Study of beauty to charm hadron decays and proton-proton collision reconstruction at LHCb experiment

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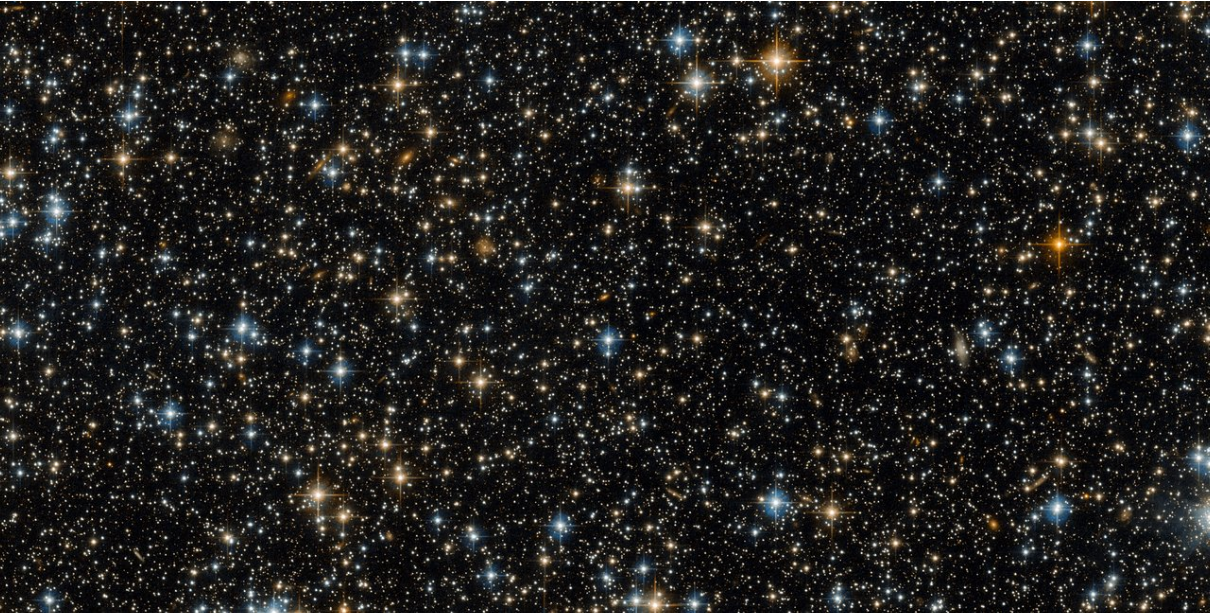
III year's KISD Students Seminar

May 10th 2024



Covered topics:

- Motivation
  - Why is there more matter than antimatter in the Universe?
  - What is the CP invariance?
- What is the LHCb experiment?
- What have I actually been working on so far?
  - $\Lambda_b^0 \to D_s^- p$ decay analysis
    - First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay
    - Published in JHEP: https://doi.org/10.1007/JHEP07(2023)075
  - Proton-proton collisions monitoring
    - PV & RTA groups
  - $B \to DX$ decays analysis
    - the Early Measurements Run3 working group
- Summary and future plans

Why is there more matter than antimatter in the Universe?

Figure: Andrei Sakharov

The Sakharov conditions!

- there must be phases of the expansion without thermodynamic equilibrium
- there must be an interaction violating the conservation of baryon number
- *there must be an interaction violating the CP invariance*

What is the CP invariance?

The C transformation

- the **particle–antiparticle** conjugation C transforms the field ϕ of the particle into a related field $\phi^\dagger$ which has **opposite quantum numbers**: the charge, lepton number, baryon number, strangeness, beauty, etc., for the antiparticle are opposite in sign to the values for the particle
- invariance under the C transformation is always **valid** in the **strong** and **electromagnetic** interactions
- **the visible spectral lines** from atoms and their antiatom partners **are identical**, and we cannot use these lines to identify antimatter in the Universe

What is the CP invariance?

The P transformation

Alice in Wonderland (1951)
Walt Disney Productions

Charge
&
Parity
in decays!

