The LHCb VELO Upgrade

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On behalf of the LHCb VELO Upgrade Group

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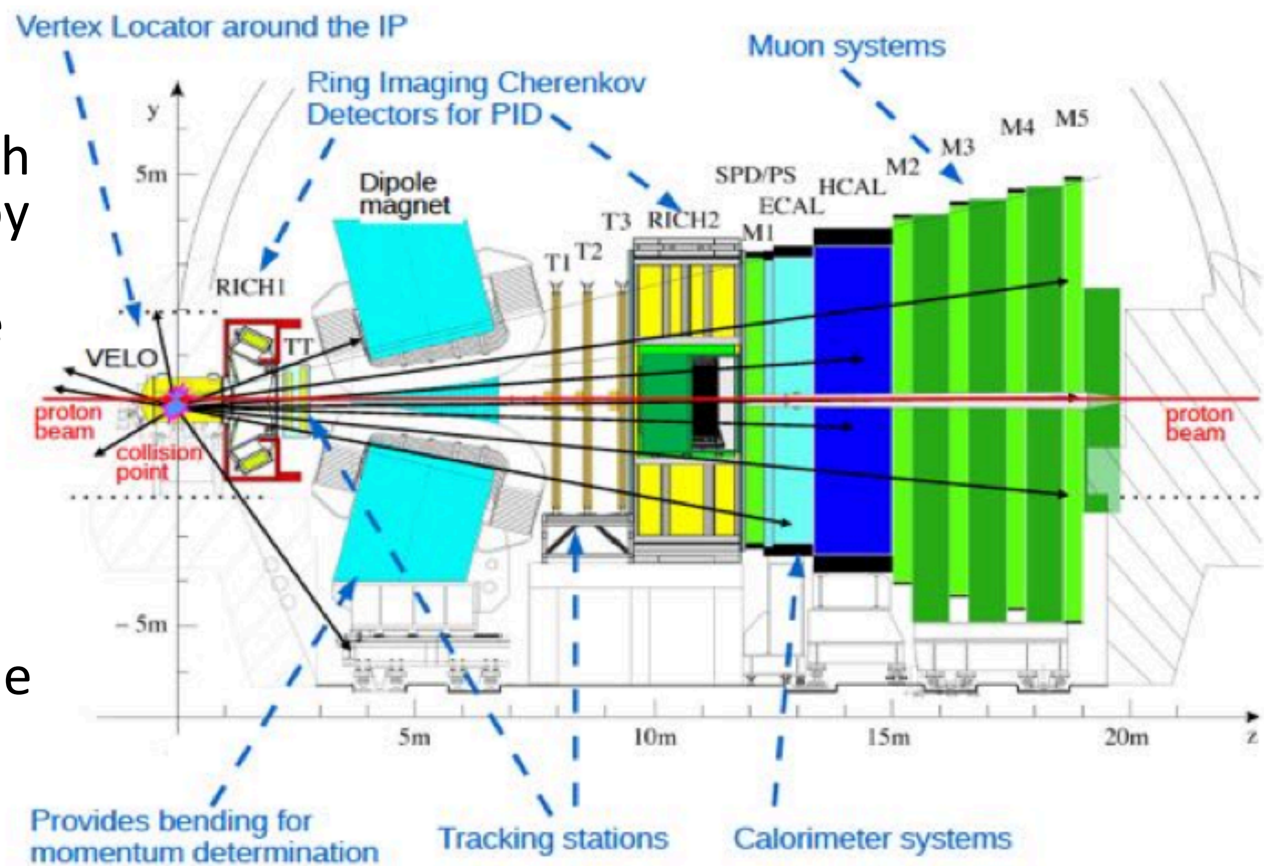
Overview

- Introduction to LHCb detector
- Upgrade motivation
- Timeline
- Brief VELO overview
- Upgrade challenges
- Upgrade details
  - Sensors
  - VeloPix
  - Micro-channel cooling
  - RF foil
- Test beam
- Summary

