Status of LHCb and its upgrade

- Collaboration matters
- LHCb YETS and preparation for 2018
- Physics output and selected physics results
- The LHCb upgrade
- Conclusions and outlook

G. Passaleva

INFN – Florence and CERN

On behalf of the LHCb collaboration

RRB – 25/04/2018

Collaboration matters 1/2

- Marie-Hélène Schune (LAL – Orsay – FR) was elected as new Physics Coordinator in June 2017 but unfortunately has had to resign due to personal reasons
  - ★ Election procedure for the new Physics Coordinator ongoing, election foreseen in May
  - ★ Former Physics Coordinator, Vincenzo Vagnoni (INFN – Bologna) and Marie-Hélène's deputy, Marc-Olivier Bettler (Cambridge) are meanwhile coordinating the physics activities.

- LHCb collaboration still growing
  - ★ Four new groups applied for membership since October 2017
  - ★ One group applied to move from associated to full membership
  - ★ Scrutiny ongoing, approvals in June 2018

- A 1st joint workshop between LHCb and BESIII was held on February 8-9, 2018 at IHEP, Beijing.
  - ★ discussed synergies between the two experiments in the field of charm physics,
  - ★ The managements of the two collaborations agreed to pursue regular contact between the collaborations on topics of common interest.

Collaboration matters 2/2

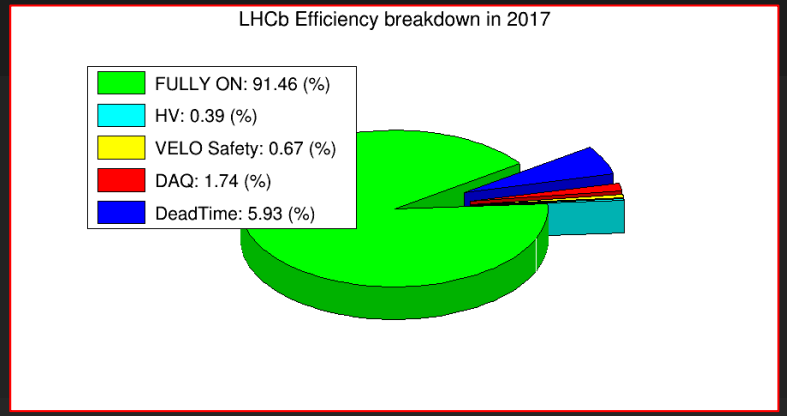
- Double LHCb/Belle II membership protocol
  - ★ forbids new LHCb members engaged in physics analysis to be part of both the LHCb and Belle II collaborations. Ensure scientific independence of the results from LHCb and Belle II.
  - ★ developed in coordination with Belle II, that endorsed a similar protocol
- Introduced the status of Technical Associate
  - ★ allows new groups to contribute to R&D activities on future LHCb upgrades.
  - ★ Technical Associate Members will not have authorship nor access to LHCb data and internal physics results.
- Adopted Guidelines for reviewing high-impact analyses
  - ★ Defines guidelines for high-impact analysis reviews
  - ★ Also encouraged by CERN management

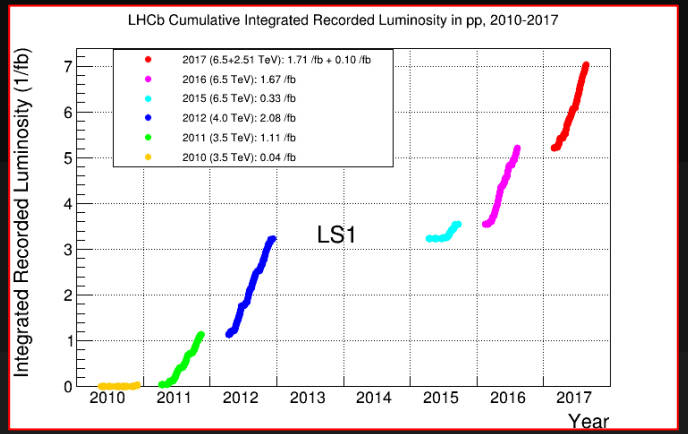
2017 YETS and 2018 LHCb run

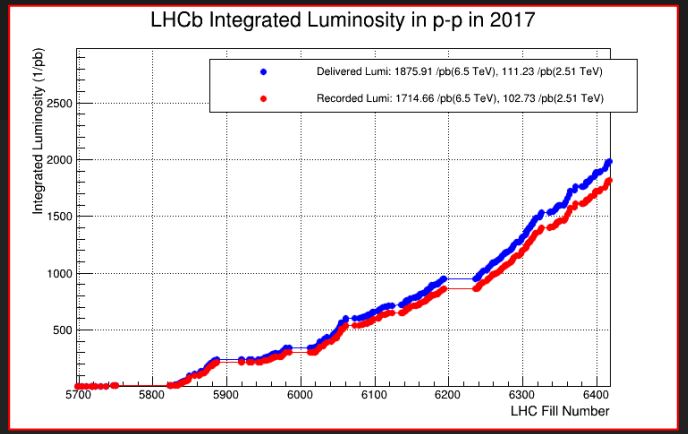
LHCb operations and performance

Detector operations in 2017

- Reached 7 fb^{-1} Run 1 + Run 2
- 1.7 fb^{-1} recorded in 2017, despite the problems in LHC many thanks to the LHC experts for the usual outstanding work!
- The LHCb performance was excellent with a DAQ efficiency close to the maximum







Summary of Year End Technical Stop (YETS)

- YETS activities went through without problems
- Maintenance activity of detectors went as planned
- Many activities on the infrastructure
- Preparation for the upgrade

Work on calorimeters

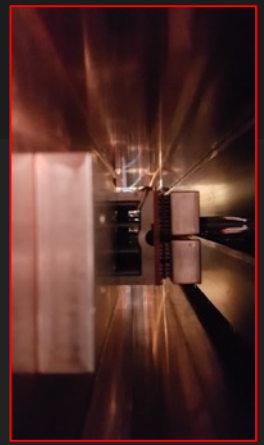
Replacing RICH HPDs

Fixing Muon GEMs

Replacement of 18kV transformers

Preparing for beam pipe “plugs” dismantling

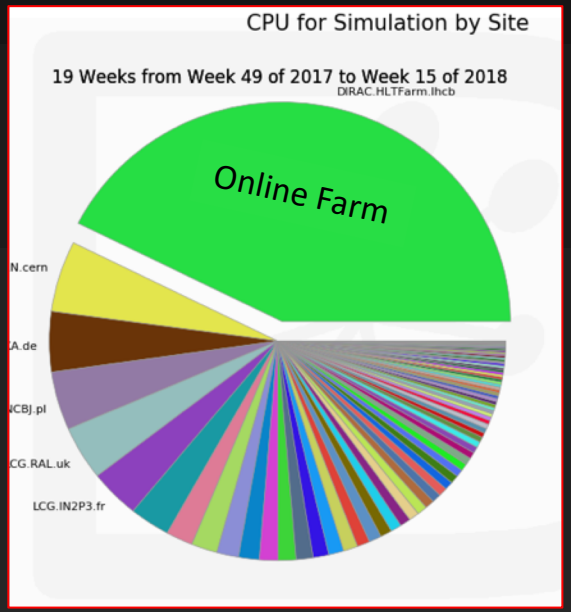
RICH upgrade EC installed in RICH 2



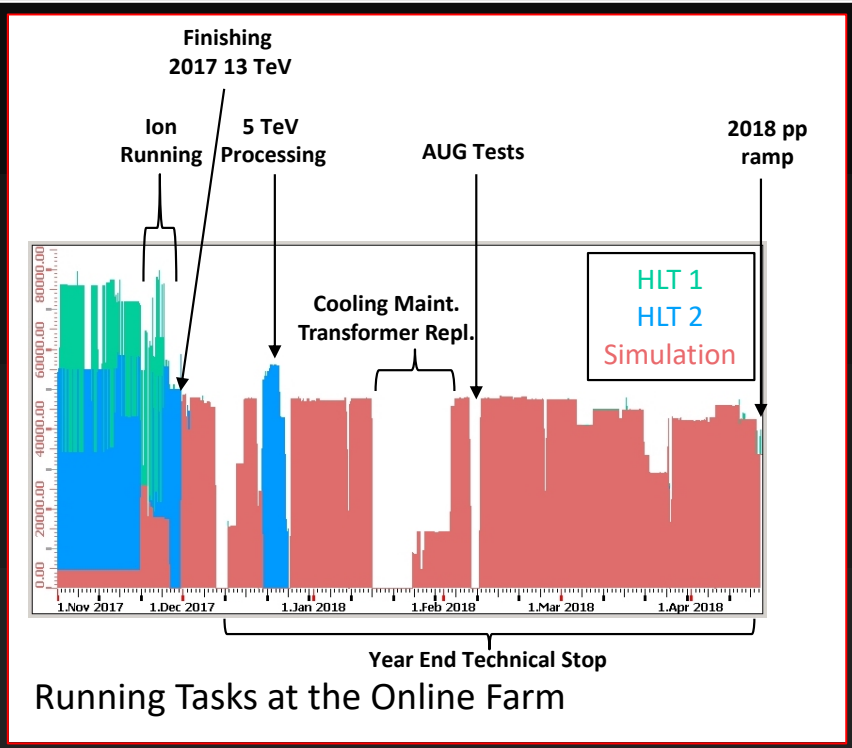
Activity on Outer Tracker

Computing resource usage

- Continued high usage of the online farm resources for simulation workflows
  - ★ Possibility to run simulation in parallel with trigger



