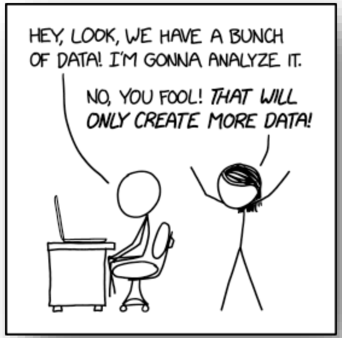
UNIVERSITY OF LIVERPOOL

LHCb Group
Physics and Data Processing & Analysis

Eduardo Rodrigues, for the LHCb group



https://xkcd.com/2582/

Group news – students

- ❑ **James Mead graduated**
  - Thesis on top production in LHCb, using neural networks for B tagging

- ❑ **Lauren Yeomans submitted her corrected thesis**
  - $B_s^0 \to \mu^+\mu^- \ (\gamma)$
  - Papers https://doi.org/10.1103/PhysRevD.105.012010 (Phys Rev D) and https://doi.org/10.1103/PhysRevLett.128.041801 (Phys Rev Lett)

- ❑ **Tom Harrison passed his viva last Tuesday**
  - Upgrade trigger 2-track lines and sensitivity studies for - $B^0 \to K_1^0 \mu^+\mu^-$ in Run 3

Group key roles

Farry	LHCb QCD, EW and Exotics WG Convenor	2018-2020	LHCb Leadership
	HE/HL-LHC SM and Top Physics Convenor	2017-2019	
	LHC Top Physics WG Convenor	2016-	
	LHC V+jet WG Convenor	2017-	
Rodrigues	LHCb Data Processing and Analysis Project Leader	2020-	
Shears	LHC Electroweak WG Convenor	2010-2020	
	LHC Precision EW Observable WG Convenor	2017-2020	
Rinnert	LHCb Real Time Analysis (RTA) Novel Computing Testbed Convenor	2019-	

← Stephen Farry sadly left us

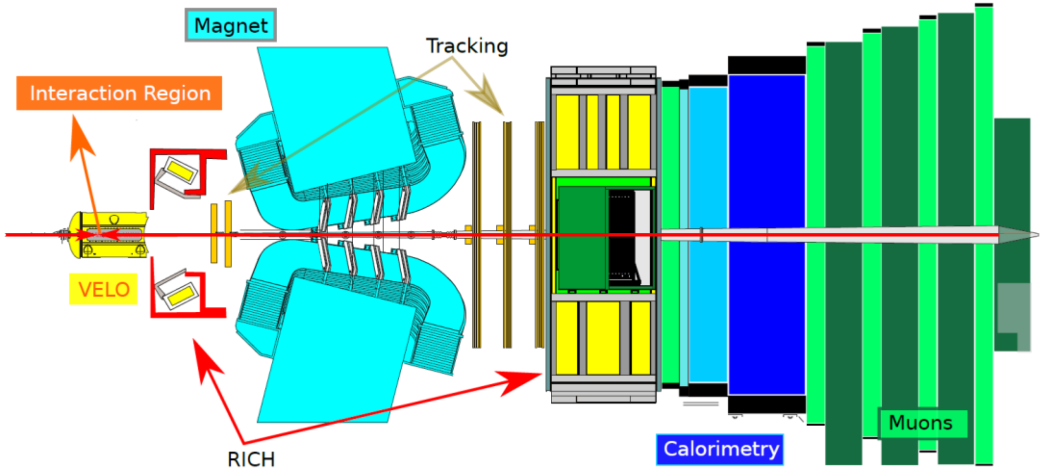
Bowcock	LHCb UK VELO Upgrade Project Leader	2015-	LHCb Upgrade Leadership
Carroll	LHCb Upgrade VELO Module Project Engineer	2015-	
Hennessy	LHCb Upgrade VELO DAQ Coordinator	2015-	
Rinnert	LHCb Upgrade VELO QA and Db Coordinator	2015-	
Vilella-Figueras	LHCb MightyPix co-convenor	2020-	

Other roles in HEP in general

- **Eduardo Rodrigues**
  - ***Hot off the press, literally – news from yesterday: CERN Scientific Associateship awarded. Start this Autumn***
  - **SWIFT-HEP WP5 (Data Analysis) co-convener**
  - **LHCP 2022 Conference, “Performance and Tools” parallel session co-convener**
  - **HSF & IRIS-HEP Analysis Ecosystems Workshop, May 2022, organising committee member**
  - **(virtual) CHEP 2021, programme committee member**

