LHCb status report

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on behalf of the LHCb Collaboration

149th LHCC meeting – open session

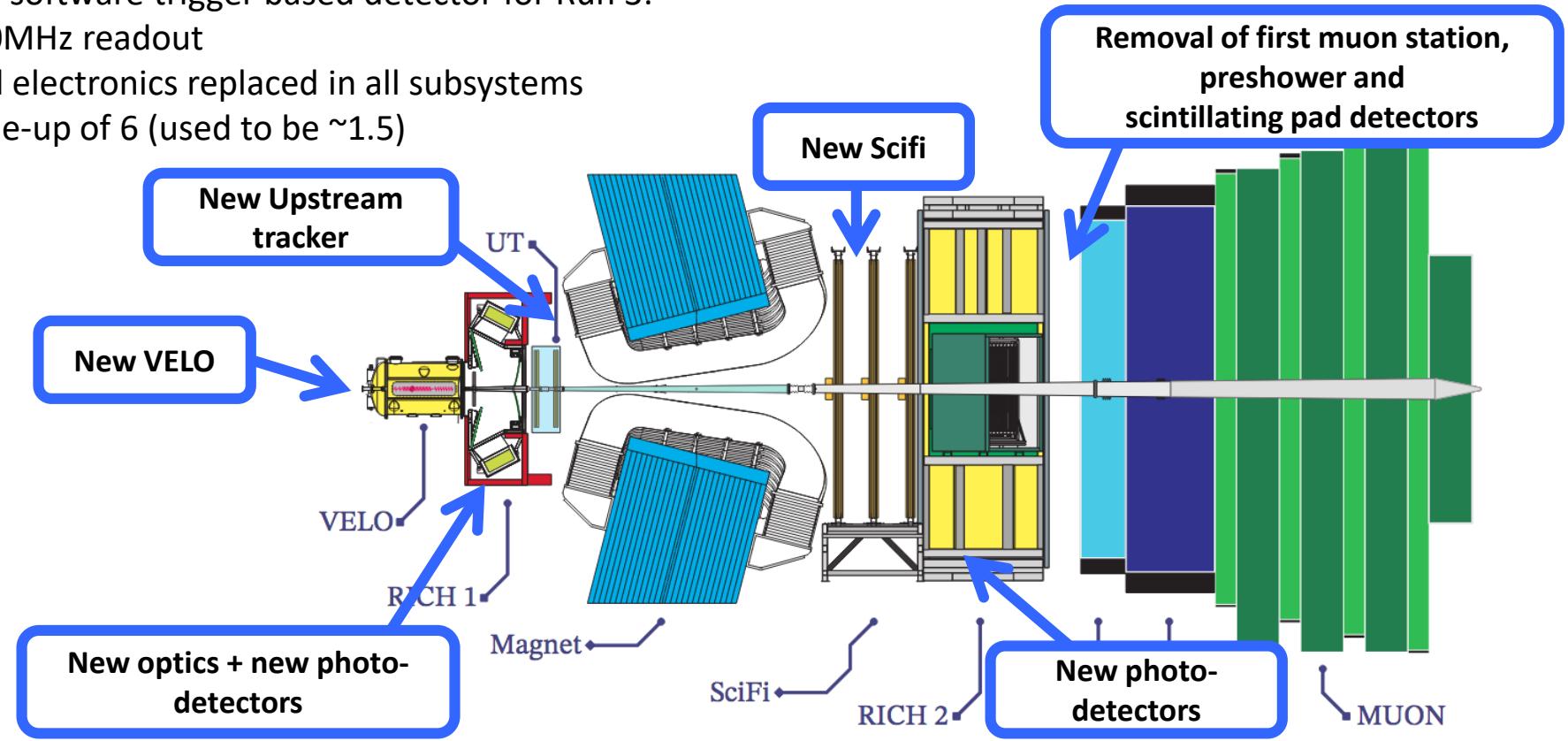
09/03/2022

IGFAE
Instituto Galego de Física de Altas Enerxías
USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA
XUNTA DE GALICIA

LHCb Upgrade I

New software trigger based detector for Run 3:

- 40MHz readout
- All electronics replaced in all subsystems
- Pile-up of 6 (used to be ~1.5)

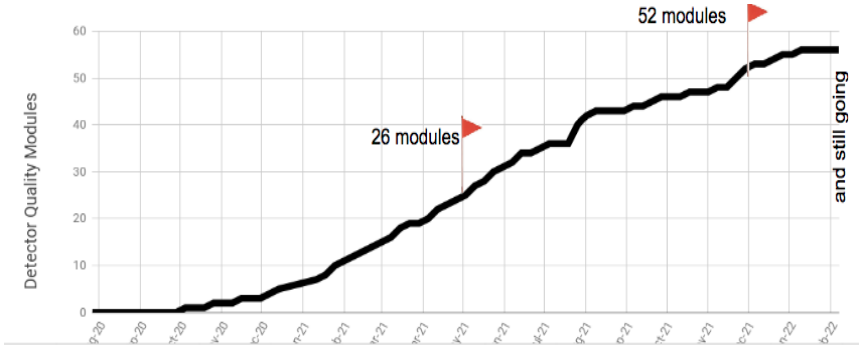


VELO

- Side C safely arrived at CERN end of January: no connection or bond wire lost in transport
- Detailed inspection, testing and fixing of last issues performed at CERN
- Installation of side C performed March 1-2

  → Commissioning launched:

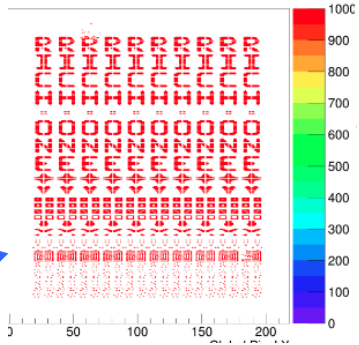
  scans, calibrations, clustering, tracking, closure
- Assembly of side A being completed
- Shipping for side A scheduled for April

