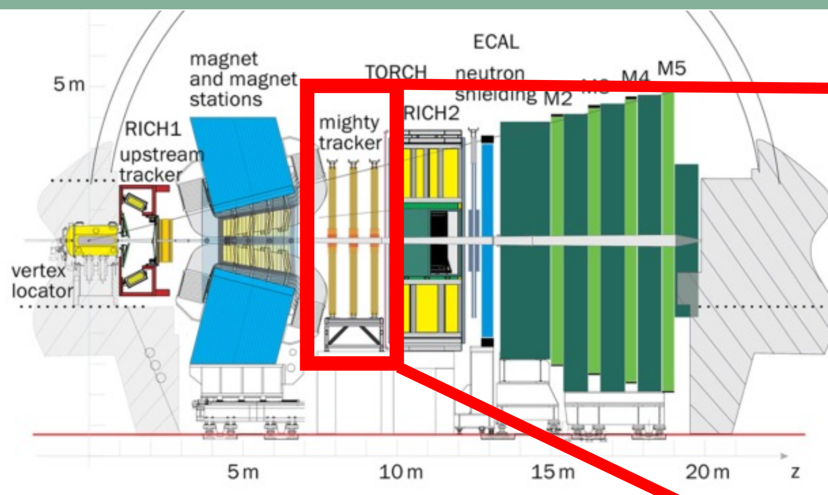
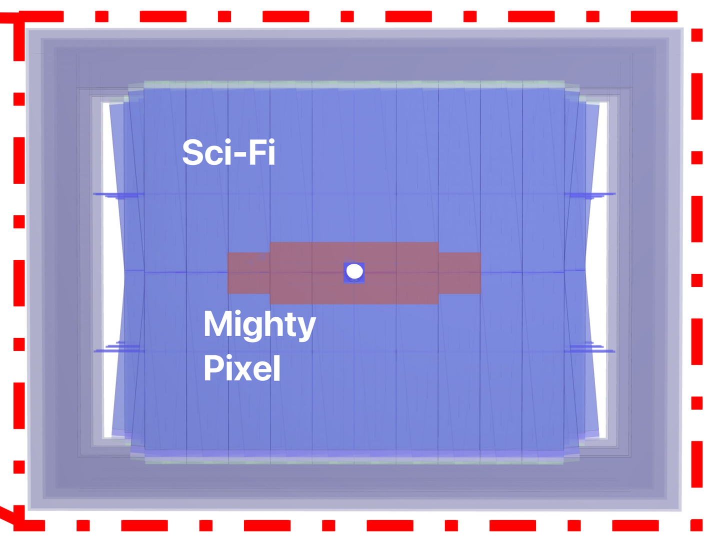
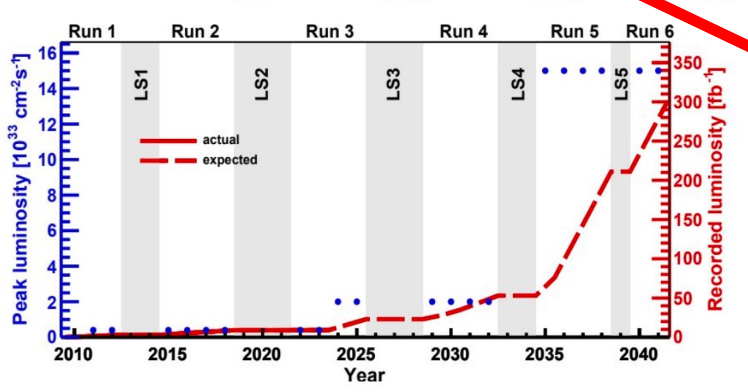
The LHCb Mighty Pixel

Tianqi Gao, on behalf of the LHCb collaboration

UNIVERSITY OF CAMBRIDGE







The Mighty Tracker within the LHCb detector is depicted in a zoomed-in front view, showcasing the support structure, the Sci-Fi, and the Mighty Pixel, with the beam pipe at the centre.

LHCb is a forward arm spectrometer ($2 < \eta < 5$) to study *b* and *c* hadron decays. **After Long Shutdown (LS4)**, the Instantaneous luminosity at LHCb increases from 2×10^{33} cm^{-2}s^{-1} to 1.5×10^{34} cm^{-2}s^{-1}. This results in **higher particle flux and radiation damage**.

