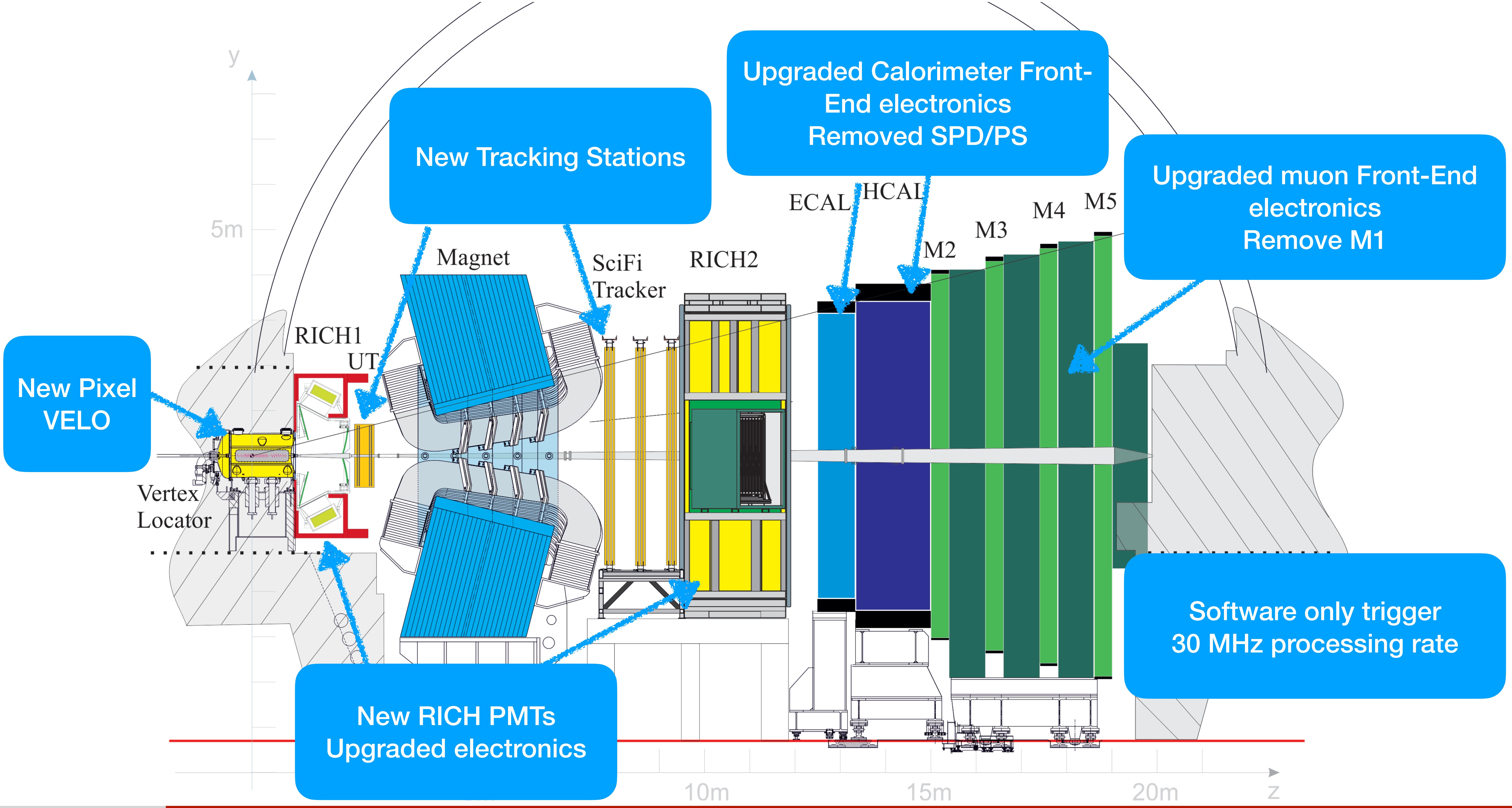
# LHCb Status Report

Adam Davis
University of Manchester
on behalf of the LHCb Collaboration
PPAP meeting
22 September 2022

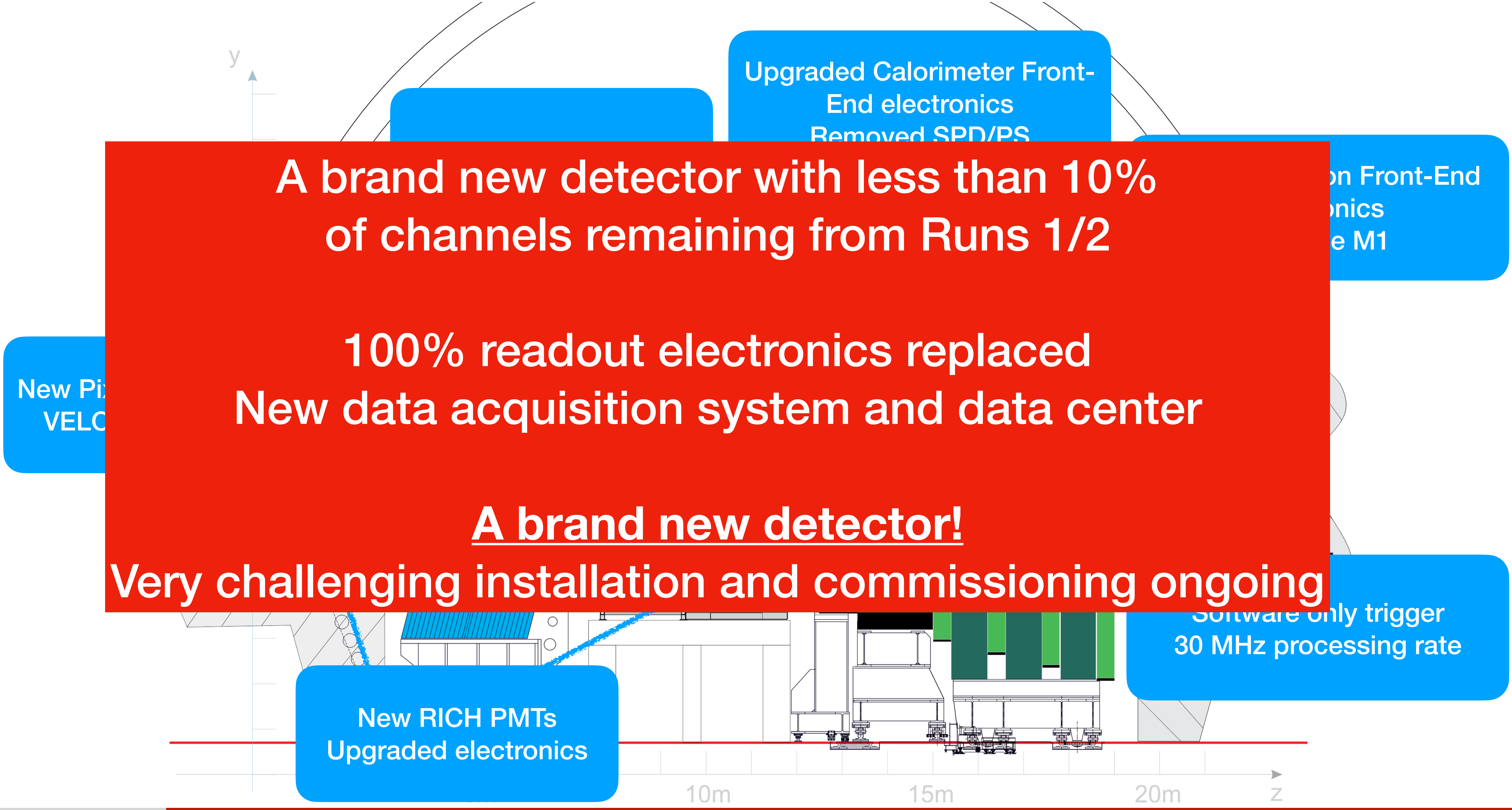
# LHCb UK

- Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, Imperial, Liverpool, Manchester, Oxford, RAL, Warwick
- Collaboration: >1100 authors, ~18% UK affiliation
- Large leadership representation across all areas of the experiment by UK members
    - VELO + RICH Upgrade I and II, TORCH, RTA, DPA, Simulation, Physics WGs
- Chris Parkes is LHCb Spokesperson (+ PI for Upgrade I)
- Nigel Watson is LHCb-UK Spokesperson
- Tim Gershon is PI for LHCb-UK Upgrade II

# LHCb Upgrade I (Now!)



# LHCb Upgrade I (Now!)

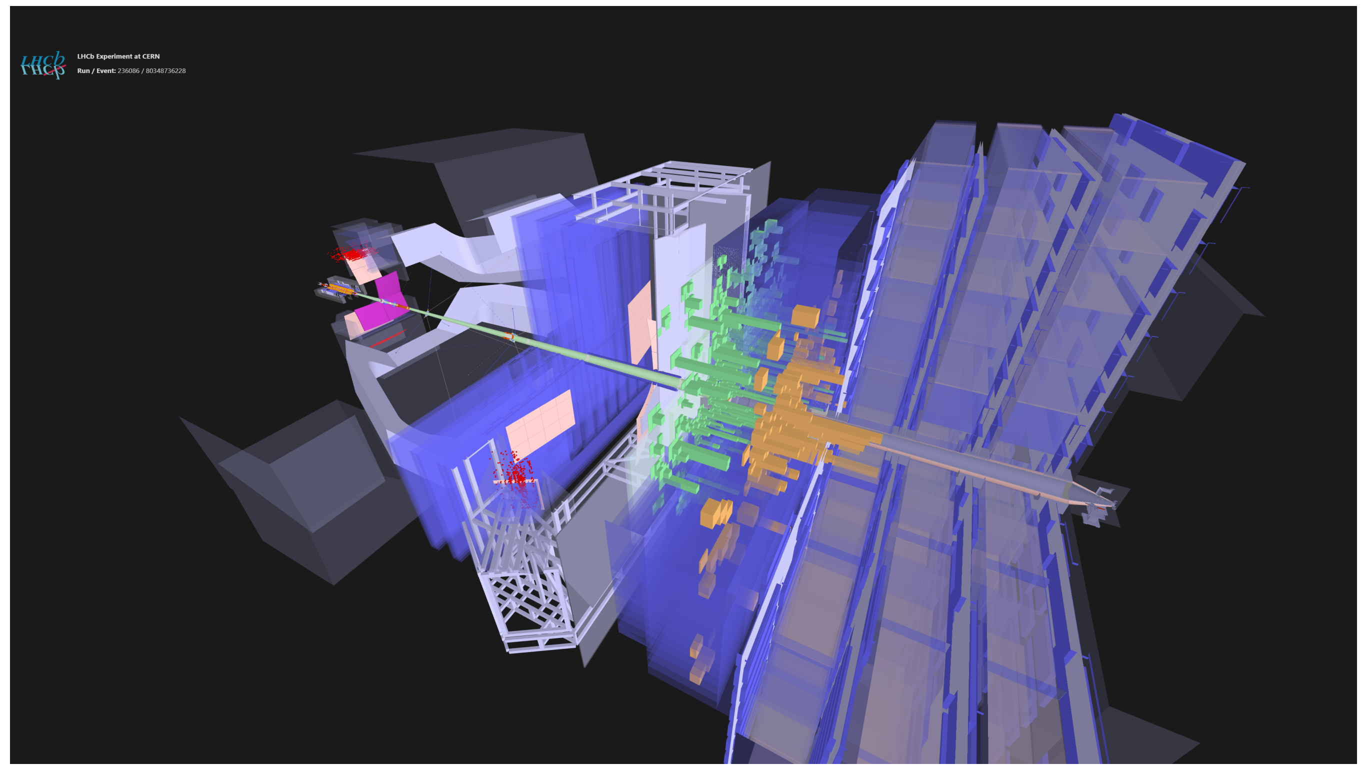



A brand new detector with less than 10%
of channels remaining from Runs 1/2

100% readout electronics replaced
New data acquisition system and data center

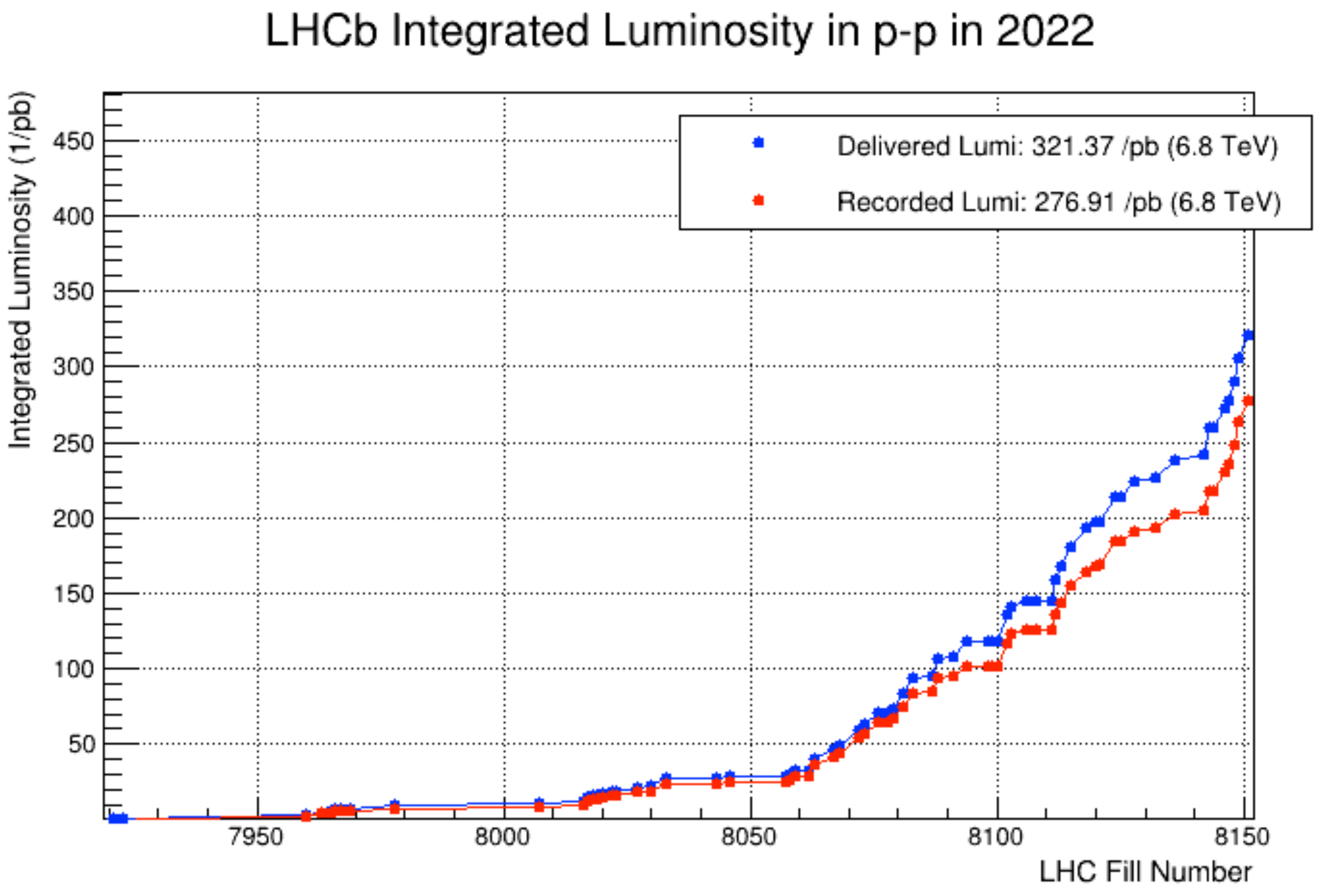
**<u>A brand new detector!</u>**
Very challenging installation and commissioning ongoing

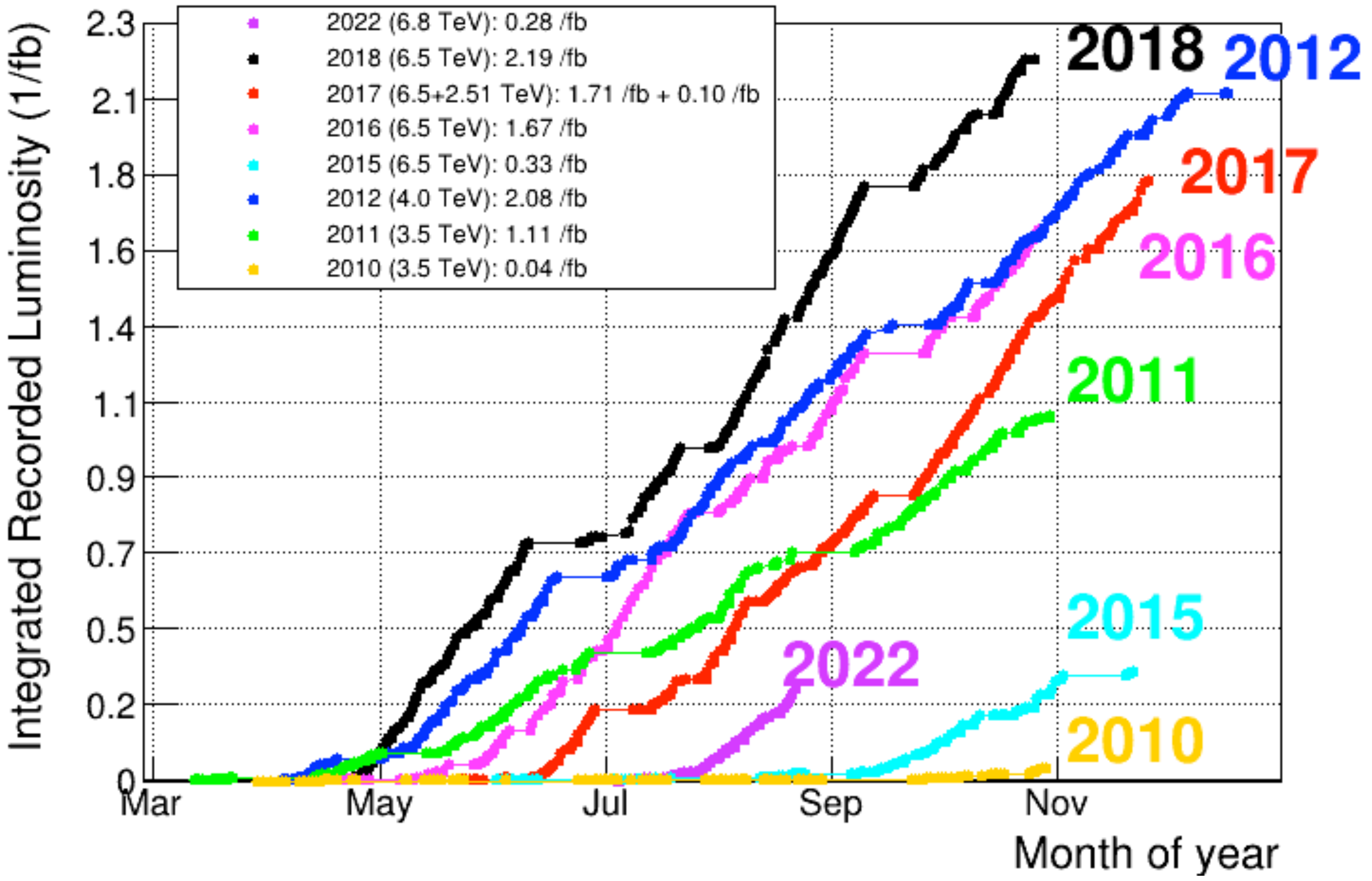
# Stable Beams 6.8 TeV




# Collected Data to Date

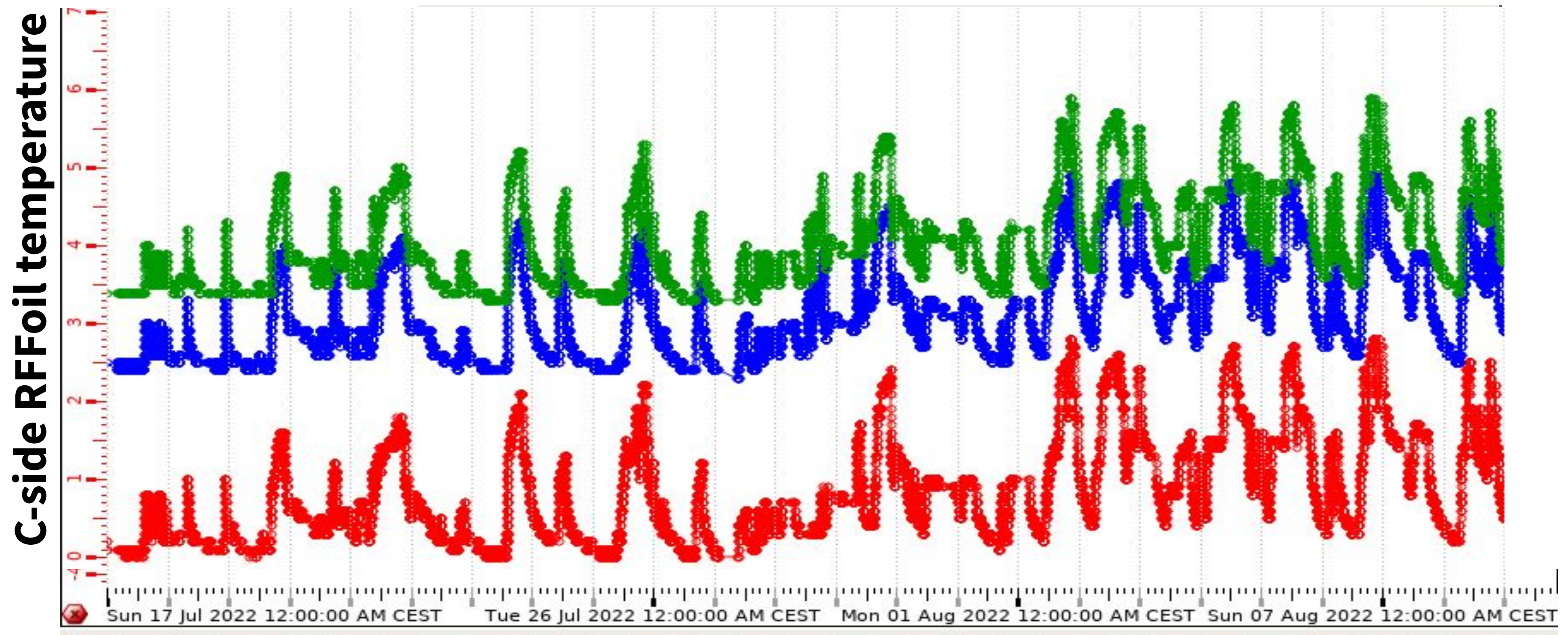
- Collection of extremely useful data for software and detector commissioning under way

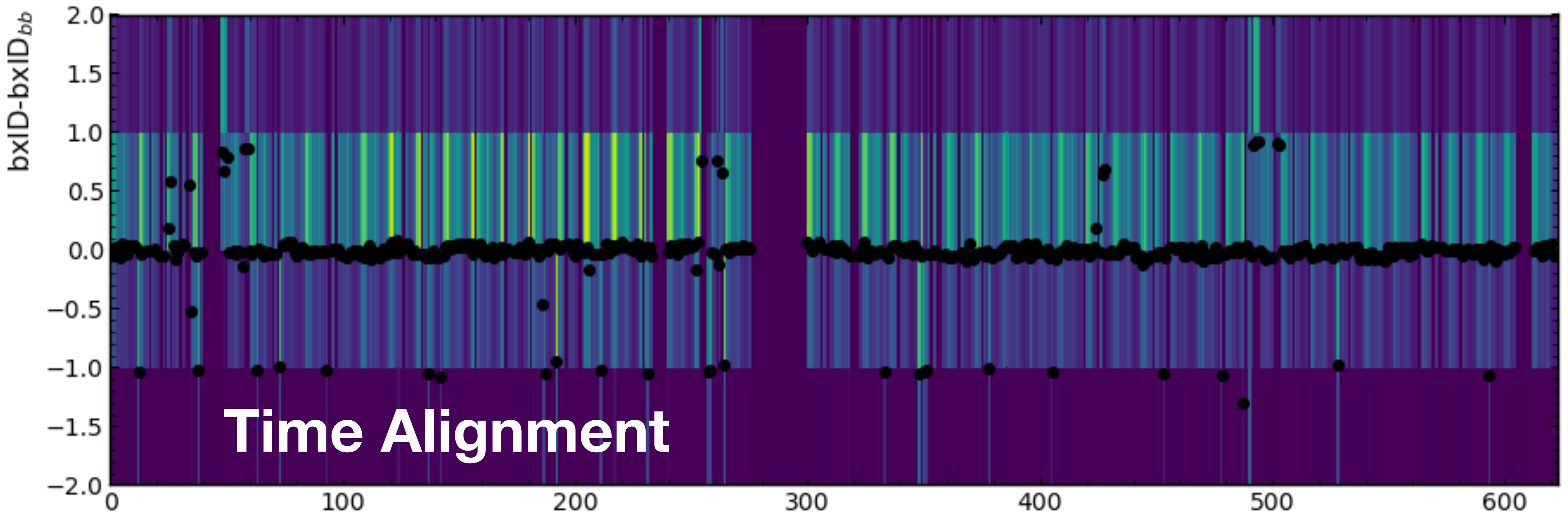


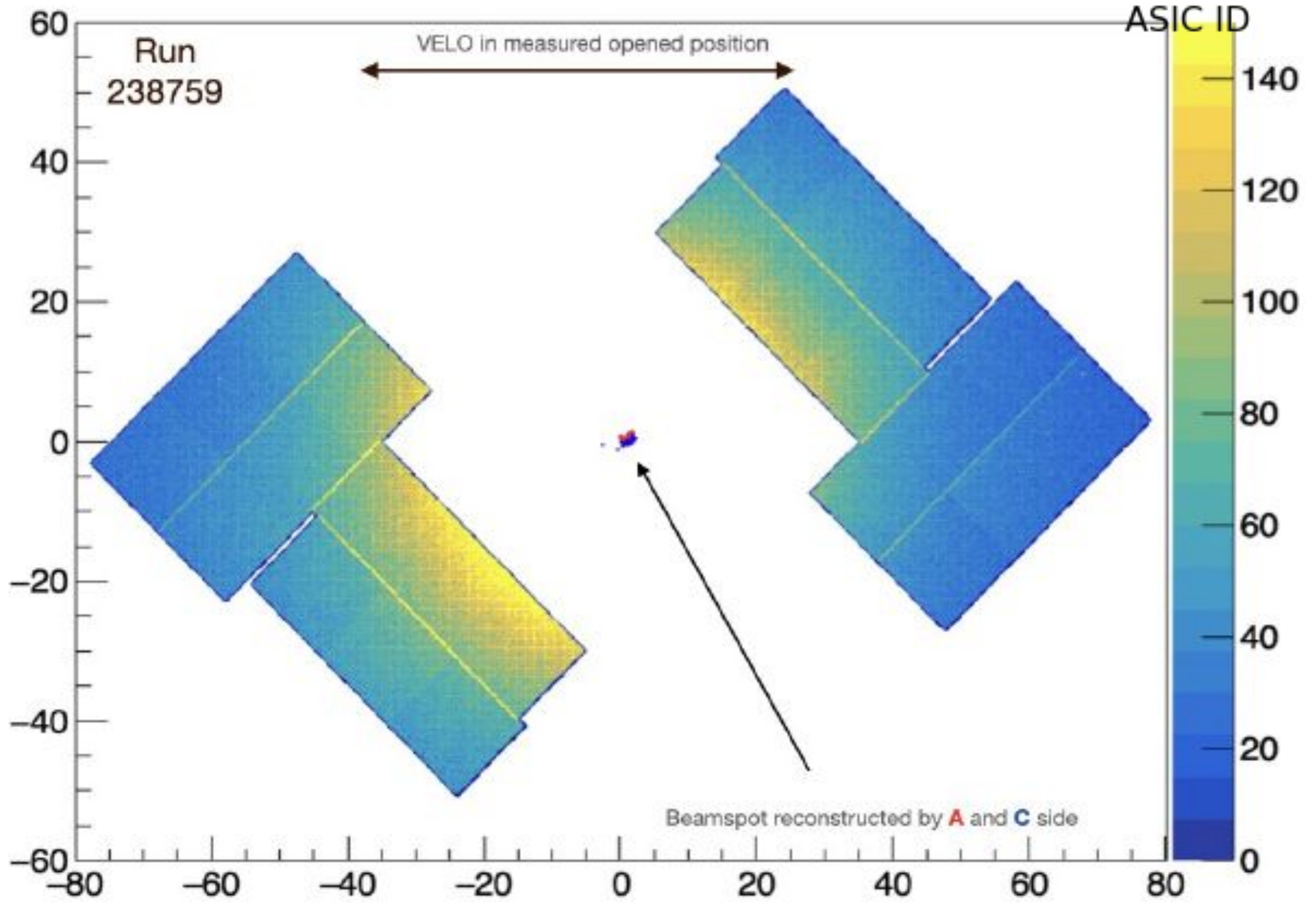



# VELO Commissioning

- High and Low Voltage connected, tested and functional. Control software ready
- $CO_2$ cooling in all 52 modules circulating and boiling reliably Temperature monitoring includes over 1200 sensors
- 98% of data links are running
- DAQ firmware ready
- In-situ front-end ASIC calibration procedure nearing finalization (including pixel thresholds and time alignment)
- VELO tracks and vertices are reconstructed
  - Essential for closing procedure
- Reconstructed vertices consistent with beam position and with metrology
- Closure procedure agreed with LHC



