The PADME Experiment

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ABSTRACT

Massive photon-like particles are predicted in many extensions of the Standard Model as possible portals to a hidden sector where Dark Matter is secluded. They are vector bosons mediating the interaction between ordinary and dark matter and can be produced in different processes through a feeble mixing to the photon. The PADME experiment at the Laboratori Nazionali di Frascati, searches for a signal of such a particle, known as a Dark Photon A', in the reaction $e^+e^- \rightarrow \gamma A'$ in a positron-on-target experiment. For this purpose, the missing mass spectrum of annihilation final states with a single photon is analysed. Collecting approximately 10^{13} POT, a sensitivity on the interaction strength down to 0.001 is achievable in the mass region $M(A') <$ 23.7 MeV.
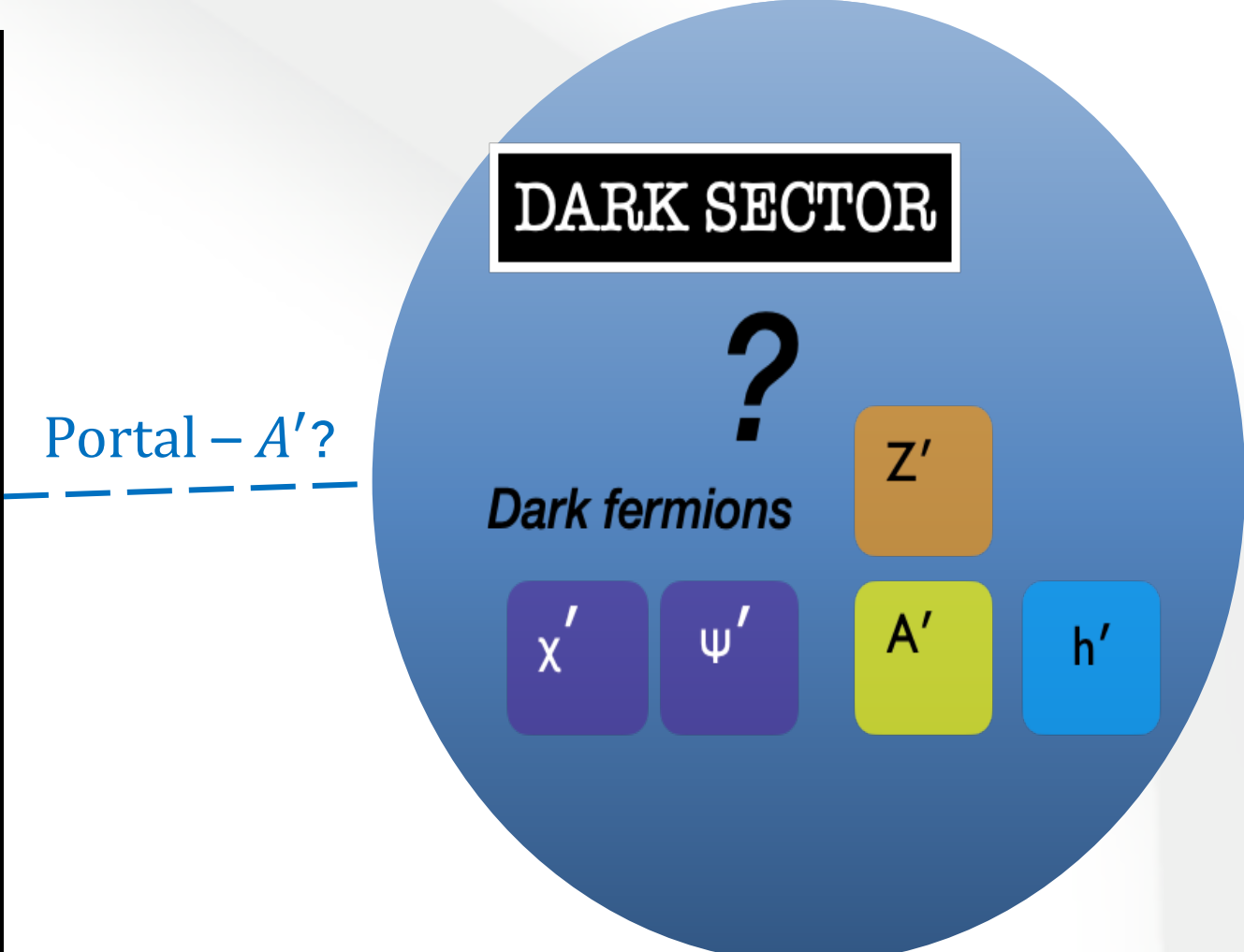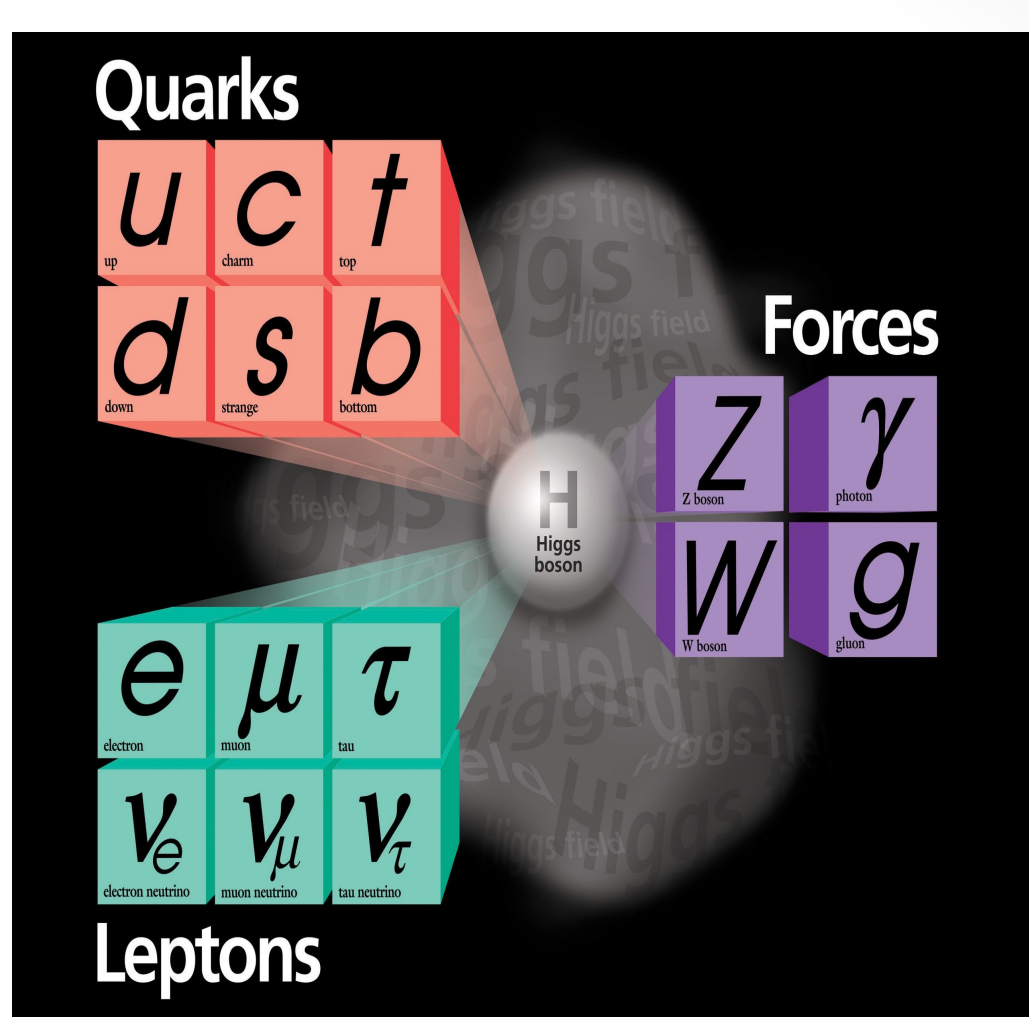PADME is also able to search for other new particles produced in e^+e^- collisions through a virtual off-shell γ, eg. long lived Axion-Like-Particles (ALPs), proto-phobic X bosons, Dark Higgs, etc.

