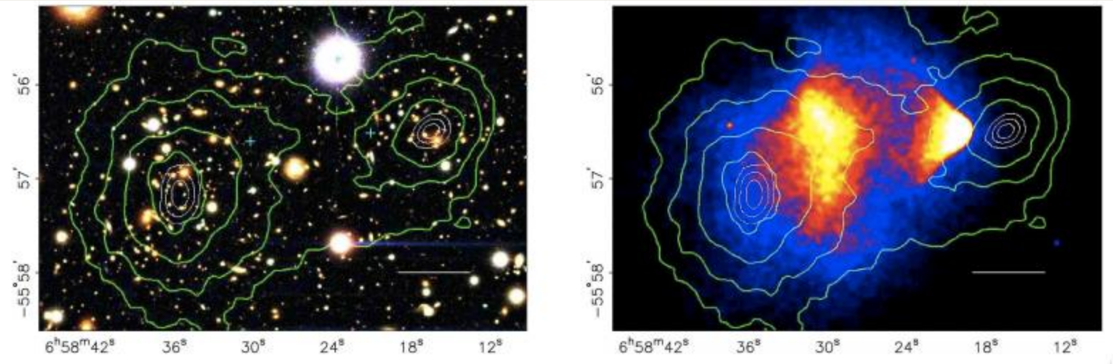
INFN
Istituto Nazionale di Fisica Nucleare

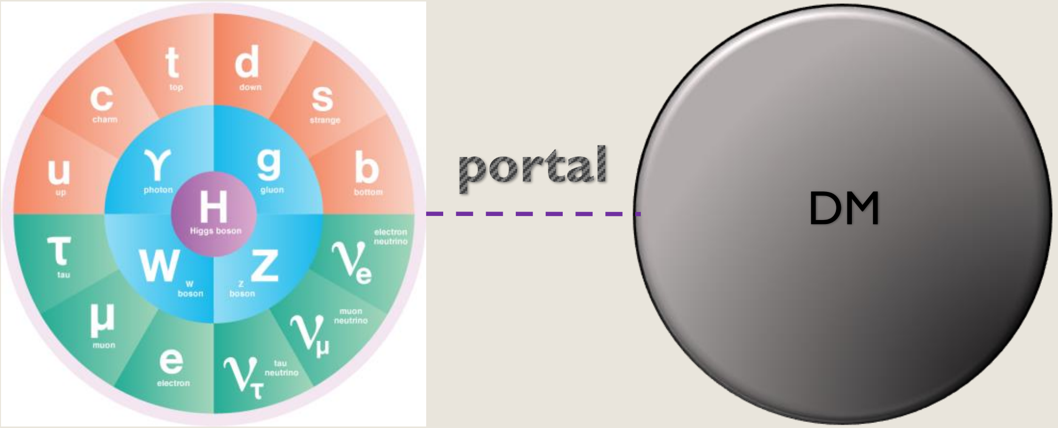
THE PADME DETECTOR

C. Taruggi – ICNFP 2020, Conference Center of the Orthodox Academy of Crete

4-12/09/20

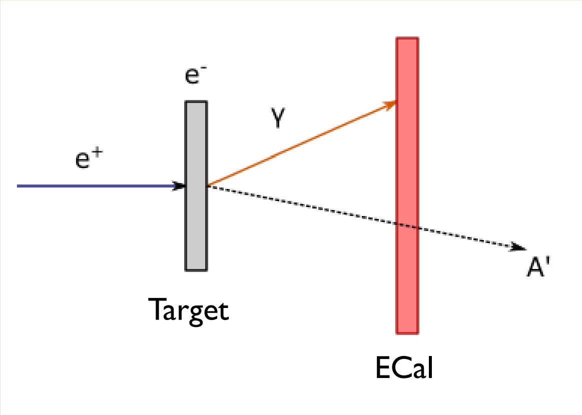
A VERY BRIEF INTRODUCTION





- No evidence of a dark matter (DM) particle in any dedicated experiment
- DM could live in a separate sector, wrt the sector where Standard Model (SM) particles live
- Dark sector (DS) theory
- A new interaction can be introduced: SM sector and DS interact through a vector boson mediator which we call dark photon (DP) or A'
- The coupling constant of the new interaction is $\varepsilon \ll 1$
- Many models and many theories can be introduced
- We focus on DP models that allow the interaction between leptons and DP