The (current) LHCb detector

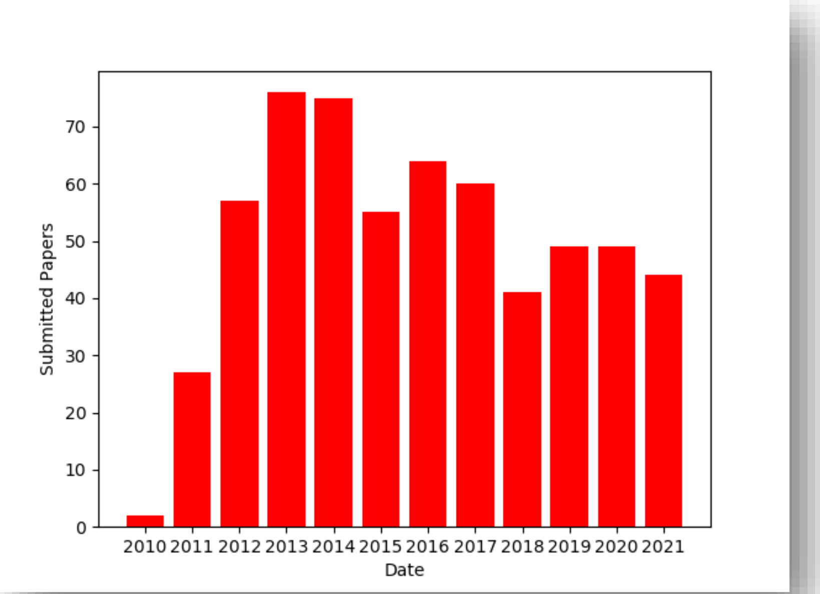
- The legacy of LHCb to Flavour Physics
  with legacy data needs no further proof ;-)
- Collected 9 fb^{-1} in Runs 1 and 2 (> 1 trillion *B* mesons)

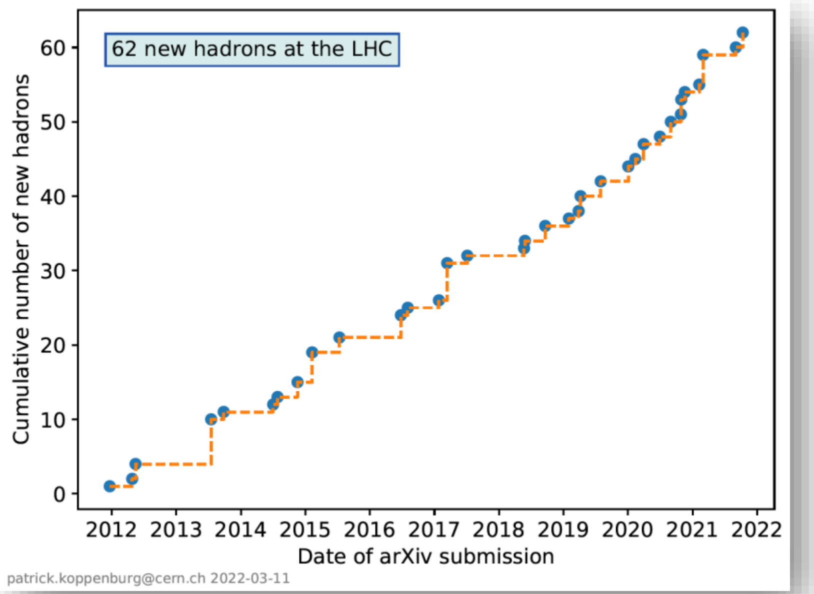


- LHCb keeps publishing beyond its original core programme.
  Key topics are:
  - CP violation in B decays
  - D0 mixing
  - Lepton Flavour Universality
  - Spectroscopy
  - Heavy ions and fixed target

Some physics highlights – LHCb in general

- ❑ **LHCb submitted its 600th publication in Nov. 2021 !**
- ❑ **Interesting info:**
  - **- First paper back in Aug. 2010**
  - **- 500th paper submitted just 2 years ago**

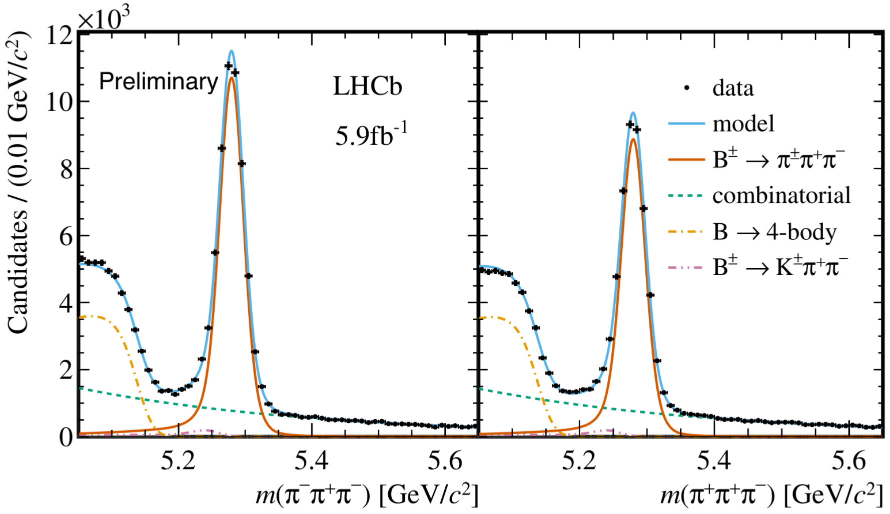




- ❑ **While on "stats":**
- ❑ **So far 62 hadrons have been discovered at the LHC, of which 55 by LHCb !**

