Future upgrade of LHCb RICH

On behalf of LHCb RICH collaboration

LHCb Timeline

LHCb detector until 2024

RICH1, Magnet, RICH2, Vertex Locator, Calorimeter, Tracking stations, Muon chamber

> Goal: Search for New Physics:

- Indirect search by measuring parameters related to CP-violation in B-decays and D-decays with unprecedented precision
- Search for signals of BSM and dark sector particles through rare decays
- Examples of expected precisions from LHCb

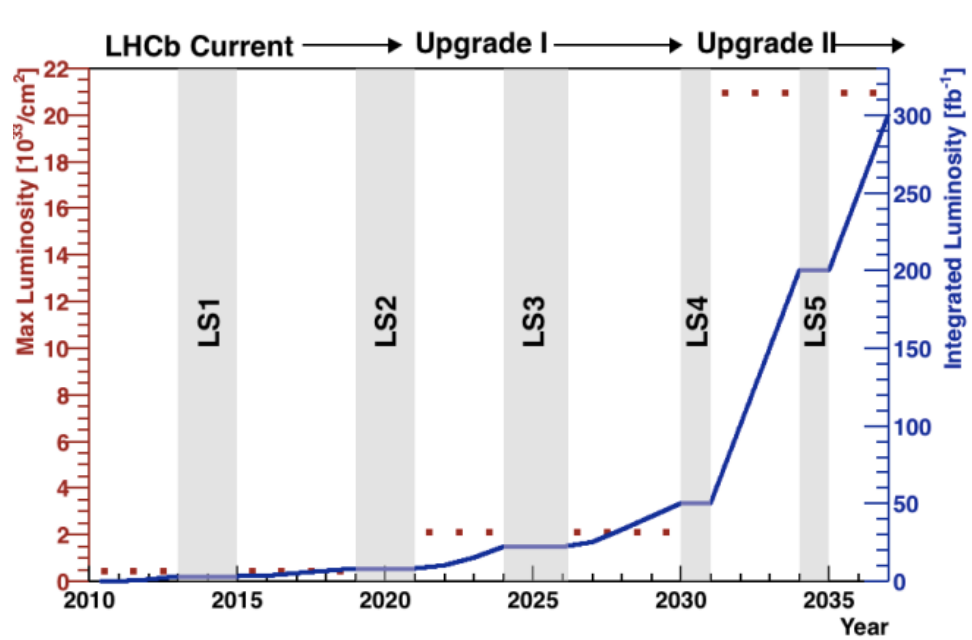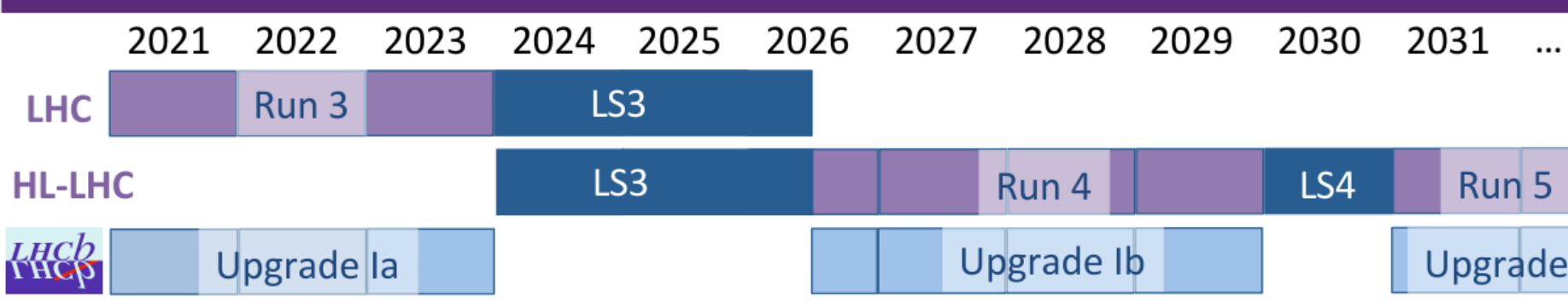| Parameter	Current	2025	HL-LHC
CKM angle γ	5.4^0	1.5^0	0.4^0
R_K	0.1	0.022	0.006
R	90 %	34 %	10 %

Three aspects of improving RICH performance with increased luminosity

> Improve single photon resolutions, yield and occupancy

$$\sigma_p = \sigma_{chromatic} \oplus \sigma_{emission\ point} \oplus \sigma_{pixel}$$

$$\sigma_t = \frac{\sigma_p}{\sqrt{N}} + Const.$$

> Measure the RICH hit time and use it in PID

  Reduce background from out-of-time hits
  Separate the primary vertices (PV) from multiple interactions using Hit Time and reduce occupancy
  Use Hit time information in the Global likelihood algorithm for PID

> Upgrade coverage in the momentum ranges below 10 GeV/c and above 80 GeV/c

  Develop novel radiators to cover this momentum range

Proposals for future LHCb detector

VELO Pixels with Timing; UT Micro strips; Magnet Side Stations; Inner/Middle/Outer Tracker; RICH; Timing / PID TORCH; ECAL Spatial resolution & Timing; Muon μRwell

$$R_K = \frac{Br(B^+ \to K^+ \mu^- \mu^+)}{Br(B^+ \to K^+ e^- e^+)} \qquad R = \frac{Br(B^0 \to \mu^+ \mu^-)}{Br(B_s^0 \to \mu^+ \mu^-)}$$

Upgrade stages	Phase 1	Phase 2
Luminosity cm^{-2}s^{-1}	2×10^{33}	2×10^{34}
ν	7.6	35

ν = Average number of pp interactions per bunch crossing

(A) : Resolutions , yield and occupancy

Upgrade Phase1a : MaPMT (R13742) with 2.78 mm pixel size for RICH1 and central part of RICH2. $\lambda > 280$ nm.
Future Upgrade : Use SiPM (Silicon Photomultiplier) with 1 mm pixel size and use $\lambda > 400$ nm.
Also considering improvements in RICH optics geometry.

