LHCb status and plans

- Run-2 status, incld. computing
- Physics output
- Upgrade progress
- Conclusions

Guy Wilkinson
(University of Oxford and CERN)
on behalf of the LHCb collaboration
26/10/2016

Run 2 status

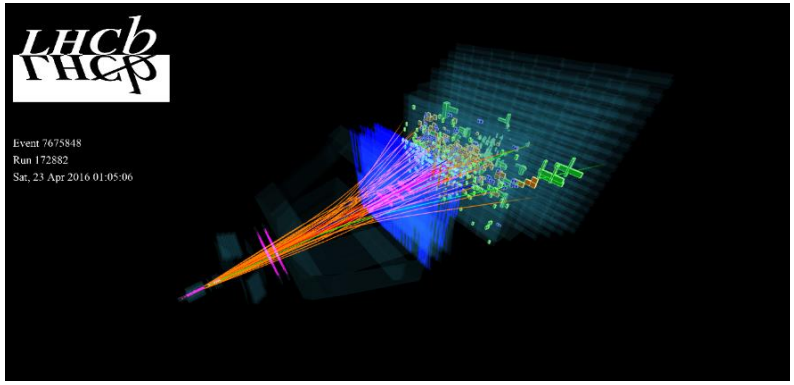
Run-2 start-up: reminder

All end of year interventions successfully completed on time.

Data-taking operations smoothly migrated to new control room.

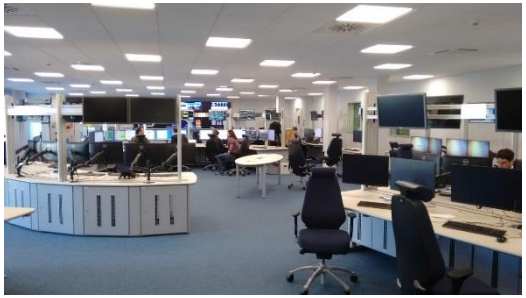
In good shape for first collisions.

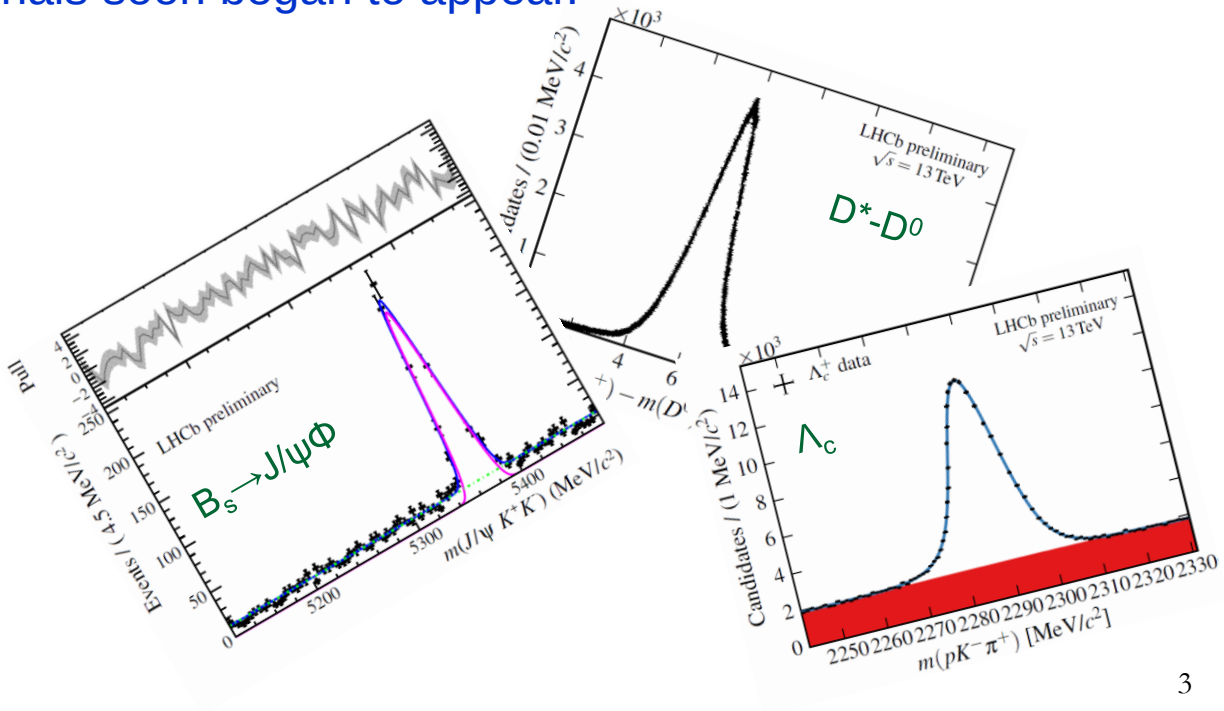
Detector alignment & calibration reached 2015 quality within a couple of days, and first benchmark physics signals soon began to appear.



First event of 2016

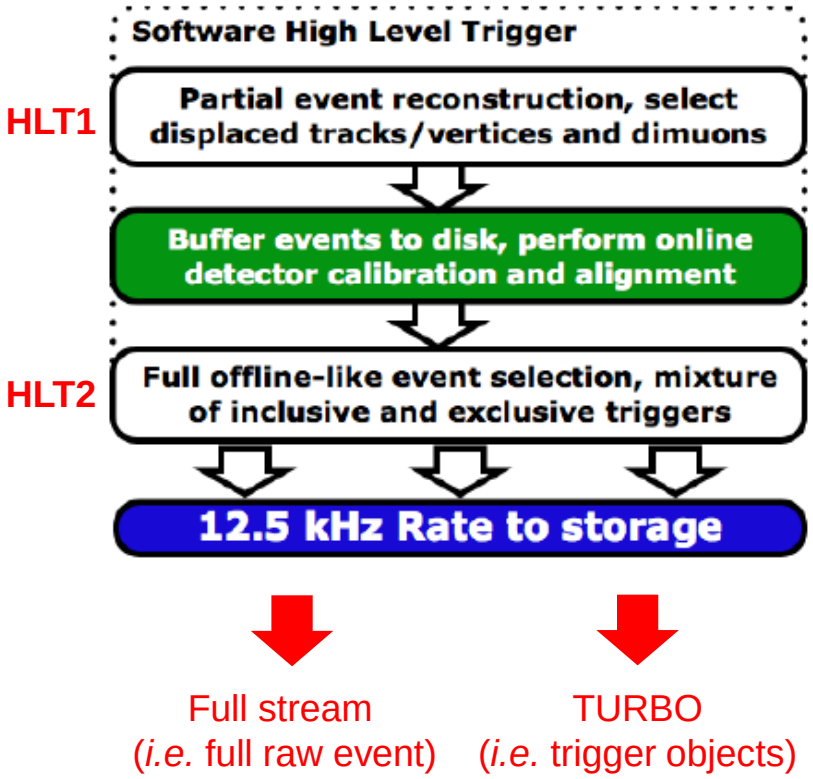
New control room





Optimising resources: the split-HLT & TURBO stream

Recall, the 'big idea' of LHCb run-2 operations: to write the first stage output of the software trigger (HLT1) onto buffer disks, to allow for calibration & alignment, before processing, hours, days or weeks later, with the second stage (HLT2).



Key advantages of this scheme:

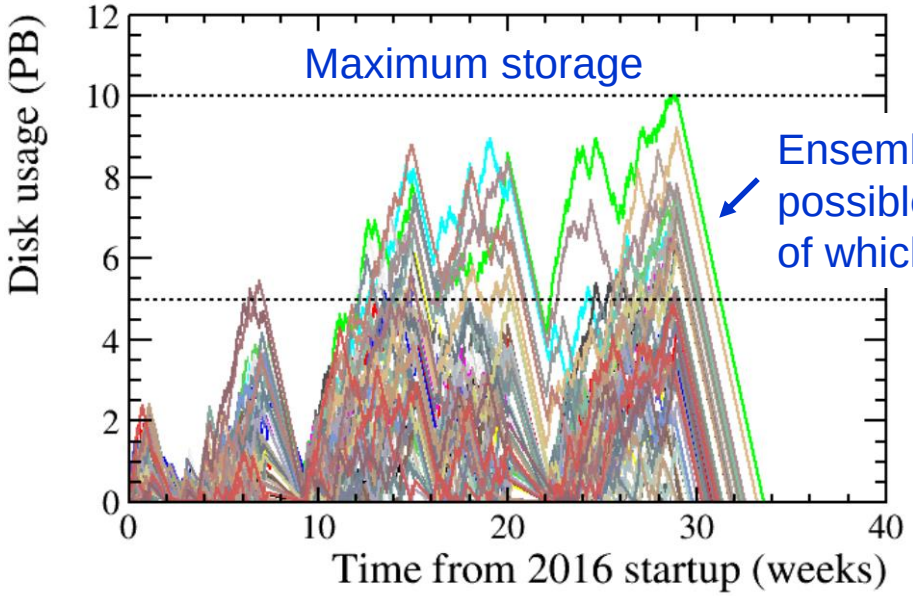
- 'Offline quality' information available In final trigger stage → better discrimination.
- No need for rounds of offline reprocessing. First processing is already optimal…
- …indeed, for many analyses TURBO stream of physics objects reconstructed in trigger are written out. These require no offline processing → use directly in analysis !

Operationally, it is important to tune HLT1 output rate not to risk overfilling buffer disks.

Optimising resources: the split-HLT & TURBO stream

Recall, the 'big idea' of LHCb run-2 operations: to write the first stage output of the s & alignment, before HLT2).

Extensive 'toy' Monte Carlos run in advance of run, with best guesses at likely fill structure and machine efficiency.



Looks good ! What could possibly go wrong…

HLT1

HLT2

able In
nation.

rocessing.
..

RBO
icted
uire no
analysis !

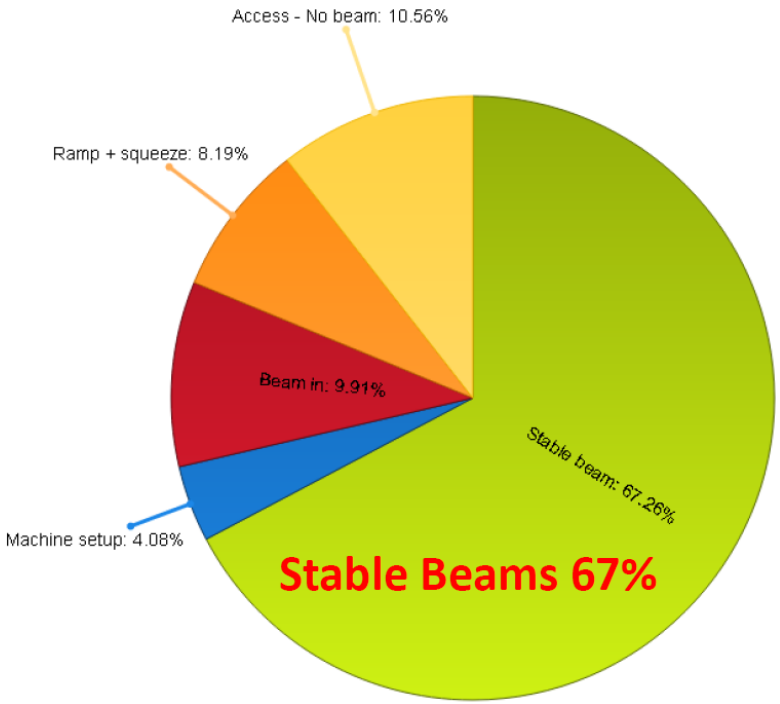
Full stream (*i.e.* full raw event)

TURBO (*i.e.* trigger objects)

Operationally, it is important to tune HLT1 output rate not to risk overfilling buffer disks.

Unforeseen blessings

However, the unprecedented machine efficiency, especially in the early summer led to a torrent of data, and one that risked flooding our available resources

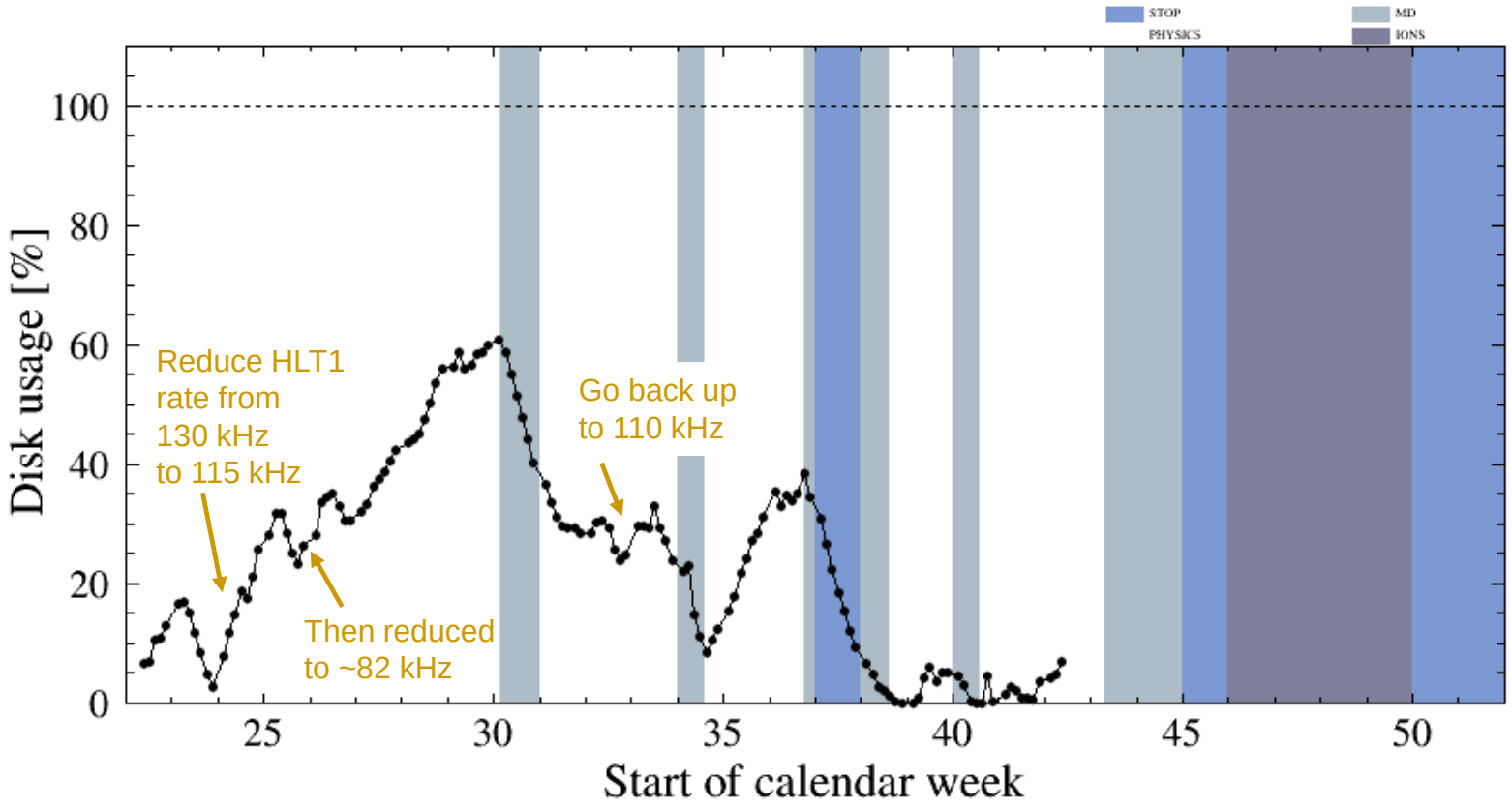


LHC 11/6 – 23/7 [Lamont, ICHEP]

Rapid action required…

Dealing with the flood

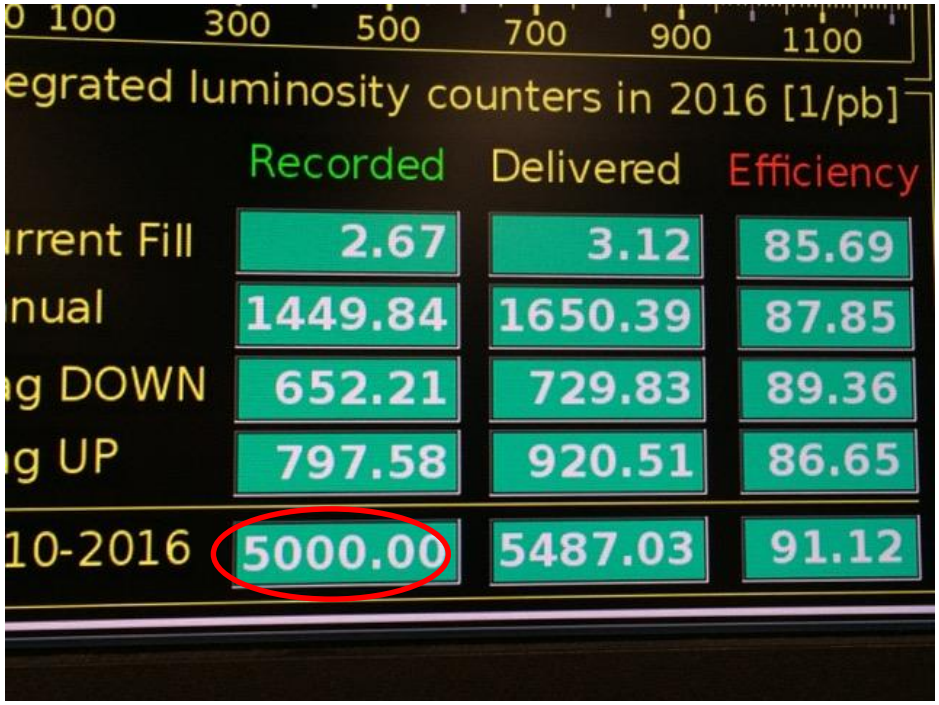
Fast changes introduced to tighten HLT1, and also to speed up HLT2.



