Prospects for Lepton Flavour Universality tests at LHCb with Run 3 data

14/11/26

Discrete 2026, Bratislava

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FSP LHCb

technische universität dortmund

color meets flavor

Gefördert durch:

Bundesministerium für Forschung, Technologie und Raumfahrt

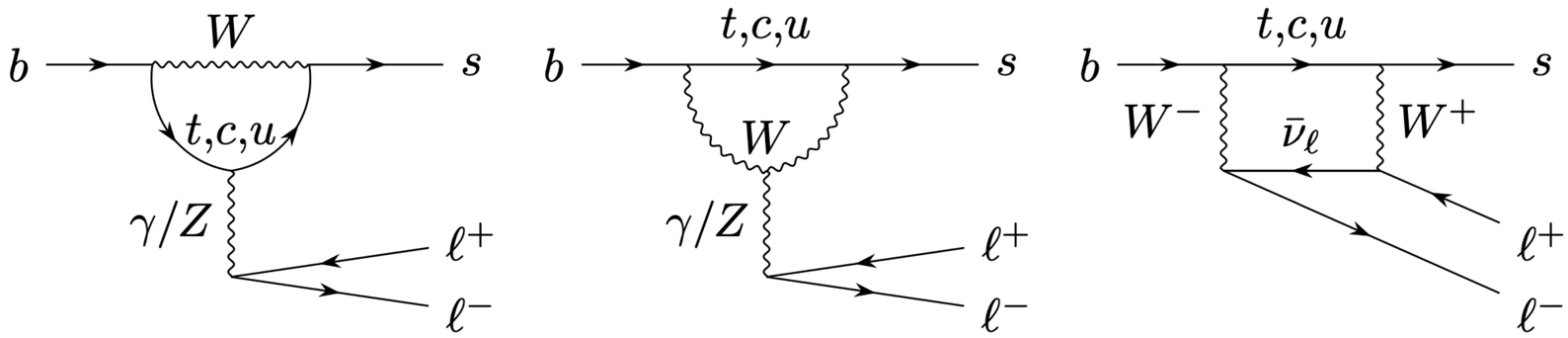
Lepton universality in the SM

- The SM predicts **lepton flavour universality** (LFU) → **same couplings** for lepton families

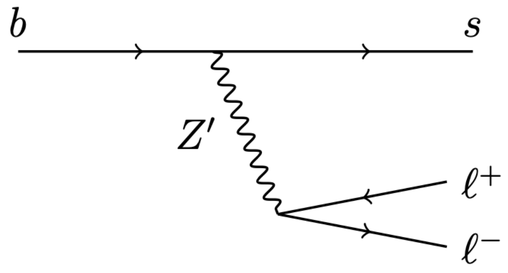
- The SM does **not** allow **flavour changing neutral currents** (FCNC) at tree level → suppression of $b \to s\ell^+\ell^-$

- **New physics** (NP) can influence these processes at tree level → possible **lepton flavour universality violation** (LFUV)

SM



NP

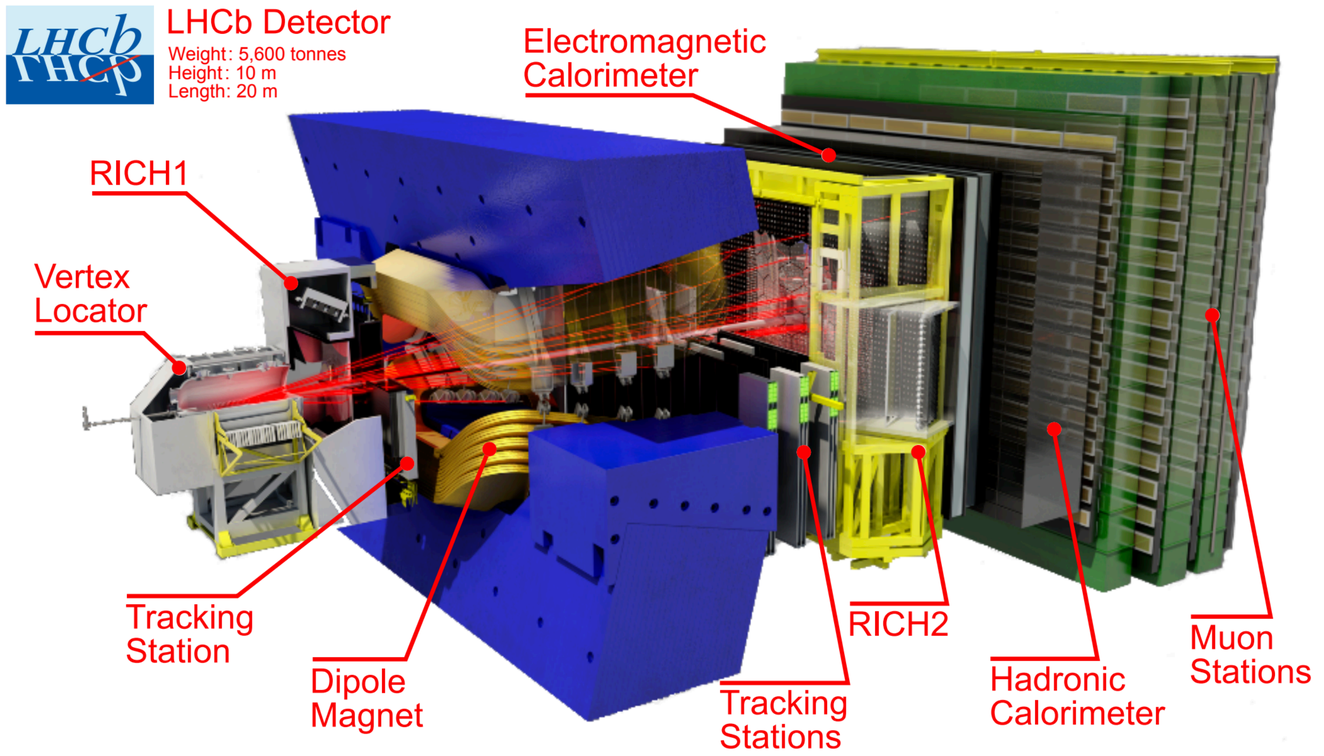


[LHCb-PAPER-2022-045]

LHCb for b physics

The LHCb experiment has been designed for the study of b and c decays

- Single arm **forward** spectrometer ($2 < \eta < 5$ acceptance region)
- Great **vertex** and **momentum** resolution for **tracks** reconstruction
- Great Particle IDentification (**PID**) to efficiently reconstruct different **leptonic** and **hadronic species**



