2023 CERN-Korean Summer Student Program

부산대학교 물리학과 장한이

Main Reference

- Large Hadrom Collider beutry experiment , CERN

https://lhcb-outreach.web.cern.ch/detector/vertex-locator-velo/

- Belyaev (2021).The history of LHCb. Eur. Phys. J. H 46:3
- JINST (2008). The LHCb Detector at the LHC. Institute of Physics Publishing and SISSA S08005

Introduction - Symmetry

Discrete symmetries **invariance of physical law under…**

- inversion of spatial coordinates (parity)
- particle <-> antiparticle (charge conjugation)

→combined symmetry CP:

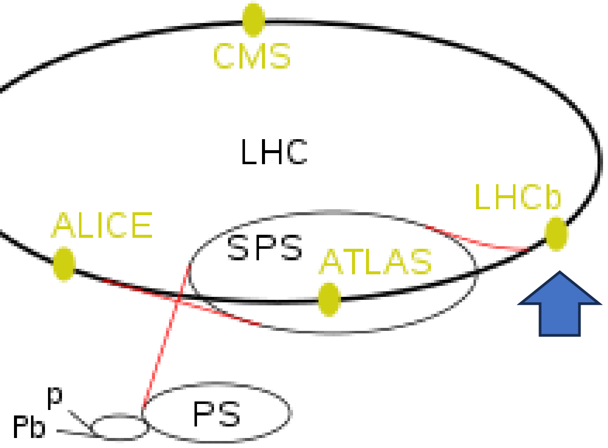
left-handed particle -> right handed antiparticle

CP violation required for matter/antimatter asymmetry in universe

But… observed is too small to explain our universe

→ Look into b physics

Introduction



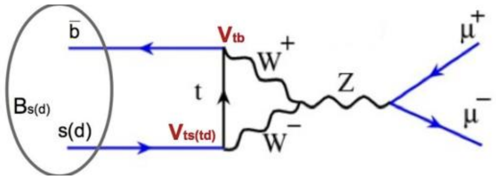
Task: 'b-physics'

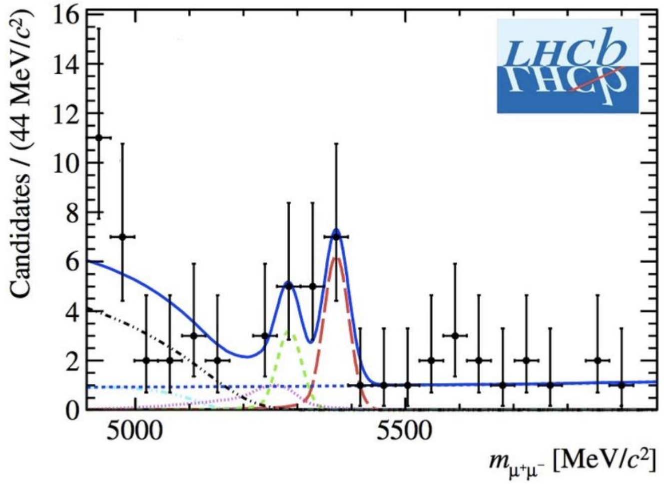
- Precise measure of CP violation (b-meson decay)
- Find BSM particle during CP?

… and more new physics beyond SM!

Ex1) Rare B meson decay

$B_{s(d)} \rightarrow \mu^+\mu^-$





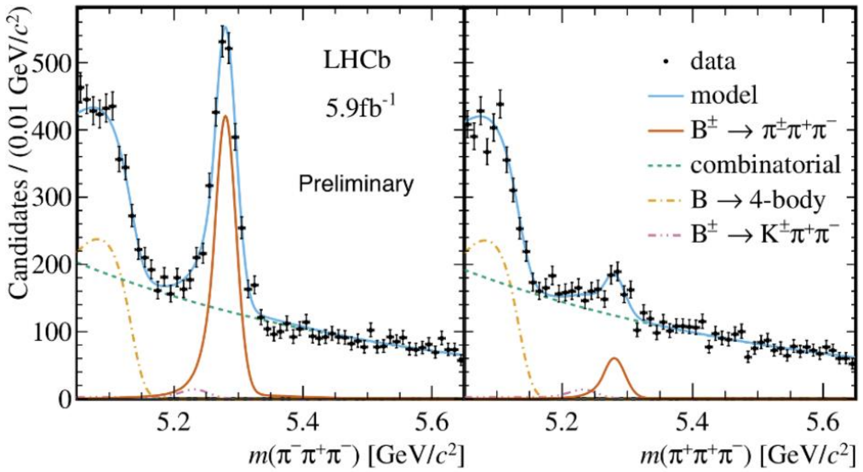
Red: $B_s \rightarrow \mu^+\mu^-$
Green: $B_d \rightarrow \mu^+\mu^-$
Blue: data fitted

BR of Bs
-experiment $(2.8^{+0.7}_{-0.6}) \times 10^{-9}$
-theory $(3.65 \pm 0.23) \times 10^{-9}$

Ex2) Direct CP violation

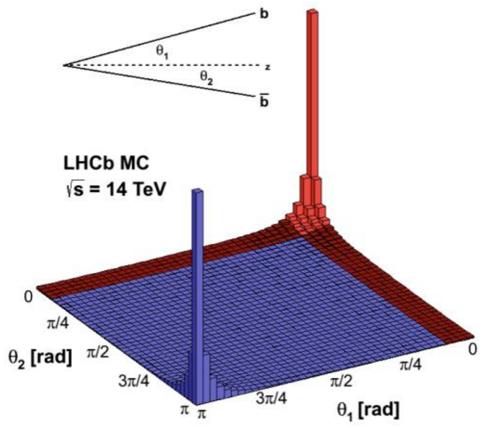
(same decay process differ for particle/anti)

