

LHCb and its upgrades

Matthew Kenzie (Cambridge)

PPAP Community Meeting

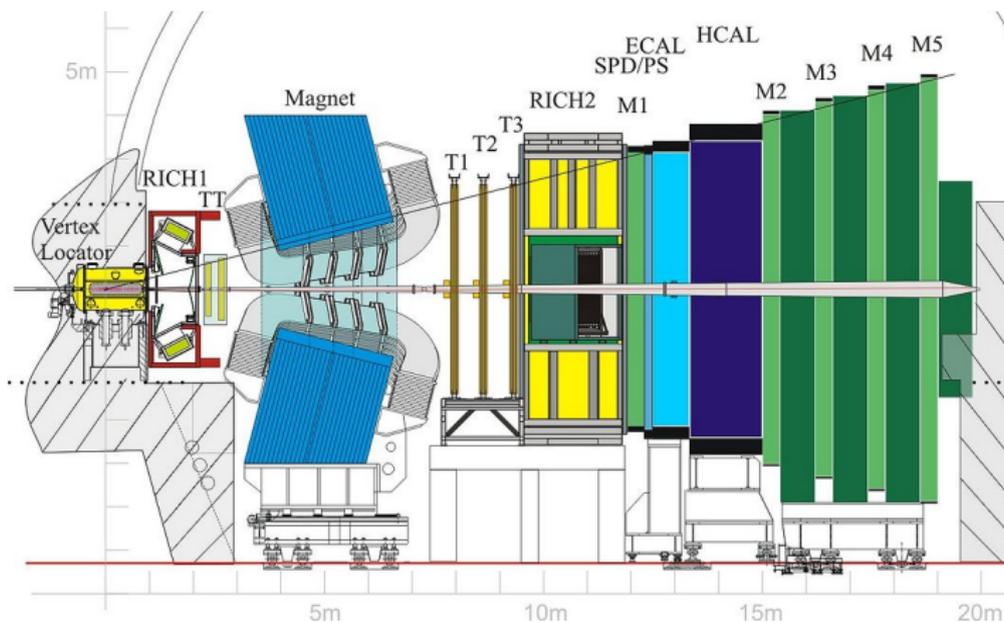
LHCb-UK: University of Birmingham, University of Bristol, University of Cambridge, University of Edinburgh, University of Glasgow, Imperial College London, University of Liverpool, University of Manchester, University of Oxford, Rutherford Appleton Laboratory, University of Warwick

17th July 2018

Overview

Our goal is to **expose BSM physics** through precision studies of **quark flavour violating processes** whilst capitalising on the **unique physics opportunities** gained from a very **forward acceptance**, exploiting the **enormous heavy flavour production of the LHC**

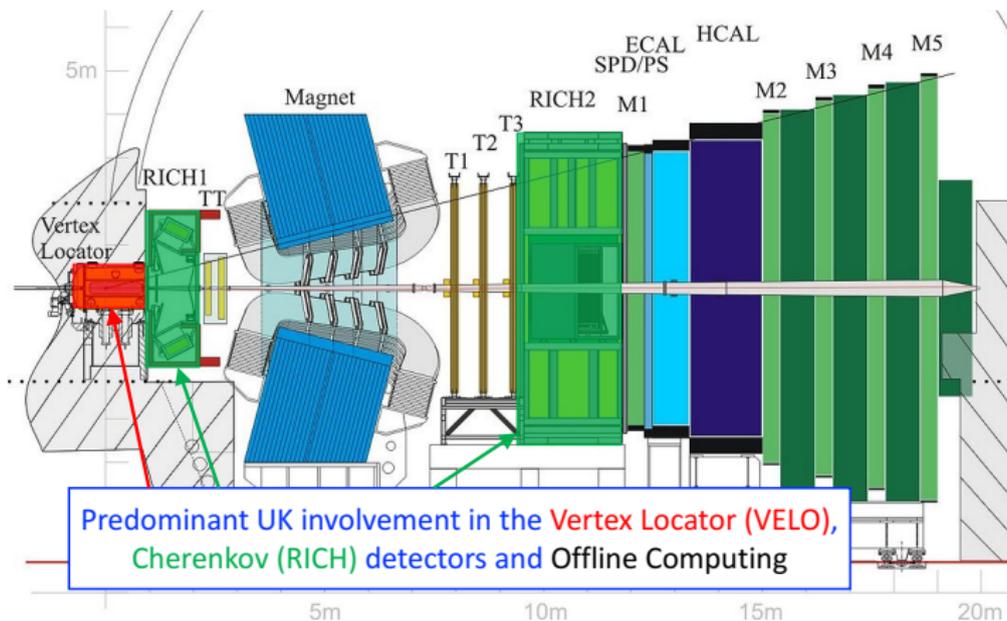
Detector performance - [Int. J. Mod. Phys. **A30** (2015) 1530022]



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UK prominence within the collaboration

- ▶ LHCb consists of 61 member institutes (of which are 11 are UK) across 15 countries
- ▶ UK contributes $\sim 157/811$ authors

