# Test beam results of HPD Hybrid Photon Detectors

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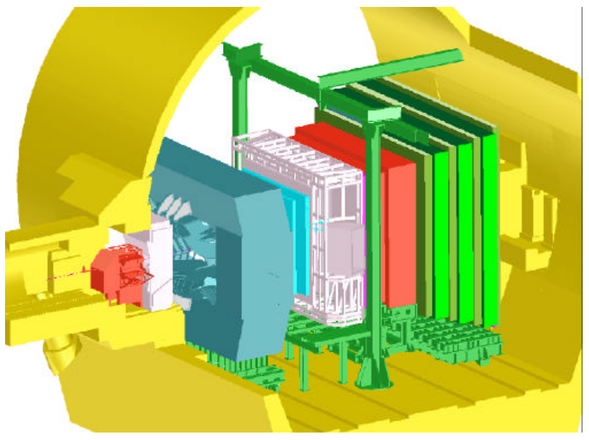
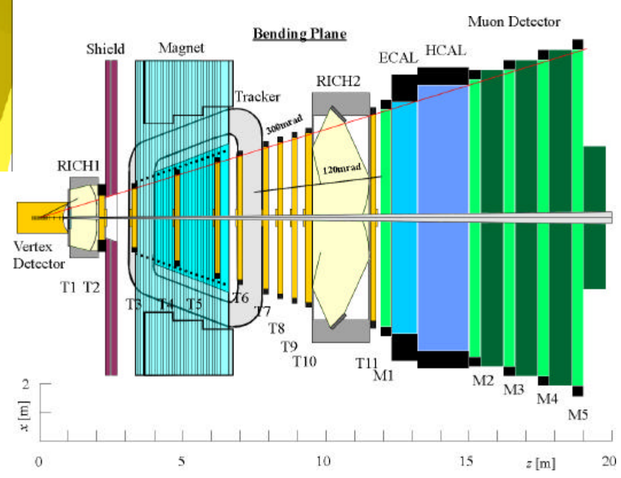
## The LHCb experiment at Large Hadron Collider



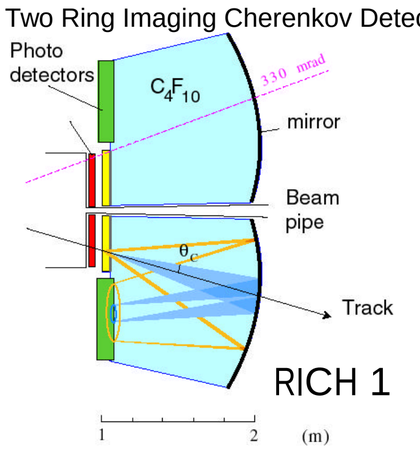
- Single arm forward spectrometer
- Investigation of CP violation in B meson decays with very high precision
- Quark flavor physics




Performances required:
- High tracking efficiency
- Pions-Kaons separation over
- 1-100 GeV/c momentum range
- High trigger efficiency

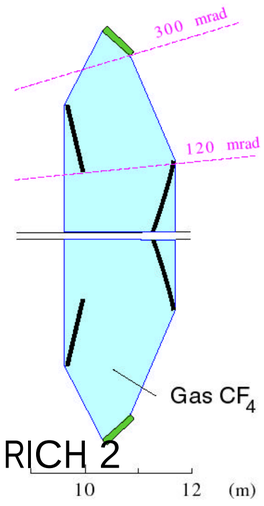
## RICH Ring Imaging Cherenkov detectors

Two Ring Imaging Cherenkov Detectors provide Hadron identification capabilities



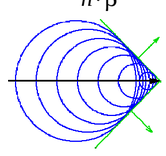

Particle identification from knowledge of its momentum and speed
Speed evaluation through RICH detectors will be affected by uncertainties originated by:

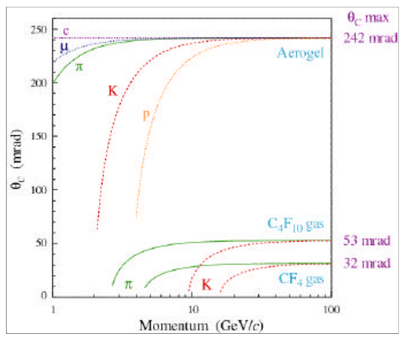
- Radiator medium properties
- Emission point uncertainty
- Medium Dispersion
- Mirrors' optical properties
- Photon detection spatial resolution
- Detection efficiency

