DARK MATTER SEARCHES WITH PADME AT THE FRASCATI BTF

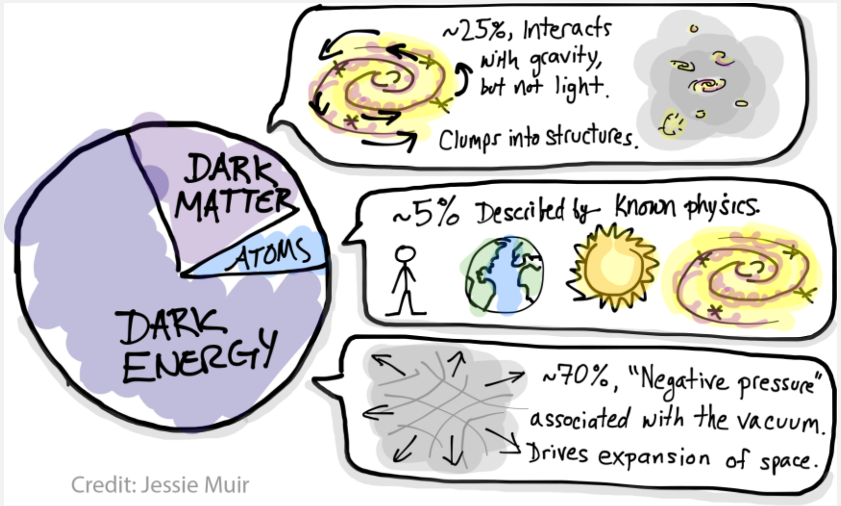
C. Taruggi for the PADME collaboration

EPS-HEP2023, Hamburg

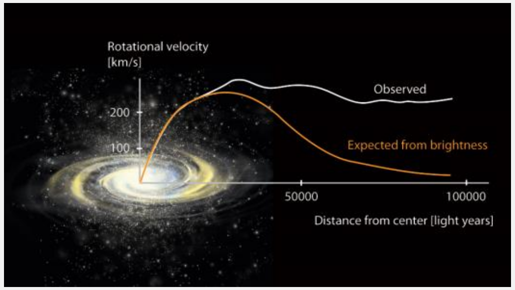
OUTLINE

- The dark matter (DM) problem
- The dark sector solution
- The PADME detector
- First runs physics results
- The beryllium anomaly: X17
- The X17 search at PADME
- Conclusions

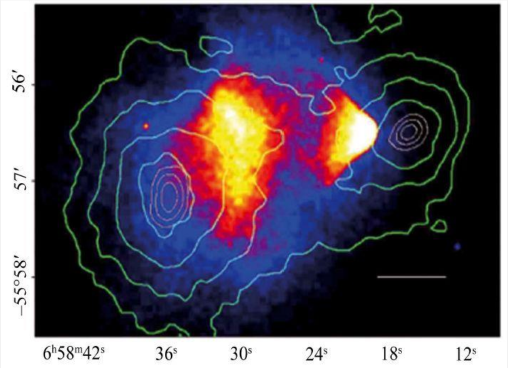
THE DM PROBLEM



- We observe cosmological phenomena that could not take place with the amount of matter we see in the Universe
- We could modify gravitational laws, but still not all these phenomena could be explained (i.e. bullet cluster)
- One possible solution is the existence of a new kind of matter, we could call dark matter (DM)



