LHCb Upgrade II

Original	2009-2018
Upgrade I	2022-2032
Upgrade II	2033-

18th November 2022, ECFA

Chris Parkes

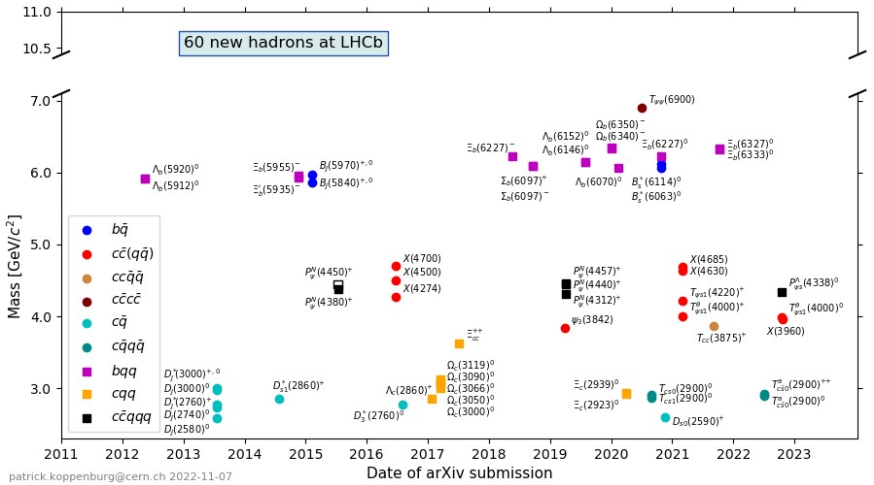
On behalf of the LHCb Collaboration

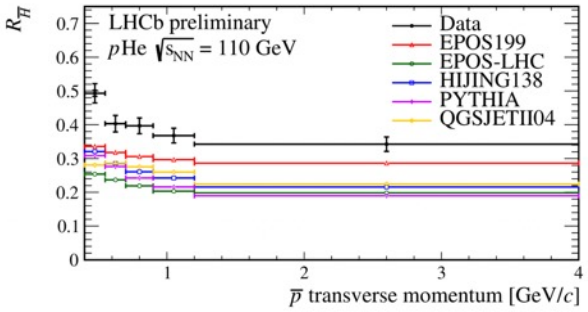
LHCb – Flavour & beyond

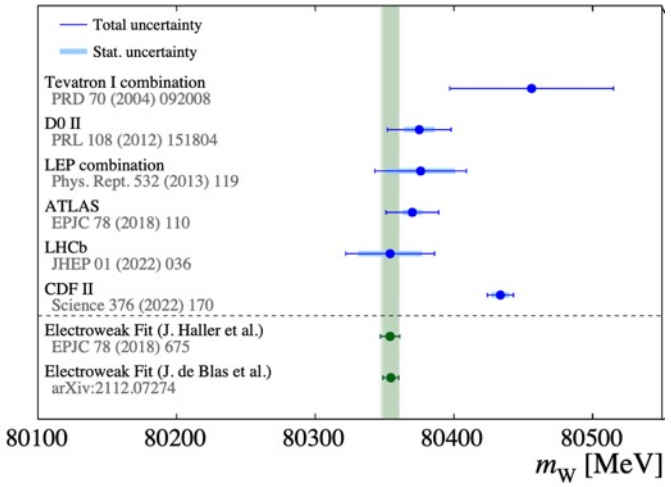
Original 2009-2018

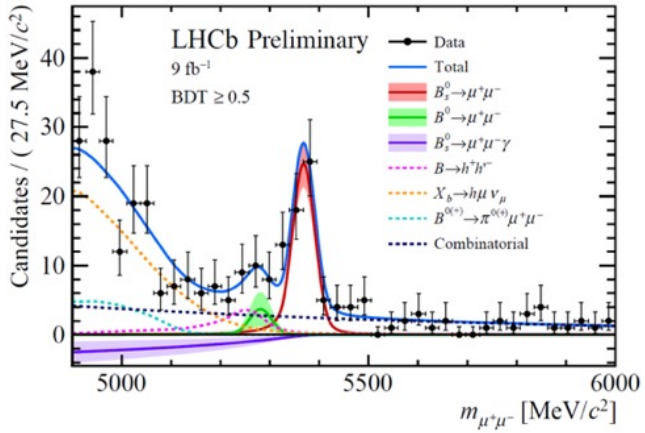
- **Future plans build on the success of the experiment during Run 1 & 2**

- > 600 physics papers (most per author of any LHC experiment)
- Series of significant discoveries
  - Rare decays
  - Matter anti-matter differences in three new systems
  - 60 of the 68 hadronic particles discovered at the LHC
- Breadth of physics programme
  - World leading experiment in core field
  - But also leading or unique far beyond
    - Heavy ions
    - Fixed Target
    - Electroweak
    - Dark Sector



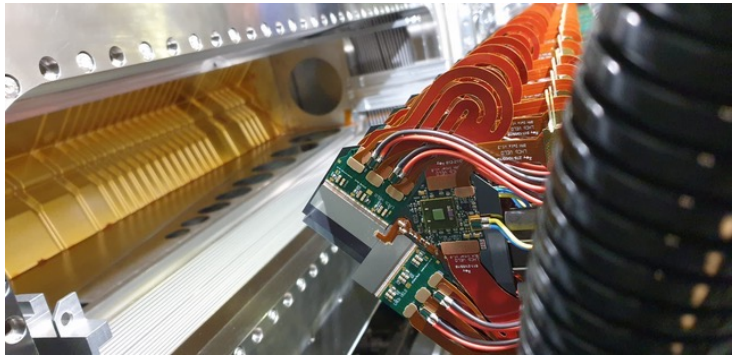


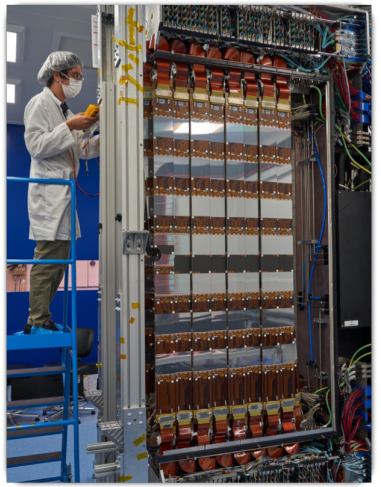


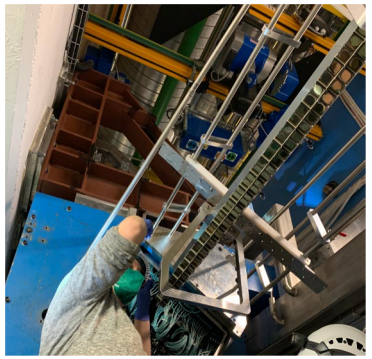


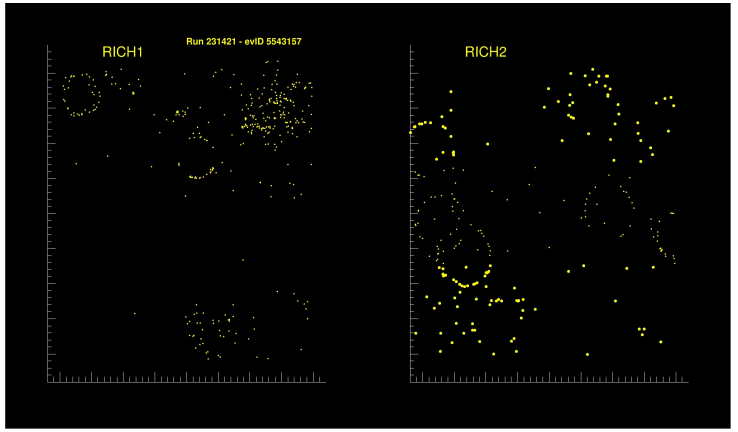
Upgrade I: major project

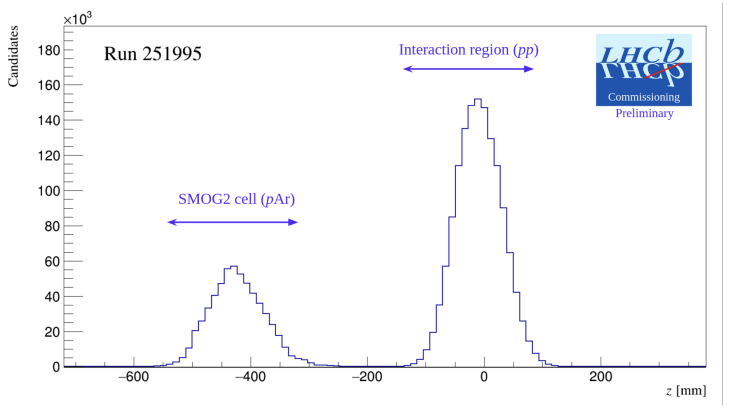
- Major project achieved **on budget**
- Commissioning of detector proceeding well

