

# LHCb Status Report

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On behalf of the LHCb collaboration

# Overview

- Upgrade I.
  - Installation.
  - Status of sub-systems.
  - Real-time analysis project.
- Upgrade II.
- Operations.
- Physics.

[https://www.youtube.com/channel/UC5pvSVqmWSyVa\\_gHD8fvJsg](https://www.youtube.com/channel/UC5pvSVqmWSyVa_gHD8fvJsg)

**LHCb Experiment**  
140 subscribers

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LHCb - Long Shutdown 2 Progress report July 2019	5:29	75 views	1 week ago
News from the LHCb Cavern: July 2019 Report		75 views	1 week ago
LHCb - Long Shutdown 2 Progress report June 2019	5:53	234 views	1 month ago
News from the LHCb Cavern: June 2019 Report		234 views	1 month ago
LHCb - Long Shutdown 2 Progress report 31 May 2019	3:35	197 views	2 months ago
News from the LHCb Cavern: 27th - 31st May 2019		197 views	2 months ago
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LHCb - Long Shutdown 2 Progress report 24 May 2019	3:30	112 views	2 months ago
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1. CERN-LHCC-2008-007
2. CERN-LHCC-2011-001
3. CERN-LHCC-2012-007
4. CERN-LHCC-2013-021
5. CERN-LHCC-2013-022
6. CERN-LHCC-2014-001
7. CERN-LHCC-2014-016
8. CERN-LHCC-2018-007
9. CERN-LHCC-2018-014
10. CERN-LHCC-2019-005

# UPGRADE I

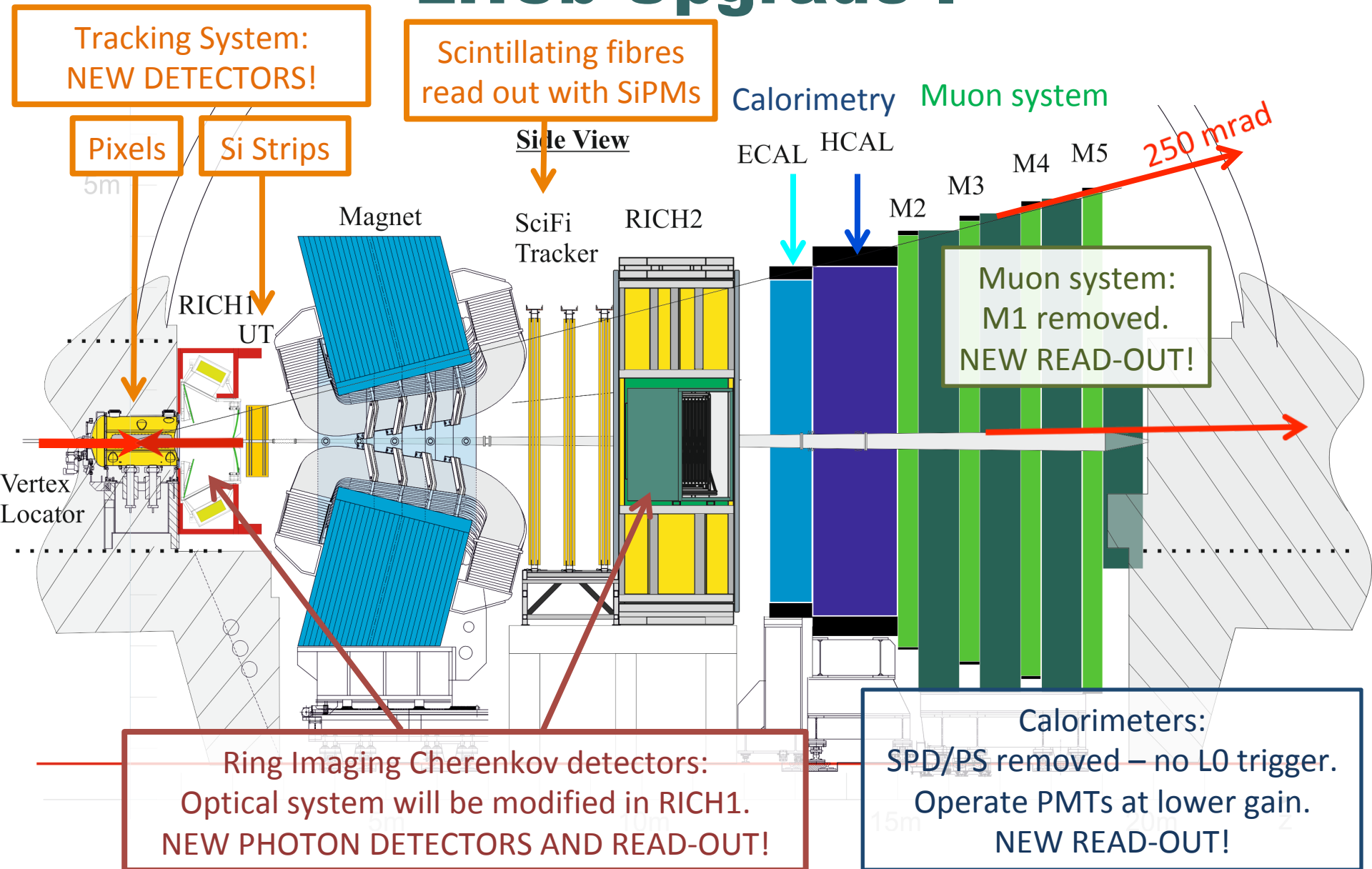
**Conditions:**

- Luminosity:  $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  (inst.),  $50 \text{ fb}^{-1}$  (int.)
- 5.2 visible interactions / crossing.

**Challenge:**

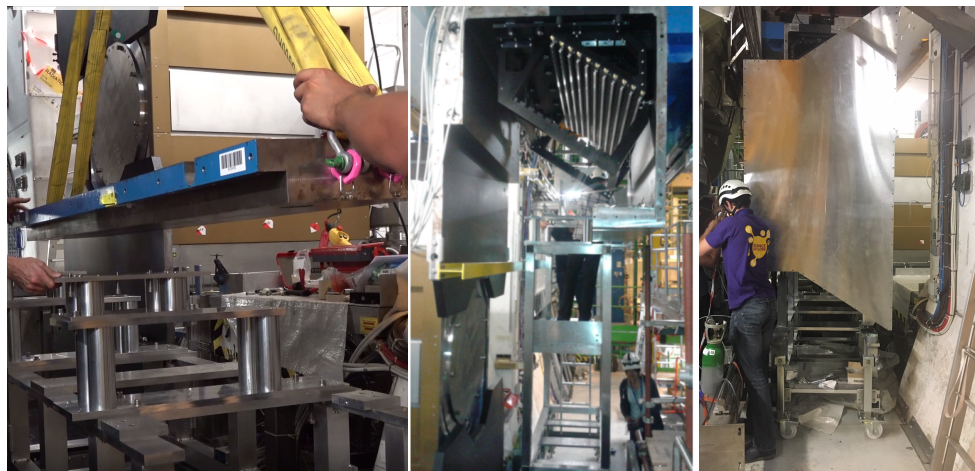
- Maintain current reconstruction performance in harsher environment.
- Read out the complete detector at 40 MHz.

# LHCb Upgrade I



# Installation

## RICH 1



### RICH 1 mechanics installed:

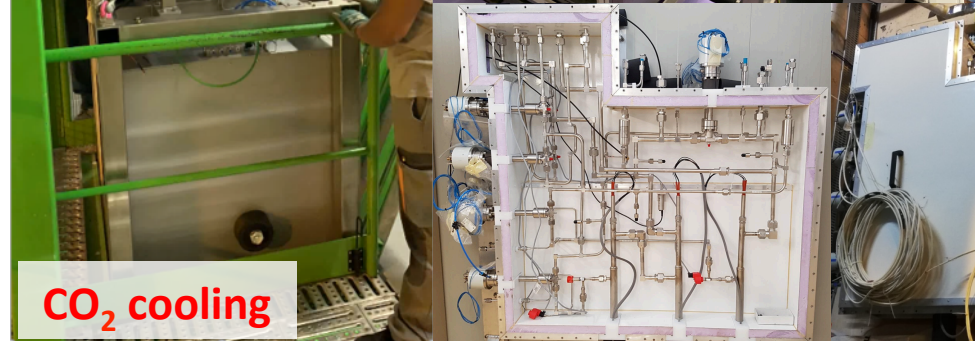
- Magnetic shielding shelves, MaPMT supports, gas enclosure.

### Detector Services:

- 30% of long distance copper cables installed.
- 100% of optical fibres installed & tested.
  - Few fibres with power loss > threshold.
- 100% of long distance pipes installed.

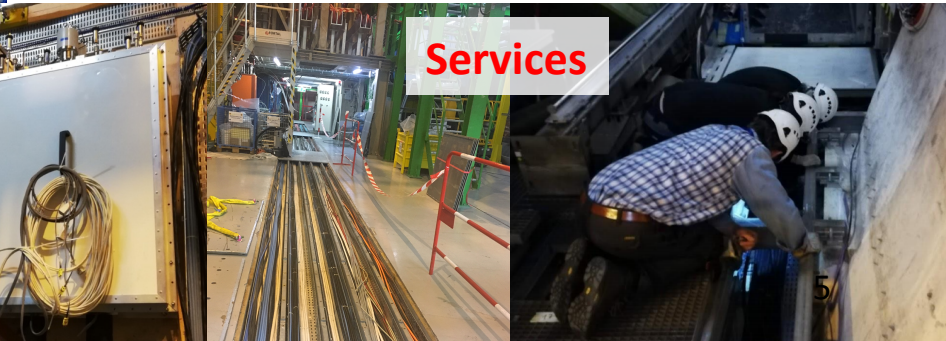
### CO<sub>2</sub> cooling plants (VELO & UT):

- CO<sub>2</sub> cooling plants and distribution boxes installed.
- Connections and first tests are being performed.



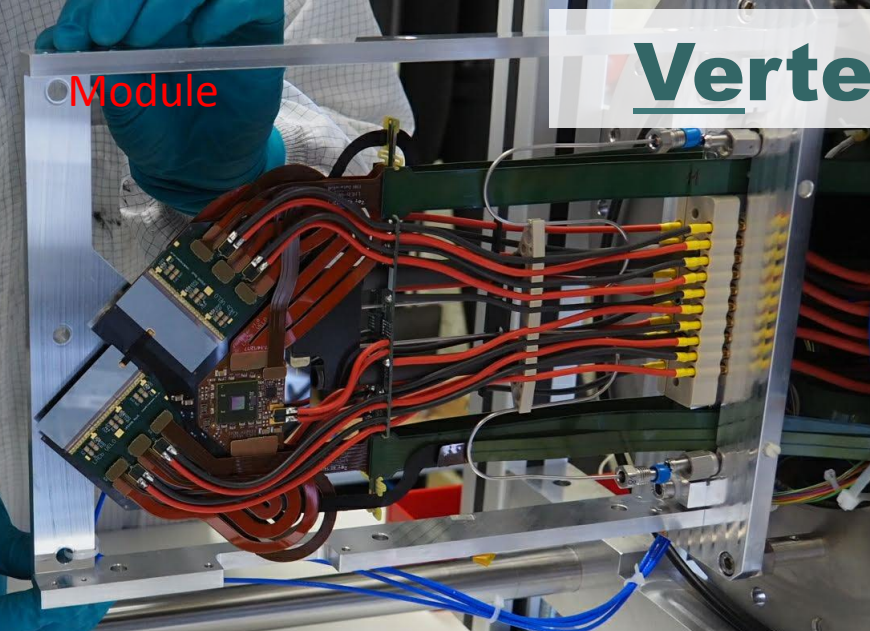
CO<sub>2</sub> cooling

Services

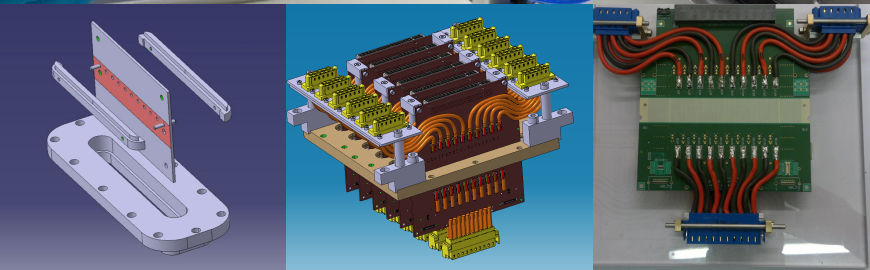


# Vertex Locator

Module



- Hybrid-pixel detector.
  - Operates in secondary vacuum.
  - Evaporative CO<sub>2</sub> cooling in silicon micro-channel substrates.
- Module production started at both sites.
  - Components delivered in batches.
  - Expected to finish by end of year.
- Vacuum feed-through boards completed.
  - Transmits all high speed signals, LV, HV, and seals secondary vacuum!
- Aluminium R.F. foil separates primary and secondary vacuum.
  - Milled to 250 μm thick.
- Mechanical structure for first half is starting to take shape.



R.F. foils

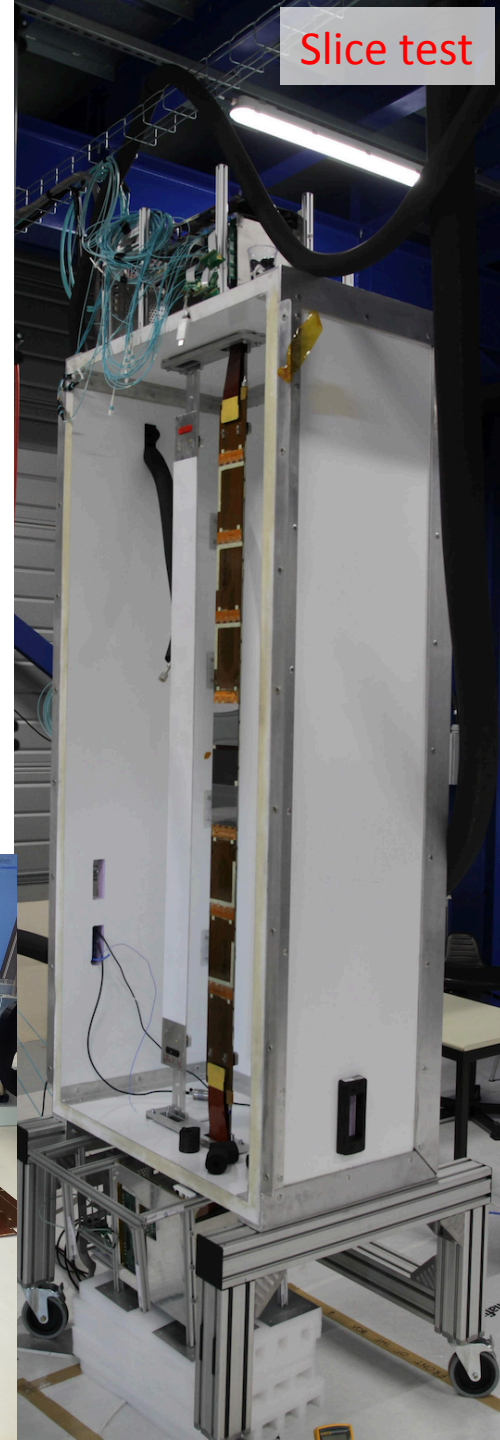
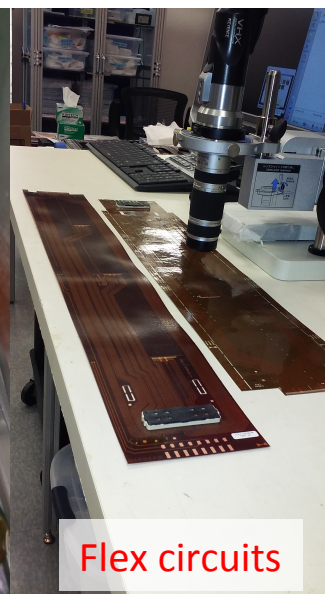
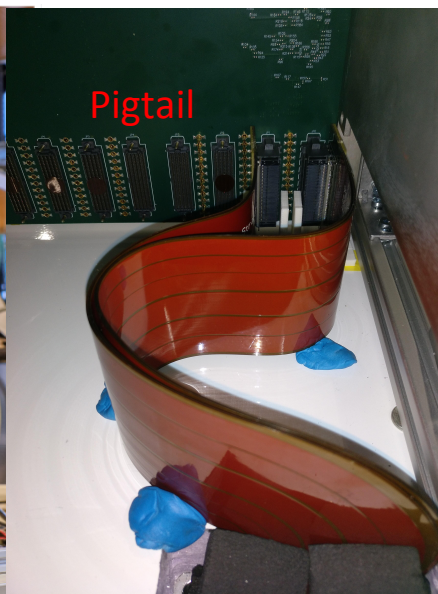
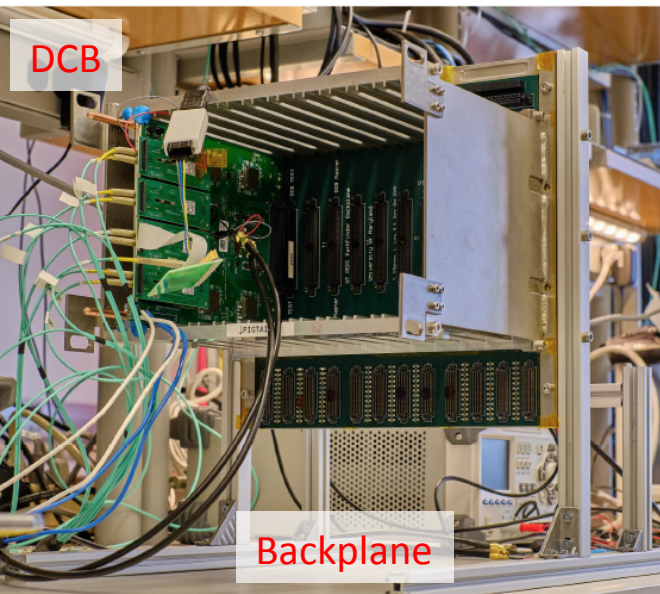


