Beam diagnostics with silicon pixel detector array at PADME experiment

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PADME Dark Photon Search

- Positron Annihilation into Dark Matter Experiment (PADME)
- located at Laboratori Nazionali di Frascati (LNF), Italy
- searching for signals from a dark photon (DP) in $e^+e^- \rightarrow \gamma A$
  - positrons on electrons form the LNF LINAC
  - ~25k positrons/bunch
  - Pulse length: ~200ns
- evaluating the missing mass of the final state by measuring the four-momentum of the ordinary recoil photon
- PADME detectors
  - Active diamond target
    - provides single-bunch X and Y profiles and multiplicity
    - area: 20x20mm²
    - thickness: 100µm
  - Charged particle veto
    - suppresses Bremsstrahlung background and registers visible decays
    - plastic scintillators (10x10x178mm³), glued in WLS fiber
    - 96 in e^- veto, 90 in e^+ veto, 16 in HEP veto
  - EM Calorimeters
    - 616 BGO crystals 21x21x230 mm³
    - cylindrical shape with central hole
    - SAC - Small angle calorimeter
    - 25 Cherenkov PbF_2 crystals 30x30x140 mm³

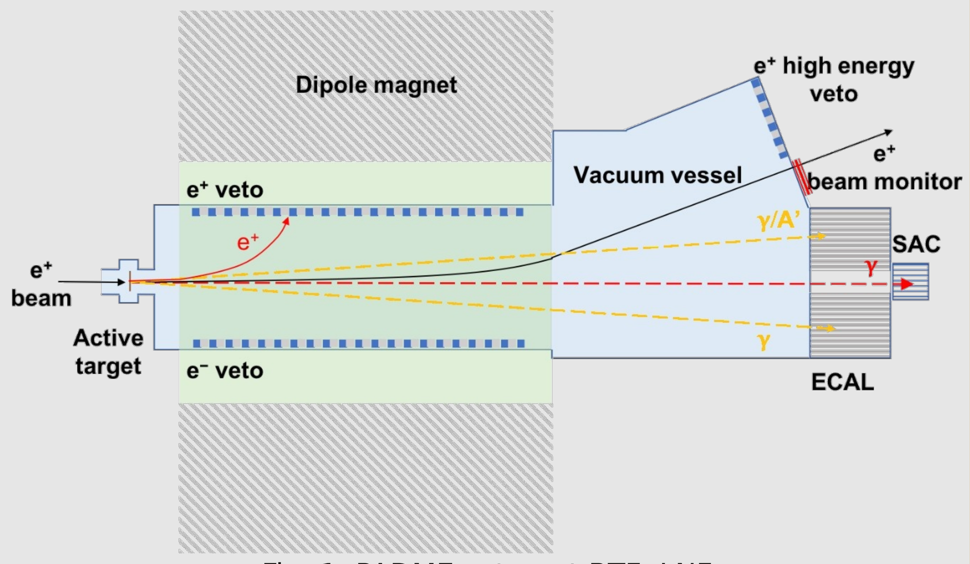

Fig. 1. PADME setup at BTF, LNF

PADME New Physics Experiments

- The X-17 anomaly
- a 17 MeV boson ind in studying nuclear de-excitation via IPC
  - e^+e^- annihilation and production of the hypothetical X-17

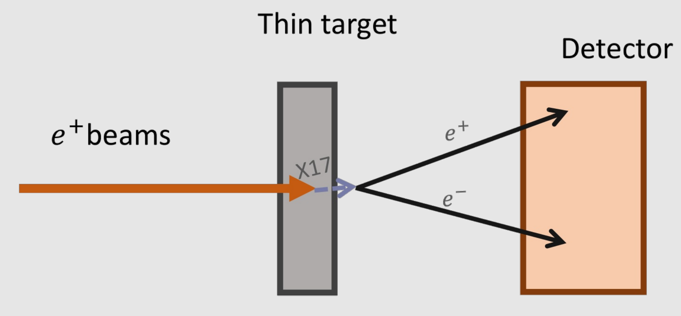

Fig. 2. Hypothetical X-17 production and decay

  - X-17 decays to e^+e^-
  - the X-17 energy is estimated by normalizing the number of the secondary produced e^+e^-, compared to the number of the incident positrons
- Why PADME is suitable to search for the hypothetical new particle X-17?
  - LINAC's fine tunable beam energy to scan the 265 – 297 MeV range
  - the PADME detectors are easily confiigurable and suitable to resonant search
    - fixed diamond target for e^+e^- annihilation
    - ETag detector can discriminate neutral and charged particles and eliminate background
    - calorimeters to measure the energy of the e^+e^-
    - large Timepix array to monitor the beam

