Test-beam campaign for the characterization of innovative photodetectors for Ring-Imaging Cherenkov applications

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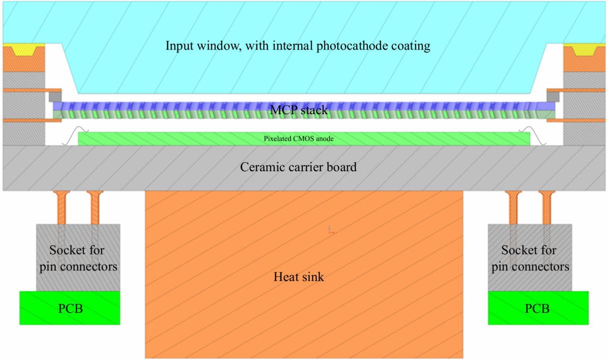
4DPHOTON project

Novel hybrid photon detector

Goal: new photodetector based on MCP with simultaneous timing (< 100 ps) and spatial resolution($\sim$ 5-10 μm) with low dark count rate at room temperature

"Hybrid" assembly based on tube kept under high vacuum

- Photocathode deposited in the inner part of the input window
- MCP stack (Chevron or Z-stack configuration)
- Pixelated CMOS anode: Timepix4 ASIC
- Ceramic carrier board
- PCBs to connect the detector to a FPGA-based DAQ system



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

Operating principle

Photon conversion producing a photo-electron

↓

The photo-electron is transported by a drift electric field onto a microchannel plate (MCP)

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The electrons cloud produced by the MCP is carried onto the input (bump-bonding) pads of the bare Timepix4 ASIC

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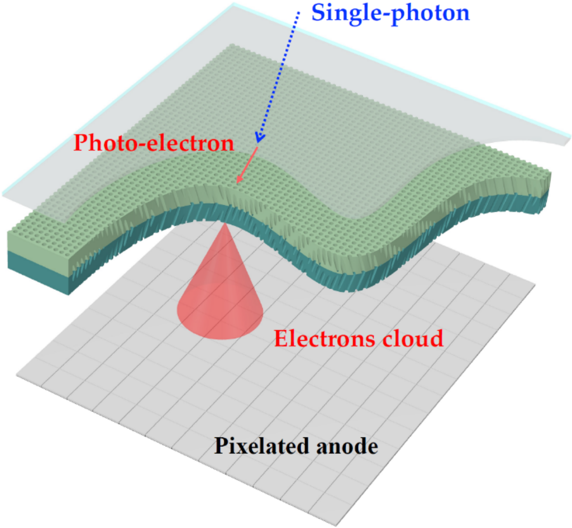
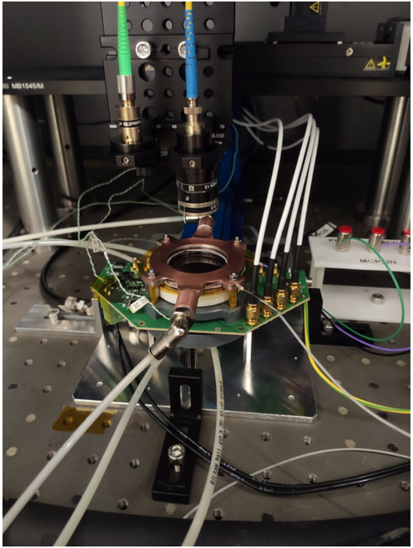
The Timepix4 ASIC will amplify, discriminate and digitize the MCP signal inside the vacuum tube



Prototype characterization

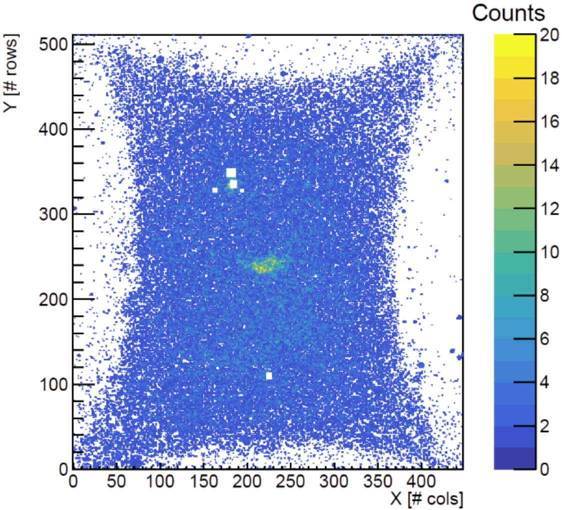
Characterization setup

- Tube prototypes received from Hamamatsu HPK mounted on custom carrier board within a dark box
- Liquid cooling system to maintain stable temperature inside the tube
- Timepix4 controlled through either SPIDR4 or custom control board developed by INFN, located outside the box
- Collimated laser 405 nm



