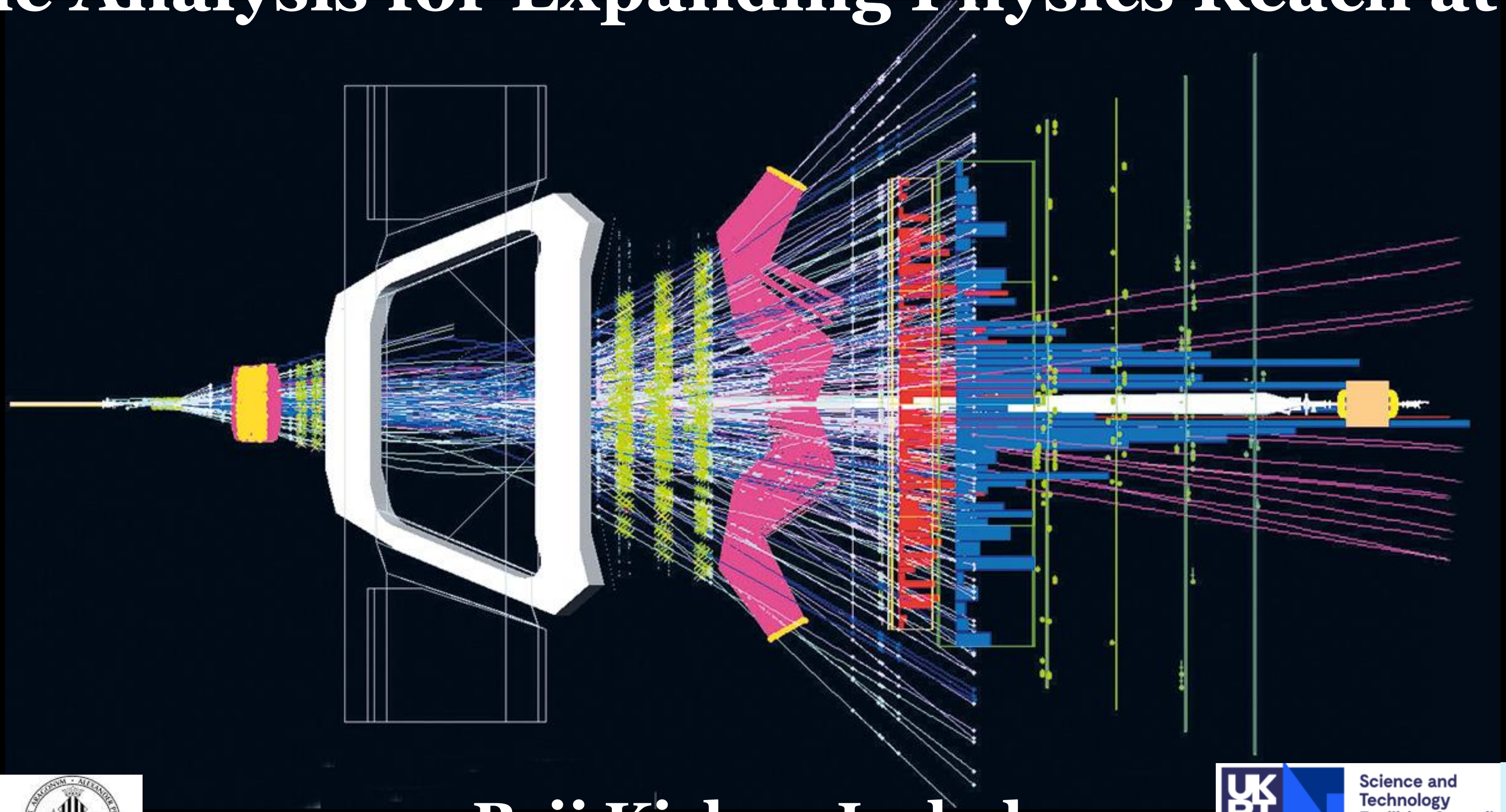
University of Warwick

03-10-2024

Triggering new discoveries: Advancements in Real-Time Analysis for Expanding Physics Reach at LHCb



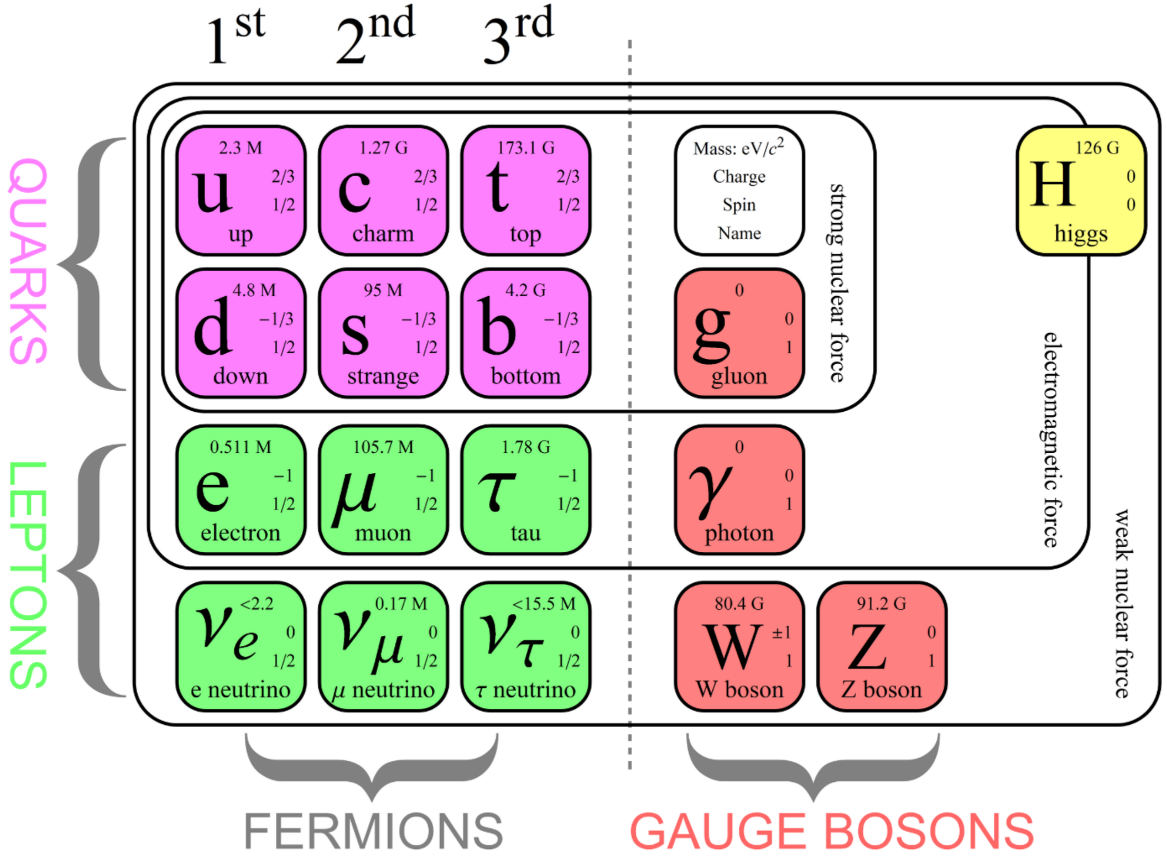
Brij Kishor Jashal

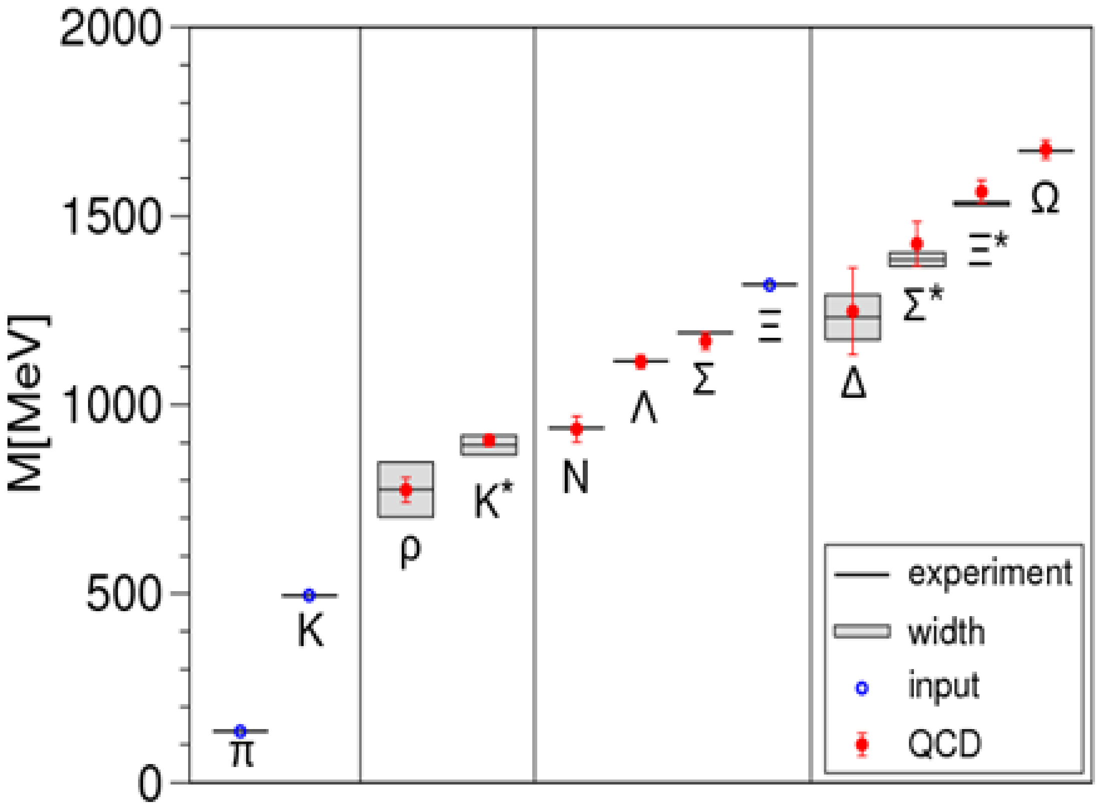
Outline

CERN-THESIS-2023-249
Eur.Phys.J.C 84 (2024) 6, 608

- Introduction
  - Physics motivation
  - The LHCb Experiment
- Real time analysis
  - Advanced High Level Trigger algorithms
  - Physics impact for long lived particles
- Summary

Fundamental particles



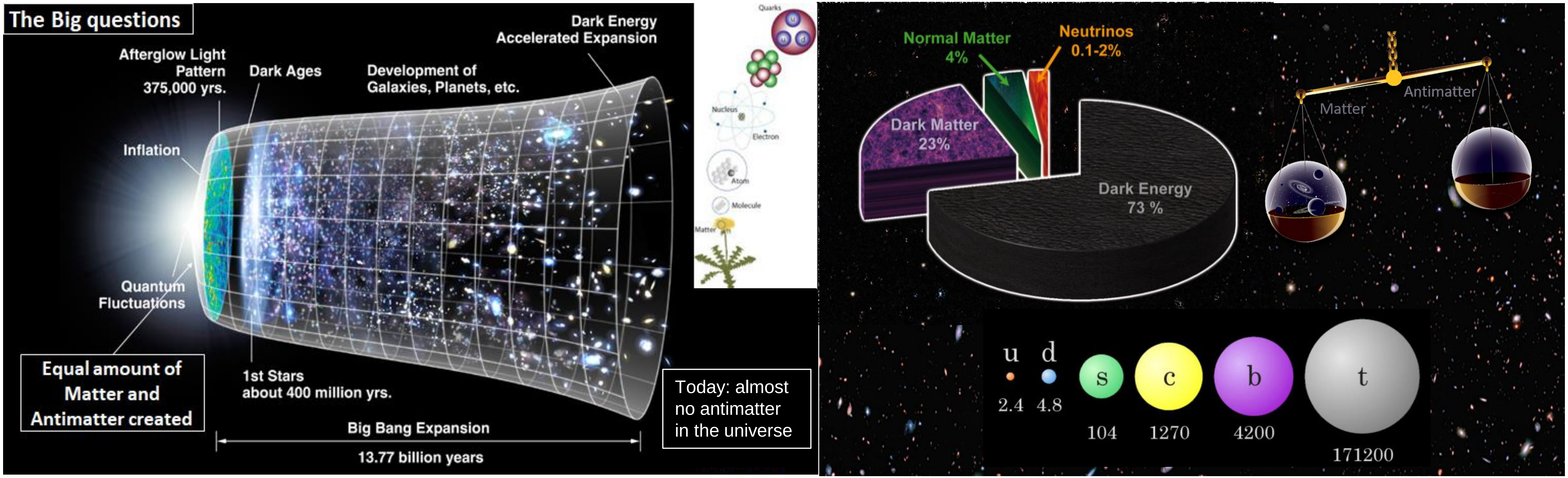


Hadron spectrum

Provides framework for understanding the behaviour of the fundamental particles and their interactions through strong, weak and EM forces

Amazing predictive capabilities

The Big question



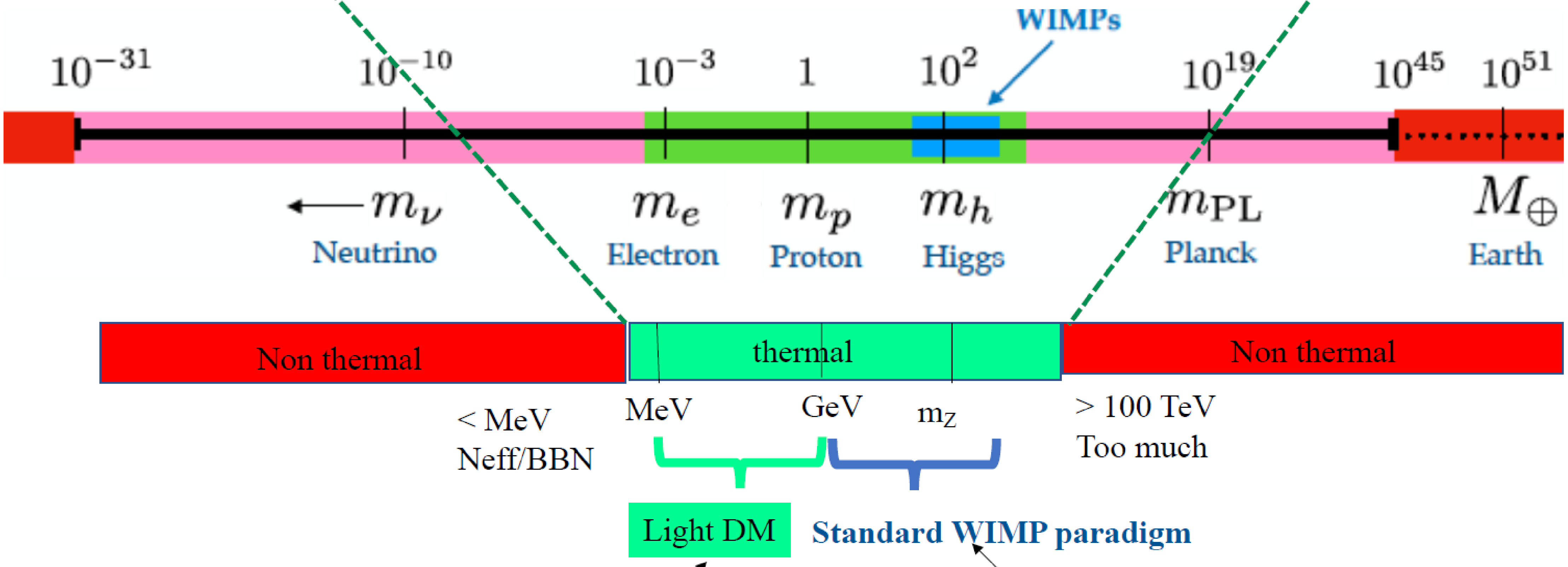
Study of behaviour of fundamental particles in the early universe could help in answering many questions

Dark Matter: a huge range of possible masses

J.Phys.G 47 (2020) 1, 010501

DM as a thermal relic from the Early Universe

- **Fritz Zwicky's 1933 Paper**: *The Redshift of Extragalactic Nebulae: Coma cluster*
- **Vera Rubin** & **Kent Ford's** 1970 paper on rotation curves of spiral galaxies



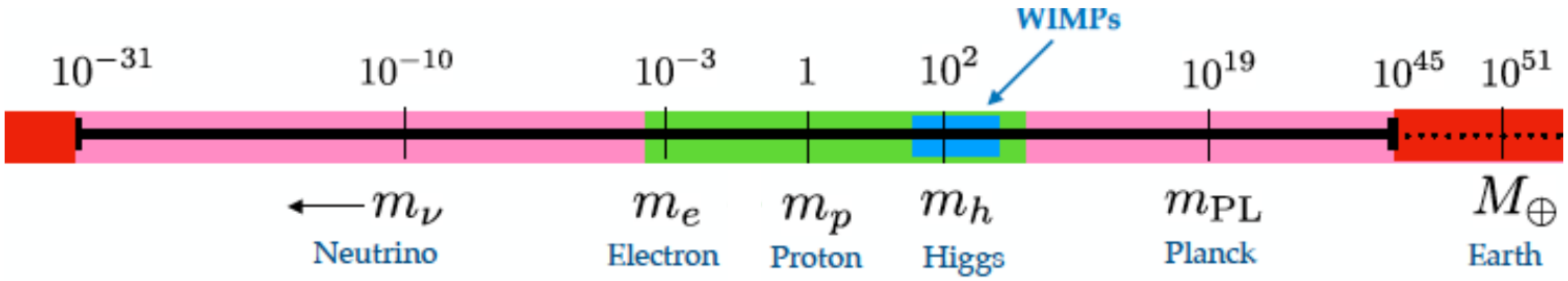
This is the range around the EW scale (Higgs)

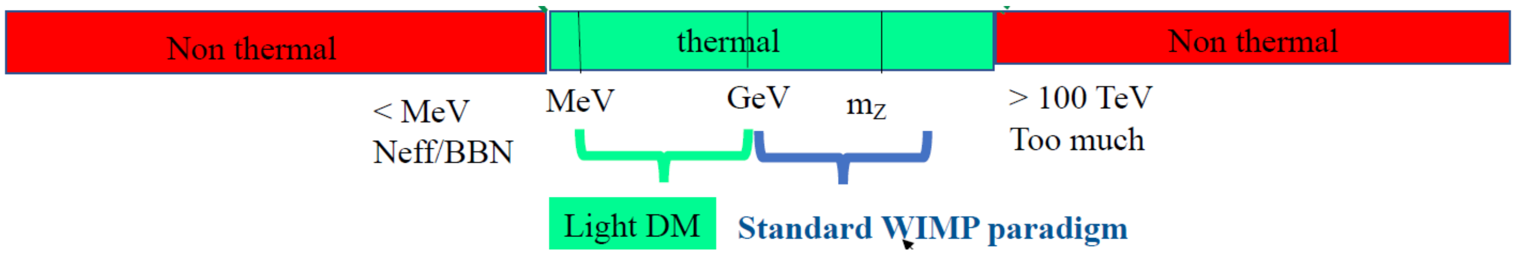
This is the range of familiar matter (electron, proton,….)

The Long-Lived Particle projects at the LHC

J.Phys.G 47 (2020) 1, 010501

Interactions with SM particles are necessary to provide mechanisms able to
deplete the DM abundance in the early Universe to the levels known today
in agreement with observations in standard cosmology.
-> DM has to interact to SM particles to deplete its initial abundance





Portal framework:
- Expand the SM with the minimal set of operators of lowest dimension gauge-invariant and renormalizable (all but the pseudo-scalar). This guarantees that the theoretical structure of the SM is preserved and any NP is just a simple (natural?) extension of what we already know..

The best portals for Thermal light Dark Matter

Couplings too tiny to produce thermal DM

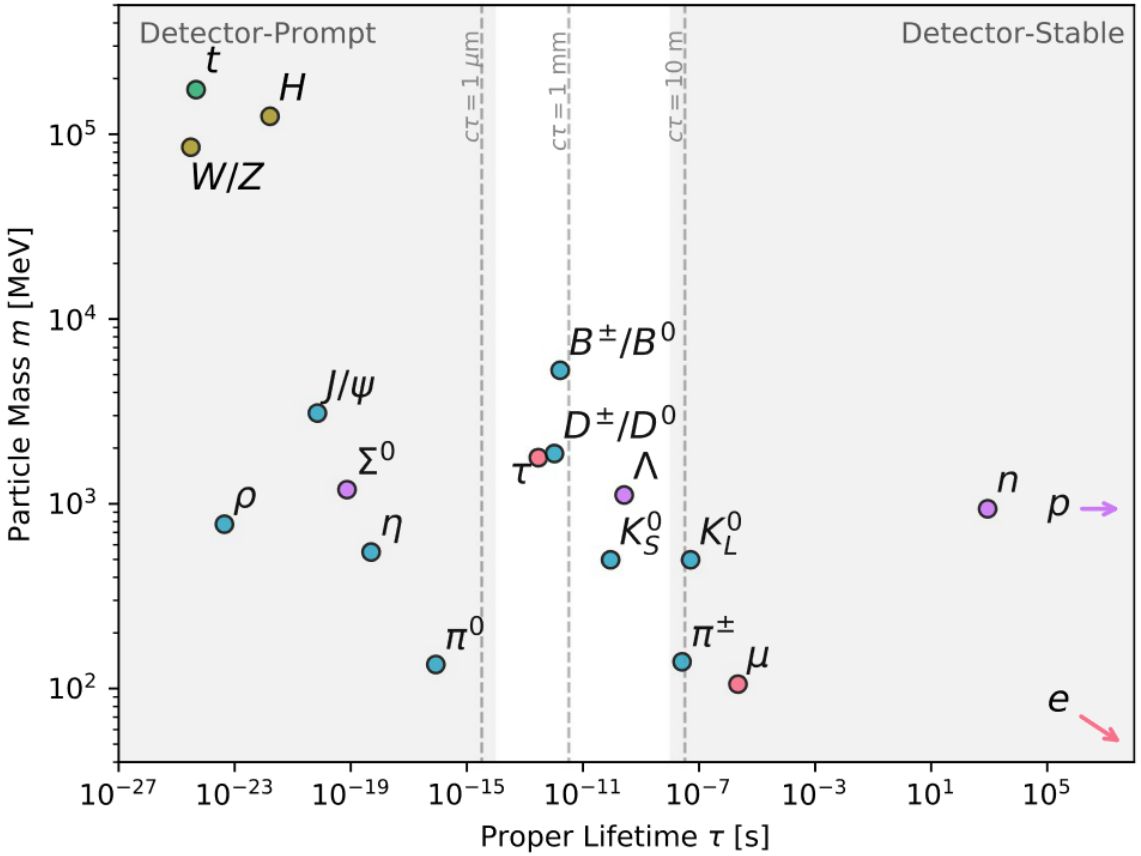
Axion is an excellent DM Candidate but in the micro-eV range

Portal	Coupling	
Vector: Dark Photon, A'	$-\frac{\varepsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	BC1, BC2, BC3
Scalar: Dark Higgs, S	$(\mu S + \lambda_{\rm HS} S^2) H^\dagger H$	BC4, BC5
Fermion: Heavy Neutral Lepton, N	$y_N L H N$	BC6, BC7, BC8
Pseudo-scalar: Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}^{\mu\nu}_i$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$	BC9, BC10, BC11

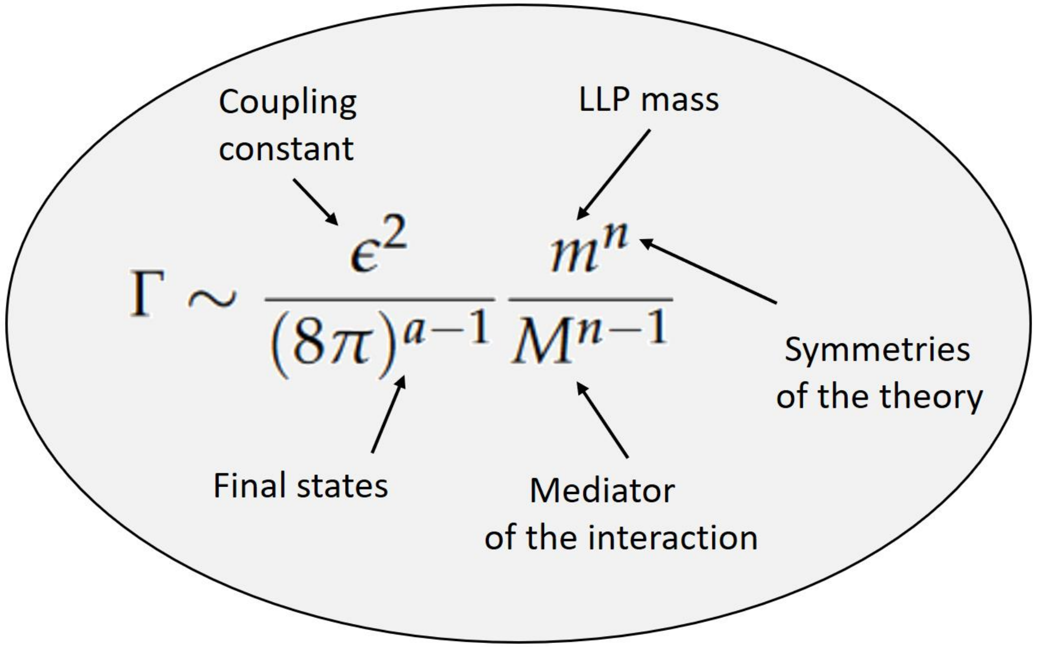
Long-lived particles (LLPs):

Long living particle are a excellent probes for new physics searches in SM and beyond.

- Particle lifetimes in the SM range from τ ~ 2 x 10^{-25} s (the Z boson) through to τ ~ > 10^{34} years (stable) (proton, electron).