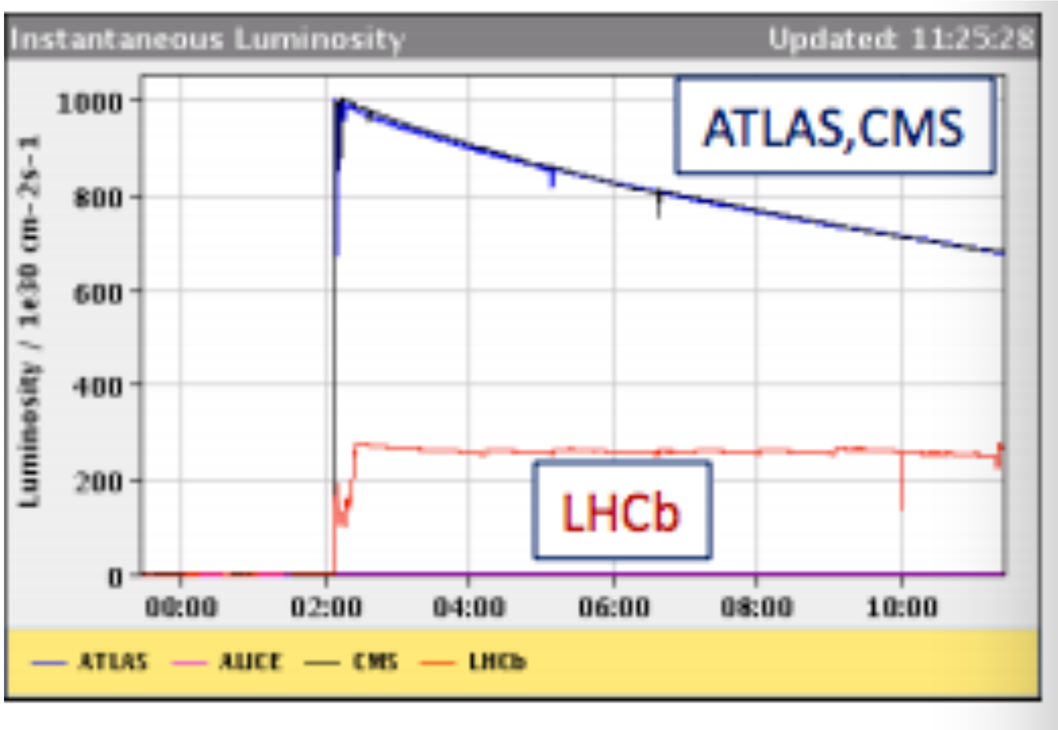
The LHCb Experiment

- Single arm spectrometer designed to search for New Physics by studying CP violation and rare decays of beauty and charm particles at LHC.
- Excellent vertex and momentum resolution, particle ID and flexible triggering



Why do we need to upgrade

- More statistics needed as no deviation has been observed from the Standard Model
- LHCb runs at a stable luminosity but may accept more from LHC
- LHCb runs at double the luminosity as it had been designed.
- Current detector is limited to 1 MHz full readout



Timeline

Beam Crossing	50 ns	-	25 ns	-	25 ns
Start up	2010, 2011, 2012	2013, 2014, 2015	2016, 2017	2018, 2019	2020, 2021, 2022+
TeV	0.9-7 8	**LS 1**	13-14	**LS 2 LHCb Upgrade**	
Instantaneous Luminosity	10^{32} 3-4 x 10^{32}		4 x 10^{32}		10 – 20 x 10^{32}
Integrated Luminosity	3 fb^{-1}		~5fb^{-1}		> 50 fb^{-1}

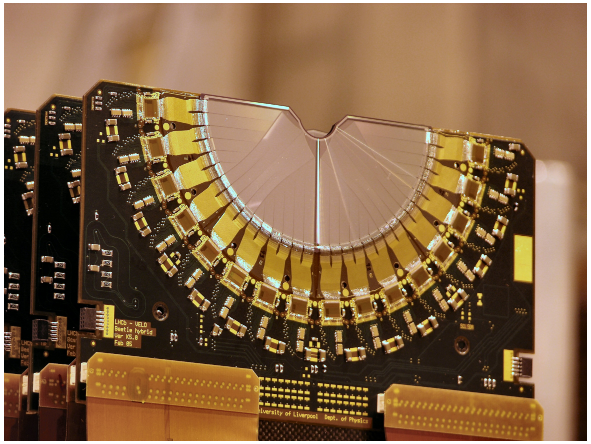
http://cds.cern.ch/record/1443882/files/LHCB-TDR-012.pdf

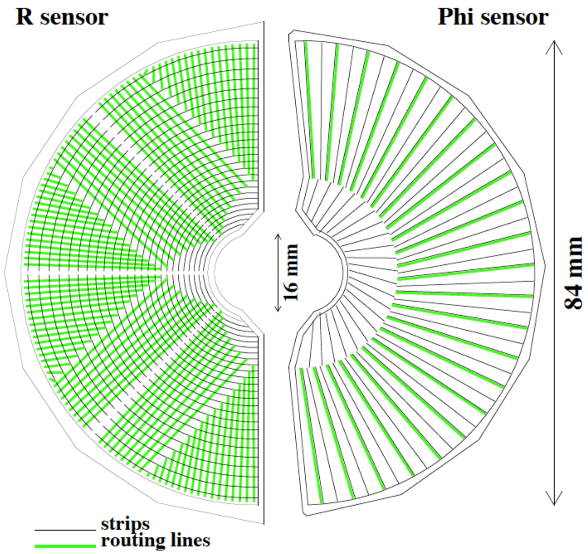
http://cds.cern.ch/record/1333091/files/LHCC-I-018.pdf

http://cds.cern.ch/record/1624070/files/LHCB-TDR-013.pdf

The current VELO

- 88 silicon sensors in a R-Φ design 300μm n-in-n Si
- Micro strip technology that is only 8.1 mm from the beam
- Separated from primary vacuum by thin RF foil
- Active CO_2 cooling





