Searching for the Dark photon with PADME

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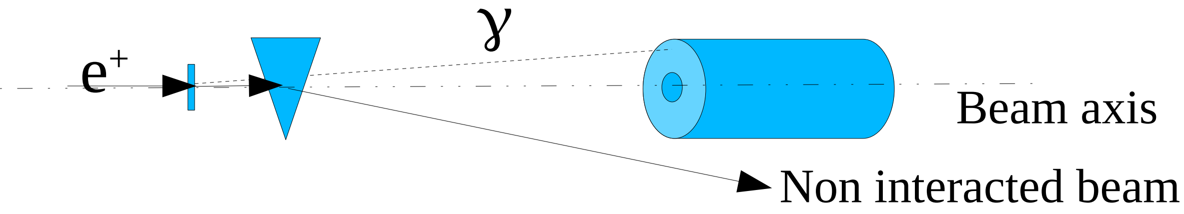
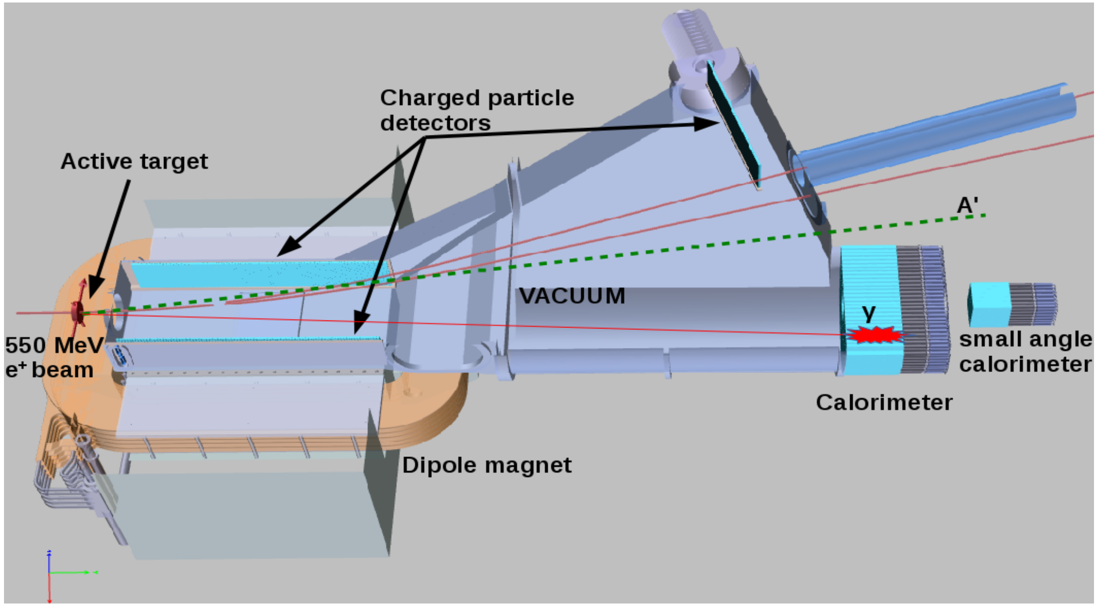
The PADME Experiment

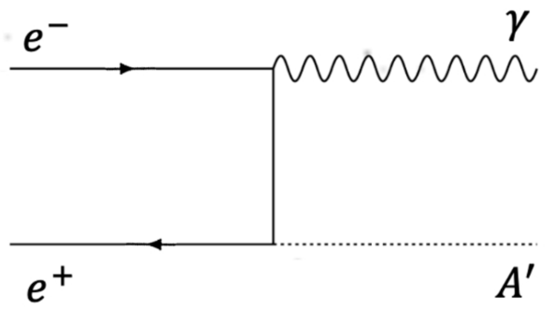
Positron Annihilation into Dark Matter Experiment





Associated production:

