LHCb status and plans

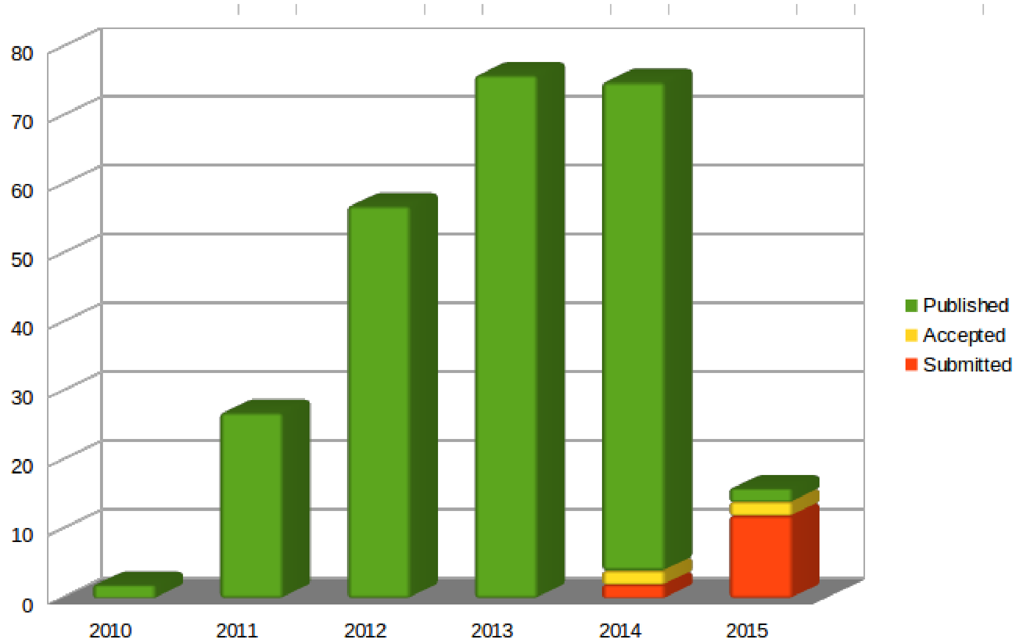
- Recent physics achievements
- Preparations for run 2
- Upgrade progress
- Conclusions

Guy Wilkinson
(University of Oxford and CERN)
on behalf of the LHCb collaboration
29/04/2015

Run-1 physics output

Status, as of Tuesday 28/04/2015

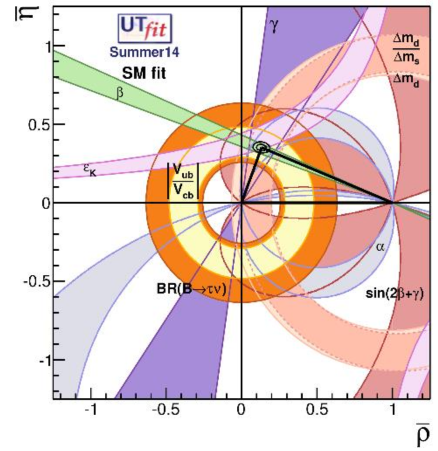
253 papers in total, integrating over published, accepted and submitted (29 since Oct RRB)



We are still exploiting run-1 data at a pretty much constant rate as last year.

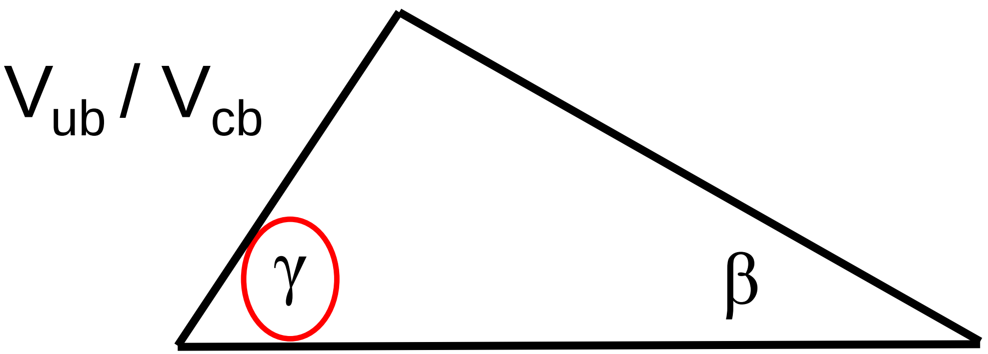
Important results are still appearing – look at a *few* selected highlights today.
We are looking forward to run-2 – but still many treasures to be mined from run 1 !

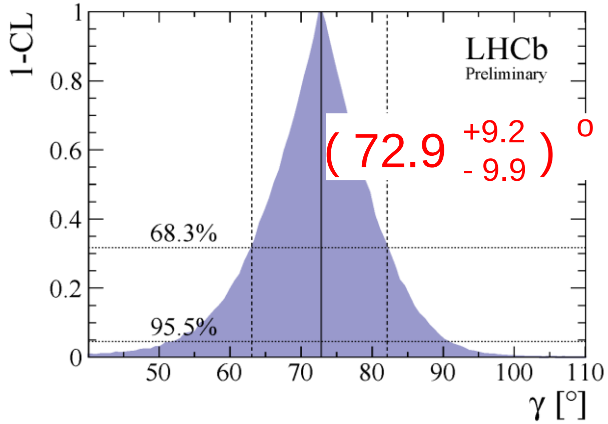
Matter-antimatter trigonometry



The Unitarity Triangle is a geometrical description of *CP*-violation within the context of the Standard Model.

We must check its consistency through precise measurements.





[LHCb-CONF-2014-004]

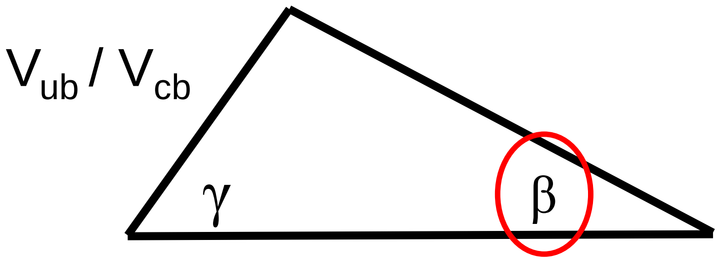
As reported in October RRB

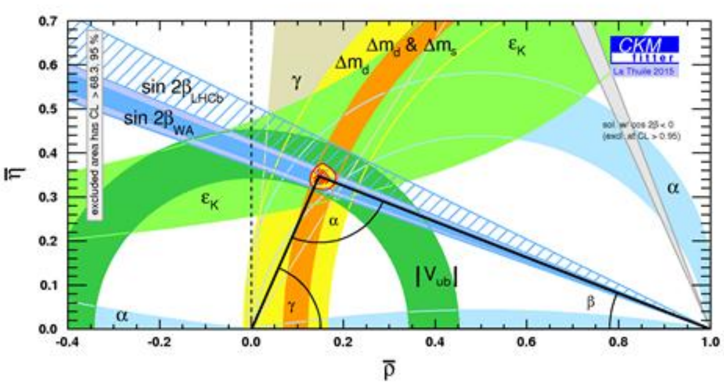
A raison d'être of LHCb is to measure γ.

Here we have already attained better precision than the *B*-factories combined.
By the end of run 2 we should be down to a few degrees.

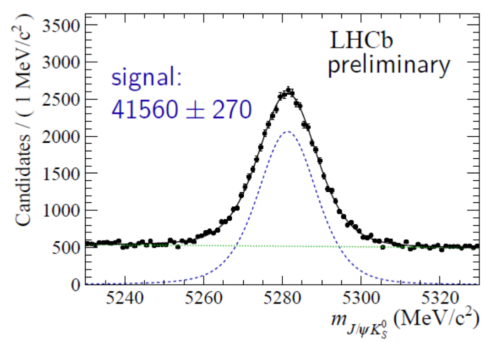
Matter-antimatter trigonometry: sin2β

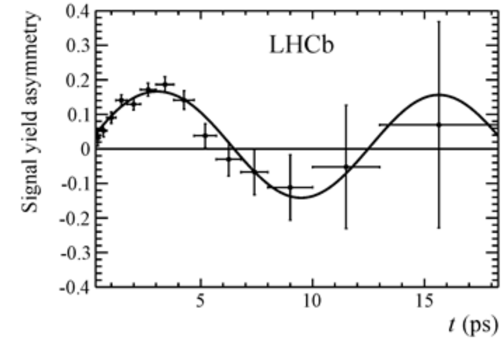
Measurement on β was the legacy of the B-factories, and helped pave way for 2008 Nobel Prize for Kobyashi and Maskawa. Now LHCb has entered the game !





This measurement requires time-dependent measurement & flavour tagging, which is trickier at a hadron collider than at an e^+e^- machine.





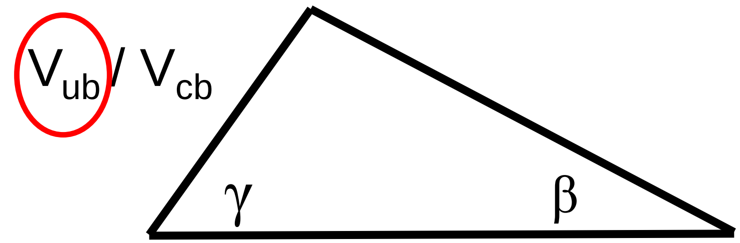
[arXiv:1503.07089]

$$\sin 2\beta_{\mathrm{eff}} = 0.731 \pm 0.035\,(\mathrm{stat}) \pm 0.020\,(\mathrm{syst})$$

(BaBar stat error = 0.036, Belle stat error = 0.029)

Precision obtained by LHCb with $B^0 \to J/\Psi K_S$ is very similar to that of the B-factories. LHCb will dominate measurement with run-2 data. Upgrade prospects exciting !

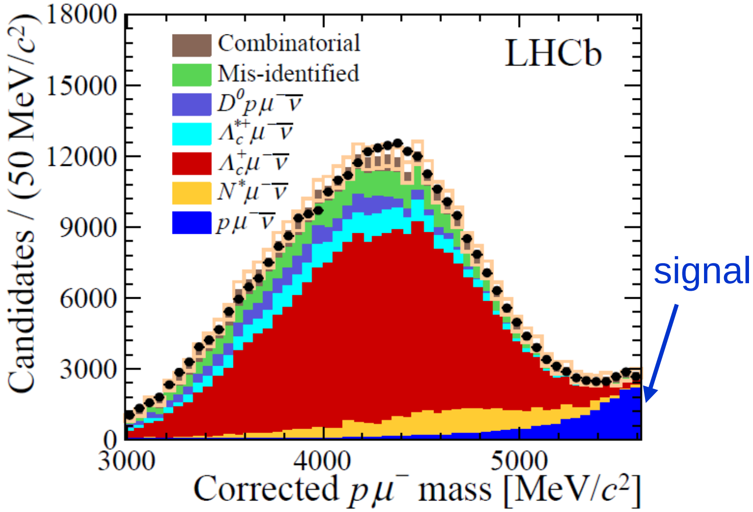
Matter-antimatter trigonometry: V_{ub}



Measurement of V_{ub} long thought essentially impossible at LHC. Challenging to separate $b \to u\mu\nu$ and $b \to c\mu\nu$ processes without any beam energy constraint.

We have now shown it can be done!
Use baryon decay $\Lambda_b \to p\mu\nu$ and benefit from RICH & vertexing capabilities.

[arXiv:1504.01568]

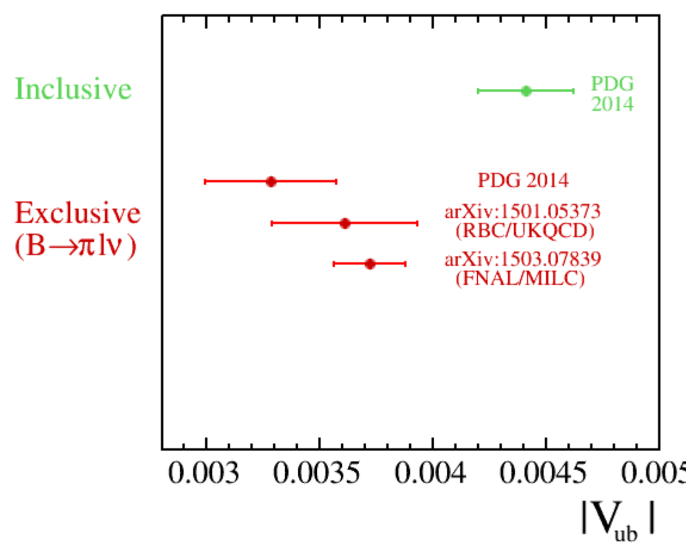


Lattice QCD needed to interpret result – productive collaboration.

Very precise result:

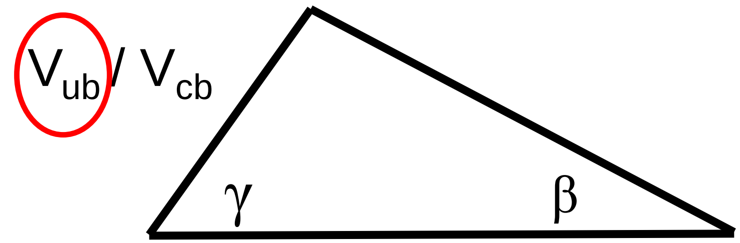
$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$$

Brings new insight to long-standing ‘inclusive vs exclusive’ V_{ub} puzzle.



tension !

Matter-antimatter trigonometry: V_{ub}



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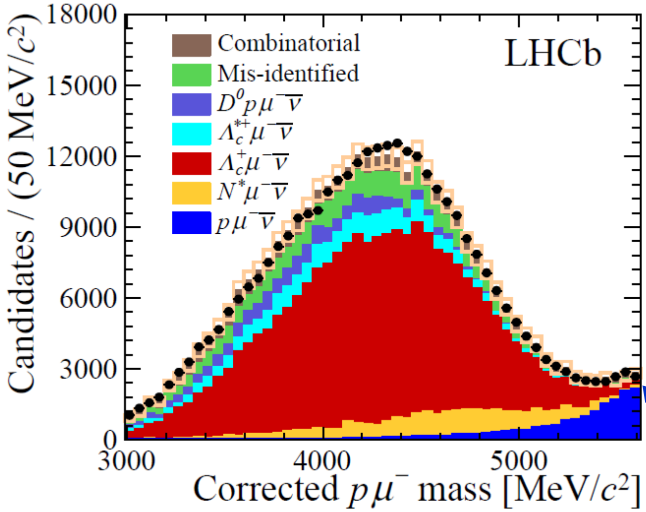

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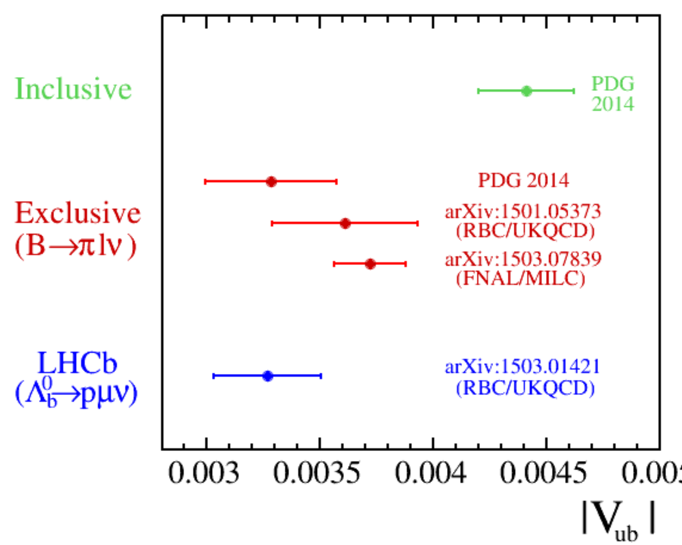
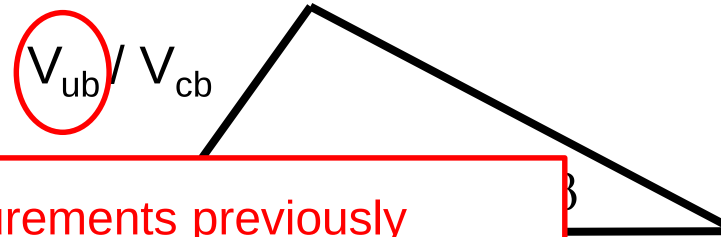


tension !