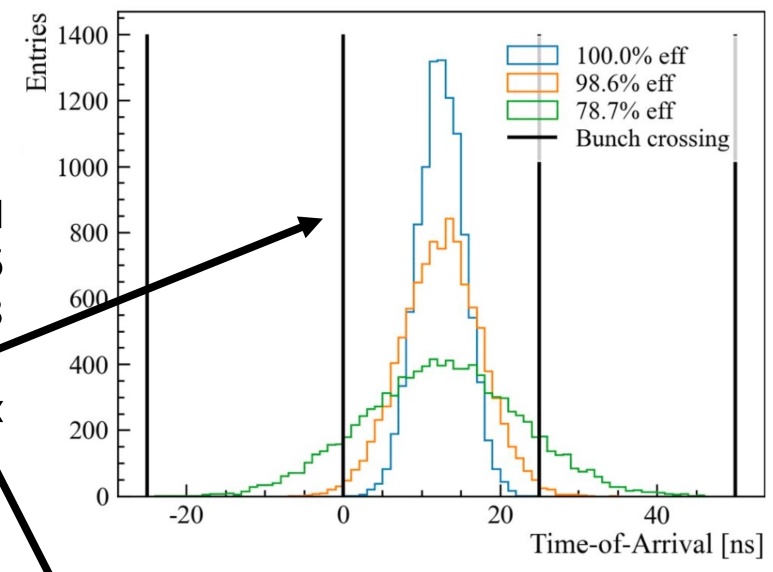
The motivation for adding pixel trackers to the inner region of the existing Sci-Fi is:

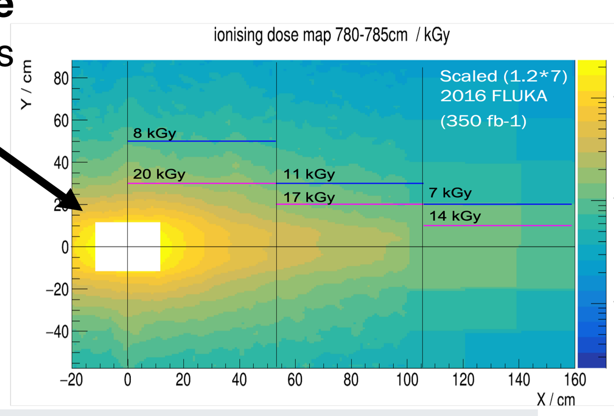
- **Increase granularity to reduce occupancy**, especially in the areas close to the beampipe, and
- add unambiguous **precision in the y-direction**, with the fibre detector more geared towards the x-axis.

Overview

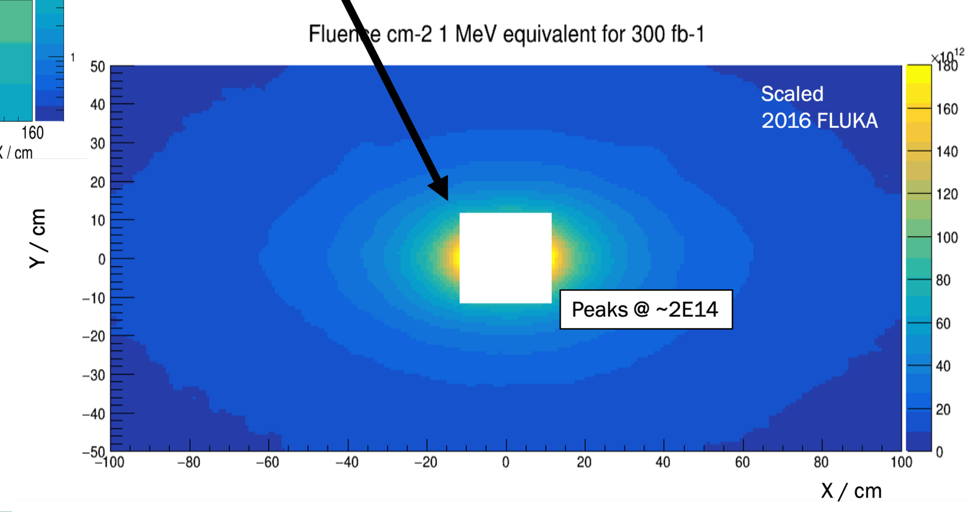
The MightyPix's main design specifications are:

- All hits need to be assigned to the correct **25 ns bunch crossing**.
- The in-time efficiency represents the percentage of all hits contained within $\pm 4\sigma$ of the sensor time resolution, which must fall inside the 25 ns hard limit. To achieve this, the time resolution must be less than 3 ns, as illustrated by the blue curve (random Gaussian distribution).
- Radiation tolerance is deduced from the **simulated dosage of 2×10^{14} MeV n_{eq}/cm^2**, plus 50% safety margin.
- The **total ionizing dose** around the beam pipe is ~ 200 kGy/20 Mrad.