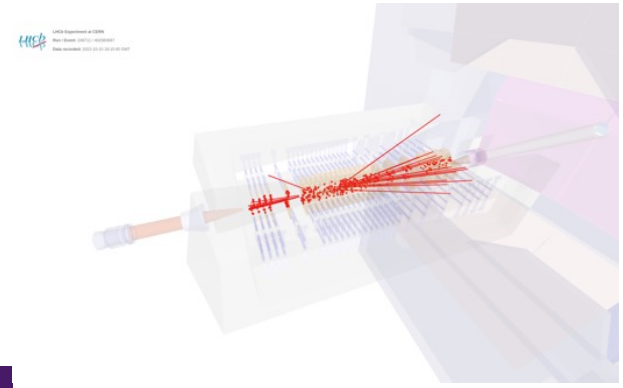






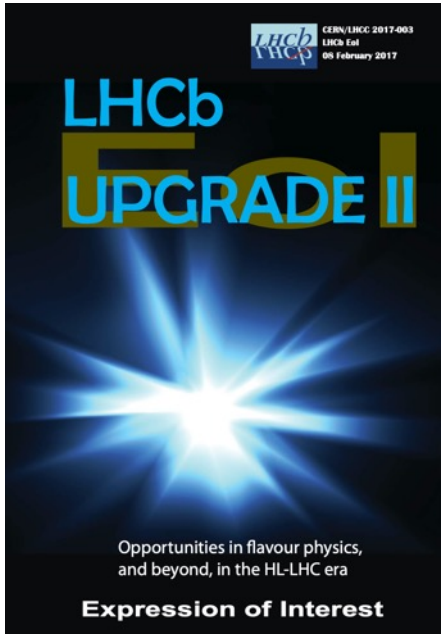






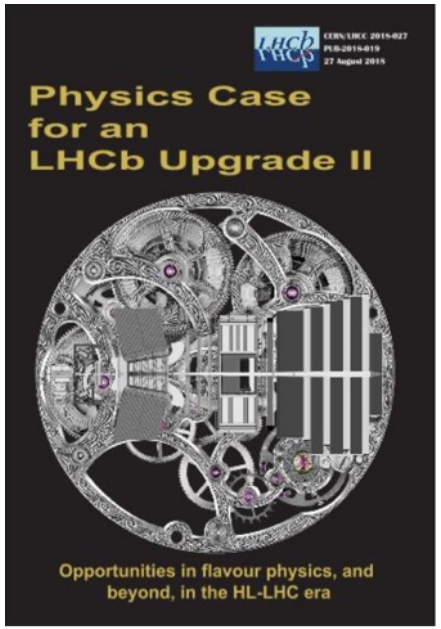
Upgrade II: approval steps so far

Expression of Interest



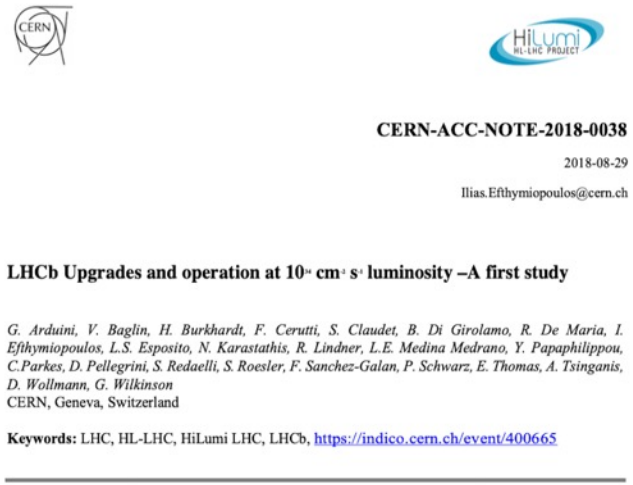
LHCC-2017-003

Physics case



LHCC-2018-027

Accelerator study



CERN-ACC-NOTE-2018-0038

2018-08-29

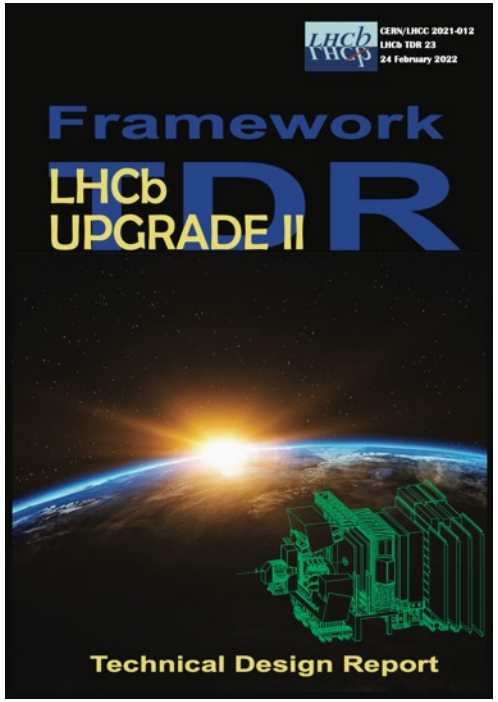
Ilias.Efthymiopoulos@cern.ch

LHCb Upgrades and operation at 10^{34} cm^{-2} s^{-1} luminosity –A first study

G. Arduini, V. Baglin, H. Burkhardt, F. Cerutti, S. Claudet, B. Di Girolamo, R. De Maria, I. Efthymiopoulos, L.S. Esposito, N. Karastathis, R. Lindner, L.E. Medina Medrano, Y. Papaphilippou, C.Parkes, D. Pellegrini, S. Redaelli, S. Roesler, F. Sanchez-Galan, P. Schwarz, E. Thomas, A. Tsinganis, D. Wollmann, G. Wilkinson
CERN, Geneva, Switzerland

Keywords: LHC, HL-LHC, HiLumi LHC, LHCb, https://indico.cern.ch/event/400665

CERN-ACC-2018-038



LHCC-2021-012

CERN Research Board September 2019

"The recommendation to prepare a framework TDR for the LHCb Upgrade-II was endorsed, noting that LHCb is expected to run throughout the HL-LHC era."

European Strategy Update 2020 ***"The full potential of the LHC and the HL-LHC, including the study of flavour physics, should be exploited"***

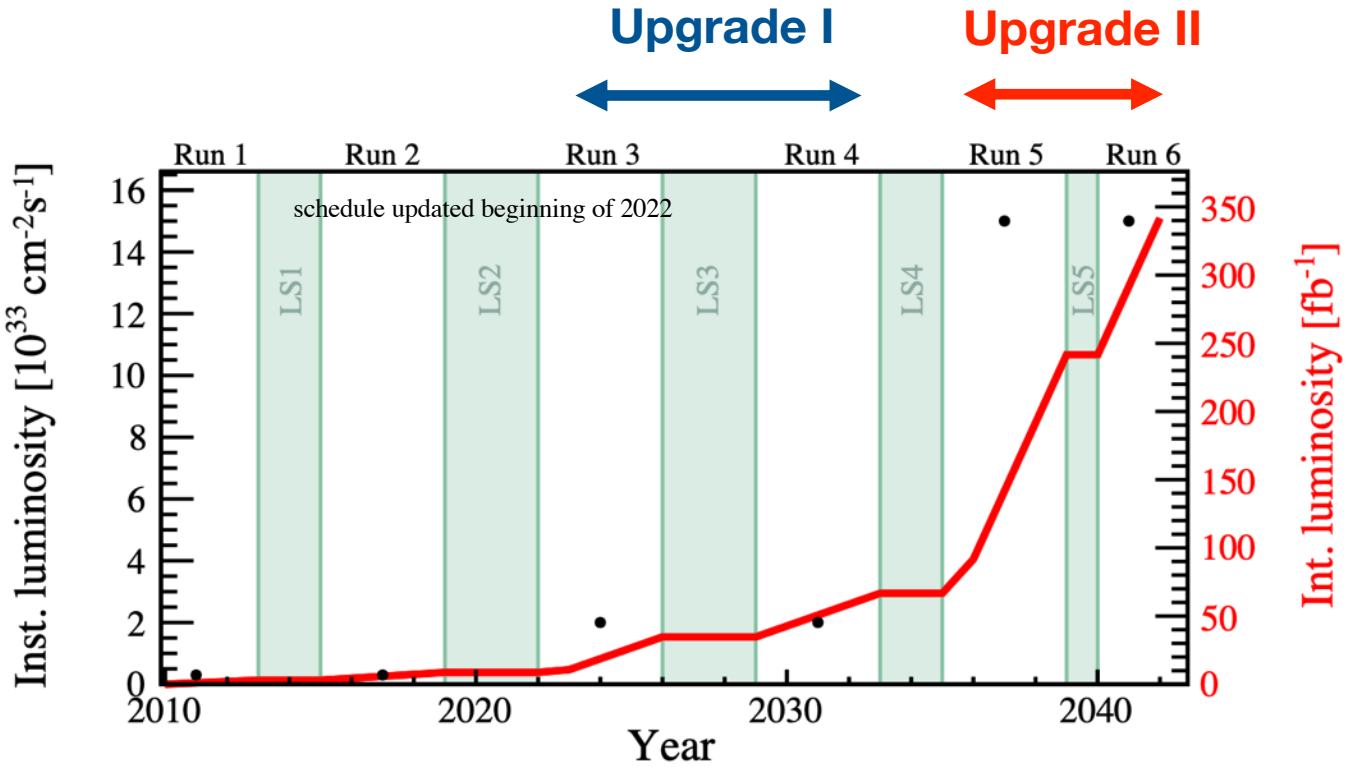
Approved March 2022 R&D programme, scoping document to be prepared followed by sub-system TDRs

LHCb Upgrades

- Physics programme limited by detector, NOT by LHC
- Hence, clear case for an ambitious plan of upgrades

Upgrade II

- *L_{peak} = 1.5x10^{34} cm^{-2} s^{-1}*
- *L_{int} = ~300 fb^{-1} during Run 5 & 6, Install in LS4 (2033)*
- *Some smaller detector consolidation and enhancements in LS3 (2026)*



