



# LHCb Upgrade II

Particle Physics Annual Meeting

18/19<sup>th</sup> May 2023



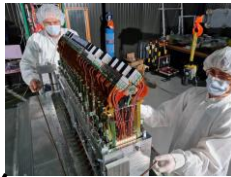
Eva Vilella-Figueras, [Ashley Greenall](#), Jan Hammerich, Karol Hennessy, Tim Jones, Ayushi Khatri, Sigrid Scherl



- **Time-line of LHC machine**
  - Long Shutdowns, their occurrence and opportunity for detector upgrades
- **LHCb upgrades**
  - Areas of interest
- **Mighty Tracker**
  - Overview, where our interests lie and current activities
- **Conclusion**

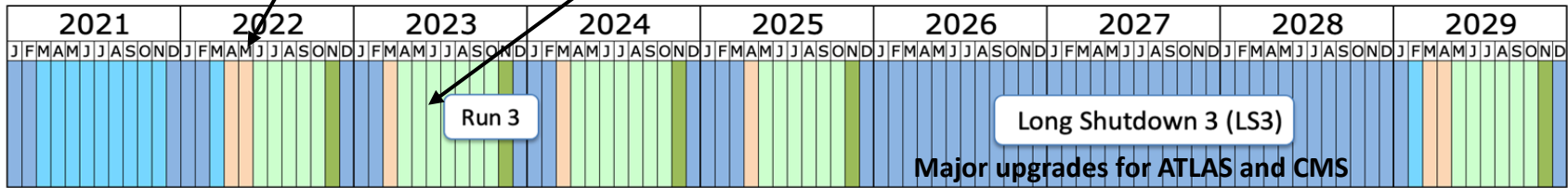


LHCb VELO Detector safely delivered to CERN from Liverpool

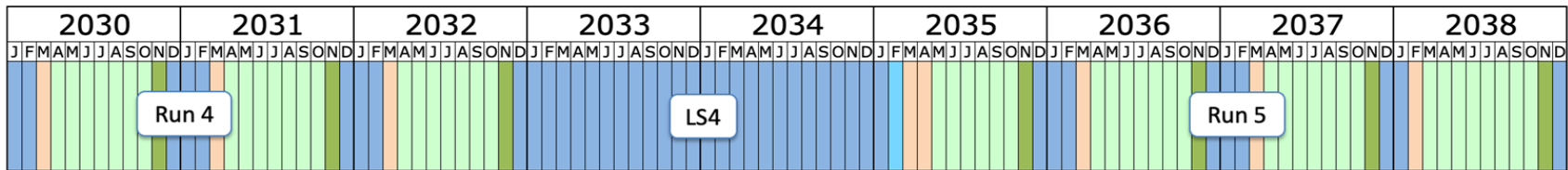


This is where we are

LHCb Upgrade 1b  
Same Luminosity as Upgrade I



## LHC Machine Schedule

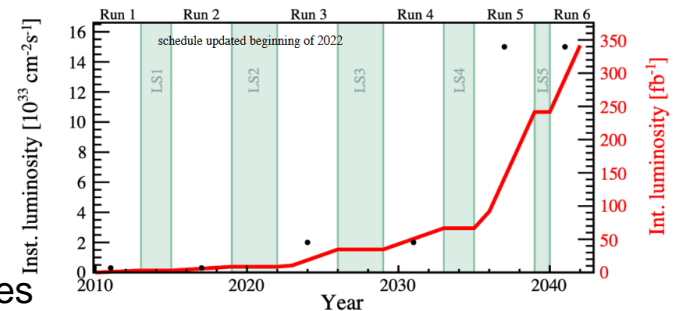


Last updated: January 2022

- Shutdown/Technical stop
- Protons physics
- Ions
- Commissioning with beam
- Hardware commissioning/magnet training