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

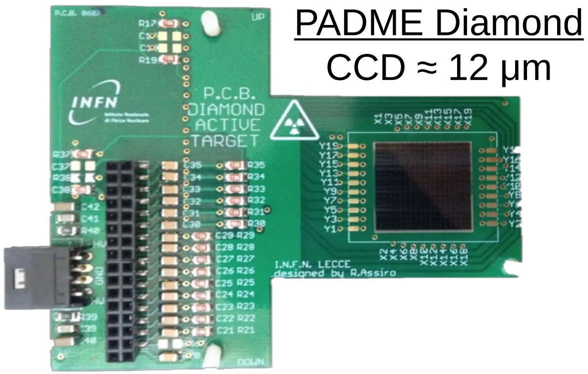


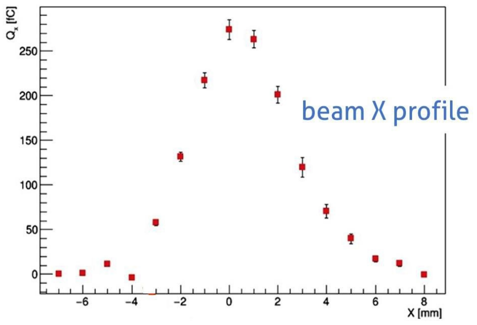
$$M_{miss}^2 = (p_{pos} + p_{elec} - p_{\gamma})^2$$

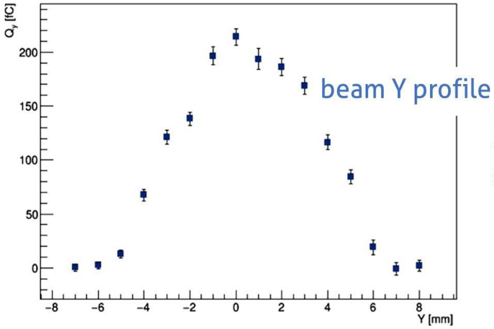
Small scale fixed target experiment

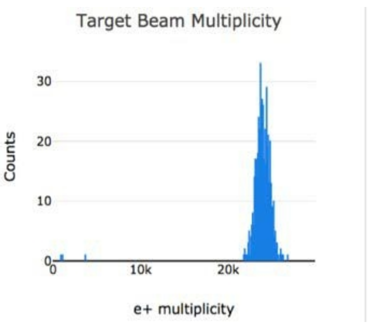
- e^+ @ Frascati Beam Test Facility
- Solid state target
- Charged particles detectors
- Calorimeters: ECal and SAC
- Beam monitoring system

