Status of LHCb and its upgrade

- Collaboration matters
- LHCb 2018 run summary
- 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 – 17/04/2019

Collaboration matters

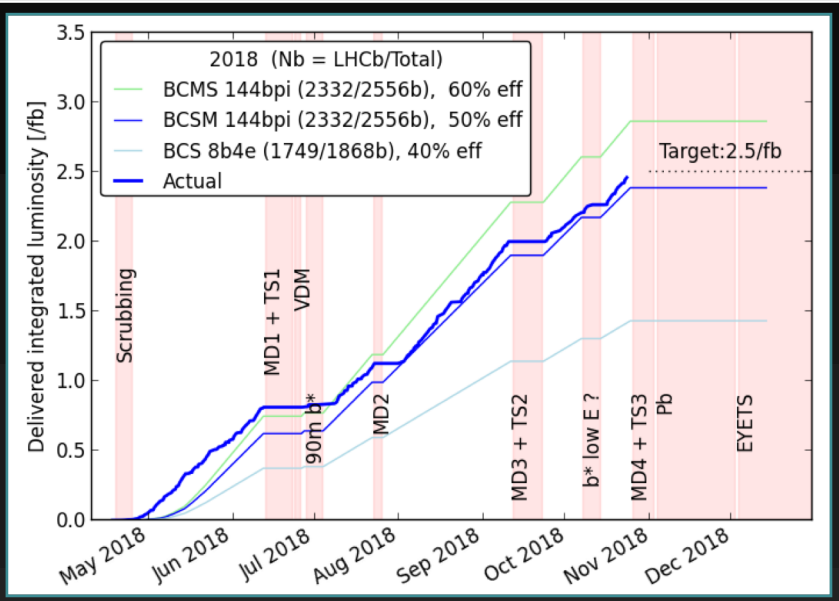
- The collaboration keeps growing
  - ★ Los Alamos National Lab group moved from associate member to full member
  - ★ Other groups queuing: discussion at the upcoming Collaboration Board in June

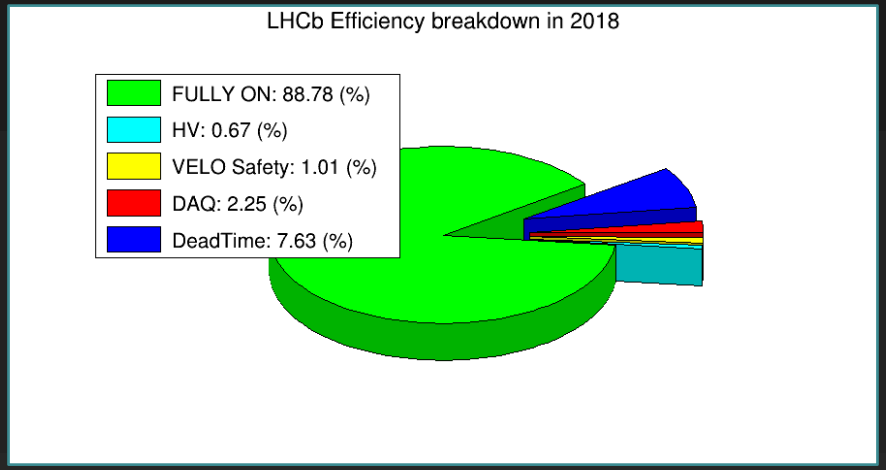
2018 LHCb run summary

A smooth luminosity harvest

2018 proton-proton run

- Excellent performance of LHC and LHCb
- Reached the target of 2.5 fb^{-1} delivered
- Slightly lower data taking efficiency
  - ★ Inefficiency dominated by a few failures due to the obsolescence of the infrastructure
  - ★ Still close to the maximum achievable of ~91%

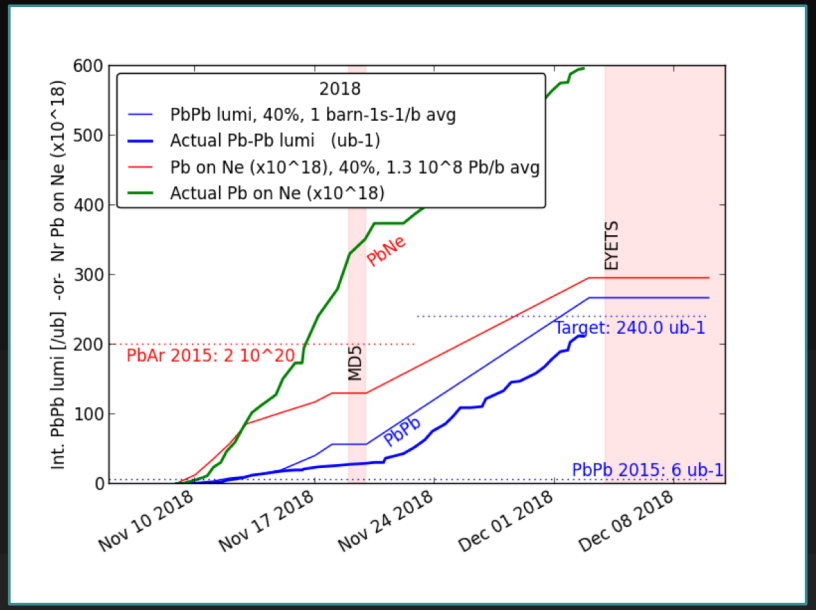


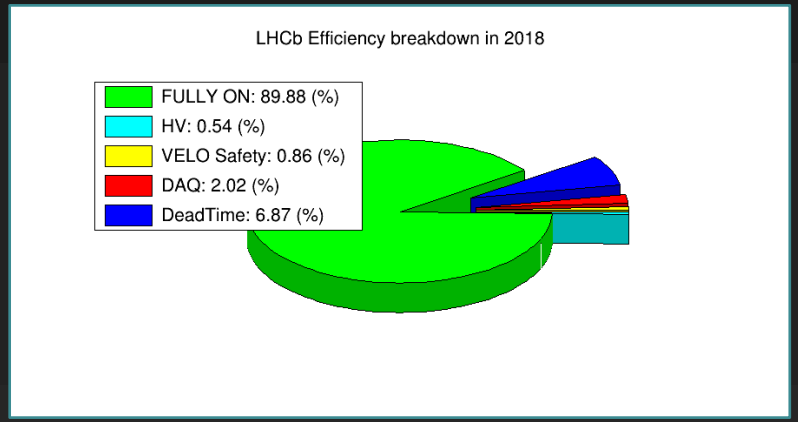


2018 heavy ion run

- Excellent Pb-Pb and Pb-Ne (fixed target) runs
- Delivered 240 μb^{-1} in Pb-Pb: x40 the sample collected in 2015!
- Delivered $6x10^{20}$ Pb on Ne in fixed target mode: x3 the Pb-Ar sample in 2015
- 90% efficiency

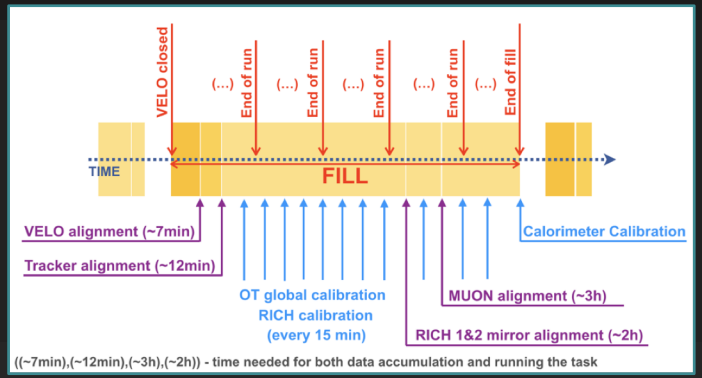
- A ~~gold~~ lead mine ready to be explored!

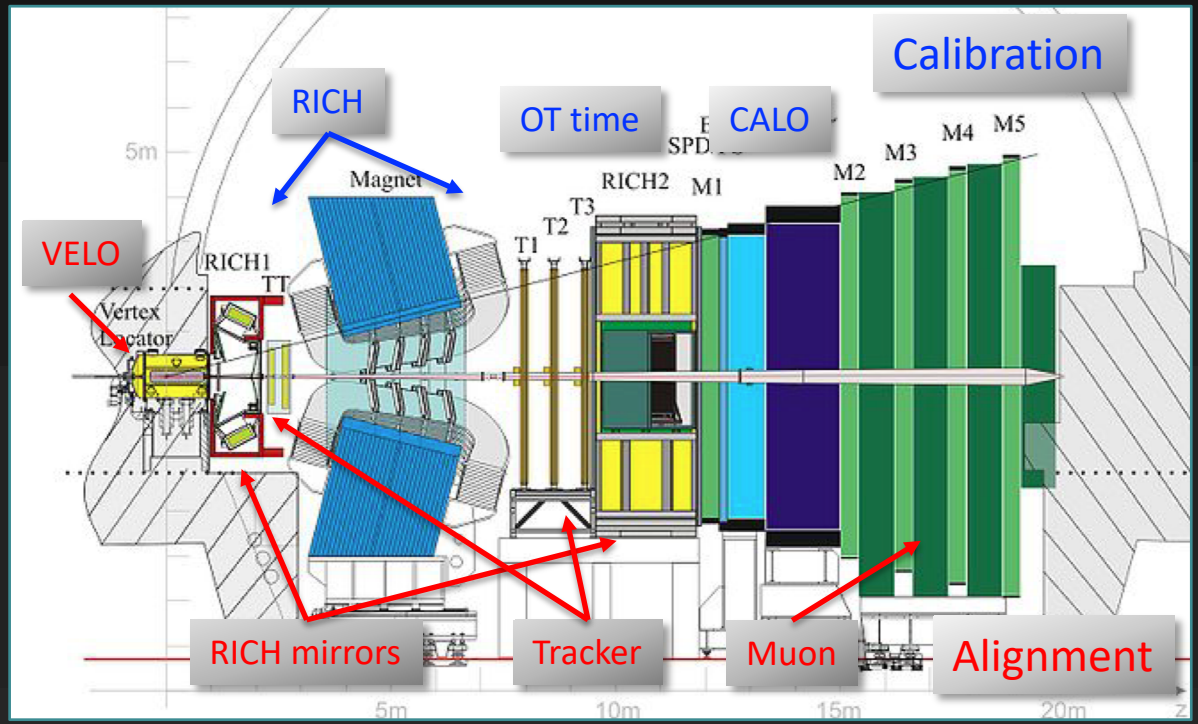




Detector operations in 2018

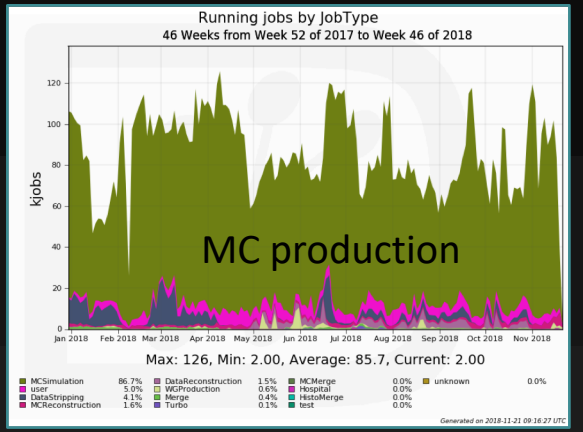
- Very smooth operations
  - ★ ☞ very stable trigger conditions ☞ easy and quick exploitation of data!
- Real time analysis!
  - ★ RT alignment and calibrations fully automated
- ☞ First physics results with the full Run1 + Run 2 already published!

