Radiation hardness tests of the CLARO-CMOS chip:

a fast and low power front-end ASIC for single-photon counting in AMS 0.35 μm CMOS technology

Authors

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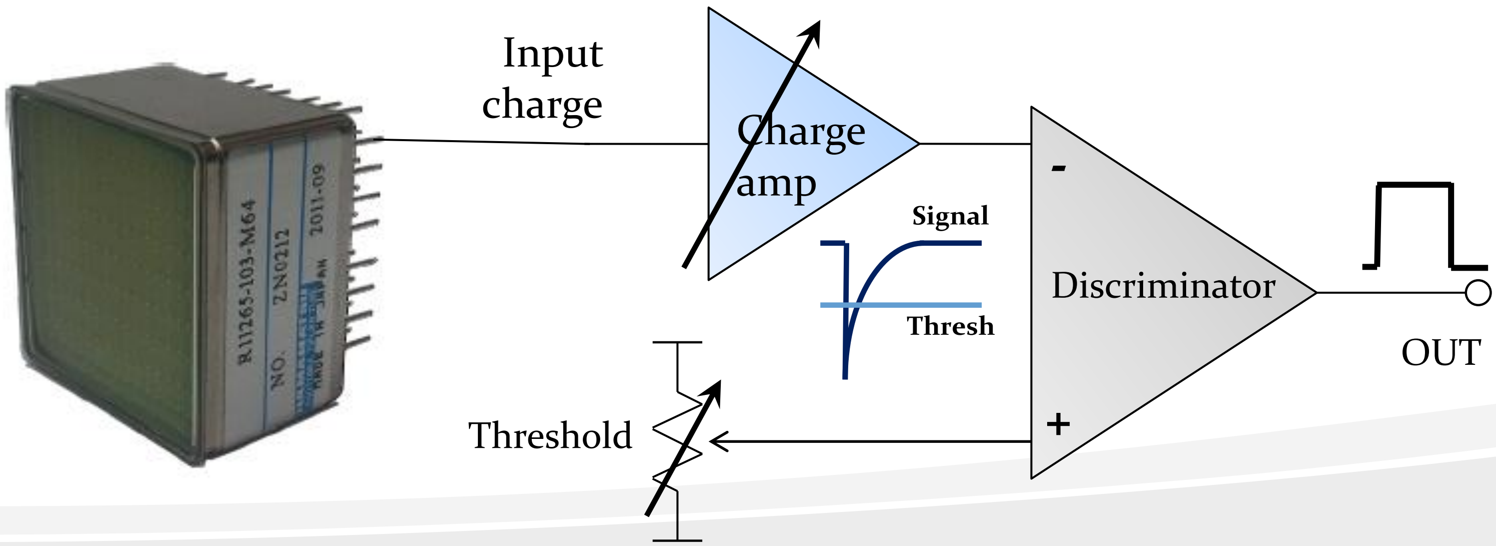
Overview of the CLARO

The CLARO is an integrated circuit designed for **single photon counting** with MaPMTs.

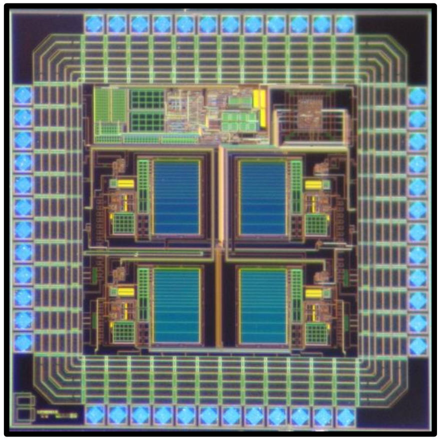
Main features

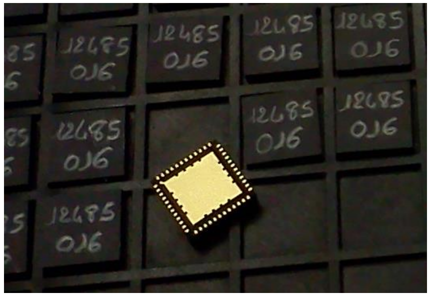
- **0.35 μm CMOS** technology from AMS → Low cost, high yield, long lifespan
- **Counts at 40 MHz** → Recovery time ~ 25 ns
- **Low power consumption** → ≤ 1 mW/channel at 2.5 V power supply
- **Settable gain (3 bits)** → 8 gain configurations
- **Settable threshold (5 bits)** → 32 threshold levels available



The CLARO chronology

- **2011**:
  - The **4 channel prototype** «CLARO-CMOS» was designed
- **2012**:
  - Deep characterization on the test bench
  - First tests with the R11265 MaPMT
- **2013**:
  - Radiation hardness tests with neutrons and X-rays
  - More tests of the CLARO-CMOS with R11265 MaPMTs
  - **Chosen as the baseline front-end ASIC for the LHCb RICH upgrade**
- **2014**:
  - Radiation hardness tests with protons
  - The **8 channels version** with improvements was designed and received few weeks ago (it will not be described here)