Senior management roles

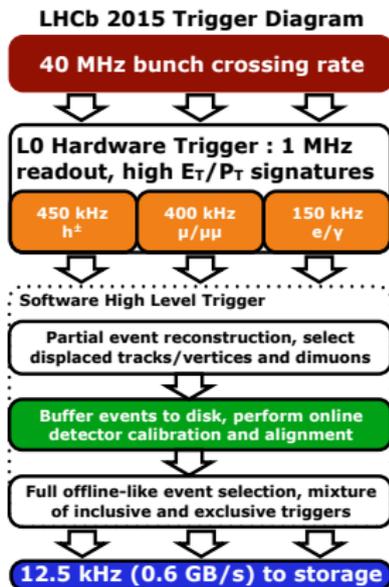
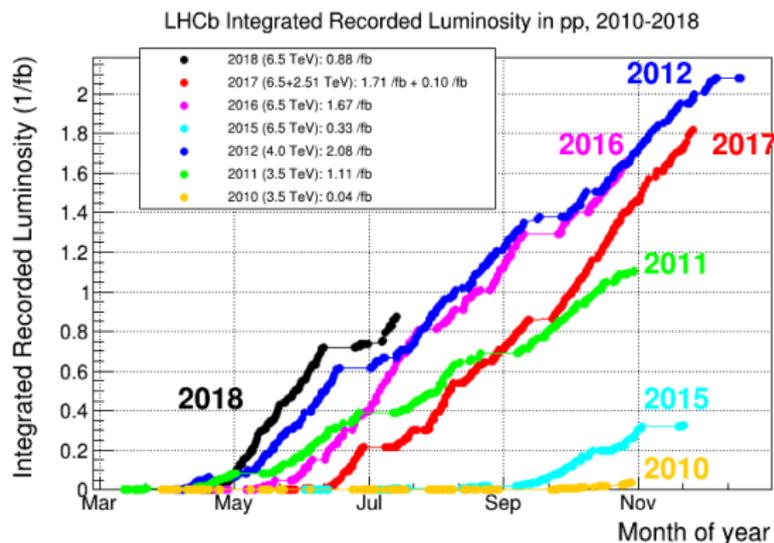
Collaboration Board Chair	Val Gibson
Deputy Spokesperson	Chris Parkes
Operations Coordinator	Silvia Borghi

- ▶ **10/28 Physics planning group** convenors at UK institutes
 - ▶ An additional 4 were PhDs at UK institutes
 - ▶ New **Physics coordinator** was also a UK PhD
- ▶ **7/24 Operation planning group** coordinators at UK institutes
- ▶ **4/17 Upgrade planning group** coordinators at UK institutes

**Whilst the LHCb collaboration continues to grow the UK component has not.
The UK maintains strong leadership positions across all areas of the experiment.**

1. Highlights of recent results

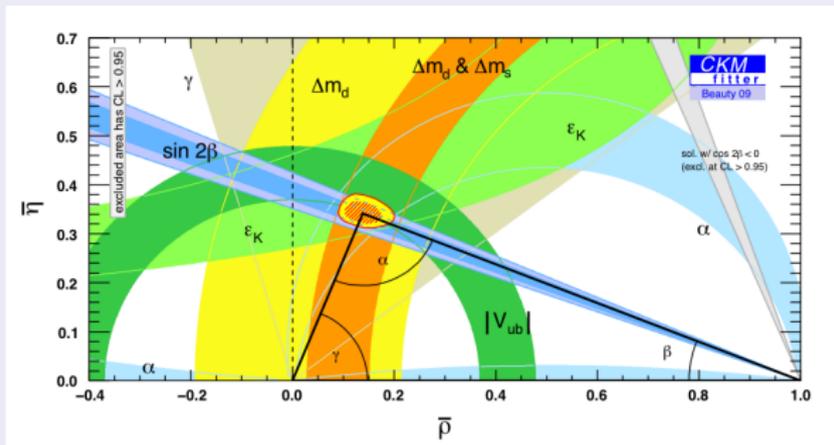
- ▶ Collected 3 fb^{-1} in **Run 1** and (estimated) additional 5 fb^{-1} in **Run 2**
- ▶ Run 2 has seen **commissioning of real-time alignment and calibration** in the trigger



- ▶ Will show a few recent results with particular **emphasis on UK involvement**

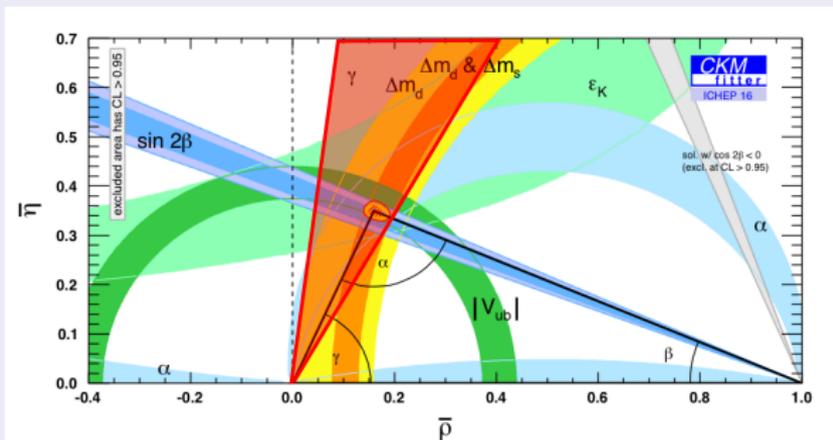
CKM unitarity and CP -violation

Unitarity Triangle 2009



CKM unitarity and CP -violation

Unitarity Triangle 2018

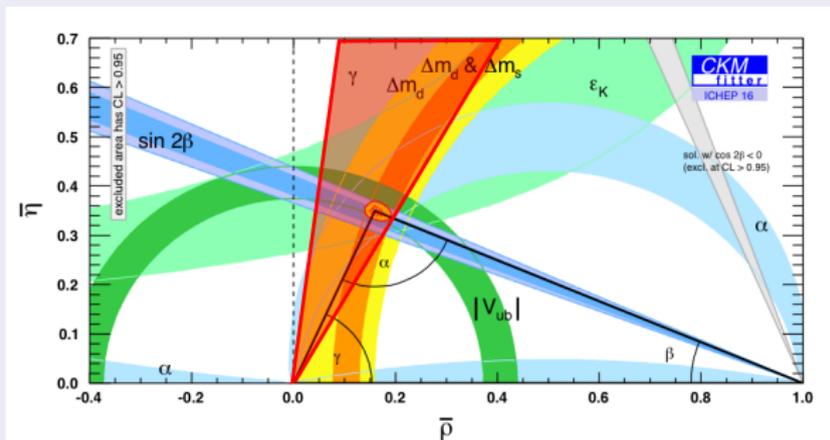


Tree-level constraints

- ▶ Uncertainty on γ now $\sim 5^\circ$
[LHCb-CONF-2018-002]
- ▶ Measurement of V_{ub} with Λ_b^0 baryons
[Nat. Phys. **10** (2015) 1038]