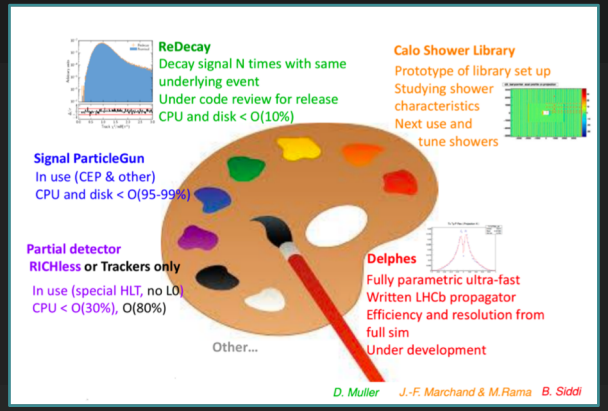


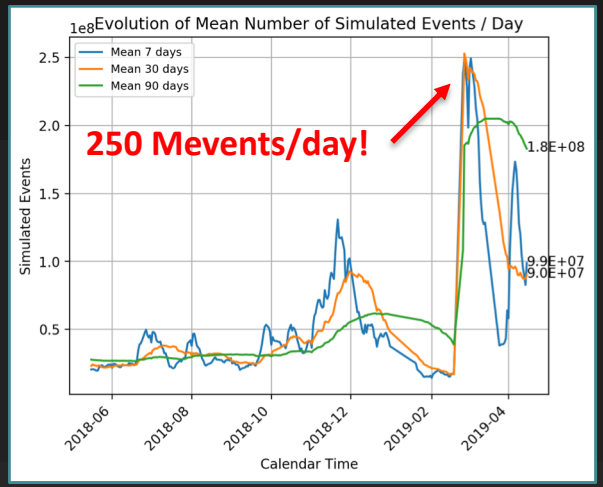


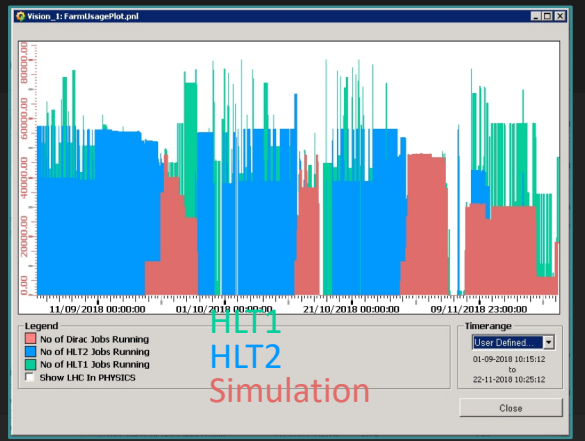
Computing resource usage

- CPU resource usage dominated by Monte Carlo production
- Optimal usage of the trigger farm helps to reduce the backlog in MC production
- We have now a wide palette of new faster simulation techniques
  - ★ Techniques like reusing many times the same underlying event or simulating only the tracking detectors are already in use with large reduction factors in CPU time







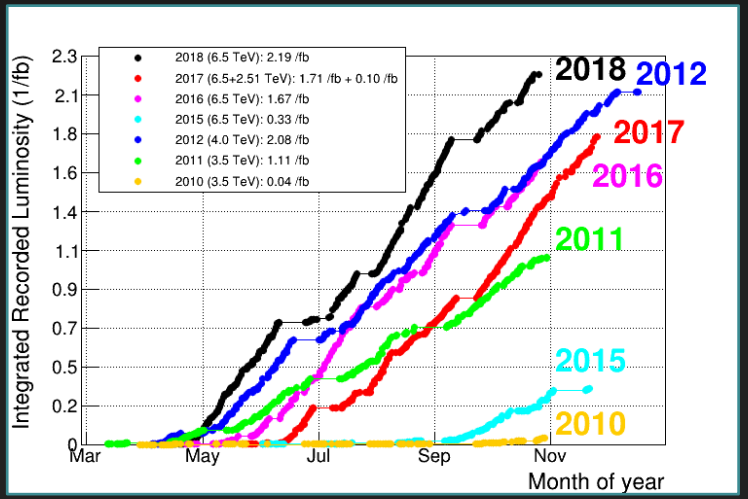


LHCb 1995-2018: the end (?)

A quick summary of a glorious history

Luminosity 2010-2018: a round 10 fb^{-1}…

- Got exactly the target luminosity that was hinted at the times of the Technical Proposal (~1998)!



Including:
- 0.04 fb^{-1} 2010 and
- 0.13 fb^{-1} 2017 (√s=5TeV)

Integrated luminosity counters in 2018 [1/pb]

	Recorded	Delivered	Efficiency
Current Fill	0.0	0.0	0.0
Annual	2190.9	2456.5	89.2
Mag DOWN	1055.7	1174.1	89.92
Mag UP	1133.7	1280.8	88.51
2010-2018	9227.1	10180.9	90.63

Excluding:
- 0.04 fb^{-1} 2010 and
- 0.13 fb^{-1} 2017 (√s=5TeV)

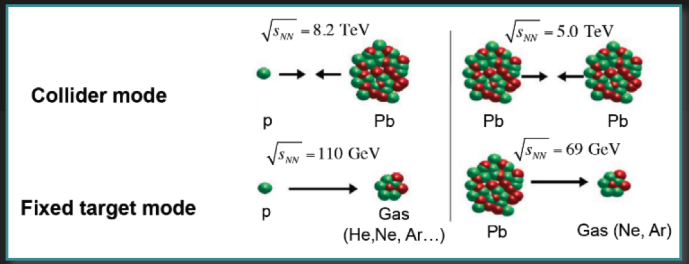
	Recorded Lumi (pb^{-1})	Delivered Lumi (pb^{-1})
2011	1.11	1.22
2012	2.08	2.20
Run-1	3.2	3.4
2015	0.33	0.36
2016	1.67	1.88
2017 (5TeV)	1.71 (0.10)	1.86 (0.13)
Run-2	3.7	4.1
Total	6.9	7.5
2018	2.19	2.45
Total	9.1	10.0

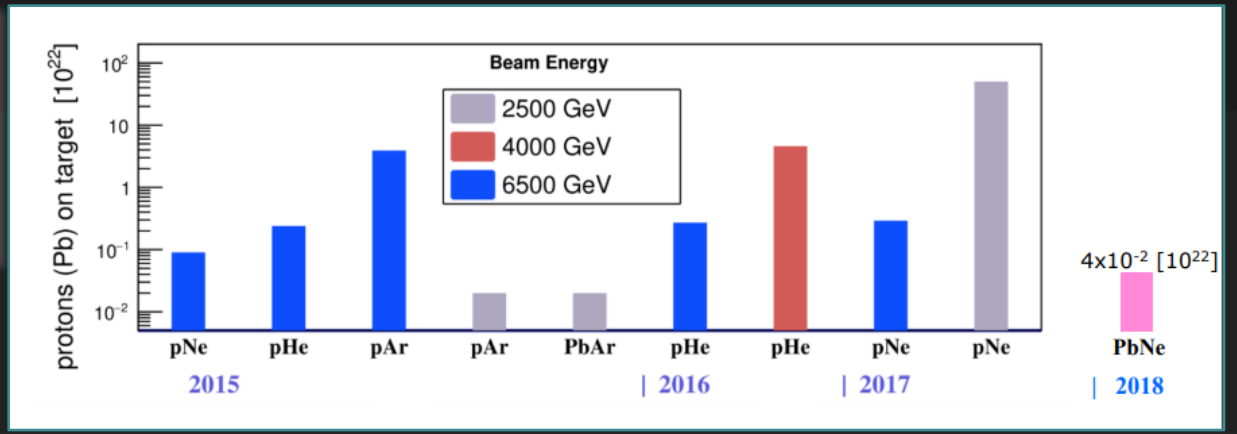
27 Nov 2018 - LHCC - N. Tuning

…in a range of running modes!

- Different c.o.m. energies
- Collider mode
- Fixed target mode
- Combined
- p-p, Pb-Pb, p-Pb, p-A, Pb-A (A= He, Ne, Ar)

E (Z TeV)	$\sqrt{s_{NN}}$							
	pp		Pb-p		Pb-Pb		Xe-Xe	
	$\sqrt{s}=2E$		$\sqrt{s}=2E\sqrt{r}$		$\sqrt{s}=2Er$		$\sqrt{s}=2Er$	
1.38	2.76	2013						
2.51	5.02	2015 2017						
3.5	7	2011	4.40		2.76	2010 LHCb off		
4	8	2012	5.02	2013 2016	3.15			
6.37			8.00		5.02	2015 2018		
6.5	13	2015-2018	8.16	2016	5.13		5.44	2017





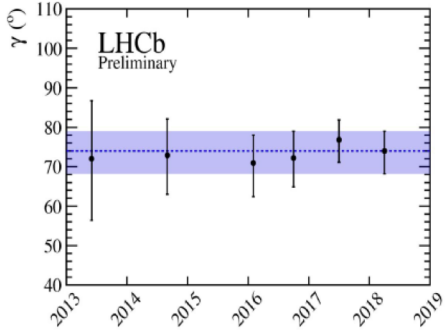
Did we achieve our goals?

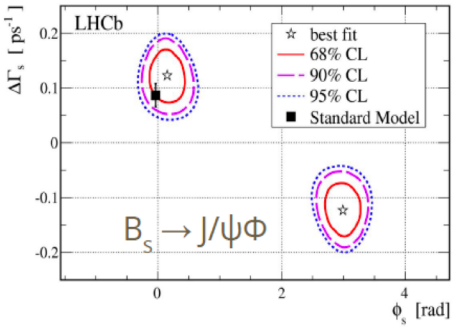
From the Roadmap document [LHCb-PUB-2009-029]:

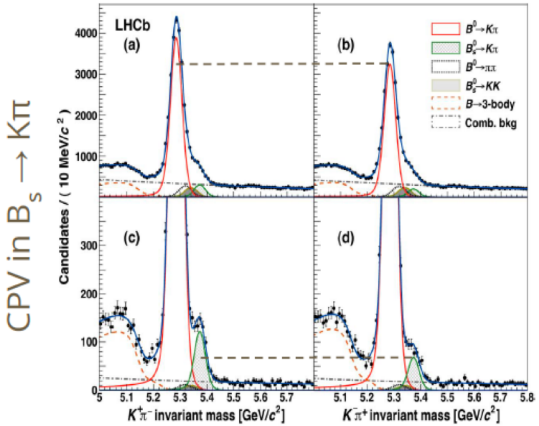
Did we achieve our goals?

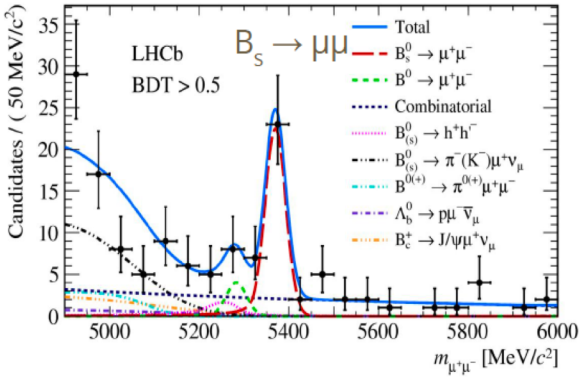
JHEP 02 (2016) 104, Phys.Rev.Lett.118 191801, LHCb-CONF-2018-002, Phys.Rev.Lett.108 101803, Phys.Rev.Lett.118 021801, Phys.Rev.Lett.110 221601

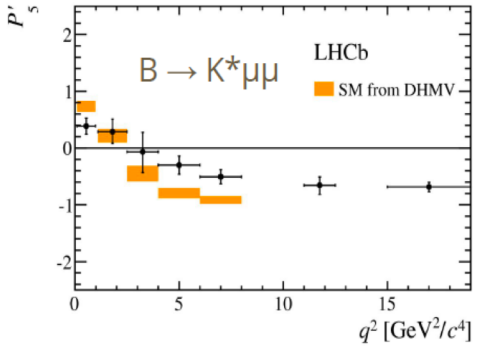
From the Roadmap document [LHCb-PUB-2009-029]:

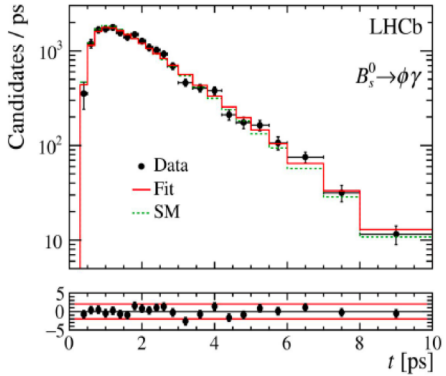








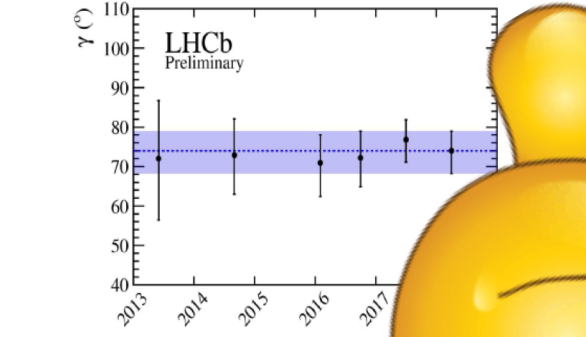


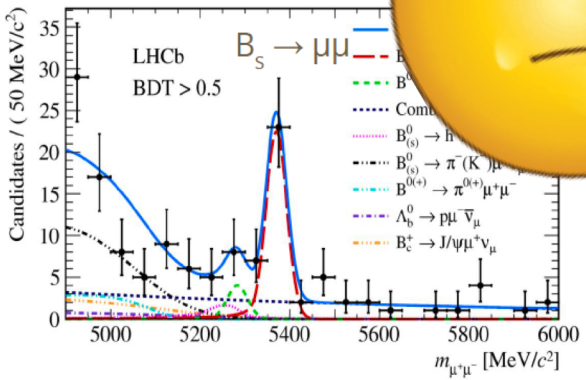


Did we achieve our goals?