Galaxy velocities distribution

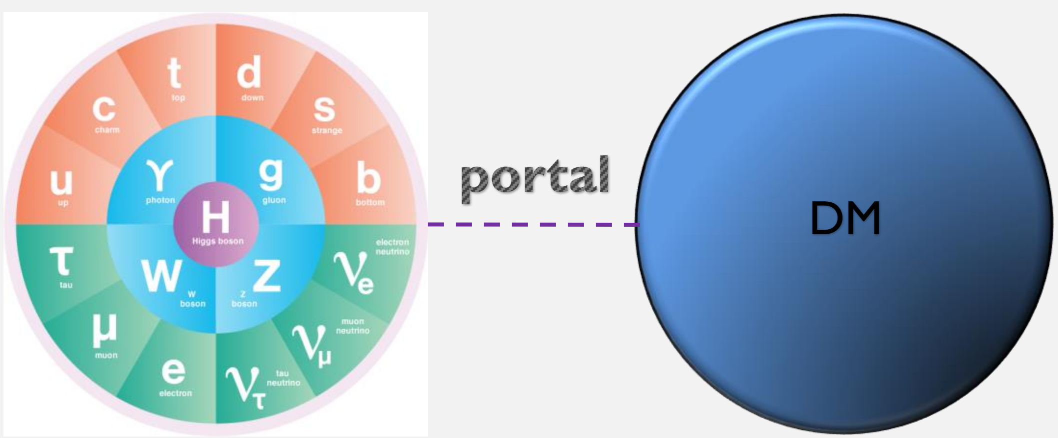


Bullet cluster

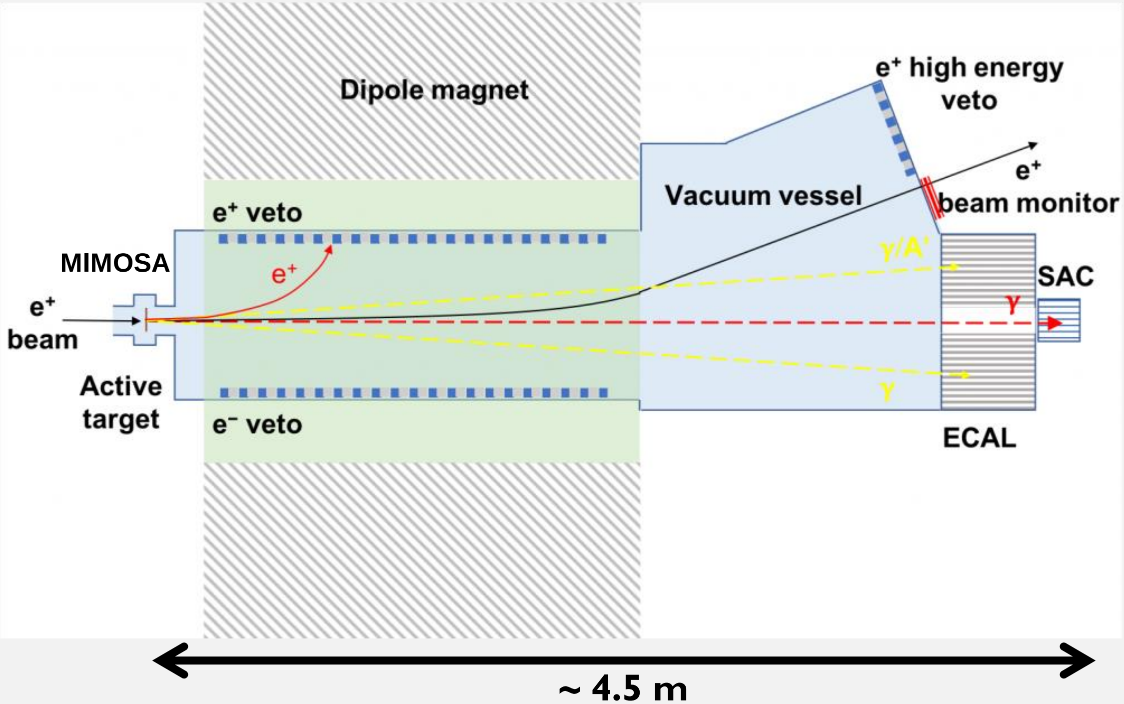
Gravitational lensing

THE DARK SECTOR SOLUTION

- After decades of searches dedicated to DM, we do not have a multiple-experiments shared proof of the detection of DM
- *One possible interpretation of this issue could be that DM lives in a separate world wrt to the one where SM particles live*
- These two worlds could be connected by a new interaction, whose mediator acts like a portal
- *We can call this separate world dark sector (DS), and the mediator dark photon (DP)*
- If the new interaction has a small coupling constant, one could explain why DM detection is so difficult

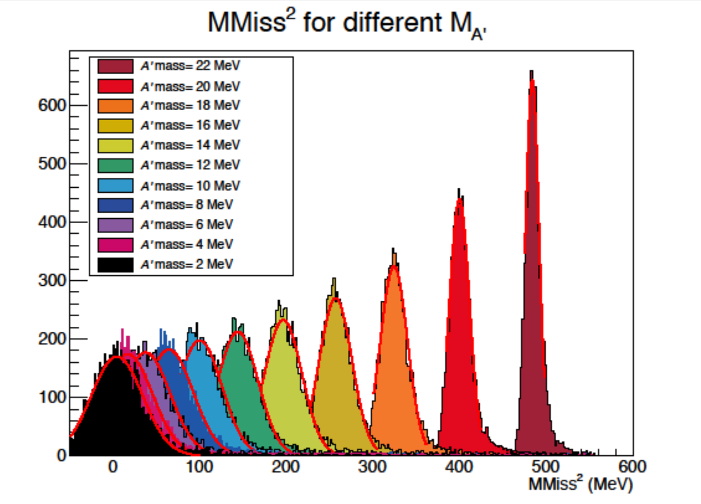


THE PADME DETECTOR



- POSITRON BEAM, ~25k-30k e^+ per bunch
- ACTIVE DIAMOND TARGET, 100 μm thickness
- MIMOSA, pixel beam 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)

