

Dark matter searches with PADME

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on behalf of the PADME Collaboration

PPC 2022, WU in St. Louis



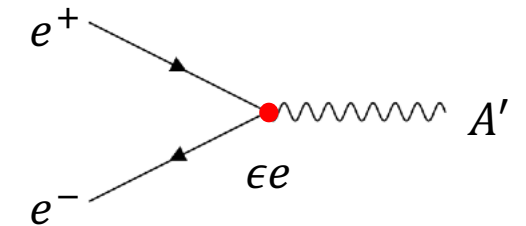
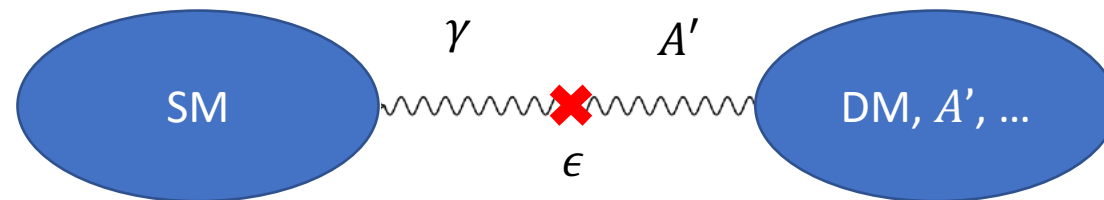
A complex dark sector and the dark photon

- Dark matter could belong to a complex dark sector
- Simple extension of the standard model (SM) is the **dark photon (A')**:
 - A' is the gauge boson of a new symmetry, $U(1)_D$, similar to photon in SM
 - Only dark matter is charged under this gauge symmetry
 - SM permits a “bridge” to the dark sector via a special γ - A' coupling:
 - Additional Lagrangian term creates an EM - A' current:
 - Finally, mass is allowed via symmetry breaking:

$$-\epsilon F'_{\mu\nu} B^{\mu\nu}$$

$$+\frac{1}{2}m_{A'}^2 A'^{\mu} A'_{\mu}$$

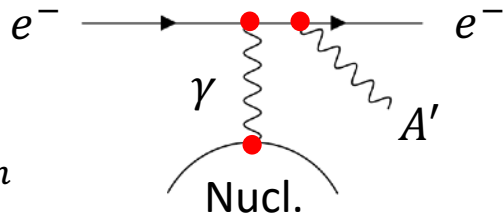
$$+\epsilon e A'^{\mu} J_{\mu}^{EM}$$



A' production and decay in accelerators

- “ A' -strahlung”

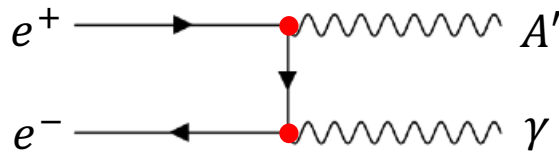
$$\sigma \propto \frac{\epsilon^2 \alpha^3}{m_{A'}^2} \quad m_{A'} < E_{beam}$$



- Associated production

$$\sigma \propto \epsilon^2 \alpha^2$$

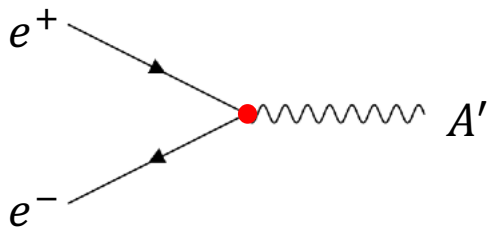
$$m_{A'} < \sqrt{2m_e E_{beam}}$$



- Resonant annihilation

$$\sigma \propto \epsilon^2 \alpha$$

$$m_{A'} \approx \sqrt{2m_e E_{beam}}$$



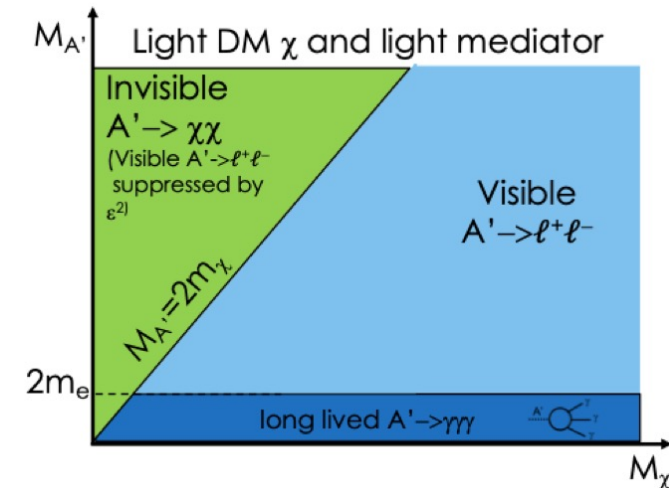
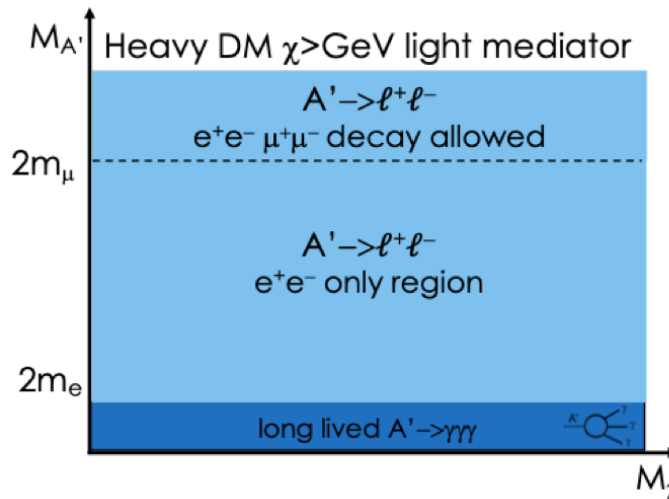
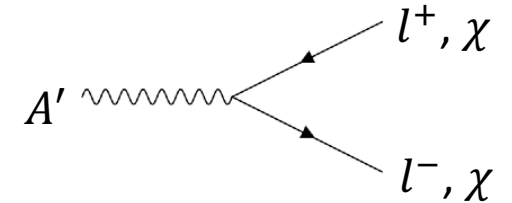
Only possible with positron beam!

Decays:

- $2m_e < M_{A'} < 2M_{DM} \rightarrow$ SM particles only

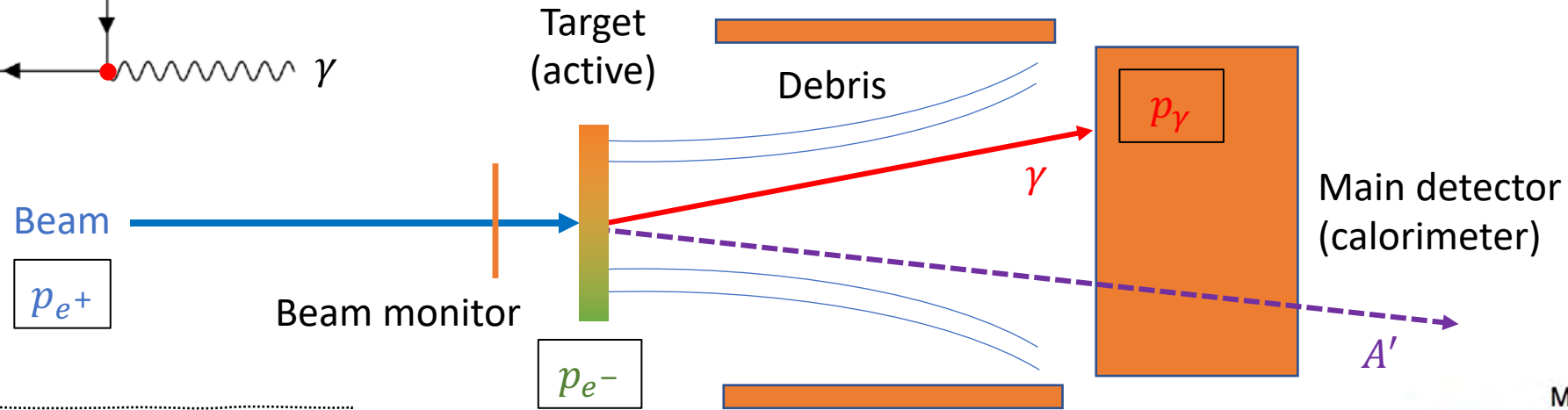
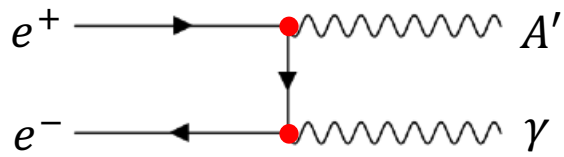
- $2M_{DM} < M_{A'} \rightarrow$ Invisible decays allowed

