

# LHCb: Physics, Velo & DPA

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Dr Juan Leite

Particle Physics Group Meeting

May 24<sup>th</sup>, 2024



# The Friendly Faces of LHCb Liverpool



Tara



David



Themis



Eva



Paras



Eduardo



Karol



Ayushi



Juan **New!**



Ashley



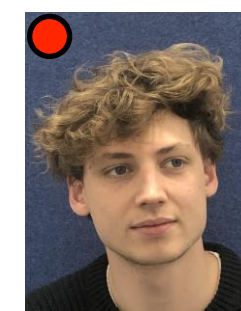
Kieran



John

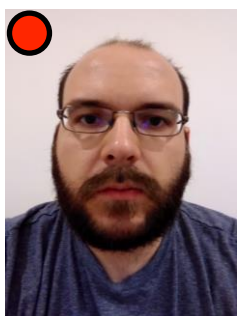


Kurt



Ned

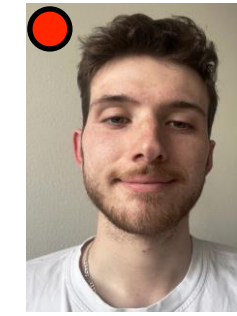
(at CERN)



**Dr** Jan



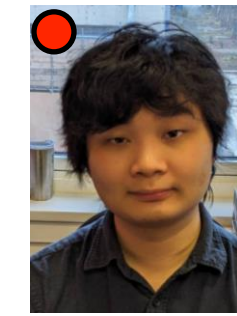
Abbie



James  
**Back from CERN!**



Sigrid



Ho Sang  
**New!**

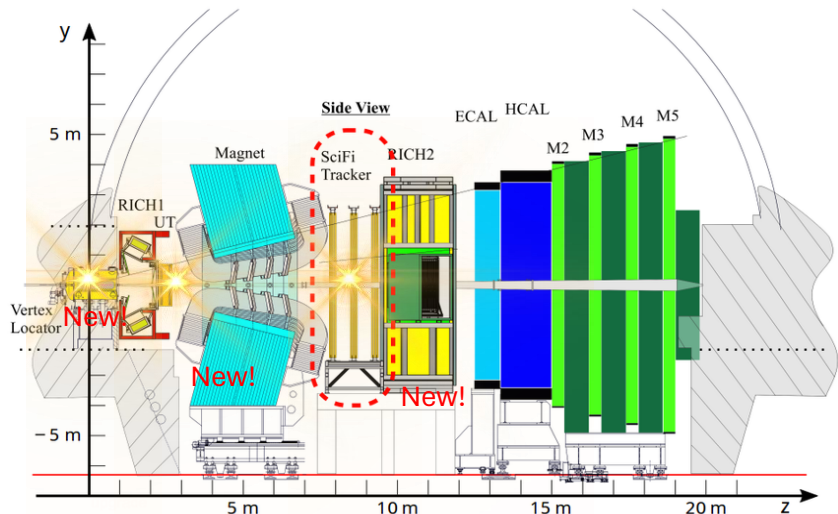


Thomas

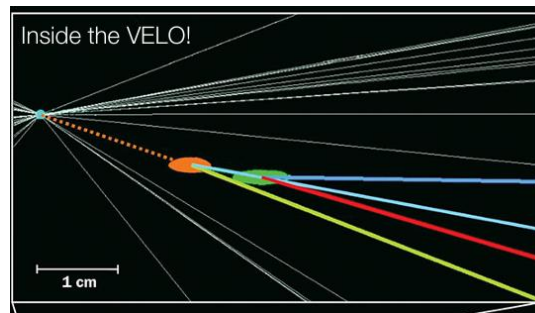
● Students (+1 in October!)

## The LHCb collaboration

“From Brits to Brazilians, Americans and Poles, the LHCb is a truly international collaboration. About 1700 scientists, engineers and technicians representing 100 different universities and laboratories from 22 countries are involved in the project (May 2023).” [Collaboration \(cern.ch\)](https://www.cern.ch)



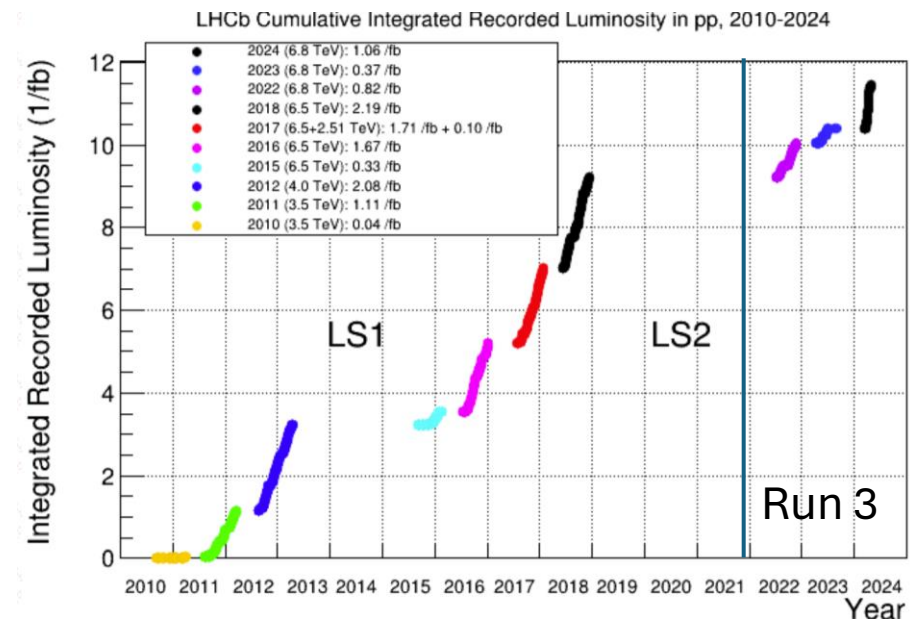
Upgrade II detector side view.  
Source → SciFi: A large Scintillating Fibre Tracker for LHCb.



## The LHCb spectrometer

Initially designed for the reconstruction b- and c-quarks particles, the LHCb detector is moving to become a general detector in the forward region. Currently, our physics programme covers:

- Hadron spectroscopy
- Rare decays
- CP-violation
- Electroweak
- Hidden sector, e.g., search for dark photons
- more



- LHCb VELO Installation & Commissioning
- LHCb VELO & Alignment Operations
- LHCb Mighty Tracker
- LHCb VELO++ software
- LHCb Quantum Computing Activities
- LHCb VELO simulation lead
- LHCb VELO DAQ
- LHCb Data Processing & Analysis Project (DPA) Leader
- HSF coordination team & HSF PyHEP WG co-convener
- SWIFT-HEP WP5 (Data Analysis) co-convener
- HFLAV Charm Decays convener
- LHCb Speakers' Bureau
- Institutional review of LHCb papers
- Worldwide LHC Computing Grid (WLCG) management board software liaison, since Sep. 2023
- LHCb RICH mirror alignment



● responsibility  
● leadership

+ Many LHCb paper committees, etc...

List of published to conference/journal since ~2022:

Analysis Facilities White Paper

FunTuple: A New N-tuple Component for Offline Data Processing at the LHCb

$$B_{(s)}^0 \rightarrow p\bar{p}$$

$$B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}$$

$$B_{(s)}^0 \rightarrow \mu^+\mu^- \text{ (and search for } B_{(s)}^0 \rightarrow \mu^+\mu^-\gamma)$$

Quantum ML for b-jet charge ID

Measurement of the W boson mass

Run 2 RICH performance

Novel sources of quantum-correlated charm

Heavy Flavour Averaging Group paper

And several more in review / leadership capacities ...

