Report on Pisa (Elba) meeting

Riccardo Ridolfi

RIPTIDE: A PROTON-RECOIL TRACK IMAGING DETECTOR FOR FAST NEUTRONS

Riccardo Ridolfi[1,2] on behalf of the RIPTIDE project
[1]Department of Physics and Astronomy, University of Bologna, [2]INFN, Section of Bologna

INTRODUCTION

Neutron detectors are an essential tool for the development of many research fields, as nuclear, particle and astroparticle physics as well as radiotherapy and radiation protection. Not ionizing directly, neutrons are detected via nuclear interactions producing charged particles or electromagnetic radiation. Consequently, the detection efficiency depends on the probability of neutron interaction in the detector and on the escape probability of the reaction products. Fast neutron detection is often based on the neutron-proton elastic scattering reaction: the ionization caused by recoil protons in a hydrogenous material constitutes the basic information for the design and development of neutron detectors. Although experimental techniques have continuously improved, proton-recoil track imaging remains still at the frontier of neutron detection systems, due to the high photon sensitivity required [1].

THE RIPTIDE PROJECT

RIPTIDE is a Recoil Proton Track Imaging (RPTI) detector for fast neutrons aiming at measuring with good efficiency all kinematic properties (energy and momentum) of incoming neutrons retrieving their trajectory from both single n-p scattering (when the primary vertex of neutron trajectory is known e.g. point-like target in fixed-target experiments) and double or multiple n-p scattering (general case) in the detector active volume. In RPTI framework the basic tool for momentum reconstruction is the two-body kinematics where the neutron energy E_n is related to the proton recoil angle and energy (ϑ_p, E_p) by the formula:

$$E_n = E_p / \cos^2 \vartheta_p \tag{1}$$

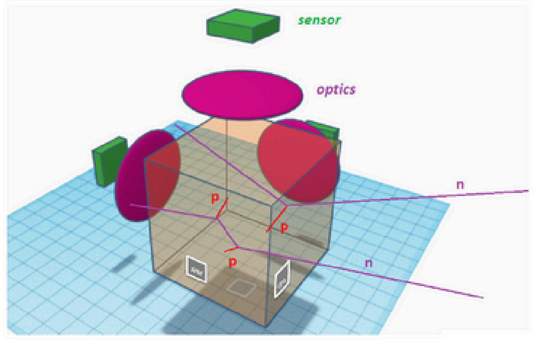

Figure 1 RIPTIDE working principle.

The RIPTIDE detector concept consists of a cubic (216 cm^3) plastic scintillator (BC-408/EJ-200) surrounded by two (or more) optical lens systems focusing the scintillation light produced by recoil protons into CMOS cameras (Fig. 1). For long enough paths, the light production is greater at the end of the range (i.e. Bragg peak) allowing to identify the track direction while the track length is linked to the proton energy. In order to measure the kinematics, we need to perform a full 3D tracking using images by CMOS cameras following promising proof-of-principle experiments [2, 3]. The detector will also be equipped with non-imaging sensors (such as commercial SiPMs) to have a fast signal acting as a trigger for the data acquisition.

PROTOTYPE CONSTRUCTION AND TESTS

The construction of the first setup began in early 2024. An optical bench inside a custom black box was designed to host the scintillator, the optical system and the camera in the darkest environment achievable. We started using an astronomy imaging camera with a continuous acquisition coupled with a SiPM or PMT to select only interesting frames (Fig. 2). After camera calibration, with this setup we were able to see integrated signals from both α and γ radioactive sources placed on the distal face of the scintillator (Fig. 4). Moreover, we are on track to test a microchannel plate (MCP) to enhance light collection to detect even minimum ionizing particles such as cosmic muons.

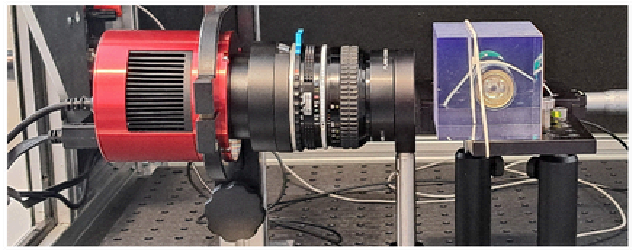

Figure 2 RIPTIDE setup with astronomy imaging camera and on-the-shelf optics.

MONTE CARLO SIMULATION AND TRACK RECONSTRUCTION

The detection concept proposed in the project has been supported through Geant4 Monte Carlo simulations with a careful choice of relevant physics lists. In particular, neutron-proton interaction has previously been tested within the framework of other experiments and it is reliable in the interesting energy range. Firstly, a few sets of mono-energetic protons ($5 < E_p < 100$ MeV) were randomly originated in the centre of the detector with isotropic momentum direction. The energy deposition of protons in the plastic scintillator volume induce the production of optical photons which are then transported to the surface for the optics simulation step. This step is performed through a custom C++ propagation code simulating the response of a simple optical system made of a lens and a large surface sensor: in this way it is possible to study the performance of the setup in terms of photon collection efficiency, light refraction and aberrations. In the following, a cube-shaped fiducial volume with a side of 40 mm was considered. Lens and sensor parameters were set in a way to cover the whole fiducial volume. By considering a realistic sensor size of 20 mm, a magnification factor of 0.5 was chosen.