PADME's main target

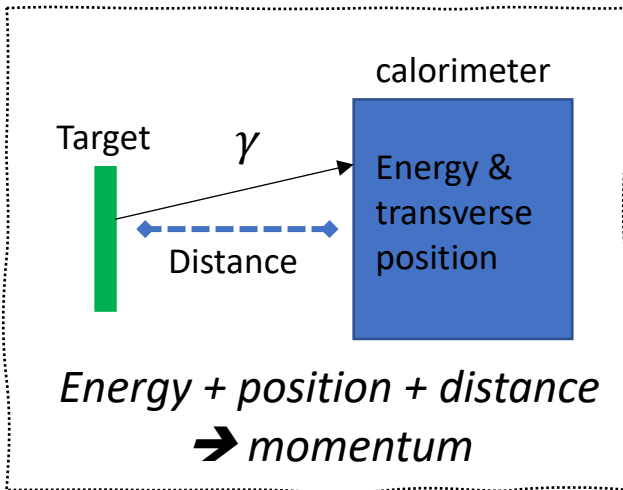


I. Oceano

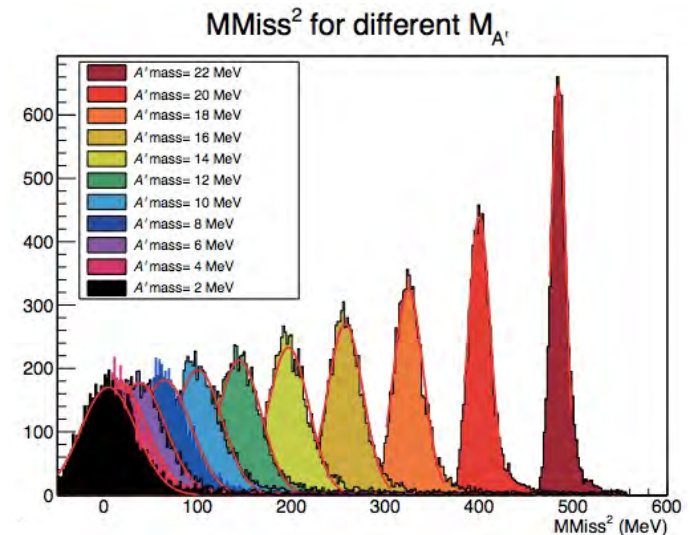
Missing-mass technique in fixed-target expts.



Search for bump in m_{miss}^2 :



$$m_{miss}^2 = (p_{e^+} + p_{e^-} + p_\gamma)^2$$





Positron Annihilation into Dark Matter Experiment

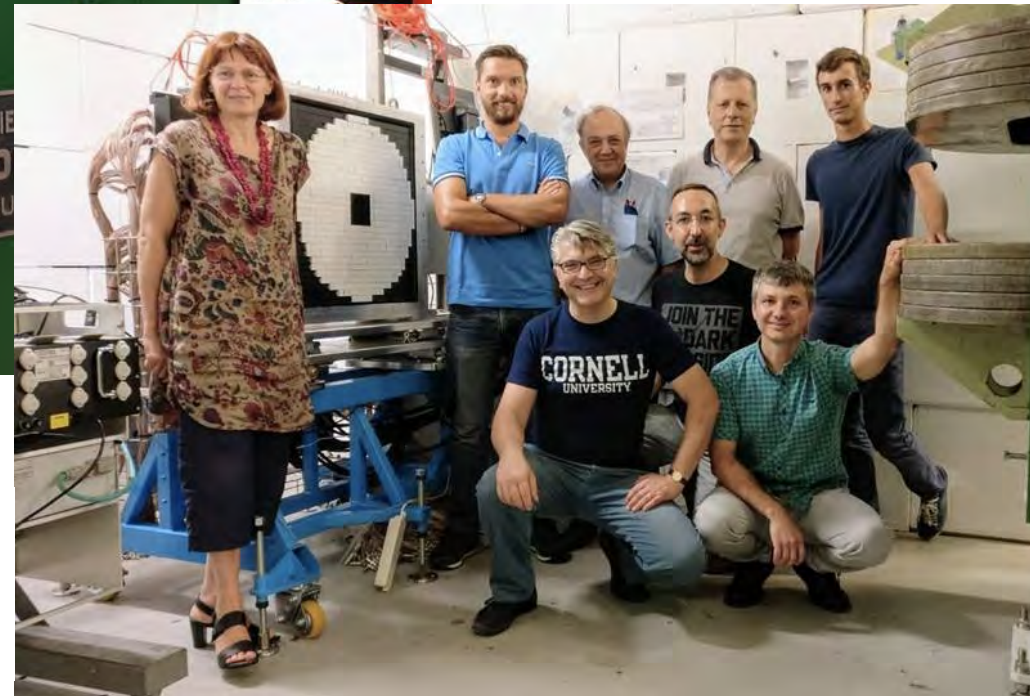


- Near Rome, Italy
- ~ 30-pp collaboration

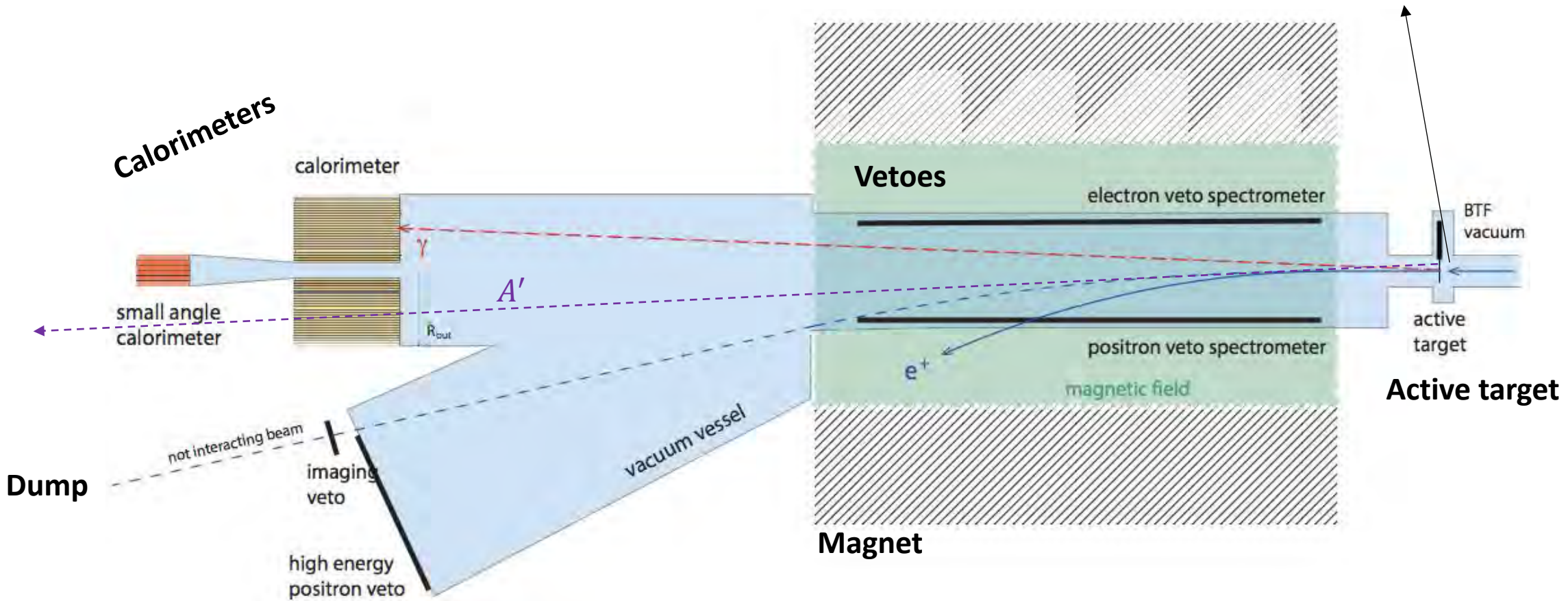
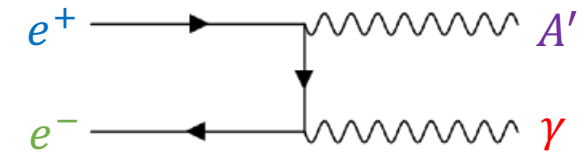