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



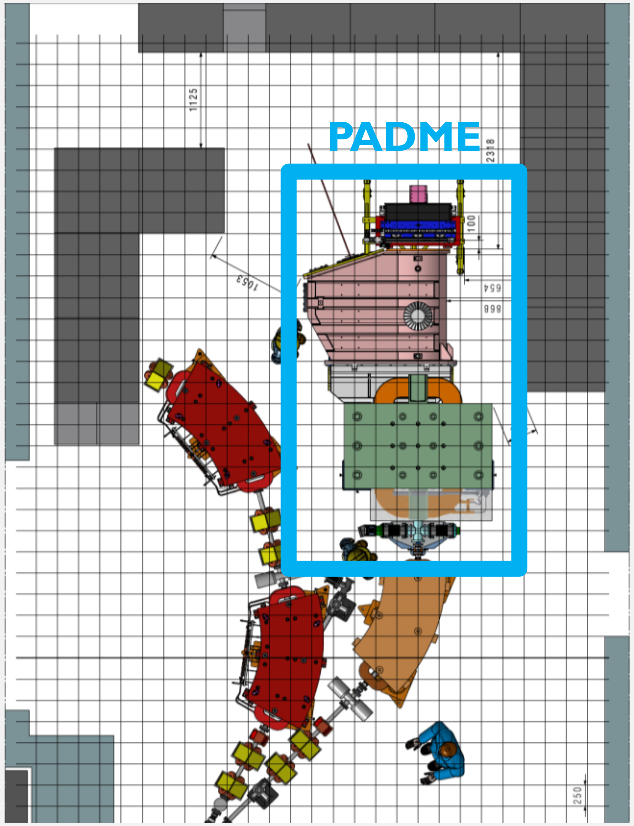
PADME is looking for the invisible decay of A' using a e^+ beam on a target:

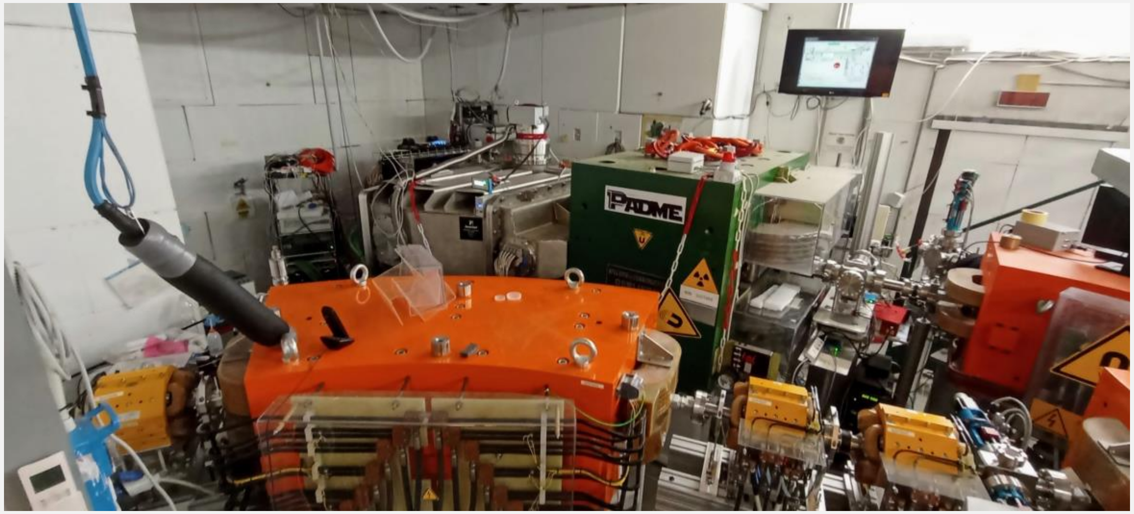
$$e^+e^- \rightarrow A'\gamma$$

with known beam energy and target at rest. The momentum of photon γ in the final state must be detected to close the kinematic of the reaction. The existence of A' can be observed as a peak in the missing mass distribution.

