PADME physics in 2018

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For all PADME team

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Outline

- Standard Model measurements
- Addressing the vector portal
  - Associate production with photons
  - Resonant production
- Axion scenarios

PADME in 2018

- Starting in mid-April
  - Or as soon as possible
- Goal: provide $X*10^{13}$ positrons on the diamond target
  - Can this statistics be reached (i.e. what is X)?
- All detectors in working condition!

Detector performance

- PADME detectors will need calibration at the start of the run
- Diamond target
  - Charge – intensity calibration
  - Strips/channels equalization
  - Beam profile monitoring

  Goal: Beam position measurement with **sub-mm** precision
- Calorimeter (as a function of energy and impact point)
  - Charge/Energy relation per single crystal
  - $E_{tot} = \Sigma E_i$ of the shower
  - Position calibration
    - Uniformity of the detector, energy scale, linearity

  Goal:

  Energy resolution: ~ 6-7 % @ 100 MeV
  Position resolution: O(mm)
  Time resolution (cluster): O(1 ns)

Detector performance

- Vetoes
  - Charge/energy deposition (might not be something critical)
  - Bar – momentum relation
  - Time alignment
    - With respect to travel path of the charged particles
    - ~1 m difference, ~3 ns
    - Partially (over)compensated by the length of the cables inside the vacuum, but channel by channel calibration seem unavoidable

  Goal:

  Time resolution: better than 1 ns

  Momentum resolution: better than 6 %

- Small angle calorimeter
  - Energy calibration
  - Timing
  - Double pulse separation

  Goal:

  Timing: O(100 ps)

  Energy resolution:

  Double pulse separation: Ability to distinguish photons

Calibration

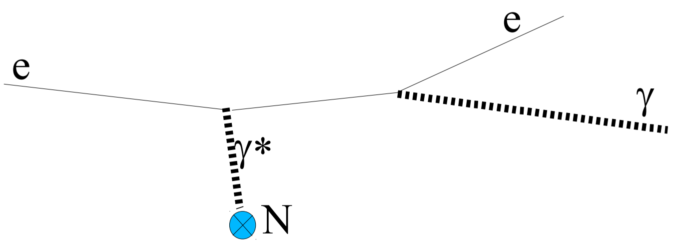
- Calorimeters
  - Both energy and timing with $e^+e^- \rightarrow \gamma\gamma$ annihilation
  - Compare the measured cross-section with the calculated one
- Charged particle detectors
  - Momentum: lower energy beam, ~single particle, deflected by the dipole directly into the bars
  - Timing: with respect to the CALO → $e^+N \rightarrow e^+N\gamma$ bremsstrahlung events with a photon in the CALO
    - This can also be used to check the momentum calibration of the vetoes during the data taking
- Medipix, Timepix, Active target
  - COG of the beam with other methods … $e^+e^- \rightarrow \gamma\gamma$ with the CALOs?
  - What is necessary is that all detectors are calibrated with respect to the Calorimeter

