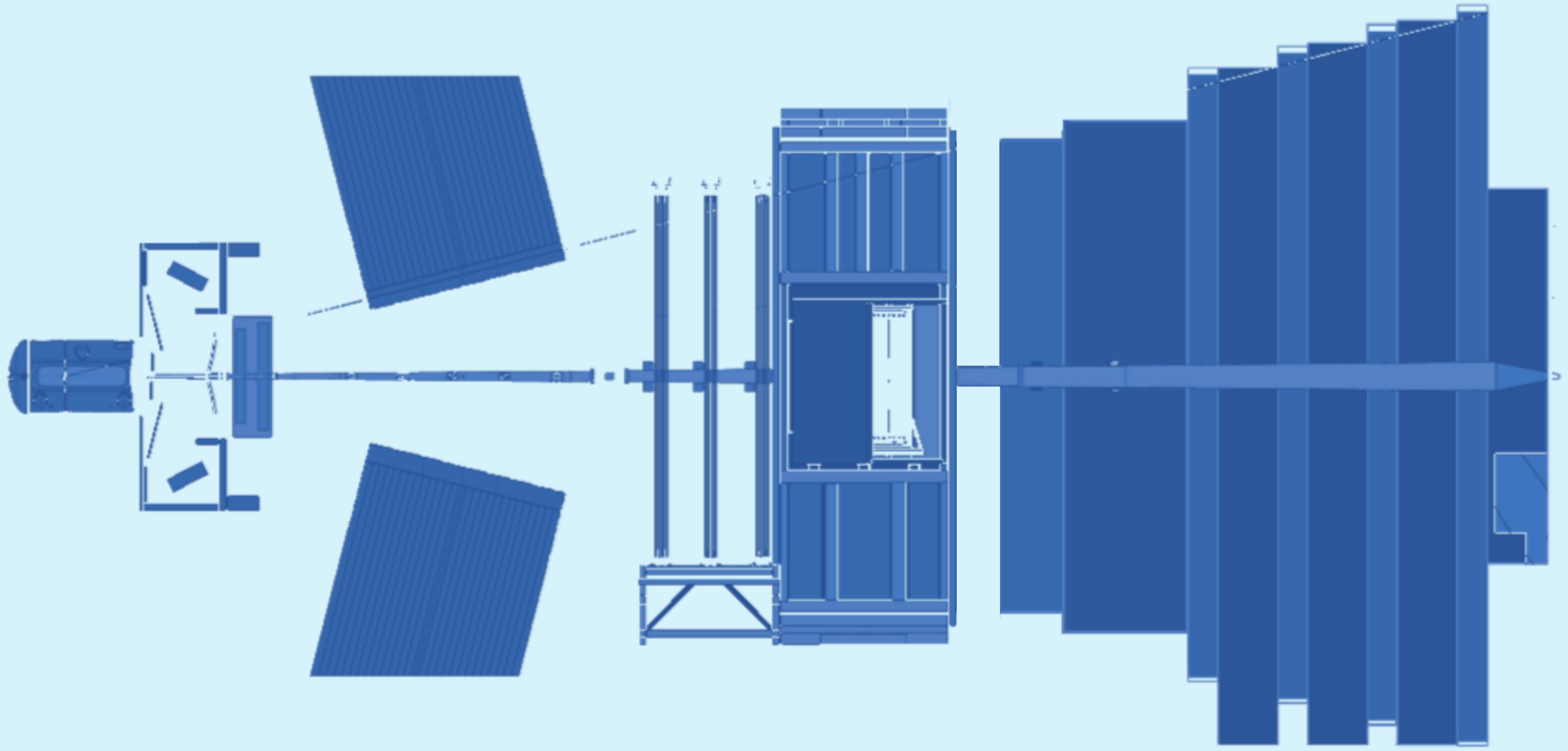
Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU 04/2025-03/2031



Measurement of $r_{J/\psi}$ with LHCb 2024 data

By: Lukas Calefice, Carla Marin, <u>Pol Vidrier</u>

XVII CPAN Days

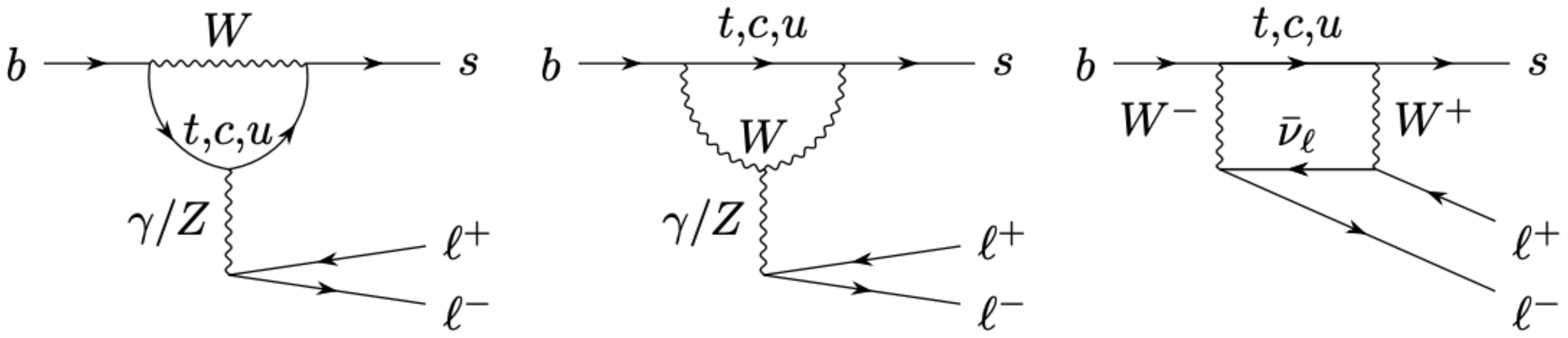
20/11/25

Physics motivation

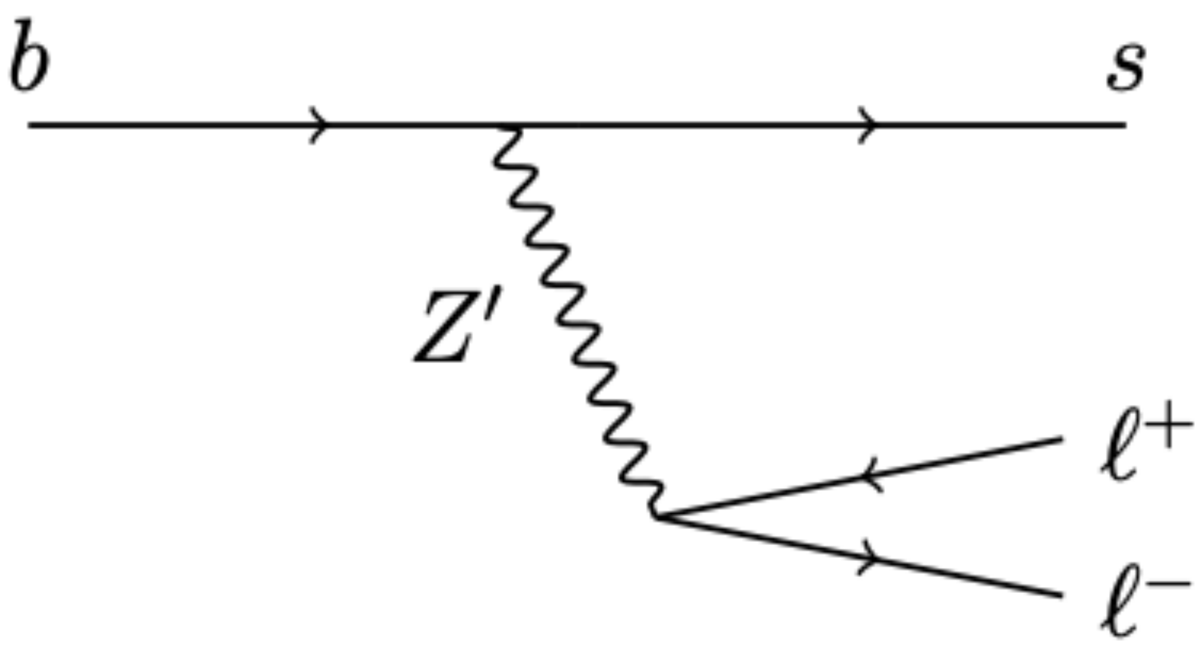
Rare Decays

- The Standard Model (SM) does <u>not</u> allow for Flavour Changing Neutral Currents (FCNC) at <u>tree level</u> $\Longrightarrow b \to s\ell\ell$ transitions are <u>suppressed</u>
  - **Rare B decays (RD):** experimentally accessible and available theory predictions $\Longrightarrow$ search for New Physics (**NP**)

<u>Leading order SM Feynman diagrams</u>



<u>**NP**</u>

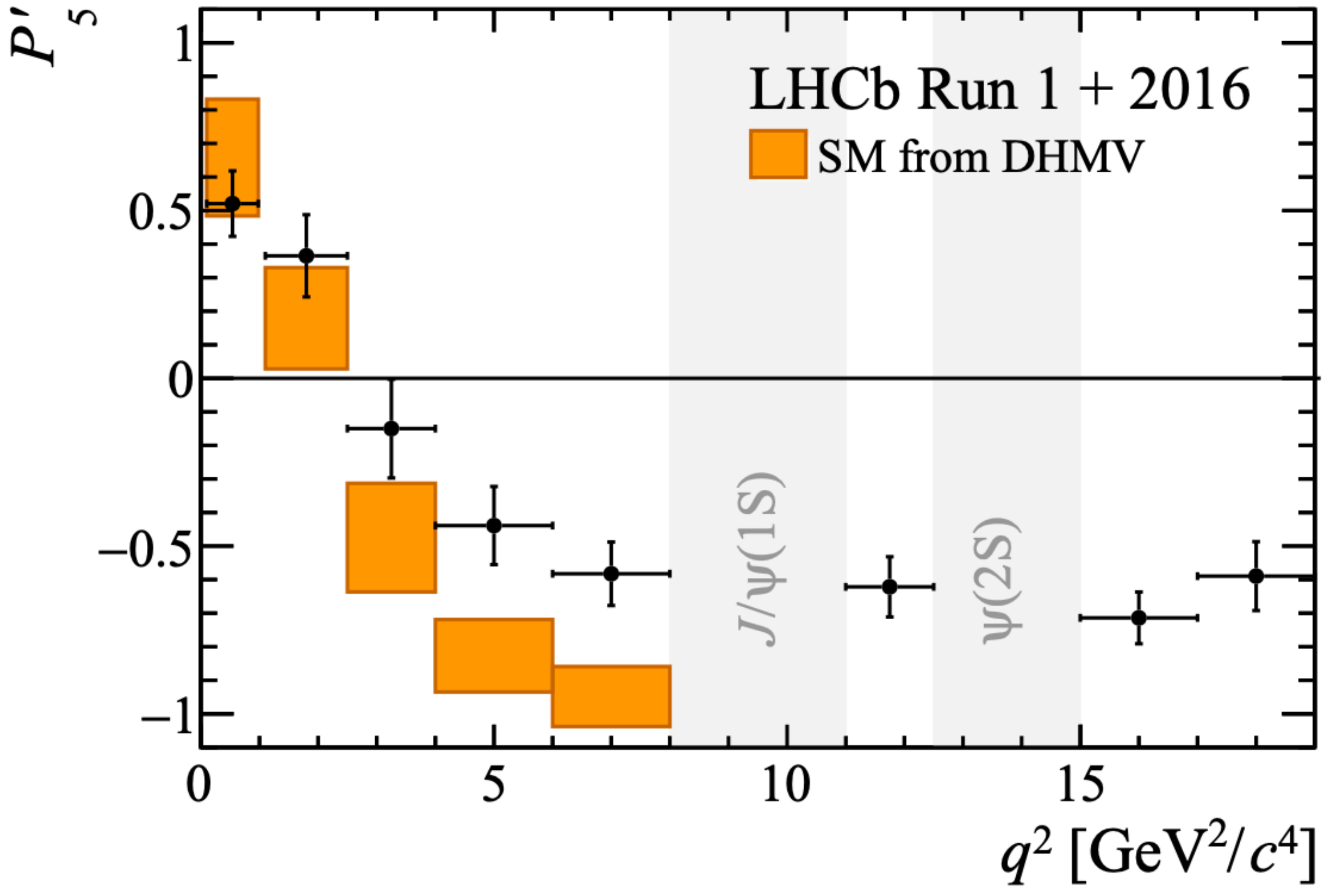


Physics motivation

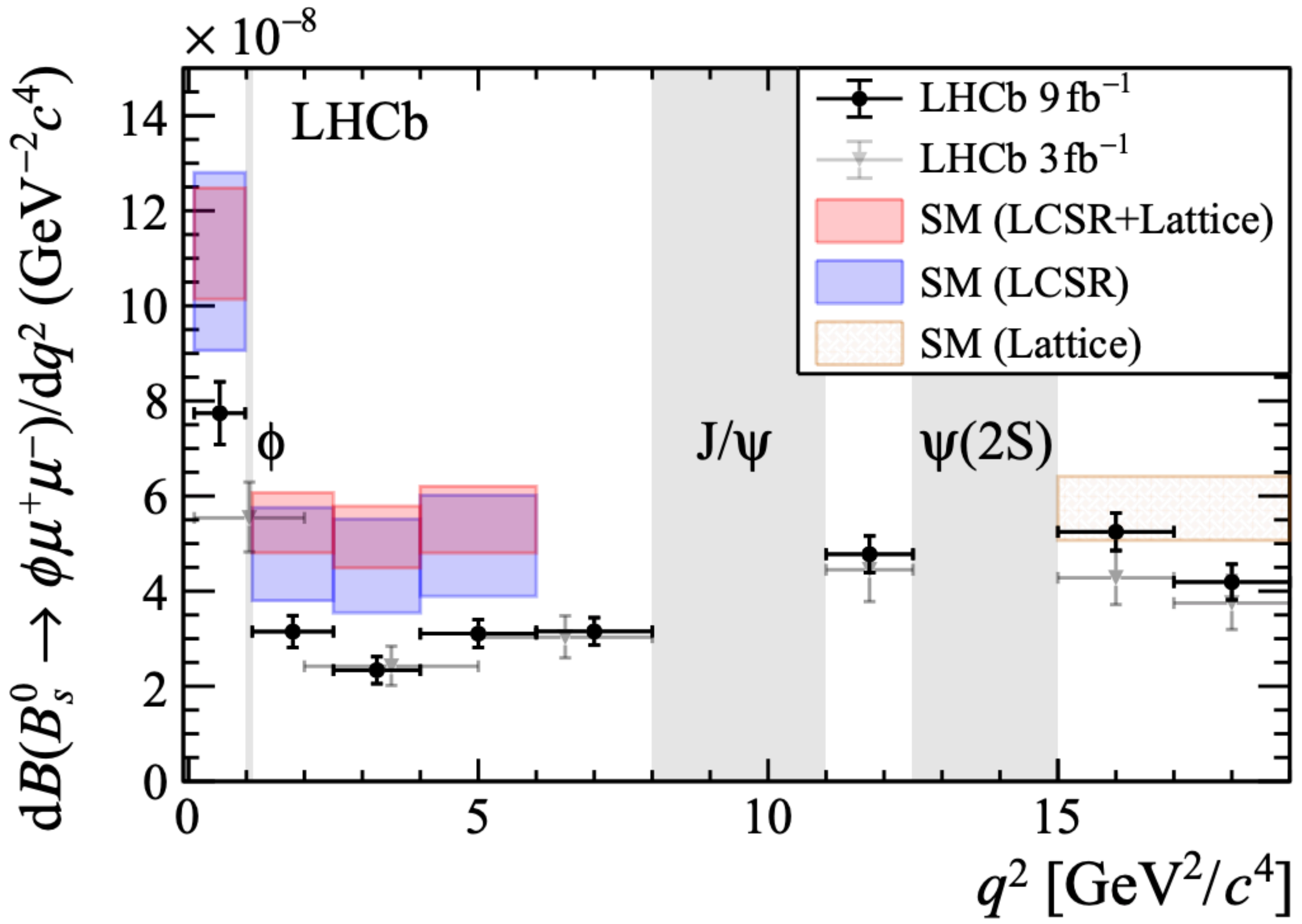
Status of RD measurements

- Deviations from SM predictions in **angular observables** and **BF**

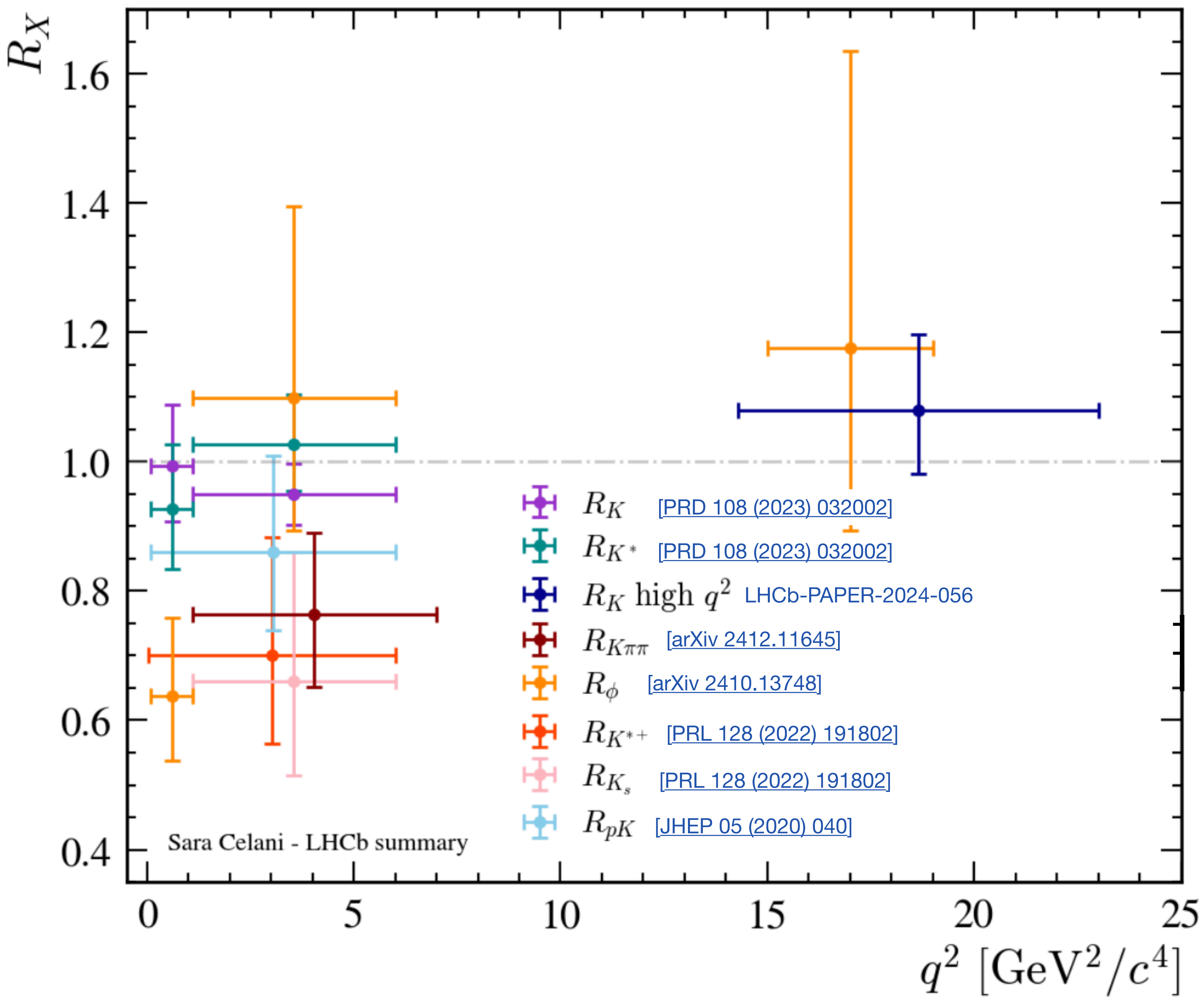
$B^0 \to K^{*0}\mu^+\mu^-$ angular
[PRL 125 (2020) 011802]



$B_s^0 \to \phi\mu^+\mu^-$ BF
[PRL 127 (2021) 151801]