$\tau = 1/\Gamma$

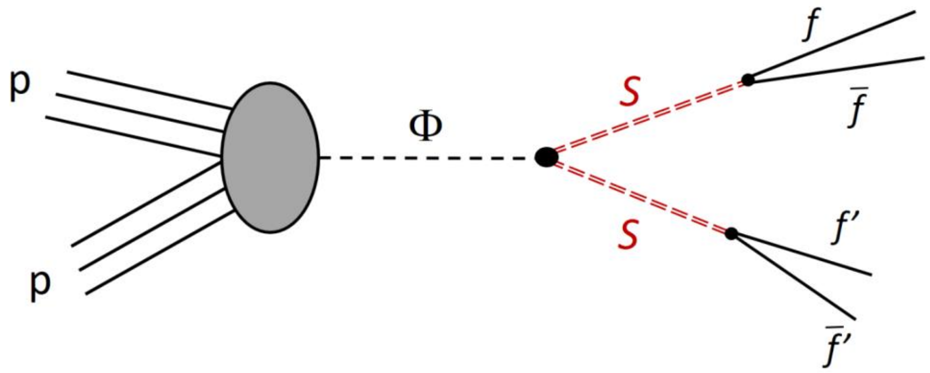


$$\Gamma \sim \frac{\epsilon^2}{(8\pi)^{a-1}} \frac{m^n}{M^{n-1}}$$

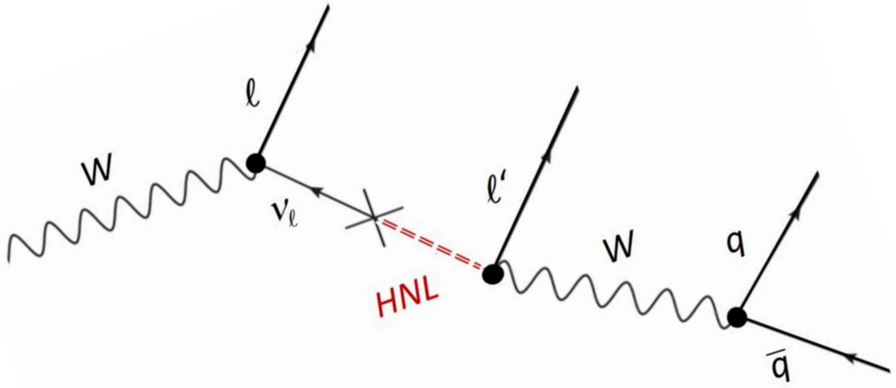
LLPs beyond the SM:

Some BSM scenarios which can include LLPs:

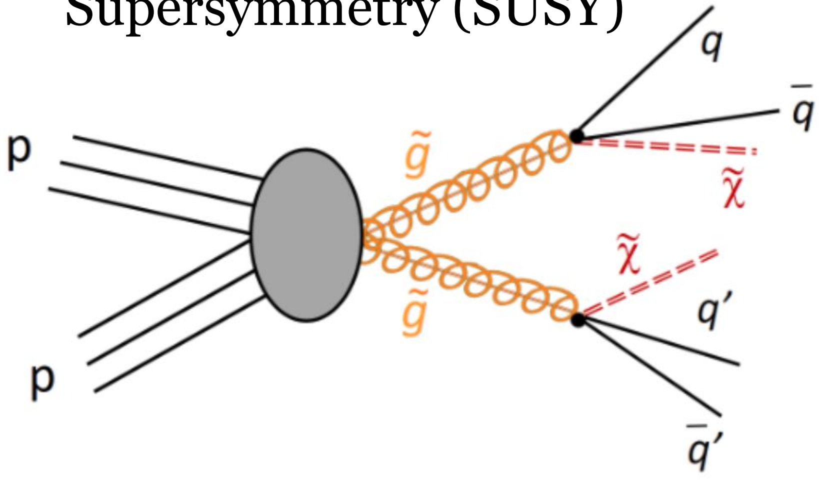
Hidden Sector particles



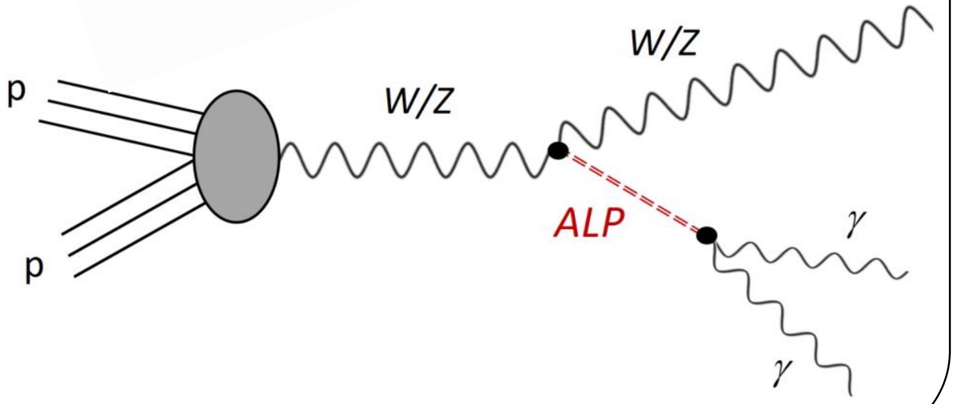
Heavy Neutral Leptons (HNLs)



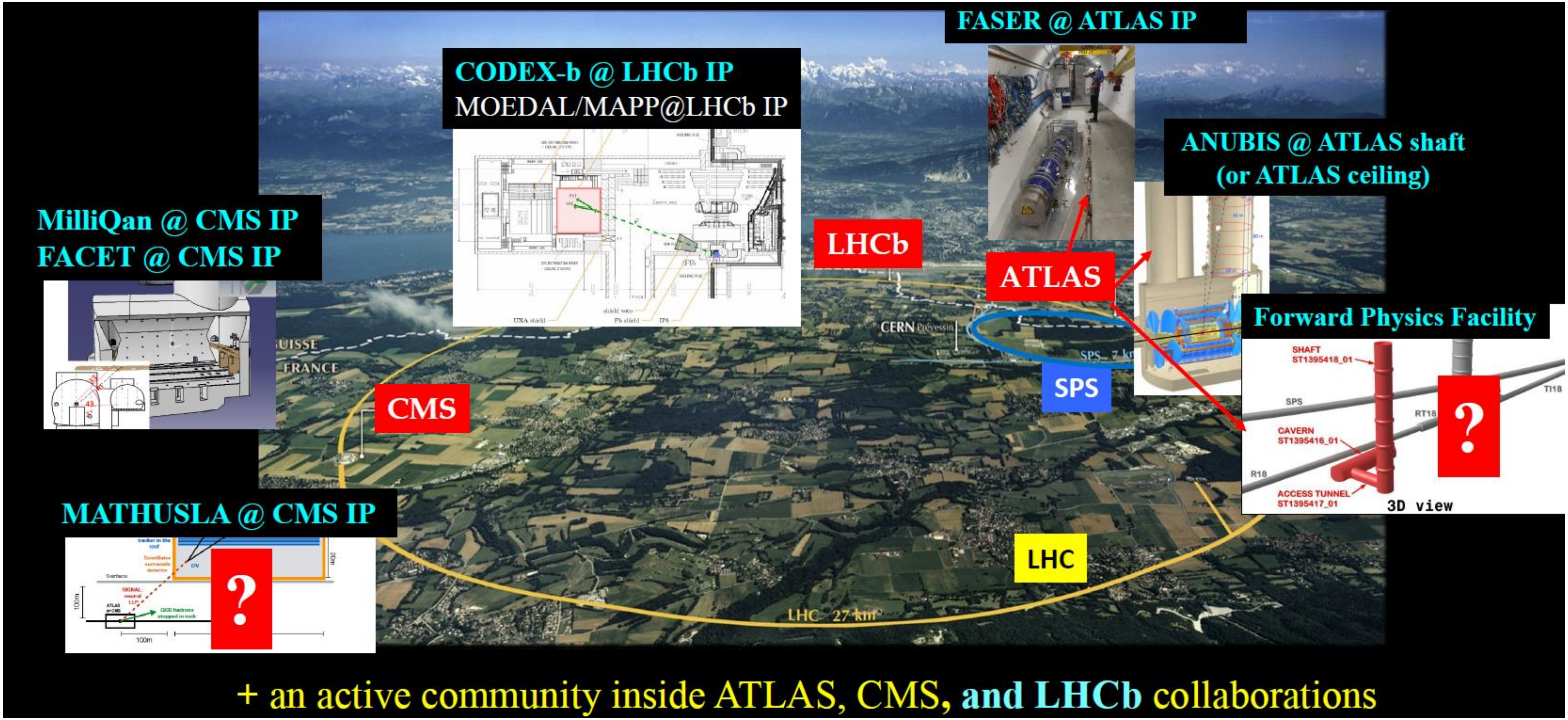
Supersymmetry (SUSY)



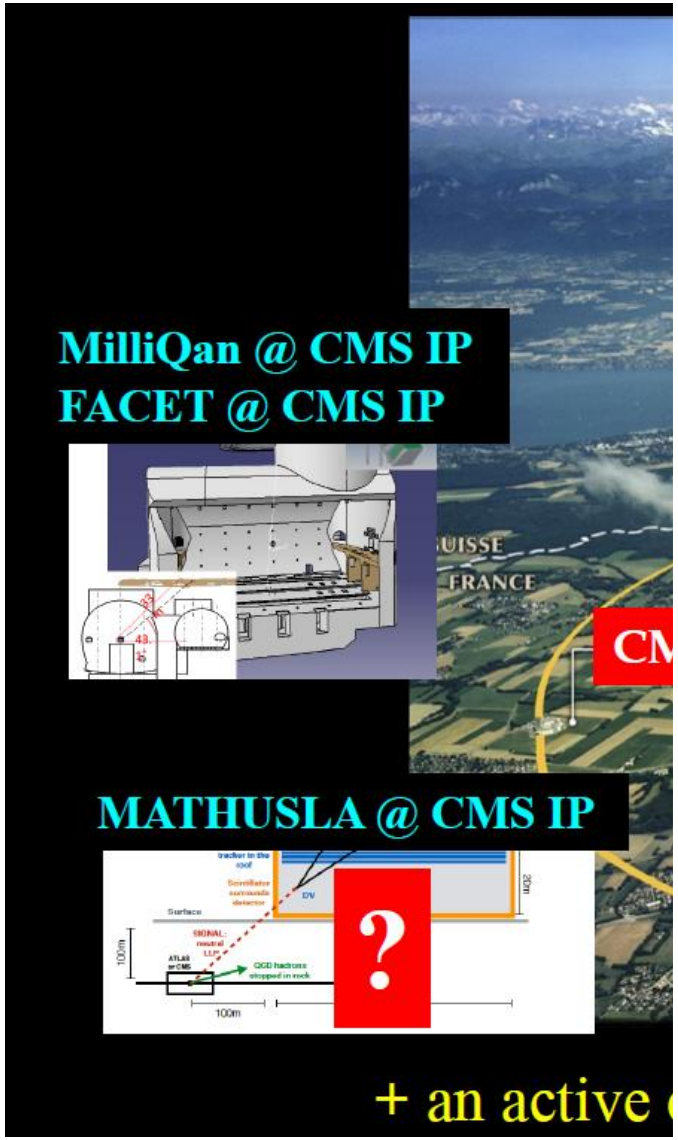
Axion-Like Particles (ALPs):



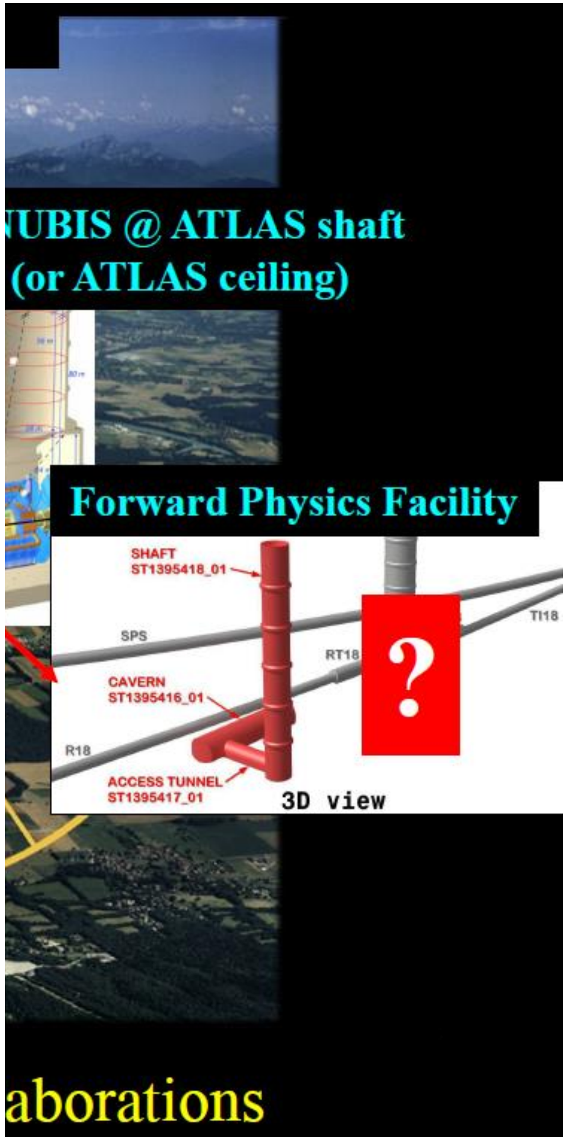
The Long-Lived Particle projects at the LHC



The Long-Lived Particle projects at the LHC



Experiment	lab	beam	particle yield/$\mathcal{L}$	technique	portals	timescale
current						
ATLAS [1382]	CERN	pp, 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Belle II [1219]	KEK	e^+e^-, 11 GeV	up to 50 ab^{-1}	visible, invis.	(1,2,3,4)	2035
CMS [1383]	CERN	pp, 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Dark(Spin)Quest [1256]	FNAL	p, 120 GeV	$10^{18} \to 10^{20}$	visible	(1,2,3,4)	2024
FASER [1052]	CERN	pp, 14 TeV	150 fb^{-1}	visible	(1,2,3,4)	2025
LHCb [1384]	LHC	pp, 13-14 TeV	up to 300 fb^{-1}	visible	(1,2,3,4)	2042
MicroBooNE [1385]	FNAL	p, 120 GeV (NuMi)	$\sim 7 \times 10^{20}$ pot	visible	(2,4)	2015-2021
NA62 [1174]	CERN	K^+, 75 GeV	a few 10^{13} K decays	visible, invis.	(1,2,3,4)	2025
NA62-dump [1386]	CERN	p, 400 GeV	$\sim 10^{18}$ pot	visible	(1,2,3,4)	2025
NA64$_e$ [1387]	CERN	e^-/e^+, 100 GeV	up to $1 \cdot 10^{13}$ e^-/e^+	$\not{E}$, visible	(1,3)	$<$ 2032
PADME [1300]	LNF	e^+, 550 MeV	$5 \cdot 10^{12}$ e^+ot	missing mass	(1)	$<$ 2023
T2K-ND280 [1388]	JPARC	p, 30 GeV	10^{21} pot	visible	(4)	running
proposed						
BDX [1389]	JLAB	e^-, 11 GeV	$\sim 10^{22}$ eot/year	recoil e	(1,3)	2024-2025
CODEX-b [1030]	CERN	pp, 14 TeV	300 fb^{-1}	visible	(1,2,3,4)	2042
Dark MESA [1390]	Mainz	e^-, 155 MeV	150 μA	visible	(1)	$<$ 2030
FASER2 [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
FLaRE [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible, recoil	(1)	2042
FORMOSA [1068]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1)	2042
Gamma Factory [1391]	CERN	photons	up to 10^{25} γ/year	visible	(1,3)	2035-2038?
HIKE-dump [1392, 1191]	CERN	p, 400 GeV	$5 \cdot 10^{19}$ pot	visible	(1,2,3,4)	<2038
HIKE-K$^+$ [1392, 1191]	CERN	K^+, 75 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2038
HIKE-K$_L$ [1392, 1191]	CERN	K_L, 40 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2042
LBND (DUNE) [1393]	FNAL	p, 120 GeV	$\sim 10^{21}$ pot	recoil e, N	(1,2,3,4)	$<$ 2040
LDMX [1271]	SLAC	e^-, 4,8 GeV	$2 \cdot 10^{16}$ eot	$\not{p}$, visible	(1)	$<$ 2030
M^3 [1394]	FNAL	μ, 15 GeV	10^{10} (10^{13}) mot	$\not{p}$	(1)	proposed
MATHUSLA [1395]	CERN	pp, 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
milliQan [1070]	CERN	pp, 14 TeV	0.3-3 ab^{-1}	visible	(1)	$<$ 2032
MoeDAL/MAPP [1396]	CERN	pp, 14 TeV	30 fb^{-1}	visible	(4)	$<$ 2032
Mu3e [1397]	PSI	29 MeV	$10^8 \to 10^{10}\mu$/s	visible	(1)	$<$ 2038?
NA64$_\mu$ [1398]	CERN	μ, 160 GeV	up to 2×10^{13} mot	$\not{p}$	(1)	$<$ 2032
PIONEER [1399]	PSI	55-70 MeV, π^+	$0.3 \cdot 10^6 \pi$/s	visible	(4)	phase I approved
SBND [1400]	FNAL	p, 8 GeV	$6 \cdot 10^{20}$ pot	recoil Ar	(1)	$<$ 2030
SHADOWS [1401]	CERN	p, 400 GeV	$5 \cdot 10^{19}$ pot	visible	(2,3,4)	<2038
SHiP [1402]	CERN	p, 400 GeV	$2 \cdot 10^{20}$ pot	visible, recoil	(1,2,3,4)	<2038



Long-lived particles (LLPs)

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10.1088/1361-6633/ac4649

10.3389/fdata.2022.1008737

Review of opportunities for new long-lived particle triggers in Run 3 of the Large Hadron Collider

Produced for the LPCC Long-Lived Particles Working Group.

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Report on Progress

Unleashing the full power of LHCb to probe stealth new physics

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CrossMark

Abstract

In this paper, we describe the potential of the LHCb experiment to detect stealth physics. This refers to dynamics beyond the standard model that would elude searches that focus on energetic objects or precision measurements of known processes. Stealth signatures include long-lived particles and light resonances that are produced very rarely or together with overwhelming backgrounds. We will discuss why LHCb is equipped to discover this kind of physics at the Large Hadron Collider and provide examples of well-motivated theoretical models that can be probed with great detail at the experiment.

Keywords: LHCb, stealth physics, BSM physics, hidden sectors, long-lived particles, dark matter

(Some figures may appear in colour only in the online journal)

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Effect of the high-level trigger for detecting long-lived particles at LHCb

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Long-lived particles (LLPs) show up in many extensions of the Standard Model, but they are challenging to search for with current detectors, due to their very displaced vertices. This study evaluated the ability of the trigger algorithms used in the Large Hadron Collider beauty (LHCb) experiment to detect long-lived particles and attempted to adapt them to enhance the sensitivity of this experiment to undiscovered long-lived particles. A model with a Higgs portal to a dark sector is tested, and the sensitivity reach is discussed. In the LHCb tracking system, the farthest tracking station from the collision point is the scintillating fiber tracker, the SciFi detector. One of the challenges in the track reconstruction is to deal with the large amount of and combinatorics of hits in the LHCb detector. A dedicated algorithm has been developed to cope with the large data output. When fully implemented, this algorithm would greatly increase the available statistics for any long-lived particle search in the forward region and would additionally improve the sensitivity of analyses dealing with Standard Model particles of large lifetime, such as K^0_S or Λ^0 hadrons.

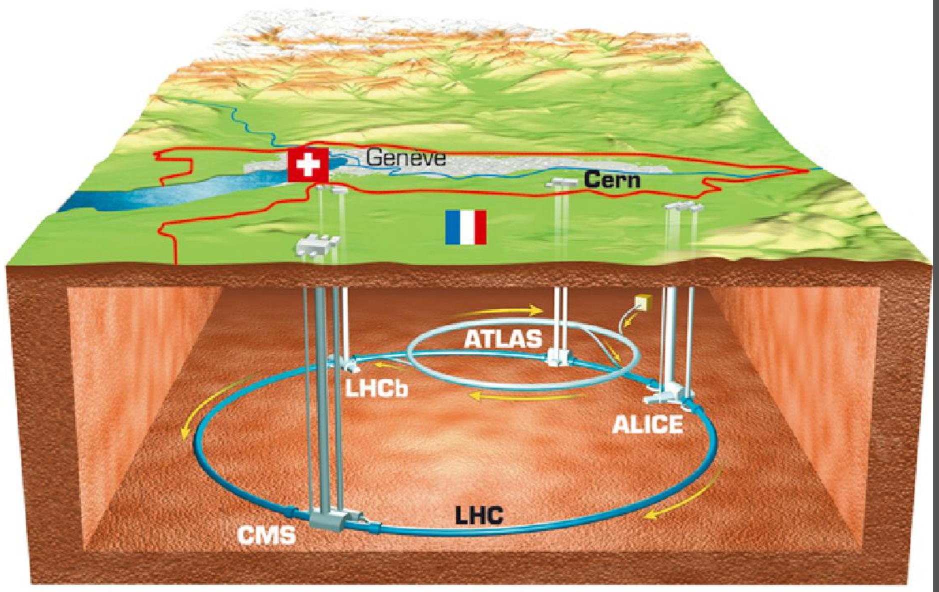
Development of reconstruction strategies and algorithms at high level trigger to detect long-lived particles

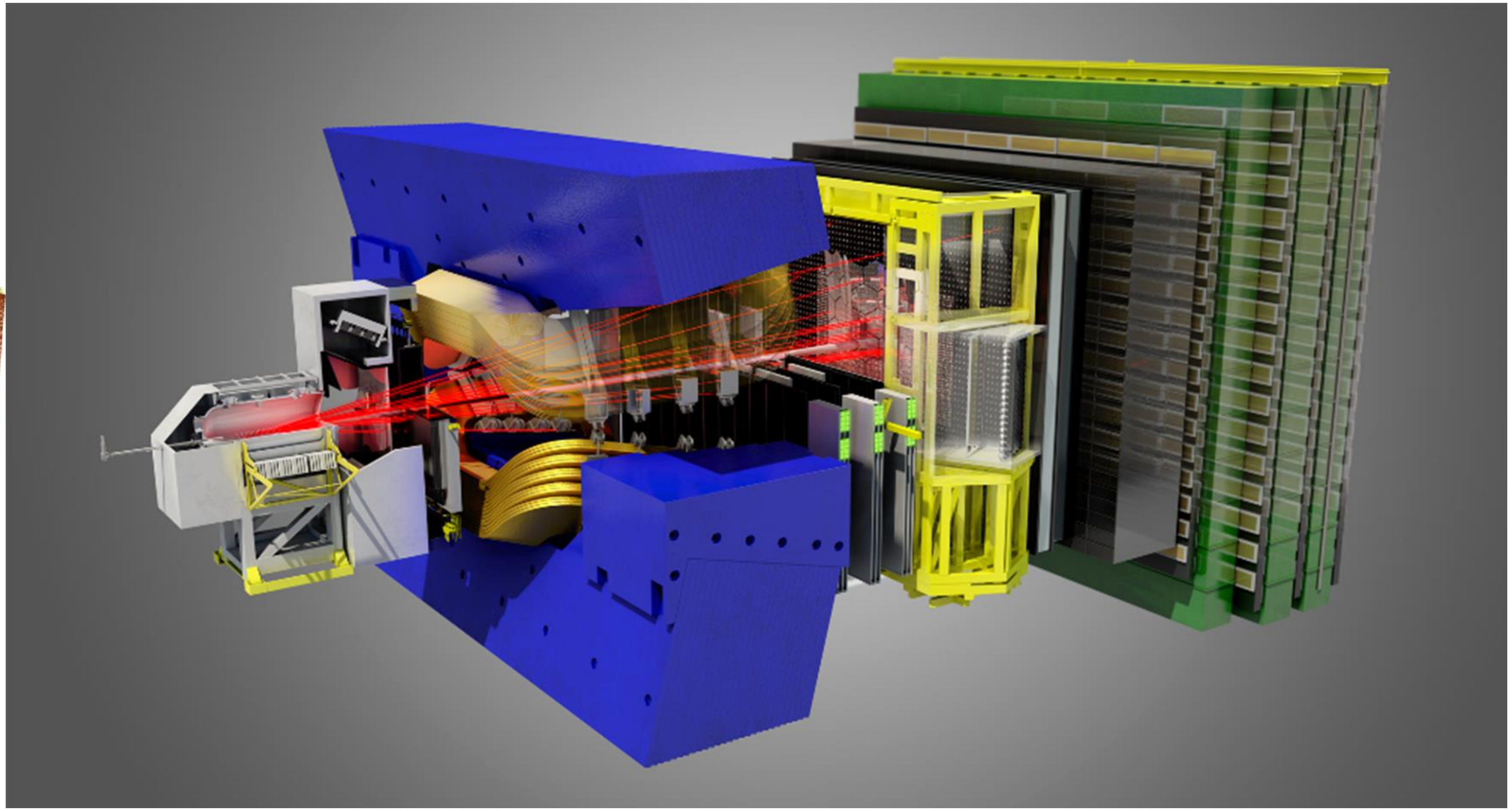
Introduction: the LHCb experiment

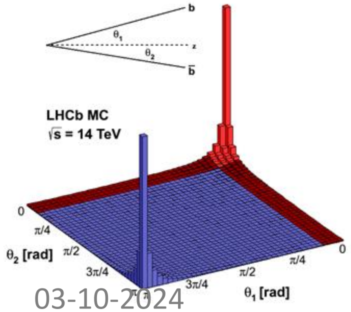
Introduction

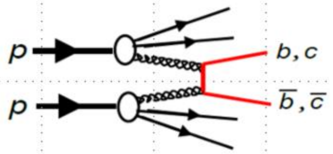
History of LHCb: 10.1140/epjh/s13129-021-00002-z

LHCb: a general purpose spectrometer in the forward direction (2<η<5), optimized for high-precision heavy--flavour physics.