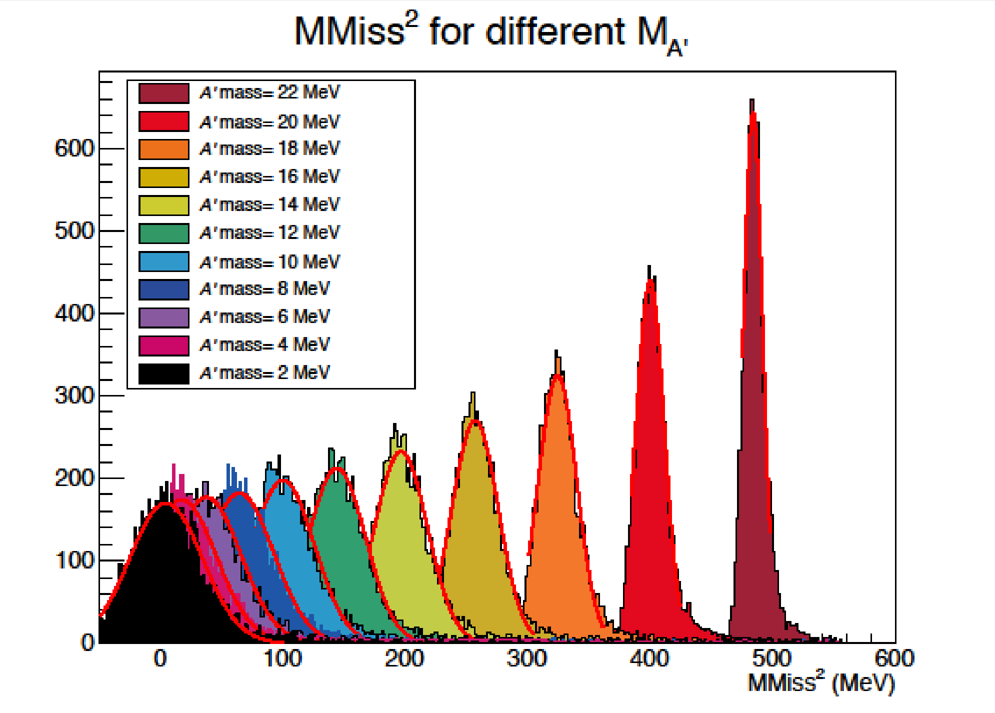
DETECTION OF DARK PHOTON IN PADME



PADME is looking for the invisible decay of A' using a e^+ beam on a target:

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

with known beam energy and target at rest. The momentum of photon γ in the final state must be detected to close the kinematic of the reaction.



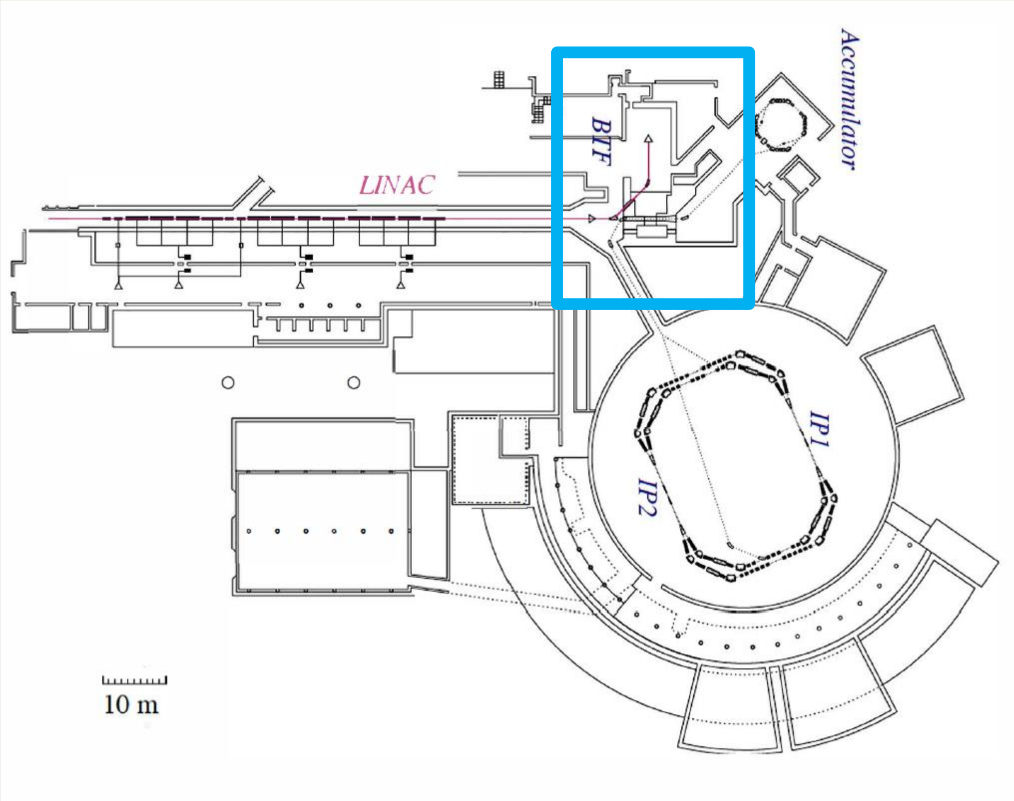
$$M^2_{Miss} = (\boldsymbol{P}_{beam} + \boldsymbol{P}_e - \boldsymbol{P}_\gamma)^2$$

