LHCb Upgrade II – One Page Summary

- Flavour physics provides a unique probe for new physics, delivering sensitivity to new particles with masses much larger than those accessible with direct searches.
    - Flavour physics provides key guide to couplings and energy scale of new physics.
- LHCb Upgrade II offers unique opportunities in flavour: the experiment will study the largest samples of heavy-flavour hadrons of all current and proposed experiments in the coming decades.
- UK provides key leadership in LHCb.
    - 11 institutes, plus 2 more joining for Upgrade II.
    - 15% of authors in the collaboration.
    - Leadership at all levels of the collaboration in recent years.
- The UK is backing LHCb Upgrade II (£49.4M through UKRI infrastructure fund).
- The 2020 European strategy update recommended that “The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.” The full-exploitation of the HL-LHC should remain our top priority. LHCb Upgrade II is crucial for delivering this recommendation.

W. Barter, on behalf of LHCb-UK

LHCb Upgrade II Physics

- Key physics deliverable: unprecedented high-precision measurements of heavy flavour hadrons, providing clear sensitivity to new physics.

- LHCb Upgrade II will collect at least 300 fb^{-1} of data following installation in LS4.
    - Factor $>10^3$ more b-hadrons produced in LHCb acceptance than at Belle II, and still factor $>10^2$ more than FCC-ee will produce operating at the Z pole. For final states composed of only charged tracks, LHCb will have much larger yields and lower backgrounds, and hence more precise measurements.
    - LHCb can also study all species of beauty hadron and has unique capability in heavy-flavour spectroscopy.

- Most measurements expected to improve by ~one order of magnitude in precision over current results.

- Detailed numbers available in Upgrade II physics case.

Flavour Physics Projections for LHCb Upgrade II

- Key improvements across heavy-flavour physics.
  Every measurement provides a key test of the Standard Model and probes potential new physics.

	Observable	Current (up to 9 fb^{-1})	Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})	Other experiments with potential to compete with LHCb precision
Tests of CKM matrix and CPV in the SM	γ	2.8°	1.3°	0.8°	0.3°	LHCb unmatched
	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6%	3%	2%	1%	Belle-2, FCC-ee
	$\phi_s^{c\bar{c}s}(B_s^0 \to J/\psi\phi)$	20 mrad	12 mrad	8 mrad	3 mrad	ATLAS, CMS
	$\phi_s^{s\bar{s}s}(B_s^0 \to \phi\phi)$	69 mrad	39 mrad	26 mrad	11 mrad	LHCb unmatched
Exploration of the Charm sector	ΔA_{CP}	29×10^{-5}	13×10^{-5}	8×10^{-5}	3.3×10^{-5}	LHCb unmatched
	A_Γ	11×10^{-5}	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}	LHCb unmatched
	Δx	18×10^{-5}	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}	LHCb unmatched
Rare Decays	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	41%	27%	11%	ATLAS, CMS
	$S_{\mu\mu}(B_s^0 \to \mu^+\mu^-)$	—	—	—	0.2	ATLAS, CMS
	$A_T^{(2)}(B^0 \to K^{*0}e^+e^-)$	0.1	0.060	0.043	0.016	FCC-ee?
	$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	0.093	0.062	0.025	FCC-ee?
	$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	${}^{+0.17}_{-0.29}$	0.148	0.097	0.038	FCC-ee?

- LHCb provides unique access to many key flavour physics observables on the timescale of the next 20 years and beyond.

LHCb Upgrade II Physics and Detector

- LHCb also offers unique/exciting opportunities beyond flavour:
  - BSM physics (e.g. sensitivity to low mass dark photons improved by 1-3 orders of magnitude compared to current limits).
  - SM measurements that provide important complementary information to those at ATLAS and CMS (e.g. W boson mass, weak mixing angle).
  - Conventional and exotic hadron spectroscopy.
  - Heavy Ion Physics (unique potential to probe quark-gluon plasma due to capability to reconstruct beauty and charm hadrons at all centralities).
- LHCb Upgrade II will also drive development of technology and skills:
  - Instantaneous luminosity of LHCb increased by an order of magnitude compared to current running conditions.
  - LHCb Upgrade II provides a bridge to projects at future accelerators.
  - Hardware: upgraded subdetectors typically require fast timing and high granularity.
  - Software: Run 3 demonstrates LHCb can deliver offline-quality reconstruction in near-real-time. Upgrade II requires scaling this to significantly more challenging operating conditions.

Requested Further Information

- Estimate of financial costs:
  - FTDR Baseline Construction Cost 175M CHF; scoping document currently with LHCC.
  - Current annual operation costs for LHCb: overall LHCb Cat A M&O budget currently ~3 MCHF; power ~0.2 MCHF.

- Environmental cost of construction and operation per year:
  - LHCb Upgrade II was first CERN project to include dedicated environmental study in FTDR, and has a dedicated lead (Heinrich Schindler) on sustainability.
  - Key drivers of LHCb environmental impact are gas emission. Reductions are envisaged eg through use of low global warming potential radiators and different gas mixtures. Overall HL-LHC also clearly important for Upgrade II environmental impact.
  - Operational contribution of LHCb is ~4400 tonnes CO_2 equivalent per year in Run 3 [more details here]. LHCb currently makes a few % contribution to overall CERN Scope 1 emissions.

- Does your project plan dedicated submission(s) for the ESPPU (if so, give details).
  - Yes – central LHCb submissions planned for early 2025.
  - Submission expected to include at least four documents: Discovery potential; Technology developments (including sustainability); Heavy ion physics; Software and Computing.