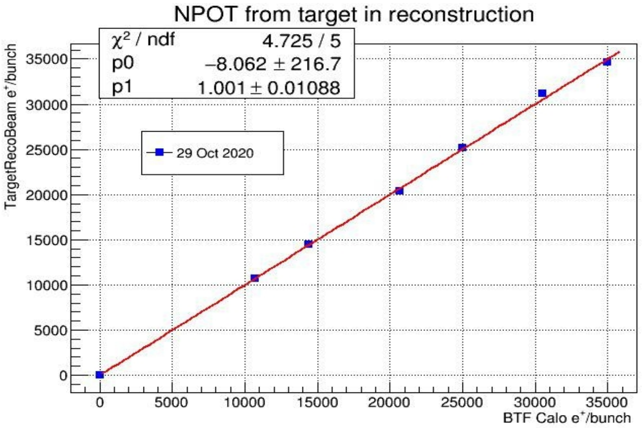
Active target



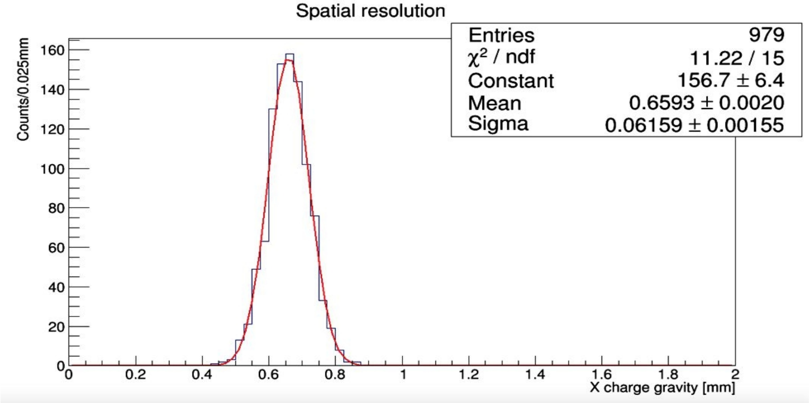






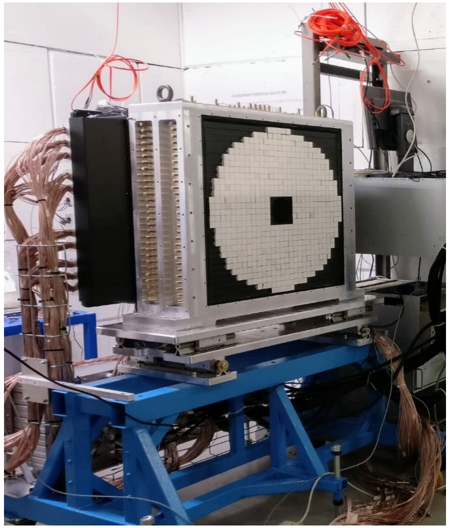


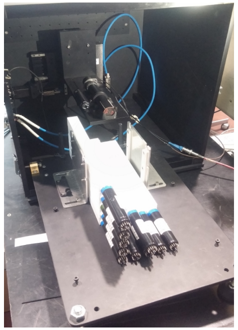
- **Polycrystalline diamond**
- 100 µm thickness:
- 16 × 1 mm strip and X-Y readout in a single detector
- Graphite electrodes using excimer laser



- *JINST* 12 (2017) 02, C02036

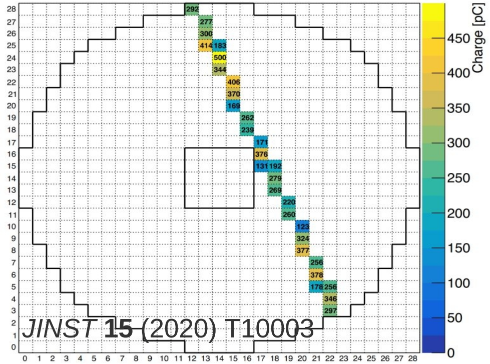
Calorimeters





ECAL: The heart of PADME

- 616 BGO crystals, 2.1 x 2.1 x 23 cm^3
- BGO covered with diffuse reflective TiO_2 paint
  - Additional optical isolation: 50 – 100 µm black tedlar foils



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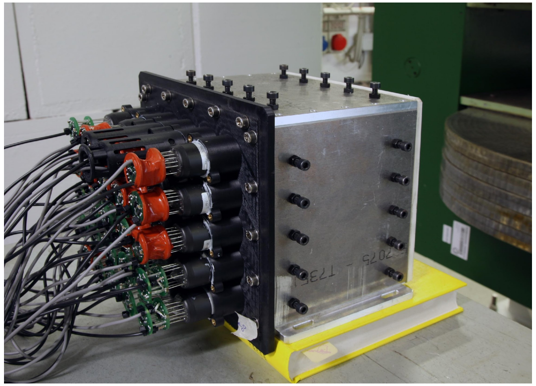
Calibration at several stages:

- BGO + PMT equalization with ^{22}Na source before construction
- Cosmic rays calibration using the MPV of the spectrum
- Temperature monitoring

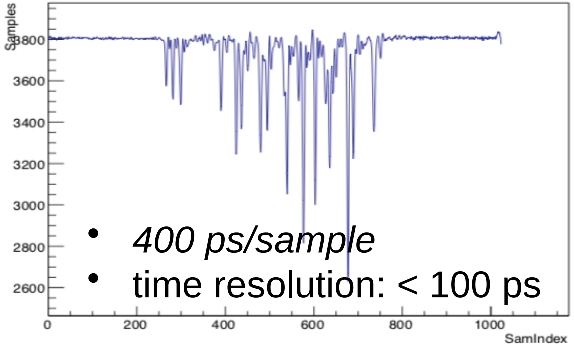


Nucl.Instrum.Meth.A 919 (2019) 89-97

Small Angle Calorimeter (SAC)

- 25 crystals - 5 x 5 matrix, Cherenkov PbF_2
- Dimensions of each crystal: 3 × 3 × 14 cm^3
- 50 cm behind ECal
- PMT readout: Hamamatsu R13478UV with custom dividers
- Angular acceptance: [0,19] mrad

