LHCb Upgrade II:
UK involvement in R&D activities

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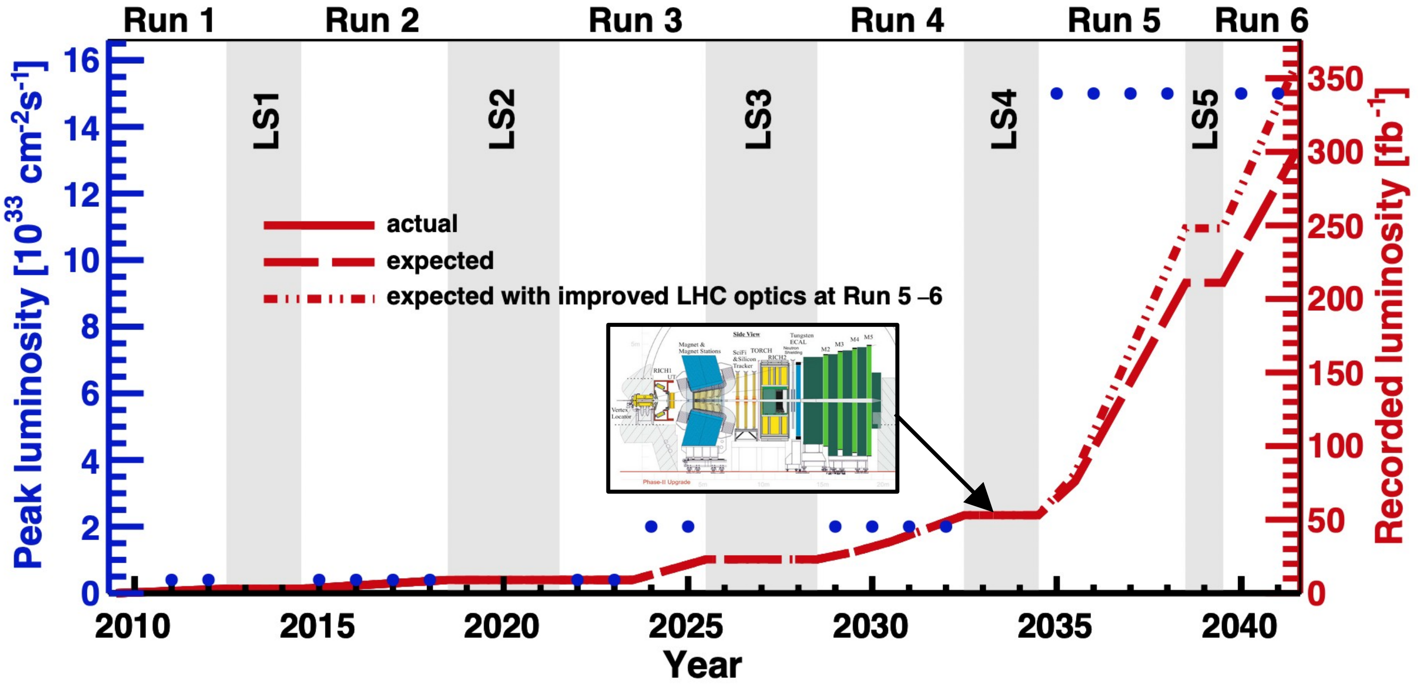
DRD UK Steering Board meeting
5 December 2023

