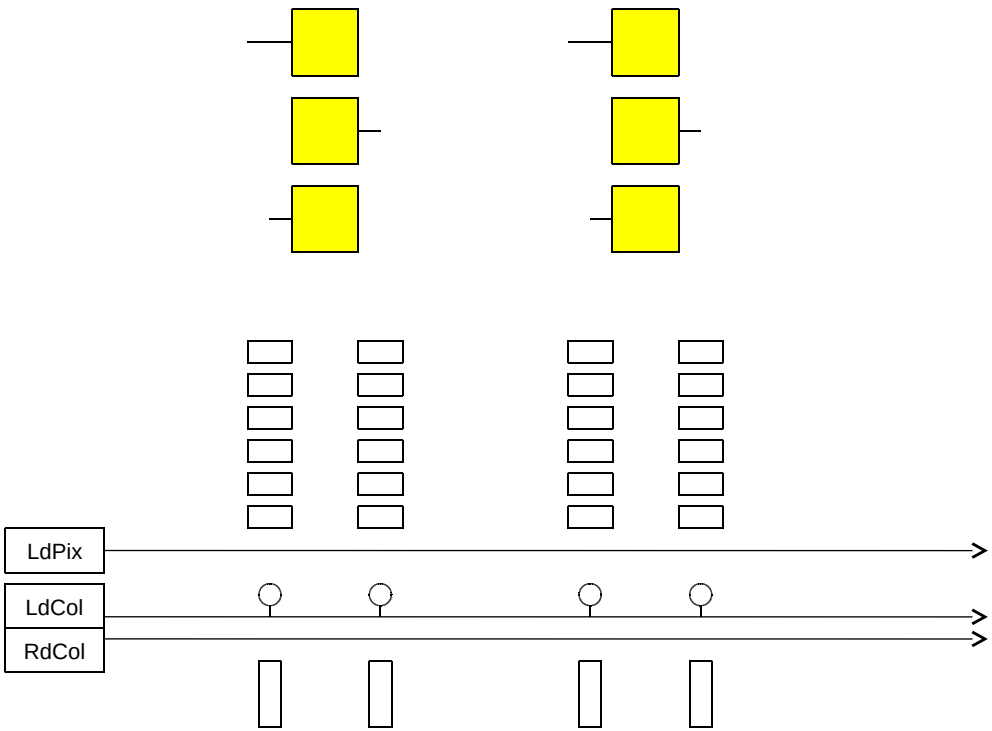

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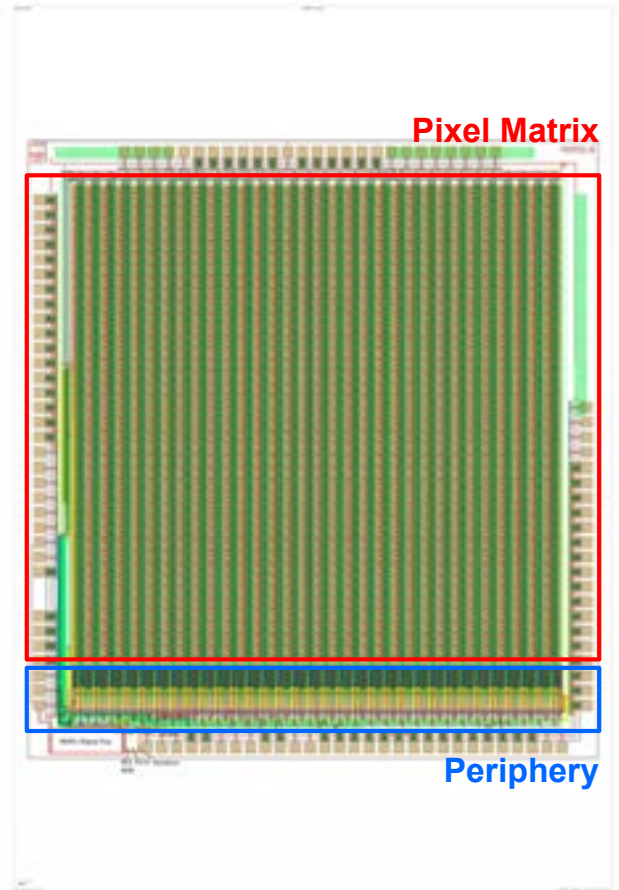
Write data from end-of-column to bus

MuPix7

Latest HV-MAPS prototype for Mu3e

- 32×40 pixels à $103 \times 80\,\mu m^2$
- Parallel data readout
  as in previous MuPix
- Fast serial data output
  - Internal state machine
  - 8b/10b encoded hit data:
    time stamp, col, row
  - LVDS link up to 1.25 Gbit/s
- 50 µm thin
- Currently under test (lab, test beam)