DCR measurement - non uniform structure

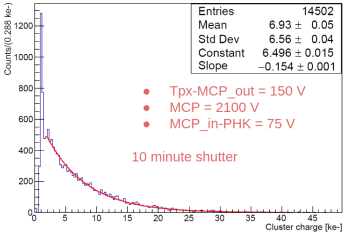
- Gain and dark count rate measurements performed
- Several HV parameters set between the different elements
- Non-uniform dark count structure
  - Curved regions on the Timepix4 sides receive less counts
  - Laser measurements ruled out the possibility of field distortions strong enough to explain the observed distribution
  - Distribution due to gain differencies across the matrix. The reason of these gain differencies is under investigation

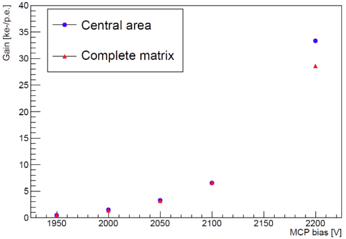


Gain measurements

Gain estimated with cluster charge distribution at different MCP voltages performing DCR measurements

- At low gain, exponential distribution as expected
- Gain estimate also considering only the central region
  - Compatible at low MCP bias
  - At higher MCP bias the low gain area along the edges is populated and affects the total gain estimation
- Working point defined at 2100 V for the MCP



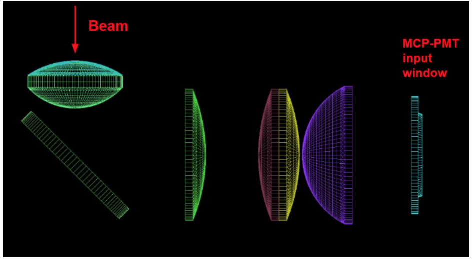


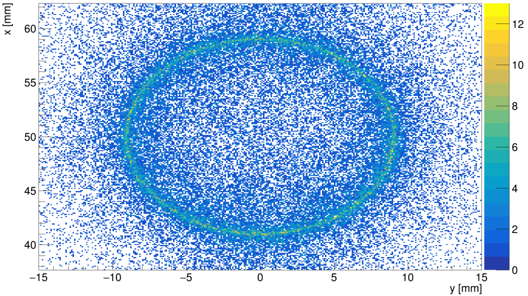
Testbeam campaign

Geant4 simulation

- Various test to optimize the configuration and study the impact of each component
  - Resolution optimisation
  - Material impact on momentum distribution
  - Background studies

- Lenses system configuration
  - Used Zemax to optimise the system
  - Incorrect description of Geant4 of the obj extracted from Zemax
  - Only commercial plano-convex lenses have been used

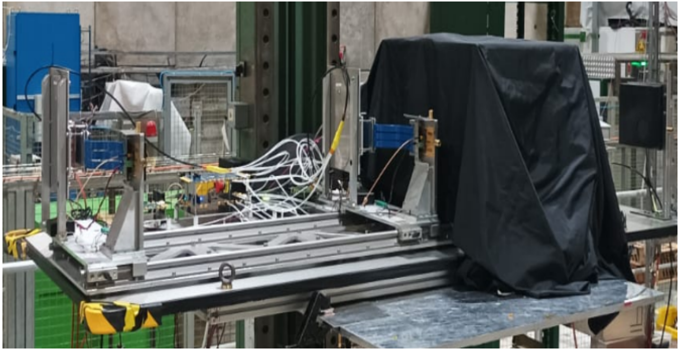




Testbeam setup 1/2

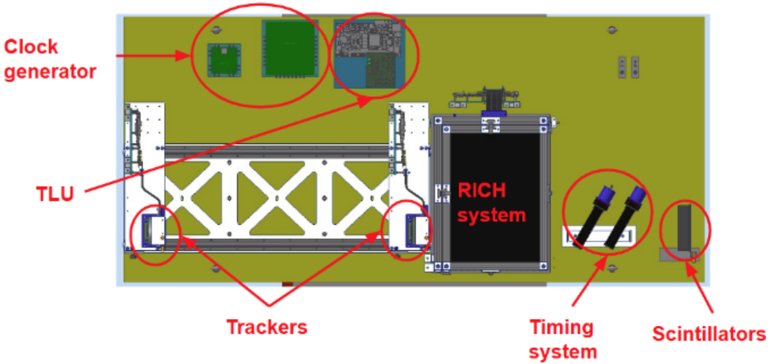
Testbeam in SPS NA beamlines (21-31 October)

- Custom Trigger Logic Unit (TLU) to use the spill extraction signal as shutter signal
- Common external reference clock
- Beam: 80 % protons, 20 % pions, 1 % muons at $E > 100$ GeV



Testbeam setup 2/2

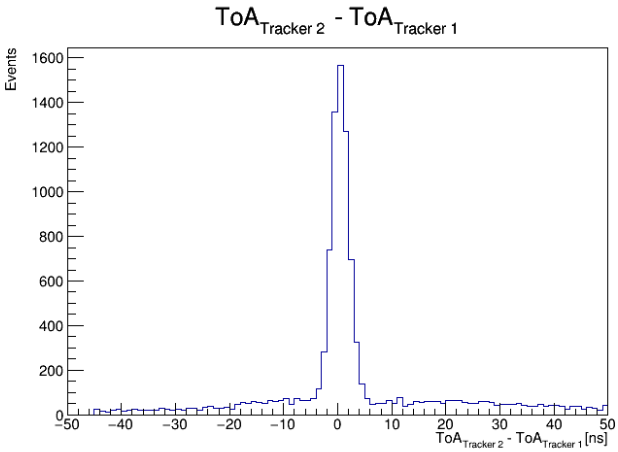
- **Trackers**: 2 Timepix4 assemblies bonded to 300 μm thick p-on-n planar Si detector
- **Lens system**: Cherenkov radiator and optics setup to produce and focus Cherenkov ring
- **4DPHOTON**: DUT, placed off-beam
- **Timing-systems**: 2 Cherenkov detectors to provide timing reference
- **Scintillators**: to monitor the beam intentsity