HLT1 then loosened as the machine efficiency dropped during August / Sept.
Optimal and dynamic use of resources to maximise physics output !

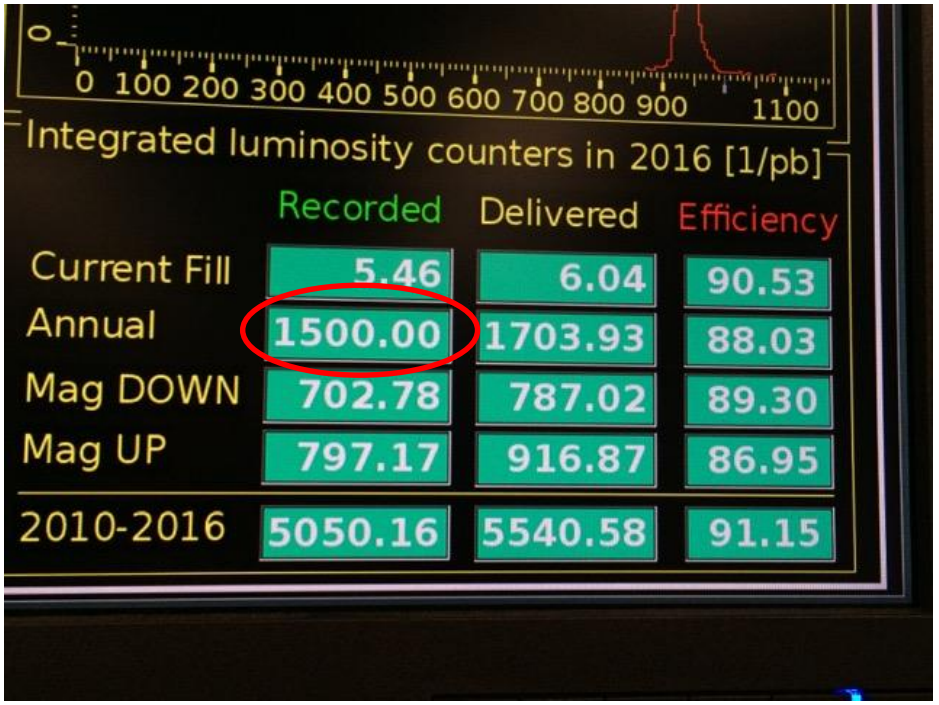
Recent milestones

Oct 12th



5 fb^{-1} since start of LHCb

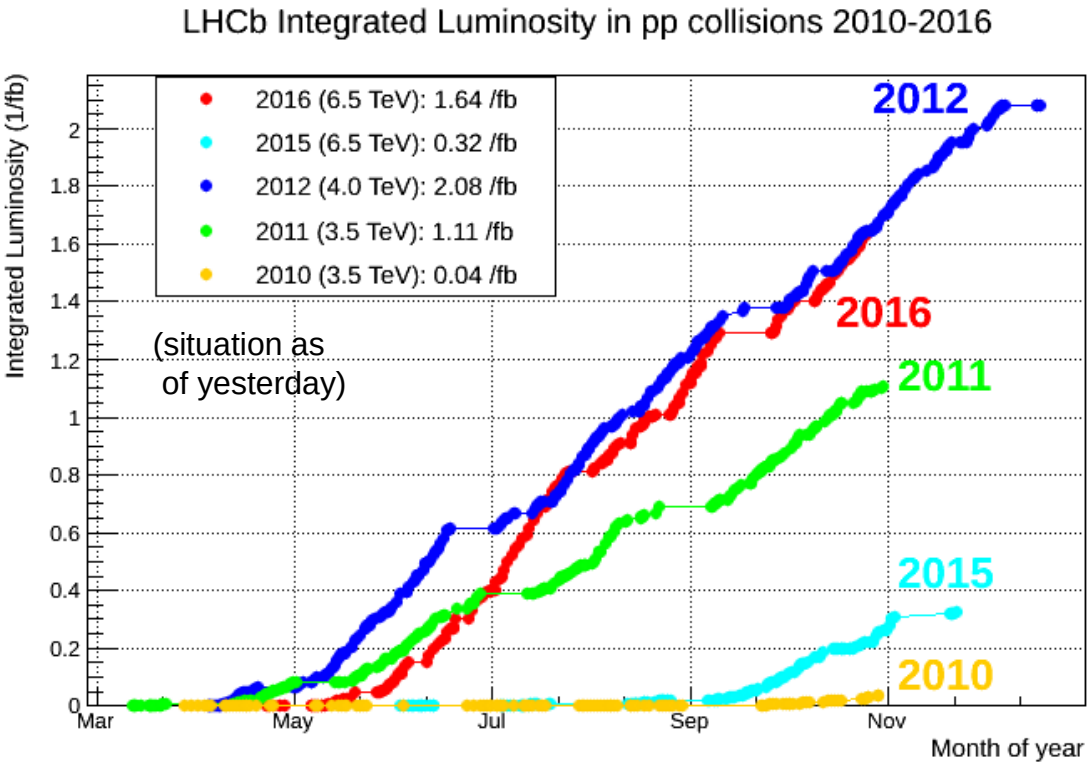
Oct 16th



1.5 fb^{-1} this year

Data collection status

We have collected data with high efficiency (~90%) throughout the year.

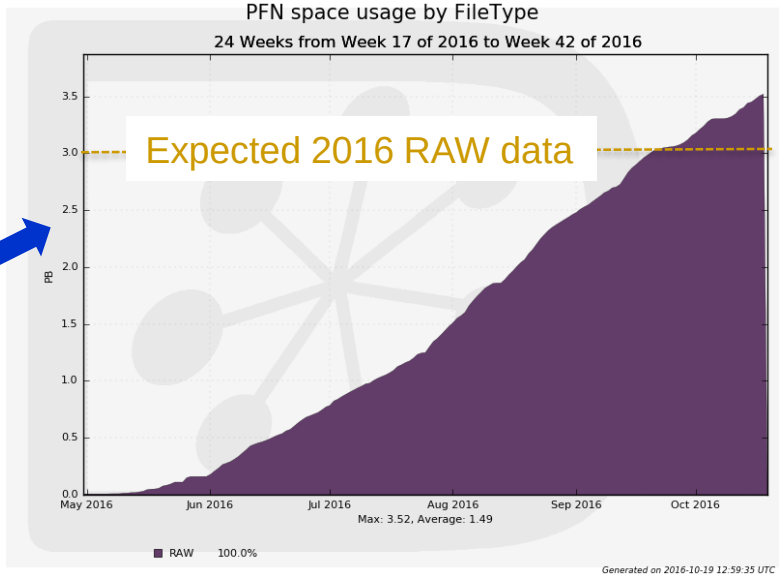


We have collected ~1.6 fb^{-1}, which given the higher E_{CM} & x-sec corresponds to a larger *bb*bar sample than collected in all of run 1. Now getting ready for *p*-Pb run.

Implications for offline computing

As for all experiments, increase in machine efficiency has had consequences for our offline computing requirements.

Reached expected RAW data volume mid-Sept, well before end of run



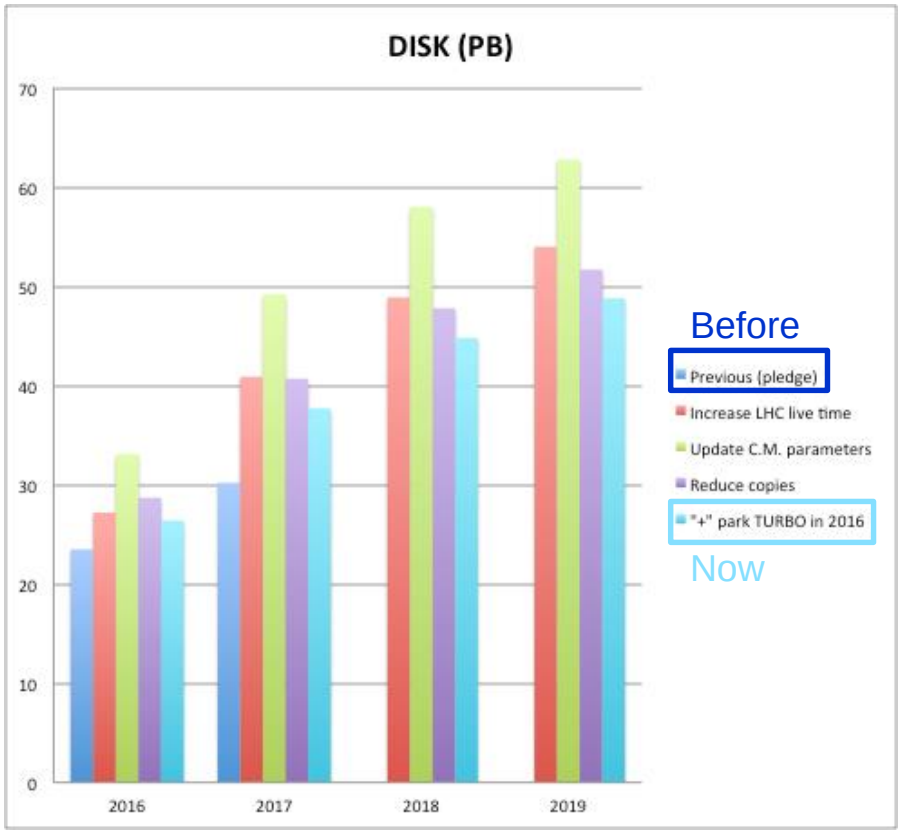
New requests have to be seen in light of mitigating actions we have already taken:

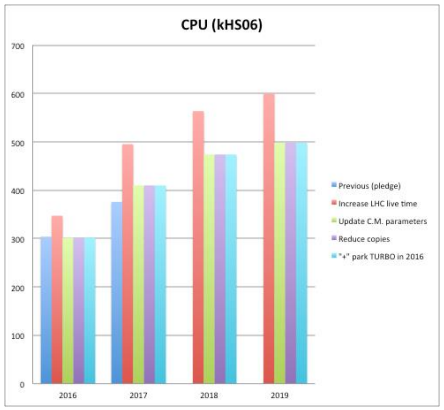
- Dropping raw data from reconstruction output → reduce tape needs;
- Increased use of TURBO stream (~ doubled in 2016) to reduce CPU needs;
- Lower requirements on disk through reduction of replicas (3 → 2 copies), parking ~1/3 of TURBO output, and data popularity purging (clean 1 PB).

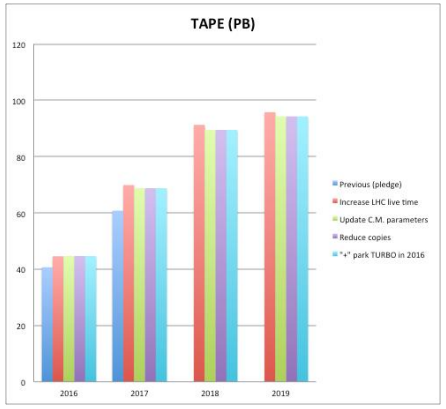
" The C-RSG applauds LHCb for proactively working to mitigate the effects of the live time increase on resource need. " C-RSG, Sept. '16

Offline computing 2016-2019 [LHCb-PUB-2016-022]

After applying the measures listed, our future requests fit within a 20% budget increase in 2017, & then maintaining this level of support constant for 2018 & 2019.



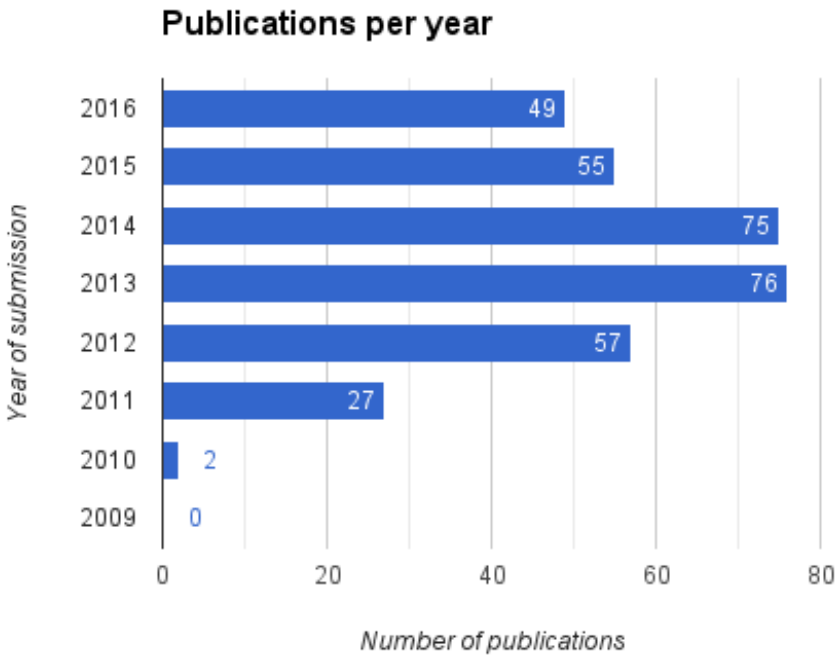




Physics output: overview & selected highlights

LHCb publications

Status, as of Wednesday 26/10/2016



341 papers in total, integrating over published, accepted and submitted
(29 since April '16 RRB)

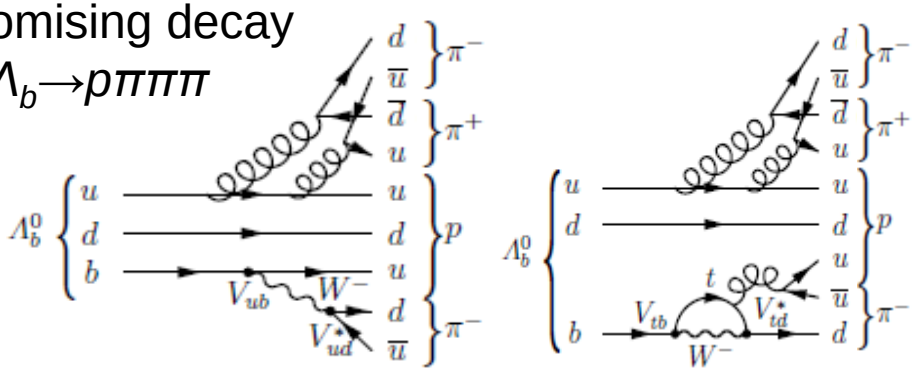
- 12 papers in last stage of editing prior to submission;
- Several preliminary results shown at summer conferences soon to be finalised;
- ~50 other analyses under review, so sure to be a bumper year !

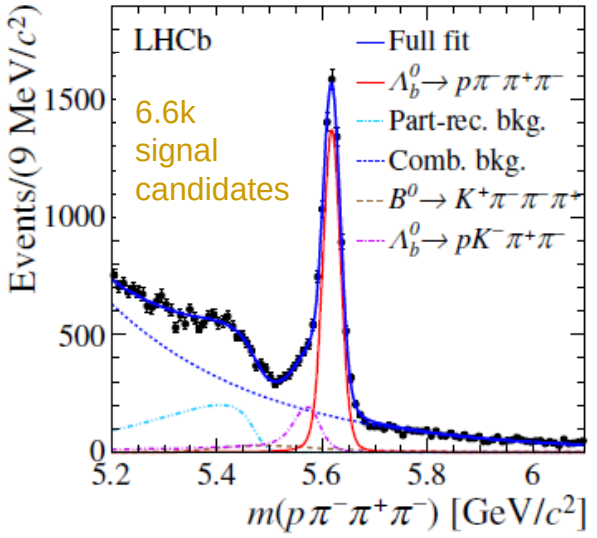
Most recent publications were still based on Run 1, but (almost) all analyses begun this year are benefitting from Run-2 data. Results will start to appear very soon !

Search for *CP* violation in b-baryon decay

CP violation in baryons has never been observed in the lab, although the universe manifests it very clearly - we are made of protons, not antiprotons !

One promising decay mode: $\Lambda_b \to p\pi\pi\pi$



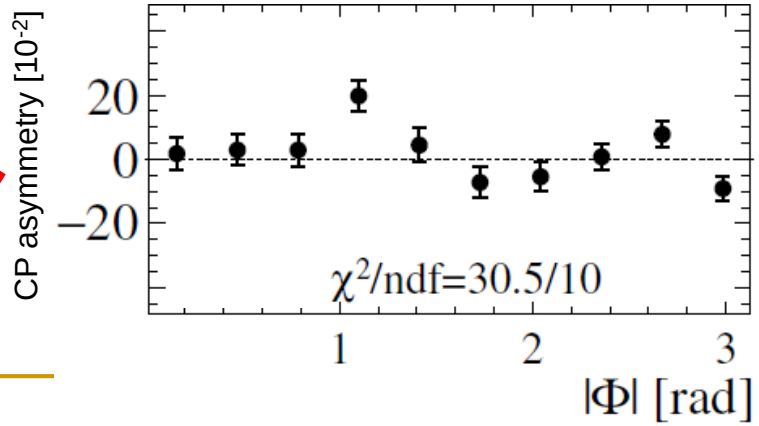


Search for *CP*-violating asymmetries in decay angle distributions of final state.

Study asymmetry in different configurations of final-state distribution (*e.g.* different bins of an angle between two decay planes)

Data incompatible with horizontal line at 0.

First ever evidence for *CP* violation in baryons; run-2 data can provide a clear discovery !

