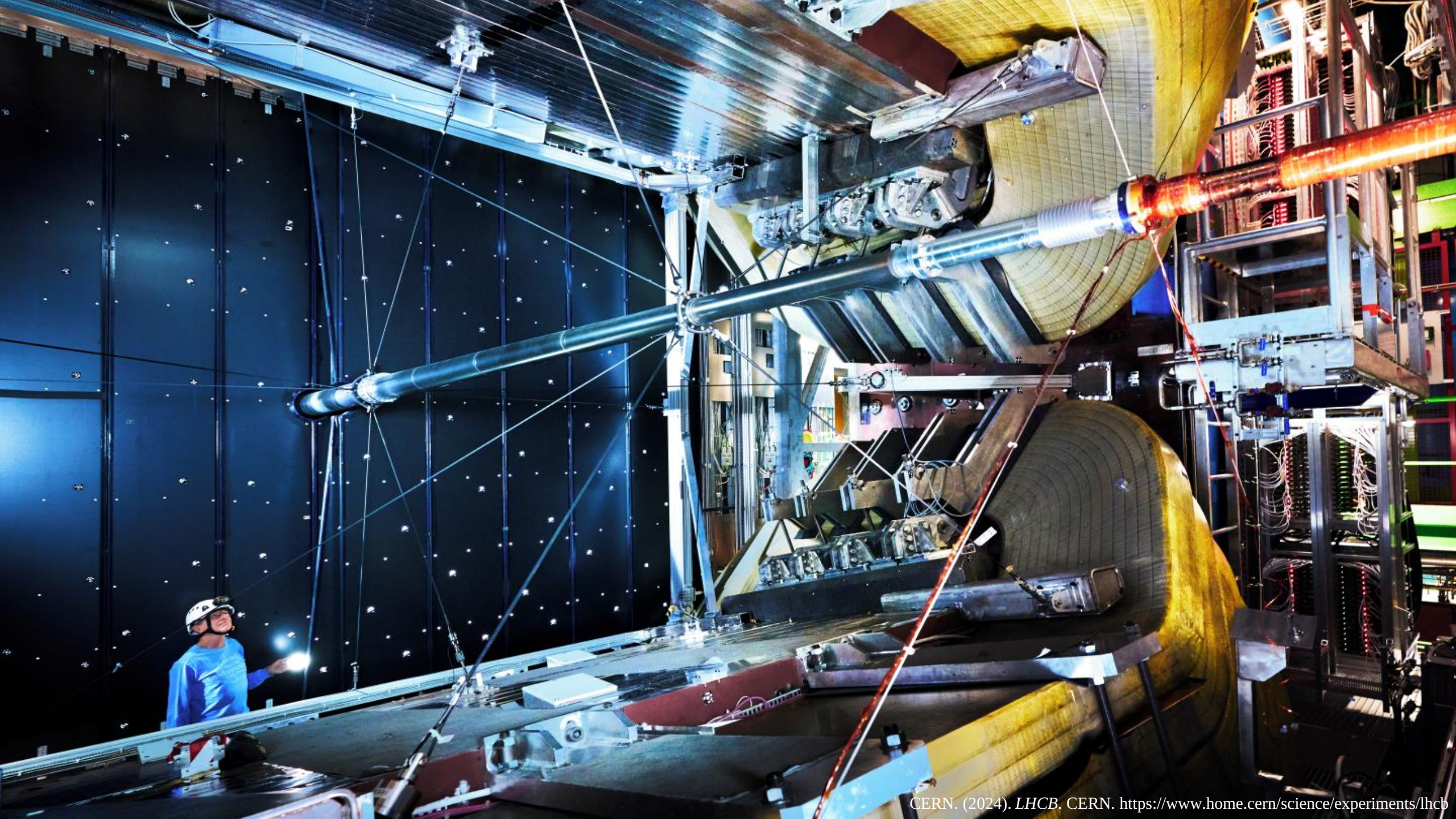
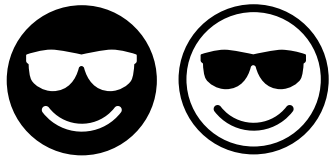
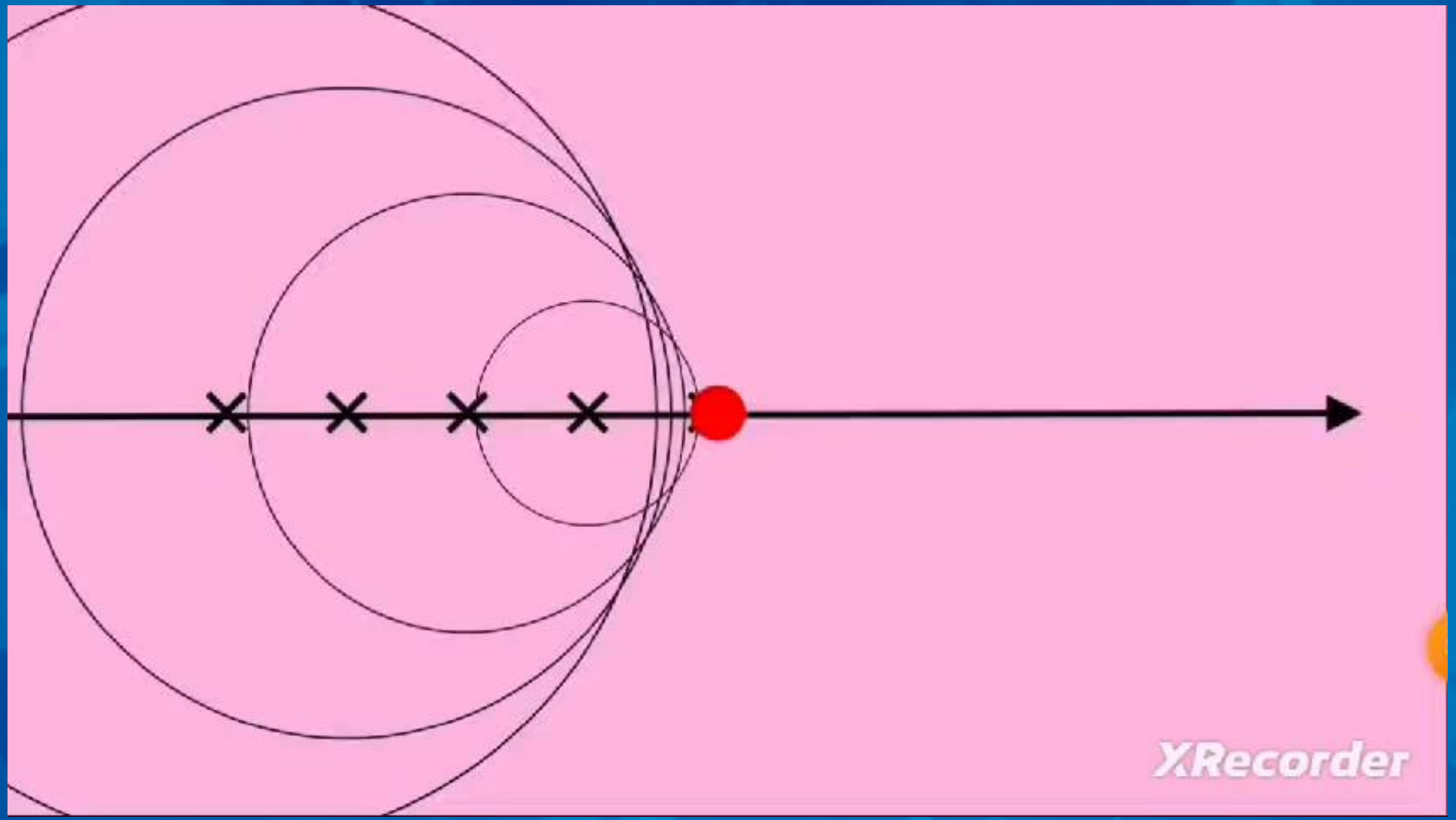


CERN. (2024). *LHCB*. CERN. https://www.home.cern/science/experiments/lhcb

LHC*beauty*

- CP violation and rare decays of b and c
- Indirect evidence
- Particle identification
- 10^{12} $b\bar{b}$ pairs per year
- Ring-imaging Cherenkov detector





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Idaho National Laboratory. (2023, August 9). *Advanced test reactor*. Idaho National Laboratory. https://inl.gov/advanced-test-reactor/

Cherenkov Radiation

- Characteristic number: Cherenkov angle
- Main resolution to be measured: Cherenkov angle resolution
- Refractive index n, particle speed v_p

