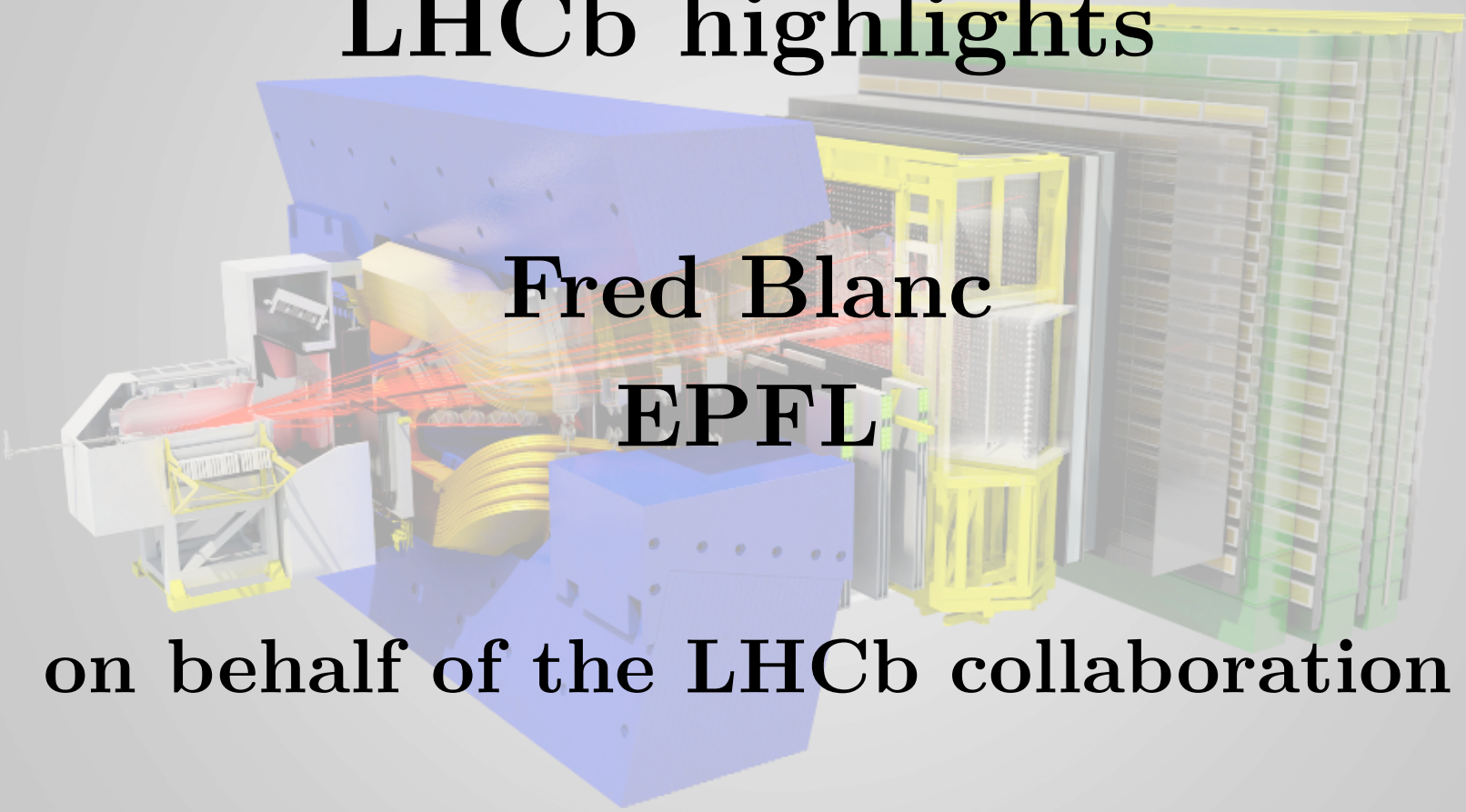
LHCb highlights

Fred Blanc
EPFL

on behalf of the LHCb collaboration

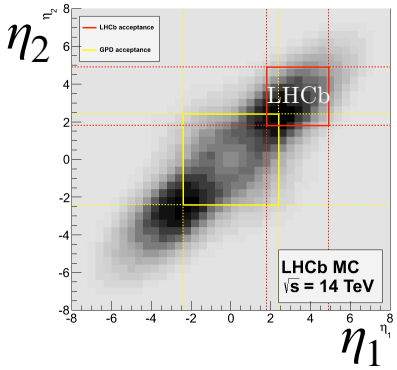


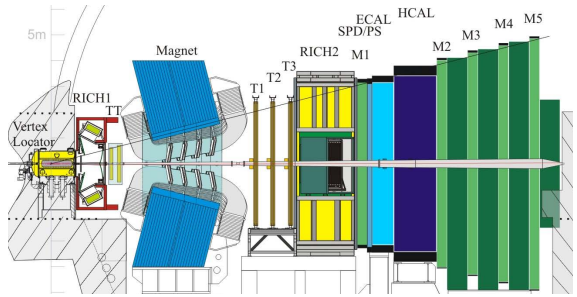
ICHEP 2022

Bologna, Italy, July 6th – 13th 2022

LHCb in a nutshell

- LHCb originally designed for the study of CP violation and rare decays in beauty and charm → and now a general purpose detector!
- $b\bar{b}$ production in pp collisions mostly in the forward direction

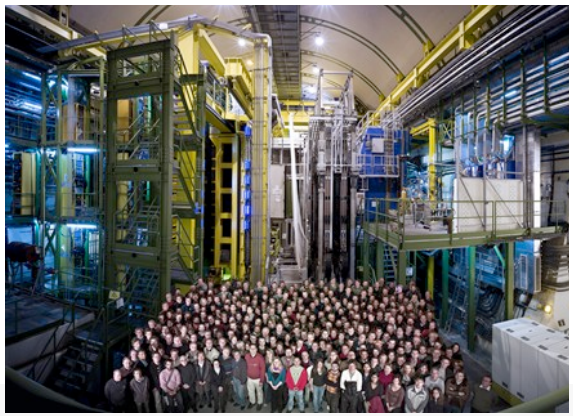


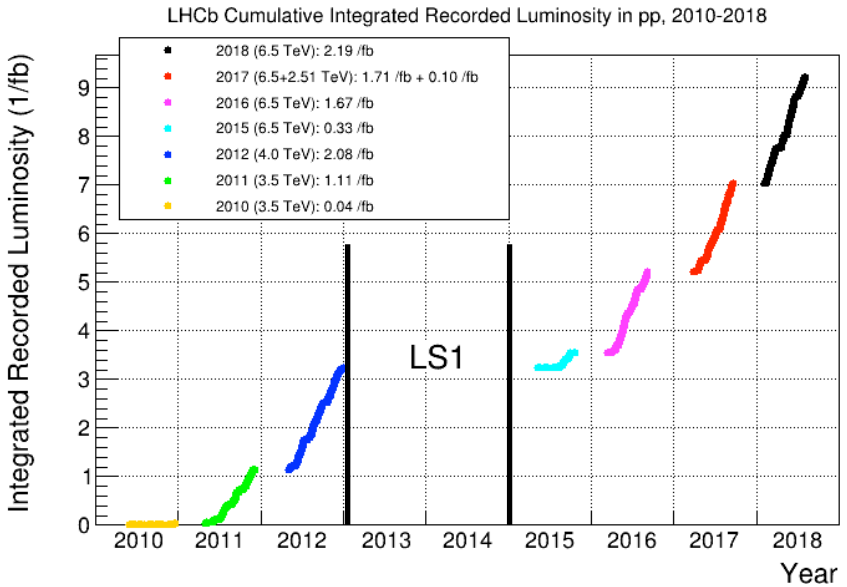


JINST 3 (2008) S08005

→ forward spectrometer ($2<\eta<5$) with excellent vertexing, tracking and particle identification ($K/\pi/p/\mu/e/\gamma$)

- Run 1+2: 9fb^{-1} of pp collisions (+pPb, PbPb, fixed-target mode)
- LHCb = 1.5k members, 1070 authors, 95 institutes, 21 countries