Mechanical structure of first half

# Upstream Tracker

- Silicon micro-strip detector.
  - Modules mounted on staves with CO<sub>2</sub> cooling.
  - Read-out electronics mounted on detector frame.
  - New 128-channel ASIC with 6-bit ADC (SALT).
- Four types of sensors.
  - n- and p-type with 512 or 1024 strips.
- Two versions of read-out ASIC (SALT).
  - Problems found in previous iterations have been solved.
  - v3.5: all wafers tested (81% yield) and first wafer being diced/sorted.
  - v3.8: first wafer has arrived and is currently being tested.
- Near-detector electronics (PEPI) fully validated in system test.
  - Data Control Boards and Low Voltage Regulators going into production.
- Read-out slice test at CERN.

Slice test



# Scintillating Fibre Tracker

Scintillating fibre  
modules

- Scintillating fibres read out with SiPMs.
  - SiPMs outside acceptance and cooled to  $-40^{\circ}\text{C}$ .
  - New ASIC for read-out (PACIFIC).
- Good progress in production & assembly
  - SiPM & flex cable production is finished.
  - Electronics production is going well.
    - All PACIFIC and Cluster Boards have been produced.
    - Master Board production and assembly is progressing.
- Cold-box production and module finishing progressing well.
- Assembly of first three C-frames in underway.
- Quarter of electronics installed on first C-frame.

Cold  
boxes

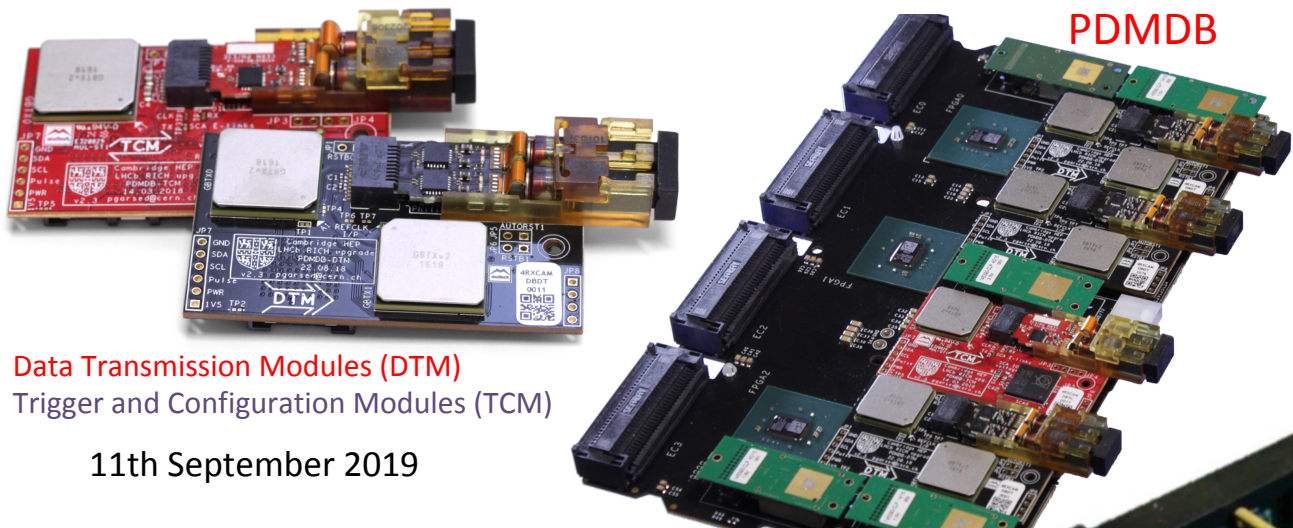
C-Frame

Front-end boxes



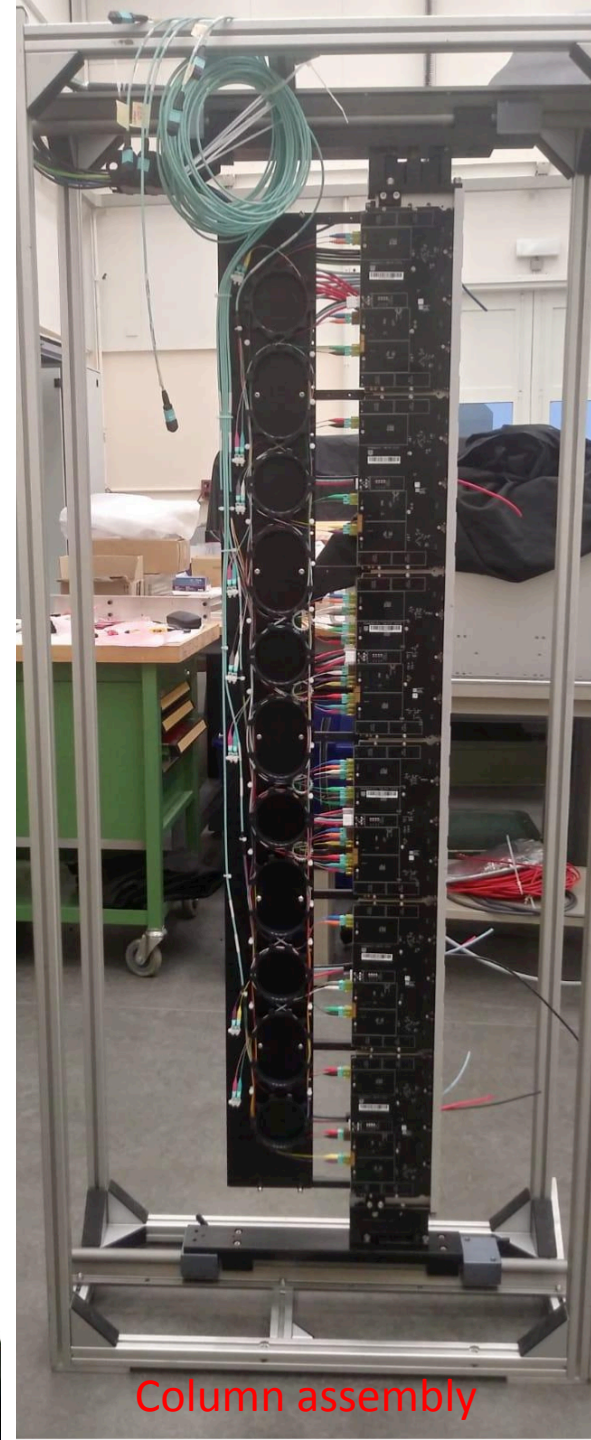
# RICH

- Upgrade of Cherenkov detectors:
  - RICH 1:  $C_4F_{10}$  (10 – 65 GeV/c).
    - modify optics to increase ring size.
  - RICH 2:  $CF_4$  (15 – 100 GeV/c).
  - Replace Hybrid Photon Detectors (HPD) with Multi Anode Photomultiplier Tubes (MaPMTs).
- QA started for all Elementary Cell (EC) components.
  - All MaPMTs produced and tested.
  - New ASIC (CLARO) plus front-end and back boards.
  - Producing 50 “certified ECs” per day → will increase soon.
- Photo Detector Module Digital Boards (PDMDB).
  - Fully-populated boards in steady production and shipped to CERN.
- RICH column production phase started.
  - Five columns being assembled: mechanics, electronics and cabling.



Data Transmission Modules (DTM)  
Trigger and Configuration Modules (TCM)

11th September 2019



Column assembly

# CALO

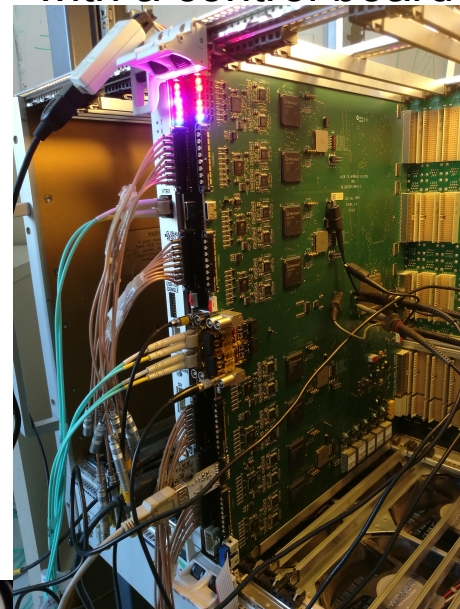
## Calorimeter upgrade strategy:

- Remove PS/SPD.
- Replace electronics:
  - 40 MHz readout (GBT).
  - Slow controls based on the GBT.
  - Better radiation tolerance.
- Adapt parts of previous system:
  - Modification of the power supplies done.
  - Modification of the crates should be completed by the end of September.

## New electronics:

- 280 front-end boards
  - Production done in 3 batches : 2 + 16 + 262 boards
  - Full production should be received and tested by spring
- 25 control boards
  - Ready for the production.
- 144 boards for the HV/Calibration/Monitoring systems
  - Fabrication finished.
  - Validation on-going.

Test of 2 FEBs in a crate with a control board



Mezzanines for the HV/Calib/Monitoring system

# MUON

## New electronics:

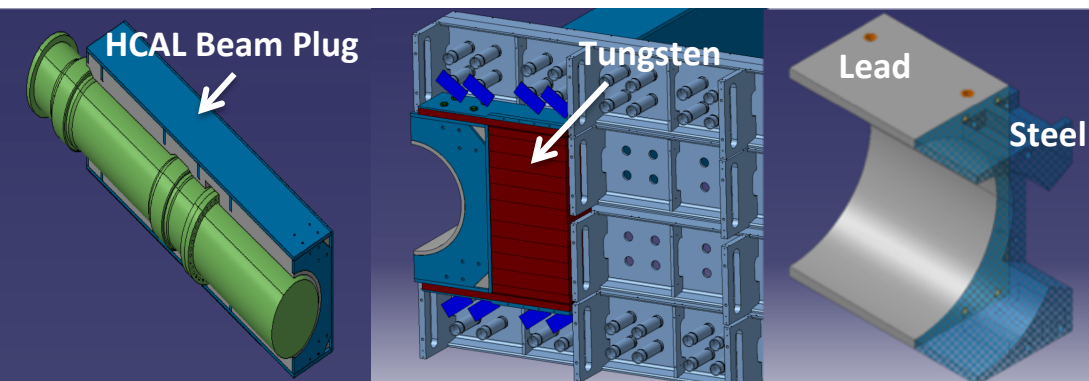
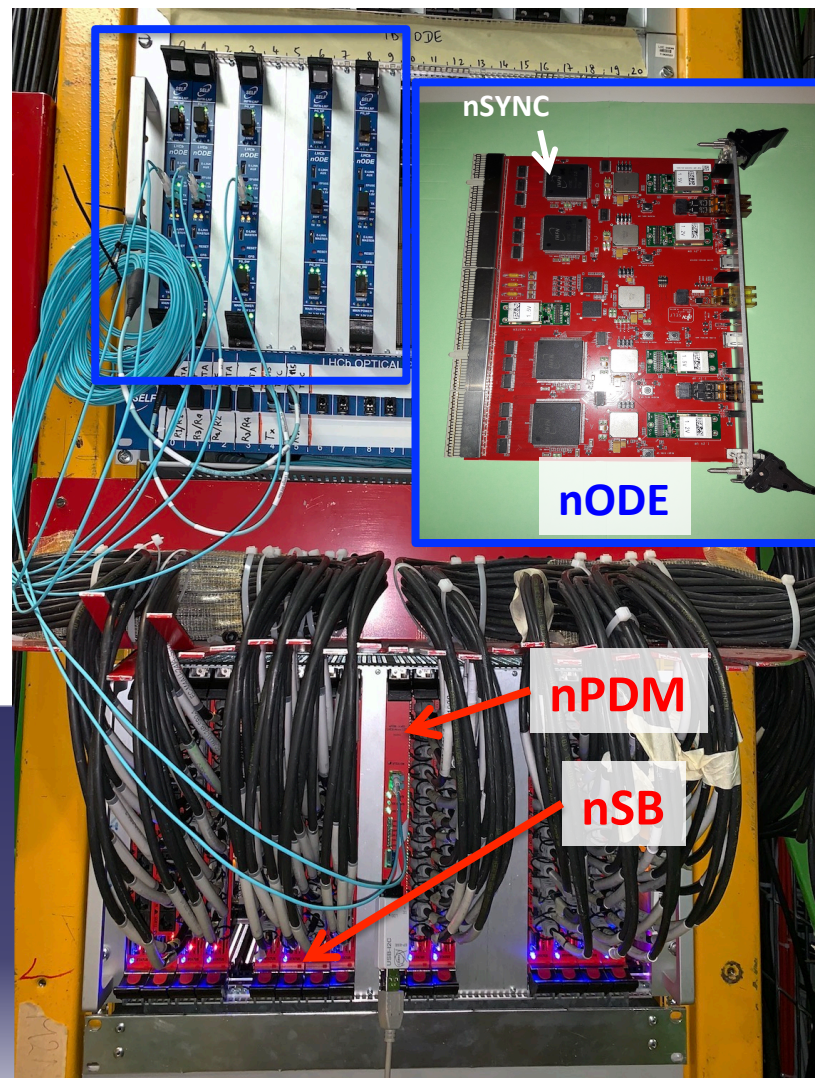
- Pre-production versions delivered.
  - nSYNCs: custom ASIC for 40 MHz read-out.
  - nODE: new Off Detector Electronics boards with four nSYNCs.
  - nSB, nPDM: service boards and pulse distribution modules for system configuration and calibration.
  - nBP: custom Back Plane for nPDM/nSB crates
- Full production will finish by December.