Changes for VELO

New VELO should have the same performance as the current VELO

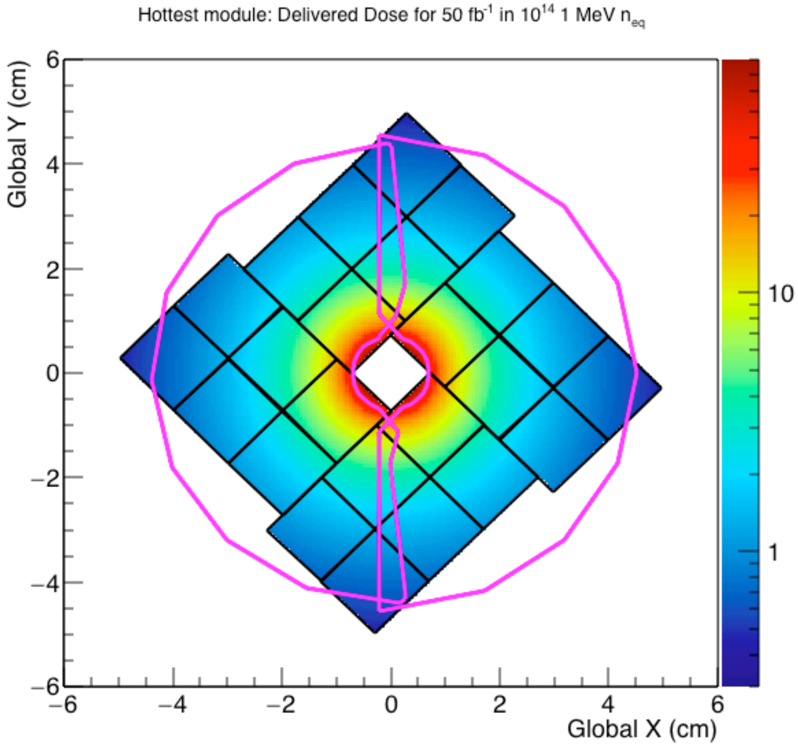
- From micro-strips to pixels
- Thinned sensor and readout chips
- 5.1 mm from beam (was 8.2mm)
- Readout data from every bunch crossing
- CO_2 cooling in micro-channels etched in Si
- New RF Foil

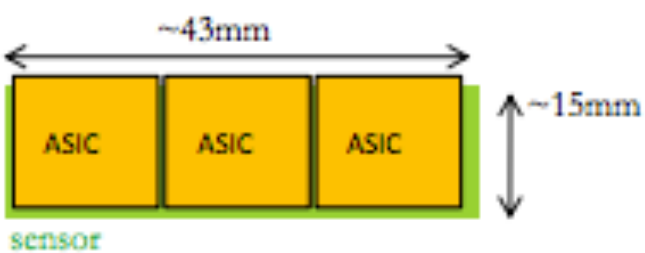
Challenges for the VELO upgrade

Non uniform Radiation Exposure	8 x 10^{15} n_{eq}/cm^2 at the close edge 0.2 x 10^{15} n_{eq}/cm^2 at outer edge
HV tolerance	1000V after 50 fb^{-1}
Readout data rate	Approximately 33 track per event per module (LHC 40MHz)
Temperature operation	Less than -20 degrees at the tip close to the beam
ASIC power consumption	Less than 3W per ASIC and up to 36W per module

Silicon sensors

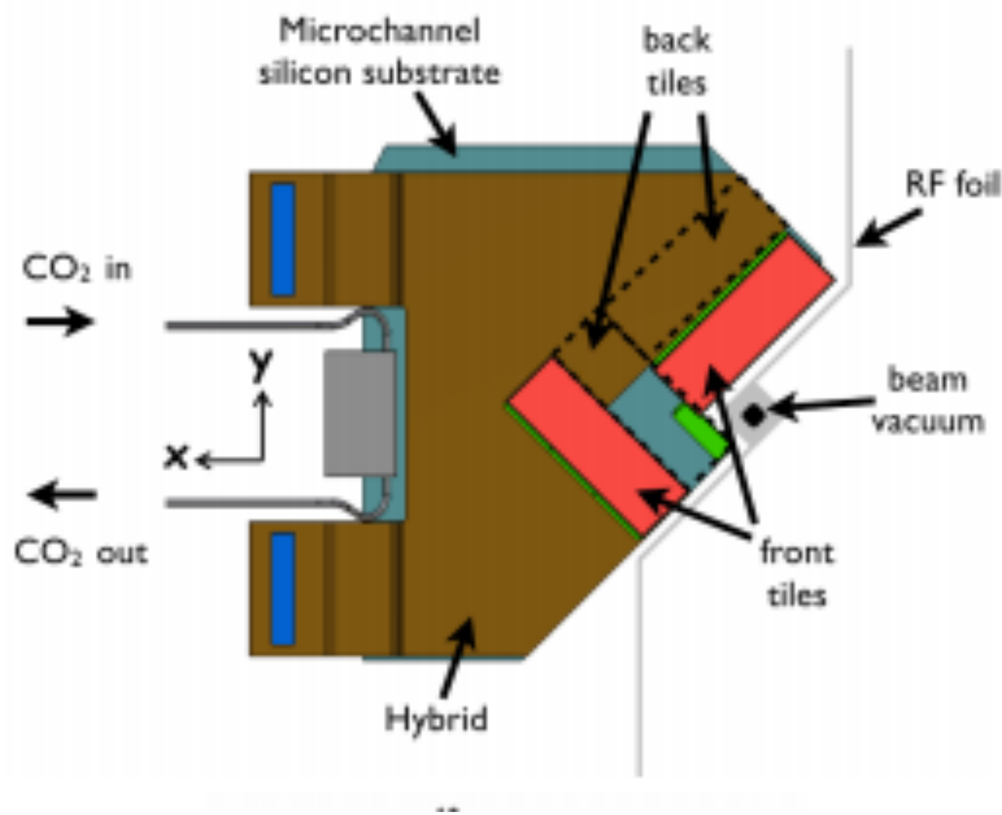
- Planar Silicon n-in-n or n-in-p
- 200 micron thickness
- 55 x 55 micron pixel size
- One tile is ~ 43 x 14 mm
- Testing sensors from HPK and Micron
  - 200 µm n-on-p is baseline
  - Micron : n-on-n and n-on-p
  - HPK n-on-p
  - Micron batch also includes more aggressive guard designs and wafers with 150 micron thickness