LHCb result agrees with exclusive results

Matter-antimatter trigonometry: V



LHCb is now performing measurements previously considered to be the preserve of the *B*-factories.

Excellent prospects for ultra-precise Unitarity Triangle tests !

Measure … nging
to separ … nstraint.

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Use baryon decay $\Lambda_b \rightarrow p\mu\nu$ and benefit from RICH & vertexing capabilities.

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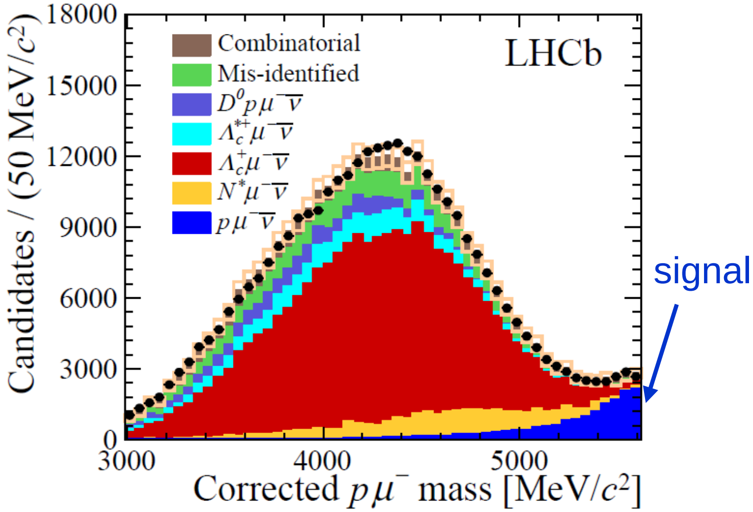

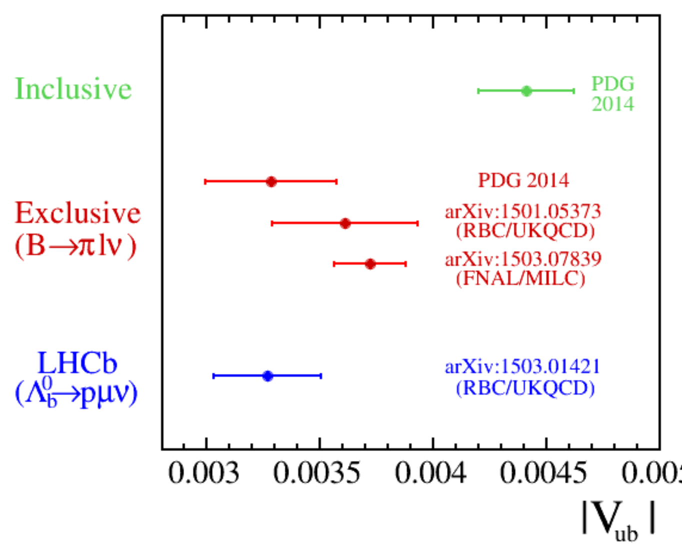

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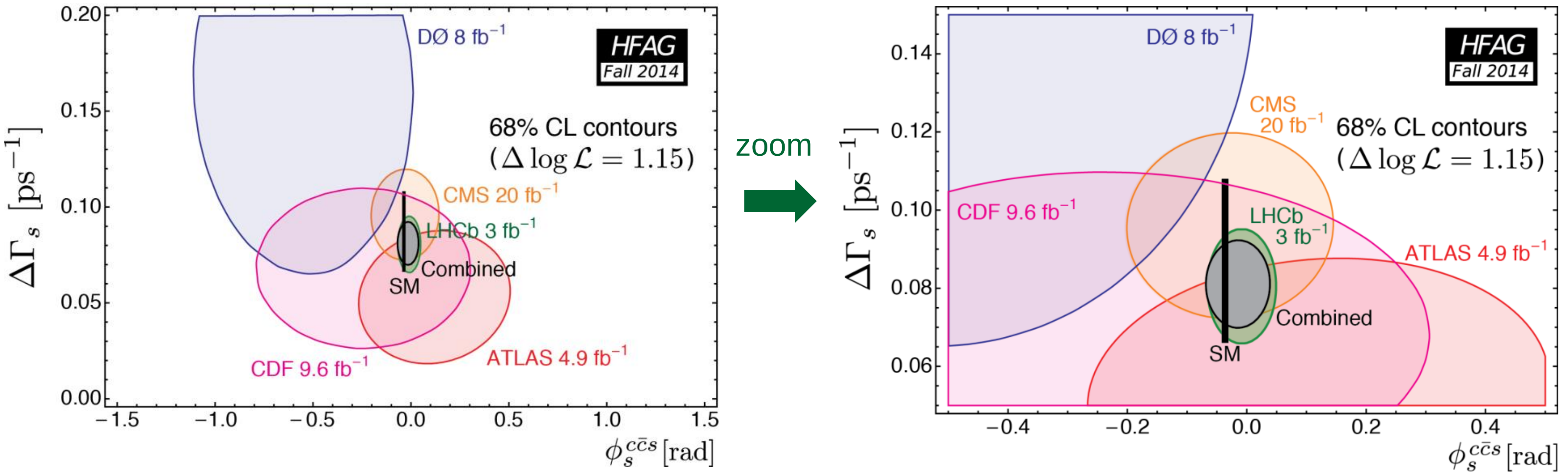
LHCb result agrees with exclusive results

Lattice QCD needed to interpret result – productive collaboration.

Exploring the B_s sector

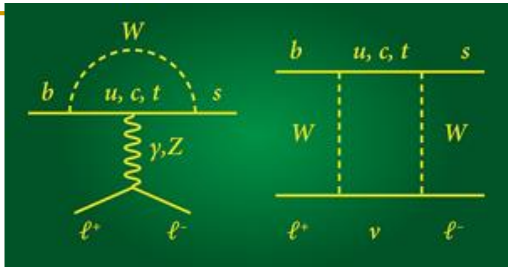
Furthermore, LHCb continues to deliver in its recognised core areas.
e.g. final run-1 results [PRL 114 (2015) 041801] on *CP* violation in B_s system, ϕ_s.



Very impressive precision obtained, but observable still consistent with the near-zero *CP*-violation expected by Standard Model.

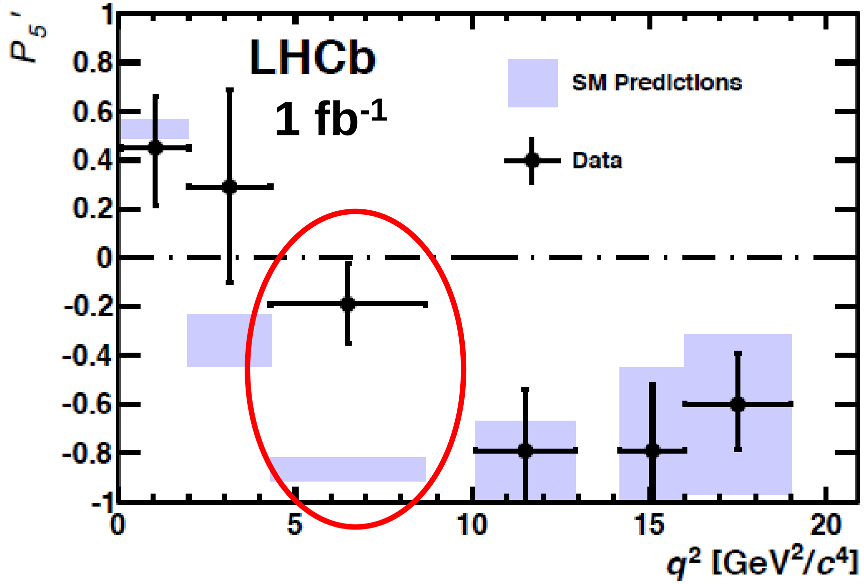
Much higher sensitivity with run-2 data and the Upgrade – picture may change !

Intriguing hints from $b\to sl^+l^-$



Decays such as $B\to K^{(*)}l^+l^-$ have been long-recognised as a promising laboratory to look for New Physics effects, mainly because of the suppressed diagrams that mediate the process.

In the decay $B\to K^*\mu^+\mu^-$ there are many observables to measure, and analysis of early run-1 data produced surprises which have led to much theory interest.

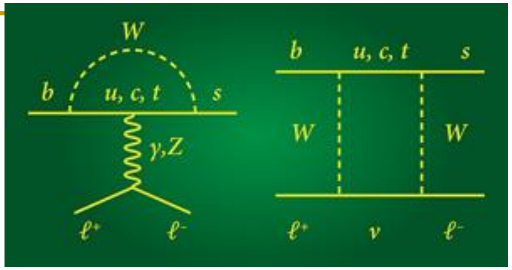


[PRL 111 (2013) 191801]

Is this discrepancy a statistical fluctuation, or a first sign of something more exciting?

Update with full run-1 dataset was presented for first time in March this year…

Intriguing hints from $b \to s l^+ l^-$



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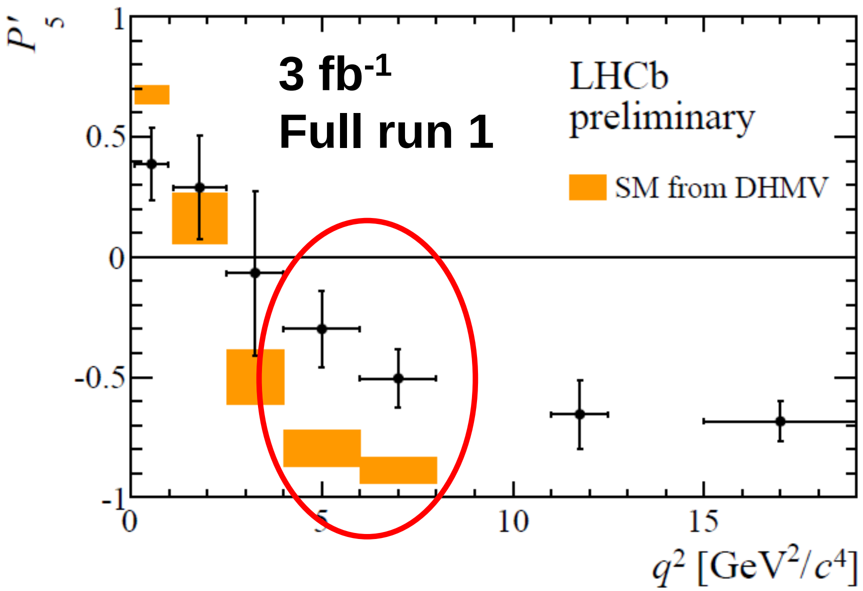


[LHCb-CONF-2015-002]

Effect remains, with very similar significance !

Does not look like a fluctuation.

Is effect driven by New Physics (*e.g.* Z' boson) or is SM prediction less clean than was promised ?

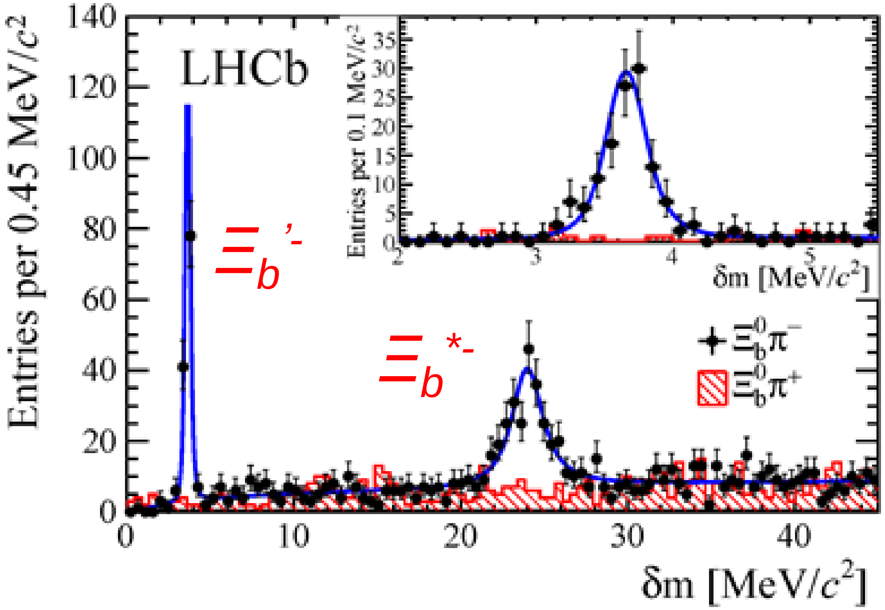
Recall there are other puzzles in these decays, *e.g.* possible violation of lepton universality in $B \to K l^+ l^-$ [PRL 113 (2014) 151601]. Need more analysis, more data, more theory…

Spectroscopy

LHCb results continue to tell us new things about the structure of hadrons.