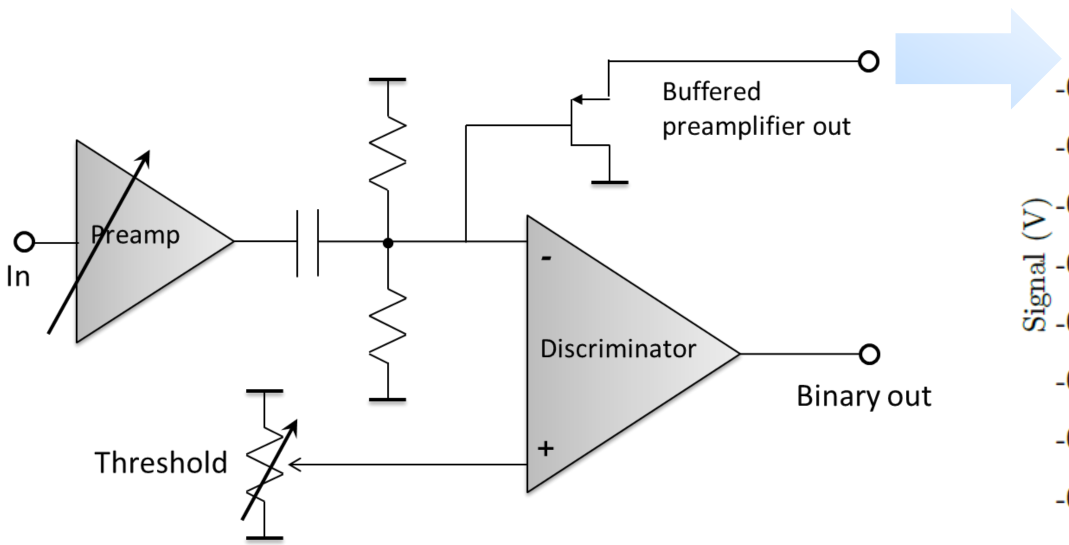


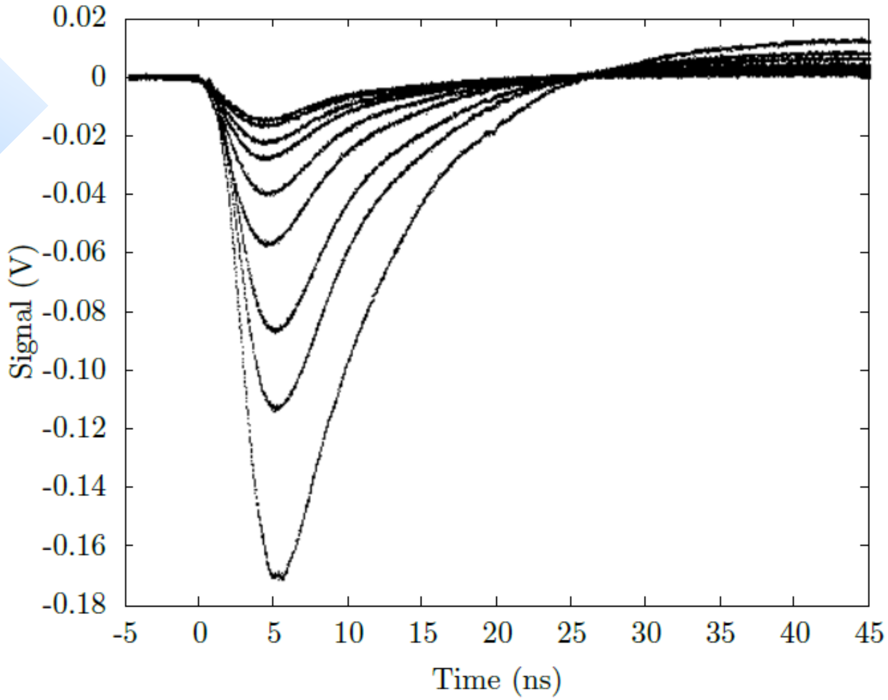


Auxiliary analog output

The analog output is buffered with a PMOS follower, and is mainly used for debugging. It is not meant to be used for single photon counting.

Signals at the analog output, for typical MaPMT signals at the input (330 ke¯ to 3.3 Me¯).



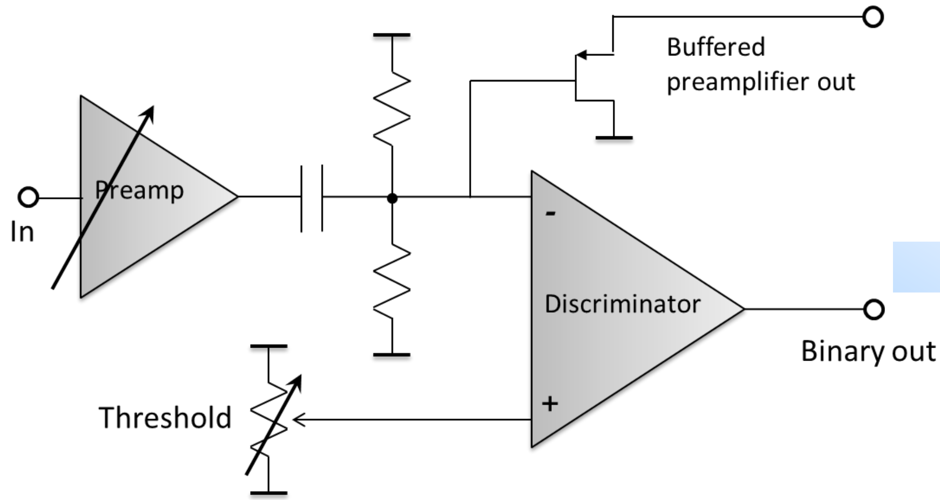


The AC coupling (55 ns) between the Preamp and the Discriminator causes the undershoot. This can lead to a threshold shift at high rate (higher than about 10 MHz).