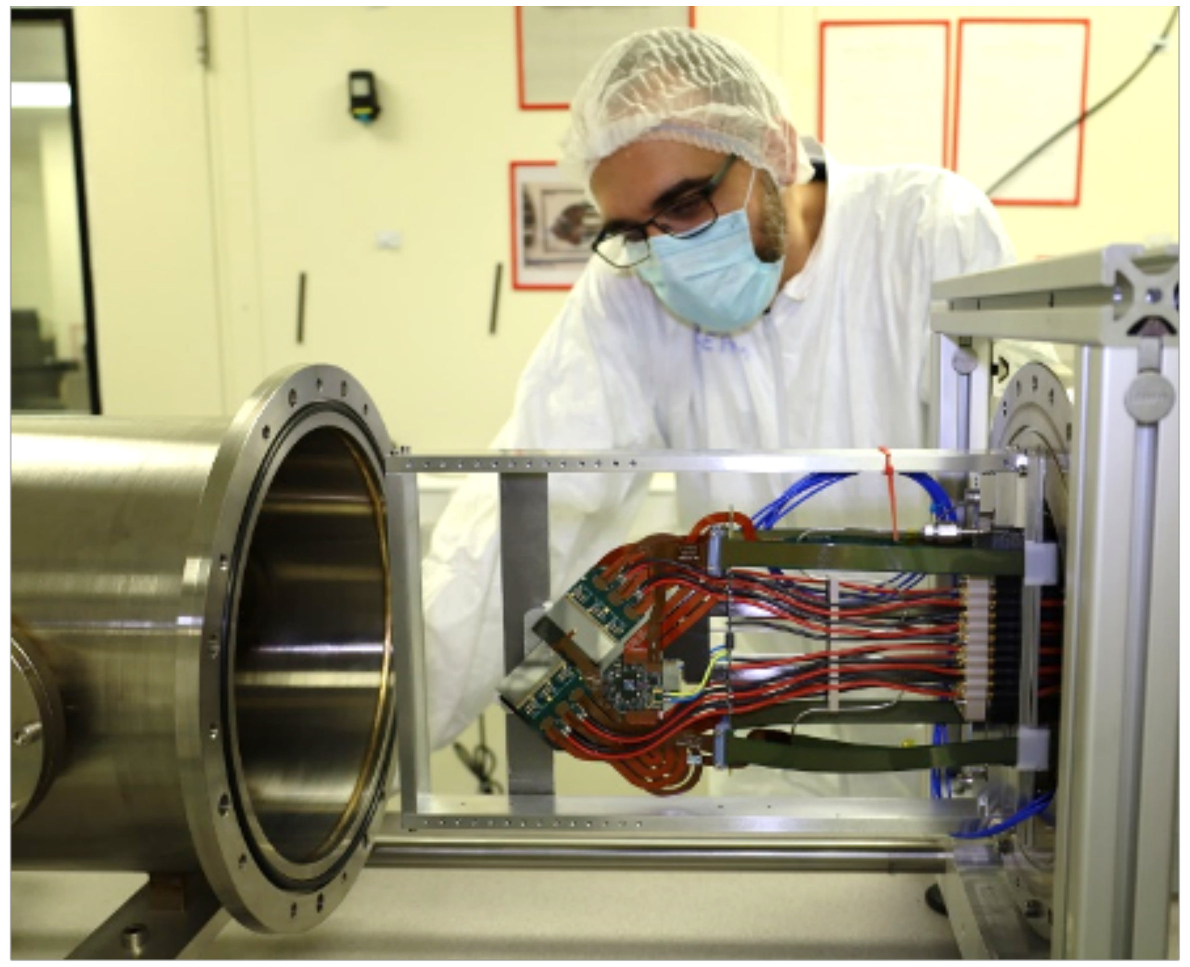



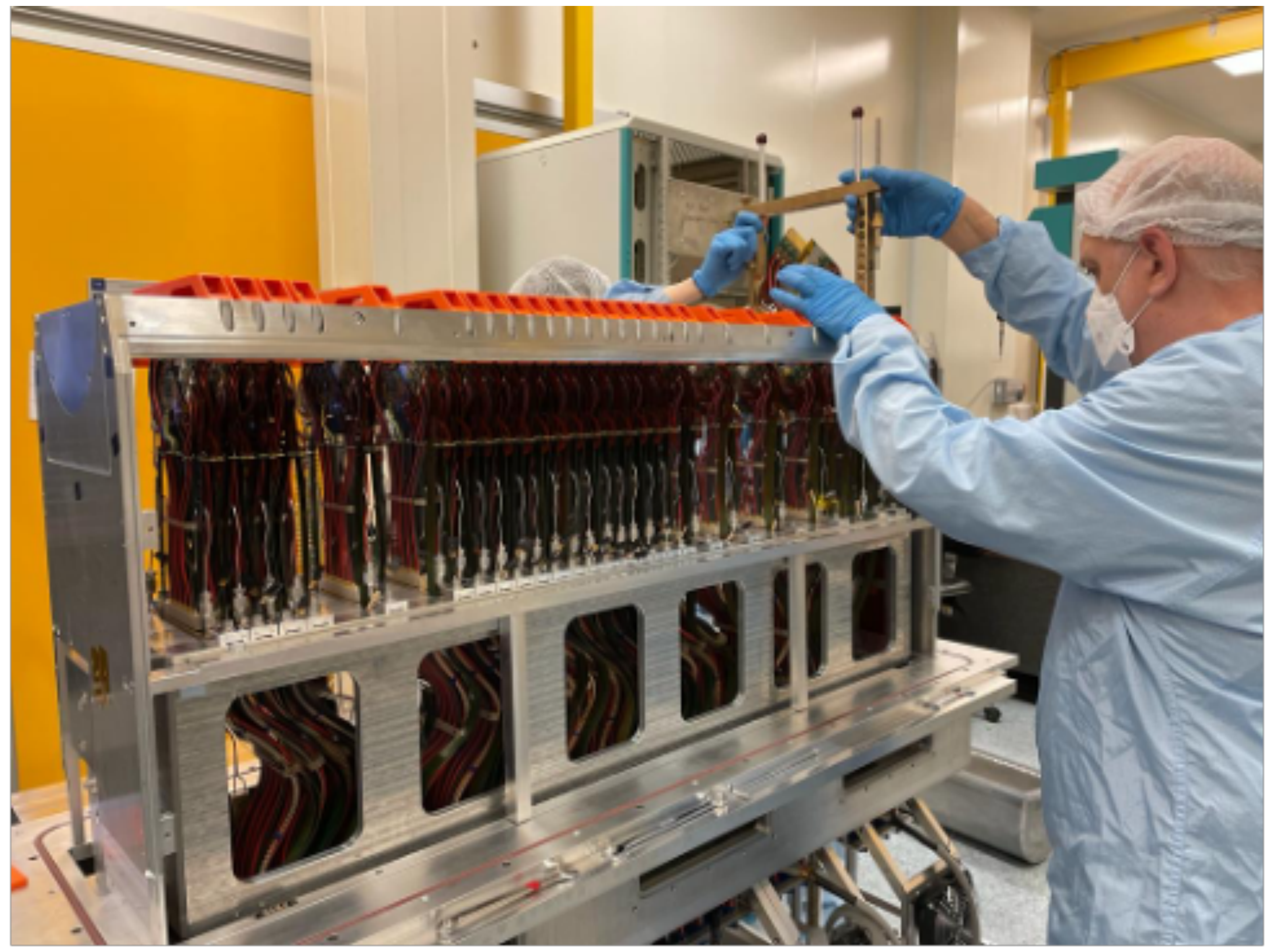
# UK VELO Contributions

- Module Production
  - Cooling (Oxford, Manchester)
  - Gluing, cabling, wire-bonding (Manchester)
  - Quality Control (Manchester)
  - OBP (Glasgow)
- Detector Assembly
  - Base (Oxford)
  - Detector Mechanics (Liverpool)
  - Module Installation and Testing (Liverpool, Manchester, Oxford)
  - Transportation to CERN (Liverpool)
- Commissioning at CERN
  - Firmware (Liverpool, Manchester)
  - Metrology (Liverpool, Manchester)
  - Alignment, Monitoring and Reconstruction (Manchester, Warwick, Oxford, Liverpool)
  - Detector Description + Simulation (Warwick, Liverpool)

Module Production



Detector Assembly



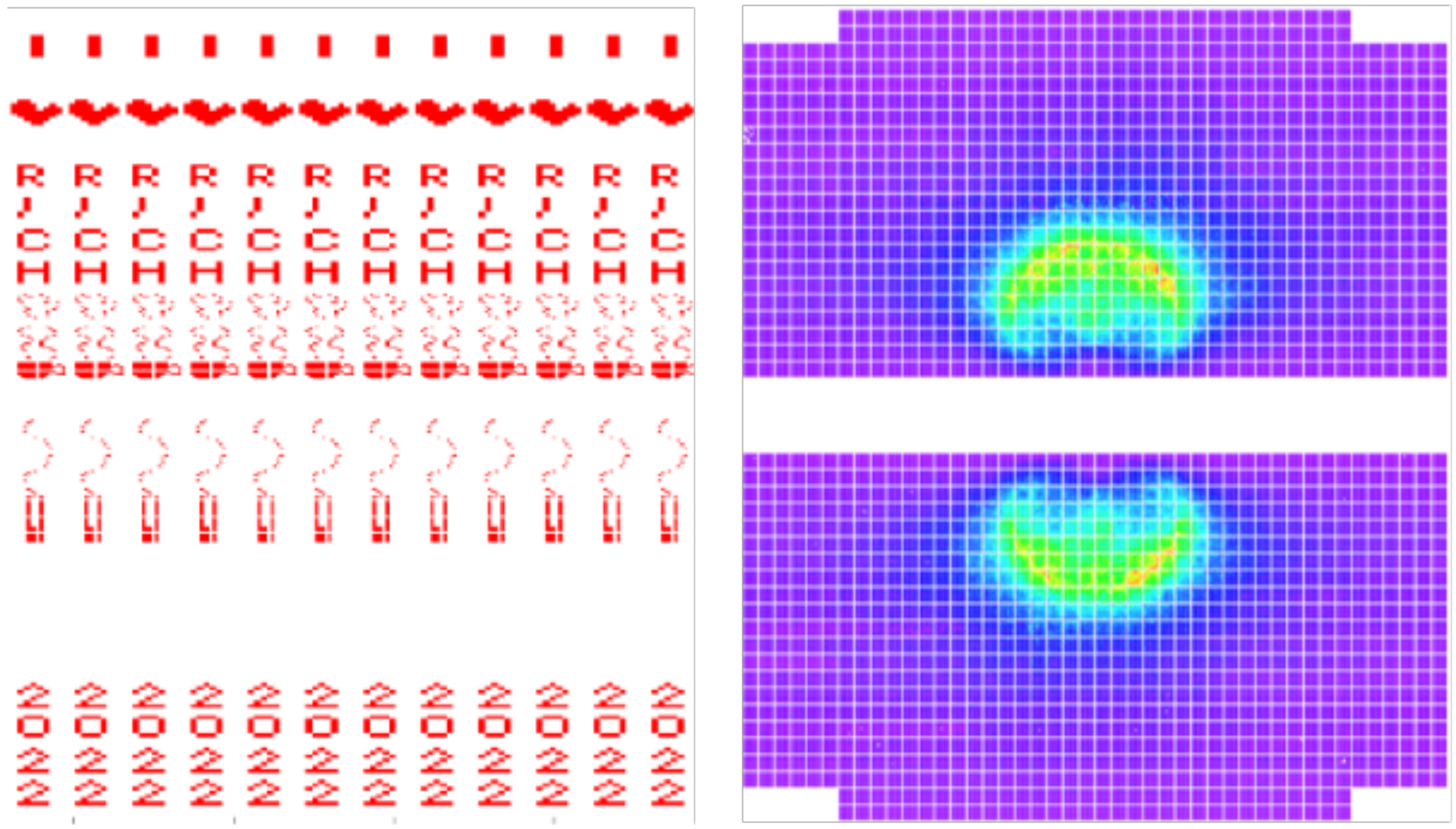
Detector Transport

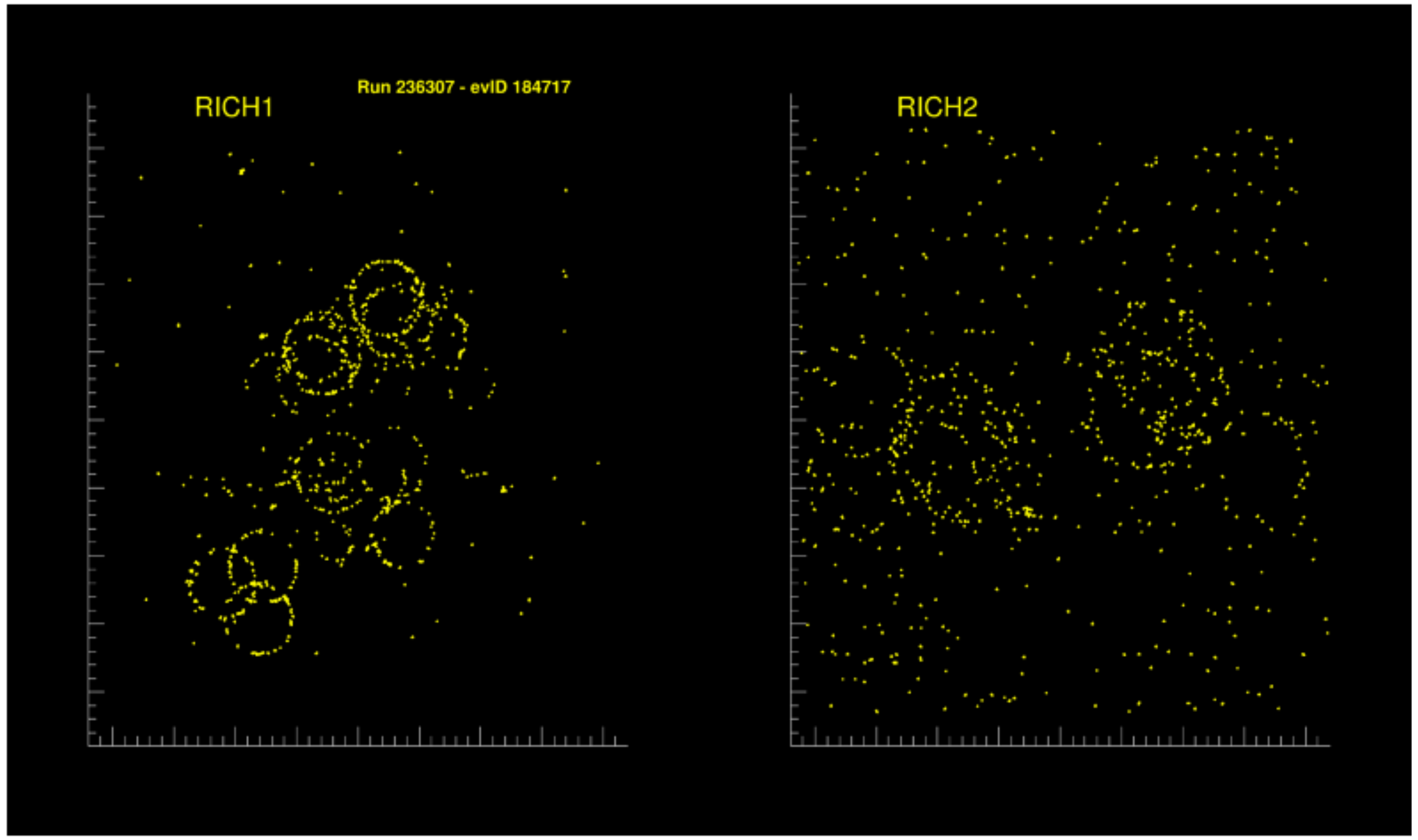

Detector Installation

# RICH

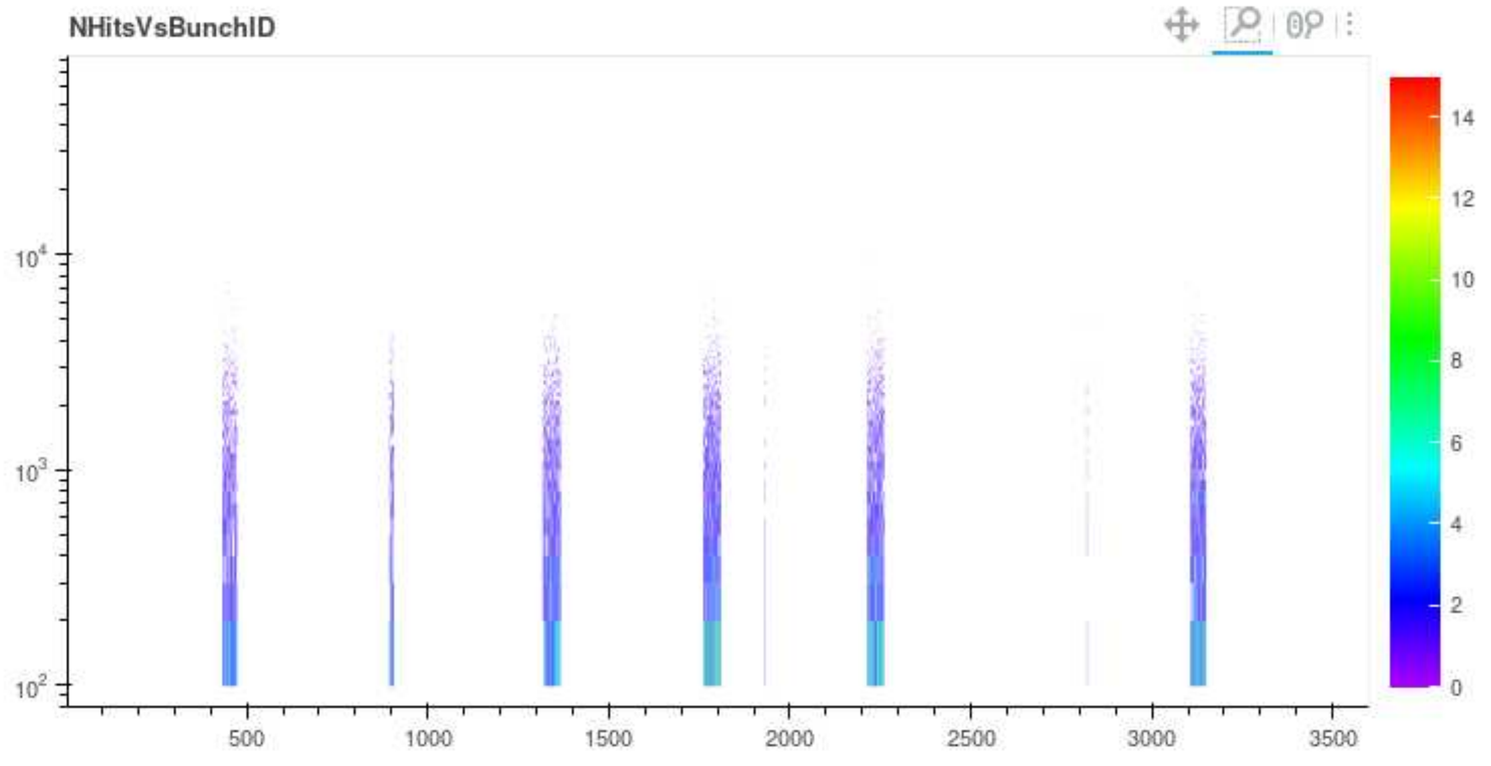
- RICH detectors successfully installed in LS2:
  - RICH2 A-side installed in February 2021
  - RICH2 C-side installed in April 2021
  - RICH1 Down-box installed in December 2022
  - RICH1 Up-box installed in January 2022
  - Commissioning well advanced!
- Hardware fully validated, taking data with collisions since pilot beam in 2021: ready for Physics production

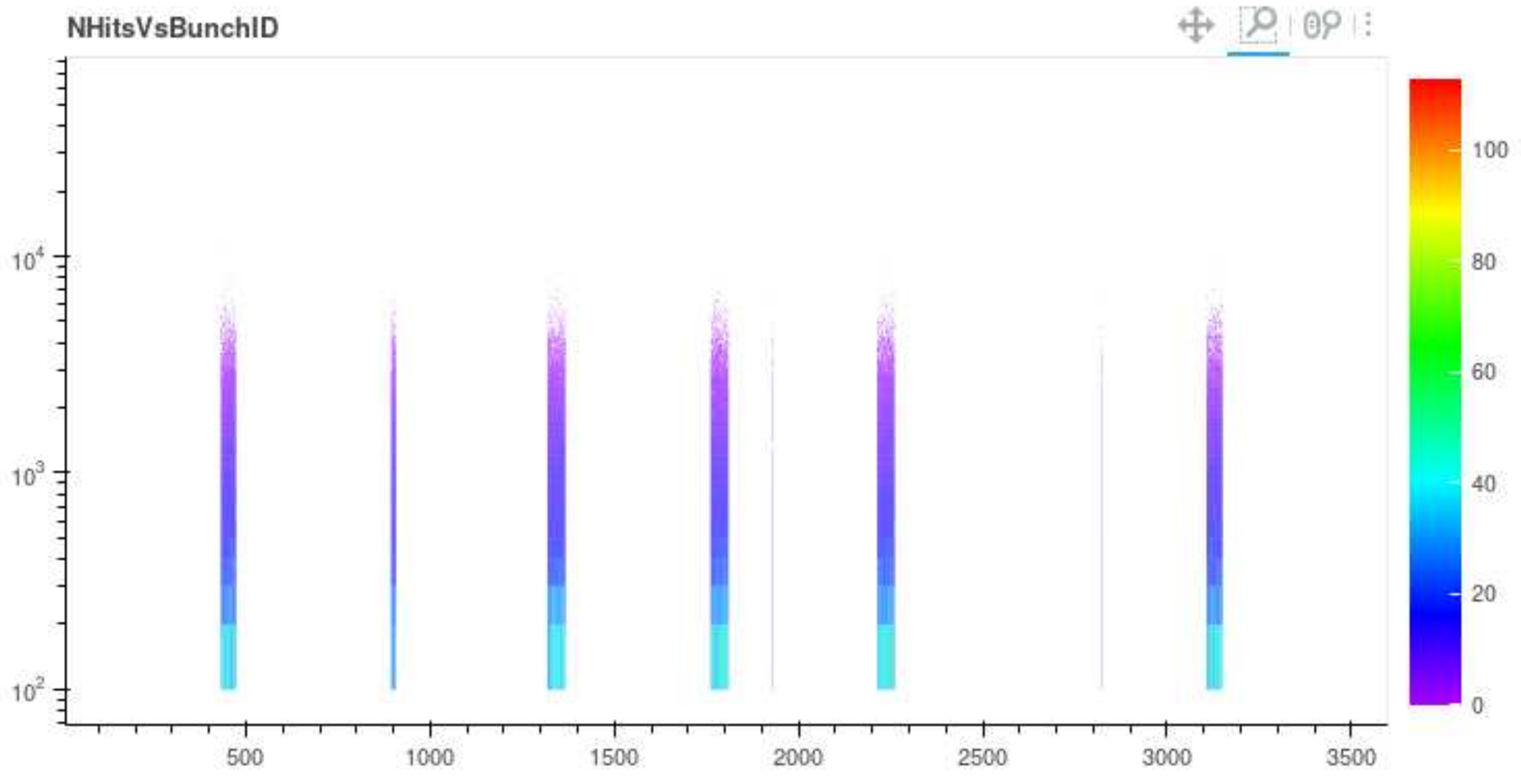
**RICH 1 hitmap**





# UK RICH Contributions

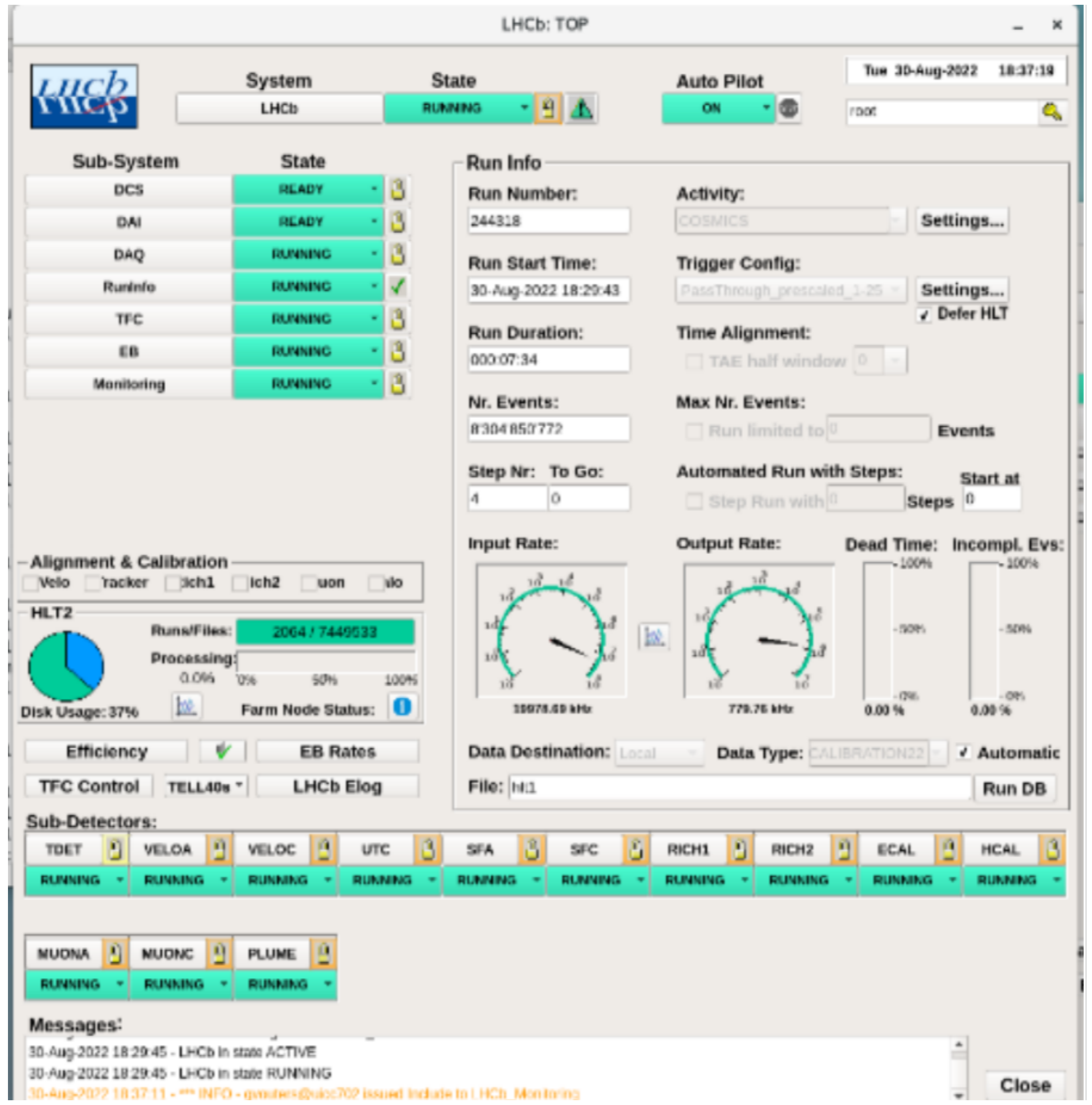


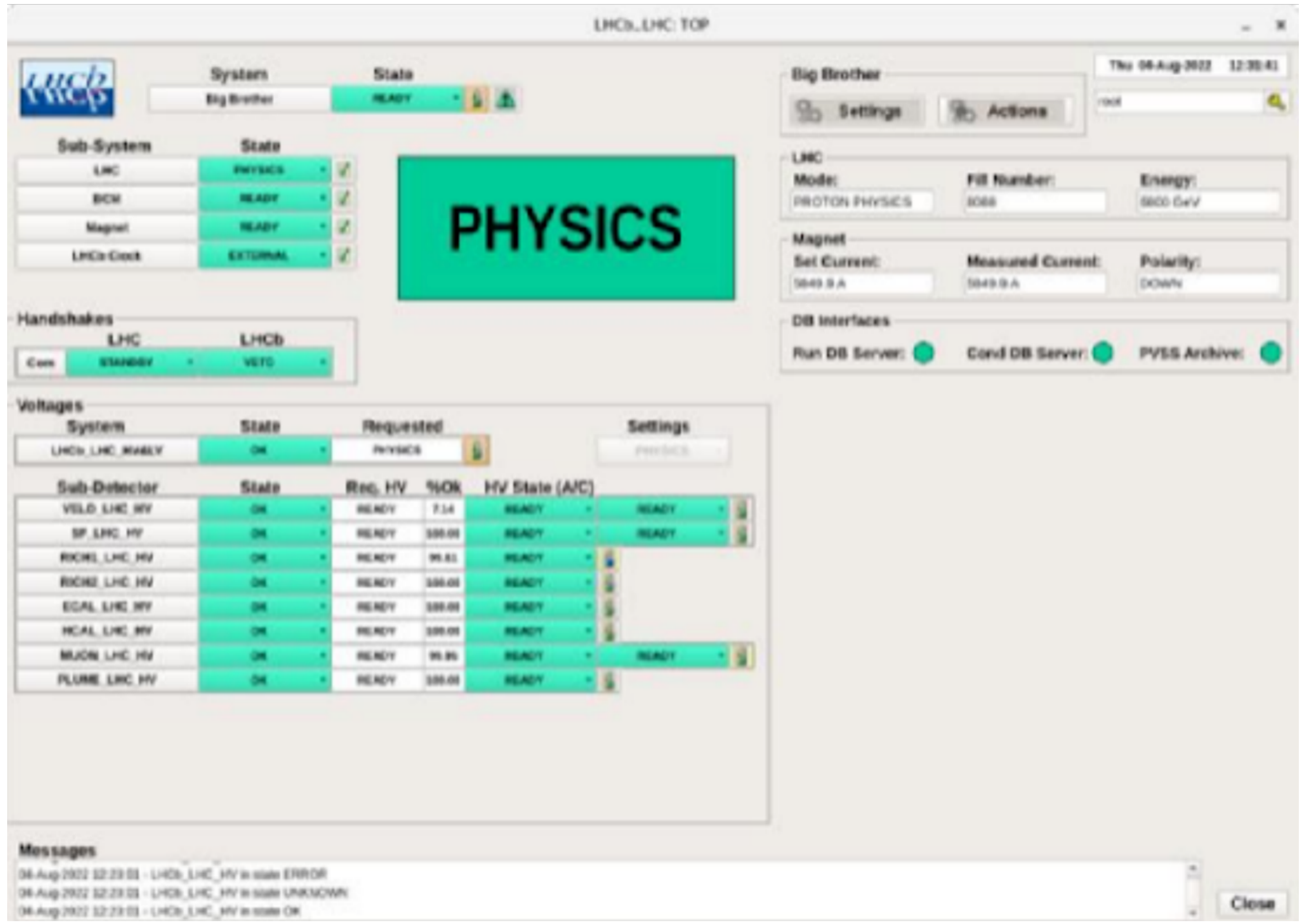




- Edinburgh: MaPMT QA, Elementary Cell QA, Commissioning
- Oxford: RICH1 Gas enclosure, Quartz, MaPMT Enclosures, cooling
- Bristol: RICH1 Column Installation tooling, Monitoring and Calibration Systems, Mirror production, assembly, alignment
- RAL: RICH1 Column Installation tooling, RICH monitoring and calibration systems, shielding
- Imperial: RICH1 Column mechanics, chassis, maintenance, installation and services, commissioning
- Cambridge: PDMDB motherboard design, production and QA, Plugins design, production and QA, DAQ, calibrations
- Birmingham: DAQ, Firmware, Commissioning

# Global Commissioning

- Low Voltage, High Voltage, and safety systems fully commissioned
- Most of DAQ is commissioned
- Progressing towards commissioning in global → Datataking with all subdetectors included in global control is next milestone
- Silvia Gambetta (Edinburgh) was Operations Coordinator up to last week. Many thanks to Silvia for her hard work!