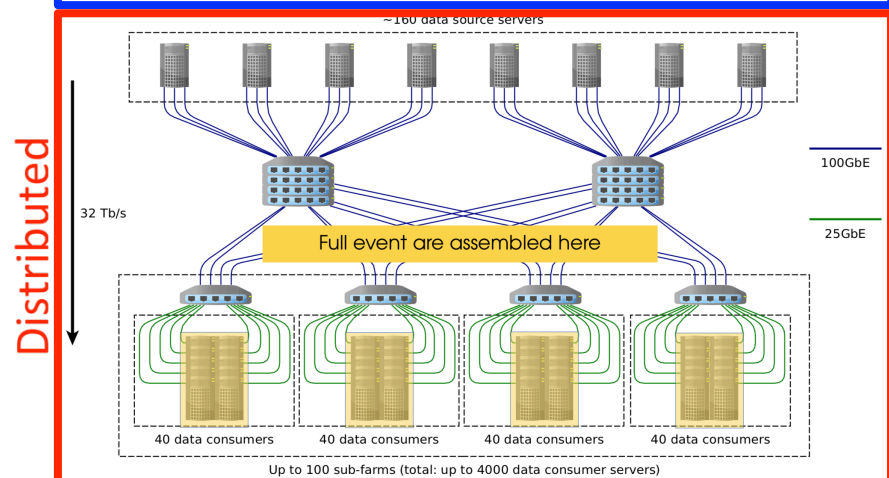
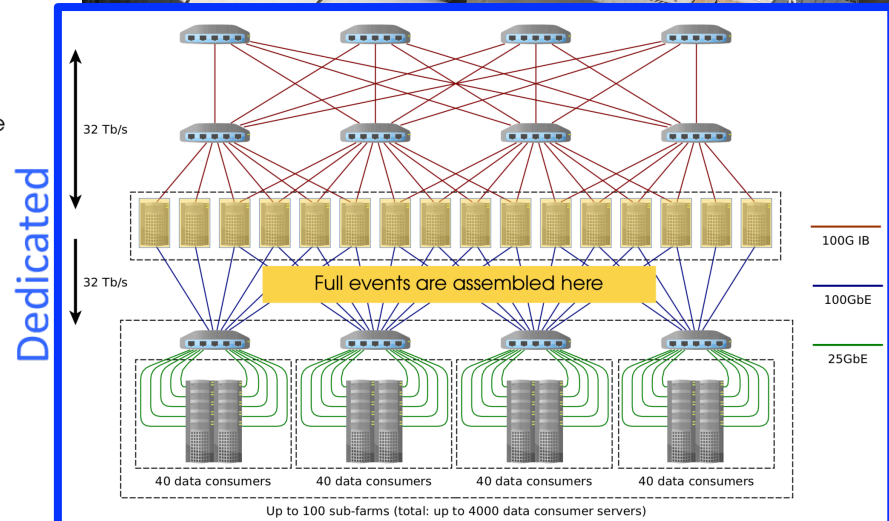
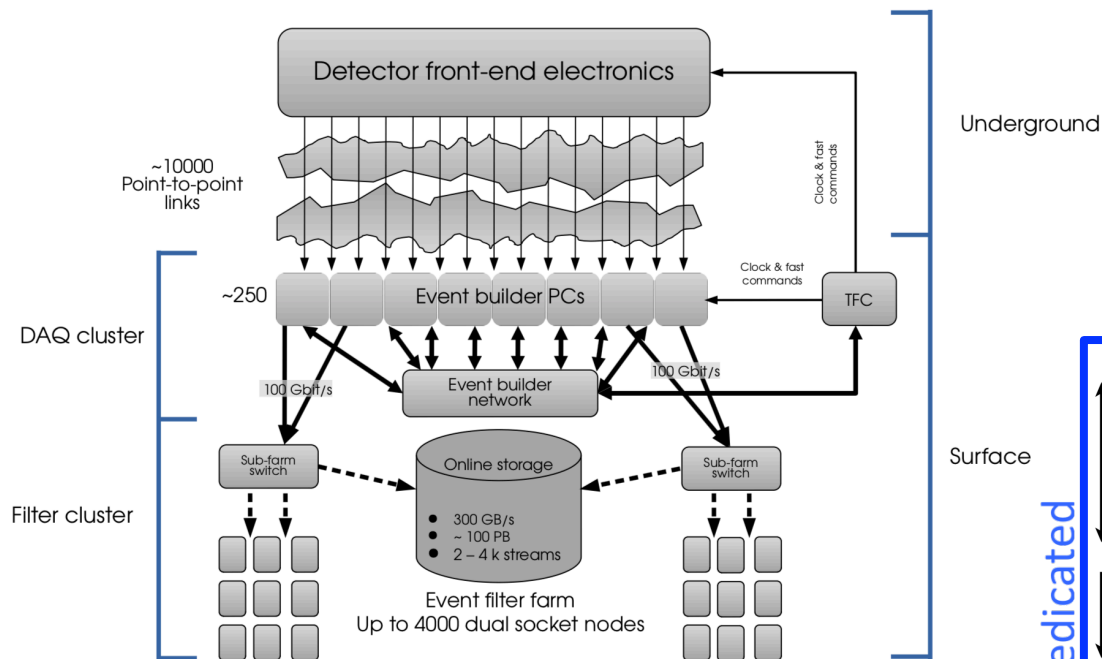
## Installation:

- First boards installed in August.
  - 8 nODE, 14 nSB & 1 nPDM.
- All communication and connectivity tests successful!

## Additional shielding in front of M2.

- Consists of three parts.
- Reduce the rate in the hottest part of M2 by ~50%.





- **Data centre on surface.**
  - Event Filter Farm and Event Builder network.
  - 6 of 6 containers installed (final two arrived last week).
- **Long distance optical fibres:**
  - 19008 fibers installed.
  - Loss measurements completed.
- **LHCb read-out cards (PCIe40)**
  - Production ~40% complete.
- **Two options for Event Builder network.**
  - Dedicated event builder network (baseline).
  - Distributed event building in the farm.
- **Vertical slice being set up to test complete data flow.**
  - Event building, monitoring and ECS.

11th September 2019

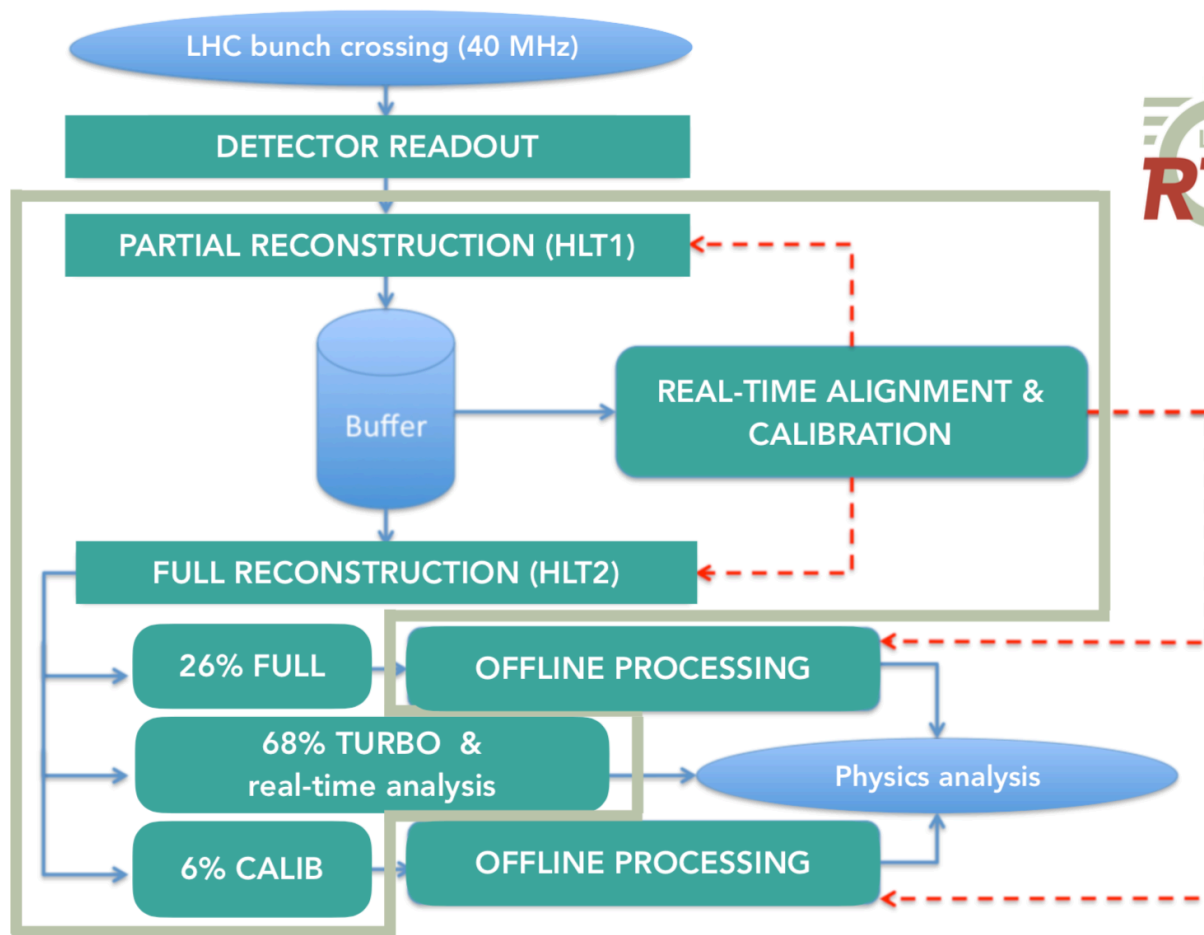
# Real Time Analysis

Run 2: JINST 14 P04013  
Comput. Phys. Commun. 208 35-42

40 Tb/s  
30 MHz non-empty pp

1-2 Tb/s  
0.5 - 1.5 MHz

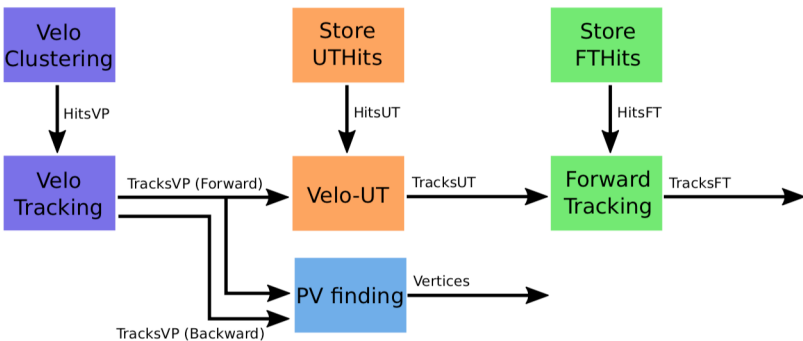
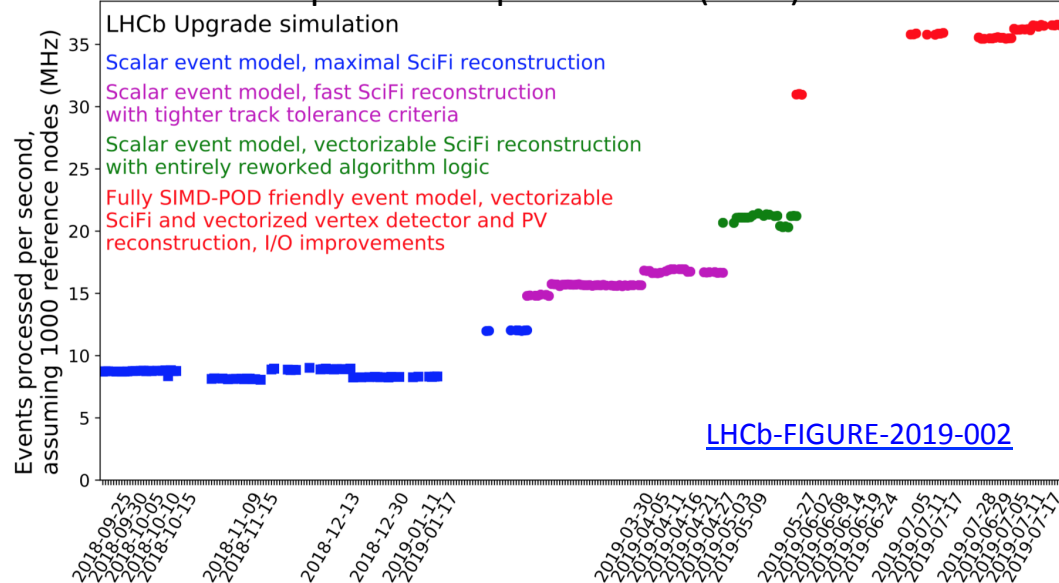
80 Gb/s



- RTA is integral part of DAQ chain in upgrade data processing.
  - Offline reconstruction in HLT2 à la Run 2.
- TURBO model for exclusive selections.
  - High-level physics objects directly from the HLT → small fraction of raw event size.

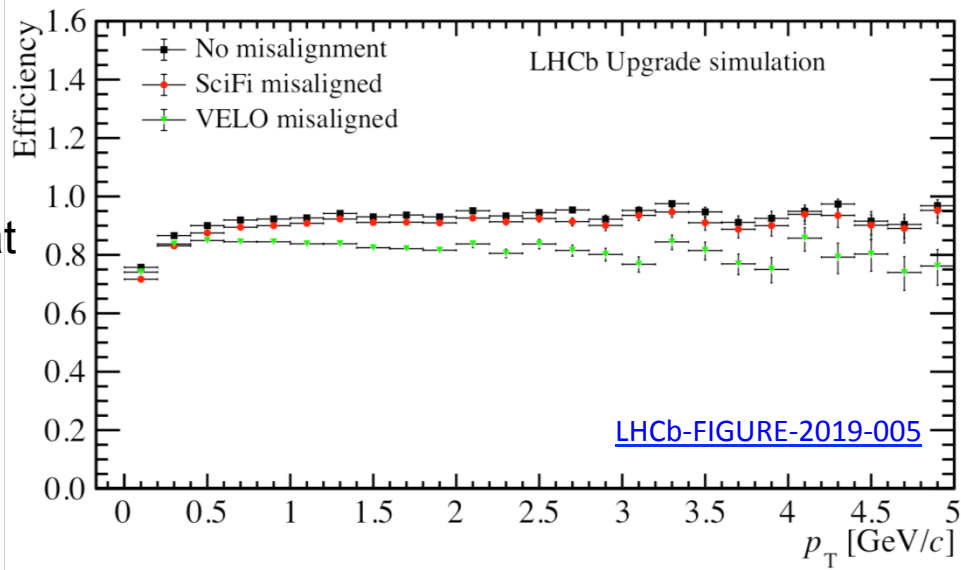
# Real Time Analysis

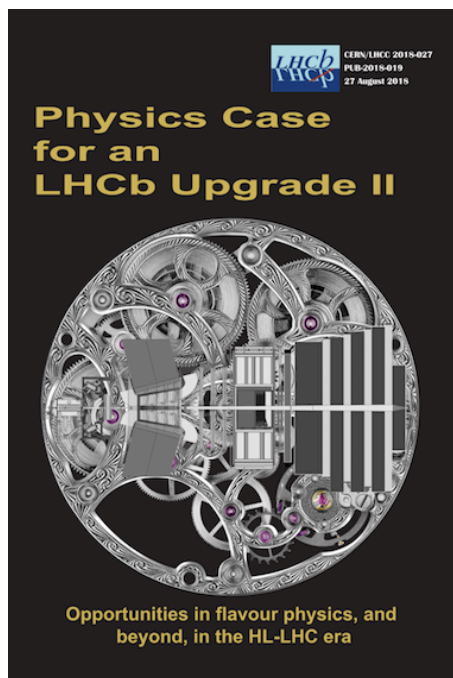
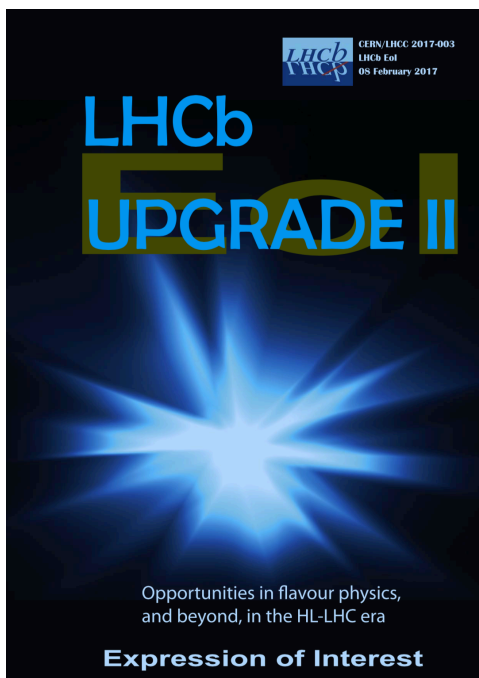
Events processed per second (MHz) vs date



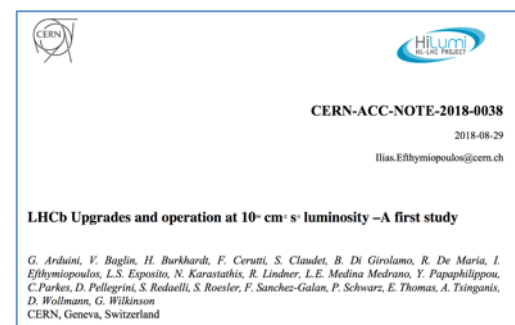
- VELO clustering and tracking merged into single vectorised algorithm.
- Minimized data being passed within reconstruction sequence.