Links here → [LHCb Public results \(cern.ch\)](https://cern.ch/lhcbpublic)

**FunTuple: A new N-tuple component for offline data processing at the LHCb experiment**

Abhijit Mathad<sup>1,2,1</sup>, Martina Ferrillo<sup>1</sup>, Sacha Barr<sup>2,3</sup>, Patrick Koppenburg<sup>4</sup>, Patrick Owen<sup>1</sup>, Gerhard Raven<sup>4,5</sup>, Eduardo Rodrigues<sup>6</sup>, Nicola Serra<sup>1</sup>

<sup>1</sup> University of Zürich, Zürich, Switzerland

<sup>2</sup> European Organization for Nuclear Research (CERN), Geneva, Switzerland

<sup>3</sup> The University of Manchester, Manchester, United Kingdom

<sup>4</sup> Nikhef National Institute for Subatomic Physics, Amsterdam, Netherlands

<sup>5</sup> VU University Amsterdam, Amsterdam, Netherlands

<sup>6</sup> Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom

<sup>1</sup> Contact author: [amathad@cern.ch](mailto:amathad@cern.ch)

Keywords: High-energy-physics, LHCb experiment, Data Processing and Offline Analysis



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PUBLISHED: August 1, 2022

**Quantum Machine Learning for b-jet charge identification**

Alessio Gianelle,<sup>a</sup> Patrick Koppenburg,<sup>b</sup> Donatella Lucchesi,<sup>a,c</sup> Davide Nicotra,<sup>c,d</sup> Eduardo Rodrigues,<sup>e</sup> Lorenzo Sestini,<sup>a</sup> Jacco de Vries<sup>d</sup> and Davide Zuliani<sup>a,c,f</sup>

<sup>a</sup> INFN Sezione di Padova



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ACCEPTED: February 18, 2023

PUBLISHED: March 6, 2023

**Novel correlated  $D^0\bar{D}^0$  systems for c/b physics and tests of T/CPT**

Paras Naik<sup>1</sup>

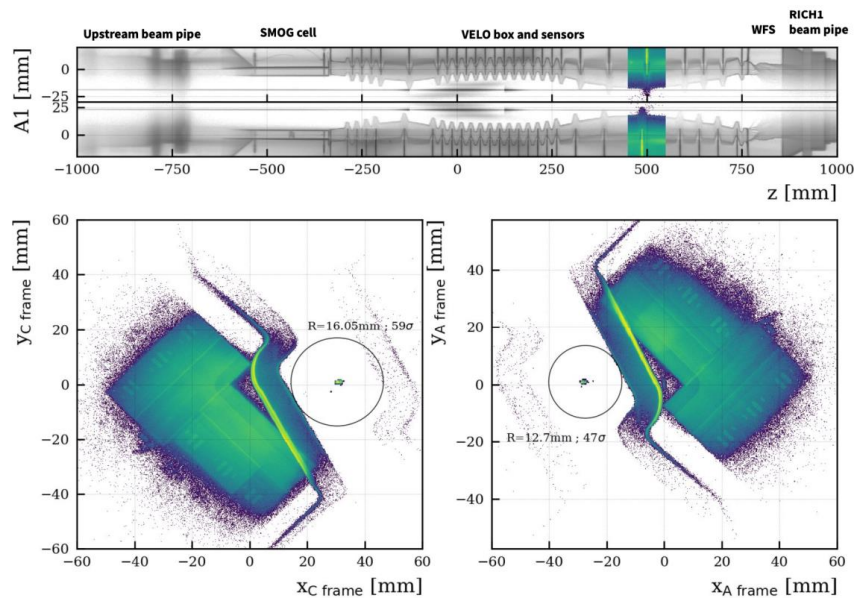
H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom

E-mail: [Paras.Naik@cern.ch](mailto:Paras.Naik@cern.ch)

# Re-installation of LHCb Velo A&C-Side

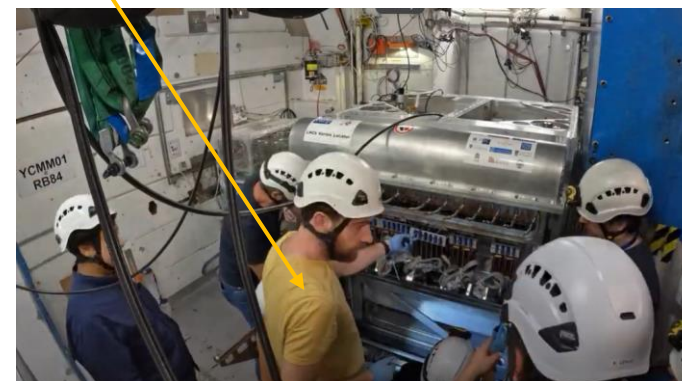


The thin aluminum (RF) foil that separates the detector modules from the LHC beam and vacuum was damaged last year by a vacuum problem, but has now been completely replaced.



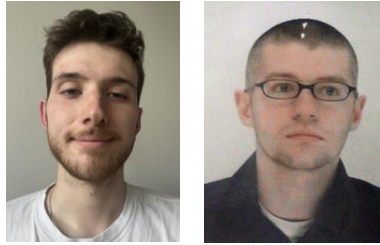
Precise Tomography of the VELO (using beam-gas)

Active Kieran participation in Re-Installation.

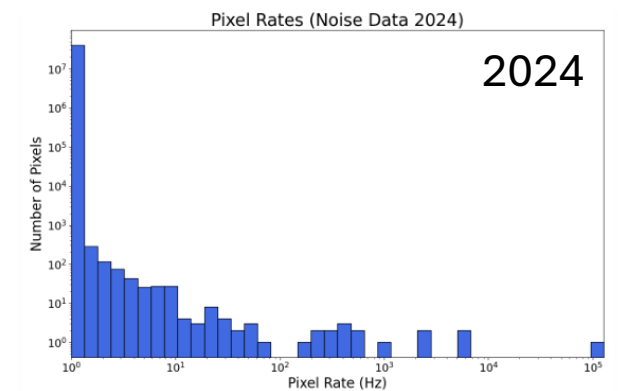
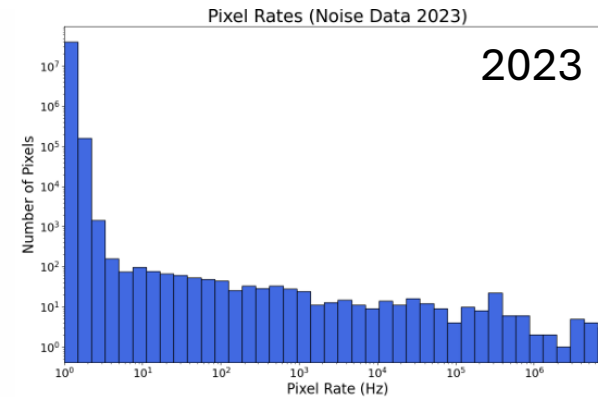
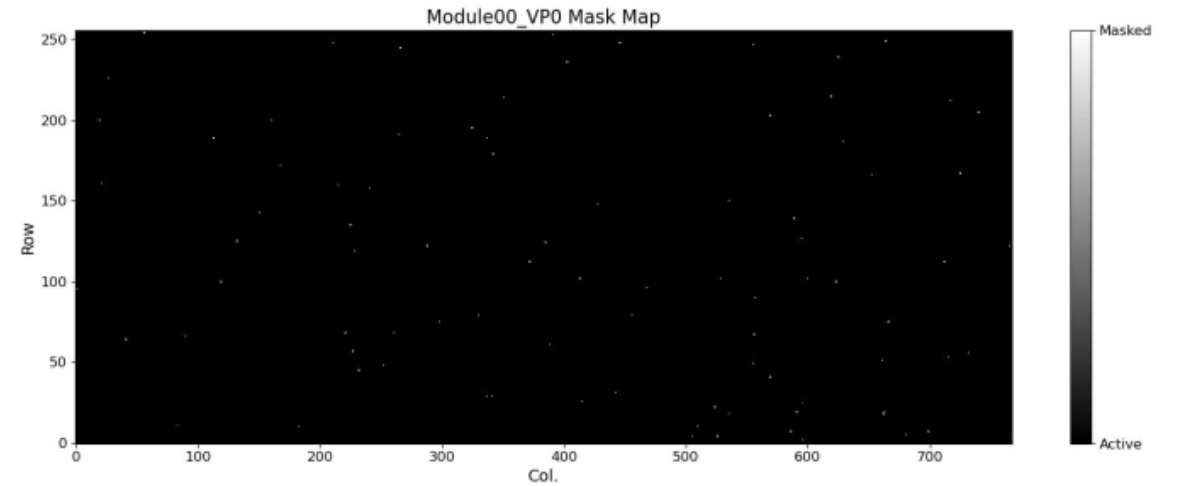


