Operation and performance of the active target of PADME

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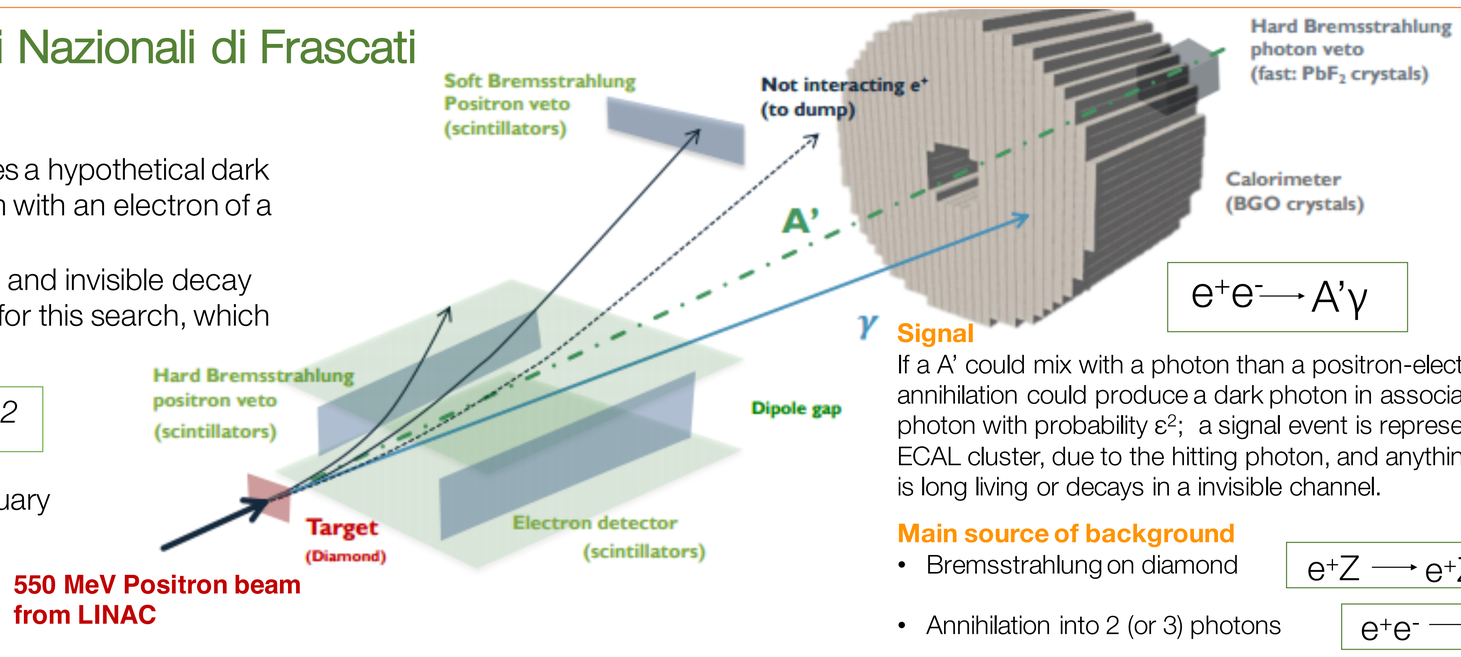
What is the aim?

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.
Several experiments around the world are looking for A' in the visible and invisible decay modes and PADME is the only one using the missing mass method for this search, which is independent from the A' decay mode.

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

PADME run I was started in September 2018 and it will end in February 2019.



$e^+e^- \longrightarrow A'\gamma$

Signal
If a A' could mix with a photon than a positron-electron annihilation could produce a dark photon in association with a photon with probability ε^2; a signal event is represented by a ECAL cluster, due to the hitting photon, and anything else, if A' is long living or decays in a invisible channel.