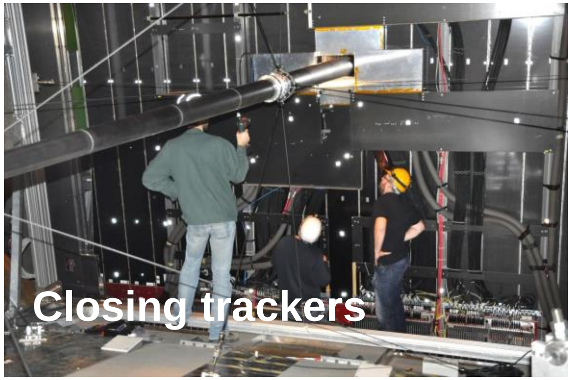
Several new particles observed since October, for example in *b*-baryon sector

[PRL 114 (2015) 062004]



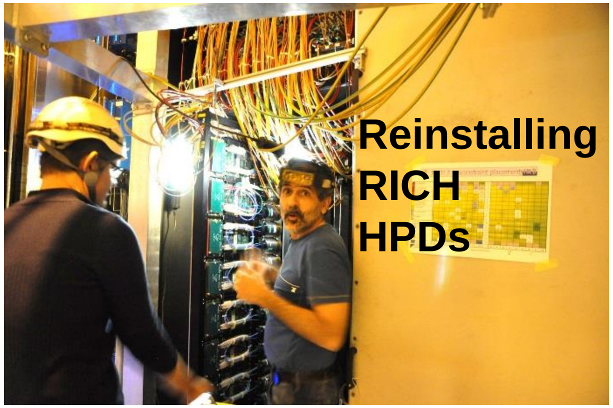
Several similar such results in the pipeline, some that are quite unexpected…

LS1 activities – preparing for run 2



LS1 activities finished *exactly* on schedule with all interventions successfully completed:

- all faults repaired
- systems 'future-proofed' for coming run
- CPU farm doubled in power



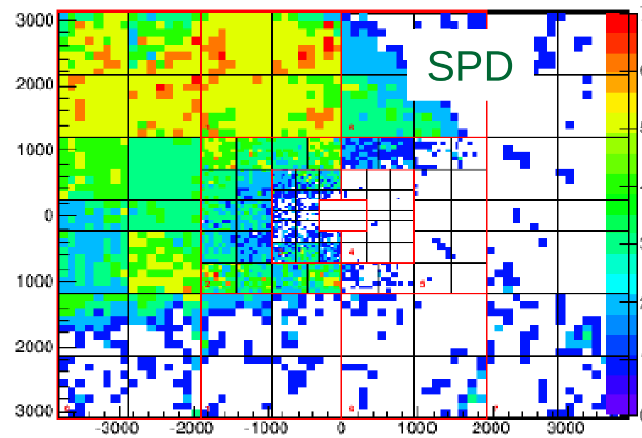
Transfer line test ('TED')

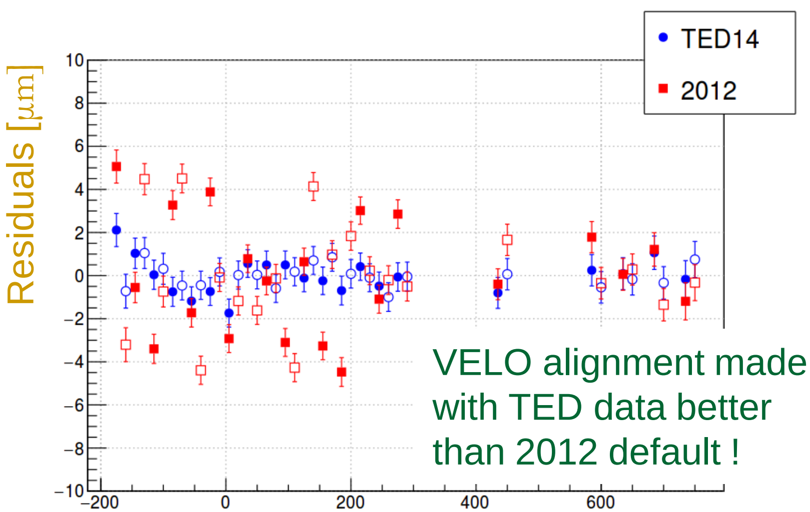
'TED' = stopper at end of transfer line just before LHCb. LHCb sees resulting muons.

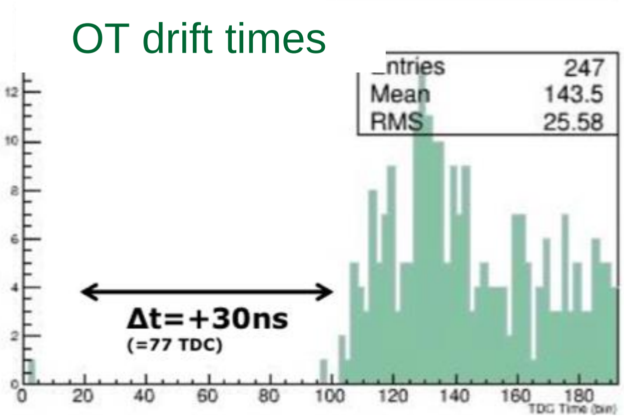
Sequence of 'commissioning weeks', increasing in intensity and focus, intended to wake up detector from hibernation, culminated in transfer line test in late Nov

Vibrant atmosphere in control room

All sub-detectors collected useful data



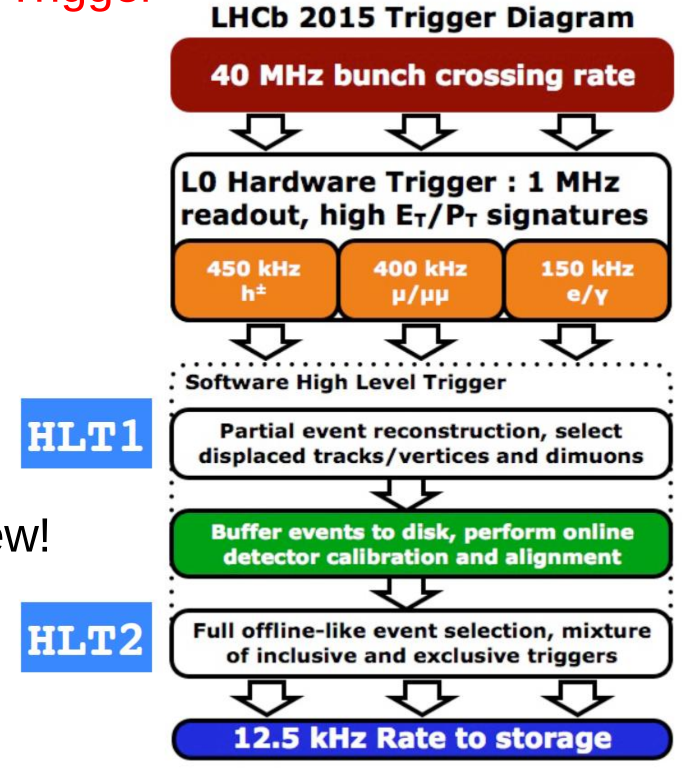




Run 2 operation

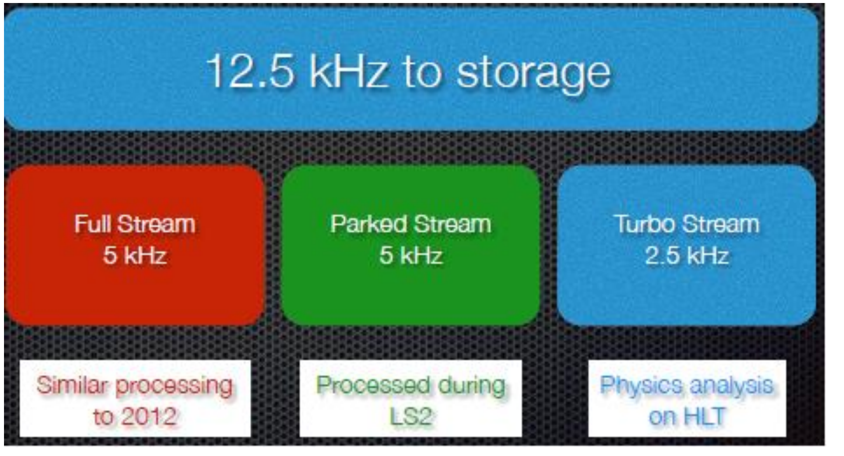
Several ambitious changes planned for operation during run II aimed at increasing physics output and making optimal use of resources

Trigger



New!

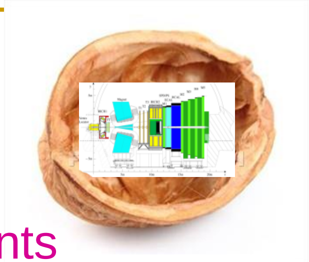
Output streams



Turbo-stream will need no offline processing. If this works well then it has important implications for Upgrade.

This splitting of HLT into two steps enables more info to be used in HLT2 (*e.g.* RICH) → improved signal-to-background separation (and helps test ideas we wish to use in Upgrade trigger)

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}

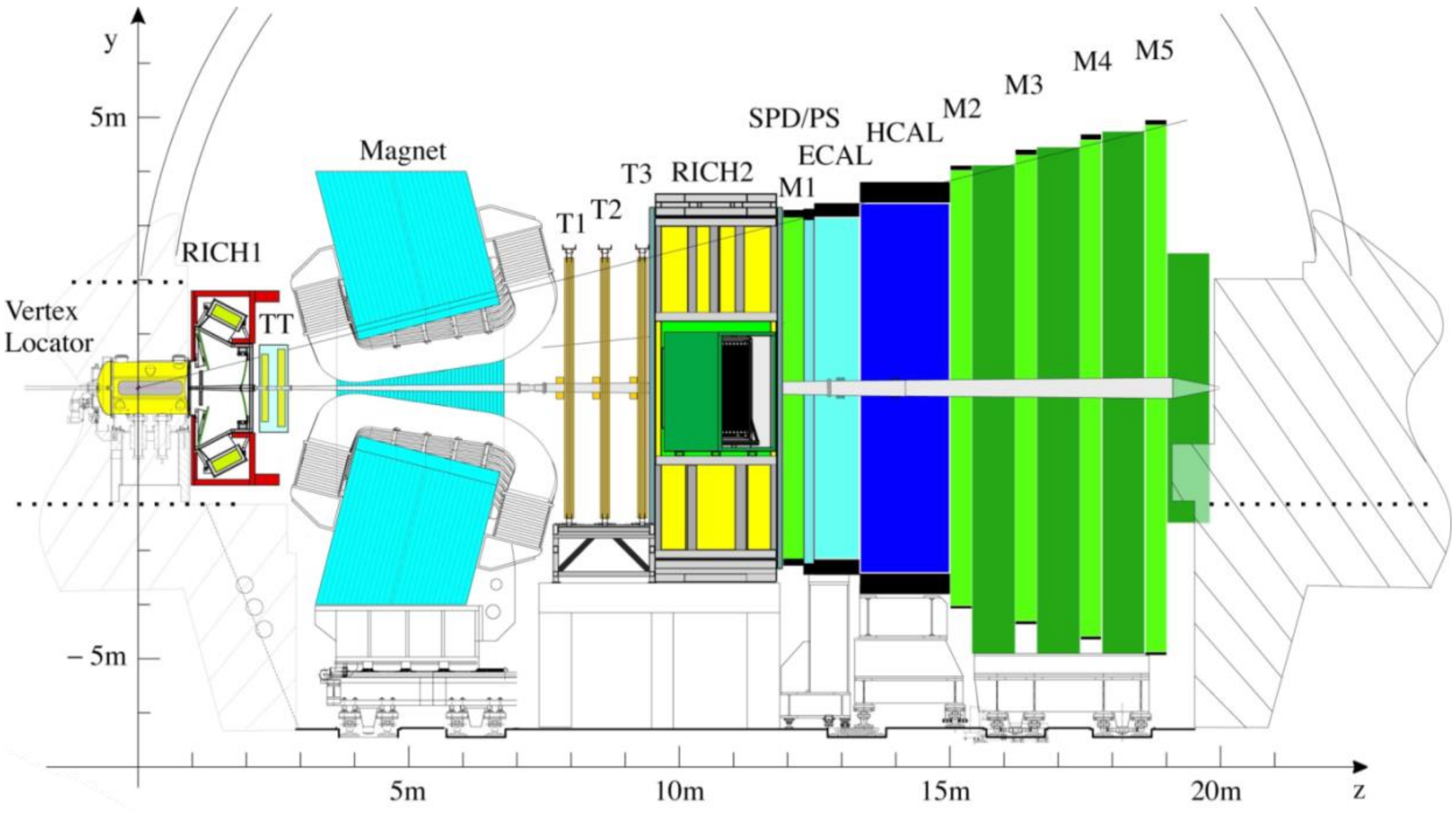
Necessitates redesign of several sub-detectors & overhaul of readout

