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Performance of the charged particle detectors of the PADME experiment

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The role of the veto system

PADME[1] (Positron Annihilation into Dark Matter Experiment) searches a hypothetical dark photon A′ produced in the annihilation between a positron of a beam with an electron of a thin diamond target.

The PADME experiment employs the missing mass method so the dark photon mass can be calculated:

$$m_{A'}^2 = (P_{beam} + P_{e^-} - P_\gamma)^2$$

PADME is sensitive to the values of A′ mass up to 23.7 MeV/c^2 and mixing parameter $\varepsilon^2 > 10^{-6}$ for 4×10^{13} Positrons On Target (POT).

SIGNAL $e^+e^- \rightarrow \gamma A'$

BACKGROUND

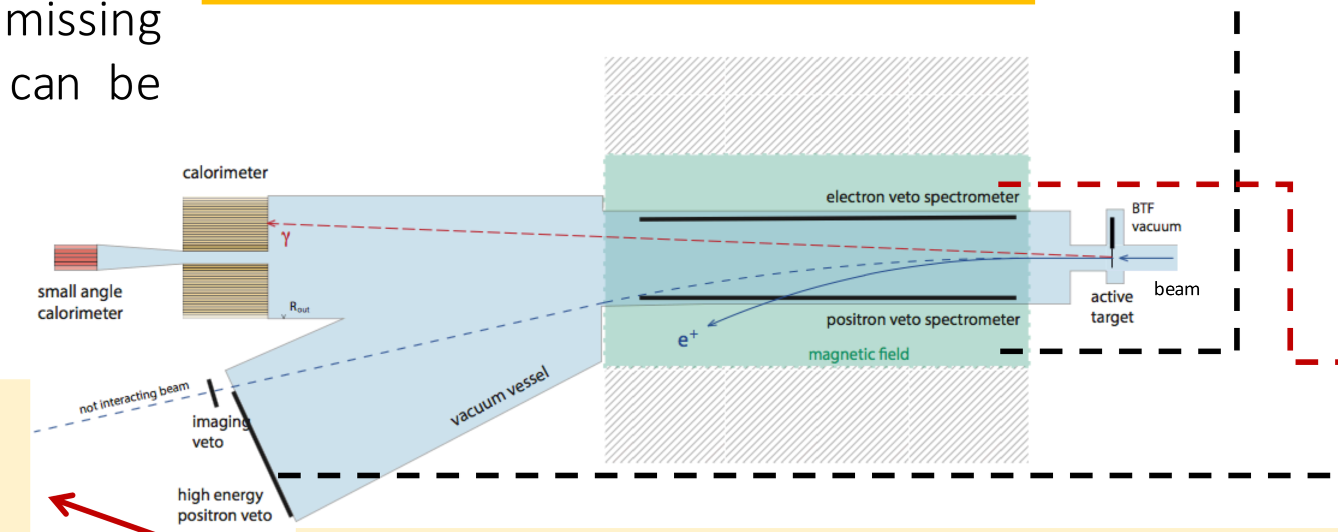
Bremmstrahlung on the active diamond target $e^+N \longrightarrow e^+N\gamma$

Annihilation into 2(or 3) SM photons $e^+e^- \longrightarrow \gamma\,\gamma\,(\gamma)$

Positrons that emit bremsstrahlung photons will have lower energy

$E_{e+} < E_{beam}$

2 different veto systems for positrons which differ from the energy of the photon emitted



1. Positron Veto in the magnetic field, covering the internal left vertical wall(1 m long) of the dipole magnet

2. HEP High Energy Positrons. Covering the momentum interval 450 < P_{e+} <550 MeV/c

A Bremmstrahlung event is identified by an ECAL or a SAC cluster and a hit in PV in time coincidence (see the Preliminary Results section) **Time reso<1ns needed!**

Energy balance with the beam may be requested to improve the bremsstrahlung event identification.

Electron veto

in the magnetic field, covering the internal right vertical wall (1 m long) of the dipole magnet to search for visible decays of the dark photon.