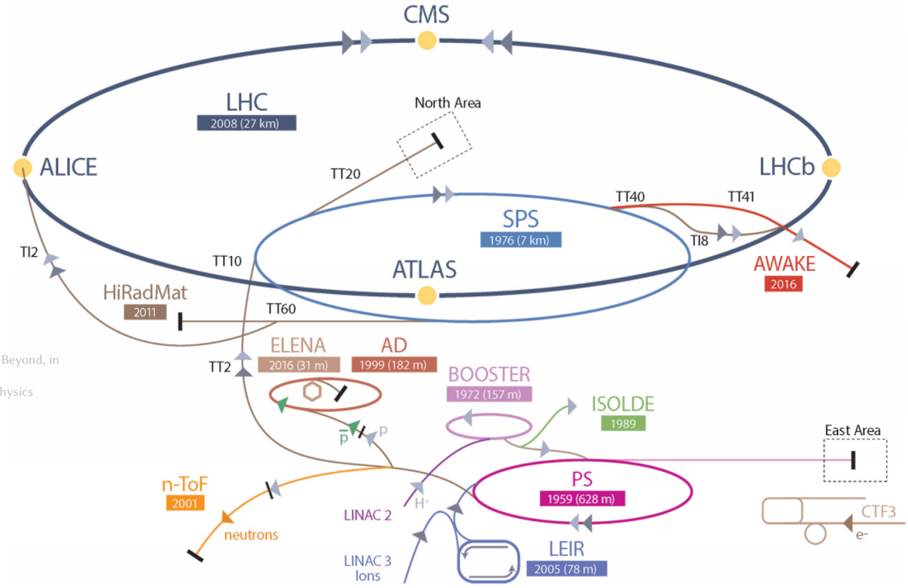
Charge
&
Parity
in decays!

CP is (slightly) broken in weak interactions!

LHC

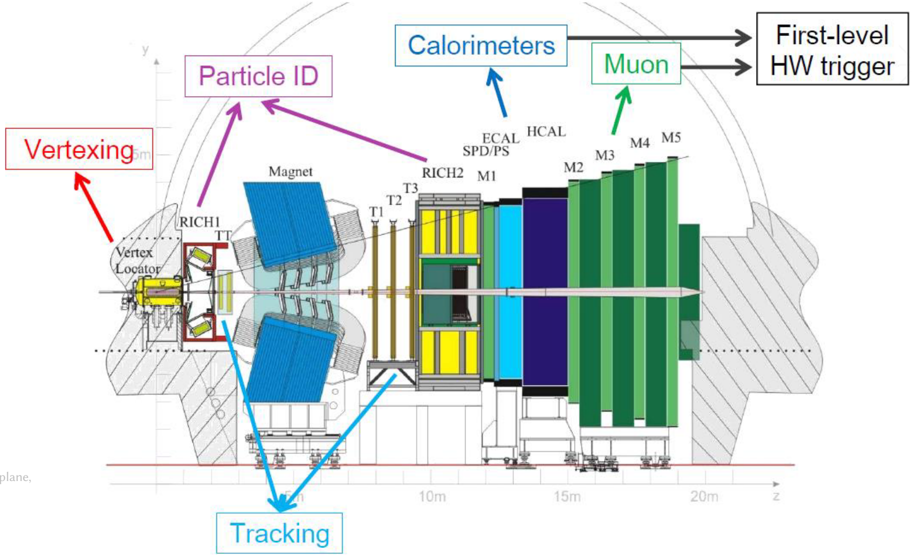
Scheme of LHC accelerator and synchrotron complex.

Hoecker, Physics at the LHC Run-2 and Beyond, in 2016 European School of High-Energy Physics



LHCb

LHCb detector structure in *yz* plane, operational for Run1 and Run2



LHCb detector view among the bending plane,

Public Domain, Accessed: 2021-05-10

Weak interactions - CKM matrix - quark mixing!

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$n \longrightarrow p + e^- + \overline{\nu}_e$$

$$u\,d\,d \longrightarrow u\,u\,d + e^- + \overline{\nu}_e$$

First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay

First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay

observation

we see this decay in our data in non-negligible yield

First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay

branching fraction

the fraction of particles which decay by an individual decay mode (here: $D_s^- p$) with respect to the total number of particles which decay (here: Λ_b^0)

First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay

Why the $\Lambda_b^0 \to D_s^- p$?