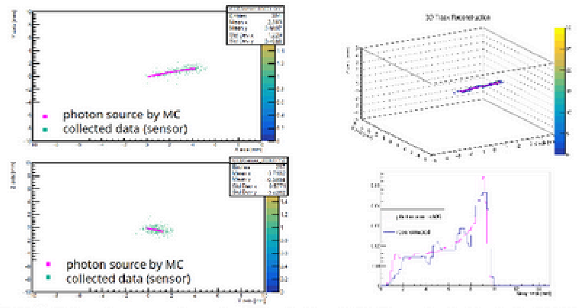

Figure 3 Data on two sensor faces, i.e. 2D projections (left). Reconstructed track of a 30 MeV proton (top right). Reconstructed vs true photon emission along the track of a 30 MeV proton (bottom right).

After the optics simulation, track reconstruction can be made in several ways such as Principal Component Analysis (PCA). The main idea behind using PCA for particle track imaging is to project the data points on a 1D subspace of the 3D geometrical space, thus representing the line to which the particle track belongs (Fig. 3). In particular, PCA was used to produce stereoscopic images of the charged particle tracks, starting from photons collected at the sensor, taking into account data from multiple mutually orthogonal planes. By combining this information from all planes, the complete 3D path of the particle can be reconstructed while the particle energy can be estimated by looking at the Bragg curve (Fig. 3). Other track reconstruction techniques are under study, namely the analysis of momenta or Convolutional Neural Networks.

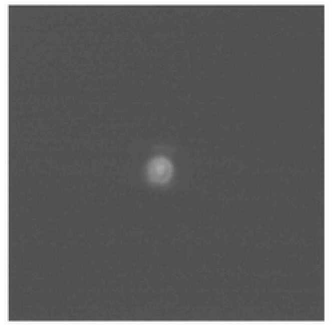

Figure 4 α source as seen by the camera with a 2 s exposure.

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REFERENCES

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https://agenda.infn.it/event/37033/

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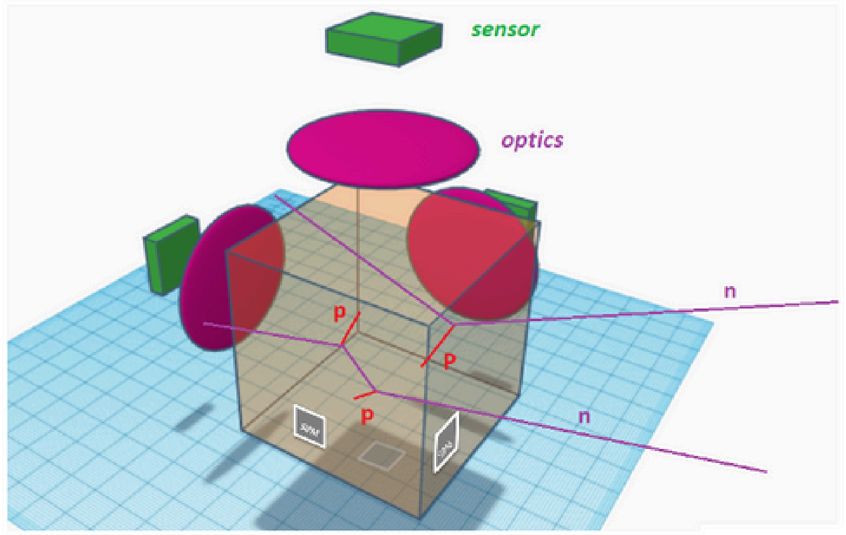

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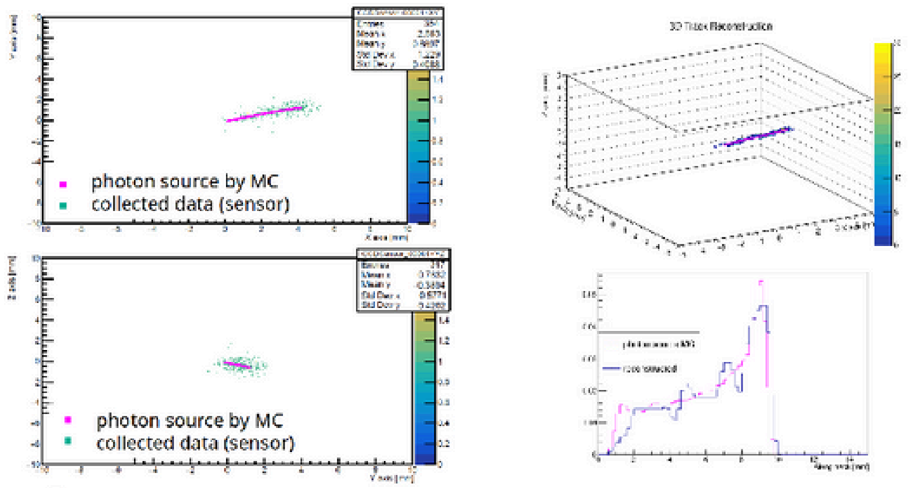

