The performance of the diamond active target of the PADME experiment

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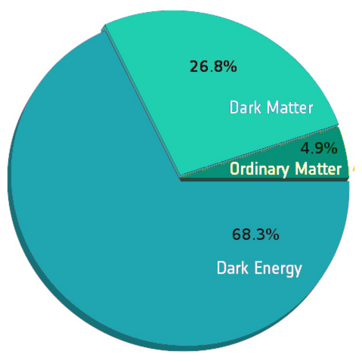
Searching for a dark photon with PADME



The visible matter alone is not able to explain some astrophysical and cosmological phenomena (gravitational lensing, velocity of rotation of the galaxies, distribution of the CMB).
It is therefore necessary to modify the gravitational laws or introduce a new type of matter that does not emit radiation.

The WIMP paradigm is challenged by LHC. A new idea introduces a hidden sector of particles interacting through a messenger with the particles of the visible sector.

New Gauge symmetry $U_D(1)$ in the hidden sector

Very weak interaction with the standard model particles by dark photon - photon mixing

$$L \sim g' q_f \bar{\psi}_f \gamma^\mu \psi_f A'_\mu \rightarrow L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$

γ — ϵ — A'

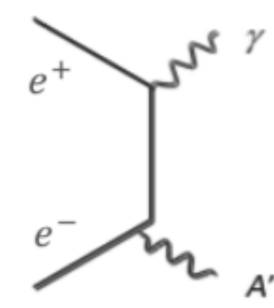
ϵ: kinetic mixing coefficient

Possible A' production process

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

Detection though the missing mass method

$$M^2_{miss} = (p_{e^-} + p_{beam} - p_\gamma)^2$$



Background

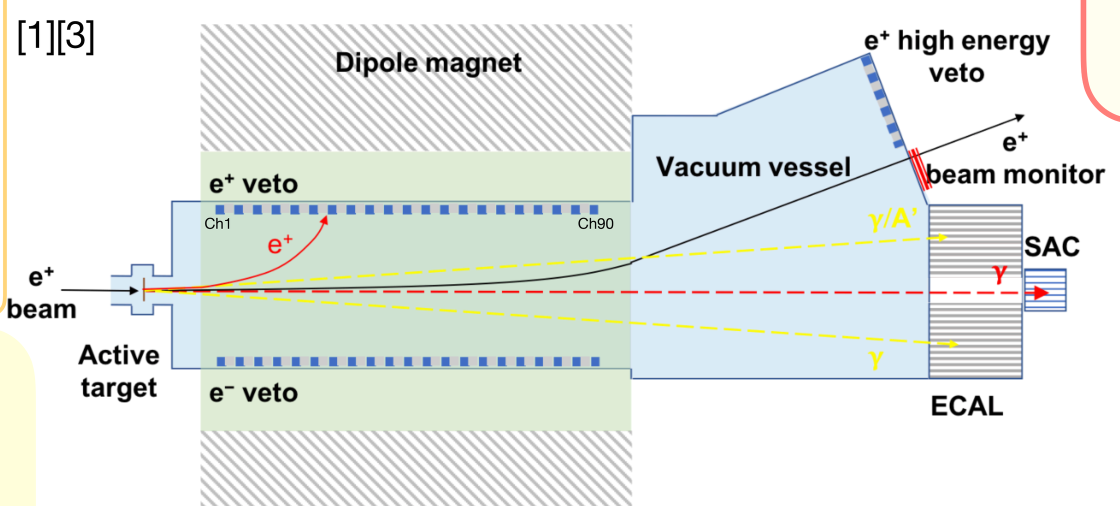
$$e^+N \rightarrow e^+N\gamma$$
$$e^+e^- \rightarrow \gamma\gamma(\gamma)$$

$\sigma(e^+e^- \rightarrow A'\gamma) \simeq 37$nb

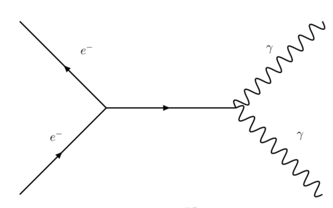
$M_{A'} = 10$ MeV

$\epsilon^2 \simeq 10^{-6}$

[1][3]