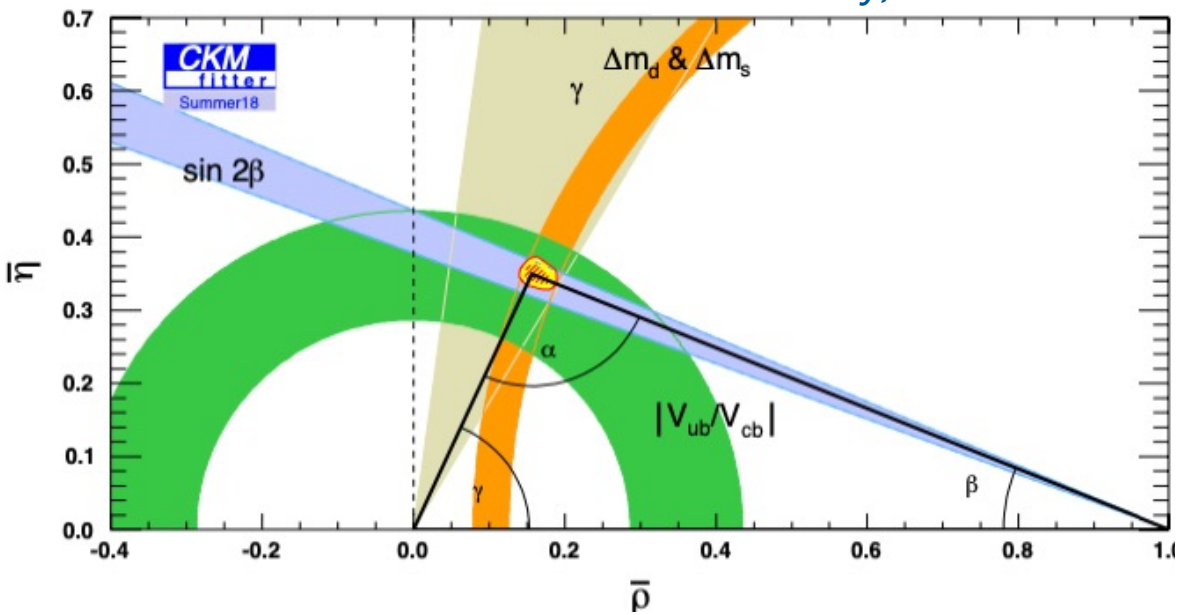
- *Potentially the only general purpose flavour physics facility in world on this timescale*

Flavour Physics at the LHC

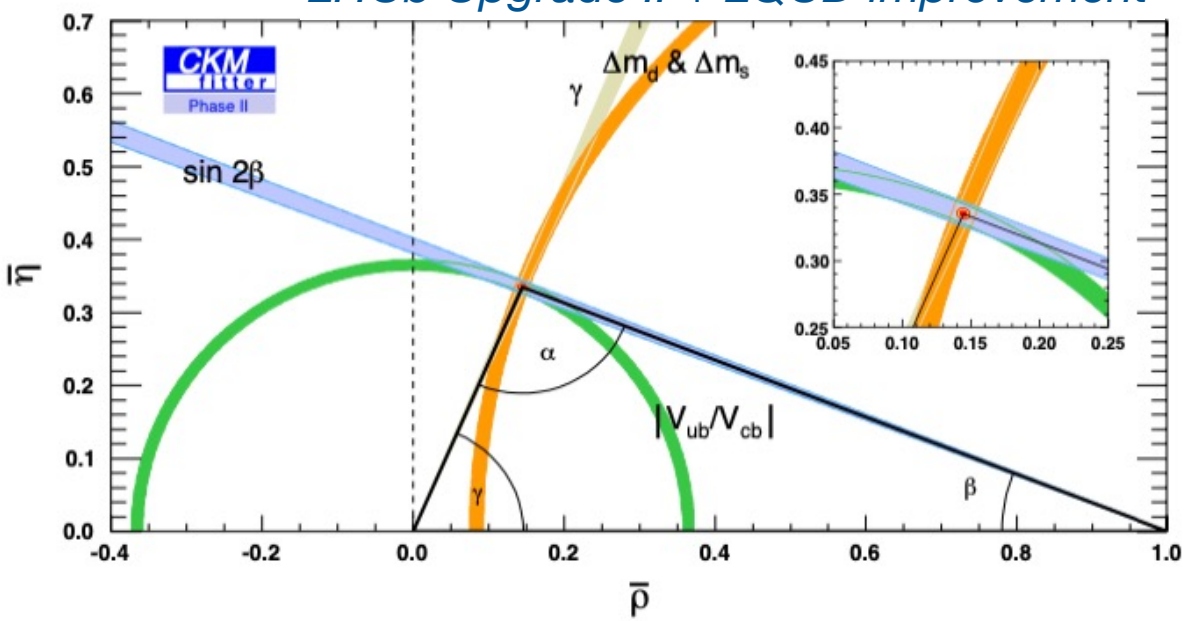
- Sensitivity to mass scales several orders of magnitude above those within reach of direct production measurements at the energy frontier
- Numerous key observables have negligible theoretical uncertainty

LHCb will test the CKM paradigm with unprecedented accuracy

LHCb only, end of 2018



LHCb Upgrade II + LQCD improvement

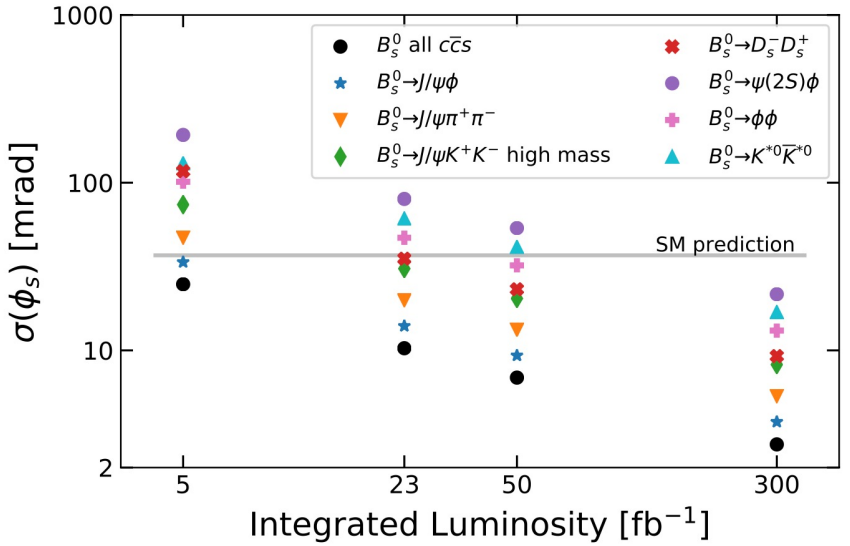


Arguably the greatest likelihood of a further paradigm shifting discovery at the HL-LHC lies with flavour physics

Potential observations

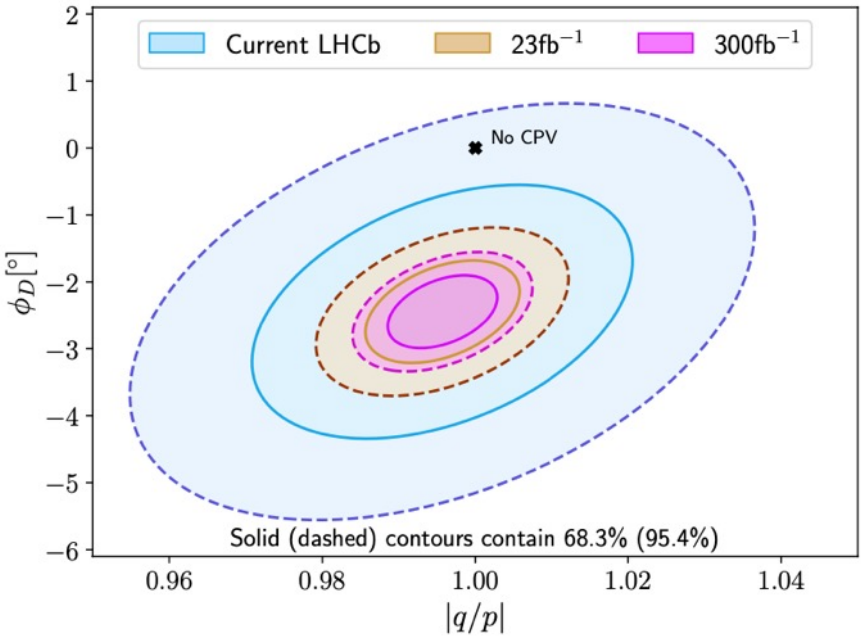
CP violating phase ϕ_s

- Sensitive to new physics – small and well predicted in SM
- Upgrade II sensitivity below SM prediction in multiple channels



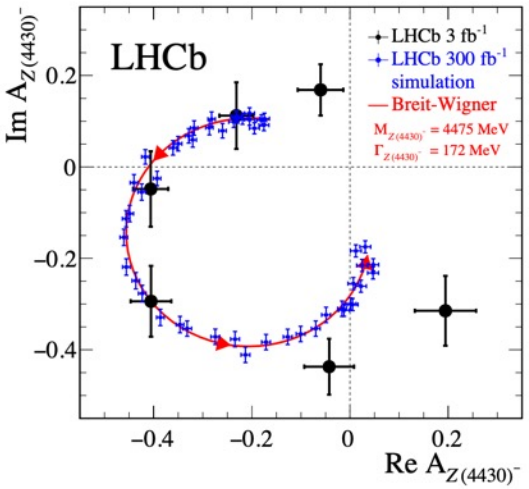
CP violation in charm

- LHCb Upgrade II is the only planned facility with a realistic possibility to observe particle anti-particle difference in charm mixing *(at >5σ if present central values are assumed)*



Further Opportunities

- Heavy Ion & Fixed Target Physics
  - General purpose heavy-ion experiment suitable for pA and AA in forward rapidity
  - e.g. pPb low-x regime beyond reach of electron ion collider
  - Particle identification key to heavy-ion programme
- Spectroscopy
  - Discovery of exotic hadrons opens new field
  - e.g. T_{cc}^{++} suggests could be long-lived exotic hadrons
  - Six-quark final states ?