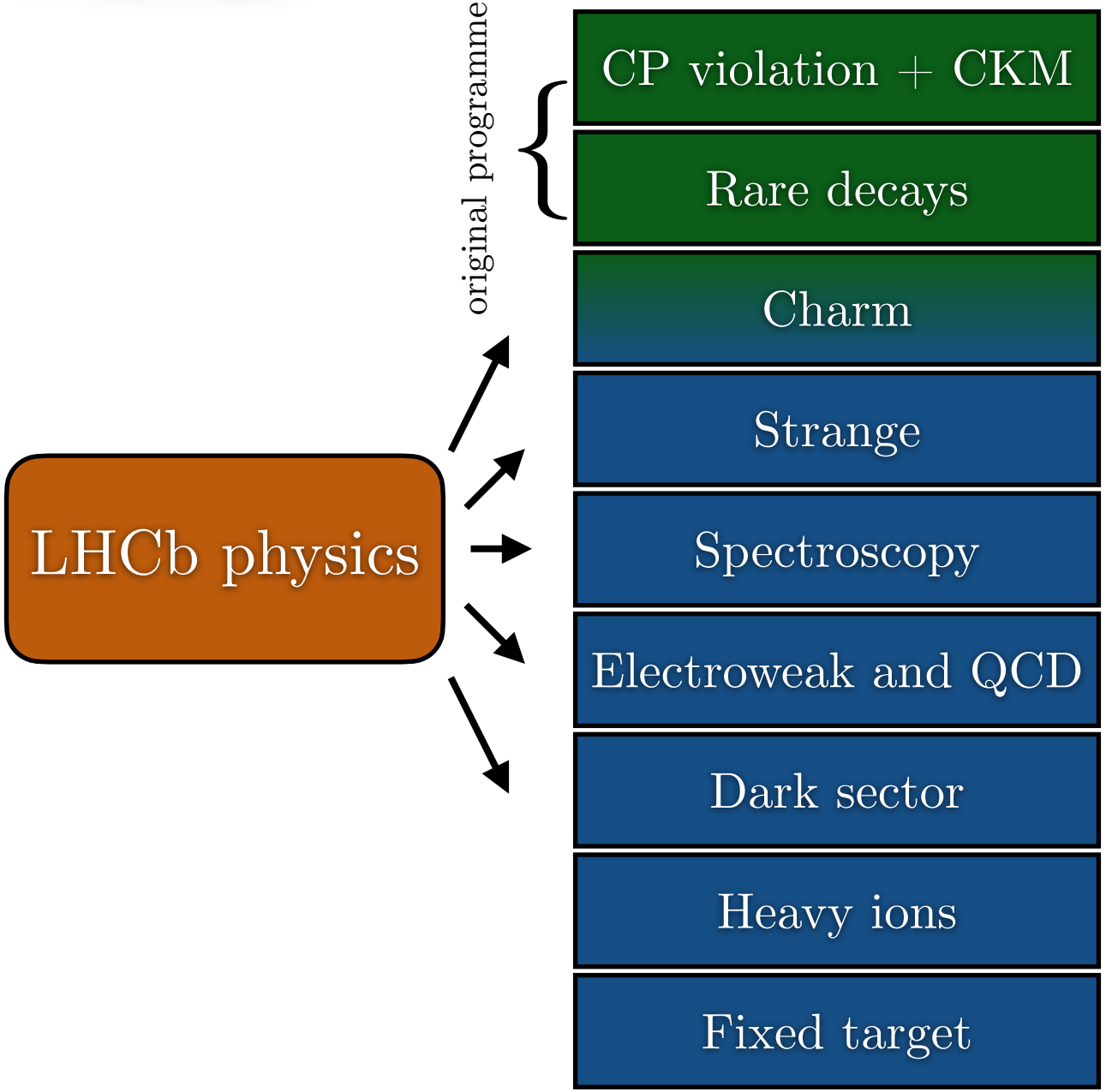




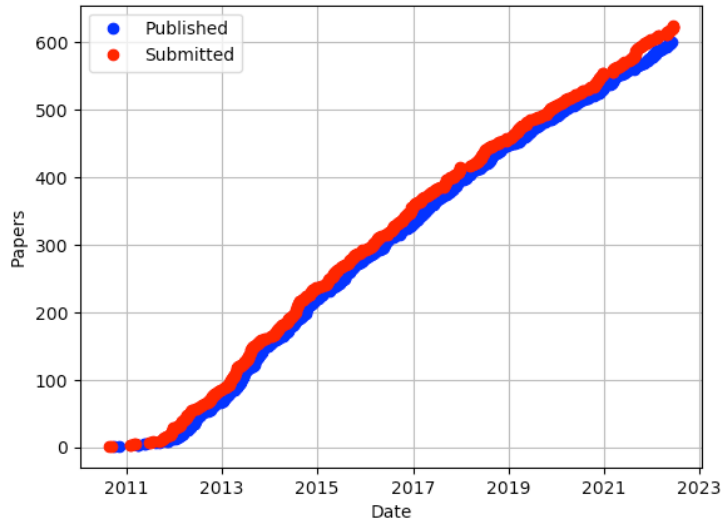
Run 1, 3fb^{-1} 7&8 TeV

Run 2, 6fb^{-1} 13 TeV

Physics programme overview



600 published papers



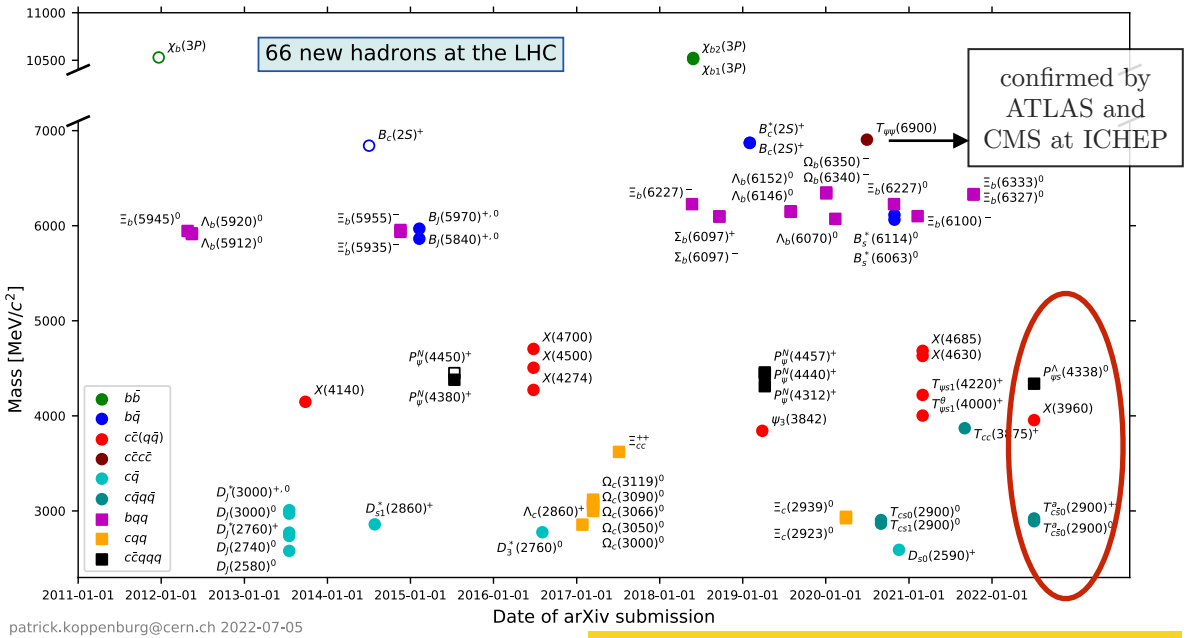
TODAY:

- New exotic hadron states
- CP violation and mixing
- New rare decays results
- Electroweak measurements
- Heavy ions and fixed target

Exotic hadronic states

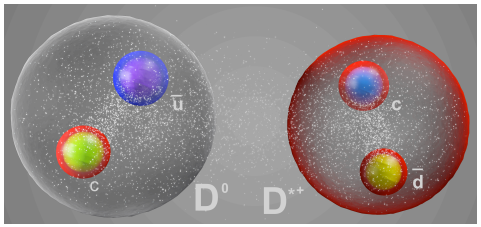
Search for exotic hadronic states

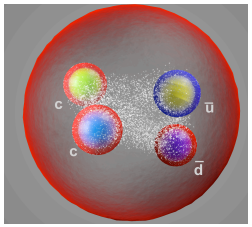
- Several conventional and exotic hadronic states discovered at the LHC, many of them (59/66) by LHCb
  - key to study of non-perturbative QCD



LHCb-FIGURE-2021-001 (update)

- nature of exotic states still unclear: loosely (hadronic molecule) or tightly bound?





Entering a new Era!

- LHCb report the observation of new exotic states
  - $T^a_{c\bar{s}0}(2900)^{++}$, $T^a_{c\bar{s}0}(2900)^0$ (tetra-quark states)
  - $P^{\Lambda}_{\psi s}(4438)^0$ (penta-quark state)

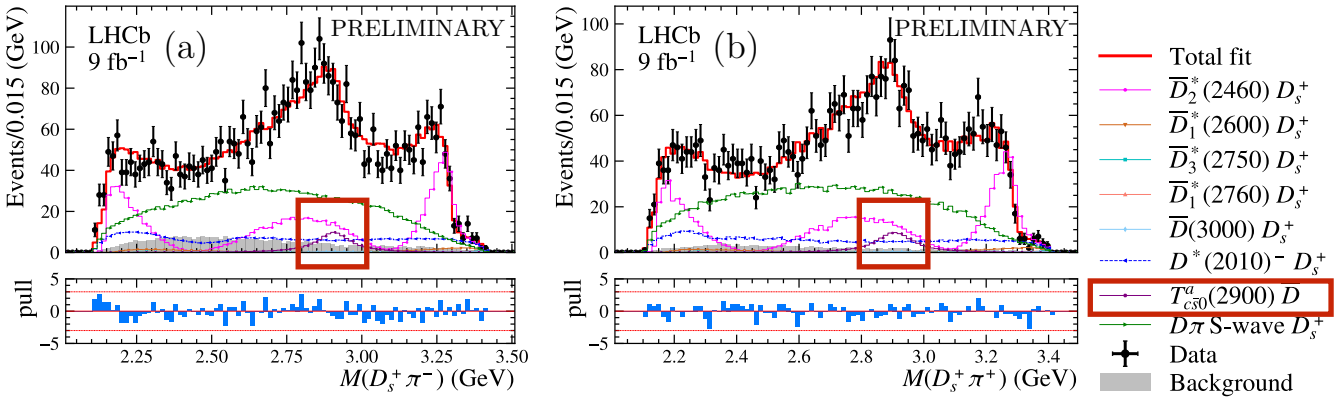
New naming convention proposed by LHCb

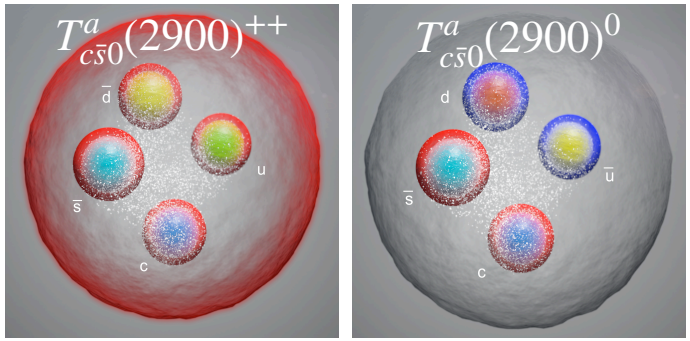
arXiv:2206.15233

New tetra- and pentaquark states

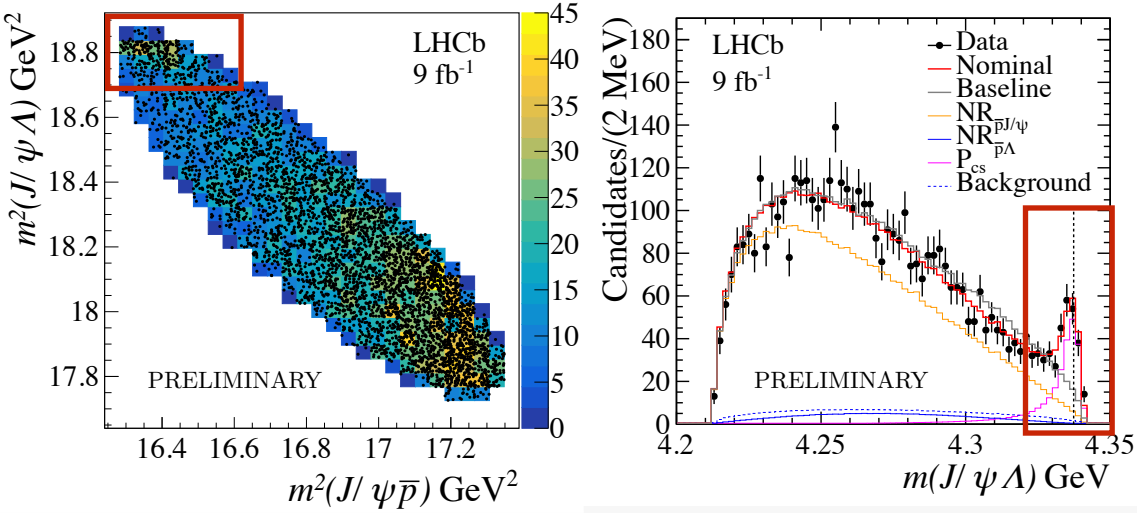
- Isospin pair of doubly charged and neutral tetraquarks:
  $T^a_{c\bar{s}0}(2900)^{++}$ $(c\bar{s}u\bar{d})$ and $T^a_{c\bar{s}0}(2900)^0$ $(c\bar{s}\bar{u}d)$

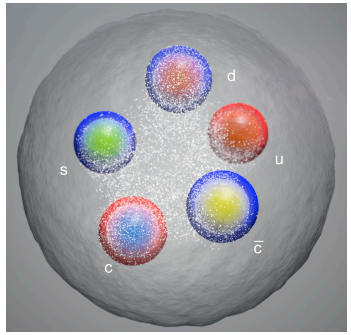
LHCb-PAPER-2022-026/027 (in preparation)





- First strange pentaquark: $P^{\Lambda}_{\psi s}(4438)^0$ $(c\bar{c}uds)$





LHCb-PAPER-2022-031
(in preparation)

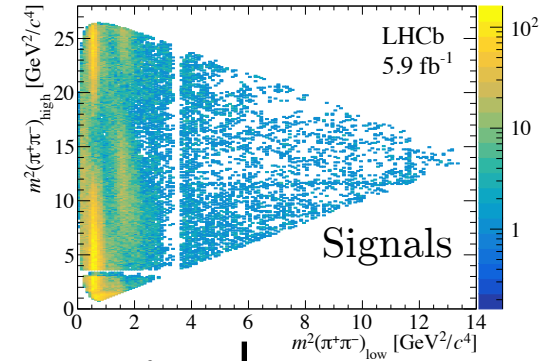
→ R. Ma & N. Neri in parallel sessions

CP violation and mixing

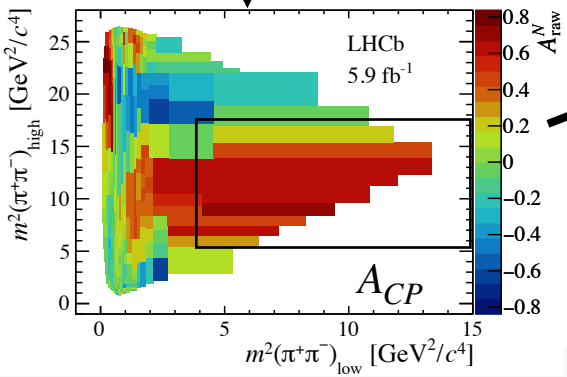
CP violation in $B^{\pm} \to h^{\pm}h^{+}h^{-}$

- Observed CPV in four decay channels:
  $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$, $B^{\pm} \to K^{\pm}K^{+}K^{-}$,
  $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$, $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$