Main source of background
- Bremsstrahlung on diamond $e^+Z \longrightarrow e^+Z\gamma$
- Annihilation into 2 (or 3) photons $e^+e^- \longrightarrow \gamma\gamma(\gamma)$

What's a dark photon?

Astronomical evidence of the existence of dark matter underlines the importance to go beyond the Standard Model of particle physics.
A new idea is the introduction of a "hidden" sector of particles interacting through a messenger with the particles of our visible sector. One of the simplest model introduces one massive vector called **Dark Photon**[2], corresponding to a broken extra U(1) gauge symmetry.

Why active diamond target?

Active: the resolution of the measured missing mass improves with the spatial resolution of the determination of the dark photon production point

Diamond (Z=6): Low Z improves Signal/Background ~ $1/Z_{TARGET}$

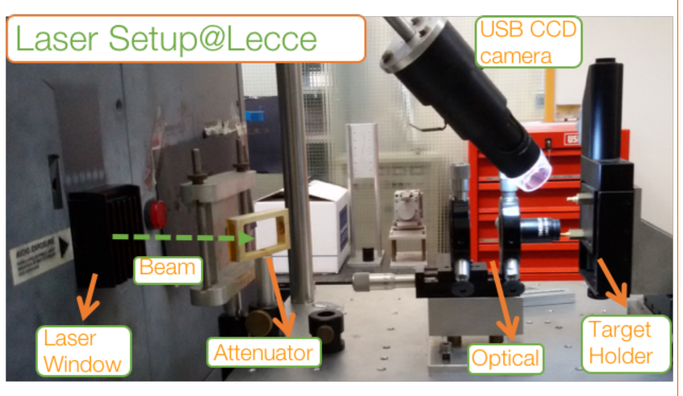
Range of A' mass from less than one MeV up to
$E_{cm} = \sqrt{2m_eE_{beam}}$ = **23.7 MeV/c²**

and mixing parameter sensitivity **$\varepsilon^2 \geq 10^{-6}$**
for 10^{13} Positron On Target (POT)[3].

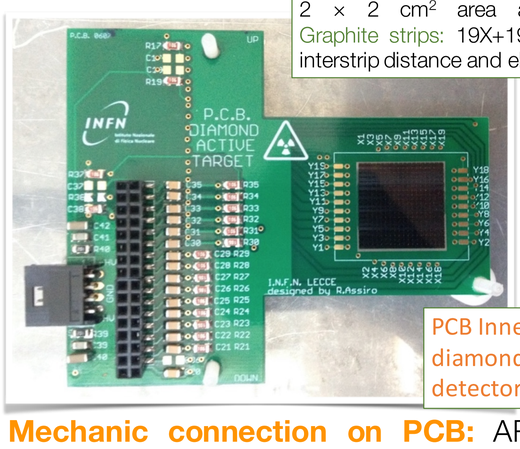
Full carbon detector

The diamond sensor[4] was fully designed and assembled at the University of Salento (Lecce) starting from a 2 × 2 cm² area and 100 μm thick **Chemical Vapor Deposition polycrystalline diamond** film purchased from the Applied Diamond Inc. (USA).

Double-sided graphitic strips as ohmic electrodes[5] were fabricated on the diamond sensor by means of an ArF excimer laser (λ=193 nm) and an automated XY micro-metric scan system.



Diamond target



Diamond sensor:
2 × 2 cm² area and 100 μm thickness.
Graphite strips: 19X+19Y, 1 mm pitch, 0.15 mm interstrip distance and electric resistance~2.5kΩ.

X Vertical Strips
Y Horizontal Strips

PCB Inner board for diamond detector interconnection.

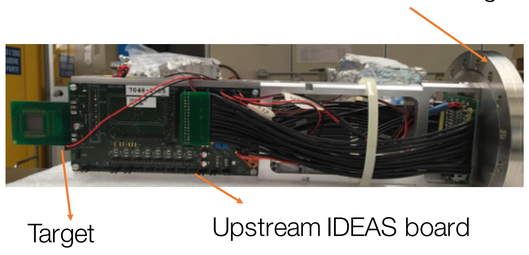
Mechanic connection on PCB: ARALDITE glue spots deposited using a dispensing system equipped with a syringe and precisely positioned with a micrometric XYZθ handling system.

