LHCb in the HiLumi LHC era

- The LS2 / phase-1 Upgrade: recap
- Belle-II: data-taking timescale
- Consolidation opportunities in LS3: phase 1b
- Towards HiLumi operation: phase 2
- Summary

Guy Wilkinson
on behalf of the UK LHCb collaboration
26/7/16

The LHCb phase-1 Upgrade: recap

Recall, the LHCb phase-1 Upgrade takes place in LS2. The two main ingredients:

1) Replacement of hardware trigger with fully software-based trigger, bringing higher efficiency and greater flexibility.

   Necessitates full detector read-out at interaction rate and the construction of the world's highest throughput DAQ system.

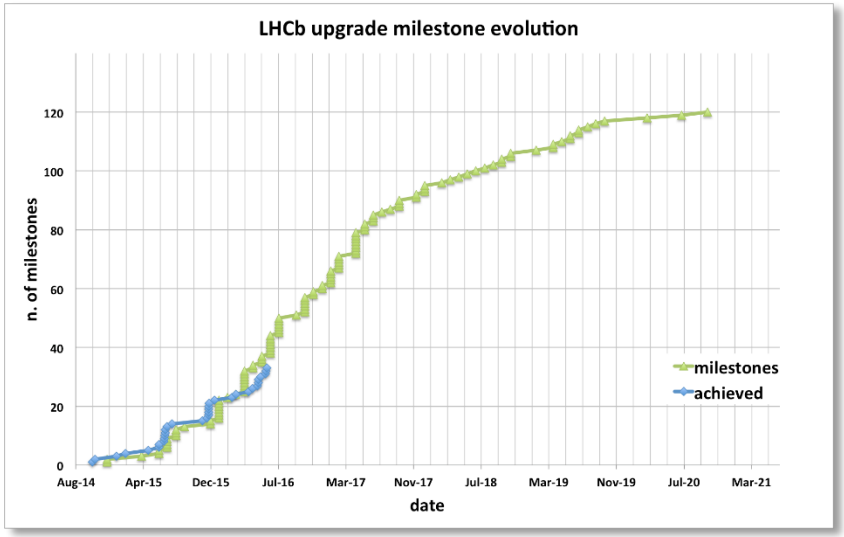
2) A rise in the operational luminosity to 2 x 10^{33} $cm^{-2}s^{-1}$, which requires redesign of many sub-detectors.

UK has a leading role in VELO & RICH projects, & also contributing to computing.

