Minimising event size, maximising physics: ML-based track isolation for LHCb's Run 3

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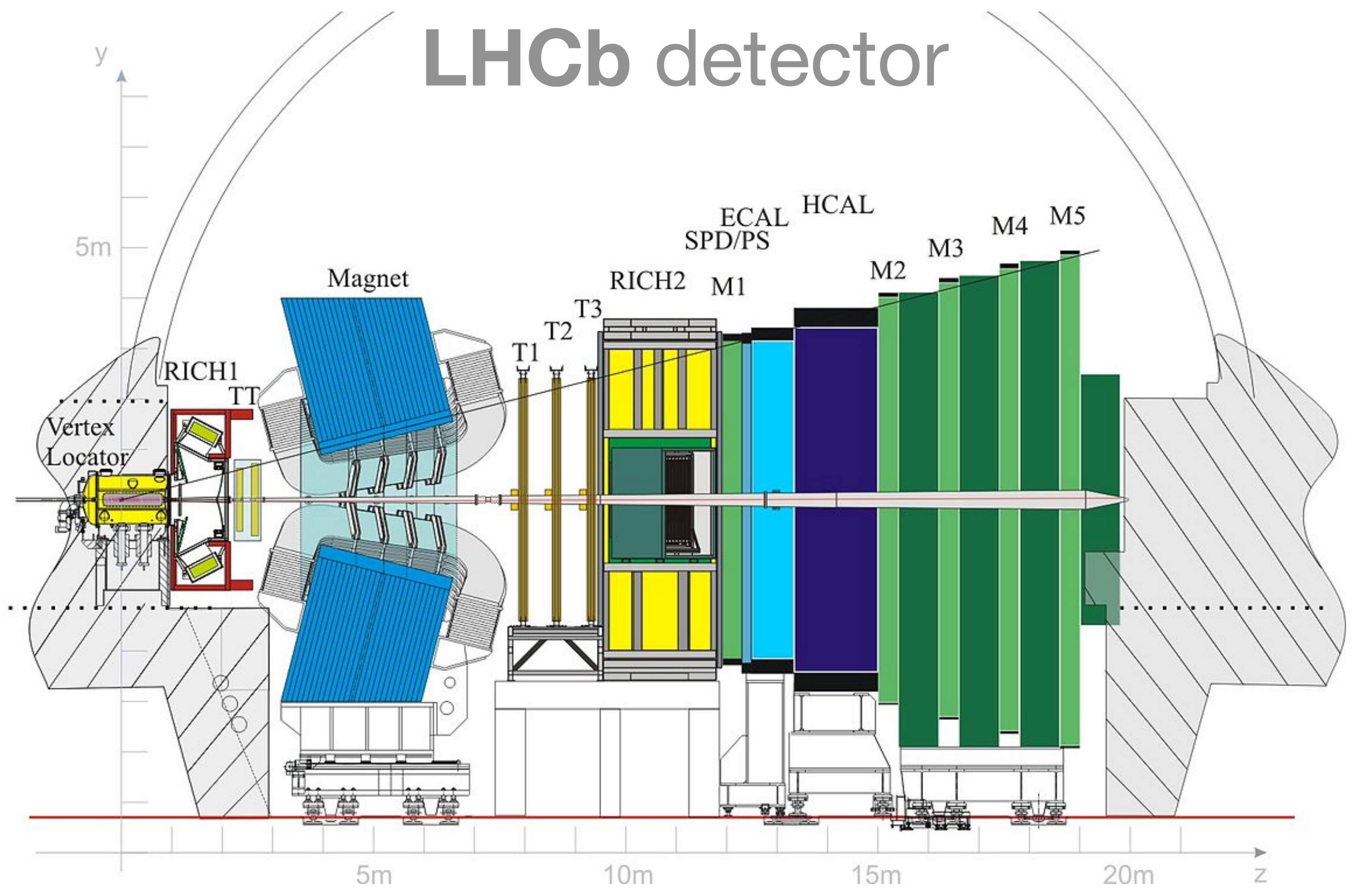
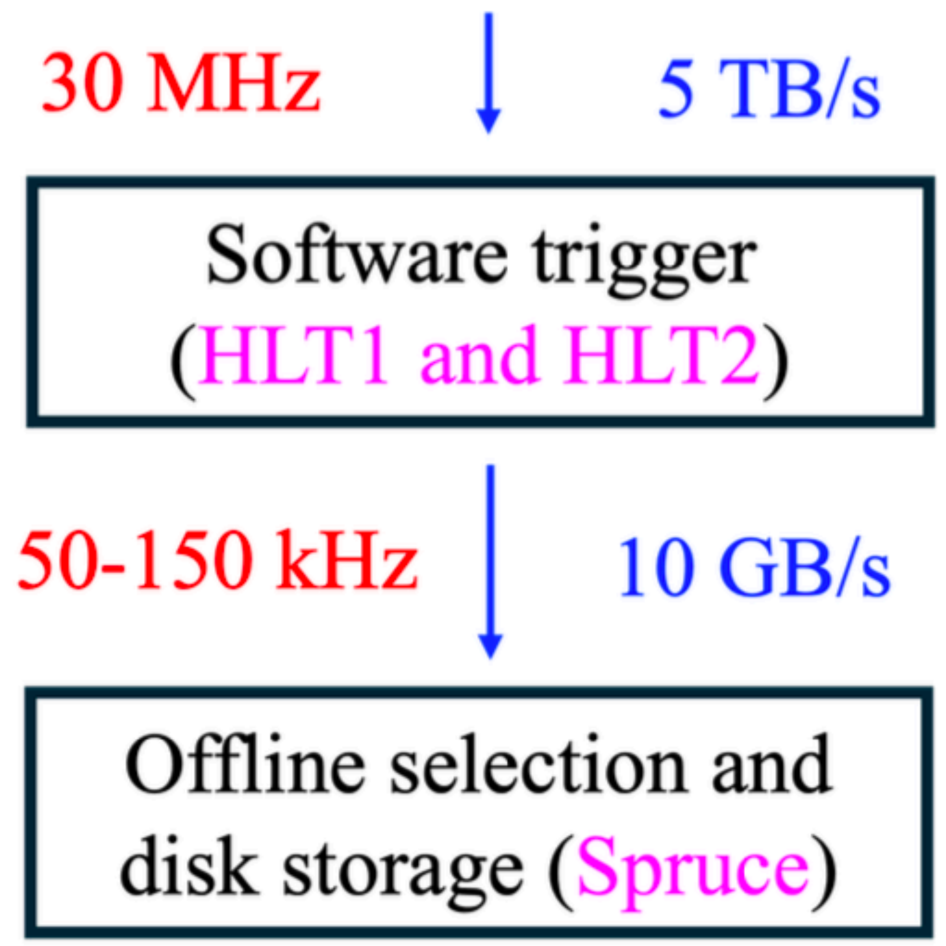
Student lightning talks at tCSC, October 18, 2024

Event size @LHCb's Run 3

- Designed to study decays of b **hadrons** produced in pp collisions.





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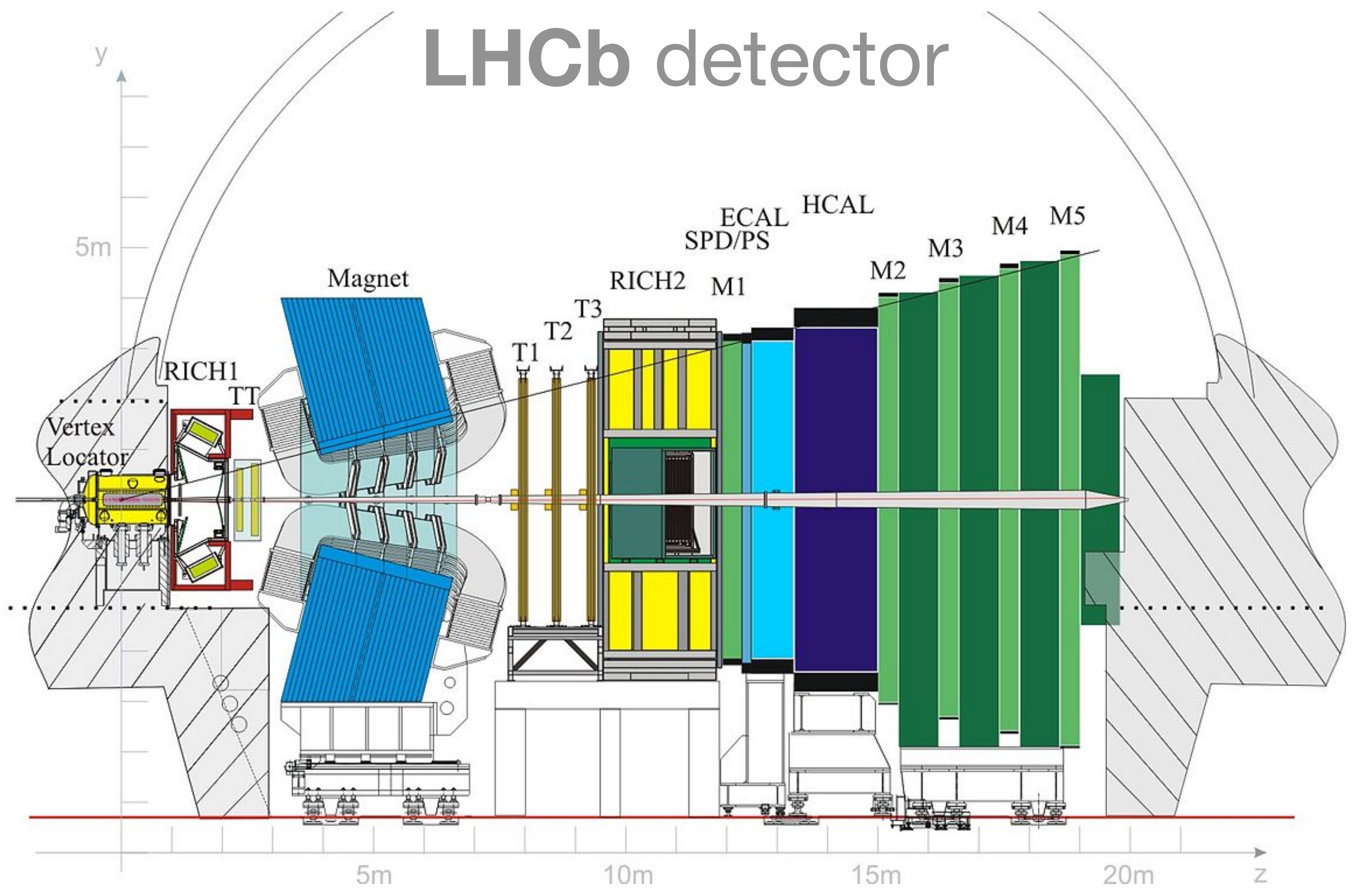