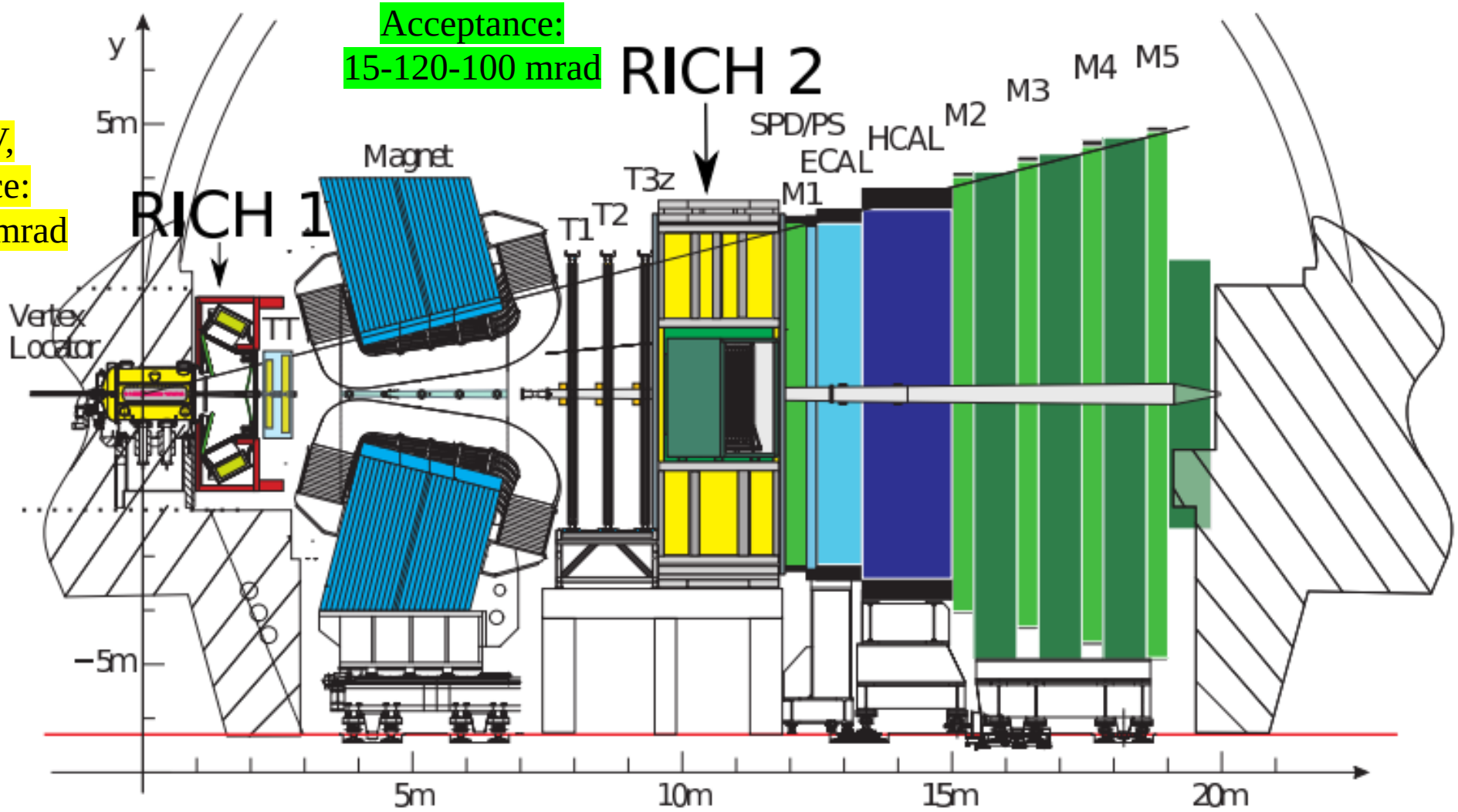
$$\cos\theta_C = \frac{1}{n\beta} \qquad \beta = \frac{v_p}{c}$$

Pavel Cherenkov's 110th anniversary of birth. Sputnik Mediabank. (2023, November). https://sputnikmediabank.com/selection/list_1007417/

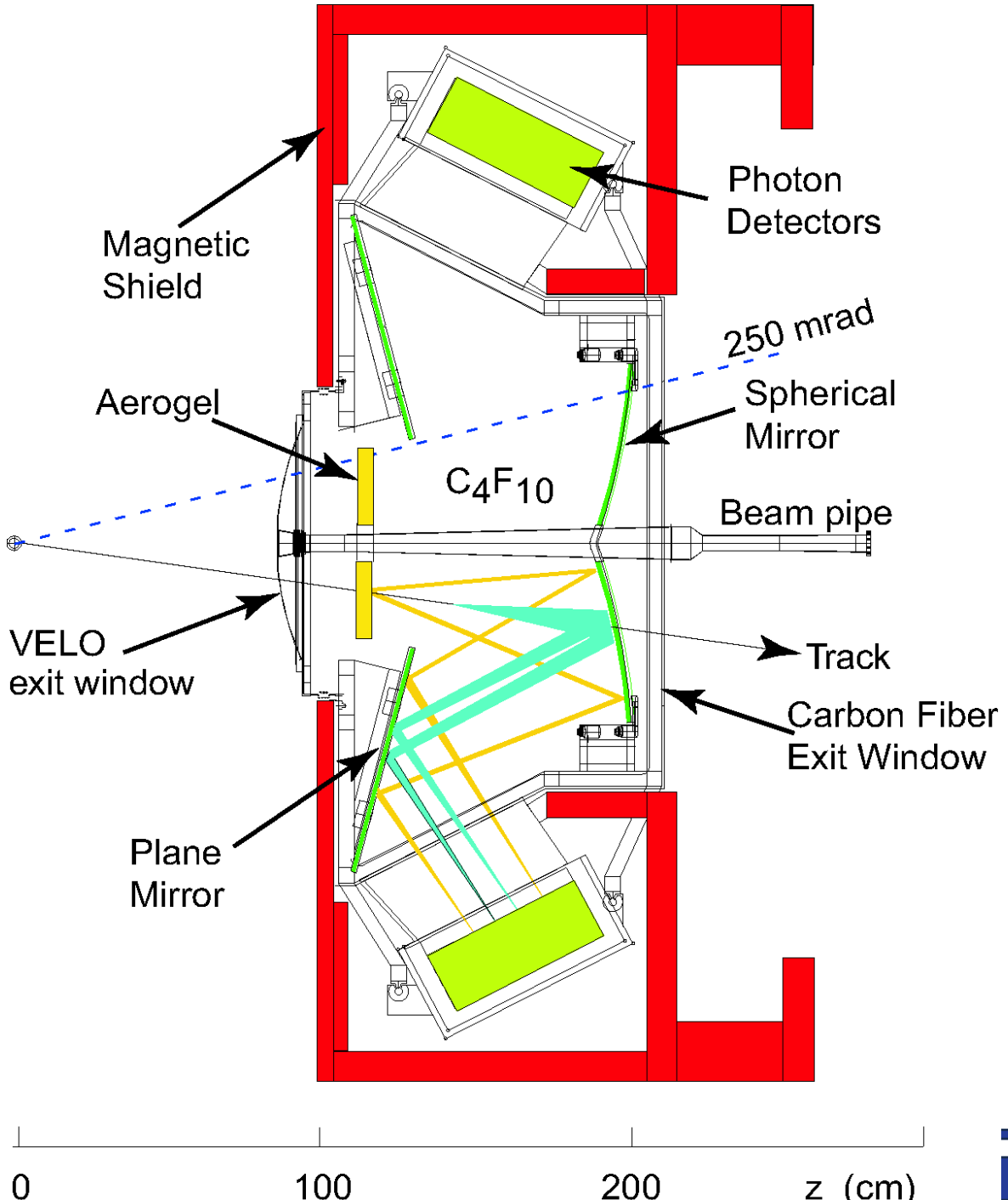
LHCb sideview

15-100 GeV,
Acceptance:
15-120-100 mrad

2-40 GeV,
Acceptance:
25-300-250 mrad



The LHCb RICH Collaboration., Adinolfi, M., Aglieri Rinella, G. *et al.* Performance of the LHCb RICH detector at the LHC. *Eur. Phys. J. C* **73**, 2431 (2013). https://doi.org/10.1140/epjc/s10052-013-2431-9



RICH1

- Optical system
  - Mirrors
  - Support structure
- Radiators
  - Gas enclosure
- Photon detectors
  - Magnetic shielding

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

Optical System: RICH1

- Primary spherical mirror CFRP
- Secondary flat mirror Simax glass
- 90% reflectivity
- Vertical halves for magnetic shielding