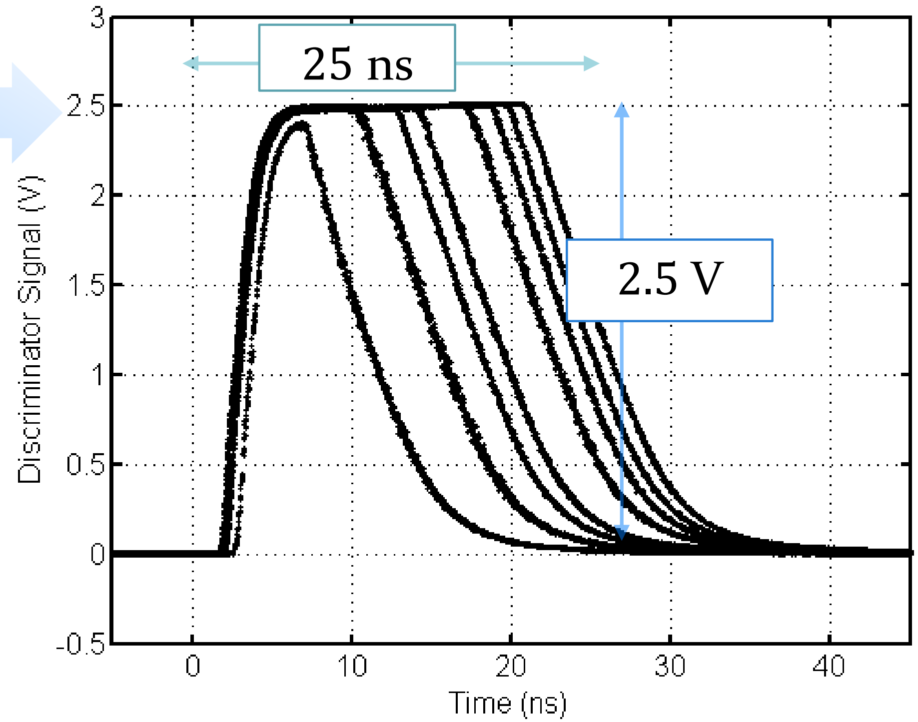
The AC coupling was removed in the new chip version.

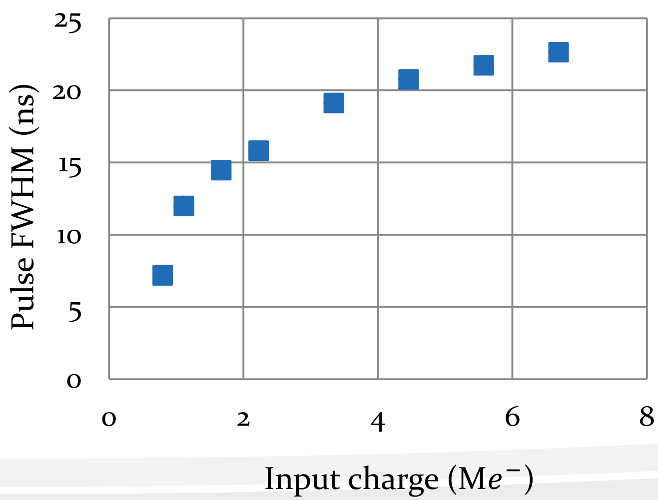
Main digital output

If the integrated charge crosses the threshold level, then a binary pulse is generated on the CLARO digital output allowing the photon counting. The pulse FWHM is lower than 25 ns.



Input charge ranges from 810 ke^{-} to 5.6 Me^{-}
Threshold level set at $\sim 800\ ke^{-}$.





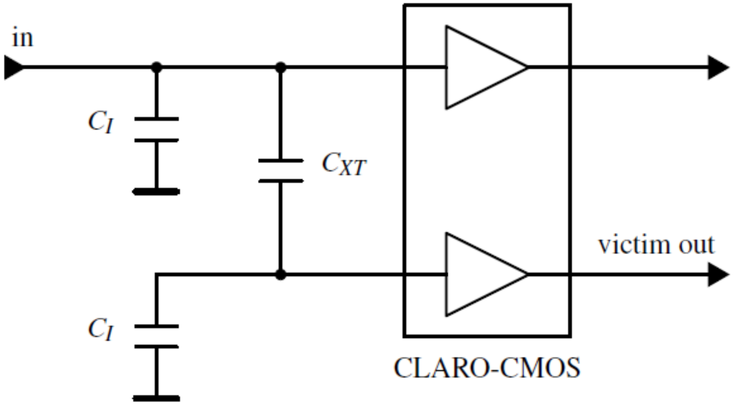
$C_I \simeq 8$ pF

$\tau_R \simeq 2.2$ ns

$\tau_F \simeq 9.3$ ns

Input capacitance

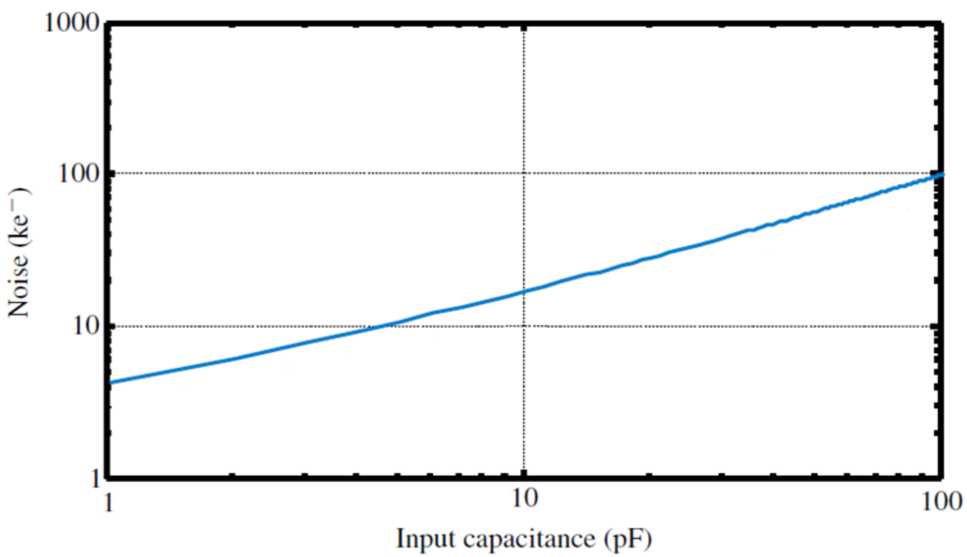
- The noise increases with the input capacitance to ground (C_I)
- The cross-talk increases with the input capacitance between neighbouring pixels

