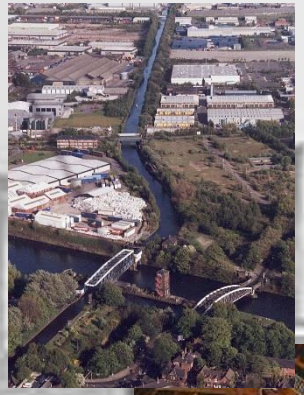
Welcome to Manchester !

G.W.
6/4/16

Welcome to Manchester !

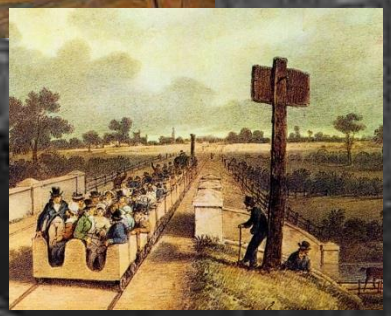
G.W.
6/4/16

Bridgewater canal & Manchester ship canal



The 'spinning jenny' (invented nearby)

Liverpool to Manchester railway



Historically, a place of:

Innovation;

Welcome to Manchester !

G.W.
6/4/16

Historically, a place of:

Innovation;

Hard work and industry;

G.W.
6/4/16

Welcome to Manchester !

George Best,
1967 European Cup Final

Historically, a place of:

Innovation;

Hard work and industry;

And, of course, glory !

The ideal place to start thinking about LHCb's future in the HL-LHC era.

Welcome to Manchester !

G.W.
6/4/16

Talk outline

Why the need for a future Upgrade,
and why the need to start talking now ?

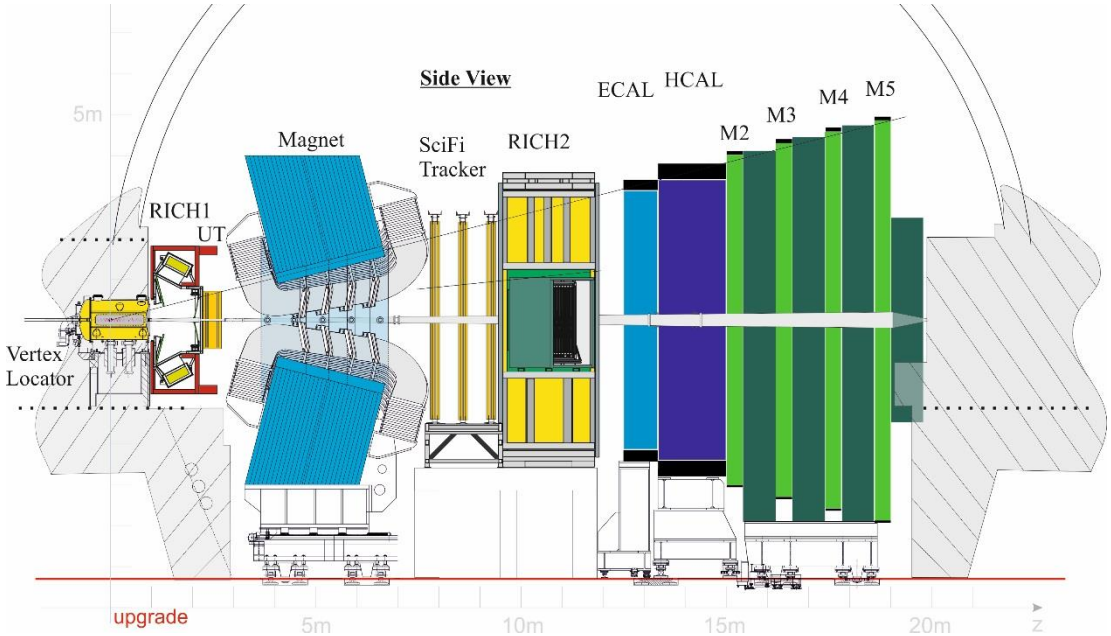
Reminder – the LHC schedule

Phase-1b Upgrade (LS3)

Phase-2 Upgrade (LS4)

LS2 Upgrade

We are well on the road to the LS2 Upgrade. This is an incredibly exciting project that will increase our physics reach enormously – thanks both to full software trigger and to the increase in running luminosity to 2 x 10^{33} cm^{-2} s^{-1}

