Data-driven efficiencies of the LHCb High-Level Trigger in Run 3

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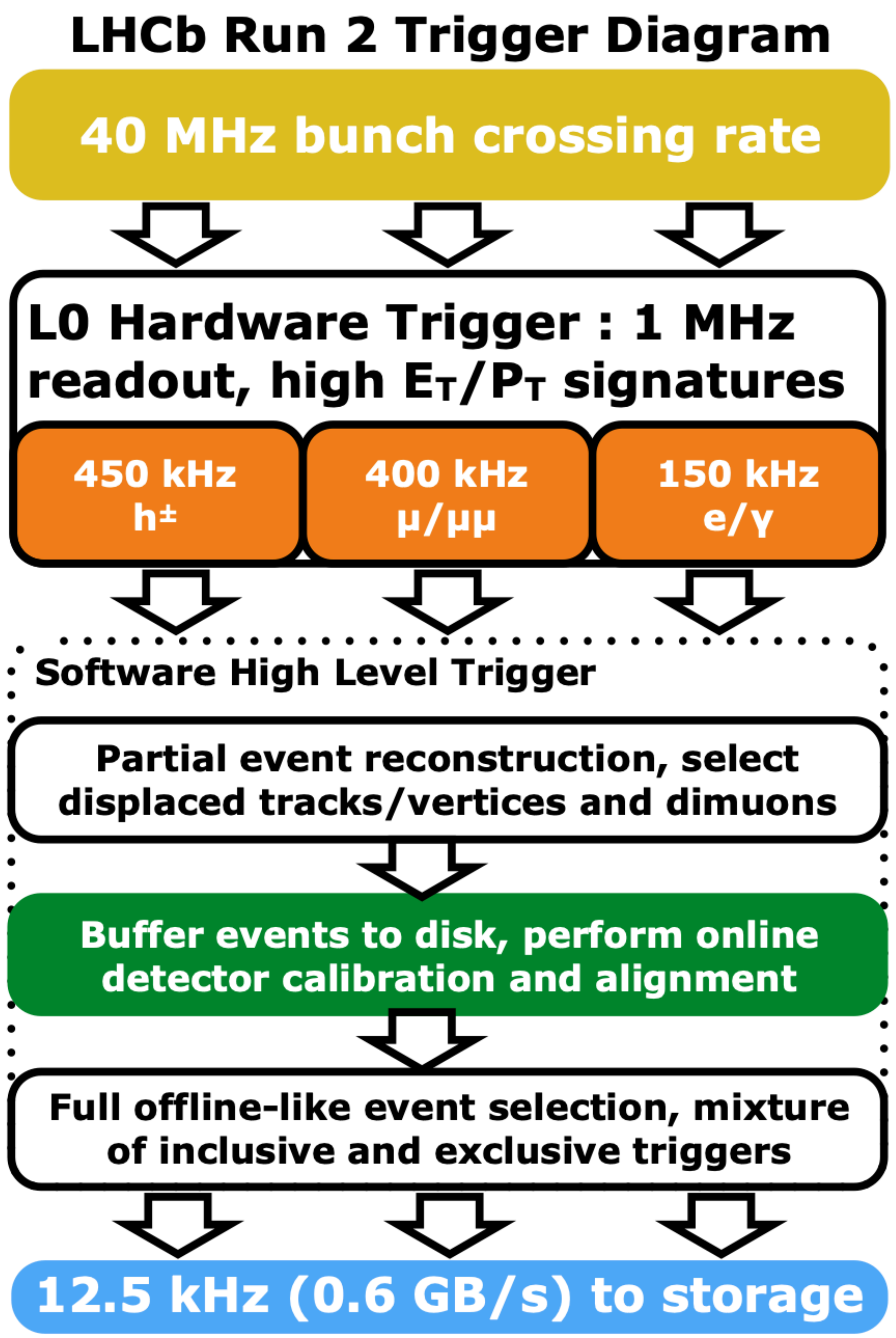
On behalf of the LHCb collaboration

Track 2, CHEP 2024, Kraków, 22nd October 2024

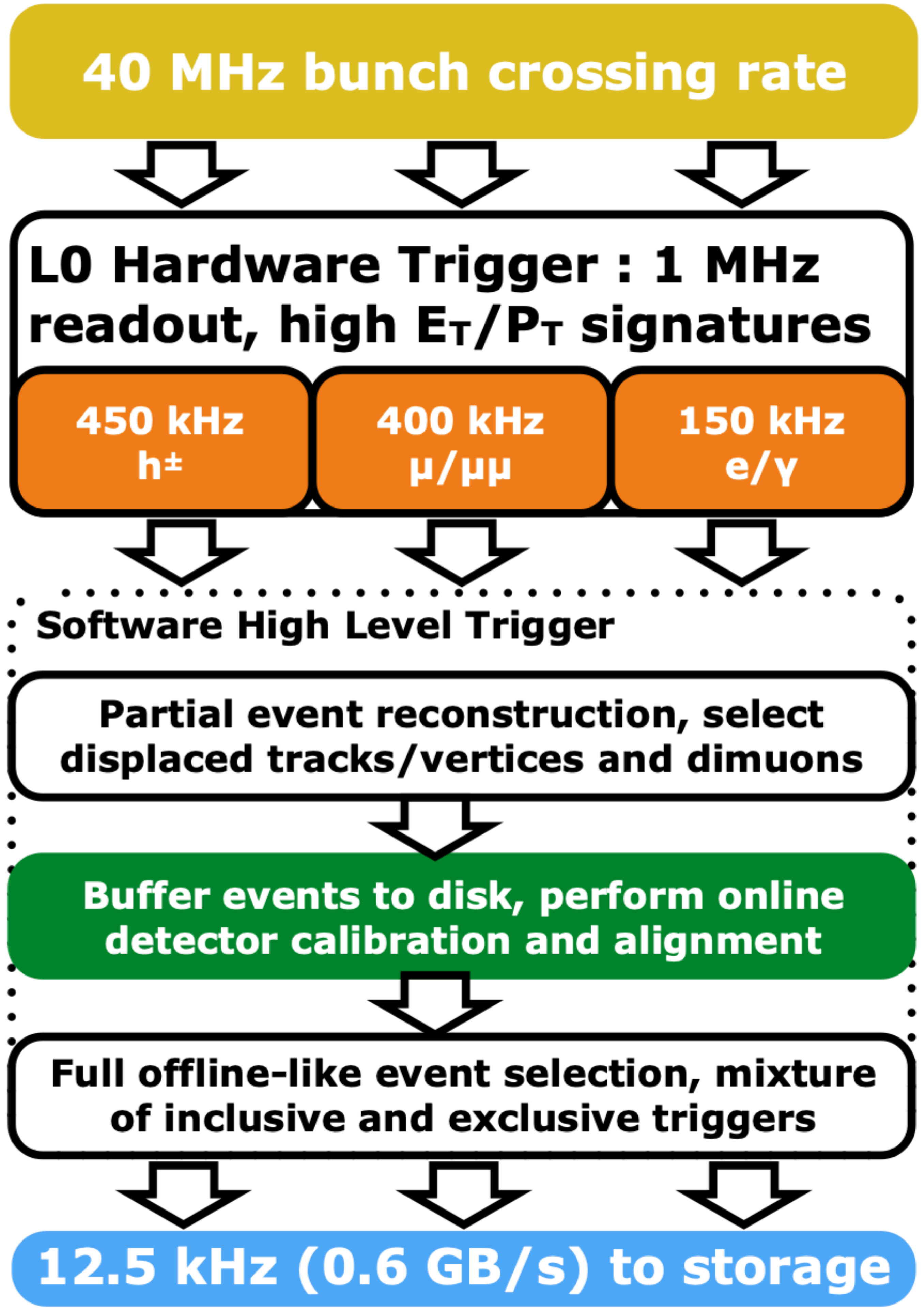
Evolution of the LHCb trigger



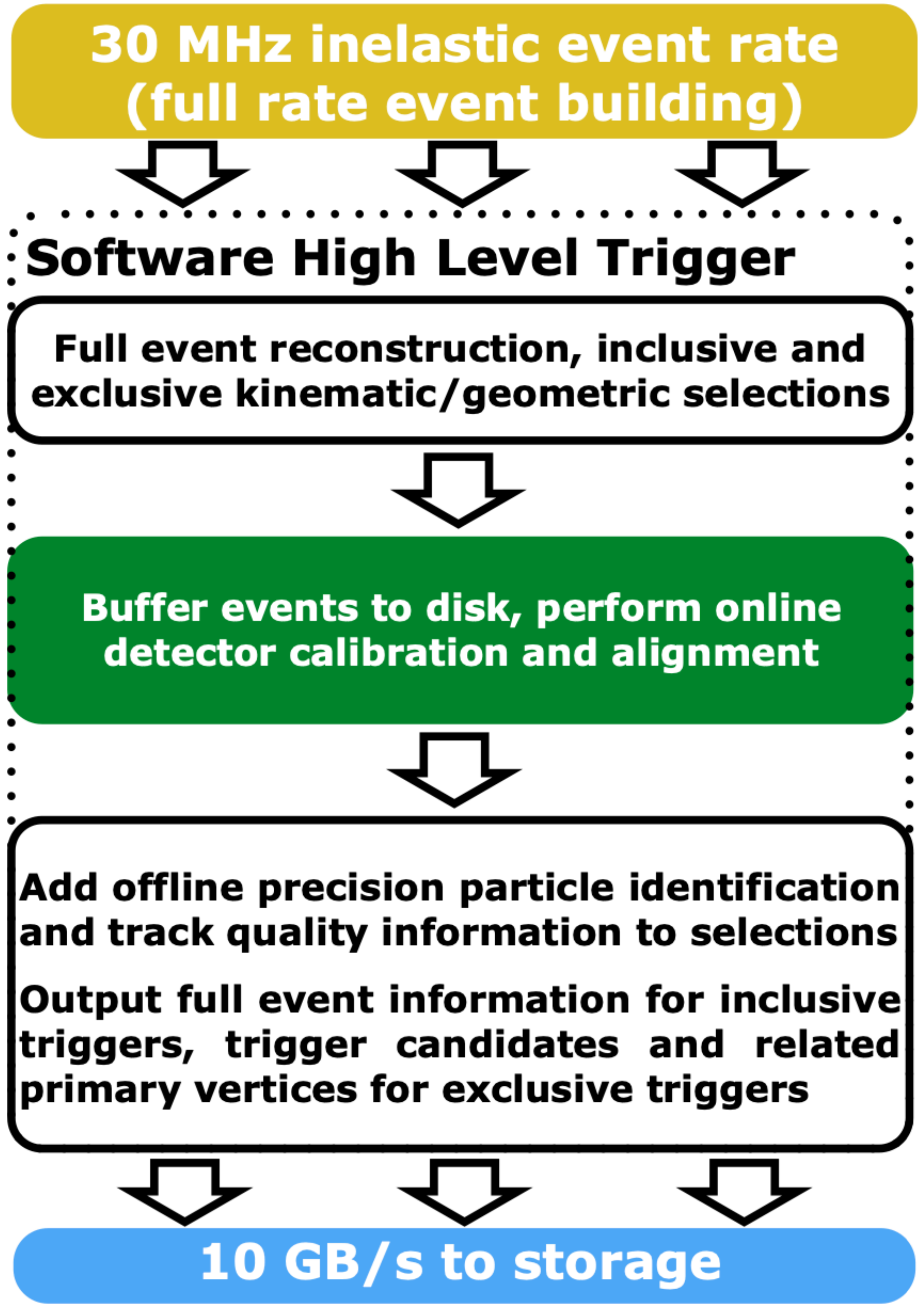
RTA and DPA dataflow diagrams for Run 1, Run 2, and the upgraded LHCb detector [LHCb-FIGURE-2020-016]

