Istituto Nazionale di Fisica Nucleare

Università di Roma Tor Vergata

The PADME experiment at LNF

C. TARUGGI - PHOTON 2019 (LNF JUNE 3RD-7TH 2019)

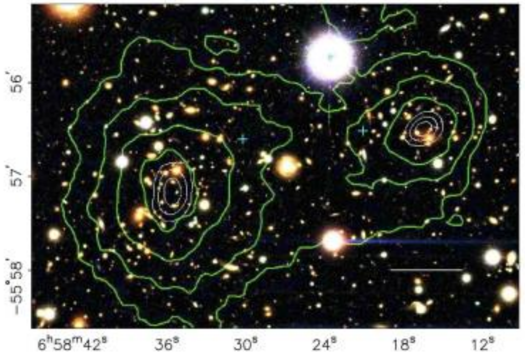
The quest for dark matter

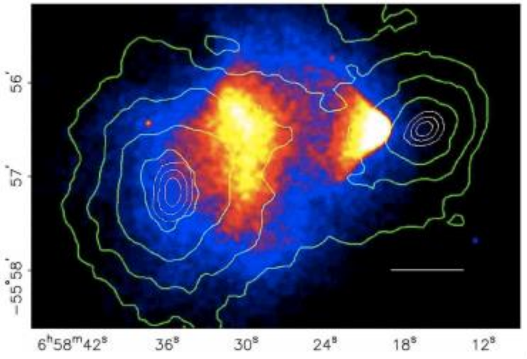
Cosmological evidence that point to the existence of dark matter (DM):

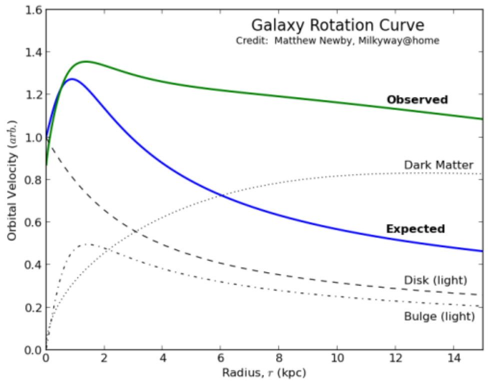
1. Rotation velocity of spiral galaxies
2. Gravitational lensing → Bullet Cluster
3. Anisotropies of the cosmic microwave background

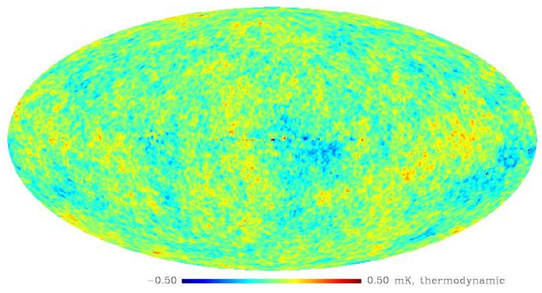
… many others

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



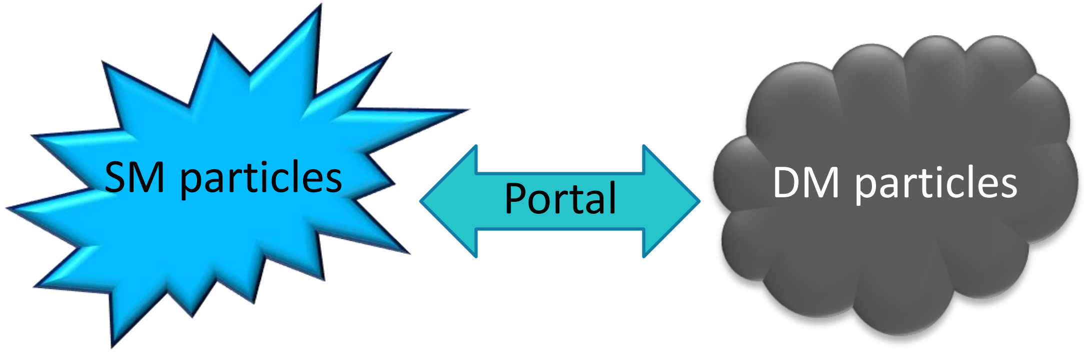






A possibile solution

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 ε

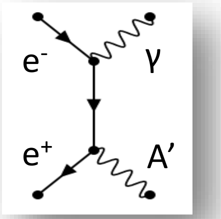
"Dark sector 2016 workshop" J. Alexander et al., arXiv:1608.0863 (2016)

PHOTON 2019, "Light dark states with electromagnetic form factors", X. Chu

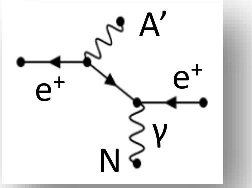
Dark photon: production

Production of A' in e^+e^- processes:

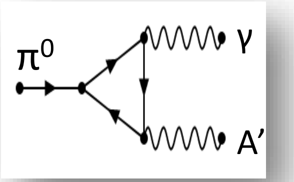
1. **ANNIHILATION:** $e^+e^- \to A' \gamma$