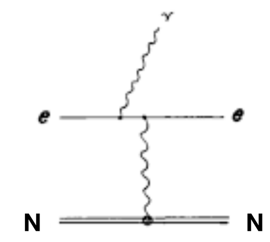


$E_{beam} = 550$ MeV



$\sigma(e^+e^- \rightarrow \gamma\gamma) = 1.55$ mb

$\sigma(e^+e^- \rightarrow \gamma\gamma\gamma) = 7.5 \times 10^{-2}$ mb



$\sigma(e^+N \rightarrow \gamma\gamma)$ E_γ, θ_γ depending

PADME target [4]

ACTIVE TARGET: The missing mass resolution improves with the precision of the photon direction (see fig.1) which can be improved with the determination of the beam-target interaction point.
Experiment requirement on beam spatial resolution < 1 mm

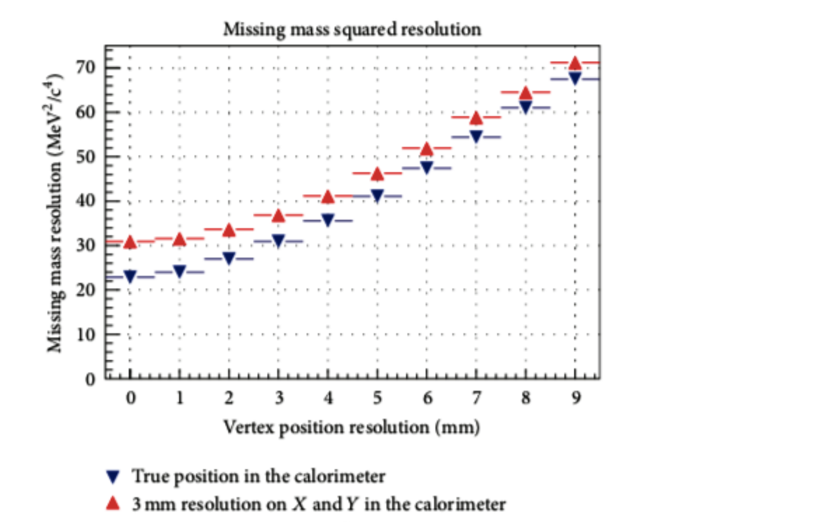


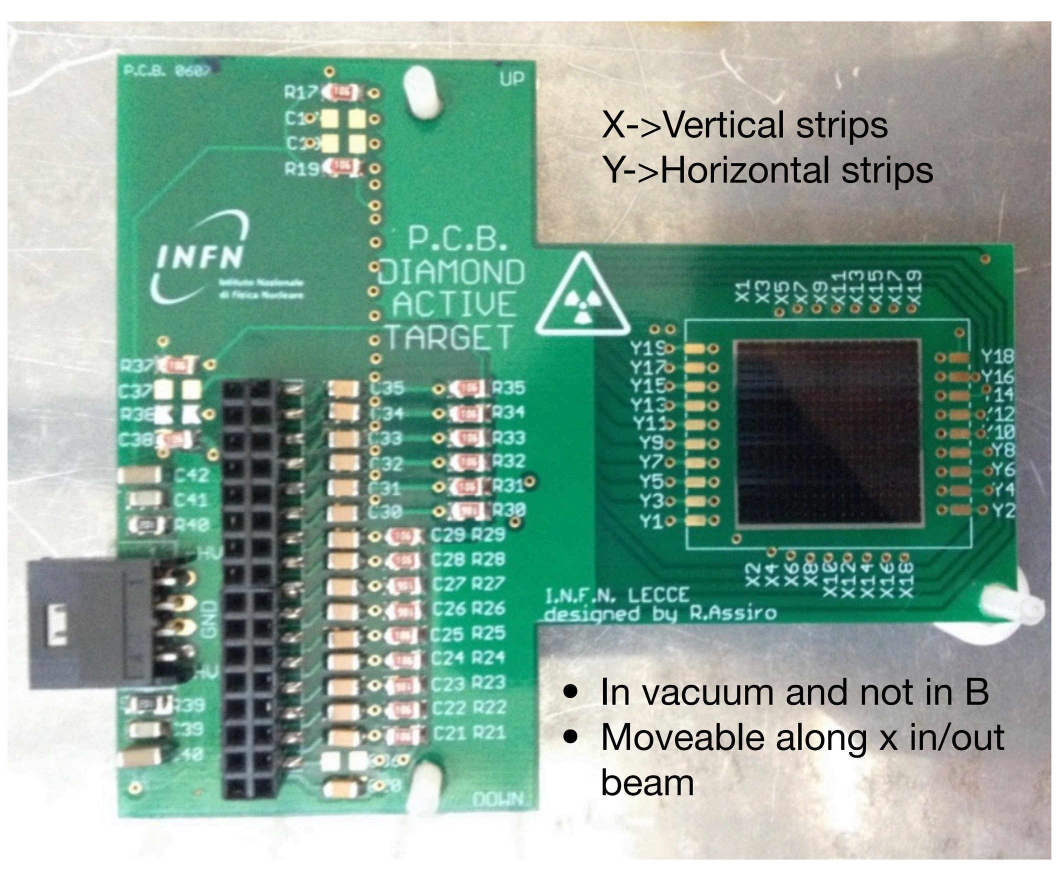
fig.1

DIAMOND TARGET: Diamond is an allotropic form of the carbon. The Z=6 improve signal/background.

$N(A'\gamma) \propto N(\gamma\gamma) \propto Z$ $\qquad N_{brem} \propto Z^2$

"Full carbon" active target

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).



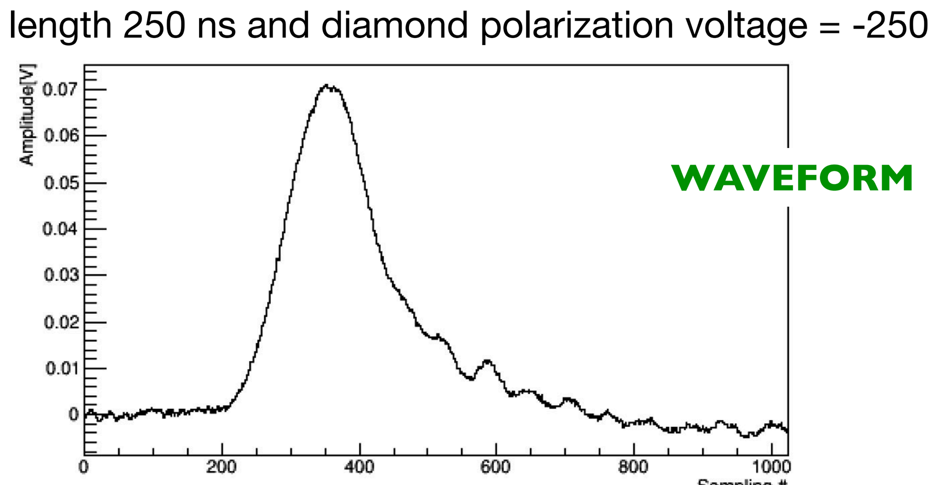
- In vacuum and not in B
- Moveable along x in/out beam

Diamond sensor: 2 × 2 cm² area and 100 μm thickness.