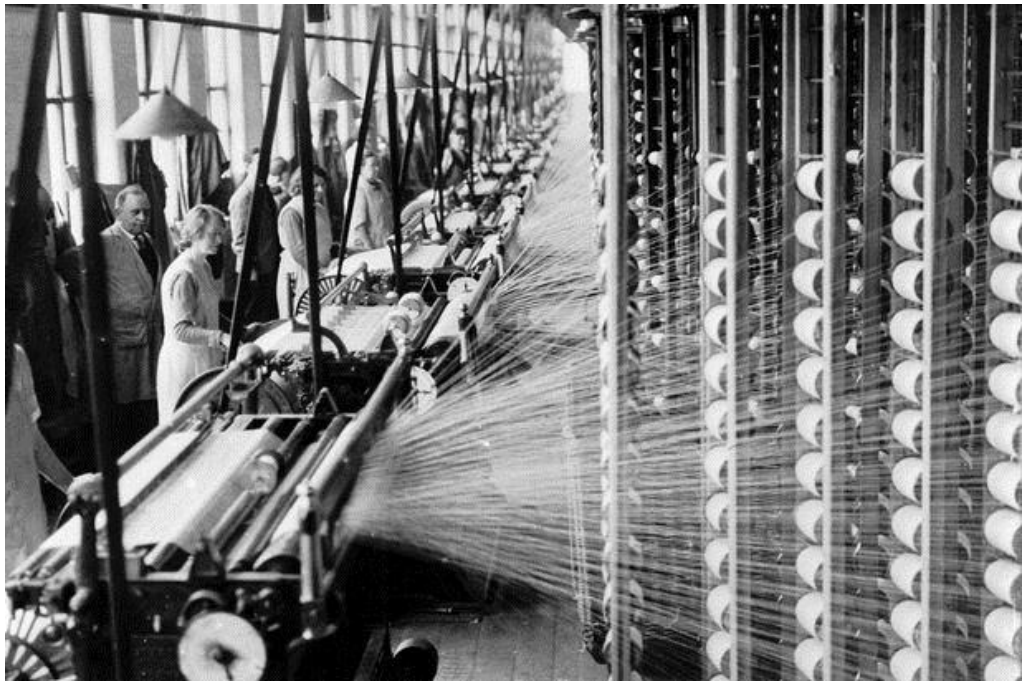


This year we enter the production phase – lots of work ahead, but outlook good !

LS2 Upgrade

We are ... ng
project t...
full softw... cm^{-2} s^{-1}

e.g. SciFi mat production



This year we enter the production phase – lots of work ahead, but outlook good !

So why start discussing future Upgrades *now*?

We are just embarking on one ambitious Upgrade. Why start discussing another ?

Any major project has a big lead-in time

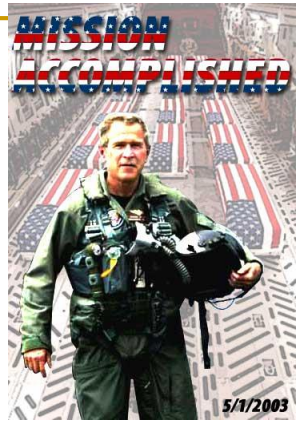
Recall first discussions of current Upgrade begin 11-12 years before installation

This long timescale is needed for:

- Roadmaps of funding agencies
- Machine and lab planning
- Necessary R&D

(It is true, however, that not all 'Upgrades' need the same degree of preparation.)

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



Usual summary of Upgrade physics reach looks very impressive…

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 CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	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.

Unwise to assume ~10% (or even 0.1% or 0.01%) is 'good enough'

Courtesy Browder and Soni

Many of the arguments for increasing the statistical precision are motivated by clear numerical facts, *e.g.* matching theoretical precision or opening up new decay modes. But history tells us that whatever the argument, improved precision is always welcome. We should exploit existing facilities to the utmost.

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

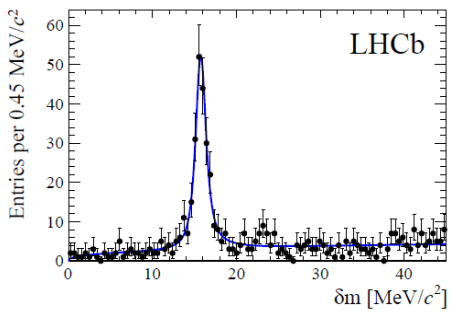
BR ($K^0_L \rightarrow \pi\pi$) ~ 2 x 10^{-3} Cronin, Fitch *et al.* , 1964

Areas for improvement ?

If all goes according to plan, our post-LS2 spectrometer will be a magnificent detector, but there will be still aspects where we could do even better.

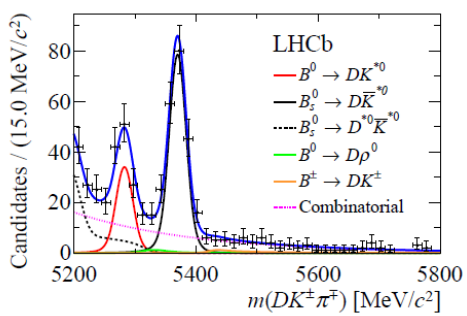
Spectroscopy and CP-violation studies are increasingly focused on high-multiplicity final states (*e.g.* 6 tracks or more)