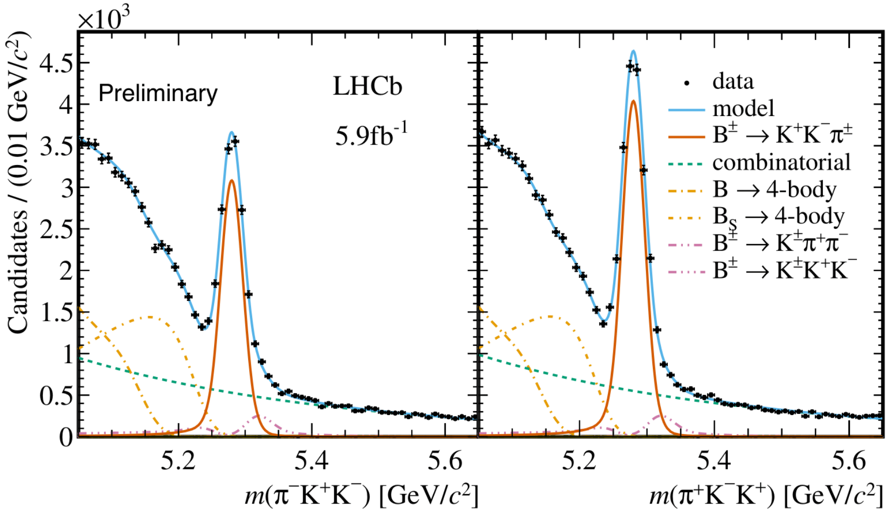
Some physics highlights – LHCb in general

Full samples (examples):

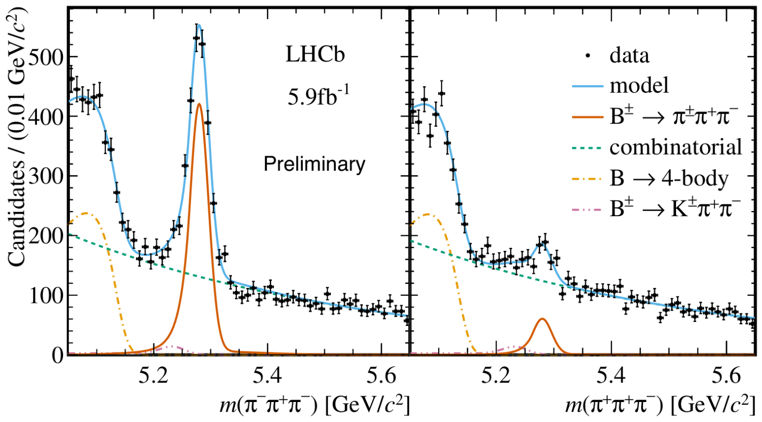


Largest CP violation ever observed !

- ❑ **Again a fantastic result from the study of hadronic decays $B^+ \to h^+ \, h'^+ h'^-$** **(several papers on these 4 "cousin" modes)**
- ❑ **CP violation observed in 3 of the 4 modes**



In a specific kinematical region of the $B^\pm \to \pi^\pm\pi^+\pi^-$ decay the CP asymmetry is as high as 75% !



Some physics highlights – LHCb in general

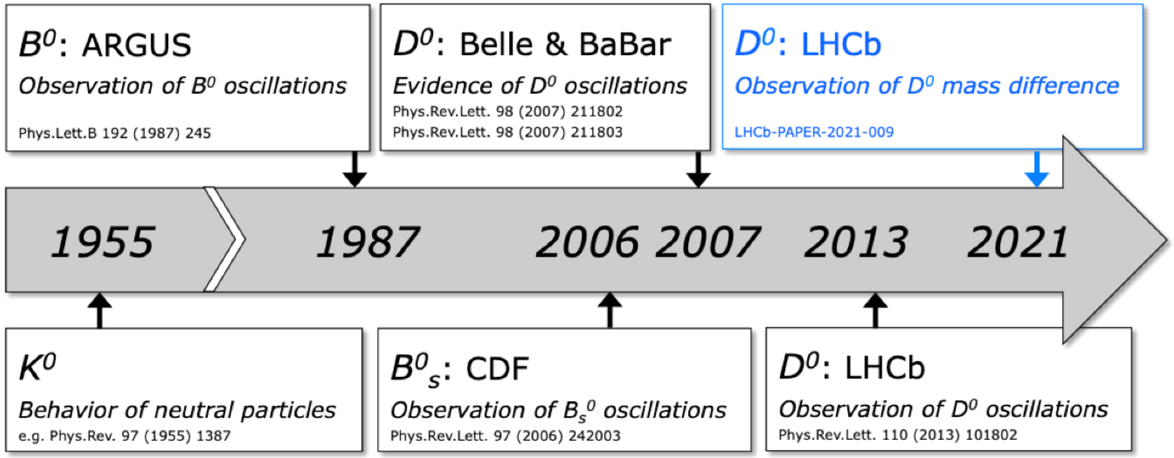
First observation of the mass difference between neutral charm mesons

❑ **Mass difference between mass eigenstates**

m_1-m_2 = 6.4×10^{-6} eV = 0.00000000000000000000000000000000000001 grams (1×10^{-38}g)