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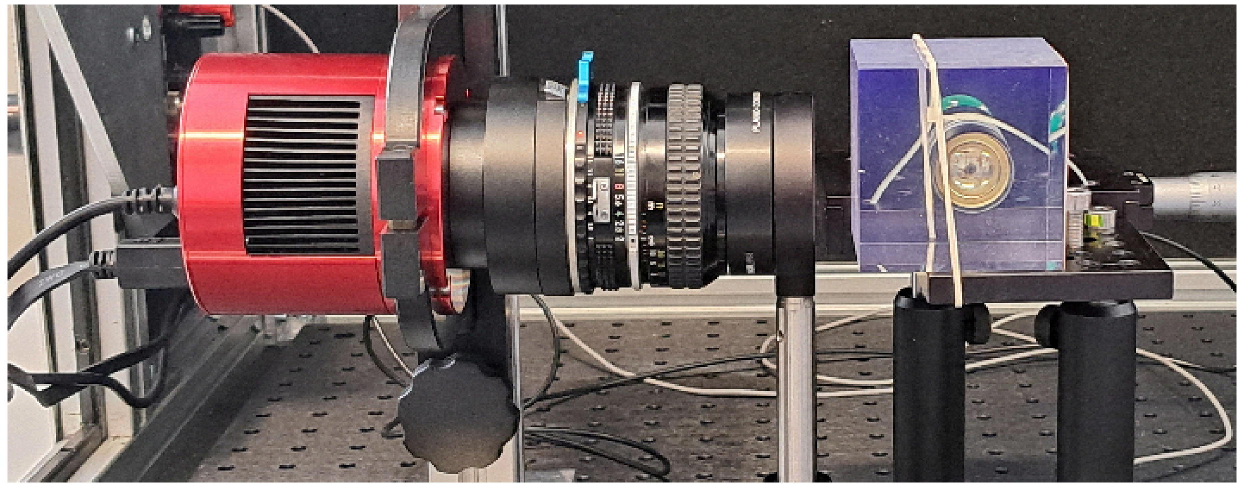

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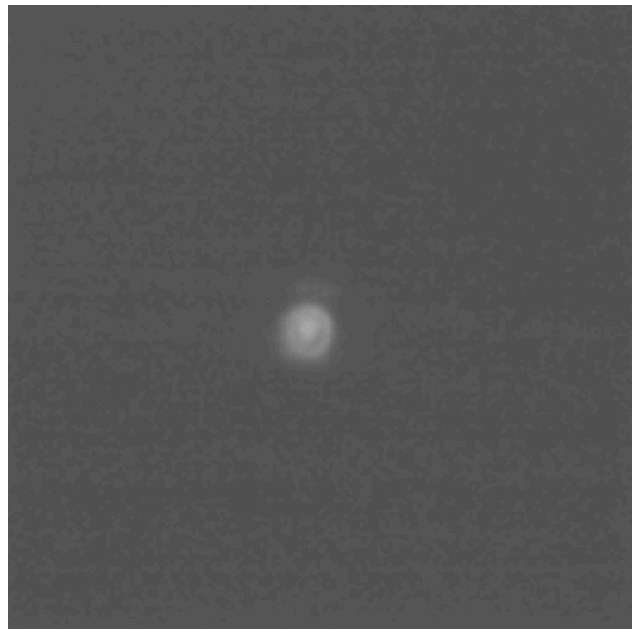

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Characterization of hybrid photodetector prototype based on MCPs and the Timepix4 ASIC