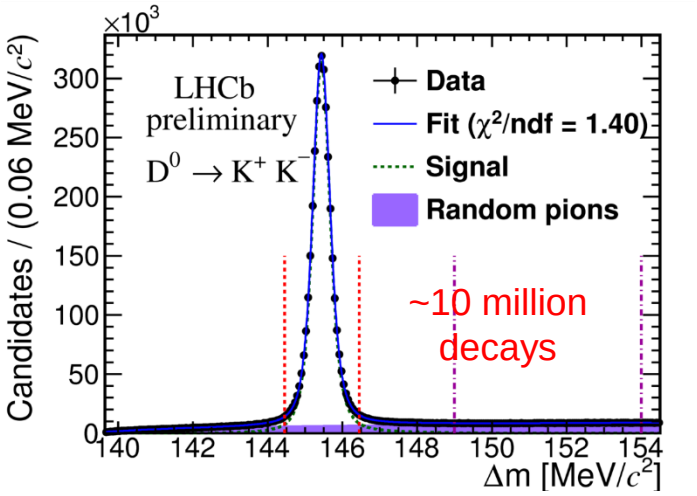


CP-violation in charm: entering the 10^{-4} regime

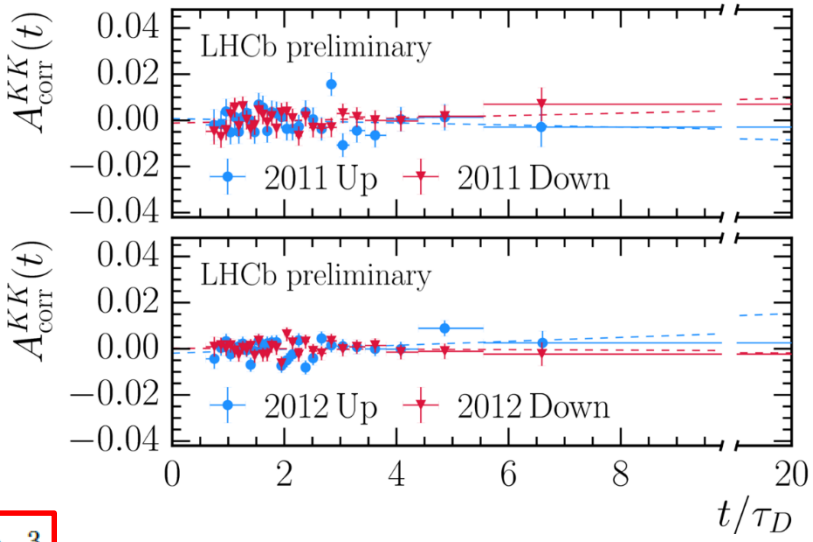
LHCb has much larger samples in charm decays to charged tracks than any previous facility (and its supremacy here will remain unchallenged by Belle II).

A key task is the search for indirect *CP*-violation in charm, so far undiscovered and predicted to be tiny in the SM. Look for time-dependent CP asymmetry, expressed in A_Γ parameter, in decay to *CP* eigenstate, such as $D^0 \to KK$ or $\pi\pi$.

Massive, clean & well-understood data sets.



Results split by different years and magnet polarities (up, down)



[LHCb-CONF-2016-009; LHCb-CONF-2016-010]

$$A_\Gamma(D^0 \to K^+K^-) = (-0.30 \pm 0.32 \pm 0.14) \times 10^{-3}$$
$$A_\Gamma(D^0 \to \pi^+\pi^-) = (\ \ 0.46 \pm 0.58 \pm 0.16) \times 10^{-3}$$

Consistent behaviour; no slope, which means no *CP* violation (yet !)

CP-violation in charm: entering the 10^{-4} regime

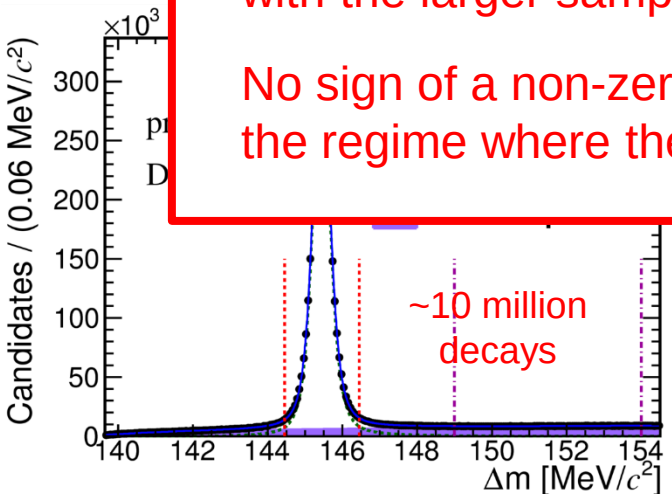
LHCb has much larger samples in charm decays to charged tracks than any previous facility (and its supremacy here will remain unchallenged by Belle II).

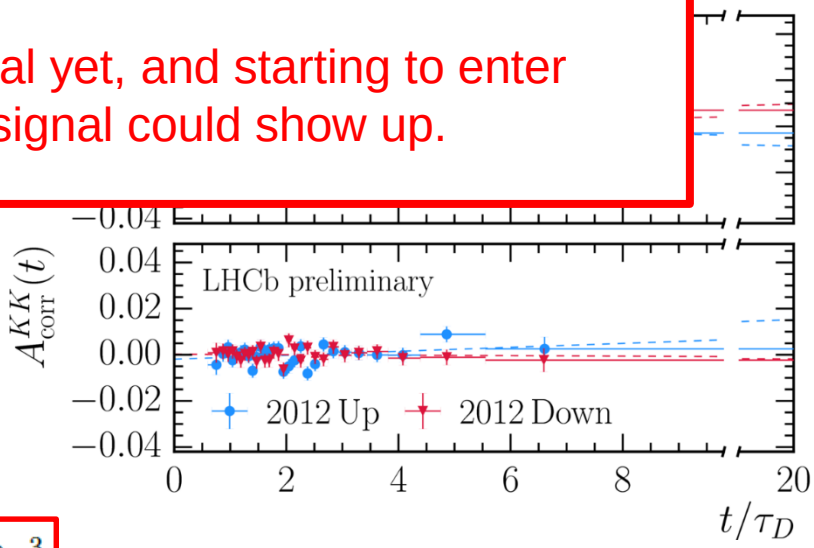
A key ta… covered and pre… metry, express… or πππ.

Some of the most sensitive measurements of any sort yet performed at the LHC !

Systematics are assigned from data and will reduce with the larger samples of run 2 and the Upgrade.

No sign of a non-zero signal yet, and starting to enter the regime where the SM signal could show up.



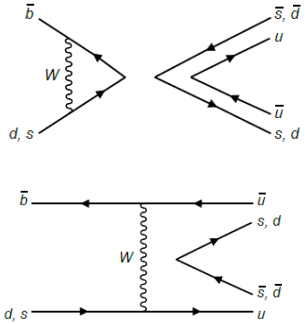


[LHCb-CONF-2016-009; LHCb-CONF-2016-010]

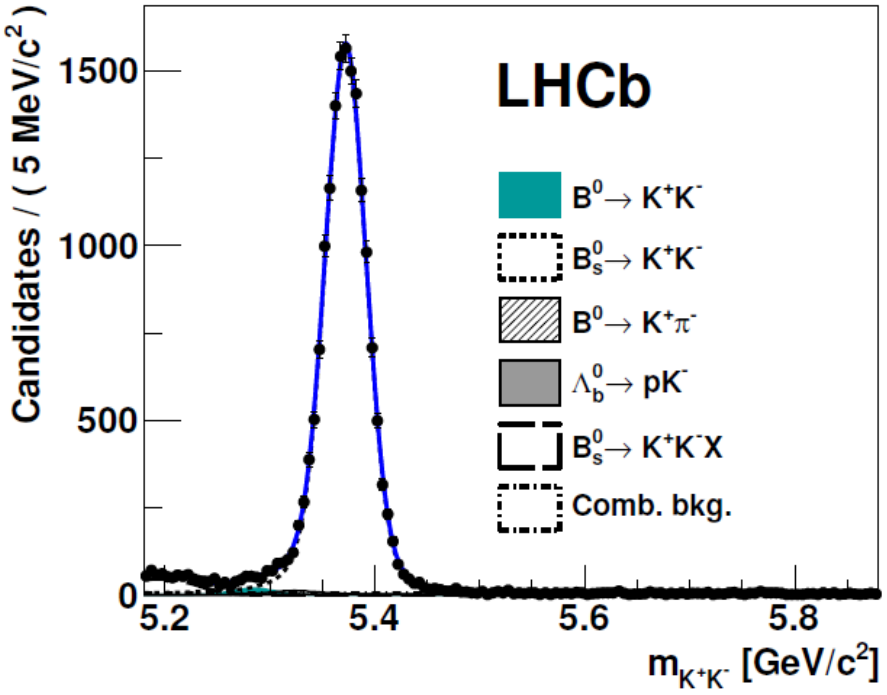
$$A_\Gamma(D^0 \to K^+K^-) = (-0.30 \pm 0.32 \pm 0.14) \times 10^{-3}$$
$$A_\Gamma(D^0 \to \pi^+\pi^-) = (\ \ 0.46 \pm 0.58 \pm 0.16) \times 10^{-3}$$

Consistent behaviour; no slope, which means no *CP* violation (yet !)

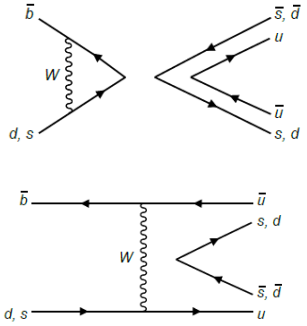
In search of the ultra-rare



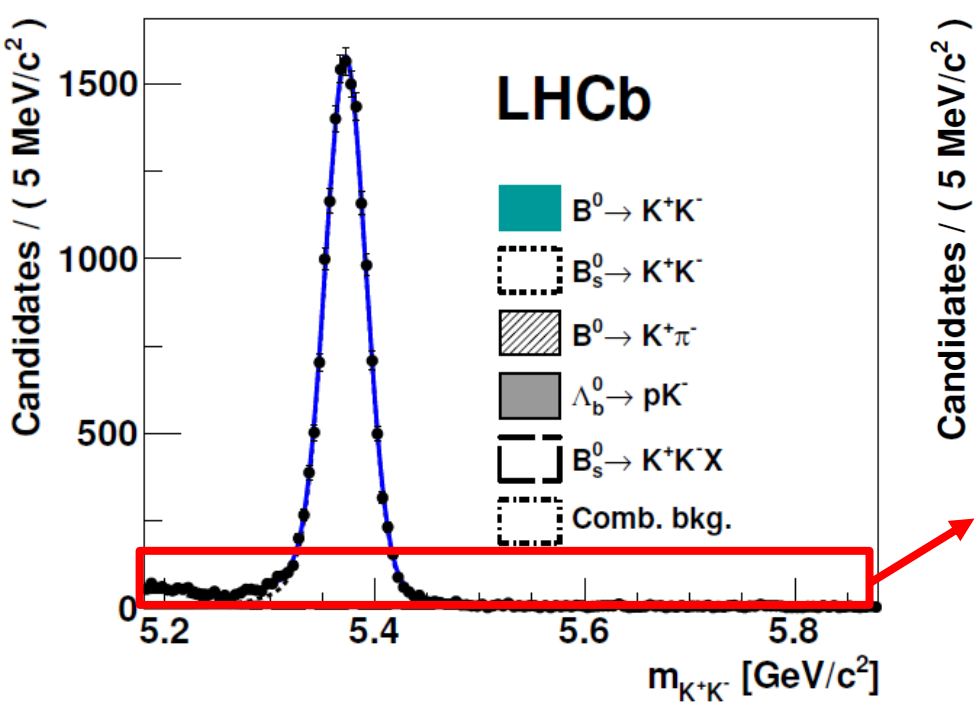
First observation of the decay mode $B^0 \rightarrow K^+K^-$. BF = 8 x 10^{-8}.
Rarest hadronic b-decay ever observed [LHCb-PAPER-2016-036].

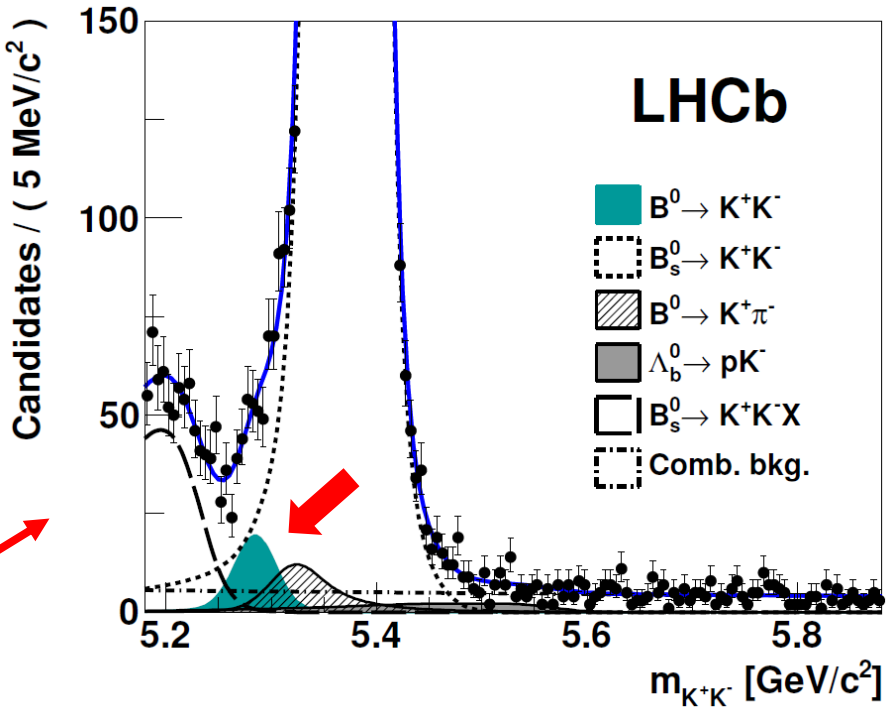


In search of the ultra-rare



First observation of the decay mode $B^0 \rightarrow K^+K^-$. BF = 8 x 10^{-8}.
Rarest hadronic b-decay ever observed [LHCb-PAPER-2016-036].



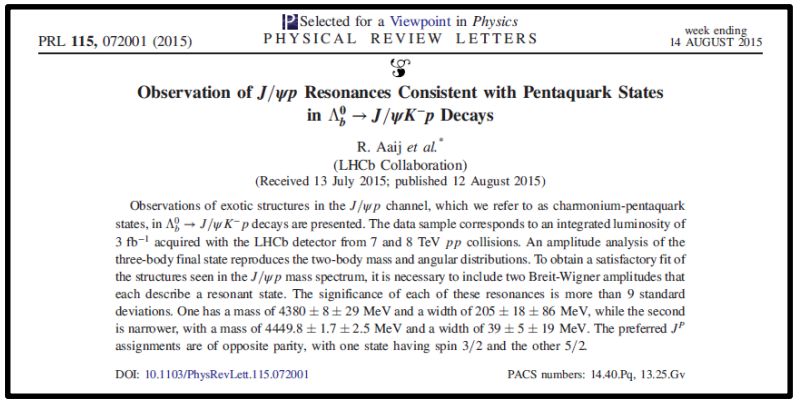


Knowing the branching fraction of this mode is necessary for understanding the role of sub-leading diagrams in flagship modes used for precision *CP*V studies.

Continued progress on exotic spectroscopy

LHCb has made very major contributions to field of exotic spectroscopy – the study of hadrons which can not be easily accommodated in naïve quark model,

e.g. discovery of pentaquark states [PRL 115 (2015) 072001] – now 265 citations.



Selected for a Viewpoint in *Physics*

PRL **115,** 072001 (2015) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2015

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

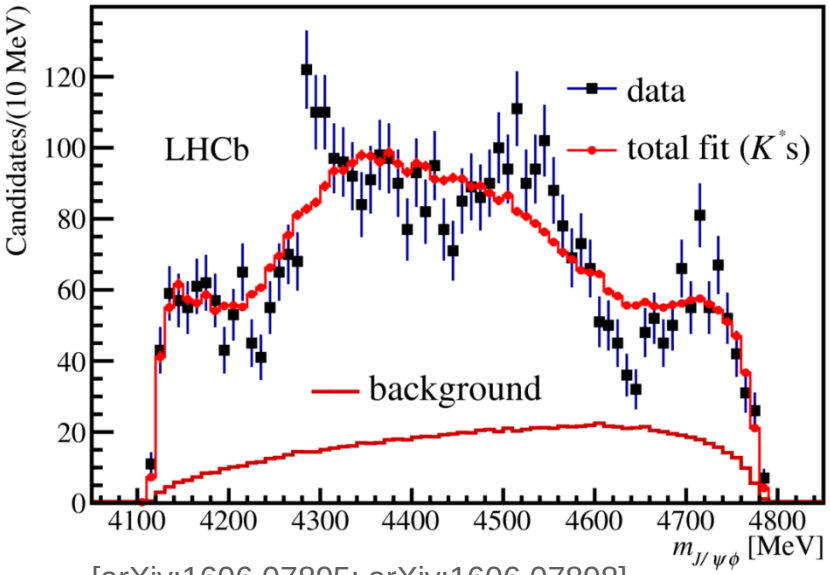
R. Aaij *et al.**
(LHCb Collaboration)

(Received 13 July 2015; published 12 August 2015)

Observations of exotic structures in the $J/\psi p$ channel, which we refer to as charmonium-pentaquark states, in $\Lambda_b^0 \to J/\psi K^- p$ decays are presented. The data sample corresponds to an integrated luminosity of 3 fb^{-1} acquired with the LHCb detector from 7 and 8 TeV pp collisions. An amplitude analysis of the three-body final state reproduces the two-body mass and angular distributions. To obtain a satisfactory fit of the structures seen in the $J/\psi p$ mass spectrum, it is necessary to include two Breit-Wigner amplitudes that each describe a resonant state. The significance of each of these resonances is more than 9 standard deviations. One has a mass of $4380 \pm 8 \pm 29$ MeV and a width of $205 \pm 18 \pm 86$ MeV, while the second is narrower, with a mass of $4449.8 \pm 1.7 \pm 2.5$ MeV and a width of $39 \pm 5 \pm 19$ MeV. The preferred J^P assignments are of opposite parity, with one state having spin 3/2 and the other 5/2.

