Online
LHCP2021
The Ninth Annual Conference on Large Hadron Collider Physics
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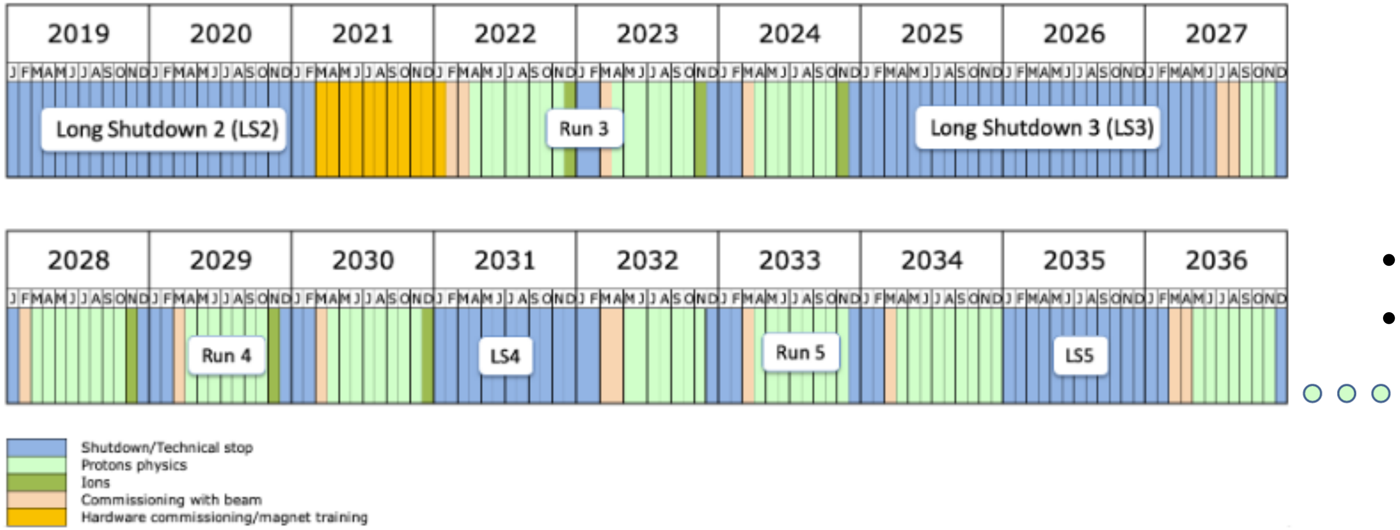
Particle identification and tracking with timing detectors in ALICE and LHCb in Run 5

Stefania Bufalino
Istituto Nazionale di Fisica Nucleare and
Politecnico di Torino
on behalf of the ALICE and LHCb Collaborations

HL-LHC an amazing opportunity



Link to LHC schedule

- HL-LHC will run from 2025 to ~ 2040
- Detector construction typically 5+ years before shutdown for installation–R&D for LS4 (LS5) projects over next five (ten) years

S. Bufalino – stefania.bufalino@cern.ch

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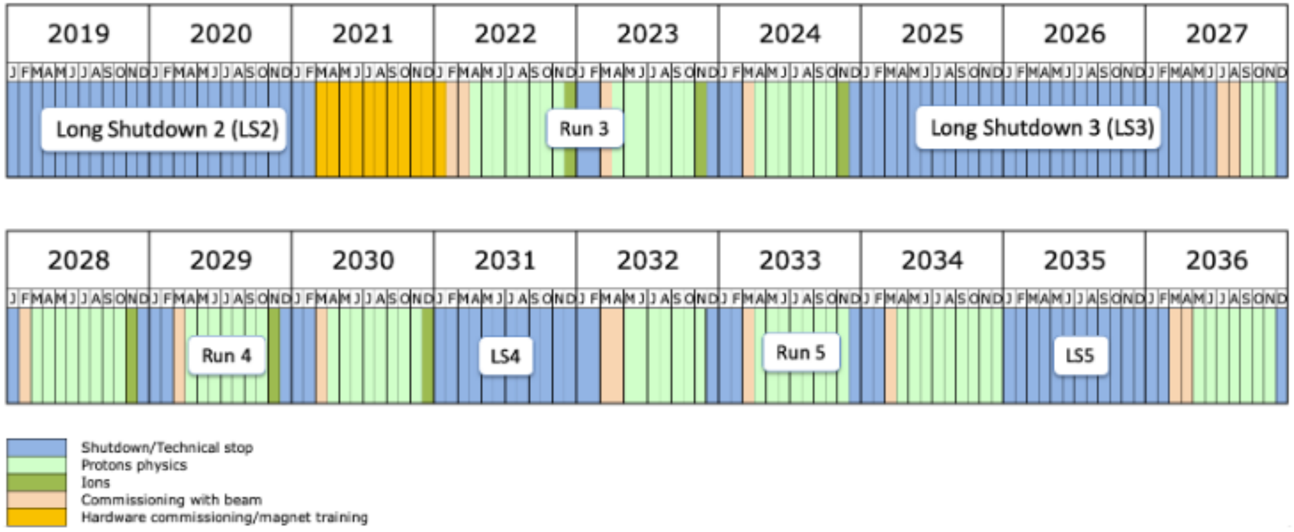


HiLumi HL-LHC PROJECT

k to [LHC schedule]

Physics programme limited by the detectors

Use of timing is key strategy to overcome challenges

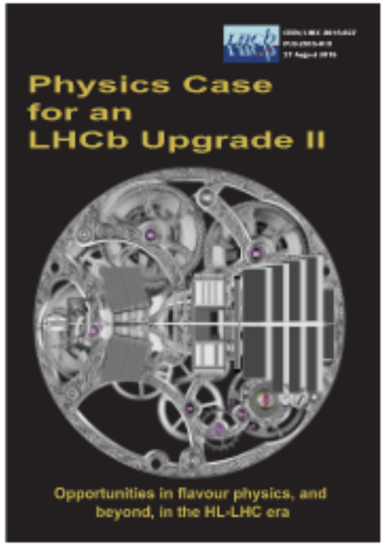
LHCb Upgrade II

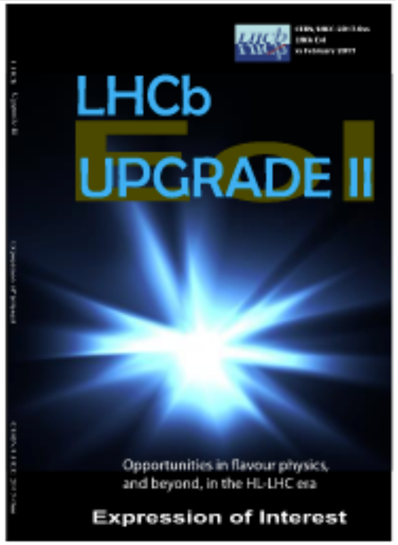
Expression of Interest and a Physics Case
[CERN-LHCC-2017-003] [CERN-LHCC-2018-027]

Mentioned in the Physics Briefing book for the 2020 European Strategy Particle Physics: "The LHCb Upgrade II…will enable a wide range of flavour observables to be determined at HL-LHC with unprecedented precision»

How?

- install a new detector for the beginning of Run 5
- operate at $\mathcal{L} \sim 1.5 \times 10^{34}\ cm^{-2}s^{-1}$
- collect 250 fb^{-1}





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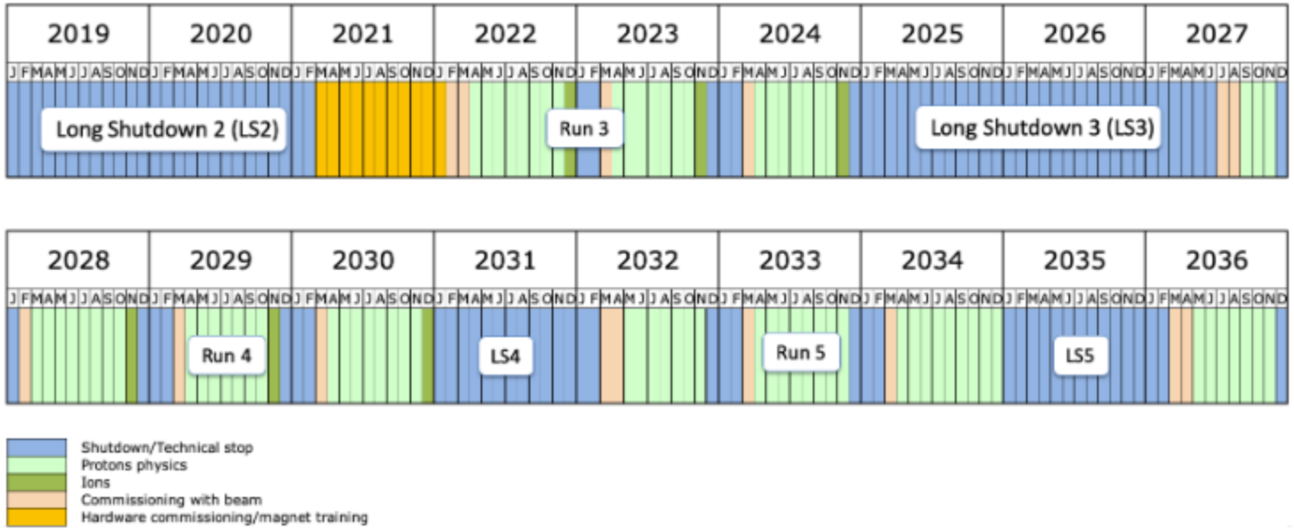

