LHCb status and plans

- Collaboration news
- Run-2 status
- Physics output
- Upgrade progress
- Conclusions

Guy Wilkinson
(University of Oxford and CERN)
on behalf of the LHCb collaboration
26/4/2017

Collaboration news

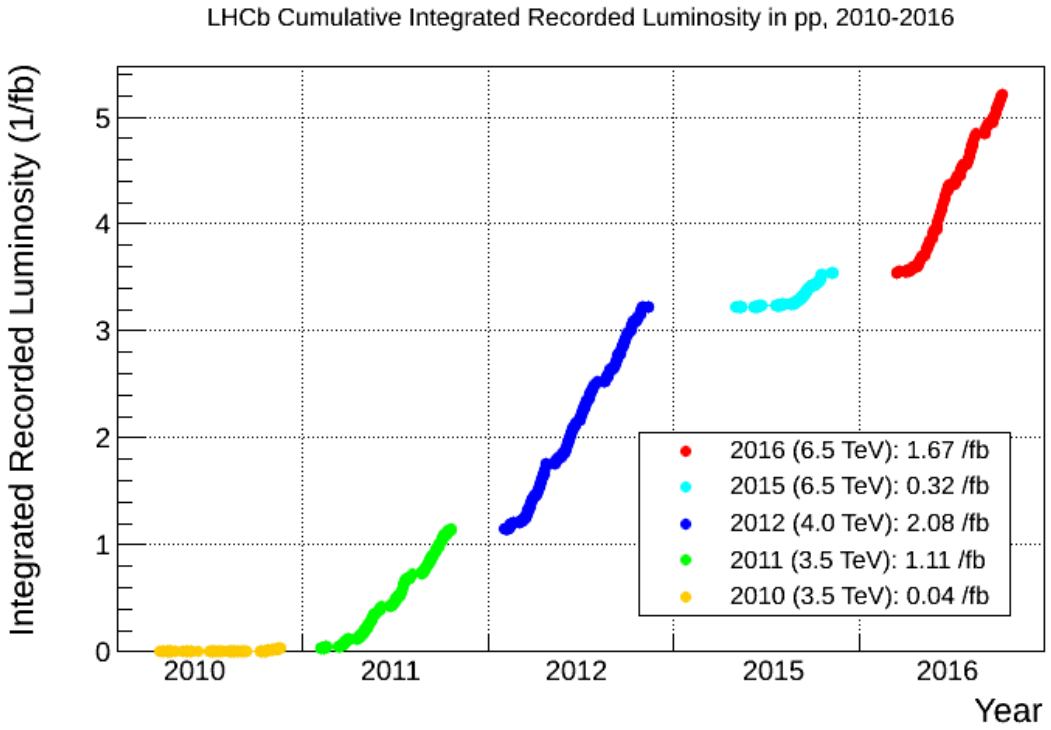
Giovanni Passaleva (Firenze INFN) has been elected as next spokesperson.
He will begin his three-year mandate in July.

Los Alamos National Laboratory (USA), has been elected as an associate member.

Run 2 status

Run-2 data collection: pp collisions

Data taking was highly successful during 2016. We operated with high efficiency (~90%) and coped well with the unforeseen very high machine availability.



We collected ~1.7 fb^{-1}, which given the higher E_{CM} & x-sec corresponds to a larger *bb*bar sample than collected in all of run 1.

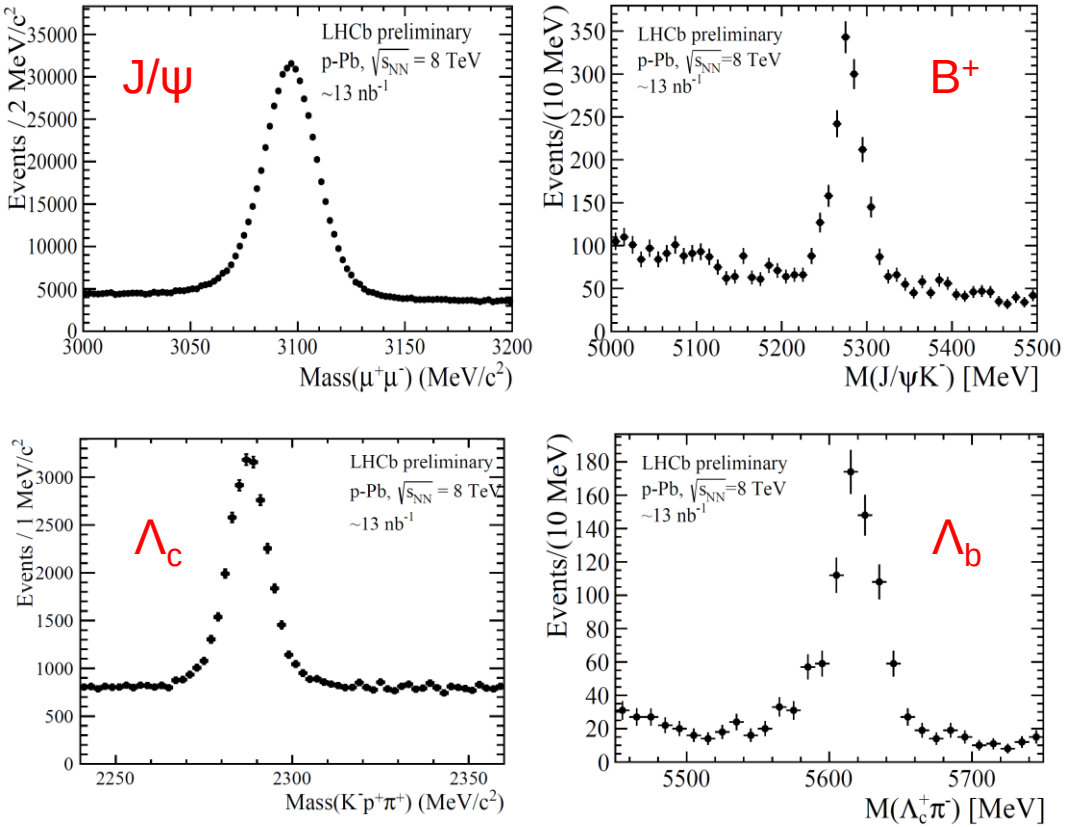
Run-2 data collection: beyond pp

In addition, experiment participated in pPb run at end of the year

- pPb ~ 13 nb^{-1}
- Pbp ~ 17 nb^{-1}

Constitutes a data sample ~20x that collected in run 1, and at higher E_{CM} (8 TeV).

Fantastic data quality !

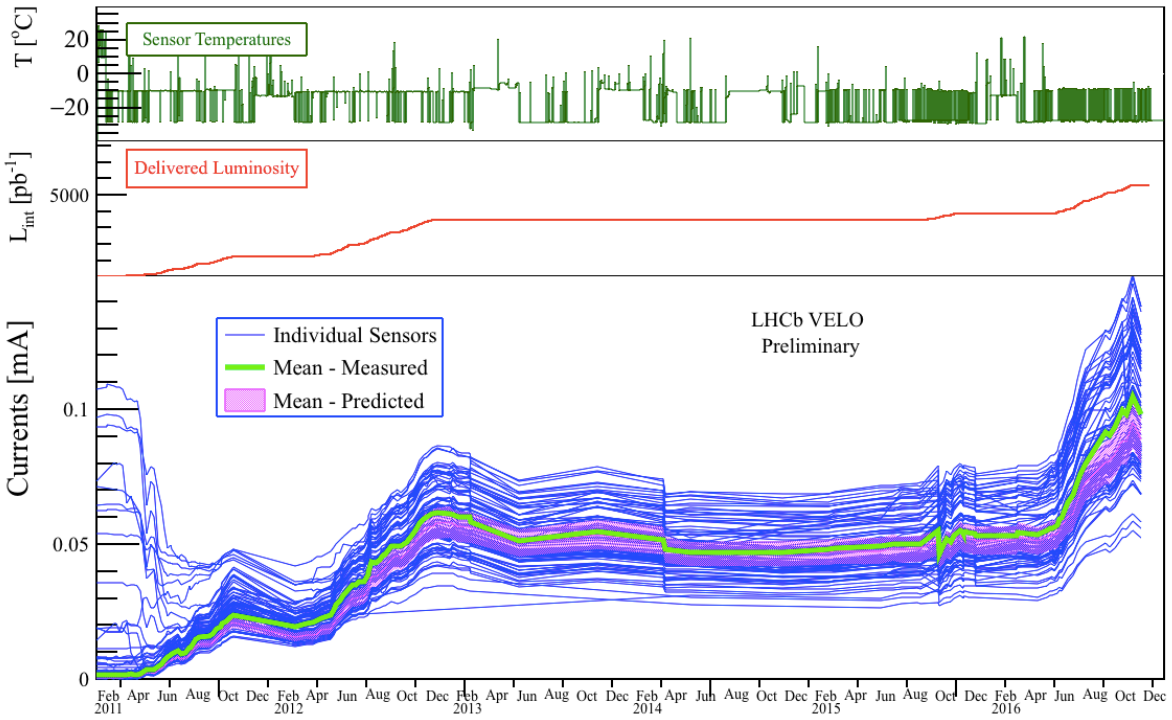


In addition, LHCb took data in fixed-target mode with gas injection – see later.

Understanding of detector & readiness for resumption of data taking

Current detector is ageing gracefully, and as expected.

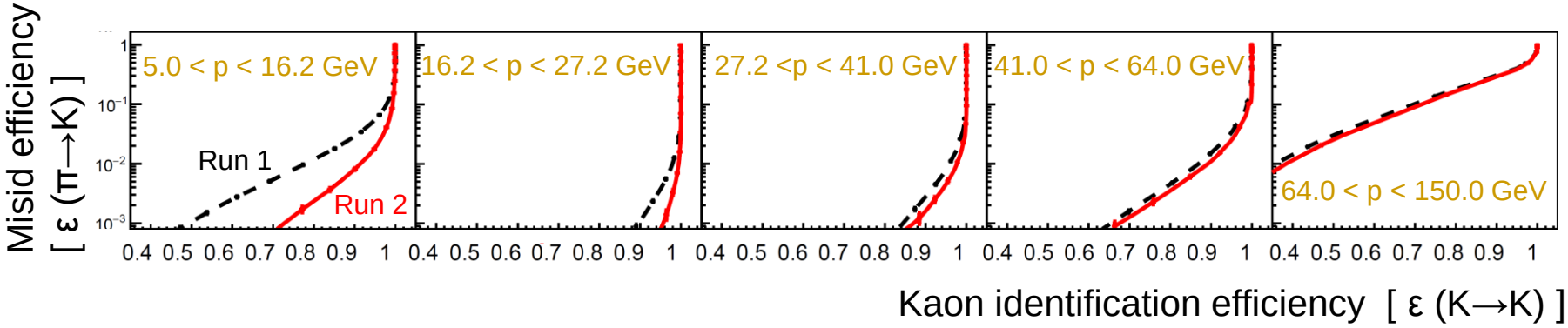
e.g. leakage currents in VELO are tracking predictions remarkably well



Understanding of detector & readiness for resumption of data taking

Performance of all sub-detectors remains good, and in some cases is improving !

e.g. RICH performance, run 1 vs. run 2 in one bin of pseudo-rapidity ($3.1 < \eta < 3.6$). at low momentum benefit from removal of aerogel; at higher momentum, benefit from improved alignment and calibration, facilitated by being done in real time.

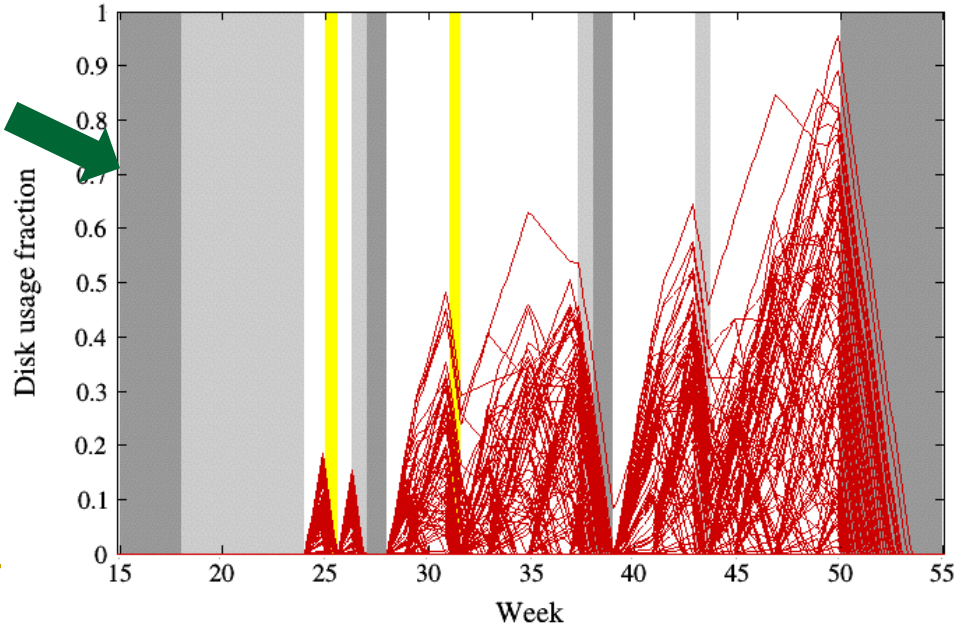


Understanding of detector & readiness for resumption of data taking

In 2016, thanks to high machine availability, we risked being drowned in data.