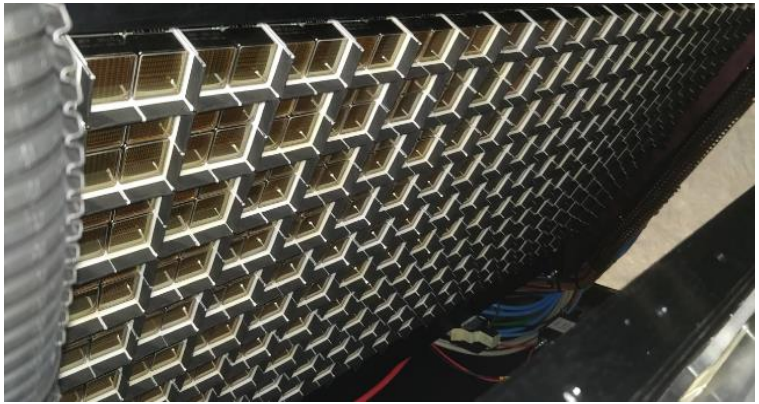


RICHs

RICH 1

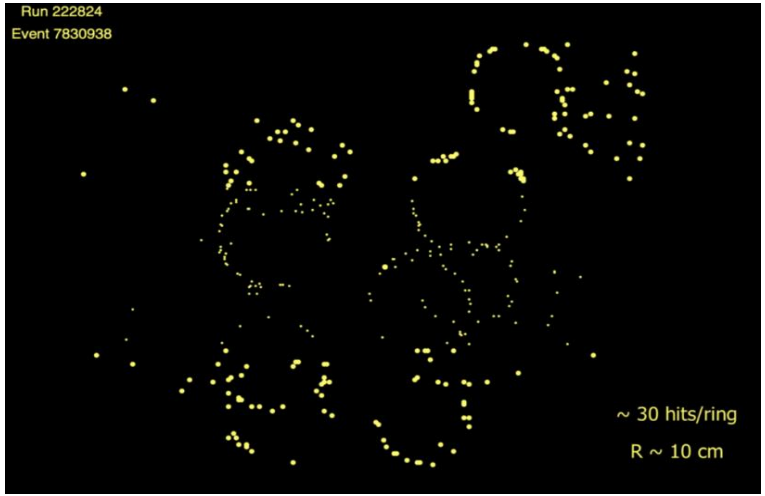
- Last MaPMT column installed end of January
- Verification of connections with test patterns
- Installation of magnetic shielding this week
- Ensure RICH 1 is light tight and installation of light leak detector
- Switching on the High Voltage





RICH 2

- Installation complete last year
- Took data during beam test in October
- Gas leak discovered 2 weeks ago: fixed last weekend



Ready in time for cavern closure

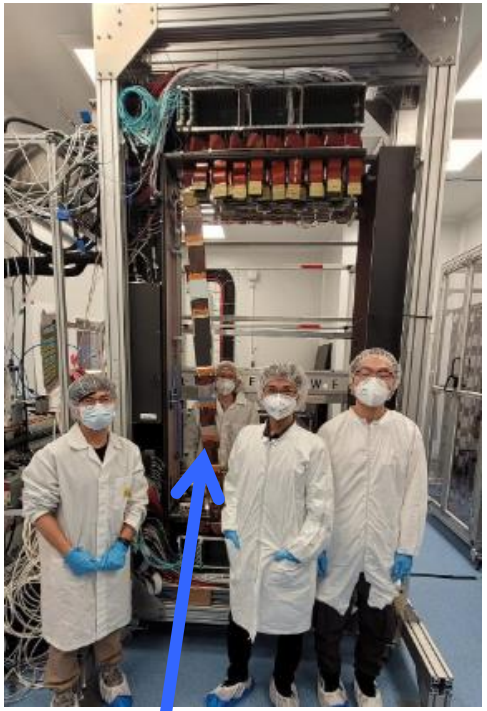
UT

Decision taken in December not to install before cavern closure:

- Complete Service and Mechanics before cavern closure
- Requested installation of first side in September
- Installation of second side during YETS

Status:

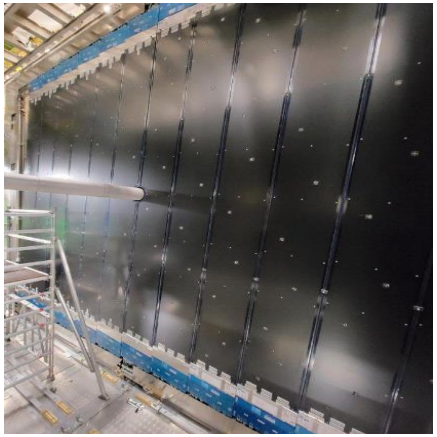
- All staves produced
- Most staves arrived at CERN
- Assembly started on the surface, first stave in UT installed
- Test installation of empty UT side last week

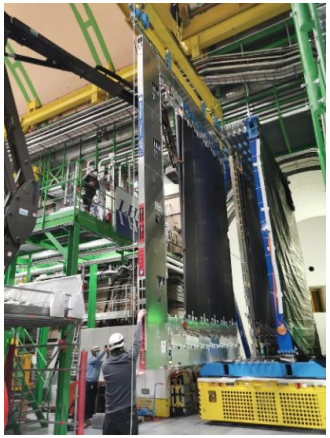


SciFi

- Installation of frames finished end of February
- Connection of last frames finished last week
- Commissioning and debugging of cable and fibre connections on-going
- Installation of few remaining Front End boxes on-going
- Alignment and closure of frames on-going:
  - Initial movement and position studies will be done over the next two to three days
  - Put the central modules within 0.2mm from their nominal design positions
  - Final closing very carefully while beam-pipe under vacuum

Ready in time for cavern closure



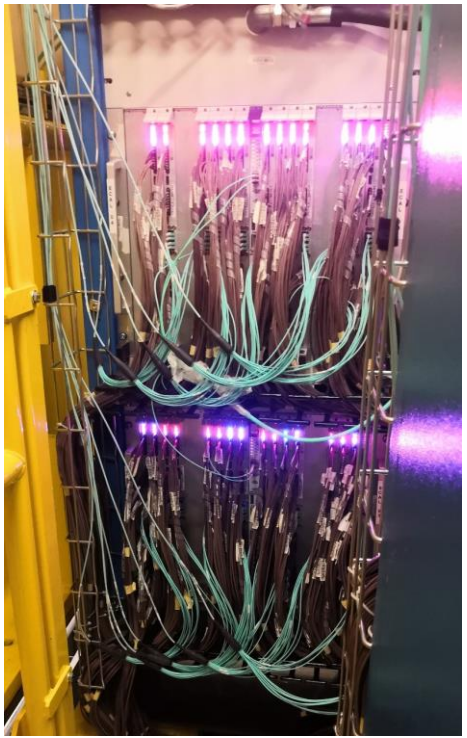


CALO

- Calibration and monitoring systems are operational
- Upgrade of CALO moving system is installed and commissioned
- New Front End Electronics and new High Voltage are installed and in commissioning