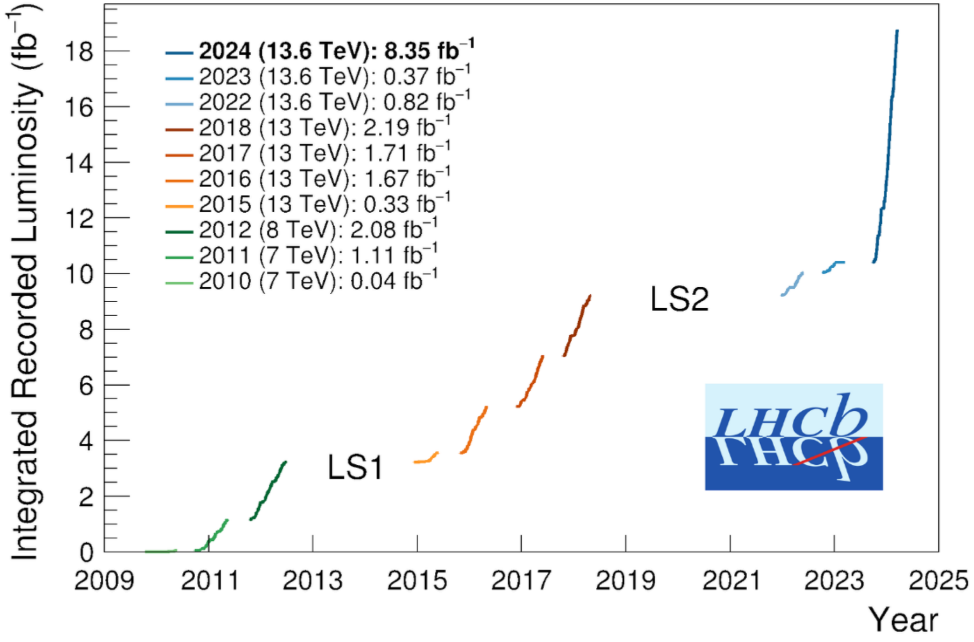


$b\bar{b}$ production cross-section ~ 600 μb at 13 TeV (300 μb at 7Tev)

~ 4% of the solid angle (2 < η < 5),
~27% of the b hadron production

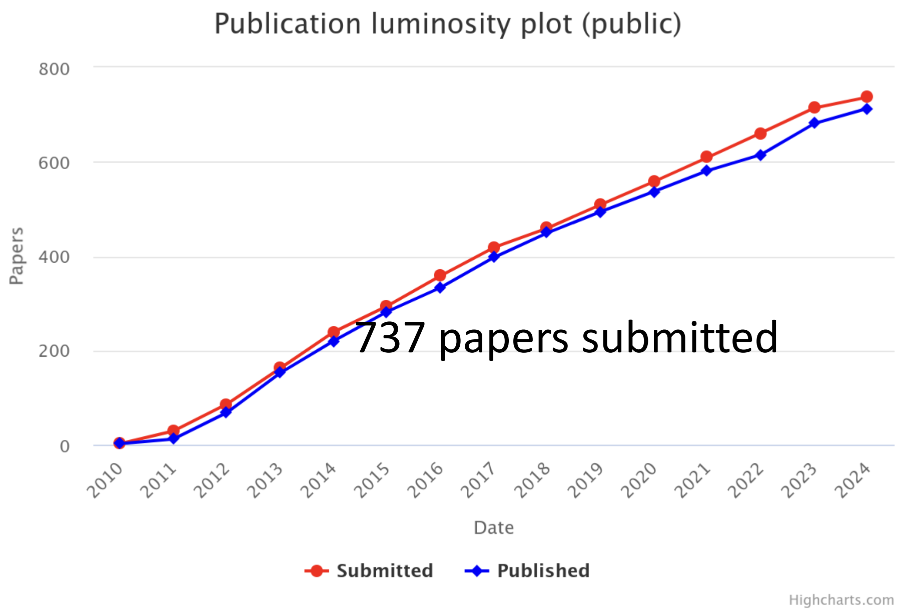
Introduction

LHCb was originally designed for the study of CP violation and rare decays in beauty and charm → and now a general purpose detector

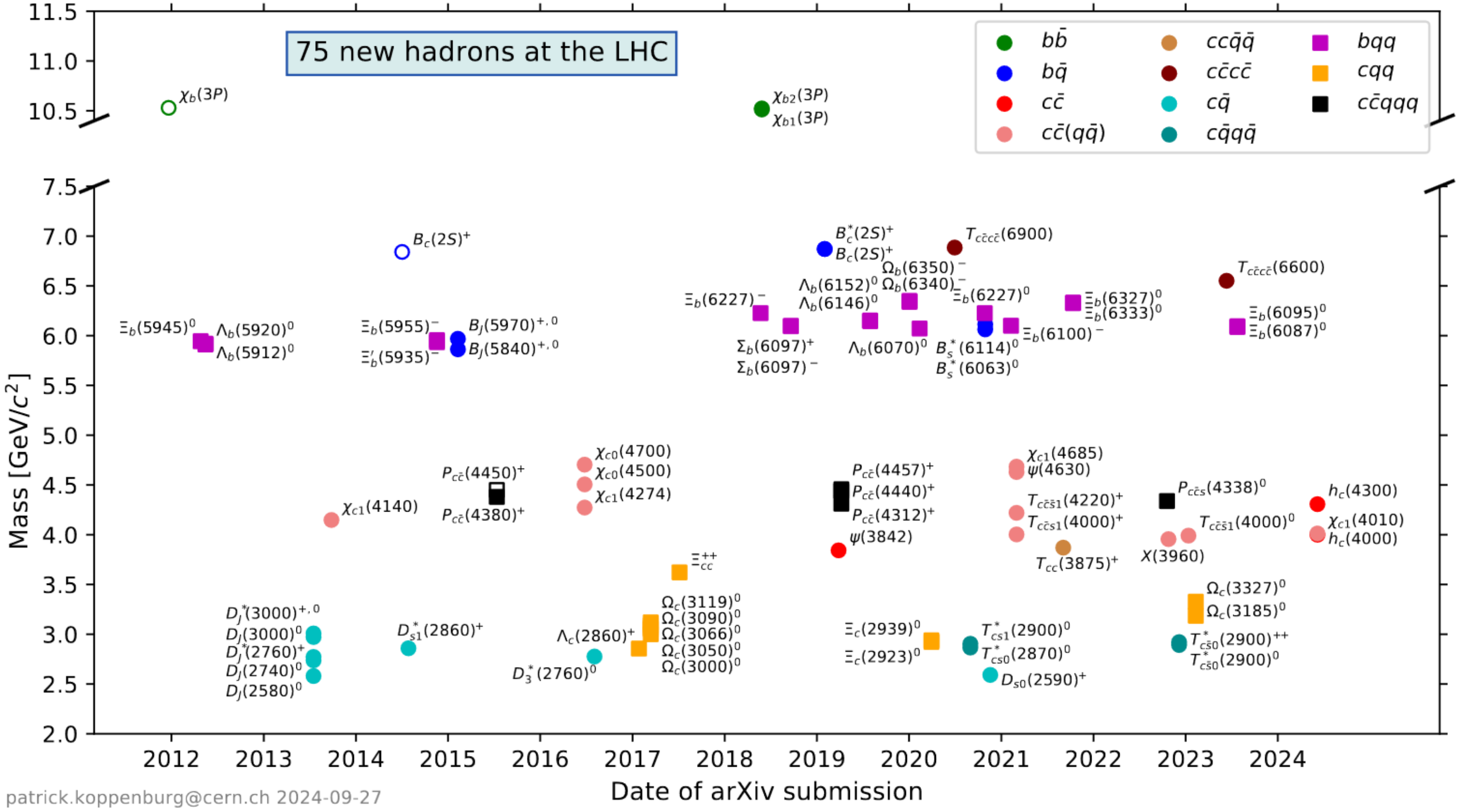


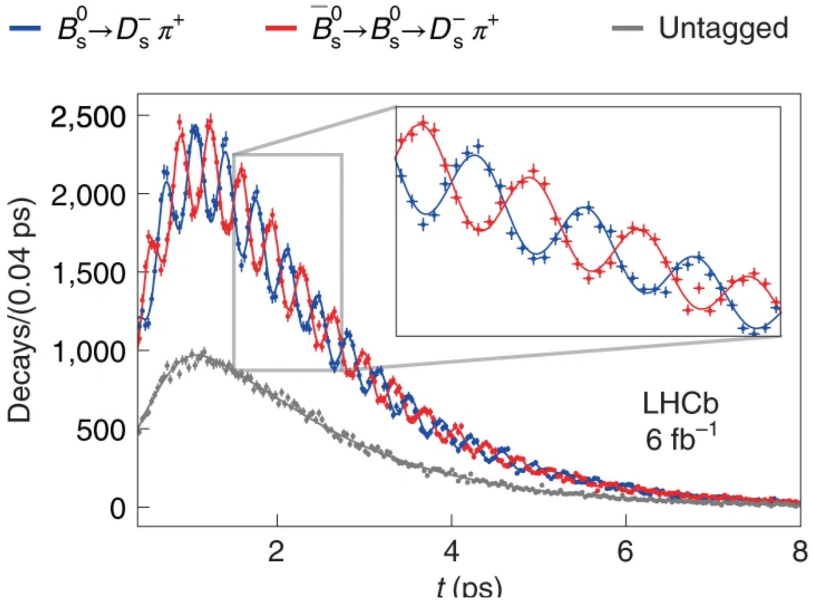
Run 1+2: 9 fb^{-1} of pp collisions (+ pPb, PbPb, fixed-target mode)
And about ~9 fb^{-1} in 2024 itself so far

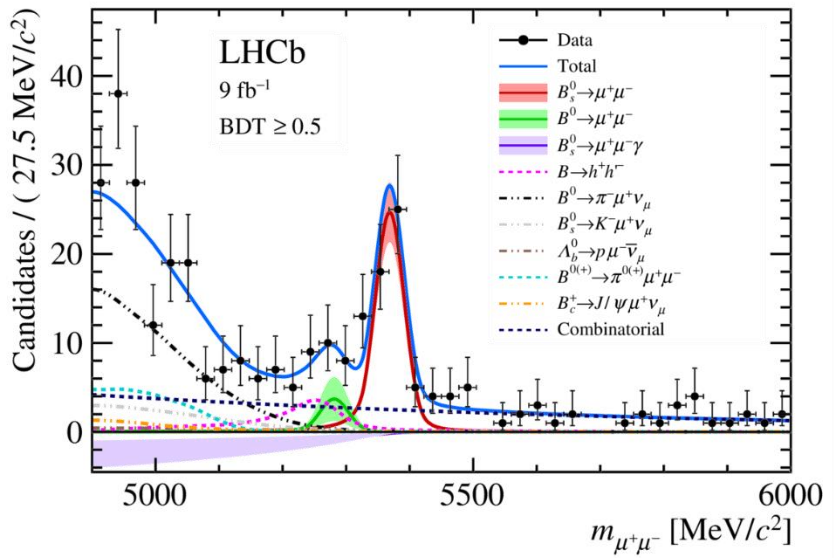
- CP Violation
- Rare decays
- Charm
- Semileptonic
- Strange
- Spectroscopy
- EW & QCD
- Heavy ions
- Fixed target



The LHCb experiment: Physics highlights

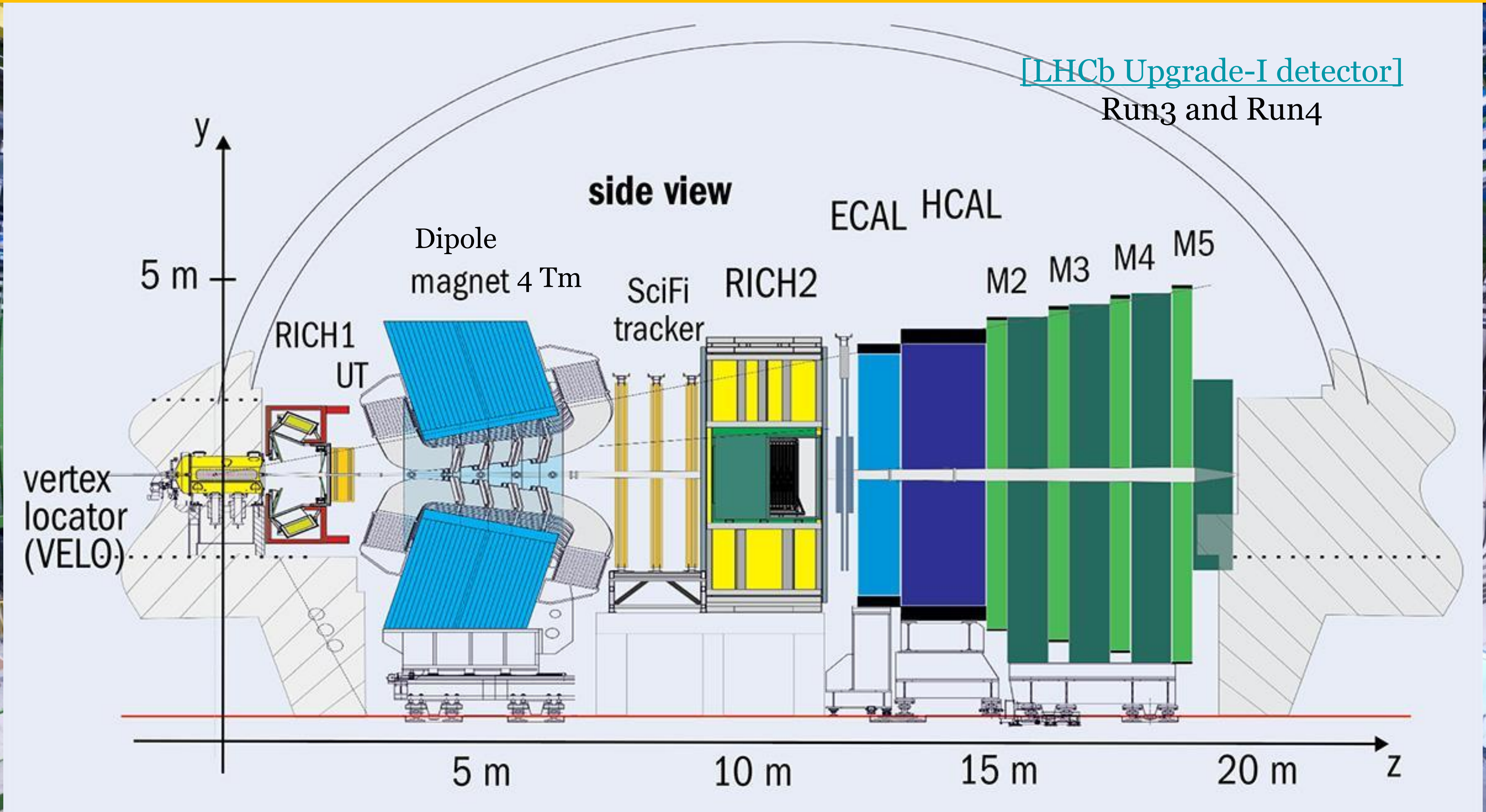






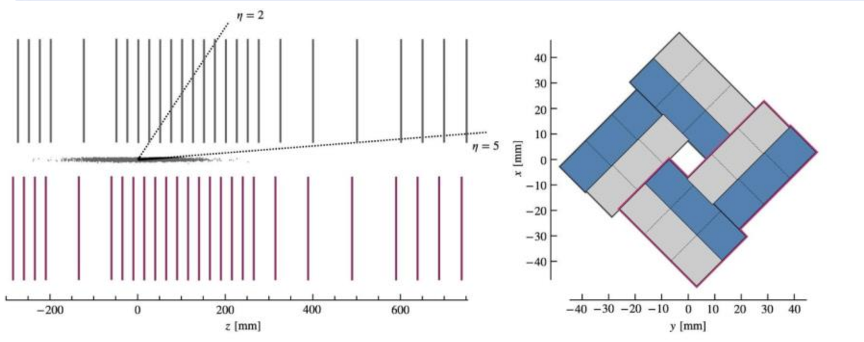
The LHCb experiment

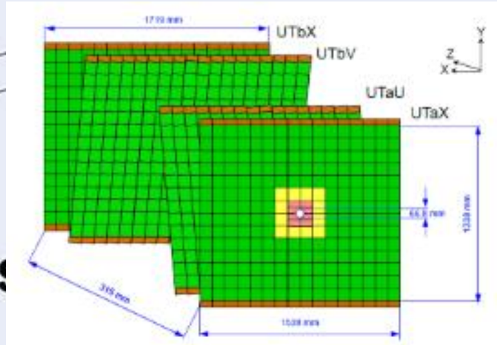
[CERN Courier: LHCb's momentous metamorphosis]

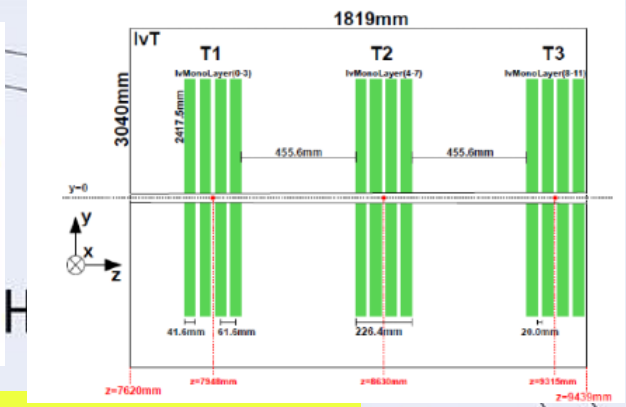


New detector with over 90% of active detector channels replaced

The LHCb experiment



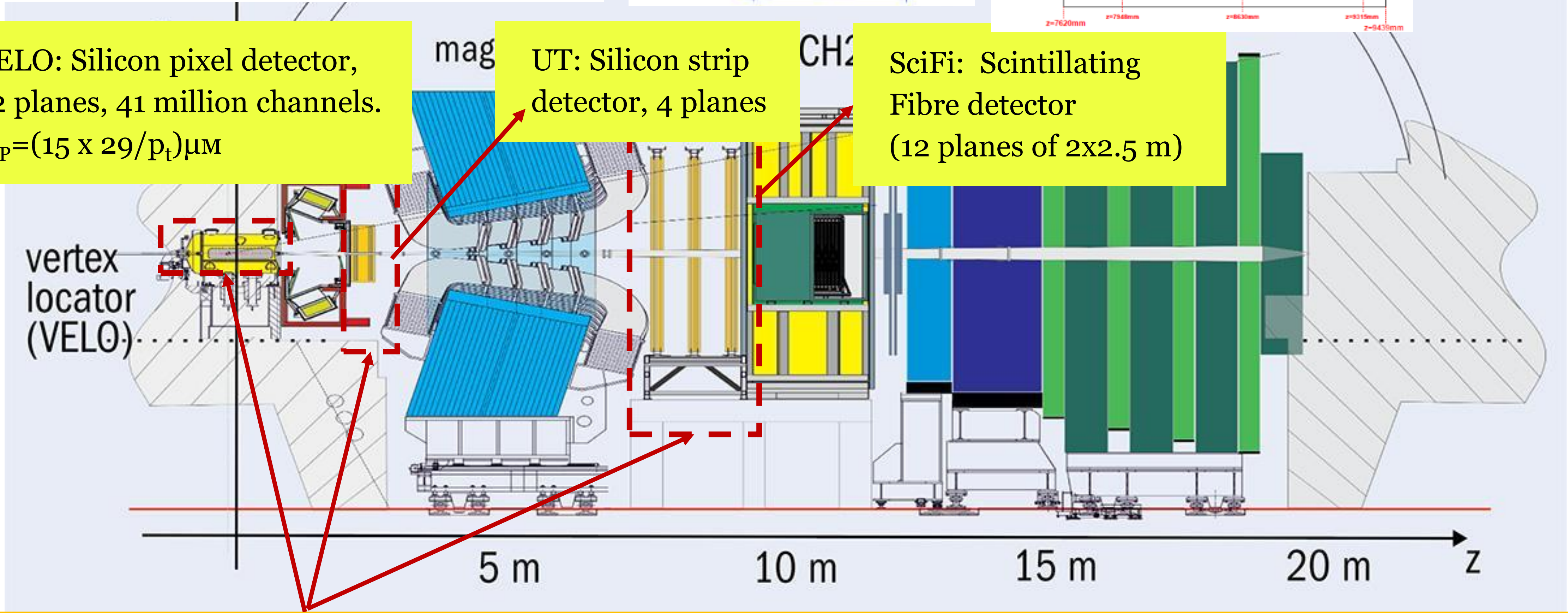




VELO: Silicon pixel detector,
52 planes, 41 million channels.
σ_{IP}=(15 x 29/p_t)μм

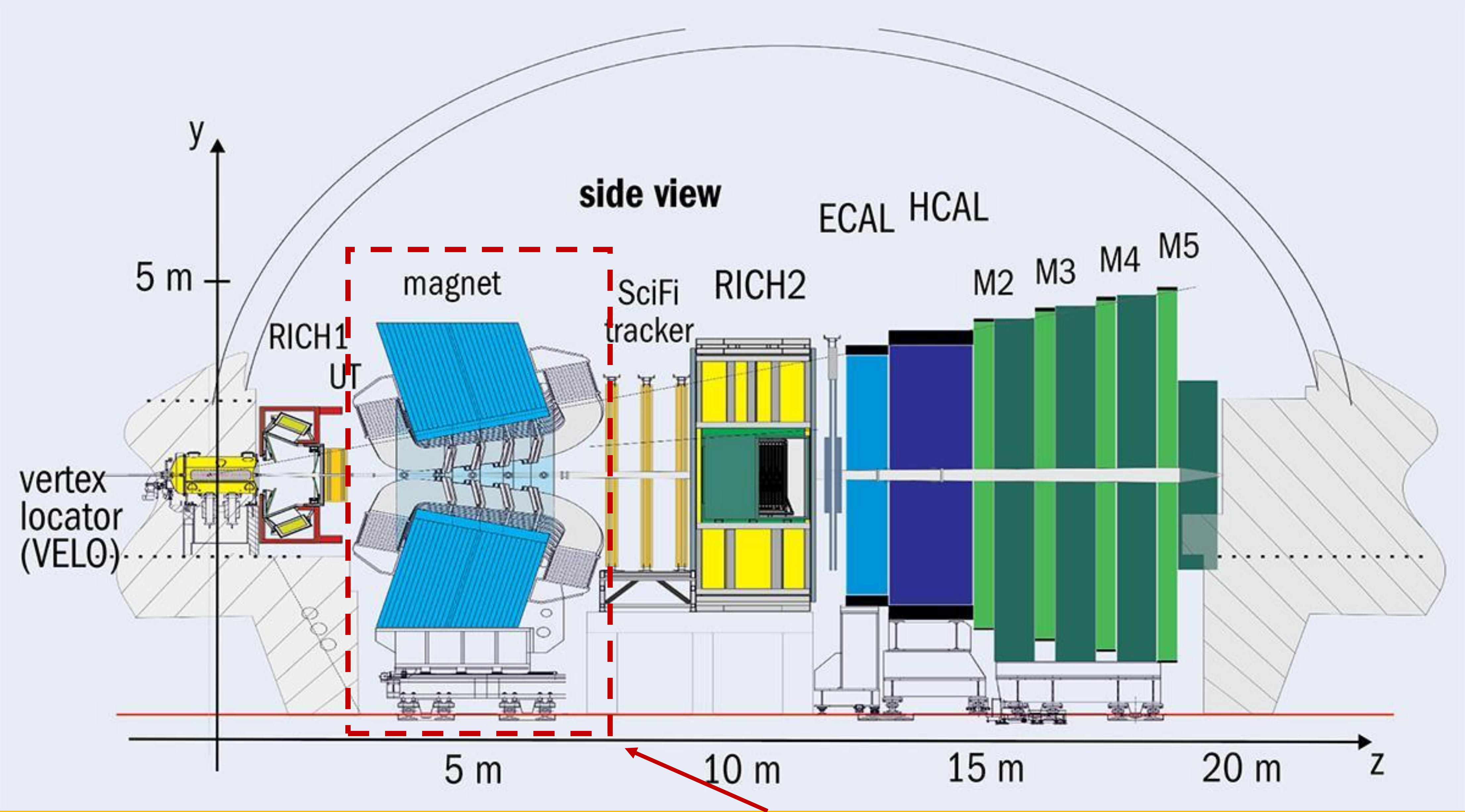
UT: Silicon strip
detector, 4 planes

SciFi: Scintillating
Fibre detector
(12 planes of 2x2.5 m)



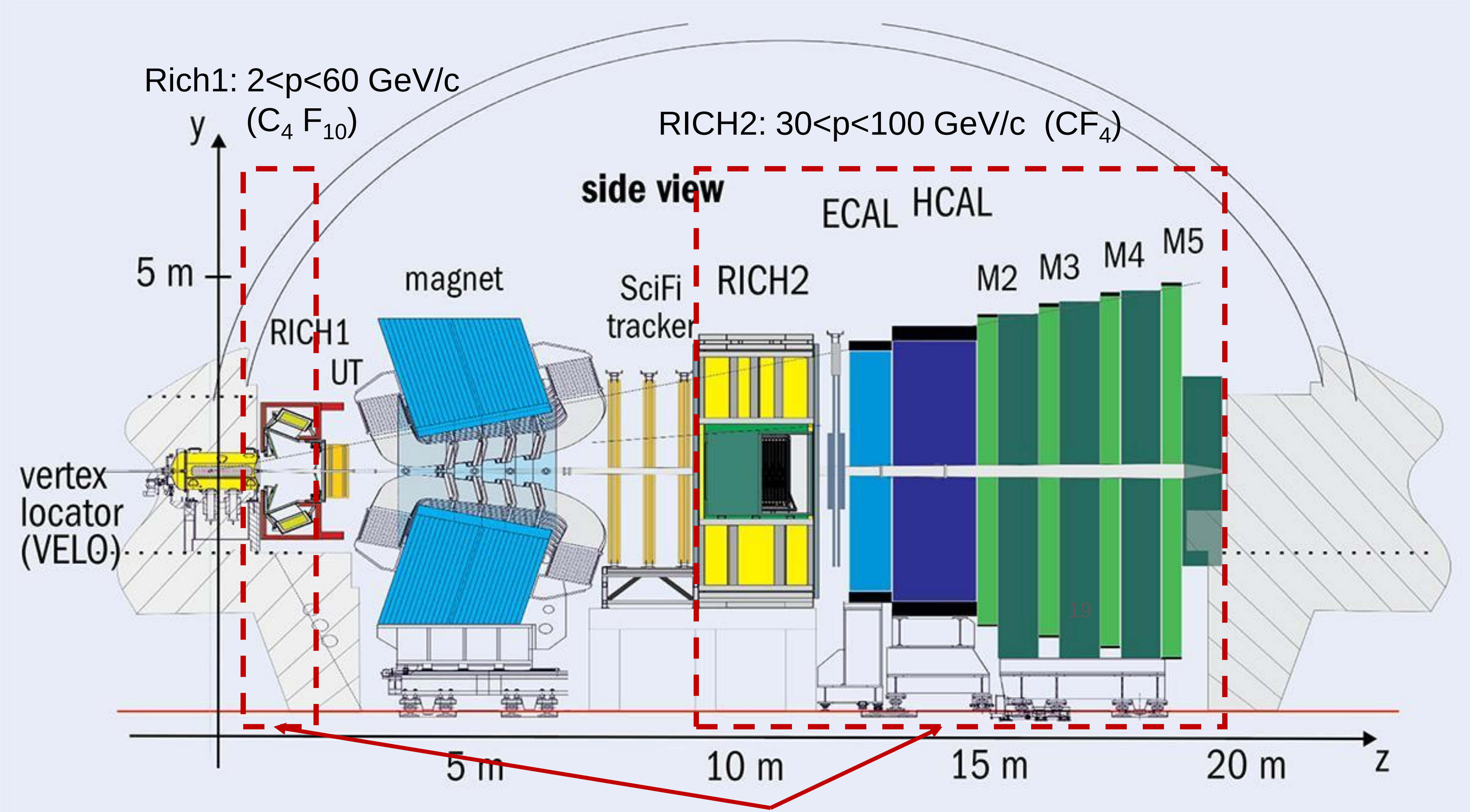
Tracking detectors: detect charged particles and localise the decay vertex