We approach 2017 with flexible trigger strategy that will allow us to respond quickly to changes in machine performance, without risk of overflowing disk buffer

Ensemble of simulated 2017 runs, assuming a mean 50% availability

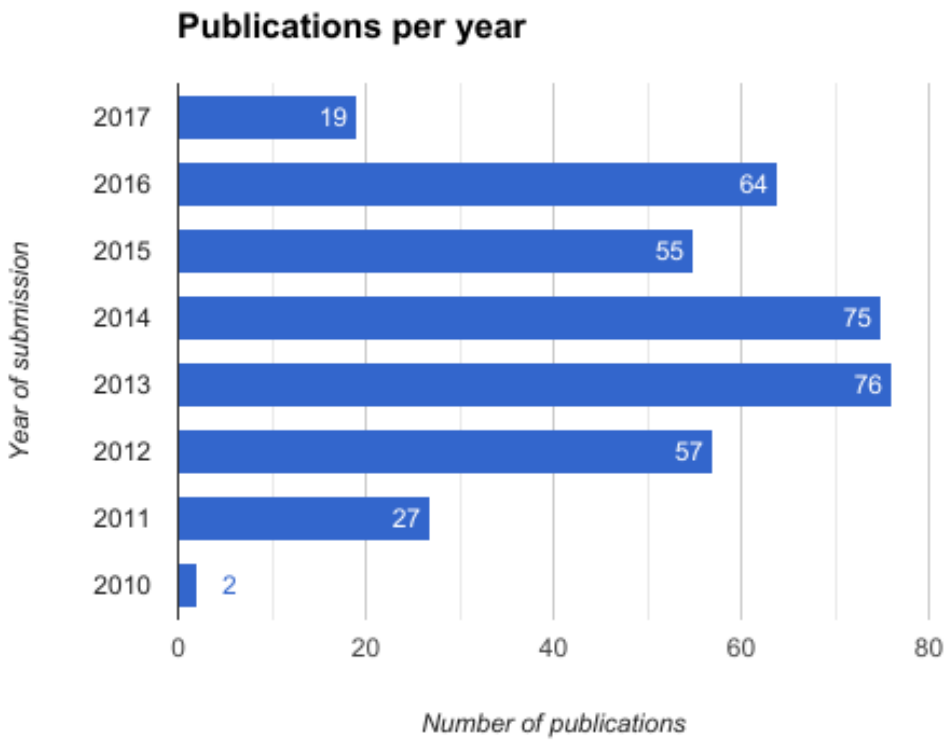


Trigger, detectors and operations good to go. Waiting for beam !

Physics output: overview & selected highlights

LHCb publications

Status, as of Wednesday 26/4/2017



375 papers in total, integrating over published, accepted and submitted (34 since Oct '16 RRB)

- 6 papers in last stage of editing prior to submission;
- Several preliminary results shown at winter conferences soon to be finalised;
- ~44 other analyses under review, targeting spring & summer

More publications in 2016 than in any other data-taking year !

The golden mode: $B_s \to \mu^+\mu^-$

[arXiv:1703.05747]

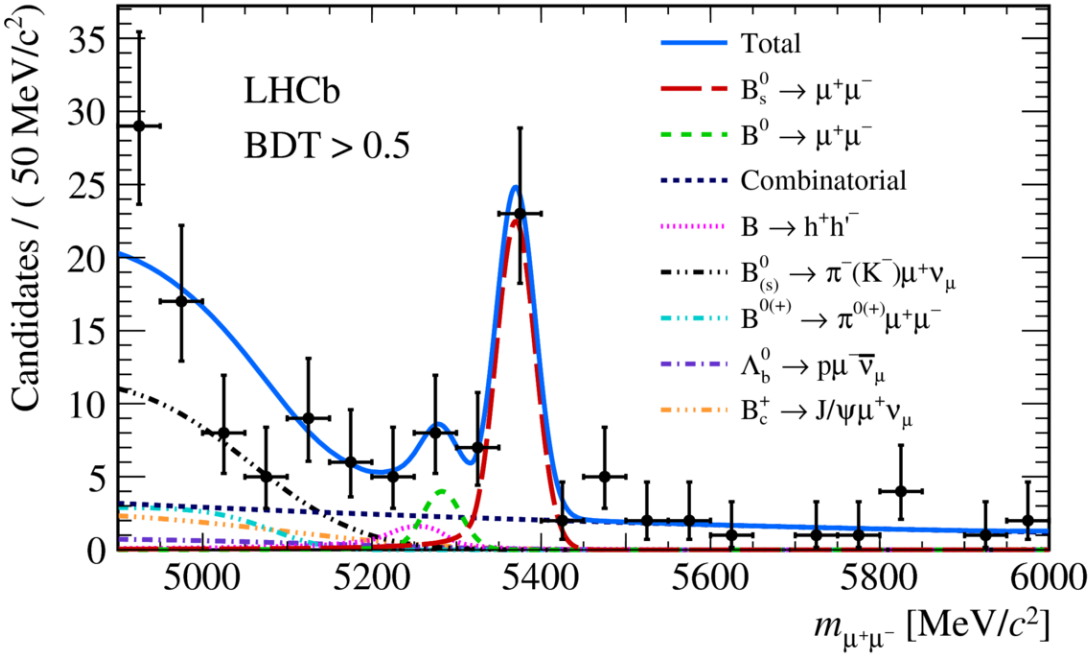
Recall: $B_s \to \mu\mu$ is ultra-rare in the Standard Model ($\sim 3 \times 10^{-9}$) & very sensitive to New Physics contributions. LHCb found first evidence in Run 1 [PRL 110 (2013) 021801] , & then a combined LHCb-CMS analysis yielded a 5σ observation [Nature 522 (2015) 68] .

We have now returned to this critical observable with an improved analysis (~50% combinatoric background than previously). Run 1 + 1.4 fb^{-1} of Run-2 data.

- 7.8 σ signal & first single-experiment observation !
- Precise measurement of branching fraction

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.0 \pm 0.6\,^{+0.3}_{-0.2}\right) \times 10^{-9}$$

- No evidence yet of the corresponding B^0_d decay



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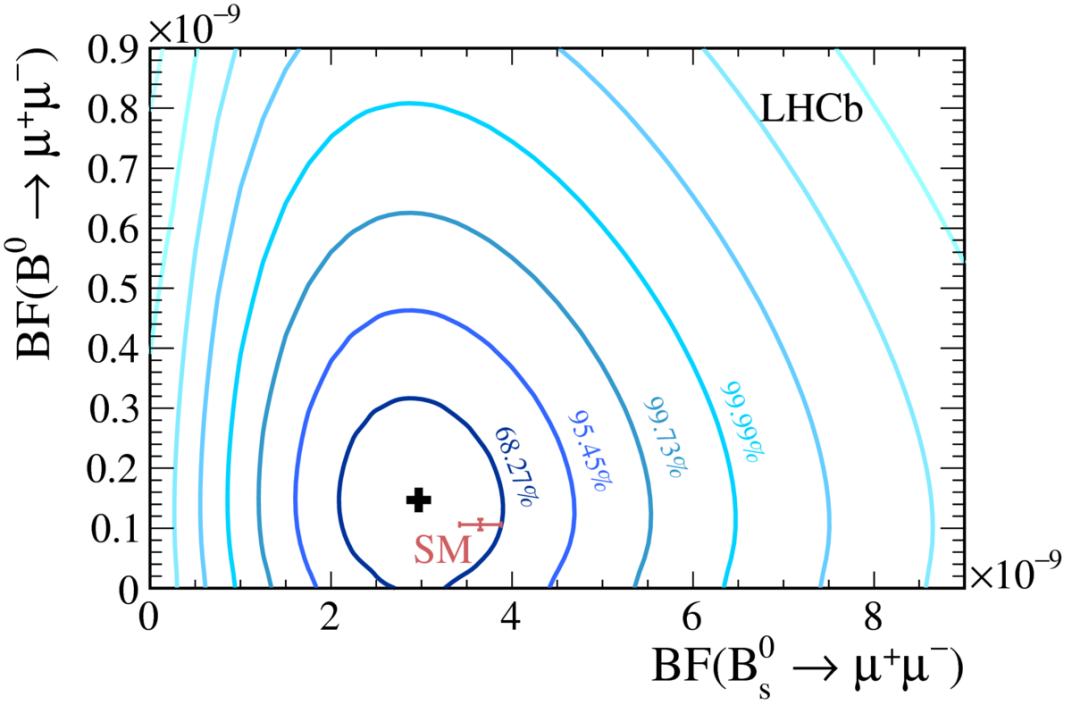
Results are very compatible with Standard Model, and will tighten further constraints on New Physics models with an extended scalar sector.



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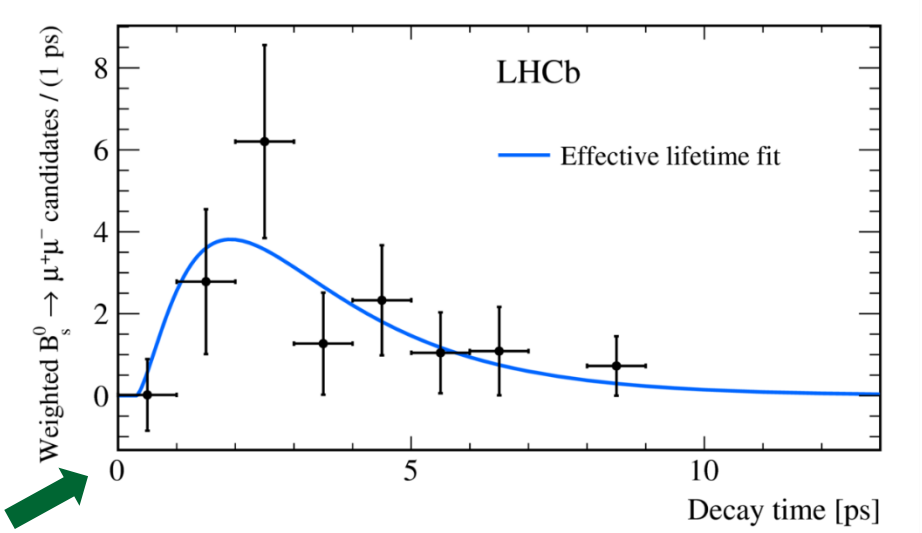
We have now returned to this critical observable with an improved analysis (~50% combinatoric background than previously). Run 1 + 1.4 fb^{-1} of Run-2 data.

This is not the end of the story !

Vital that these branching ratios are measured ever more precisely - a key goal of the LHCb Upgrade.

In addition, we may start to probe over observables associated with the decay, *e.g.* the effective lifetime.

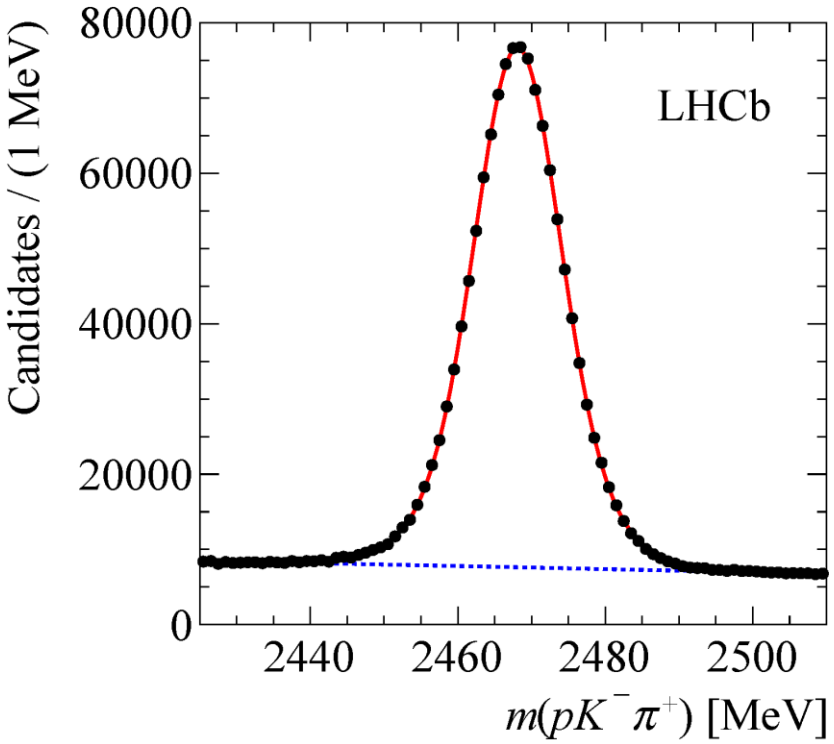


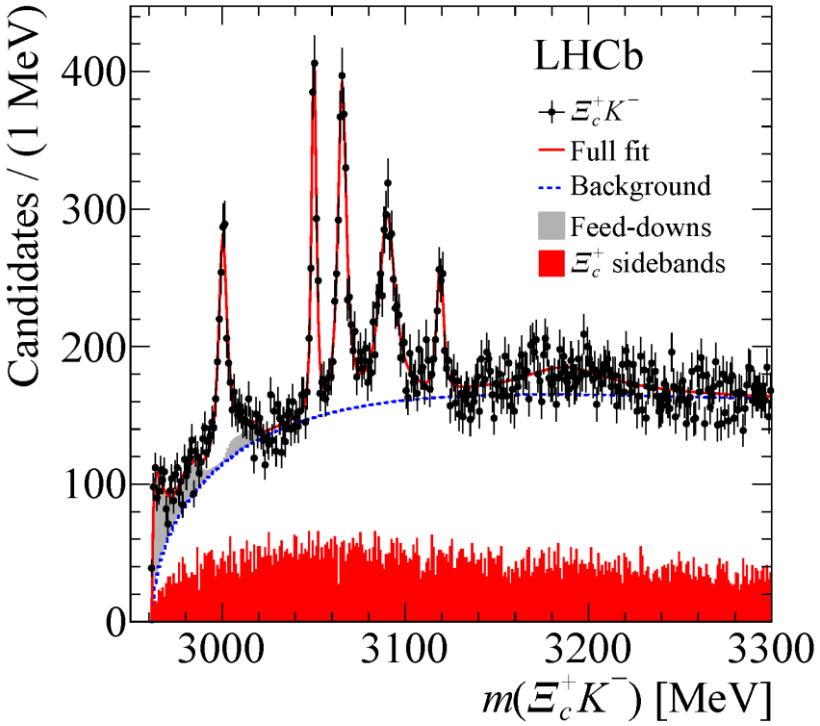
Proof-of-principle measurement

Spectroscopy: the famous five

New, exciting, results continue to emerge in hadron spectroscopy [arXiv:1703.04649].