# Software Infrastructure

- From European strategy update:

4

**Other essential scientific activities for particle physics**

D. Large-scale data-intensive software and computing infrastructures are an essential ingredient to particle physics research programmes. The community faces major challenges in this area, notably with a view to the HL-LHC. As a result, the software and computing models used in particle physics research must evolve to meet the future needs of the field. ***The community must vigorously pursue common, coordinated R&D efforts in collaboration with other fields of science and industry, to develop software and computing infrastructures that exploit recent advances in information technology and data science. Further development of internal policies on open data and data preservation should be encouraged, and an adequate level of resources invested in their implementation.***

- Software is on equal footing with hardware, especially moving towards the HL-LHC era. Investment is essential for future success

# Software Infrastructure

- From European strategy update:

4

**Other essential scientific**

**Invaluable contributions from UK institutes, often above and beyond the call of duty**

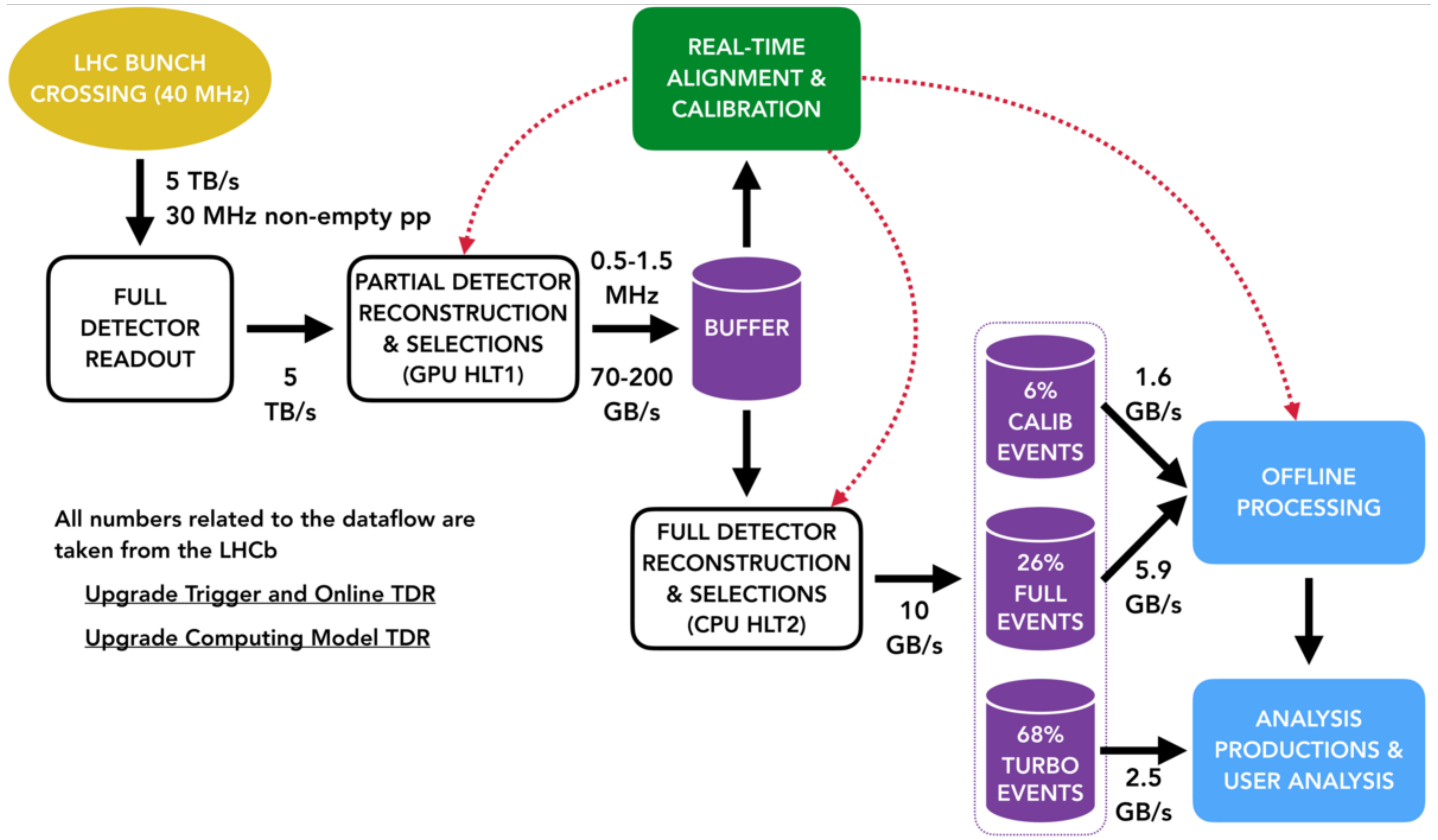
**Without the key contributions of these experts, we would not be in a position to take data**

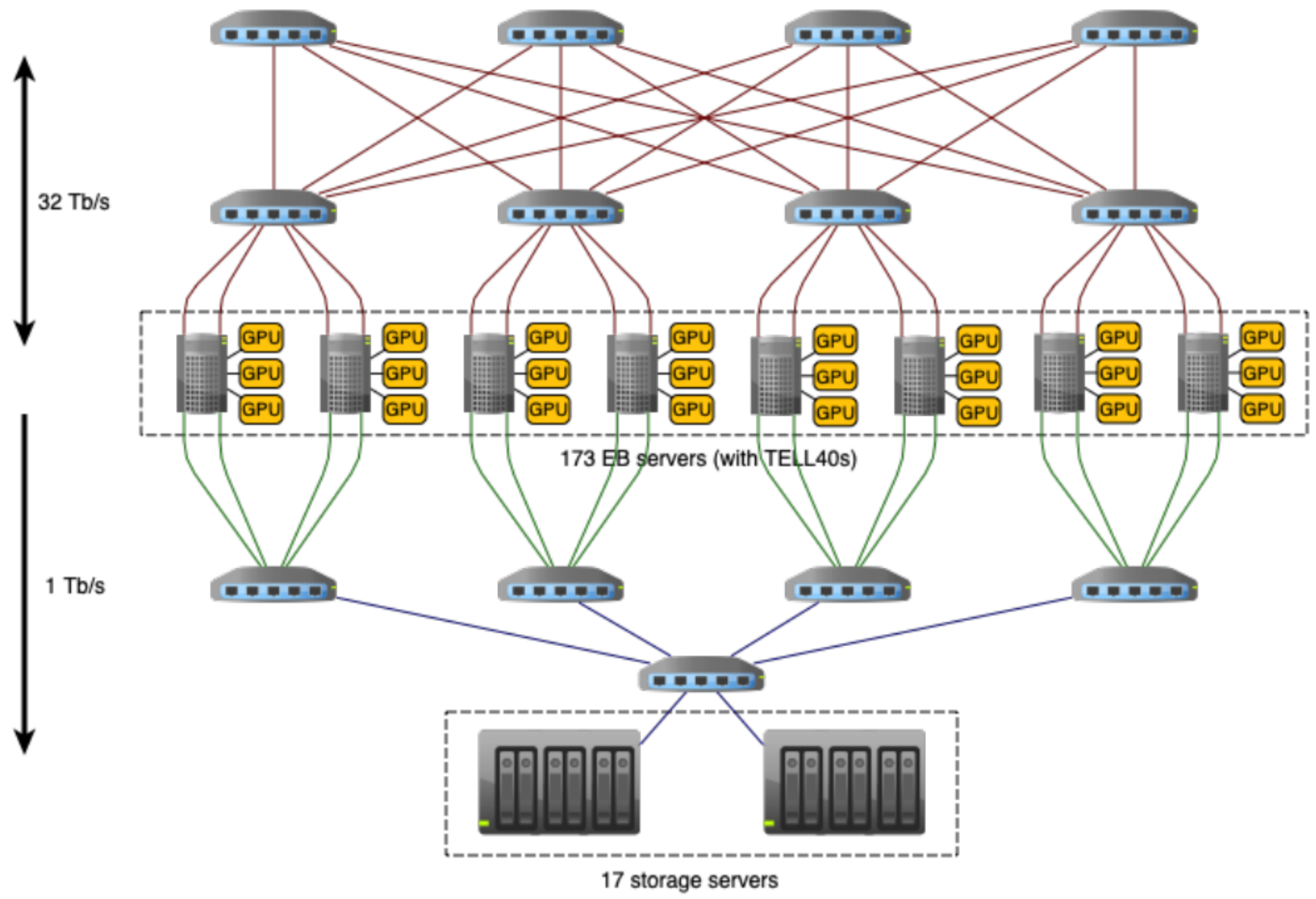
***policies on open data and data preservation should be encouraged, and an adequate level of resources invested in their implementation.***

- Software is on equal footing with hardware, especially moving towards the HL-LHC era. Investment is essential for future success

# Real Time Analysis + Online

- Responsible for reducing the 40 MHz bunch crossing rate to ~1 MHz without the use of a hardware level trigger
- Uses <u>novel system with GPUs</u> which are interleaved in the event building farm
- Tests of EB and trigger including many different subsystems, with varying event sizes and increasingly higher rates, with good performance up to 25 MHz
- <u>System able to cope with the expected luminosity</u>
- Includes survey misalignments measurements, triggering on Calo activity
- Track reconstruction is commissioned and functional in VELO, SciFi and Muon systems
- <u>Triggering on tracks next big goal (happening now)</u>



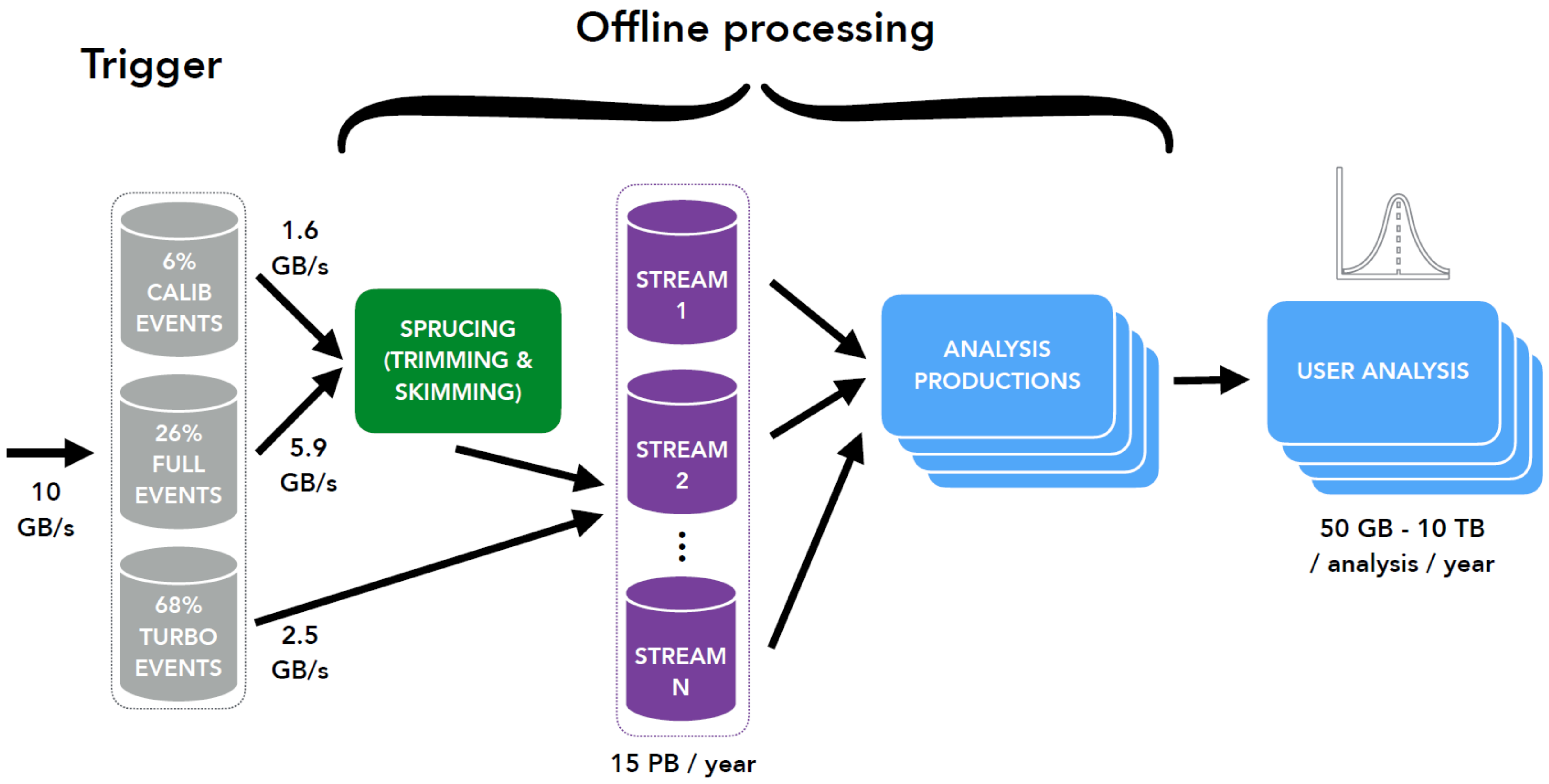
# Data Processing & Analysis

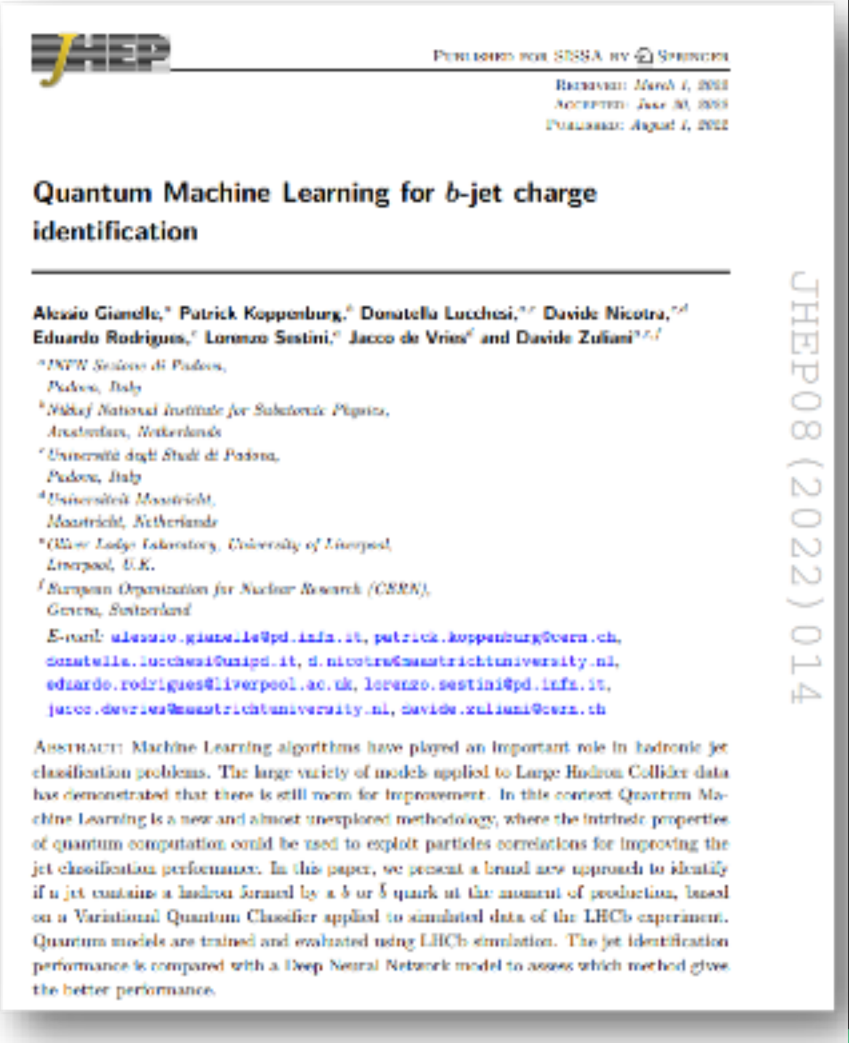
- Responsible for the processing of events after the second software trigger

- Scope includes the development of offline tools for Run 3 and beyond, coordination of productions for analysts, maintenance of legacy software, innovative software initiatives and Analysis Preservation/Open data

- PL + DPL of DPA are at UK institutes, major contributions from involved institutes

- First publication: J. High Energ. Phys. 2022, 14 (2022)





JHEP

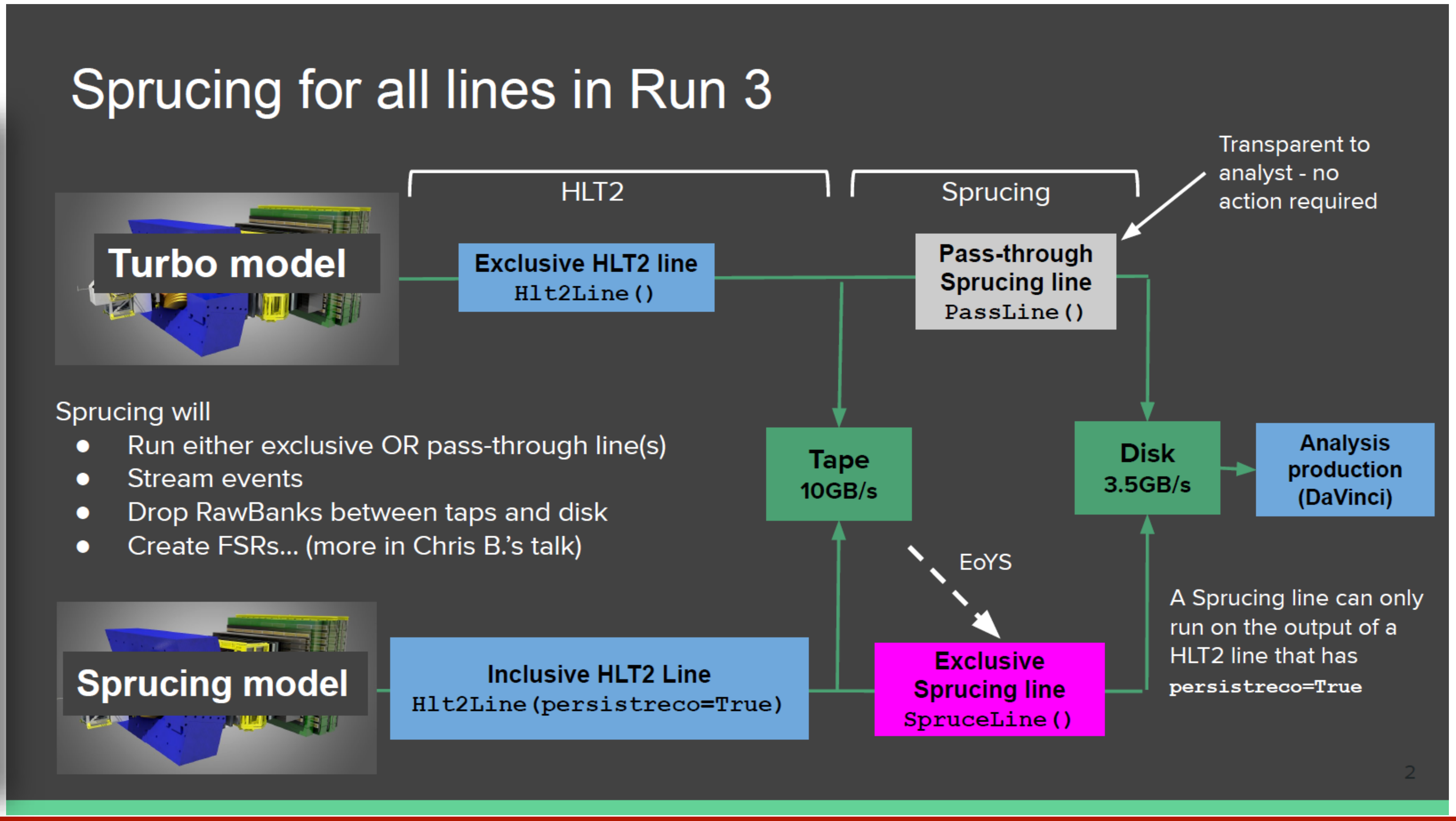
Published for SISSA by Springer

Quantum Machine Learning for b-jet charge identification

Alessio Gianelle, Patrick Koppenburg, Donatella Lucchesi, Davide Nicotra, Eduardo Rodrigues, Lorenzo Sestini, Jacco de Vries and Davide Zuliani

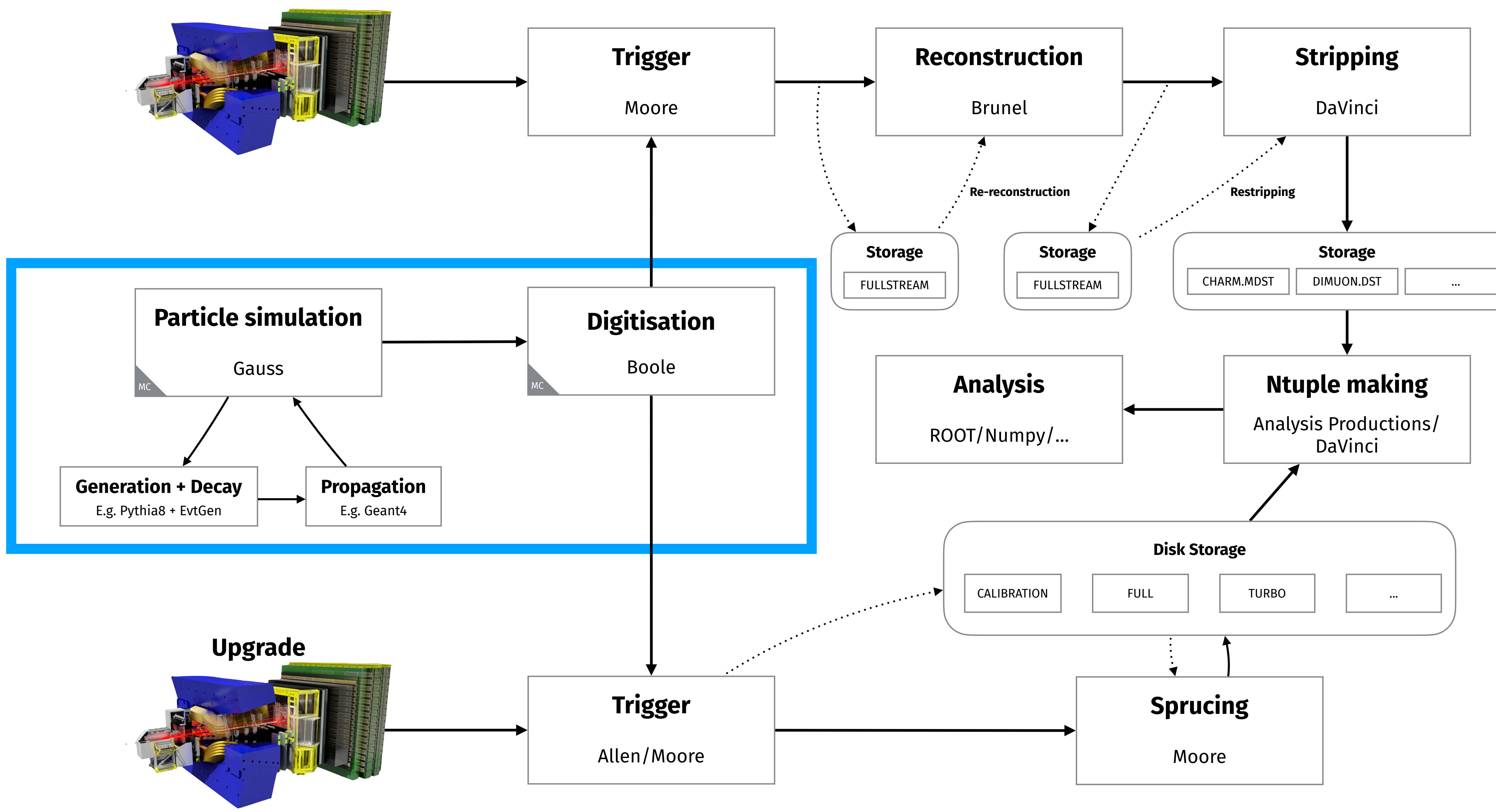
JHEP08(2022)014

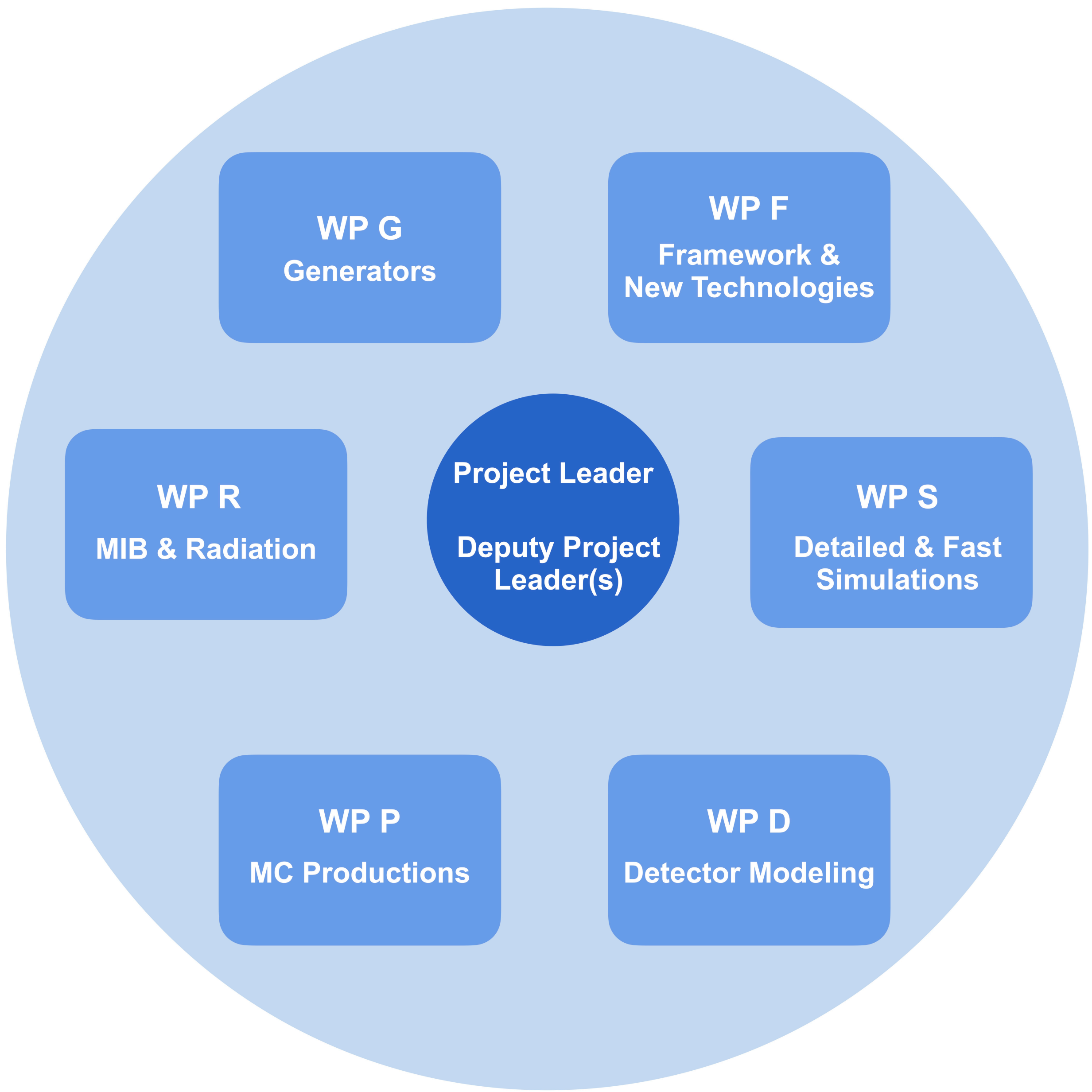
Abstract: Machine Learning algorithms have played an important role in hadronic jet classification problems. The large variety of models applied to Large Hadron Collider data has demonstrated that there is still room for improvement. In this context Quantum Machine Learning is a new and almost unexplored methodology, where the intrinsic properties of quantum computation could be used to exploit particles correlations for improving the jet classification performance. In this paper, we present a brand new approach to identify if a jet contains a hadron formed by a b or b̄ quark at the moment of production, based on a Variational Quantum Classifier applied to simulated data of the LHCb experiment. Quantum models are trained and evaluated using LHCb simulation. The jet identification performance is compared with a Deep Neural Network model to assess which method gives the better performance.