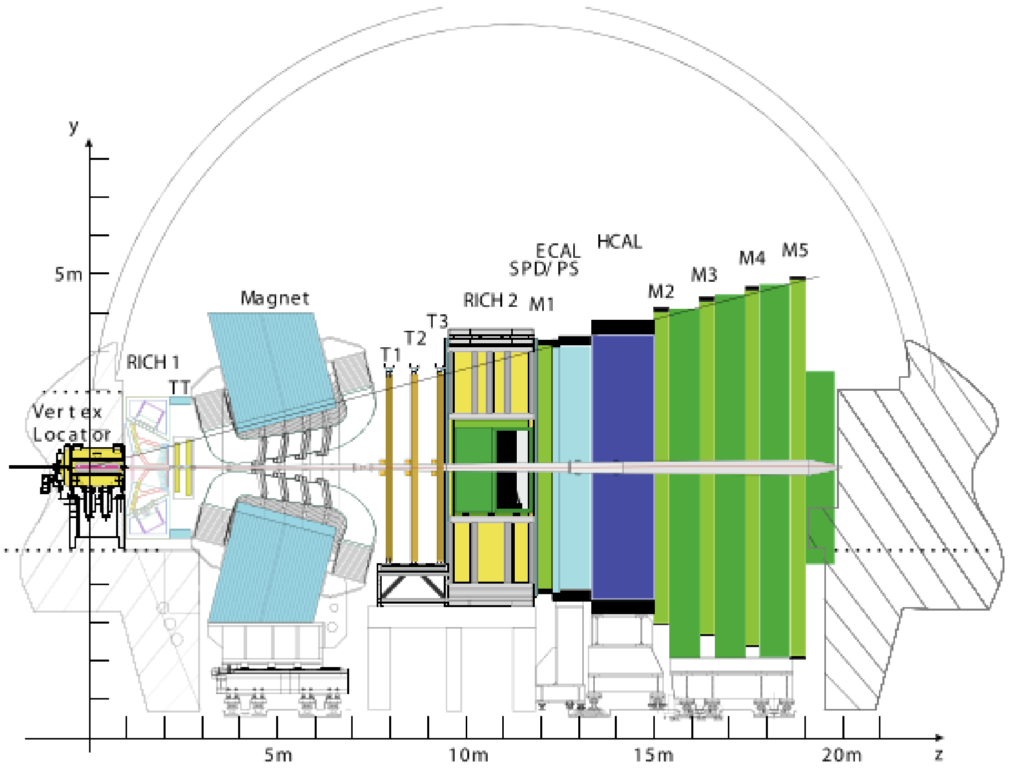
B decay to three pions



Detector overview

- b, c quark (hadron) high flux when small angle respect to proton beam
  →Detect only in forward cone





①VELO: Precise vertex measurement

② Trajectory construction (TT, T1~T3)

③ Spectrometer(TT, T1~T3): dipole magnet bend particle in the horizontal plane + measure trajectory of charged particle → **momenta**

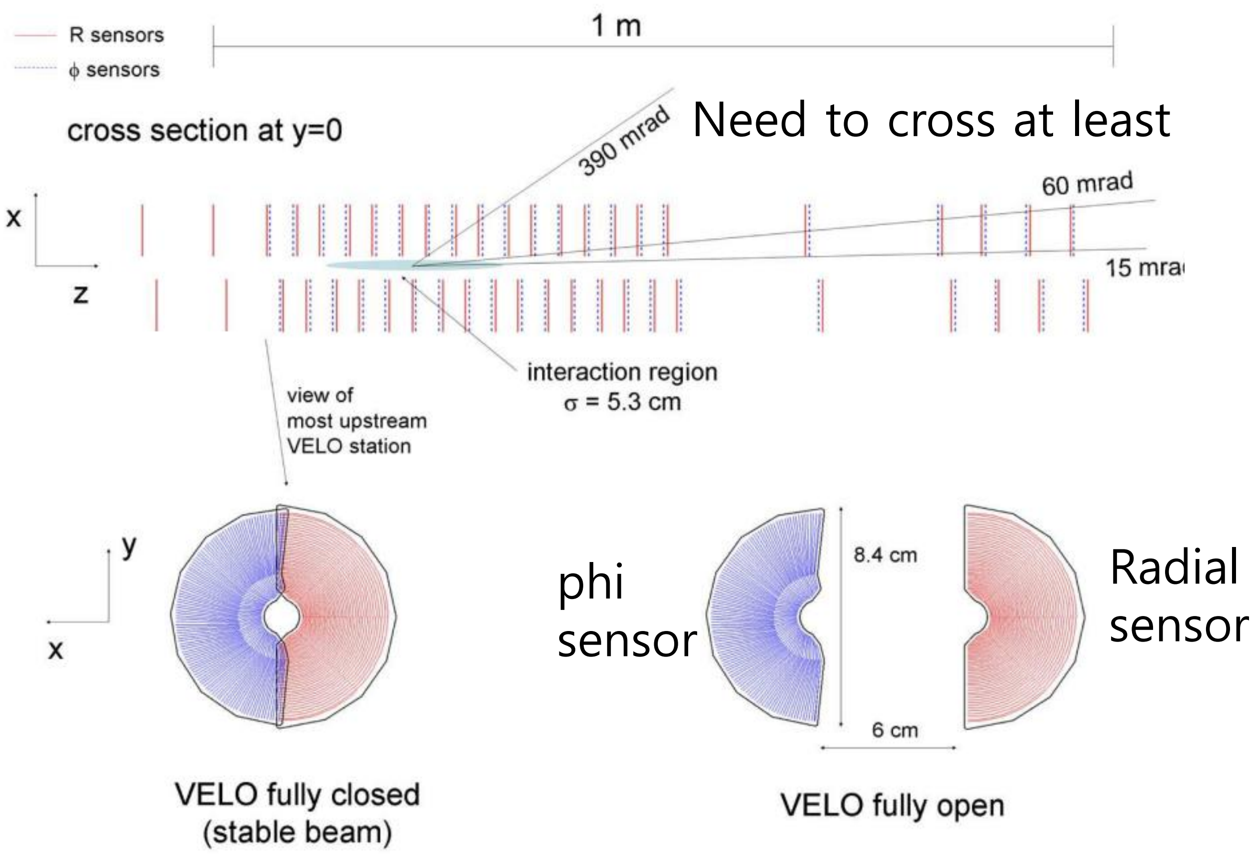
④ Calorimeter(ECAL, HCAL): measure E of e-, photon, hadron

