

# ESR Talk 7

## ML for RTA in neutral meson LFV studies and traffic predictions

SMARTHEP Annual Meeting 2023, Lund University

28<sup>th</sup> November 2023

Johannes Albrecht, **Jamie Gooding**

Technische Universität Dortmund



# About me

- ▶ Working at TU Dortmund on the LHCb experiment.
- ▶ Research interests include:
  - ▶ RTA for trigger systems.
  - ▶ Tests of the Standard Model in neutral B meson decays.
  - ▶ Fast analysis software.
- ▶ Non-research interests include:
  - ▶ Coffee
  - ▶ Karaoke
  - ▶ Travel
  - ▶ Ipswich Town



**2018-2022**  
**MPhys**

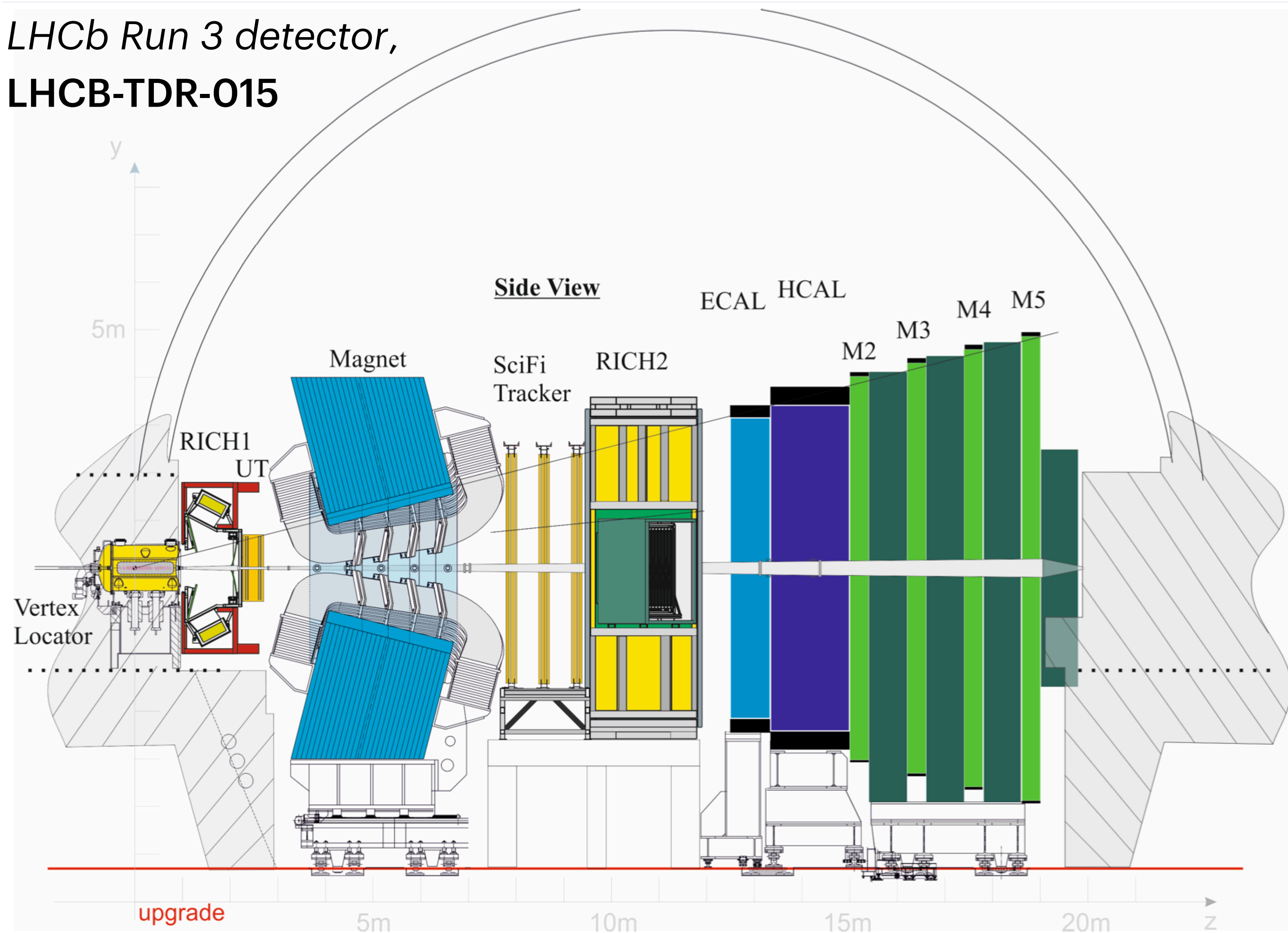
**2022-**  
**Doctorate**



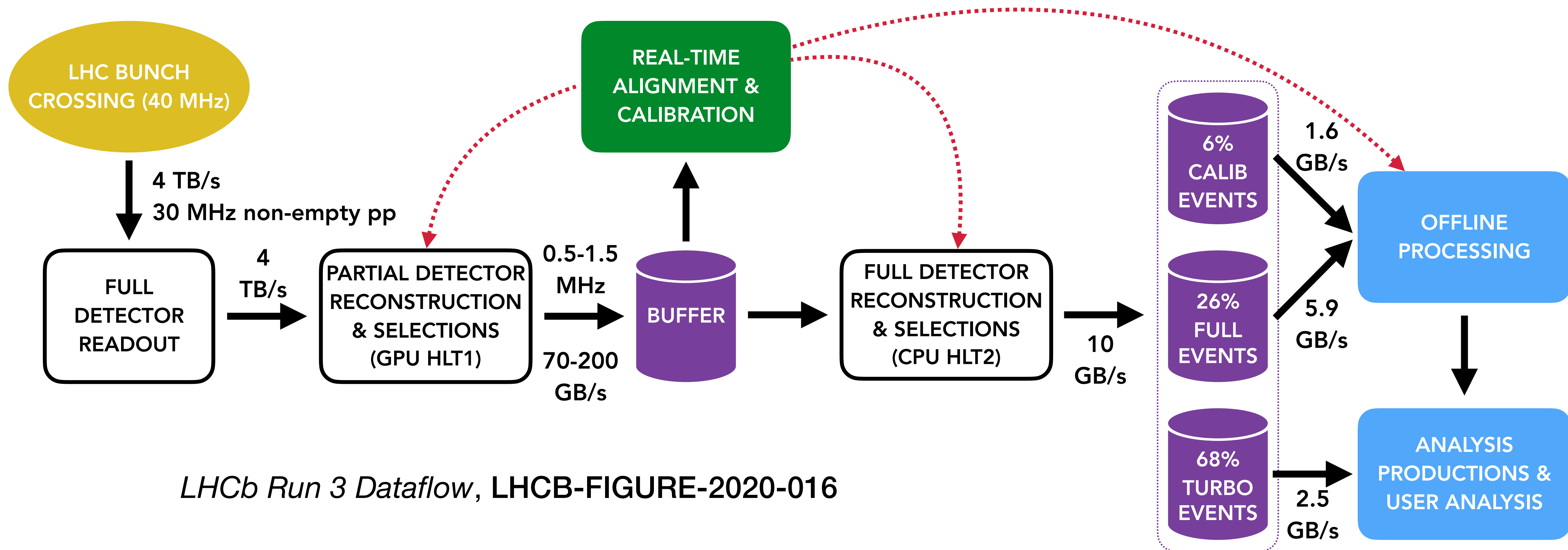
# Real-time analysis at LHCb

- ▶ LHCb experiment significantly upgraded for Run 3.
- ▶ Many sub-detectors replaced.
- ▶ Trigger redesigned entirely:
  - ▶ L0 hardware trigger removed.
  - ▶ First software-only trigger operating at 30 MHz 🎉

LHCb Run 3 detector,  
LHCb-TDR-015



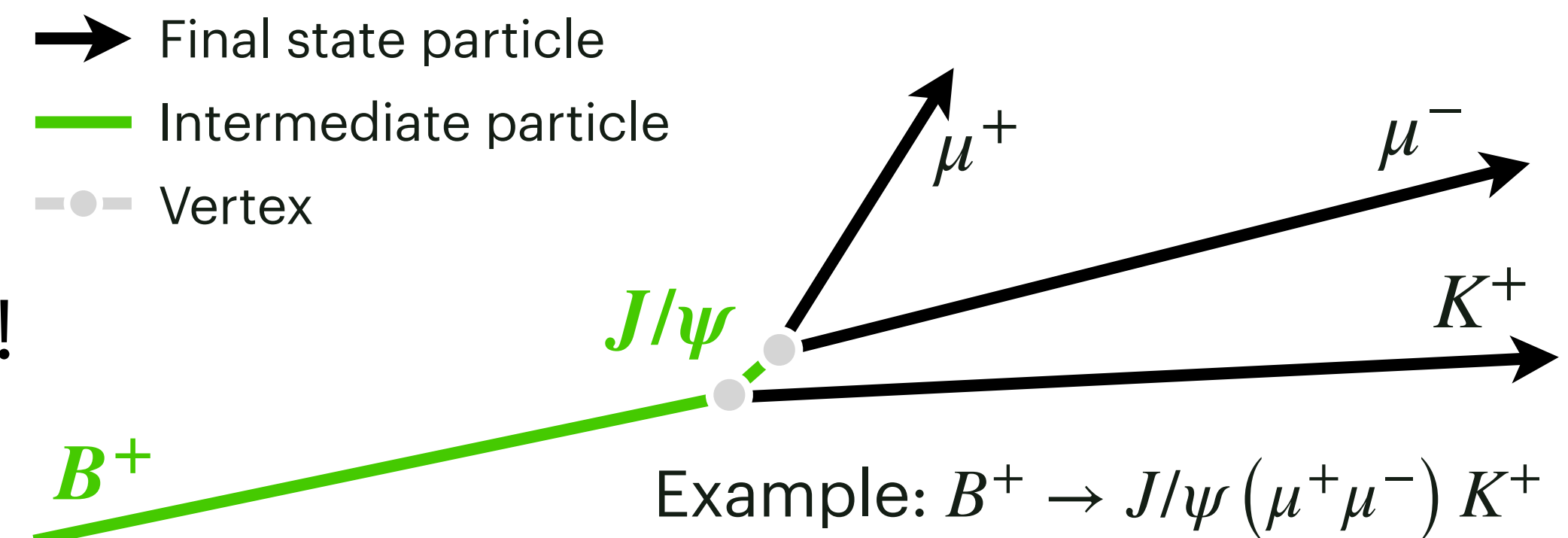
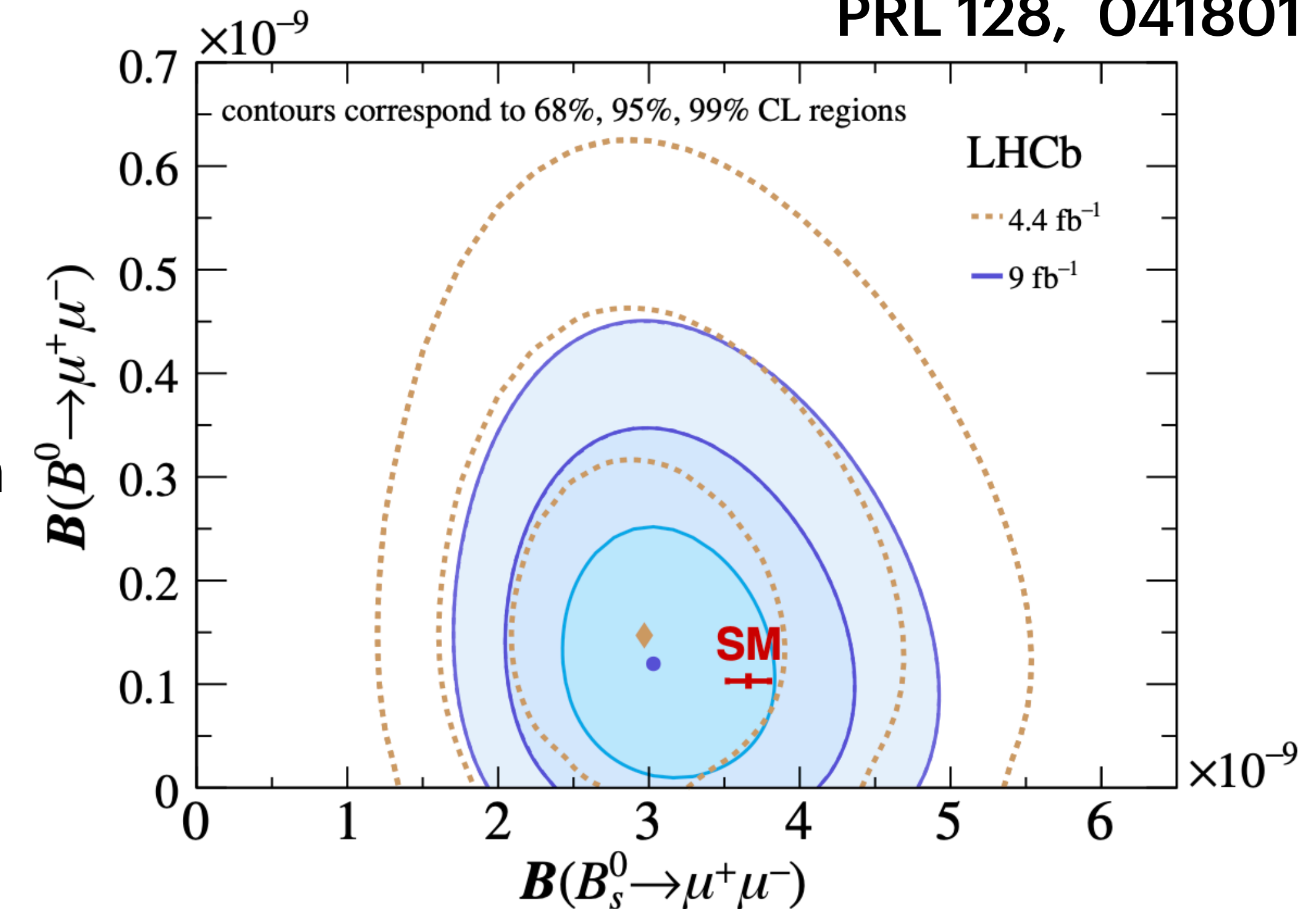
# Cut-based inclusive dilepton trigger