DOI: 10.1103/PhysRevLett.115.072001 PACS numbers: 14.40.Pq, 13.25.Gv

This year we have returned to the study of the J/ψΦ spectrum in $B^+ \to J/\psi\Phi K^+$, other experiments (CDF, D0, CMS) have reported a narrow structure, the X(4140).



[arXiv:1606.07895; arXiv:1606.07898]

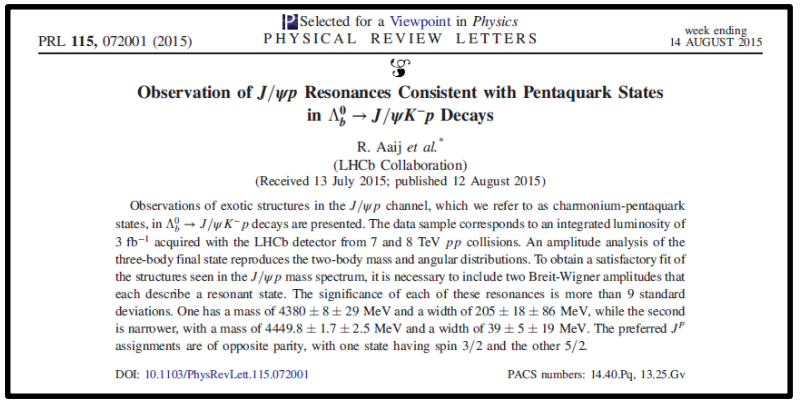
Spectrum in undeniably lumpy, most obviously *above* the *X*(4140) region (CMS & D0 had also seen evidence of structure ~4300 MeV)

Very importantly, a model based on conventional PDG states cannot describe data. So must inject exotics….

Continued progress on exotic spectroscopy

LHCb has made very major contributions to field of exotic spectroscopy – the study of hadrons which can not be easily accommodated in naïve quark model,

e.g. discovery of pentaquark states [PRL 115 (2015) 072001] – now 265 citations.



Selected for a Viewpoint in *Physics*

PRL **115,** 072001 (2015) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2015

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

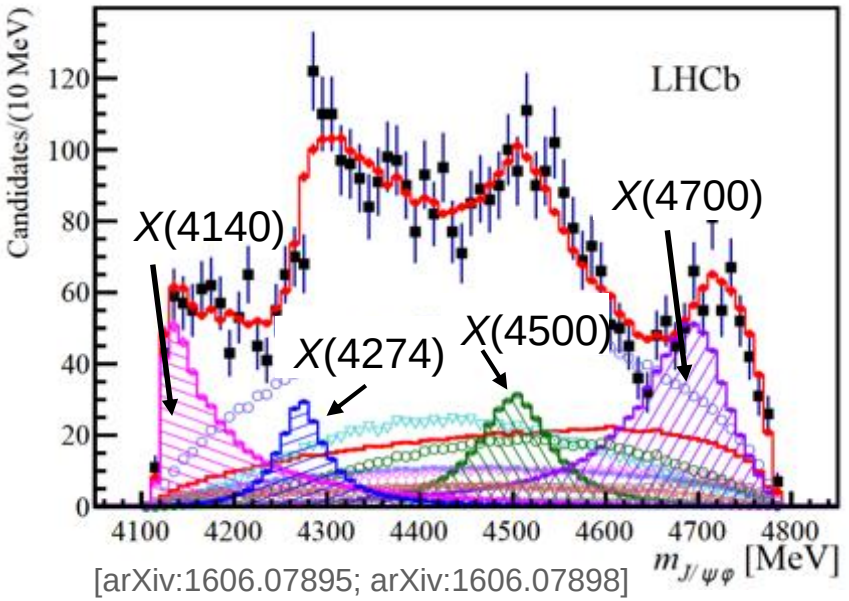
R. Aaij *et al.**
(LHCb Collaboration)

(Received 13 July 2015; published 12 August 2015)

Observations of exotic structures in the $J/\psi p$ channel, which we refer to as charmonium-pentaquark states, in $\Lambda_b^0 \to J/\psi K^- p$ decays are presented. The data sample corresponds to an integrated luminosity of 3 fb^{-1} acquired with the LHCb detector from 7 and 8 TeV pp collisions. An amplitude analysis of the three-body final state reproduces the two-body mass and angular distributions. To obtain a satisfactory fit of the structures seen in the $J/\psi p$ mass spectrum, it is necessary to include two Breit-Wigner amplitudes that each describe a resonant state. The significance of each of these resonances is more than 9 standard deviations. One has a mass of $4380 \pm 8 \pm 29$ MeV and a width of $205 \pm 18 \pm 86$ MeV, while the second is narrower, with a mass of $4449.8 \pm 1.7 \pm 2.5$ MeV and a width of $39 \pm 5 \pm 19$ MeV. The preferred J^P assignments are of opposite parity, with one state having spin 3/2 and the other 5/2.

DOI: 10.1103/PhysRevLett.115.072001 PACS numbers: 14.40.Pq, 13.25.Gv

This year we have returned to the study of the J/ψΦ spectrum in $B^+ \to J/\psi\Phi K^+$, other experiments (CDF, D0, CMS) have reported a narrow structure, the X(4140).



[arXiv:1606.07895; arXiv:1606.07898]

A good description of spectrum requires four (!) non-standard contributions, all of which are present at >5σ level.

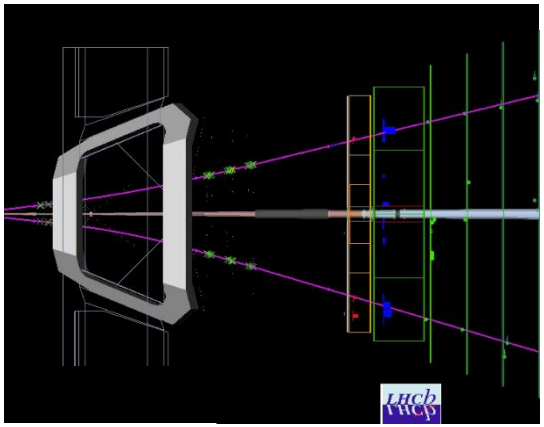
X(4140) found to have larger width than in previous analyses, and its quantum numbers are found to be 1^{++}.

Also determine quantum numbers of other states *e.g.* X(4274) also 1^{++}.

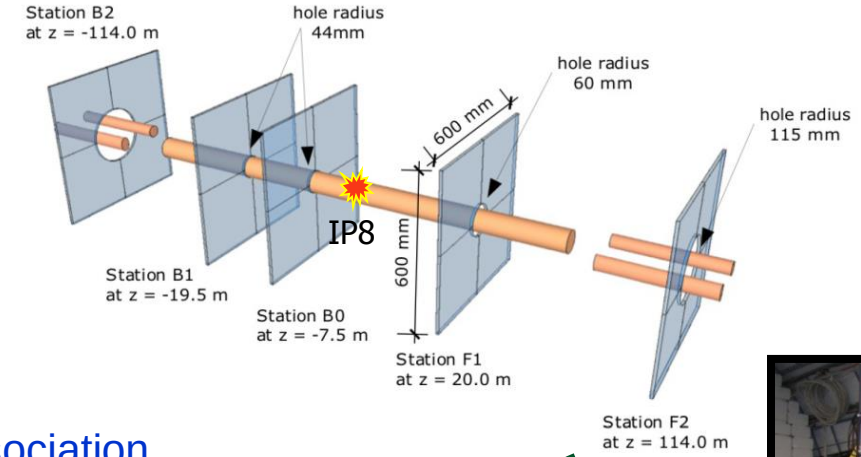
Beyond flavour: central exclusive production

LHCb's unique geometry and instrumentation give it exciting opportunities in many fields beyond flavour physics, *e.g.* central exclusive production (CEP).

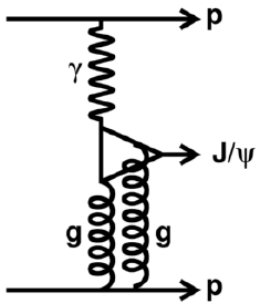
CEP $J/\psi \to \mu^+\mu^-$ production studies with 2015 data…

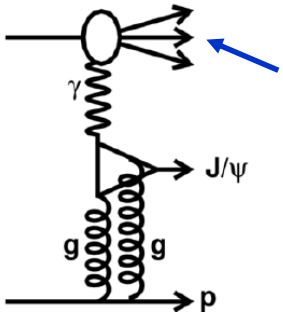


Suppress disassociation background with Herschel system of forward scintillators, installed in 2015



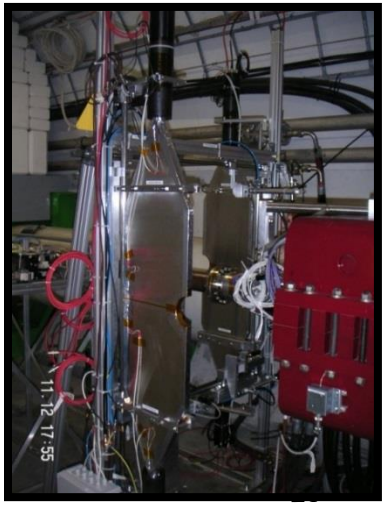
...but is it true signal or proton disassociation background ?





these particles not seen in spectrometer (low angle)

Station at z=114 m, in garage position



Beyond flavour: central exclusive production

LHCb's unique geometry and instrumentation give it exciting opportunities in many fields beyond flavour physics, *e.g.* central exclusive production (CEP).

CEP J/ψ→μ⁺μ⁻ production

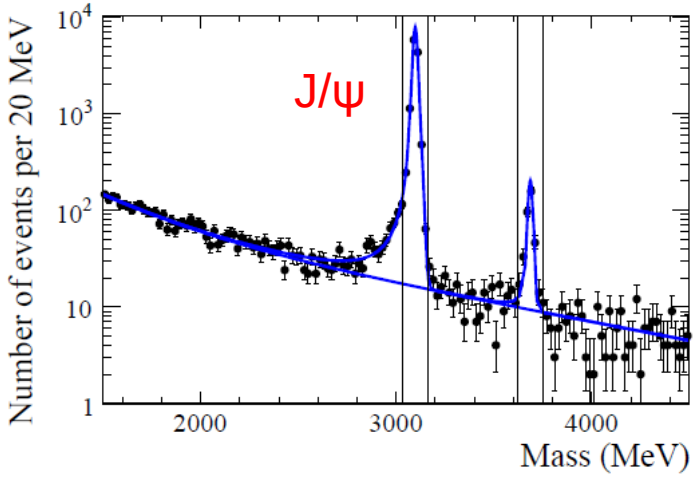
Suppress disassociation background

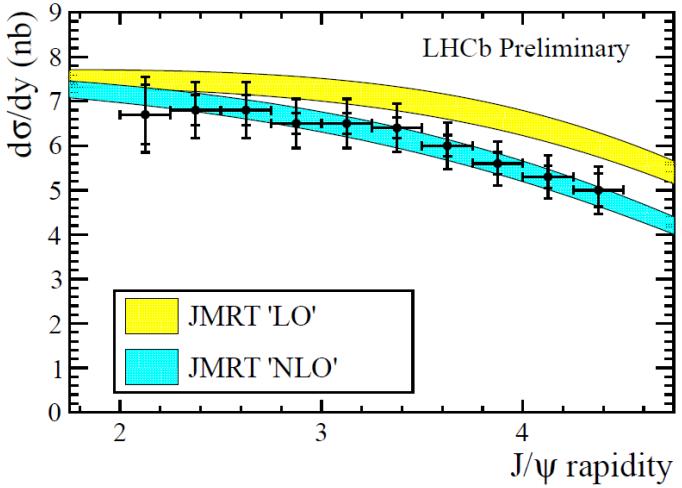
stu

...b

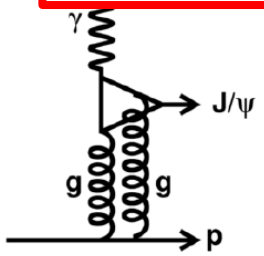
tru

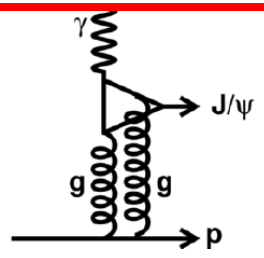
Precise measurement yields good agreement with NLO prediction





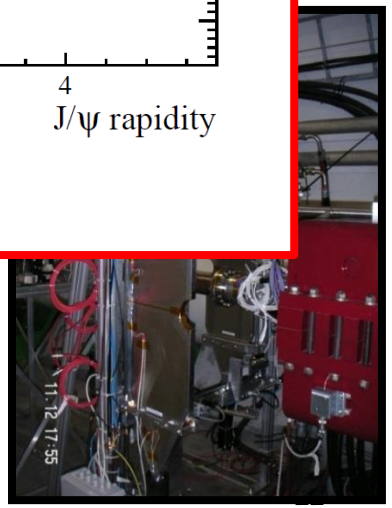
[LHCb-CONF-2016-007]





not seen in spectrometer (low angle)

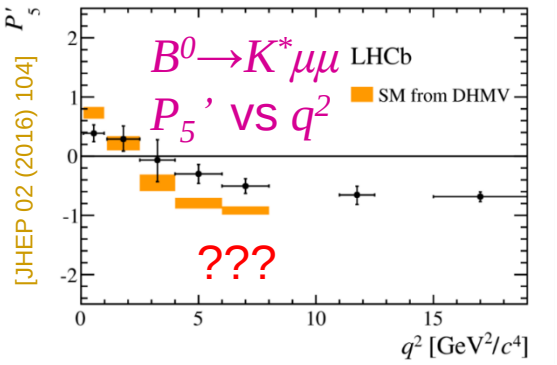
Station at z=114 m, in garage position

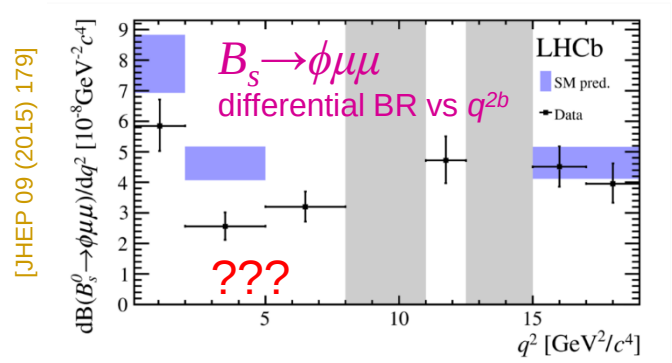


But what about ?

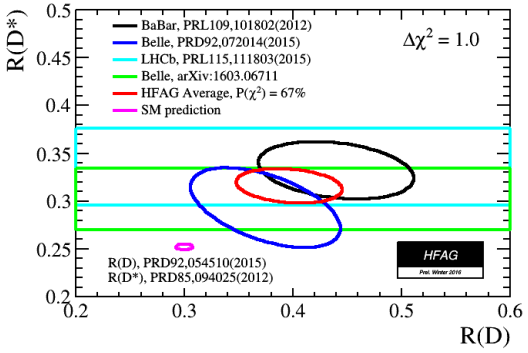
There are several intriguing anomalies in b-physics, some old, some more recent.

Anomalous behaviour in $b \to s l^+ l^-$ observables

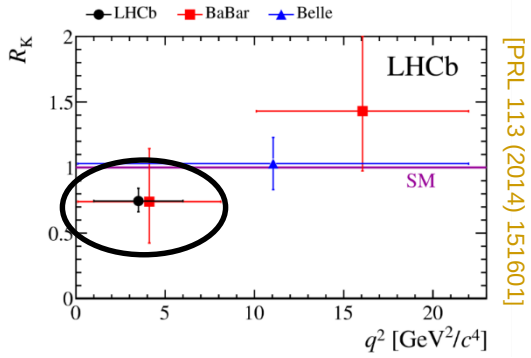




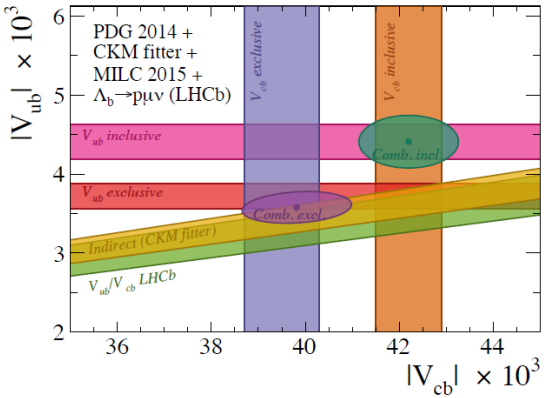
Hints of lepton universality violation in $B \to D^{(*)} l\nu$ …



…and in $B \to K l^+ l^-$



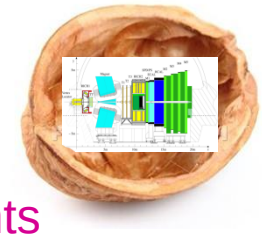
Longstanding inconsistency in exclusive vs inclusive V_{ub} and V_{cb} determinations.