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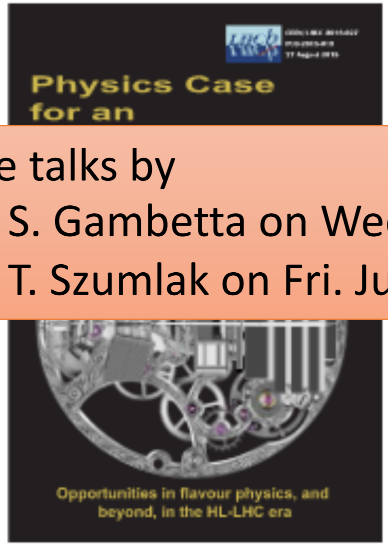

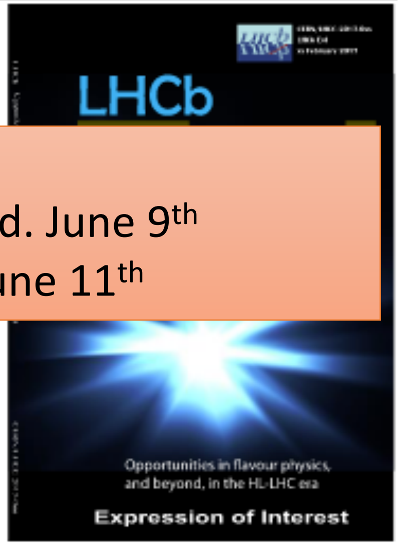

See talks by
- S. Gambetta on Wed. June 9th
- T. Szumlak on Fri. June 11th

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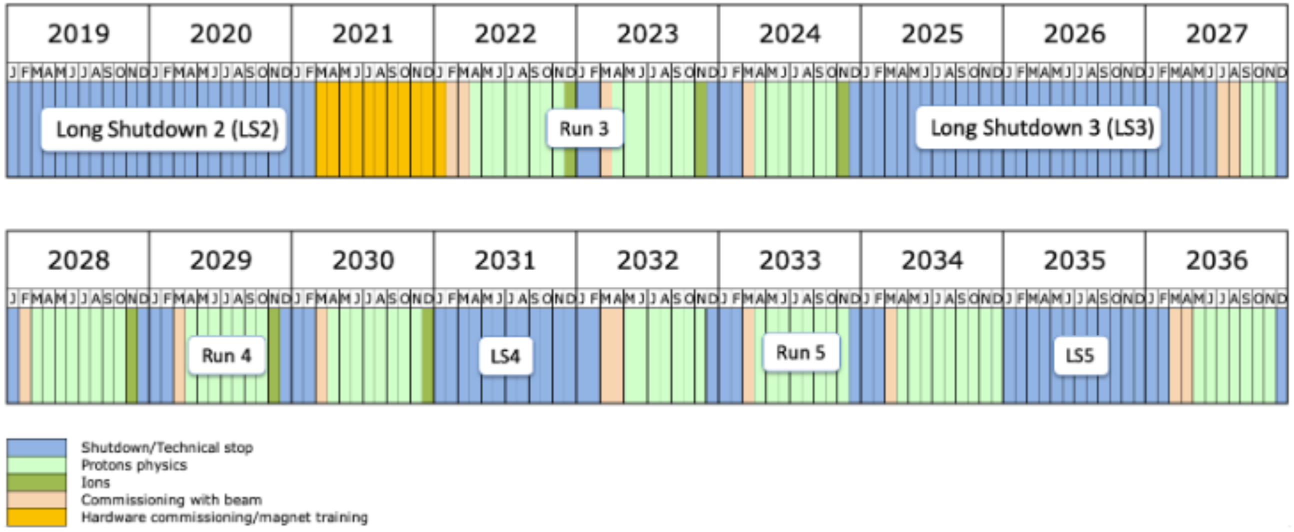


k to [LHC schedule]

Physics programme limited by the detectors

Use of timing is key strategy to overcome challenges

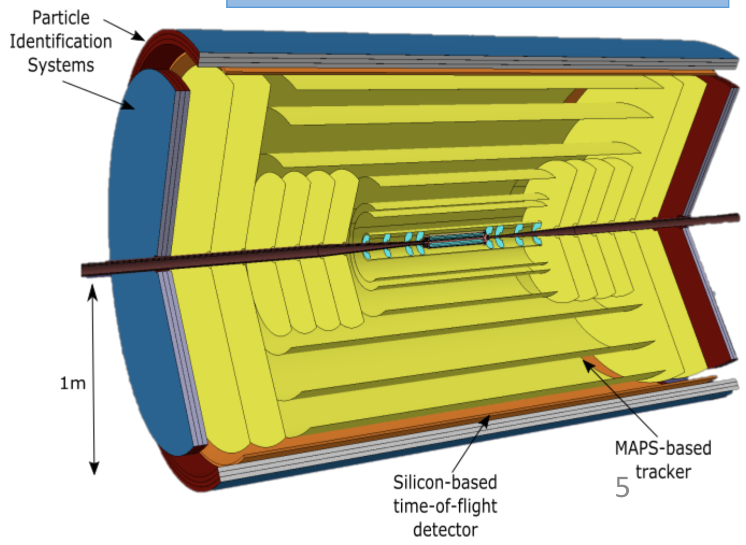
"Ambition to design a new experiment to continue with a rich heavy-ion programme at the HL-LHC" mentioned in the [Update of the European strategy for particle physics]

2019: first document outlining possible concepts and physics opportunities https://arxiv.org/abs/1902.01211

How?

- Increase rate capabilities: luminosities x20-x50 higher than in ALICE in Run 3-4 ($<L_{NN}>$ ~ up to 10^{34} $cm^{-2}s^{-1}$)
- Improve vertexing: innermost layers possibly inside beam pipe
- Tracking over a wide momentum range (down to a few tens of MeV/c) and rapidity coverage ($|\eta| \leq 4$)

ALICE 3



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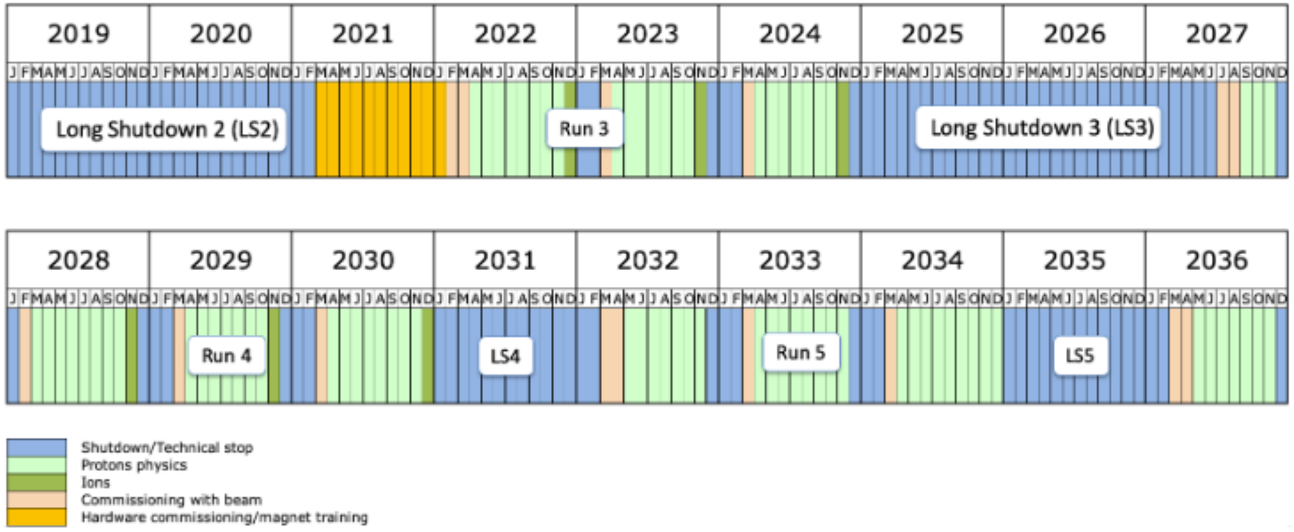