2. **BREMSSTRAHLUNG:** $e^{+/-} N \to e^{+/-} A'$

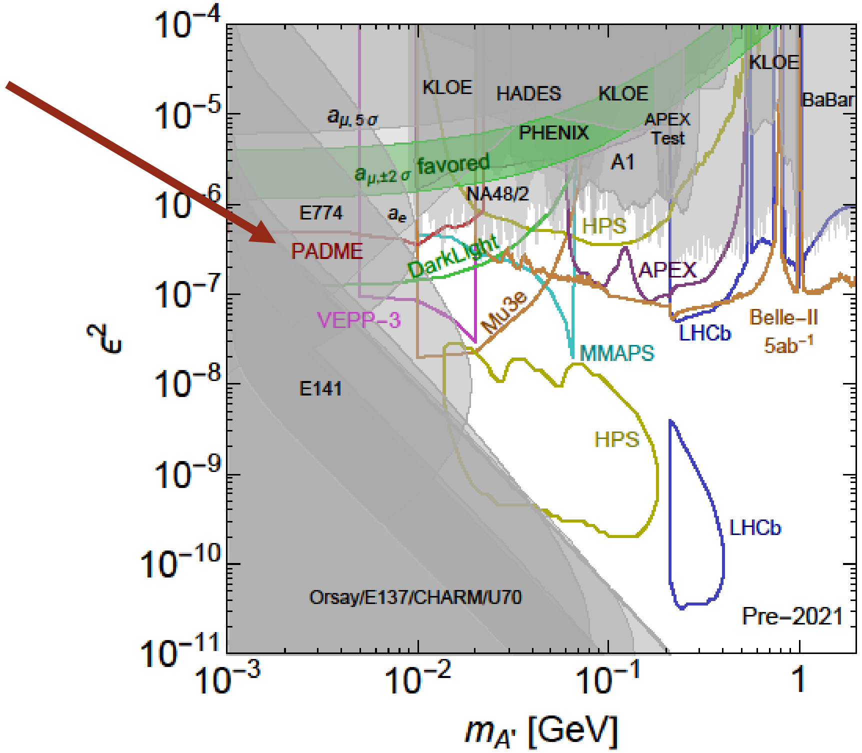


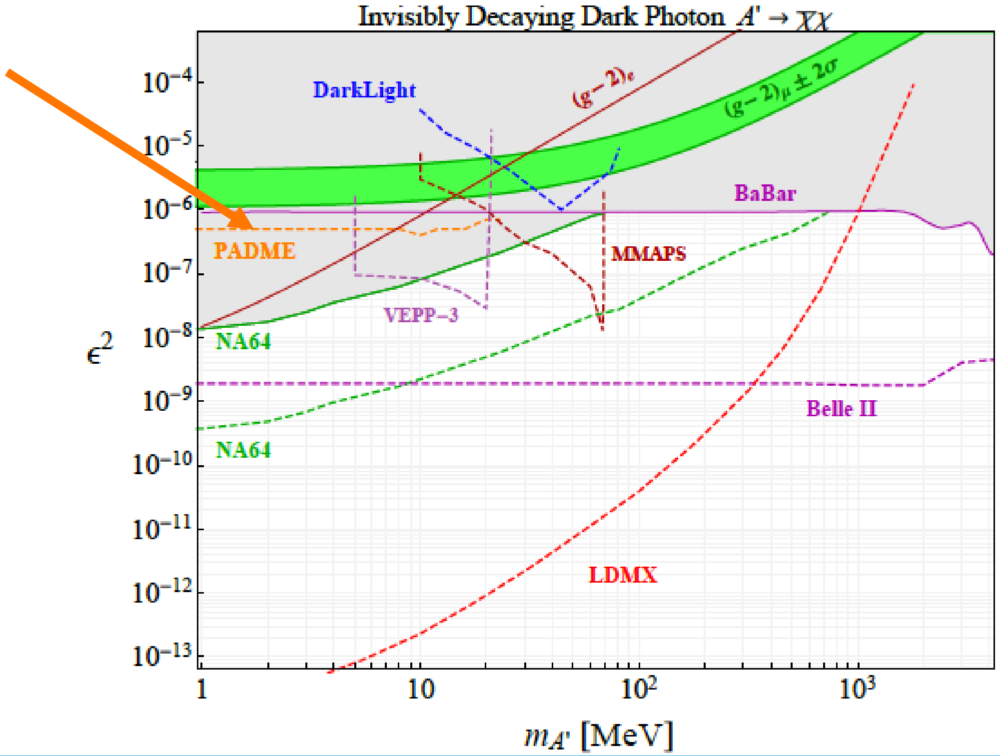
3. **MESON DECAY:** $\pi^0, \eta, \ldots \to A' \gamma$



Dark photon: decays

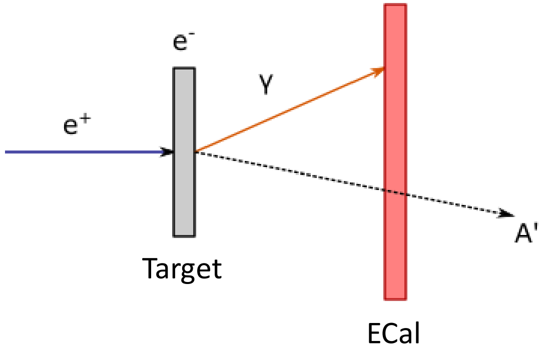
- **Visible**, in SM particles if $m_{DM} \geq m_{A'}/2$
- **Invisible**, in DM particles if $m_{DM} \leq m_{A'}/2$

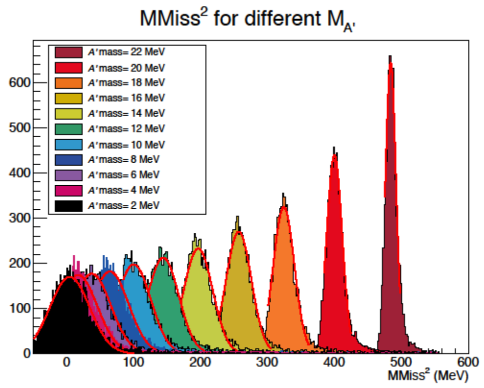




Detection of dark photon in PADME

PADME is looking for the invisible decay of A' using a e^+ beam on a target: $e^+e^- \rightarrow A'\gamma$.
e^+ beam energy is known, and e^- target is at rest, so we need to detect the photon γ in the final state to close the kinematic of the reaction.





- A' is produced by e^+e^- annihilation: it's undetected, but can be found by missing mass search:

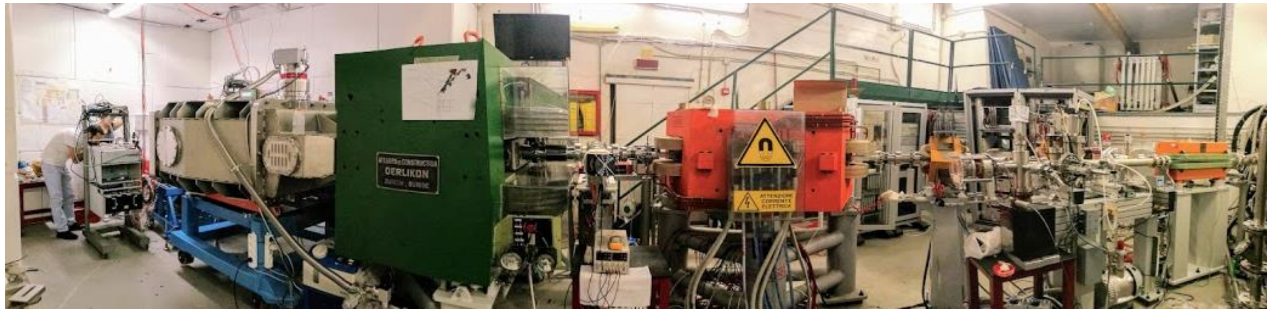
$$m^2_{miss} = (\boldsymbol{P}_{beam} + \boldsymbol{P}_e - \boldsymbol{P}_\gamma)^2$$

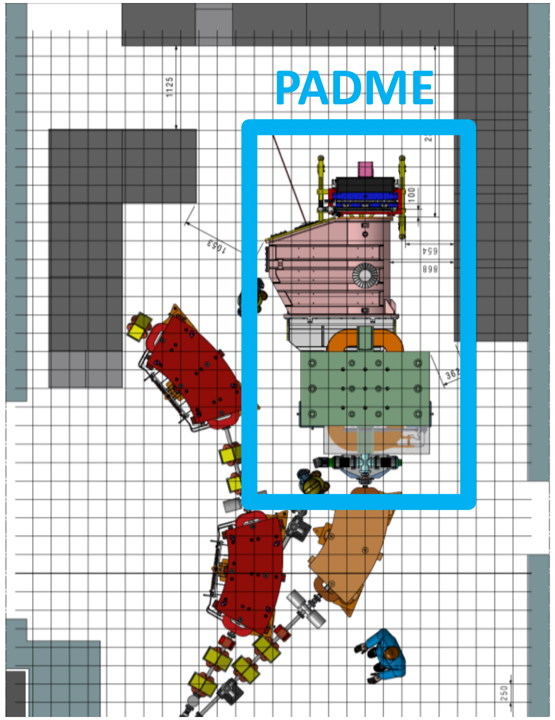
- Only assumption: lepton coupling

- 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. Giacchino's talk «A light dark matter portal: the axion like particle»