Online Farm contributing 40% of CPU time to monte carlo simulation productions



Running Tasks at the Online Farm

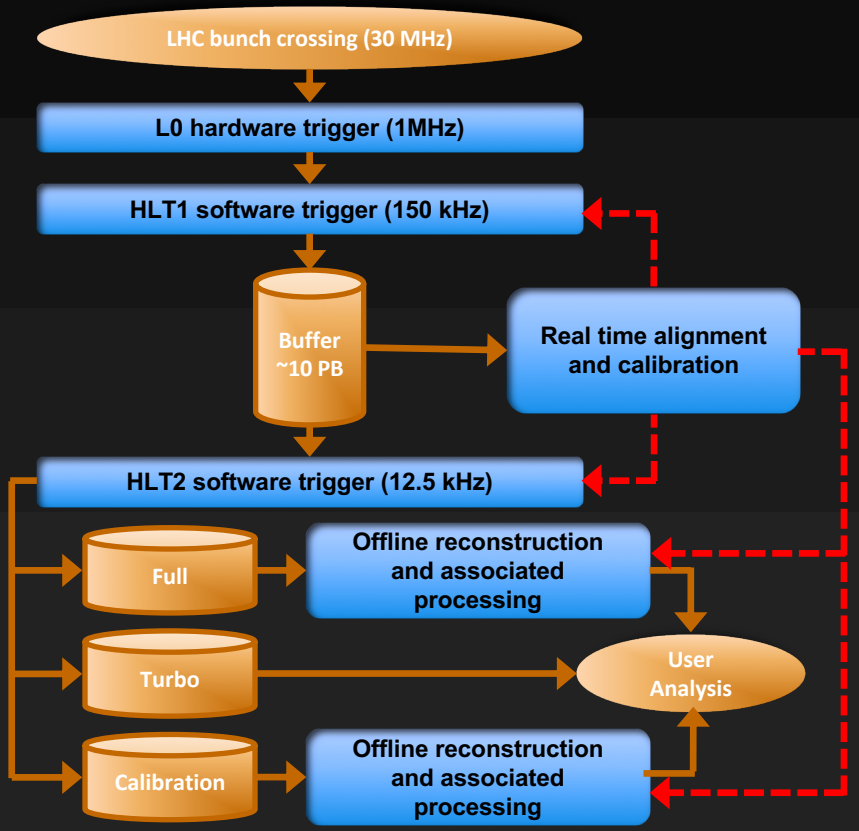
LHCb forecast of computing requests

- Resource increase in 2019 and 2020 generally within «constant funding»
- Part of 2020 resources will be used for the preparation of the upgrade (simulation and system tests)
- Resources for analysis preservation (30kHS06, 0.5PB) and open data access (0.5PB disk) not included

LHCb		2018			2019		2020	
		CRSG	Pledged	Pledged / CRSG	Request	2019 req./ 2018 CRSG	Request	2020 req. / 2018 CRSG
WLCG CPU	Tier-0	88	88	100%	86	98%	98	111%
	Tier-1	253	250	99%	271	107%	328	130%
	Tier-2	141 kHS06	164 kHS06	116%	152 PB	108%	185 PB	131%
	HLT	10	0	0%	10	100%	10	100%
	Sum	492	502	102%	519	105%	621	126%
Others		n/a	0	n/a	10	n/a	10	n/a
Total		**492**	**502**	**102%**	**529**	**108%**	**631**	**128%**
Disk	Tier-0	11.4	11.40	100%	14.1	124%	17.7	155%
	Tier-1	24.5	26.30	107%	27.9	114%	31.4	128%
	Tier-2	5.7	3.7	65%	6.8	119%	8.5	149%
	Total	**41.6**	**41.4**	**100%**	**48.8**	**117%**	**57.6**	**138%**
Tape	Tier-0	33.6	33.60	100%	35	104%	36.1	107%
	Tier-1	45.6	56.90	125%	50.9	112%	55.5	122%
	Total	**79.2**	**90.5**	**114%**	**85.9**	**108%**	**91.6**	**107%**

Run 2018: Run2 strategy

- Buffer all events to disk before running HLT2
- Real-time alignment and calibration procedure before HLT2
- Full offline-like reconstruction in HLT2
- Turbo stream for physics analysis directly on the trigger output



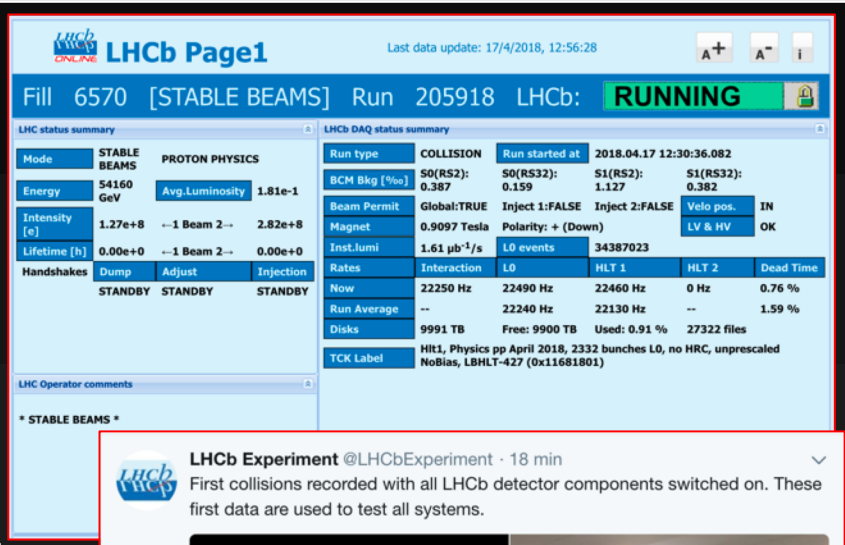
Run 2018: plan for operations

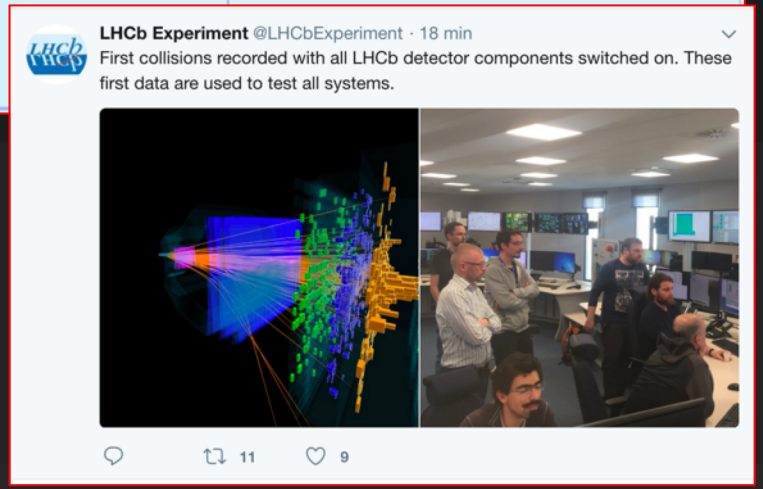
- Last year of running for the current LHCb!

- Stable operation conditions as last year:
- Same reconstruction
- Same alignment and calibration strategy.
  - ★ Some further tuning of the selection
  - ★ Work ongoing to fully automate ECAL π^0 calibration

- Same trigger strategy, aiming at stable running conditions

- Run 2018 is restarting smoothly, we hope to collect as much luminosity as possible!

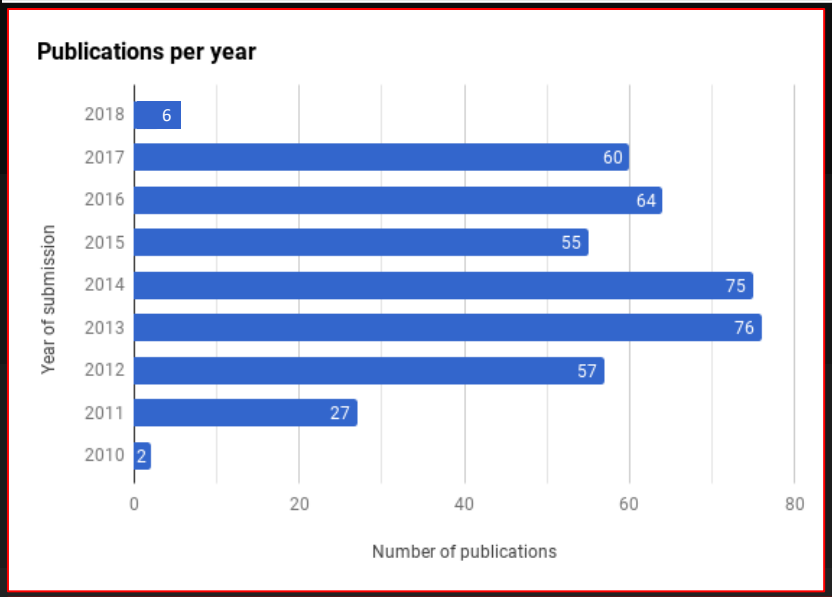




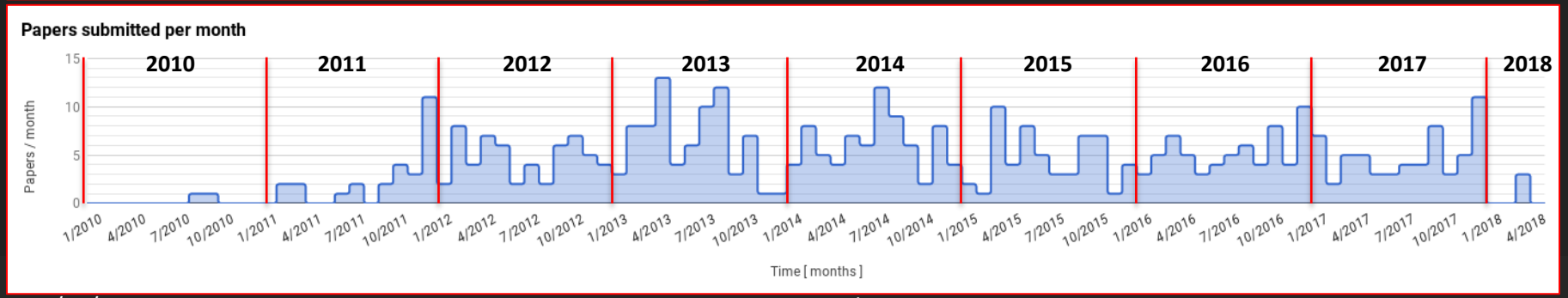
Physics output and selected physics results

Paper production

Physics: paper production



- 422 papers submitted (22 since Oct '17 RRB)
  - ★ 60 in 2017
  - ★ 14 other papers being processed within the Editorial Board
- 40 further analyses under review



Meson oscillations at work

- *Measurement of CP asymmetry in $B^0_s \longrightarrow D^{\mp}_s K^{\pm}$ decays*
- *D^0 - $\overline{D}^0$ mixing*