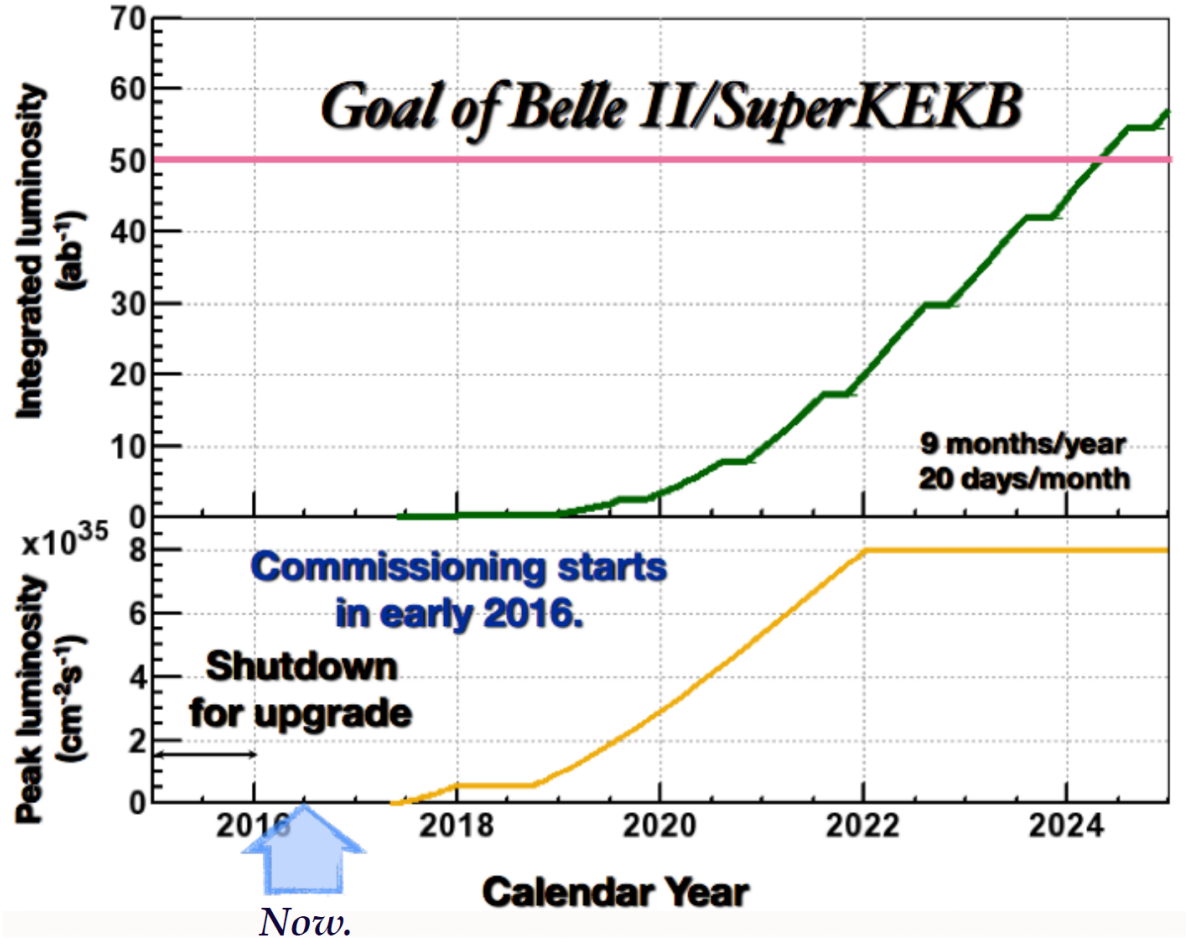
Verdict of May 2016 LHCC:

- LHCb is pushing the envelope in many respects and moving into new territory; developing new paradigms for collider detectors.
- The collaboration has set the bar high for the upgrade and are to be commended for their drive and vision

Requirement to be ready for LS2 imposes a very tight schedule, but we remain on track.



Meanwhile, way out East…



Beams now circulating in SuperKEKB.

In the LHC time-frame, serious production begins in LS2, and continues through Run 3.

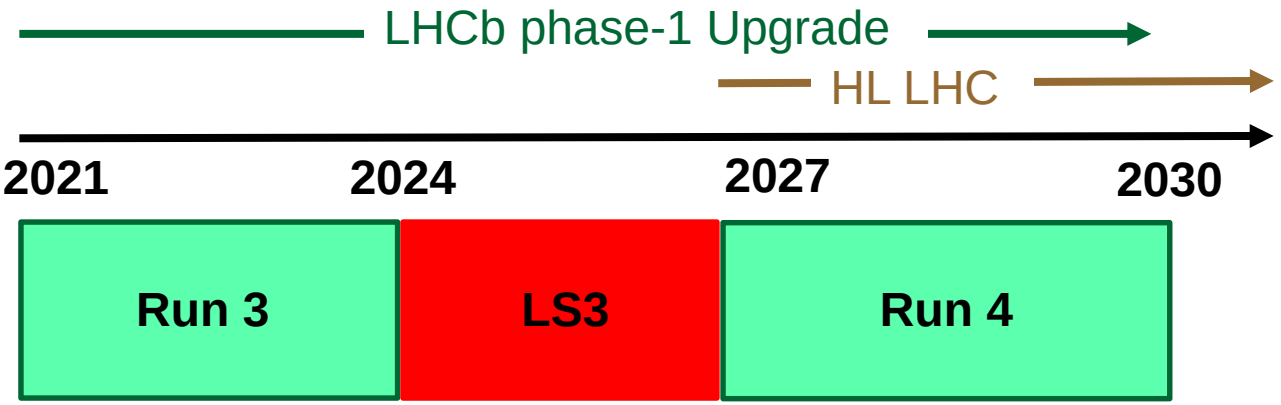
Exciting physics programme, which is (mostly) complementary to LHCb.