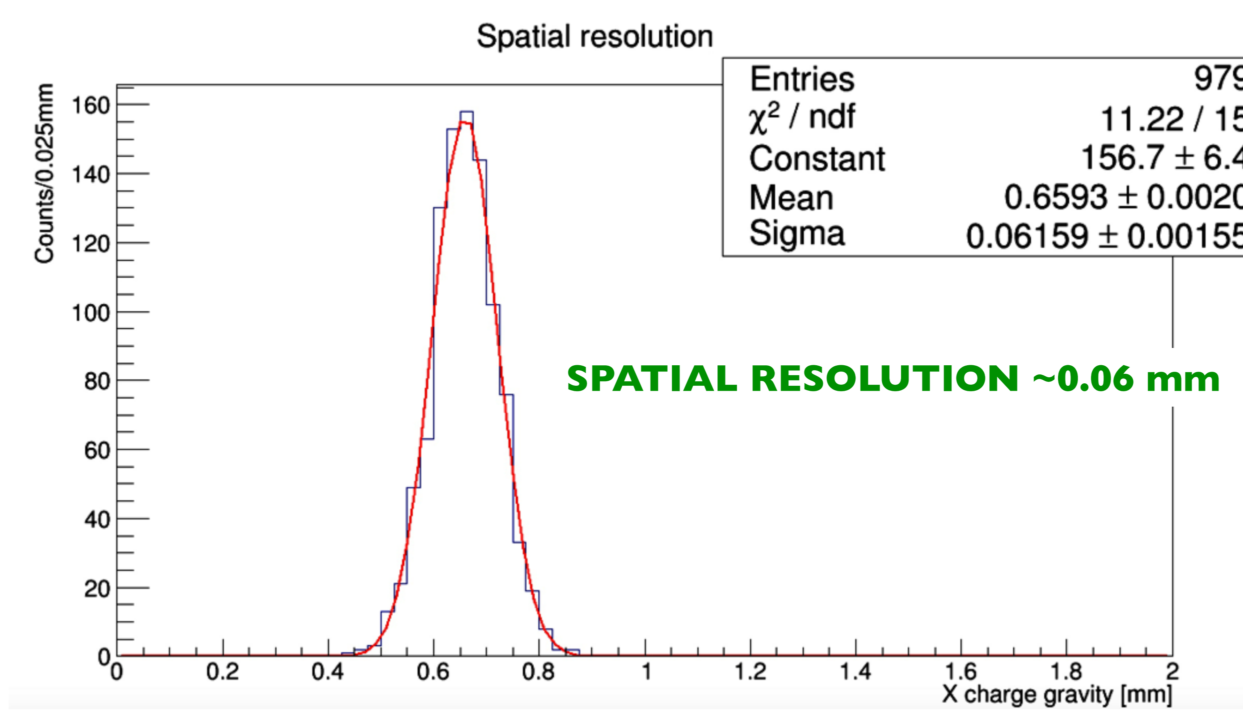
Graphite strips [2]: 19X+19Y, Instrumented strips 16X+16Y, 1 mm pitch, 0.15 mm interstrip distance and electric resistance~2.5kΩ.

Active Target Performance

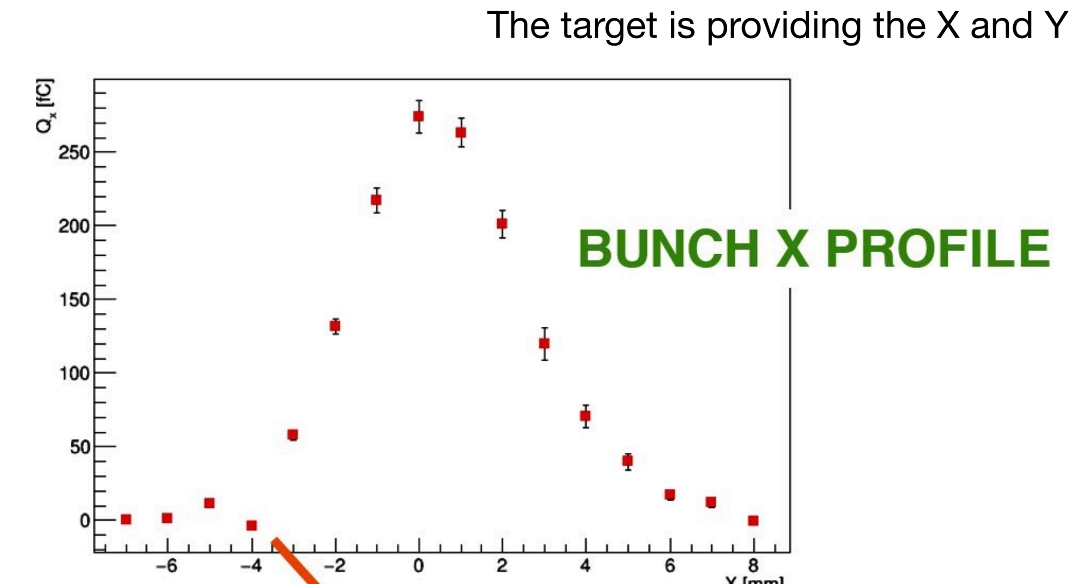
Data taken with bunch multiplicity ~ 20000 e+ bunch length 250 ns and diamond polarization voltage = -250 V