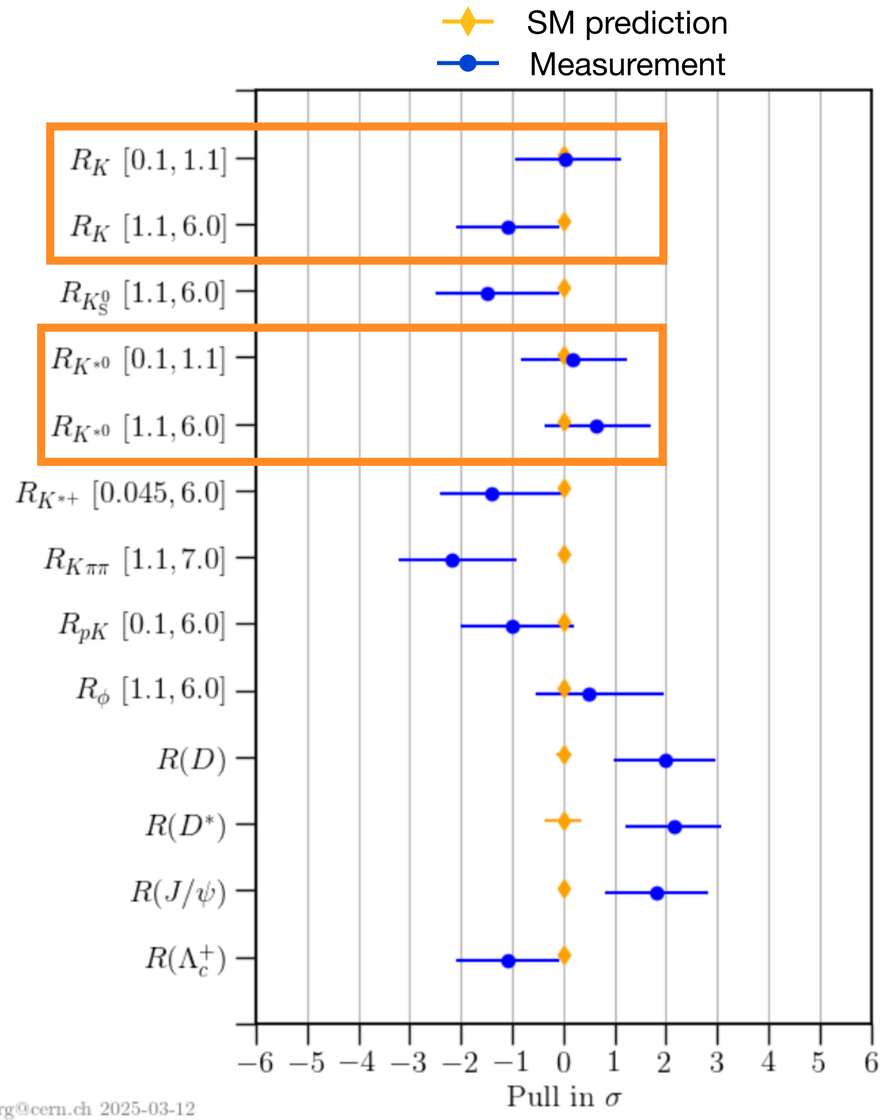
[arXiv:1510.04466] Run 1 and 2 configuration

LFU tests at LHCb

- **Tests** of LFU at LHCb can be performed via R_X observables → **ratios** of branching fractions with different final state leptons
- The observables R_{K,K^*} are defined as follows:

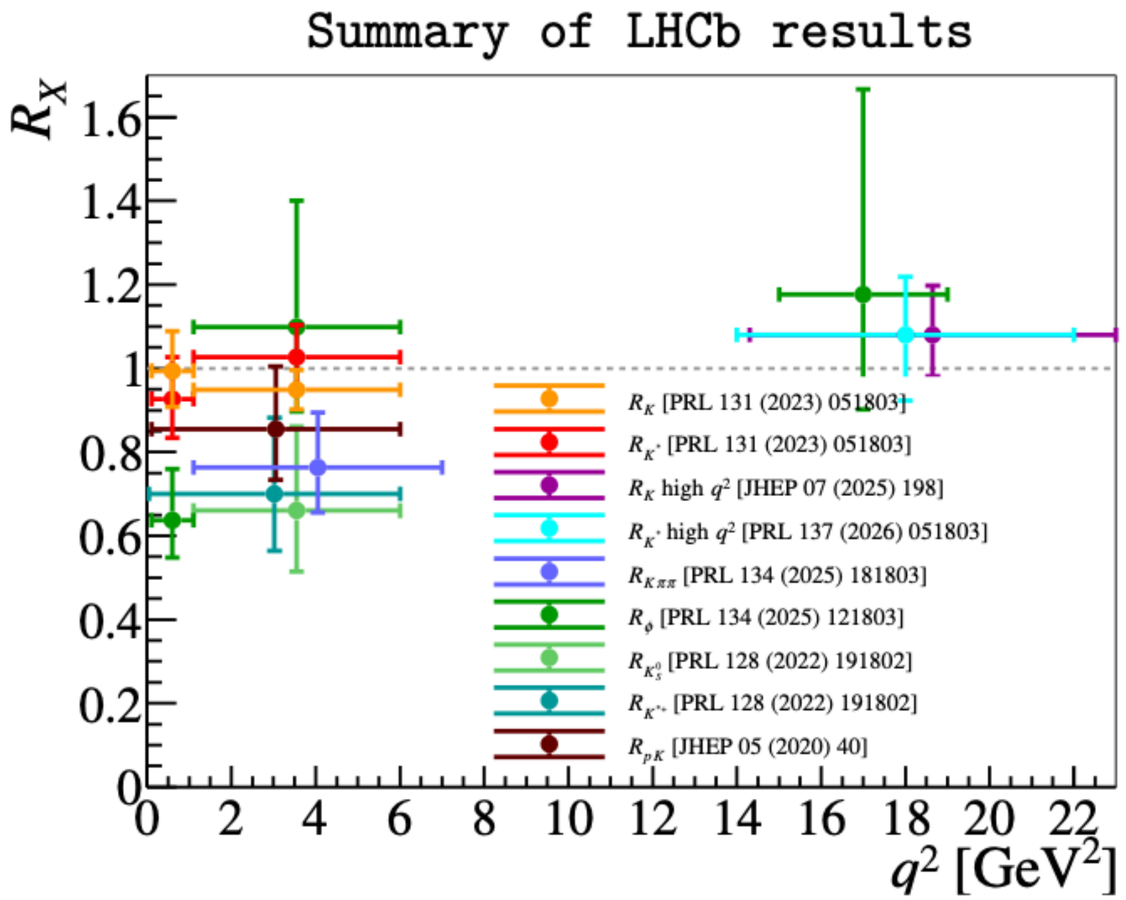
$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma\left(B^{(+,*0)} \to K^{(+,*0)}\mu^+\mu^-\right)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma\left(B^{(+,*0)} \to K^{(+,*0)}e^+e^-\right)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

- **Deviations** from SM predictions would indicate **LFUV**
- This observables are used to constrain Wilson Coefficients (**WC**) related to LFUV in Effective Field Theory (**EFT**)