$(m_1$-$m_2)/(D^0\text{mass}) = 3\times10^{-15}$

❑ **LHCb "writing the textbook chapter" in this area**

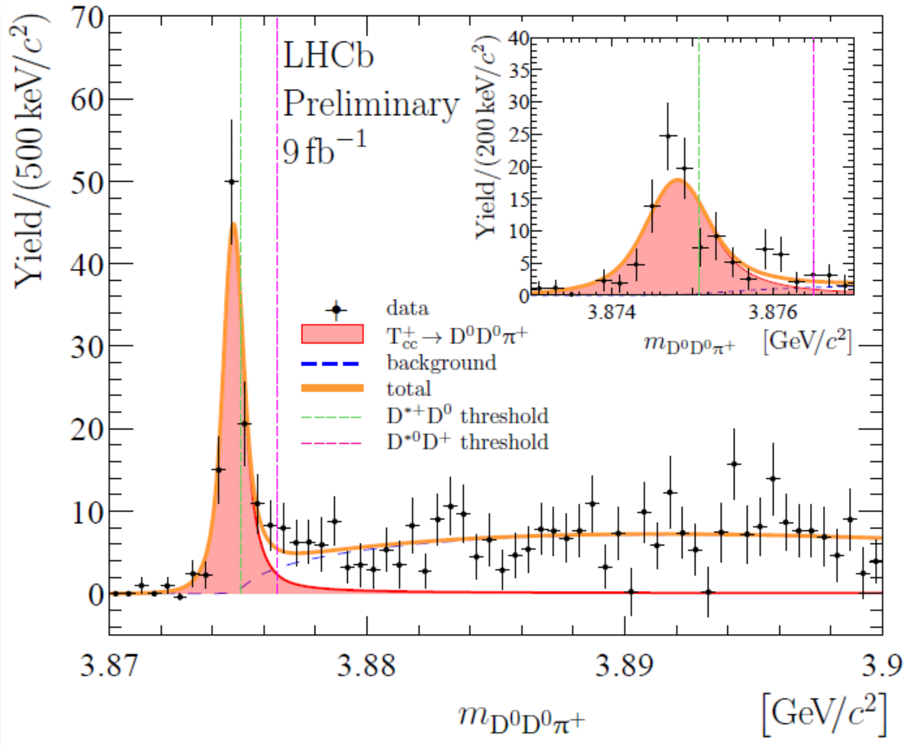


Some physics highlights – LHCb in general

First observation of a doubly charmed tetraquark

- First observation of a doubly charmed tetraquark, T_{cc}^{+}

- Narrow peak in the $D^0\ D^0\ \pi^+$ mass spectrum just below the $D^{*+}\ D^0$ mass threshold



- Crucial observation as it proved that a long-lived exotic particle stable with respect to the strong interaction does exist in nature

- In fact all exotic hadrons observed so far decay via the strong interaction

Some physics highlights – LHCb in general

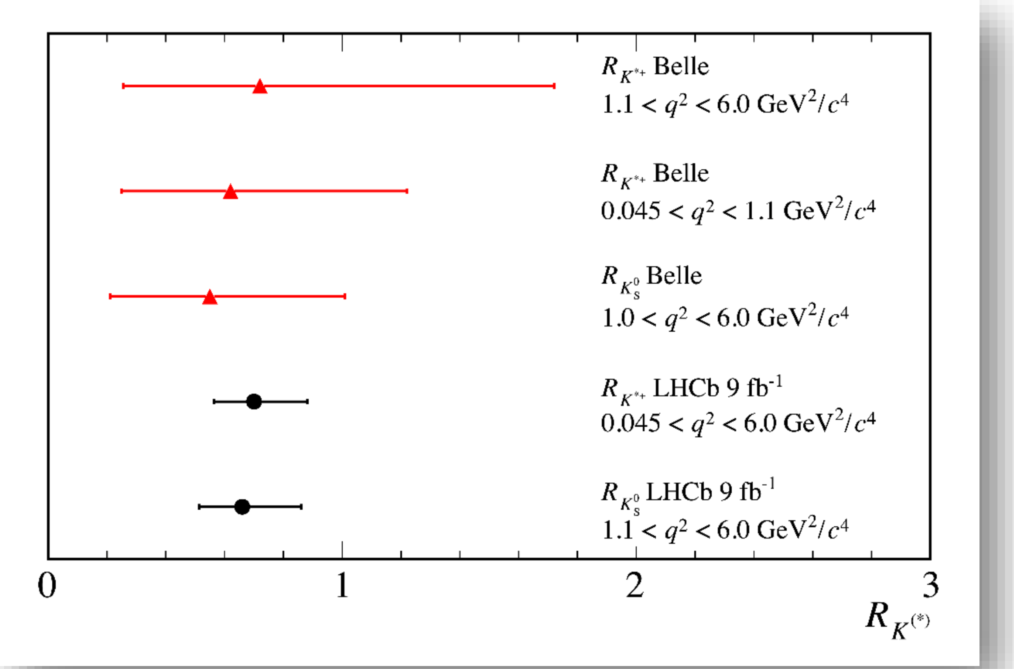
Lepton flavour universality tests

- ❑ Arguably the hottest topic these days !
- ❑ LHCb consistently publishing intringuing and exciting results since a few years
- ❑ Example of a recent result

Test of lepton universality using $B^0 \to K_S^0 l^+ l^-$ and $B^+ \to K^{*+} l^+ l^-$ decays.