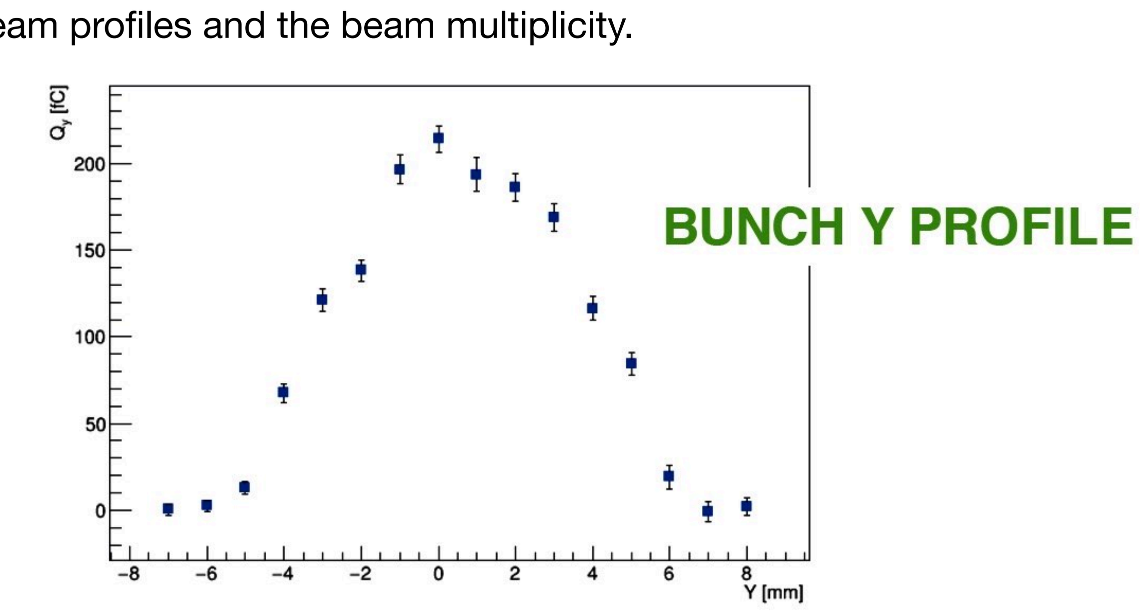
Example of a front-end signal of the central strip X8 strip digitized at 1Gsample/s with 12 bit ADC.