We have plenty more to say on these using complementary channels, new analysis techniques, and of course run-2 data. Stay tuned in the coming months !

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 2×10^{33} cm^{-2} s^{-1}

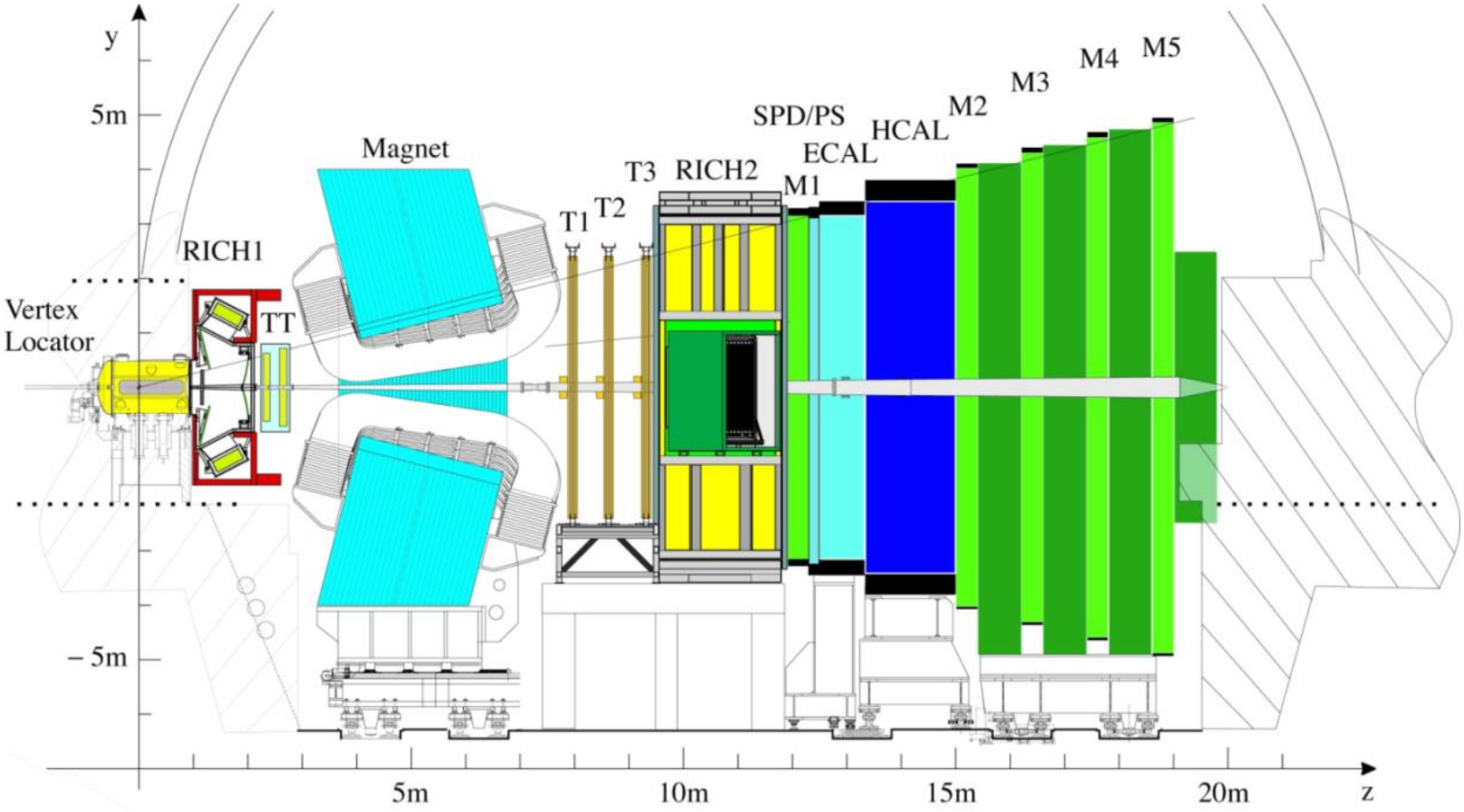
Necessitates redesign of several sub-detectors & overhaul of readout

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

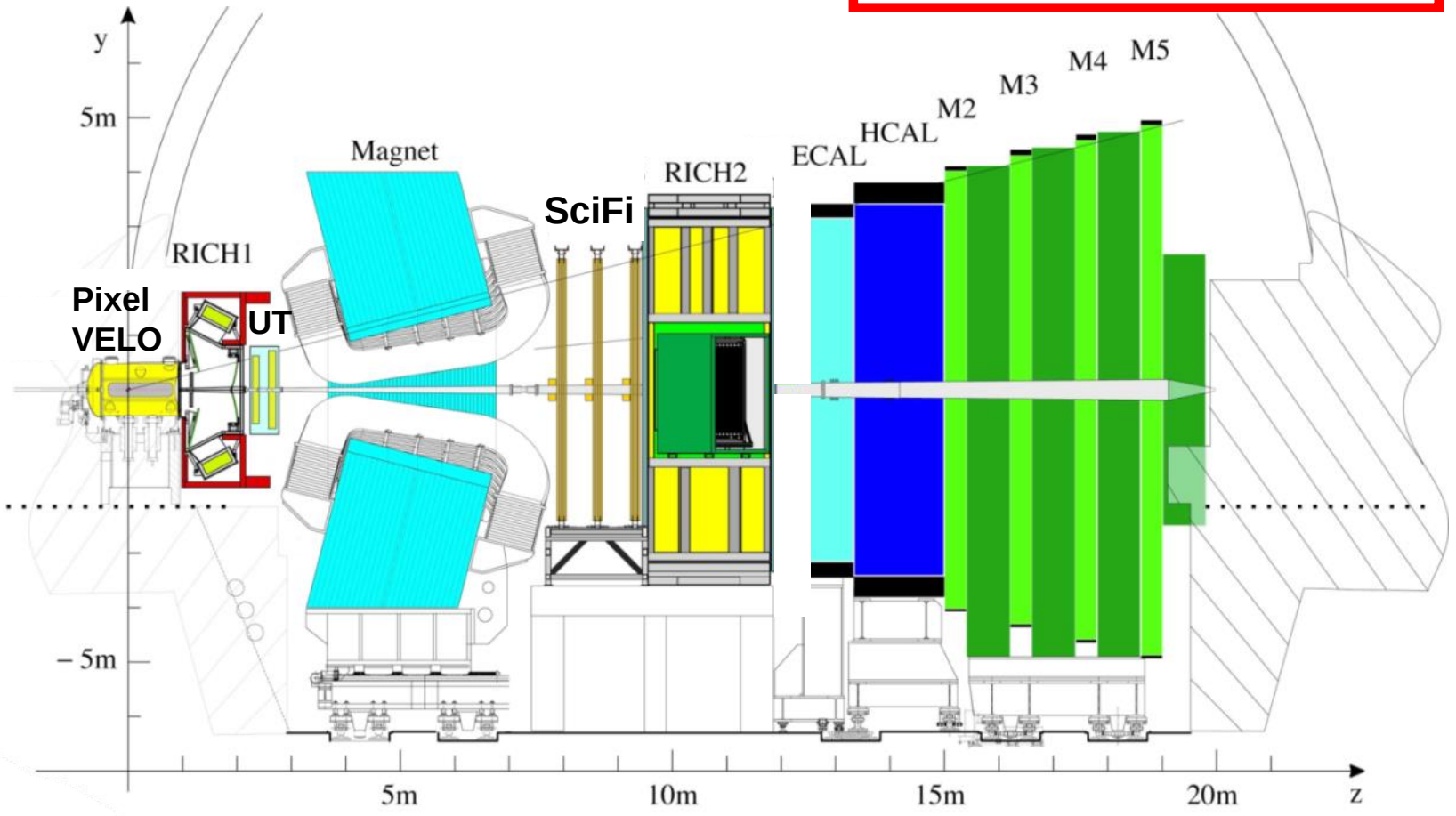
Current detector



Upgrade overview

Current detector → upgraded detector

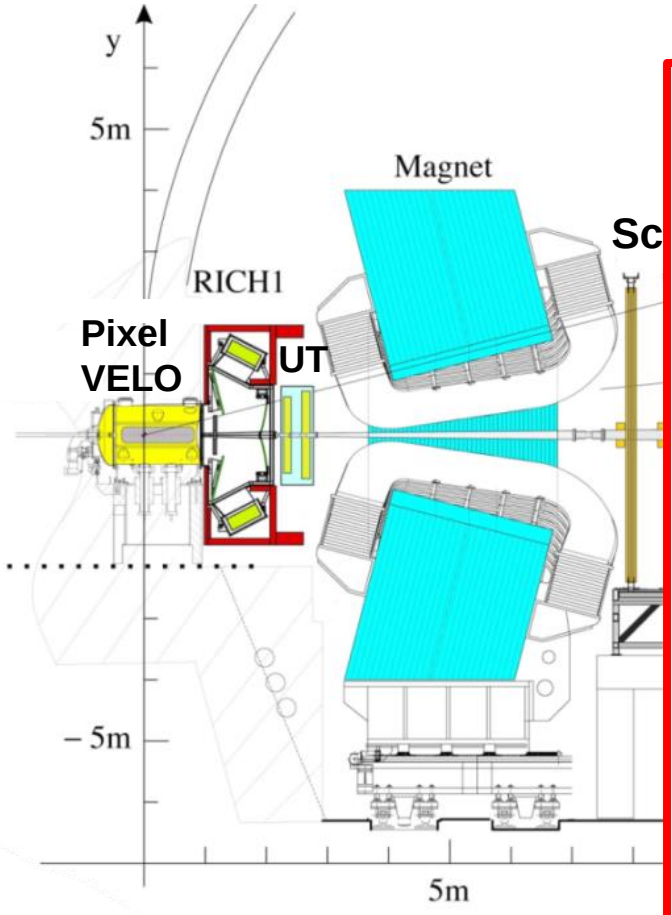
All sub-detectors read out at 40 MHz for software trigger



Upgrade overview

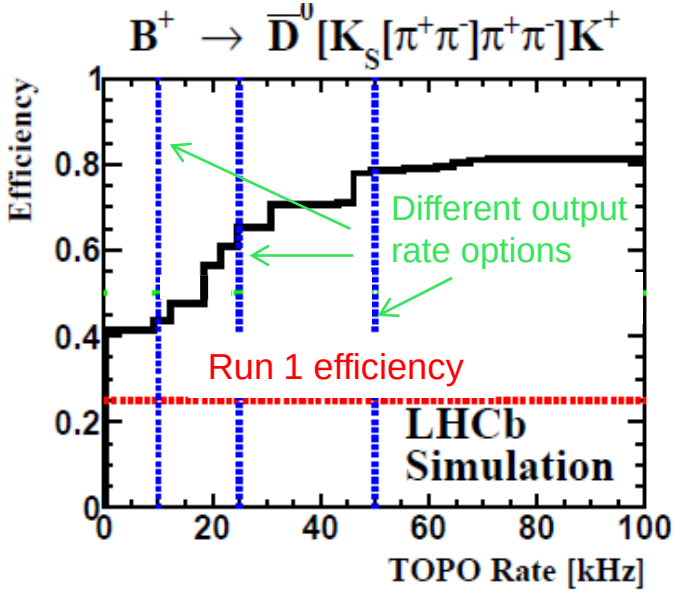
Current detector → upgraded detector

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



Upgrade software trigger

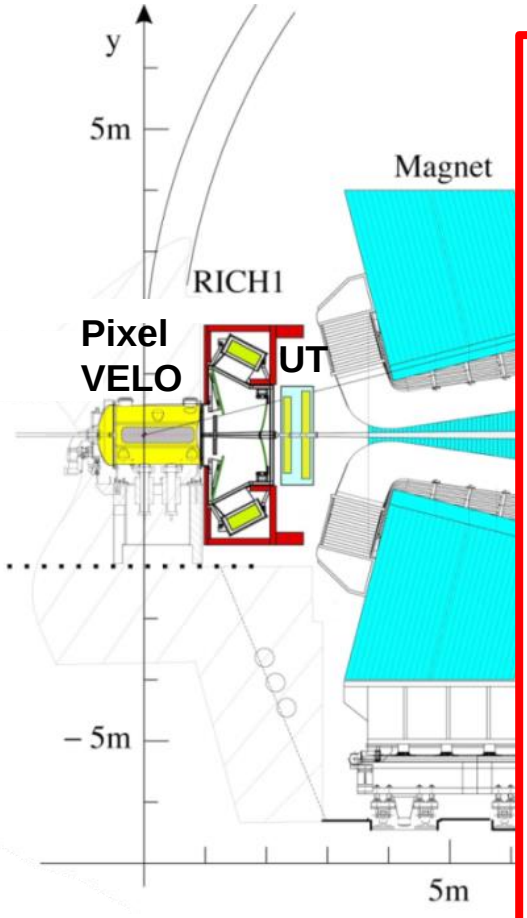
Full event information → much improved efficiency



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

Upgrade computing

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

We will present a 's/w and computing TDR' at end of 2017.

Computing project re-organised to facilitate progress. Global s/w architect has now joined LHCb.

September hackathon

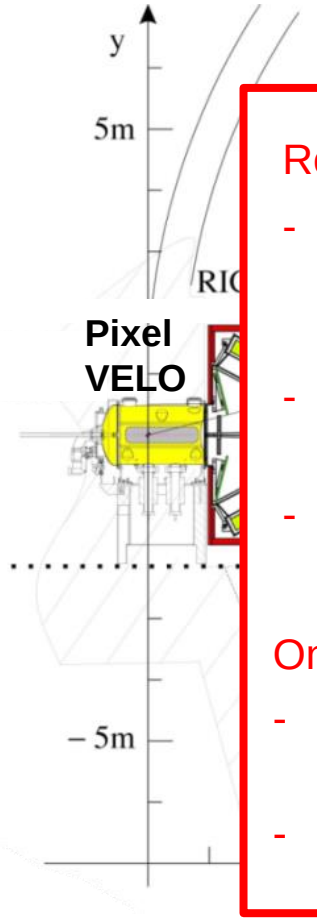
Demonstrators being developed for Q1 2017. Regular 'hackathons'. Computing workshop in Paris next month.

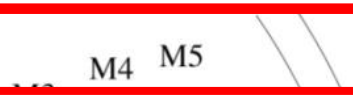
.

Upgrade overview

Current detector → upgraded detector

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





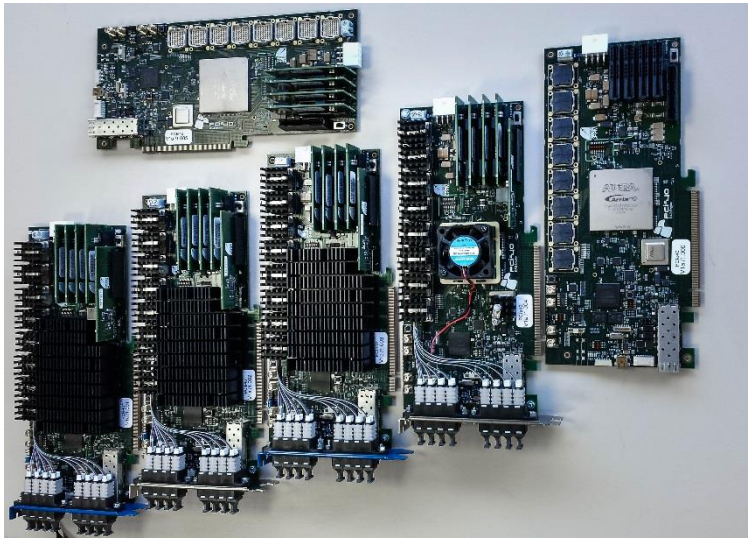
Readout progress:

- New versions of PCIe40 prototype available for sub-detector testing;
- Defining total number of boards required;
- Production will start in second half of 2017

Online progress:

- Event-building performance under test at HPC centres;
- Progress on TFC architecture.