- Latest **Lepton Flavour Universality** (LFU) LHCb results



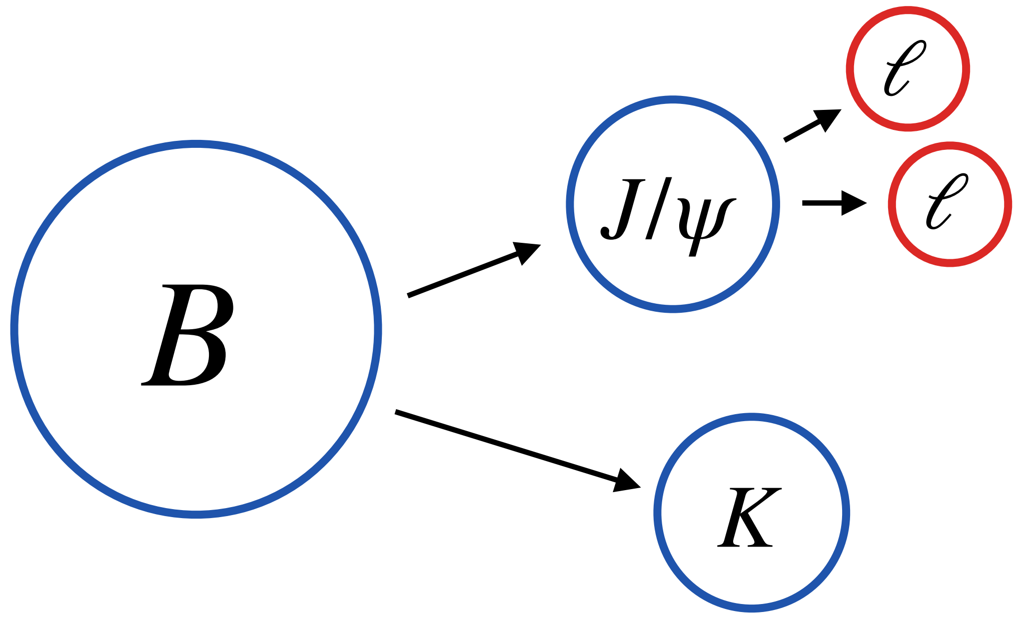
Physics motivation

$r_{J/\psi}$ and its role in RD

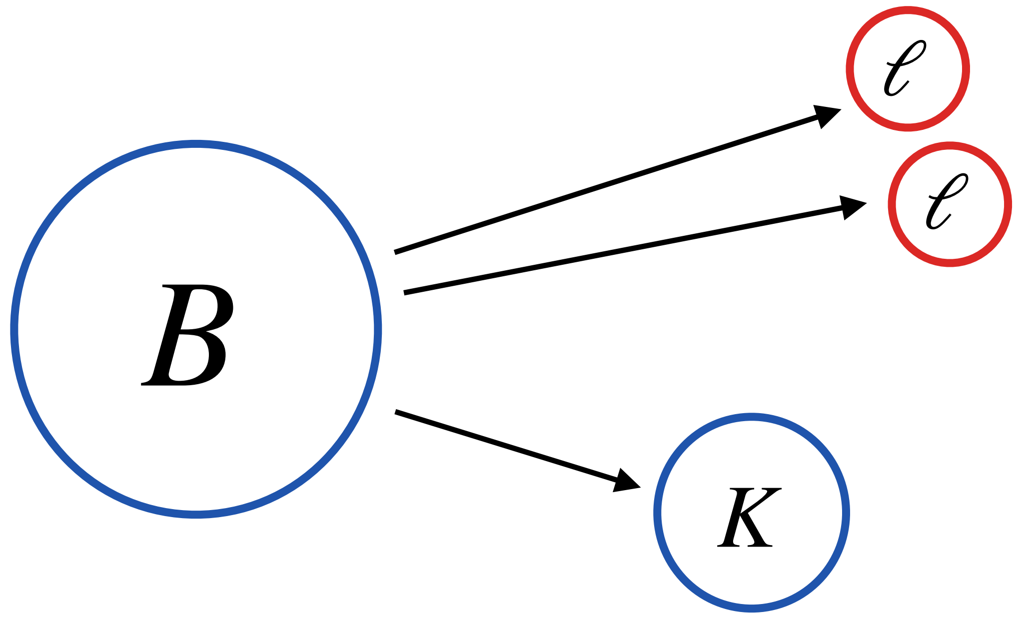
- $r_{J/\psi}: BF(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)/BF(B^+ \to J/\psi(\to e^+e^-)K^+) \Longrightarrow$ strong validation for RD using **muons** and **electrons**

- Control channels for Rare Modes $\Longrightarrow$ same final state w/ $\uparrow BF$

Resonant Mode



Rare Mode



- Used for LFU double ratios $\Longrightarrow$ **cancel detector uncertainties**

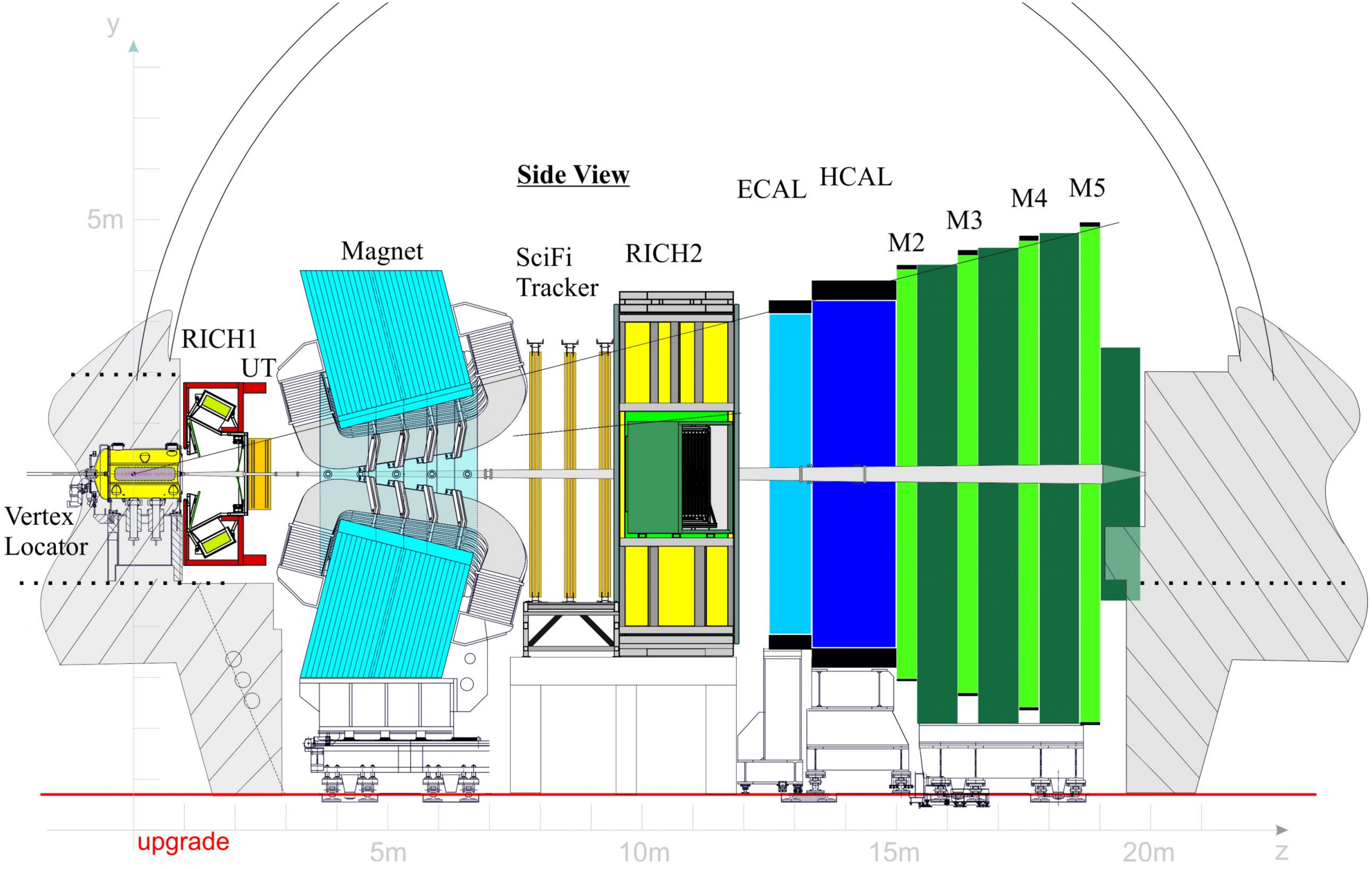
$$\frac{\dfrac{BF(B^+ \to K^+\mu^+\mu^-)}{BF(B^+ \to K^+e^+e^-)}}{r_{J/\psi}\ \boxed{\dfrac{BF(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)}{BF(B^+ \to J/\psi(\to e^+e^-)K^+)}}}$$

LHCb Upgrade I detector

An almost new detector

- Almost all subdetectors (**TRK** and **PID**) completely renewed
- Designed to run at **x5 larger instantaneous luminosity** than in previous runs
- New and innovative trigger system
- This allowed LHCb to take as much data in 2024 than in all Run1+2!

[JINST 19 (2024) P05065]



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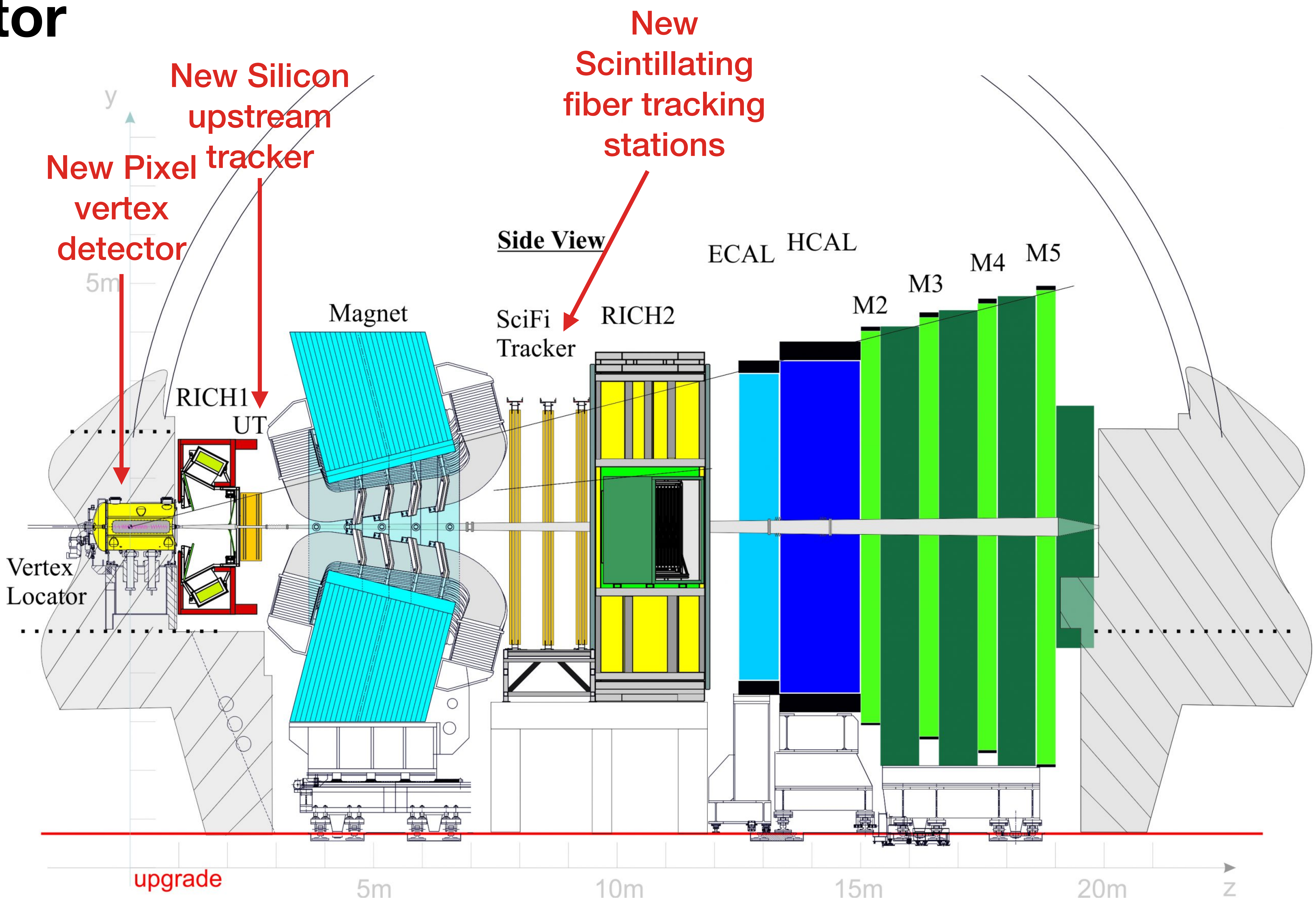

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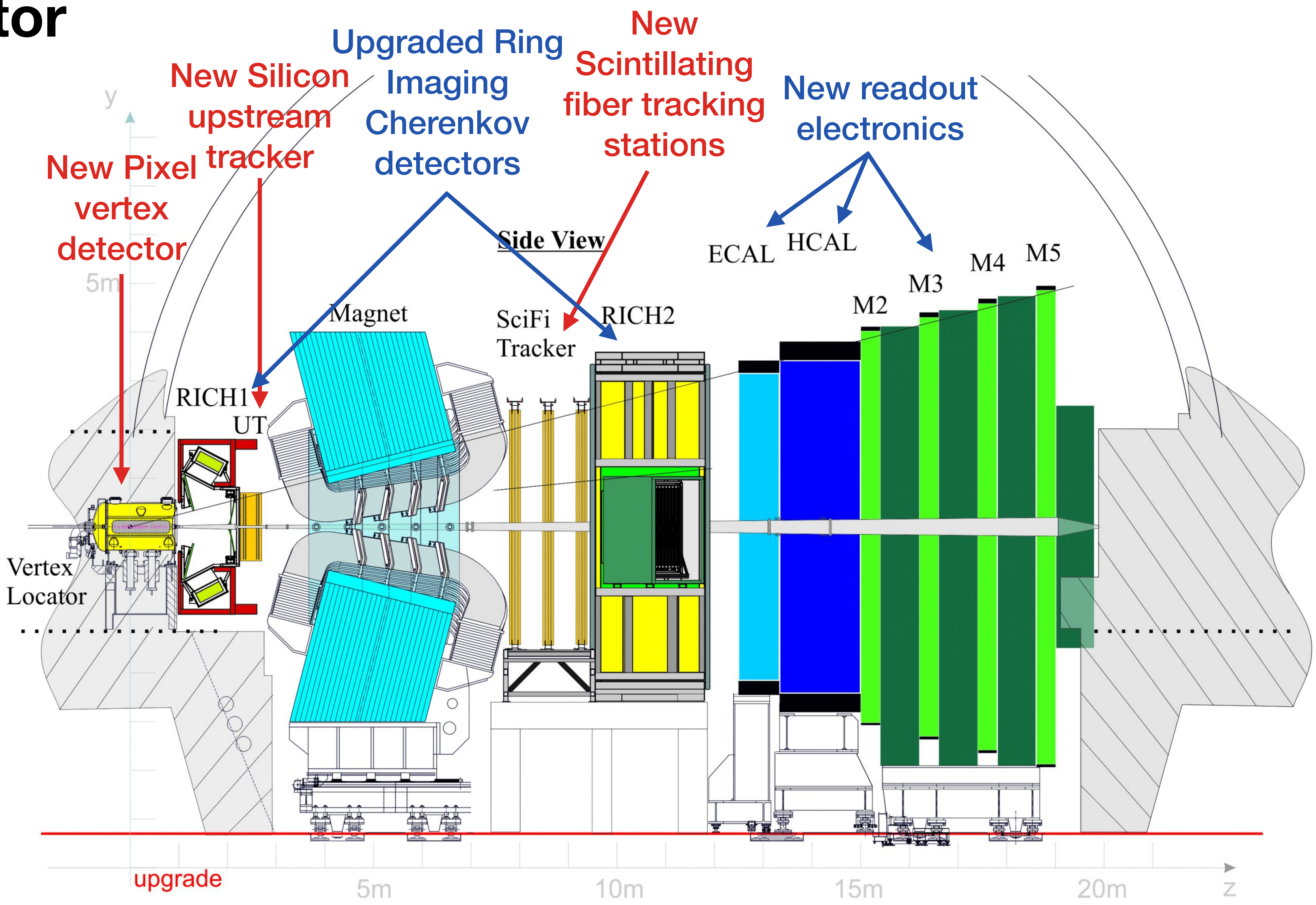

LHCb Upgrade I detector

A fully software-based trigger system

- The new **fully software-based trigger** at 30MHz and **replaces the old hardware trigger**. The reconstruction changed to accommodate the higher multiplicity
- In two steps:
  - **High Level Trigger 1 (HLT1):** partial reconstruction on **GPUs** at 30MHz
  - **High Level Trigger 2 (HLT2):** offline-quality full reconstruction in **CPUs**
- Offline quality level thanks to the **real-time alignment and calibration**

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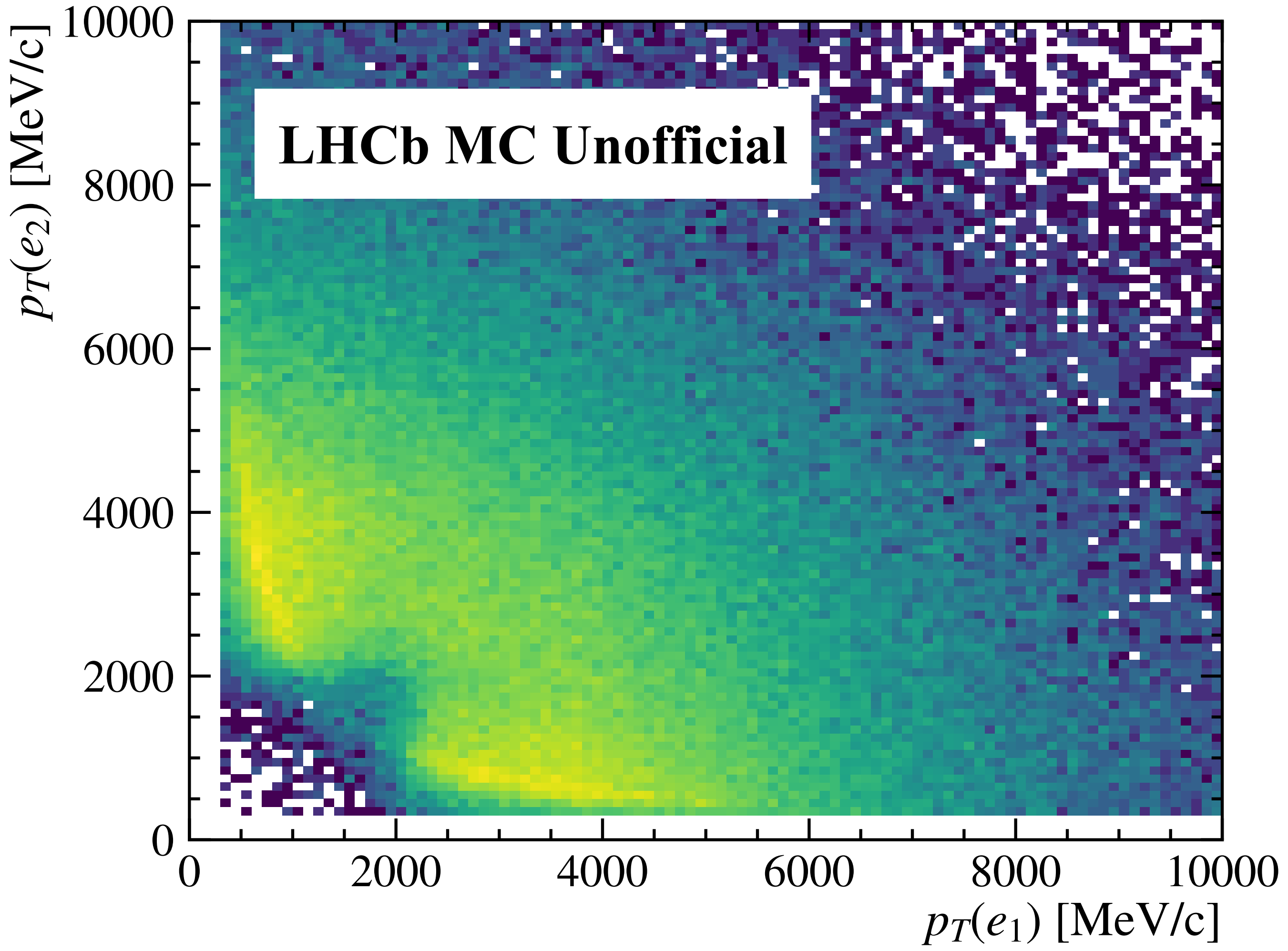
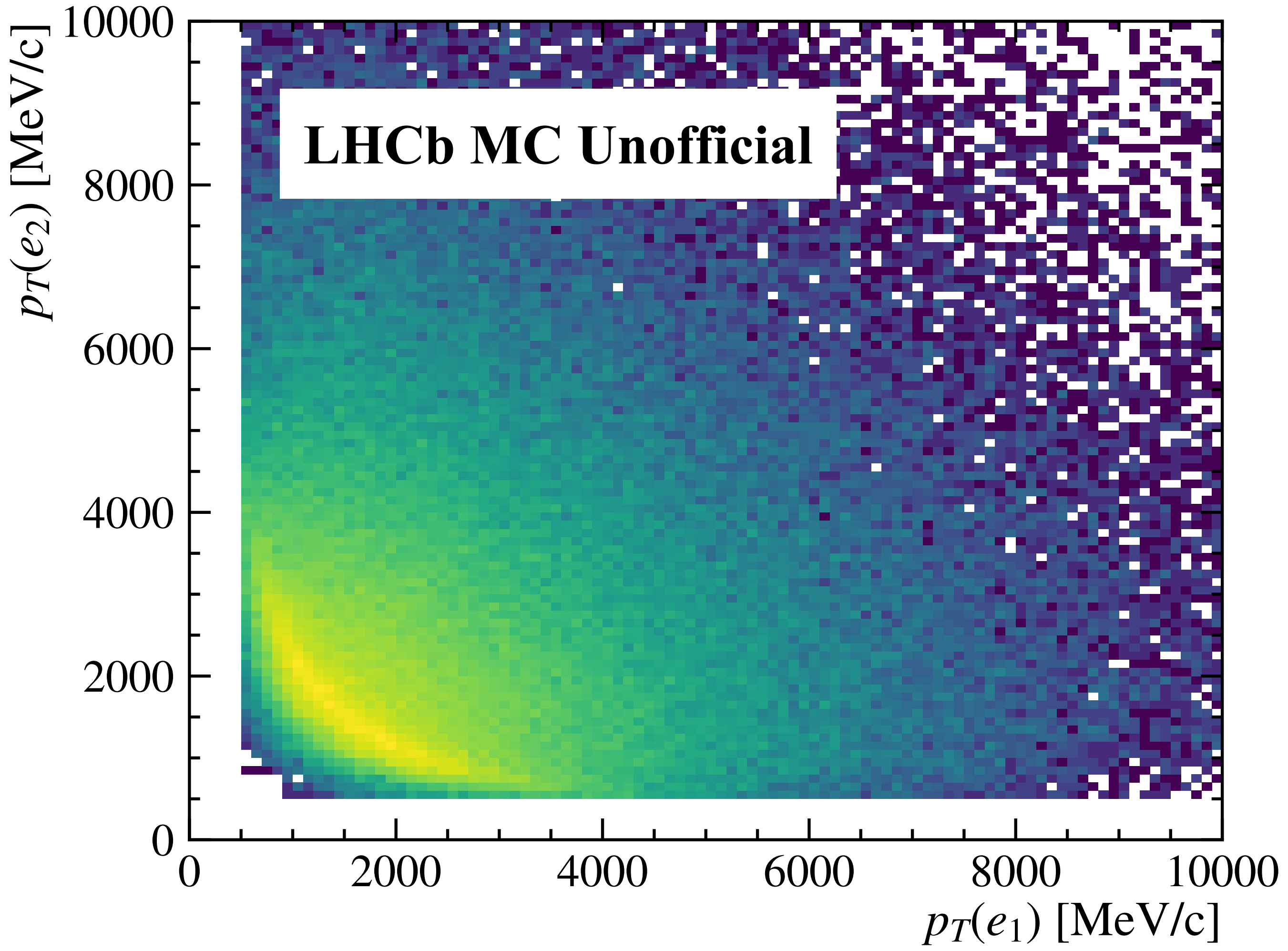
- Offline quality level thanks to the **real-time alignment and calibration**
- With the removal of the hardware trigger, a new area of the phase space for electrons is unlocked at low momentum!