Currently, no plans to continue beyond ~2025.

Eugenio Paoloni, FPCP 2016, Caltech

The LHCb phase-1 Upgrade: data-taking schedule and opportunities

The goal of the phase-1 Upgrade is to collect ~50 fb^{-1}, around x5 int. lumi. of current experiment (with improved trigger, remember). This can be done in run 3 & run 4.



The software trigger will allow us to refine & improve data taking strategy each year.

Moreover the (very) long shutdown of LS3 will provide opportunity to consolidate the project, enhance LHCb with new capabilities that will bring extended physics opportunities in run 4, and even lay the foundations for the further future.

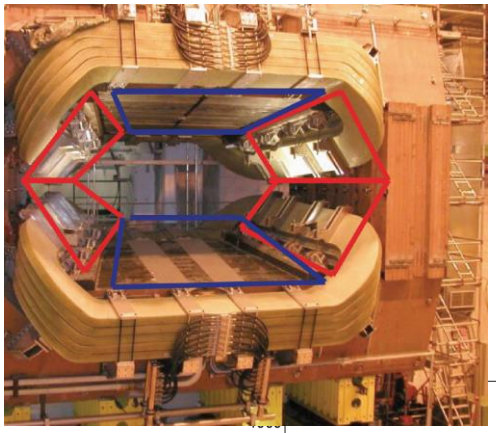
→ a phase-1b 'Upgrade' (very much a consolidation of what will have been put in place during the previous long shutdown)

Phase-1b opportunities

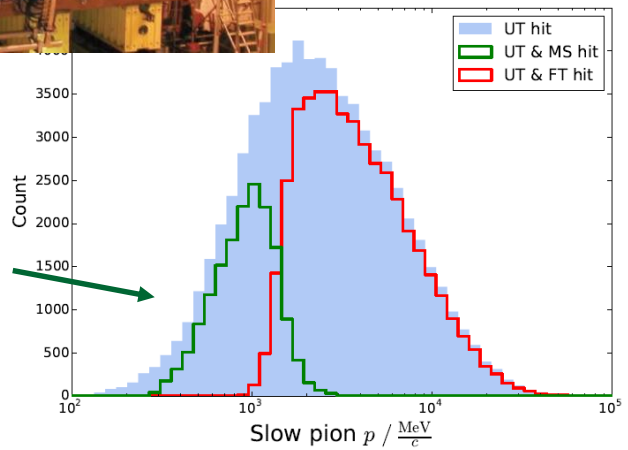
Several possibilities are under active consideration for enhancing the detector's performance, which could be installed during LS3.

- Side-chambers within dipole
- Novel TORCH detector, for fast timing and low-p PID
- Inner Si tracker
- New photodetectors in central region of RICH-1
- Higher performant technology in inner region of ECAL
- Replacement of HCAL with additional muon shielding, and new detectors in high rate regions

Increase acceptance for soft tracks, *e.g.* slow pions from D* decays. Substantial gains for high multiplicity final states, *e.g.* exotic hadron studies.