LHCb Upgrade 2:
The ultimate HL-LHC flavour physics experiment

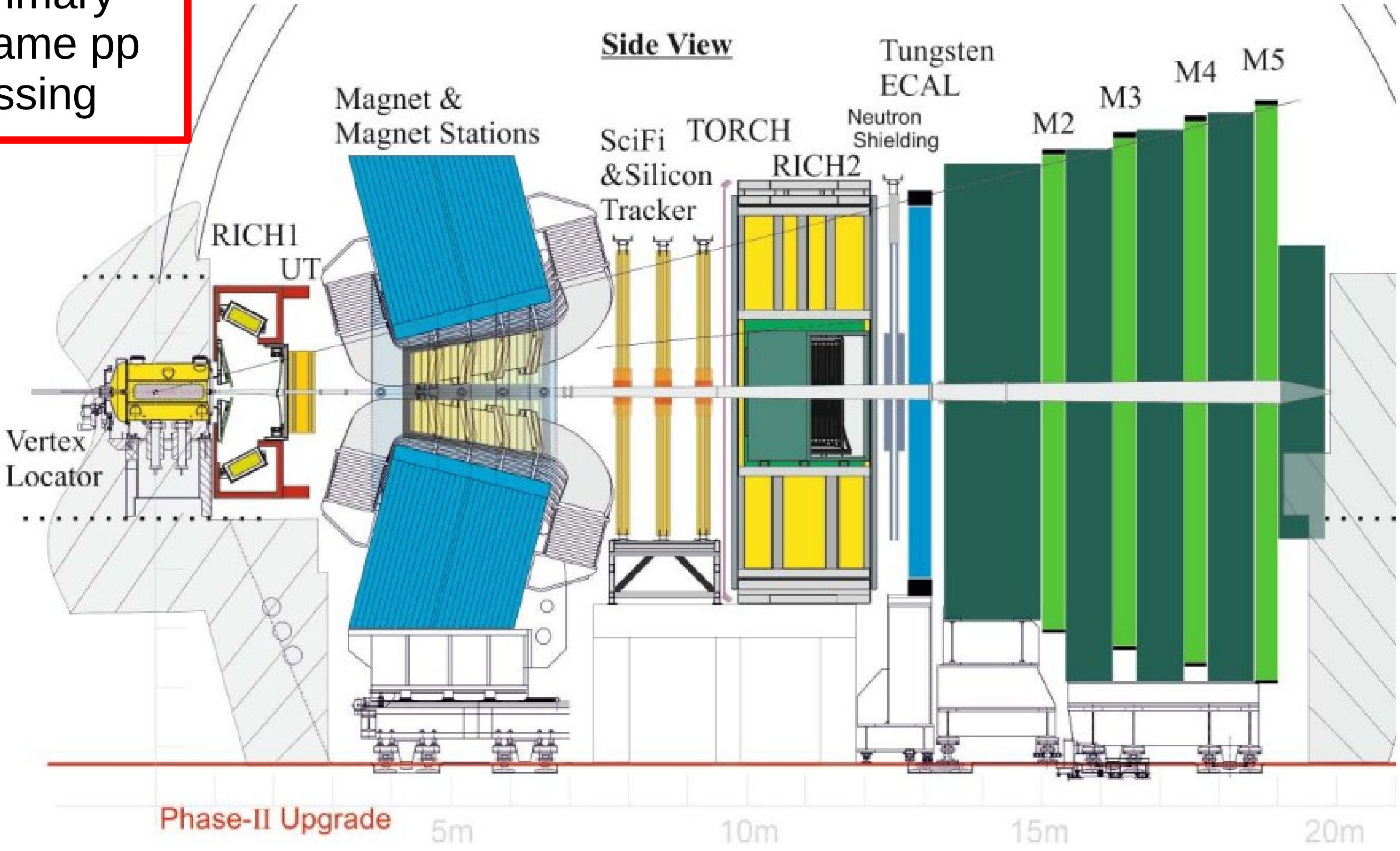


50 fb^{-1} design goal of Upgrade 1 will be achieved by LS4
Opportunity to design detector to increase sample to 300 fb^{-1} or more
Only way to achieve ESPPU goal of full HL-LHC exploitation, including flavour physics

Crucial to use precision timing information to separate primary vertices in same pp bunch crossing

LHCb Upgrade II

CERN-LHCC-2017-003
CERN-LHCC-2021-012



LHCb Upgrade II

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CERN-LHCC-2021-012

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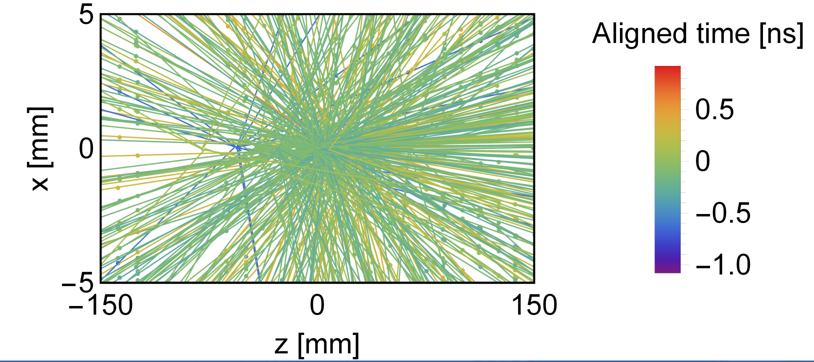
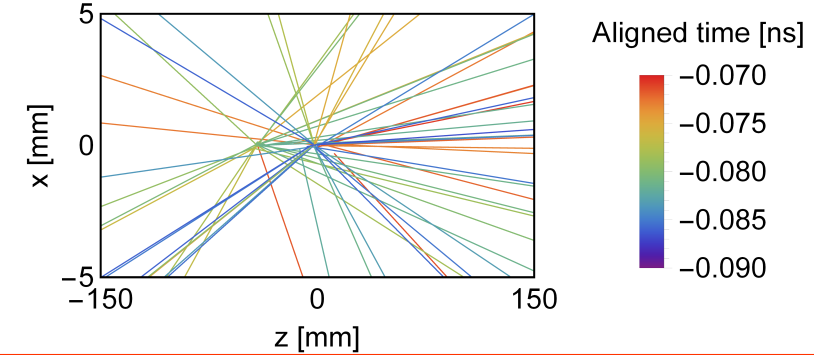
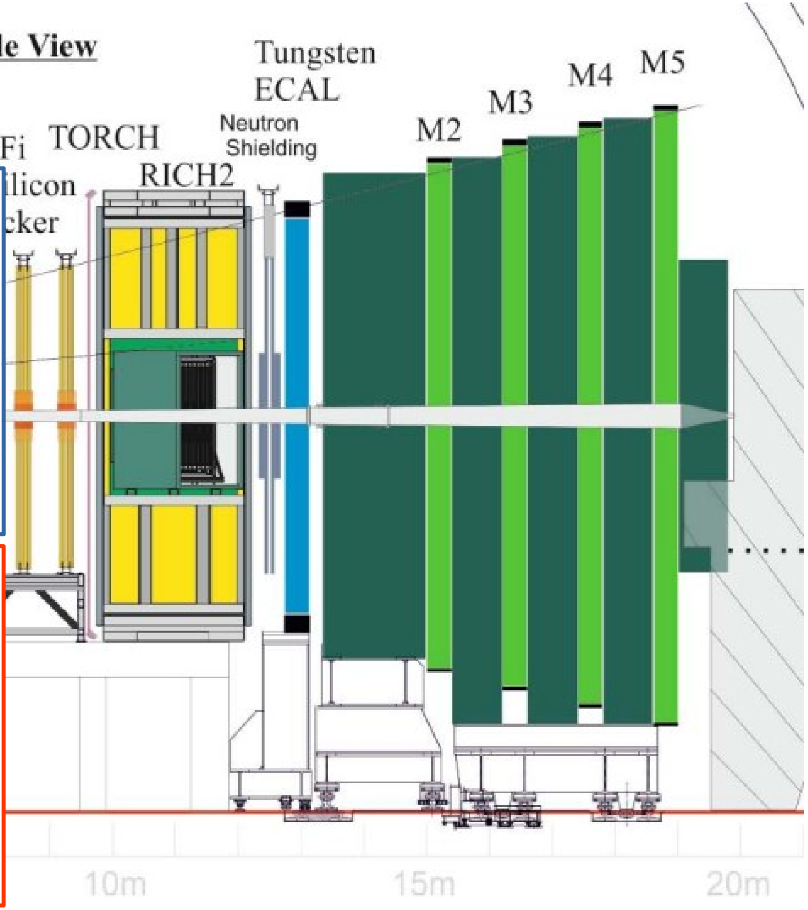
Require 20 ps window







