LHCb status report

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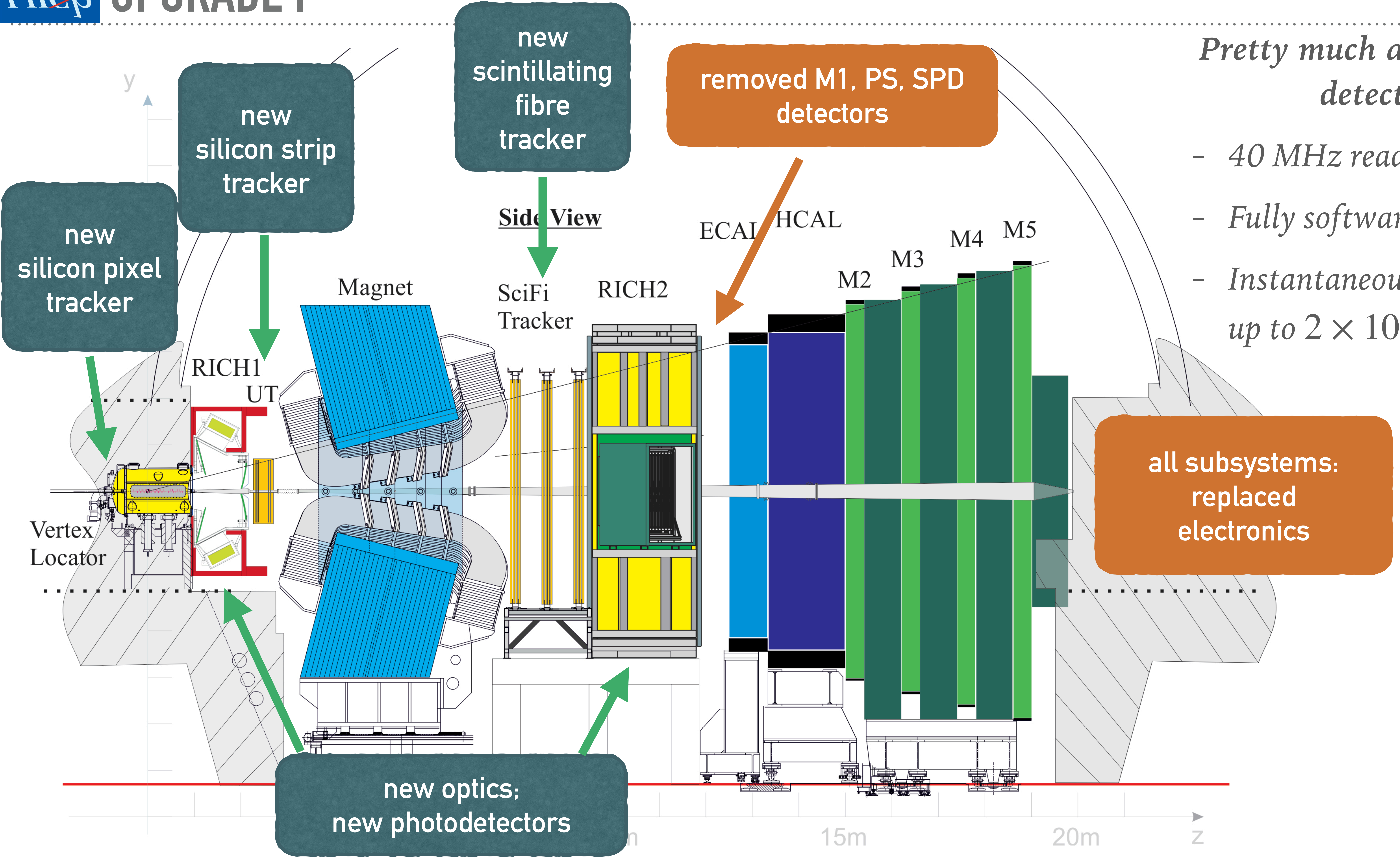
on behalf of the LHCb Collaboration

147^{th} LHCC meeting – open session
01/Sep/2021

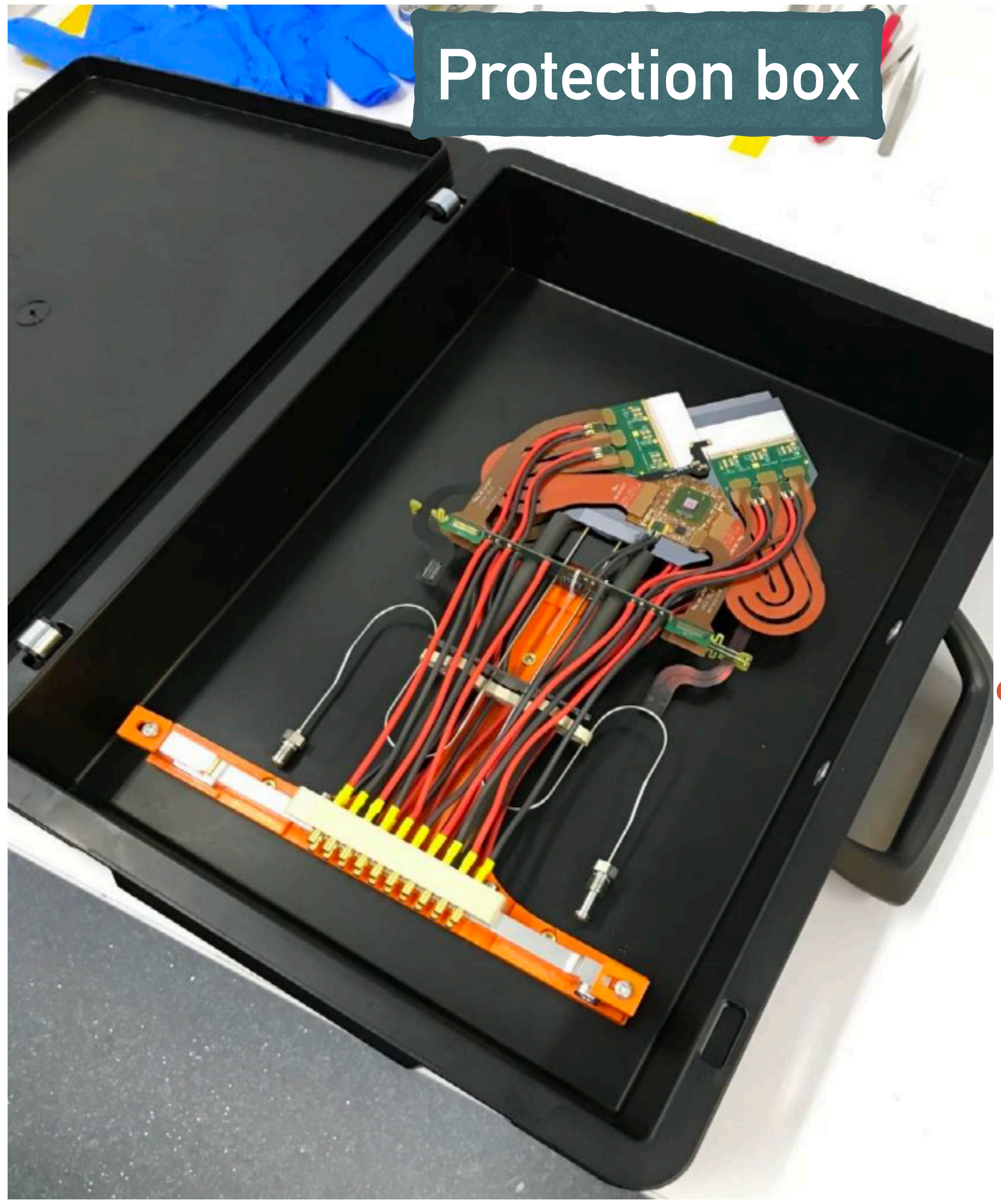
photo: Janina Nicolini

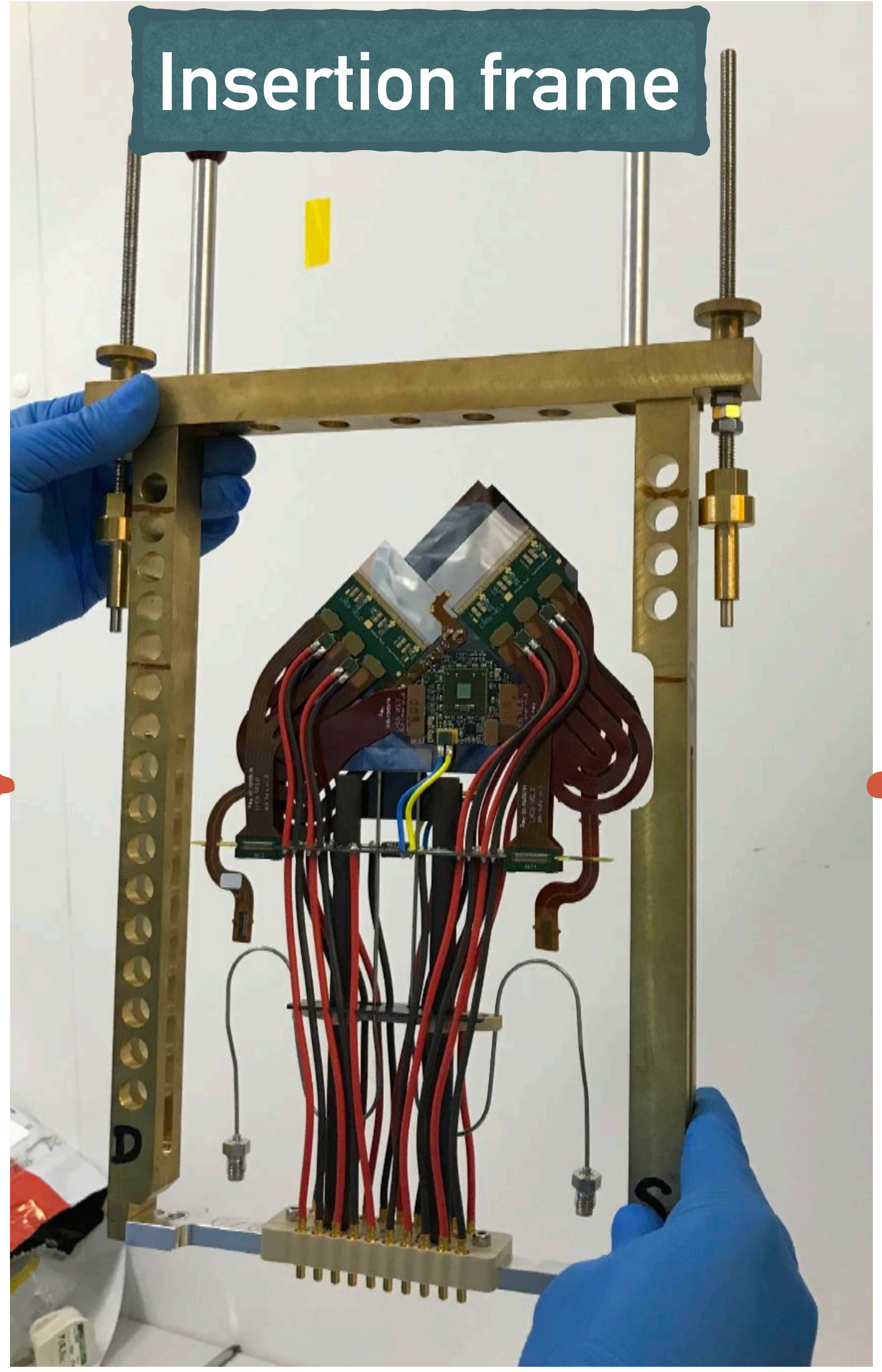


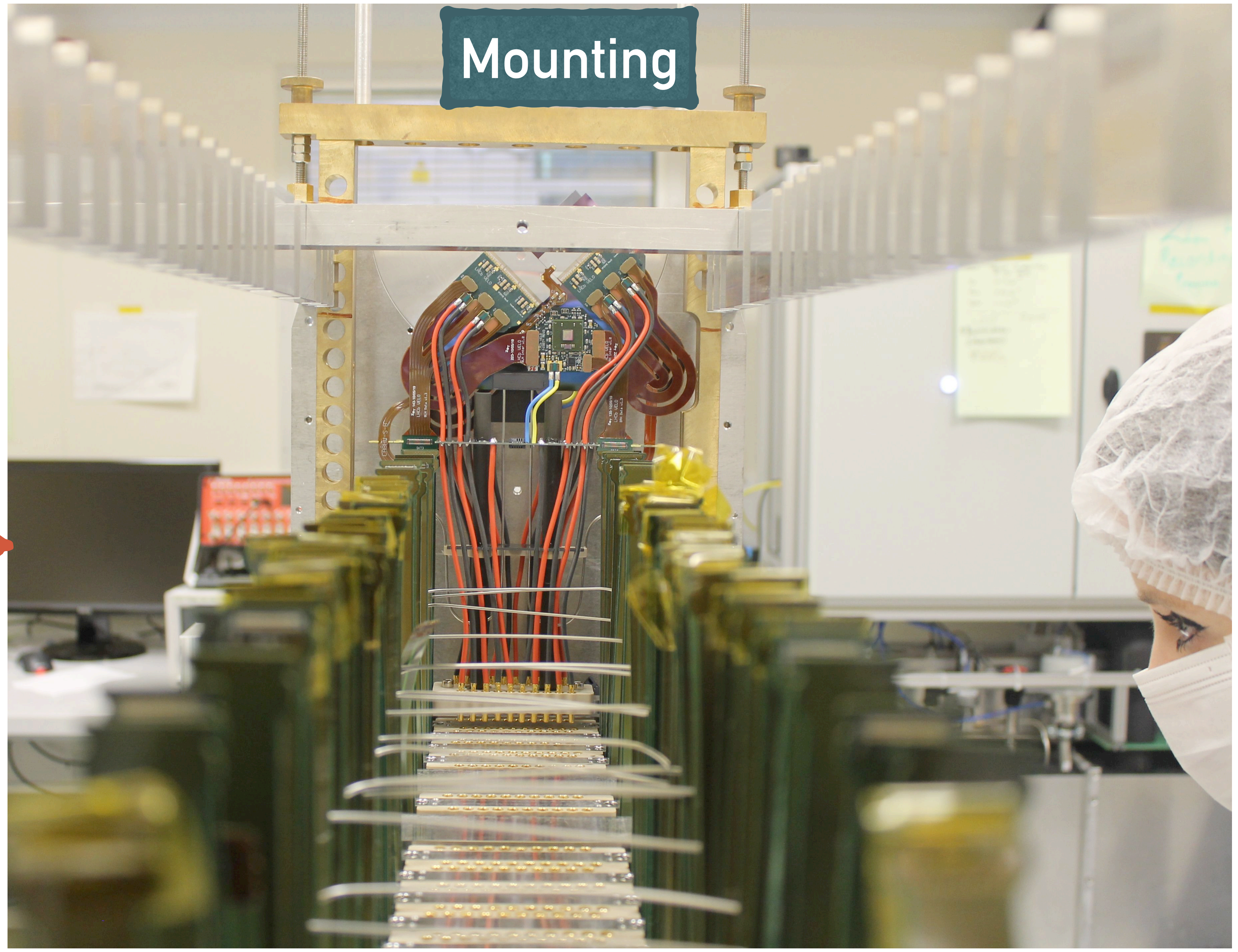
Pretty much a brand new detector!

- *40 MHz readout*
- *Fully software trigger*
- *Instantaneous luminosity up to* $2 \times 10^{33}\ cm^{-2}s^{-1}$

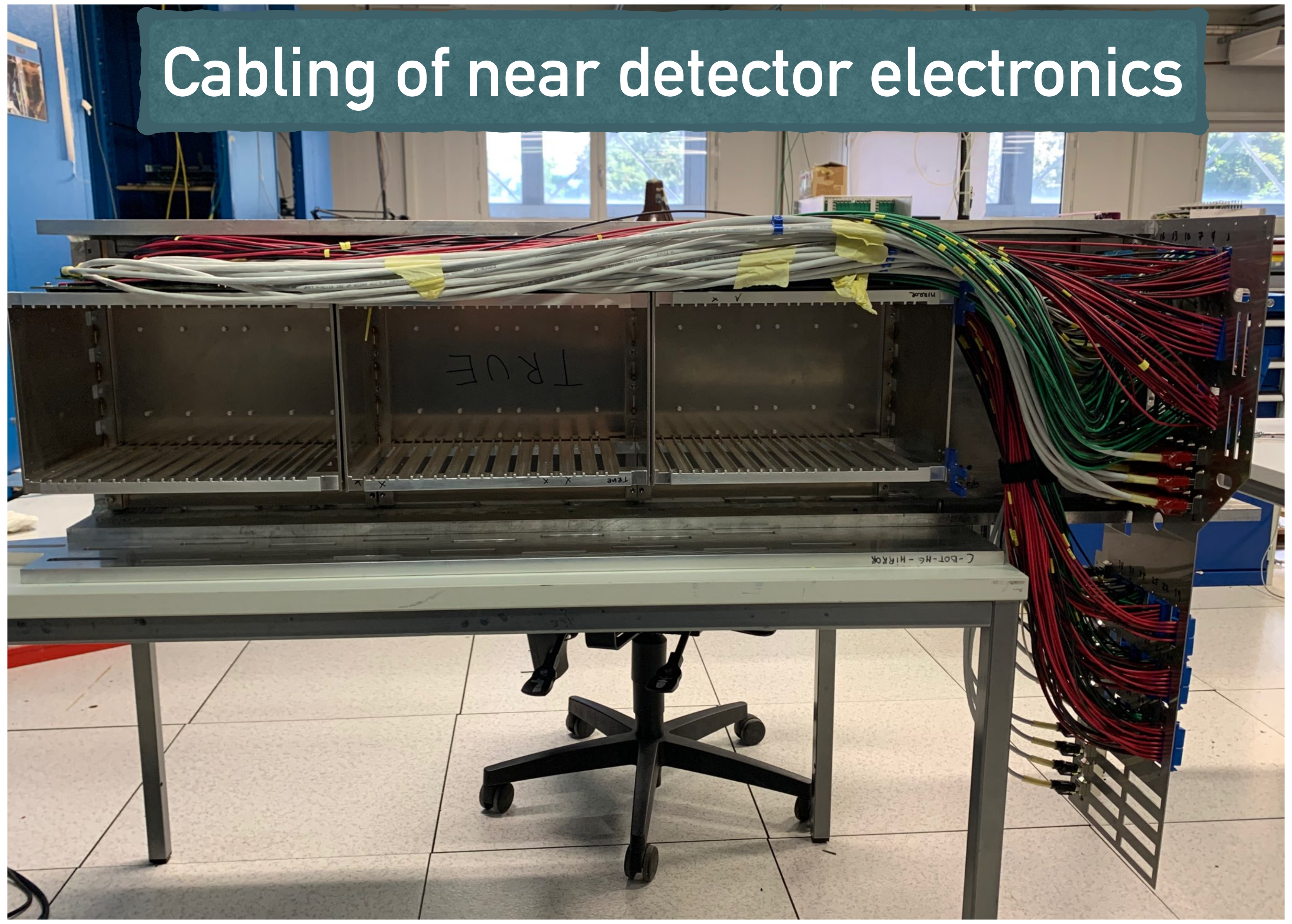
- Installed the cooling infrastructure
- 41/52 modules ready
- Started mounting the first production modules
- A tight schedule, but assembly moves well