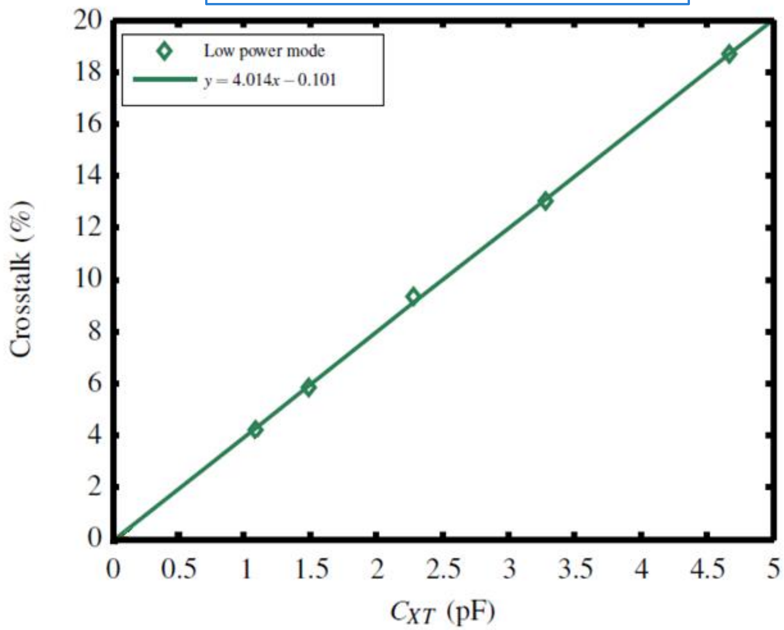


The minimization of input capacitance guides the layout of the CLARO PCBs.

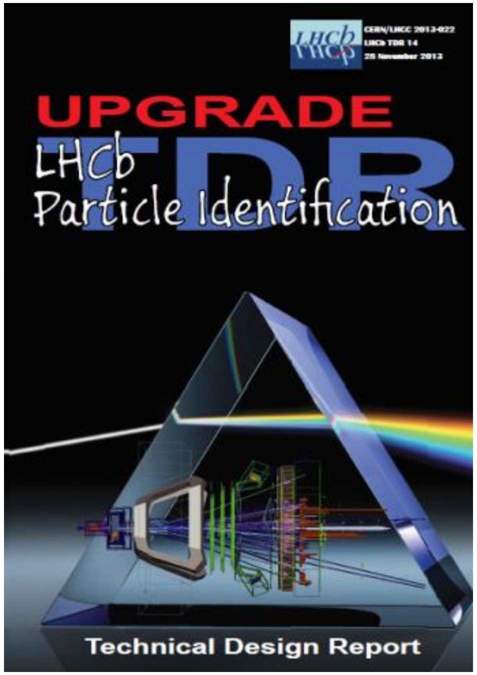
It is one of the main reasons to keep low the number of channels per chip, so that the length of the traces connecting the pixels to the chip is minimized.

$C_{XT} \simeq 0.5$ pF
(due to the MaPMT)



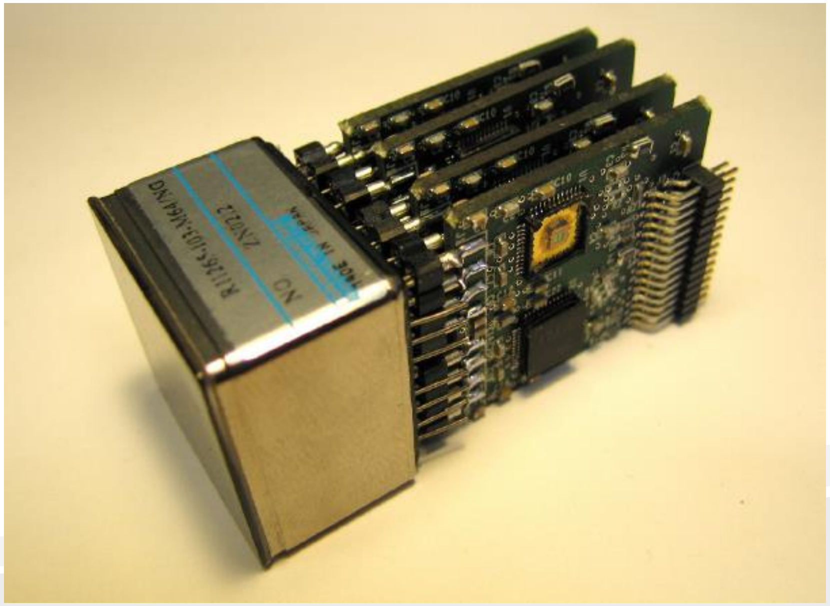


CLARO and LHCb upgrade

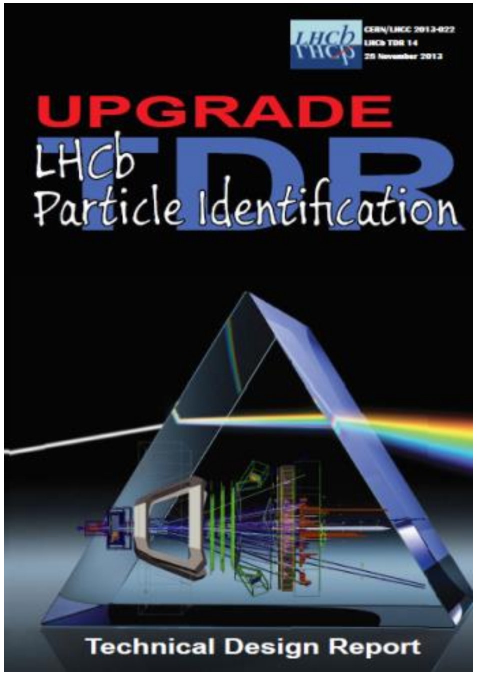


In agreement with the LHCb Technical Design Report (November 28, 2013), the CLARO was chosen as the baseline front-end ASIC for reading the Hamamatsu R11265 MaPMT, the baseline photon sensors for upgrade of the LHCb RICH detectors.