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

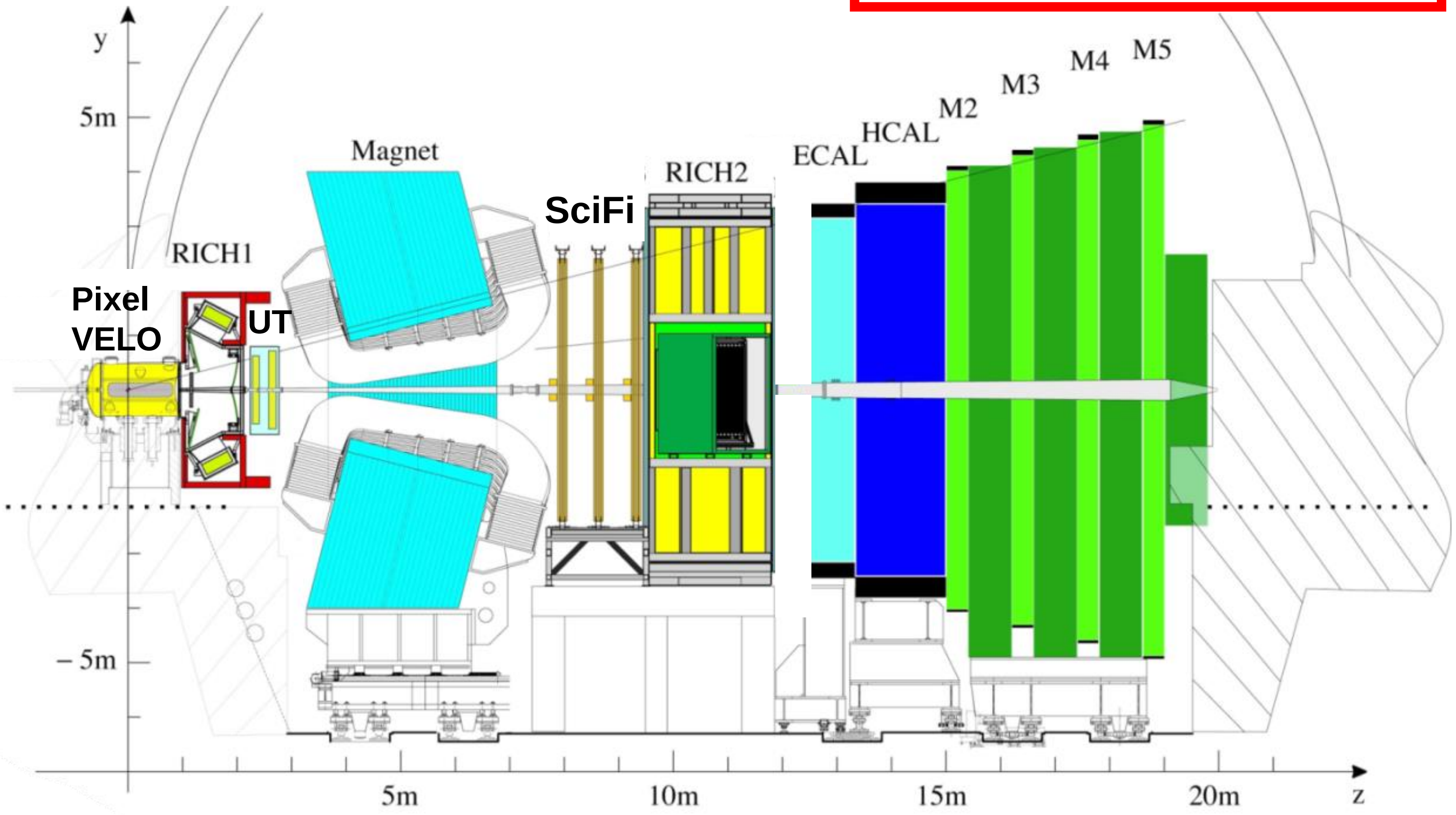
Current detector



Upgrade overview

Current detector → upgraded detector

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



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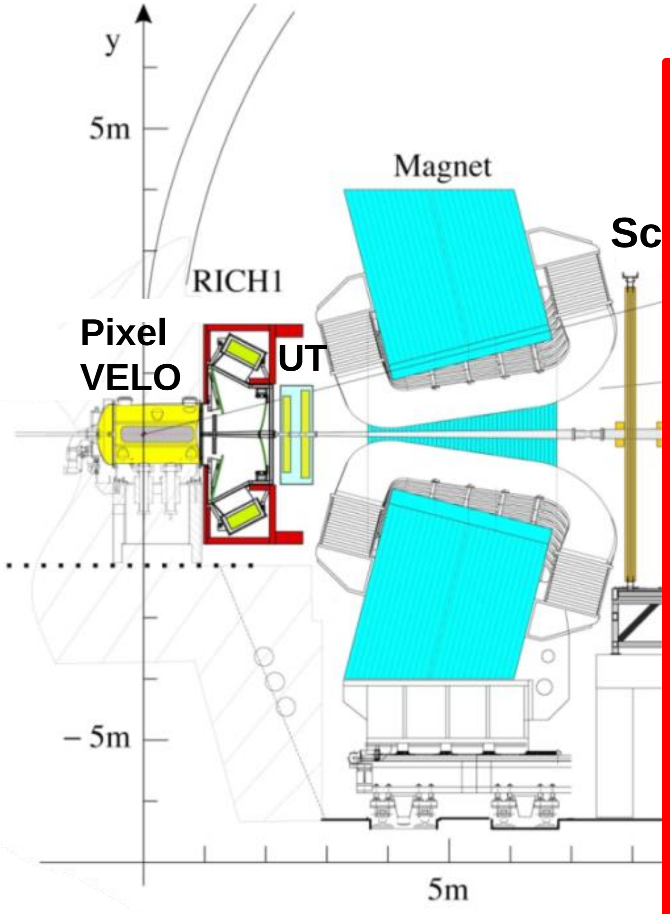
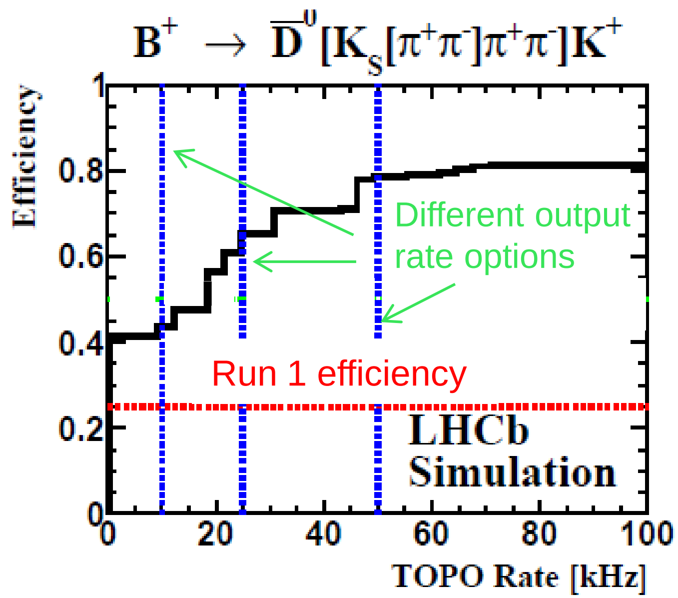


Upgrade software trigger

Full event information → much improved efficiency



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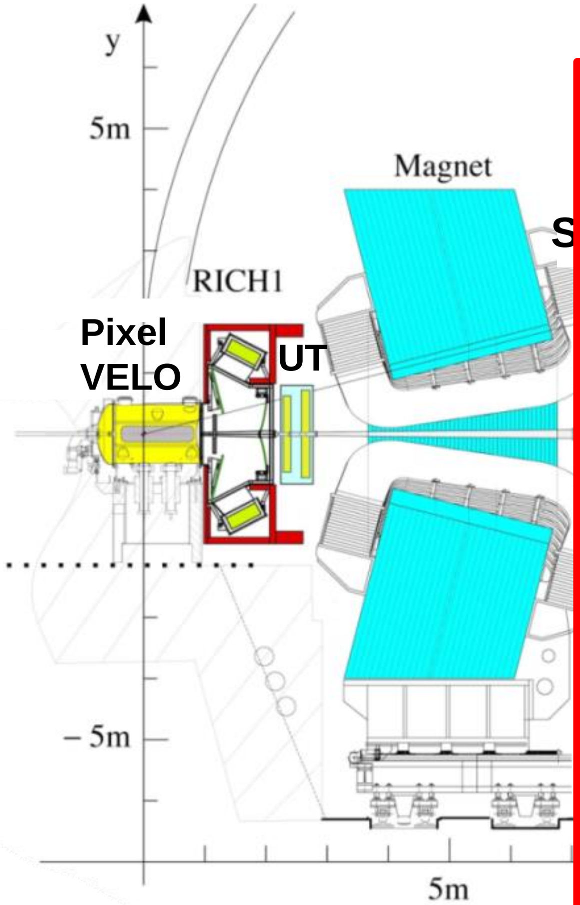
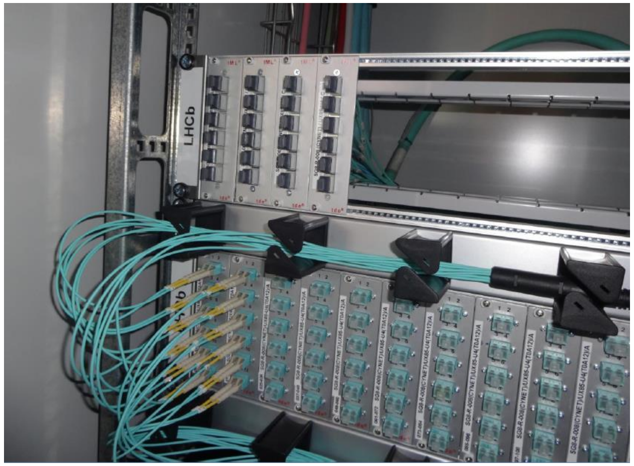


Readout: recent progress with fibres

Long (~300 m) test fibres installed between pit & surface. Now subjected to bit error tests.



Bit error rate of 10^{-17} observed, well within specs

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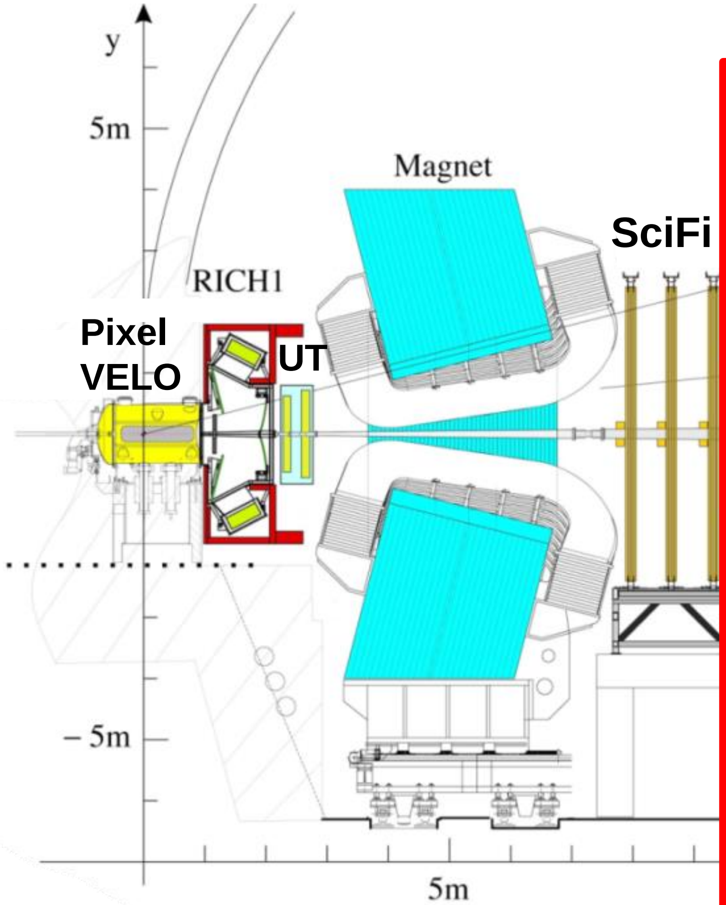

Readout: recent progress with firmware

PCBs of prototype readout board have been delivered & boards under assembly.

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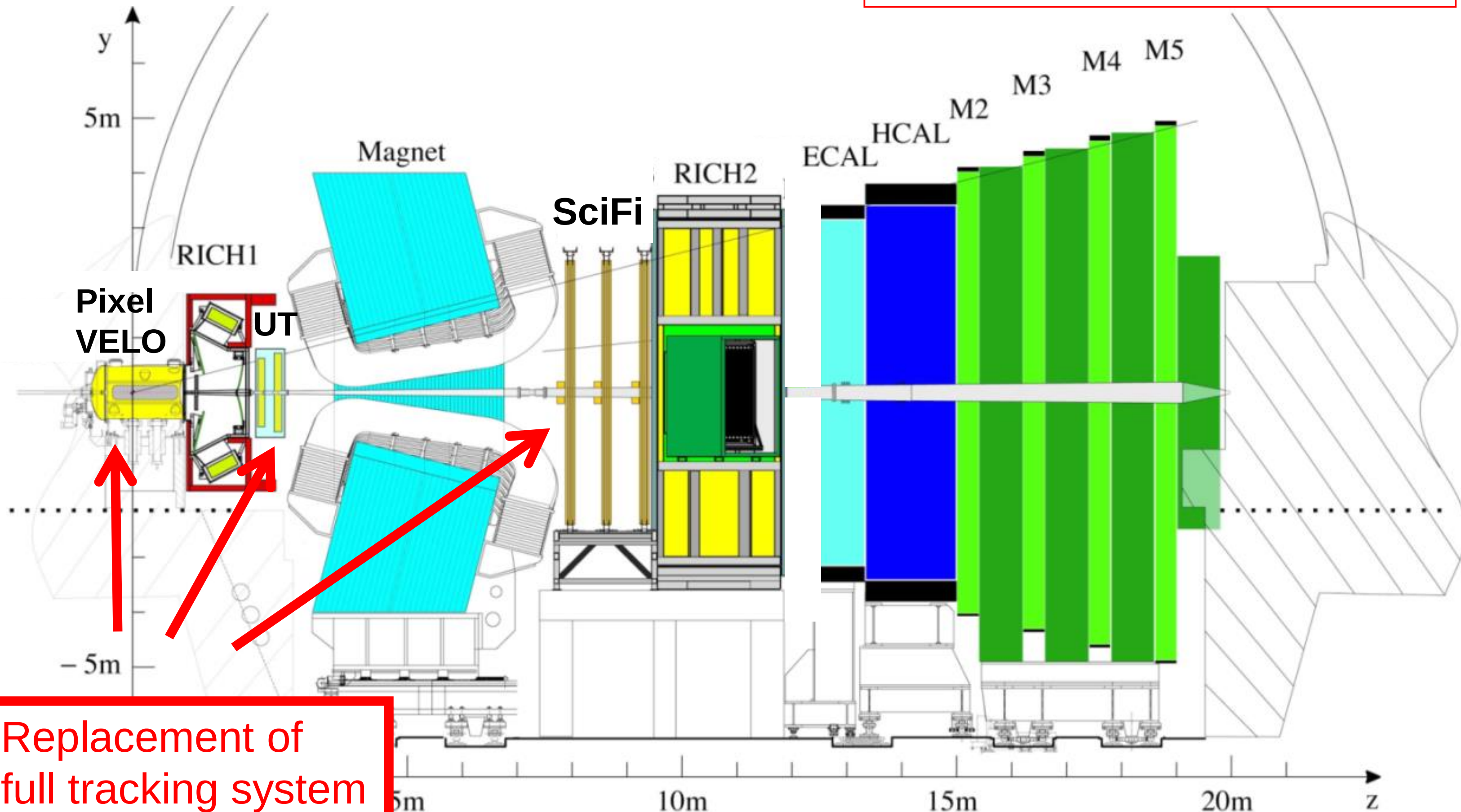

Replacement of full tracking system

Upgrade overview

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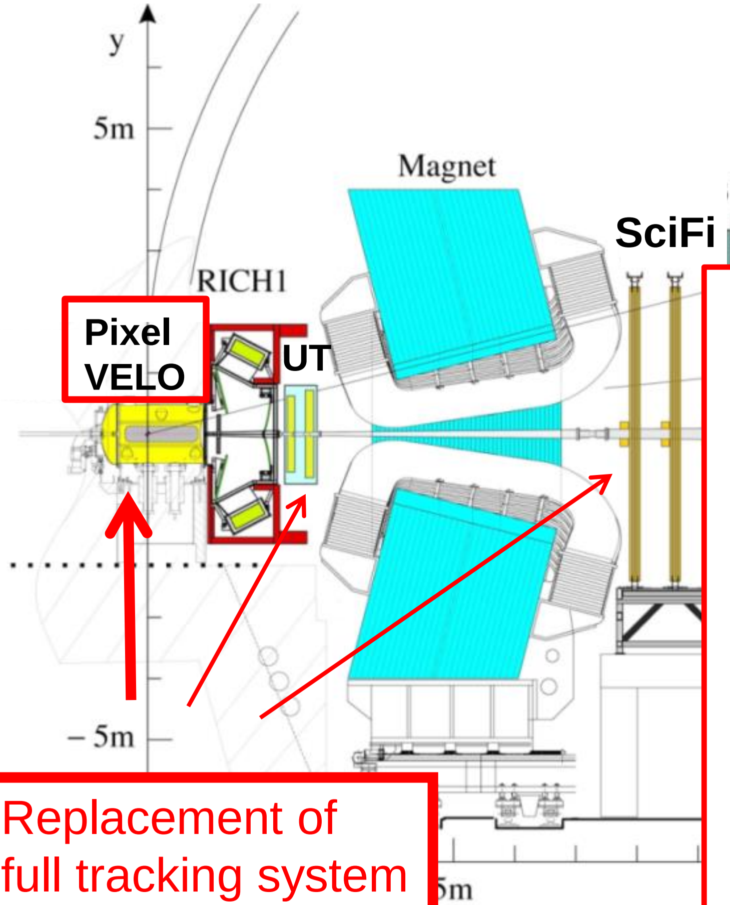
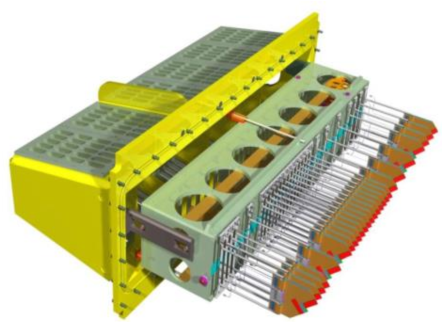


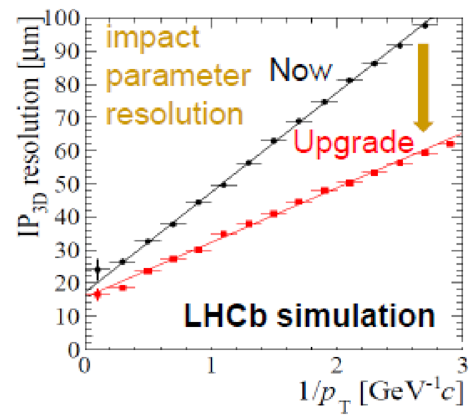
Replacement of full tracking system

Pixel Vertex Locator (VELO)