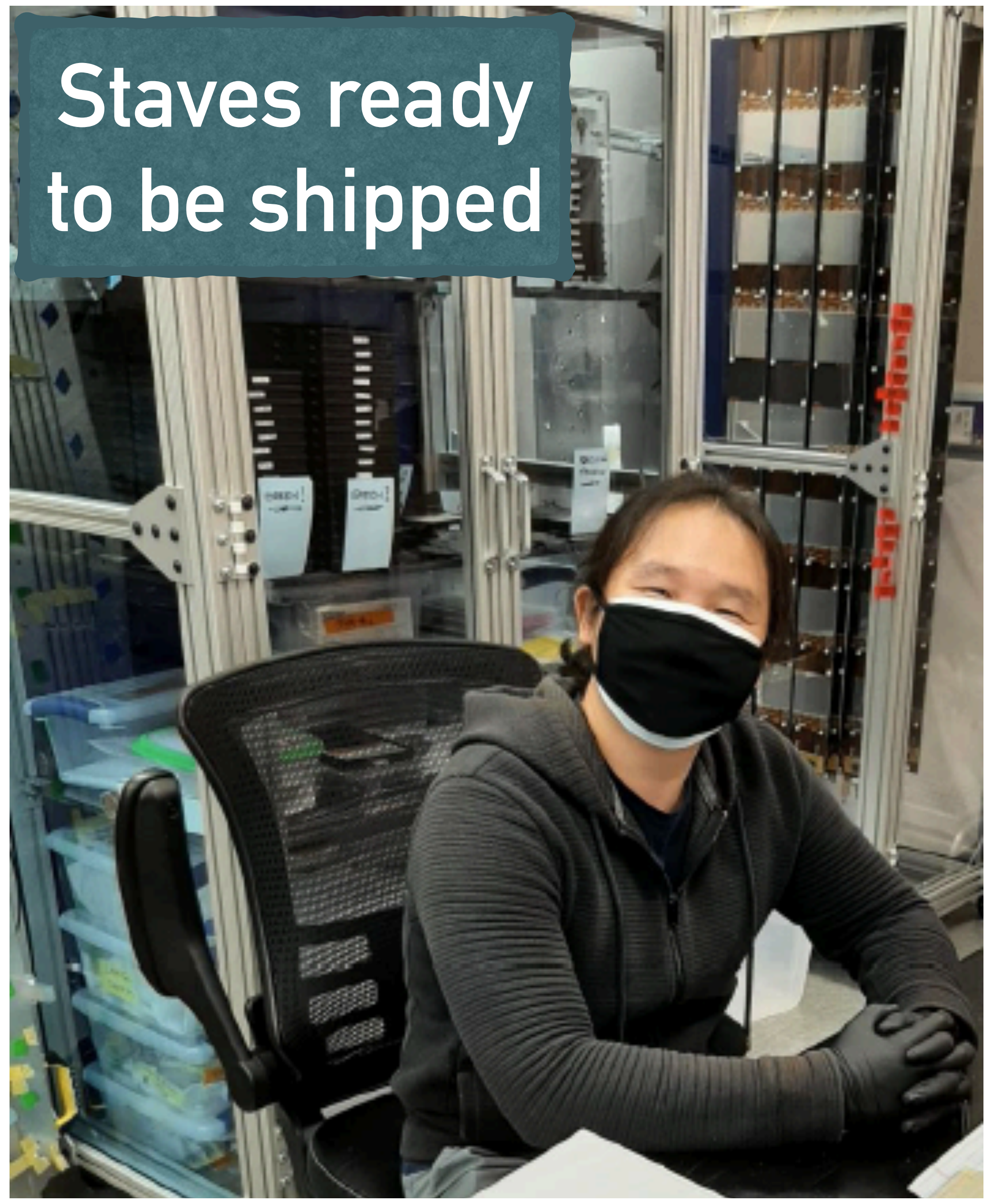


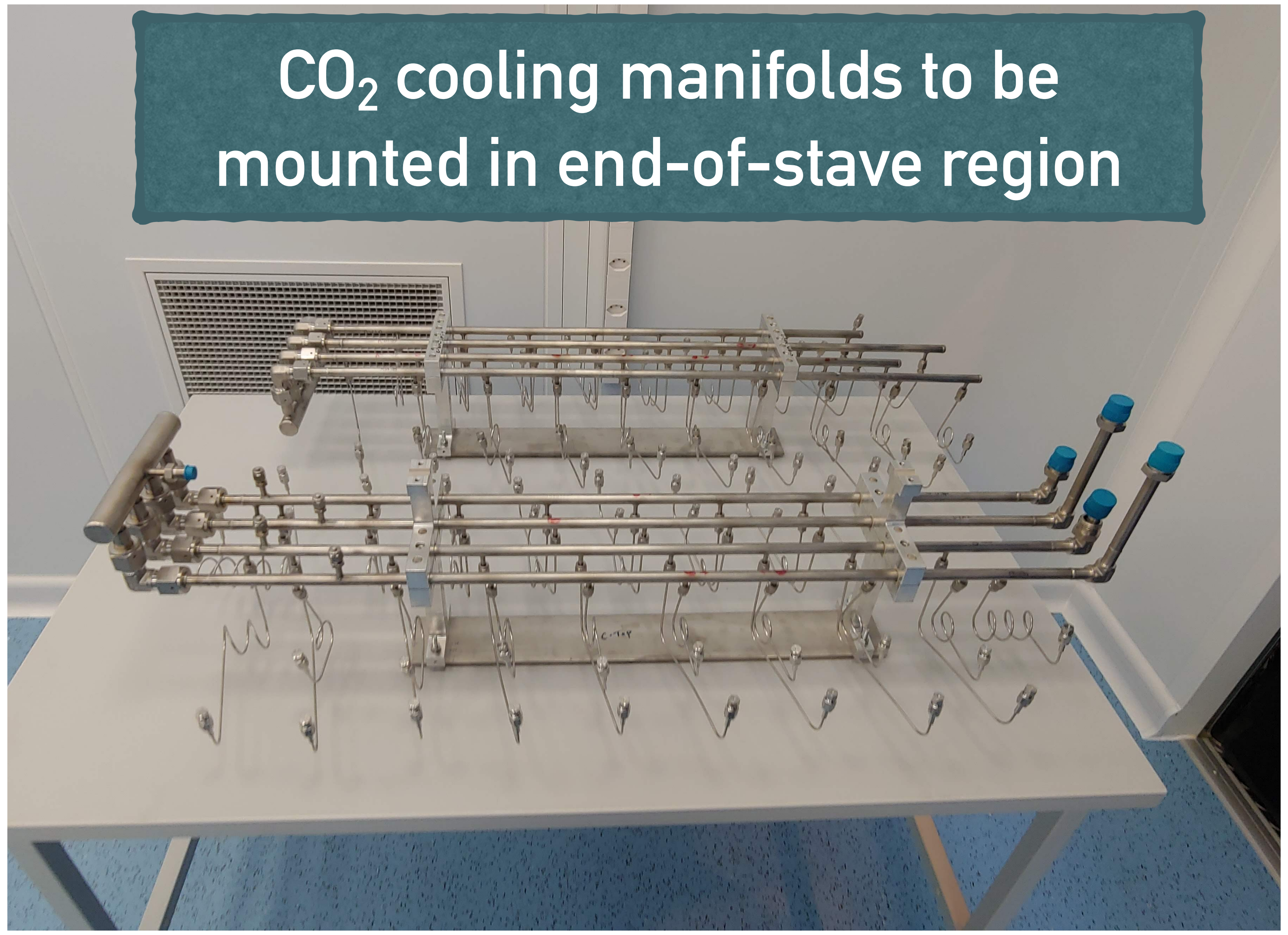




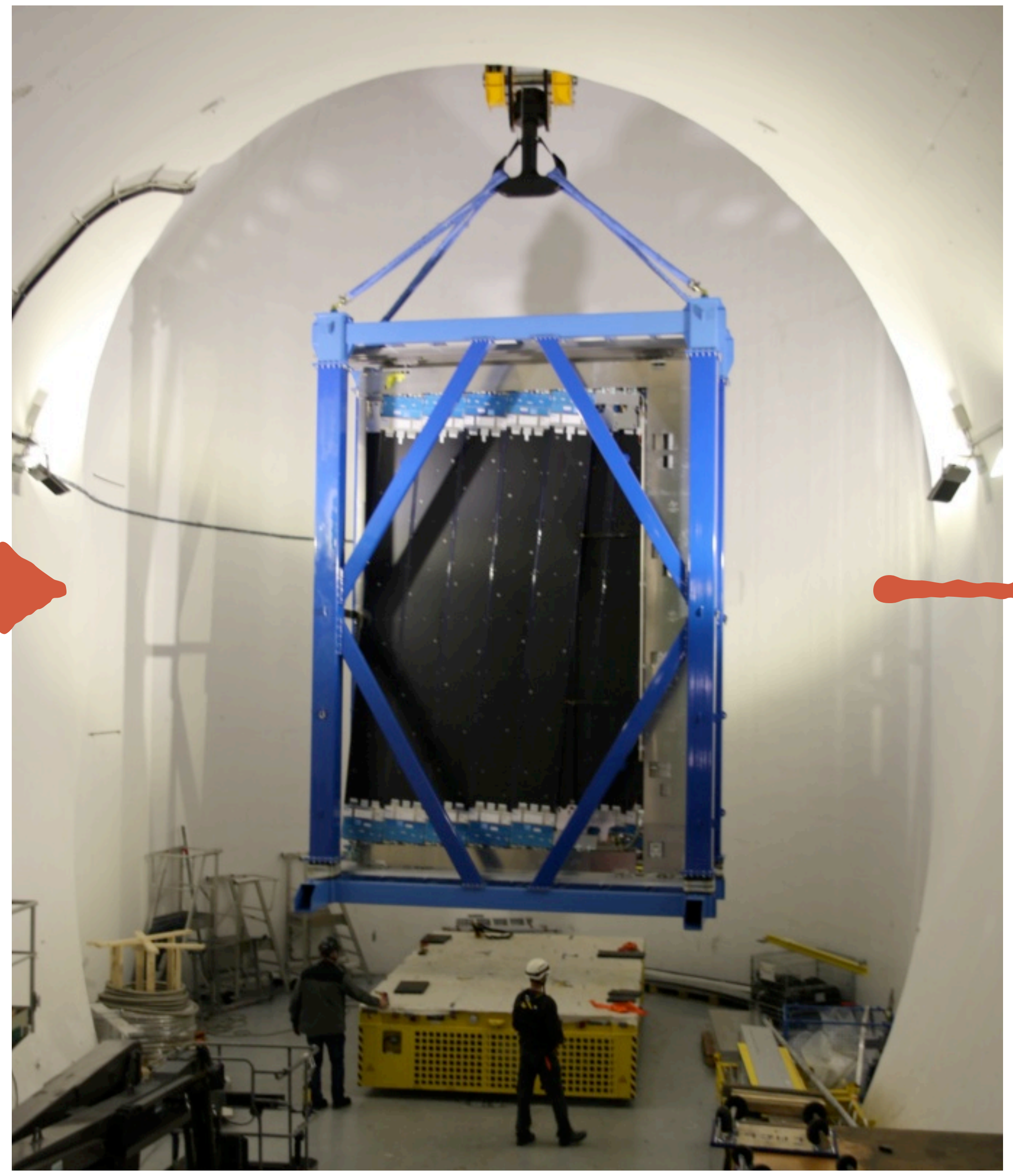
- Detector modules:
    - Outer-region modules: 933 ready, i.e. 888 nominal + spares
    - Inner-region modules: majority ready, yet below nominal needs
- Modules being mounted on staves & shipped to CERN
    - Only 20(+5)/68 staves at CERN now
- Stave mounting infrastructure being prepared at CERN
    - Stave mounting expected to start in October
- A very tight schedule, strong commitment to meet it

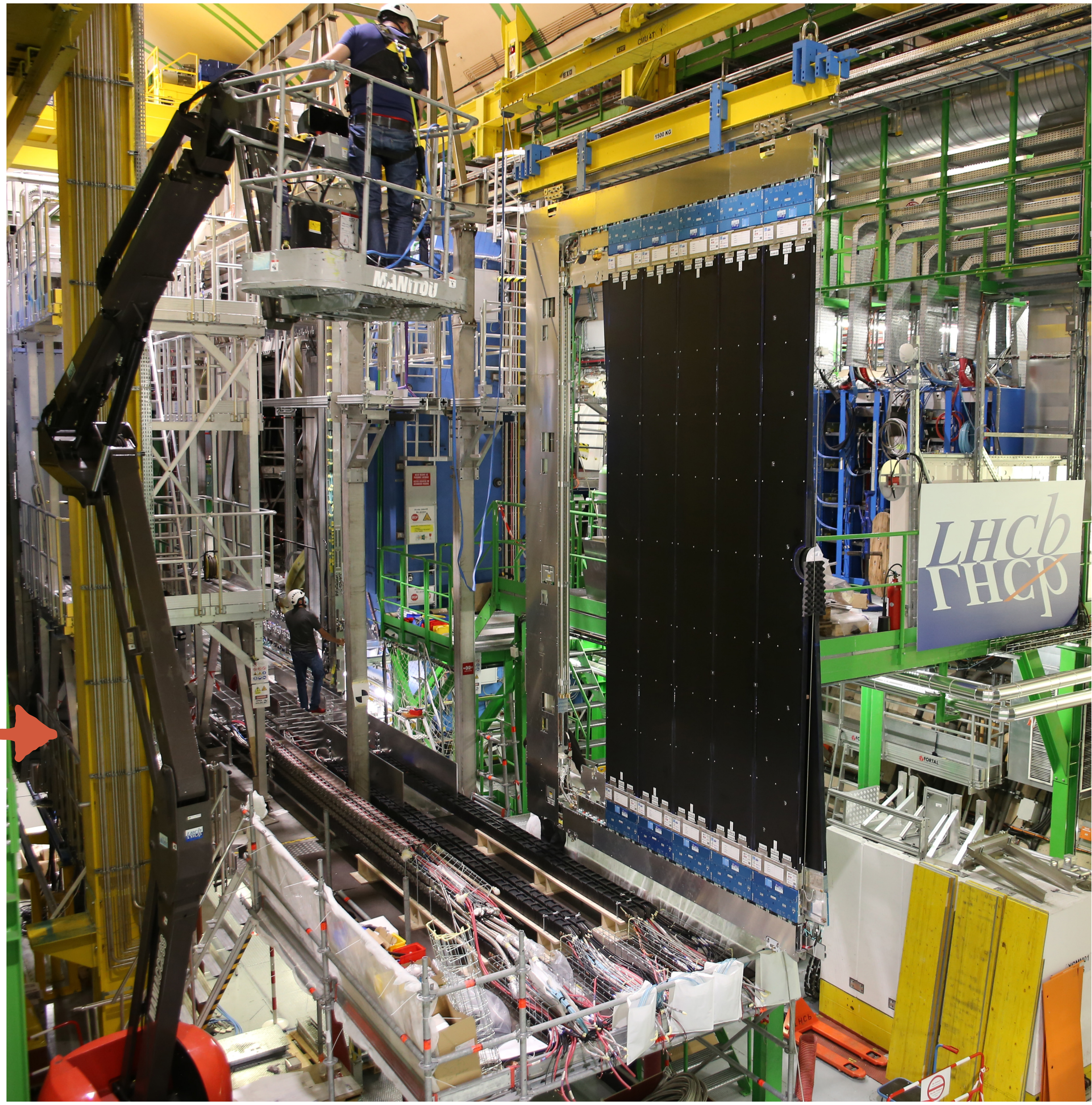






- **A half of the whole detector (C-side) is now installed, connected and aligned!**
  - Services connected and being prepared for powering

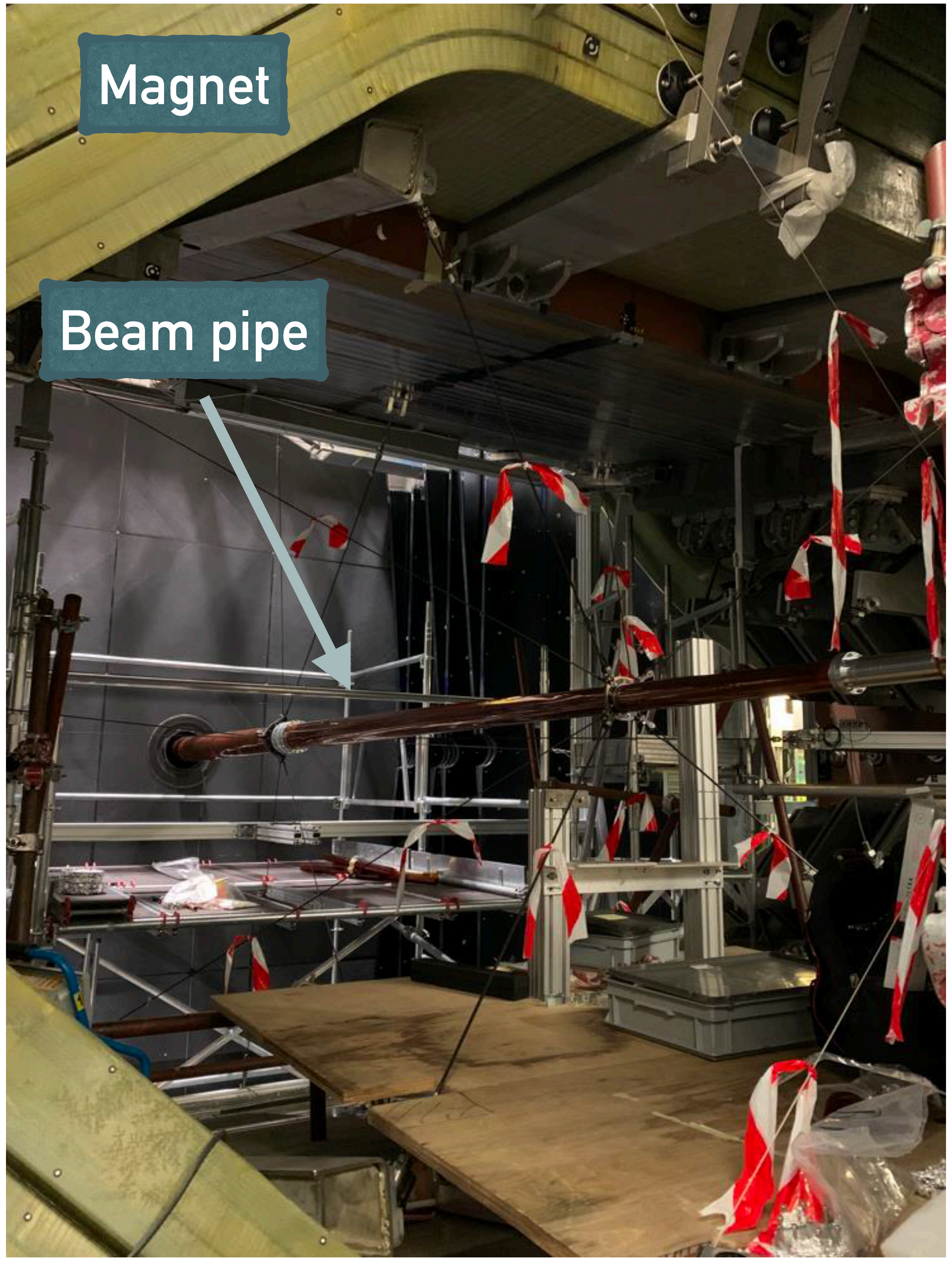




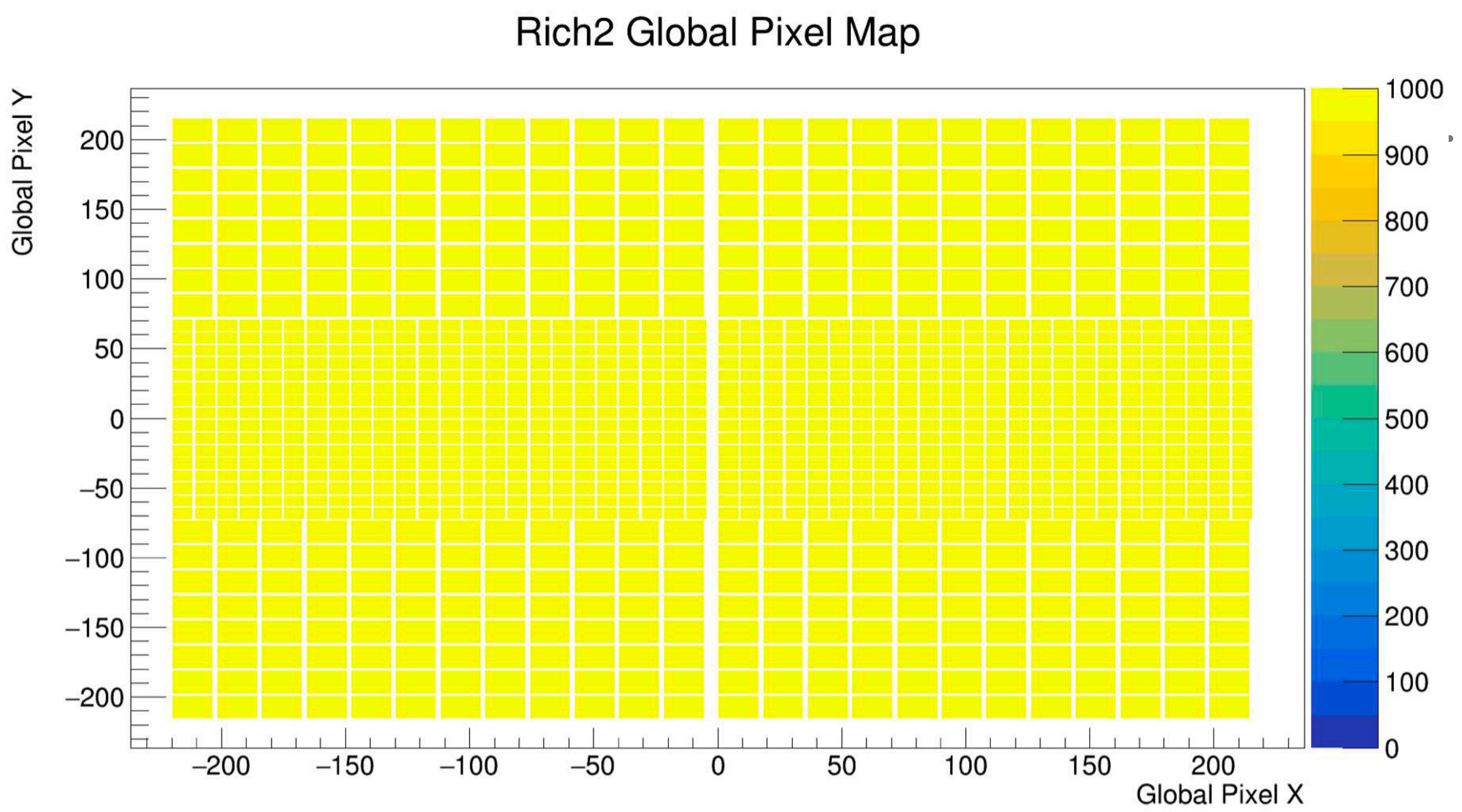
- **Assembly and testing** of the **A-side** frames in full steam
  - Installation of connectors & services ongoing
  - Installation of frames to start in November

BEAM PIPE

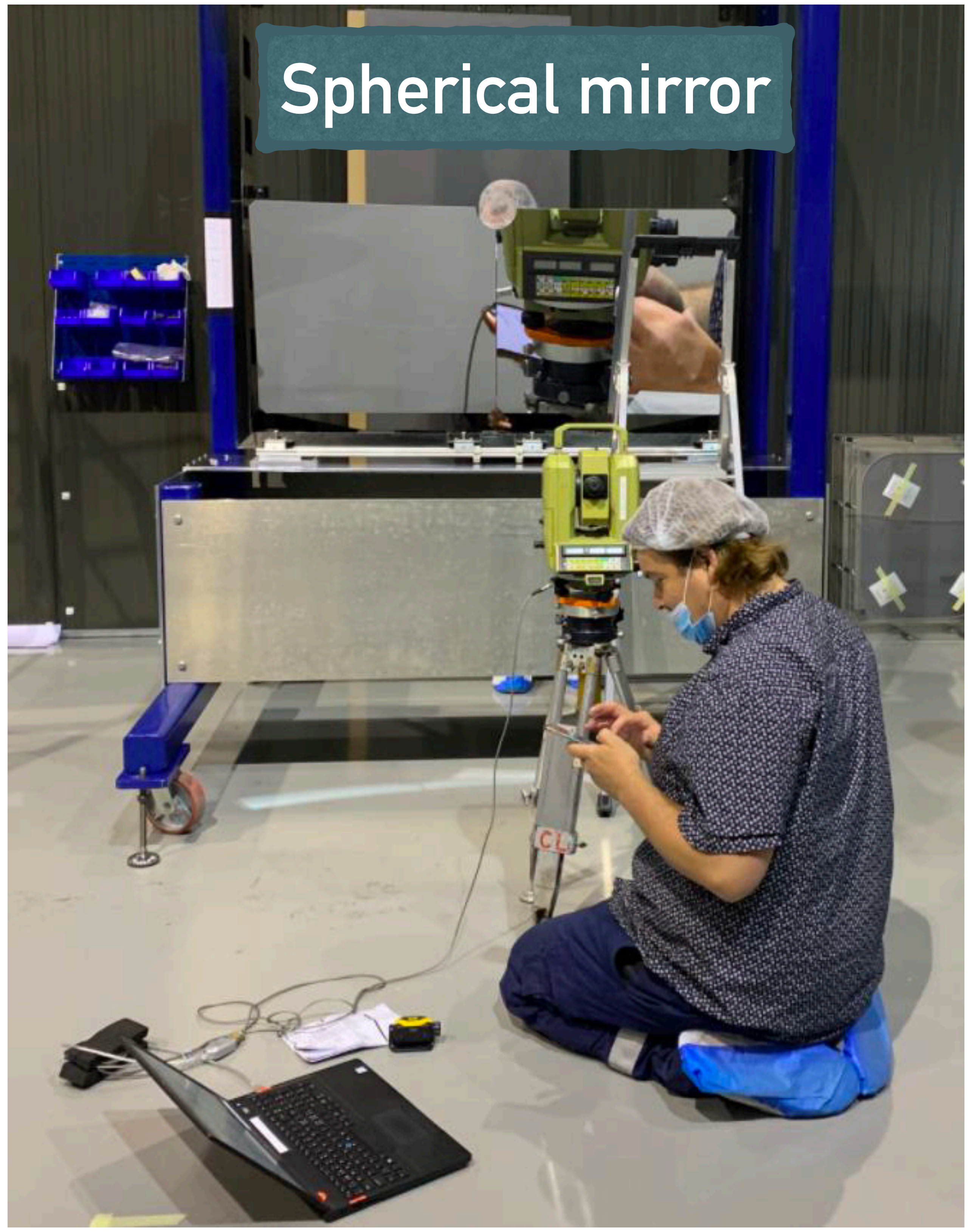
- Completion of the SciFi C-side allowed to install the final segments of the beam pipe inside the LHCb cavern
- Pumping and leak tests successful; now under vacuum
- **Bake-out** of the beam pipe ongoing