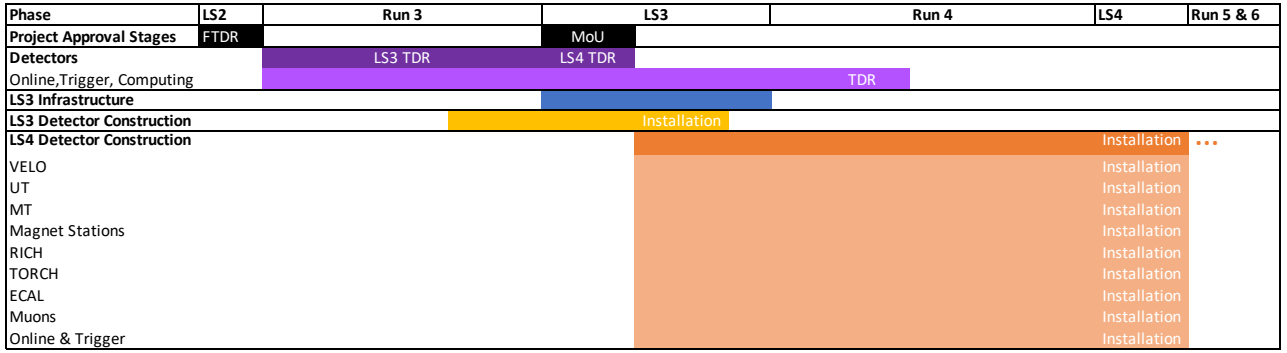


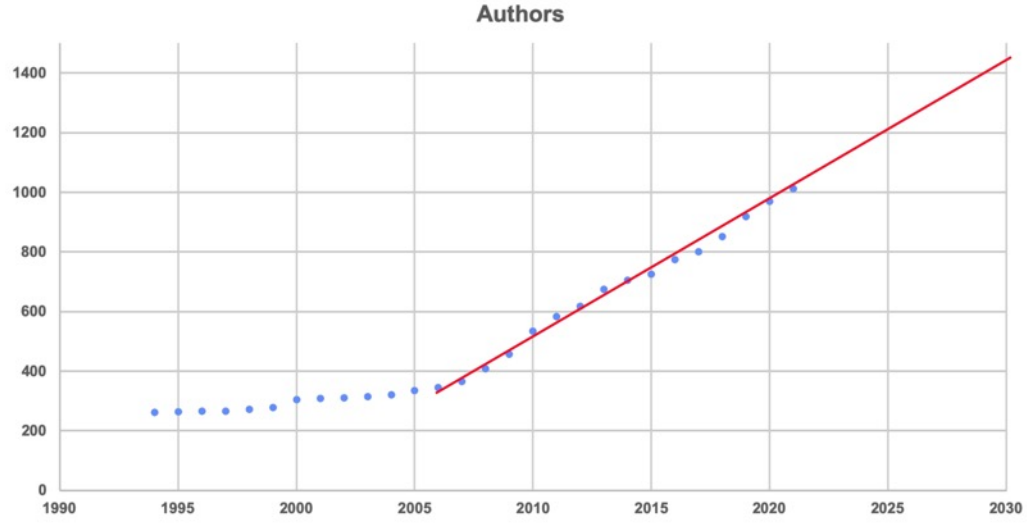
Topic	Comment
Spectroscopy	Enormous yields in gold-plated final states *e.g.* 4M $\Lambda_b^0 \to J\psi p K^-$ decays ('pentaquark' mode)
Higgs	Measure Higgs-charm Yukawa within factor 2 to 3 of SM value
$\sin^2\theta_W$	Uncertainty $< 10^{-4}$, better than LEP/SLD
Proton structure	Precision probes at extremely low and high Bjorken-x values, with $Q^2 > 10^5\,\mathrm{GeV}^2$
Hidden sector	Sensitivity to most of relevant parameter space for dark-photon models

Status and Stages in Process

- Support from full collaboration
- Process from FTDR to installation defined with LHCC
- R&D underway leading to subdetector TDRs
- Funding agency discussions underway One significant construction award and many R&D grants – including generic applications
- Expanding collaboration

Detector	Countries involved
VELO	BR, CERN, ES, FR, IT, NL, PL, RU, SE, UK
UT	CN, FR
Magnet Stations	PL, US
Mighty Tracker (SciFi + MAPS)	BR, CH, DE, ES, SE, UK
RICH	CERN, IT, PL, RO, SI, UK
TORCH	CERN, UK, SI
ECAL	AU, CERN, CN, ES, FR, HU, IT, RU, US
Muon	IT, RU
RTA	BR, CERN, CN, DE, ES, FR, IT, NL, PL, RU, UK, US
Online	CERN, FR



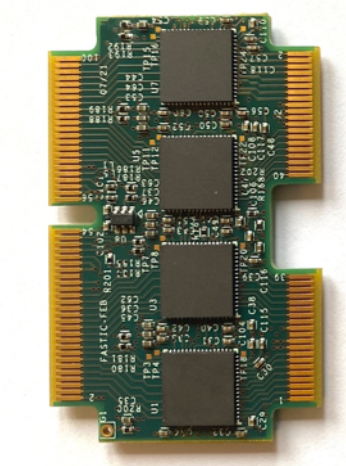


Opportunities for the detector at LS3

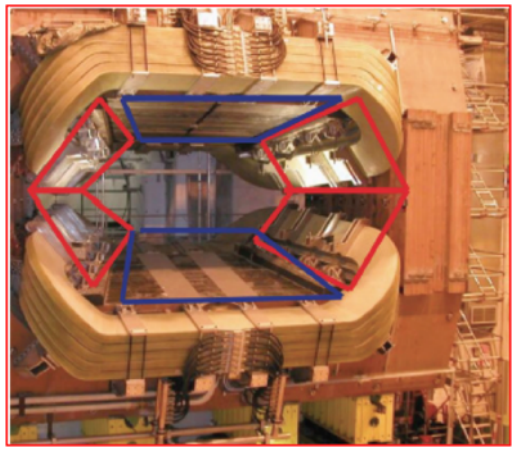
Modest consolidations with physics benefits already in Run 4 while preparing UII

driven by ageing
driven by technology
driven by physics

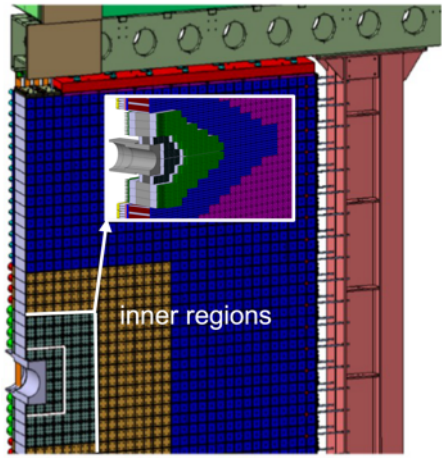
Detector	Proposal
SciFi consolidation	Replace inner modules (12X + 12stereo)
MAPS modules	2 layers, 1 m^2 each
Magnet Stations	full installation
RICH	new FEE electronics
ECAL	32+144 inner modules
RTA	Downstream tracking with FPGA



RICH electronics with timing



Magnet Stations



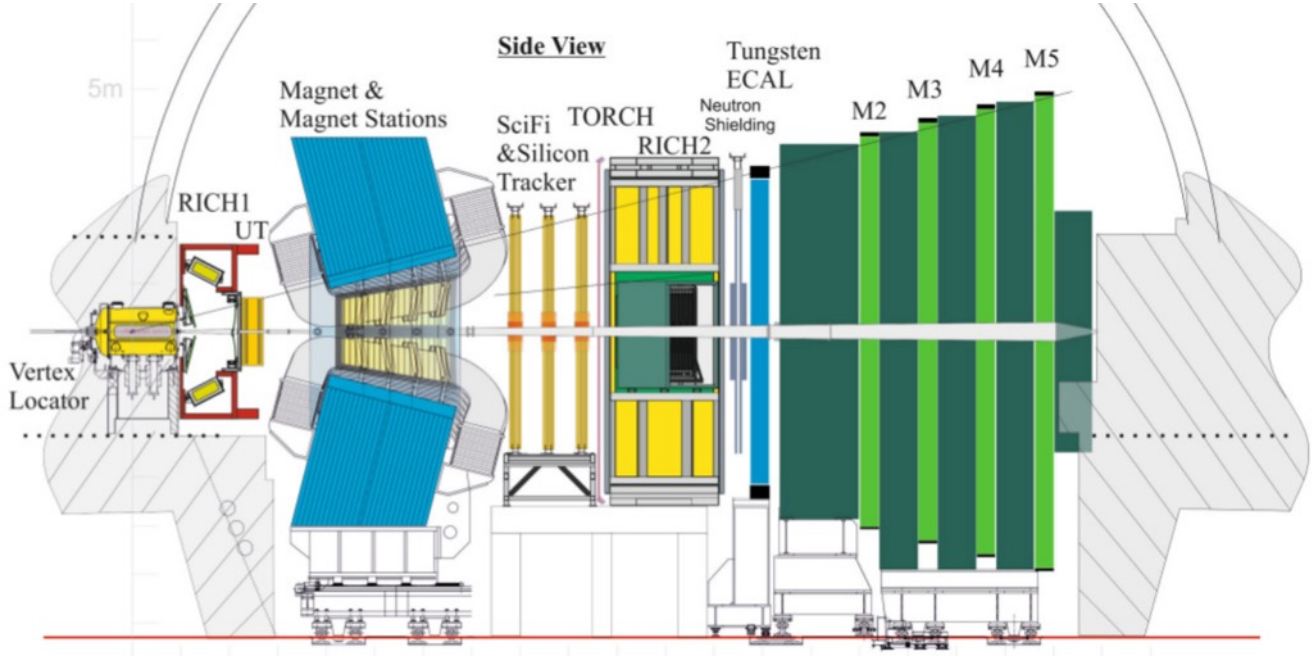
ECAL inner modules

- Consolidation & Upgrade II preparatory work
- Reused for Upgrade II
  - Costs accounted as part of Upgrade II for reused elements
- Proceed with LS3 TDRs before those for Upgrade II
  - Work already proceeding on some of these

Careful evaluation of what can be achieved on this timescale

The detector challenge & opportunity

Targeting same performance as in Run 3, but with pile-up ~40!



