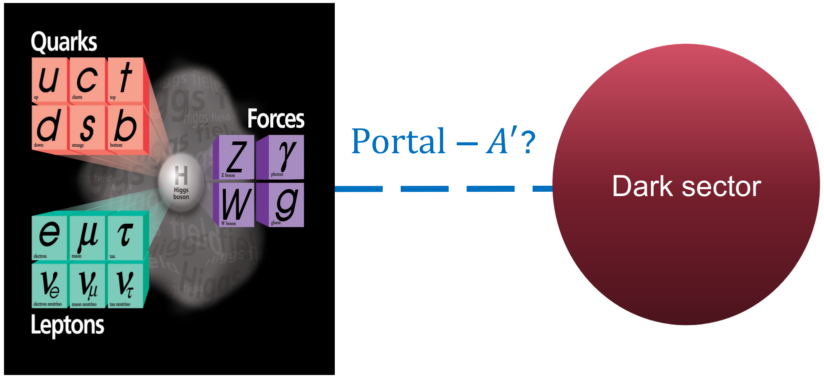
The PADME Experiment

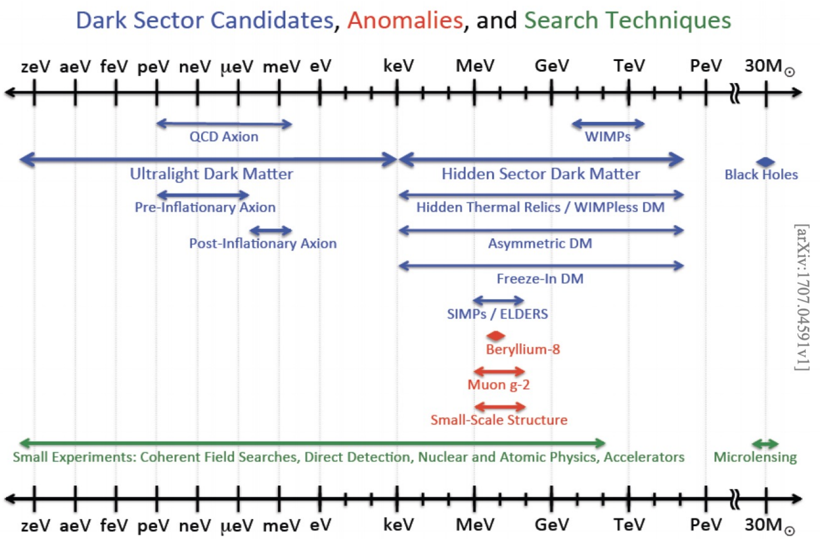
Elizabeth Long

Sapienza Università di Roma/INFN Sezione di Roma

The Dark Photon

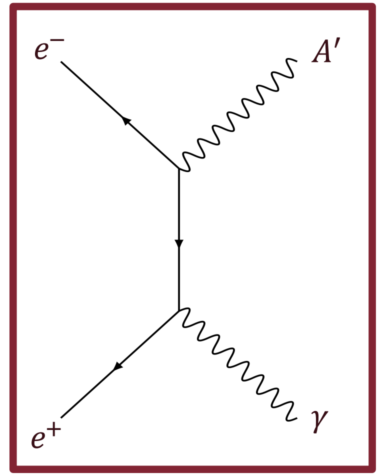
- Among the simplest SM extensions, “portal” models are good candidates for DM
- These models predict the existence of a new mediator particle which would couple both to dark sector particles and (feebly) to the SM
- The dark photon (A') is a massive vector portal, SM-A' coupling $\epsilon \ll 1$ => hidden
- A dark photon could explain other anomalies eg:
  - Muon g-2
  - ATOMKI anomaly
  - …

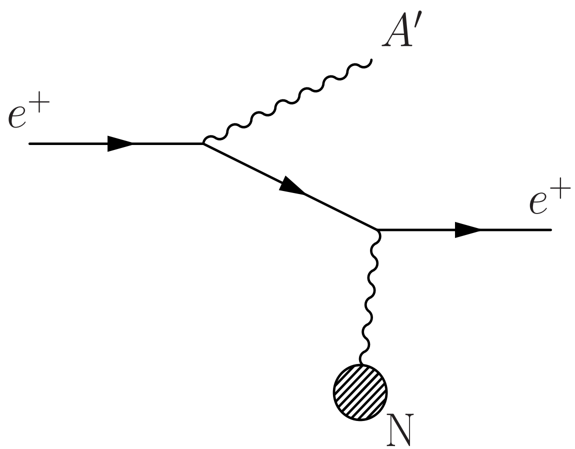


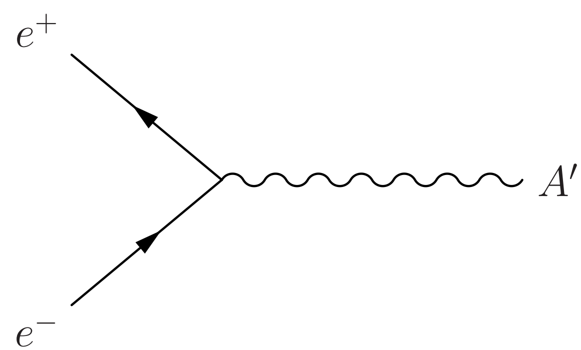


Dark Sector Production at PADME

- Positron Annihilation to Dark Matter Experiment:
  - Associated production: $e^+e^- \to \gamma A'$
  - A'-strahlung: $e^+N \to Ne^+A'$
  - Resonant annihilation: $e^+e^- \to A'$
- Production mechanisms are identical for both A' and alps
- Up to 550 MeV e^+ beam on diamond target