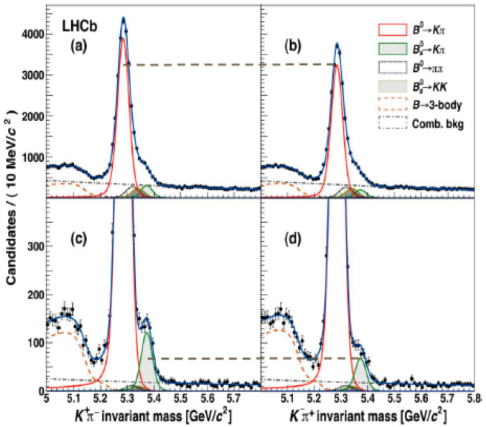
JHEP 02 (2016) 104, Phys.Rev.Lett.118 191801, LHCb-CONF-2018-002, Phys.Rev.Lett.108 101803, Phys.Rev.Lett.118 021801, Phys.Rev.Lett.110 221601

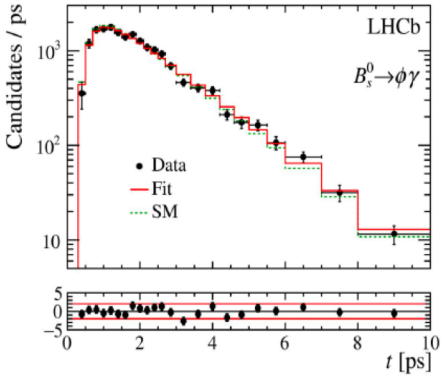
From the Roadmap document [LHCb-PUB-2009-029]:





CPV in $B_s \to K\pi$

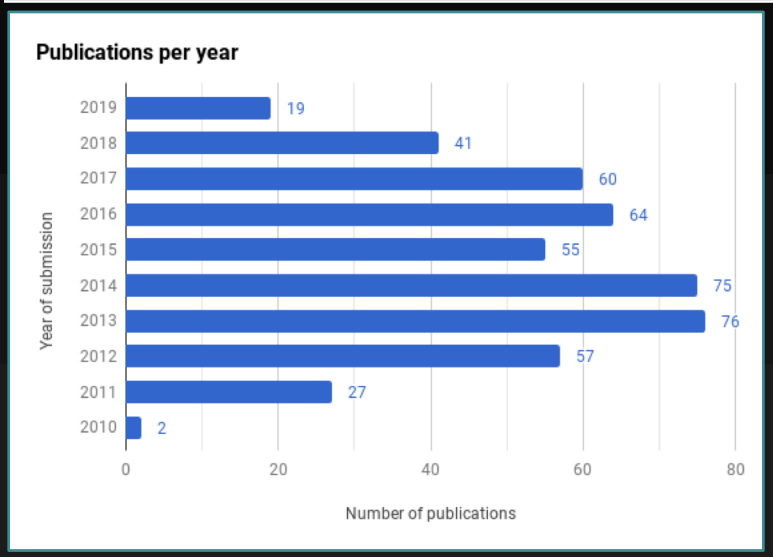




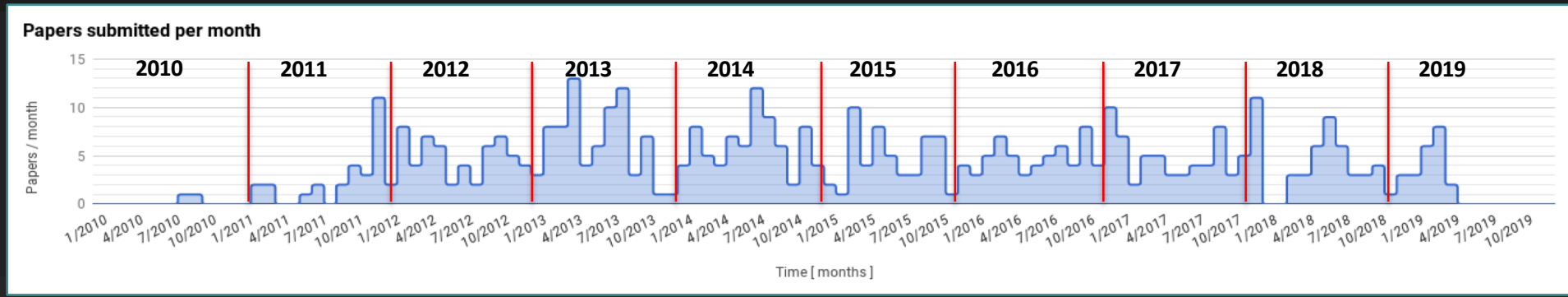
Mission accomplished… and a lot more!

An overview of recent physics highlights

Physics: paper production



- 476 papers submitted (25 since OCT '18 RRB)
  - ★ 41 in 2018, already **19 in 2019**
  - ★ 15 other papers being processed within the Editorial Board
- 21 further analyses under review
- …a good start!

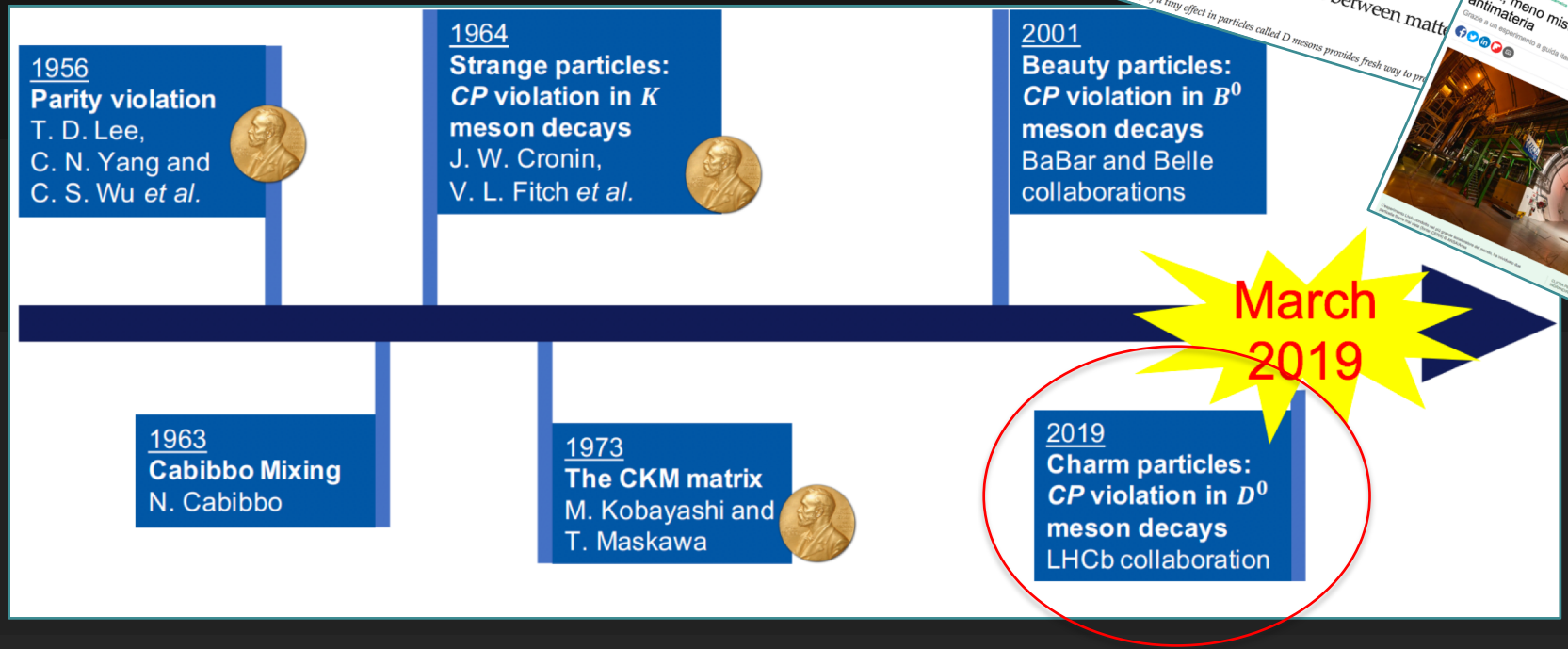


Surprising charming landscapes

- *Observation of CP violation in charm*
- *Measurement of mass difference of D^0 mass eigenstates*

Observation of CP violation in charm

- Long awaited, finally observed!



Observation of CP violation in charm

New!

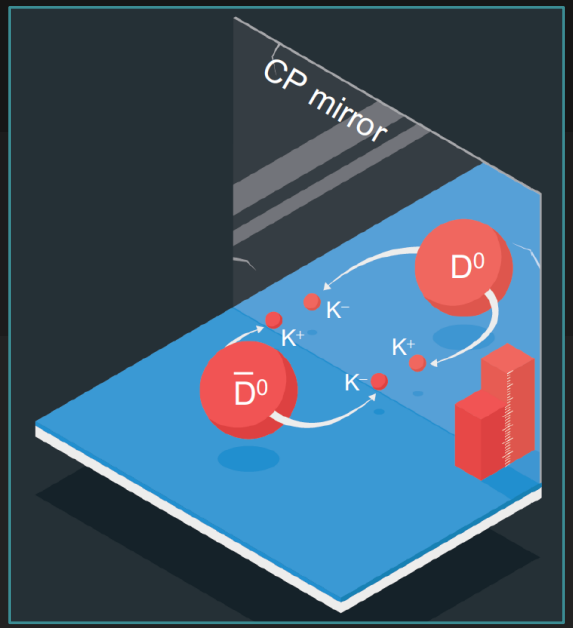
[arXiv:1903.08726 Run1+Run2 9 fb^{-1}]

Full run 1 + Run 2 sample!

- Count how many D^0 and anti-D^0 decay into $\pi^+\pi^-$ and K^+K^-
  - ★ ☞ If matter = antimatter the number of the two decays should be equal
- For technical reasons we prefer to measure the difference in matter-anti-matter asymmetry between decays into $\pi^+\pi^-$ and K^+K^-: ΔA_{CP}
  - ★ should be exactly zero if matter = antimatter
- Result:

$$\Delta A_{CP} = (-15.4 \pm 2.9)\times 10^{-4}$$

- A tiny but significant (5.3 σ !) difference from zero!
- Roughly compatible with the SM, which however is way more uncertain than data
- Opens a new field of investigation



Obs

- Count hov
  - ★ ☞ If r
- For techni
  between
  - ★ shoul
- Result:

ΔA_C

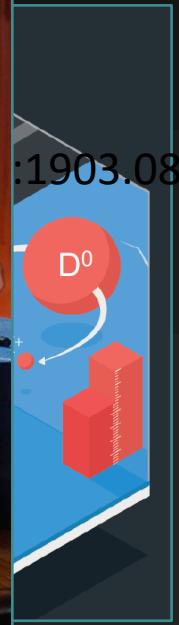
- A tiny b
- Roughly c
  is way mo
- Opens a n

26 Run1+Run2 9 fb^{-1}]

un 2 sample!

etry

:1903.08726

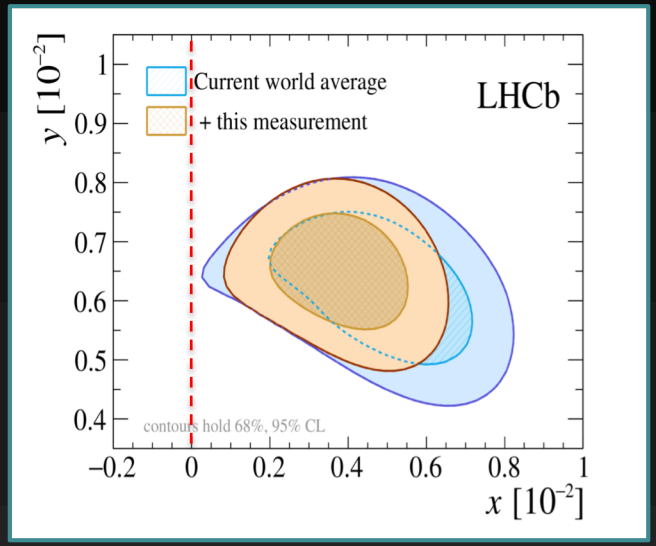


Oscillations of charm mesons

New!

arXiv:1903.03074 Run1 3 fb^{-1}]

- Neutral mesons can “oscillate”, i.e. transform into each other: $M^0 \leftrightharpoons \overline{M}^0$
- The two quantum states in which these mesons incarnate when freely flying have slightly different masses m_H and m_L
- $x \equiv \tau\Delta m$, $\Delta m \equiv (m_H - m_L)$ determine how fast they transform into each other.