Measurement of CP asymmetry in $B^0_s \to D^{\mp}_s K^{\pm}$ decays

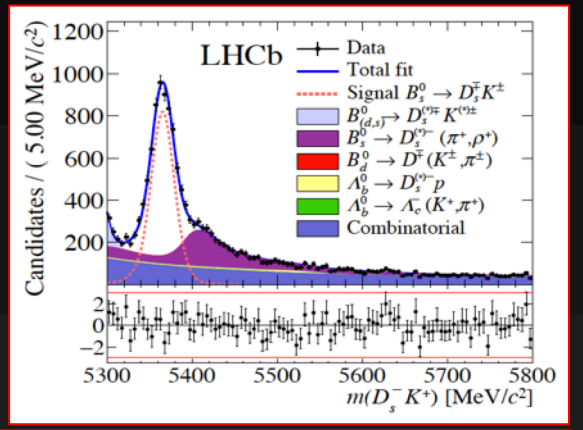
JHEP 03 (2018) 059 **RUN1 3fb^{-1}**

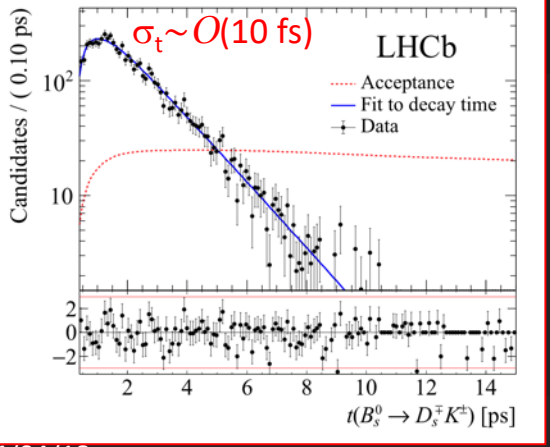
- CP violation arises in the interference between mixing and decay
  - ★ ☞ sensitive to ($\gamma - 2\beta_s$)

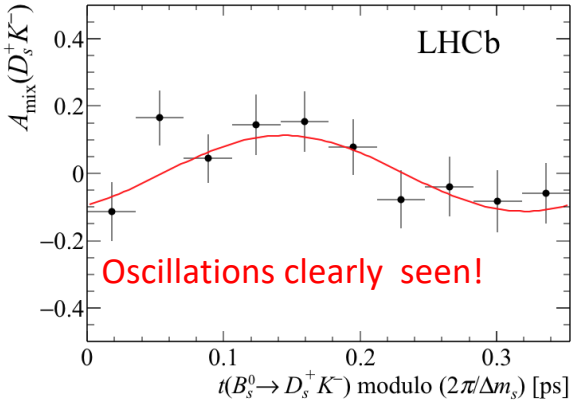
$$\frac{\Gamma(B^0_s(t)\to D_s^- K^+)-\Gamma(\overline{B^0_s}(t)\to D_s^- K^+)}{\Gamma(B^0_s(t)\to D_s^- K^+)+\Gamma(\overline{B^0_s}(t)\to D_s^- K^+)} = \frac{C_f\cos(\Delta m_s t)-S_f\sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2)+A_{\Delta\Gamma_s}\sinh(\Delta\Gamma_s t/2)}$$

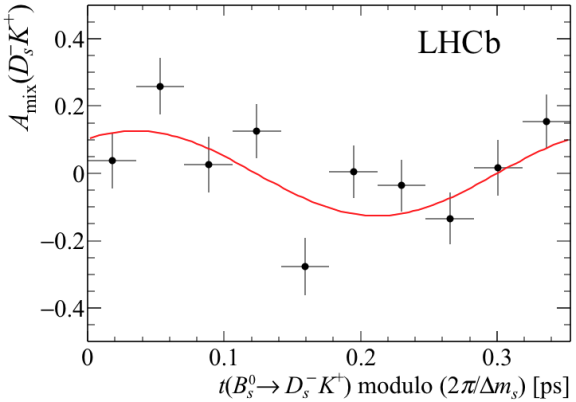
$$C_f = \frac{1-r_{D_sK}{}^2}{1+r_{D_sK}{}^2} \qquad S_f = \frac{2r_{D_sK}\sin(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}{}^2} \qquad A_f^{\Delta\Gamma} = \frac{-2r_{D_sK}\cos(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}{}^2}$$

- $r_{DsK} \sim 0.4$









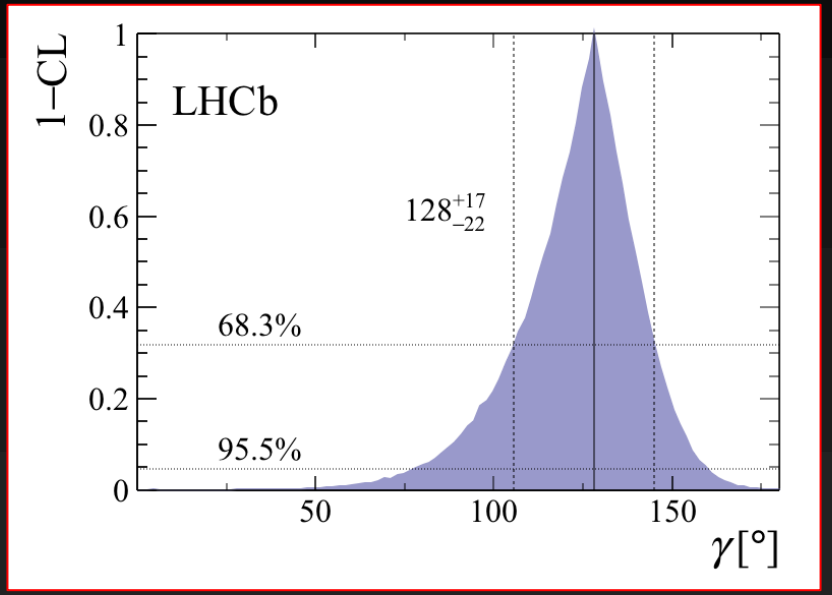
Measurement of CP asymmetry in $B^0_s \to D^{\mp}_s K^{\pm}$ decays

JHEP 03 (2018) 059 **RUN1** **3fb^{-1}**

- Results

$$
\begin{aligned}
C_f &= 0.73 \pm 0.14 \pm 0.05 \\
A_f^{\Delta\Gamma} &= 0.39 \pm 0.28 \pm 0.15 \\
A_{\bar{f}}^{\Delta\Gamma} &= 0.31 \pm 0.28 \pm 0.15 \\
S_f &= -0.52 \pm 0.20 \pm 0.07 \\
S_{\bar{f}} &= -0.49 \pm 0.20 \pm 0.07
\end{aligned}
$$

$$
\begin{aligned}
\gamma &= (128\,^{+17}_{-22})^\circ \\
\delta &= (358\,^{+13}_{-14})^\circ \\
r_{D_sK} &= 0.37\,^{+0.10}_{-0.09}
\end{aligned}
$$



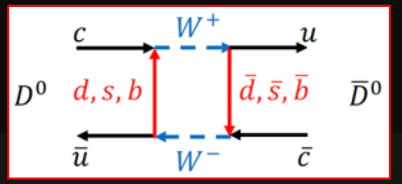
- Evidence for *CP* violation is found at about 3.8σ

- γ measurement not yet competitive, but…
  - ★ ~11° at the end of Run II
  - ★ ~2° at the end of upgrade

D^0 - $\overline{D}^0$ mixing and CP violation with $D^0 \to K^+\pi^-$

Phys. Rev. D 97 (2018) 031101. **RUN1+2 5fb^{-1}**

- Charm is the only up-type quark where we can look for flavor/CP violation

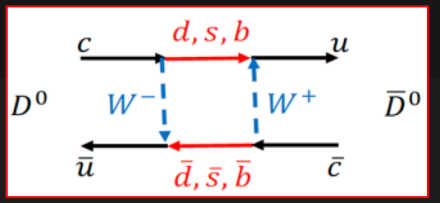


- Mixing can be studied through the interference between different decay amplitudes to the same final states
- The ratio between "wrong" and "right" sign decays depends on decay time *t* if mixing is present

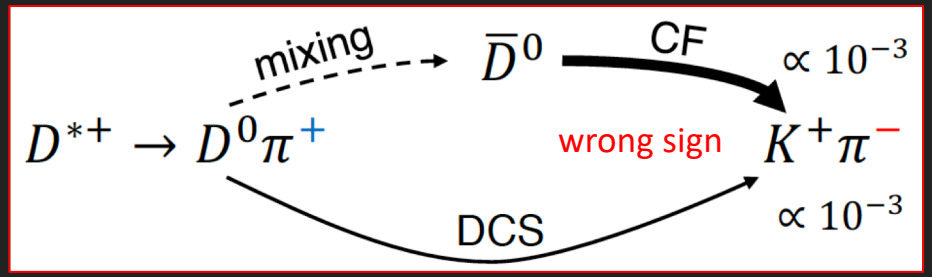
$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}\,y't + \frac{x'^2 + y'^2}{4}t$$

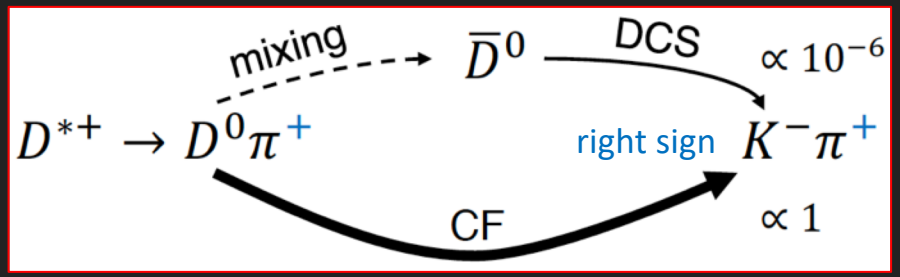
$$y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{\Gamma_H + \Gamma_L}$$

$$x = \frac{\Delta m}{\Gamma} = \frac{m_H - m_L}{(\Gamma_H + \Gamma_L)/2}$$



- R(t) can also be sensitive to CP violation (in that case R(t) is different for D^0 and $\overline{D}^0$