Fixed-target experiment

- ~ 500 MeV positrons
- ~ 25k POT / bunch
- Bunch length ~ 200 ns

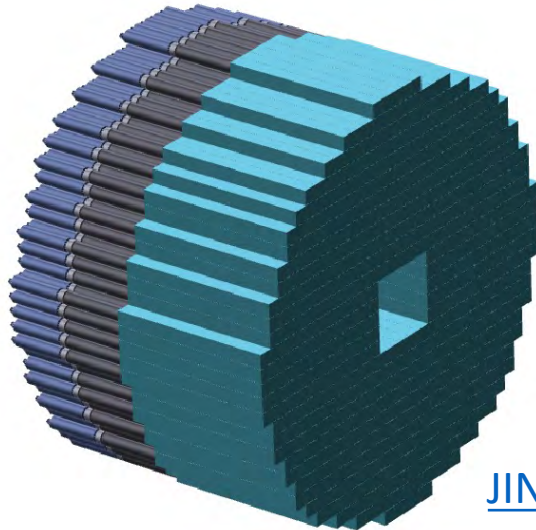


PADME detectors



$$m_{miss}^2 = (p_{e^+} + p_{e^-} + p_{\gamma})^2$$

PADME calorimeters

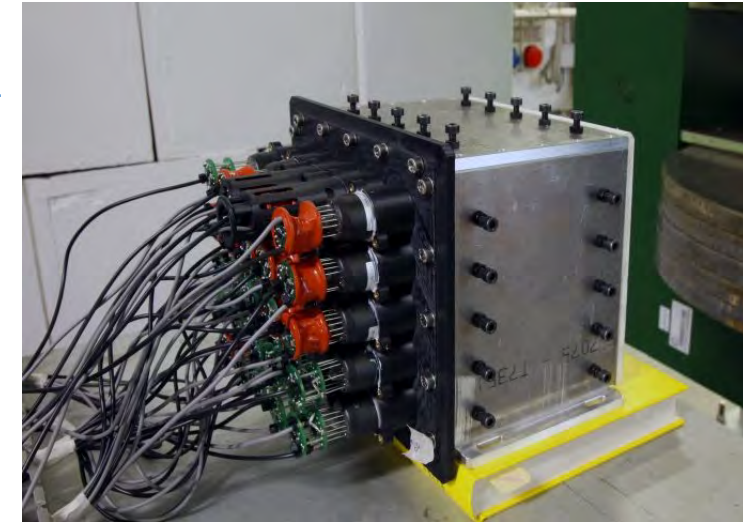


[NIM A 919 \(2019\) 89](#)

[JINST 15 \(2020\) T10003](#)

Electromagnetic calorimeter

- 616 scintillating BGO crystals from old L3 expt. at LEP
- 3 m downstream of target
- Single-crystal dimensions: $2.1 \times 2.1 \times 23 \text{ cm}^3$
- BGO scintillation time: $\sim 300 \text{ ns}$
- Central square hole (5x5 SC) to evade Bremsstrahlung
- Angular reach: 20–65 mrad
- Energy resolution: $\sim 2\%/\text{Sqrt}[E]$

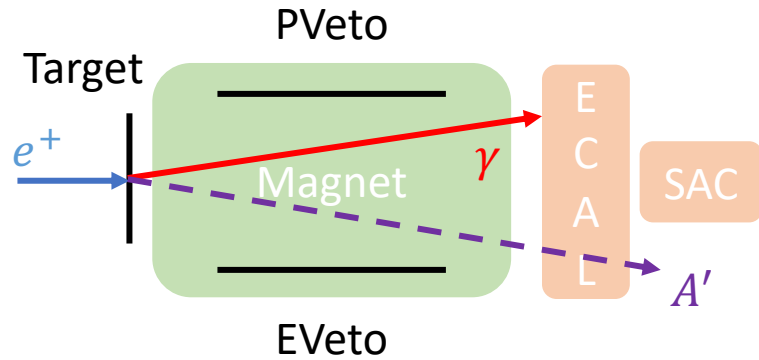


Small-angle calorimeter

- 25 Cherenkov PbF_2 crystals
- Immediately downstream of ECAL
- Single-crystal dimensions: $3.0 \times 3.0 \times 14 \text{ cm}^3$
- PbF_2 dead time: $\sim 3 \text{ ns}$
- Fits behind the ECAL central square hole
- Angular reach $< 20 \text{ mrad}$
- Energy resolution: $\sim 6\%/\text{Sqrt}[E]$