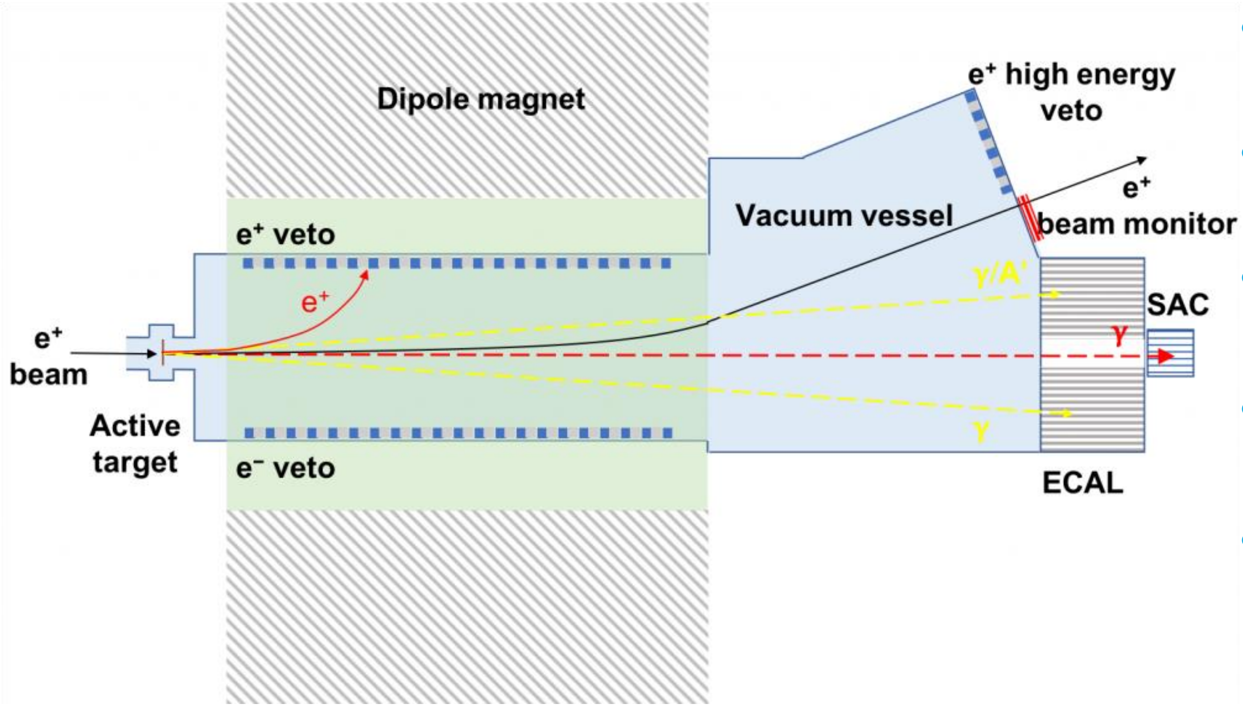
PADME beamline





- 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

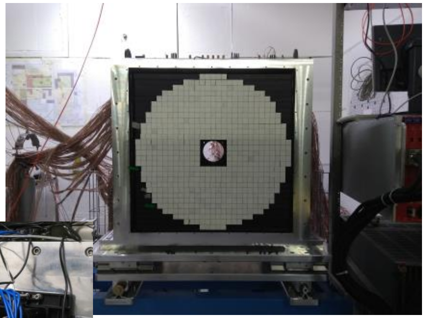
The experimental setup

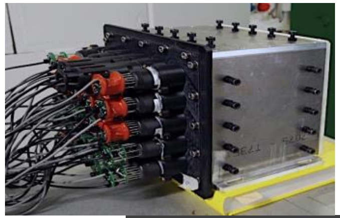


- Positron beam: ~ 20k e^+ per bunch
- Diamond target, 100 μm thickness
- Dipole magnet, 0.45 T
- Vacuum vessel, 10^{-5} mbar
- Charged particles plastic scintillators veto system
- BGO electromagnetic calorimeter (ECAL)
- Fast PbF_2 small angle calorimeter (SAC)