The LHCb experiment



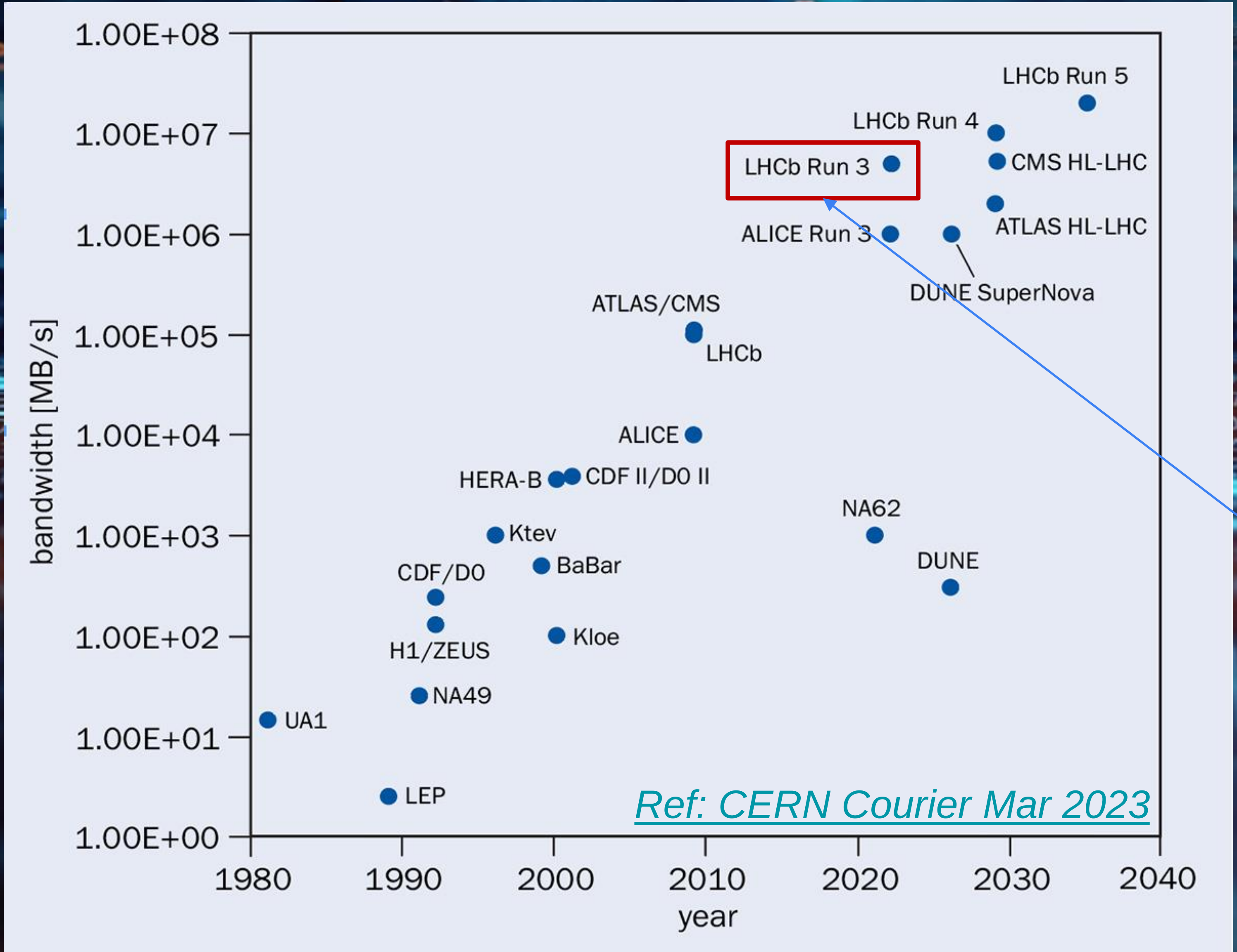
Dipole Magnet (~4 Tm): bend charged particles path to measure momentum

The LHCb experiment



RICH1 and 2, calorimeters, and muon chambers for particle identification

Computing Challenges (The problem now)



40 Tbits/sec
~ 115 Peta bytes per day

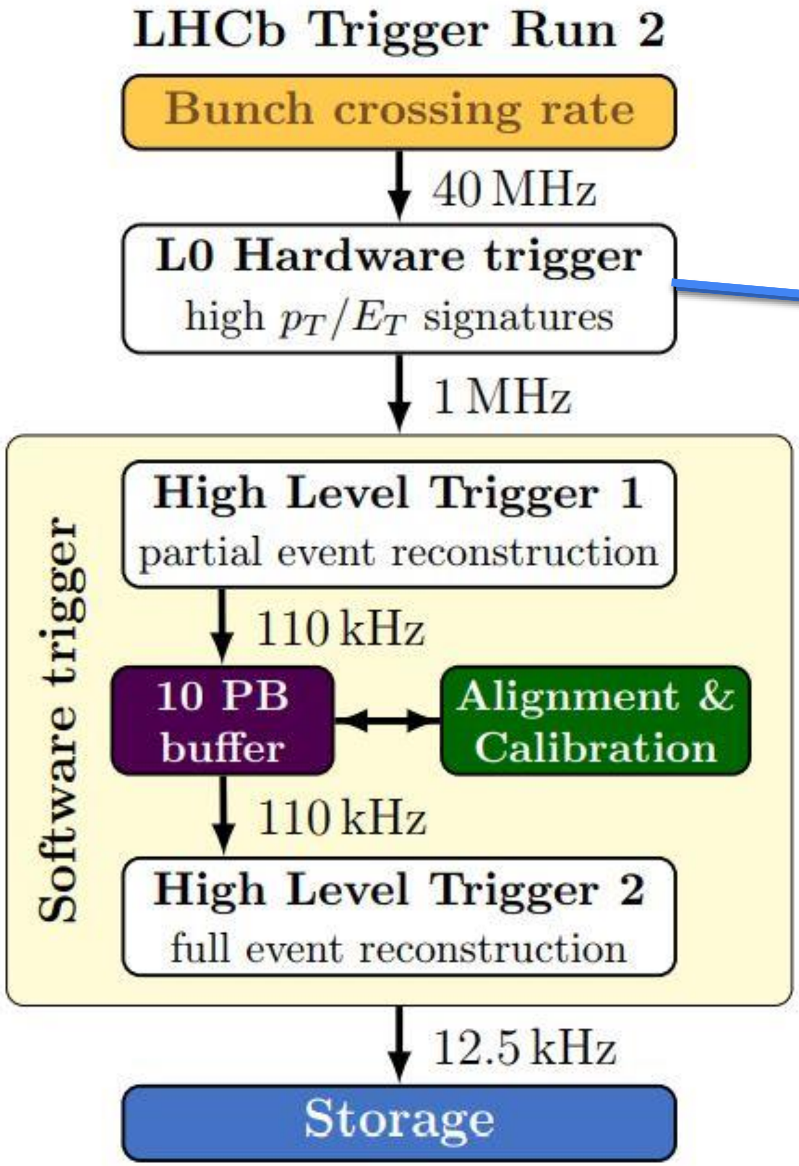
The biggest real-time data processing challenge in HEP

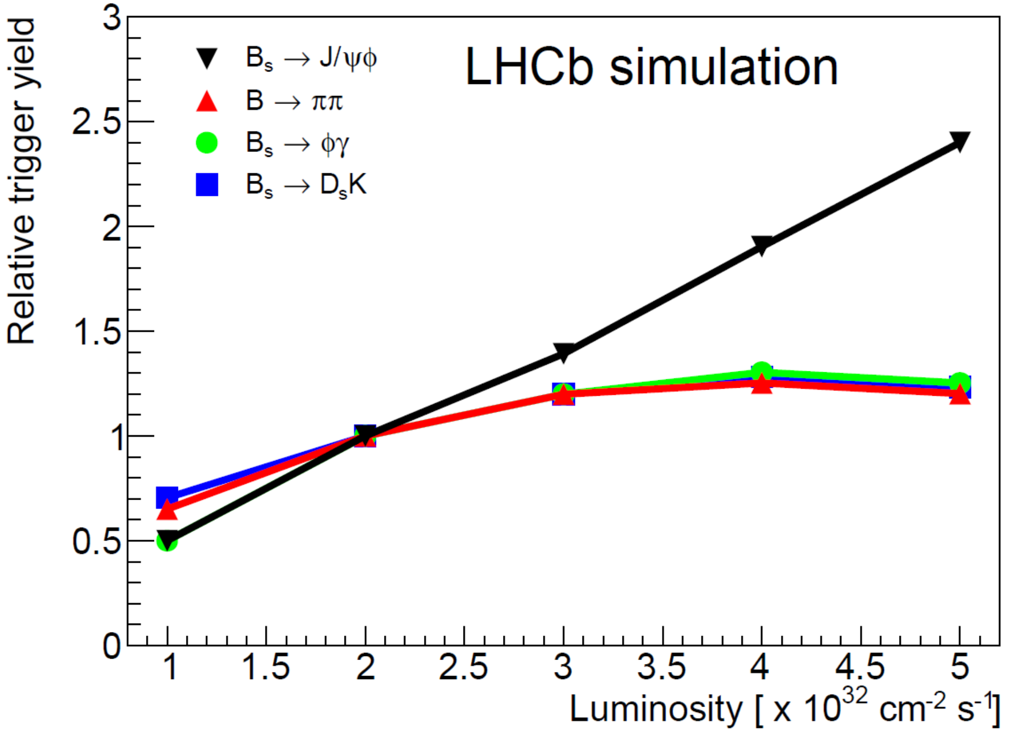
What to keep and what to discard ?

we have to be very careful
with what we dismiss..

Real Time Analysis

The LHCb experiment: Trigger system

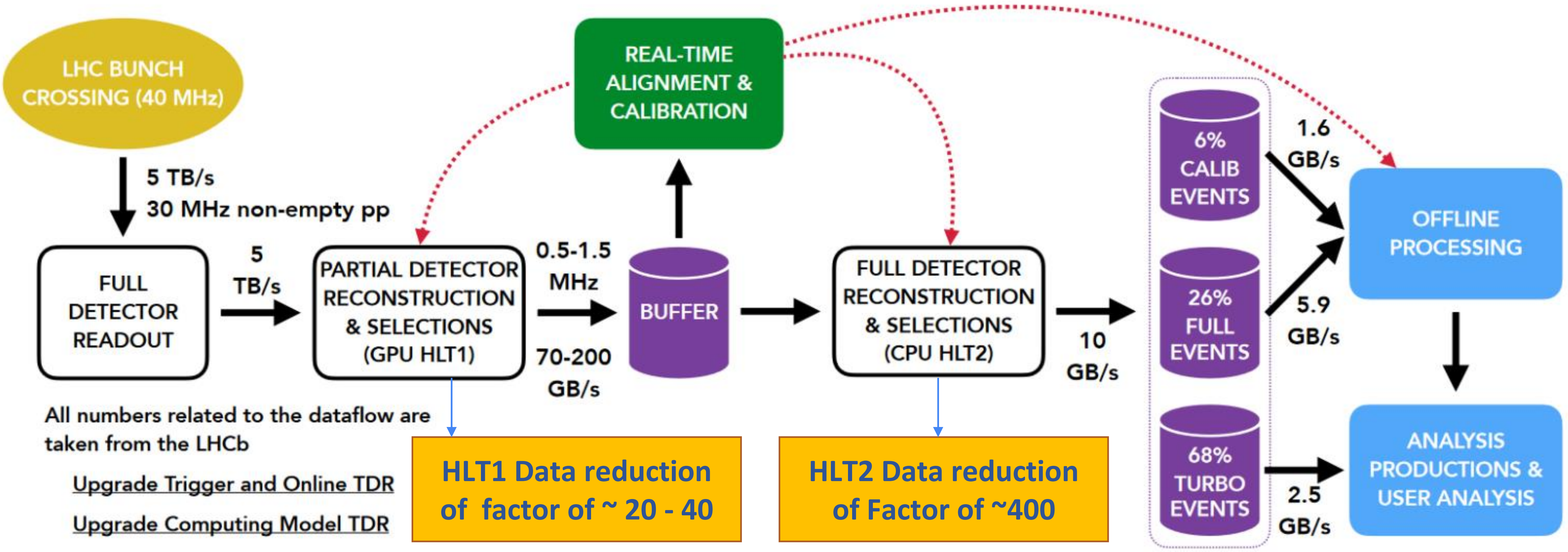




- At high luminosities, hardware trigger cannot cope with the event rate and starts rejecting interesting events.
- Need to study properties of events in real time of collision.

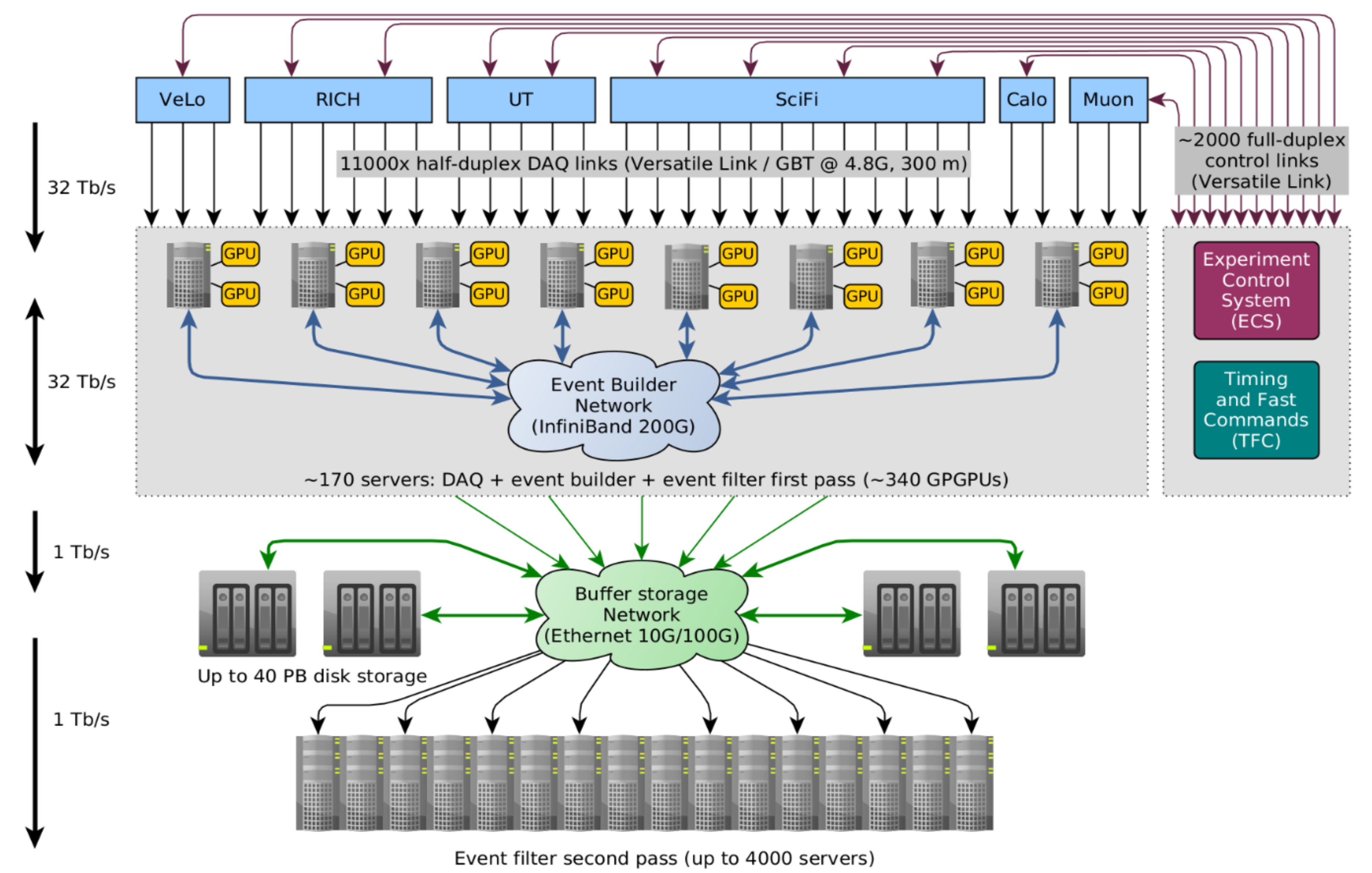
LHCb Run3 Trigger

Bandwidth [GB/s] ~ **Trigger output rate** [kHz] x **Average event size** [MB]



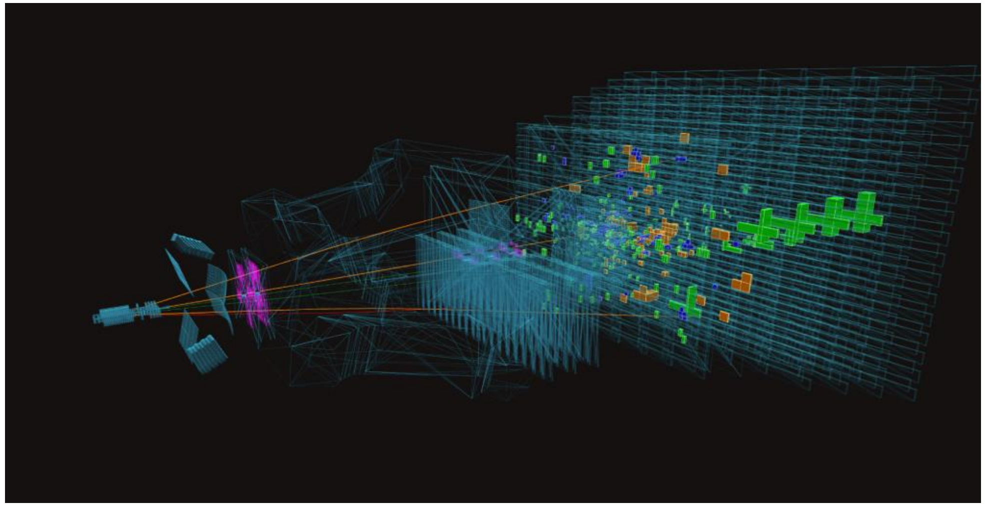
HLT1: Partial reconstruction of charged particle trajectories and few simple selection lines
HLT2: Full reconstruction and selection based on different decay chains and signatures
Must reduce without the loss in fidelity

LHCb Run3 Trigger



What is tracking and why do we need it ?

Track reconstruction (Tracking)

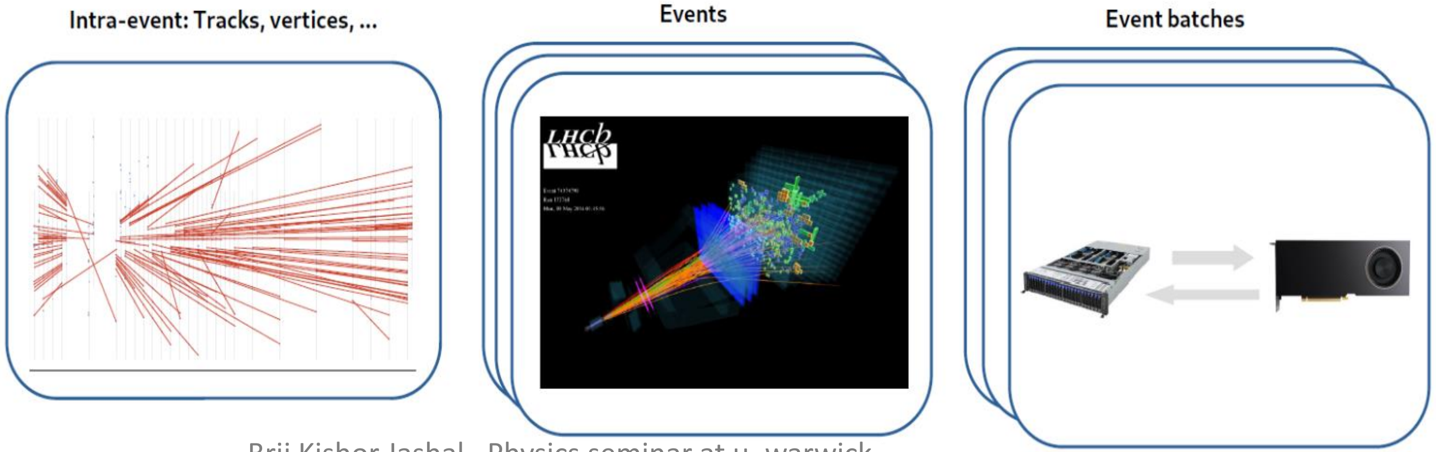


What

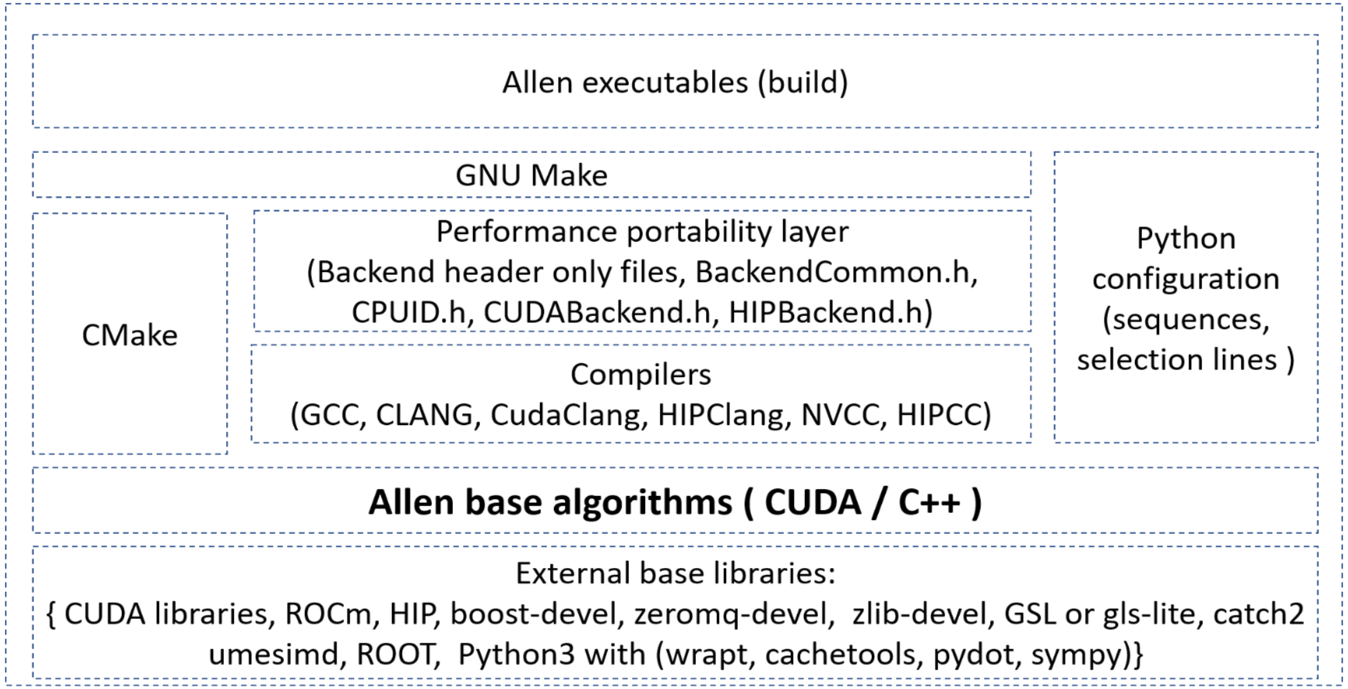
- Tracking deals with converting the signal from a subdetector (hits, clusters…) into a trajectory.
- Roughly speaking, two phases: pattern recognition and track fitting

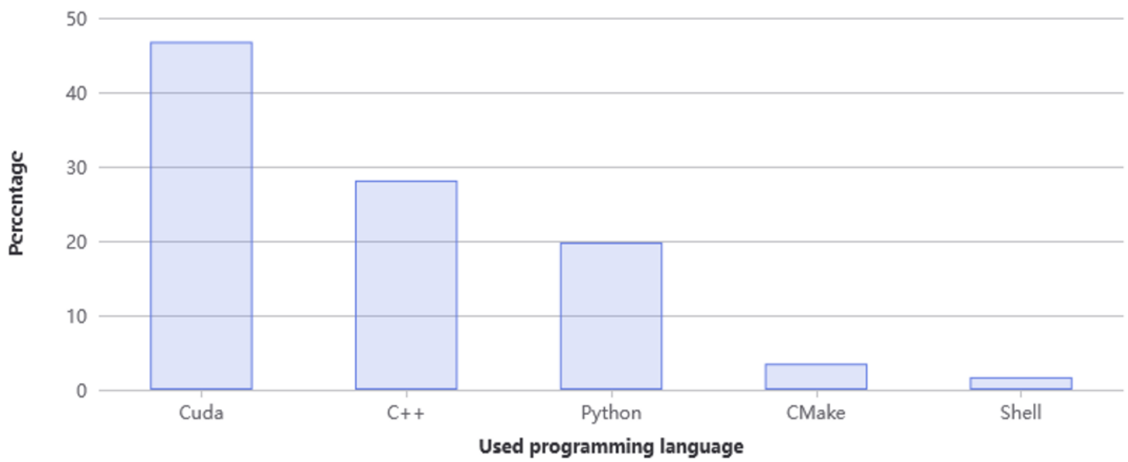
Why

- We need to reconstruct trajectories of particles in our detector to:
  - Build vertices, measure decay topologies;
  - Measure momenta → measure invariant masses, angular variables (so… do physics).