LHCb Run 3 Dataflow, LHCB-FIGURE-2020-016

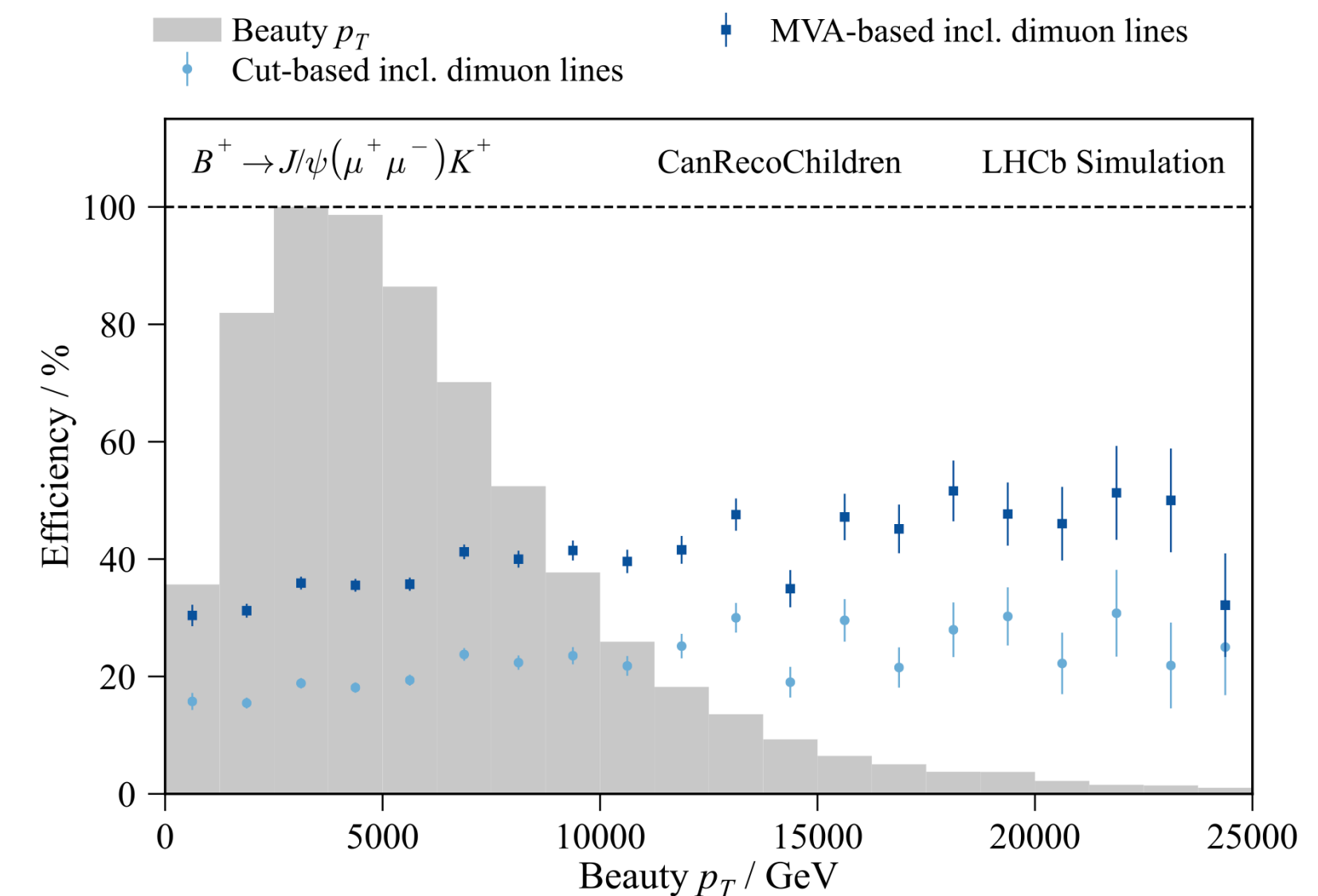
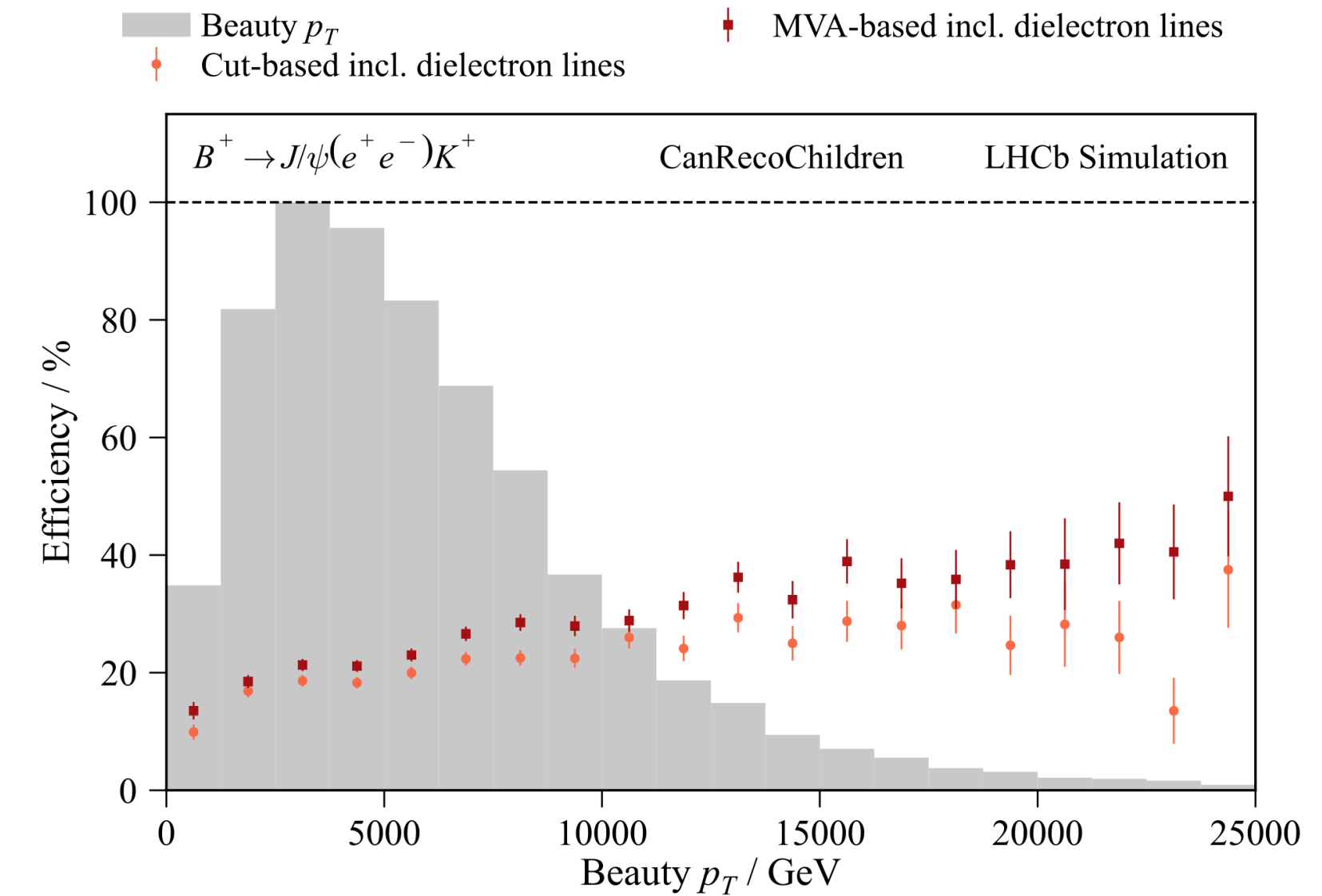
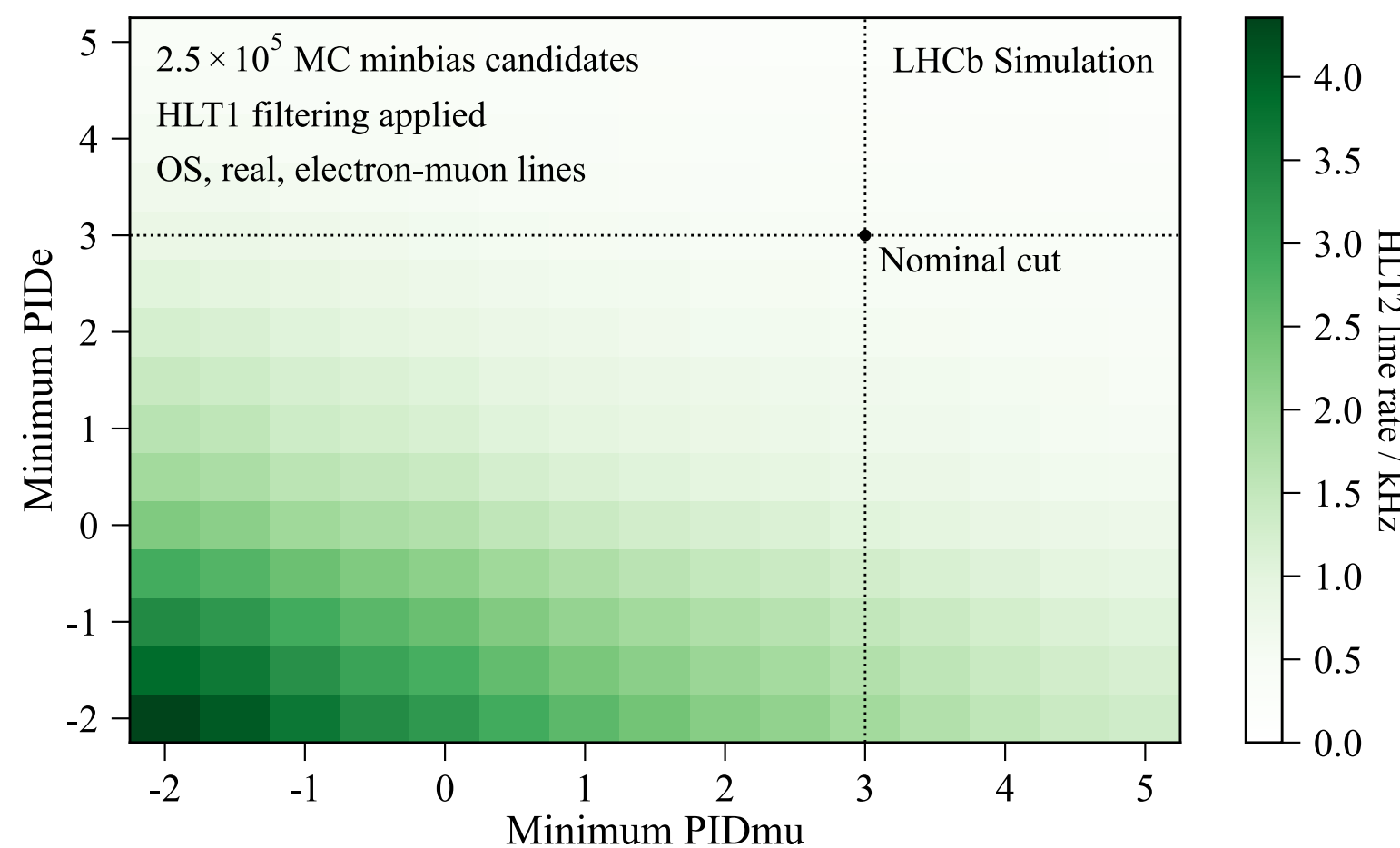
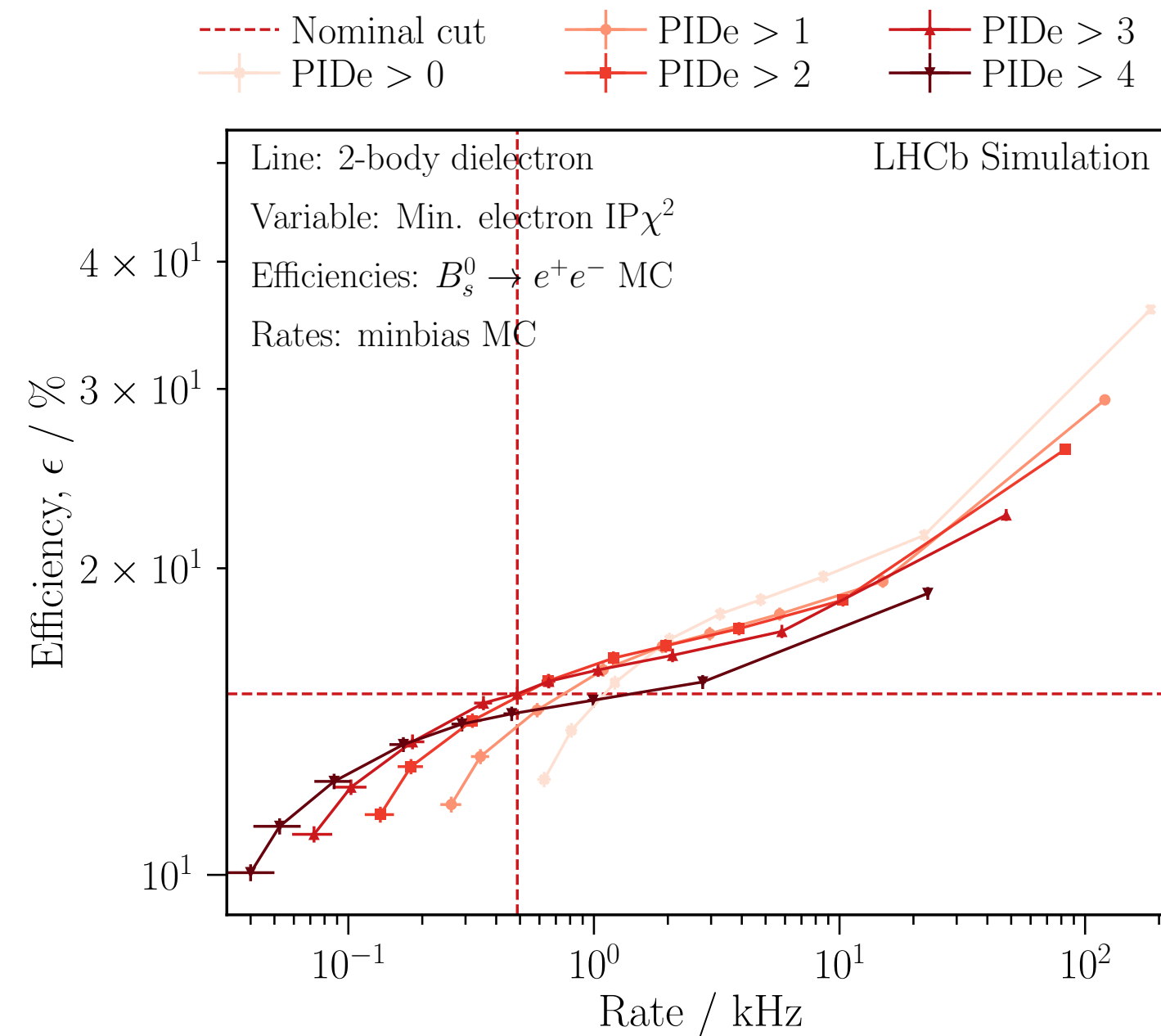
# Cut-based inclusive dilepton trigger