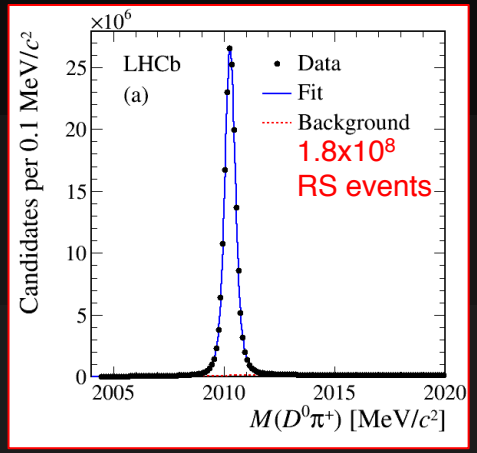


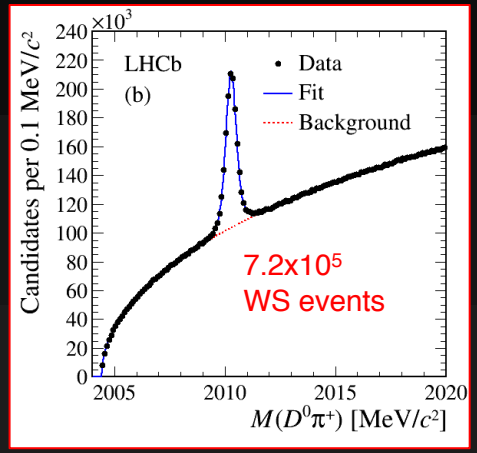


D^0 - $\bar{D}^0$ mixing and CP violation with $D^0 \to K^+\pi^-$

- Results

Phys. Rev. D 97 (2018) 031101. **RUN1+2 5fb^{-1}**





Run 2 signal yields ~ 2 times larger than Run 1

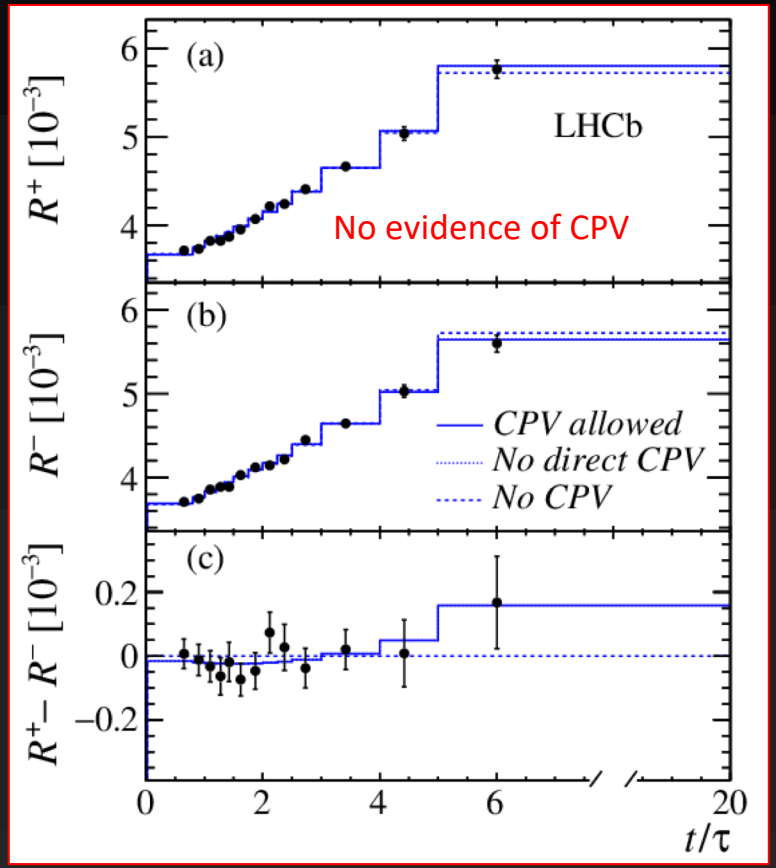
- Assumunig CP conservation:

  $R_D = (3.454 \pm 0.031)\ 10^{-3}$

  $x_0'^2 = (3.9 \pm 2.7)10^{-5}$

  $y_0' = (5.28 \pm 0.52)\ 10^{-3}$

- LHCb dominates the scene
  (other measurements precision ~x10 worst)



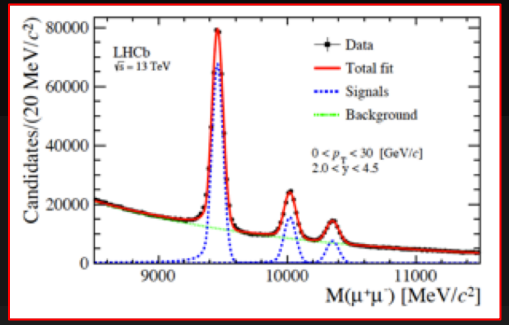
Υ production at $\sqrt{s}$ = 13 TeV

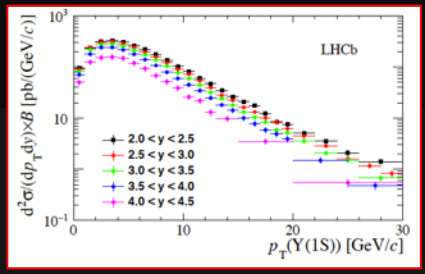
Measuring standard candles

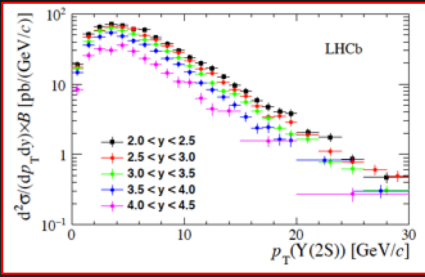
ϒ production at √s = 13 TeV

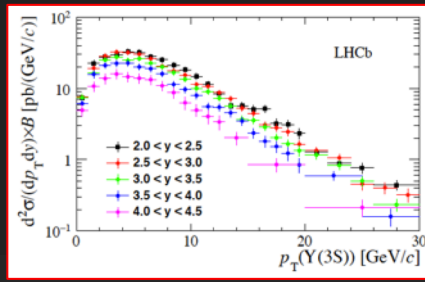
PAPER-2018-002 **RUN2 0.3 fb^{-1}**

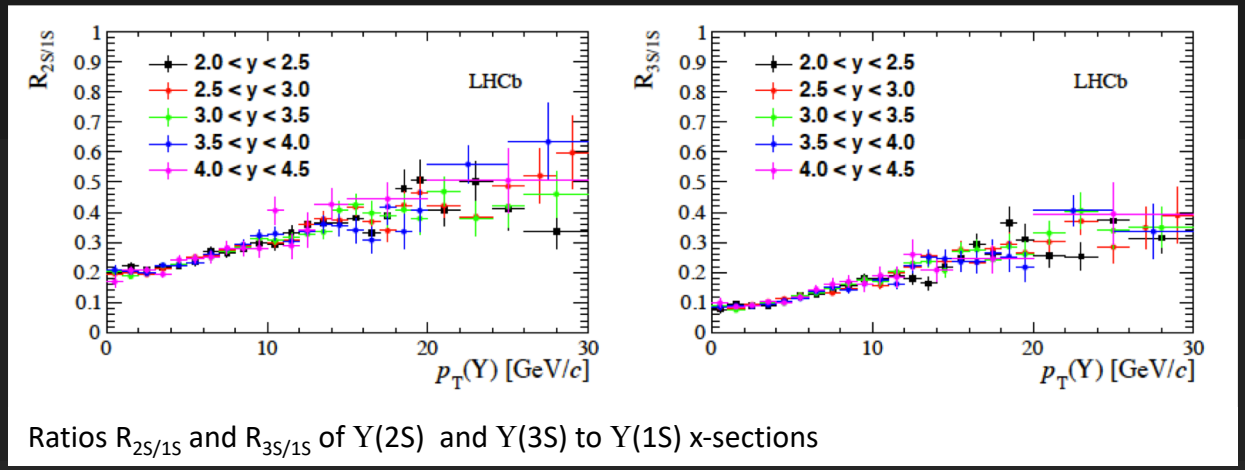
- Measure the double differential production cross-sections in p_T and y over the range $0 < p_T < 30$ GeV/c and $2.0 < y < 4.5$
- Dimuon final states
- Use 277 pb^{-1}, collected in 2015
- About half a million ϒ candidates
- A lot of high precision data.











Ratios $R_{2S/1S}$ and $R_{3S/1S}$ of ϒ(2S) and ϒ(3S) to ϒ(1S) x-sections

top pair production at √s = 13 TeV

High p_T physics in the forward region

top pair production at √s = 13 TeV

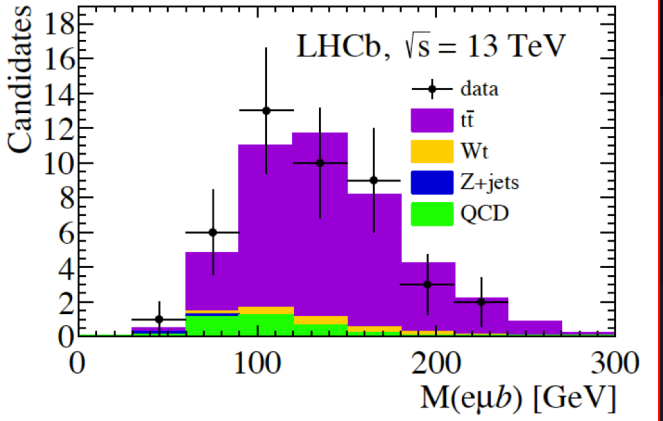
arXiv:1803.05188 **RUN2 2 fb^{-1}**

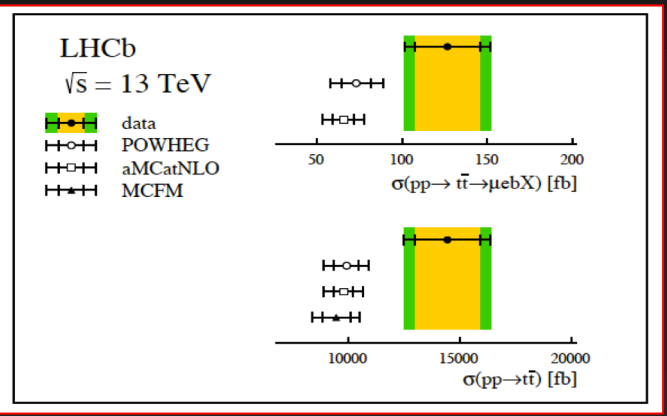
- tt production in LHCb acceptance: sizeable rates of qq and qg scattering, higher than in the central region, in addition to gg fusion
- ☞ Potential interest to study FB production asymmetries

- 1st measurement of top production with Run 2 data
  - ★ use high-momentum electrons, muons and *b*-jets
  - ★ About 87% of selected events correspond to the signal process, highest purity measurement of top physics at LHCb to date

- Still statistically limited, but will not remain so for long

$$\sigma_{t\bar{t}} = 126 \pm 19\,(\text{stat}) \pm 16\,(\text{syst}) \pm 5\,(\text{lumi})\ \text{fb}$$