- the $\Lambda_b^0 \to D_s^- p$ decay constitutes a background to other analysis
  - the study of CP violation with $B_s^0 \to D_s^{\mp} K^{\pm}$ decays (with $\Lambda_b^0 \to D_s^- p$ one of the contributing backgrounds in the signal region)

Weak interactions - CKM matrix - quark mixing!

Why the $\Lambda_b^0 \to D_s^- p$?

- $\mathcal{B}(\Lambda_b^0 \to D_s^- p) \propto |V_{ub}|^2$
  - V_{ub} - a CKM matrix element

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\Lambda_b^0 \to D_s^- p$$

Weak interactions - CKM matrix - quark mixing!

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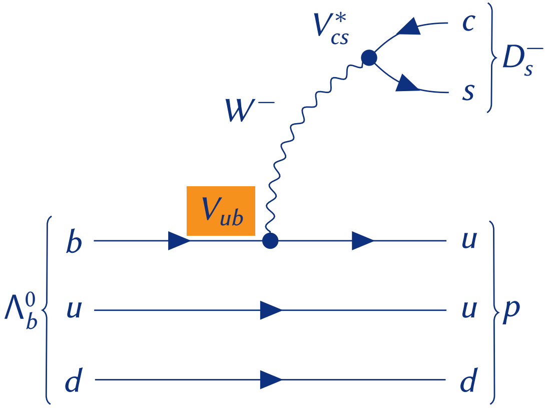
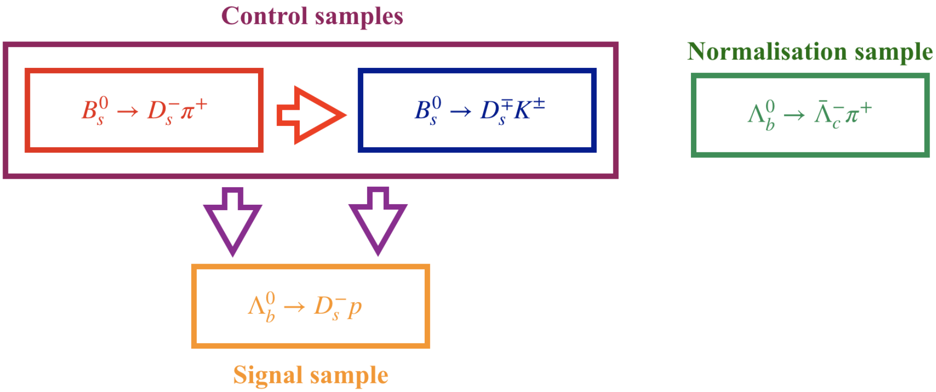


$$\Lambda_b^0 \to D_s^- p$$

How did we do it?
(I'm omitting a lot here!)

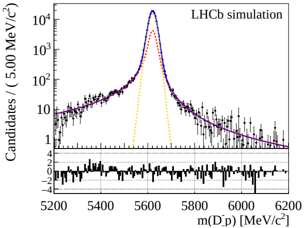
The general idea

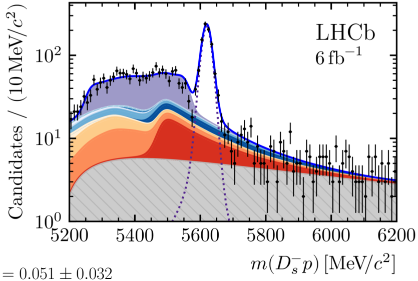
- Using data, not MC samples!
  - the data-driven approach to calculate the contributions from the $B_s^0 \to D_s^{\mp} h^{\pm}$