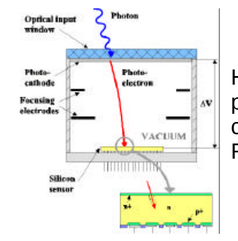



Speed of the charged particle determined from the coherent Cherenkov radiation emission angle

$$\cos(\theta_C) = \frac{1}{n \cdot \beta} \qquad \beta > \frac{1}{n}$$

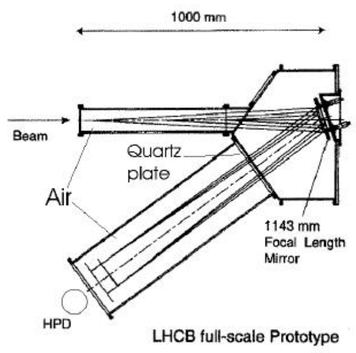





HPDs are the photon detectors chosen for LHCb RICHs

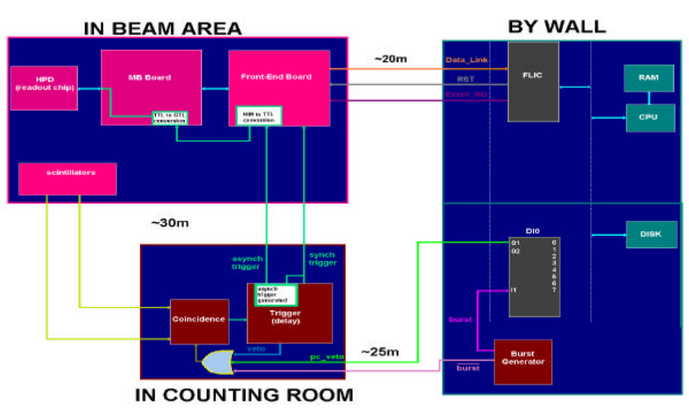
## The test beam setup




**PS T9 Test beam area, east hall**
- 10 GeV/c negative particles

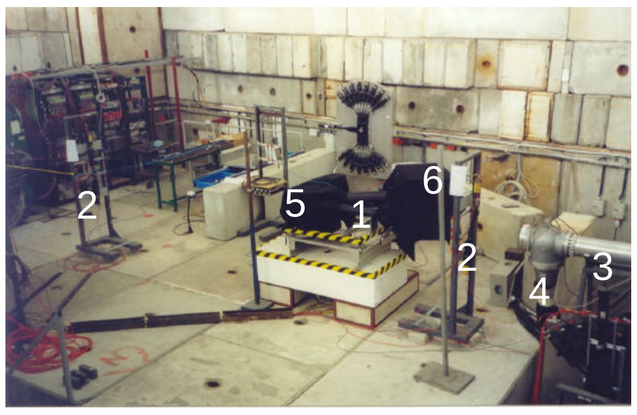
**Vessel**
- RICH1 prototype
- Air rings

**Triggering system**
- 4 scintillators coupled to PM tubes
- T9 Cherenkov counter

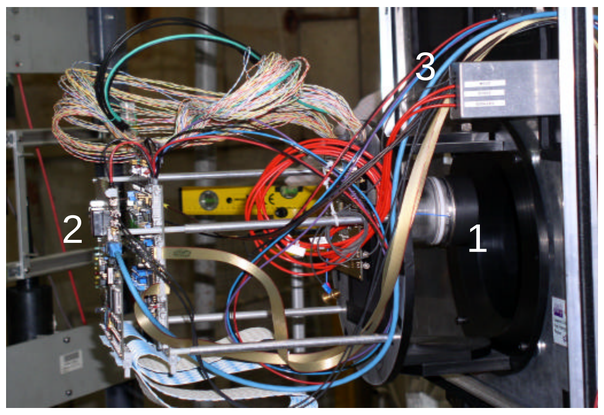



**Triggering and readout electronics and software developed.**
**Main features:**
- Synchronization to beam bursts
- Data and control signals acquisition/generation
- Data transfer from HPDs chips to RAM
- Integrity data check
- Data storage to disk
- Real time hits display
- Quasi-real time statistics
- Data format conversion routines