- Localised CP asymmetries

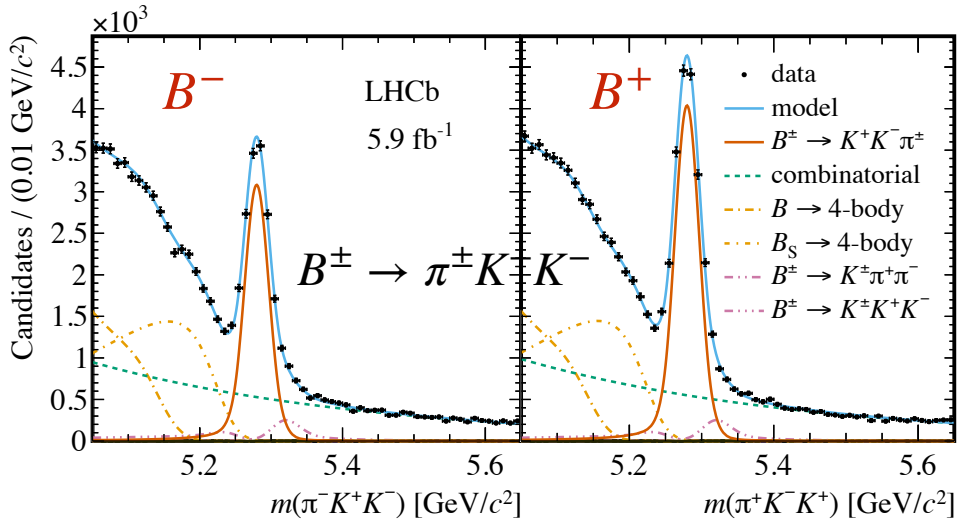


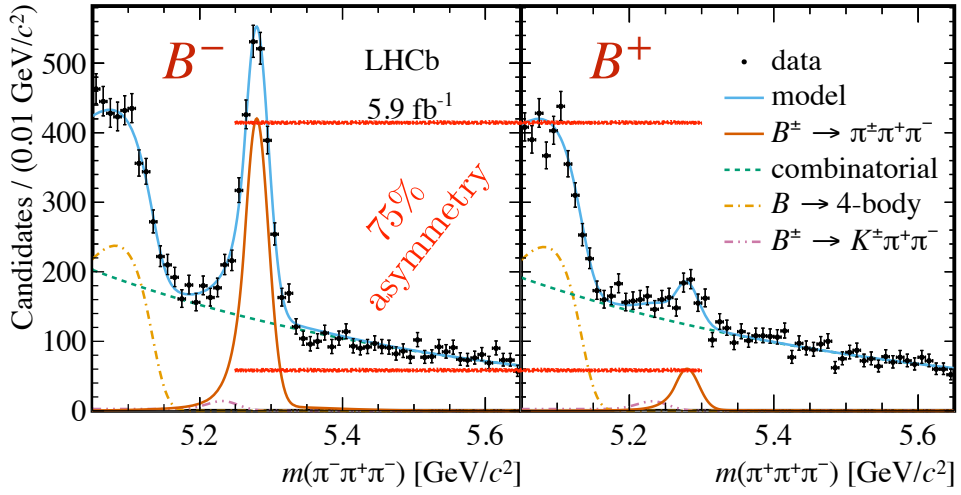
Regions of equal populations



$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$

2270±60 signals





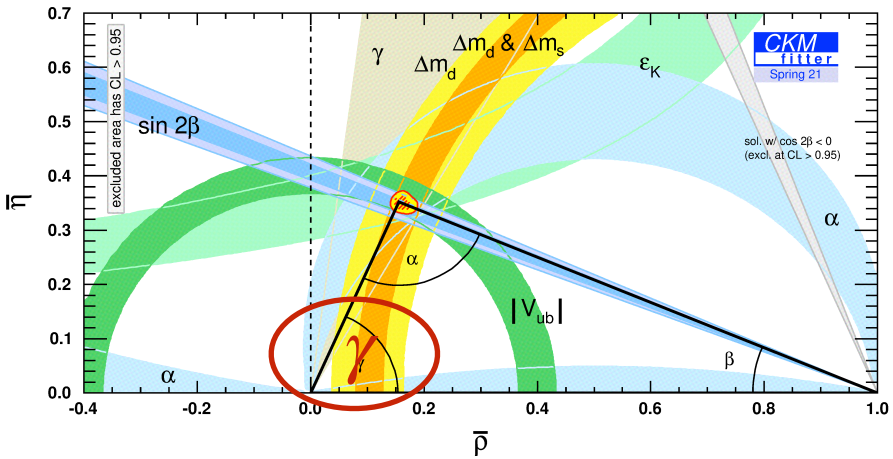
High localised CP asymmetries → learn about the relation between decay channels (via $\pi\pi \leftrightarrow KK$ rescattering)

LHCb-PAPER-2021-049/050

→ A. Gomes in parallel sessions

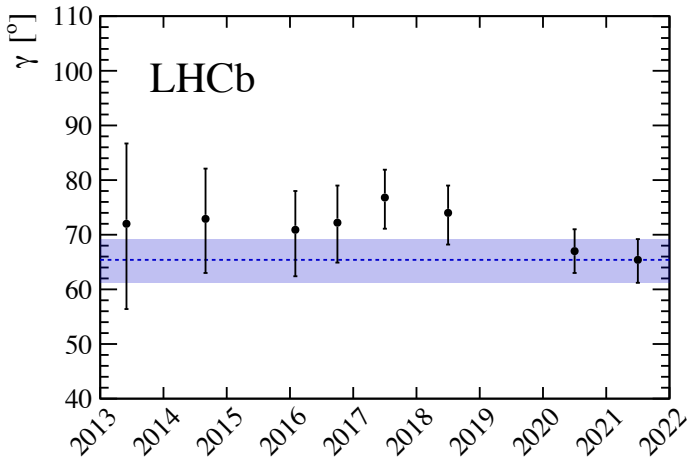
CKM angle γ and charm mixing

- γ from combination of 15 B-decay and 9 D-decay LHCb measurements
  - simultaneous fit of γ and D^0 mixing parameters ($x \equiv \Delta M/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$)



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

JHEP 12 (2021) 141

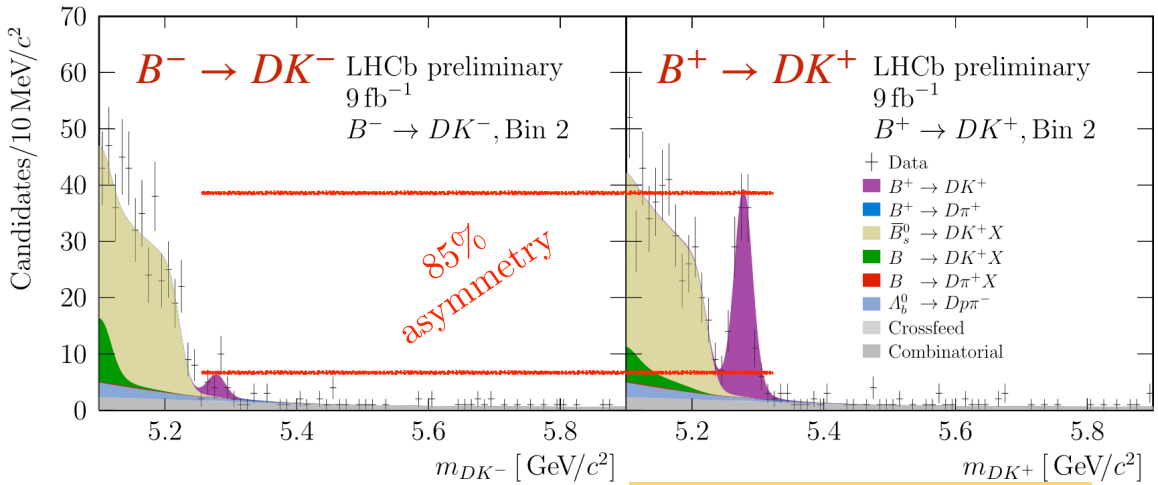


- New measurement of γ with $B^\pm \to D(\to K^\mp\pi^\pm\pi^\pm\pi^\mp)K^\pm$

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

  - (second) most precise single determination of γ
  - largest A_{CP} ever measured [in one phase-space bin]

LHCb-PAPER-2022-017 (in preparation)



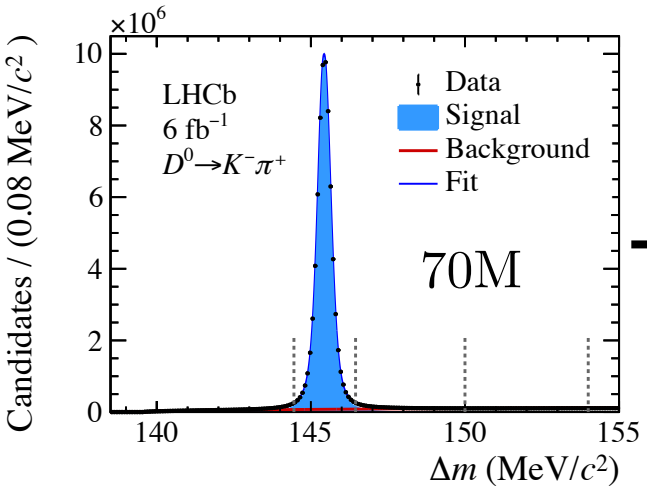
→ T. Evans in parallel sessions

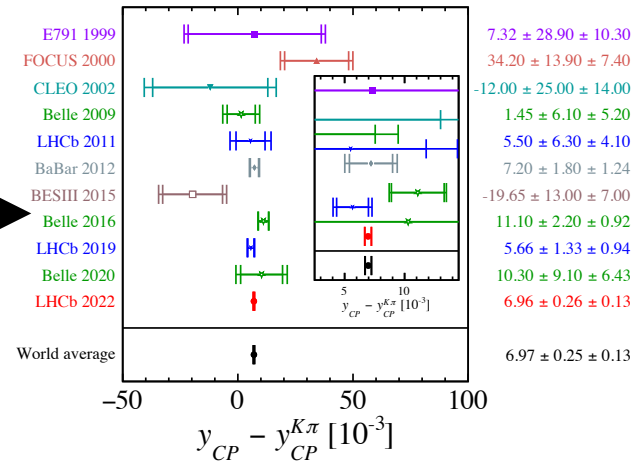
Charm mixing

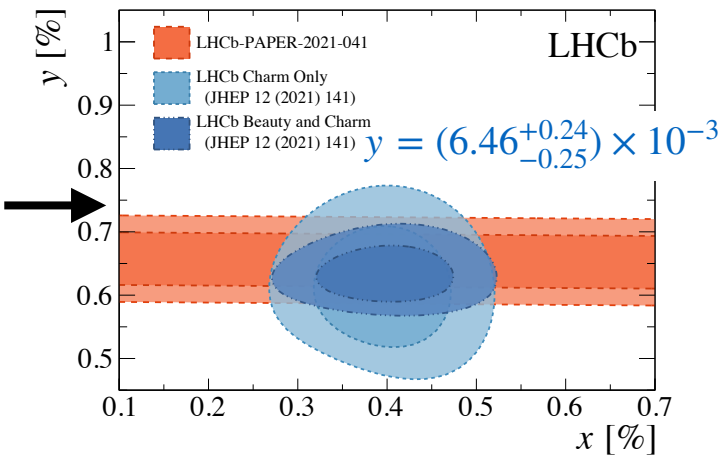
- Lifetime difference between $D^0 \to K^-\pi^+$ and $D^0 \to f$ $(f = \pi^+\pi^-, K^+K^-)$

$$\frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to f)} - 1 = y^f_{CP} - y^{K\pi}_{CP} \approx y(1 + \sqrt{R_D}) \qquad y_{CP} - y^{K\pi}_{CP} = (6.96 \pm 0.26 \pm 0.13) \times 10^{-3}$$