- ▶ Dilepton (i.e. lepton pair) events vital to LHCb physics programme:
  - ▶ **Rare decays searches:** measuring branching fractions of rare processes (right).
  - ▶ **Lepton universality tests:** comparing branching fraction ratios, e.g.,  $R_K$  and  $R_K^*$ , [2212.09153](#).
  - ▶ **Angular analyses:** BSM effects probed in angular observable measurements, [PRL 125, 011802](#).
- ▶ Inclusive triggers exploit  $b$  kinematics/topology:
  - ▶ MVA-based topological/dilepton triggers.
  - ▶ **Validation provided by a cut-based alternative.**
    - ▶ Can also be used to better understand detector!
- ▶ Further selections spruce inclusive trigger outputs.



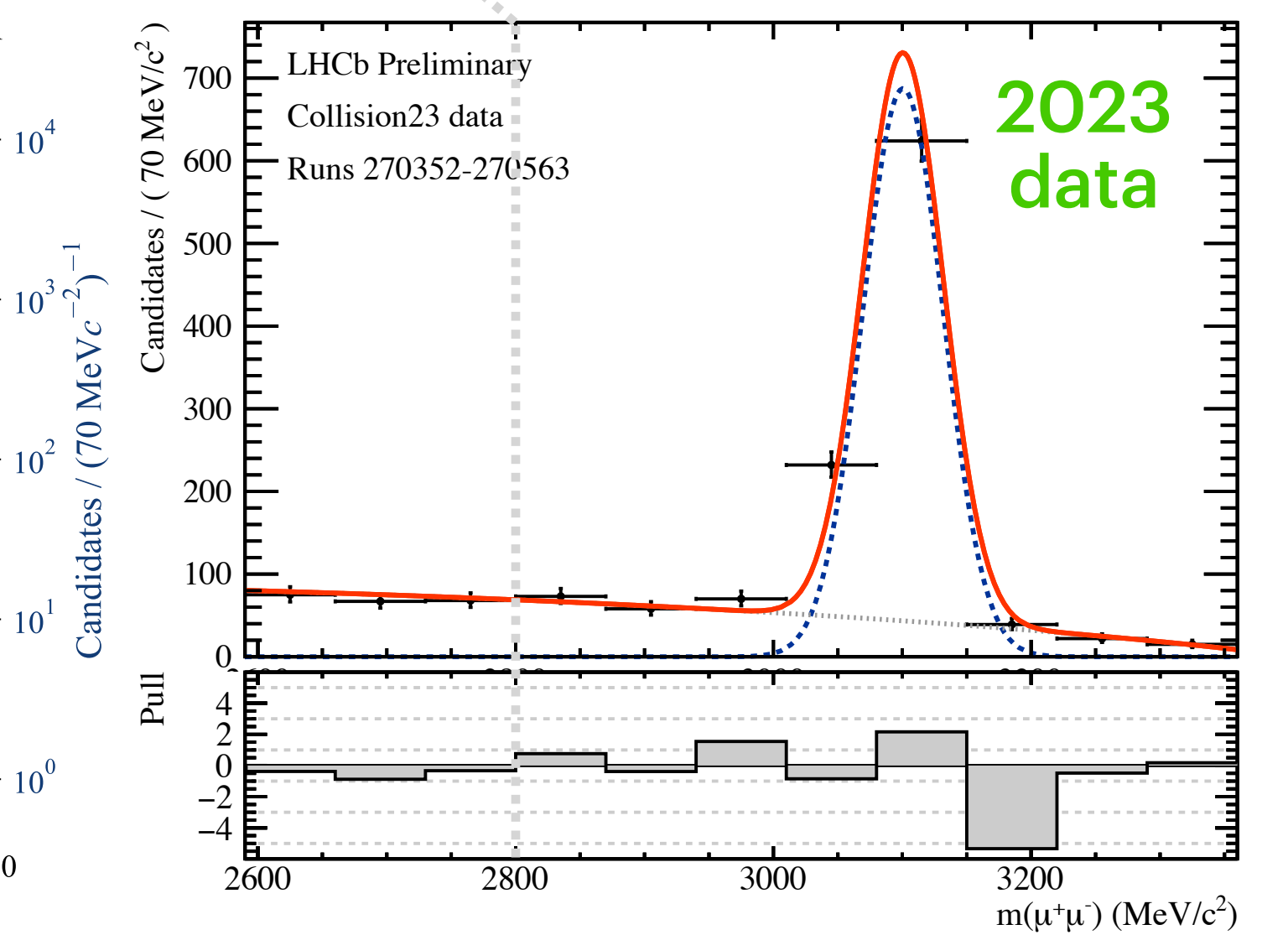
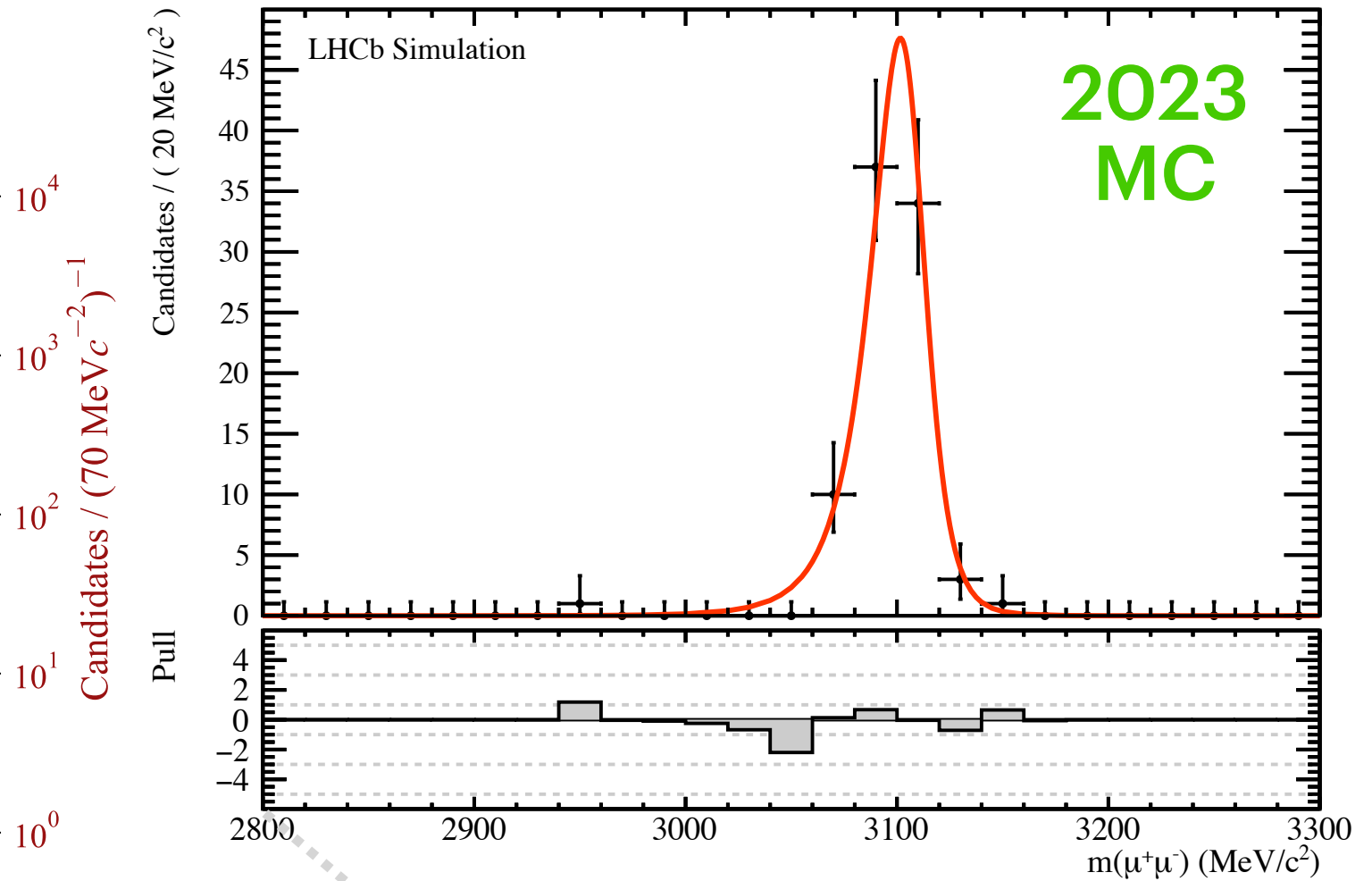
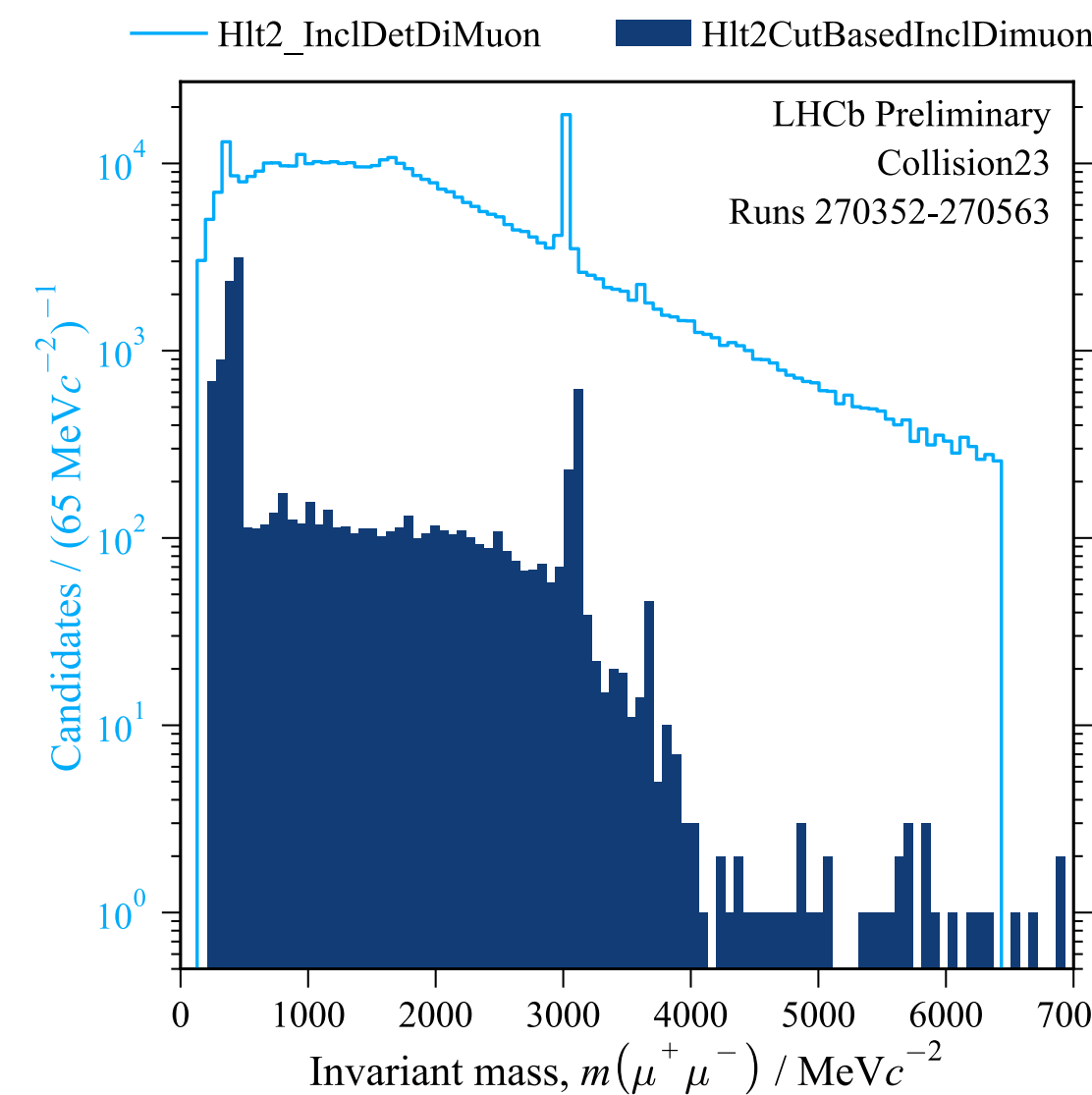
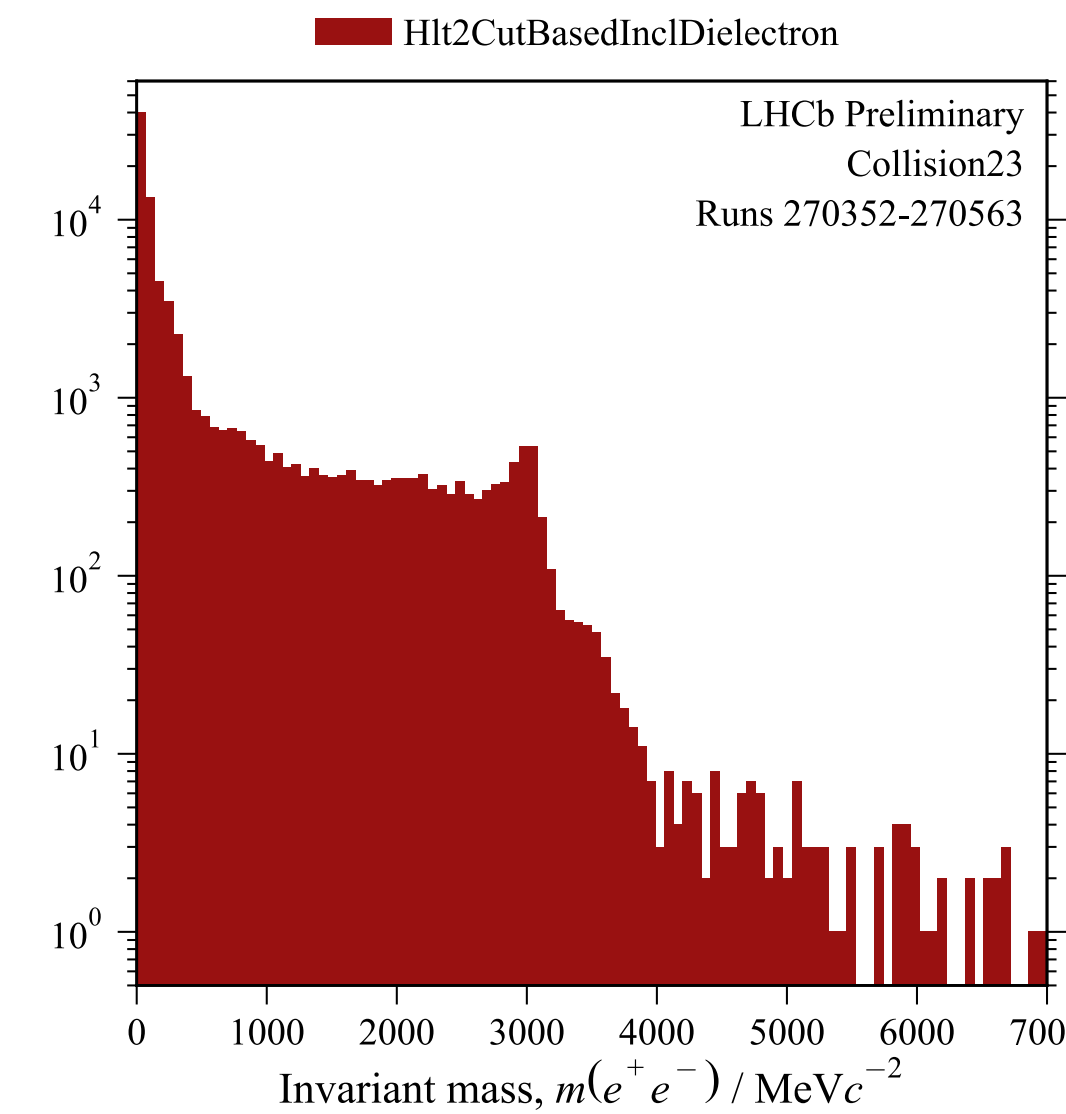
# Cut-based $\ell\ell$ trigger development

- ▶ Cuts of initial tuning from optimisation of rate and efficiency.
  - ▶ Rate must be  $\mathcal{O}$  (seconds).
  - ▶ Efficiencies should be comparable to MVA trigger.
- ▶ Input from WGs on physics impacts of cuts on e.g., PIDx.
- ▶ Merged in March 2023 🎉
- ▶ Next step: look at performance on data...