- New event model implemented.
- Launched data challenges to validate event model, reconstruction, etc.
- Prototype partial reconstruction running at 30 MHz → minimum requirement (DAQ).
- Physics validation of new algorithms is underway.
- Hardware accelerator options for HLT1 also being studied (GPU&FPGA).





1. CERN-LHCC-2017-003
2. CERN-LHCC-2018-027



# UPGRADE II

## Conditions:

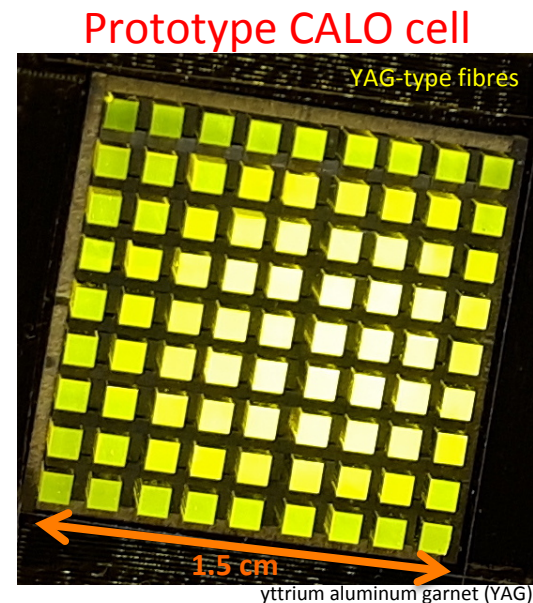
- Luminosity:  $1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  (inst.),  $300 \text{ fb}^{-1}$  (int.)
- 40 visible interactions / crossing.

## Challenge:

- Maintain current reconstruction performance in much, much harsher environment.
- Develop detectors with timing information for VELO & Particle ID.

## Upgrade II

- Active R&D across collaboration.
  - ECAL testbeam at DESY in November.
  - CMOS tracker chip in design.
  - Silicon with timing capabilities.
  - Photon sensors with timing .
  - New MPGDs ( $\mu$ -RWELL) for high-rate muon detection.
- Internal detector reviews being held.
- Strong collaboration with accelerator group.
- Framework TDR expected in 2021.

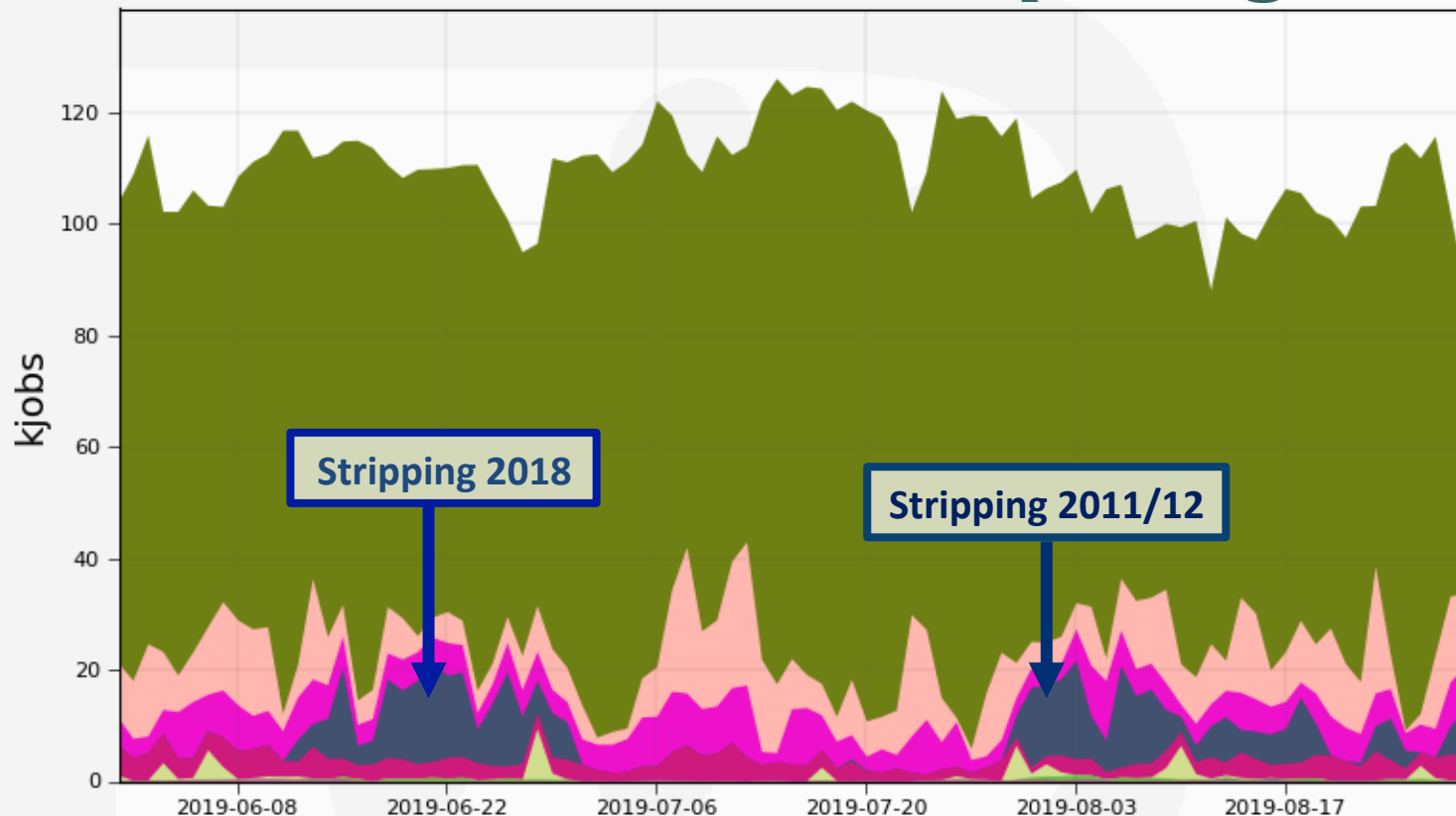




Offline Computing

# OPERATIONS

# Offline computing



Simulation

Fast Simulation

User jobs

MC reconstruction

Max: 126, Min: 88.1, Average: 109, Current: 88.6

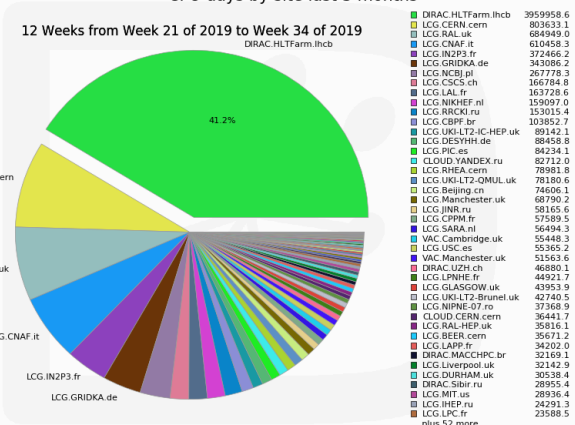
MCSimulation	78.4%	MCreconstruction	2.9%	MCMerge	0.0%	unknown
MCFastSimulation	8.7%	WGProduction	0.5%	MCReprocessing	0.0%	
user	5.2%	Merge	0.2%	DataReconstruction	0.0%	
DataStripping	4.1%	Hospital	0.1%	test	0.0%	

- 90% of running jobs related to simulation.
- Online HLT farm being used for MC production.
- Re-stripping of Run 1 & 2 data is underway.

11th September 2019

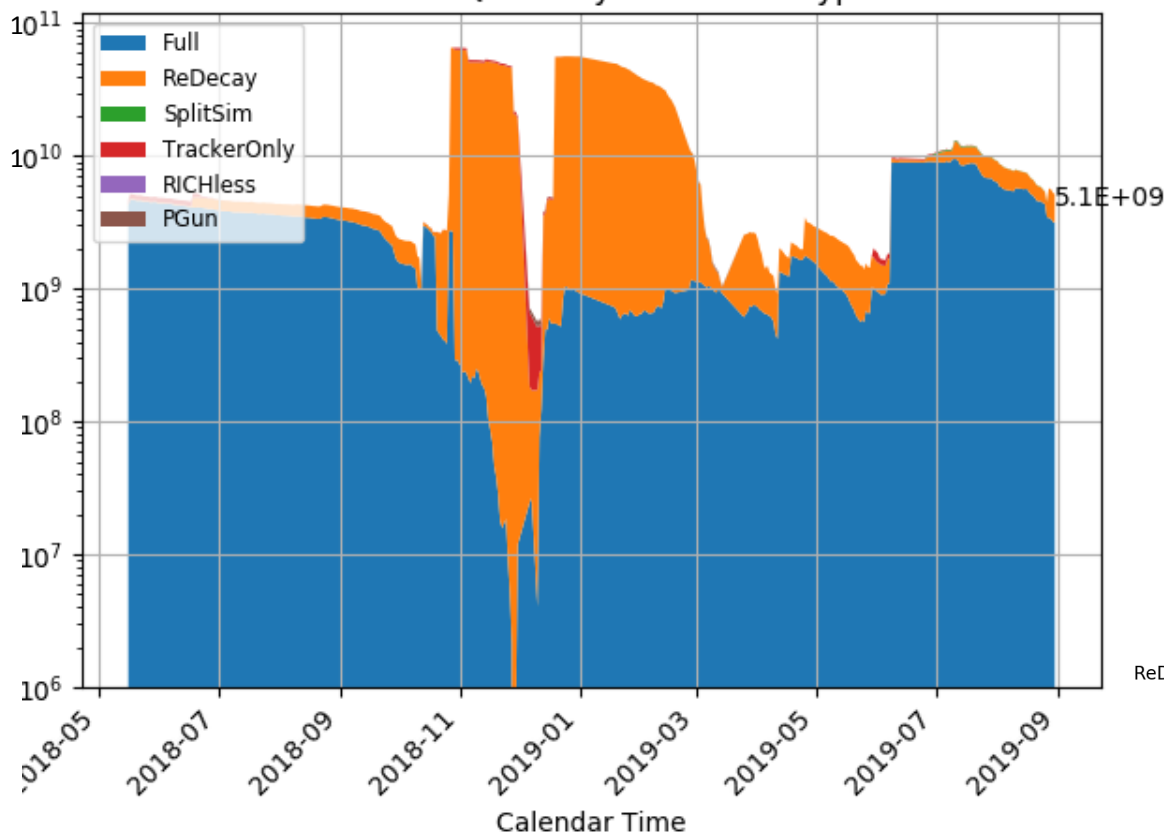
139th LHCC Meeting - OPEN Session

CPU days by site last 3 months



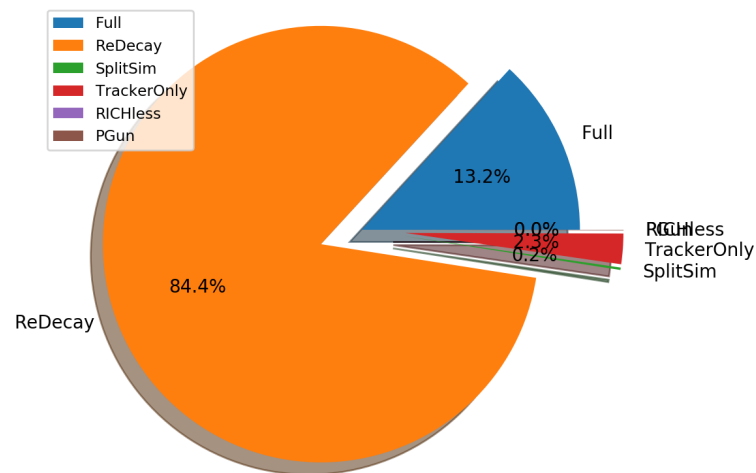
# Simulation

Events in Queue by Simulation Type



- Full simulation
- Fast simulation (ReDecay)
- Fast simulation (Tracker only)
- Fast simulation (Particle gun)

All Events Last 365 Days by Simulation Type



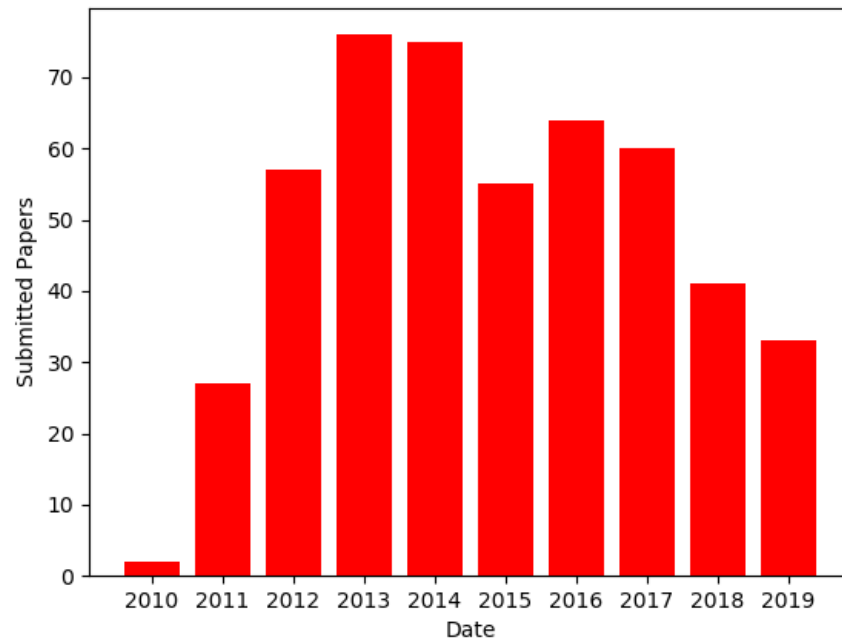
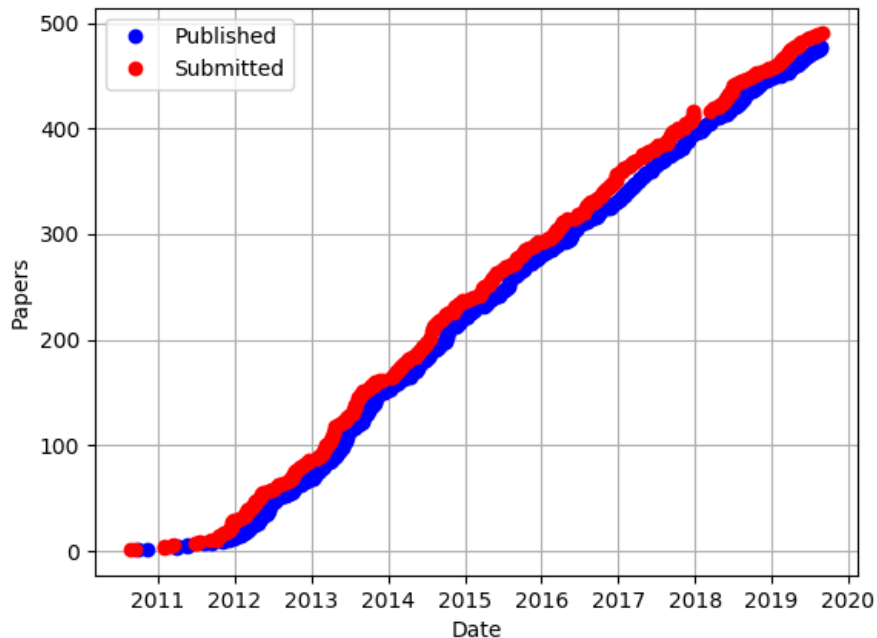
- Around 90% of MC events produced with fast simulations in the last year.