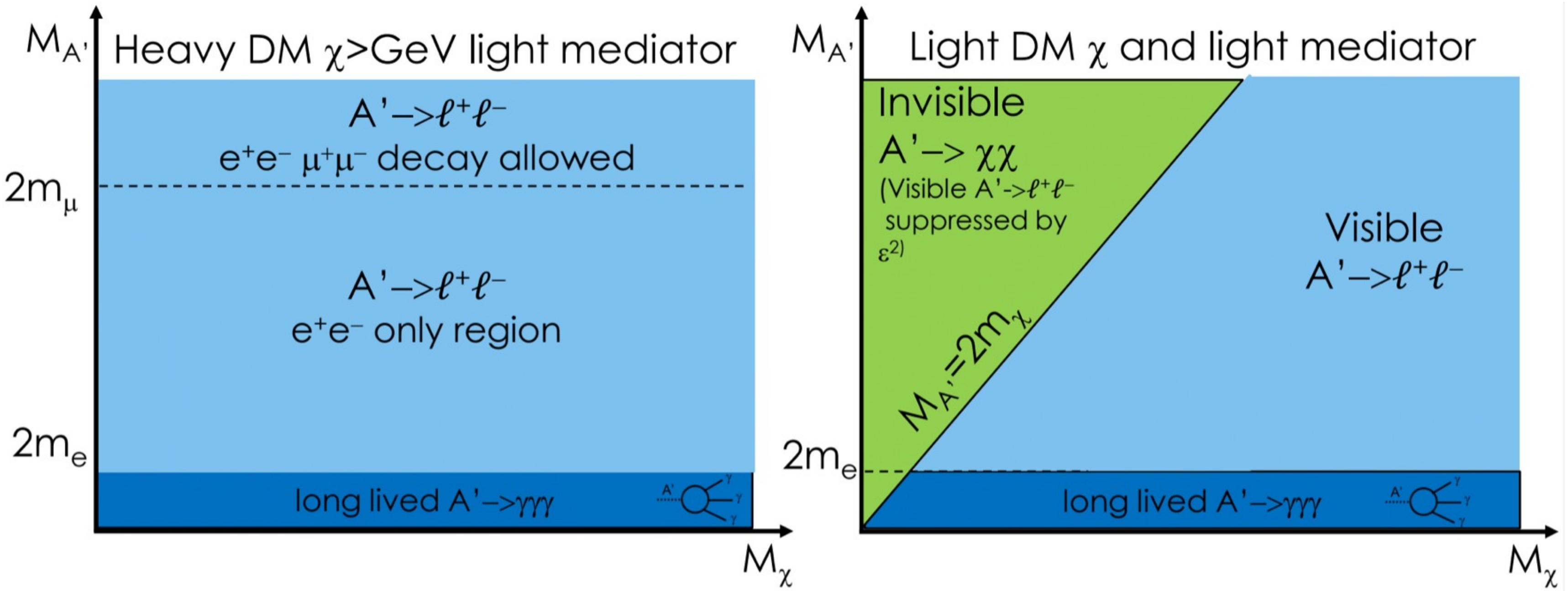


$$\frac{\sigma(e^+e^- \to A'\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} = \frac{N(A'\gamma)}{N(\gamma\gamma)} \times \frac{Acc(\gamma\gamma)}{Acc(A'\gamma)} = \epsilon^2 \times \delta$$

δ = phase space correction, analytically calculable

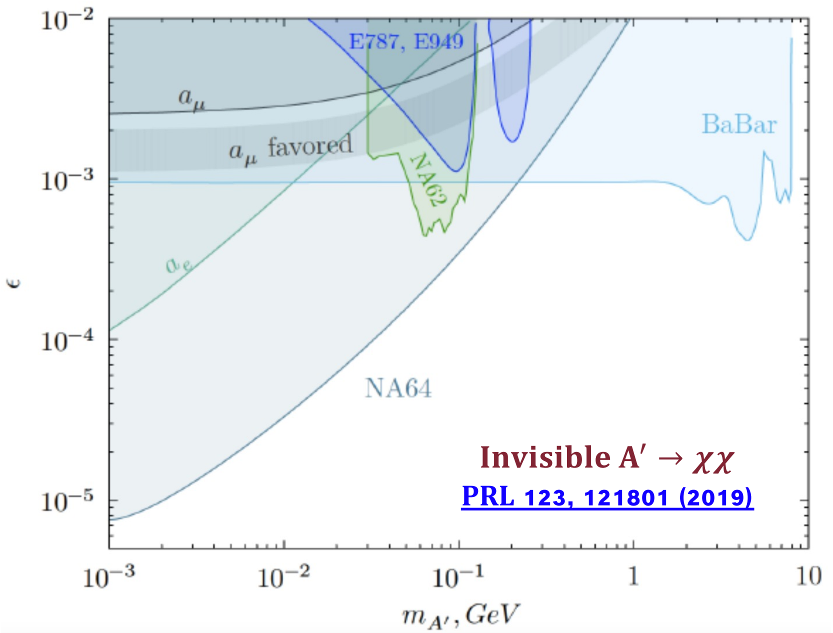
Models and Decays

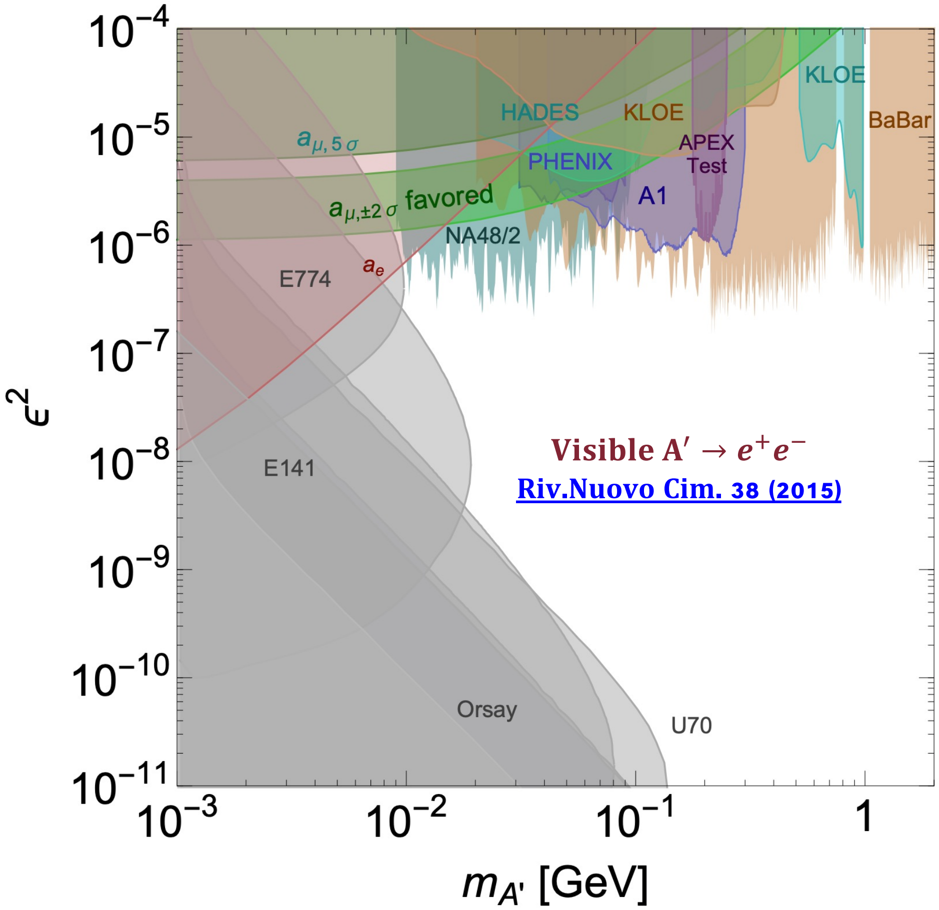
- Dark photons: $e^+e^- \rightarrow \gamma A'$
  - Final states:
    - Visible $\mathrm{A}' \rightarrow e^+e^-$
    - Invisible $\mathrm{A}' \rightarrow \chi\chi$



