https://cds.cern.ch/record/2776420/

LHCb Upgrade II next steps

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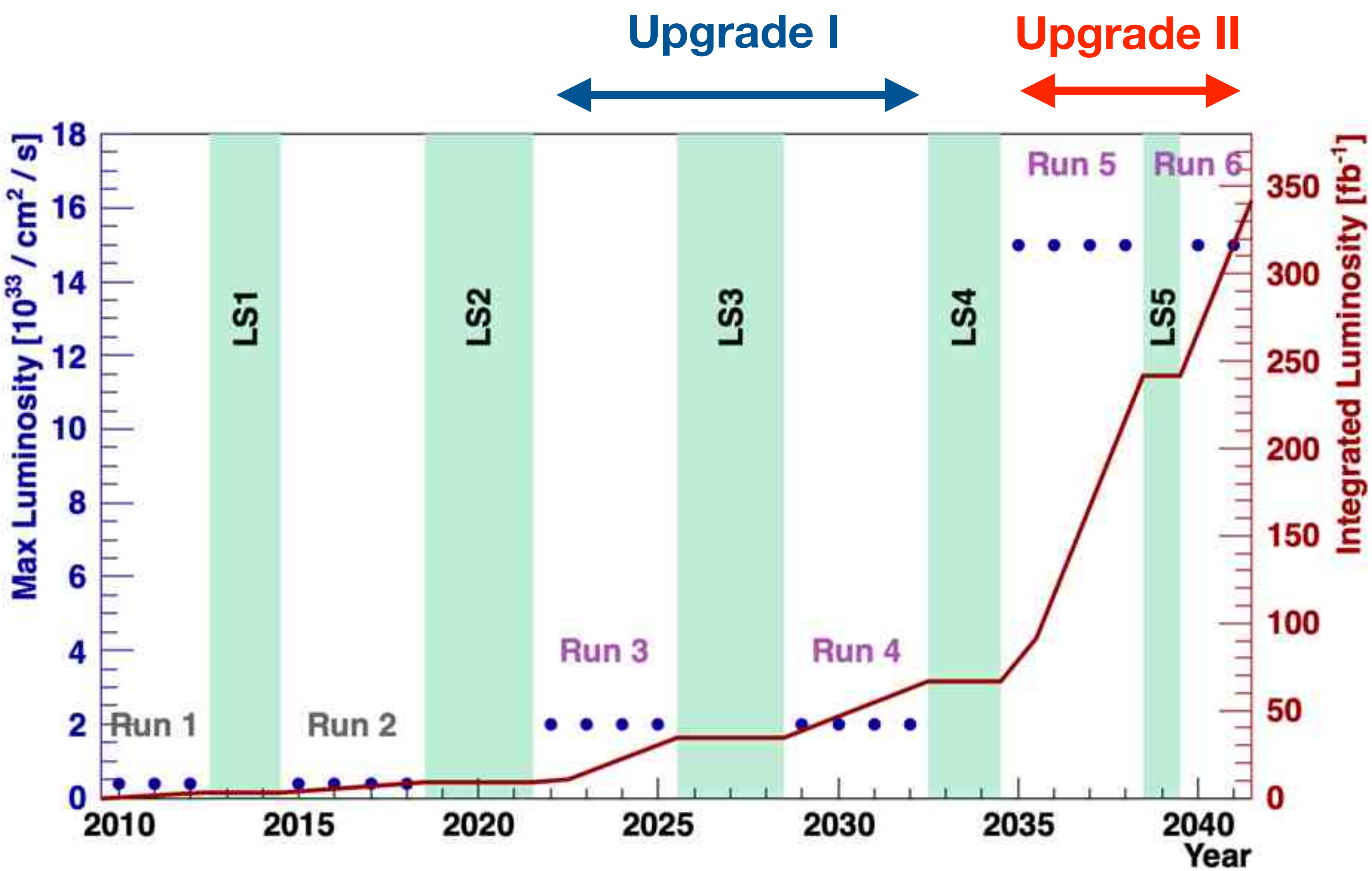
Magnet Station Retreat
September 26h 2022

LHCb upgrades

Physics programme limited by detector, and NOT by the LHC, so there's a clear case for an ambitious plan of upgrades

Upgrade I starting now!!

- *L_{peak} = 2x10^{33} cm^{-2} s^{-1}*
- *L_{int} = 50 fb^{-1} during Run 3 & 4*
- *Healthy competition with Belle II at 50 ab^{-1}*



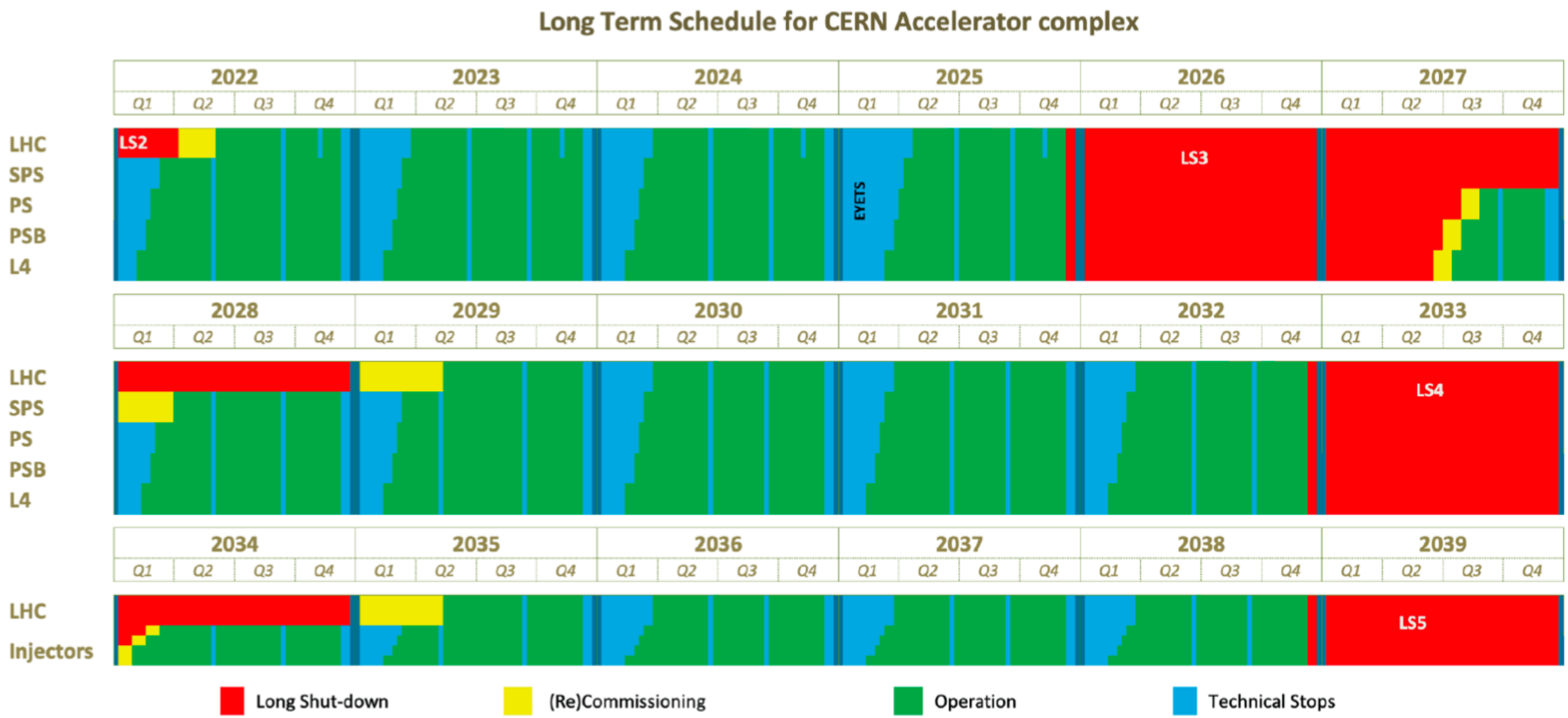
Upgrade II

- *L_{peak} = 1.5x10^{34} cm^{-2} s^{-1}*
- *L_{int} = ~300 fb^{-1} during Run 5 & 6*
- *Potentially the only general purpose flavour physics facility in the world on this timescale*

Long-term HL-LHC schedule

Mid-term schedule for HL-LHC is official and approved by Council until LS3.

