LHCb Upgrade II

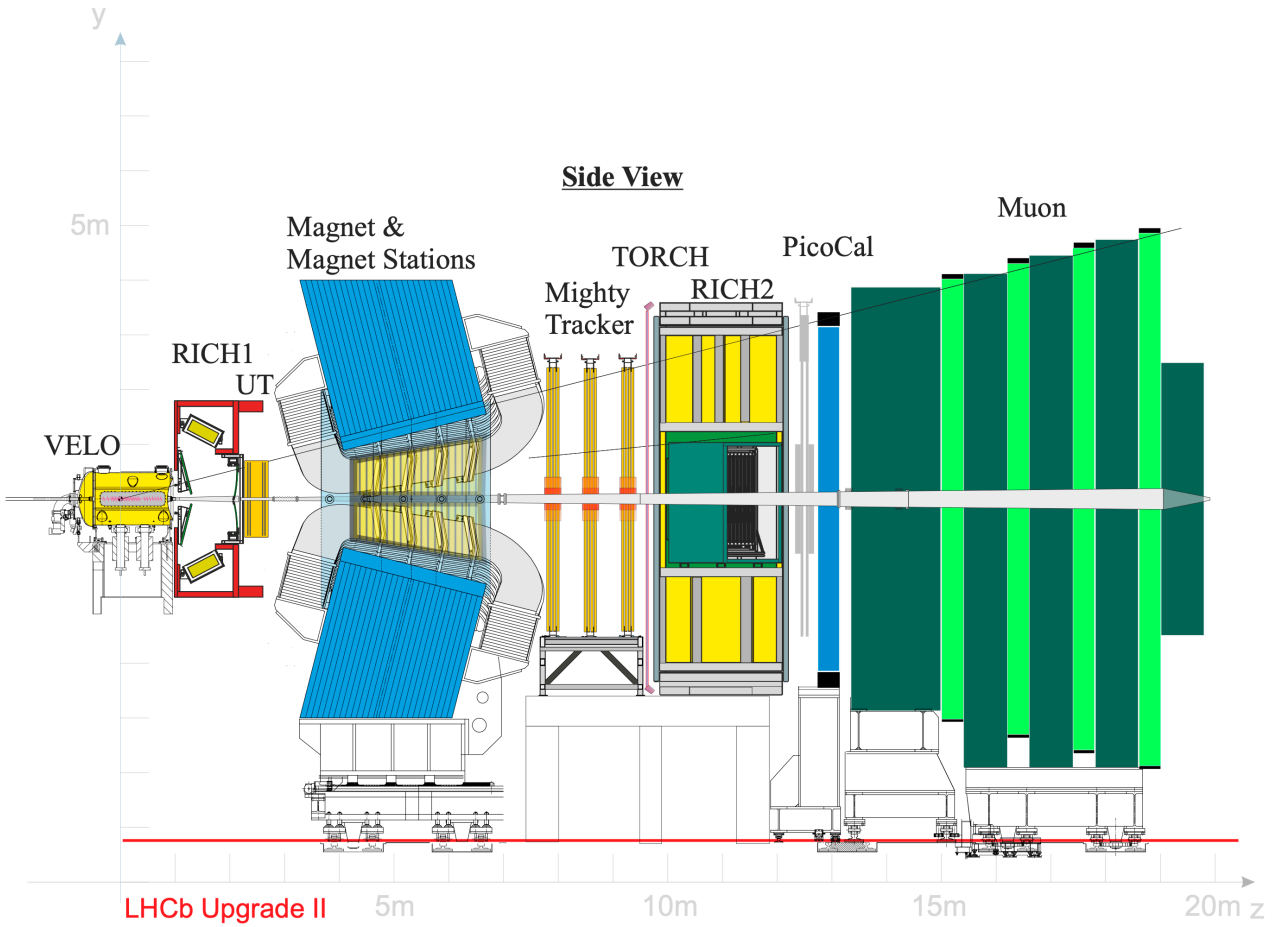
Karol Hennessy
on behalf of Eva, Sigrid, Ashley, Jan, Ayushi, Tara, Kurt, Kieran

2024-05-24

UNIVERSITY OF LIVERPOOL

LHCb

LHCb Upgrade II



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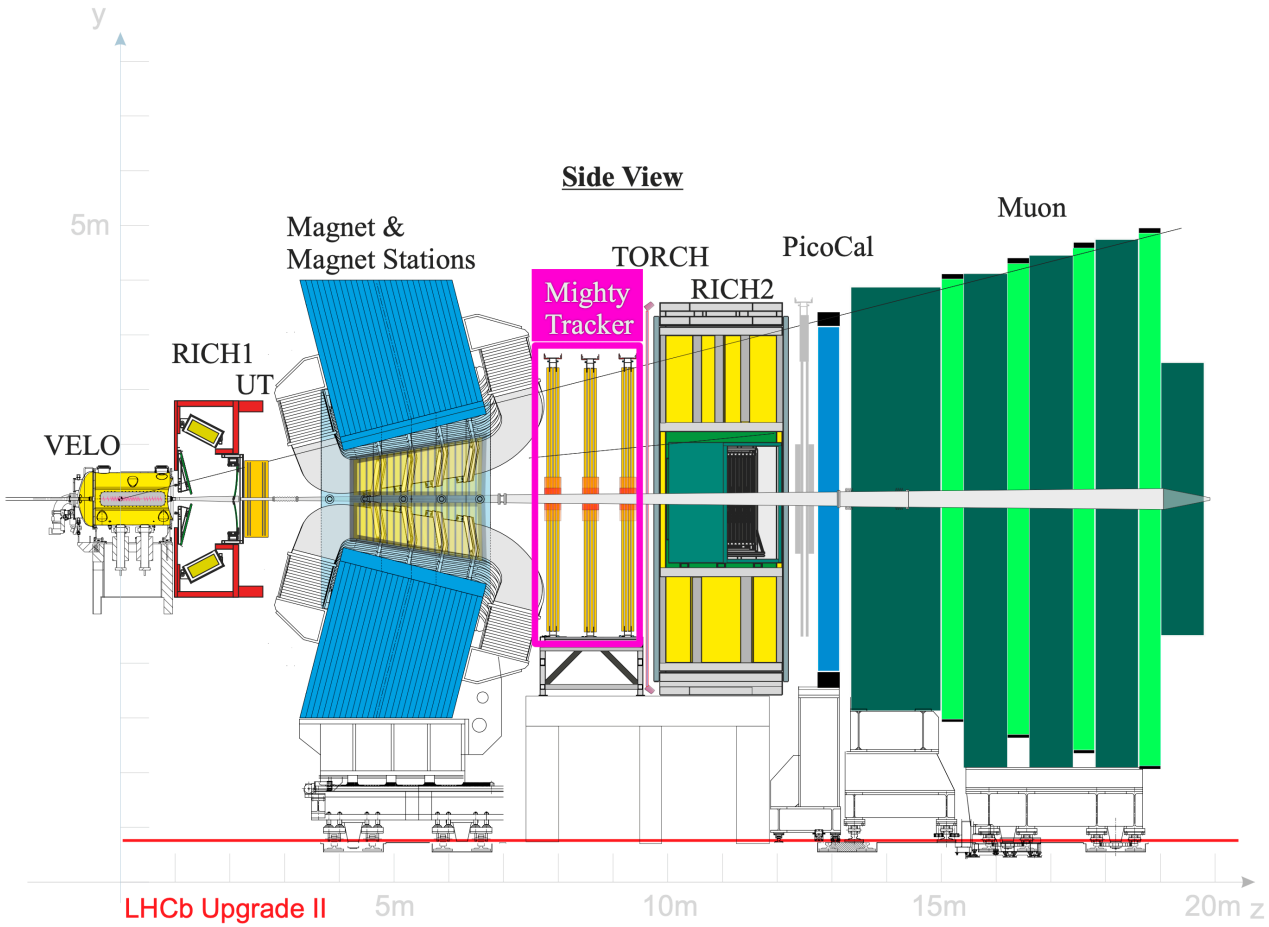
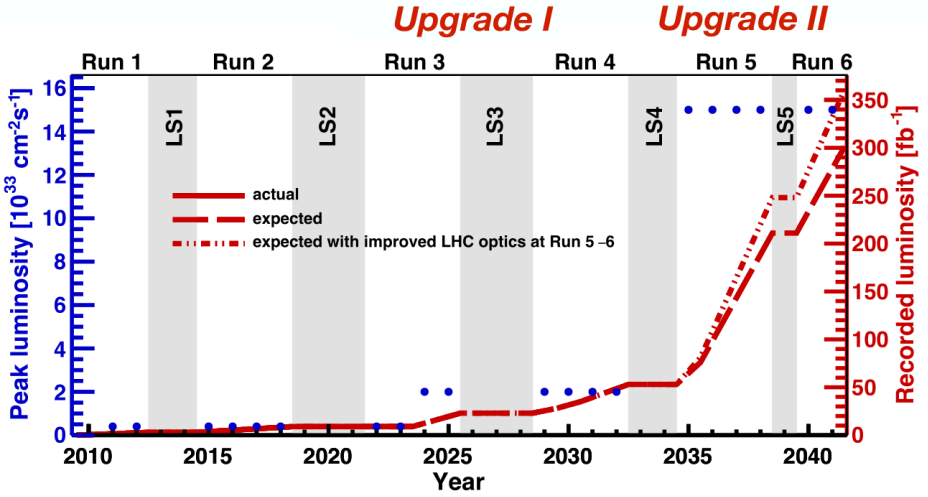