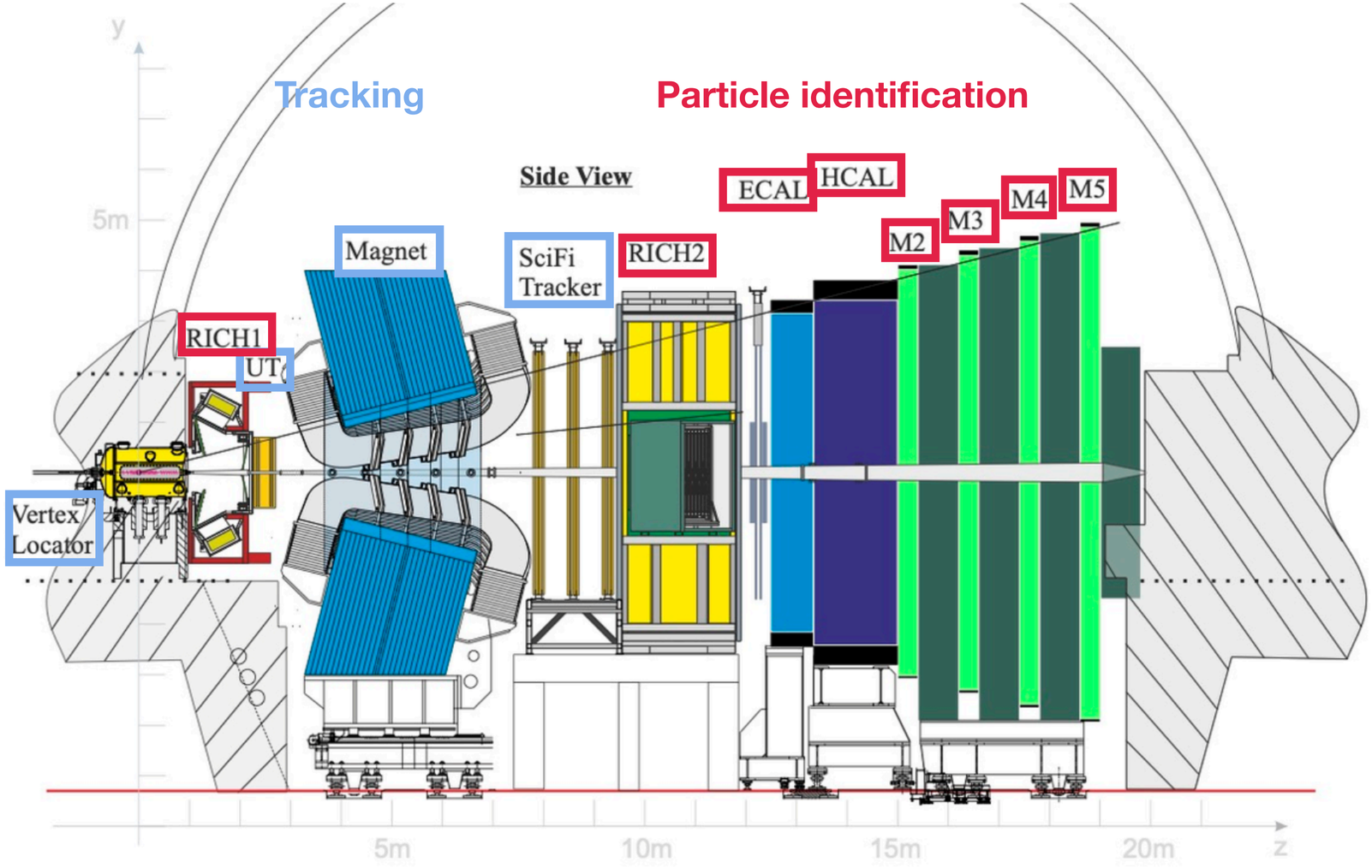
LFU tests at LHCb

- Data from **Run 1** and **Run 2** used for many analysis
- Most recent analysis is R_{K*} in the high q^2 region was presented this year [arXiv:2611.00230]
- Overall, LFU tests are **compatible** with the **SM**
- The uncertainty is dominated by statistics → **LHCb Upgrade I**!



[Rare and very rare decays at LHCb,
Daniele Provenzano (LHCb collaboration)
at XV International Conference on New Frontiers in Physics]

LHCb detector in Run 3



[LHCb-TDR-012]

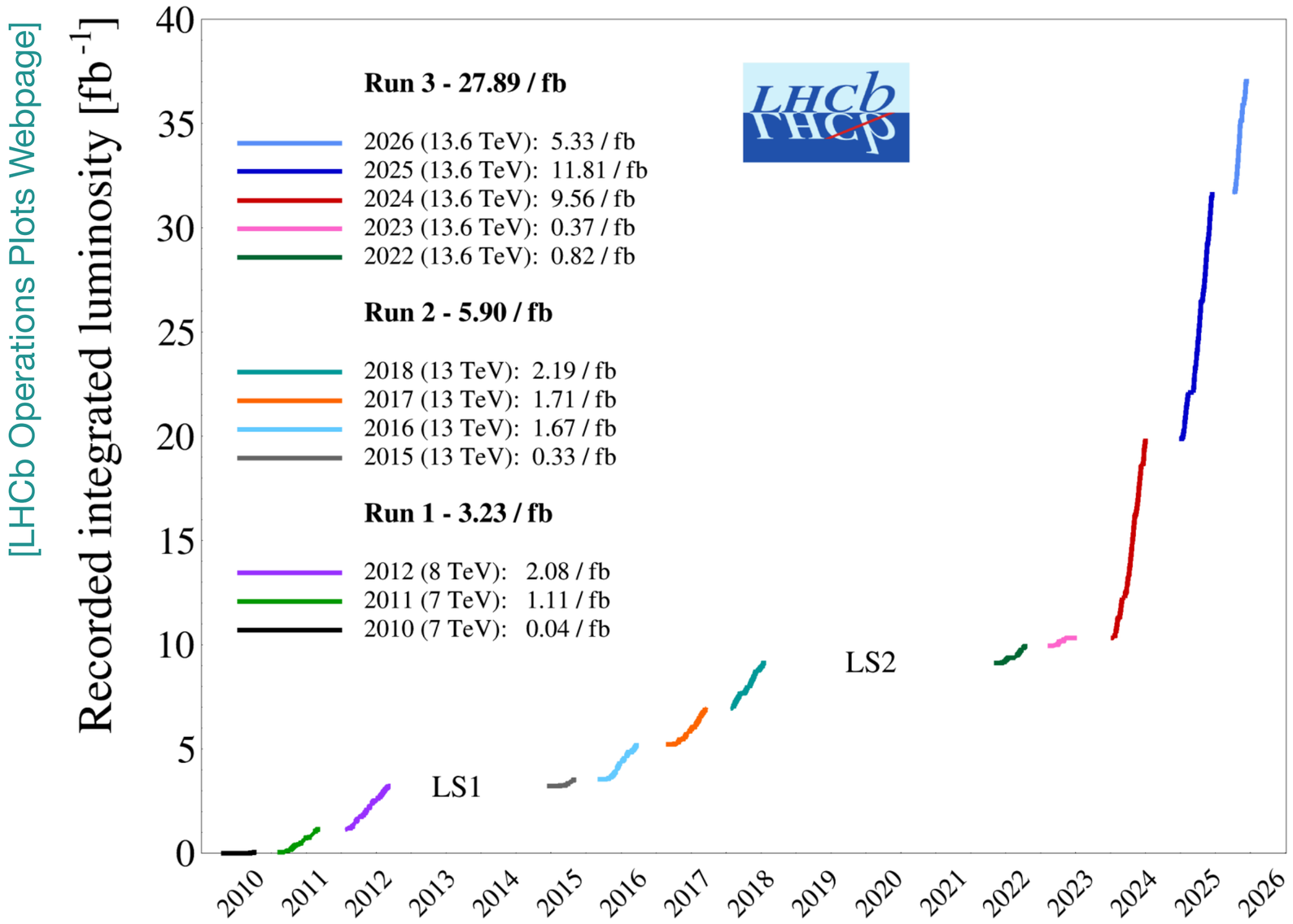
Run 3 have x5 istantaneous luminosity of Run 1&2 → need for better **tracking** and **trigger**

