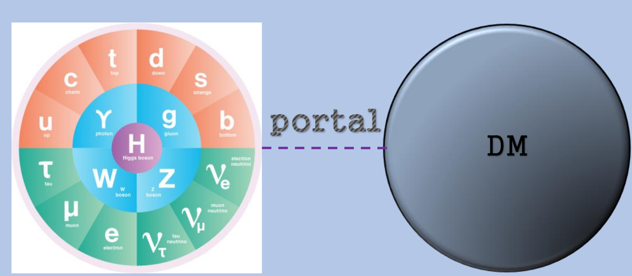
International Conference on Technology and Instrumentation in Particle Physics – May 24–28, 2021

THE PADME CALORIMETER

C. Taruggi for the PADME collaboration

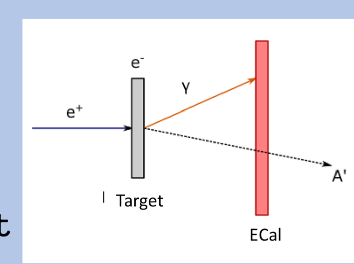
Laboratori Nazionali di Frascati, 00044 Frascati (RM), Italia

The experiment



Over recent decades, many experiments have searched for evidence of dark matter (DM): nevertheless no signal of a DM candidate has yet been reproduced by independent experiments.

A possible solution comes from dark sector (DS) theories: DM could live in a separate world from SM particles. In the simplest model, a portal could connect these two worlds, acting as the mediator of a new interaction. The mediator is called dark photon (DP) or *A'*. Assuming that A' couples to leptons, it could be produced through Bremsstrahlung (e⁺ N → e⁺ N A') or annihilation (e⁺ e⁻ → γ A').

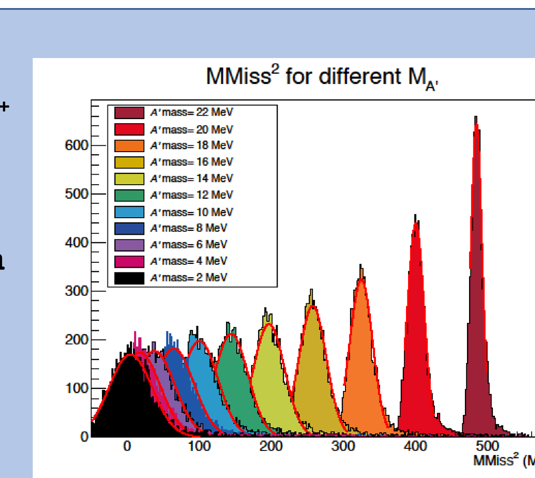


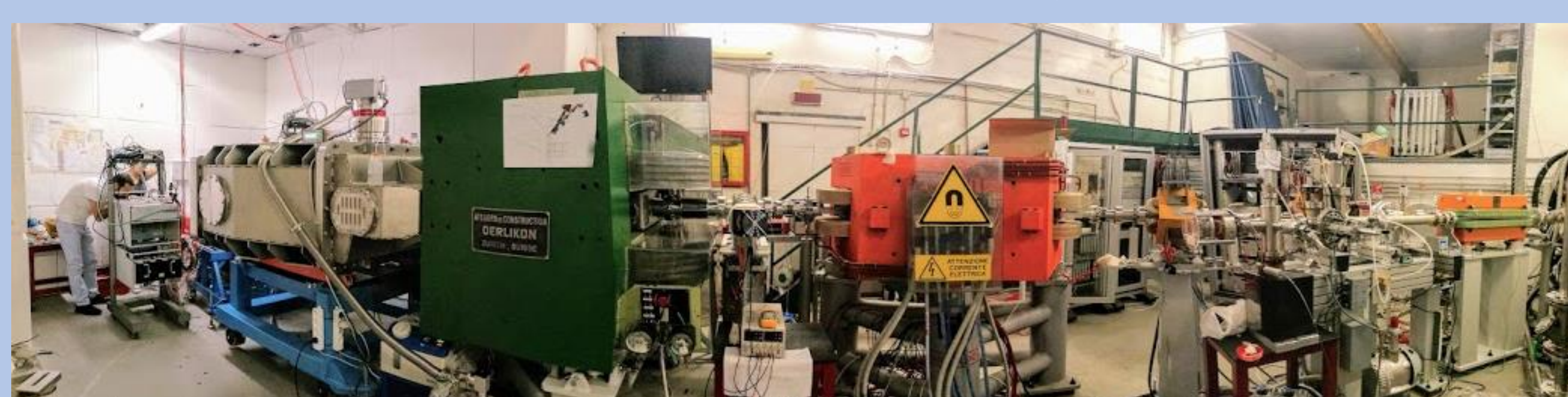
PADME is looking for the invisible decay of A' using a e⁺ beam on a target:

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

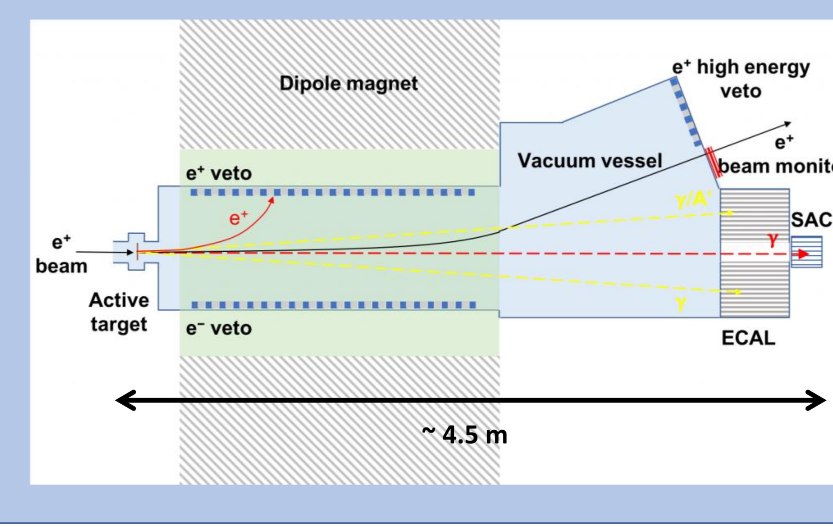
with known beam energy and target at rest. The momentum of the γ in the final state must be measured to reconstruct the kinematic of the reaction.

$$M^2_{Miss} = (\boldsymbol{P}_{beam} + \boldsymbol{P}_e - \boldsymbol{P}_\gamma)^2$$





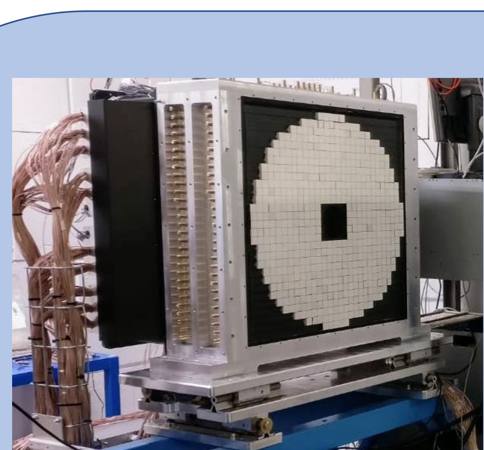
- Positron beam, ~25k–30k e⁺ per bunch
- Active diamond target, 100 µm thickness
- Mimosa, pixel tracker
- Dipole magnet, 0.45 T
- Vacuum vessel, 10^{-5} mbar
- Charged particle veto system, plastic scintillators
- BGO electromagnetic calorimeter (ECal)
- PbF_2 small angle calorimeter (SAC)
- Positron beam monitor (TimePix3)



