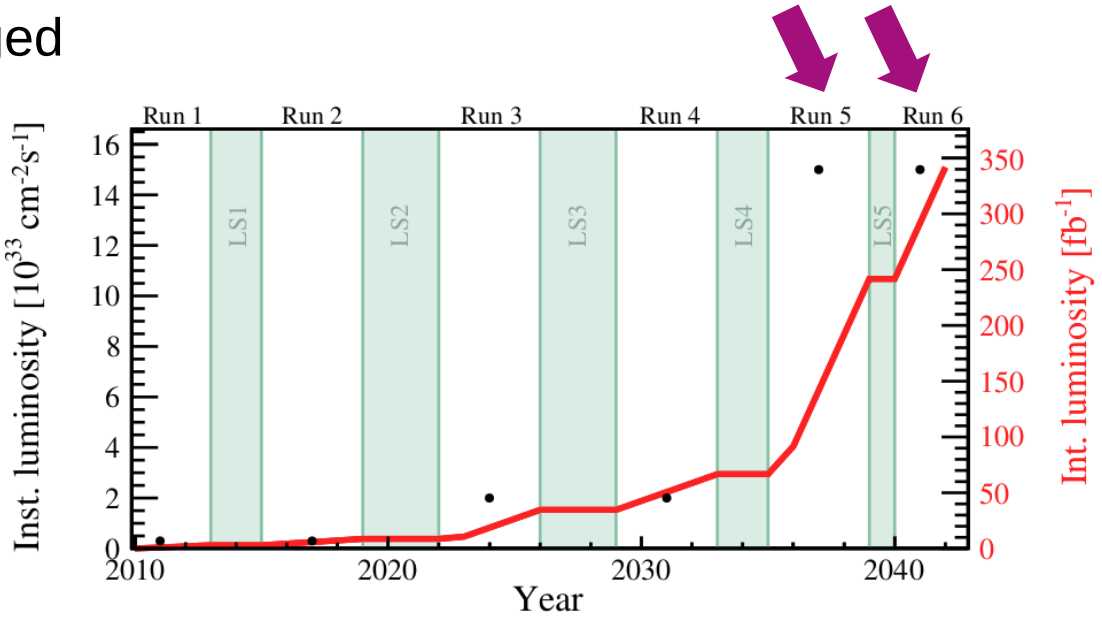
The plans of the future upgrade LHCb Tracker (Mighty Tracker)

Toko Hirono* on behalf of the LHCb Collaboration

*** Institute for Data Processing and Electronics, Karlsruhe Institute of Technology**

LHCb Upgrade II

- LHCb upgrade II is planned for Long Shutdown 4 to cope with the new operating conditions of High Luminosity LHC (L_{int} = 300 fb^{-1}, L_{inst} = 1.5 x 10^{34} /cm^2 /s)
  - Higher radiation dose
  - Increased particle multiplicities and rates
- Principle of LHCb Upgrade II:
  - General layout of the detector remain unchanged
  - Sub-detector (*incl.* **Mighty Tracker**) **will be upgraded**



Mighty Tracker in LHCb experiments

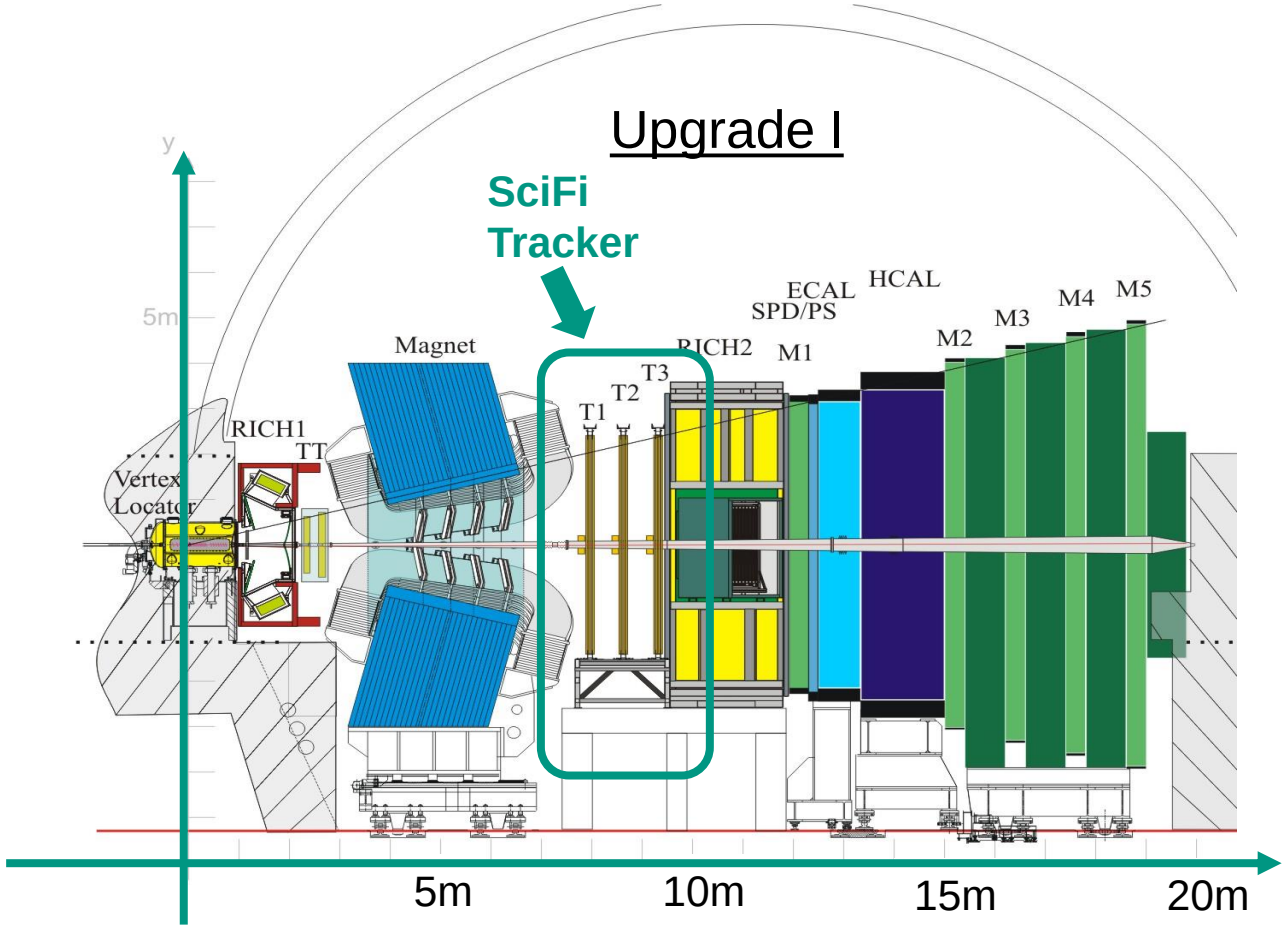
- LHCb is a forward-arm spectrometer

- Upgrade I (SciFi Tracker)
  - 3 tracking stations downstream of the magnet
    - Scintillating fibers