Fig. 3. PADME setup used for X-17

Timepix detector

- Timepix3 chip
  - 256x256 pixels
  - pixel size of 55µmx55µm
  - provides ToA (Time-of-Arrival) and ToT (Time-over-Threshold) measurement for an individual pixel
  - two modes of operation:
    - a frame mode, in which an integral number of the fired pixels is provided for predefined interval of time
    - more precise data-stream mode providing continuous information for ToA for every event in a pixel with sampling rate of 1.56ns
- PADME's Timepix detector setup
  - consists of array of 2x6 Timepix3 sensors from ADVACAM
  - read out by high-speed ZEM4310 interface module boards
  - grouped in pairs of two and transfer data/commands to 6 NUC PC units
  - two power boards
  - water cooling system for the sensors
  - external module, providing 40MHz clock signal, needed for the right operation and synchronization of the chips
  - the whole system is managed by a separate powerful PC unit

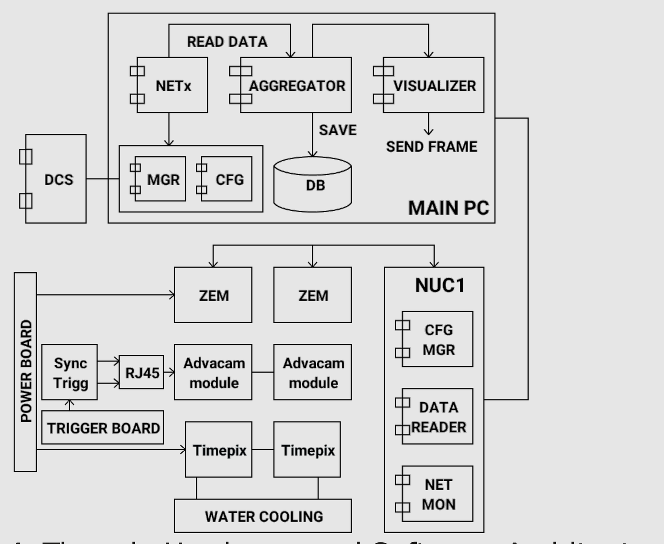

Fig. 4. Timepix Hardware and Software Architecture

Readout Framework

- bidirectional client-server system for data aggregation and management of the Timepix detectors
- consists of three distinct components:
- a communication and operational module for configuration and management of the sensors and the PC unit chain
  - based on a finite-state machine model
  - operates the hardware units from a configuration files and/or the input from the monitoring application provided by the user
  - communication between the units is based on ZeroMQ messaging library
- a data storing module of the acquired data, serving both readout modes of operation
  - based on SQLite3
  - stores the row data output and the meta information of the operational parameter s for every

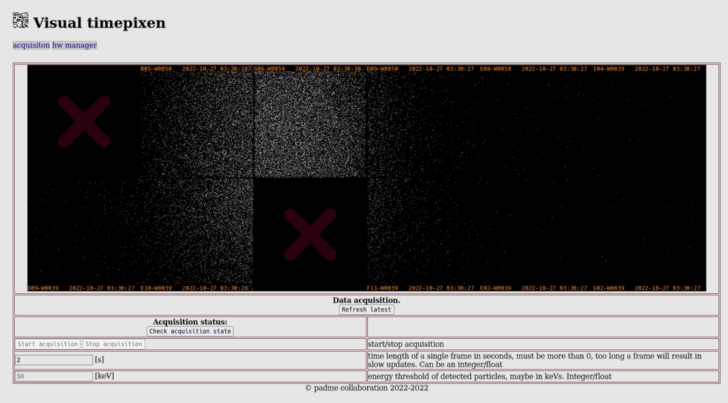

Fig. 5. Web interface for visualization and control chip

- a web-based application that provides graphical user interface for beam monitoring and control of the data repetition parameters
  - based on bottlepy application server and chiby, a javascript micro-library for the user interface
  - provides visual information for the beam spread to the user, a picture based on the data gathered in a frame mode
  - provides functionality for manipulating:
    - acquisition time
    - threshold
    - bias
    - repeatability interval of the aggregated data frames

Discussion

The presented DAQ and analysis framework for the 2x6 Timepix3 array enable PADME to improve its beam monitor capability, allowing to perform at best its physics program.
Exploiting the sophisticated streaming mode readout of the Timepix sensors, providing pixel time resolution of 1.56 ns, a comprehensive real time information for the beam flux and spread is available. This is performed by measuring beam particles which do not interact with the diamond target. The precise knowledge of beam characteristics in terms of number and spatial distributions is a key element not only for dark photon studies (like those performed in PADME Runs I and II) but also for investigating the existence of new dark sector particles produced by means of a resonant production mechanism (as the search for an hypothetical X-17 state performed during Run III).