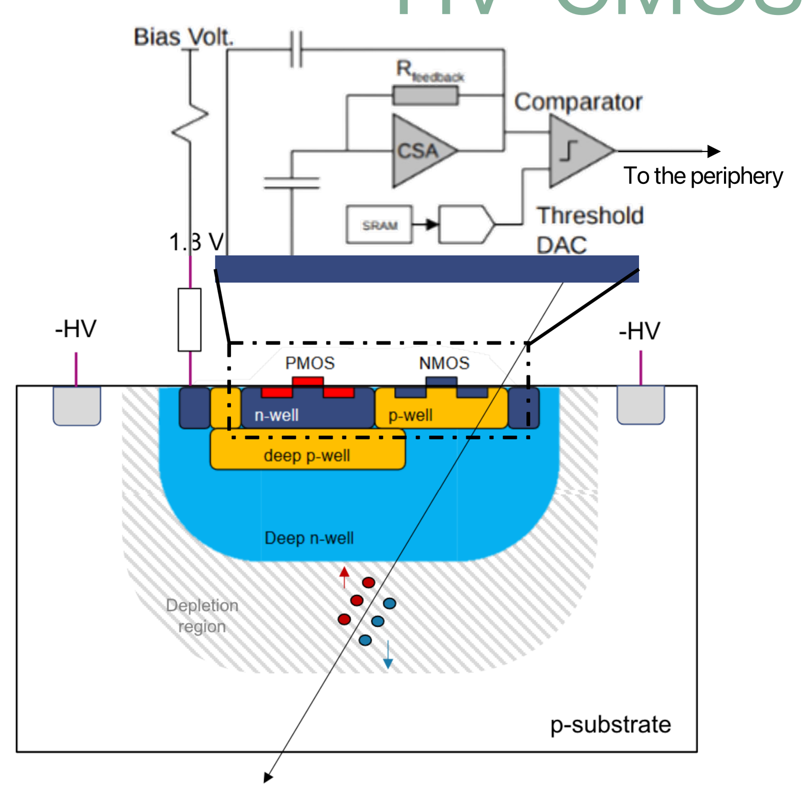




	Design Specification
Time resolution	~ 3 ns
In-time efficiency	> 99% within 25 ns window
Radiation tolerance	3×10^{14} MeV n_{eq}/cm^2
Total ionising dose	20 - 40 Mrad
Pixel size	< 100 µm x 300 µm
Power consumption	< 150 mW/cm^2



HV-CMOS Pixel detector



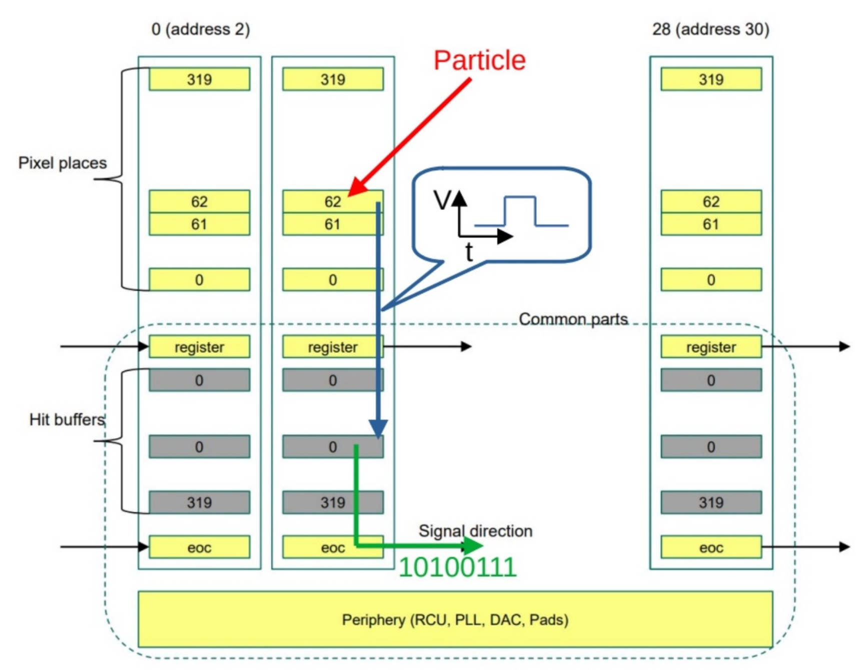
In-pixel CMOS contains:

- CMOS Amplifier
- Pixel DAC storage (SRAM)
- Digitalisation circuits

The periphery contains:

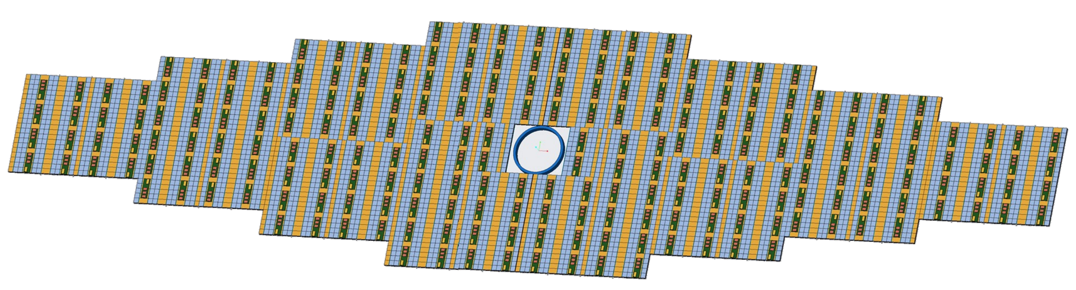
- One hit buffer per pixel
- Configuration and communication structures
- Clock generation

- Designed at KIT, the Mightypix is a HV-CMOS pixel detector.
- Fabricated using **commercial 180 nm** HV-CMOS process
- Deep n-well diode with high-voltage bias
  - Diode depletion ~ $\sqrt{(HV)}$
  - Charge collection via drift
- All components in the pixel such as the amplifier and comparator are **CMOS**
- Tuneable DACs for each pixel, such as signal threshold and equalisation bits.
- Comparator signals are sent to the periphery

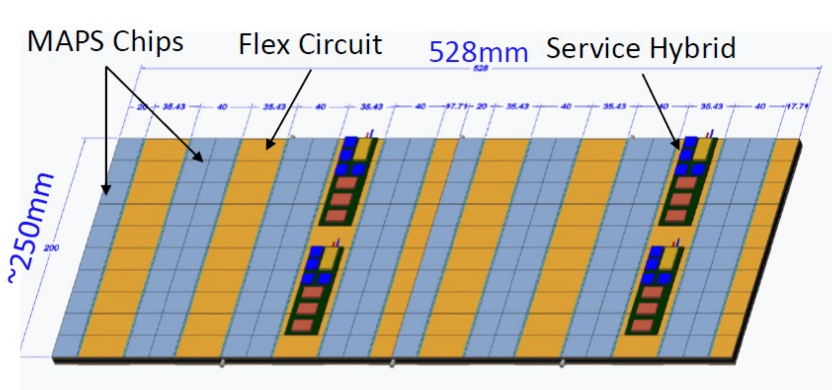


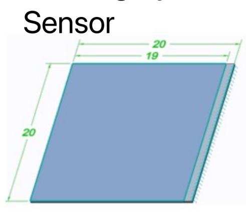
[Ivan Peric (KIT)]

Design & Cooling



The Framework technical design report (FTDR) version of the Mighty pixel layout is on the left, the sensor area is **3.0 m²**.