# Cut-based $\ell\ell$ trigger performance


- ▶ First data taken with cut-based inclusive dilepton trigger in Summer 2023.
- ▶ Insights of direct trigger output from monitoring histograms.
- ▶  $J/\psi$  and  $\psi(2S)$  peaks seen 🎉
- ▶ However, efficiency lower than anticipated by  $\sim 10\times$ ...
  - ▶ Retuning ongoing ahead of 2024 data-taking.





- ▶ Understanding of trigger efficiencies crucial to many analyses, often required for normalisation and systematics.
- ▶ TISTOS method well-established in LHCb:
  - ▶ Trigger on Signal (TOS) → trigger fired on signal in event.
  - ▶ Trigger independent of Signal (TIS) → trigger fired on rest of event.
  - ▶ Trigger on both (TOB) → trigger fired on **both** signal and non-signal objects.
  - ▶ Data **always** selected by some lines—take a subsample from TIS on a line, evaluate TOS efficiency of another line on subsample.
- ▶ TISTOS algorithm now available for both HLT1 and HLT2.
- ▶ Aim to evaluate Run 3 trigger efficiencies in  $B^+ \rightarrow J/\psi K^+$ , similarly to Run 1 (*right*).

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)



CERN-LHCb-PUB-2014-039  
LHCb-PUB-2014-039  
December 11, 2015

## Data driven trigger efficiency determination at LHCb

S. Tolk<sup>1</sup>, J. Albrecht<sup>2</sup>, F. Dettori<sup>3</sup>, A. Pellegrino<sup>1</sup>

<sup>1</sup> Nikhef, Amsterdam, Netherlands  
<sup>2</sup> TU Dortmund, Germany  
<sup>3</sup> CERN, Geneva

**Abstract**

We demonstrate in detail the trigger efficiency evaluation of the LHCb trigger system purely on data with the so-called TISTOS method. The discussion includes an explicit overview of the uncertainty propagation. Additionally, we present a way to reduce the systematic uncertainty of the TISTOS method by binning the phase space. As an example, the binning is performed in the  $B$  meson phase space for  $B^+ \rightarrow J/\psi K^+$  decays.

A large sample of simulated events is used to determine the systematic uncertainties. Following the procedure discussed in this note, the trigger efficiency can be correctly determined for any dataset of sufficient size, including a realistic determination of systematic uncertainties.

The developed method is used to measure the trigger efficiency of  $B^+ \rightarrow J/\psi K^+$  events in a dataset corresponding to an integrated luminosity of  $3 \text{ fb}^{-1}$ , collected in 2011 and 2012. The numerical values determined here have been used for the  $3 \text{ fb}^{-1}$  measurement of the branching fraction of the rare decay  $B_s^0 \rightarrow \mu^+ \mu^-$ .

© CERN on behalf of the LHCb collaboration, license CC-BY-3.0.

**LHCb-PUB-2014-039**

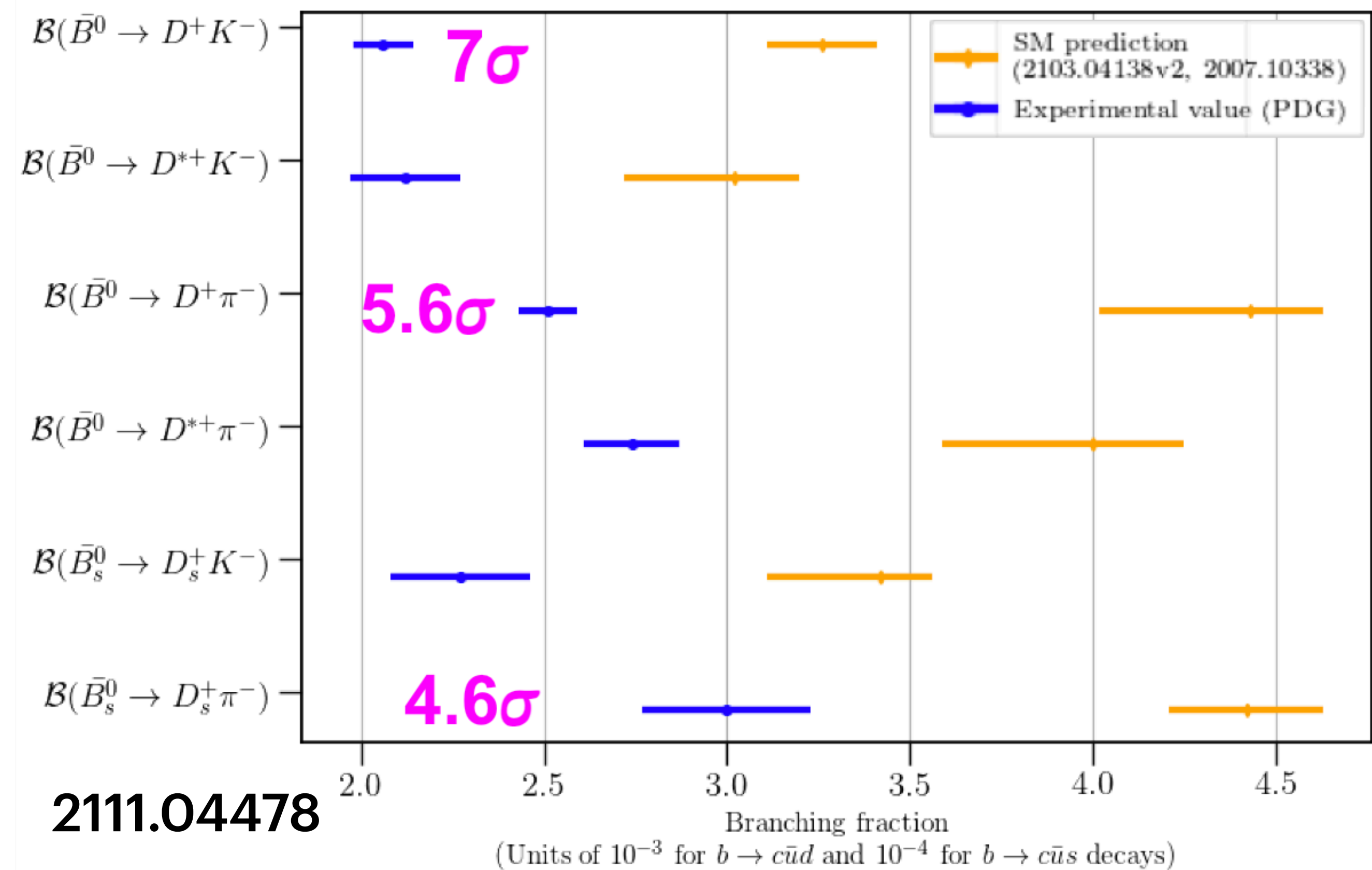
LHCb-PUB-2014-039  
11/12/2015

Run 2 measurement of  $A_{\text{fs}}^s$  in  $\bar{B}_s^0 \rightarrow D_s^+ \pi^-$

# Motivating $A_{fs}^s$

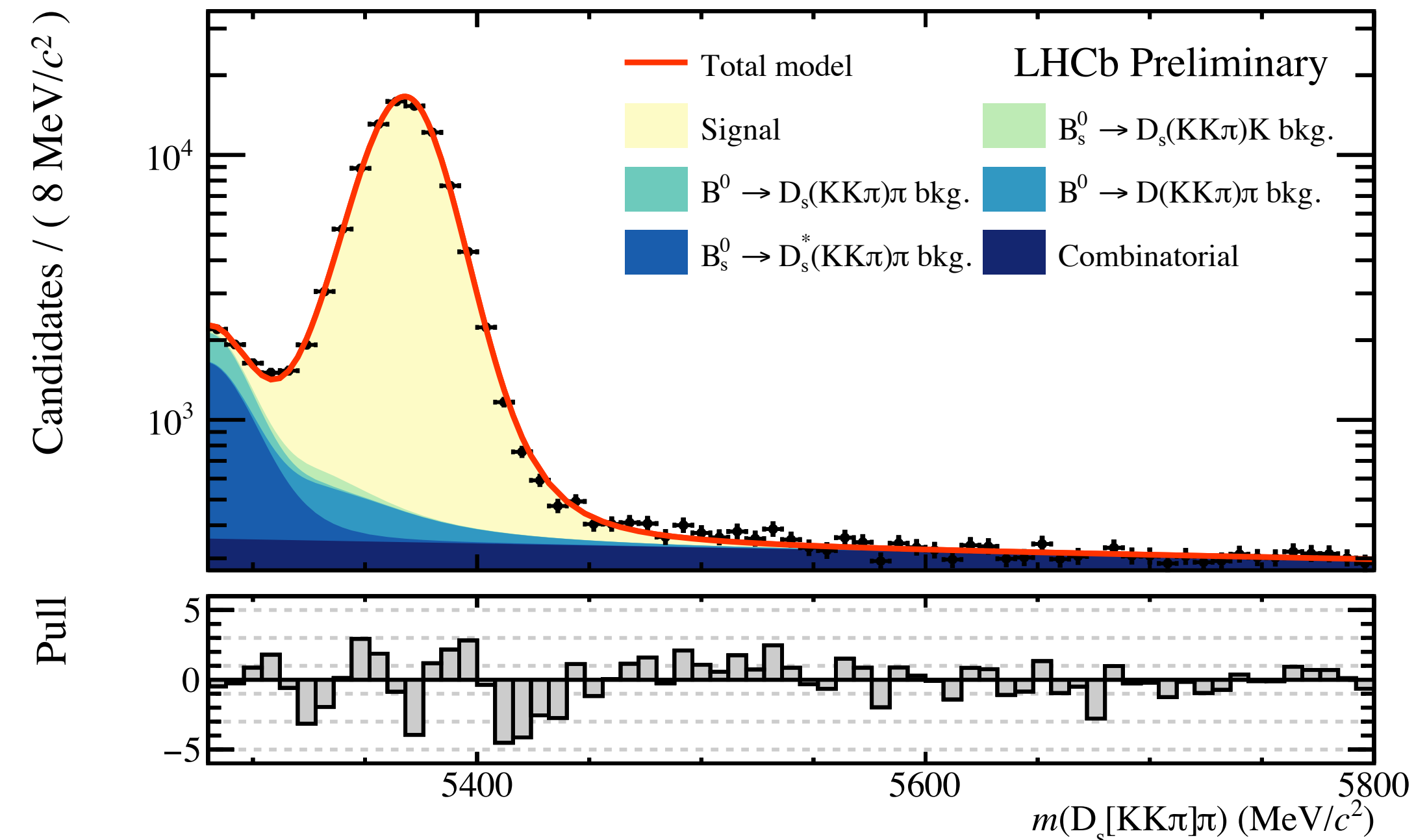
- ▶ Tree-level  $\bar{B}_{(s)}^{(*)0} \rightarrow D_{(s)}^{(*)+} h^-$  branching fraction measurements **disagree with SM predictions**.
- ▶ Measuring CP asymmetry in  $\bar{B}_s^0 \rightarrow D_s^+ \pi^-$  decays,  $A_{fs}^s$ , may shed light (**theory input vs new physics**); independent of theory assumptions.
- ▶ Can extract  $A_{fs}^s$  from the **untagged, time-integrated** CP asymmetry:

$$\left\langle A_{\text{untagged}}^s \right\rangle = \frac{N(D_s^+ \pi^-) - N(D_s^- \pi^+)}{N(D_s^+ \pi^-) + N(D_s^- \pi^+)} - A_{\text{det.}} - A_{\text{prod.}} \frac{\int e^{-\Gamma_s t} \cos(\Delta M_s t) \epsilon(t) dt}{\int e^{-\Gamma_s t} \cosh\left(\frac{\Delta M_s t}{2}\right) \epsilon(t) dt} - \sum_i f_{\text{bkg}}^i A_{\text{bkg}}^i$$