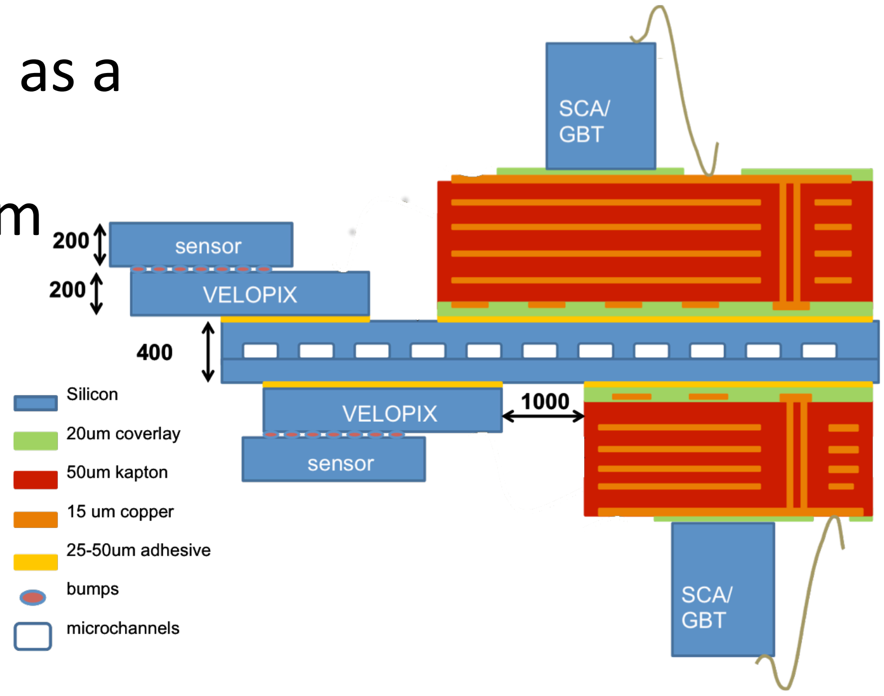
Modules

- 12 ASICs mounted on a L-shaped modules
- Four sensor tiles, two on each side of substrate
- Power and readout traces on Kapton flex
- Silicon substrate with etched micro-channels for evaporated CO_2 cooling



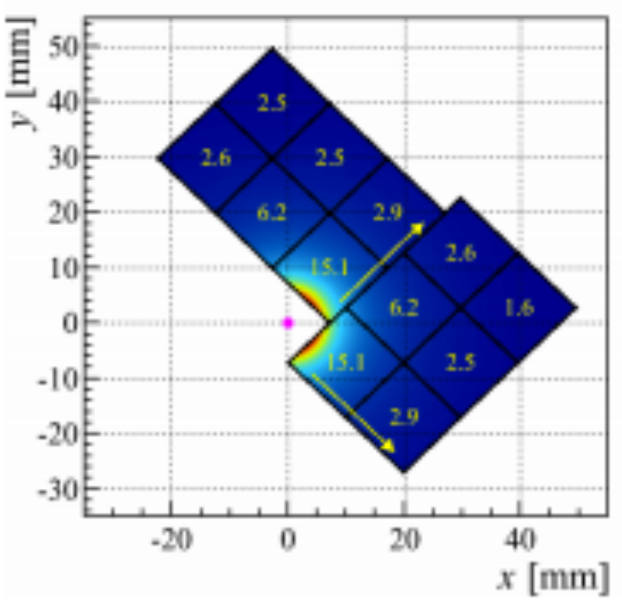
VeloPix ASIC

- MediPix➔TimePix➔TimePix3➔VeloPix
- VeloPix designed by CERN MediPix group and Nikhef
- TimePix3 ASIC are currently used as a prototype in beam tests
- 256 x 256 pixels, gives ~ 14x14mm active area
- 130nm CMOS technology
- Data driven readout
- Binary readout
- Zero suppressed data
- Fast front-end : Timewalk < 25ns
- Expected threshold ~1000e$^-$



VeloPix challenges

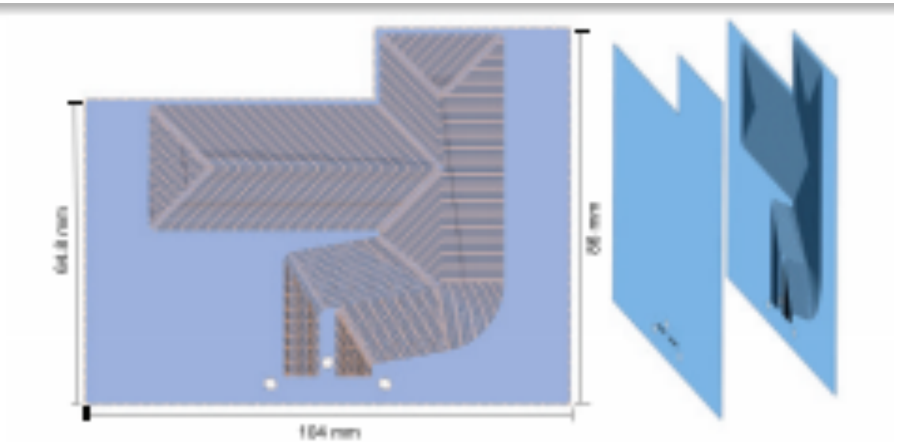
- The hottest chips have approximately 600 (900) Mhits/s per chip
  - Grouping of pixel hits 2x4 super pixel (30% data reduction)
  - Increase output bandwidth
  - Optimize buffering
- Output bandwidth of VeloPix
  - Average 13Gbit/s ; peak 20Gbit/s
  - 4 links at ~ 5Gbit/s



Data rate [Gbit/s] for hottest module.