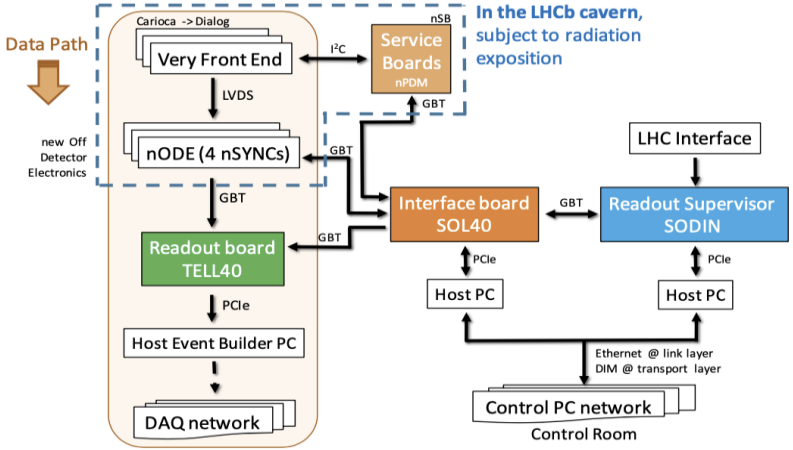
- Update of firmware of Front End board planned to add more functionalities (counters, usage of the commands…)
- Testing the quality of the 8000 connections between the photomultipliers and the Front End boards on-going

Ready in time for cavern closure



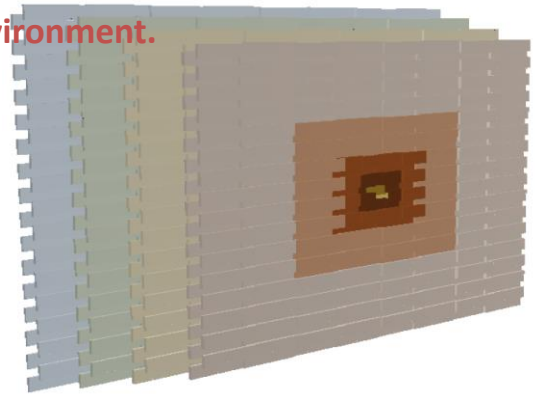
Muon

- Chambers and very Front End: all ok; working on residual ~100 problematic channels out of 100k
- Low Voltage, High Voltage, Gas, Temperature: ready and tested during beam test in October
- Front End electronics (ECS and DAQ): all new boards tested and ready
- Monitoring: rewritten from scratch



Ready in time for cavern closure

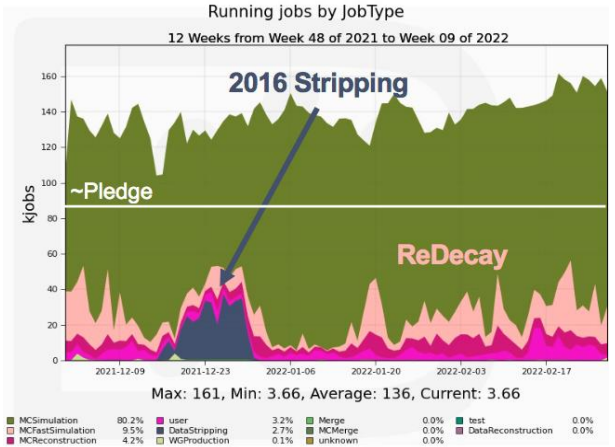
Muon firmware and software being updated to Run 3 detector and environment.



Computing and Online

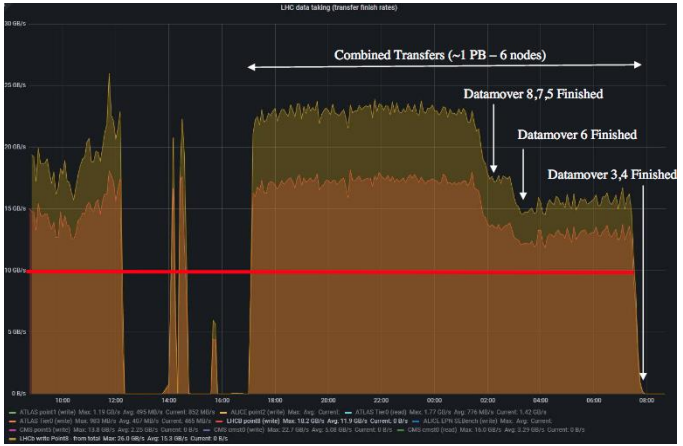
Computing

- Reprocessing of Run2 data finished last year
- Computing work dominated by MC production (93%)
- Simulating about 260 million events per day
- 2023 resources request under review



Online

- Most of the GPUs for HLT1 installed
- Disks and servers for HLT1 buffer arrived and installed
- Disks and servers for HLT2 buffer arrived last week
- Preparing for data taking:
  - Exercising data transfer from P8 to EOS and Tier1 sites
  - Tape challenges in preparation



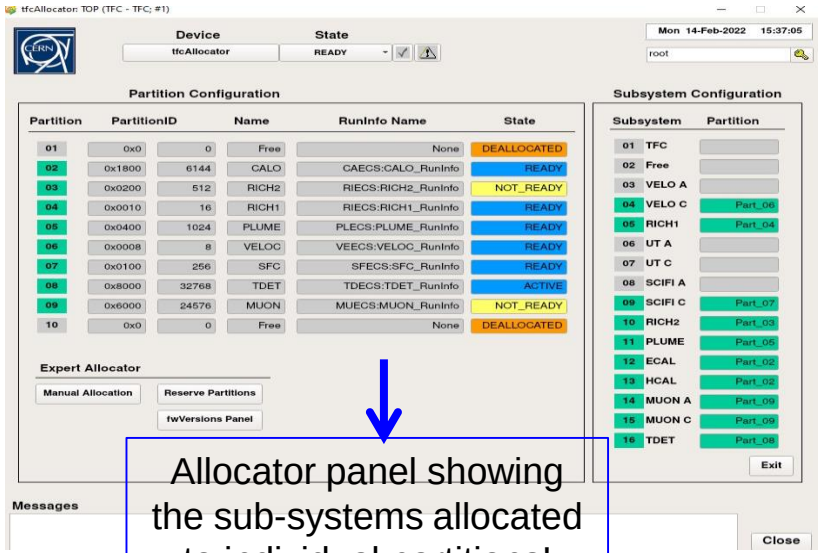
Commissioning

- October test beam good preparation for cosmics
  - First integration sessions in December
  - Included RICH2, MUON, ECAL, HCAL in LHCb partition
  - Exercise the full system and study any issues