A nice video can be found here → [Re-Installation LHCb VELO A&C-Side \(short version\)](#)

## Noise of the VELO



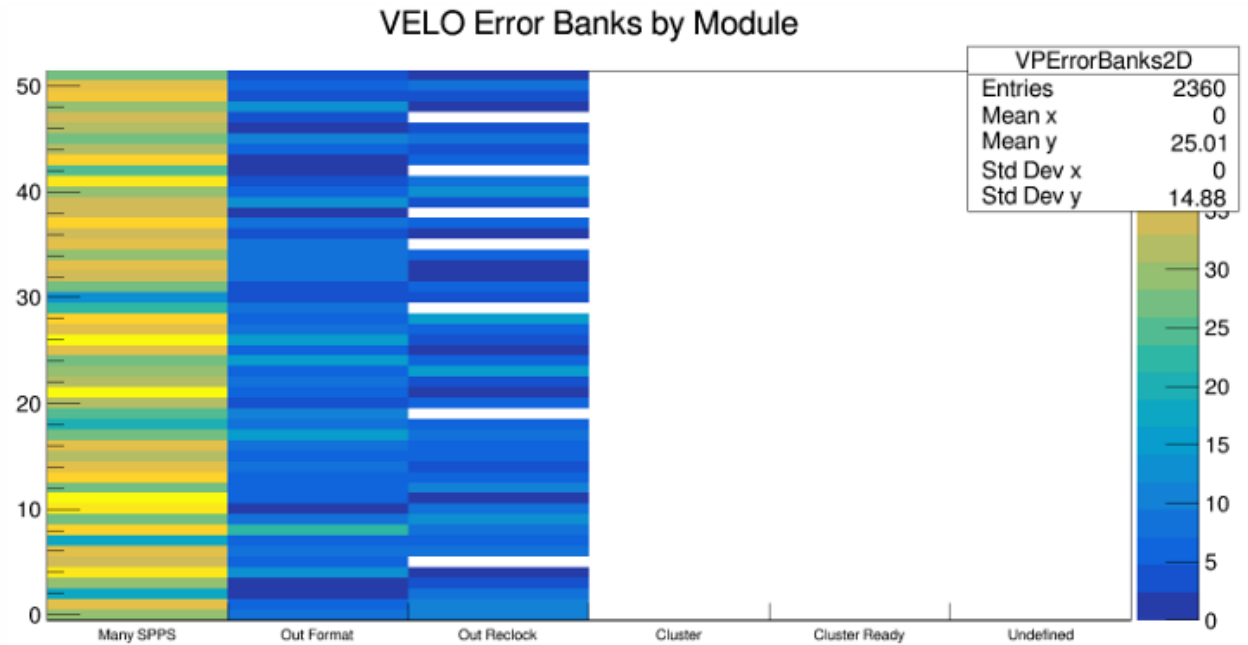
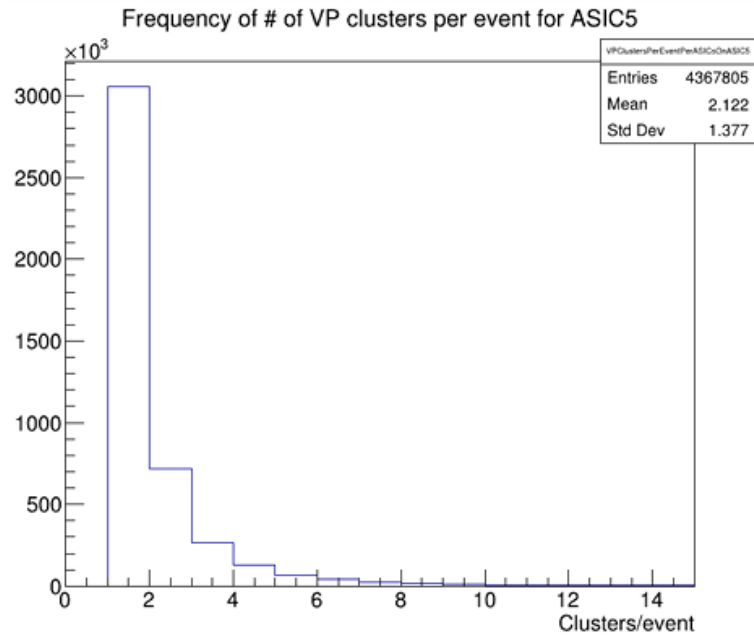
- Aim is to minimise noise via masking, monitor noise, and investigate any anomalies
- Considerable progress over the last commissioning year
- The number of masked pixels has been reduced
- Reduced the noise rate



# New Monitoring plots



New VELO monitoring error plots are available in the Monet web interface for real-time data acquisition checking.





## DAQ and Front-end

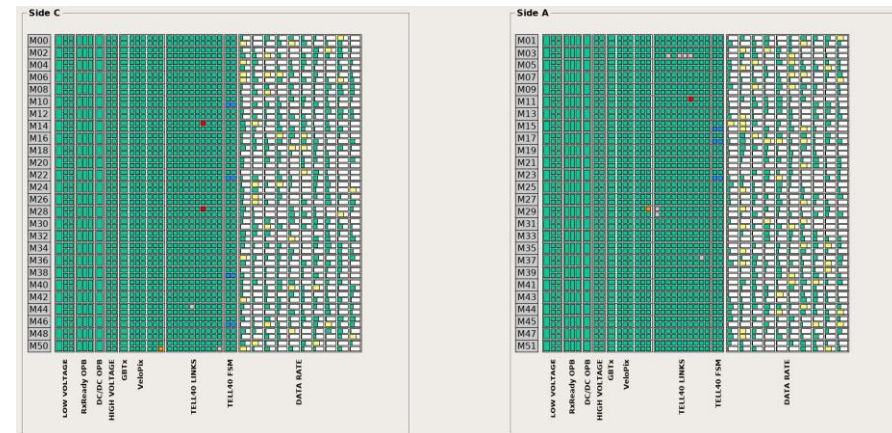


Goal: Achieve the full data-taking efficiency at nominal luminosity

- Lots of improvements to firmware/software for monitoring and error handling in the last year.
- Latest efficiency numbers in the last week are 92-95% for full LHCb
  - Still some room for improvement but we're off to a **very good start in 2024.**