PRD 105 (2022) 092013



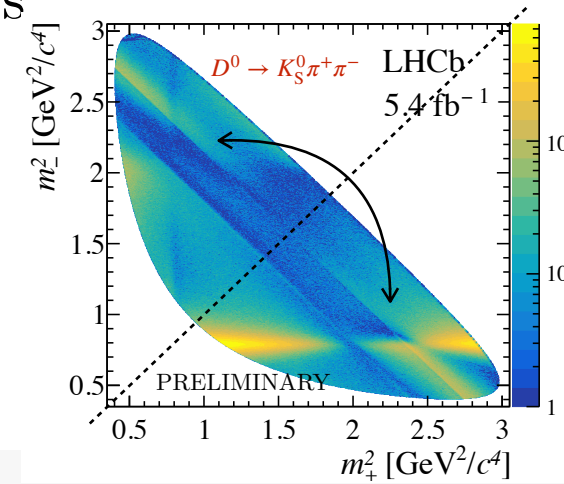


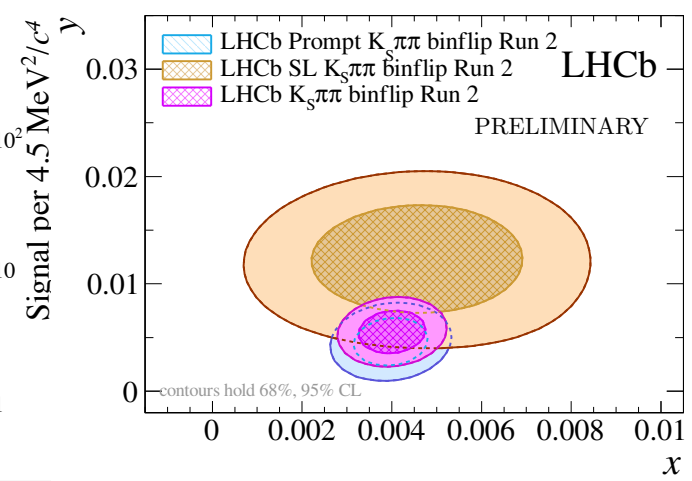


- Charm mixing parameters in $D^0 \to K^0_S\pi^+\pi^-$ decays from $\bar{B} \to D^0\mu^-\bar{\nu}_\mu X$

→ "bin-flip" method

LHCb-PAPER-2022-020 (in preparation)





→ S. Ek-In in parallel sessions

First charm CPV in single channel

- CPV in charm small in the standard model ⇒ sensitive to new physics
- CPV in charm observed in time-integrated difference of CP asymmetries

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-15.4 \pm 2.9) \times 10^{-4}$$ [PRL 122 (2019) 211803]

- New measurement of $A_{CP}(K^-K^+)$:

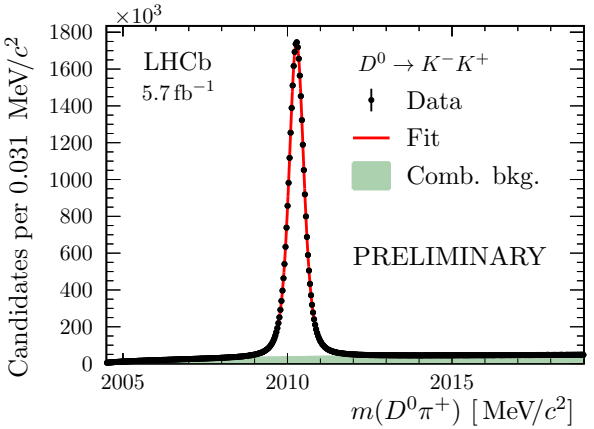
$$A_{CP}(K^-K^+) = [6.8 \pm 5.4\,(\text{stat}) \pm 1.6\,(\text{syst})] \times 10^{-4}$$

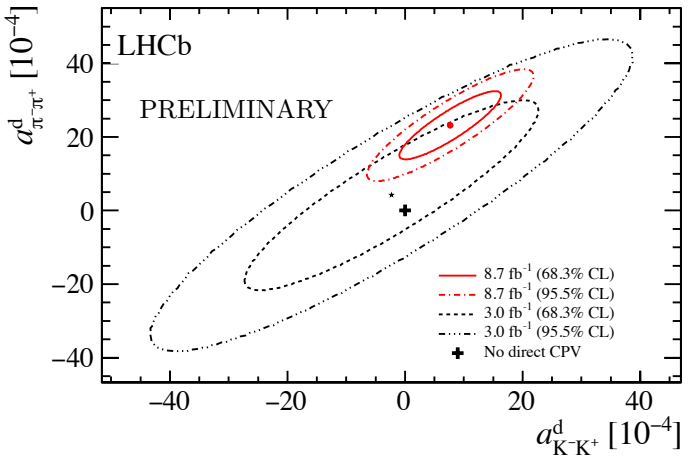
and determine the direct CP asymmetries

$$a^d_{K^-K^+} = (7.7 \pm 5.7) \times 10^{-4}$$
$$a^d_{\pi^-\pi^+} = (23.2 \pm 6.1) \times 10^{-4}$$

→ 3.8σ evidence for direct CP violation in $D^0 \to \pi^-\pi^+$!

→ unclear if SM or new dynamics in charm decays





LHCb-PAPER-2022-024 (in preparation)

→ S. Maccolini in parallel sessions

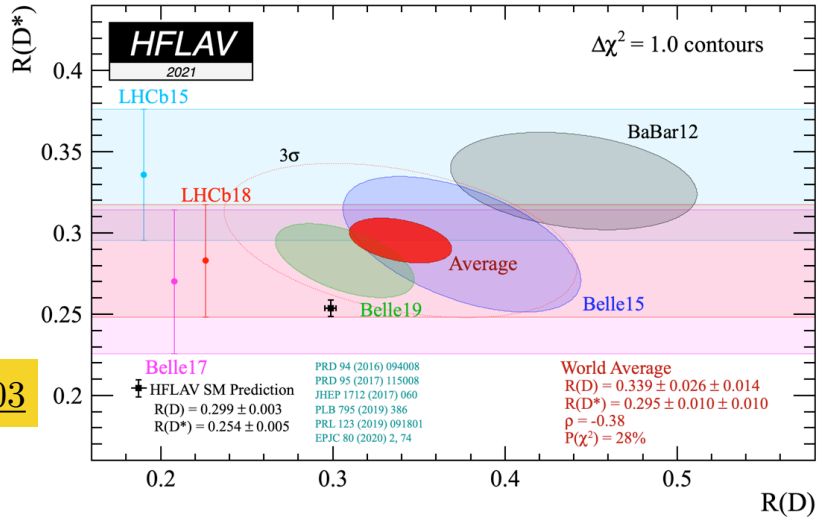
Rare decays

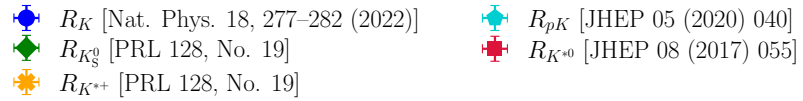
Lepton flavour universality

- LFU in $b \to c\ell\nu$ decays
  - tree-level processes involving 2nd & 3rd generations show 3.3σ tension with SM
  - Recent input from LHCb:
    - observation of $\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$ PRL 128 (2022) 191803

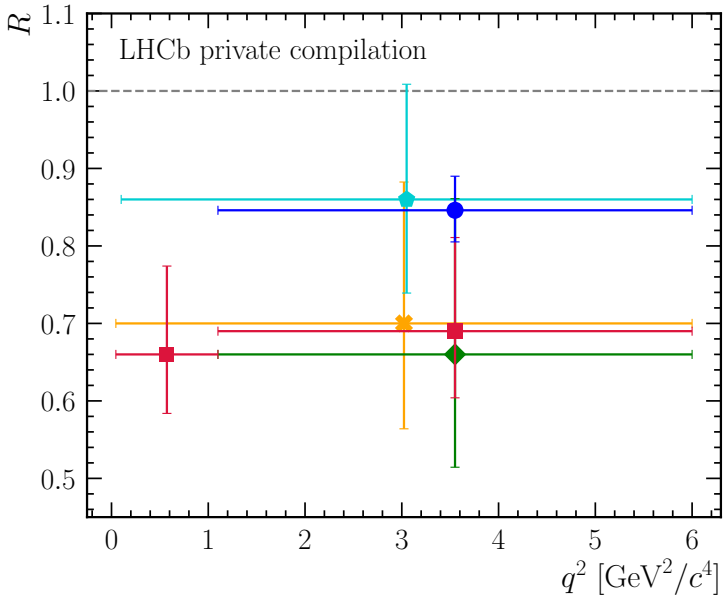
      $\to \quad R(\Lambda_c^+) = 0.242 \pm 0.026 \pm 0.040 \pm 0.059$

      compatible with SM $R(\Lambda_c^+)_{\rm SM} = 0.340 \pm 0.004$ [PRD 99 (2019) 055008]





- LFU in $b \to s\ell\ell$ decays
  - $R \equiv \mathcal{B}(B \to X\mu^+\mu^-)/\mathcal{B}(B \to Xe^+e^-)$
  - R_K about 3.1σ below SM (Run 1+2, 9fb^{-1})
  - Updates in preparation on full data set:
    - R_{pK}, R_ϕ, $R_{K\pi\pi}$
    - unified analysis of R_K and R_{K*} with more q^2 bins, will provide final result on Run 1 + Run 2



→ S. Schmitt & R. Puthumanaillam in parallel sessions

Lepton flavour (number) violation

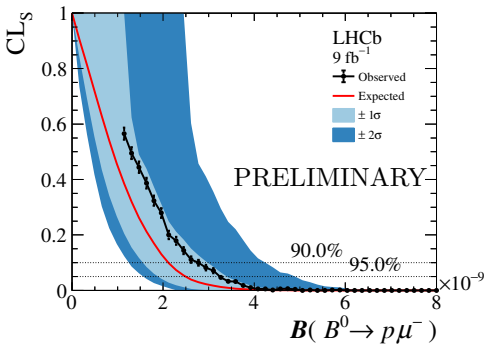
- Search for $B^0_{(s)} \to p\mu^-$

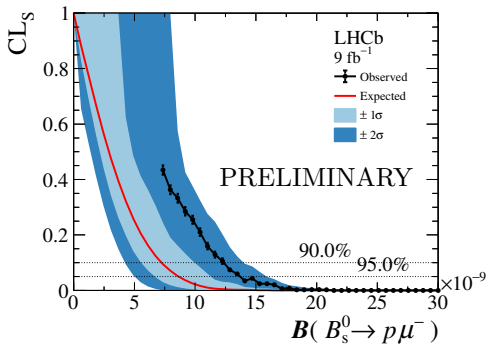
  (also Baryon number violating)

$\mathcal{B}(B^0 \to p\mu^-) < 2.6(3.1) \times 10^{-9}$ @90%(95%) C.L.

$\mathcal{B}(B^0_s \to p\mu^-) < 1.2(1.4) \times 10^{-8}$ @90%(95%) C.L.

LHCb-PAPER-2022-022 (in preparation)





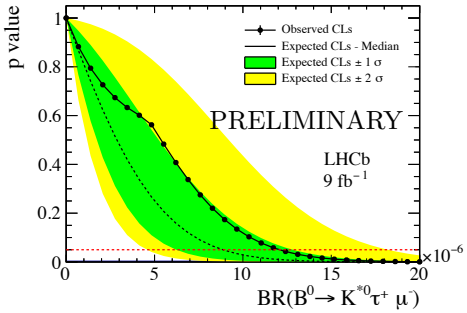
- Search for $B^0 \to K^{0*}\tau^\pm\mu^\mp$

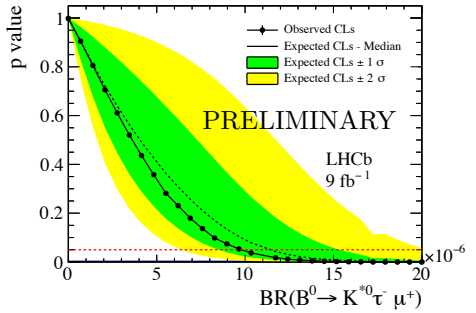
  - partial $\tau^\pm \to \pi^\pm\pi^+\pi^-(\pi^0)\bar{\nu}_\tau$ reconstruction

$\mathcal{B}(B^0 \to K^{*0}\tau^+\mu^-) < 1.0(1.2) \times 10^{-5}$ @90%(95%) C.L.

$\mathcal{B}(B^0 \to K^{*0}\tau^-\mu^+) < 8.2(9.8) \times 10^{-6}$ @90%(95%) C.L.