- Main backgrounds: SM annihilation $e^+e^- \rightarrow \gamma\gamma$, SM Bremsstrahlung $e^{+/-} N \rightarrow e^{+/-} N \gamma$
- A' could be produced by e^+e^- annihilation, and observed as missing mass
- Only assumption: lepton coupling
- New limits on coupling for any particles produced in e^+e^- annihilation can be obtained (dark photon, dark Higgs, Axion Like Particles)

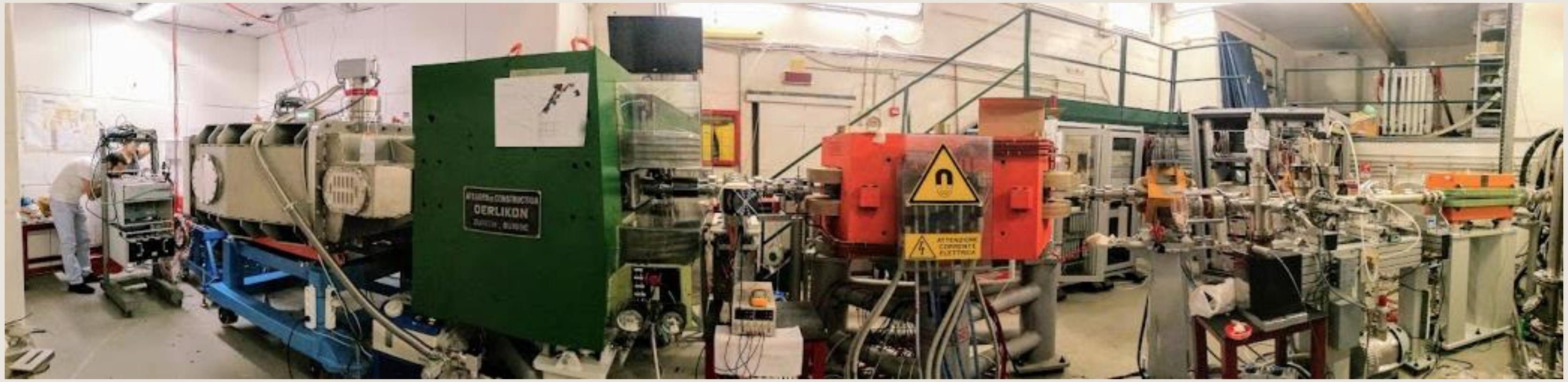
DAΦNE ACCELERATOR COMPLEX

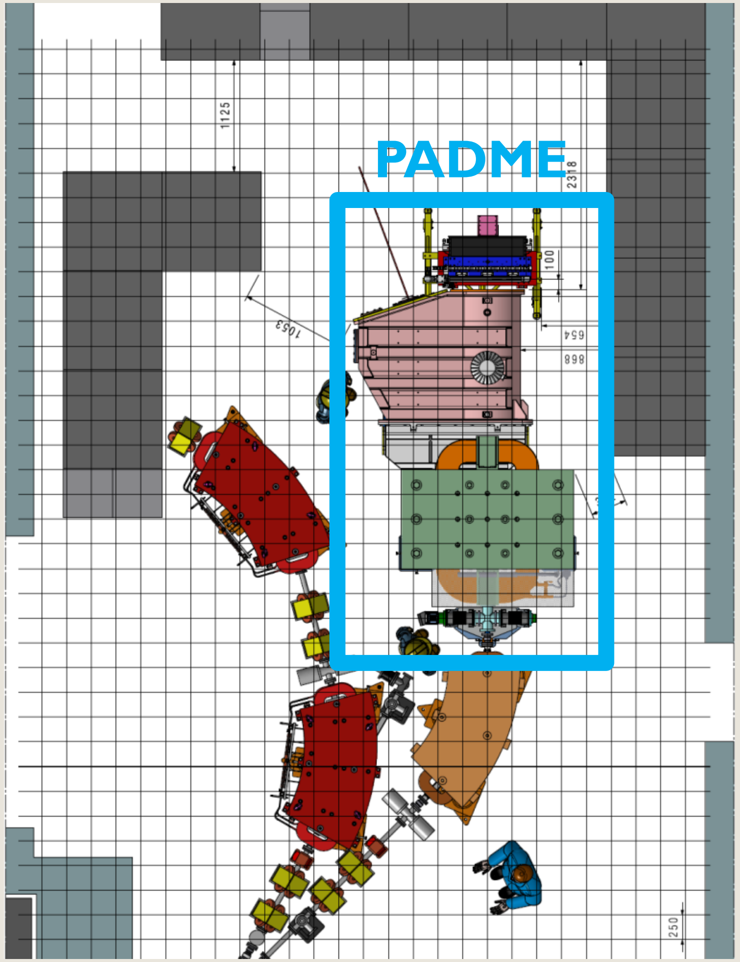
1. PADME is installed in the Beam Test Facility (BTF) of the Laboratori Nazionali di Frascati
2. BTF is part of the DAΦNE accelerator complex
3. LINAC can inject particles into the storage ring (DAΦNE) or provide beam to the BTF
4. DAΦNE is a positrons/electrons collider (E^{cm}_{Φ} = 1.02 GeV)
5. At the Beam Test Facility (BTF) users can get electron/positron beams generated by the LINAC. Two beam lines are available