Current constraints

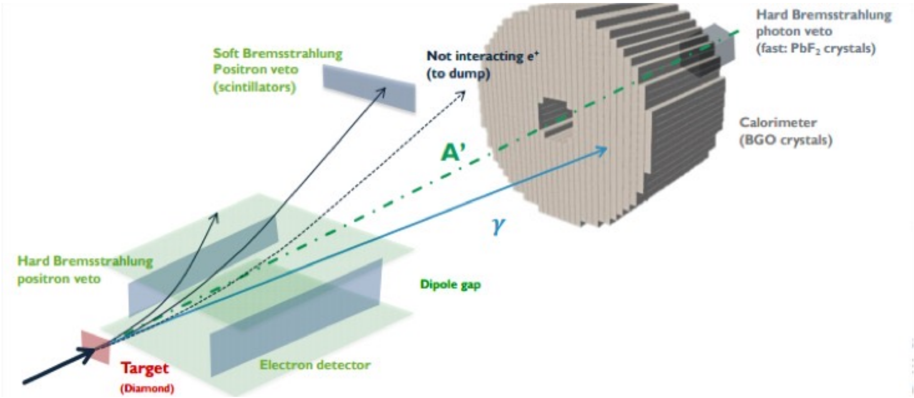
- Dark photons: $e^+e^- \to \gamma A'$
  - Final states:
    - Visible $A' \to e^+e^-$
    - Invisible $A' \to \chi\chi$





The PADME detector

- The PADME detector is made of:
  - Active diamond target (100μm)
  - Electromagnetic Calorimeter (616 BGO crystals): measures position & energy of annihilation photons
  - Small Angle Calorimeter (25 PbF_2 crystals): measures bremsstrahlung photons
  - 3 charged-particle vetoes (Positron Veto, Electron Veto, High Energy Positron Veto) placed inside/outside magnetic field to detect bremsstrahlung
- It's installed in the Beam Test Facility (BTF) hall at the National Laboratories of Frascati (LNF)



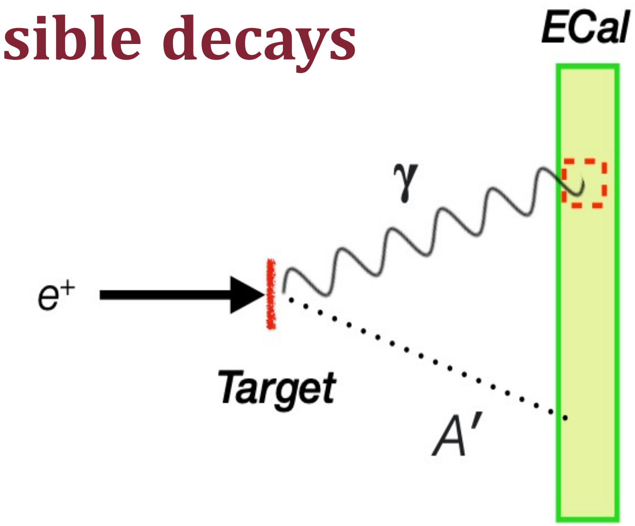
PADME beam conditions:

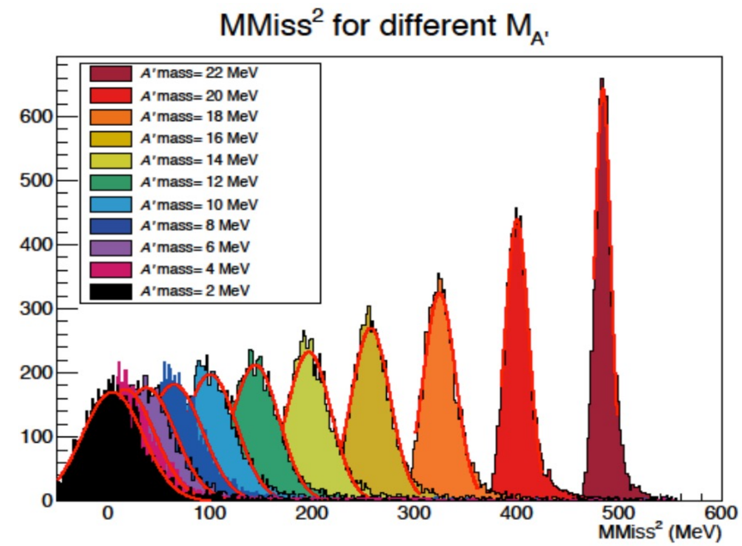
- E_{beam} up to 550 MeV
- Up to 30k e^+ per bunch
- Up to 320 ns bunch length
- 49 bunches/s

Dark Sector Detection at PADME: invisible decays

- PADME was designed to search for invisible $A' \rightarrow \chi\chi$ decays
- The signal is one standard model photon (from the production) in the electromagnetic calorimeter and nothing elsewhere
- It's a bump-hunting experiment: searching for an excess of events above the background
- The ΔM^2_{miss} distribution then gives access to $M_{A'}$:

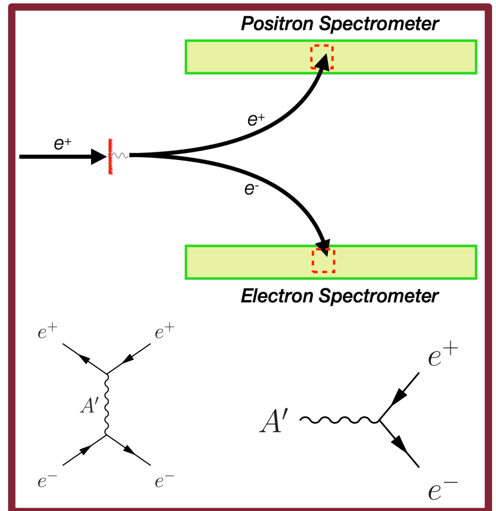
$$M^2_{A'} = \left(P_{beam} + P_{e^-} - P_\gamma\right)^2$$



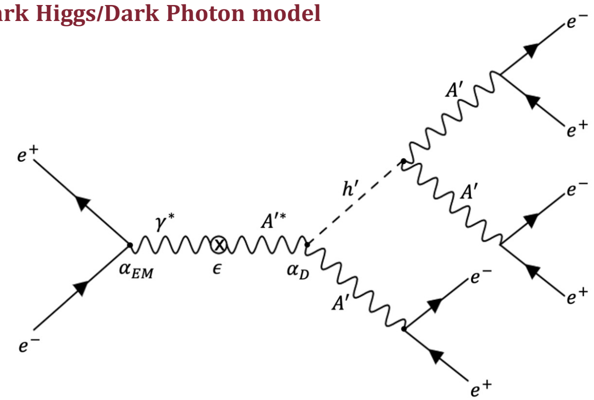


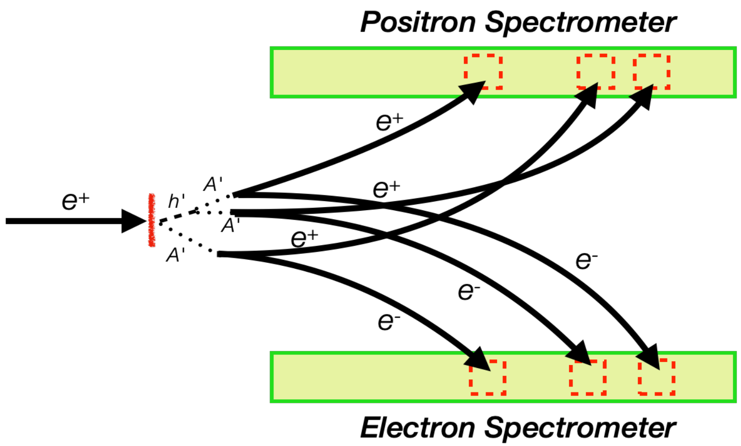
Dark Sector Detection at PADME: visible decays