- Sub-detectors are now regularly working in their own partition → Using central timing distribution, readout firmware, Event Builder and online infrastructure

- Significant Global Commissioning only after cavern closure
  - RICH1+RICH2+MUON+CALO commissioning advanced
  - Advanced commissioning of online systems with particular attention to online infrastructure, clock, timing and controls
  - Trackers will need to finalize commissioning with beam, benefit from accesses and periods with no beam

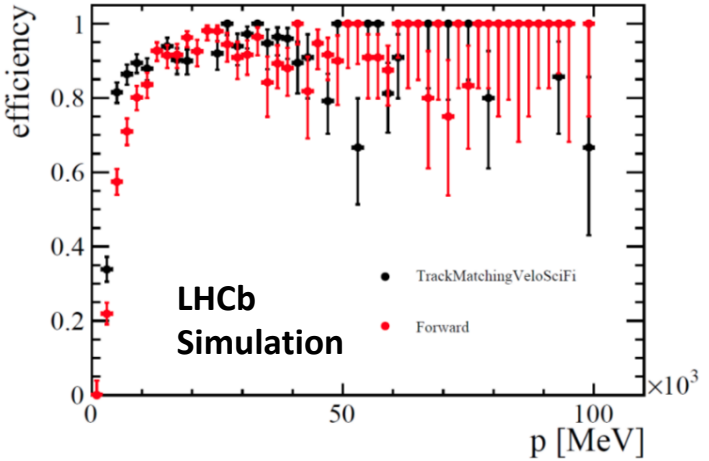
- Full Experiment System Test (FEST) weeks
  - Run simulated data through the whole online and offline chain
  - 4 weeks to date, 2 since November, next end of March



Allocator panel showing the sub-systems allocated to individual partitions!
→ Almost full house!

Real Time Analysis (Trigger)

- HLT1 reconstruction and selections are in good shape
- HLT2 reconstruction is in good shape and selections are actively being worked on (852 HLT2 lines to date, 562 of which fully use the new framework)
- Alignment and calibration work is in good shape
- Commissioning and integration work is on-going, beam test data and FEST weeks very helpful
- HLT1 tracking w/o UT studies: improved tracking efficiencies for slightly higher ghost rates
  → some lines might need retuning



	HLT1 tracking w/o UT		Conventional HLT1 tracking	
	Bs -> ϕϕ	Min Bias	Bs -> ϕϕ	Min Bias
Hl1TrackMVA	21 %	3.8 %	21 %	1.8 %
Hlt1TwoTrackMVA	32 %	2.1 %	31 %	1.5 %

LHCb Upgrade II

CERN-LHCC-2021-012

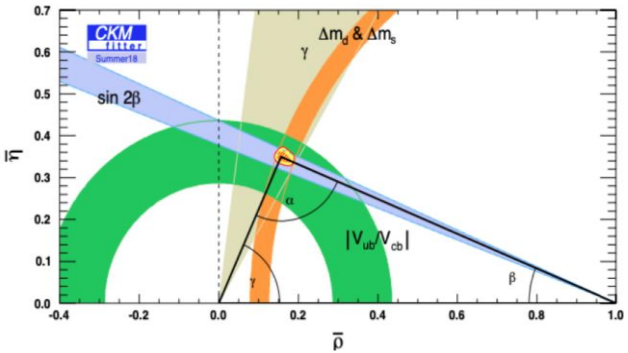
Fully realise the flavour physics potential of the HL-LHC

- Installation during LS4 of the LHC
- Peak luminosity ~$1.5 \times 10^{34} cm^{-2} s^{-1}$ (pile-up ~40)
- Integrate 300 fb^{-1} through the lifetime of the HL-LHC
- Replacement of all existing spectrometer components to increase the granularity, reduce the amount of material in the detector and to exploit the use of new technologies

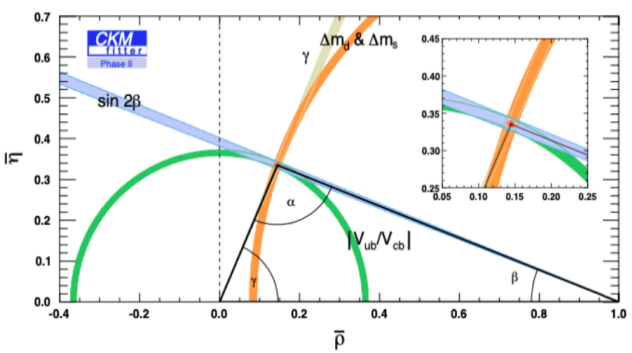
Framework TDR released:

- physics motivation, sub detector design, environmental impact, schedule + cost
- LHCC recommendation session today