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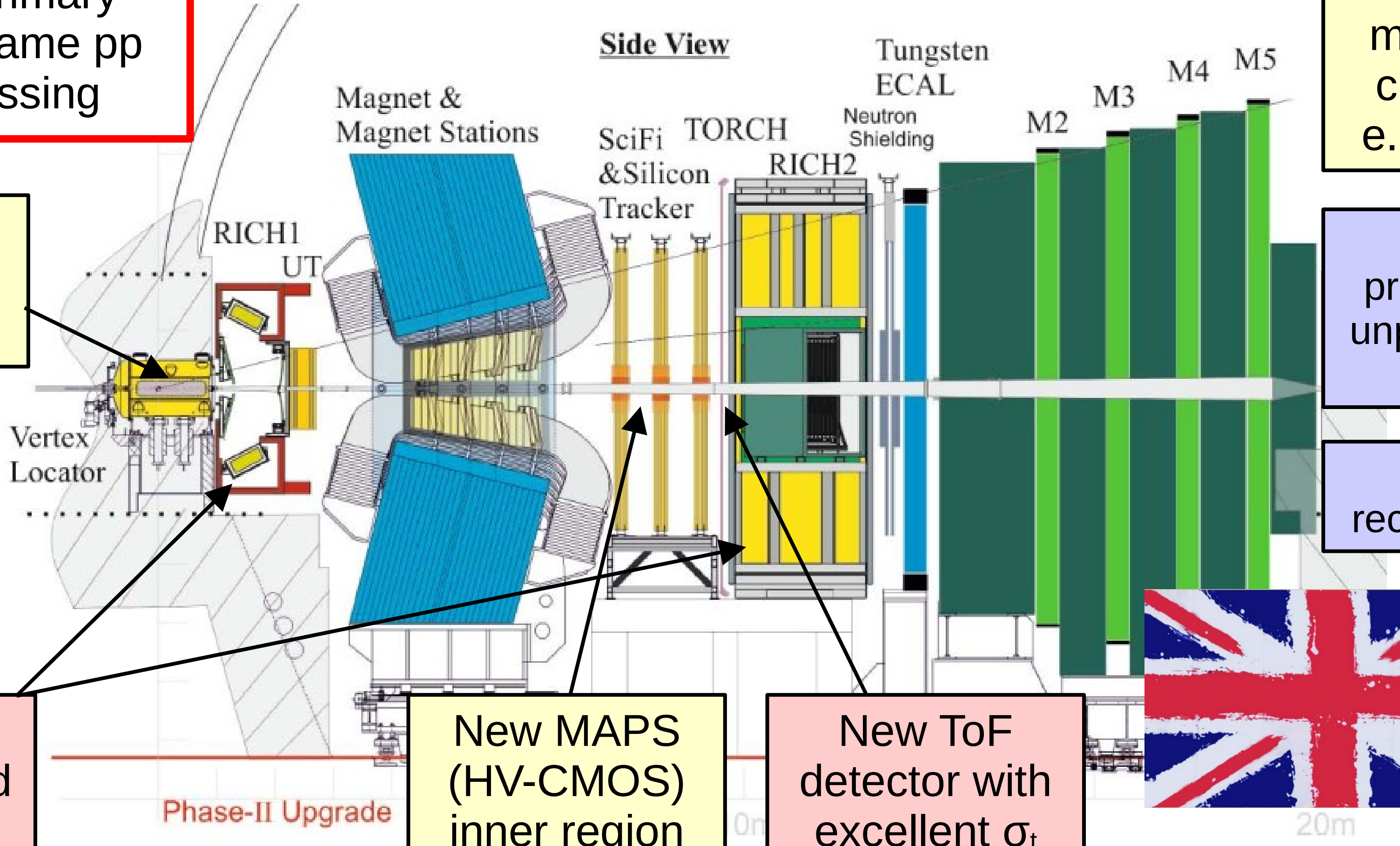