Main physics backgrounds

- **Signal: one photon in ECAL**

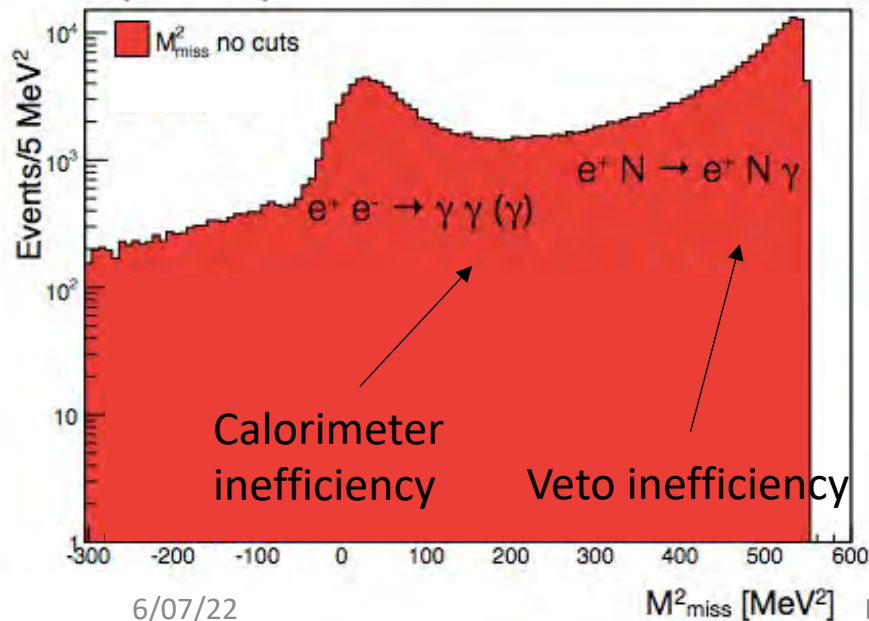
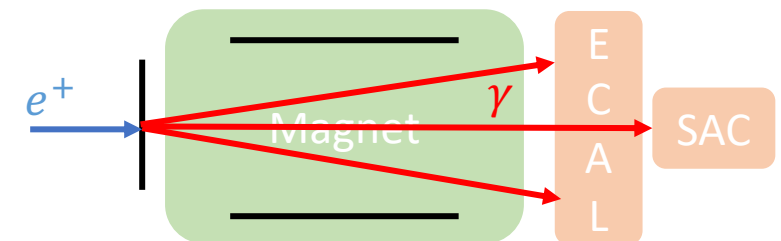
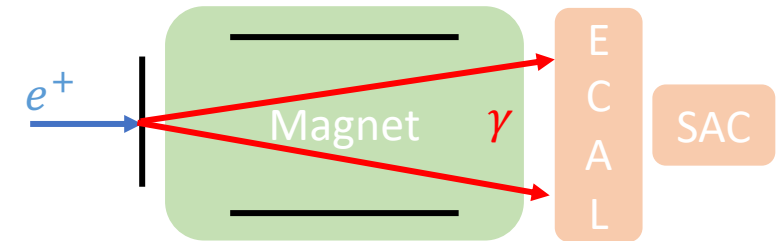
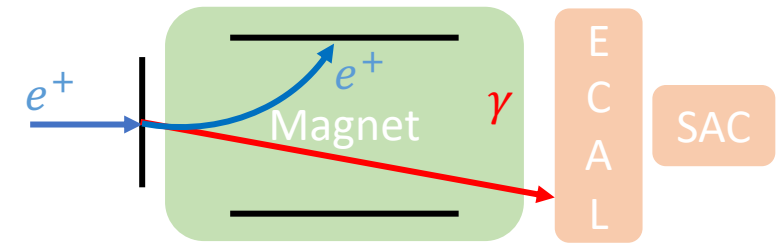


- Bremsstrahlung:
 $\sigma(e^+N \rightarrow e^+N\gamma) = 4000 \text{ mb}$
 One photon in ECAL +
 One positron in veto
 Sum of energies = beam energy

- 2γ -annihilation:
 $\sigma(e^+e^- \rightarrow \gamma\gamma) = 1.55 \text{ mb}$
 Two photons in ECAL
 Correlated energy and angle

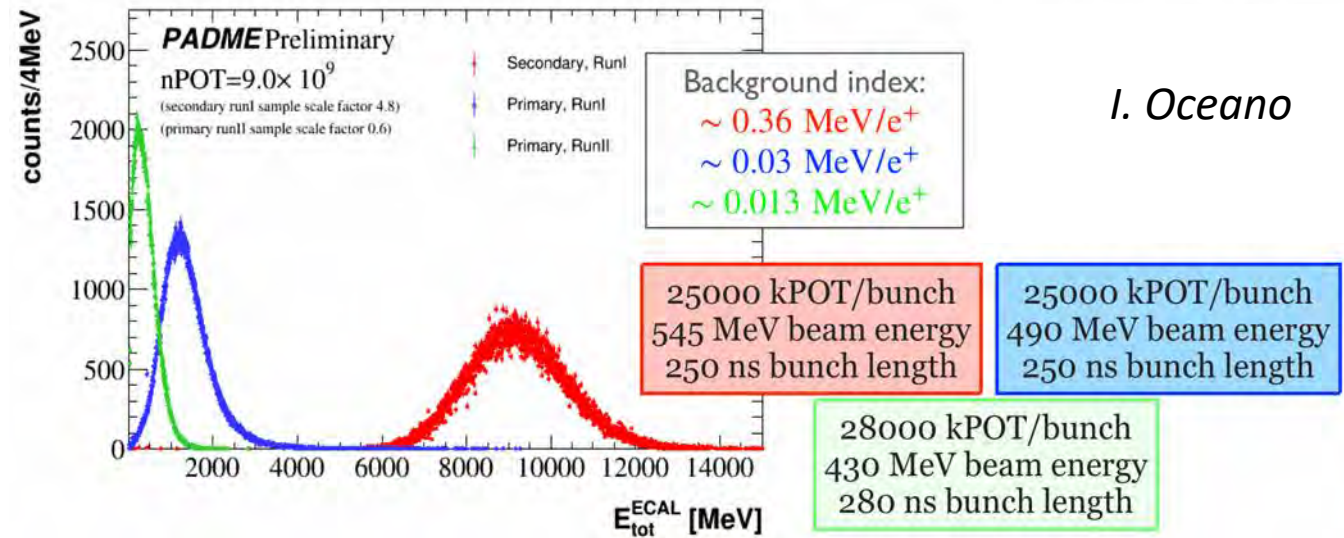
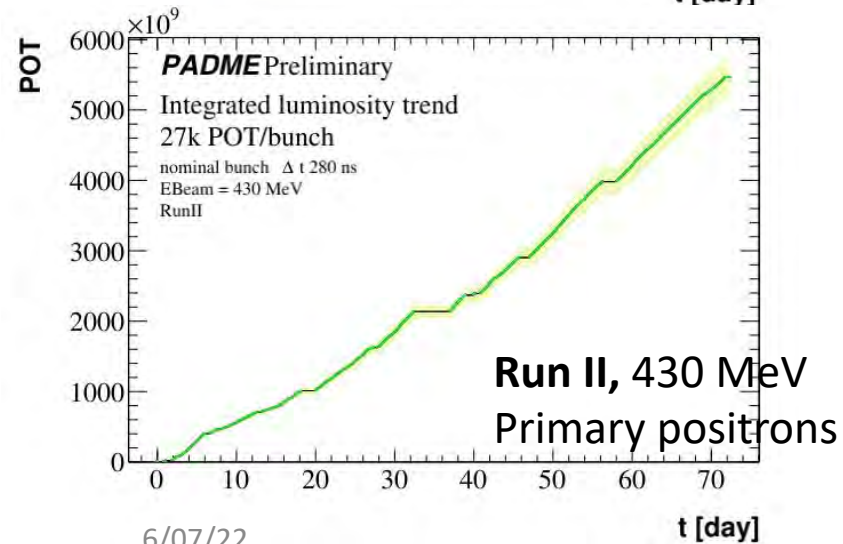
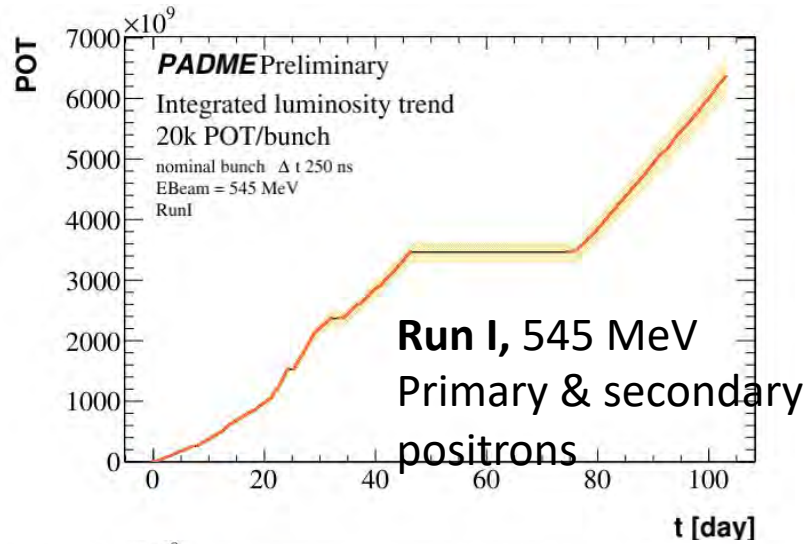
- 3γ -annihilation:
 $\sigma(e^+e^- \rightarrow \gamma\gamma\gamma) = 0.08 \text{ mb}$
 Two photons in ECAL +
 one photon in SAC
 No kinematic constraints