$\Xi_b^* \to \Xi_b \pi$,
$\Xi_b \to \Xi_c \pi$,
$\Xi_c \to pKK\pi$

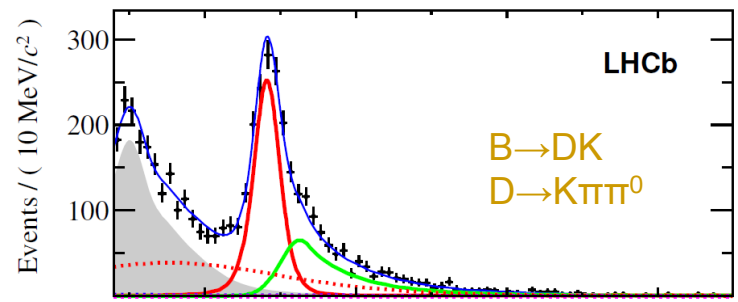


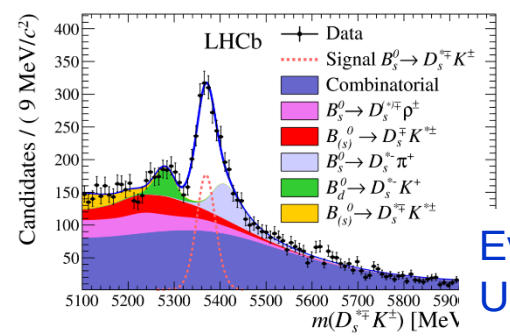
Improved tracking acceptance could have big benefits for sample sizes

$B^0 \to DK\pi$
$D \to K_S\pi\pi$



Impressive work already done with π^0 and γ's, but performance still lags far behind charged track analyses





$B_s \to D_s^* K$
$D_s^* \to \gamma D_s$

Even tougher at Upgrade. Could a different ECAL technology help ?

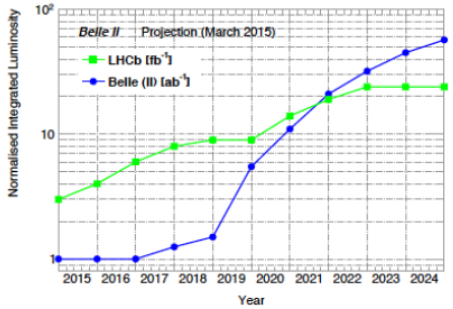
And remember, we have competition…

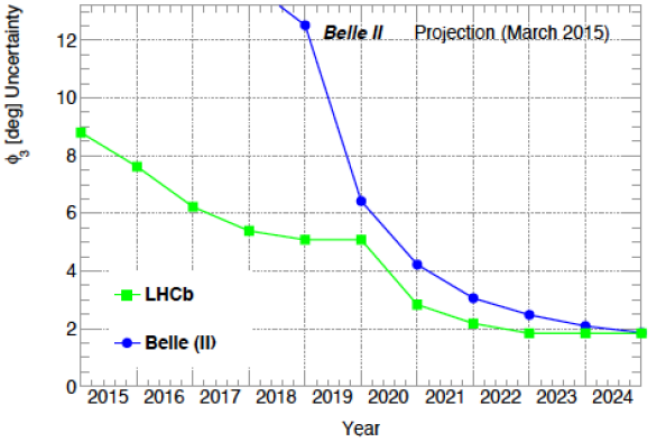
Browder, Krakow, April 2015

See talk by Botjan Gotlob, tomorrow.

Belle II/LHCb competition

Not "Complementarity"





Belle II behind LHCb until 2020

P. Urquijo's projections based on current best information, Sensitivities include Belle II detector improvements

BELLE2-NOTE-PH-2015-004
DRAFT Version 2
April 7, 2015

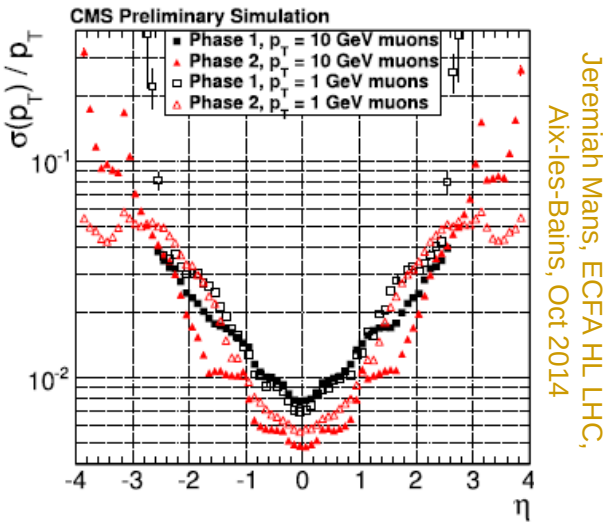
"There is tough competition from LHCb. Cannot take our time at Belle II. The "complementarity" story is fading away….." Browder

And remember, we have competition…

GPD phase-2 upgrades

New capabilities of GPDs, and CMS in particular, will strengthen their opportunities in flavour physics, should they choose to take them