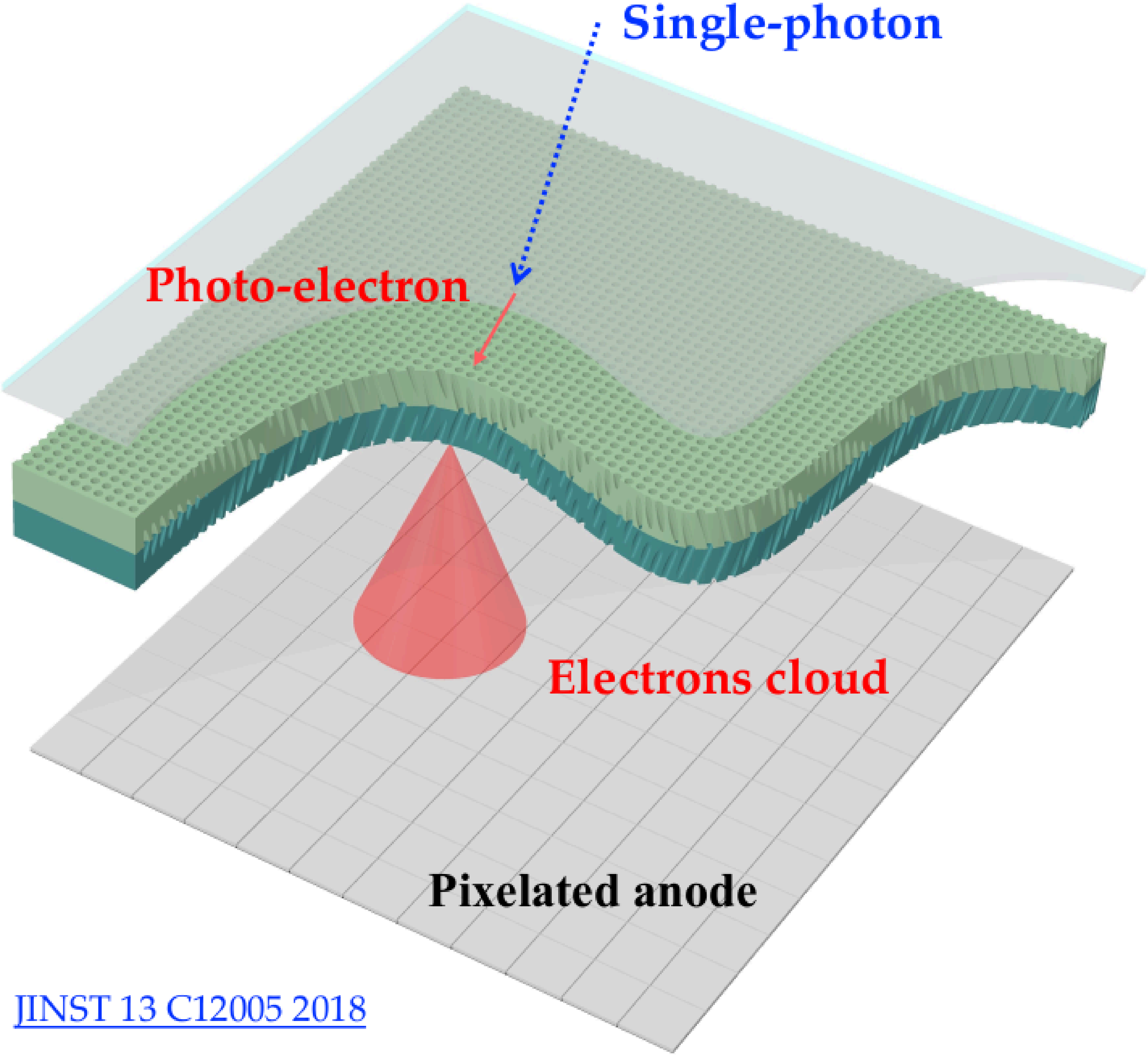
J.A. Alozy[a], R. Ballabriga[a], N.V. Biesuz[b], R. Bolzonella[b,c], M. Campbell[a], V. Cavallini[b,c], A. Cotta Ramusino[b], **M. Fiorini[b,c]**, E. Franzoso[b], M. Guarise[b,c], X. Llopart[a] , G. Romolini[b,c], A. Saputi[b]