Data Streaming Mode

The software module to operate the detector in the more effiicient data-stream mode was completed during Run III after having solved some issues related to:

- heat dissipation of the chips;
- stability and synchronization of the 12 chips;
- trigger operation.

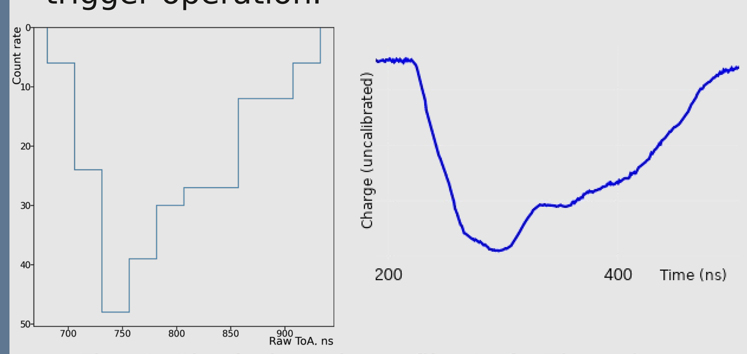

Fig. 6. Single bunch profile. Left: Timepix, right: lead glass detector

PADME aggregated data in data-streaming mode for few test runs at the end of Run III. These measurements prove that a more precise knowledge of the beam parameters can be obtained for the future runs. The developed analysis framework provides knowledge about the beam profile distribution over X and Y axes, without the limiting factor the frame mode, in which it is unable to identify two or more events occurred in a single pixel for the duration of the frame.
Time synchronization with the rest of the detectors is made exploiting the fact that the beam line provides a buched beam with a fixed repetition rate of 50 Hz and is verified with the data from the lead glass detector.

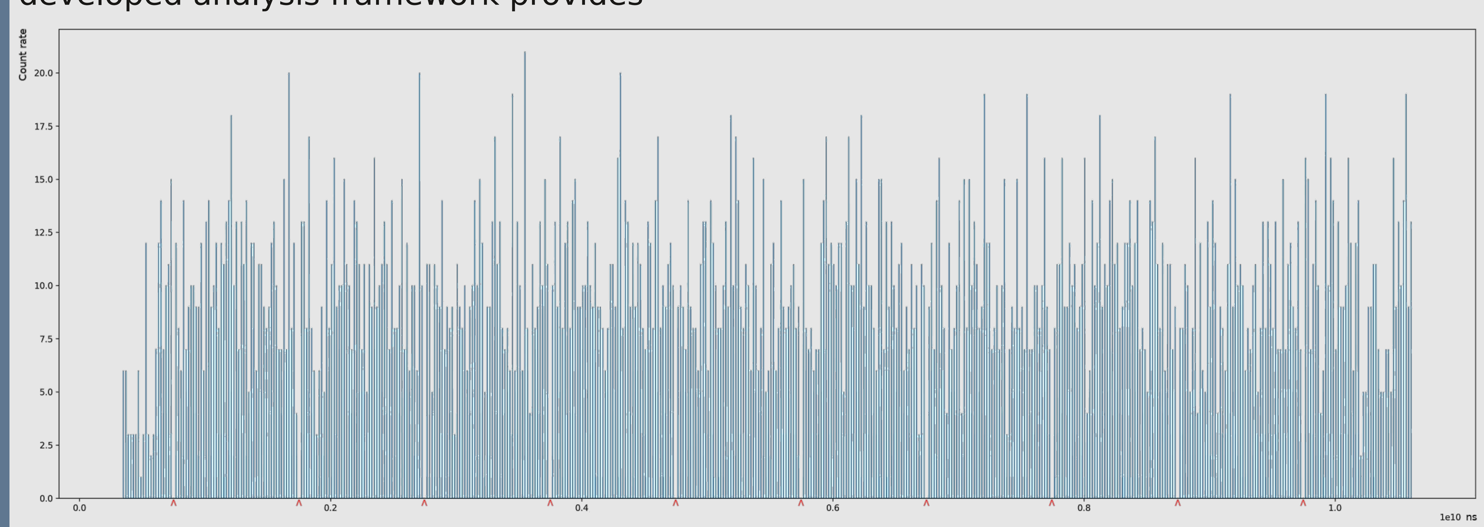

Fig. 7. Number of particles per bunch (200ns).
The red arrows mark the bunch gap at 50Hz.