- The value of x is very tiny for charm mesons: no confirmation that this is not zero until now!
- Can be enhanced by the presence of new particles beyond the SM
- Recent smart and precise measurement by LHCb provide the most precise determination of x by a single experiment
  $x = [2.7 \pm 1.6(\text{stat}) \pm 0.4(\text{syst})] \times 10^{-3}$

- **New WA provides first evidence of a mass difference between the neutral D mesons**
- Another step into precision charm physics

Precision is our business

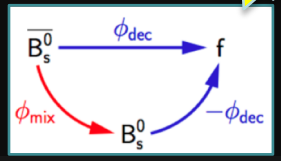
- *Measurement of the B_s mixing phase ϕ_s*

New measurement of the B_s mixing phase ϕ_s

New!

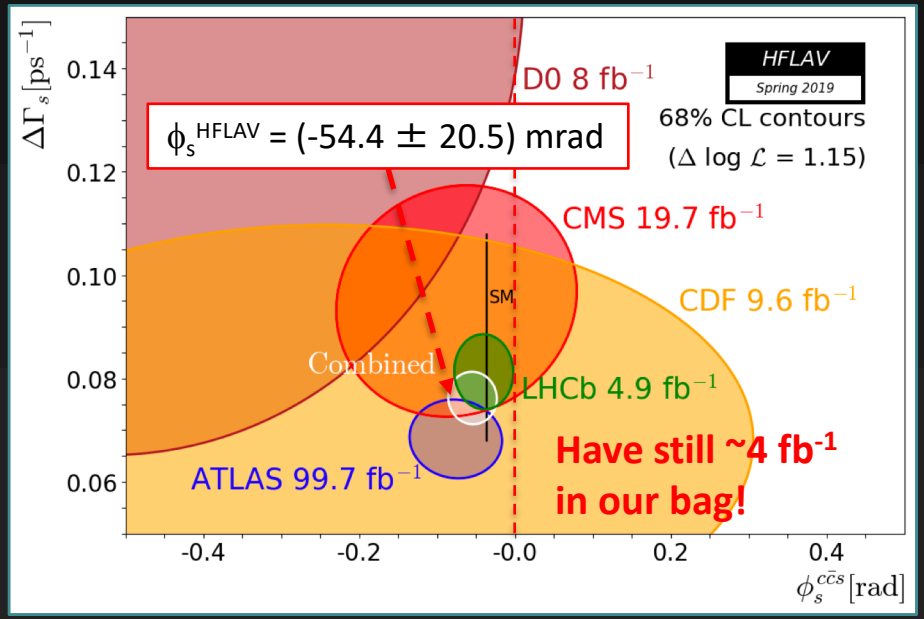
[LHCB-PAPER-2019-013 Run2 1.9 fb^{-1}]

- Measure the phase difference between the two processes
- Precisely determined within the SM:
  $\phi_s^{SM} = (-37.4 \pm 0.7)$ mrad



- VERY sensitive to contributions from new particles beyond the SM
- Very high precision measurement
- LHCb uses two decays: $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$
- New result just released using part of Run 2 data, combined with Run 1 yields

$$\phi_s = (-40 \pm 25) \text{ mrad}$$



- Combined value approaching the sensitivity to observe a non zero value!

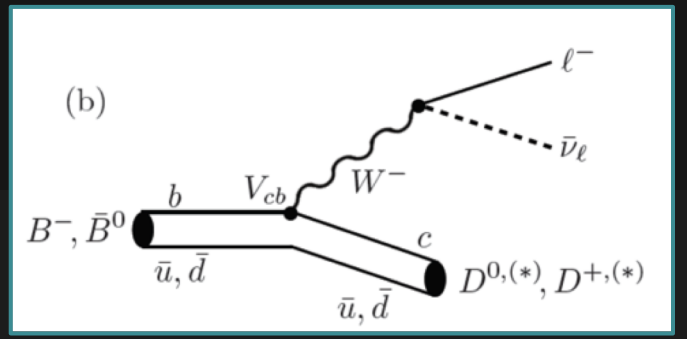
Rare decays, a window on new physics

- *Test of lepton flavour universality: new measurement of R(K)*

Tests of lepton flavour universality

- Lepton flavour universality can be checked in several B meson decays involving leptons in the final state

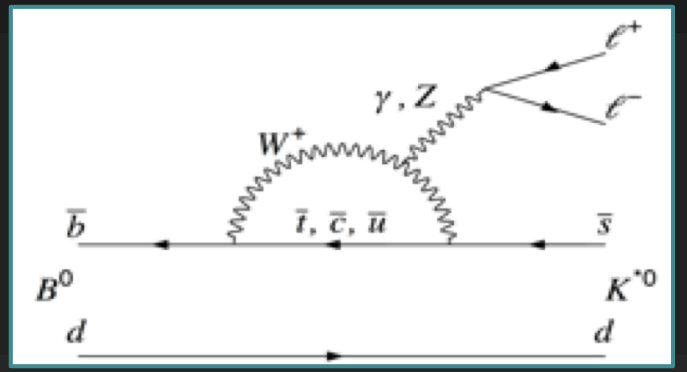
- Two main classes of decays have been studied:
  - ★ Semileptonic $B^0 \to D^{(*)-} l^+ \nu$ - tree level decay
  - ★ $b \to s l^+ l^-$ decays e.g. $B^0 \to K^{(*)0} l^+ l^-$ - FCNC decays



- Observables:

$$R(D^*) = \frac{BF(B \to D^* \tau \nu)}{BF(B \to D^* \mu \nu)} \overset{SM}{=} 0.252 \pm 0.003$$

$$R(K^{(*)}) = BF(B \to K^{(*)} \mu^+ \mu^-) / BF(B \to K^{(*)} e^+ e^-) \underset{SM}{\sim} 1$$



- Theoretically clean!

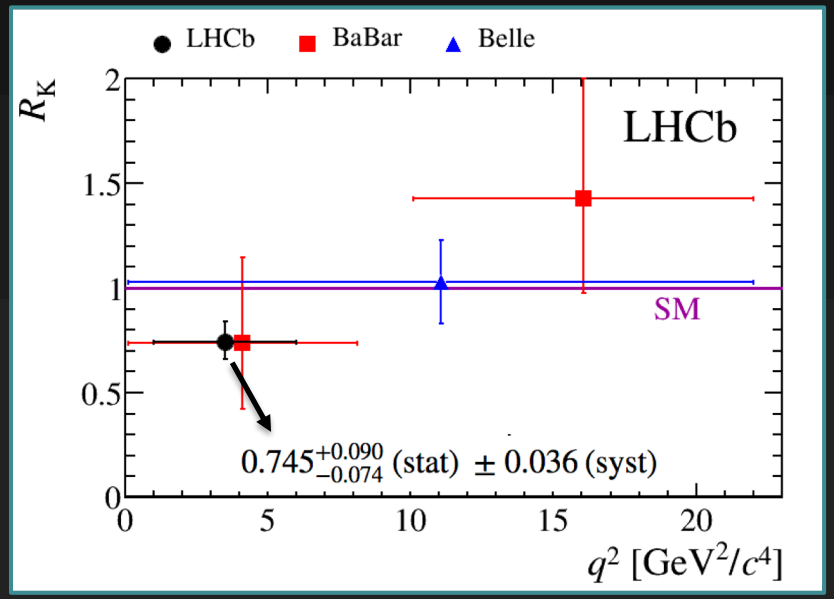
Tests of lepton universality: R(K) and R(K*)

[Phys. Rev. Lett. 113 (2014) 151601, JHEP 08 (2017) 055 Run1 3 fb^{-1}]

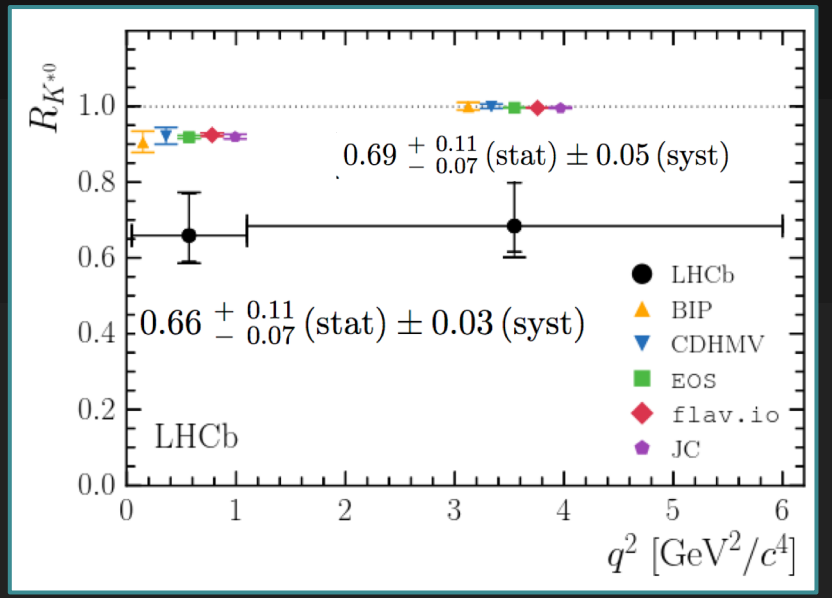
Test the LFU in electroweak penguin decays (e.g. the class of FCNC decays $b \to s l^+ l^-$)

- Old results for R(K) and R(K*):

[Phys. Rev. Lett. 113 (2014) 151601]



[JHEP 08 (2017) 055]



~2-2.5 σ away from SM

Tests of lepton universality: new measurement of R(K)

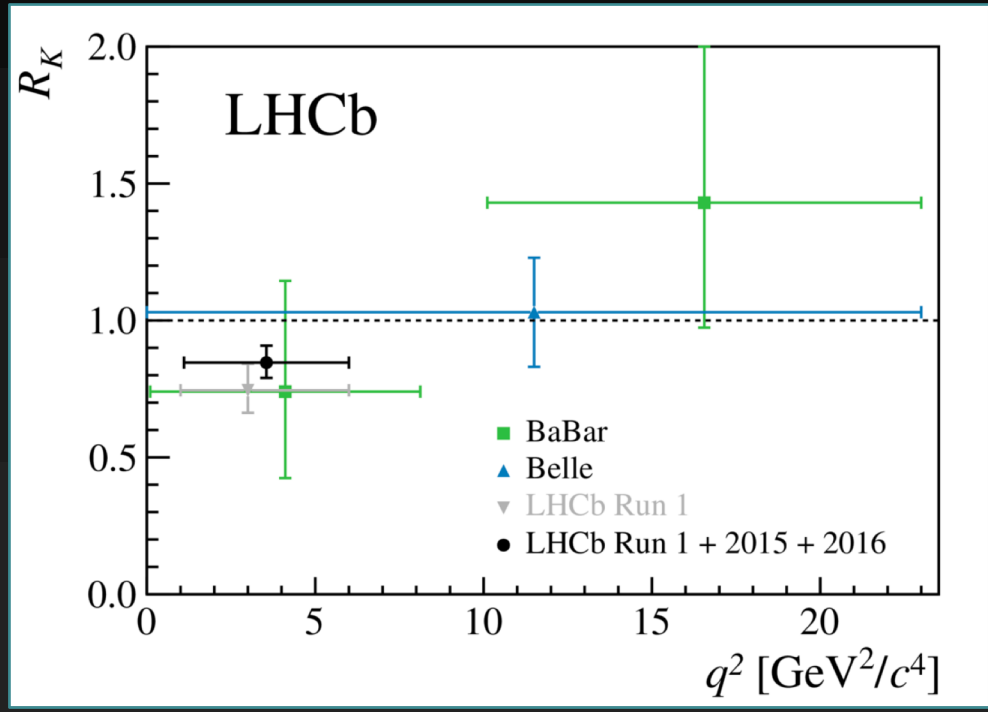
New!