Data acquisition and online

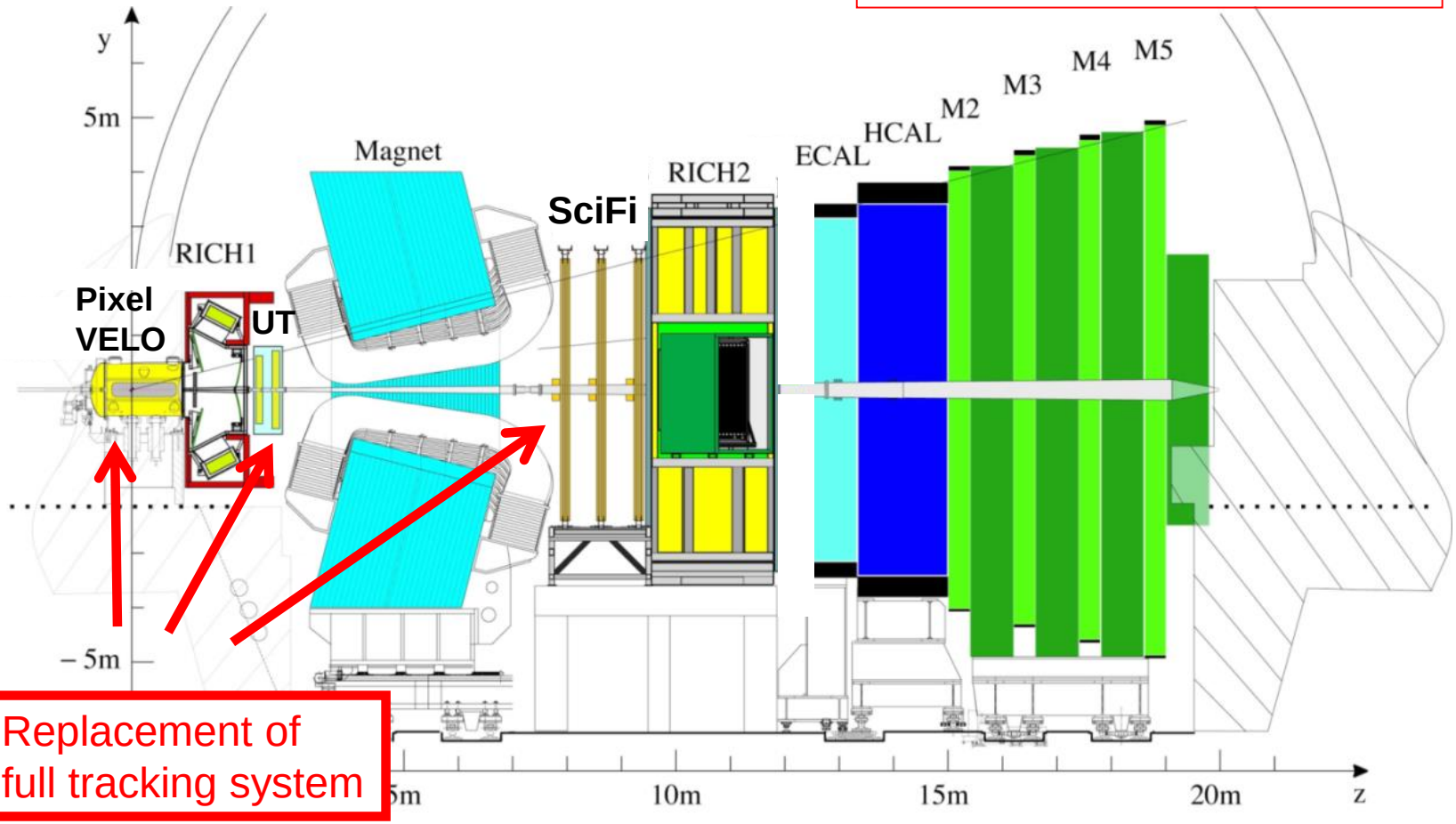


Prototypes of the PCIe40 at various stages during assembly

Upgrade overview

Current detector → upgraded detector

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

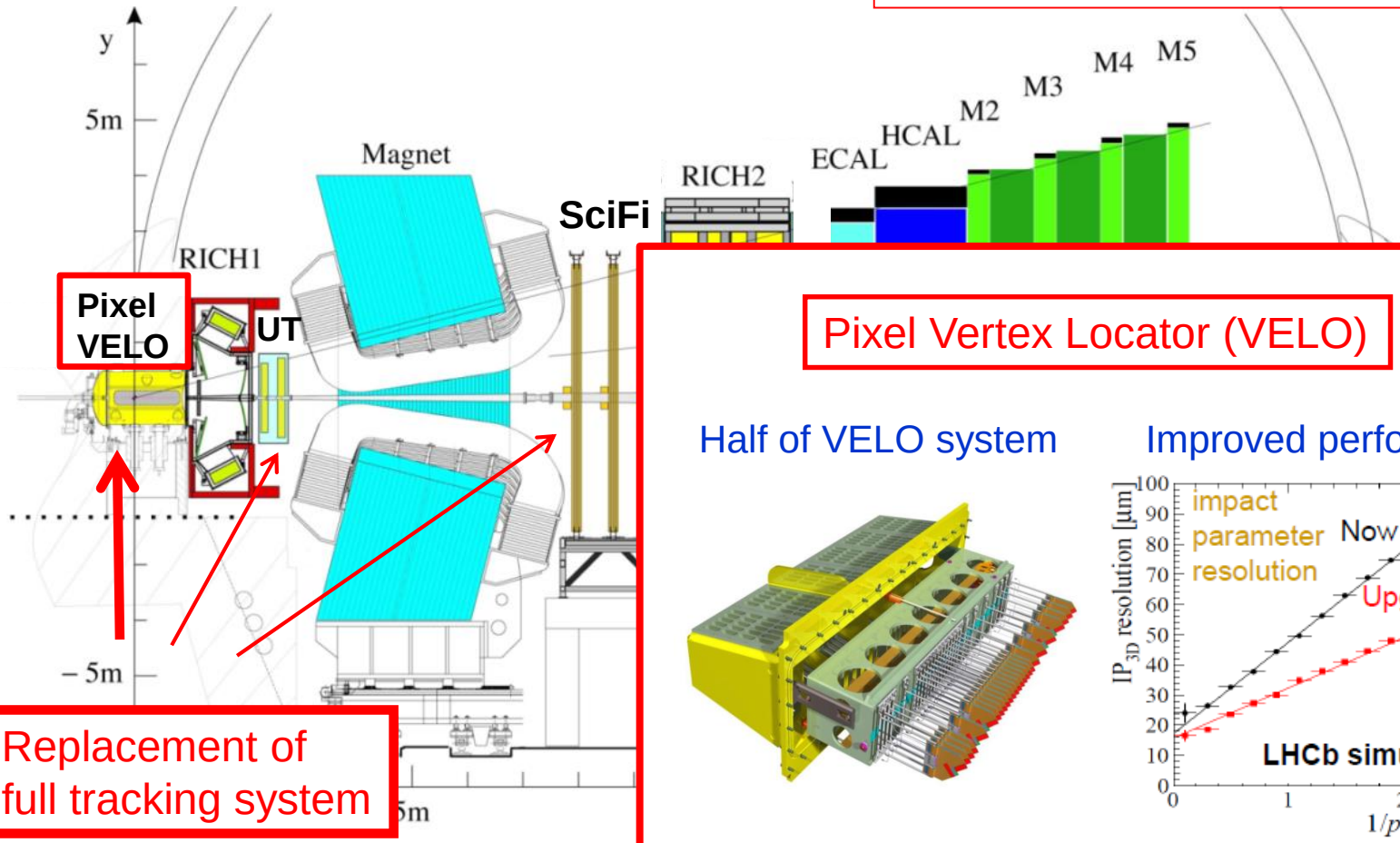


Replacement of full tracking system

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)

Half of VELO system

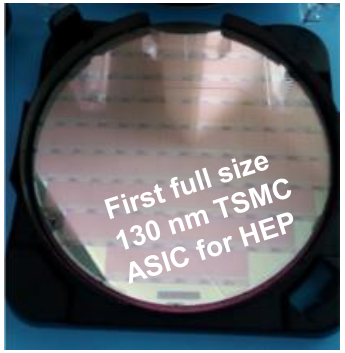
Improved performance

VELO: achievements & challenges

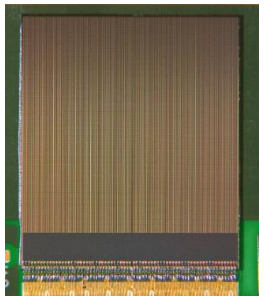
Great progress on many areas of the project, *e.g.* the front-end ASIC (VeloPix)

- Design started 2013;
- Submitted end of May;
- Wafers arrive 31st August;
- Diced, then tests started immediately. All results to date are ***excellent !***

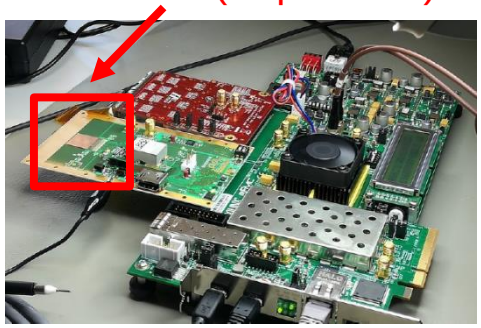
Wafers



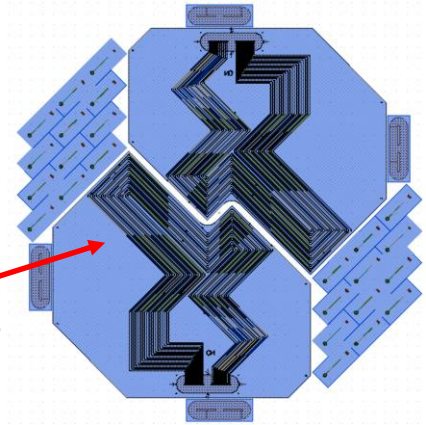
Diced ASIC



Bonded, powered and under test (September)



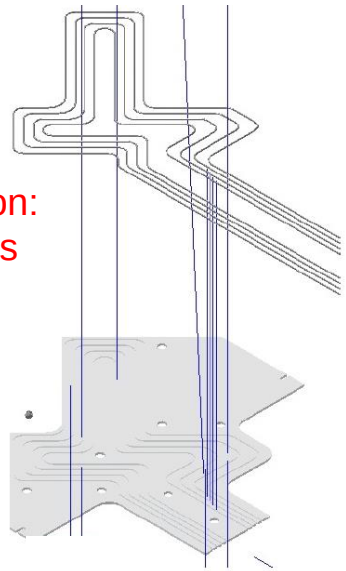
Challenges remain ! For example, the baseline cooling option ('microchannels') is delayed. Does not yet imperil rest of project, but:



Drawing of substrate, which is being manufactured by industrial collaborator

- Very careful planning now needed;
- Backup solution now being pursued as parallel project;
- Decision will be made Q1 2017. No implications for anything beyond module design.

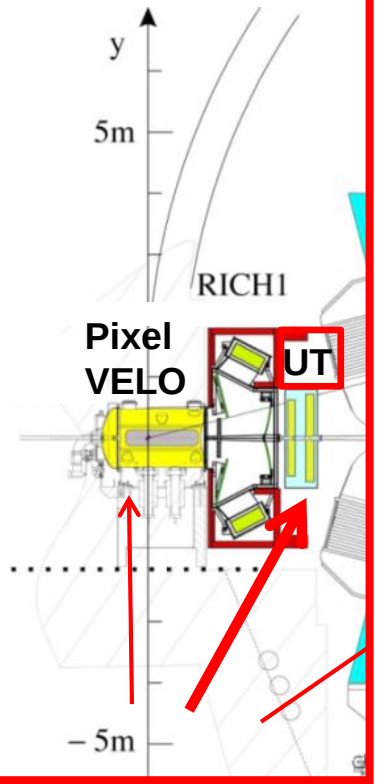
A backup option: steel capillaries embedded in trenches



Upgrade overview

Current detector → upgraded detector

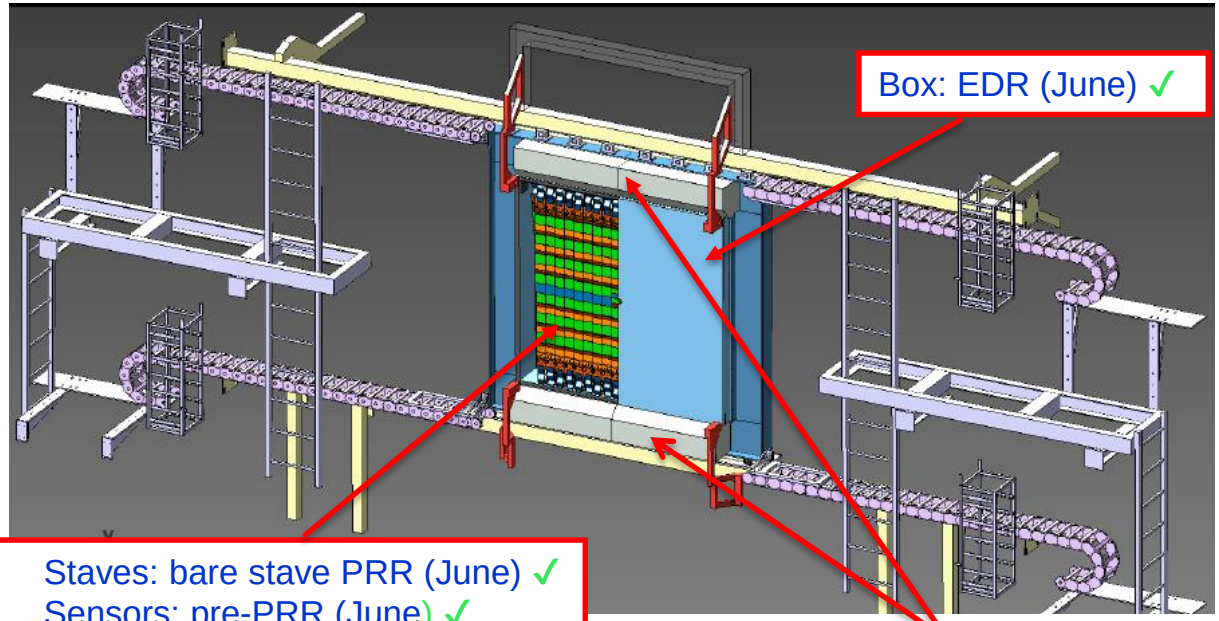
All sub-detectors read out at 40 MHz for software trigger



Replacement of full tracking syste

Upstream Tracker (UT)

Si-strip detector in front of magnet
Much progress since April on all sub-projects.



Box: EDR (June) ✓

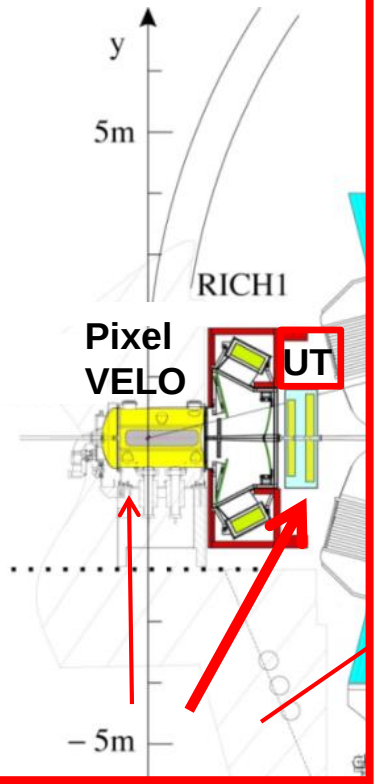
- Staves: bare stave PRR (June) ✓
- Sensors: pre-PRR (June) ✓
- SALT 128
- Hybrids
- Flex cables

Peripheral electronics: EDR (July) ✓

Upgrade overview

Current detector → upgraded detector

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

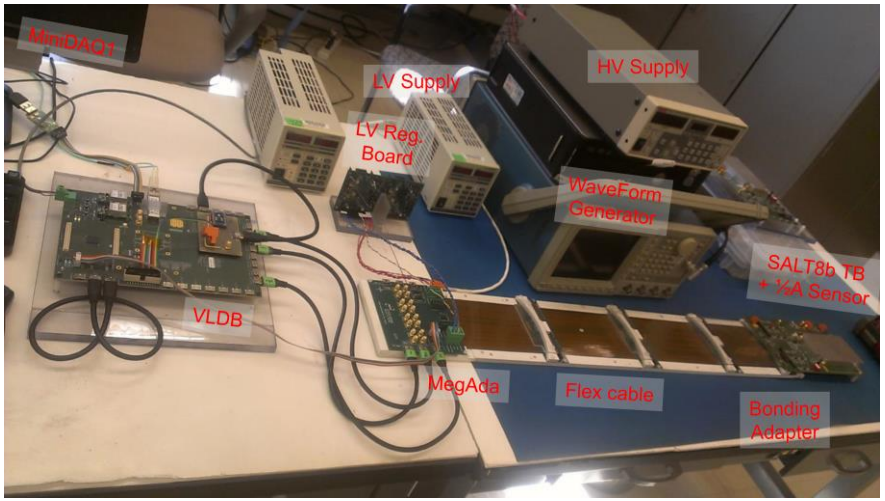


Replacement of full tracking syste

Upstream Tracker (UT)

Si-strip detector in front of magnet

- All tests, including radiation robustness, complete on sensors; order about to be placed with supplier.
- Good progress testing 8-channel version of front-end ASIC (SALT8b). Being integrated in 'slice test' of full electronics chain.