$R_{K_S^0} = 0.66^{+0.20}_{-0.14}(\text{stat})\,^{+0.02}_{-0.04}(\text{syst})$ for $1.1 < q^2 < 6.0\ \text{GeV}^2/c^4$

$R_{K^{*+}} = 0.70^{+0.18}_{-0.13}(\text{stat})\,^{+0.03}_{-0.04}(\text{syst})$ for $0.045 < q^2 < 6.0\ \text{GeV}^2/c^4$

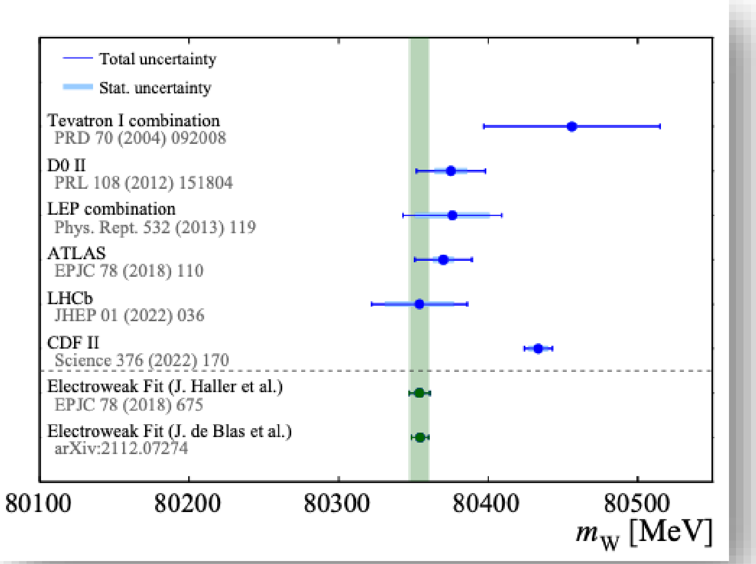


- ❑ No doubt more is in the pipeline …
  … also with $D^{0,+,*}$, Λ_c^+, etc., replacing kaons

Some physics highlights – Liverpool involvement

Stephen Farry, Tara

LHCb-FIGURE-2022-003



Measurement of the W boson mass

- Very important parameter of the Standard Model
- Measurement from a simultaneous fit of the muon q/p_T distribution of a sample of $W^+ \to \mu^+ \upsilon$ decays and the ϕ* distribution of a sample of $Z^0 \to \mu^+\mu^-$ decays
- W boson mass is determined to be

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

(uncertainties correspond to contributions from statistical, experimental systematic, theoretical and parton distribution function sources.)

- Result is an average of results based on three recent global parton distribution function sets
- Measurement agrees well with the prediction of the global electroweak fit and with previous measurements

https://arxiv.org/abs/2109.01113

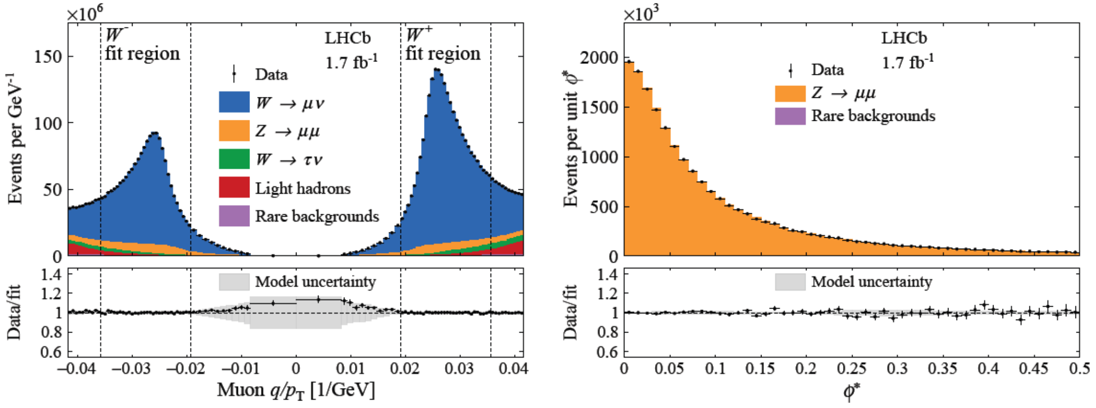


Figure 11: Distributions of (left) q/p_T and (right) ϕ^* compared to the model after the m_W fit.