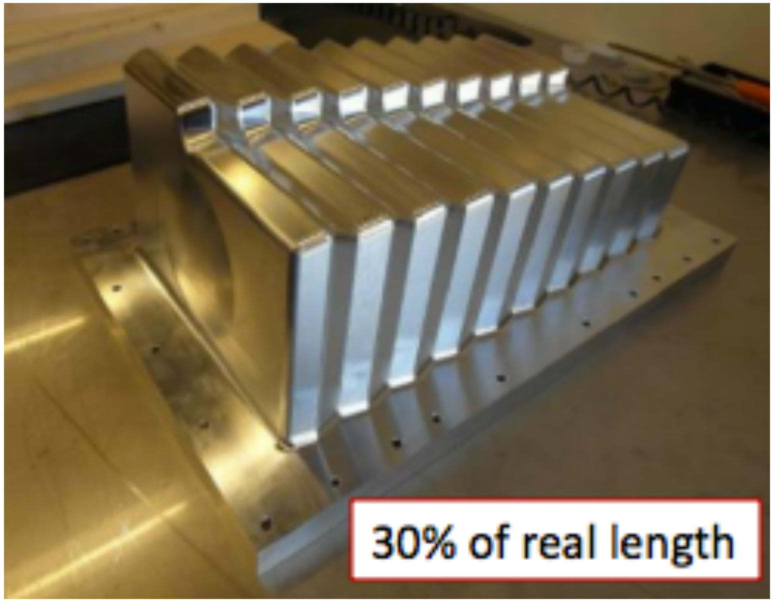
Micro-channel cooling

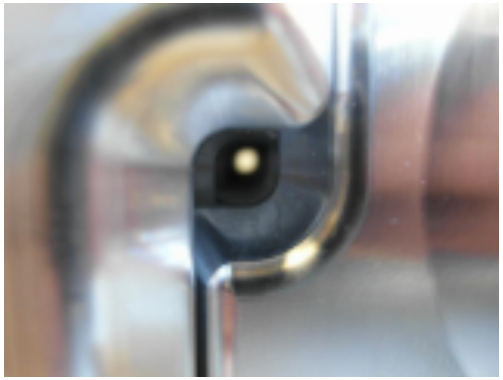
- Evaporative CO_2 flows via micro-channels etched into Silicon substrate.
- Bring the coolant directly to the power dissipation areas.
- Keep the sensors at -20 degrees to reduce damage from radiation
- Less material, no CTE mismatch
- Channel cross-section 120 x 200 μm^2



RF foil

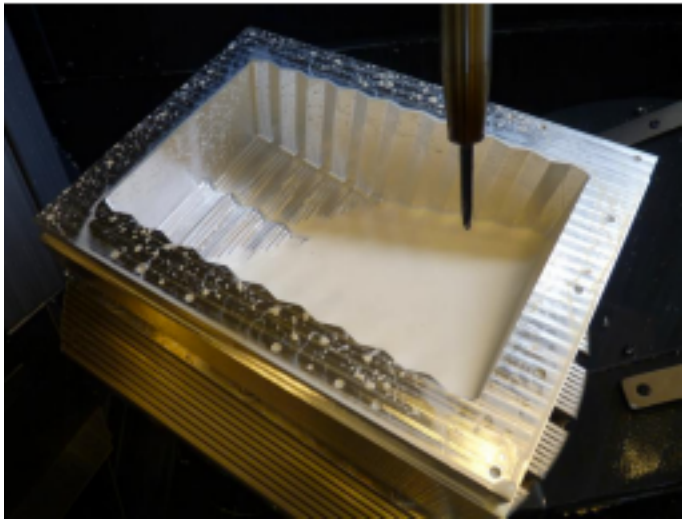
- Separates Accelerator and VELO vacua
- Vacuum tight
- Electrically conductive
- Low mass
- Thermally stable and thermally conductive
- Radiation hard