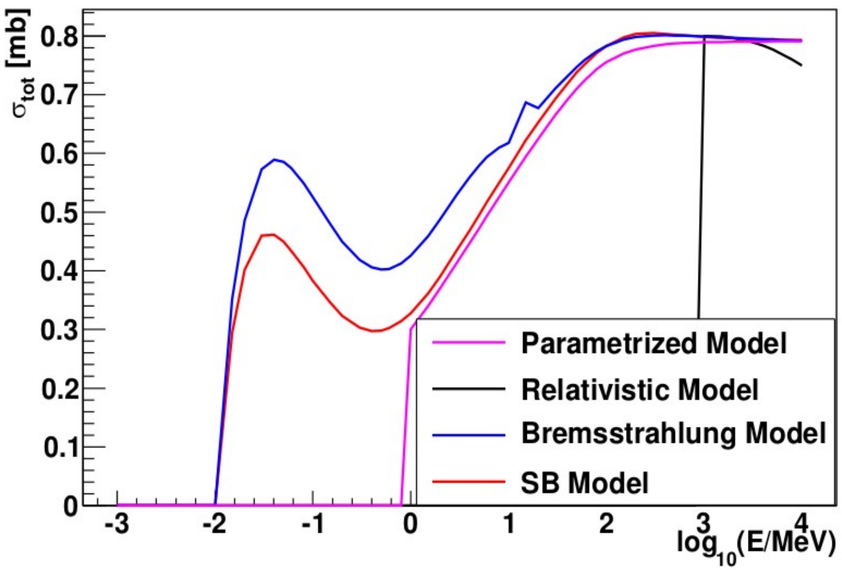
Bremsstrahlung

- Usually thoroughly simulated through GEANT4
- Different models exist
  - Parametric – up to version 9.4
  - Seltzer-Berger model (present default)

$$\frac{d\sigma}{dk} = \frac{d\sigma_n}{dk} + Z\frac{d\sigma_e}{dk}$$

    - Parametrization of tabulated data
    - Takes into account e-N and e-e interactions



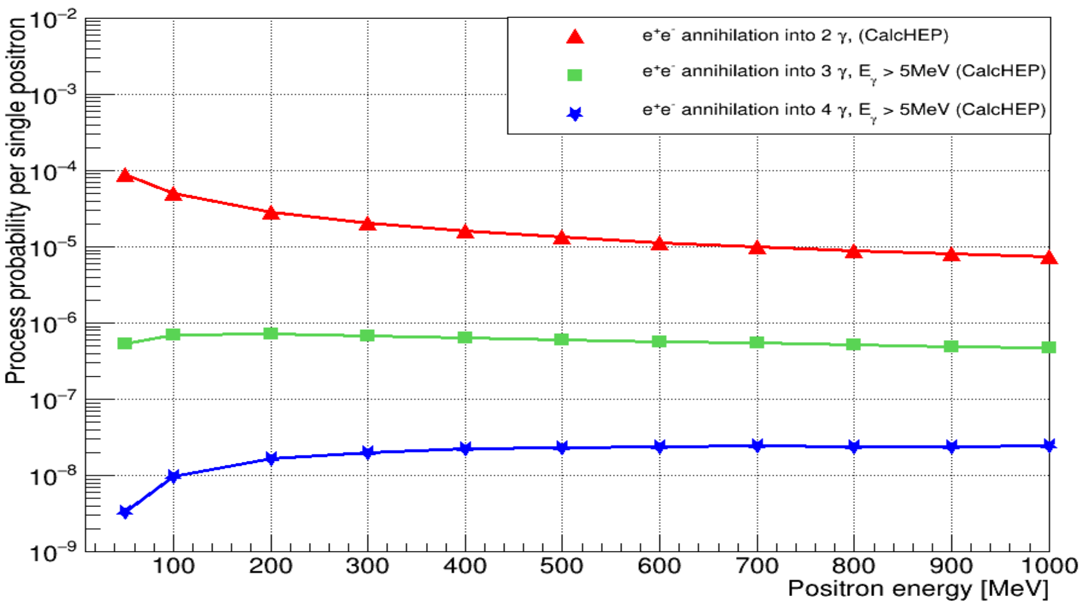


- GEANT4 model uncertainties
  - Parametric: 4-5 % for E_{e+} > 1 MeV
  - SB model: 3-5% for E_{e+} > 50 MeV
- @ 10^{13} events the number of background events due to bremsstrahlung per given A' mass interval varies from $10^4 – 10^5$ ($\sqrt{N}/N \leq 1\%$, model uncertainty dominates!)
  - Data driven (i.e. measurement) dominated analysis strategy

Annihilation: multi-photon

- We could even go further – $e^+e^- \to N\gamma$

Interaction probability on a 100 μm carbon target



- The low energy part of $e^+e^- \to N\gamma$ is absorbed in the virtual corrections of $e^+e^- \to (N\text{-}1)\,\gamma$