The Calorimeter

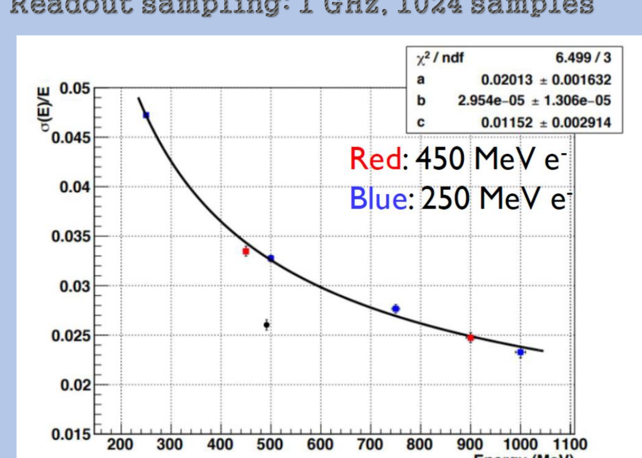
The calorimeter of the experiment consists of two detectors, the **Electromagnetic Calorimeter (ECal)** and the **Small Angle Calorimeter (SAC)**. A signal in PADME is a SM photon in the ECal, and no other particles in the other detectors. The ECal must detect this SM photon in the final state to reconstruct the kinematic of the experiment. The main backgrounds of the experiment is Bremsstrahlung radiation e⁺ N → e⁺ N γ, which is most intense (~ 10^2 MHz) at small angles to the beam. For this reason, the ECal has a hole in the center, which allows Bremsstrahlung radiation to pass through. The SAC is designed to stand the high rate of Bremsstrahlung. The other principal source of background is the annihilation into two or three SM photons: e⁺ e⁻ → γ γ (γ). The correlation of photon events in the SAC and ECAL allows the tagging of 2– γ and 3– γ events.

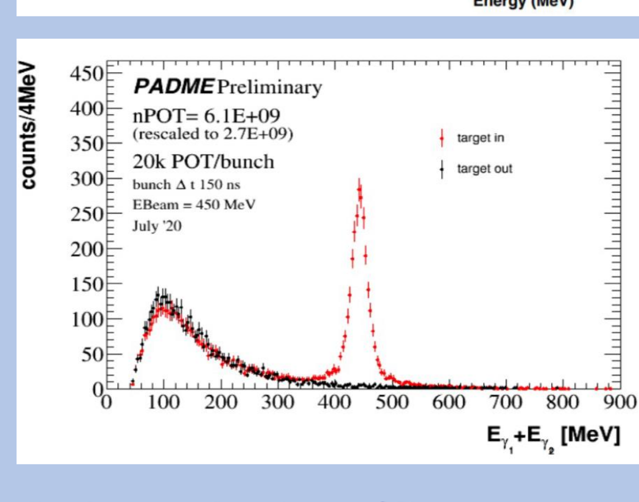
The Electromagnetic Calorimeter

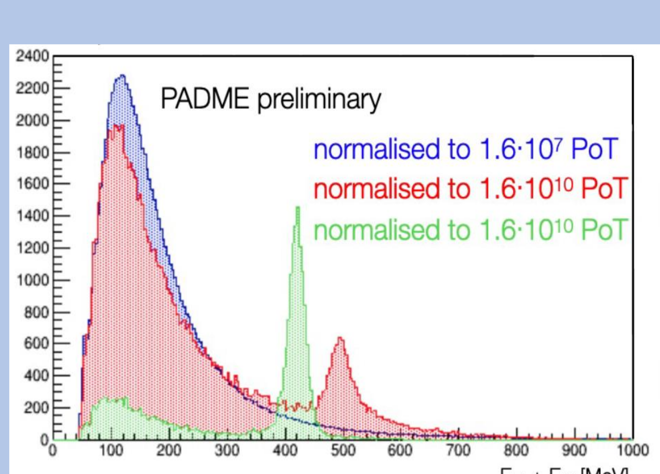


- It consists of 616 (2.1 × 2.1 × 23 cm³) BGO crystals, with ~300 ns decay time, optically coupled to HZC Photonics XP1911 PMT
- It is designed to detect the γ in the final state in order to reconstruct the kinematics of the process
- It has a cylindrical shape of radius ~ 30 cm, and a central hole of 10.5 × 10.5 cm² (Bremsstrahlung rate too high for BGO)
- BGO crystals were reused from the L3 experiment: the energy resolution of the crystals was measured and lie in the range (1–2)%/√E for electrons and photons of energy ≤ 1 GeV
- Angular coverage: [15.7, 82.1] mrad
- Readout sampling: 1 GHz, 1024 samples