LHCb-PAPER-2022-021 (in preparation)





- Search for $B^0 \to K^{0*}\mu^\pm e^\mp$ and $B^0_s \to \phi\mu^\pm e^\mp$

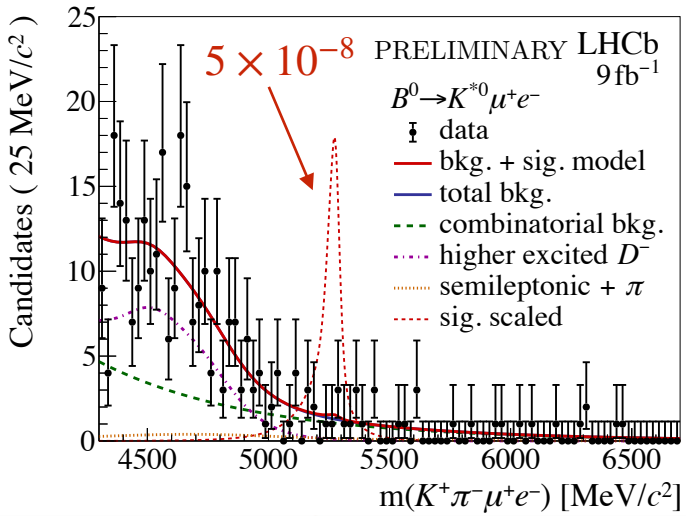
$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7(6.9) \times 10^{-9}$ @90%(95%) C.L.

$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8(7.9) \times 10^{-9}$ @90%(95%) C.L.

$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1(11.7) \times 10^{-9}$ @90%(95%) C.L.

$\mathcal{B}(B^0_s \to \phi\mu^\pm e^\mp) < 16.0(19.8) \times 10^{-9}$ @90%(95%) C.L.

LHCb-PAPER-2022-008

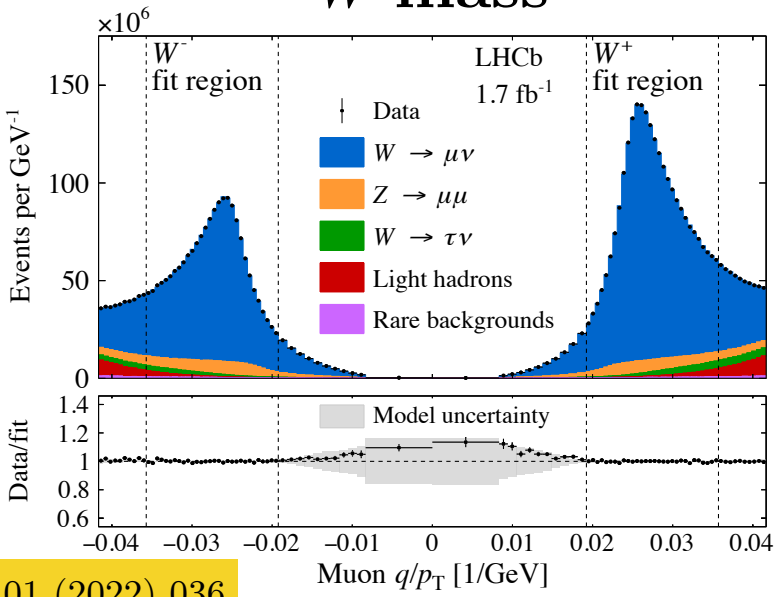


→ L. Bian in parallel sessions

Electroweak, heavy ions and fixed target

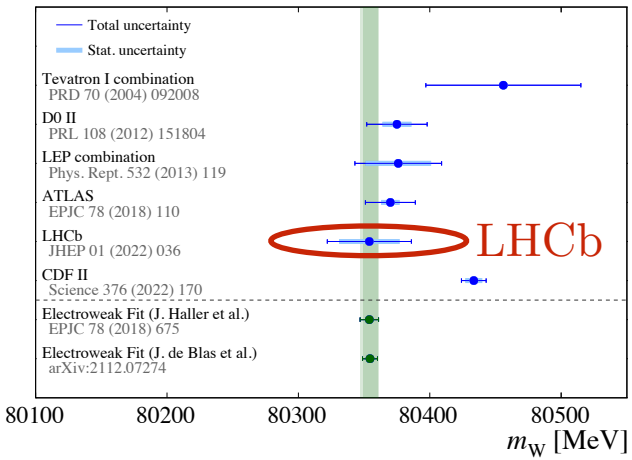
W mass and Z production

W mass

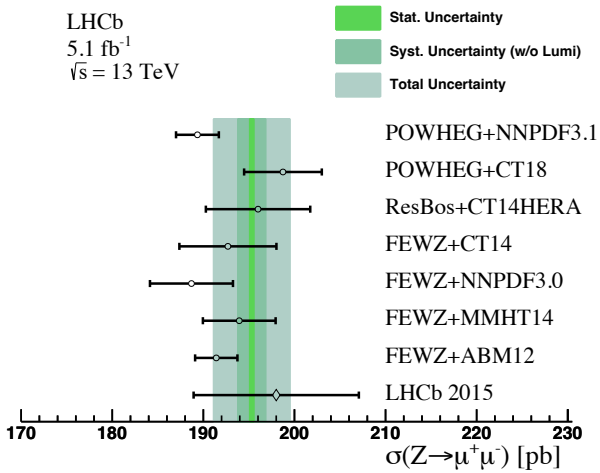


JHEP 01 (2022) 036

$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{syst}} \pm 17_{\text{th}} \pm 9_{\text{PDF}}$ MeV

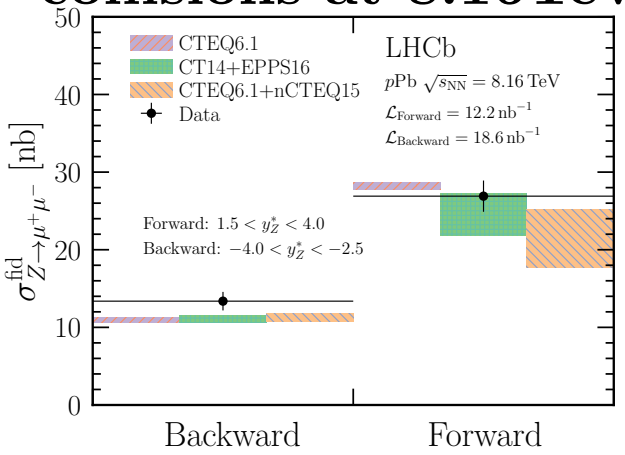


Z production in pp collisions at 13TeV



LHCb-PAPER-2021-037

Z production in pPb collisions at 8.16TeV



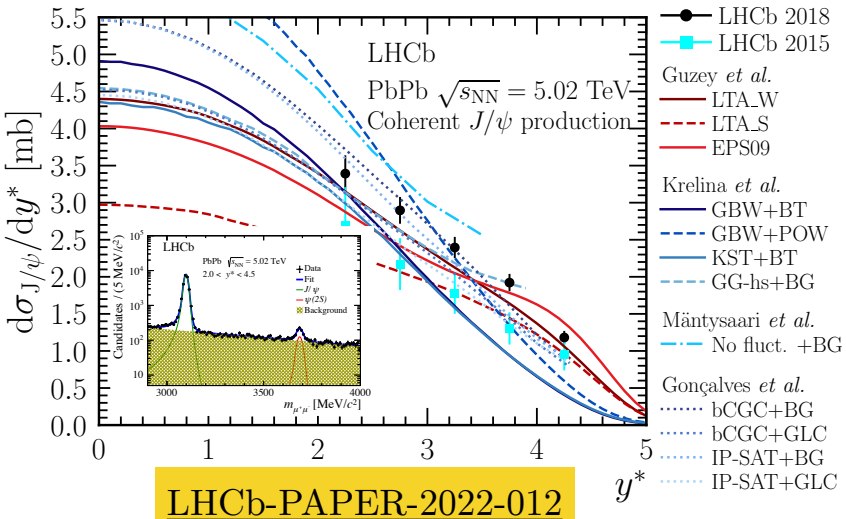
LHCb-PAPER-2022-009

→ M. Ramos Pernas & D. Lucchesi in parallel sessions

Heavy ions and fixed target

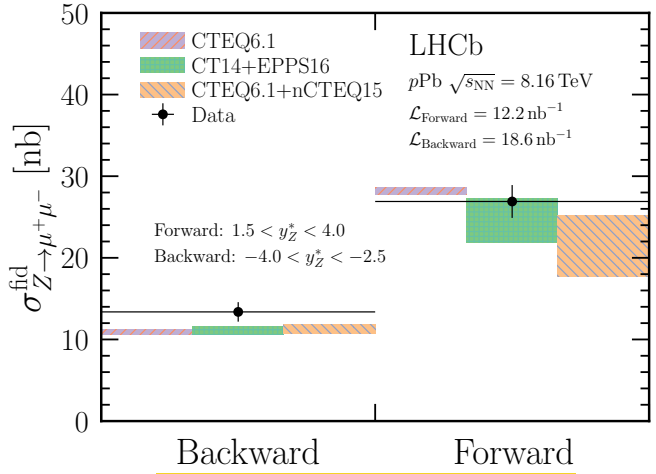
- Several results from rich **heavy-ion** physics programme

Charmonium production in PbPb at 8.16TeV



LHCb-PAPER-2022-012

Z production in pPb at 8.16TeV

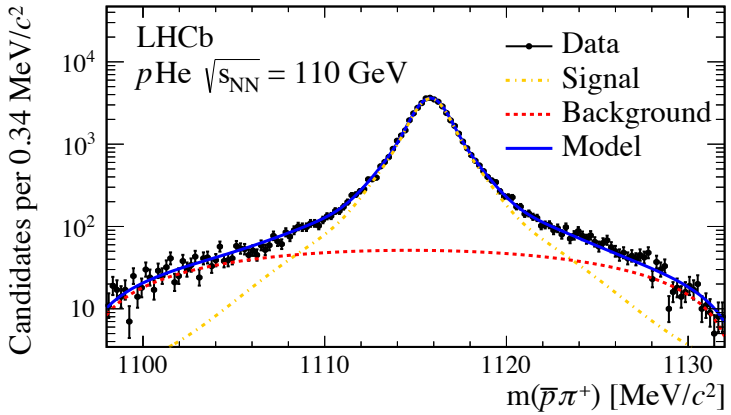


LHCb-PAPER-2022-009

- SMOG
  - gas injection system for fixed-target physics
  - New results
    - $\bar{p}$ production in pHe at 110GeV
    - charmonia production in pNe at 68.5GeV
    - J/Ψ production in PbNe at 68.5GeV

LHCb-PAPER-2022-014 (in preparation)
LHCb-PAPER-2022-011 (in preparation)

$\bar{p}$ production in pHe at 110GeV



LHCb-PAPER-2022-006

Beyond LS2

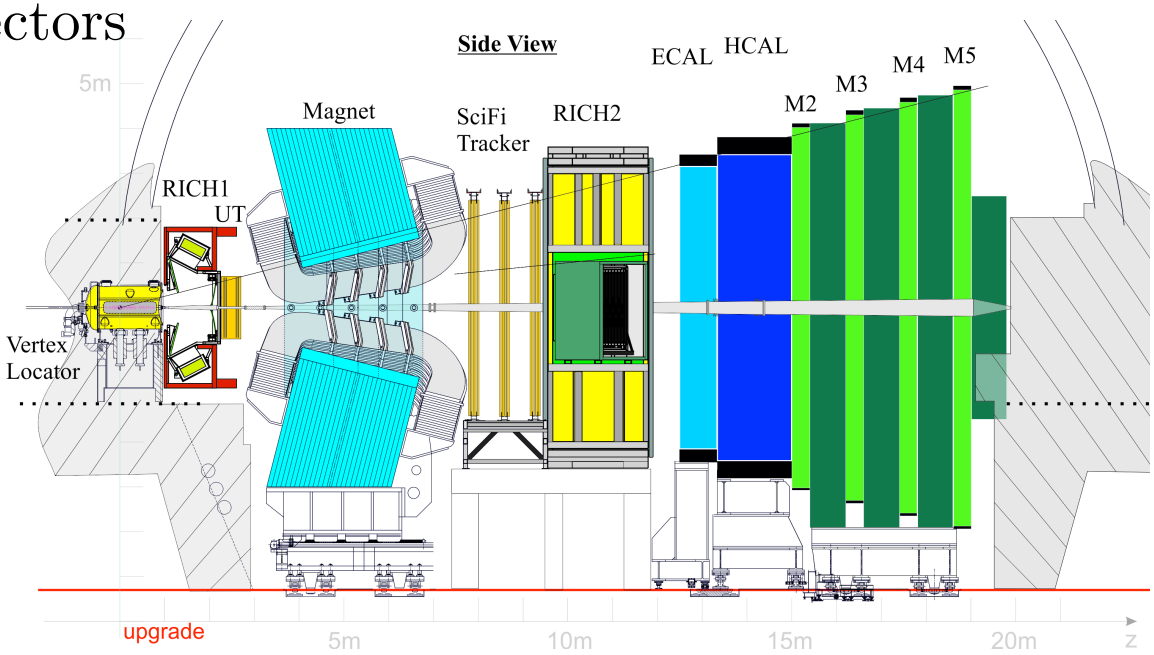
LHCb upgrade I (Runs 3+4)