$\Gamma(\text{annihilation}) = \Gamma(e^+e^- \to \gamma\gamma) + \Gamma(e^+e^- \to \gamma\gamma\gamma) + \Gamma(e^+e^- \to \gamma\gamma\gamma\gamma) + \ldots \approx 1.05 \text{ x } \Gamma(e^+e^- \to \gamma\gamma)$

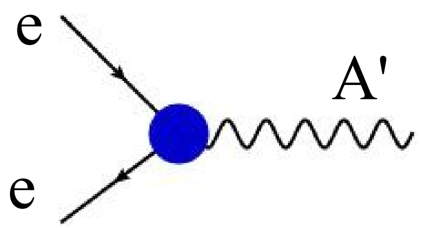
Measurement of the multiphoton annihilation necessary

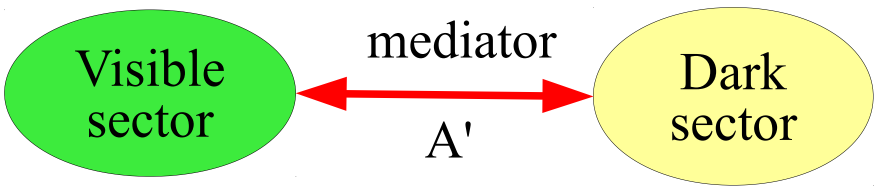
PADME physics

- The PADME physics program is inevitably related to **precise calibration** and **monitoring of the calibration** of the detectors
- Background understanding
  - The background in the New Physics searches is the calibration tool
  - Understanding the Standard Model processes is the ticket to the “big event”
- Major background sources (or major SM processes)
  - Multiphoton annihilation
    $e^+e^- \rightarrow \gamma\,\gamma$, $e^+e^- \rightarrow \gamma\,\gamma\,\gamma$, $e^+e^- \rightarrow \gamma\,\gamma\,\gamma\,\gamma$, ….
  - Bremsstrahlung in the field of the nuclei
  - Photon emission in the field of orbital electrons
- Bremsstrahlung differential cross-section measurements at different energy in the O(100 MeV) interval and (if possible) materials highly desirable
- Multiphoton annihilation to be studied and compared with MC generators

New gauge bosons

- The effective interaction that can be studied is





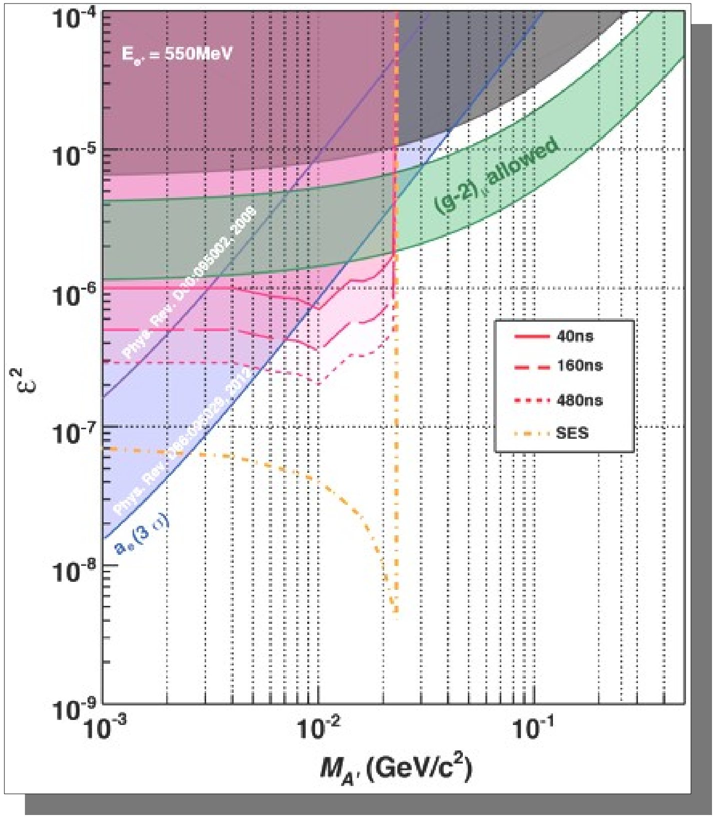
$$\mathcal{L} \sim g'q'\,\overline{\Psi}\,(\gamma_\mu + \alpha'_a \gamma_\mu \gamma^5)\Psi A'^\mu, \;\; usually\ \alpha'_a = 0$$