Rad. hard pixels with timing

All with mechanical challenges e.g. cooling

Data processing at unprecedented rates

Fast, 4D reconstruction

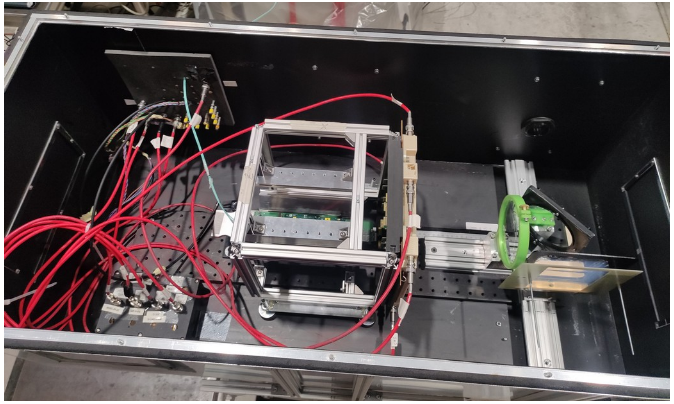
Fast photon detectors and electronics

New MAPS (HV-CMOS) inner region

New ToF detector with excellent σ_t

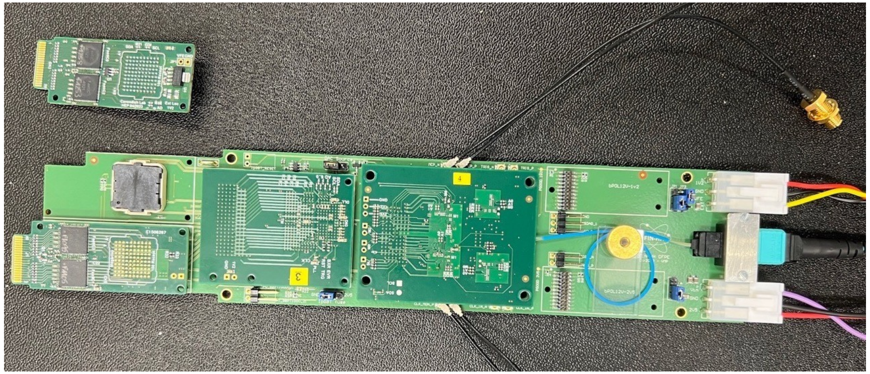
RICH

- Photon detectors
  - Testing LAPPD & SiPMs as candidates
    - Timing response, granularity, radiation hardness



Latest LAPPD workshop
https://indico.bnl.gov/event/18642/

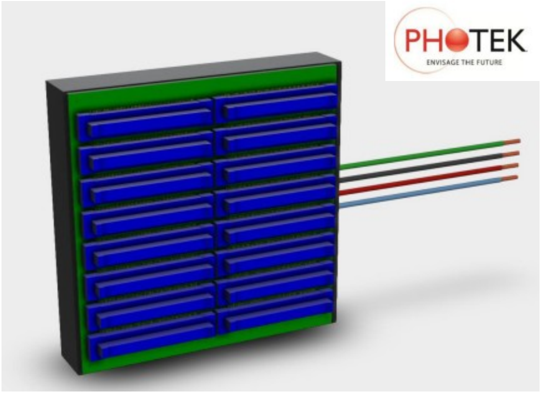
- Electronics
  - ASIC development: FastIC → FastRICH



- Mechanics
  - Cooling solutions
  - Minimising GWP risk
    - Leak-proof vessels, alternatives to high GWP radiator gases

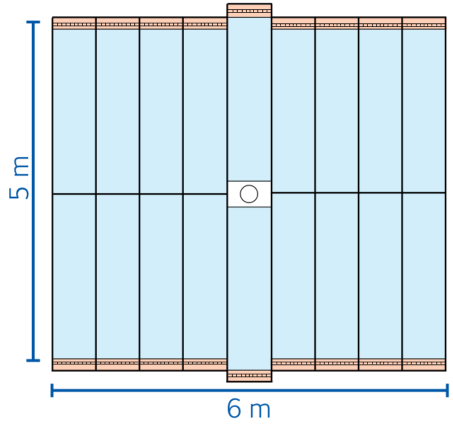
TORCH

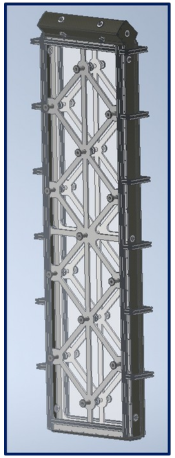
- Photon detectors
  - Developing next generation MCP-PMTs
    - Collaboration with Photek
  - SiPMs also an option for highest occupancy region



- Electronics
  - Synergy with RICH

- Mechanics
  - Carbon fibre support for large quartz plates

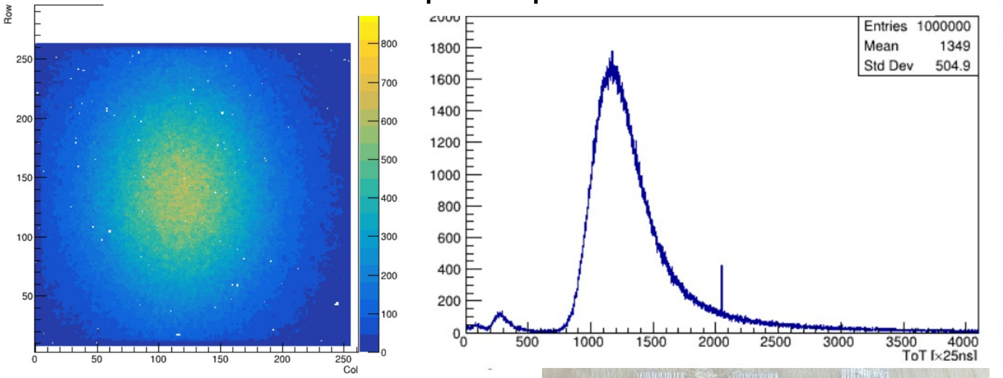


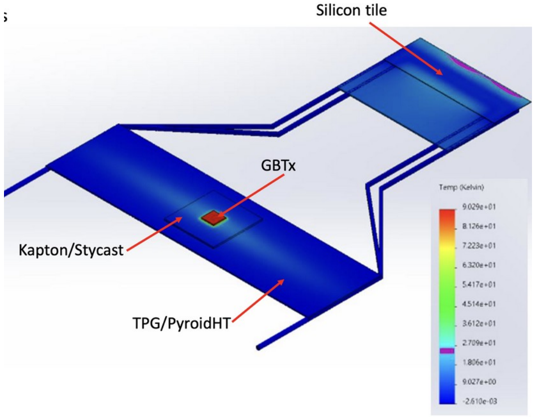


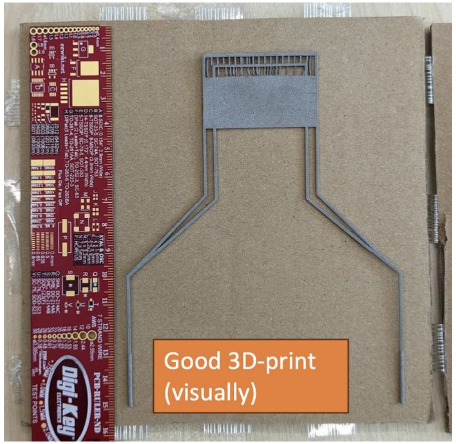
VELO

- Sensor
  - LGADs for testbeam telescope
- Data transfer
  - Silicon photonics
- Substrate
  - Developing additive manufacturing process
    - Collaboration with Royce institute (Sheffield)
- RF shield
  - Ultra-thin low-Z composite solution