Same spectrometer footprint, innovative technology for detector and data processing

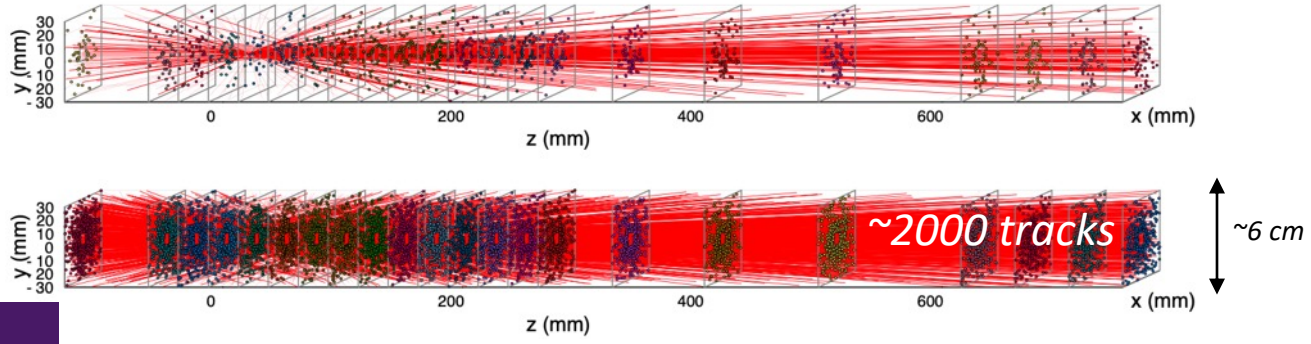
Key ingredients:

- granularity
- fast timing (few tens of ps)
- radiation hardness

VErtex LOcator (VELO)

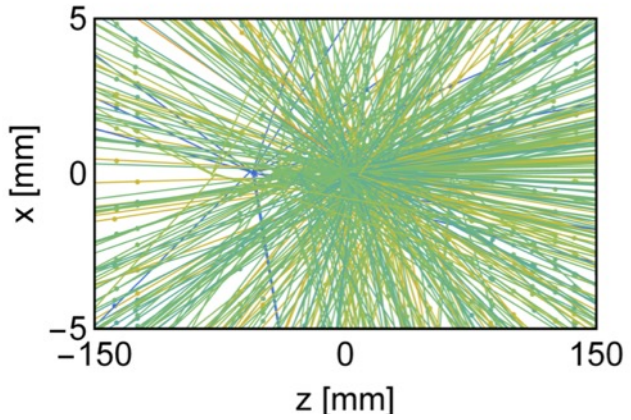
Run 3: pile-up ~6

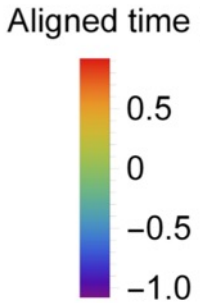
Upgrade II: pile-up ~42



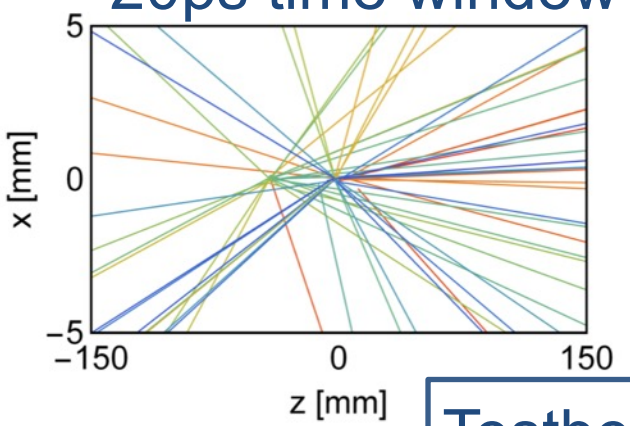
4D Vertexing: Extra Dimension of Precision Timing

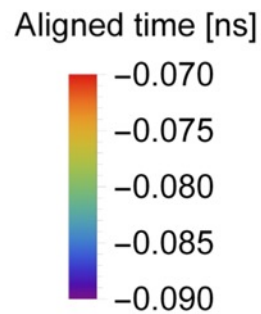
42 interactions

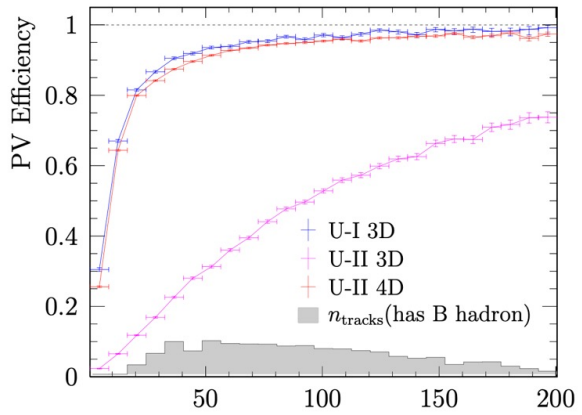




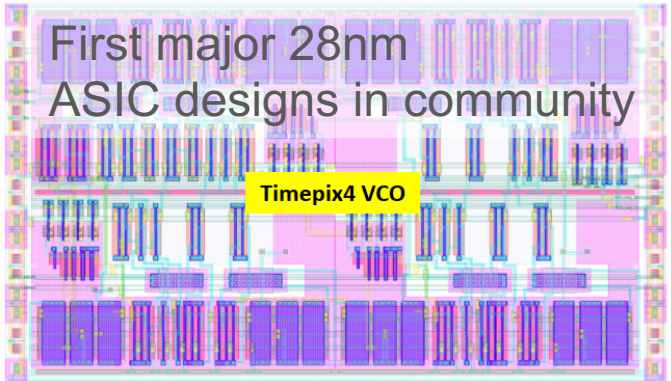
20ps time window



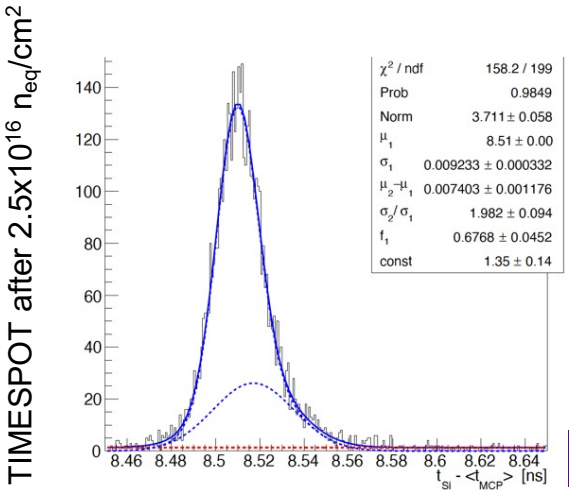




- **4D tracking**
- Ensures similar performance to Upgrade I
  - ~ 50ps, 50μm²
- Extreme lifetime fluence
  - $6\times10^{16} n_{eq}/cm^2$

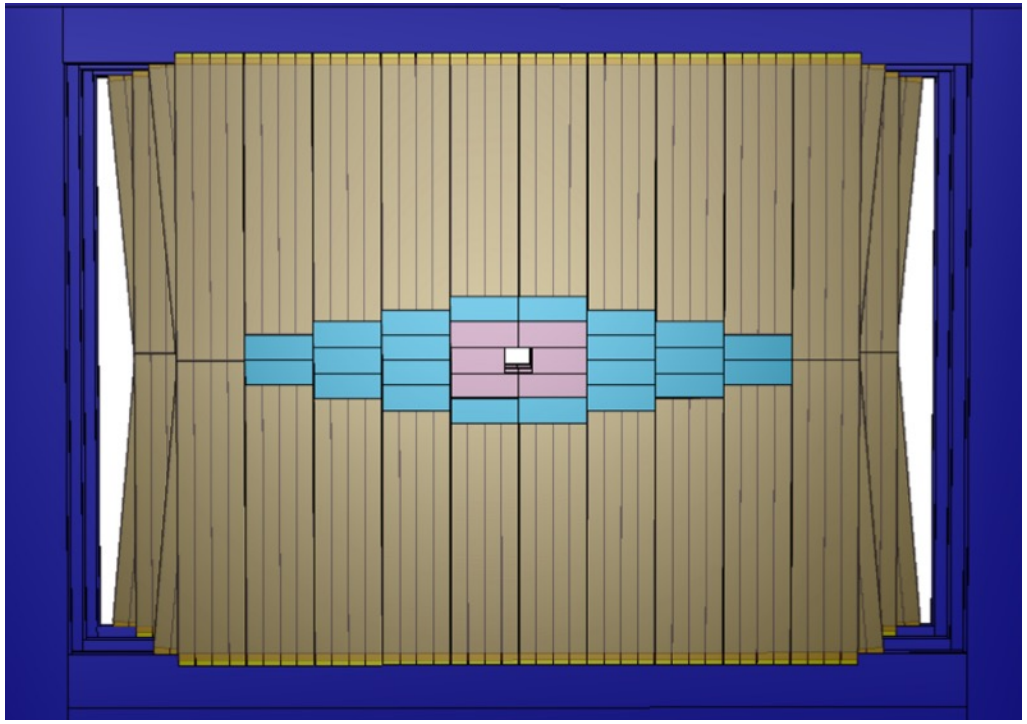


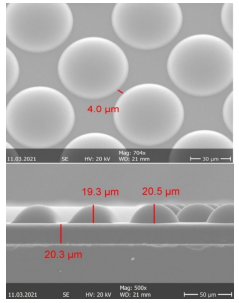
Testbeam
3D detectors, 15ps
LGAD & thin planar also studied