Run2

$B^+ \to J/\psi(\to e^+e^-)K^+$





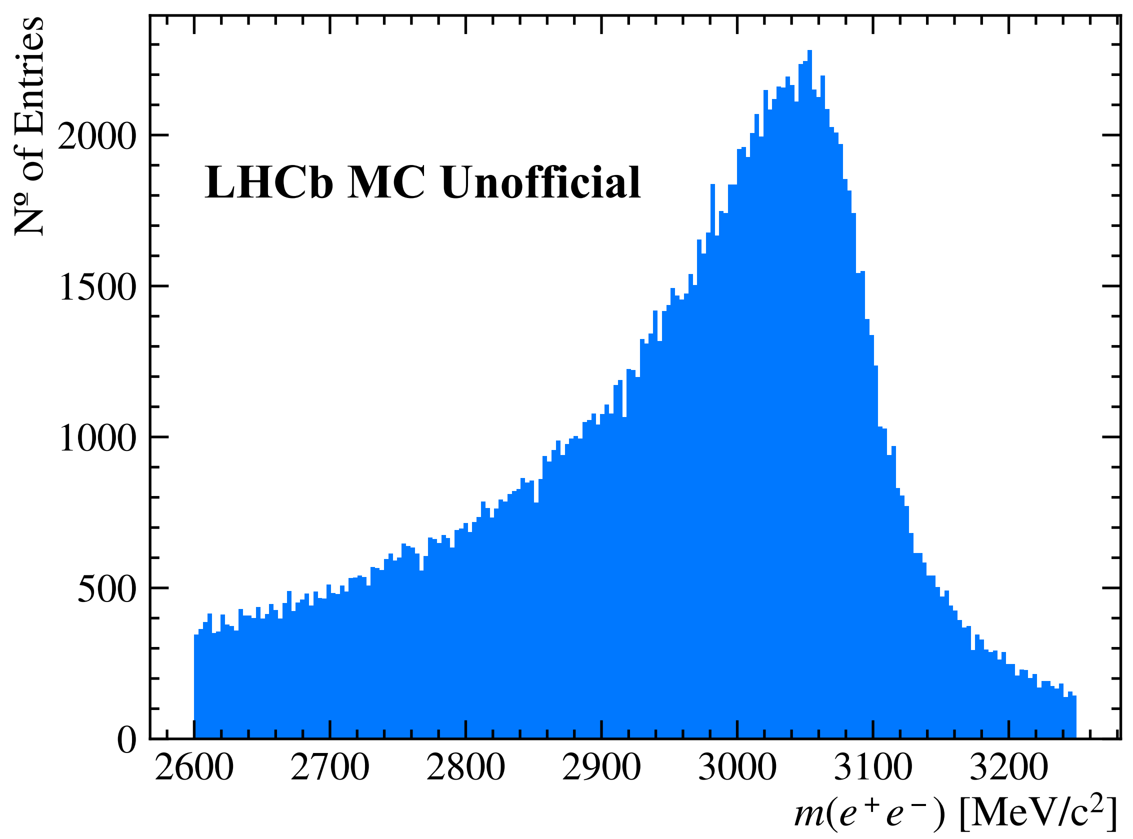
Run3

$B^+ \to J/\psi(\to e^+e^-)K^+$

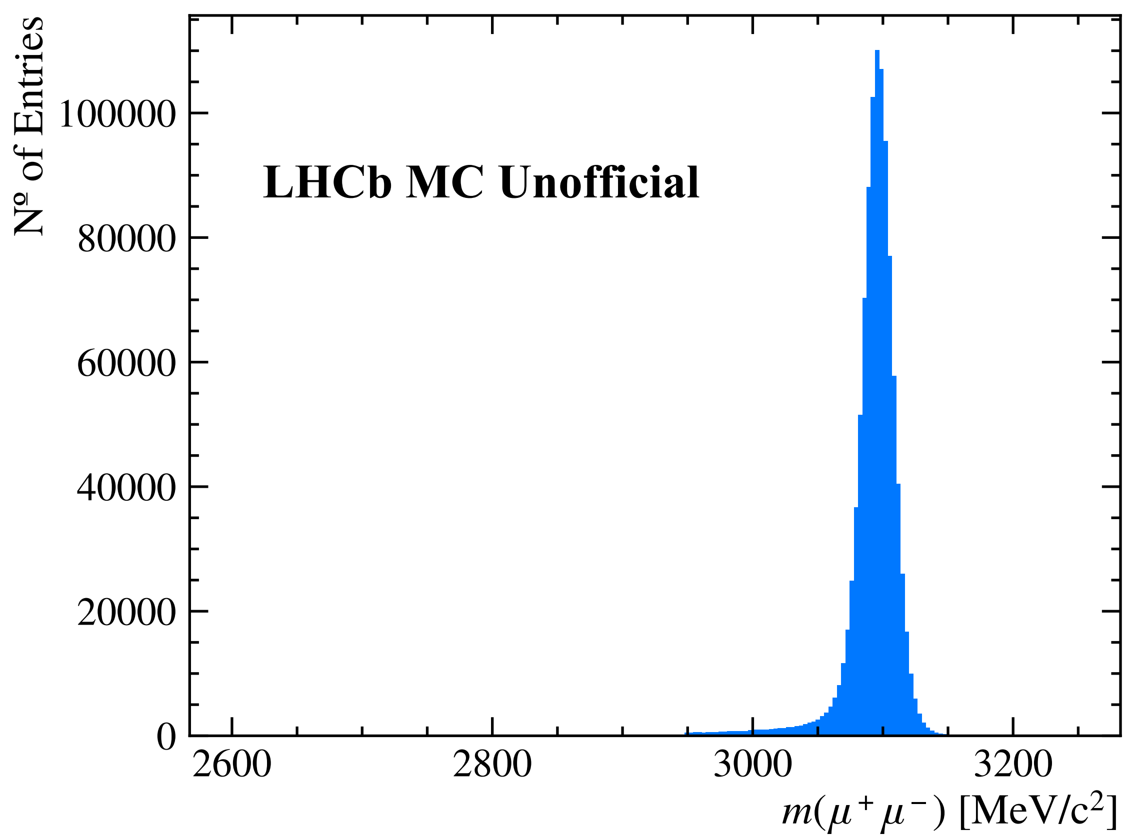
Electrons in LHCb

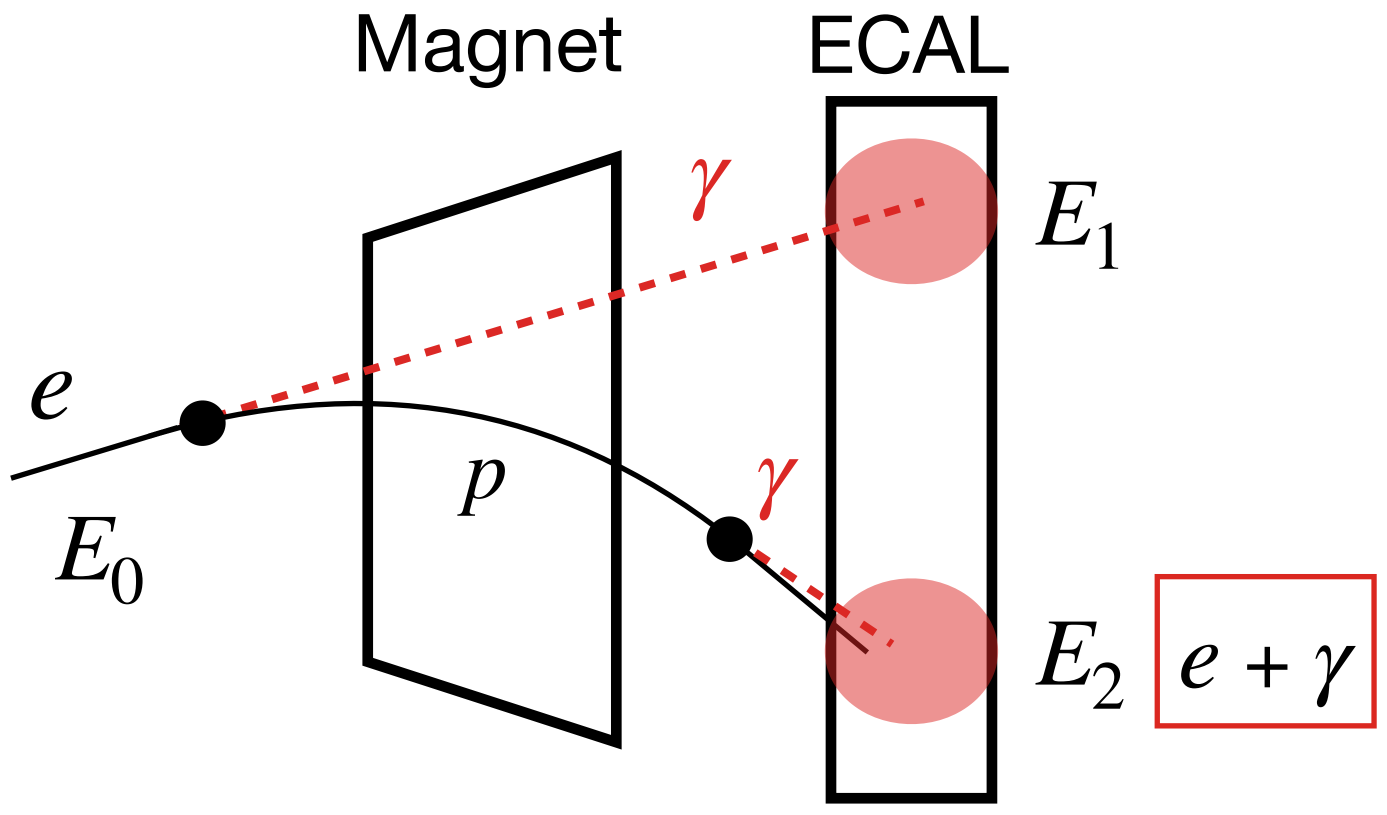
- Electrons emit bremsstrahlung photons when traversing detector material (mainly VELO) $\Longrightarrow$ **energy loss**
- Electron tracks before the magnet are matched to ECAL clusters for Brem recovery $\Longrightarrow$ **improves momentum resolution but still worse than muons**

Electrons



Muons





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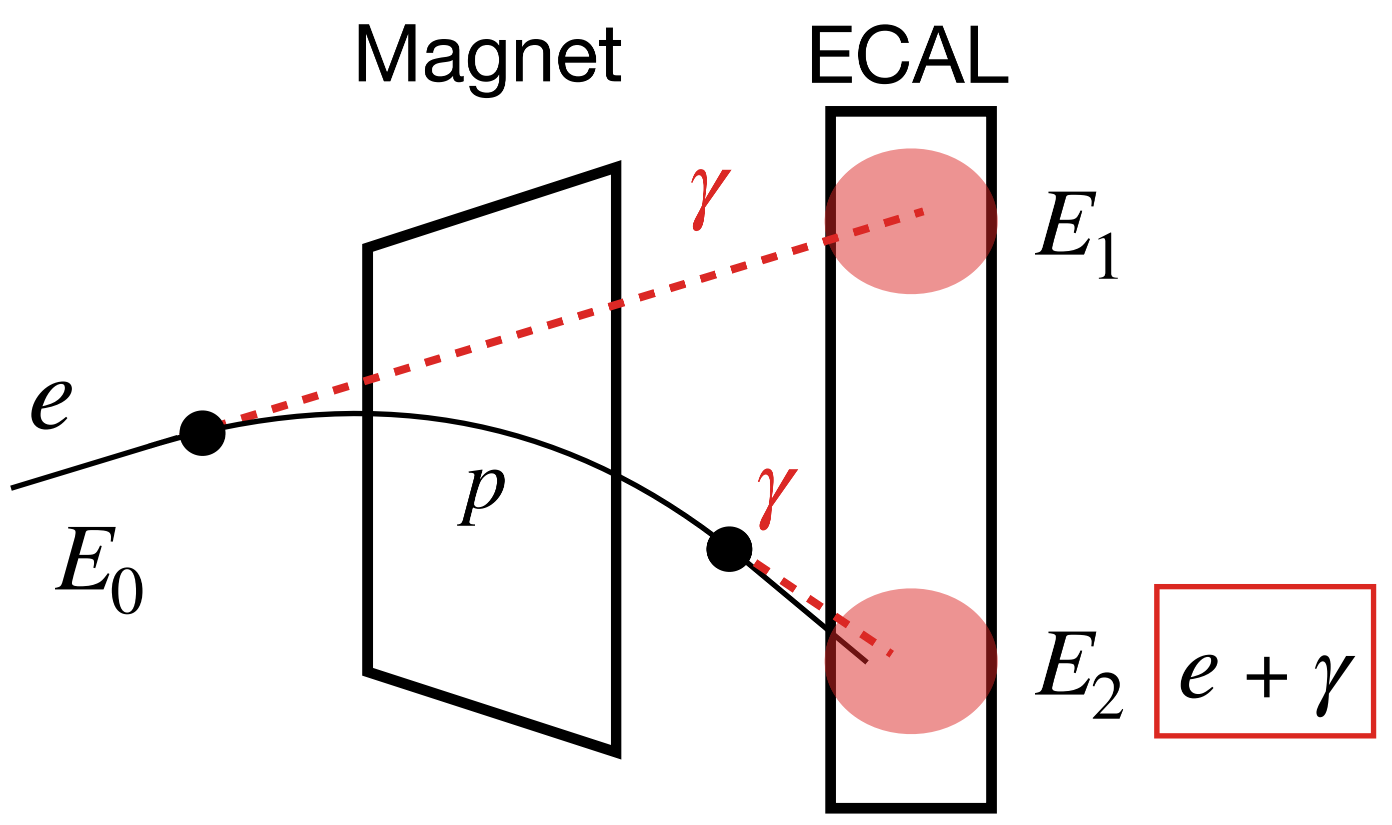