- Using the vetoes as spectrometers gives us access to visible final states
- Of particular interest are:
  - Resonant A' production with $A' \rightarrow e^+e^-$
  - $e^+e^- \rightarrow 3(e^+e^-)$ via dark Higgs: standard model background is supressed by α^6, giving a high BSM signal/SM background ratio



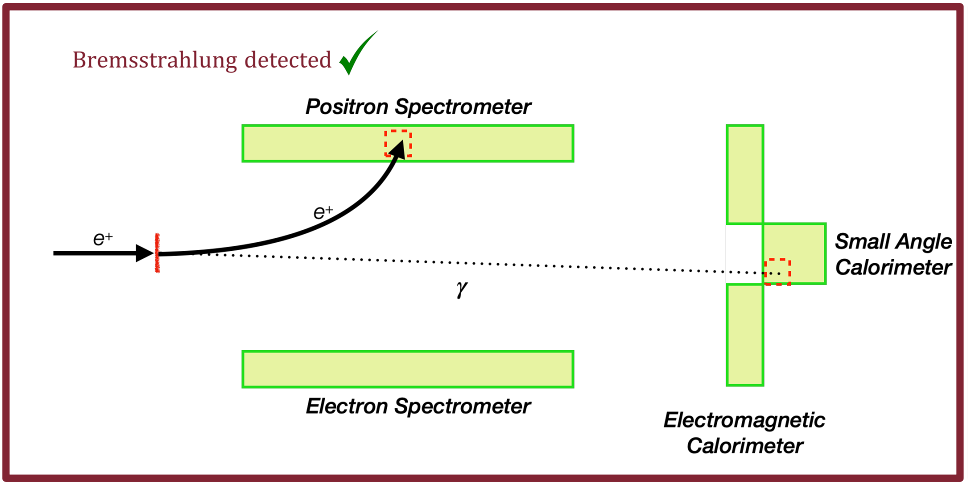
Dark Higgs/Dark Photon model

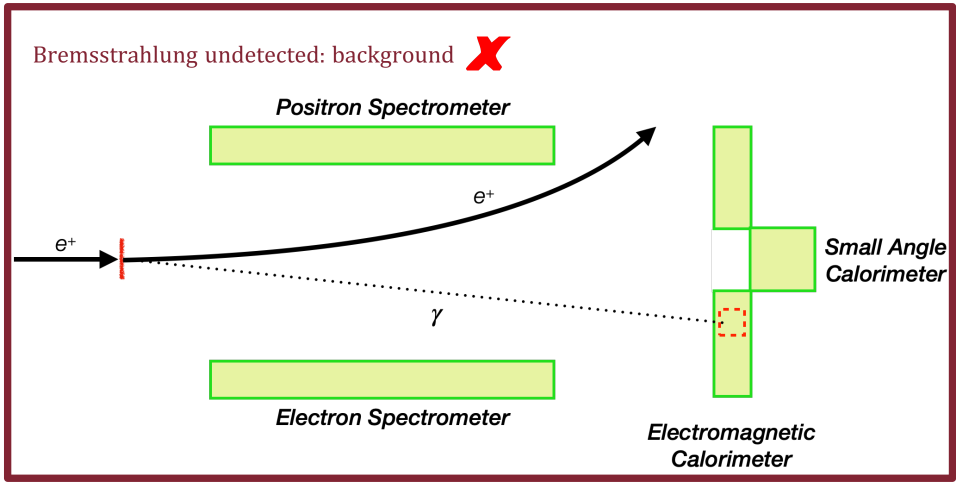




Background to invisible decays

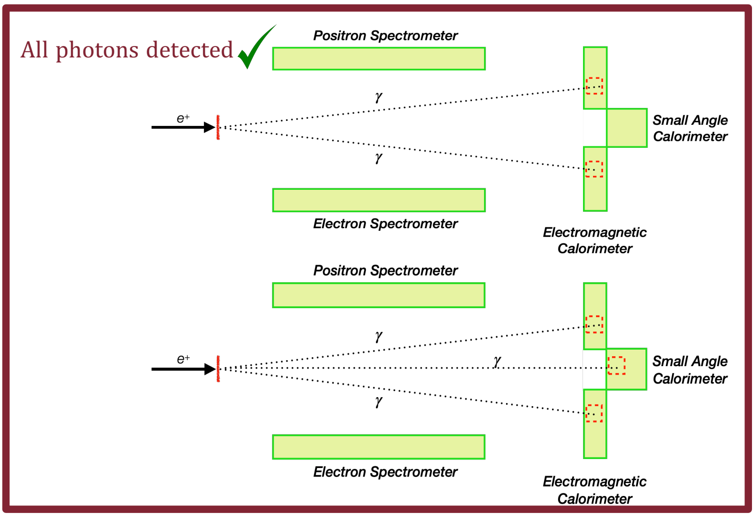
- Two principle sources of background:
  - Bremsstrahlung in the target: missing e^+
  - 2 (3) photon annihilation where 1 (2) of the photons goes undetected
- Bremsstrahlung suppression:
  - Positron veto detects the positron
  - Very fast Small Angle Calorimeter (SAC) detects the photon (usually soft & forward)