ILGAD on Timepix4 operated in testbeam







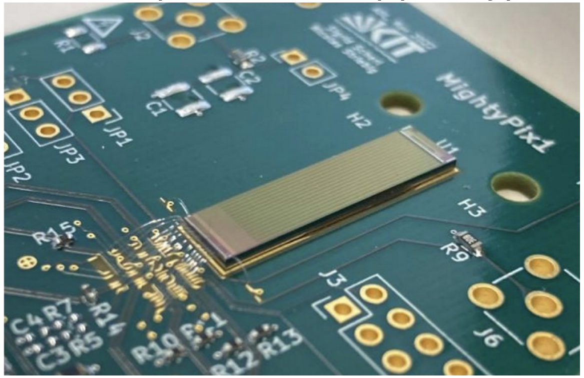
Mighty Tracker

- MightyPix chip
  - evolution of ATLASpix & mupix
  - LHCb compatibility & characterisation

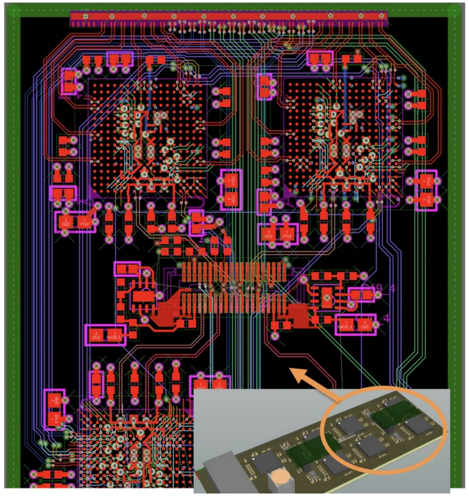
- Electronics & data transfer
  - on & off-module

- Module assembly
  - Cooling challenge

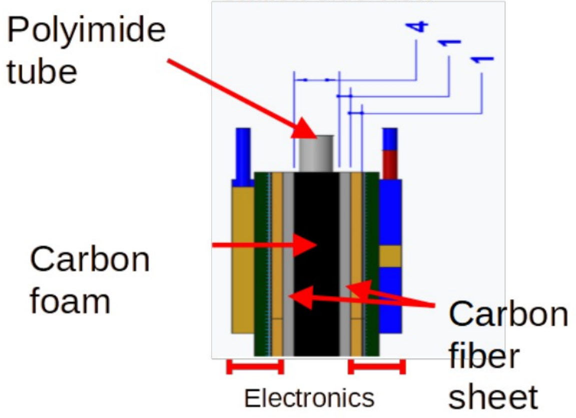
¼ size (0.5 cm x 2 cm) prototype



Design of off-chip module electronics
with multi-layer PCB layout



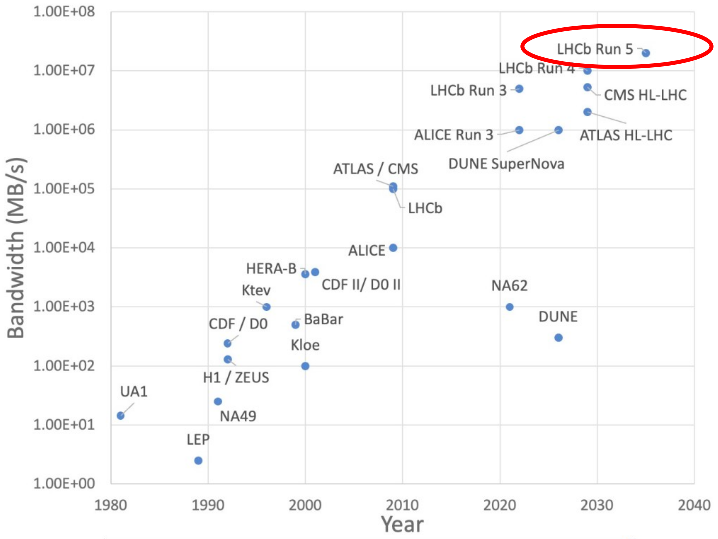
station side view

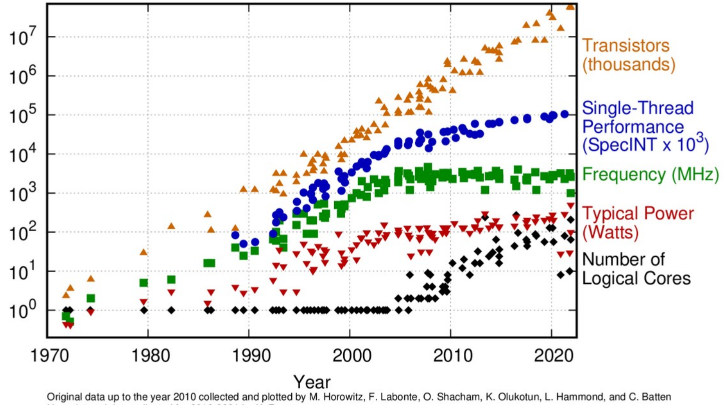


Data processing

- LHCb data processing scheme must continue to evolve to cope with Upgrade II data rates
  - More complicated events, including timing information
  - Develop algorithms to best exploit most suitable computing architectures
    - Run 3 HLT1 tracking on GPUs; VELO clustering on FPGAs
    - Extend to PID, HLT2 … investigate other accelerators (IPUs)