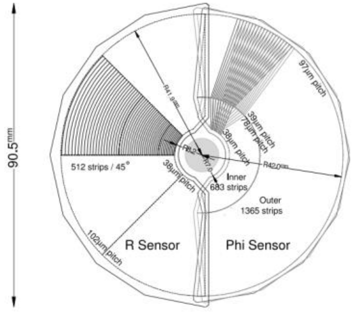
⑤ PID (RICH1, RICH2)

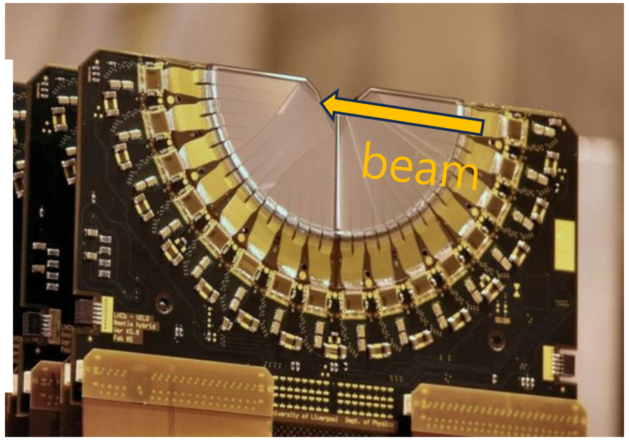
⑥ Muon station (M1~M5)

Vertex Locator (VELO)

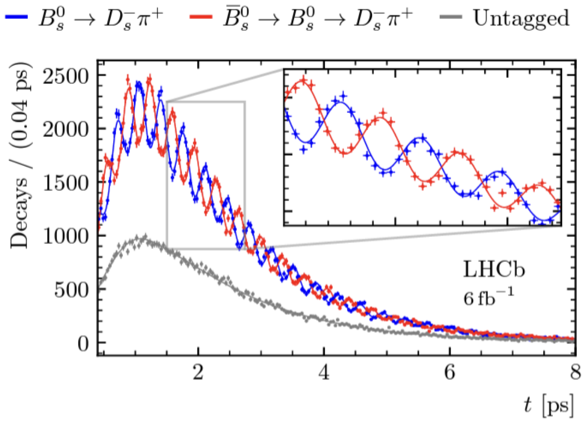
- Reconstruct point of origin(collision point) & decay(secondary particle) → presence of B, 10micron accuracy.
- B-meson short life time → 7mm distance from beam line when measuring
- 6cm distance when beam injected & stabilizing







- Time resol: 40-50 fs / B oscillation: ~tens fo fs



- two row of half-moon shaped silicon detector (0.3mm thick)

Tracking system

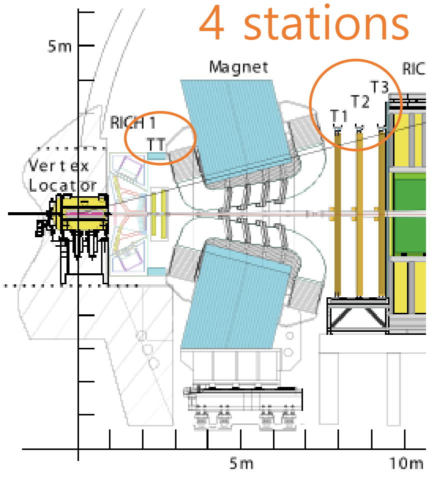
- Reconstruct trajectory & momenta of charged particle
- TT (Tracker Turicensis): Si detector, low angle
- IT (Inner Tracker): Si detector, low angle
- OT (Outer Tracker): Straw tube gas detector, high angle

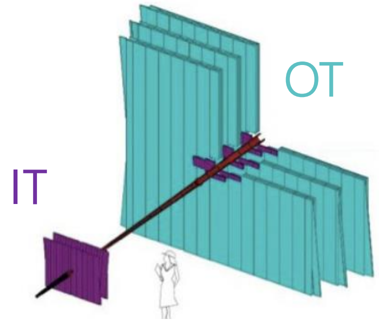
Micro strip sensor, ~$11m^2$

(distance~$200\mu m$, resol~$50\mu m$, thickness)