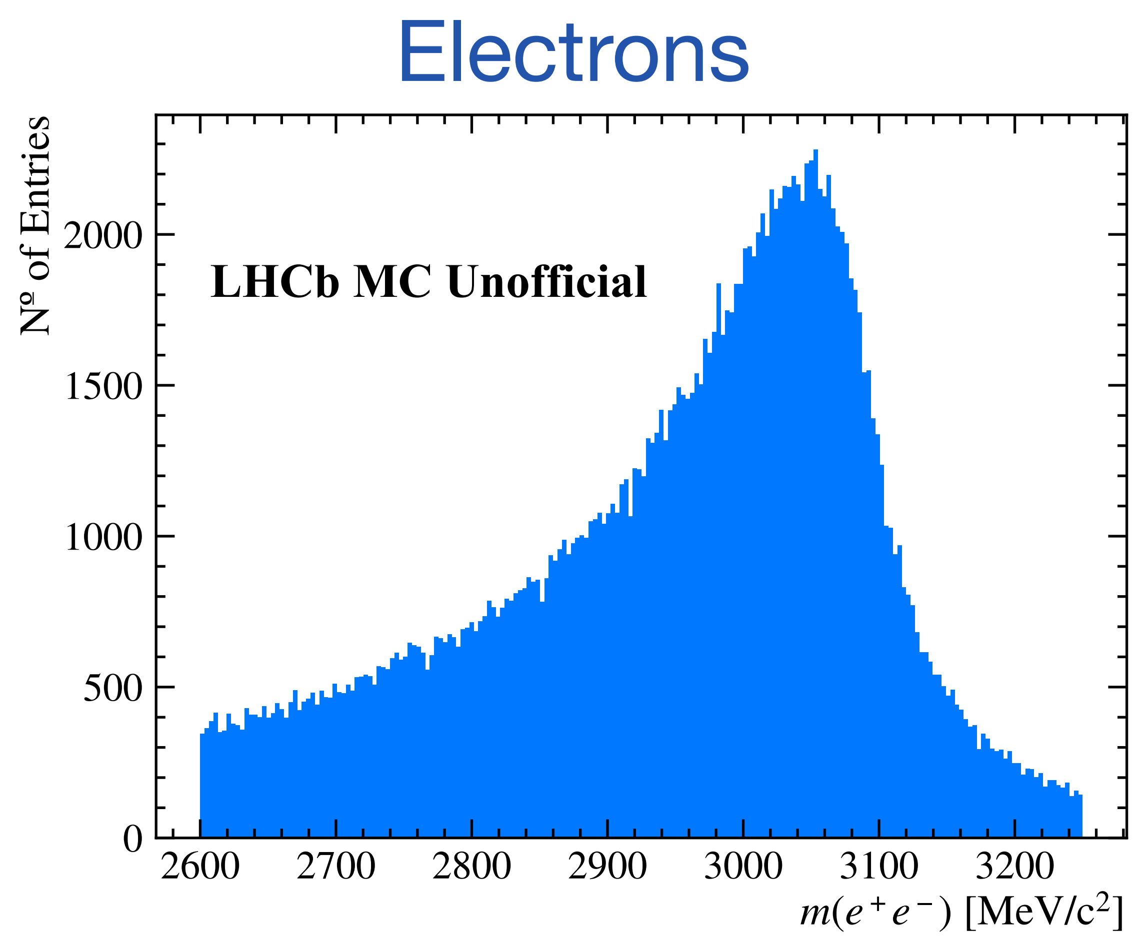

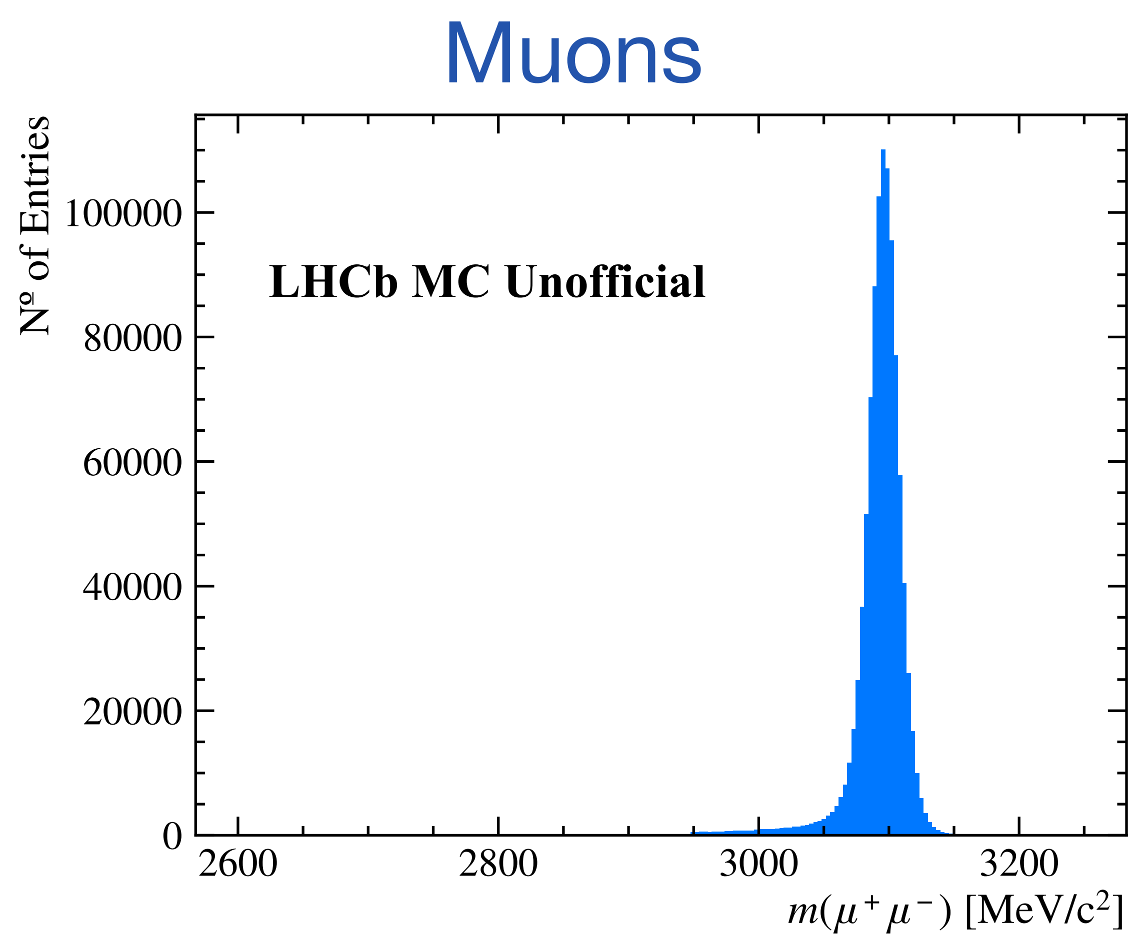

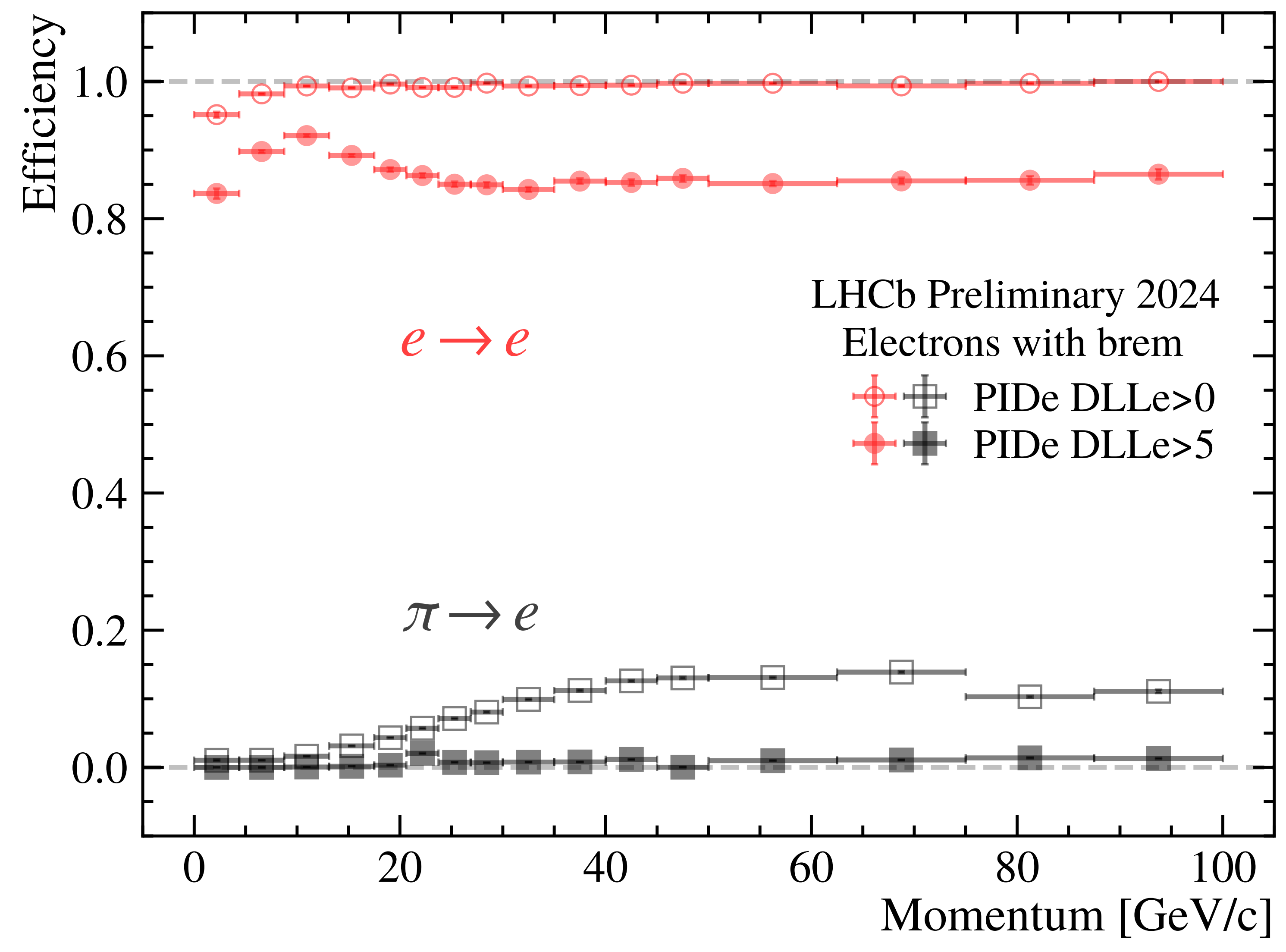

[LHCb-FIGURE-2024-038]

- Electron **identification** is very important in LHCb $\Longrightarrow$ **Controlling Electron ID and MisID rates are crucial!**

Worked on ElectronID 2024 studies
[COMCHA Talk]

Motivation and overview

- **Goal:** Measure single ratio $r_{J/\psi}$ in $B^+ \to J/\psi K^+$ with LHCb 2024 data. A high-purity, well studied channel

$$\boxed{r_{J/\psi} = \frac{N(B^+ \to K^+ J/\psi(\to \mu^+\mu^-))}{N(B^+ \to K^+ J/\psi(\to e^+e^-))} \cdot \frac{\varepsilon(B^+ \to K^+ J/\psi(\to e^+e^-))}{\varepsilon(B^+ \to K^+ J/\psi(\to \mu^+\mu^-))} = 1 \pm (10^{-4})}$$ [PDG]

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- In order to:
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  - Study low momentum electrons only accessible with Run 3 detector
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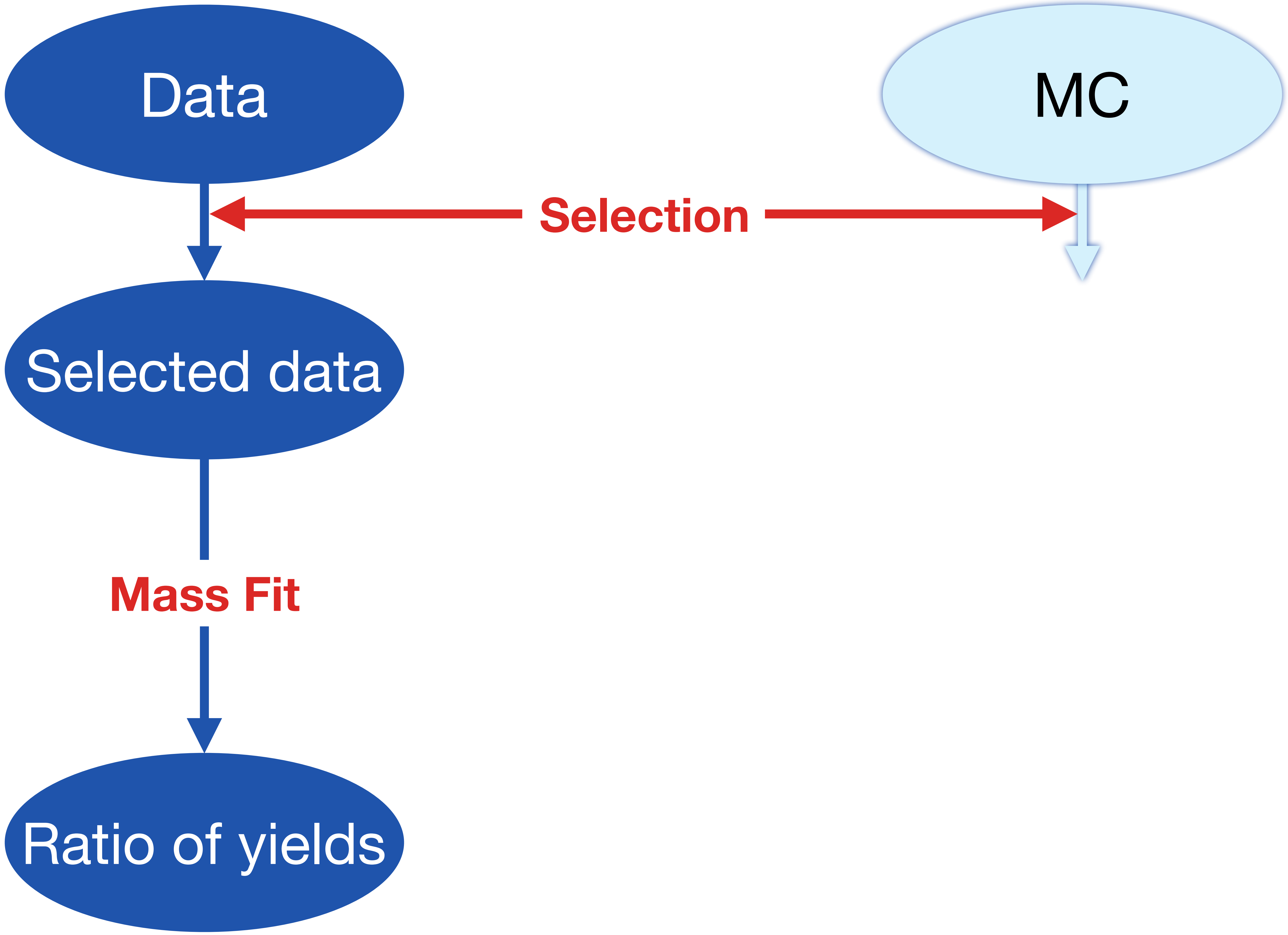
  - Set the ground for other measurements with muons and electrons in LHCb using Run 3 data
- **Ingredients:**
  - Signal yields: selection, background studies, mass fit
  - Efficiencies: Trigger, Tracking, Kinematics & geometry, PID

Measurement strategy

Measurement strategy



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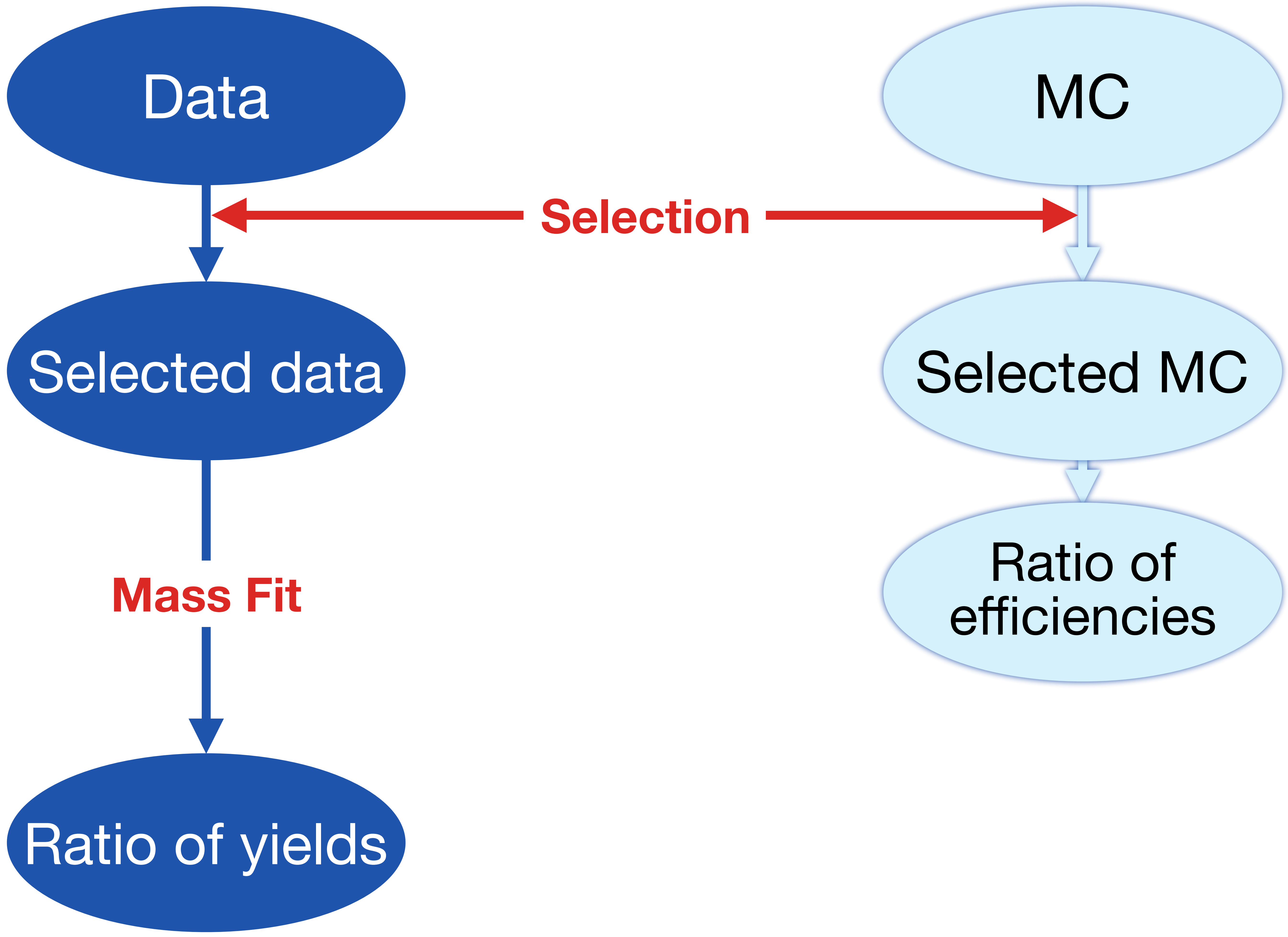

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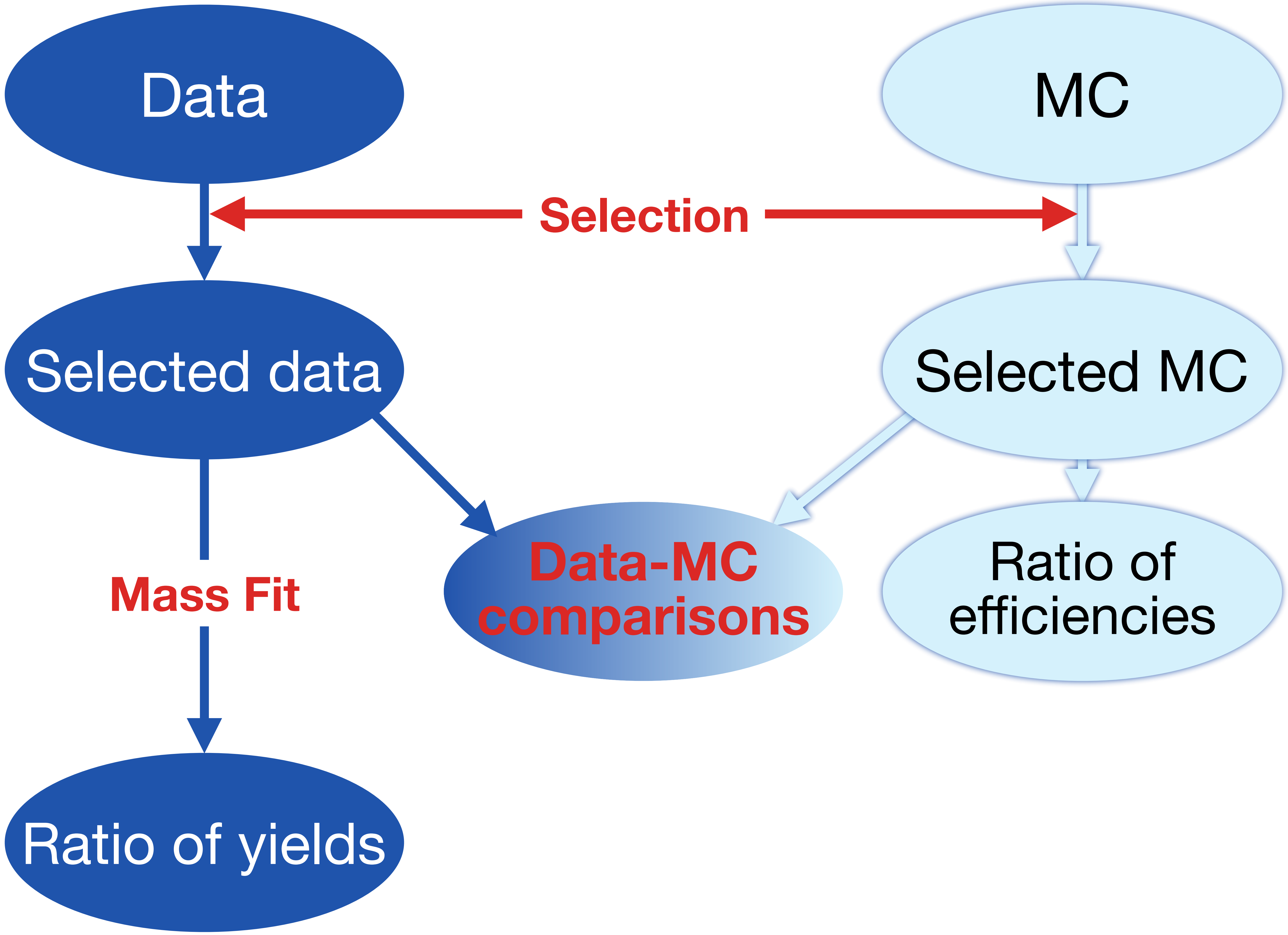

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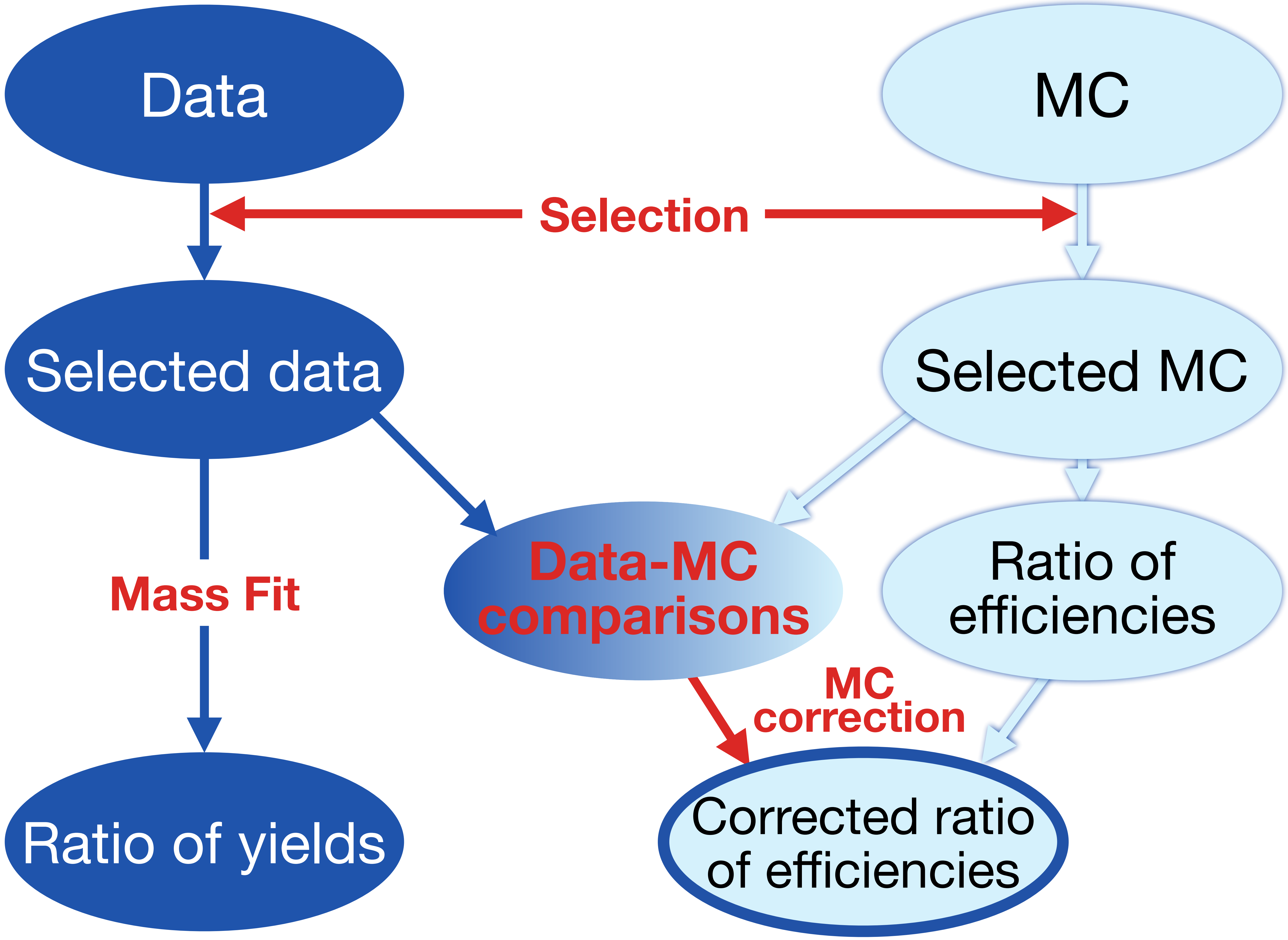