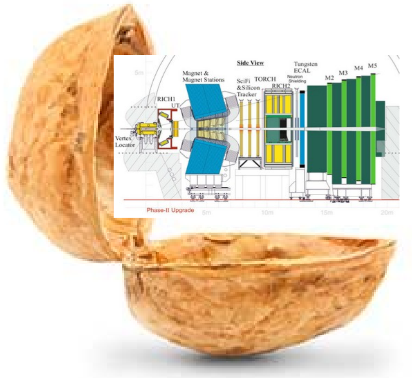
- Similar evolution of simulation required
  - Use of heterogeneous architectures & accelerators
  - Full simulation + fast (parametrised) simulation
  - Avoid potential bottlenecks to physics output





Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2021 by K. Rupp

LHCb Upgrade 2 in a nutshell



- Unique science programme with BSM discovery potential
  - Unprecedented sensitivity for B & D physics
  - Broad (general purpose) programme
    - Unique forward acceptance
    - spectroscopy, EW precision measurements, top quark and Higgs physics, dark sector, heavy ions and fixed target physics ...
  - Beyond √N scaling with new subdetectors and reconstruction techniques
- Exciting technology roadmap
  - high granularity, fast timing, extreme radiation hardness
  - developments with impact both inside and outside of HEP
    - relevant for many future experiments, and possible DRD collaborations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back [redacted]
[redacted] up
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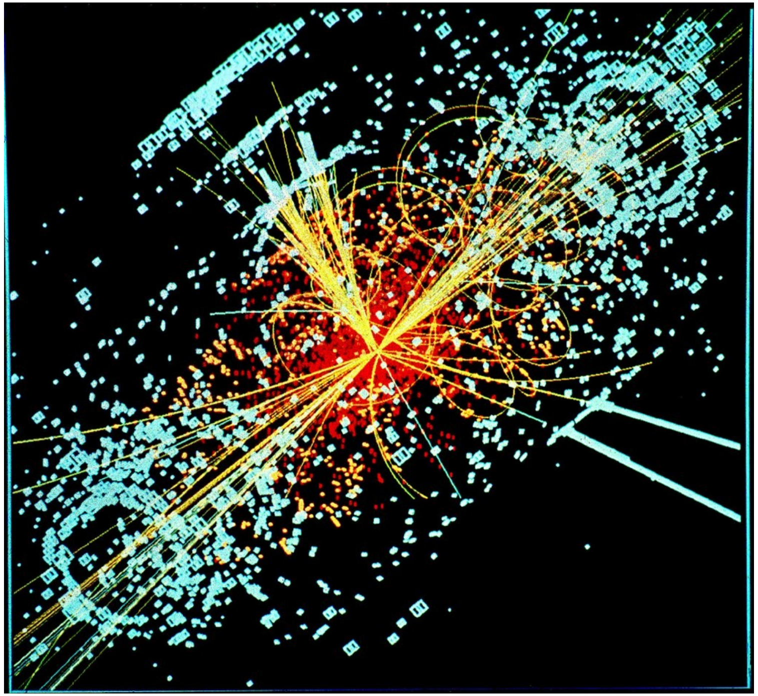
LHCb Upgrade II Science Case



Two main ways to search for physics beyond the Standard Model at the LHC

1) Look for new heavy particles produced “on-shell”
   - Produced centrally → ATLAS & CMS
   - Limited by available collision energy

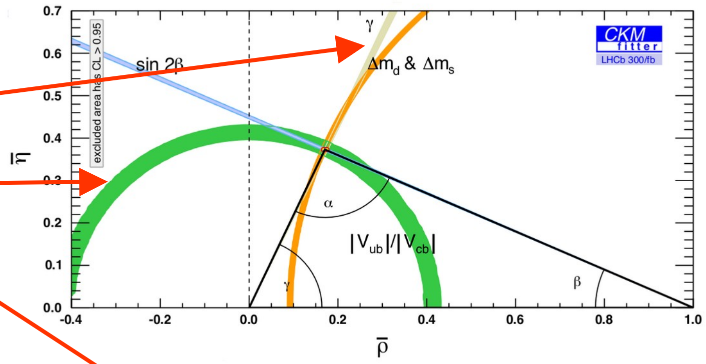
2) Look for influence of off-shell particles in loop processes
   - Exploit copious production of beauty and charm hadrons in forward acceptance → LHCb
   - Limited by precision, i.e. by available sample size
   - Sensitive to very high energy scales