Front-end:

- Developed tools to easily generate new VELO configurations
- New libraries for recipes, optimized calibrations
- Scaling legacy code to full detector operation

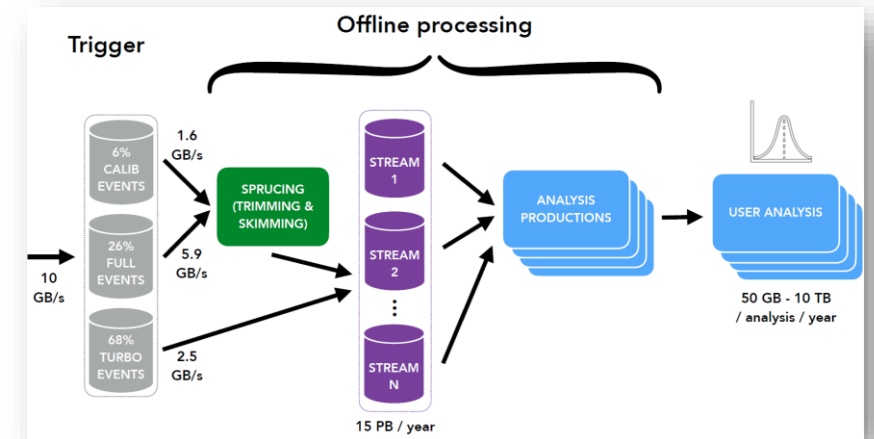


Operational monitoring of DAQ (whole detector view)

# LHCb Data Processing & Analysis (DPA)



- The DPA project addresses the challenges due to the very large increase in data volume due to new operational trigger rate of 1MHz.
- Centralized skimming and trimming of a significant fraction of HLT2 outputs. Centralized analysis productions for physics analysts.
- Heavy contributions to the analysis software itself and innovative analysis techniques, including Quantum Machine Learning (generating great interest even outside LHCb!)

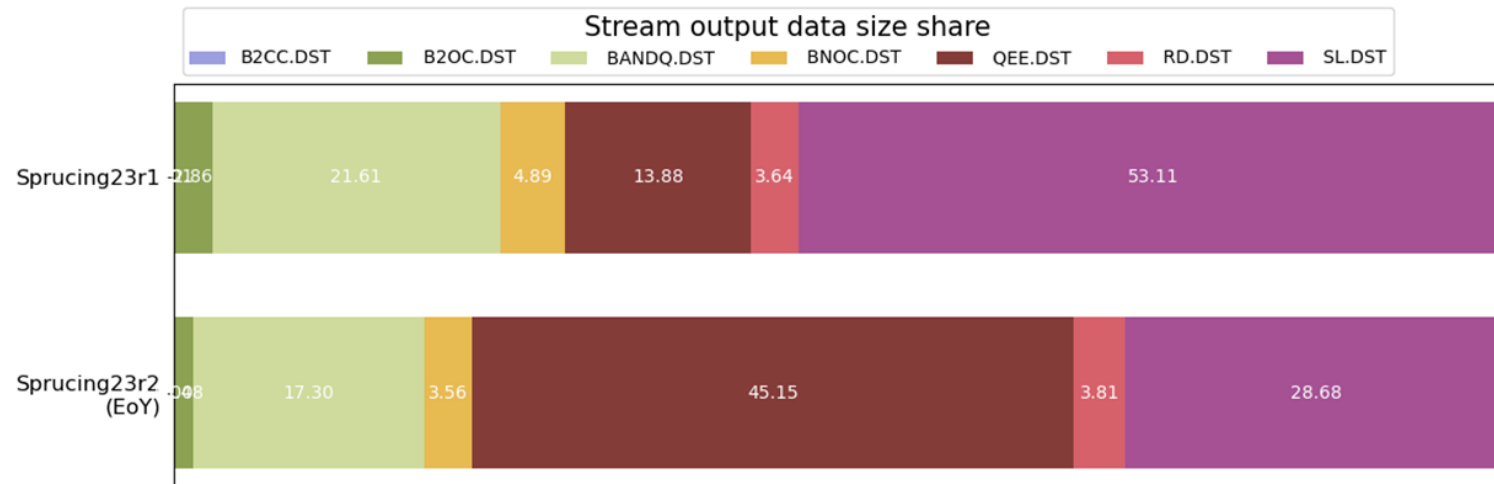


Centralised offline data processing, selections and streaming that runs on the output of HLT2 in Run 3 and beyond.

## DPA status:

“We got no real showstoppers or issues during commissioning and are smoothly doing our part of the data taking process.”

# Sprucing campaigns in Collision23 pp overview



Clear differences between EoY and “concurrent” data size share.

Sprucing23r1: 2023 concurrent campaign

Sprucing23r2 (EoY): the End-Of-Year campaign when everything got Spruced with updated+new selections from the various physics WGs.

# Open Data & Ntuple Wizard



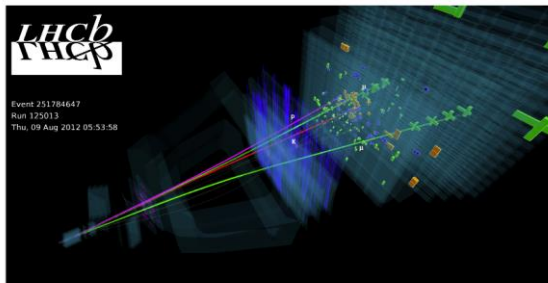
LHCb experiment released all Run 1 data at the end of Dec/2023 - 800 terabytes are now available

- This data can be used for research and education purposes
- An [open forum](#) was created for feedbacks and how the data is used

## LHCb experiment releases all of its Run 1 proton-proton data

The latest release makes LHCb research data, used by researchers to produce a number of significant results, available to anyone for a wide range of physics studies

11 JANUARY, 2024 | By LHCb collaboration

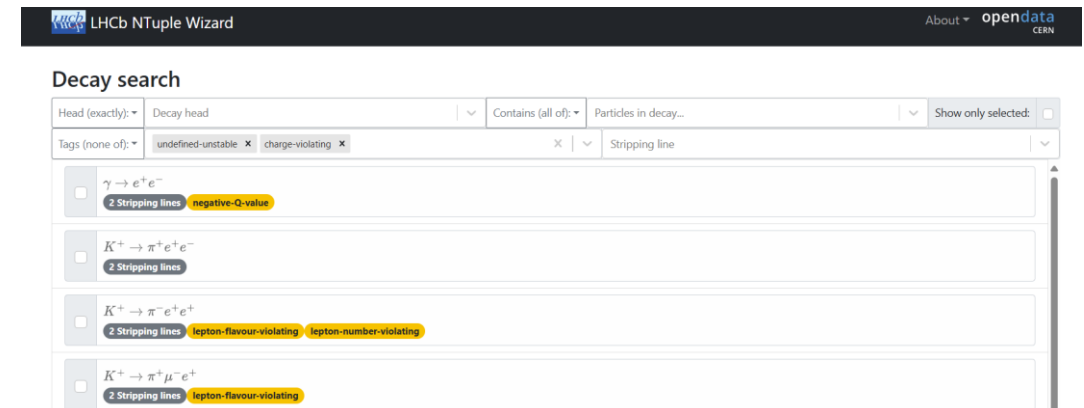


An event display recorded in 2012, during LHC Run 1. (Image: LHCb collaboration)

[LHCb experiment releases all of its Run 1 proton-proton data | CERN \(home.cern\)](#)