A set of PCBs to interface the R11265 MaPMT to the CLARO were designed and tested. The design allows to minimize the stray capacitance at the inputs of the chip.



CLARO and LHCb upgrade



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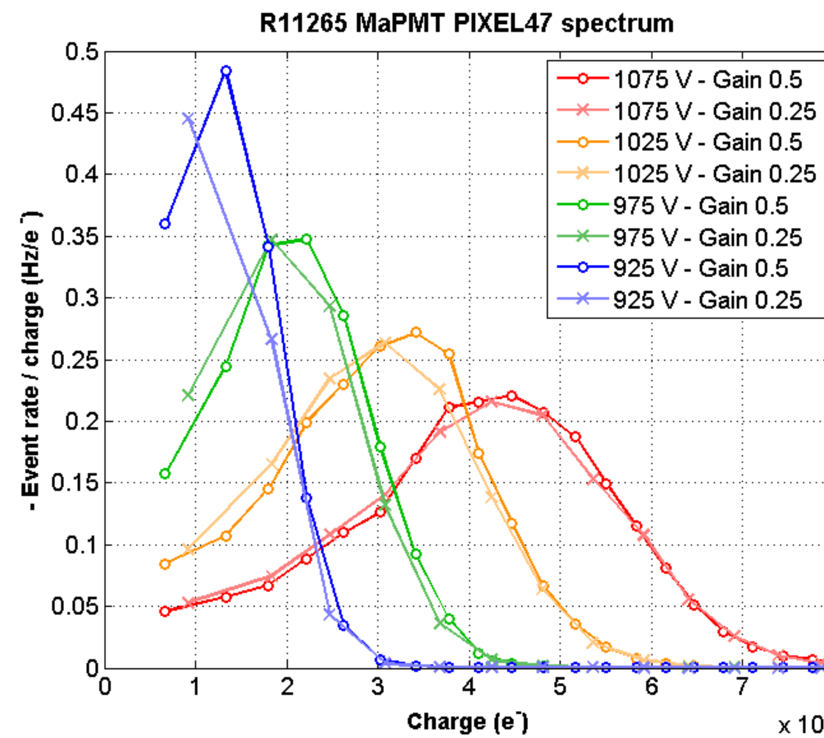


By illuminating the MaPMT with a LED and by counting the signal rates during a CLARO threshold scan, the single photon spectra of the MaPMT can be measured.

The spectra look good, the S/N ratio is more than adequate.

For further information, please visit the poster about CLARO presented by Paolo Carniti

LHCb upgrade – Radiation environment

Accordingly to the estimations provided by M. Karacson[a], the worst case radiation levels expected in the RICH-1 and RICH- 2 detectors for 1 year running in the current geometrical configurations are[b]:

	Neutrons $1\ MeV\ n_{eq}\ [cm^{-2}]$	**Hadrons** $E_H > 20\ MeV\ [cm^{-2}]$	**Total ionizing dose** $[krad]$
RICH-1	$\mathbf{6.1 \cdot 10^{11}}$	$2.3 \cdot 10^{11}$	39.6
RICH-2	$3.1 \cdot 10^{11}$	$1 \cdot 10^{11}$	15.9

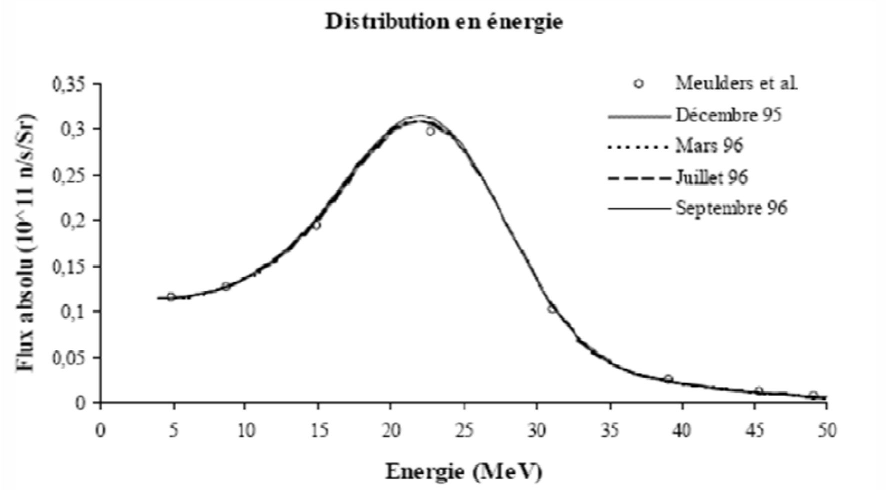
NOTE

- Final geometry and materials have not been implemented.
- 10-30% of statistical errors.
- No safety factor included

a) Presented on February 14th, 2013 at the LHCb Upgrade Electronics Meeting (http://indico.cern.ch/event/225746/contribution/2/material/slides/0.pdf).
b) Assumptions: 1 year running ($10^7\ s$), LHC luminosity: $L = 2 \cdot 10^{33}\ s^{-1} cm^{-1}$, cross section $\sigma = 84\ mbarn$

Neutron irradiation

The neutron irradiation was performed in Louvain-la-neuve (Belgium) in May 2013.



SETUP DETAILS

- Primary 50 MeV deuteron beam on beryllium target producing the high flux neutron beam.
- Average energy of the neutron beam: 23 MeV.
- Low contamination: gamma (2%), p and e (0.02%).
- Neutron fluence of 10^{14} cm^{-2} reachable in 1 hour typically.
- Good uniformity over the CLARO chip area.
- 3 CLARO PCBs installed at different distances (different fluences coming from beam geometry): from 20 cm to 26 cm.

Neutron irradiation

The neutron irradiation was performed in Louvain-la-neuve (Belgium) in May 2013.