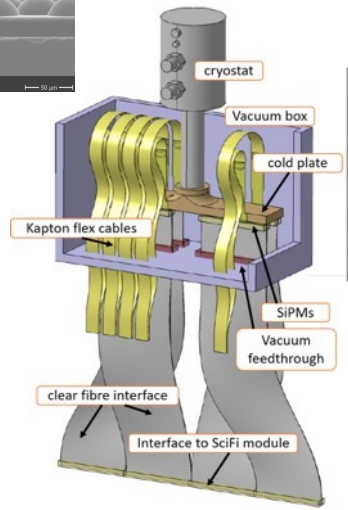


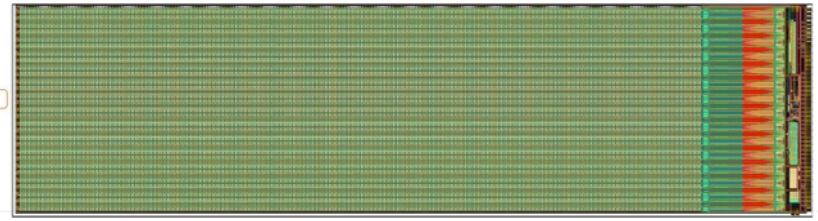
Tracker: Rad Hard DMAPs, first of kind at LHC

- Monolithic Active Pixel Sensors in the inner region ($50\times150\mu m^2$)
  - Radiation requirements in UT $3\times10^{15}n_{eq}/cm^2$
  - low-cost commercial process, low material budget
- Scintillating fibres in the outer region
  - radiation-hard fibres, cryogenic cooling, micro-lens enhanced SiPMs





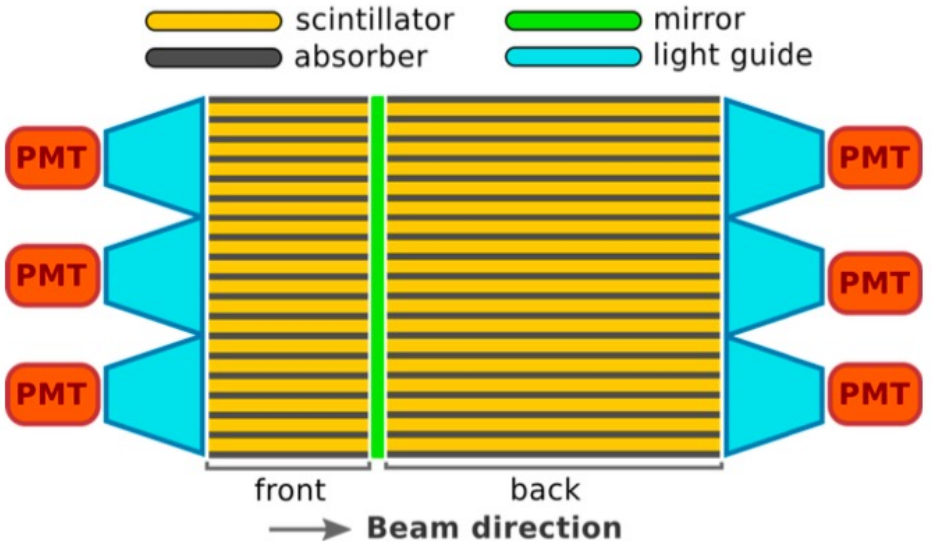


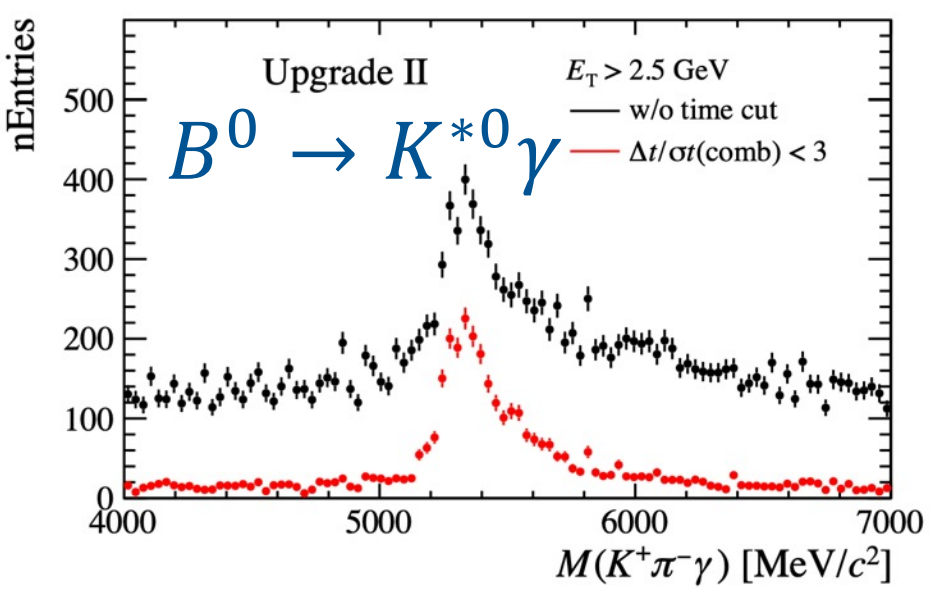


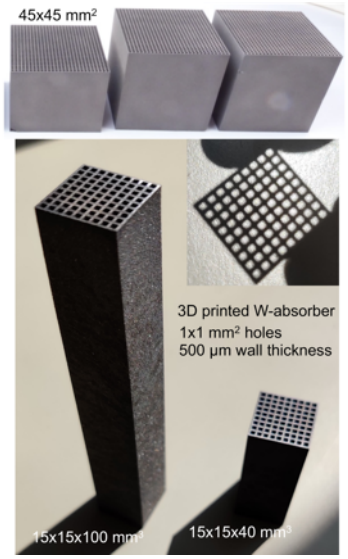
MightyPix1 1/4 scale chip in fabrication

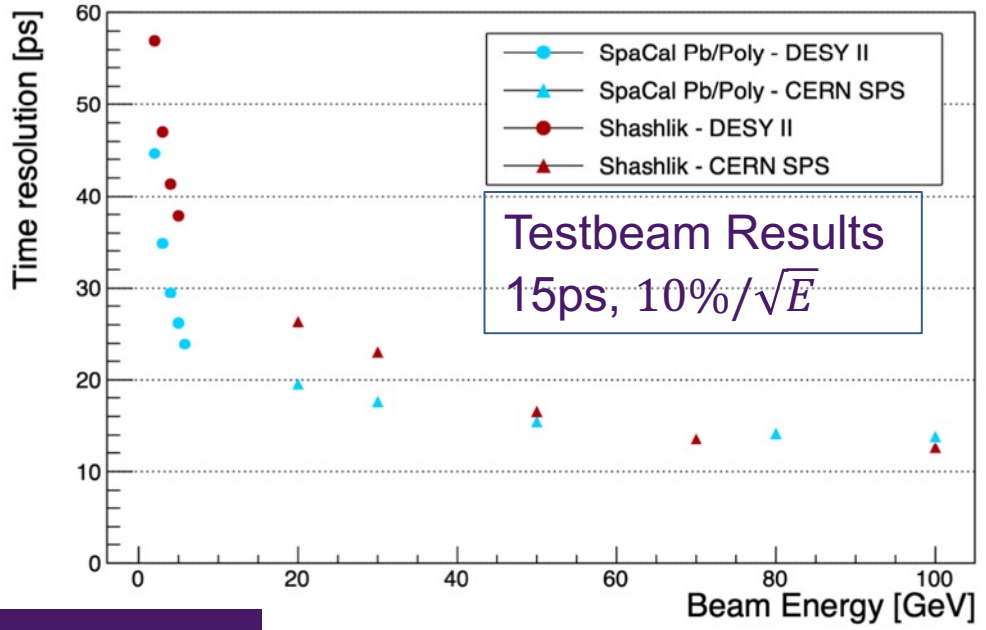
5D Calorimetry: Precision timing

- Goal: achieve energy resolution and reconstruction eff. ~ to Run1&2
  - pile-up, radiation up to 1MGy
- Requires: granularity, precision timing
- Different technologies in different regions
- Crystal fibres R&D for highest fluence regions
- Extensive R&D