For tests of MuPix see:
T41.7, T44.2, T44.3

DAQ Concept

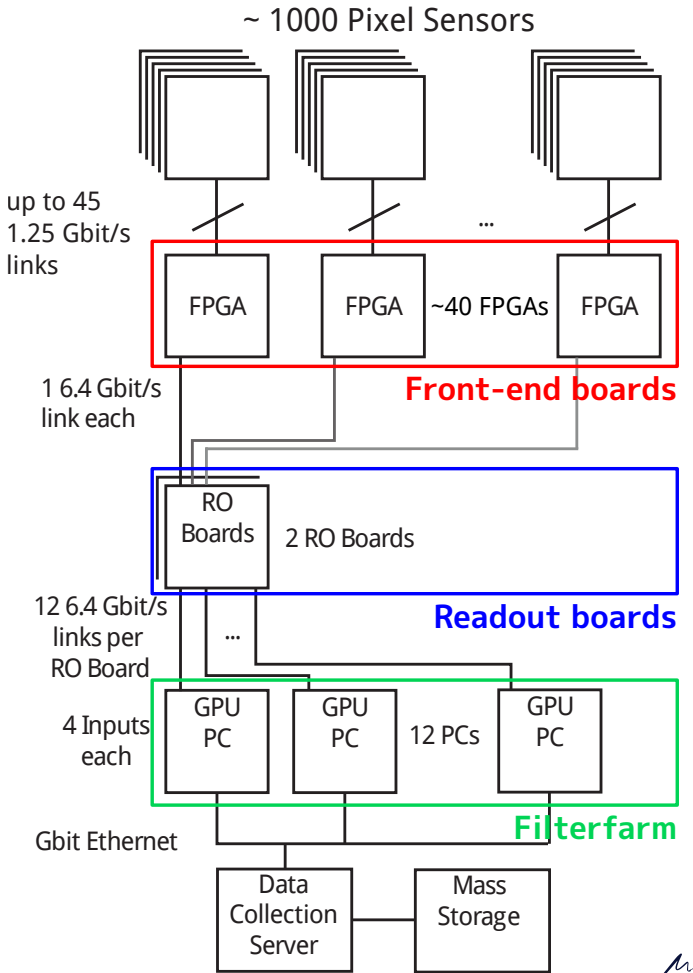
Triggerless data acquisition

Front-end board

- Buffer and merge data of $\mathcal{O}(15)$ sensors
- Time-sorting
- Slow control
- Altera Stratix IV
- Optical link

Readout board

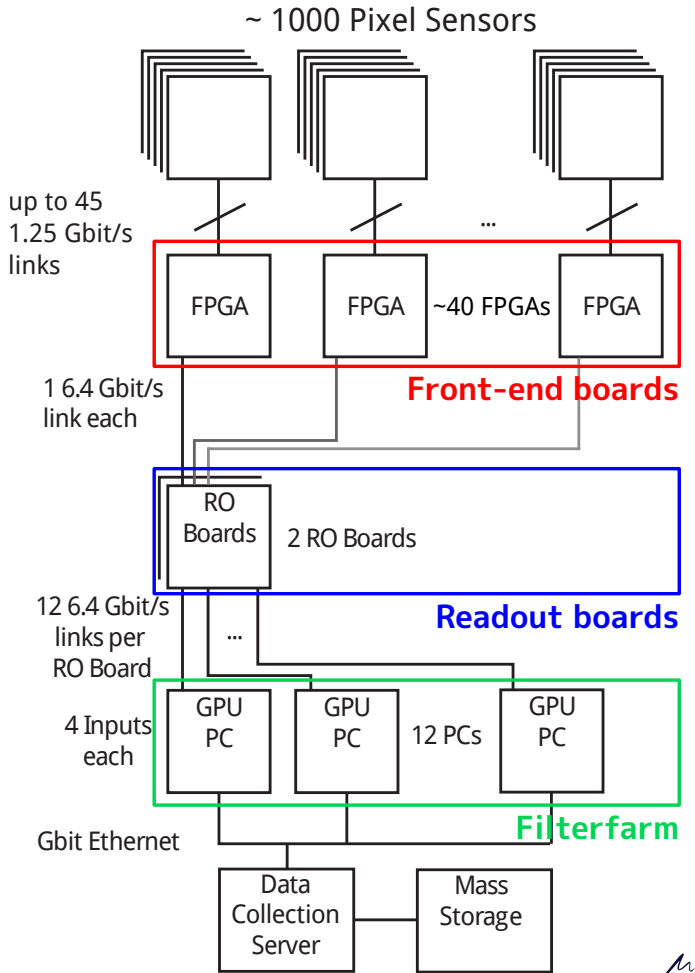
GPU filterfarm



DAQ Concept

Triggerless data acquisition

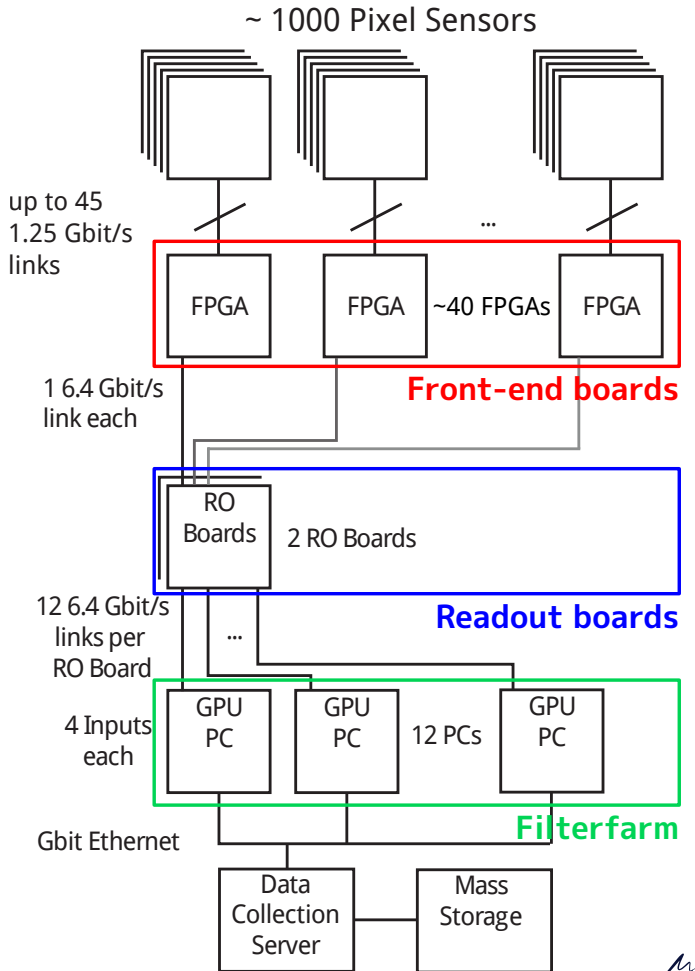
- Front-end board
- Readout board
  - Switch between front-end and filterfarm
  - Merge data of sub-detectors
  - Altera Stratix V
- GPU filterfarm