Recoverable D* decays



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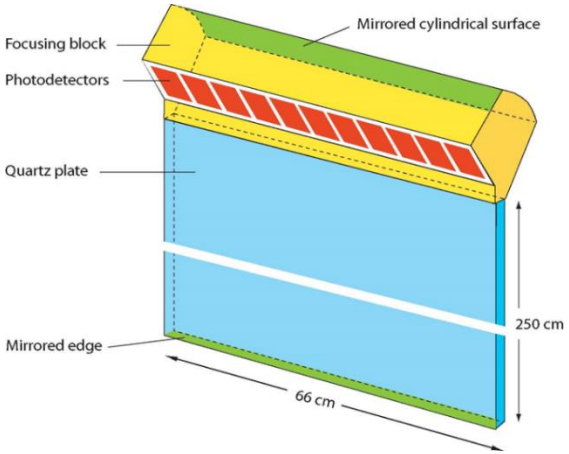
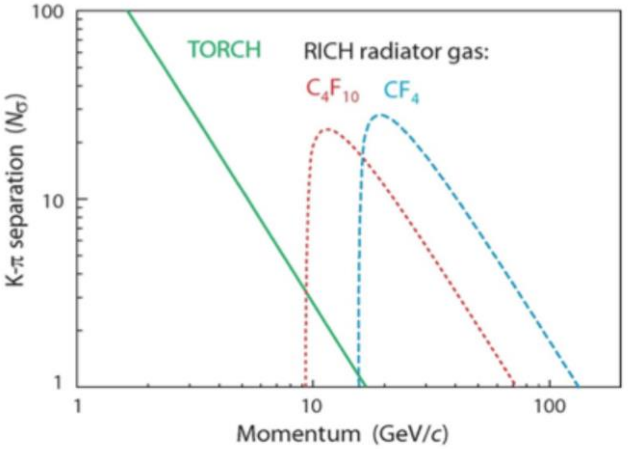
Prototype construction & photodetector development supported by ERC grant.



One TORCH module. compact → several candidate locations wthin LHCb detector.



Provides PID in 2-10 GeV/*c* region below coverage of RICH system.

Fast timing (goal of ~15 ps per track) very interesting for pile-up mitigation.

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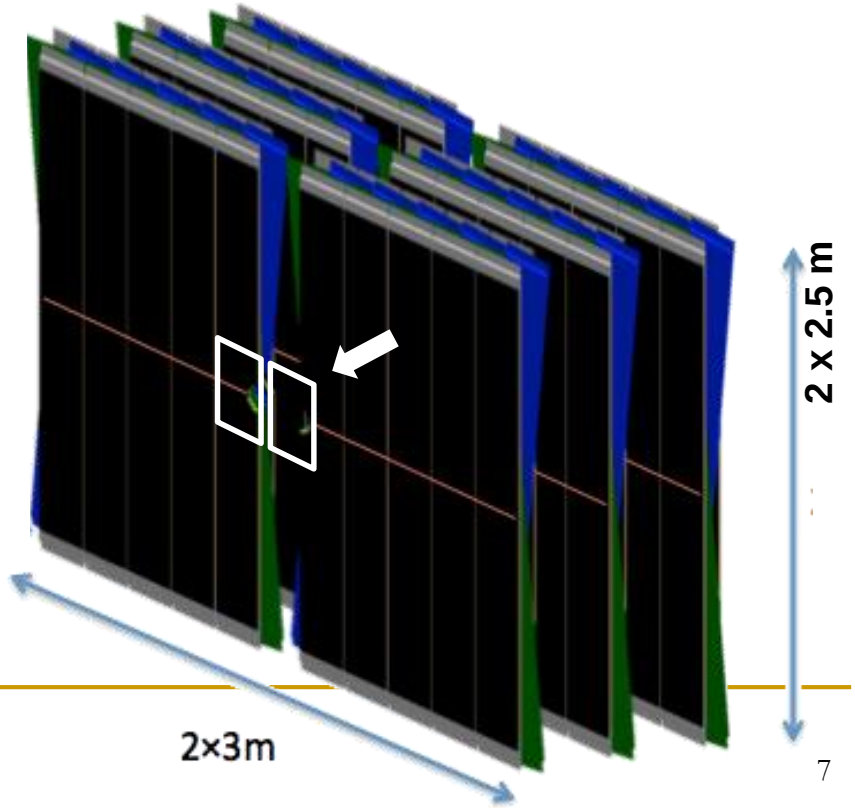
Improved tracking performance achievable by replacing inner most region of SciFi with Si-based (CMOS?) inner tracker, which will also approach closer to beam-pipe.