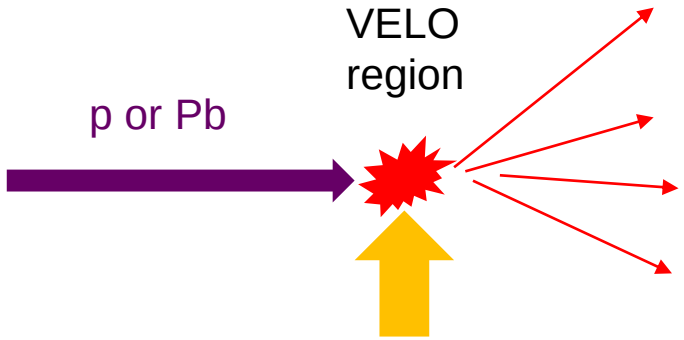
Take these and add a kaon…





Five (!) new narrow states found in the $\Xi_c^+K^-$ spectrum → excited Ω_c^0 baryons.

Fixed-target physics



LHCb is the only experiment at the LHC that can operate in fixed-target mode, making use of unique gas-injection SMOG system.

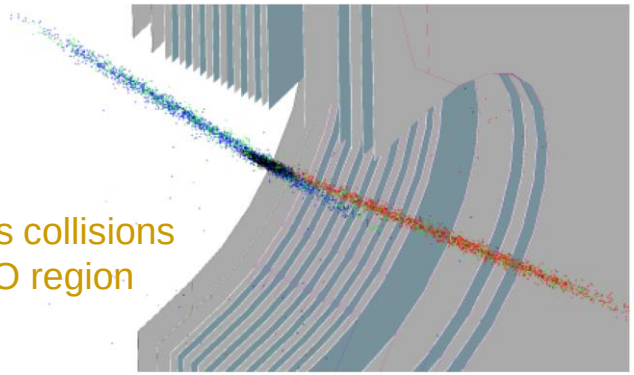
This allows many studies of relevance to heavy-ion physics…
…but also to particle astrophysics.

Studies of anti-matter in space (*e.g.* anti-protons) have shown an apparent excess that has been interpreted as arising from annihilating dark matter.

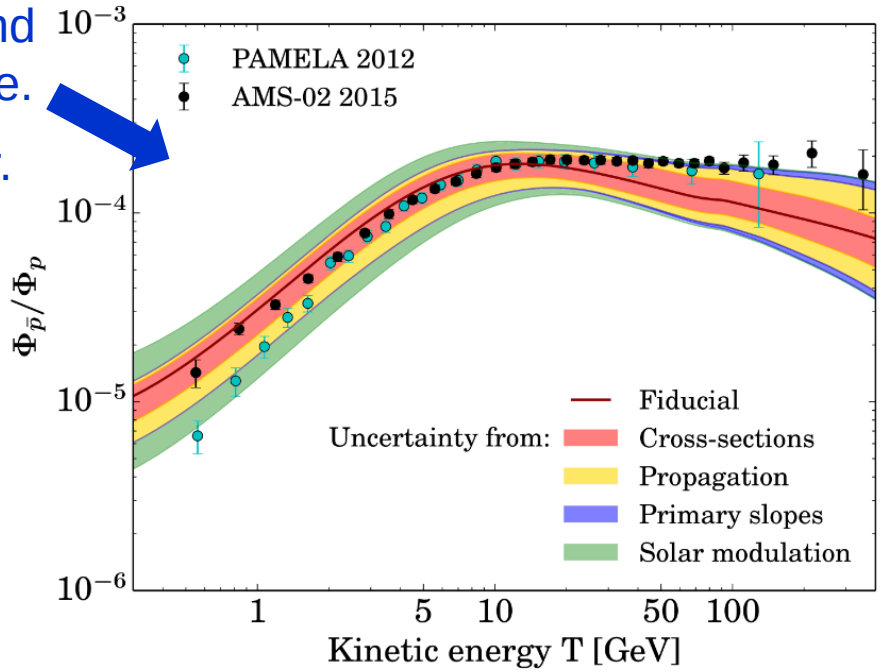
However uncertainties from SM background coming from cosmic ray collisions are large.

→ Need to measure cross-sections better.
e.g. p + He → p-bar + X

SMOG to the rescue !



beam–gas collisions in VELO region



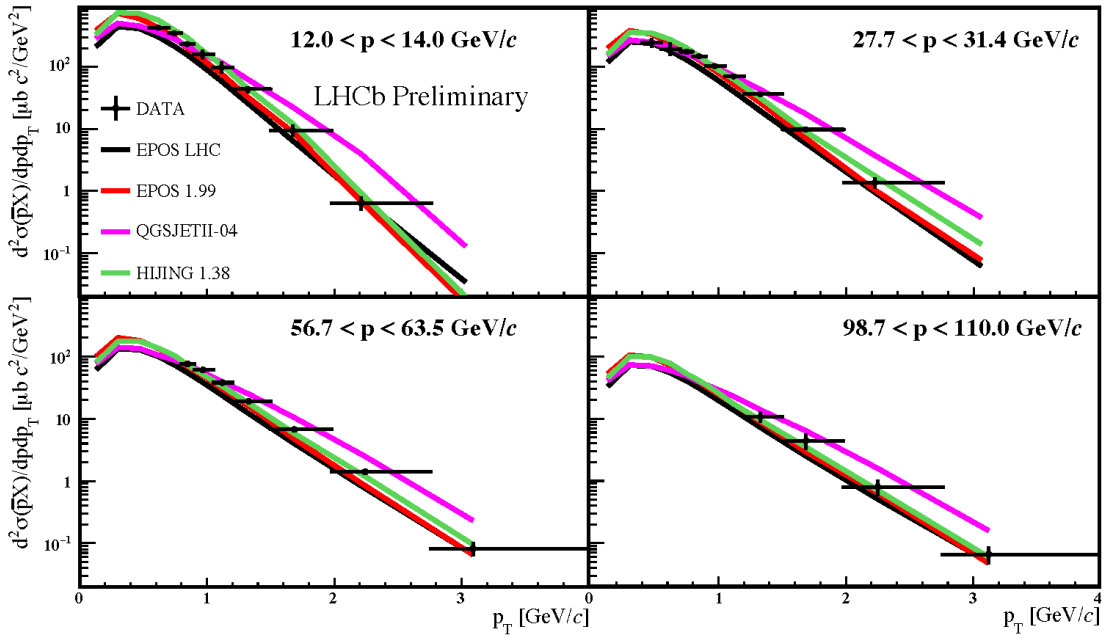
Fixed-target physics

VELO region

p or Pb

First such measurements of this process ($\sqrt{s_{NN}}$ = 110 GeV).
Cross-section measured in different kinematic bins, often to ~10%.

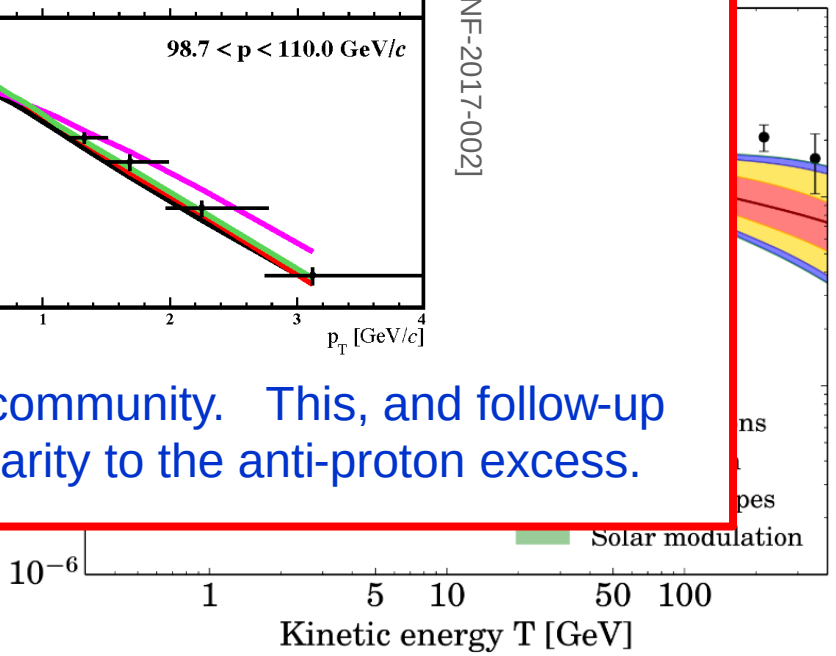
Data can discriminate between Monte Carlo models (wide spread)



[LHCb-CONF-2017-002]

Now being digested by the cosmic ray community. This, and follow-up measurements, has potential to bring clarity to the anti-proton excess.

in VELO region



Hot news from last week !

Science stories from Tues 18th

Discovery of first living, ~1m long, giant shipworm

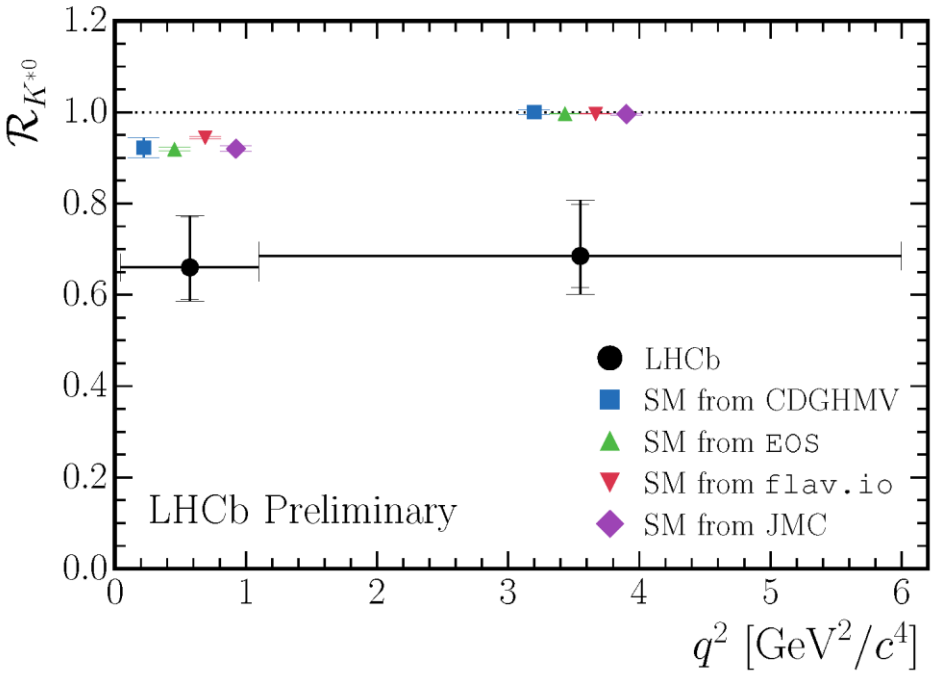
Hot news from last week !

Science stories from Tues 18th

Seminar presenting long-awaited LHCb Run-1 R_{K^*} result [LHCb-PAPER-2017-013]

Essentially ratio of decay rates of $B^0 \to K^* \mu^+ \mu^-$ to $B^0 \to K^* e^+ e^-$, here evaluated in two bins of lepton invariant-mass.

Lepton Universality means R_{K^*} should be unity (or very close) in Standard Model. (Negligible uncertainty in prediction.)



R_{K^*} is found to be low in both bins, by up to ~2.5 sigma.

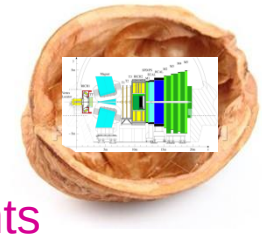
A fluctuation ? Quite possible…

…although, intriguingly, a *very* similar result was already found in the measurement of the analogous quantity, R_K, in $B^+ \to K^+ l^+ l^-$ decays. [PRL 113 (2014) 151601].

We have enough data on tape, & more to come, to confirm/rule out these hints !

Progress to LS2 Upgrade

The Upgrade in a nutshell



Indirect search strategies for New Physics, *e.g.* precise measurements & the study of suppressed processes in the flavour sector become ever-more attractive following the experience of run-1 LHC that direct signals are elusive

Our knowledge of flavour physics has advanced spectacularly thanks to LHCb. Maintaining this rate of progress beyond run 2 requires significant changes.

The LHCb Upgrade

1) Full software trigger
- Allows effective operation at higher luminosity
- Improved efficiency in hadronic modes

2) Raise operational luminosity to 2 x 10^{33} cm^{-2} s^{-1}

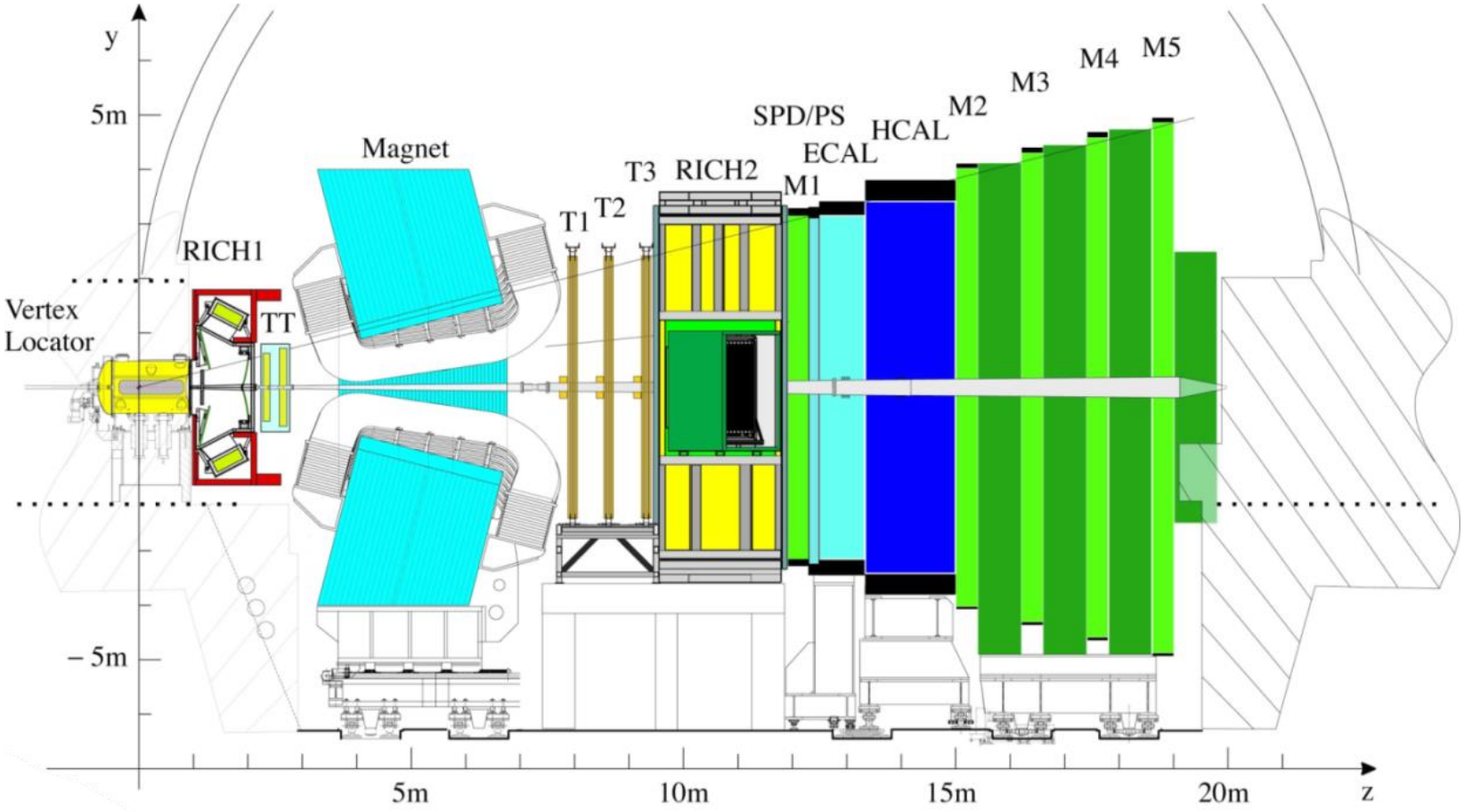
Necessitates redesign of several sub-detectors & overhaul of readout

Huge increase in precision, in many cases to the theoretical limit, and the ability to perform studies *beyond the reach of the current detector*.