DAQ Concept

Triggerless data acquisition

- Front-end board
- Readout board
- GPU filterfarm
  - Fast track finding and online reconstruction
  - Reduce data rate by a factor ~ 1000
  - T41.6



Summary

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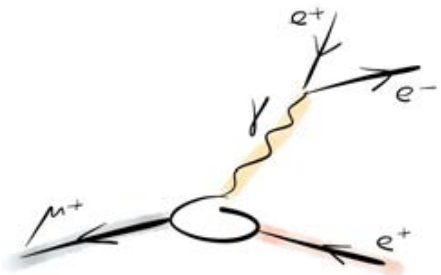
Search for LFV decay $\mu \to eee$ with a sensitivity of BR $< 10^{-16}$ (90% CL)



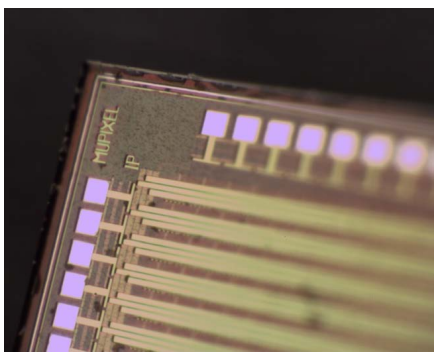
HV-MAPS:

Thinned active pixel sensors

Zero-suppressed readout

MuPix7:

First HV-MAPS with fast serial data output



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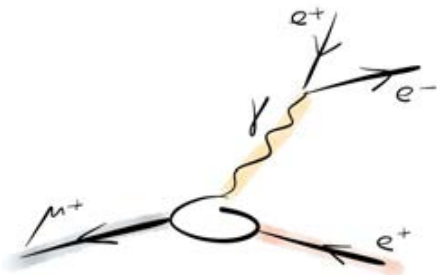

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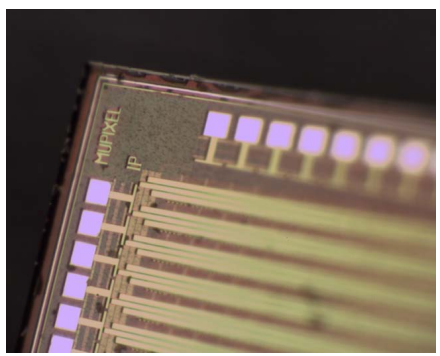