# Analysis status

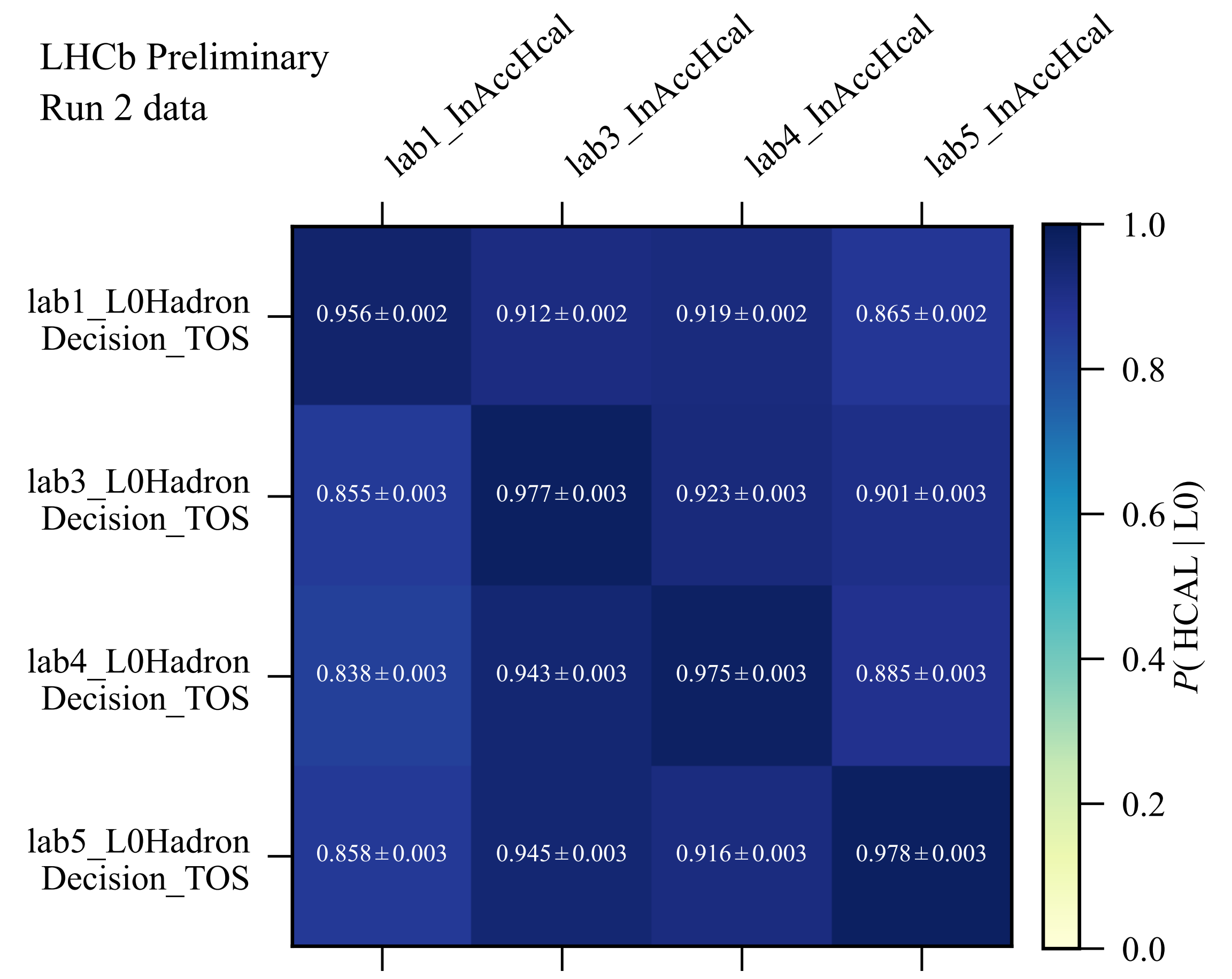
- ▶ Measure  $\langle A_{\text{untagged}}^s \rangle$  in  $5.7 \text{ fb}^{-1}$  of Run 2 proton-proton data:
  - ▶ Offline selection reduces to  $\mathcal{O}(10^6)$  candidates.
  - ▶ Extract signal yields,  $N(D_s^\pm \pi^\mp)$ , from NLL fit to invariant mass,  $m(D_s^\pm \pi^\mp)$ .
  - ▶ Corrections to  $\langle A_{\text{untagged}}^s \rangle$  in good standing (e.g.,  $A_{\text{prod.}}, A_{\text{det.}}$ ), many systematics already evaluated.
- ▶ Planning to enter WG review in December.



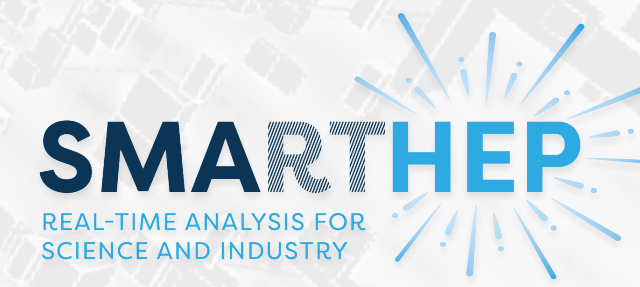
Example fit (combined  $N(D_s^\pm \pi^\mp)$  yields) over Run 2.

# L0 trigger studies

- ▶ L0 hardware trigger still present in Run 2; much to be understood.
- ▶ L0Hadron main line of interest—require TOS on any final state track.
- ▶ Efficiency forms component of  $A_{det.}$ , need to evaluate → use L0HadronTables tool (*right*).
  - ▶ Preliminary results appear to show no asymmetry within statistical sensitivity 🎉
- ▶ Need to understand L0 effect on separation of tracks in HCAL.



# Fast offline analysis tools



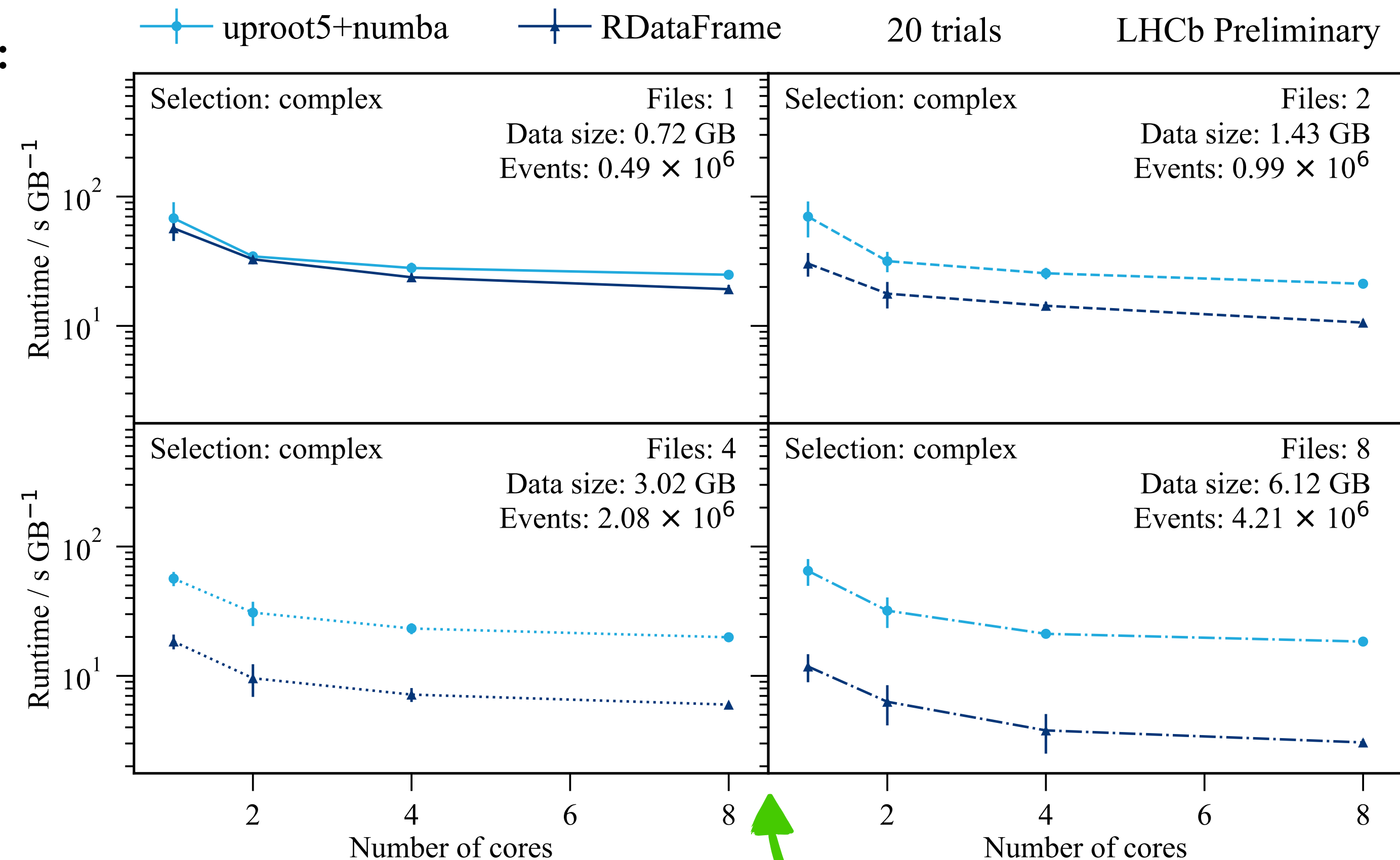
Measurement exposes analysis bottlenecks:

- ▶ Offline selection,  $\mathcal{O}$  (hours).
- ▶ Fitting,  $\mathcal{O}$  (minutes), but many toys required (fit stability, background asymmetry, etc.).