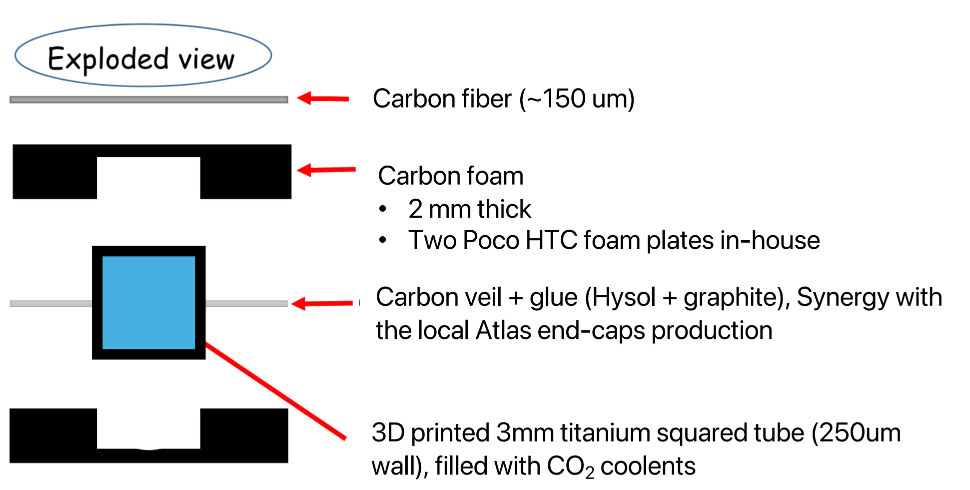
The MightyPix Sensor

The design of each module is not finalized, each column of a module has 12 or 13 sensors depending on the orientation. The modules around the beam pipe will have fewer columns due to the shape requirement.

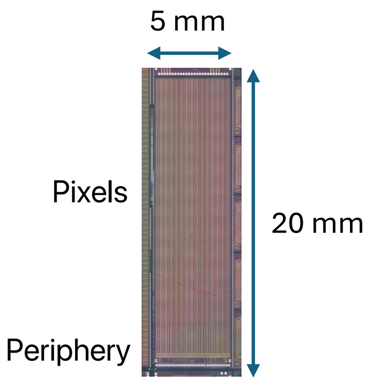
The maximum potential active area of each sensor is 2 x 2 cm².

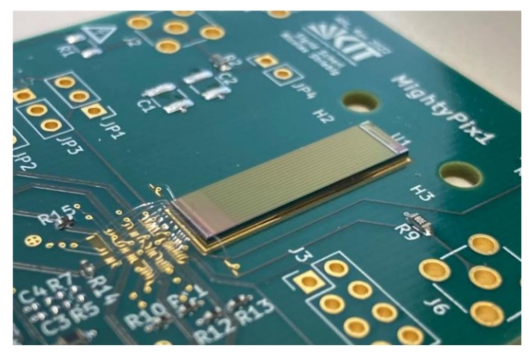
The cooling is supplied by a titanium tube with CO2 coolant sandwiched by carbon foam, which is then enclosed by carbon fibers. With sensors glued on both sides.

The chip operation temperature is under investigation, preliminary results with 3×10^{14} MeV n_{eq}/cm^2 irradiated sister sensors show that the sensor needs to be cooled to **≤ 2 ºC** to achieve the time requirement. The power consumption is ~ 600 mW per sensor and ~ 300 W per module.



The Mightypix1





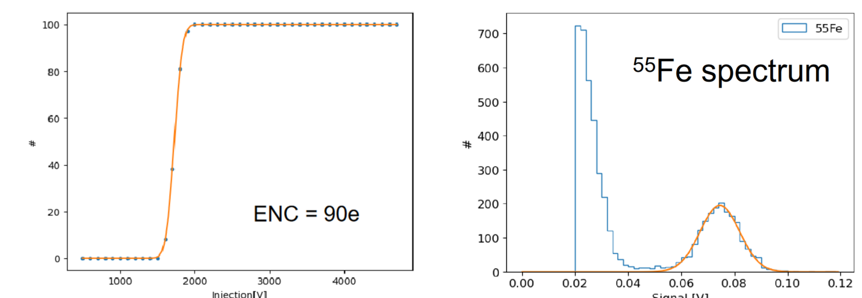
[Karlsruhe Institute of Technology]

The Mightypix1 is the initial version of the Mighty Pixel sensor, designed for performance testing. These sensors were fabricated using TSI's 180 nm process. The test results will be used to enhance future iterations.

- Chip size: 5 × 20 mm²
- **Pixel size: 165 × 50 µm²**
- 2 × 32 bit words:
  - Pixel address
  - Time-of-Arrival (ToA)
  - Time-over-Threshold (ToT)
- 3 data links: 1.28 Gbit/s, 640 Mbit/s and 320 Mbit/s
- Digital Interface:
  - Shift register
  - Inter-Integrated Circuit (I2C)
  - Timing and Fast Control (TFC)