k to LHC schedule

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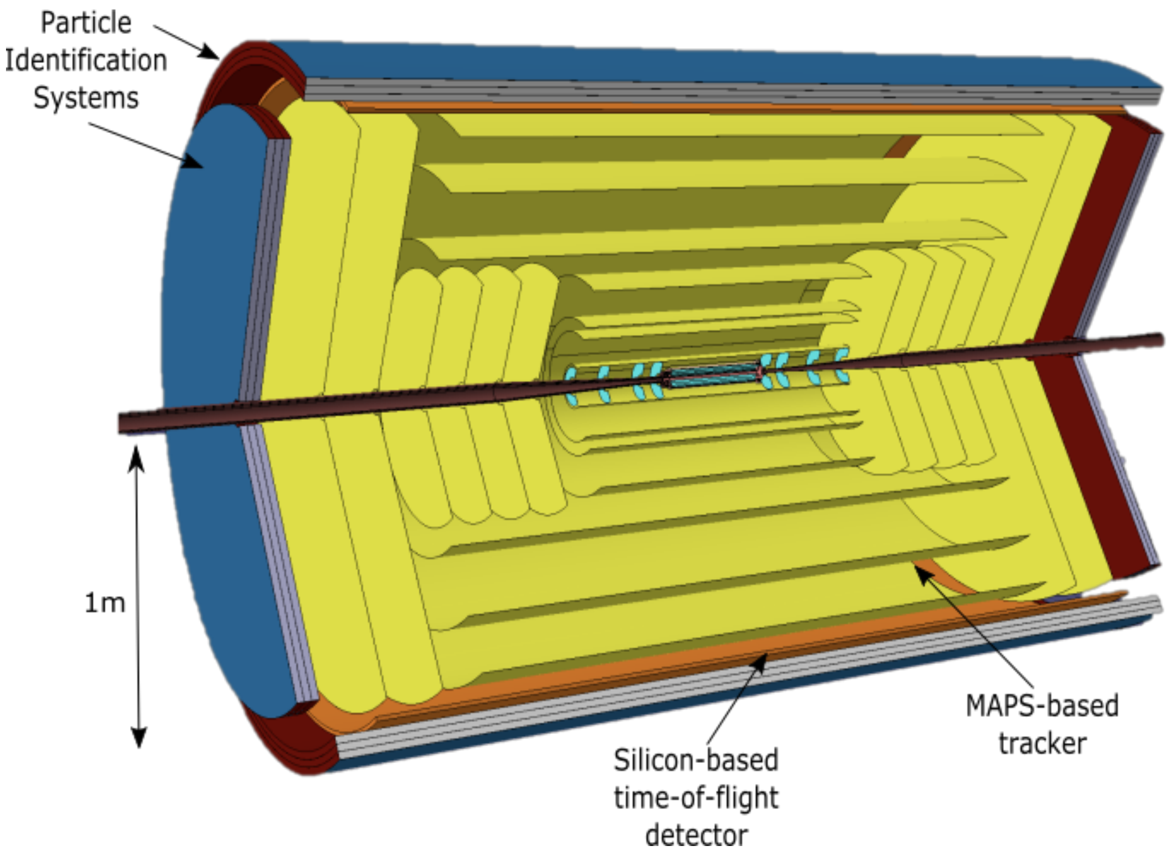
A next heavy ion generation experiment

ALICE 3: compact layout



physics goals drive detector requirements

Physics Potential

- Access doubly and triply heavy-quark hadrons
- Precise dielectron measurements
- Soft and ultra-soft photons

Unprecedented insight into QGP world:
heavy-quark coalescence, medium temperature,
chiral-symmetry restoration

A next heavy ion generation experiment

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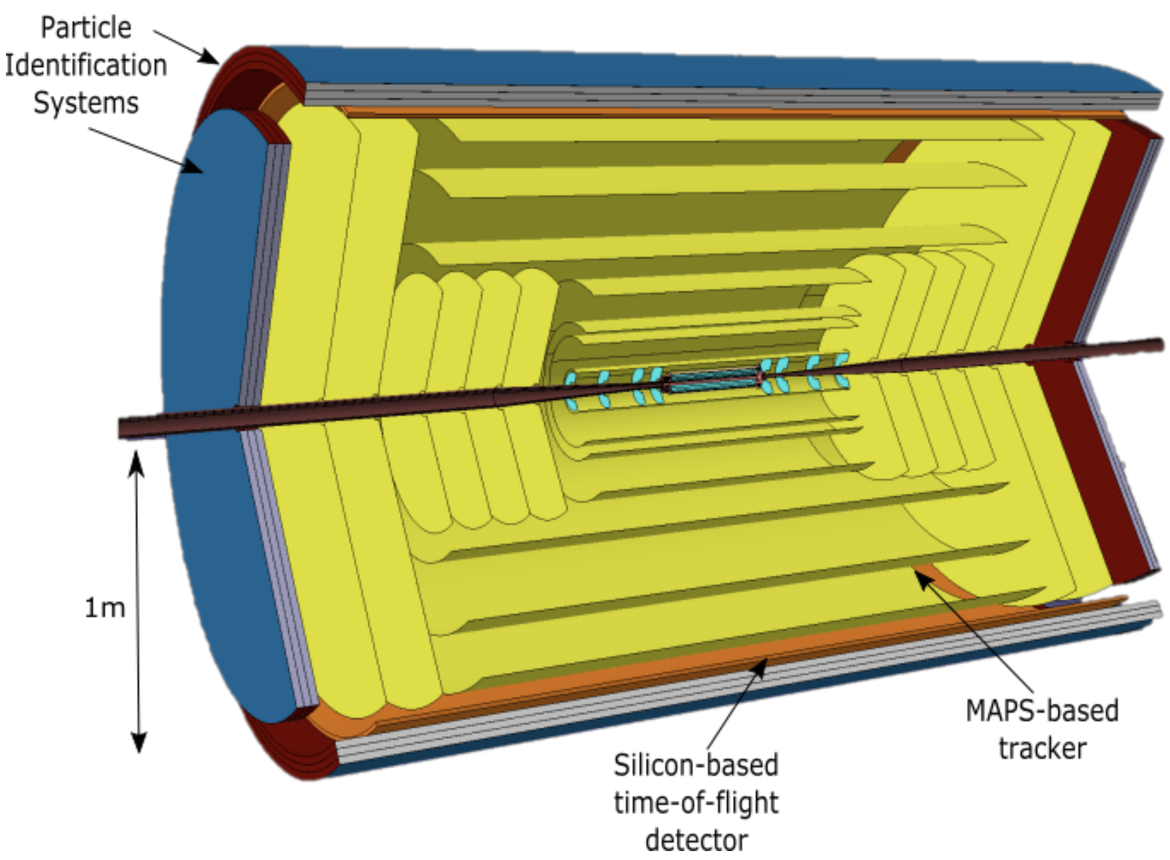
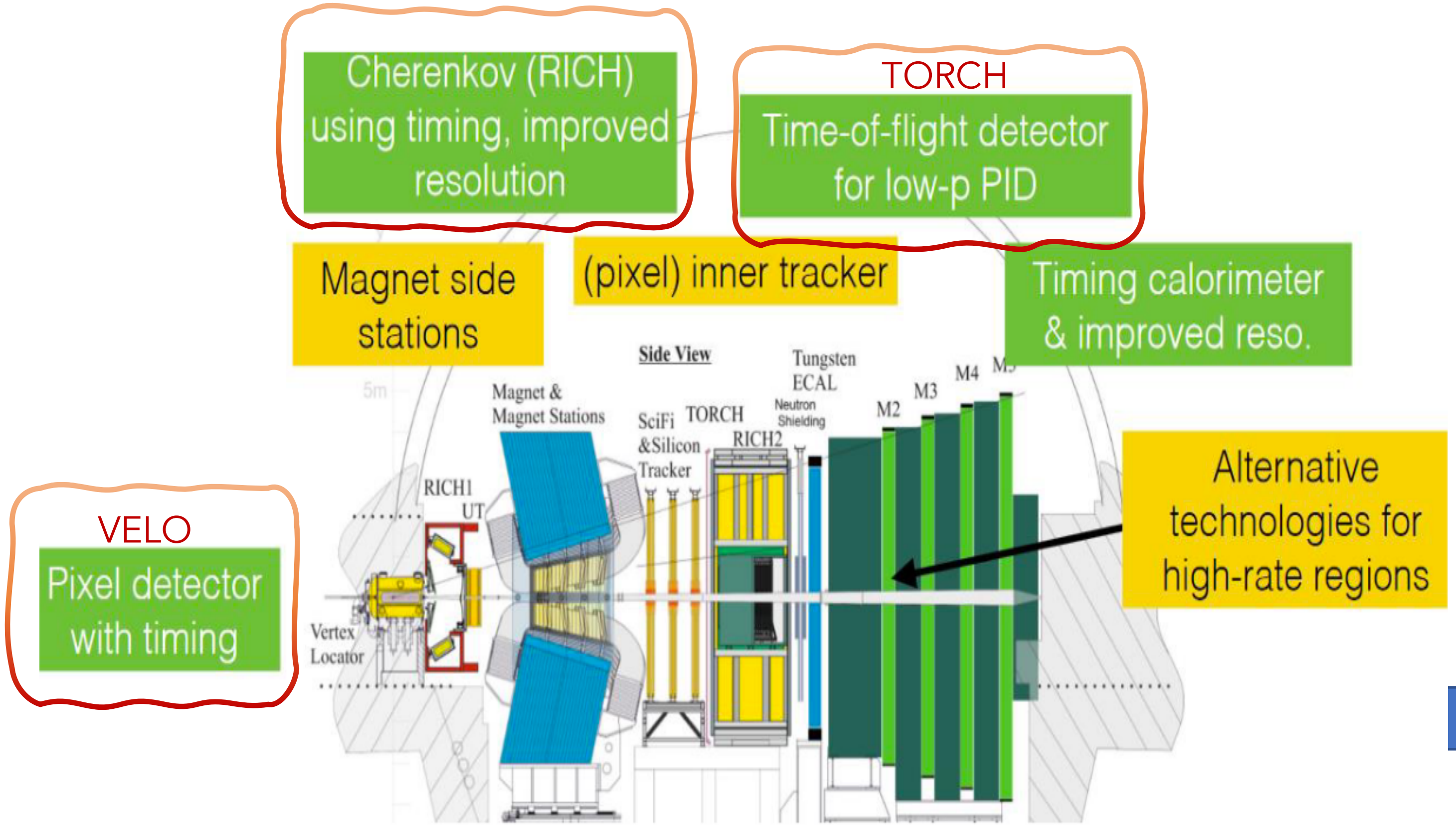