Frame Mode

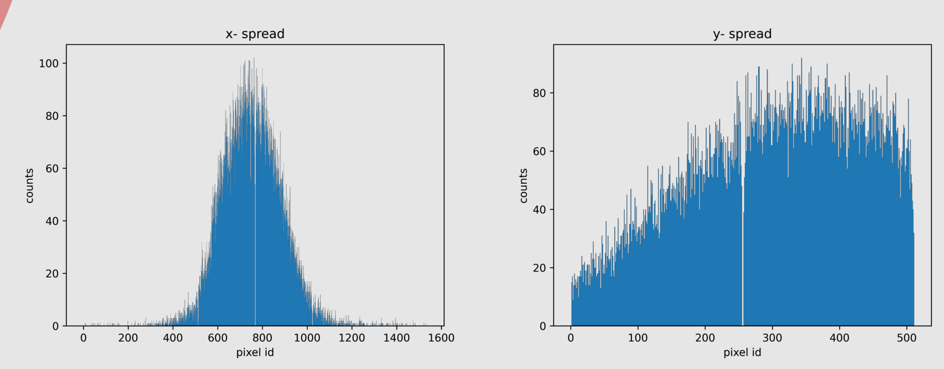

Fig. 8. Beam profile for X and Y axes for a single frame.

The 12 Timepix chips operated in the frame mode for the majority of PADME Run III.
Data were aggregated in a repeated interval of time for a frame period of 1s acquisition time.
The stored data provides ToA and ToT measurements for the individual fired pixels.
The currently developed analysis framework is capable of:

- estimating the spread of the beam on X and Y directions
- and the total number of fired pixels for every run with different energy of the incident positrons.

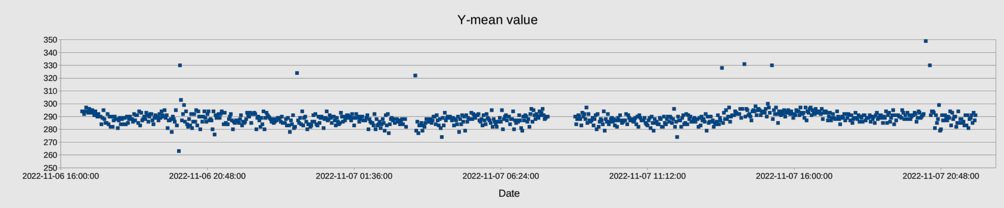

Fig. 9. Mean values of the Center of Gravity in Y direction (2 chips) in relative pixel size.

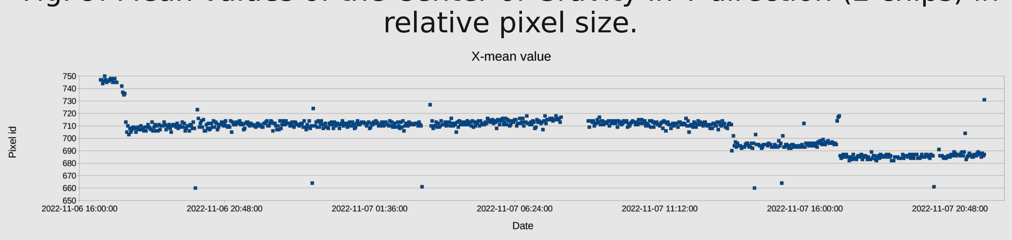

Fig. 10. Mean values of the Center of Gravity in X direction (6 chips) in relative pixel size.

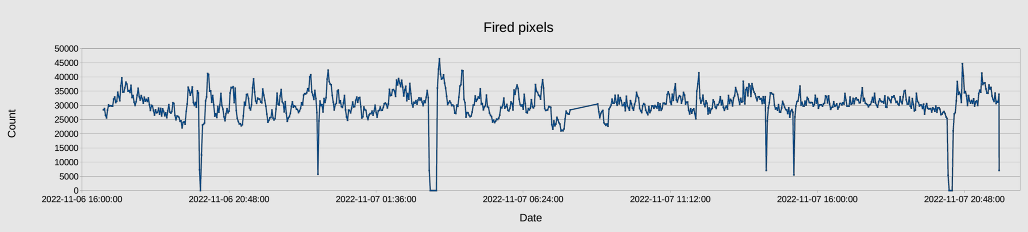

Fig. 11. Number of registered particles.

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