- Allen software project: Framework developed for processing LHCb´s HLT1 on GPUs
- Standalone software project: https://gitlab.cern.ch/lhcb/Allen
- Primarily developed using CUDA to process events in parallel and exploit data-parallelism within events
- Single Instruction Multiple Threads (SIMT) design with custom **performance portability layer.**

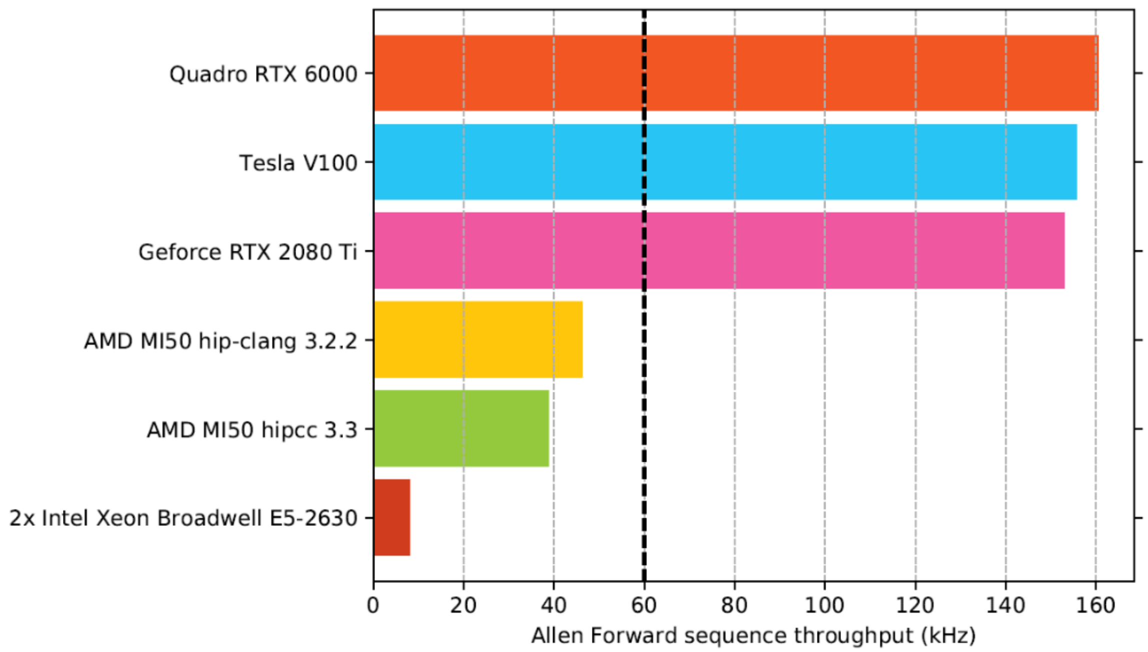




HLT1 framework: Performance Portability Layer (PPL)

Comput Softw Big Sci 4, 7 (2020)

Framework supports multiple platforms and architectures: Heterogeneous



allenpr BOT 6:33 PM

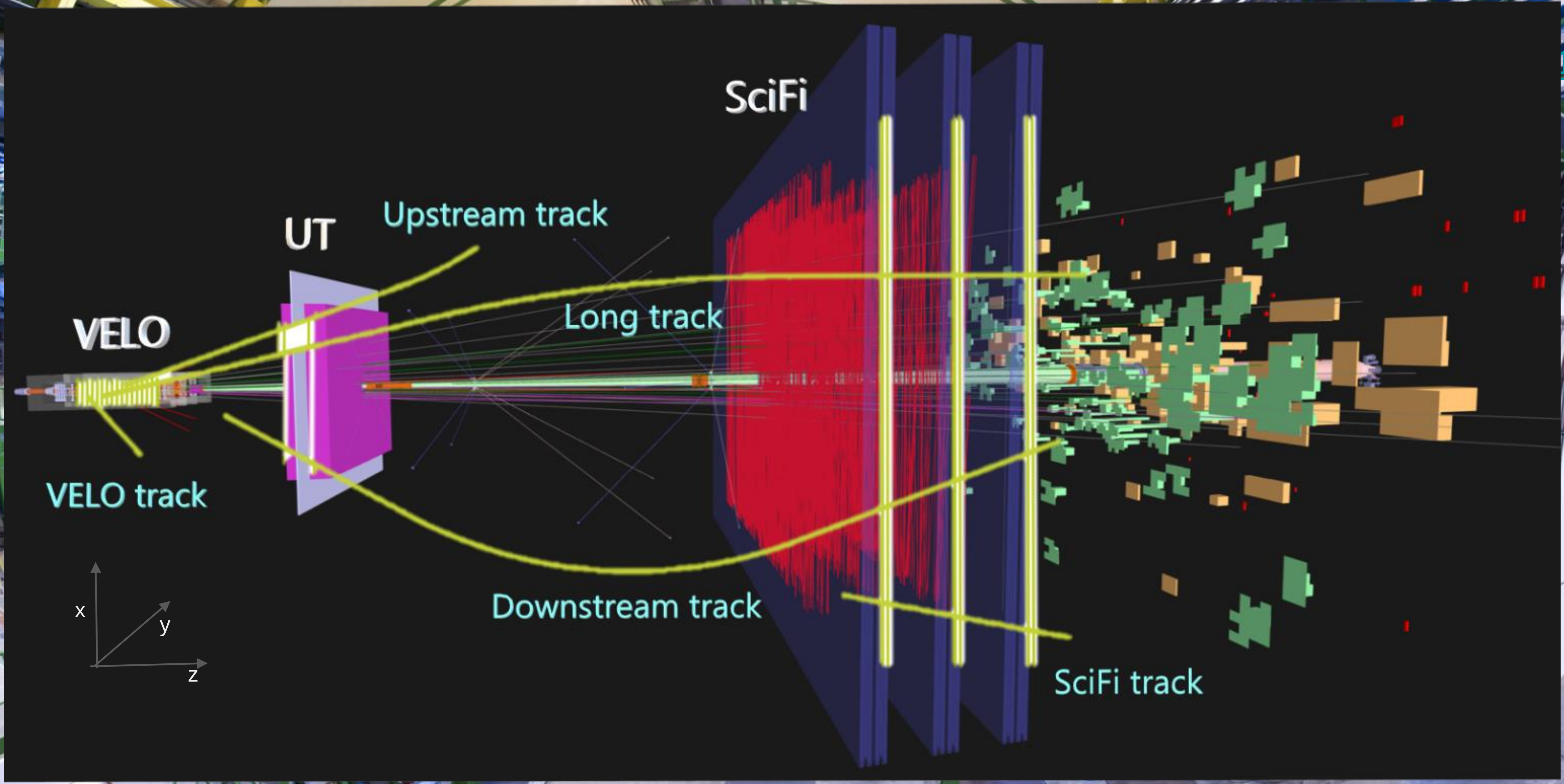
Throughput of branch `master (cba2475b)`, sequence `hlt1_pp_default` over dataset `upgrade-magdown-sim10-up08-30000000-digi_01_retinacluster` build options `default`:

NVIDIA GeForce RTX 3090	194.90 kHz (1.01x)
NVIDIA RTX A6000	193.36 kHz (1.02x)
NVIDIA RTX A5000	156.89 kHz (0.98x)
MI100	124.00 kHz (1.00x)
NVIDIA GeForce RTX 2080 Ti	123.29 kHz
AMD EPYC 7502 32-Core	21.33 kHz (1.00x)

20 40 60 80 100 120 140 160 180 200

Long-lived particles and Tracking

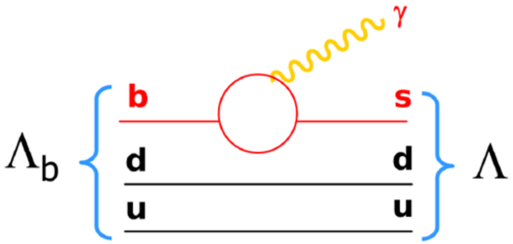
Tracking: LHCb track types

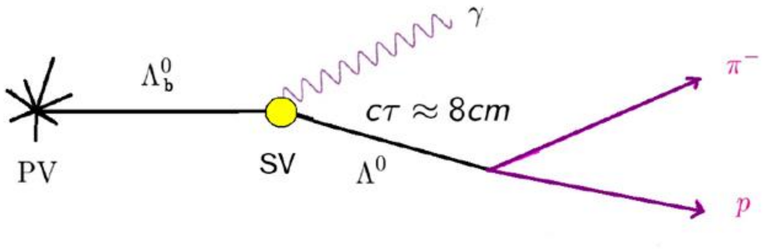


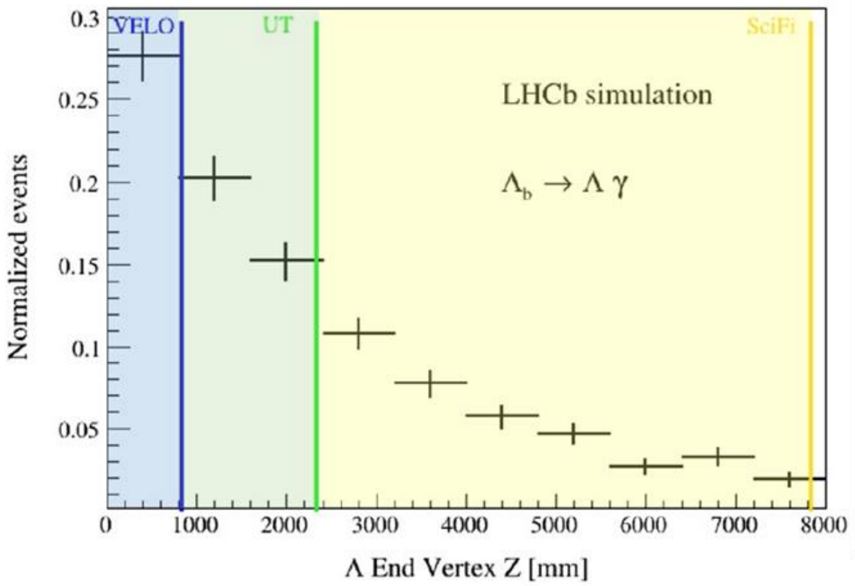
[16]

LLPs in SM

- Λ are decay products of b-baryon decays which have a rich spin structure





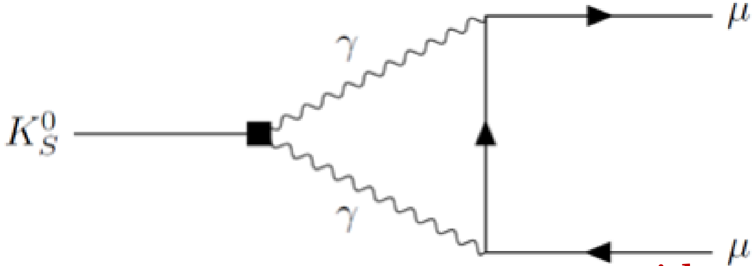


	LL	DD	TT	HLT1 eff (TOS)
Λ^0	12%	51%	37%	< 10%

without downstream

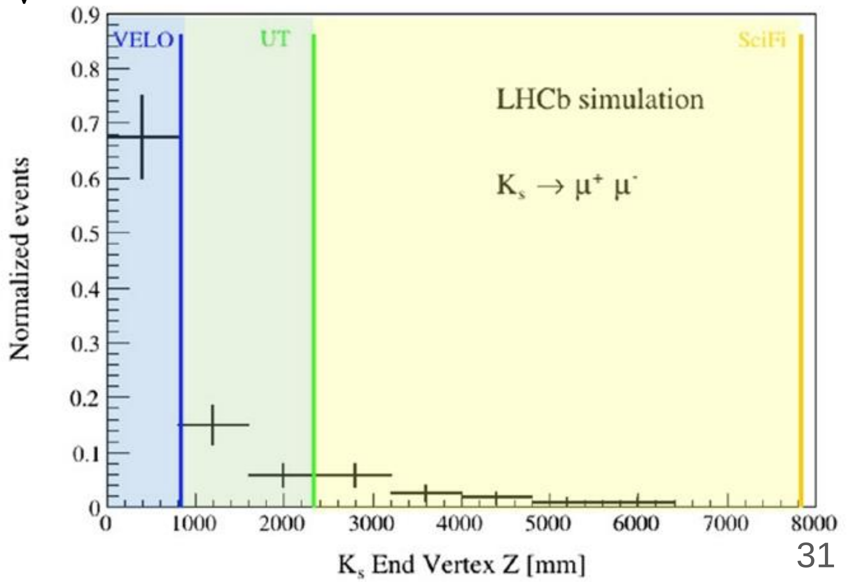
- K_s are common decay products in b and charm decays → important for CPV studies

$K_S \to \mu^+\mu^-$



without downstream

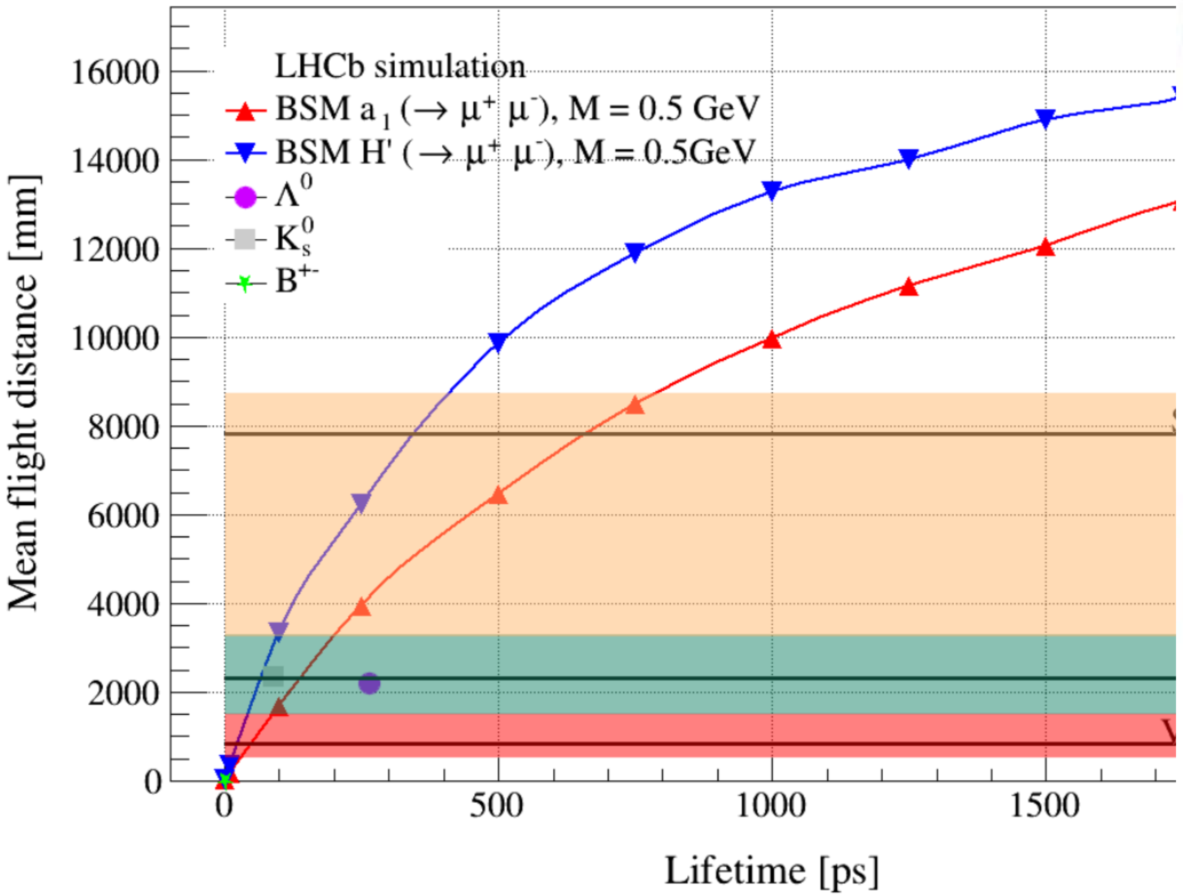
	LL	DD	TT	HLT1 eff (TOS)
K_s^0	46 %	38 %	16 %	< 25%

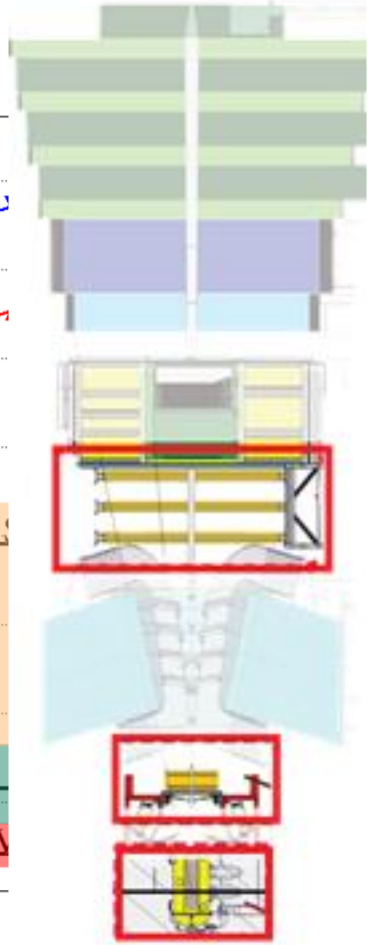


BSM/SM Long-lived particles and Tracking (Why ?)

2022.1008737

- Particles with displaced secondary vertex (LLPs)
  - Distance between primary and secondary vertex >~ 3 m
    - For K_S^0 Λ^0 , Ξ^-. with typical boost of $\beta\gamma$ ~10-100 and lifetime $\tau \sim 10^{-11}$ - 10^{-10} s . c, ($L = \beta\gamma.c.\tau$)
  - No dedicated reconstruction or selection at HLT1 level in Run1 and 2





BSM / NP Long-Lived Particles and Tracking (Why?)

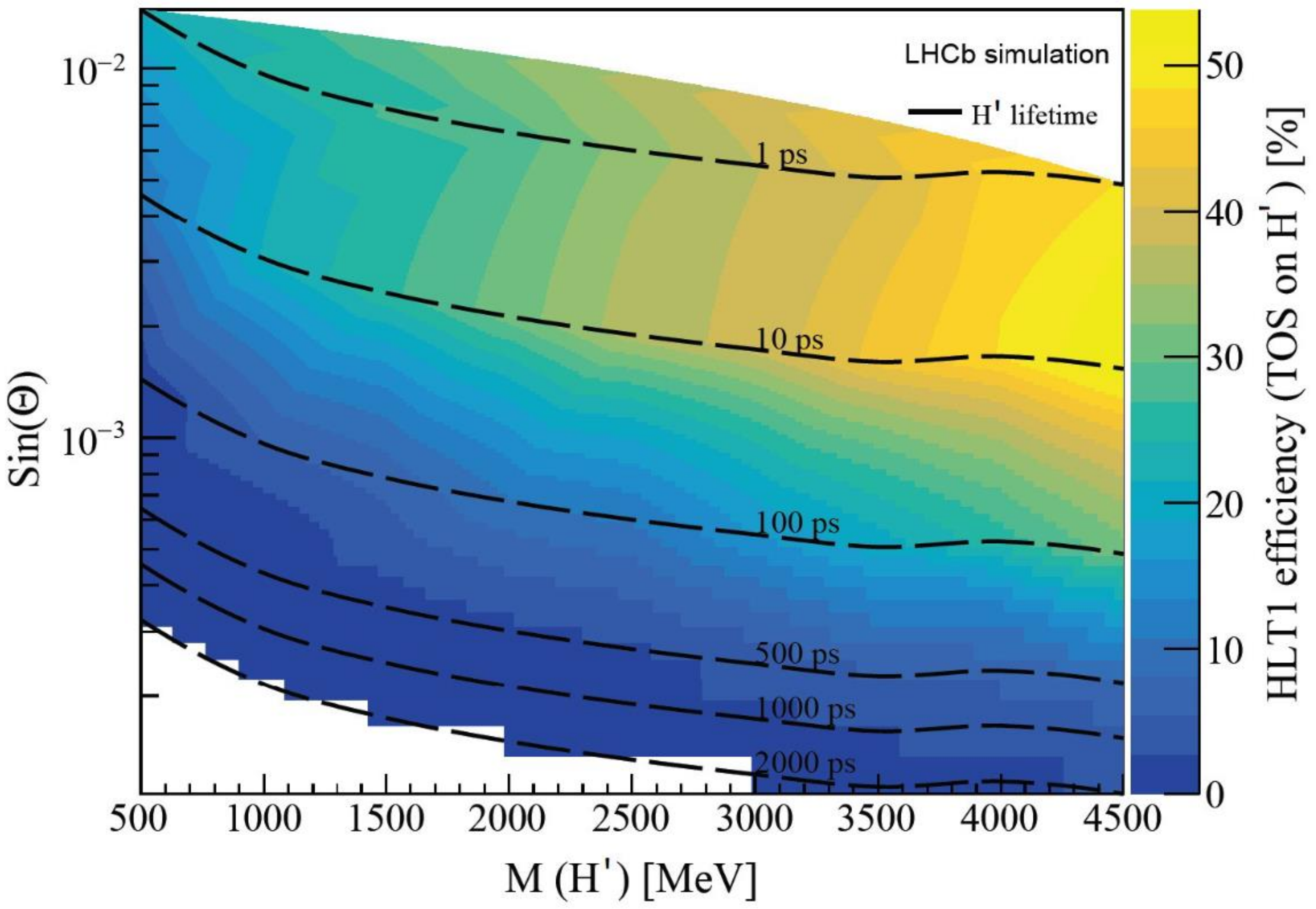
2022.1008737

BSM: sensitivity to $B^+ \rightarrow K^+ H' [\rightarrow \mu^+\mu^-]$

HLT1 effect when triggering on the H' decay products:

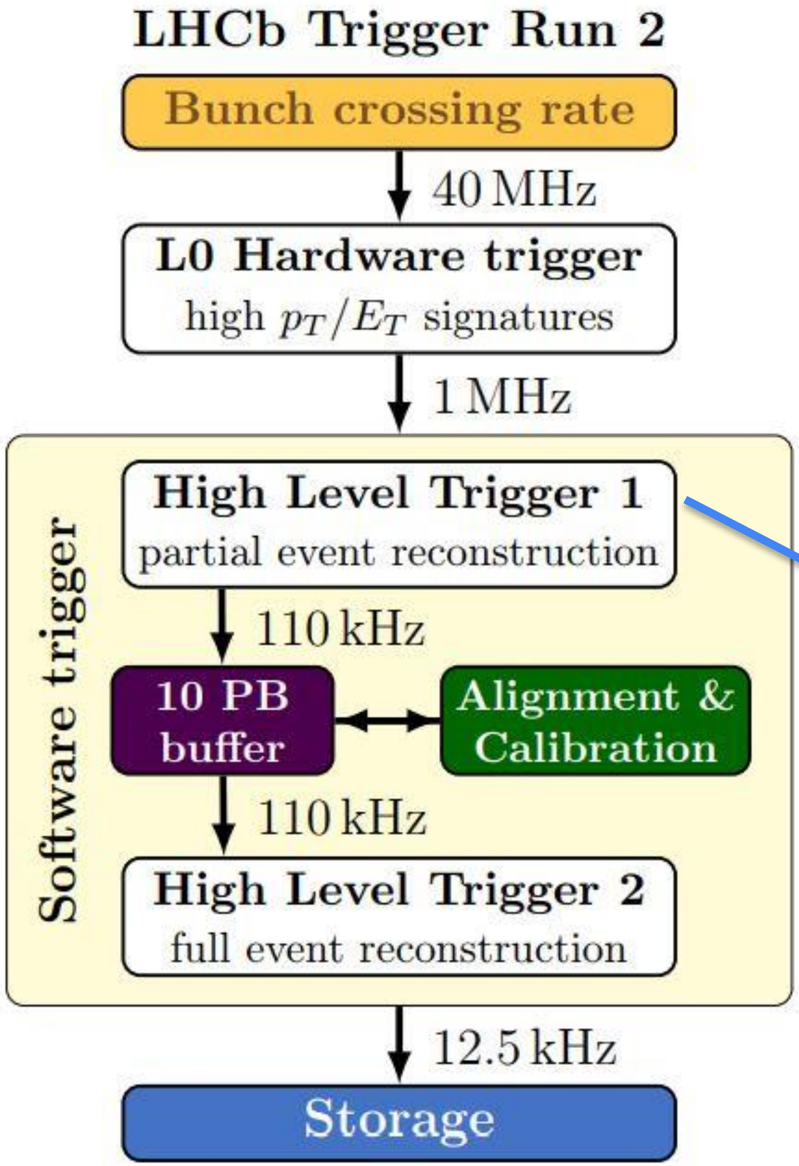
- Decent efficiency (30-50 %) for low lifetime
- Poor efficiency (< 10 %) for τ > 100 ps
- Loss in sensitivity for small H' mass

Need for dedicated LLP trigger if H' is long-lived



HLT1 Algorithms

Algorithms: HLT1 sequence (Run-2)