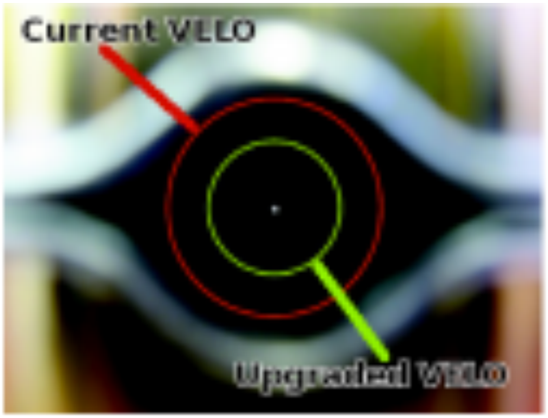




RF foil

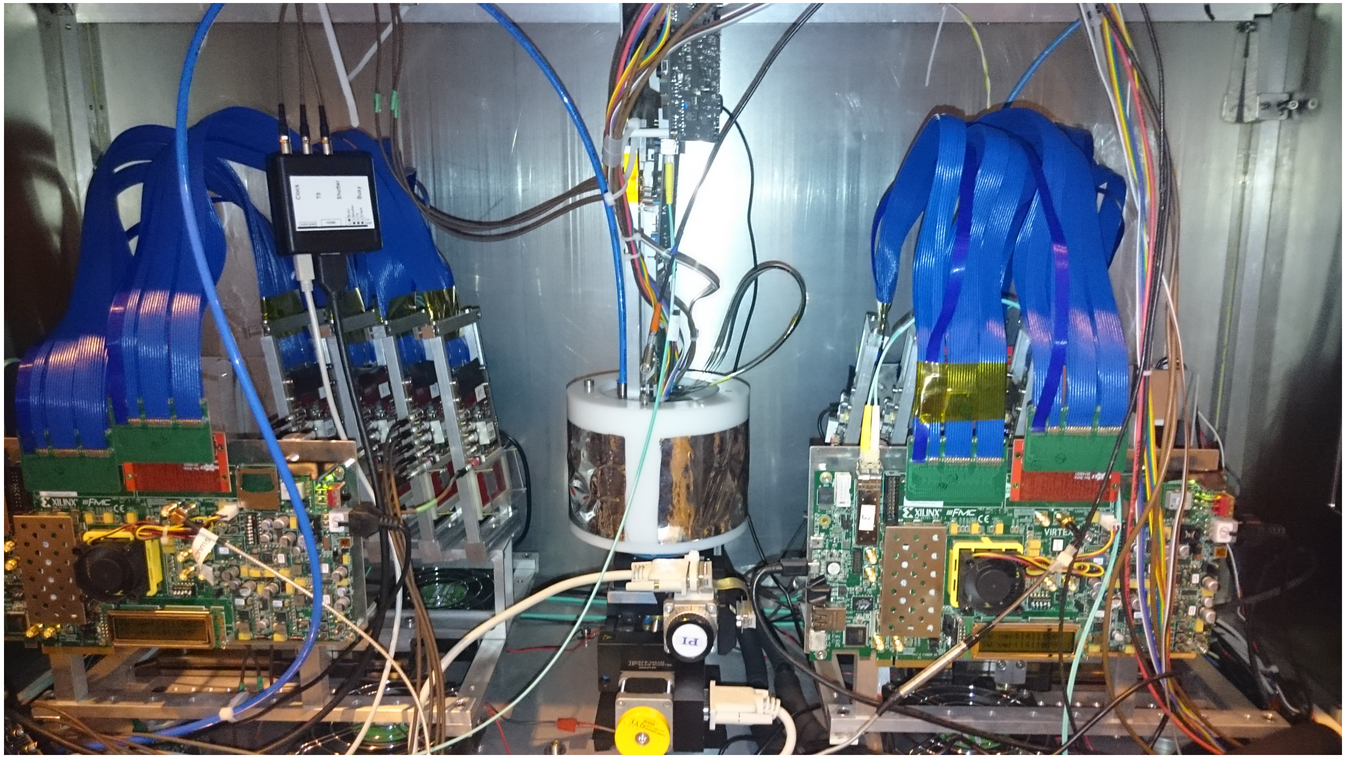
- Material and fabrication
  - Aluminum (AlBeMet) < 300 µm thick top foil
  - 500 µm thick walls
  - Milled from solid block of Aluminum
  - Local chemical thinning with NaOH after milling (under discussion)





Test beam

- Commissioned the TimePix3 telescope in July/August 2014 at CERN PS
- Successful test beam campaign at CERN SPS in November/October 2014 and May 2015
  - Characterization of prototype assemblies
  - High rate test of TimePix3
  - Irradiated sensors were also tested