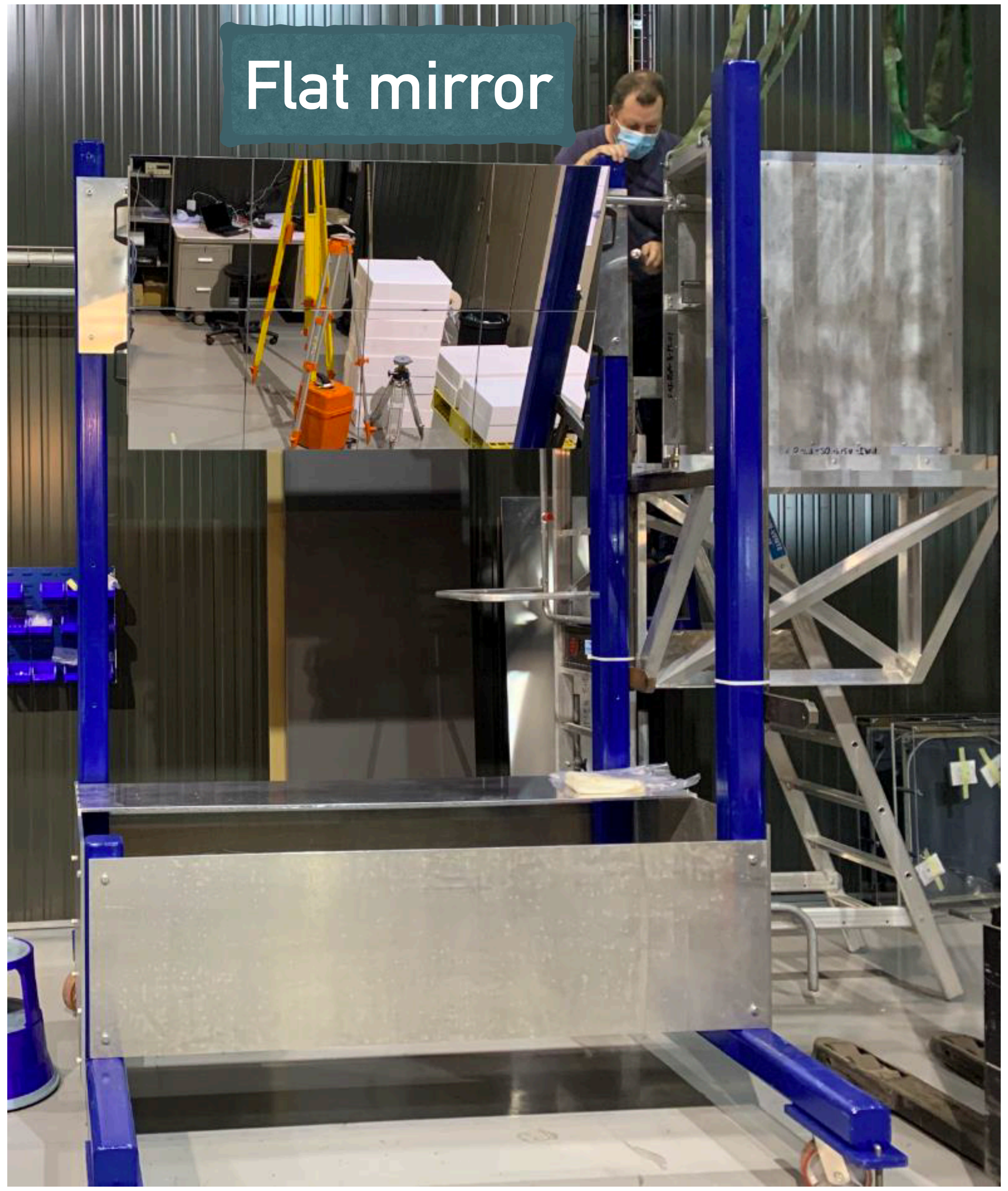


LHCb-TDR-014



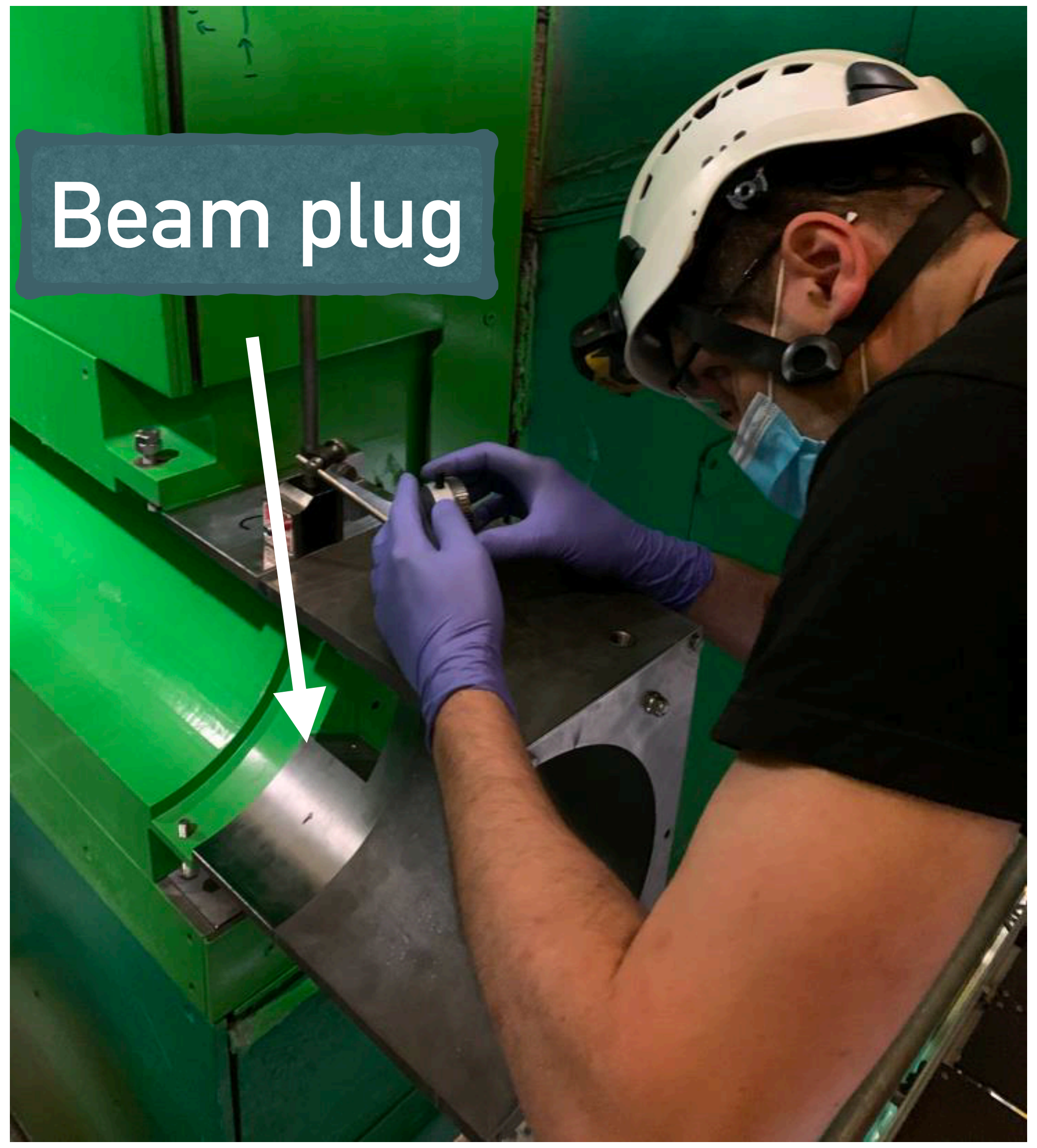
- RICH2: installation complete, commissioning ongoing
- RICH1: installed lower quartz window and the PMT enclosure
  - Survey and alignment of RICH1 mirrors successful, preparation for **installation (Sep/Oct)**





detectors are in place

- **Shielding** lead plugs installed in the M2 inner section, surrounding the beam pipe
  - same done last year in the inner section of the HCAL
  - limits the background rate in the inner sections of muon stations

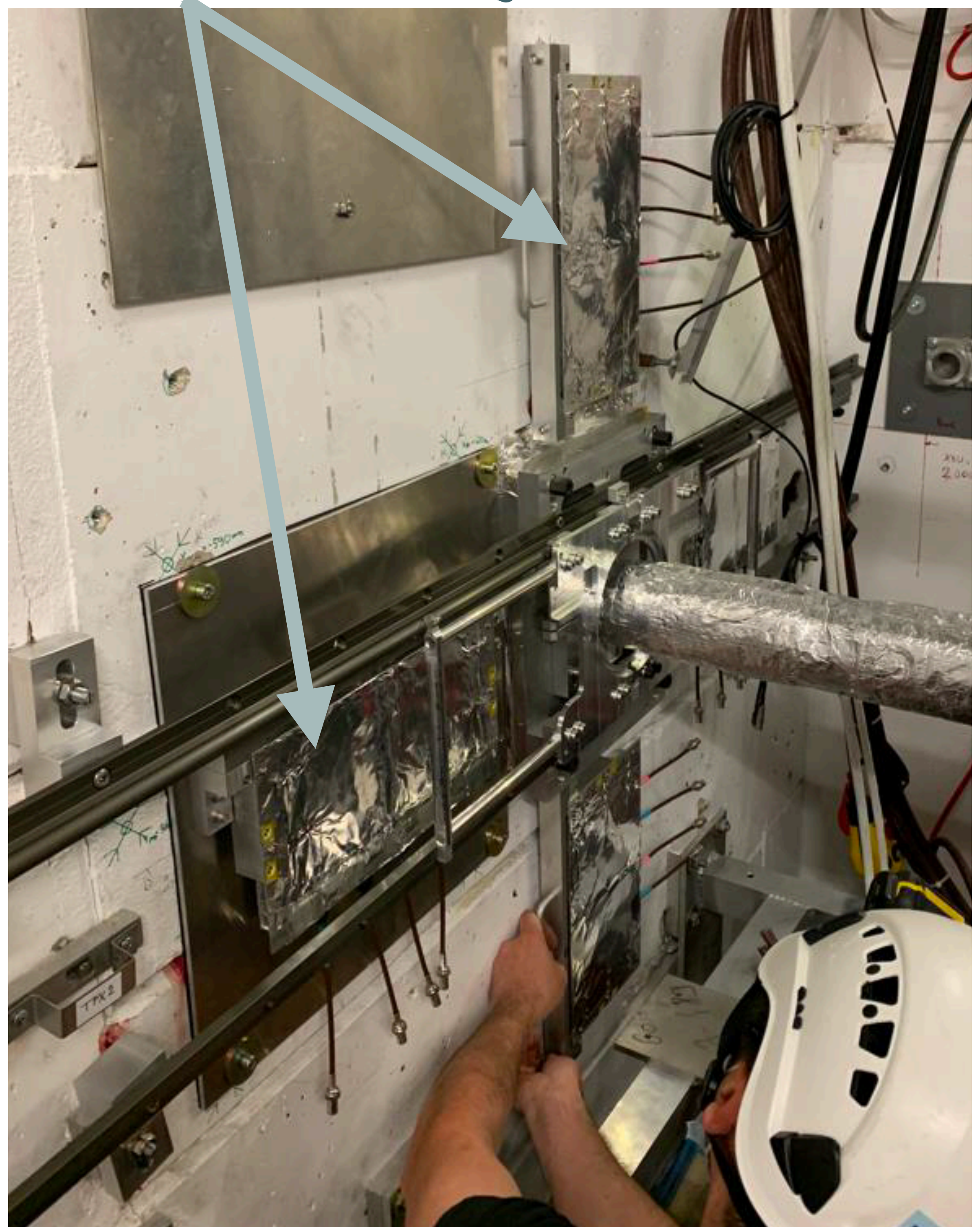


- Most of calorimeter **front-end boards** installed, are being connected
  - completion in September
- Calorimeter systems and services installed
  - Fibres, power supplies, PMT cables
  - Control units connected to the farm

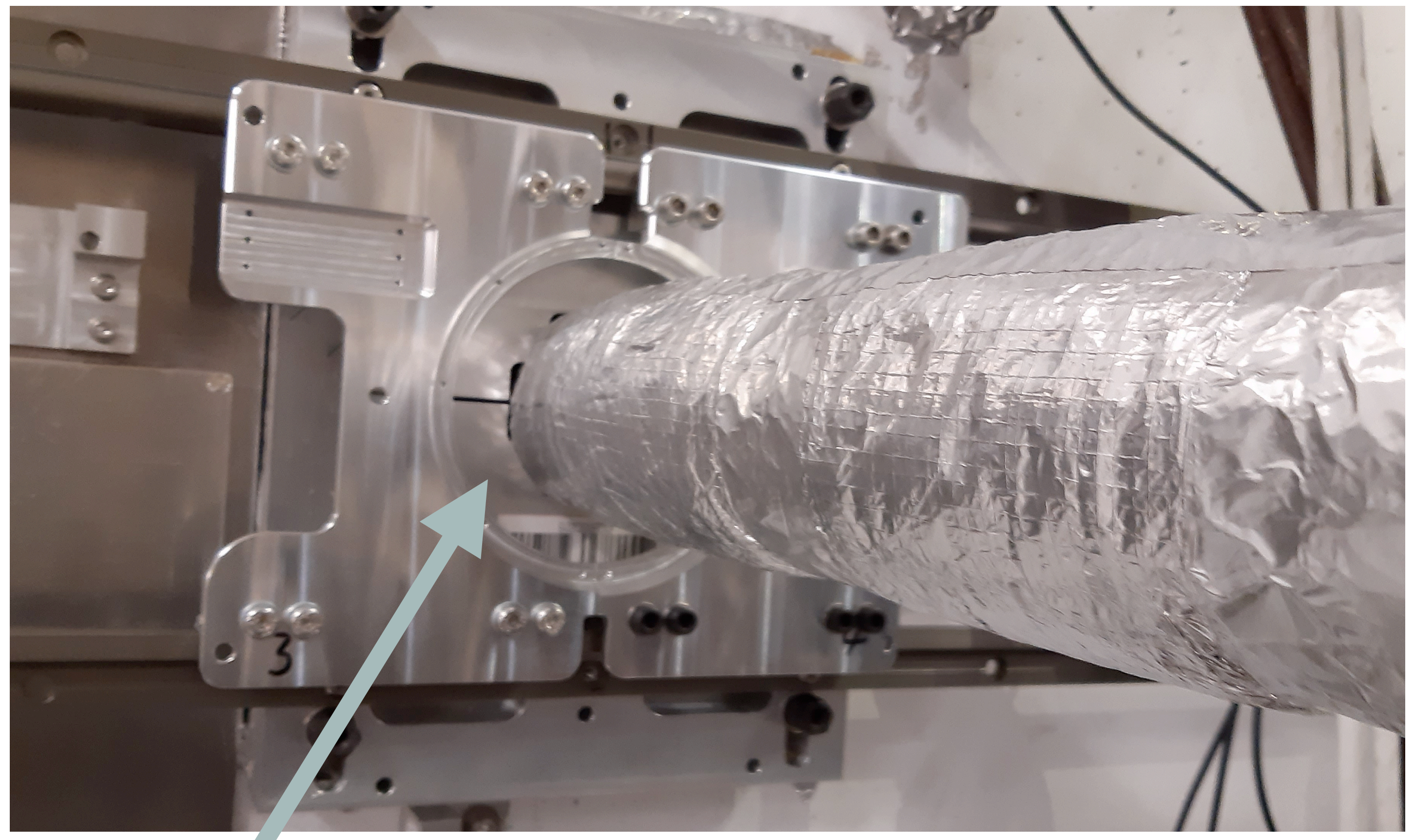
- Commissioning ongoing for the calorimeter & muon system

- **PLUME (luminosity detector):**
  support structure and cables installed;
  connectors in progress

- **RMS (Radiation Monitoring System):**
  measurement plates installed, electronics in preparation



- **BCM (Beam Conditions Monitor):**
  support rails and cables installed

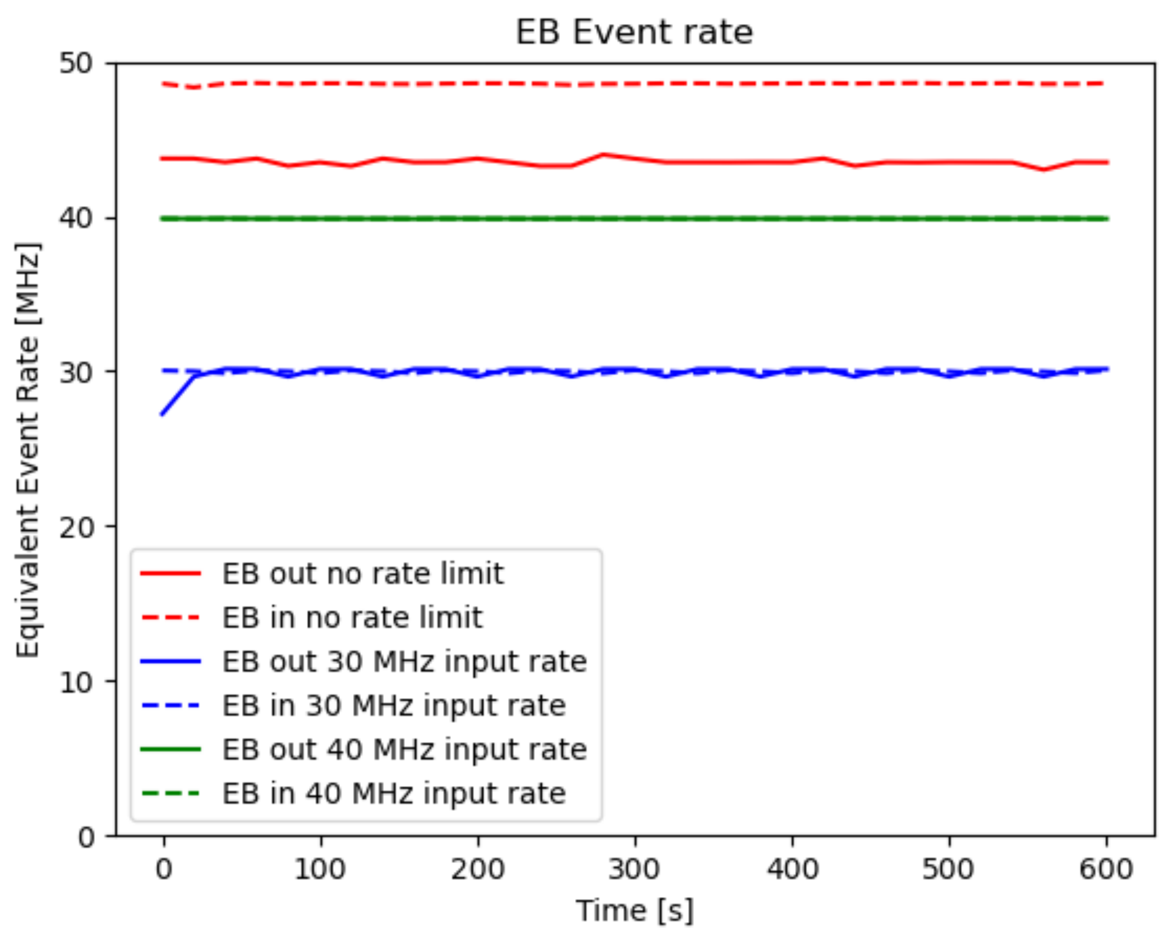


REAL-TIME ANALYSIS (TRIGGER)

- Successful Production Readiness Review for the **HLT1 GPU system**

Scope of the review:

- Is the HLT1 performance adequate on the candidate GPUs?
- Can 1 GPU per event builder server cope with the 40 MHz data rate?
- Choice of the "best" option for LHCb



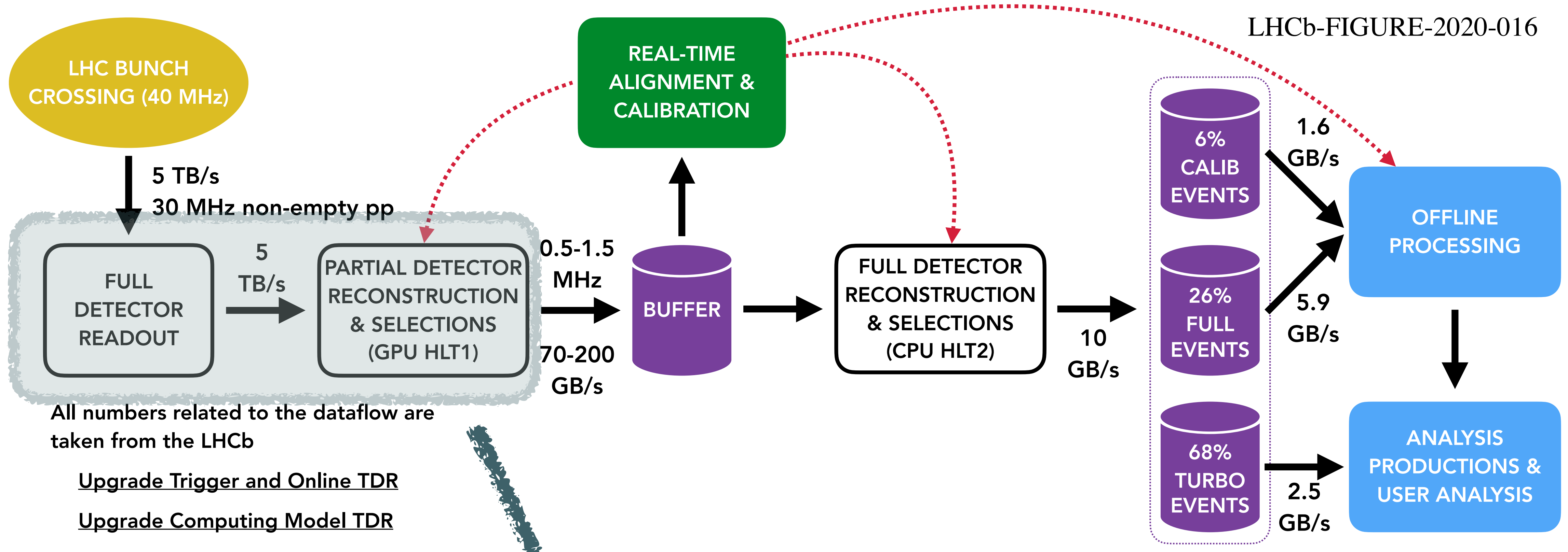
- purchase of the GPUs planned very soon

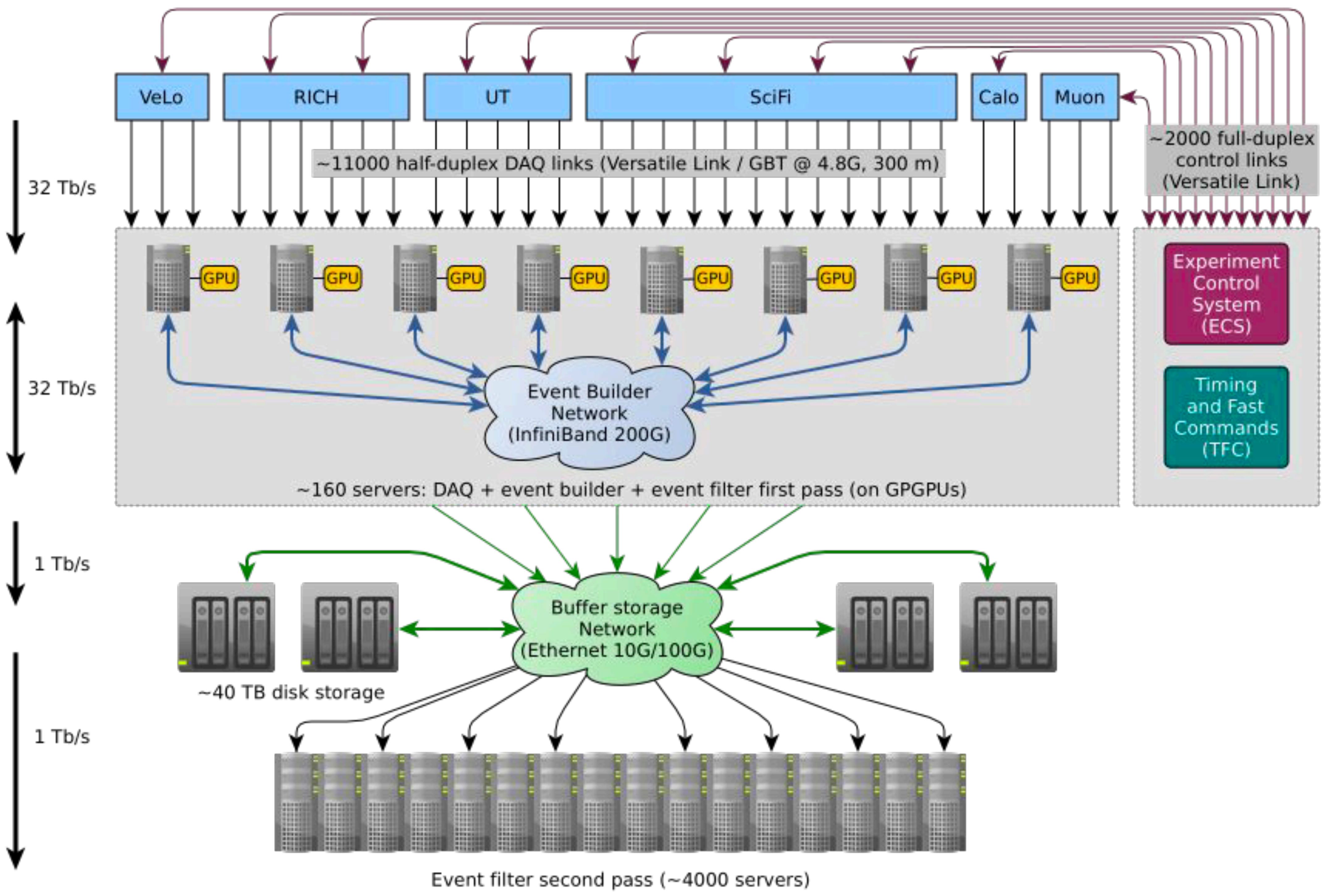
- **HLT2** throughput evolving with lots of physics selections added