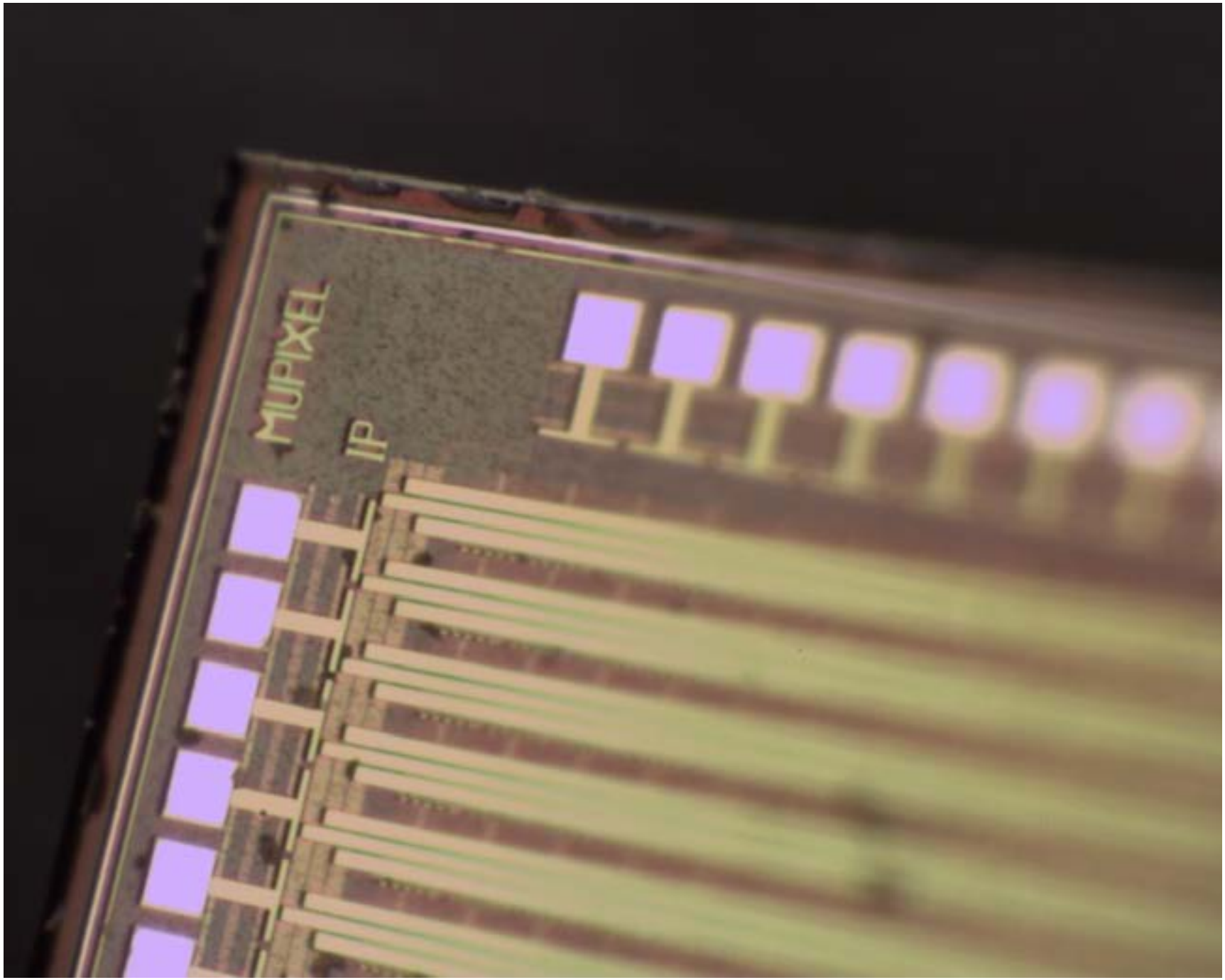
Triggerless data acquisition

Further talks on Mu3e/MuPix:

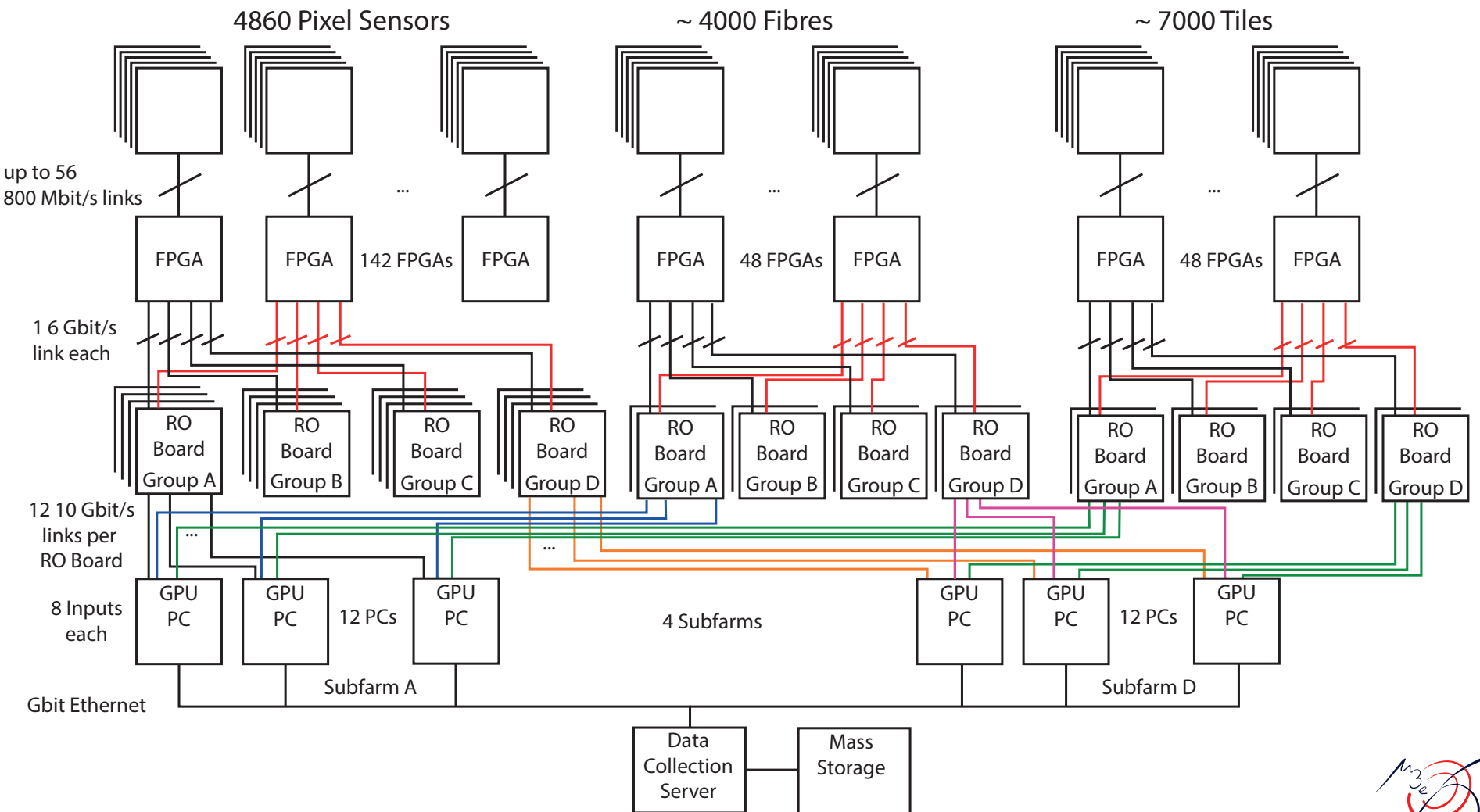
T34.9: Cooling

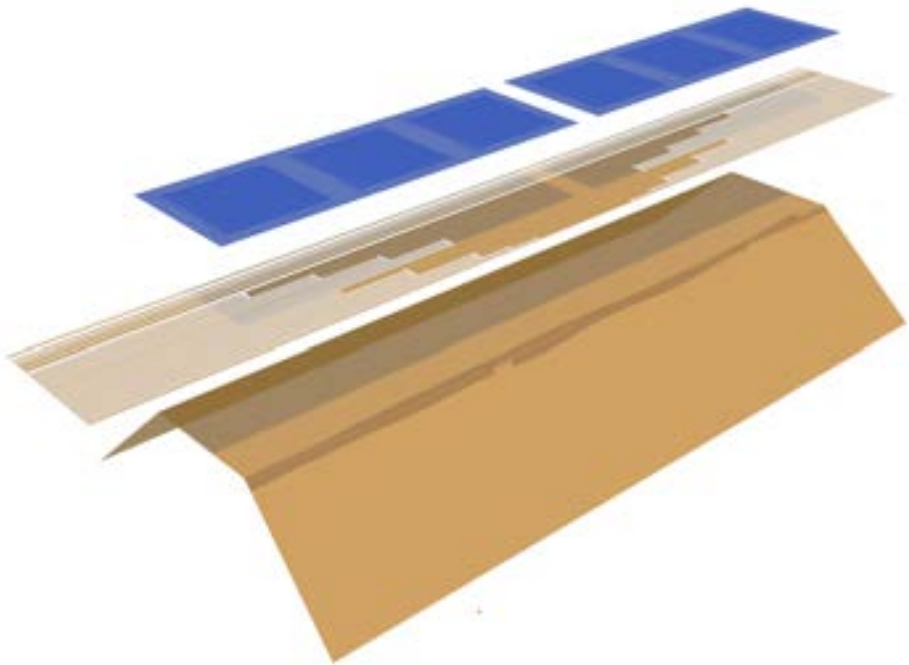
T41.6: GPUs

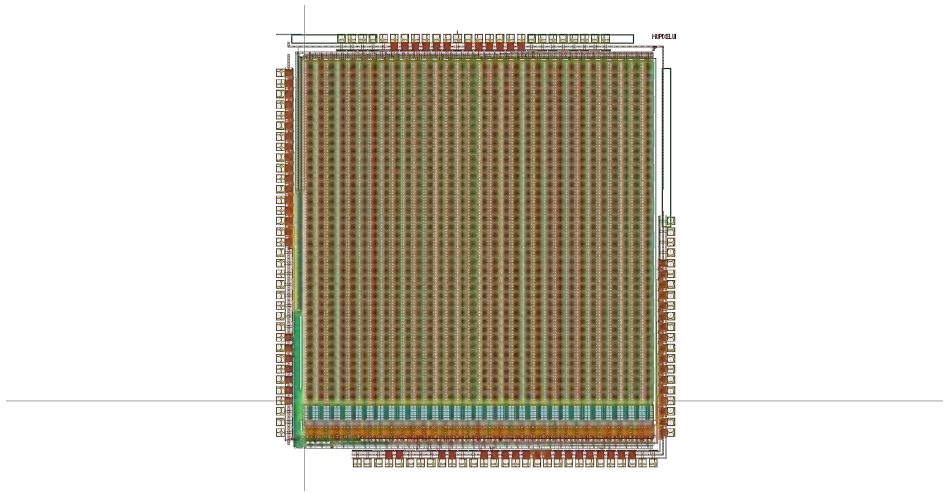
T41.7, T44.2, T44.3: MuPix and MuPix telescope


MUPIXEL
IP

Readout Concept







Outlook

MuPix6: successfully tested
MuPix7: test beam campaigns at DESY, MAMI and PSI
MuPix8: reduce pin count
MuPix9: large active area ($1 \times 2\text{cm}^2$)