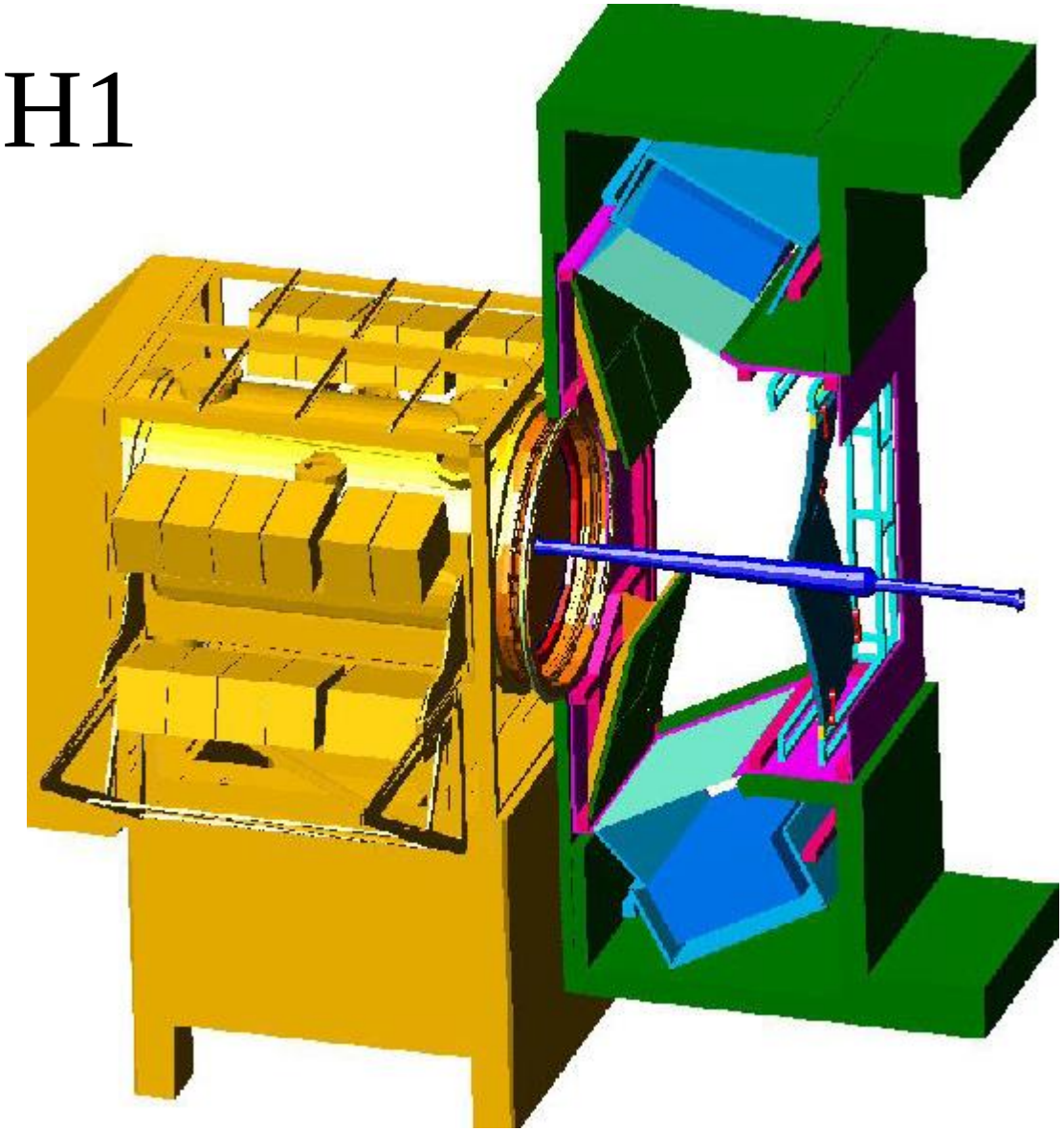
CARBON-FIBRE REINFORCED POLYMER

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

Simax Glass teapot 1L. " Simax Glass Teapot 1l. (n.d.). https://muller-nv.be/en/simax-glass-teapot-1l/

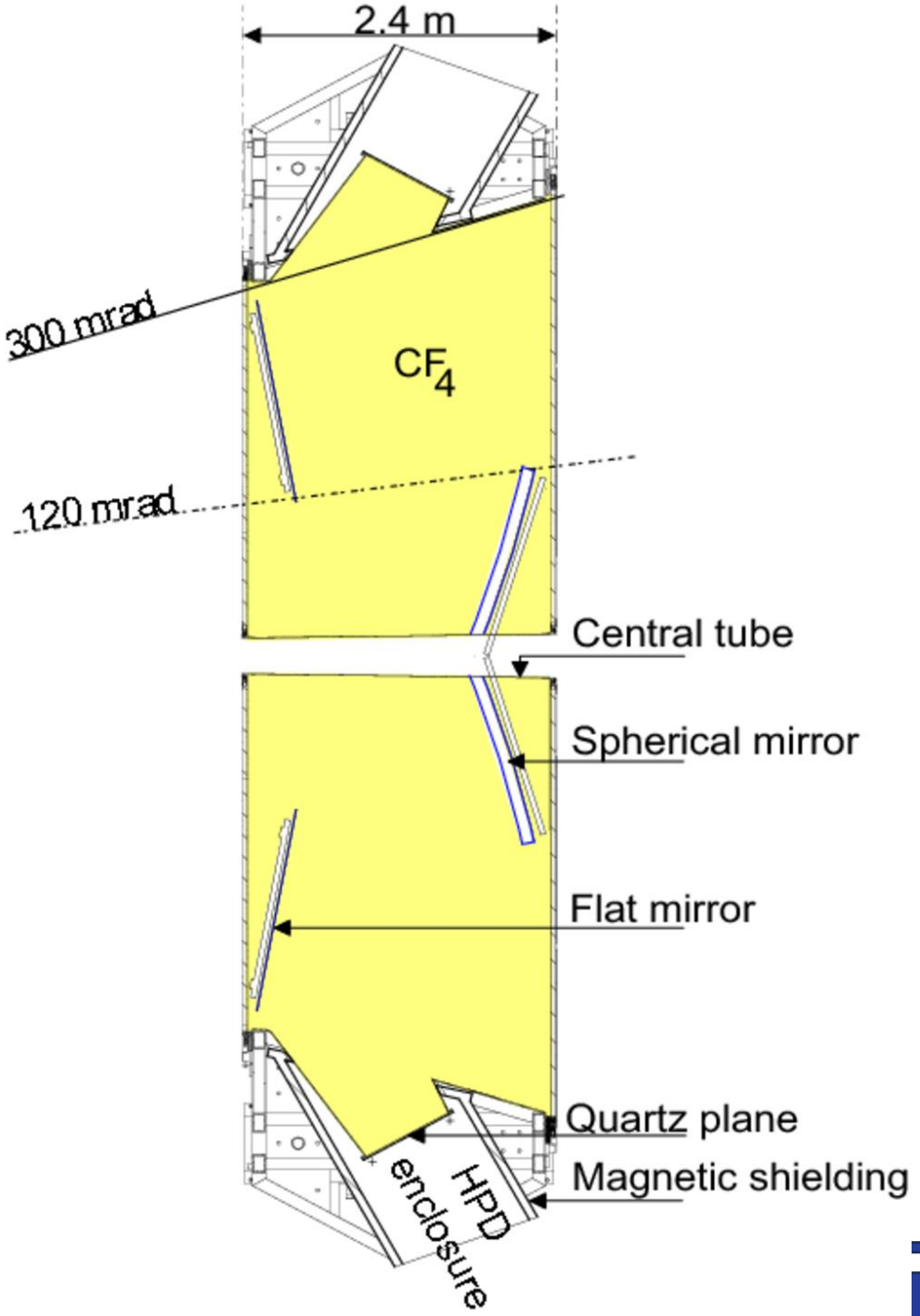
Design Constraints: RICH1

- Material budget
  - CFRP, systems outside acceptance
  - 8% X_0
- Beampipe
  - Low angle acceptance
- Magnetic shielding
  - Heavy!



The characteristic amount of matter traversed is called the radiation length X_0, measured in $g \cdot cm^{-2}$

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures



RICH2

- Optical system
  - Mirrors
  - Support structure
- Radiators
  - Gas enclosure
- Photon detectors
  - Magnetic shielding

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

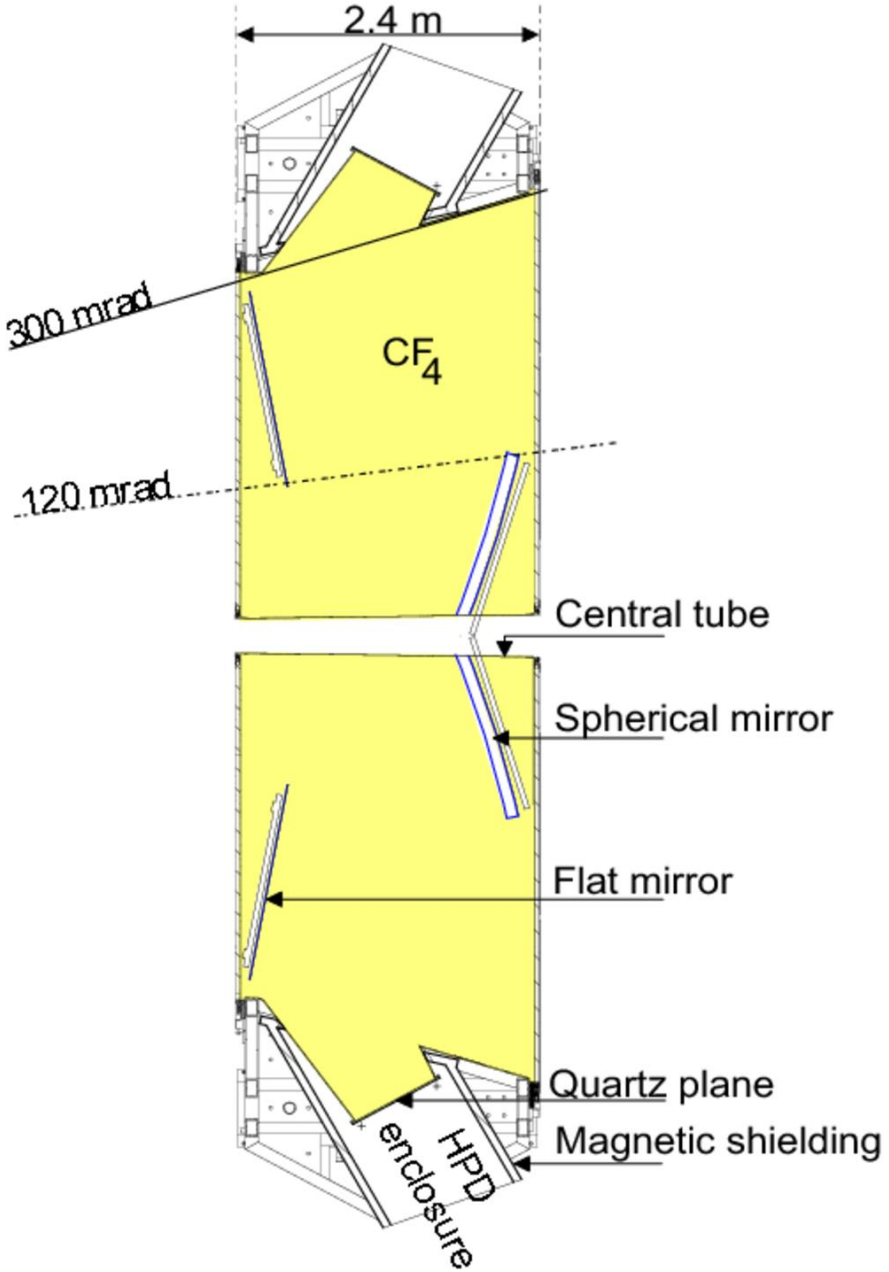
Optical System: RICH2

- Simax glass only
  - 15% X_0
- Greatest challenge: stability
- Horizontal halves