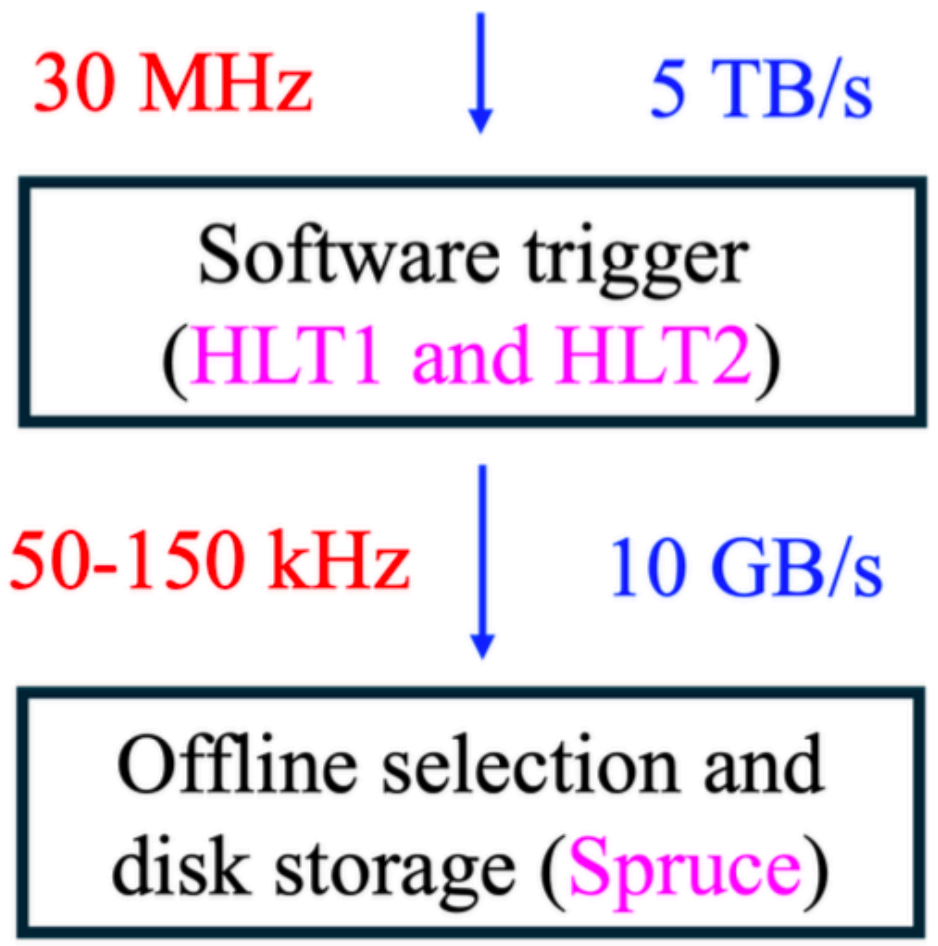

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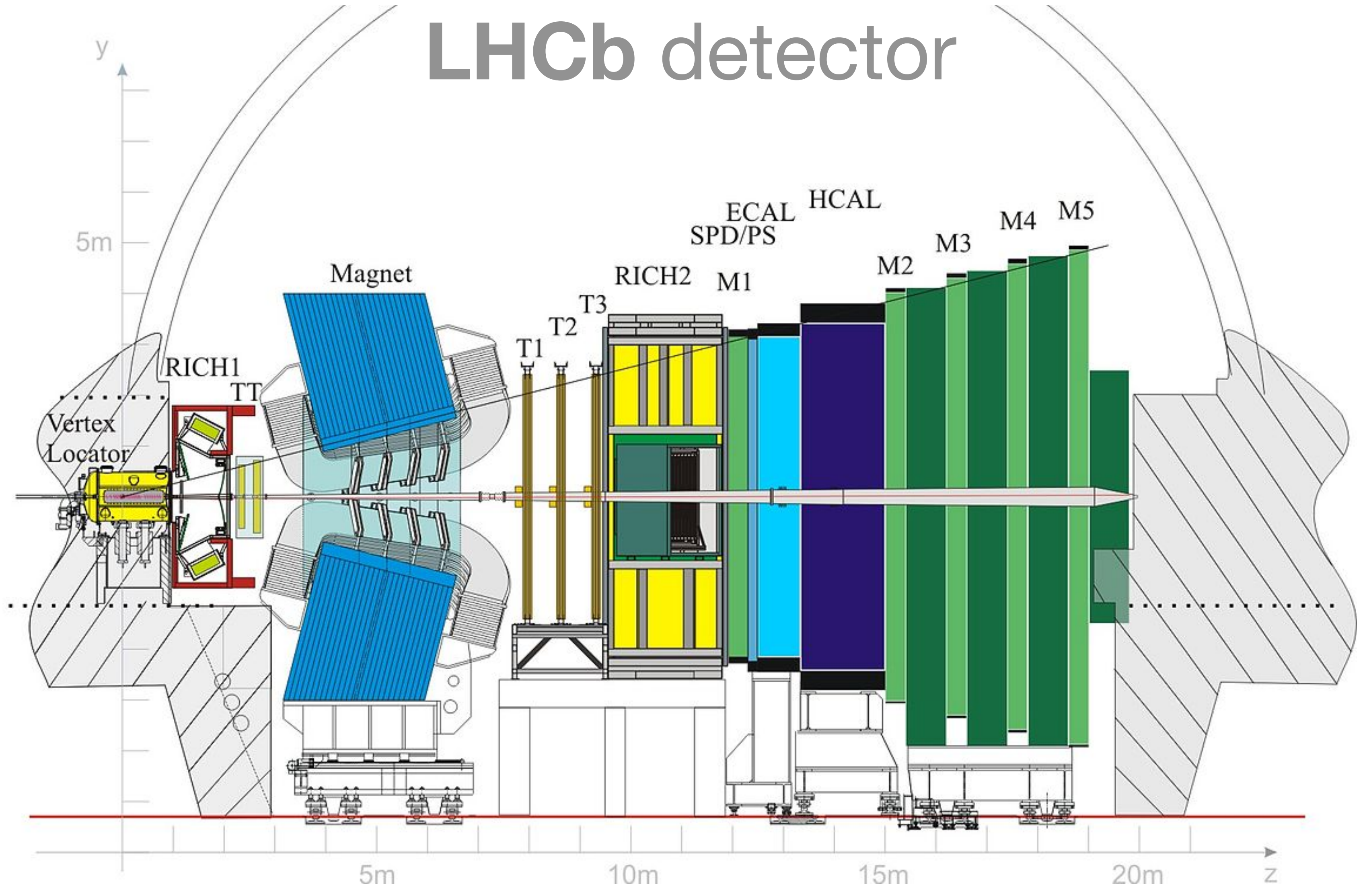

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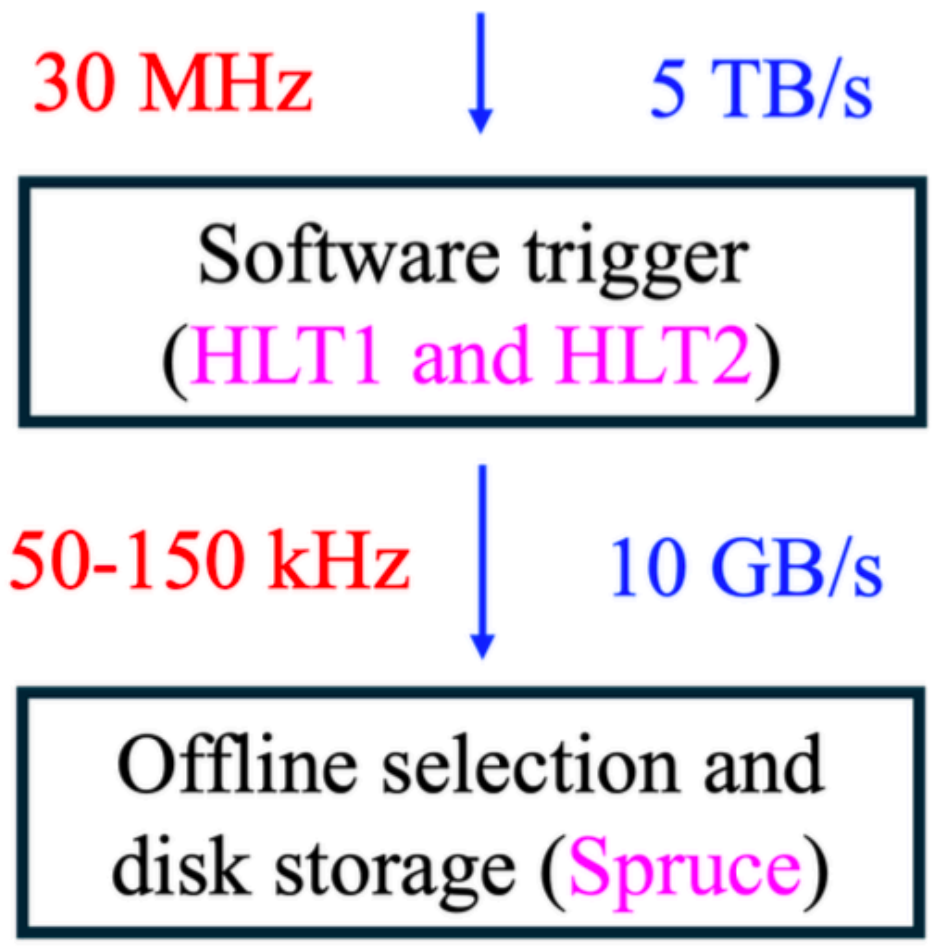