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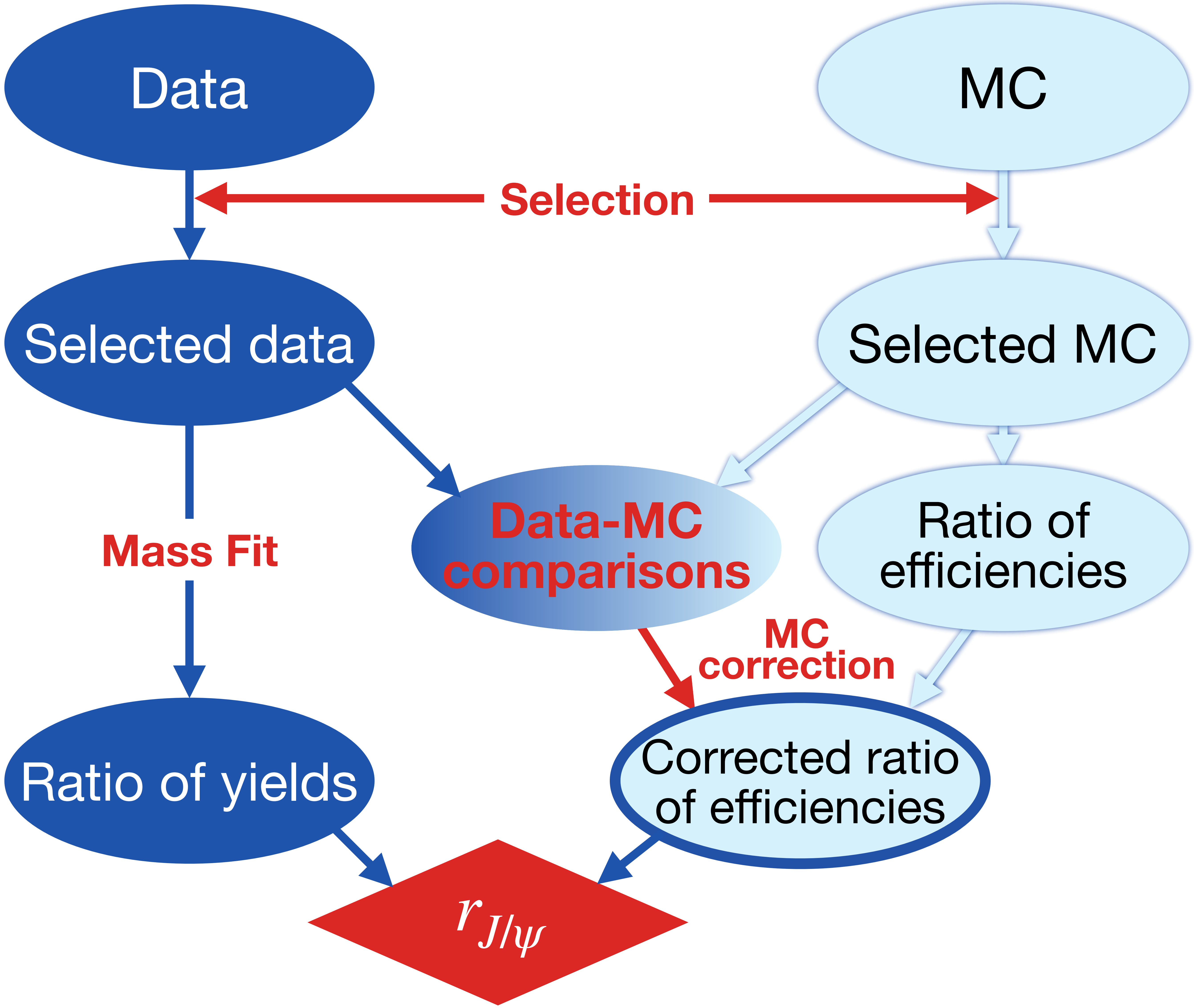

Data selection and mass fit

- **Selection:**
  - Kinematics and acceptance
  - Clone tracks veto
  - Semileptonic veto $\Longrightarrow$ suppress $B^+ \to D^0(\to Ke\nu_e)\pi^+$
  - Charm veto $\Longrightarrow$ suppress $B^+ \to \bar{D}^0(\to K^+\pi^-)e^+\nu_e$
  - ParticleID

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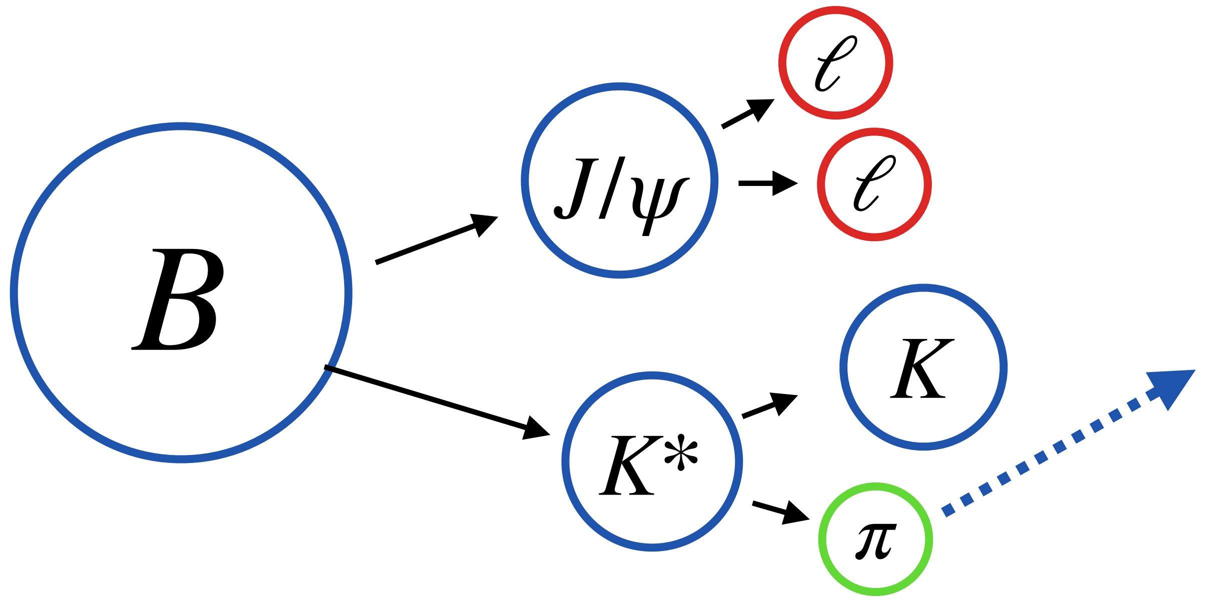
Miss a particle in the reconstruction $\Longrightarrow$ small peak on the left side of the real B mass value



If you miss this pion, it looks like $B \to J/\psi(\to \ell\ell)K$!

Data selection and mass fit

- **Fit strategy:** on the m(B^+) with J/ψ constraint
  - From simulation $\Longrightarrow$ extract signal and background shapes
  - Yields, combinatorial slope, mean and width allowed to vary

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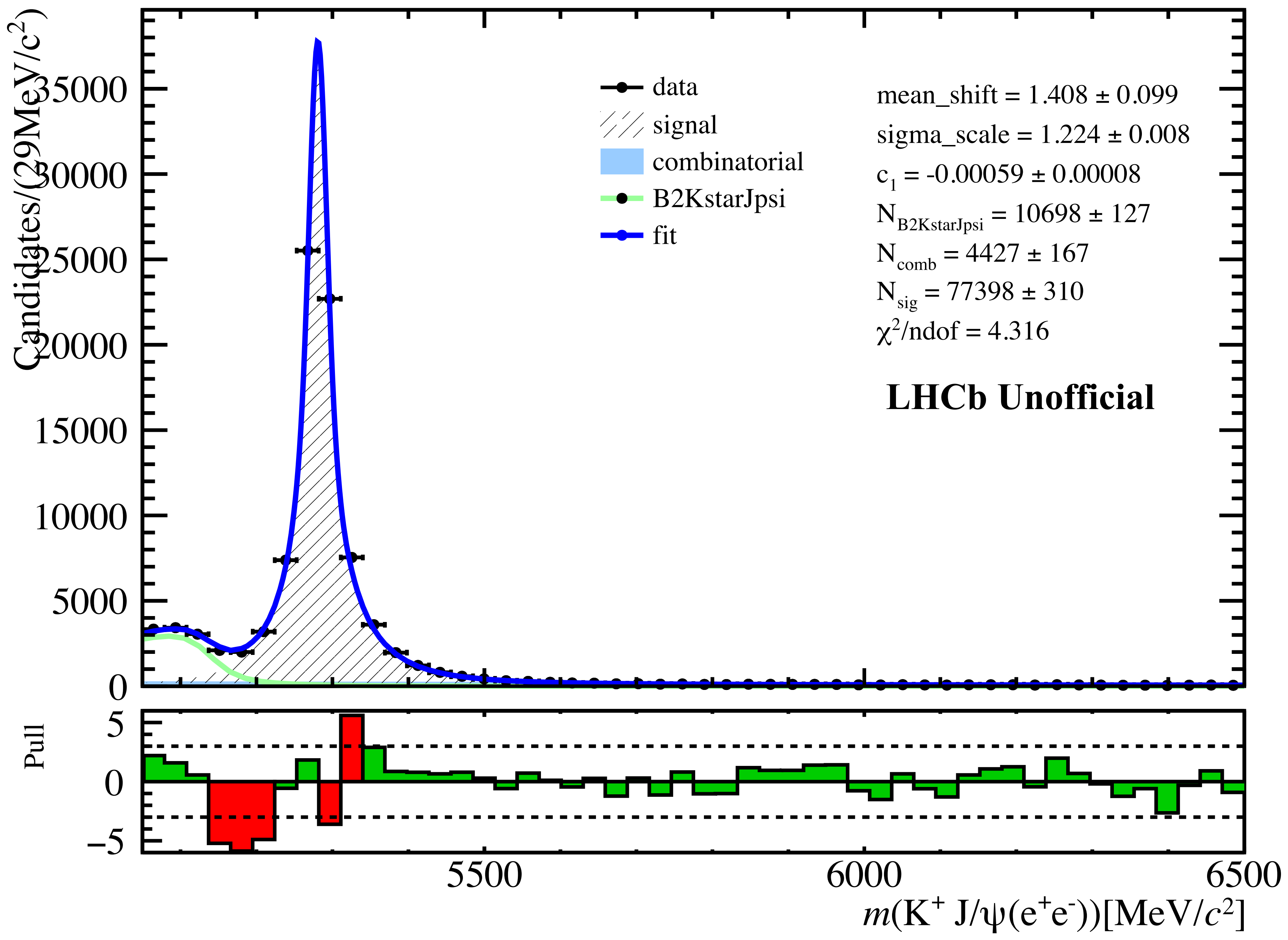
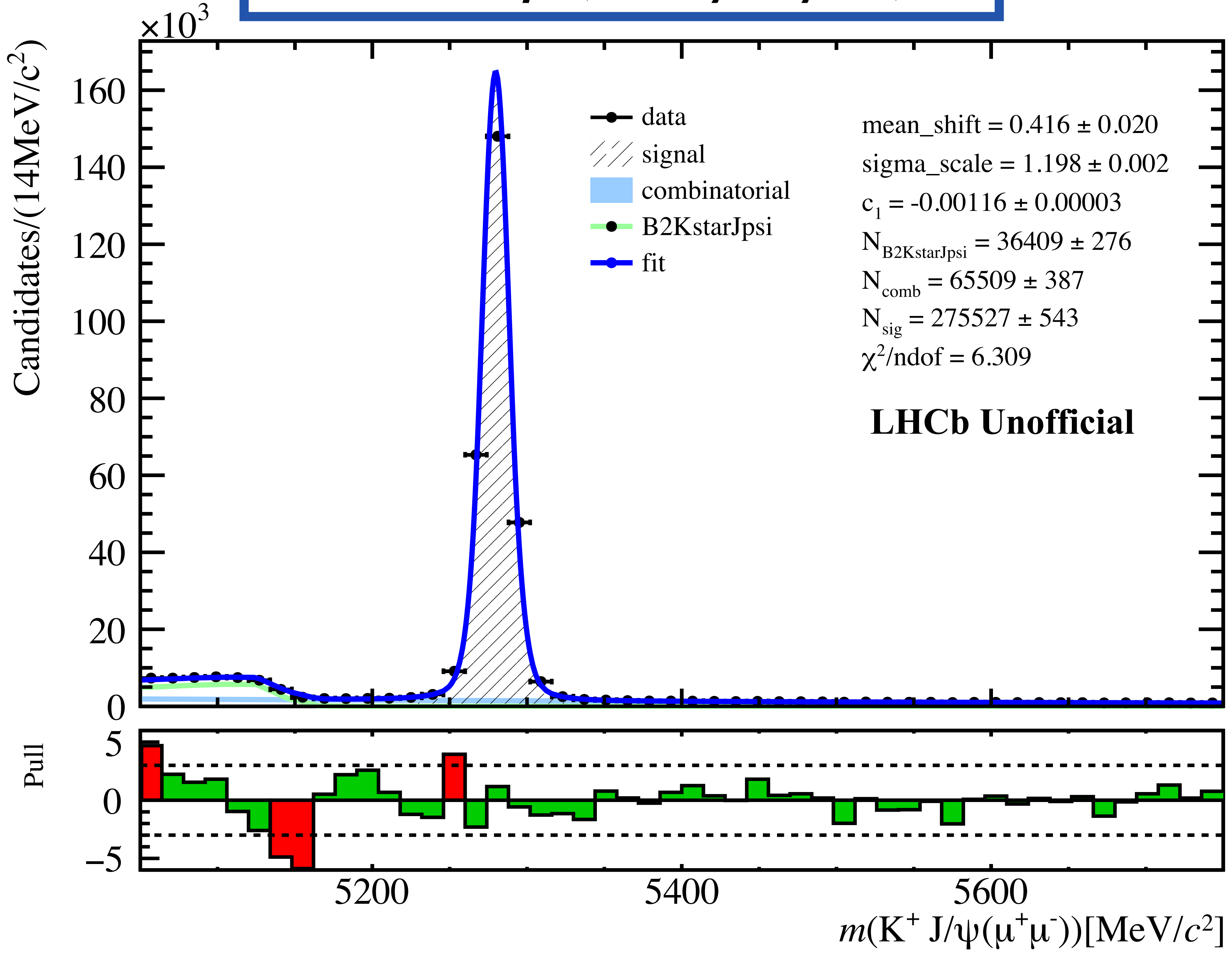


$B \to J/\psi(\to \mu^+\mu^-)K$



Good description of the data, final tuning WIP

Fit validation with toys

- Pseudo-experiments (toys) generated from the data fit model
- For each toy:
  - Generated yields drawn from a **Poisson distribution** with $\mu =$ yield from data fit
  - Mass shapes of different contributions generated with **same models and parameter values**
- Each toy is then fitted with same strategy as real data
- Accurate and stable fit $\Longrightarrow$ pull distr with $\mu = 0$ and $\sigma = 1$ for all parameters

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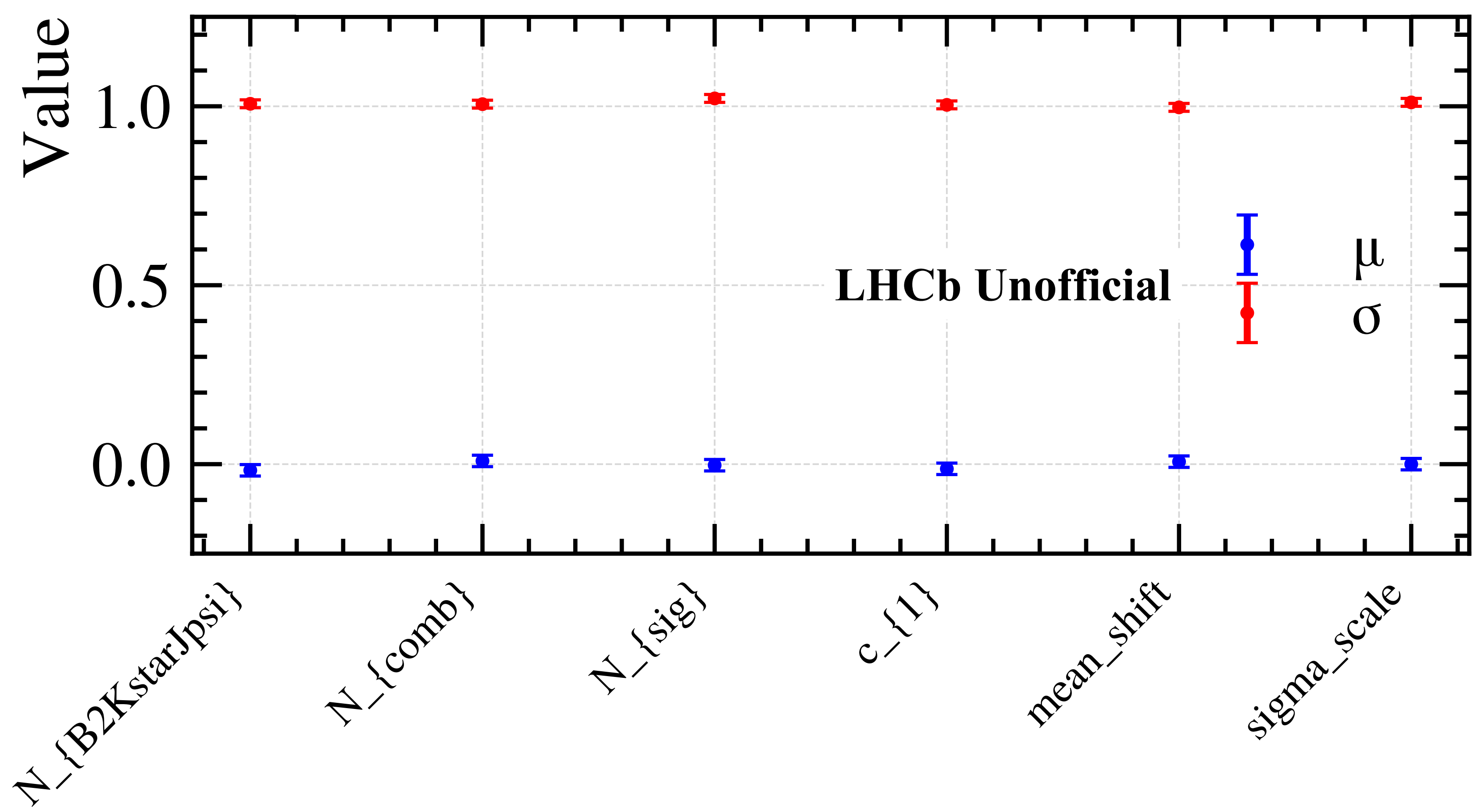
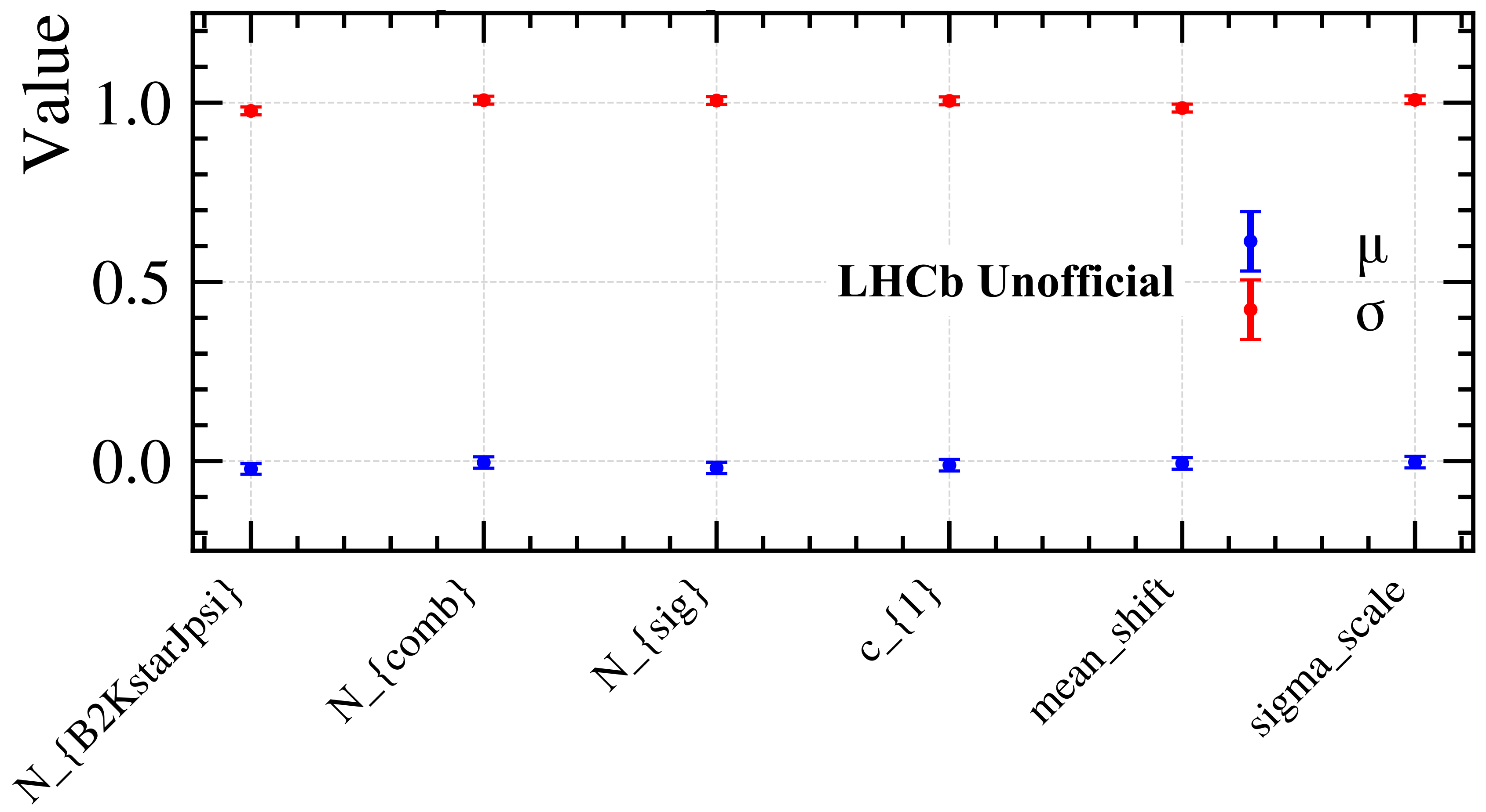
Muons



