"Rats live on no evil star"

The campaign for flavour physics at 10^{34}

Guy Wilkinson
University of Oxford
28/5/17

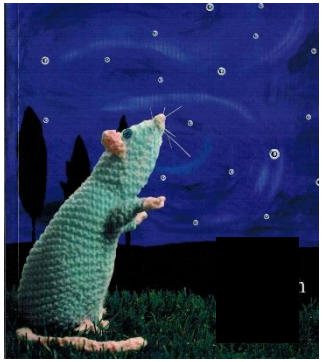
The poetry of palindromes

Able was I ere I saw Elba

The poetry of palindromes

Able was I ere I saw Elba

Rats live on
no evil star



A Santa lived
as a devil
at NASA

Dammit I'm mad

The poetry of palindromes

Able was I ere I saw Elba

Desserts, I stressed

The poetry of palindromes

Able was I ere I saw Elba

As I pee, sir, I see Pisa

The poetry of palindromes

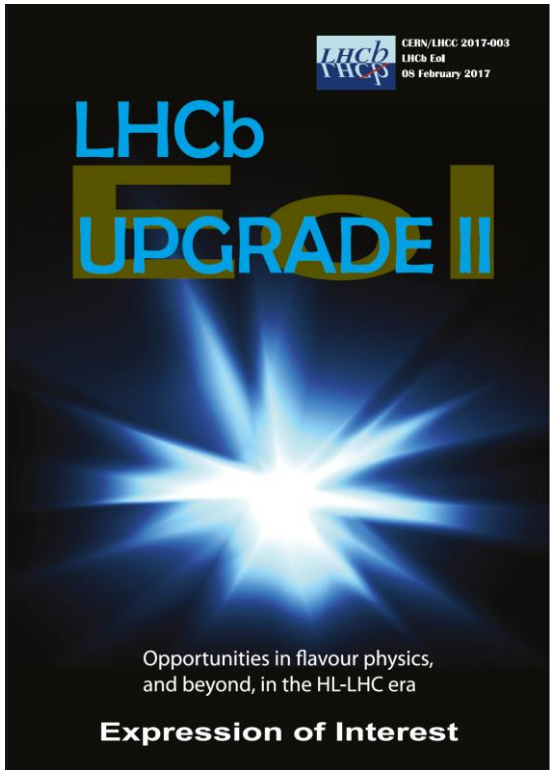
Able was I ere I saw Elba

I, man, am regal;
a German am I

The poetry of palindromes

Are we not drawn onward,
we few, drawn onward
to [a] new era ?

(symmetry breaking)



Elba: lessons (to us all) from history

The glory years

Emperor of flavour physics

An enforced pause

Plotting the stage-II project

The new campaign

Not quite what was promised in the TDR

(Slide first shown at Super-B workshop, Elba, 30/5/11)

Elba: lessons (to us all) from history

The glory years

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Plotting the stage-II project

The new campaign

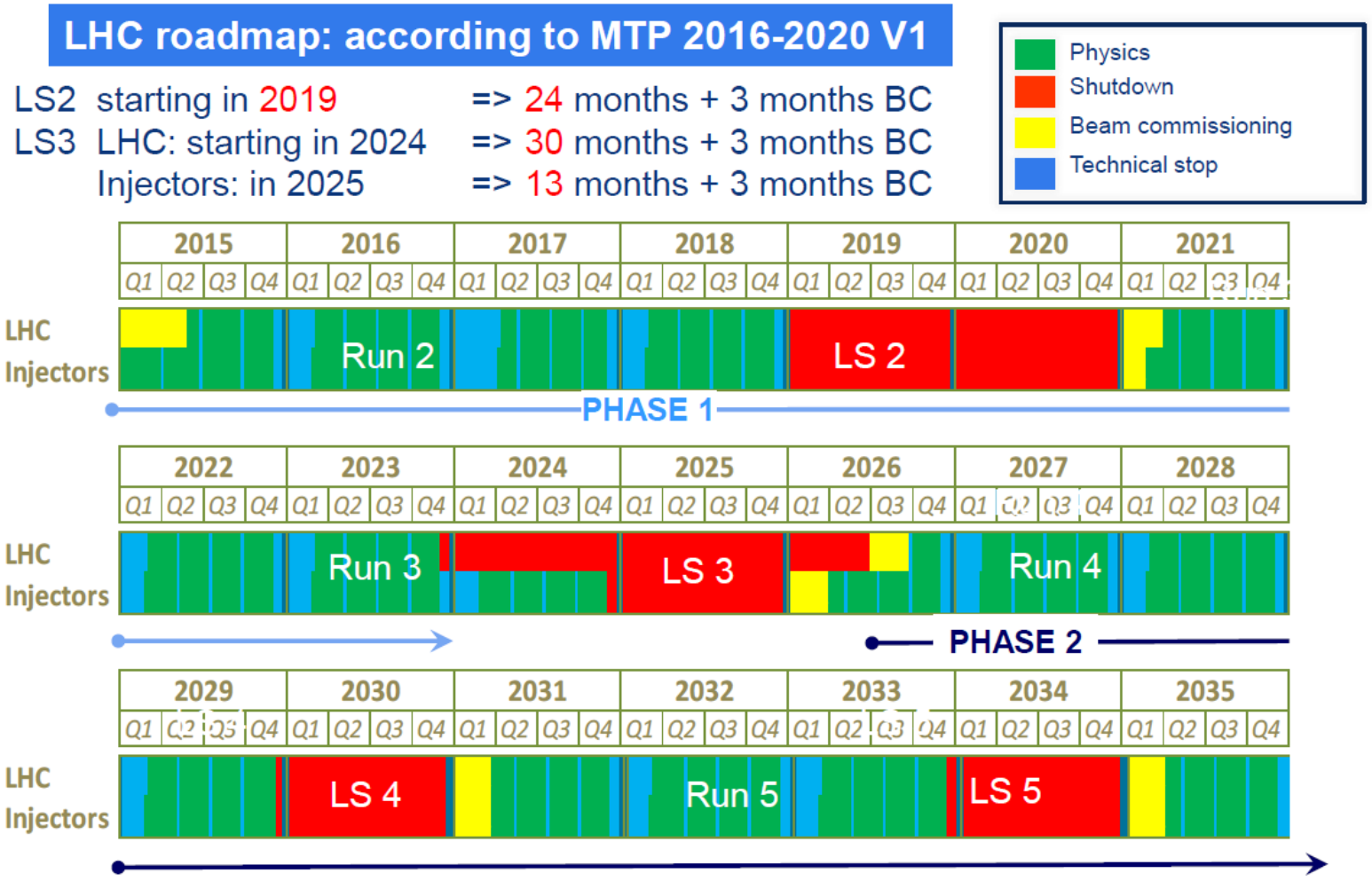
Not quite what was promised in the TDR

History tells us:

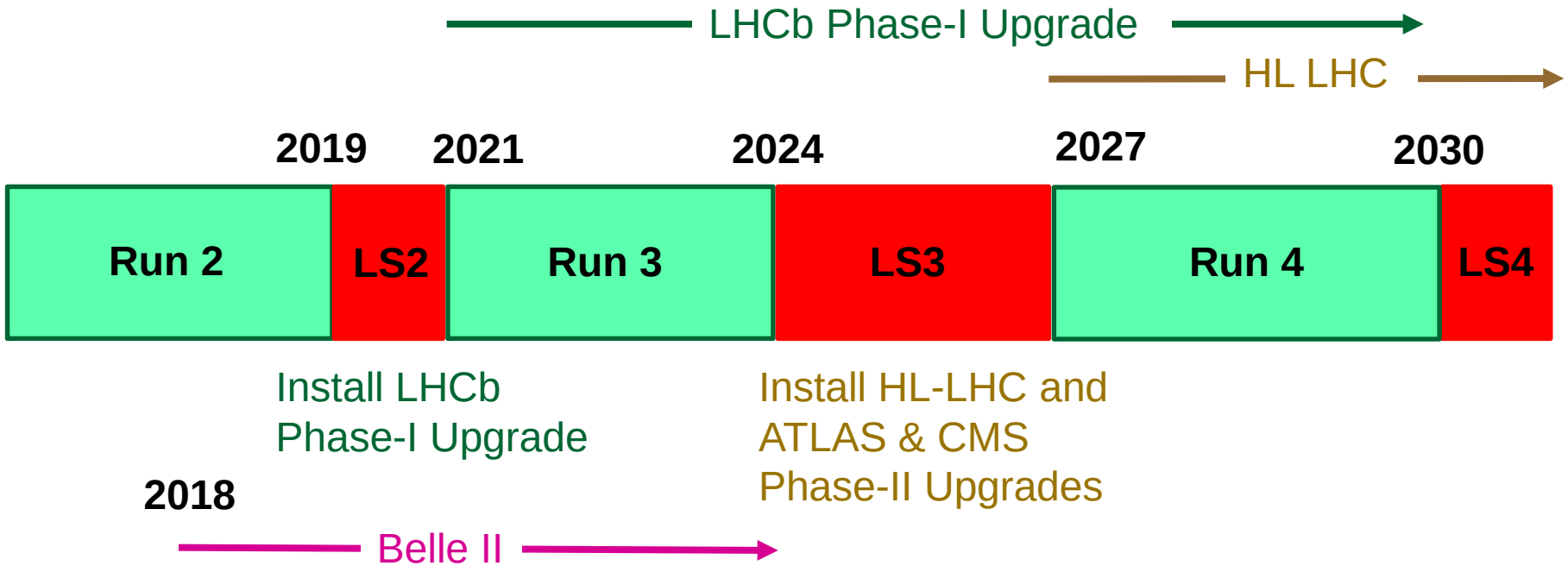
- plan carefully
- choose realistic goals
- do not underestimate the competition

(Slide first shown at Super-B workshop, Elba, 30/5/11)

The LHC schedule up to 2035



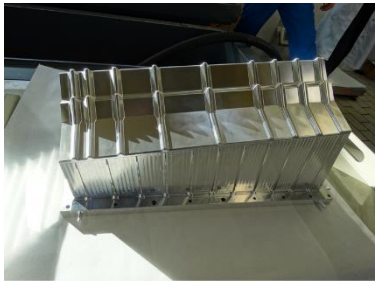
The LHC schedule up to 2030



Progress with Phase-I Upgrade

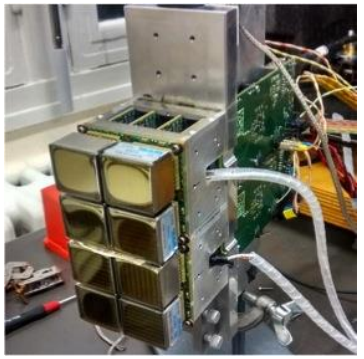
Intense activity in all sub-systems, with many now entering the production phase.

