Hybrid single-photon imaging detector with embedded CMOS pixelated anode

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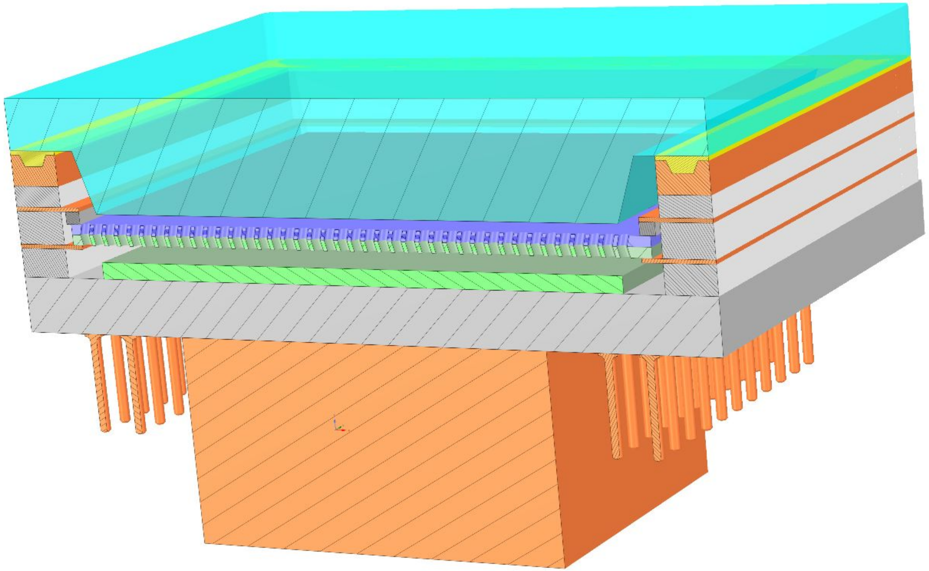
Overview

- Project goal and motivations
- The hybrid detector operating principle and assembly
- The Timepix4 ASIC
- Conclusions



Project goal and motivations

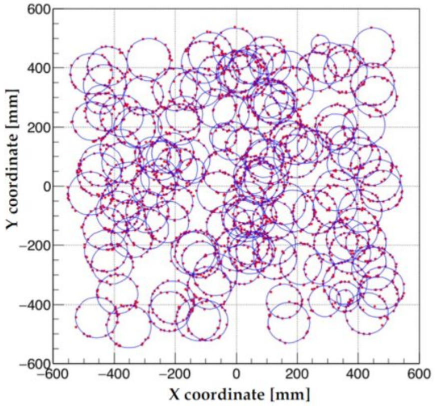
Goal: production of a new photodetector able to measure single photons with simultaneous excellent timing and spatial resolution.

Such a detector could enable significant advances in:

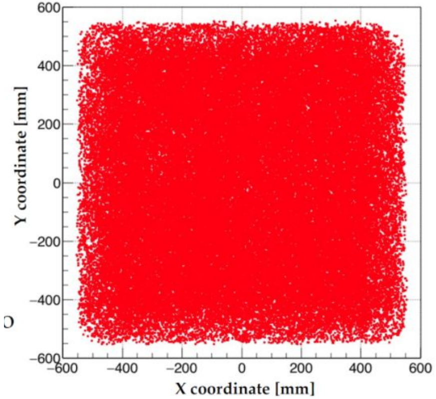
- particle physics
- life sciences
- optical quantum physics
- in general other fields where a single photon detection with high timing and spatial resolution are required

LHCb Ring Imaging CHerenkov detectors

➢ Rings overlap in high multiplicity environments
➢ Global fitting allow to extract PID
➢ Current detectors not adequate in an environment like the High Luminosity LHC



