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Timing Resolution Studies for the MightyPix: A Proposal

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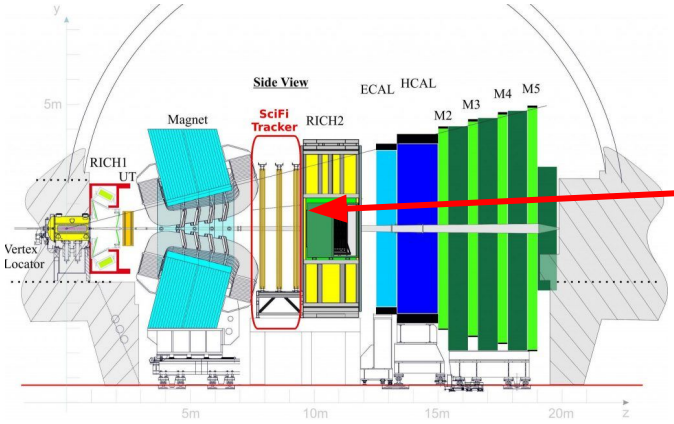
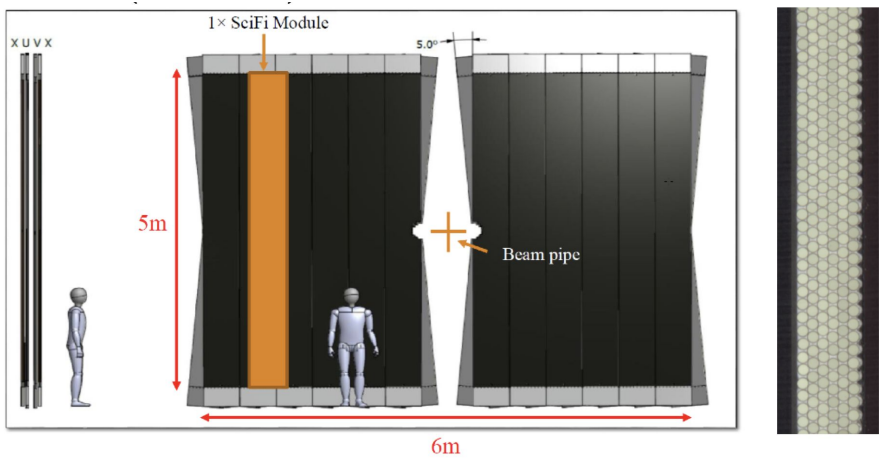
The LHCb SciFi

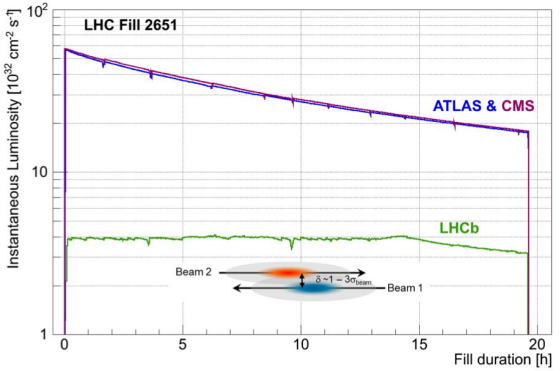




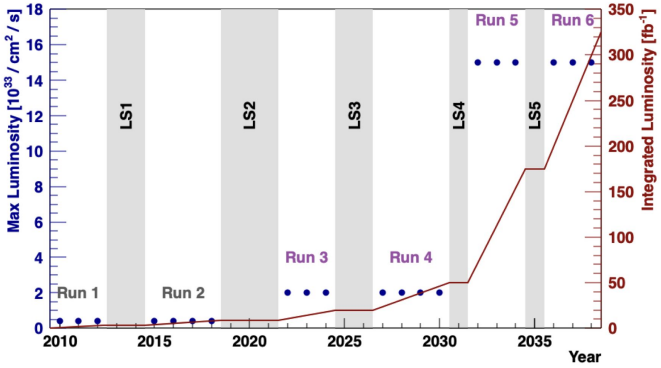
- SciFi is a downstream tracker made entirely of plastic scintillator rods read out by SiPM's
- It has 3 stations with 4 detection planes (XUVX) and an acceptance area of 6 m x 5 m
- Each detection plane has 6 layers of 2.5 m long densely packed 250 μm diameter fibre arrays
- One end is readout with multi channel SiPM's and the other has a mirror