physics goals drive detector requirements

- **Large acceptance:** truly-cylindrical layers + endcaps (|η|<4 coverage)
- Low mass tracker:
  - ~12 tracking barrel layers based on CMOS sensors
  - ~ 0.1 % X_0 vertexing layers
  - ~ 1 % X_0 tracking layers
- High resolution
  - < 3 μm vertexing layers
  - ~ 10 μm tracking layers
- Particle ID:
  - Silicon TOF for hadron and low p_T electron ID with ~ 20 ps timing resolution
  - Shower Pixel Detector for photons and high p_T

Timing is the key!

LHCb Phase-II Upgrade detector



Physics Potential

- Improvement in sensitivities for selected CP-violating observables
- Improvement in sensitivities for selected rare decays and lepton-universality tests

Experimental sensitivity to New Physics scales several orders of magnitude above those accessible to direct searches

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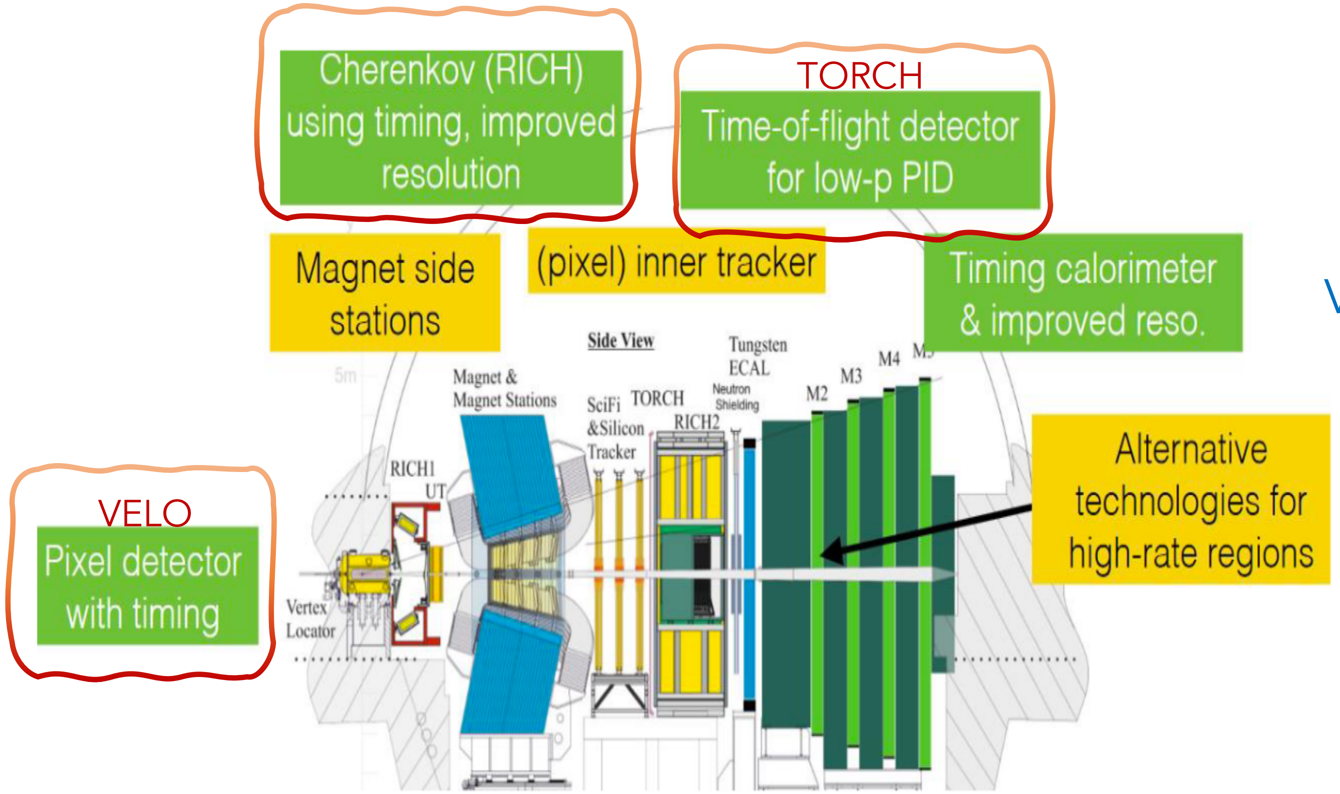
LHCb Phase-II Upgrade detector



TORCH

- large area time of flight detector to provide PID in the GeV/c momentum range
- exploit prompt production of Cherenkov light in a quartz radiator plate to provide a fast timing signal.
- aim for a resolution of 10-15 ps per track

VELO

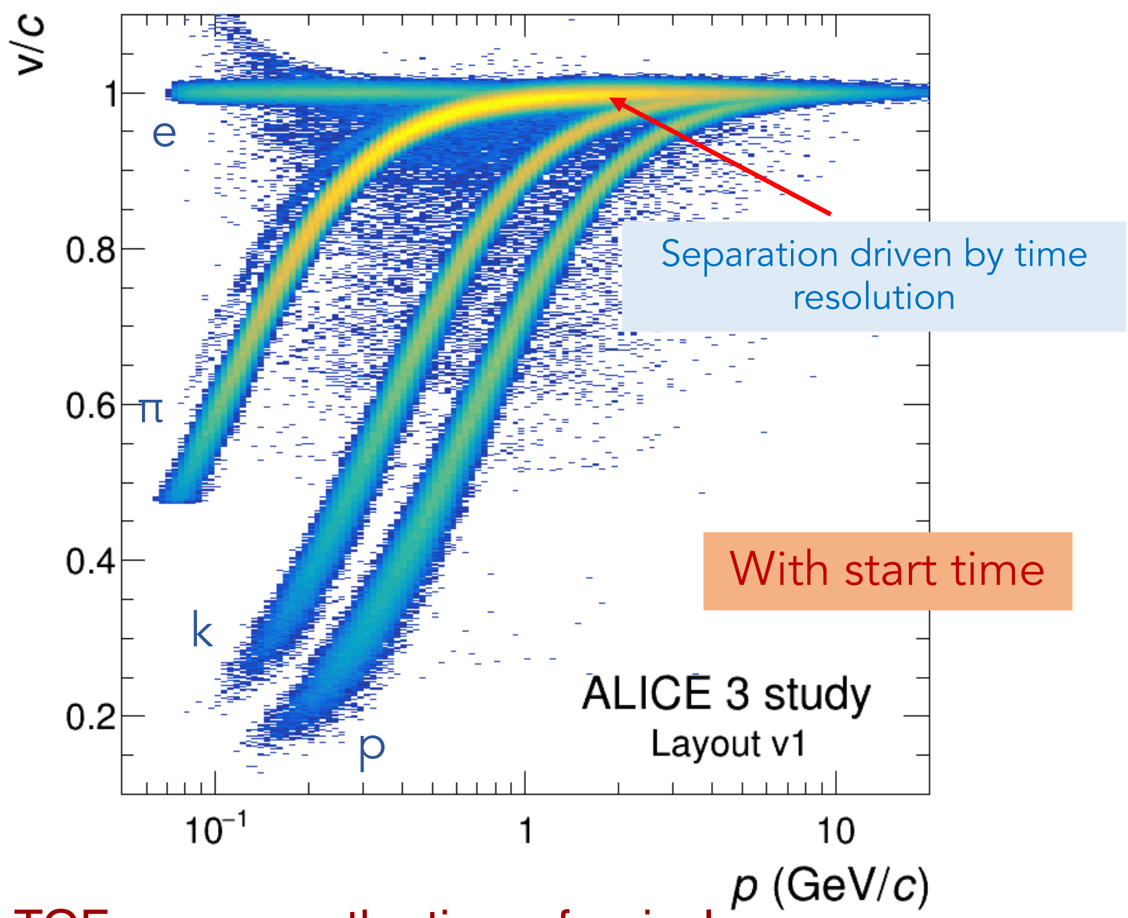
- 7.5 times more pile-up than upgrade I
- reduce fraction of fake tracks with 4D tracking
- timing to remove effective pile-up (timestamp required ~ 50 ps) and to improve PV reconstruction