Long-term schedule after LS3 is now semi-official and can be taken as the baseline by the experiments



Presence of LHCb Upgrade II is guaranteed by LS4 of 2 years

LS5 is also planned, which implies a Run 6 :)

Physics case: the full table

Upgrade I will not saturate precision in many key observables ⇒ Upgrade II will fully realise the flavour-physics potential of the HL-LHC

Key observables in flavour physics

Observable	Current LHCb (up to $9\,\text{fb}^{-1}$)		Upgrade I ($23\,\text{fb}^{-1}$)	Upgrade I ($50\,\text{fb}^{-1}$)	Upgrade II ($300\,\text{fb}^{-1}$)
CKM tests					
γ ($B \to DK$, *etc.*)	4°	[9, 10]	1.5°	1°	0.35°
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	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%	[29, 30]	3%	2%	1%
$a_{\rm sl}^d$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002

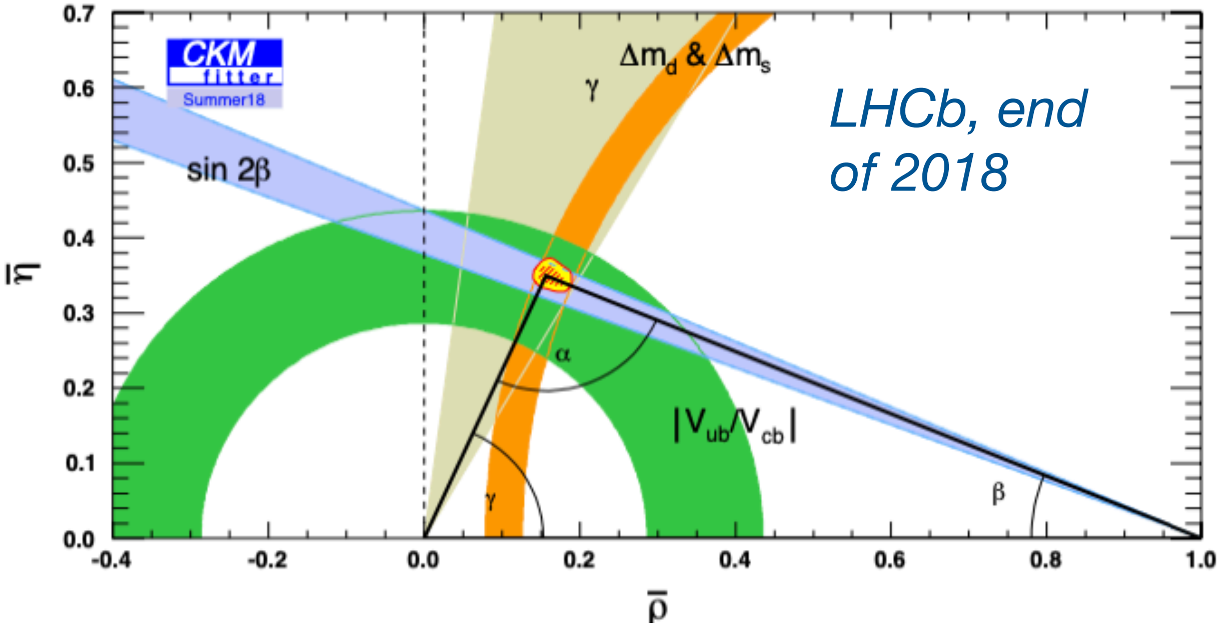
LHCC-2018-027

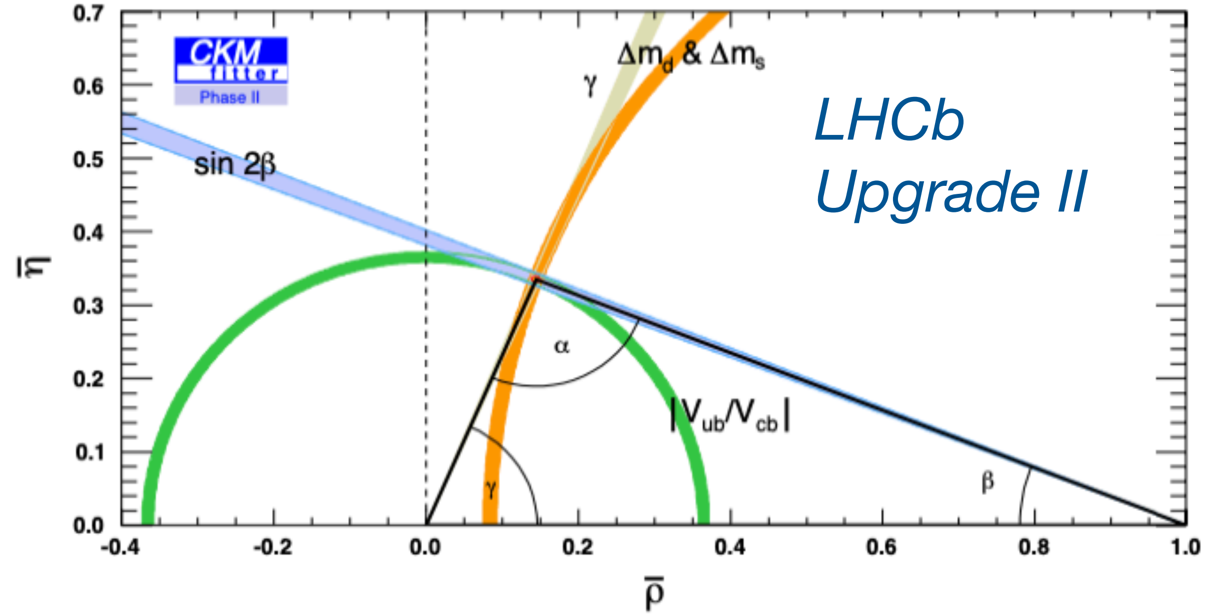
updated for FTDR

NOT ONLY: *LHCb, as a general purpose detector in forward region, will keep pursuing an ambitious programme in spectroscopy, EW precision and Higgs physics (* $\sim 2-3 \times y_{SM}^c$ *), dark sector and other exotic searches, heavy ions and fixed target physics ...*