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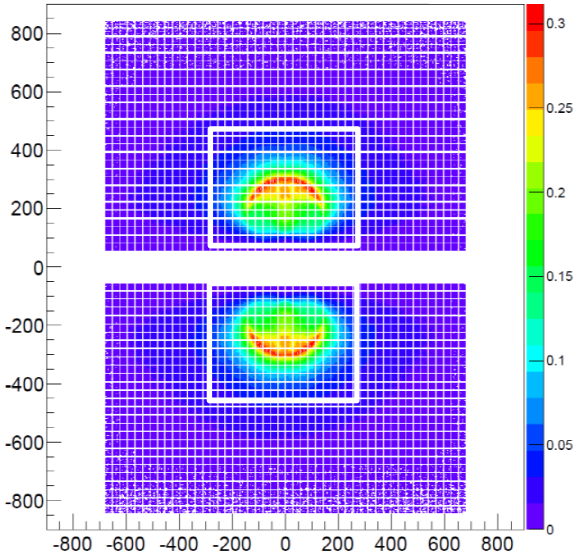
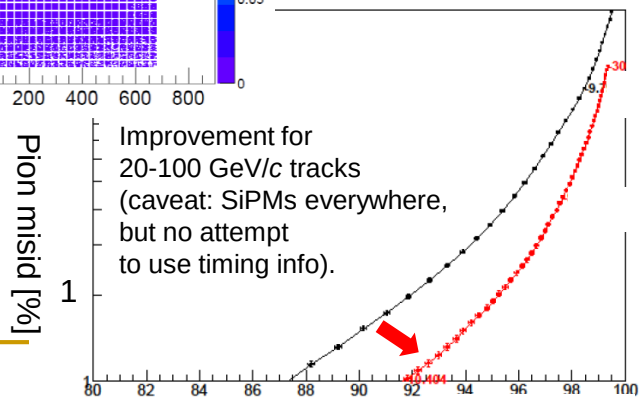
Higher resolution SiPMs provide better performance in most critical region of photodetector plane.



Other benefits:

- Reduced chromatic dispersion
- Possibility to use fast-timing info



Natural first step towards RICH for high lumi operation (see later)

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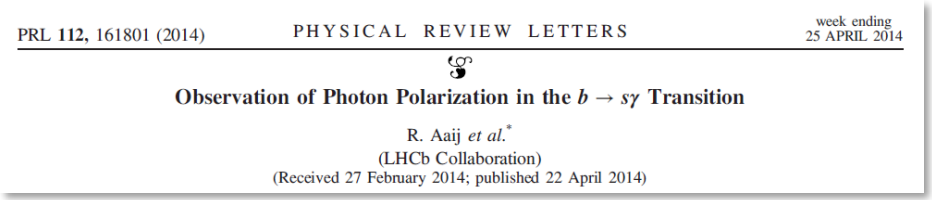
LHCb has demonstrated B-physics with neutrals possible at hadron machine, *e.g.*

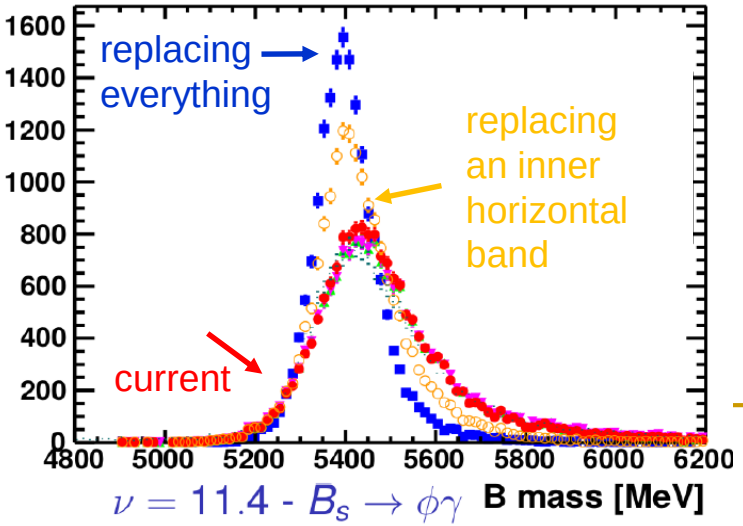


PRL 112, 161801 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Observation of Photon Polarization in the $b \to s\gamma$ Transition

R. Aaij *et al.**
(LHCb Collaboration)
(Received 27 February 2014; published 22 April 2014)

Innermost modules of Pb-shaslik ECAL will need replacing in LS3. Tungsten-based technology change in inner region under study.