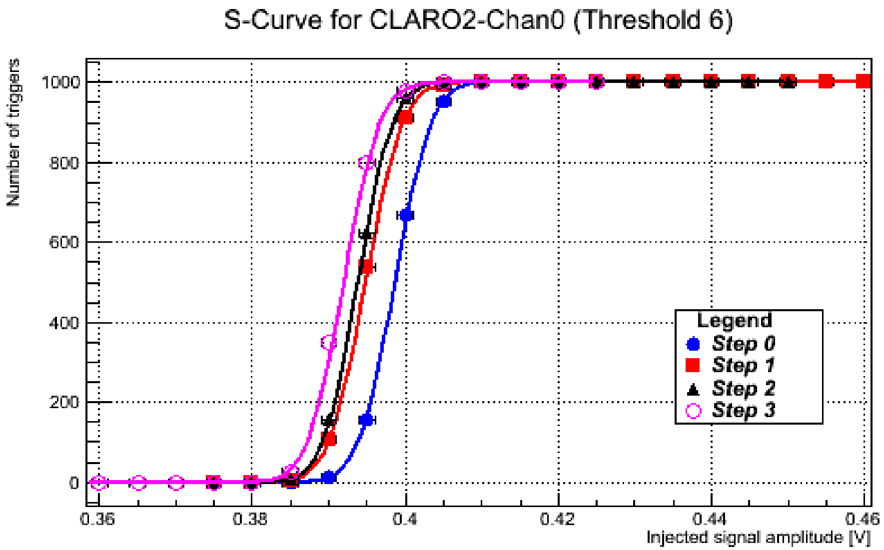
MEASUREMENTS PERFORMED

During irradiation:

- Online monitoring of threshold voltage and supply current

Before/after irradiation:

- Measurement of linearity curves
- Measurement of S-curves (burst of 1000 pulses sent to all CLARO inputs simultaneously: the number of discriminated output signals is measured for different input signal amplitudes)

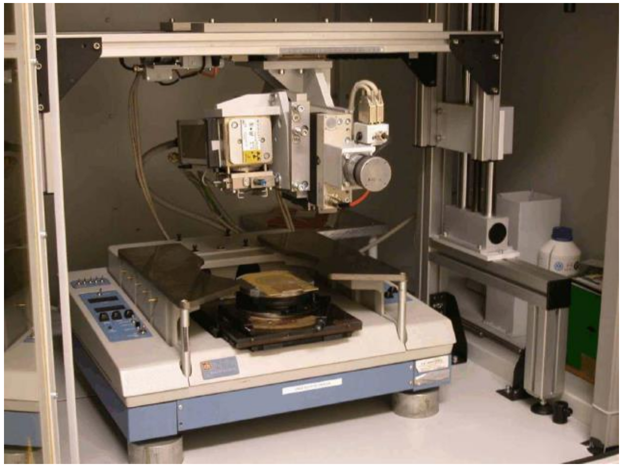


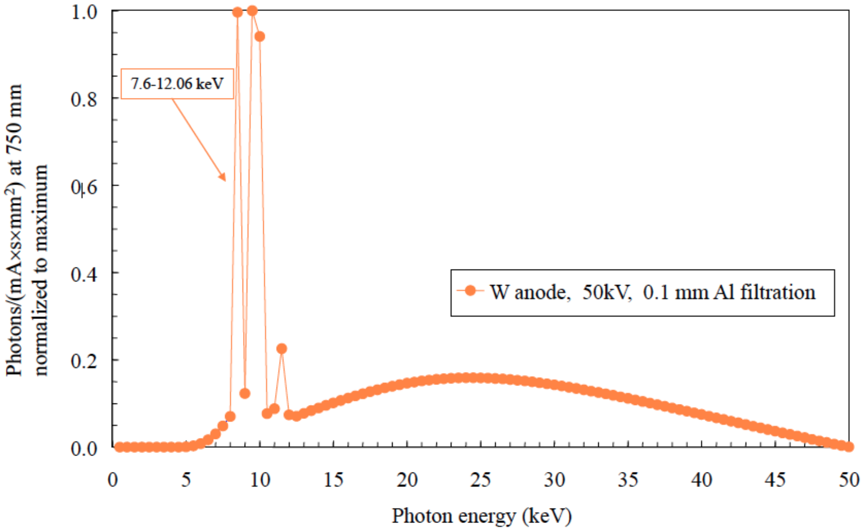
The 3 CLAROs samples were powered and irradiated up to 10^{14} 1 MeV n_{eq} cm^{-2} (~ 160 years in LHCb) in three steps (equivalent to 4, 40 and 160 years in LHCb respectively).

- No SEU / SEL observed
- No variation in supply current
- No significant variation in thresholds and noise

X-ray irradiation

The X-ray irradiation was performed in Legnaro (Italy) in September 2013.