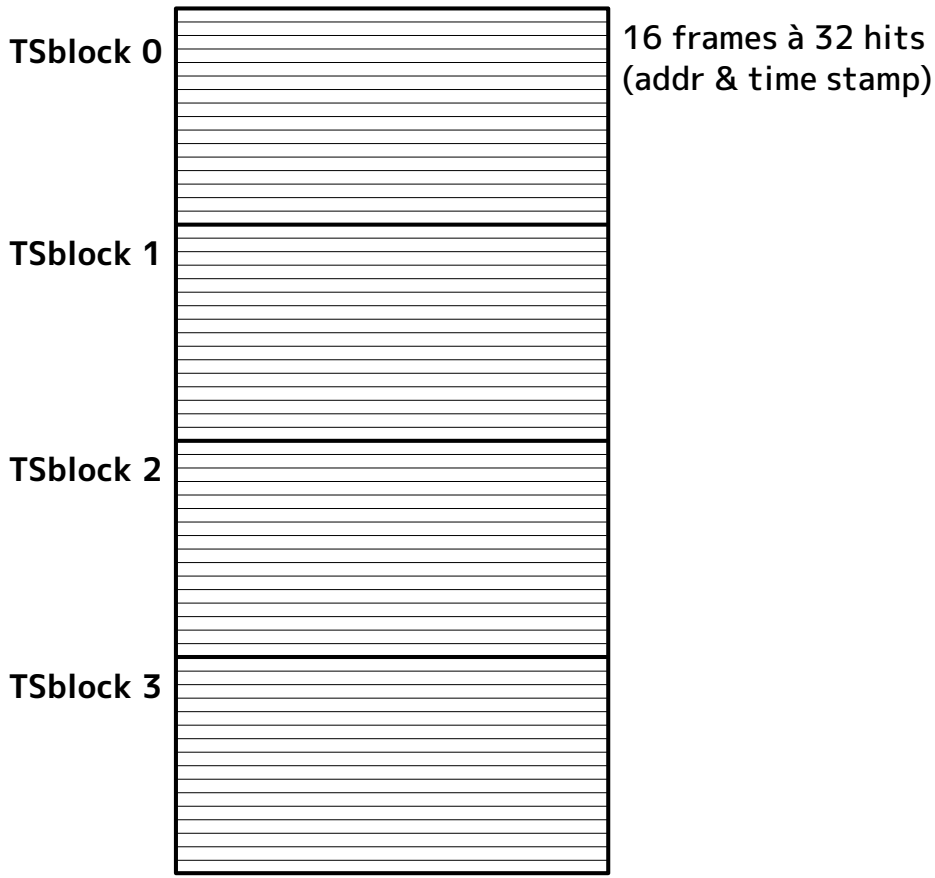
1st full readout chain with MuPix7 by this year

Readout Concept

Front-end board

- Buffer data in large memory (6 kB)
- Address is time stamp
- Data is delayed by $\leq$ 16 frames ($\sim$ 50 ns)

$\Rightarrow$ Divide into 4 blocks à 16 frames



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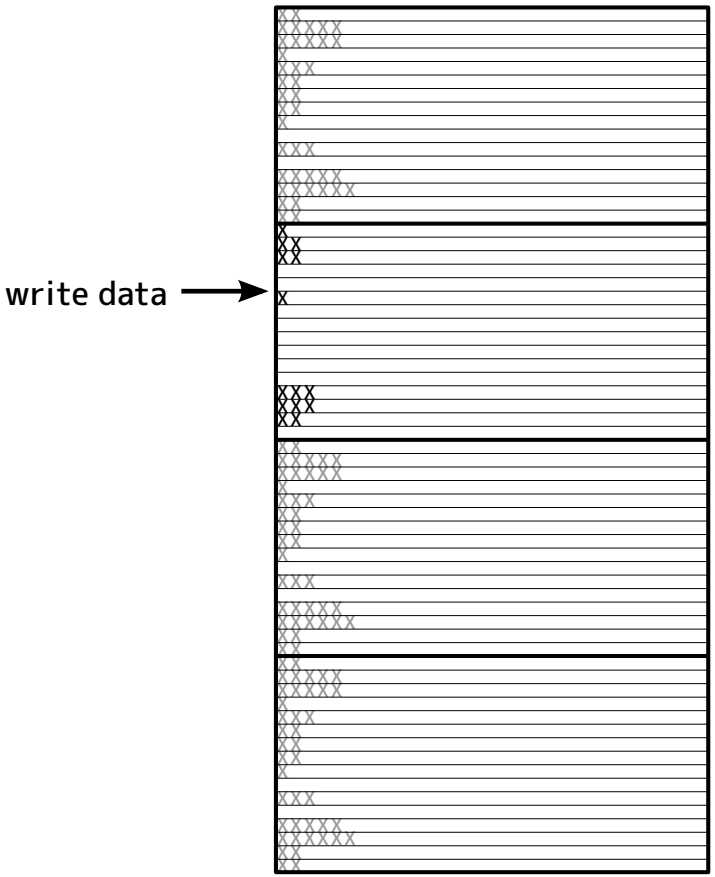

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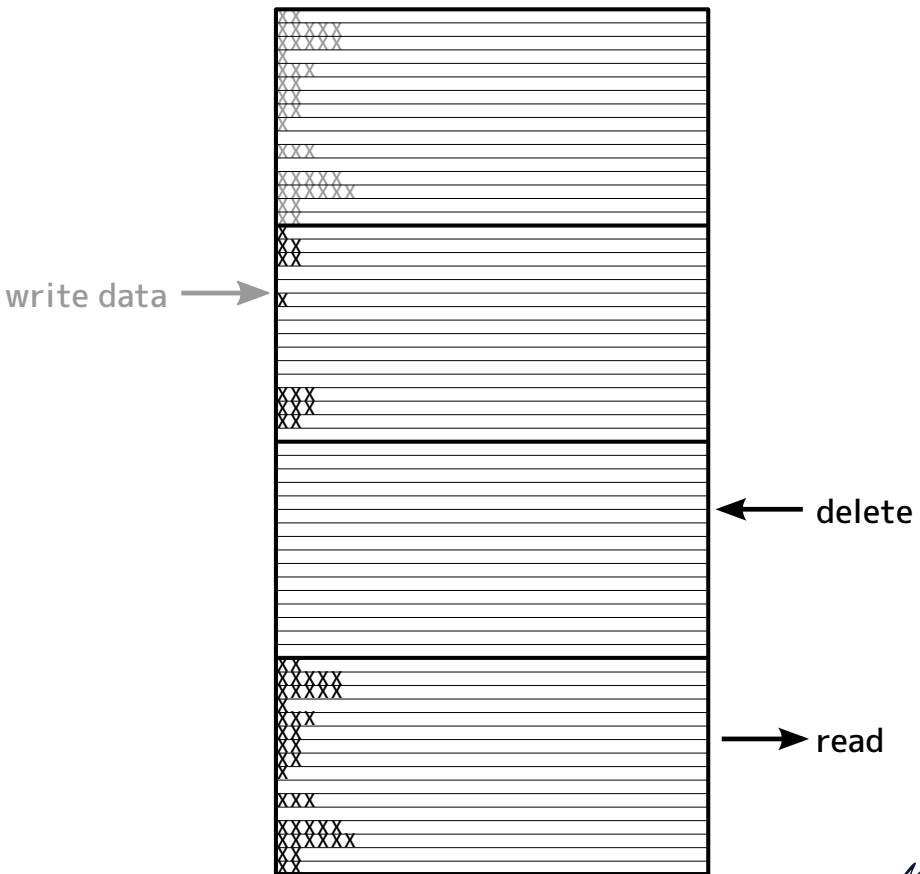