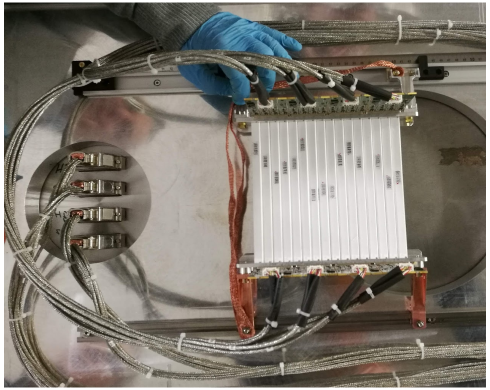
Recorded bunch



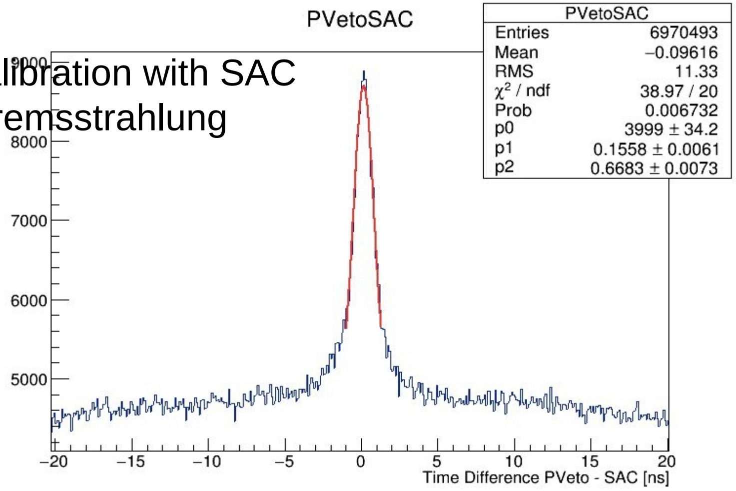
- *400 ps/sample*
- time resolution: < 100 ps

Charged particle detectors

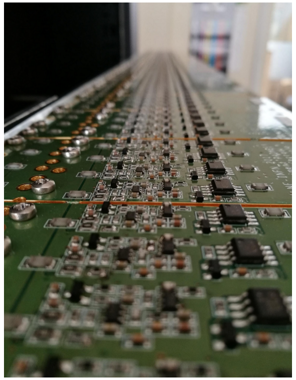
- Three sets of detectors detect the charged particles from the PADME target (at E_{beam} = 550 MeV):
  - **PVeto**: positrons with 50 MeV < p_{e+} < 450 MeV
  - **HEPVeto**: positrons with 450 MeV < p_{e+} < 500 MeV
  - **EVeto**: electrons with 50 MeV < p_{e+} < 450 MeV
- 96 + 96 (90) + 16 (x2) scintillator-WLS-SiPM RO channels
- Segmentation provides momentum measurement down to ~ 5 MeV resolution



Time calibration with SAC using Bremsstrahlung events



- Custom SiPM electronics, Hamamatsu S13360 3 mm, 25µm pixel SiPM
- Differential signals to the controllers, HV, thermal and current monitoring



JINST 19 (2024) 01, C01051

- Online time resolution: ~ 2 ns
- Offline time resolution after fine T_0 calculation – better than 1 ns