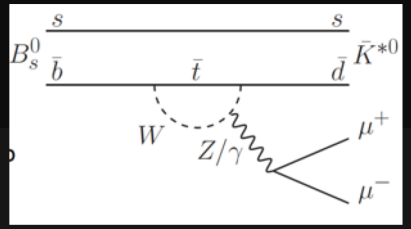
Study of {b,c}$\to${d,u}$\ell^+\ell^-$

The partners of b$\to$s$\ell^+\ell^-$ transitions

Evidence for the decay $B^0_s \to \overline{K}^*(892)^0\mu^+\mu^-$

arXiv:1804.07167 **RUN1+2 4.6fb^{-1}**

- Look to measure the branching fraction of the rare decay
  - ★ Heavily suppressed b → d$\ell\ell$ transition - SM expectation for BR $O(10^{-8})$
  - ★ potential to observe effects of new particles that are comparable to the Standard Model

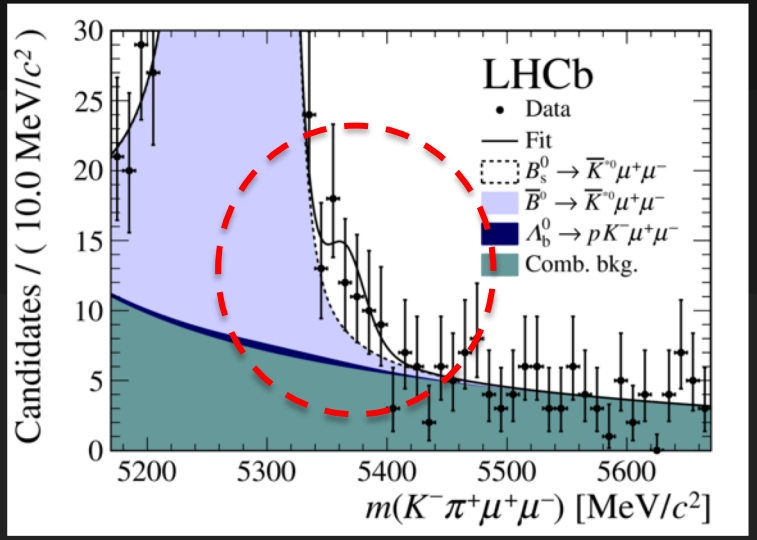


- Could be used with $B^0 \to K^{*0}\mu^+\mu^-$ to get a measurement of V_{td}/V_{ts}

- Counterpart of the b → s$\ell\ell$ transitions
  - ★ ☞setting the ground work for angular analysis and study of LFUV with upgraded LHCb

- Results:

$$\mathcal{B}(B^0_s \to \overline{K}^{*0}\mu^+\mu^-) = [2.9 \pm 1.0\,(\text{stat}) \pm 0.2\,(\text{syst}) \pm 0.3\,(\text{norm})] \times 10^{-8}$$



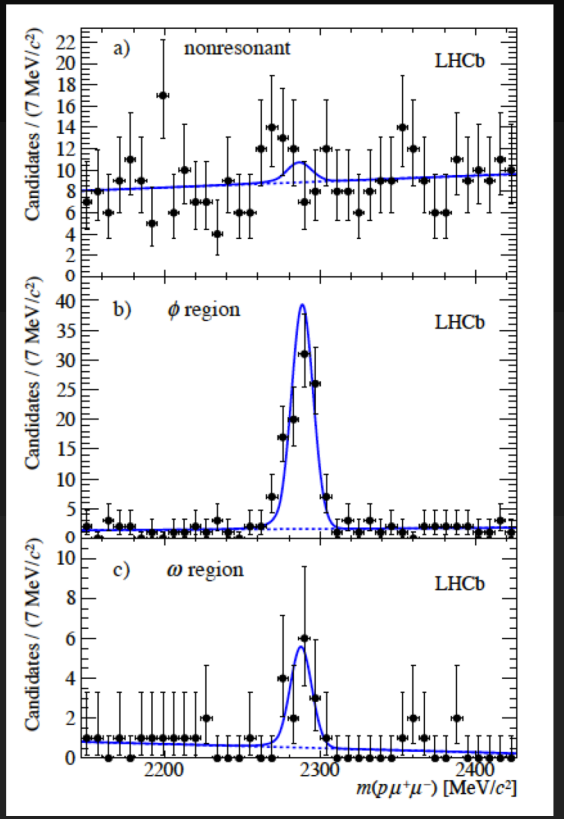
38±12 signal events 3.4σ significance

Search for the rare decay $\Lambda_c \to p\mu\mu$

PAPER-2017-039 **RUN1+2 5fb^{-1}**

- FCNC decay, heavily suppressed in the SM
  - ★ analogue of $b \to s l^+ l^-$ in the charm sector
  - ★ non resonant decay very suppressed in SM, sensitive to new physics
  - ★ decay may occur also through an intermediate resonance decaying into a dimuon pair
- Analysis performed in three regions of dimuon mass: ω, ϕ and non-resonant
- No evidence for the non-resonant component
  - ★ Set an upper limit
  - ★ Improvement of two orders of magnitude with respect to BaBar [PRD 84 (2011) 072006]
- For the first time the signal is seen in the ω region with a statistical significance of 5σ

$$\mathcal{B}(\Lambda_c^+ \to p\omega) = (9.4 \pm 3.2\ (\text{stat}) \pm 1.0\ (\text{syst}) \pm 2.0\ (\text{ext})) \times 10^{-4}$$



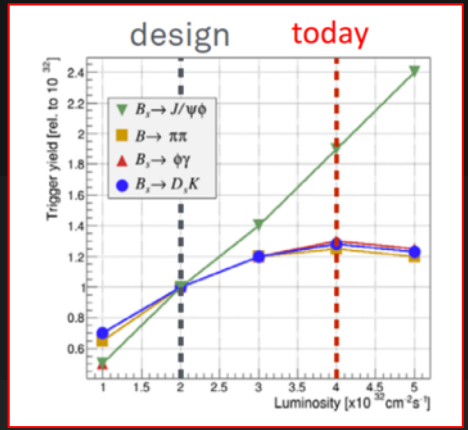
The LHCb upgrade

The LHCb upgrade

- An LHCb Upgrade is scheduled, with installation in 2019-2020 (LHC LS2) and first data-taking in Run 3 (2021-2023). The motivation is to take increased advantage of the huge rate of heavy-flavour production at the LHC.

1. Full software trigger
   - Allows effective operation at higher luminosity
   - Improved efficiency in hadronic modes
2. Raise operational luminosity by factor five to 2 x $10^{33}cm^{-2}s^{-1}$

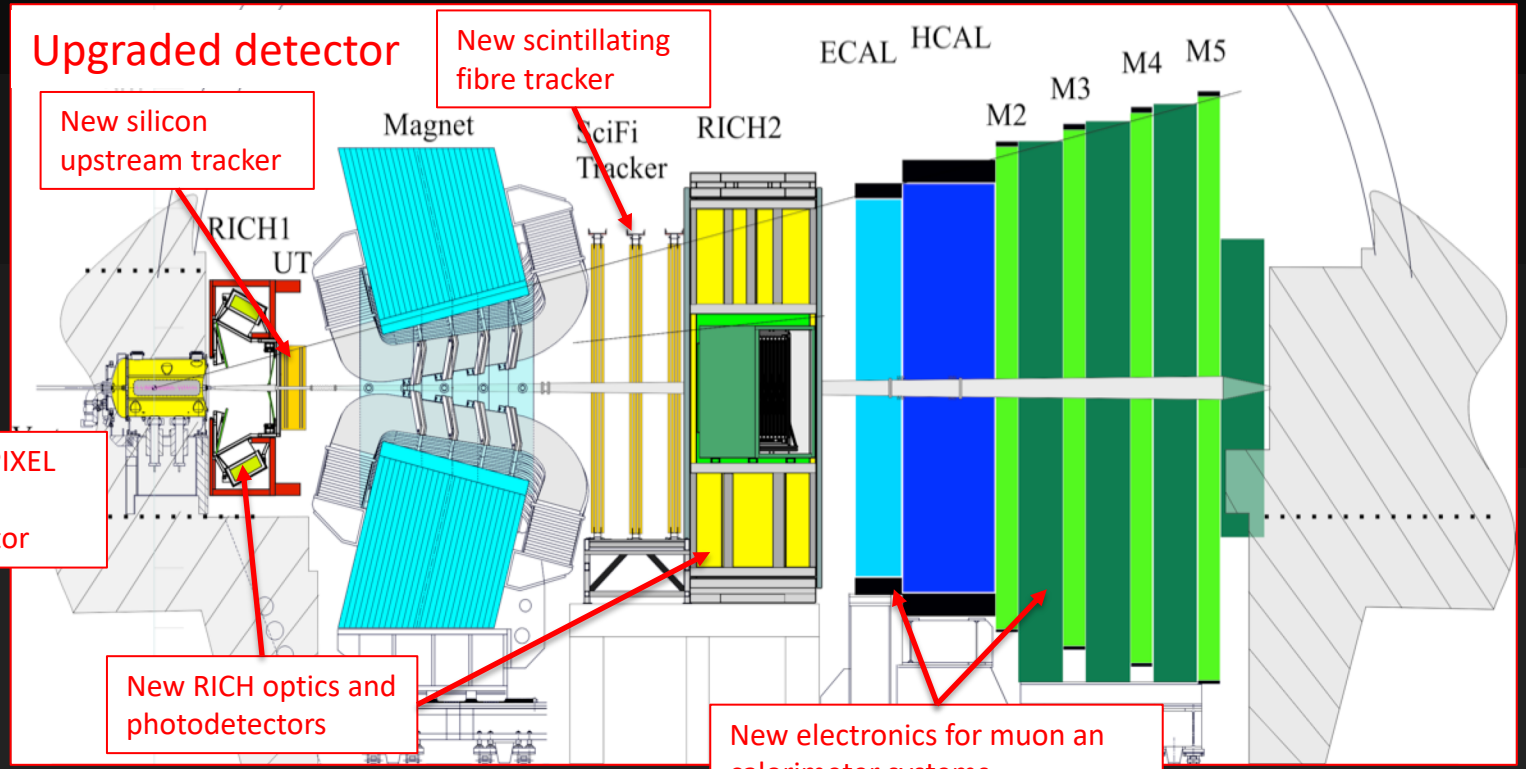
- Necessitates redesign of several sub-detectors and overhaul of readout



- 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')