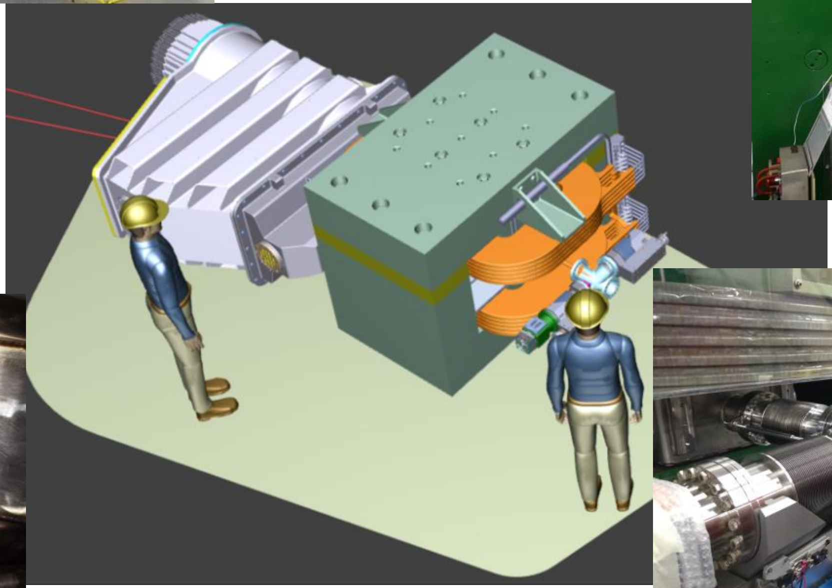
Overview of the detectors

ECAL

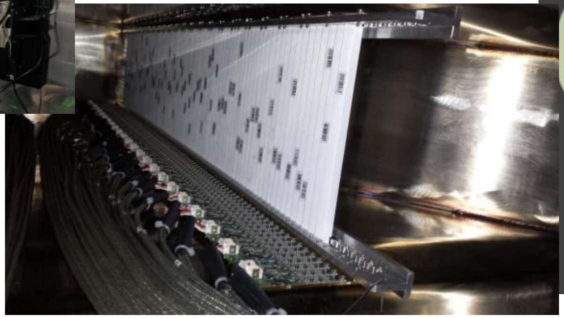




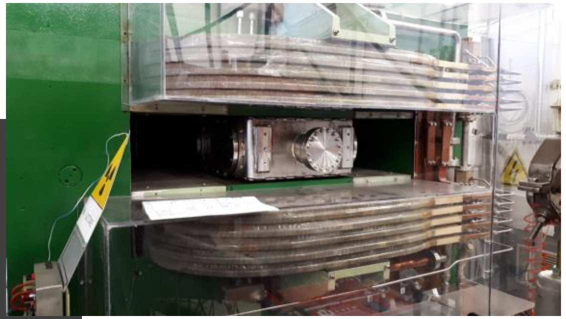
SAC



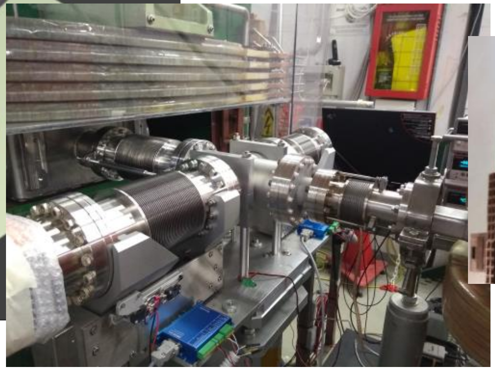
TimePix3

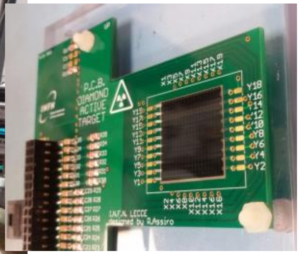


Veto



Magnet



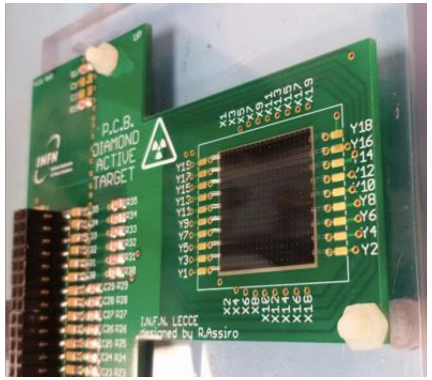


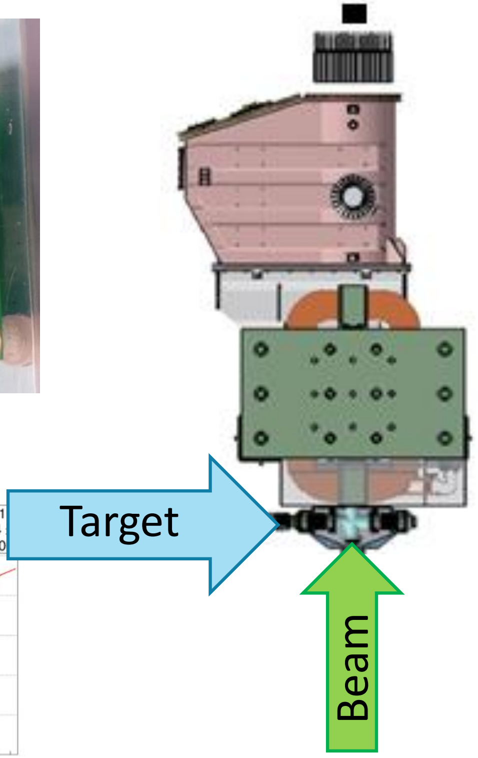
Target

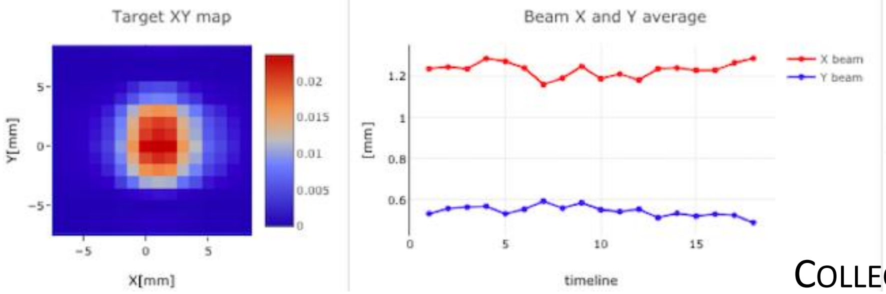
Target region

PADME – diamond target (INFN LE)

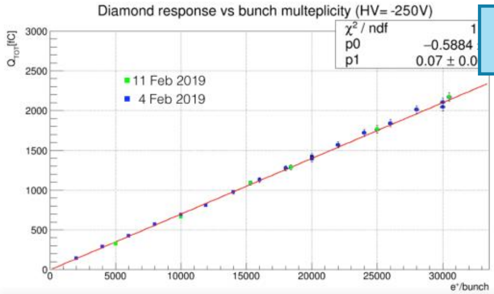
- CVD (*Chemical Vapour Deposition*) 20 × 20 × 0.1 mm^3 policrystal diamond
- 16 × 16 connected graphitic strips (x and y), made in Lecce
- Active target: it gives information about incoming beam (position, size and intensity)
- Very good linearity of collected charge with respect to number of e^+/bunch