  → Now in operation

- Upgrade II (Mighty Tracker)
  - 3 tracking stations
    - Scintillating fibers
    - **HV CMOS monolithic active pixel sensor (HV-MAPS)**

  → Higher hit-rate capability and radiation hardness to survive in Run 5, 6



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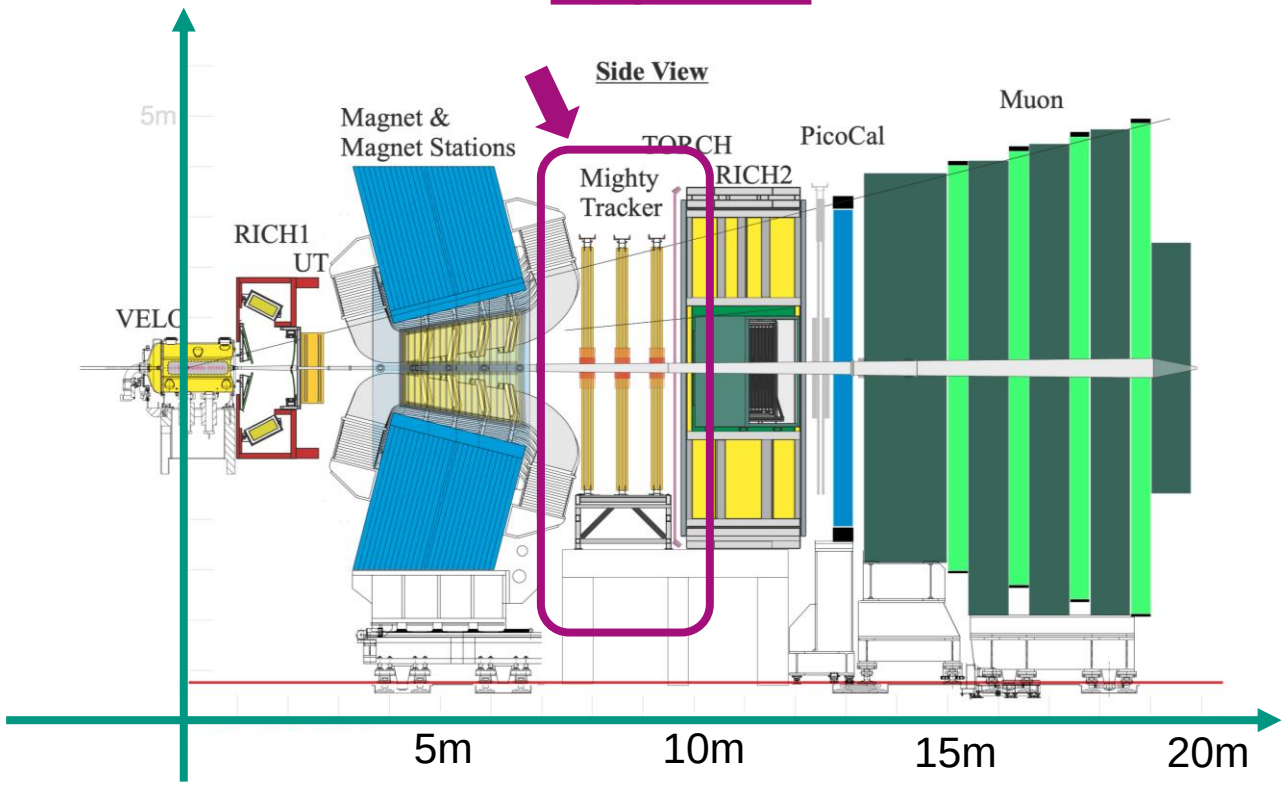
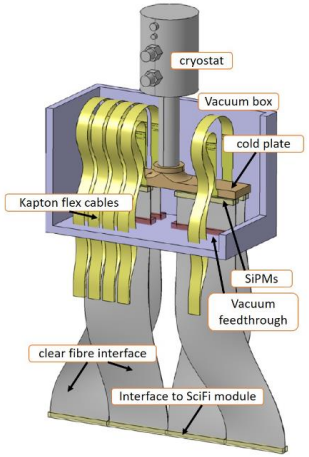
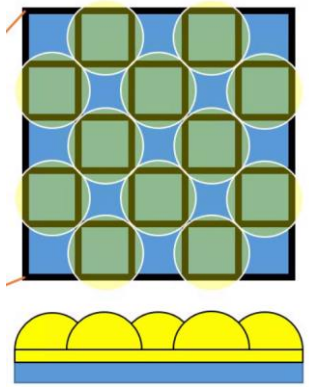
Upgrade II



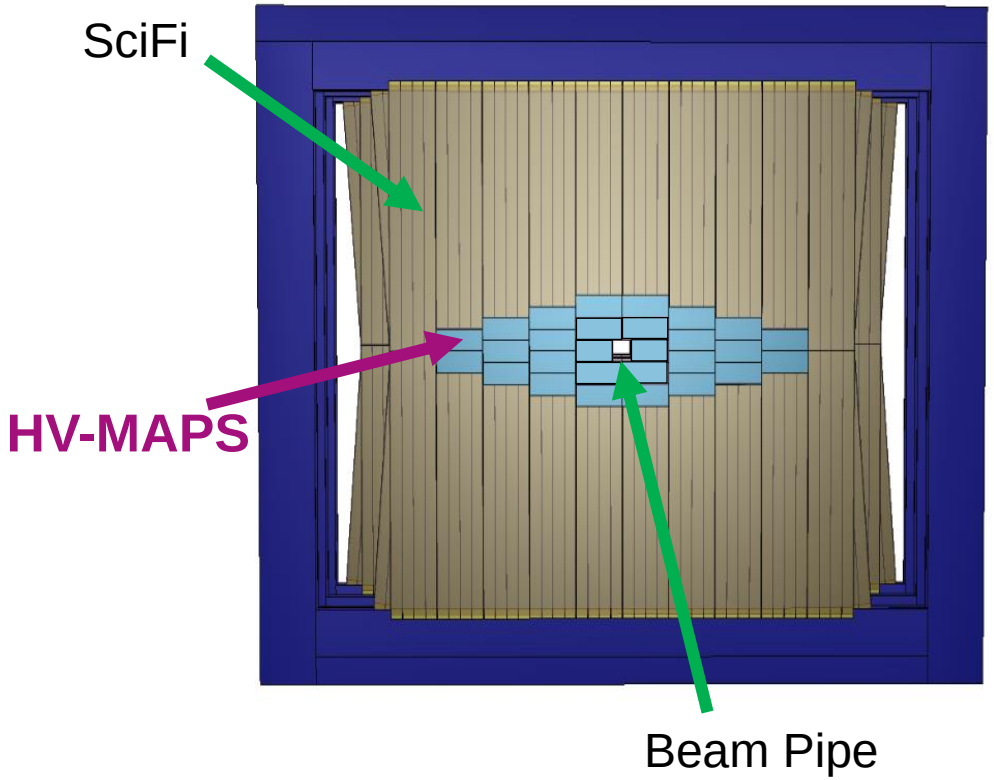
Mighty Tracker (Outer Tracker)

- Moderate occupancy region
  - 6 SciFi layers / station = 18 layers
  - Ongoing R&D to mitigate rad-damage, increase hit-rate capability
    - Fibre improvements
    - Cryogenic cooling for lower noise
    - Micro-lens enhanced SiPM
      to concentrate signal and reduce noise from in-active region ….