	Throughput (Evt/s)	Impact
Reconstruction	181.9	---
B2OC (76 lines)	174.6	-4.02%
Hyperon (99 lines)	173.0	-4.90%
B2OC+Hyperon	165.5	-8.99%

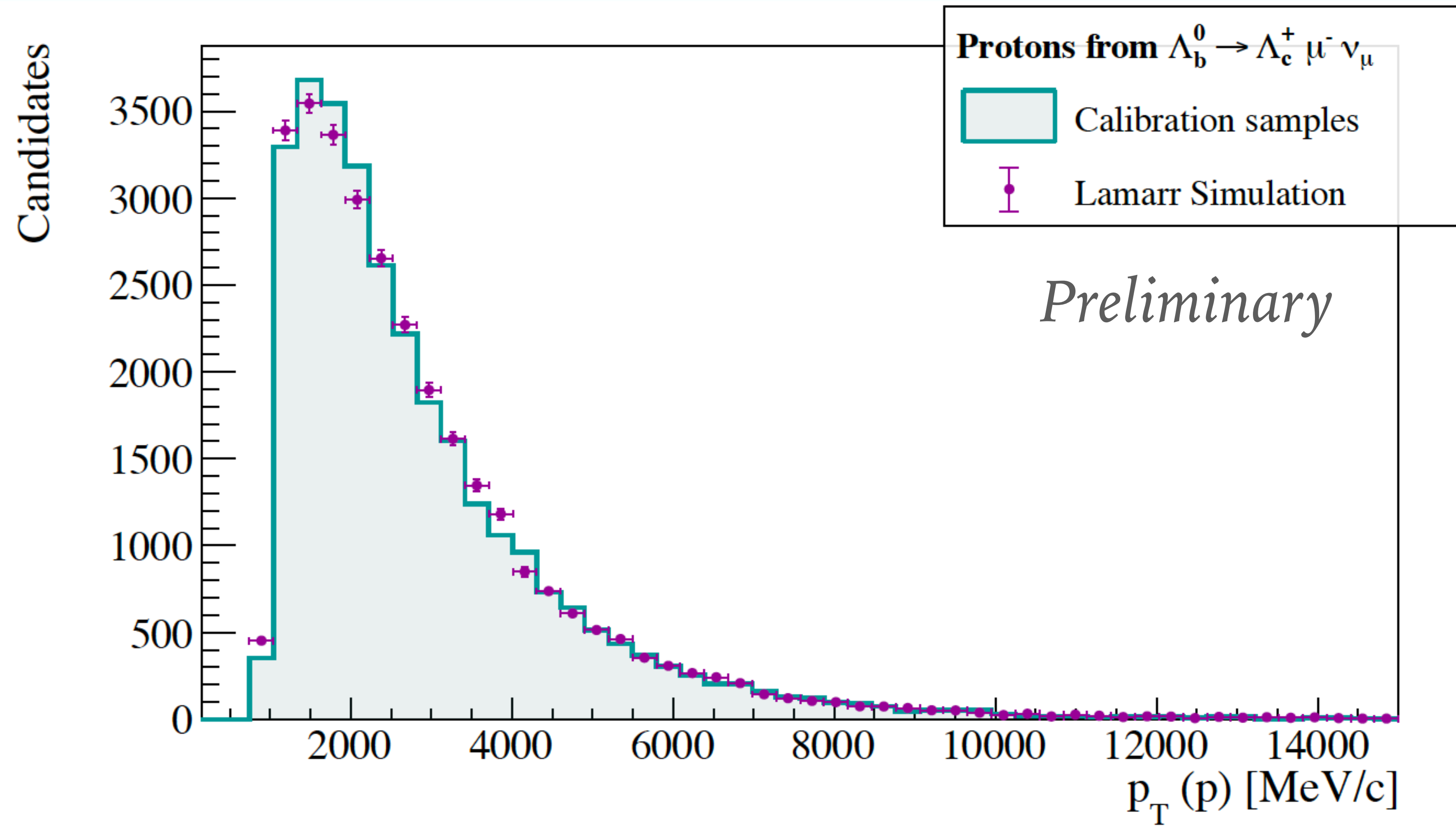
slowdown within acceptable margins

LHCb-FIGURE-2020-016

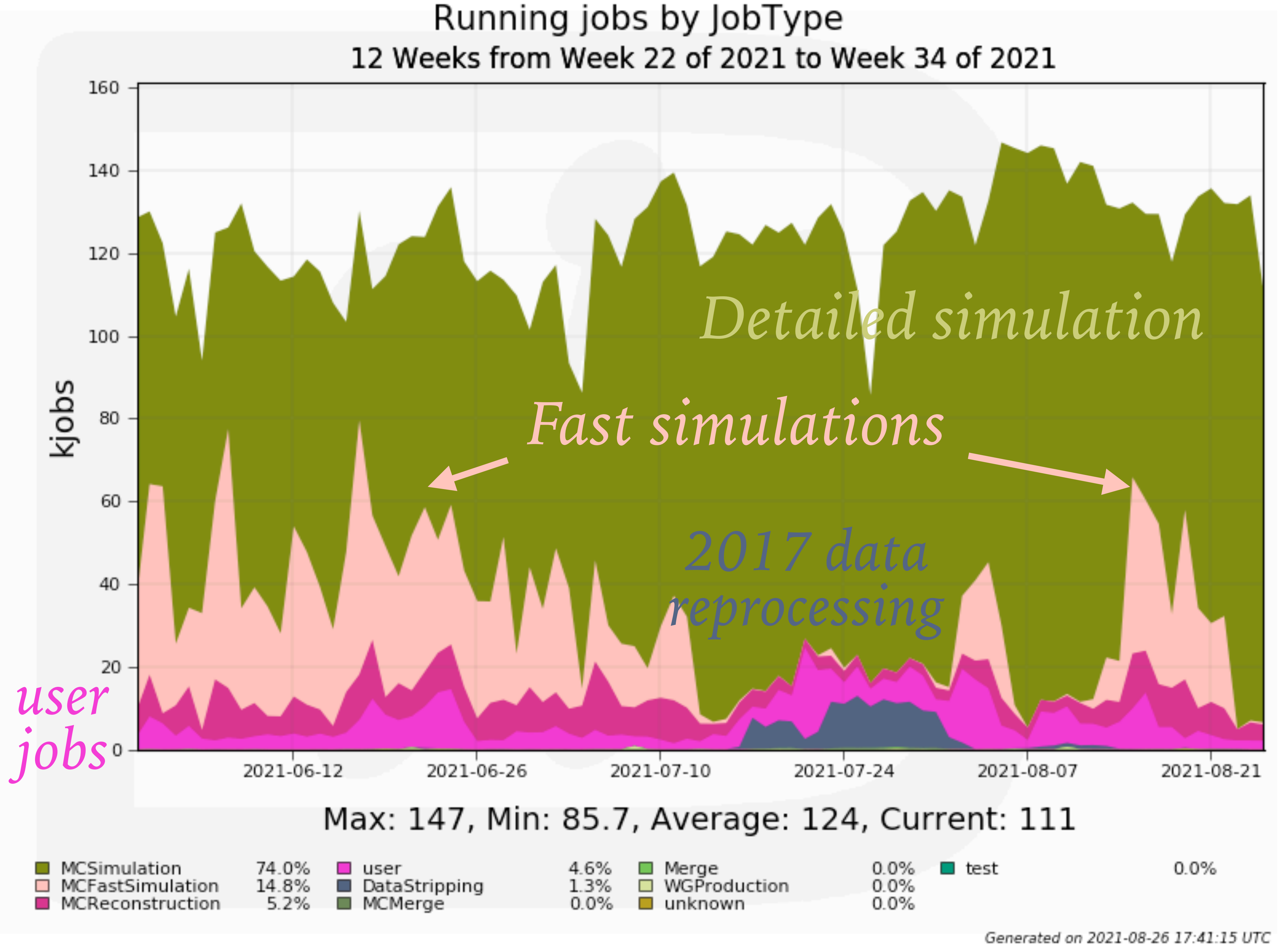




- **FEST (Full Experiment System Test) campaigns**
  - Joint effort of Online, RTA, DPA, Simulation teams; one-week commissioning event
  - **June**: successful campaign
    - **Idea:** send **simulated** data through the **parts** of our data processing chain
    - Tested HLT and offline processing (sprucing) chains
    - Work on monitoring
  - **October**FEST upcoming: plan to test the complete data processing chain
- **Fast simulation developments:** testing of the simulation based on simple parametrisations and machine learning (Lamarr project)
  - achievable speedup up to 1000x compared to nominal detailed simulation



- Reprocessing of **Run 2** data: 2017 done, 2018 and 2016 in preparation
  - main purpose: adding new physics channels to be studied



- Addressing the challenges of offline processing and analysis with **massive datasets for Run 3**
- Centralised skimming of data selected by inclusive triggers: "sprucing"
- Rethinking the **analysis workflow**:
  - Centralised analysis tuple productions
  - Exploiting recent ROOT developments
  - Efficient **analysis preservation**
- Preparation of **Open Data release**
- R&D on **innovative analysis techniques**, for example promoting GPUs in physics analyses

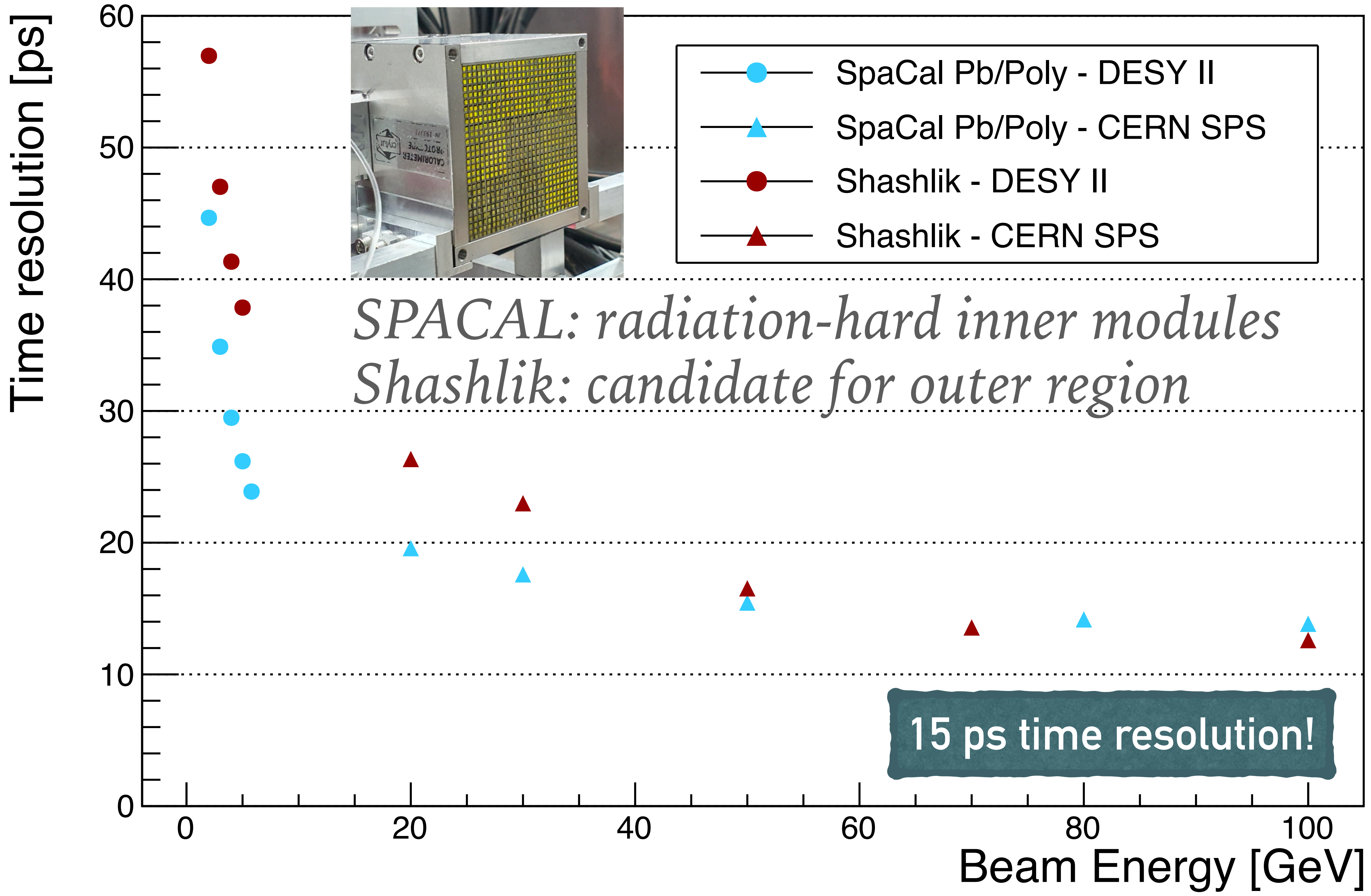
- Draft of the Upgrade II Framework Technical Design Report handed to LHCC this week
  - outlines options for detector design and enabling our physics programme

our target: ~50 fb^{-1} per year

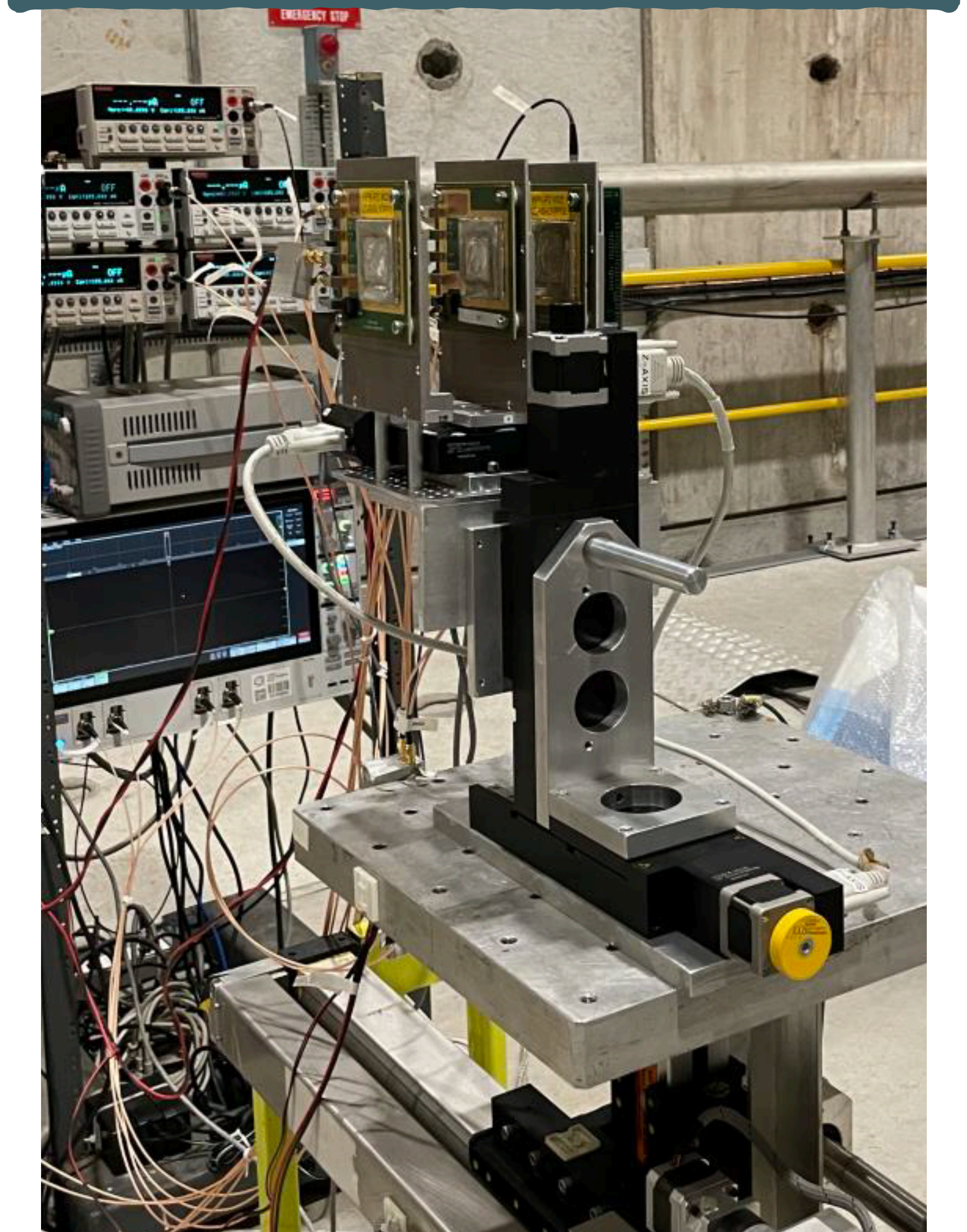
- Recent test beams of detector prototypes for VELO, RICH, calorimeter and tracker

Thanks to our accelerator colleagues for the excellent performance of the SPS!

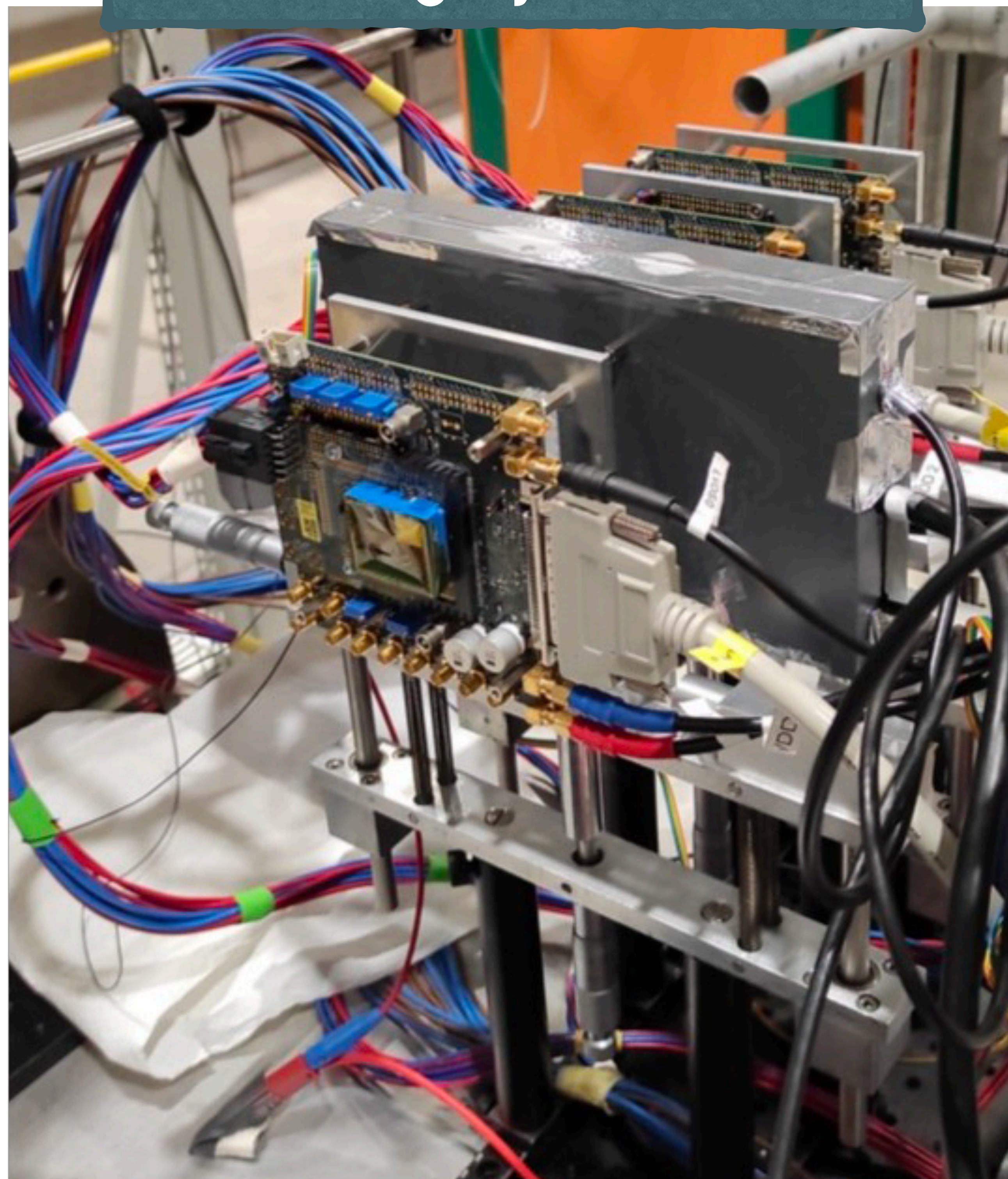
Time resolution study for the ECAL prototypes