	e^-	e^+
Maximum beam energy (E_{beam})	750 MeV	550 MeV
LINAC energy spread	0.5%	0.5%
Typical charge	2 nC	0.85 nC
Bunch lenght	1.5-200 ns	1.5-200 ns
LINAC repetition rate	1-50 Hz	1-50 Hz
Typical emittance	1 mm mrad	~1 mm mrad
Beam spot size	< 1 mm	< 1 mm
Beam divergence	1-1.5 mrad	1-1.5 mrad



EXPERIMENTAL HALL & BEAMLINE

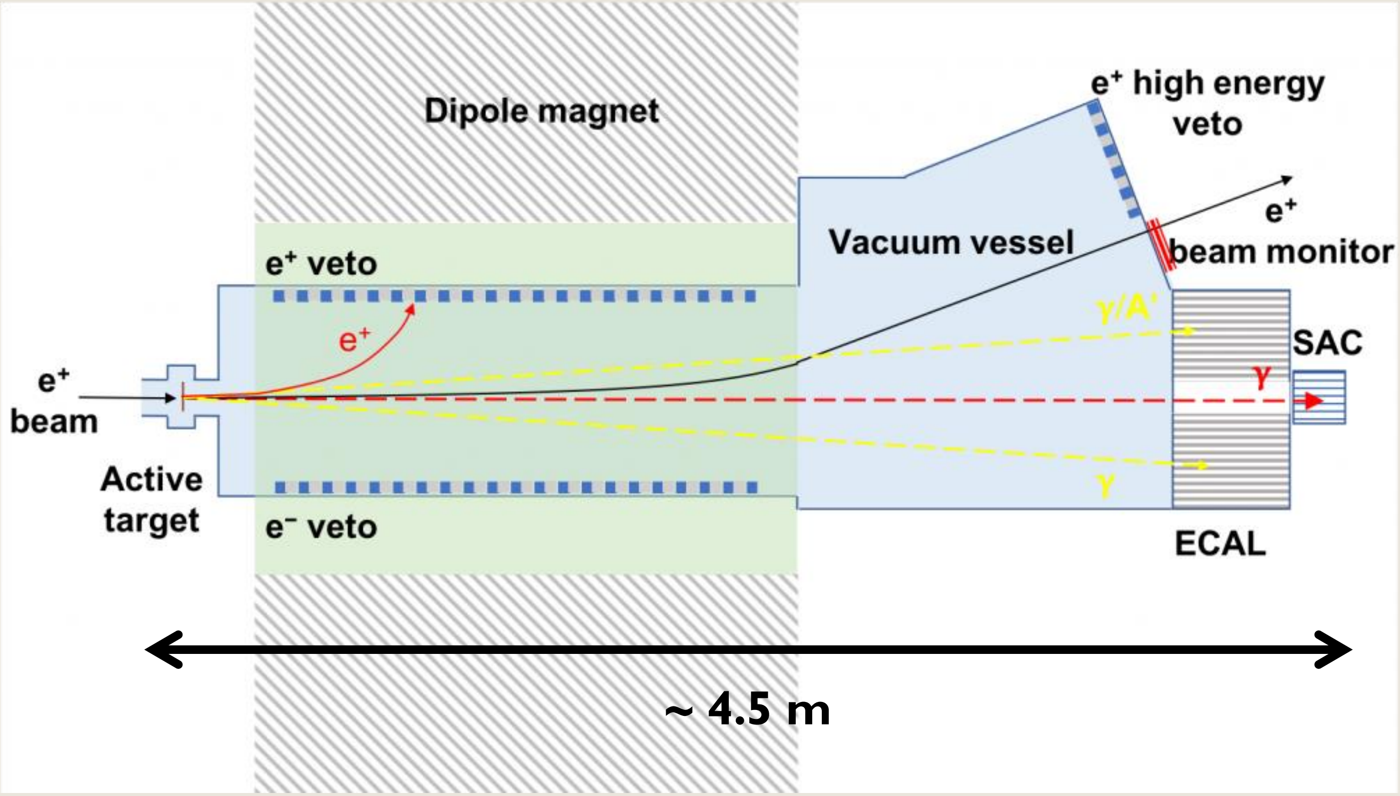




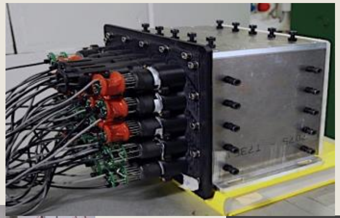
- PADME is installed on beam line 1 (BTF1) of the LNF Beam Test Facility