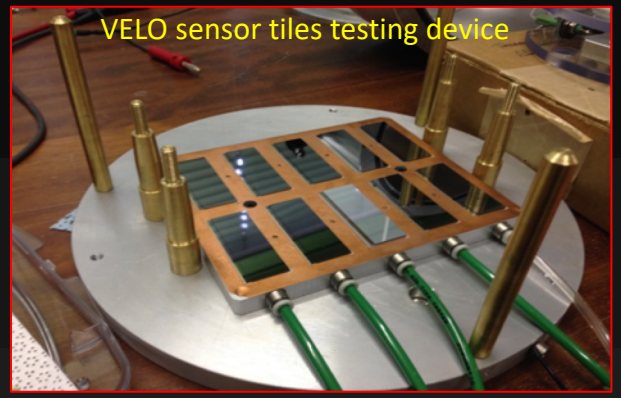
The LHCb upgrade in a snapshot

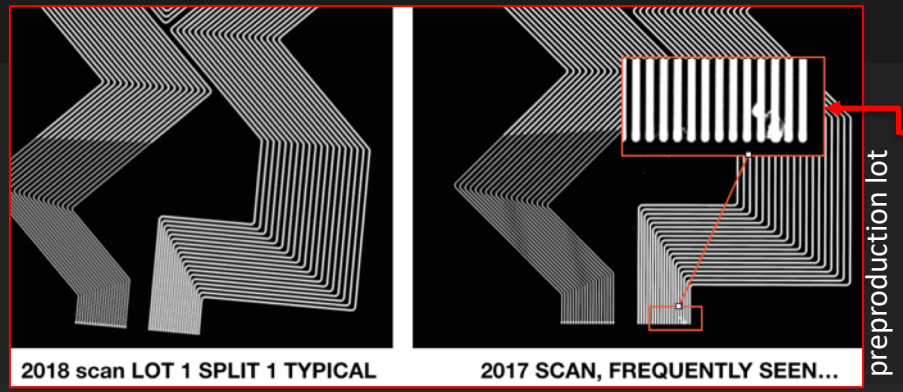
All sub-detectors read out at 40 MHz for a **fully software trigger**



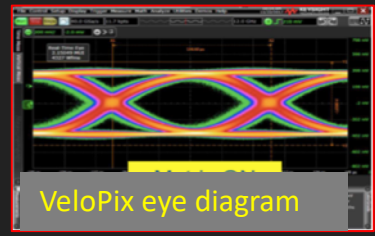
LHCb upgrade: VELO

- VELO project progressing very well
- VeloPix:
  - ★ First wafers received
  - ★ SEL and SEU problems fixed in the last version
  - ★ High rate output signals now OK
  - ★ Wafer tests started: yield ~68%
- Sensors:
  - ★ Sensors must be tested in vacuum: challenging !
  - ★ Test method and setup finalized: start Q&A for production
- Cooling substrate production started, high yield, excellent quality



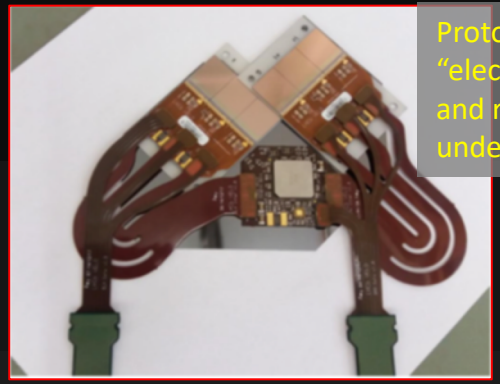


tiny voids seen in preproduction are not present in the production lot

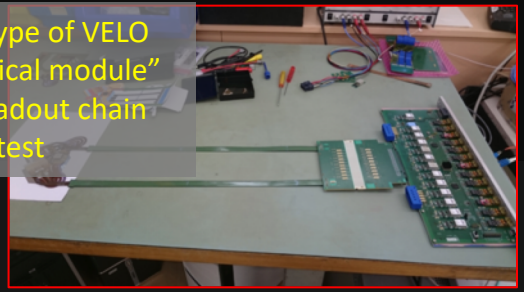


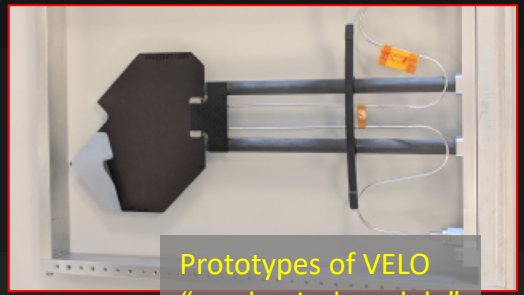
LHCb upgrade: VELO

- Modules and mechanics
- Readout chain:
  - ★ Full “electrical module” ready
  - ★ Tests of the full readout chain ongoing
  - ★ Design of signal cables finalised
- Module mechanics:
  - ★ Finalising the infrastructure preparation of the production: huge work!
  - ★ Gluing is a challenge: large thermal excursions, thermal properties, radiation hardness,… tests ongoing to define the optimal glue and optimal gluing patterns
- Detector mechanics:
  - ★ Very complex structure, many different parts
  - ★ In production
  - ★ Cooling plant and installation infrastructure progressing

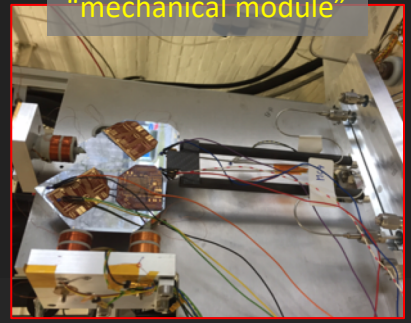


Prototype of VELO “electrical module” and readout chain under test





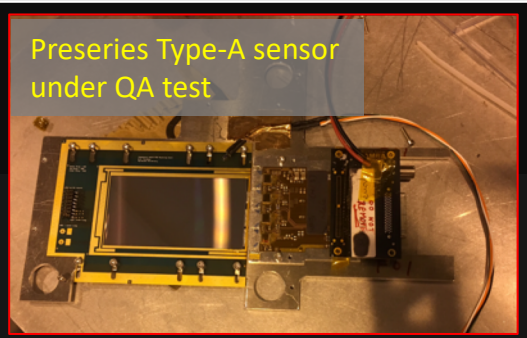
Prototypes of VELO “mechanical module”

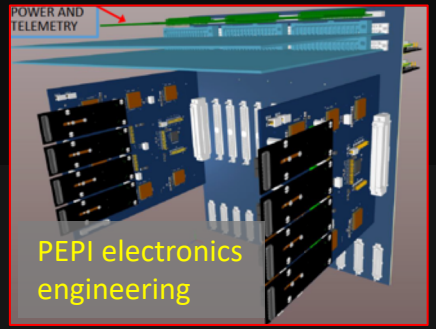


Construction of the “module base”

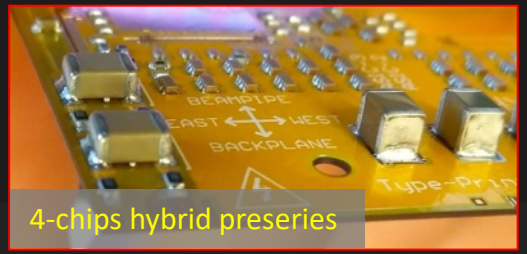
LHCb upgrade: UT

- First 25 “Type A” sensors delivered end of February. QA well advanced, no problems seen
- Tenders for FLEX cables and hybrids ready
- “PEPI” electronics progressing well
- Integration and installation details being worked out
- Integration infrastructure at CERN being prepared

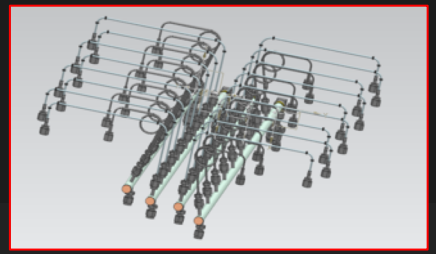

Preseries Type-A sensor under QA test

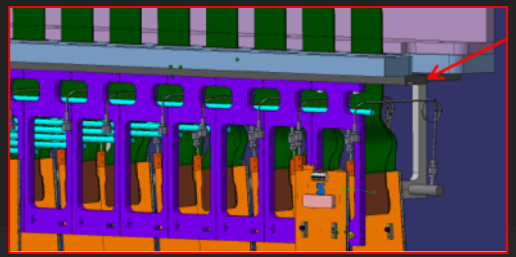


PEPI electronics engineering



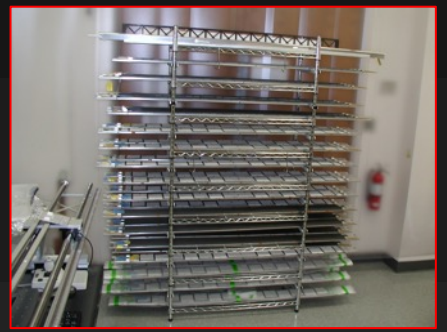
4-chips hybrid preseries


Design of the cooling manifold


Integration of the stave supporting area

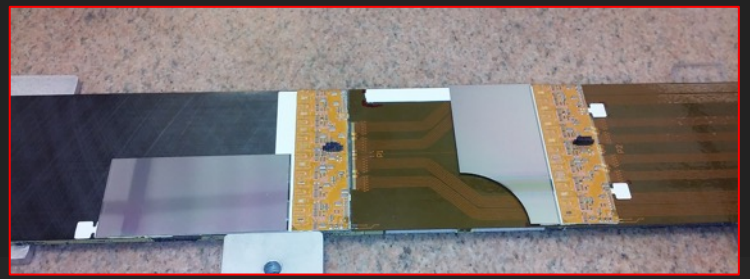
LHCb upgrade: UT

- Bare stave construction is in full swing
- Module construction is being exercised



Bare stave construction activities

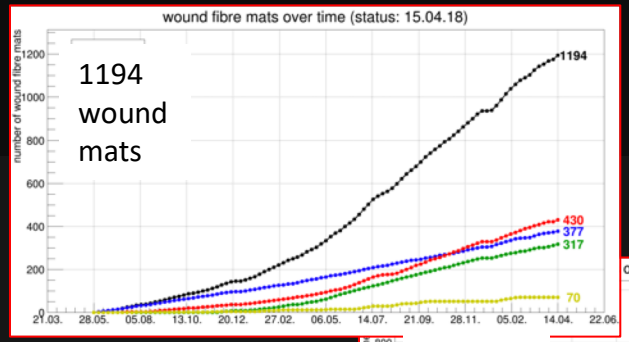
- SALT front-end chip is still delayed and represents a major concern
  - ★ Identified problems in the analog front-end in the latest version
  - ★ A new version reworked by the manufacturer, being tested now