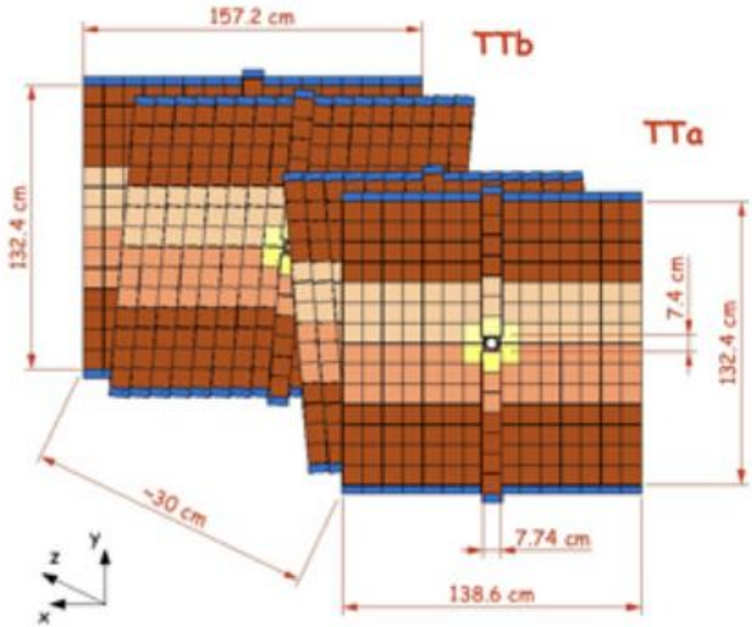
Gas filled straw tube, ~6m*5m

(cell dia~5mm, resol~ $205\mu m$)

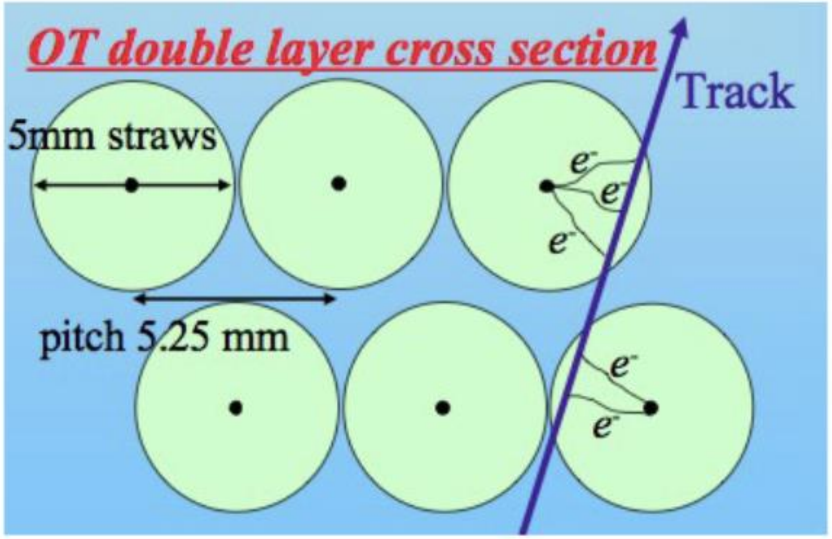




- **TT** – 4 stations (hori+vertical & 5° tilt)



- **OT** – drift time detector, 4 frames, Ar/CO2 gas



RICH system (PID)

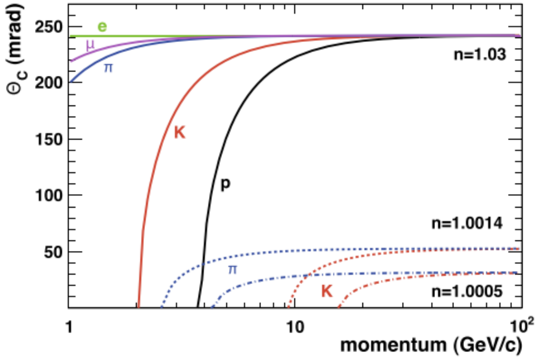
$$\cos\theta_c = \frac{c}{nv}$$

- Measure Cherenkov radiation: Shape of cone depend on velocity -> Mass & Charge -> PID
- PID of $\pi, K,$
- RICH1: low momenta (1~60GeV)
- RICH2: high momenta (15~100GeV)

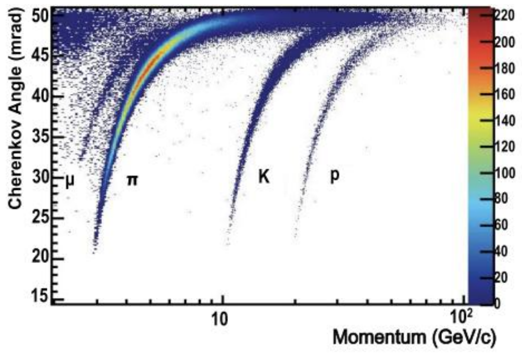
Aerogel layer (high n)

C_4F_{10} gas layer: π, K PID (10~60GeV)