* σ at 550 MeV beam energy





PADME data taking and beam background

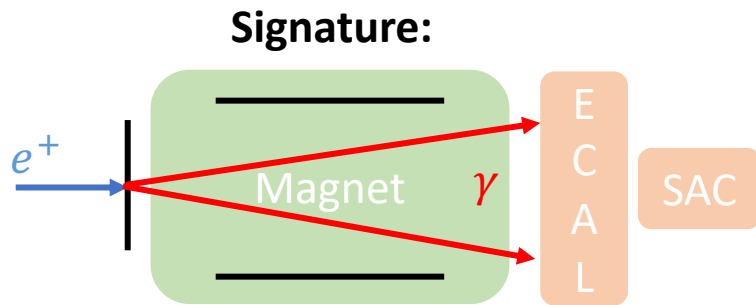


I. Oceano

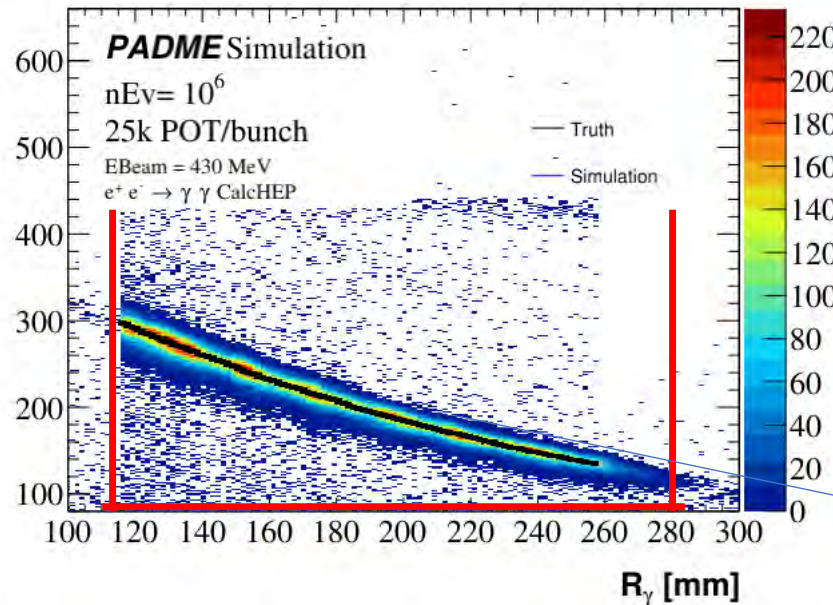
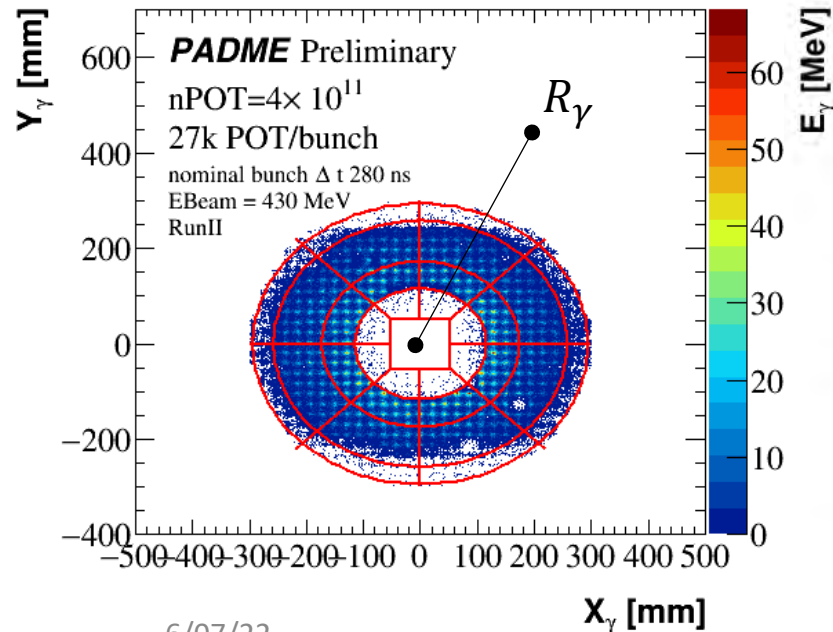
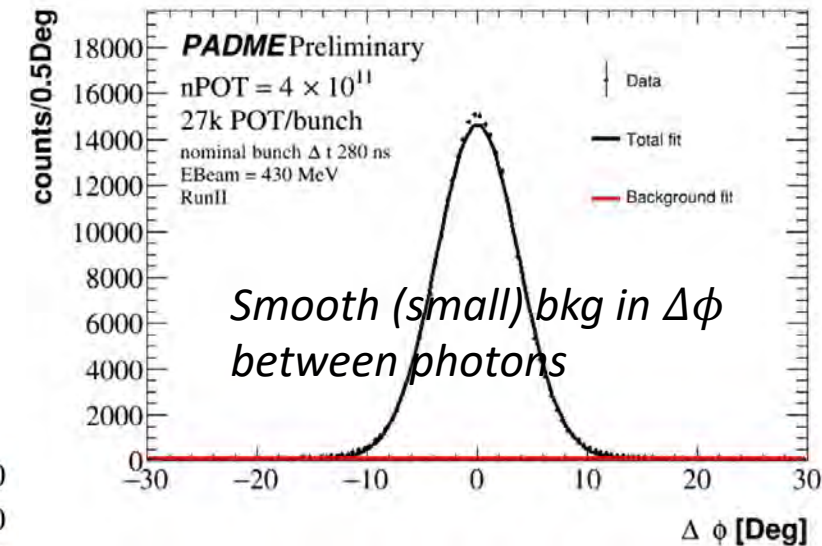
- Unexpected beam background in Run I caused significant more energy deposition in ECAL than predicted
- Culprit was the showering of primary beam positrons on the Beryllium window separating the accelerator vacuum from the experimental vacuum
- Developed comprehensive MC simulation to study and mitigate this background in Runs II and III

[arXiv: 2204.05616](https://arxiv.org/abs/2204.05616)
(submitted to JHEP)

New $e^+e^- \rightarrow \gamma\gamma$ cross-section measurement



- 2 γ -selection:**
- $|\Delta t| < 10$ ns between photons
 - $E_\gamma > 90$ MeV for both photons
 - $115.9 < R_{\gamma_1} < 285$ mm
 - $|\Delta E(\theta)| < 100$ MeV for both