CKM unitarity and CP -violation

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Tree-level constraints

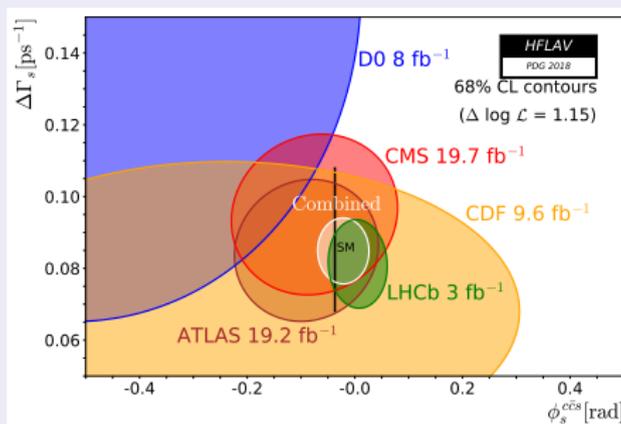
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[Nat. Phys. **10** (2015) 1038]

Loop-level constraints

- ▶ $\sin 2\beta_{\text{eff}}$ competitive with B factories
[JHEP **11** (2017) 170]
- ▶ World best for $\Delta m_d/\Delta m_s$
[EPJ **C76** (2016) 412]

CKM unitarity and CP -violation

HFLAV for PDG 2018



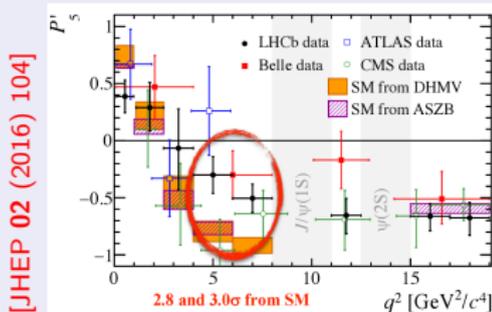
Loop-level measurements

- ▶ Precision measurement of ϕ_s in golden $b \rightarrow c\bar{c}s$ modes
 - [PRL **114** (2015) 041801]
- ▶ Also in BSM sensitive loop-dominated $b \rightarrow s\bar{s}s$ and $b \rightarrow d\bar{d}s$ modes (unique to LHCb)
 - [LHCb-CONF-2018-001], [JHEP **03** (2018) 140]

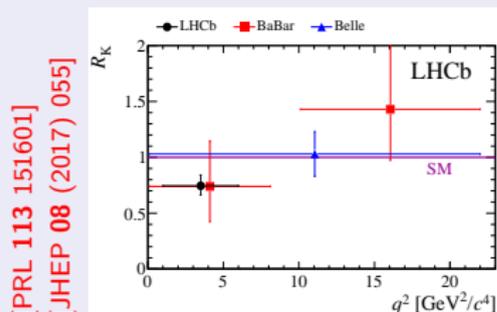
Flavour anomalies

► Deeper understanding is a key aim for Run 2 analysis

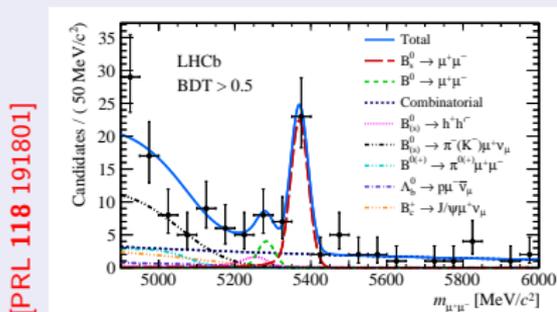
$B \rightarrow K^* \mu\mu$ angular observables



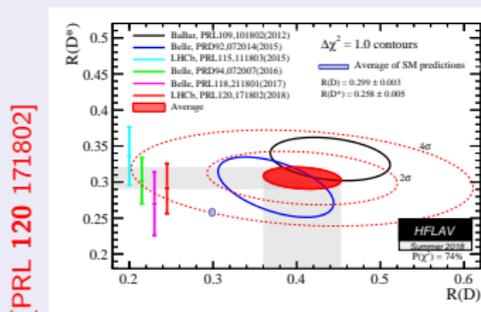
LFU in $B \rightarrow K^{(*)} \ell\ell$ (R_K and R_{K^*})



Interplay with $B_s^0 \rightarrow \mu\mu$



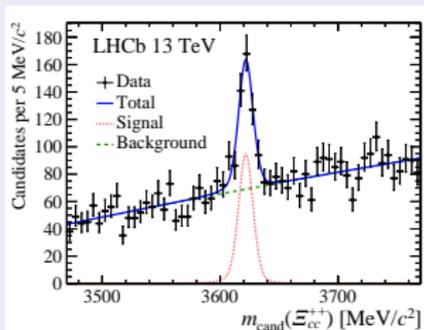
LFU in $B \rightarrow D^{(*)} \ell\nu$ (R_D and R_{D^*})



Other recent UK highlights

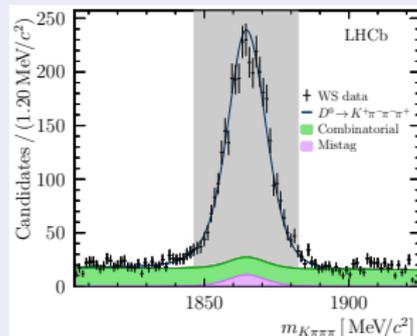
Observation (and lifetime) of Ξ_{cc}^+

[PRL submitted]
[PRL 119 112001]



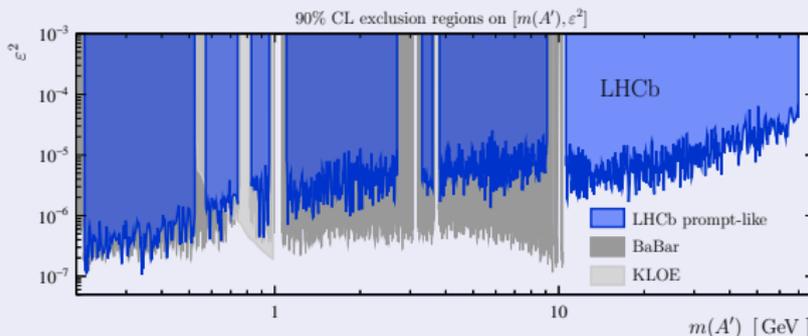
Doubly Cabibbo suppressed study in $D \rightarrow K3\pi$