Statistics

New results since last LHCC

# PHYSICS RESULTS

# LHCb publications!



- 490 papers published by LHCb.
- 33 submitted for publication in 2019.
  - Eight since the last LHCC.

# Since previous LHCC

Submitted

**PAPER-2018-049:** Measurement of  $\psi(2S)$  production cross-sections in proton-proton collisions at  $\sqrt{s} = 7$  and 13 TeV

**PAPER-2019-008:** Precision measurement of the  $\Lambda_c^+$ ,  $\Xi_c^+$  and  $\Xi_c^0$  baryon lifetimes

**PAPER-2019-013:** Updated measurement of time-dependent CP-violating observables in  $B_s^0 \rightarrow J/\psi K^+ K^-$  decays

**PAPER-2019-019:** Measurement of CP violation in the  $B_s^0 \rightarrow \phi\phi$  decay and search for the  $B^0 \rightarrow \phi\phi$  decay

**PAPER-2019-021:** Measurement of CP observables in the process  $B^0 \rightarrow DK^{*0}$  with two- and four-body  $D$  decays

**PAPER-2019-022:** Search for the lepton-flavour violating decays  $B^+ \rightarrow K^+ \mu^\pm e^\mp$

\* **PAPER-2019-023:** Observation of the  $\Lambda_b^0 \rightarrow \chi_{c1}(3872)pK^-$  decay

\* **PAPER-2019-025:** Observation of new resonances in the  $\Lambda_b^0 \pi^+ \pi^-$  system

Preliminary

**PAPER-2019-017:** Amplitude analysis of the  $B^\pm \rightarrow \pi^\pm \pi^+ \pi^-$  decay

**PAPER-2019-018:** Observation of several sources of CP violation in  $B^+ \rightarrow \pi^+ \pi^+ \pi^-$  decays

**PAPER-2019-020:** Observation of the of the fragmentation-fraction ratio  $f_s/f_u$  variation with  $B$ -meson kinematics

\* **PAPER-2019-024:** Measurement of  $\eta_c(1S)$  production at  $\sqrt{s} = 13$  TeV

\* **PAPER-2019-029:** Search for the doubly charmed baryon  $\Xi_{cc}^+$

\* **CONF-2019-002:** Search for  $K_s^0 \rightarrow \mu^+ \mu^-$

\* **New results**

... many more under review

# Observation of the $\Lambda_b^0 \rightarrow \chi_{c1}(3872)pK^-$ decay

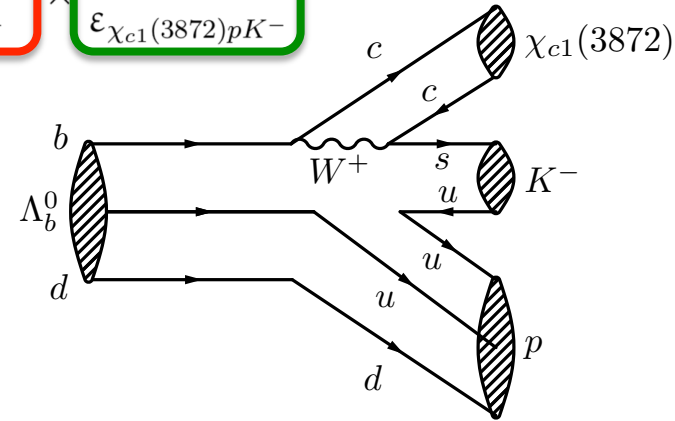
LHCb-PAPER-2019-023, arXiv:1907.00954, submitted to JHEP

simulation

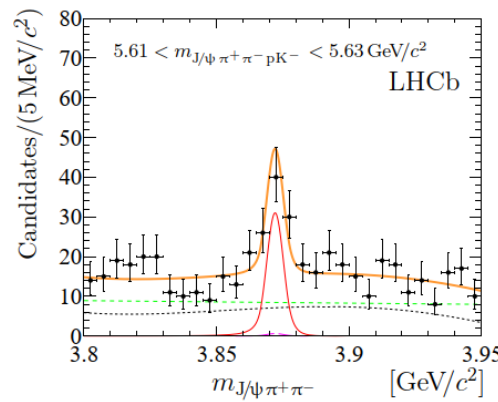
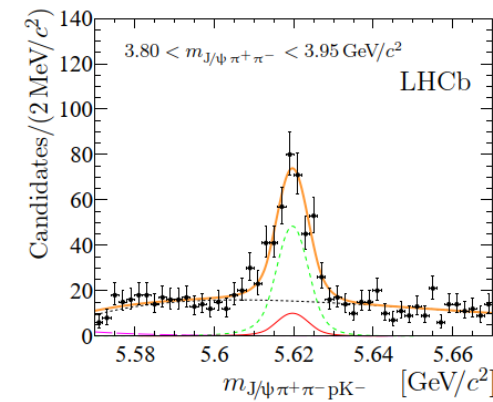
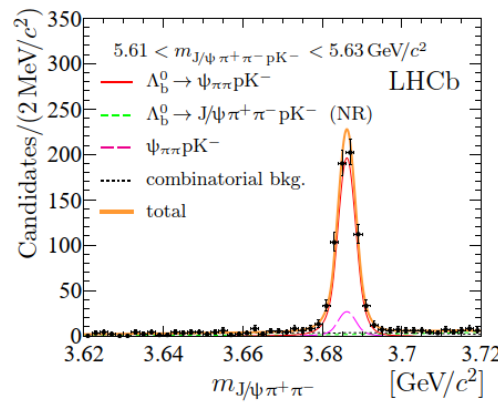
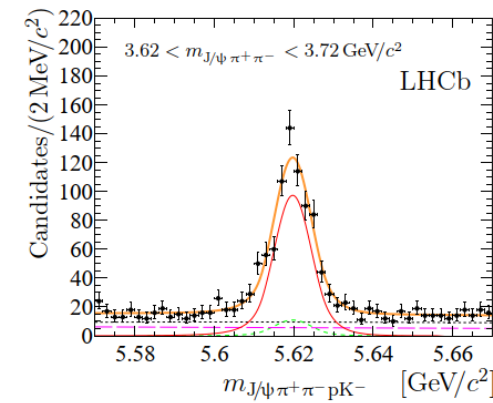
Run 1&2, 4.9 fb<sup>-1</sup>

$$R = \frac{\mathcal{B}(\Lambda_b^0 \rightarrow \chi_{c1}(3872)pK^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \psi(2S)pK^-)} \times \frac{\mathcal{B}(\chi_{c1}(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\mathcal{B}(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} = \frac{N_{\chi_{c1}(3872)pK^-}}{N_{\psi(2S)pK^-}} \times \frac{\epsilon_{\psi(2S)pK^-}}{\epsilon_{\chi_{c1}(3872)pK^-}}$$

data



$\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$



$\chi_{c1}(3872) \rightarrow J/\psi \pi^+ \pi^-$

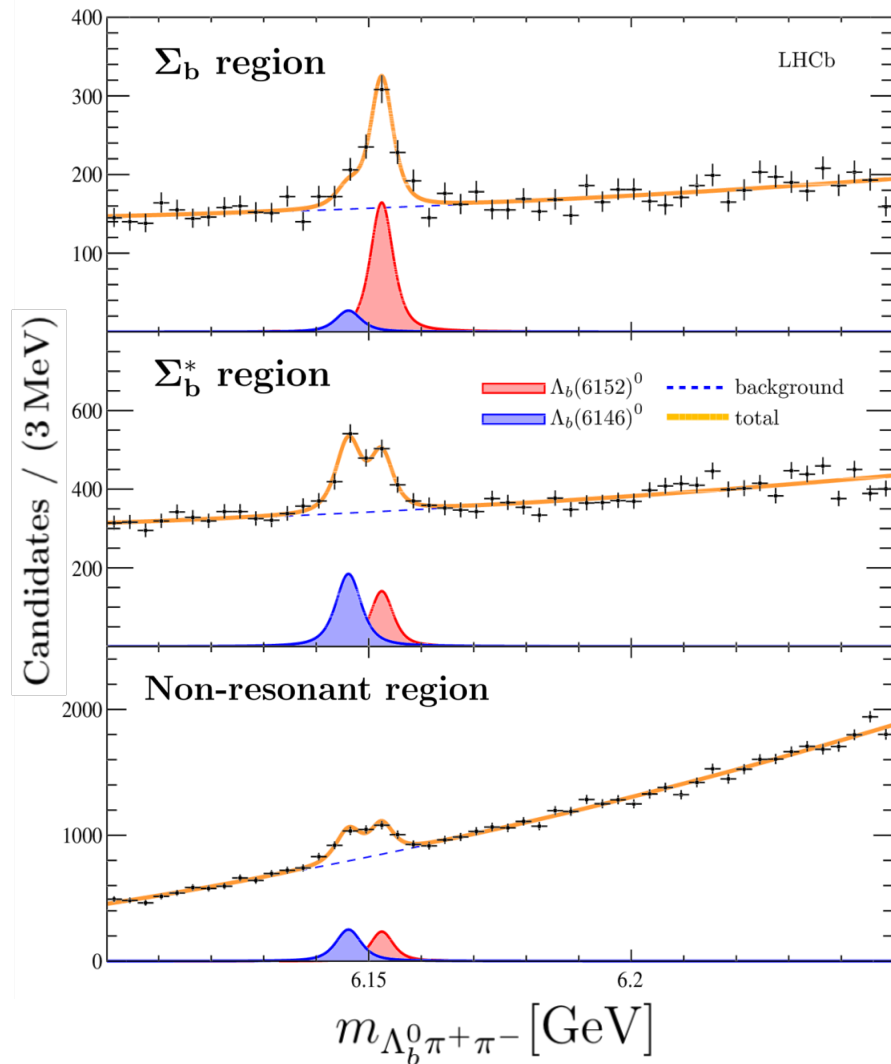
- Structure of  $\chi(3872)$  studied widely in b-meson decays.
  - Not yet understood.
- Search for  $\chi_{c1}(3872)$  in b-baryon decays.
  - Run 1 & partial Run 2 data set.
  - Signal yields determined from 2-D unbinned EML fit to mass distributions.
- $\Lambda_b^0 \rightarrow \chi_{c1}(3872)pK^-$  decay observed for first time.
  - Significance of the observed signal  $> 7\sigma$ .
- Branching fraction measured w.r.t.  $\Lambda_b^0 \rightarrow \psi(2S)pK^-$  decays.

$$R = (5.4 \pm 1.1 \text{ (stat)} \pm 0.2 \text{ (syst)}) \times 10^{-2}$$

# Observation of new resonances in the $\Lambda_b^0 \pi^+ \pi^-$ system

LHCb-PAPER-2019-025, arXiv:1907.13598, submitted to PRL

Run 1&2, 9 fb<sup>-1</sup>



- New structure observed in  $\Lambda_b^0 \pi^+ \pi^-$  spectrum.
- Uses full LHCb data set.
  - $\sqrt{s} = 7, 8 \text{ \& } 13 \text{ TeV}$ .
  - $L = 9 \text{ fb}^{-1}$ .
- Two almost degenerate narrow states.
- Masses of new states:
  - Doublet of  $\Lambda_b(1D)^0$  states.

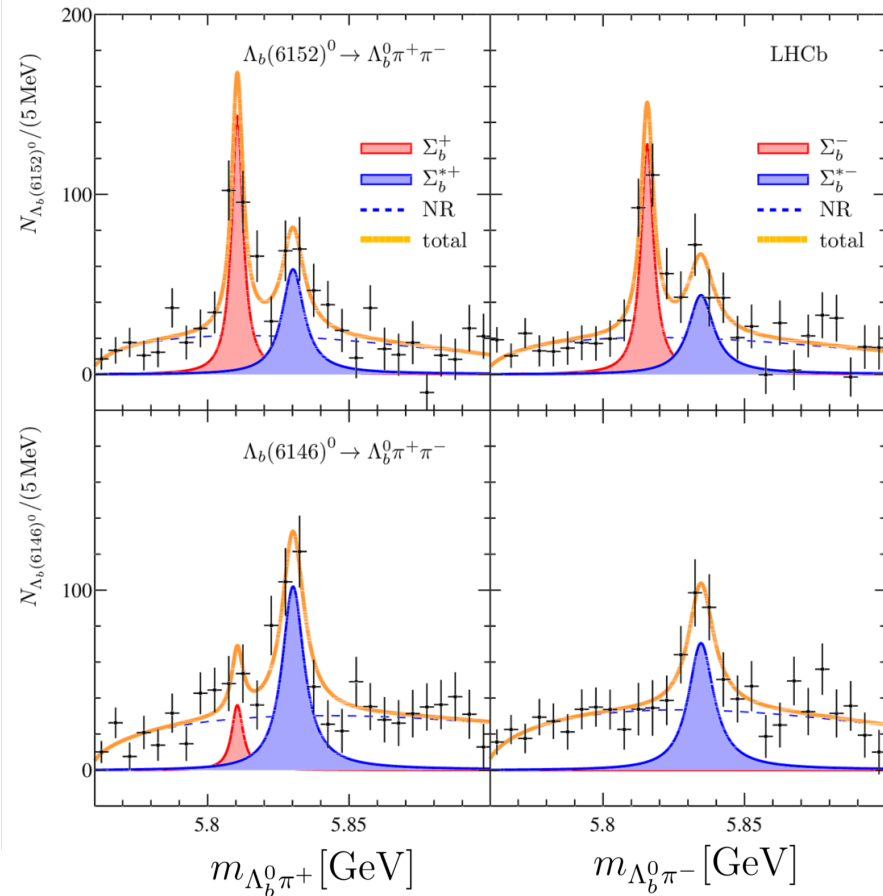
$$\begin{aligned} m_{\Lambda_b(6146)^0} &= 6146.17 \pm 0.33 \pm 0.22 \pm 0.16 \text{ MeV} \\ m_{\Lambda_b(6152)^0} &= 6152.51 \pm 0.26 \pm 0.22 \pm 0.16 \text{ MeV} \\ \Gamma_{\Lambda_b(6146)^0} &= 2.9 \pm 1.3 \pm 0.3 \text{ MeV} \\ \Gamma_{\Lambda_b(6152)^0} &= 2.1 \pm 0.8 \pm 0.3 \text{ MeV} \end{aligned}$$



# Observation of new resonances in the $\Lambda_b^0 \pi^+ \pi^-$ system

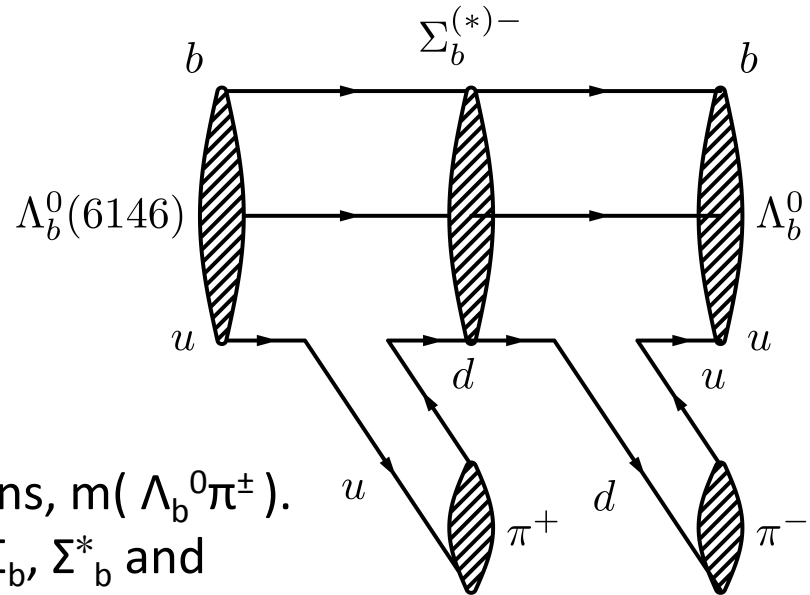
LHCb-PAPER-2019-025, arXiv:1907.13598, submitted to PRL

Run 1&2, 9 fb<sup>-1</sup>



## ■ New structure observed in $\Lambda_b^0 \pi^+ \pi^-$ spectrum.

- $\Lambda_b(6152)^0$  decays via intermediate  $\Sigma_b$  and  $\Sigma_b^*$ .
- $\Lambda_b(6146)^0$  decays via  $\Sigma_b^*$ .