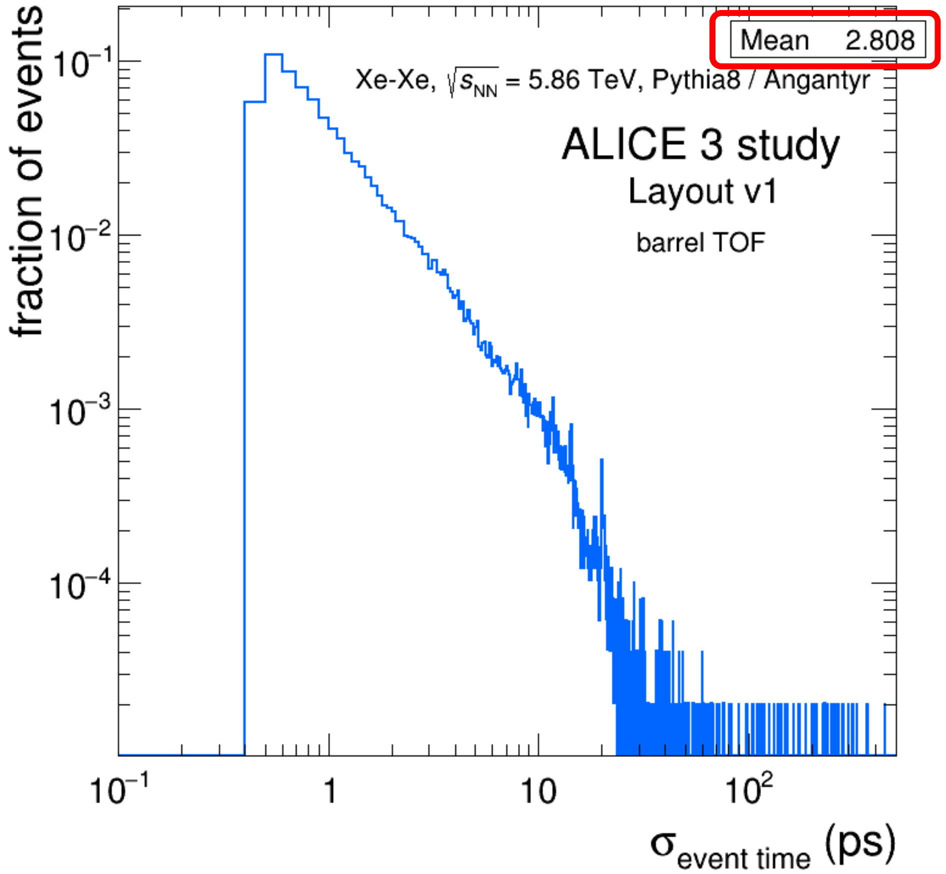
RICH Detectors

- current detectors would have 100% occupancy
- timing allows to recover loss of PID performance
- possible time resolution of ~ 100 ps

Timing is the key!

ALICE 3: TOF performance





TOF measures the time of arrival
- needs start time for good PID performance
- collision time jitter ~ 300 ps (9 cm bunch length)

TOF can measure the event time
- combinatorial algorithm (min. 2 tracks)
- resolution ∝ 1 / √Ntracks

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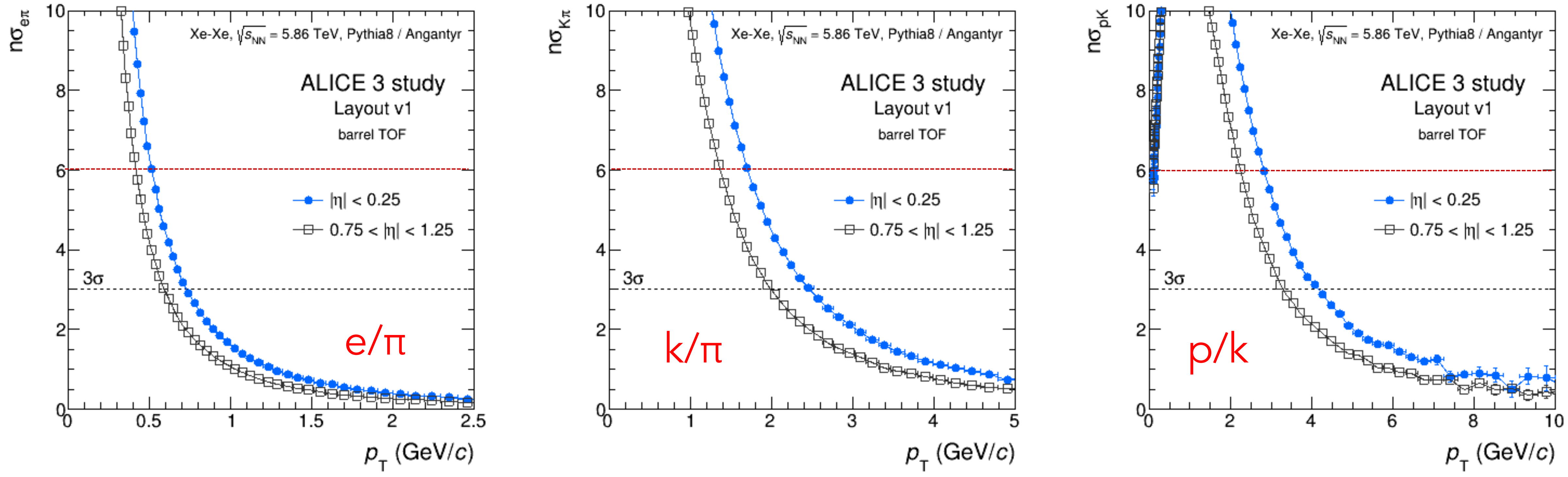
ALICE 3: PID performance



- B = 0.2 T, |**η**| < 0.25 and 0.75<**η** < 1.25
- Straight track approximation
- 20 ps time of flight resolution at R = 1 m

3σ (6σ) separation at |η| < 0.25 up to

- e/π ~ 750 (600) MeV/c
- k/π~ 2.6 (1.9) GeV/c
- p/k~ 4.2 (3.2) GeV/c

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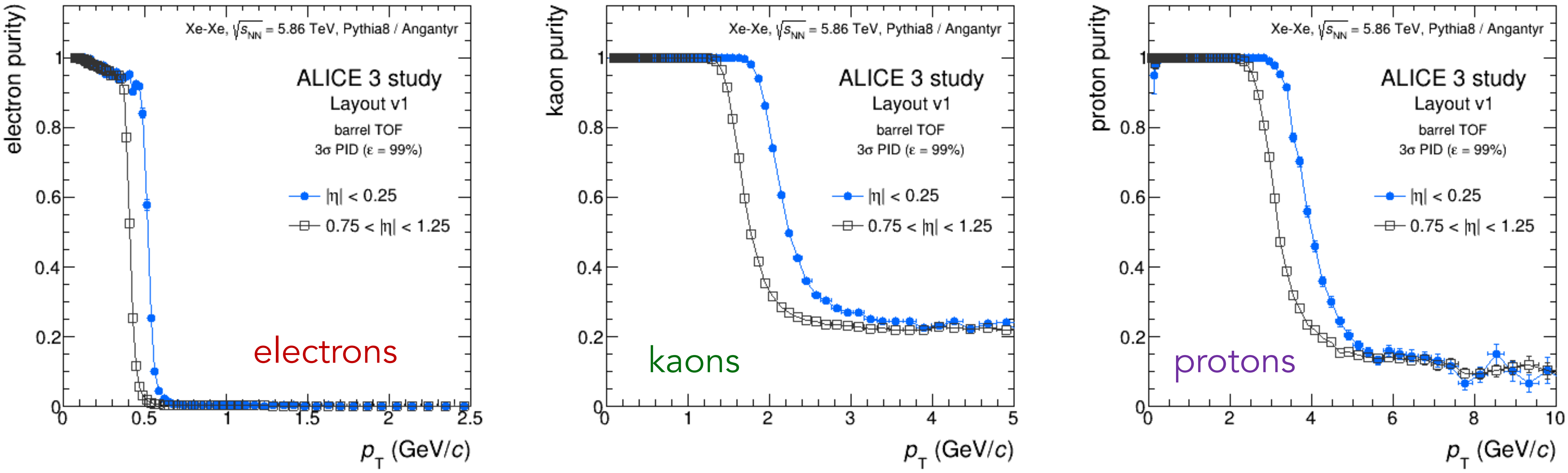
ALICE 3: PID performance