[a] CERN [b] INFN Ferrara [c] University of Ferrara

16th Pisa Meeting on Advanced Detectors

La Biodola, May 27th 2024

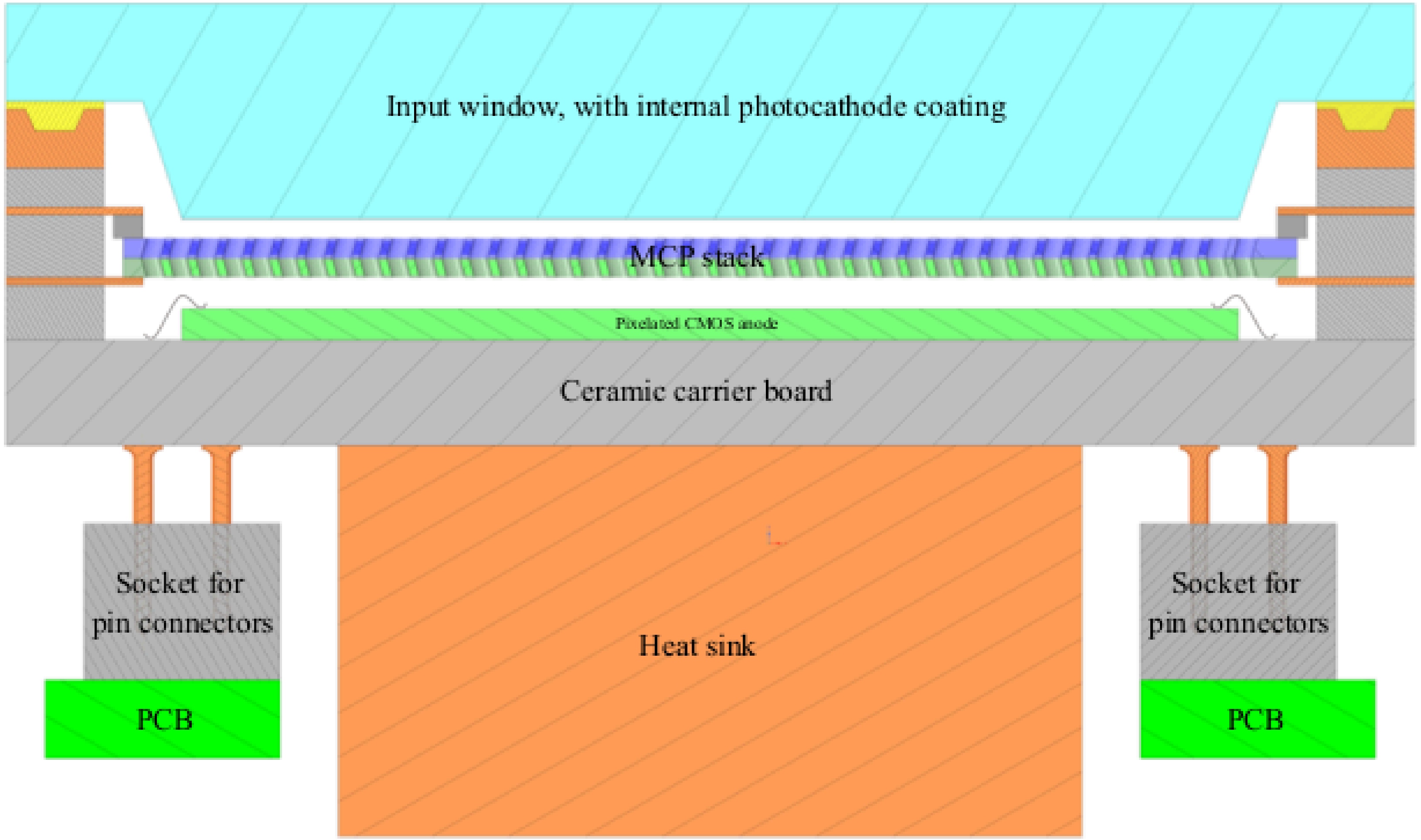
Hybrid MCP-PMT concept



[JINST 13 C12005 2018]

- Entrance window + photocathode
- Microchannel plate stack
- Timepix4 ASIC as pixelated anode
  - Electron cloud (pixels cluster)
  - **55μm × 55μm** pitch
  - **0.23 M pixels** measuring arrival time and duration of input signals
  - **7 cm^2** active area
  - Up to **2.5 Ghits/s**
  - Local signal processing

Detector geometry



- Shortest photocathode-to-MCP distance
  - Preserve impact position information
- Optimized MCP-to-anode distance for optimal cluster dimension
  - Improvement in both position and timing resolutions (centroiding)
- Ceramic carrier transmits electrical signals to and from the Timepix4 through a series of of vias and pins
  - Heat sink for Timepix4 (~5 W thermal power)

Pixelated anode: Timepix4 ASIC

- Timepix4 ASIC in 65 nm CMOS (TSMC) **silicon pixel technology**
  - Developed and produced by the Medipix4 Collaboration for hybrid pixel detectors
- Charge sensitive amplifier, single threshold discriminator and TDC based on Voltage Controlled Oscillator
  - 4-side buttable (TSV)
  - Data-driven and frame-based read-out