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

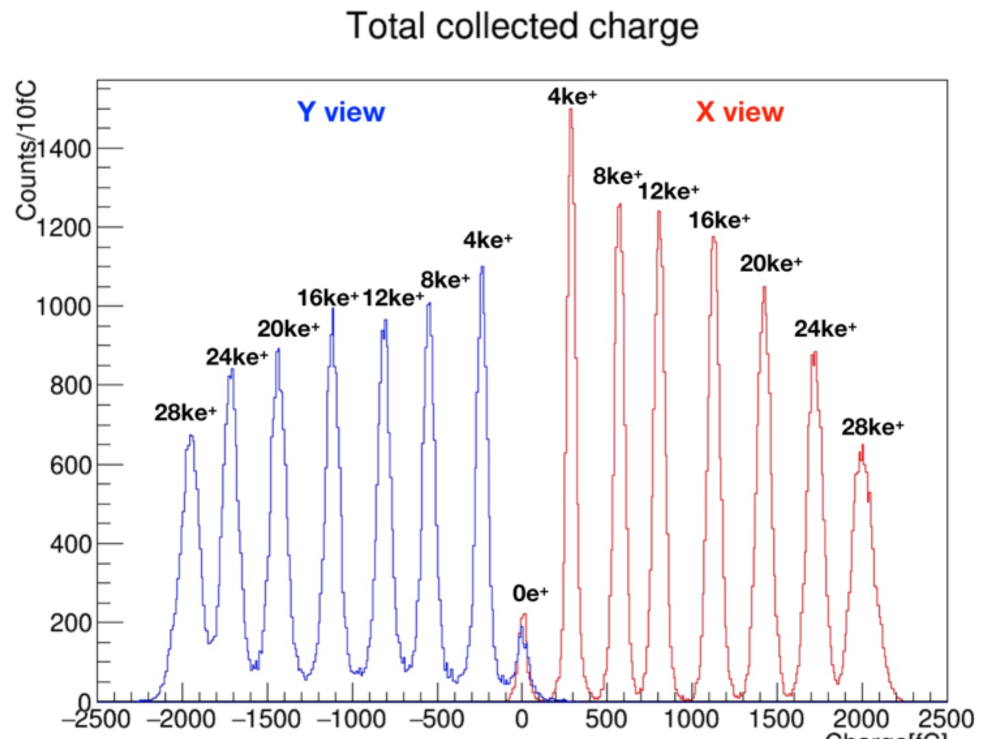


One dead strip out of 32

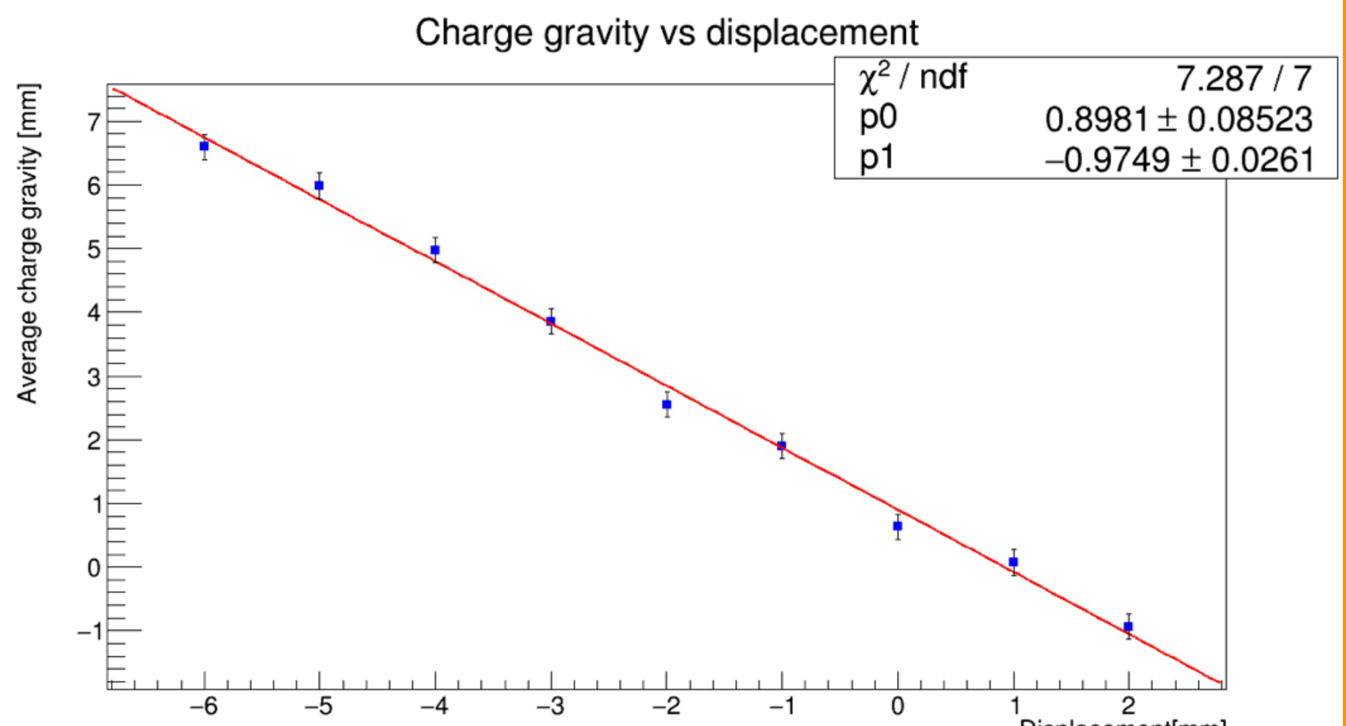


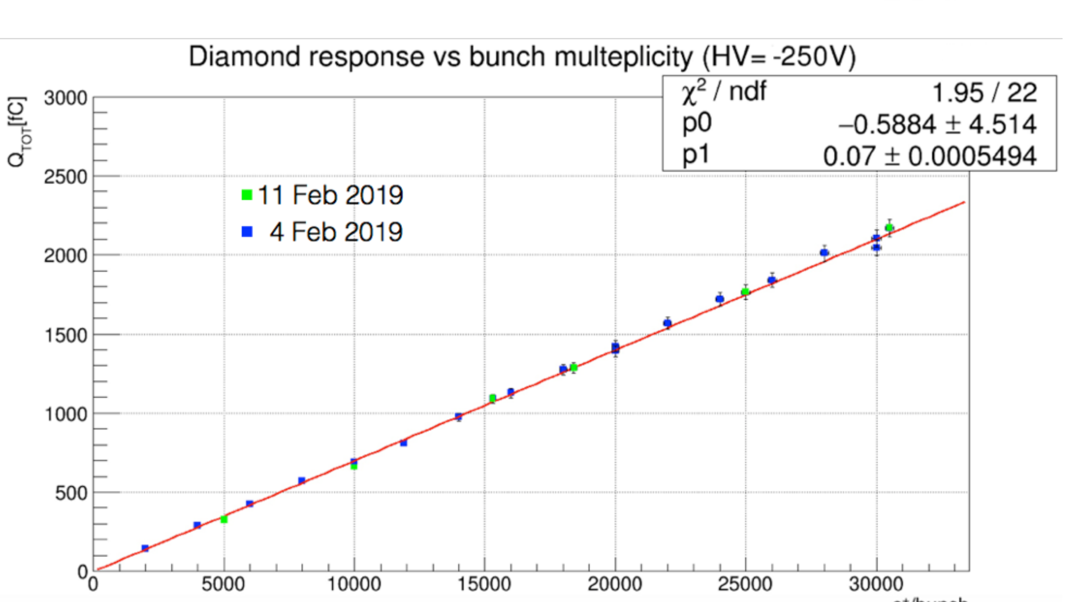
Active Target Calibration

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