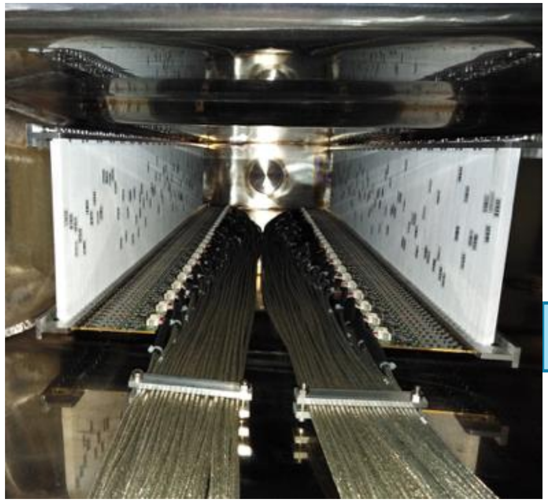
BEAM MONITOR, EXAMPLE

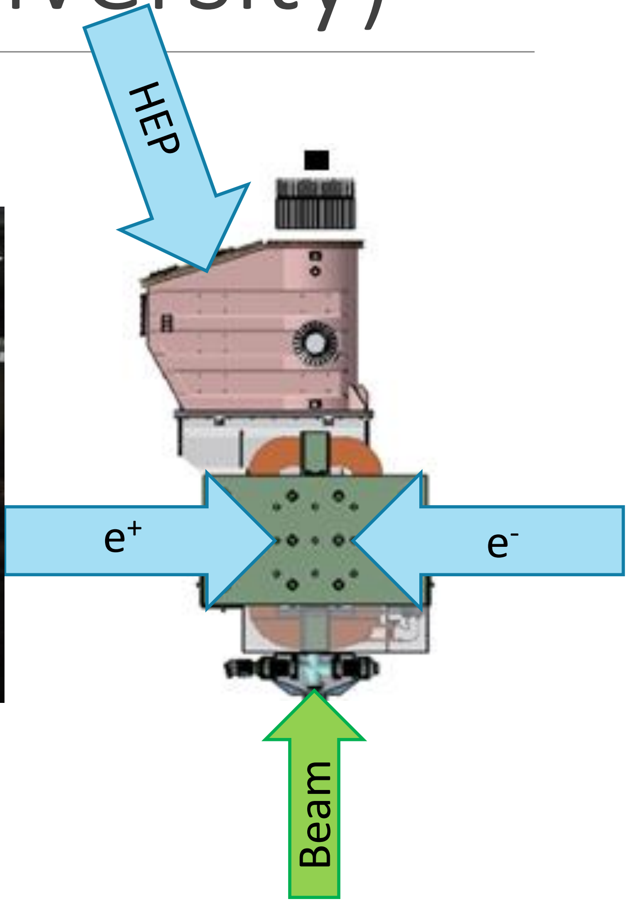


COLLECTED CHARGE VS BEAM MULTIPLICITY (EVALUATED BY LEAD GLASS CHERENKOV CALORIMETER)

PADME – e^+/e^- vetoes (Sofia University)

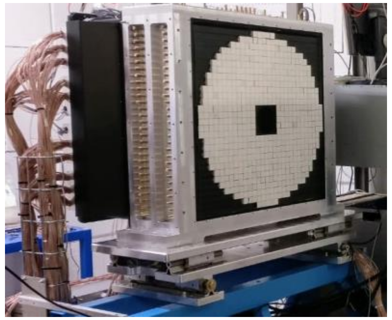
- 96 (e^-) + 90 (e^+) + 16 (HEP, high energy positron) scintillating bars
- 1.1 × 1 × 17.8 cm^3 plastic scintillators
- 1.2 mm WS fibers glued to each scintillator
- SiPM Hamamatsu S13360 3 × 3 mm^2 25 µm cell
- e^-/e^+ vetoes in vacuum (10^{-5} mbar) and magnetic field (~ 0.45 T)

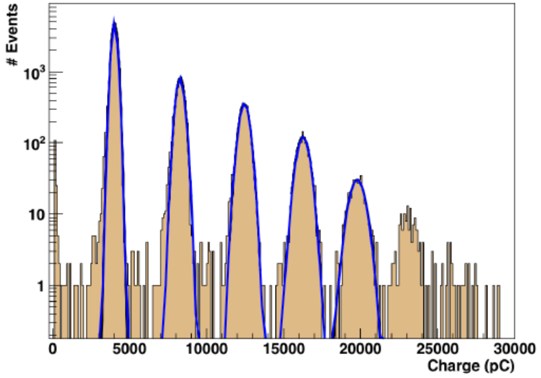




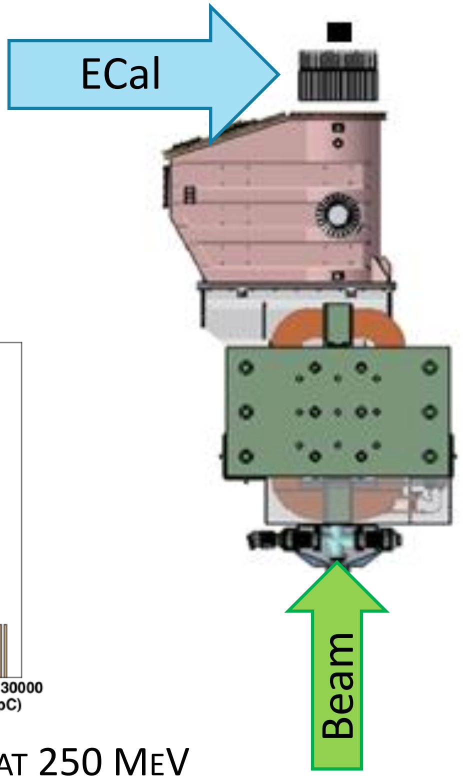
PADME – ECal

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



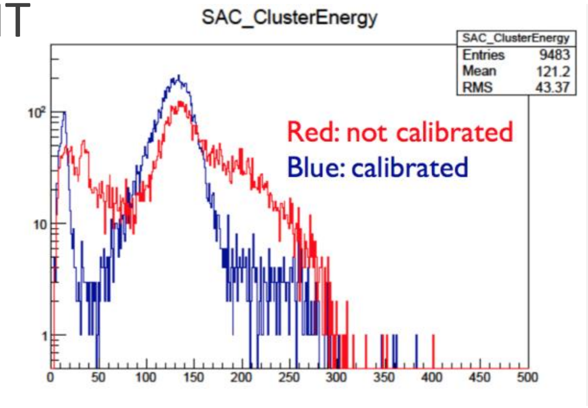


CHARGE DISTRIBUTION FOR ECAL PROTOTYPE AT 250 MEV

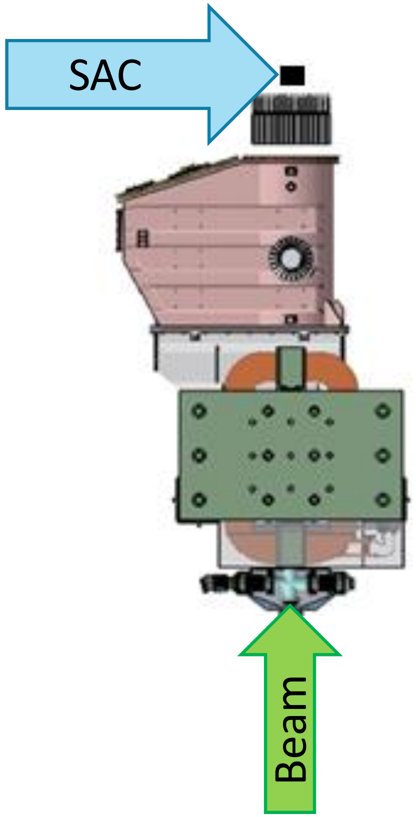


PADME – SAC

- 25 3 × 3 × 14 cm^3 PbF_2 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

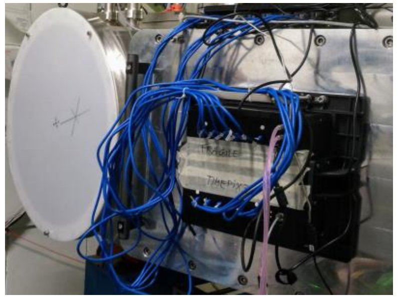


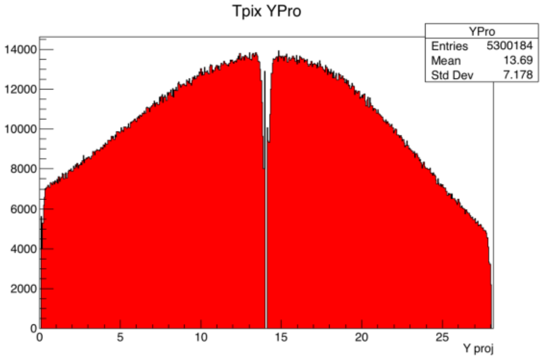
SAC cluster energy
before & after calibration