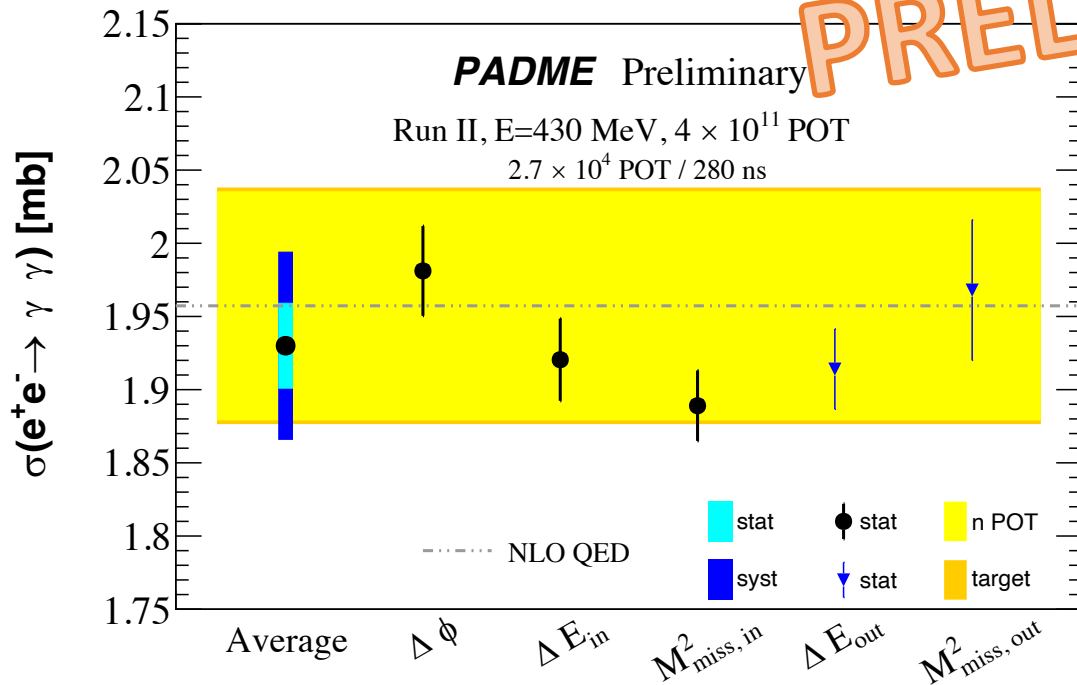
- Signal extraction:**
- Use the kinematic observable $\Delta\phi = \phi_1 - \phi_2 + \pi$ to fit signal and background
 - Extract signal yield (3×10^5) and derive cross-section

Correlation $f(R_\gamma(\theta_\gamma))$ derived w/ MC
 \rightarrow define $\Delta E = E_\gamma - f(\theta_\gamma) \approx 0$ MeV

Precise $\sigma(ee \rightarrow \gamma\gamma)$ at low $\sqrt{s} = 21$ MeV

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

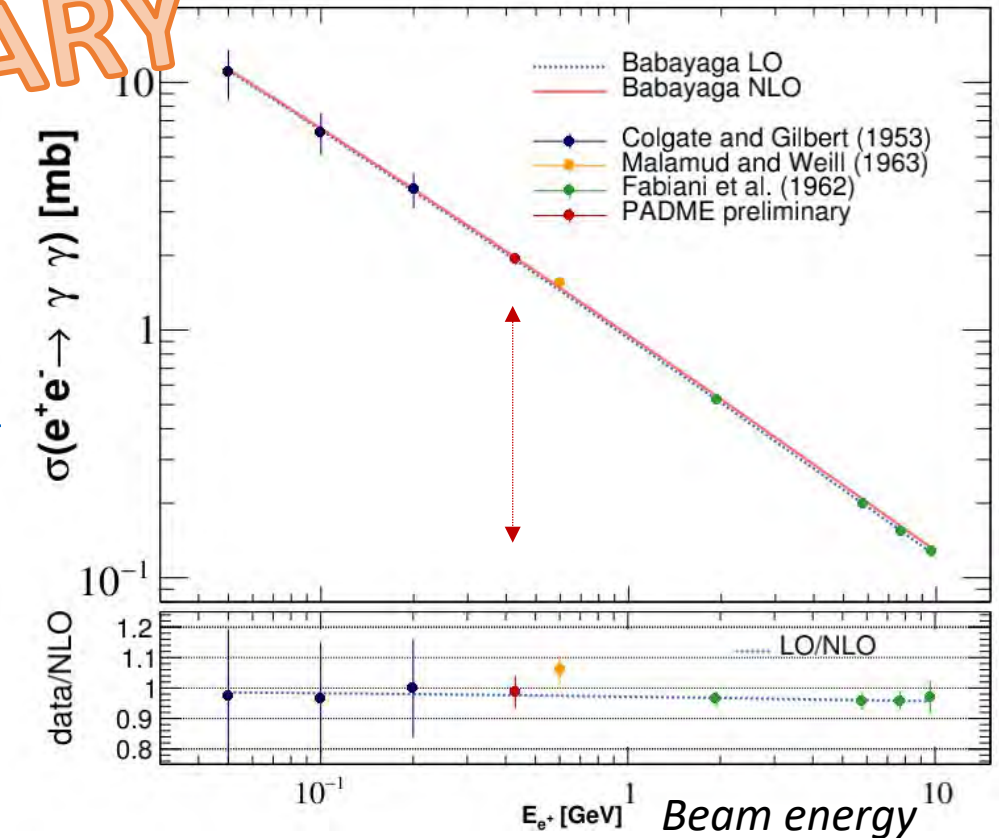
$$\sigma(e^+e^- \rightarrow \gamma\gamma(\gamma)) = 1.9573 \pm 0.0005 \text{ (stat)} \pm 0.0020 \text{ (syst)} \text{ mb} \text{ (QED@NLO)}$$



PRELIMINARY

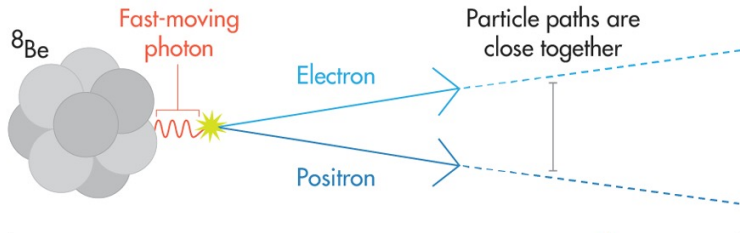
QED@NLO
[arXiv:0801.3360](https://arxiv.org/abs/0801.3360)
(Babayaga)