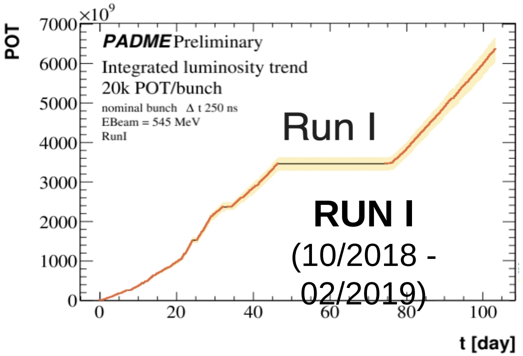
PADME RUN I and II

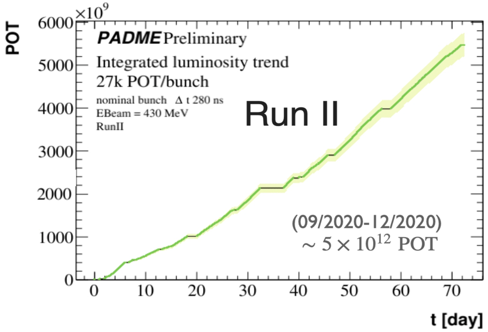
Run I and PADME commissioning

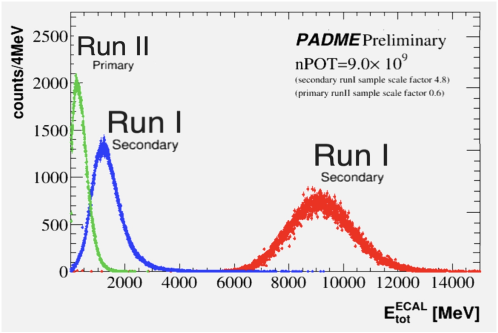
- Started in Autumn 2018 and ended on February 25th
  - ~7 x 10^{12} PoT recorded with secondary beam
  - PADME DAQ, Detector, beam, collaboration commissioning
  - Data quality and detector calibration
- PADME test beam data
  - July 2019, few days of valuable data
    - Certification of the primary beam
  - Detector performance/calibration checks
  - Primary beam with E_{beam} = 490 MeV

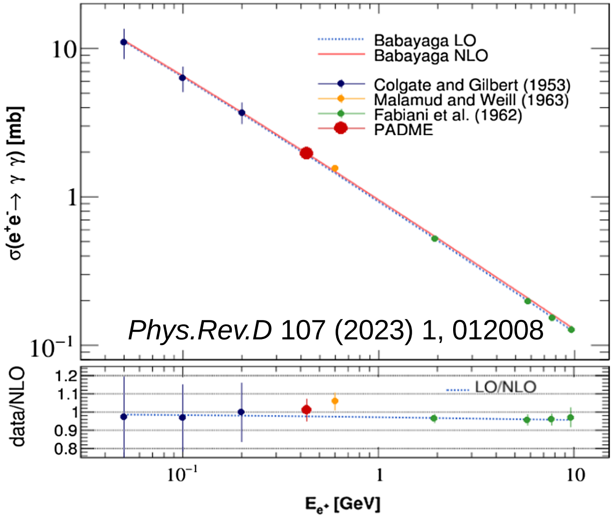
RUN II: primary beam

- July 2020
  - New environment/detector parameter monitoring and control system
  - Remote operation confirmation
- Autumn 2020:
  - A long data taking period with O(5x10^{12}) e^+ on target
  - E_{beam} = 430 MeV









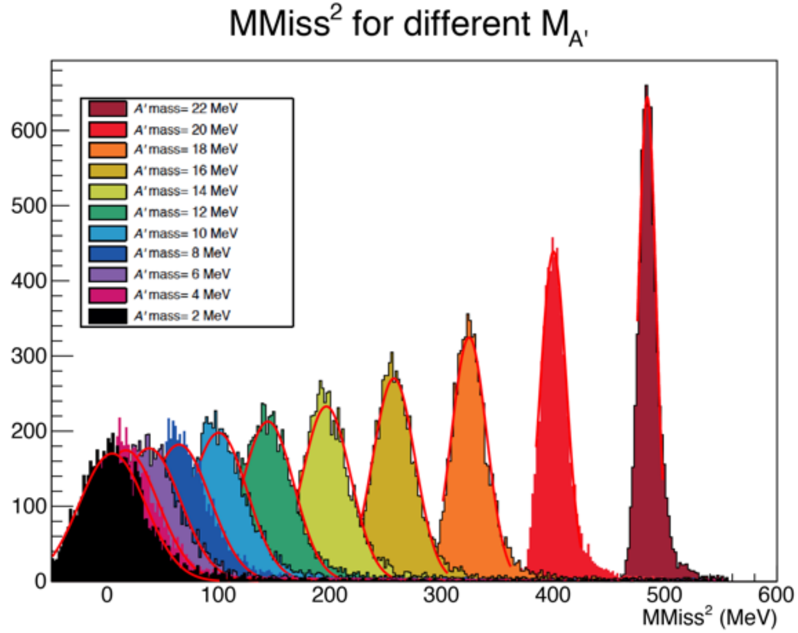
Single photon events treatment

$$N_{A'} = N_{pots}\sigma(\epsilon)\frac{\rho d \mathcal{N}_A Z}{M}$$

5 x 10^{12}
for Run II

0.0106/barn
(number of e^-/unit of area of the target)