Half of VELO system



Improved performance



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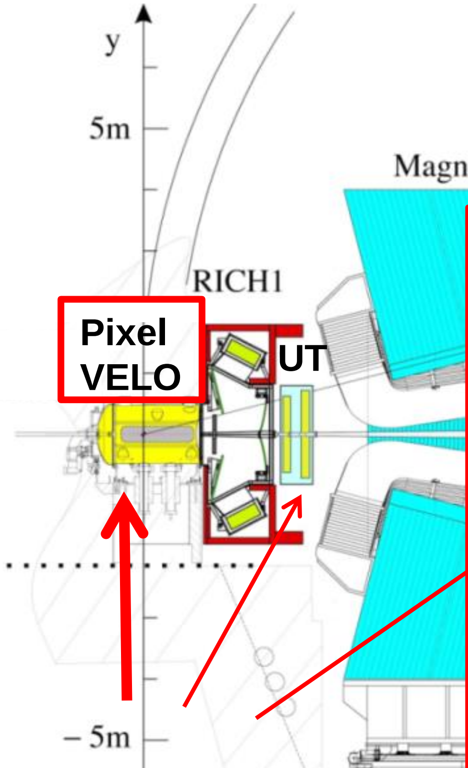
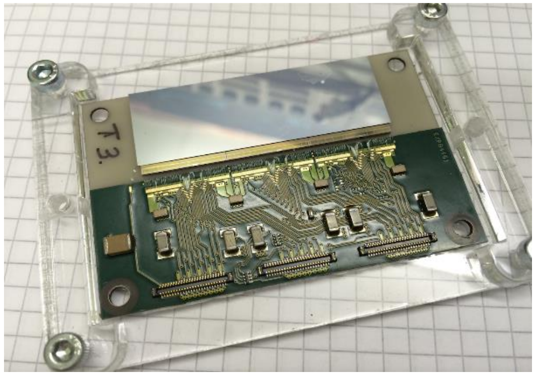
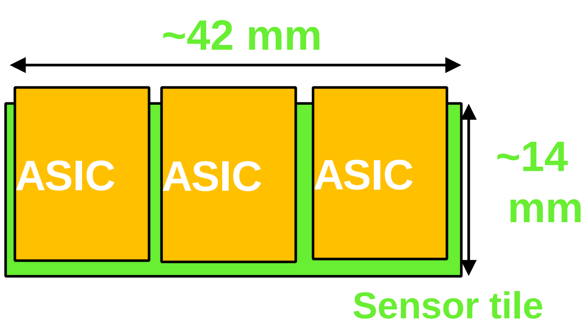


Pixel VELO

Replacement of full tracking system

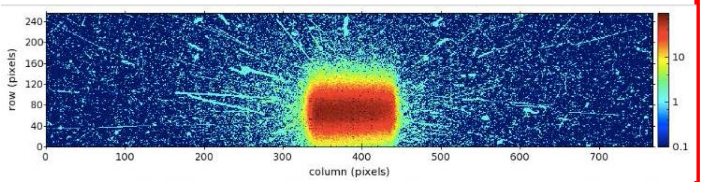
VELO: progress with sensor-ASIC-hybrid assemblies





Assembly of prototype sensor, plus 3 ASICs and quarter-hybrid.

Successful testbeam evaluation.



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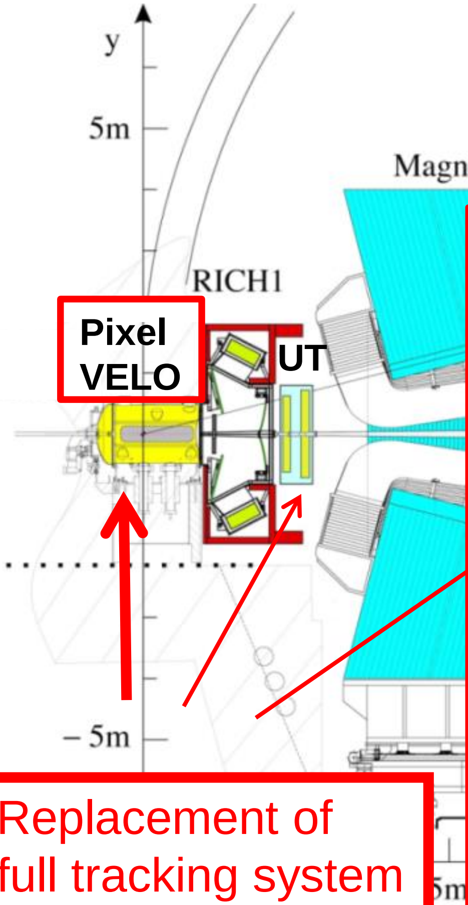
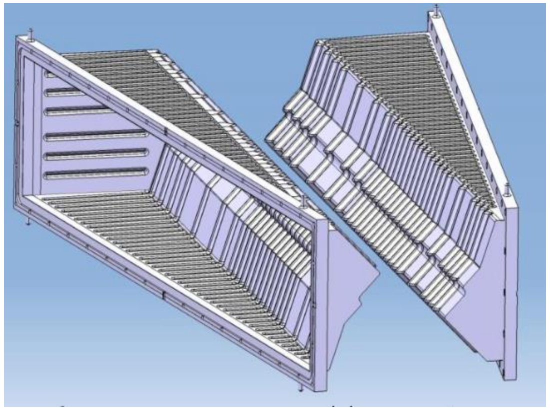
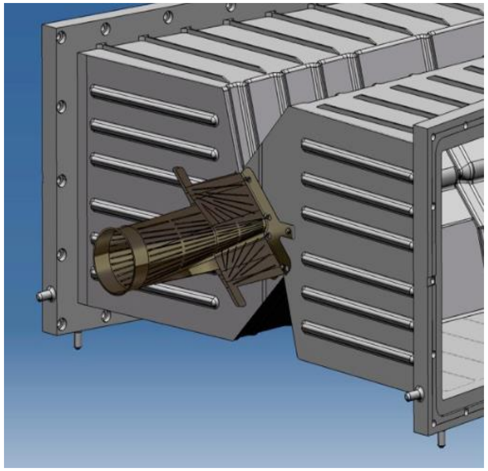


Replacement of full tracking system

VELO: progress with RF foil

Advanced design exists of vacuum box and wakefield suppressor.





Manufacture of first prototype is about to begin.

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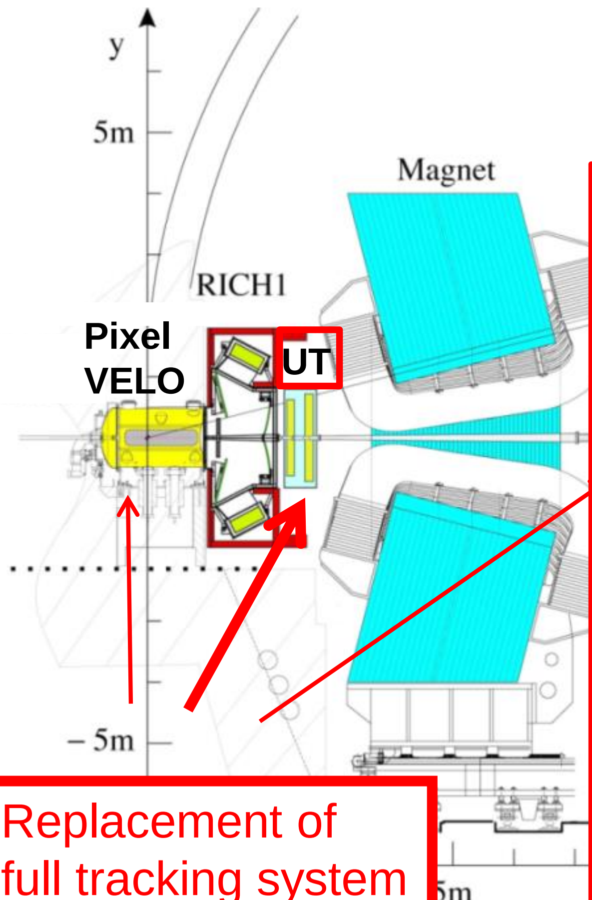
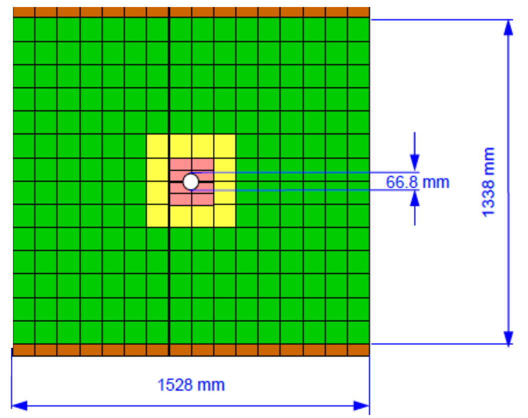


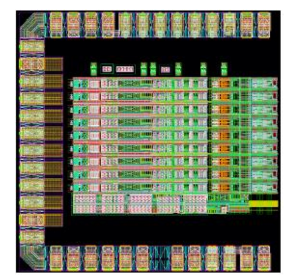
Replacement of full tracking system

Upstream Tracker (UT)

Si strip detector before magnet



SALT8 ASIC



Recent achievements:
- submission of prototype ASIC
- testbeam evaluation of irradiated sensors

Extensive series of EDRs scheduled for June.

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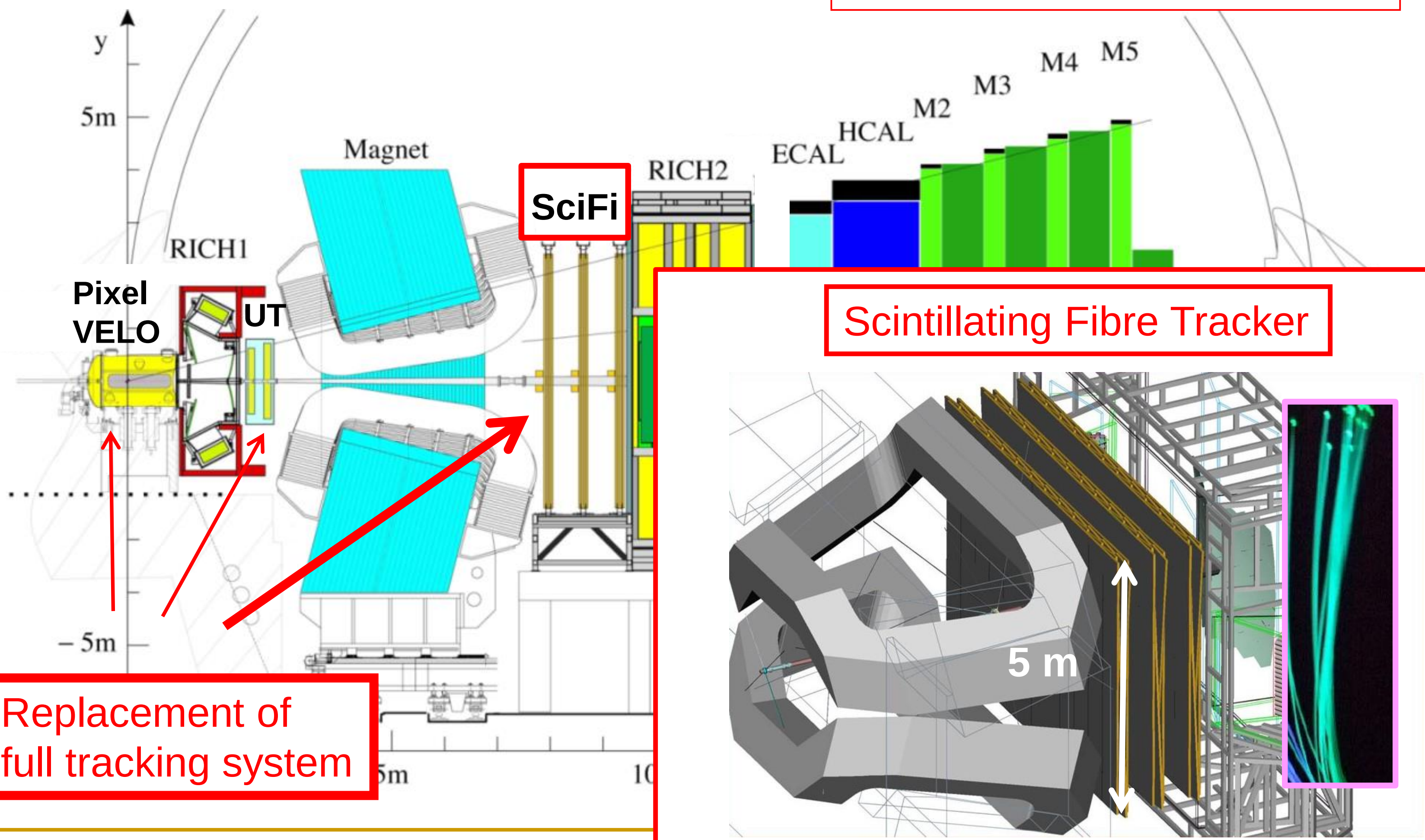
Current detector → upgraded detector

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



Scintillating Fibre Tracker

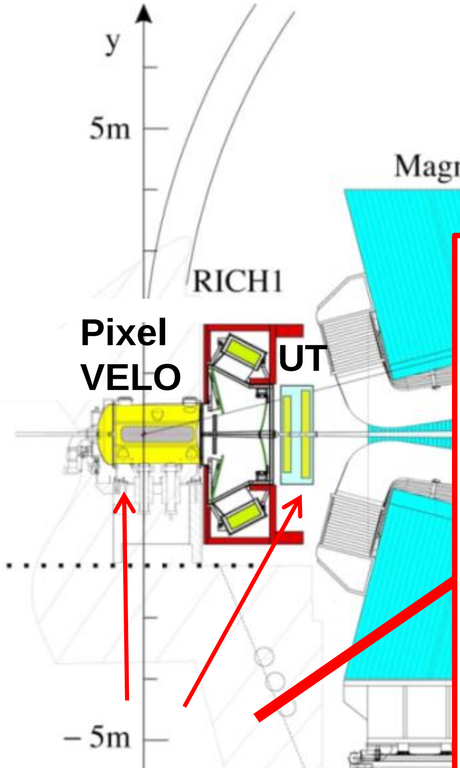
5 m

Large scale system (~12,000 km of fibres)