Evolution of the LHCb trigger

LHCb Run 2 Trigger Diagram



LHCb Run 3 Trigger Diagram



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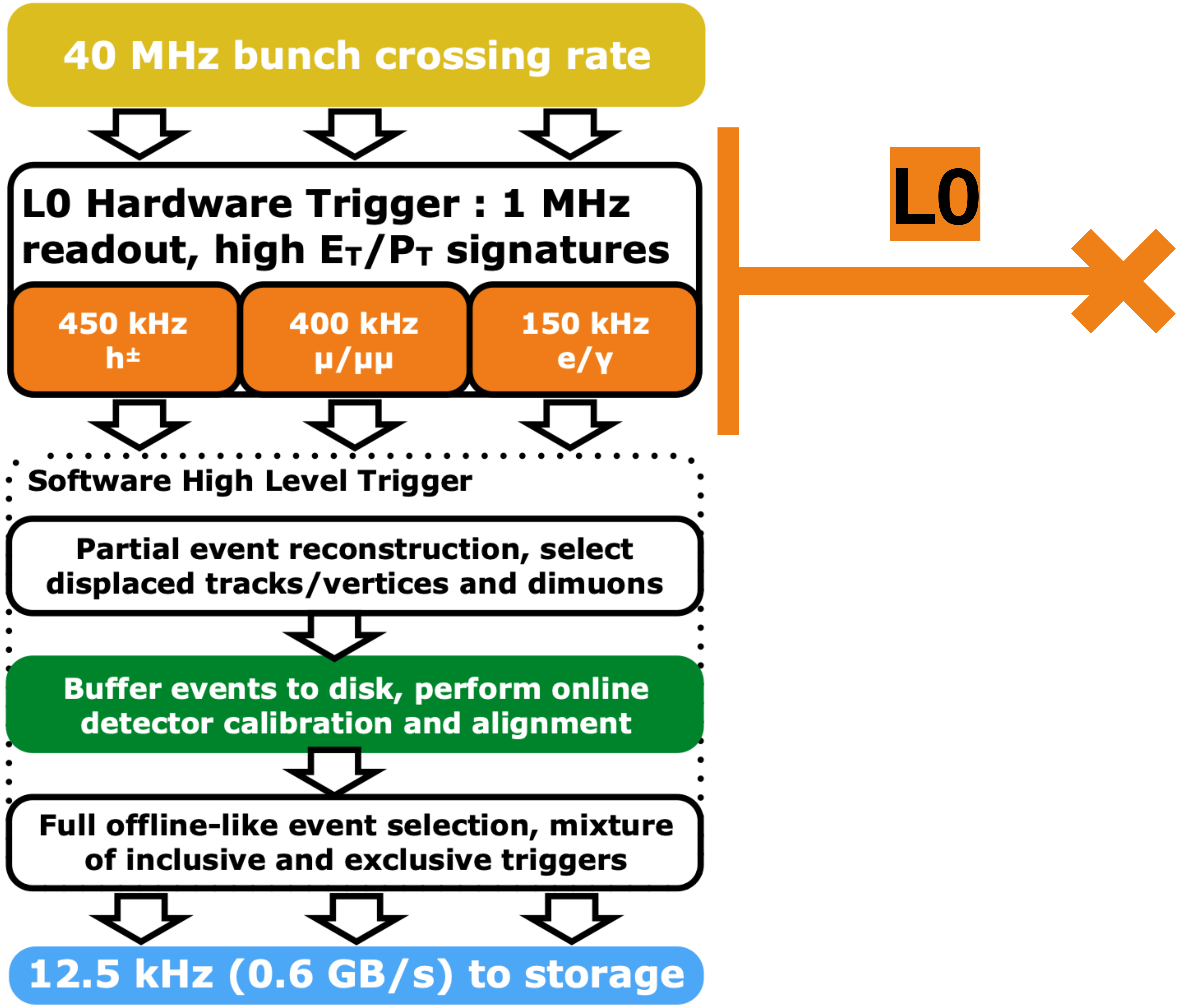
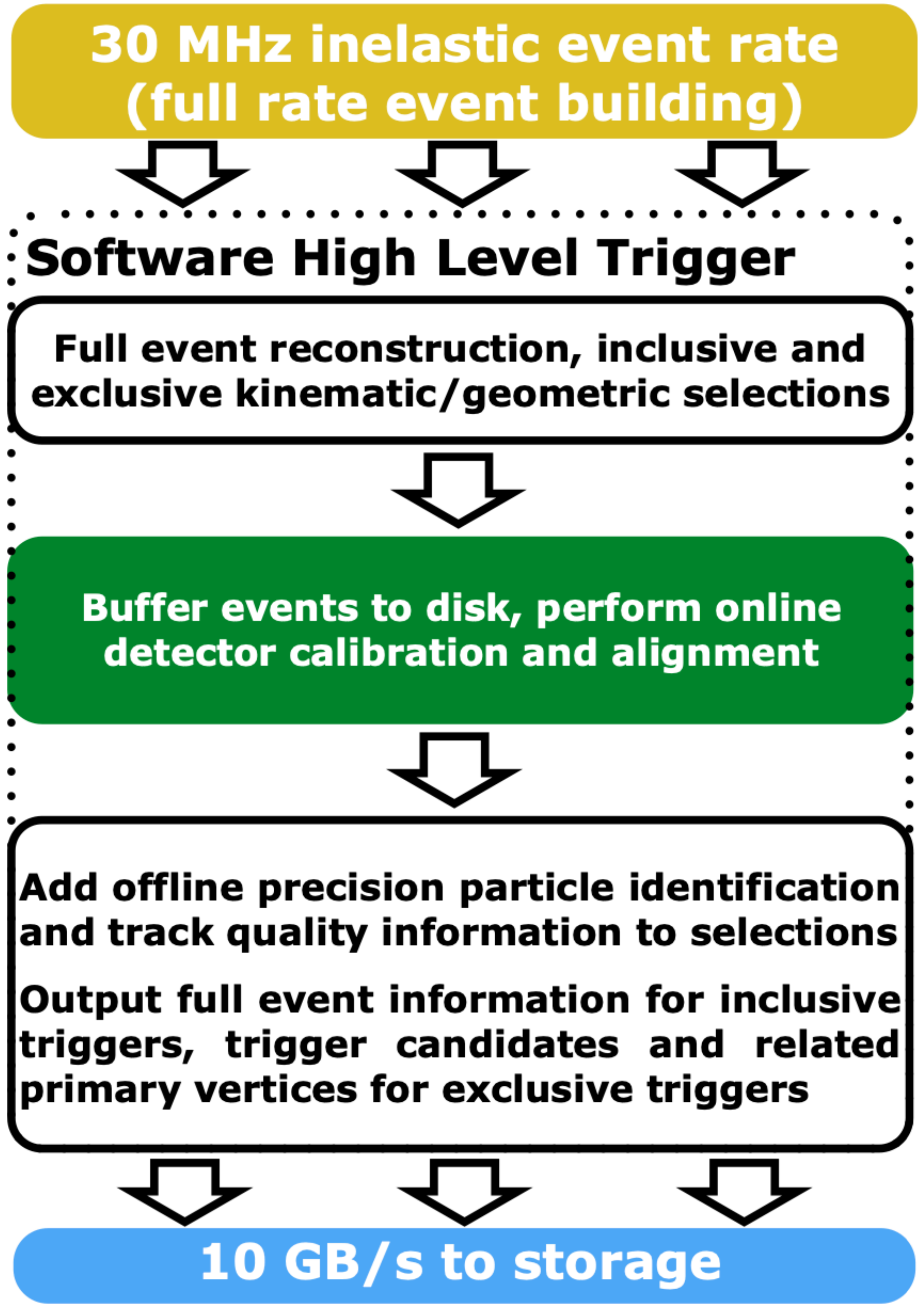


LHCb Run 3 Trigger Diagram



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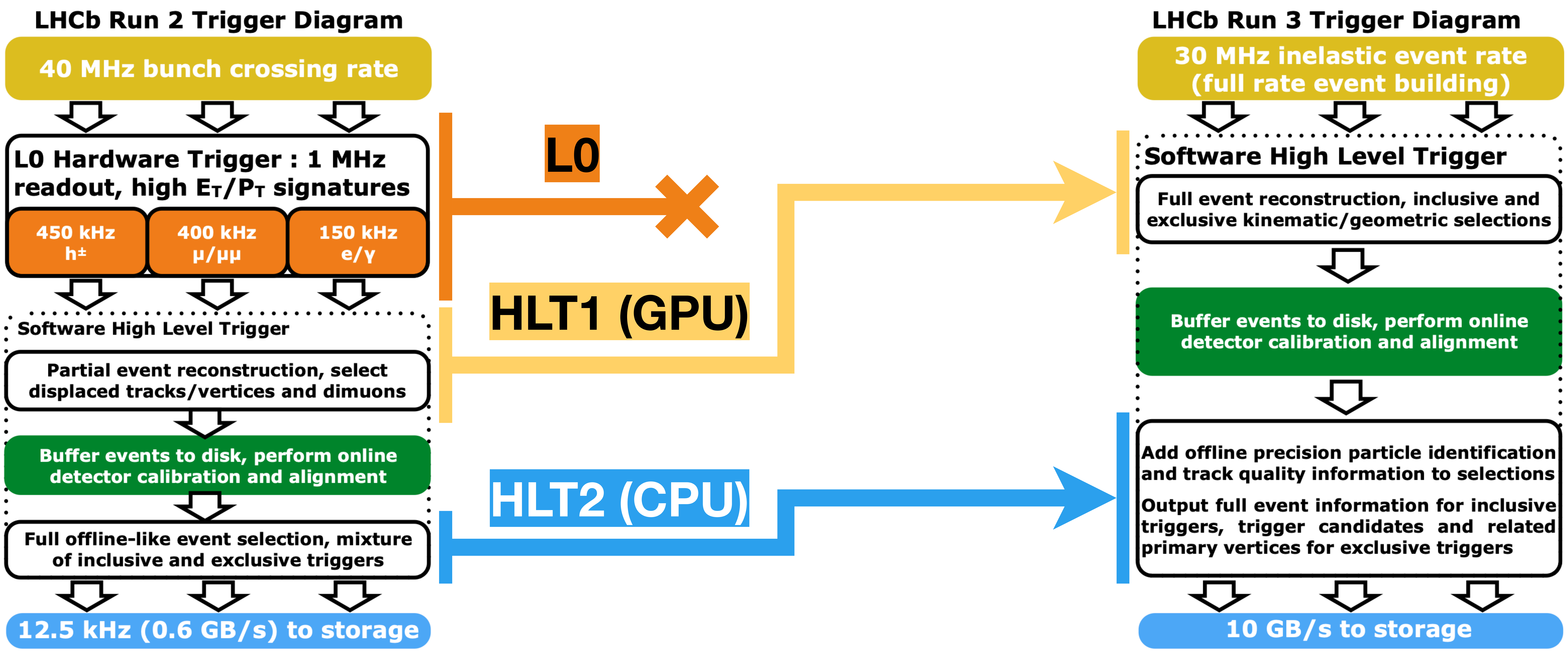
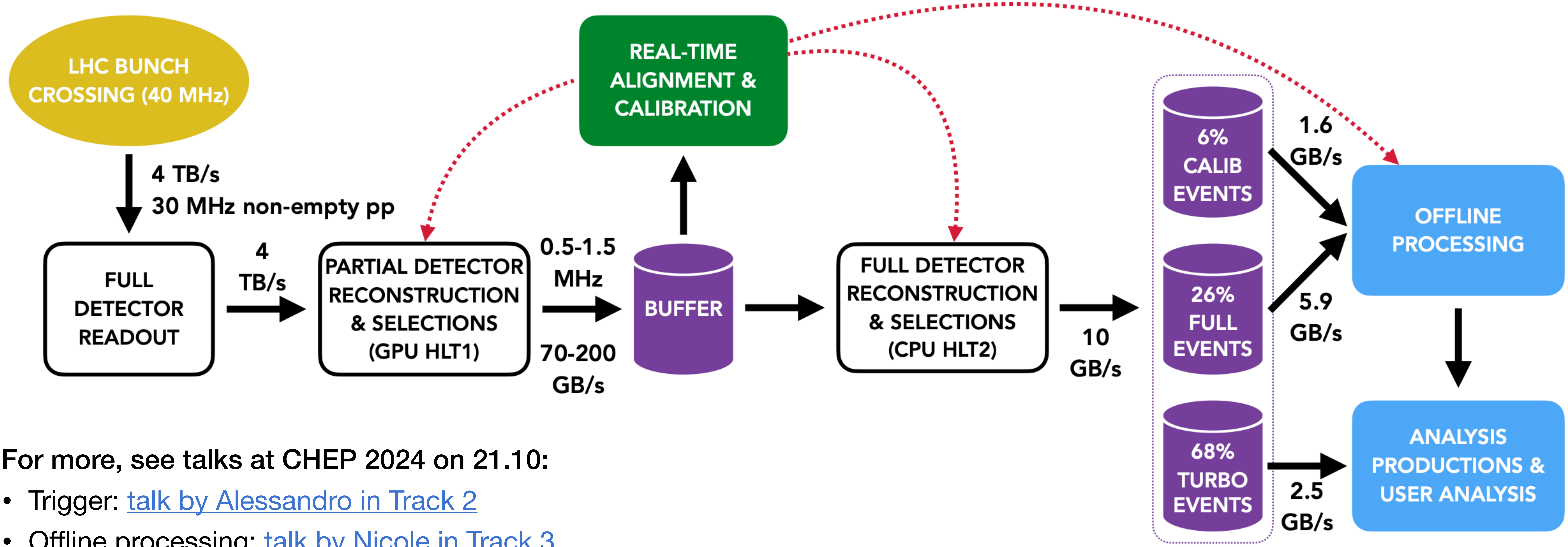