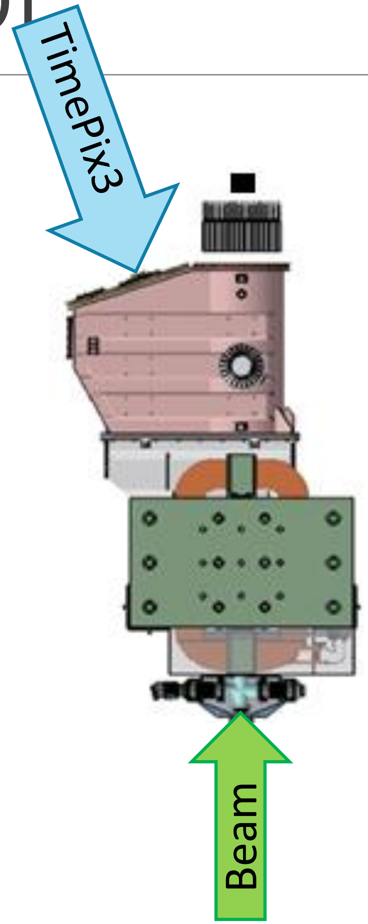
PADME – TimePix3 beam monitor

- Single sensor: 256 × 256 matrix, pixel size 55 µm
- Whole detector: 12 sensors (786 432 pixels), 8.4 × 2.8 mm^2
- Monitor the not interacting e^+ beam
- Operating in standalone mode during run I
- So far, the biggest TimePix3 array used for particle physics





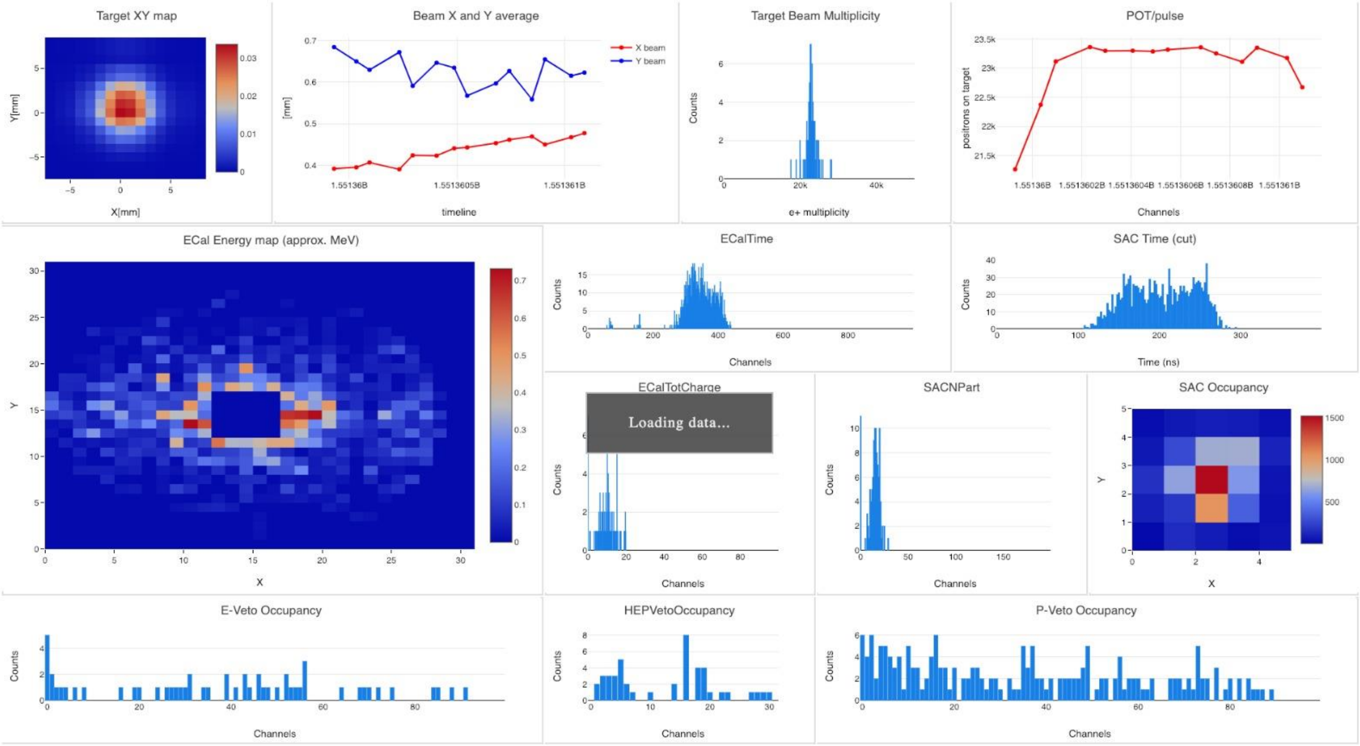
BEAM DIVERGENCE (Y AXIS)



Data taking: run I

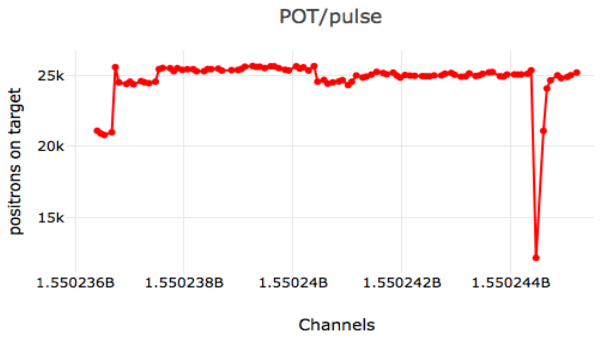
Main technical purposes for run I:

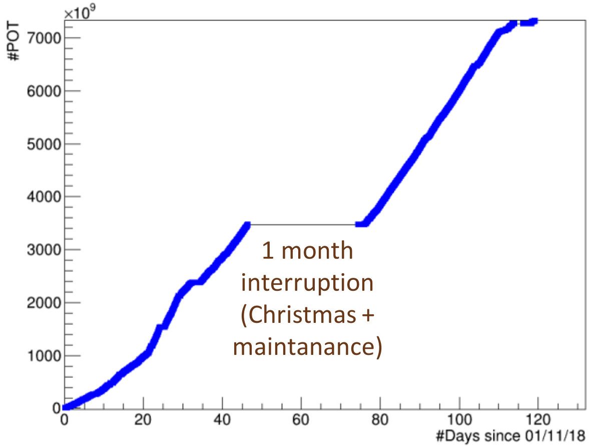
- Online monitor and detector control system for every subdetector
- Calibration for every detector
- Best beam configuration
- Background studies
- Information about POT (positron on target, per bunch)
- Collect a sample of order of 10^{12} POT