[arXiv:1903.09252 Run1 + Run 2 5 fb^{-1}]

- New measurement re-analysing Run 1 data and adding ~2 fb^{-1} of Run 2 data

$$R_K = 0.846^{+0.060}_{-0.054}(\text{stat})^{+0.016}_{-0.014}(\text{syst})$$

- Situation essentially unchanged: still 2.5σ away from the SM prediction
  - ★ Better precision but central value closer to the SM
- Need more data: inclusion of 2017+2018 data will double the statistics
- Other measurements in preparation
  - ★ Update of R(K*), other decay channels



Spectroscopy: new peaks on the horizon

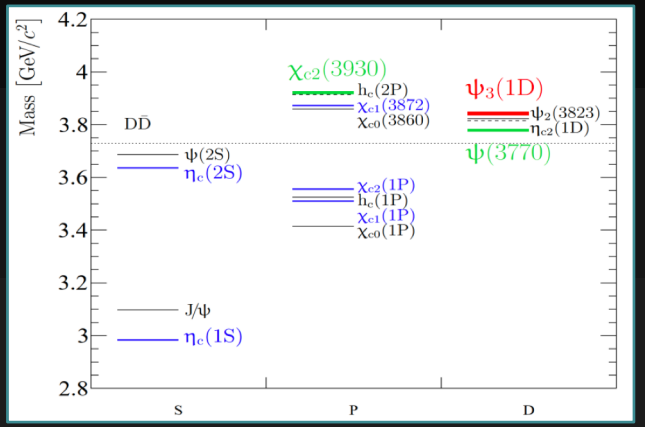
- *New state in D^0D^0 and D^+D^- mass spectra*
- *Observation of new pentaquark states*

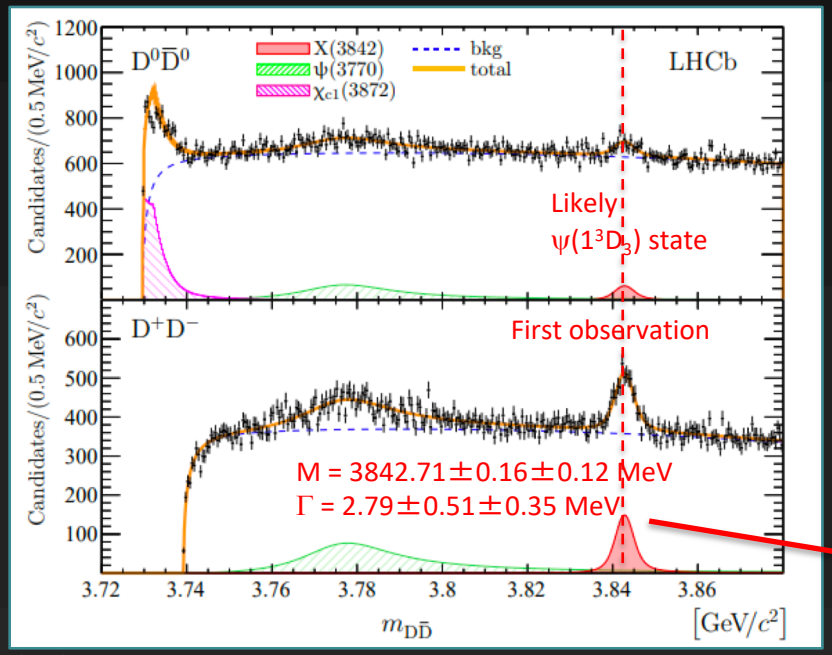
Observation of a new state in $D\bar{D}$ mass spectrum

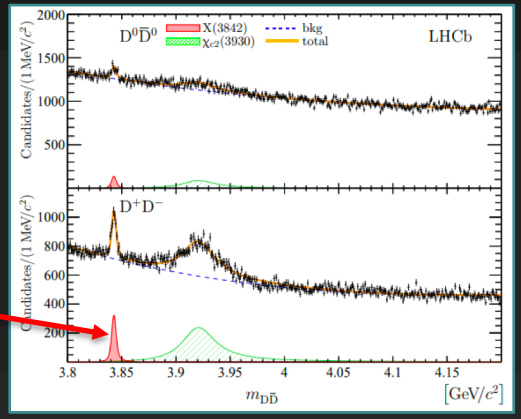
New!

[arXiv:1903.12240 Run1 + Run 2 9 fb^{-1}]

- D mesons keep providing surprises !
- New state observed in the invariant mass spectra of $D^0\bar{D}^0$ and D^+D^-, likely to be $\psi(1^3D_3)$
- First observation of a spin 3 charmonium state!







Full run 1 + Run 2 sample!

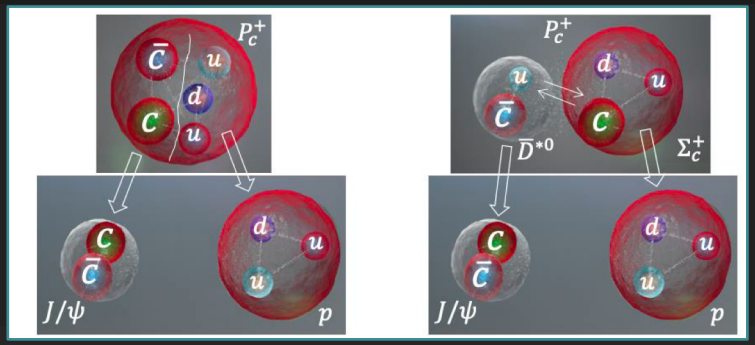
Several other charmonium states observed in the same spectra

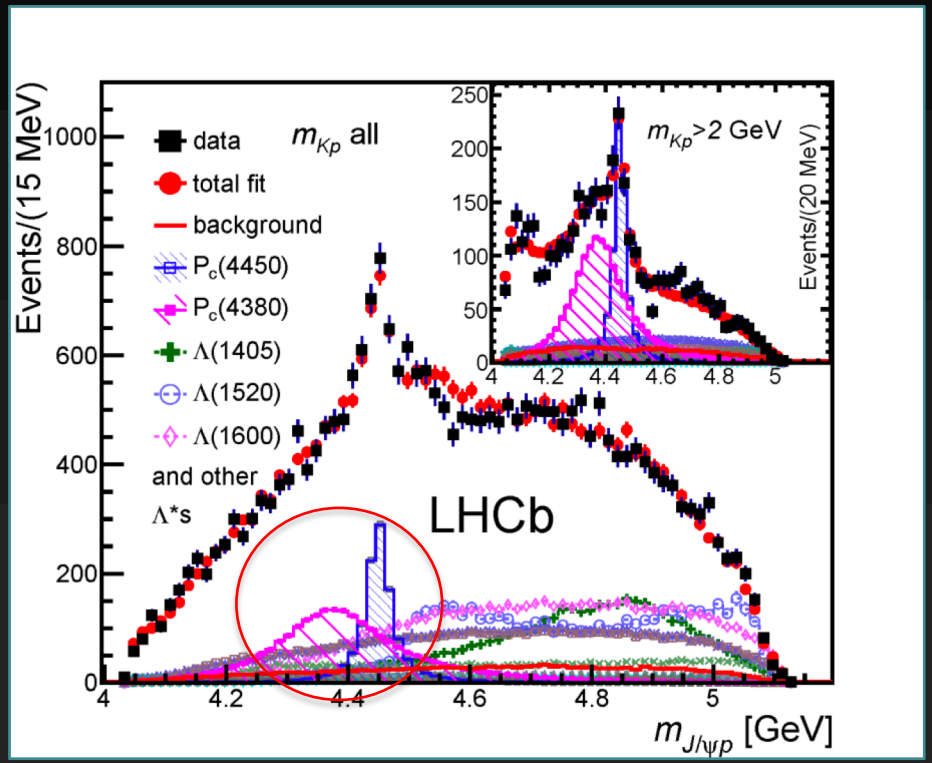
Observation of new pentaquark states

[Phys. Rev. Lett. 115 (2015) 072001 Run1 3 fb^{-1}]

- First pentaquarks observed by LHCb four years ago using $\Lambda_b \rightarrow J/\psi pK$
- Two charged states: one narrow dubbed $P_c(4450)$ and one broader dubbed $P_c(4380)$, decaying into $J/\psi p$

- Great theoretical interest in understanding the nature of the new states
  - ★ Tightly bound vs molecular states





Observation of new pentaquark states

New!

[arXiv:1904.03947 Run1 + Run 2 9 fb^{-1}]

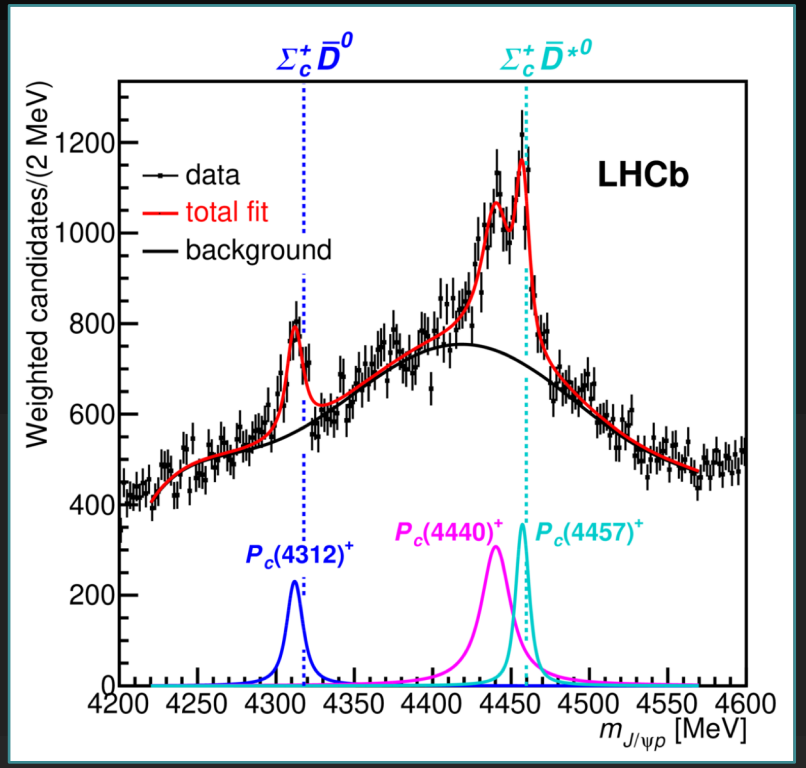
- Update by LHCb using full Run 2 statistics
- A new peak now emerges from background! $P_c(4312)$

- In addition, the $P_c(4450)$ reveals now a more complex structure with two different peaks
- Further confirmation of the previous pentaquark discovery

- Extremely important new input to shed light on the nature of these exotic states! (*)

- (*) submitted one week ago, already >10 papers published on arXiv on the subject

Full run 1 + Run 2 sample!