RTA and DPA dataflow diagrams for Run 1, Run 2, and the upgraded LHCb detector LHCb-FIGURE-2020-016

The LHCb Trigger in Run 3



For more, see talks at CHEP 2024 on 21.10:

- Trigger: talk by Alessandro in Track 2
- Offline processing: talk by Nicole in Track 3

RTA and DPA dataflow diagrams for Run 1, Run 2, and the upgraded LHCb detector LHCb-FIGURE-2020-016

TISTOS for trigger efficiencies

- ***In principle***, efficiencies should be as simple as $\varepsilon^{\text{True}}_{\text{Trig.}} = N_{\text{Trig.}}/N_{\text{All}}$

Data driven trigger efficiency determination at LHCb LHCb-PUB-2014-039

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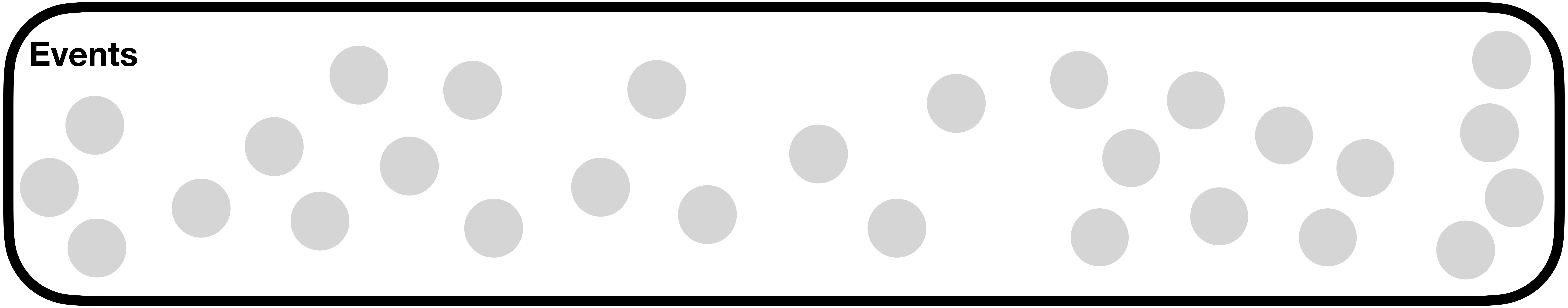
- ***In practice***, our data has no “truth” information:

  → How can we calculate a trigger efficiency? *We’ll need some categories…*



Data driven trigger efficiency determination at LHCb LHCb-PUB-2014-039

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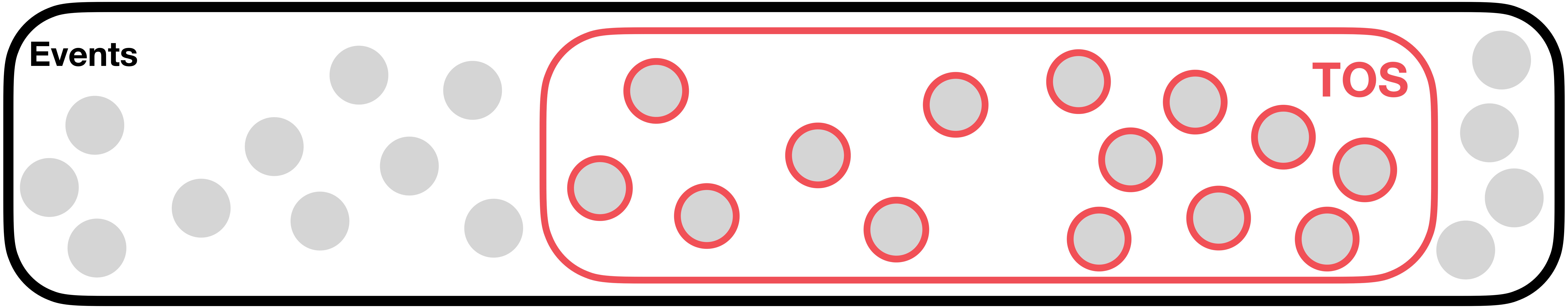

"Triggered on signal" events

70% of all hits in common with hits of signal candidate

Data driven trigger efficiency determination at LHCb [LHCb-PUB-2014-039]

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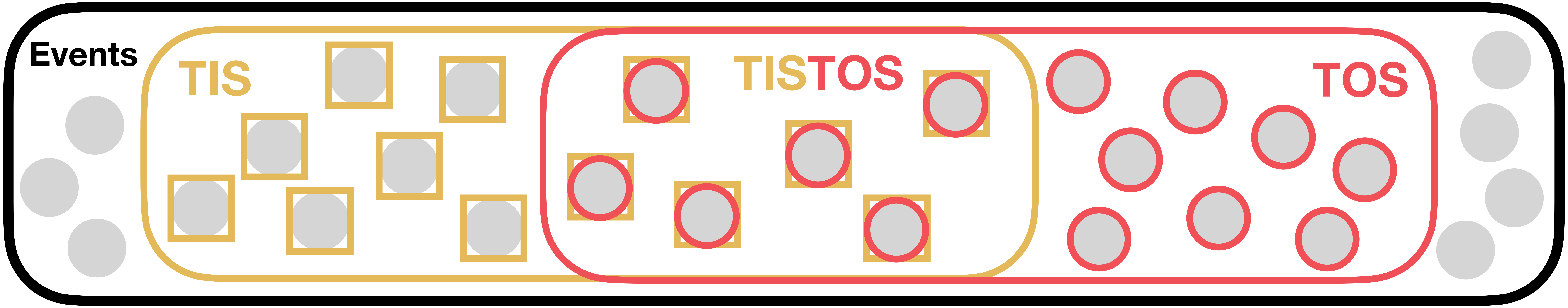


"Triggered independent of signal" events

Any candidate has < 1% of hits in common with hits of signal candidate

"Triggered on signal" events

70% of all hits in common with hits of signal candidate

Data driven trigger efficiency determination at LHCb LHCb-PUB-2014-039

TISTOS for trigger efficiencies

- From the TISTOS categories, define tag-and-probe efficiencies:

$$\varepsilon_{\text{TOS|TIS}} = \frac{N_{\text{TISTOS}}}{N_{\text{TIS}}}$$

(ε_{TOS} in the TIS subsample)

$$\varepsilon_{\text{TIS|TOS}} = \frac{N_{\text{TISTOS}}}{N_{\text{TOS}}}$$

(ε_{TIS} in the TOS subsample)

  - But these only cover the tagged subsample…

- Assuming TIS efficiency ($\varepsilon_{\text{TIS|TOS}}$) identical for any subsample ($\varepsilon_{\text{TIS}} \equiv \varepsilon_{\text{TIS|TOS}}$), define a more general trigger efficiency (across all events):

$$\varepsilon_{\text{Trig.}} = \frac{N_{\text{Trig.}}}{N_{\text{TIS}}} \frac{N_{\text{TISTOS}}}{N_{\text{TOS}}}$$

- *But does the assumption above hold?* Need to account for TIS-TOS correlation

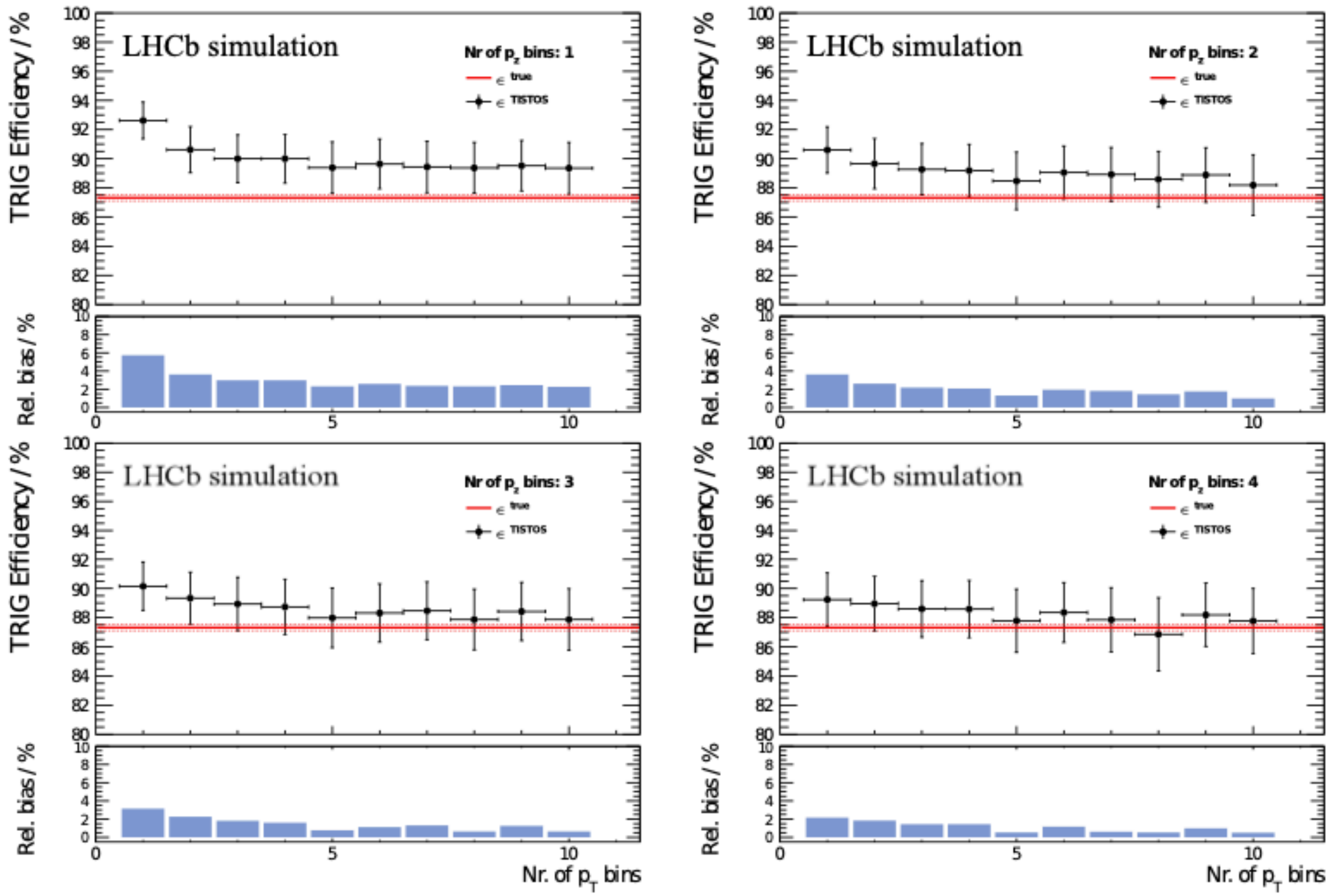
Data driven trigger efficiency determination at LHCb LHCb-PUB-2014-039