CF_4 gas layer: 15~100GeV

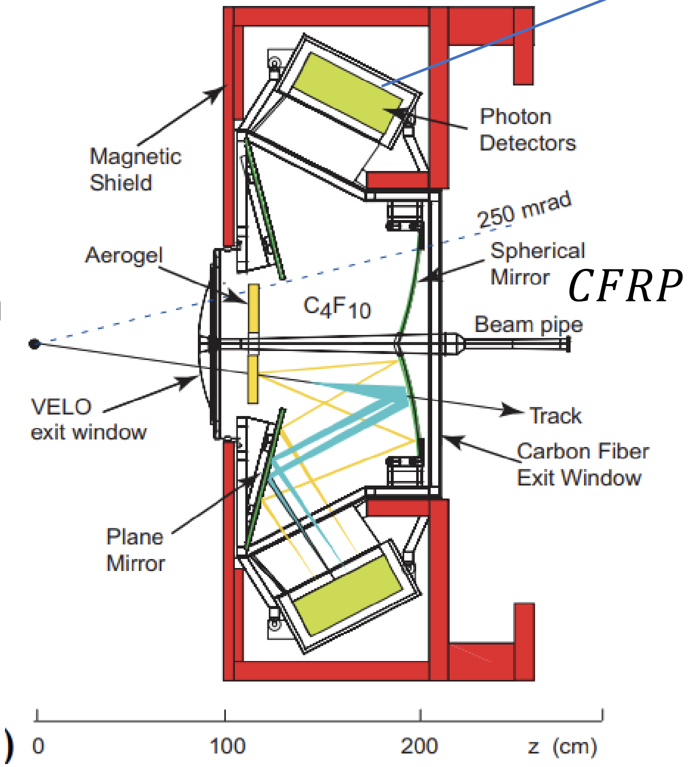


Value of Cherenkov radiation

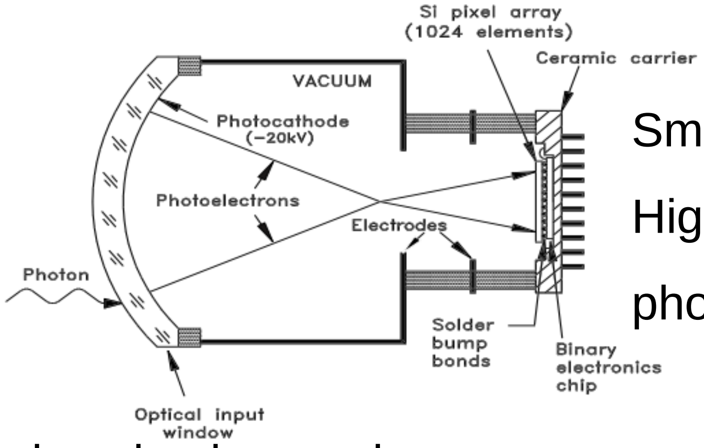


LHCb data

- **RICH1**



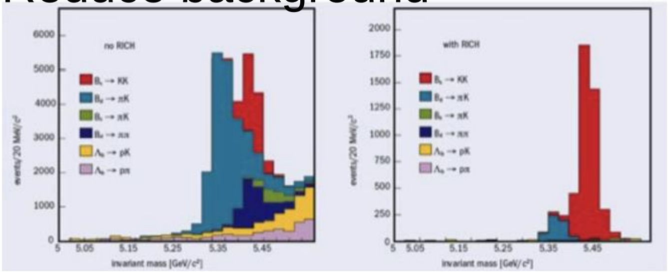
Hybrid Photon Detector



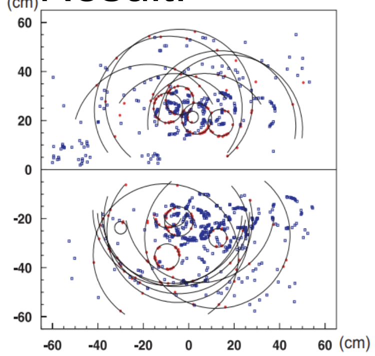
Small pixel Si detector

High eff for single photoelectron

Reduce background



Result:



Calorimeter (ECAL, HCAL)

- Measure Energy: Stop the particle → measure energy loss

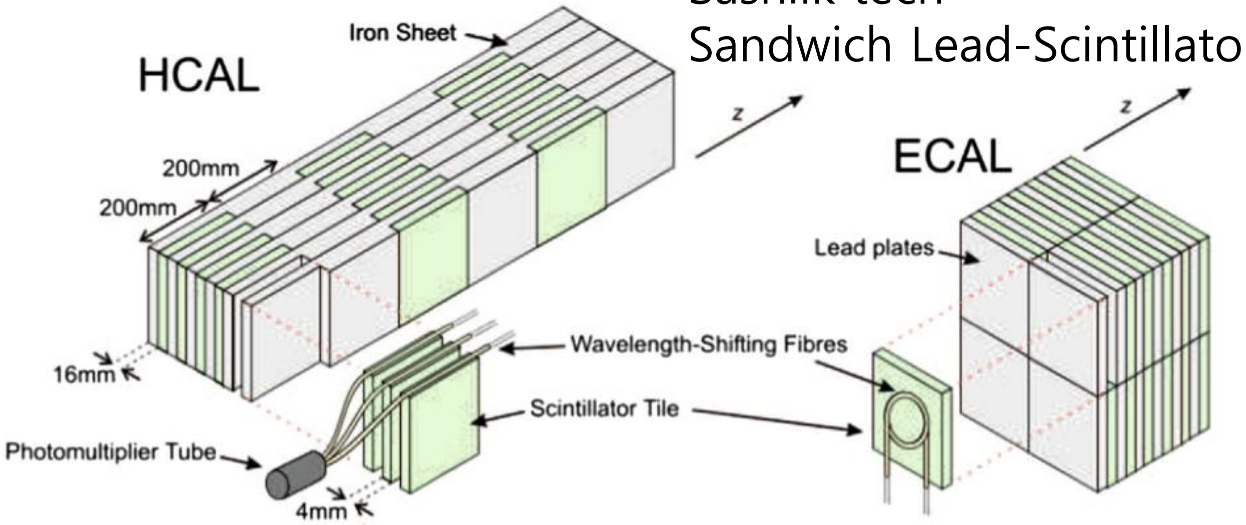
- Scintillator Pad Detector (SPD): particle charged or neutral?
- Preshower Detector (PS) : electromagnetic character of particle