Flexible trigger and unique acceptance also opens up opportunities in other topics apart from flavour ('a general purpose detector in the forward region')

Upgrade overview

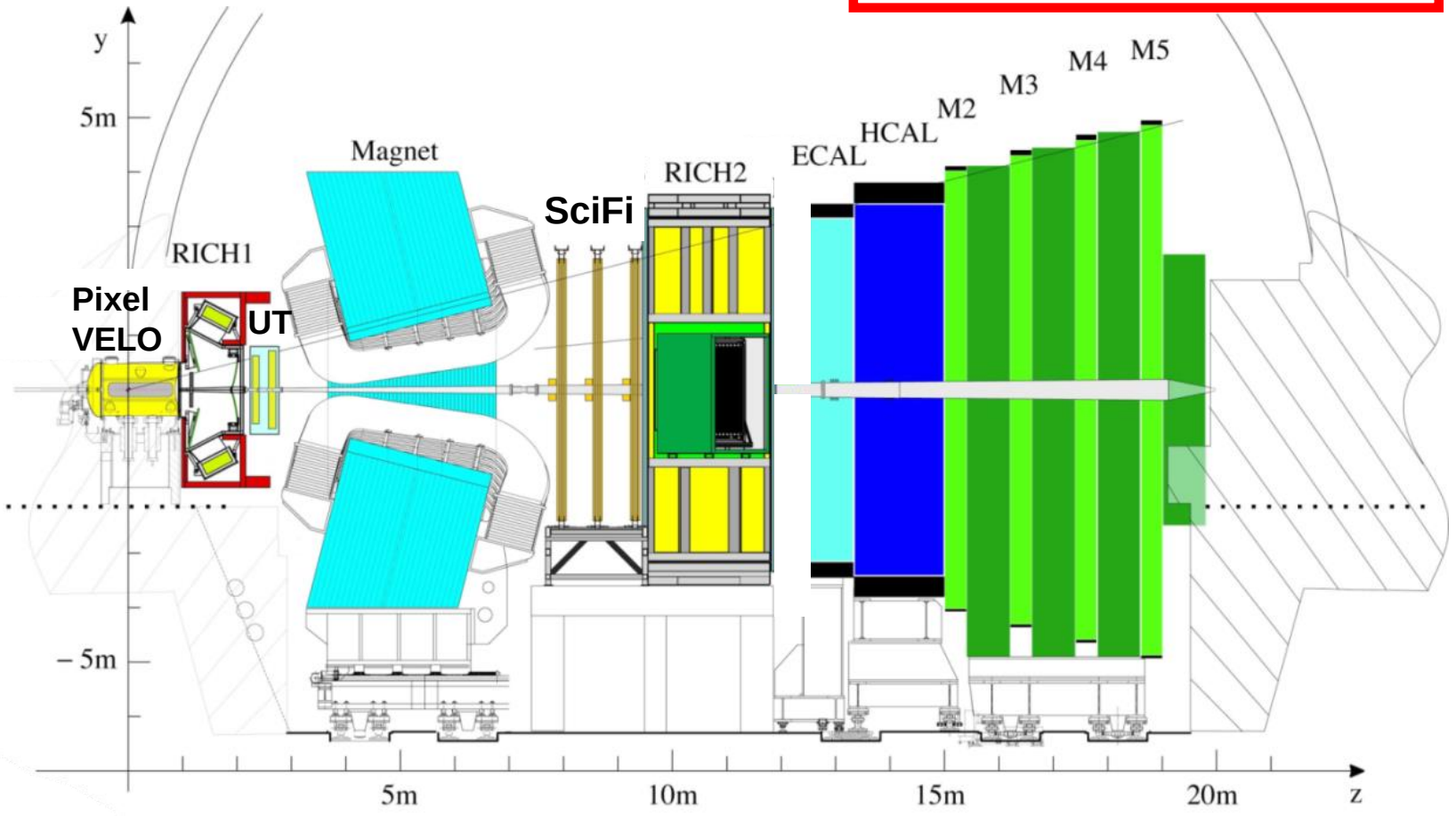
Current detector



Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger



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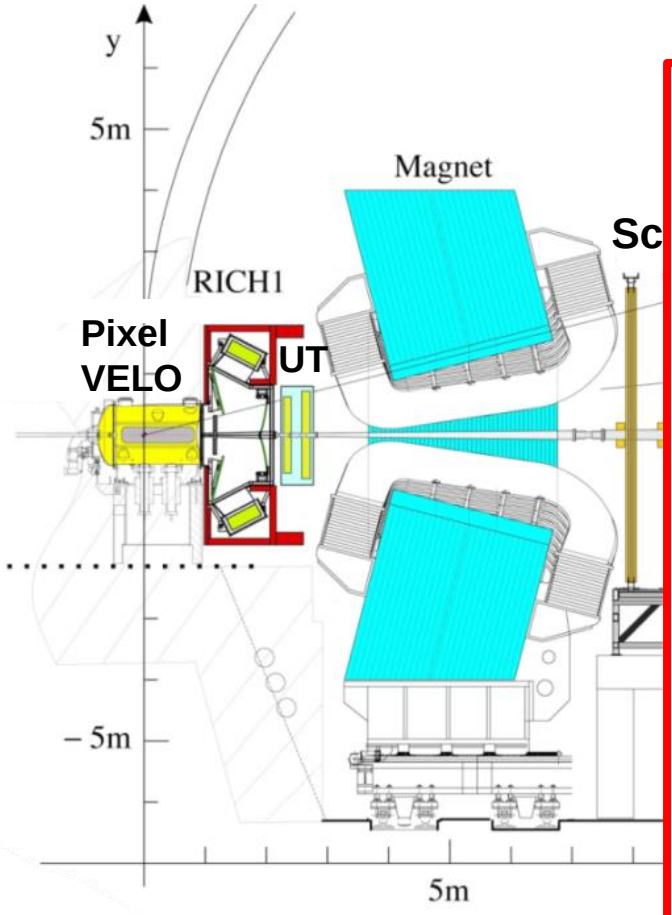
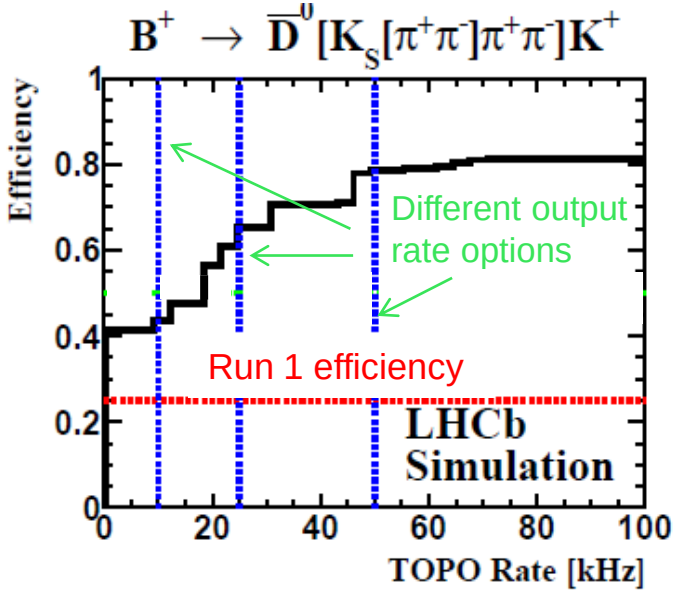


Upgrade software trigger

Full event information → much improved efficiency

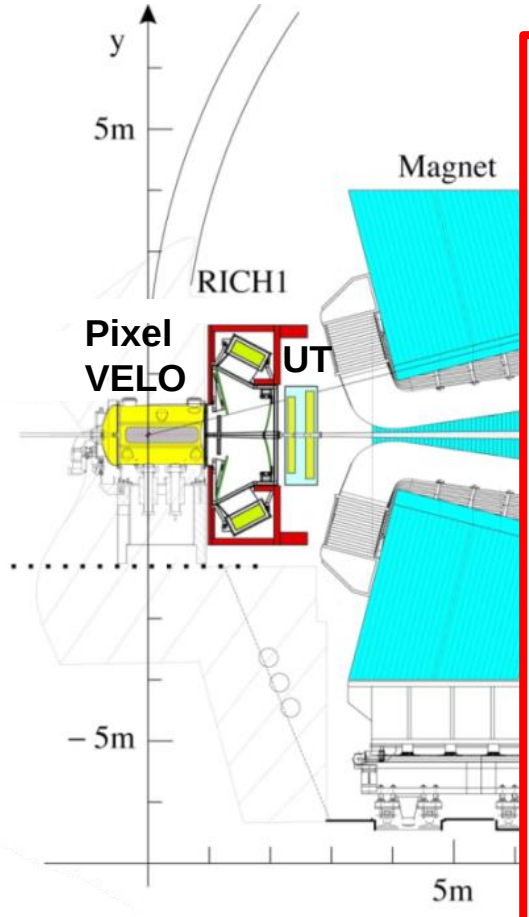


NB: many of run-2 innovations can also be considered as R&D for the Upgrade trigger !

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger



Trigger and computing

Redesign of LHCb event model, and optimal exploitation of modern computing technologies essential for Upgrade trigger (& offline computing).

Measurements on recent CPUs show year-on-year improvement factor lower than had been foreseen

→ essential to benefit from multi-thread / vectorisation !

Recent achievements:

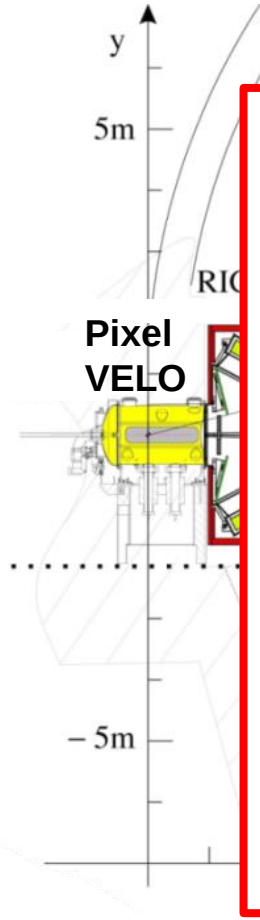
- Full reconstruction sequence now running;
- Vectorisation demonstrators, *e.g.* of RICH code, have shown significant improvement.

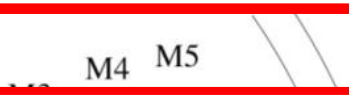
On track for Software & Computing TDR at end of year.

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

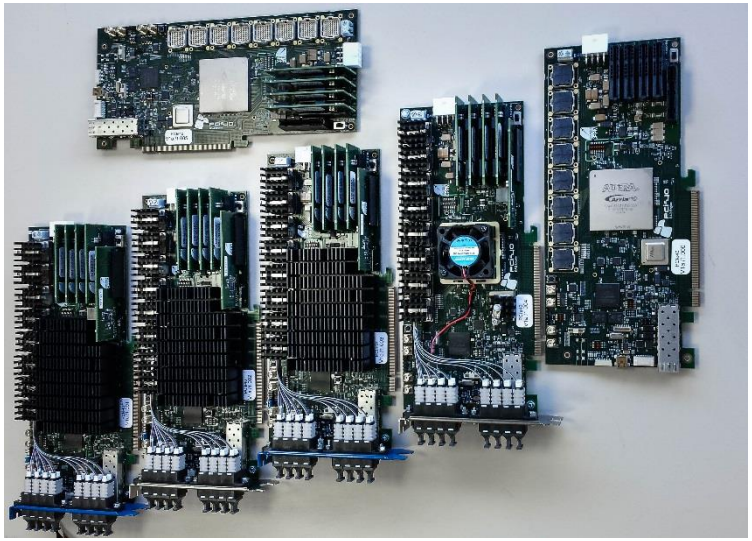




Readout progress:

- New versions of PCIe40 prototype available for sub-detector testing;
- Defining total number of boards required;
- Project underwent successful review at start of month;
- Invitation for tender imminent;
- Production will start before end of year.