LHCb Upgrade II  
7-10 x Luminosity

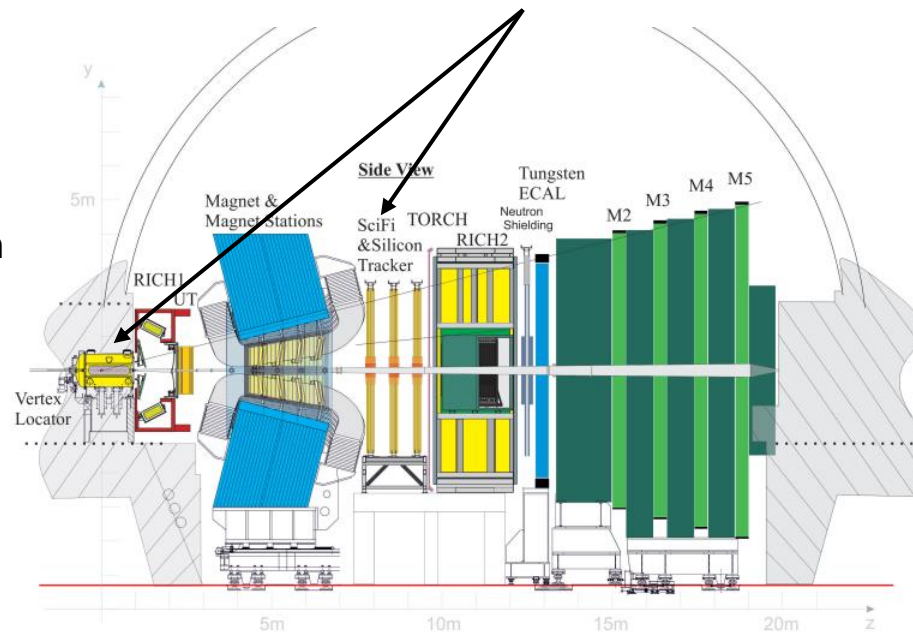
Upgrade I Upgrade II



- Physics programme limited by detector and NOT by the LHC
  - Primarily due to radiation damage to existing detectors
- Provides an opportunity for detector upgrades
  - Occurring at both LS3 (2026) and LS4 (2033)
- Liverpool positioning itself in considering exploiting these upgrades

## Liverpool's interests

LHCb Side Elevation

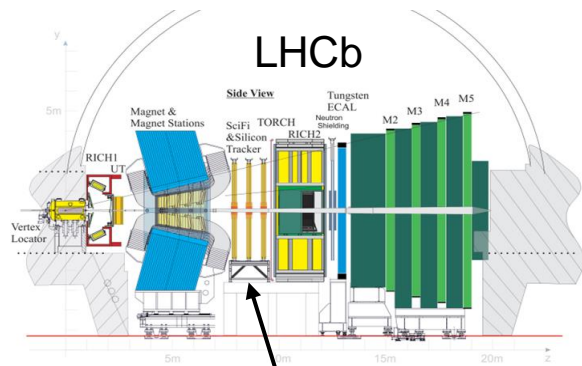


Interest shown towards 2 sub-detector systems:

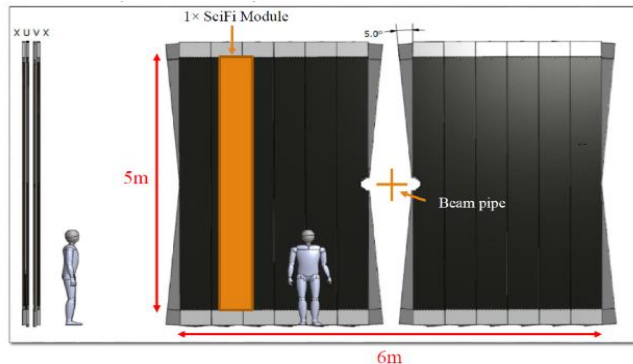
1. **Upgraded Vertex Locator** - still under discussion
2. **Mighty Tracker** - Activity currently aligned, a combined scintillating fibre & HV-CMOS detector (SCiFi & Silicon Tracker)