**These will only get worse in Run 3 (and beyond...)**

+

*This isn't exclusive to LHCb*



Experts willing (enthusiastic!) to help:

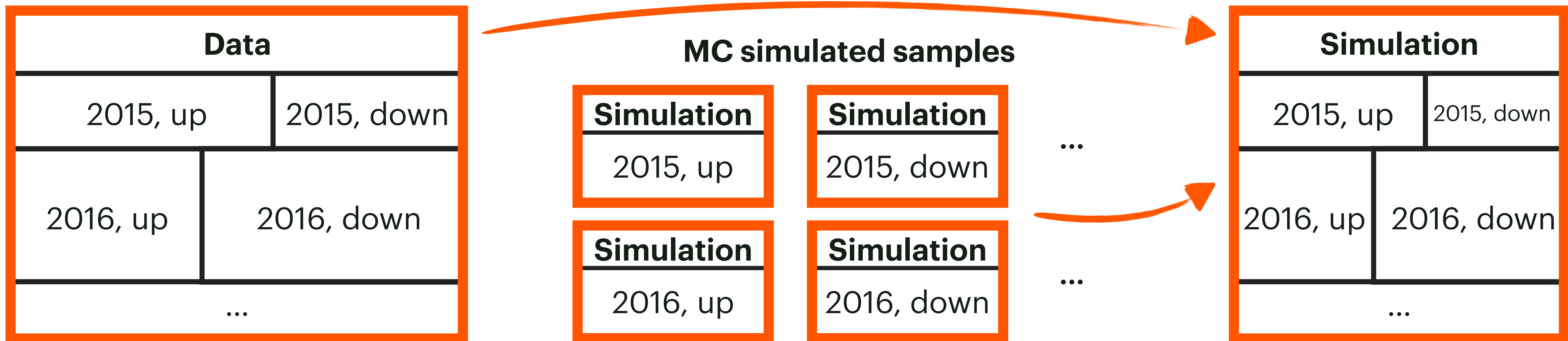
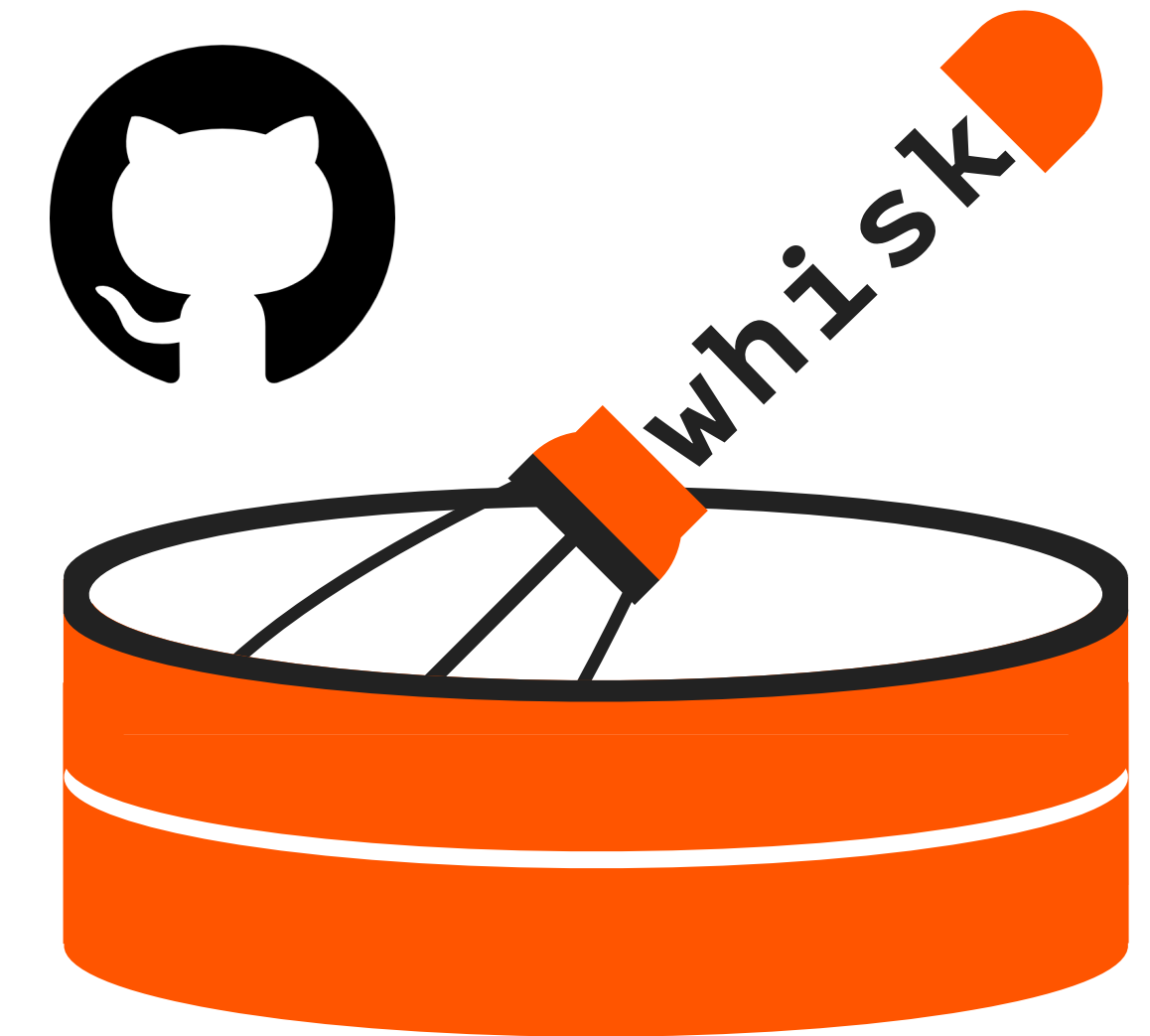
- ▶ Now collaborating RDataFrame + RooFit developers on optimising selection/fitting.
- ▶ Able to better leverage expertise and technology (e.g. GPUs).

**Presented  $A_{fs}^S$  offline selection benchmarking to ROOT developers**

Often have categorised data and MC simulation of each category.  
whisk to simplify combining MC proportionate to data:

- ▶ Generate a “recipe” from the data, listing proportions.
- ▶ “whisk” category-specific samples together from file/recipe to combine proportionately.

Work in progress, proof of concept with Awkward arrays prepared.



# Other activities



## RTA HLT Piquet

- ▶ Responsible for operating the LHCb trigger.
- ▶ Work on trigger commissioning tasks.

## Data Manager

- ▶ Responsible for general LHCb operation (alongside Shift Leader).

## RTA Software Shifter (remote)

- ▶ Responsible for maintenance tasks, e.g, testing, review, in LHCb RTA software.



Semester

● **Winter 2022/23**

Tutoring *“Einführung in die Kern- und Elementarteilchenphysik”* (KET, introduction to Nuclear & Particle Physics) in English.

Snakemake introduction in Bachelor programming course

● **Summer 2023/24**

Talk on fitting, plotting and presentation in Bachelor talk series

Supervision in “Advanced Laboratory course: Particle physics” of the “Analysis of CP violation with LHCb data” lab.

● **Winter 2023/24**

Tutoring *KET in German*.

● **Summer 2024/25**

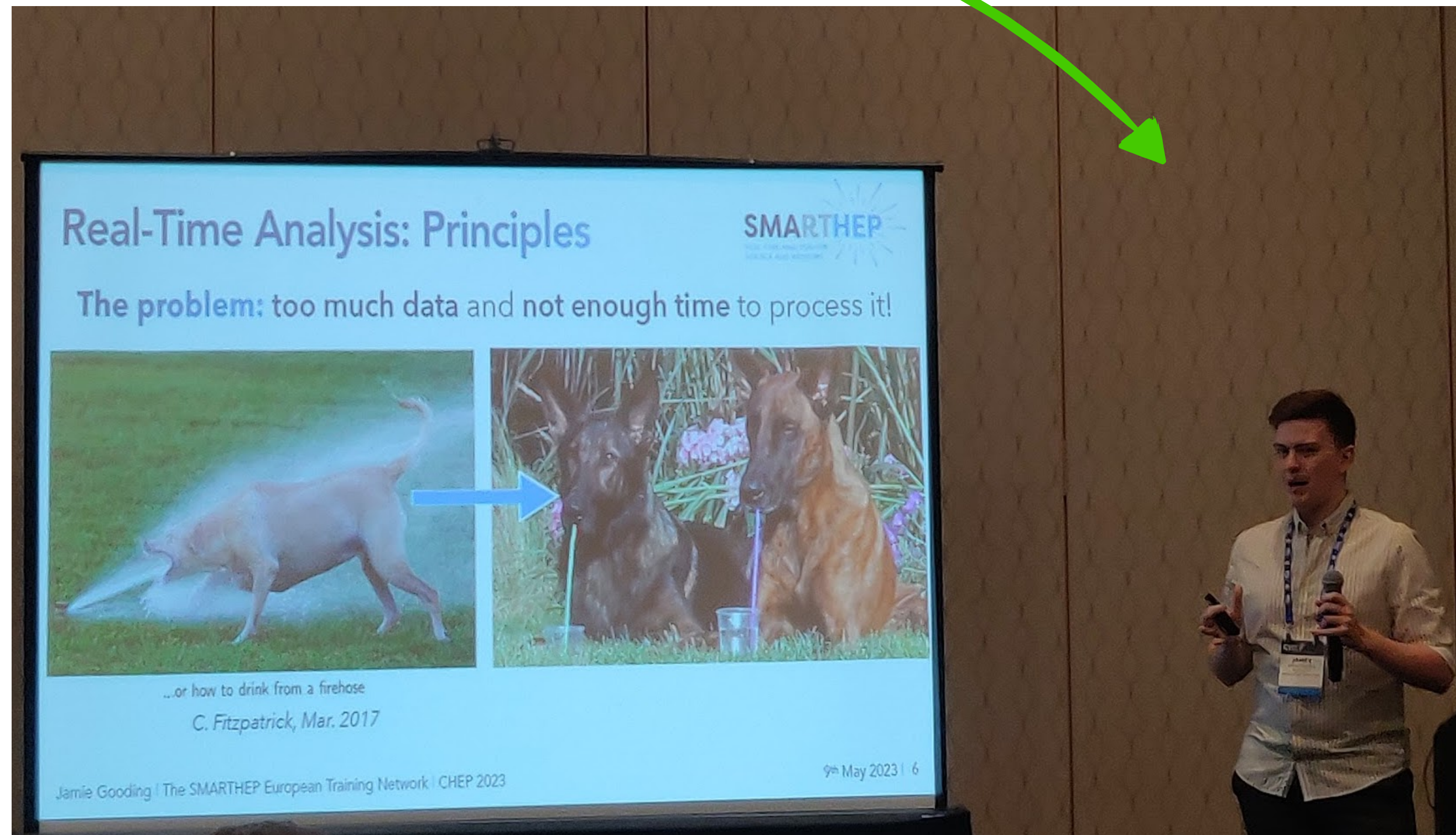
Supervision of DAAD RISE intern for ~3 months, working on data-driven efficiencies.

2021

**Dortmund RISE track  
record not terrible!**



## Presented SMARTHEP at CHEP 2023 in Norfolk, Virginia



Thanks Leon,  
Carlos, Pratik,  
Micol + many  
more!