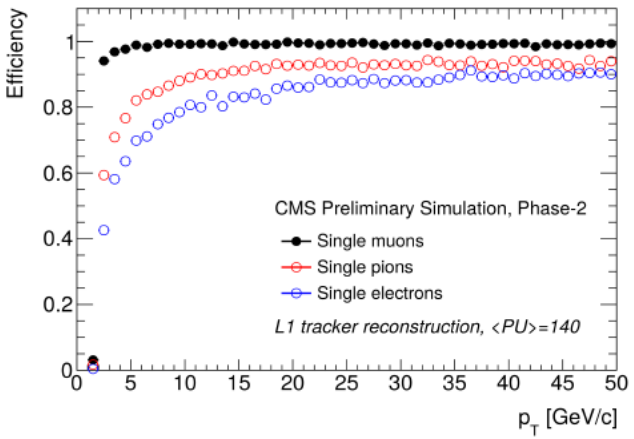
e.g. new CMS tracker



Jeremiah Mans, ECFA HL LHC, Aix-les-Bains, Oct 2014

Significantly improved p resolution

e.g. CMS new L1 track trigger



Anders Ryd, ECFA HL LHC, Aix-les-Bains, Oct 2014

Could allow CMS to accumulate large samples even in hadronic modes!

See talk this morning by Fabrizio Palla.

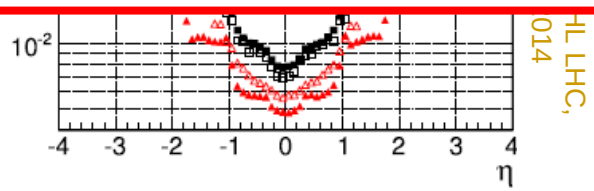
And remember, we have competition…

GPD phase 2 upgrades

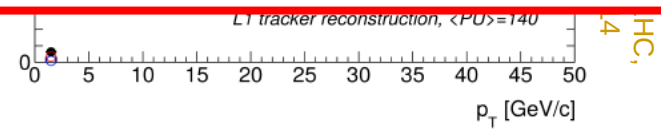
New capabilities of GPDs, and CMS in particular, will strengthen

In physics competition is not at all a bad thing ! Rather it can help us raise our game and focus our thinking.

We should not propose a future Upgrade at IP8 for the sake of it, rather because we think the physics justifies it, and that a dedicated heavy-flavour experiment at the LHC continues to be the best approach.



Significantly improved p resolution



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And remember, we have competition…

GPD phase 2 upgrades

But be warned, high-spending competition does not guarantee success

Manchester rivals locked in self-absorbed and increasingly expensive competition

Net transfer spending in last 3 seasons

£ 199 M £ 251 M

Current league standings:

Premier League
Standings

#	Team	GP	W	D	L	GF	GA	GD	PTS
1	Leicester City	32	20	9	3	55	31	24	**69**
2	Tottenham	32	17	11	4	57	25	32	**62**
3	Arsenal	31	17	7	7	52	30	22	**58**
4	Man. City	31	16	6	9	56	32	24	**54**
5	Man United	31	15	8	8	39	27	12	**53**
6	West Ham	31	13	12	6	49	37	12	**51**

i.e. scrabbling for 4th place

See talk this morning by Fabrizio Palla.

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Whereas, ignored by all:

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4	Man. City	31	16	6	9	56	32	24	**54**
5	Man United	31	15	8	8	39	27	12	**53**
6	West Ham	31	13	12	6	49	37	12	**51**

Net transfer spending in last 3 seasons

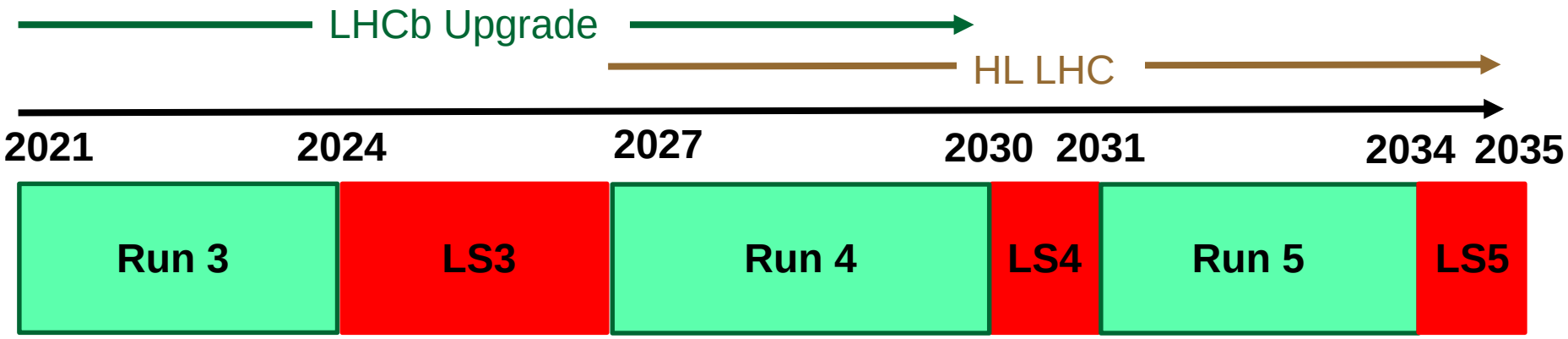
£ 49 M

5000/1 outsiders at start of season
now well placed for unlikely triumph

See talk this morning by Fabrizio Palla.