LHCb Run2 HLT1 trigger configuration

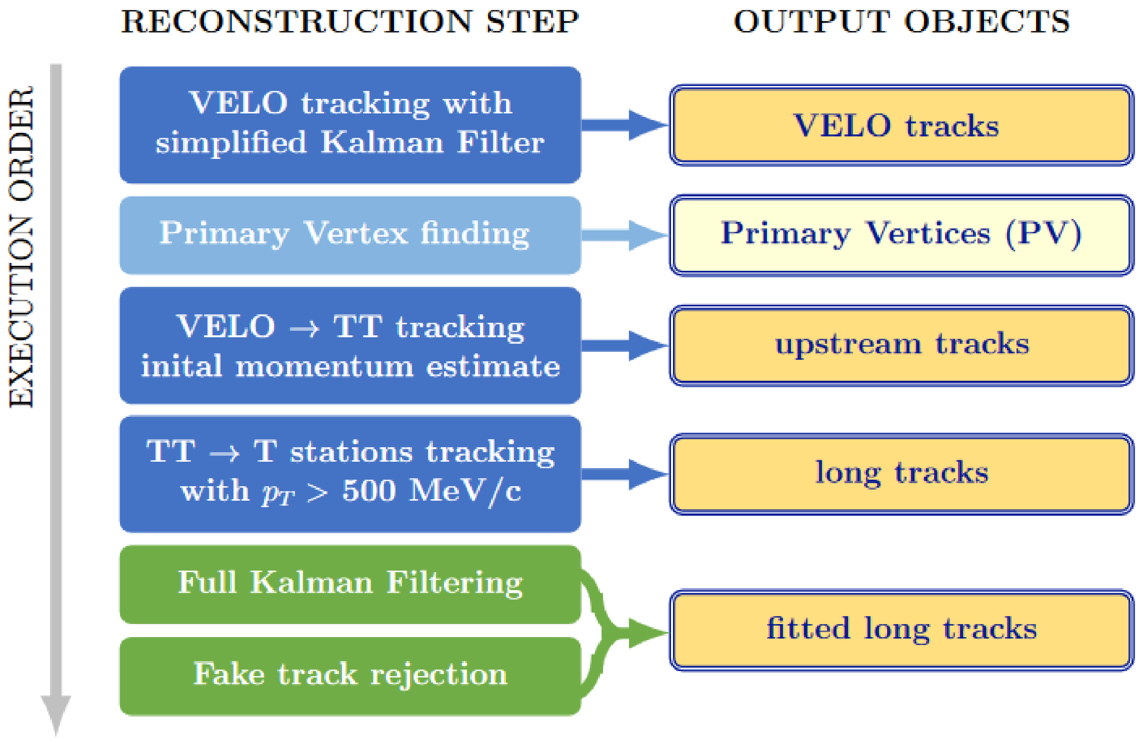
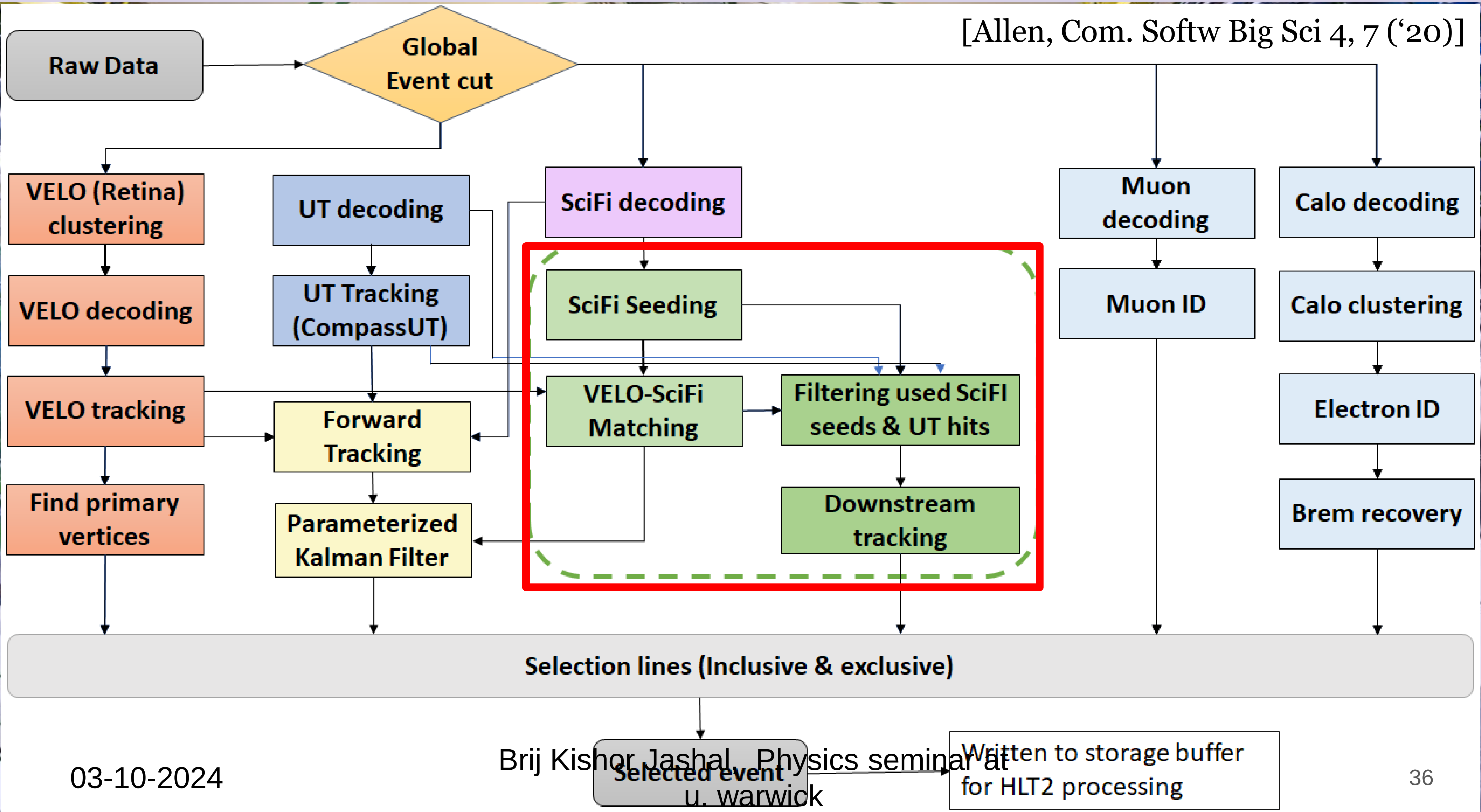
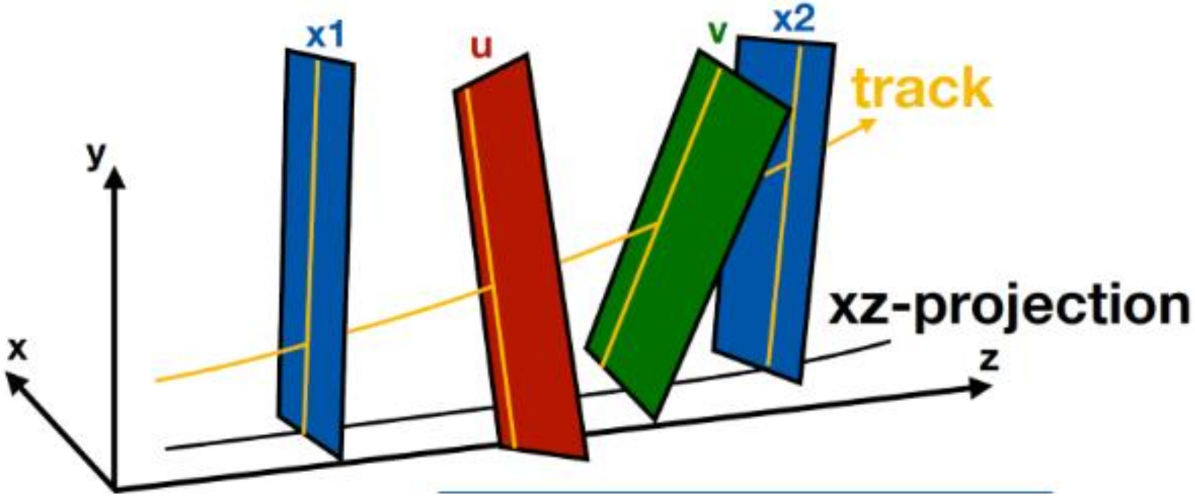


Figure 4: Sketch of the HLT1 track and vertex reconstruction.

Algorithms: HLT1 sequence (Run-3)



Algorithms: SciFi Seeding and Velo-SciFi Matching



Standalone SciFi seeding algorithm (HybridSeeding)

- 2.7 meters long fibers, 250 µm diameter
- 12 layer with ~450 hits each (average),
- 3 stations spread over 1.8 meters ub x-u-v-x geometry, u and v being layers titled by a +/- 5° stereo angle

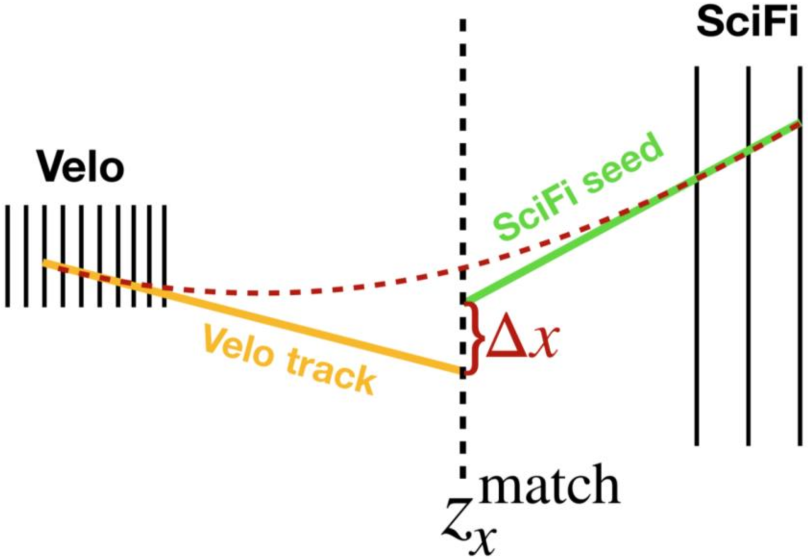
➢ Two iterations with two main components of algorithm

Seeding_XZ

Seeding_confirmTracks

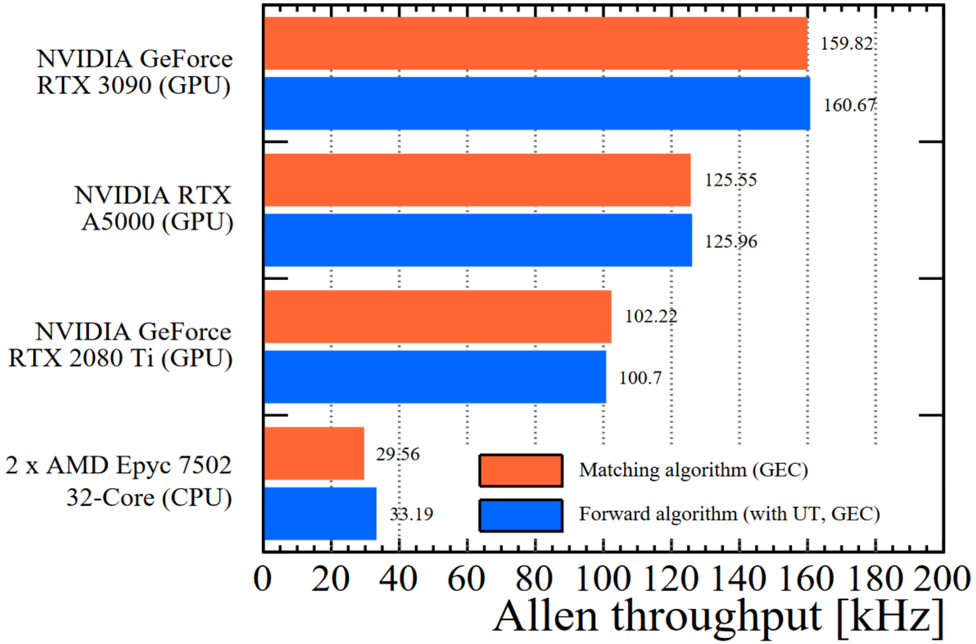
Velo-SciFi Matching

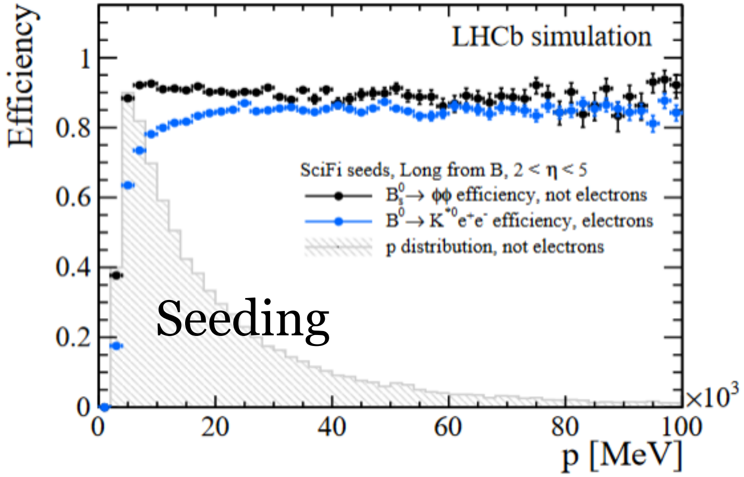
- SciFi seeds matched to Velo tracks to produce Long tracks
- Start with SciFi seeds and parallelize over SciFi loops
- Velo/SciFi seeds extrapolated to magnet as lines ("Kink" approximation)

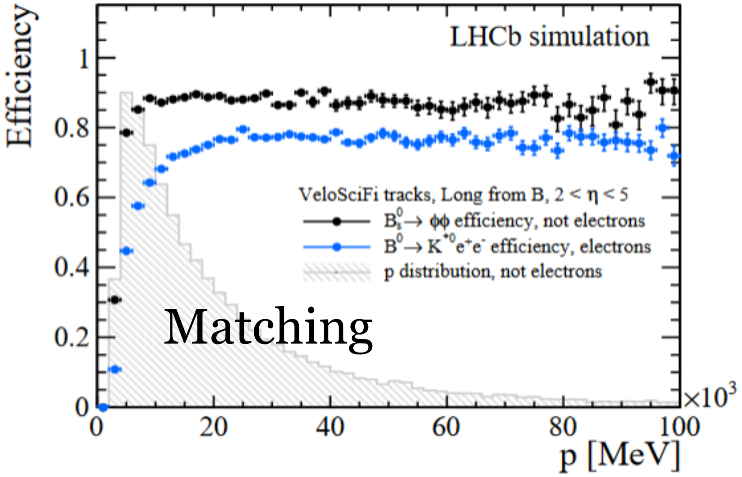


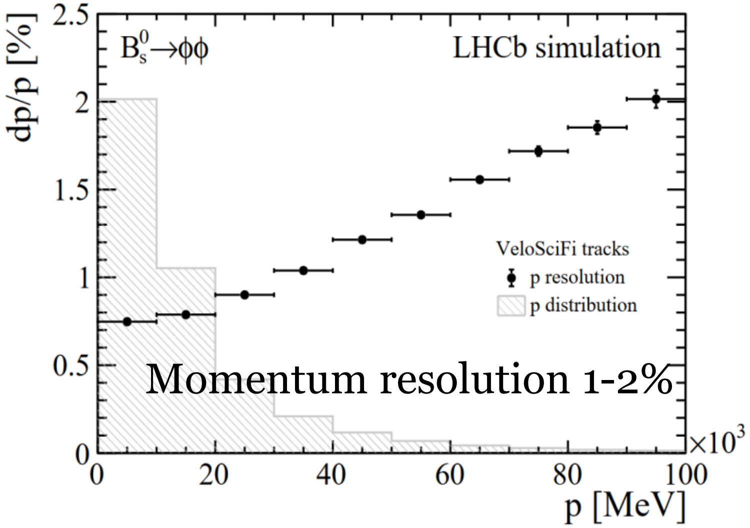
Algorithms: Performance: Seeding + VeloSciFi Matching

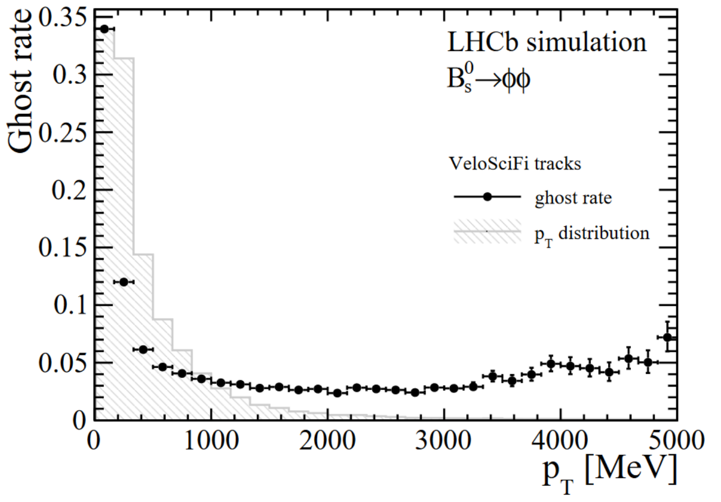
Matching produces standard long tracks covering entire detector



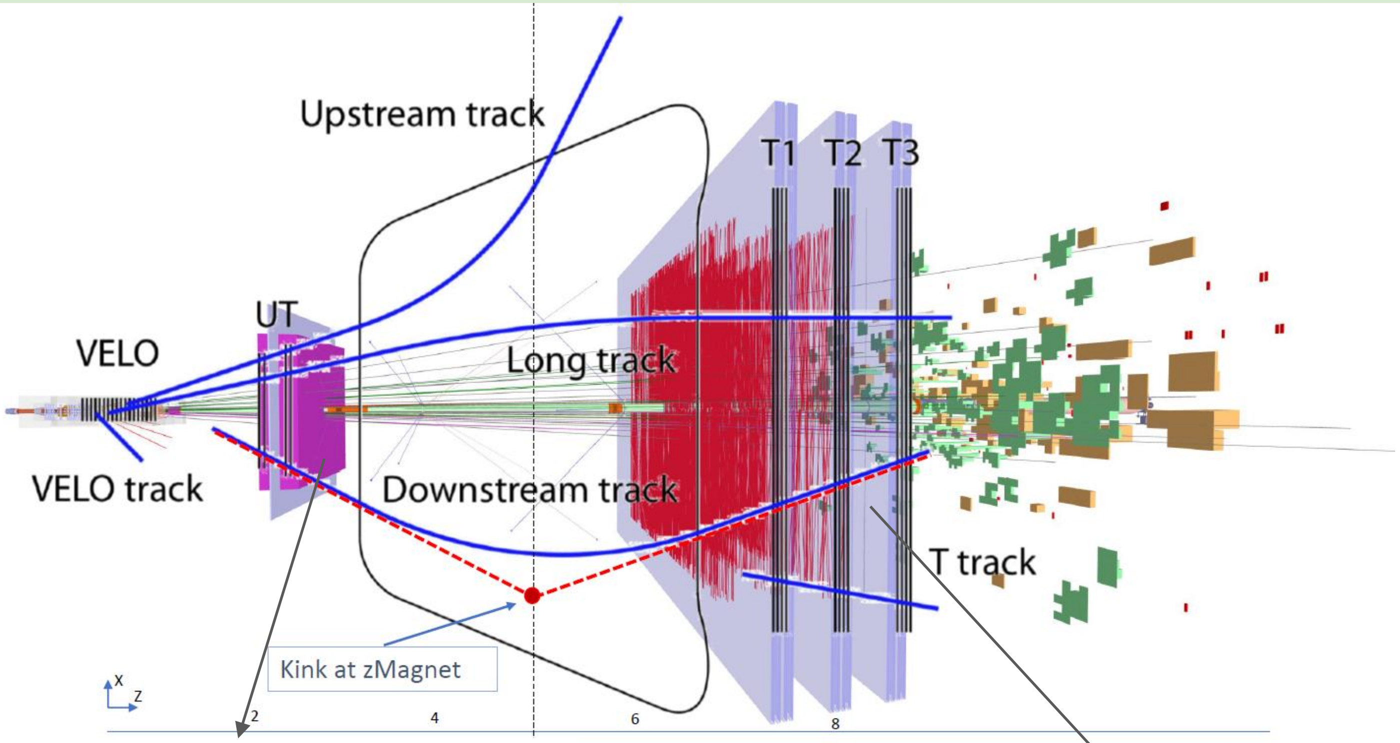


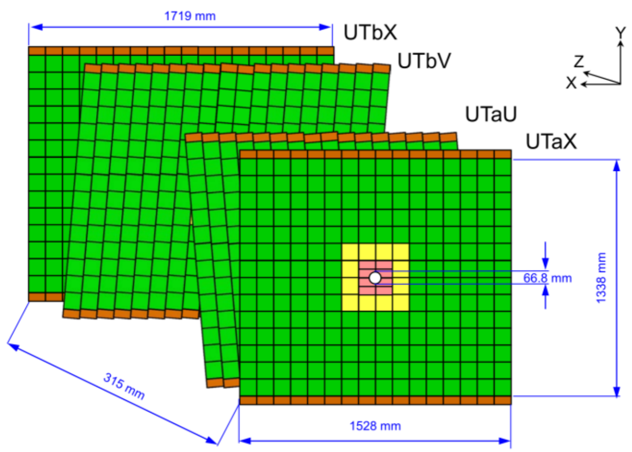


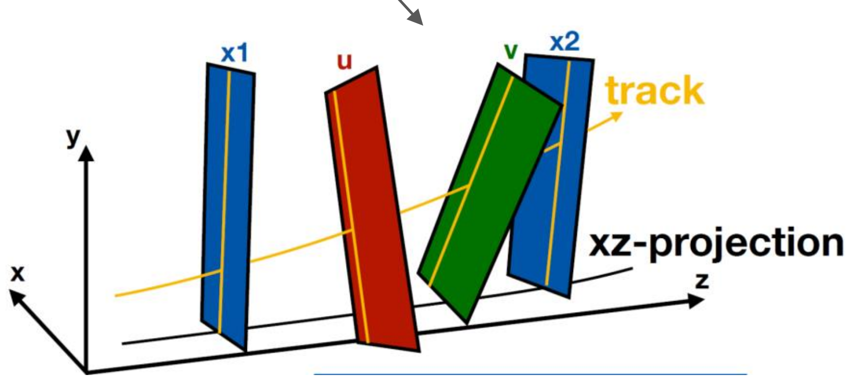




Downstream algorithm: design strategy







Extrapolate SciFi seeds to UT

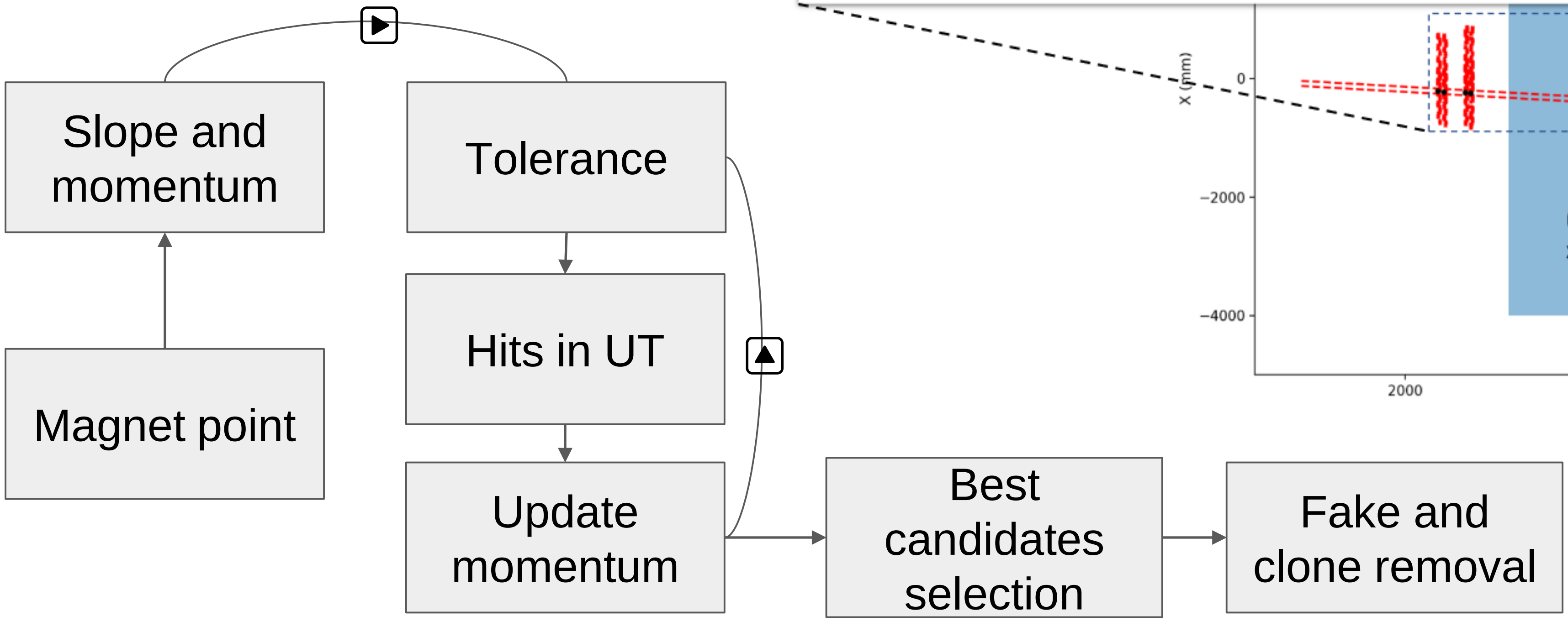
- Take the output of SciFi seeding
- Filter out the used seeds
- Extrapolate to UT stations (through *magnet point*)

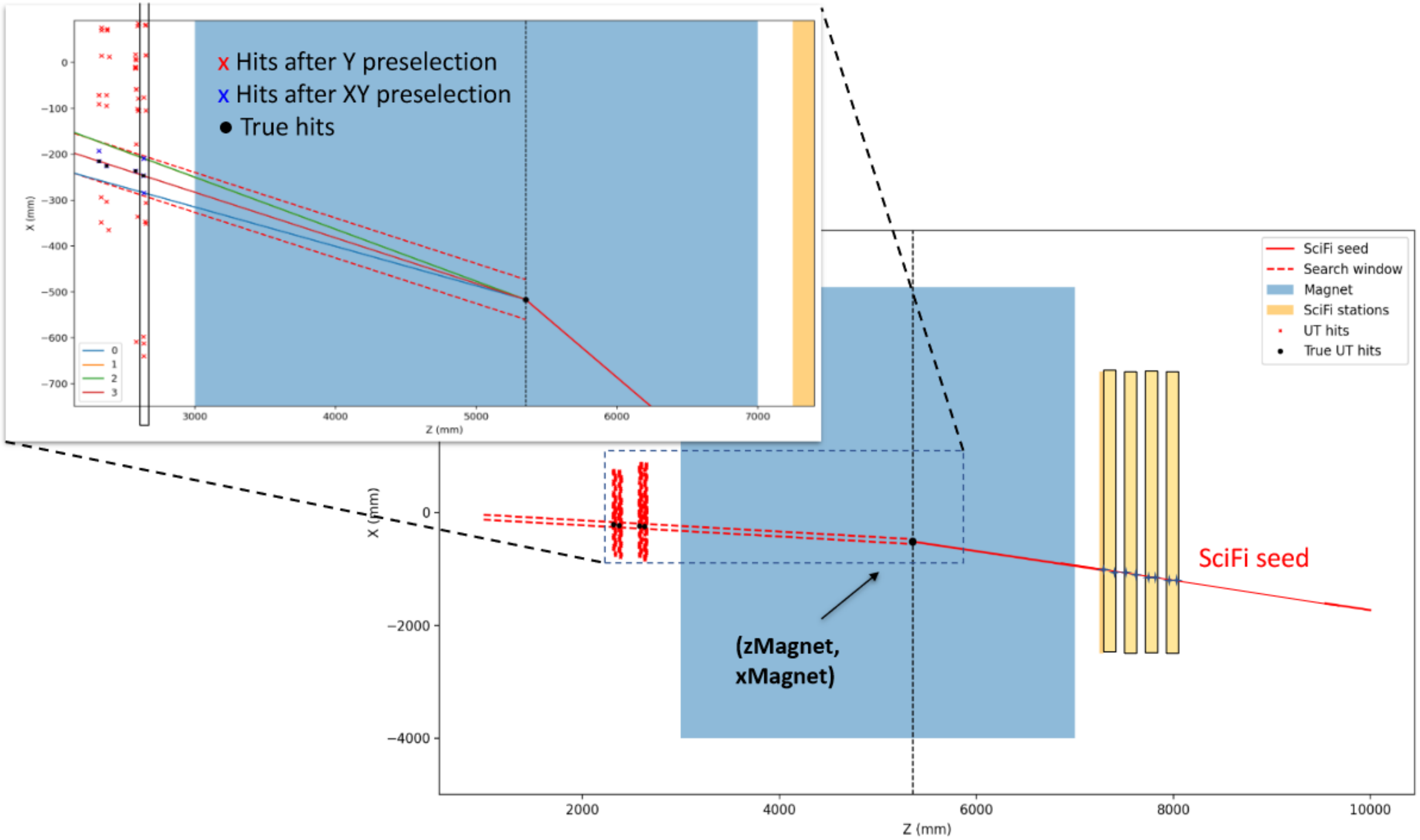
Downstream algorithm: track model

Track state:

$$\vec{S}_i = (x, y, t_x, t_y, q/p)^T$$

Track model:





Downstream algorithm: implementation

Algorithm is divided into 3 main kernel functions:

Kernel function 1:
128 SciFi seeds per thread block

- Filtering used SciFi seeds
- For each input SciFi seed, extrapolate to last x layer (UTbX)
- Store up to 10 best candidates
- Update slope of each candidate using magnet point and hit position.