TISTOS for trigger efficiencies

- Correlation between TIS and TOS from correlation of signal and "rest of event"
- In sufficiently small phase-space (signal p_T, p_z, etc.), correlation negligible
- Integrate TIS/TOS/TISTOS terms over phase space (*see right*):

$$\varepsilon_{\text{Trig.}} = \frac{N_{\text{Trig.}}}{\sum_i \frac{N_{\text{TIS}} N_{\text{TOS}}}{N_{\text{TISTOS}}}}$$

where each i is a sufficiently small phase space bin

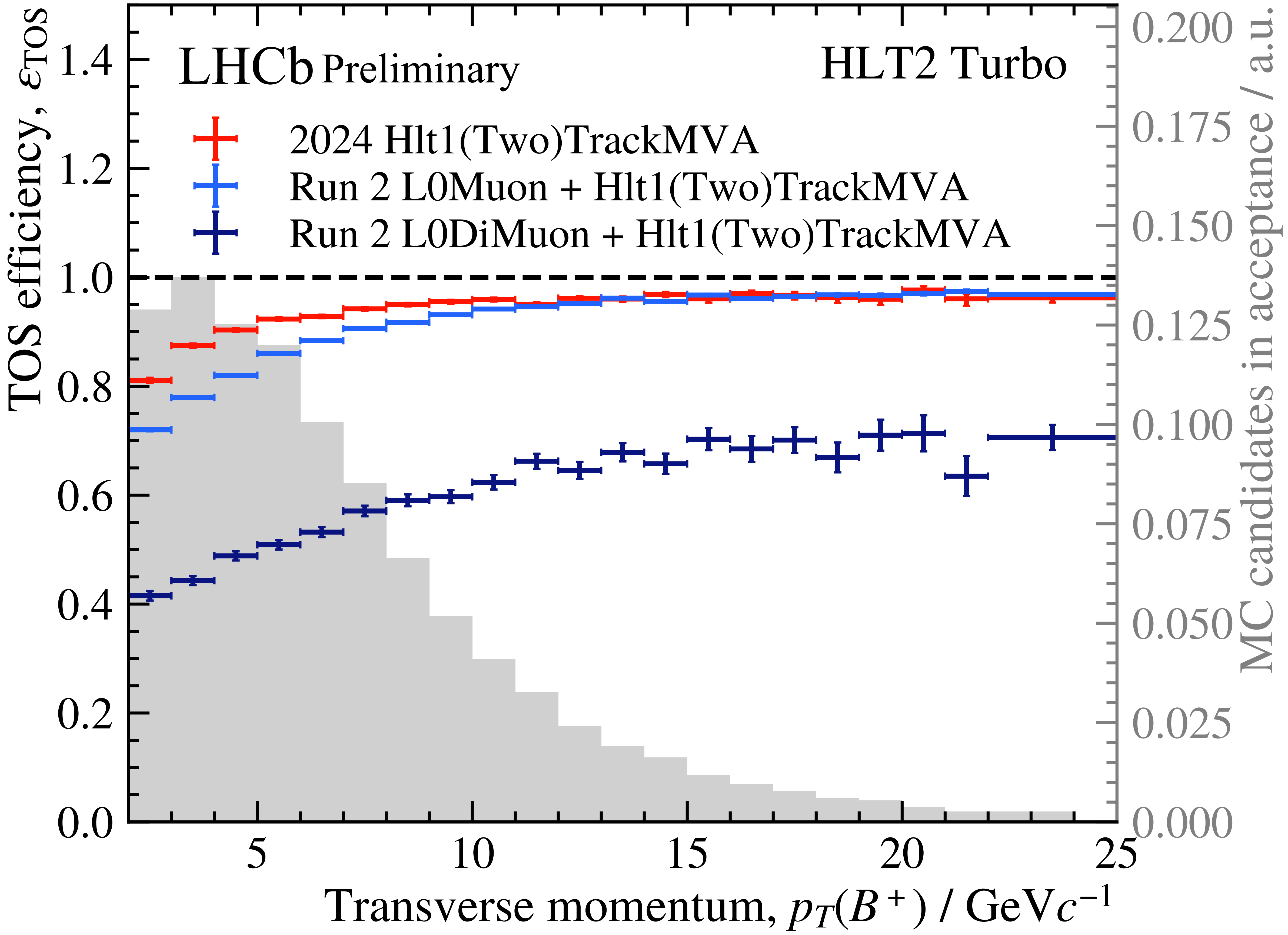


Data driven trigger efficiency determination at LHCb [LHCb-PUB-2014-039]

Trigger efficiencies in 2024

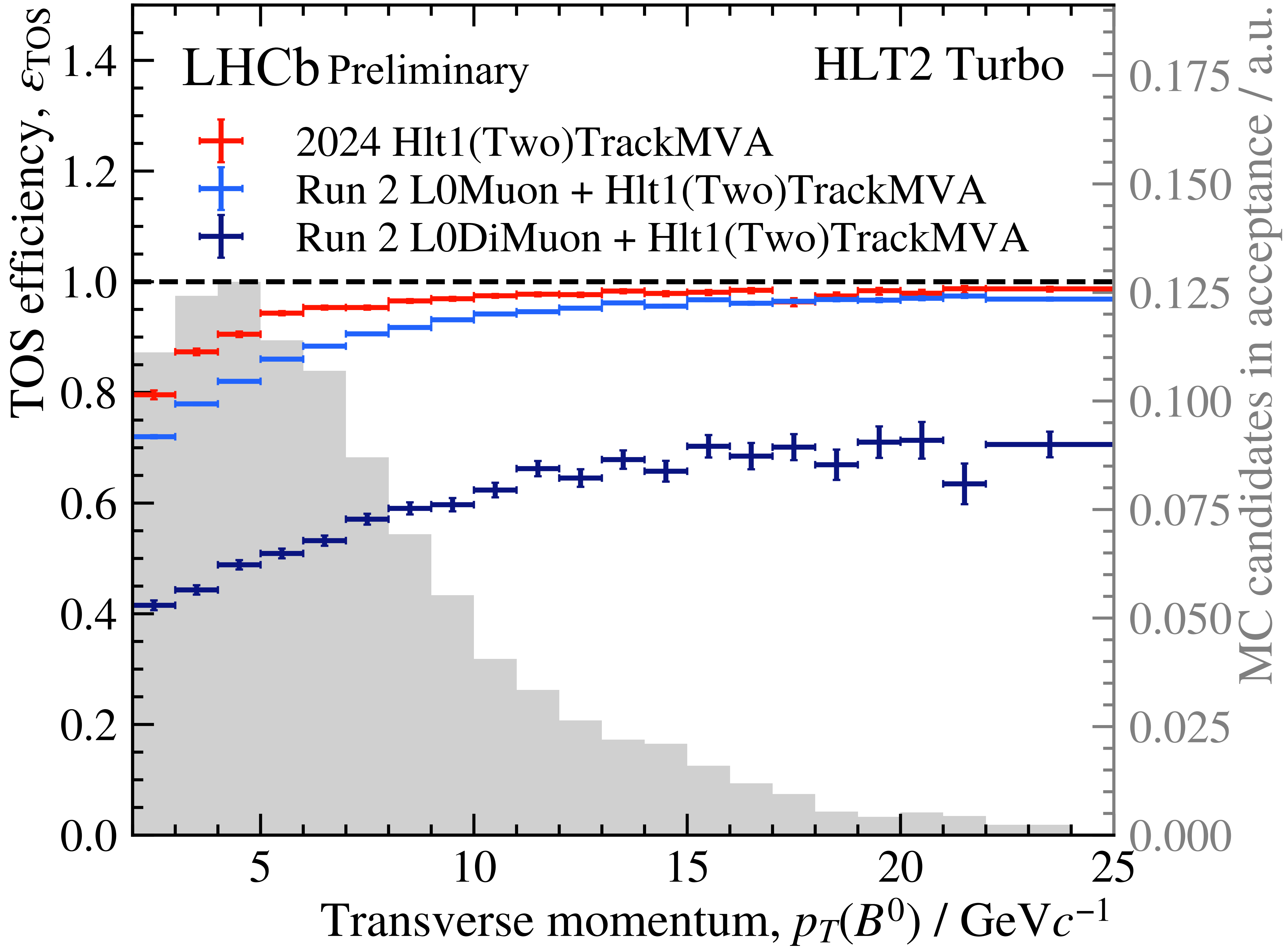
- Evaluate HLT1 efficiencies in LHCb 2024 data and compare to Run 2 L0×HLT1 efficiencies
- Consider 4 different categories of decays:
  - Dimuon b decay: $B^+ \to J/\psi\left(\mu^+\mu^-\right)K^+$ and $B^0 \to J/\psi\left(\mu^+\mu^-\right)K^{*0}\left(K^+\pi^-\right)$
  - Dielectron b decay: $B^+ \to J/\psi\left(e^+e^-\right)K^+$ and $B^0 \to J/\psi\left(e^+e^-\right)K^{*0}\left(K^+\pi^-\right)$
  - Hadronic b decay: $B^+ \to \overline{D}^0\left(K^+\pi^-\right)\pi^+$ and $B^0 \to D^-\left(K^+\pi^-\pi^-\right)\pi^+$
  - Hadronic c decay: $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$
- 2024 efficiencies calculated in bins of top-level composite p_T
- Run 2 efficiencies sourced from Run 2 trigger performance paper, JINST 14 (2019) P04013
  - L0 trigger lines chosen based on category, e.g., `L0Hadron` for hadronic decays

Dimuon b decays



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

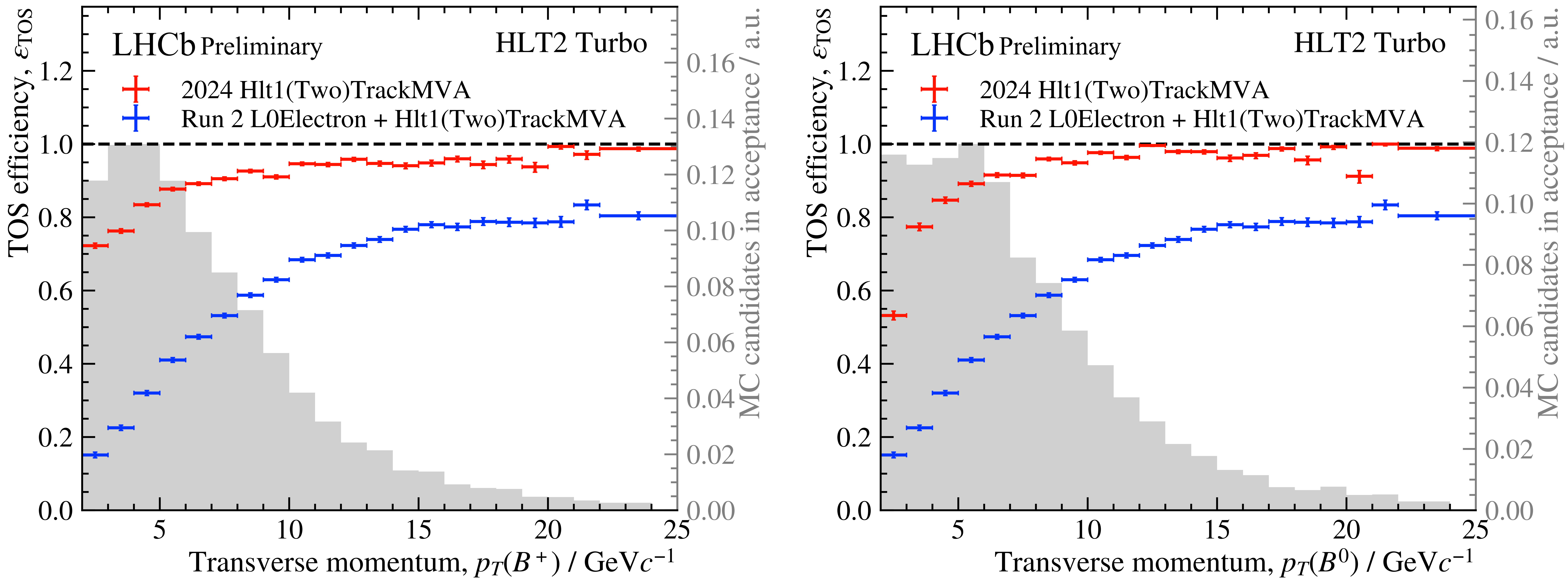
(Run 2 efficiencies in $B^0 \to J/\psi\left(\mu^+\mu^-\right)K^{*0}\left(K^+\pi^-\right)$)



$$B^0 \to J/\psi\left(\mu^+\mu^-\right)K^{*0}\left(K^+\pi^-\right)$$

HLT1 trigger efficiencies in 2024 data [LHCb-FIGURE-2024-030]