Removed hardware trigger:

- Allow increase of selected events with increase of luminosity
- better electron and muon agreement

Recorded luminosity in Run3

- Recorded **luminosity** at LHCb during **2024** ~ 28fb^{-1} → **3x greater** than entire Run 1 and Run 2 (**2010-2018**)
- **New detector** conditions → **different phase space** conditions for many analysis

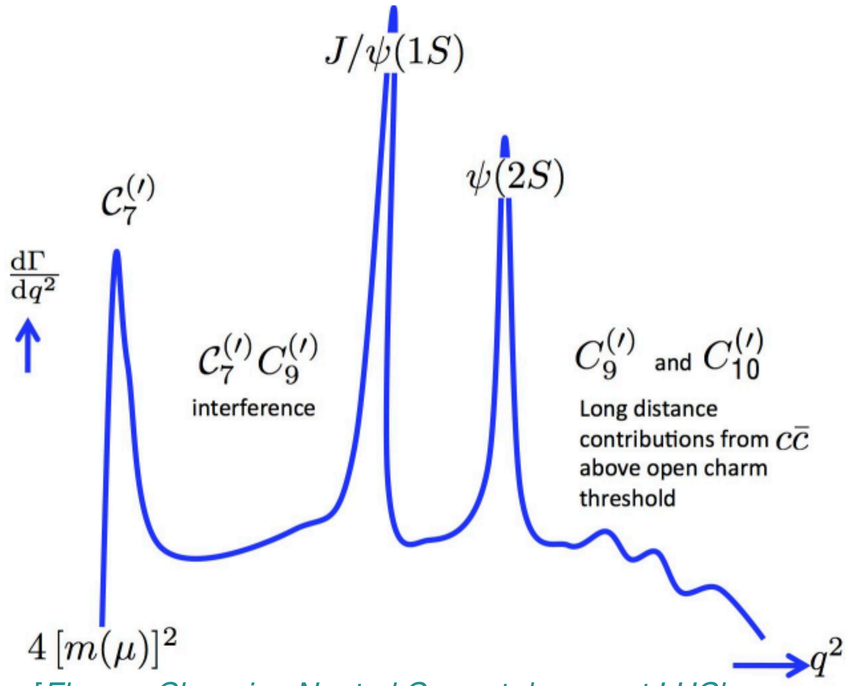


J/ψ resonant channel

- Experimentally, the reconstruction of **electrons** and **muons** is very **different** → high statistics control channels needed
- **Resonant** channels are well understood and **LF conserving**
- **Double ratio** using resonant and non-resonant channels → **systematic** effects simplify

$$R^{EXP}_{K,K^*}(q_a^2, q_b^2) = \frac{\frac{N}{\varepsilon}\left(B^{(+,*0)} \to K^{(+,*0)}\mu^+\mu^-\right)}{\frac{N}{\varepsilon}\left(B^{(+,*0)} \to K^{(+,*0)}e^+e^-\right)} r^{K,K^*}_{J/\psi},$$

where $r^{K,K^*}_{J/\psi} = \frac{\frac{N}{\varepsilon}\left(B^{(+,*0)} \to K^{(+,*0)}J/\psi(\to e^+e^-)\right)}{\frac{N}{\varepsilon}\left(B^{(+,*0)} \to K^{(+,*0)}J/\psi(\to \mu^+\mu^-)\right)}$

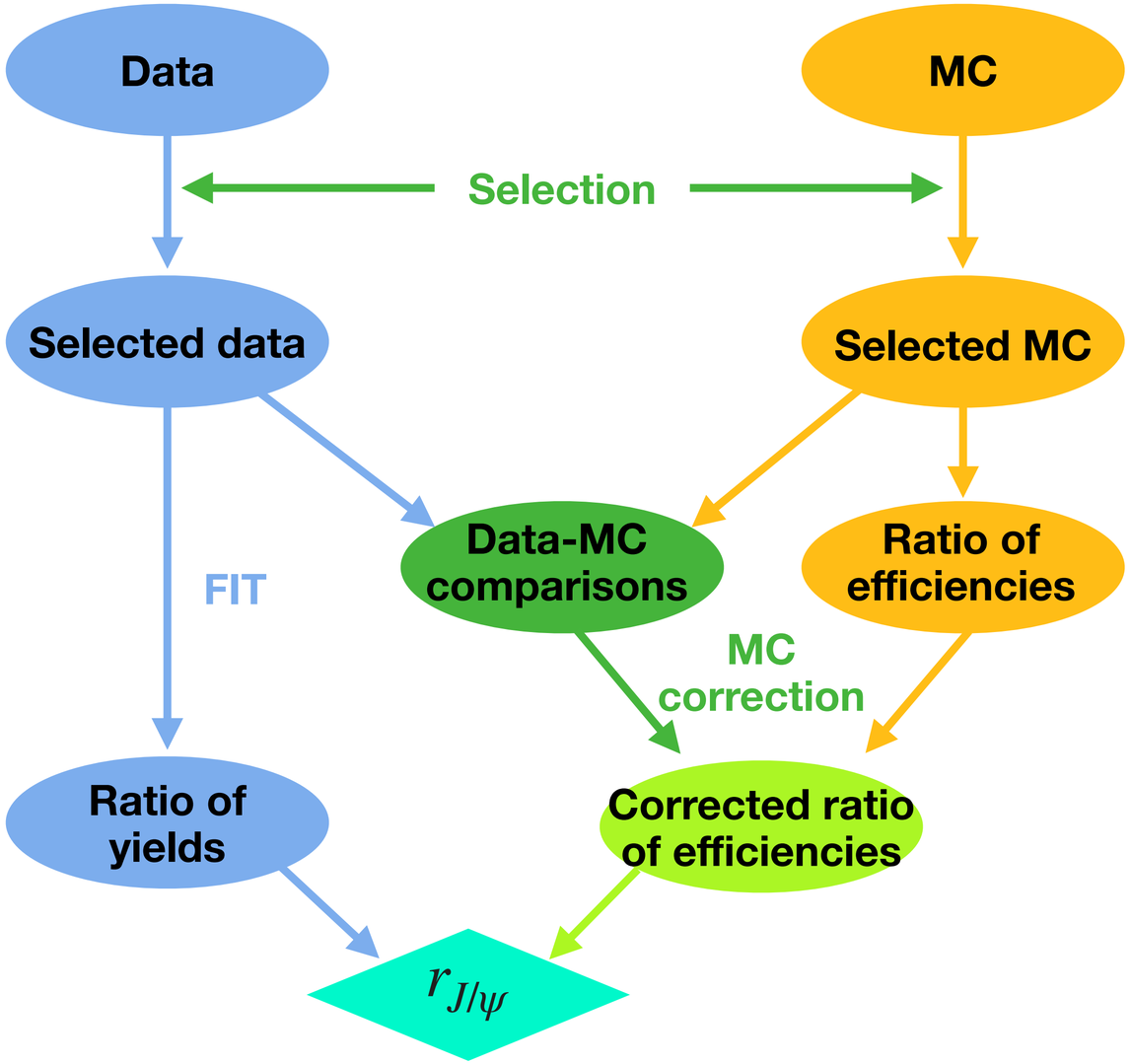


[*Flavour Changing Neutral Current decays at LHCb,* C. Marin (LHCb Collaboration) at 59th Rencontres de Moriond - EW+U 2024]