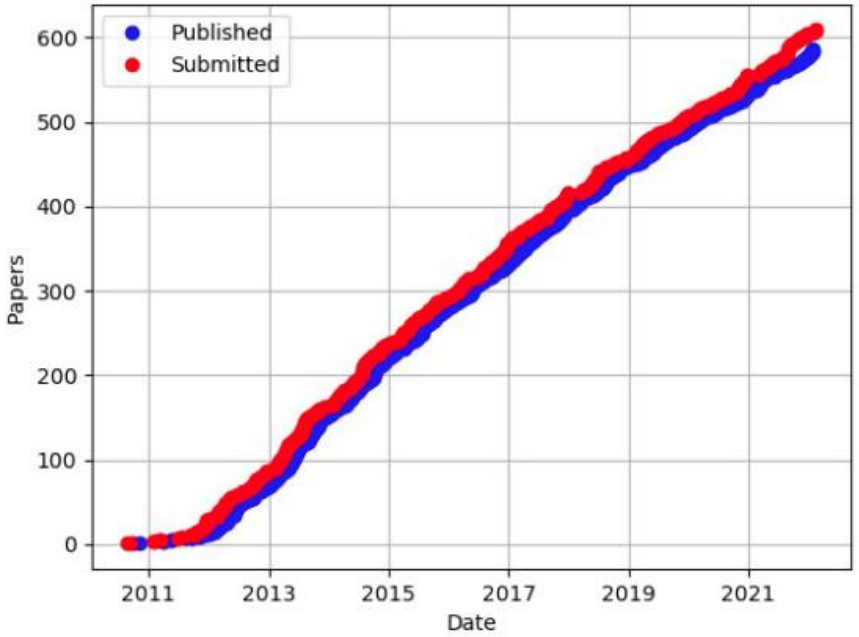
LHCb only, end of 2018

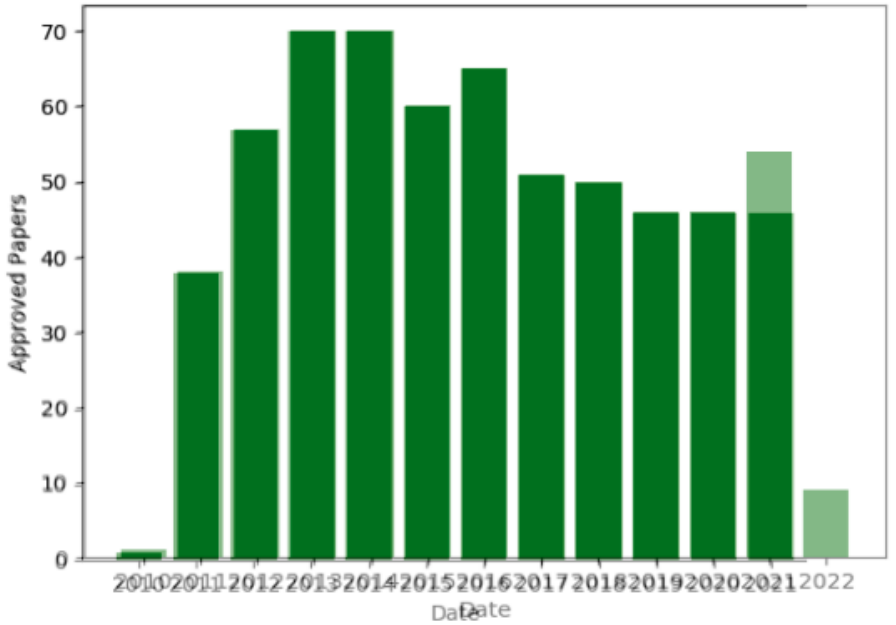


LHCb Upgrade II + LQCD improvement



Physics results





Physics results

covered in this presentation

Papers submitted since last LHCC:

- [PAPER-2021-052] Observation of the doubly charmed baryon decay $\Xi^{++}_{cc} \to \Xi'^{+}_{c}\pi^{+}$
- [PAPER-2021-044] Observation of the decay $\Lambda^{0}_{b} \to \Lambda^{+}_{c}\tau^{-}\nu_{\tau}$
- [PAPER-2021-041] Measurement of the charm mixing parameter y_{CP}–$y_{CP}^{K\pi}$ using two-body D^0 meson decays
- [PAPER-2021-047] Study of charmonium and charmonium-like contributions in $B^{+} \to J/\psi\eta K^{+}$ decays
- [PAPER-2021-042] Search for the decay $B^0 \to \phi\mu^{+}\mu^{-}$
- [PAPER-2021-043] Observation of the $B^0 \to D^{*0}K^{+}\pi^{-}$ and $B^{0}_{s} \to D^{*0}K^{-}\pi^{+}$ decays
- [PAPER-2021-036] Constraints on the CKM angle γ from $B^{\pm} \to Dh^{\pm}$ decays using $D \to h^{\pm}h'^{\mp}\pi^{0}$ final states
- [PAPER-2021-037] Precision measurement of forward Z boson production in proton-proton collisions at $\sqrt{s}$=13 TeV
- [PAPER-2021-040] Observation of $\Lambda^{0}_{b} \to D^{+}p\pi^{-}\pi^{-}$ and $\Lambda^{0}_{b} \to D^{*+}p\pi^{-}\pi^{-}$ decays
- [PAPER-2021-039] Searches for rare B^{0}_{s} and B^0 decays into four muons
- [PAPER-2021-030] Measurement of the photon polarization in $\Lambda^{0}_{b} \to \Lambda\gamma$ decays
- [PAPER-2021-048] First measurement of $Z \to \mu^{+}\mu^{-}$ angular coefficients in the forward region of pp collisions at $\sqrt{s}$=13 TeV

Preliminary since last LHCC:

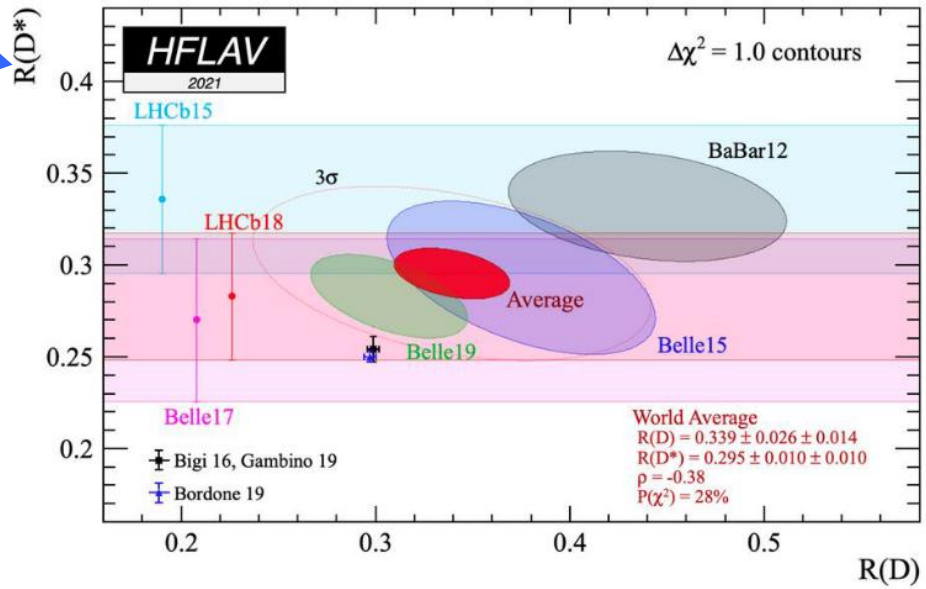
- [PAPER-2021-045] Observation of ω contribution in the $X(3872) \to \pi^{+}\pi^{-}J/\psi$ decays

Many new results for the Moriond conferences!