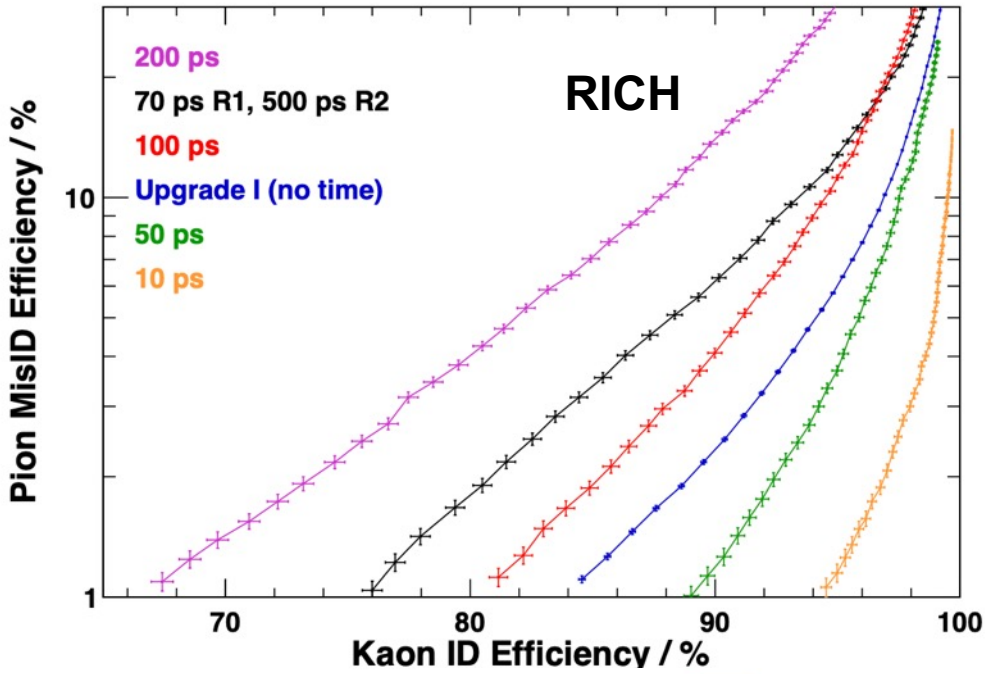
Particle ID: π/K/p – RICH & TORCH with Timing

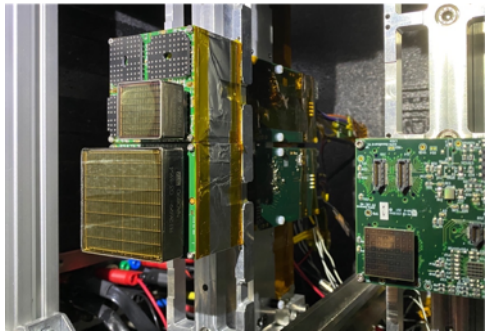
- Hadron particle identification key to LHCb unique physics capabilities

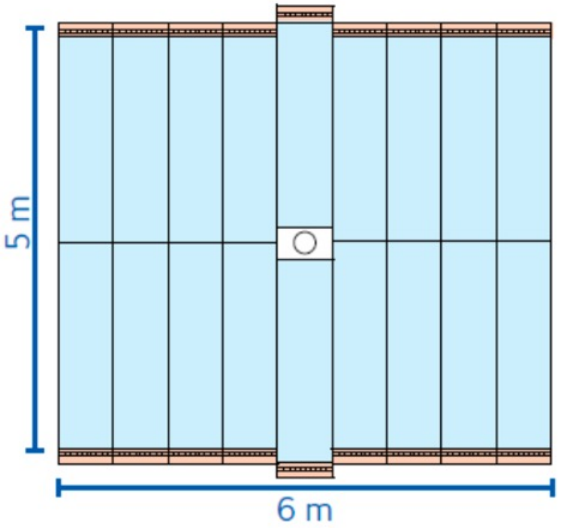
- RICH 1 & 2 geometry maintained
- Time of flight TORCH system
  - Cover wide momentum range

- In both systems precision timing is crucial for Upgrade II performance

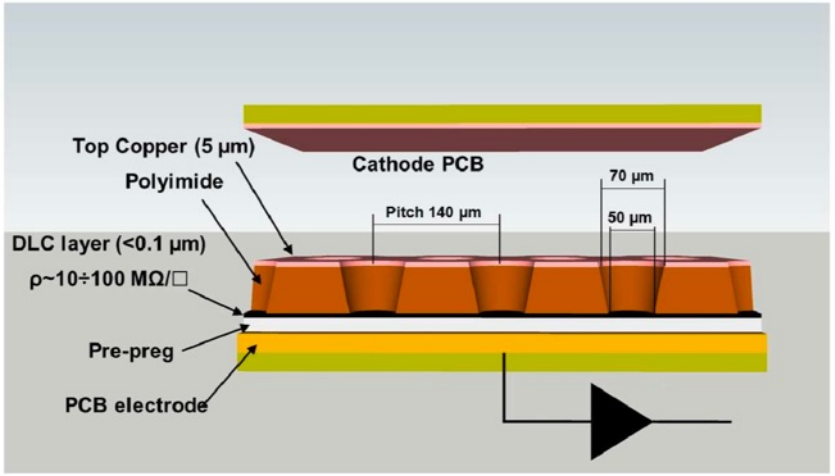
- RICH: Time-stamping each photon with a resolution of few tens of ps
- TORCH: 10-15 ps time resolution per track
- Synergy on electronics readout

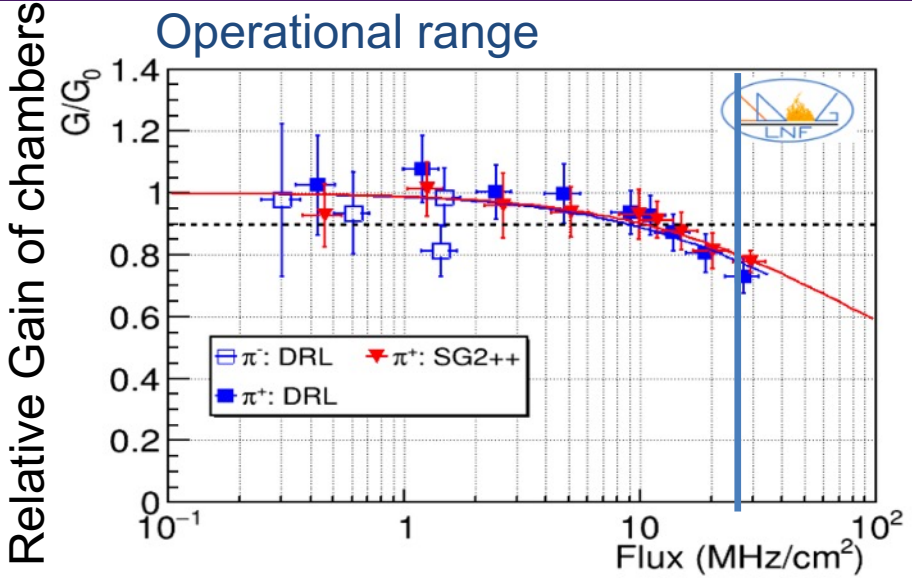






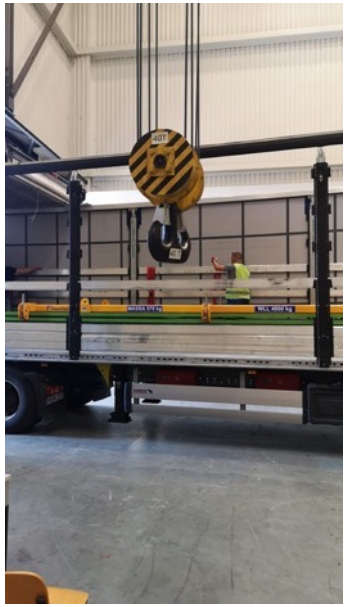
Muons





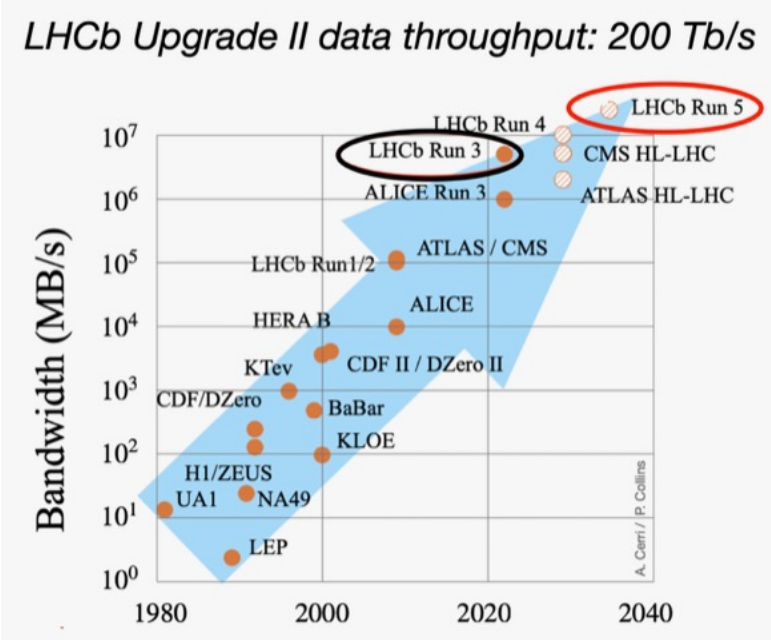
DLC sputtering machine CERN/INFN

- Novel micro-pattern gas detectors for innermost region
- Reuse existing multi-wire proportional chambers in other region
- Additional shielding $(6\lambda_I \rightarrow 10\lambda_I)$ will be installed in front of Muon detector in place of HCAL, which will bring down the rate by a factor of ~2