Trigger to see if e-,p, π^0

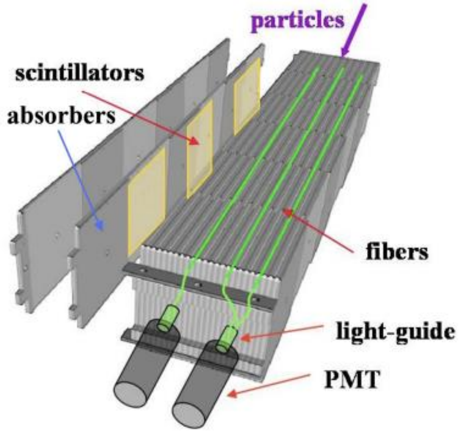
- Electromagnetic calorimeter: measure electron, photon
- Hadron calorimeter: measure hadron (proton, neutron …)

- Process: hit metal →secondary particle→excite polystyrene molecule in plastic→emit UV→energy!

Sashlik tech
Sandwich Lead-Scintillator



- HCAL



Muon System

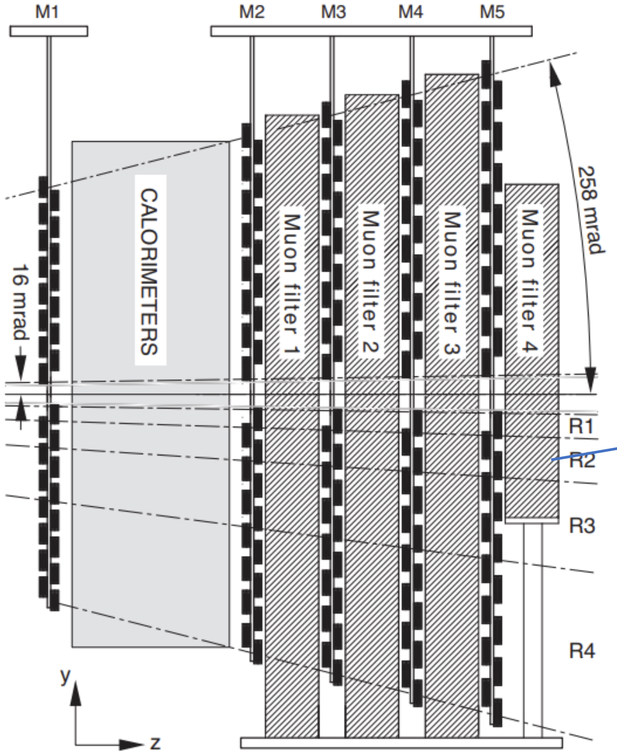
- Measure Muon: Multi Wire Proportianol Chamber @M2~M5

-fast

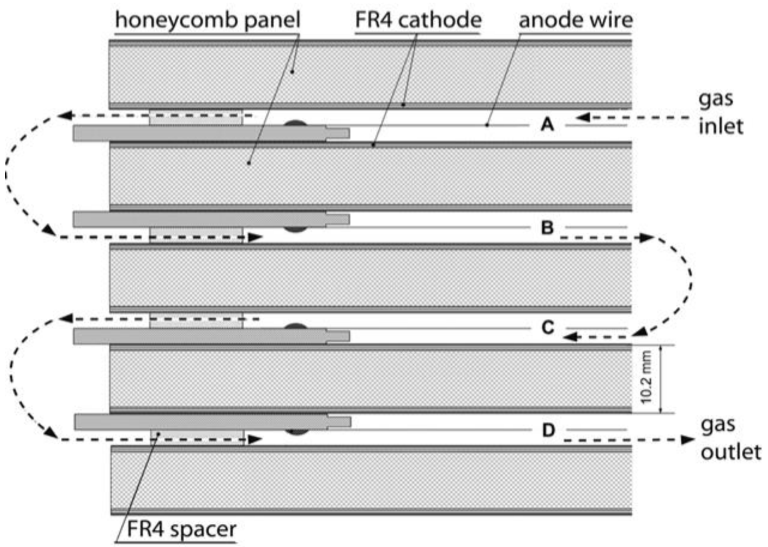
M1~M3: spatial resol good → observe track direction & p_t

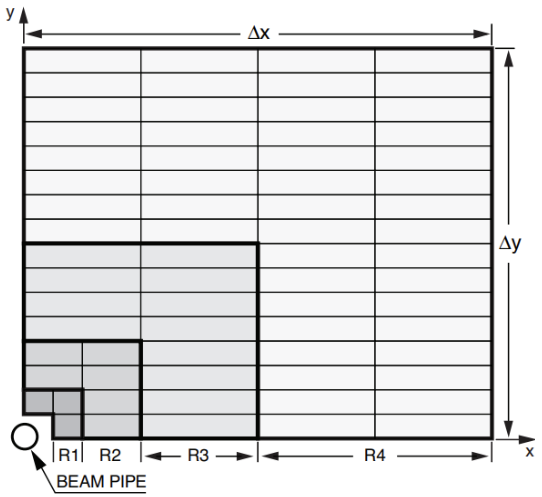
M4~M5: limited spatial resol, identify penetrating particle

- R1~4: segmentation scale ratio 1:2:4:8
- Time resol ~5ns, gas Ar/CO2/CF4
- Run1&2: M1 provide momentum at early state → trigger system.



Iron absorber (80cm)





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VELO

Two volume of vacuum!