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

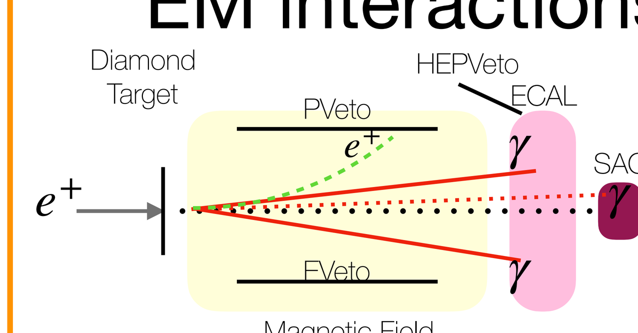




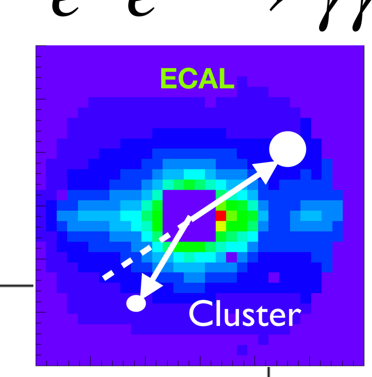
CCD=Charge Collection Distance

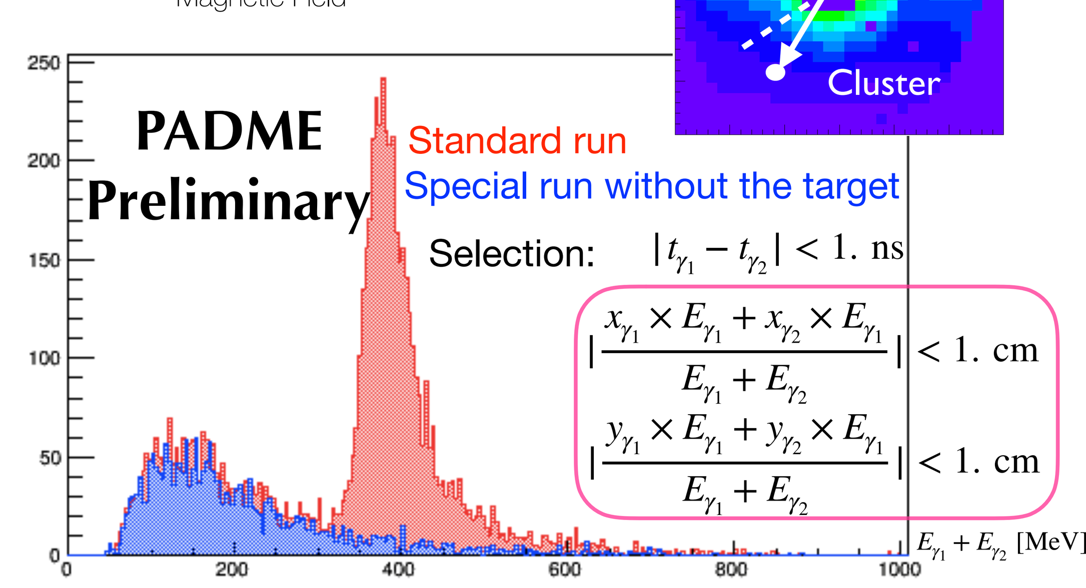
=Total charge [e-] / Bunch multiplicity / (36 e-/ μm) ~ 12 μm