[EPJ C78 (2018) 443]

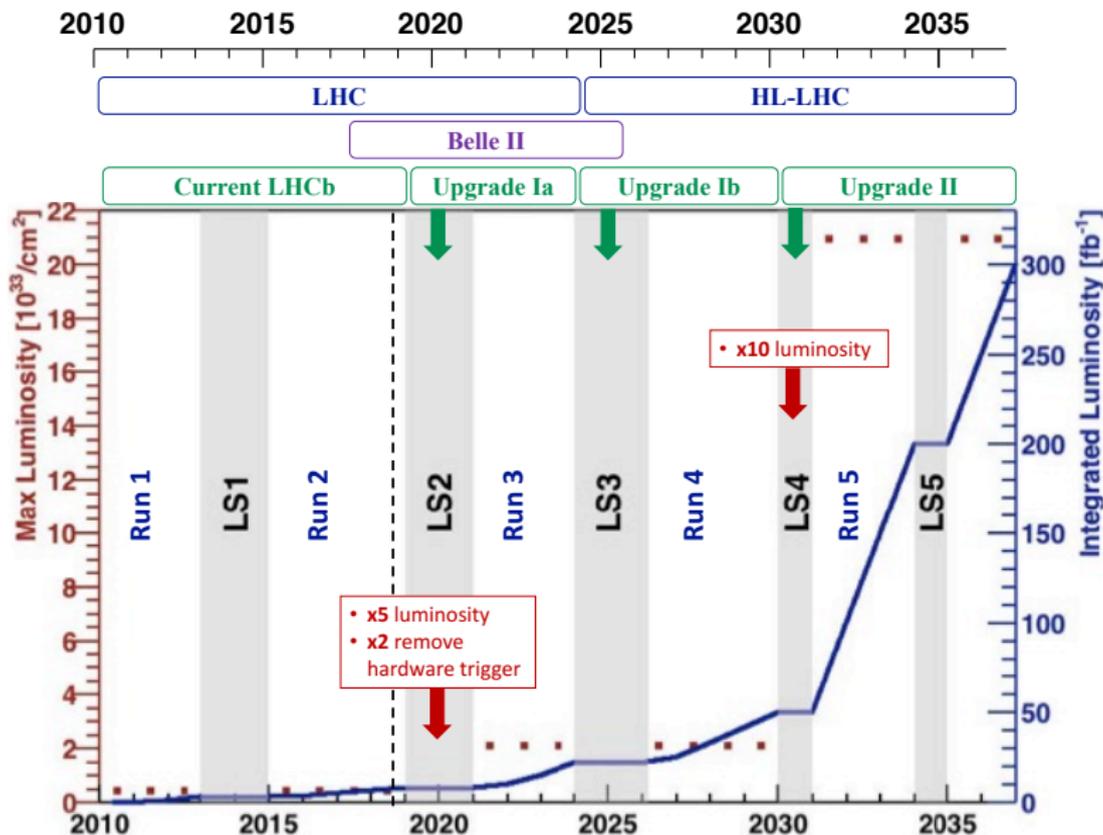


Dark photon search

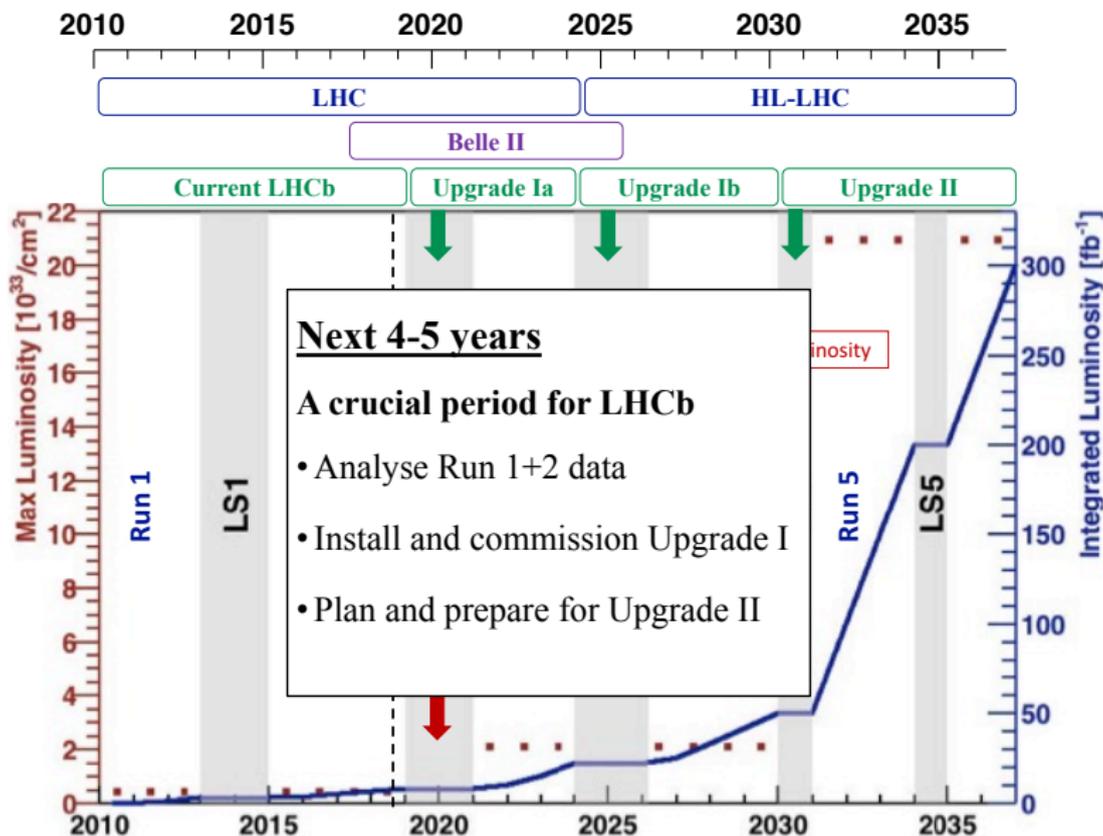
[PRL 120 061801]