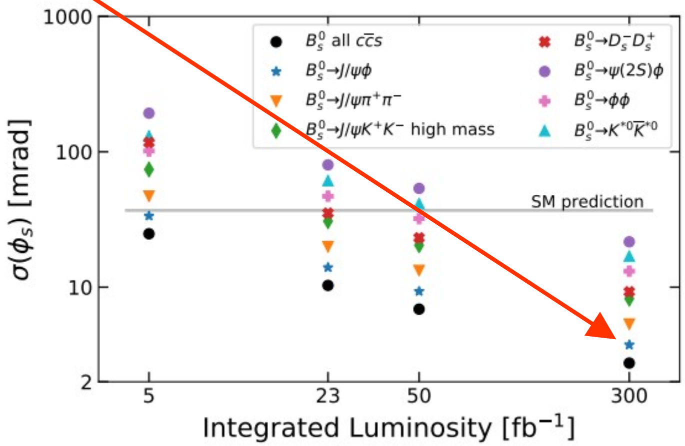
CERN-LHCC-2018-027
CERN-LHCC-2021-012

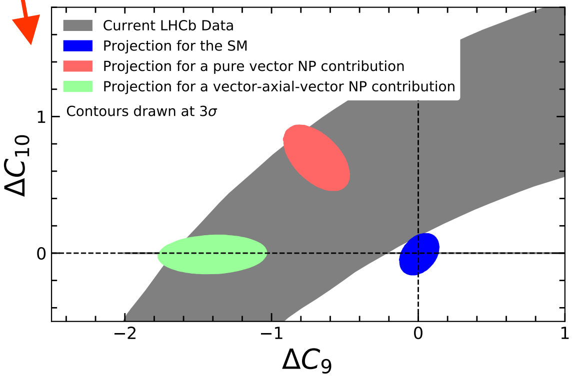
LHCb Upgrade II Science Case

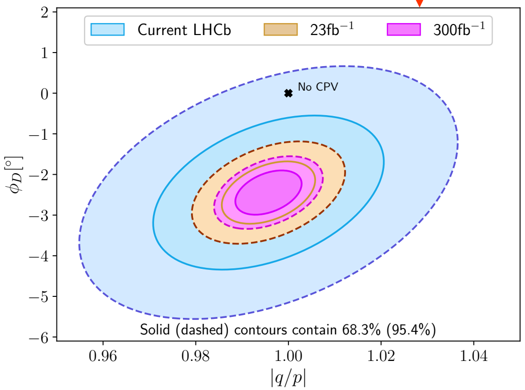
some “Current LHCb” numbers out-of-date

Observable	Current LHCb (up to 9 fb^{-1})	Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests				
γ ($B \to DK$, *etc.*)	4° [10, 11]	1.5°	1°	0.35°
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad [12]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6% [13, 14]	3%	2%	1%
Charm				
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5} [7]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5} [15]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5} [8]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays and Lepton Universality Tests				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69% [16, 17]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—	—	—	0.2
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044 [18]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12 [19]	0.034	0.022	0.009









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LHCb Upgrade II Science Case

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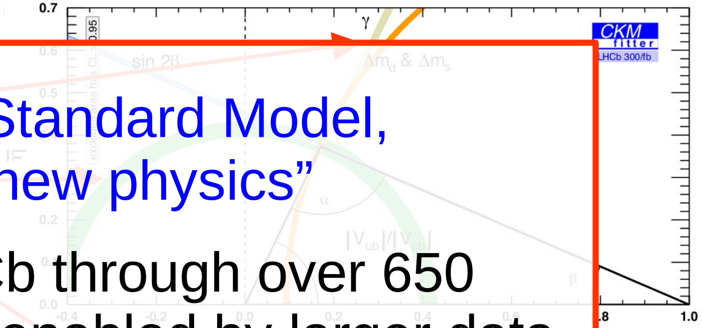
Observable	Current LHCb	Upgrade I	Upgrade II



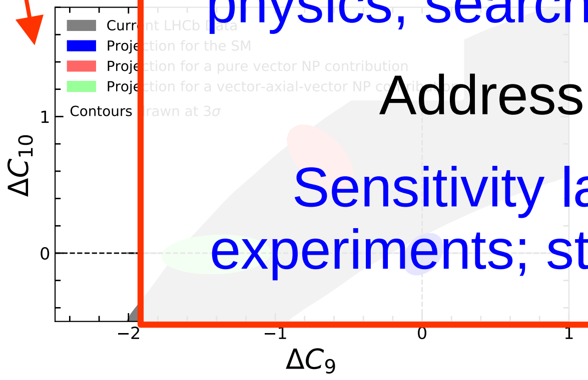
A huge range of precise tests of the Standard Model, with unique potential to discover “new physics”

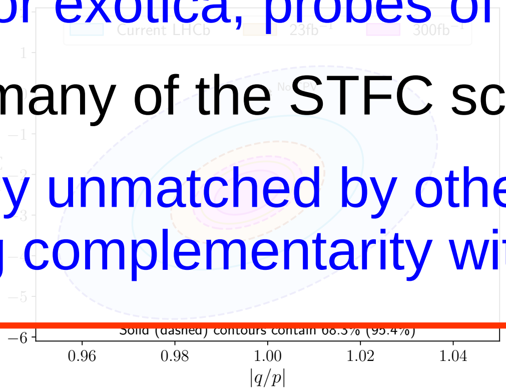
Builds on programme developed by LHCb through over 650 publications to date, with new opportunities enabled by larger data sample and new/improved detection capability

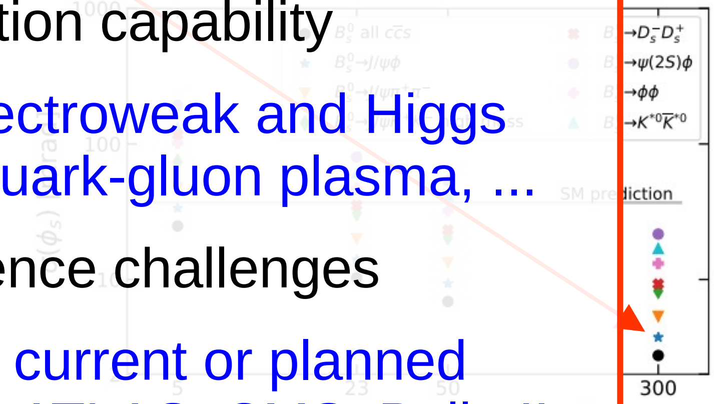
Includes hadron spectroscopy, QCD, electroweak and Higgs physics, searches for exotica, probes of quark-gluon plasma, ...