LHCb Upgrade II

- Physics programme limited by detector, NOT by LHC
- Therefore, we should **upgrade to get the maximum physics LHC can deliver**



Upgrade I

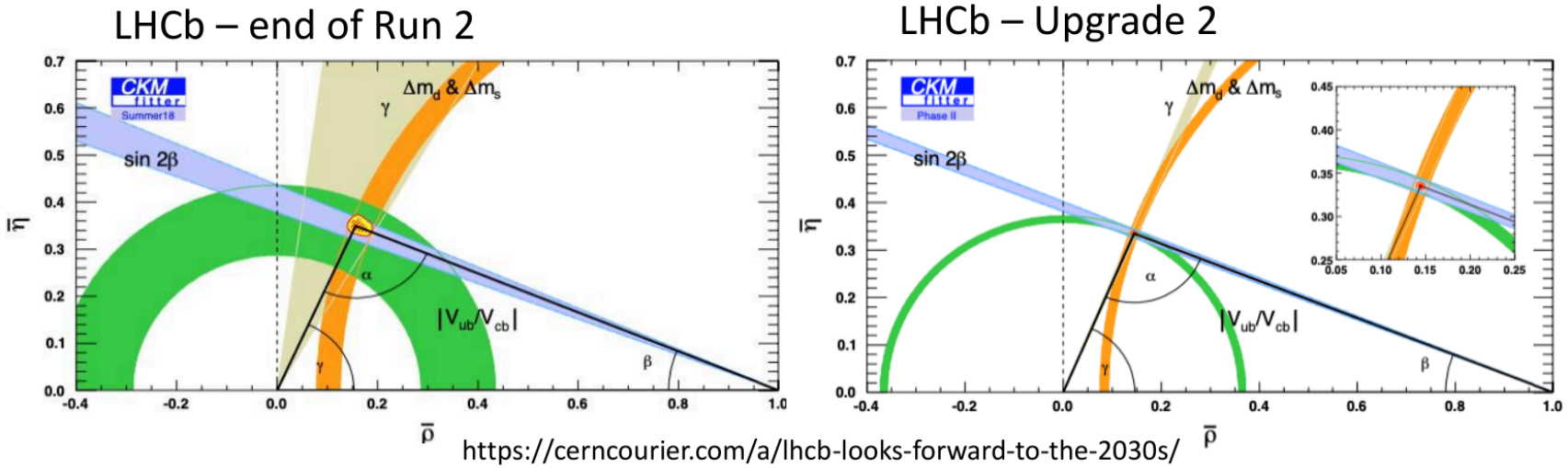
- $L_{peak} = 2 \times 10^{33} cm^{-2} s^{-1}$

Upgrade II

- $L_{peak} = 1.5 \times 10^{34} cm^{-2} s^{-1}$
- $L_{int} = 300 fb^{-1}$ during Runs 5 & 6. **Installation in LS4**

Upgrade II motivation

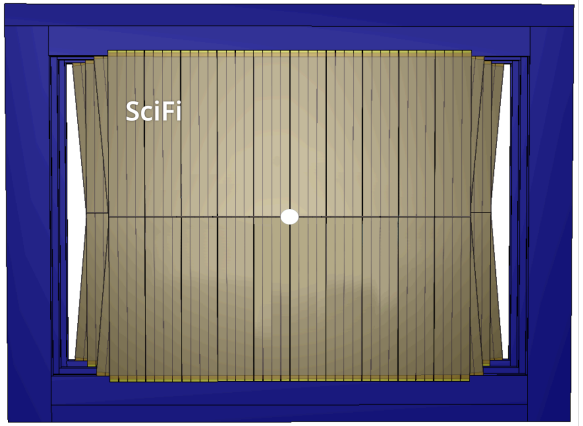
- Sensitivity to mass scales several orders of magnitude above those within reach of direct production measurements at the energy frontier
- Numerous **key observables** have negligible theoretical uncertainty
- Test of **CKM matrix to unprecedented accuracy**
- Flavour sector has arguably a *great likelihood* for discovery at HL-LHC



Mighty Tracker

Mighty Tracker

- Scintillating Fibre (**Sci-Fi**) outer tracker
- To cope with the **increased pile-up** replace the inner section with a silicon pixel detector
- 6 layers
- Mighty Tracker is required to be
  - low-mass
  - cooled below $0°C$
  - have modest spatial resolution



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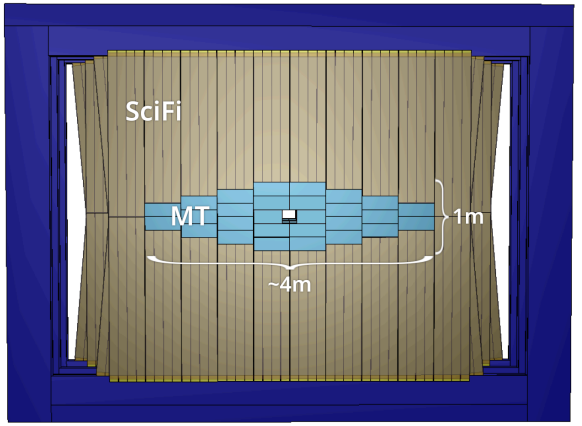

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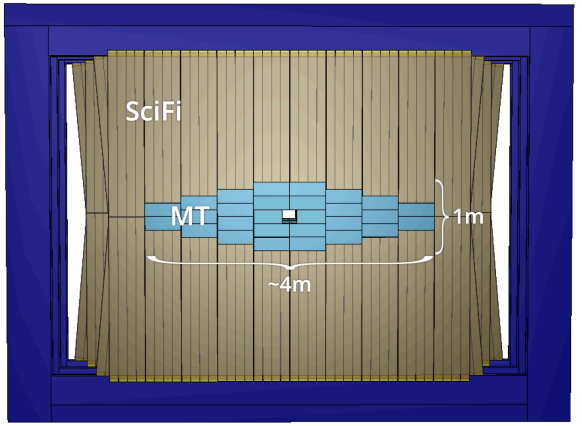
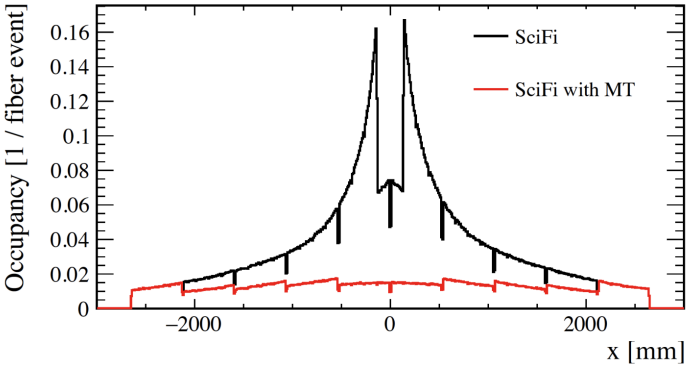
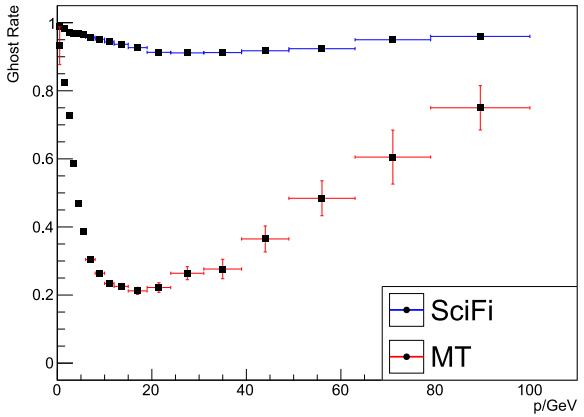