Front view

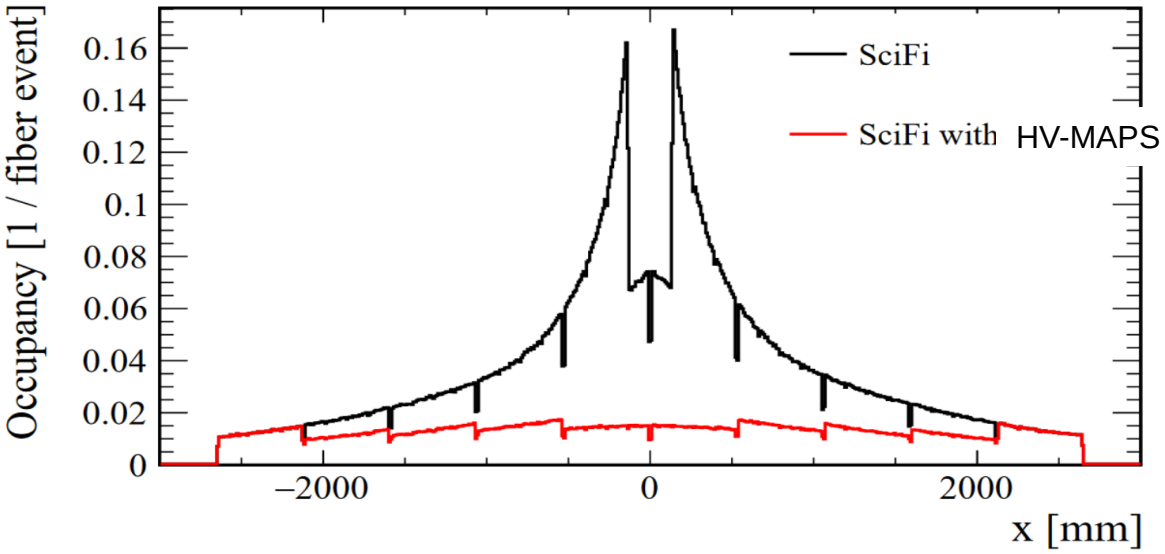


Source: Framework LHCb TDR for LHCb Upgrade II

Mighty Tracker (Inner Tracker)

- High occupancy regions:
  - 28 **HV-MAPS modules** / station
  - Chips on both side to cover entire module

SciFi occupancy w/ and w/o HV-MAPS



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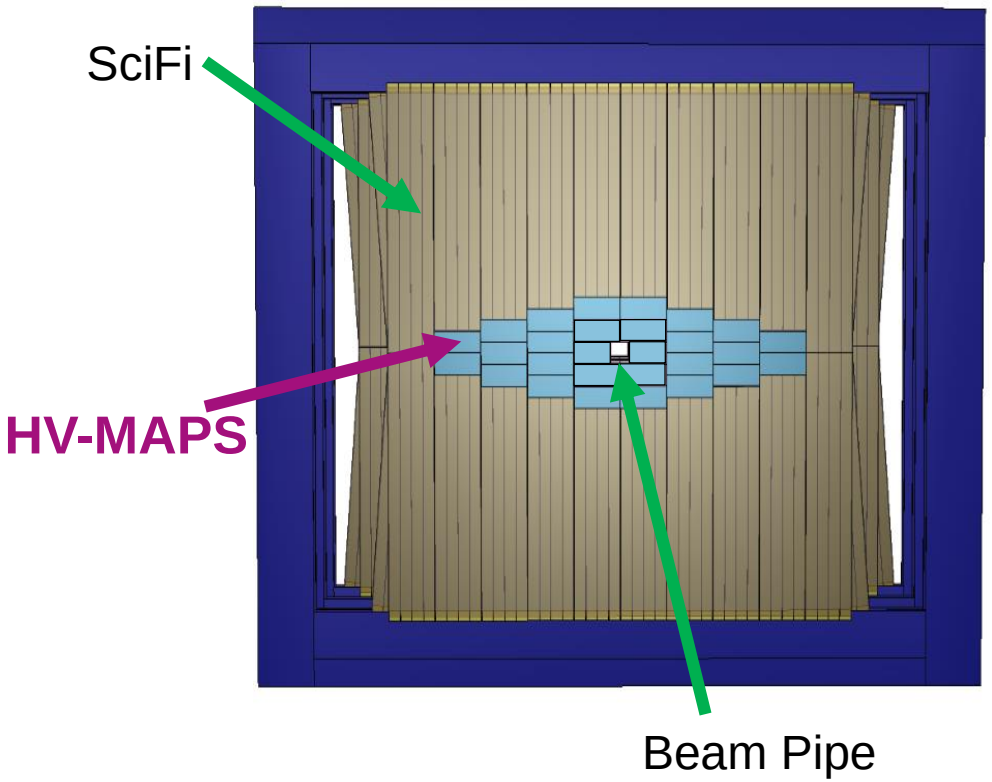

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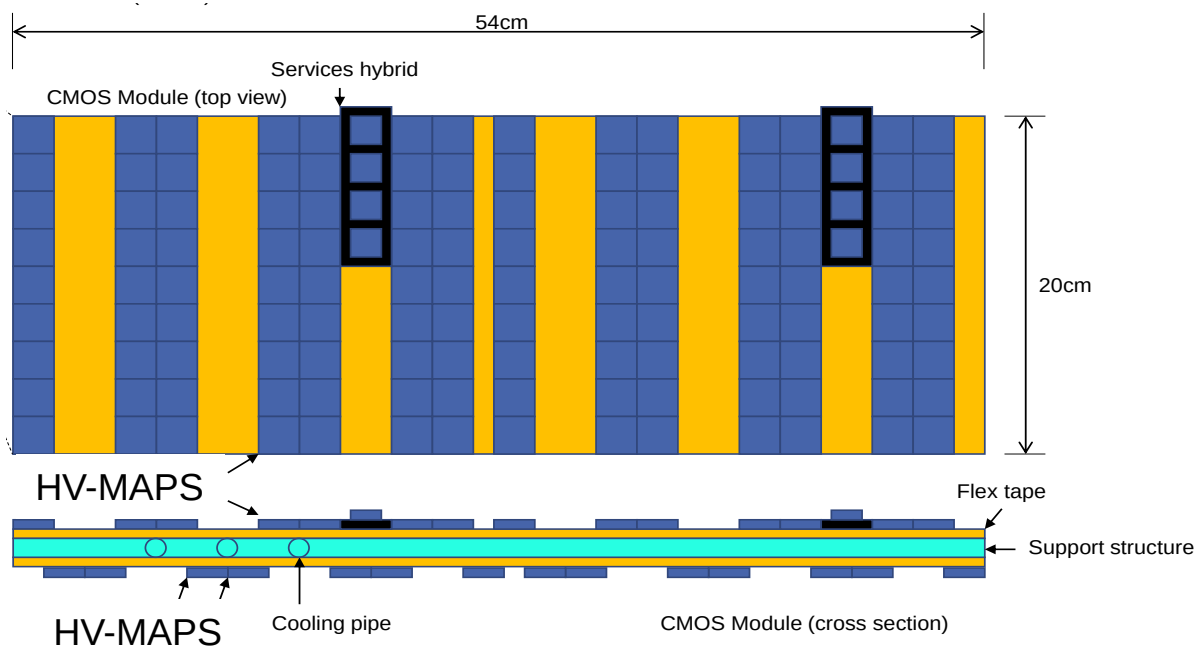