EM interactions on the Target



$$e^+e^- \rightarrow \gamma\gamma$$





Selection: $|t_{\gamma_1} - t_{\gamma_2}| < 1.$ ns

$$\left|\frac{x_{\gamma_1} \times E_{\gamma_1} + x_{\gamma_2} \times E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}}\right| < 1. \text{ cm}$$

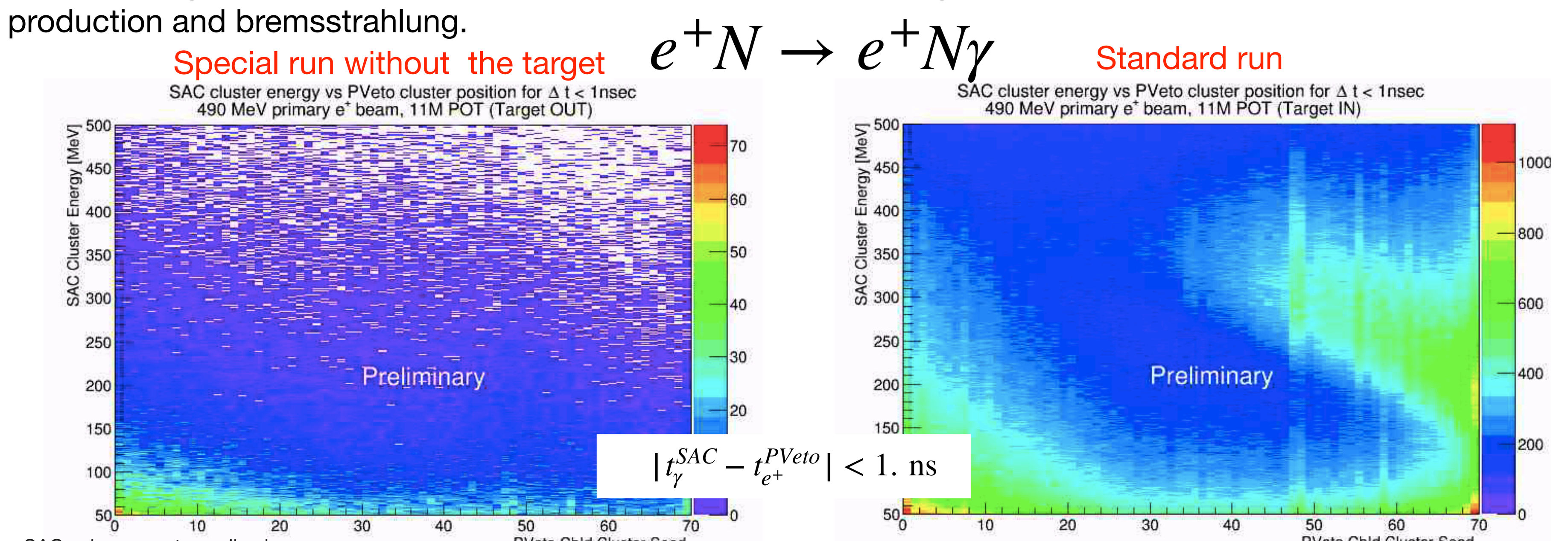
$$\left|\frac{y_{\gamma_1} \times E_{\gamma_1} + y_{\gamma_2} \times E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}}\right| < 1. \text{ cm}$$

$E_{\gamma_1} + E_{\gamma_2}$ [MeV]

Sum of the energy of two photons in e+e- annihilation candidate events. In red events with the target in the default position in the beam line. In blue events with the target off the beam line.

The comparison of the data in a standard run (20000 e+/bunch) with a special run (same beam configuration) with the target off the beam line allows to establish clear signatures for the processes of two photon production and bremsstrahlung.

$$e^+N \rightarrow e^+N\gamma$$



$|t^{SAC}_\gamma - t^{PVeto}_{e^+}| < 1.$ ns

The PADME detector observes the two standard electromagnetic processes only when the diamond target is crossed by the positron beam.

[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] M. De Feudis et al, Diamond graphitization by laser-writing for all-carbon detector applications, Diam. Relat. Mater. 75, 25-33 (2017).

[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;