Prototype 40 MHz readout board



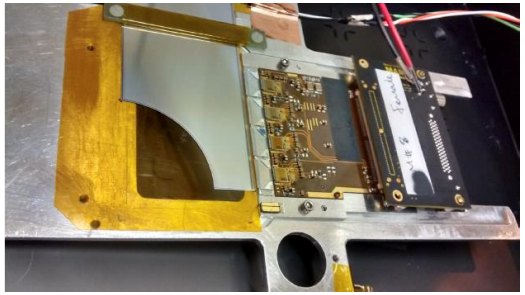
Prototype RF box for VELO

Mat production for SciFi

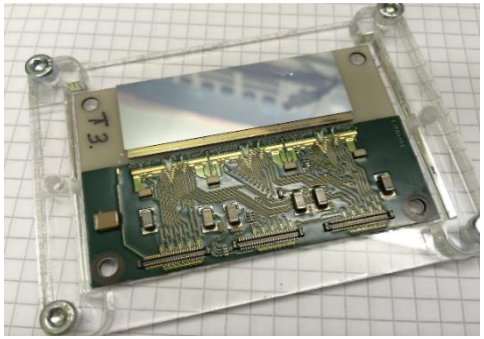


Photodetectors for RICH 1

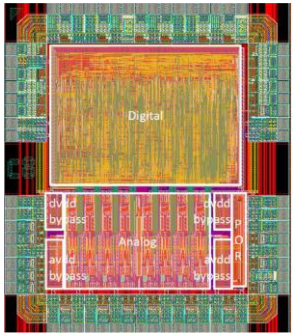
Spare production of muon chambers



Evaluation of Si modules of Upstream Tracker



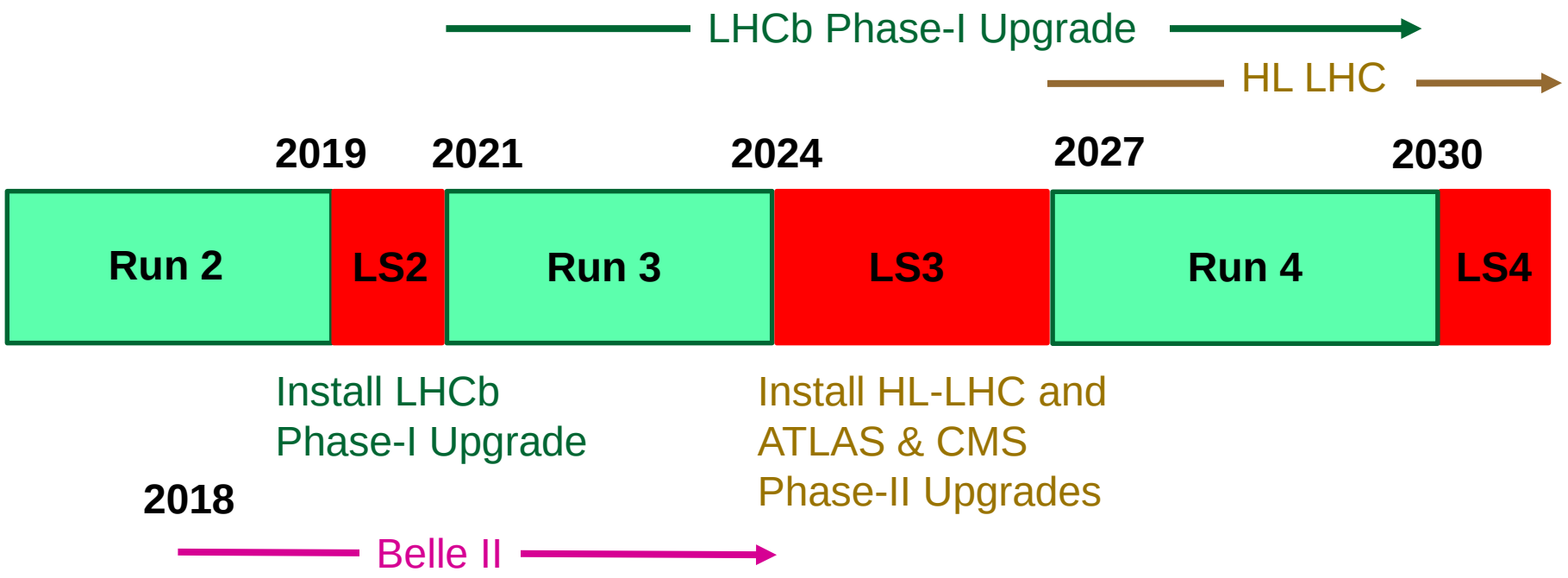
VELO sensor bump-bonded to ASICs + quarter hybrid



RICH ASIC

"Not impossible that it will be ready in time"
statement of LHCC chair following recent in-depth review

The LHC schedule up to 2030

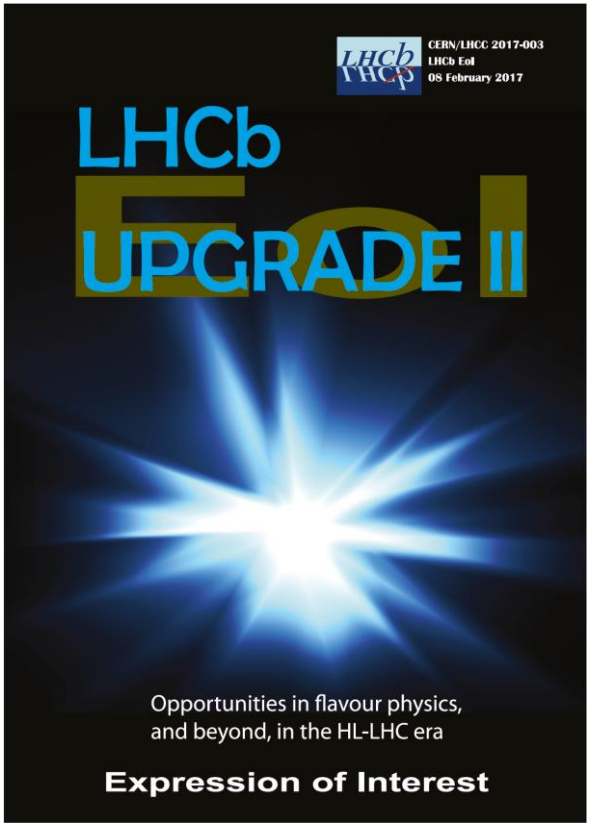


Unaware of any plans for future e^+e^- Y(4S) plans beyond Belle II.

The LHCb Phase-I Upgrade will enable experiment to integrate 50 fb^{-1} by end of Run 4. Significant progress beyond then requires a new experiment.

LHCb Phase-II Upgrade

Serious thinking began a couple of years ago, & in April 2016 a workshop was held in Manchester. This year an Expression of Interest was submitted to the LHCC.



[CERN-LHCC-2017-003]

"It is proposed to upgrade the LHCb experiment in order to take full advantage of the flavour-physics opportunities at the High Luminosity LHC (HL-LHC).
…..

This project will extend the HL-LHC's capabilities to search for physics beyond the Standard Model, and implements the highest-priority recommendation of the European Strategy for Particle Physics (Update 2013), which is to exploit the ***full potential of the LHC*** for a variety of physics goals, including flavour."

LHCC reaction to EoI and this workshop

From LHCC minutes:

- The **LHCC notes** the submission of the EoI for LHCb upgrades beyond Phase-I, and **encourages** LHCb to pursue the physics studies and collaboration with the LHC experts to motivate these upgrades with a solid physics case, taking into account the expected results from LHCb Phase-I and Belle II, and establish feasible running conditions that do not interfere with other LHC experiments. The **LHCC urges** the LHCb management to ensure that these activities have no impact on the on-going Phase-I upgrades, which must take priority.

So, they expect us to advance with the physics case and kindly ask our machine friends to continue with their studies. Informally, they expect to hear from us again on this topic in about a year from this meeting (*i.e.* spring 2018).

- we will hear more from the machine this morning
- much of workshop will be spent brainstorming to develop the physics case

At this stage they are less concerned with the detector aspects, but we need to be, so detector discussion will constitute the other half of this workshop.