Some physics highlights – Liverpool involvement

Abbie, Tara

Z forward-backward asymmetry

- ❑ **Towards an extraction of the Weinberg angle**
- ❑ **Run 2 analysis**

- ❑ **Please refer to Abbie’s presentation …**

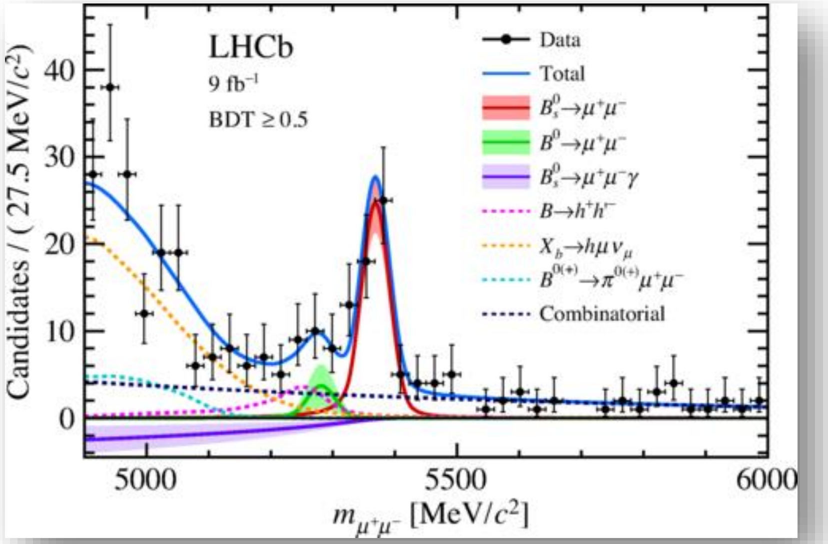
Some physics highlights – Liverpool involvement

Study of $B \to \mu^+\mu^- \ (\gamma)$

- ❑ **Legacy measurement using the full Run 1 and Run 2 dataset**
- ❑ **Also now including first limit on $B_s^0 \to \mu^+\mu^- \gamma$ at high invariant mass (complementary physics sensitivity)**

- ❑ **Lauren did the fit for the $\mu^+\mu^- \gamma$ final state and the PID for the decays**
- ❑ **The results are all SM consistent and limit several sorts of NP processes:**

$$\begin{aligned}
\mathcal{B}(B_s^0 \to \mu^+\mu^-) &= (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}, \\
\mathcal{B}(B^0 \to \mu^+\mu^-) &= (1.2^{+0.8}_{-0.7} \pm 0.1) \times 10^{-10}, \\
\mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma) &= (-2.5 \pm 1.4 \pm 0.8) \times 10^{-9} \\
\text{with} \quad m_{\mu\mu} &> 4.9 \ \text{GeV}/c^2.
\end{aligned}$$



Some physics highlights – Liverpool involvement

Study of $B^0 \to K_1 \mu^+\mu^-$

- Tom worked on the upgrade trigger 2-track selection lines and sensitivity studies for $B^0 \to K_1^0 \mu^+\mu^-$ in Run 3
- James: plan is to compare to $K^*\mu^+\mu^-$ non-resonant contribution and measure the amount of right-handed weak current in the decays from the parity opposite K^* compared to K_1^0
- See also James's presentation
- Example plot for the HLT optimisation:
  - Compares his NN (blue line) with the existing MVA lines for a range of signal/background retentions
  - Tom's NN is more performant than any of the existing HLT2,
- Went on to study the upgrade trigger and showed one could get full fitted like performance from unfitted tracks + NN saving considerable time in the trigger pathways

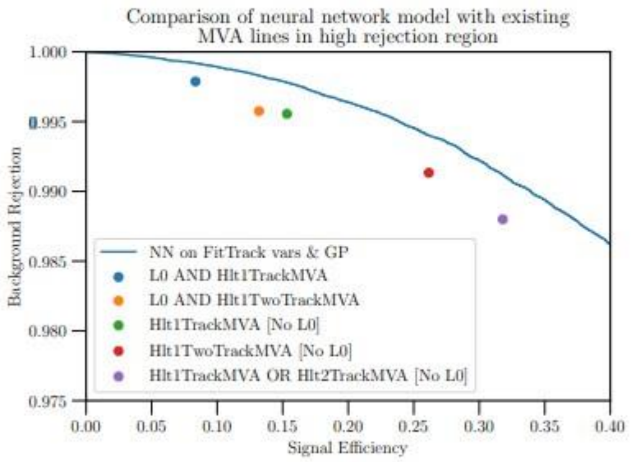
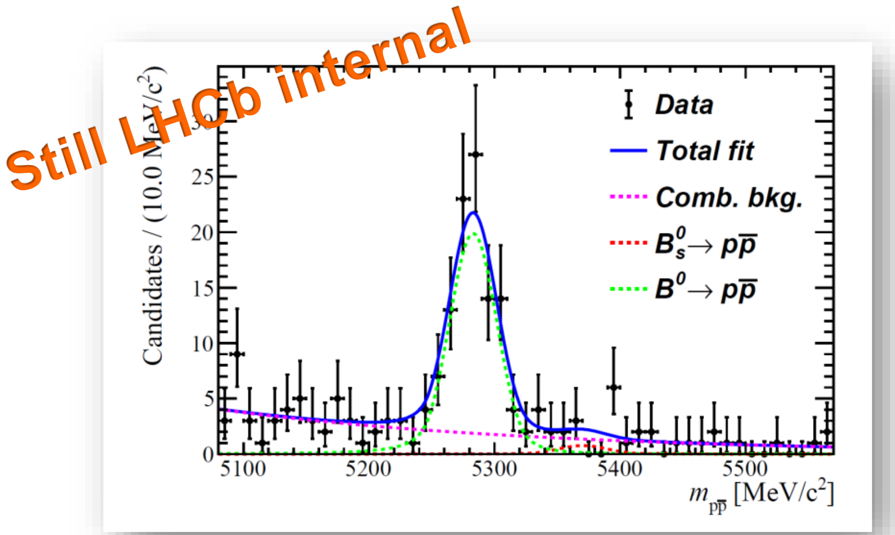