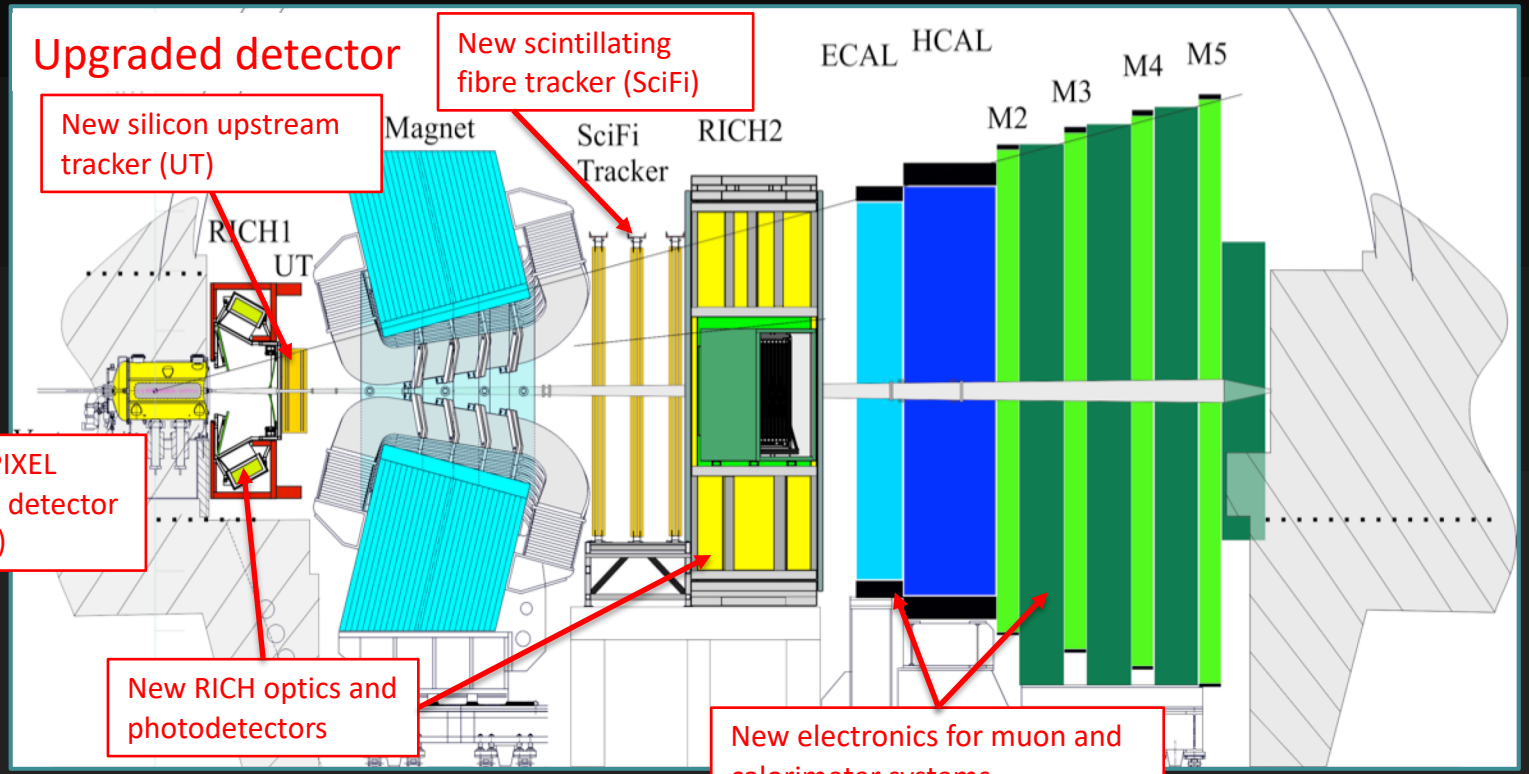
Upgrade

A look to the ~~future~~ present

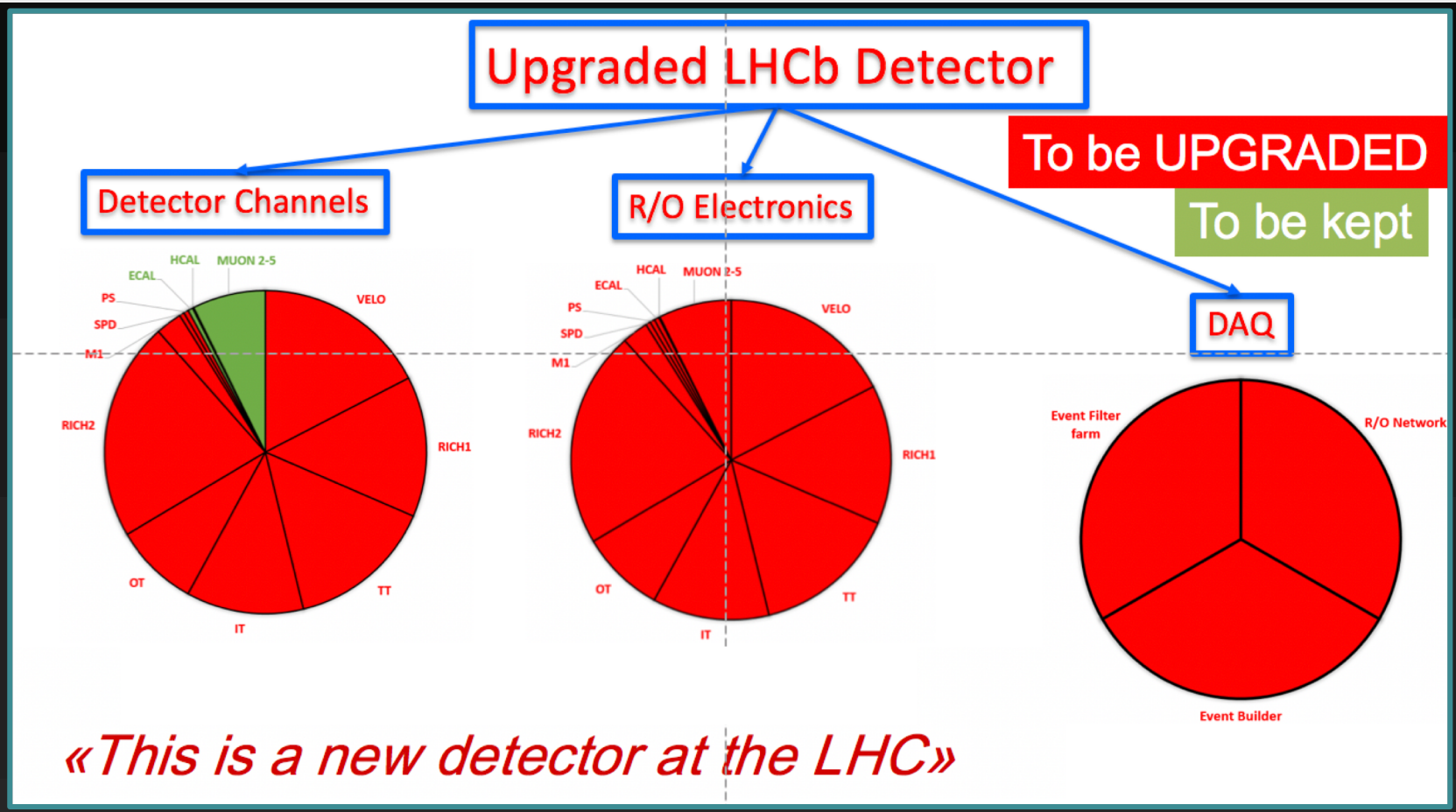
The LHCb Upgrade I in a snapshot

[CERN-LHCC-2012-007]

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



LHCb Upgrade in snapshot

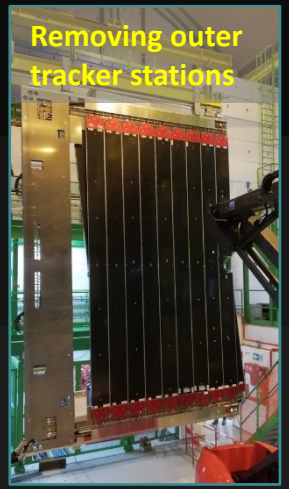


Upgrade: installation

Preparing the ground for the new season

Very intense activity at LHCb site!

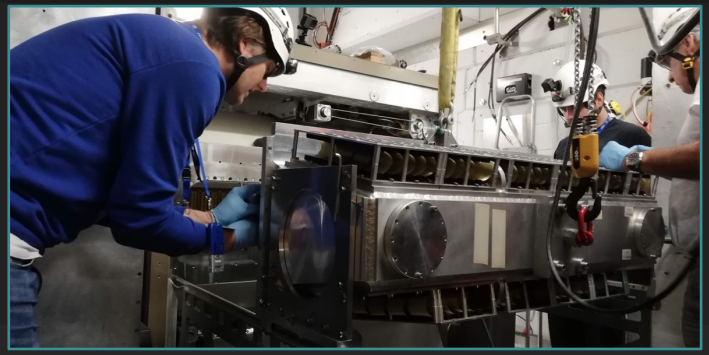
- Activities to dismantle the old sub-detectors progressing very well and on schedule
- Impressive organization!
- Preparation of infrastructure also progressing well
- Prepare for the first installations in summer
- Watch our weekly videos!
  https://www.youtube.com/watch?v=CKLu1xewv7I



HLT farm containers

Dismantling of M1 muon station

Removing the old VELO



Removing the beam pipe

Upgrade: construction

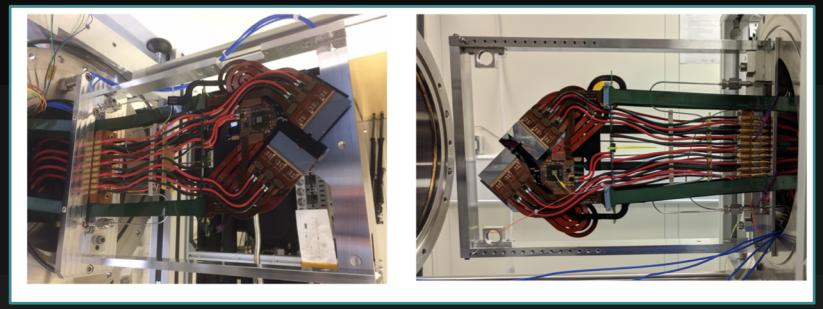
Building for success

LHCb upgrade: VELO

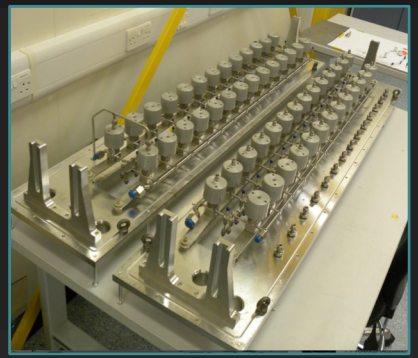
- VELO project progressing very well, although schedule tight given the complexity of the project
- Start of the production of the 52 modules imminent
- Other components progressing on schedule

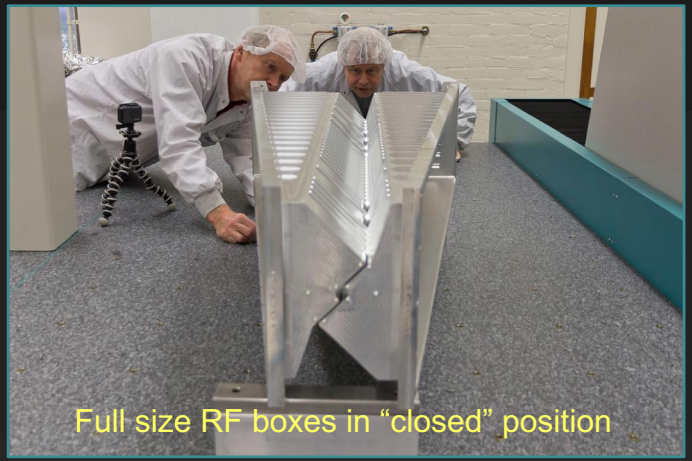
- Mechanics progressing well
- RF foil production ongoing

Full VELO modules

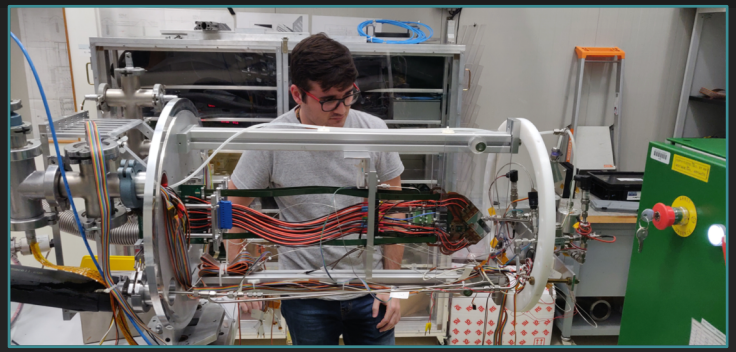


Isolation volumes





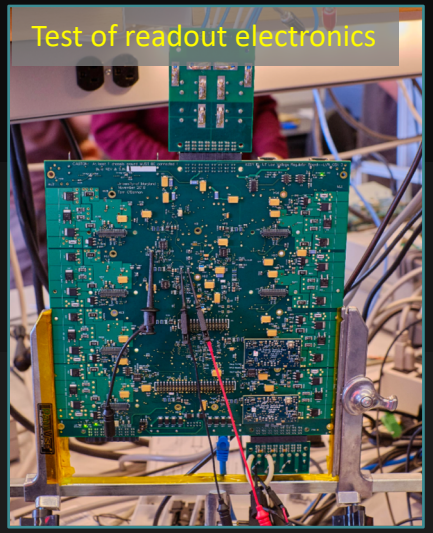
Velo module test setup



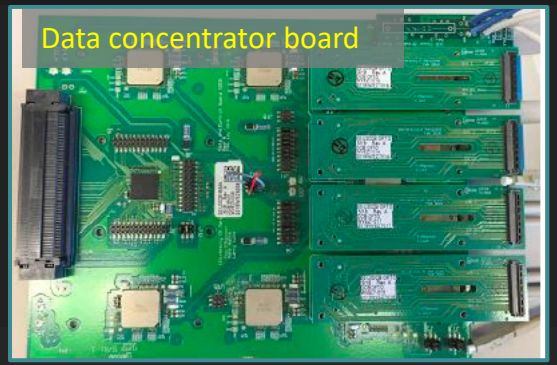
LHCb upgrade: UT

- Sensors: received all A-type, and B,C,D pre-series.
- Readout electronics: production started
- Flex cables pre-series available, under test
- Bare staves: production finished

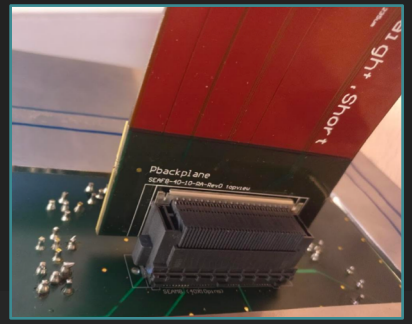
- Integration infrastructure at progressing full speed



Prototype stave shipped at CERN



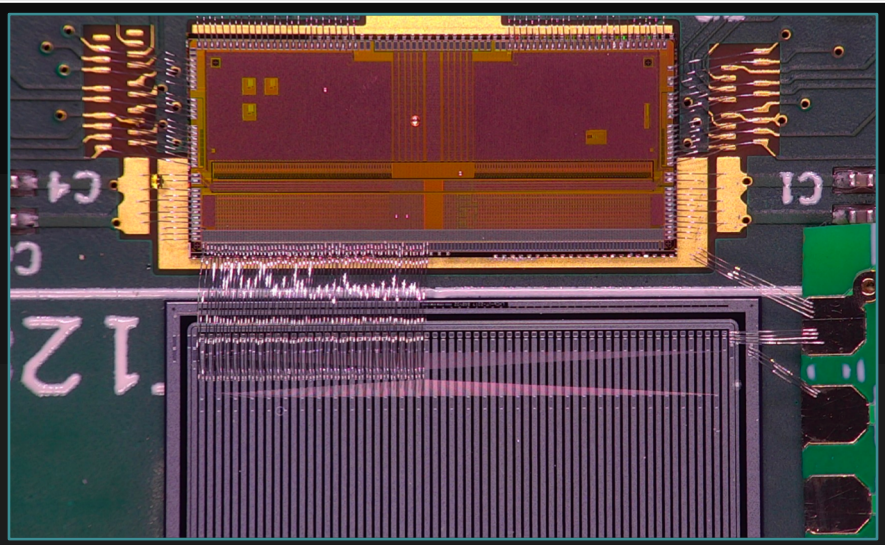
Detail of the fixation of flex cables to the readout electronics