- Major upgrade of all sub-detectors

→ $\mathscr{L}_{\text{peak}} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

pile-up ≈ 5

→ fully software trigger for 40MHz readout



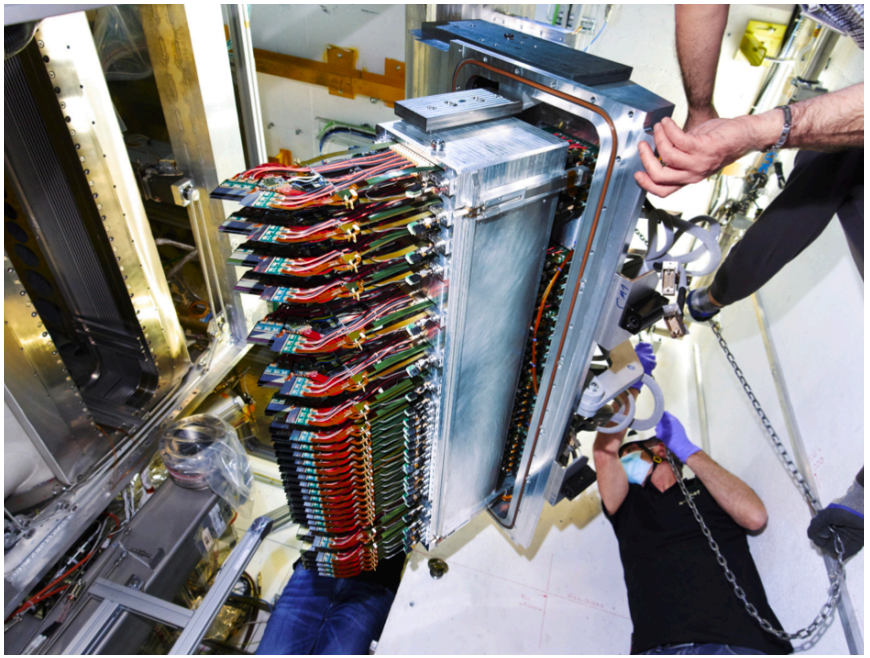
- New pixel-detector **VELO**
- New **RICH** mechanics, optics, photodetectors
- New Silicon strip upstream tracker **UT** (installation at end of year)
- New **SciFi** tracker
- New electronics for **MUON** and **CALO**
- New luminometer **PLUME**

Installed for operations in Run 3

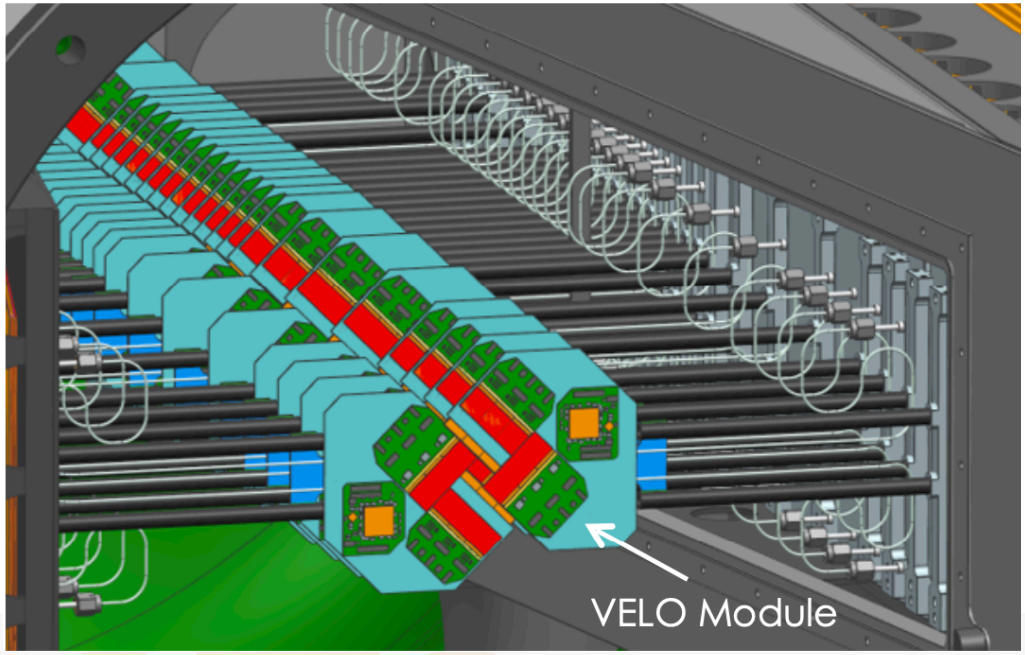
Upgrade I: VELO

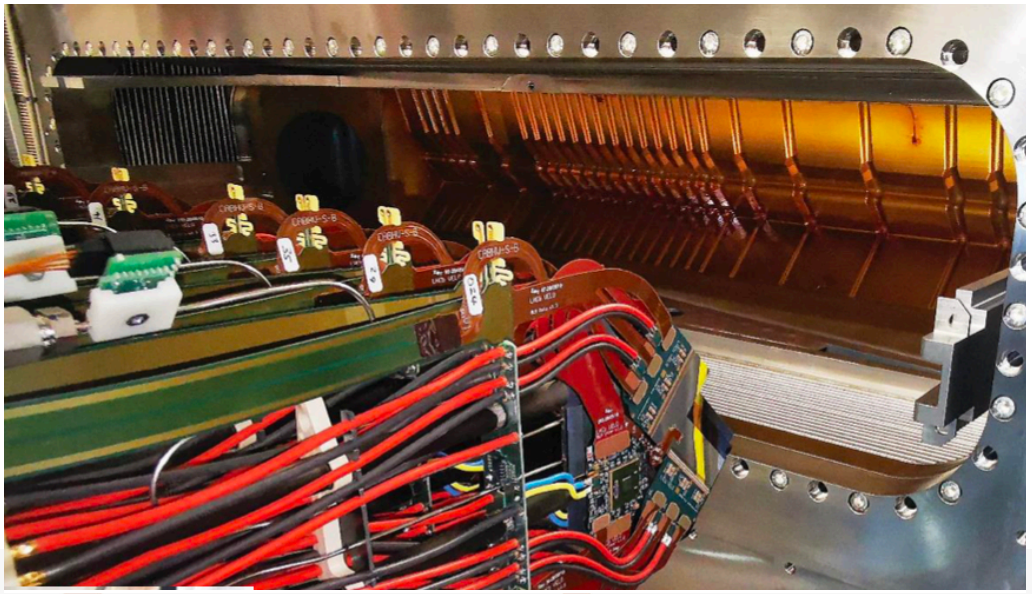
CERN-LHCC-2013-021

- Vertex pixel detector, 5mm from beam
  - innovative microchannel CO_2 cooling
- Installation completed in May
- Commissioning progressing very well!
  - in process of calibration, time and spatial alignment, tuning, while maintaining detector safety



VELO installation

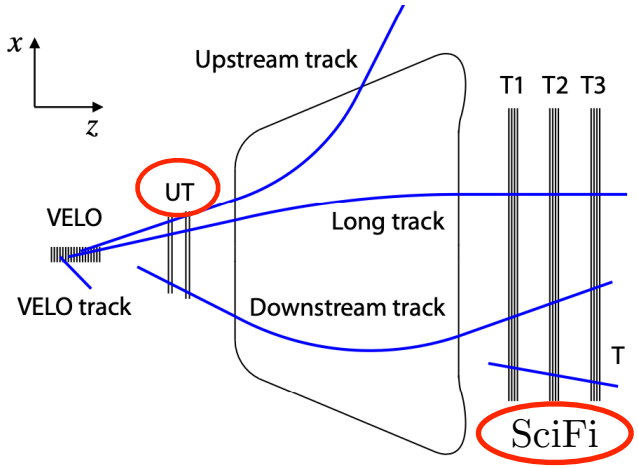


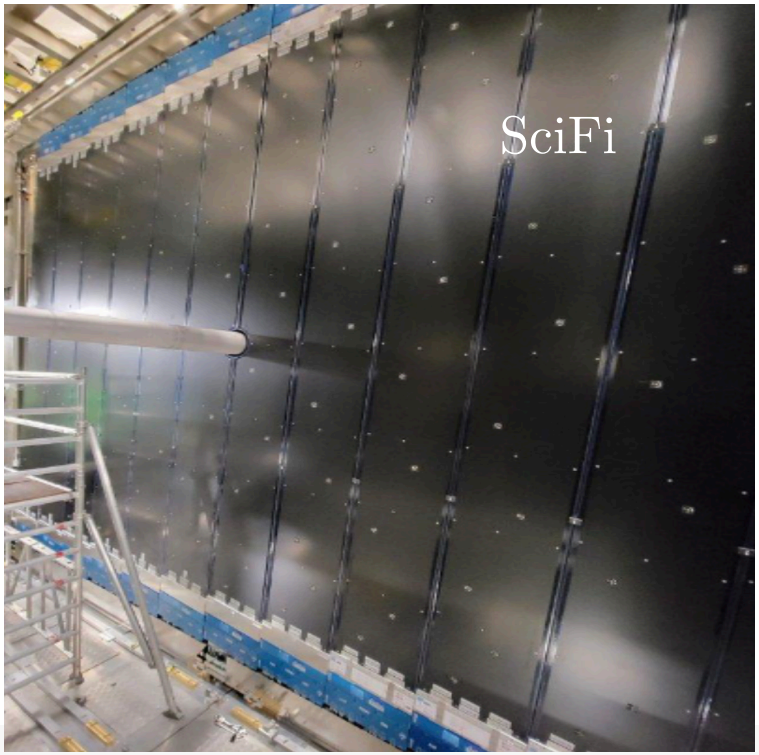


Upgrade I: UT and SciFi

CERN-LHCC-2014-001

- UT Silicon strips tracker upstream of magnet
  - Silicon strip detector with integrated cooling
  - 68 staves, arranged in 4 planes
  - assembly ongoing, installation at end of year (not essential for early physics operation)
- SciFi tracker downstream of magnet
  - scintillating fibres readout by SiPMs
  - 340m², 11'000 km scintillating fibres
  - 4096 128-channel SiPMs
  - fully installed for Run 3