Monte Carlo estimations of the missing mass distribution for different Dark photon masses



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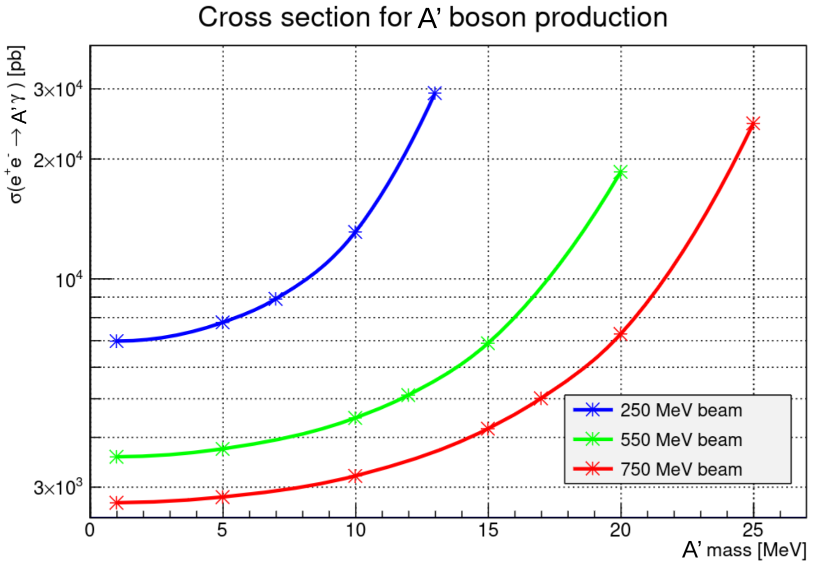
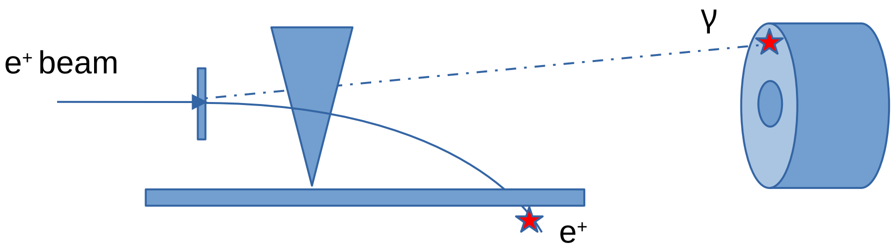
Check obtained cross-section values using γγ result

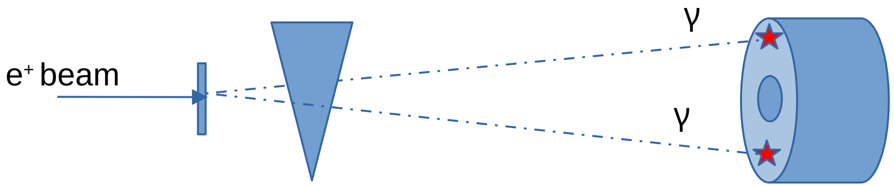
$$\frac{\sigma(e^+e^- \to U\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} = \epsilon^2 * \delta$$

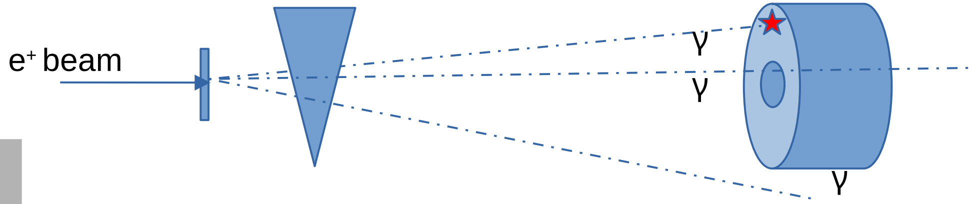


Main background processes

- **Bremsstrahlung in the field of the target nuclei**
  - Photons mostly @ low energy, background dominates the high missing masses
  - An additional lower energy positron that could be detected due to stronger deflection
- **2 photon annihilation**
  - Peaks at $M_{miss} = 0$
  - Quasi symmetric in gamma angles for $E_\gamma > 50$ MeV
- **3 photon annihilation**
  - Symmetry is lost – decrease in the vetoing capabilities
- **Radiative Bhabha scattering**
  - Topology close to bremsstrahlung