THE BEAM TEST FACILITY (BTF)

- At the BTF users can get electron/positron beams generated by the LINAC. Two beam lines are available
- PADME is installed on beam line 1 (BTF1)
- A beam with these properties allows exploring dark photon masses $m_{A'} \leq 23.7$ MeV
- A detailed MC simulation of the beamline was necessary to understand beam-induced background

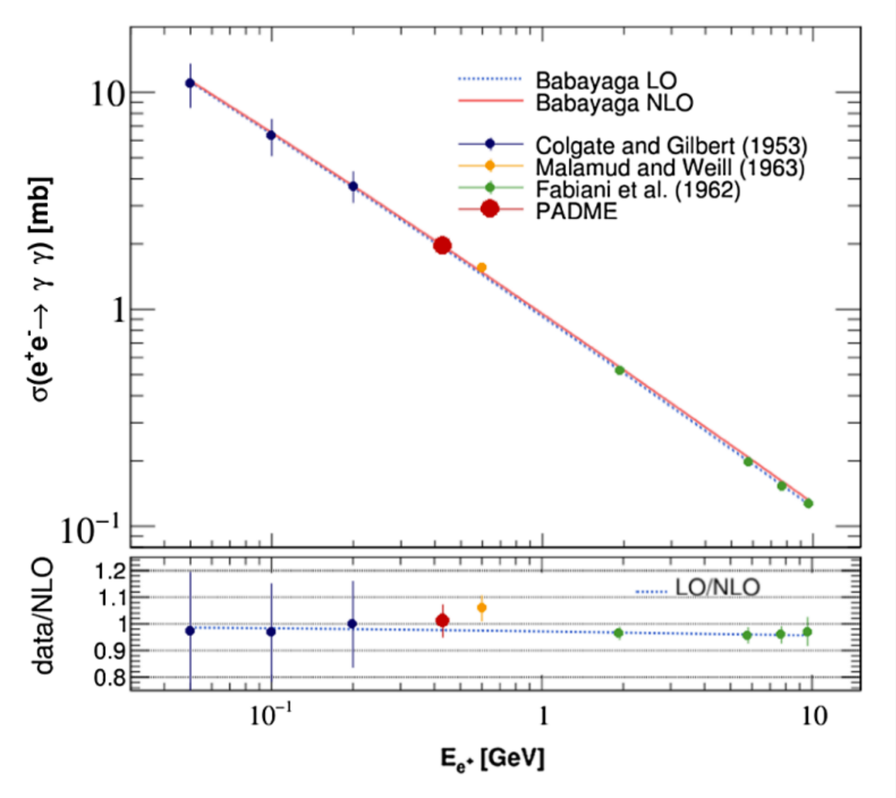




PADME beam:
energy 550 MeV (max),
multiplicity ~ 20k e^{+}/bunch,
bunch duration 200 ns,
frequency 49 Hz

FIRST RUNS PHYSICS RESULTS

- Two data taking were performed between 2018 and 2020
- Different configurations of the beamline were used in order to lower the beam-induced background
- The first measured physics process was the multi-photon annihilation $e^+e^- \rightarrow \gamma\,\gamma\,(\gamma)$ (Phys. Rev. D 107, 012008, I. Oceano)
- Last measurement under 500 MeV with a 20% precision was carried on in 1953

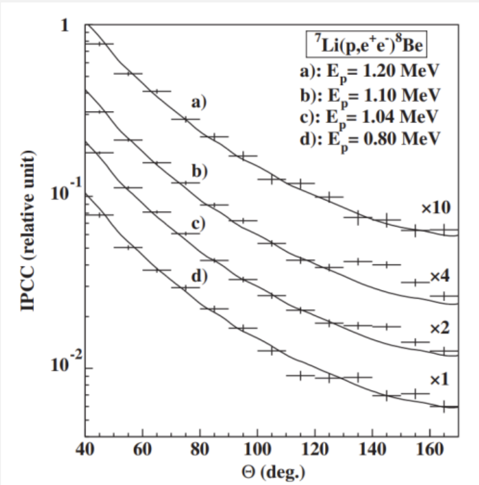


COMPARISON BETWEEN OUR EXPERIMENTAL RESULT AND THEORY PREDICTIONS, AT THE LEADING ORDER AND NEXT-TO-LEADING ORDER APPROXIMATION, FOR THE POSITRON ANNIHILATION CROSS SECTION IN FLIGHT AS A FUNCTION OF THE POSITRON ENERGY

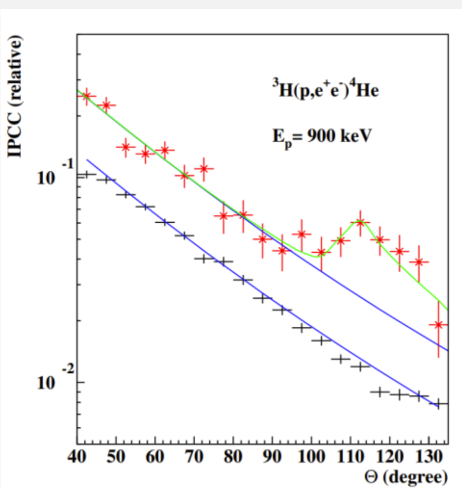
$\sigma(e^+e^- \rightarrow \gamma\gamma(\gamma))$ = 1.930 ± 0.029 (stat) ± 0.057 (syst) ± 0.020 (target) ± 0.079 (lumi) mb