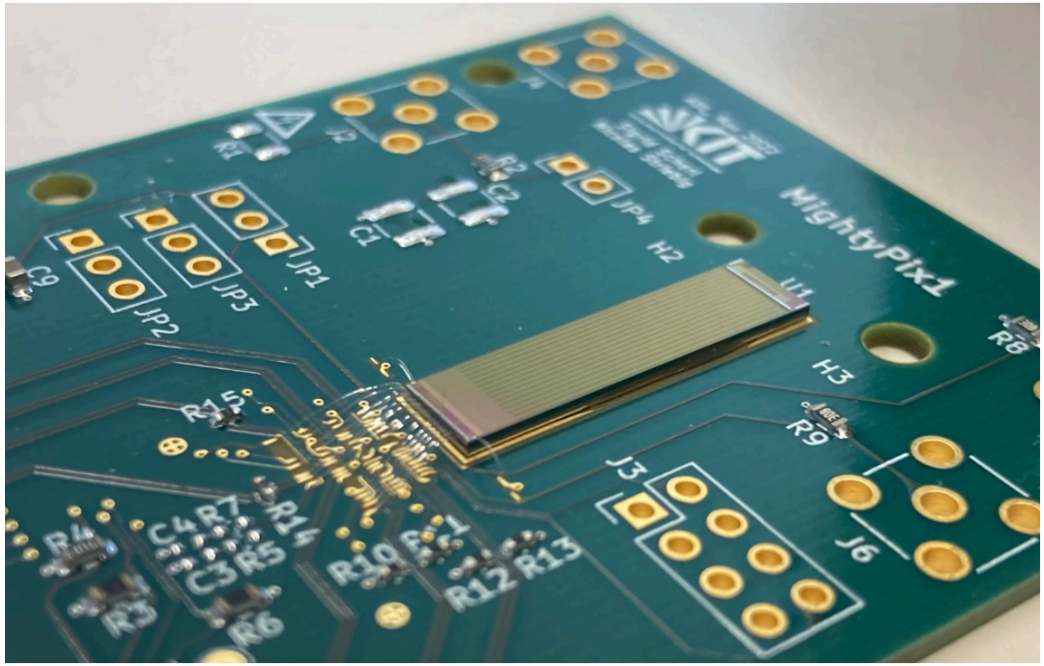




MightyPix

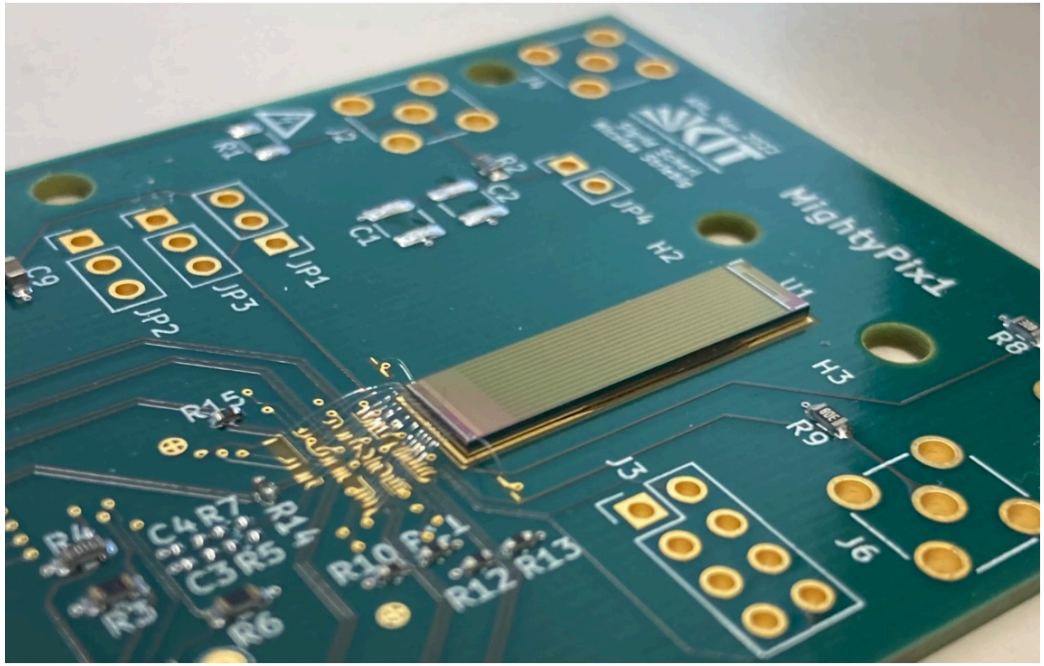
MightyPix

- This time last year we had defective MightyPix v1
  - Tried to repair with **Focused Ion Beam** surgery - failed
  - Tried again with a different company - success !
- Found some other issues
  - synchronisation, wrong timestamping, missing shielding
  - Compiled a series of “lessons learned”
- But **we can still test!** :)



MightyPix

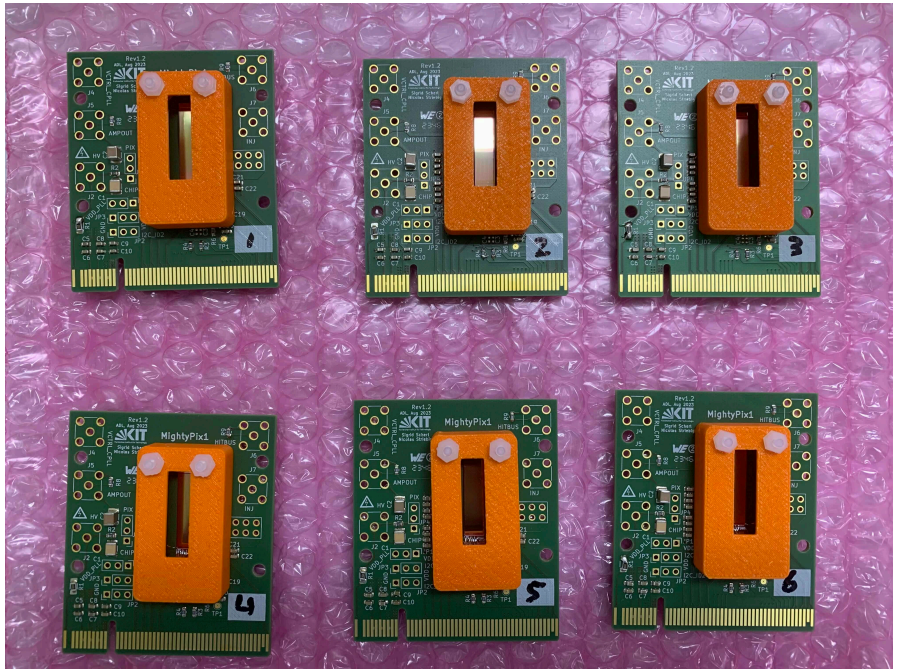
- Suspension of TSI 180 nm CMOS process
  - Search for a new foundry
  - Primary candidates **AMS** and **LFoundry**
    - Submitted to LFoundry in April (with guard rings developed by RD50)
  - We have experience with both
- Will also submit to AMS
- Need to **submit MightyPix 2 in 2025**



MightyPix v1 Testing

Sigrid Scherl

- **6 FIB'd MightyPix v1's tested at Liverpool**
- checked configuration and leakage current