- PADME nominal beam properties: e^+ energy 550 MeV, multiplicity ~ 20k e^+/bunch, bunch duration 200 ns, frequency 49 Hz
- A beam with these properties allows exploring dark photon masses $m_{A'} \leq 23.7$ MeV

THE DETECTOR

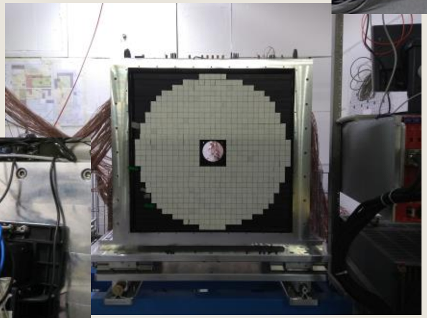
- POSITRON BEAM, ~20k e^+ per bunch
- ACTIVE DIAMOND TARGET, 100 µm thickness
- MIMOSA, pixel tracker
- DIPOLE MAGNET, 0.45 T
- VACUUM VESSEL, 10^{-5} mbar
- CHARGED PARTICLES VETO SYSTEM, plastic scintillators
- BGO ELECTROMAGNETIC CALORIMETER (ECal)
- PbF_2 SMALL ANGLE CALORIMETER (SAC)
- POSITRON BEAM MONITOR (TimePix3)