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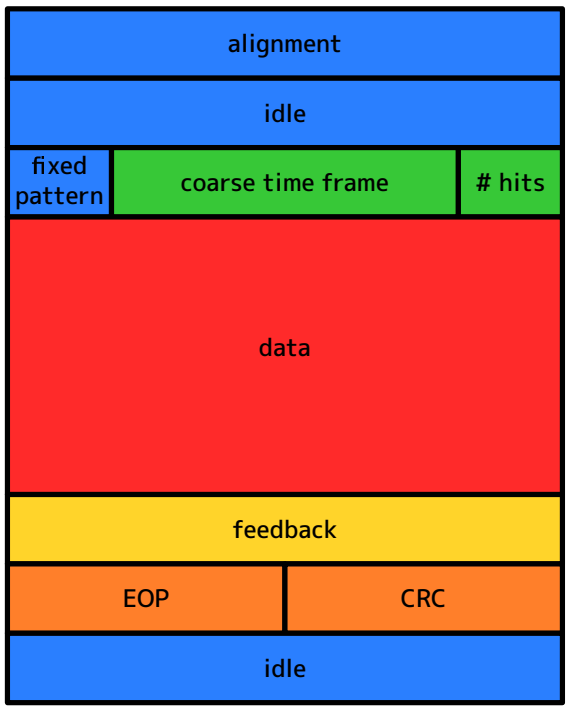
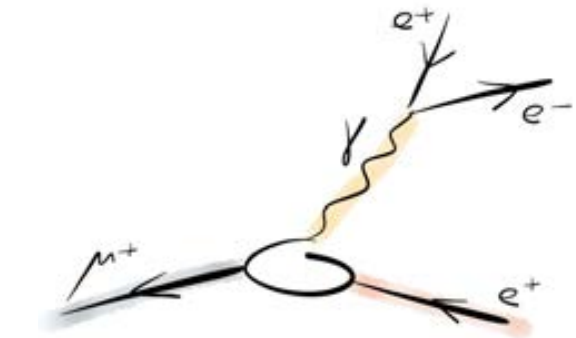
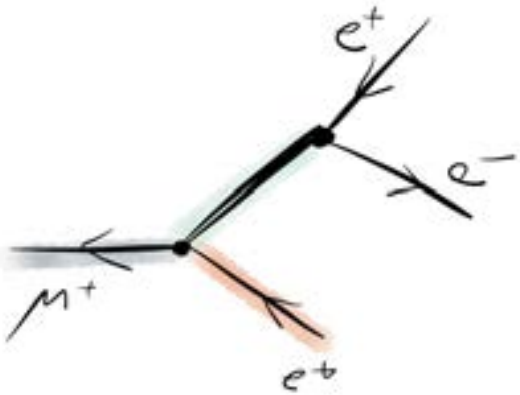
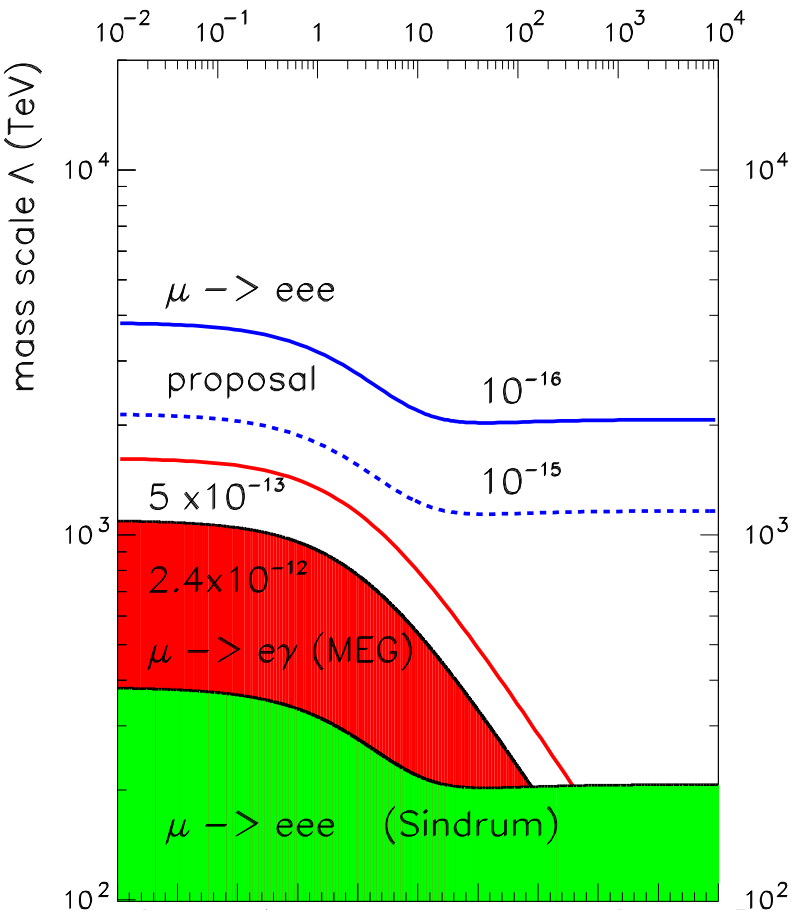