Dielectron *b* decays



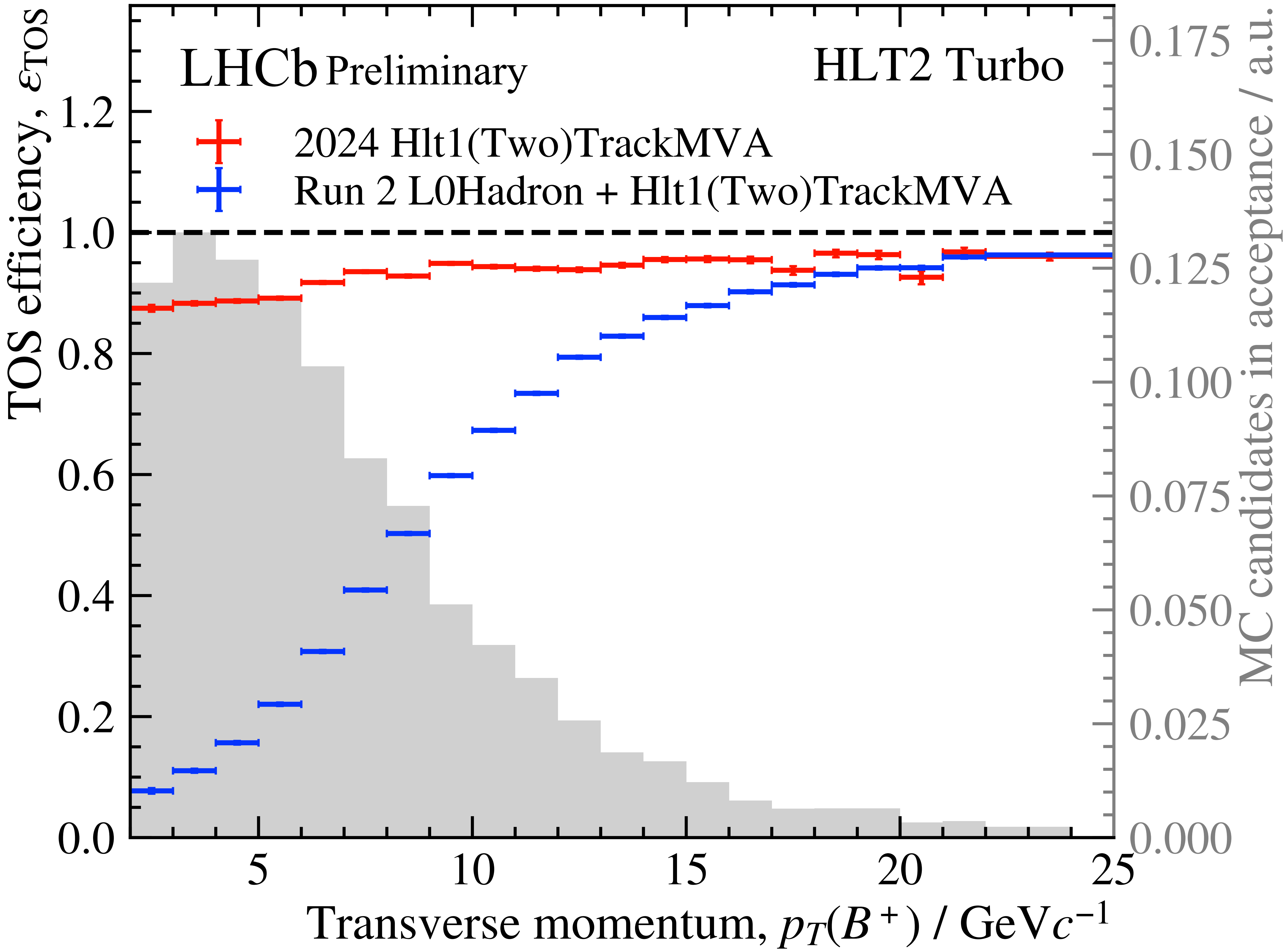
$B^+ \to J/\psi\left(e^+e^-\right) K^+$

$B^0 \to J/\psi\left(e^+e^-\right) K^{*0}\left(K^+\pi^-\right)$

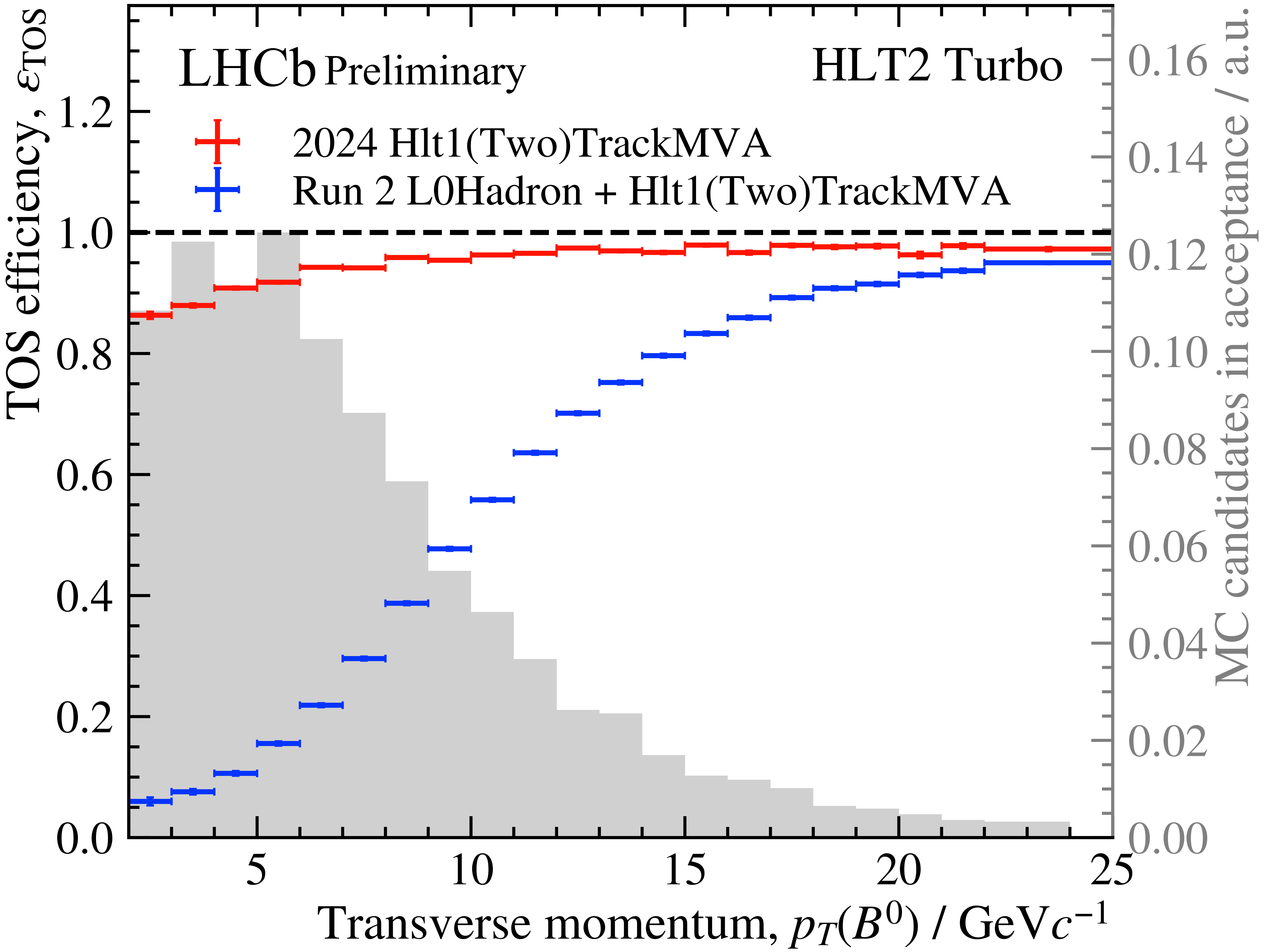
(Run 2 efficiencies in $B^0 \to J/\psi\left(e^+e^-\right) K^{*0}\left(K^+\pi^-\right)$)

HLT1 trigger efficiencies in 2024 data [LHCb-FIGURE-2024-030]

Hadronic b decays



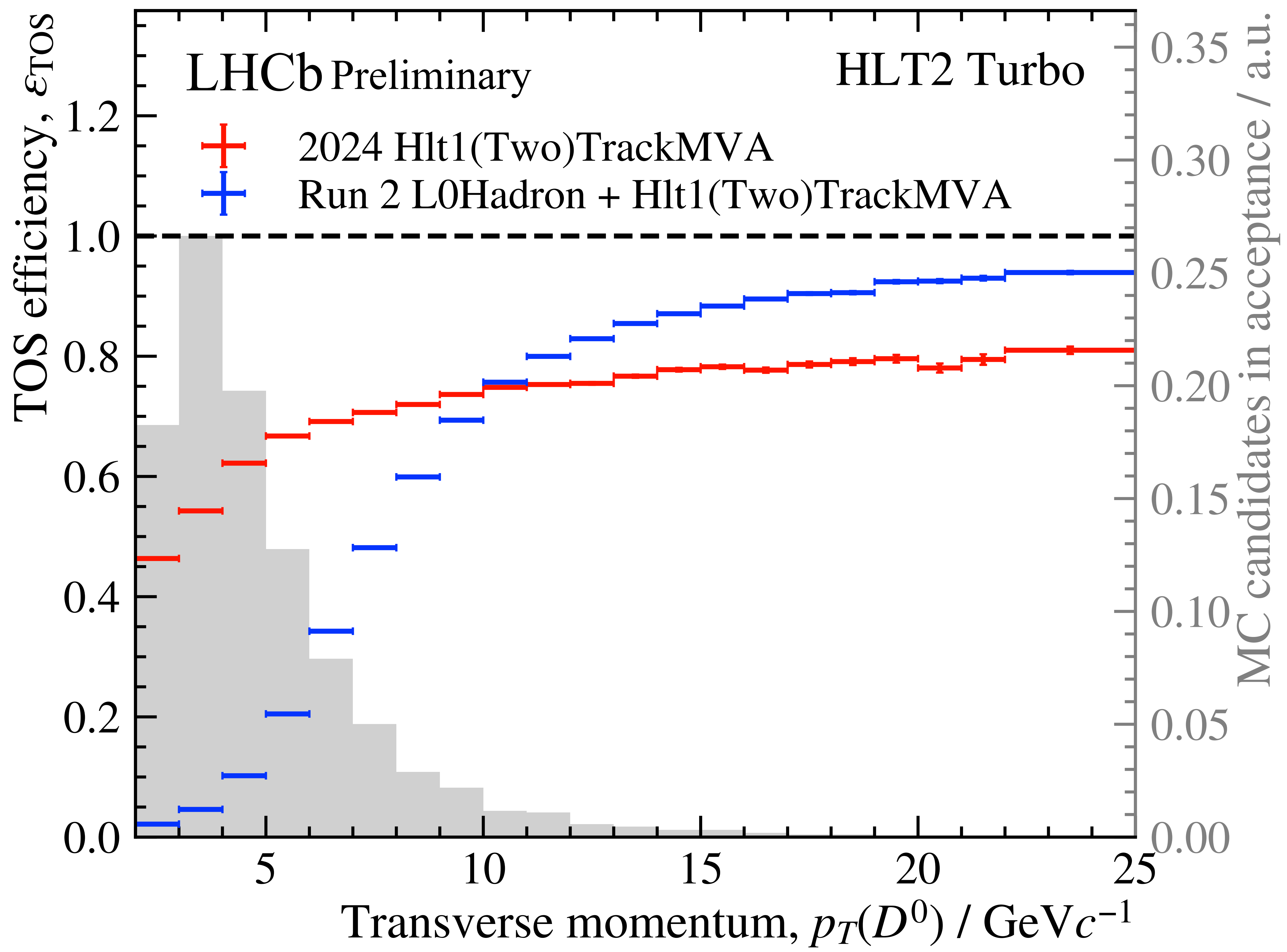
$B^+ \to \overline{D}^0 \left(K^+\pi^-\right) \pi^+$



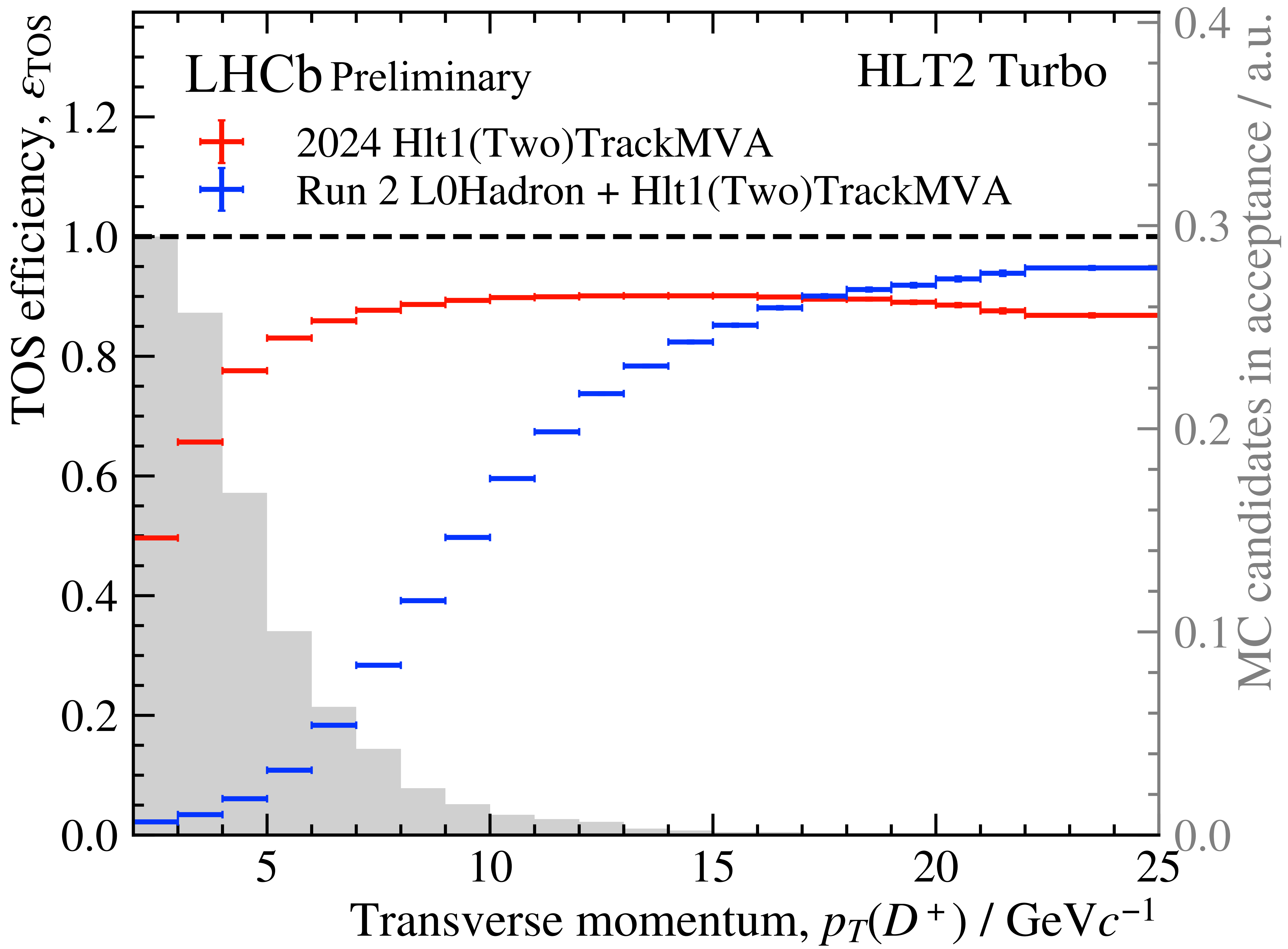
$B^0 \to D^- \left(K^+\pi^-\pi^-\right) \pi^+$