Data acquisition and online



Prototypes of the PCIe40 at various stages during assembly

Upgrade overview

Current detector → upgraded detector

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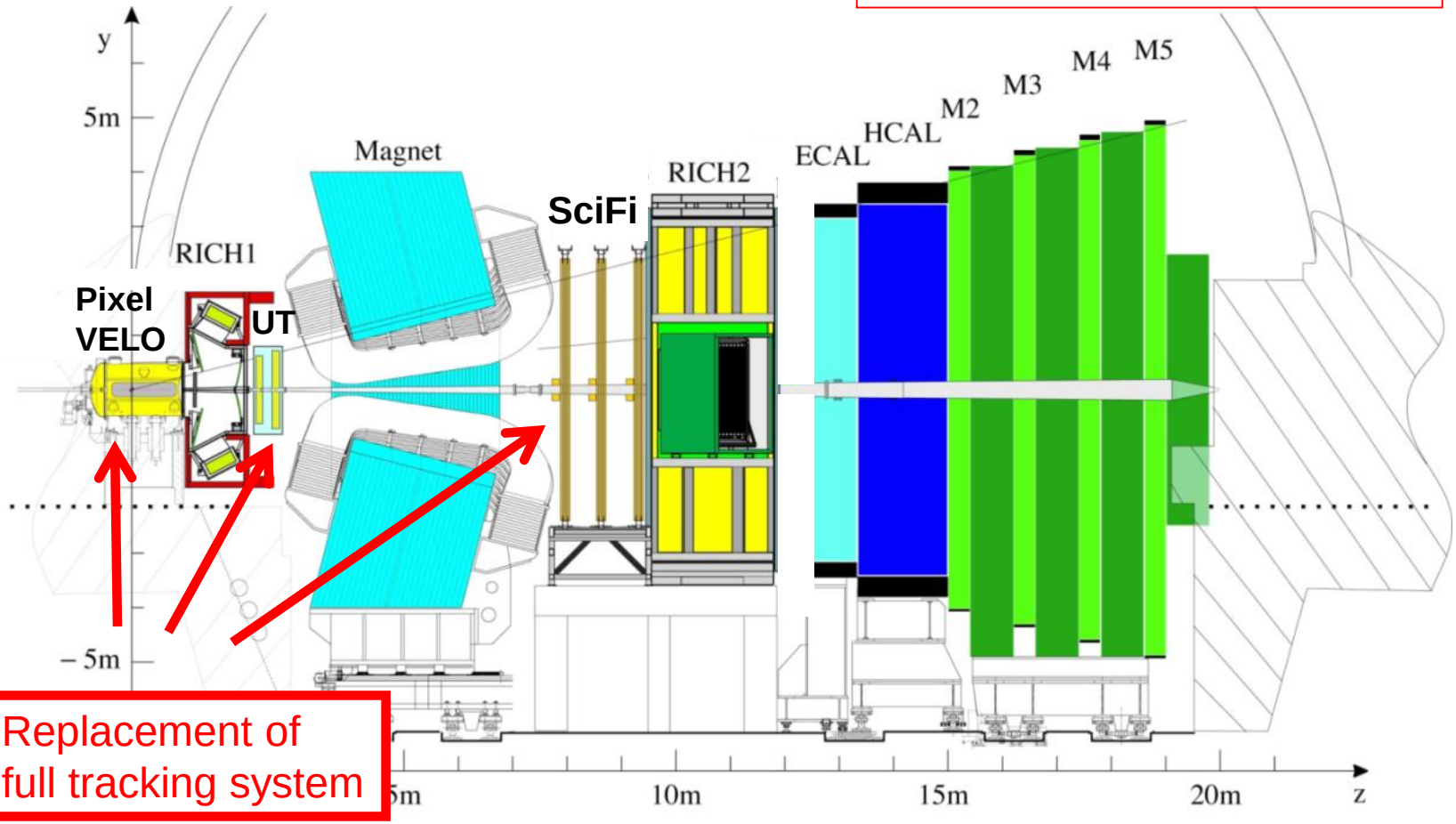
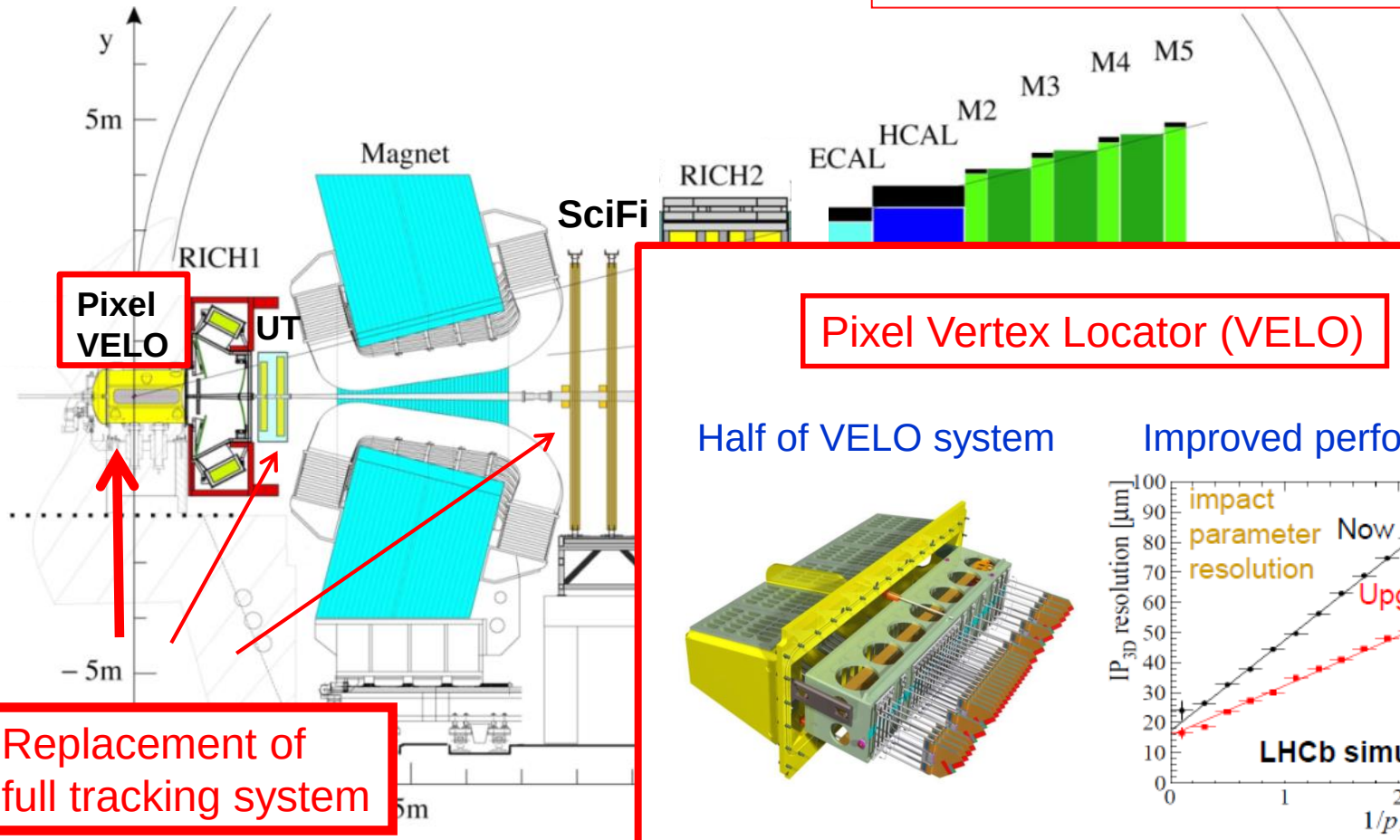


Replacement of full tracking system

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger



Pixel Vertex Locator (VELO)

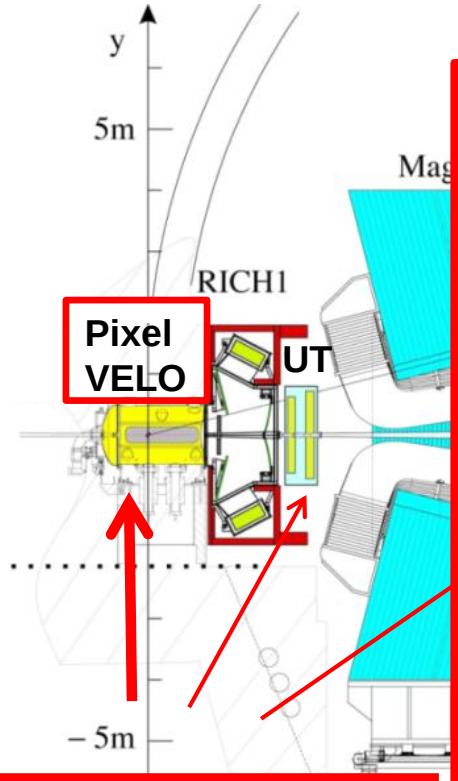
Half of VELO system

Improved performance

Upgrade overview

Current detector → upgraded detector

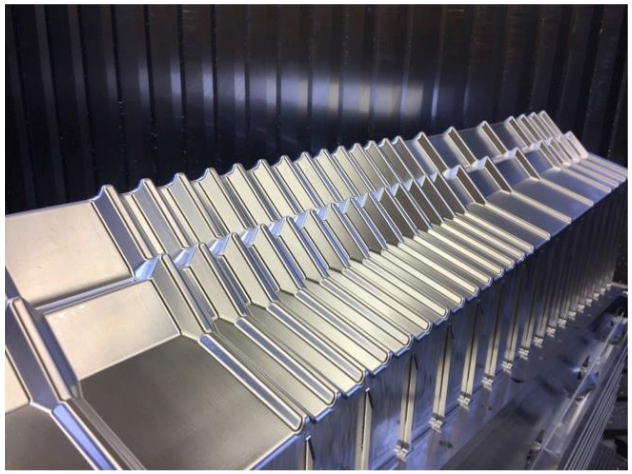
All sub-detectors read out at 40 MHz for software trigger



Replacement of full tracking system

Pixel Vertex Locator (VELO)

- ASIC (VeloPix) performing well under tests. However, second submission possible to provide full robustness against radiation.
- Successful sensor PRR in Dec. Manufacturer and technology now chosen.
- Full-scale prototype of RF-foil box produced. Leak tests encouraging !
- Work ongoing on mechanics.

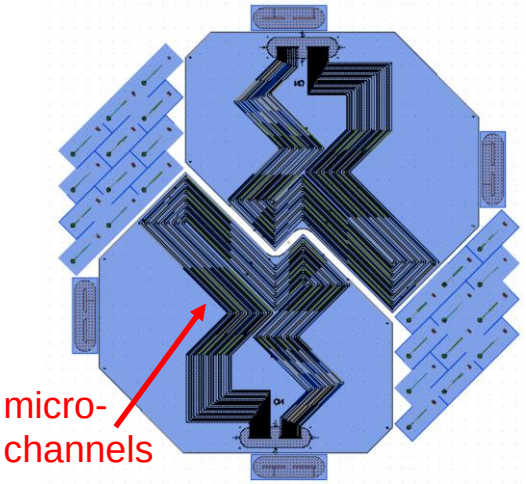


VELO: progress with cooling

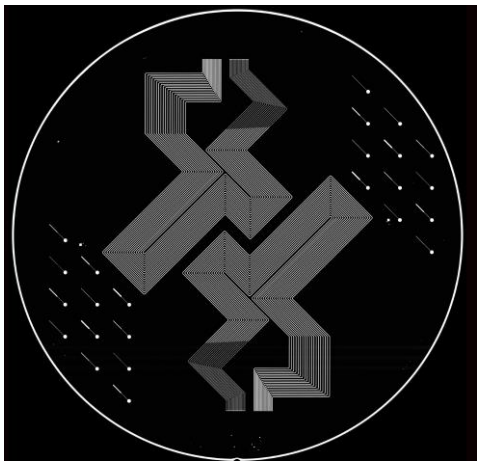
Statement from October RRB: " Challenges remain ! The baseline cooling option ('microchannels') is delayed. "

Excellent progress – high quality bonded and diced substrates produced ahead of (revised) schedule by industrial supplier.

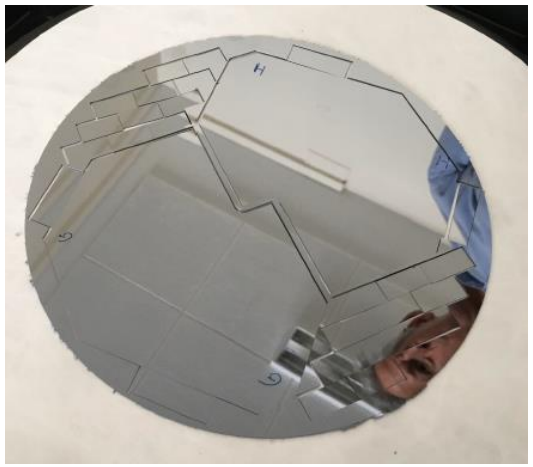
After bonding



drawing



Scanning Electron Microscope (SEM) image, showing very few defects



Diced wafer at CERN

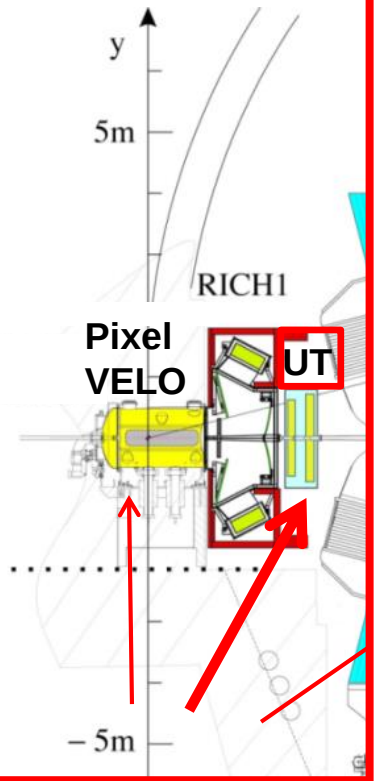
Focus is now on performing robust soldering of connector to substrate. In parallel, a second solution is being pursued based on pipes embedded in ceramic substrate.

Fully on track to make a final decision in the summer at time of module EDR.

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger



Replacement of full tracking syste

Upstream Tracker (UT)

Si-strip detector in front of magnet

- Critical path item: submission of ~final SALT128 design.
  - Excellent understanding of remaining problems (noise immunity, radiation robustness).
  - Submission in May: timescale OK !
- Preproduction sensors under evaluation.
- Excellent progress with flex cables.
- Stave assembly procedure defined.