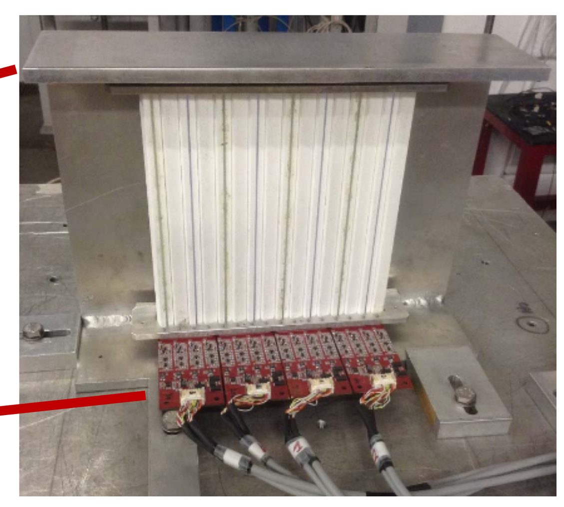
PADME is located at the Beam Test Facility [2] (BTF) of the Laboratori Nazionali di Frascati, it uses a positron beam of 490 MeV, up to 550 MeV

Veto system parameters

SUPPORT FRAME

Alluminum support structure to hold an array of 96(16) scintillating bars for PV and EV (HEP) together with the FEE boards

Scintillating bars are parallel to the magnetic field direction and rotated around their longitudinal axis by 0.1 rad to minimize geometrical inefficiencies

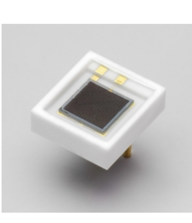


Silicon photo-multiplier SiPM

FRONT-END ELECTRONICS (FEE)

- ✓ Able to work inside vacuum
- ✓ Sustain stationary magnetic field of 0.6 T
- ✓ Low Operating Voltage
- ✓ Cheap

Hamamatsu 13360



FEE channel includes a transimpedance amplifier (gain=4)

HV regulation module+voltage end current monitor

One FEE board serves 4 channels

GAIN≈10^5 -10^6

FEE operates in vacuum!

Signals will be digitized by **CAEN V1742**

SCINTILLATING BARS

SCINTILLATORS

Polystyrene-based scintillating plastic bars with 1,5% POPOP produced by **UNIPLAST**

DIMENSION Long side perpendicular to the beam!

Cross section: 10x10 mm^2 **Length**: 200 mm (to be cut and polished)

OPTICAL FIBERS

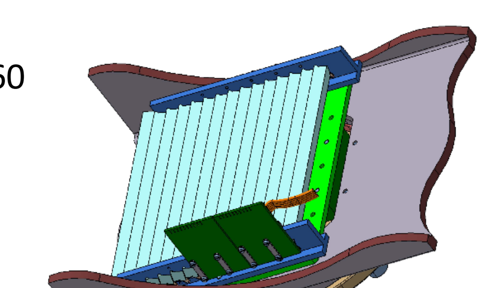
BCF-92 optical fibers housed in a longitudinal groove of cross section 1.3x1.3 mm^2

BCF-92

- light attenuation length is > 3.5 m
- maximal absorbition at 400nm, matching POPOP emission
- maximal emission at 492 nm (Wave Length Shifter)

Veto system prototype and beam test

- **16 bars** cut at the desidered length (of approximately **180 mm** to fit into the dipole magnet clearance) and covered with a chemical reflector; 4 counters served by each board (in green in Fig. A)
- Support holding scintillators and FE boards assuring thermal coupling to the vacuum vessel
- WLS fibers of type BCF-92; some of them glued with Eljen EJ500 optical epoxy cement
- Optical contacts improved with Saint-Gobain BC-630 silicone optical grease support holding
- S12572 Hamamatsu used for the first prototype, noisy than the 13360



A

A prototype of the first version of the HEP detector of PADME was tested in April 2017 [3] .

Beam test performed in order to evaluate the performance of different scintillators species, with different readouts.