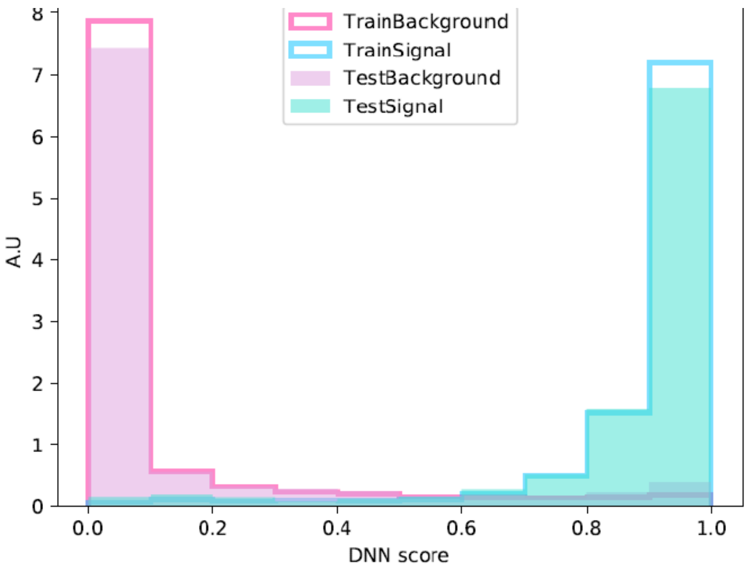
  - $q_f \to 0$ for some flavours

- Such textbook scenario could address the $(g_\mu$-2) discrepancy, abundance of antimatter in cosmic rays, signals for DM scattering
  - General U'(1) and kinetic mixing with B (A', Z')
    - Universal coupling proportional to the q_{em} $\quad L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$
    - Just single additional parameter – ε
  - Leptophilic/leptophobic dark photon
- Other messenger types possible (neutrino, higgs, ALP)
- **Rich dark sector?**

New gauge bosons @ PADME

- Associate production of A'
  - With 10^{13} positrons the expected sensitivity is at the level of 10^{-5}
    - But only in case we understand the background :)
  - Still room for improvement
    - Implementation of AI





Cutting at given value of the DNN score, we get a signal efficiency and corrisponding background rejection