DARK SECTOR PORTAL MODELS
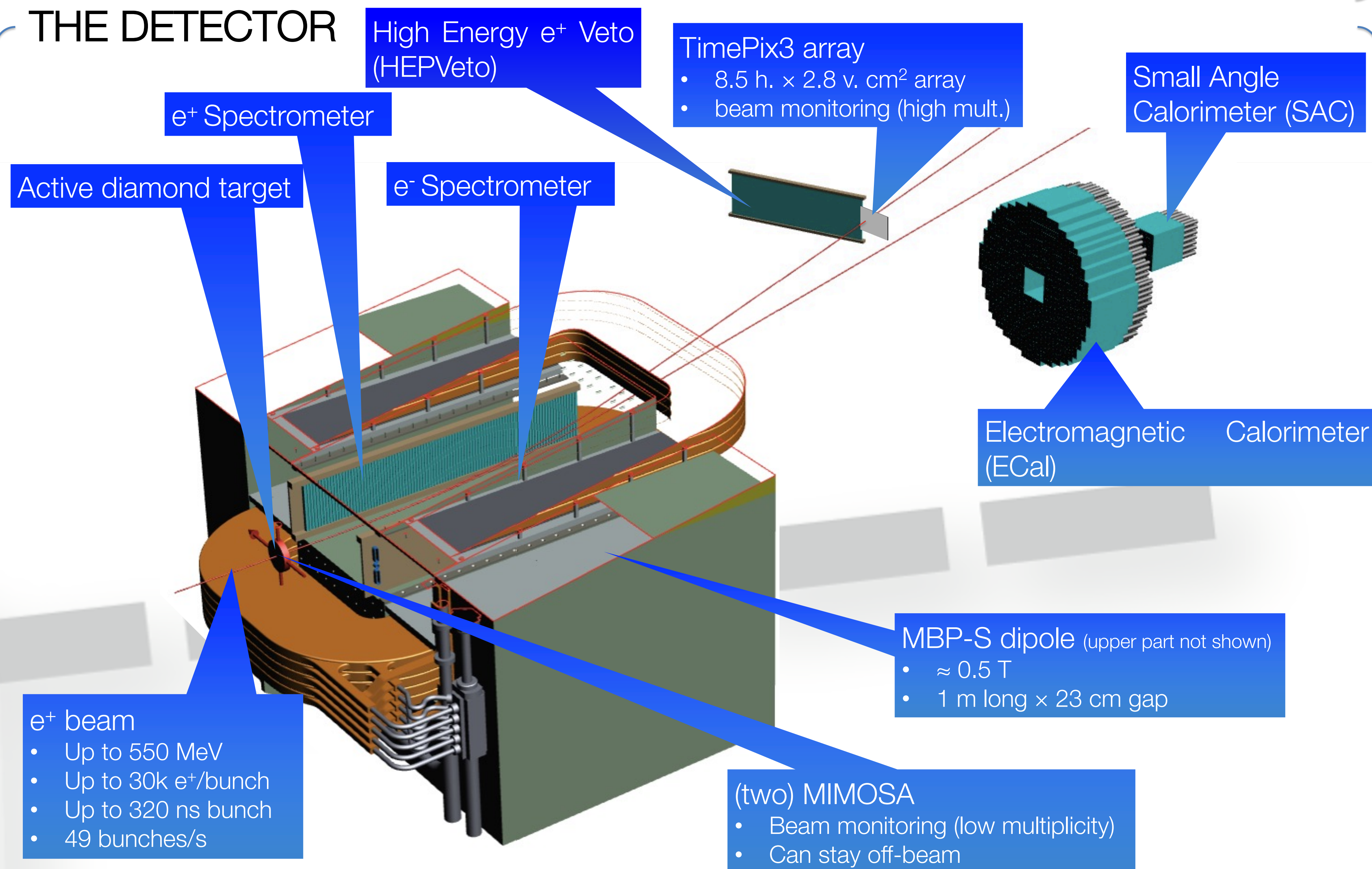
In portal models of dark mater, any and all dark matter particles inhabit a sector of their own. They would potentially be able to interact with other particles within the dark sector but they would only be able to interact with SM particles via a mediator "portal" particle.
PADME is searching for two potential portal particles: massive vector bosons (dark photons, A') and massive pseudo-scalars (axion-like particles, ALPs).
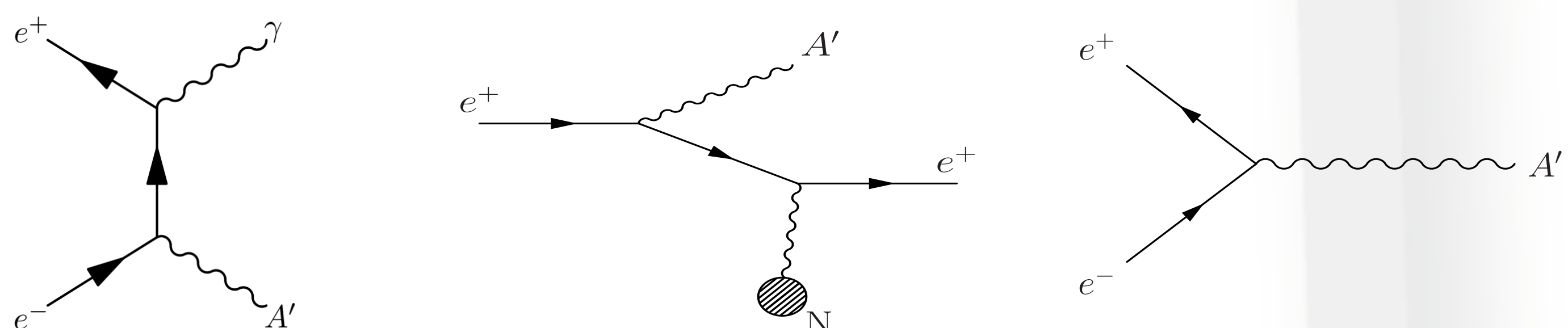The couplings of these particles to the SM would be $\ll 1$ meaning that the dark sector would be "hidden" from the SM.