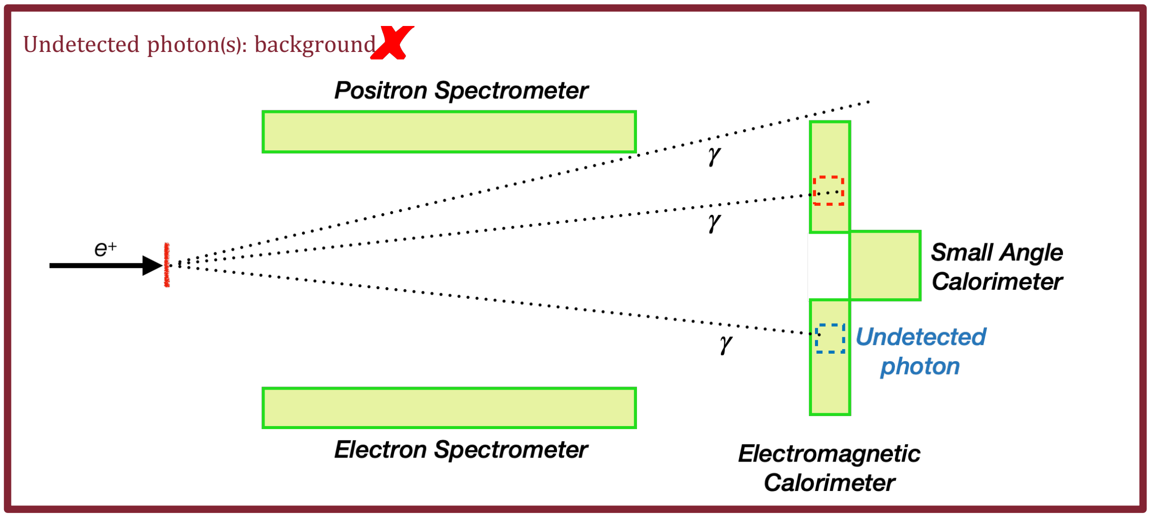




Background to invisible decays

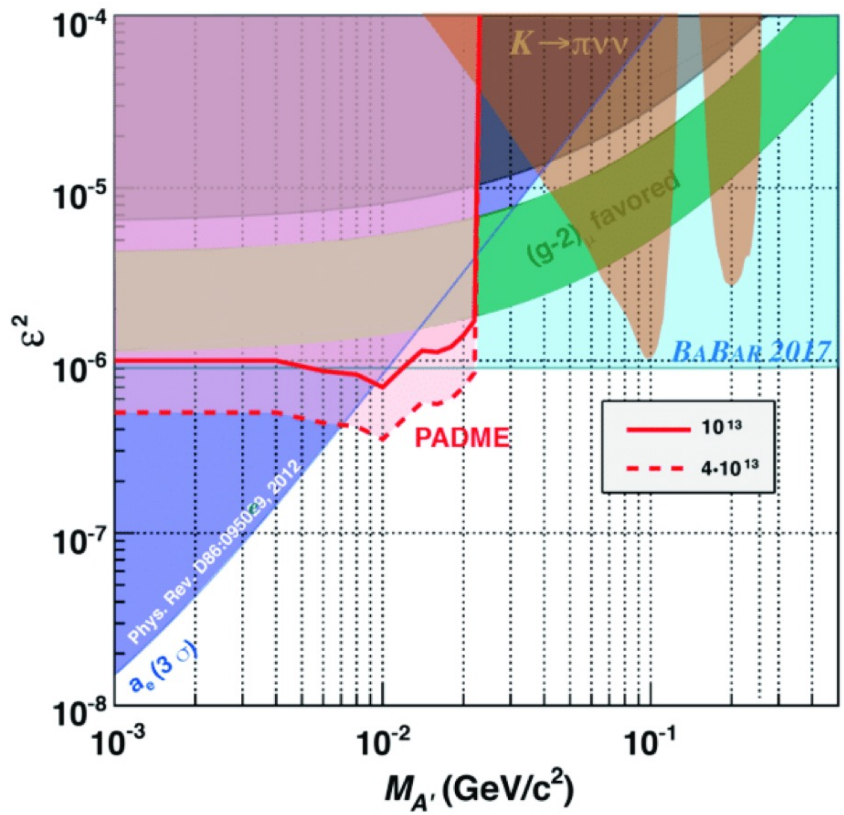
- Two principle sources of background:
  - Bremsstrahlung in the target
  - 2 (3) photon annihilation where 1 (2) of the photons goes undetected
- Annihilation background suppression:
  - 2 in-time photons in Electromagnetic Calorimeter (ECal)
  - Maximise granularity, angular coverage and energy resolution of ECal





Projected Physics Reach: Invisible decays

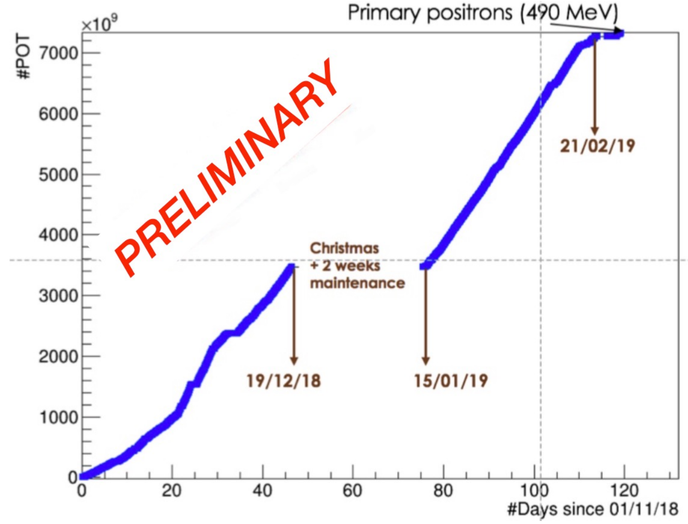
- The mass reach of PADME is governed by the beam energy
$$\sqrt{s} = \sqrt{2m_e * E_{beam}}$$
- At maximum $E_{beam} = 550$ MeV, maximum $m_{A'} < 23.7$ MeV
- The reach in coupling strength depends on pile-up and beam background
- With 10^{13} total positrons on target, $\epsilon > 10^{-3}$



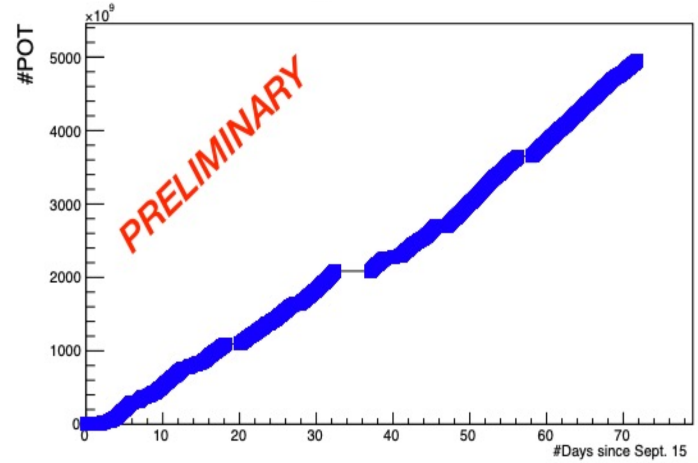
Data collected

- Detector was fully installed in Sept. 2018
- Run 1 (Oct 2018-March 2019) had 2 configurations:
  - Secondary e^+ beam (before 21/2/19):
    - positrons produced by e⁻ beam on Cu target before the entrance of the BTF hall
  - Primary e^+ beam (after 21/2/19):
    - positrons produced directly in the LINAC by a W-Re e^+ converter placed just after the e^- production point
- Run 2 (Sept 2020-Dec 2020) used the primary e^+ beam and improved beamline setup
- Acquired luminosity measurement:
  - Run1 = 7×10^{12} POT
  - Run2 = 5.5×10^{12} POT
  - Precision = 5%