Testbeam analysis - Event selection 1/2

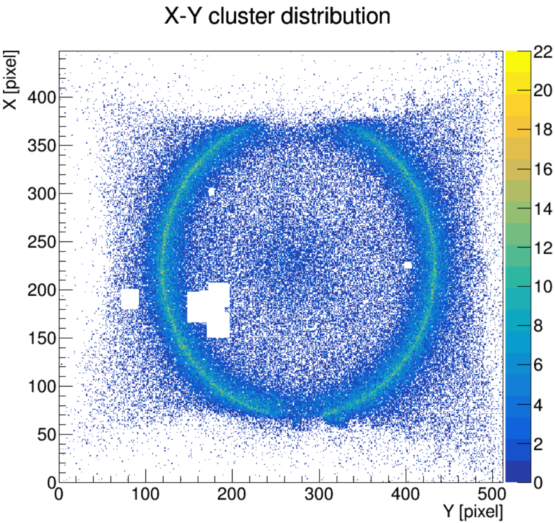
Initial event selection:

- Only one hit in each tracker, $\Delta t_{max} = 10$ ns
- At least 1 hit in the 4DPHOTON detector within 5 ns from the second tracker hit
- Every hit in the 4DPHOTON detector within 50 ns from the second tracker hit
- At least 10 hit in the 4DPHOTON detector (expected 15-20)



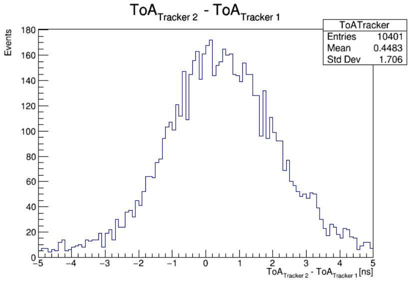
Testbeam analysis - Event selection 2/2

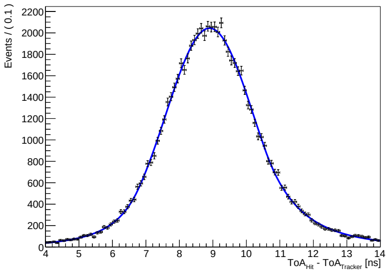
- ▷ Cherenkov ring observed
  - ▷ Ring appears slightly distorted $\rightarrow$ small misalignment in the optical system
  - ▷ Observed ring position and dimension as expected from the simulation
- ▷ Same non-uniform dark count structure



Testbeam analysis - Time resolution 1/2

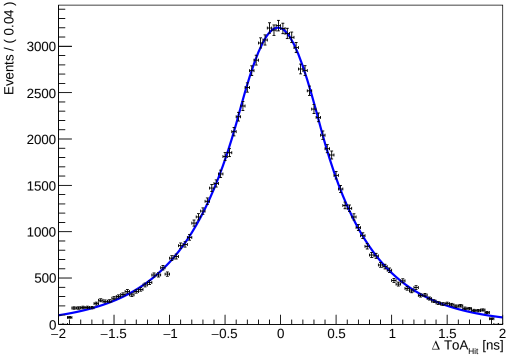
- Reference timing system noisy, low-resolution, and unreliable
    - Using tracker as reference
    - Low resolution, low voltage applied (100V)
    - High contribution in the detector resolution
- For each photon in the ring candidates calculate $\mathrm{ToA}_{\mathrm{Hit}} - \mathrm{ToA}_{\mathrm{Tracker}}$
- Fit the distribution using a Crystal Ball function to account for background from noise and non-Cherenkov events.
- Resulting in $\boldsymbol{\sigma_{\mathrm{4DPHOTON}} \simeq 1.3}$ **ns**





Testbeam analysis - Time resolution 2/2

- To eliminate external contributions → ring hits used as reference
  - Randomly divide ring hits into two subsystems
  - Subtract hits from one subsystem to the other
- Resulting in $\boldsymbol{\sigma_{\text{4DPHOTON}}} \simeq$ **400 ps**
- This result is closer to the expected values of $\boldsymbol{\sigma_{\text{expected}}} \simeq$ **100 ps** (as measured in lab)



Conclusion

Next steps and conclusions

- Another testbeam in schedule for the end of the year
  - Change the time reference system → simulate new setup with different materials and dimensions
  - Improve tracker performance
- To improve the current measurements:
  - New calibration measurements for the trackers and 4DPHOTON
  - Test other strategy using different time references
  - Test and deeper characterisation of the detector in laboratory
- Expected resolution close the measured one → to be improved during the next testbeam!