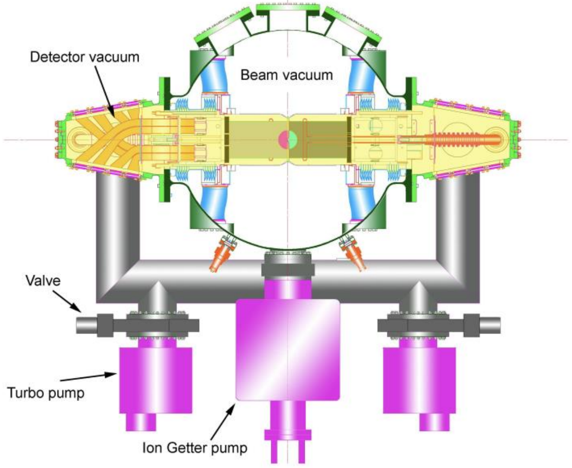


Figure 5.2: Cross section of the VELO vacuum vessel, with the detectors in the fully closed position. The routing of the signals via kapton cables to vacuum feedthroughs are illustrated. The separation between the beam and detector vacua is achieved with thin walled aluminium boxes enclosing each half.

RF-foils

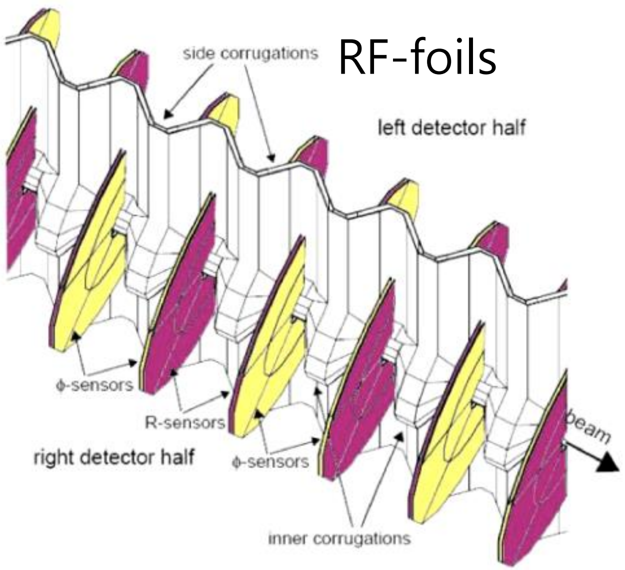
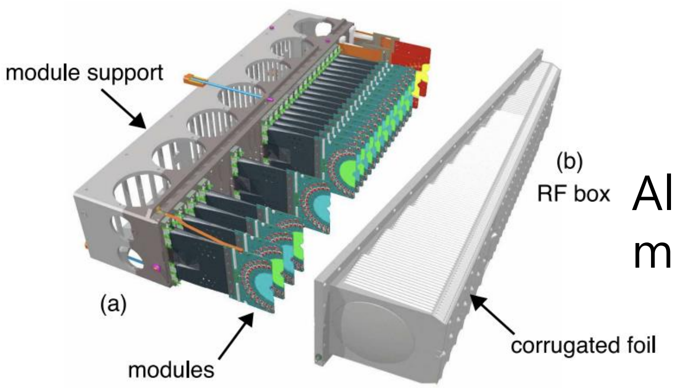


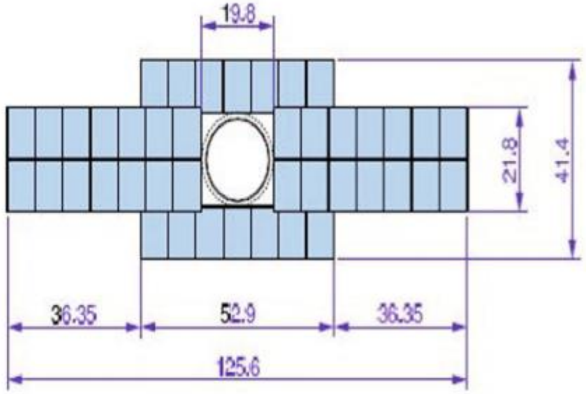
Figure 5.3: Zoom on the inside of an RF-foil, as modelled in GEANT, with the detector halves in the fully closed position. The edges of the box are cut away to show the overlap with the staggered opposing half. The R- and ϕ-sensors are illustrated with alternate shading.



Al box to minimize muti scattering

Figure 5.8: Exploded view of the module support and the modules (a), and the RF box (b). The corrugated foil on the front face of the box, which forms a beam passage can be seen. Its form allows the two halves to overlap when in the closed position.

Tracking system



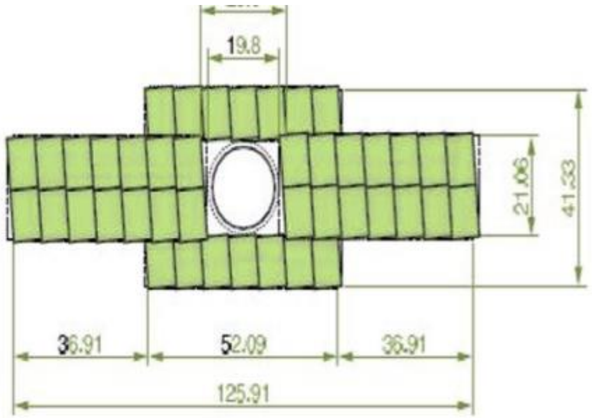
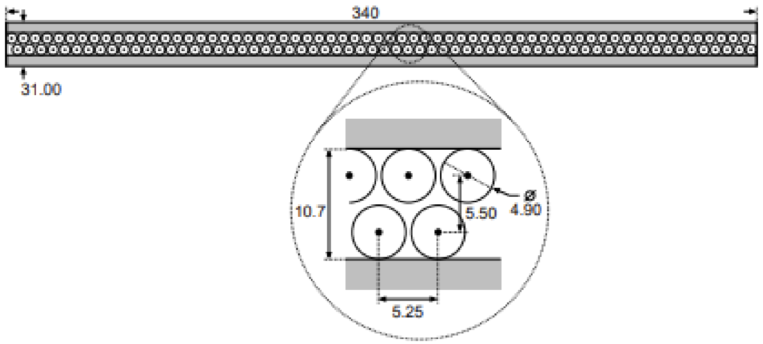