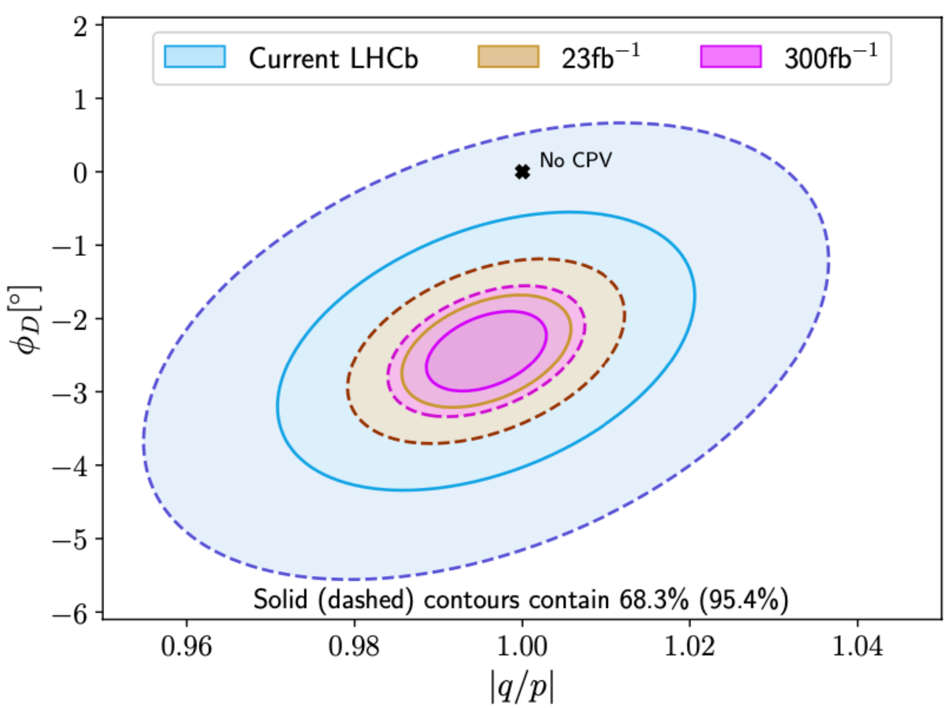
Physics case: a few examples

LHCb Upgrade II will test the CKM paradigm with unprecedented accuracy





CP violation in charm



Only planned facility with a realistic possibility to observe CPV in charm mixing

Heavy Ions

Unique forward coverage: in combination with particle identification and precision tracking, gives access to many observables of interest.

Increased granularity of the detector at Upgrade II will provide the potential to cover the full centrality range, while the addition of Magnet Stations will improve the efficiency for low momentum tracks.

The success of the UII physics programme relies on HL-LHC providing to LHCb ~50 fb^{-1}/year during Run 5 and Run 6, and on a detector with similar performance as the present one

Machine considerations

CERN-ACC-2018-038

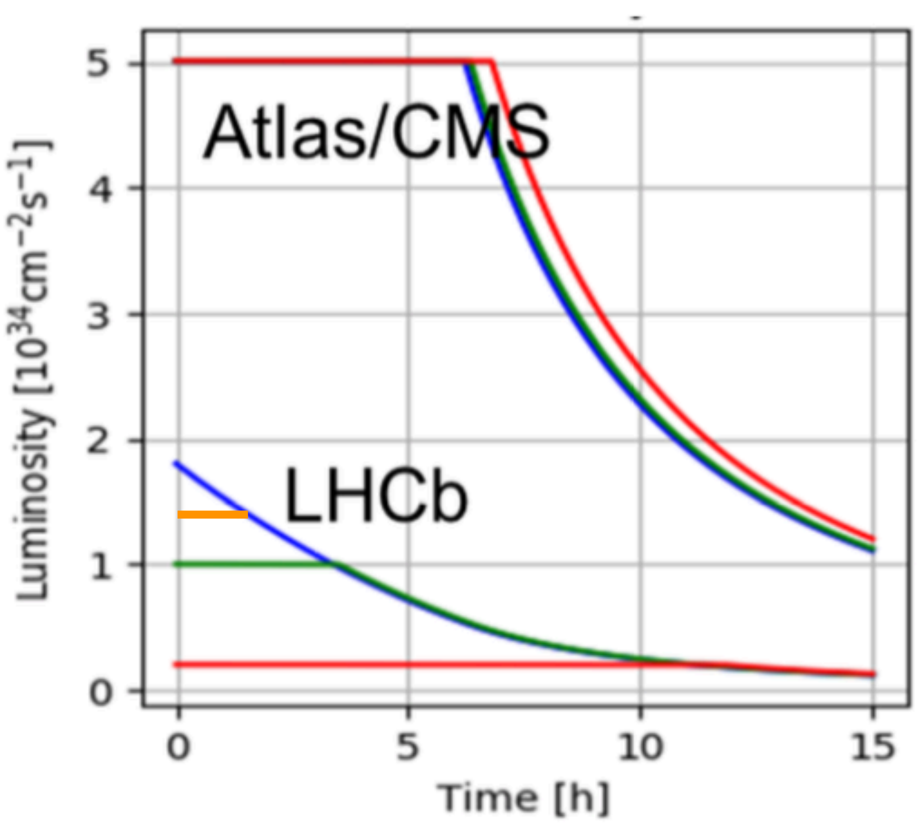
Machine studies indicate feasibility of LHCb operation at ~10^{34} and achieving ~50 fb^{-1} per year, with negligible impact on ATLAS/CMS

Integrated luminosity projections at LHCb for different peak luminosity scenarios

L_{peak} [10^{34} cm^{-2} s^{-1}]	1.0	1.5	2.0
L_{int} [fb^{-1}/year]	42.5	49.9	51.0

- *2.0x10^{34} peak lumi disfavoured since pushes machine (and detector) parameters to the limit for ~no gain in integrated lumi*

→ *we assume 1.5x10^{34} as the baseline*



Impact on machine infrastructure: need to increase protection for both machine elements and cryogenic equipment in the UX85 cavern

- *erection of a shielding wall to protect the cryogenic equipment: complex logistic and interference with LHCb, 21 months needed → LS3 is the optimal period for execution*

Intervention on LHC cryo infrastructure

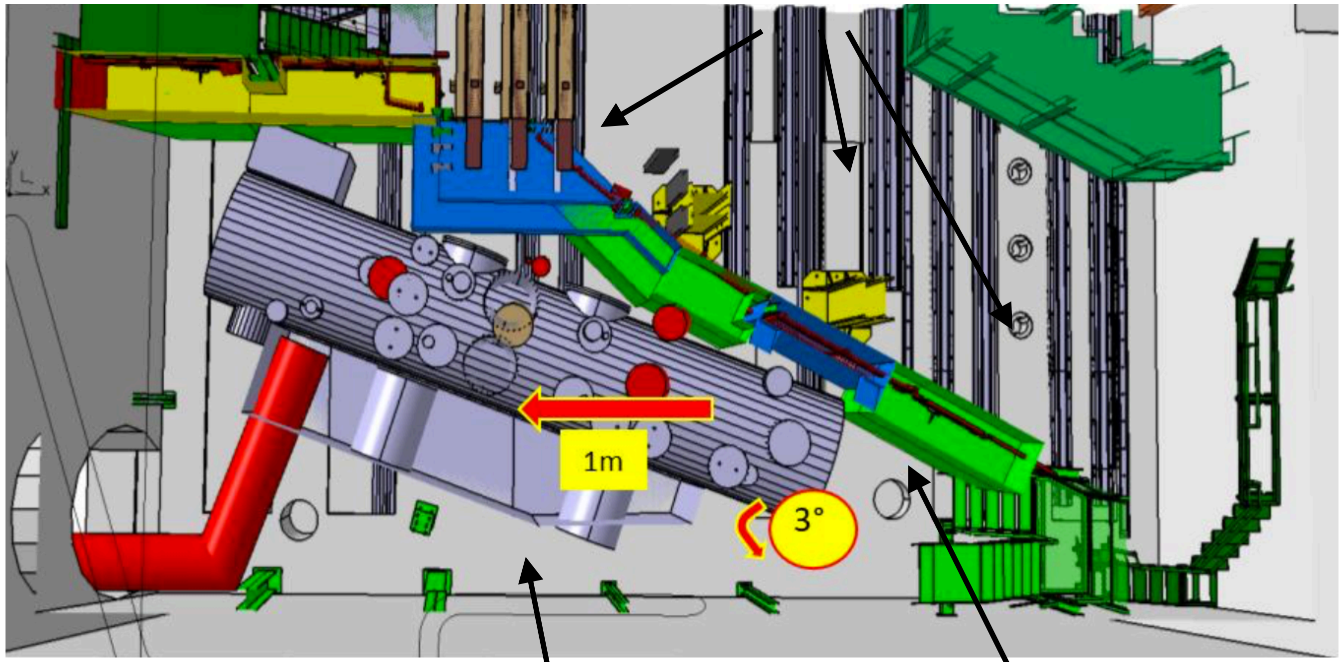
The plan of interventions needed to cope with higher radiation levels due to LHCb UII has been also discussed at the HL-LHC executive committee