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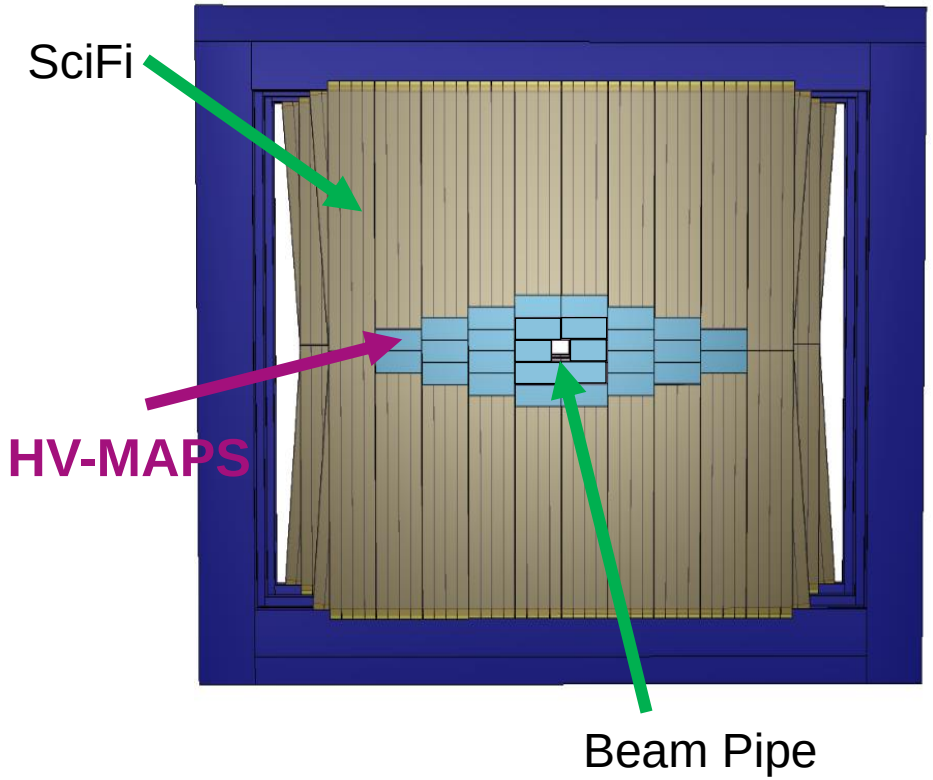

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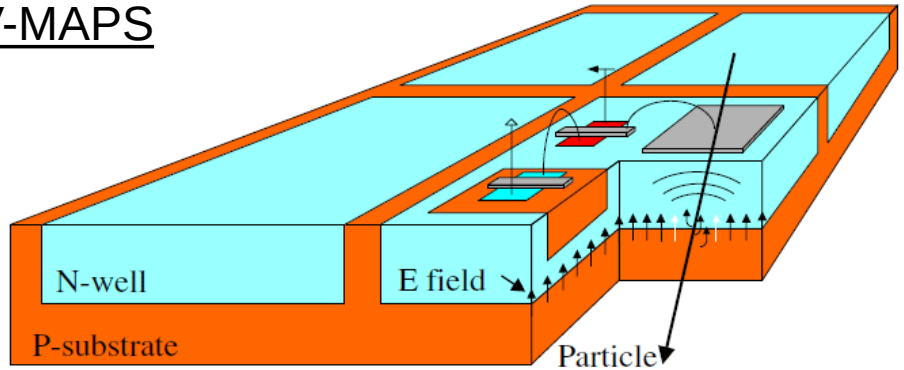
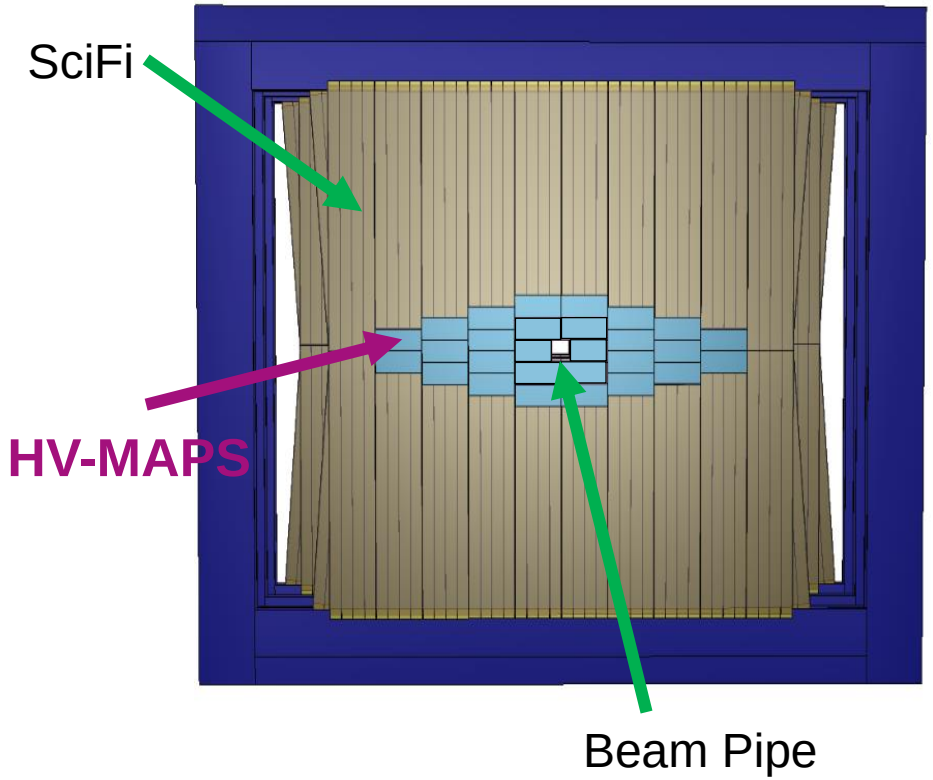
HV-MAPS



Silicon pixel detector
Sensor and readout electronics in one chip
Readout is isolated from substrate(sensor)
→ High bias voltage → Charge collection by drift → rad-hard

Front view



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MightyPix (HV-MAPS for Mighty Tracker)