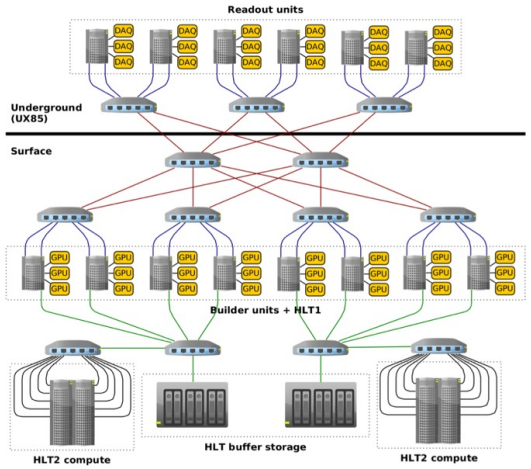


Iron slabs from Opera for LHCb Upgrade II arrived at CERN

Online & Offline



Event-builder architecture



- Novel trigger system for Upgrade I
  - Fully software trigger
  - HLT1 based on GPUs
- Similar concept planned for Upgrade II
- But at 200Tb/s!
  - Further exploitation of hybrid architectures: CPU, GPU, FPGA…
- Offline computing requirements are significant
  - Upgrade I model not sustainable
  - LHCb Upgrade II in Run 5 issues similar to ATLAS & CMS Phase II of Run 4
  - Coordination with WLCG and the HEP Software Foundation on mitigation

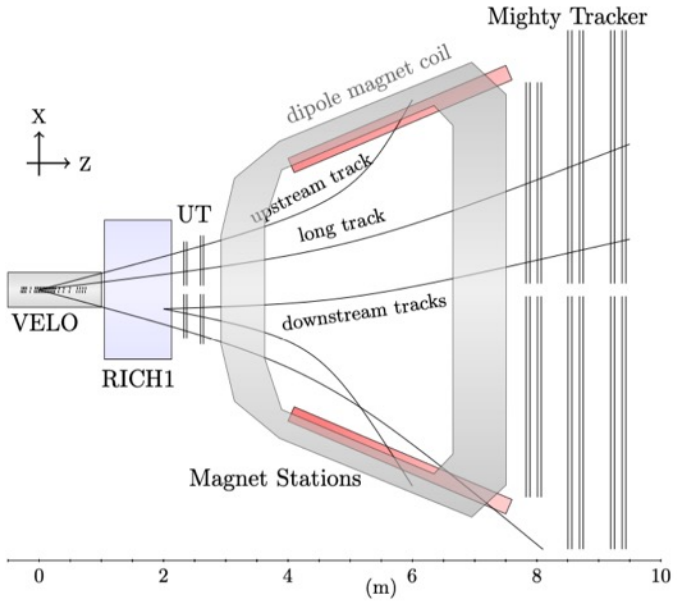
LHCb Upgrade II: Summary

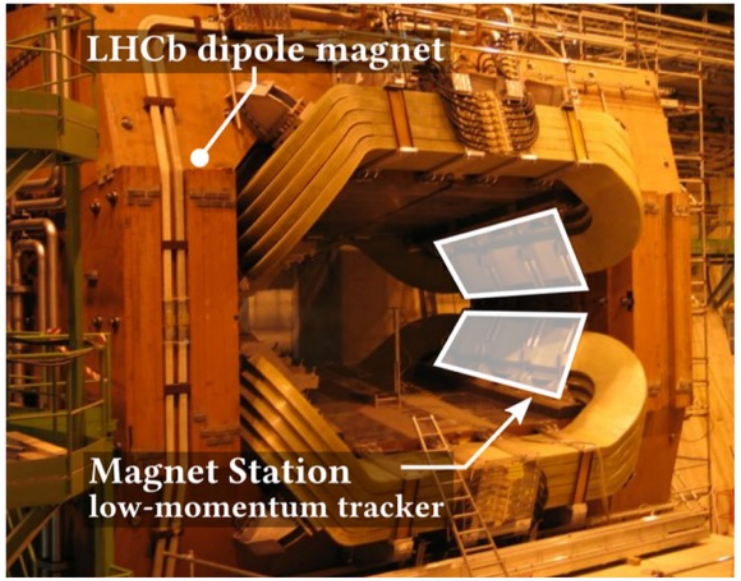
- Fully exploit HL-LHC
  for flavour physics *& beyond*
- Major project for LS4 (2033-2034)
- R&D phase
  - leading to subdetector TDRs in early LS3
  - Innovative technologies
  - Pathfinder to future accelerator projects
- Ambitious detector, proven accelerator
  - R&D proof of technologies advancing
- First funding of construction bids has been made
- Collaboration continues to expand

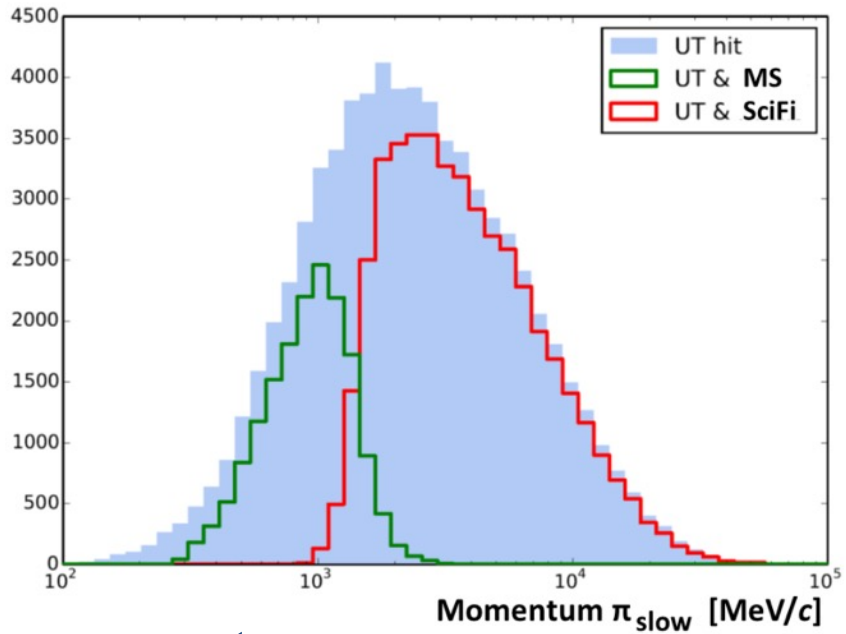
Phase	LS2	Run 3	LS3	Run 4	LS4	Run 5 & 6
Project Approval Stages	FTDR		MoU			
Detectors		LS3 TDR	LS4 TDR			
Online,Trigger, Computing				TDR		
LS3 Infrastructure						
LS3 Detector Construction			Installation			
LS4 Detector Construction					Installation	...
VELO					Installation	
UT					Installation	
MT					Installation	
Magnet Stations					Installation	
RICH					Installation	
TORCH					Installation	
ECAL					Installation	
Muons					Installation	
Online & Trigger					Installation	

Backup

Magnet Stations: expanding physics potential



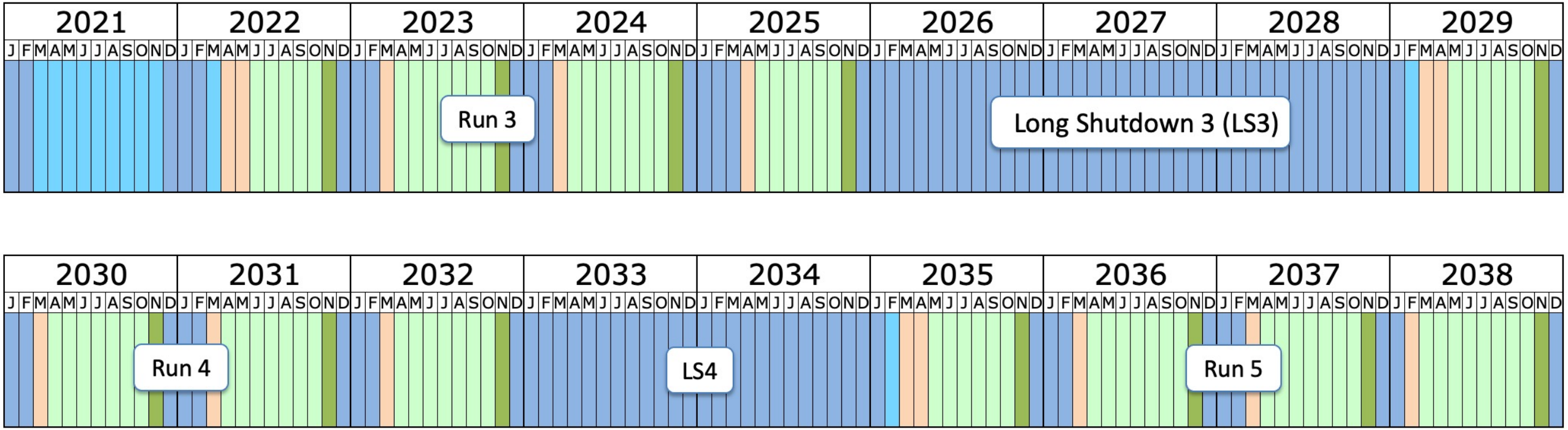




- Low momentum particles swept out by magnet
- Instrument walls of magnet with scintillating bars
- Obtain sub-% momentum measurement
- Significant increase of acceptance for low momentum

e.g. factor of ~2 gain in prompt D^{*+} with slow π

LHC Schedule



LS4 extended to allow installation

+ Run 6