Results from GEANT4 based simulations listed below for RICH1. Similar results obtained from RICH2 also. Simulations use beam conditions of Phase1a upgrade.

RICH1: Phase1a	Overall mrad	Chromatic mrad	Emission.pt. mrad	Pixel mrad	Yield
MaPMT	0.78	0.57	0.36	0.45	41.2
SiPM	0.40	0.11	0.36	0.15	47
SiPM+a new geometry version	0.22	0.11	0.12	0.15	34

Expecting to improve the current resolution (0.34 mrad) from tracking, to make the best use of SiPM in RICH.

RICH1: peak occupancy	MaPMT	SiPM+ a new geometry version
Phase1a upgrade	28 %	3.1 %
Future upgrade (Phase 2)	>100 %	14.2 %

Improvements in tracking system and RICH geometry are expected to further enhance the PID performance.

RICH Kaon ID

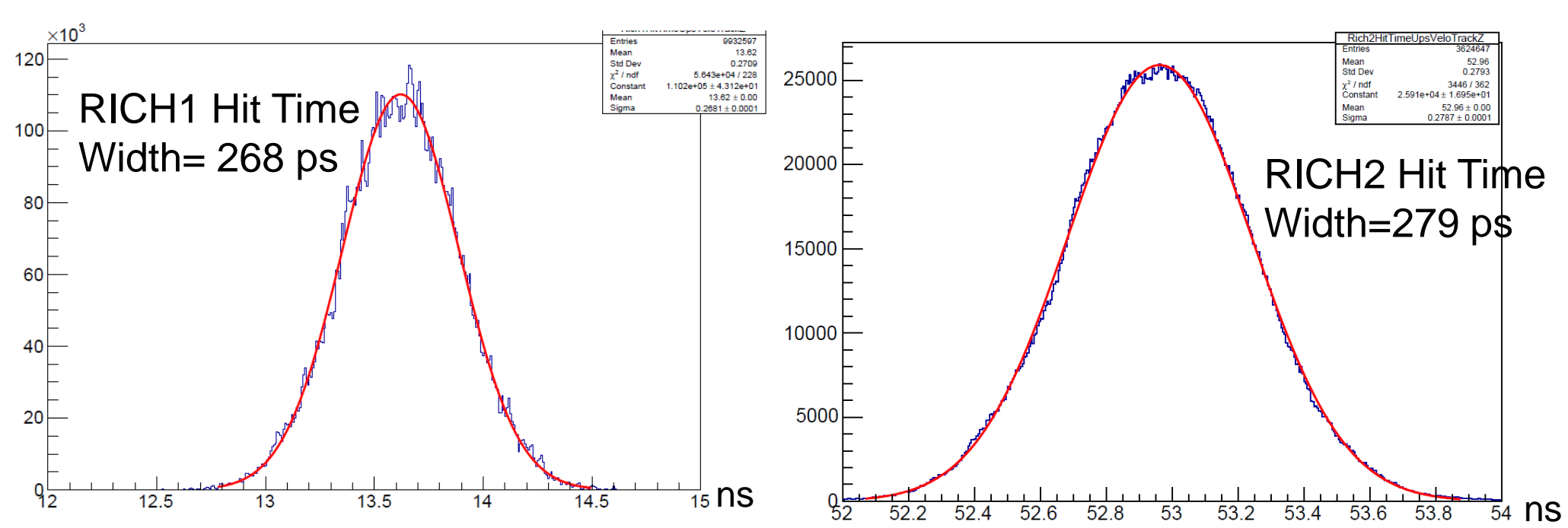Phase1a with MaPMT; With SiPM; **Preliminary**