Upgrade overview

Current detector → upgraded detector

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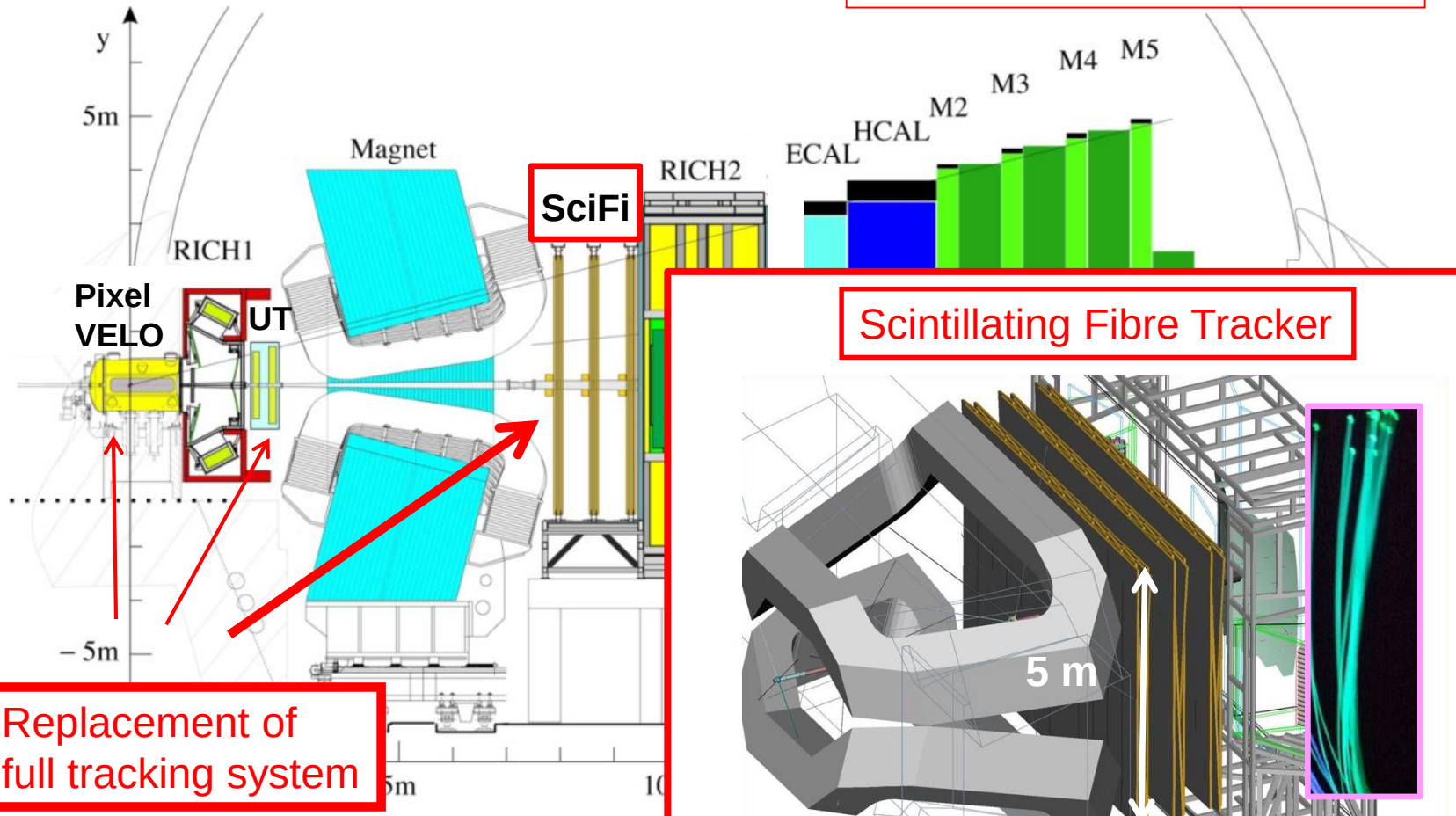


Replacement of full tracking system

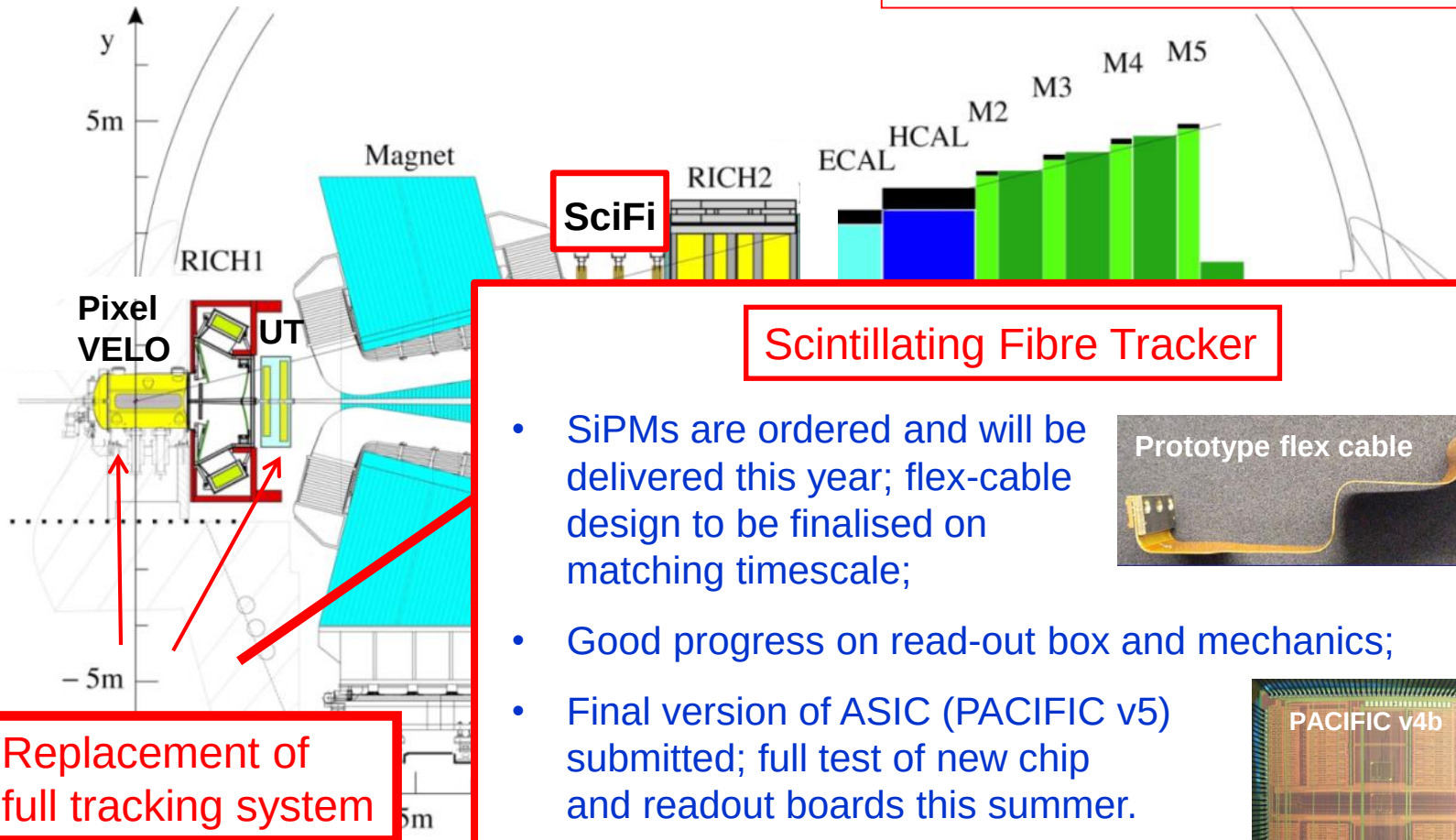
Scintillating Fibre Tracker

Large scale system (~11,000 km of fibres)

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

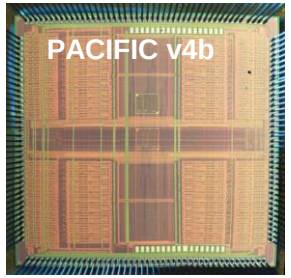


Replacement of full tracking system

Scintillating Fibre Tracker

- SiPMs are ordered and will be delivered this year; flex-cable design to be finalised on matching timescale;

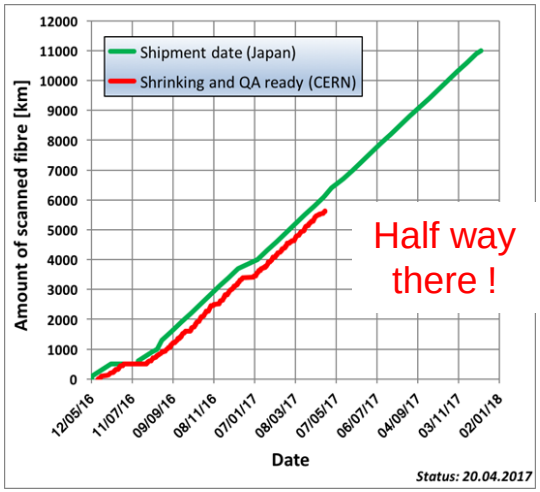
- Good progress on read-out box and mechanics;
- Final version of ASIC (PACIFIC v5) submitted; full test of new chip and readout boards this summer.



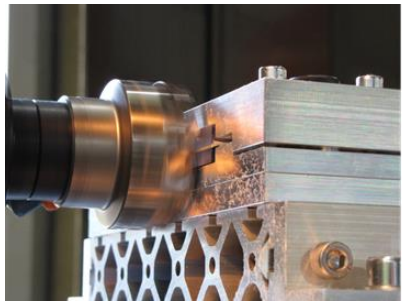
- Mat and module production proceeding well →

SciFi – mat & module production is ongoing

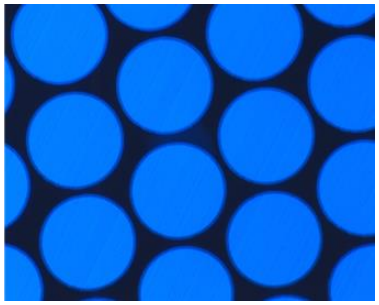
Fibre supplier is now in steady-state delivery mode: 300 km / 2 weeks.



Three mat centres in full production mode. PRR of final centre this week !



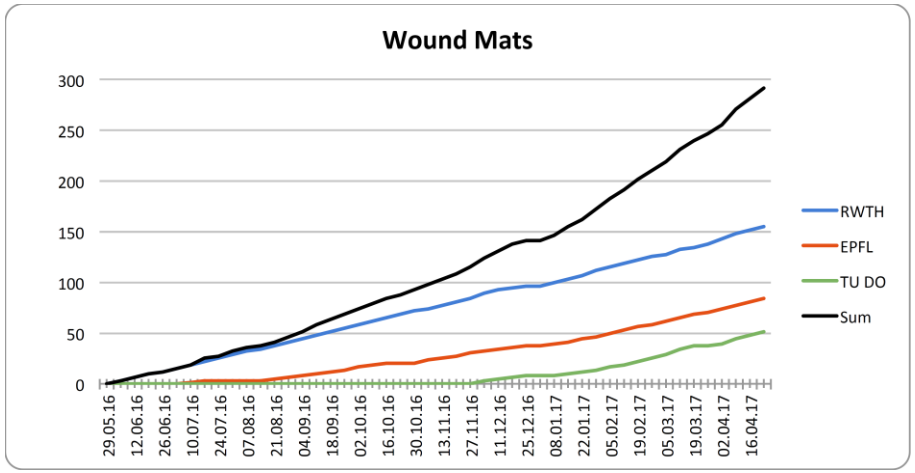
Milling of mat endpiece



Fibres after machining

Module production Underway.

Mat production at around 25% of total required.