Simax Glass teapot 1L. " Simax Glass Teapot 1l. (n.d.). https://muller-nv.be/en/simax-glass-teapot-1l/

Design Constraints: RICH2

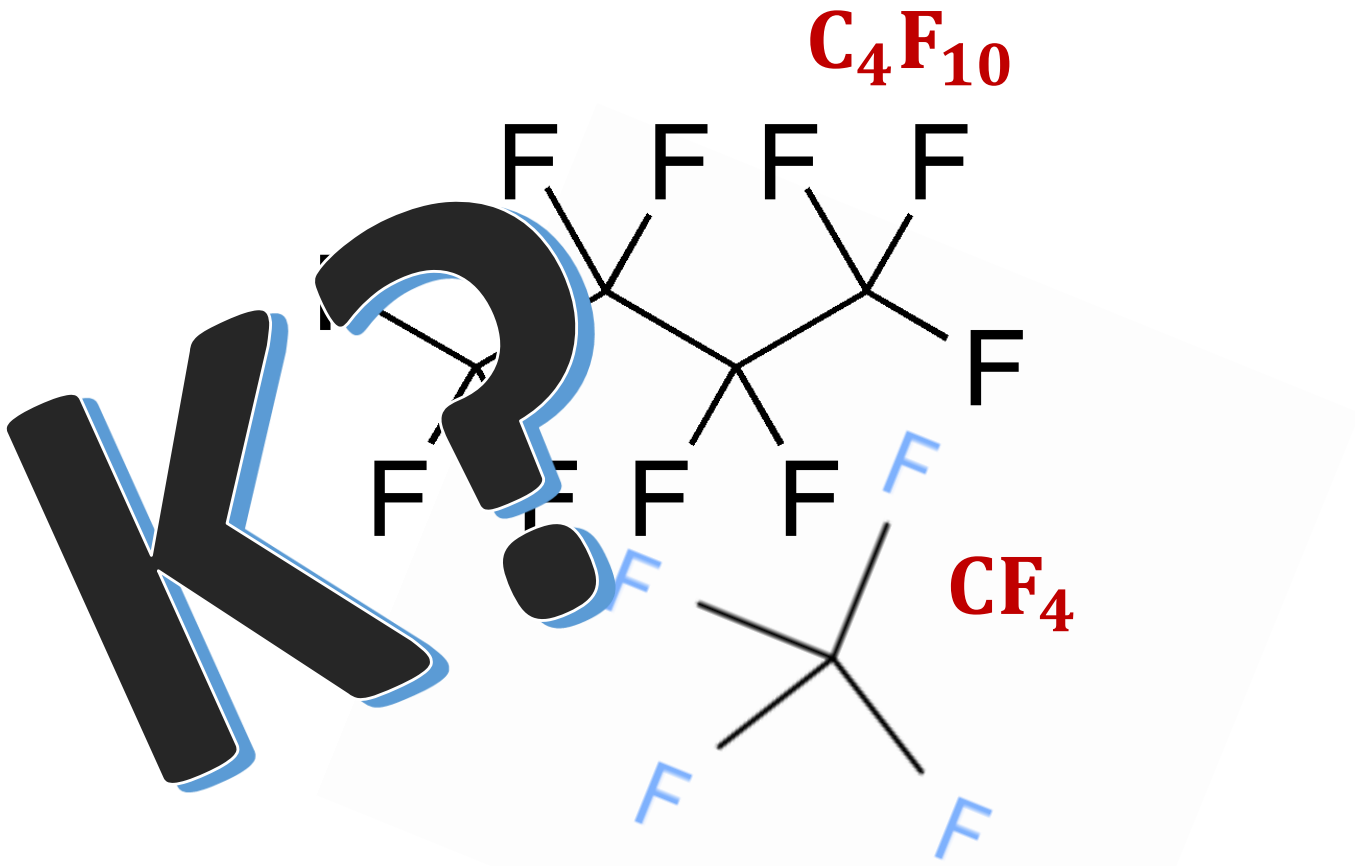
- Supporting structures outside acceptance
- Iron shielding
- Lower limit of acceptance
  - 15 mrad
  - Beampipe clearance 45 mm



LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

Gas Radiators

- Fluorocarbon gases
  - Room temperature & pressure
- Low dispersion
- Refractive indices (0C, 101.3 Pa, 400nm) are 1.0014 (C_4F_{10}) and 1.0005 (CF_4)

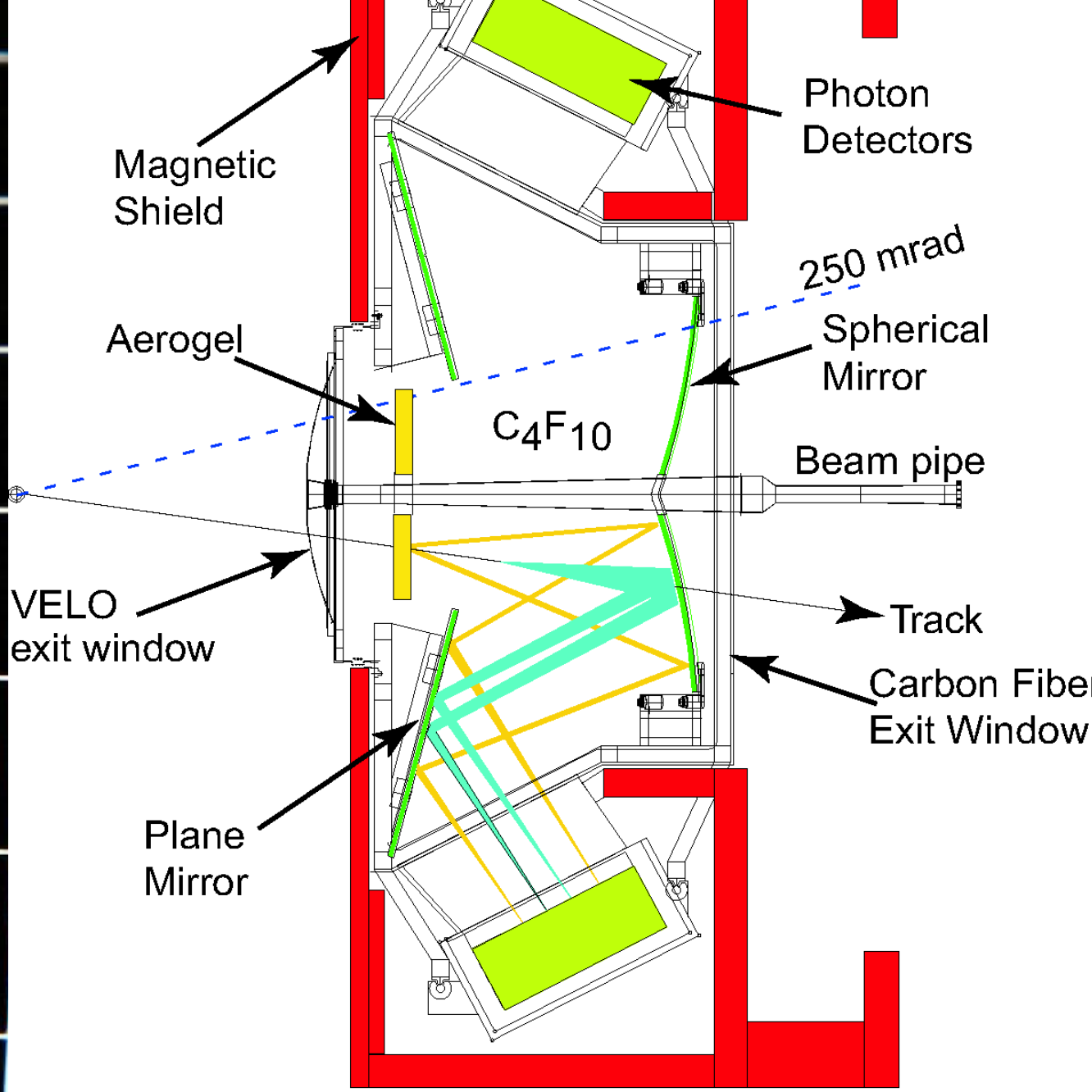


Wikimedia Foundation. (2023, October 31). *Perfluorobutane*. Wikipedia. https://en.wikipedia.org/wiki/Perfluorobutane

Carbon tetrafluoride SDF/mol file - CF4 - over 100 million chemical compounds: CCDDS. Mol. (n.d.). https://www.molinstincts.com/sdf-mol-file/CARBON-TETRAFLUORIDE-sdf-CT1001636577.html