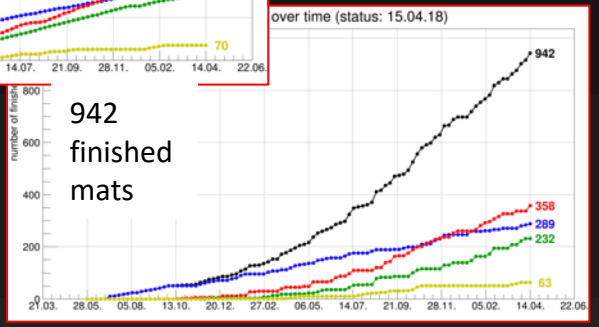
Test of UT module assembly

LHCb upgrade: SciFi

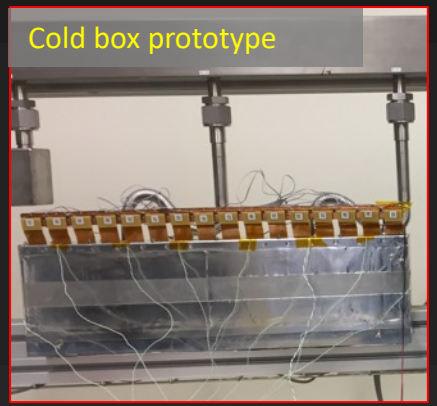
- 12000 km of fibers delivered !
- Fibre mat production almost completed (1024 needed)
- Module production progressing according to schedule
- First batch of 1000 flex cables with SiPMs delivered
- First wafers of FE-ASIC (PACIFIC 5) being received and sent
  for packaging
- Orders for readout electronics being placed
- Production of cold boxes started

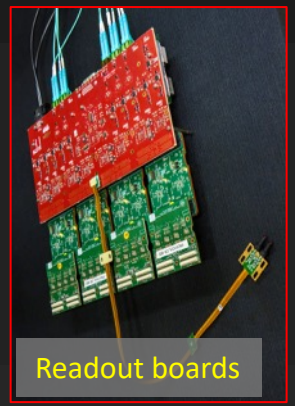


1194 wound mats

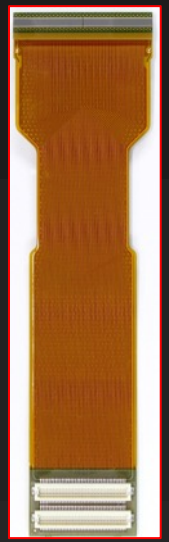


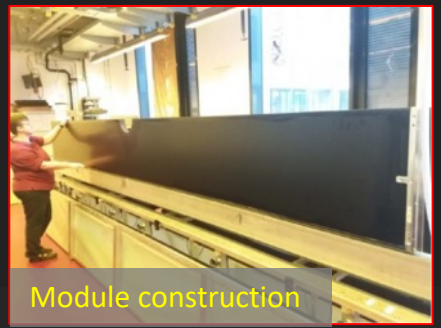
942 finished mats

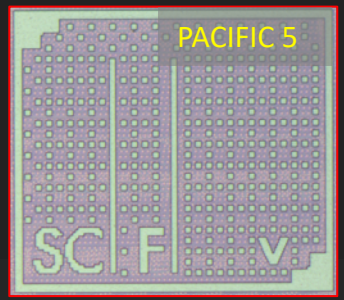




Flex cable with SiPM array







LHCb upgrade: SciFi

- Design of C-Frames and preparation for assembly progressing
  - ★ First prototyoe in construction
- Assembly structure built at CERN
- Preparation of buildings for installation in the pit ongoing
- Modules keep arriving at CERN and stored in an assembly hall

C-Frame prototype top beam

Assembly, transportation and installation tool

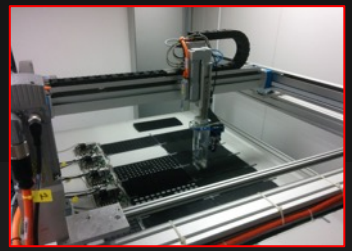
Cutting SX8 walls to allow SciFi access

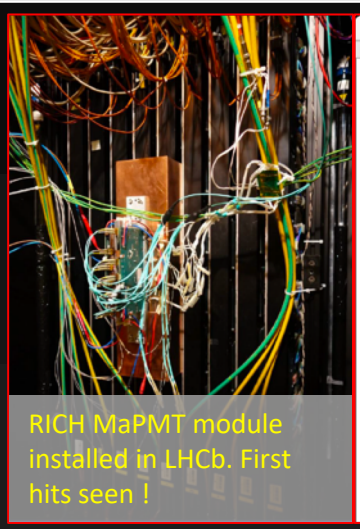
SciFi module boxes at P8

LHCb upgrade: RICH, Muon, Calorimeters

- RICH
  - ★ Over 80% of MaPMT production already received and QA certified.
  - ★ 20k of the 35k CLAROs have been tested (32k needed)
  - ★ Decision on Digital Board FPGA taken (was waiting for radiation tests)
  - ★ All mechanics milestones achieved! Go full steam to finalise construction and to installation
  - ★ A module with MaPMTs installed in LHCb: first light seen!
- Muon
  - ★ Tender for nSync/nODE about to be launched
  - ★ PRR for nSB/nPDM mid May, tender starts straight after
  - ★ Full electronics production completed by end 2018.
- Calorimeters
  - ★ Analog chip: production completed by Nov 2017, tests ongoing
  - ★ "All-electronics PRR" held in February 2018. Production ready to be launched

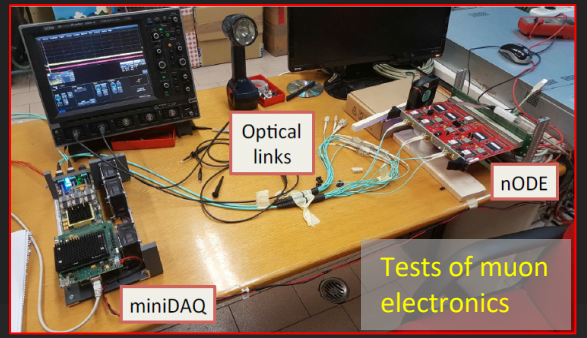
Robotised QA of ICECAL chips





RICH MaPMT module installed in LHCb. First hits seen !

Tests of calorimeter electronics

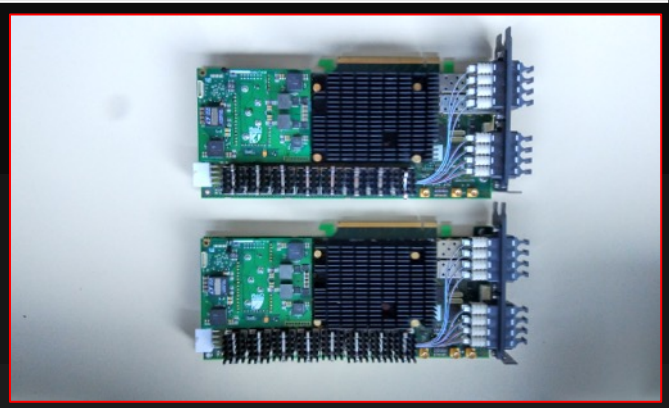


Tests of muon electronics

LHCb upgrade: Online and computing

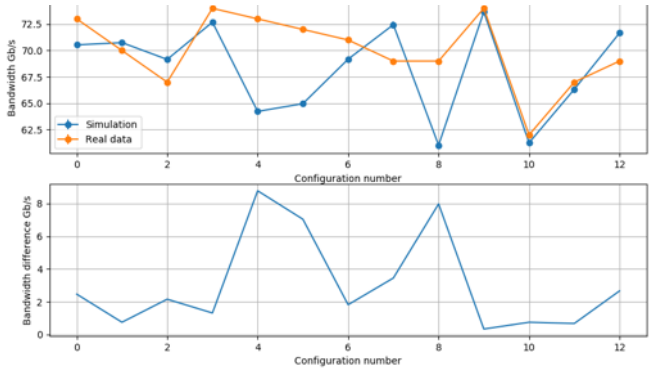
- PCIe40
  - ★ Tender for PCIe40 boards completed and order placed
  - ★ PCIe40 production of 1st batch of 24 progressing as expected.

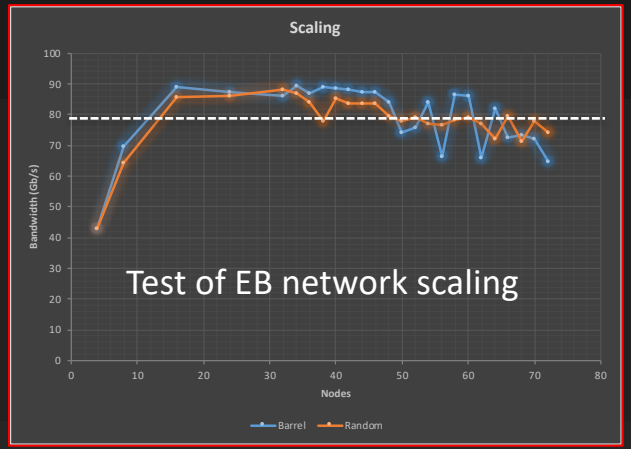
- Scaling of event builder network still under test
  - ★ Simulation is nicely reproducing data
  - ★ Will be very helpful to understand problems and bottlenecks



PCIe40 boards – preseries production

Event builder detwork simulation

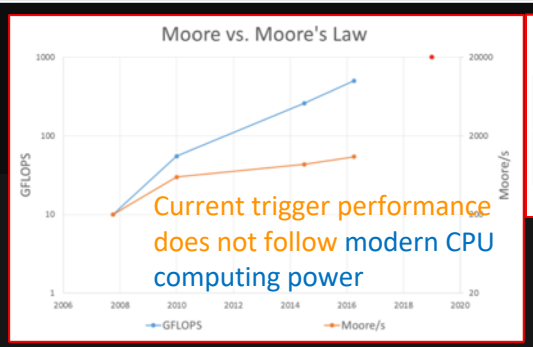




Target: 80Gb/s on 500 nodes

LHCb upgrade: software & computing TDR

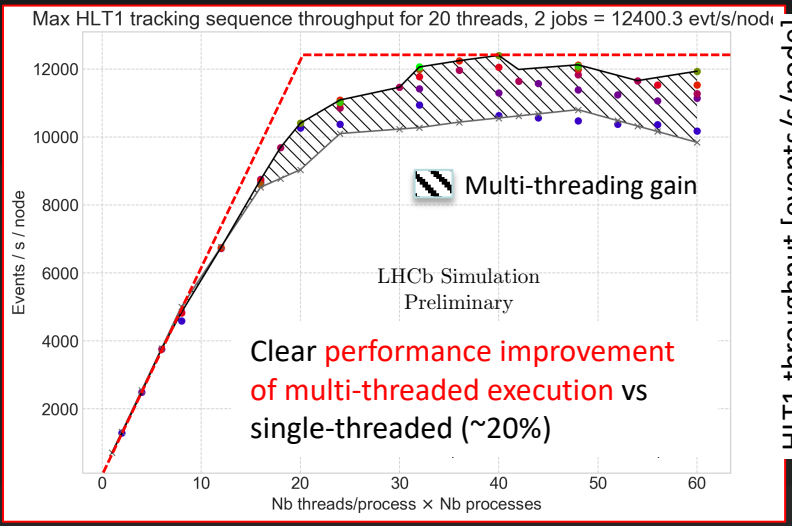
- Upgrade HLT will process data at 30 MHz – challenging !
  - ★ Need software modernization
  - ★ Need proper software engineering
  - ★ Exploit modern CPU features (multi-threading, vectorization)
  - ★ Huge effort ongoing, substantial progress in many areas