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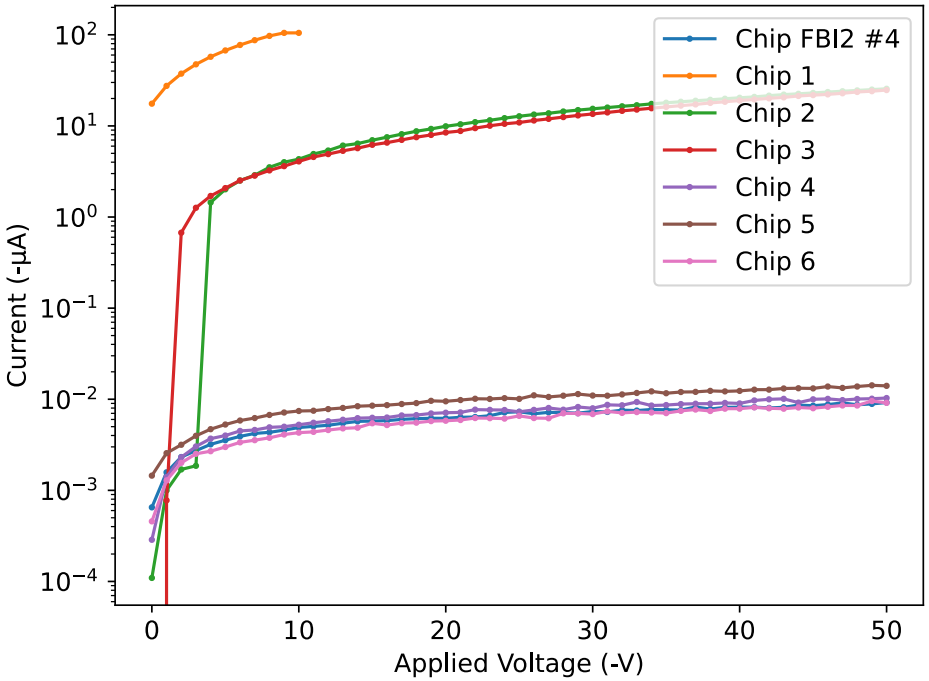
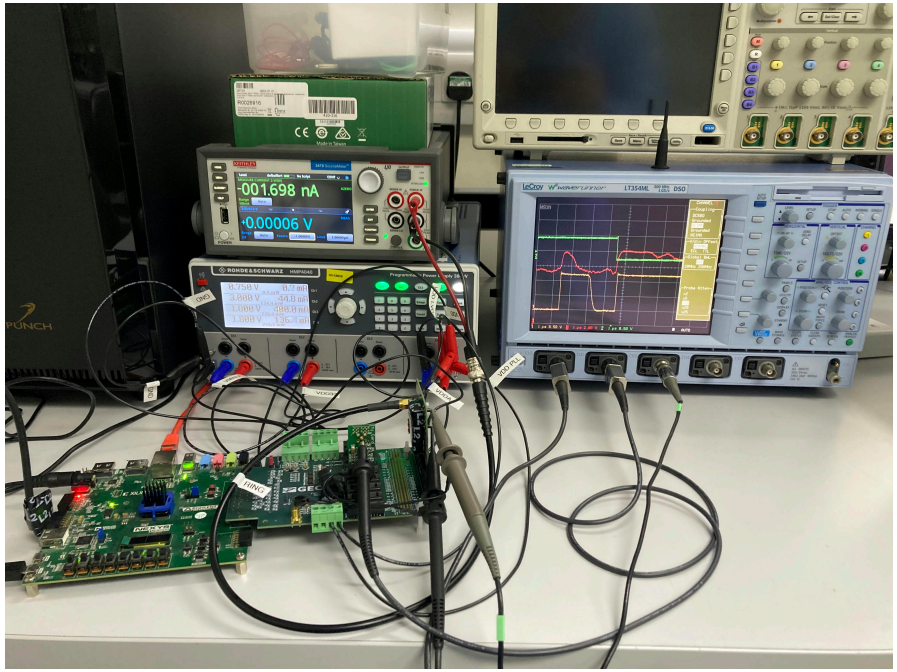




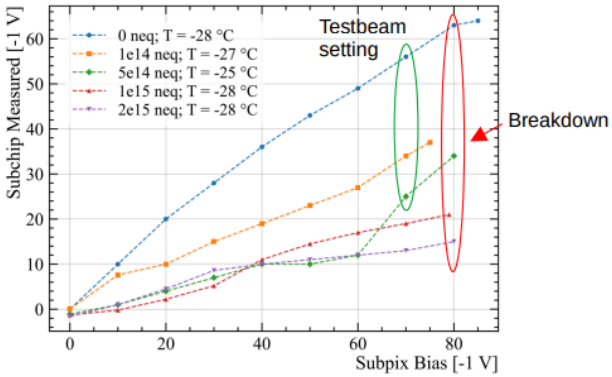
MightyPix v1 test stand in LSDC

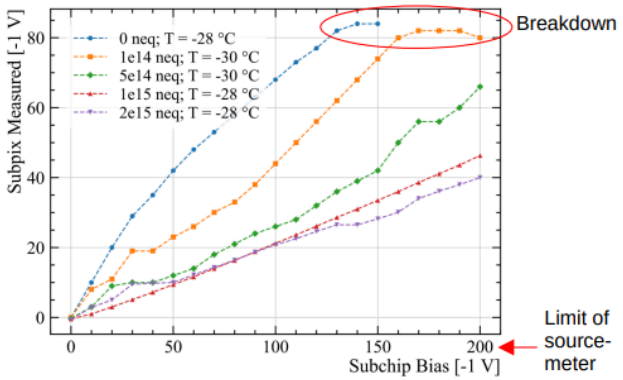
- distributed to UK sites

Testbeam

Ayushi Khatri

- **DESY**: 11th-24th March 2024
- Under test:
  - Telepix (MightyPix' cousin)
    - irradiated ($1 \times 10^{15} n_{eq}$) and unirradiated
  - MightyPix v1 unirradiated



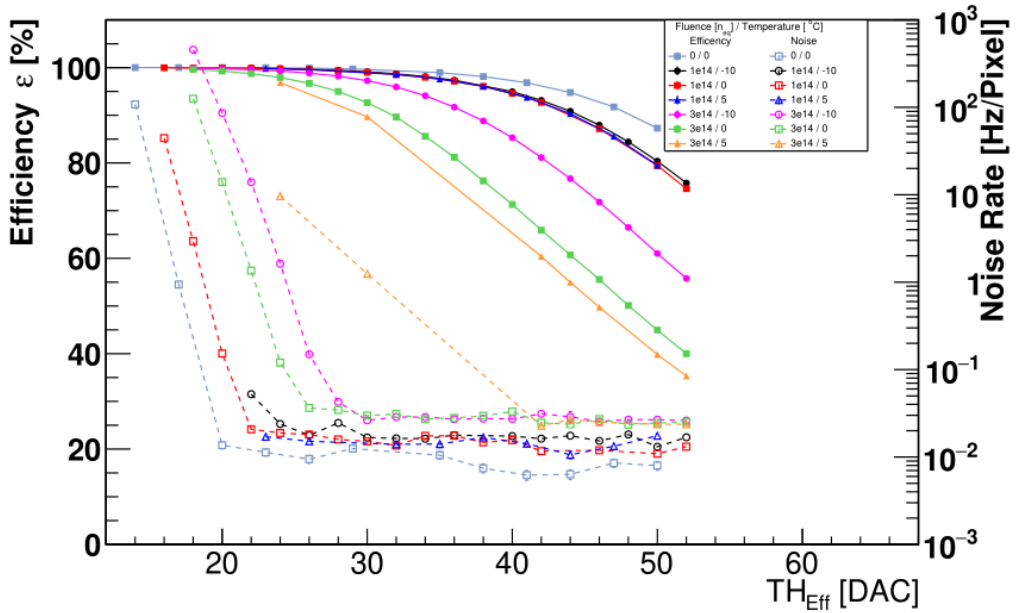


  - wrong bias scheme, being revised

Testbeam

Dr. Jan Hammerich

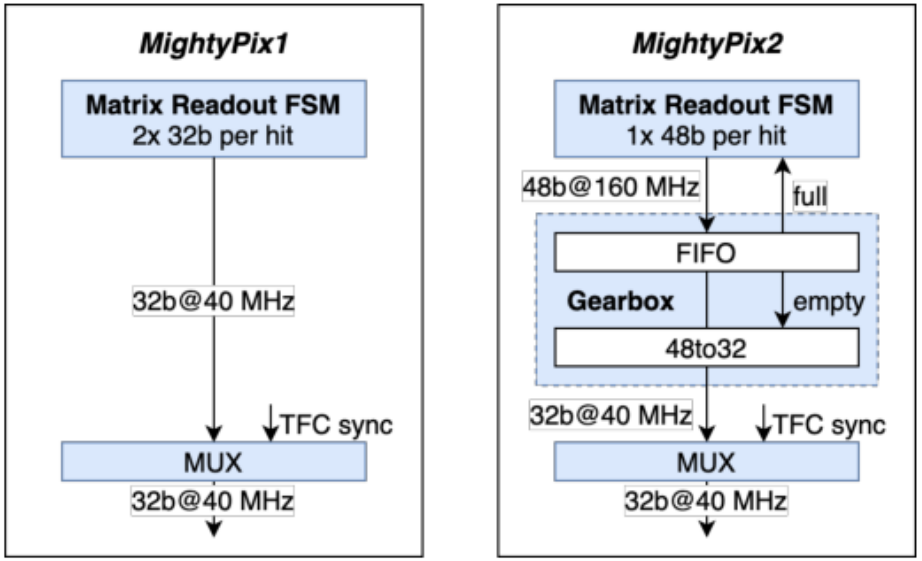
- Studies of ATLASPix 3.0 and 3.1
  - more MightyPix cousins
  - several irradiations
  - signficant degradation beyond $3 \times 10^{14} n_{eq}$
- Improved understanding of previous testbeam data
- **Congratulations to Jan on passing his viva :)**