PCB back side electrical contacts (X strips): back-end holes filled one by one with a 2-component conductive adhesive EPOXY E-solder 3025 glue with a syringe and monitoring online the electrical resistance of the contacts.

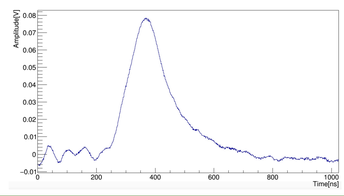
PCB front side electrical contacts (Y strips): wire bonding with 25 μm aluminum wire.

Front-end electronics

Diamond target inner board placed between two IDEAS boards equipped with 16 channel AMADEUS chip to readout 16 X + 16 Y strips. Diamond target mechanical and electrical connected on a vacuum flange with the final mechanical support.

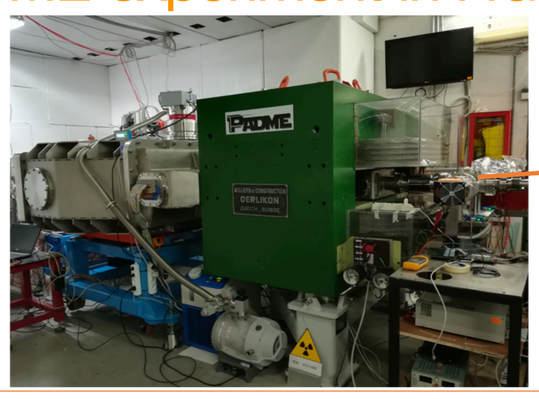


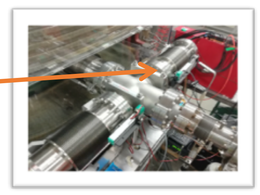
Example of a front-end signal of the central strip X8 strip digitized at 1Gsample/s with 12 bit ADC.



An average charge gain of 1300 was obtained by electronic channels pulse test calibrations

PADME experiment in Frascati



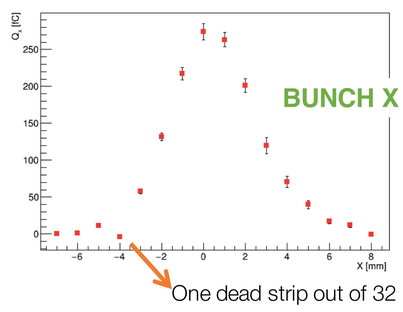


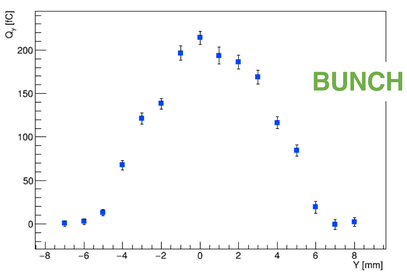
Target in vacuum

Active target performance

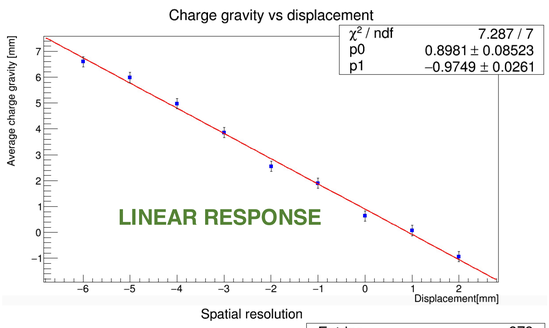
The target is providing the X and Y beam profiles and the beam multiplicity.