(B) : RICH Time measurement

> RICH Hit time from LHCb simulations using PYTHIA+EVTGEN+ GEANT4

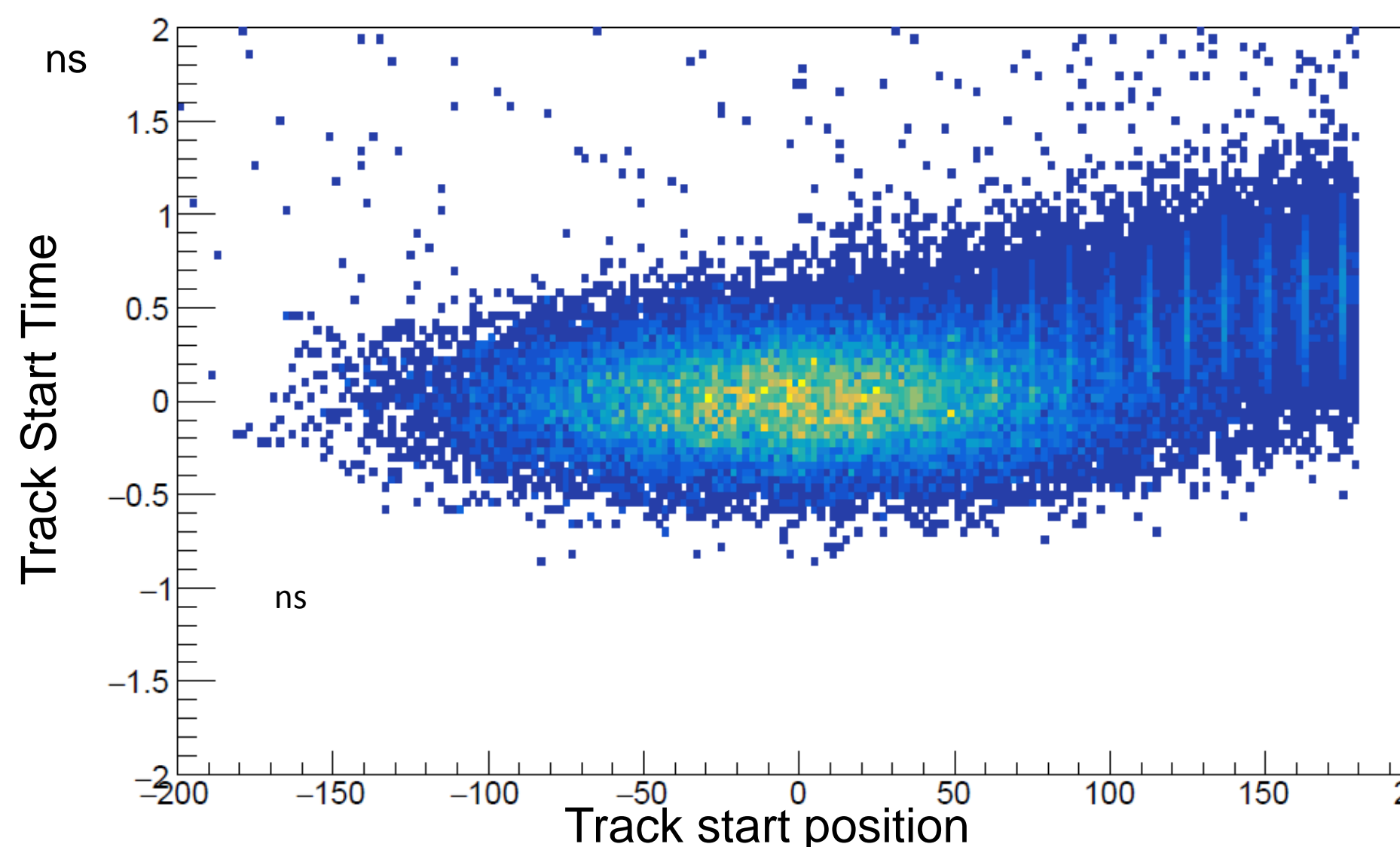> Primary Vertex generator model the beam bunches as 4D-Gaussians (X,Y,Z, time)