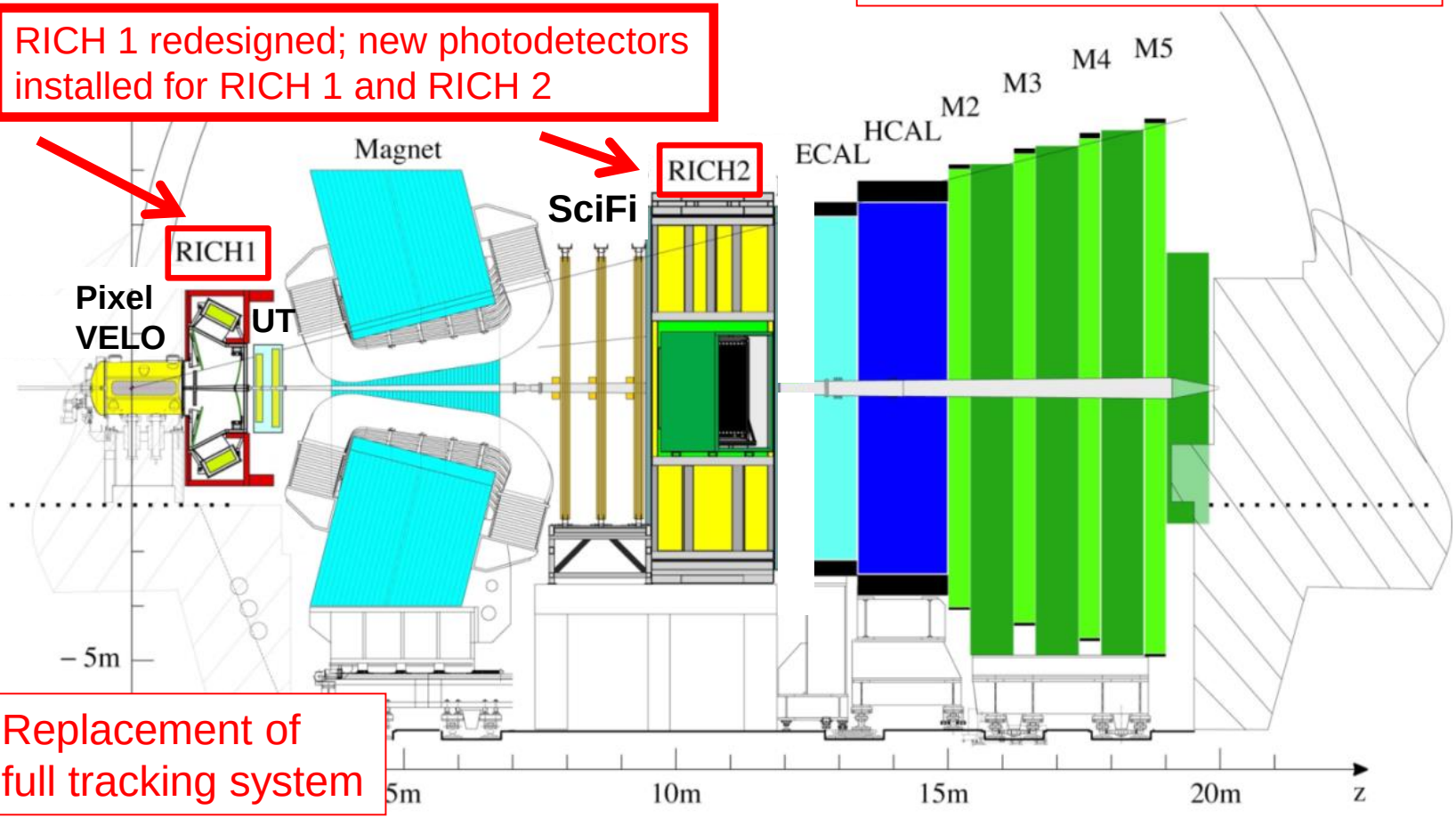


Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



Replacement of full tracking system

Upgrade overview

Current detector → upgraded detector

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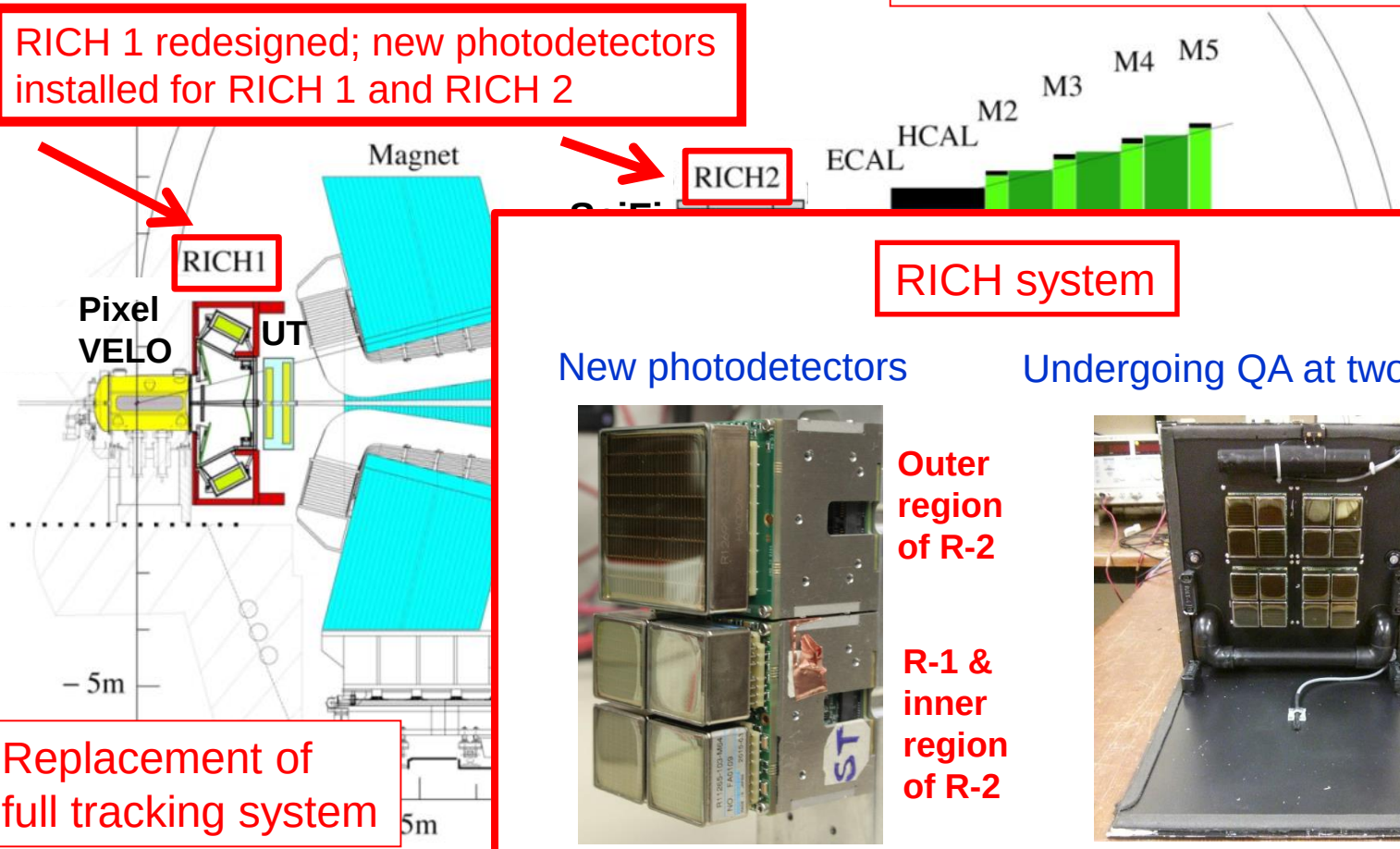


Replacement of full tracking system

RICH system

New photodetectors

Outer region of R-2

R-1 & inner region of R-2

Batches of MaPMTs arriving monthly since September.

Undergoing QA at two centres

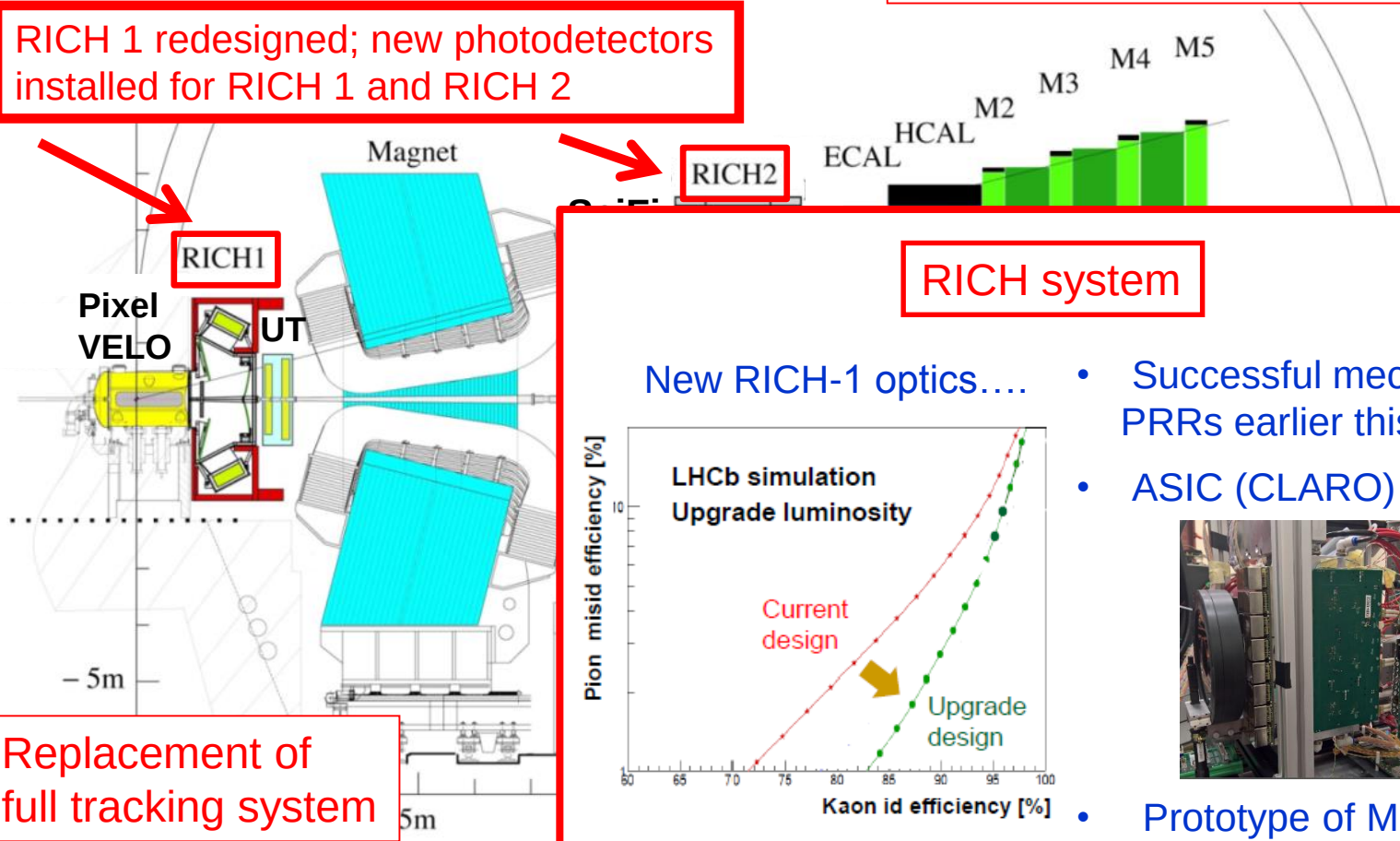
Quality is excellent !

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



Replacement of full tracking system

RICH system

New RICH-1 optics….

…good performance at high luminosity.

- Successful mechanics PRRs earlier this month;
- ASIC (CLARO) ready;

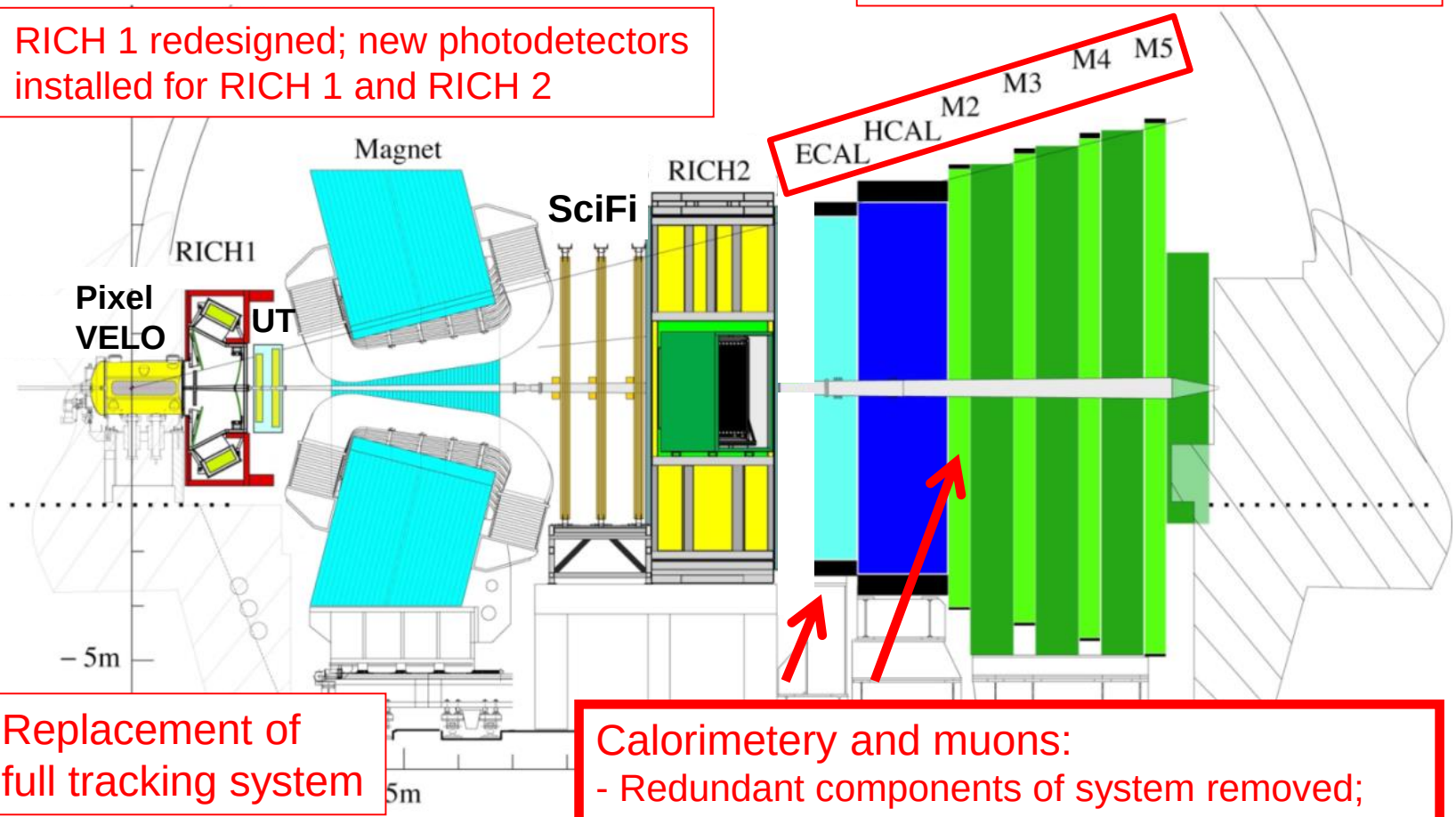
- Prototype of MaPMT, frontend and readout successfully operated.

Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

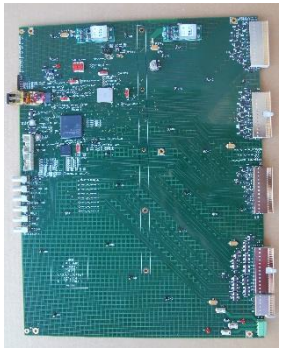
RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



Replacement of full tracking system

Calorimetery and muons:
- Redundant components of system removed; new electronics added; more shielding included

Calo system



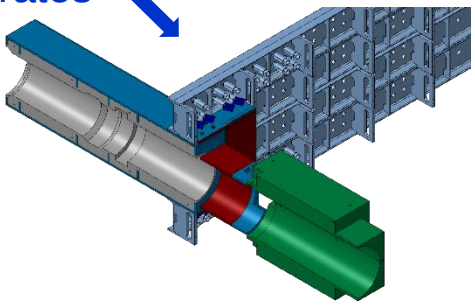
Good progress with all electronics:

- ASIC production imminent;
- First prototype of control board.