# Simulation

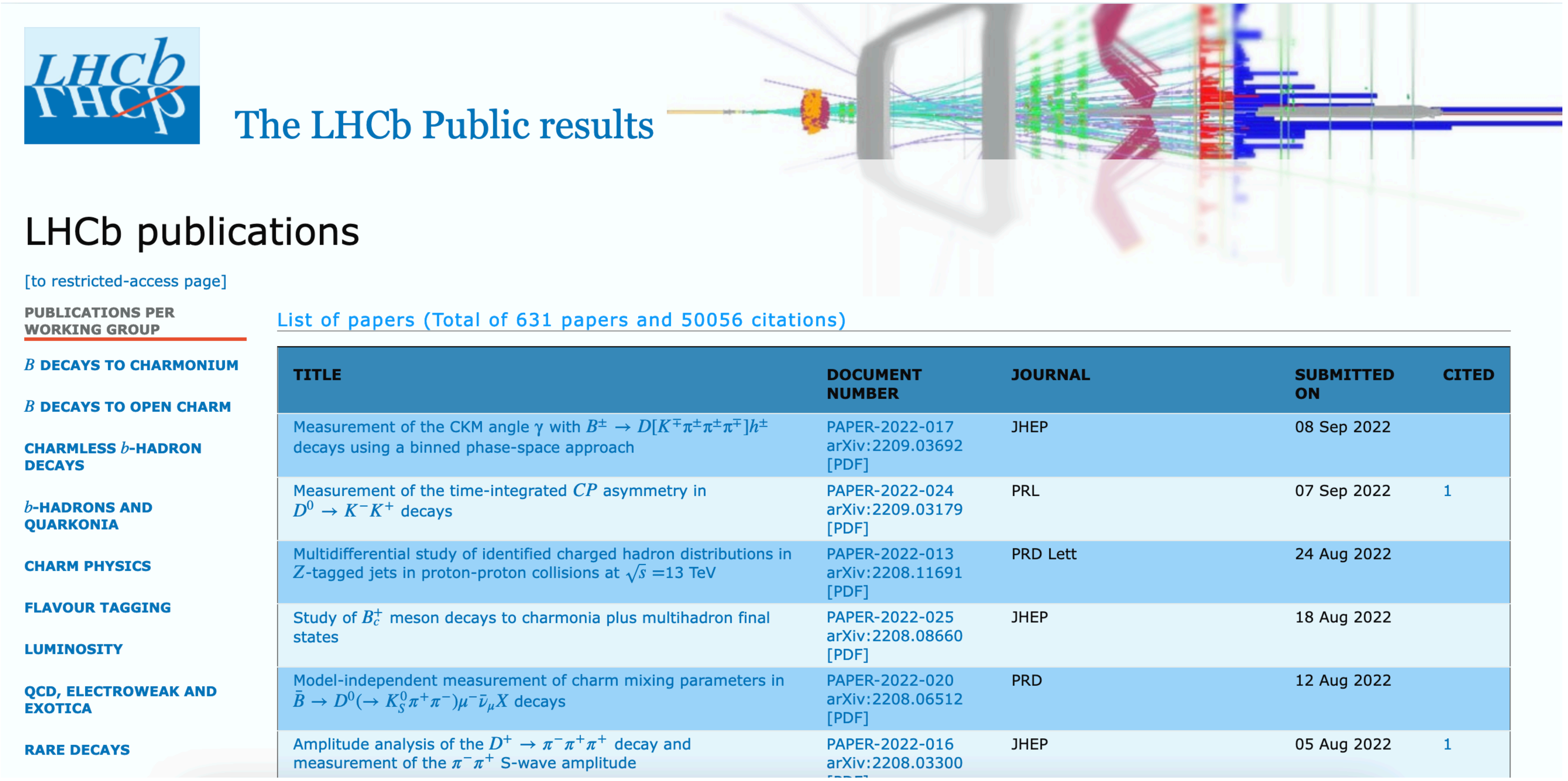
- Responsible for ensuring accurate and correct simulation for the entirety of the LHCb collaboratio (both for physics analysis and for studies for detector upgrades)
  - <u>PL + DPL of Simulation Project are at UK institutes</u>, major contributions from involved institutes
- 6 work-packages formed, allowing for the development of solutions for Run 3 and the HL-LHC era
  - Includes the developments for Generators, detailed and fast simulations, Detector Modeling, production of samples for analysis and detector studies, and Machine Induced Background/Radiation studies.



# Physics Results

- Many results over the large spectrum of accessible physics at LHCb
- I do not have time to cover them all!
- Full details at [LHCb Public Results page]


The LHCb Public results

LHCb publications

[to restricted-access page]

PUBLICATIONS PER WORKING GROUP

- $B$ DECAYS TO CHARMONIUM
- $B$ DECAYS TO OPEN CHARM
- CHARMLESS $b$-HADRON DECAYS
- $b$-HADRONS AND QUARKONIA
- CHARM PHYSICS
- FLAVOUR TAGGING
- LUMINOSITY
- QCD, ELECTROWEAK AND EXOTICA
- RARE DECAYS

List of papers (Total of 631 papers and 50056 citations)

| TITLE | DOCUMENT NUMBER | JOURNAL | SUBMITTED ON | CITED |
|---|---|---|---|---|
| Measurement of the CKM angle γ with $B^{\pm} \to D[K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}]h^{\pm}$ decays using a binned phase-space approach | PAPER-2022-017 arXiv:2209.03692 [PDF] | JHEP | 08 Sep 2022 | |
| Measurement of the time-integrated $CP$ asymmetry in $D^0 \to K^-K^+$ decays | PAPER-2022-024 arXiv:2209.03179 [PDF] | PRL | 07 Sep 2022 | 1 |
| Multidifferential study of identified charged hadron distributions in $Z$-tagged jets in proton-proton collisions at $\sqrt{s}$ =13 TeV | PAPER-2022-013 arXiv:2208.11691 [PDF] | PRD Lett | 24 Aug 2022 | |
| Study of $B_c^+$ meson decays to charmonia plus multihadron final states | PAPER-2022-025 arXiv:2208.08660 [PDF] | JHEP | 18 Aug 2022 | |
| Model-independent measurement of charm mixing parameters in $\bar{B} \to D^0(\to K_S^0\pi^+\pi^-)\mu^-\bar{\nu}_\mu X$ decays | PAPER-2022-020 arXiv:2208.06512 [PDF] | PRD | 12 Aug 2022 | |
| Amplitude analysis of the $D^+ \to \pi^-\pi^+\pi^+$ decay and measurement of the $\pi^-\pi^+$ S-wave amplitude | PAPER-2022-016 arXiv:2208.03300 | JHEP | 05 Aug 2022 | 1 |

# Direct CP Violation in Charm

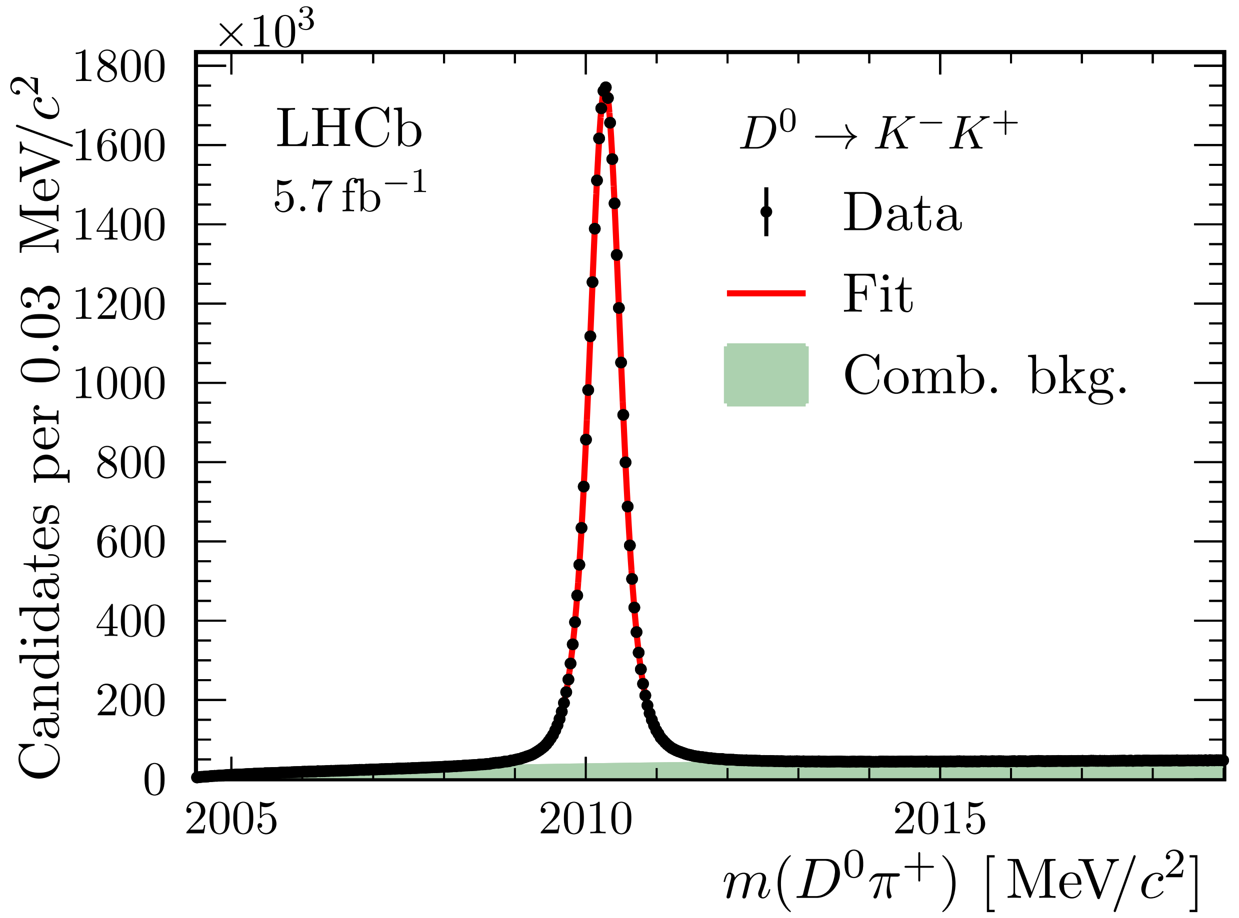
LHCb-PAPER-2022-024 Submitted to PRL

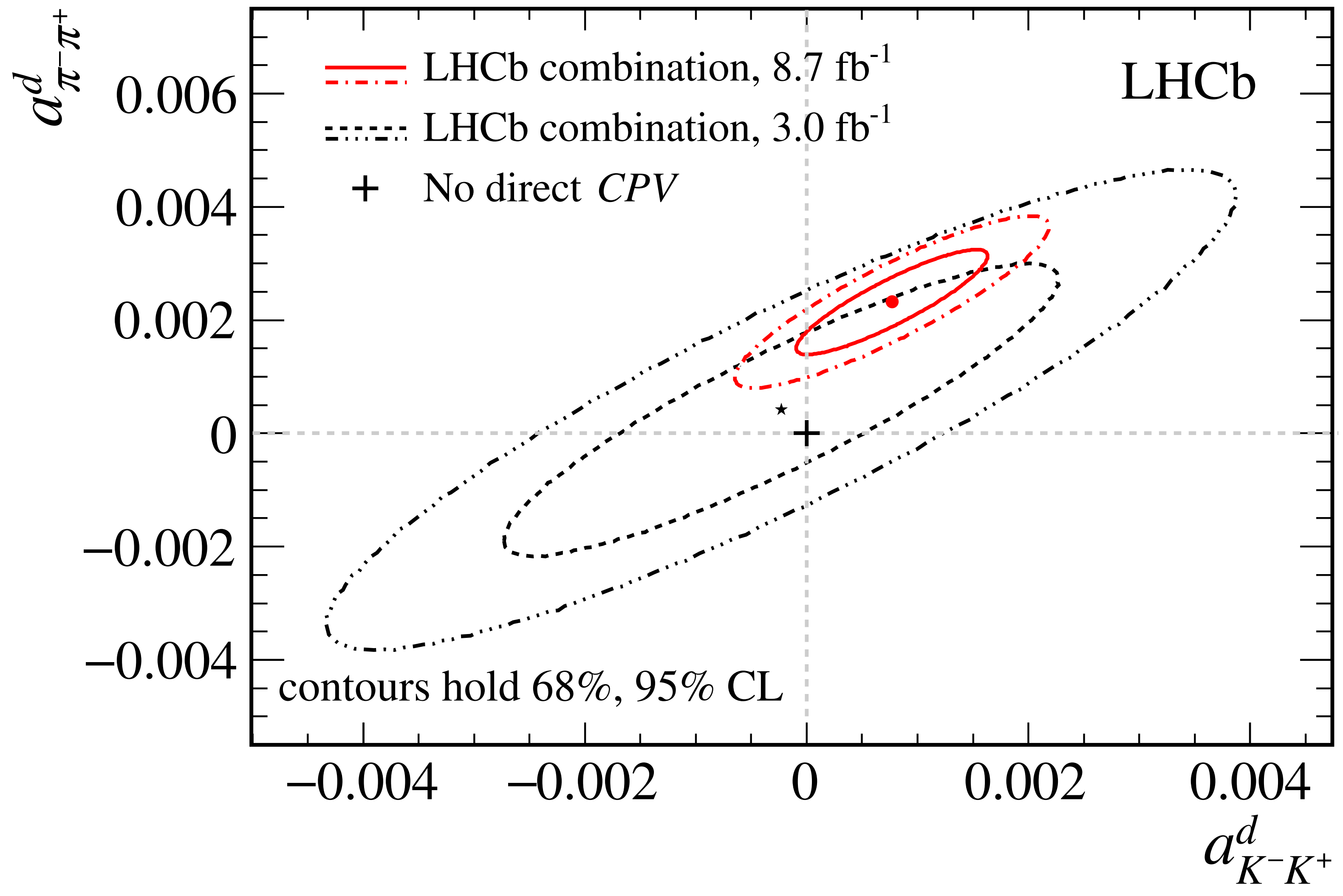
- $\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-) = (-15.4 \pm 2.9) \times 10^{-4}$, measured to be non-zero at $>5\sigma$
- Important to measure individual CP asymmetries to test U-spin prediction that $A_{CP}(KK) = -A_{CP}(\pi\pi)$ is correct
- $A_{meas}(KK) = A_{CP}(KK) + A_P(D^{*+}) + A_D(\pi^+_{tag})$
- Use full Run 2 Dataset with prompt $D^{*+} \to D^0\pi^+$
- Use two calibration procedures to remove production and detection asymmetries

$$A_{CP}(KK) = [6.8 \pm 5.4(\text{stat}) \pm 1.6(\text{syst})] \times 10^{-4}$$

- Combine with previous measurement to determine direct CP asymmetries

$$A_{CP} \simeq a_f^d + \frac{\langle t \rangle_f}{\tau_D} \Delta Y_f$$




$a^d_{KK} = (7.7 \pm 5.7) \times 10^{-4}$
$a^d_{\pi\pi} = (23.2 \pm 6.1) \times 10^{-4}$
**Non-zero at 3.8$\sigma$!**
**First evidence of CPV in a specific charm hadron decay**

# Model Independent measurement of Charm Mixing Parameters

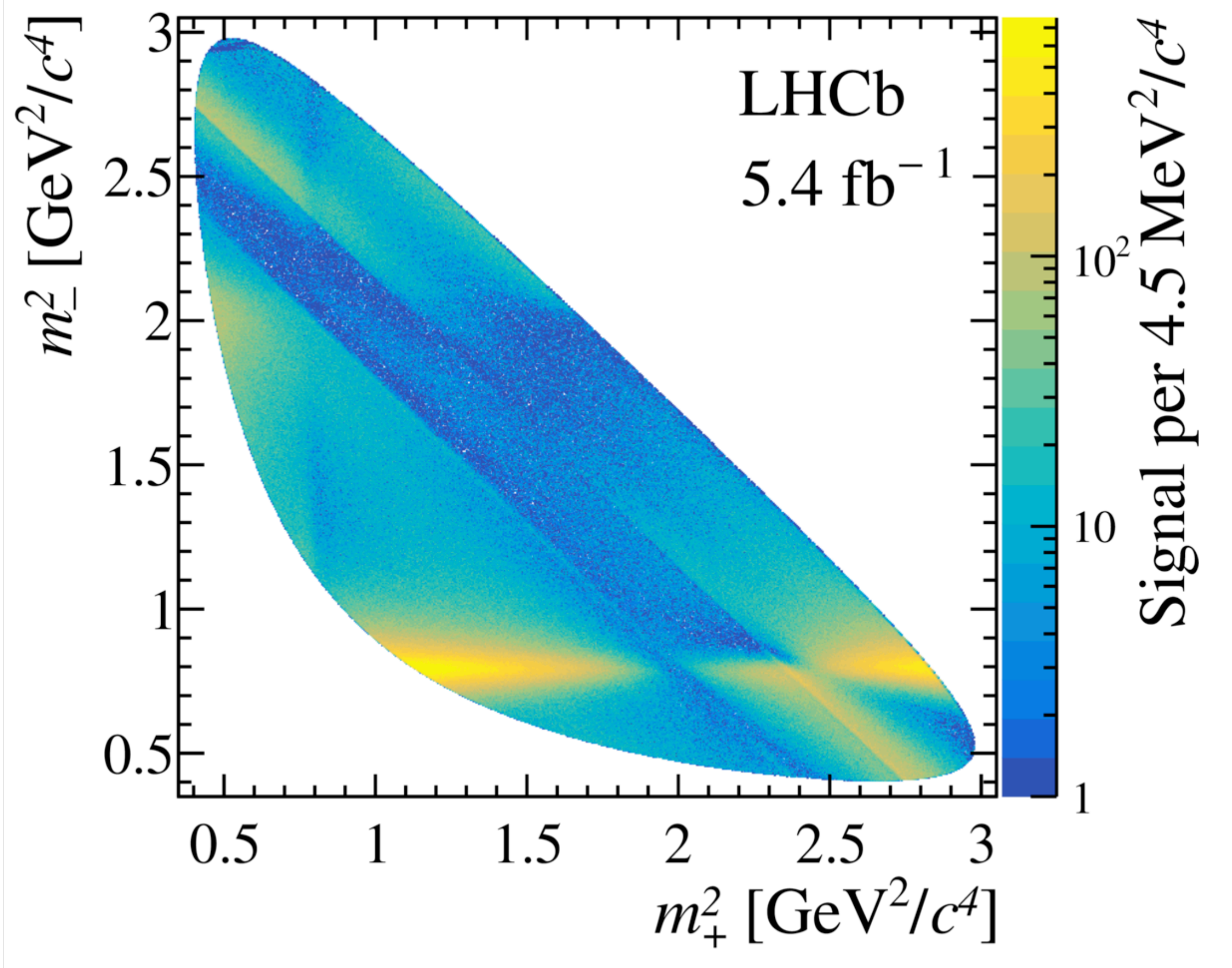
LHCb-PAPER-2022-020 Submitted to PRD

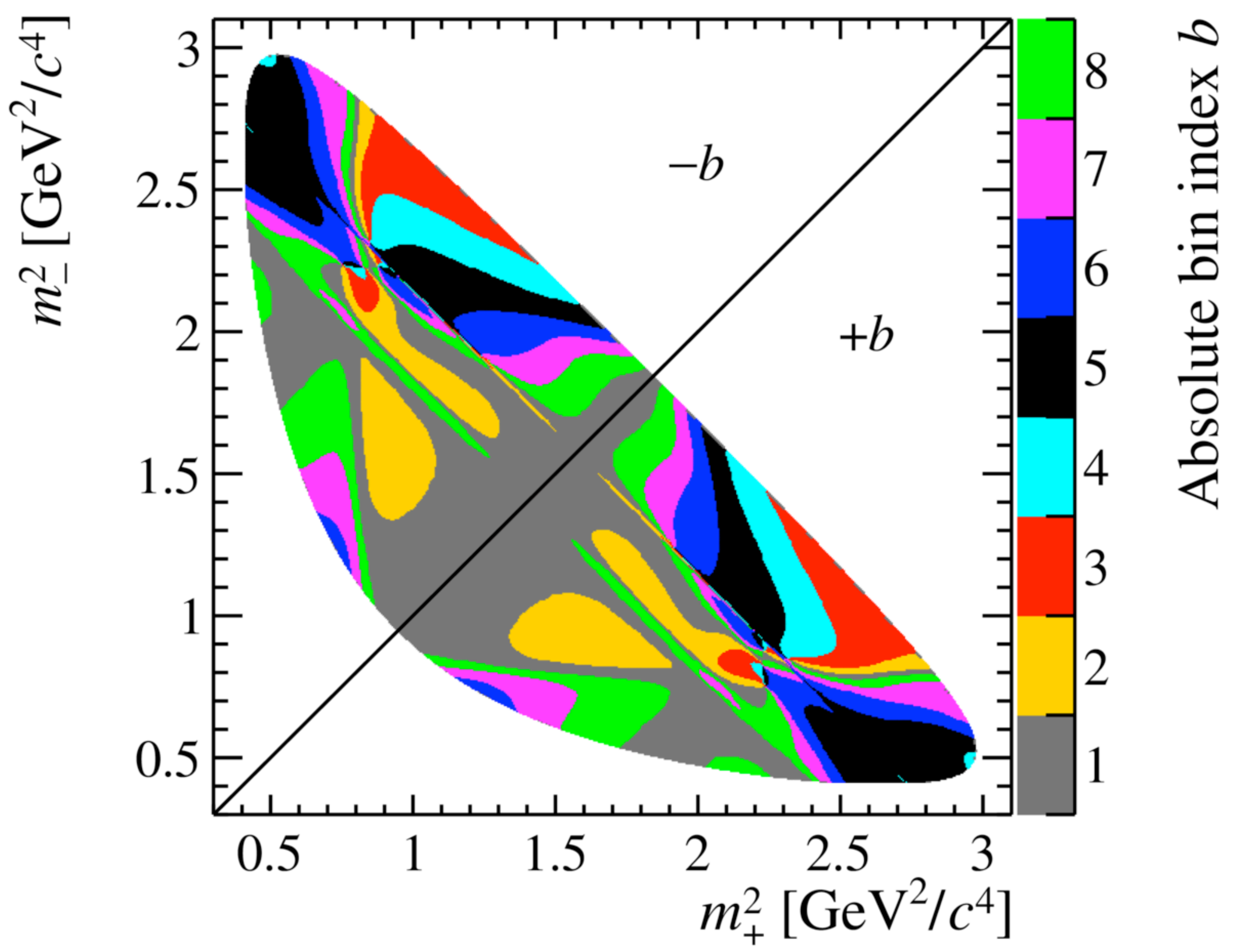
- $D^0$ flavour eigenstates $\neq$ mass eigenstates $\rightarrow$ mixing of neutral mesons

$$x = (0.40 \pm 0.05) \times 10^{-2}$$
$$y = (0.55 \pm 0.13) \times 10^{-2}$$
$$|q/p| = 1.012^{+0.050}_{0.048}$$
$$\phi = 0.061^{+0.037}_{-0.044} rad$$

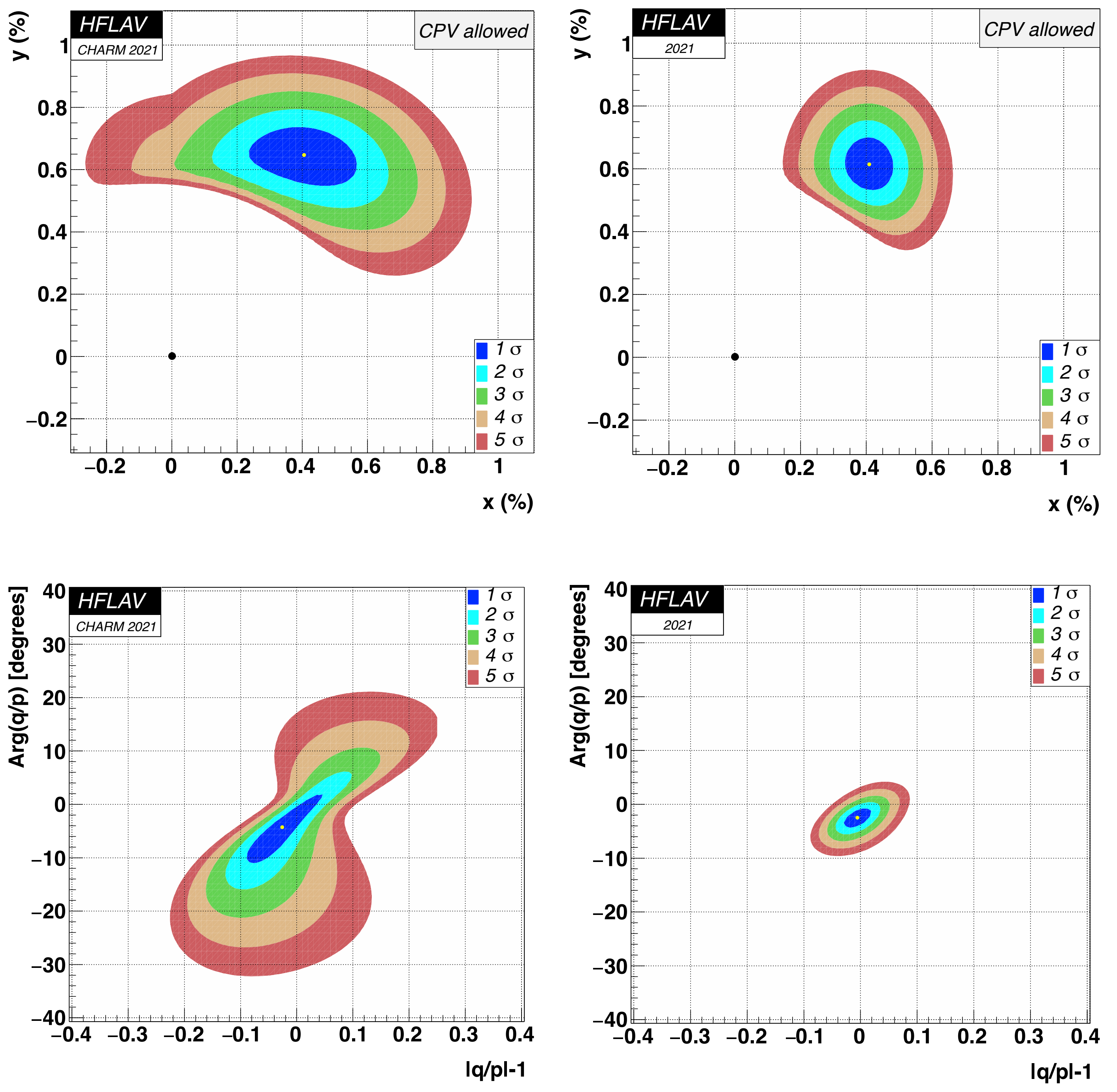
- Measurements of oscillation parameters $x = \Delta M/\Gamma, y = \Delta\Gamma/2\Gamma$ and CPV parameters $|q/p|, \phi$ extractable from comparison of phase space bins of $D^0 \rightarrow K_s^0\pi^+\pi^-$