> PDF calculated when the bunches travel towards the collision point at beam crossing angles
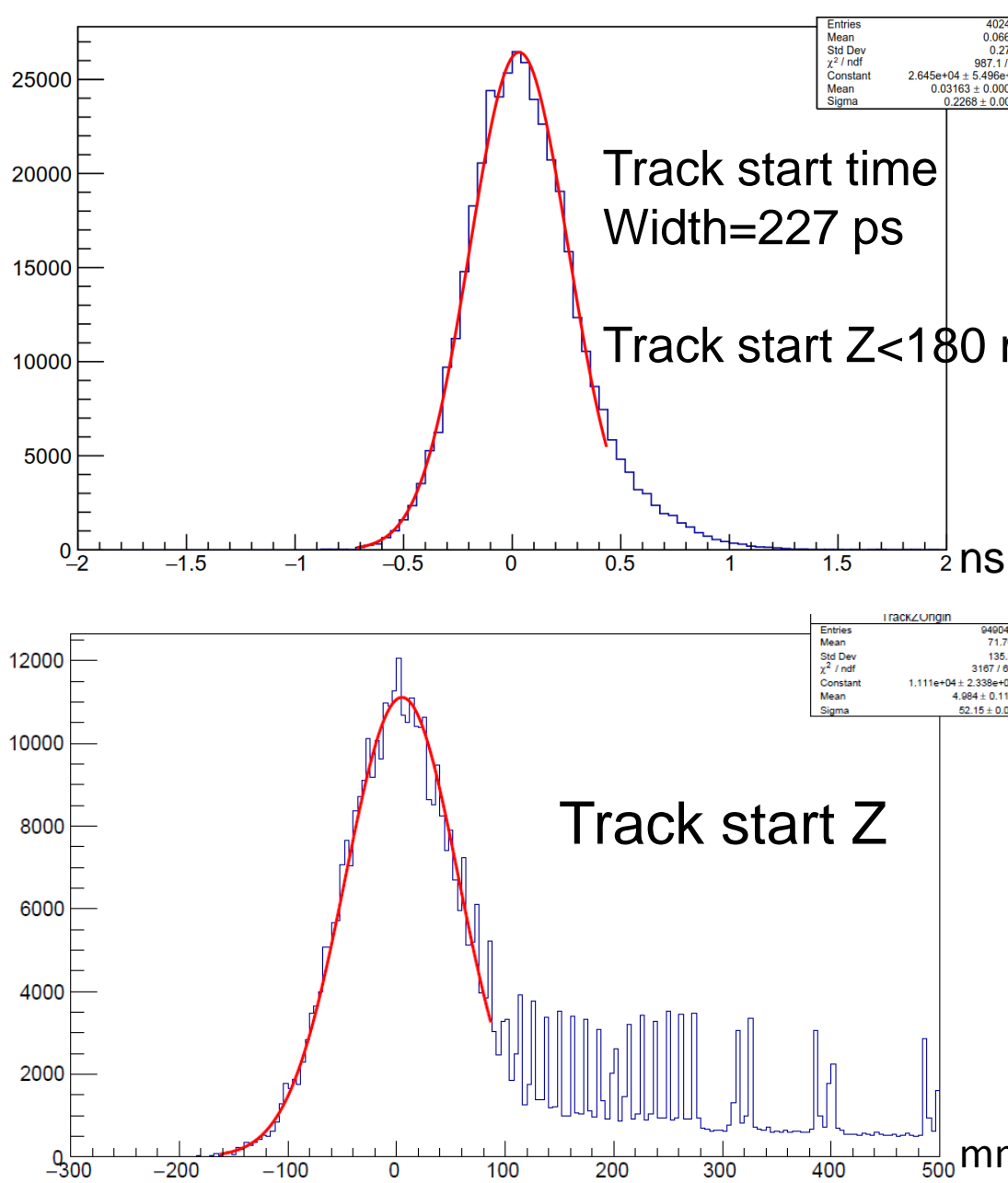
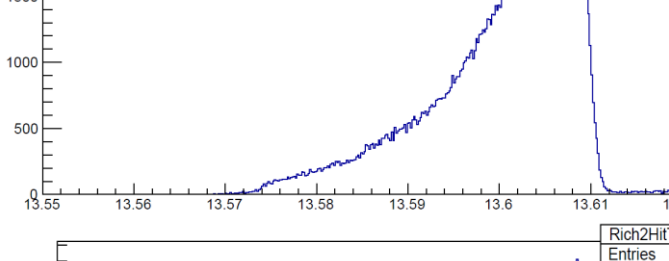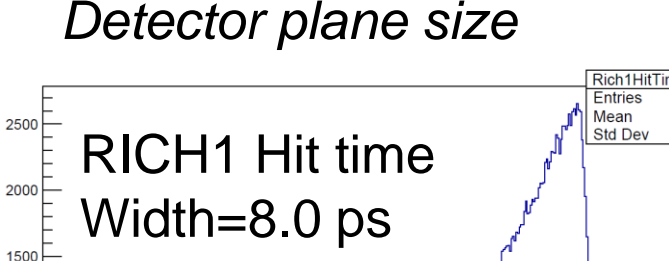> A Markov chain sampler used to sample from the 4D - PDF