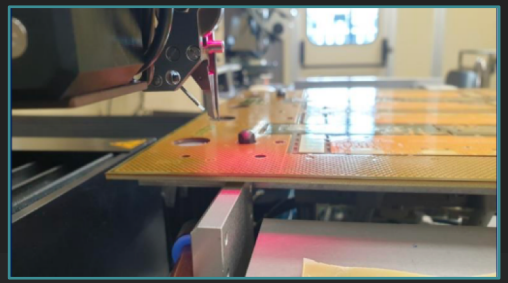
LHCb upgrade: UT

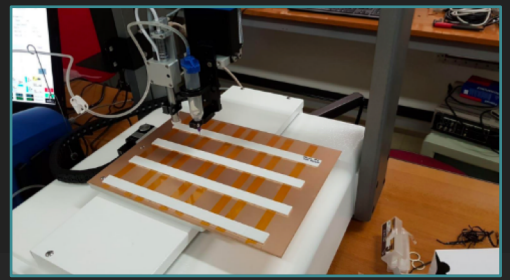
- SALT v3 received and tested
- Issues seen in the previous version largely fixed
- Tested on beam at Fermilab. Results very encouraging
- Go for production

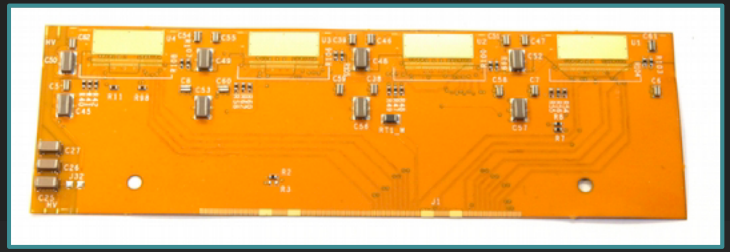
- ASIC finalized ☞ finalise hybrid and start production
- hybrid Q&A and assembly tools ready



SALT v3 wire-bonded to a sensor





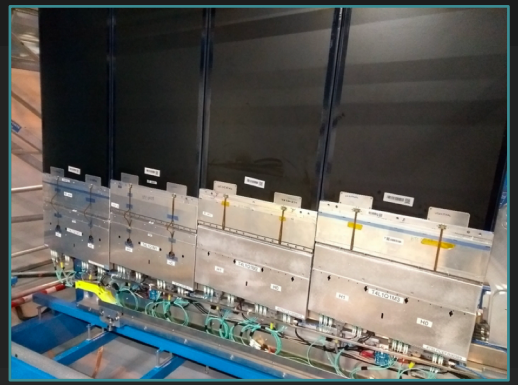


LHCb upgrade: SciFi

- Modules: production completed
  - A large pile stacked at CERN. Final tests ongoing
- Electronics: in mass production
- Production of cold boxes started
- C-frame construction underway

Assembly of module + cold box

Modules assembled on the prototype C-Frame



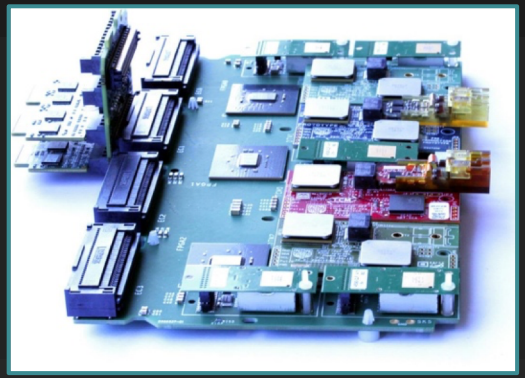
Prototype C-frame in construction at P8

RICH

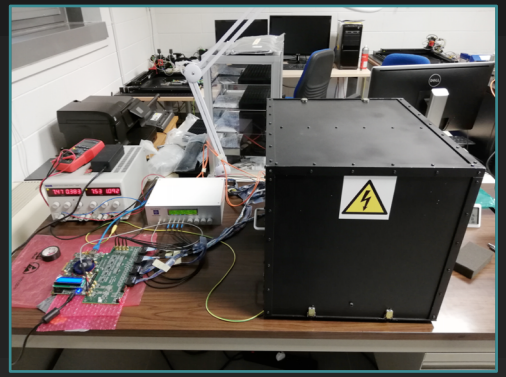
- To be produced for RICH1+2: 22+24 = 46 columns (+spares)
  - ★ MaPMTs: all 3500 tested
  - ★ CLARO: full prod received, 100k, QA 100%
  - ★ Digital readout board (PDMDB): production pf PCBs completed, first complete board being received
  - ★ Readout boards production and QA started
- Dismantling of RICH1 well advanced – on schedule


Dismantling mirrors of RICH1

PDMDB



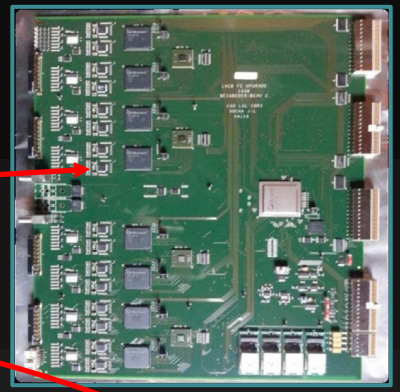
Setup for Q&A of readout boards




Dismantling of RICH1-to-VELO interface

Muon+CALO

- To be produced: electronics boards + shielding plugs
  - ★ All electronics in production
  - ★ ASICs:
    - ICECAL chips in hand and tested
    - nSYNC all received and tested

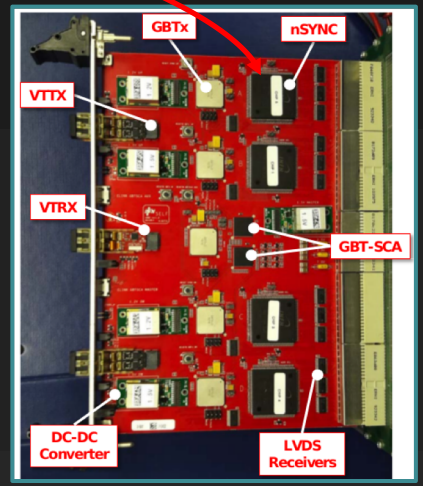


CALO FEB
278 needed

+21 CB
+144
HV/Calib/Moni

- New shielding plug, 3 parts, design finalized, order placed in December, parts expected in the coming month

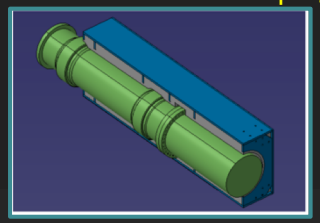
- On schedule for installation and commissioning, starting ~now

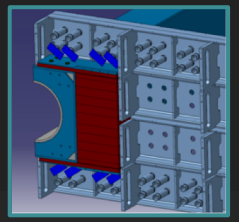


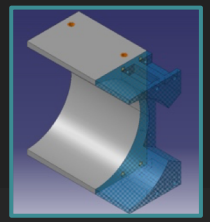
Muon nODE
148 needed

+120 nSB
+8 nPDM

Details of the new Muon shielding plugs







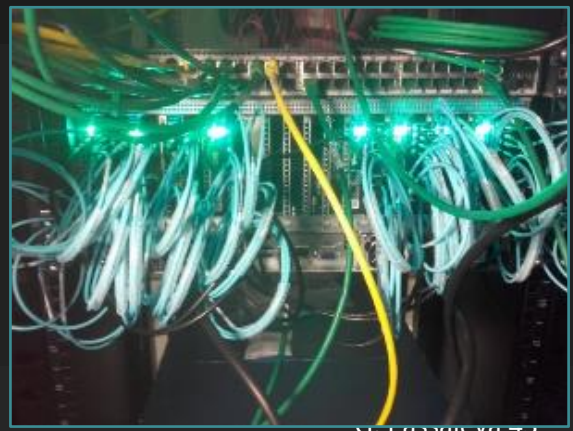
LHCb upgrade: Online and computing

- Containers for Event Filter Farm and Evt Builder:
  - ★ First 4 EFF modules installed 2 morein Nov 2019
- Event Builder:
  - ★ simulation of traffic is now working for 500 nodes and gives confidence in scalability of system.
- Vertical Slice Test will allow checking simulation results at a scale of 20% of the final system.
- Decide on Event Builder technology after a review in May 2019

First PCIe40 ready at contractor

Installation of one of the HLT farm modules

Vertical slice setup already cabled with fibres and operational

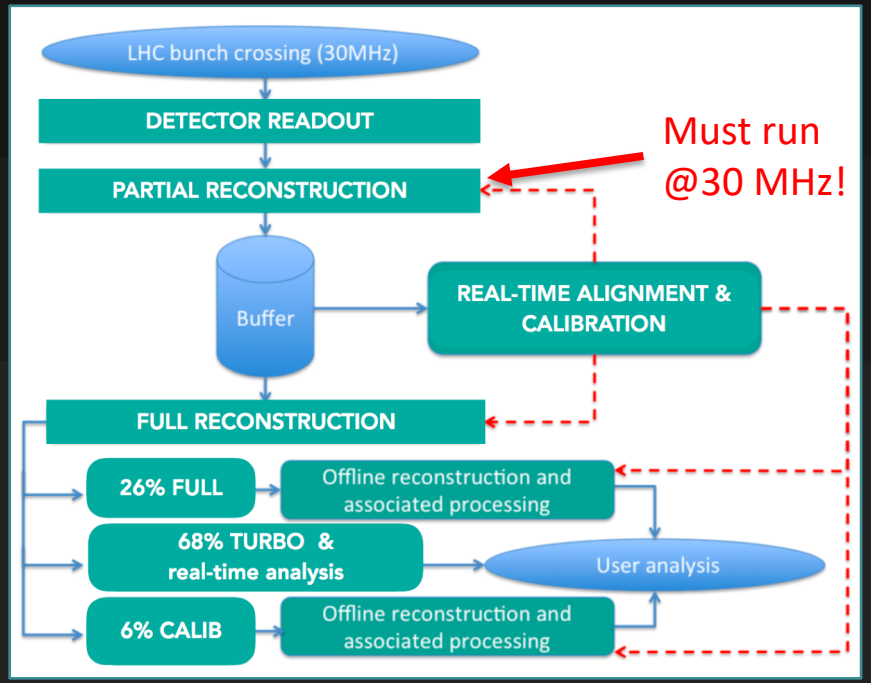


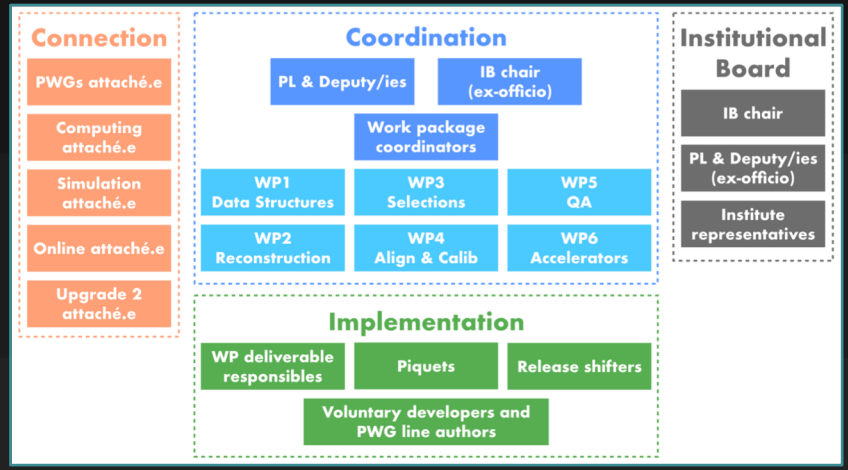
LHCb upgrade: software & computing and computing model TDRs

- Both approved by Research Board
- Very fruitful review by the LHCC

Real-Time Analysis project

- Created to organize the development, operation and maintenance of the all-software trigger
- Large collaboration effort (> 50 FTE)