The road ahead – the LHC schedule

A sketch of the LHCC schedule, post LS2, is given below (also see here)



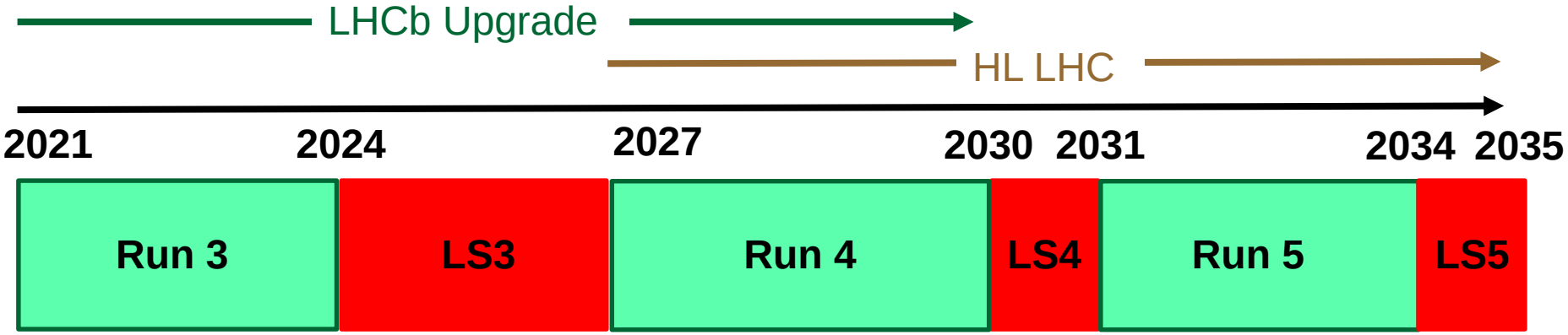
Note that already there is a feeling that the 2½ years allocated for LS3 is too short.

Schedule post LS3 is surely not written in stone, and indeed a version already exists where run 4 is prolonged by one year (*i.e.* LS4 occurs in 2031).

Investment in HL LHC means that runs 4 & 5 must be ~3 years, and also LS4 & LS5 cannot be long (but maybe the currently allocated 1 year for each is too aggressive).

The road ahead – future opportunities

With $L = 2 \times 10^{33}$ cm^{-2}s^{-1} we can assume ~7.5 fb^{-1} per year (less in 2021).



Run 1 & 2 + **20 fb^{-1}** Run 1 & 2 + **20 + 30 fb^{-1}**

Two observations (and some nomenclature) when looking beyond run 3.

(1) We can extend physics reach by improving detector. L33, being long, offers an excellent opportunity for such a plan. Desirable that [physics reach] $_{\text{run 4}}$ >(>) [physics reach] $_{\text{run 3}}$.

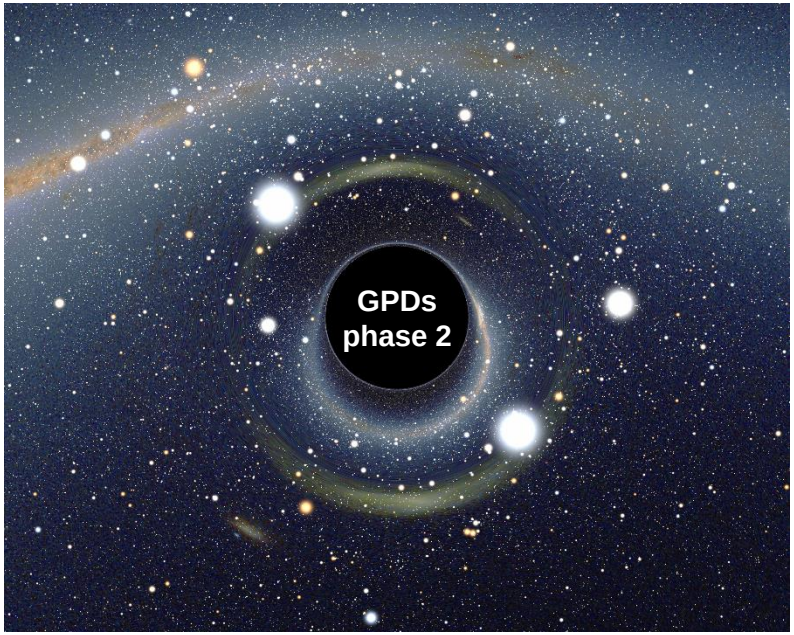
No paradigm shift, only (semi-)adiabatic improvements, hence **phase-1b Upgrade**.