Ntuple Wizard is the future open Run 2-3 data

- Handles the Ntuple step, skipping the necessity of knowledge about LHCb software reducing the barrier for external analysts
- Web interface available for tests for LHCb users



LHCb NTuple Wizard

About open data CERN

Decay search

Head (exactly): ▾ Decay head | Contains (all of): ▾ Particles in decay... ▾ Show only selected:

Tags (none of): ▾ undefined-unstable × charge-violating × | Stripping line ▾

- $\gamma \rightarrow e^+ e^-$   
2 Stripping lines negative-Q-value
- $K^+ \rightarrow \pi^+ e^+ e^-$   
2 Stripping lines
- $K^+ \rightarrow \pi^- e^+ e^+$   
2 Stripping lines lepton-flavour-violating lepton-number-violating
- $K^+ \rightarrow \pi^+ \mu^- e^+$   
2 Stripping lines lepton-flavour-violating

## Purely Baryonic B decays and Baryon decays to purely baryonic final states



- Purely baryonic decays are a class of particle decay that is essentially unexplored.
- First look at  $\Lambda_b^0 \rightarrow \Lambda_c^+ \Lambda_c^- n^0$  using Run 2 data
  - First time performed and unique at Liverpool
- Run 3 Trigger lines analyses under development for the decay channels:
  - $\Lambda_b^0 \rightarrow \Lambda_c^+ \Lambda_c^- n^0$ 
    - $B^+ \rightarrow \Lambda_c^+ \Lambda_c^- K^+$  (norm channel)
  - $\Lambda_b^0 \rightarrow p \bar{p} n^0$
  - $B_{(s)}^0 \rightarrow p \bar{p}$  and  $B_{(s)}^0 \rightarrow p \bar{p} p \bar{p}$ 
    - $B_s^0 \rightarrow J/\psi(1S) \phi(102), J/\psi(1S) \rightarrow p \bar{p}$
    - $B_0 \rightarrow J/\psi(1S) K^{*0}(892), J/\psi(1S) \rightarrow p \bar{p}$



More info on [Ned's talk](#) and in the article below

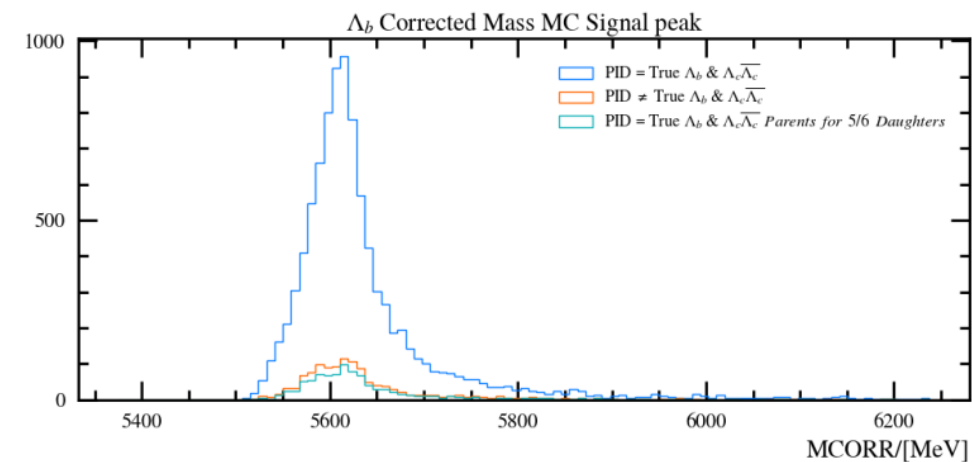
Article | [Open access](#) | Published: 04 February 2019

### Baryon decays to purely baryonic final states

[Y. K. Hsiao](#), [C. Q. Geng](#) & [Eduardo Rodrigues](#)

[Scientific Reports](#) **9**, Article number: 1358 (2019) | [Cite this article](#)

2134 Accesses | 1 Citations | 1 Altmetric | [Metrics](#)



## Search for right-handed weak decays



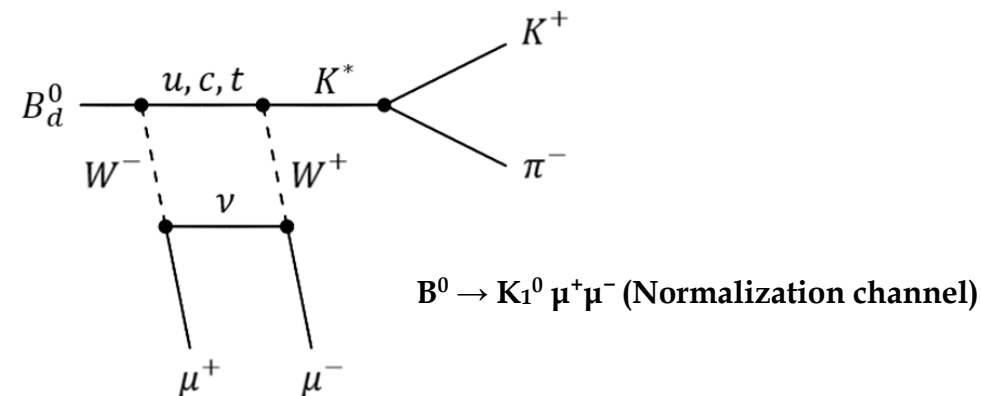
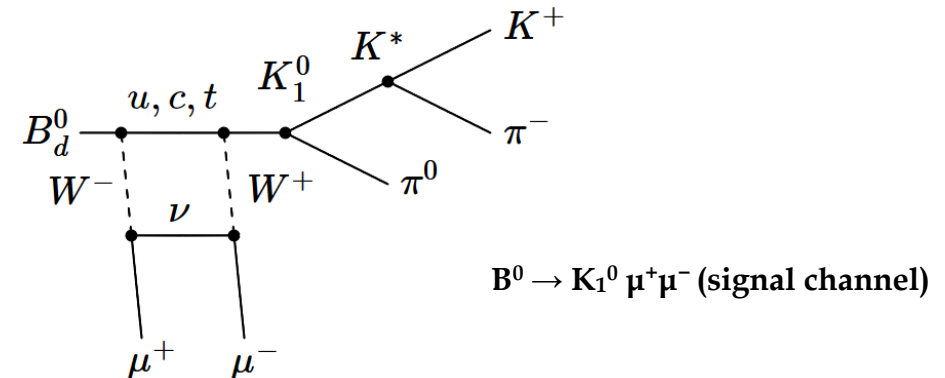
Status: **in progress...**

To search for right-handed weak decays by using parity doubling, we compare two channels with opposite parity products (in this case  $B^0 \rightarrow K_1^0 \mu^+ \mu^-$  and  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ ) where there is a cancellation of SM interactions that would otherwise dilute any BSM contributions.

- Aims to observe the decay  $B^0 \rightarrow K_1^0 \mu^+ \mu^-$  and use  $K_1^0$  and  $K^{*0}$  to perform a sensitive search for the relative contributions of left- and right-handed weak currents in B decays.
- The Run 2 & Run 3 lines are complete for the  $K_1^0$  channel. Run2 data is collected and Run3 is being collected. Current analysis will use Run2 data only.

More info on [James' talk](#).