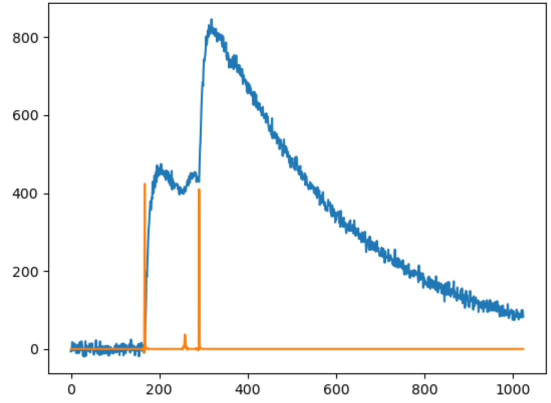






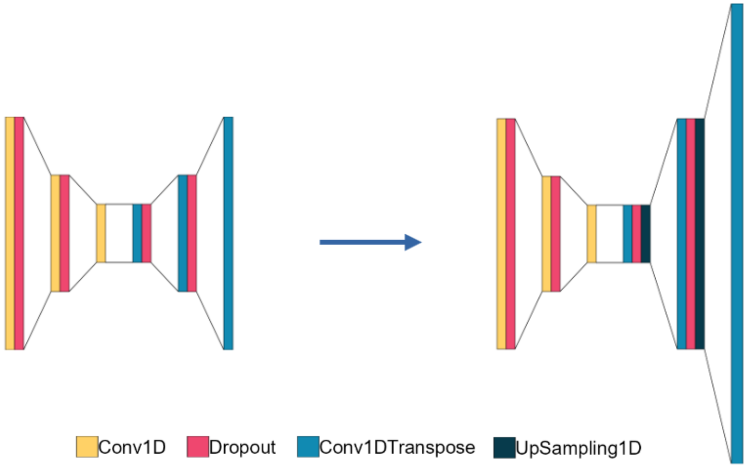
Background process	Cross section e^+@550 MeV beam	Comment *Carbon target*
$e^+e^- \to \gamma\gamma$	1.55 mb	
$e^+ + N \to e^+ N \gamma$	4000 mb	$E\gamma > 1$MeV
$e^+e^- \to \gamma\gamma\gamma$	0.16 mb	CalcHEP, $E\gamma > 1$MeV
$e^+e^- \to e^+e^-\gamma$	180 mb	CalcHEP, $E\gamma > 1$MeV