LHCb During LS4 and Run 5

- During Run 5, LHCb wants to make use of the HL-LHC conditions
  - LHCb will run at the same luminosity during Run 3 and Run 4
    - Beam levelling
- $\mathcal{L}_{max} = 2x10^{33}\ cm^{-2}s^{-1} \rightarrow \mathcal{L}_{max} = 1.5x10^{34}\ cm^{-2}s^{-1}$
- The current SciFi detector will not be able to operate at these luminosities
  - Radiation damage in the scintillating fibres
  - Increased occupancy in the areas nearest the beam pipe
- Therefore, during LS4, the SciFi must be upgraded to maintain or improve the tracking performance

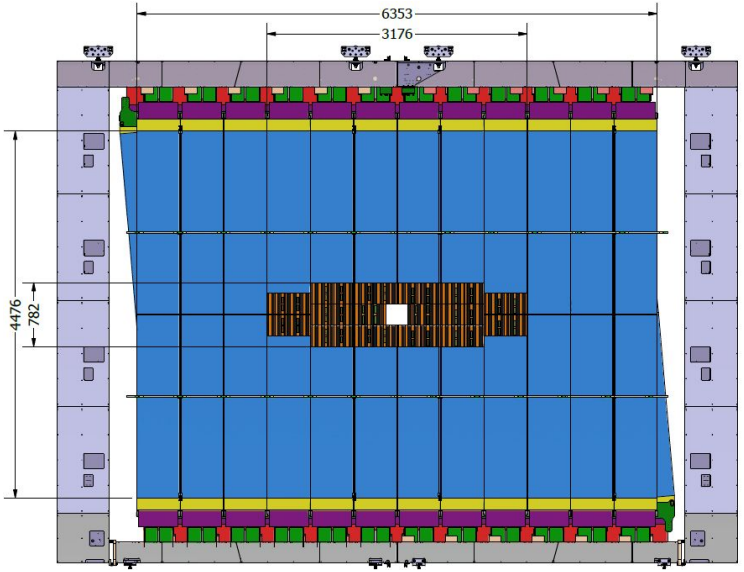


Beam levelling LHCb



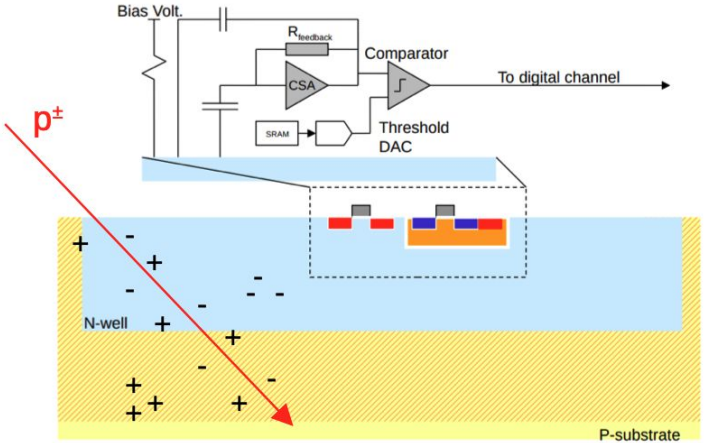
The LHCb Mighty Tracker

- Replace the inner region with a pixel detector, while keeping the scintillating fibres in the outer region
- High Voltage Monolithic Active Pixel Sensors (HV-MAPS)
  - Called MightyPix
  - Based on MuPix and ATLASPix designs
- ~46000 silicon sensors covering an area of 18 m^2
  - Number of layers still being debated
- Cooling systems design is still undecided but depends on the power consumption and required operational temperature
- The scintillating fibres will be renewed and the SiPM's performance and cooling will be improved