## The test beam area and the HPD in place

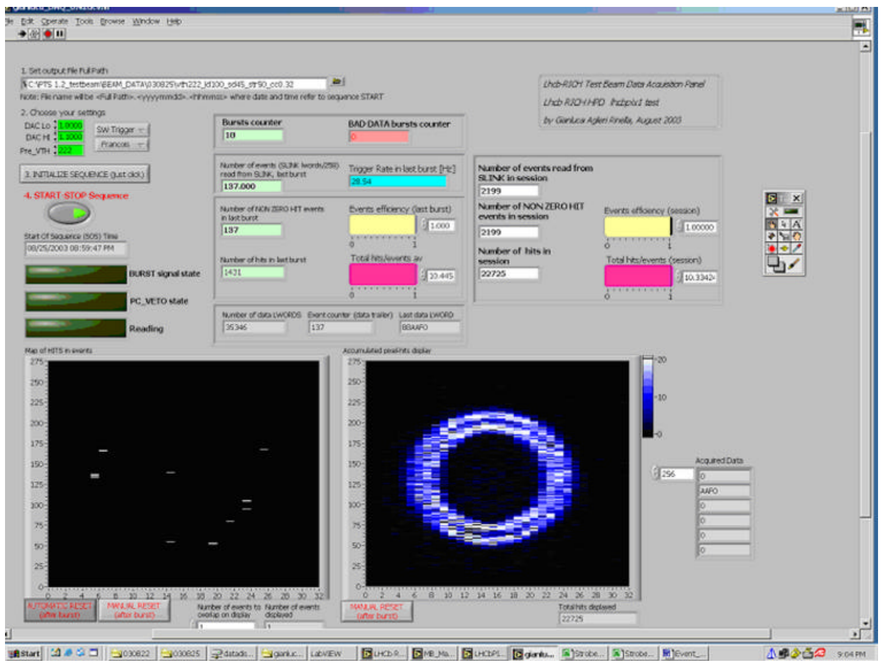



**T9 experimental area, CERN.**
**In evidence:**
1. RICH 1 prototype (vessel)
2. Scintillators (triggering)
3. Beam pipe
4. Cherenkov counter
5. Mirror location
6. HPD location



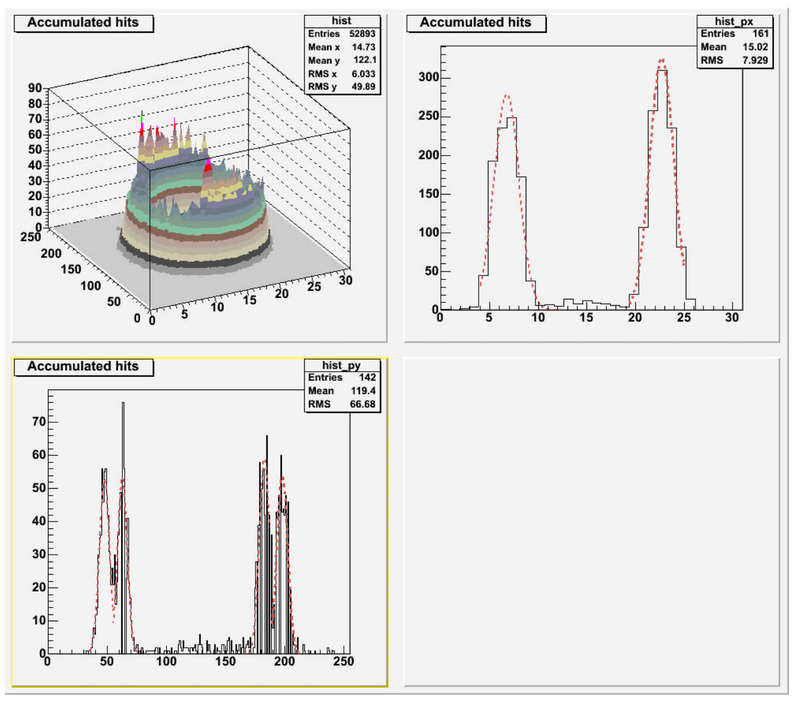

**HPD detector mounted on the vessel.**
**In evidence:**
1. HPD tube
2. Read out electronics
3. HV, control and data connections