- A first order calibration of the scintillating units was performed using a ^{22}Na source
- The second calibration with cosmic rays was performed after the assembly of the calorimeter
- The energy resolution of the calorimeter (black dot) is better than thatof the prototype used during early test beam
- Process under analysis: annihilation into 2γ
- The removal of the target from the experiment allows the beam background to be studied: the signal is clearly separated from background!
- Beam optimization studies were performed to lower the beam–induced background

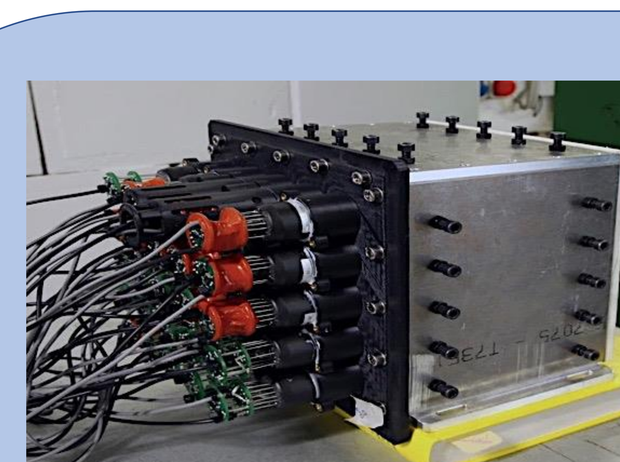






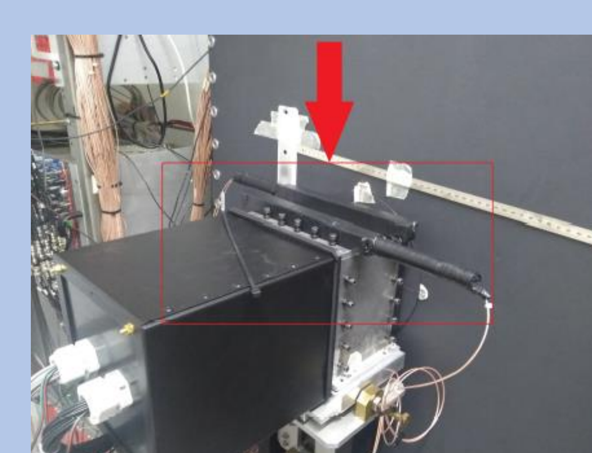
- Run1: secondary beam, 25k positrons/bunch, 545 MeV, 250 ns
- Run1: primary beam, 25k positrons/bunch, 490 MeV, 250 ns
- Run2: primary beam, 28k positrons/bunch, 490 MeV, 280 ns