THE DETECTOR

- High Energy e^+ Veto (HEPVeto)
- e^+ Spectrometer
- Active diamond target
- e^- Spectrometer
- TimePix3 array
  - 8.5 h. × 2.8 v. cm² array
  - beam monitoring (high mult.)
- Small Angle Calorimeter (SAC)
- Electromagnetic Calorimeter (ECal)
- MBP-S dipole (upper part not shown)
  - ≈ 0.5 T
  - 1 m long × 23 cm gap
- e^+ beam
  - Up to 550 MeV
  - Up to 30k e^+/bunch
  - Up to 320 ns bunch
  - 49 bunches/s
- (two) MIMOSA
  - Beam monitoring (low multiplicity)
 - Can stay off-beam

PRODUCTION MECHANISMS

The nominal production mechanism at PADME is associated production of an A' with a SM γ but A'-strahlung and resonant annihilation are also accessible to PADME. All of these mechanisms are identical for both A' and ALPs.
Calculating the ratio of $e^+e^- \rightarrow \gamma A'$ candidate events to $e^+e^- \rightarrow \gamma\gamma$ events gives us access to the coupling constant ϵ:

$$\frac{\sigma(e^+e^- \rightarrow A'\gamma)}{\sigma(e^+e^- \rightarrow \gamma\gamma)} = \frac{N(A'\gamma)}{N(\gamma\gamma)} \times \frac{Acc(\gamma\gamma)}{Acc(A'\gamma)} = \epsilon^2 \times \delta$$

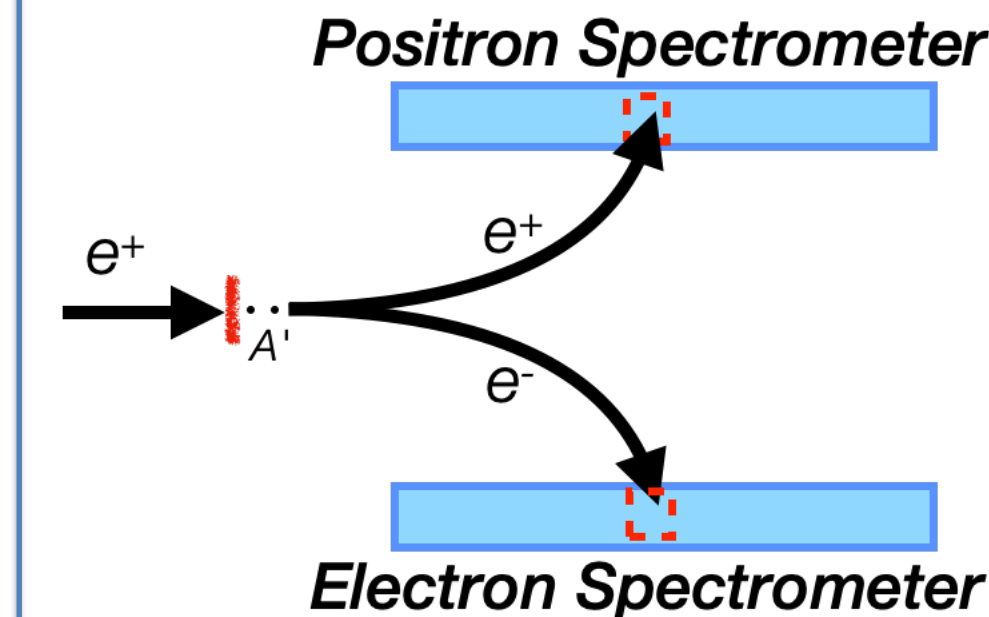## EXPERIMENTAL SIGNATURE: INVISIBLE CHANNEL
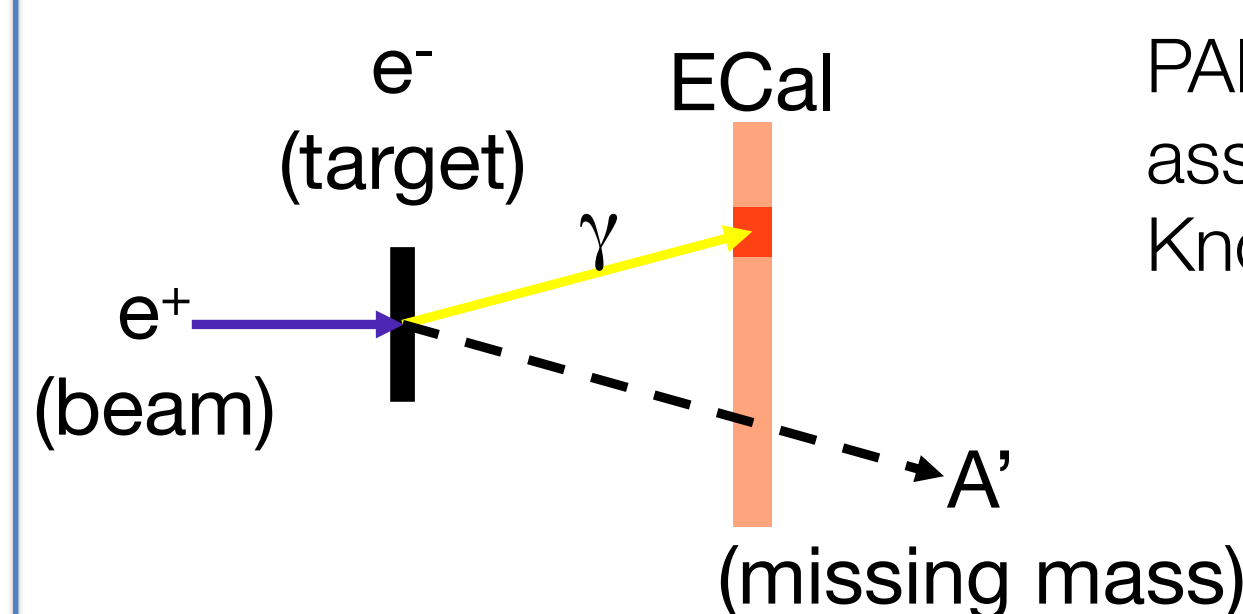
PADME's nominal signal channel looks for the γ produced in associated production with the A'.
Knowing the kinematics of the process, we can reconstruct $M_{A'}$:

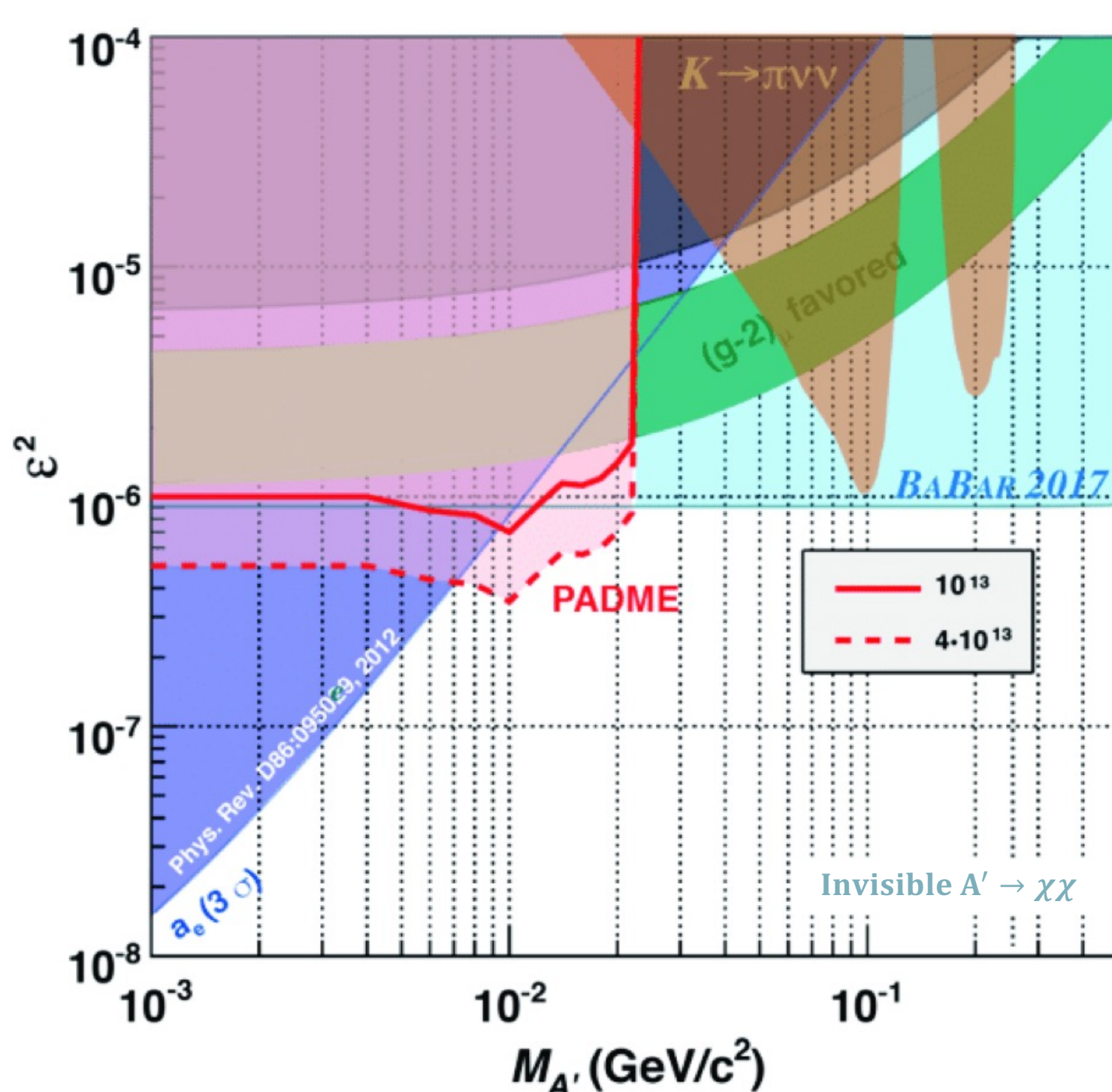$$M_{A'}^2 = \left(E_{beam} + M_{e^-} - E_\gamma\right)^2$$