Mighty Tracker, made up of 2 detector systems,

1. Scintillating Fibres – SciFi
2. **Silicon tracker – made up of a HV-CMOS detector (Liverpool's interest)**



Existing SciFi

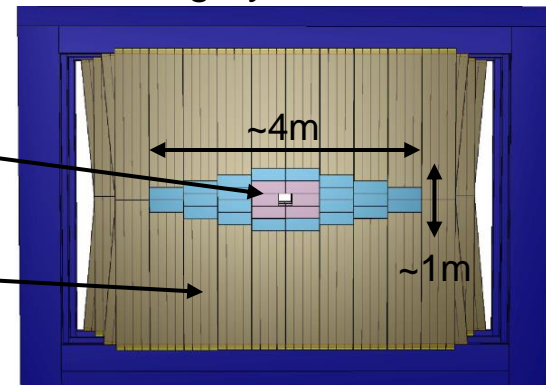


Mighty Tracker

HV-CMOS

Fibres

Upgrade



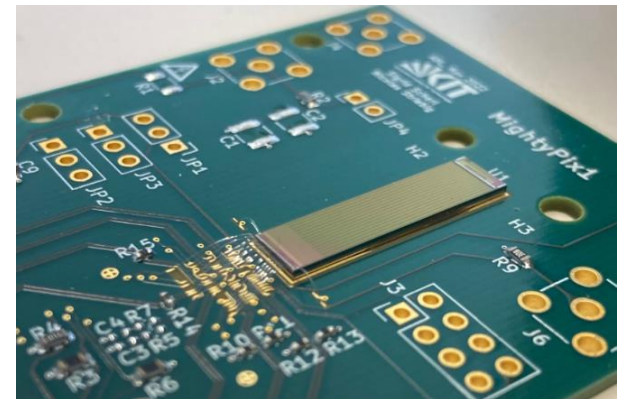
Planning staged installation of HV-CMOS sensors during LS3 and LS4 shutdowns, 2026 and 2033 respectively

1. Inner Tracker U1b (pink)
  - Approx 4.0m<sup>2</sup> of silicon
2. Inner + Middle U11 (blue + pink)
  - Approx 18.0m<sup>2</sup> of silicon, 46000 sensors

**Near term timeline of 2027 installation is very aggressive for U1b  
TDR planned for spring 2024**

- HV-CMOS Pixel chip  $\longrightarrow$  **MightyPix**
  - Based on existing ATLASPix and MuPix devices
- ASIC design and verification is done by KIT at Karlsruhe, Germany
  - **With inputs from Liverpool**
  - **Plus, qualification of prototype ASICs (ATLASPix3 & MuPix10) – Irradiation & Testbeam studies**
- First prototype chip: **MightyPix1**
  - Chip size: 20mm x 5mm (full length column,  $\frac{1}{4}$  width)
  - Pixel size: 165 $\mu$ m x 55 $\mu$ m
  - Time resolution: <3ns
  - Up to 1.28Gbs Data output rate
- Submitted as MPW (May 2022) implemented in TSI 180nm process
  - Delivered Q1 2023
- **Testing indicated chip is non-working**
  - Problem identified to a single node not being connected
  - Missed at the verification stage

MightyPix1

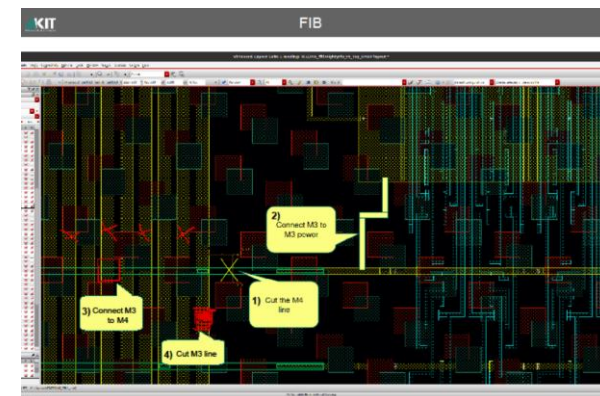
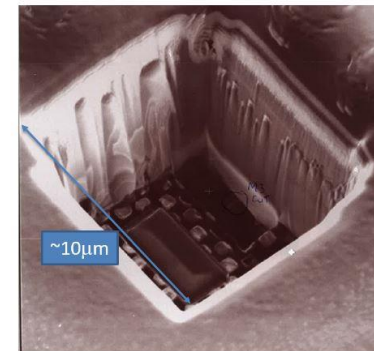