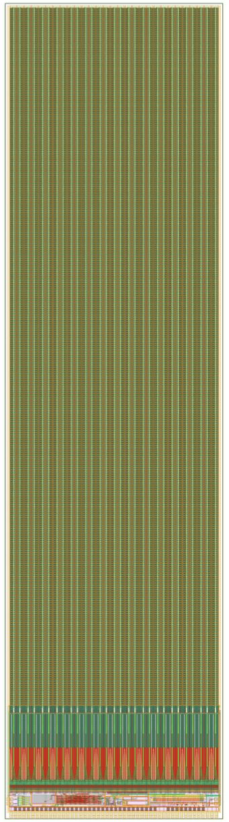
HV-MAPS

- Unlike hybrid pixel detectors, HV-MAPS are integrated into the same piece of silicon
  - This makes production easier and cheaper
  - Lower material budget lower
- n-well/p-substrate diode acts as the active sensor
- A reverse bias voltage creates the depletion region
  - Thickness determined by the substrate resistivity and the bias voltage
  - If the full thickness is not depleted, the sensor can be further thinned
- Charge collection via drift
- The readout is isolated from HV by the deep n-well

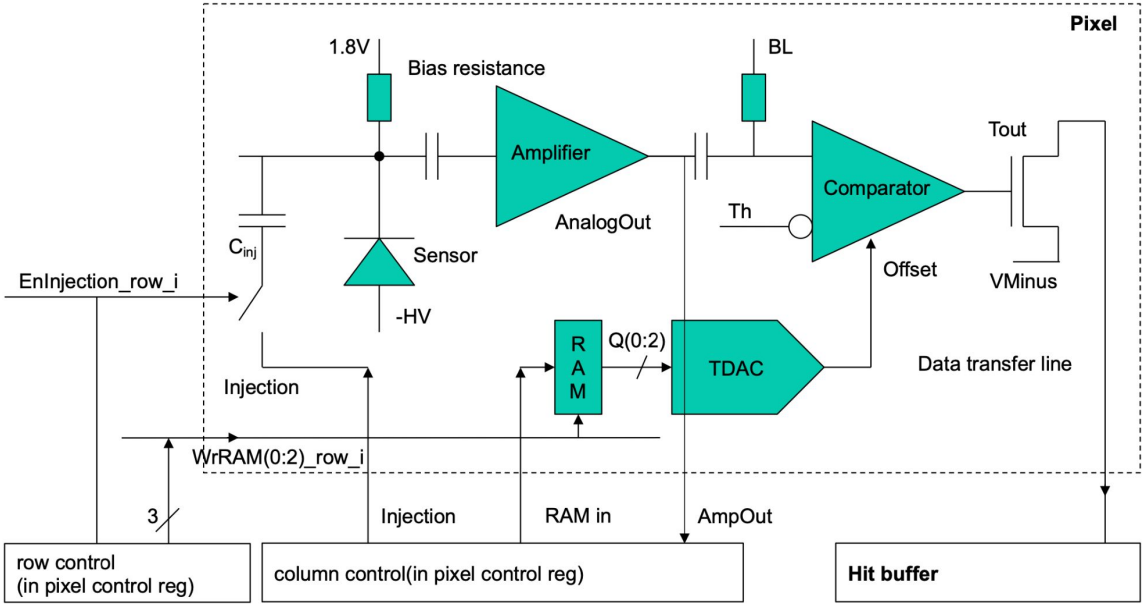


LHCb MightyPix

- Key requirements are:
  - fast timing: < 4 ns
  - radiation tolerance up to 6 x 10^{14} 1MeV n_{eq}/cm^2
  - > 99 % efficiency within 25 ns
- MightyPix parameters are:
  - Chip size: ~2cm x 2cm
  - Pixel Size: ~50µm x 150 µm
  - Thickness: 150 µm
  - Power Consumption: < 0.15 W/cm^2
  - Binary readout preferred
- Cooling < 0 ℃