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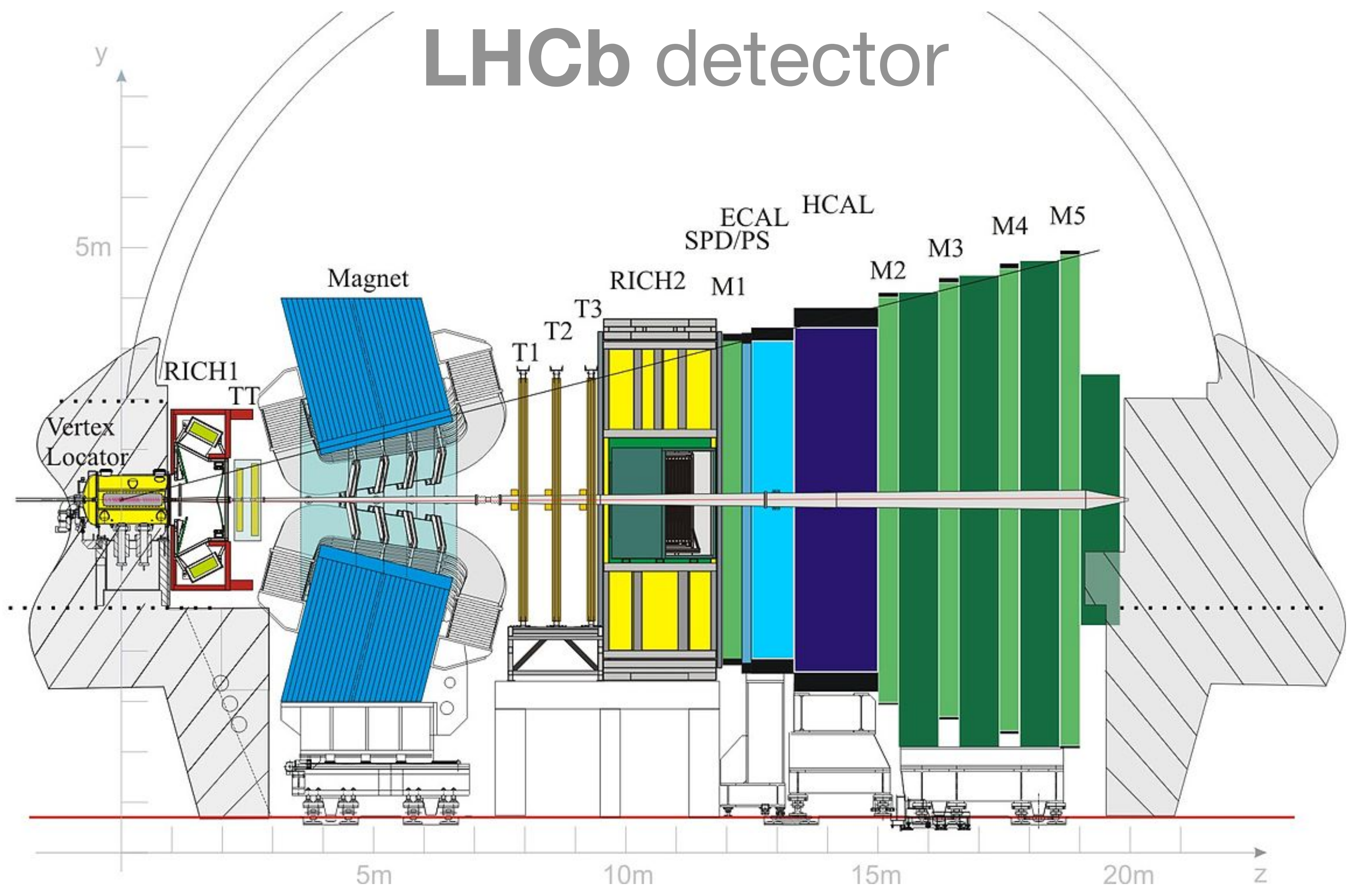
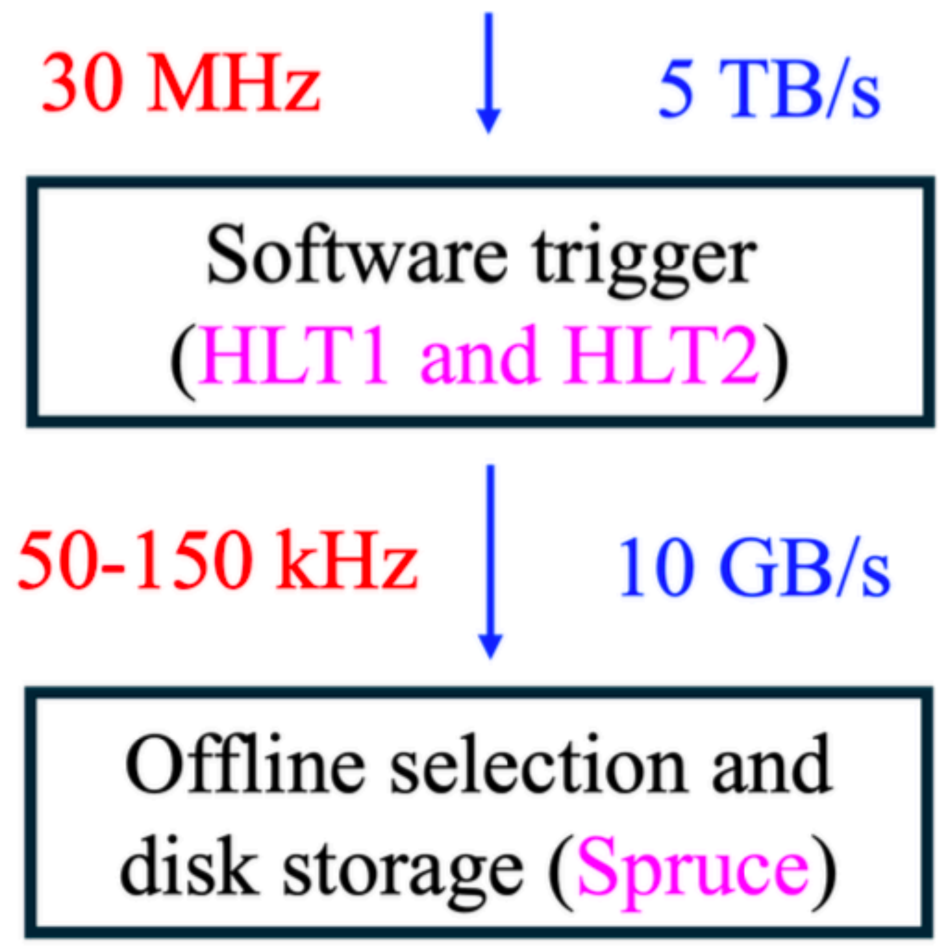
  → **storing 10 GB/s is ~315 PB/year costing ~86 million EUR/year.**





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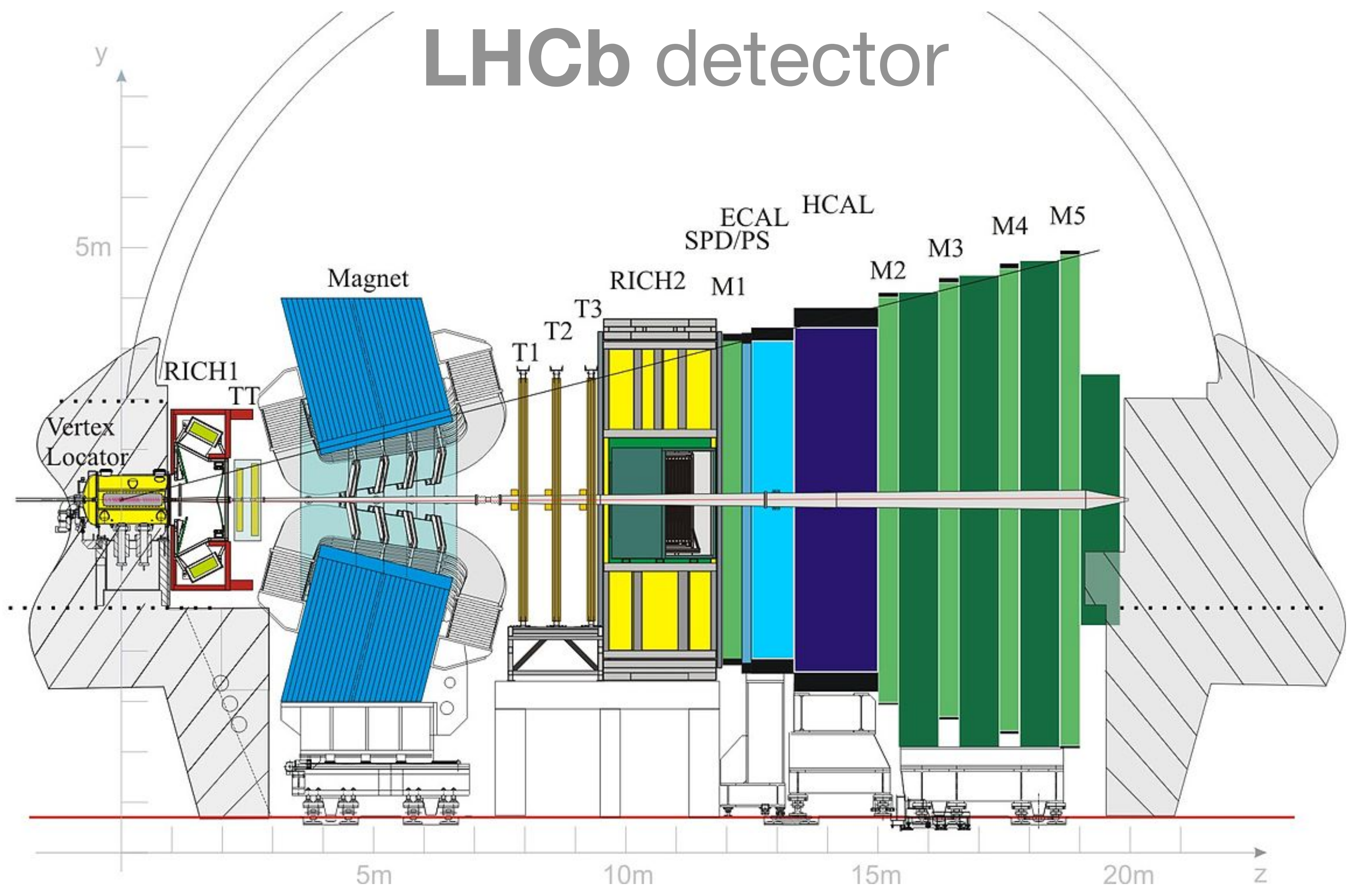