Upgrade overview

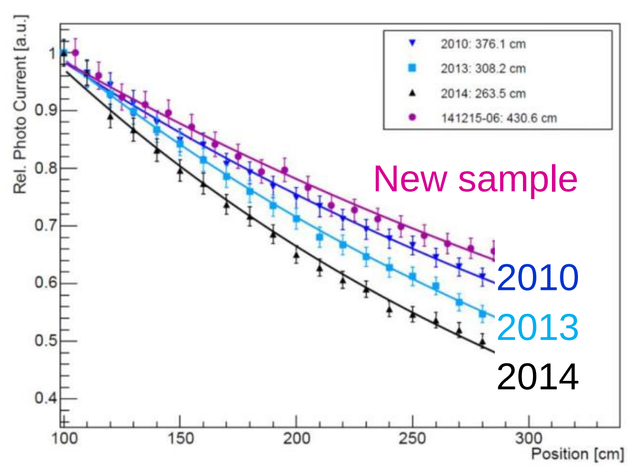
Current detector → upgraded detector

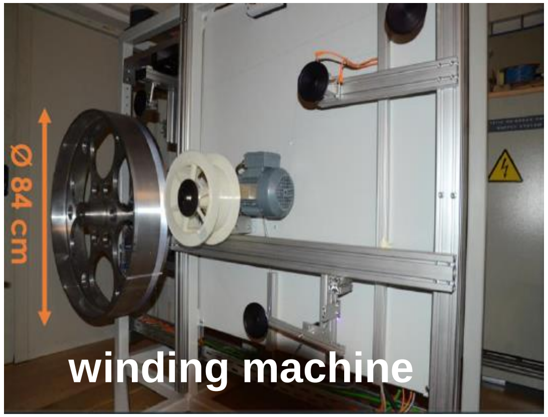
All sub-detectors read out at 40 MHz for software trigger



Replacement of full tracking system

SciFi: progress in fibre understanding & production plans

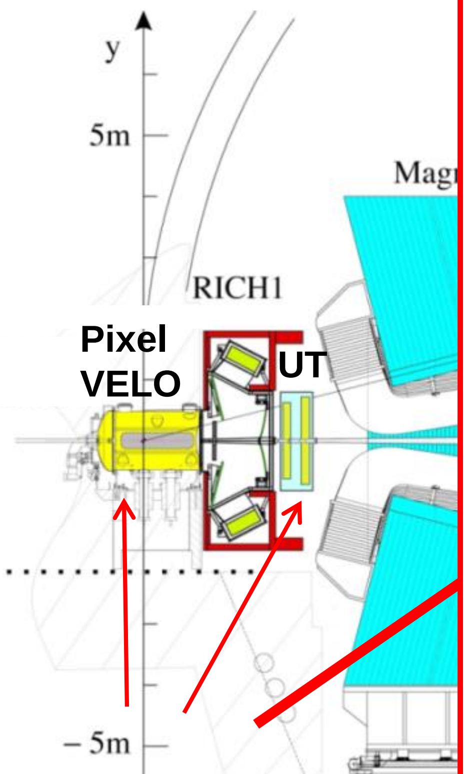




Attenuation length now back to the excellent values that were observed around 2010. Preparation advanced for fibre-mat production in institutes, *i.e.* first winding machine acquired.

Upgrade overview

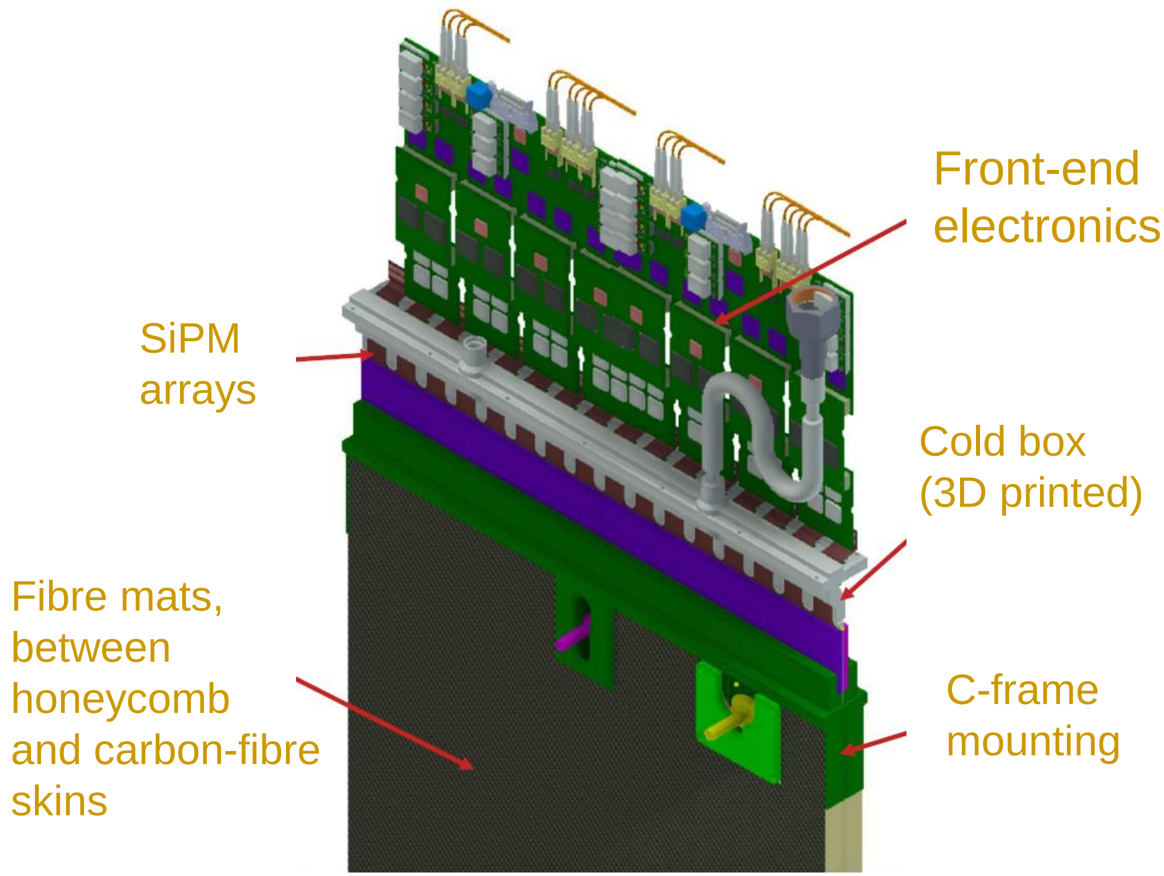
Current detector → up



Replacement of full tracking system

SciFi: progress in mechanics design

Design of read-out box and connection to module.



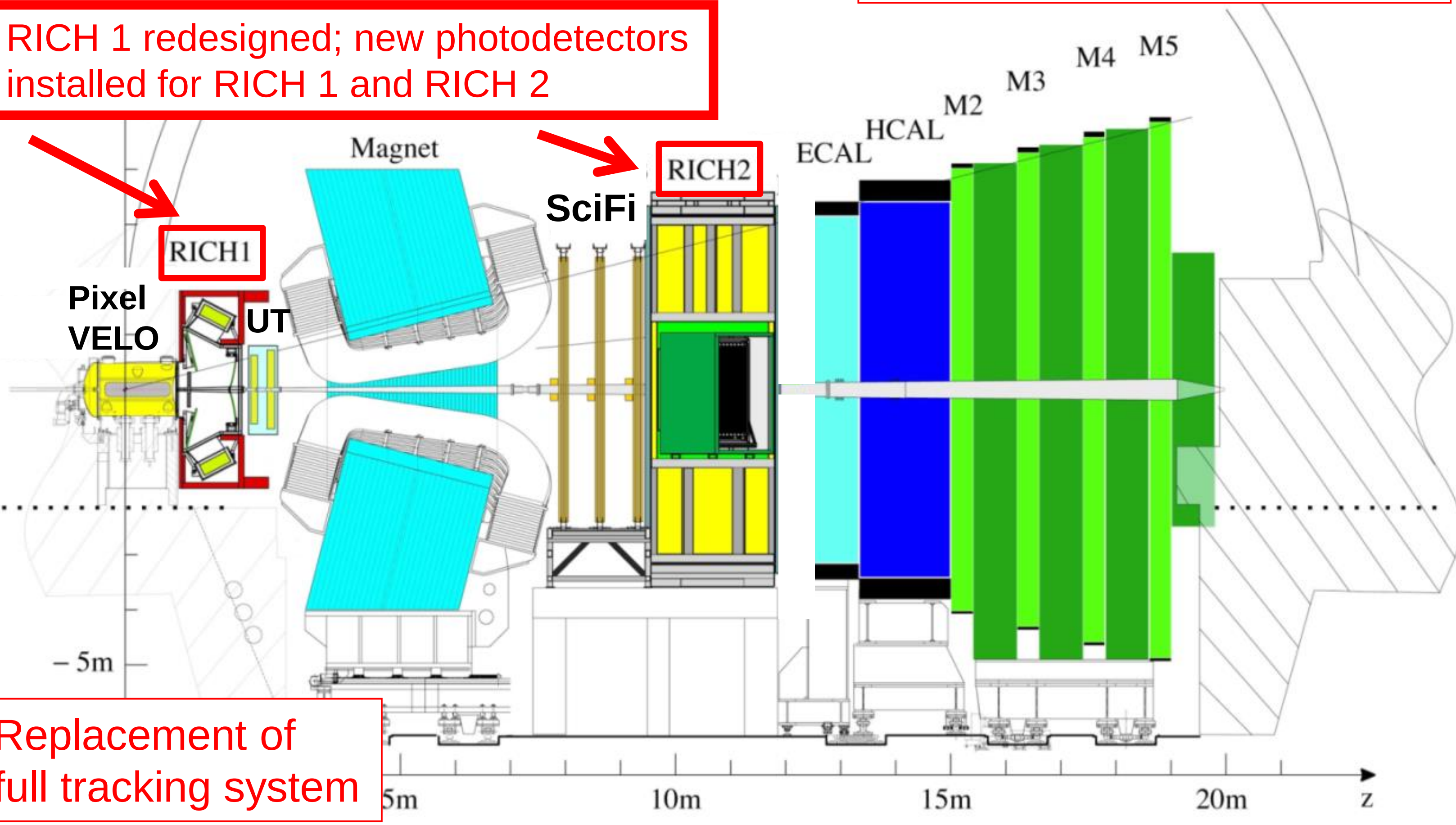
EDR will occur this summer (large prototype being built).

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



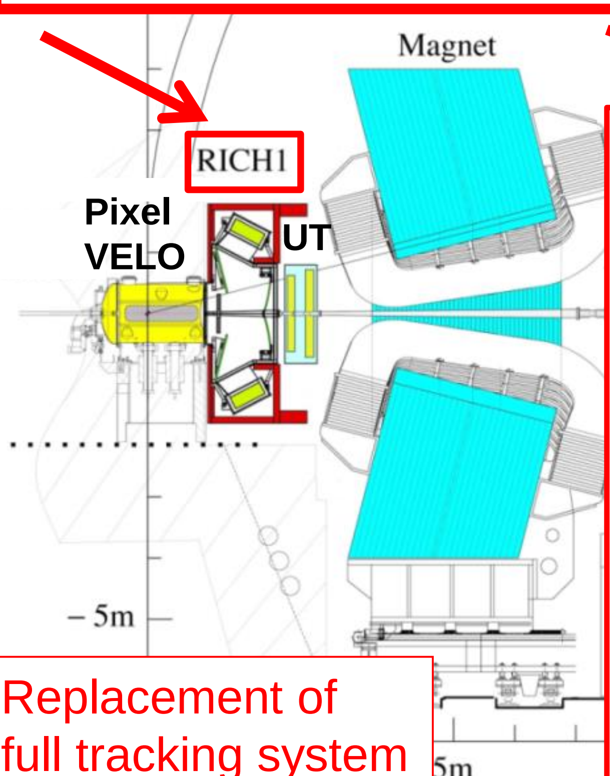
Replacement of full tracking system

Upgrade overview

Current detector → upgraded detector

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

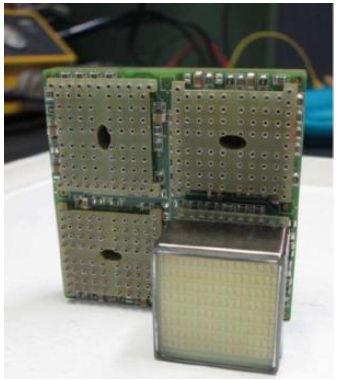
RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



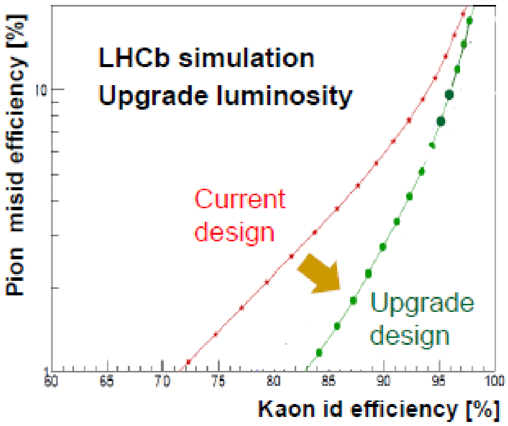
Replacement of full tracking system

RICH system

New photodetector



New RICH-1 optics….



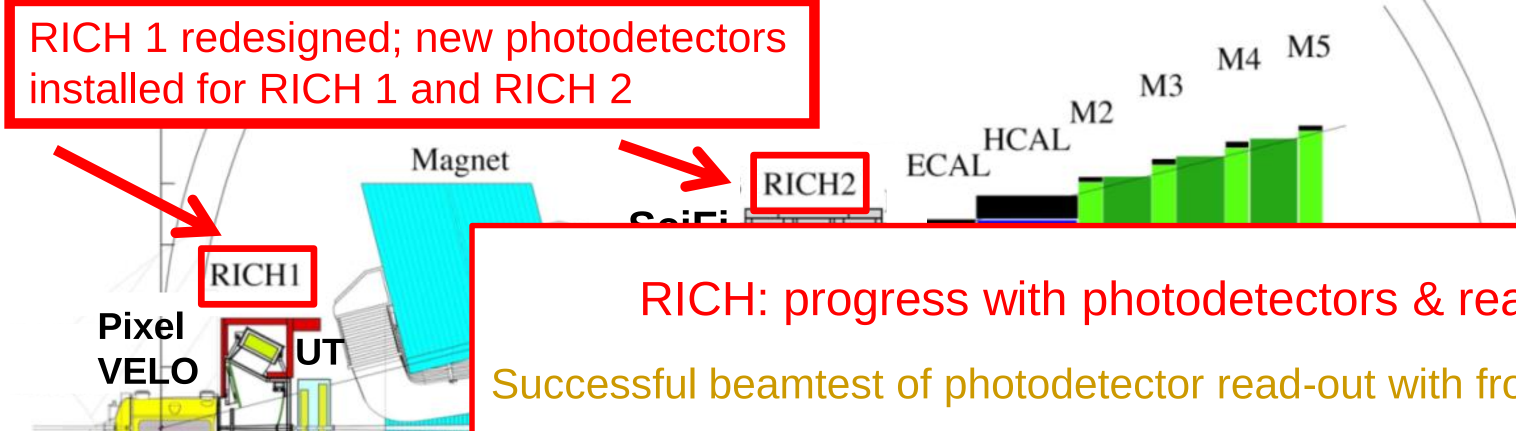
…good performance at high luminosity.