Best performance (< 1 ns) for scintillators with **glued fibers**.

Scintillator species	Readout/Light collection
Fiber glued in the groove	Scintillator only
Fiber glued and aluminised	Fiber and scintillator
No fiber used	Scintillator only
Fiber in the groove	Fiber and scintillators

Inefficiency

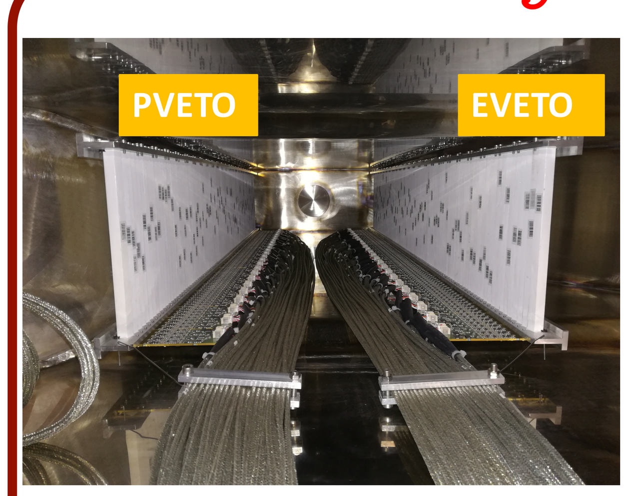
- below 0.1% at all distances for scintillators with optical fibers
- increasing quickly with the distance from SiPM for scintillators without fibers

Noise below 1% for all scintillators

Final Choice for the real detector:

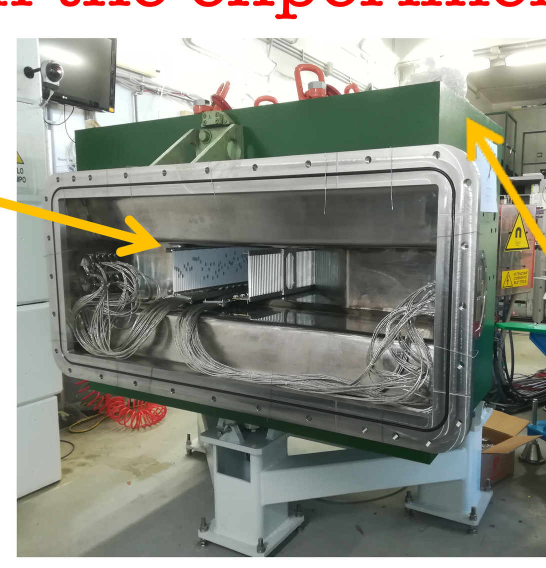
scintillator with glued fibers in the groove, with both readouts.

The assembly of the vetoes in the experiment



96+96 sintillating bars act as PVeto and EVeto system of the experiment.

Readout from both sides only for HEP Veto (16 bars).



All the vetoes stuff was assembled in the experiment since September 2018.

The **PVeto** and the **Eveto** are located inside the internal vacuum chamber, in the magnetic dipole.

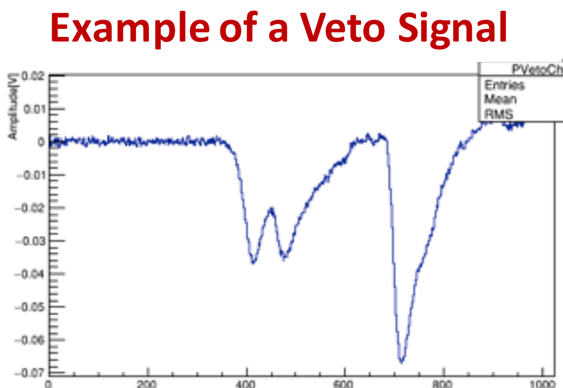
The **HEP Veto** is located between the PVeto and the ECAL region, near the beam dump.