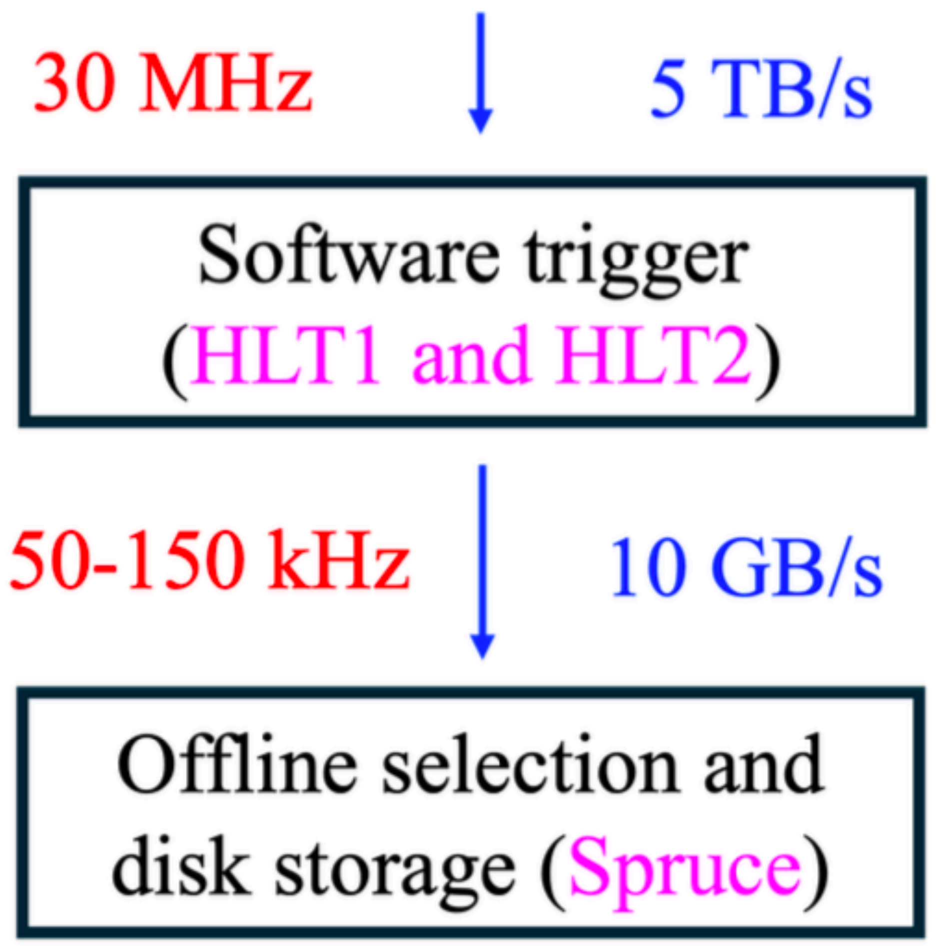

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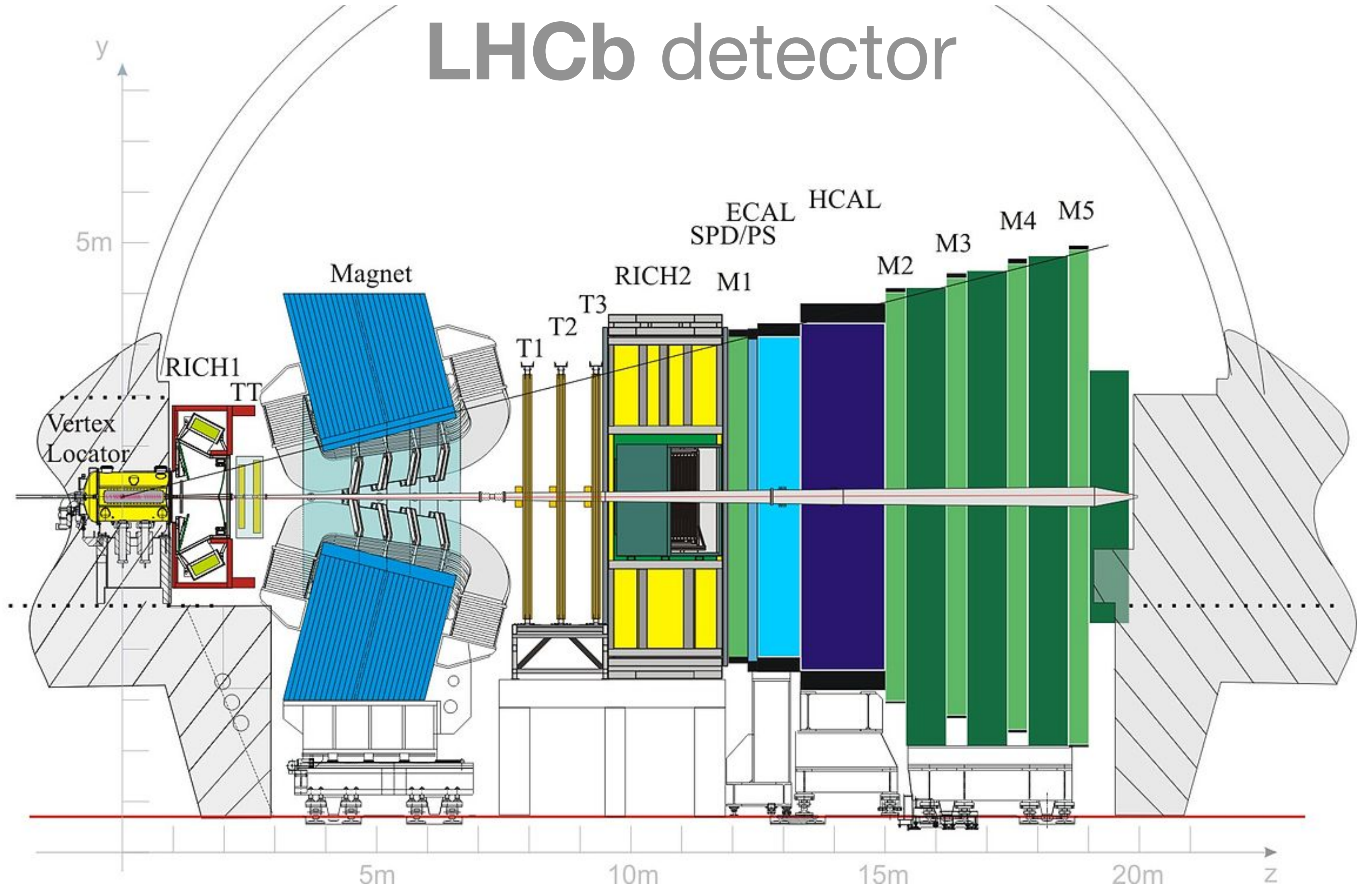

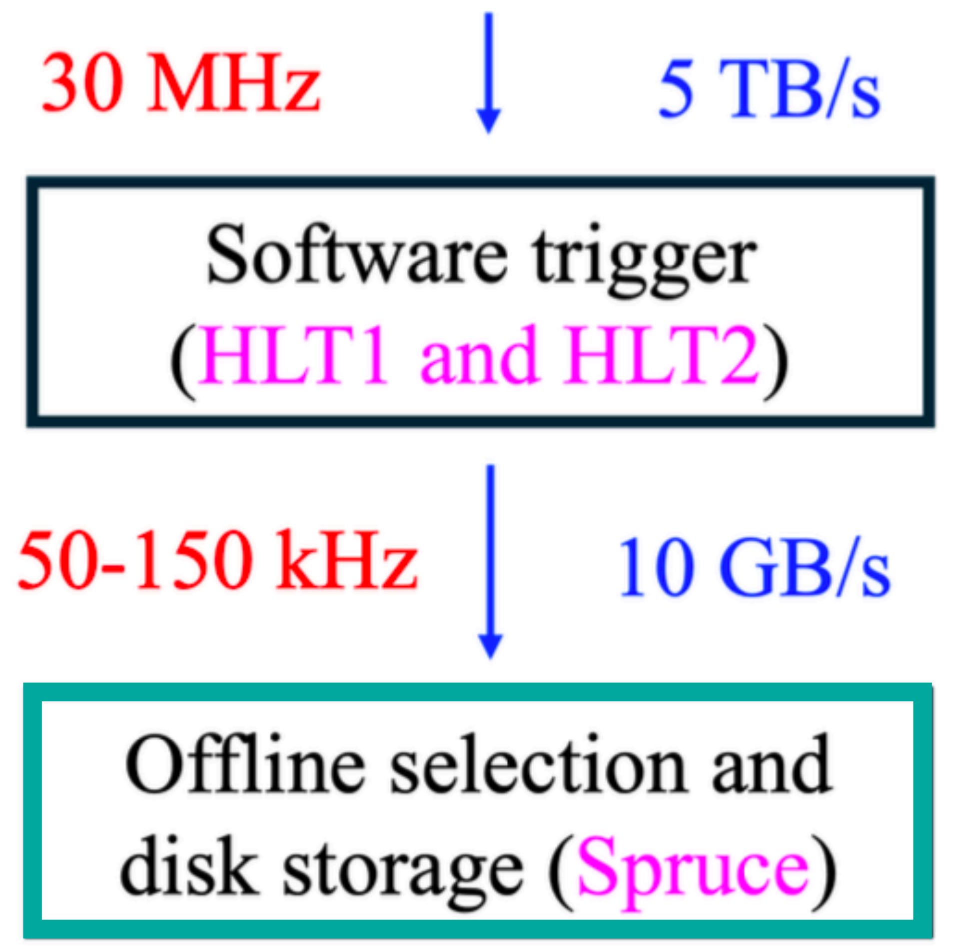

New ML tool → minimising event size saved to disk without loosing important physics.

Maximising physics @LHCb

e.g. semileptonic decays

- **Decays with a neutrino** can only be partially reconstructed.

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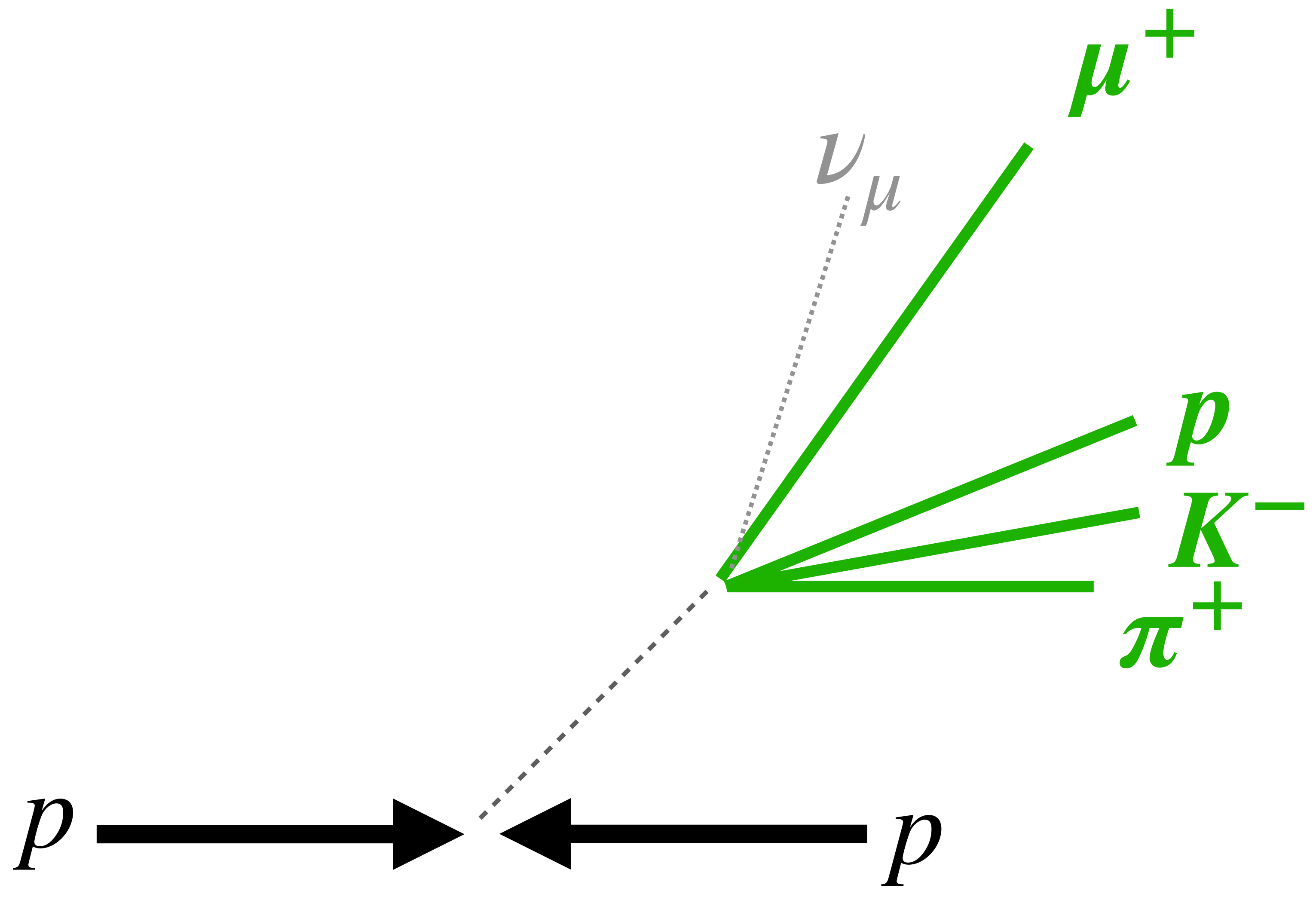
$$\Lambda_c^+ \to p K^- \pi^+$$