- 0.1% mismatch rate assumed in the simulation
- detector effects and start-time included
- At |η| <0.25 excellent performance (>90% purity) up to ~500 MeV/c (electrons), ~2 GeV/c (kaons) and ~4 GeV/c (protons)

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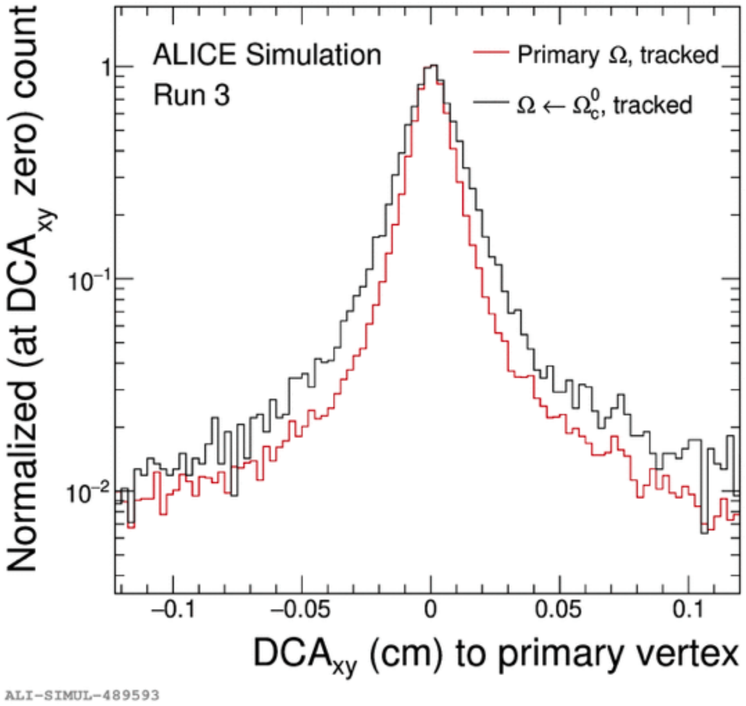
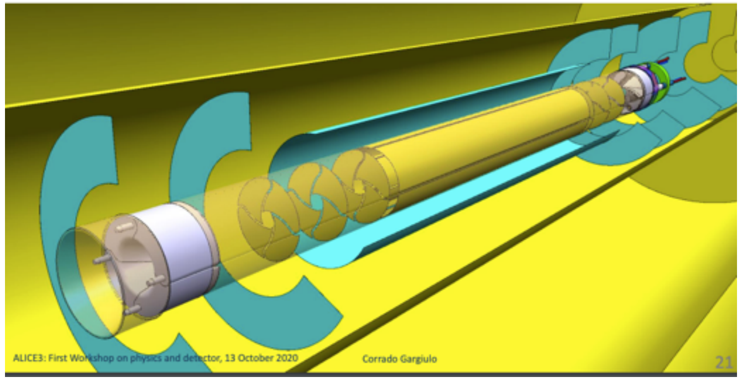
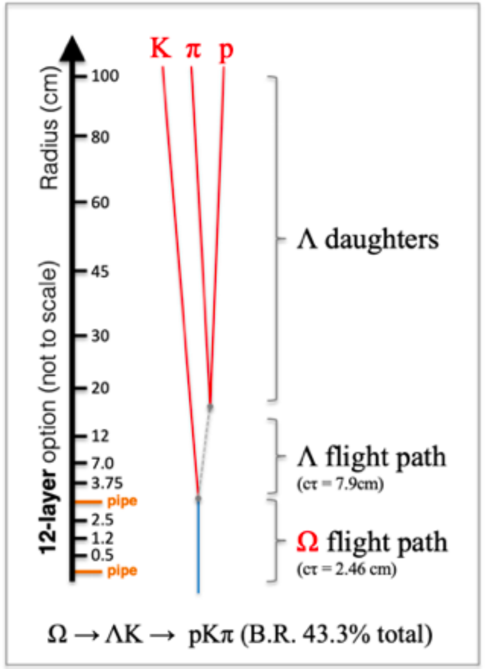
ALICE 3: strangeness tracking

strangeness tracking with ITS2

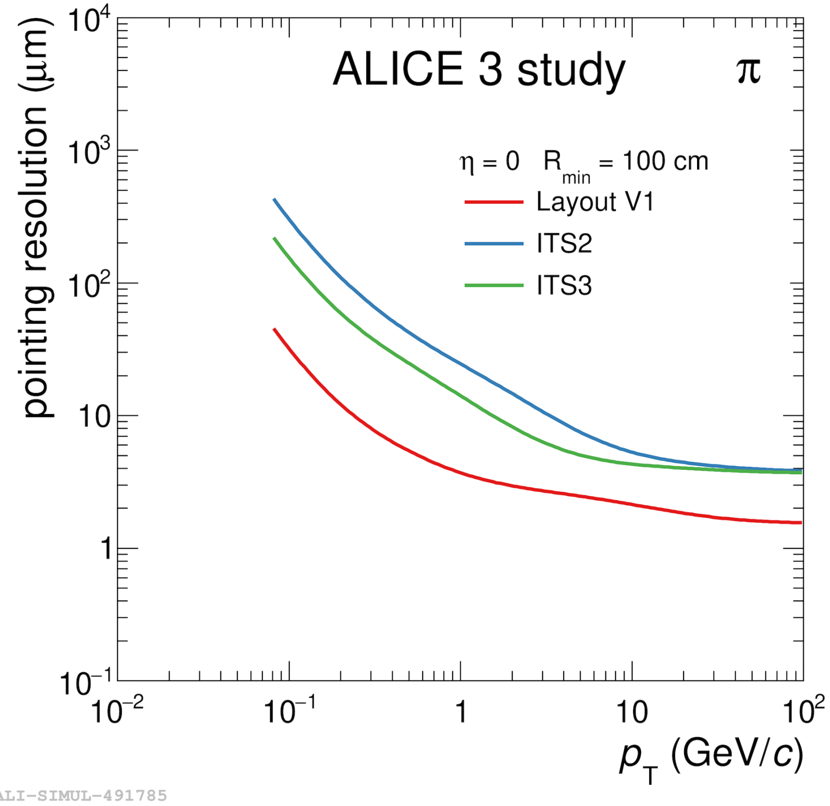




strangeness tracking in Run 5



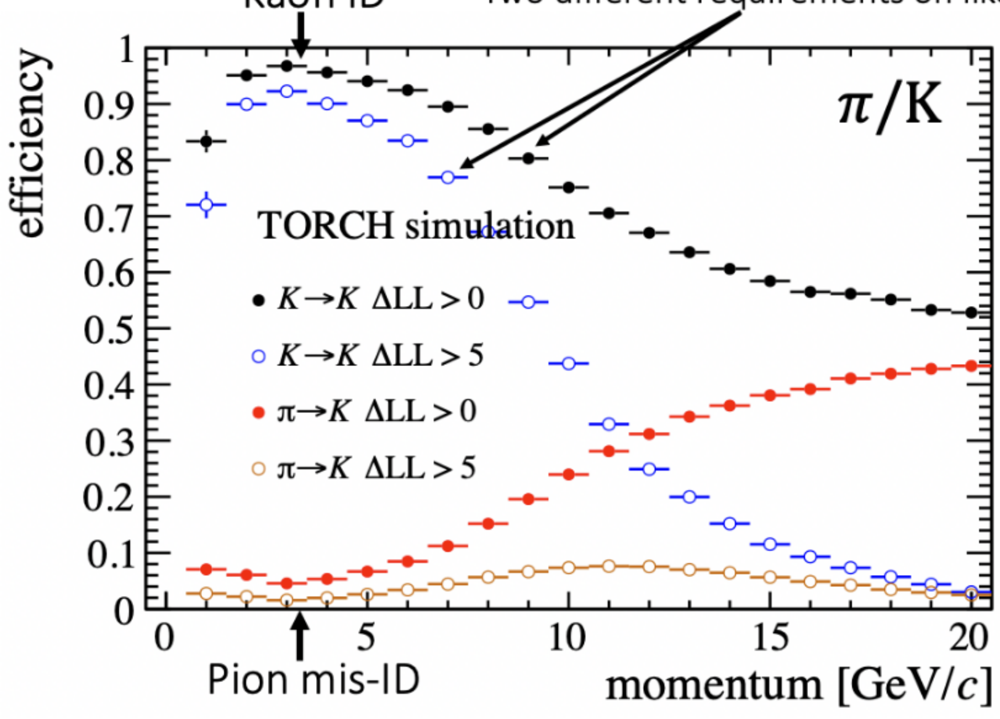
Impact parameter resolution with retractable layer