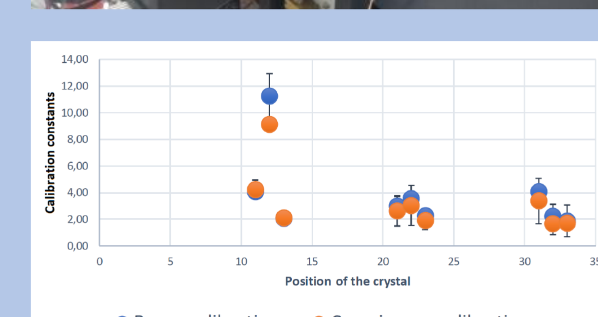
The Small Angle Calorimeter

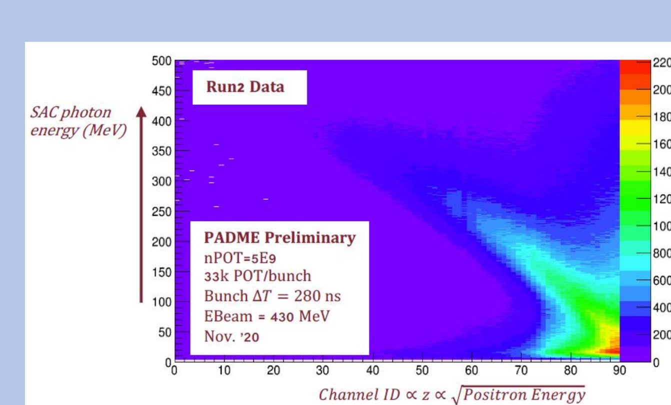


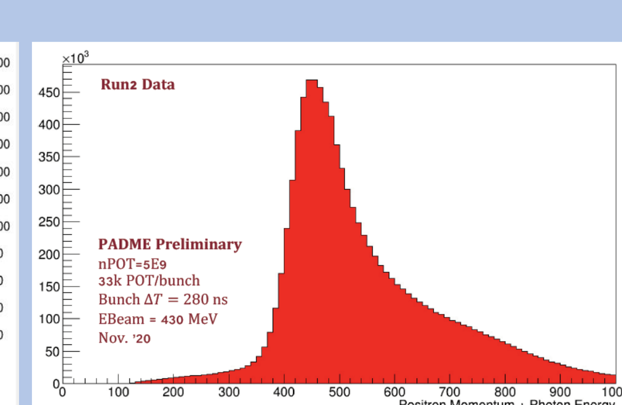
- It consists of 25 (3 × 3 × 14 cm³) PbF_2 crystals, coupled to fast Hamamatsu R13478UV PMT
- The fast signals (~2 ns) of Cherenkov crystals can cope with the rate (~100 MHz) of Bremsstrahlung radiation
- Angular coverage: [0, 18.9] mrad
- Readout sampling: 2.5 GHz, 1024 samples

- Two independent calibrations (beam and cosmic rays) were performed
- The first calibration was obtained firing a single–positron beam on each of the 9 central crystals of the detector
- The second calibration was performed using a cosmic rays trigger system.
- Two sets of calibration constants were extracted from the two measurements
- The results show a good agreement between the two sets (≤10% for all the units except one which was substituted later)
- The physics process under analysis is Bremsstrahlung e+ N → e+ N γ, where the photon reaches the SAC and the positron reaches the PVeto
- The plots of $E_\gamma + p_{e+}$ show a correlation: the energy and the momentum are correctly reconstructed!









Further reading

1. M. Raggi, V. Kozhuharov, «Proposal to Search for a Dark Photon in Positron on Target Collisions at DAΦNE Linac», Adv. High Energy Phys. 2014 959802 (2014)
2. M. Raggi, V. Kozhuharov and P. Valente, «The PADME experiment at LNF», EPJ Web Conf. 96, 01025, 2015
3. V. Kozhuharov, M. Raggi, «Results and perspectives in dark photon physics», Rivista del Nuovo Cimento, 38:449505, 2015.
4. P. Valente et al., «Linear Accelerator Test Facility at LNF Conceptual Design Report», arXiv:1603.05651, 2016
5. G. Piperno, «The PADME experiment at Laboratori Nazionali di Frascati», Frascati Physics Series, 63:1924, 2016
6. P. Valente et al., «Linear Accelerator Test Facility at LNF Conceptual Design Report», arXiv:1603.05651, 2016
7. P. Valente et al., «Long beam pulses with SLED compression in DAΦNE LINAC», Journal of Physics: Conference Series, 874 012017, 2017
8. M. Raggi et al., «Performance of the PADME calorimeter prototype at the DAΦNE BTF», Nucl. Instrum. Meth. A 862, 31, 2017
9. A. Frankenthal et al., «Characterization and Performance of PADMEs Cherenkov–Based Small Angle Calorimeter», Nuclear Instrumentation Methods A, 919:8997, 2019
10. M. Raggi et al., «Performance of the PADME Calorimeter prototype at the DAΦNE BTF», Nuclear Instrumentation Methods A, 862:3135, 2017
11. P. Albicocco et al., «Characterisation and performance of the PADME electromagnetic calorimeter», Journal of Instrumentation 15 T1003, 2020.