1) The solution to diminish the radiation effects is being studied and it is proposed to install a shielding wall (80 cm thick concrete in combination with 40 cm thick iron) to protect the cryogenic equipment from the High Energy Hadron fluence. This requires the movement of some existing equipment

this is in the FTDR

2) In addition, an upgrade of the present refrigerator is needed to stand the additional heat load (~300 W) caused by the collision debris.

not in the FTDR



LHCb request: anticipate the above intervention to LS3, otherwise duration of LS4 needs to be extended by at least 6 months

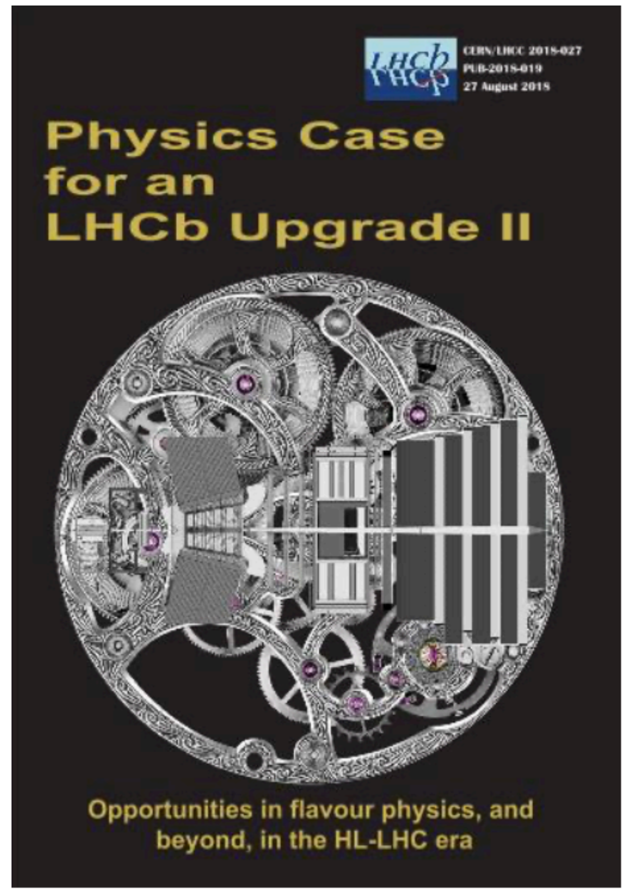
Additional resources needed by the machine to deal with this request, discussion ongoing

LHCb upgrade II: previous steps

Expression of Interest

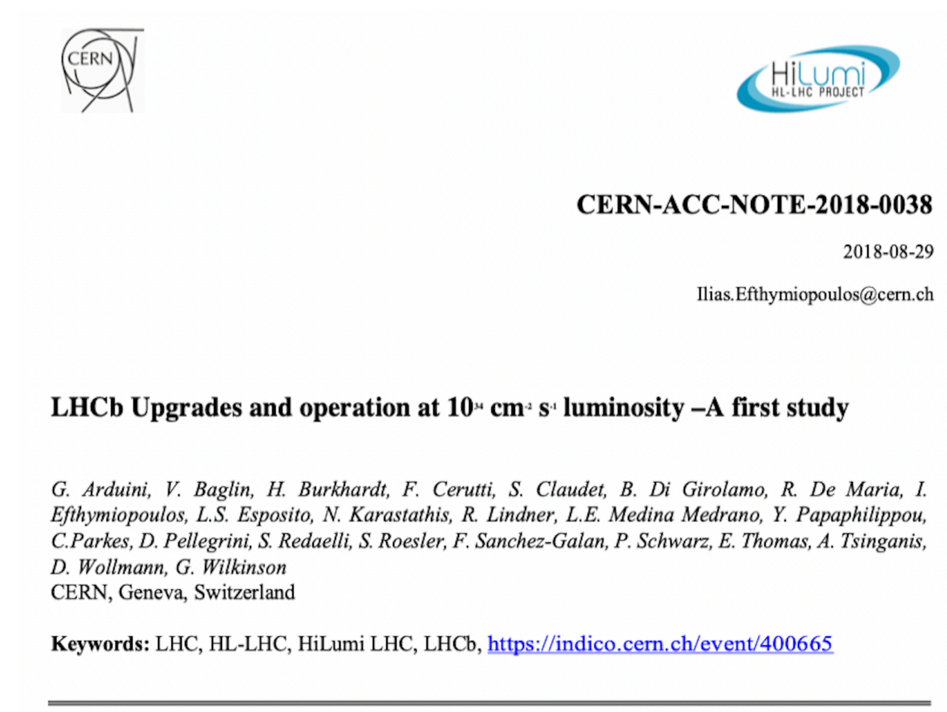
LHCC-2017-003

Physics case



LHCC-2018-027

Accelerator study


CERN-ACC-NOTE-2018-0038

2018-08-29

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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

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"*

LHCb Upgrade II Framework TDR

CDS link https://cds.cern.ch/record/2776420/

165 pages, 10 chapters

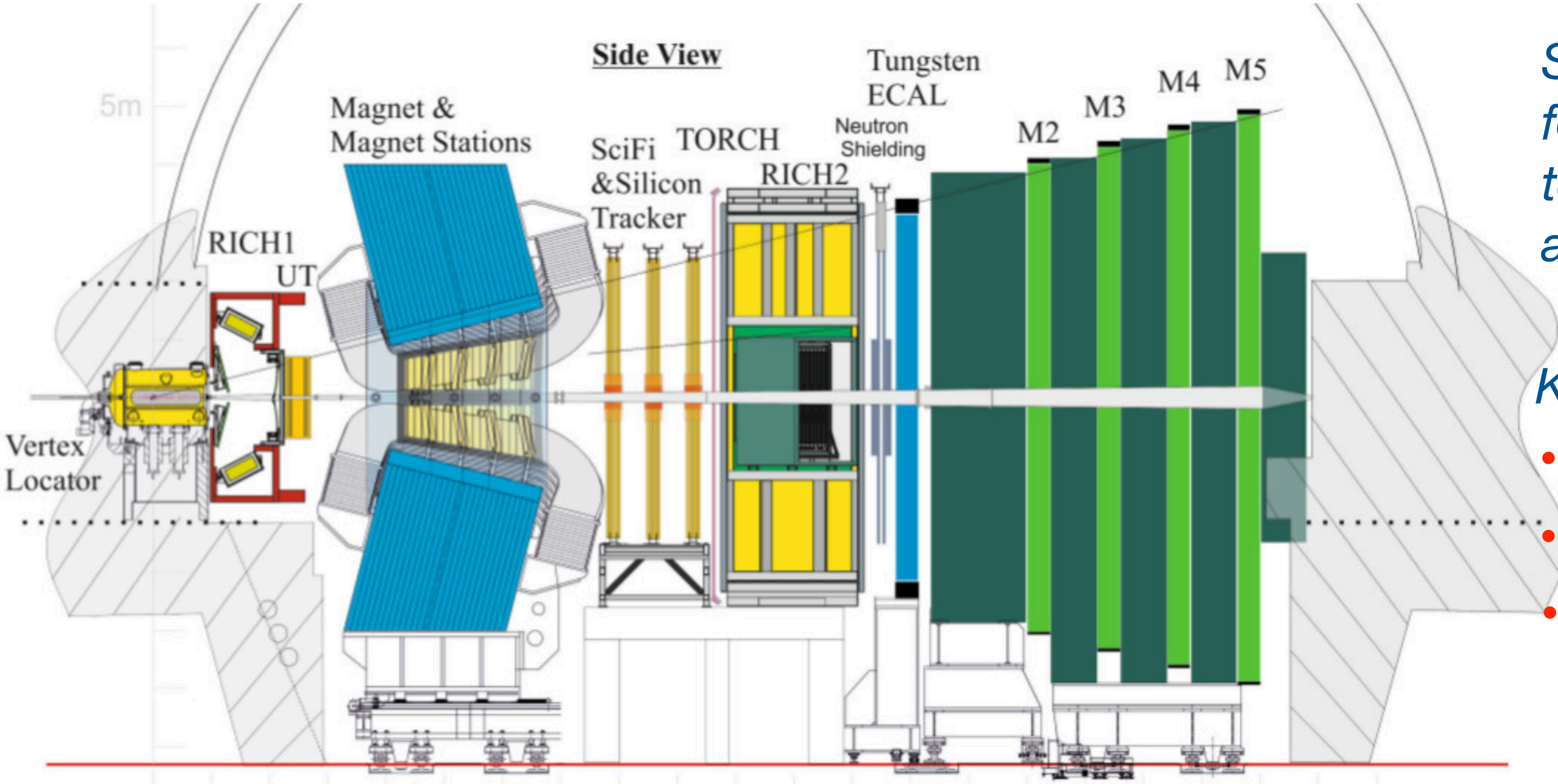
1. *Executive summary*
2. *Introduction*
3. *Tracking detectors*
4. *Particle identification detectors*
5. *Data acquisition and online processing*
6. *Simulation and offline computing*
7. *Infrastructure*
8. *Environmental protection and safety*
9. *Project timeline*
10. *Detector scenarios and costs*