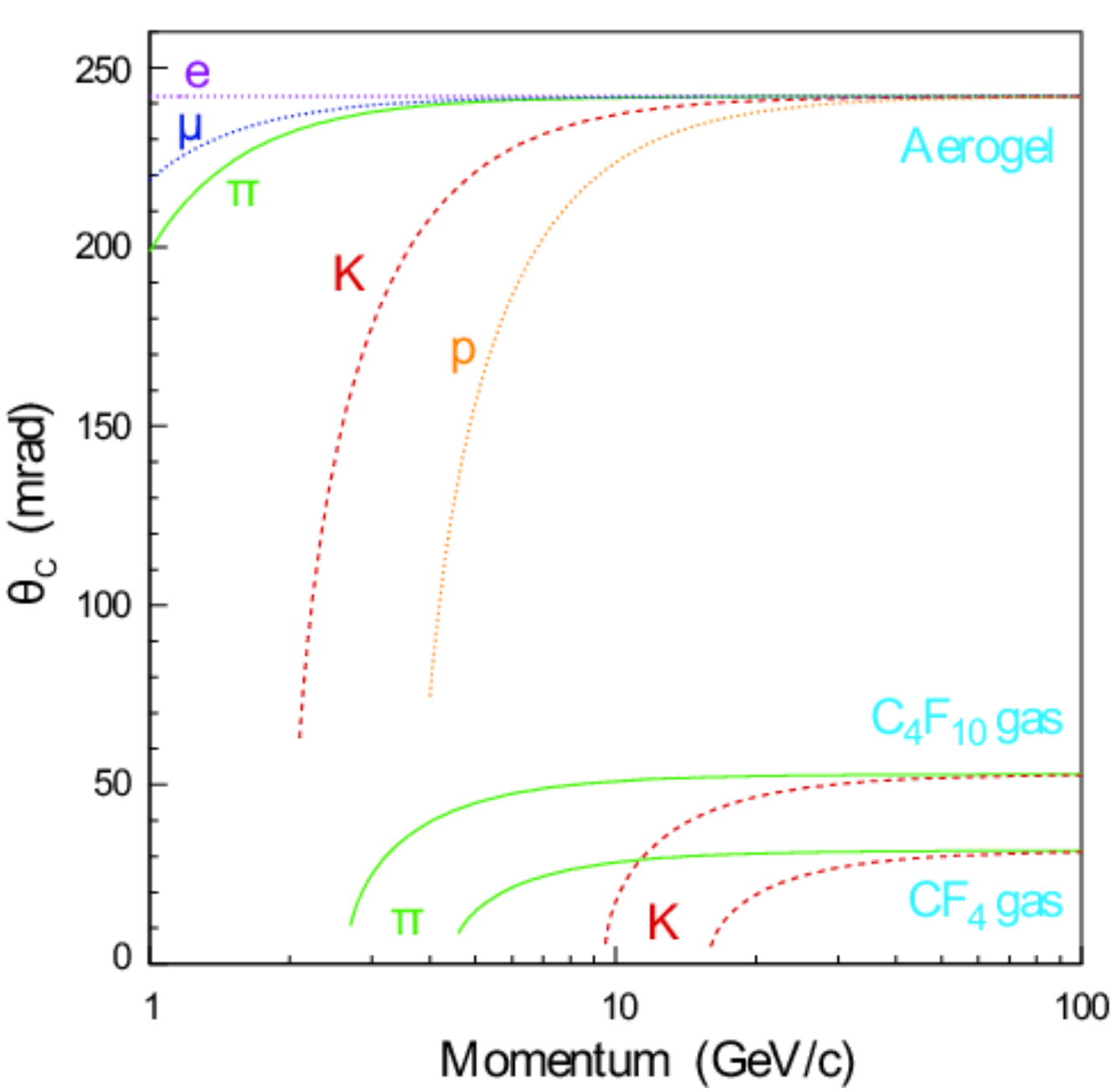
Aerogel

- RICH1
- 50 mm thick wall
- Refractive index 1.03
- High quality & clear



Classic SilicaTM disc. BuyAerogel.com. (n.d.). http://www.buyaerogel.com/product/classic-silica-disc/

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures



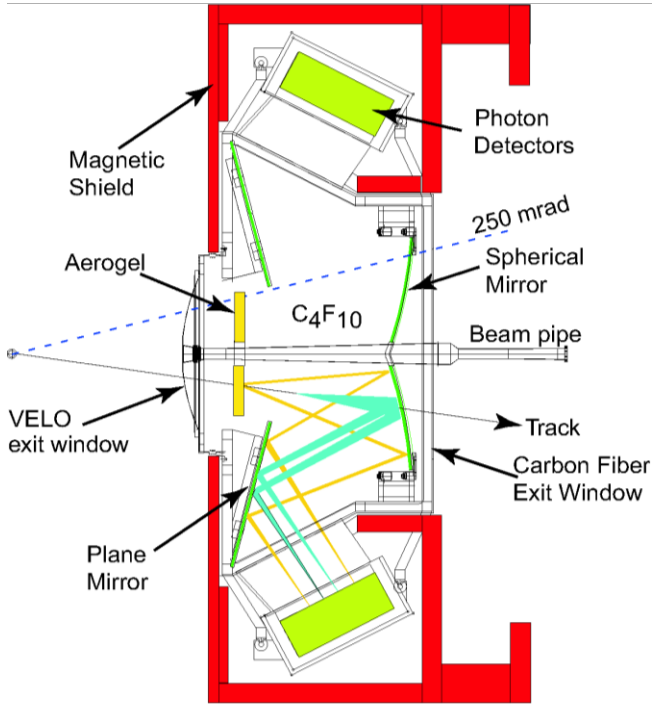
Cherenkov angle versus particle momentum in RICH radiators

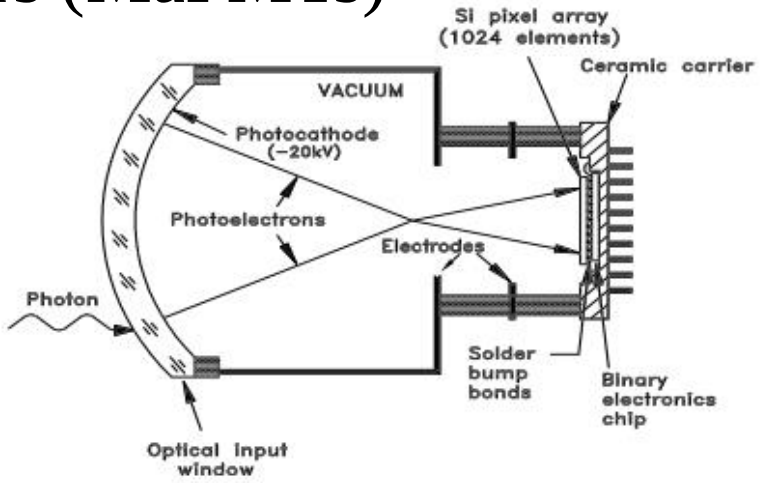
$$\cos\theta_C = \frac{1}{n\beta} \qquad \beta = \frac{v_p}{c}$$

https://twiki.cern.ch/twiki/pub/LHCb/RICHPicturesAndFigures/radiators.png

Photon Detectors

- Pixel Hybrid Photon Detectors (HPDs)
  - Photoelectron acceleration
  - 5000 electron-hole pairs
  - 75 mm diameter tubes,1024 pixels
  - 196 tubes in RICH1, 288 in RICH2
- Multi Anode Photomultipliers (MaPMTs)
  - Improved resolution





LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

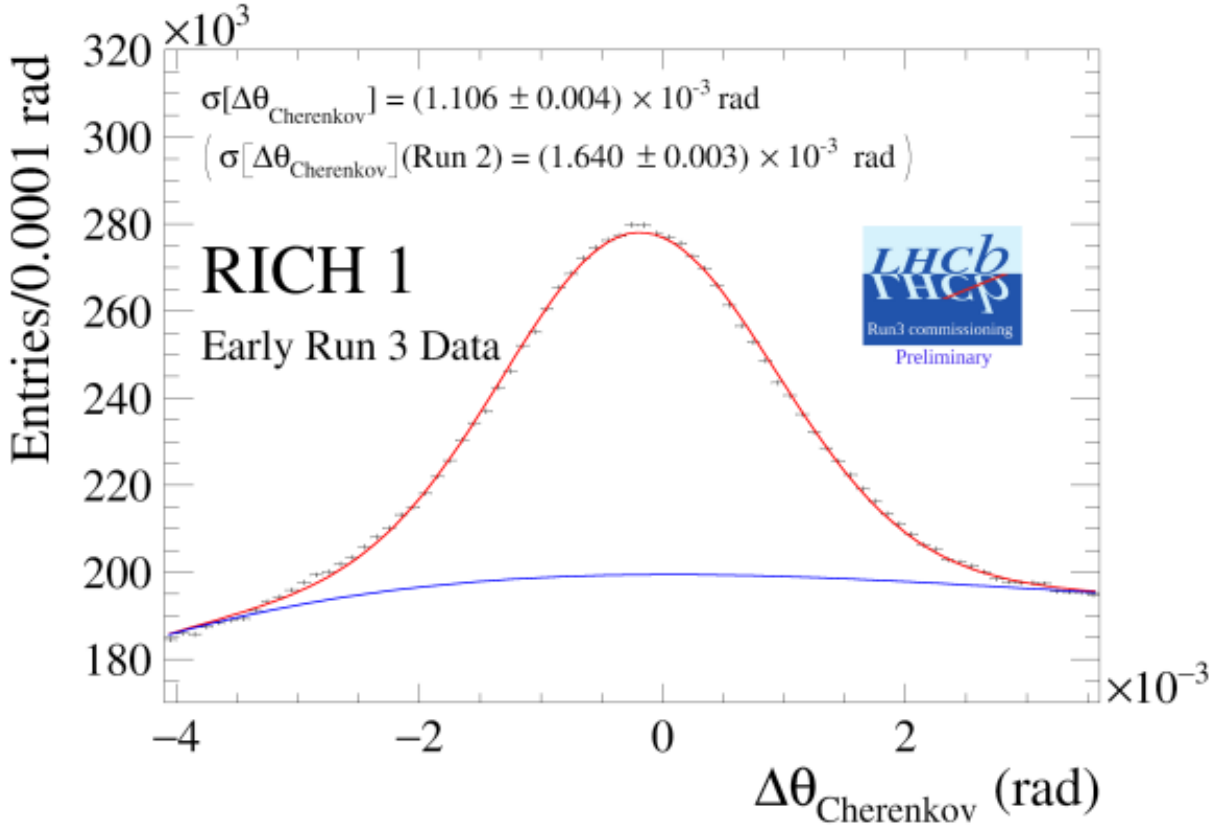
The LHCb Collaboration *et al* 2008 *JINST* **3** S08005**DOI** 10.1088/1748-0221/3/08/S08005

Figure 6.7: Left: a schematic and right: a photograph of the pixel-HPD.