- Requirements:
  - Pixel size: < 100 µm x 300 µm
  - Hit-rate capability: > 17 MHz/cm^2
  - In-time efficiency: > 99% with correct assignment to 25ns bunch-crossing (BX)
  - Radiation hardness: > 6 x 10^{14} n_{eq}/cm^2
  - Noise rate: < 5Hz / pixel
  - Power consumption: < 150 mW/cm^2
  - Compatible with the LHCb readout system
    - 4 x 1.28 Gbps data links/chip
    - Slow control
    - Timing and Fast Control (1command / BX)

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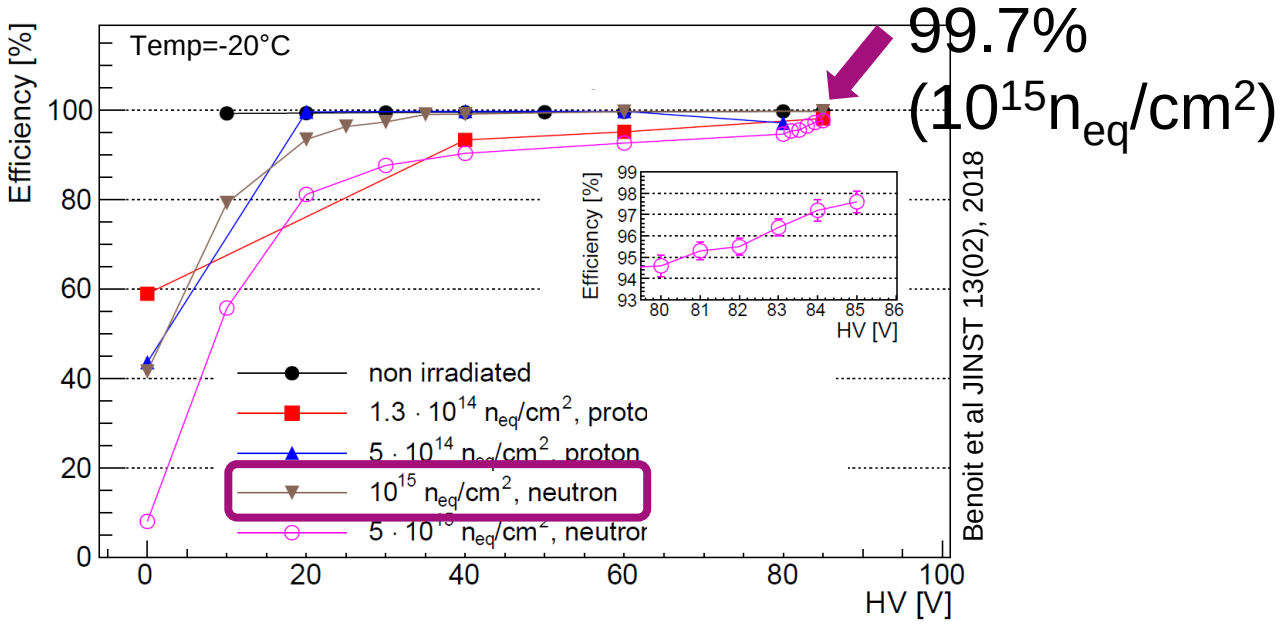
HV-MAPS
from other projects

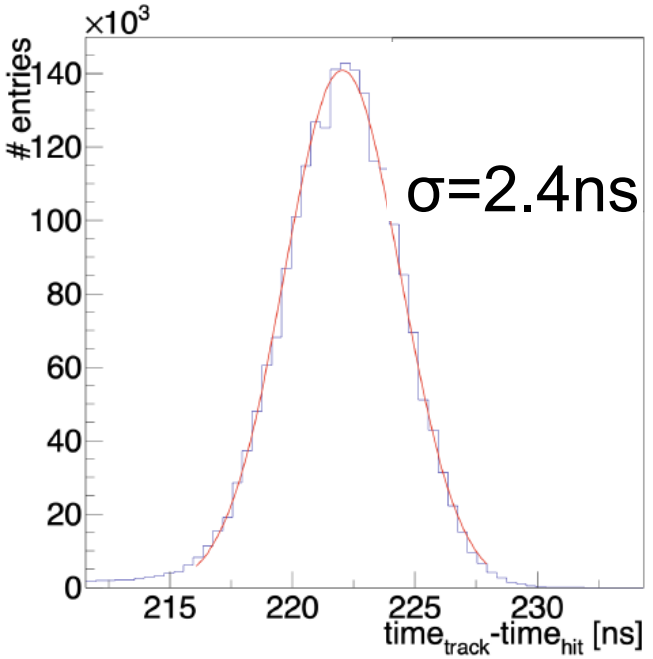
Results from the HV-MAPS Family

Efficiencies of irradiated CCPDv4 chip



99.7%
($10^{15} n_{eq}/cm^2$)

Time resolution of TELEPIX chip



- MightyPix R&D
  - Finding optimum pixel size, operating temperature, power consumption for Mighty Tracker using a dedicated prototype **and** various HV-MAPS chips from other projects

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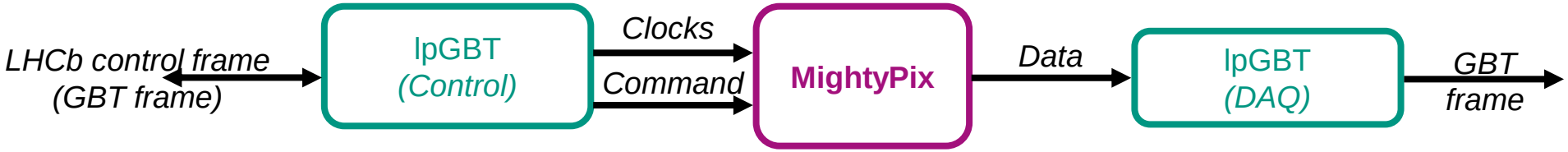
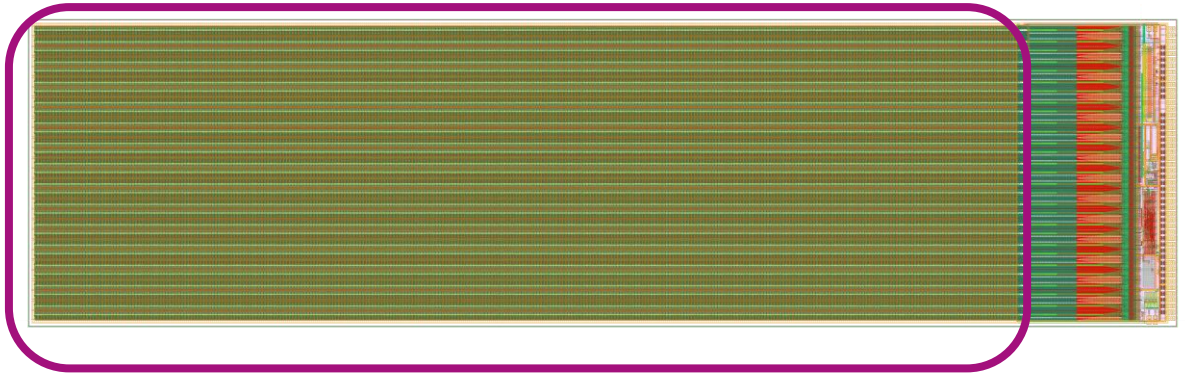
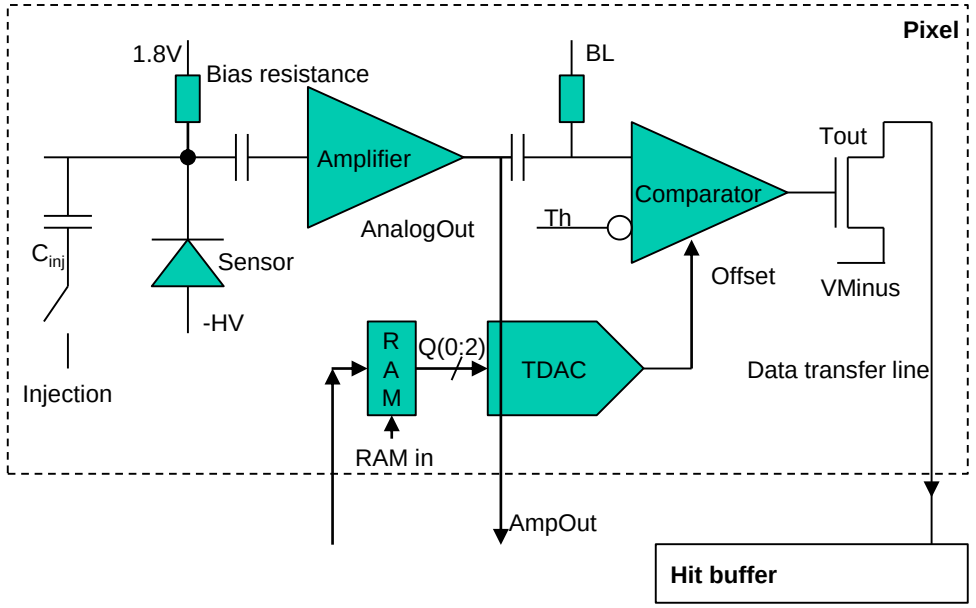
} Dedicated prototype