No. positrons collected: Run 1

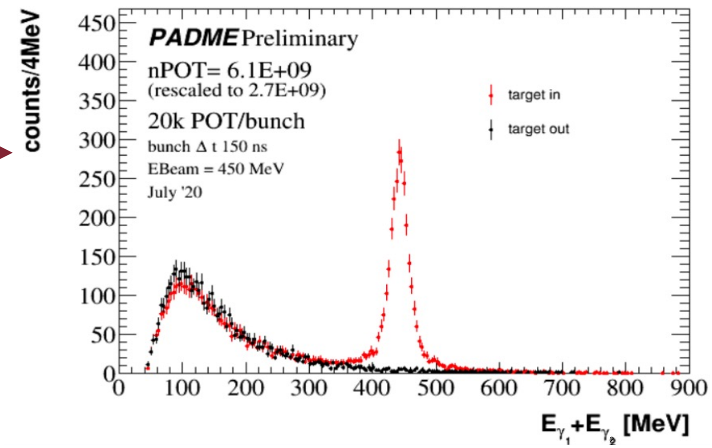


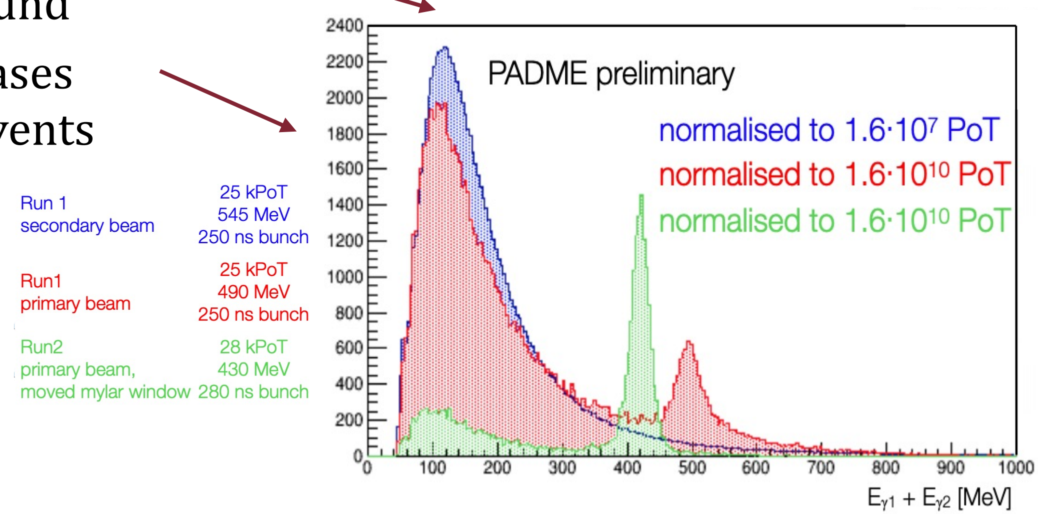
No. positrons collected: Run 2



Data quality checks

- 2 photon annihilation energy spectrum shows:
  - Beam background at low $E_{\gamma_1} + E_{\gamma_2}$ is well understood and very distinct from signal
  - Going to primary beam is extremely effective in improving $E_{\gamma_1} + E_{\gamma_2}$ resolution due to $\sim 1000\times$ lower beam background
  - Optimising beam setup decreases the beam background in $\gamma\gamma$ events by $\sim 10\times$





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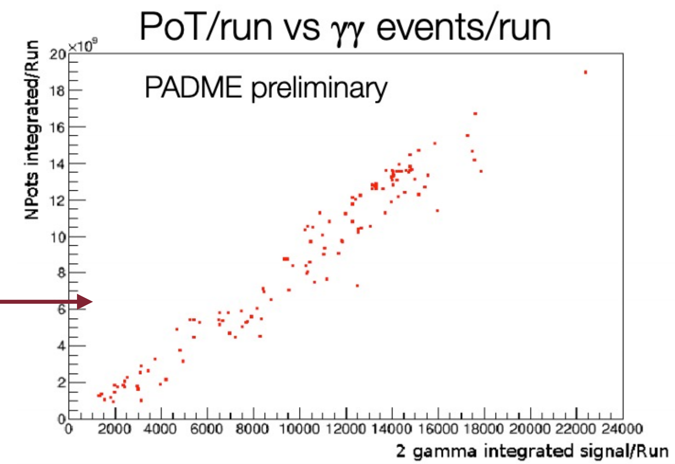
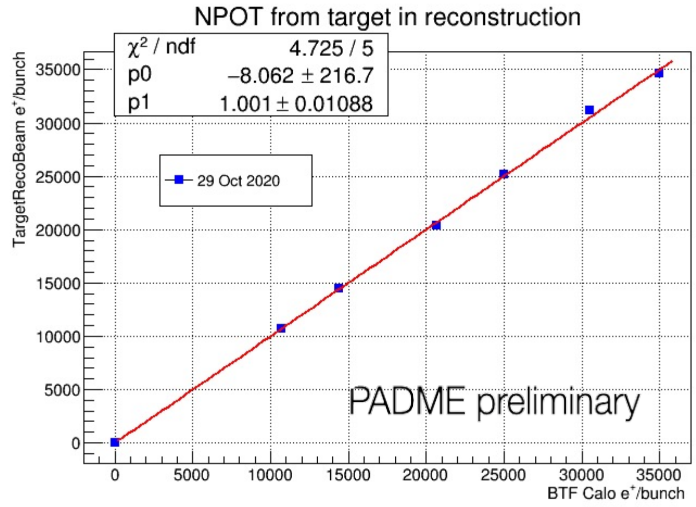
Data quality checks

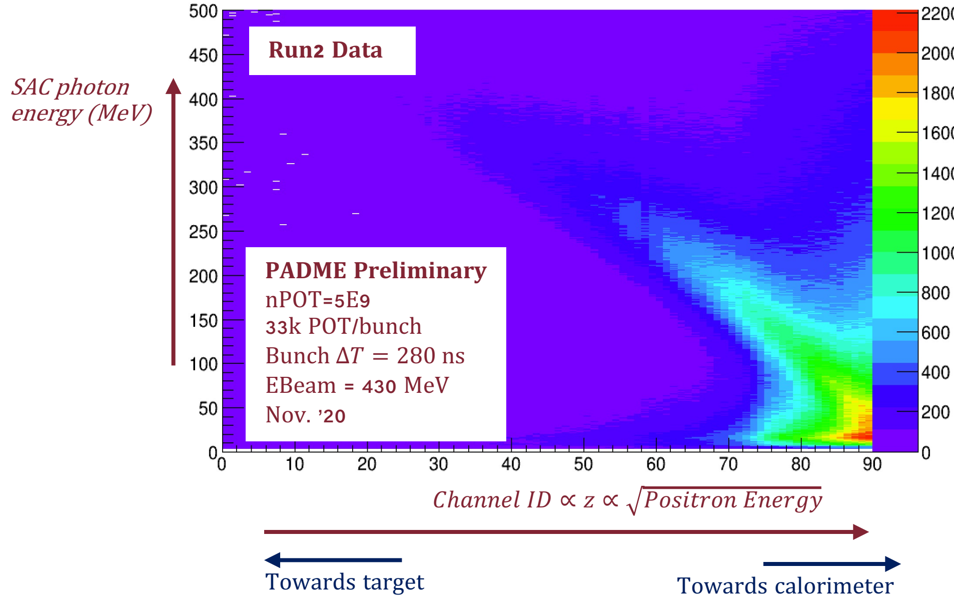
- POT measured is linear wrt no. $\gamma\gamma$ events => luminosity is well measured & both ECal & target are operating in linear regime
- Target response is linear with POT: target was designed for 5000 POT but is still linear at 35000 POT