- Background subtracted mass distributions,  $m(\Lambda_b^0 \pi^\pm)$ .
- Results of fits with a model comprising  $\Sigma_b$ ,  $\Sigma_b^*$  and non-resonant(NR) components are superimposed.

# Measurement of $\eta_c(1S)$ production at $\sqrt{s} = 13$ TeV

LHCb-PAPER-2019-024 (LHCb preliminary)

Run 2, 2.0 fb<sup>-1</sup>

$$\frac{\sigma_{\eta_c}^{\text{prompt}}}{\sigma_{J/\psi}^{\text{prompt}}} = \frac{N_{\eta_c}^{\text{prompt}}}{N_{J/\psi}^{\text{prompt}}} \times \frac{\epsilon_{J/\psi}}{\epsilon_{\eta_c}} \times \frac{\mathcal{B}_{J/\psi \rightarrow p\bar{p}}}{\mathcal{B}_{\eta_c \rightarrow p\bar{p}}} = 1.69 \pm 0.15 \pm 0.10 \pm 0.18$$

$$\frac{\sigma_{\eta_c}^b}{\sigma_{J/\psi}^b} = \frac{\mathcal{B}_{b \rightarrow \eta_c X}}{\mathcal{B}_{b \rightarrow J/\psi X}} = \frac{N_{\eta_c}^b}{N_{J/\psi}^b} \times \frac{\epsilon_{J/\psi}}{\epsilon_{\eta_c}} \times \frac{\mathcal{B}_{J/\psi \rightarrow p\bar{p}}}{\mathcal{B}_{\eta_c \rightarrow p\bar{p}}} = 0.48 \pm 0.03 \pm 0.03 \pm 0.05$$

data     simulation     PDG

Preliminary

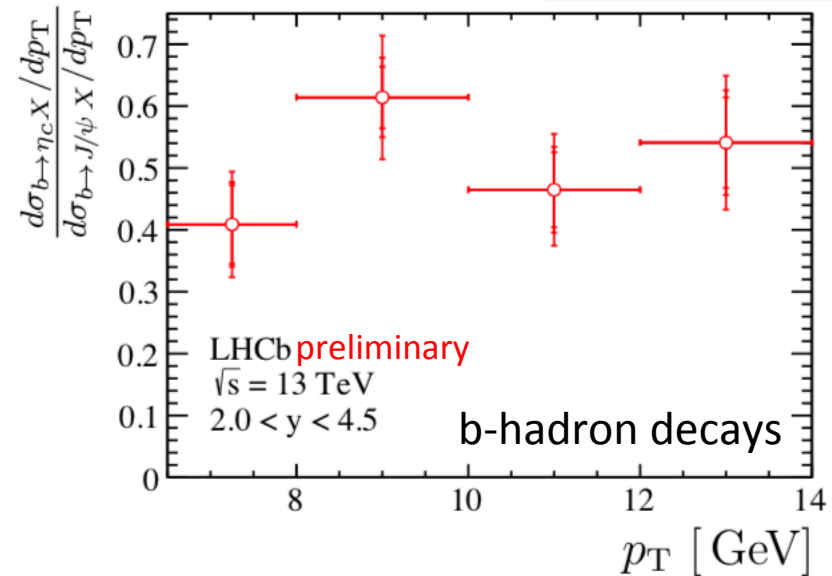
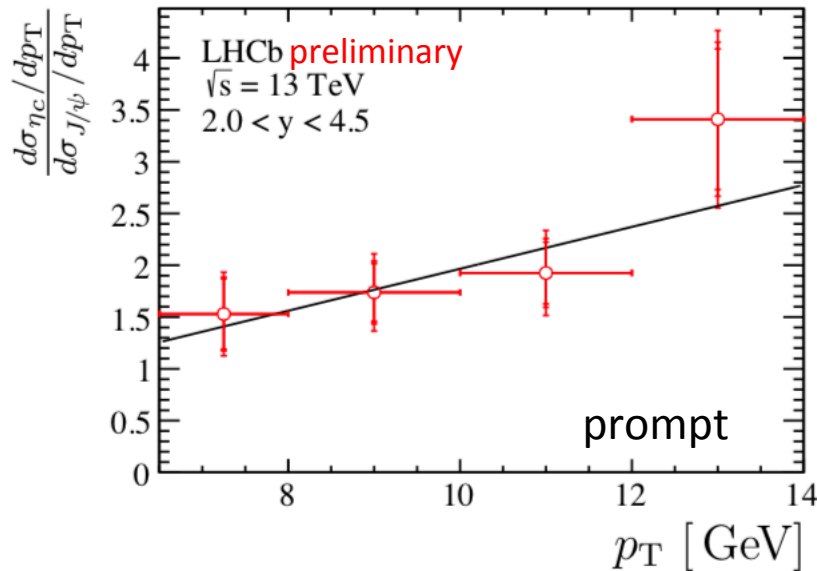
- Measure differential cross-section of  $\eta_c(1S) \rightarrow p\bar{p}$  decays.
  - Kinematic region:  $2.0 < y < 4.5$  and  $6.5 < p_T < 14.0$  GeV.
- First measurement of relative  $\eta_c(1S)$  cross-section.
  - Prompt production and from inclusive-b decays.
  - Normalisation determined using  $J/\psi \rightarrow p\bar{p}$  decays.
- Determine absolute cross-section and branching fraction.
  - $\sigma_{\eta_c} = 1.26 \pm 0.11 \pm 0.08 \pm 0.14$   $\mu\text{b}$  (using  $\sigma_{J/\psi}$  from arXiv:1509.00771).
  - $BR_{b \rightarrow \eta_c X} = (5.51 \pm 0.32 \pm 0.29 \pm 0.77) \times 10^{-3}$  (using  $BR_{b \rightarrow J/\psi X}$  from PDG).

Preliminary

# Measurement of $\eta_c(1S)$ production at $\sqrt{s} = 13$ TeV

LHCb-PAPER-2019-024 (LHCb preliminary)

Run 2, 2.0 fb<sup>-1</sup>



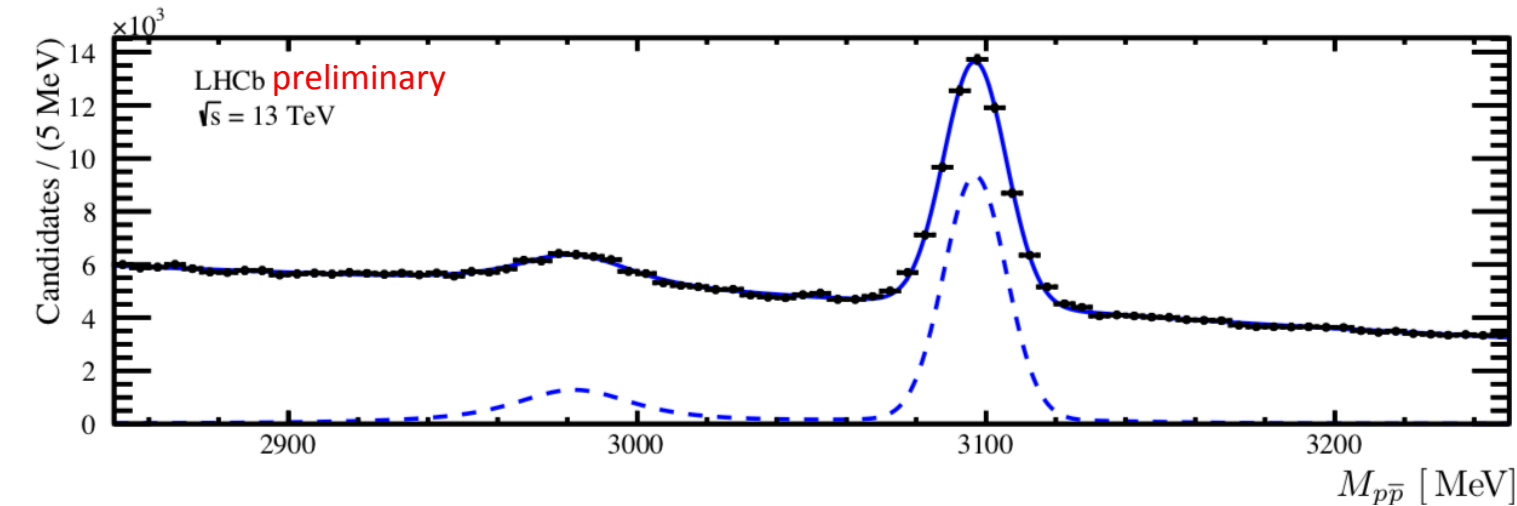
- Measure differential cross-section of  $\eta_c(1S) \rightarrow ppbar$  decays.
  - Kinematic region:  $2.0 < y < 4.5$  and  $6.5 < p_T < 14.0$  GeV.
- First measurement of relative  $\eta_c(1S)$  cross-section.
  - Prompt production and from inclusive-b decays.
  - Normalisation determined using  $J/\psi \rightarrow ppbar$  decays.
- Determine absolute cross-section and branching fraction.
  - $\sigma_\eta = 1.26 \pm 0.11 \pm 0.08 \pm 0.14$   $\mu\text{b}$  (using  $\sigma_{J/\psi}$  from arXiv:1509.00771).
  - $BR_{b \rightarrow \eta X} = (5.51 \pm 0.32 \pm 0.29 \pm 0.77) \times 10^{-3}$  (using  $BR_{b \rightarrow J/\psi X}$  from PDG).

Preliminary

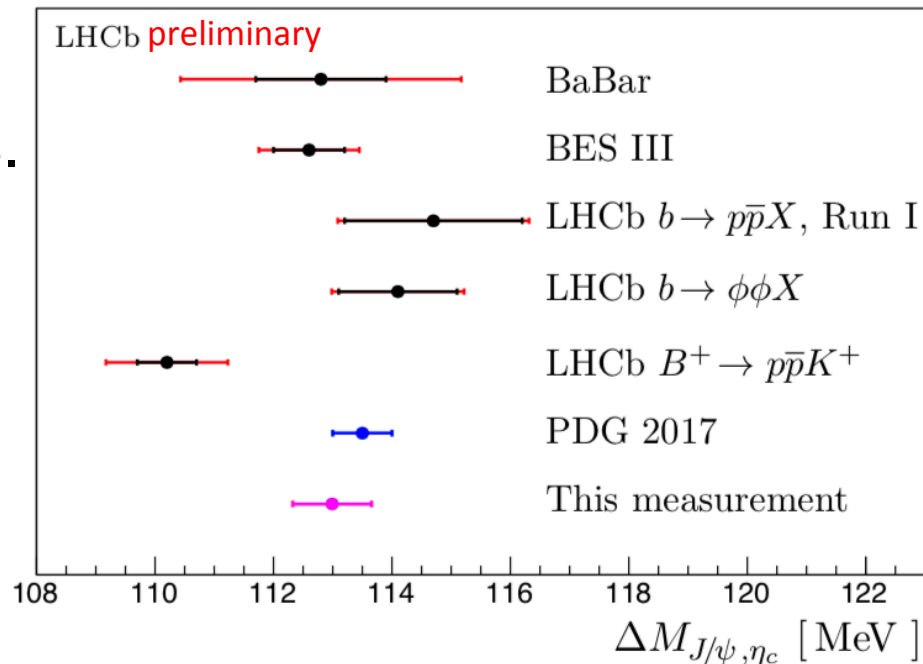
# Measurement of $\eta_c(1S)$ production at $\sqrt{s} = 13$ TeV

LHCb-PAPER-2019-024 (LHCb preliminary)

Run 2, 2.0 fb<sup>-1</sup>



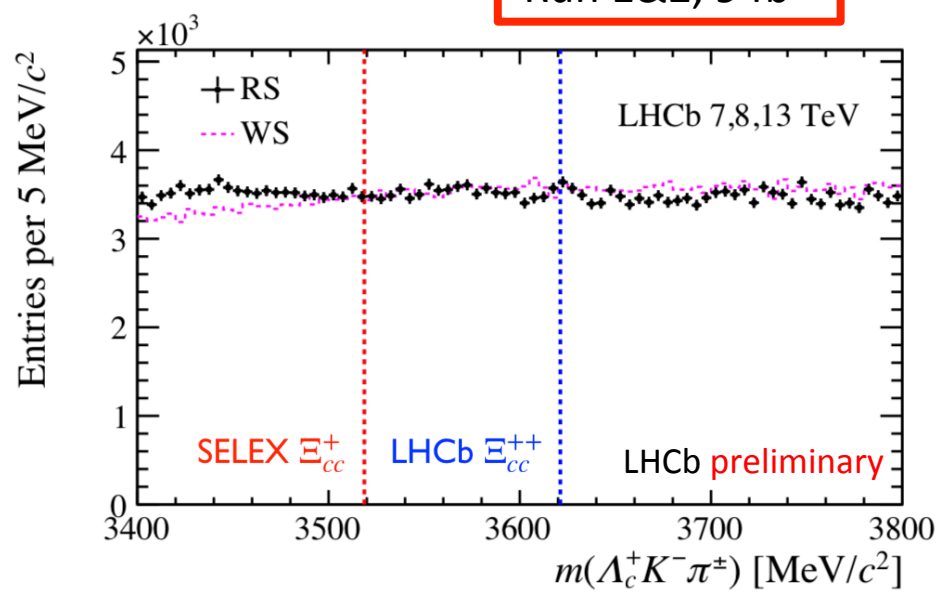
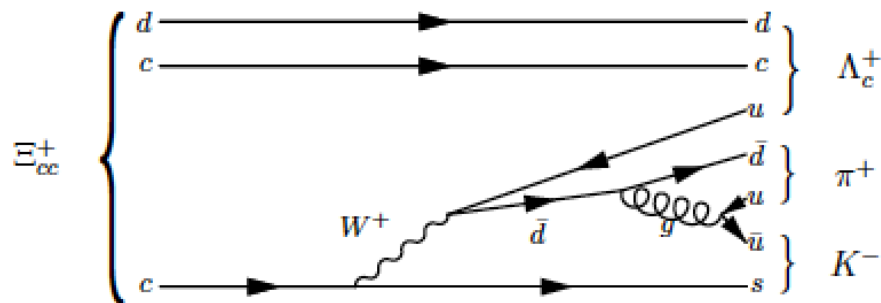
- Measured  $J/\psi$  and  $\eta_c$  mass difference using  $b \rightarrow \eta_c X$  decays.
  - Extracted from extended maximum likelihood fit to  $M_{p\bar{p}}$ .
- Most precise  $\eta_c$  mass determination to date:
  - $\Delta m_{J/\psi, \eta_c} = 113.0 \pm 0.7 \pm 0.1$  MeV



# Search for the doubly charmed baryon $\Xi_{cc}^+$

LHCb-PAPER-2019-029 (LHCb preliminary)