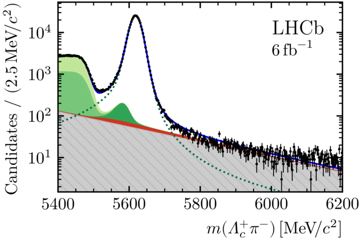


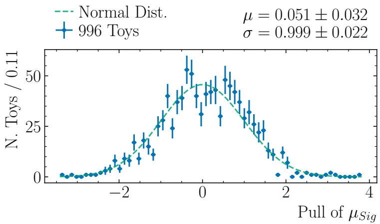
$\Lambda_b^0 \to D_s^- p$ decay analysis:

- Modelling of the signal and background shapes for the decays
- Invariant mass fits
- Systematic studies
- Validation

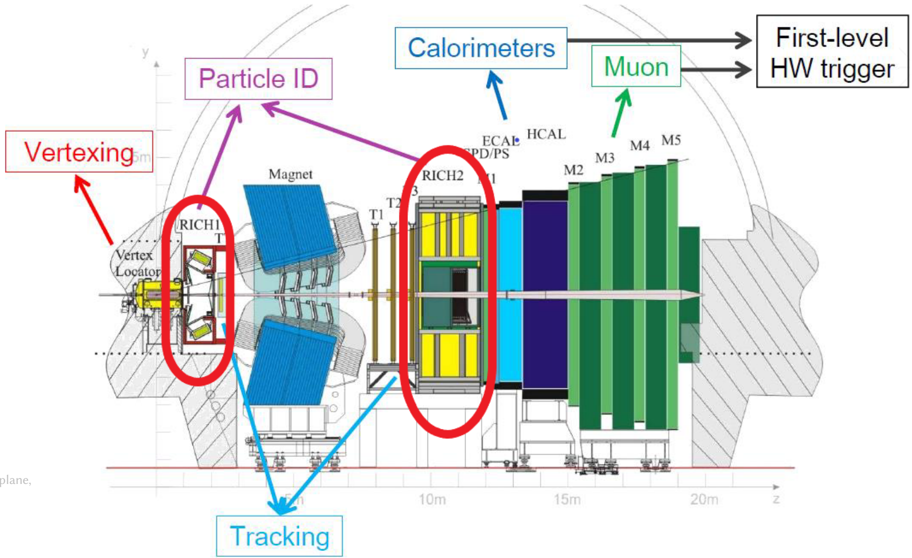








LHCb



LHCb detector structure in *yz* plane, operational for Run1 and Run2

LHCb detector view among the bending plane,

Public Domain, Accessed: 2021-05-10

PID from RICH helps a lot!

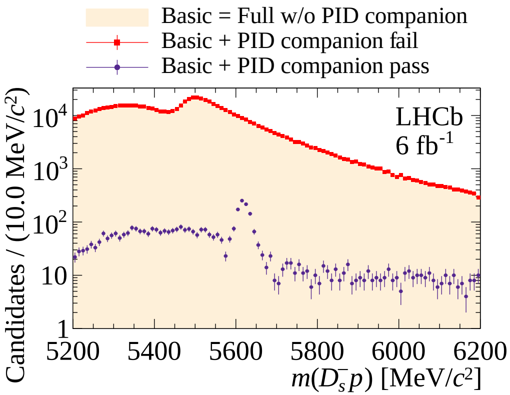


Figure: The $m(D_s^- p)$ invariant-mass distributions after the full selection without the PID requirement on the companion track (filled area) and passing (circles) or failing (squares) this selection.

Results

Previous estimations (from PDG):

Γ_{55} pD_s^- $< 4.8 \times 10^{-4}$ CL=90% 2364

$\Gamma(\Lambda_b^0 \to pD_s^-)/\Gamma_{\text{total}}$ Γ_{55}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< \mathbf{4.8 \times 10^{-4}}$	90	AAIJ	2014Q	LHCB	pp at 7 TeV

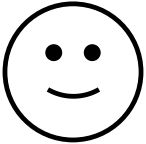
References:

AAIJ 2014Q JHEP 1404 087 Searches for Λ_b^0 and Ξ_b^0 Decays to $K_S^0\,p\pi^-$ and $K_S^0\,pK^-$ Final States with First Observation of the $\Lambda_b^0 \to K_S^0\,p\pi^-$ Decay

Our result:

https://doi.org/10.1007/JHEP07(2023)075

$$\mathcal{B}(\Lambda_b^0 \to D_s^- p) = (12.6 \pm 0.5 \pm 0.3 \pm 1.2) \times 10^{-6}$$



- I'm the **contact author** of this analysis!
- The results have been shown on the **EPIPHANY** conference in 2023!

