The Padme experiment at LNF

C. Taruggi - Photon 2019 (LNF June 3rd-7th 2019)
The quest for dark matter

Cosmological evidence that point to the existence of dark matter (DM):

1. Rotation velocity of spiral galaxies
2. Gravitational lensing → Bullet Cluster
3. Anisotropies of the cosmic microwave background
   ...
   ... many others

Nevertheless, there is no evidence of a DM particle in any dedicated experiment.
A possible solution

DM could interact with SM particles by *portals*, which means by a new interaction.

- The simplest model introduces a U(1) symmetry
- Its mediator is a vector boson called *dark photon (A')*
- DM particles live in the dark sector, SM particles are neutral under the new symmetry
- Coupling constant between SM particles and DM particles is $\epsilon$


PHOTON 2019, “Light dark states with electromagnetic form factors”, X. Chu
Dark photon: production

**Production of A’ in e⁺e⁻ processes:**

1. **ANNIHILATION:**  \[ e^+e^- \rightarrow A'\gamma \]

2. **BREMSSTRAHLUNG:**  \[ e^+/e^- N \rightarrow e^+/e^- A' \]

3. **MESON DECAY:**  \[ \pi^0, \eta, ... \rightarrow A'\gamma \]
Dark photon: decays

- **Visible**, in SM particles if \( m_{\text{DM}} \geq m_{\text{A}}/2 \)
- **Invisible**, in DM particles if \( m_{\text{DM}} \leq m_{\text{A}}/2 \)
Detection of dark photon in PADME

- A’ is produced by e^+e^- annihilation: it’s undetected, but can be found by missing mass search:
  \[ m^2_{miss} = (P_{beam} + P_e - P_\gamma)^2 \]

- Only assumption: lepton coupling

- New limits on coupling for particles produced in e^+e^- annihilation (dark photon, dark Higgs, Axion Like Particles)

For ALPs search in PADME, see F. Giachino’s talk «A light dark matter portal: the axion like particle»
PADME beamline

- PADME is placed in the Beam Test Facility of the Laboratori Nazionali di Frascati
- PADME beam properties: $e^+$ energy 550 MeV, multiplicity ~ 20k $e^+/bunch$, bunch duration 250 ns, frequency 49 Hz
- This beam allows us to reach dark photon masses $m_{A'} \leq 23.7$ MeV
The experimental setup

- Positron beam: ~ 20k e\(^+\) per bunch
- Diamond target, 100 μm thickness
- Dipole magnet, 0.45 T
- Vacuum vessel, 10\(^{-5}\) mbar
- Charged particles plastic scintillators veto system
- BGO electromagnetic calorimeter (ECAL)
- Fast PbF\(_2\) small angle calorimeter (SAC)
Overview of the detectors
PADME – diamond target (INFN LE)

- **CVD** (*Chemical Vapour Deposition*) 20 × 20 × 0.1 mm³ policrystal diamond
- 16 × 16 connected graphitic strips (x and y), made in Lecce
- Active target: it gives information about incoming beam (position, size and intensity)
- Very good linearity of collected charge with respect to number of e⁺/bunch
PADME – $e^+ / e^-$ vetoes (Sofia University)

- 96 ($e^-$) + 90 ($e^+$) + 16 (HEP, high energy positron) scintillating bars
- $1.1 \times 1 \times 17.8$ cm$^3$ plastic scintillators
- 1.2 mm WS fibers glued to each scintillator
- SiPM Hamamatsu S13360 $3 \times 3$ mm$^2$ 25 μm cell
- $e^- / e^+$ vetoes in vacuum ($10^{-5}$ mbar) and magnetic field ($\sim 0.45$ T)
PADME – ECal

- 616 $2.1 \times 2.1 \times 23$ cm$^3$ BGO crystals, scintillation light, $\sim$ 300 ns decay time
- Coupled to HZC Photonics XP1911 PMT
- Cylindrical shape of radius $\sim$ 30 cm, central hole ($10.5 \times 10.5$ cm$^2$), Bremsstrahlung rate too high for BGO
- Angular coverage: [20, 93] mrad
- Readout sampling: 1 GHz, 1024 samples

CHARGE DISTRIBUTION FOR ECal PROTOTYPE AT 250 MeV
PADME – SAC

• 25 3 × 3 × 14 cm³ PbF₂ crystals (Cherenkov radiation)
• Very fast signals (~ 4 ns)
• Coupled to fast Hamamatsu R13478UV PMT
• Readout sampling: 2.5 GHz, 1024 samples
• Angular coverage: [0, 20] mrad
• Beam calibration performed on 9/25 crystals, giving good results on reconstructed data
PADME – TimePix3 beam monitor