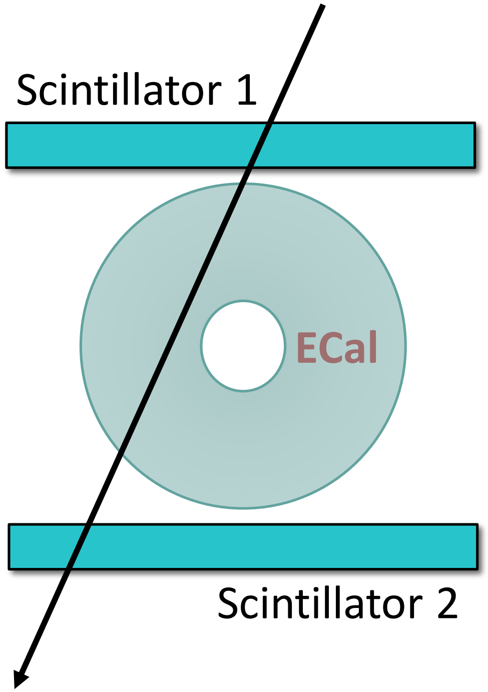
Estimate of POT

- 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
- **<u>Total on 21/02/19</u>**: 7.4×10^{12} (preliminary, must include uncertainty!)

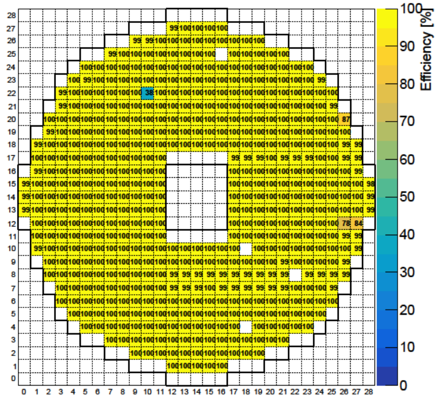




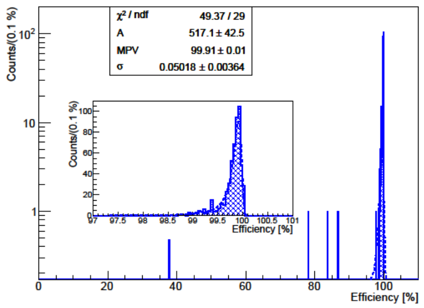
ECal performance: CR calibration



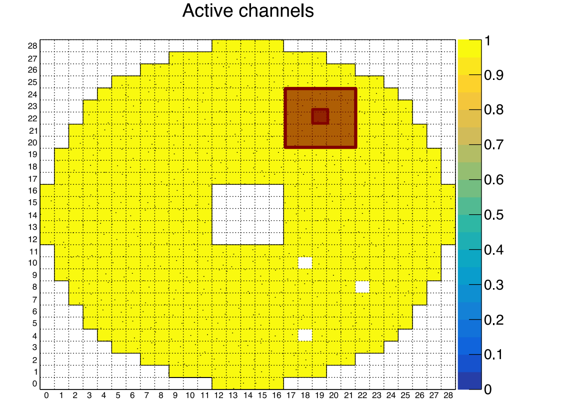
- Cosmic trigger runs during data taking (5 Hz)
- **Selection of vertical CR**: at least 3 consecutive SUs in the same column, no signal in SUs in the same row
- **Efficiency**: signal has energy ≥ 5 MeV → ratio between logic AND in 3 SUs in column and logic AND of upper and lower SUs
- **Average efficiency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

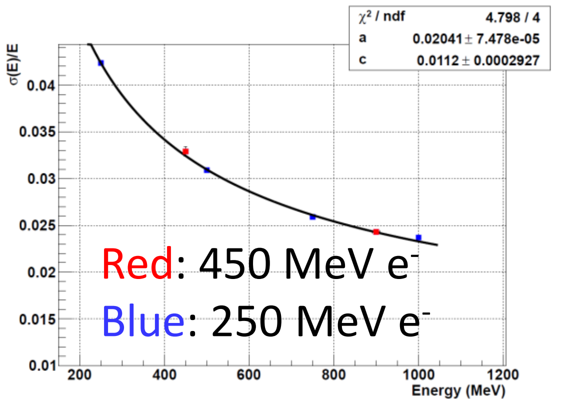


EFFICIENCY (MAP & HISTOGRAM)



ECal performance: clustering



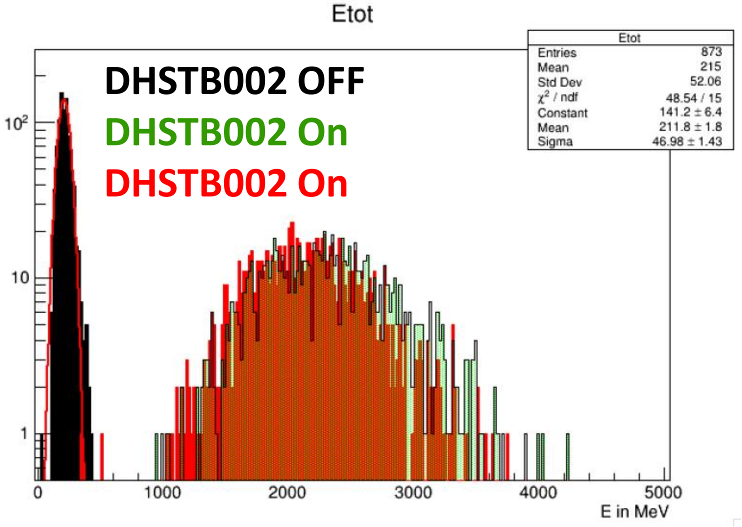


ENERGY RESOLUTION VS BEAM ENERGY IN ECAL PROTOTYPE

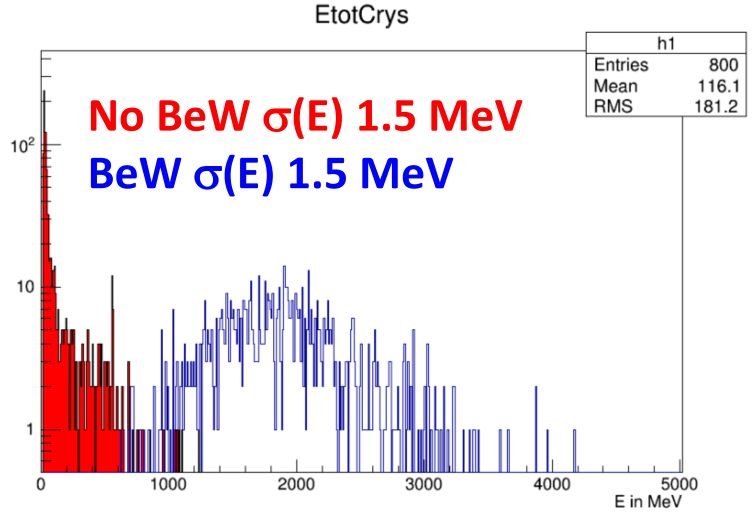
- Seed: SU with maximum energy
- Cluster: 5 × 5 matrix around seed
- Cluster SU must be in time (±10 ns around seed time)
- SU charge must be > E_{thr} (1 MeV)
- Single particle run @ 490 MeV pointing to the calorimeter for single hit reconstruction
- Multihit reconstruction: template fitting (work in progress)