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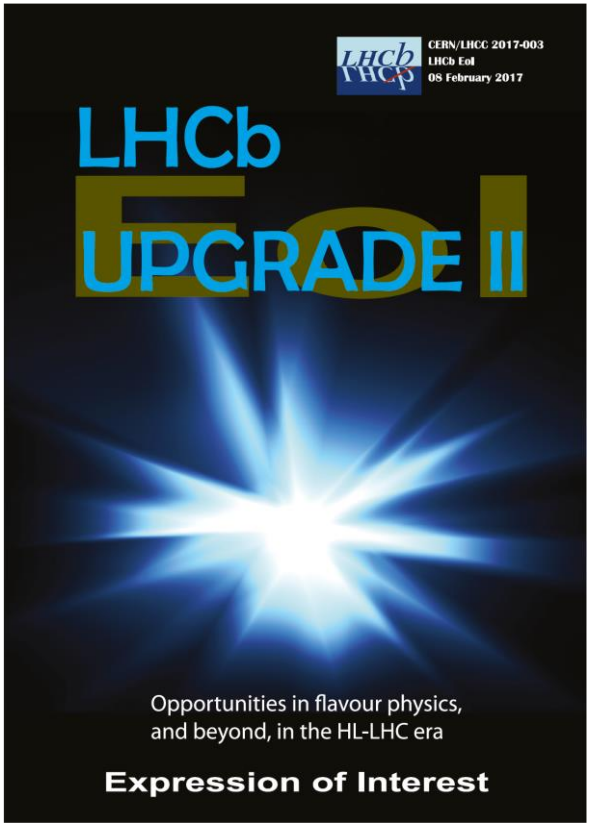

[CERN-LHCC-2017-003]

- Install in LS4 (~2030), after Phase-I Upgrade.
- Integrate ~300 fb^{-1} within a couple of LHC runs.
- … requires detector to be able to operate at ~1-2 x 10^{34} $cm^{-2}s^{-1}$.
- Comprehensive flavour physics programme + general-purpose forward physics (as now), but targeting clean measurements currently limited by statistics, and new observables.

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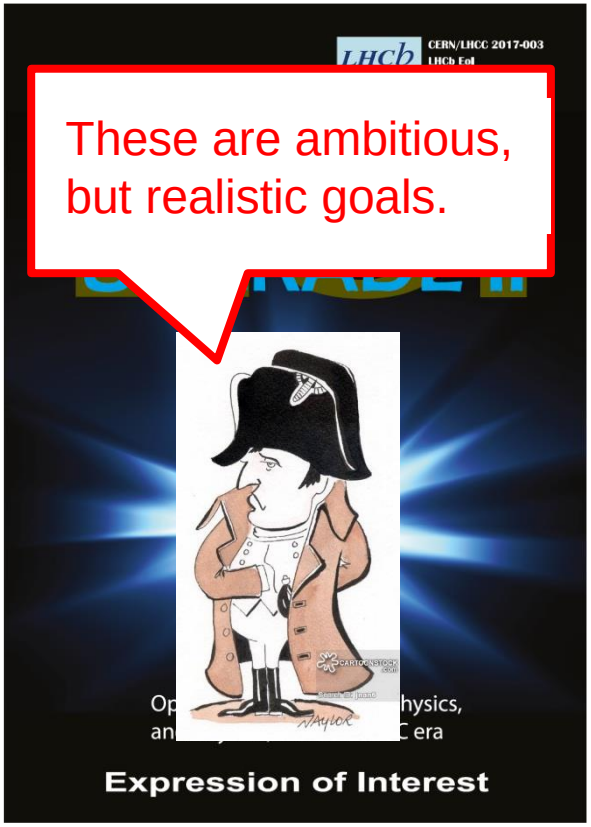

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Physics goals and potential

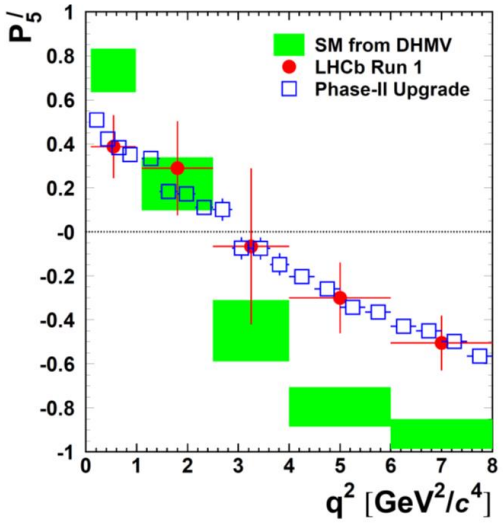
Phase-I Upgrade, together with Belle II, should bring big advances in our knowledge of the flavour sector. But still many important, theoretically clean, observables will remain statistics limited, and others will be out of reach.

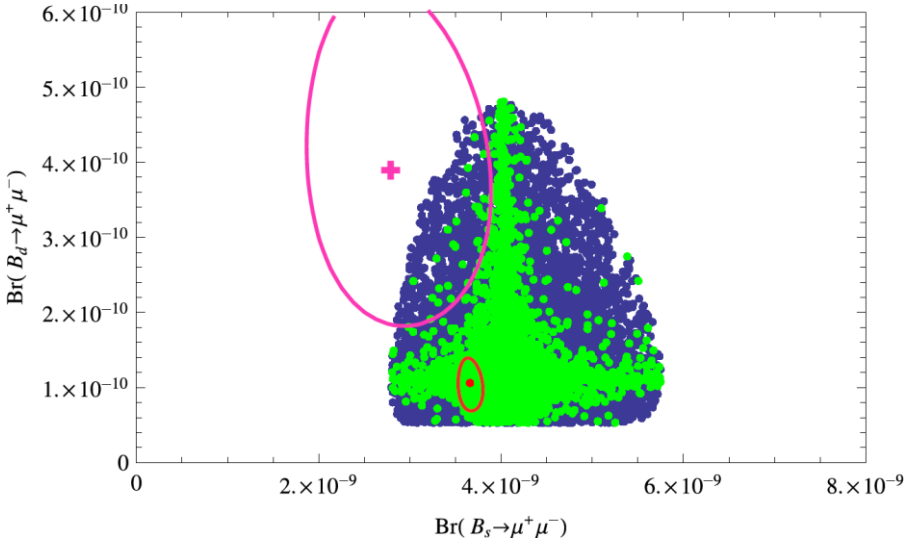
Phase-II Upgrade will be capable of a broad spectrum of important measurements in flavour sector. Some key goals are as follows:

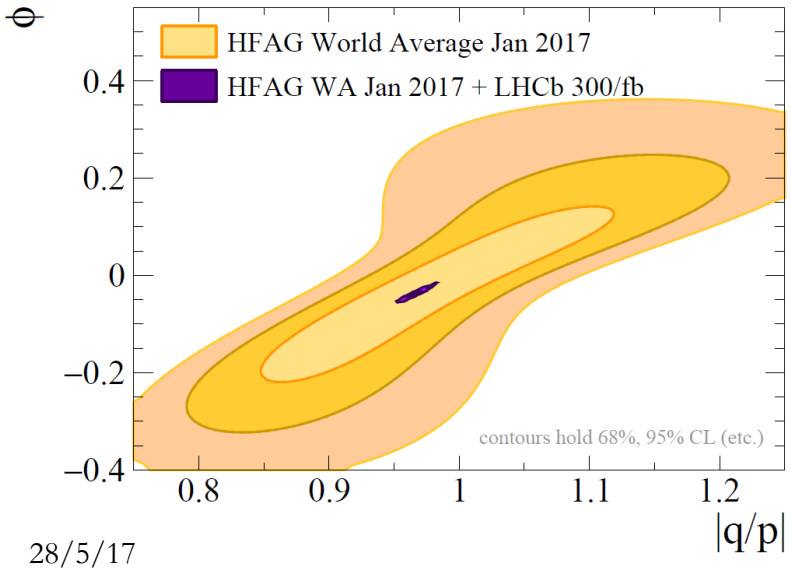
- Comprehensive measurement programme of observables in $b \to s l^+ l^-$ and $b \to d l^+ l^-$, employing both muon and electron modes;
- Measurement of CPV phases γ and φ_s, with precision of 0.4^o and 3 mrad respectively;
- Measurement of $BR(B_d \to \mu\mu)/BR(B_s \to \mu\mu)$ to < 20%, and first precise measurement of associated observables
- Wide ranging lepton universality measurements in $b \to c l \nu$, exploiting full range of b hadrons;
- CPV in charm down to 10^{-5}.

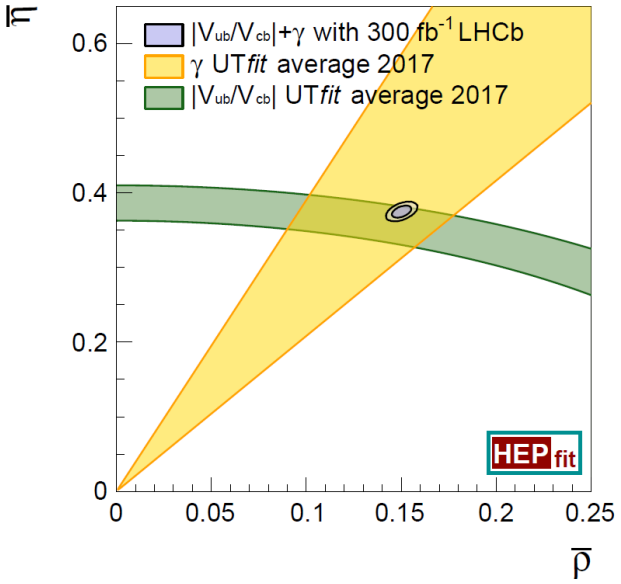
Also will be able to make major discoveries in spectroscopy, and pursue a wide and unique programme of general physics measurements in forward region.

Physics goals and potential









Machine considerations

Raising luminosity requires lowering β*. Turning IP8 into another high luminosity interaction point is very challenging, as this requirement was not in HL-LHC baseline.

Some preliminary scenarios:

	β^* [m]	Maximum $\mathcal{L}$ $[\times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$		Target levelling $\mathcal{L}$ $[\times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	Fill length [h]		Levelling time [h]		$\int \mathcal{L}\,dt$ $[\mathrm{fb}^{-1}/\mathrm{yr}]$		
		−	+		−	+	−	+	−	+	
	3	1.04	0.78	0.20	8.1	8.1	8.1	8.1	10	10	Phase-I (best case)
Can be done	2	1.53	1.04	1.00	7.7	7.8	2.8	0.4	39	31	
	2	1.53	1.04	/	7.6	7.8	/	/	43	31	No levelling
Will be very tough	1	2.90	1.66	1.00	7.5	7.6	6.0	3.5	48	42	
	1	2.90	1.66	2.00	7.3	7.5	2.3	0	73	48	
	1	2.90	1.66	/	7.2	7.5	/	/	80	48	No levelling

- Lots of work from our machine friends, but all results still preliminary.
- In particular, further work needed to understand beam-beam effects and what it means for both us and ATLAS/CMS.
- More information in talk of Ricardo De Maria.

Machine considerations

Raising luminosity requires lowering β*. Turning IP8 into another high luminosity interaction point is very challenging, as this requirement was not in HL-LHC baseline.

Some

Current limit on maximum integrated luminosity of 300 fb^{-1}

- Set by lifetime of inner triplets
- Assumes improved shielding
- Achievable within a couple of LHC runs (*i.e.* within lifetime of HL-LHC)

Maybe we can dream of even more, but for now this number is our baseline.

Can be done

Will be very tough

β [m]	dt /yr]	
	$+$ 10	Phase-I (best case)
	31	
	31	No levelling
	42	
	48	
	48	No levelling

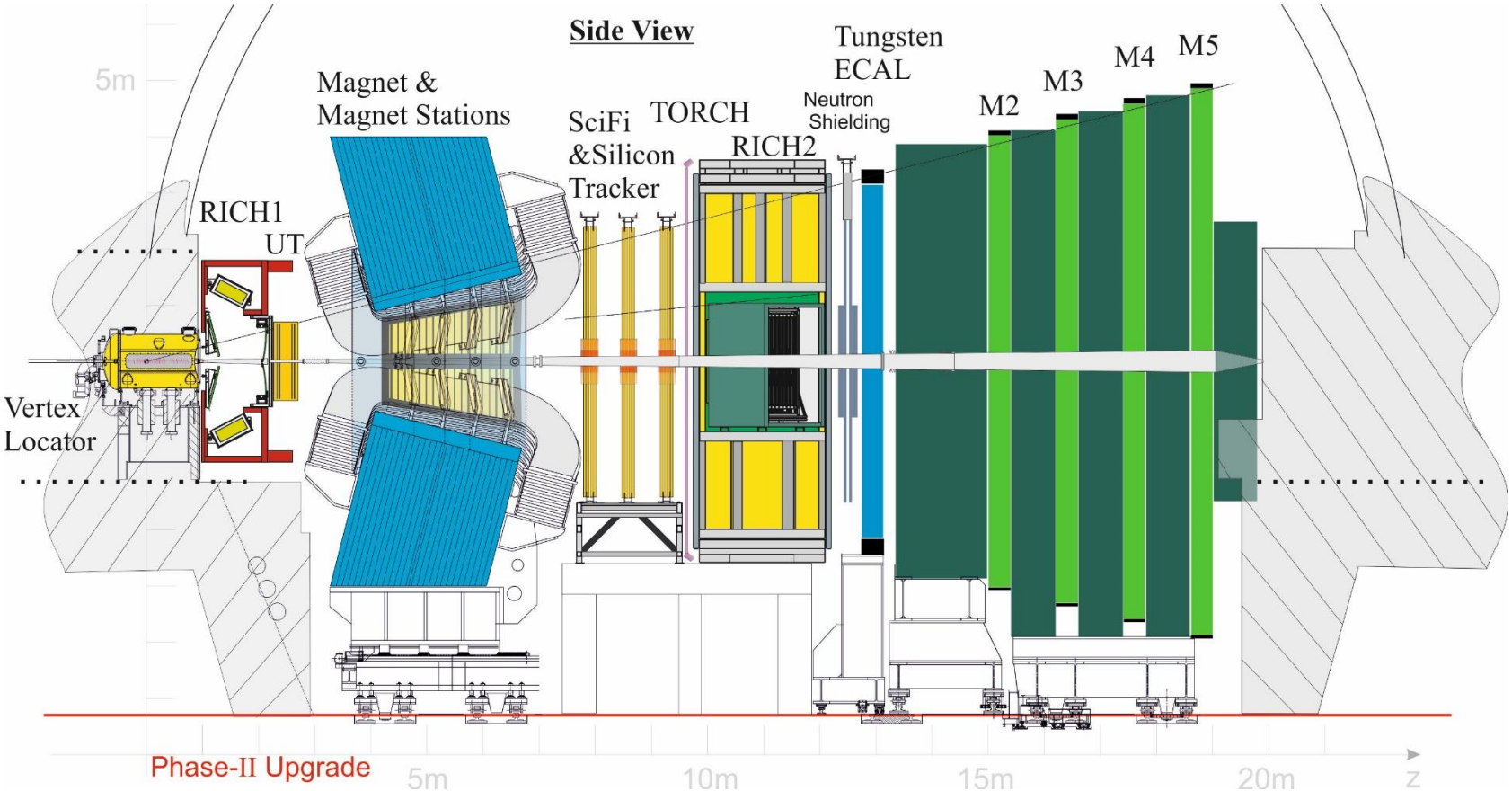
ary.