- Single sensor: 256 × 256 matrix, pixel size 55 μm
- Whole detector: 12 sensors (786 432 pixels), 8.4 × 2.8 mm²
- Monitor the not interacting e⁺ beam
- Operating in standalone mode during run I
- So far, the biggest TimePix3 array used for particle physics
Data taking: run I

Main technical purposes for run I:

• Online monitor and detector control system for every subdetector
• Calibration for every detector
• Best beam configuration
• Background studies
• Information about POT (positron on target, per bunch)
• Collect a sample of order of $10^{12}$ POT
Estimate of POT

➢ Online monitor uses 1/5 of the data
➢ Results are affected by reconstruction efficiency
➢ Improved target calibration was performed after data taking, so reconstructed data must be reprocessed to have a better estimate of POT
➢ Expected uncertainty on POT: 20-25%
➢ Data quality studies might also reduce this estimate
➢ **Total on 21/02/19**: $7.4 \times 10^{12}$ (preliminary, must include uncertainty!)
ECal performance: CR calibration

- Cosmic trigger runs during data taking (5 Hz)
- **Selection of vertical CR**: at least 3 consecutive SUs in the same column, no signal in SUs in the same row
- **Efficiency**: signal has energy ≥ 5 MeV → ratio between logic AND in 3 SUs in column and logic AND of upper and lower SUs
- **Average efficiency** ~ 99.6% (excluding external SUs)
- 4 broken SU, could be possibly repaired before run II
ECal performance: clustering

- Seed: SU with maximum energy
- Cluster: $5 \times 5$ matrix around seed
- Cluster SU must be in time ($\pm 10$ ns around seed time)
- SU charge must be $> E_{\text{thr}}$ (1 MeV)
- Single particle run @ 490 MeV pointing to the calorimeter for single hit reconstruction
- Multihit reconstruction: template fitting (work in progress)
The main cause for beam background seems to be due to the beam hitting beryllium window separating BTF vacuum from PADME vacuum.

Beam energy resolutions > 0.5% are incompatible with beam spot and beam background.

Background energy distribution in data is very similar to MC one with 2 MeV energy resolution.
Data taking: run II

➢ July 2019 will be devoted to calibration runs and to reduce beam background

➢ A new calibration tool with a $^{22}$Na source placed on step motors will be mounted on ECal, to provide more precise calibration constants

➢ TimePix3 data taking will be implemented within the PADME DAQ (also silicon detector MIMOSA, in the target region)

➢ Early promising results with a different beam at the end of run I, beam background 3 times smaller with the respect to the beam used during data taking

➢ Data quality analysis in progress, waiting for new results of subdetectors calibration

➢ The collaboration asked for physics run II to start at the end of 2019 (~ 90 days of data taking)
Conclusions

▪ On 4/10/18 PADME started its search for dark photon, the possible mediator of a new interaction between Standard Model particles and dark matter particles

▪ The closed kinematic of the experiment allows to look for dark photon using the missing mass distribution from the annihilation of a 550 MeV positron beam on a diamond target

▪ Run I showed how reliable the DAQ system is, but also a beam background that must be kept under control. Last days of run I showed that the background can be 3 times smaller with a different beam configuration

▪ A 3 weeks test beam in July ‘19 will provide calibration data and a better beam background control. A new physics run is expected at the end of 2019

▪ We collected $\sim 10^{12}$ POT during Run I, we need to reach $\sim 10^{13}$ POT (about 90 days of data taking)
Backup
PADME - MIMOSA

MIMOSA-28: monolithic pixel tracker in vacuum (first time)
20.8 μm pitch, 20.2 × 22.7 mm² area
It gives information about beam position and divergence
It cannot be used during data taking, a step motor moves target and MIMOSA on position
Two kinds of board provide trigger in PADME:

- CPU trigger board (6 inputs)
- Trigger distribution boards (2 × 32 channels)

CPU trigger boards generate signal in 3 configurations:

1. BTF bunch, for physics runs
2. Cosmics, for calibration runs
3. Random, for pedestal studies

Data are collected by a two-level readout system:

- L0 PCs collect data from every board and (eventually) perform zero suppression
- L1 PCs perform event merging and process rawdata into .root files
Calibration studies

**Target**: calibrated at the end of run I, data will be reprocessed to take into account the results of the calibration. Very good reproducibility and linearity of the calibration data

**ECal**: first order calibration on scintillating units before calorimeter assembly. Cosmic ray calibration results in agreement with first calibration within 11%

**SAC**: beam calibration performed on 9/25 crystals, giving good results on reconstructed data. A new calibration run will be performed in July, reaching all the crystals in the matrix
Understanding beam background

New MC simulation introduces:
- Magnet geometry of beamline (especially magnet DHSTB002)
- Target support (beam could interact with PCB)

From simulation, target energy acceptance is ±5 MeV (~1%). From data, beam energy resolution is <1%!

Energy resolution on target strongly depends on beam energy resolution.