Resonances have **greater cross-section** and **no WC dependancy** → optimal control channel

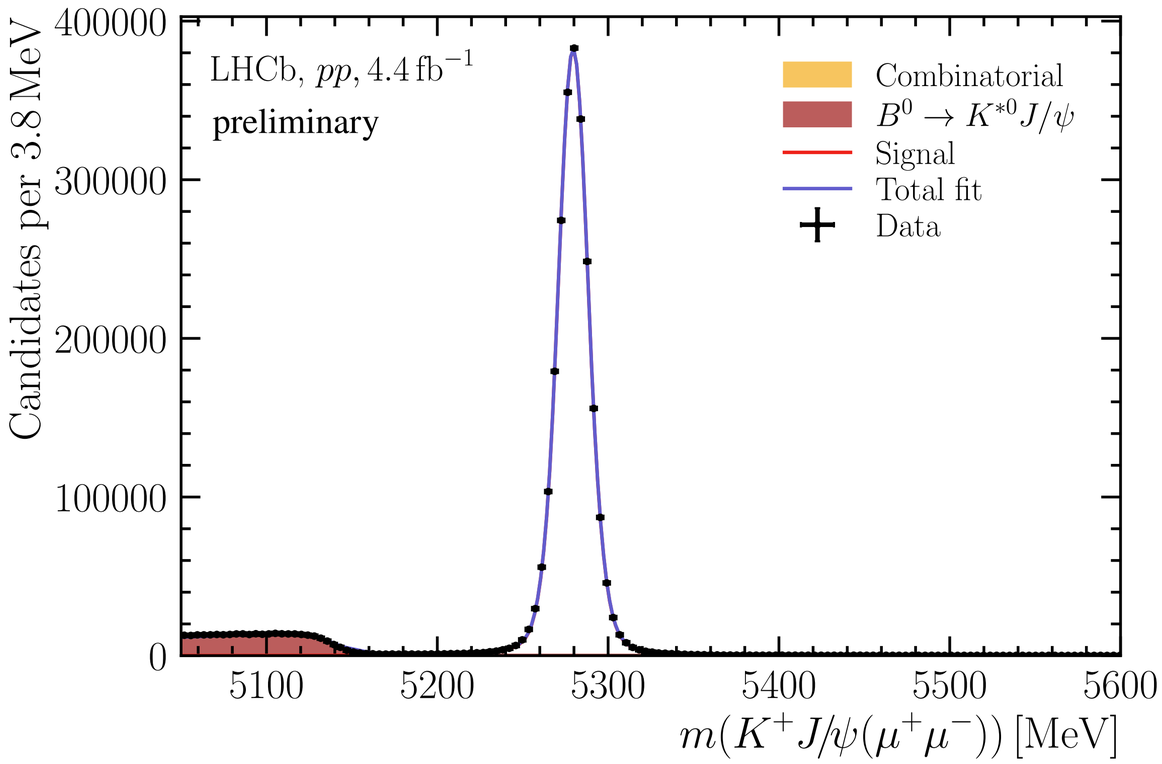
Strategy for $r_{J/\psi}$ measurement with 2024 data

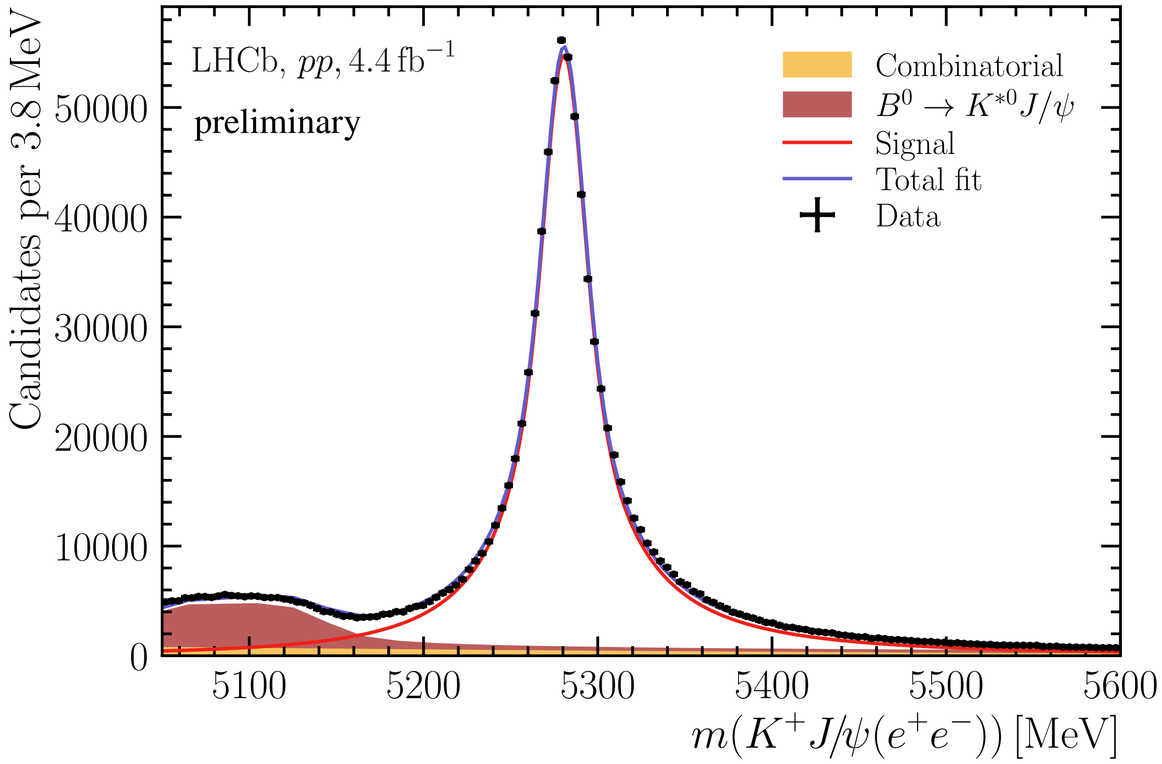
- Total of 9.56fb^{-1} in 2024 **alone**
- Important analysis to **understand** data and MC from **Run 3**
  - Different electron phase space
  - New trigger and reconstruction
- Correction **procedure** and **tools** to be applied for **later analysis** such as R_{K,K^*}
- Data taking **conditions changing** throughout 2024 $\rightarrow$ $r_{J/\psi}$ measured in **different** data "**blocks**"