Addressing many of the STFC science challenges

Sensitivity largely unmatched by other current or planned experiments; strong complementarity with ATLAS, CMS, Belle II







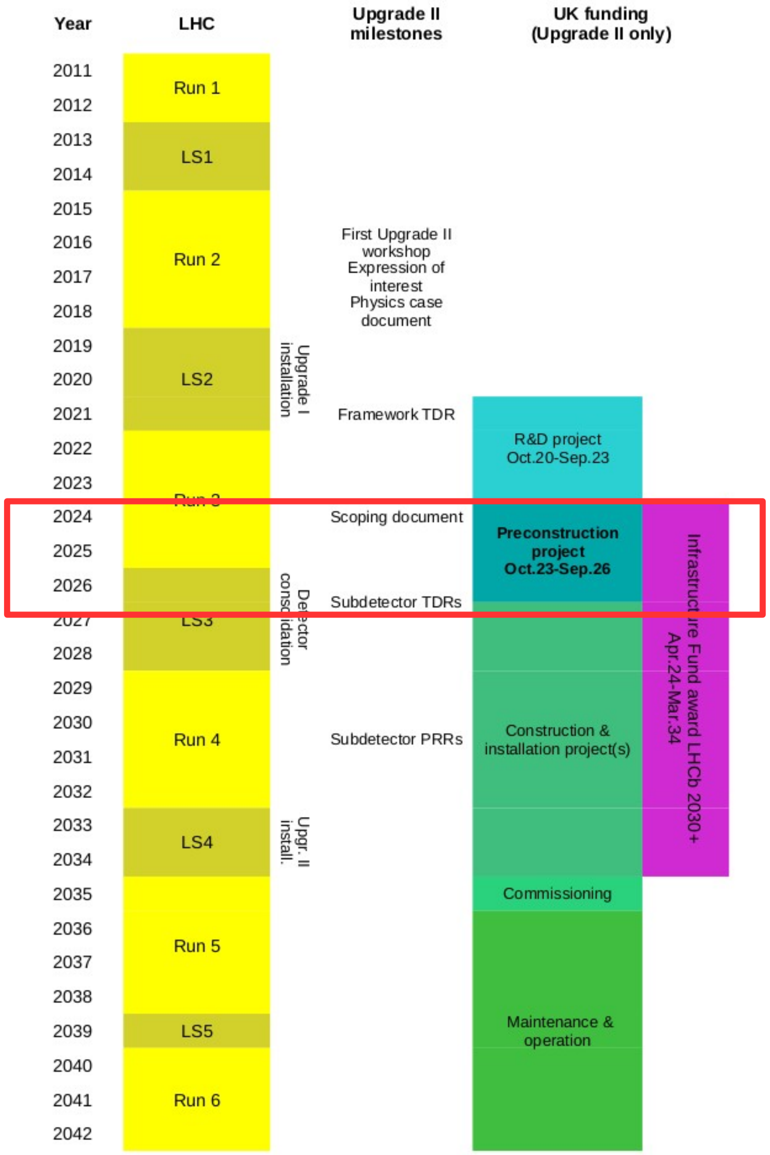
Timeline and UK context

International

- CERN approval processes being established by RRB & LHCC (CERN-LHCC-2022-012, in preparation)
- First step:
  - Framework TDR (2021) + Scoping document (2024)
- Second step:
  - Subdetector TDRs (2026/7)

UK

- Initial R&D project 2020-~~23~~24
- Preconstruction phase 20~~23~~24-26
- UKRI Infrastructure Fund award (LHCb 2030+)
  - Full business case approval expected after Scoping Document



Impact – economic

Strategic technologies:
- ultra-fast detectors
- CMOS technology
- Si photodetectors
- data chain, ...

TORCH detector R&D has already brought a new product to market

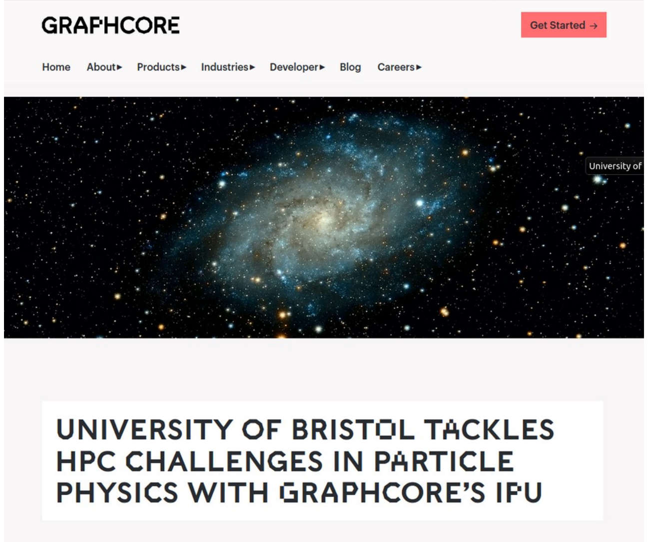

PHOTEK
ENVISAGE THE FUTURE

PCS-256

Multi-Channel Photon Counting System

AuraTek™
DISCOVERY AT THE SPEED OF LIGHT

The AuraTek PCS-256 is an innovative, photon counting system that combines a Multi-Anode MCP-PMT with the high performance TOFPET readout electronics. The easy-to-use system contains 256 independent, high performance photon counting channels, each having a time stamp with 44 ps resolution and timing performance of < 100 ps rms after amplitude walk correction. The system is self-triggering and event driven, with time and amplitude data provide for each photon detected. The maximum count rate for each channel is 160 kcps, with a maximum total system count rate of about 10 Mcps. An optional user provided event identifier can be time stamped and included in the data stream by replacing one of the 256 anodes with an external input. The 160 MHz



Collaboration with industry on novel MIMD architecture

Strong engagement with DRD activities
at UK and European levels