Electrons



Study with 4000 toys

Efficiency computation without corrections

	MC
	RAW Efficiency
Muons	0.17517 ± 0.00016
Electrons	0.05439 ± 0.00012

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Ratio of yields

Without any correction!

$$\boxed{r_{J/\psi}^{RAW} = 1.105 \pm 0.006}$$

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$$r_{J/\psi}^{RAW} = 1.105 \pm 0.006$$

Run2 $r_{J/\psi}$

[PRL 131 (2023) 051803]

R2p1 L0I inc $w(B^+)$	$1.131 \pm 0.005 \pm 0.003$
R1 L0L exc $w(B^+)$	$1.299 \pm 0.005 \pm 0.003$
R1 L0L inc $w(B^+)$	$1.280 \pm 0.005 \pm 0.002$
R2p1 L0I inc $w(B^+)$	$1.131 \pm 0.005 \pm 0.003$
R2p1 L0L exc $w(B^+)$	$1.392 \pm 0.005 \pm 0.003$
R2p1 L0L inc $w(B^+)$	$1.365 \pm 0.004 \pm 0.002$
R2p2 L0I inc $w(B^+)$	$1.117 \pm 0.003 \pm 0.003$
R2p2 L0L exc $w(B^+)$	$1.412 \pm 0.004 \pm 0.003$
R2p2 L0L inc $w(B^+)$	$1.384 \pm 0.003 \pm 0.003$

Electrons-muons difference much smaller than in Run 2, thanks to the hardware-less trigger

MC corrections

- **Discrepancies** in description of variables in data and simulation ⇒ <u>bias in efficiency</u> evaluation after selection

- Corrections depend on each other. To not correct twice ⇒ **Order matters**

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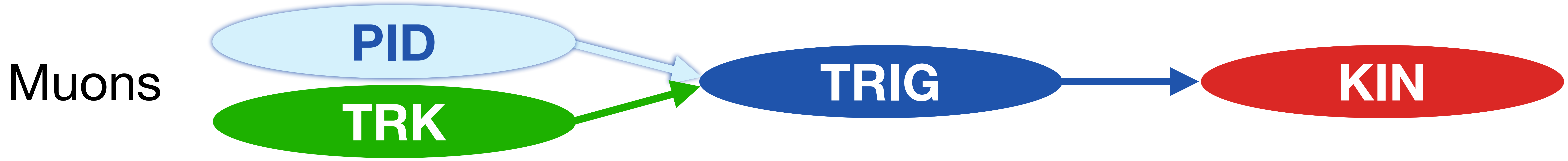

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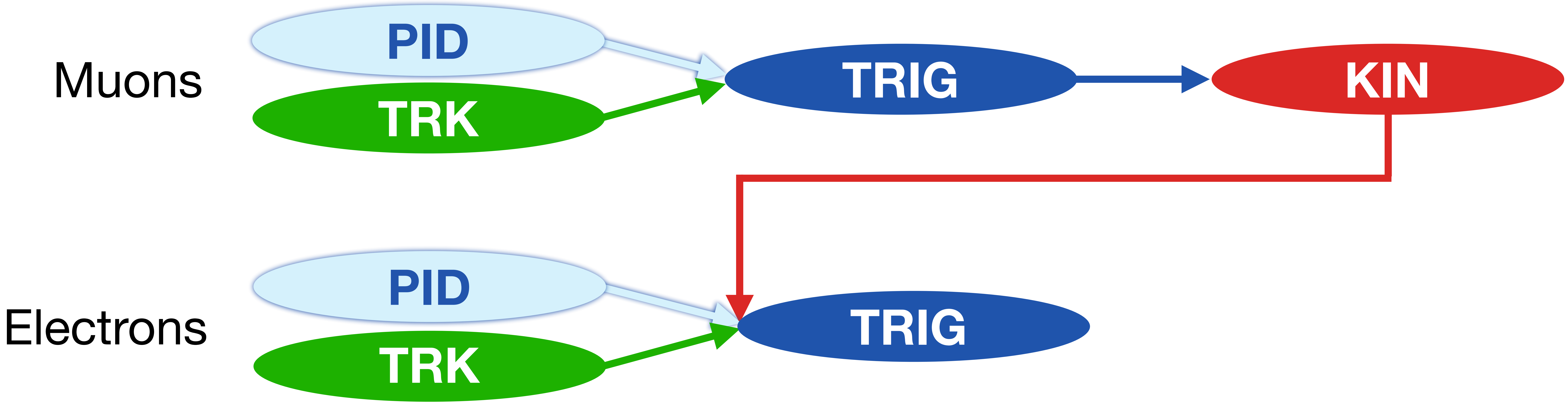
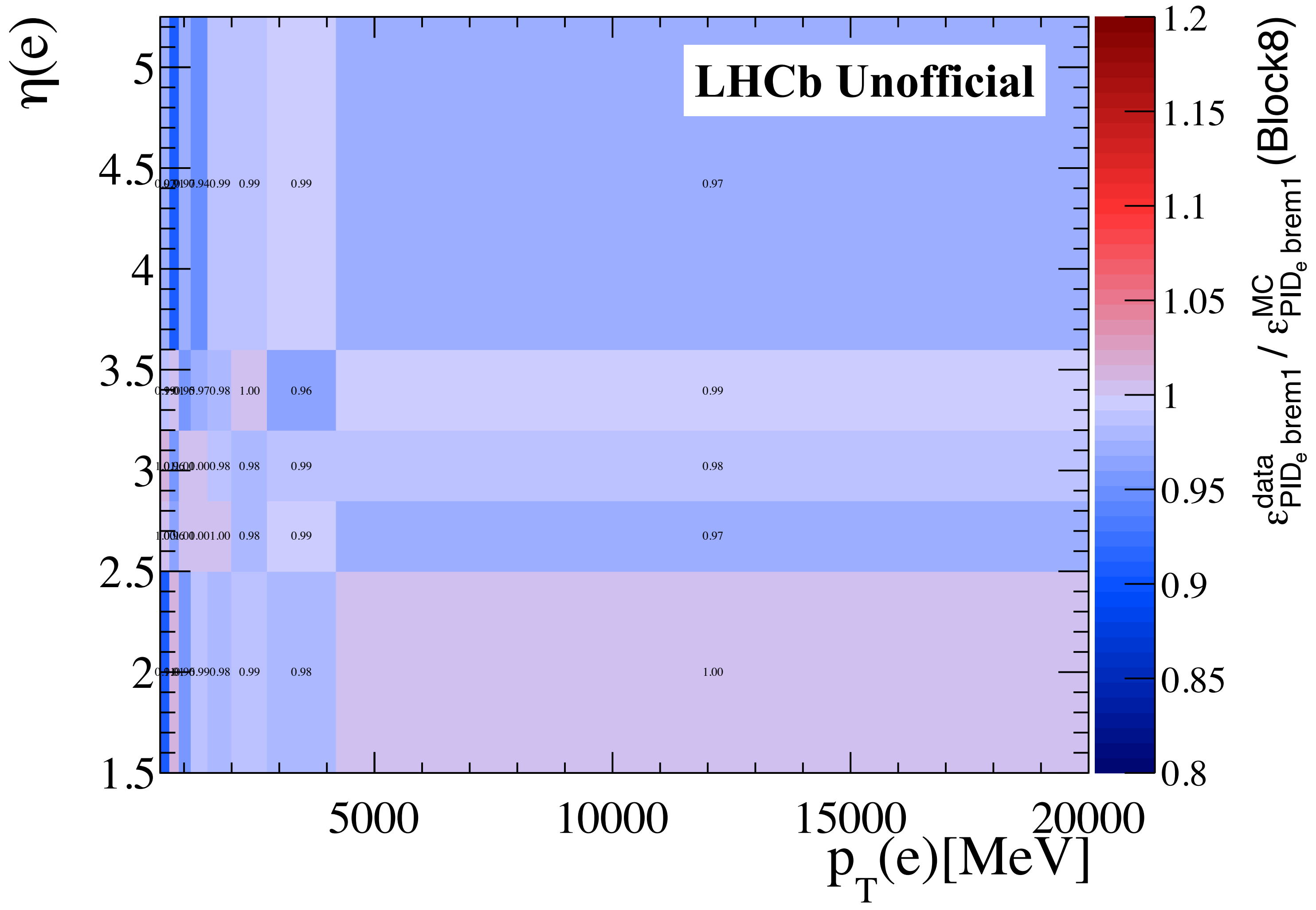


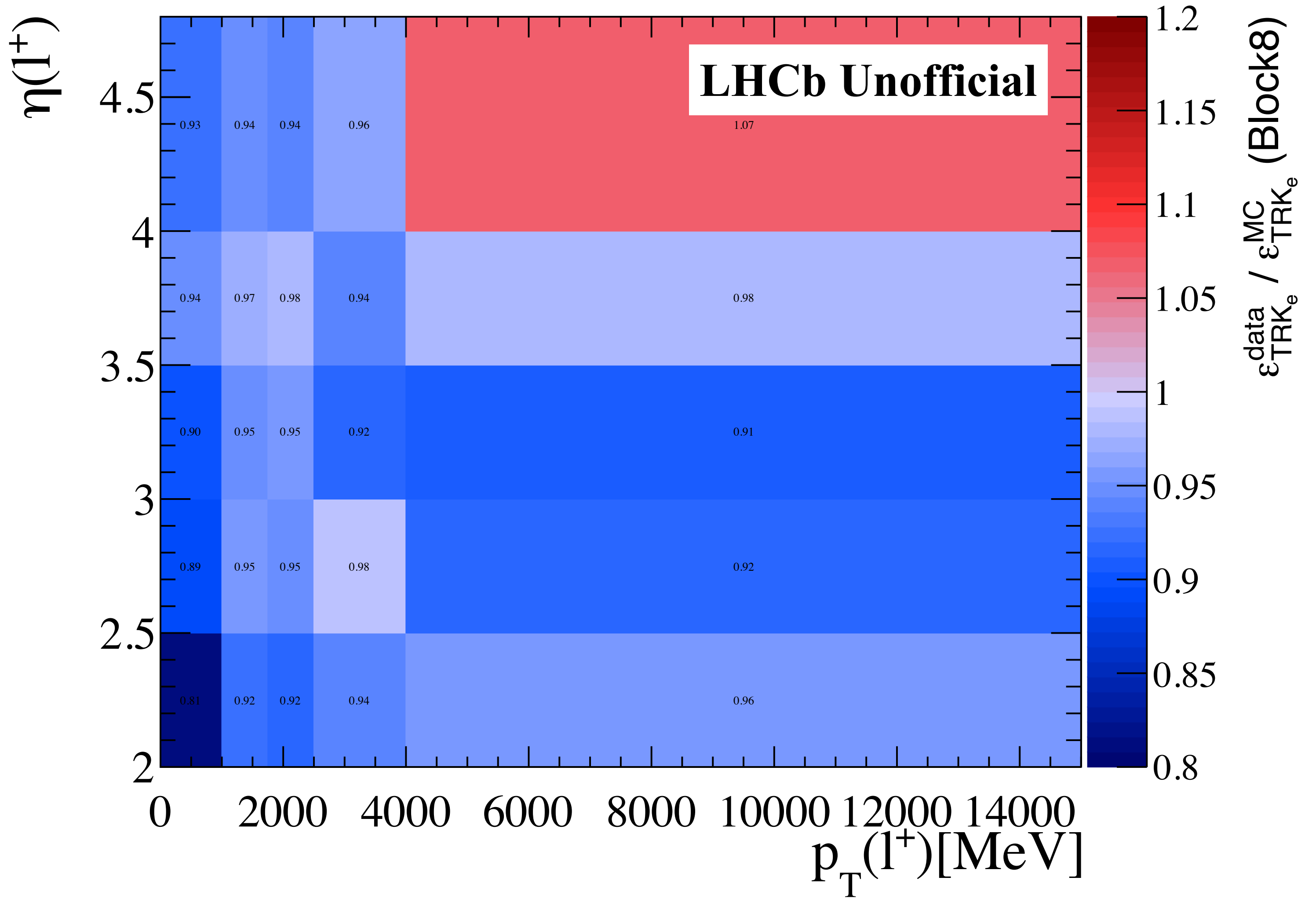
PID, tracking and trigger corrections

- Correction maps for each correction step and channel developed as part of this analysis using **LHCb-wide calibration tools** $\Longrightarrow$ important for their validation
- Data/Simulation maps used, obtained with data-driven techniques:
  - **PID maps** $\Longrightarrow$ In kinematic bins and split in electrons with/without brem
  - **Tracking efficiency maps** $\Longrightarrow$ In kinematic bins and split in electrons with/without brem
  - **Trigger efficiency maps** $\Longrightarrow$ In kinematic bins

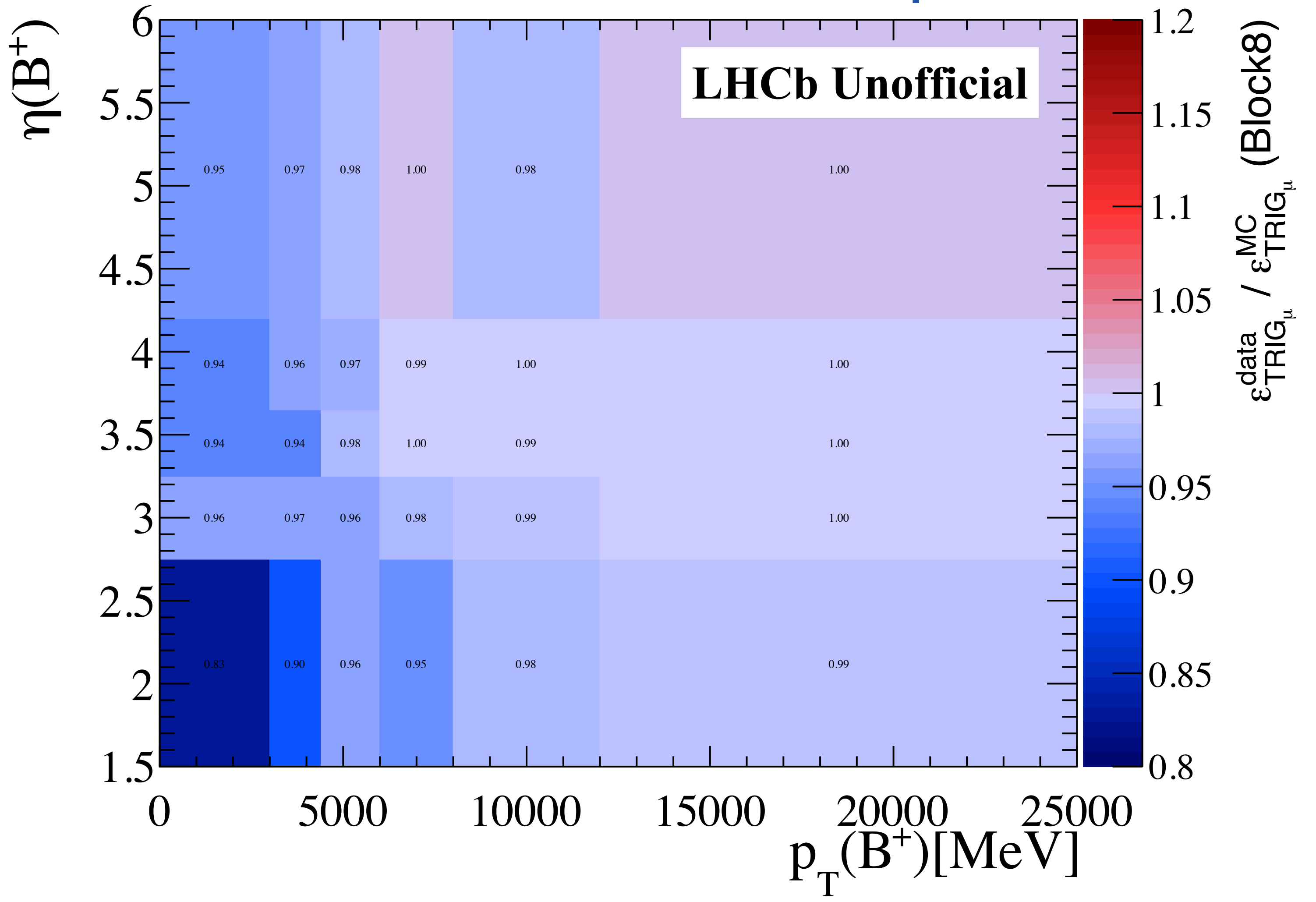
Electrons with brem PID map



Muons TRK map



Muons TRIG map



Corrections O(%) but up to 20% in extreme regions

Kinematic correction

- Correction from **comparison** of MC with PID, TRK and TRIG weights vs selected data

- Multidimensional reweighter trained on muon data targeting B p, p_T, η, and event multiplicity $\Longrightarrow$ applied to electrons as well