> Using B events

PV Time vs Z

Using tracks which created hits in RICH

Track start time Width=227 ps
Track start Z<180 mm

Track start Z

RICH hit time spread from Detector plane size

RICH1 Hit time Width=8.0 ps

RICH2 Hit time Width=46.9 ps

Using Particle gun events

RICH1 Hit Time Width= 268 ps

RICH2 Hit Time Width=279 ps

RICH Hit Time

Track start time
-5 mm< Track start position < 5 mm
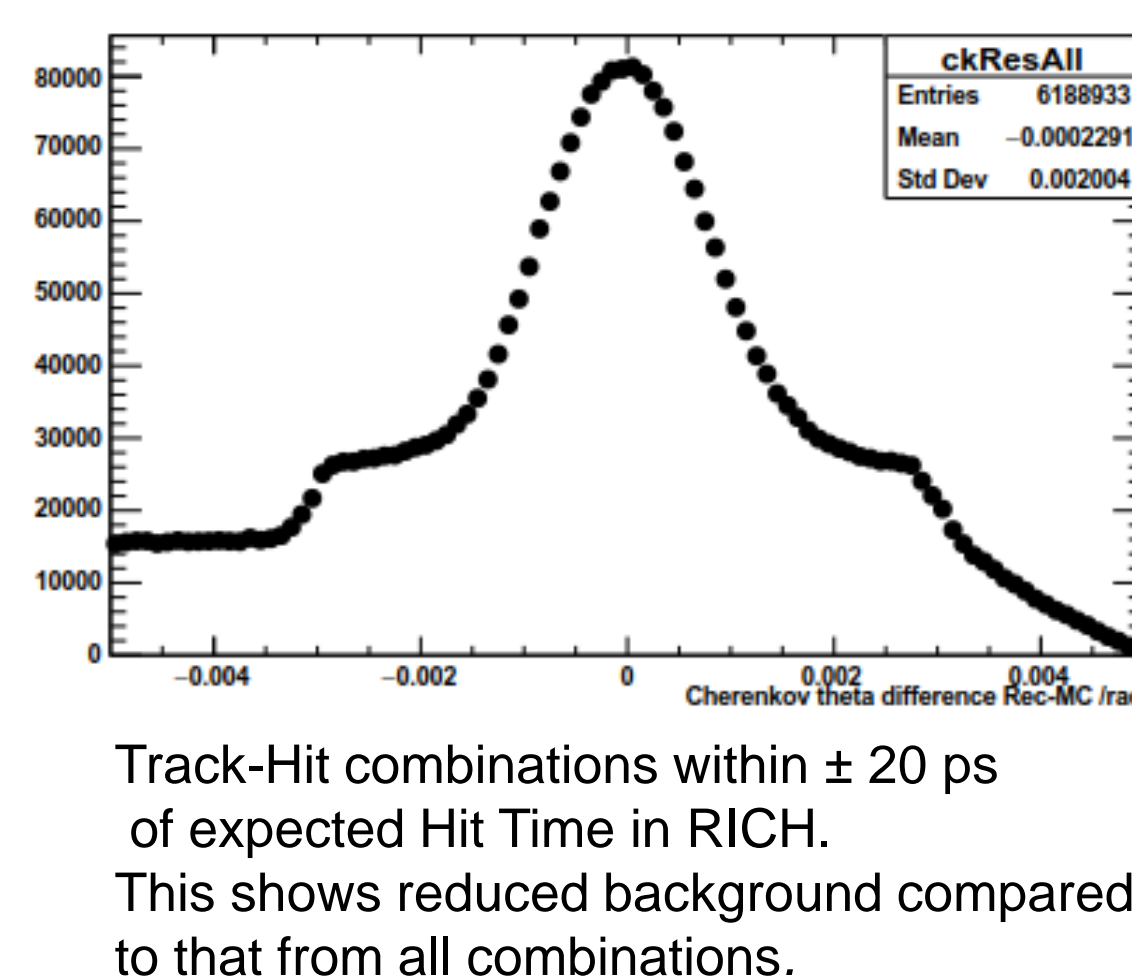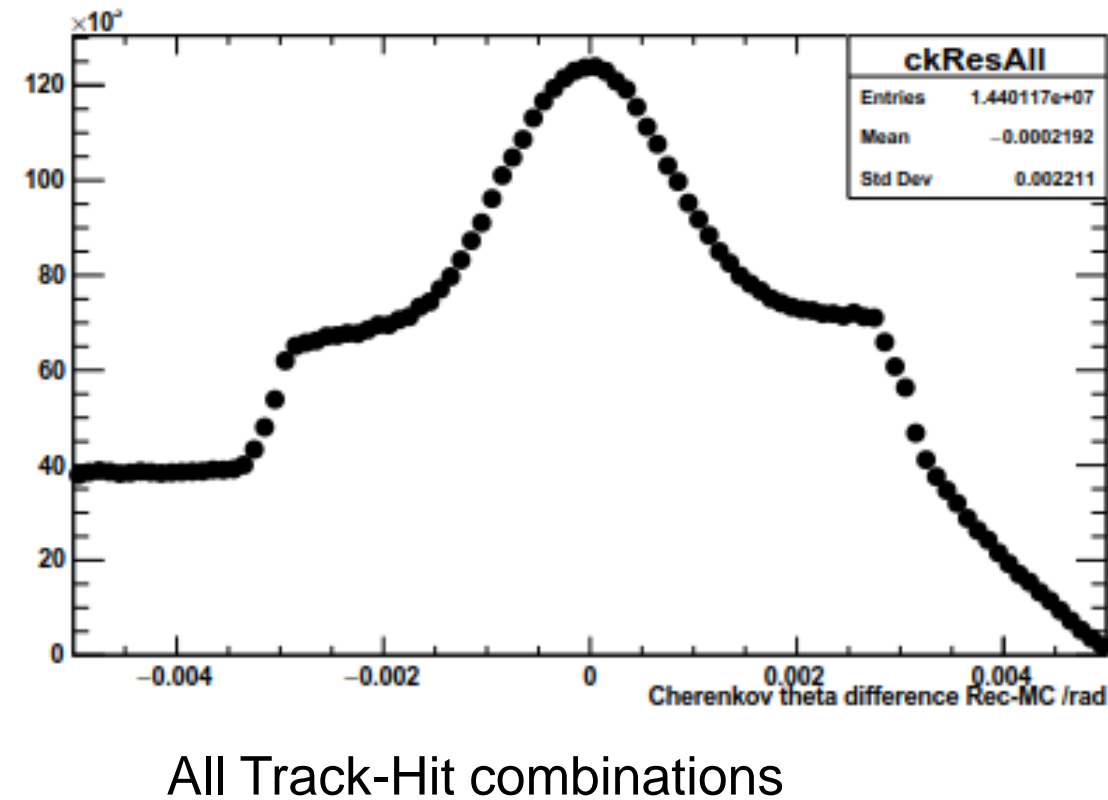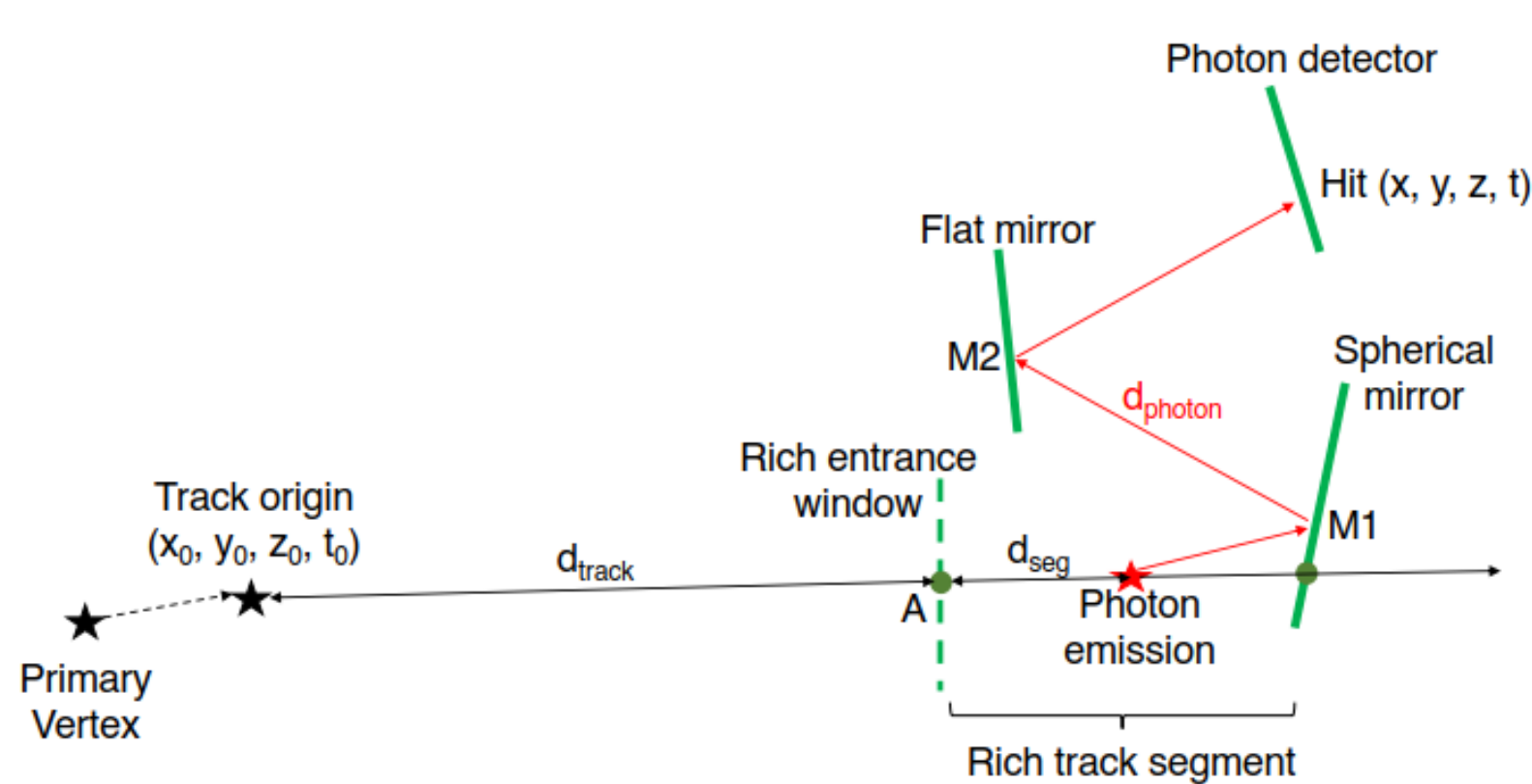