- 2016-2018 dataset (5.4 fb$^{-1}$) using $B \rightarrow D^0\mu\nu X$ decays, combine with previous "prompt" analysis



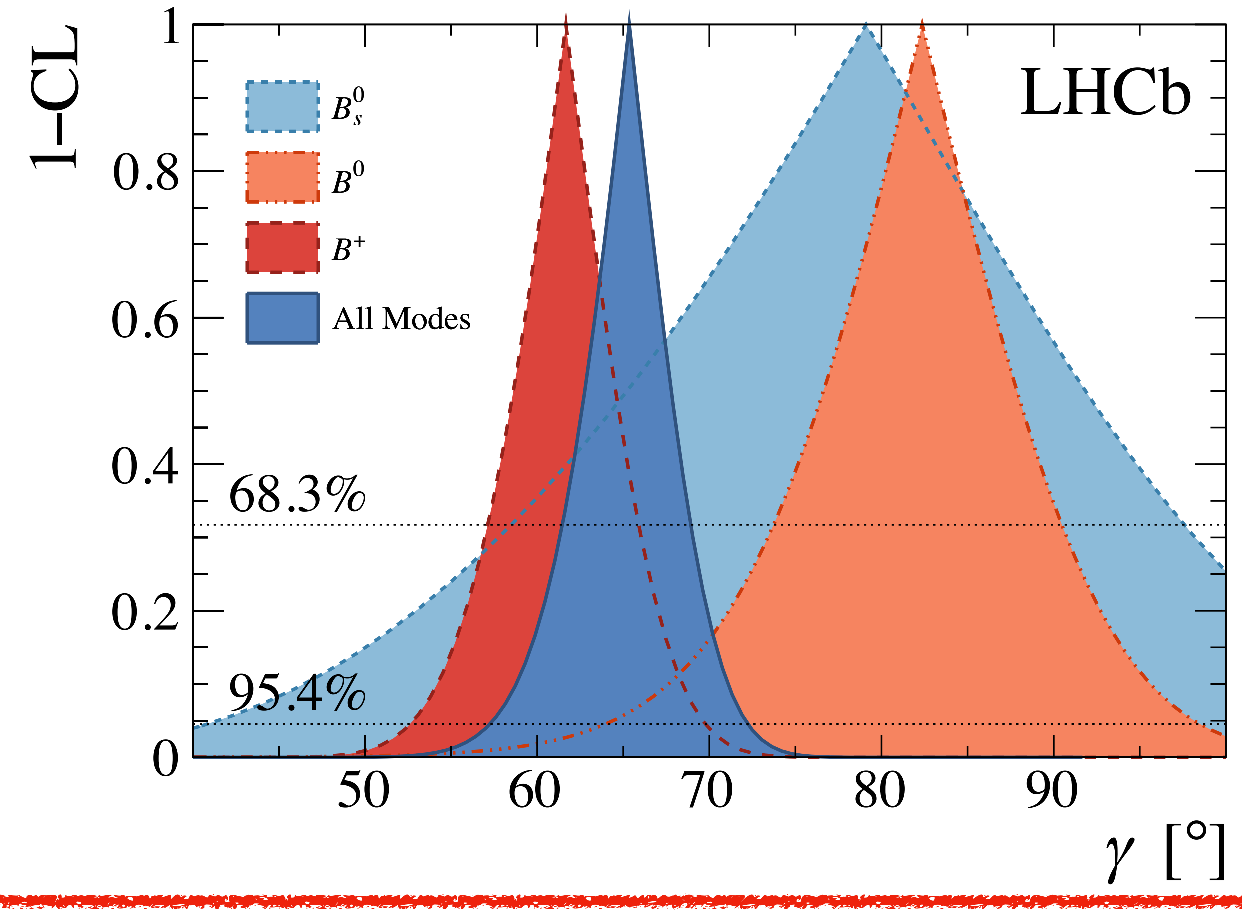

**Consistent with prompt analysis**



# Ultimate Precision: Beauty + Charm Combination

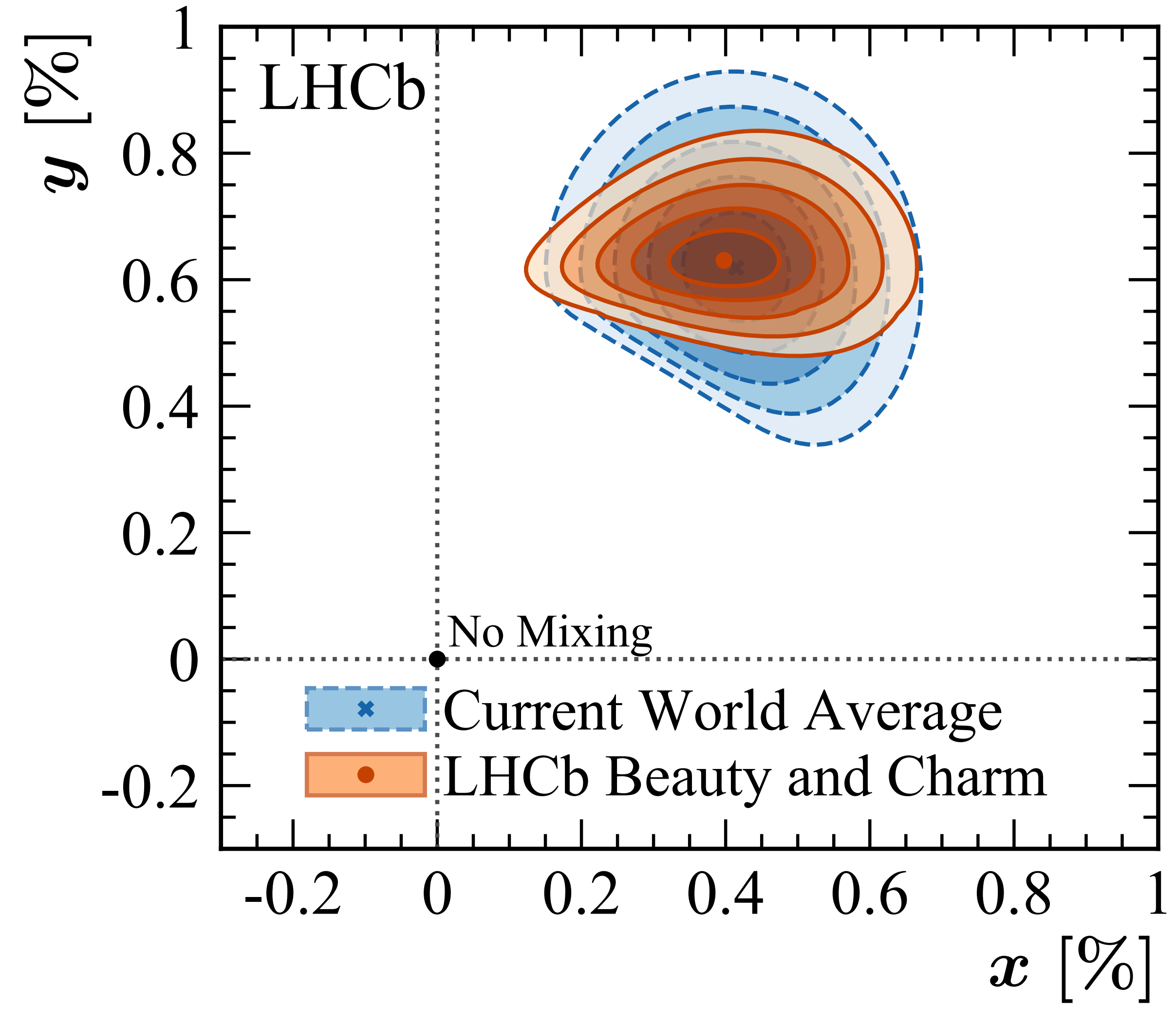
JHEP 12 (2021) 141

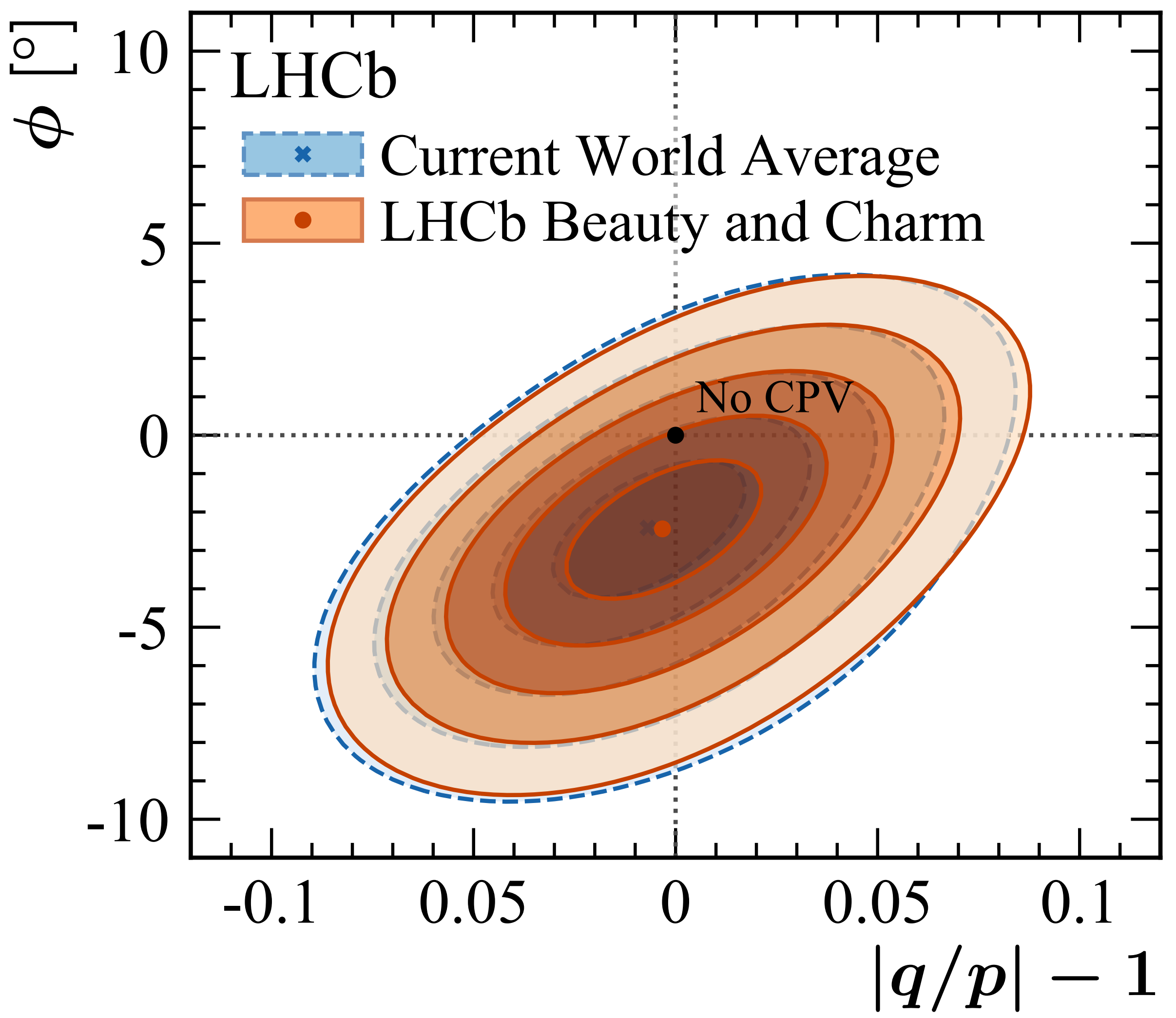
- Traditionally provide joint fit of all LHCb results to provide average of measurement of $\gamma$
- Combine information with Charm system to leverage joint inputs for ultimate precision on all inputs → leverages correlations across measurements to further constrain $y$ in the charm system and constrain charm mixing in $\gamma$ extraction
- Many new measurements added
- Most precise measurement of $\gamma$ from single experiment, Charm parameter improvement w.r.t. HFLAV combination at time of publication. Sensitivity to $\gamma$ is now at 4°, even without all modes analyzed.
- Stay tuned for more updates soon!




$$\gamma = \left(65.4^{+3.8}_{-4.2}\right)^{\circ} \qquad x = \left(0.400^{+0.052}_{-0.053}\right)\% \qquad y = \left(0.630^{+0.033}_{-0.030}\right)\%$$

| $B$ decay | $D$ decay | Ref. | Dataset | Status since Ref. [17] |
|---|---|---|---|---|
| $B^\pm \to Dh^\pm$ | $D \to h^+h^-$ | [20] | Run 1&2 | **Updated** |
| $B^\pm \to Dh^\pm$ | $D \to h^+\pi^-\pi^+\pi^-$ | [21] | Run 1 | As before |
| $B^\pm \to Dh^\pm$ | $D \to h^+h^-\pi^0$ | [22] | Run 1 | As before |
| $B^\pm \to Dh^\pm$ | $D \to K^0_S h^+h^-$ | [19] | Run 1&2 | **Updated** |
| $B^\pm \to Dh^\pm$ | $D \to K^0_S K^\pm\pi^\mp$ | [23] | Run 1&2 | **Updated** |
| $B^\pm \to D^*h^\pm$ | $D \to h^+h^-$ | [20] | Run 1&2 | **Updated** |
| $B^\pm \to DK^{*\pm}$ | $D \to h^+h^-$ | [24] | Run 1&2(*) | As before |
| $B^\pm \to DK^{*\pm}$ | $D \to h^+\pi^-\pi^+\pi^-$ | [24] | Run 1&2(*) | As before |
| $B^\pm \to Dh^\pm\pi^+\pi^-$ | $D \to h^+h^-$ | [25] | Run 1 | As before |
| $B^0 \to DK^{*0}$ | $D \to h^+h^-$ | [26] | Run 1&2(*) | **Updated** |
| $B^0 \to DK^{*0}$ | $D \to h^+\pi^-\pi^+\pi^-$ | [26] | Run 1&2(*) | **New** |
| $B^0 \to DK^{*0}$ | $D \to K^0_S\pi^+\pi^-$ | [27] | Run 1 | As before |
| $B^0 \to D^\mp\pi^\pm$ | $D^+ \to K^-\pi^+\pi^+$ | [28] | Run 1 | As before |
| $B_s^0 \to D_s^\mp K^\pm$ | $D_s^+ \to h^+h^-\pi^+$ | [29] | Run 1 | As before |
| $B_s^0 \to D_s^\mp K^\pm\pi^+\pi^-$ | $D_s^+ \to h^+h^-\pi^+$ | [30] | Run 1&2 | **New** |
| $D$ decay | Observable(s) | Ref. | Dataset | Status since Ref. [17] |
| $D^0 \to h^+h^-$ | $\Delta A_{CP}$ | [31–33] | Run 1&2 | **New** |
| $D^0 \to h^+h^-$ | $y_{CP}$ | [34] | Run 1 | **New** |
| $D^0 \to h^+h^-$ | $\Delta Y$ | [35–38] | Run 1&2 | **New** |
| $D^0 \to K^+\pi^-$ (Single Tag) | $R^\pm$, $(x'^\pm)^2$, $y'^\pm$ | [39] | Run 1 | **New** |
| $D^0 \to K^+\pi^-$ (Double Tag) | $R^\pm$, $(x'^\pm)^2$, $y'^\pm$ | [40] | Run 1&2(*) | **New** |
| $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$ | $(x^2+y^2)/4$ | [41] | Run 1 | **New** |
| $D^0 \to K^0_S\pi^+\pi^-$ | $x$, $y$ | [42] | Run 1 | **New** |
| $D^0 \to K^0_S\pi^+\pi^-$ | $x_{CP}$, $y_{CP}$, $\Delta x$, $\Delta y$ | [43] | Run 1 | **New** |
| $D^0 \to K^0_S\pi^+\pi^-$ | $x_{CP}$, $y_{CP}$, $\Delta x$, $\Delta y$ | [44] | Run 2 | **New** |



# Measurement of $\gamma$ with $B^{\mp} \to D^0[K^{\pm}\pi^{\mp}\pi^{\pm}\pi^{\mp}]h^{\mp}$

LHCb-PAPER-2022-017 (Submitted to JHEP)

- Decays of the form $B^{\mp} \to D^0[K^{\pm}\pi^{\mp}\pi^{\pm}\pi^{\mp}]h^{\mp}$ are sensitive to the CKM angle $\gamma$ by

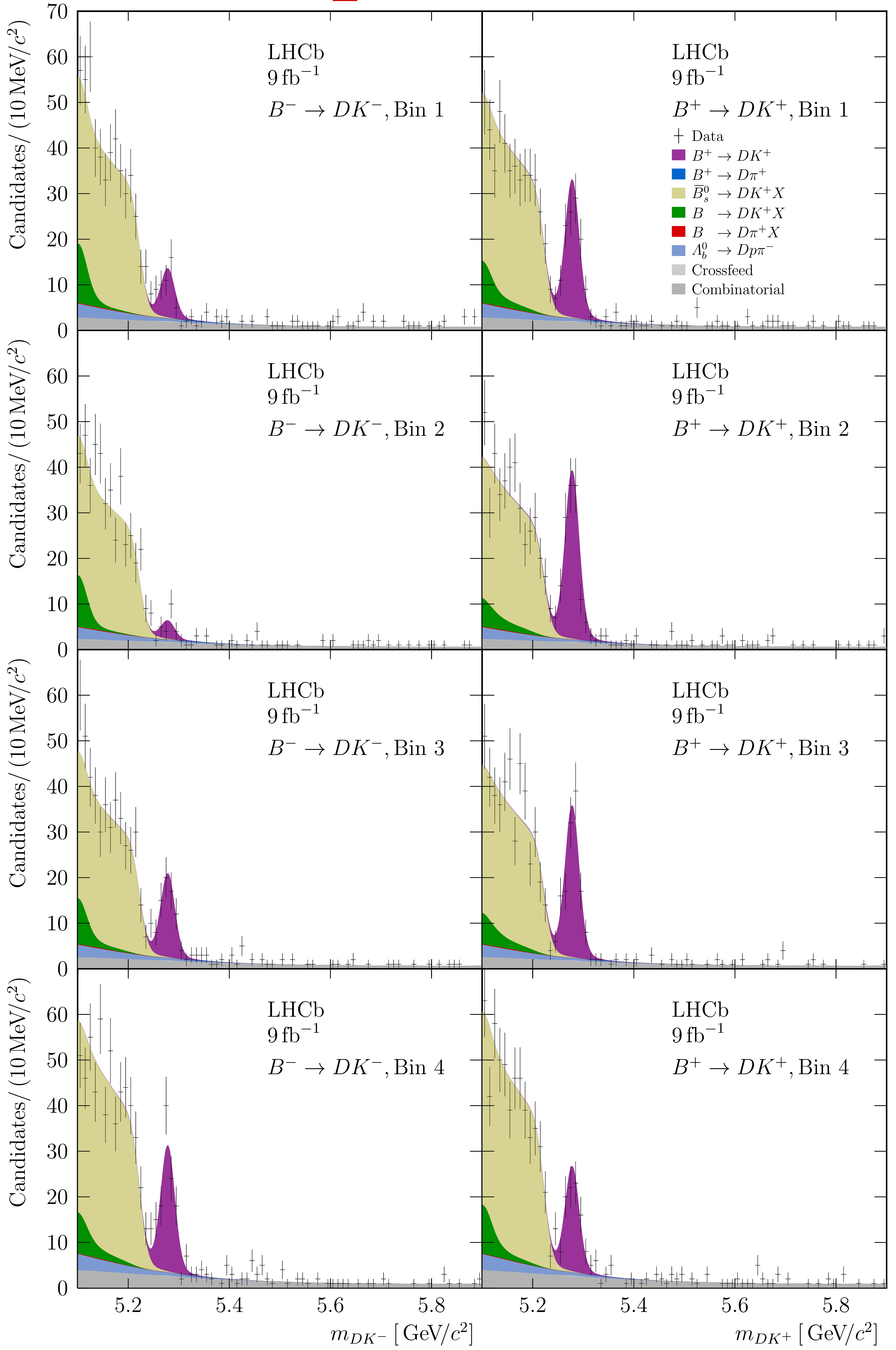
$$\Gamma_{B^{\pm}\to D^0[K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}]K^{\pm}} \propto r_{K3\pi}^2 + (r_B^K)^2 + 2r_{K3\pi}r_B^K R_{K3\pi}\cos(\delta_B^K + \delta_{K3\pi} \pm \gamma)$$

$$\Gamma_{B^{\pm}\to D^0[K^{\pm}\pi^{\mp}\pi^{\mp}\pi^{\pm}]K^{\pm}} \propto 1 + (r_{K3\pi}^2 r_B^K)^2 + 2r_{K3\pi}r_B^K R_{K3\pi}\cos(\delta_B^K - \delta_{K3\pi} \pm \gamma)$$

- Interference effects sensitive to $\gamma$ → study in bins of $D^0 \to K3\pi$ phase space using $B \to Dh^{\pm}[h = K, \pi]$
- Use Ratios of OS to LS $K^{\pm}$ to extract $\gamma$
- Full Run 1/2 dataset

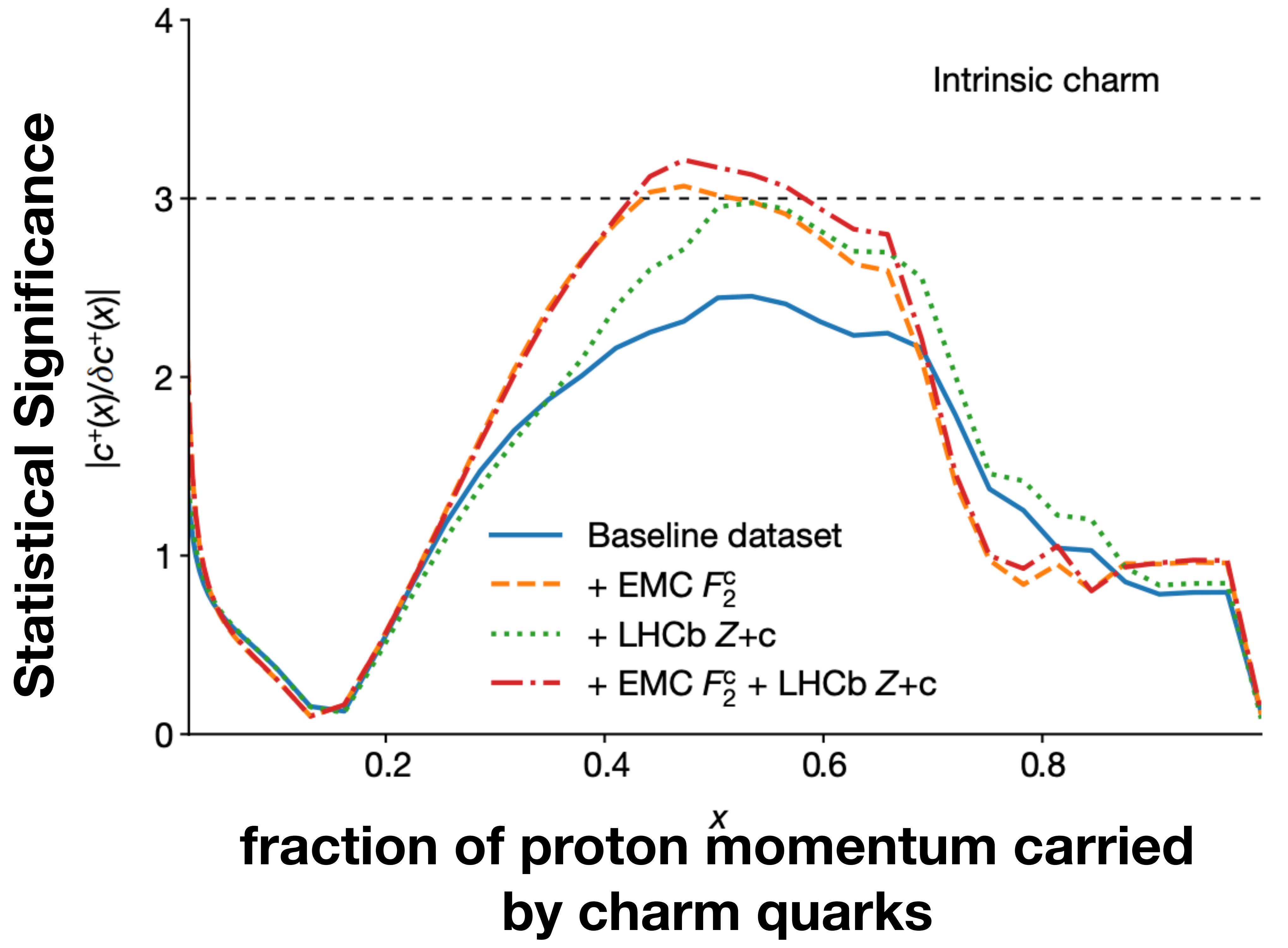
$$\gamma = \left(54.8^{+6.0+0.6+6.7}_{-5.8-0.6-4.3}\right)^{\circ}$$

- Most precise extraction of $\gamma$ from a single $D$ decay mode
- Largest ever observed CPV in one bin!