2. Medium to Long Term Plans

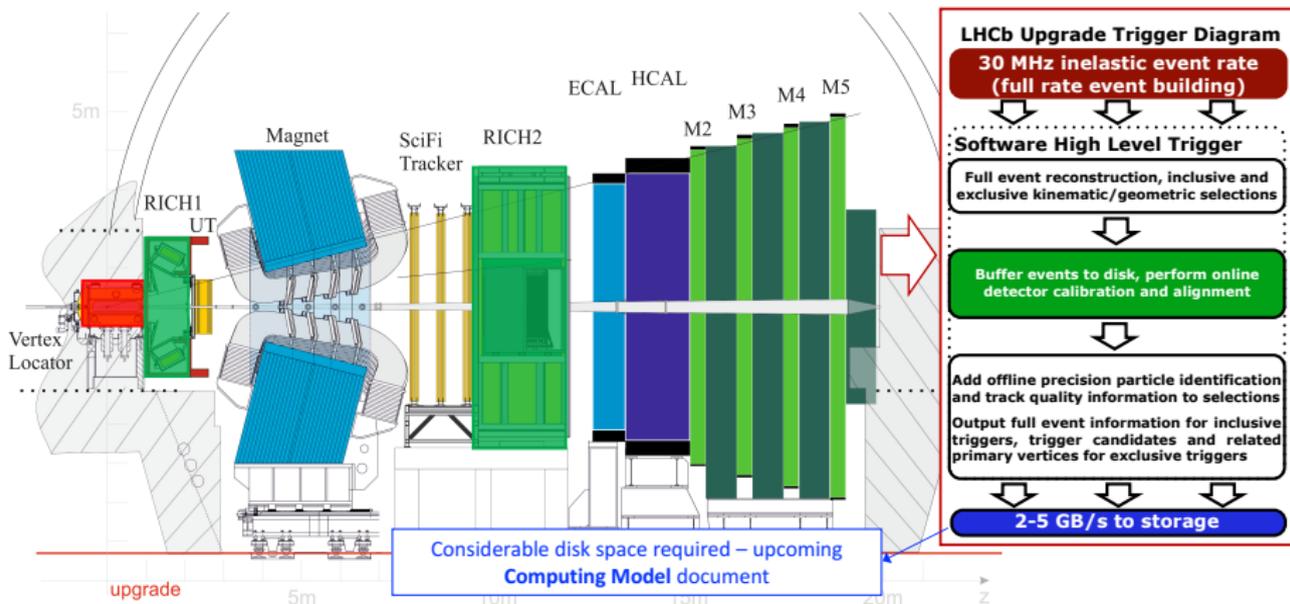


2. Medium to Long Term Plans



Upgrade Ia

- ▶ The largest throughput DAQ system ever built
- ▶ **A major construction project making good progress and largely on schedule**
- ▶ Predominant UK involvement in **VELO**, **RICH** and **Offline Computing**

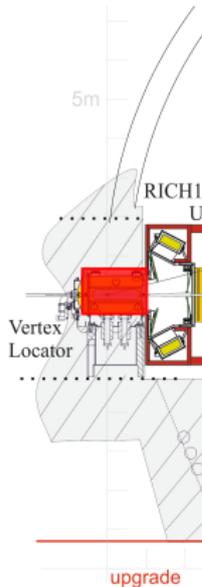
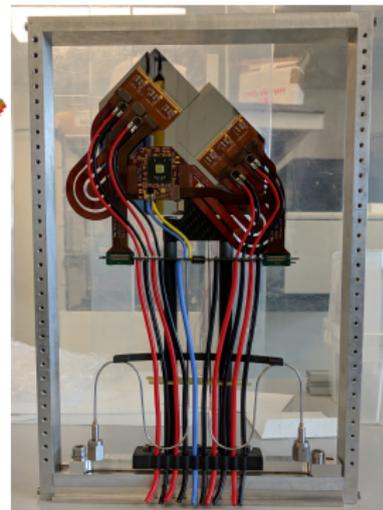
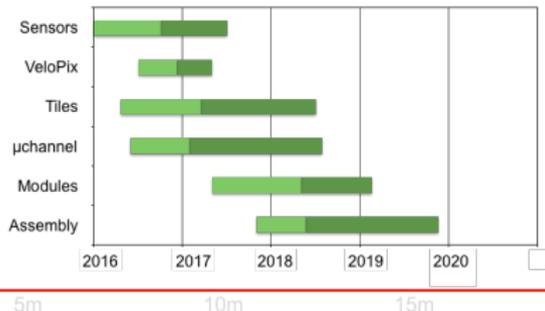
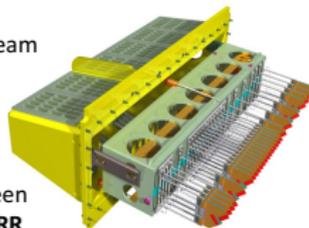


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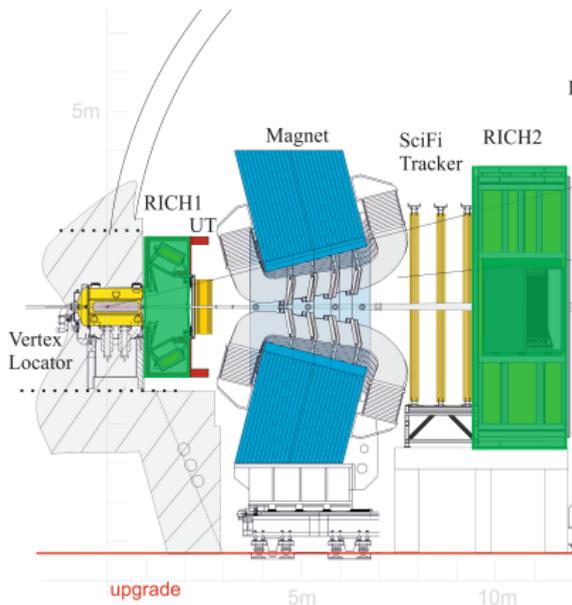
VELO