PADME SUBDETECTORS IN A NUTSHELL

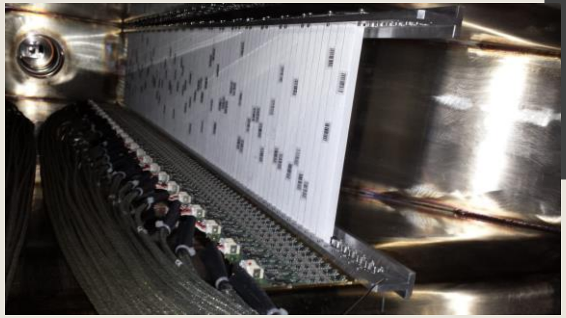


SAC

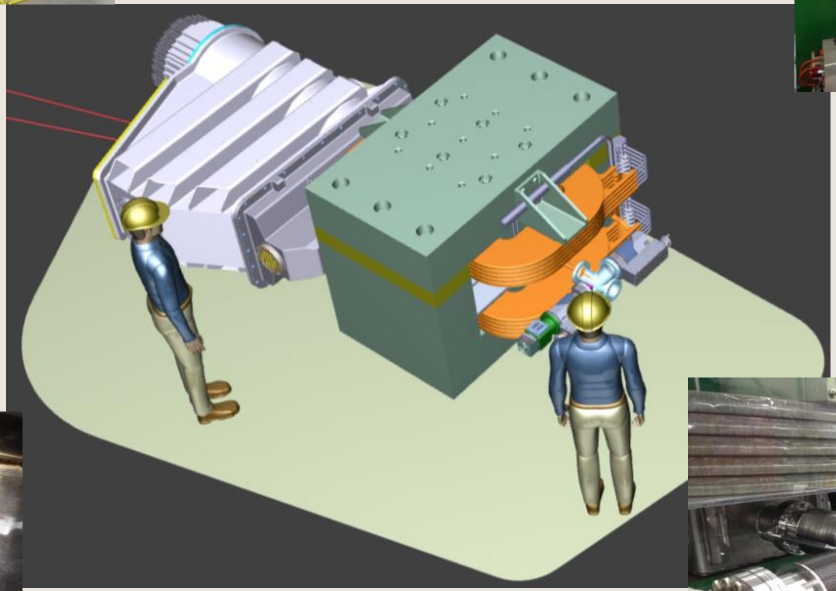


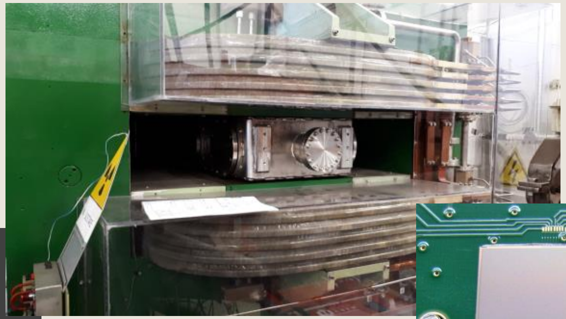
ECal

TimePix3

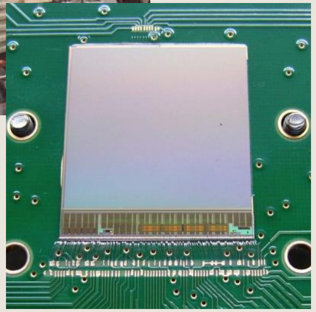


Veto

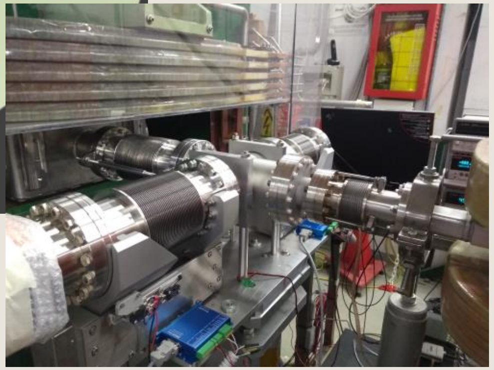




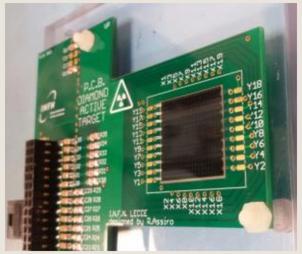
Magnet



Mimosa



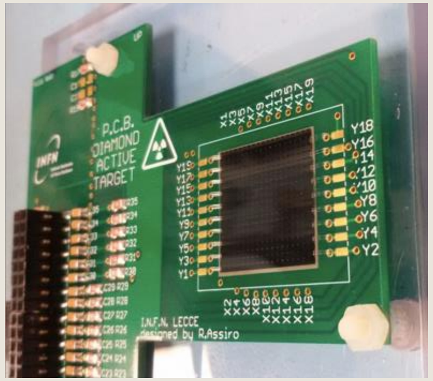
Target region

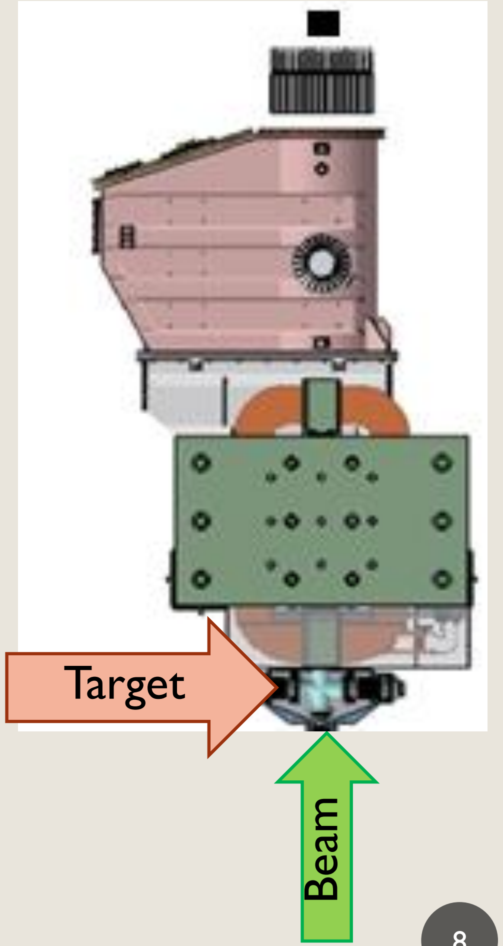


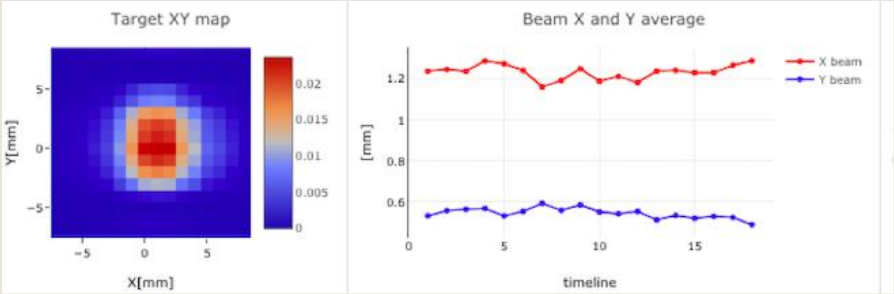
Target

DIAMOND ACTIVE TARGET (INFN-LE)

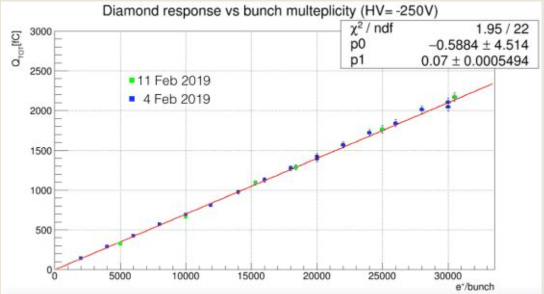
- CVD (*Chemical Vapour Deposition*) $20 \times 20 \times 0.1$ mm^3 policrystal diamond
- 16×16 connected graphitic strips (x and y), made in Lecce
- Active target: it gives information about incoming beam (position, size and intensity)