Selection and fit to data

- MC and data pass through **cut-based** selection
- Signal and partially reconstructed background shapes extracted from **MC**, combinatorial background extrapolated by **high mass tail**
- Observed a 2x increase in yield/luminosity compared to Run 1-2 [LHCb-PAPER-2026-048 in preparation]



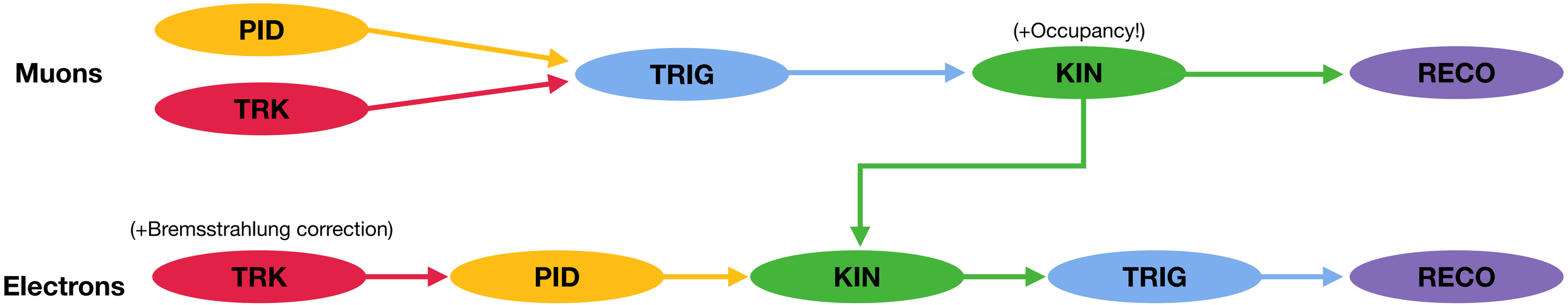


MC corrections

- **Discrepancies** in description of variables in data and MC → **bias** in **efficiency** evaluation after selection
- Corrections to MC to include:
  - Trigger (**TRIG**) efficiency (needed for correct total efficiency evaluation)
  - Particle Identification (**PID**) efficiency (used in selection and in trigger)
  - Tracking (**TRK**) efficiency (tracking reconstruction used in trigger)
  - B **kinematic** variables (corrections are binned in kinematics)
  - **Detector occupancy** variables (correlation with kinematics resolution)
  - **Reconstruction** variables (correlation with kinematic variables but also widely used in rare analysis MVAs)

Correction chain

- **Kinematic** correction to be done on B, also at generation level
  - Assumed to be the **same** for **both lepton** channels so **muon** channel used as **training** but…
- …**PID**, **TRK** and **TRIG** need to applied to muon channel **first** in order to remove dependence
- **Electron** channel undergoes **TRK**, **PID** and **KIN** correction first, **followed** by **TRIG**
- **Reconstruction** variables correction applied last and separately



Efficiencies correction (TRK, PID, HLT1)

- **Weights** for each **step** are computed as **ratio** of efficiencies in **data** and **MC** control samples in bins of P_T and η of the daughters (for TRK and PID) or of the B (for HLT1)

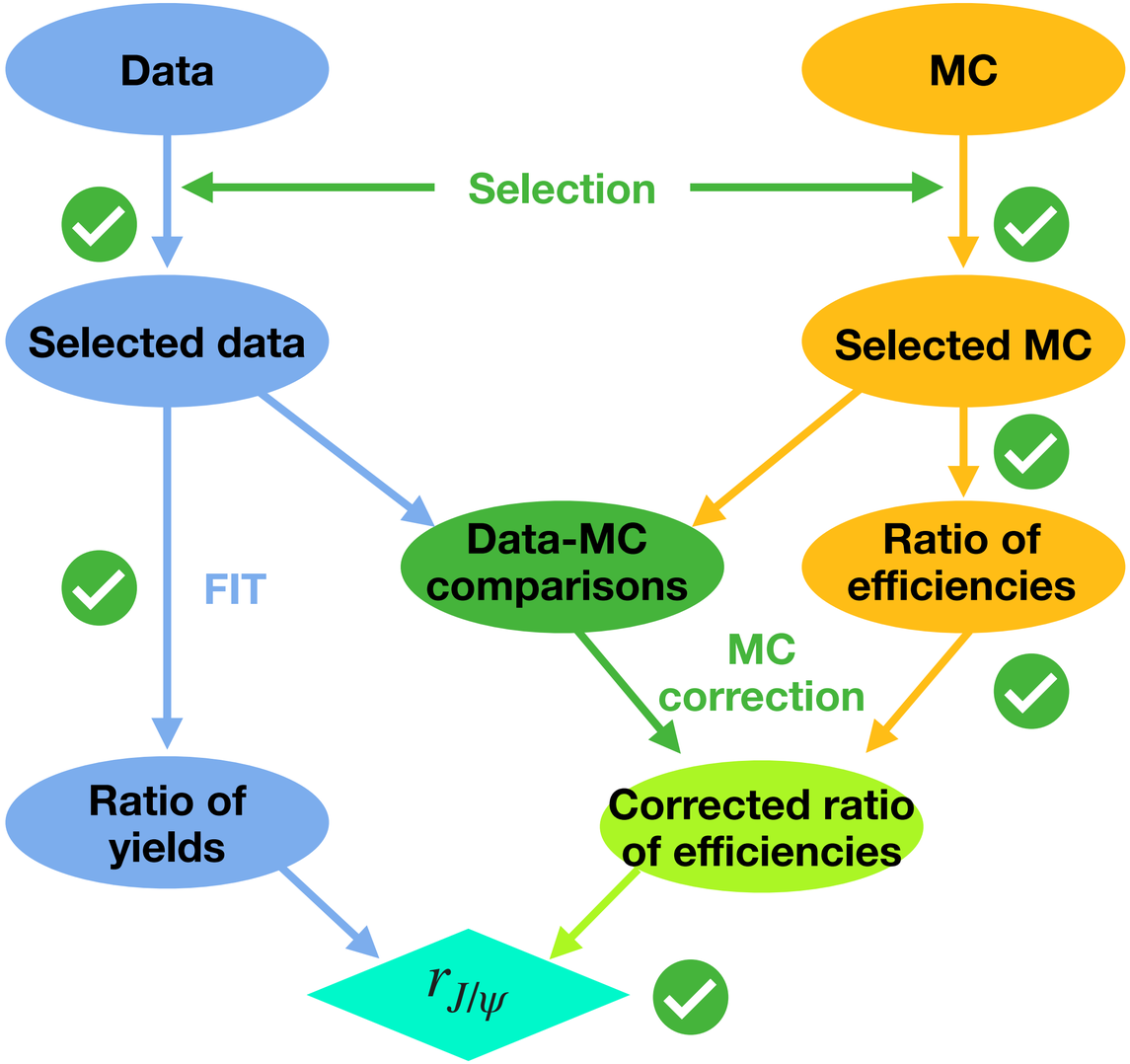
$$w_{\mathrm{STEP}}(P_T,\eta) = \frac{\varepsilon^{data}_{\mathrm{STEP}}(P_T,\eta)}{\varepsilon^{MC}_{\mathrm{STEP}}(P_T,\eta)}$$