- Such correlations can be useful in separating out primary vertices
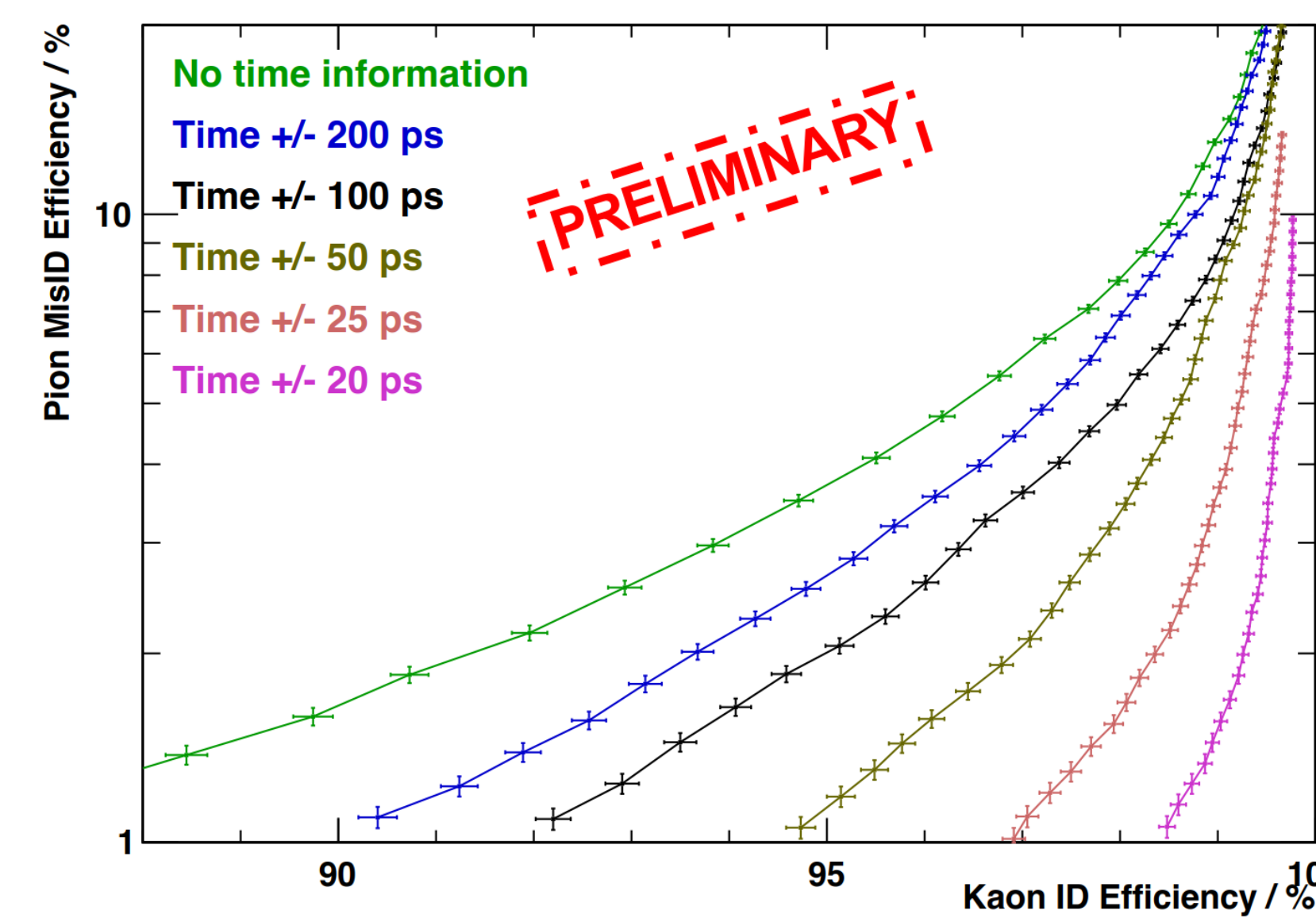- Silicon photomultiplier is one of the options being investigated for measuring space and time coordinates.