- Very good linearity of collected charge with respect to number of e^+/bunch
- With the present front-end electronics, it can count from 5k







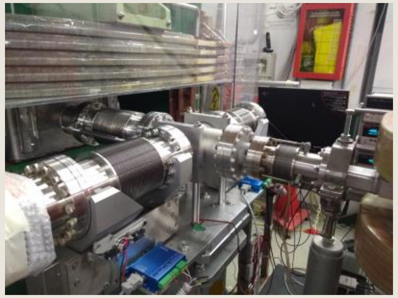
BEAM MONITOR, EXAMPLE



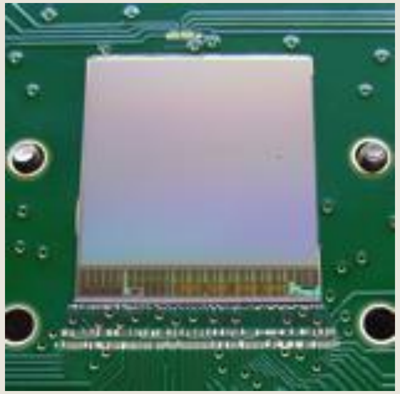
COLLECTED CHARGE VS BEAM MULTIPLICITY

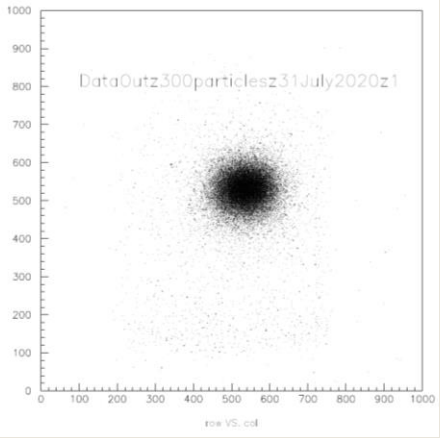
MIMOSA

- 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
- The best performance of MIMOSA is obtained with a multiplicity of ~ 300-1000 particles per bunch: however, preliminary studies show that the detector can give information about the beam up to 3k particles per bunch
- It cannot be used during data taking (it would deteriorate the beam), but can be used before to setup the beam: a step motor moves target and MIMOSA on position