Plans for SPD/PS removal advancing.

Muon system

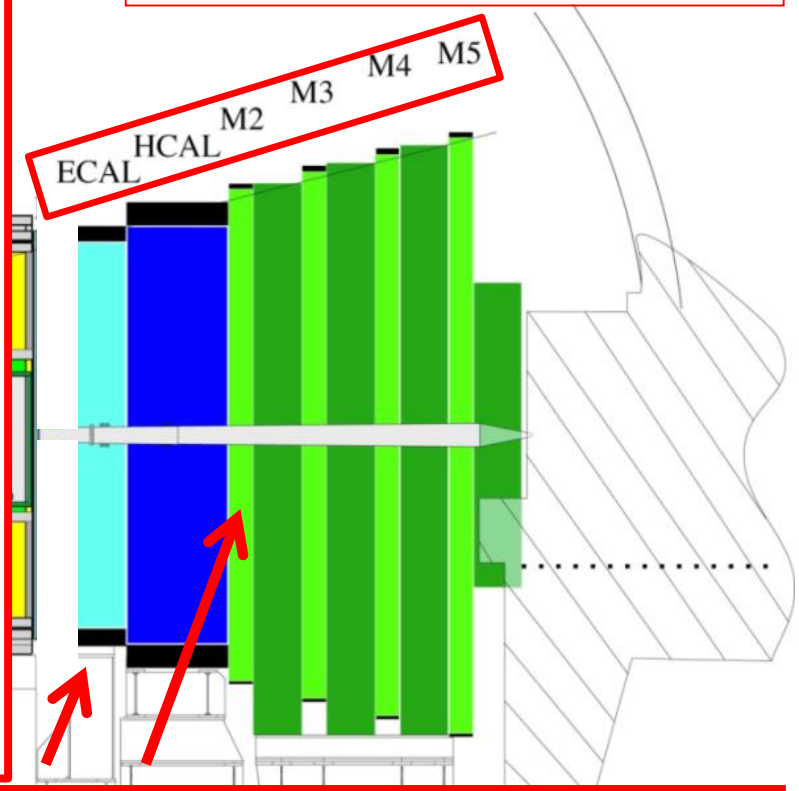
Additional shielding passed EDR in Jan; will reduce rates in M2 by ~50%.



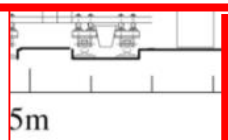
Production of spare MWPCs almost complete.

New ASIC (nSYNC) submission recently received. Production scheduled for autumn.

All sub-detectors read out at 40 MHz for software trigger



Replacement of full tracking system

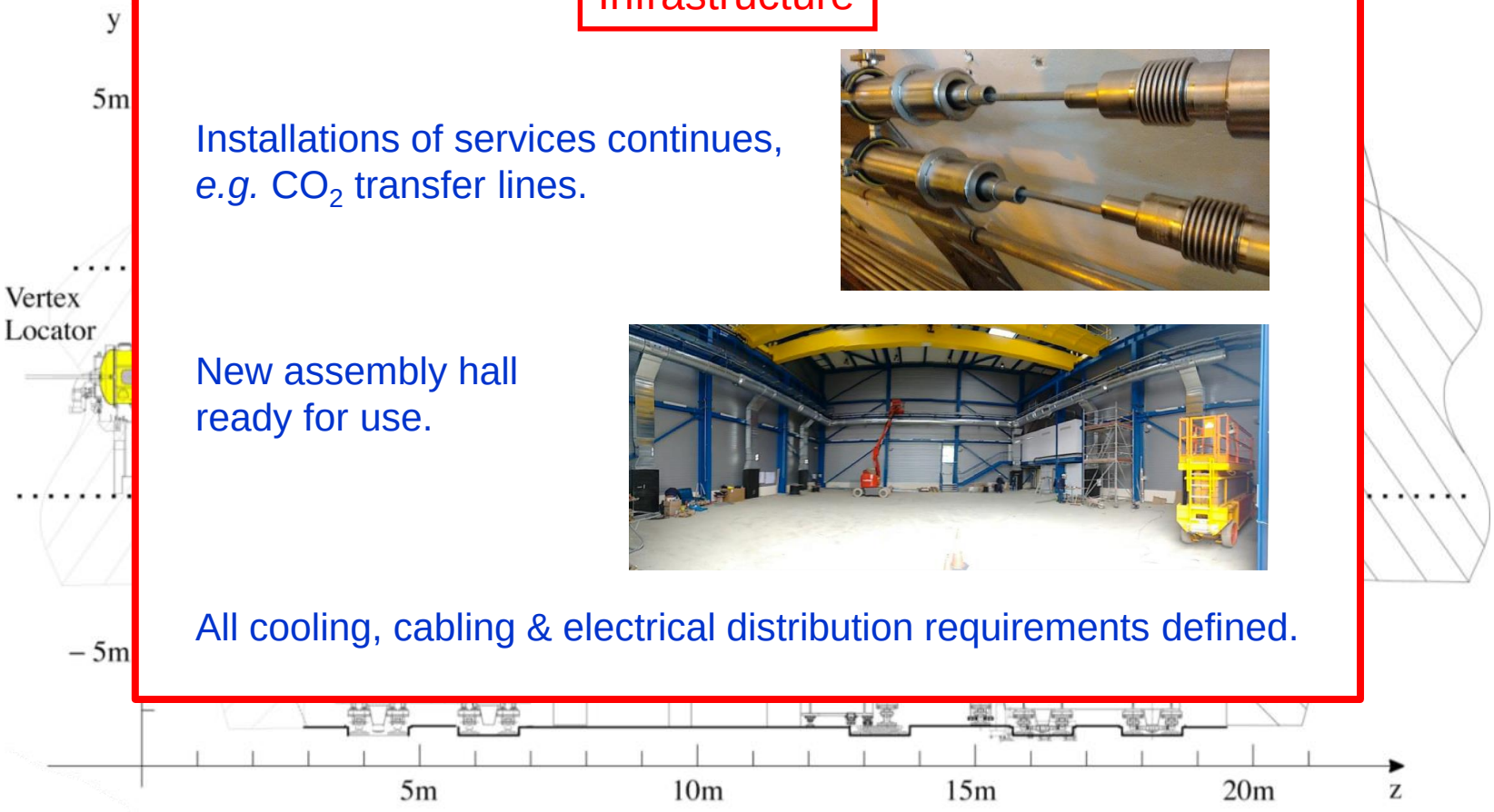


Calorimetery and muons:

- Redundant components of system removed; new electronics added; more shielding included

Upgrade overview

Current detector



Infrastructure

Installations of services continues, *e.g.* CO_2 transfer lines.

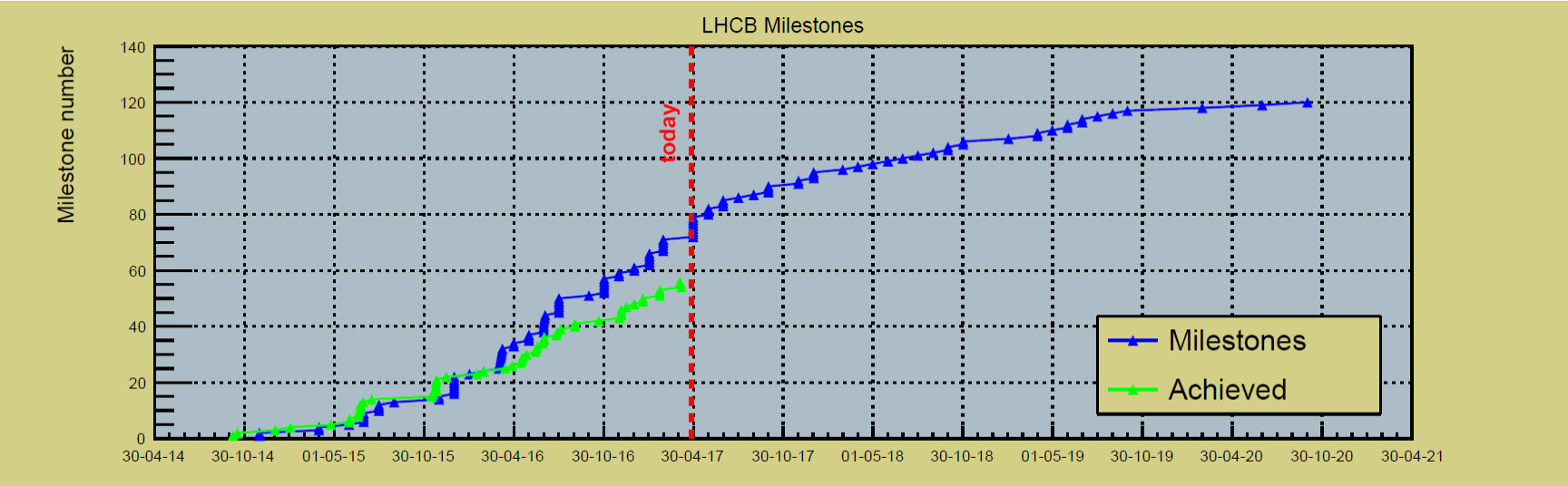
New assembly hall ready for use.

All cooling, cabling & electrical distribution requirements defined.

Project tracking & milestones

Comprehensive internal review performed at start of year. One important ingredient was updating of risk registers. Outcomes endorsed by LHCC.

Annual LHCC review scheduled for next month.



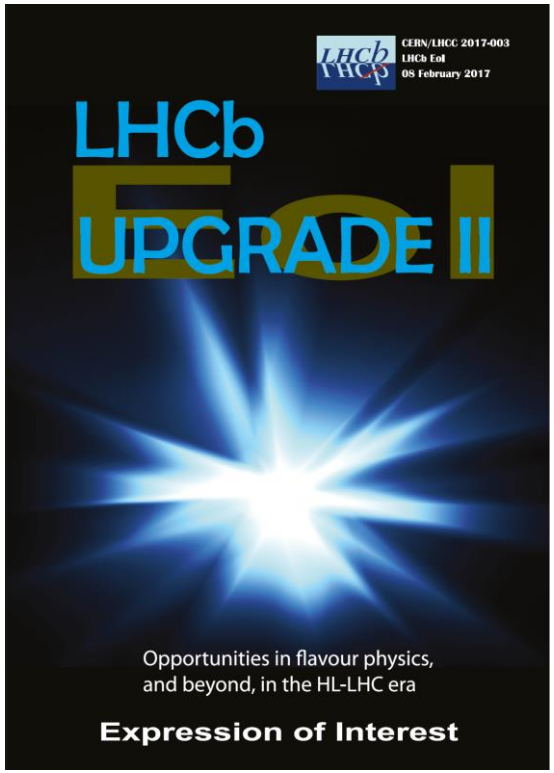
When surveying overall milestones, we are behind schedule. However:

- We are still on course to be ready for start of run 3;
- Carefully following critical items. This strategy has resulted in much progress.

Looking further forward…

Serious thinking now underway about a phase-II Upgrade that would occur in LS4 (~2030) & allow full exploitation of flavour potential of the machine in HL-LHC era.

Expression of Interest submitted to February LHCC [CERN-LHCC-2017-003]



- Install in LS4 (~2030), after Phase-I Upgrade.
- Detector to be able to operate at ~2 x 10^{34} $cm^{-2}s^{-1}$;
- Integrate ~300 fb^{-1};
- Comprehensive flavour physics programme and general-purpose forward physics (as now), but targeting clean measurements currently limited by statistics, and new observables;
- Modest activities foreseen for LS3 in consolidation of Phase I & in preparation for next step.

Important to start the discussion now, but rest assured that we will not be distracted from Phase-I challenges !

Conclusions

Run-2 operation has been very successful, with detector working well.
2016 was a very productive year; we hope for the same in 2017.

LHCb continues to deliver important measurements in flavour physics, spectroscopy, & beyond. Some very interesting results are emerging…
Watch this space !

LS2 Upgrade will deliver huge increase in physics:

- good progress on all subsystems;
  challenges inevitably emerge, but are being tackled appropriately;
- critical items are being followed closelyl
- we remain on track.

Expression of Interest submitted for a Phase-II Upgrade.

Backups

Money Matrix including Common Fund (kCHF)

Funding Agency	VELO	UT	SciFi	RICH	CALO	MUON	Readout Boards	Total Detectors	Common Fund	CF & detectors
BRASIL	60		150					210	666	876
CHINA			150					150	175	325
FRANCE			2310		1085		380	3775	1508	5283
GERMANY			3840					3840	912	4752
GERMANY MPG									210	210
IRELAND									35	35
ITALY		480		2000		1554		4034	2735	6769
NETHERLANDS	1320		1920					3240	596	3836
POLAND	75	650		48				773	456	1229
ROMANIA				450				450	175	625
RUSSIA			2600		362	45		3007	1157	4164
SPAIN	375		150		455			980	596	1576
SWITZERLAND		810	2500					3310	877	4187
TURKEY									35	35
UK	2919			3405				6324	2735	9059
UKRAINE									105	105
UN. STATES		4310						4310	561	4871
CERN	1044	250	1550	2982		100		5926	2174	8100
Total	***5793***	***6500***	***15170***	***8885***	***1902***	***1699***	***380***	**40329**	***15710***	***56039***
TDR cost	*5793*	*6500*	*15170*	*10089*	*1902*	*1699*	*380*	*41533*	*15710*	*57243*
Underfunding				*1204*				*1204*		*1204*

Organisation of Upgrade Activities

New body, Upgrade Planning Group, established to oversee Upgrade Activities

- Spokesperson (chair)
- Deputy Spokesperson
- Technical Coordinator
- Physics Coordinator (or representative)
- Upgrade Detector Coordinator
- Upgrade Performance Coordinator
- Upgrade Resources Coordinator
- Upgrade Data Processing Coordinator

New positions created for this body

Upgrade activities for each sub-system are pursued within existing 'Projects' (*i.e.* VELO Project deals with current detector and Upgrade) – this optimises use of expertise and resources, and keeps lines of communication clear.

Exceptions are the new detectors: the Upstream Tracker and the Scintillating Fibre Tracker, where new Projects have been created.