Phase-1b upgrade – practical considerations

LS3 is not so far in the future – limited time for R&D activities, particularly since we are/will be very busy working towards, installing & commissioning phase-1 Upgrade.

We will have had barely 3 years experience of operating our new detector, and will presumably be focused on operational innovations (as in LS1), repairs *etc*. Our s/w trigger will give us plenty of opportunity to tune our physics strategy.

Resources for phase-1b improvements will be scarce. GPD phase-2 upgrades are a black-hole of funding (but to be fair, they are driving the HL-LHC programme).



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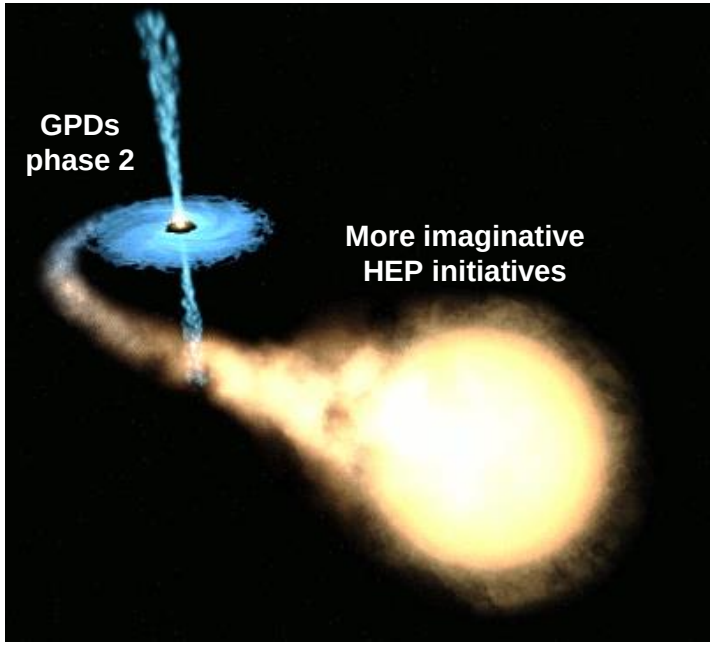


Nonetheless:

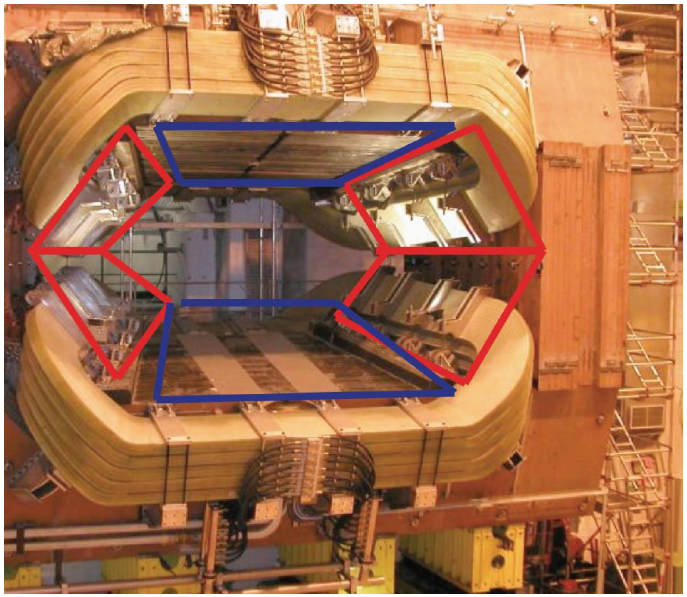
- We can already see possible ways to improve our detector (tracking, ECAL…)
- For some systems intervention is already known to be required (*e.g.* ECAL)
- LS3 is very long – an opportunity !

Phase-1b Upgrade (LS3)

Talks on most of these items

There are many possible improvements worth investigating which have the potential to extend our physics capabilities in specific areas. Some possibilities:

- Magnet side chambers.
- New shielding for muon system (remove HCAL?); new chambers in M2, M3…?
- Innermost region of ECAL will need replacing in LS3. Rather than using existing spares instead consider higher performant option, and equipping larger area (*e.g.* horizontal band).
- TORCH: as standalone PID detector, or as timing device, perhaps embedded in ECAL ?
- (Probably SciFi will need some modules replacing.)