HLT1 trigger efficiencies in 2024 data [LHCb-FIGURE-2024-030]

Hadronic c decays



$D^0 \to K^-\pi^+$ (tagged from $D^{*+} \to D^0\pi^+$)

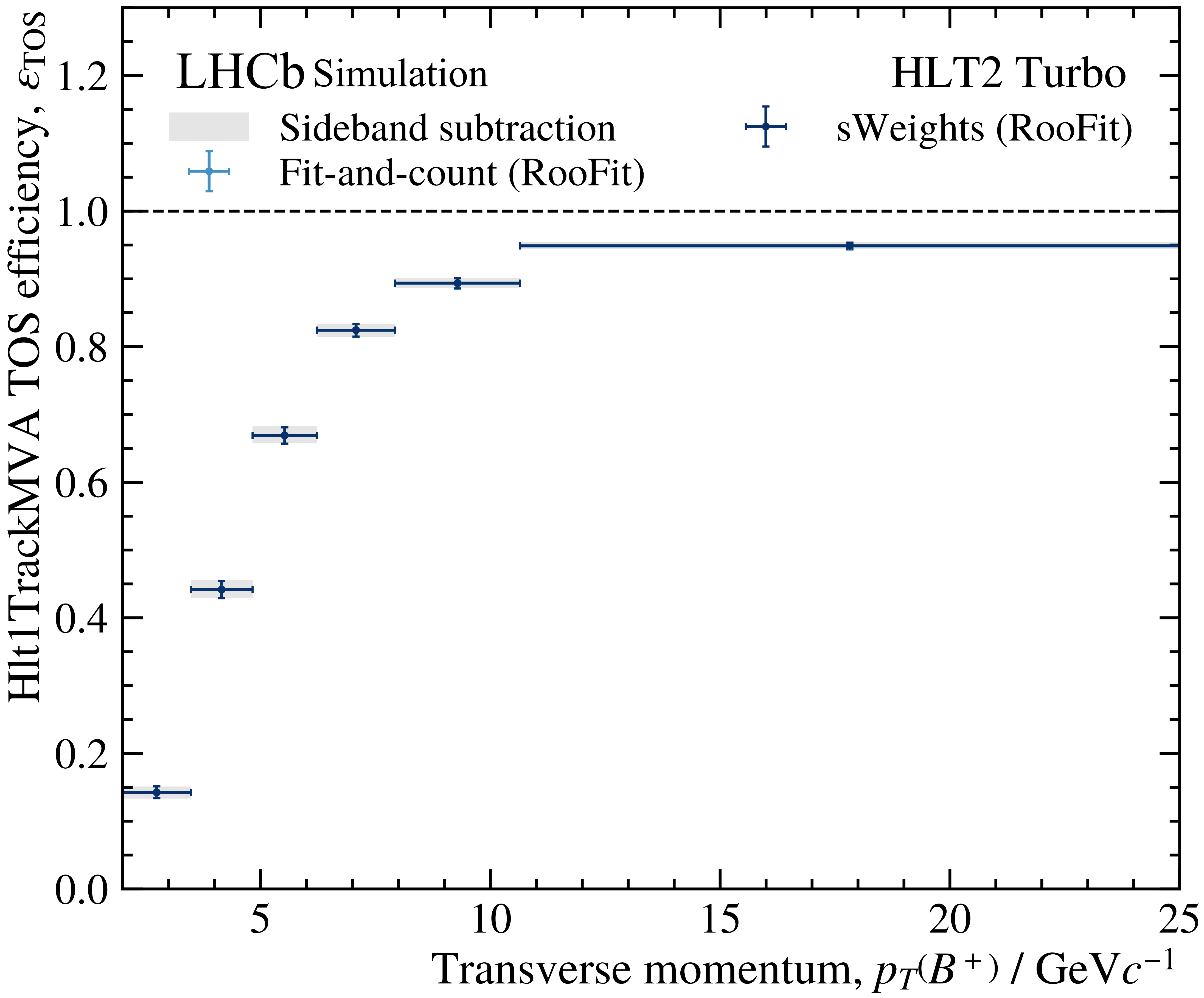


$D^+ \to K^-\pi^+\pi^+$

HLT1 trigger efficiencies in 2024 data [LHCb-FIGURE-2024-030]

TriggerCalib

- Previously, calculations implemented in each analysis; developed tool to centralise this
- TriggerCalib calculates $\varepsilon_{\text{TOS|TIS}}$, $\varepsilon_{\text{TIS|TOS}}$, $\varepsilon_{\text{Trig.}}$
  - PyPI package: `pip install triggercalib`
  - Efficiencies calculated in 1D or 2D binning
  - Signal isolated by sideband subtraction/fit-and-count (fit in each bin)/*sWeights* (*see right*)
  - Support for fitting with both `RooFit` and `zFit`
  - Intended for Run 3, applicable to Runs 1 & 2
- Tool is analysis ready, with first users already implementing into analysis workflows



Conclusion

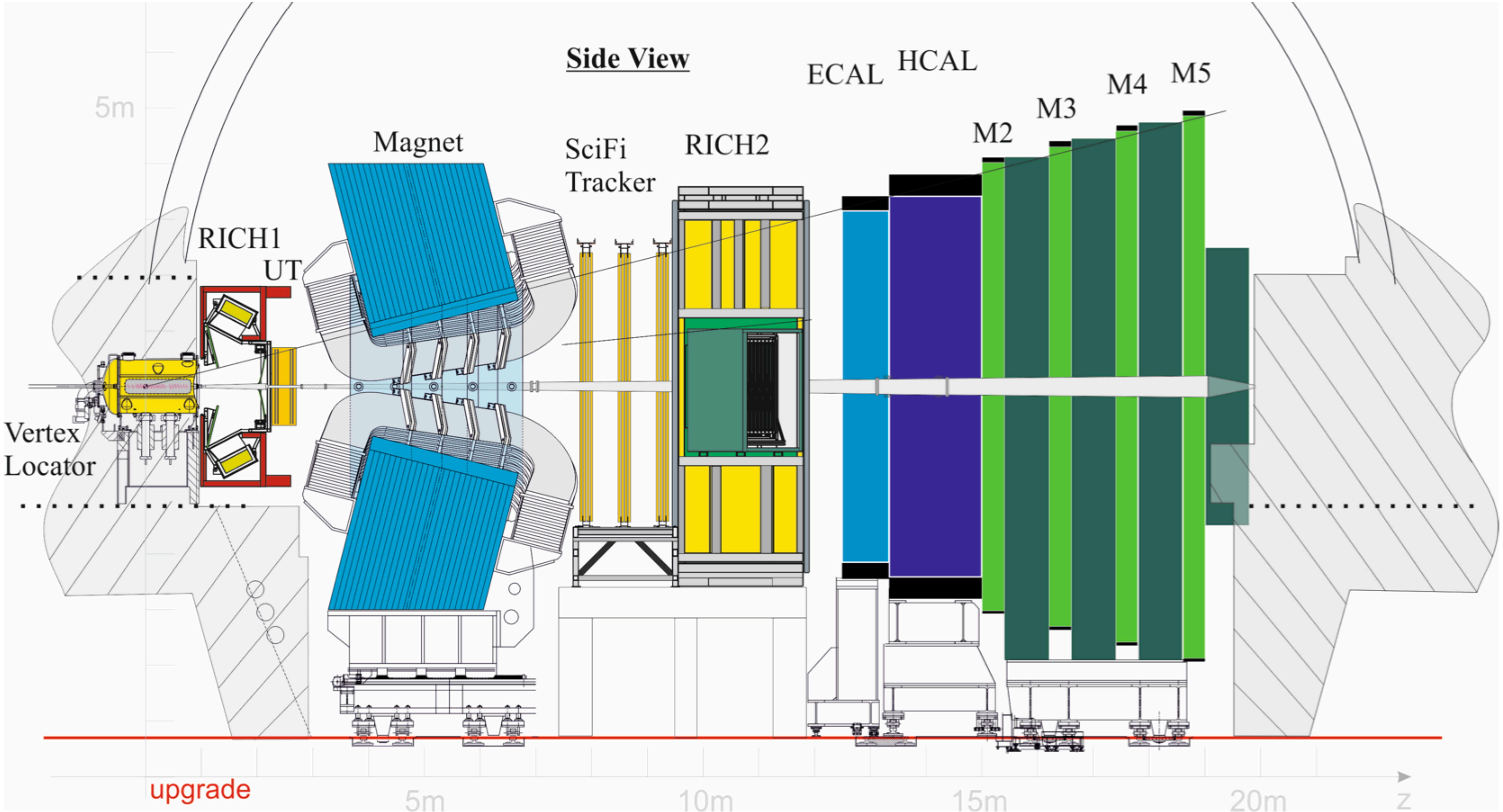
- TISTOS method provides data-driven approach to trigger efficiency calculations
  - Successfully validated on Run 3 MC simulation
- HLT1 efficiencies in 2024 data demonstrate significant improvement against Run 2 through removal of L0 (LHCb-FIGURE-2024-030)
  - Notable gains at low p_T in hadronic and dielectron decays → plenty of physics for Run 3
- TriggerCalib developed as a one-stop-shop for TISTOS calculations
  - Under development, though ready for analysis and already being adopted within LHCb

Thank you for your attention

Any questions?