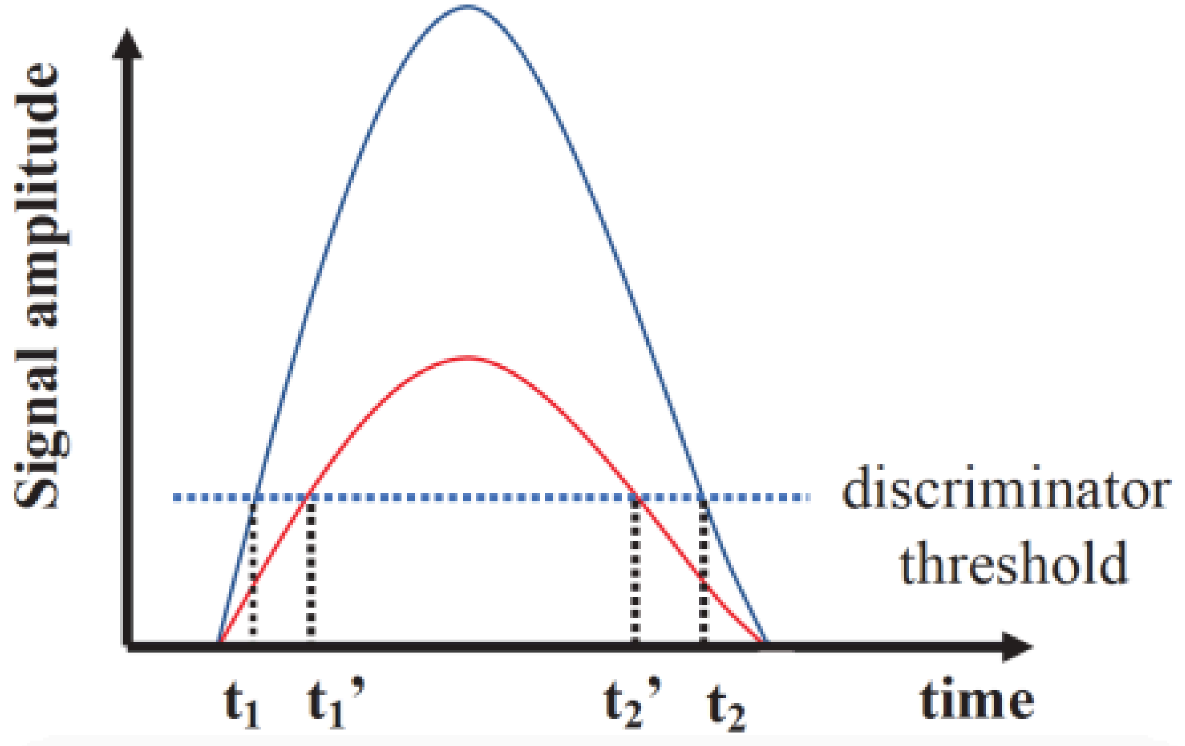
JINST 17 C01044 2022

Technology			**CMOS 65 nm**
Pixel Size			55 µm × 55 µm
Pixel arrangement			4-side buttable 512×448 (0.23 Mpixels)
Sensitive area			6.94 cm^2 (2.82 cm × 2.46 cm)
Read-out Modes	Data driven	Mode	TOT and TOA
Read-out Modes	Data driven	Event Packet	64-bit
Read-out Modes	Data driven	Max rate	358 Mhits/cm^2/s
TDC bin size			**195 ps**
Readout bandwidth			≤163.84 Gbps (16× @10.24 Gbps)
Equivalent noise charge			50-70 e^-
Target global minimum threshold			<500 e^-