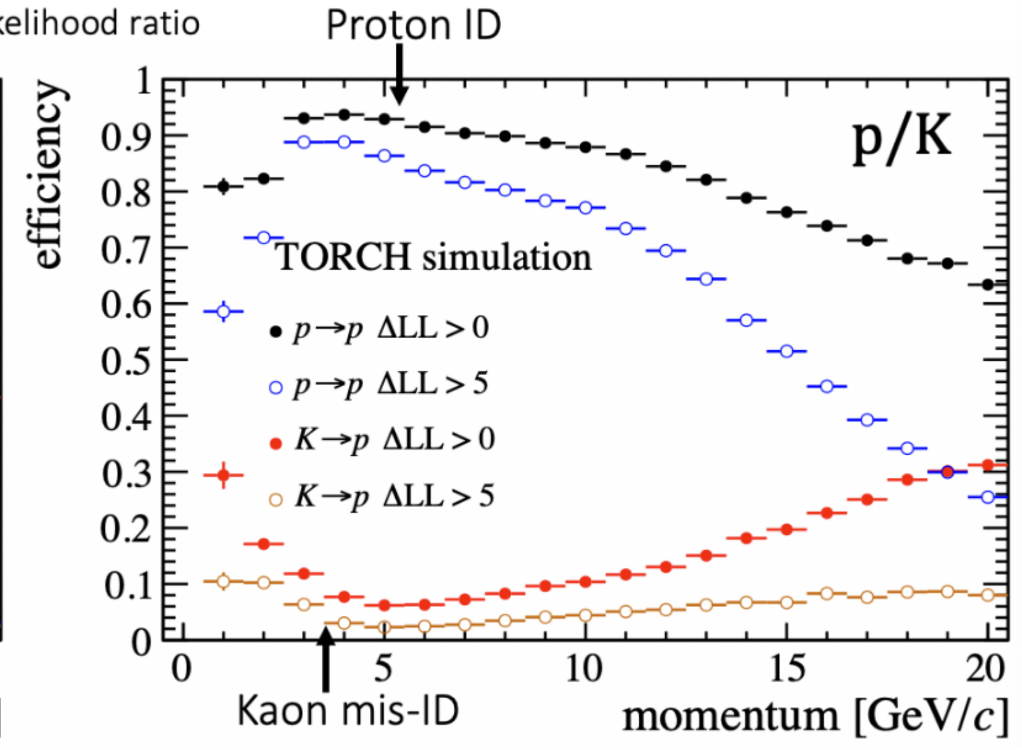


- impact parameter resolution < 10 μm for $p_T > 0.2$ GeV/c
- Simulation effort ongoing also for heavy flavour channels

LHCb PID performance with TORCH

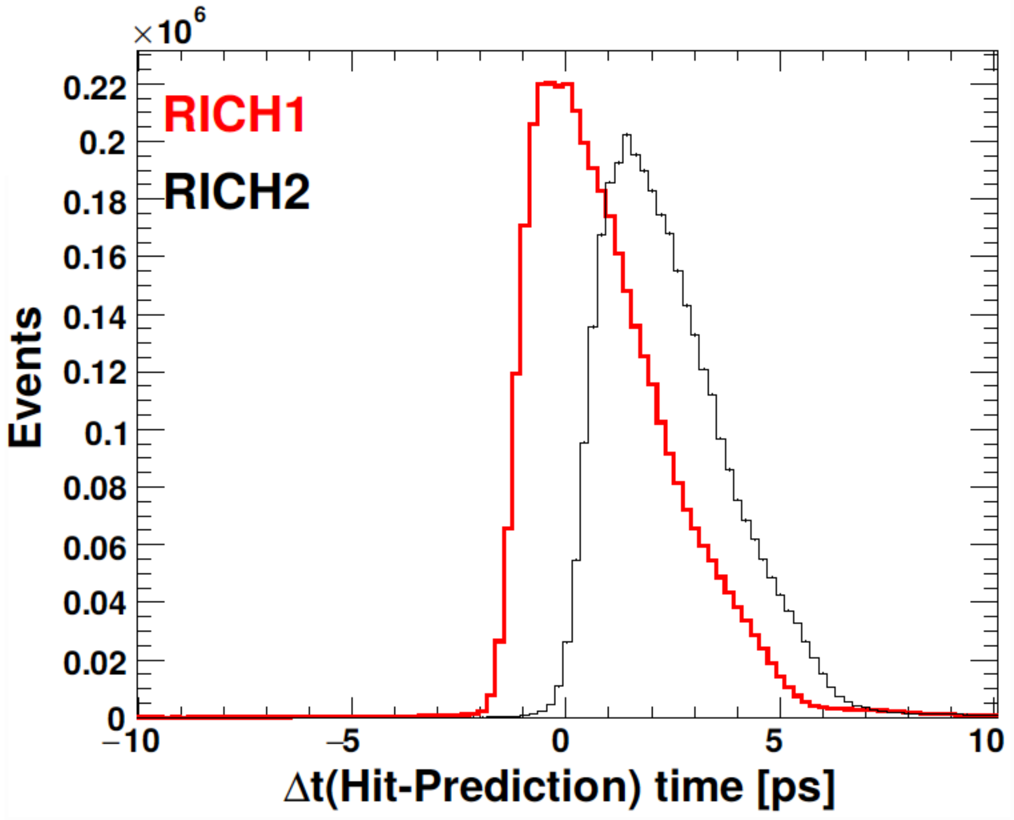
Two different requirements on likelihood ratio



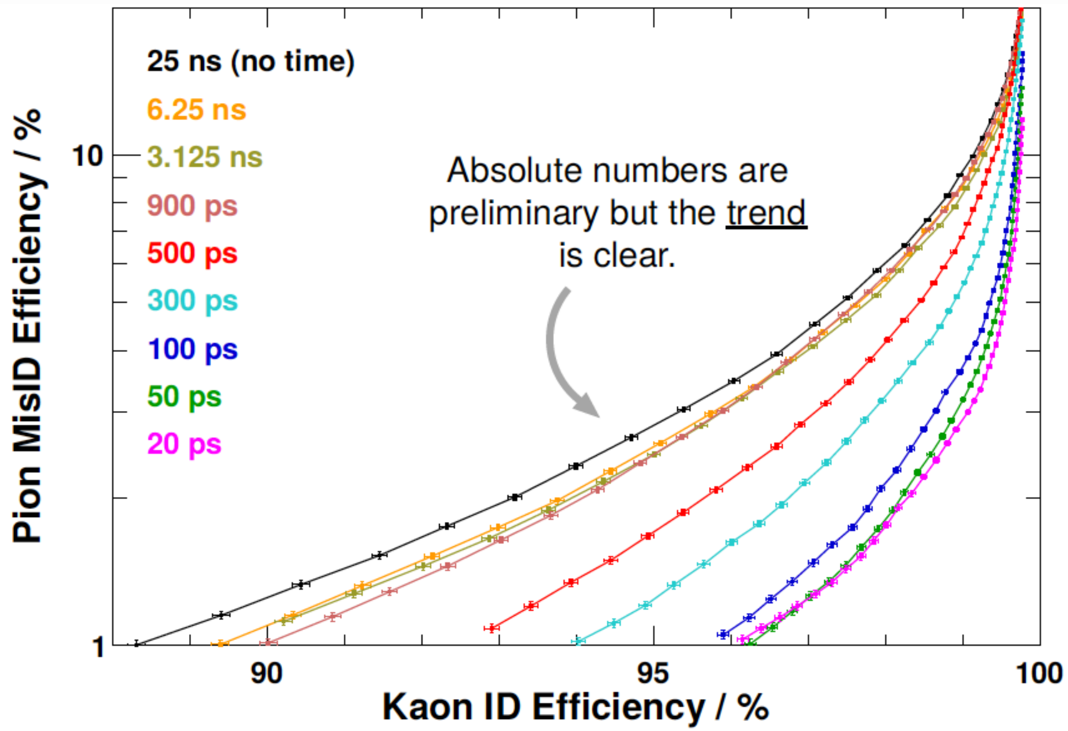


- TORCH simulated in Upgraded LHCb detector framework (GEANT4)
- PID performance determined for Upgrade II conditions (Run 5)
- Good separation expected between π/K/p in the 2–10 GeV/c range and beyond
- Performance modelling ongoing