Test of timing sensors for VELO vs incidence angle

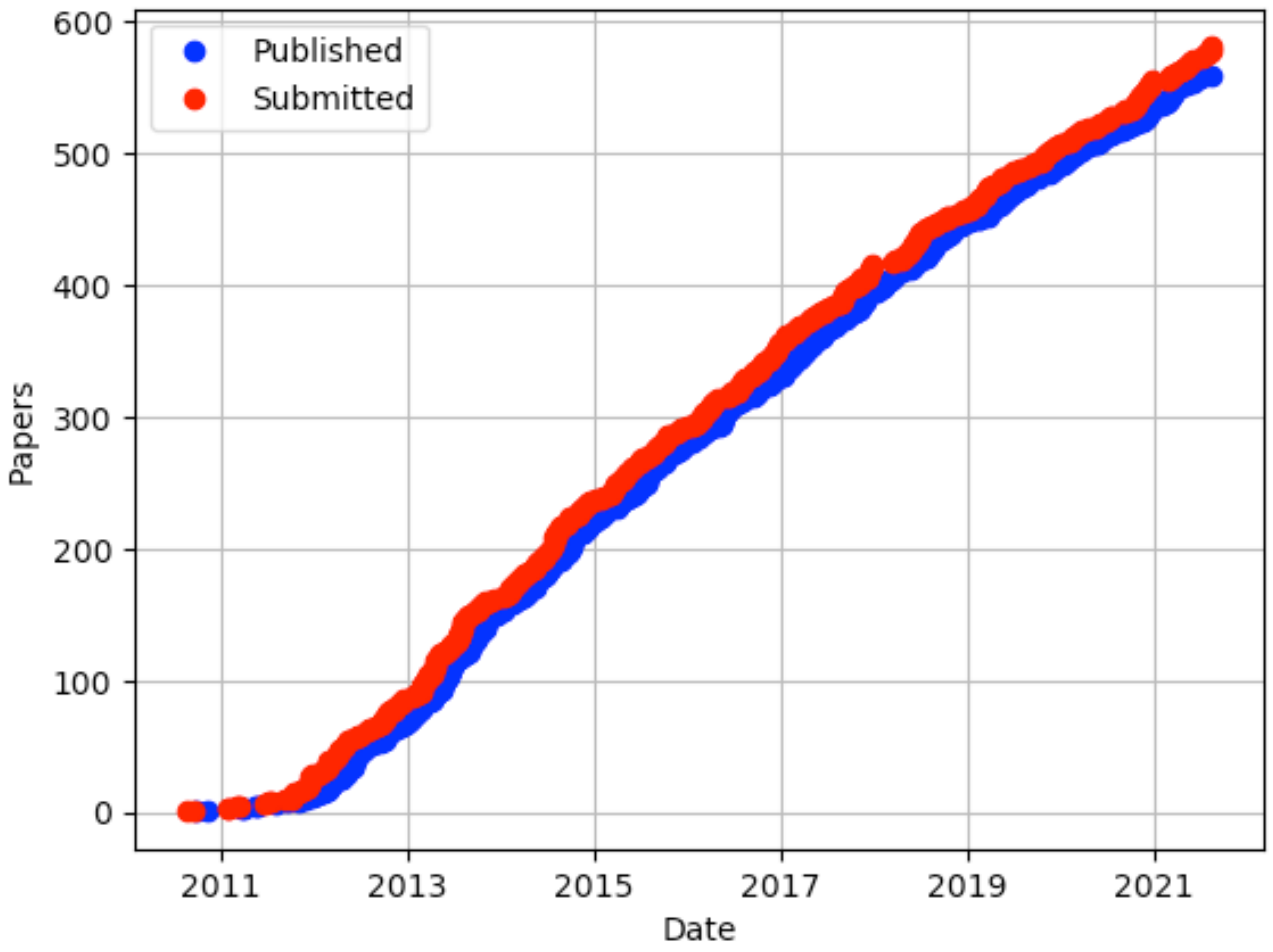


Silicon pixels (HV-MAPS) for Mighty Tracker

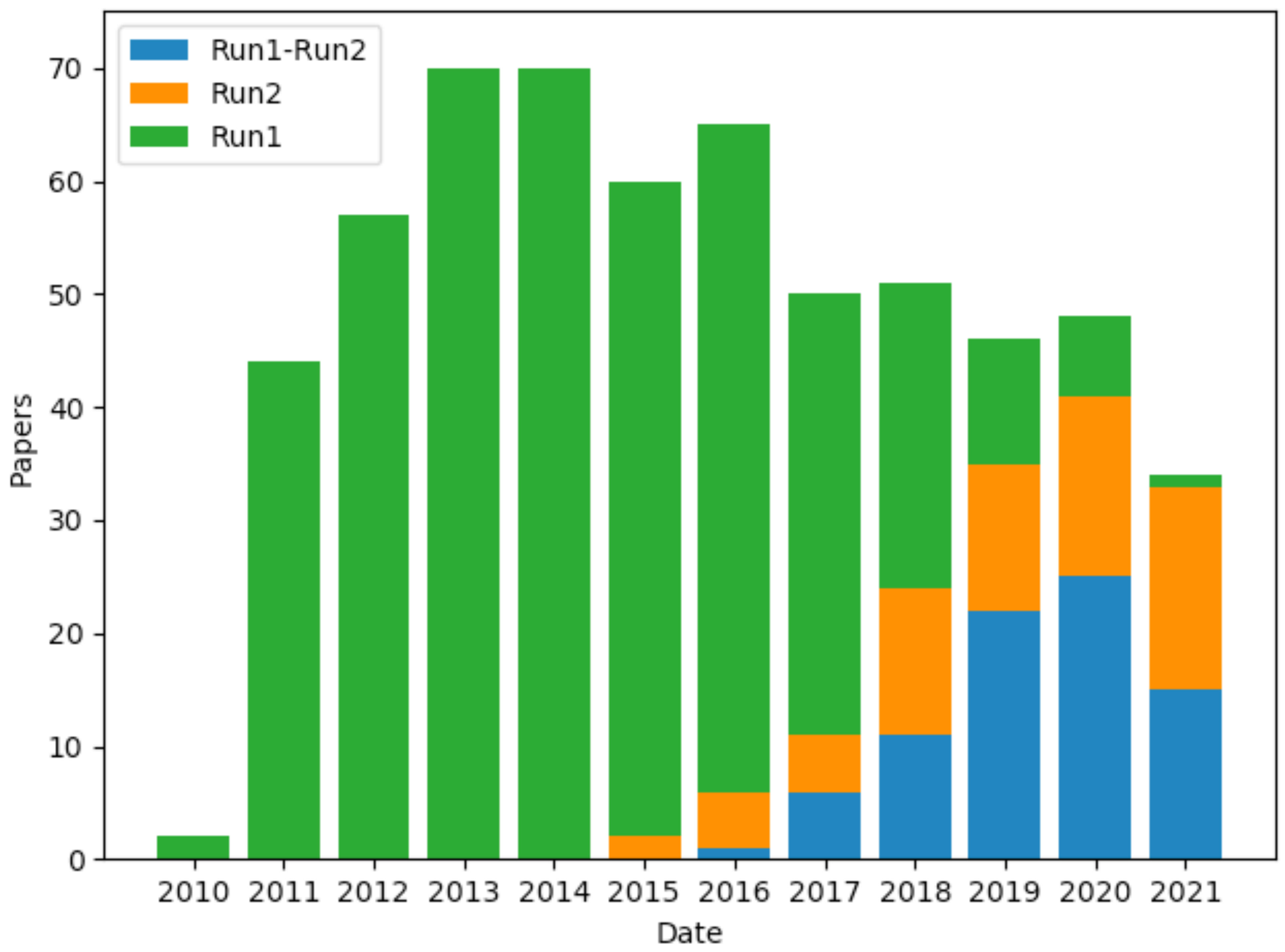


- Legacy measurements with the complete Run 2 (+ Run 1) LHCb dataset

LHCb physics publications



LHCb physics publications per year



Papers submitted since the last LHCC

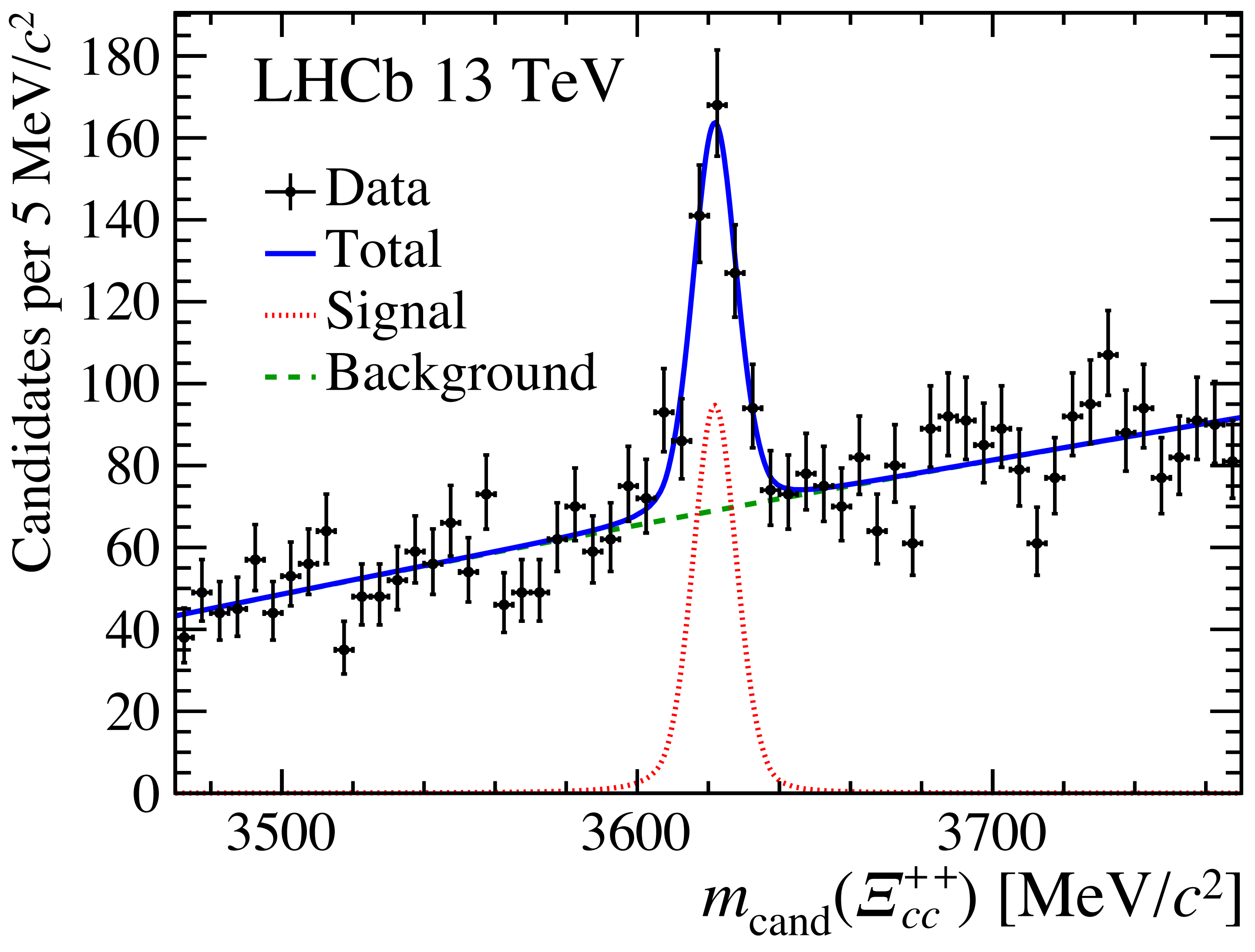
- [PAPER-2021-009] Observation of the mass difference between neutral charm-meson eigenstates
- [PAPER-2021-012] Observation of excited Ω_c^0 baryons in Ω_b^- decays
- [PAPER-2021-013] Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}} = 5$ TeV
- [PAPER-2021-010] Measurement of prompt charged-particle production in pp collisions at $\sqrt{s} = 13$ TeV
- [PAPER-2021-016] Observation of a $\Lambda_b - \overline{\Lambda_b}$ production asymmetry in proton-proton collisions at $\sqrt{s} = 7, 8$ TeV
- [PAPER-2021-022] Angular analysis of the rare decay $B_s^0 \to \phi\mu^+\mu^-$
- [PAPER-2021-018] Evidence for a new structure in the $J/\psi p$ and $J/\psi\bar{p}$ systems in $B_s^0 \to J/\psi p\bar{p}$ decays
- [PAPER-2020-043] Study of J/ψ photo-production in lead-lead peripheral collisions at $\sqrt{s_{NN}} = 5$ TeV
- [PAPER-2021-017] Search for the radiative $\Xi_b^- \to \Xi^-\gamma$ decay
- [PAPER-2021-008] Measurement of the $B_s^0 \to \mu^+\mu^-$ decay properties and search for the $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-\gamma$ decays
- [PAPER-2021-007] Analysis of neutral B-meson decays into two muons
- [PAPER-2021-015] Measurement of the nuclear modification factor and prompt charged particle production in pPb and pp collisions at $\sqrt{s_{NN}} = 5$ TeV

Preliminary since the last LHCC

- [PAPER-2021-019] Search for the doubly charmed baryon Ξ_{cc}^+ in $\Xi_c^+\pi^+\pi^-$ final state
- [PAPER-2021-020] Measurement of J/ψ production cross-section in pp collisions at $\sqrt{s} = 5$ TeV
- [PAPER-2021-021] Measurement of the lifetimes of promptly produced Ω_c^0 and Ξ_c^0 baryons
- [PAPER-2021-023] Updated search for B_c^+ decays to two charm mesons
- [PAPER-2021-024] Measurement of the W boson mass
- [PAPER-2021-025] Observation of two new excited Ξ_b^0 states decaying to $\Lambda_b^0 K^-\pi^+$
- [PAPER-2021-026] Measurement of chic1(3872) production in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV
- [PAPER-2021-027] Observation of the suppressed $\Lambda_b^0 \to D^0 pK^-$ decay with $D^0 \to K^+\pi^-$ and measurement if its CP asymmetry
- [PAPER-2021-028] Search for exotic massive long-lived particles decaying semileptonically
- [PAPER-2021-029] Study of Z bosons produced in association with charm in the forward region
- [PAPER-2021-030] Measurement of the photon polarization in $\Lambda_b^0 \to \Lambda\gamma$ decays
- [PAPER-2021-031] Observation of an exotic narrow doubly charmed tetraquark
- [PAPER-2021-032] Study of the doubly charmed tetraquark T_{cc}^+
- [PAPER-2021-033] Simultaneous determination of CKM angle γ and charm mixing parameters

- States with two charm quarks (rather than a $c\bar{c}$ pair):

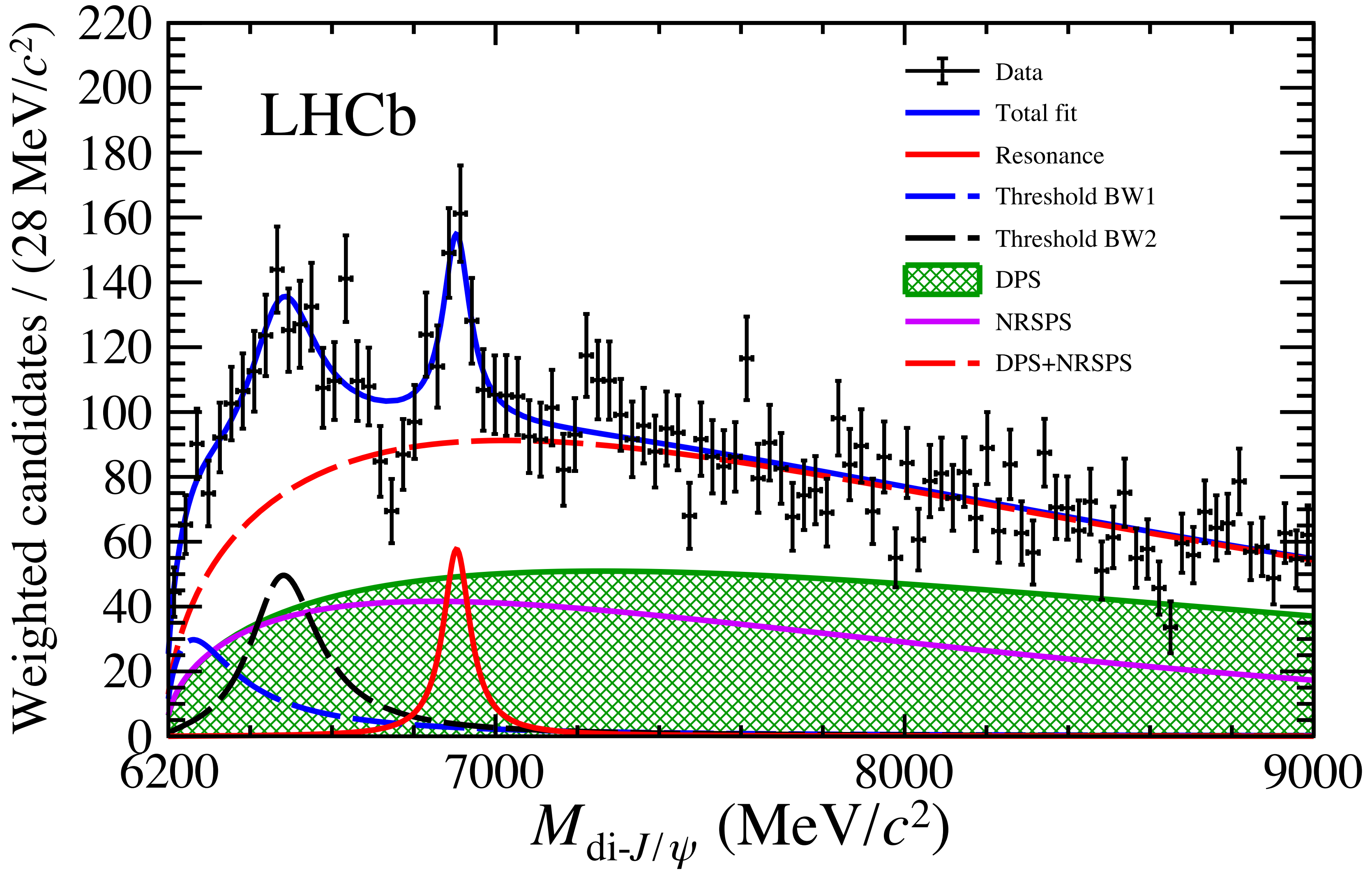
2017



$\Xi_{cc}^{++}\,(ccu)$

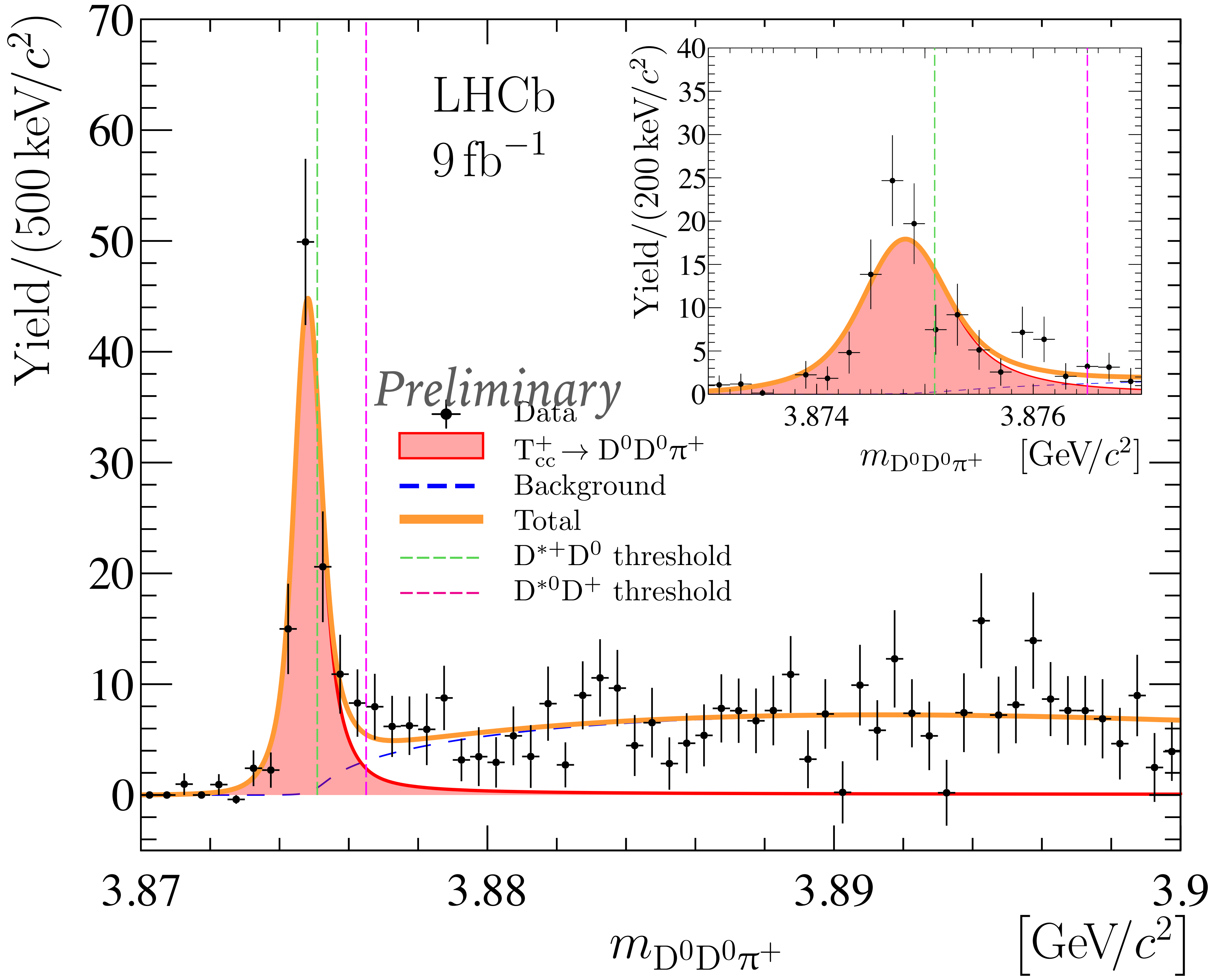
also: searches for Ξ_{cc}^{+} (ccd)

2020

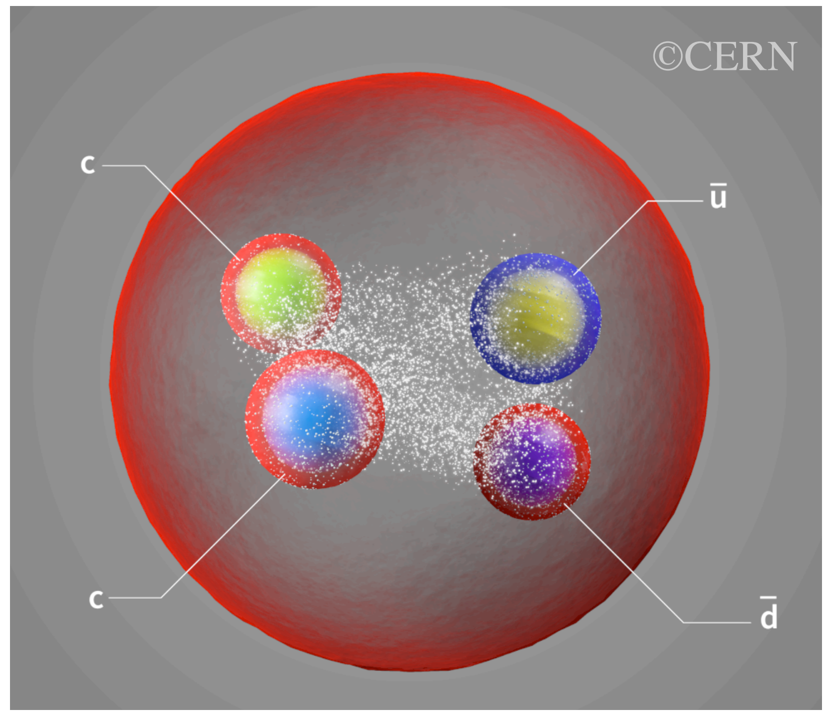


structure in $m(J/\psi J/\psi)$: $(cc\bar{c}\bar{c})$

2021: NEW



$T_{cc}^{+}\,(cc\bar{u}\bar{d})$



- Now: Observation of a narrow peak in $m(D^0D^0\pi^+)$ at the threshold
  - manifestly exotic state: $cc\bar{u}\bar{d}$; expected isospin 0 and $J^P = 1^+$

- Mass measurement: relativistic Breit-Wigner lineshape gives $\delta m \equiv m_{T_{cc}^{+}} - (m_{D^{*+}} + m_{D^0}) = -273 \pm 61(\text{stat}) \pm 5(\text{syst})^{+11}_{-14}(J^P)\ \text{keV}/c^2$;

  mass ~3874.8 MeV/c^2

  - consistent with some of theoretical predictions
- **width** $\Gamma_{\text{BW}} = 410 \pm 165(\text{stat}) \pm 43(\text{syst})^{+18}_{-38}(J^P)\ \text{keV}$ the smallest BW width of any known exotic state
- A more physical lineshape model explored as well, in upcoming [PAPER-2021-032]
  - A plethora of other studies: pole position, multiplicity dependence, characteristic size, etc: stay tuned for our papers!
- This result likely implies existence of a **weakly**-decaying $bb\bar{u}\bar{d}$ state (a tetraquark flying some mm before decay?)

More details in our CERN-LHC seminar on 14th September.