- **Efficiencies** are extracted (in data or MC) via **tag and probe methods** for each correction step

$$\epsilon^{(data,MC)}_{\mathrm{STEP}}(P_T,\eta) = \frac{N^{\mathrm{STEPtag+probe}}_{(data,MC)}}{N^{\mathrm{STEPtag}}_{(data,MC)}}(P_T,\eta)$$

Status of $r_{J/\psi}$ measurement with 2024 data

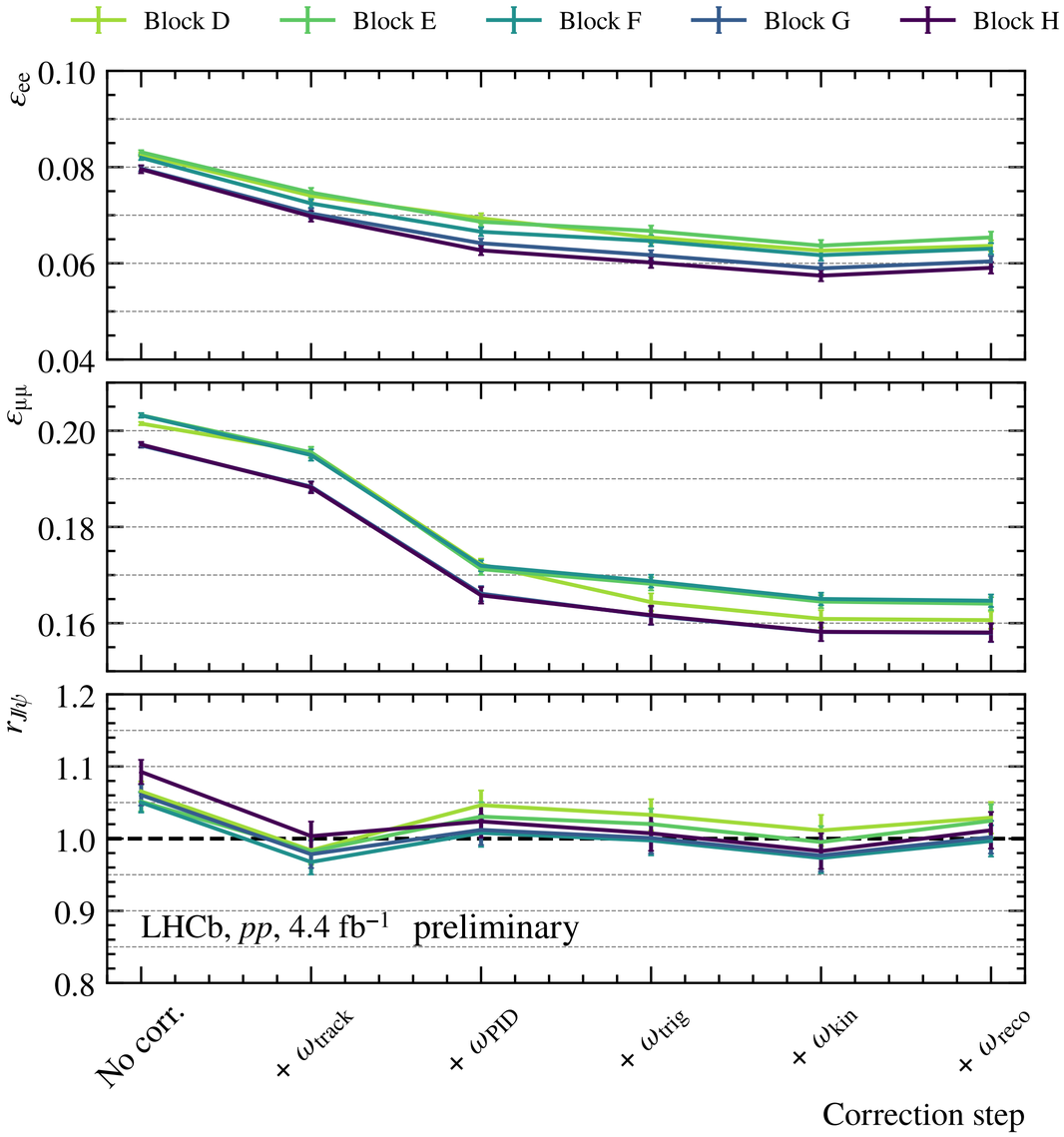
- **Ratio of yields** is influenced by the **fit**
- **Corrections** to MC are sensible to **correlations** in the **chain** and choices of **binnings/variables** to correct
- Various **systematic** uncertainties and cross checks have been **evaluated**
- $r_{J/\psi}$ values obtained for **different** data taking **conditions**, corresponding to ~ 4.4fb^{-1} **of data**



Results

- The efficiency **corrections sizes** are in **agreement** between blocks
- Most **sizeable** corrections come from **PID** and **TRK**
- The results for $r_{J/\psi}$ are **consistent with 1** and **compatible** between **different conditions**
- The averaged result is $1.012 \pm 0.002(\text{stat.}) \pm 0.018(\text{syst.})$ → great **improvement** from Run 1 and 2 $0.034(\text{syst.})$!
- Paper is under preparation [LHCb-PAPER-2026-048]

[LHCb-PAPER-2026-048 in preparation]



Conclusions

- The analysis for the measurement of $r_{J/\psi}$ is the **first** Rare Decay analysis with **electrons** using data taken from LHCb during Run 3
- The framework used for corrections to $r_{J/\psi}$ is already **being used** in **different** other Run 3 **analysis** in rare non-resonant modes
- **Promising** prospects for Run 3 **LFU analysis** thanks to **reduction** of **systematic** uncertainties