Courtesy of Sigrid Scherl

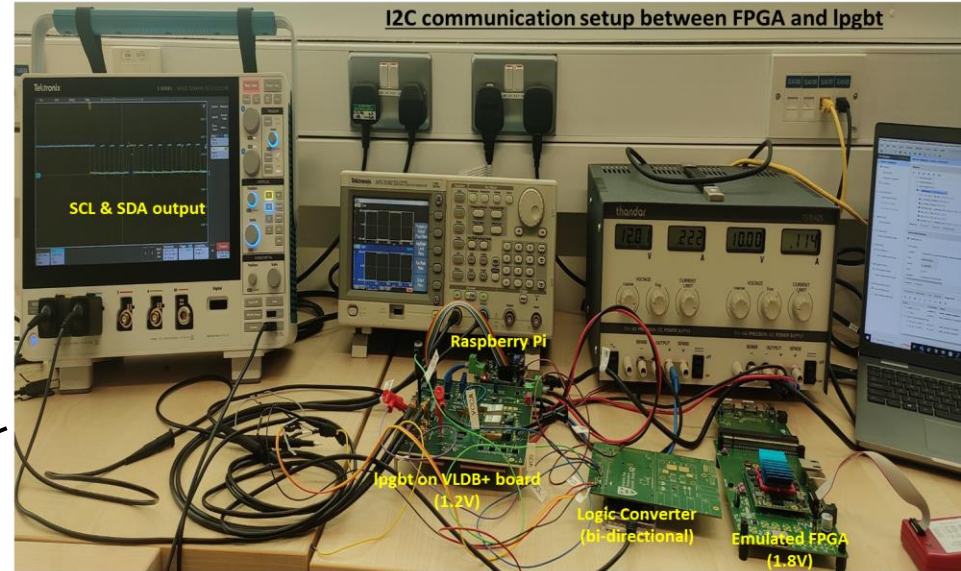
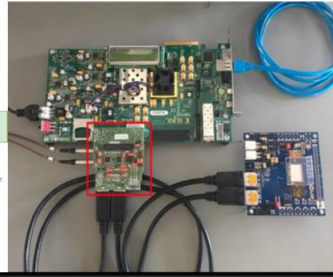
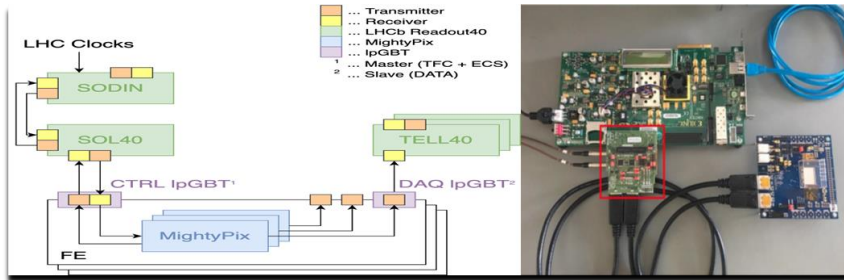


- MightyPix1 is very important as precursor to **MightyPix2**
  - Exploits full reticle coming in at 20mm x 20mm
  - LHCb DAQ compatible, improved radiation hardness, SEE mitigation, integrated LDOs, ...
- Evaluation of MightyPix1 analogue front-end especially important
  - Timing performance, dynamic range, susceptibility to radiation damage, ...
  - Feeding back into design of MightyPix2 – if necessary
- MightyPix2 originally scheduled for submission Q2/Q3 2023
  - Submission turnaround is typically 6 months
- **Feeds into U1b TDR submission spring 2024 – we're running late**
- Investigated fixing existing MightyPix1s using Focused Ion Beam (FIB)
  - Can cut/add metal at the nanometer scale - £1800/chip
- Has been used successfully with ATLAS prototype chips
  - 3 out of 4 chips working – expected yield (from vendor)
  - Work undertaken very similar to that required for MightyPix1
- 5 x MightyPix1 submitted for FIB
  - **All returned die tested and still non-functional**
  - Suggestion that the re-work is non-optimal
- Pursuing companies within Europe for alternative FIB source
  - ASIC program in state of flux – uncertainty upon how to advance
  - Hopefully will be resolved very soon

ATLAS FIB



Courtesy of KIT



```
File Edit View Search Terminal Tabs Help
akhatr@gamma:~/work/I2C_lpGBT/mighty/IpGBTLib/lowLevelDrivers

$ ls
$ cd mighty_i2c_ctrl/
$ python 12ctest.py
Output: data read successfully with VTRX+ as slave
data_read = [40]
```