- A lot of interest in the spectrum of (excited) Ξ_b baryons:
  - *2012, CMS*: $\Xi_b(5945)^0$
  - *2014, LHCb*: $\Xi_b'(5935)^-$ *and* $\Xi_b(5955)^-$
  - *2018, LHCb*: $\Xi_b(6227)^-$
  - *2020, LHCb*: $\Xi_b(6227)^0$
  - *2021, CMS*: $\Xi_b(6100)^-$

$\Xi_b^0 = (usb)$

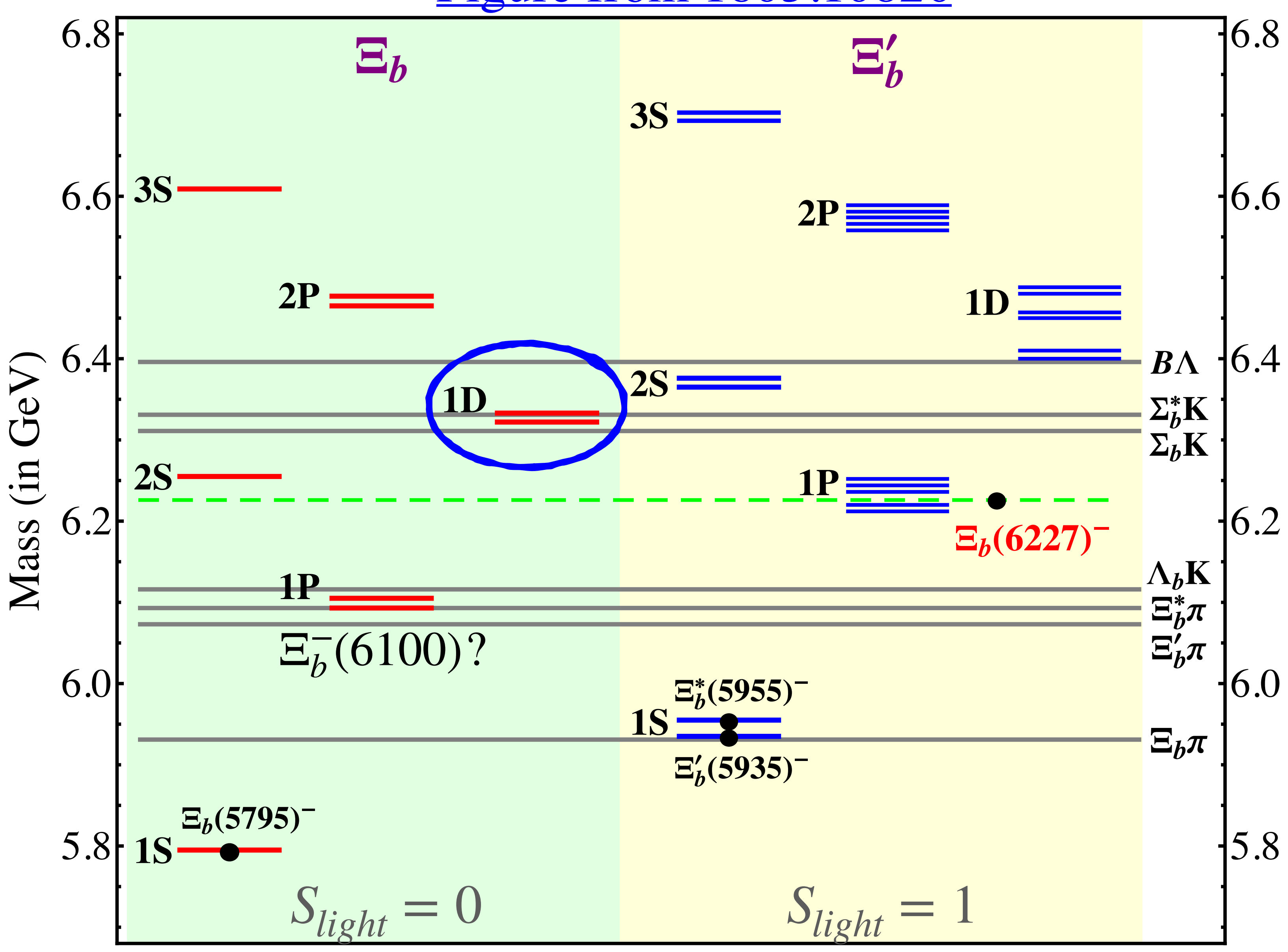
$\Xi_b^- = (dsb)$

- Now, search for 1D states: predicted† to decay to $\Sigma_b^{(*)}K$

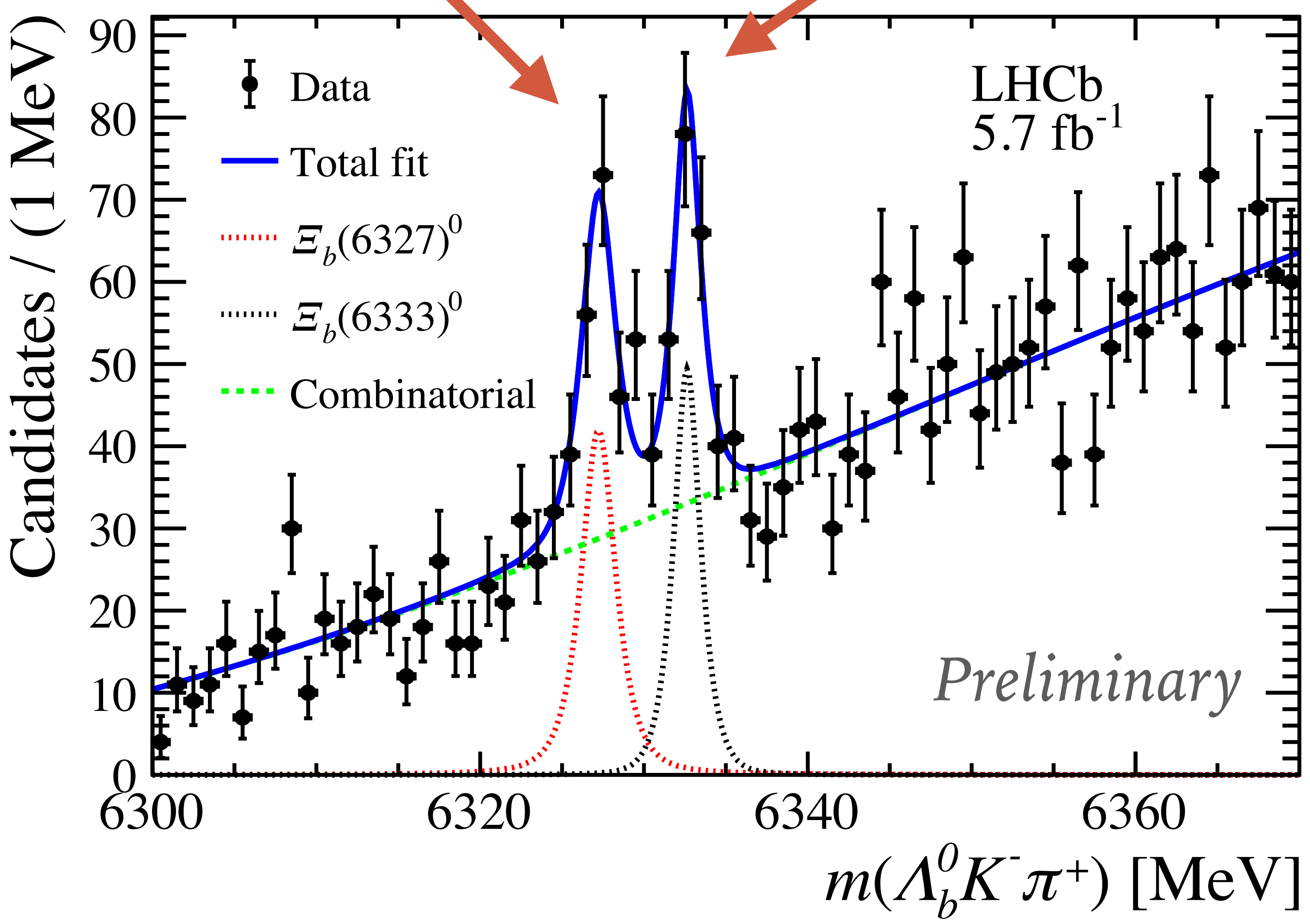
†1803.00364; 1910.03318

- Inspect the $\Lambda_b^0 K^- \pi^+$ spectrum:

Figure from 1805.10826



$\Xi_b(6327)^0$ $\Xi_b(6333)^0$

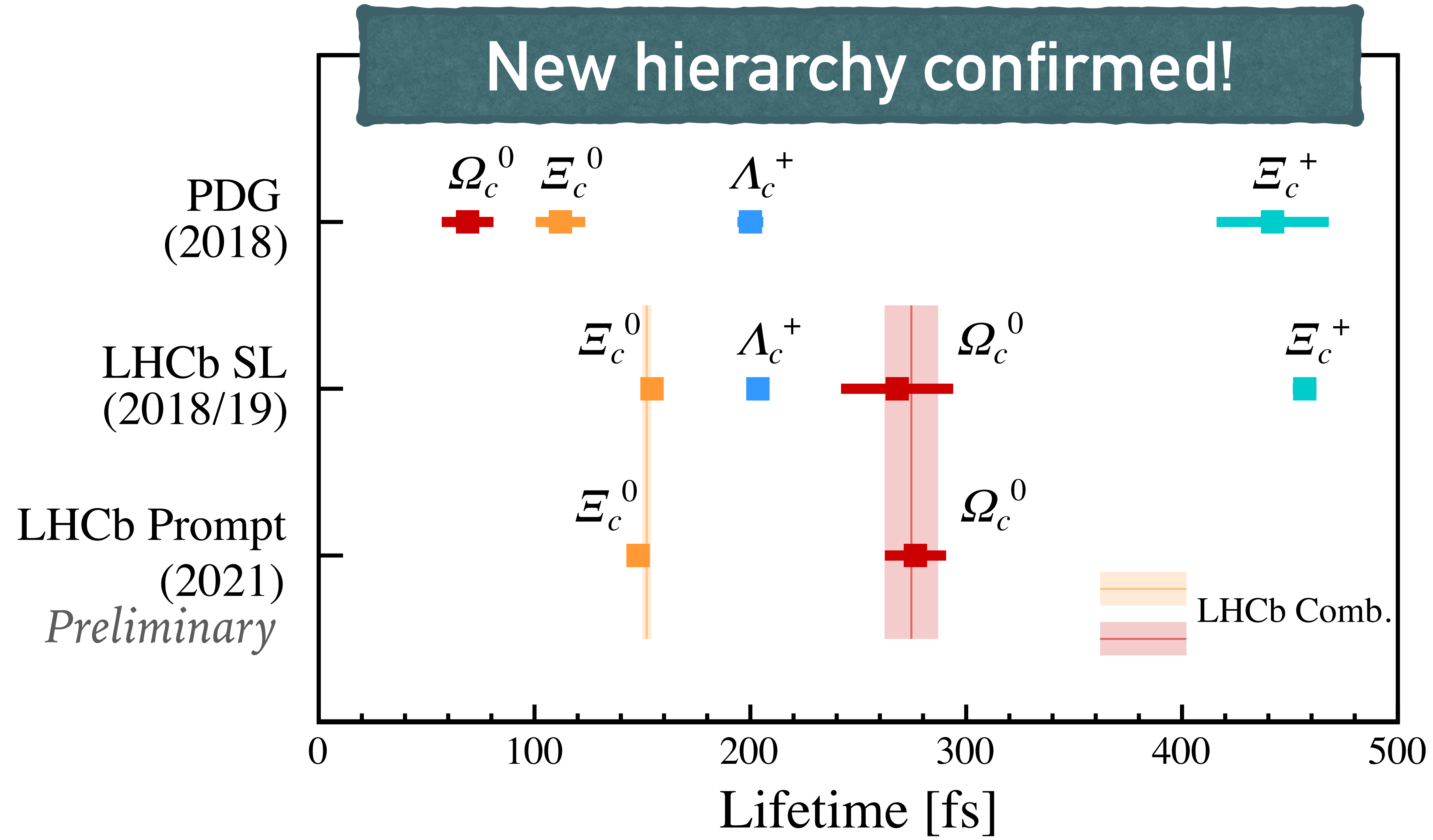


Two new states observed,

matching expectations of 1D states.

$$m_{\Xi_b(6327)^0} = 6327.28^{+0.23}_{-0.21} \pm 0.08 \pm 0.24\,\text{MeV},$$
$$m_{\Xi_b(6333)^0} = 6332.69^{+0.17}_{-0.18} \pm 0.03 \pm 0.22\,\text{MeV},$$
$$\Gamma_{\Xi_b(6327)^0} < 2.20\ (2.56)\ \text{MeV at 90\% (95\%) CL},$$
$$\Gamma_{\Xi_b(6333)^0} < 1.55\ (1.85)\ \text{MeV at 90\% (95\%) CL},$$

- PDG'2018: $\tau(\Xi_c^+) > \tau(\Lambda_c^+) > \tau(\Xi_c^0) > \tau(\Omega_c^0)$; $\tau(\Omega_c^0) = 69 \pm 12$ fs (fixed-target data)
  (usc) (udc) (dsc) (ssc)
- LHCb, 2018-2019: measurement of lifetimes of charm baryons produced in **semileptonic** decays of beauty baryons PRL 121 (2018) 092003; PRD 100 (2019) 032001
  - Lifetimes of Ω_c^0 and Ξ_c^0 changed significantly, **new hierarchy**: $\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$; $\tau(\Omega_c^0)$ **four times larger than the world average**
- **Now: we measure the lifetimes of Ω_c^0 and Ξ_c^0 with prompt production**
  - larger signal, but higher backgrounds
  - relative measurement: $\Xi_c^0, \Omega_c^0 \to pK^-K^-\pi^+$ vs $D^0 \to K^+K^-\pi^+\pi^-$

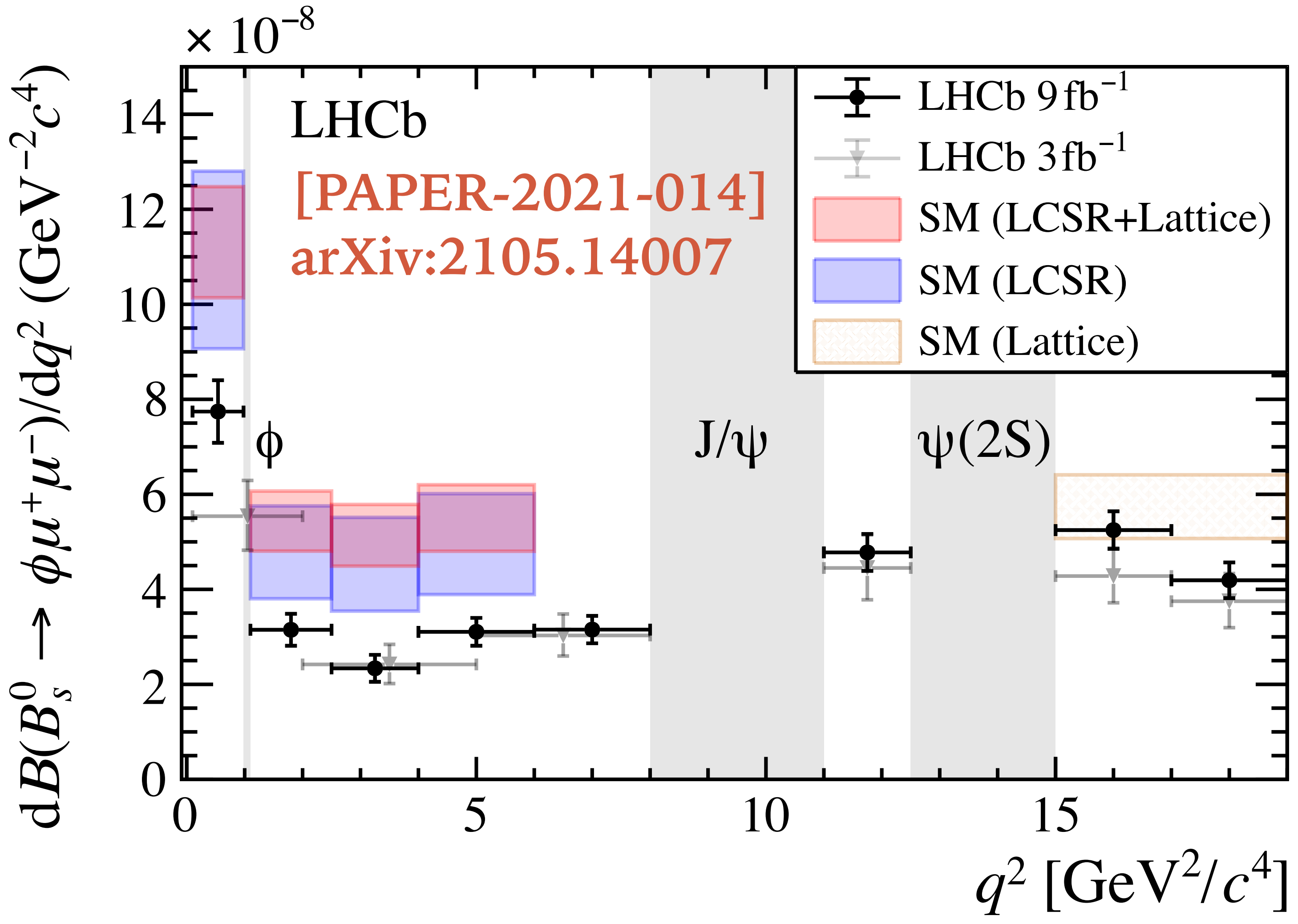


Average of LHCb results:

$\tau(\Omega_c^0) = 274.5 \pm 12.4$ fs

$\tau(\Xi_c^0) = 152.0 \pm 2.0$ fs

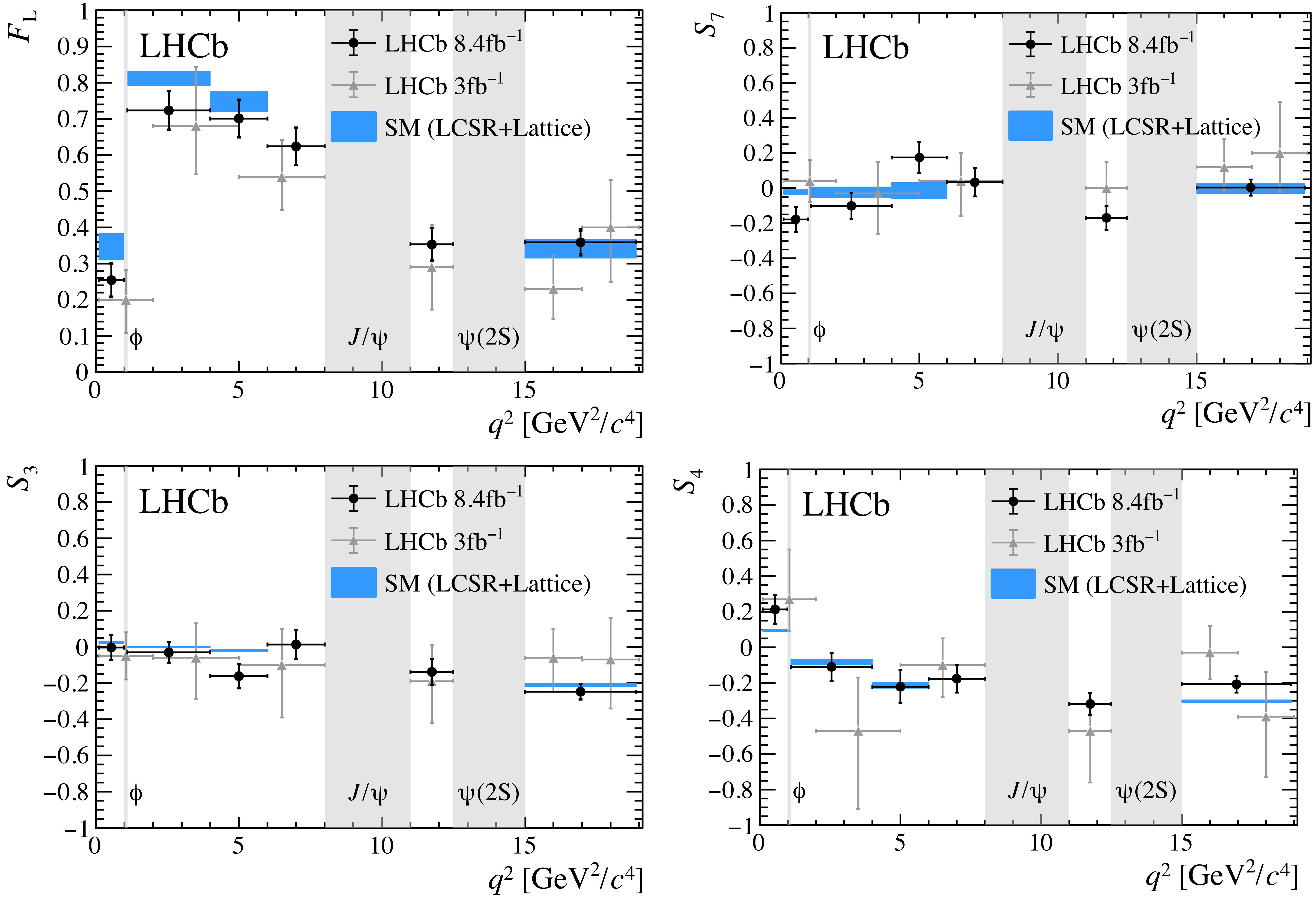
- $B_s^0 \to \phi\mu^+\mu^-$ decay:



Differential BF
3.6σ below SM (lattice+LCSR)
1.8σ below SM (LCSR)

Untagged analysis – no separation of $B_s^0/\overline{B_s^0}$ – no observables like P_5' here (which show anomalies in $B^0 \to K^{*0}\mu^+\mu^-$)

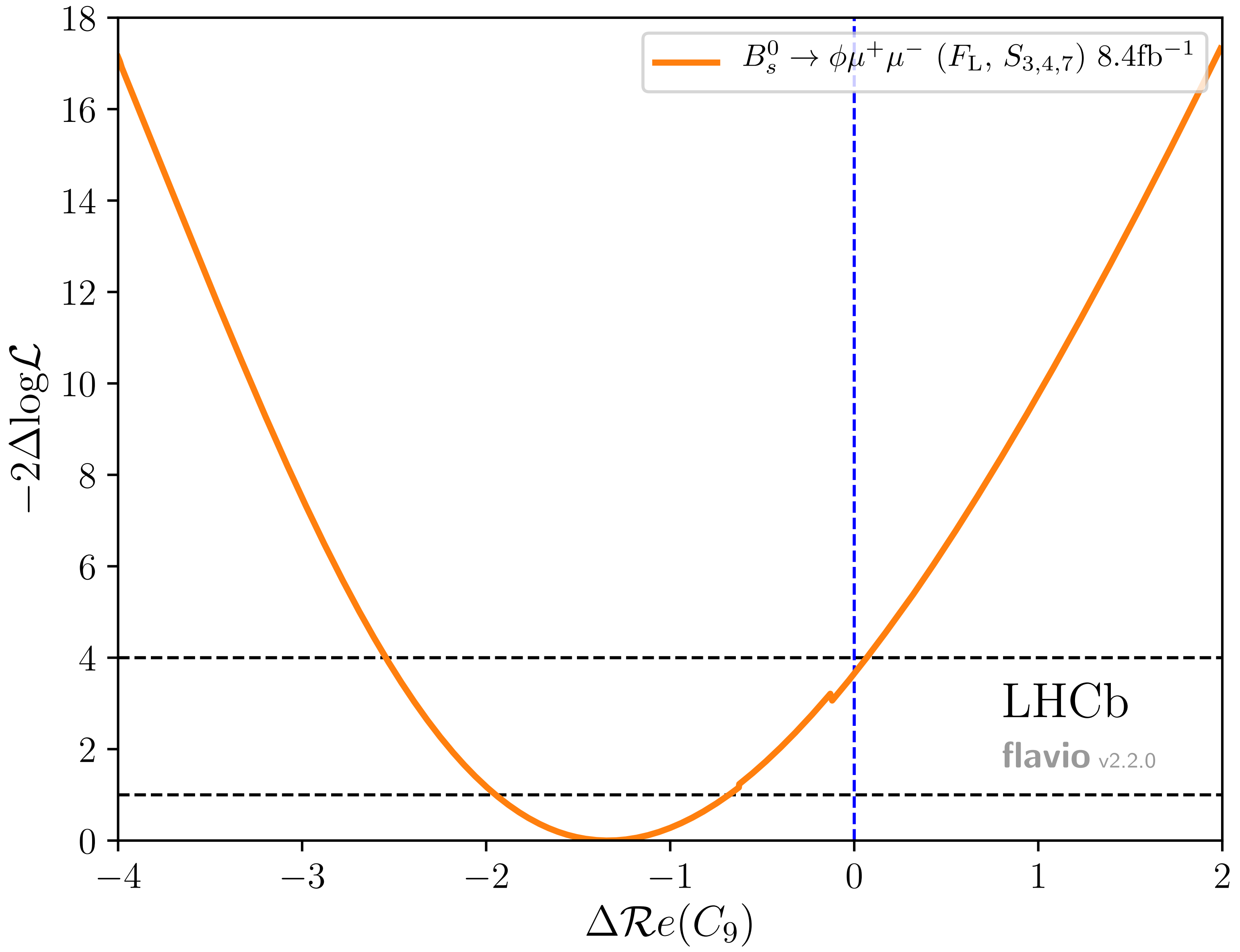
***Angular analysis** performed with **untagged** B_s^0*