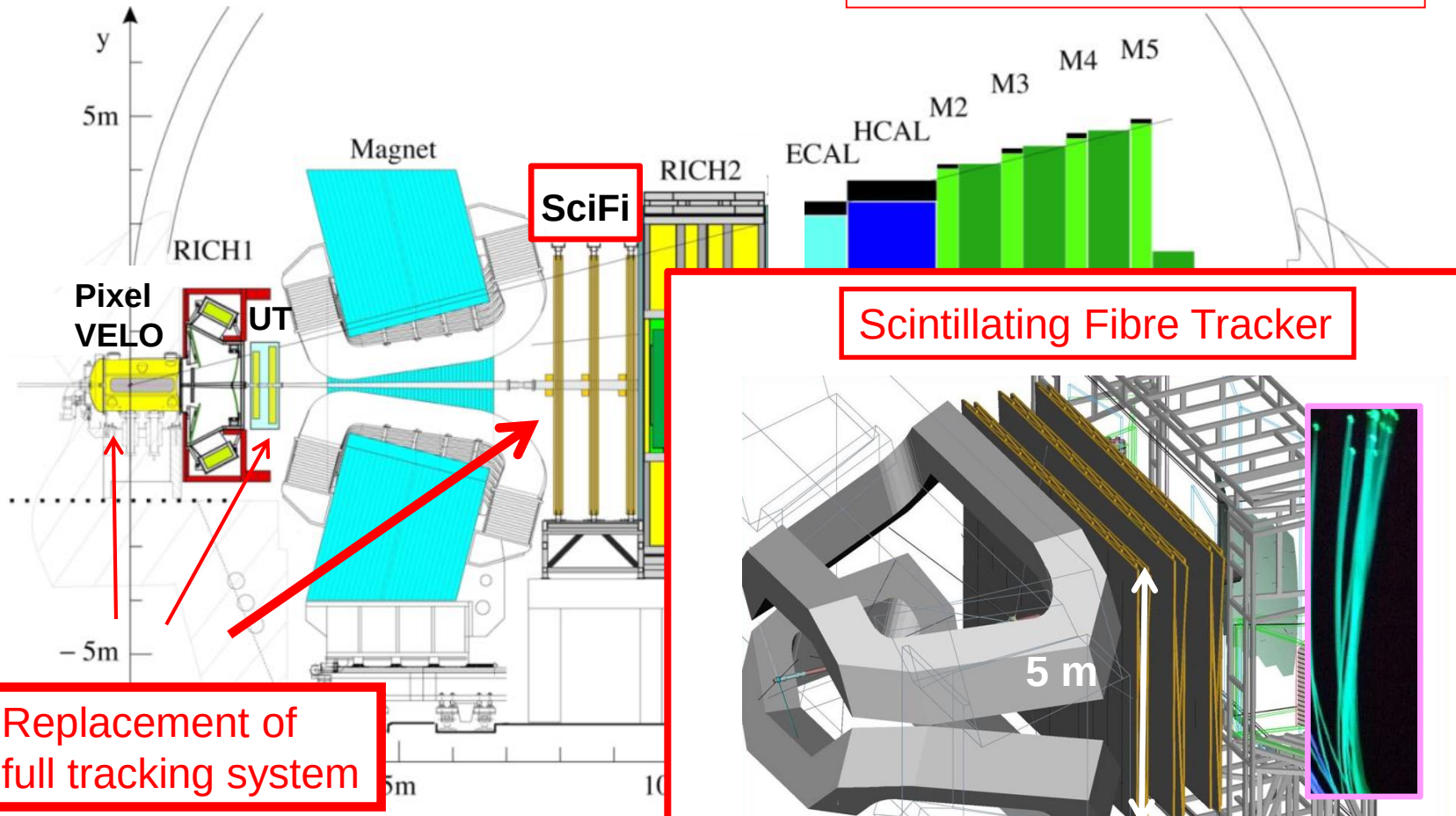


- First version of final 128-channel ASIC received & under test.

Upgrade overview

Current detector → upgraded detector

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



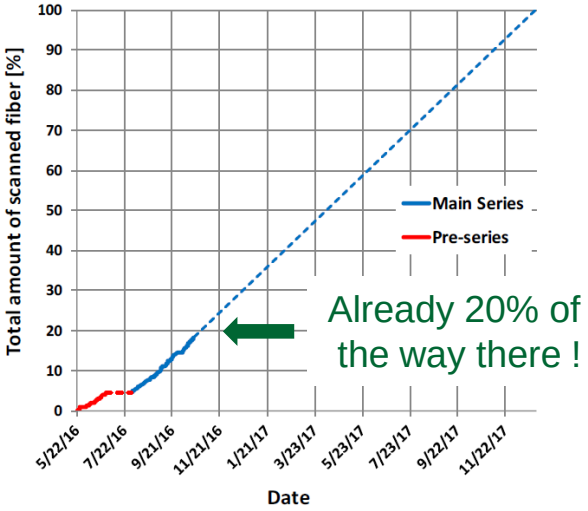
Replacement of full tracking system

Scintillating Fibre Tracker

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

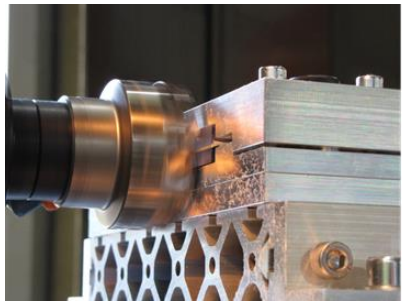
SciFi – production phase is underway !

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

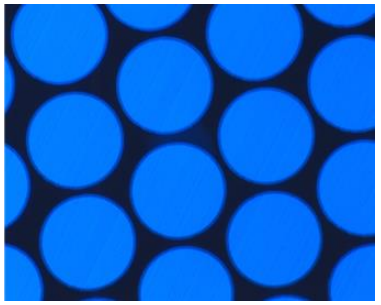


One of two module production centres now certified & manufacturing modules.

Three mat centres passed PRR & in full production mode, a 4th will join soon.



Milling of mat endpiece



Fibres after machining

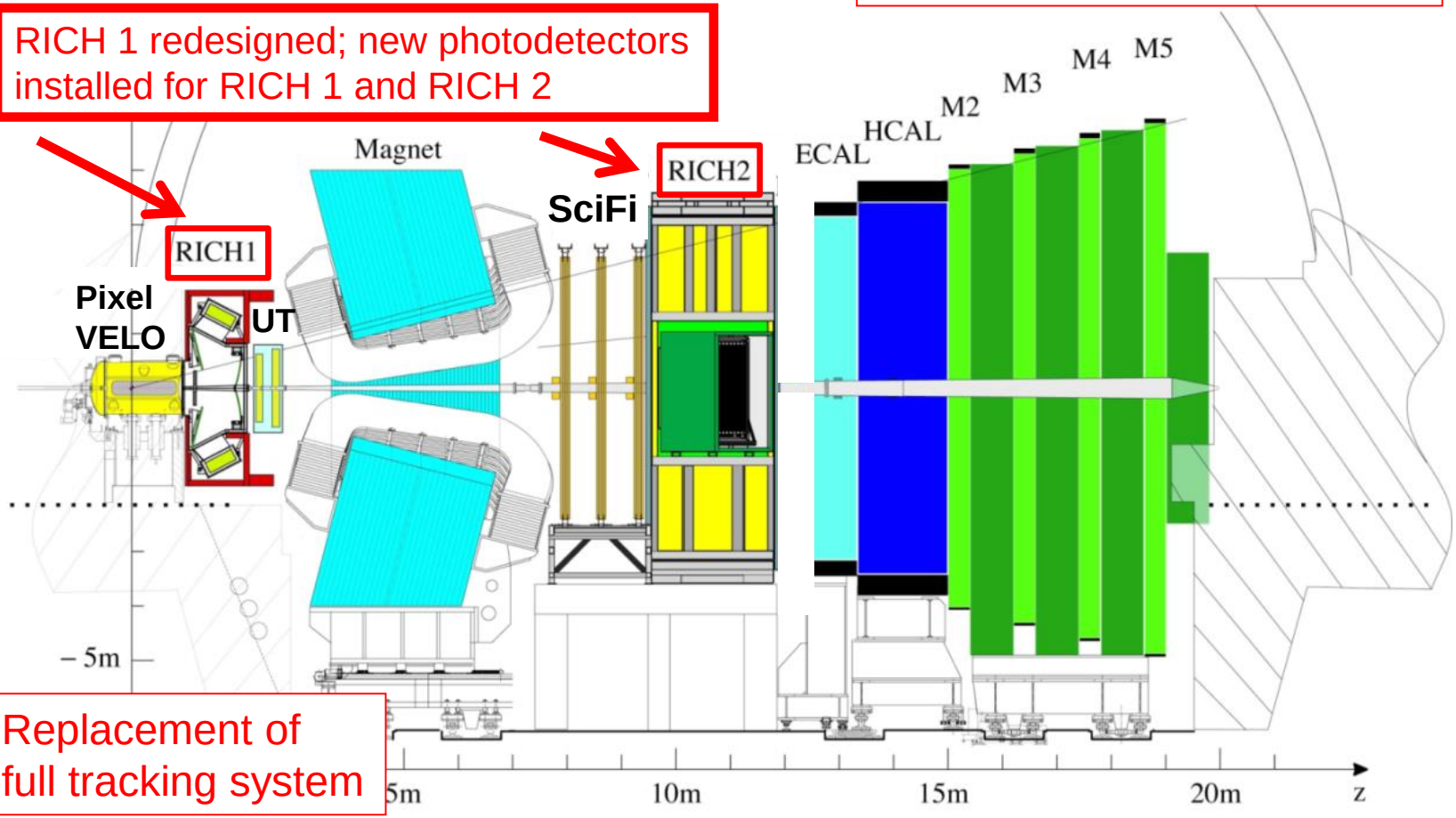
Much progress elsewhere, *e.g.* 'cold box' which holds SiPMs at -40° C.

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



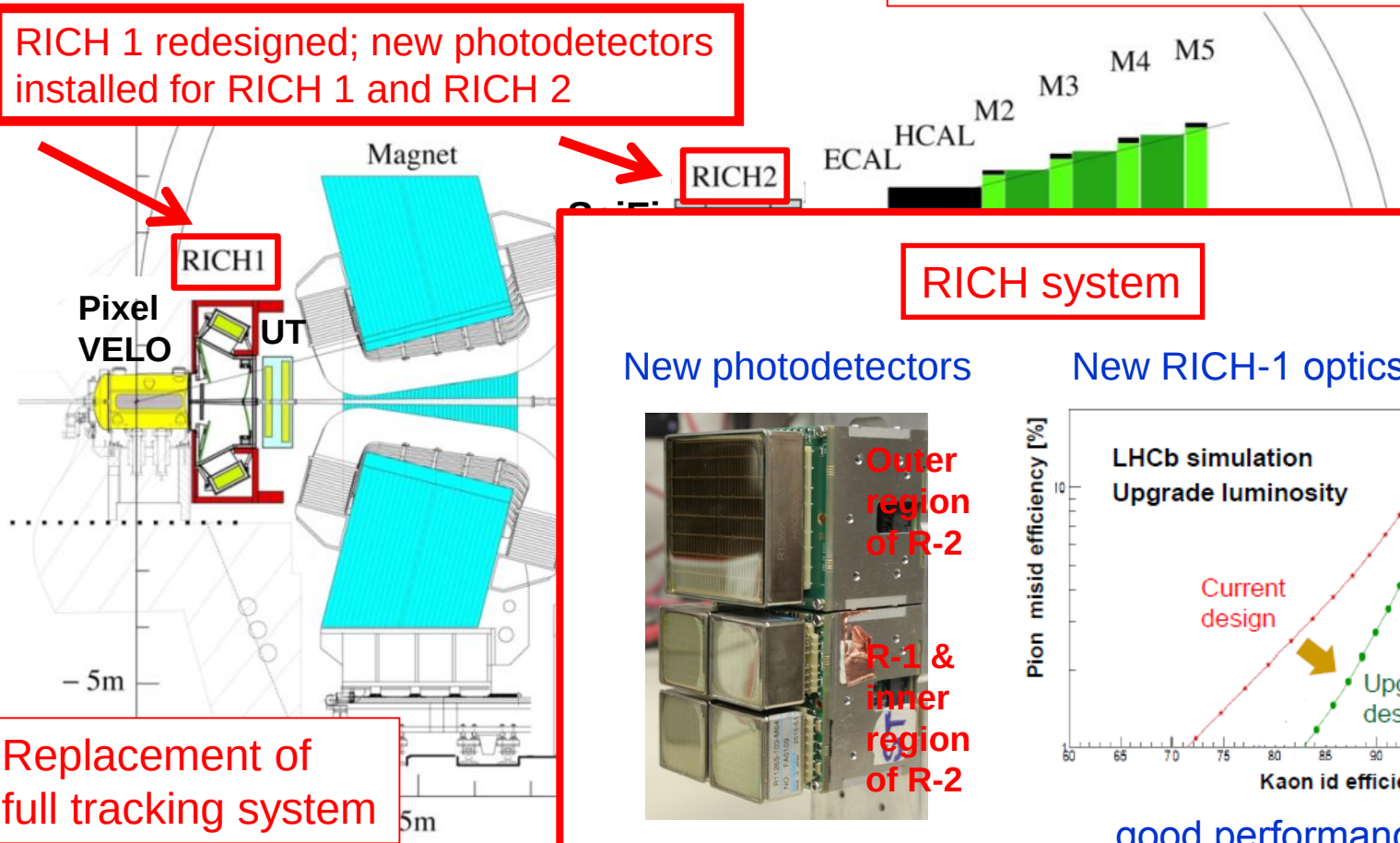
Replacement of full tracking system

Upgrade overview

Current detector → upgraded detector

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

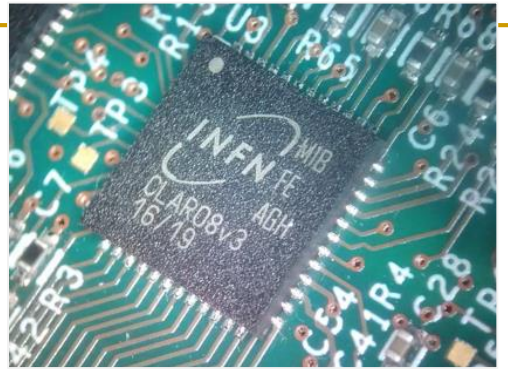
New photodetectors

Contract awarded & pre-series have arrived.

New RICH-1 optics….

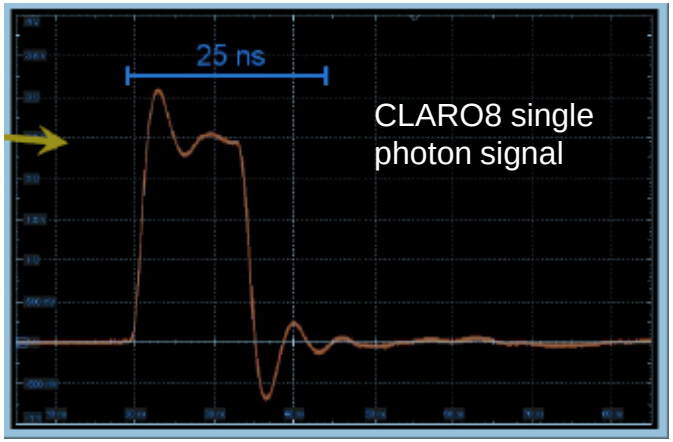
…good performance at high luminosity.

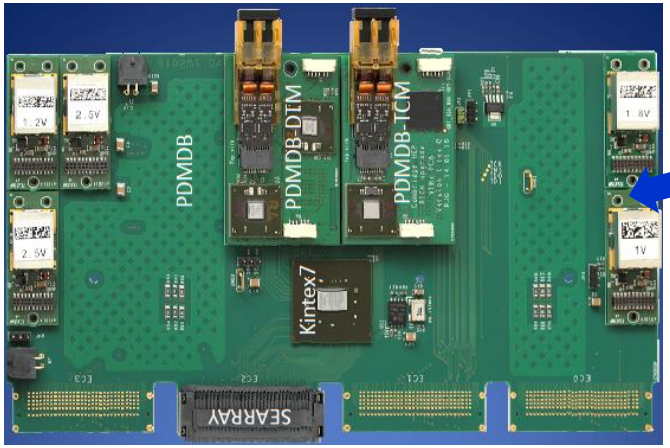
RICH progress



Two delays / concerns highlighted in April, now successfully overcome:

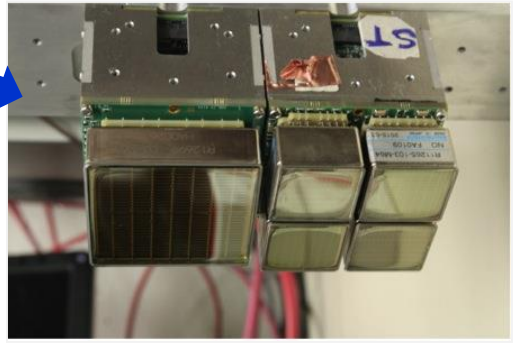
- May: successful EDR for RICH mechanics.
- New submission of front-end ASIC (CLARO) required with improved radiation resistance in digital part. CLARO 8v3 received back in May. All tests satisfactory – good to go !





Progress in many other areas, *e.g.*

- Successful EDR of the digital board;
- Successful PRR of ‘elementary cell’;
- Qualification of pre-series of MaPMTs ongoing.