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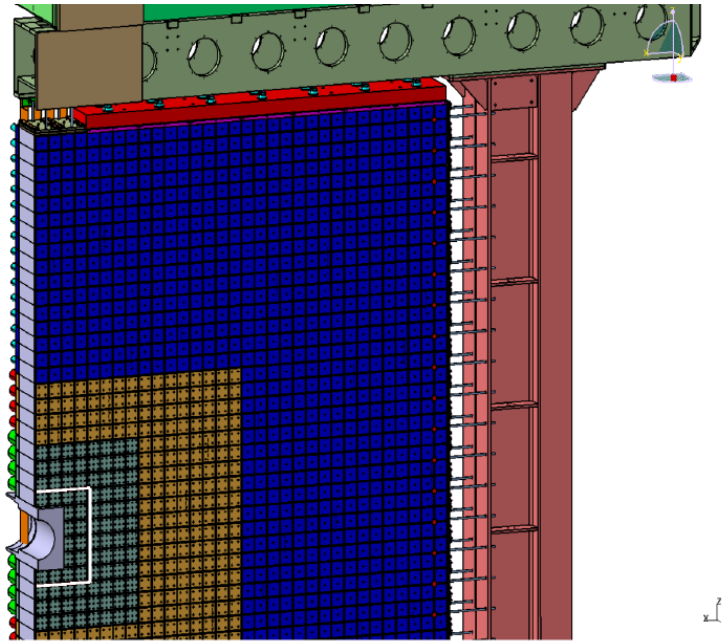

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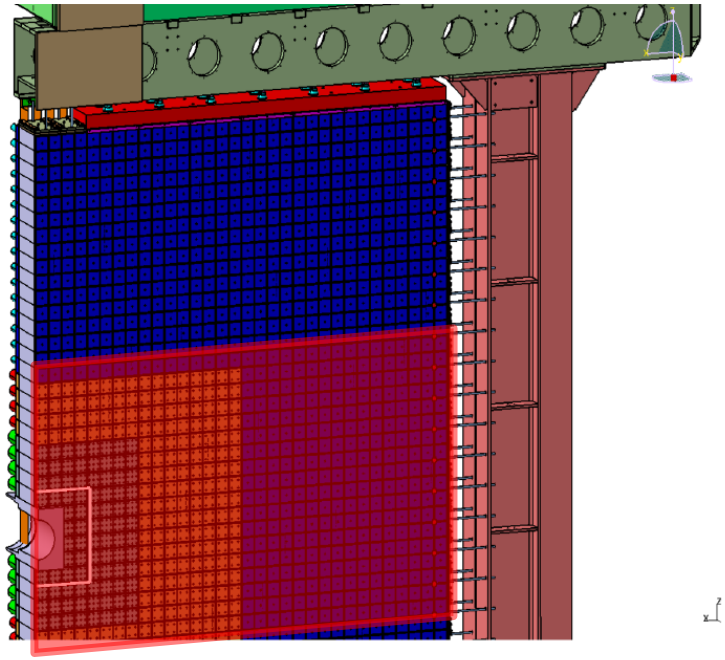

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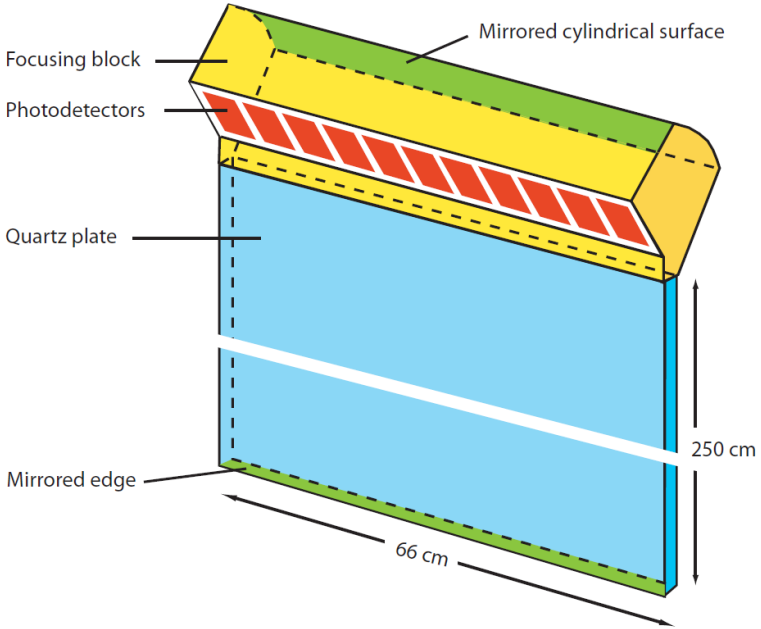