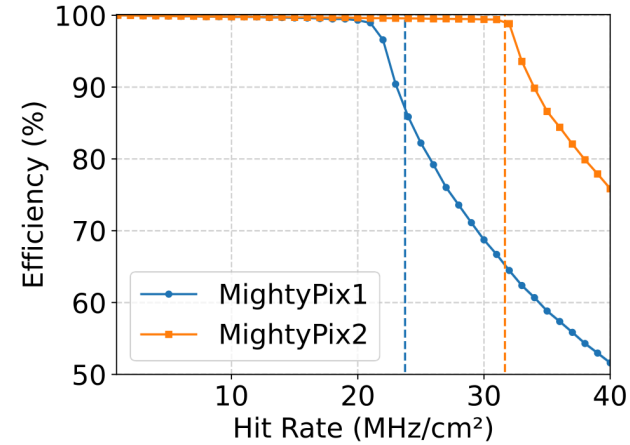


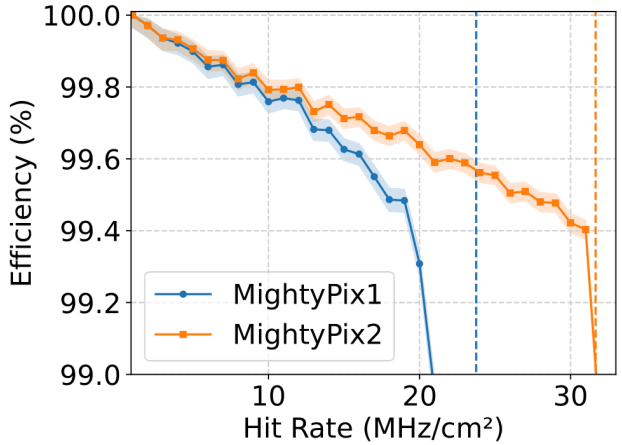
Design optimisation and prototyping

MightyPix Efficiency Improvements

Sigrid Scherl





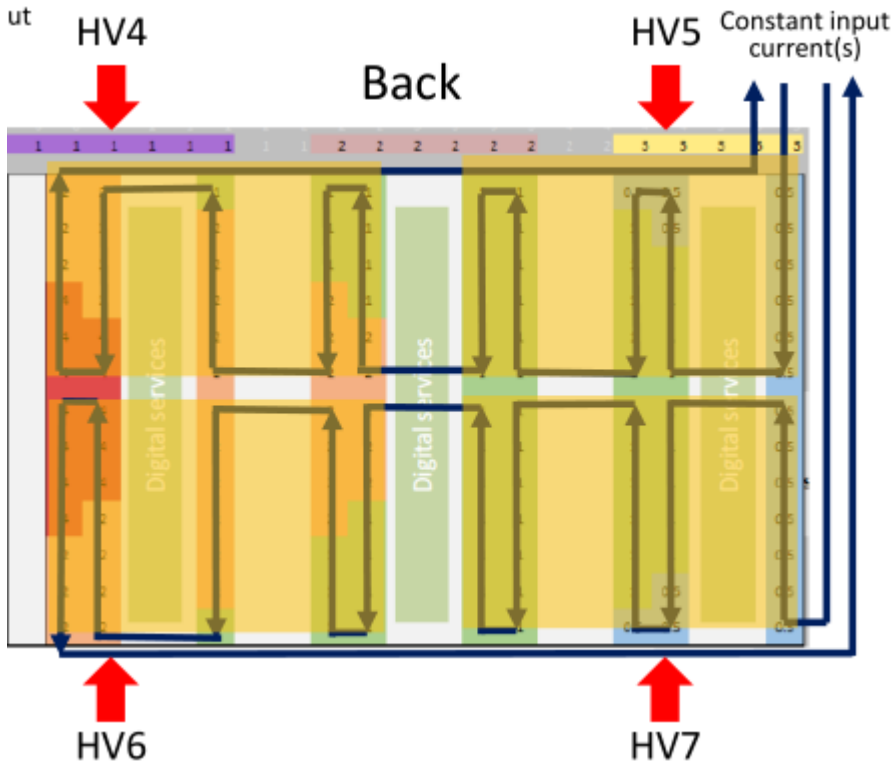


- Improvements to readout FSM
- MightyPix 2 hit rate efficiency above 99.5% @ 30 MHz/cm^2 (former limit 20 MHz/cm^2)
- Trying to replicate tests with MightyPix 1 in the lab

Sensor HV

Ashley Greenall

- HV to be distributed across many sensors
- Examining different routing schemes
- **How to improve redundancy?**
  - add HV switch per submodule flex
  - reduce loss of sensors from 42 to 7(6)
  - Closely following ATLAS ITk work



Example HV routing

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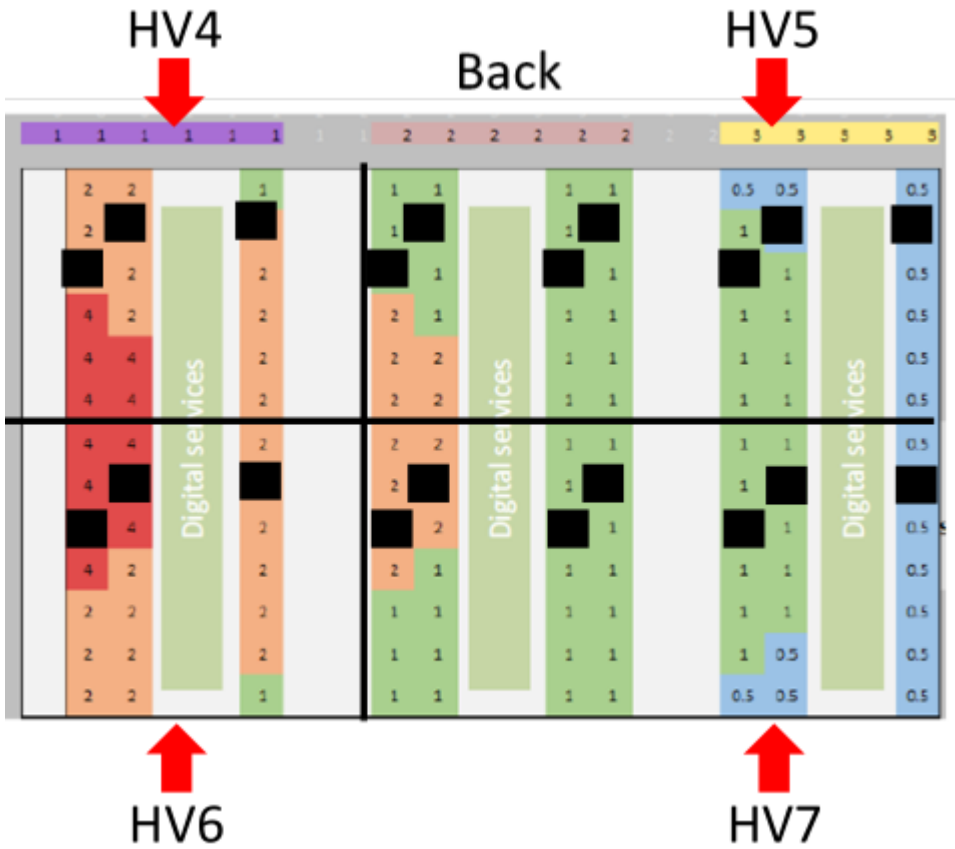
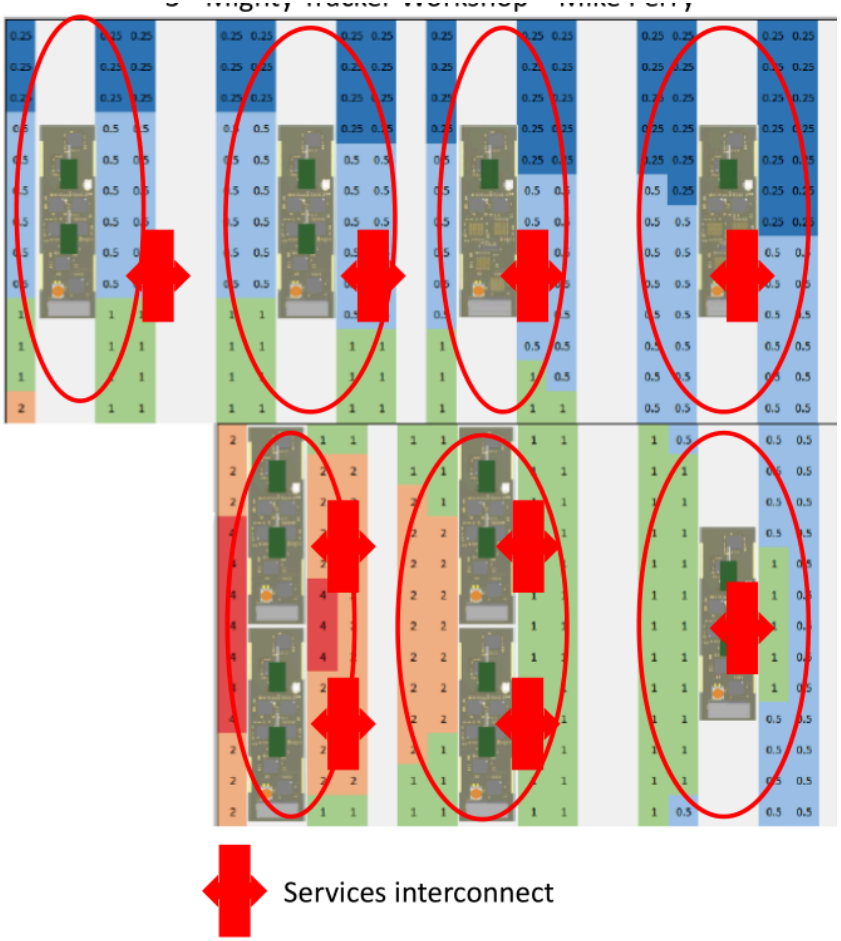