X. Llopart (CERN)

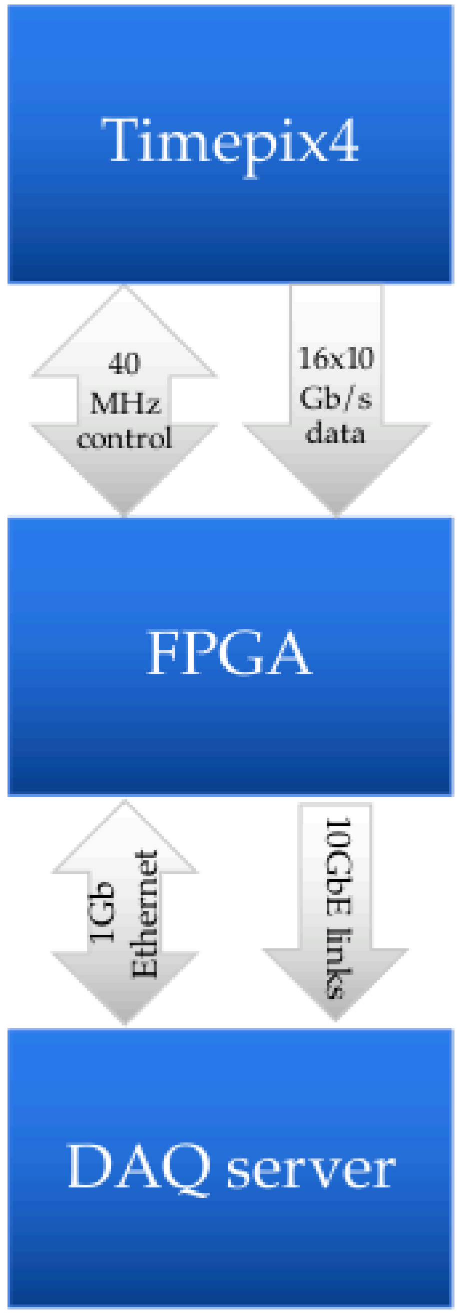
Timepix4 hit data

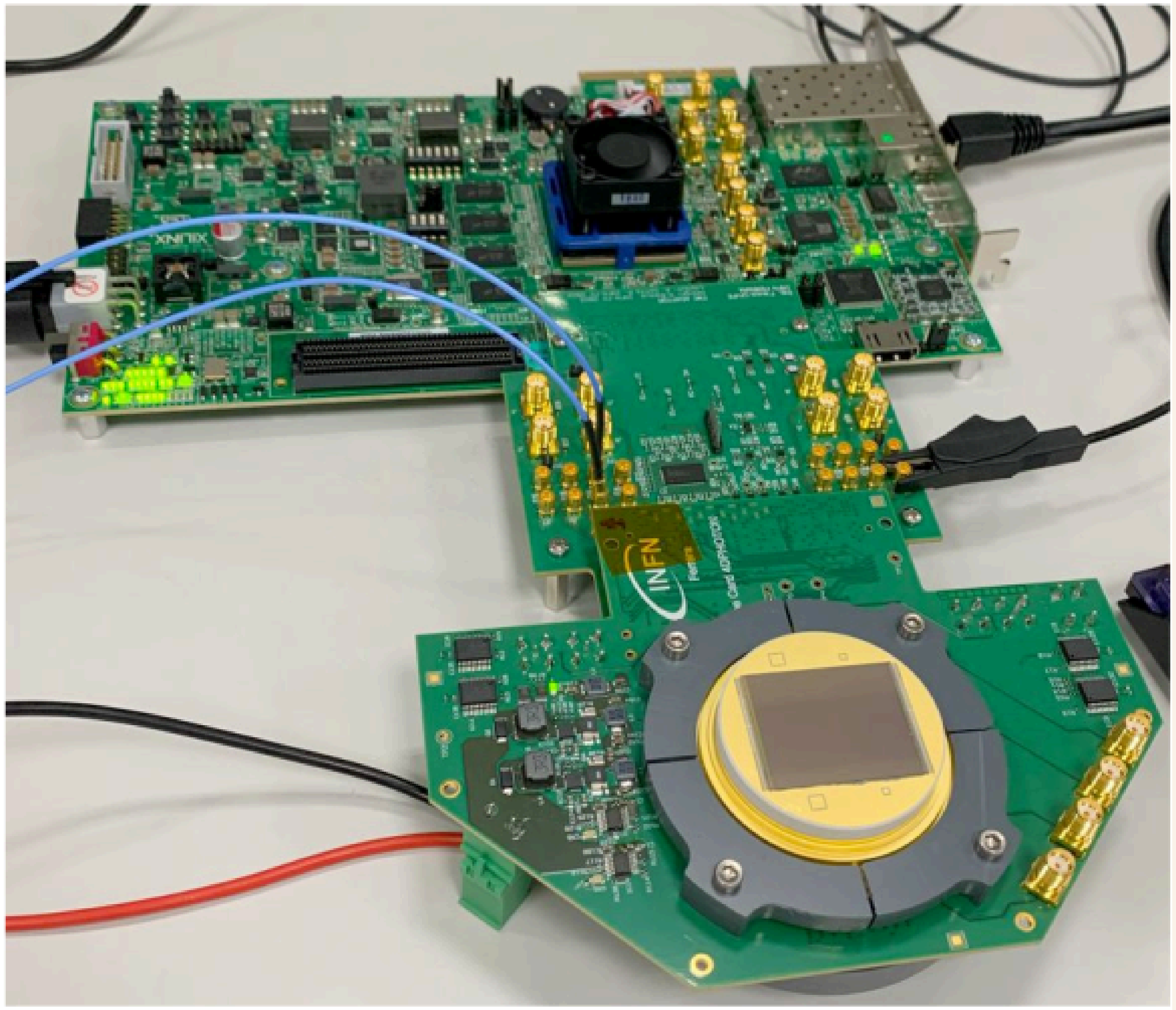
- Measure Time-of-Arrival (ToA=t_1) and Time-over-Threshold (ToT=t_2-t_1)
  - **TDC** bin size: 195 ps (**56 ps r.m.s. resolution** per pixel)
- Electron cloud spread over a number of pixels → cluster
- Use ToT information (proportional to the charge in a pixel) to:
  - Correct for time-walk effect in every pixel
  - Improve **position resolution** by centroid algorithm
    - Go from $55\mu m/\sqrt{12} \sim 16\mu m$ down to **5-10 μm r.m.s.** (MCP channels pitch)
  - Improve **timing resolution** by multiple sampling
    - Many timing measurements for the same photon → **few 10s ps r.m.s.**



Electronics and DAQ

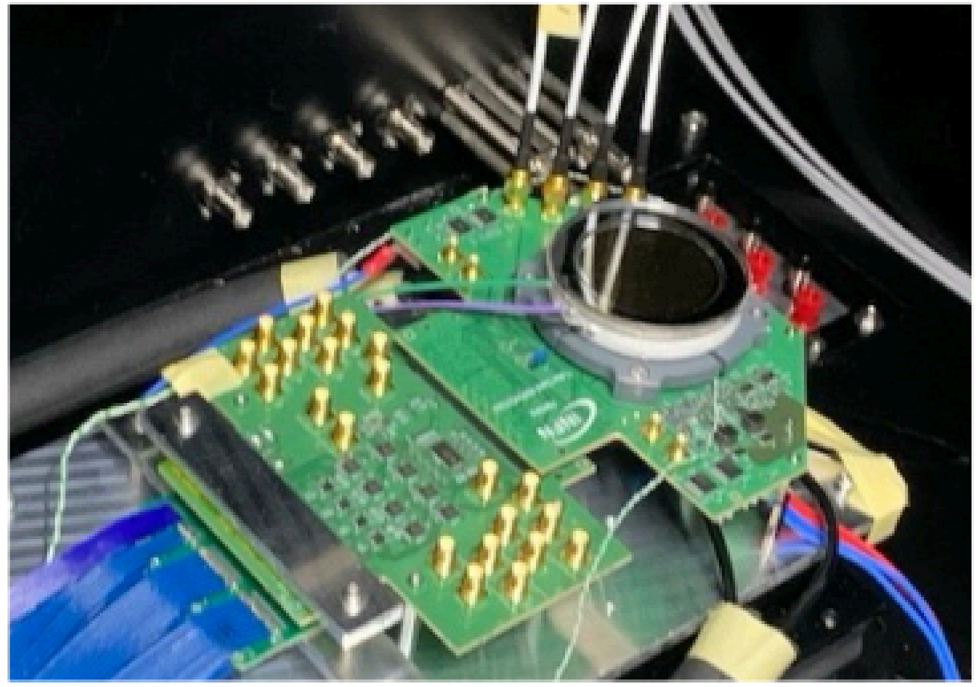
- On-detector electronics
  - Timepix4 ASIC in the tube; regulators; Electro-optical transceivers link the ASIC to an FPGA-based board for the exchange of configuration (slow control) and the collection of event data; etc.
- Off-detector electronics
  - FPGA far from detector
- The FPGA performs serial decoding and sends the data to a PC for data analysis and storage using fast serial data links