LHCb Run 1-2:
➔ ~ 2000 photons in 25 ns
➔ ~ 100 rings



LHCb simulation in HL LHC:
➔ ~ 100 k photons in 25 ns
➔ ~ 5000 rings

Need for a new detector with fine granularity and time resolution of *O(10ps)*

The detector operating principle

A photon produces a photo-electron in a high quantum efficiency Photocathode

⇩

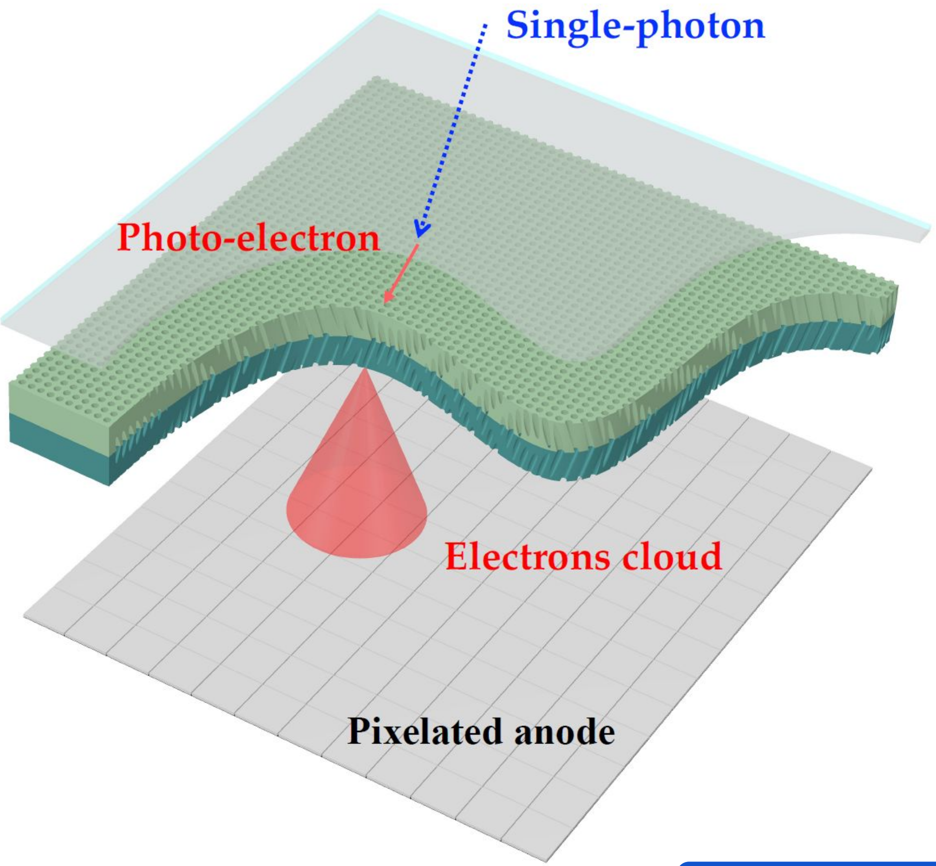
The electron enters a MicroChannel Plate (MCP) double stack, where it releases secondary electrons producing a cloud

⇩

The electrons cloud spreads over a pixelated anode, where the electrons are detected

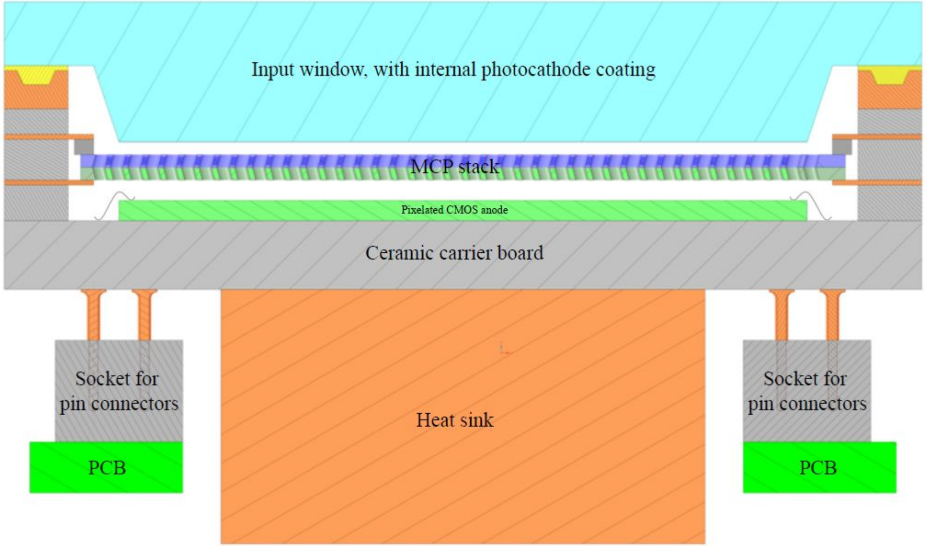
⇩

Pixelated electronics embedded inside the vacuum tube will amplify, discriminate and digitize the MCP signal



The hybrid detector assembly

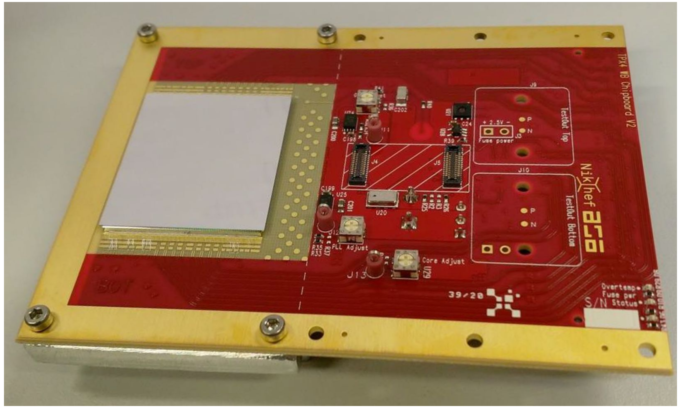
- **“Hybrid” assembly**: many components inside a tube kept in under high vacuum (~ 10^{-10} mbar)
- Photocathode deposited in the inner part of a transparent input window
- Pixelated CMOS anode: **Timepix4 ASIC**
- **Ceramic carrier board**
  - interface between the inner and the outer parts of the detector
  - high speed connections through pins connected to the sockets
  - custom Pin Grid Array for I/O signals
- **Heat sink** (ASIC power 5 W)
- **PCB** to connect the detector to a FPGA-based DAQ system