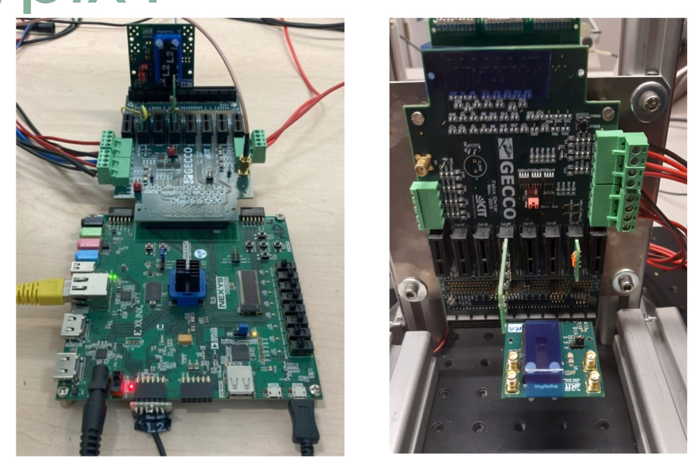
Problem:

- Wrong connection in config bits input
  - Repaired some sensors using Focused Ion Beam.
- Column crosstalk
  - Shielding traces were not tied down

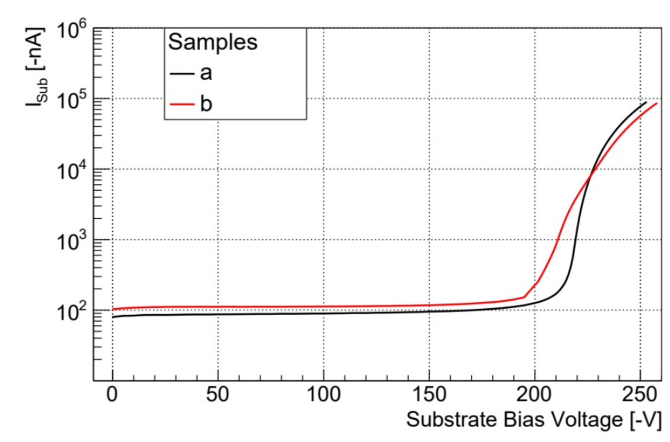


S curve & 55Fe spectrum from the Mightypix1.

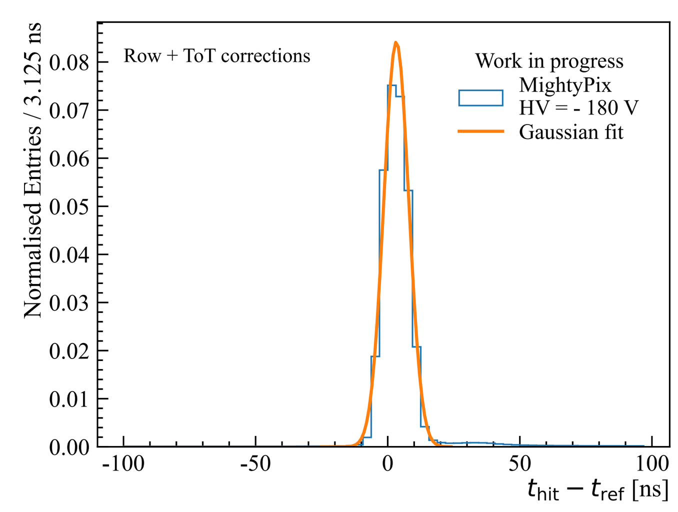
- 5.9 keV X-ray produces ~1,639 e- in silicon, the **peak is well separated from the noise floor**.
- Low Equivalent noise charge (ENC) at 90 e



Testing setups at KIT and Heidelberg
Modified GECCO DAQ system as the readout



- Breakdown seen at ~200V
- 370 Ωcm substrate resistance
- Higher bias voltage = larger depleted region = larger signals



Promising early timing Lab results from the FIB repaired sensors, using SR-90 with scintillating fibers as reference.

Conclusions

The Mightypix1 is the prototype of the Mighty Pixel sensor. Initial looks indicate that the **Mightypix sensors should meet the requirements** of the project. These sensors were recently repaired and delivered for testing. We also perform tests on the Mightypix's sister sensors, to stay on track with the planned testing phase and produce suggested changes/improvements for the Mightypix2 submission.

What's next for Mightypix:

- The Mightypix2 will be fabricated using AMS foundry's 180 nm process, the sensor design is expected to be **submitted in Q1 2025** and **delivered by Q3 2025**.
- **Modification needed** due to foundry change
- **LFoundry's 150nm** process is **the alternative** foundry for supply security. The LF-Mightypix prototype of size 3.3 x 4 mm² was recently submitted to Lfoundry.

The timeline is planned for **LS4 installation in 2033** and **operational in RUN5 in 2035**.

Contact: tianqi.gao@cern.ch