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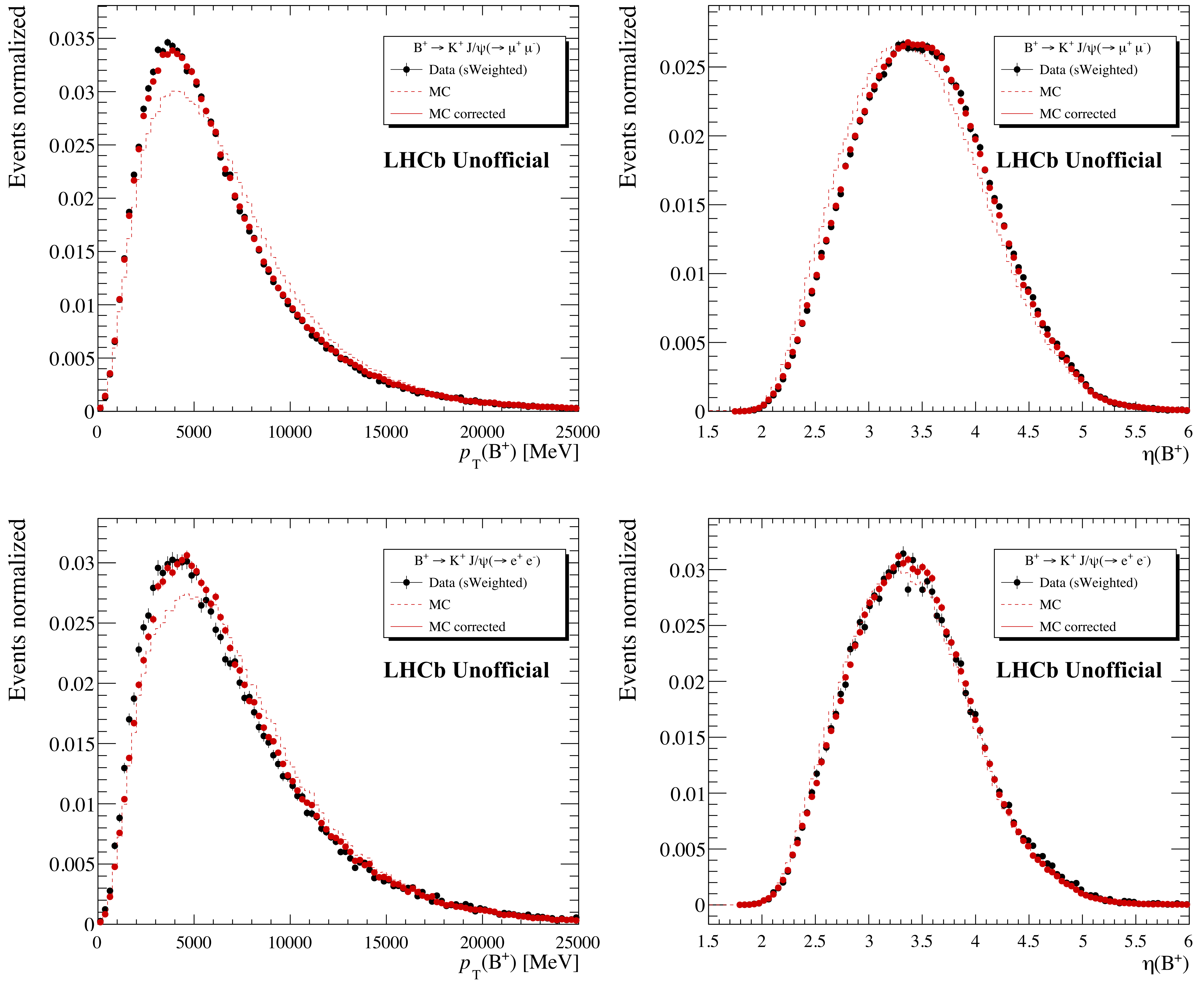
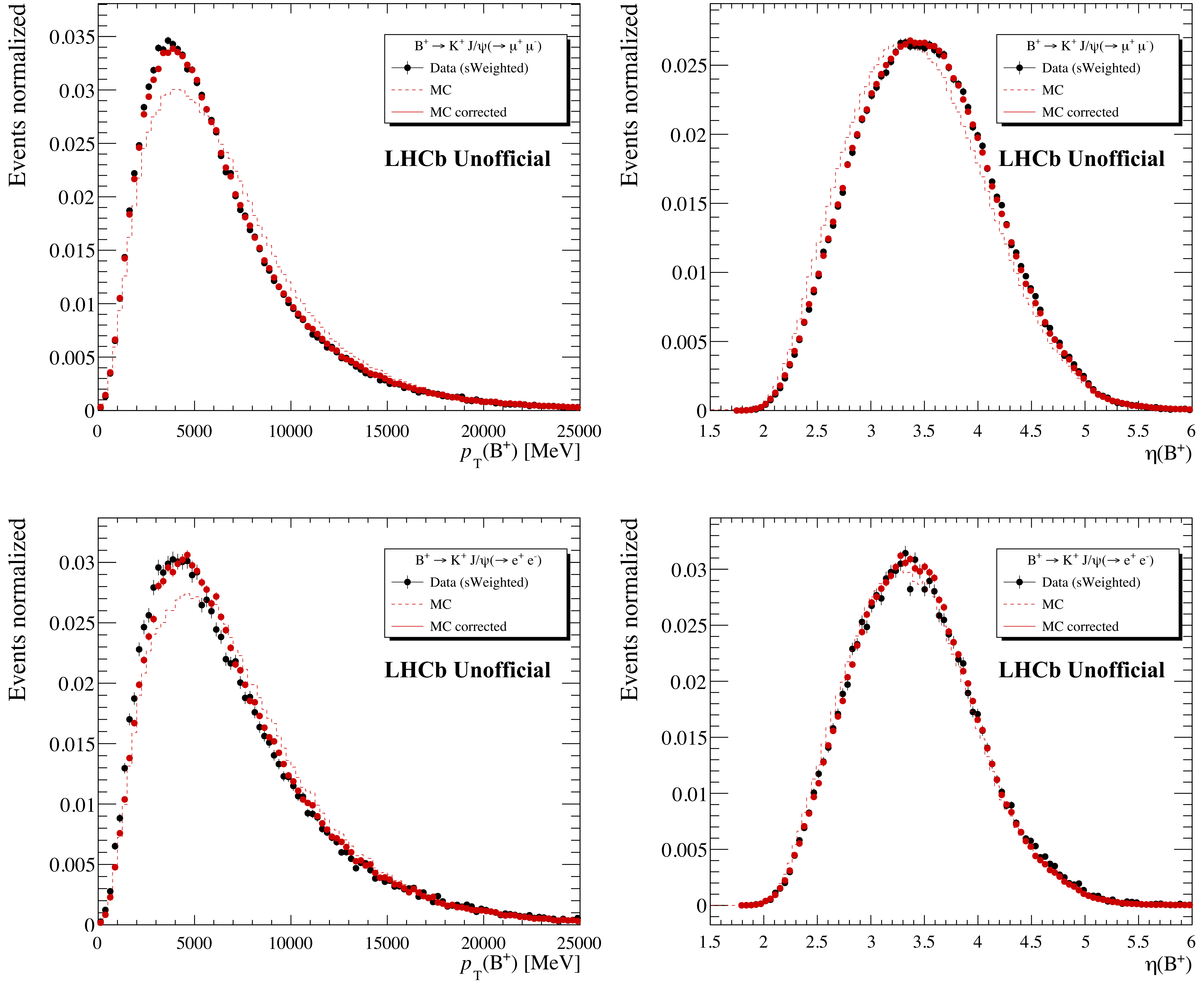


Kinematic correction

- Correction from **comparison** of MC with PID, TRK and TRIG weights vs selected data
- Multidimensional reweighter trained on muon data targeting B p, p_T, η, and event multiplicity $\Longrightarrow$ applied to electrons as well
  - Good agreement in the muons sample
  - **WIP**: fix residual differences in electron mode

Muons

Electrons



q^2 correction

On electrons only

- Resolution of the dielectron invariant mass squared, q^2, **differs** between data and simulation
    - Cut in q^2 selects the J/ψ mass window $\Longrightarrow$ needs correction
- Dependency of brem recovery efficiency with occupancy $\Longrightarrow$ effect not well reproduced in MC
- **Smear the simulated** q^2 to **match** the data resolution

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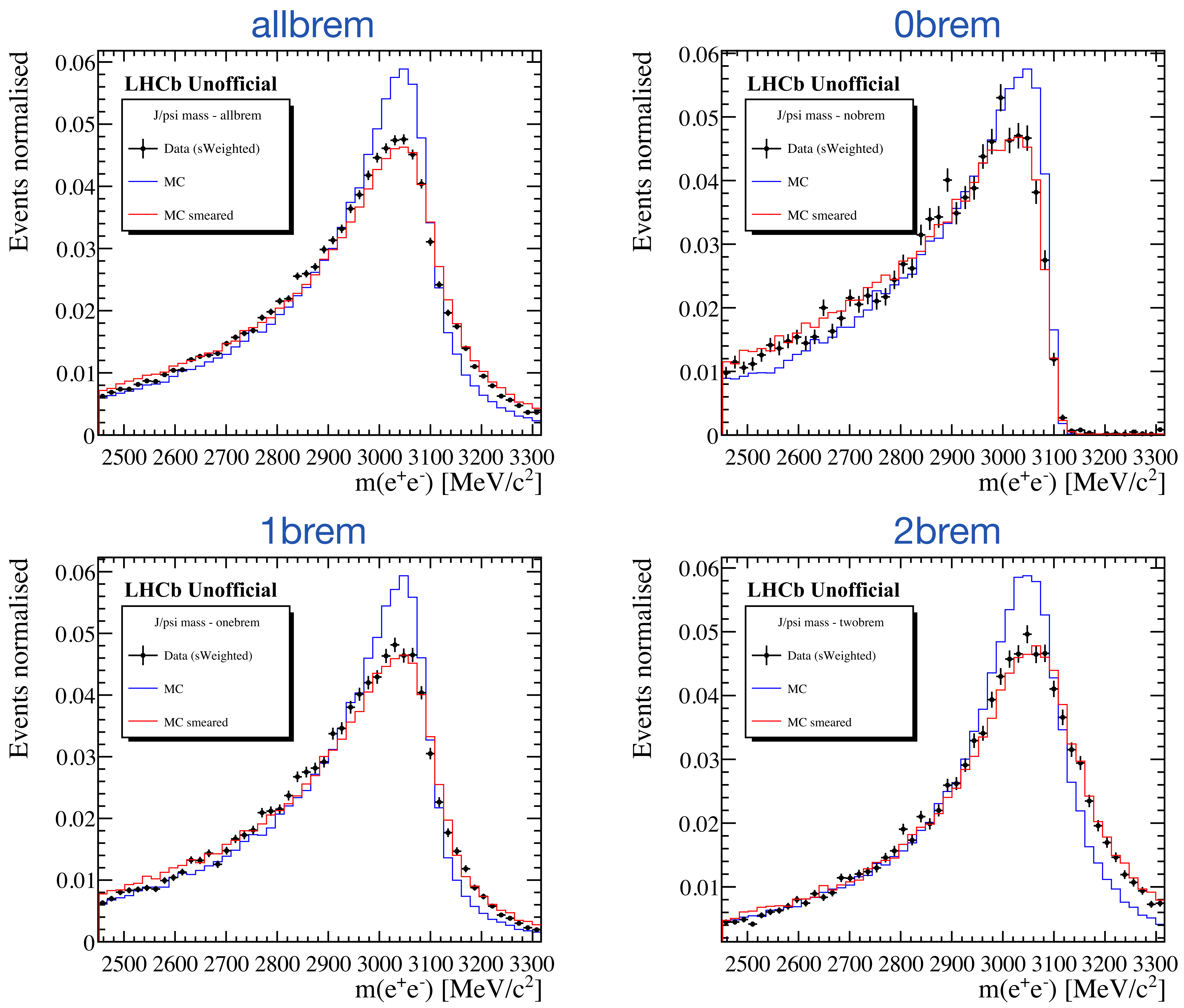
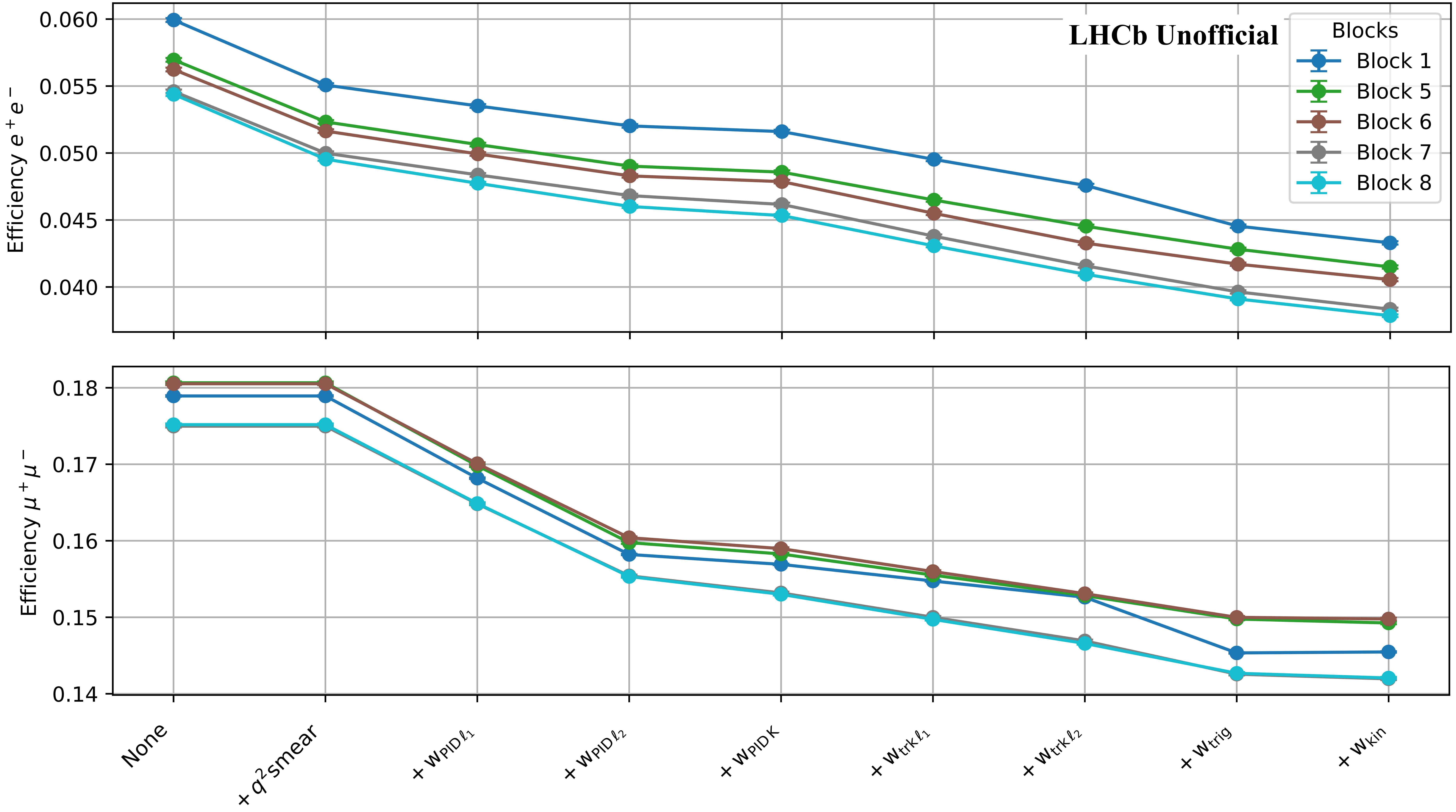
- Dependency of <u>brem recovery efficiency</u> with <u>occupancy</u> $\Longrightarrow$ effect not well reproduced in MC
- **Smear the simulated** q^2 to **match** the data resolution



Efficiencies evolution with corrections



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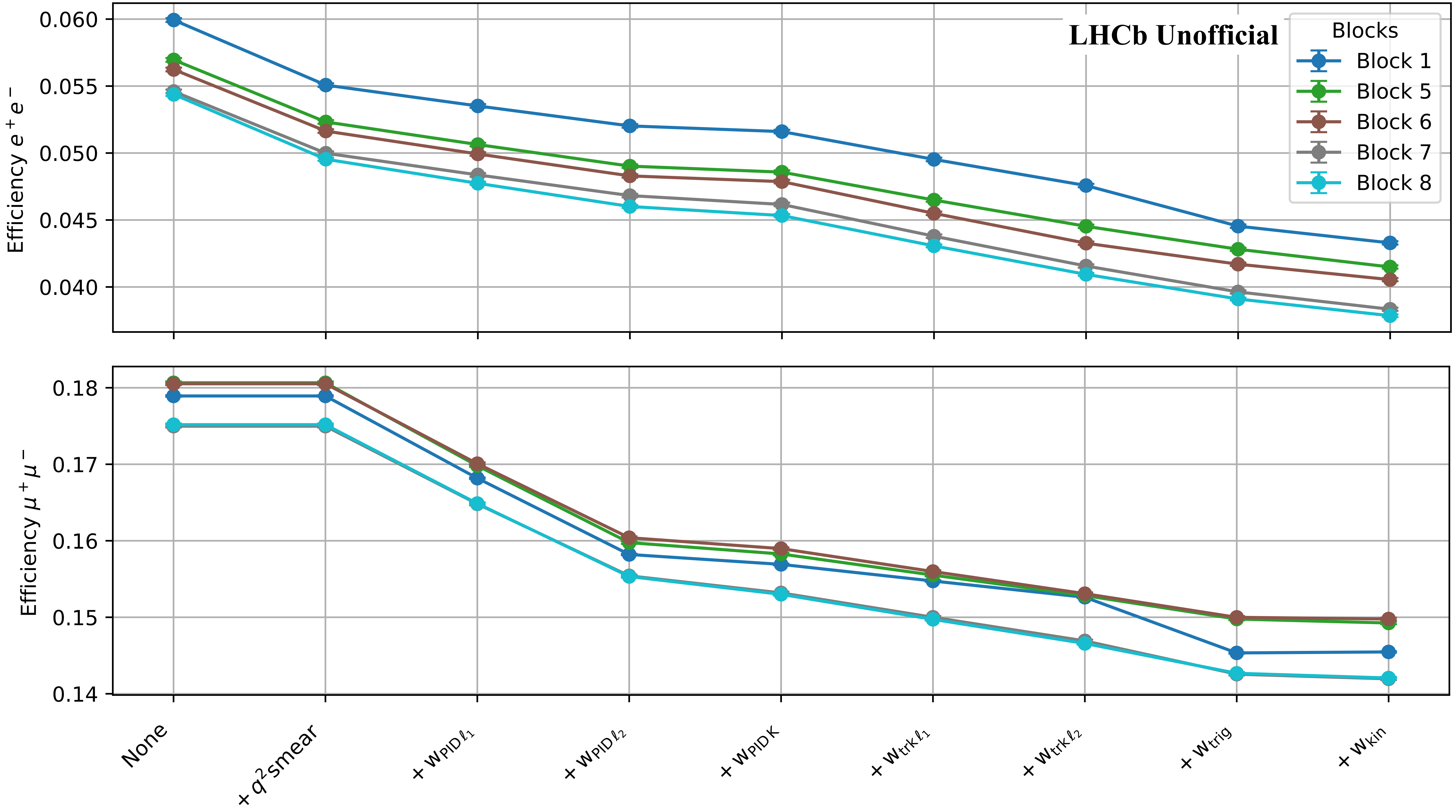
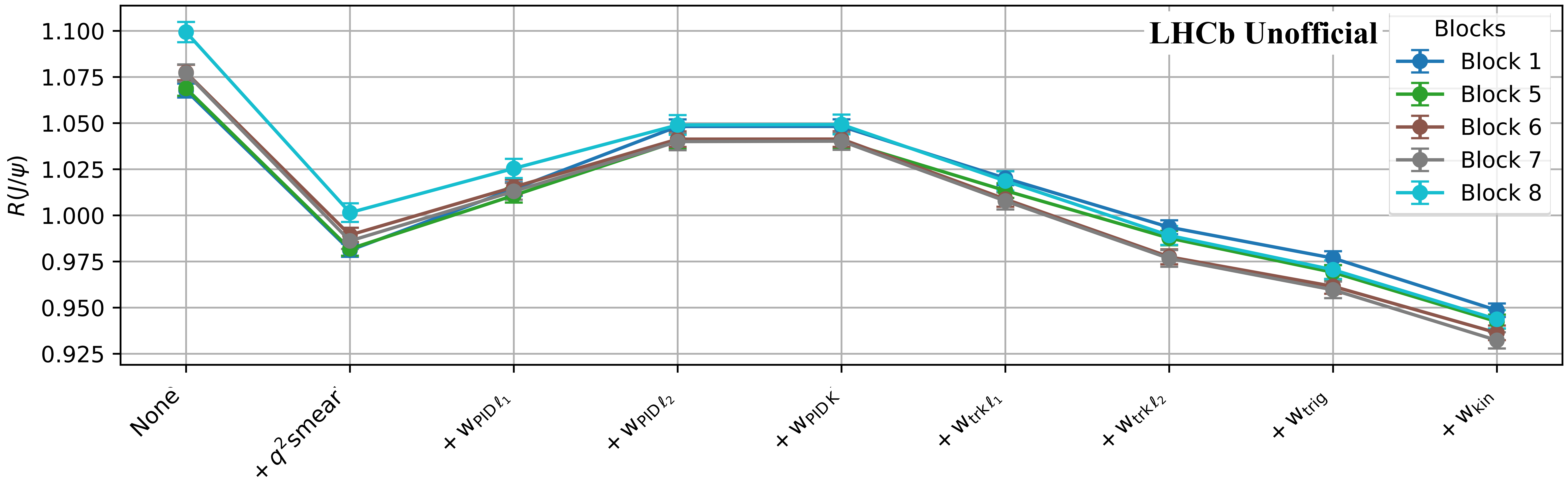


q^2smear only for electrons!