MightyPix1: the First Prototype

- The first prototype chip deliciated to Mighty Tracker
  - TSI 180nm process
  - Resistivity of wafer: 370 Ωcm
  - Chip size: Full length (20mm) x ¼ width (5mm)
  - 3 blocks:
    - Pixel Matrix
      - Sensor matrix with analog readout
      - Pixel size: 55 x 165 µm
    - Hit-buffer with ToA and ToT per pixel
    - Digital periphery
      - Column-drain architecture readout logics
      - 1.28Gbps x 1 data link
      - I2C interface for slow control
      - Timing and Fast control command decoder
      - 40MHz to 640MHz PLL x 2 types





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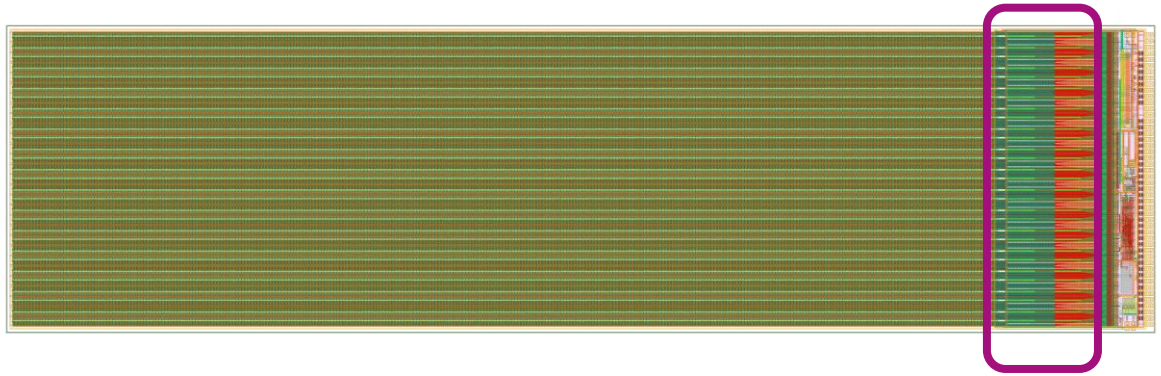

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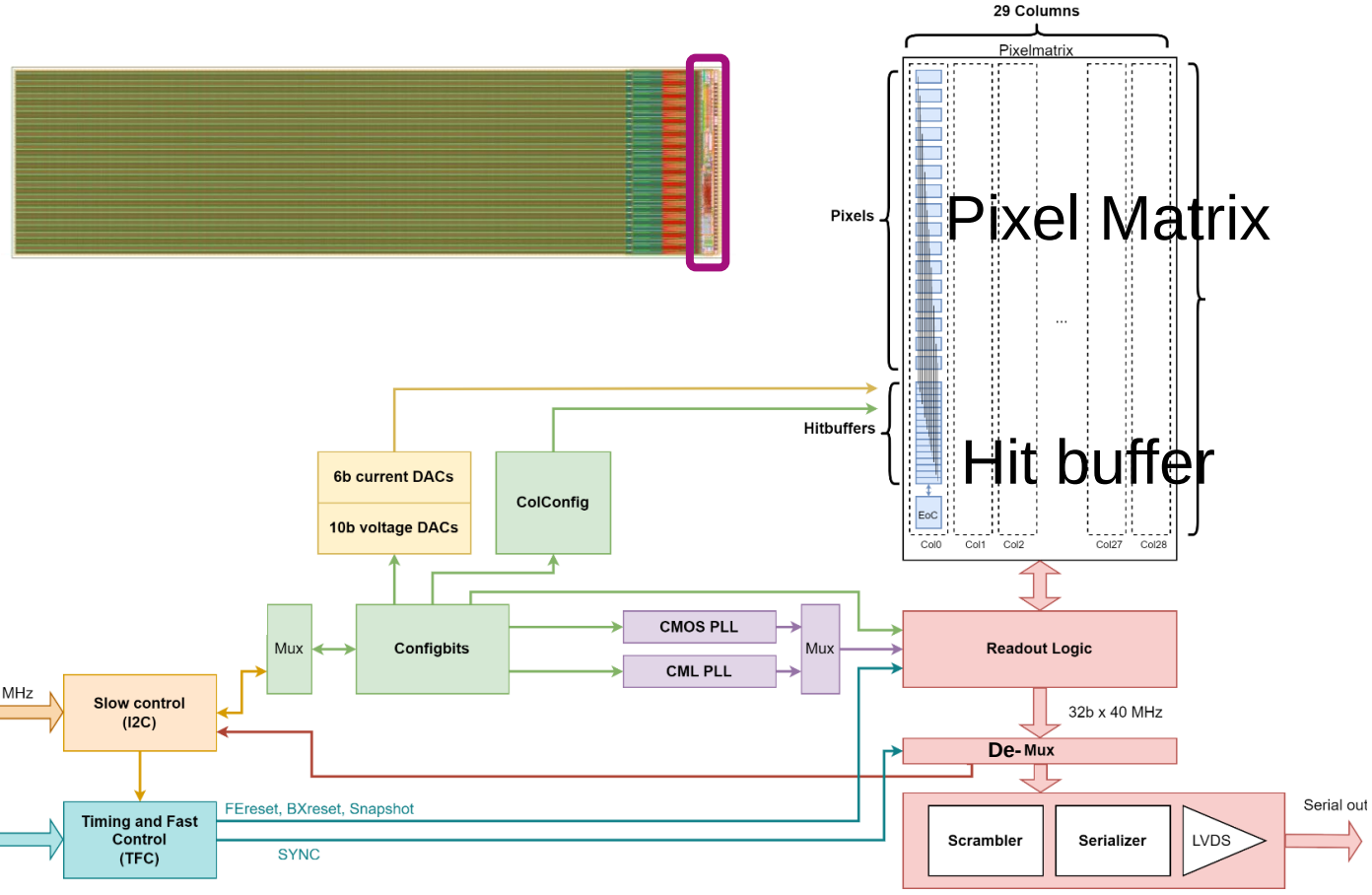