Observation of the decay $\Lambda_b^0 \to \Lambda_c^+ \tau^- \nu_\tau$ (1/2)

- Hints of Lepton Flavour Universality violation in the meson sector R(D) and R(D*)

$$R_{D^*} = \frac{\mathcal{B}(B \to D^{(*)} \tau \nu)}{\mathcal{B}(B \to D^{(*)} \mu \nu)}$$



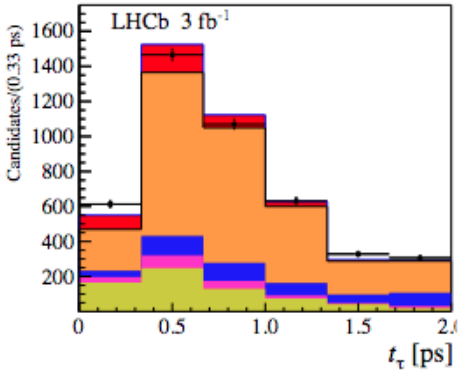
- $R(\Lambda_c^+)$ can be below or well above SM , when satisfying R(D*)-R(D) constraints

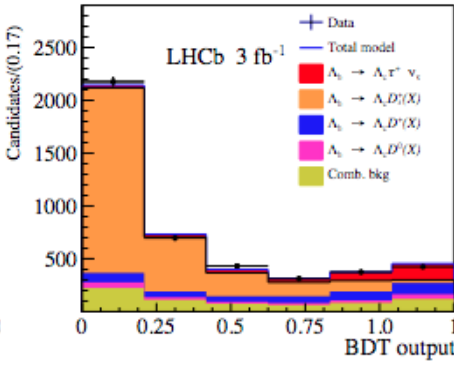
$$\mathcal{R}(\Lambda_c^+) \equiv \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)}$$

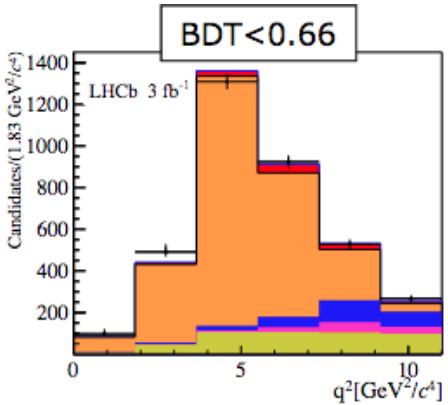
- Complementary constraints with baryonic decay
  - Spin ½ spectator
  - Different NP couplings
- Unique to LHCb

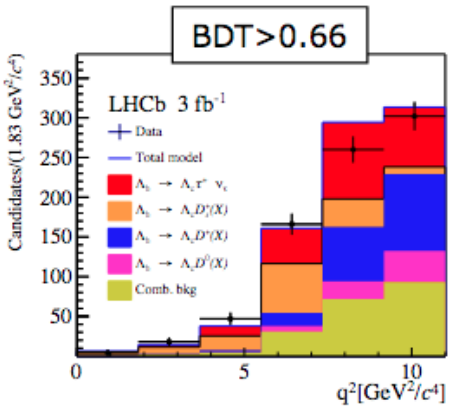
Observation of the decay $\Lambda^0_b \to \Lambda^+_c \tau^- \nu_\tau$ (2/2)

- Reconstruct $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$
- Simultaneous 3D fit to τ, q^2, BDT
- **First observation of $\Lambda^0_b \to \Lambda^+_c \tau^- \nu_\tau$ with 6σ significance**
- $\mathcal{B}(\Lambda^0_b \to \Lambda^+_c \tau^- \nu_\tau) = (1.50 \pm 0.16 \pm 0.25 \pm 0.23)\%$
- $\mathcal{R}(\Lambda_c^+) \equiv \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)} = 0.242 \pm 0.026 \pm 0.040 \pm 0.059$
  in agreement with SM prediction of 0.324 ± 0.004
- **Provides constraints on NP models, such as those for which large values of $R(\Lambda^+_c)$ are allowed by existing $R(D^{(*)})$ measurements**









Measurement of the charm mixing parameter y_{CP}–$y_{CP}^{K\pi}$ using two-body D^0 meson decays (1/2)

D^0 mixing due to mass eigenstates ≠ flavour eigenstates

$$Prob(D^0 \to \bar{D}^0, t) = \left|\frac{q}{p}\right|^2 \frac{e^{-\Gamma t}}{2}(\cosh(y\Gamma t) - \cos(x\Gamma t))$$

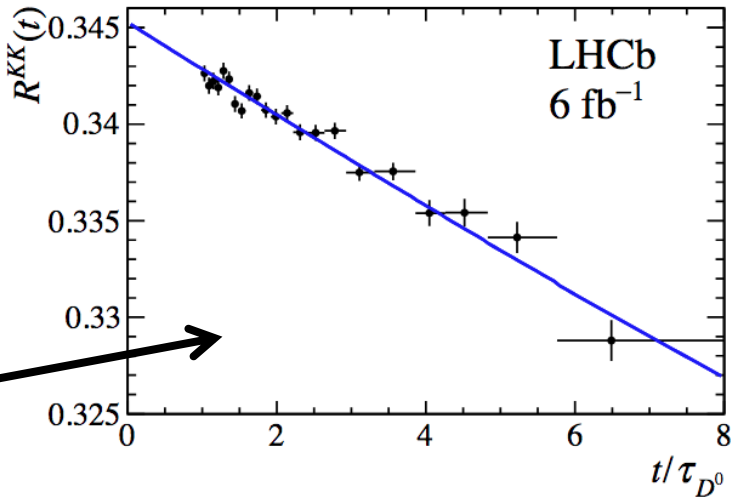
$$x = \frac{m_1 - m_2}{\Gamma}$$

$$y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

y is small (~10^{-3}) and difficult to predict, experimental determination of y is important to improve charm sector predictions

$$y_{CP}^{f} - y_{CP}^{K\pi} \approx y(1 + \sqrt{R_D})$$

$$R^{KK}(t) = \frac{dN(D^0 \to K^-K^+, t)}{dN(D^0 \to K^-\pi^+, t)} \propto e^{-(y_{CP}^{KK} - y_{CP}^{K\pi})t/\tau_{D^0}}$$