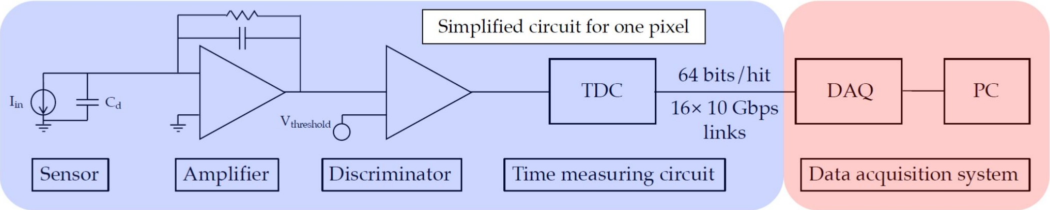


[M. Fiorini et al, JINST 13 (2018) C12005]

Pixelated anode: Timepix4 ASIC

- ASIC in **65 nm CMOS**
  - Developed by Medipix4 collaboration
- 512 ✕ 448 pixels (55 µm ✕ 55 µm each)
- **Large active area**: ~ 7 cm^2
- Bump pads used as anode



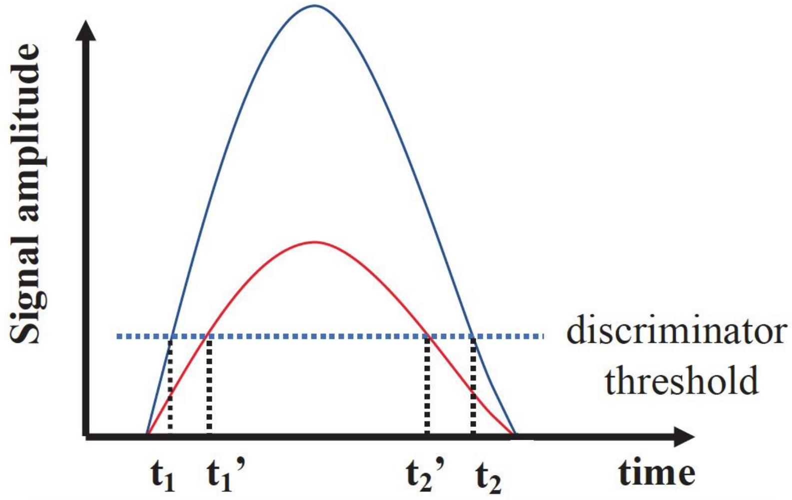


- Signal from MCP amplified and discriminated
- Time-stamp provided by Time to Digital Converter (TDC)
  - 195 ps bin size (**~ 56 ps r.m.s. resolution**)
- **High rate capability**:
  - maximum bandwidth: **160 Gb/s**
  - maximum hit rate: **2.5 Ghits/s**
- Signal informations provided:
  - pixel coordinates
  - Time of Arrival
  - Time over Threshold
- Output:
  - 64 bits of data per event and per pixel with 64B/66B encoding
  - transmitted on 16 high speed links @10 Gbps

[X. Llopart *et al* 2022 *JINST* **17** C01044]

Timepix4 ASIC timing and position resolutions

- For each pixel, combined measurement of:
  - ToA: Time of Arrival (t_1)
  - ToT: Time over Threshold (t_2 - t_1)
- 3D clustering (2D space and time)
  - multiple sampling improves timing resolution
  - **cluster ToA “weighted average”** (with respect to ToT) improves resolution to **order of *O(10 ps)***
- Equivalent charge released in the pixel estimated from ToT
- ToT allows also to:
  - Correct Time-walk effect (i.e. t_1’ - t_1)
  - **Improve spatial resolution** on cluster centroid
    - (55 µm/√12) **~16 µm ⟶ ~ 5 µm**



[X. Llopart *et al* 2022 *JINST* **17** C01044]

Summary

Development of a new detector for single photons in the visible range:

- vacuum tube based
- MCP double stack
- Timepix4 CMOS ASIC as anode

It will allow to detect up to 10^9 photons/s with simultaneous measurement of time and position with high resolution

High resolution of a MPC fully exploited

High-rate data acquisition (up to ~160 Gb/s)

Detector and DAQ system under development

Thanks for your attention

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