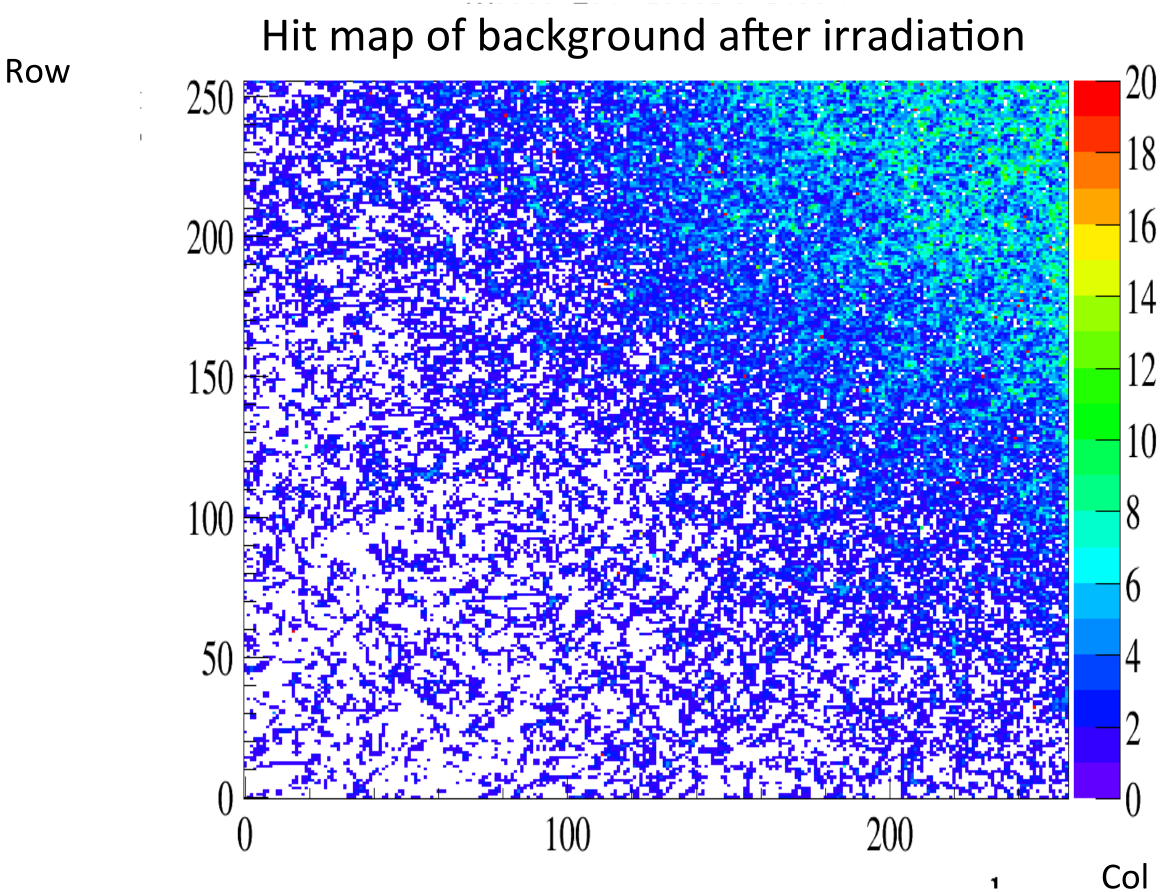


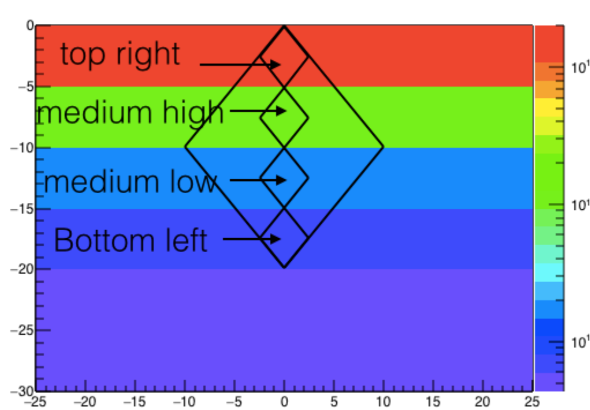
What did we test?

- Overall 14 Devices under test so far, 8 were irradiated
  - Two triples, 12 singles
- 5 Micron and 9 HPK
- 5 at JSI and 3 at KIT, triples from KIT
- 8 Telescope planes that were commissioned in July
- We have more test beams and more sensors to test in the coming year

Test beam

- S14 non-uniformly irradiated at KIT to maximum fluence of 2 x10^{15} 1MeV n_{eq} cm^{-2}





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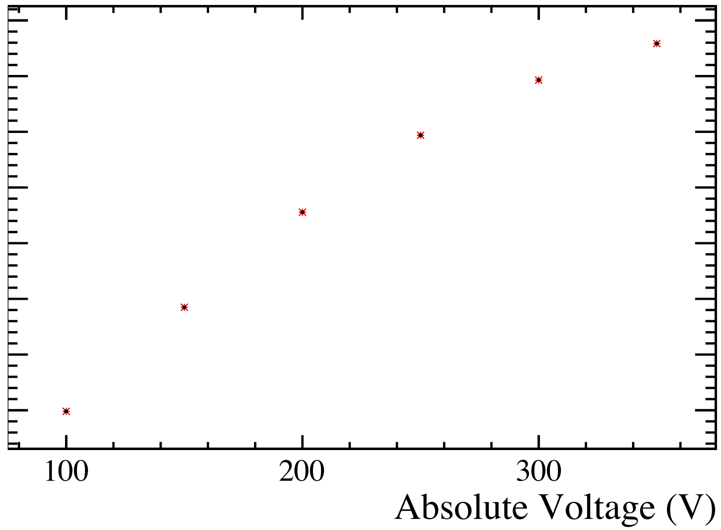
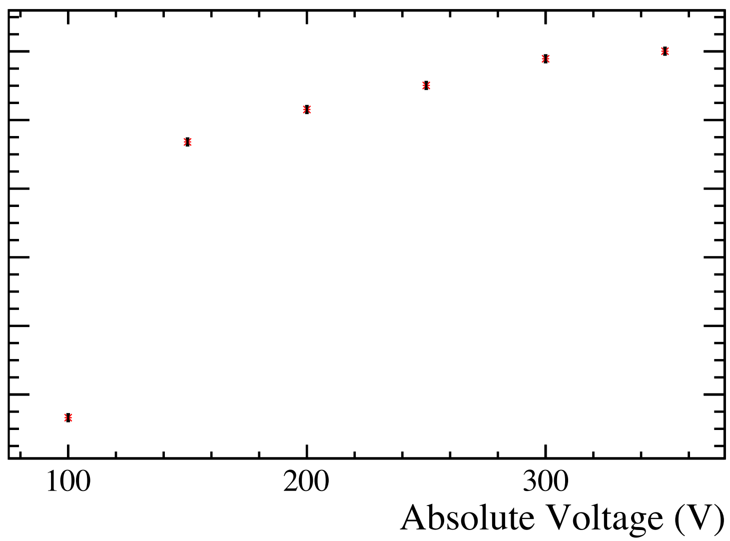
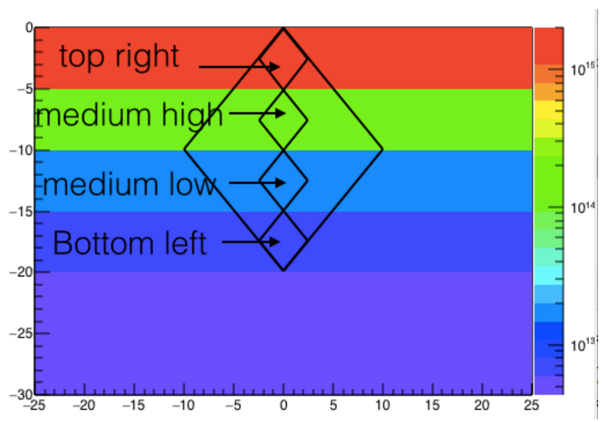
Some prelim results