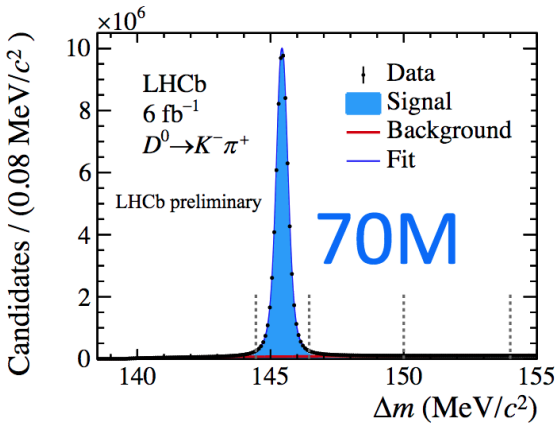
Measurement of the charm mixing parameter y_{CP}–$y_{CP}^{K\pi}$ using two-body D^0 meson decays (2/2)

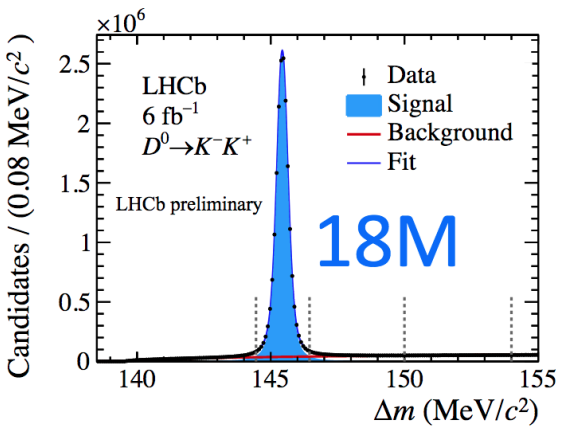
- $D^0 \to K^-\pi^+$ as normalization channel: first analysis so precise it has to account for mixing via doubly Cabibbo suppressed $D^0 \to K^+\pi^-$ decays
- Compatible with world average and **more precise by a factor of 4**

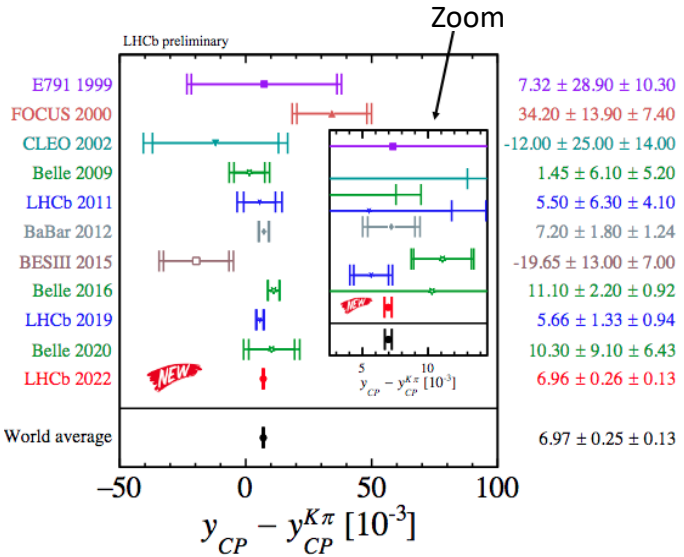
$$y_{CP} - y_{CP}^{K\pi} = (6.96 \pm 0.26 \pm 0.13) \times 10^{-3}$$

- LHCb combination: **improve sensitivity on y by factor of 2**

$$y = \left(6.46 \pm^{+0.24}_{-0.25}\right) \times 10^{-3}$$

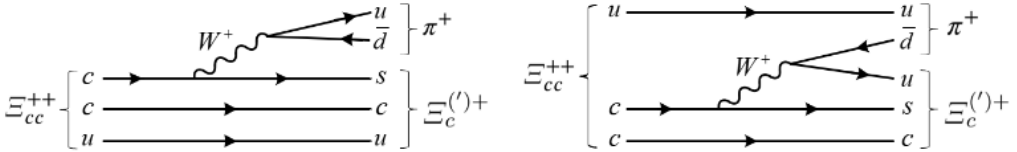






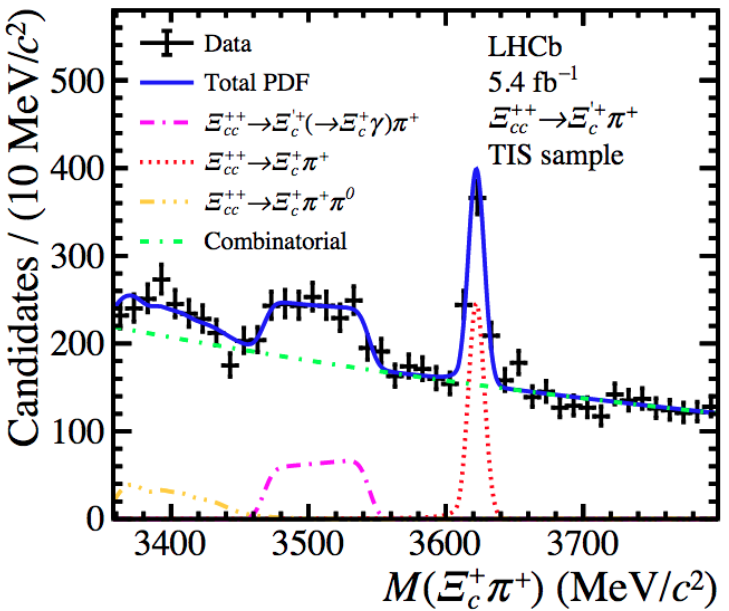
Observation of the doubly charmed baryon decay $\Xi^{++}_{cc} \to \Xi'^{+}_{c}\pi^{+}$

- **This measurement can be used to test various theoretical models**
  - Internal structure: (cu)c vs (cc)u
  - Internal and external W-emission in decay
  - Flavour wave-function symmetry



- $\Xi^{++}_{cc} \to \Xi'^{+}_{c}(\to \Xi^{+}_{c}\gamma)\pi^{+}$ with photon not reconstructed
- **3rd observed decay mode of Ξ^{++}_{cc}**
- The result is not consistent with current theoretical predictions, and will provide input for future calculations

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^{+}\pi^{+})}{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^{+})} = 1.41 \pm 0.17 \pm 0.10$$

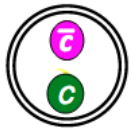


Discovery of sizeable ω contribution to $\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$ decays

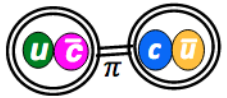
Internal structure of $\chi_{c1}(3872)$ unknown
→ **isospin can give insight**

- $\chi_{c1}(3872) \to \rho^0 J/\psi$ isospin violating
- $\chi_{c1}(3872) \to \omega J/\psi$ isospin conserving

Charmonium ?