Cherenkov angle resolution for reconstructed photons detected by RICH1 (left) and RICH2 (right) using early Run 3 Data

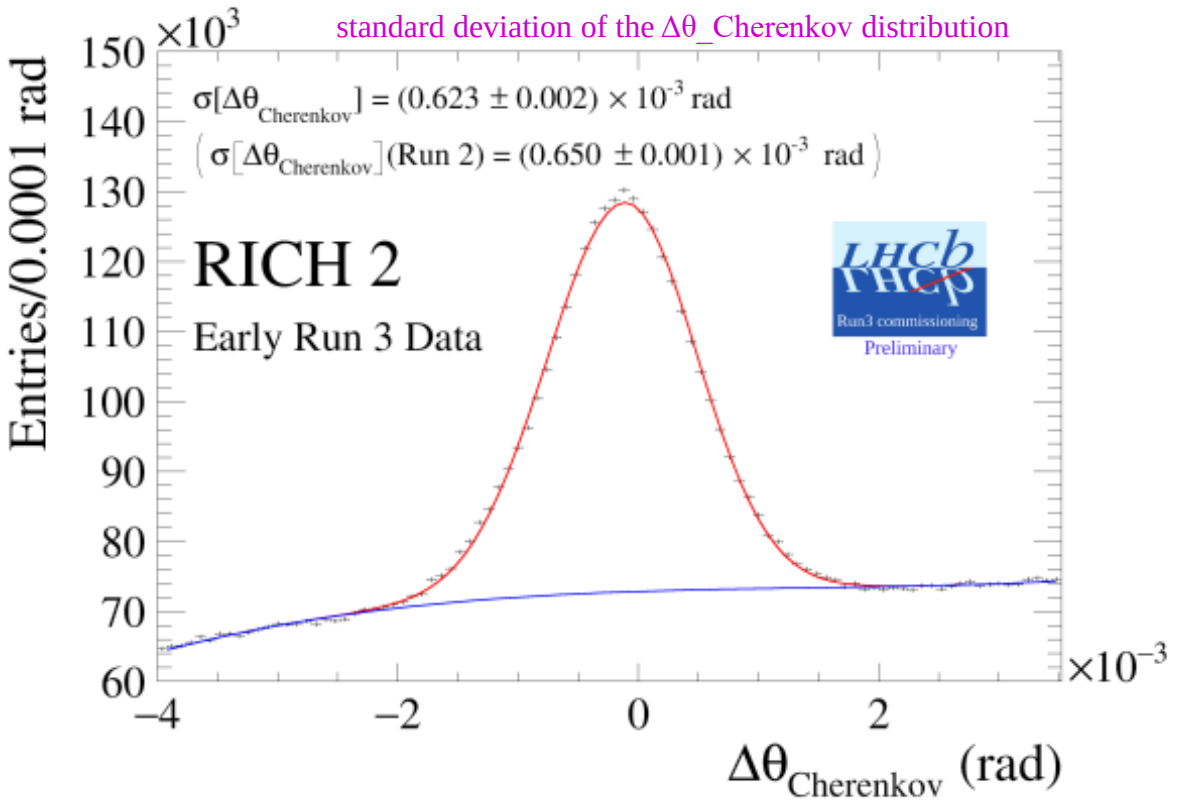
Gaussian fit = good performance

how often a particular Δθ Cherenkov is observed

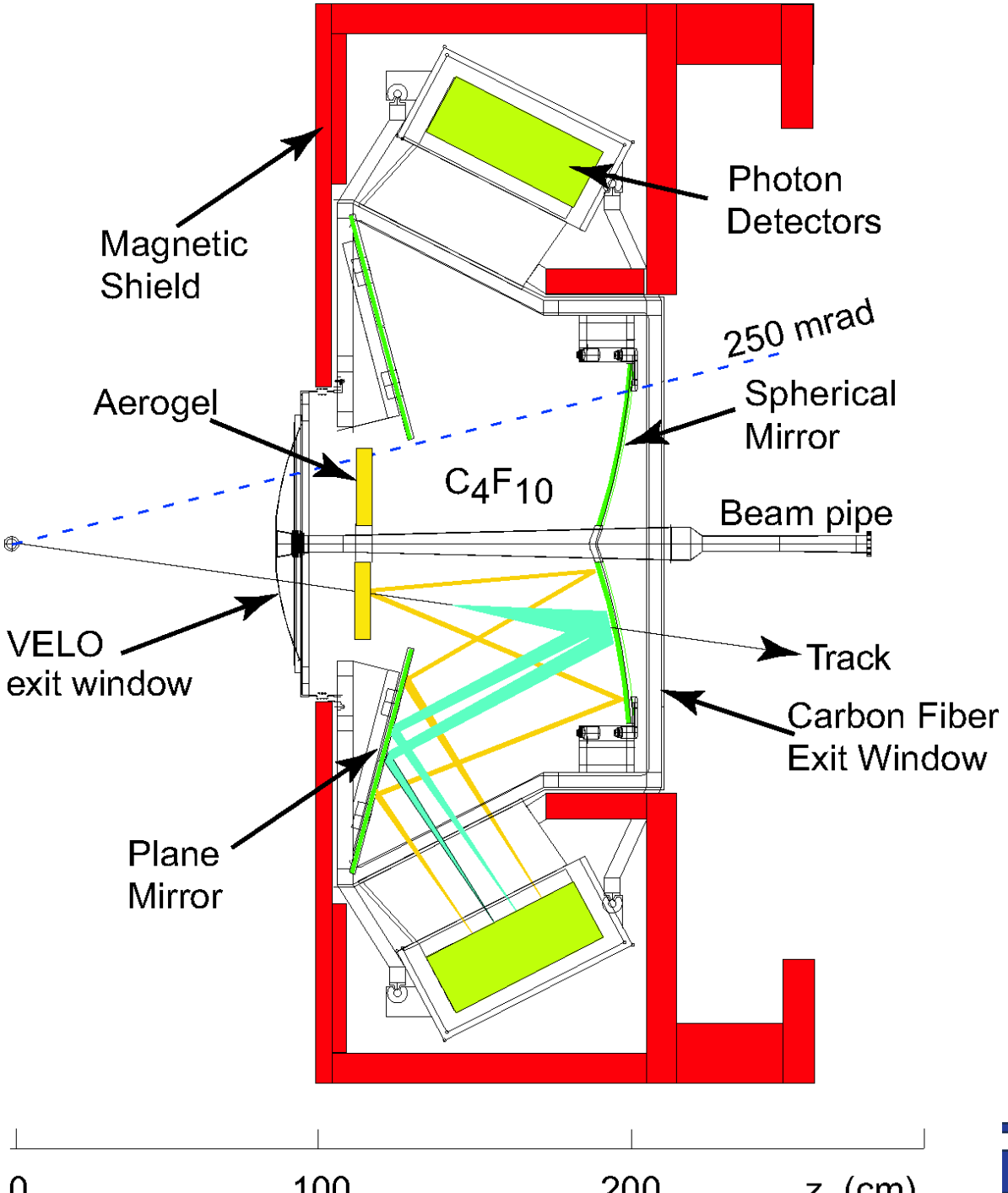


difference between the measured Cherenkov angle and the expected Cherenkov angle

standard deviation of the Δθ_Cherenkov distribution



LHCb collaboration. (2023). RICH Performance Plots - Cherenkov Angle Resolutions for RICH 1 and RICH 2. Geneva; CERN.