Signal candidate

Maximising physics @LHCb

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  → **degraded discrimination power.**

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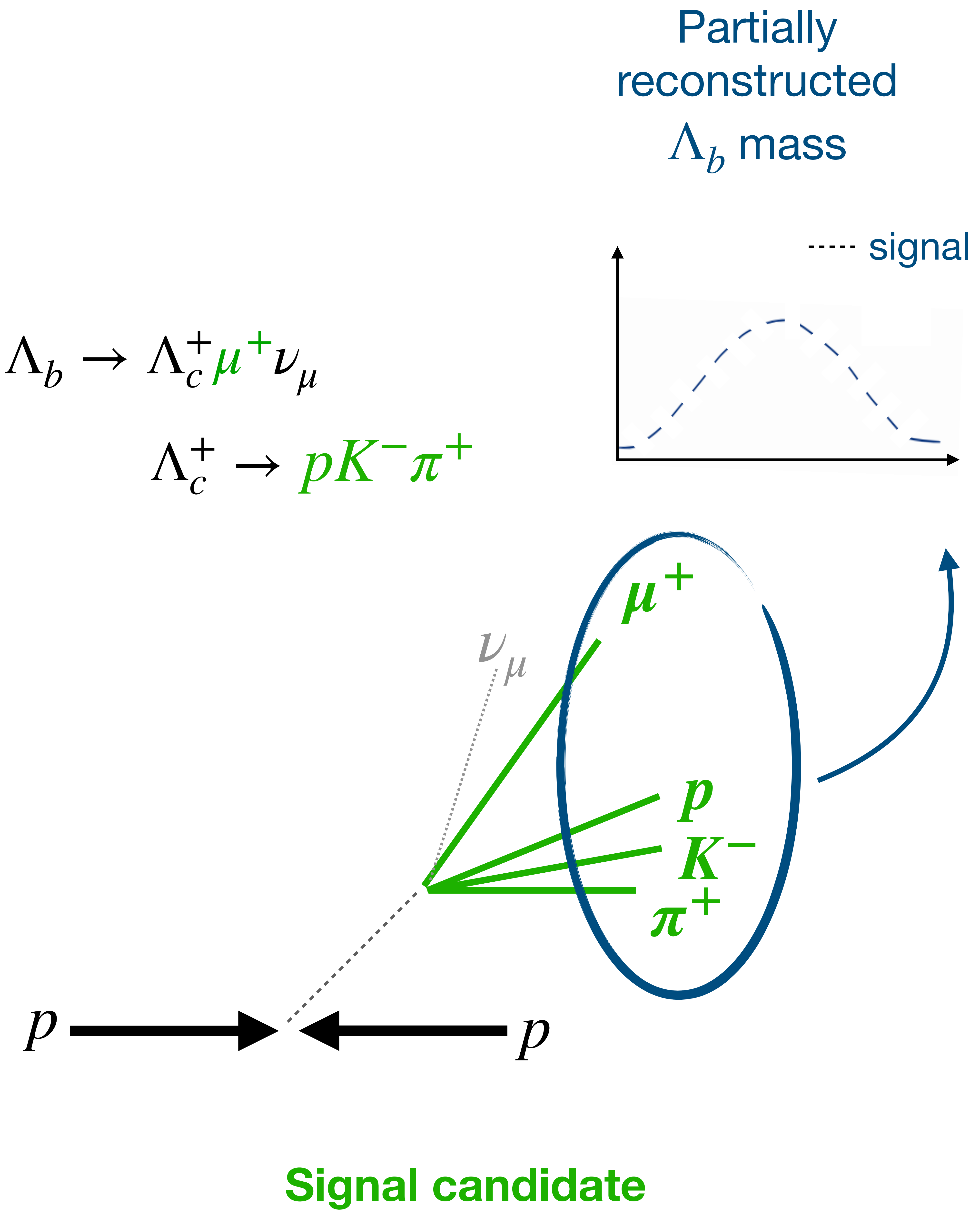

Maximising physics @LHCb

- **Decays with a neutrino** can only be partially reconstructed.

  → **degraded discrimination power.**

  → **large rates of partially reconstructed backgrounds.**

$\Lambda_b \to \Lambda_c^{*+} \mu^+ \nu_\mu$

$\Lambda_c^{*+} \to \Lambda_c^+ \pi^+ \pi^-$

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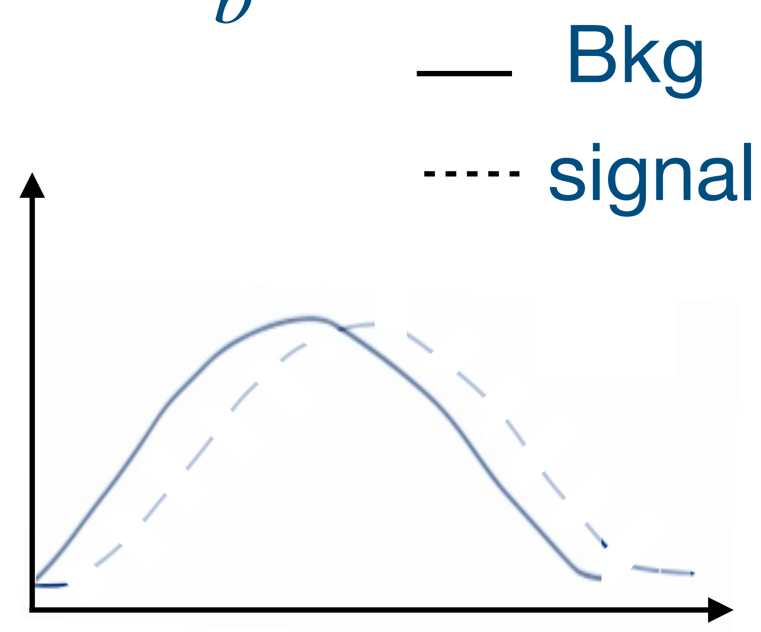
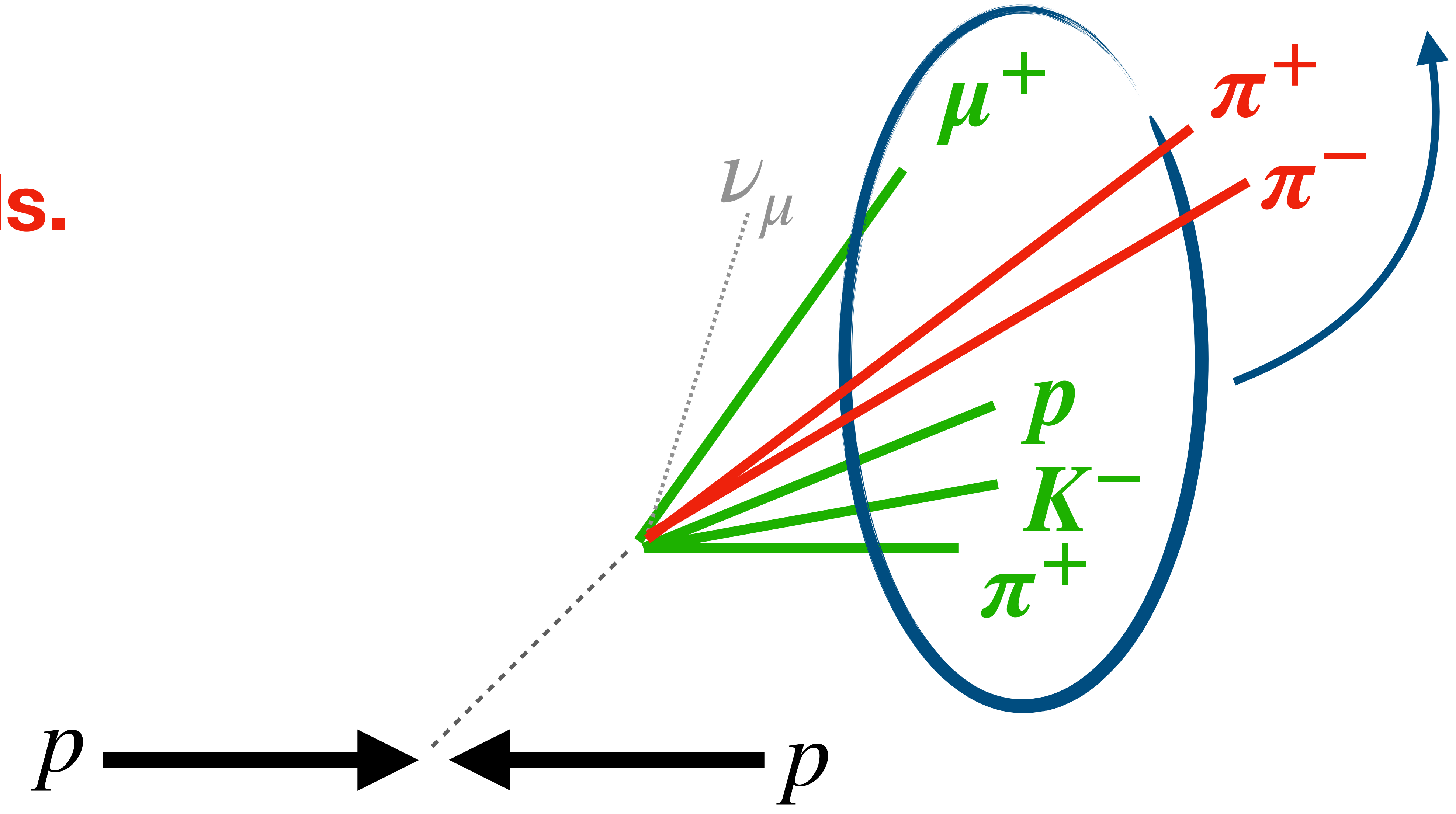
Partially reconstructed Λ_b mass