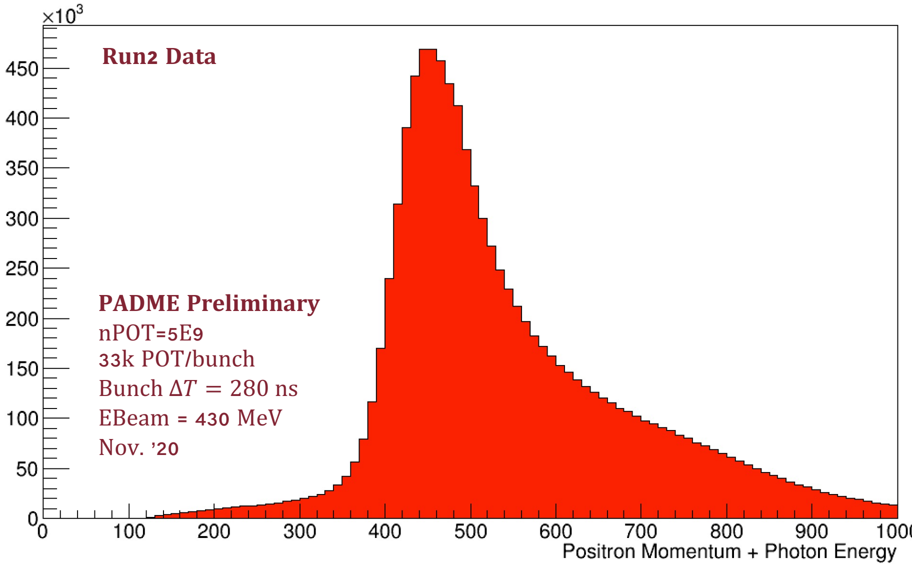


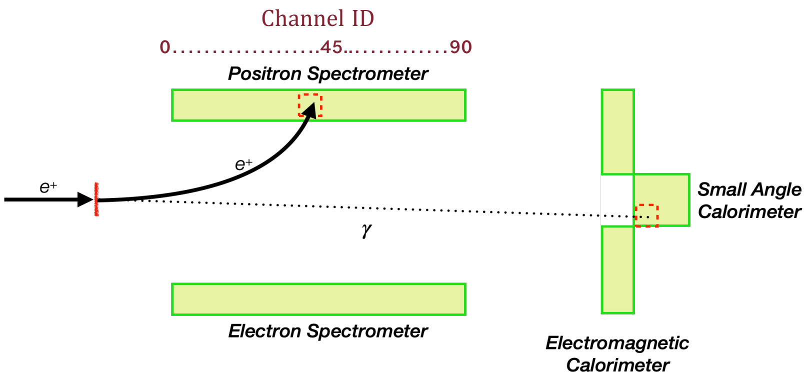


Data quality checks

- Bremsstrahlung studies show:
  - We are able to match Bremsstrahlung e^+ and γ
  - We are able to measure energy of γ and momentum of e^+



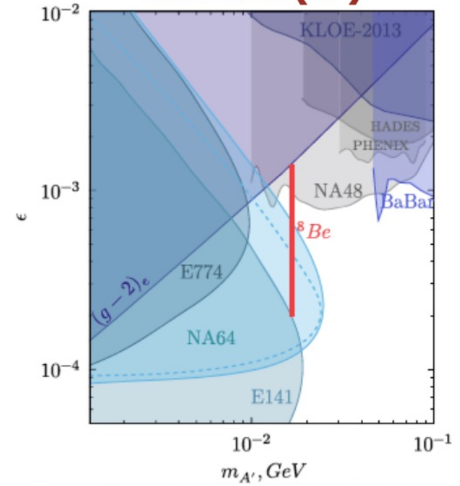




Future studies

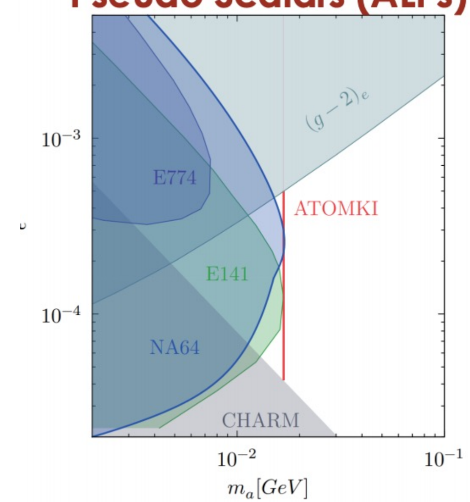
- We also intend to study the ^{8}Be/^{4}He X17 anomaly (A. J. Krasznahorkay, et al. Phys. Rev. Lett. 116, 042501, [https://arxiv.org/abs/2104.10075v1)](https://arxiv.org/abs/2104.10075v1)
- The e^+ energy needed to produce a 17 MeV particle on resonance is 282 MeV
- LNF is the only facility in the world able to do this.

Vectors (A')

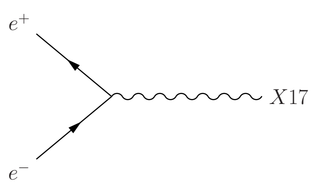


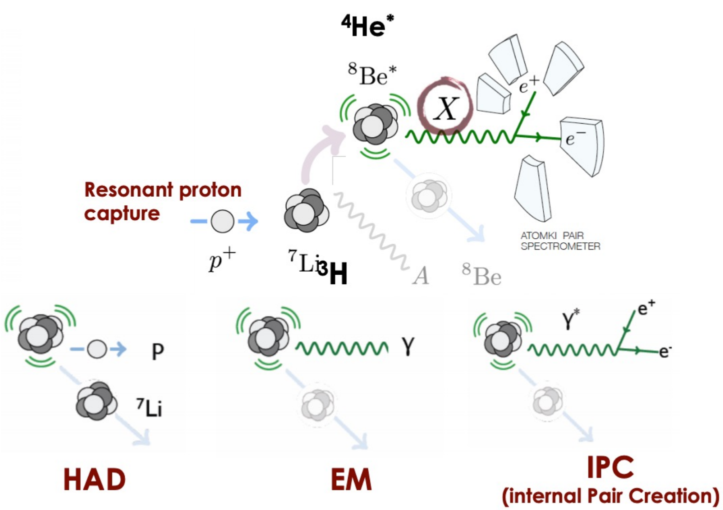
Phys. Rev. D 101, 071101(R) (2020)