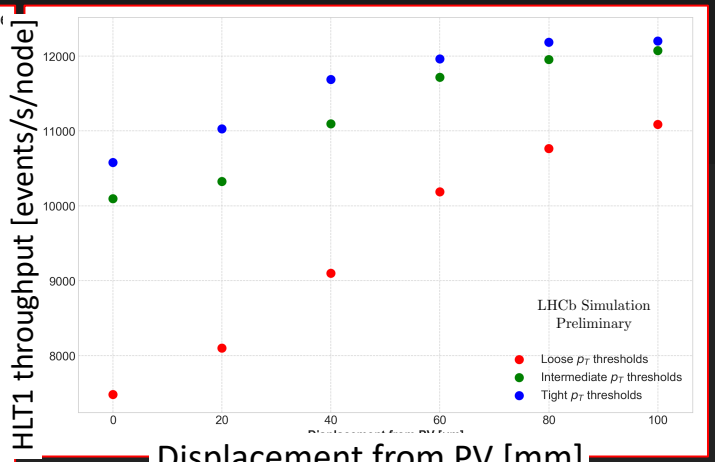


		SSE4		AVX2	
		time (s)	Speedup	time (s)	Speedup
double	scalar	233.462		228.752	
	vectorized	122.259	1.90	58.243	3.93
float	scalar	214.451		209.756	
	vectorized	55.707	3.85	26.539	7.90

Table 3.3: Performance of vectorized Rich's Ray Tracing

Vectorization can give up to an ideal x8 speed-up factor





Tracking algorithm optimization

Throughput dependence on tracking requirements
Significant gain by tightening impact parameter and p_T cuts

However this affects the physics program

A factor 2 in throughput is gained with respect to previous studies

LHCb upgrade: software & computing TDR

- TDR on upgrade software and computing about to be released to LHCC
  - ★ Summarizes core software solutions to enable HLT implementation
  - ★ All aspects of data processing (Simulation, offline, distributed computing,…) are discussed
  - ★ Will be complemented with a Computing Model document where computing resources will be discussed (in preparation, submission: summer 2018)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2017-XXX
April 11, 2018

LHCb Upgrade Software and Computing Technical Design Report

The LHCb collaboration

Abstract

This document reports the Research and Development activities that are carried out in the software and computing domains in view of the upgrade of the LHCb experiment. The implementation of a full software trigger implies major changes in the core software framework, in the event data model, and in the reconstruction algorithms. The increase of the data volumes for both real and simulated datasets requires a corresponding scaling of the distributed computing infrastructure and resources. An implementation plan in both domains is presented, together with a risk assessment analysis.

Upgrade II (LS4)

- LHCb issued Expression of Interest in an LS4 Upgrade II, a HL-LHC era flavour physics experiment, in February 2017:
  - ★ Modest consolidation in LS3 (~2025)
  - ★ LS4 Upgrade II installation (~2030)
  - ★ Collect ~ 50 fb^{-1} / yr, > 300 fb^{-1} total
- Presented to LHCC and encouraged to continue to a physics case document and proceed with discussions with LHC
  - ★ Physics document in preparation, present preliminary version for end May 2018
- Workshop in Annecy to review physics and detector options


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

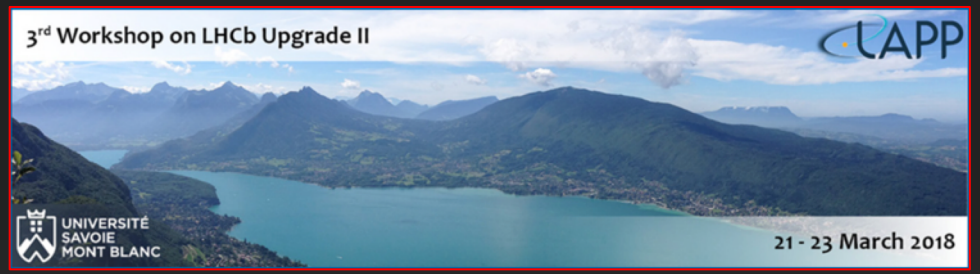
CERN-LHCC-2018-xxx
March 21, 2018

Physics case for an LHCb Upgrade-II :
Opportunities in flavour physics,
and beyond, in the HL-LHC era

The LHCb collaboration

Abstract

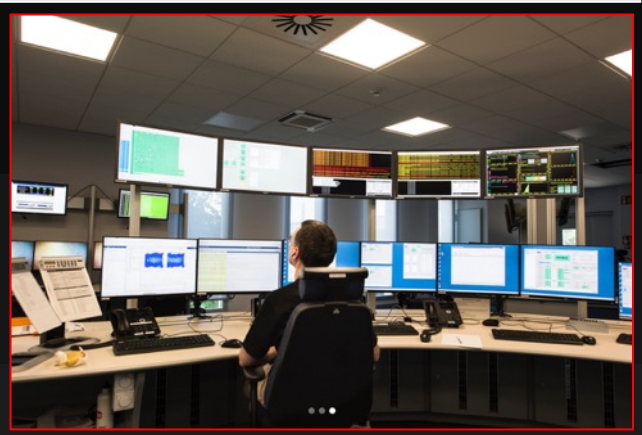
- At this point no action from RRB requested, for info. only
  - ★ TDR timescale 2020



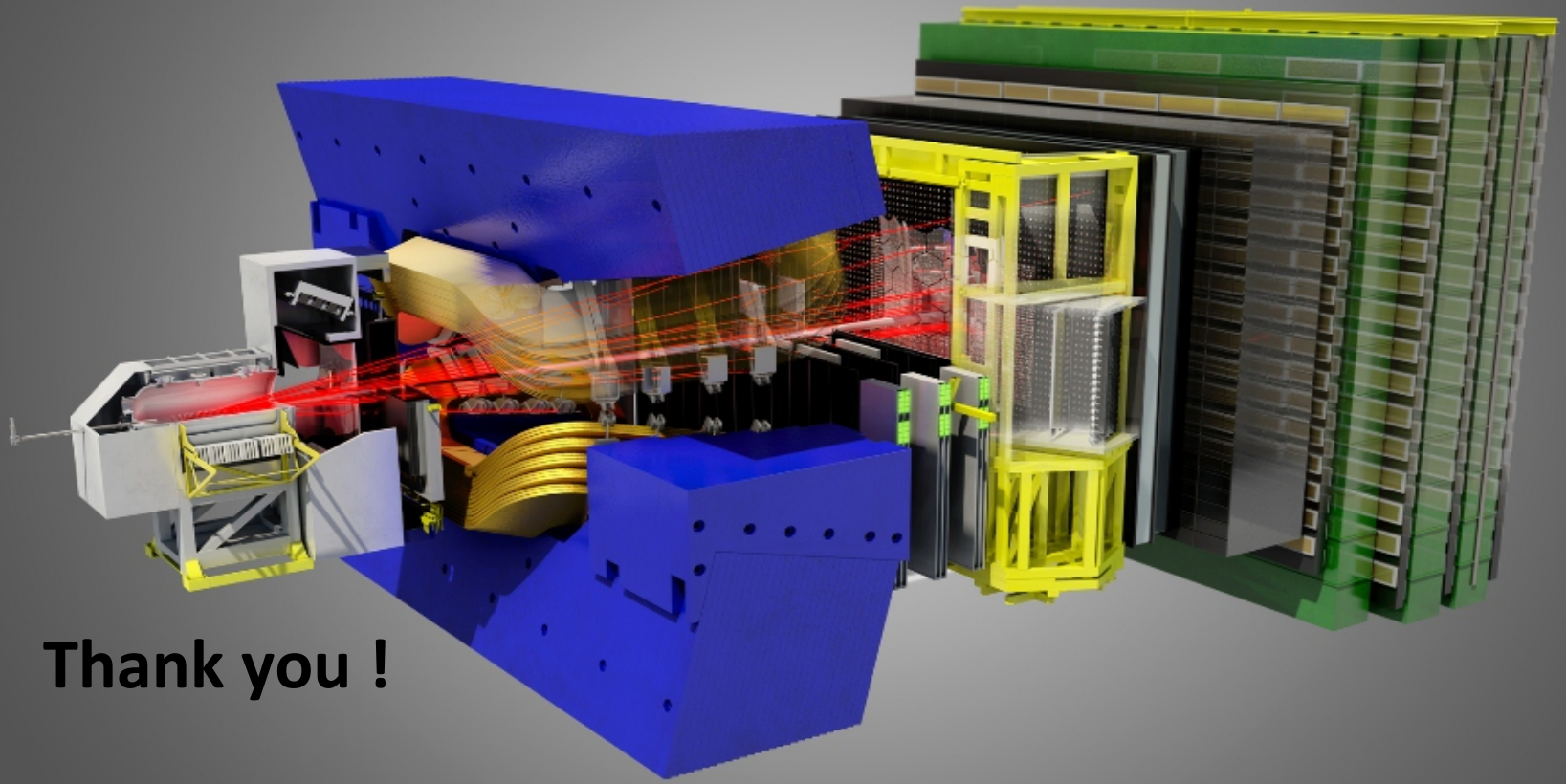
Conclusions and outlook

Conclusions and outlook

- LHCb run in 2017 was very smooth with detector working very well
- YETS activities completed successfully
- 2018 run starting very well
- LHCb continues to provide a wealth of excellent physics results
  - ★ Also preparing the ground for high statistics measurements in the upgrade phase



- The march towards the LS2 upgrade is continuing
  - ★ All subsystems progressing - crucial steps forward in critical projects
  - ★ Schedule is tight and some delays represent major concerns
- Looking into the far future:
  - ★ Expression of Interest for future upgrades submitted
  - ★ Preparing a physics case document



Thank you !