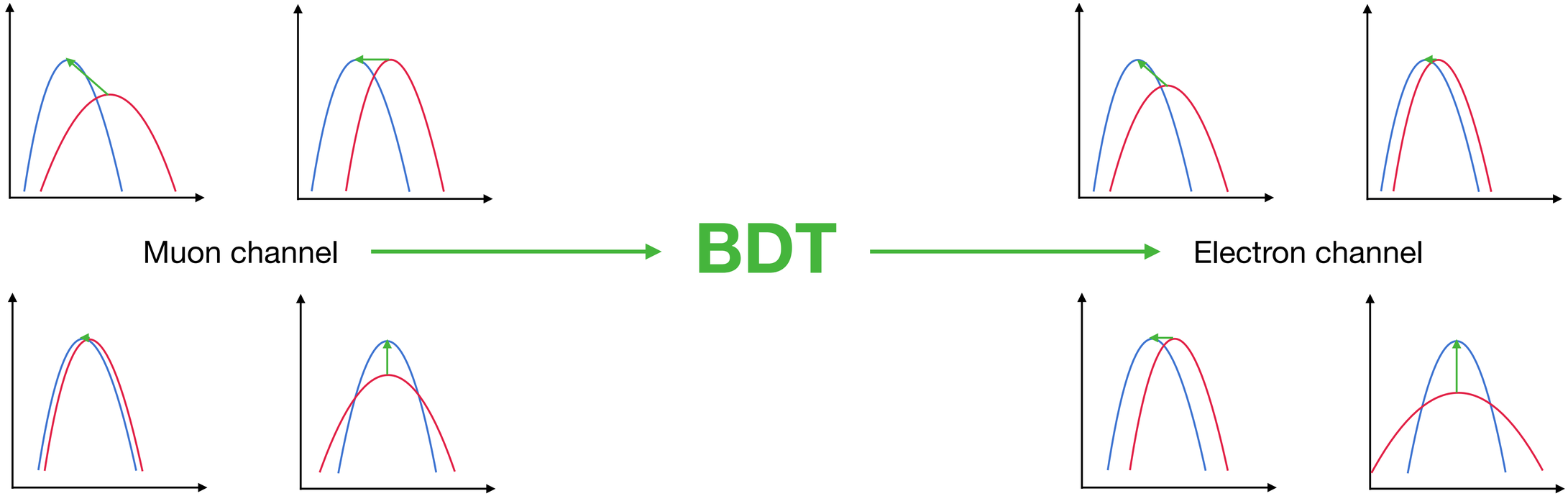
Thank you for your attention

Do you have any questions?

Backup

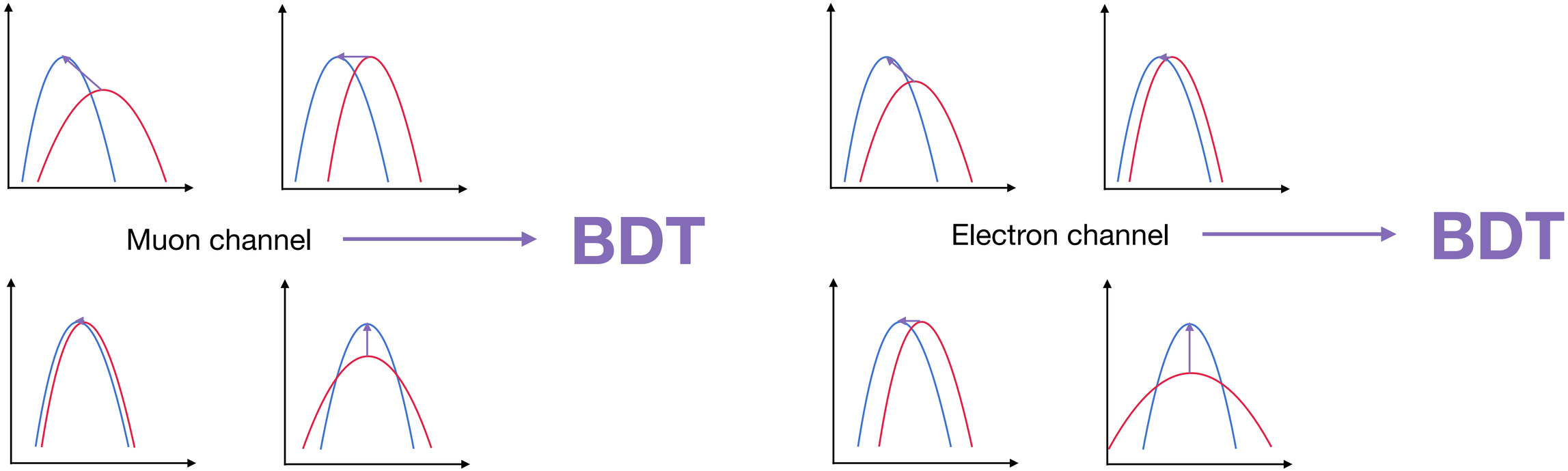
Kinematic correction

- Corrected by **weighting** the **simulation** according to the variable distributions of **background subtracted data**
- The distribution of reconstructed **kinematics** of the B and **occupancy** variables in data is used as a target for a **BDT**.

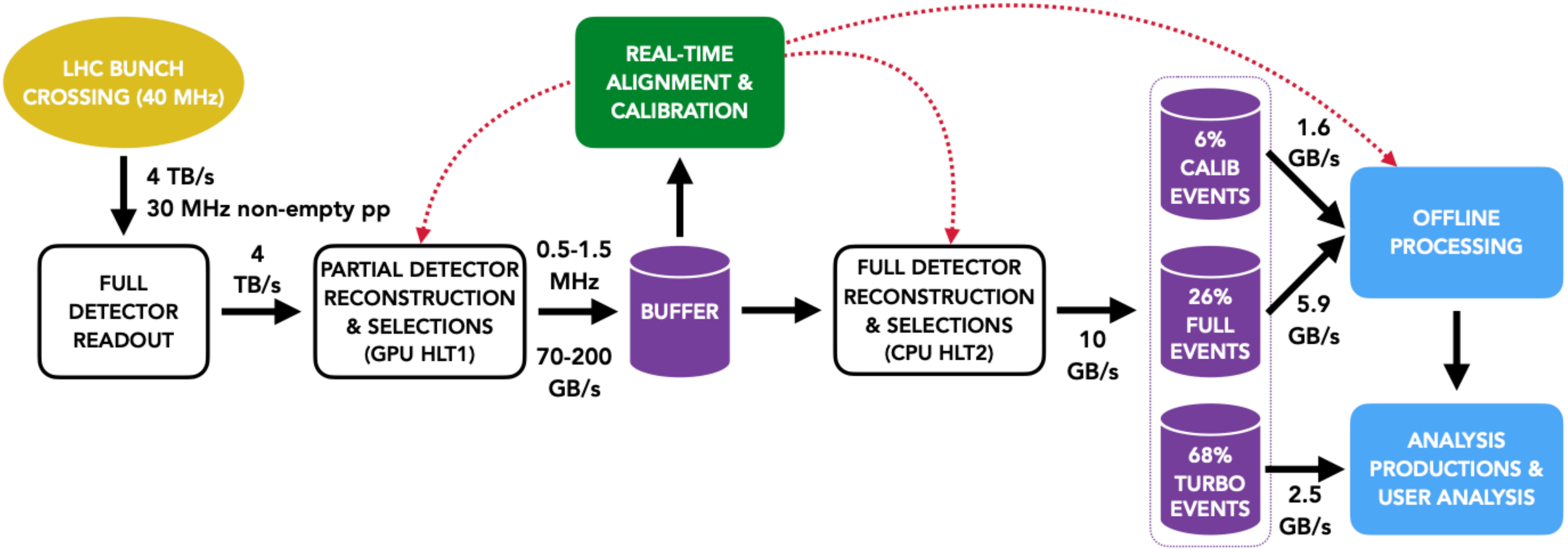


Reconstruction correction

- Corrected by **weighting** the **simulation** according to the variable distributions of **background subtracted data**
- The distribution of **reconstruction variables** of the B in data is used as a target for a **BDT**. Need to preserve KIN and OCC agreement → previously used variables in the kinematic step are also added



Trigger flow



[LHCB-FIGURE-2020-016]