Good separation between signal and background

- 2018 data is the best place to test the NN performance

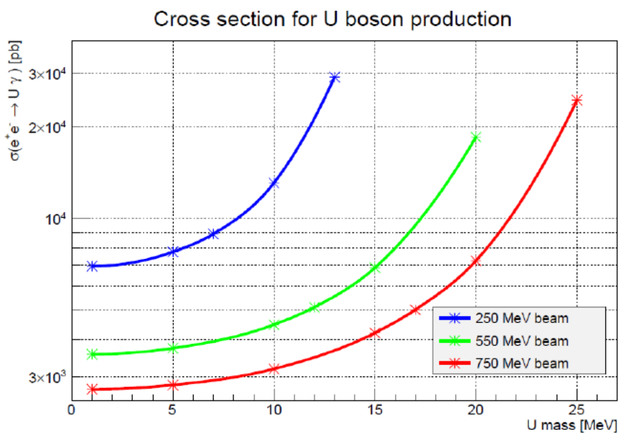
more info: I. Oceano's talk

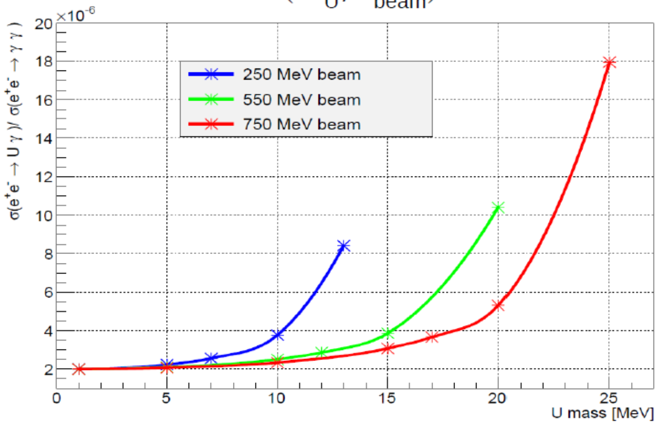
Resonant production of A'

LNF seminar, 25.02.2014

For ε = 10^{-3}

$\delta = \delta(M_U, E_{beam})$





- Increasing of the cross section with the approach of the kinematics limit – resonant production of U
  - Speculation on the possibility to scan the region 10MeV - 23 MeV by varying the beam energy?