QED @ NLO $\sigma(e^+e^- \rightarrow \gamma\gamma(\gamma))$ = 1.9573 ± 0.0005 (stat) ± 0.0020 (syst) mb

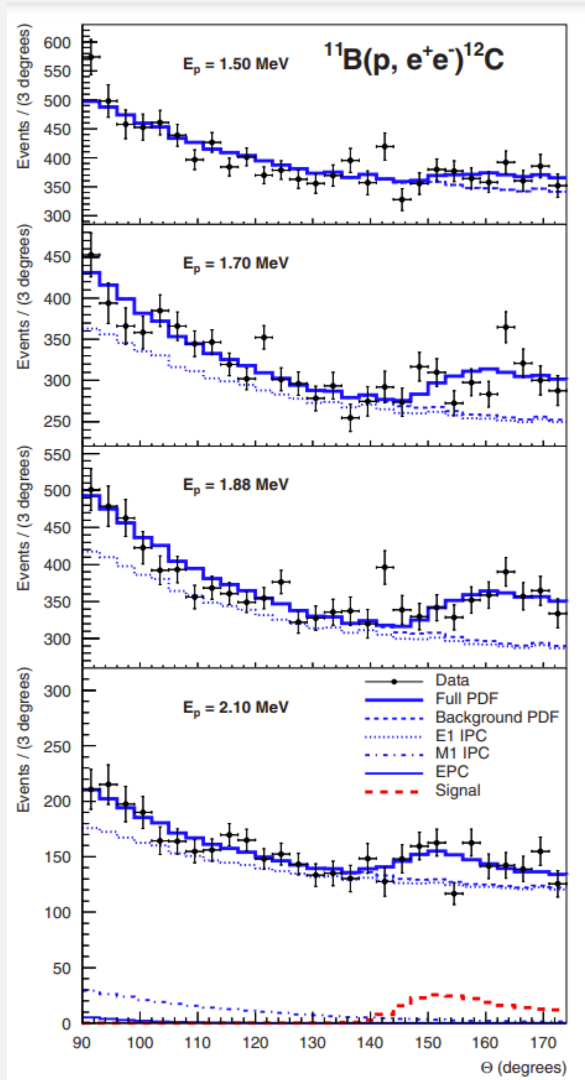
THE BERYLLIUM ANOMALY: X17



ANGULAR CORRELATIONS OF THE e^+e^- PAIRS ORIGINATED FROM THE 18 MeV TRANSITION OF THE ^{7}Li (p,γ); ^{8}Be REACTION



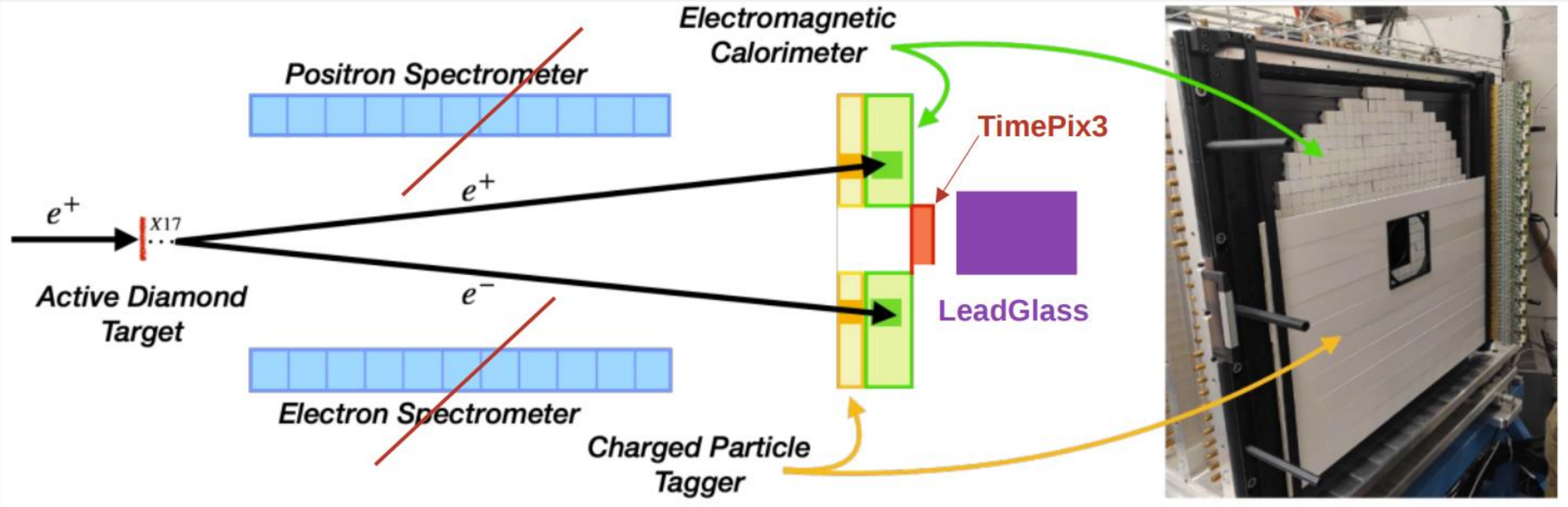
ANGULAR CORRELATIONS OF THE e^+e^- PAIRS MEASURED IN THE ^{3}H(p,γ); ^{4}He REACTION AT E_p=900 keV