Run 1&2, 9 fb<sup>-1</sup>

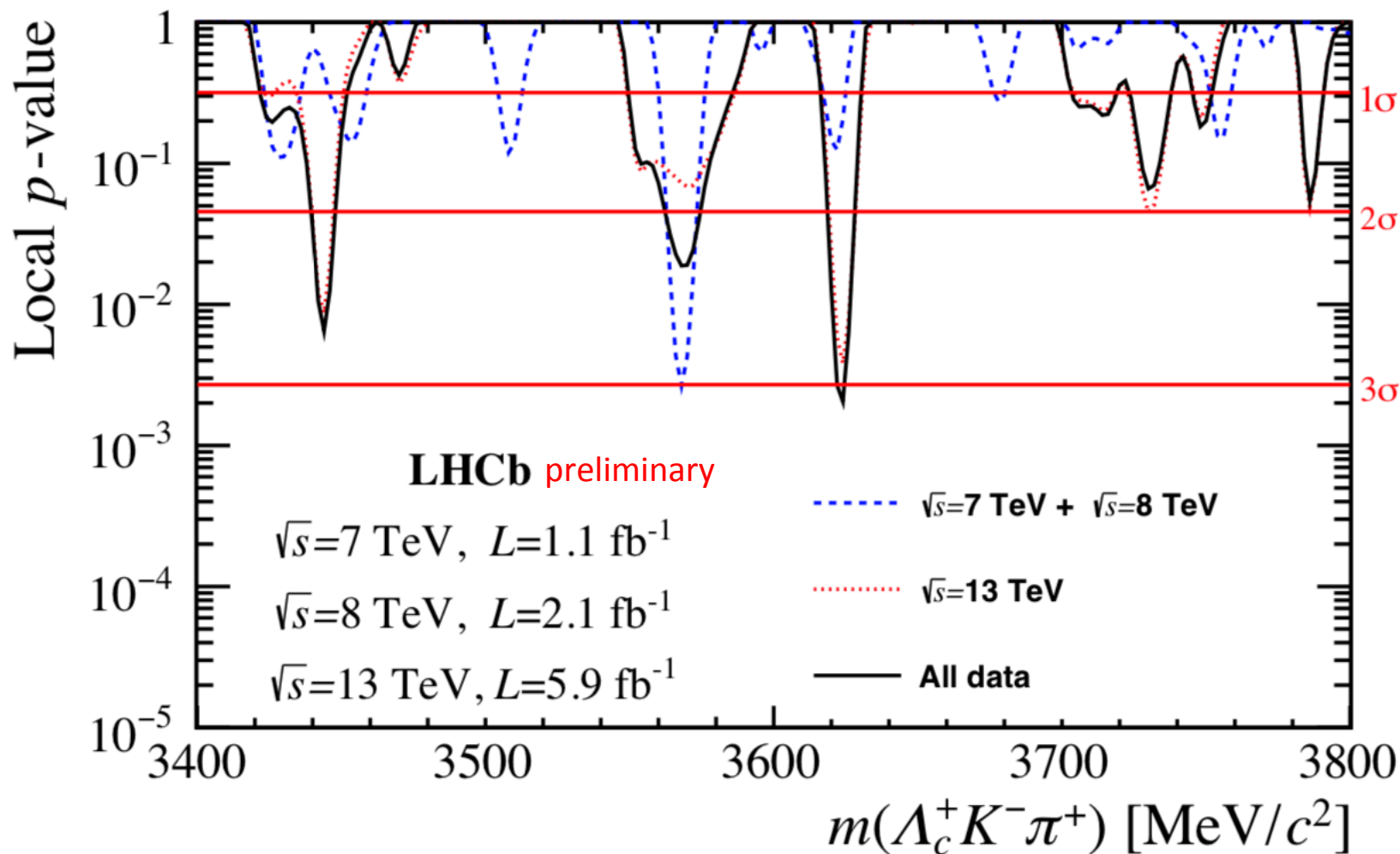


- Search for  $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$  decay ( $\Lambda_c^+ \rightarrow p K^- \pi^+$ ).
  - Predicted mass similar to  $\Xi_{cc}^{++}$  but with shorter lifetime.
  - Branching ratio  $\sim 10\%$ .
  - Observed by SELEX collaboration. [PRL. 89 (2002) 112001, arXiv:hep-ex/0208014]
- Based on LHCb Run 1 & 2 data.

# Search for the doubly charmed baryon $\Xi_{cc}^+$

LHCb-PAPER-2019-029 (LHCb preliminary)

Run 1&2, 9 fb<sup>-1</sup>

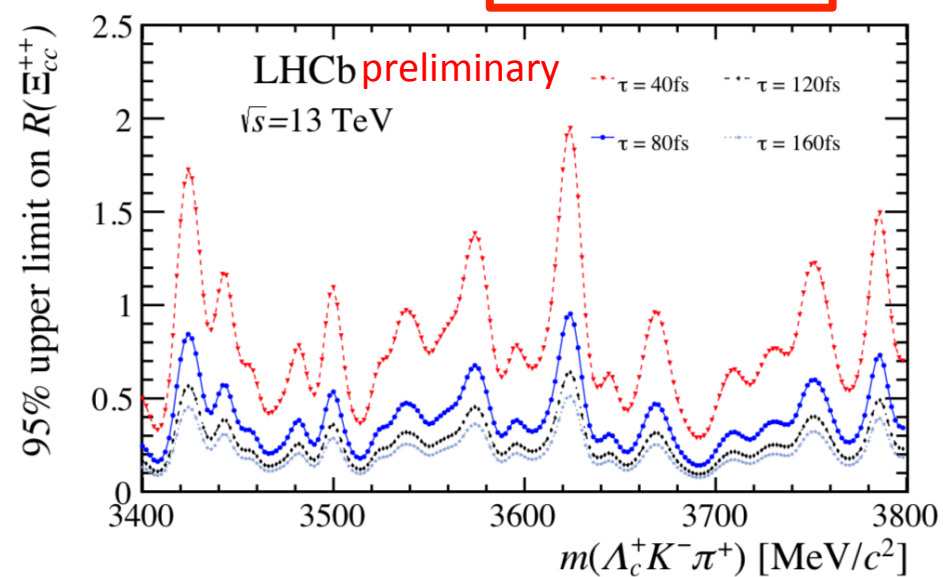
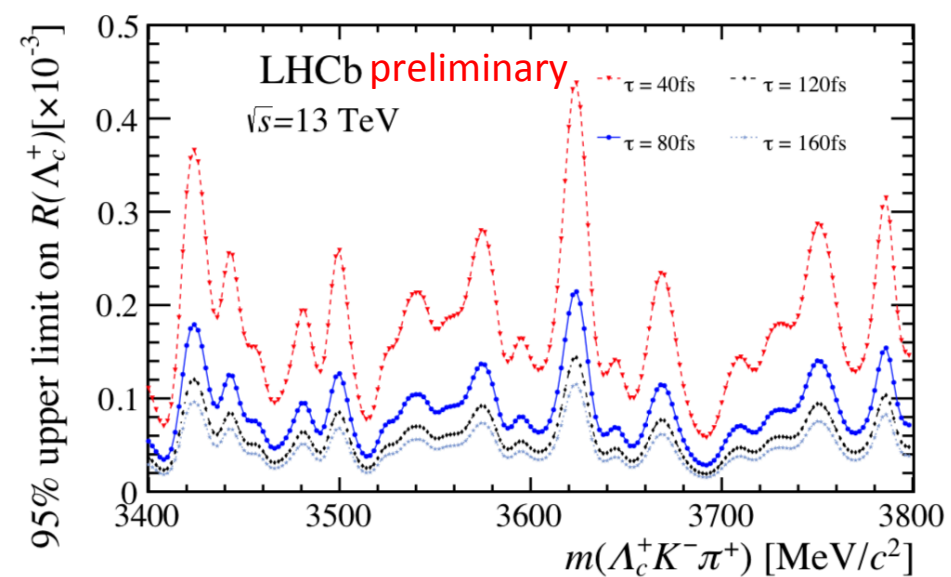


- Local significance of 3.1σ around  $m=3620$  MeV/c<sup>2</sup>.
- Global significance of 1.7σ → no observation.

# Search for the doubly charmed baryon $\Xi_{cc}^+$

LHCb-PAPER-2019-029 (LHCb preliminary)

Run 1&2, 9 fb<sup>-1</sup>



$$R(\Lambda_c^+) \equiv \frac{\sigma(\Xi_{cc}^+) \times \mathcal{B}(\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)}$$

$$R(\Xi_{cc}^{++}) \equiv \frac{\sigma(\Xi_{cc}^+) \times \mathcal{B}(\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+)}{\sigma(\Xi_{cc}^{++}) \times \mathcal{B}(\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+)}$$

- Set upper limits on  $R$  as a function of mass for different lifetime hypotheses.

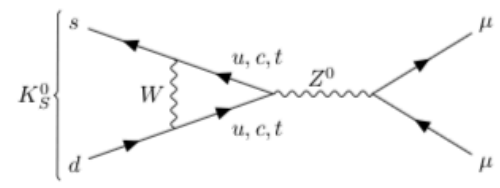
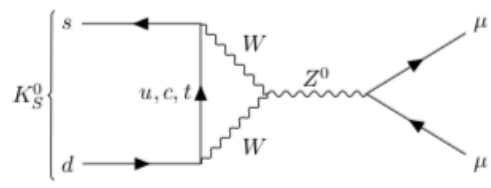
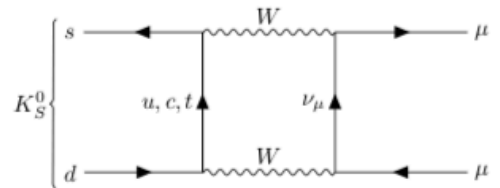
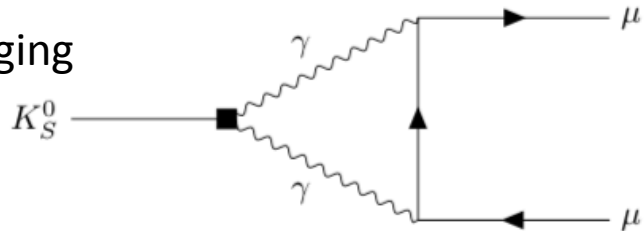
Run 2, 5.6 fb<sup>-1</sup>

SM: BR  $\sim 5 \times 10^{-12}$   
[JHEP 05 (2018) 024]  
[JHEP 01 (2004) 009]  
[NPB 366 (1991) 189]

LHCb-CONF-2019-002 (LHCb preliminary, presented at KAON yesterday\*)

\* See <https://indico.cern.ch/event/769729/contributions/3510936/> for more details.

- Strongly suppressed Flavour-changing Neutral Current (FCNC) transition.  $K_S^0 \rightarrow \gamma \gamma$
- Dominated by long distance contributions through  $K_S^0 \rightarrow \gamma \gamma$ .



Preliminary result obtained from the posterior probability of the branching fraction in the fit [LHCb-CONF-2019-002].

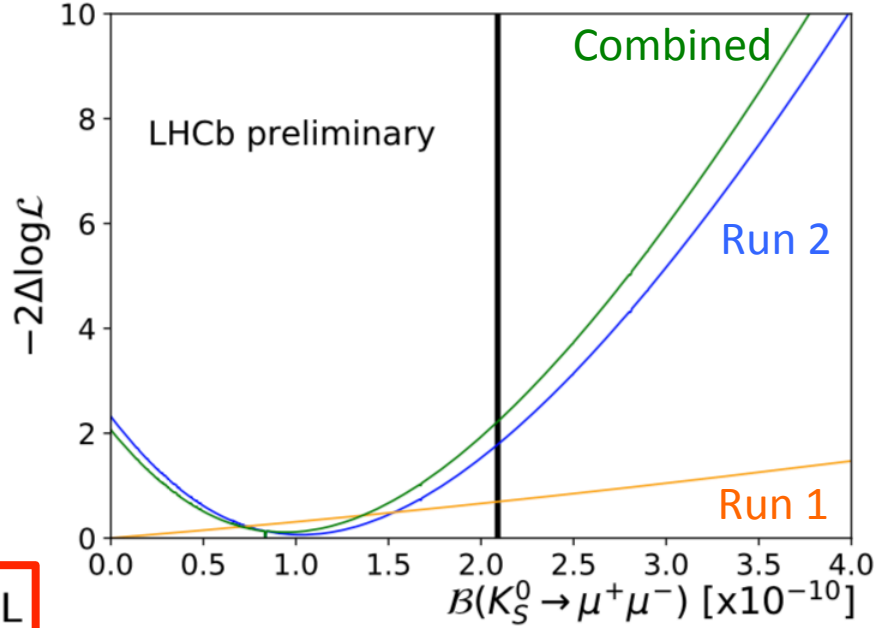
Using Run-II data only:

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) < 2.2(2.6) \times 10^{-10} \text{ at } 90(95)\% \text{ CL}$$

$$\text{Minimum: } \mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) = 1.03_{-0.68}^{+0.76} \times 10^{-10}$$

Combine with Run 1 [JHEP 01 (2013) 090]

$$\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-) < 2.1(2.4) \times 10^{-10} \text{ at } 90(95)\% \text{ CL}$$





Summary

# CONCLUSIONS

# Summary

## Upgrade I:

- Significant progress made by all sub-detectors.
  - Installation is underway!
  - All sub-detectors moving into production mode.
- Schedule is still tight.

## Upgrade II:

- Lots of R&D across collaboration.
- Preparing for Framework TDR.

## Physics:

- Many interesting results published.
  - Observations of new decay modes.
  - Precision measurements of branching fractions and masses.
  - Limits on very rare decays.
- Many more in the pipeline.



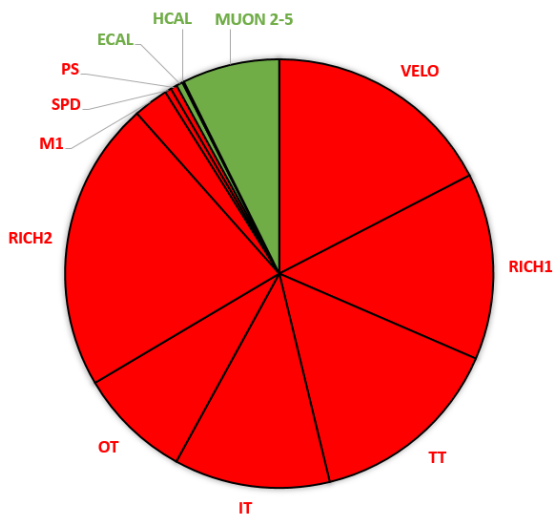
MORE?