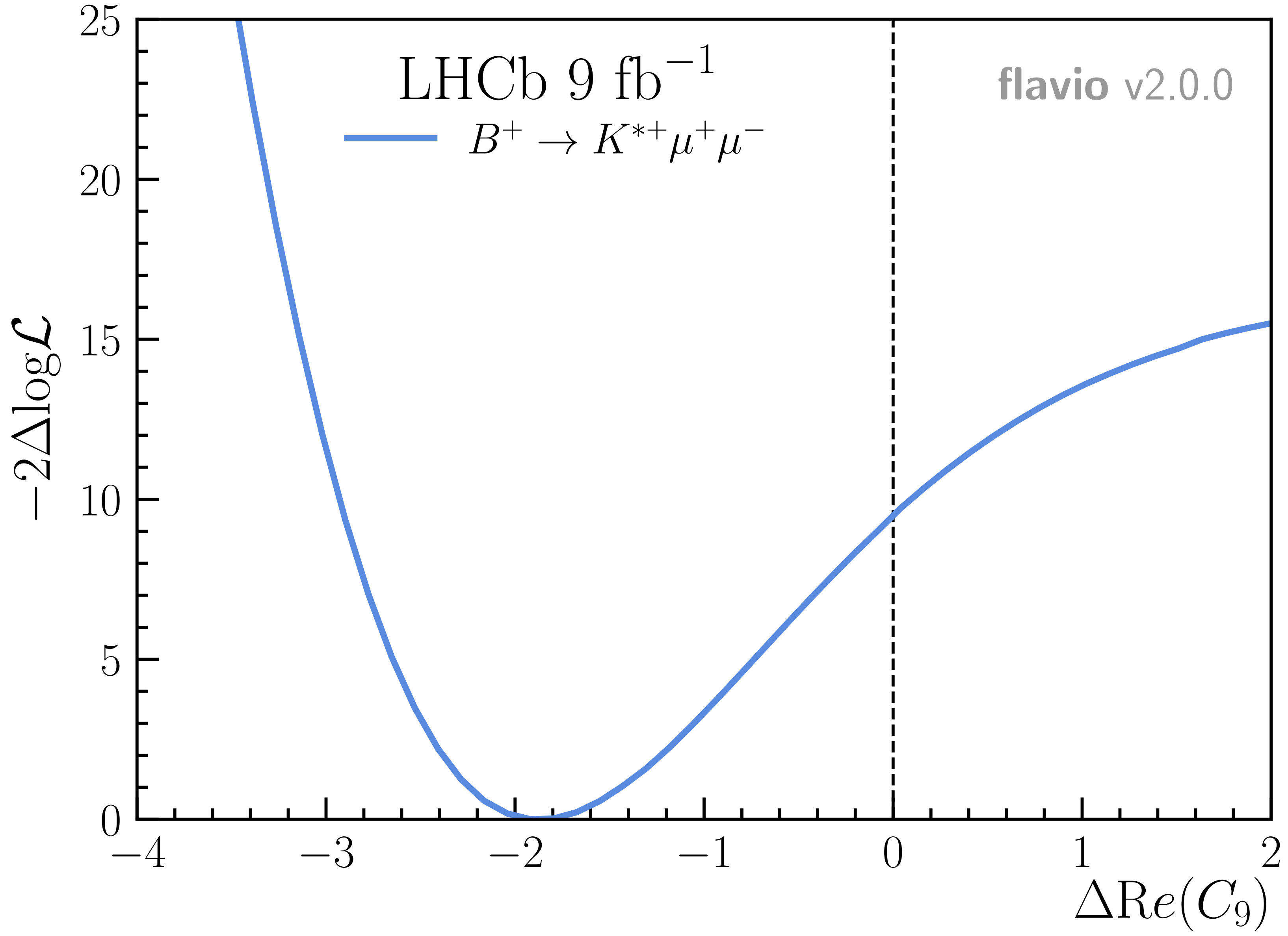
Results compatible with SM, but some deviation in F_L: same as in $B \to K^*\mu^+\mu^-$?

- Interpretation of recent LHCb results in terms of the Wilson coefficient C_9 (vector coupling in the EFT)
- The three recent LHCb angular analyses **consistently** favour a negative shift in $\Delta Re(C_9) \equiv Re(C_9) - Re(C_9^{SM})$:

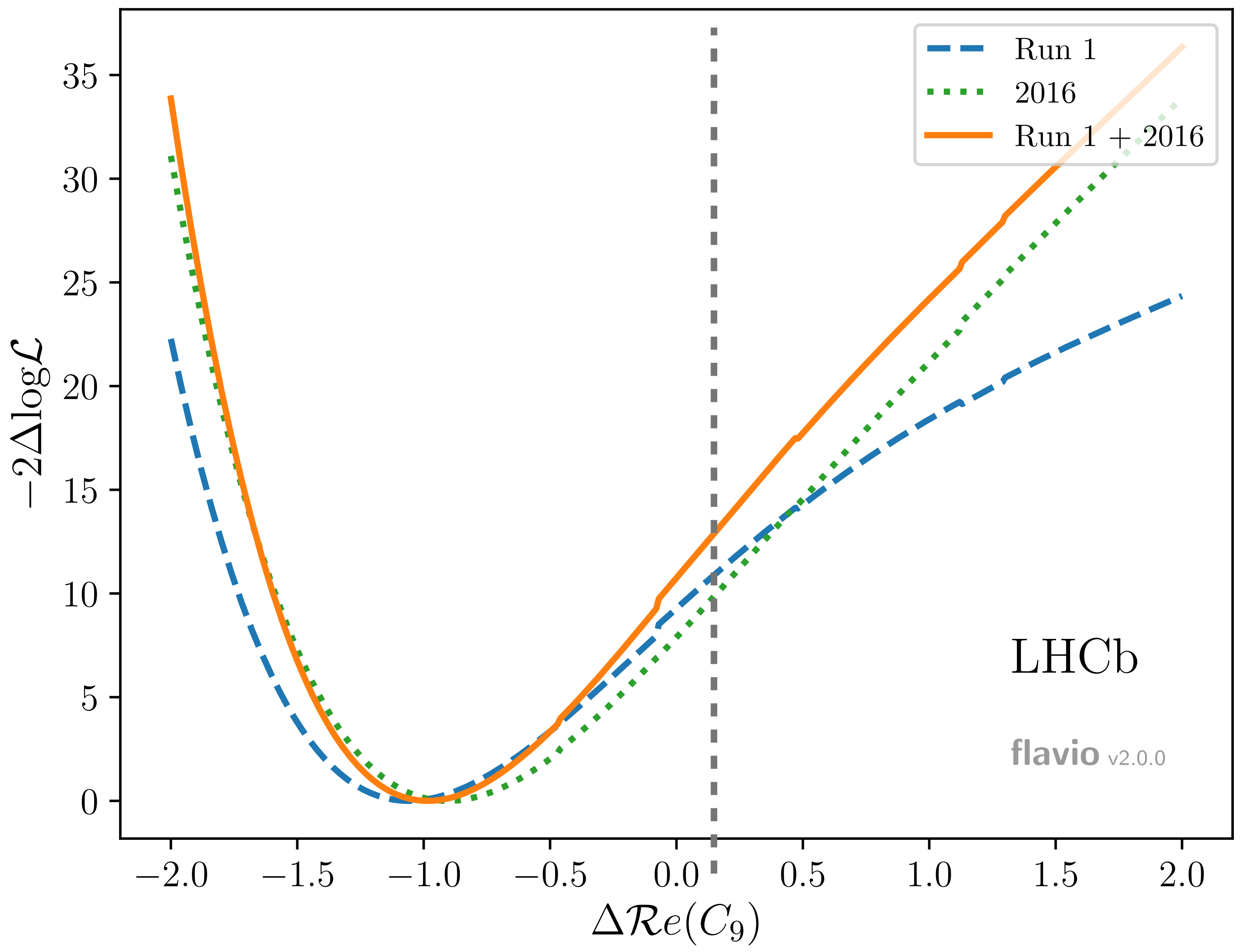
$B_s^0 \to \phi\mu^+\mu^-$
[PAPER-2021-014]



$B^+ \to K^{*+}\mu^+\mu^-$
[PAPER-2020-041] / PRL 126 (2021) 161802



$B^0 \to K^{*0}\mu^+\mu^-$
[PAPER-2020-002] / PRL 125 (2020) 011802



These and other results will be discussed at the LHC Flavour Anomaly workshop on 20 October.

- Simultaneous combination of LHCb results in UT angle γ and D^0 mixing parameters – for the first time!

Combination of Run1+2 results (some are still Run1)

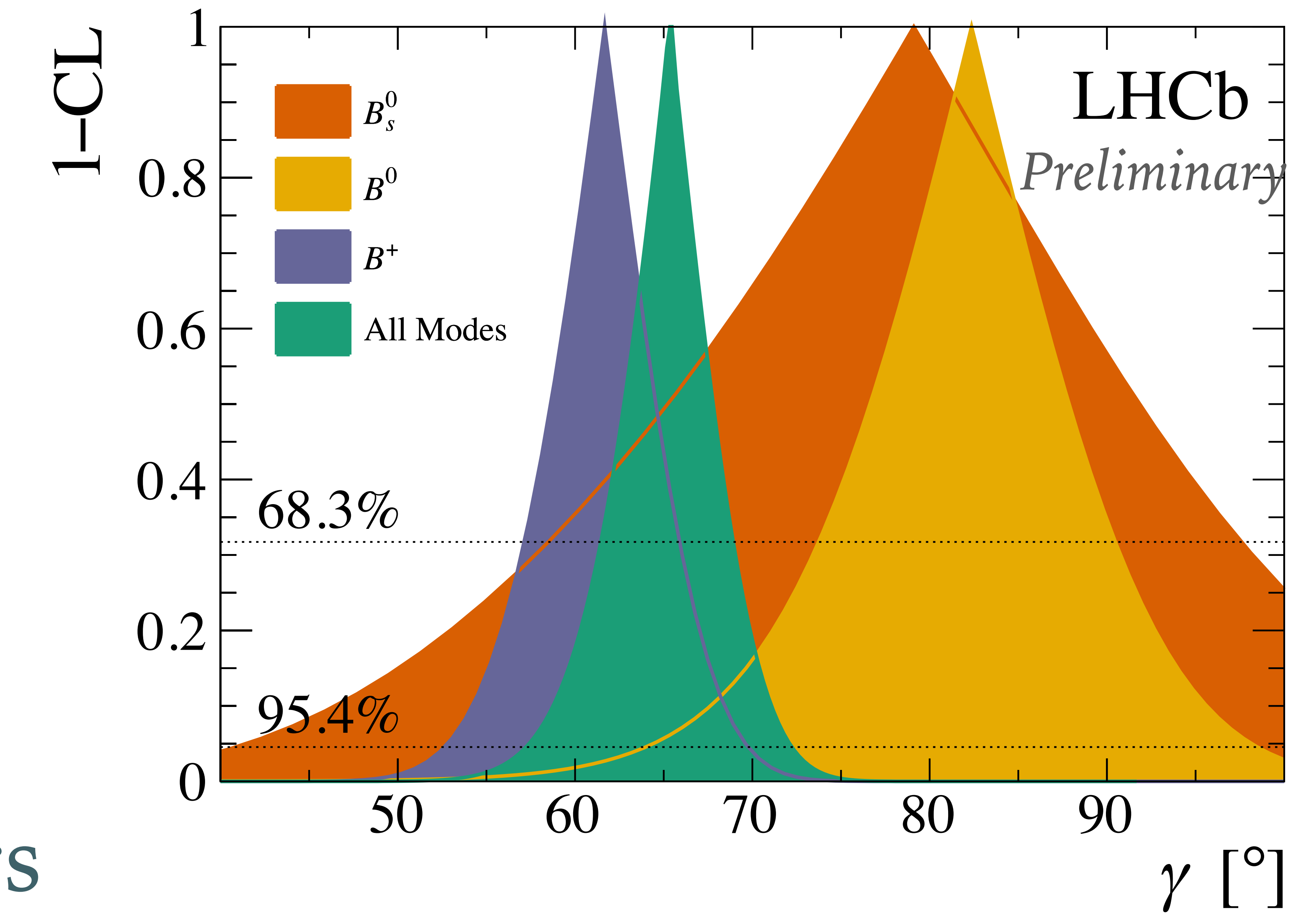
- Charm mixing parameters enter the $B \to Dh$ interference amplitudes (sensitive to γ!) – useful to consider correlations to improve precision
- More than 20 LHCb publications (151 observables) used in this combination; updated inputs on hadronic parameters, strong phases in D decays, etc.
- **This results in a world's most precise value:**

$$\gamma = \left(65.4^{+3.8}_{-4.2}\right)^\circ$$

Excellent agreement with the global fits:

UTFit (2021): $\gamma = 66.1 \pm 2.1$

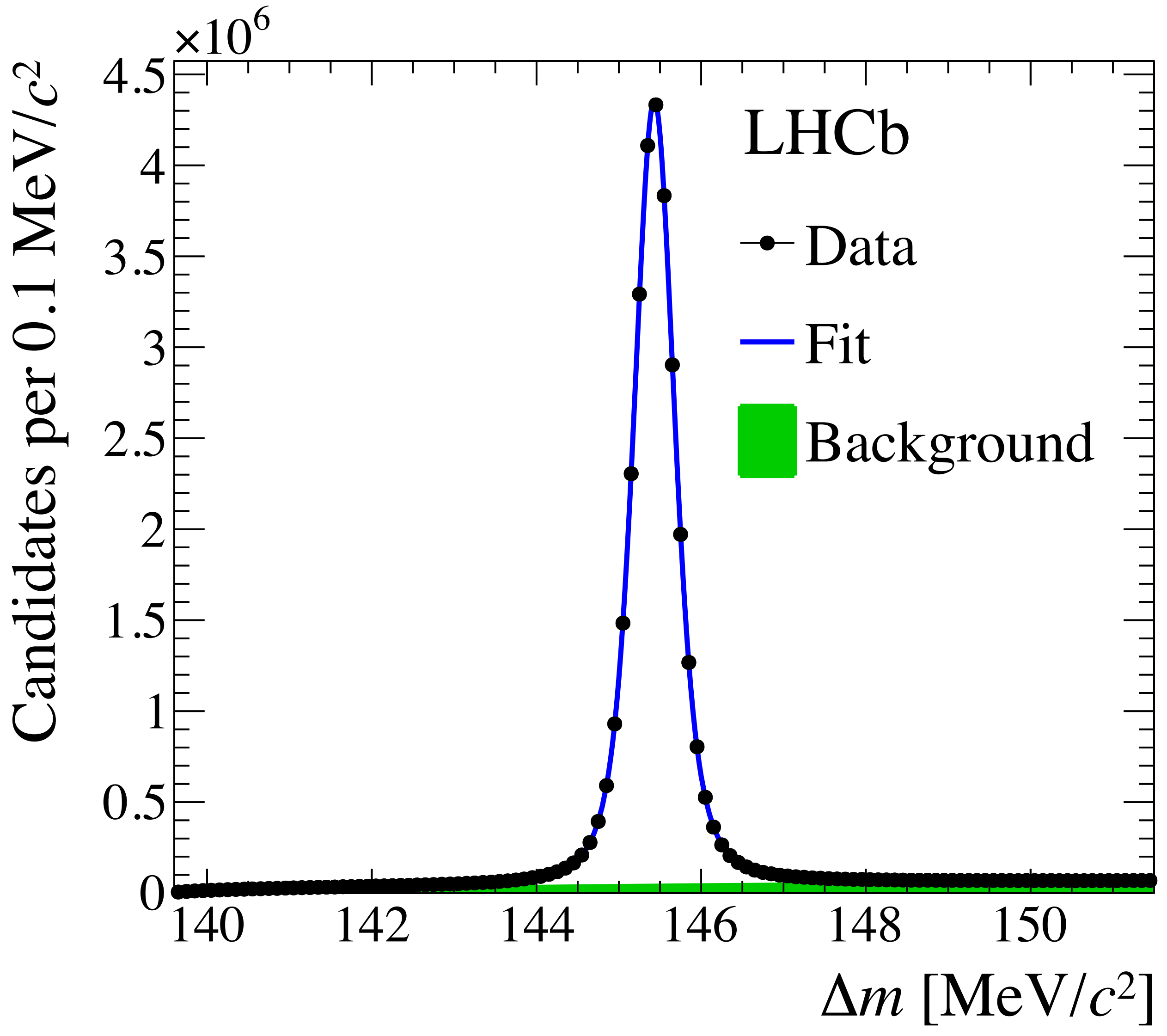
CKMFitter (2019): $\gamma = 65.6^{+0.9}_{-2.7}$



- As an input to this combination:
we updated the measurement of charm mixing parameters

- Study $D^0 \to K_S\pi^+\pi^-$; D^0 can oscillate to $\overline{D}^0$ which decays to same final state
- D^0 mixing: mass eigenstates $D_{1,2} \equiv pD^0 \pm q\overline{D}^0$ differ from flavour eigenstates
  - Described by dimensionless parameters $x \equiv \left(m_{D_1} - m_{D_2}\right)/\Gamma$ and $y \equiv \left(\Gamma_{D_1} - \Gamma_{D_2}\right)/(2\Gamma)$

30 million signal events; tagged by $D^{*\pm}$

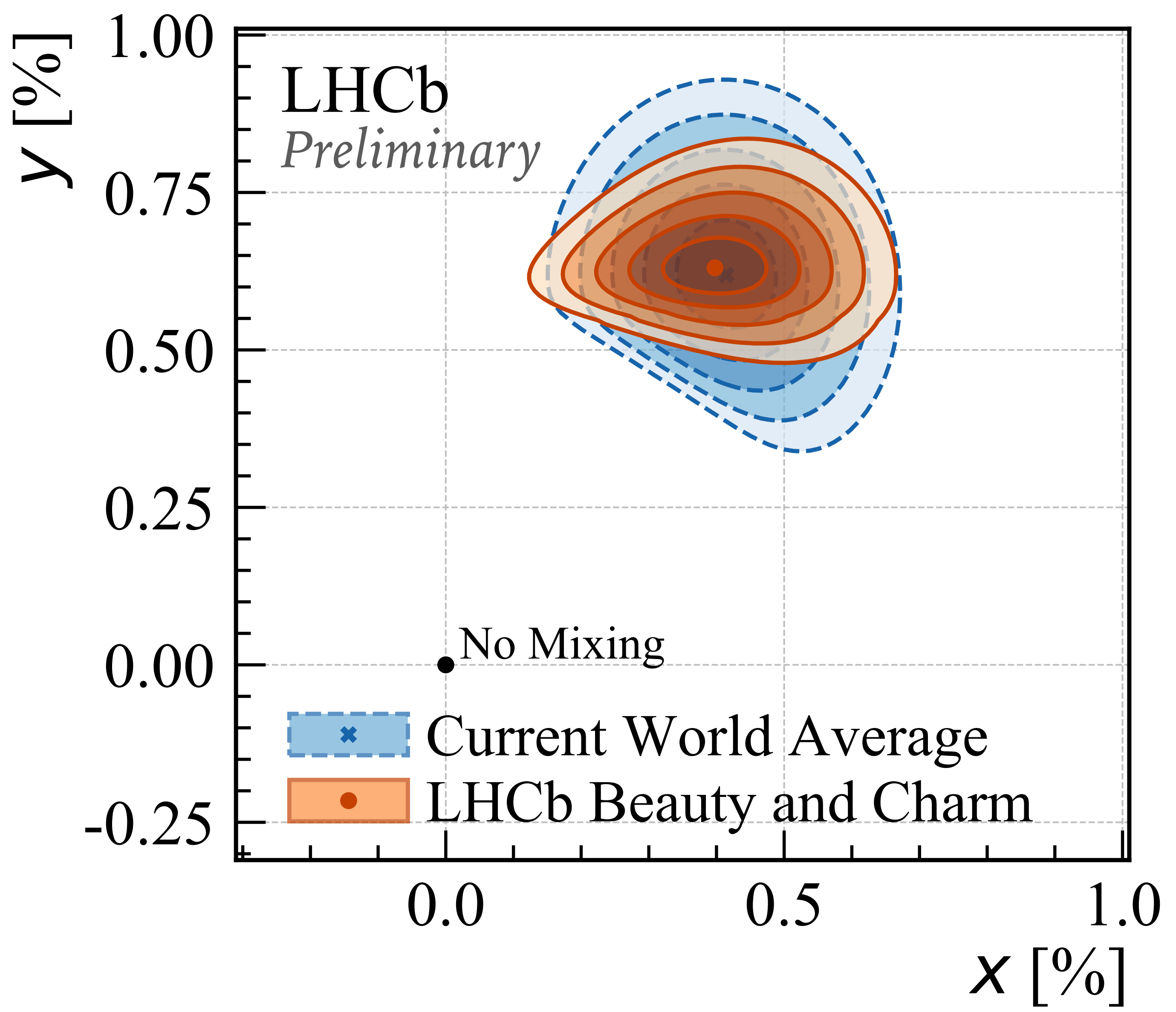


Bin-flip method:
- Split Dalitz plot in regions of "equal" strong phase
- Fit to decay time in each bin

Mass difference of the D0 mass eigenstates:

$$x = \left(3.98^{+0.56}_{-0.54}\right) \times 10^{-3} \to \; m_{D_1} - m_{D_2} = 6.4\,\mu\text{eV}$$

First observation of a non-zero mass difference (x)!