$D^0\bar{D}^{*0}$ molecule ?

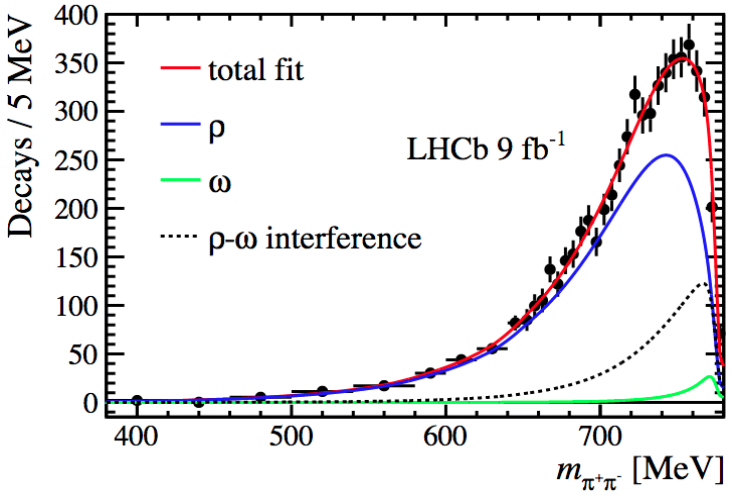


Diquark tetraquark ?

First analysis to take into account ρ^0-ω interference:

- ω contribution w/o interference: (1.9 ± 0.4 ± 0.3) % consistent with previous measurements
- **ω contribution w/ interference: (21.4 ± 2.3 ± 2.0)%**

- Isopin violating component ρ^0 properly quantified for the first time
  → **too large by an order of magnitude for $\chi_{c1}(3872)$ to be a pure charmonium state**



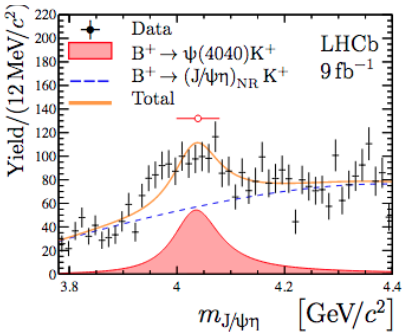
Study of charmonium and charmonium-like contributions in $B^+ \to J/\psi \eta K^+$ decays

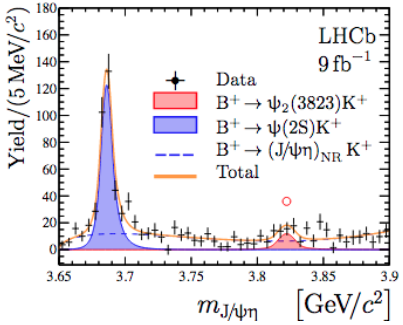
PAPER-2021-047

- Full spectroscopy of J/ψη mass spectrum
- Search for 12 known charmonium and charmonium-like states:
  2 observations + 10 branching ratio limits

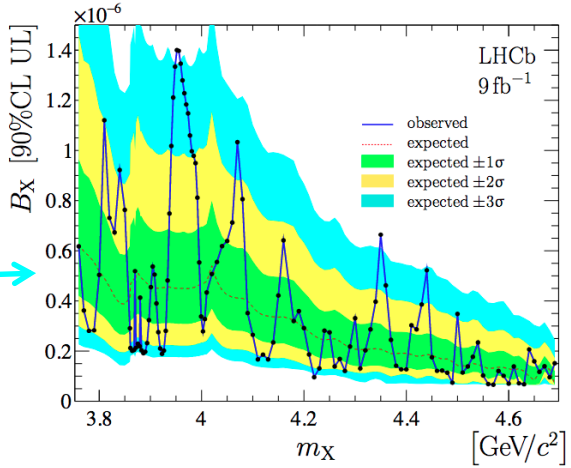
$\mathcal{B}(B^+ \to \psi_2(3823)(\to J/\psi\eta)K^+) = (1.25^{+0.71}_{-0.53} \pm 0.04) \times 10^{-6}$

$\mathcal{B}(B^+ \to \psi(4040)(\to J/\psi\eta)K^+) = (8.53 \pm 2.35 \pm 0.30) \times 10^{-6}$





	R(3760)
ψ(3770)	R(3790)
$\psi_3(3842)$	$Z_c(3900)^0$
ψ(4160)	ψ(4230)
ψ(4415)	ψ(4360)
	ψ(4390)



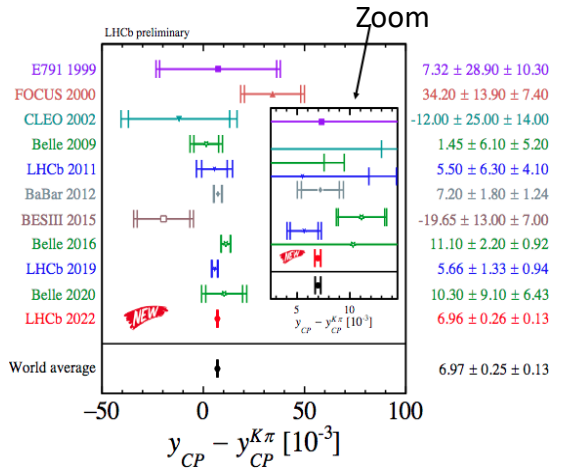
- **Some models for $\chi_{c1}(3872)$ predict a partner state X'$_c$** → search for states in J/ψη mass spectrum

$\mathcal{B}(B^+ \to X'_C(\to J/\psi\eta)K^+) < 3.9 \times 10^{-7}(90\,\%\ CL)$ Improvement on previous limits by an order of magnitude

Summary

Wide physics programme:

- World's most precise charm mixing measurements
- Lepton flavour universality tests in baryonic sector, semi-leptonic decay with τ
- Exotics and spectroscopy



For the months ahead we are looking forward to the challenge of commissioning the entire readout and trigger, and soon, the completion of the VELO installation and the UT.