EXPERIMENTAL SIGNATURE: VISIBLE CHANNEL

Using the magnetic field and the charged particle spectrometers, we can also search for visible final states.
The position of final state particles in the spectrometers gives us access to their momenta and therefore the mass of the particle that produced them.

## PADME PHYSICS REACH: $A' \rightarrow$ INVISIBLE

With PADME's nominal beam energy of 550 MeV we're sensitive to $M_{A'} <$ 23.7 MeV.

The reach in coupling strength ϵ depends on beam background and pile-up, but with 10^{13} positrons on target we should be able to probe $\epsilon > 10^{-3}$.

EXPERIMENTAL BACKGROUND

There are two main sources of background to invisible decays at PADME:
- Bremsstrahlung where the photon ends up in the ECal & the positron goes undetected
- 2 (3) photon annihilation where 1 (2) of the photons are undetected
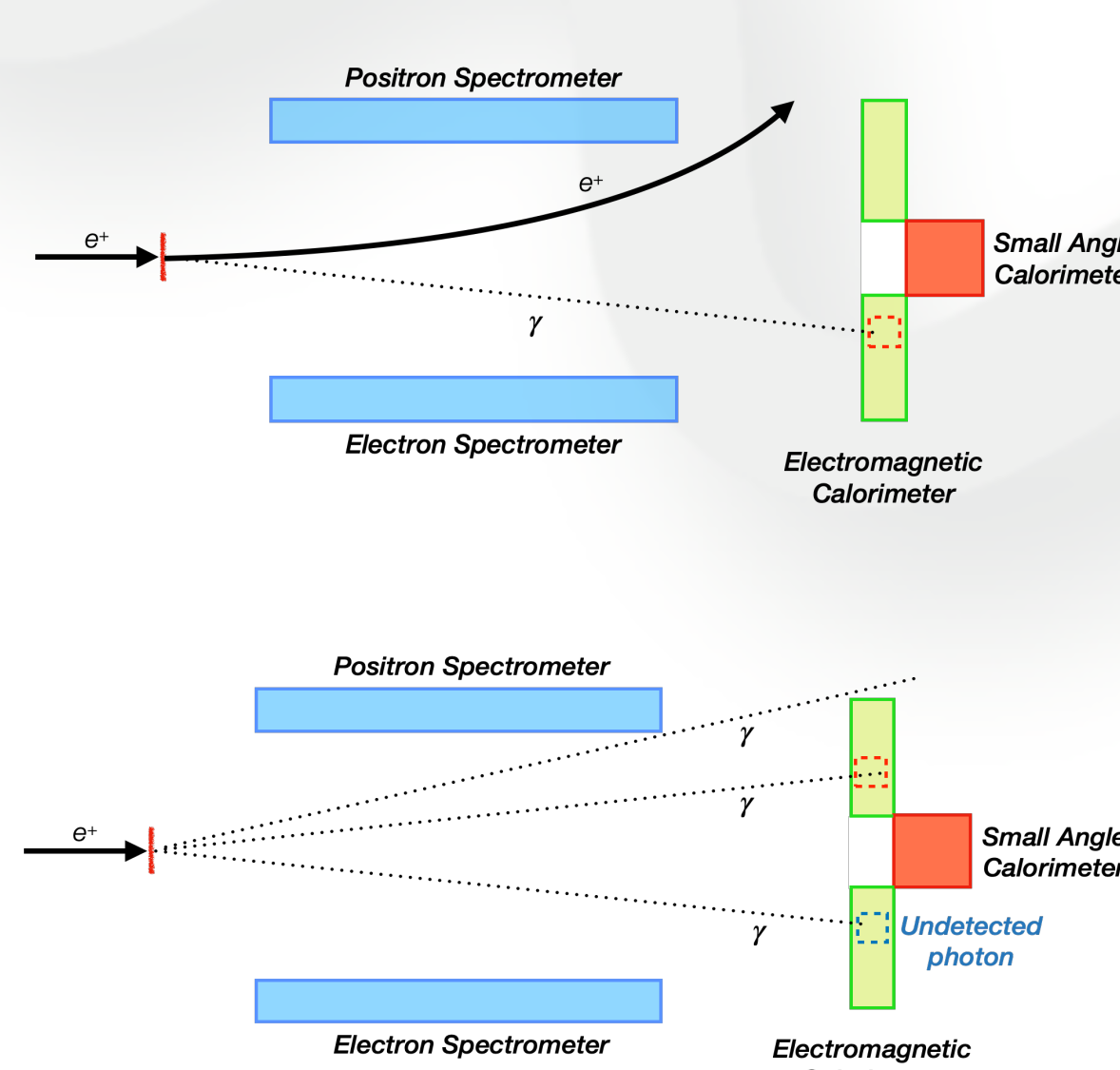
The angular distribution of Bremsstrahlung photons is sharply peaked at small angles to the beam. For this reason, the ECal was built with a hole in the centre behind which the Small Angle Calorimeter was built to reject Bremsstrahlung photons.
Positrons that lose energy through Bremsstrahlung are rejected in either the positron spectrometer (PVeto) or in the high-energy positron veto (HEPVeto).
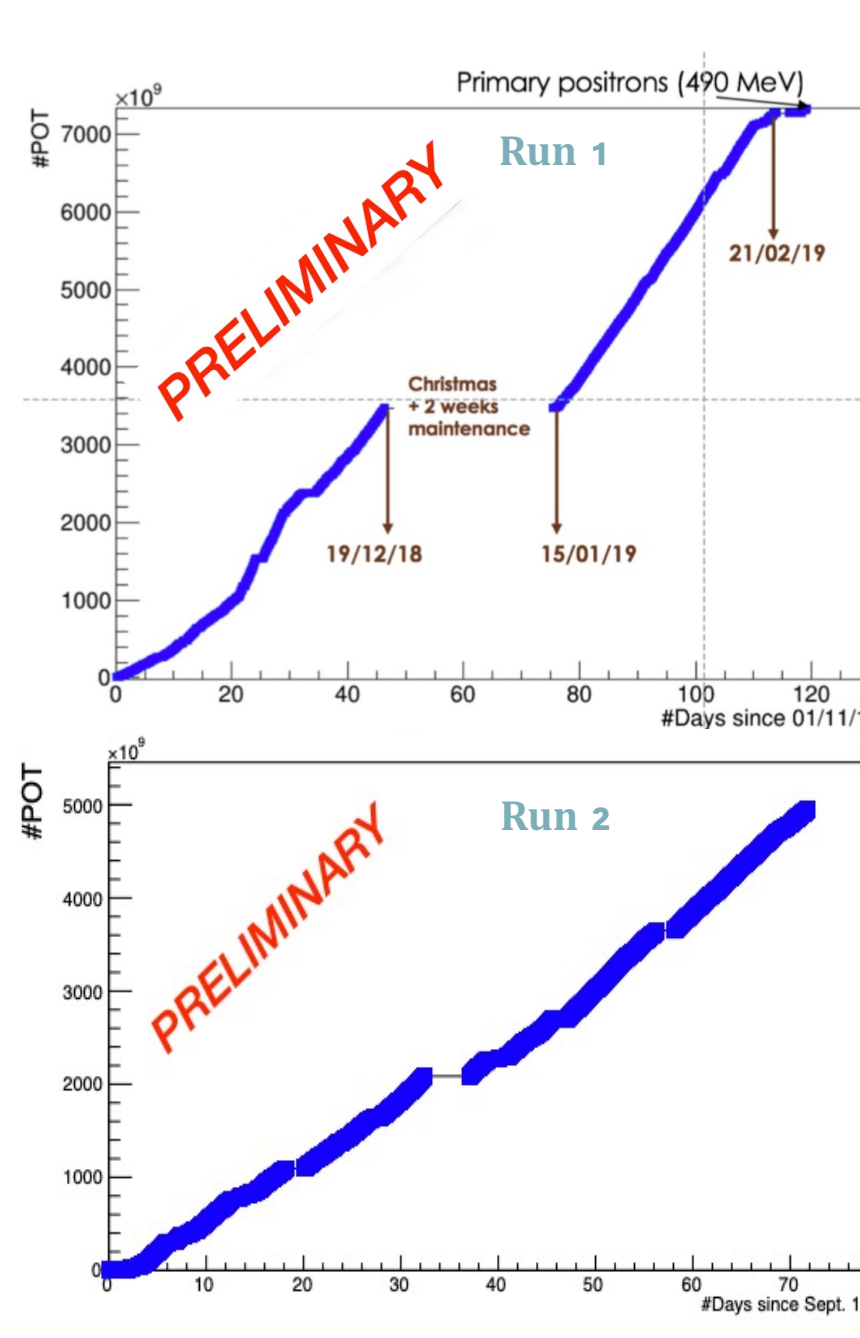
To avoid the loss of annihilation photons, the ECal was built with the highest angular coverage, maximum granularity and best energy resolution possible.