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2022-272
LHCb-PAPER-2022-038
3 February 2023

First observation and branching fraction measurement of the $\Lambda_b^0 \to D_s^- p$ decay

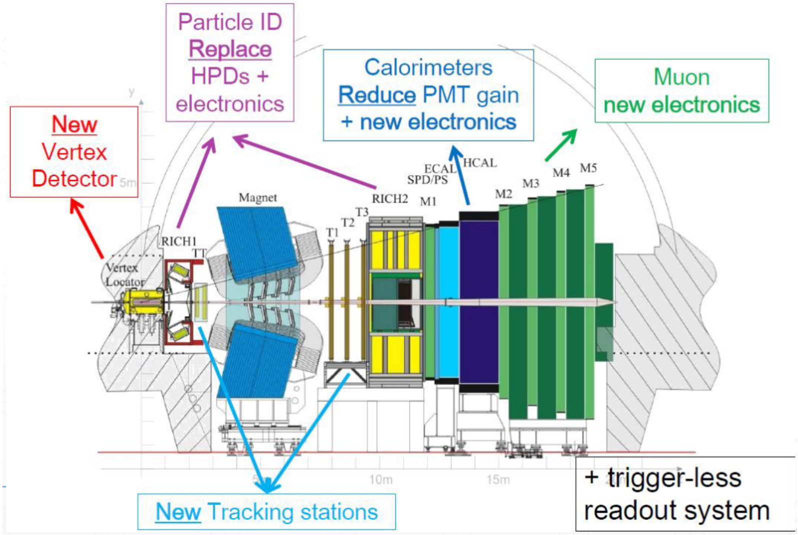
LHCb collaboration

Abstract

The first observation of the $\Lambda_b^0 \to D_s^- p$ decay is presented using proton-proton collision data collected by the LHCb experiment at a centre-of-mass energy of $\sqrt{s} = 13\,\text{TeV}$, corresponding to a total integrated luminosity of $6\,\text{fb}^{-1}$. Using the $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ decay as the normalisation mode, the branching fraction of the $\Lambda_b^0 \to D_s^- p$ decay is measured to be $\mathcal{B}(\Lambda_b^0 \to D_s^- p) = (12.6 \pm 0.5 \pm 0.3 \pm 1.2) \times 10^{-6}$, where the first uncertainty is statistical, the second systematic and the third due to uncertainties in the branching fractions of the $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $D_s^- \to K^- K^+ \pi^-$ and $\Lambda_c^+ \to p K^- \pi^+$ decays.

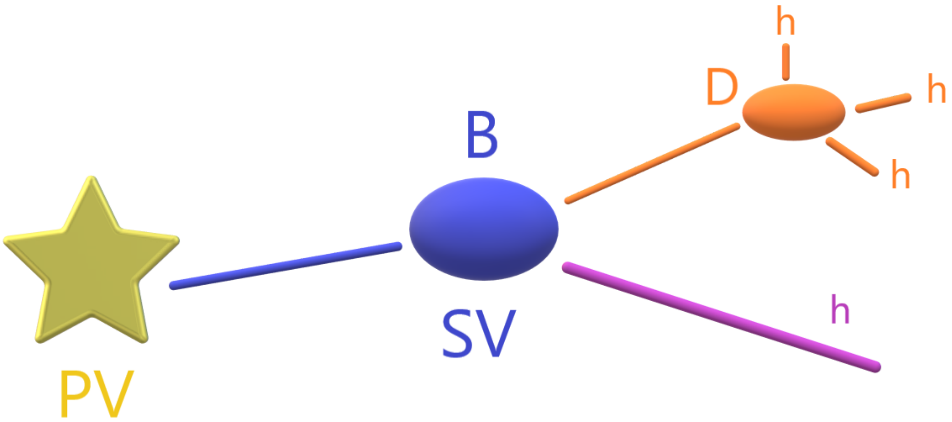
LHCb Upgrade II

- New possibilities!
- · · · but also, new challenges!
- Need for new checks on fresh data, updates on fast online monitoring and tuning!