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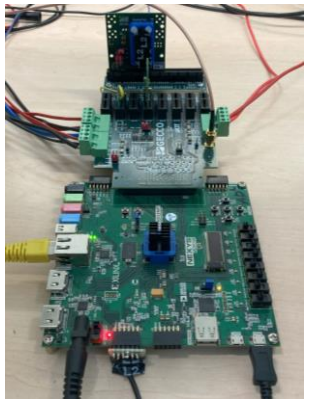
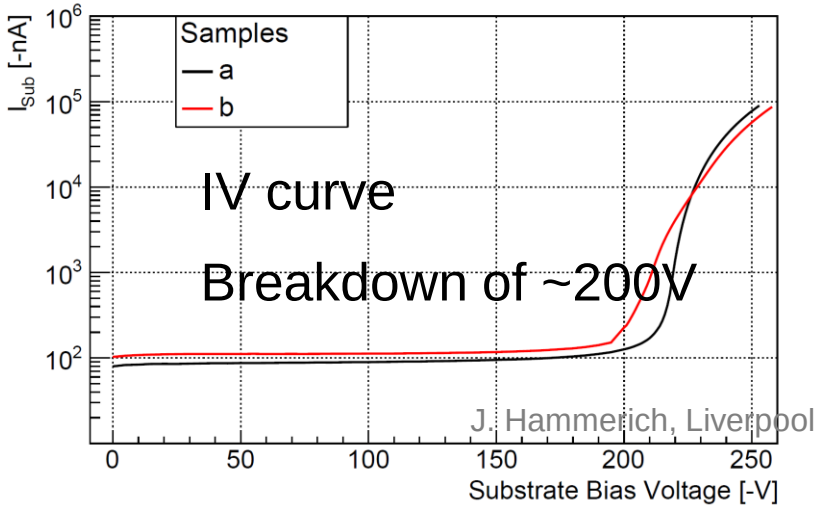
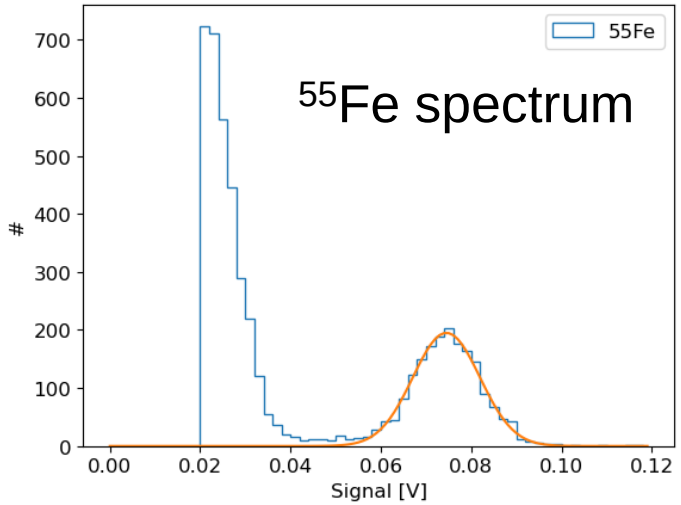
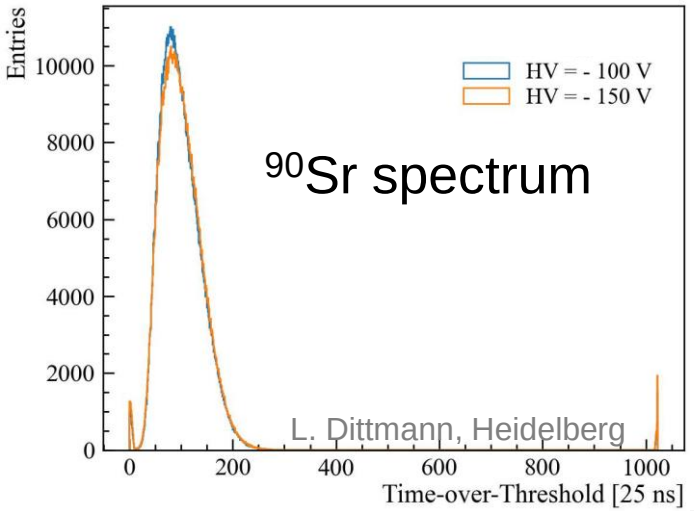
First results of Mightypix1