Fig. 4.10

A comparison of the performance of a neural network classifier (line) and the existing MVA lines (points) in evaluating single tracks. The neural net model is displayed as a curve, as it outputs a continuous value, to which any cut can be applied. "FitTrack vars & GP" refers to the variables listed in section 4.6.1, which have been refined via the Kalman fit procedure.

Some physics highlights – Liverpool involvement

- **Continuation of work on hadronic (charmless) decays**
  - Funny enough, all 3 analyses foreseen to get published this year



$$\mathcal{B}(B^0 \to p\overline{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8}$$

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

1) Run-2 update of $B^0_{(s)} \to p\,\overline{p}$ analysis

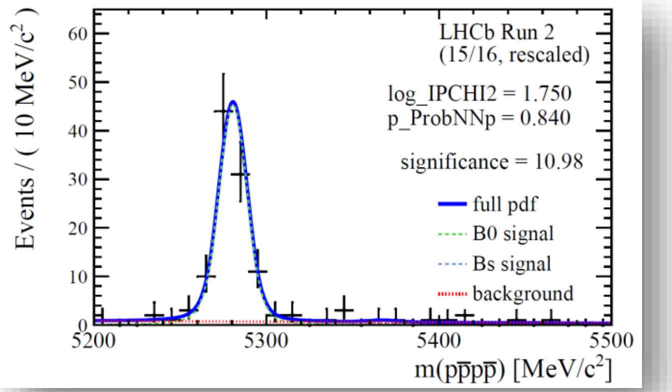
- Analysis on run-I sample saw first observation of B^0 mode, the rarest B^0 decay ever observed
- Run-2 analysis in collaboration with Chinese colleagues from Wuhan
- Final steps of approval. Submission "due" next month

2) First search for purely baryonic (charmless) decays, with $\Lambda_b^0 \to \Lambda\, p\, \overline{p}$

- In collaboration with EPFL
- PhD student did a private unblinding for viva in Sep. 2021
- In 2nd iteration with review committee

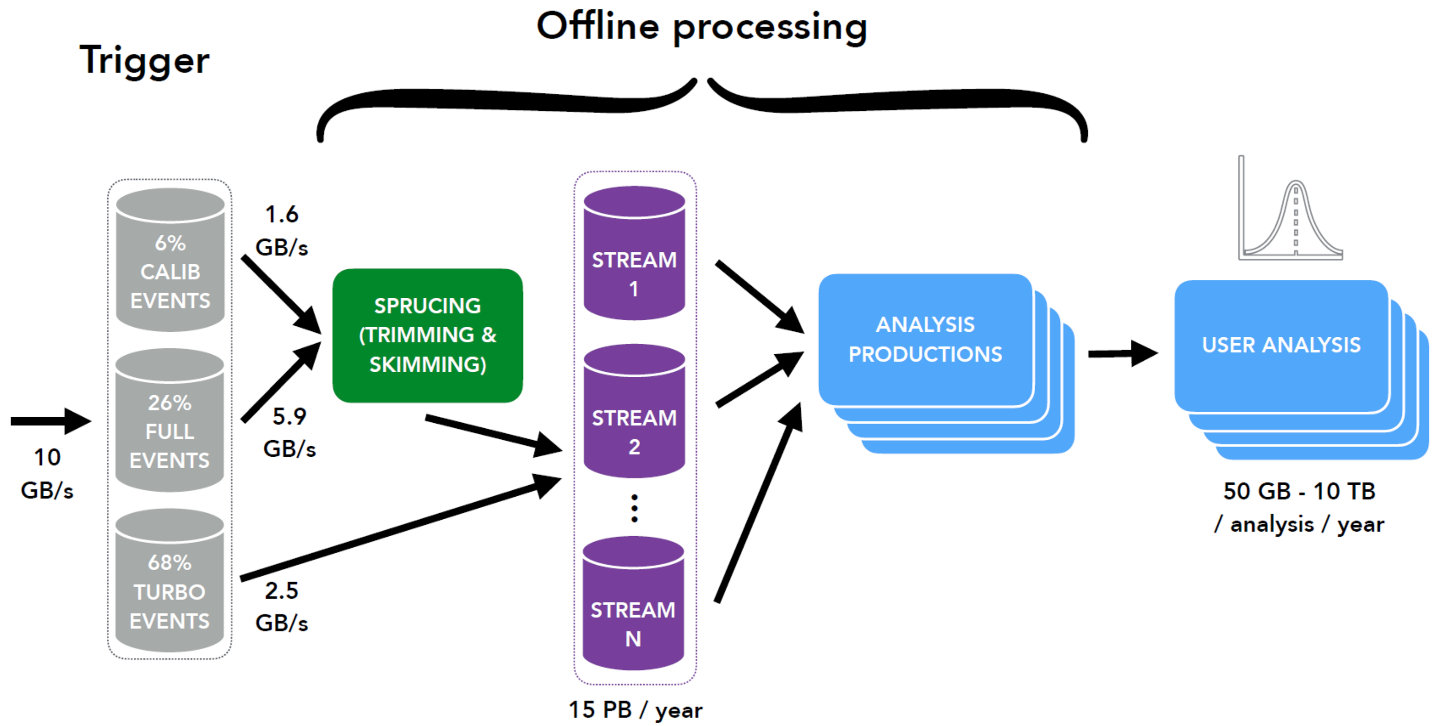
3) First search for $B^0_{(s)} \to p\,\overline{p}\,p\,\overline{p}$ decays at LHCb