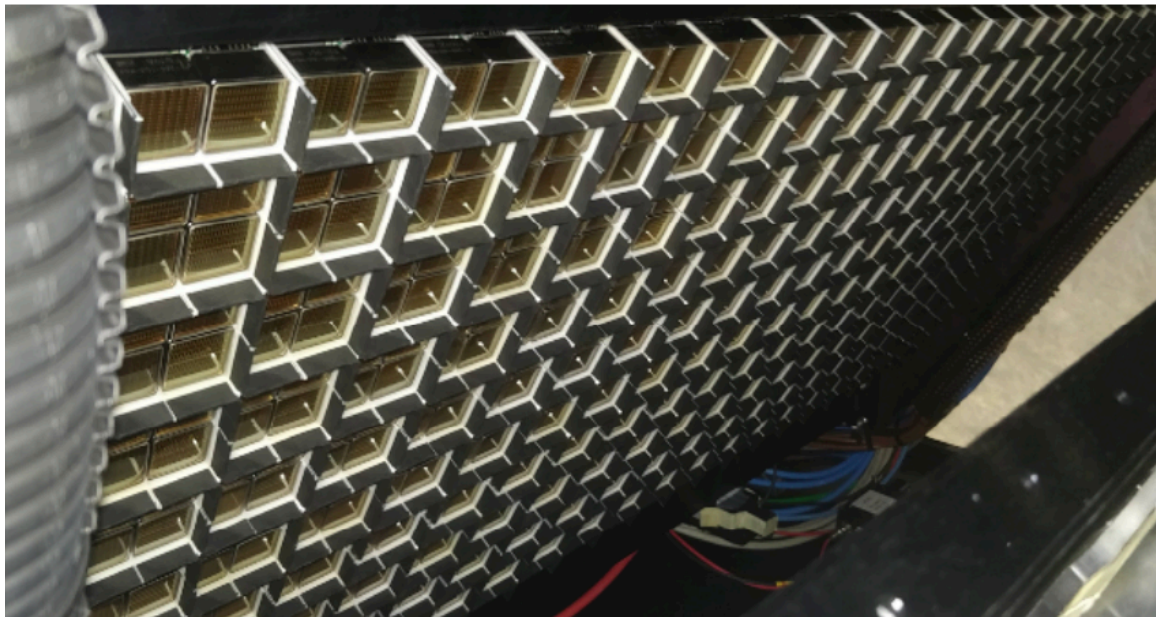




Upgrade I: RICH 1+2

CERN-LHCC-2013-022

- Particle identification system essential for flavour physics programme
  - new MaPMTs with increased granularity
  - 40MHz readout electronics
  - new RICH1 mirrors with increased focal length ⇒ 1/2 occupancy
  - installed for Run 3



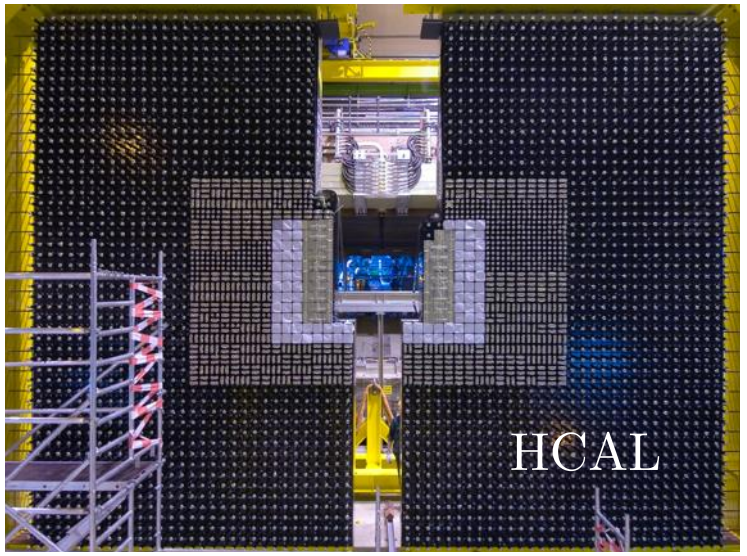
RICH 1 MaPMTs after installation (upper side)

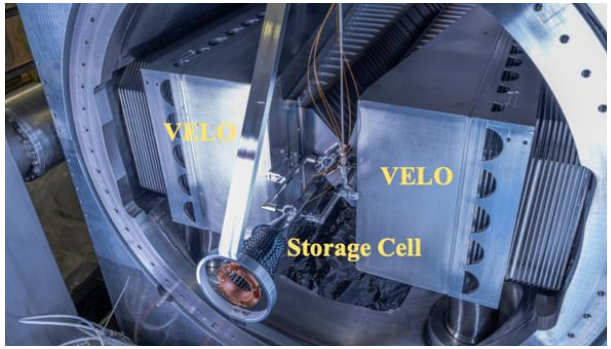
RICH 2 MaPMTs

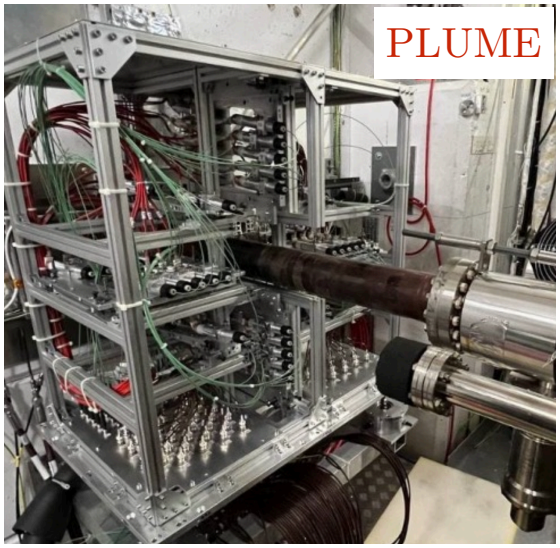
Upgrade I: CALO, MUON, PLUME, ...

All installed for Run 3

- CALO + MUON: existing detectors + new electronics → 40MHz
- Shashlik calorimeters ECAL & HCAL
- MUON CERN-LHCC-2013-022
  - 4 MWPC layers
  - iron filters
- New luminometer: PLUME
  - quartz tablets readout with PMT CERN-LHCC-2021-002
  - per-bunch luminosity measurement
- SMOG2 gas target
  - for fixed-target physics
  - gas targets for He, Ne, Ar (+ possibly H_2, D_2, N_2, Kr, Xe) CERN-LHCC-2019-005





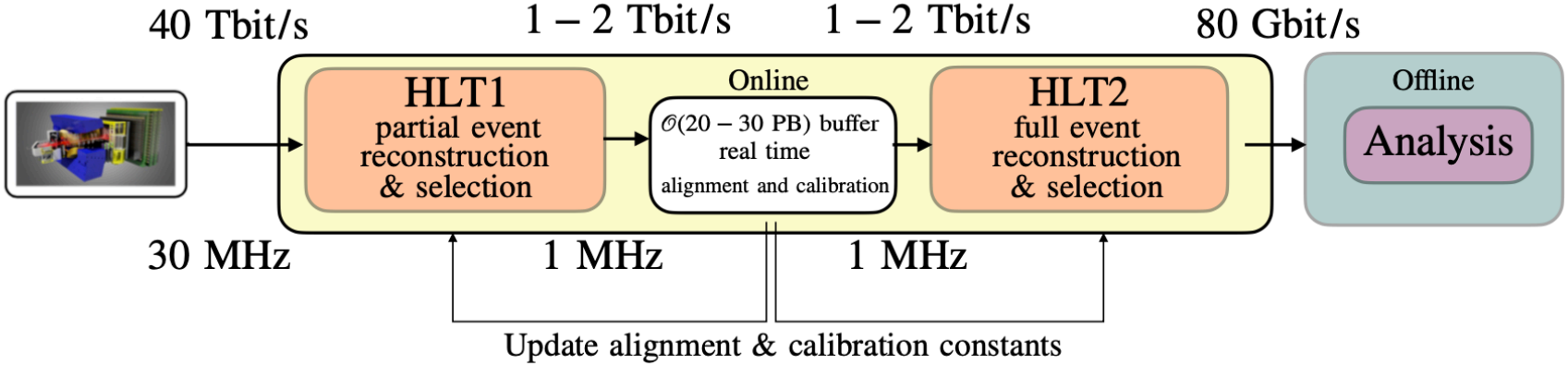


→ E. Spedicato in poster session
& E. Graverini in parallel sessions

Upgrade I: Fully software trigger

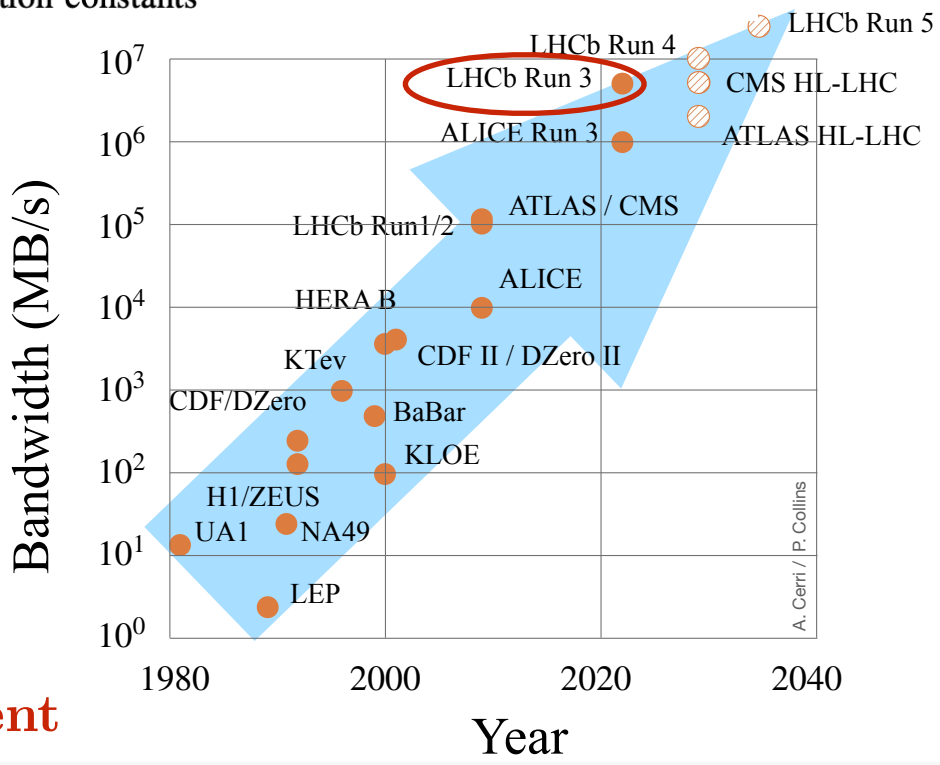
CERN-LHCC-2014-016
CERN-LHCC-2020-006

- All subdetectors read out at 40MHz → full software trigger



- 30MHz of inelastic collisions reduced to 1MHz in HLT1 (tracking +vertexing+muon ID)
  - running on GPUs