PADME PHYSICS REACH: $A' \rightarrow$ VISIBLE
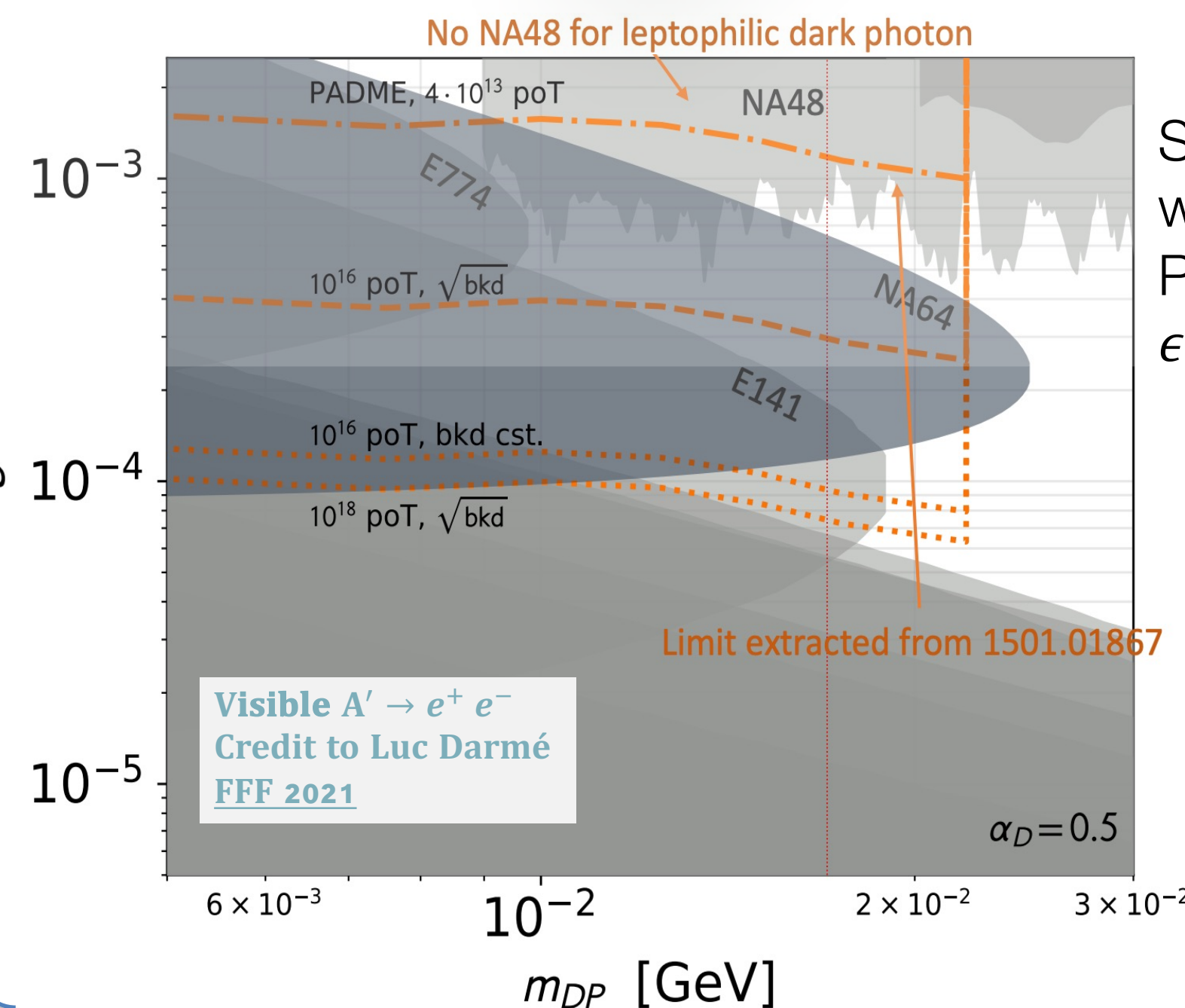
Searching for visible final states with 4×10^{13} positrons on target, PADME should be sensitive to $\epsilon > 0.9\times10^{-3}$.

EXPERIMENTAL STATUS

So far PADME has had 2 data-taking runs. The total number of positrons on target (POT) collected in these two runs is:
- Run 1 = 7×10^{12} POT
- Run 2 = 5.6×10^{12} POT
These numbers are measured with 5% precision.

Significant improvements to the beamline were performed between Run 1 and Run 2, reducing beam background and increasing $e^+e^- \rightarrow \gamma\gamma$ yield significantly.

PADME preliminary
normalised to $1.6\cdot10^7$ POT
normalised to $1.6\cdot10^{10}$ POT
normalised to $1.6\cdot10^{10}$ POT

Run 1 secondary beam — 25 kPoT, 545 MeV, 250 ns bunch
Run1 primary beam — 25 kPoT, 490 MeV, 250 ns bunch
Run2 primary beam, moved mylar window — 28 kPoT, 430 MeV, 280 ns bunch