## First observed Cherenkov air rings with 40 MHz HPD tubes prototypes




- Data taken in the test beam using two tube prototypes named LHCb#8 and LHCb#9
- Rings generated from **pions** and **electrons** were recorded
- Average number of **hits per event** (=per particle) is determined to be used for detection efficiency evaluation
- The histograms of the hits of all the events in a run on the 32*256 pixels are **sliced** at the center. Fits to the radial hits distributions with Gaussian profiles are used to determine the **average diameter of the ring** shaped distribution on the chip. This measure is to be used for Cherenkov angle determination

## Data Analysis




## Cherenkov angles

The **diameters** of the ring shaped intersections between the HPDs' entrance window and Cherenkov light cones are obtained from the diameters of the rings on the chip taking into account:
- tubes' electron optics demagnification
- photon refraction at the window entrance surface.

Introducing the distance between the mirror and the detector entrance window (L=1144 +/-5 mm) the value of the observed Cherenkov angle is obtained. This can be compared with the expected angle for 10 GeV/c nominal momentum electrons (β 1) determined considering a model of the air refractive index and it's value at λ=250nm. Data for electrons and pions are shown.

**ELECTRONS**

| Tube | Diameter on chip [mm] (3σ error) | Diameter at entrance surface of quartz window [mm] | Observed Cherenkov Angle [mrad] | Expected saturated Cherenkov angle for electrons in air [mrad] |
|---|---|---|---|---|
| LHCb#8 | 9.67 (±1.0) | 53.9 (±6.5) | **23.6** (±2.9) | **23.7** |
| LHCB#9 | 9.37 (±1.2) | 52.2 (±7.3) | **22.8** (±3.5) | **23.7** |

**PIONS**

| Tube | Diameter on chip [mm] (3σ error) | Diameter at entrance surface of quartz window [mm] | Observed Cherenkov Angle [mrad] | Expected saturated Cherenkov angle for electrons in air [mrad] |
|---|---|---|---|---|
| LHCb#8 | 7.61 (±1.2) | 42.3 (±6.7) | **18.5** (±3) | **19.1** |
| LHCB#9 | 7.61 (±1.1) | 42.3 (±5.9) | **18.5** (±3) | **19.1** |

## Detection efficiency

Data from electron runs were used for evaluating the **detection efficiency (DE)** of the two detectors in a real-world like environment.
In order to evaluate the **expected average number of recorded photon hits**:
- an accurate fit of the **refractive index** of normal air
- ambient parameters (temperature and pressure)
- air's absorption
- **reflectivity of the mirror**
- dielectric boundaries reflections
- measured HPDs' **cathode Quantum Efficiency**

have been considered together with Cherenkov photon generation law in the following integral over the HPDs active wavelength interval:

$$N = \int_{\lambda} \frac{2\pi Z^2 \alpha L}{\lambda^2}\left[1 - \frac{1}{n^2(\lambda)\cdot\beta^2}\right] \cdot R_M(\lambda) \cdot T(\lambda) \cdot QE(\lambda)\, d\lambda$$

Observed number of hits per event comes from data corrections for clustering were included. The ratio of this number to the expected photon yield gives the Anode+Front End Chip **Detection Efficiency**. Data in the table refer to electron runs.
Error bars generate from uncertainties on mirror reflectivity, HPD QE, air's refractive index and absorption curve.

| Tube | Expected number of photon hits | Observed number of hits per event | Detection Efficiency % |
|---|---|---|---|
| LHCb#8 | **11.6** (±0.72) | 10.06 | **87** ± 5.4 |
| LHCB#9 | **12.8** (±0.80) | 10.58 | **83** ± 5.2 |

***This work is indebted to people of LHCb-RICH HPD test beam team, CERN EP/TA2 group and LHCb-RICH group**