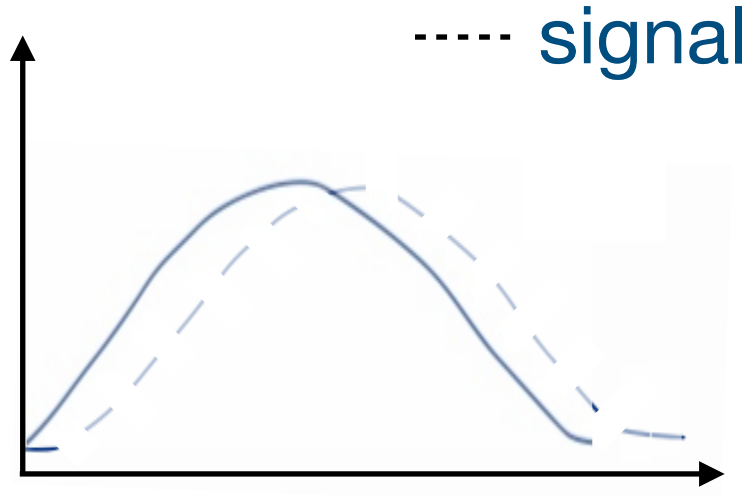


Signal candidate

Additional "Signal tracks"

Maximising physics @LHCb

Partially reconstructed Λ_b mass



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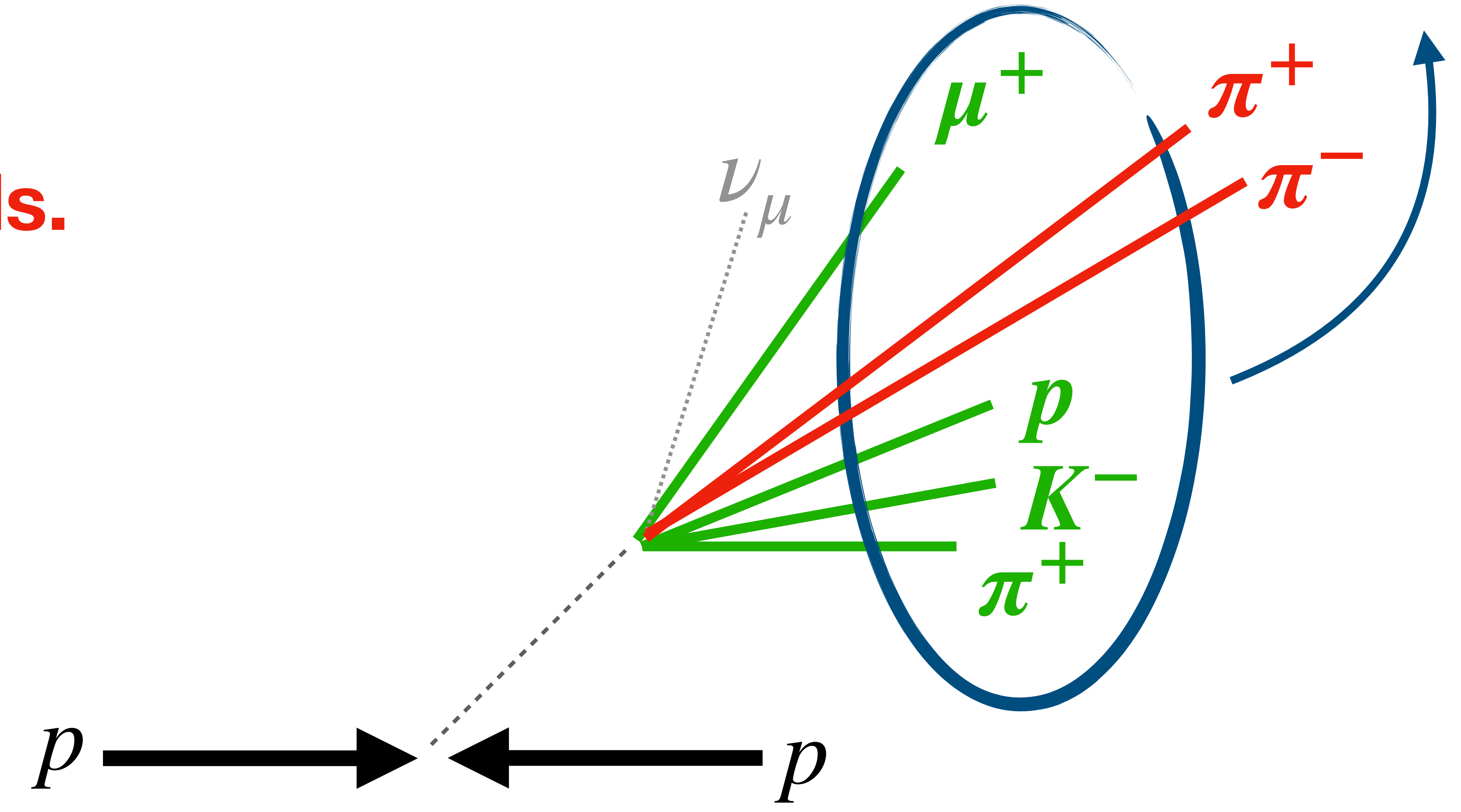
- **Decays with a neutrino** can only be partially reconstructed.

  → **degraded discrimination power.**

  → **large rates of partially reconstructed backgrounds.**

- **Reducing these backgrounds is crucial!**

  → **Isolation** : making sure that the **signal candidate is isolated from all other tracks in the event**.



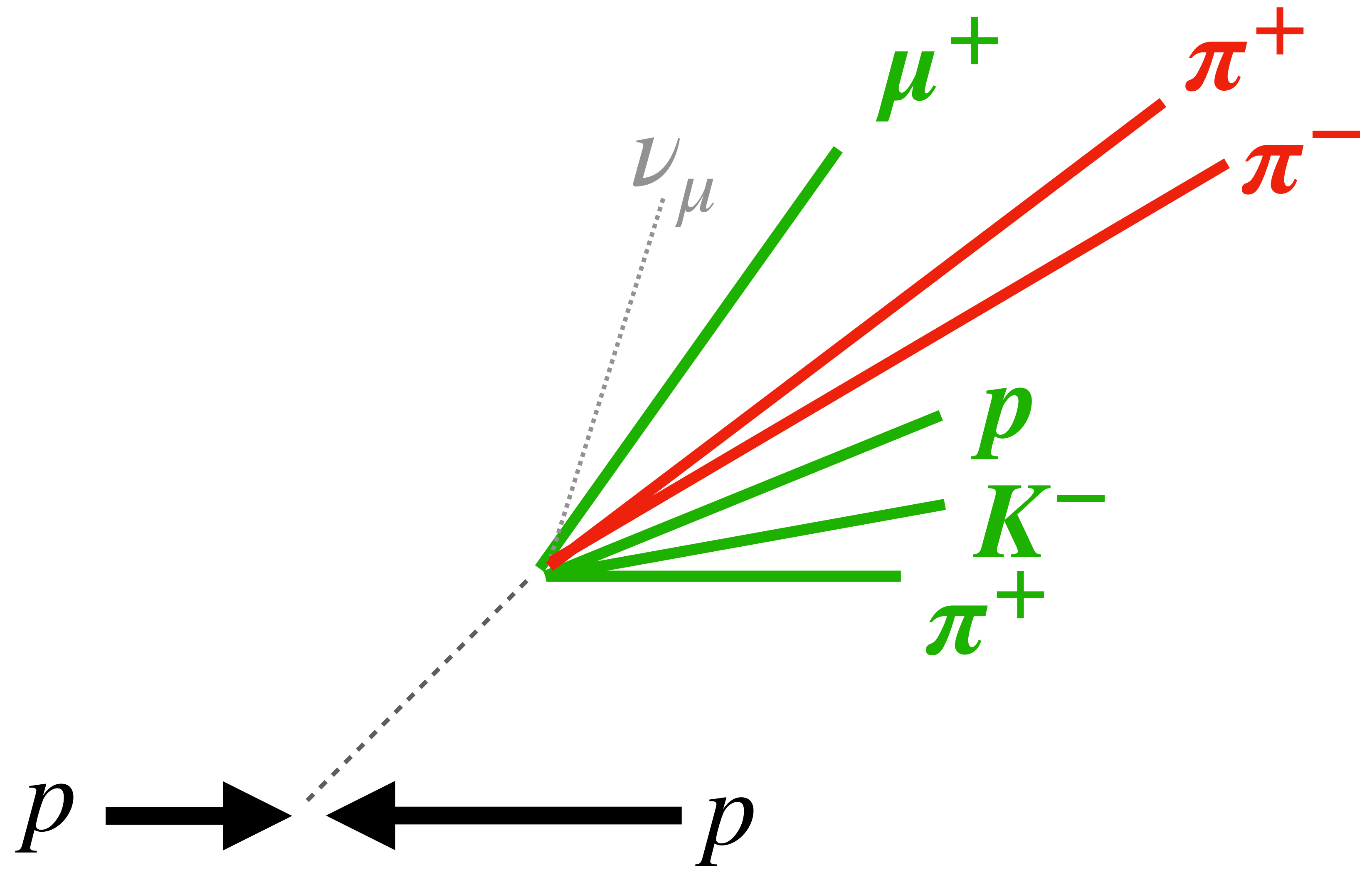
Signal candidate

Additional "Signal tracks"