### The SMARTHEP European Training Network

James Andrew Gooding<sup>1,\*</sup>, Leon Bozianu<sup>2</sup>, Carlos Cocha Toapaxi<sup>3</sup>, Pratik Jawahar<sup>4</sup>, and Micol Olocco<sup>1</sup>

<sup>1</sup>Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany

<sup>2</sup>Département de Physique Nucléaire et Corpusculaire, Université de Genève, Geneva, Switzerland

<sup>3</sup>Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

<sup>4</sup>Department of Physics and Astronomy, University of Manchester, Manchester, United Kingdom

**Abstract.** Synergies between **M**Achine learning, **R**eal-Time analysis and **H**ybrid architectures for efficient **E**vent **P**rocessing and decision-making (SMARTHEP) is a European Training Network, training a new generation of Early Stage Researchers (ESRs) to advance real-time decision-making, driving data-collection and analysis towards synonymity. SMARTHEP brings together scientists from major LHC collaborations at the frontiers of real-time analysis (RTA) and key specialists from computer science and industry. By solving concrete problems as a community, SMARTHEP will further the adoption of RTA techniques, enabling future High Energy Physics (HEP) discoveries and generating impact in industry. ESRs will contribute to European growth, leveraging their hands-on experience in machine learning and accelerators towards commercial deliverables in fields that can profit most from RTA, e.g. transport, manufacturing, and finance. This contribution presents the training and outreach plan for the network, and is intended as an opportunity for further collaboration and feedback from the CHEP community.

#### 1 Introduction

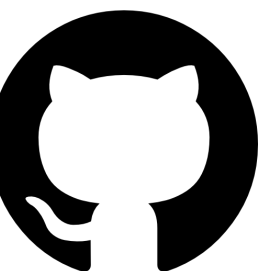
The Synergies between **M**Achine learning, **R**eal-Time analysis and **H**ybrid architectures for efficient **E**vent **P**rocessing and decision making (SMARTHEP) European Training Network is an EU Horizon-funded training network, with a focus on the development of expertise in real-time analysis (RTA) techniques through applications to High Energy Physics (HEP) research and industry. The network centres around the training of 12 Early Stage Researchers (ESRs) between September 2022 and September 2025.

#### 2 SMARTHEP as a European Training Network

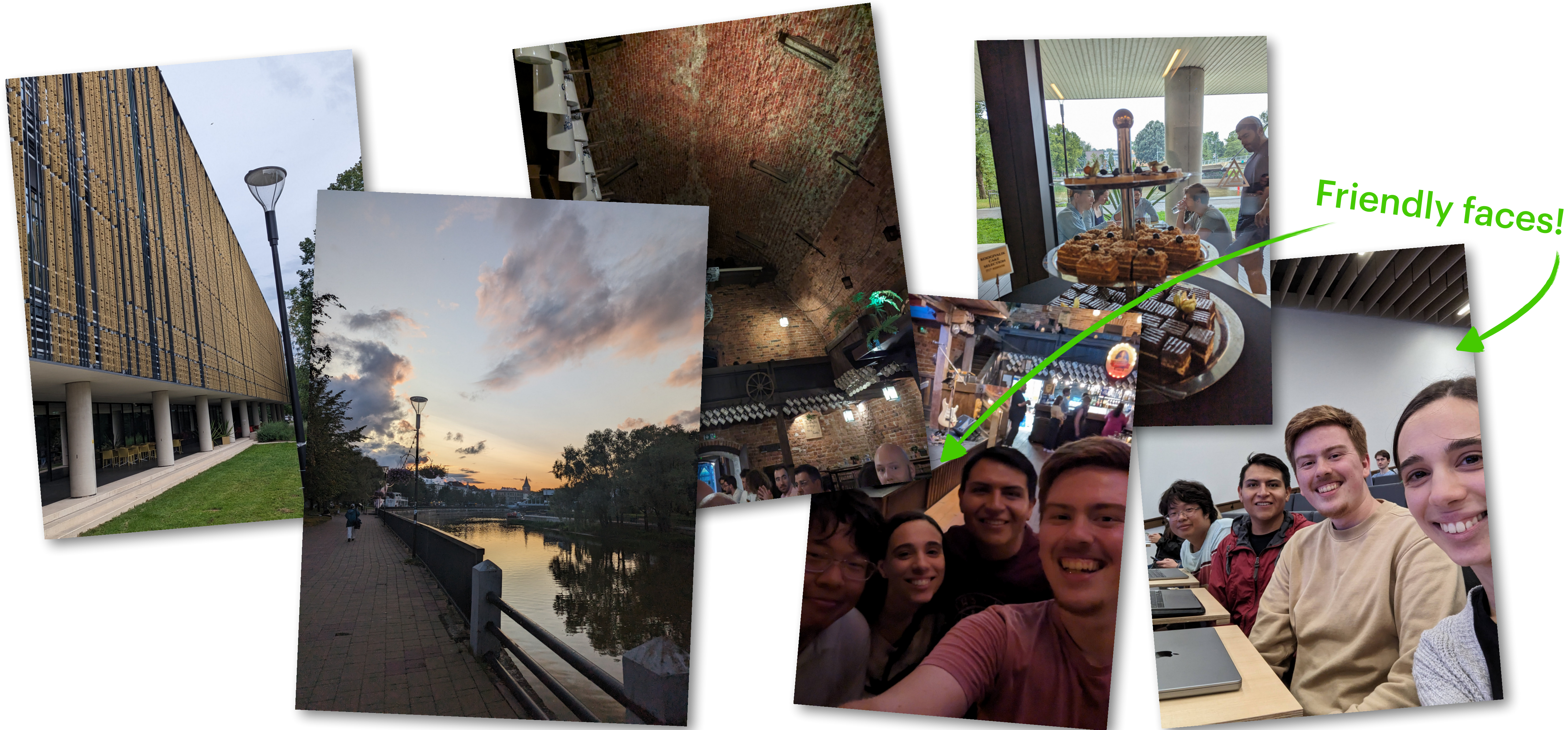
As a European Training Network (ETN), the primary aim of the network is in training ESRs, whilst deepening synergies between HEP and industry. The network takes a novel approach to building such synergies, structuring each ESR position (a 3 year period of doctoral study) around academic and industrial secondments. To achieve this, the network is formed of a

\*e-mail: Jamie.Gooding@cern.ch

Proceedings in EPJ WoC  
Expected June 2024



# CERN School of Computing 2023



Friendly faces!

## 109th LHCb Week/German LHCb Groups Meeting

- ▶ Presented  $A_{fs}^S$  status twice in two weeks.
- ▶ Audience of entire LHCb experiment + German LHCb groups.

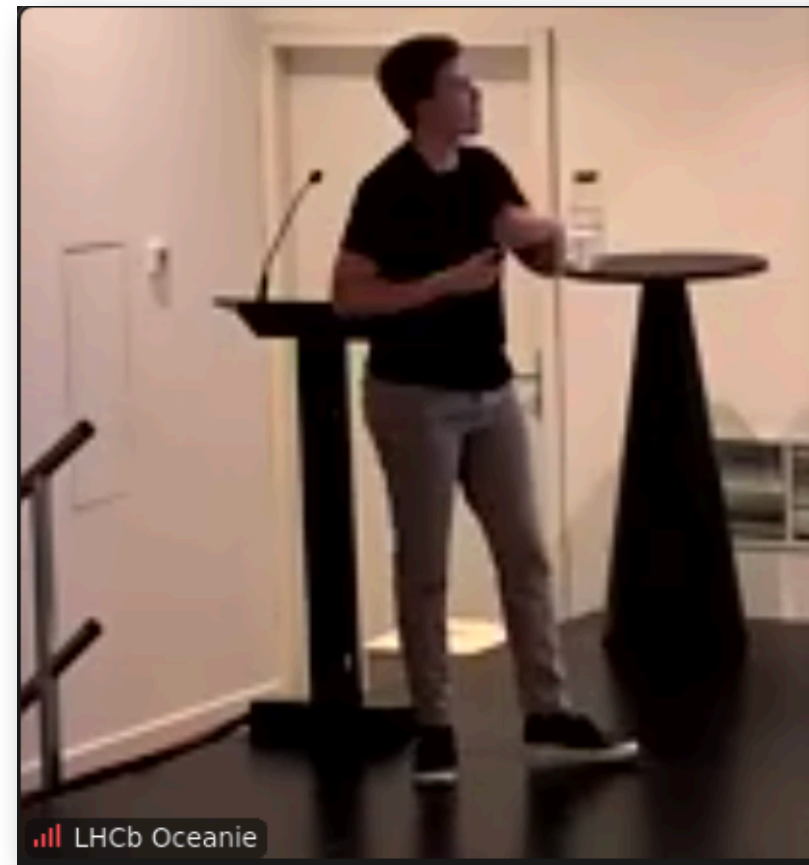
$\bar{B}_{(s)}^{(*)0} \rightarrow D_{(s)}^{(*)+} h^-$  decays and  $b \rightarrow c \bar{u} q$  anomaly

$\bar{B}_{(s)}^{(*)0} \rightarrow D_{(s)}^{(*)+} h^-$  decays are tree-level in the SM—many under good theoretical control, particularly  $\bar{B}_s^0 \rightarrow D_s^{(*)+} \pi^-$  and  $\bar{B}^0 \rightarrow D_s^{(*)+} K^- \dots$

- ▶ Measurements and SM (QCDF)- predictions of branching fractions disagree.
  - ▶ Tension of  $4.6\sigma$  in  $\bar{B}_s^0 \rightarrow D_s^+ \pi^-$ .
- ▶ New Physics (NP) at tree-level increasingly credible: [arxiv:2111.04478](https://arxiv.org/abs/2111.04478).

Decay Mode	SM prediction (2013, 2016, 2020)	Experimental value (LHCb)	Significance
$B(\bar{B}^0 \rightarrow D^+ K^-)$	~3.5	~2.5	$7\sigma$
$B(\bar{B}^0 \rightarrow D^+ \pi^-)$	~3.5	~2.5	$5.6\sigma$
$B(\bar{B}_s^0 \rightarrow D_s^+ \pi^-)$	~3.5	~2.5	$4.6\sigma$
$B(\bar{B}_s^0 \rightarrow D_s^+ K^-)$	~3.5	~2.5	-
$B(\bar{B}_s^0 \rightarrow D_s^+ \pi^-)$	~3.5	~2.5	$4.6\sigma$

J. Gooding | 109th LHCb Week | Time-integrated measurement of  $A_{fs}^S$  in  $\bar{B}_s^0 \rightarrow D_s^+ \pi^-$  | 26th September 2023 | 2



## CSC 2023 Lightning Talk

- ▶ Introduced the LHCb Run 3 trigger.
- ▶ Audience of physics/computing early career researchers.
- ▶ 5 minute lightning talk format.

## Training and workshops

Netzwerk Teilchenwelt particle physics communication workshop

TU Dortmund German B1 course

Quarterly LHCb Weeks

German Physical Society spring meeting 2023\*

LHCb Rare Decays Hackathon

Neckarzimmern German  $b$  physics retreat

Software Framework(s) for LHCb's future workshop†

\*Disrupted by COVID †Last week!

- ▶ A busy year, but plenty of learning and plenty of fun!
- ▶ Cut-based inclusive  $\ell\ell$  trigger retuning well underway.
- ▶ Expect  $A_{fs}^S$  analysis to wrap up by the summer.
- ▶ Secondments approaching ever faster:
  - ▶ LHCb HLT Commissioning at CERN in Spring 2024
  - ▶ TBC at Ximantis in Winter 2024
- ▶ Hoping for another year of progress and collaboration!

✉ [jamie.gooding@cern.ch](mailto:jamie.gooding@cern.ch)

🌐 @goodingjamie