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HCAL's primary role in LHCb is in trigger at earliest level. No longer needed at Upgrade, certainly after early years.

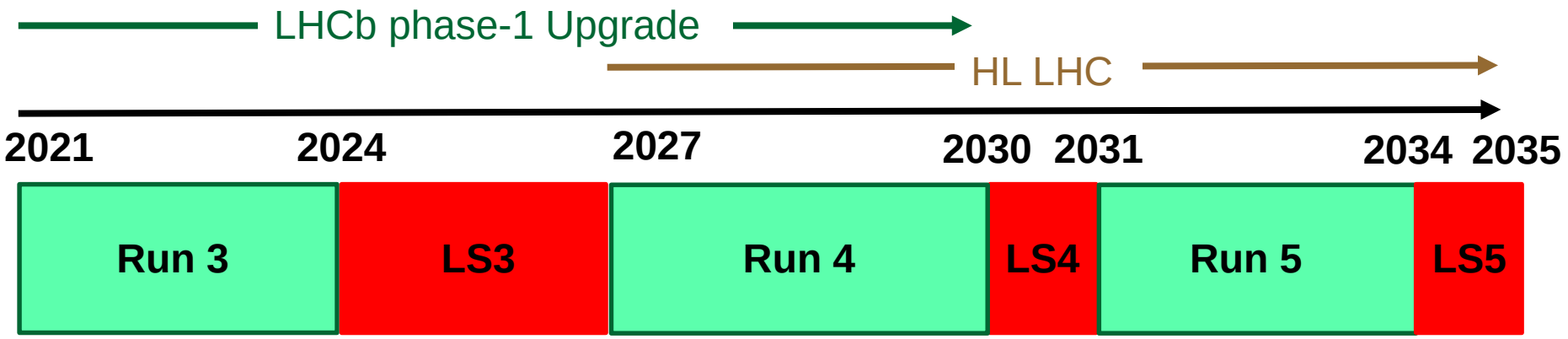
Engineering design of proposed new iron-shielding in HCAL region.

Replace with iron to reduce punch-through rate to muon system by a factor of 2.

Physics benefits, technological feasibility and cost of each option under study. UK playing a leading role in several of these initiatives.

Phase-2 possibilities

By LS4 it is likely that the phase-1 Upgrade will have integrated the target 50 fb^{-1}



Physics case for phase-2 Upgrade – isn't it 'mission accomplished' with 50 fb^{-1} ?

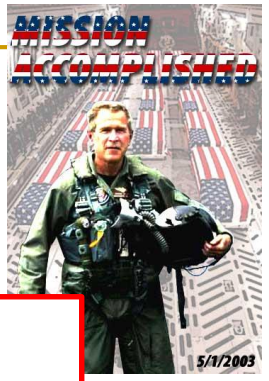
Usual summary of phase-1 Upgrade physics reach is very impressive…

['old' table from EPJ C 73 (2013) 2373; arXiv:1208.3355.if re-made with current numbers the argument would remain]

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\,\phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\,f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\rm fs}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\,A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [19, 20]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\,K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
CP violation	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

…but in most cases we do not reach the theory uncertainty. Even if we do, one can speculate that this theory uncertainty may decrease. And there are many important observables not listed here where improved precision will be essential.

Physics case for phase-2 Upgrade – isn't it 'mission accomplished' with 50 fb^{-1} ?