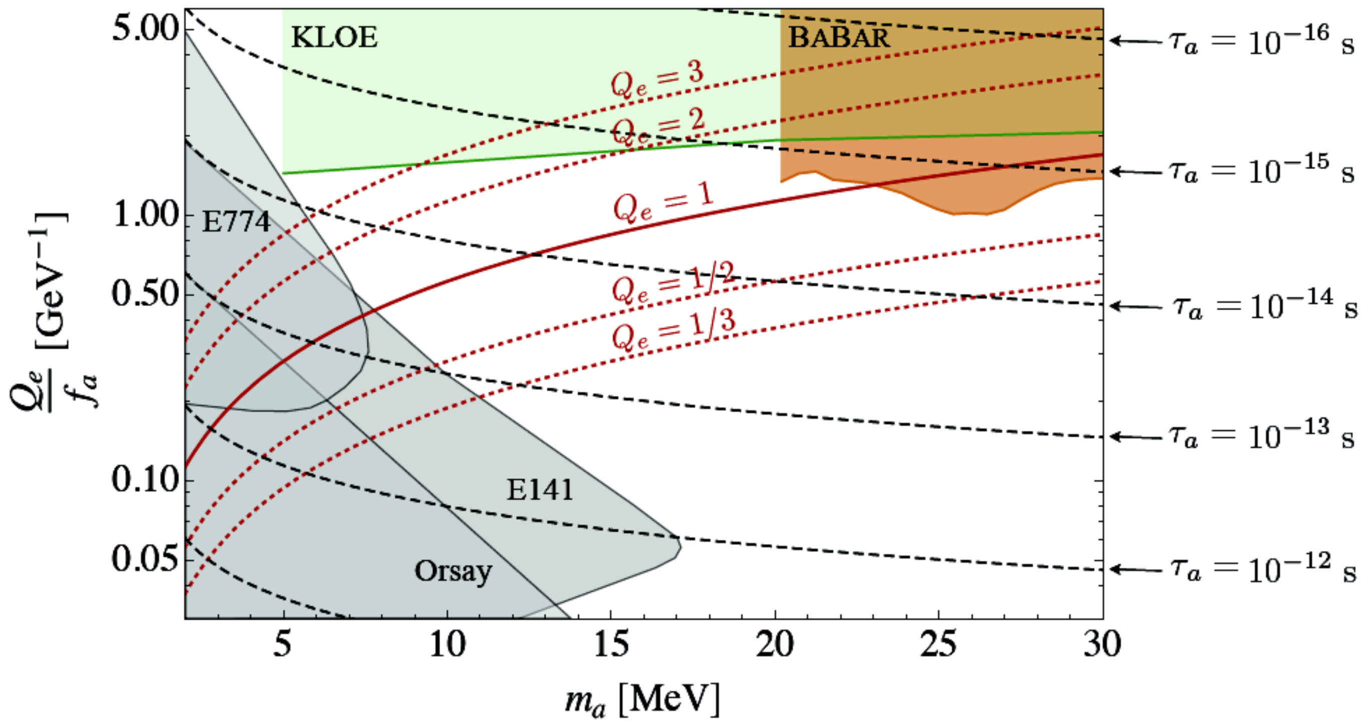
more info:
E. Nardi's talk

- Seem still viable for a thin target experiments
  - Could even be a possibility in 2018?
  - Lower acceptance due to lower gamma energy
    - But also better resolution on the M^2_{miss}

Axion like particles

- Many different models
  - Common – new pseudo-scalar
  - Varying from ALP-photon only coupling to ALP-electron only coupling
  - Different models at different stage of exclusion

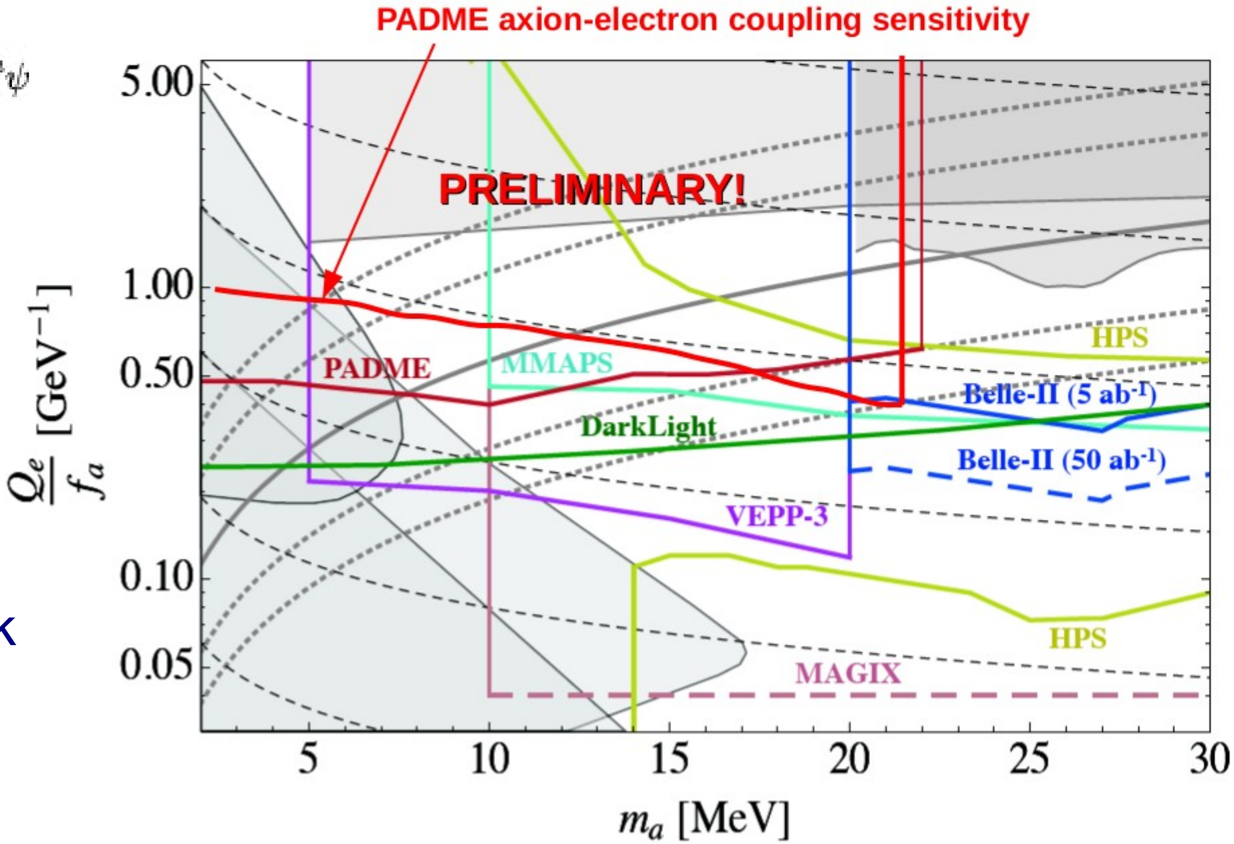
arXiv:1710.03764



Axion like particles, a-e coupling

- Dark photon experiments seem to be a powerful probe to this scenario
- Preliminary studies started, but the message is optimistic