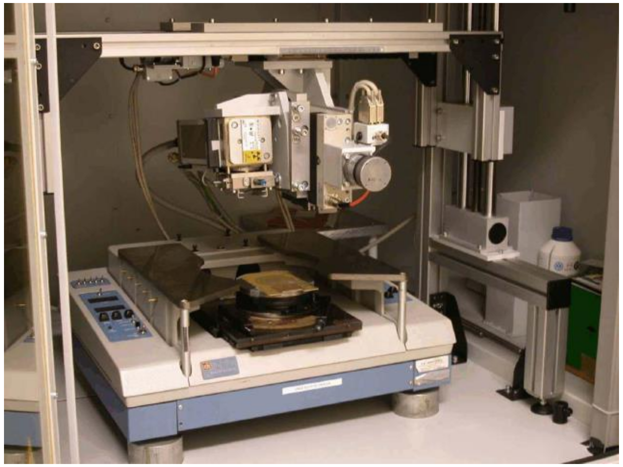


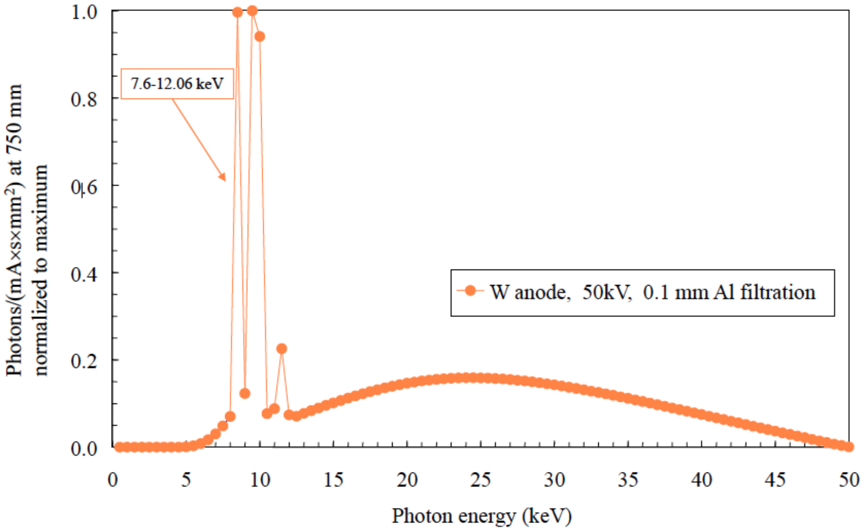
SETUP DETAILS

- Tube with W anode (7.4 – 12.06 keV, maximum tube voltage ≃ 50 kV)
- Laser pointer for an accurate samples location.
- Good uniformity over the CLARO chip area.
- Chip lid removed (bare ASIC).
- 2 new CLARO PCBs installed at different distances from target: one at 10 cm (~500 rad/s) and the other at 6 cm (780 rad/s).

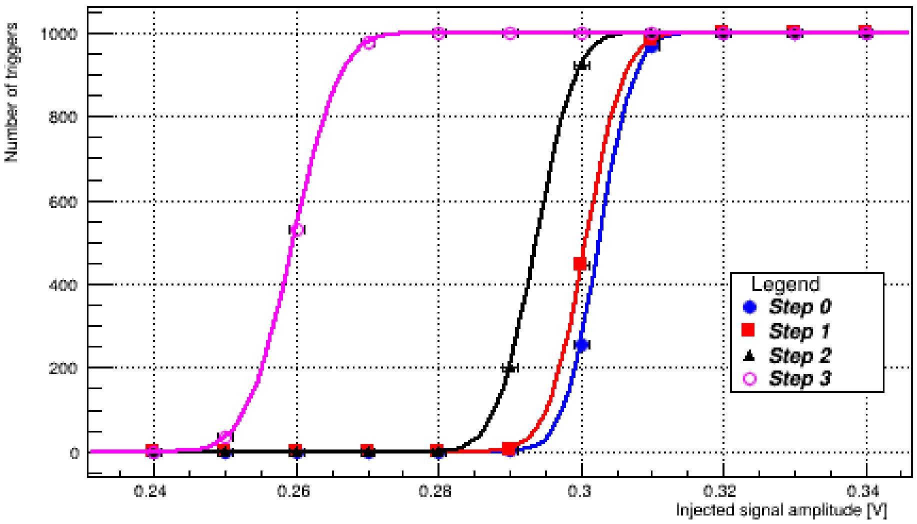
X-ray irradiation

The X-ray irradiation was performed in Legnaro (Italy) in September 2013.





The 2 bare CLAROs samples were powered and irradiated up to 4 Mrad (~ 110 years in LHCb) in three steps (equivalent to 1, 10 and 110 years in LHCb respectively).

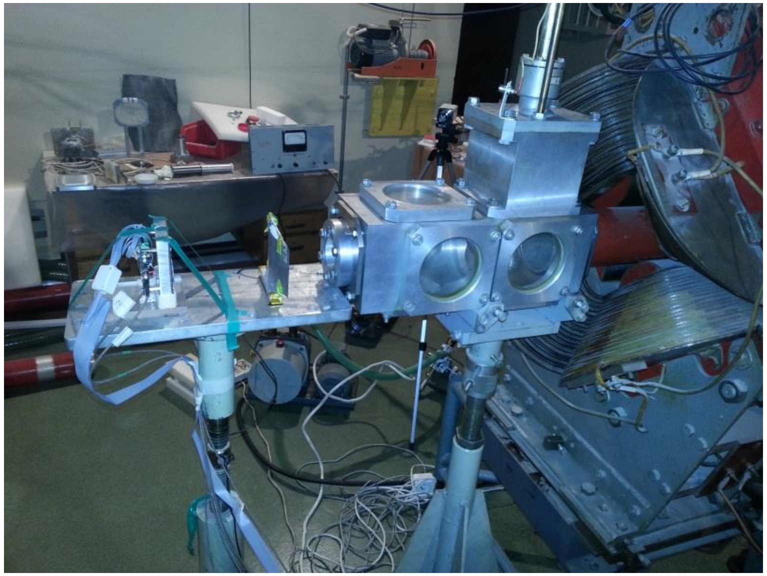


- No SEU / SEL observed
- 10−15% decrease in supply current
- 10−15% variation in channel threshold

Proton irradiation

The proton irradiation was performed in the Institute of Nuclear Physics, Polish Academy of Sciences in Krakow (Poland) in February 2014.