ANGULAR CORRELATIONS OF THE e^+e^- PAIRS MEASURED AT DIFFERENT PROTON ENERGIES

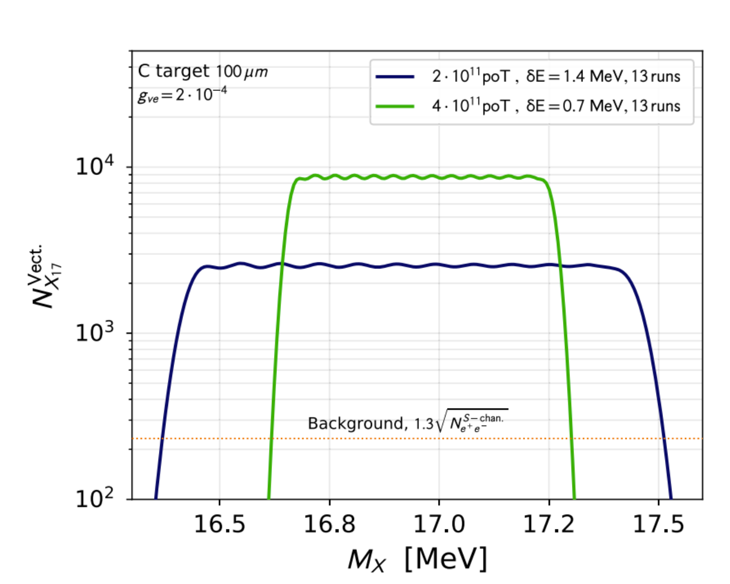
- During a nuclear experiment studying the IPC of ^{8}Be, the A. Krasznahorkay collaboration from ATOMKI (Hungary) discovered an anomaly in the angular emission of e^+e^- couples
- The same anomaly was observed in the decay of ^{4}He and ^{12}C
- The anomaly is compatible with the emission of a 17 MeV particle, called the X17 boson (most probably a vector particle)
- BTF is the only facility in the world that is able to deliver a positron beam with the precise characteristics to perform the resonant production of the X17 boson
- **Luckily, PADME was already there!**

THE X17 SEARCH AT PADME



- In order to perform the X17 measurement, PADME underwent a detector update
- The signal: $e^+e^- \rightarrow X17 \rightarrow e^+e^-$
- The magnetic field was turned off, so that the e^+e^- pairs can be detected by the ECal
- In order to discriminate between the γ and the e+/-, a plastic scintillator charged particle tagger (ETagger) was developed, and placed in front of the ECal
- The SAC was removed, in its place the TimePix3 beam monitor and a leadglass calorimeter were placed, used as luminosity monitor

THE RESONANT STRATEGY



Number of expected vector X17 as function of M_X, for the conservative (blue curve) and aggressive (dashed green) scanning configurations for $g_{Ve} = 2 \times 10^{-4}$. The dotted orange line corresponds to the square root of the number of Bhabha events

[«Resonant search for the X17 boson at PADME», Phys. Rev. D 106, 115036]

***Analysis strategy**: scan of the energy, luminosity calibration, fit of the background and search for resonance*

- The X17 boson could be produced at resonance in PADME/BTF
- The X17 production cross-section at resonance has a very sharp increase wrt to the background (mainly Bhabha)
- A beam energy of 282 MeV could lead to an available c.m. energy of $\sqrt{s} \approx 17$ MeV
- For this reason, an energy scan with step of 0.7 MeV was performed between 260 MeV and 300 MeV (10^{10} positrons on target per point, equal to ~ 25 h per point)
- The beam energy spread σ_E is a crucial parameter for the signal-to-background optimization:

$$N_{X17}^{Vect} \simeq 1.8 \times 10^{-7} \times \left(\frac{g_{Ve}}{2\times10^{-4}}\right)^2 \left(\frac{1\ MeV}{\sigma_E}\right)$$