Upgrade overview

Current detector → upgraded detector

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

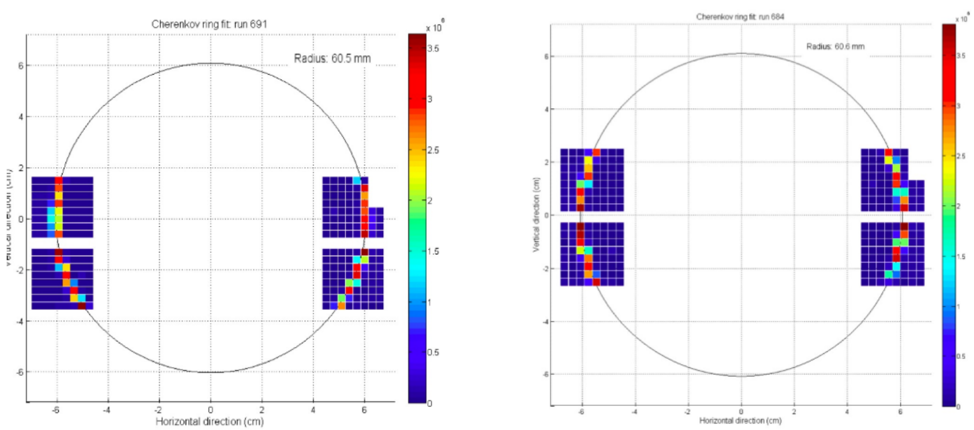
RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2



Replacement of full tracking system

RICH: progress with photodetectors & readout

Successful beamtest of photodetector read-out with frontend ASIC.



Successful EDRs passed for ASIC, FE board & elementary cell.

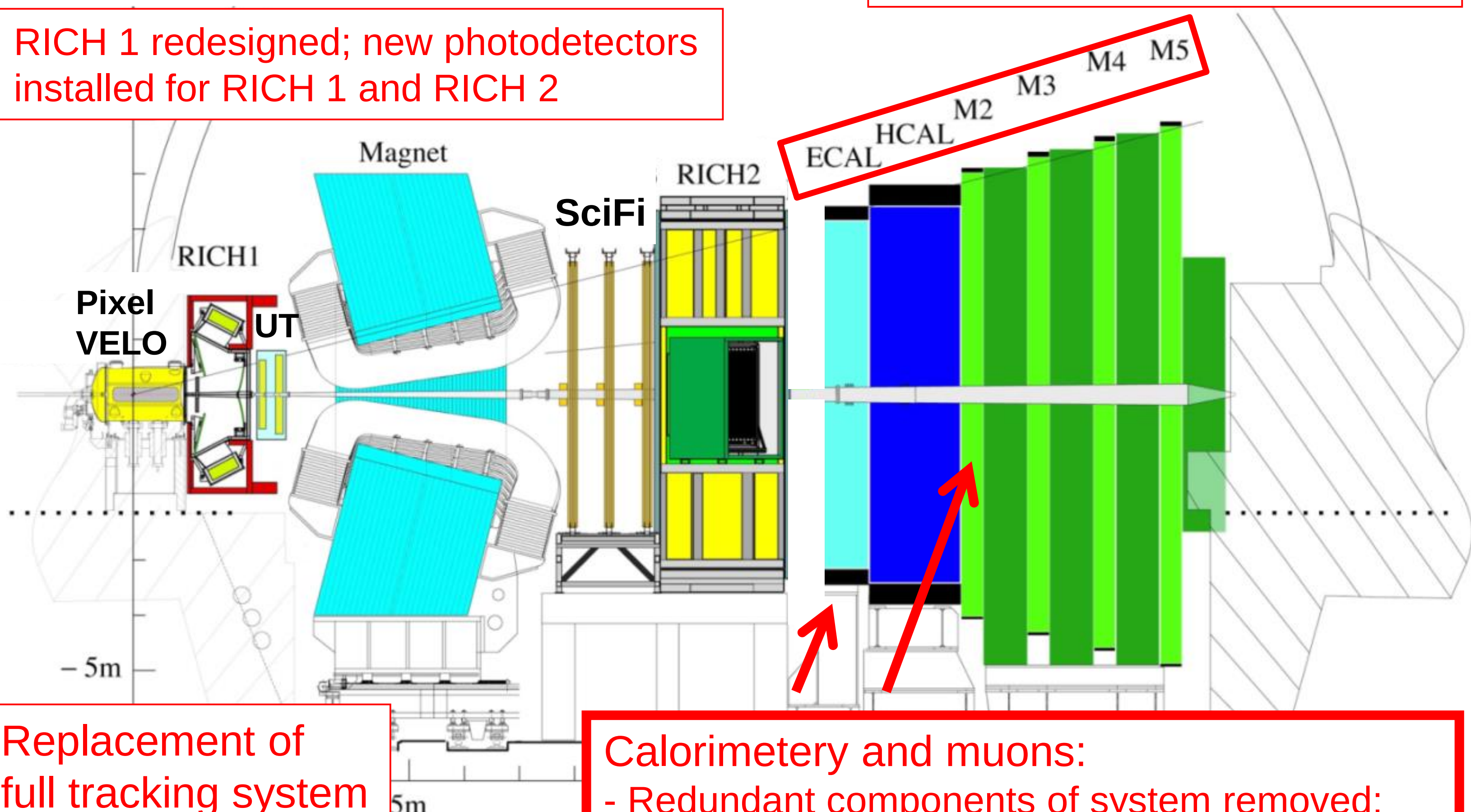
Order of photodetectors will be placed very soon !

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

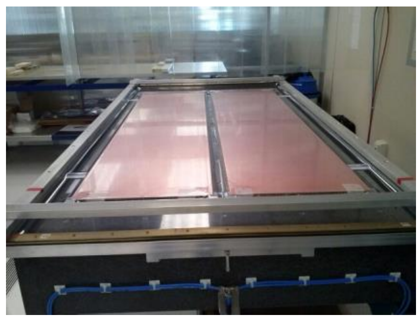
Decision now taken on analogue front-end electronics – we will adopt ASIC solution, & accompanying EDR took place last week.

Design of new front-end board underway.

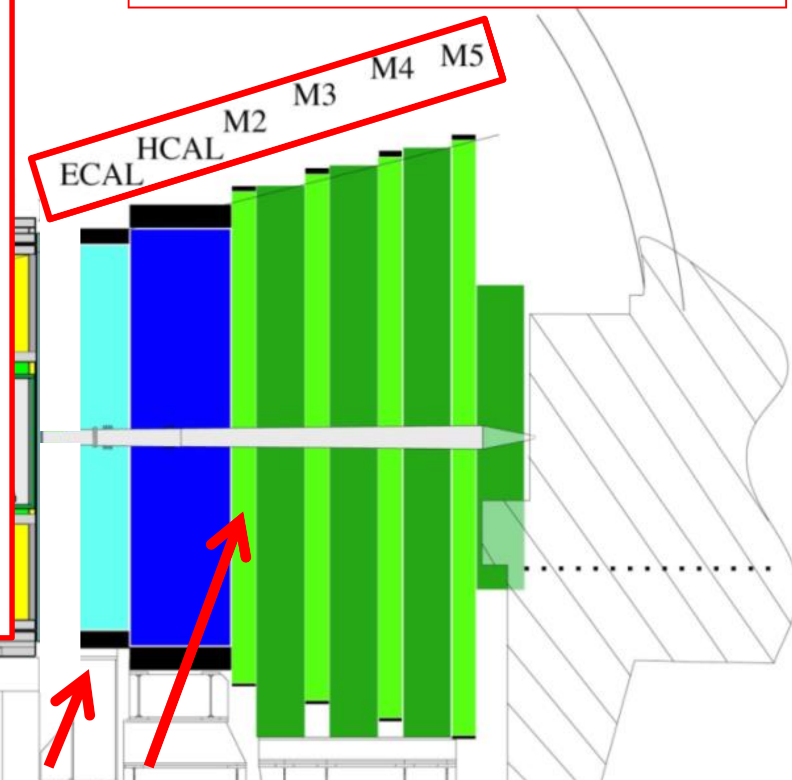
Muon system

Work embarking on spare MWPCs.

Simplified readout design (no need for hardware LLT).



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

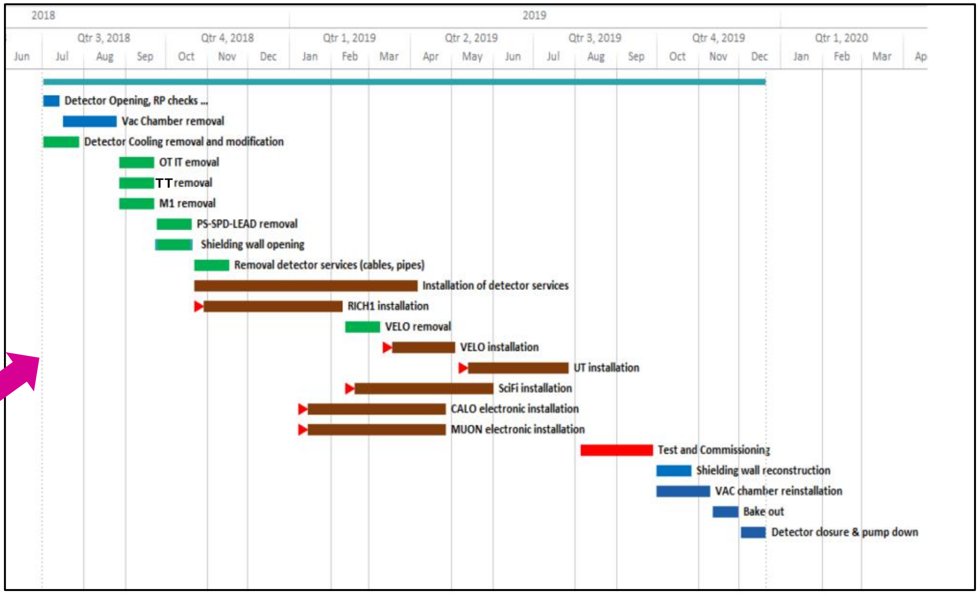
Upgrade – overall status

Exciting progress on all sub-systems.

Work is being tracked by a series of milestones, which will be followed both internally & scrutinised by LHCC. Many important EDRs *etc* over next half-year.

In parallel, important work has begun of evaluating demands on infrastructure (*e.g.* cables, cooling, engineering *etc.*), discussed in workshop involving CERN technical departments.

An LS2 schedule already exists.



Situation with funding is positive:

- for common items ~85%
- for detector ~75%

of funding is already in place (*i.e.* MoU addendum signed, or money committed &/or known to be available). Many thanks to the funding agencies for their support!

Conclusions

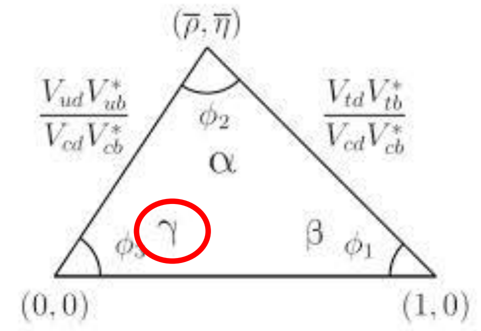
LHCb continues to harvest rich results from run 1
- delivering in core areas
- expanding capabilities to ‘impossible’ measurements
- intriguing hints have emerged that will be further explored with Run-2 data

LHCb ready and fully operational for run 2 – all LS1 activities complete.
Ambitious, but realisable, changes to operation planned
to increase physics output and optimise resources.

Upgrade will deliver huge increase in physics:
- excellent progress on all subsystems
- final R&D, procurement, and construction underway/about to start
- milestones defined to allow progress to be carefully followed

Backups

Mapping the unitarity triangle: world's best measurement of the angle γ

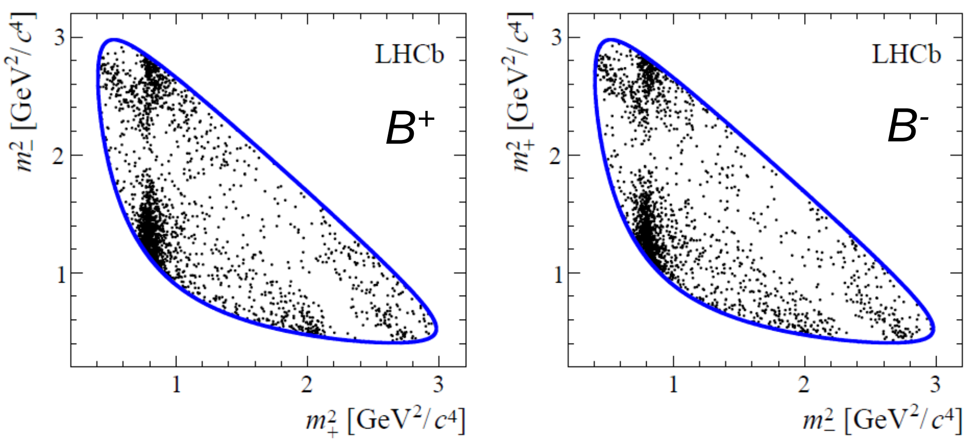


Standard Model description of CP-violation encoded in the unitarity triangle.

One of most important goals of LHCb is a precise measurement of the angle γ, which prior to LHC turn-on was known with a precision of ~30°

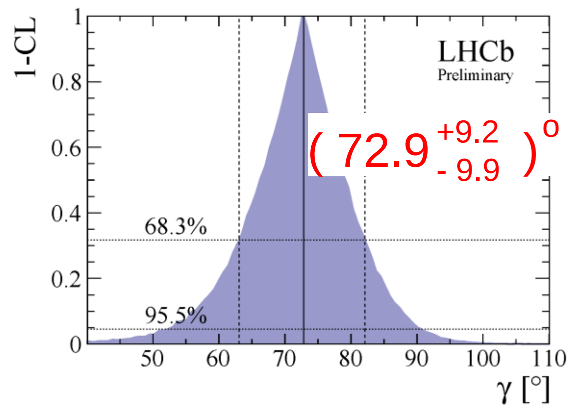
Run-1 $B \rightarrow D(K_S\pi\pi)K$ sample, D Dalitz plots

arXiv:1408.2748; accepted by JHEP



Differences between these distributions related to γ

Combination of all LHCb analyses…

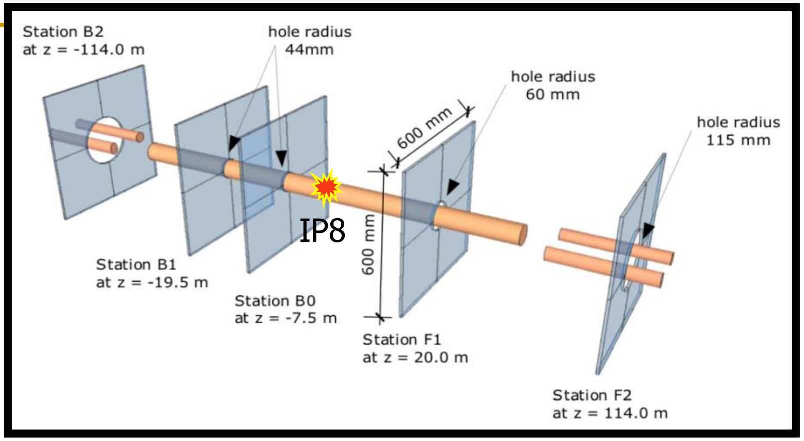


LHCb-CONF-2014-004

…a precision better than the B-factories combined

Still very important run-I results to come.
The goal is to reach 3-4° with run-II data.