# Not Just Flavour Physics - Intrinsic Charm

- Including recent study of Z bosons produced in association with charm in the forward region at LHCb [Phys. Rev. Lett. 128, 082001 (2022)], a global analysis finds evidence for intrinsic charm in the proton. The NNPDF Collaboration, Nature, 17th Aug 2022

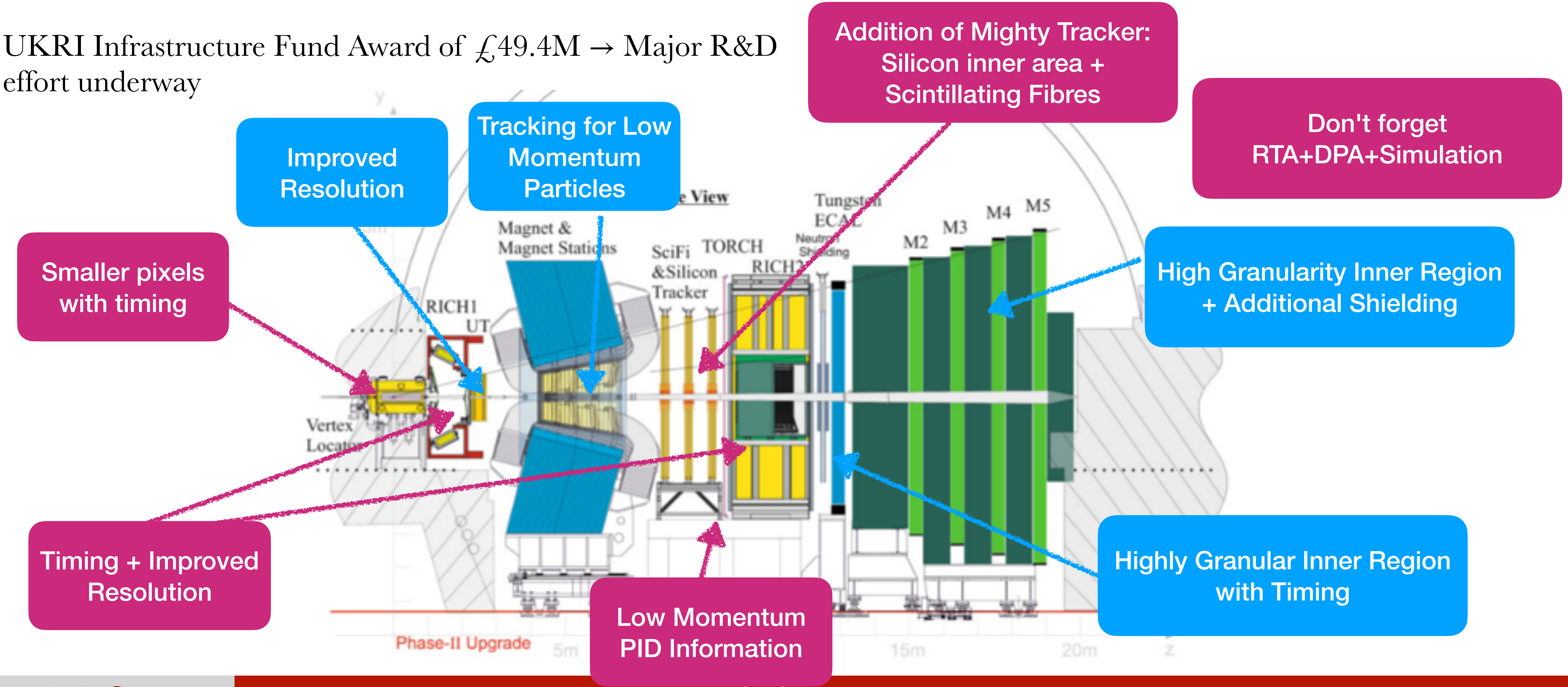



**LHCb continues to provide very relevant information in a wide variety of physics areas**

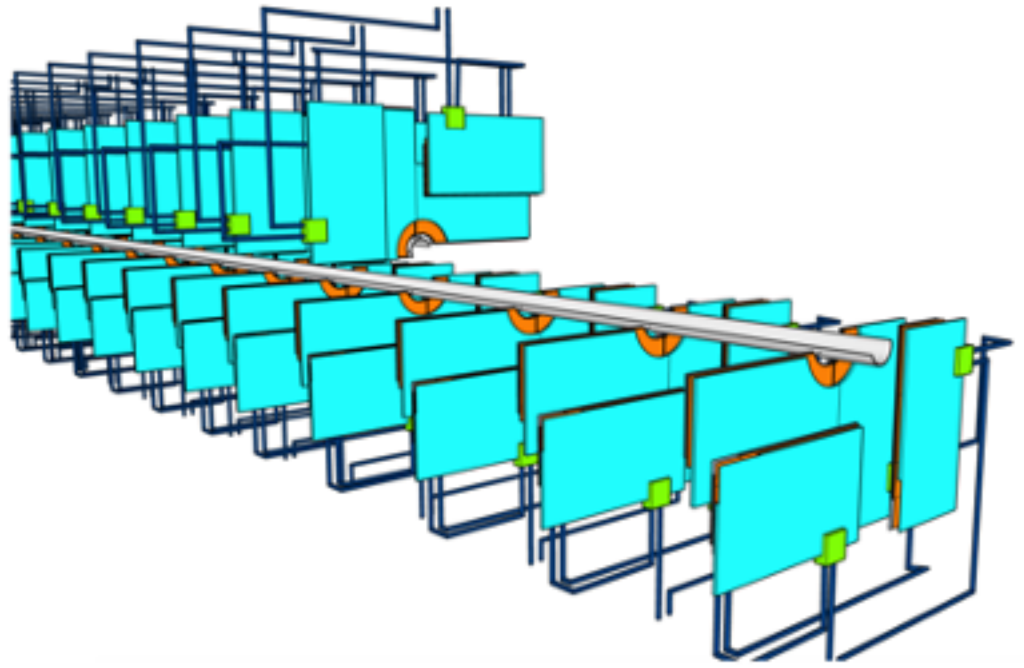
# LHCb Upgrade II

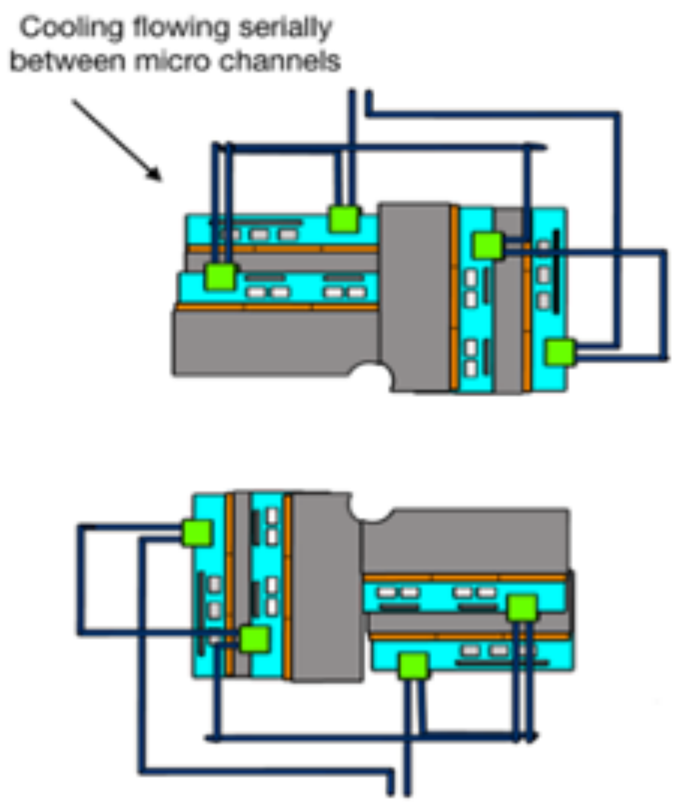
UK contributions

- Fully exploit the HL-LHC for flavour physics
- Framework TDR approved by LHCC
- UKRI Infrastructure Fund Award of £49.4M → Major R&D effort underway

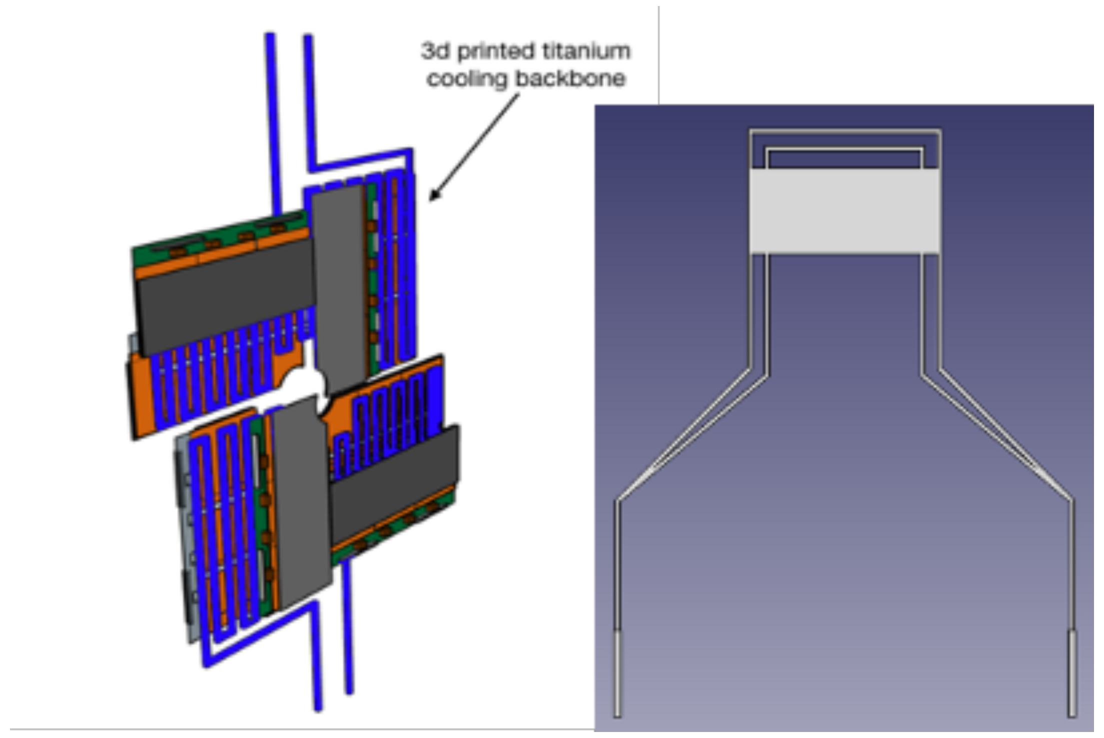


# Upgrade II VELO





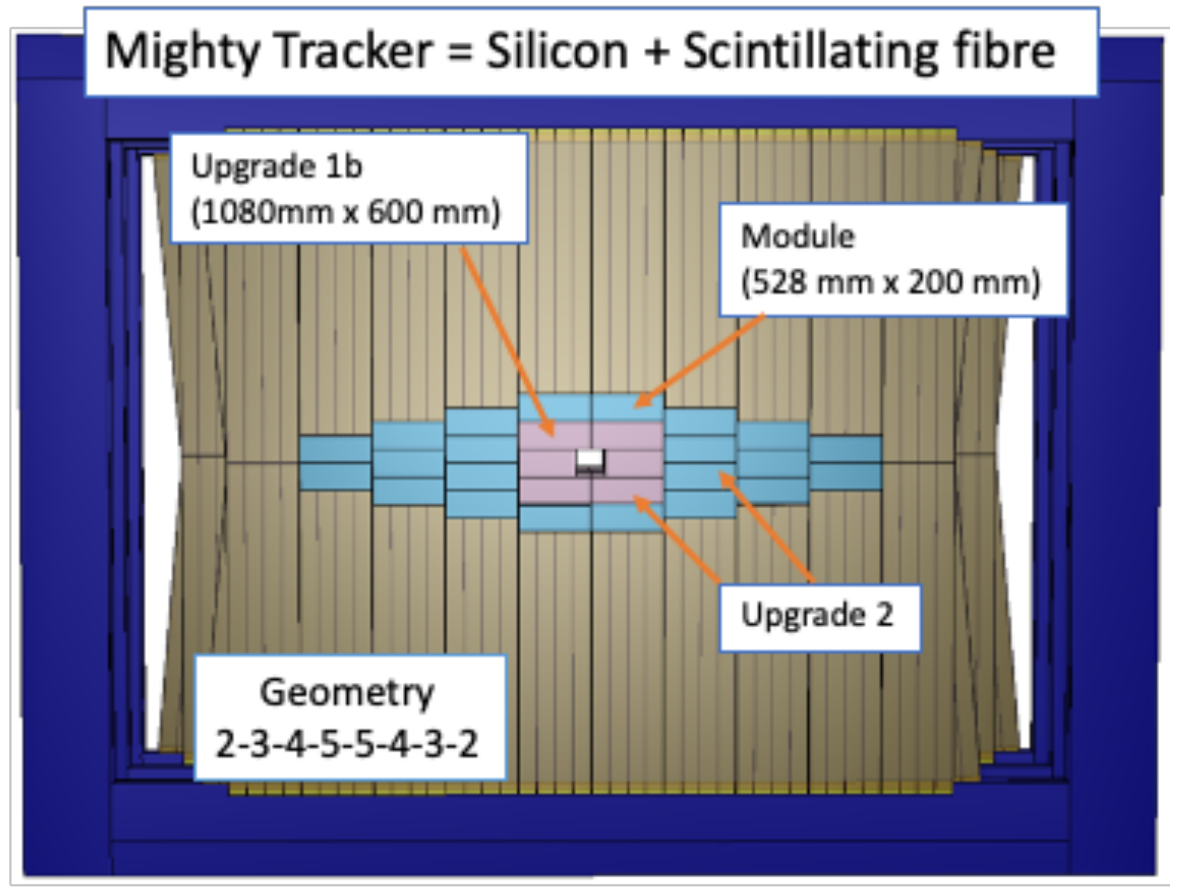

- VELO Sensor R&D targets timing, radiation hardness
- Could incorporate thin planar, LGAD, 3D or new concepts
- Two Scenarios being considered now:
  - Scenario A: Similar layout to U1, 5.1mm from beampipe, similar RF foil
  - Scenario B: 12.5mm distance to beam, lighter (or no) RF foil, smaller pixel size



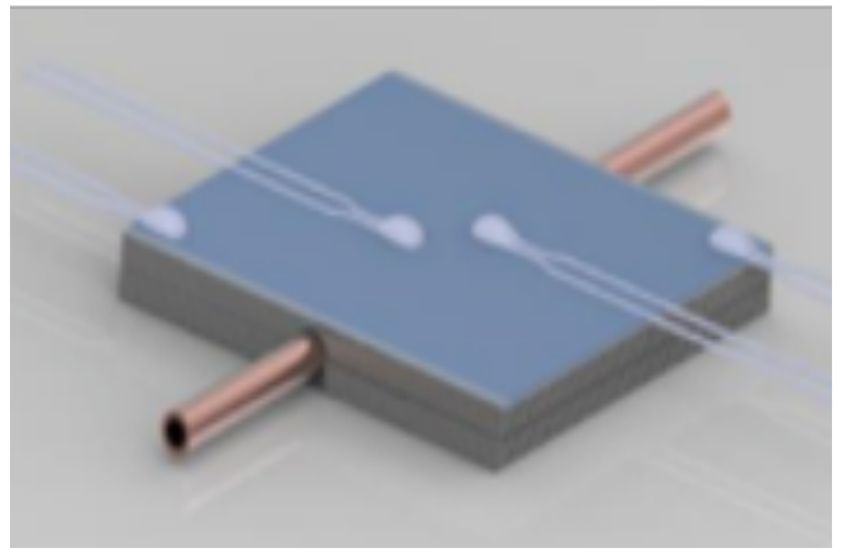

- Cooling
  - Smaller microchannel cooling to reduce cost, but more challenging to integrate. Collaboration between Oxford and 3T
  - Exploring 3D printing onto titanium cooling backbone - cheaper with more flexible design and integration to services easier
  - Potential collaboration with Royce Institute (Sheffield) and UoM MECD-Mechanics department
- RF Foil
  - Goal: reduce the material budget to minimize material interactions
  - Under study: merging of primary and secondary volumes, allows reduction of innermost region thickness from 150$\mu m$ to 20 – 30$\mu m$

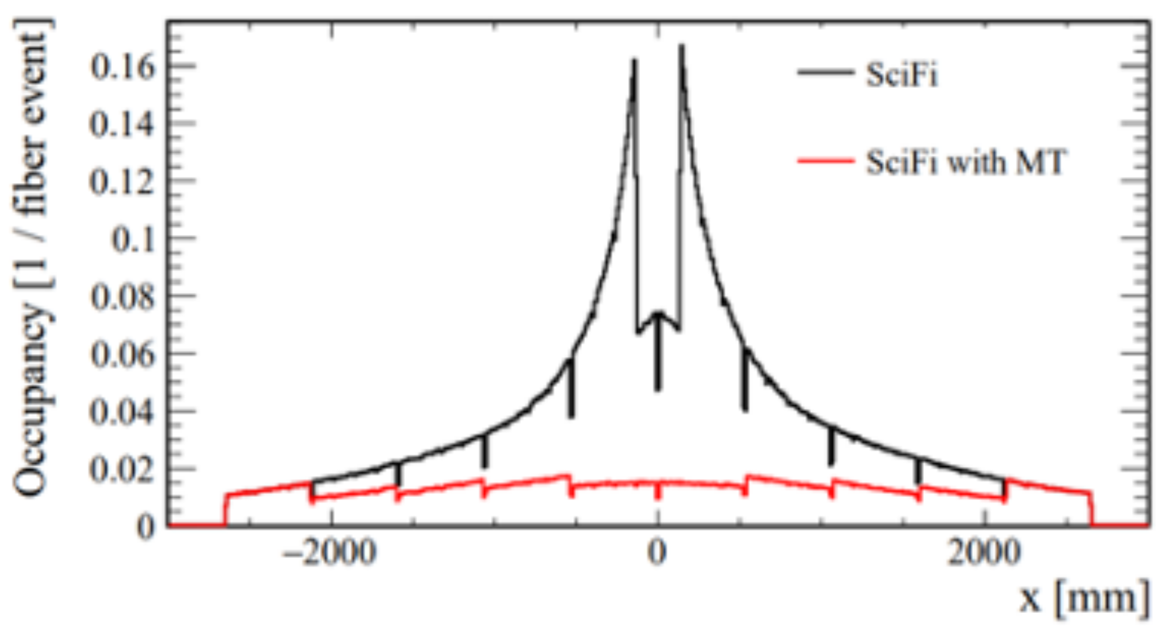
# Mighty Tracker

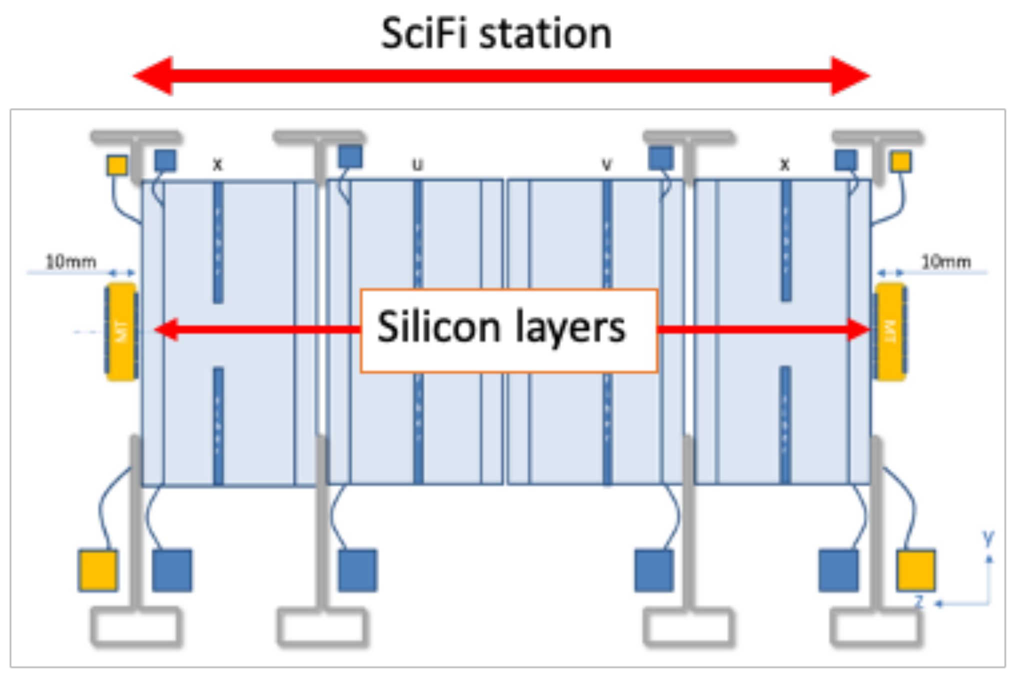
- In Runs 5-6, $\mathscr{L}_{\text{inst}} = 1.5 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$, $7.5\times$ higher than Upgrade 1
- Increase in radiation dose detrimental to inner region of the SciFi
- Replace inner most regions with silicon based technology → HV-CMOS is suitable
- Aim for full geometry upgrade in 2031, scope for Run 4 on inner most purple region
- Layers currently under design (28 modules per layer, with 26 long and 2 short)
- Cooling based on polymide tubes embedded in carbon foam, satisfying operational requirements
- Many Ongoing Activities, led by UK institutes

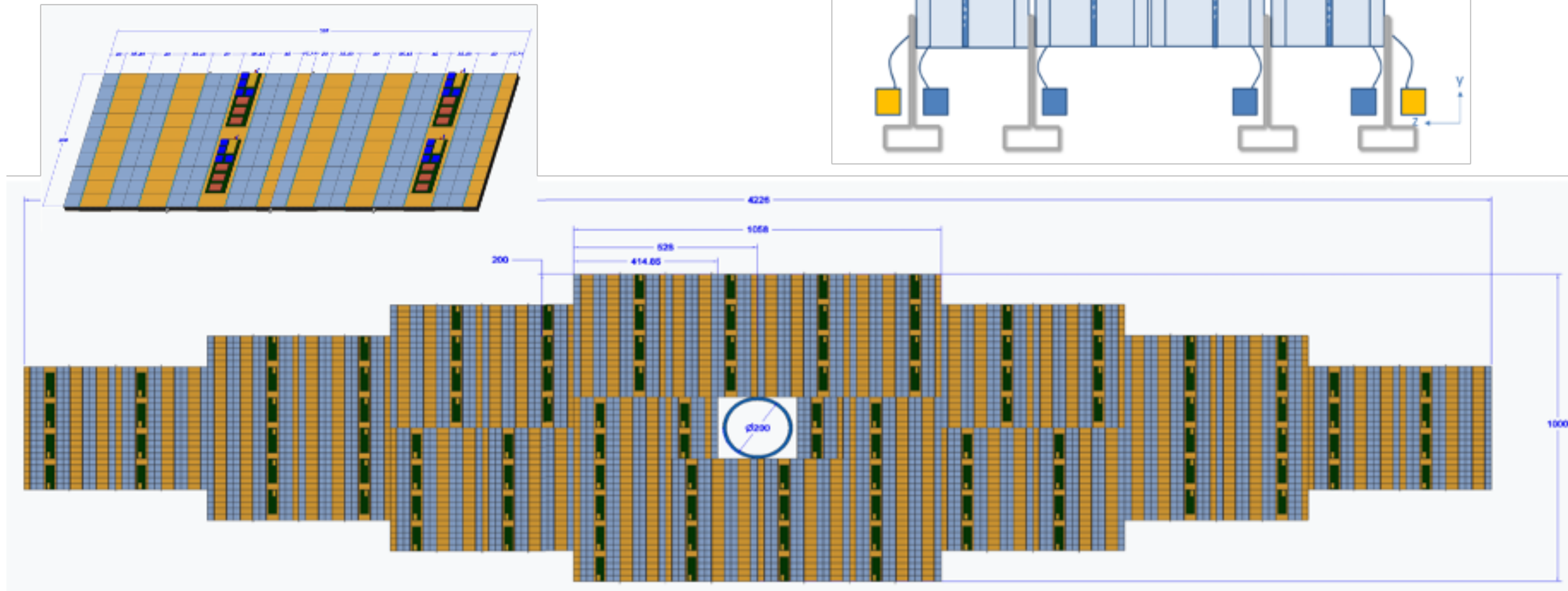



Small prototypes



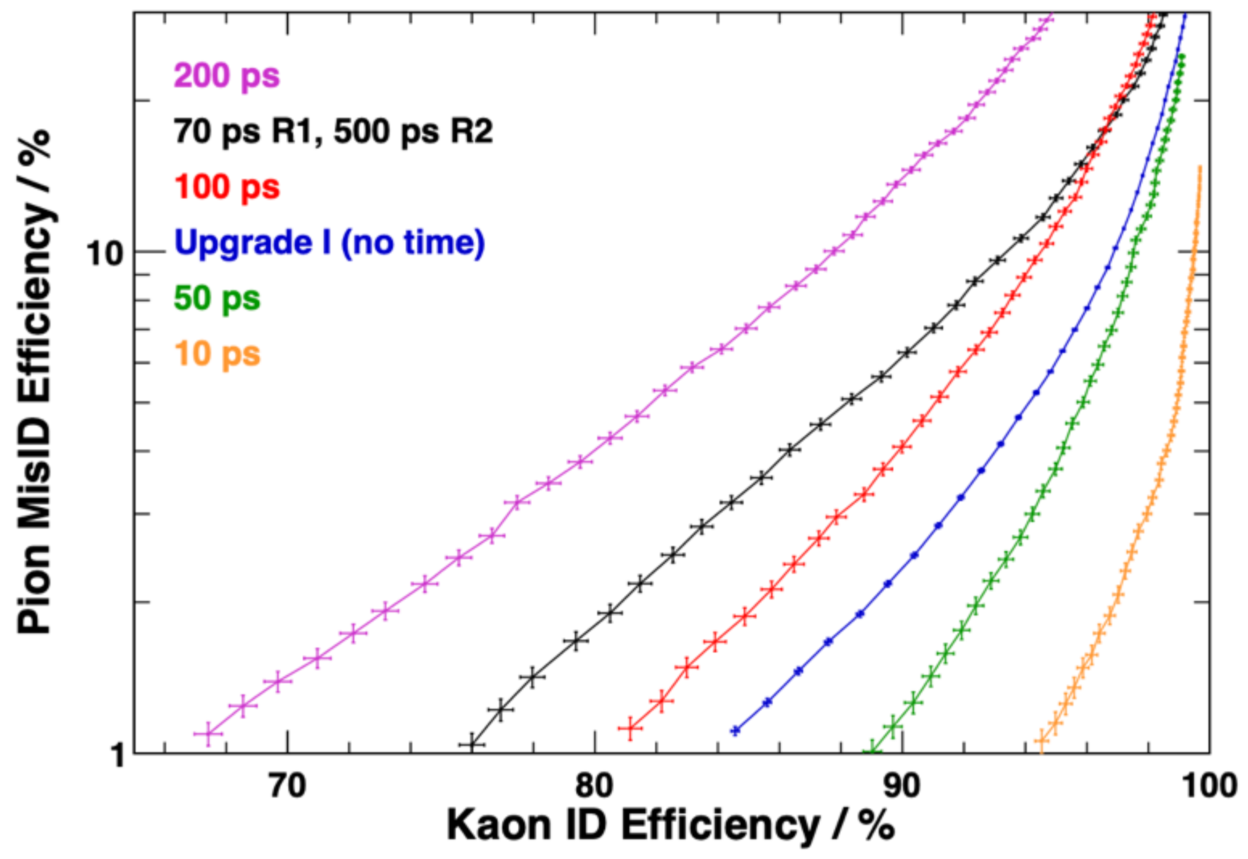


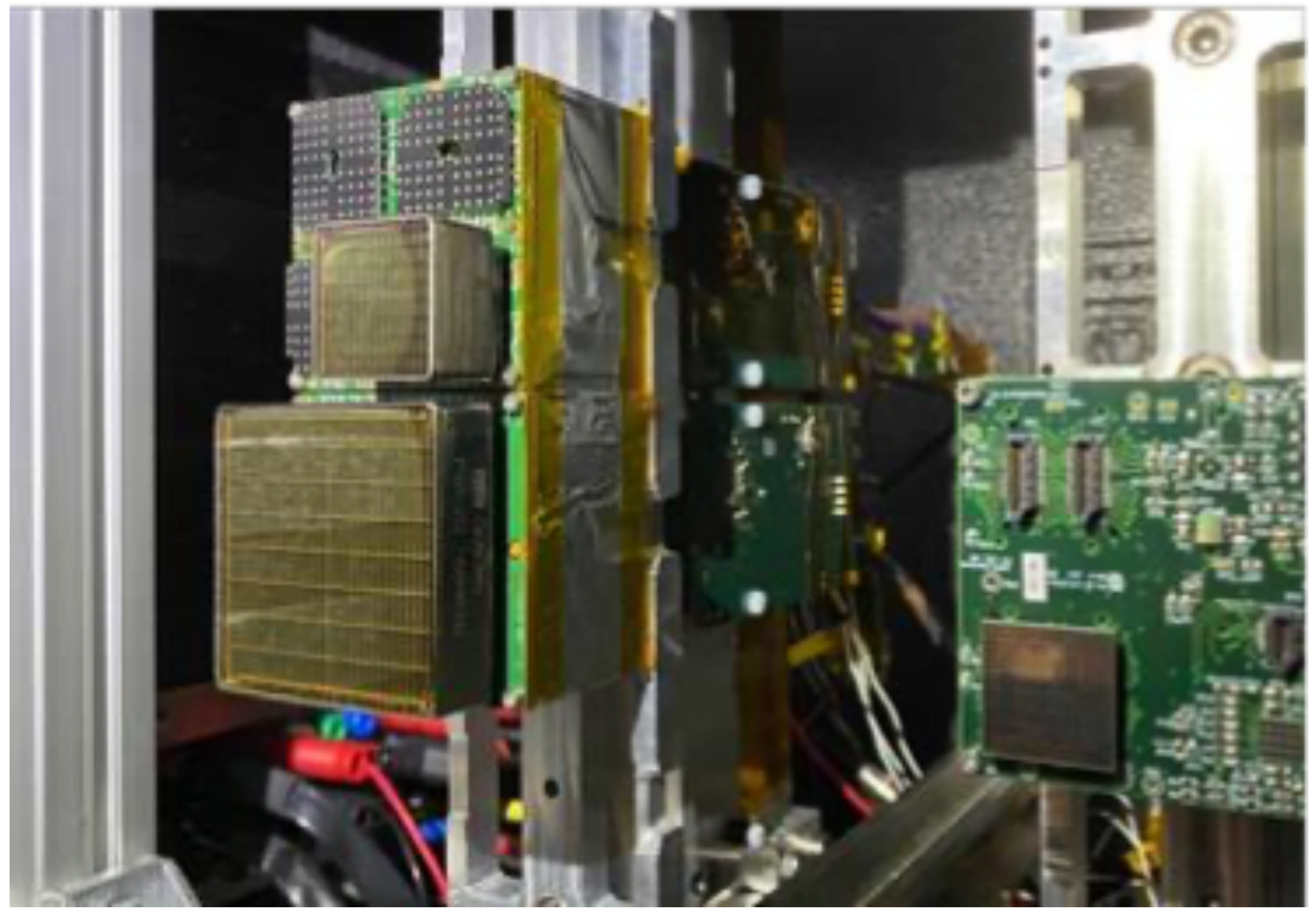



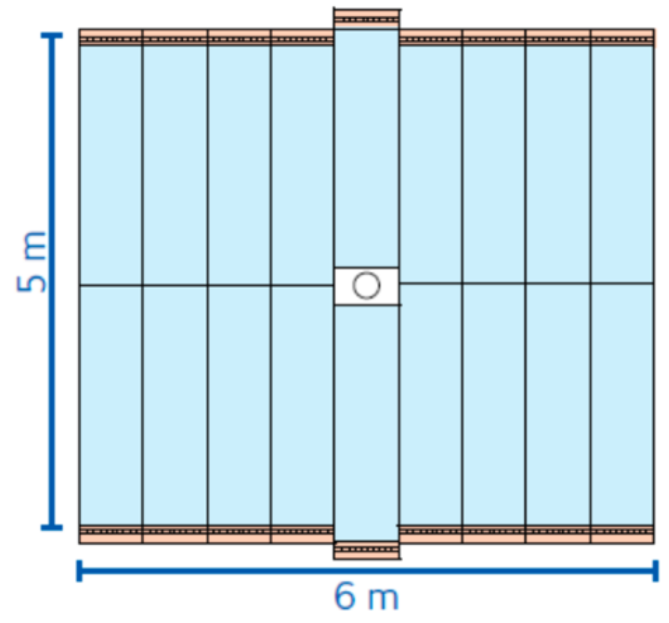
# RICH + TORCH

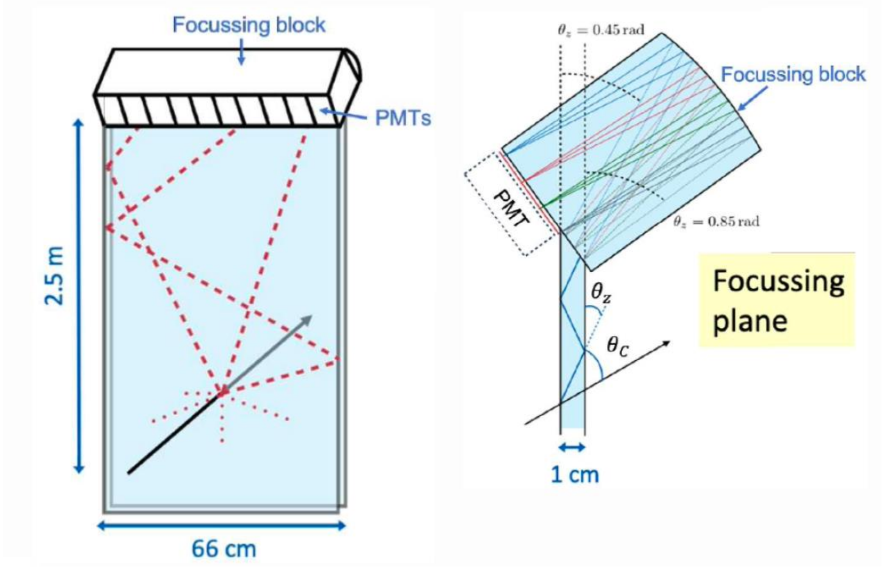
- RICH 1 & 2 will maintain same geometry, reduce pixel size using SiPM or MCP
- Time-stamping of each photon with high precision → critical for PID performance
- Design FastRICH based on Fast IC (tested in testbeam) with added features for data compression, internal TDC, etc.