1113 authors from 91 institutes

LHCC review concluded in March 2022

The detector challenge

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



Same spectrometer footprint, innovative technology for detector and data processing

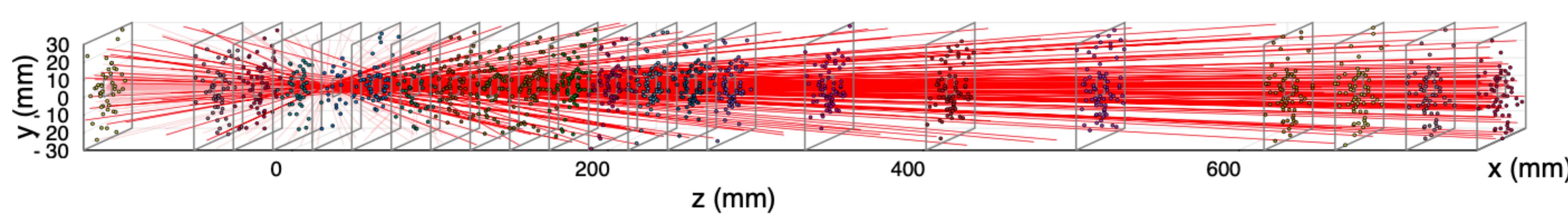
Key ingredients:

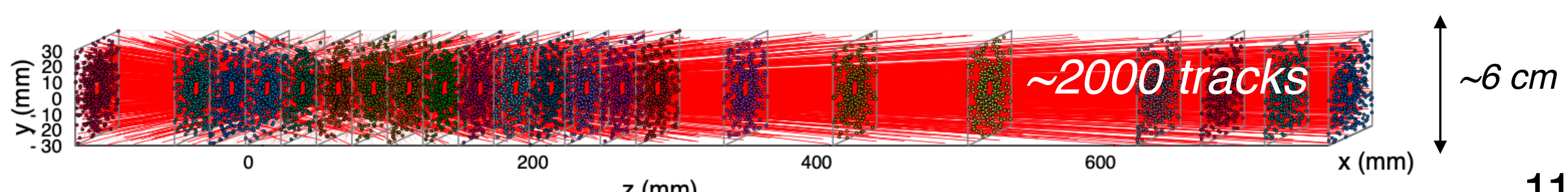
- *granularity*
- *fast timing (few tens of ps)*
- *radiation hardness (up to few $10^{16} n_{eq}/cm^2$)*

VErtex LOcator (VELO)

Run 3: pile-up ~6

Upgrade II: pile-up ~40



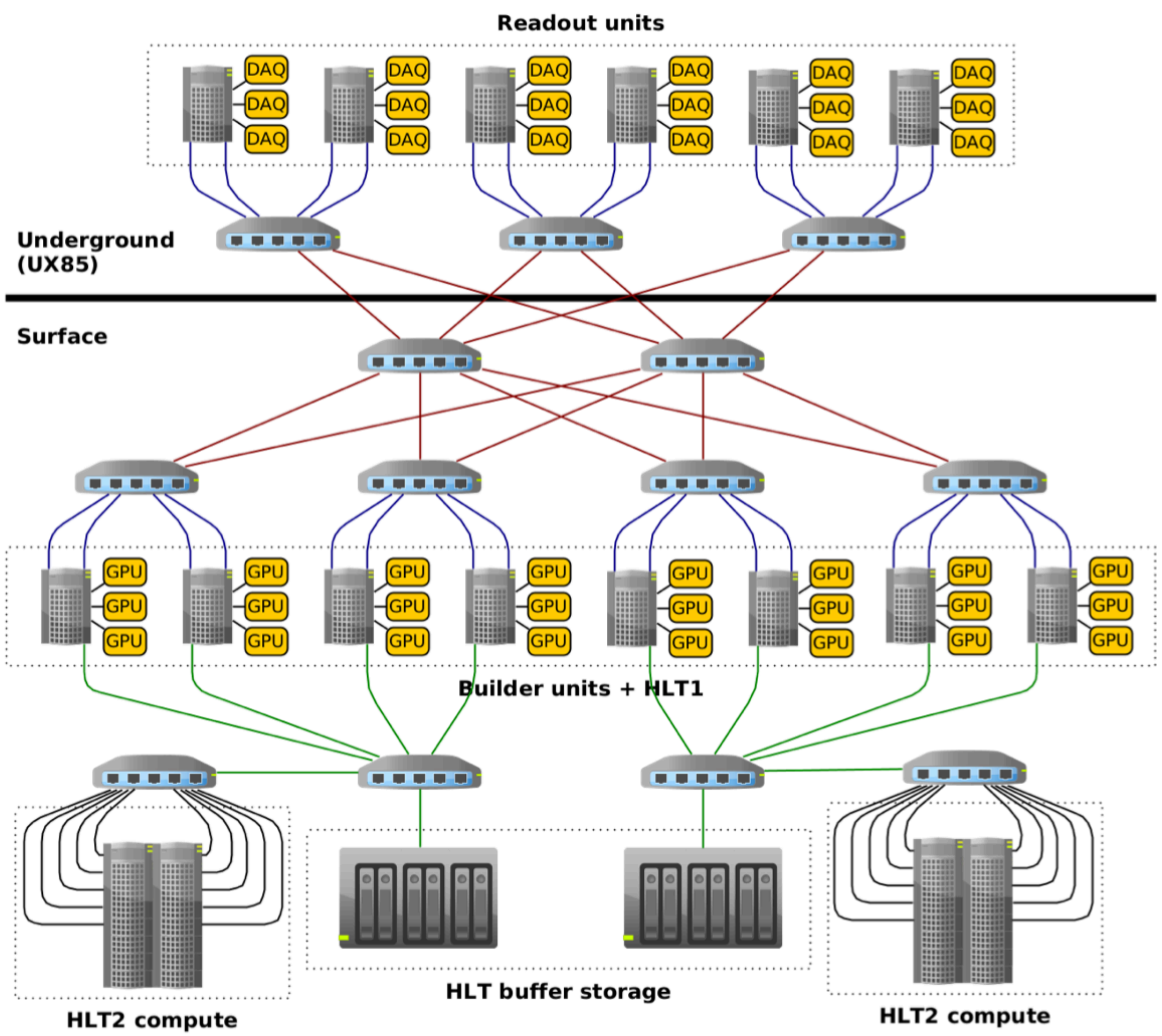


The trigger&online challenge

NEW at Run3

Full software trigger implemented for the fist time at an hadron collider!