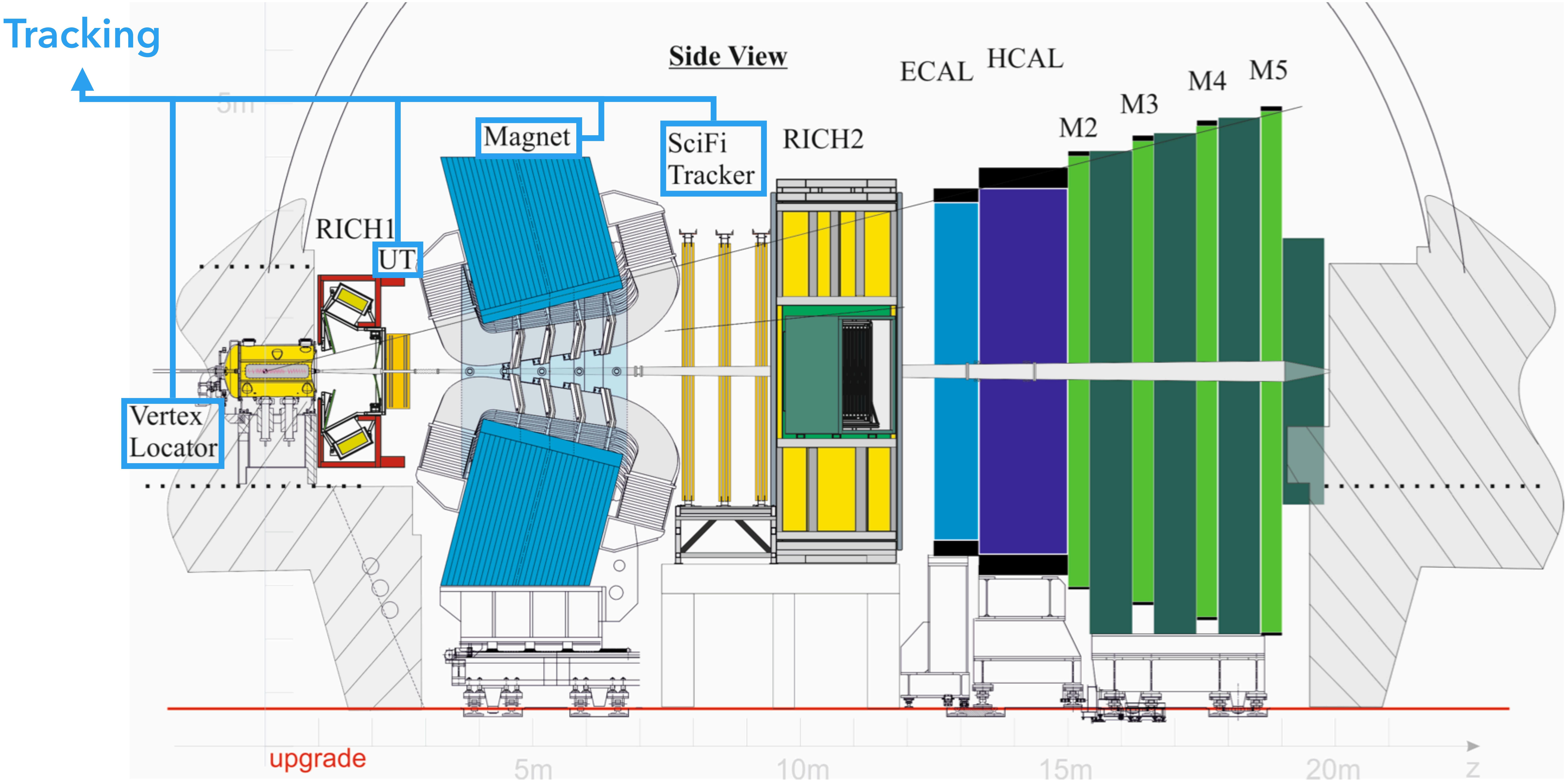
Backup

The LHCb experiment in Run 3



Framework TDR for the LHCb Upgrade [LHCb-TDR-12]

The LHCb experiment in Run 3



Framework TDR for the LHCb Upgrade [LHCb-TDR-12]

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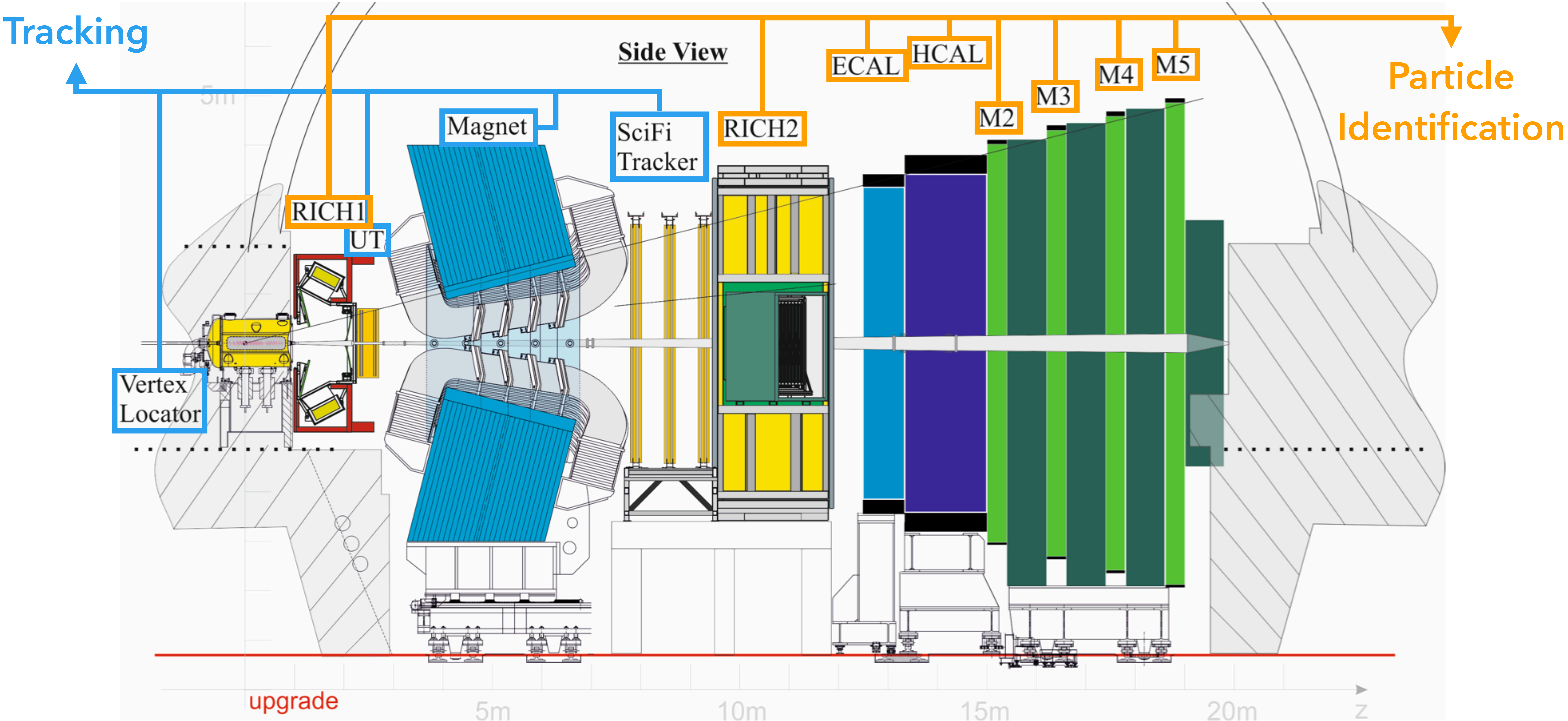
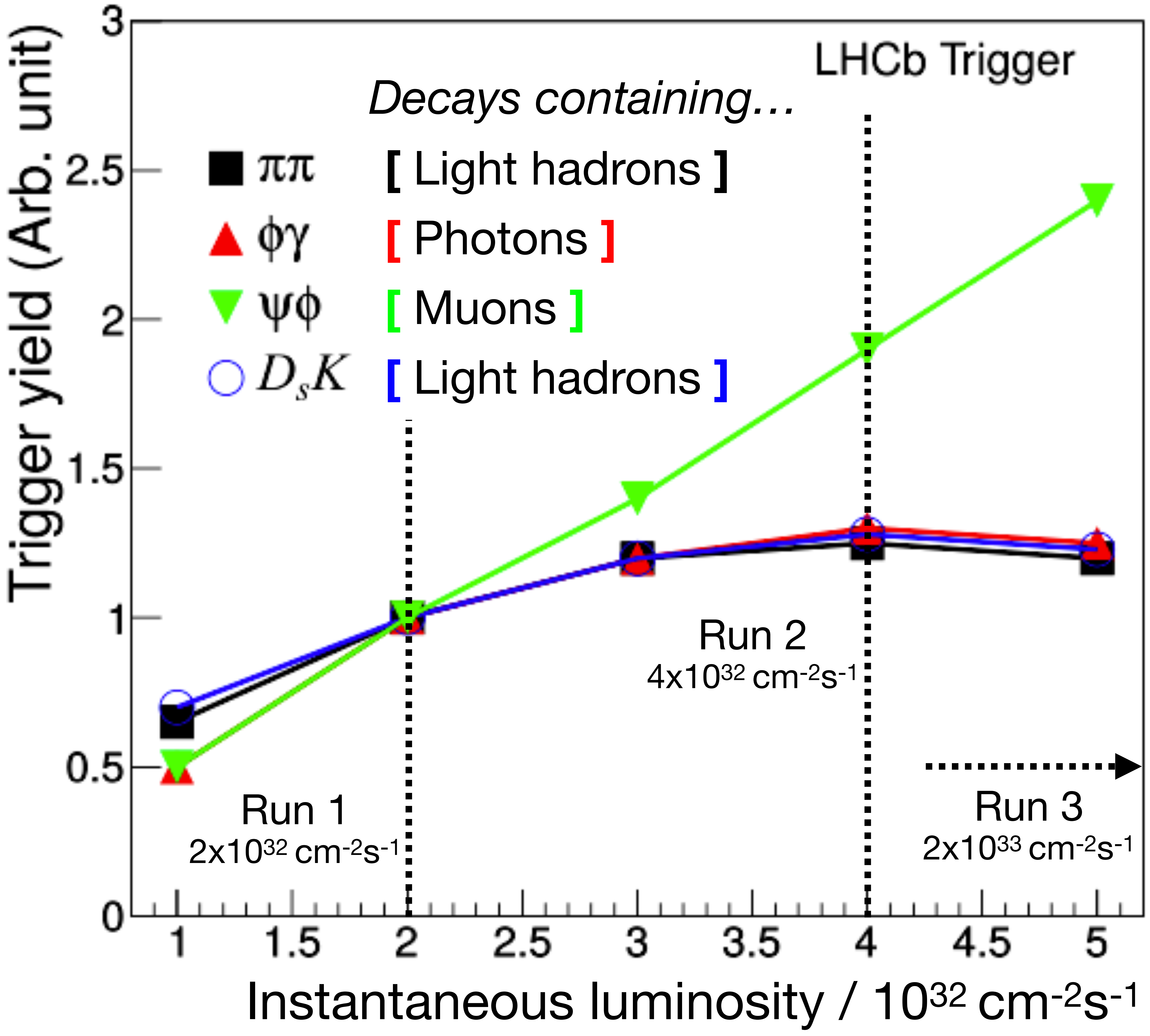


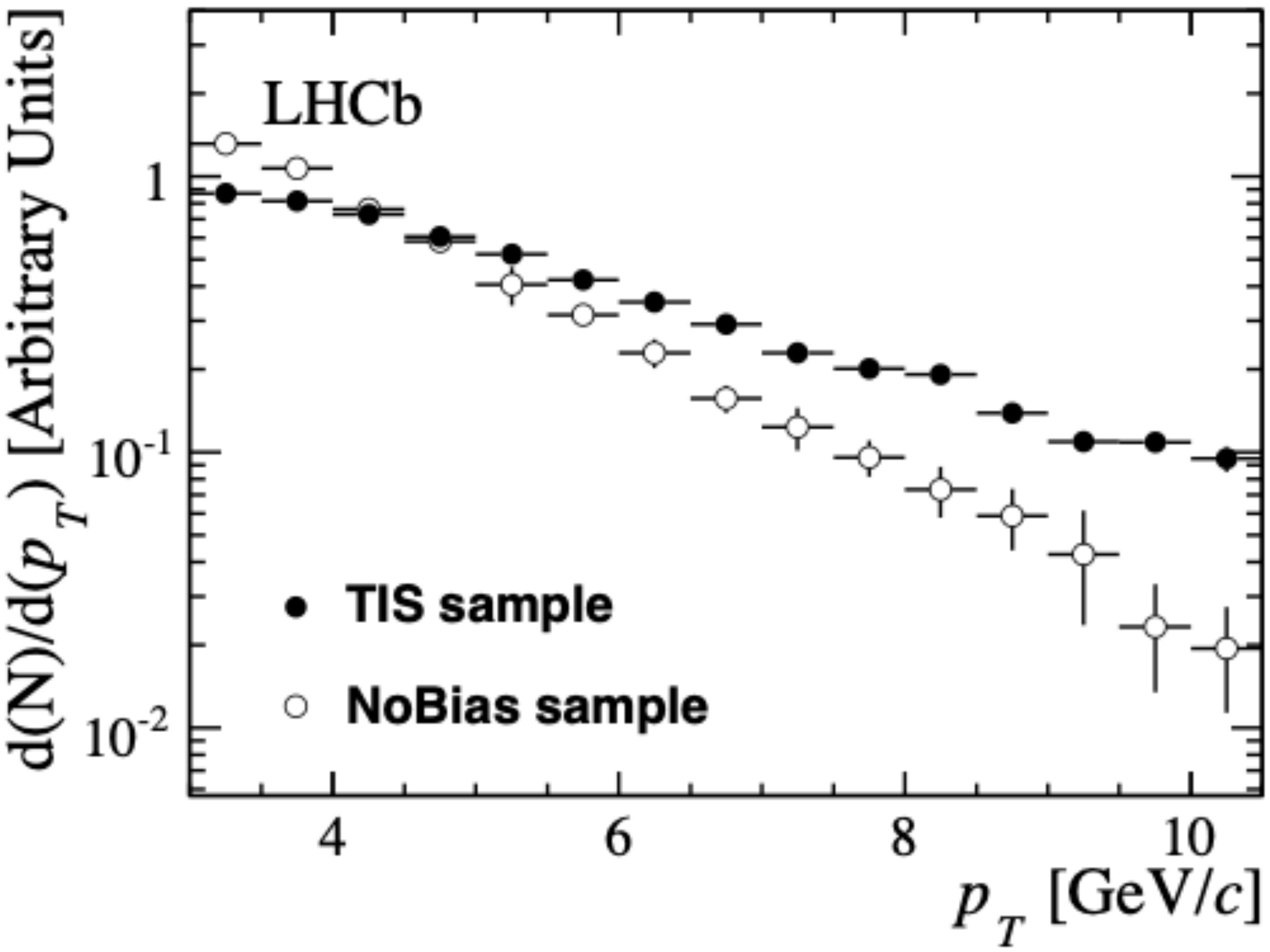
Framework TDR for the LHCb Upgrade [LHCb-TDR-12]

Why remove the L0 trigger?