HV Switches in black

Serial Powering

Ashley Greenall

- Serial Powering now considered default
  - **Saves space on service boards**
  - **Reduces material**
- Locked to service boards
- To be included in MightyPix 2
- Several design iterations on hybrids/ modules for optimal layout - nothing final yet
- Have 3 ATLASPix samples
  - use to gain experience with Serial Powering

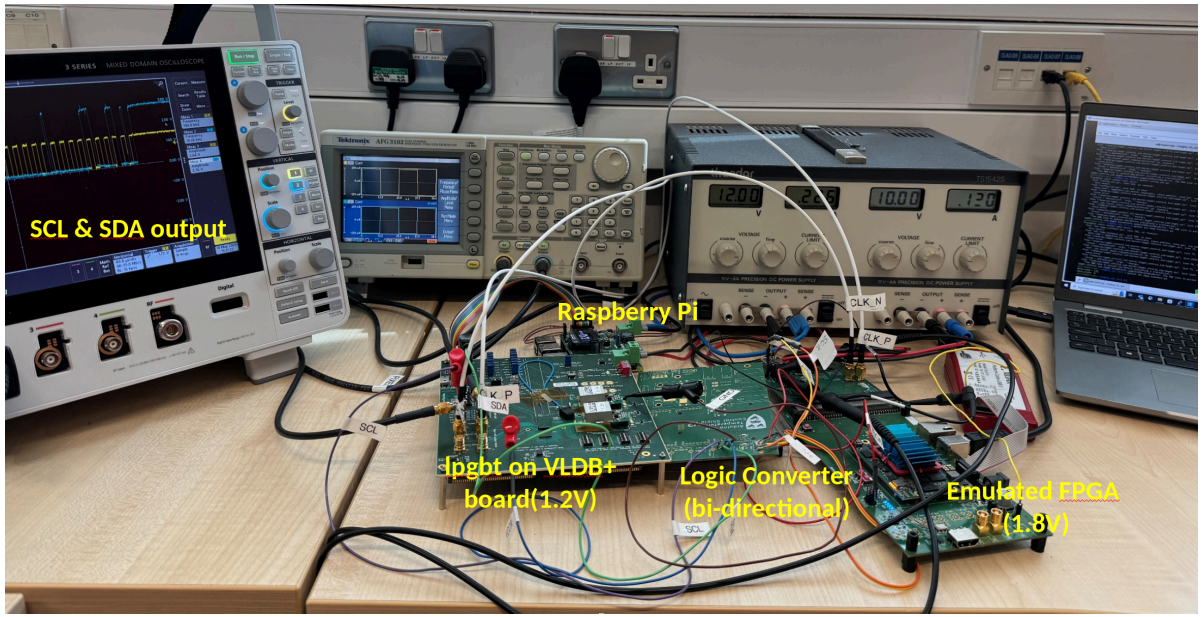


Serial power loops

FPGA prototyping

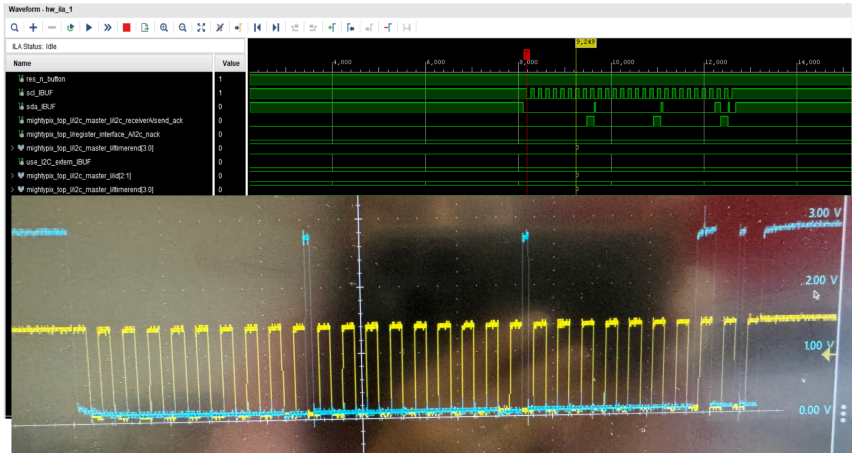
Ayushi Khatri

- Idea: **use an FPGA to emulate MightyPix**
  - Test digital functionality
- Connect to VLDB+ and talk to MightyFPGA over I^2C



VLDB+ & MightyFPGA setup

- Successfully managed to talk to MightyFPGA over I^2C and configure and read back internal registers

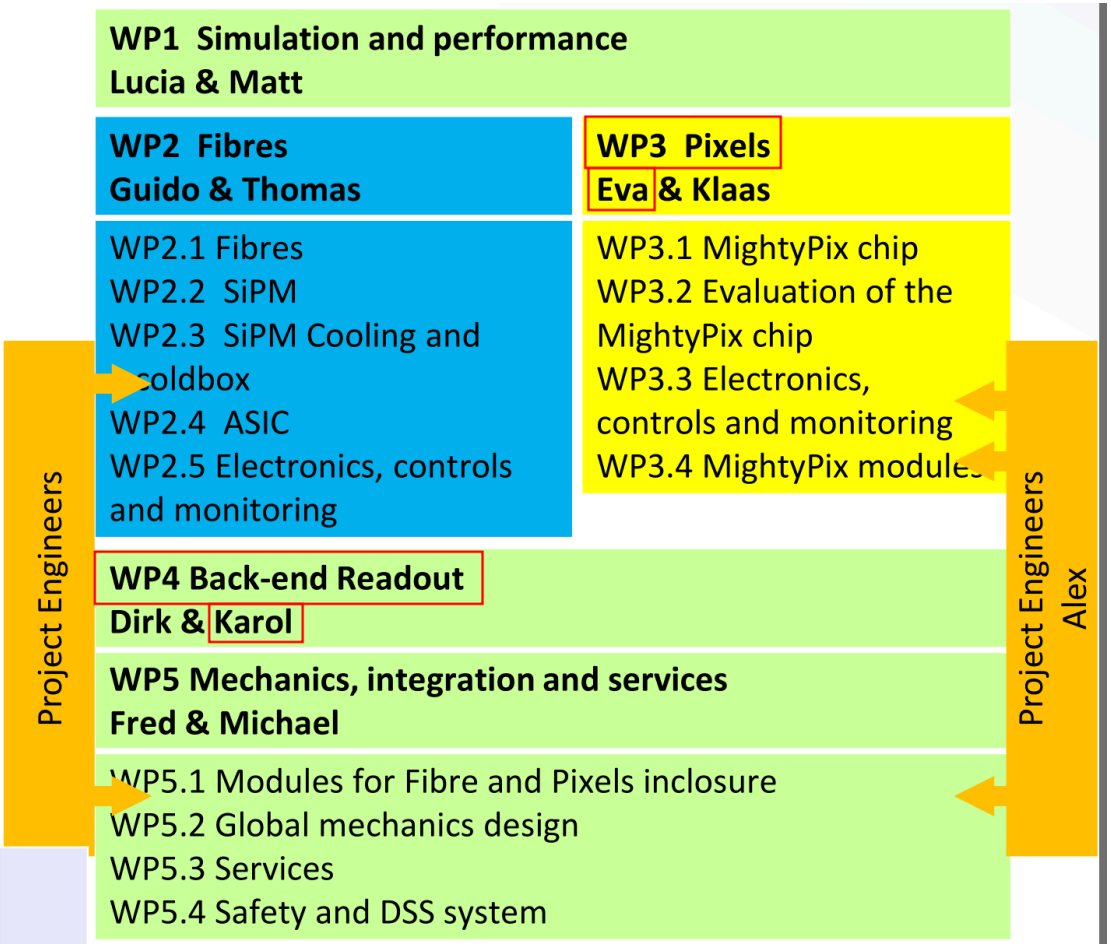


Communication from lpGBT to MightyFPGA

Coordination

Weekly meeting of Extended Coordination team:

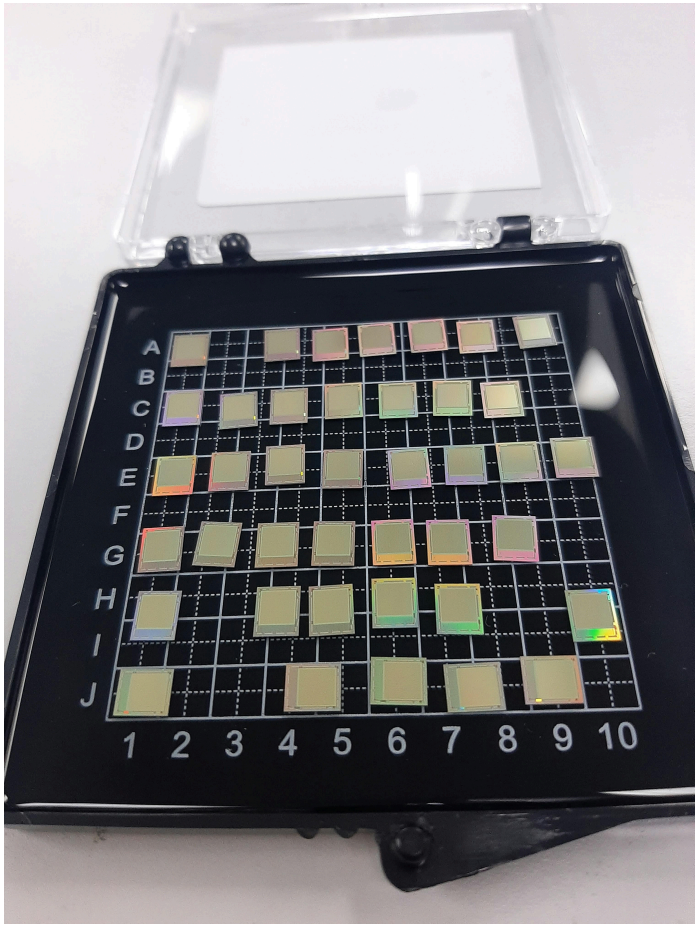
- ✓ WP0: Blake, Fred, Matt & PP
- ✓ WP1: Lucia (& Matt)
- ✓ WP2: Guido & Thomas
- ✓ WP3: Eva & Klaas
- ✓ WP4: Dirk & Karol
- ✓ WP5: Michael (& Fred)
- ✓ Project engineers: Alex & ?



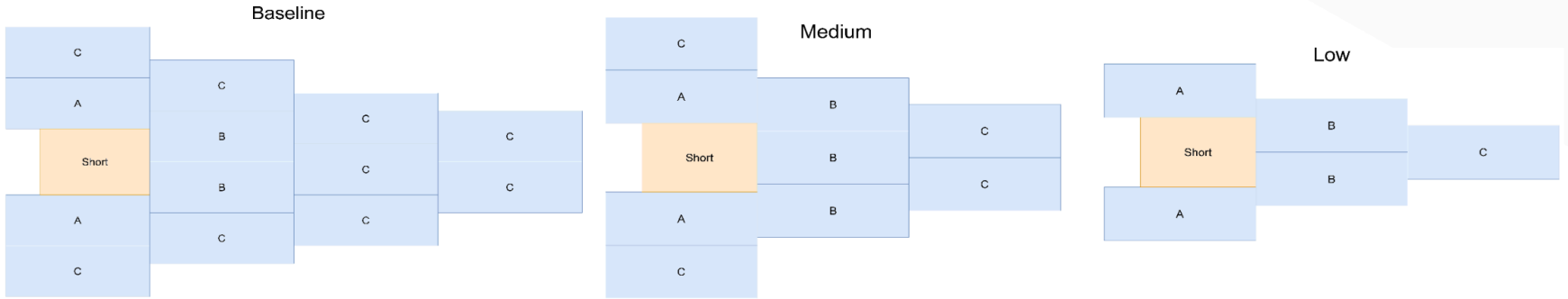
Recent developments...

Eva Vilella

- Forming a working group to **develop a high radiation tolerant MightyPix type chip** in LFoundry
- Capitalise on recent advancements achieved through CERN-RD50
  - **RD50-MPW4 chip** - **Liverpool design**
    - small pixel
    - high radiation tolerance
    - for more details see Jan's talk
- We will make the chip for the Mighty Tracker but **also for the UT**.
- **Kick-off meeting in June** with essentially Liverpool, RAL and the UT.



Scoping



18m² / 3m²
Full / layer

12.7m² / 2.1m²
Full / layer

7.6m² / 1.3m²
Full / layer

- Feb. had to submit a scoping document for Upgrade 2 with scenarios for 100%, 85%, 70% cost.
- Likely result: reduction in silicon area; reduce DAQ margins

Writing the scoping document was great fun, and not boring!"
— No-one Ever

4th Mighty Tracker Workshop at Liverpool

2–4 Jul 2024
126 Mount Pleasant, Lecture Theatre 113
Europe/Zurich timezone

Enter your search term

Overview
Timetable
Registration
Participant List

Contact
vilella@hep.ph.liv.ac.uk
A.J.Reid@liverpool.ac.uk
hannah.melia@liverpool…

The workshop will be held at Liverpool

It will start on **Tuesday 2nd July** in the morning and will end on **Thursday 4th July** in the afternoon.

The workshop will be held **in-person on the University campus in the Liverpool city centre**. The room is **Lecture Theatre 113 at 126 Mount Pleasant** (map). Remote attendance (via zoom) will be arranged for those who cannot travel, but attendance in person is highly encouraged.

Registration is now open with deadline of 23rd June. You are kindly asked to register quickly and indicate whether you will be attending in person.

A workshop dinner will be held on Wednesday 3rd. Participants are expected to pay directly for their dinner. Further information will be provided at a later date.

There is no registration fee, but registration is required for everyone attending to determine the number of participants (size of the room) and participation to the workshop dinner.