- In particular, further work needed to understand beam-beam effects and what it means for both us and ATLAS/CMS.
- More information in talk of Ricardo De Maria.

Document proposes candidate solutions for challenges of performing flavour physics in environment of μ up to 50 and high irradiation.

Aim is to retain current performance in key parameters, & also to improve capabilities in certain areas (*e.g.* ECAL, low momentum tracking *etc.*) Hence improvement in physics reach will be significantly greater than merely going from 50 fb^{-1} → 300 fb^{-1}.

Common themes: improved granularity, radiation hardness and fast timing.



Detector challenges

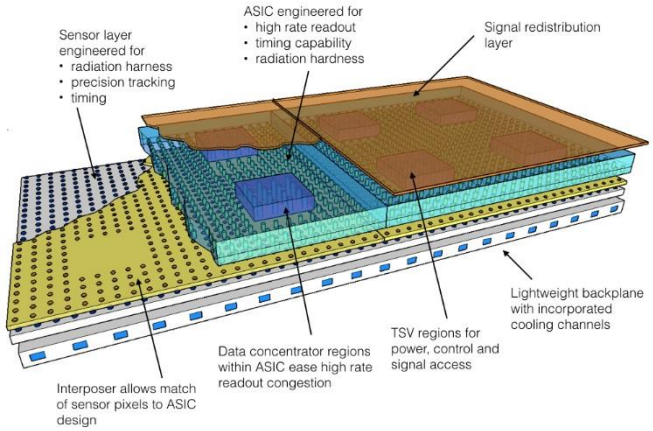
Candidate solutions proposed for each sub-system. All of these need to be further developed, but the intention is to show that there are no immediate show-stoppers.

VELO

Halve pixel dimensions
Halve sensor thickness
→ ~ recover current performance

Fast-timing necessary – Timepix4 may already have many of the features necessary for ASIC.

Reduction / removal of RF foil v. interesting.

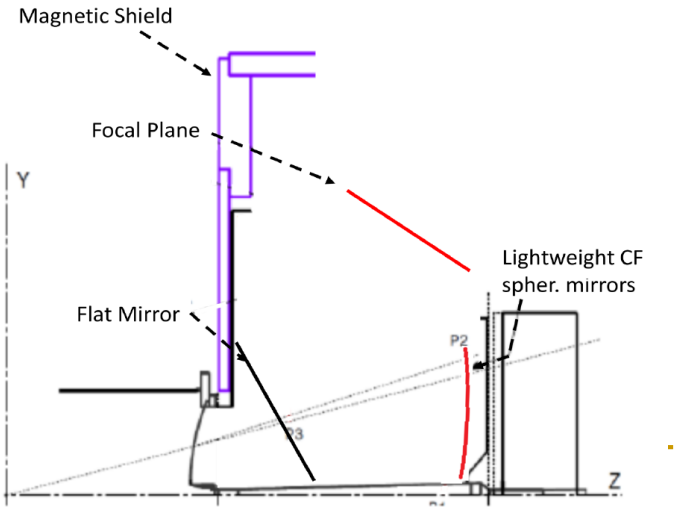


RICH

Go to photodetectors with ~1/5 pixel area

Change optics

Improve response in visible (*e.g.* SiPMs)



Detector challenges

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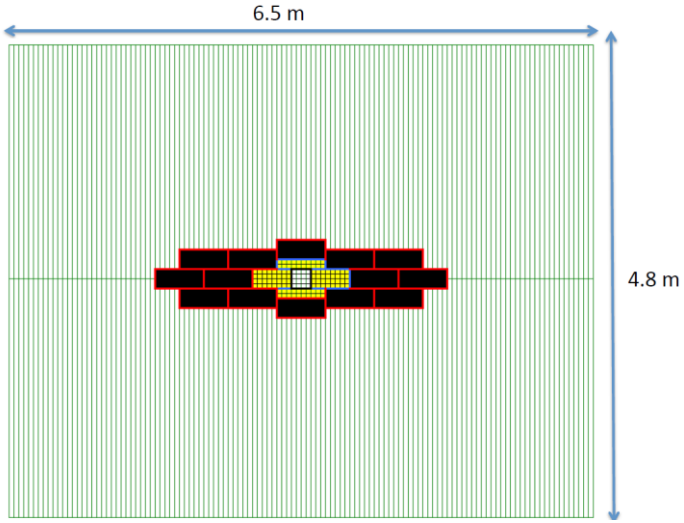
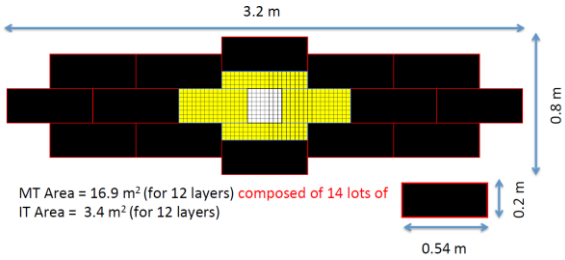
Tracker

Hybrid solution with fibres in outer region and silicon in inner / middle regions.