- Unique baryonic decay in more than 1 way
- In collaboration with Chinese and US colleagues
- In advance status with review committee, unblinding granted very recently
- Example of expectations for run 2 – TOY spectrum:



"Data Processing & Analysis" (DPA) project for the offline workflow

- ❑ **Very large increase in data volume wrt. Run II brings challenges to offline data processing and analysis**
  - **- Need to adapt to trigger throughput and workflow model: 30 MHz of inelastic collisions down to 1 MHz after HLT1**
- ❑ **DPA built around 2 main ideas:**
  - **- Centralised skimming and trimming (aka Sprucing) of significant fraction of HLT2 outputs**
  - **- Centralised analysis productions for physics WGs and users**



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DPA project

Offline processing/selections/analysis

- WP1 - Sprucing
- WP2 - Analysis Productions
- WP3 - Offline Analysis Tools
- WP4 - Innovative Analysis Techniques
- WP5 - Legacy Software & Data
- WP6 - Analysis Preservation & Open Data

DPA – good activity “publicly”

DPA

Search docs

WORK PACKAGES
- WP1 - Sprucing
- WP2 - Analysis Productions
- WP3 - Offline Analysis Tools
- WP4 - Innovative Analysis Techniques
- WP5 - Legacy Software & Data
- WP6 - Analysis Preservation & Open Data

DOCUMENTATION
- Contributing
- Conferences
  - Talks
  - Posters
  - Preparation and review instructions
- Joint RTA/DPA liaisons
- Publications

MISCELLANEOUS
- Storage group area
- Useful links

Conferences

Page collecting **conference talks and posters** related to the DPA project. **Conference proceedings** are collected in the publications page.

Note

DPA abstracts are typically prepared by the DPA coordination team and/or the Speaker’s Bureau. Any LHCb colleague is encouraged to suggest conferences and topics of their interest, and should not hesitate to let the project leader or the coordination team know in due time.

See below for preparation and review instructions.

Talks

Conference	Date	Title	Abstract	Presenter(s)	Slides
ROOT Users workshop	09-12/05/2022	LHCb Analysis Models	-	Patrick Koppenburg	LHCb-TALK-2022-074
HSF Analysis Facilities Forum Kick-off Meeting	25/03/2022	Analysis Facilities activities in LHCb	-	Donatella Lucchesi	On Indico agenda
Snowmass 2021 Workshop Quantum Computing for HEP	1-3/12/2021	Quantum Machine Learning for b-jet tagging at LHCb	-	Davide Nicotra	LHCb-TALK-2021-367
CERN’s Open Science Strategy WG Meeting	20/09/2021	Open Science at LHCb	-	Sebastian Neubert	On Indico agenda
EPS-HEP	26-30/07/2021	Run-3 offline data processing and analysis at LHCb	SB link	Nicole Skidmore	LHCb-TALK-2021-177

Posters

Event	Date	Title	Presenter(s)	Poster
Lepton-Photon 2021	10/01/2022	Run-3 offline data processing and analysis at LHCb	Martina Ferrillo	POSTER-2022-1063 (recording)
11th LHC students poster session	18/11/2021	Quantum Machine Learning at LHCb	Davide Nicotra	POSTER-2021-1055
11th LHC students poster session	18/11/2021	New generation offline software for the LHCb Upgrade I	Martina Ferrillo	POSTER-2021-1056

Preparation and review instructions

DPA – Liverpool involvement

- A bit everywhere as I'm PL ;-)
- Personally more involved with the analysis software and the Innovative Analysis Techniques WP

- The first DPA project paper … is a paper on Quantum Computing !
- First application of QML to the task of jet charge identification

Quantum Machine Learning for *b*-jet identification

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 $\bar{b}$ 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.

- Paper submitted to the arXiv in February - https://arxiv.org/abs/2202.13943 !
  - Got 2 weeks ago a minor revision from JHEP
- LHCb (+ Liverpool) public news foreseen when the paper gets published
  - This may well be the first UK HEP paper on QC