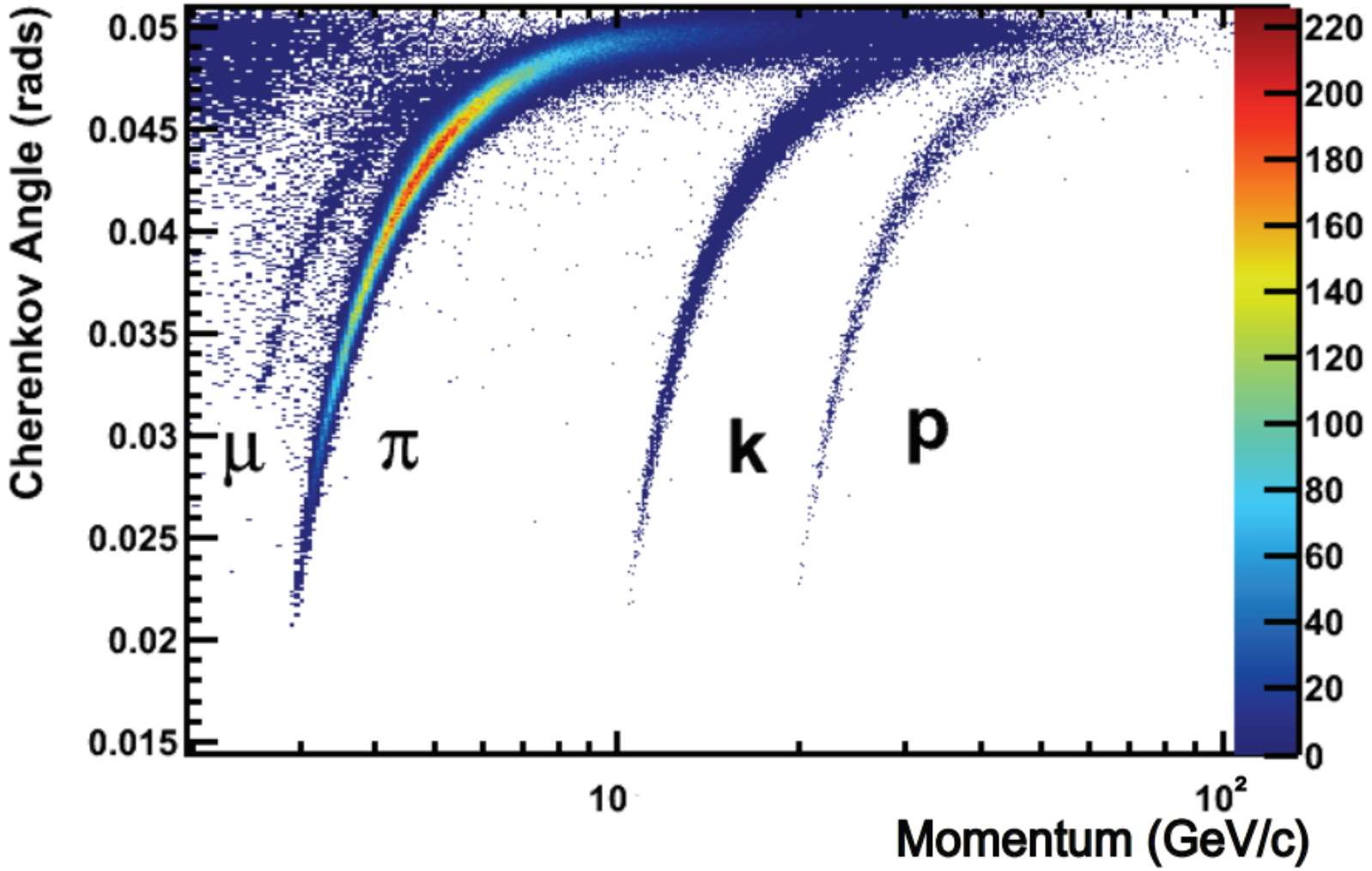


A Day in RICH

- Coordinate information
  - Vertex locator
- Cherenkov photons generated
- Photon detectors
  - Impact points recorded
- Cherenkov angle
  - Midway assumption
  - Emission point error

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

Reconstructed Cherenkov angle as a function of track momentum in the C_4F_{10} radiator



- Isolated rings
- Distinct bands based on mass
- 2% of all tracks

The LHCb RICH Collaboration., Adinolfi, M., Aglieri Rinella, G. *et al.* Performance of the LHCb RICH detector at the LHC. *Eur. Phys. J. C* **73**, 2431 (2013). https://doi.org/10.1140/epjc/s10052-013-2431-9

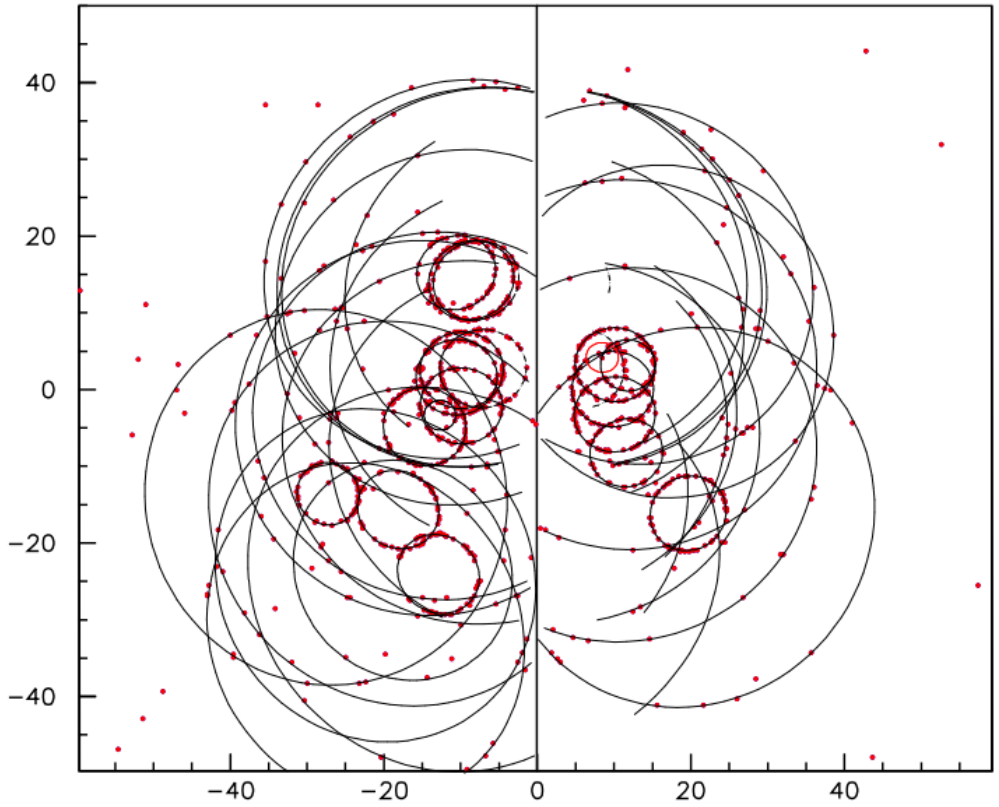


Figure 11: Event display of a simulated $B_d^0 \to \pi^+\pi^-$ event, with the photodetector planes of RICH 1 drawn side by side (scale in cm), and the Cherenkov rings superimposed.