And it's not just flavour…

- Hadronic spectroscopy

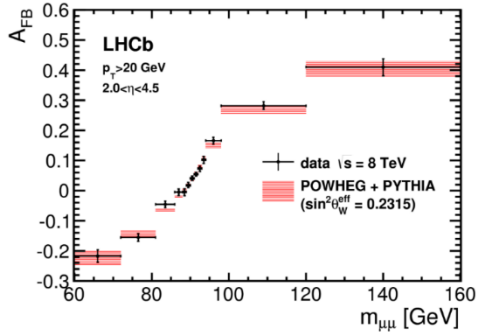
  We wish to perform amplitude analyses for exotic hadron studies in which we currently only have a handful of events (or none). Need 1000's…

- EW physics

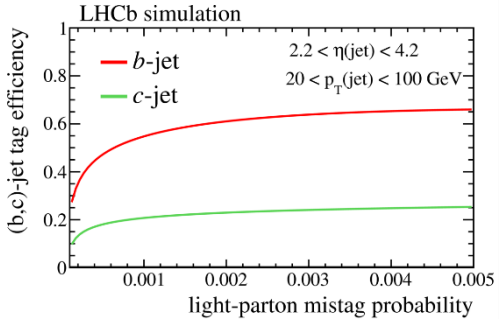
  LHCb's capabilities in EW physics Already well demonstrated (*e.g.* best LHC measurement of $\sin^2\theta_W$)

- Many others

  e.g. LHCb has superb beauty and charm tagging performance. Opportunities for H→ccbar if sample size can be boosted ?



[JHEP 11 (2015) 190]



[JINST 10 P06013]

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Phase-2 possibilities – flavour physics at very high luminosity

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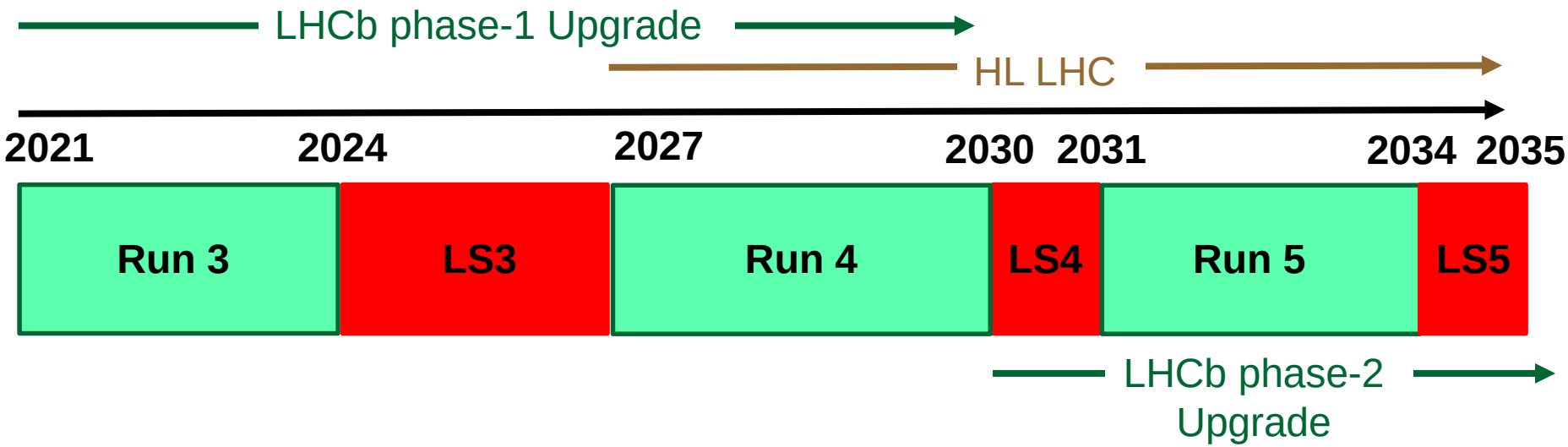

The data-doubling time will be prohibitive for further progress with the same detector.

Hence an opportunity for a phase-2 Upgrade ! To increase yields in most modes of interest the only option is to raise luminosity. Considerations point to a target of ~2 x 10^{34} cm^{-2} s^{-1} & ~300 fb^{-1}. This scheme would bring a 3rd high-lumi IP to the LHC.