- Non-uniformly irradiated sensor
- Charge collection efficiency in the highly irradiated corner(red) and a lower(green) irradiated section.







Summary

- Velo upgrade installation in 2019
- Luminosity 2 x 10^{33} (5 times more than current VELO)
- Planar Silicon pixels, 55 x 55 μm^2
- VeloPix ASICs
- Active area 5.1mm from beam
- Evaporative CO_2 cooling in Silicon micro-channel substrate
- 300 µm thick RF-box milled from solid block of Al

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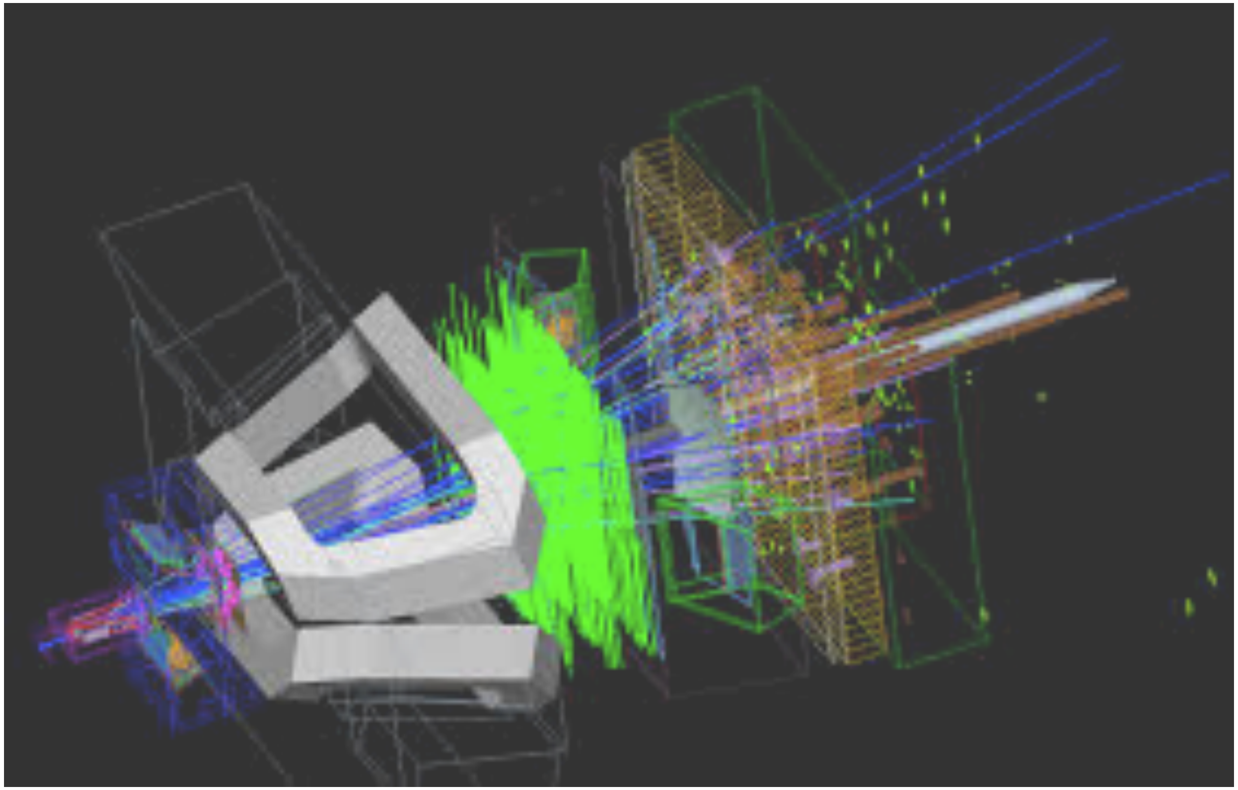

COLSTON RESEARCH SOCIETY

NETWORKING FOR KNOWLEDGE

Thank you to Colston Research Society and University of Bristol Alumni Society for travel funding.

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ALUMNI AND FRIENDS

THE ALUMNI FOUNDATION

Backup

Data acquisition

- Differential copper link from ISIC inside of vacuum tank
- Optical link ~300 m long
- 12 x 10 Gigabit Ethernet outputs
- CPU Farm
- DAQ module TELL40, common for LHCb, ATCA standard
- Data flow of whole VELO ~ 2.5 Terabit/s
- All signals coming from sensors have a timestamp which need to be arranged into an event