HLT1 fully based on GPU will process ~40 Tb/s from detector



Event-builder architecture for Upgrade II

Upgrade II

~200 Tb/s from detector

x5 ATLAS/CMS phase 2 (after L0)

~800 Gb/s on disk

x2 ATLAS/CMS phase 2

Exploit hybrid architectures: CPU, GPU, FPGA,…

- *baseline assumes full reco (HLT1+HLT2 on GPU)*
- *testbed with new technologies in Run 3 readout environment*

LHCC recommendations on FTDR

- *Continue R&D to complete TRDs on the proposed schedule*
- *Continue investigating descoping and other cost-saving possibilities*
- *Careful planning of personnel resources, in addition to what is needed to operate and maintain the present detector, to make data analysis, and to carry out LS3 activities*

LHCC proposed to the RRB* an approval process in multiple steps during a special meeting held on June 24th

the approval steps will follow what has been done for ATLAS/CMS phase 2

**Resource Review Board = meetings of CERN management and Funding Agencies to approve expt. budget*

The Upgrade II approval process

WELL-DONE!

1.1 Letter of Intent: *overall description of the upgrade programme, with discussion of physics notation and performance, detector elements, plan for R&D, technologies*

"LHCb has fulfilled this step with the submission of the EoI, the Physics case document and the FTDR, all very favourably review by LHCC"

WE'RE HERE

1.2 Scoping Document: *estimated cost scenarios (baseline and descoped) with analysis of physics performances, person-power and funding profiles, project organisation and milestones, list of TDRs and project schedule; the document will be complemented by a money matrix (country vs sub detectors) to be agreed with Funding Agencies*

"Some elements of this have been fulfilled by LHCb with FTDR"

2 Subdetector TDRs: *fully detailed design, respecting the envelope of the Scoping Document*

3 Start of construction

Scoping document: what is requested

LHCC recommendation: wrt FTDR we need to complete the evaluation on the descoping options, by presenting a cost table and physics performance studies (at the same level of what presented for baseline scenario)

- *multiple options are also possible (lumi decrease, reduce detector features)*
- *assessing the physics impact of reducing a certain detector feature is also recognised as very important for strengthening the baseline design*

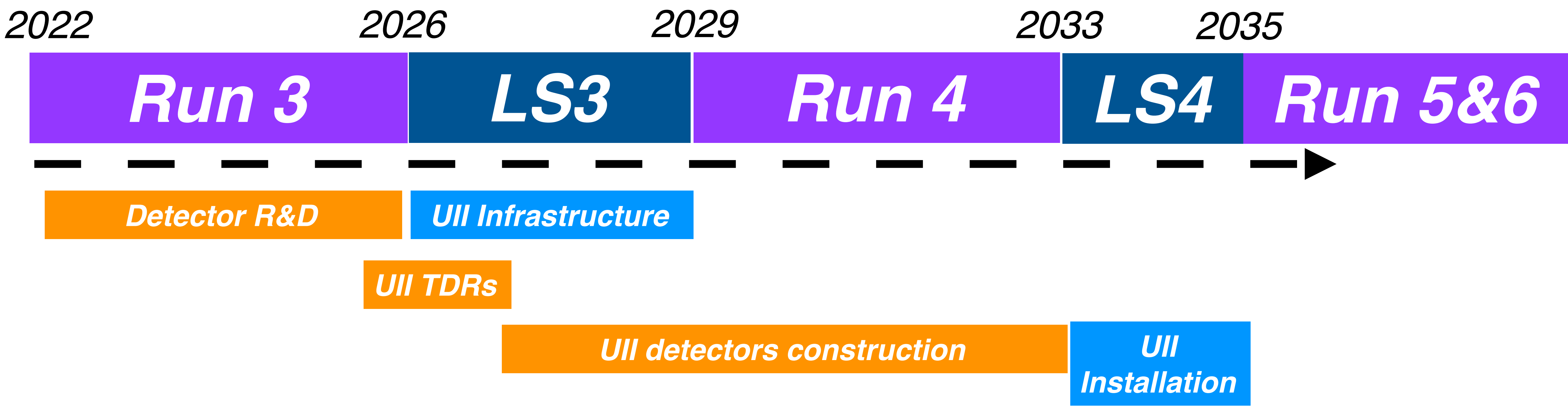
Particular emphasis has been put by both LHCC and CERN DG on presenting a credible plan for person-power, demonstrating that we're able to carry on both data taking and physics exploitation of Upgrade I detector and preparation of Upgrade II

In parallel to the preparation of the Scoping document, we need to discuss and agree with the funding agencies on a preliminary money matrix which shows the expected contributions to the various sub-projects

Next discussion with the RRB on october 27th

Plans for the Scoping Document

Upgrade II timeline



Timeline for Scoping Document

- Depends on us, but not convenient to delay too much for the following reasons: discussion started with FAs, need to secure the project funding by providing the required informations, face competition from other initiatives (ALICE, BelleII, NA62++), plan for the infrastructure work at LS3 (both us and LHC)

*- **A couple of years from now seems a convenient target,** which would still allow to deliver the TDRs at beginning of LS3*

Opportunities for the detector at LS3

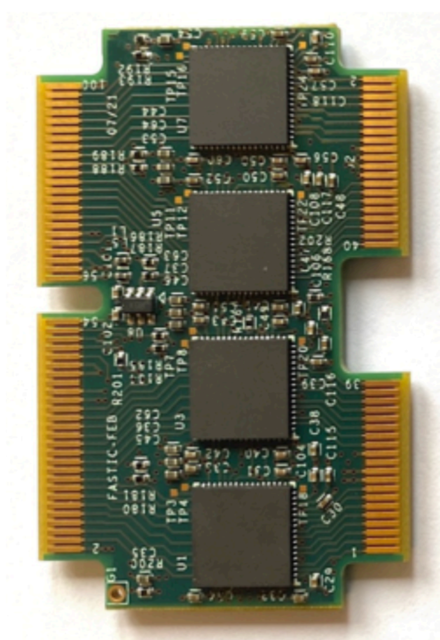
Limited-size detector consolidations also proposed for LS3, which will bring some physics benefits already in Run 4 while anticipating features of the UII