PADME ML methods

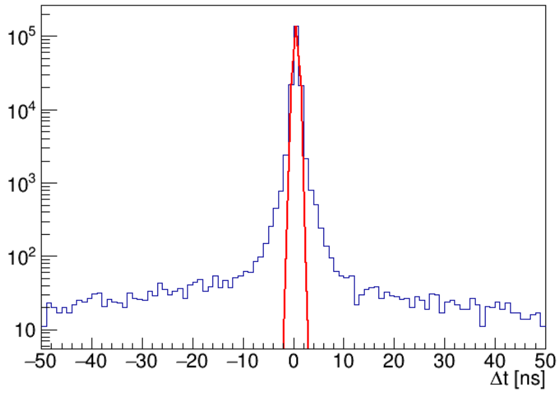


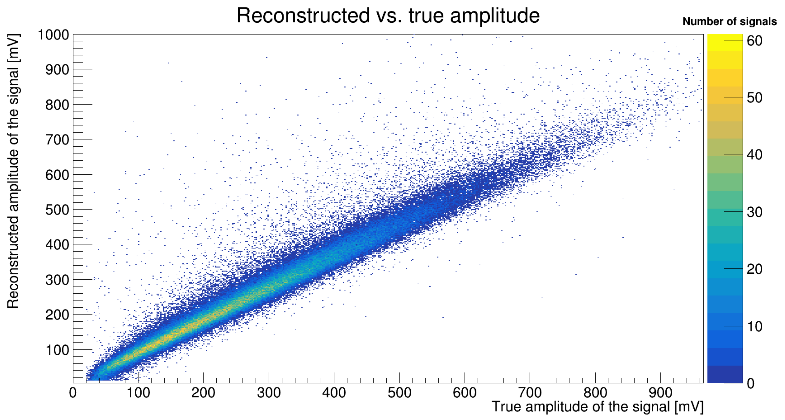
Modified autoencoder

Keeps the waveform length but only extracts signal arrival times and amplitudes



Performance of the algorithms evaluated on synthetic data





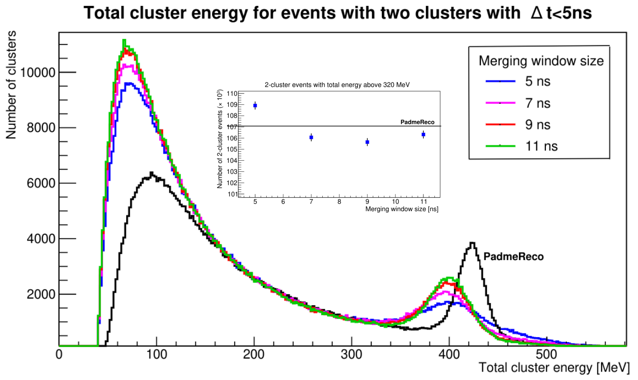
- Models already implemented in the real data reconstruction
- Achievement of better time resolution by upsampling

Event analysis and background cuts

Background events are rejected first in the ECal by:

- Defining a minimal energy and time isolation criteria for single clusters
- Applying geometry cuts

Machine learning models were tested for the reconstruction of e+e-→γγ events in Run II data and compared to the conventional reconstruction

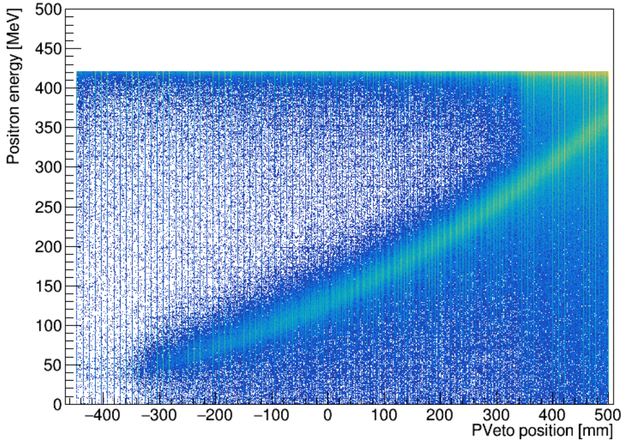


Bremsstrahlung:

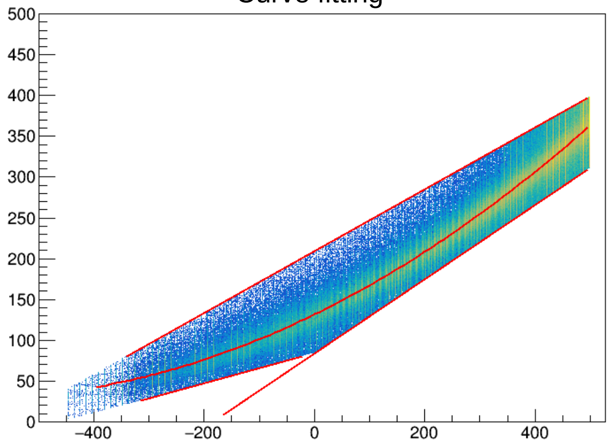
- Clusters in the SAC are matched with positrons in the PVeto to obtain the relation between the positron energy and its position in the veto.
- This relation is used to reject ECal single clusters as Bremsstrahlung events.
- Technique extended by adding the HEPVeto

Bremsstrahlung fitting using the Pveto and the SAC on MC data

Event selection



Curve fitting



Conclusions

- PADME Run II collected 5 x 10^{12} positrons on target
- Analysis of events where a single photon is registered in the calorimeter uses the missing mass technique to probe for a Dark photon in the 2-20 MeV mass range
- Main issue: precise estimation of the different background processes
  - Bremsstrahlung
  - $e+e- \rightarrow \gamma\gamma(\gamma)$ events
- Different event rejection procedures explored on MC data; ML reconstruction aims to achieve more precise results