Confirmation of working I2C link

Ayushi Khatri & Karol Hennesy

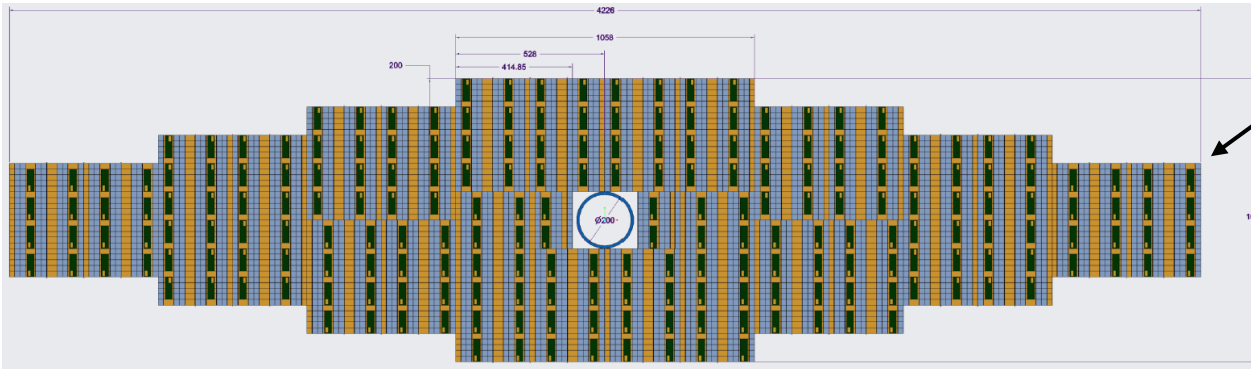
- Emulation of digital readout of MightyPix1
  - ASIC design successfully simulated, synthesized and implemented on Xilinx FPGA using Vivado
  - Chip configuration confirmed by scoping of output waveforms
- Have also checked out I2C communication is working – used for configuration of MightyPix1
  - Firstly, checking out LpGBT to VTRx+ I2C link
    - CERN derived Gbit Transceiver and Optical data link
  - Then successfully swapped to FPGA, emulating as MightyPix1
- No showstoppers identified





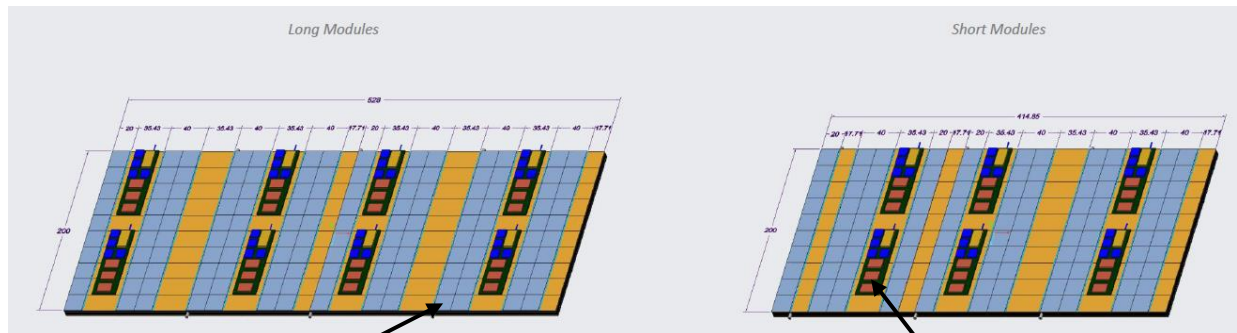
- Still very much at the conceptual stage
  - Definition of module form-factor, topology, readout architecture, powering etc. yet to be fixed
  - Expect decision to be made towards end of year
- Lack of ASICs compounds matters
  - MightyPix1 initially being used as a test vehicle
    - Checking out chip susceptibility to EMI from DCDC converters, data transmission, ...
  - Followed by development of flex circuits and their assembly tooling using full sized chips
- Furthermore, U1b modules might not necessarily be the same as those installed at U11
  - For example, Serial powering is being discussed for U11 but not considered for U1b
- Progress is being made
  - Taking advantage of experience gained from current ATLAS ITk builds
  - Making everything as modular as possible with testability introduced at the outset

## Mighty Tracker



Carbon fibre cores with integrated cooling

- Targeting 2 module types, predominantly Long modules with a small number of Short modules
  - Short modules being used in the proximity of the beam pipe hole



20mm x 20mm Silicon sensors  
MightyPix

Services module cw Gbit Fibre  
data links + powering

Under discussion for U1b

- Powering, DCDC or direct
  - U2 serial powering?
- Services module location
- Modularity of sensor arrays
- Whilst having no space...



- LHCb Upgrade II provides Liverpool an opportunity to participate in future detector builds
    - Exploiting our expertise in ASIC & electronic design, mechanics, assembly and integration
    - Taking us up to and beyond 2033
  - Early days, but group are already proactive within the Mighty Tracker community
    - Providing steers on both ASIC and module designs
  - As usual things are not going as planned, vis: non-working ASICs
    - The lack of ASICs impeding module development
    - **Highlights how exposed detector R&D and builds are to ASIC delivery schedules**
      - This is not peculiar to the Mighty Tracker
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# Thank You