Phase-2 Upgrade: machine challenges

Feasibility of ~10^{34} operation at IP8 must be established reasonably quickly, as preparations must be made for installing appropriate shielding elements around IP.

Already many studies carried out by HL-LHC team. The preliminary conclusion is encouraging!

Minimum β* of between 1 and 2 m should be attainable.

NB: minimal impact on ATLAS/CMS.

Studies are ongoing.

Integrated luminosities

Levelled luminosity LHCb [10^{34} $cm^{-2}s^{-1}$]	Opt fill length (IP1/5) [h]	Integrated luminosity ATLAS/CMS [fb^{-1}/y]	Integrated luminosity LHCb [fb^{-1}/y]	β* IP8 [m]	Levelling time IP8 [h]
0.2 (nom.)	9.3	261	10.4	3	9
1	9.1	258	28	3	0.5
1	9	257	37	2	3
1	8.8	256	47	1	6
2	9.1	258	28	3	0
2	8.9	257	41	2	0
2	8.5	253	70	1	2

- Scaling and impact of additional burn-off without aperture constraints
- Integrated luminosity in Atlas/CMS substantially independent from LHCb one
- No levelling in LHCb if low β* not reachable.

G. Arduini

from Oct '15 HL-LHC/LARP meeting

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One attractive scenario

- Scaling and impact of additional burn-off without aperture constraints
- Integrated luminosity in Atlas/CMS substantially independent from LHCb one
- No levelling in LHCb if low β* not reachable.

G. Arduini

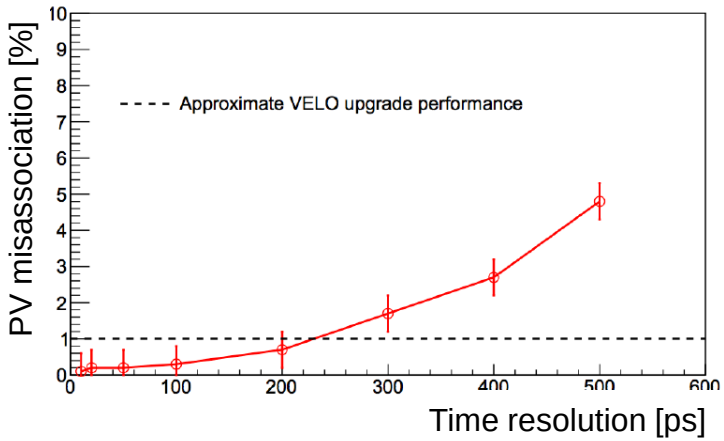
from Oct '15 HL-LHC/LARP meeting

Phase-2 upgrade: detector challenges

Clearly the challenges of are very daunting. Although we can benefit from several of the initiatives being proposed for phase-1b, and of course the R&D performed for the phase-2 ATLAS/CMS Upgrades, significant new developments will be required.

New VELO and RICH detectors (UK specialities) will be central to project.
First thinking and preliminary studies already underway:

VELO time-resolution studies for associating correct primary vertex and B-decay vertex



RICH changes under consideration

- SiPMs with ~1mm pixel size to reduce occupancy & spatial resolution
- 'Red-shifted' quantum-efficiency response, to reduce chromatic error
- Mods to RICH-1 optics (using light-weight mirrors) to reduce emission point error
- Use of fast timing information

Very stimulating detector-development problems, with great physics rewards !

Summary

The phase-1 LHCb Upgrade is progressing well. It will be installed during LS2 and will be ready to begin data-taking at the start of run 3.

The extended long shutdown of LS3 provides an excellent opportunity to consolidate the phase-1 project, augmenting the detector to enhance the physics performance during run 4.

- Several options under active evaluation;
- A first plan will emerge by end of year;
- It is acknowledged that resources are scarce, and any proposal must reflect this (this is not a new upgrade…).

The HiLumi LHC also opens the door to the possibility of performing precision flavour physics and a general forward programme at very high luminosity.

- Machine studies ongoing, but look promising;
- Exciting detector challenges !

Preliminary discussions with the CERN management and LHCC have taken place. These plans will be formally communicated to the LHCC early in 2017.

Backups