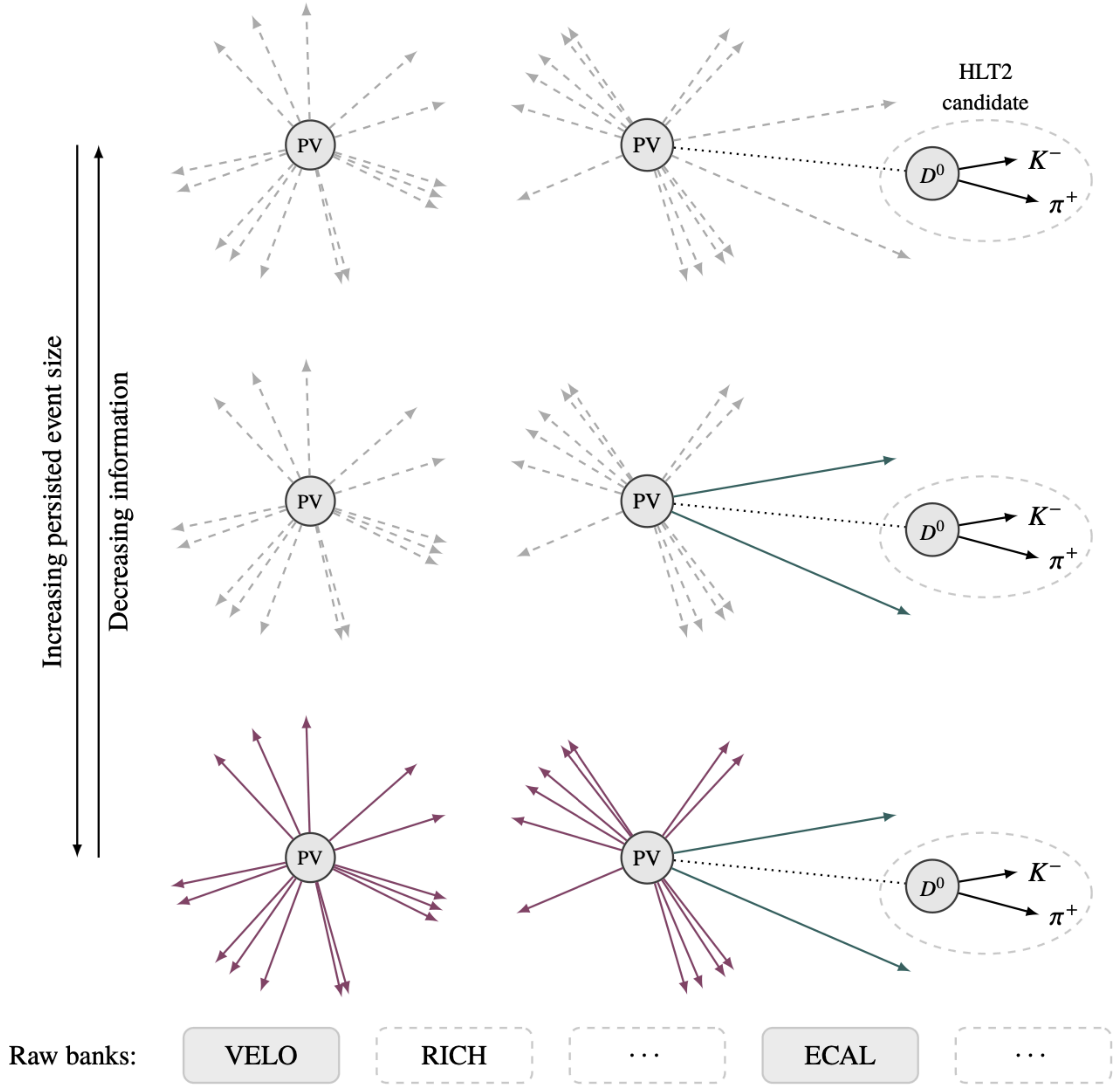
The LHCb Upgrade J. Phys. Conf. 878 (2017) 012012

TIS phase-space dependence



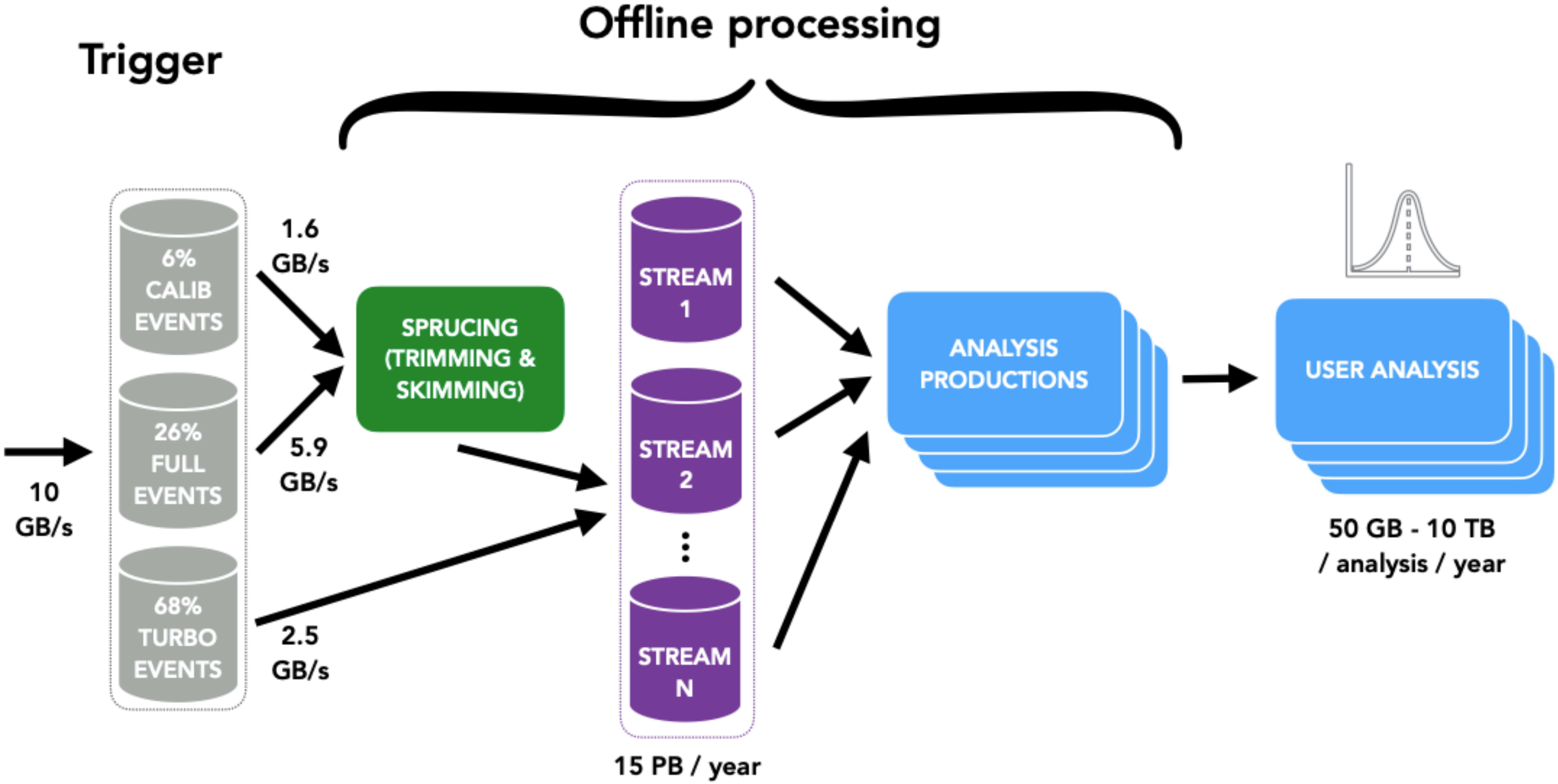
The LHCb trigger and its performance in 2011 JINST 8 (2013) P04022

The LHCb Turbo event model



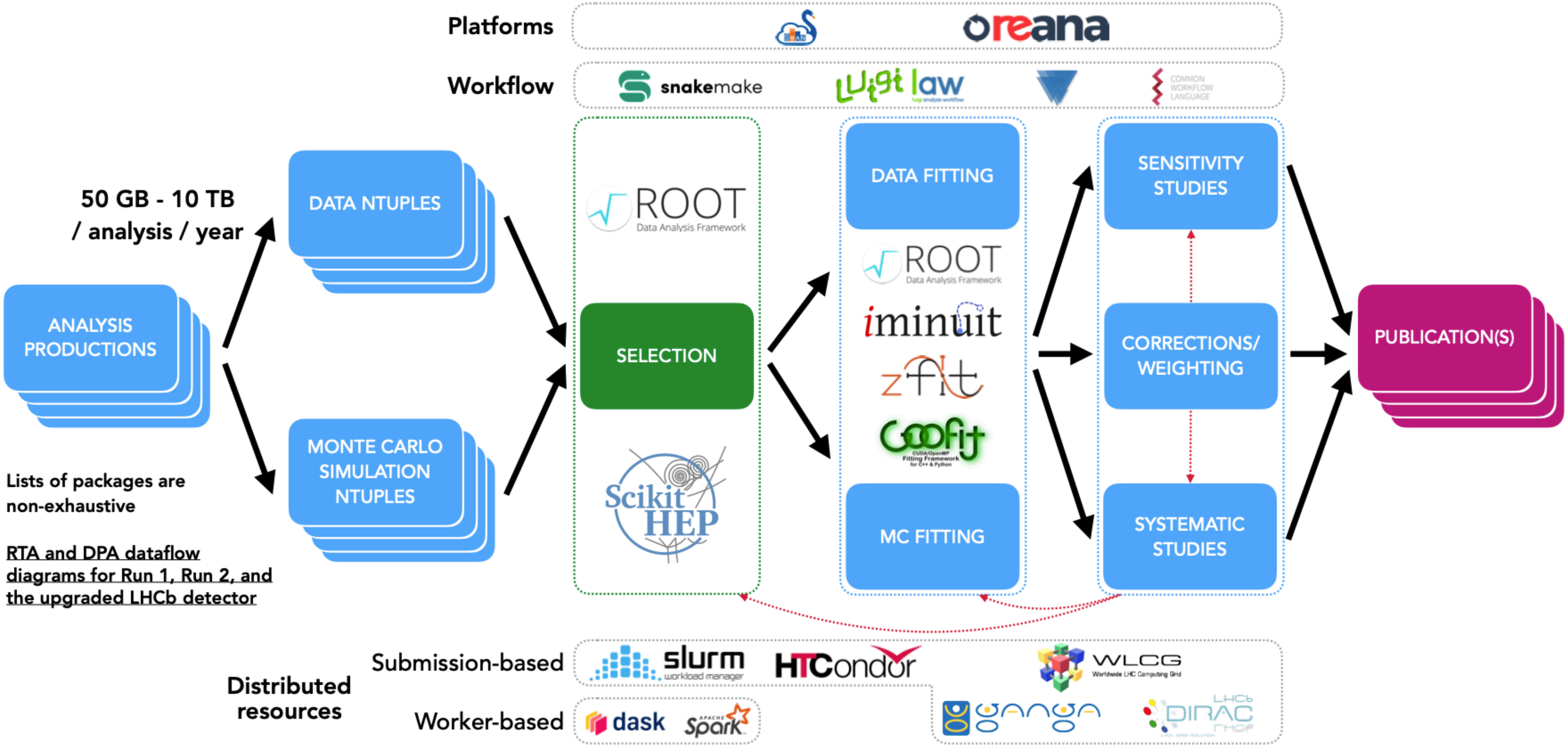
A comprehensive real-time analysis model at the LHCb experiment [JINST 14 (2019) P04006]

Offline data processing at LHCb



RTA and DPA dataflow diagrams for Run 1, Run 2, and the upgraded LHCb detector LHCb-FIGURE-2020-016

LHCb user analysis



Dataflow diagrams for LHCb user analysis in Run 3 LHCb-FIGURE-2024-002