Challenging software development need strong organization

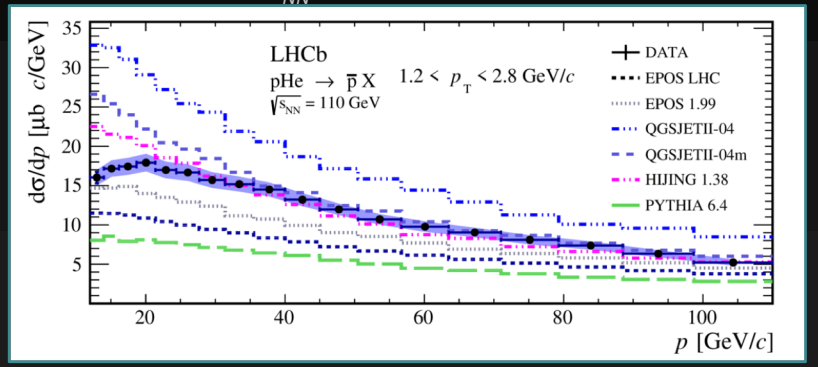
Fixed target physics at LHCb

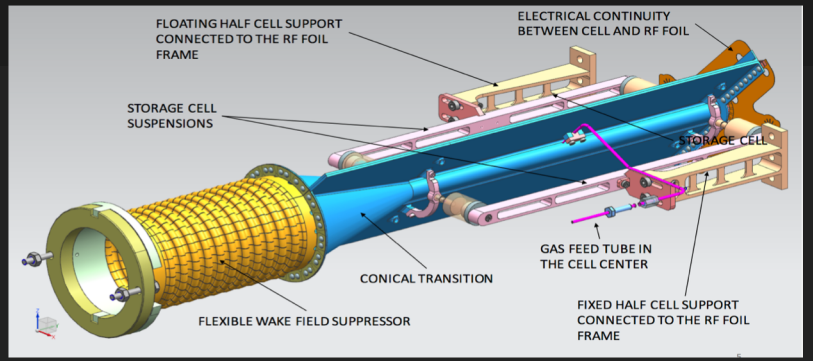
- LHCb has a unique fixed target physics programme at LHC
  - ★ Based on injection of gas inside the LHC beam pipe at our interaction point (the “SMOG” system)
  - ★ Can inject noble gases He, Ar, Ne
  - ★ Heavy ions
  - ★ Cosmic ray physics

- Now upgrading it
  - ★ Storage cell for better confinement of gas
  - ★ Can in principle use more diverse gases e.g. H, D, N, O (cosmic ray physics)
  - ★ Approved by LHCC and LHC panels
  - ★ Will be installed in LS2

[Phys. Rev. Lett. 121 (2018)]

Measurement of antiproton production in pHe collisions at $\sqrt{s_{NN}}$=110 GeV





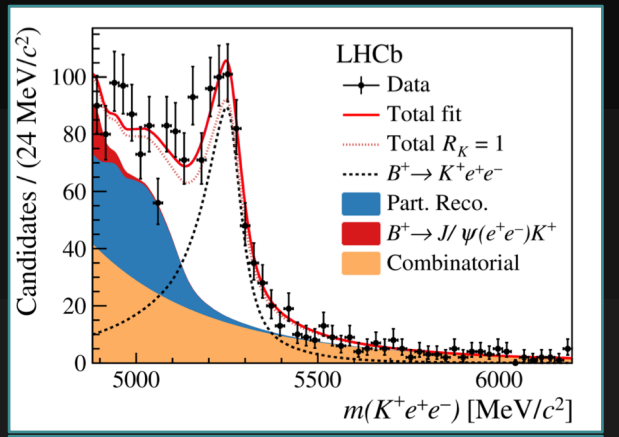
Technical drawing of the gas storage cell to be installed inside the VELO

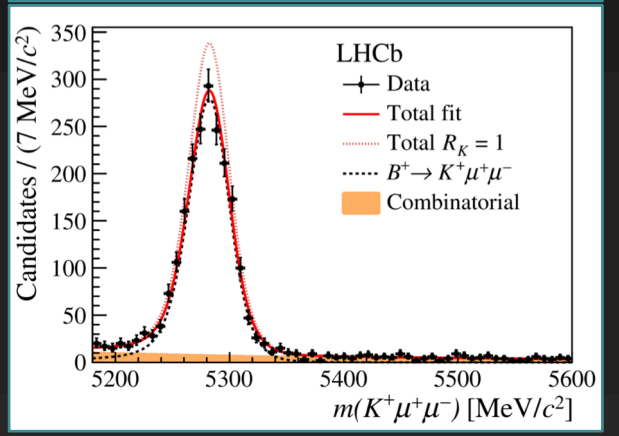
Conclusions and outlook

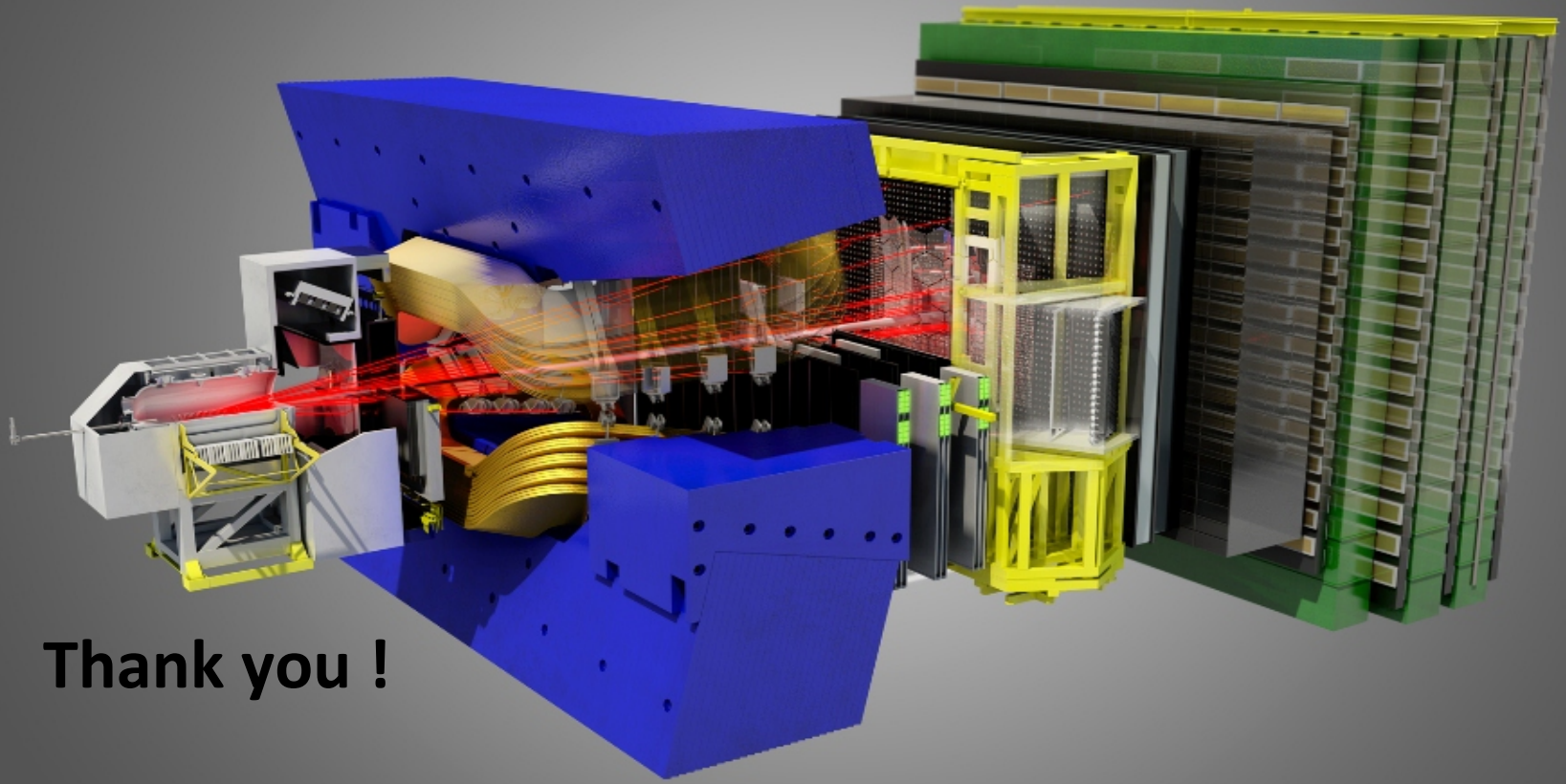
Conclusions and outlook

- 2018 run completed a successful first phase of LHCb
  - ★ Collected record luminosity in proton-proton and Pb-Pb
  - ★ We were delivered 10 fb^{-1} which was the goal in our Technical Proposal in 1998 !
- LHCb continues to provide a wealth of excellent physics results
- The march towards the upgrade I is continuing
  - ★ All subsystems progressing - installation ongoing!
  - ★ Schedule is tight, working hard to be ready for LHC Run 3!
- Looking into the far future:
  - ★ Expression of Interest for future upgrades submitted
  - ★ Physics case document released
  - ★ Green light from LHCC to proceed to TDRs
  - ★ A lot of opportunities !

[arXiv:1903.09252 Run1 + Run 2 5 fb^{-1}]







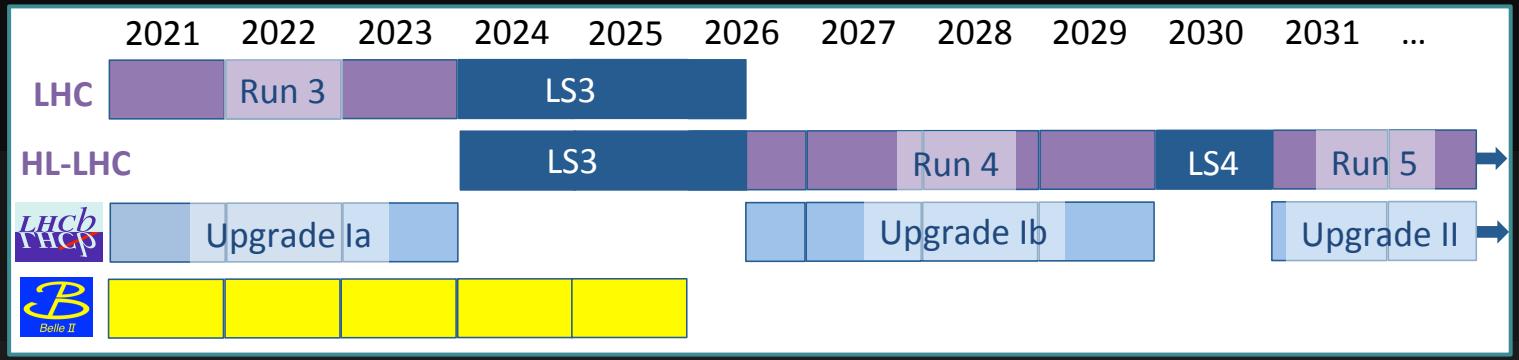
Thank you !

BACKUP SLIDES

Upgrade II

LHCb Upgrade II: the ultimate exploitation of LHC for flavour physics

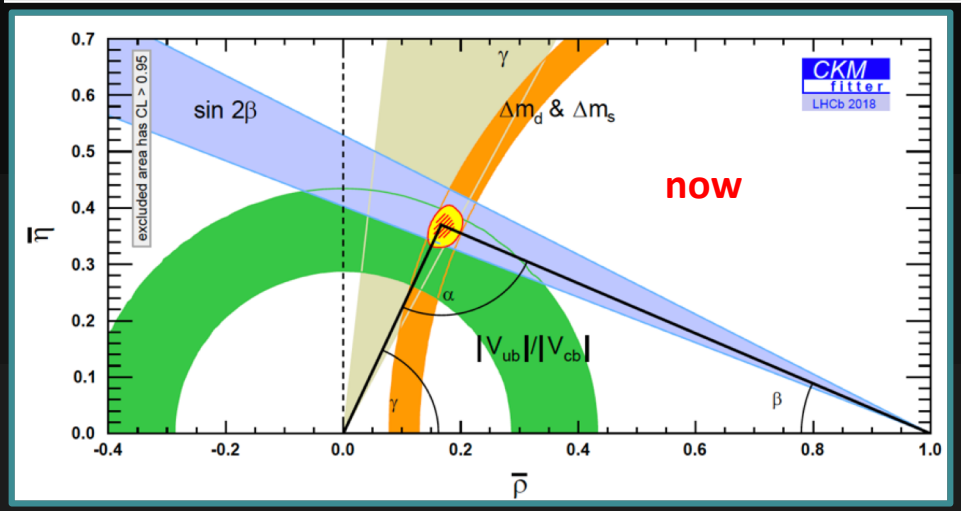
LHCb Upgrade II



[arXiV:1808.08865]

- Aim to fully exploit HL-LHC for flavour physics and other opportunities in the forward direction
- Aim to collect > 300 fb^{-1} at $L = 2x10^{34}$, x10 with respect to Upgrade I
- Consolidate in LS3, Major upgrade in LS4
- Expression of Interest issued in 2017
- Feasibility study performed by LHC experts [CERN-ACC-NOTE-2018-0038]
- Physics case document released
- Green light from LHCC to proceed to TDRs (expected ~late 2020)

Physics Case – CKM unitarity triangle evolution



300 fb^{-1}