Signal Reconstruction

Vetoes signals digitized at 2.5 GS/s

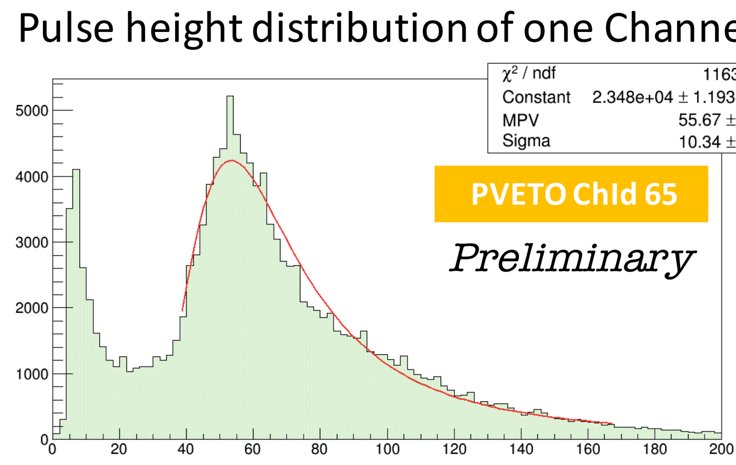
- ✓ FEE operates in vacuum
- ✓ Multi-hit reconstruction for each veto signal performed

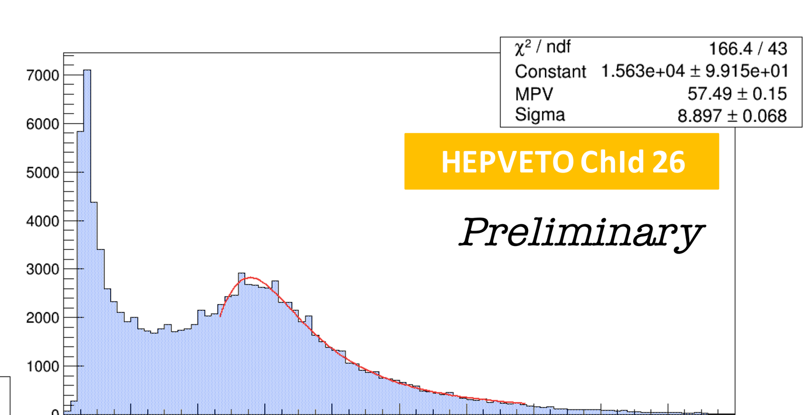
Example of a Veto Signal

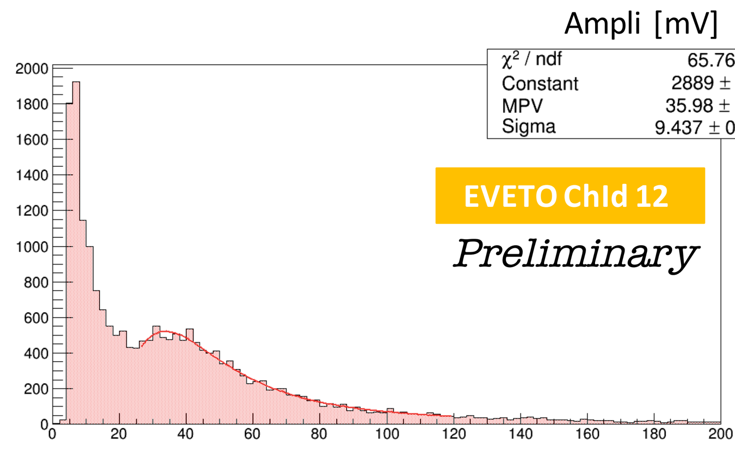


Pulse height distribution of one ChannelId for each Veto, with BTF Trigger (49 Hz)