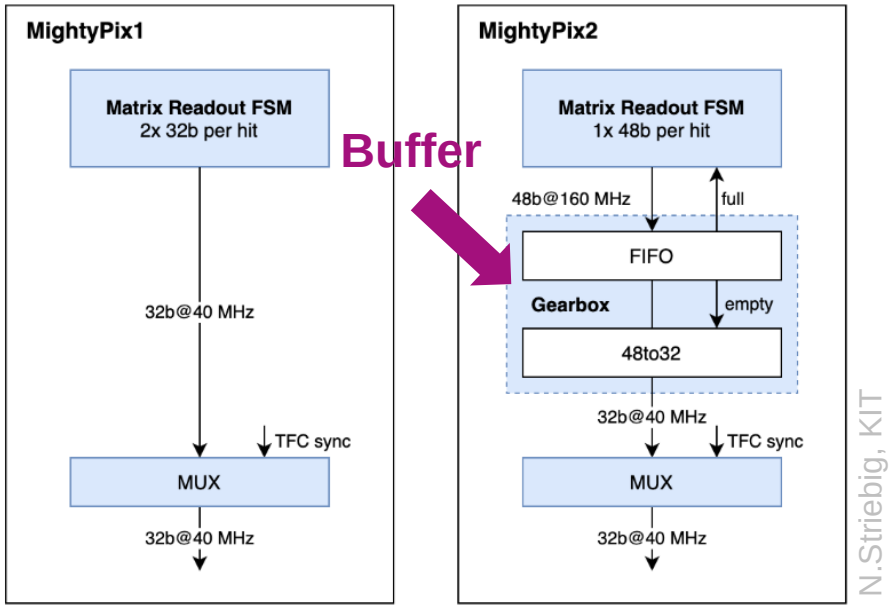




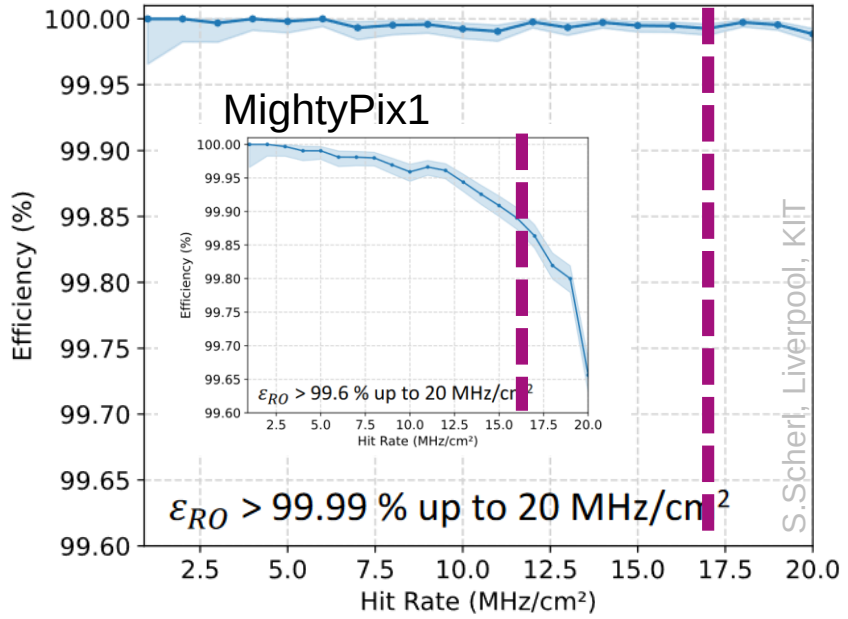
- Submitted in 2022
- Tests started in Summer of 2023
- Basic functionalities including newly implemented digital interfaces are tested using electrical signals & radioactive sources
  - PLL
  - 1.28 Gbps data link
  - I2C interface
  - TFC command decoder
- Waiting for irradiation and beam tests

Next Step (MightyPix 2)

- First **full size** chip (*cf.* Mightypix1 = ¼ size)
  - Deleting features for debugging
  - 4 x 1.28Gbp data links
    - ~100% readout efficiency at the hit rate of **>17MHz/cm²**
  - Serial powering and more to test in MightyPix modules



Simulated Readout Efficiency (MightyPix2)

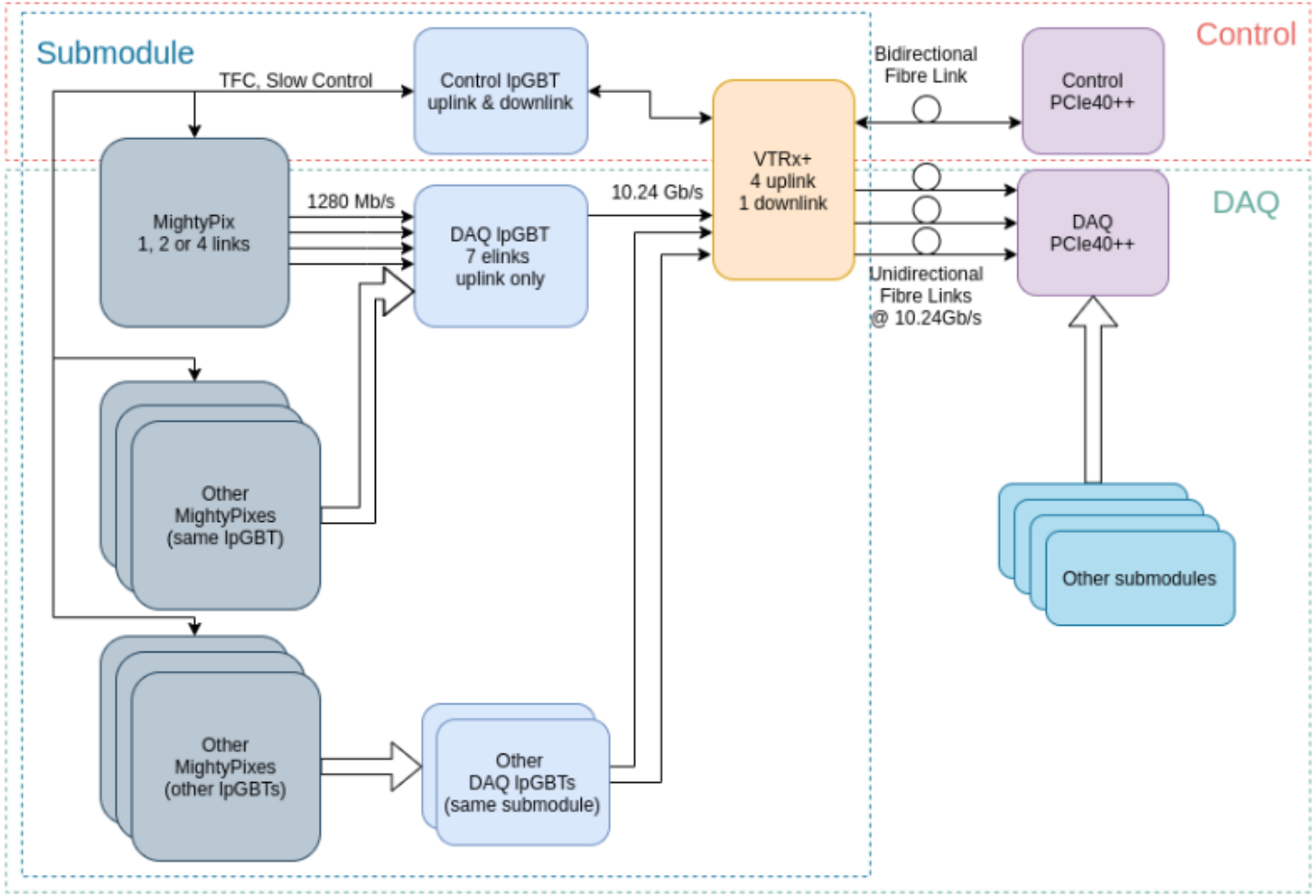


Summary

- Mighty Tracker is designed for LHCb upgrade II
  - “Hybrid tracker” of SciFi and HV-MAPS (MightyPix)
    - R&D of SciFi for mitigate rad-damage, increase hit-rate capability
    - R&D of MightPix
      - 1st prototype chips (full column-length x 1/4 width of the final chip) were produced
        - Basic functionalities incl. the digital interfaces has been tested
        - Tests with beam is planned in the beginning of 2024 (efficiency, time resolution etc.)
      - Conceptual design of MightyPix 2 has been already started

Back up

HV-MAPS Module (Control &DAQ)



Focused Ion Beam Fixing (FIB) of Mightypix1

- There is a mistake in MightyPix1 design
  - Better design verification
    - The mistake was overlooked during the design-verification (simulation)
  - Repairing the mistake by FIB
    - Cutting and adding lines in the chip
    - 5 FIBed chips → 4 FIBed and repaired chips
    - 18 more chips were FIBed