Kernel function 2:
256 candidates per thread block

- Add hits from rest of the UT layers
- Find best combination of U/V hits
- Compute the scores based on distance b/w extrapolation and real UT hit positions

Kernel function 3:
256 candidates per thread block

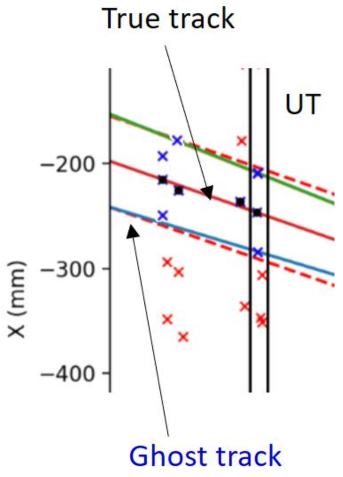
- Find best candidate based on the scores from previous function
- Check for hit duplication
- Perform ghost killing

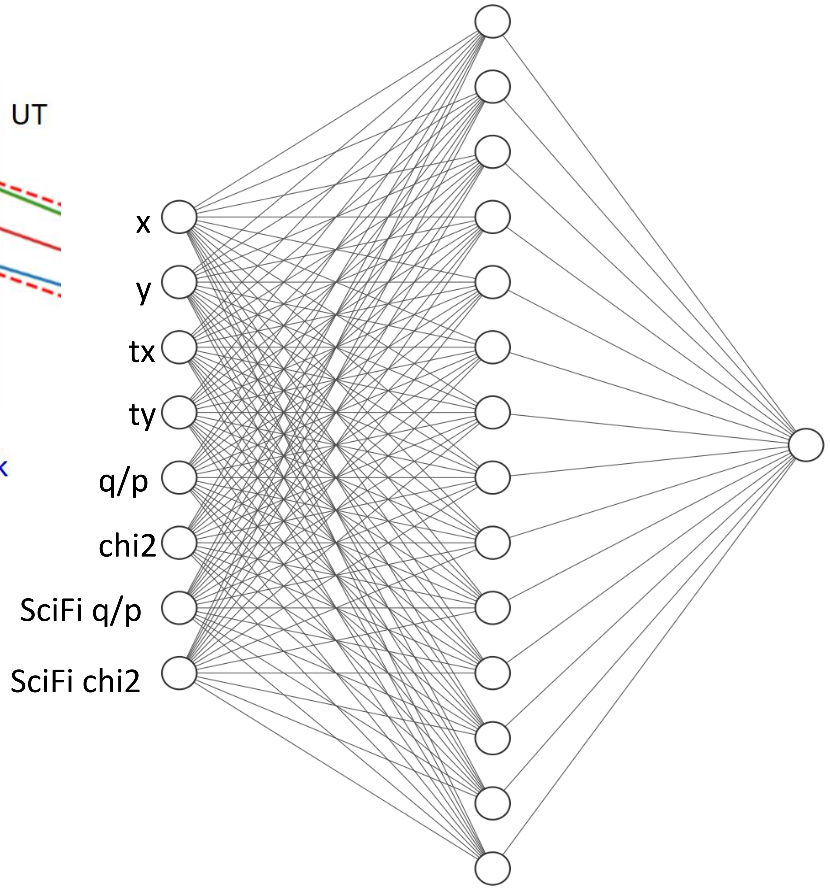
Prepare output:

- Copy hits and tracks to output (compact SOA container)
- Create standard multi-event viewer

Downstream algorithm: ghost killer neural network

- A single hidden (14 nodes) layer fully connected NN
- It utilizes **8 variables** as input:
  - *Downstream* track state (**$x, y, t_x, t_y, q/p, \chi^2$**)
  - SciFi track properties (**$q/p, \chi_y^2$**)
- The model was trained using $B_s \to \phi\phi$ events.
- In order to boost speed, certain C++/CUDA tricks are applied, such as using **static structs**, employing **fast math functions**, and **unwinding for-loops**.





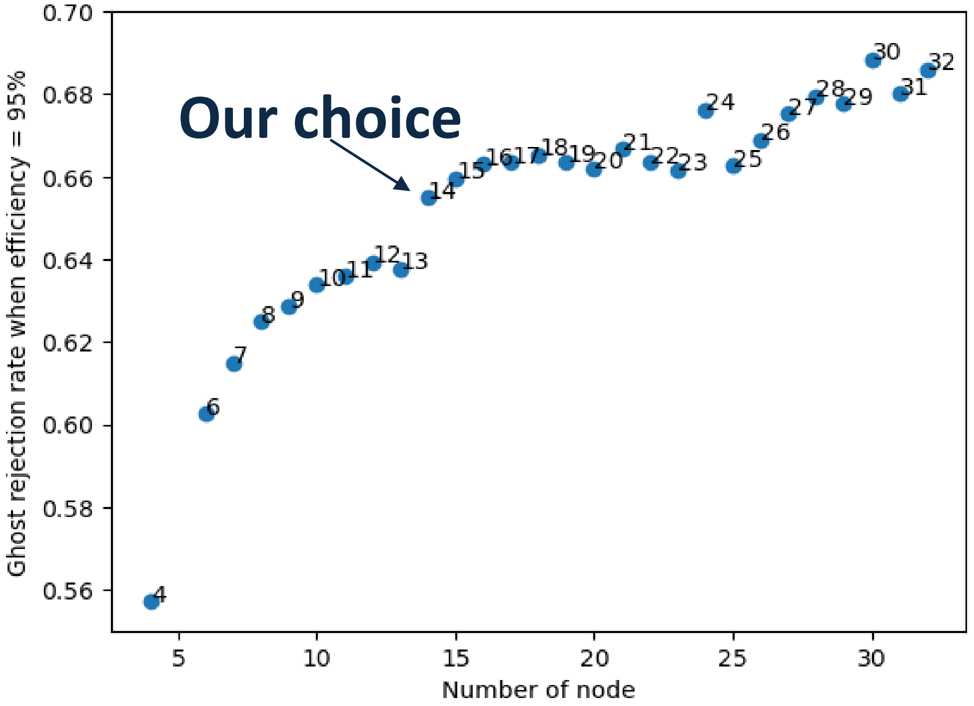

```
namespace DownstreamGhostKiller {

  namespace Model {
    constexpr unsigned num_node = 14;
    constexpr unsigned num_input = 8;
```

```
...
namespace ActivateFunction {
  // rectified linear unit
  __device__ inline float relu(const float x) {
    return x > 0 ? x : 0;
  }
  // sigmoid
  __device__ inline float sigmoid(const float x) {
    return __fdividef(1.0f, 1.0f + __expf(-x));
  }
} // namespace ActivateFunction
```

```
// First layer
DownstreamHelpers::unwind<0, Model::num_node>([&](int i) {
  DownstreamHelpers::unwind<0, Model::num_input>([&](int j) {
    h1[i] += input[j] * Model::weights1[i][j];
  });
  h1[i] = ActivateFunction::relu(h1[i] + Model::bias1[i]);
});
```

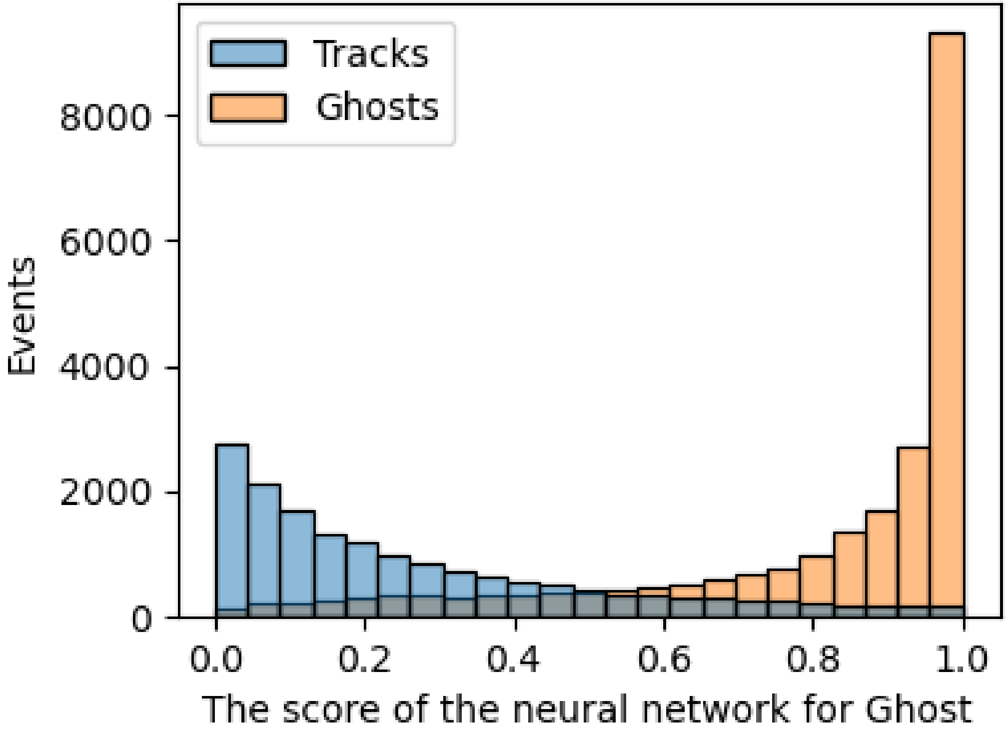
Algorithm design: ghost killer neural network

Ghost rejection vs number of nodes in the hidden layer



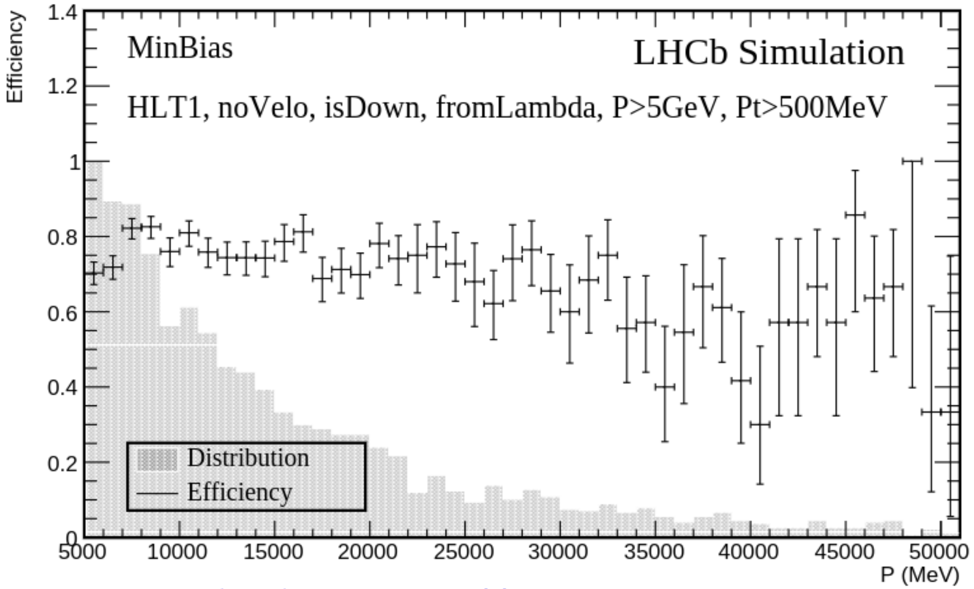
Num Operation = Num Input * Num node

Distribution of the classifier output: default threshold value 0.5

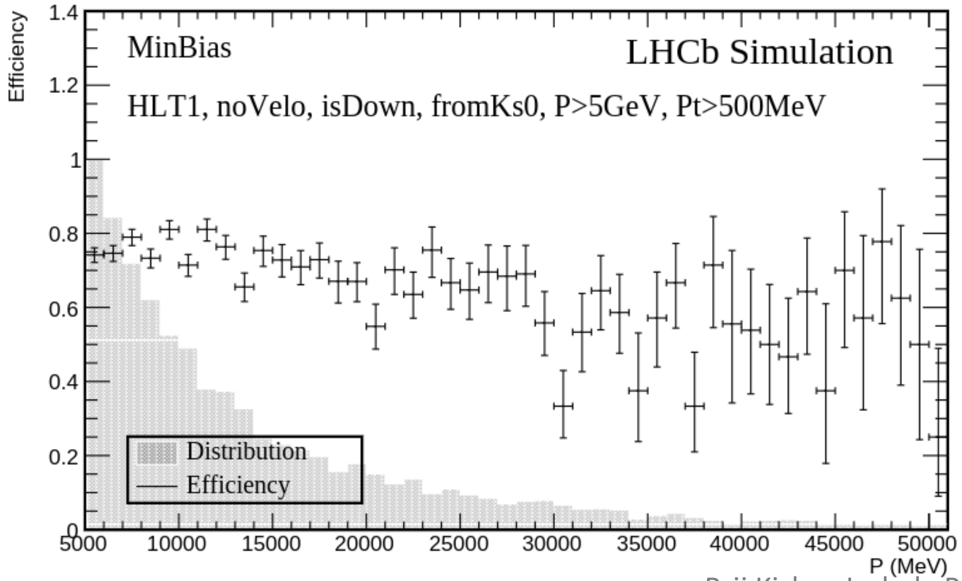


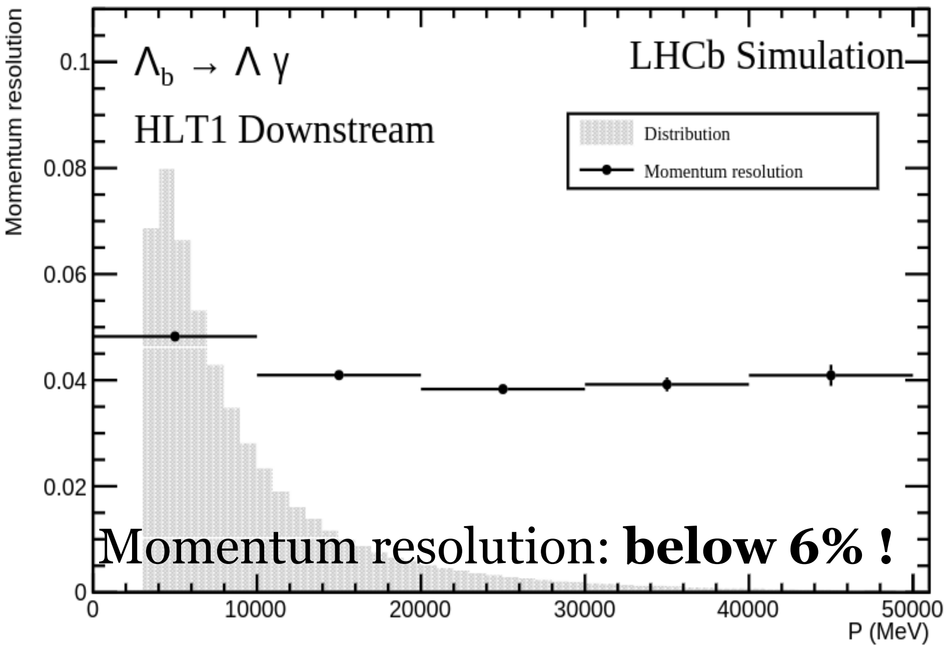
Downstream algorithm: Physics performance Λ and K_s

LHCb-FIGURE-2023-028

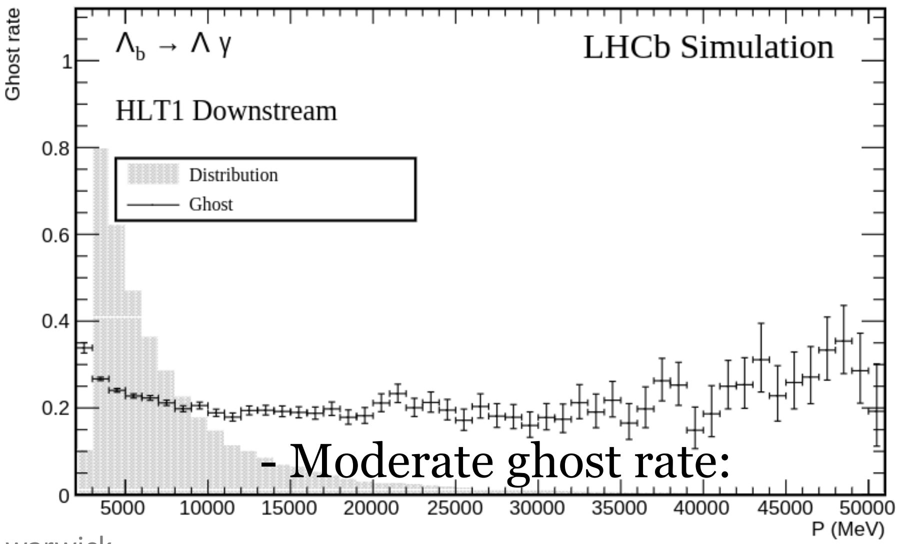


- Good physics efficiency: <u>**75-80%**</u>





Momentum resolution: **below 6% !**



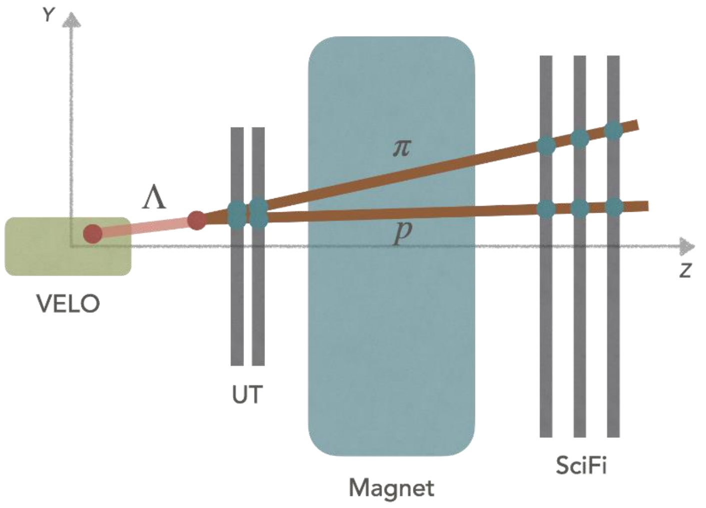
- Moderate ghost rate:

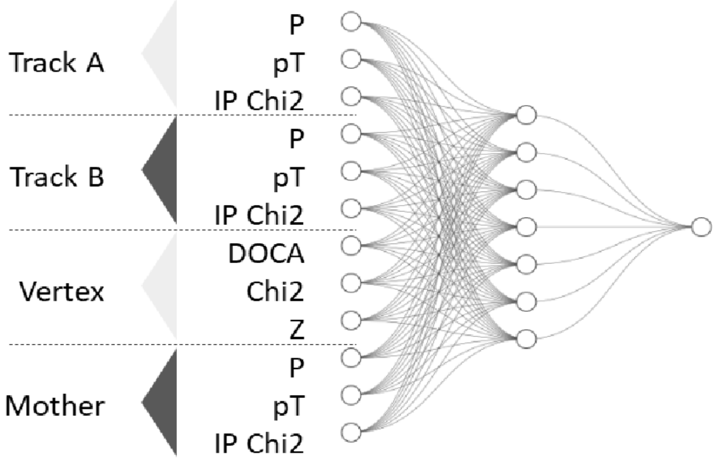
Trigger lines using HLT1 *Downstream*

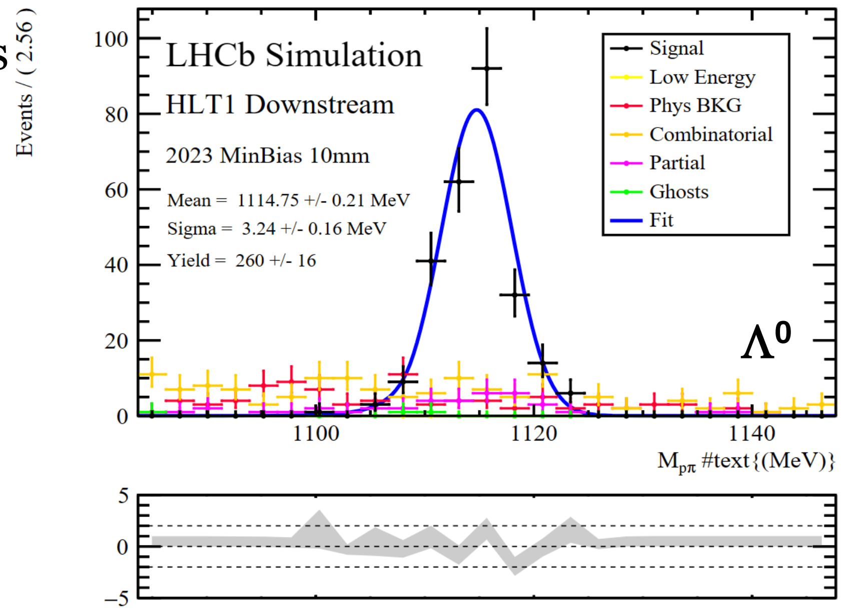
For developing the trigger (selection) lines for decays involving two tracks (Λ's and K_s's) requires **vertexing.**

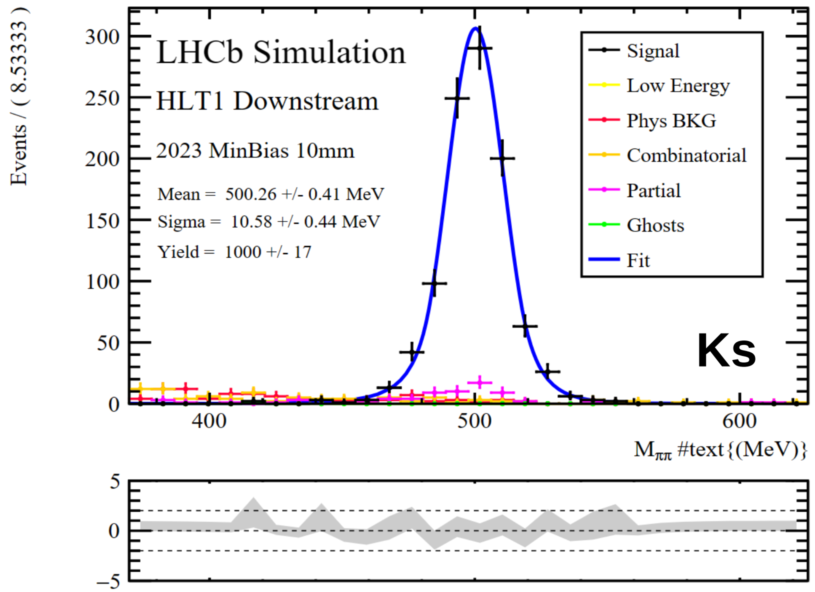
- Vertex reconstruction of two downstream tracks requires extrapolating from UT to the origin vertex

- High throughput with good background rejection in selection lines.





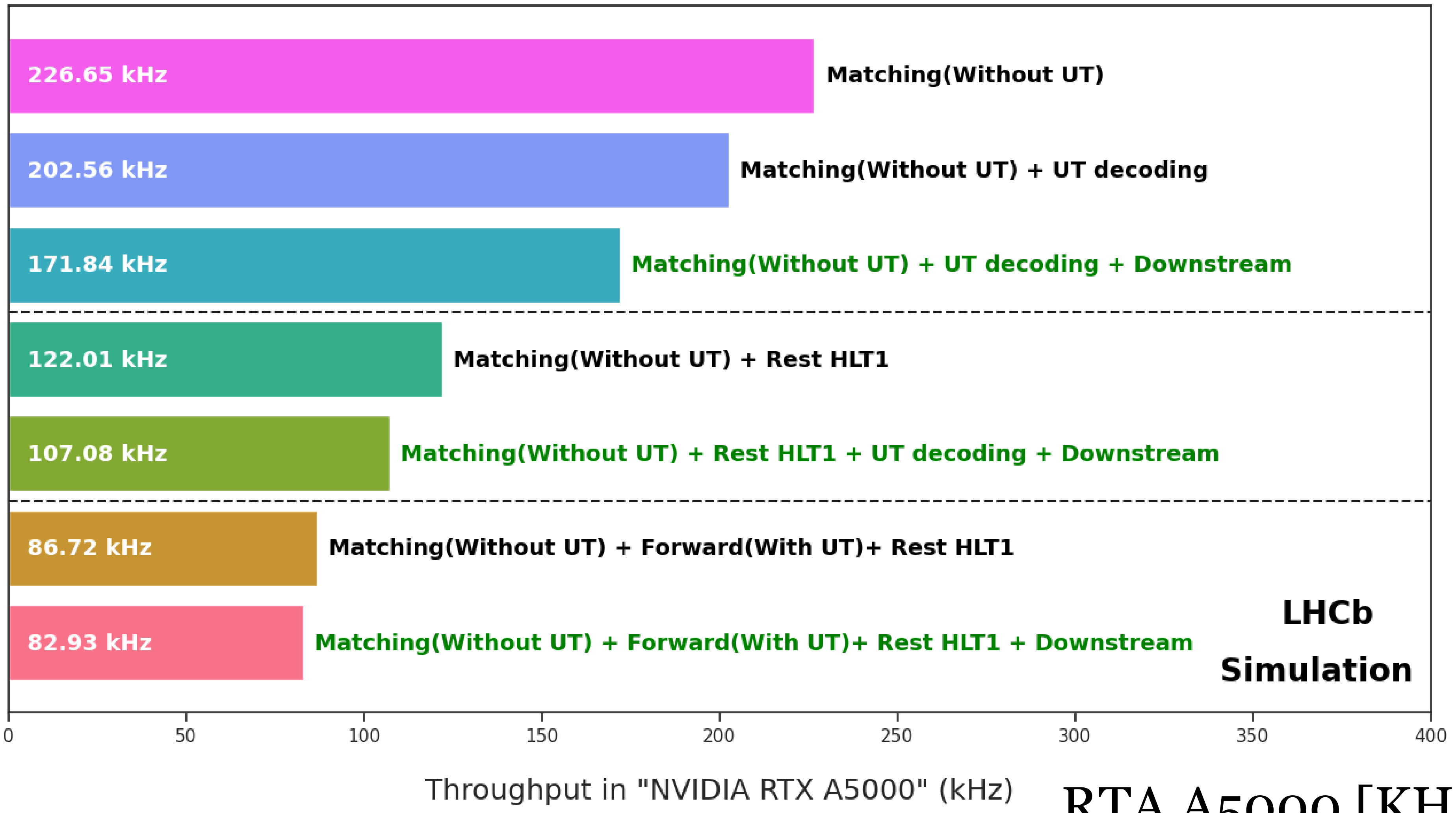




Downstream algorithm: Throughput of HLT1 sequences

LHCb-FIGURE-2023-028

HLT1 sequence for *long* and *downstream* tracking reconstruction:



RTA A5000 [KHz]

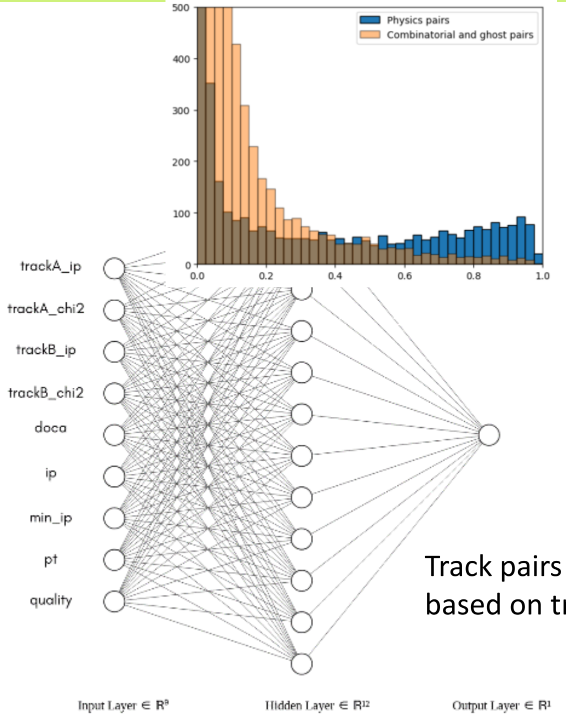
Buffer Scanner (BuSca) scheme

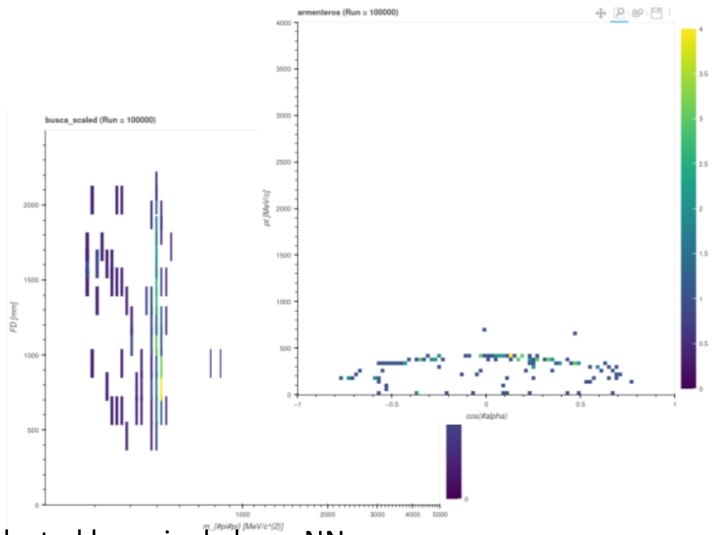
Allen !1600

Extension of the Downstream reco. and vertexing:

- Select high-quality candidates through a dedicated NN.
- Fill 2D histograms and create trigger lines.