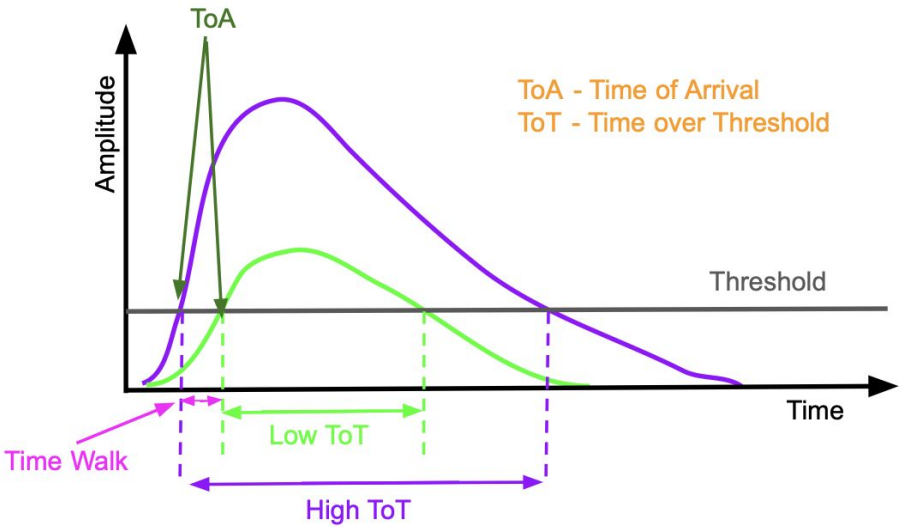
MightyPix Analogue Readout



- Sensor Diode
- Charge Sensitive Amplifier
- Comparator
- Threshold Tune DAC
- Data then sent to the periphery of the chip for further processing

https://indico.cern.ch/event/1223972/contributions/5262041/attachments/2602200/4493474/MightyPix_SigridScherl.pdf

Reminder of Timing Concepts



- ToA - Time when the signal crosses the threshold
- ToT - Time that the signal is over the threshold

- Timewalk refers to the time variation in the ToA of an event depending on the amplitude of a signal
- A signal with low ToT takes longer to reach threshold and is at risk of being registered in the next bunch crossing
- The time resolution improves if you correct for timewalk

MightyPix Timing Specification

- For operation at the LHC it is critical that hits are assigned to the correct 25 ns bunch crossing
- MightyPix requires a time resolution of < 4 ns
- This has so far been achieved for small systems
    - However may not be achievable for the full detector
        - Drifting LHC clock
        - Irradiation damage
- If we do not achieve the desired time resolution we may have spill over
    - Increased occupancy, more noise hits
    - Decreased tracking efficiency
- What are the magnitudes of spill over and can we limit it?
    - This requires simulation

MightyPix and Allpix2

- I would like to simulate MightyPix using Allpix2
  - To measure the timing resolution with the current design and how it varies when making changes
- Two different scenarios have been proposed
  - Introducing a more granular time stamp, currently the time stamp is the LHC bunch crossing
  - Keep ToT information, events with low ToT may have a “late” ToA that is registered in the next bunch crossing
- Both could help identity signals that have been assigned to the wrong bunch crossing benefiting the tracking efficiency but its not clear what effect this has on the power consumption
  - If we need to improve cooling capabilities due to increased power consumption, it can increase the material budget and have an negative effect on the tracking
- So far I have familiarising myself with how to use allpix2 while waiting on TCAD simulations
  - TCAD will be provided by Annie Meneses Gonzalez

Conclusions

- LHCb will upgrade its current downstream tracking detector during LS4
  - SciFi → Mighty Tracker
  - One key change is the implementation of silicon tracking layers near the beam pipe made up of HV-MAPS called MightyPix
- A key performance requirement of the MightyPix is a time resolution < 4ns
  - It is not clear if chip changes are needed to achieve this resolution
  - Simulations are needed
- These simulations are in the very early stages
  - I have made a MightyPix Model
  - I wait for TCAD simulations
  - Lots of reading and questions need to be asked regarding different simulation settings
- Hopefully I will have some interesting results at the next user meeting!

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Thanks!