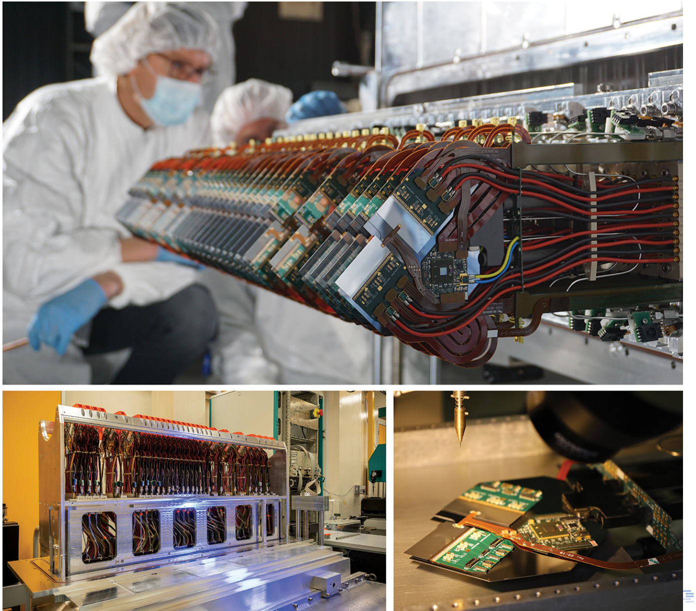


Framework TDR for the LHCb Upgrade II: Opportunities in flavour physics, and beyond, in the HL-LHC era

Decay at LHCb (beauty to charm)



Vertex Locator



Inspecting the alignment (top); a fully assembled detector half (bottom left); and wire bonding of the ASICs to the front-end hybrids (bottom right). Credits: M. Milovanovic; McCoy Wynne; STFC/A O'Connor

VELO's voyage into the unknown, CERN Courier, May 2022

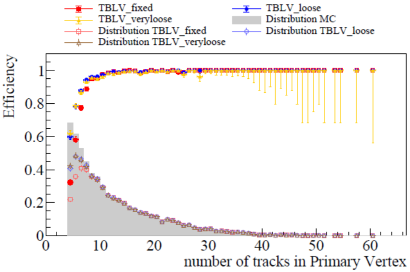
Vertex Locator

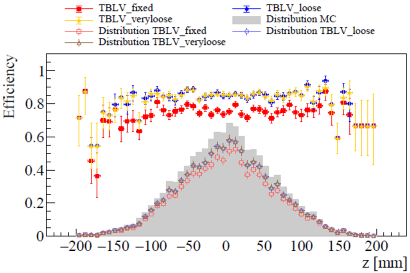
Milling the solid aluminium block (left), and the completed RF foils in the closed position (right). Credit: M. Kraan

VELO's voyage into the unknown, CERN Courier, May 2022

Proton-proton collisions monitoring:

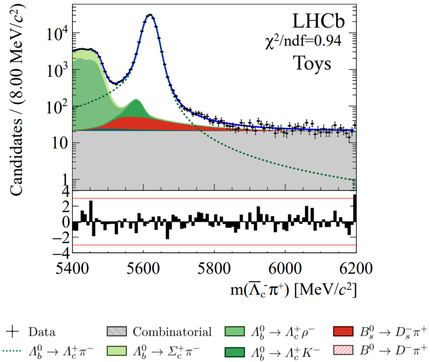
- in 2022/2023 I started working for the LHCb Real-Time Analysis Project (RTA)
  - development and sustaining central software
  - monitoring and optimization of proton-proton collisions detection algorithms in the LHCb detector
    - PV reconstruction algorithm optimization for 2023 conditions (different VELO position considered)
    - integrating *InteractionRegion* information about VELO position to PV reconstruction algorithms
    - *VertexCompare* - comparison of primary vertex reconstruction between CPU and GPU algorithms, and real-data resolution monitoring

