Cherenkov light detection for the LHCb RICH Upgrade
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1. LHCb spectrometer and the RICH detectors

2. Present photodetector: pixel Hybrid Photon Detector (HPD)

3. Photodetection up to 40 MHz: study of a Flat–Panel
The LHCb Detector

The LHCb experiment has been designed to study CP violation and rare decays in the b–quark sector
The RICH Detectors

- 2 RICH detectors cover a wide momentum range: RICH1 (1–60GeV/c), RICH2 (15–100GeV/c)
- 3 Cherenkov radiators: gaseous $CF_4$ and $C_4F_{10}$, solid silica aerogel
- Spherical and flat mirrors
- Pixel Hybrid Photon Detectors (HPD) outside the detector acceptance
- Magnetic shielding structures
The LHCb Detector

- $\sqrt{s_{LHC}} = 14 \text{ TeV}$
- $\mathcal{L} = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
- Single interaction per bunch crossing
- $\sim 500 \mu b \ b\bar{b}$ cross section
- $10^{12} b\bar{b}$ pairs produced/year
- $p/K/\pi$ separation needed in the final states (ex: $B \rightarrow K\pi$; $B \rightarrow D\pi (D \rightarrow K\pi)$)
The pixel Hybrid Photon Detector (HPD)

- Vacuum tube with quartz window and multi-alkali photocathode (PC)
- Wavelength coverage 200–600 nm
- Pixel matrix of $32 \times 32$ columns with $500 \mu m \times 500 \mu m$ pixel size
- Pixel detector bump bonded on a binary readout chip encapsulated in the vacuum tube
- 3 high voltages needed to accelerate and focus photoelectrons onto the anode
- Cross focusing system and demagnification factor of 5 (granularity at PC level of $2.5 \times 2.5 mm^2$)
- Nominal operating voltage: -20 kV, ~5000 electron-hole pairs released
RICH Operation

The system is ready and working!

Real cosmic events in the RICH1 detector
Cosmic events rate: 0.38mHz
Waiting for pp collisions...
The LHCb detector was designed to work at a luminosity of \( \mathcal{L} = 2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \) (the LHC designed \( \mathcal{L} = 10^{34} \text{cm}^{-2}\text{s}^{-1} \))

\[ \downarrow \]

In order to collect more statistics for physics measurements:

- Increase data acquisition by a factor of 20
- Provide a new front–end electronics

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The photodetection upgrade

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Study for a possible new photodetector
Activity of the Milano–Bicocca group

First step is the study of the characteristics of several different phototubes.
Crucial requirements:

- Fast readout
- Single photon detection
- Good spatial resolution
- Economic considerations

→ Preliminary results from tests of the HAMAMATSU® H9500
Flat–Panel Characteristics

- 16 × 16 anode pixel matrix of 3 × 3 mm²
- Bialkali photocathode with a spectral response from 300–650 nm
- 12 multiplier dynodes
- Supply voltage up to 1100 V
- Average supply current < 200 µA
- Average gain of 1.5 × 10⁶ el/photon
In a RICH detector an important issue is the single photon efficiency

Noise and cross-talk are crucial issues

Datasheet gives cross-talk (CT) for the H9500 device of 5% measured with a large photon signal

Different working condition for single photon detection
In a RICH detector an important issue is the single photon efficiency

⇒ Noise and cross–talk are crucial issues

〜 Datasheet gives cross–talk (CT) for the H9500 device of 5% measured with a large photon signal

〜 Different working condition for single photon detection
The cross-talk effect is the capability, for a photoelectron, to escape from a dynode (the first is the dominant) into a contiguous one, and generates a detectable signal.

**Signal generated from many photons (Datasheet case)**

Many input photons

5% Probability = 5% of electrons leak

5% signal Amplitude at the anode. A cross-talk signal is always present

**Signal generated by a single photon (Cherenkov signal)**

Single input photon

5% Probability of 1 el to leak

Few el generated, 4 – 5

A few number of signals, but with large fraction of the original signal

When cross-talk happens the signal at the anode undergoes to 20% - 30% of amplitude reduction
The test Set-Up

- Multi anode PhotoMultiplier Tube (MaPMT) H9500
- Commercial blue LED (470 nm)
- Optical fibers
- Mask with 256 holes of $R = 1\, \text{mm}$

- Front-end from Syracuse University with a digital readout\textsuperscript{a}

\textsuperscript{a}M. Artuso, Nucl. Instr. And Meth. A, 553, 130-134, 2005
The Cross–Talk evaluation

Acquisition method from Syracuse University: measurements of the signal as a function of the increasing threshold ($T_1 \rightarrow T_2 \rightarrow T_\infty$)

$\Rightarrow$

Fit obtained considering the integral of a Gaussian distribution of the signal overall the threshold range and for several supply voltages

$\Rightarrow$
The Cross–Talk evaluation

To measure the cross–talk, data from a cluster of 5 pixels are analysed, the central pixel (CP) is illuminated and correlated signals from the lateral pixel (LP) are collected.

Simulation ⇒

On the left the signal and CT at the end of the dynode chain, on the right simulated spectra from the front–end electronics.
The Cross-Talk measurements

Comparison between measured and simulated spectra for CP and cross-talk signals. The measurements are taken with a supply voltage of 900 V.
The Cross–Talk measurements

- Shape of the simulation in good agreement with the measurements
- Cross–talk probability of 5% obtained with single photon signals (different working condition from datasheet case)
- Reduction of the $\sim 35\%$ of the real signal due to cross–talk effect

Example: considering a Cherenkov ring of 20 hit pixels, one pixel is due to cross–talk effect
LHCb and the RICHes subdetectors are ready to take data
We are waiting for pp collisions!!!

For a possible RICH upgrade a new photodetector is necessary
   Noise and cross-talk studies are going on for different photodetectors (results from H9500 have been shown)
   First results are promising
Spare Slides
The calibration of the system is achieved injecting at the preamplifier input a known charge through a test capacitance.