Muon system

Replace HCAL with iron slabs to halve rate in chambers.

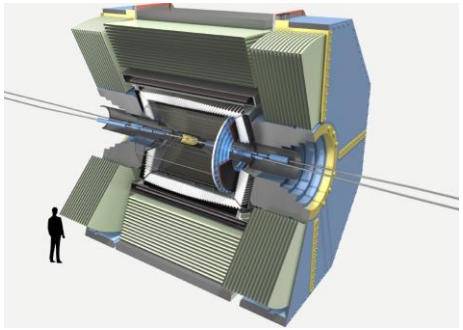
New high-rate chambers in hottest regions.

Do not underestimate the competition

In flavour physics, three main competitors can be identified:

1) Belle II

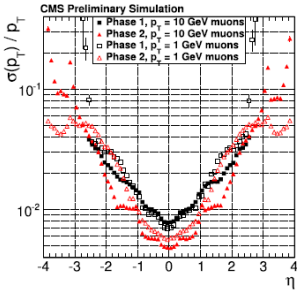
Competitor in the best sense of the word.
A very good thing for flavour physics & for LHCb !

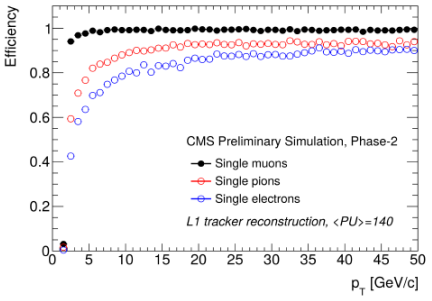


Still, we need to emphasise our traditional advantages vs. e^+e^- and also look to strengthen in those areas where Belle II leads.

2) CMS (and ATLAS) Phase-II Upgrades

e.g. CMS new track and track trigger





New attributes of GPDs after Phase-II Upgrades will bring enhanced capabilities in flavour physics.

Its likely, however, their strengths will remain in same areas as now (*e.g.* B→μμ). So these should not be overemphasised in our own programme.

Do not underestimate the competition

The third competitor is the Phase-I LHCb Upgrade itself.

The full-software trigger will magnify the lumi increase of the Phase-I Upgrade, ensuring a big step-up in yields for non-muonic modes w.r.t. current LHCb. The step-up from Phase I to Phase II will 'only' be a factor of 6.

Expected integrated yields in relative units of run-1 data set

	Non-muonic modes	Muonic modes
Run 1	1	1
Run 2	4.3	4.3
Phase I	60.3	32.3
Phase II	393.6	199.0

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A friendly sceptic

The overall picture is very impressive, but the sceptic may focus on this factor 6.

Therefore we must:

- Identify good physics arguments to justify this step;
- Look for detector enhancements that will bring added worth to the Phase-II data set.

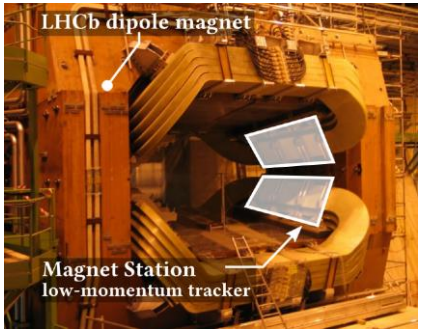
Detector improvements

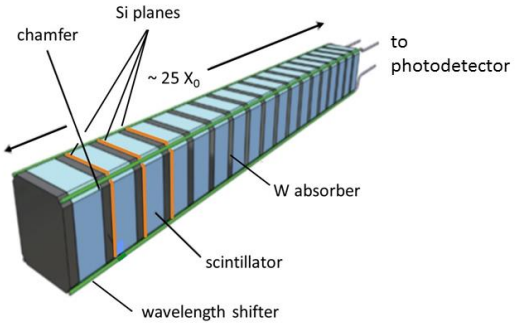
Possible to conceive of detector enhancements which will bring additional physics reach on top of what will come from the increase in integrated luminosity.

- Increased tracking acceptance

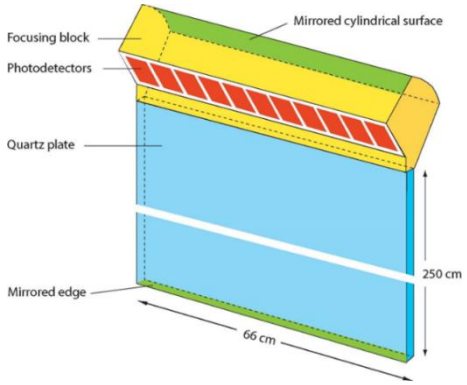
  Magnet stations

  Approach closer to beam pipe in downstream tracker





- Improved ECAL
- Improved low-momentum PID (*i.e.* TORCH)
- Thinning / removal of VELO RF foil
- Improved downstream trigger capabilities



Let us try this week to identify measurements where these could have big impact.

Possible LS3 activities

EoI presents several first steps that could be carried out during LS3. Wise to make use of what is a very long shutdown, but also to improve Phase-I physics.

Table 5.1: Summary of the modifications under consideration for LS3, and those for Phase-II (LS4). Priorities will be assigned for the LS3 activities after further studies.