Track isolation @LHCb

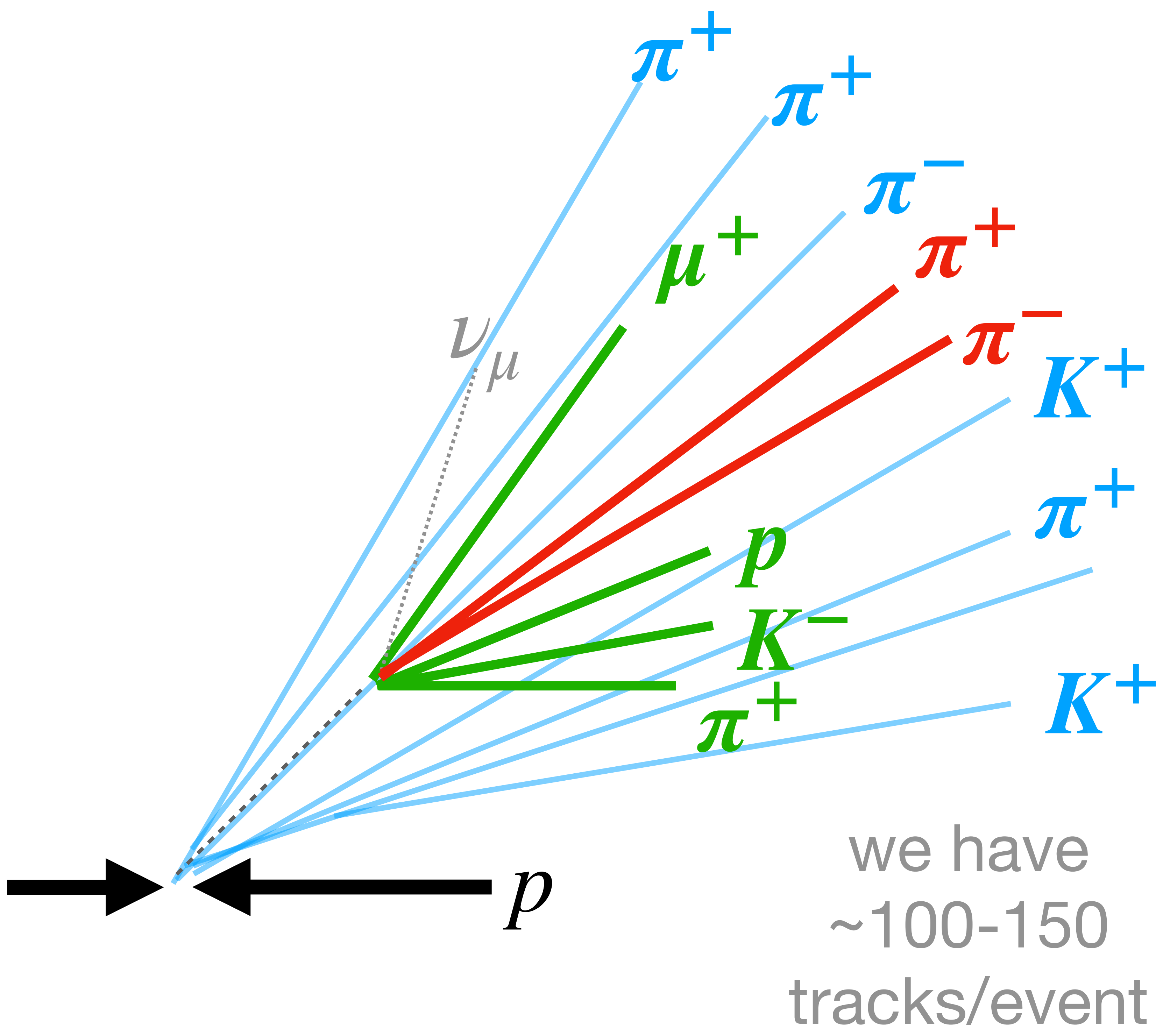
- For each **signal candidate** we have to correctly identify:

  → **Extra tracks coming from the signal candidate**.



Track isolation @LHCb

- For each **signal candidate** we have to correctly identify:
  - → **Extra tracks coming from the signal candidate**.
  - → **Tracks produced in other processes**.



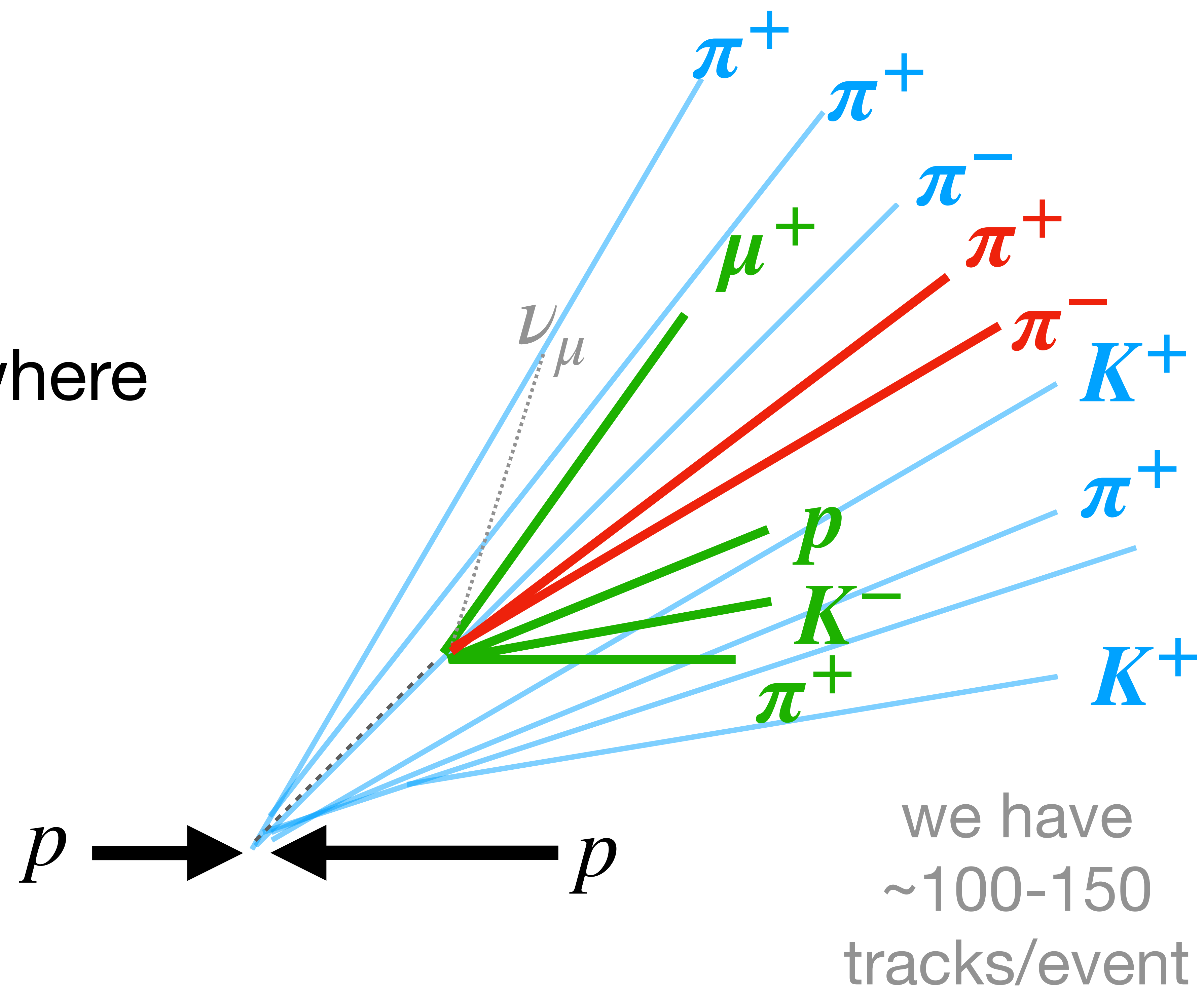
Track isolation @LHCb

- For each **signal candidate** we have to correctly identify:

  → **Extra tracks coming from the signal candidate**.

  → **Tracks produced in other processes**.

- **In Run 1 & 2 → all tracks/event saved to offline analysis**, where isolation was performed with different methods.



Track isolation @LHCb

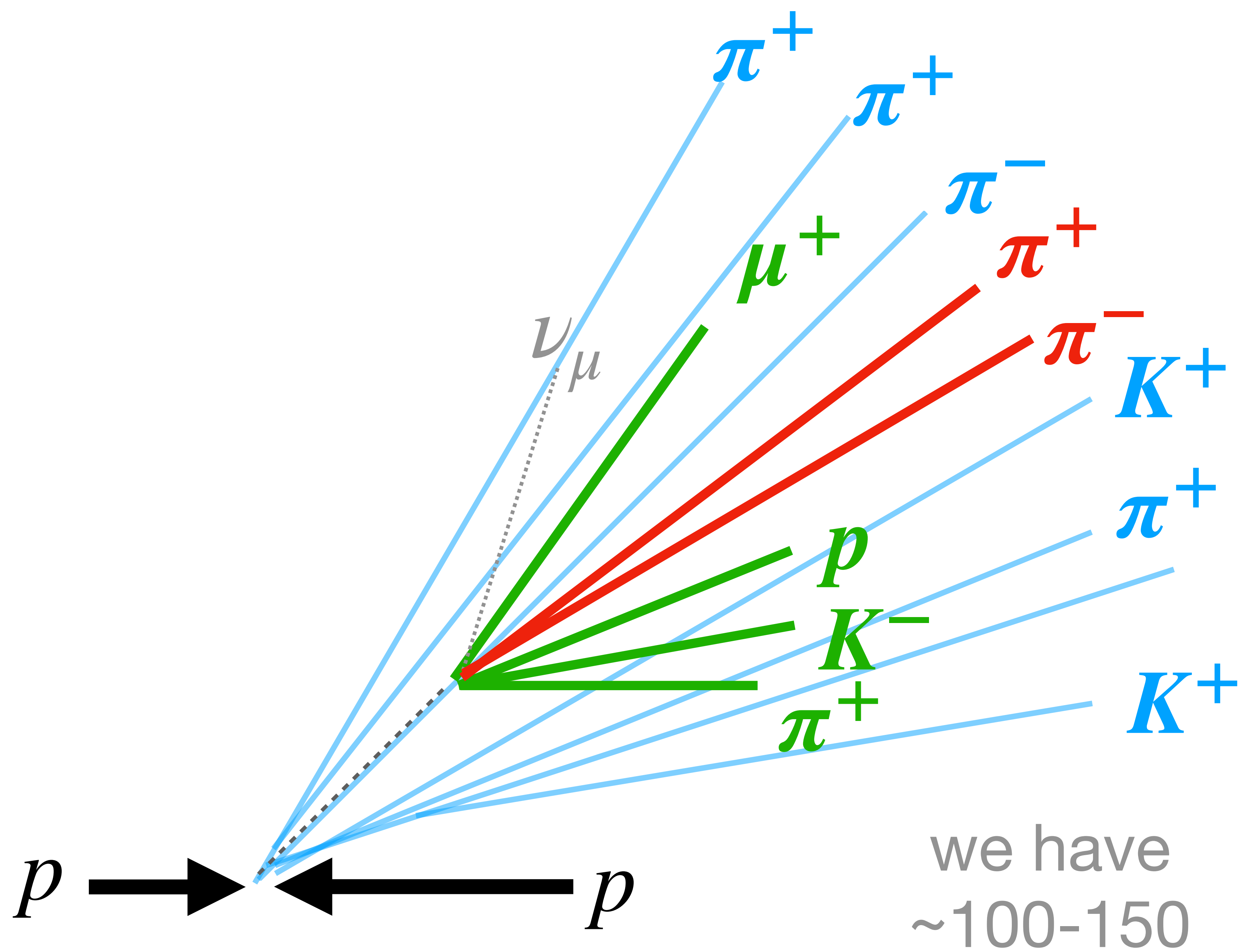
- For each **signal candidate** we have to correctly identify:

  → **Extra tracks coming from the signal candidate**.

  → **Tracks produced in other processes**.

- **In Run 3** → can **no longer save all tracks/event** to offline analysis due to space limitations, but isolation is still crucial!

- **Solution** → train ML-based classifier to **save only *relevant tracks* to offline analysis**.



Training sample

Selecting a broad range of topologies, final state particles and extra signal tracks.

- **Cocktail of semileptonic modes** simulated with LHCb Run 3 data-taking conditions.

→ representing semileptonic analyses @LHCb.