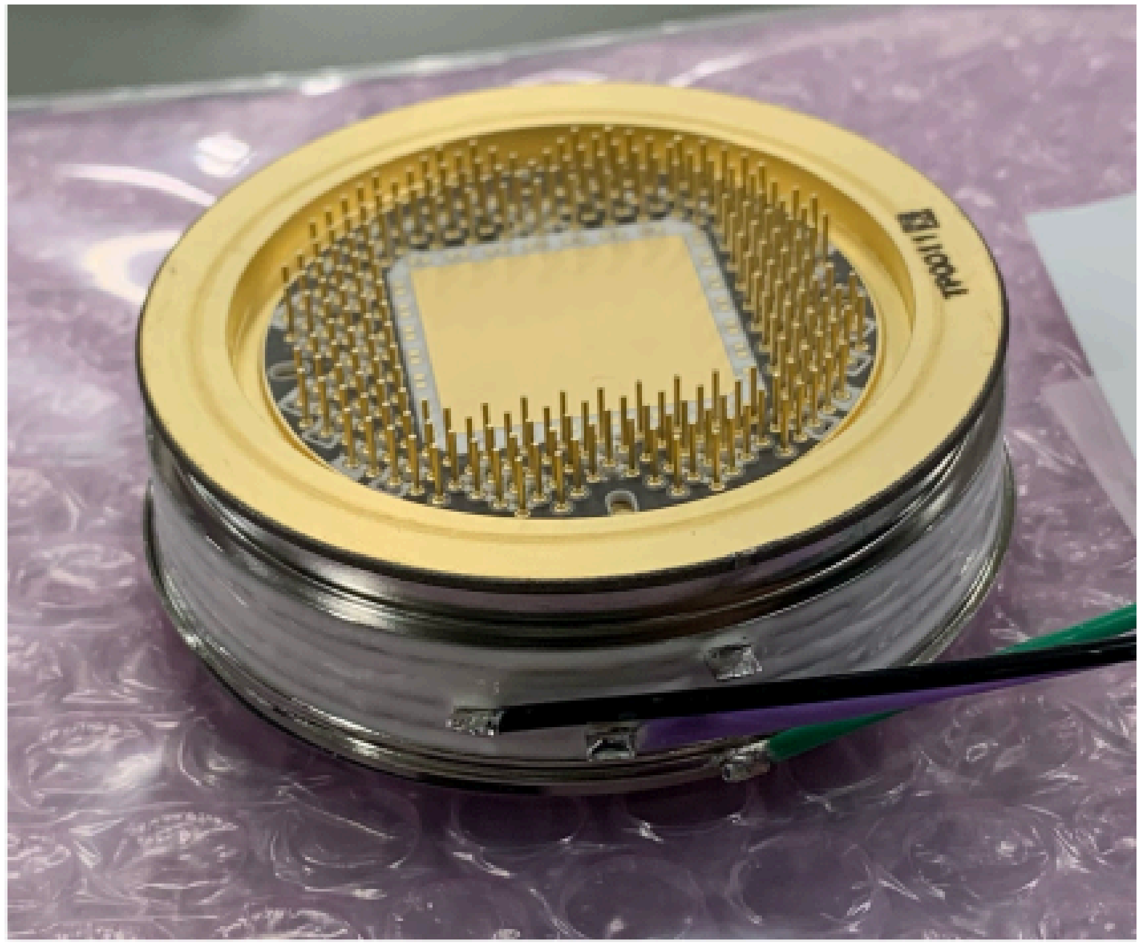




Prototype vacuum tube

- Prototype vacuum tubes produced by Hamamatsu Photonics
  - First one delivered a couple of weeks ago
- Main characteristics:
  - Multi-alkali S20 photocathode
    - Peak QE >30% at 380 nm for the first produced sample
  - 6 μm MCP channel diameter (7.5 μm pitch)
- Different variants being produced for complete device characterization
  - 2-MCP stack and 3-MCP stack
  - 1d/2d/3d end-spoiling





DRD4 collaboration

- New groups are welcome to join DRD4
  - For more information: https://drd4.web.cern.ch
  - If interested, please contact us (or simply subscribe to the "drd4-interested" list to be informed about ongoing activities)

Group photo at the DRD4 Constitutional meeting (CERN, January 2024)