LHCb PID performance with RICH

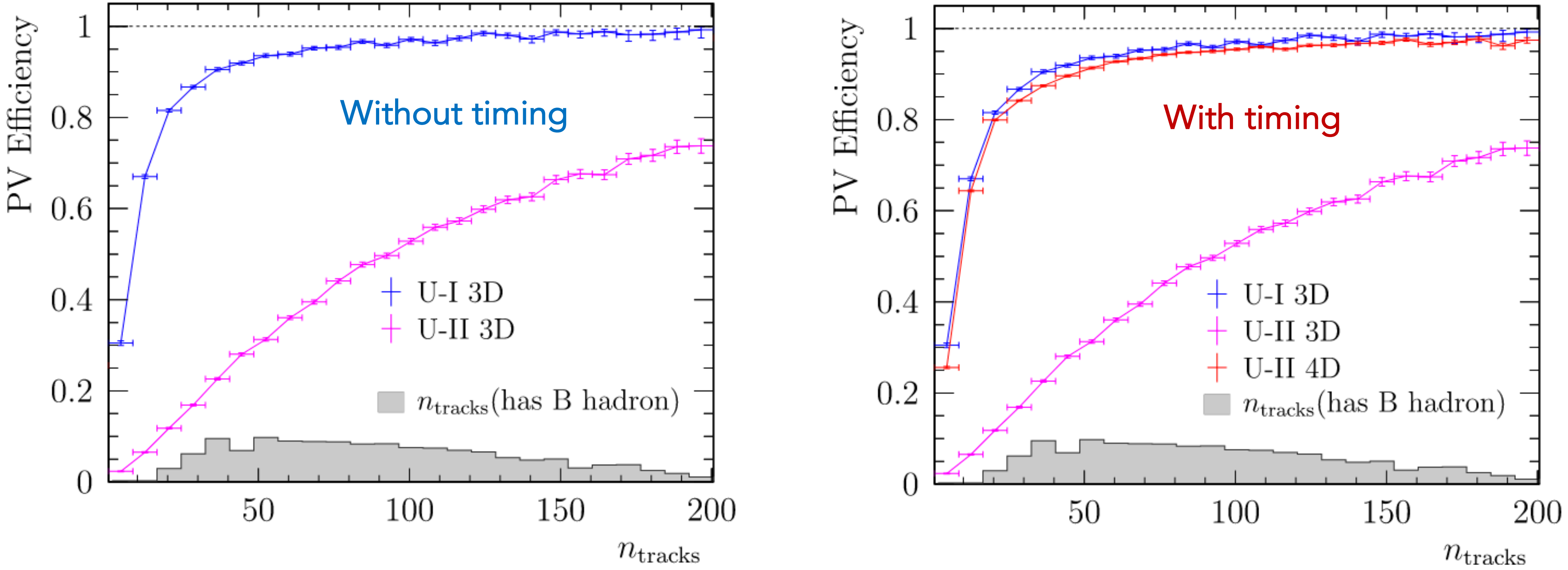


For a given track the time of arrival (ToA) of Cherenkov photons on the detector plane can be predicted to better than 10 ps



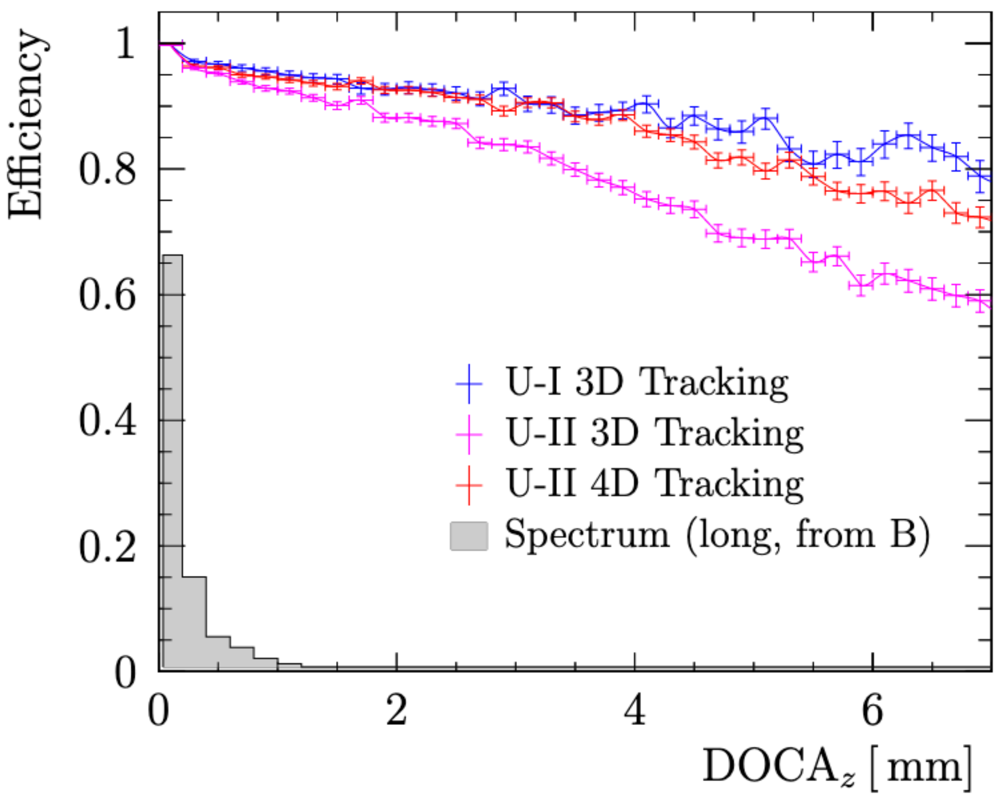
- Clear improvement as time gates of smaller width are applied around the predicted hit time.
- The trend highlights the benefit of pursuing the best time resolution for the future detector technologies.

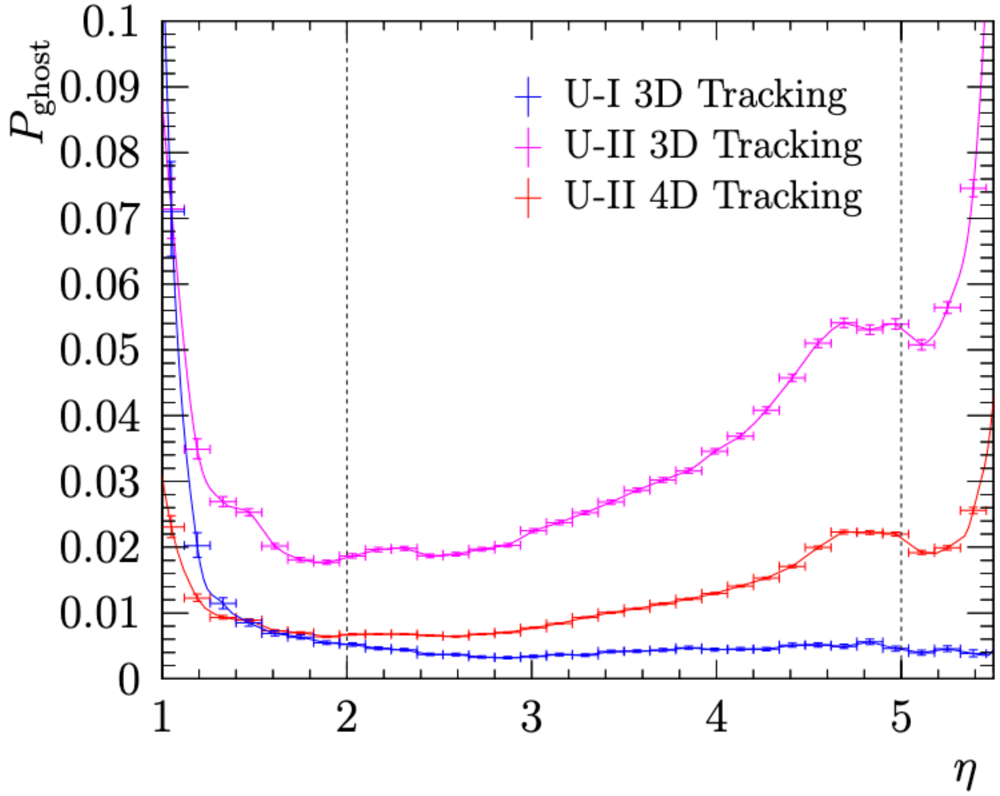
LHCb phase II challenge: vertexing



- At ~50 interactions / bunch crossing, primary vertex separation is comparable to the per-track pointing resolution to the beam axis (~1 mm) : reconstruction becomes tough.
- Adding 50 ps/ hit timestamp almost completely recovers the Upgrade-I vertex reconstruction efficiency

LHCb phase II challenge: 4D tracking





Four-dimensional tracking brings improvements to:

- Tracking efficiency and its spatial uniformity, important for control of systematic uncertainties as correlated with decay times.
- Large reduction in ghost rate (down to~1%).

Summary

- High luminosity running presents many opportunities and challenges for experiments
- Exciting physics cases under study from LHCb and ALICE
- Promising results shown for PID and tracking performances
- R&D effort driven by physics and the use of timing is a key strategy to overcome challenges
- Short term plan:
  - Letter of Intent by the end of 2021 for the ALICE 3 project
  - Framework TDR for the LHCb Upgrade phase II