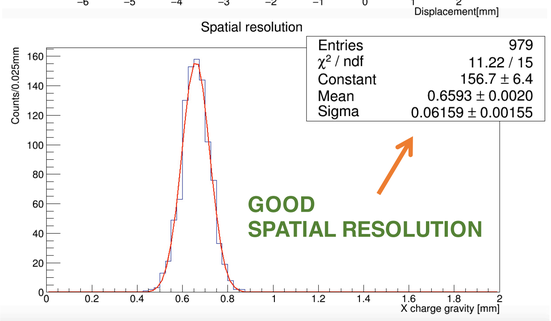
Data taken with bunch multiplicity ~ 20000 e⁺ and diamond polarization voltage = -250 V





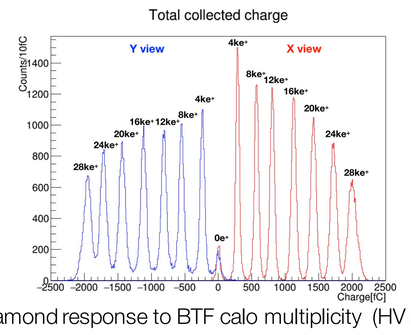
The linearity of the average beam position measured with the charge weighting algorithm was studied moving the target in the X direction.



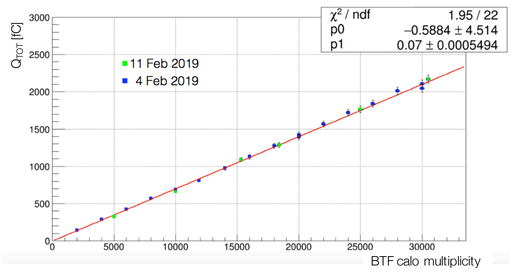


Response to bunches of different e⁺ multiplicity

The positron bunch multiplicity is evaluated using a fully containment Lead-Glass Cherenkov calorimeter.



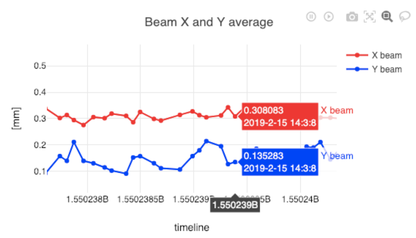
Diamond response to BTF calo multiplicity (HV = -250 V)

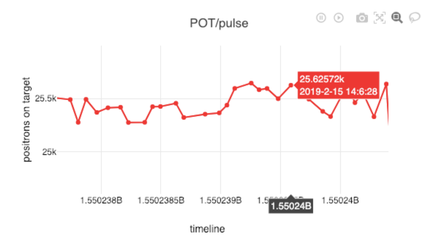


The diamond sensor Charge Collection Distance is given by :
CCD = Total charge [e-] / Bunch multiplicity / (36 e-/ μm) ~ 12 μm

Active target operation

Timeline trends of the X and Y beam position and the number of e⁺ on target are provided on the monitor of the experiment.





Conclusions

A thin and large size CVD diamond detector with double-sided laser made graphitic readout strips is successfully operated continuously and stably in a high energy experiment as a full carbon active target since September 2018.

The diamond detector performances measured on situ show excellent beam monitor capability:
- single bunch X and Y beam profiles
- good spatial resolution and linearity with charge weighting algorithm.
- linear response to the beam bunch multiplicity

The PADME diamond active target fulfils its design goals to provide the beam interaction region with better than 1 mm precision and to measure the integrated luminosity at percent level.

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] J. Alexander et. al., "Dark Sectors 2016 Workshop: Community Report", arXiv:1608.08632 [hep-ph] (2016);
[3] M.Raggi, "Status of the PADME experiment and review of dark photon searches", EPJ Web of Conferences 179, 01020 (2018);
[4] G. Chiodini on behalf of Active Target PADME group , "A diamond active target for the PADME experiment", JINST 12 C02036;
[5] M. De Feudis et al, Diamond graphitization by laser-writing for all-carbon detector applications, Diam. Relat. Mater. 75, 25-33 (2017).