### Feynman diagrams



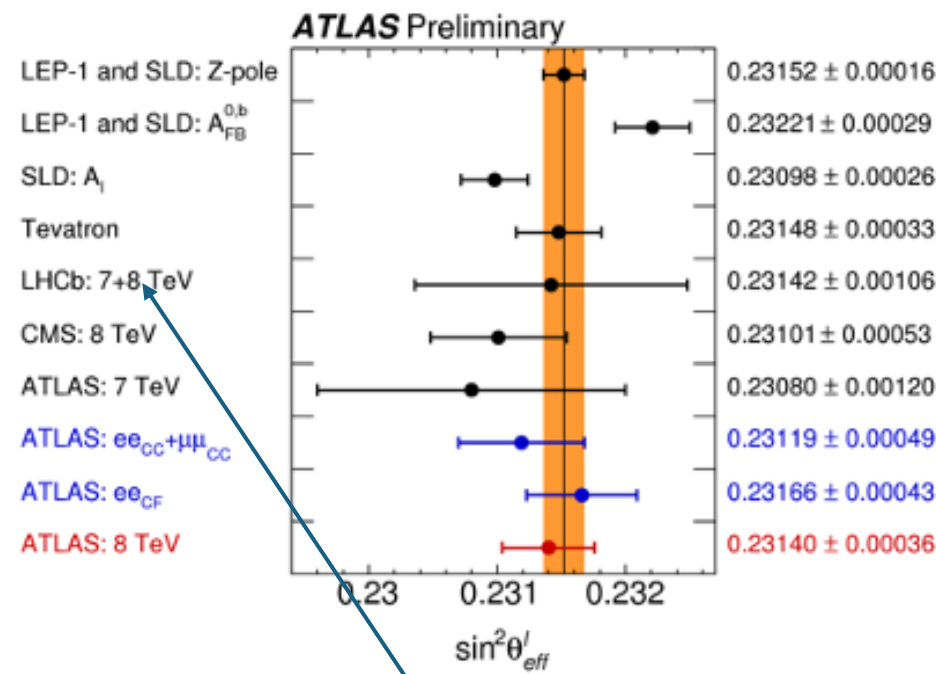
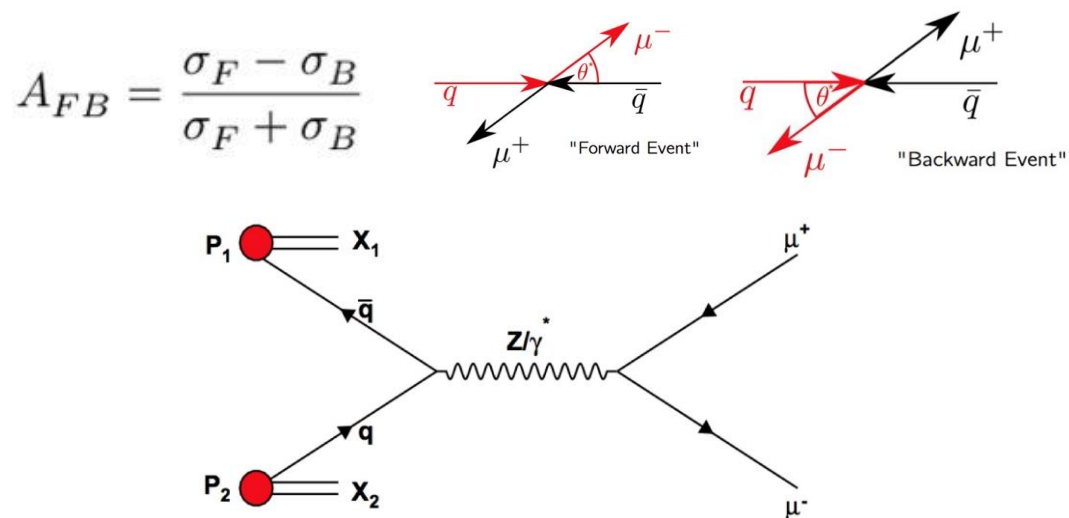
## Z decay Forward-backward Asymmetry



Status: **LHCb Review**

- Study of the asymmetry  $A_{FB}$  in  $Z \rightarrow \mu^+\mu^-$  decays, with Run 2 (13 TeV) data. The interference between Z boson and virtual photon gives rise to a non-zero  $A_{FB}$  value.

- Knowing  $A_{FB}$  allows us to measure key electroweak parameters, such as  $\sin^2(\theta_W)$



Performed in Liverpool!  
(by Joe Price, et al.) - [JHEP 11 \(2015\) 190](#)

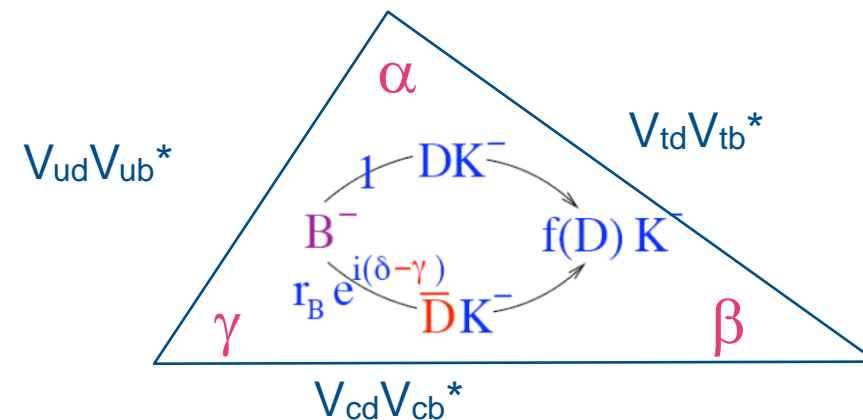
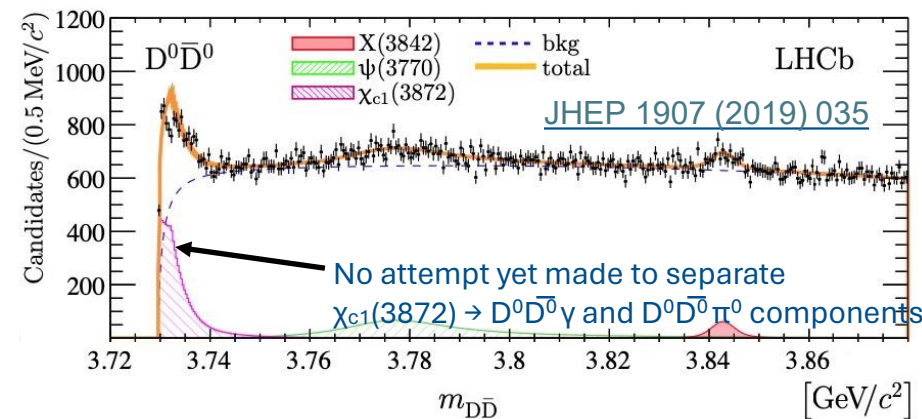
## Quantum Correlated Charm

Status: **in progress...**



### JHEP 03 (2023) 038:

- Charm correlations exist in  $J^{PC} = 1^{++}$  sources such as  $\chi_{c1}(3872) \rightarrow D^0 \bar{D}^0 \{\pi^0, \gamma\}$
- Leading uncertainty on CKM phase  $\gamma$  is due to knowledge of D decay phases
- Expect (conservatively) to reduce total D decay error on CKM phase  $\gamma$  by factor  $\sqrt{2}$  with Run 3 and Run 4 data.