> RICH reconstruction : Using a fast modelling of RICH Hit Time for PID

> Avoid backgrounds from out-of-time Hits

Photon detector; Flat mirror; Hit (x, y, z, t); M2; d_photon; Spherical mirror; Rich entrance window; M1; Track origin (x_0, y_0, z_0, t_0); d_track; A; d_seg; Photon emission; Primary Vertex; Rich track segment

All Track-Hit combinations

Track-Hit combinations within ± 20 ps of expected Hit Time in RICH. This shows reduced background compared to that from all combinations.

RICH Kaon ID

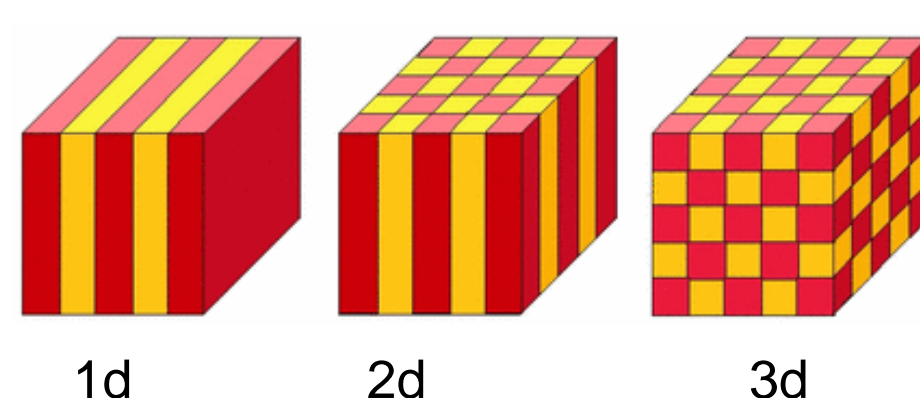No time information; Time +/- 200 ps; Time +/- 100 ps; Time +/- 50 ps; Time +/- 25 ps; Time +/- 20 ps; **PRELIMINARY**
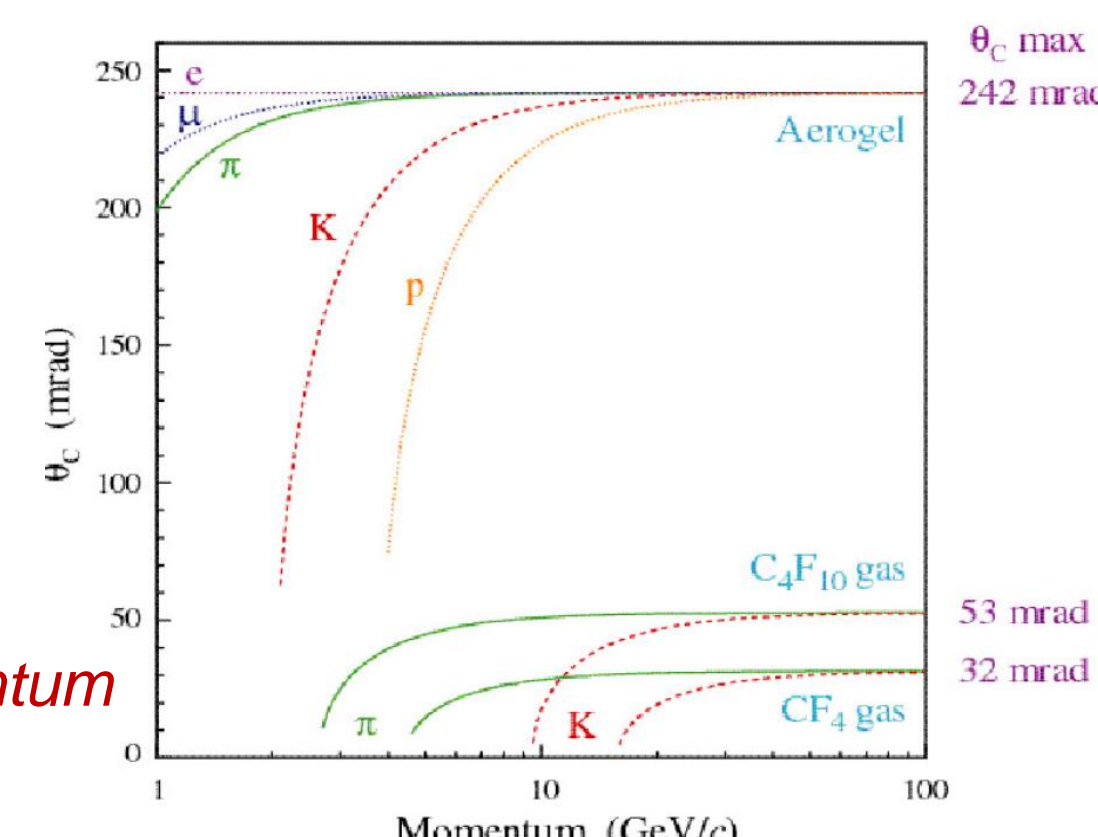
PID improves by restricting to hits within a time window
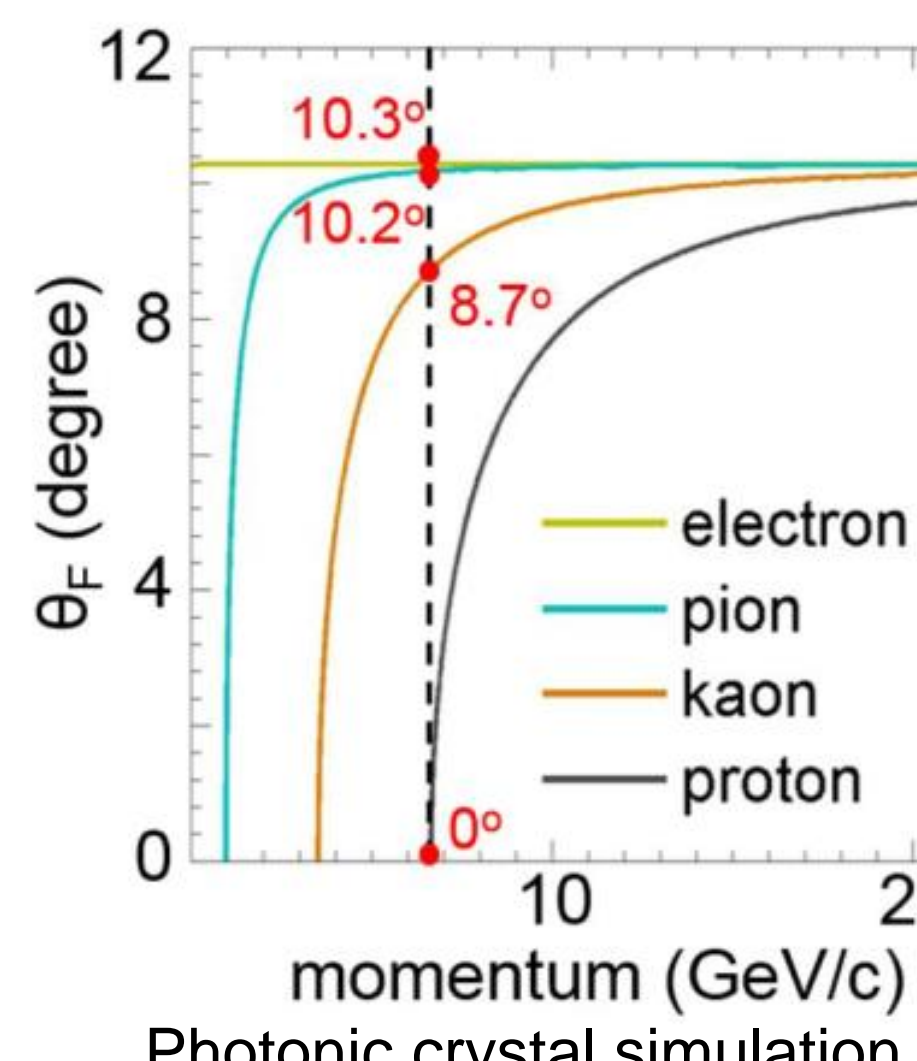
(C) : Extend momentum coverage

> No signal below 9.3 GeV/c from kaons and 17.8 GeV/c from protons. Using 'veto mode' for now, in these low momentum regions.

> Above 80 GeV/c all tracks are essentially saturated.

> Thin radiators may save detector space.

> Photonic crystals are made from transparent dielectric materials.

> Possibility of using them as radiators, is under investigation.

> Photonic crystal create an effective refractive index different than those of the component materials they are made of .

1d, 2d, 3d

Cherenkov angle vs Momentum

Conventional radiators used in LHCb RUN1
Aerogel removed in LHCb RUN2.

θ_F (degree); electron; pion; kaon; proton; 10.3°; 10.2°; 8.7°; 0°

momentum (GeV/c)
Photonic crystal simulation

Further information:

Presentation: Saturday

Sajan Easo

RICH-2018 conference Moscow, Russia

Ref: https://www.nature.com/articles/s41567-018-0138-4