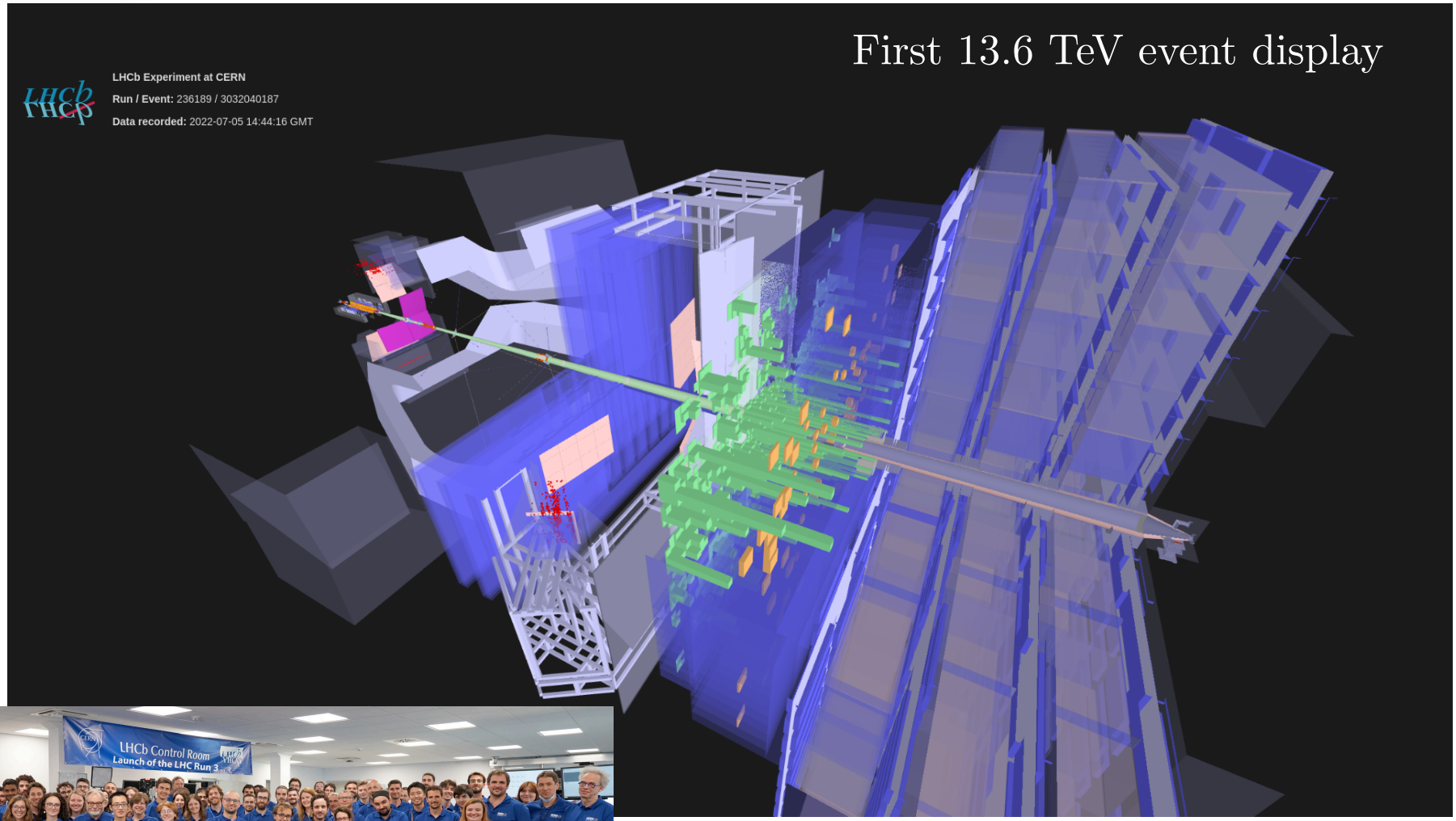
- Hadronic yield ×10 relative to Run 2



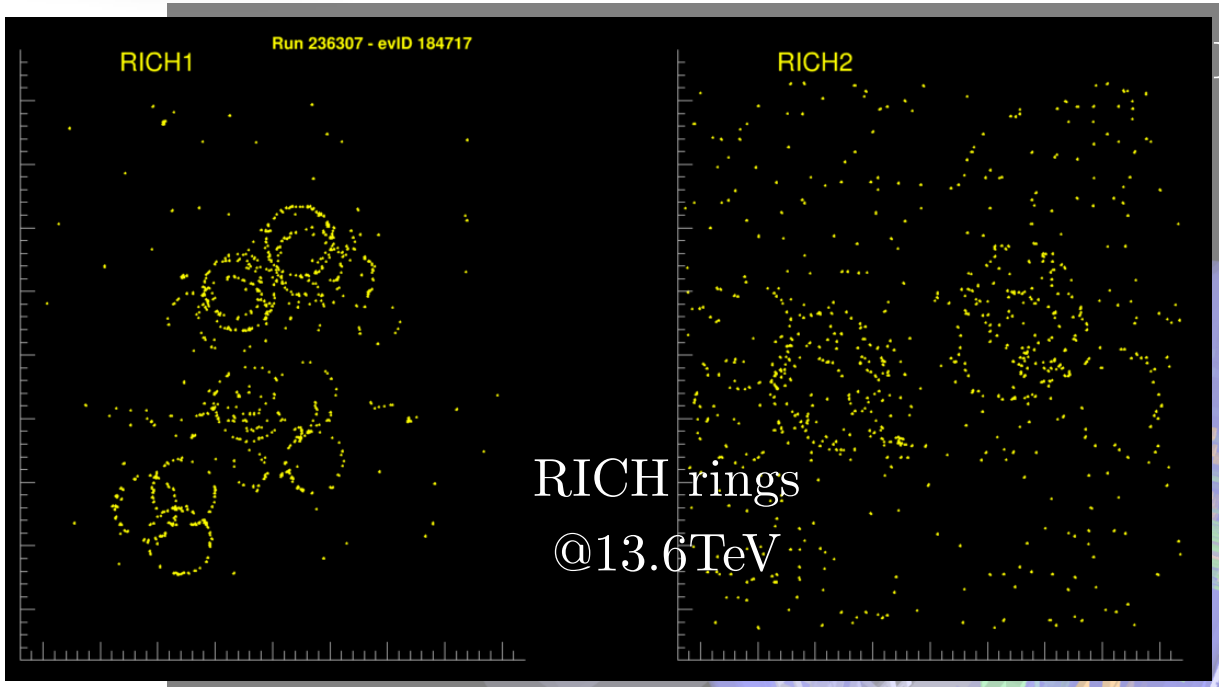
Highest throughput of any HEP experiment

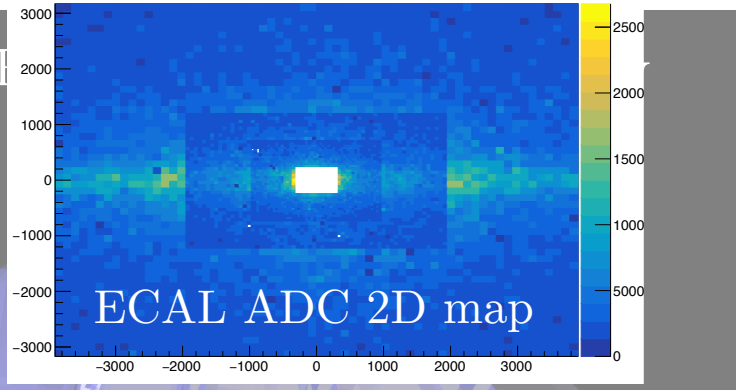
→ Ch. Agapopoulou in parallel sessions

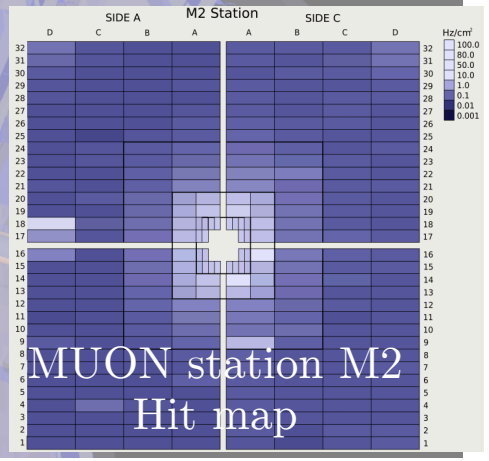
First data at 13.6TeV

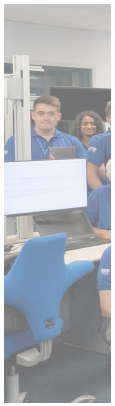


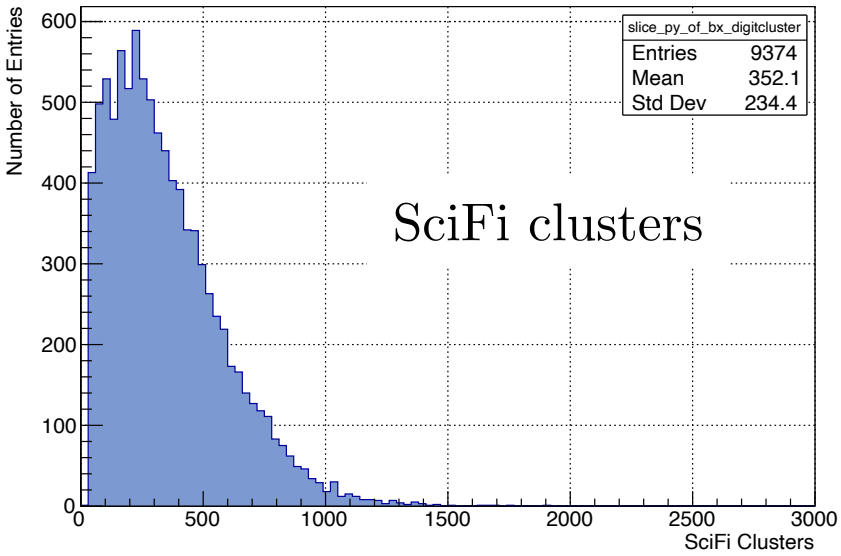
First data at 13.6TeV

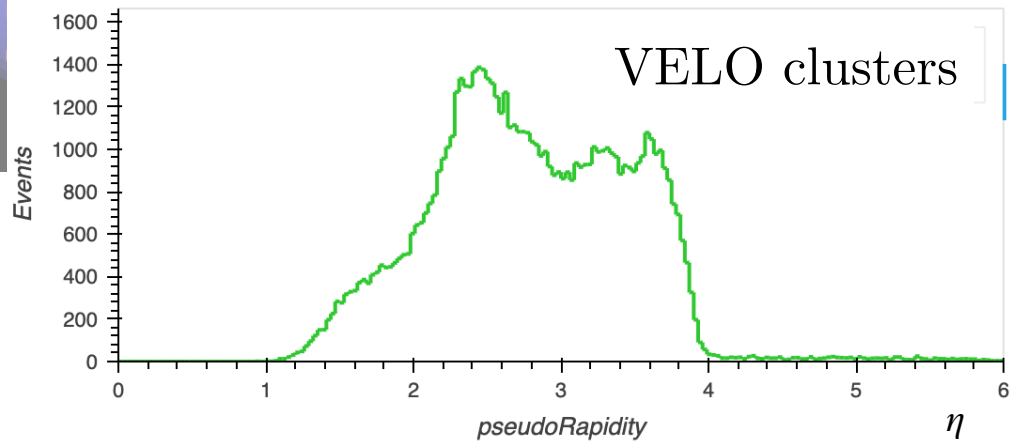












LHCb at HL-LHC (LS4)

- $\mathscr{L}_{\text{peak}} = 1.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, $\mathscr{L}_{\text{int}} \simeq 300\text{fb}^{-1}$ (Run 5+6) , Pile-up ~ 40
- Starting R&D phase of new technologies

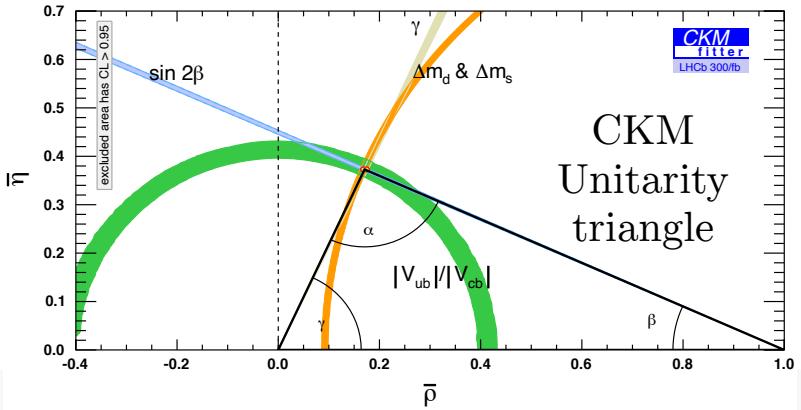
bridge to future accelerators

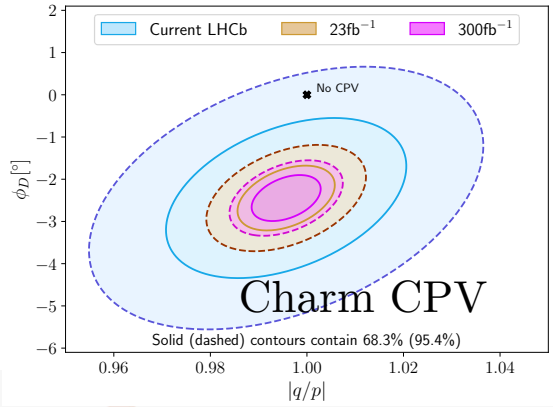
- precision timing for tracking and PID
- extreme radiation hardness
- low-cost monolithic pixels
- cryogenic cooling (for SiPMs)

→ LHCb welcomes new collaborators!

LHCC-2021-012

- Unprecedented sensitivity expected for flavour physics and beyond





→ J. Wang in parallel sessions

Summary

- Broad physics programme at LHCb
  - Flavour physics, spectroscopy, electroweak, dark sector, heavy ions...
- New upgrade I detector starting NOW!
  - recorded first collisions at 13.6 TeV
- Planning for the future:
  - Upgrade II detector: FTDR approved
    → R&D towards subdetector TDRs