Online Monitoring

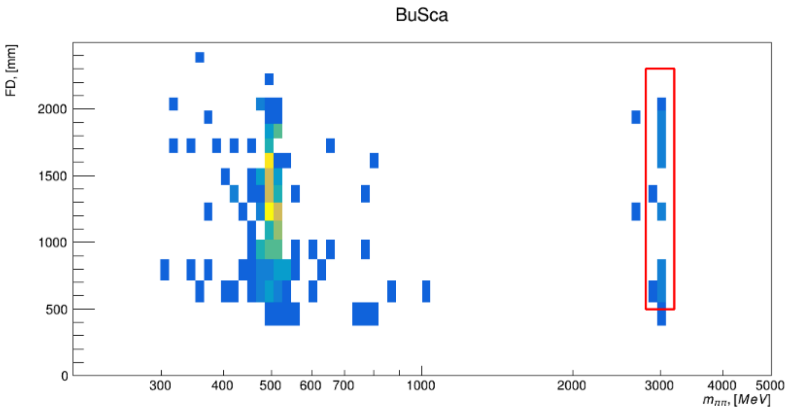


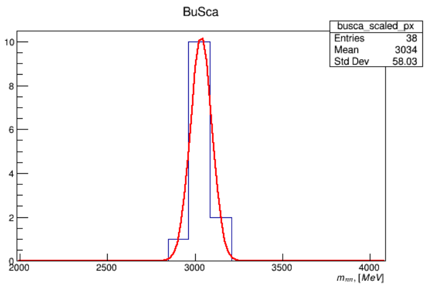


Track pairs selected by a single layer NN based on track and vertex quality

Create HLT1 lines

HLT1DownstreamBuSca

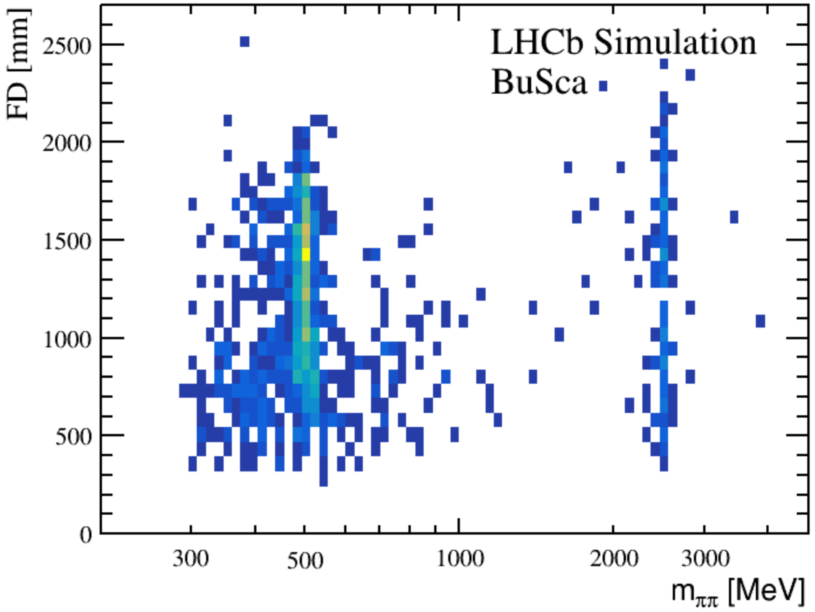


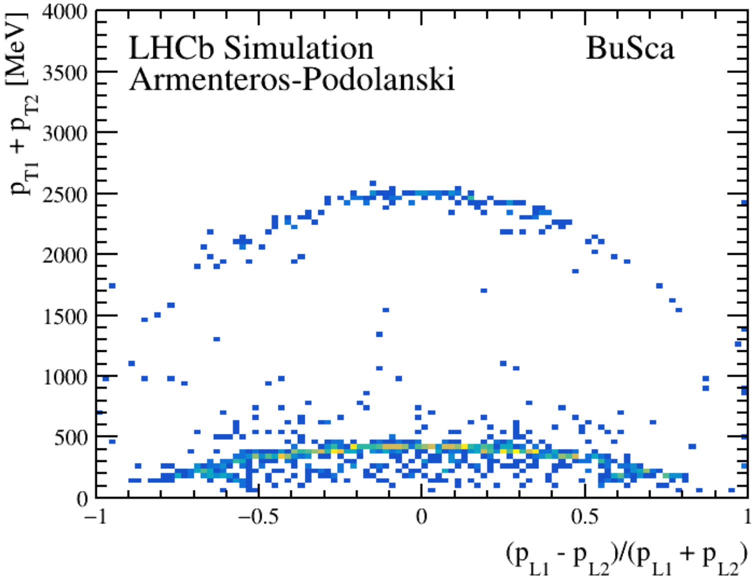


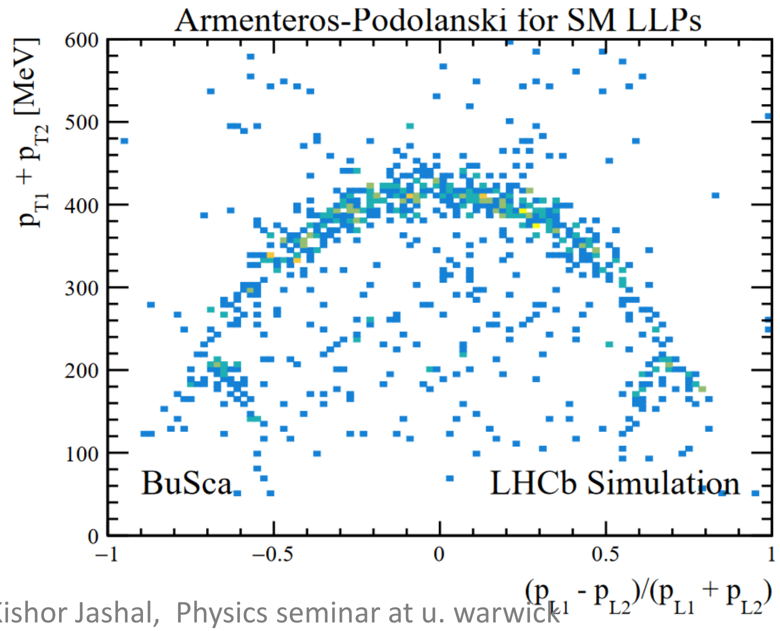
HLT1_BuSca_Mass
- HLT1_BuSca_PID
- HLT1_BusCa_Multitrack
- HLT1DownstreamBuSca_prescaled (bkgstudies)

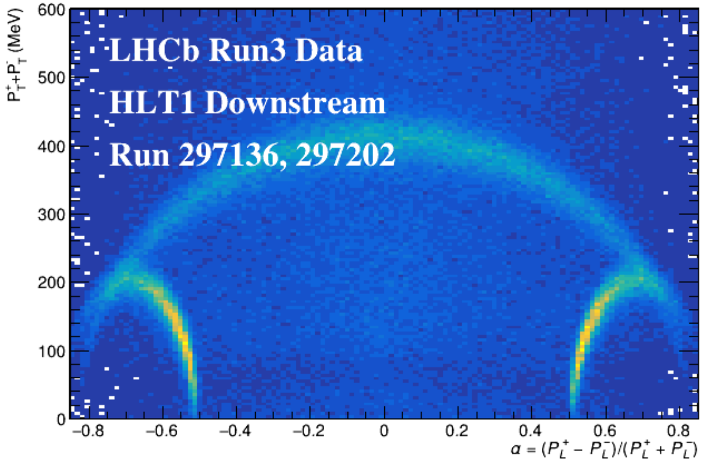
Buffer Scanner (BuSca)

LHCB-FIGURE-2024-018







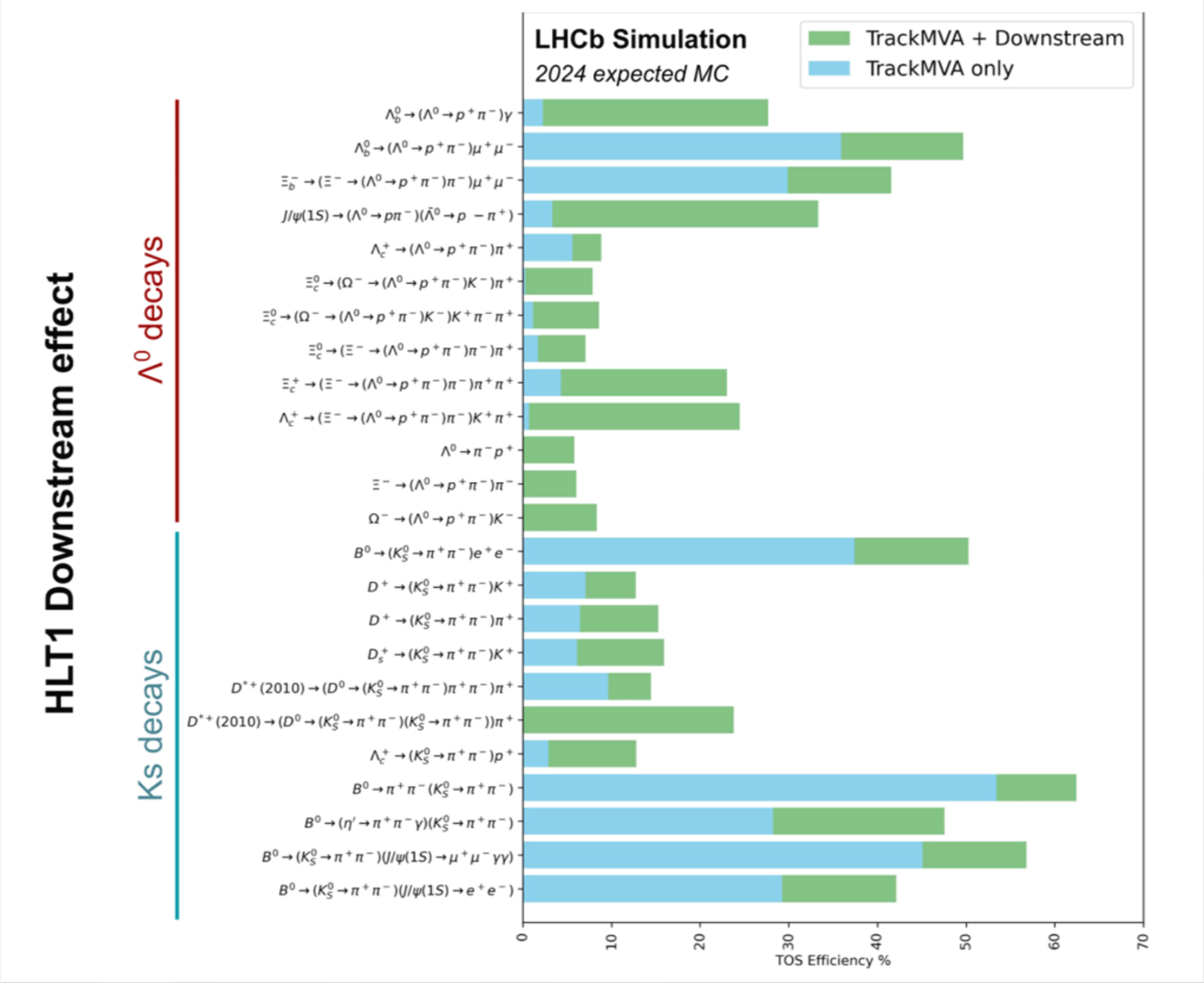


Physics impact of *Downstream*

Physics impact of *Downstream:* SM

Impact on many other decay channels

Channel	DD/LL proportion	Interest
***b*-hadron decays**		
$\Lambda_b^0 \to \Lambda\gamma$	3.4	γ polarization, BR
$\Xi_b^- \to \Xi^-\gamma$	25	γ polarization, BR
$\Omega_b^- \to \Omega^-\gamma$	13	γ polariation, BR
$B^+ \to K_S^0 K_S^0 \pi^+$	2.8	CPV, BR
$B^+ \to K_S^0 K_S^0 K^+$	2.7	CPV, BR
$B_s^0 \to K_S^0 K_S^0$	3.6	CPV, BR
Charm physics		
$\Lambda c^+ \to \Lambda K^+$	4.4	Polarization studies
$\Xi_c^- \to \Xi^-\pi^-$	8.4	Polarization studies
$D^0 \to K_S^0 K_S^0$	1.8	CPV
$J/\psi \to \Lambda\bar{\Lambda}$	4.8	Polarization studies, BR
Strange physics		
$K_S^0 \to \mu^+\mu^-$	0.6	BR
$K_S^0 \to \mu^+\mu^-\mu^+\mu^-$	0.8	BR
$K_S^0 \to \gamma\mu^+\mu^-$	0.8	BR



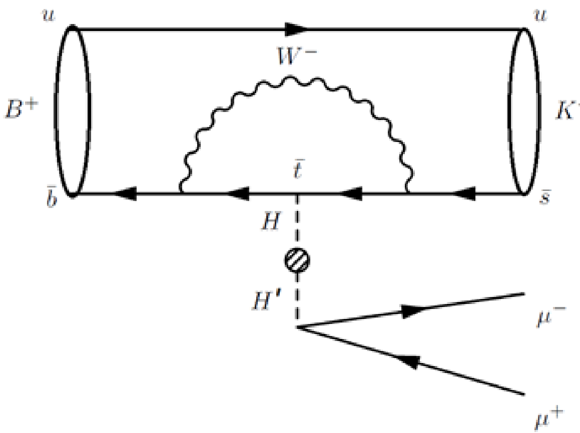
Physics impact of *Downstream: BSM*

2022.1008737

LHCb's capabilities of probing BSM physics can significantly increase due to *Downstream* tracking at HLT1

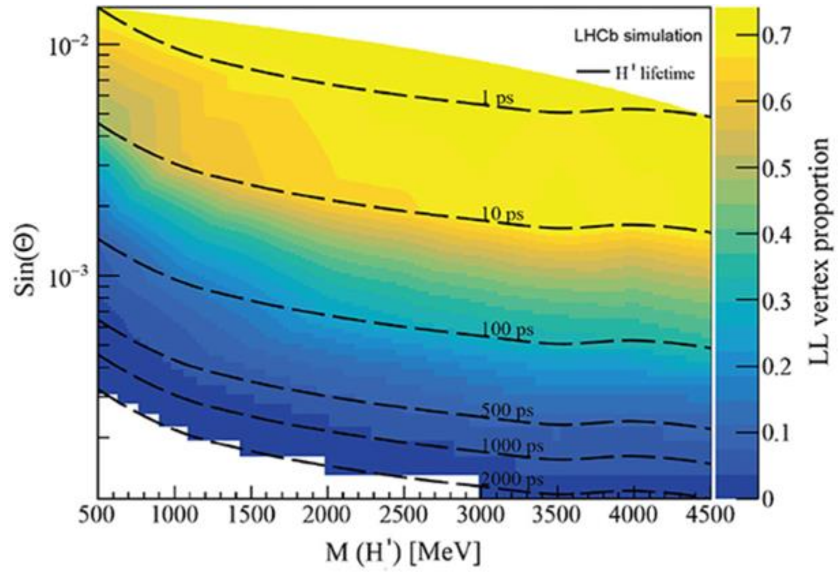
Dark boson in the Hidden sector: the SM Higgs mixes with H'

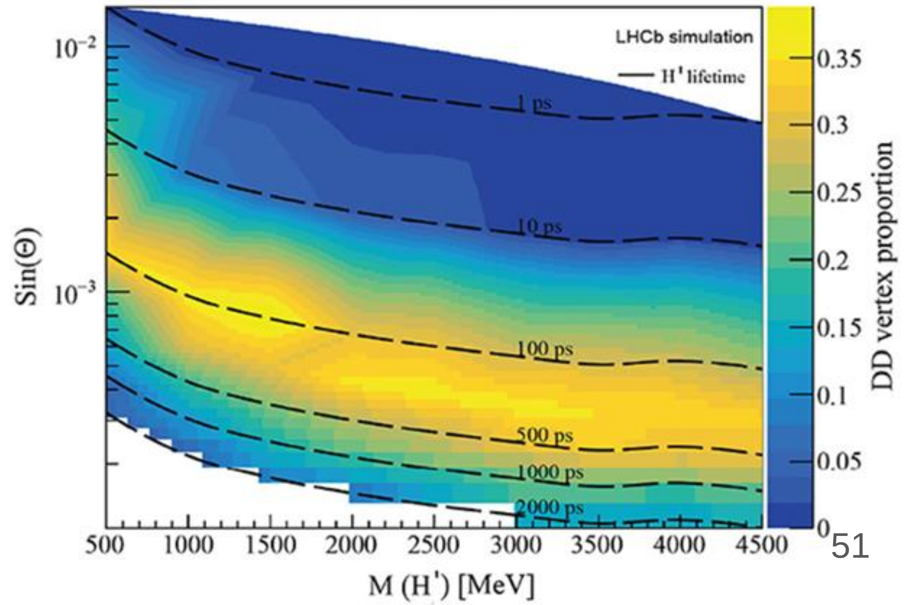
h = H cos θ + H' sin θ



$$\Gamma\left(H' \to \ell\ell\right) = \sin^2\theta \frac{G_F m_{H'} m_\ell^2}{4\sqrt{2}\pi}\left(1 - \frac{4m_\ell^2}{m_{H'}^2}\right)^{3/2}$$

$$B \to H'(\to \mu^+\mu^-)K$$





Impact of the trigger on H' signal (TOS) at HLT1 level:
- High suppression for low H' mass for t < 10ps
- Strong suppression for t > 10ps in all range of H' masses

Upgrade-I LHCb as lifetime frontier experiment

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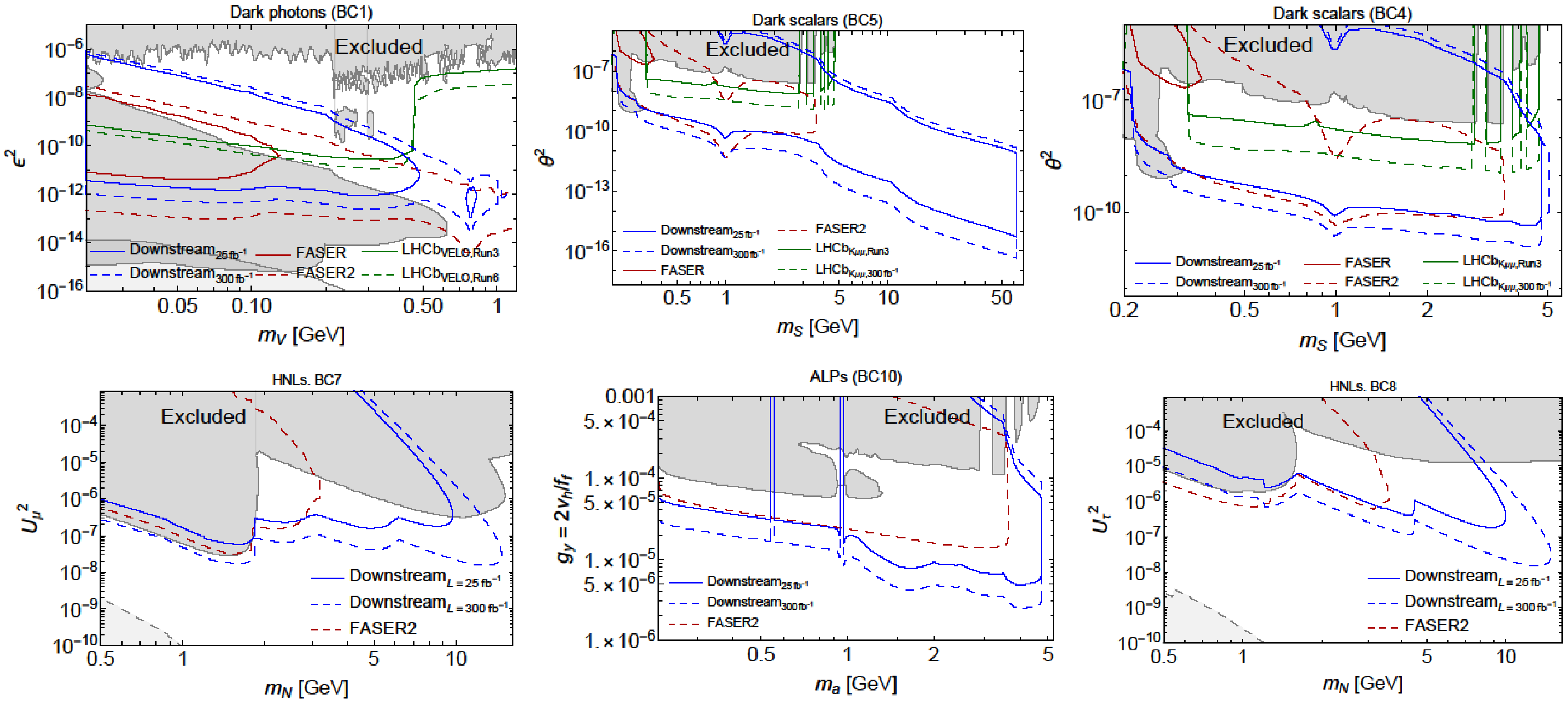

Physics impact of *Downstream: LHCb as lifetime frontier experiment*

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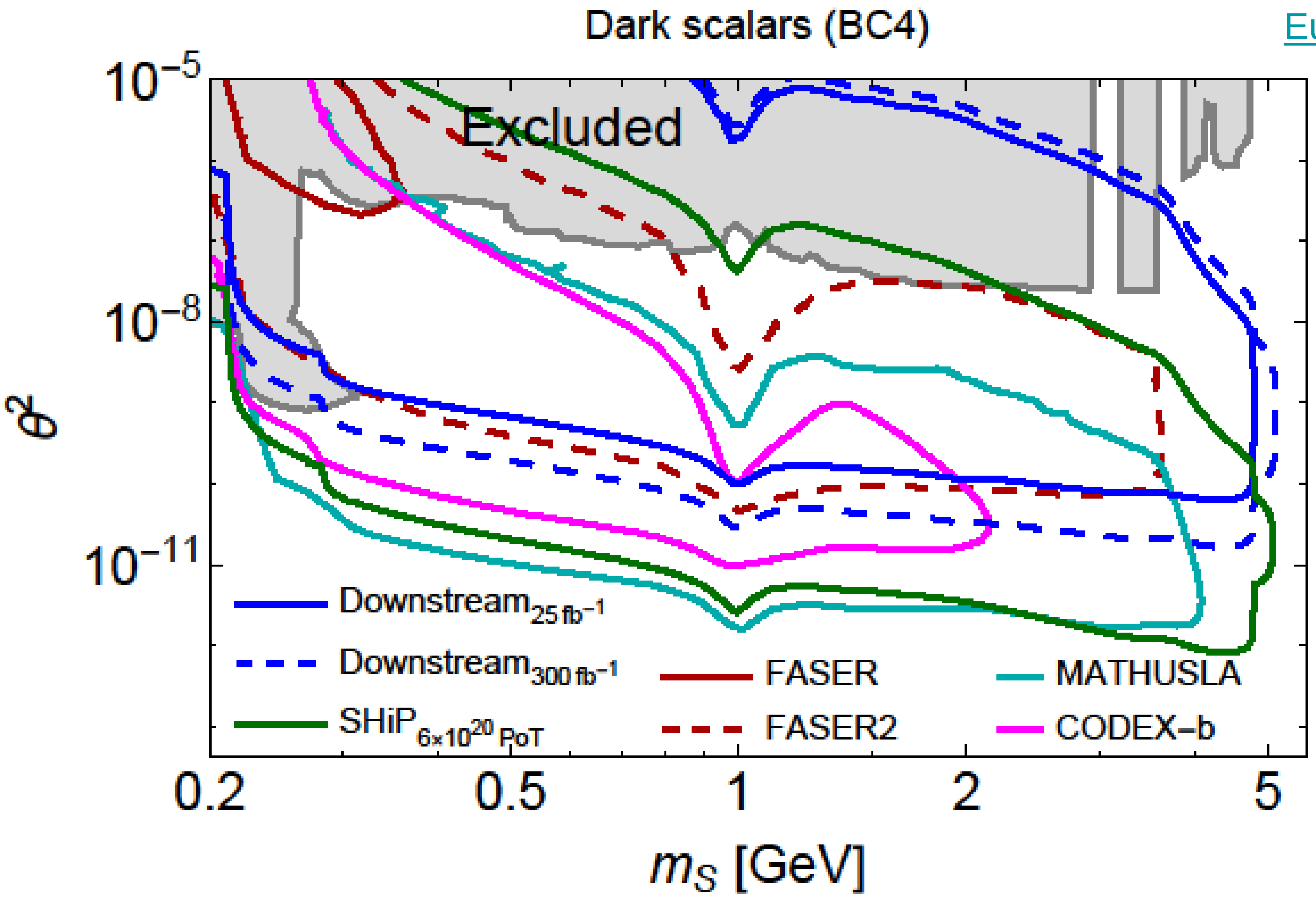

Summary

- LHCb as lifetime frontier experiment
  - In Run1 and Run2 LHCb could probe lifetimes of upto 100 ps
  - But now in Run3 with new HLT1 with downstream algorithm it is possible to probe BSM physics for lifetimes from 100 ps to 2000 ps.
  - Not just the BSM, but also huge impetus to the physics program with SM LLPs
  - Huge physics gains made possible by investing in software and algorithms.

Thank you