Travel to Liverpool

VELO U2

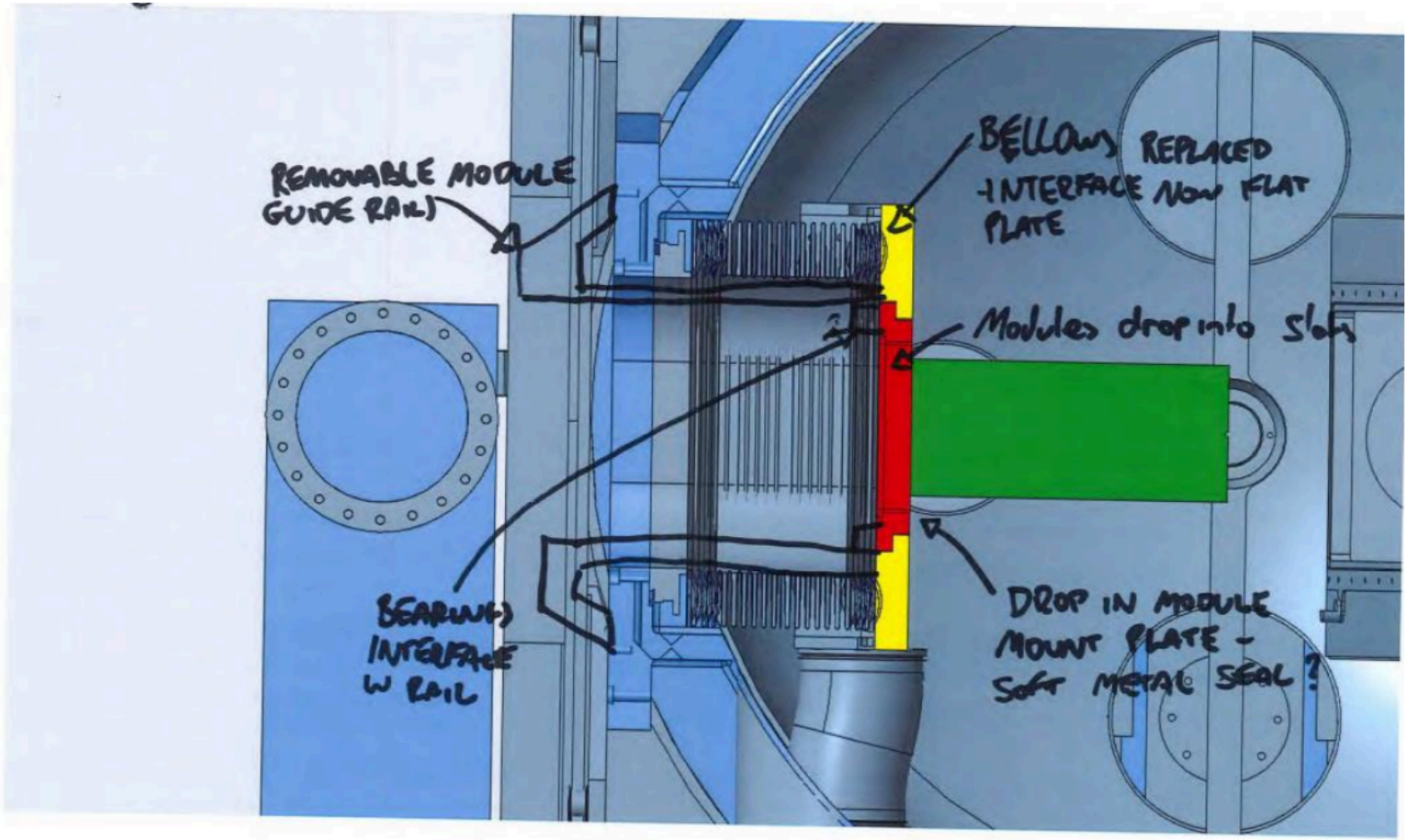
VELO U2 Mechanics

Kieran Bridges

- Current radiation damage estimates mean upgrade 2 VELO modules unlikely not survive the lifetime of the experiment
- Kieran developing the **mechanics for a replacable module system**
  - Top level design requirement
  - Possibility to upgrade modules
- Challenges:
  - contamination; radiation exposure; cooling, power, electronic connections…

VELO U2 Mechanics

Kieran Bridges

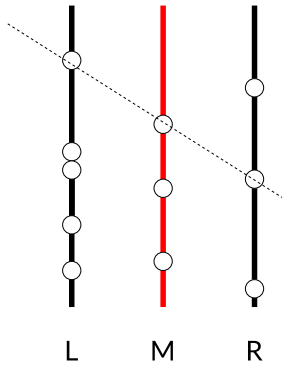


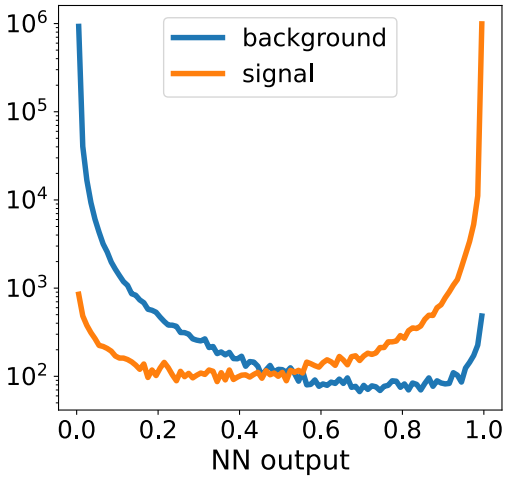
Data Processing for U2

ML Tracking on FPGAs

Kurt Rinnert, Karol Hennessy

- Use LHCb VELO as a test-bed.
- Connect the dots
  - Take 3 detector planes (**L**eft, **M**iddle, **R**ight)
  - **make all combinations of triplets from hit clusters**
  - **choose the "best" triplet**
  - Train the machine on LHCb MC data
- NN developed using PyTorch
- **Port the resulting models to FPGA**
- Performance: high efficiency ~ 92%, purity ~ 97%, low ghost rates





oneAPI framework

- Write code in **C++** and **SYCL** (Data Parallel C++)
- Verify and Deploy to accelerator (GPU, FPGA)
- *Open Standard*
- **In four months, we managed to put the triplet finding algorithm on the FPGA, and verify the results**
- Next:
  - optimising for throughput
  - Integrate with existing DAQ workflow
  - compare to GPU
- Overall impression: Despite a few small annoyances, the framework is very powerful. **Potential to open FPGA programming to software developers**

BittWare IA-840f FPGA card

Thanks for listening!

PS… a vote for reinstating the Christmas meeting

PS... a vote for reinstating the Christmas meeting

Pro	Con
People aren't on holidays, they already have one at the end of the month	Bah humbug!
Fewer conferences	
Students/LTAs get to travel home for winter break (cost saving)	
It's at a known time of year (not announced with 2 weeks notice)	
Christmas jumpers	

Backup

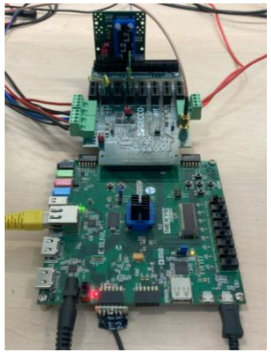
MightyPix

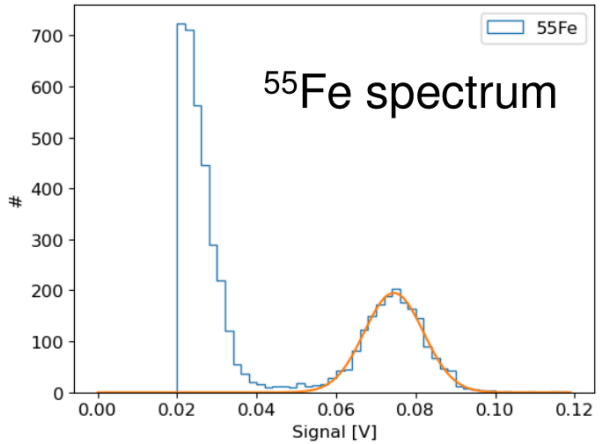
- The Mighty Tracker design centres around a new chip - **MightyPix**
- Based on knowledge from **ATLASPix** and MuPix
- **TSI 180 nm** process
- **HV-CMOS**: Sensing element and readout circuit on same chip

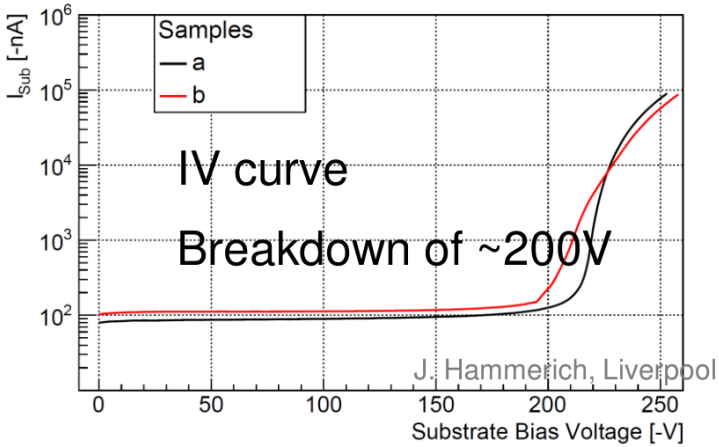
Requirements	
Pixel size	$< 100\mu m \times 300\mu m$
In-time efficiency	> 99%
Radiation tolerance	$6 \times 10^{14} \cdot 1MeVn_{eq} \,/\, cm^2$

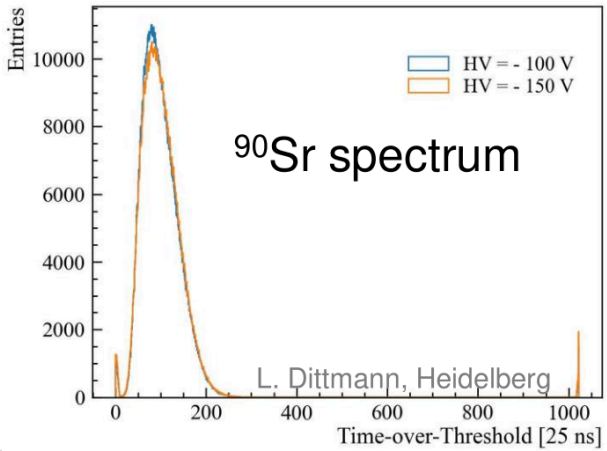
Mighty v1 results

T. Hirono, L. Dittmann









MightyPix v1 lessons learned

- configuration problem
  - missing load signal ; analog config not possible
  - workaround : FIB surgery
  - lesson : check coverage, improve testing
- synchronisation problem
  - no proper communication possible between modules
  - modified model files
  - workaround : power cycle chip
  - lesson: use design defaults

MightyPix v1 lessons learned

- Timestamp wrong
  - workaround: BXID reset before 4095
  - unit test all submodules
- Missing shielding
  - causes coupling between adjacent columns
  - workaround: increase threshold voltage, reduced time resolution
  - lesson: formal checklist and DRC error signoff