## Quantum Correlated Charm

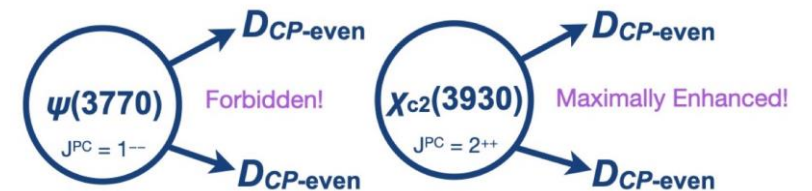
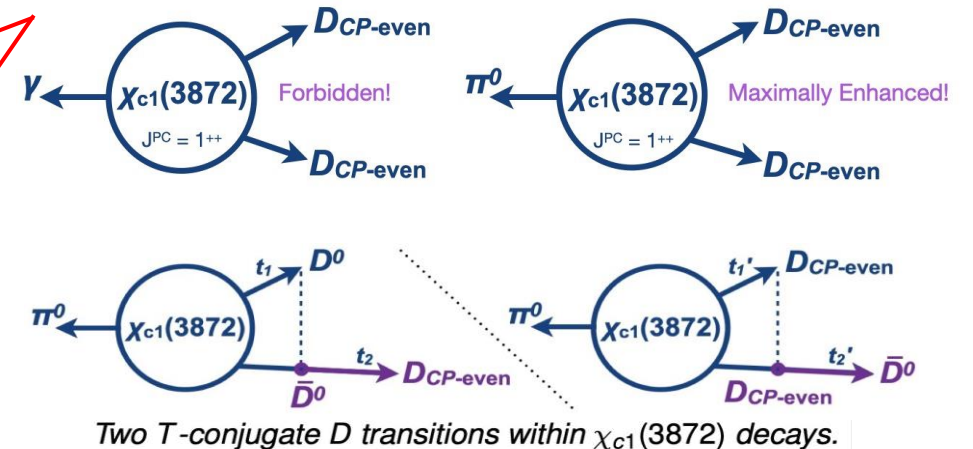
Status: **in progress...**



JHEP 03 (2023) 038:

- By clever reconstruction
  - $\chi_{c1}(3872) \rightarrow D^0 \bar{D}^0 \gamma$  is forbidden;  
 $\chi_{c1}(3872) \rightarrow D^0 \bar{D}^0 \pi^0$  doubled
  - Isolating  $D^0 \bar{D}^0 \pi^0$  lineshape allows separation of  $D^0 \bar{D}^0$  C-states – crucial for D decay phase studies.
  - Novel idea to use  $\chi_{c1}(3872)$  decays to test charm T (time-reversal) conservation
    - Only LHCb can test T in charm
- Remove (enhance) C = -1 (+1)  $D^0 \bar{D}^0$  resonances in  $B \rightarrow D^0 \bar{D}^0 X$  amplitude analyses
  - Currently quantifying the impact of this technique for tetraquark searches

Studies being performed by **Ho Sang**



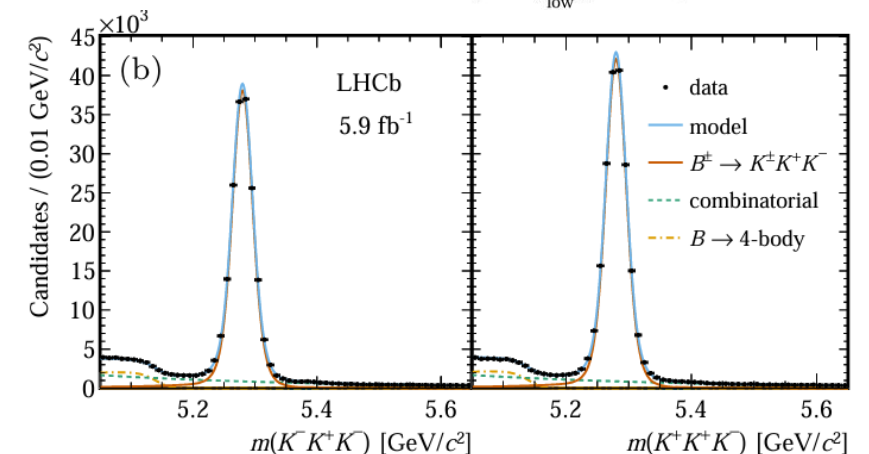
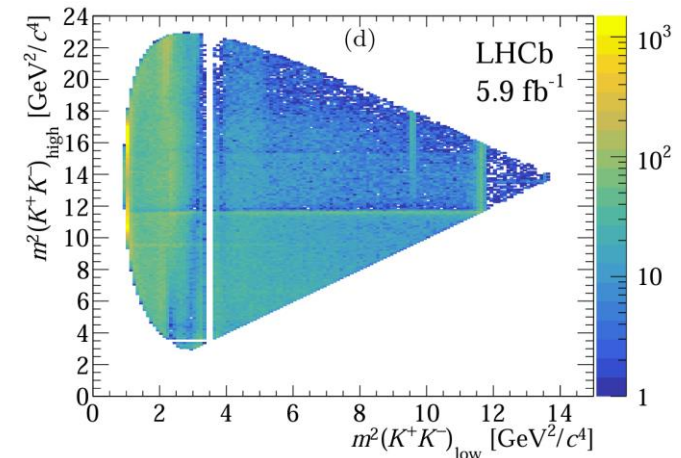
More info: [IOP HEPP presentation](#)  
[Paras' Liverpool Seminar](#)

# Amplitude analysis of $B^+ \rightarrow K^- K^+ K^+$



Status: **in progress...**

- First analysis of LHCb for this decay channel
  - Run 2 data sample with 365k candidates
- Aims to determine the resonance structure and perform a model dependent CP-violation study of the  $B^\pm \rightarrow K^\mp K^\pm K^\pm$  decay
- Approaches that will be used to describe the Dalitz plot
  - Isobar model
  - Quasi-Model Independent (QMI)
  - K-Matrix (maybe)
  - S-wave phenomenological models
- Preparing GooFit (Framework to perform Dalitz plot fits on GPU) to reach the required numerical precision
- This analysis is being performed along with LHCb CBPF-Brazil group



2206.07622 (arxiv.org)

We've made present on several conferences in 2023/2024:

**WLCG/HSF Workshop 2024**, DESY, Hamburg, 13-17 May 2024 - plenary at closing session "HSF: summary and next steps"

**WLCG/HSF Workshop 2024**, DESY, Hamburg, 13-17 May 2024 - The Scikit-HEP project - overview and future

**Joint GridPP / SWIFT-HEP Workshop**, Sheffield, 25-27 March 2024 - Updates on C&SW in CERN/SFT

**Joint APP, HEPP and NP Conference** 8-11 April 2024 - Novel sources and uses of quantum-correlated charm systems

**Joint APP, HEPP and NP Conference** 8-11 April 2024 - Search for Right-Handed Weak Decays with the LHCb Detector

**LHCb-UK Meeting** January 2024

**24<sup>th</sup> IEEE Real Time conference** (Vietnam), FPGA Tracking with oneAPI

**VERTEX 2023** , Status of the Vertex Locator

**CKM 2023**, Rare kaon and charm decays at LHCb

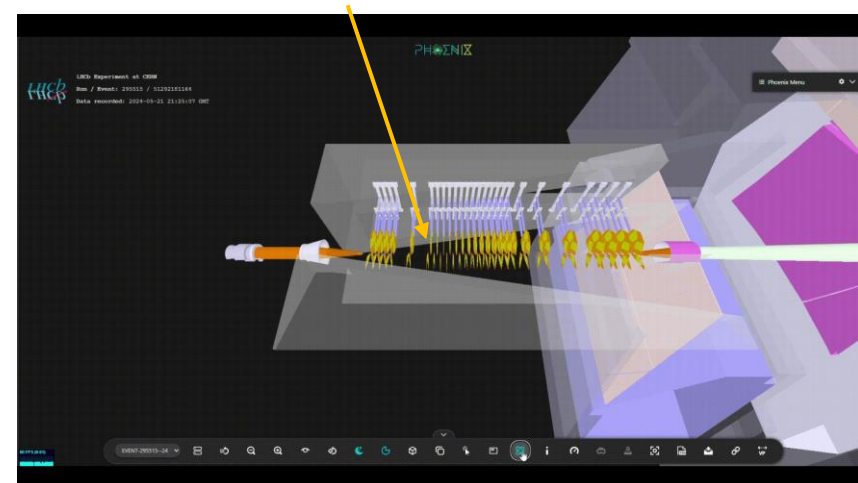
Obrigado pela atenção!