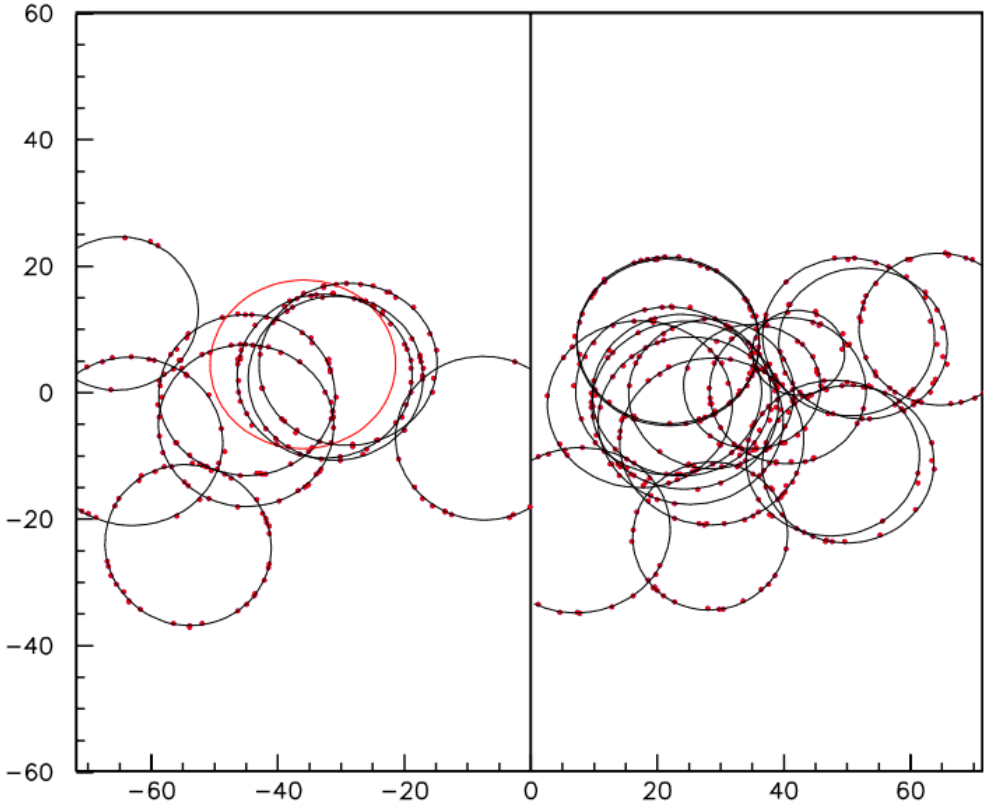
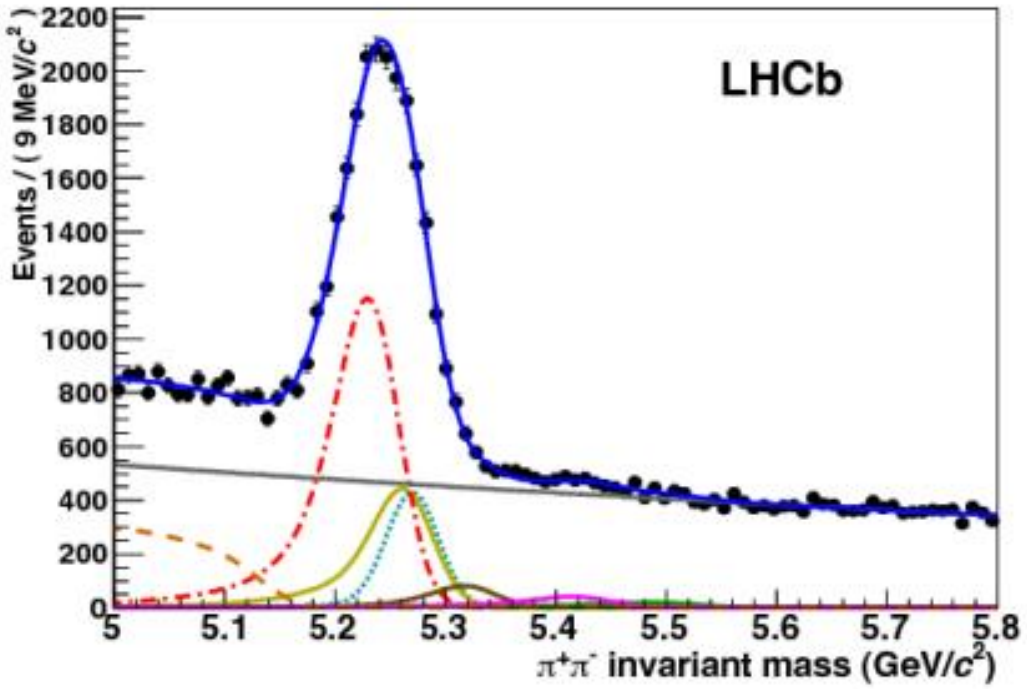
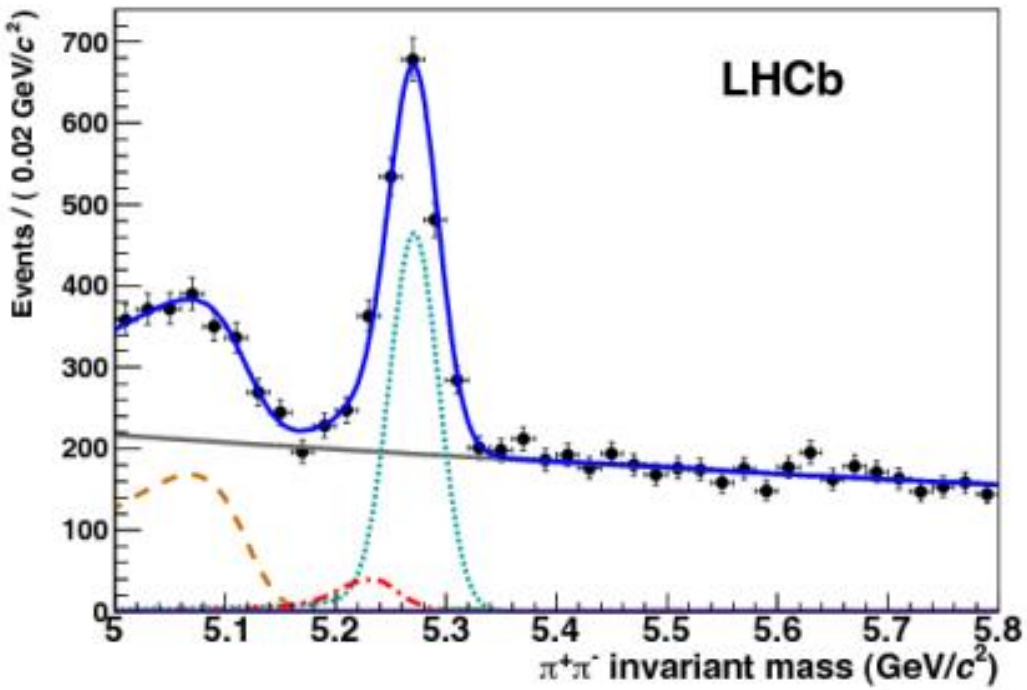


Figure 12: Event display of the same event as Fig. 11, for RICH 2.

Before & after RICH…





Invariant mass distribution for B decays, before RICH information (left) and after (right). Decay modes are eliminated by particle identification.

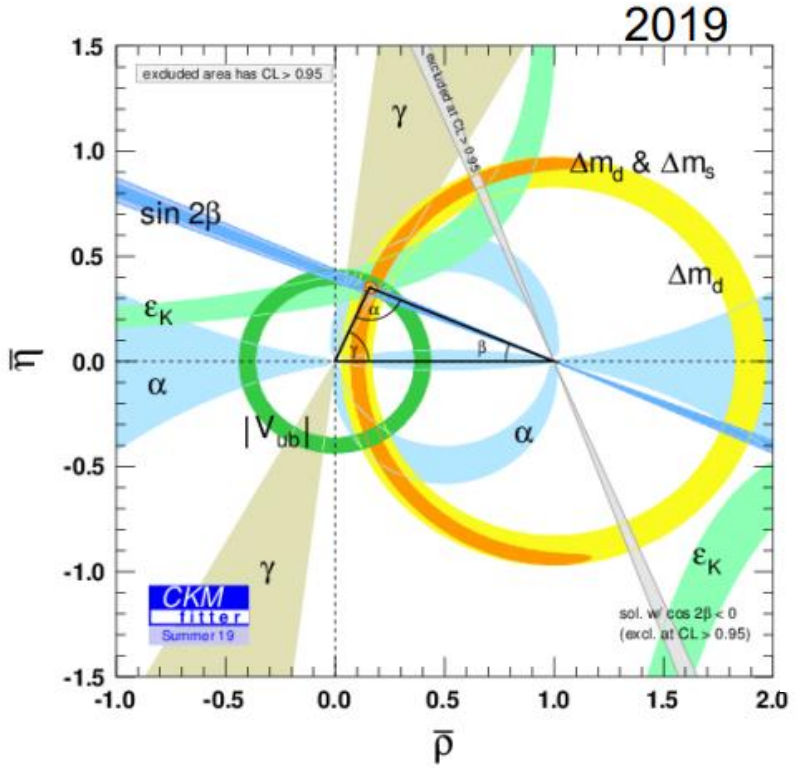
The LHCb RICH Collaboration., Adinolfi, M., Aglieri Rinella, G. *et al.* Performance of the LHCb RICH detector at the LHC. *Eur. Phys. J. C* **73**, 2431 (2013). https://doi.org/10.1140/epjc/s10052-013-2431-9

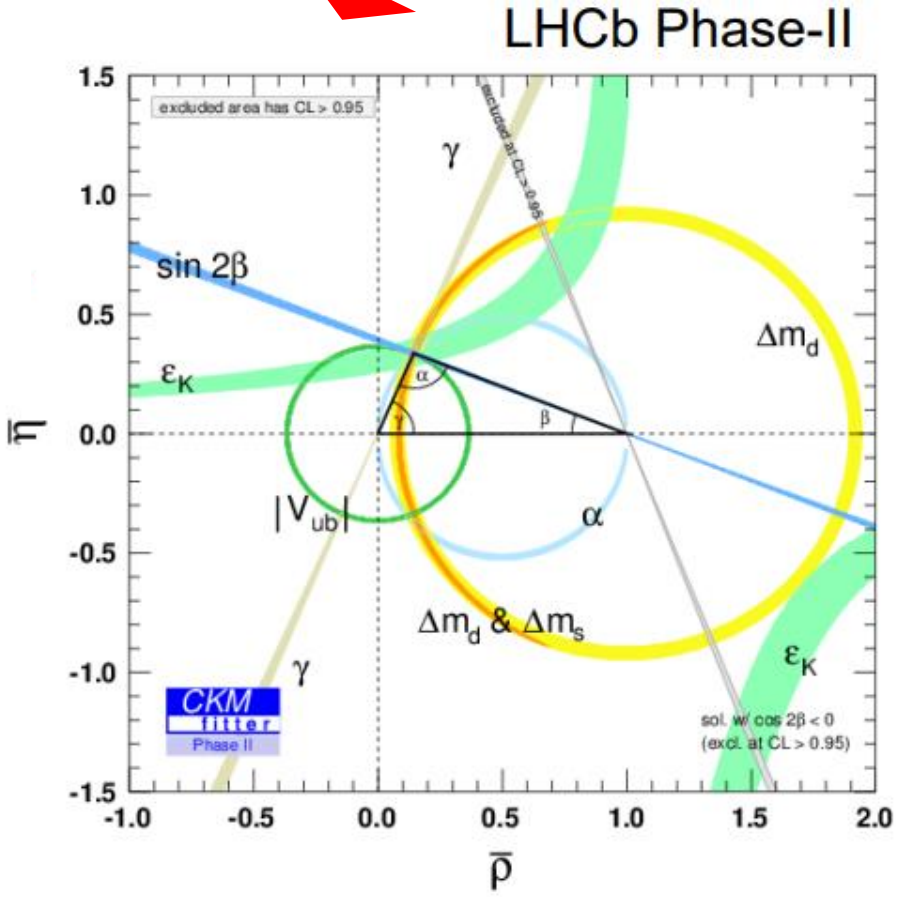
We need RICH because

- Identification of charged hadrons (even muons!)
- Distinguish the final states
- Bonus: efficient flavour tagging & trigger

Future?

- Better precision!
- More data!
- RICH with timing!





- (next big thing…)

Alessio, F. (2020). The LHCb Upgrades for Run3 and Run4. CERN.

Thank you!

Questions?

LHCb Collaboration. (2022). *Pictures, figures, and plots*. LHCB Collaboration. https://twiki.cern.ch/twiki/bin/viewauth/LHCb/RICHPicturesAndFigures

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