- Silicon pixels up to 5mm from beam line
- 52 modules in L-shaped config
- Some delays but **on track for production**
- No major technical issues foreseen
- **Yesterday completed module PRR**



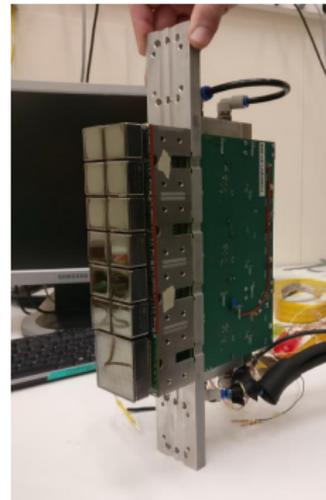
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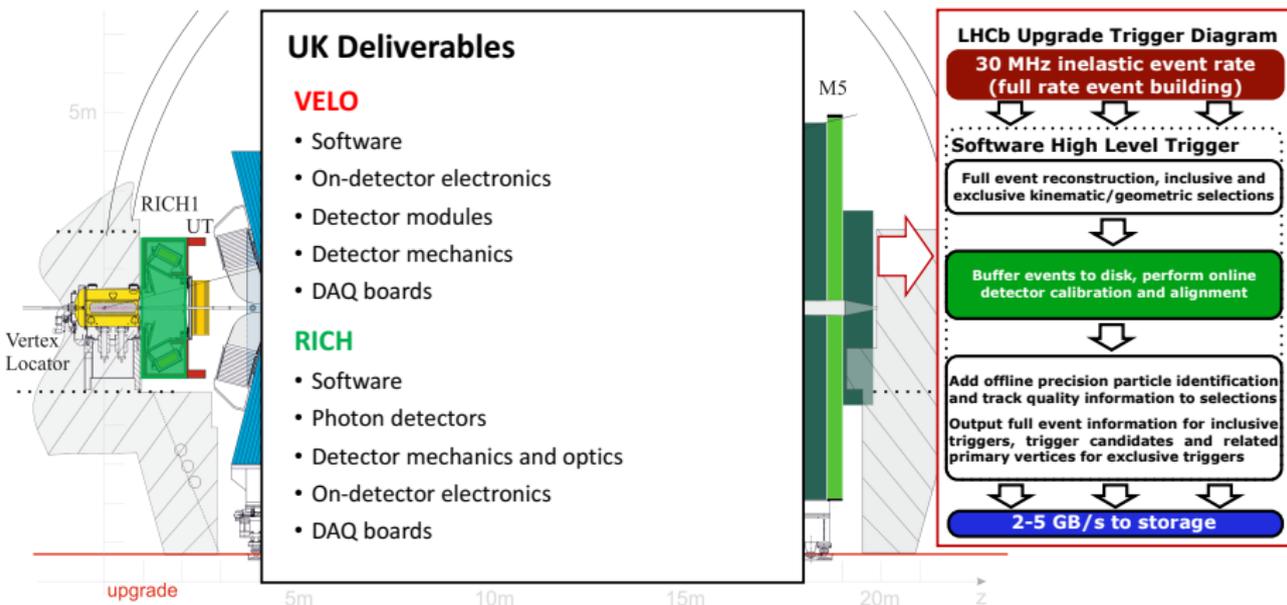
RICH

- New photon detectors
- New readout and services
- New optics and gas enclosure (RICH1)
- Test module **already installed and running**
 - Collecting light behind current system
- **All PRRs passed**
 - **No show stoppers**
- Moving to production, installation and commissioning phase



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Upgrade Ib - II

Exciting ideas for consolidation of Upgrade I and preparation of Upgrade II

► **Mighty (CMOS) Tracker**

- Downstream tracking near the beam pipe
- Complement Upgrade I SciFi detector

► **TORCH**

- Time-of-flight using Cherenkov light
- PID for low momentum objects

► **Magnet side stations**

► **ECAL**

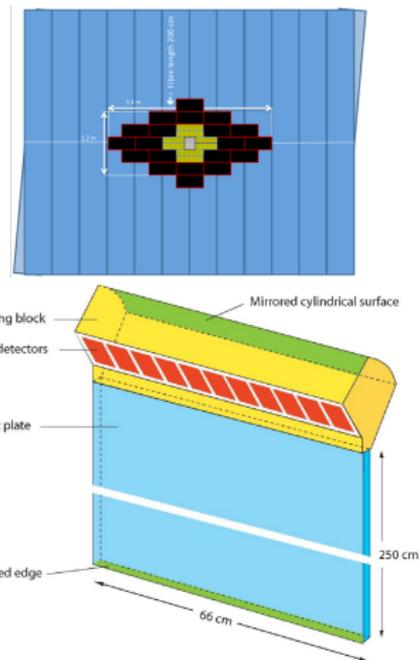
► **Timing VELO**

► **Timing RICH**

► **UK has an R&D grant for TORCH**

- Worldwide R&D ongoing for fast-timing and calorimetry in Upgrade Ib-II

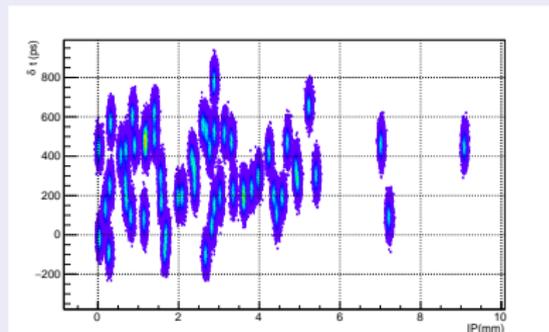
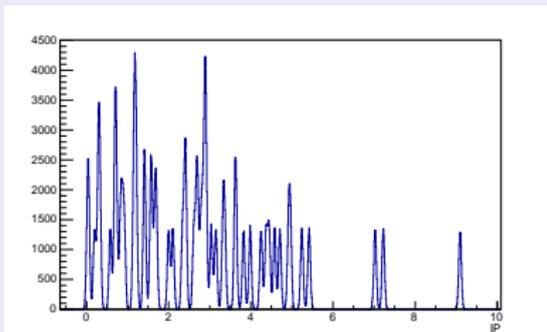
► **Upgrade Ib TDRs aiming for LHCC in Sep 2020**