Data/ MC comparison

Data



MC



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 ~ 10^{12} POT during Run I, we need to reach ~ 10^{13} POT (about 90 days of data taking)

Backup

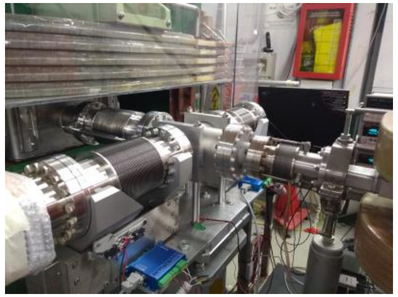
PADME - MIMOSA

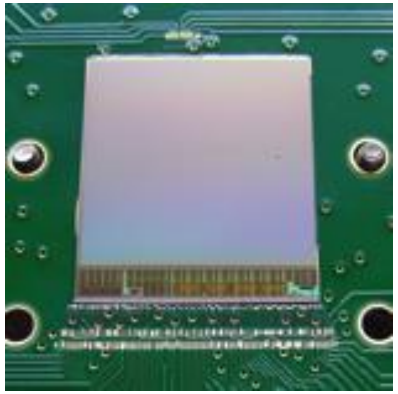
MIMOSA-28: monolithic pixel tracker in vacuum (first time)

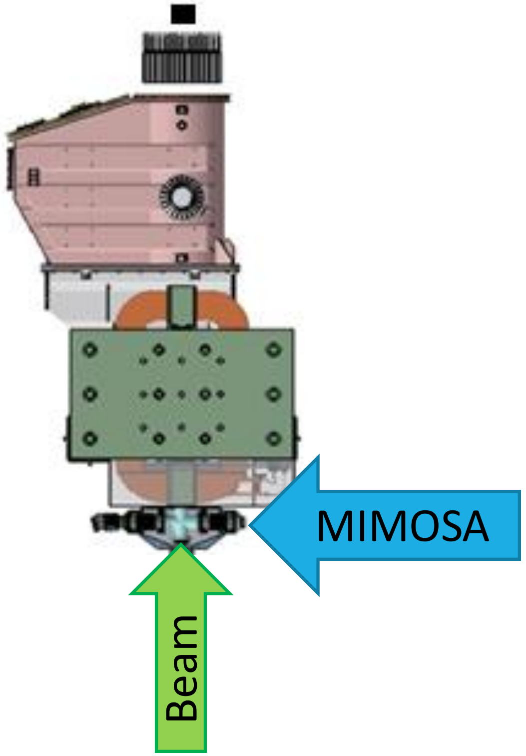
20.8 μm pitch, 20.2 × 22.7 mm^2 area

It gives information about beam position and divergence

It cannot be used during data taking, a step motor moves target and MIMOSA on position







PADME – Trigger and DAQ (Roma1/Roma 3)

Two kinds of board provide trigger in PADME:

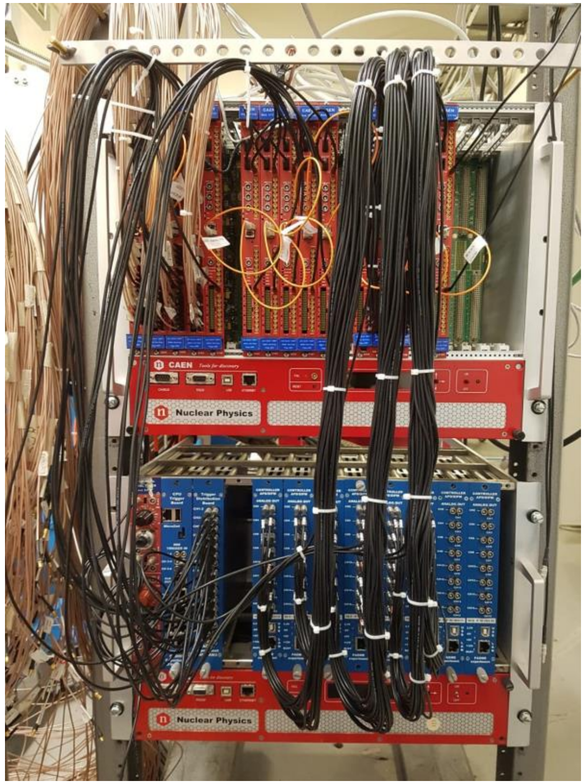
- CPU trigger board (6 inputs)
- Trigger distribution boards (2 × 32 channels)

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

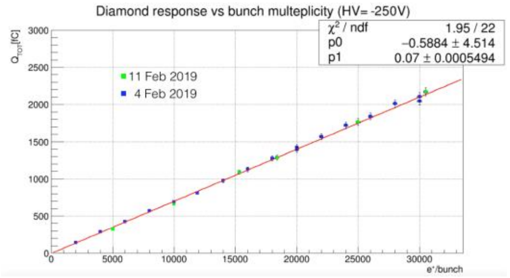


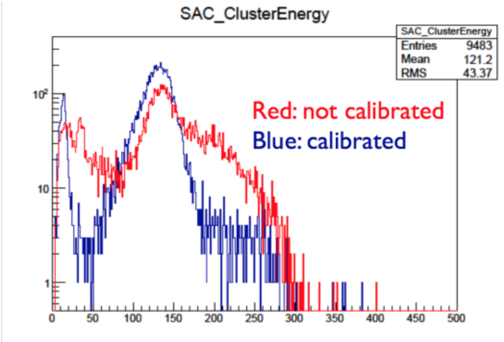
Calibration studies

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

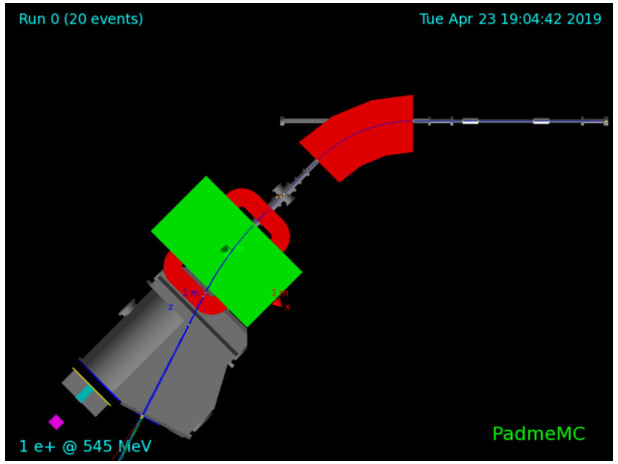
ECal: first order calibration on scintillating units before calorimeter assembly. Cosmic ray calibration results in agreement with first calibration within 11%

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.