Theory

Loop and tree diagram

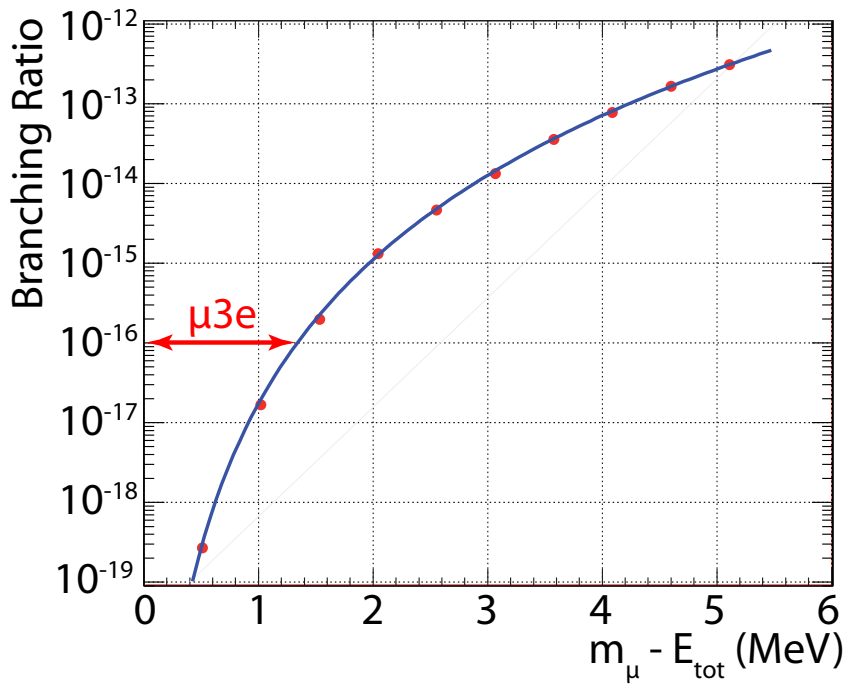






Theory

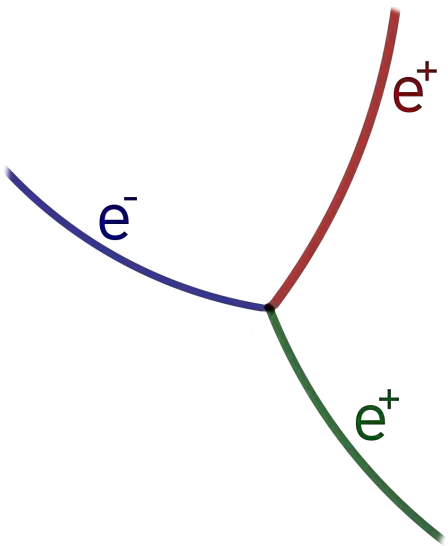
Internal conversion decay



Missing energy carried away by neutrinos

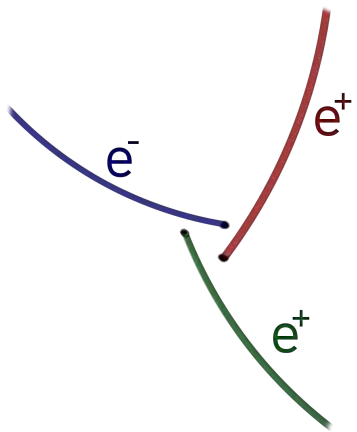
Background

Signal



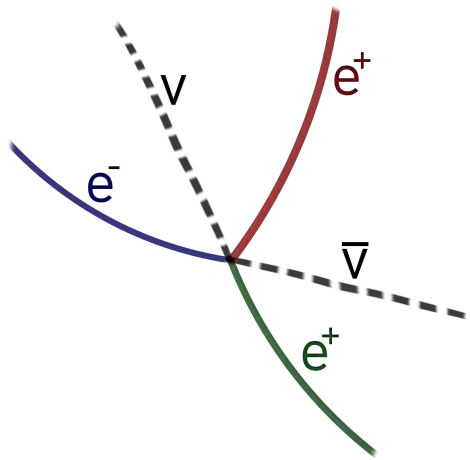
Common vertex
Coincident in time
Momenta sum up to muon mass

Accidental combinations



No common vertex
Not coincident
Deviations from muon mass

Internal Conversion Decay



Common vertex
Coincident
Missing energy due to neutrinos