Plug this in our global combination:

$$x = \left(0.400^{+0.052}_{-0.053}\right)\,\%$$

value of x dominated by our latest result

$$y = \left(0.630^{+0.033}_{-0.030}\right)\,\%$$

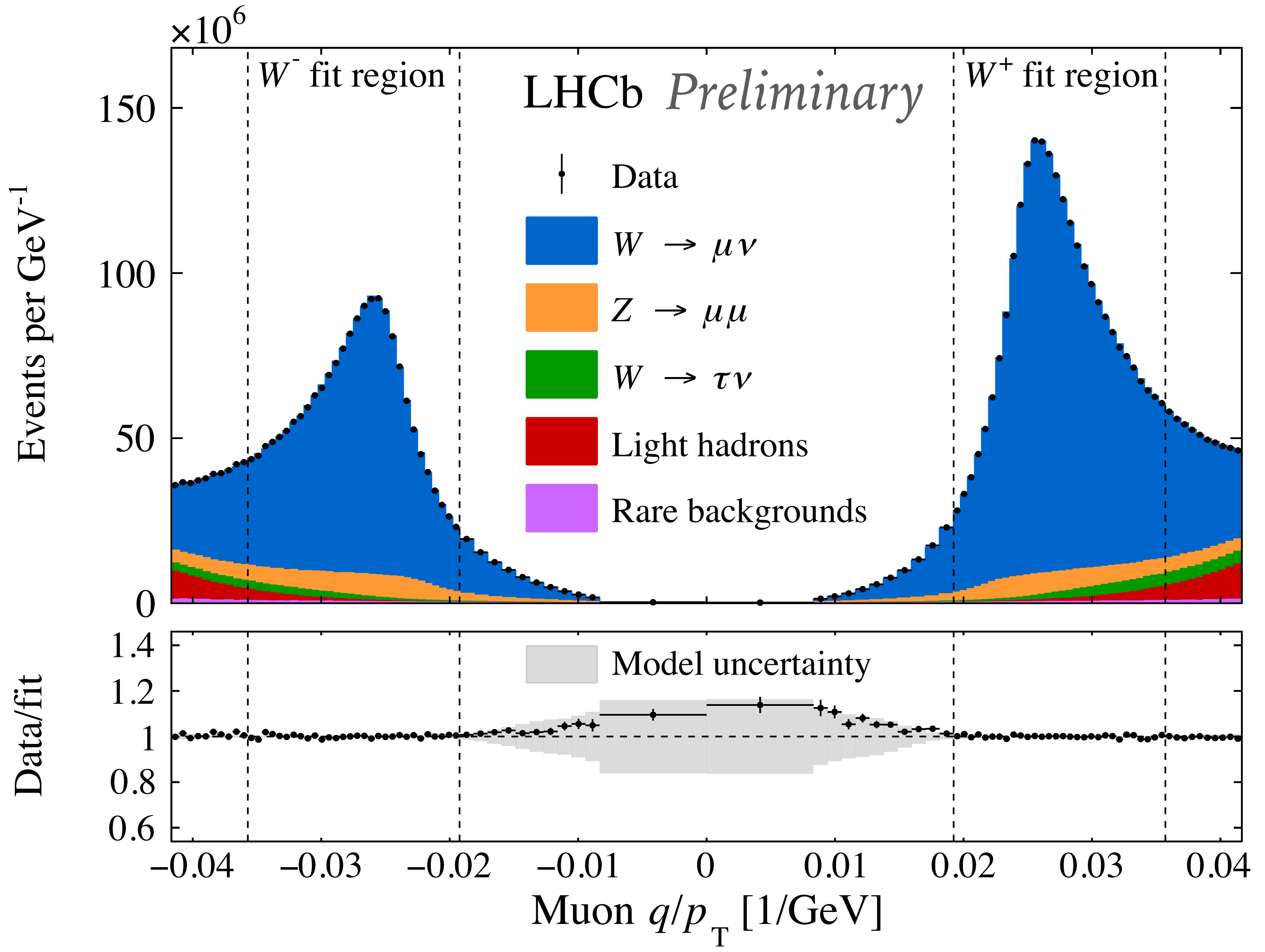
value of y twice more precise than the world average

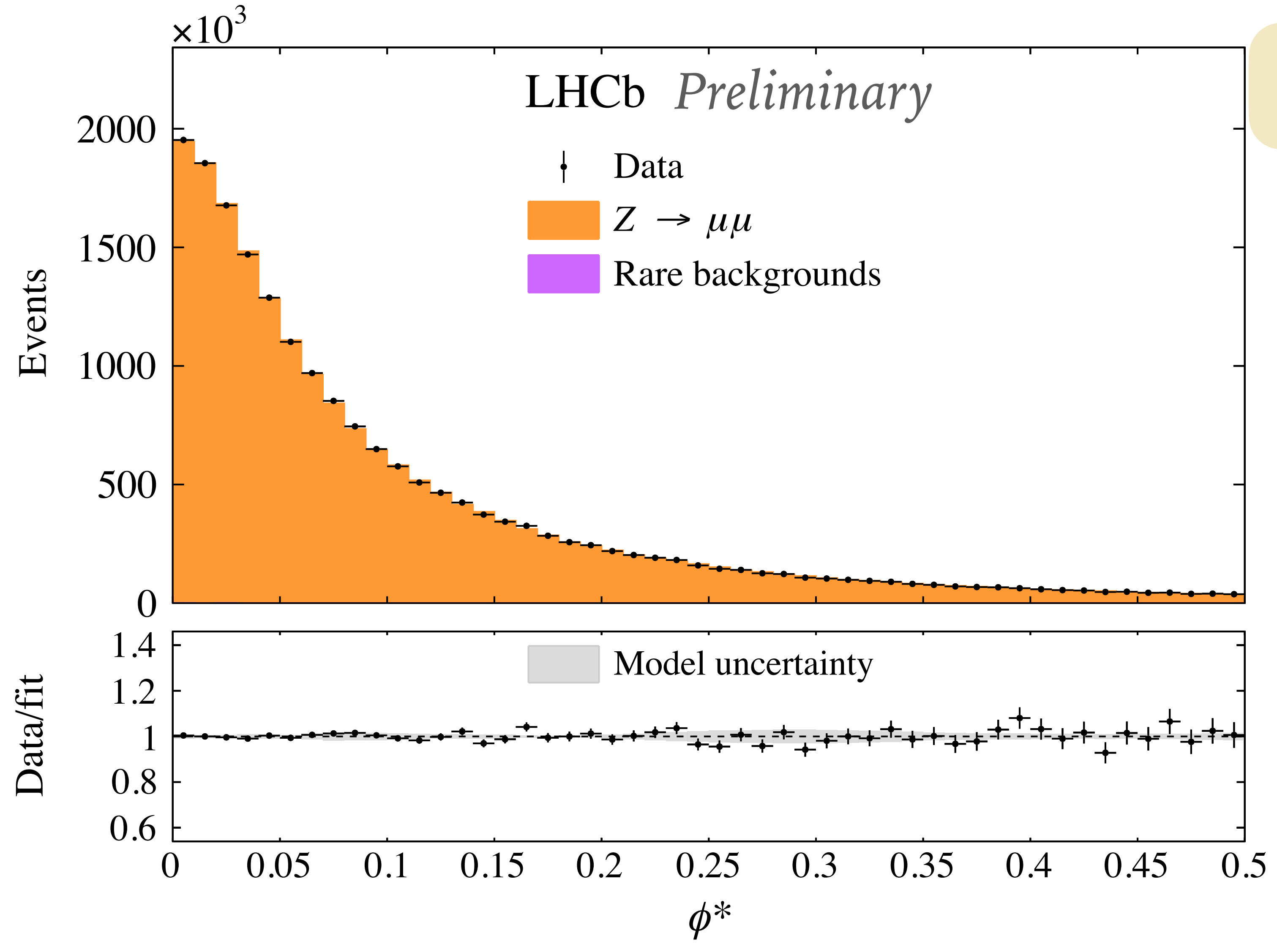
See the CERN seminar by Mika Vesterinen for the details

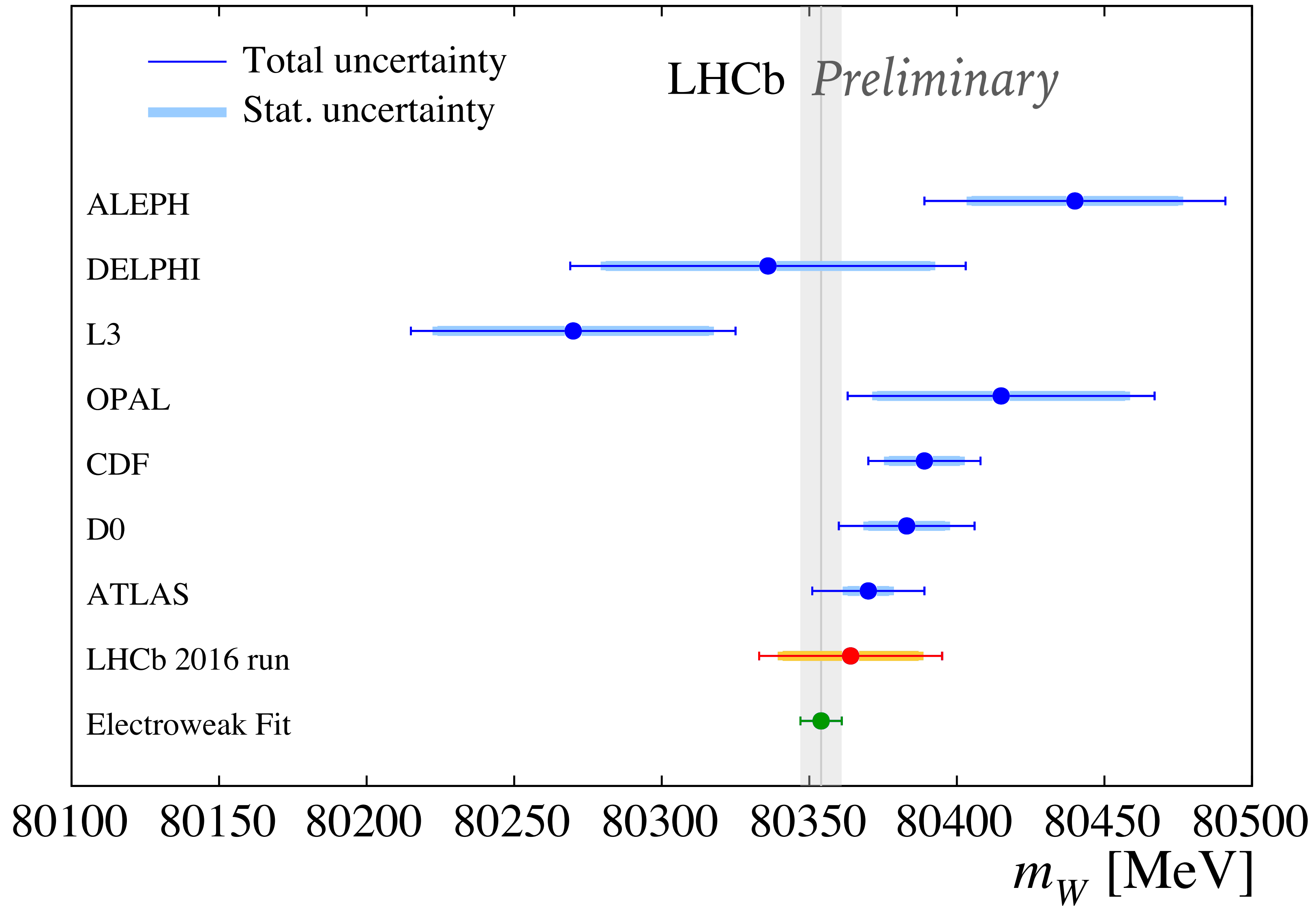
- m_W is an important parameter of the Standard Model, sensitive to BSM contributions
  - Challenging experimentally: $W \rightarrow \mu\nu_\mu$ leaves one track
- Measured at LHCb for the first time: high-rapidity measurement brings **complementarity** due to partly orthogonal PDF uncertainties (compared to low-rapidity)
- Fit to the q/p_T of the muon from $W \rightarrow \mu\nu_\mu$, simultaneously with angle ϕ^* in $Z \rightarrow \mu\mu$
  - Requires a very precise control of systematic effects: notably, detector alignment

proof-of-principle measurement

$$m_W = 80364 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}$$

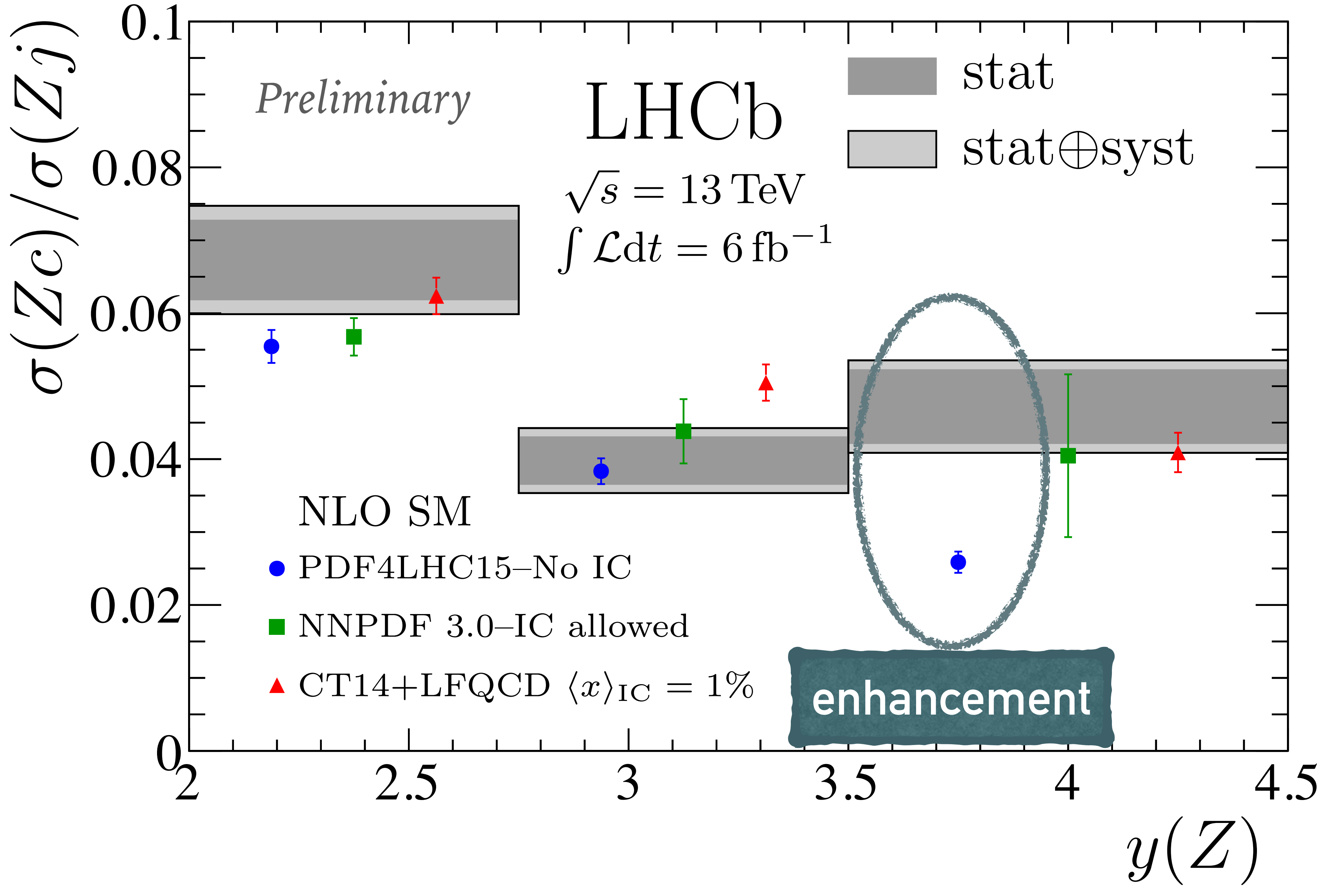






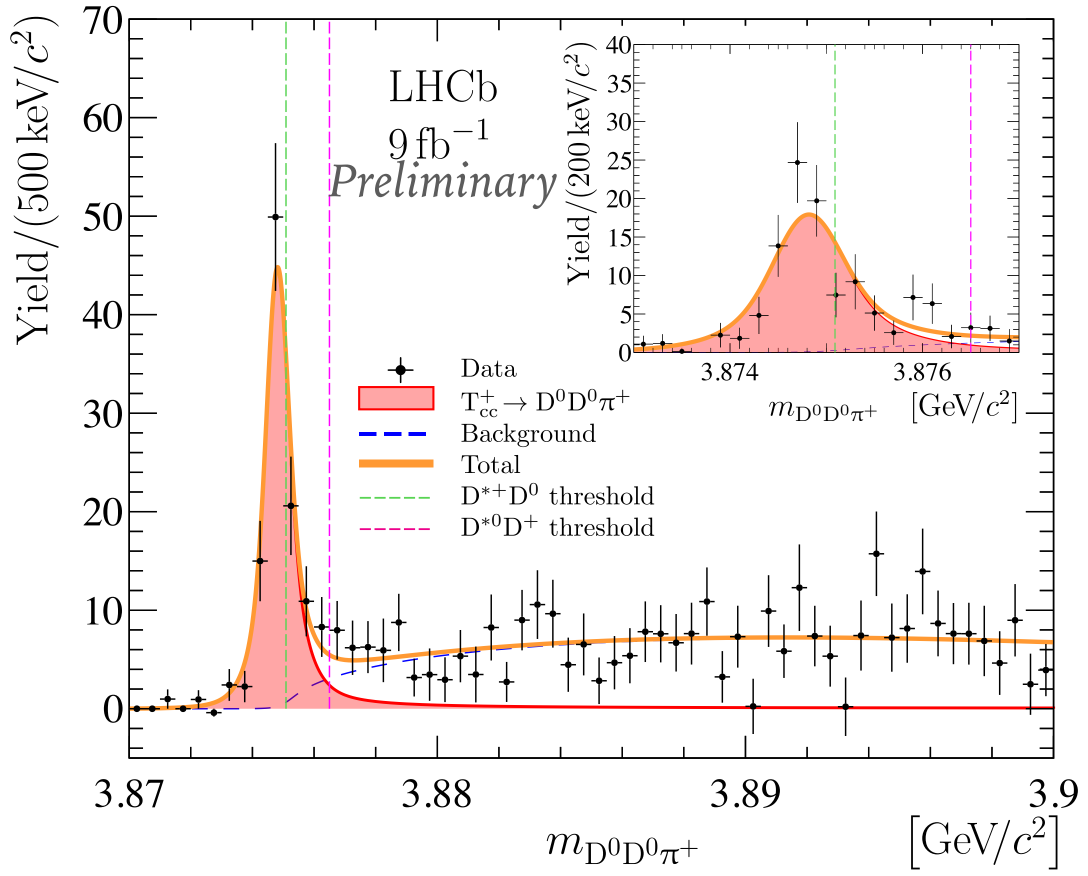
A full-Run2 LHCb measurement will benefit from theory development.

- Measure events where Z boson is produced together with a c-quark jet
  - First such measurement in the forward region!
- **Enhancement** found at high rapidities
  - Can be explained by presence of a high-x charm component inside the proton – ‘**intrinsic charm**’
  - A global PDF analysis is needed for a complete interpretation.

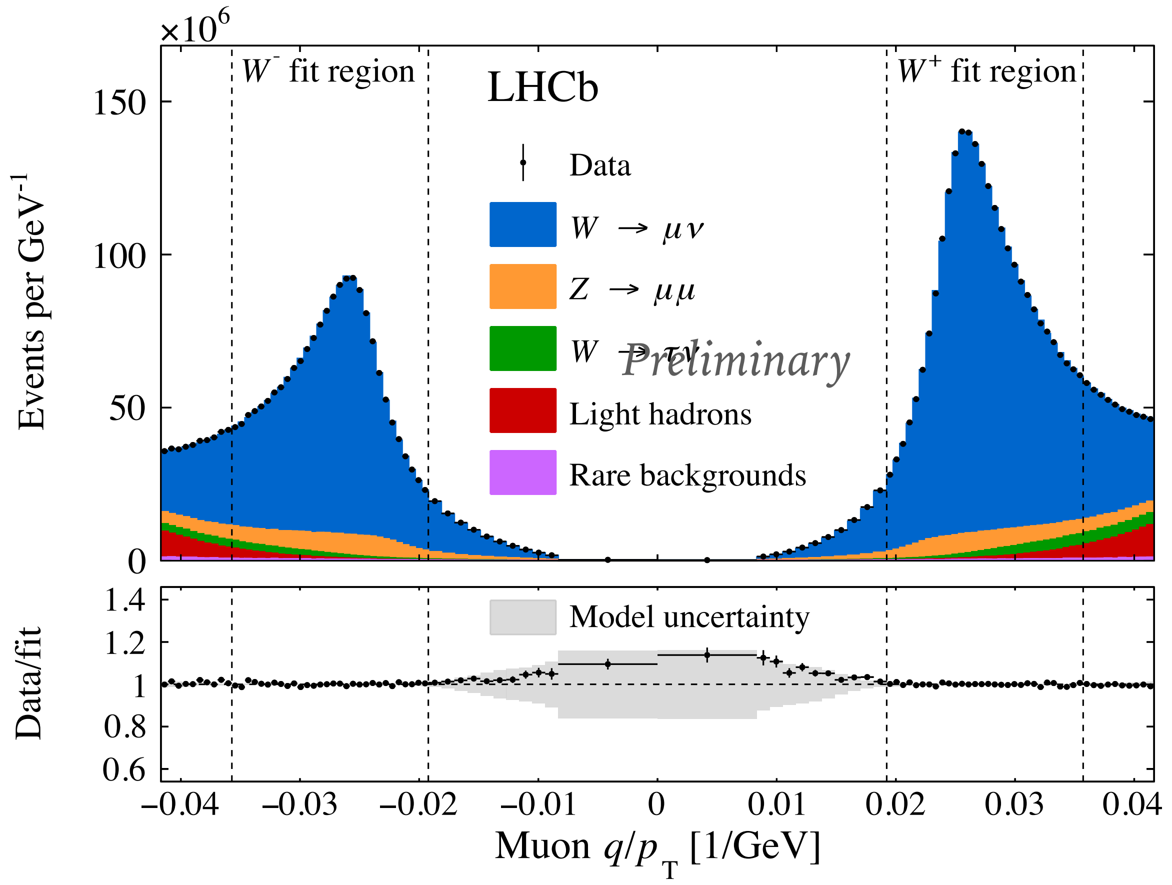


LHCb is truly a general-purpose detector, providing measurements in the forward region and complementing the other LHC experiments.

- **Collecting harvest from our flavourful Run 1 + Run 2 datasets**
  - Precision on the UT angle γ improved from $\sim 20°$ to $\sim 4°$ during the years of LHCb operation
    - The γ is now known more precisely than α
  - Important contributions to hadron spectroscopy
  - High-p_T physics in forward region

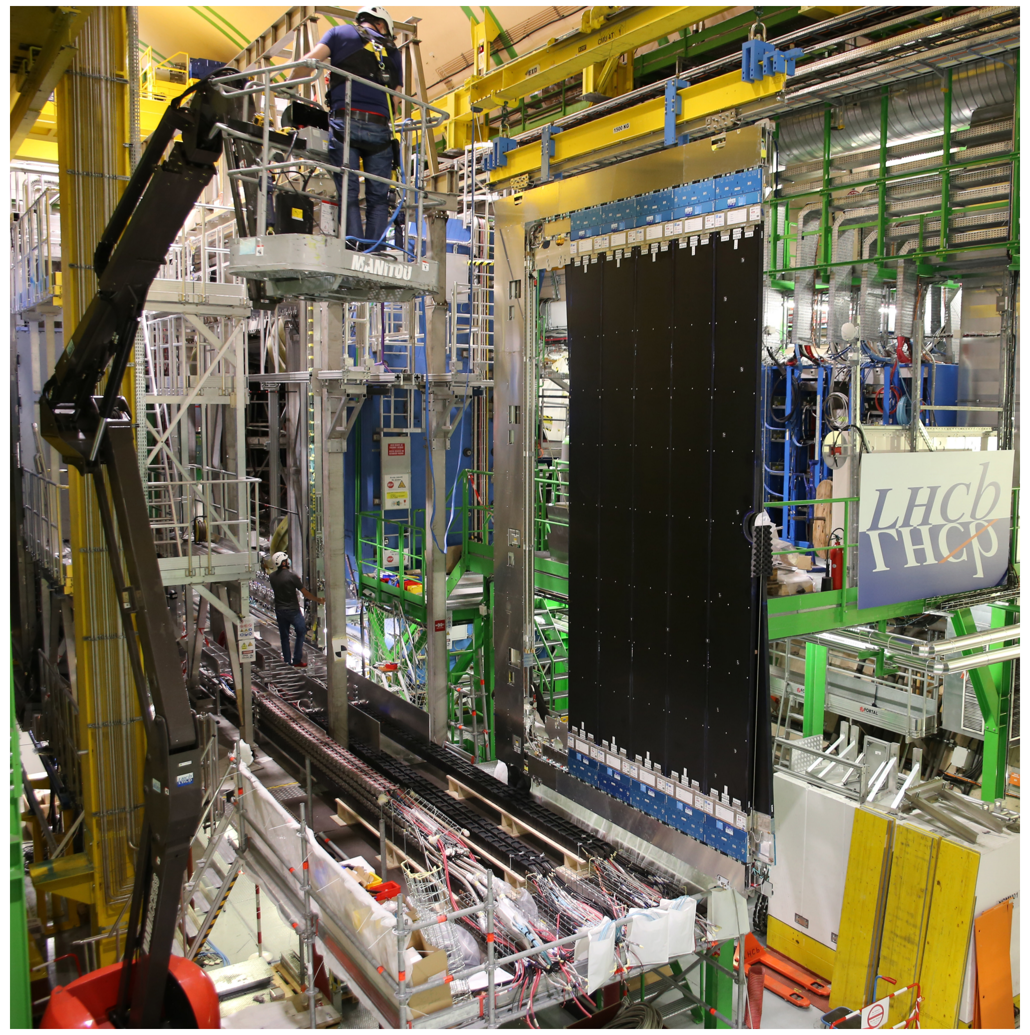


Charming tetraquark



W-boson mass

- **LHCb Upgrade I is in its crucial phase**
  - Multiple systems installed & in commissioning
  - For the others, schedule is tight but we put all possible effort to meet it



SciFi installation

- **Mapping the future of particle physics with our planned Upgrade II**

VTRX STATUS

- VTRX: transceiver to the optical systems (common between LHC experiments)
- Issue: at high temperatures, glue emits gas which condensates and prevents transmission
  - Solution: bake-out
- LHCb: bake-out in progress, done for some subdetectors, replacement in progress and will finish in time
  - Exception: SciFi and RICH2 where VTRX are under active cooling (and sometimes hard to replace)