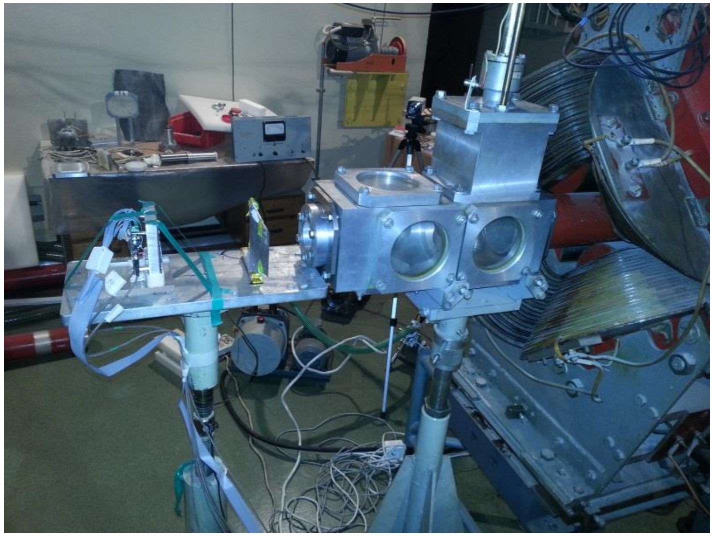
- Beam energy: 50–60 MeV.
- Beam diameter ~ 1 cm.
- High dose rate (~ 1.2 krad/s).
- Irradiation time precision: ~ 0.1 s.
- Chip lid removed (bare die ASICs).
- 3 new CLARO PCBs were installed, powered and tested.

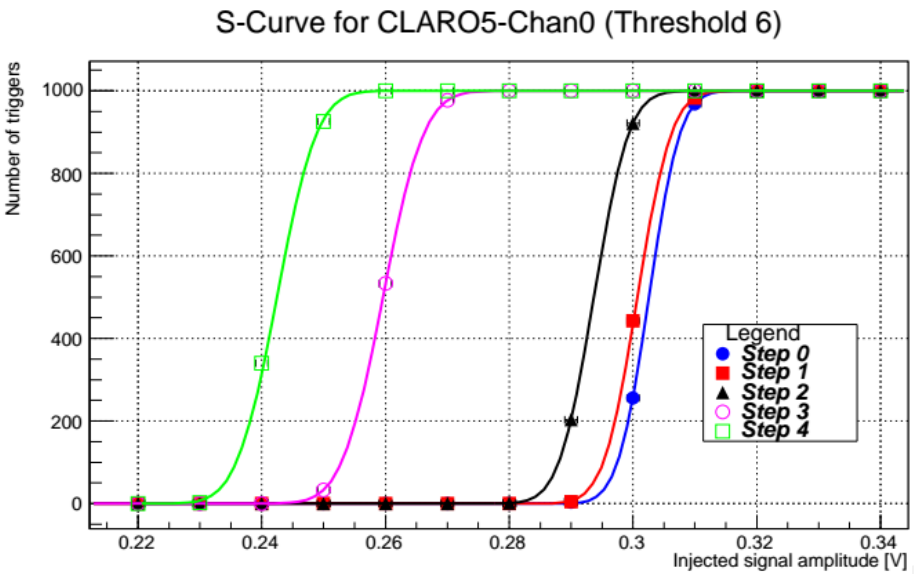


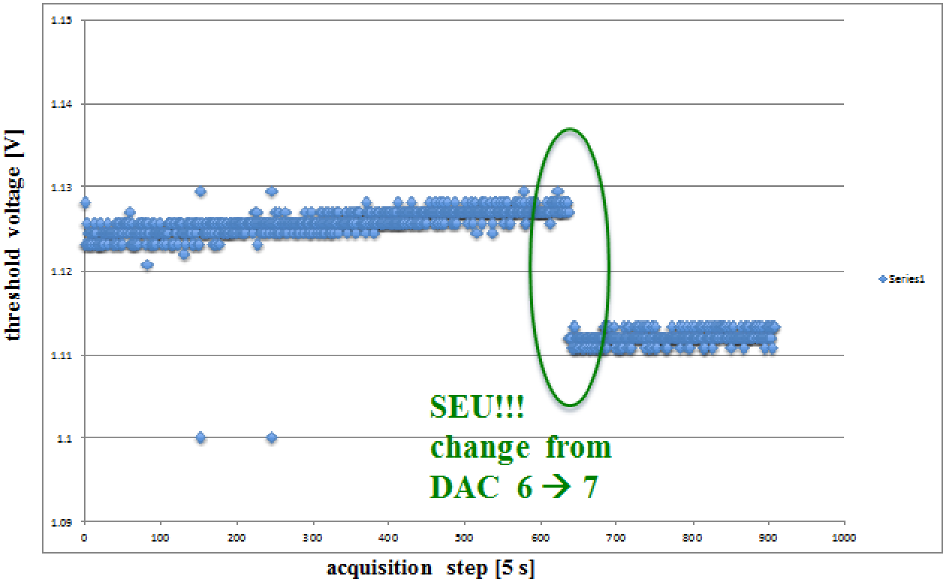
Proton irradiation

3 samples (with the lid removed) were powered and irradiated up to 7.6 Mrad (~ 190 years in LHCb) in four steps (equivalent to 1, 10, 100 and 190 years in LHCb respectively).

- 1 SEU observed
- No SEL observed
- 10−15% decrease in supply current
- 15−20% variation in channel threshold







Conclusions and plans

CLARO 4

- The 4-channel CLARO-CMOS is an integrated circuit realized in 0.35 μm AMS.
- Although it is designed in a relatively old technology, the prototype demonstrated the capability of the chip to count single photons from MaPMTs at a 40 MHz rate with a low power consumption (< 1 mW / channel).
- The technology turned out to tolerate radiation levels more than a factor of 10 larger than the worst case scenario foreseen in ten years of operation in the upgraded LHCb (1 Mrad total dose, hadrons up to 10^{13} (n,p) cm^{-2})

WHAT'S NEXT? CLARO 8

- An 8-channel improved version of the chip was designed earlier in 2014.
- Amplifier DC-coupled to the discriminator
- Finer threshold steps
- Configuration register protected against SEU by triple modular redundancy and equipped with a SEU counter.
- The first samples were received few weeks ago and the first tests are ongoing.

The end

Thank you for the attention!