Prod	**EventType**	**Decay process**
dzl	11584030	$B^0 \to D^{*-} e^+ \nu_e$, $\bar{D}^0 \to K^+ \pi^-$
dzl	11584010	$B^0 \to D^{*-} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$ $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
dzl	11574020	$B^0 \to D^{*-} \mu^+ \nu_\mu$, $\bar{D}^0 \to K^+ \pi^-$
dzl	11574010	$B^0 \to D^{*-} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$, $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
dzl	12685400	$B^+ \to D^{**0} e^+ \nu_e$, $\bar{D}^0 \to K^+ \pi^-$
dzl	12883000	$B^+ \to D^{**0} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$, $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
dzl	12874020	$B^+ \to D^{**0} \mu^+ \nu_\mu$, $\bar{D}^0 \to K^+ \pi^-$
dzl	12874040	$B^+ \to D^{**0} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$, $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
dzl	11686000	$B^0 \to D^{**-} e^+ \nu_e$, $\bar{D}^0 \to K^+ \pi^-$
dzl	11883000	$B^0 \to D^{**-} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$, $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
dzl	11874060	$B^0 \to D^{**-} \mu^+ \nu_\mu$, $\bar{D}^0 \to K^+ \pi^-$
dzl	11873030	$B^0 \to D^{**-} \tau^+ \nu_\tau$, $\bar{D}^0 \to K^+ \pi^-$, $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
dzl	12874010	$B^+ \to D^{*,**} D^{(*)}_{(s)} X$, $\bar{D}^0 \to K^+ \pi^-$, $D^{(*)}_{(s)} \to \mu X$
kl	12143001	$B^+ \to K^+ J/\psi(\to \mu^+ \mu^-)$
kl	13774000	$B^0_s \to D^{(*)-}_s \mu^+ \nu_\mu / B^0_s \to D^{(*)-}_s \tau^+ \nu_\tau$, $D^-_s \to K^+ K^- \pi^-$, $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
LcL	15576011	$\Lambda^0_b \to \Lambda_c(2593)^+ \mu^+ \nu_\mu$, $\Lambda_c(2593)^+ \to \Lambda^+_c \pi^+ \pi^-$, $\Lambda^+_c \to p^+ K^- \pi^+$
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LcL	15876031	$\Lambda^0_b \to \Lambda_c(2880)^+ \mu^+ \nu_\mu$, $\Lambda_c(2880)^+ \to \Lambda^+_c \pi^+ \pi^-$, $\Lambda^+_c \to p^+ K^- \pi^+$
pl	15576010	$\Lambda^0_b \to \Lambda_c(2593)^+ \mu^+ \nu_\mu$, $\Lambda_c(2593)^+ \to \Lambda^+_c \pi^+ \pi^-$, $\Lambda^+_c \to p^+ K^- \pi^+$

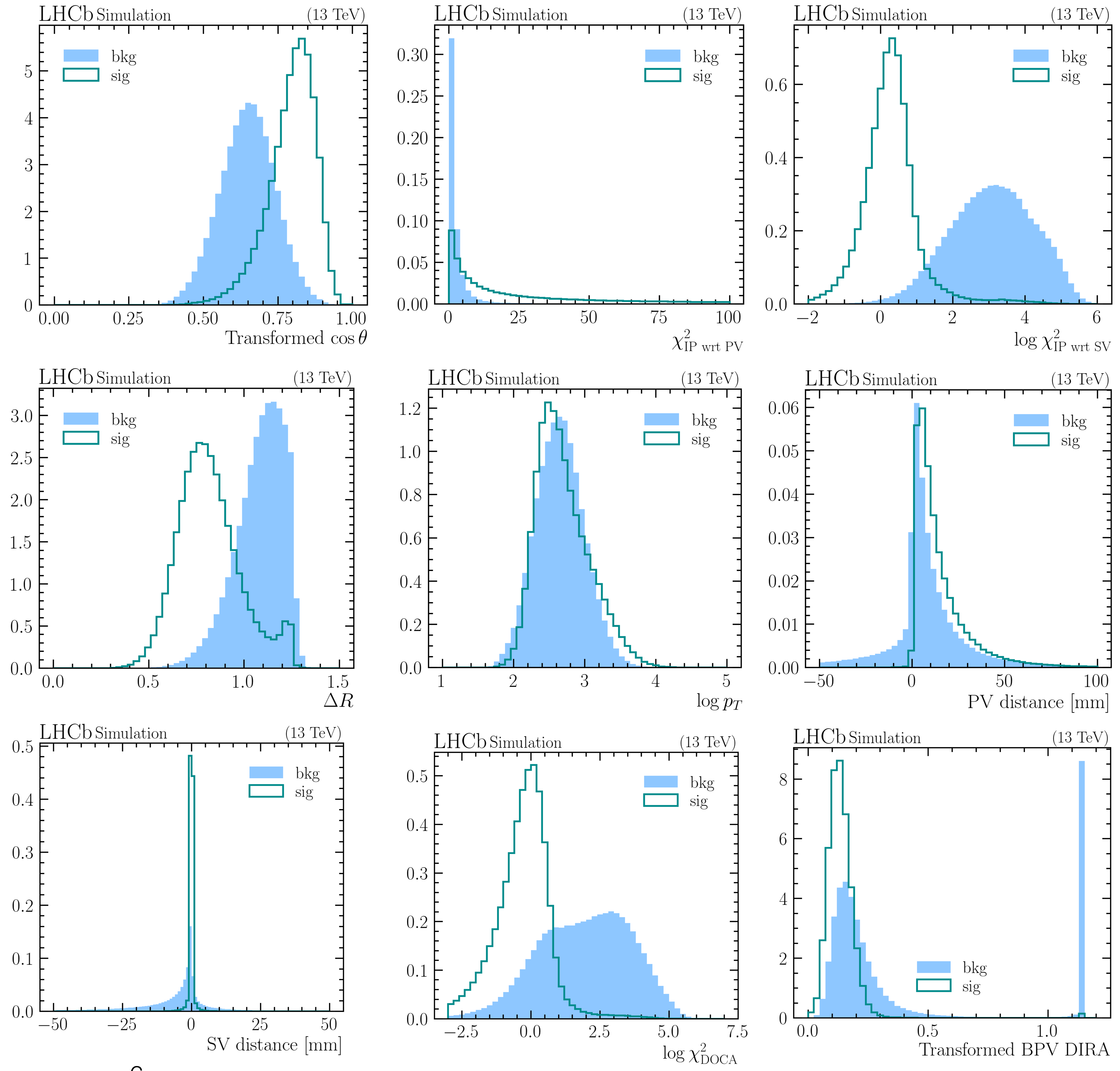
5 Table 2: Analysis production summary.

Input features

- **Signal** and **background** distributions of input features.

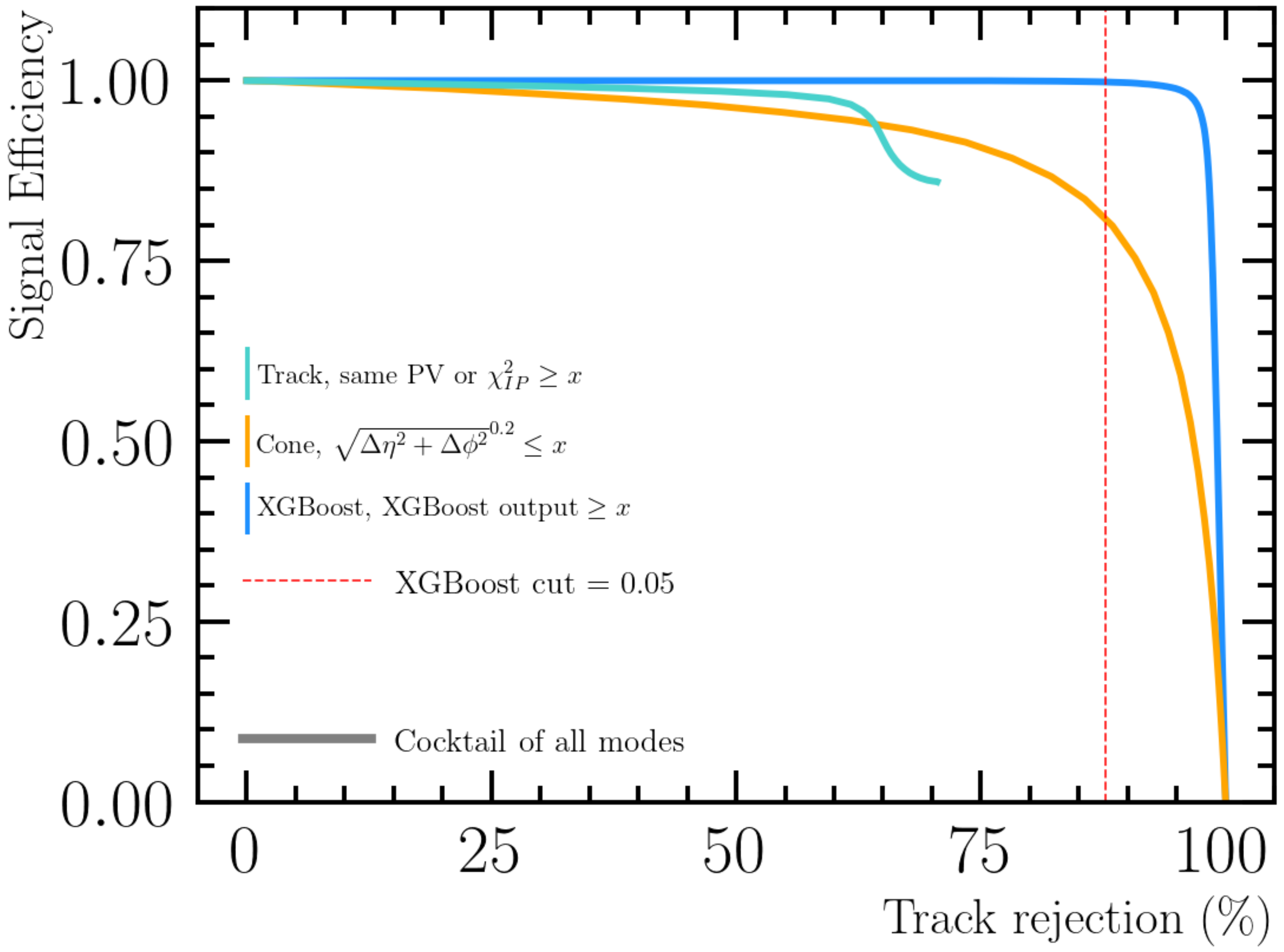
  → mostly geometric variables.

- **Overall good discrimination power!**



ML training and result

- **ML model**: XGBoost.
- **Training objective**: maximise AUC.
- **Hyper parameters**: optimised with Optuna.



- **Performance**: signal efficiency vs. track rejection.

  → XGBoost clearly outperforms the classical methods, Track and Cone, **used in Run 1&2.**

- Nominal cut: saves >99% relevant tracks & rejects ~87% tracks per event.

- **Tool is in LHCb data processing:**

  → event size is kept below required limit and relevant tracks are saved to offline analysis :-)