Fig. 7 The LHCb inner detector, (left) a vertically-aligned layer, (right) a stereo layer



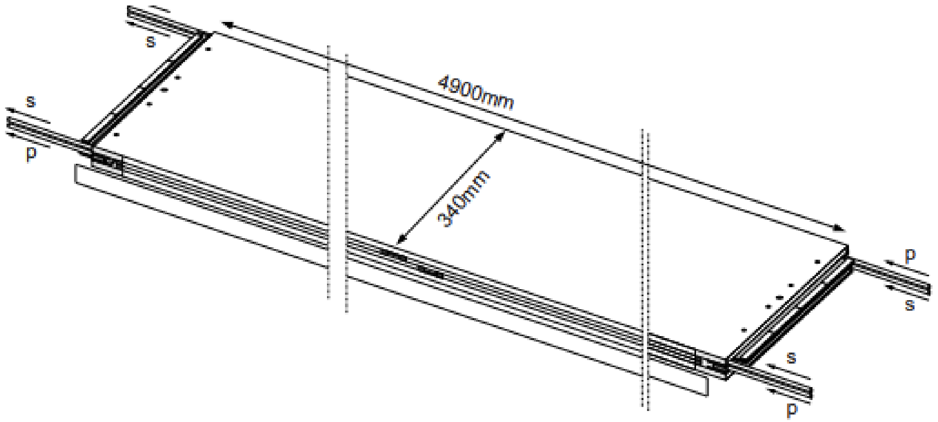
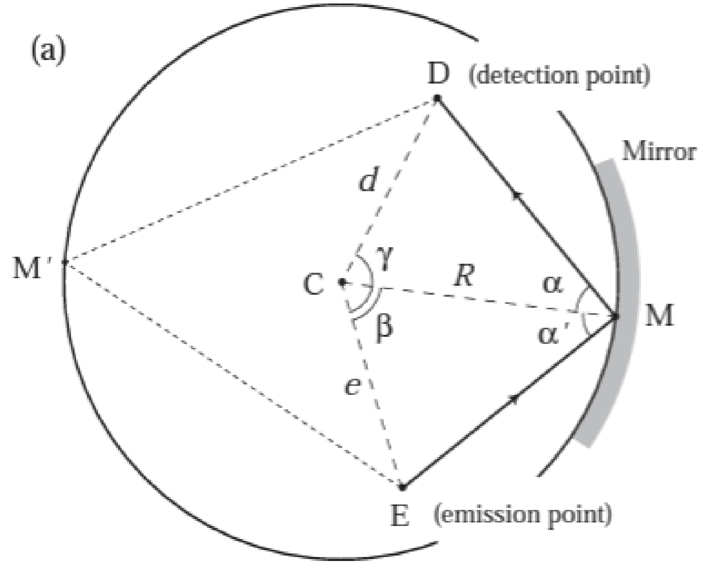


Figure 5.36: Cross section of a straw-tubes module (left) and overview of a straw-tubes module design (right).

Cherenkov radiation



through the radiator.[4] The solution follows from the fact that the point of reflection (M, see Fig. 3) must lie on a plane defined by the points of emission (E) and detection (D), and the centre-of-curvature (C) of the mirror. Thus one can solve for β (the angle between the emission and reflection points, about C) in this plane, without loss of generality. The requirement that the angle of reflection is bisected by the normal to the mirror surface, i.e. $\alpha = \alpha'$, implies:

$$\begin{aligned} \tan\alpha' &= \frac{e\sin\beta}{R - e\cos\beta} \\ = \tan\alpha &= \frac{d\sin(\gamma-\beta)}{R - d\cos(\gamma-\beta)} = \frac{d\,(\sin\gamma\cos\beta - \cos\gamma\sin\beta)}{R - d\,(\cos\gamma\cos\beta + \sin\gamma\sin\beta)}\,, \end{aligned} \tag{1}$$

where R is the radius-of-curvature of the mirror, and d and e are the distances from the centre-of-curvature to the detection and emission points. Putting $d_x = d\cos\gamma$ and

$d_y = d\sin\gamma$ (the components of the vector $\vec{CD}$, parallel and orthogonal to $\vec{CE}$ respectively) and rearranging gives:

$$(Rd_y + 2ed_x\sin\beta)\cos\beta = R(e + d_x)\sin\beta + ed_y(1 - 2\sin^2\beta). \tag{2}$$

Squaring both sides and rearranging again gives a quartic equation for $\sin\beta$:

$$\begin{aligned} 4e^2d^2\sin^4\beta \;-\; 4e^2d_yR\sin^3\beta + \left(d_y^2R^2 + (e+d_x)^2R^2 - 4e^2d^2\right)\sin^2\beta \\ +\; 2ed_y(e - d_x)R\sin\beta + (e^2 - R^2)d_y^2 = 0\,. \end{aligned} \tag{3}$$