Upgrade II

- ▶ **Machine requirements** can be met to deliver $50 \text{ fb}^{-1}/\text{year}$ to LHCb
 - ▶ “a range of potential solutions for operating the LHCb Upgrade II ... permitting the collection of 300 fb^{-1} or more at IP8” - [CERN-ACC-NOTE-2018-003]
- ▶ **Detector requirements** in high pileup and high occupancy environment
 - ▶ Maintaining performance of the tracking, flavour tagging and particle identification requires **precise timing**
- ▶ **Large increase in physics reach**

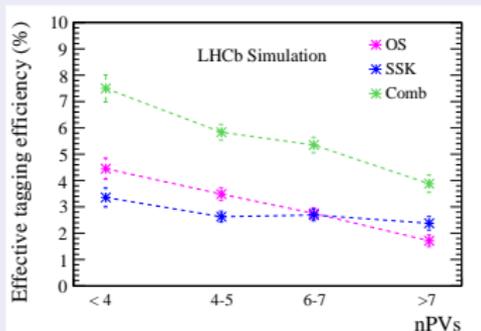
Example of timing to help associate correct primary vertex (in VELO)



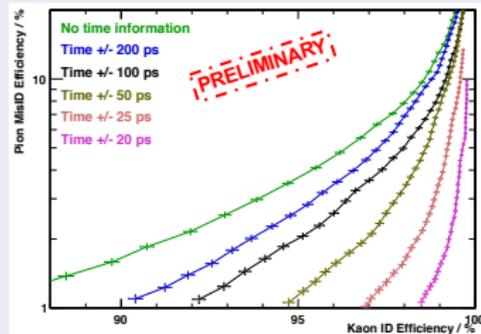
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Flavour tagging efficiency
(with current detector)



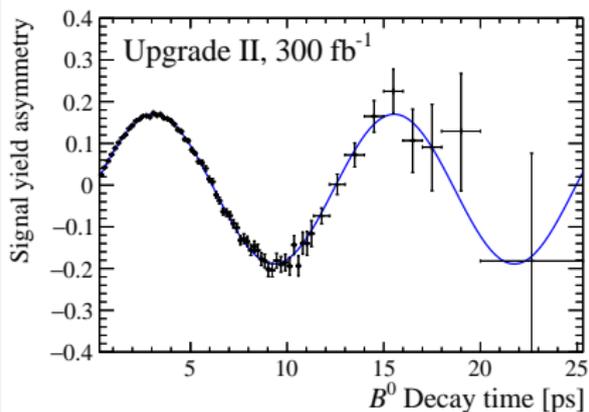
PID efficiency
(with current detector)



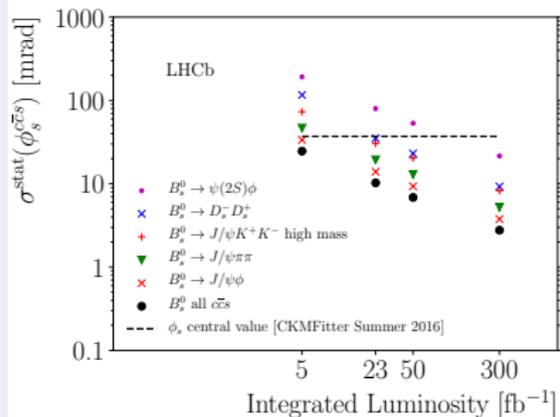
Time-dependent CPV in Upgrade II

- ▶ Vital to maintain **decay-time resolution** and **flavour-tagging** performance
 - ▶ Requires timing detectors
- ▶ Uncertainty on ϕ_s goes below the SM prediction for **several different modes**
- ▶ World best measurement of $\sin(2\beta)$

TD asymmetry in $B^0 \rightarrow J/\psi K_S^0$



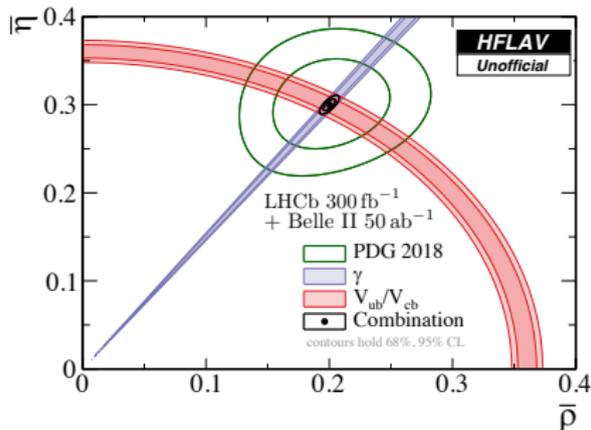
Uncertainty on ϕ_s



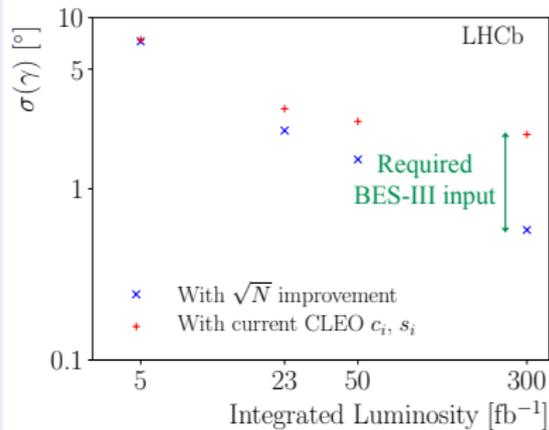
Time-integrated CPV in Upgrade II

- ▶ Unprecedented precision ($\sim 0.3^\circ$) in **theoretically clean** extraction of γ
 - ▶ **Close collaboration with BES-III required** (see Sneha Malde's talk)