- Main backgrounds: Bhabha scattering and γγ production

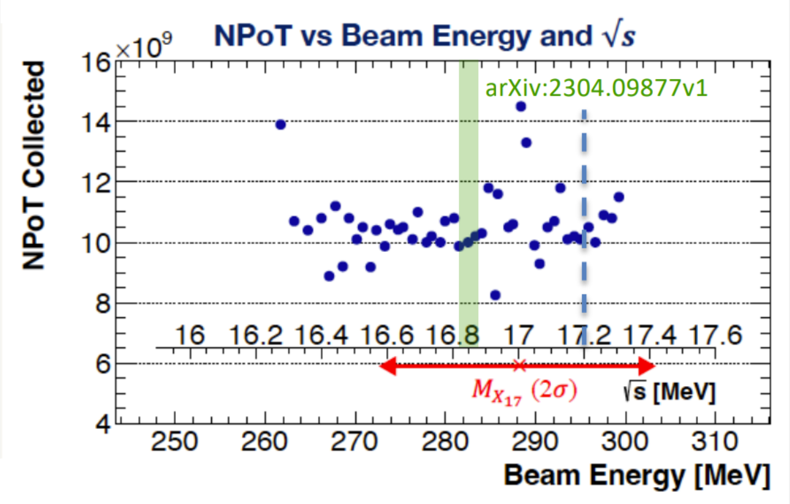
PRELIMINARY RESULTS

Data collected (10^{10} POTs per energy point):

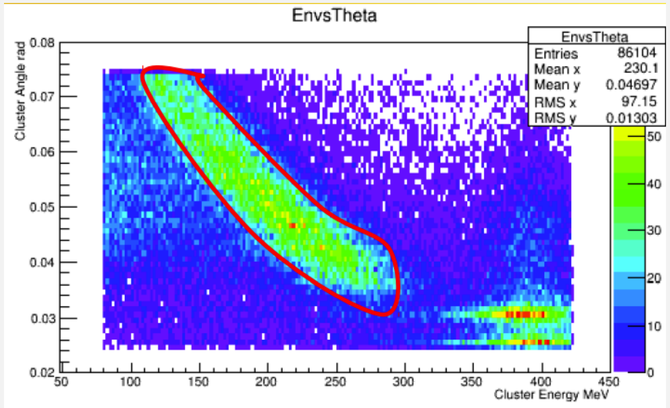
- 47 points around the X17 resonance
- 6 points out of resonance (5 below, 1 above), to compare data/MC and check the systematics
- 3 points without target (for background studies)

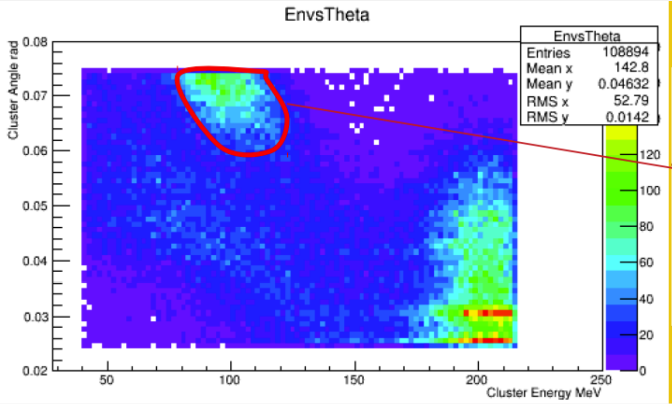
First studies: $N(e^+e^- + \gamma\gamma)/N_{POT}$

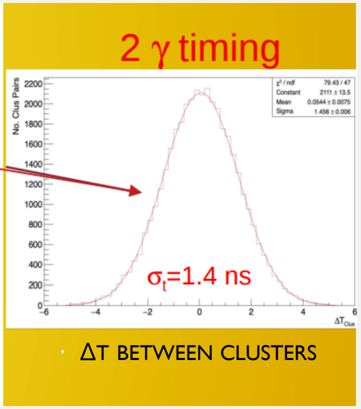
A good signal/background separation can be obtained using the kinematic relation between E_γ and θ_γ, and 2 clusters in time in ECal (Δt < 5 ns).