**BACK UP**

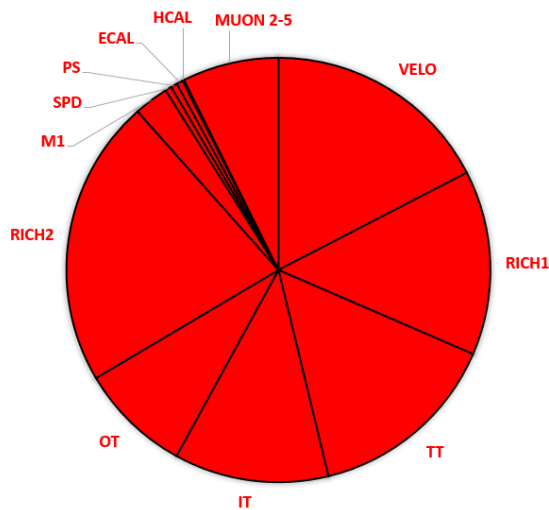
# LHCb Upgrade I

## Upgraded LHCb Detector

### Detector Channels



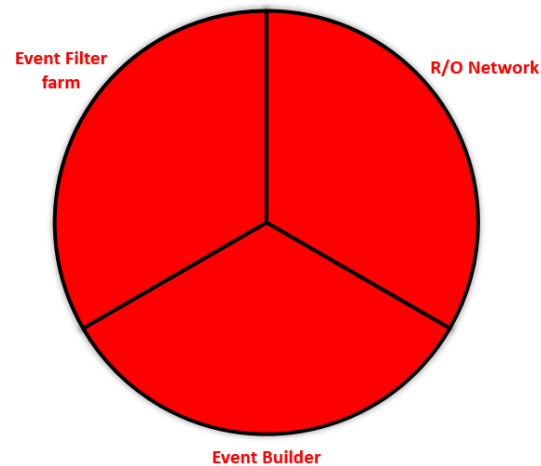
### R/O Electronics

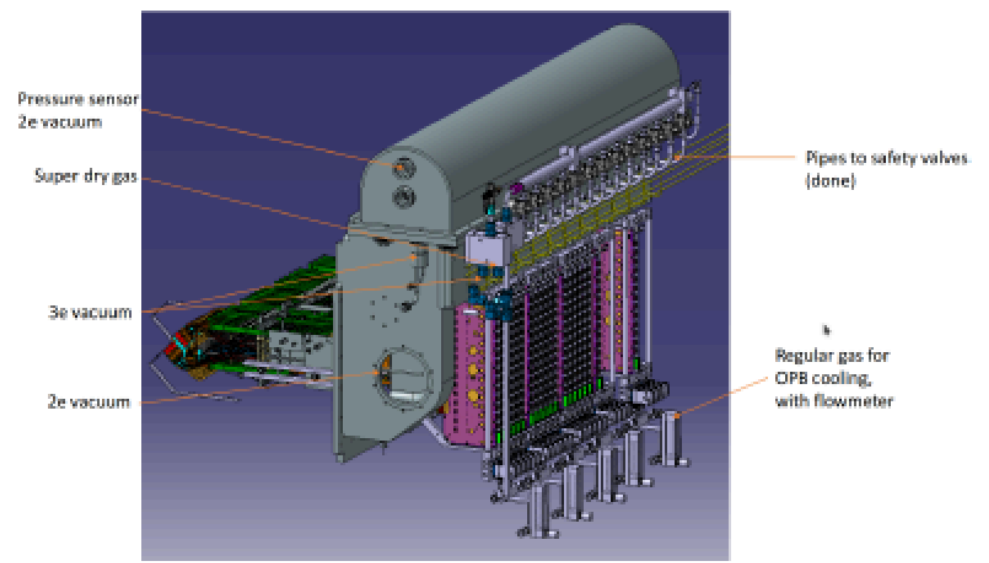
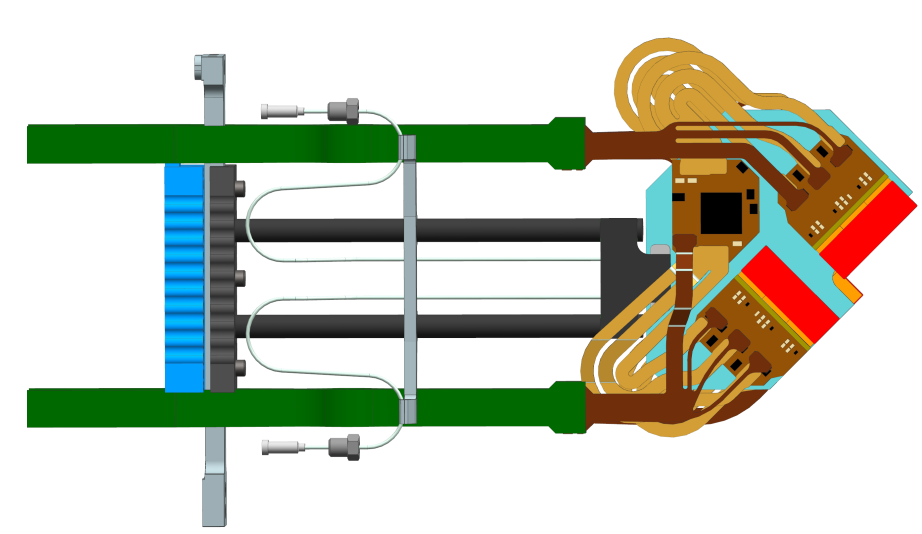
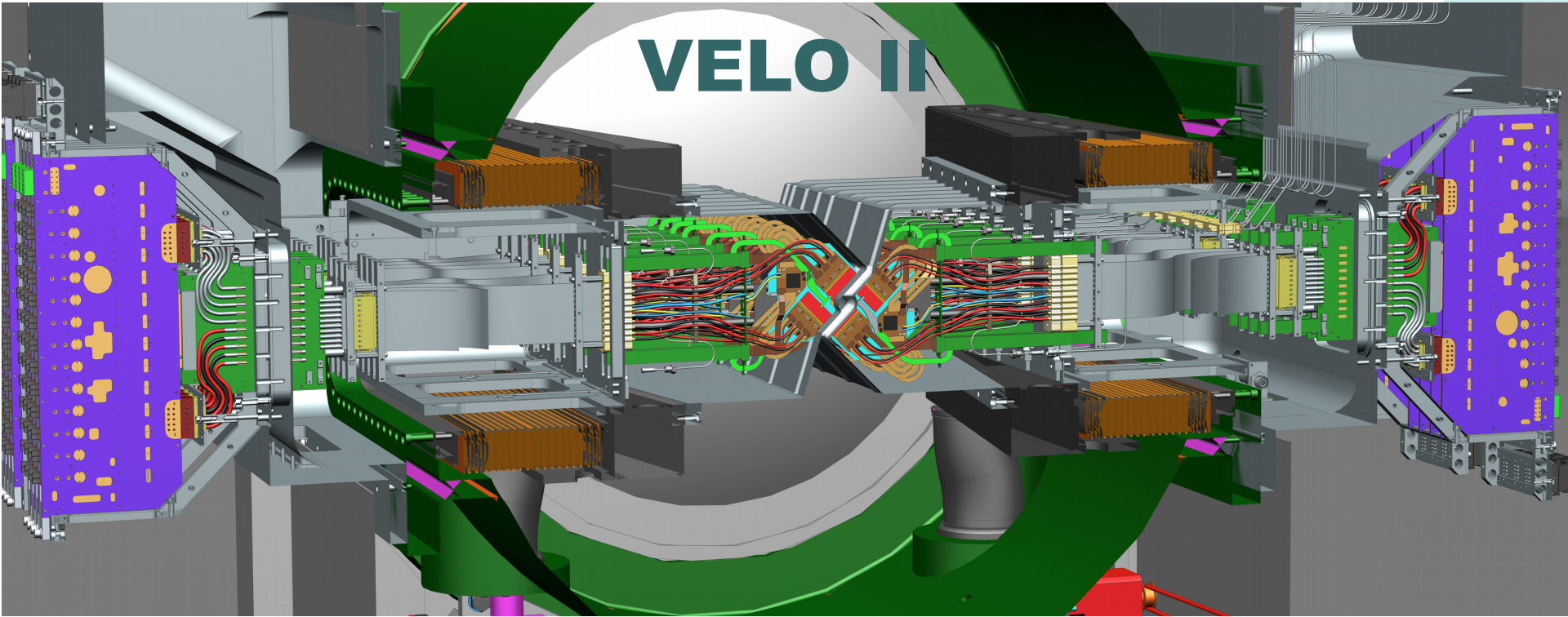


To be UPGRADED

To be kept

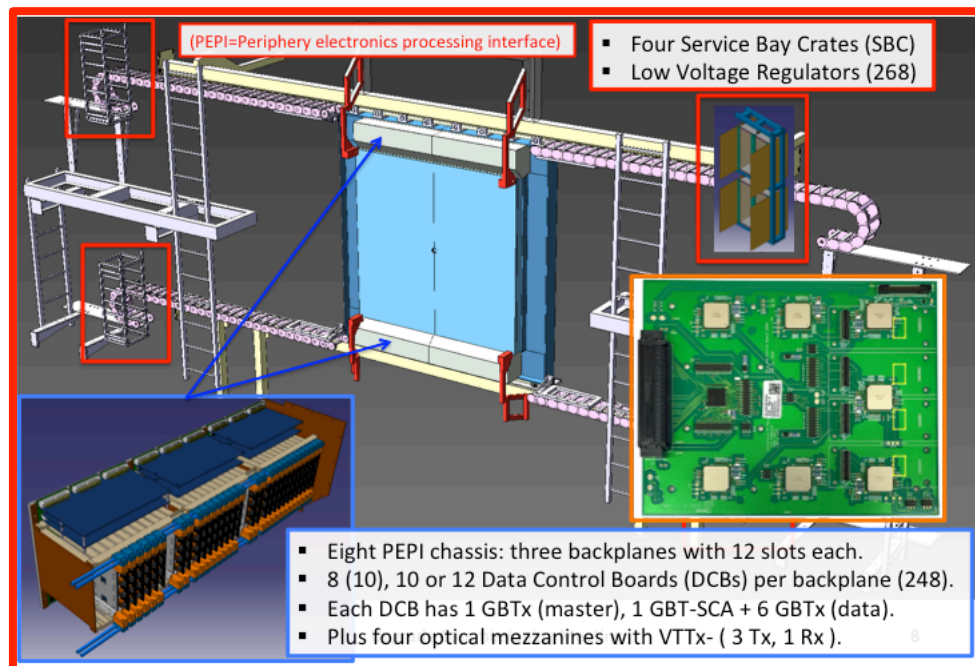
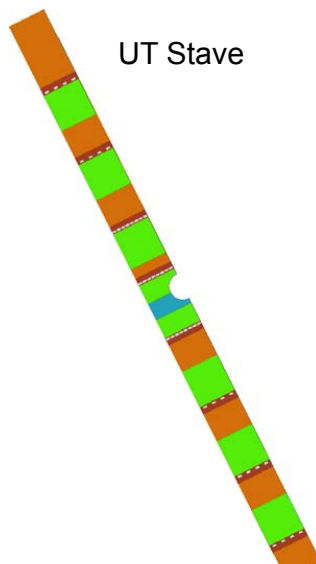
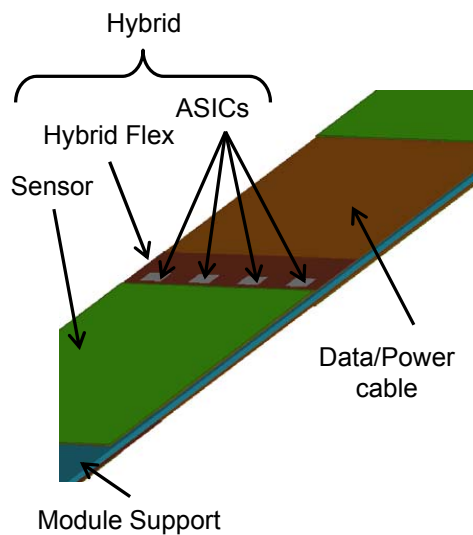
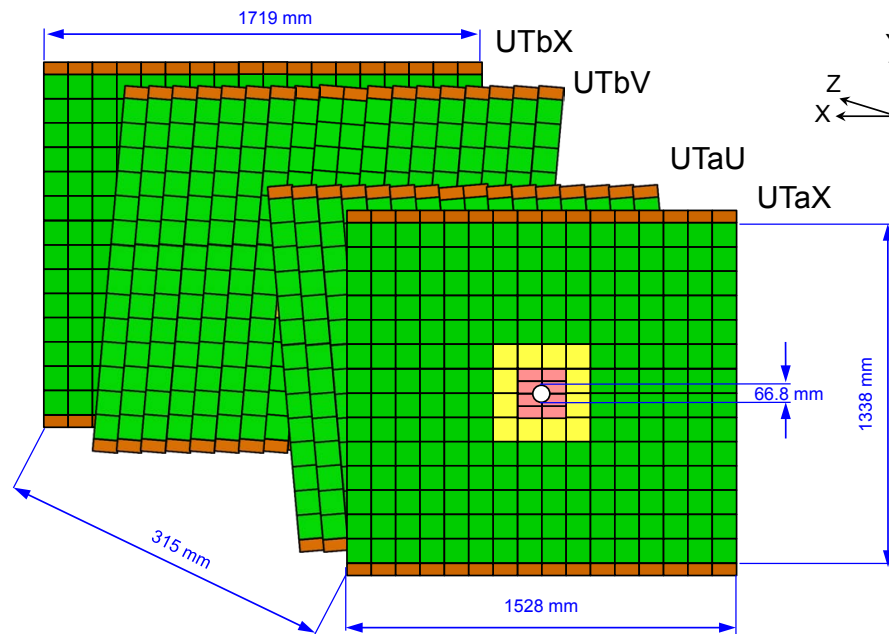
### DAQ





# Upstream Tracker

- Replace TT with new silicon strip detector.
  - Four layers (x, u, v, x) as now.
  - Sensors with 512 or 1048 strips.
  - 68 staves / 968 sensors.
  - 536,576 strips  $\approx 2 \times (TT+IT)$ .
- Read out with SALTv3 ASIC.
  - 128 channels with 6-bit ADC.
  - Pedestal & common-mode subtraction, zero-suppression.
  - Output up to 6 SLVS e-links per ASIC.
  - 1048 4-asic read-out sectors = 4192 ASICs.
- PEPI electronics outside acceptance.
  - Distributes TFC&ECS signals.
  - Collects serial data from ASICs (320 Mbps).
  - Transmits optical serial data via GBTx/VTTx ( $\sim 4.8$  Gbps).



11th September 2019

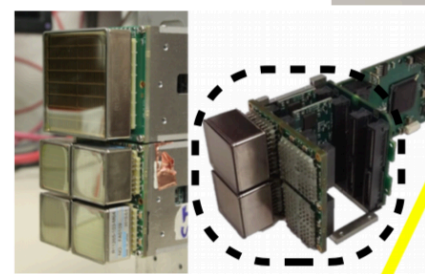
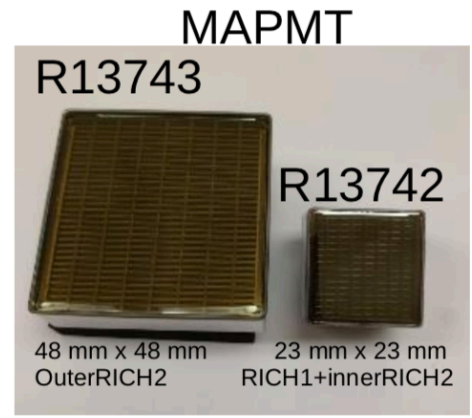
# RICH

**RICH1:**  
Change everything but the magnetic shielding

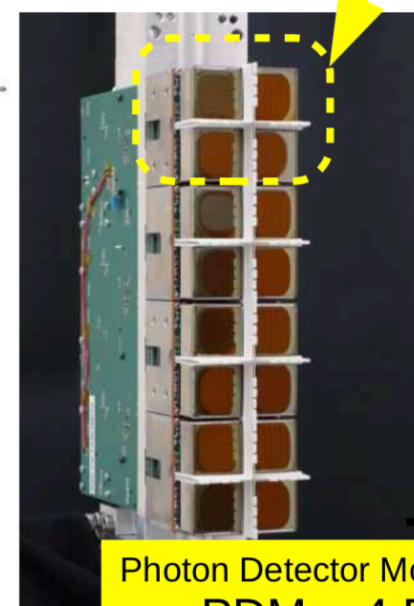
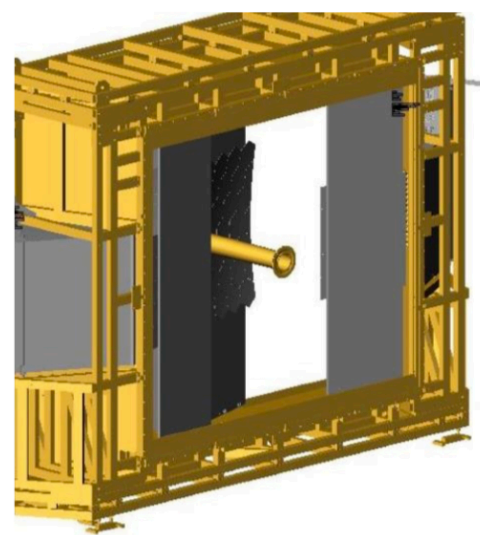
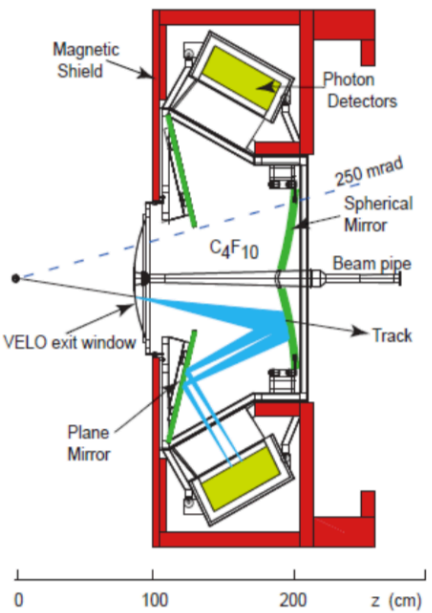
- mirrors, gas enclosure, quartz windows
  - Photon detectors, electronics, detector mechanics
- => 22 columns

**RICH2:**  
Change only detectors

- Photon detectors, electronics, detector mechanics
- => 24 columns



Elementary Cell  
EC = 4 or 1 xMAPMT + Baseboards



A column = 6 PDMs (on a "cold bar")

Photon Detector Module  
PDM = 4 ECs