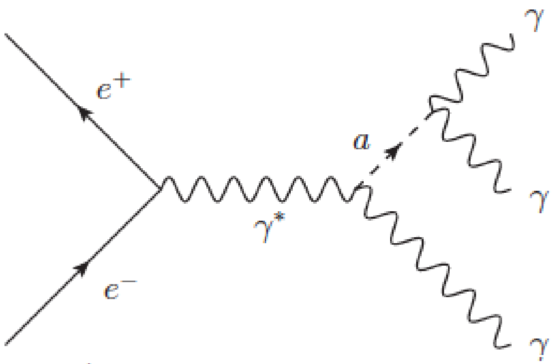
$$\mathcal{L} = i\frac{g_{ae\bar{e}}}{2m_e}\partial_\mu a\bar{\psi}_e\gamma_5\gamma^\mu\psi$$



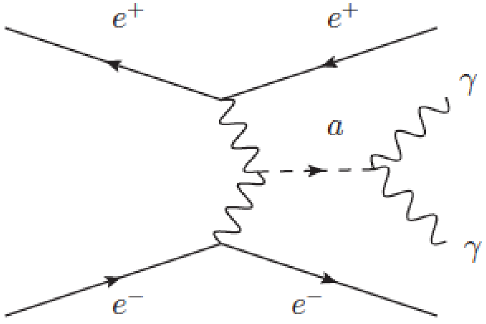
more info:
R. Simeonov's talk

Axion like particles

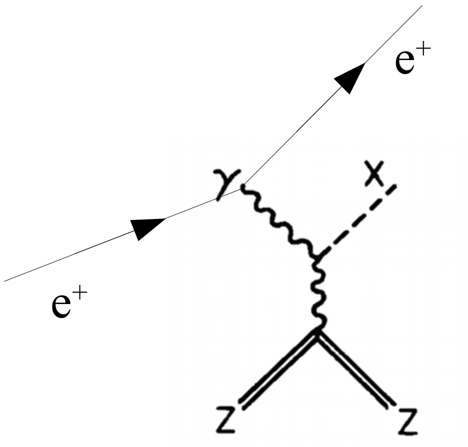
- PADME is also sensitive to multiphoton and multiparticle events
- ALPS production through a-γ coupling