BLUE: ENERGY POINTS COLLECTED BY PADME
RED: MASS RANGES COVERED BY ATOMKI
GREEN: MASS RANGE FIT RESULTS AS IN ARXIV:2304.09877V1 (^{8}Be AND ^{4}He)
DASHED: MASS LIMIT FROM ARXIV:2209.10795V2 (^{12}C)



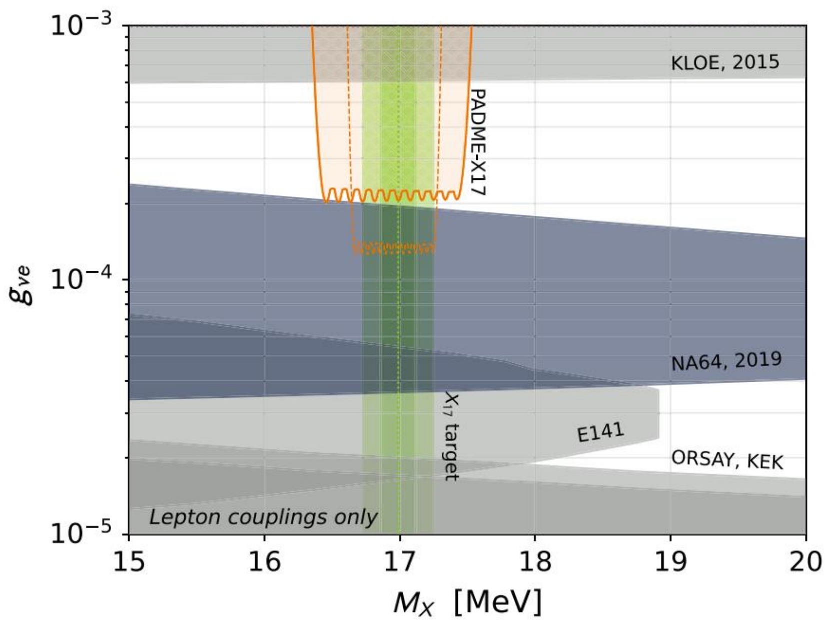




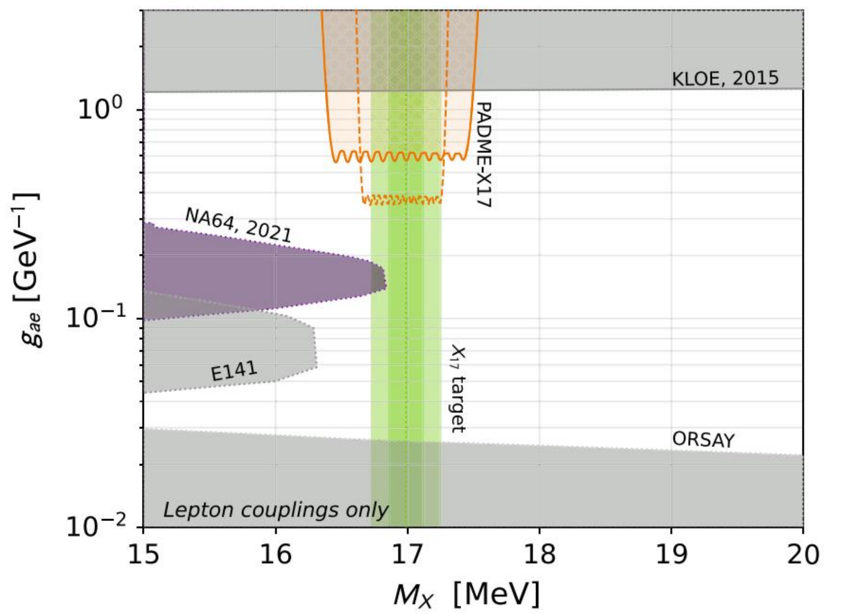
CLUSTER ANGLE VS CLUSTER ENERGY ABOVE RESONANCE (LEFT) AND BELOW (RIGHT)

EXPECTED SENSITIVITIES

PADME maximum sensitivity is achieved in the vector case.



VECTOR



PSEUDO-SCALAR

CONCLUSIONS

- PADME studies the annihilation process e^+e^- using a positron beam (max energy 550 MeV) on a fixed target to produce new physics particles
- PADME first two data taking (2018 – 2020) were crucial to optimize the beam and to finalize the detector calibrations and data reconstruction
- A reliable Montecarlo simulation of the experiment, including the beam line, has been developed
- The first physics result, regarding the multi-photon annihilation $e^+e^- \rightarrow \gamma\,\gamma\,(\gamma)$, was published (Phys. Rev. D 107, 012008)
- PADME third data taking (2022) was carried out to search for the X17 boson, a particle that could be involved in the anomaly decay of ^{8}Be, ^{4}He and ^{12}C observed by A. Krasznahorkay collaboration
- The preliminary studies on backgrounds are promising, and backgrounds looks under control
- The analysis strategy for the X17 search can be found in Phys. Rev. D 106, 115036