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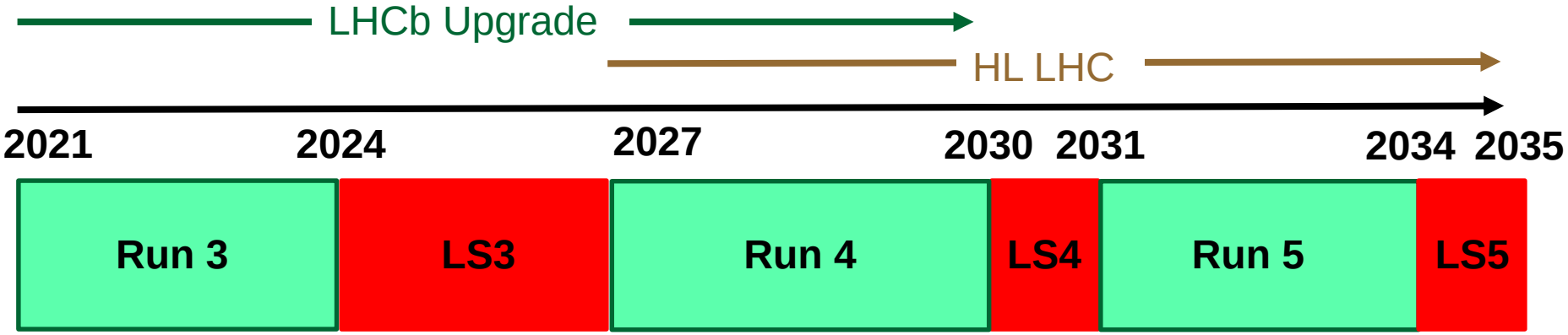

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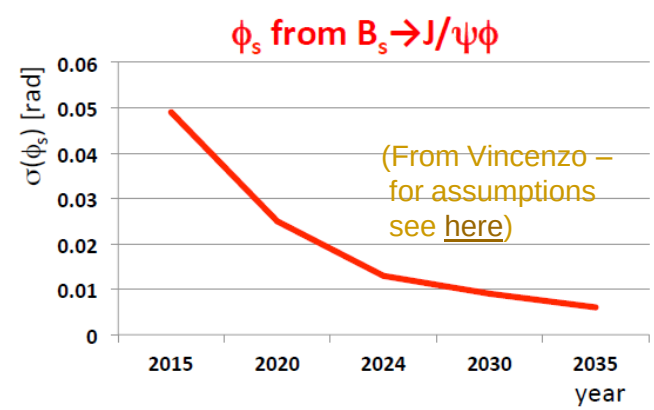
No paradigm shift, only (semi-)adiabatic improvements, hence **phase-1b Upgrade**.

(2) By LS4 we should have our 50 fb^{-1}.
Data-doubling time again becomes prohibitive
→ consider higher lumi: **phase-2 Upgrade**.



Phase-2 Upgrade – machine aspects

Any significant rise in instantaneous luminosity will require changes to the detector. Therefore aim for large step to justify the effort, *e.g.* order of mag. → 2 x 10^{34} cm^{-2} s^{-1}.

Can IP8 be run at this lumi ?

Be warned, IP8 does not have a simple 'luminosity knob', still not one that can be turned up to 2 x 10^{34} cm^{-2} s^{-1}.

Even if it can, there may well be implications for our running strategy *e.g.* inverting polarity, levelling *etc*.

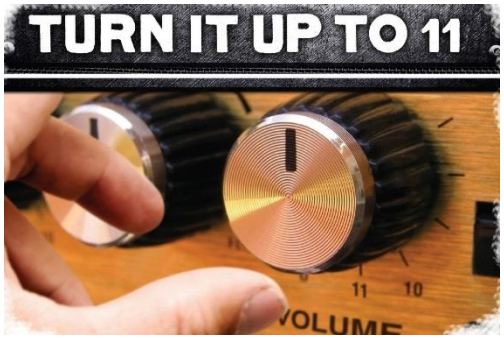
(Reaching higher luminosity easier with fixed IP, rather than displaced scheme considered in earlier meetings, so focus on this scenario for now.)

Integrated luminosity limited by radiation damage in inner triplets: ~300 fb^{-1}.

Lots of work underway from our machine friends – see report by Riccardo de Maria.

LHCb TTFU group

"You see, most blokes will be playing at 10. You're on 10, all the way up, all the way up...Where can you go from there? Nowhere. What we do, is if we need that extra push over the cliff...eleven. One louder."



Phase-2 Upgrade – LHCb aspects

Running at 2 x 10^{34} $cm^{-2}s^{-1}$ / accumulating ~300 fb^{-1} requires work on our side !

Define physics case – initially keep as broad as possible.

see tomorrow morning's talks

Find, on paper at least, a detector solution. Challenges:

- Radiation damage
- Occupancy
- Fast timing
- Data rates
- Cost

talks from all subsystems

Will this solution still be able to deliver a full range of flavour physics (*e.g.* time-dep CPV), or will it be necessary to specialise (*e.g.* rare decays) ?

In summary

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Most work related to future Upgrades is at an embryonic Stage, or indeed about to begin. The purpose of this meeting is more to agree on the right questions rather than to give answers.

Important to get a clear idea soon of what is possible in LS3.

Be warned – the structure of the agenda mixes both phase-1b and phase-2 topics (and this is probably no bad thing).

Once more, thanks to Chris and colleagues for hosting us !

Backups