Thank you for your attention!

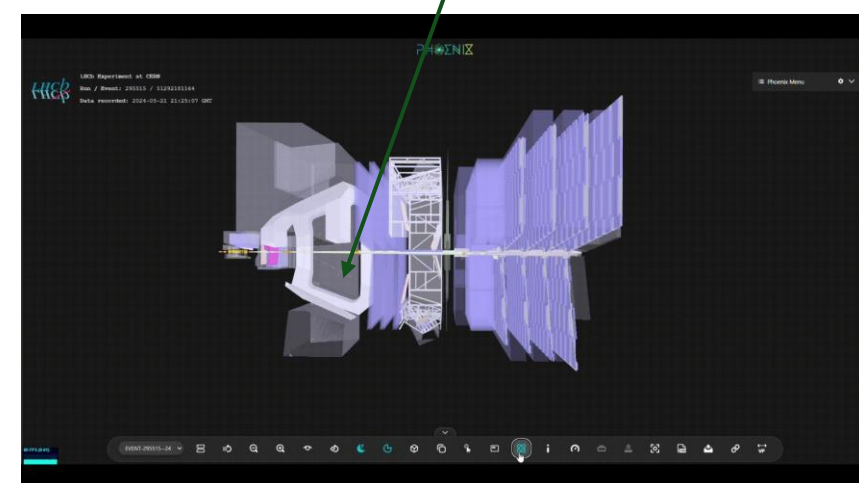


First collisions at the world-record energy for a brand-new LHCb detector at LHCb. Source → [lhcb-outreach.web.cern.ch](https://lhcb-outreach.web.cern.ch)

Protons collide at the interaction point inside VELO



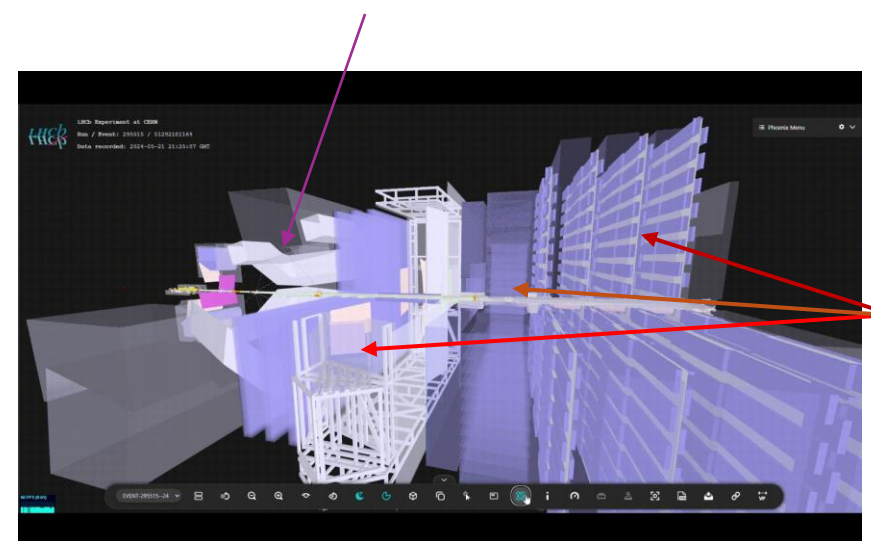
Charged tracks are bent by magnets allowing momentum determination with excellent resolution



Long tracks are created by extending the VELO tracks to the SciFi stations and matched with SciFi hits.

VELO: Provides precise vertex positions, tracking and decay time.

Performance numbers:  
[LHCb Performance Numbers \(cern.ch\)](https://cern.ch/lhcb-performance-numbers)



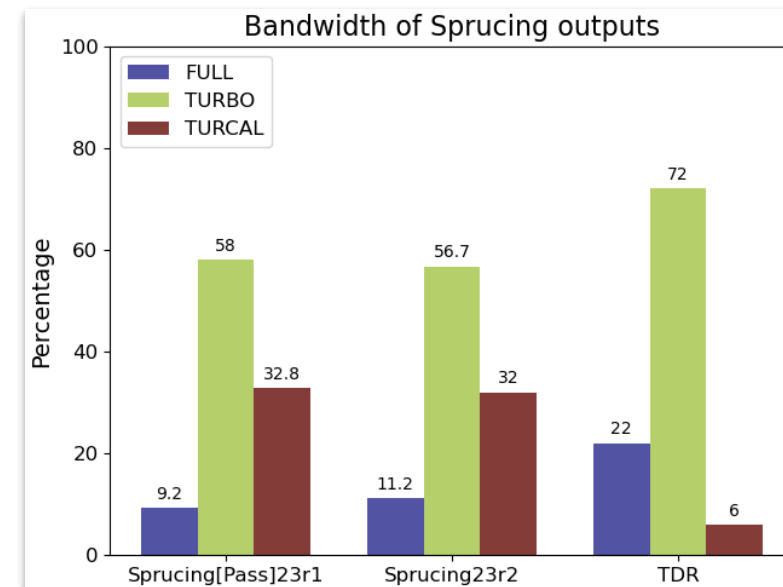
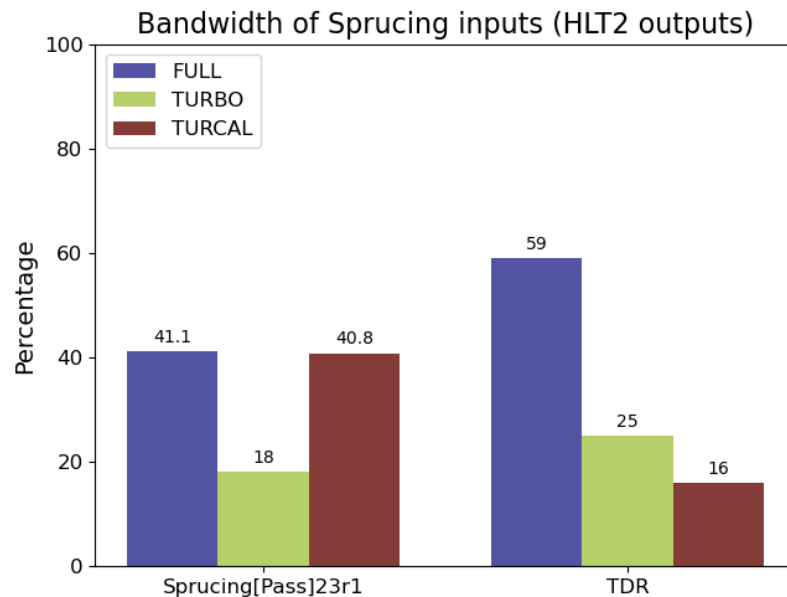
Precise particle identification is provided by **RICH** and **Muon stations**. Energy is determined by the **calorimeters**.

# Sprucing (and HLT2) bandwidths in Collision23 pp campaigns



How is Sprucing bandwidth division compared to [Technical Design Report](#) (TDR) projections?

And for HLT2?



The share of outputs is different from TDR!