Tree-level CKM constraints with 300 fb^{-1}



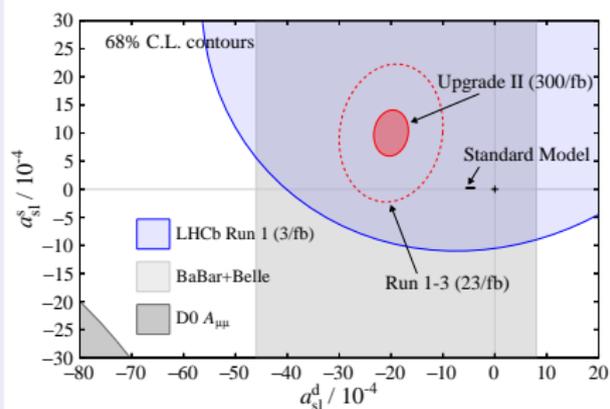
γ sensitivity with $B^\pm \rightarrow [D^0 \rightarrow K_S^0 hh] K^\pm$



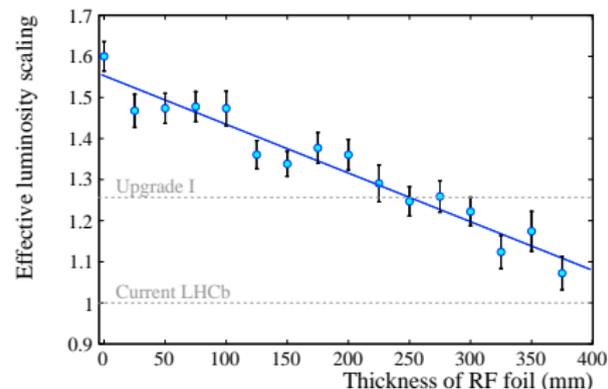
Semileptonic CPV with Upgrade II

- ▶ Particular gain for semileptonics with reduction of RF foil thickness
 - ▶ Use of TORCH for V_{ub} with $B_s^0 \rightarrow K_{\mu\nu}$

Semileptonic Asymmetries with 300 fb^{-1}



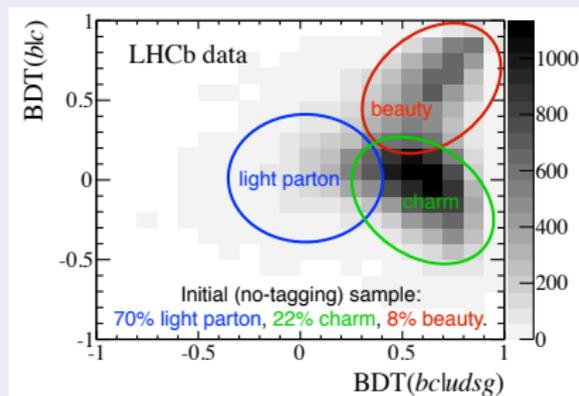
Effect of reduced RF foil



Other physics opportunities with Upgrade II

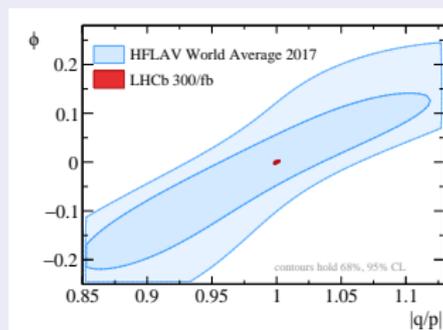
- ▶ Many, many other physics opportunities in **Charm**, **Rare Decays**, **SM measurements** and **BSM searches**

$H \rightarrow c\bar{c}$

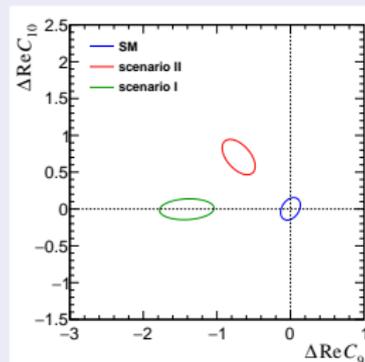


- ▶ With 300 fb^{-1} can set upper limit on charm Yukawa coupling of $\approx 7y_{\text{SM}}^c$

Charm Mixing at 300 fb^{-1}



Wilson Coefficients fits at 300 fb^{-1}



Summary I/II

1. The LHCb experiment is performing exceptionally well

- ▶ Delivering an incredibly **broad physics programme**
- ▶ Some **exciting and unexpected results** across a diverse range of topics
- ▶ Detector **operation** and data **exploitation** funded through CG and external grants (e.g. fellowships, ERC, etc.)

2. The first Upgrade (Ia) is on good track to deliver physics in Run 3 (2021)

- ▶ Design and prototype stages are largely complete
- ▶ Moving onto production, installation and commissioning
- ▶ **Funding is in place until 2020**
 - ▶ **R&D** and **construction** covered by PPRP grant plus CG effort
 - ▶ Need **extensions for key posts** for **installation and commissioning** - requested through the CG
- ▶ **R&D, proto-typing & construction all covered by a single grant**
 - ▶ This adds significant challenges (timescale + risk)
 - ▶ Although on track to have UK deliverables on time and in budget
 - ▶ **For future upgrades we would hope to have a funded R&D phase followed by a proto-type and construction phase**

3. A clear vision to exploit the precision flavour physics potential of the HL-LHC

- ▶ R&D ongoing at a small level for future upgrades
 - ▶ Through small grants or unfunded effort
 - ▶ Modest effort has been requested in the CG to continue this
- ▶ EoI and forthcoming Physics Document for Upgrade II
- ▶ Anticipate submitting an **Sol to STFC later this year for UK involvement in Upgrades Ib and II**
- ▶ Collect at least 300 fb^{-1} and extend physics reach to unprecedented levels

4. LHCb Upgrades Ia, Ib and II are an essential part of the UK and European particle physics programmes in the medium and long term future

- ▶ UK input to the European Strategy process must reflect this

The full exploitation of LHC + HL-LHC data should remain a top priority for the UK. This includes the extensive flavour physics program of LHCb and its upgrades