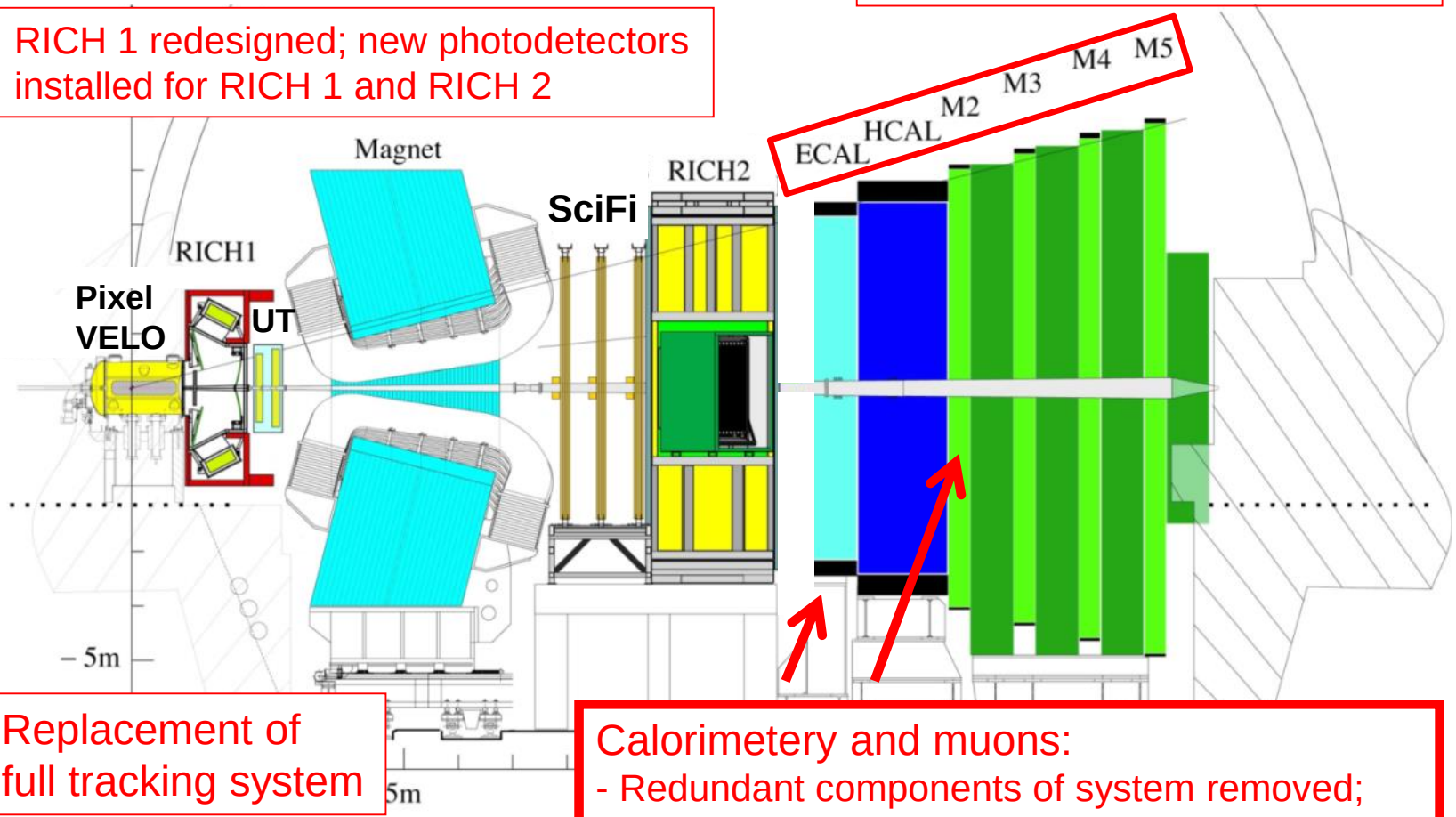


Upgrade overview

Current detector → upgraded detector

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

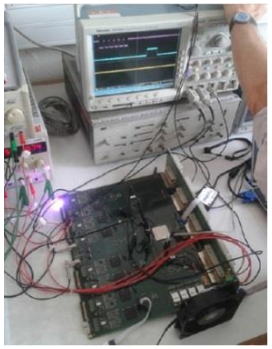
RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



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:

- Last week: PRR of front-end ASIC

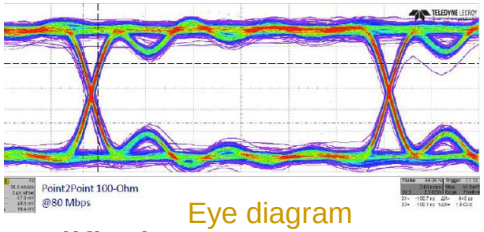
Infrastructure & tooling being prepared.

Muon system

Many of required spare MWPCs now available, & being shipped to CERN.

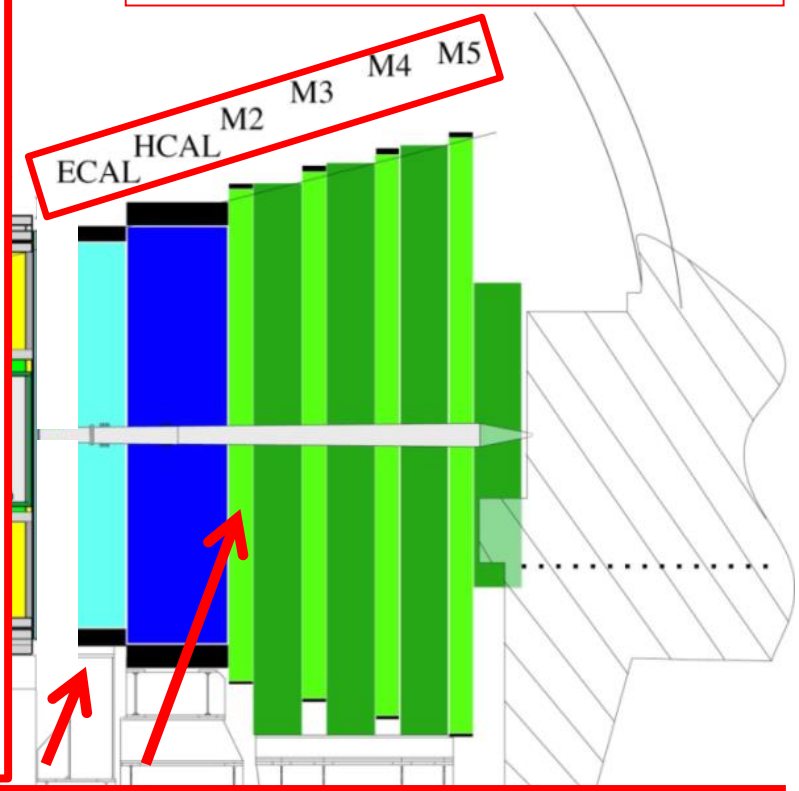
Excellent progress on new electronics.

- front-end ASIC delivered;
- high-speed backplane fully qualified



Eye diagram for backplane (80 Mbps)

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

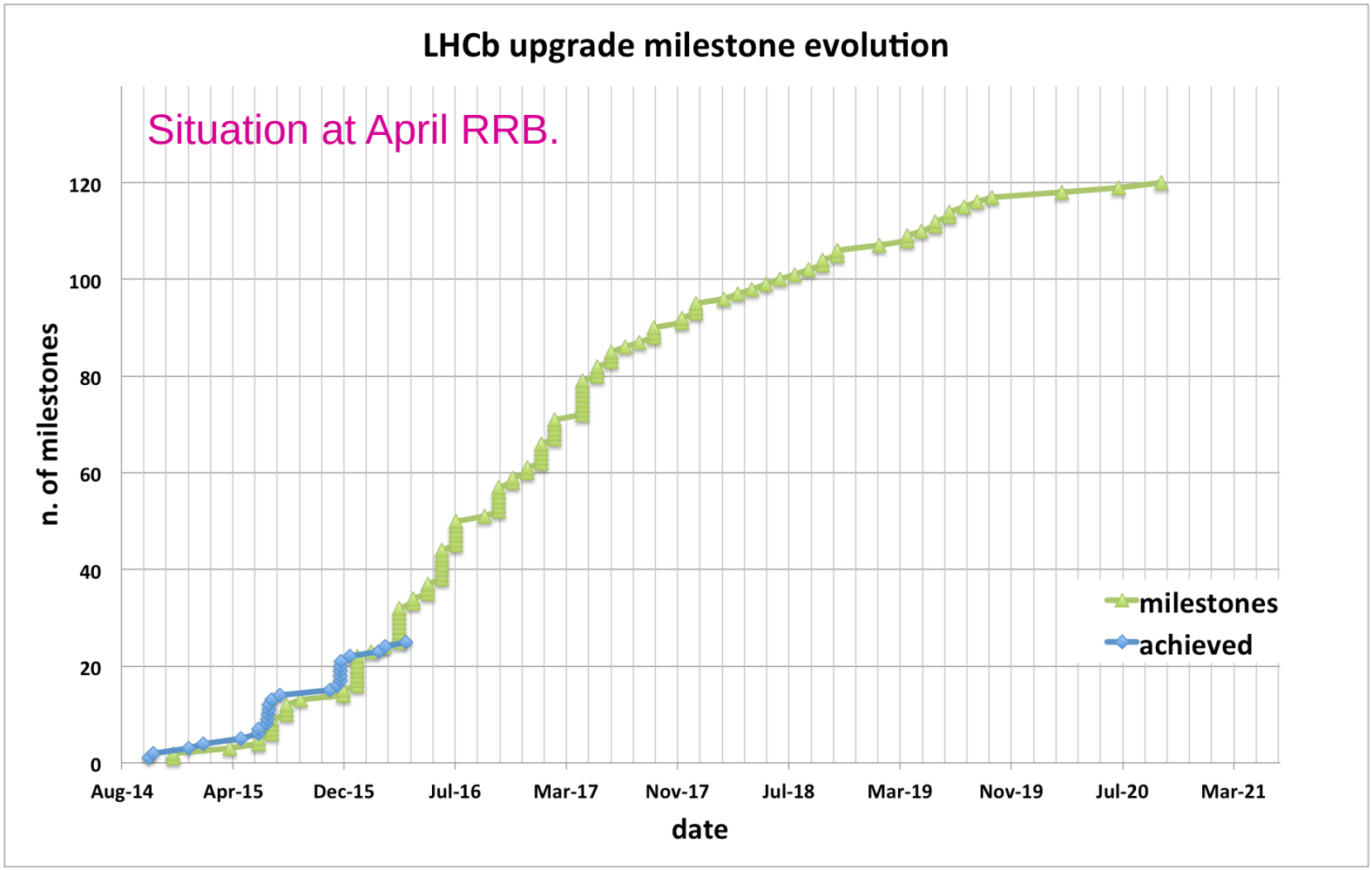


Replacement of full tracking system

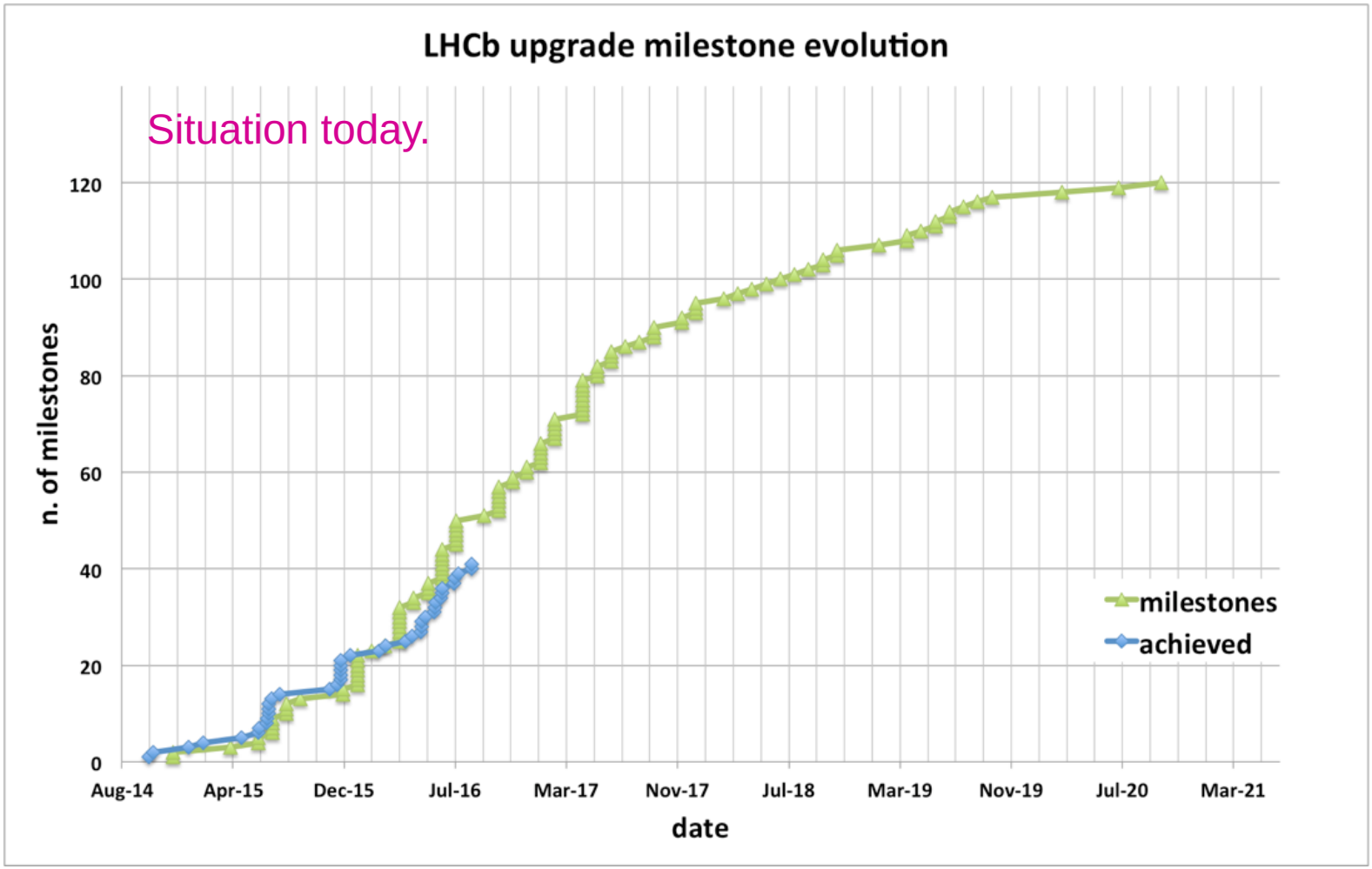
Calorimetery and muons:

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

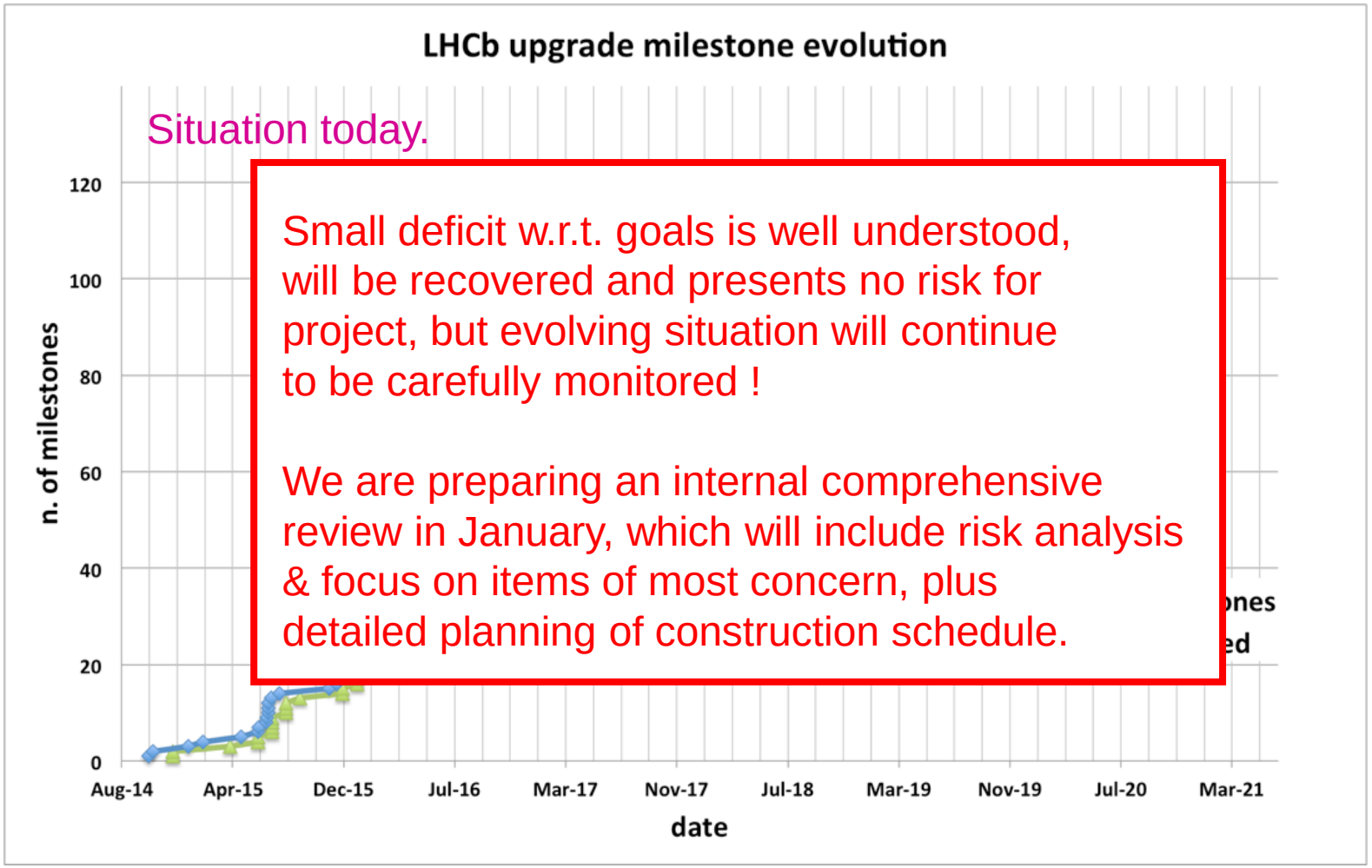
Upgrade milestones



Upgrade milestones



Upgrade milestones



Conclusions

Run-2 operation has been very successful, with detector working well.
We have responded rapidly to the (very welcome)
challenge of the remarkable machine performance.

LHCb continues to deliver important results in flavour physics, spectroscopy, and beyond. In certain areas we are reaching exceptional (10^{-4}) precision.

Core flavour-physics analyses are now fully exploiting run-2 data.

LS2 Upgrade will deliver huge increase in physics:

- good progress on all subsystems;
  challenges inevitably emerge, but are being tackled appropriately;
- SciFi system now in production phase, other projects soon to follow;
- progress being carefully monitored through milestones,
  with comprehensive internal review scheduled for January.

Finally, discussions already underway about consolidation activities in LS3, & also about a possible 2nd, high-luminosity, Upgrade, on longer time-scale (LS4).

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.