driven by ageing

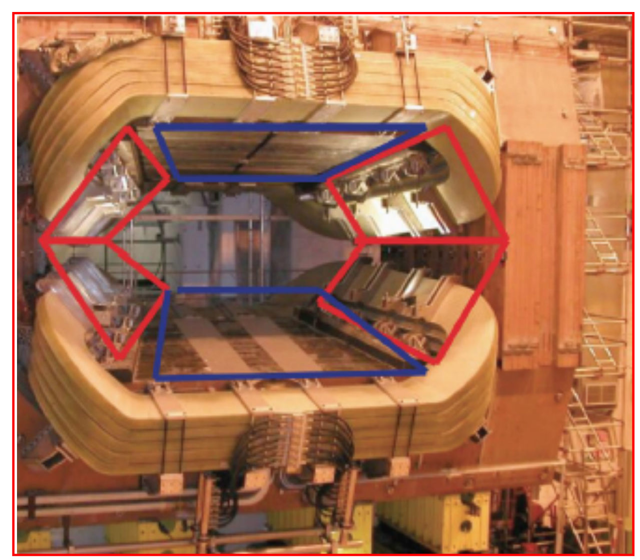
driven by technology

driven by physics

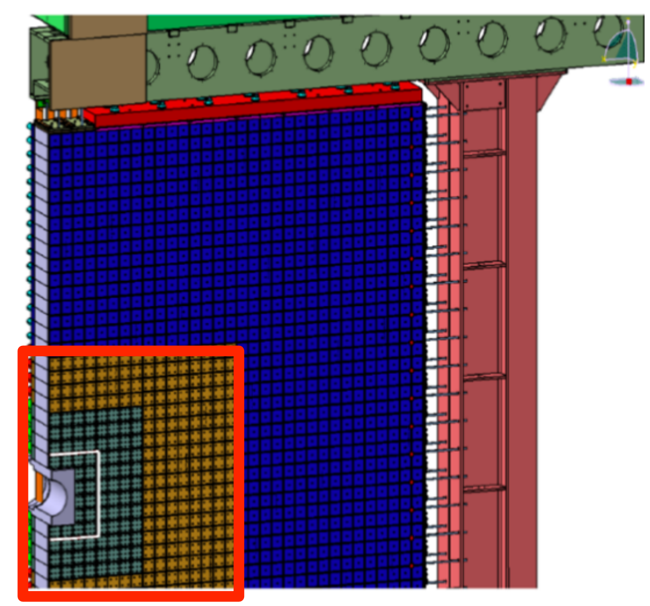
Detector	Proposal
SciFi consolidation	Replace inner modules (12X + 12stereo)
MAPS modules	2 layers, 1 m^2 each
Magnet Stations	full installation
RICH	new FE electronics
ECAL	32+144 inner modules
RTA	Downstream tracking with FPGA



RICH electronics with timing



Magnet Stations!!



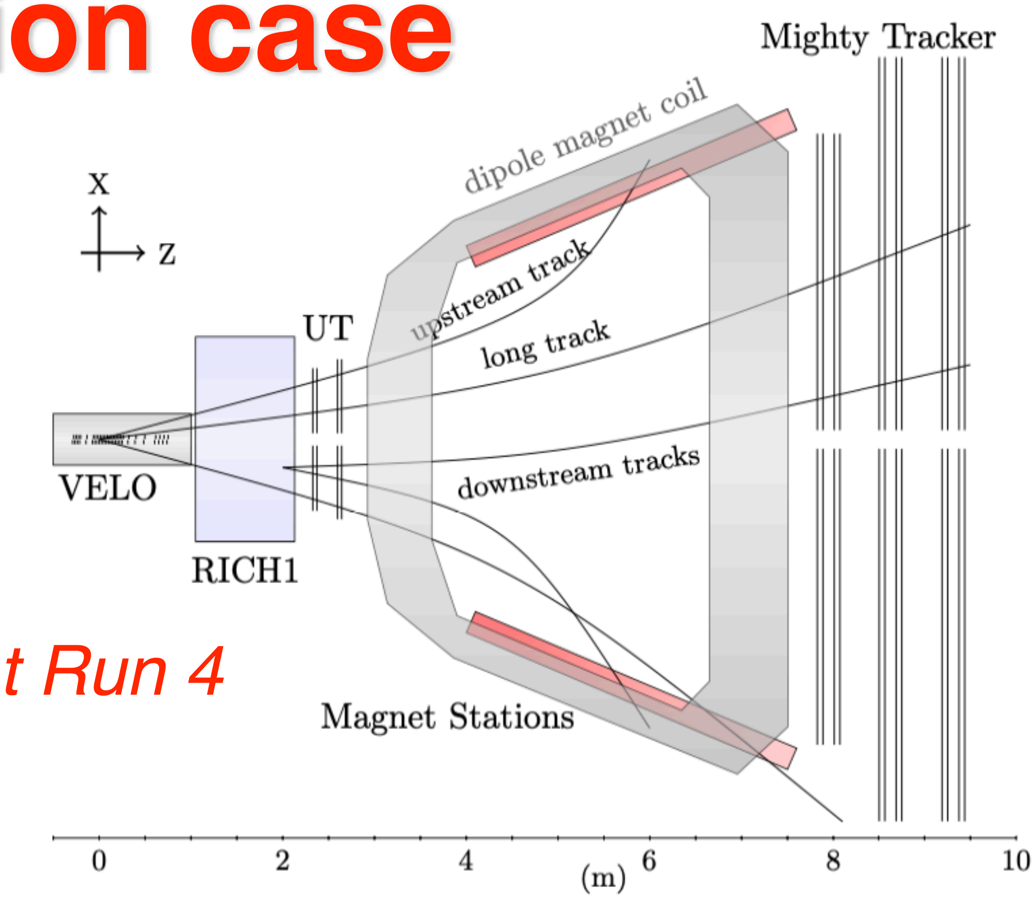
ECAL inner modules

Careful evaluation needed on what can be achieved on this timescale

Light-weight TDRs due within max early-2024 to be ready for installation at beginning of LS3 (2026): U2PG is organising reviews to prepare this phase

The Magnet Station case

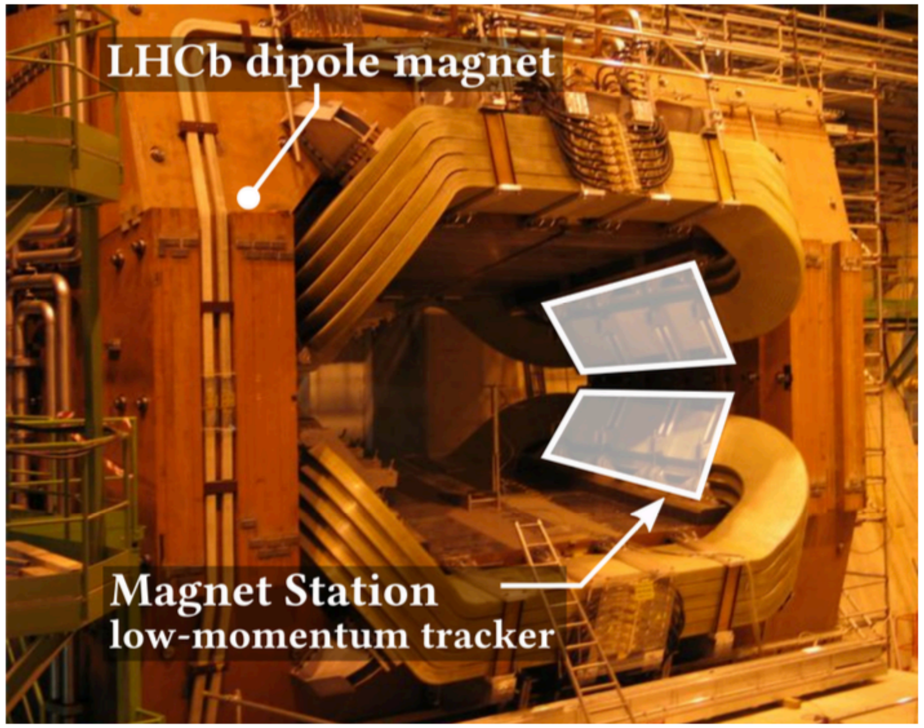
- *Improvement of momentum resolution of upstream tracks to a sub-percent level*
- *Increase of acceptance for low momentum tracks*