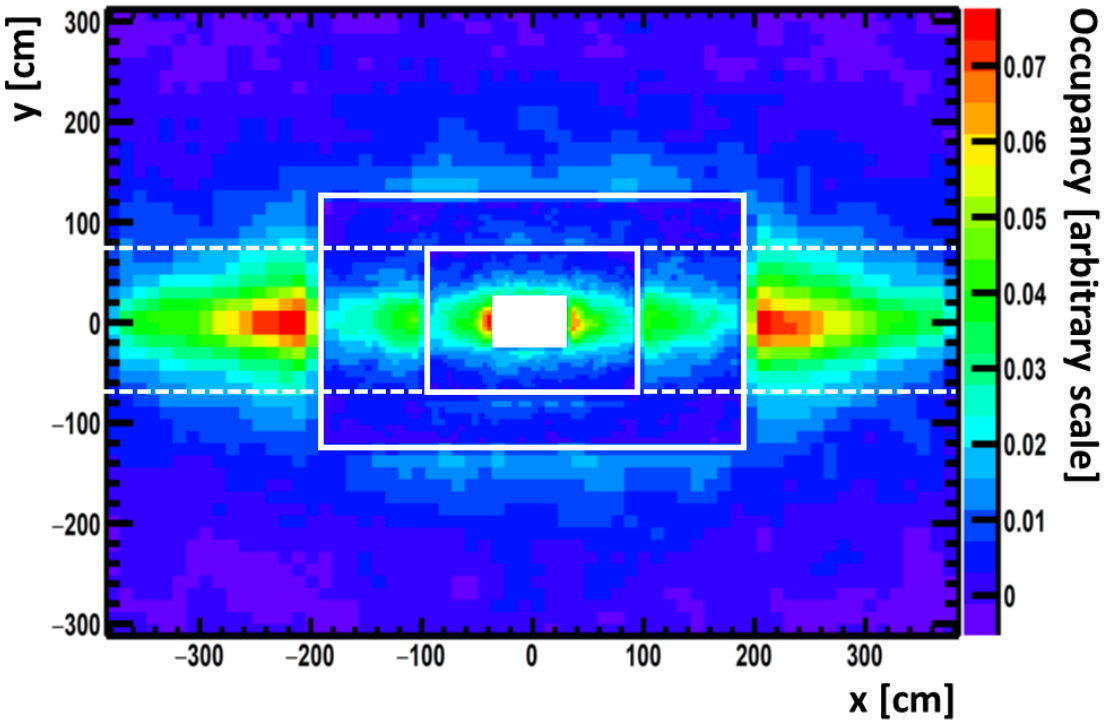
Detector	LS3	Phase-II
VELO	Deployment of prototype modules	New detector with fast timing
Tracking	Insert Silicon IT, modify SciFi; install MS	Silicon UT and IT, SciFi OT
RICH	New photodetectors for selected regions; use of timing information	New optics; full replacement of photodetectors
TORCH	Installation	Higher granularity photodetectors
CALO	Tungsten sampling modules installed in inner region	New modules in middle and outer regions
Muon	Replace HCAL with iron shielding; installation of high-rate chambers	Complete chamber installation
Trigger and data processing	Adiabatic software improvements; review of offline processing; installation of downstream track-finding processor	Expansion/replacement of links, readout boards and servers and servers

Remember, be realistic !

However, it is unlikely that we will have the resources to realise all these ideas. ECAL comes first. For others we will need to prioritise. No attempt to do this in EoI.

Possible LS3 activities: inner region of ECAL

Already now that an intervention will be required during LS3 to replace innermost part of inner region. A good opportunity to replace full inner region with new tungsten modules, if possible including Si planes and fast-timing information.



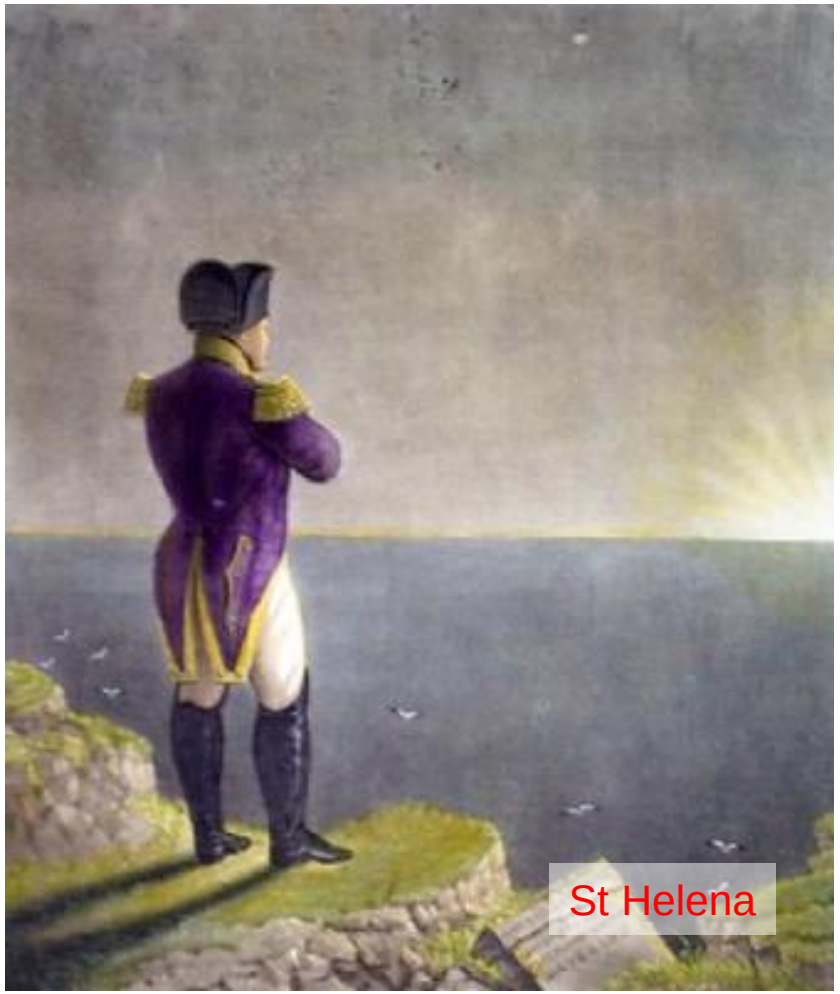
We could use existing inner modules in middle region, middle modules in outer region *etc.* and replace full horizontal band where large fraction of physics lies.

Did I do, O God, did I as I said I'd do? Good! I did.

Let us look forward to a stimulating workshop, out of which new physics ideas will emerge, and clear directions for detector R&D aimed at high lumi operation and, in some cases, suitable for installation LS3.

Aside from SuperKEKB, the HL LHC is the only future accelerator project that we can be sure will happen.

Flavour-physics must not be exiled from this tremendous opportunity !

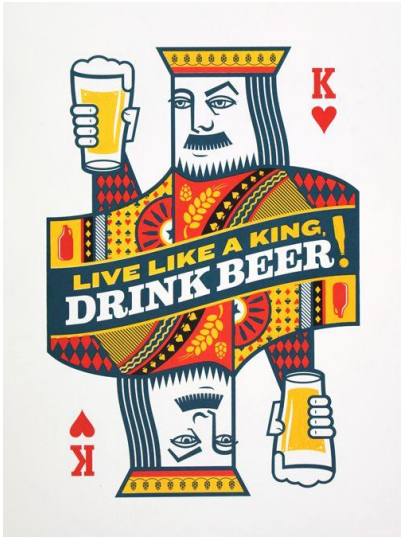


Backups

The poetry of palindromes

Able was I ere I saw Elba

Lager, sir, is regal



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