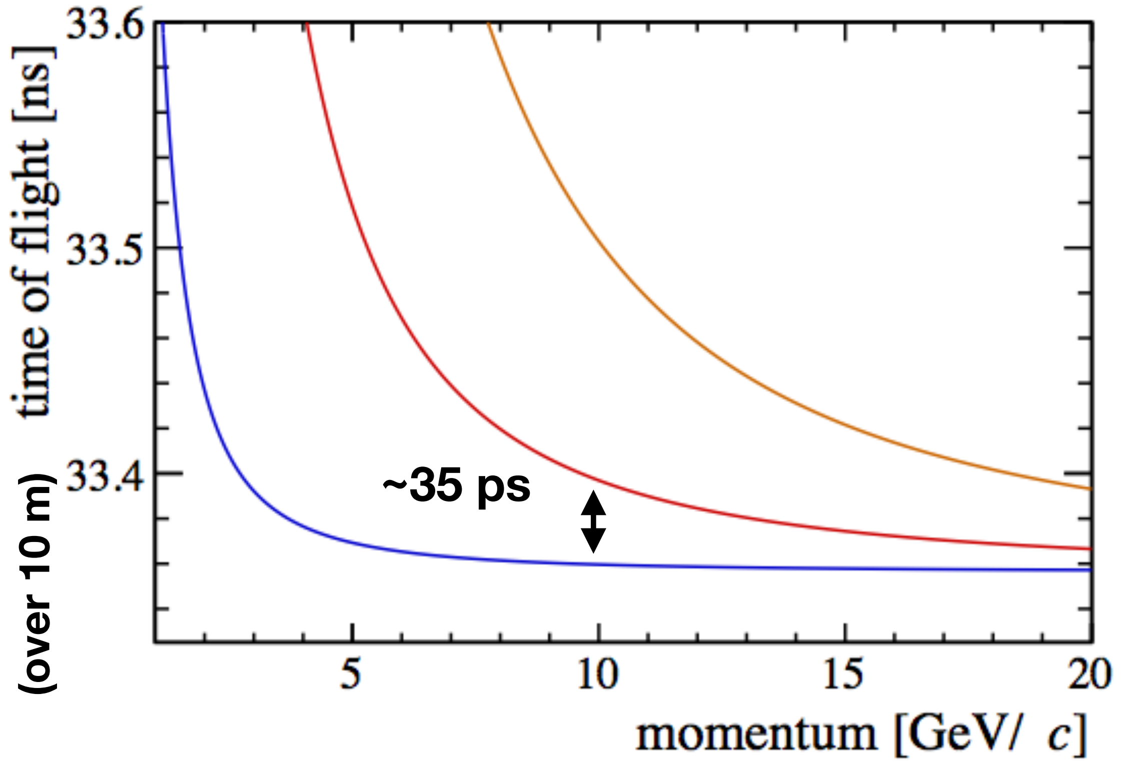


- TORCH is a new detector to enhance low momentum PID capabilities → improve background suppression + aid in Flavour Tagging
- Cherenkov Photons transported by TIR in quartz block, focused and detected on MCP-PMTs
- Aim for 10-15 ps resolution/track → requires 70 ps/photon resolution (30 in total per track)



# Conclusion

- Commissioning of Upgrade I LHCb detector is progressing well.
- Promising steps towards nominal datataking, with LHCb efficiently taking advantage of all provided data to test and calibrate the detector and acquisition system
- The reach of LHCb physics results is wide → cannot be encapsulated in an individual talk
- The UK plays a prominent and essential role in LHCb physics, detector hardware, software and Upgrades I and II
- Without support for both hardware and software, we would not be able to produce the bouquet of physics results we have now

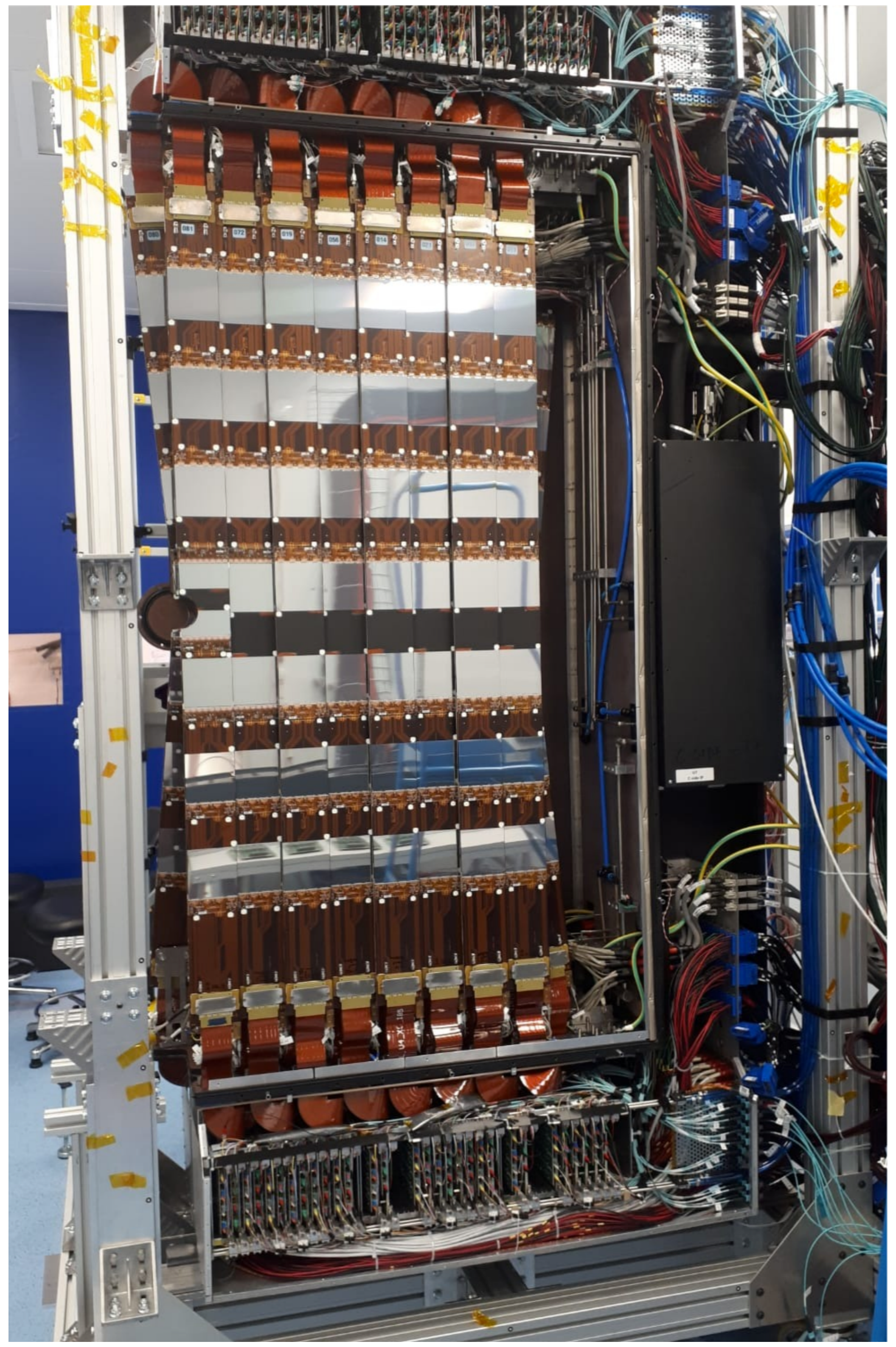

LHCb

# Backup

# UT+SciFi

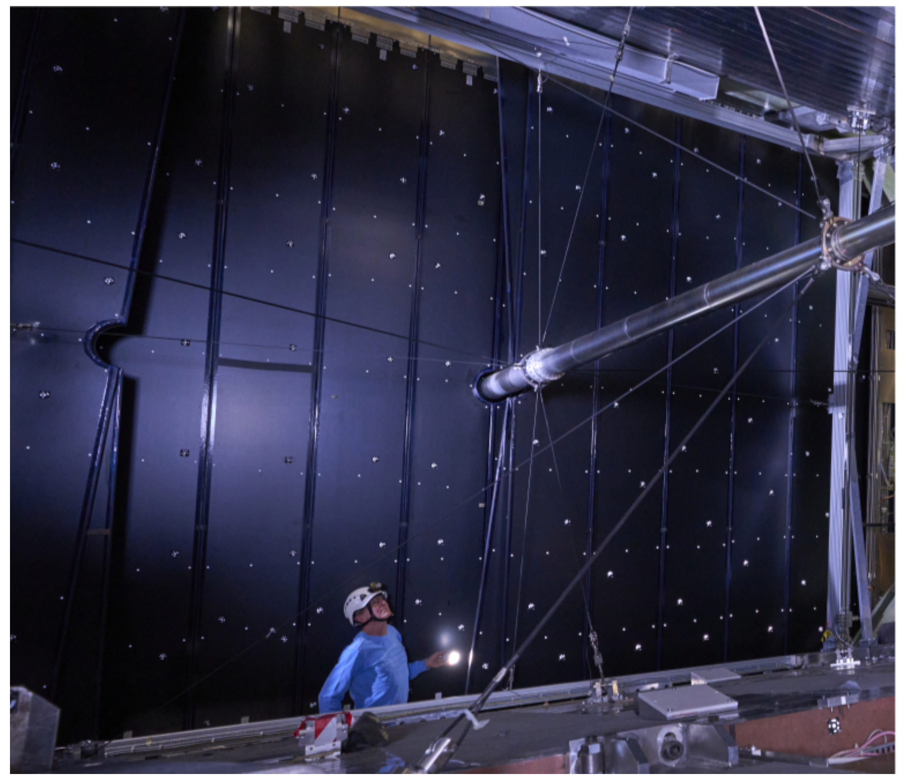
## UT

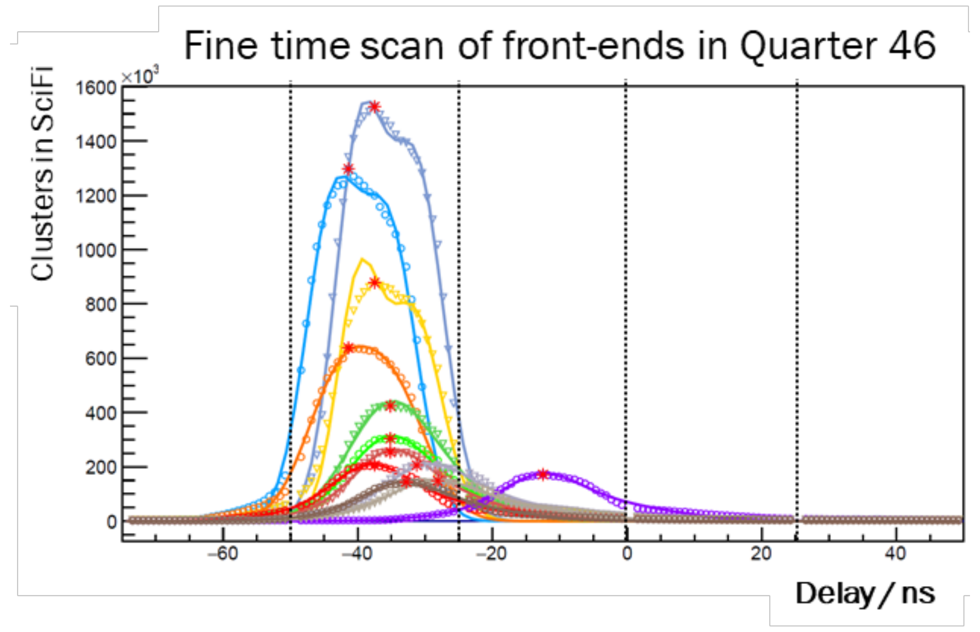
- 34/34 staves installed on one half of the detector - 47 good staves at CERN (out of 68 needed)
- Flex cable installation completed
- Plan for safe closing envelope around beampipe and closing of underground box under discussion
- Maximal use of down-times for installation: preparation of cables, cable chains, services and monitoring
- Good progress towards full installation during YETS



## SciFi

- Readout electronics performing well
- All services worked without intervention
- Commissioning
  - Developed necessary tools for time alignment of the detector
  - Threshold calibration procedure complete →essential for track reconstruction
- Very stable system. Ready for track reconstruction when beams return

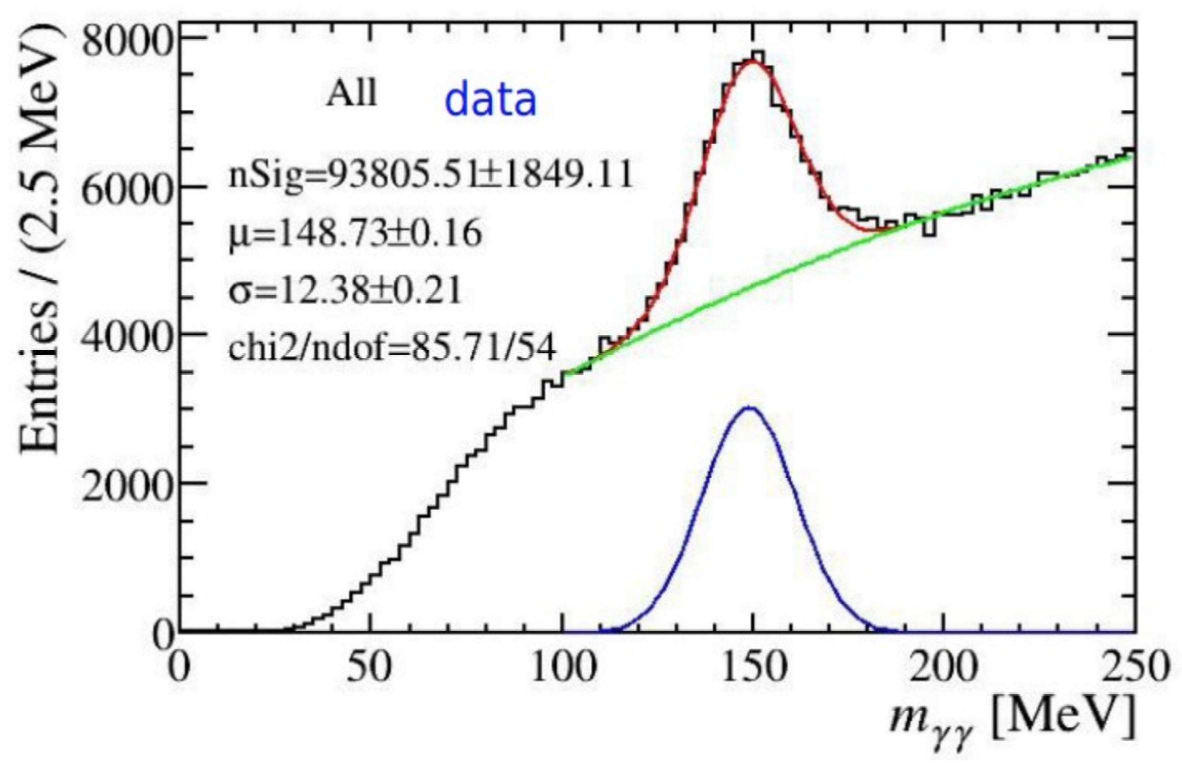


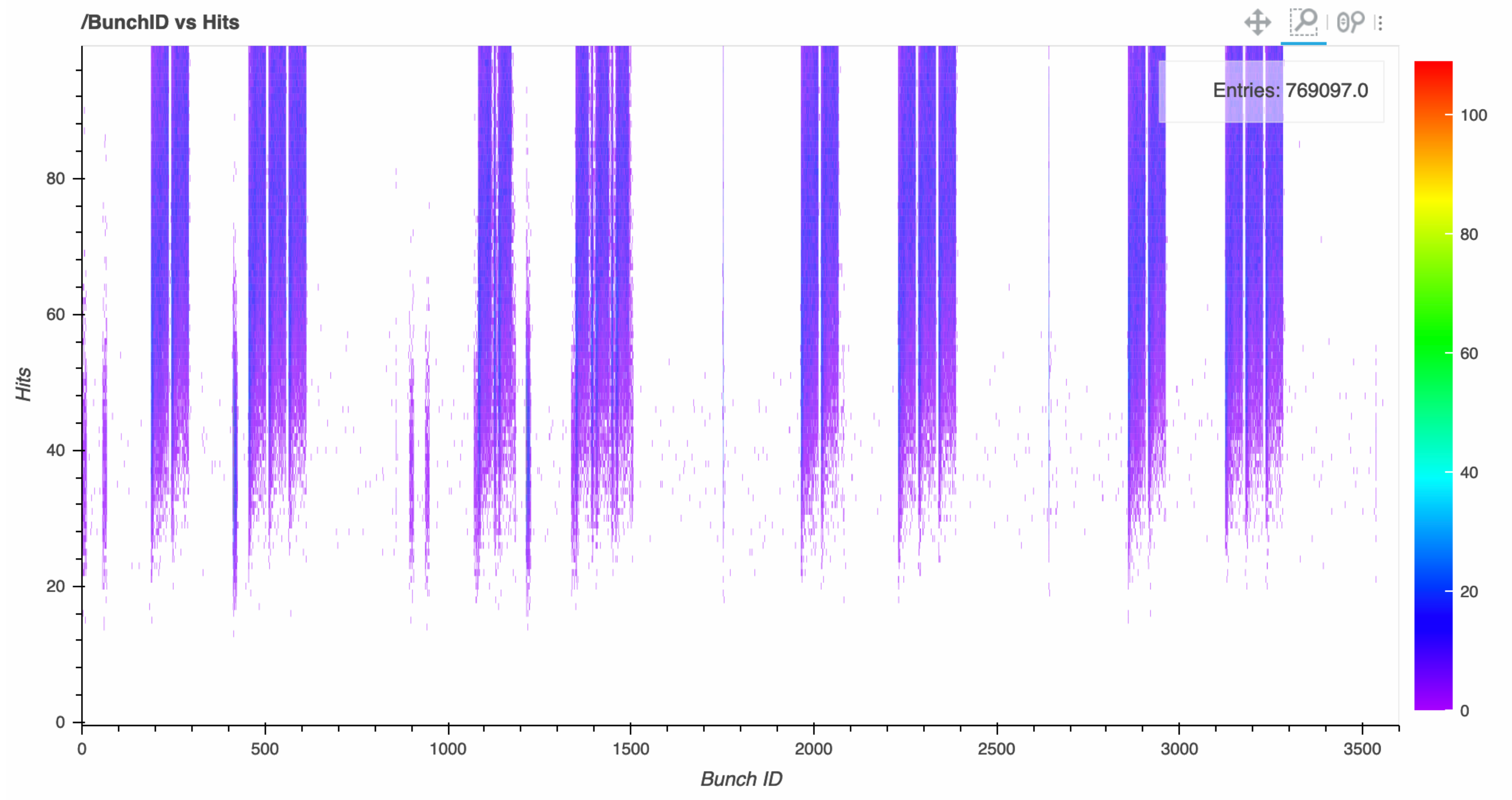


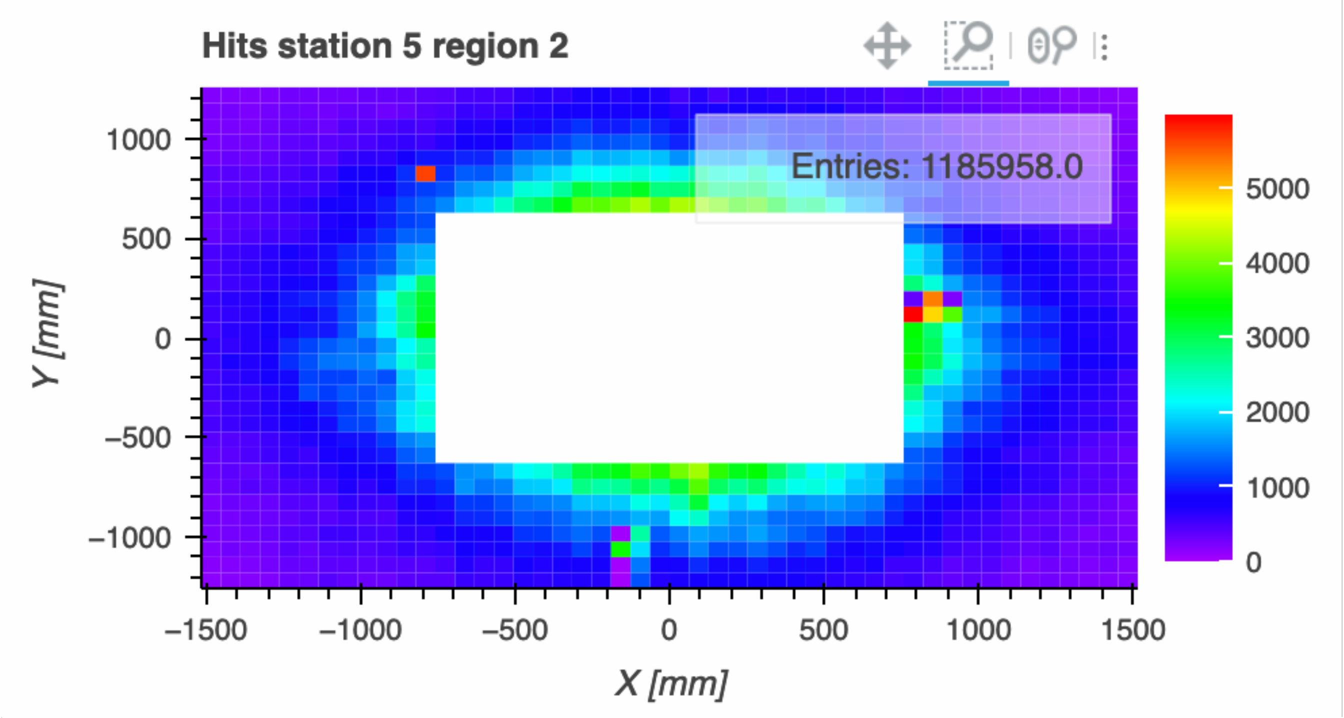
# Calorimeters + Muon

- Installation completed end of 2021
- Bit Error Rate tests show all fibres for ECAL/HCAL work as expected
- In global commissioning state since spring
- First collisions allowed time alignment of individual calorimeter cells
- Coarse energy calibration performed using LED system
- Energy calibration for $\pi^0$ reconstruction under development → close collaboration between detector and reconstruction teams essential

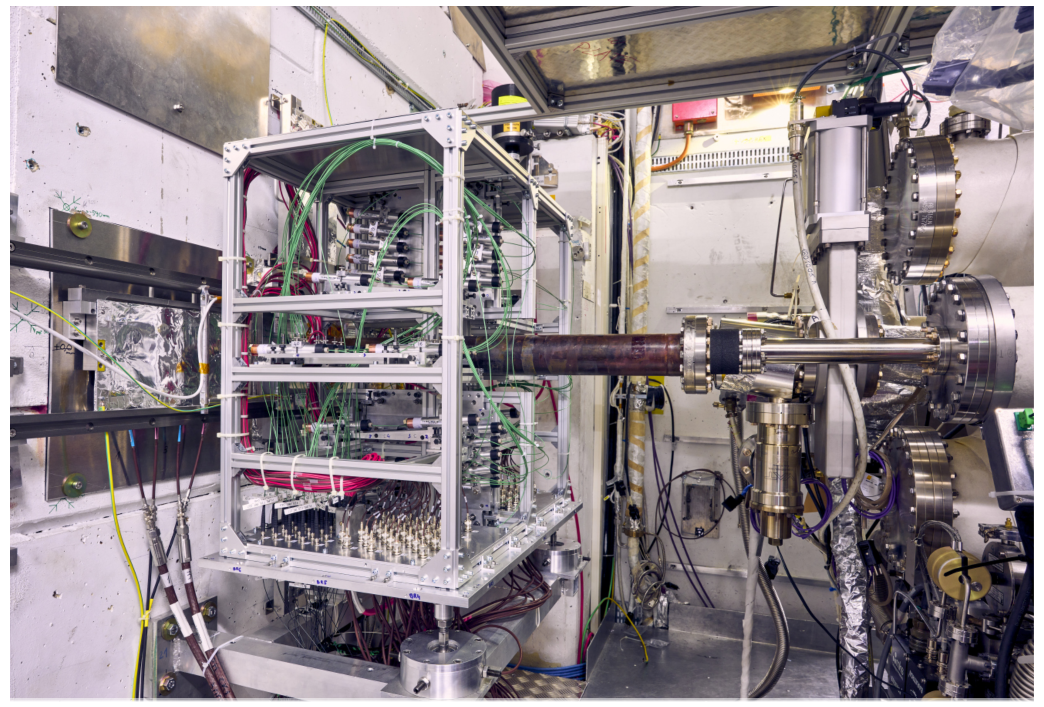
- All connectivity (both data and controls) active
- HV is commissioned
- No issues observed with LHC intensity ramp
- Muon system is aligned to LHC clock since October 2021
- Work ongoing for final time alignment and standalone Muon reconstruction
- Successfully taking part in the commissioning at the pit