Pseudo Scalars (ALPs)



arXiv:2104.13342v1 [hep-ex] 27 Apr 2021





Conclusions

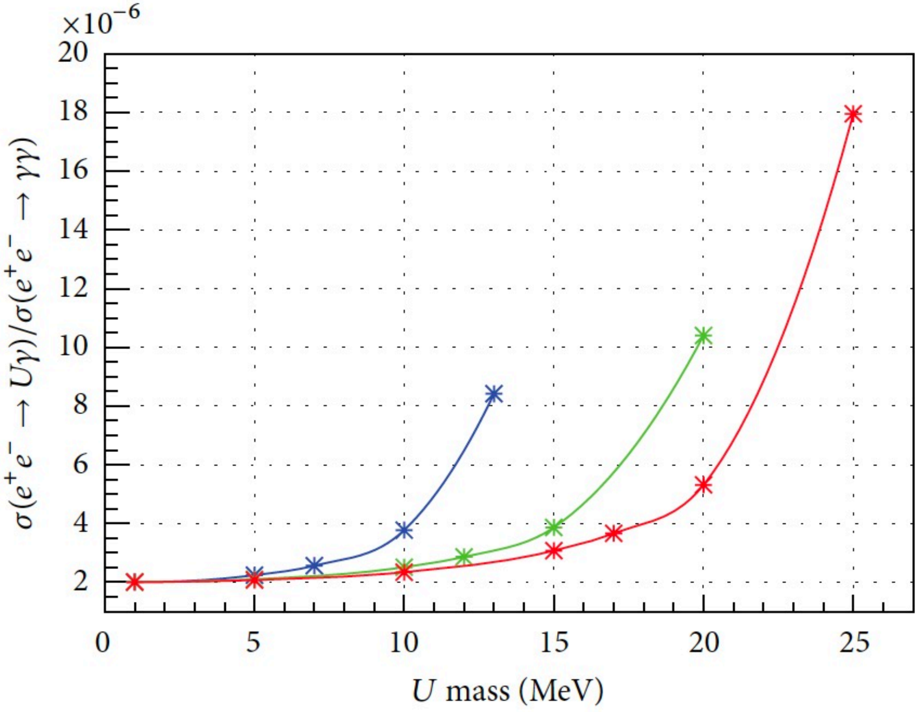
- PADME was designed and constructed to search for a dark photon in e+e- annihilation
- There are a number of accessible models and final states available to PADME
- We have a good understanding of our detector a
- PADME collaboration is now performing physics analysis on data from Run2
- Further reading is available here:

  - 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 (2014) 959802 [arXiv:1403.3041].
  - R. Assiro et al., Performance of the diamond active target prototype for the PADME experiment at the DAΦNE BTF, Nucl. Instrum. Meth. A 898 (2018) 105 [arXiv:1709.07081].
  - Characterisation and performance of the PADME electromagnetic calorimeter, JINST 15 T10003 (2020) [arXiv:2007.14240] .
  - S. Ivanov and V. Kozhuharov, The charged particle veto system of the PADME experiment, AIP Conf. Proc. 2075 (2019) 080005.
  - A. Frankenthal et al., Characterization and performance of PADME's Cherenkov-based small-angle calorimeter, Nucl. Instrum. Meth. A 919 (2019) 89 [arXiv:1809.10840].

Backup

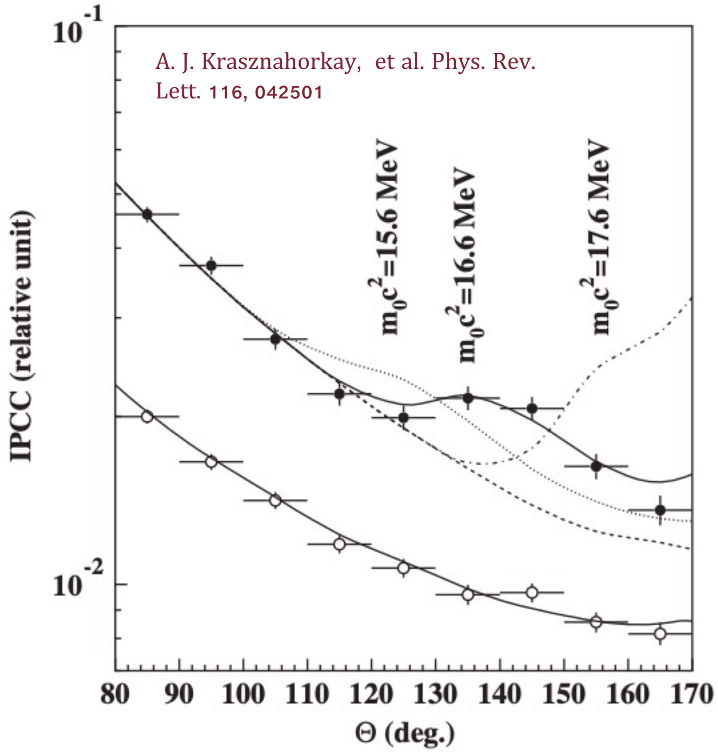
Phase space correction to cross section

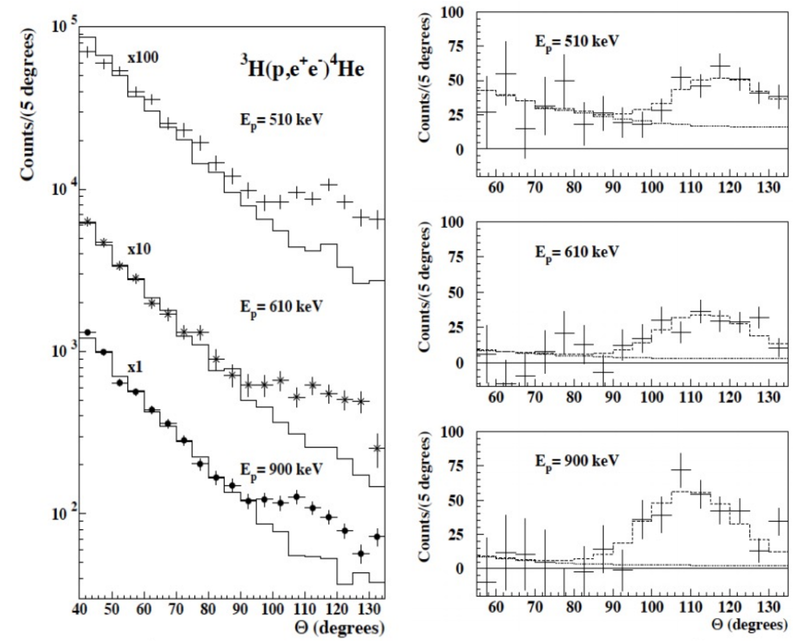
- For $E_{beam} = 250\ MeV, 500\ MeV, 750\ MeV$, with $\epsilon^2 = 1\times10^{-6}$:



X17 Anomaly

- Internal Pair Creation shows a bump in opening angle spectrum, as measured by ATOMKI in Hungary





https://arxiv.org/pdf/2104.10075v1.pdf

E_p	IPCC	B_x	Mass	Confidence
(keV)	$\times 10^{-4}$	$\times 10^{-6}$	(MeV/c^2)	
510	2.5(3)	6.2(7)	17.01(12)	7.3σ
610	1.0(7)	4.1(6)	16.88(16)	6.6σ
900	1.1(11)	6.5(20)	16.68(30)	8.9σ
Averages		5.1(13)	16.94(12)	
^{8}Be values		6	16.70(35)	