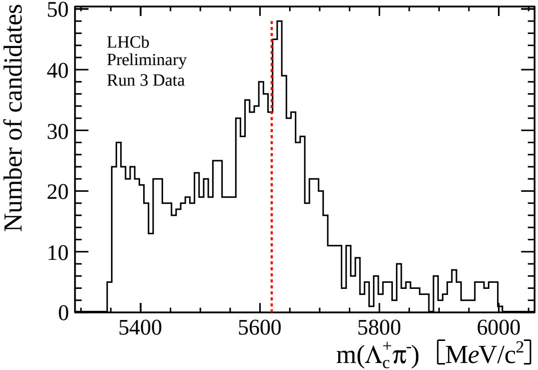




$B \to DX$ decays analysis:

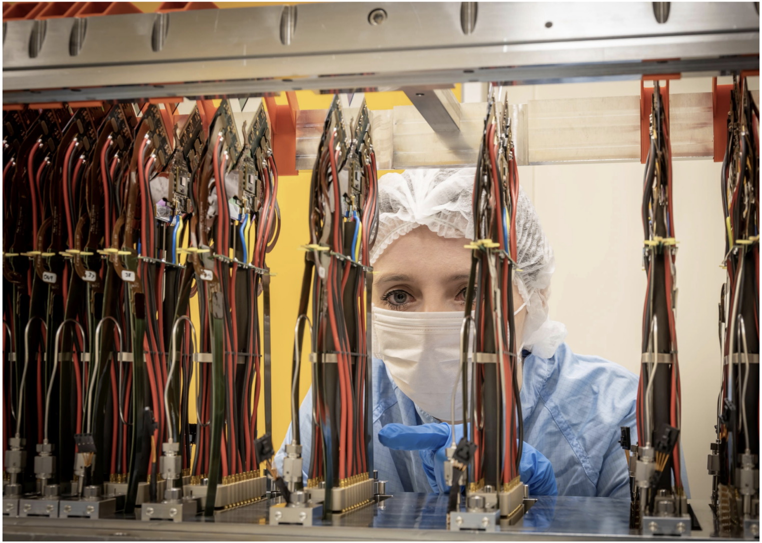
- **automation** of data selection procedure and preparation of invariant mass fits
- preliminary **2022**/2023/2024 dataset analysis, with a verification, including the use of pseudoexperiments



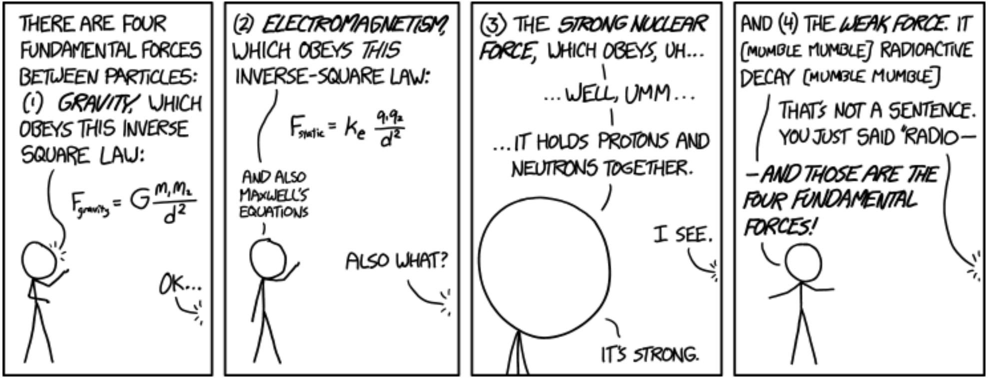


Summary

- first half of my PhD
  - physics analysis
- second part
  - technical development of the detector
- there is still need on checks, tuning, writing new algorithms and analysing new data!



Thank you!



xkcd

Backup slides

What had to be done? (A lot!)

- Trigger strategy and Stripping selection
- Kinematic selection
- BDT & `ProbNNp` optimisation
- PID selection
- Charmless backgrounds consideration
- The fully reconstructed misidentified decays veto
- Efficiency calculations
- Misidentified backgrounds estimation
- Modelling of the signal and background shapes for the decays
- Invariant mass fits
- Systematic studies
- Validation