100 kEvents recontructed





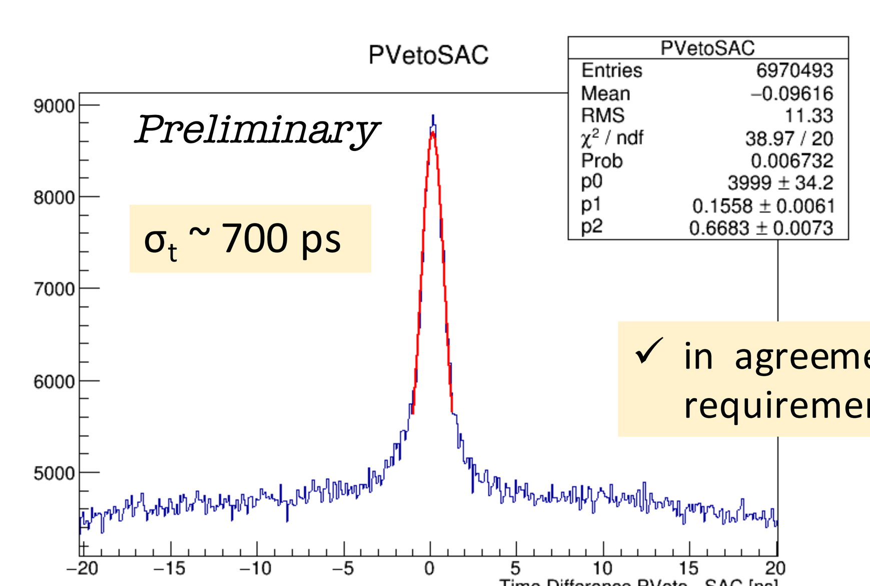


Energy Calibration Constants obtained for each Veto channel

Preliminary Results

TIME RESOLUTION

Difference in time between PVeto and one of the center crystals of the SAC (small angle calorimeter, placed just behind the ECAL hole).



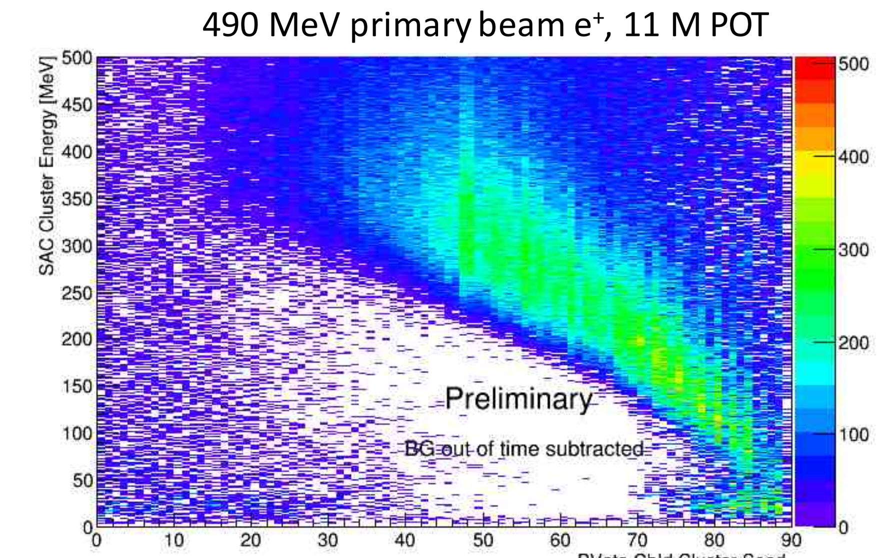
✓ in agreement with time requirement

BREMSSTRAHLUNG EVENTS

Time allignment between PVeto and SAC allows to see bremsstrahlung events.

SAC cluster energy vs PVeto position for Δt < 1ns

490 MeV primary beam e+, 11 M POT



SAC gains are not equalized

References

[1] M. Raggi and V. Kozhuharov, "*Proposal to Search for a Dark Photon in Positron on Target Collisions at DAΦNE Linac*," Adv. High Energy Phys., 2014;

[2] A. Chigo, "*Commissioning of the DAFNE beam test facility*", Nucl. Instrum. Meth. A 515, pp. 524-542, 2003;

[3] F. Ferrarotto et al., "*Performance of the prototype of the charged particle veto system of the PADME experiment*," IEEE Transactions on Nuclear Physics, Vol. 65, pp. 2029 - 2035, 2018, DOI: 10.1109/TNS.2018.2822724.