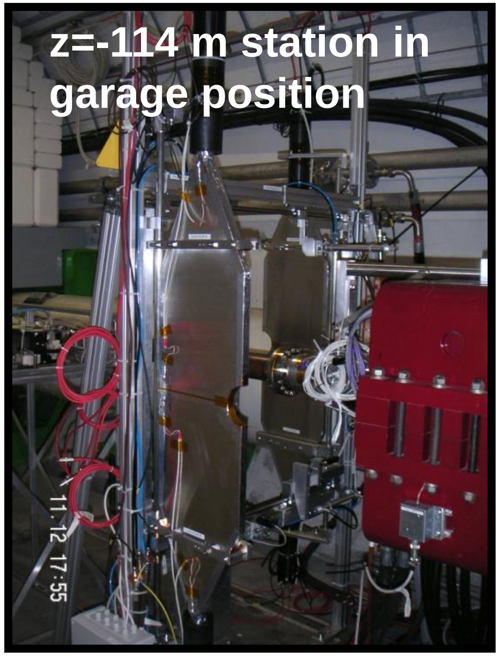
High Rapidity Shower Counters for LHCb – HeRSCheL



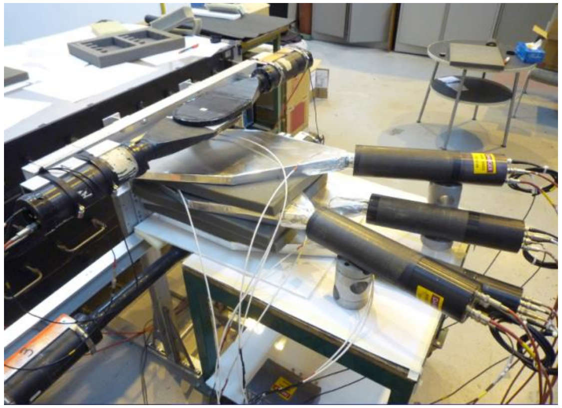
System of forward-shower scintillator planes installed in tunnel up to 114 m away from IP to help in definition of forward rapidity gaps. Main physics motivation is Central Exclusive Production.

Five planes, with phototubes and readout optimised for high rate 25 ns operation.

All stations installed and commissioned



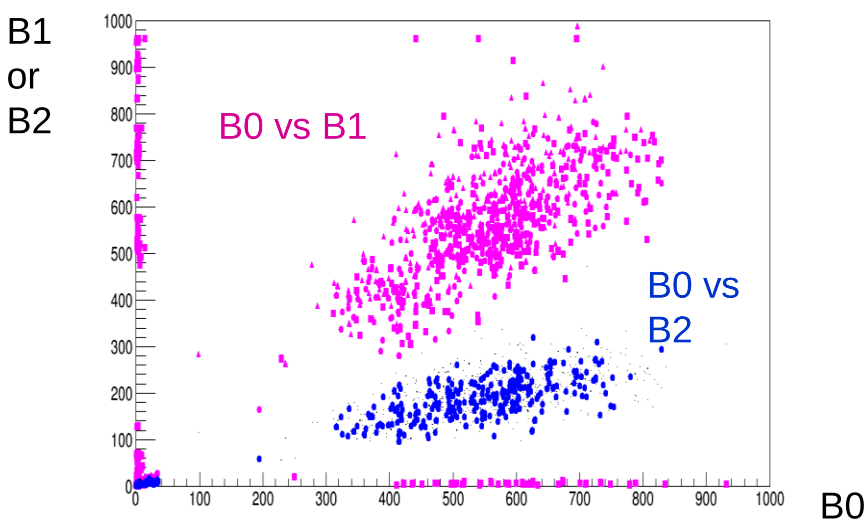
HeRSCheL - early results



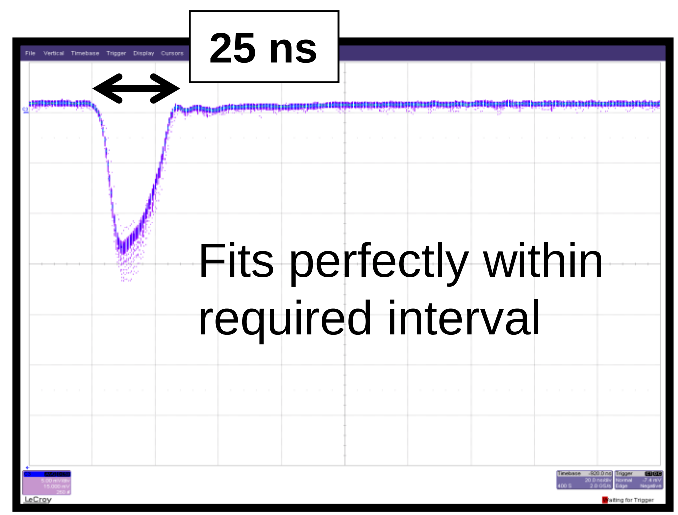
Cosmic calibration campaign shows ~170 p.e.s / MIP

Results from beam muons in tunnel (November ‘TED’ tests)

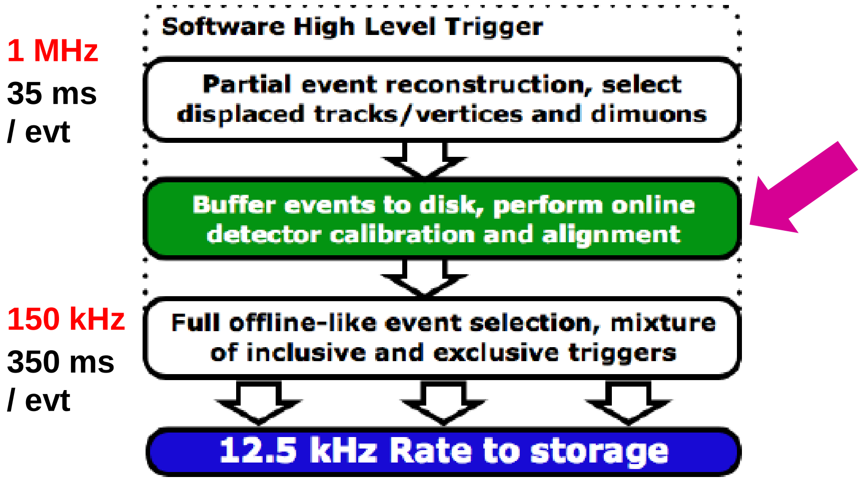
Correlation between stations



Beam pulse from furthest station



Changes for run 2: 'split HLT'

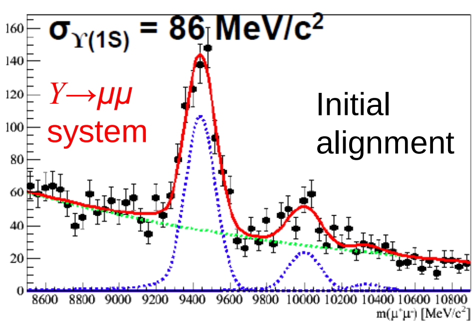


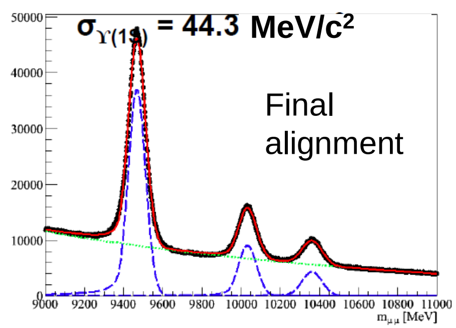
New step in software HLT trigger between the initial and final selections

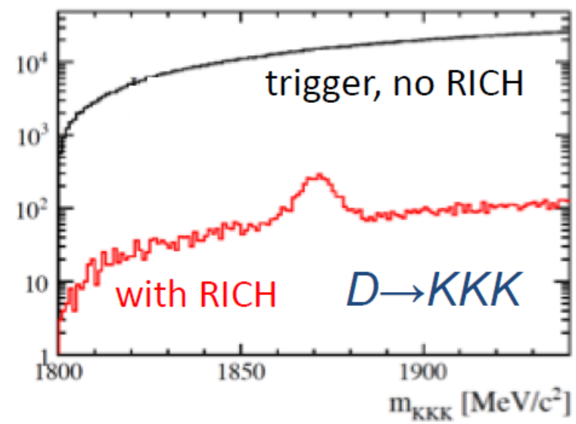
Here the events are written to local disks (~4 PB available) while calibration and alignment is performed.

Only when this is satisfactory is second stage of HLT executed.

This step important, as better alignment provides better signal discrimination. Also means we can trust information we would not use otherwise in HLT (*i.e.* from RICH).



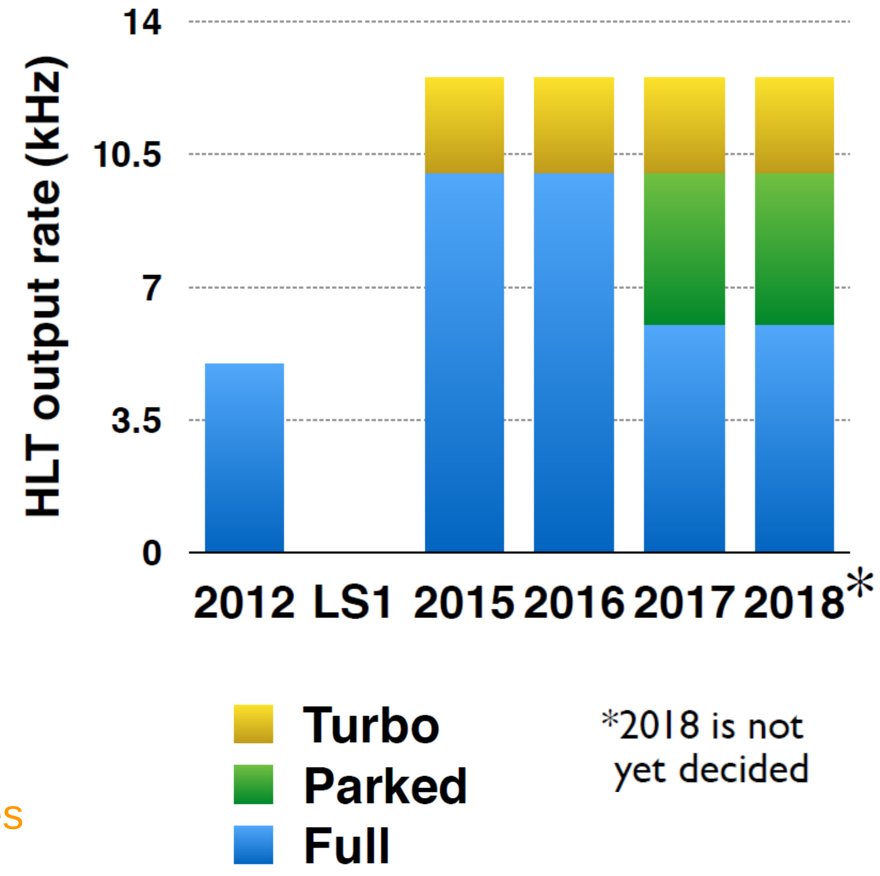




Goal is to improve background rejection, & to do online much of what was traditionally done offline, also reducing demands on GRID.

Changes for run 2: different output rate/stream philosophy

- Increase in overall output rate for conventional 'full' stream (these are the data which go for offline reconstruction on the GRID)
- Deployment of 'turbo' stream
  - HLT reconstruction is now very close to offline quality
  - Therefore why not attempt to use data as reconstructed in HLT directly for analysis (*i.e.* no offline processing) ?
  - We will attempt a proof-of-principle with early 2015 x-section measurements
  - If this works well, it has big consequences for, *e.g.* our Upgrade processing model !



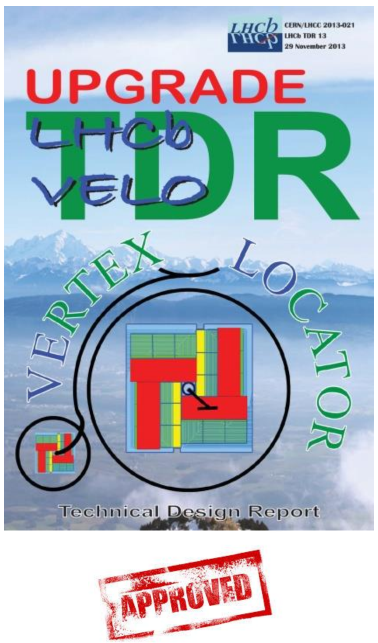
- 'Parked' stream – data that will be reconstructed during LS2

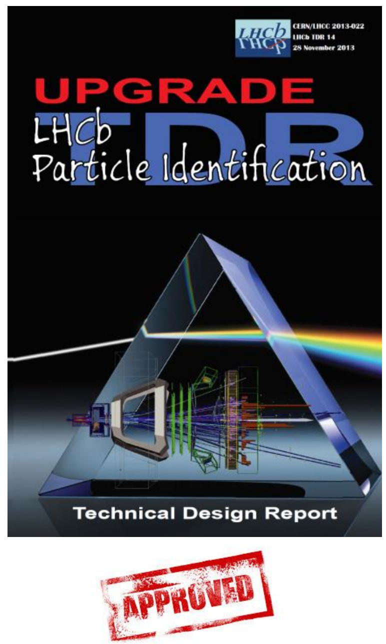
Money Matrix including Common Fund (kCHF)

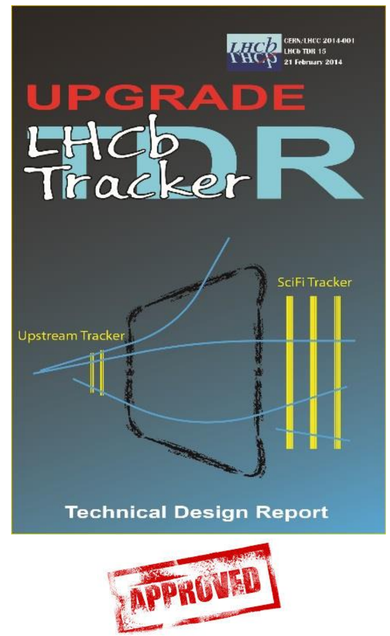
Funding Agency	VELO	UT	SciFi	RICH	CALO	MUON	Readout Boards	Total Detectors	Common Fund	CF & detectors
BRASIL	60		150					210	666	876
CHINA			150					150	175	325
FRANCE			2310		1085		380	3775	1508	5283
GERMANY			3840					3840	912	4752
GERMANY MPG									210	210
IRELAND									35	35
ITALY		480		2000		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*

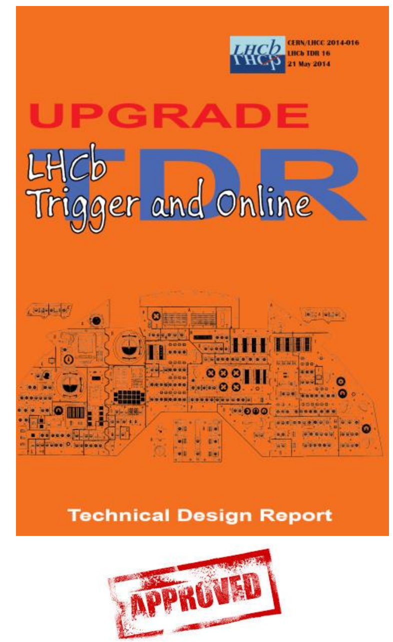
Completion of upgrade TDRs

All* upgrade TDRs have now been approved by the Research Board (the last two since April '14 RRB). We have final & achievable technology choices for all systems.









We have now organised ourselves for the next phase of the programme, *i.e.* final stages of R&D, engineering and production readiness reviews, and production

* Caveat: a computing TDR is foreseen for Q1 2017

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.

Milestones

Milestones of all systems, plotted against time