In preparation

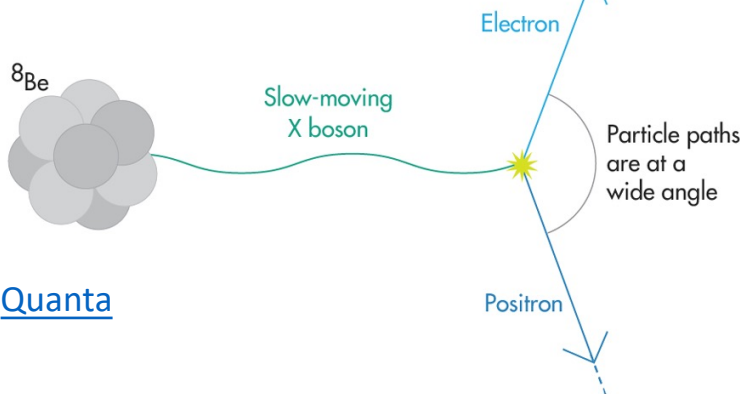


X17 search and resonant production

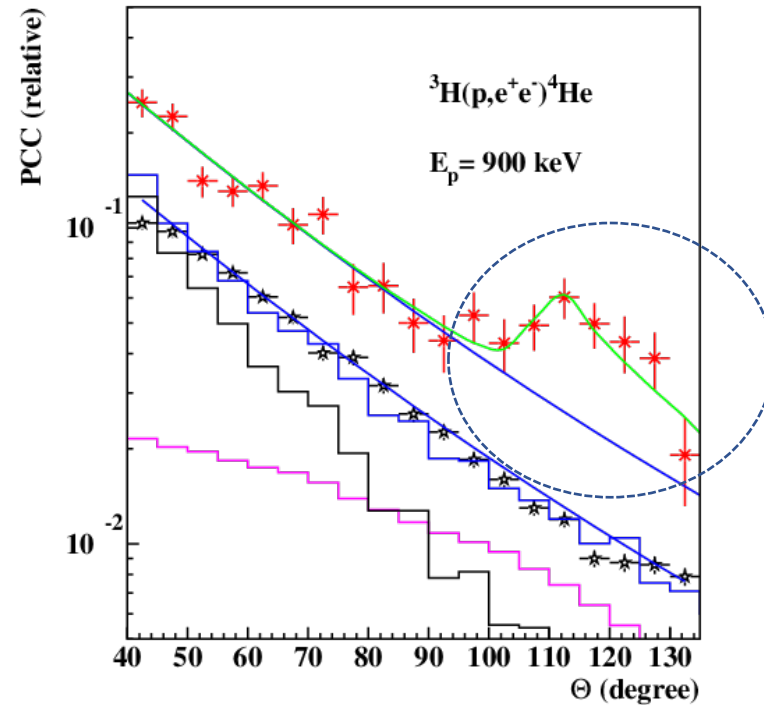
EXPECTED ^8Be TRANSITION



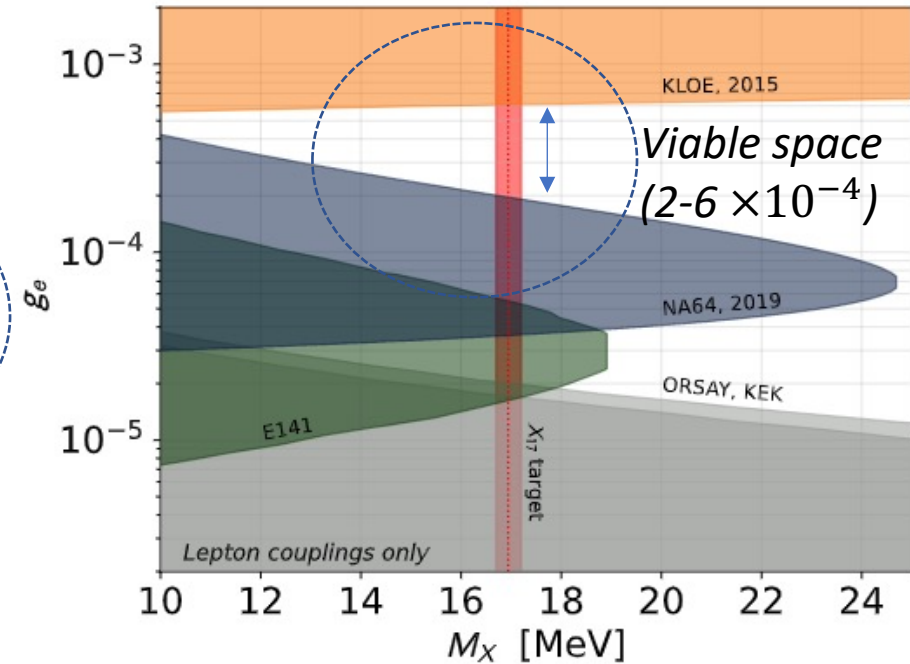
HYPOTHETICAL



[Quanta](#)



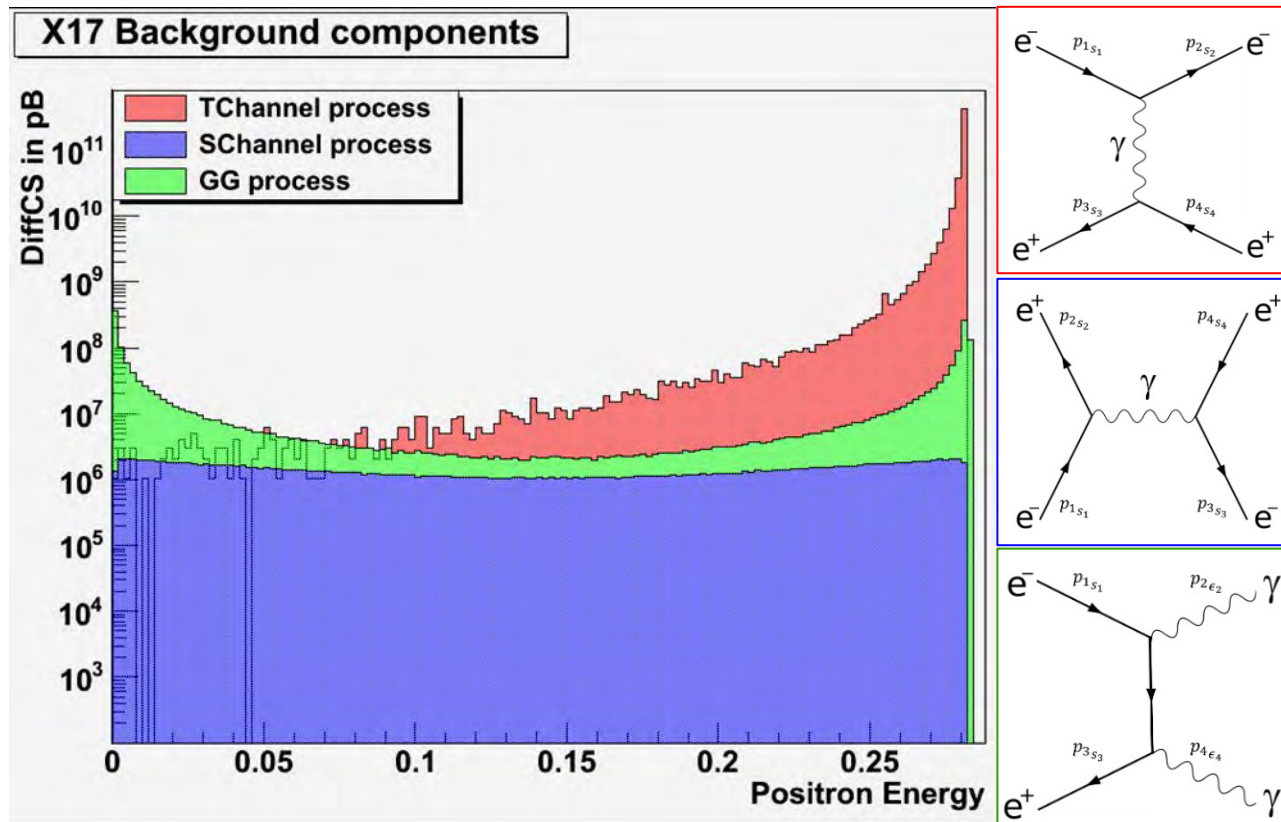
L. Darmé, E. Nardi, M. Raggi



- Recent results indicate anomalous excesses in ^4He and ^8Be atomic measurements of internal pair creation
- A possible explanation is the existence of a new protophobic boson with 16.7 MeV mass (X17)
- Some viable parameter space remains, which PADME has the capability to investigate with reasonable statistics

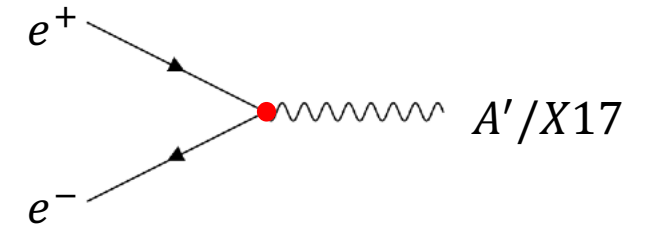
PADME search for X17 in Run 3

Main backgrounds:

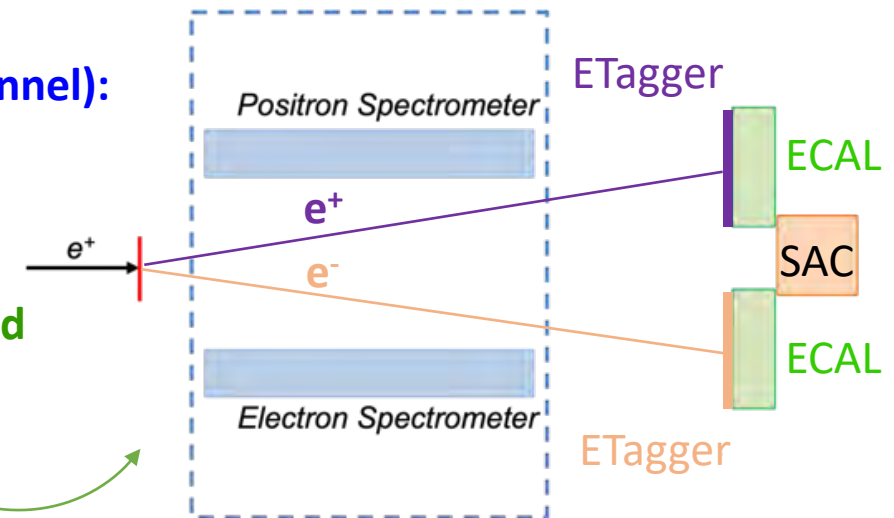


Resonant production:

$$E_{beam} = 282 \text{ MeV}$$



New detector to distinguish e/γ ECAL clusters:

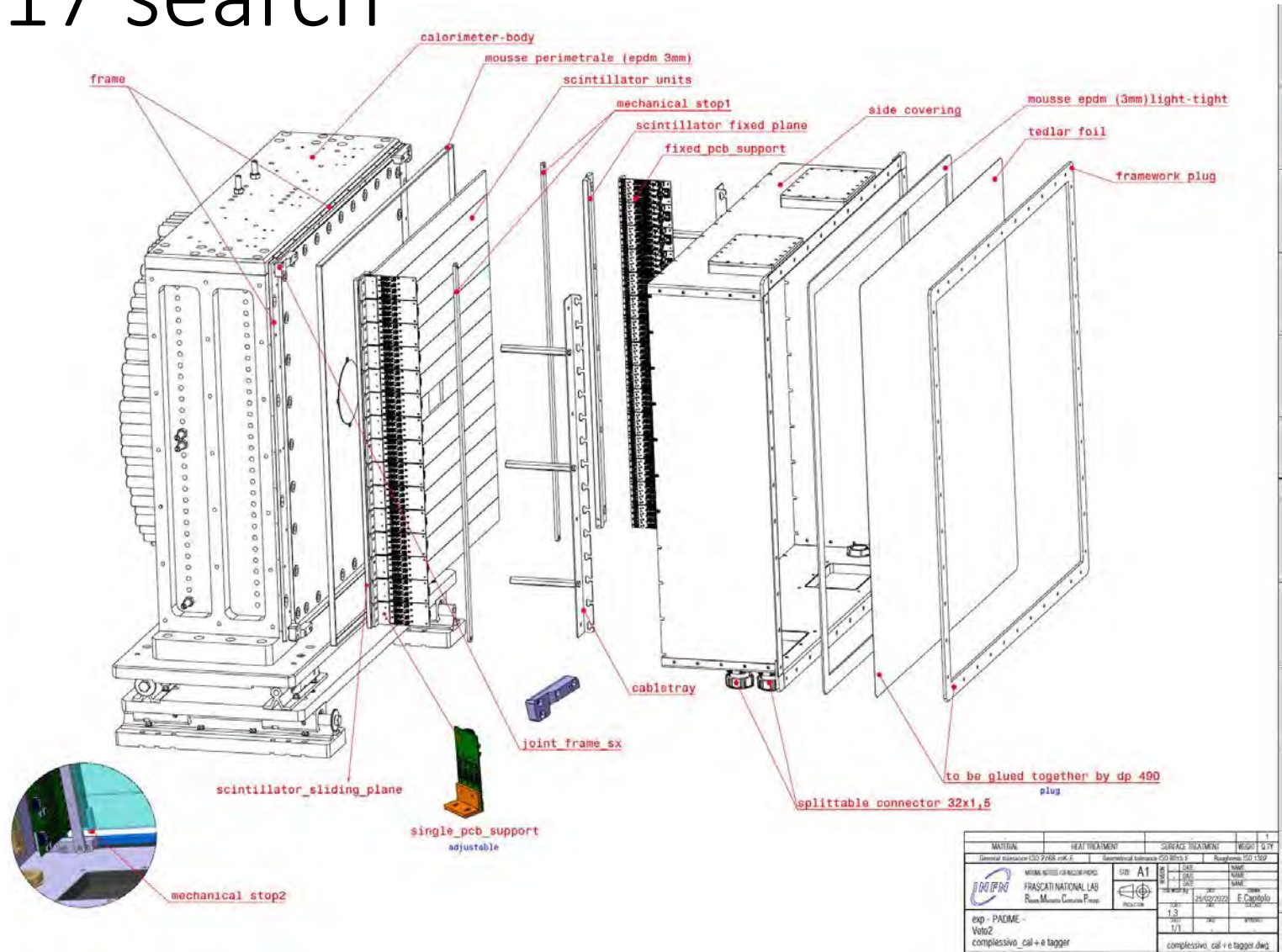
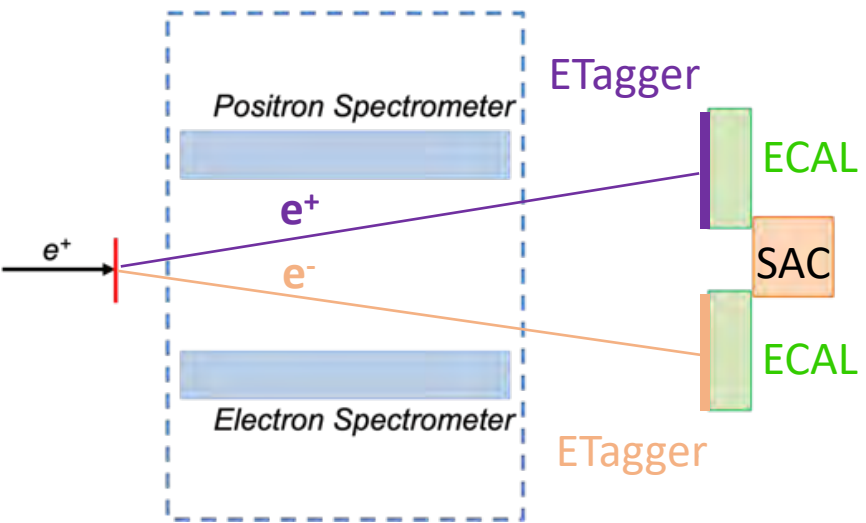




Conclusions

- PADME is a fixed-target experiment with a unique positron beam searching for the dark photon using a missing-mass technique
- Sensitive to low-mass dark photons in the range ~ 20 MeV, with a positron beam energy of ~ 500 MeV
- First two data-taking runs enabled the calibration and commissioning of the experiment, as well as a precise measurement of $\sigma(e^+e^- \rightarrow \gamma\gamma)$ at $\sqrt{s} = 21$ MeV \rightarrow first improvement in several decades
 - Dark photon analysis on this dataset currently underway
 - Other models (e.g., ALPs, scalar Higgs) are also under consideration
- Next run of PADME will be dedicated to a direct search for X17 using resonant production with a beam energy of 282 MeV, and a new electron tagger
- Stay tuned for more results from PADME soon!

New tagger for X17 search



MATERIAL	HEAT TREATMENT	STORAGE TREATMENT	WEIGHT	QTY
General reference: ISO 2768 mSf, 6	Dimensional tolerance: ISO 2768 mSf, 6	Reference: ISO 1509		
FRASCATI NATIONAL LAB Rome, Museo Galileo Firenze	SIZE: A1	DATE: 25/02/2022	1.3	1/1
exp - PADME - Voto2				
complessivo_cal++e_tagger				