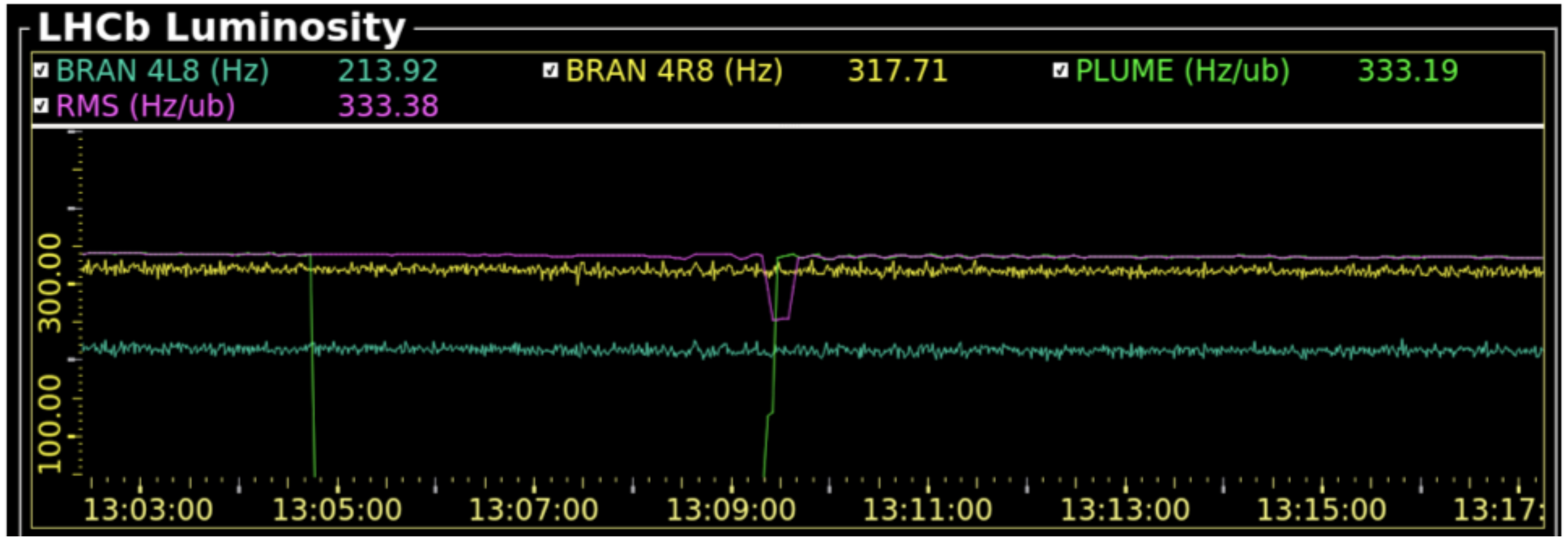



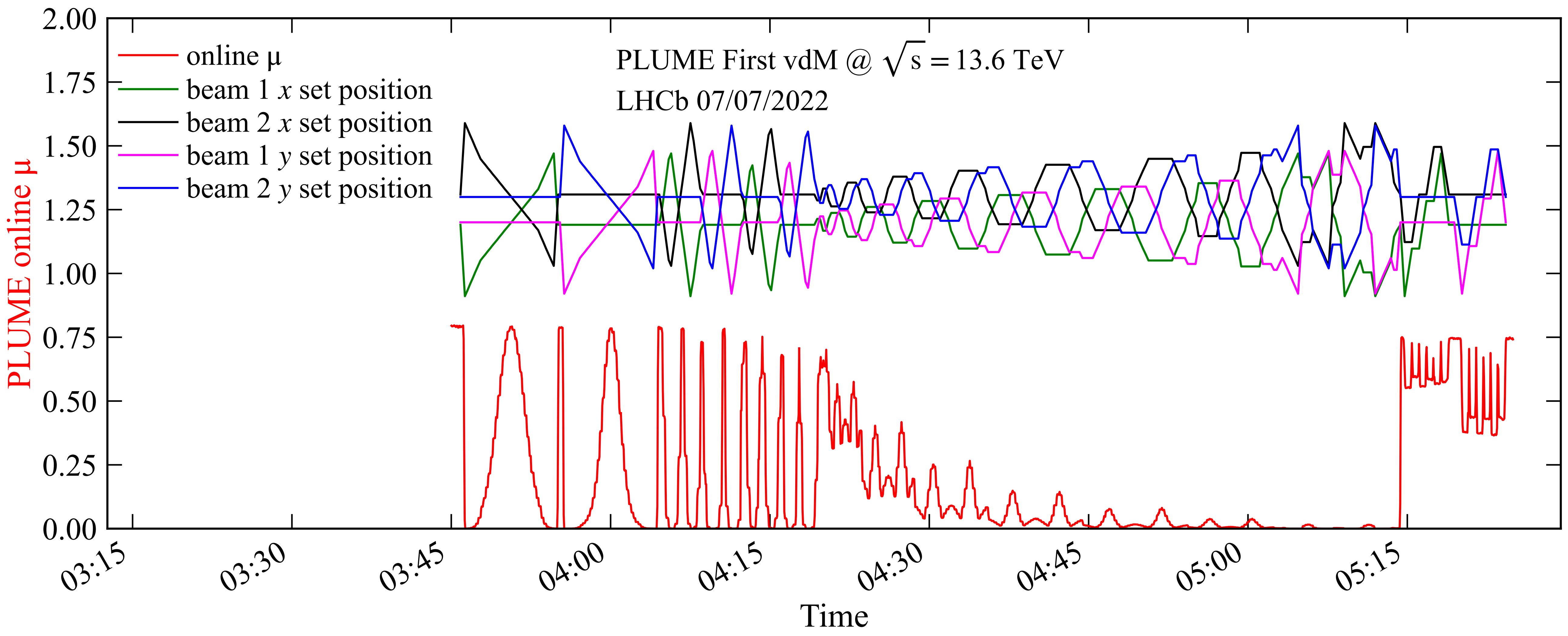



# PLUME



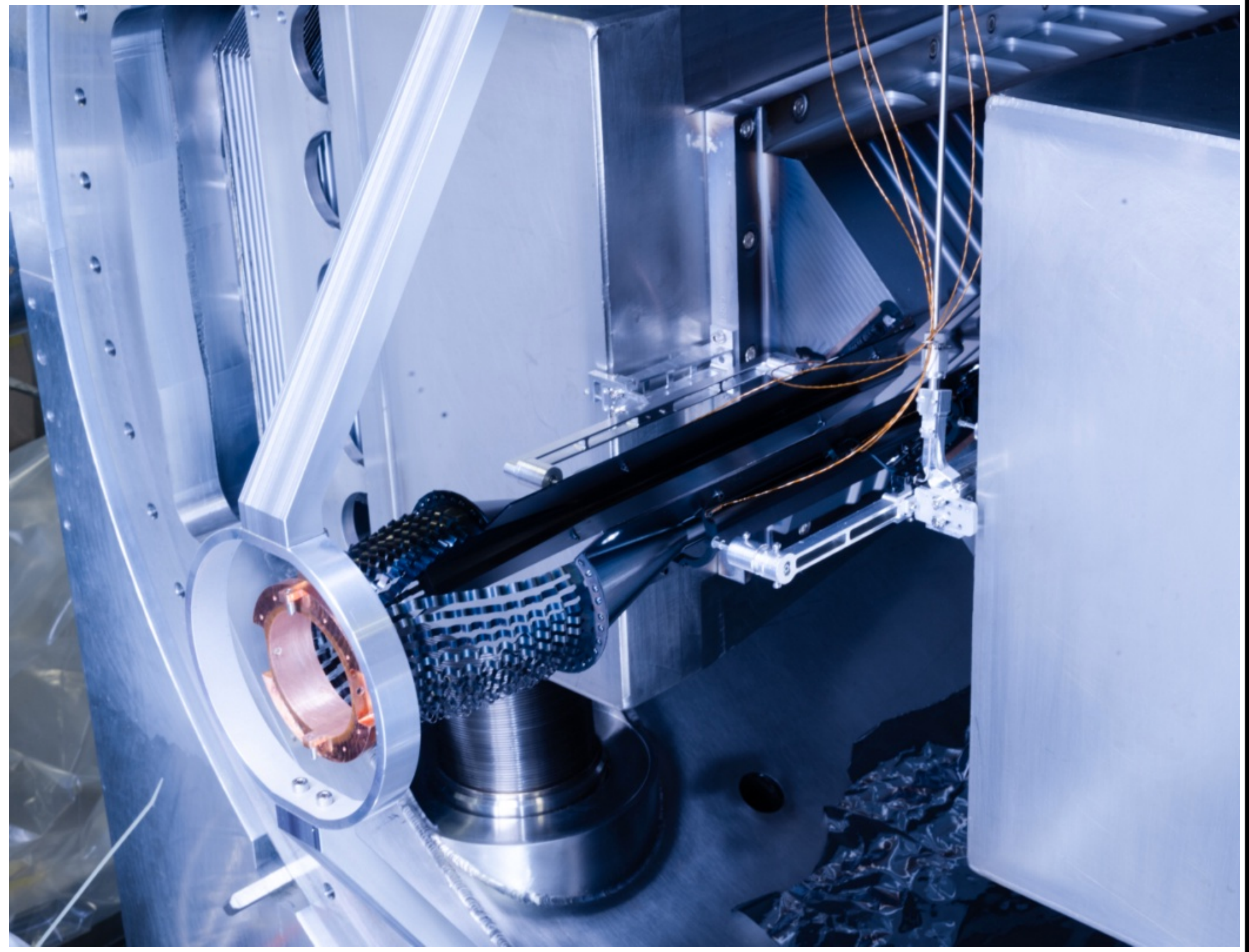
- PLUME: New dedicated luminometer
  - Online Luminosity
  - Visible interactions per bunch crossing for lumi leveling
- Instantaneous luminosity provided to the LHC primarily by PLUME, RMS when unavailable (cross-calibrated) now in place
- Van der Meer scan performed at beginning of July to calibrate instantaneous luminosity provided by PLUME at 13.6 TeV

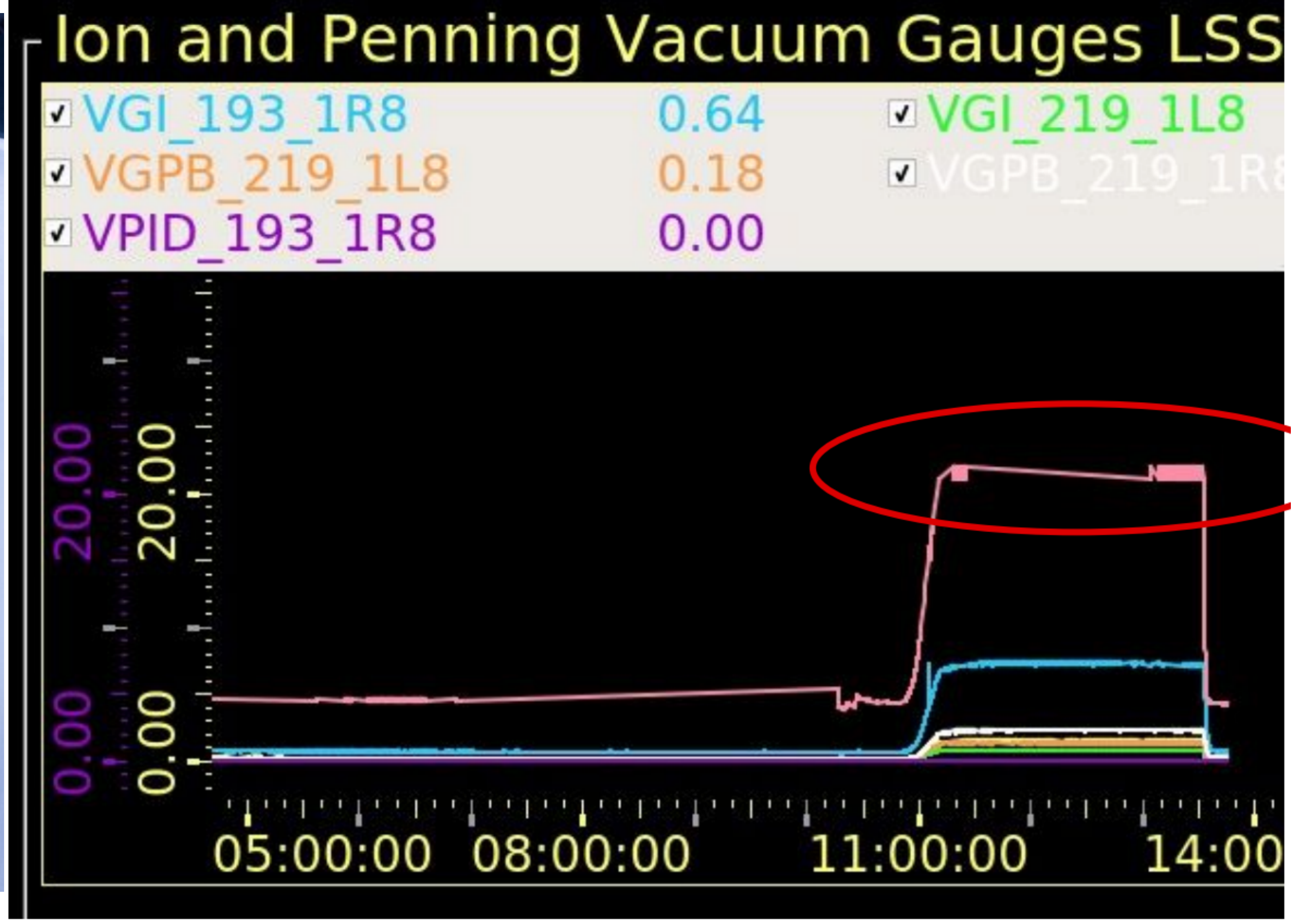


# SMOG2

- Gas injection system and storage cell inside the beam pipe at the VELO position
- Ne injection tests: Very stable operation
  - Gas injection and vacuum recovery in 30 min
- RICH and SMOG time alignment completed
- SMOG contributing significantly to detector commissioning
  - Increase of detectors activity
  - Increase of rate of collisions



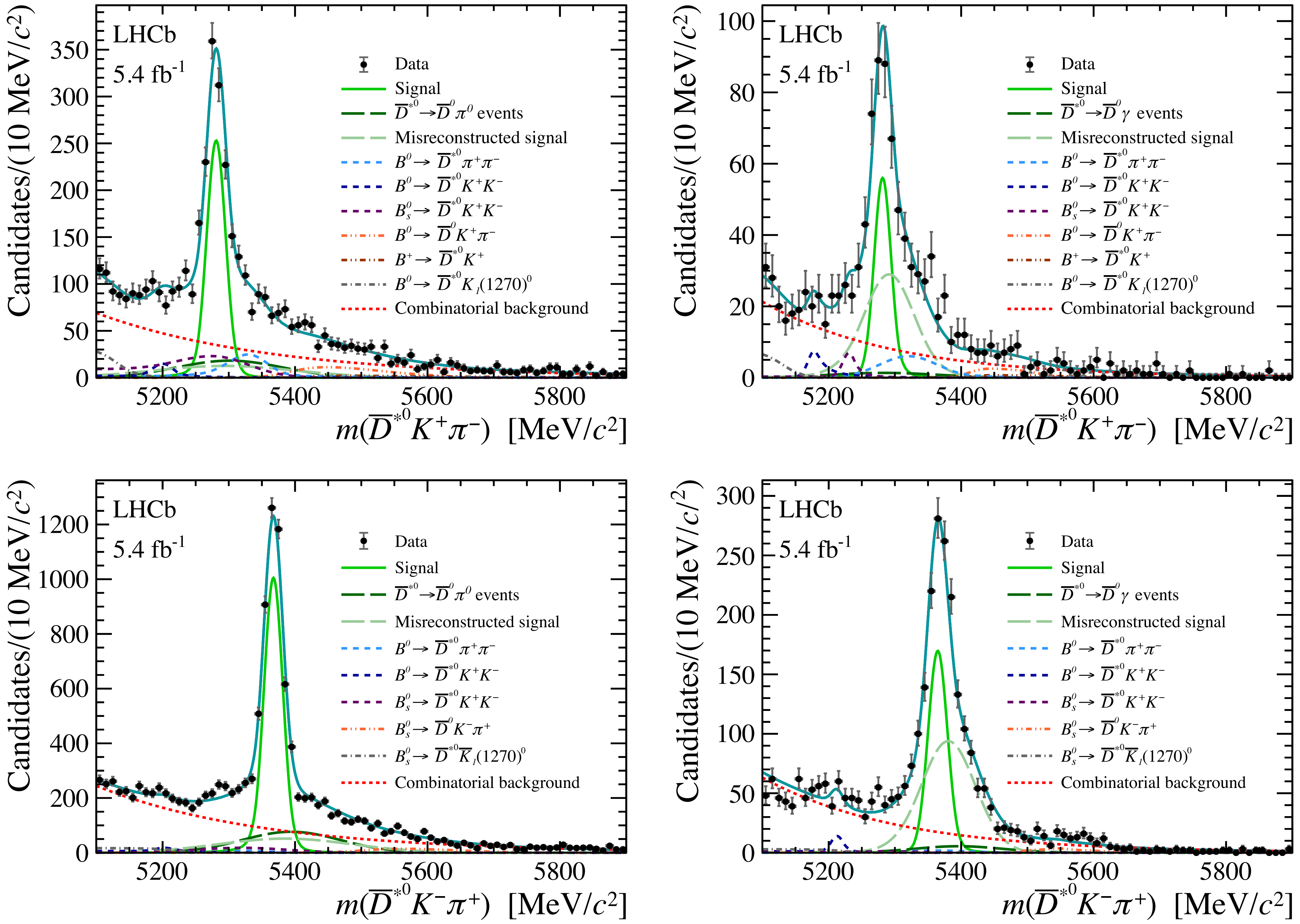



# And More!

## Observation of $B^0 \to \overline{D}^{*0} K^+ \pi^-$ and $B_s^0 \to \overline{D}^{*0} K^- \pi^+$ decays

[Phys. Rev. D105 (2022) 072005]

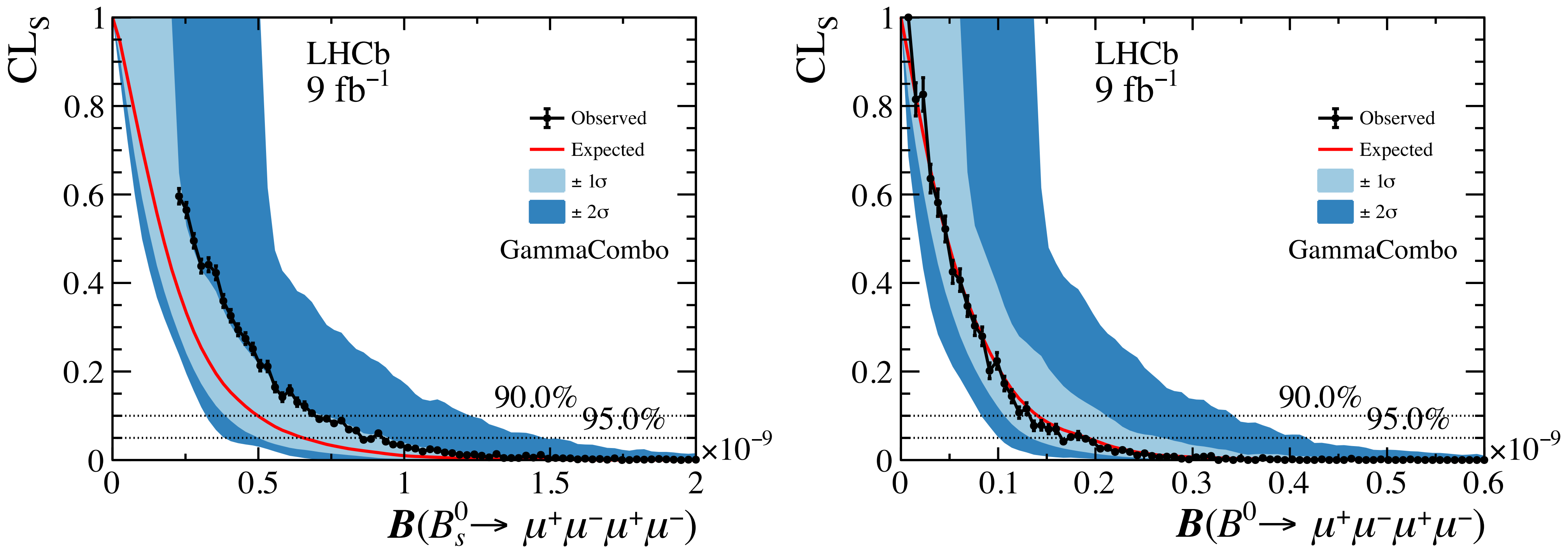
$D^{*0} \to D^0 \gamma$ $\qquad$ $D^{*0} \to D^0 \pi^0$




$$\mathcal{B}(B^0 \to \overline{D}^{*0} K^+ \pi^-) = (5.18 \pm 0.27 \pm 0.34 \pm 1.84) \times 10^{-5}$$

$$\mathcal{B}(B_s^0 \to \overline{D}^{*0} K^- \pi^+) = (7.30 \pm 0.18 \pm 0.56 \pm 2.59 \pm 0.23) \times 10^{-4}$$

## Searches for rare $B_s^0$ & $B^0 \to 4\mu$ [JHEP 03 (2022) 109]




$\mathcal{B}(B_s^0 \to 4\mu) < 8.6 \times 10^{-10}$ $\qquad$ $\mathcal{B}(B^0 \to 4\mu) < 1.8 \times 10^{-10}$ $\qquad$ 95% cl

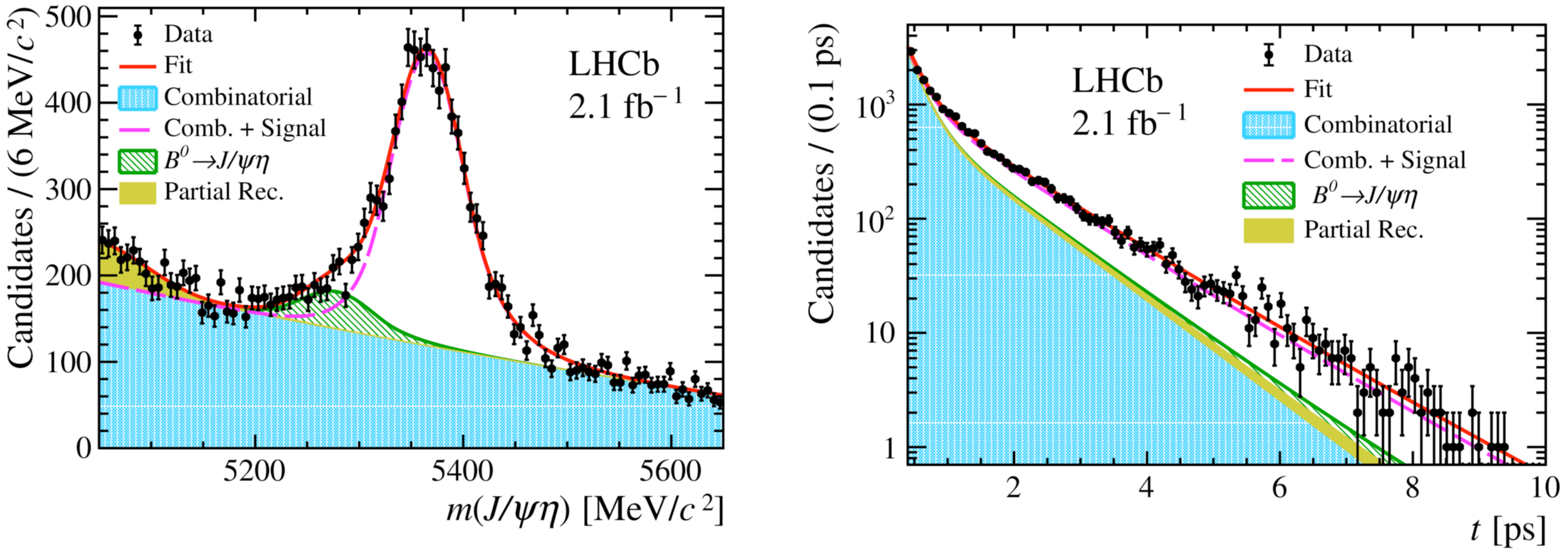
$\mathcal{B}(B_s^0 \to a(\mu^+\mu^-)a(\mu^+\mu^-)) < 5.8 \times 10^{-10}$ $\qquad$ $\mathcal{B}(B^0 \to a(\mu^+\mu^-)a(\mu^+\mu^-)) < 2.3 \times 10^{-10}$

$\mathcal{B}(B_s^0 \to J/\psi 2\mu) < 2.6 \times 10^{-9}$ $\qquad$ $\mathcal{B}(B^0 \to J/\psi 2\mu) < 1.0 \times 10^{-9}$

## Measurement of $\tau_L$ using $B_s^0 \to J/\psi \eta$

[LHCb-PAPER-2022-010]

**Submitted to Eur. Phys. J. C**



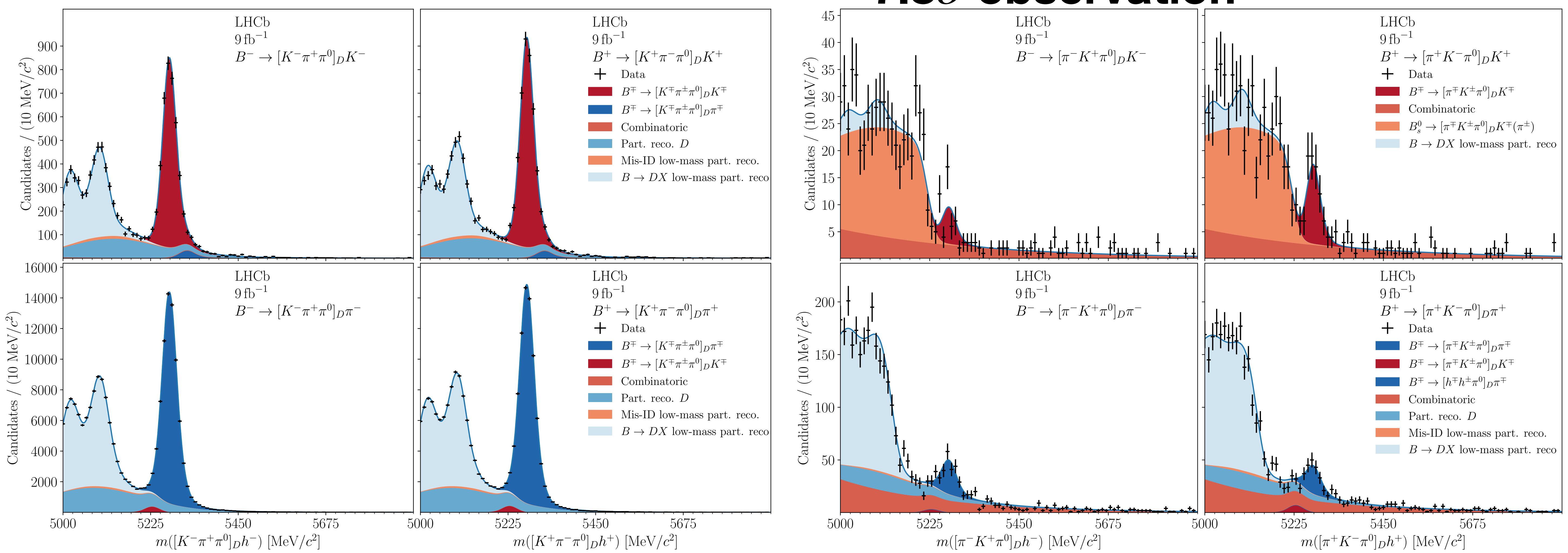

Run1+2 Combination: $\tau_L = 1.452 \pm 0.014 \pm 0.007 \pm 0.002$ ps

# More Beauty!

**Constraints on CKM angle $\gamma$ from $B^{\pm} \to D[h^{\pm}h'^{\mp}\pi^0]h''^{\pm}$**

[JHEP 07 (2022) 099]

**7.8$\sigma$ observation**



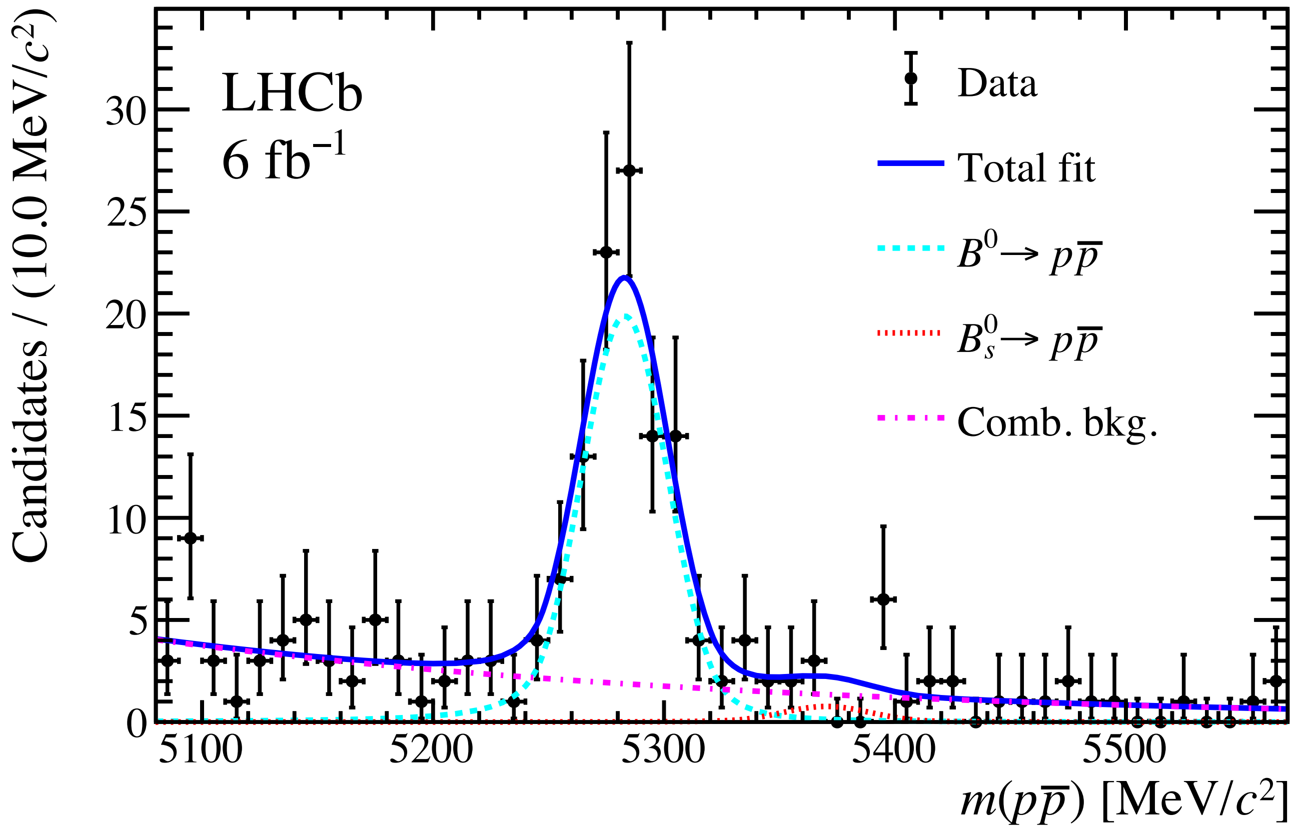
$$R_{ADS(K)} = (1.27 \pm 0.16 \pm 0.002) \times 10^{-2}$$

$$A_{ADS(K)} = -0.38 \pm 0.12 \pm 0.02$$

**Search for $B_s^0 \to p\bar{p}$**

[LHCb-PAPER-2022-004]

**Submitted to PRD**




$$\mathcal{B}(B_s^0 \to p\bar{p}) < 4.4(5.1) \times 10^{-9} @ 90\,\% \, (95\%) CL$$

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.13 \pm 0.05 \pm 0.03) \times 10^{-8}$$