$(e^+e^- \to \gamma^* \to \gamma + a)$



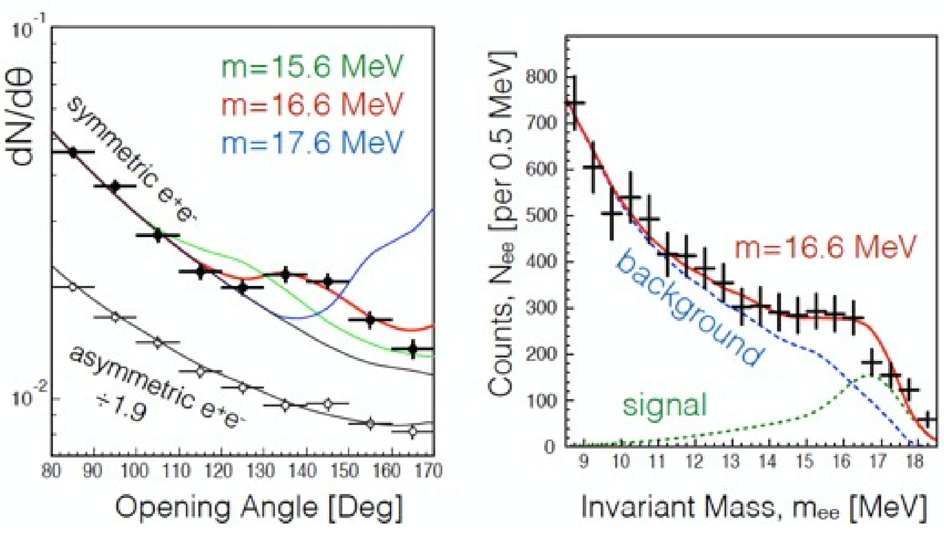
$(e^+e^- \to e^+e^- + a)$

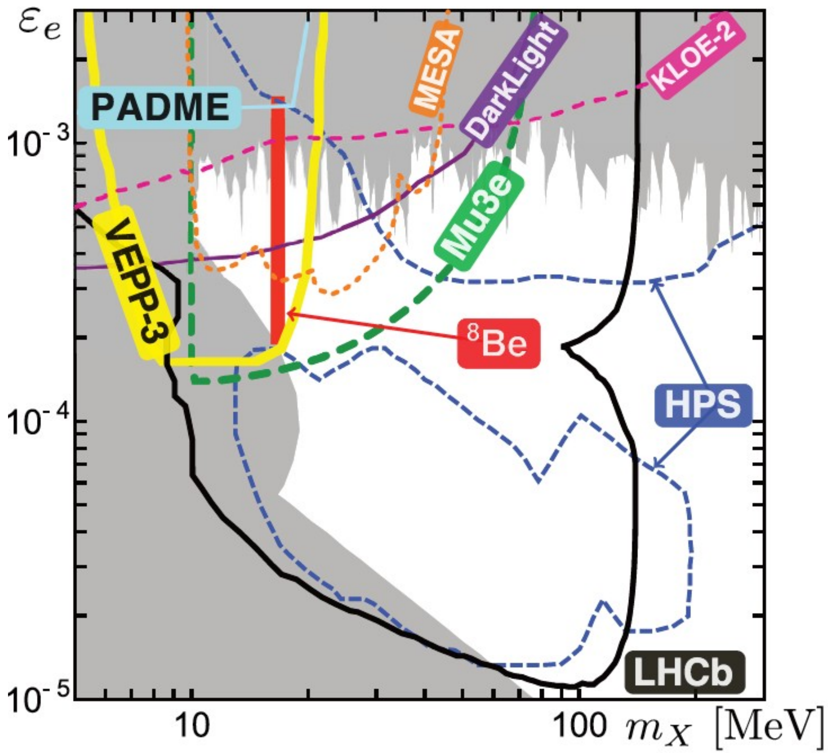


- A dedicated analysis necessary since the acceptance is dependent on the relative kinematic properties of the two photons
- Search for structures in the di-photon invariant mass in multi-particle events?
  - 3 photons 2 photons + e^+ + e^- 2 photons + e^+
  - Lower SM background, good timing of the detectors to suppress it

Be-8 vector particle

- Still unexplained effect





- Requires specific arrangement of couplings to fermions
  - But we already know that Nature is not arbitrary
- Sensitivity in 2018 seems limited and that a dedicated resonant production in beam dump mode might be necessary

more info: E. Nardi's talk

See also: arXiv1802.04756v1

Conclusions

- The 2018 PADME physics will mainly be devoted to the understanding of the SM processes in the energy range of O(100 MeV)
- Several important results expected from PADME
  - Bremsstrahlung cross-sections at different energied
  - Bremsstrahlung cross-sections for different materials (if possible)
  - Multiphoton annihilation cross-sections
- All these are prerequisites for the major PADME goal – probing the Dark Sector using e+ on target
- Even if statistically limited, we can also hope for the unexpected
  - No other experiment performed a dedicated search for A' or ALPs in positron on target scenario!

    So … stay tuned and start preparing the tools for the best experiment performance :)