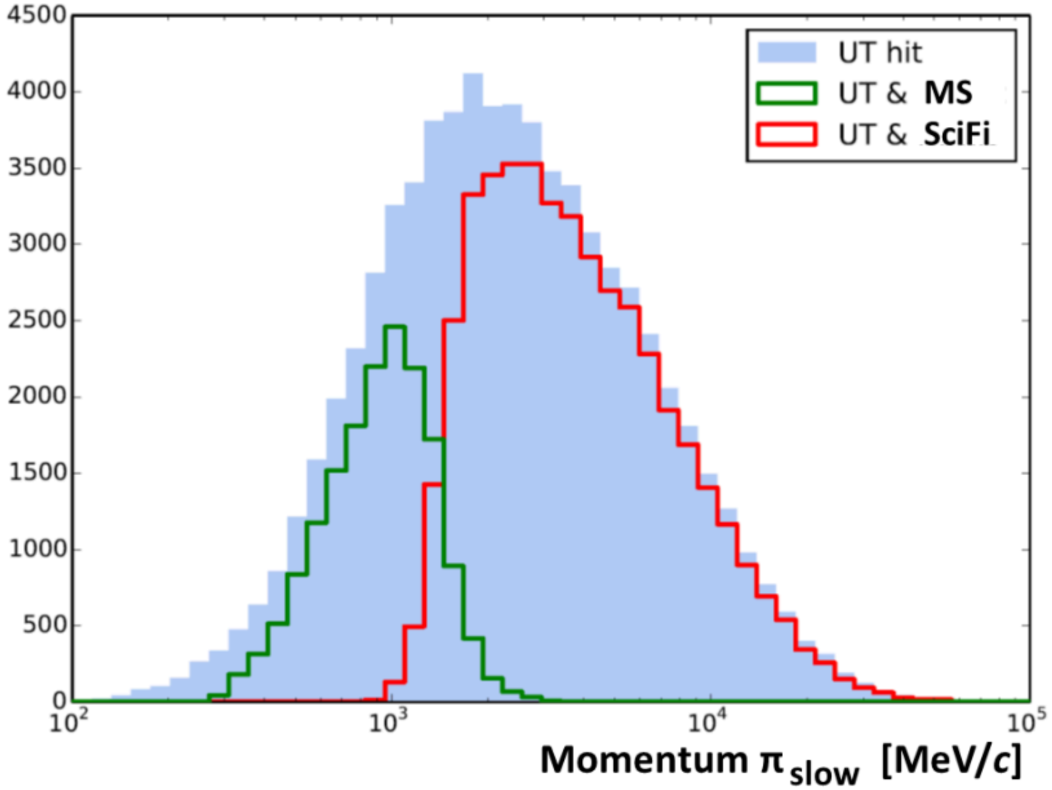


Significant benefit for the physics program already at Run 4

Investment on the detector is not lost for Run 5

→ This proposal fits very well with LS3





U2PG reviews for LS3 projects

Upgrade 2 Planning Group will organise and follow project reviews of LS3 projects, covering the following points:

- *Physics motivation for Run 4;*
- *Technical readiness for TDR;*
- *Financial and human resources, with money matrix of countries/institutes and components (guarantees not required but strong feasibility);*
- *Safety margins on cost and person-power;*
- *Schedule of TDR and construction;*
- *Accounting of LS3 project cost in Upgrade II core must be clearly defined.*

If approved, then proposal to be taken to TB for approval of project to proceed to a light-weight TDR (to be submitted to LHCC)

*The following U2PG members will act as referees for **Magnet Stations:** Marcel Merk, Paula Collins, Tim Gershon*

Timescale of review to be determined by the referees with the proponents, keeping in mind that lightweight TDR is due within early-2024

Conclusions

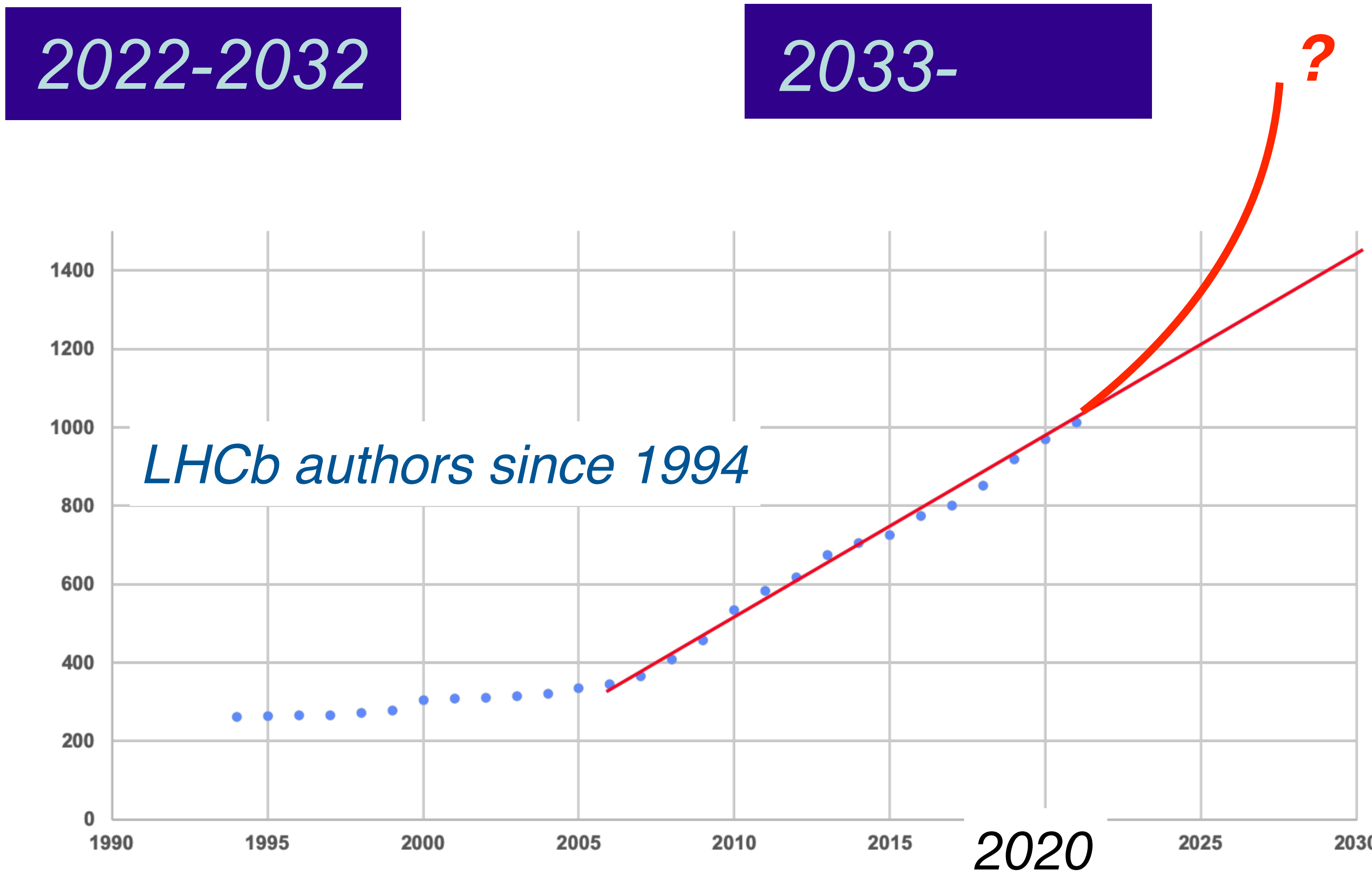
After the FTDR publication, the Upgrade II is now proceeding to the next steps: R&D, design optimisation, discussion with Funding Agencies

A Scoping Document is requested before we can proceed to sub-detector TDRs

We need to carefully balance and prioritise btw the different activities…

Physics results	**Constructed: now commission!**	**It's taking shape!**
Original	*Upgrade I*	*Upgrade II*
2009-2018	*2022-2032*	*2033-*

…and of course we need many new collaborators!!



SPARES

Preparation of infrastructure during LS3

Based on the present experience, 2 years is the bare minimum to install the new LHCb detector during LS4

This is assuming that the intervention on the LHC cryogenic equipment is performed at LS3, otherwise a significant interference should be accounted for

A longer LS3 beneficial for LHCb only if it makes possible the intervention on the LHC cryogenic equipment

Preparation work on LHCb infrastructure for UII also planned:

- *Additional shielding for Muon detector in place of HCAL*
- *New platforms for ECAL FE electronics*
- *Refurbishment of underground infrastructure for UII online system*
- *Power distribution*
- *Safety systems*
- *Assembly buildings*

Muon shielding