Muons are corrected more in PID and electrons more in TRK+TRIG

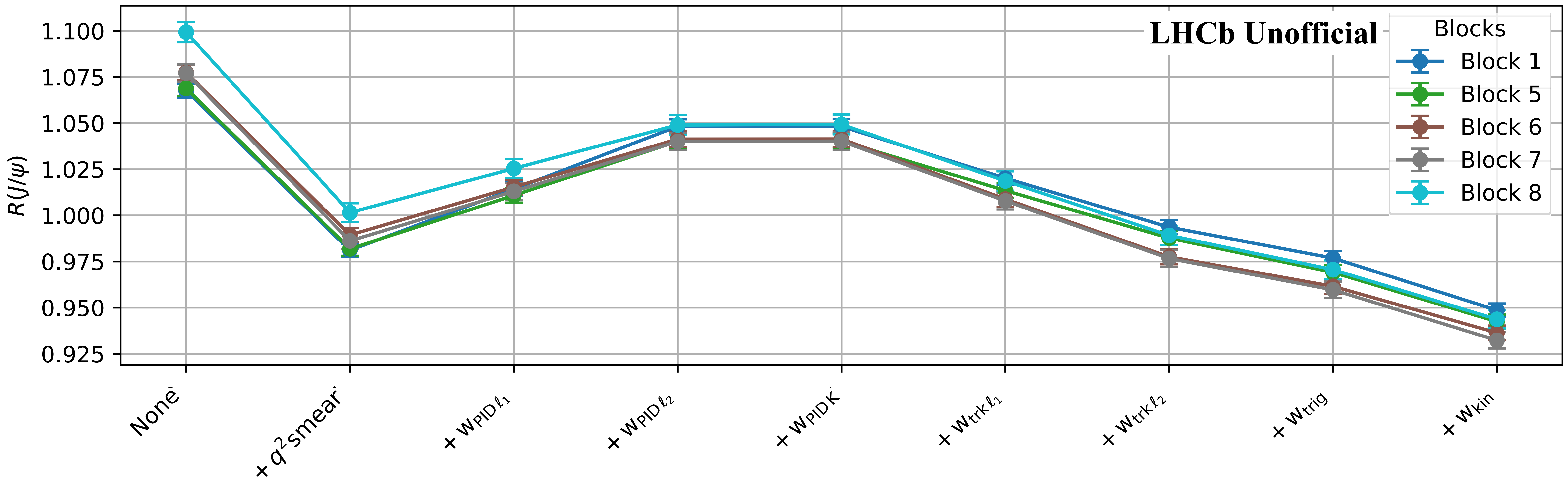
$r_{J/\psi}$ evolution with corrections

Muons/Electrons



$r_{J/\psi}$ evolution with corrections

Muons/Electrons



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Conclusions and prospects

- Analysis of the measurement of $r_{J/\psi}$ in an advanced stage
- Important analysis to evaluate reconstruction of **electrons** and **muons** with new Upgrade I detector and accessing lower momenta electrons
- Developed tools to correct main MC mis-modelling $\Longrightarrow$ **critical** for this and future Run 3 measurements
- Results already quite good but improvements ongoing
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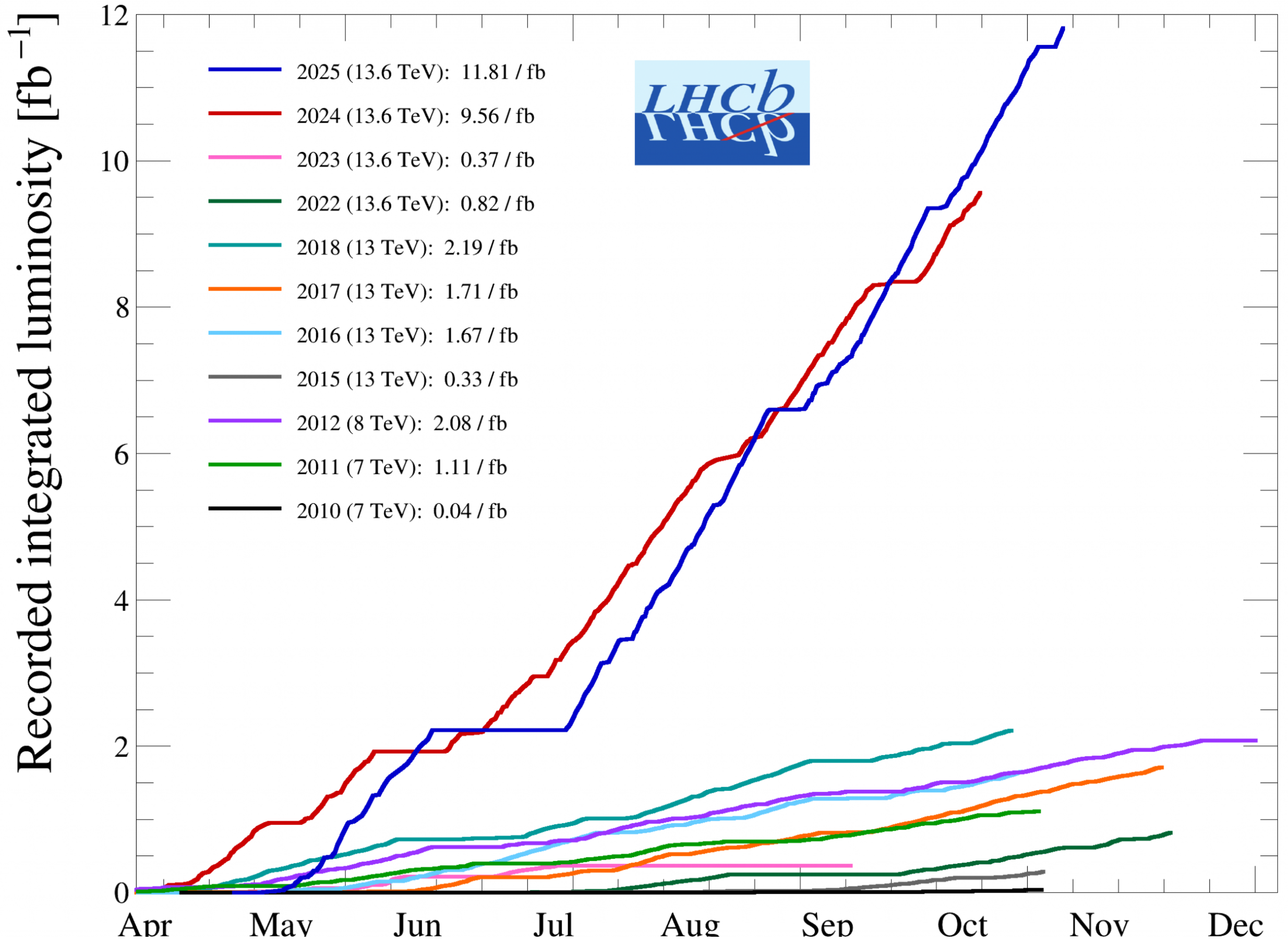

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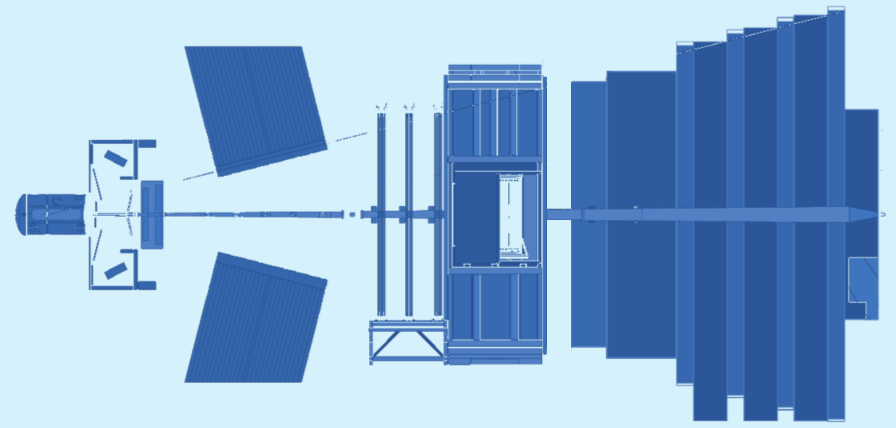

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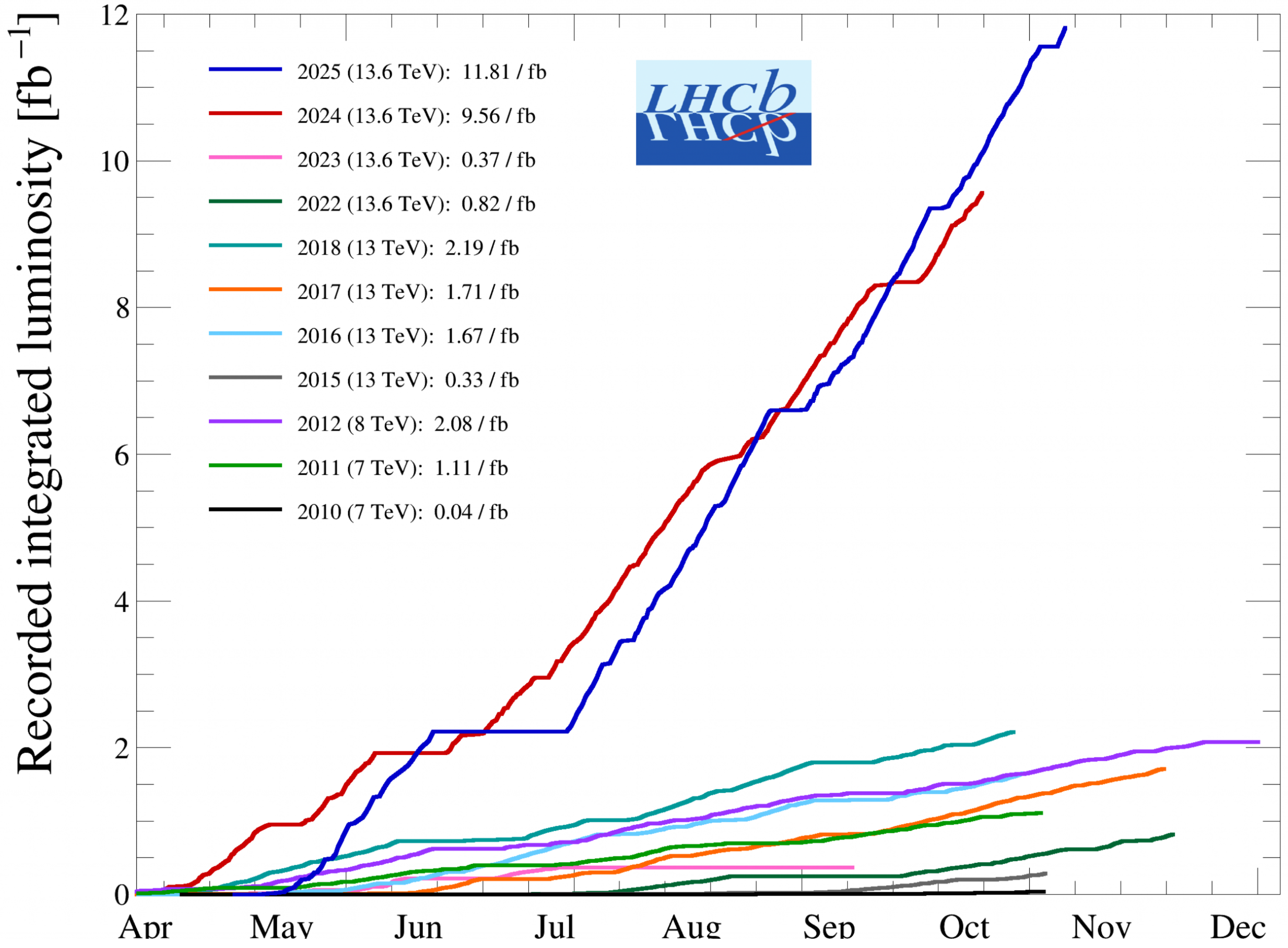


Thank you for your attention!

Back-Up

q^2 correction

Formula used

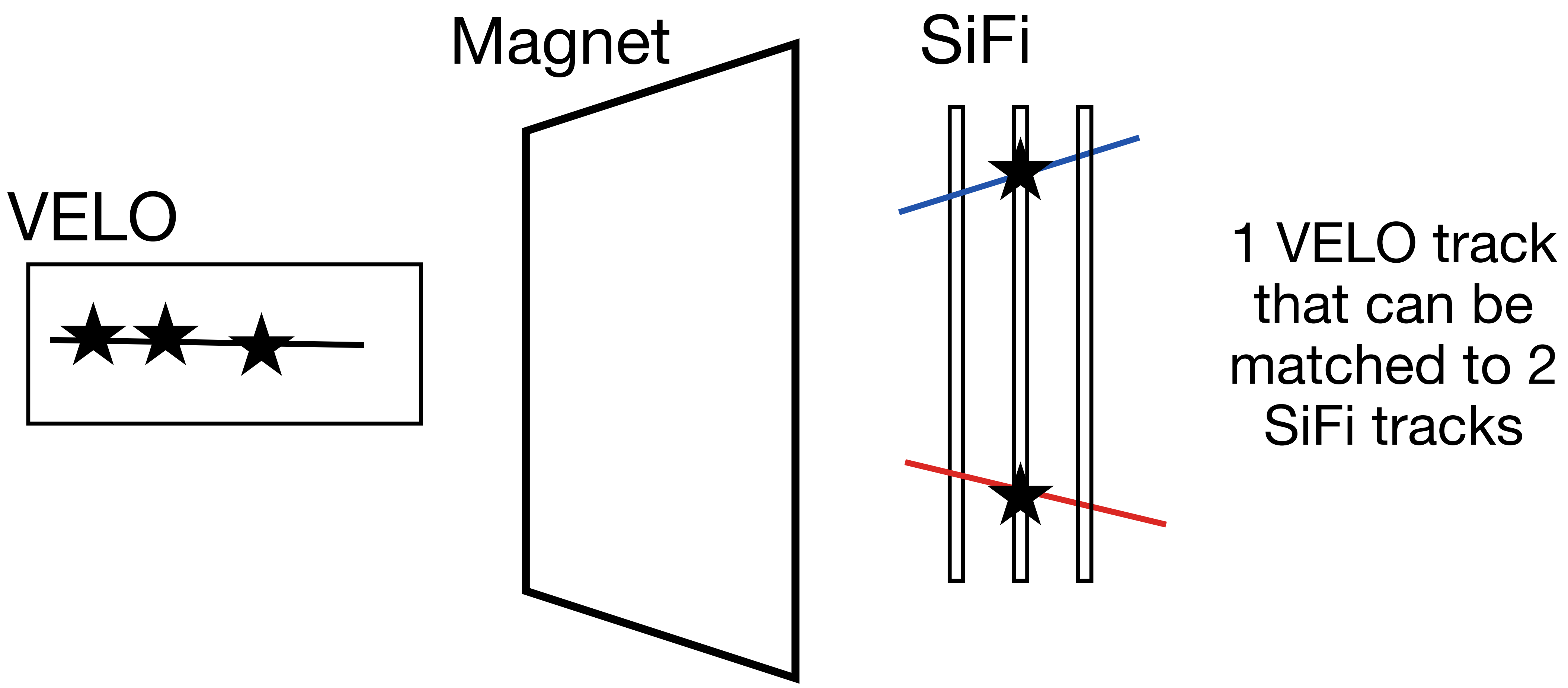
$$m_{\text{smeared}} = m_{\text{true}} + s_\sigma \cdot (m_{\text{reco}} - m_{\text{true}}) + \Delta\mu + (1 - s_\sigma) \cdot (\mu_{\text{MC}} - m_{J/\psi}^{\text{PDG}})$$

where:

- m_{true} is the true dilepton mass before final state radiation, obtained from the generator-level kinematics;
- m_{reco} is the reconstructed dilepton mass in simulation;
- s_σ is the ratio of the mass resolution widths in data and simulation ($\sigma_{\text{data}}/\sigma_{\text{MC}}$);
- $\Delta\mu = \mu_{\text{data}} - \mu_{\text{fit}}^{\text{MC}}$ is the mass shift between data and MC peak positions;
- μ_{MC} is the fitted mean mass in simulation;
- $m_{J/\psi}^{\text{PDG}}$ is the nominal J/ψ mass from the PDG.

Clones in LHCb and m(B^+) with J/ψ constraint

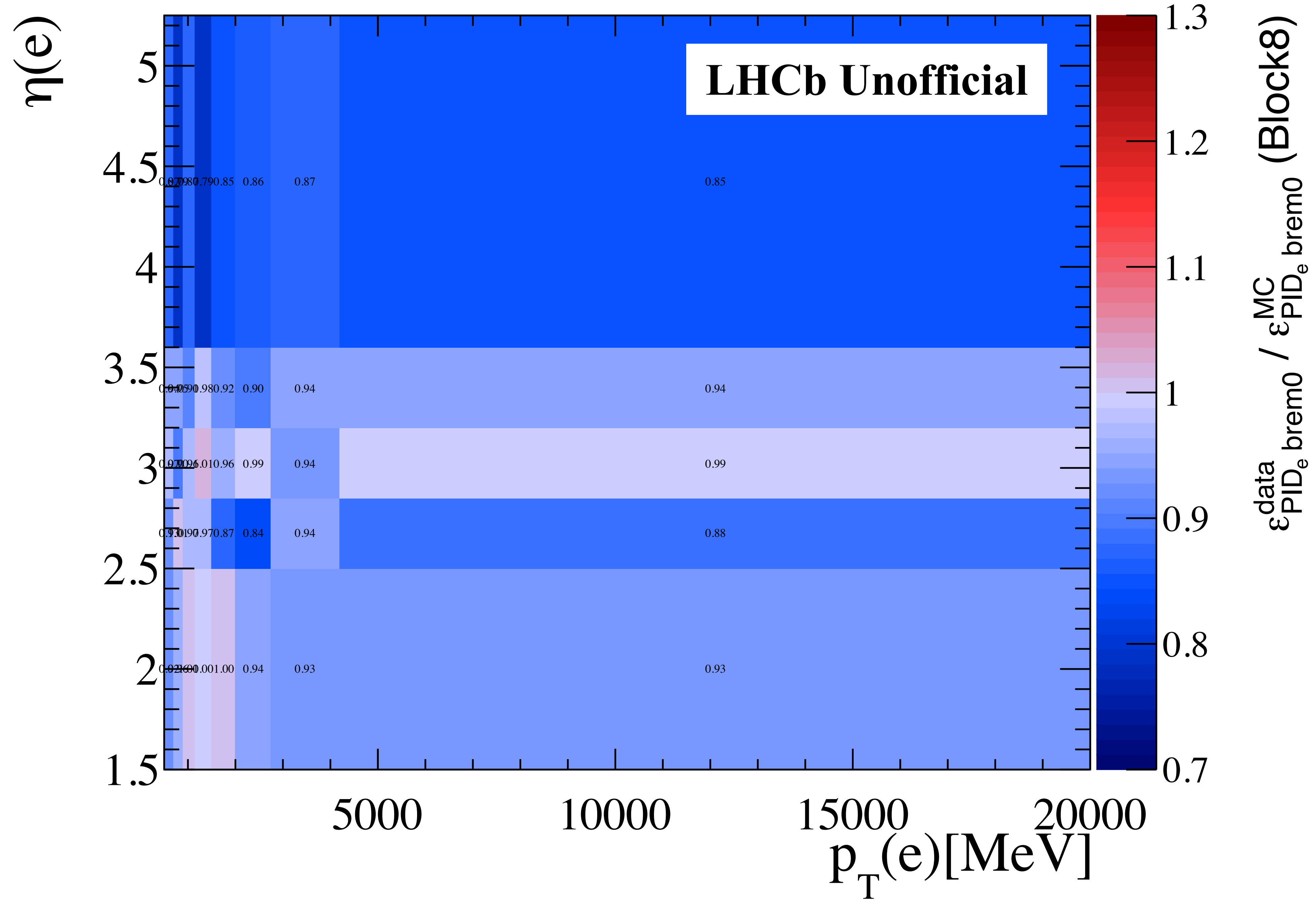
- Clones:



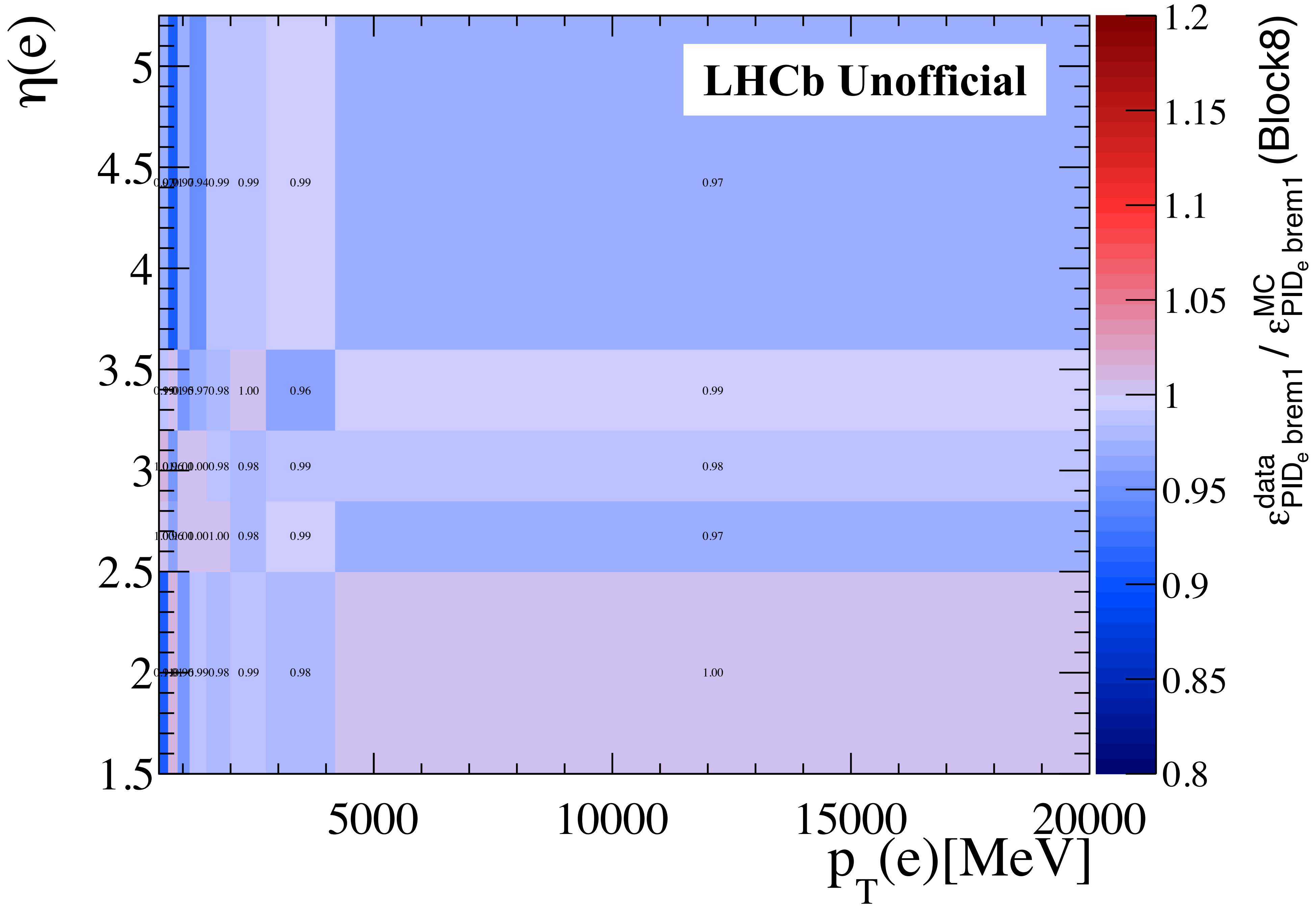
- <u>B mass</u> with constraint:
    - <u>J/ψ mass constraint</u> that $\sim$ mass of the di-electrons = mass of J/ψ

Efficiency maps with/without brem

Electrons without brem PID map



Electrons with brem PID map



Evaluation of the flatness of $r_{J/\psi}$

- Cross-check **control of efficiencies** in different regions $\Longrightarrow$ plot $r_{J/\psi}$(variable of interest)
- Dataset split in bins of a given variable $\Longrightarrow$ recompute $r_{J/\psi}$ for each bin
- If there is no dependence $\Longrightarrow$ $r_{J/\psi}$ should be **flat**