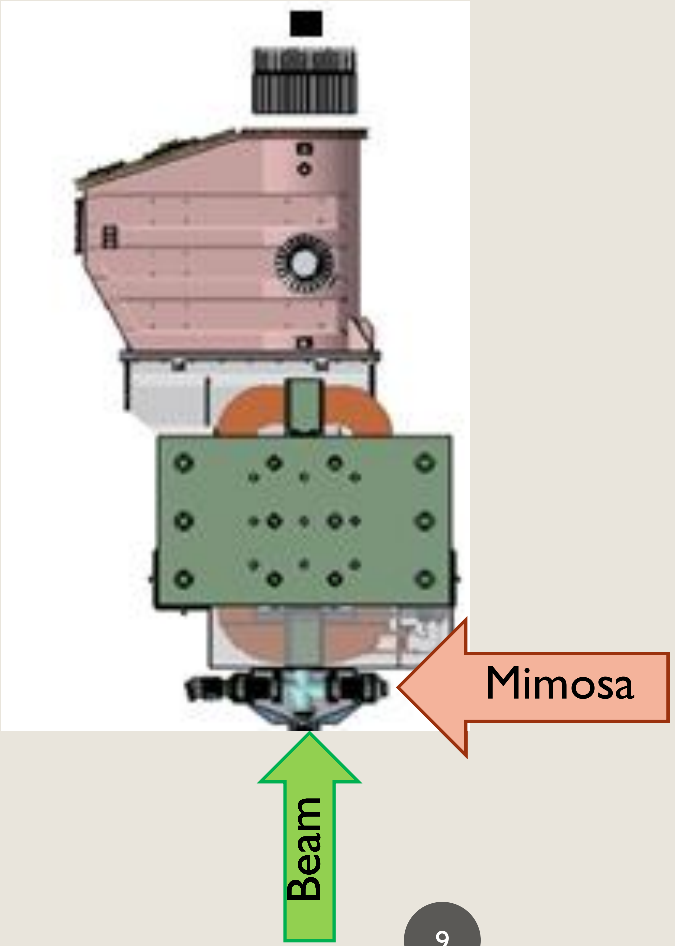


TARGET REGION



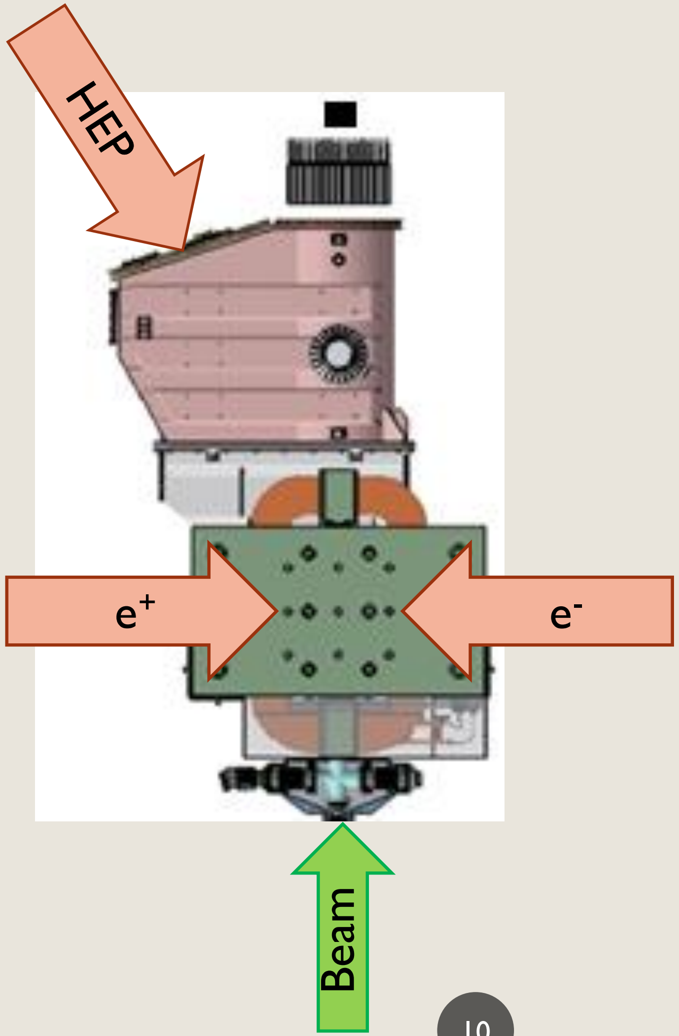


MIMOSA BEAM SPOT



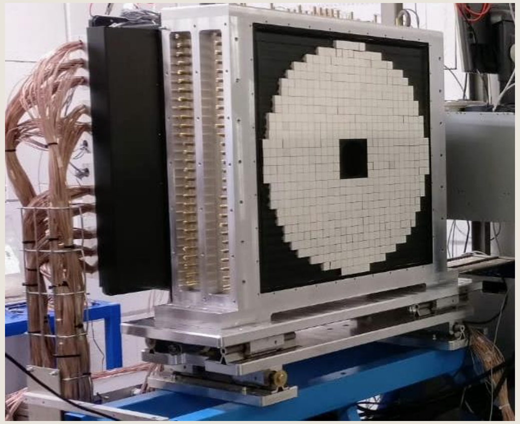
POSITRON/ELECTRON VETOES (SOFIA UNIVERSITY)

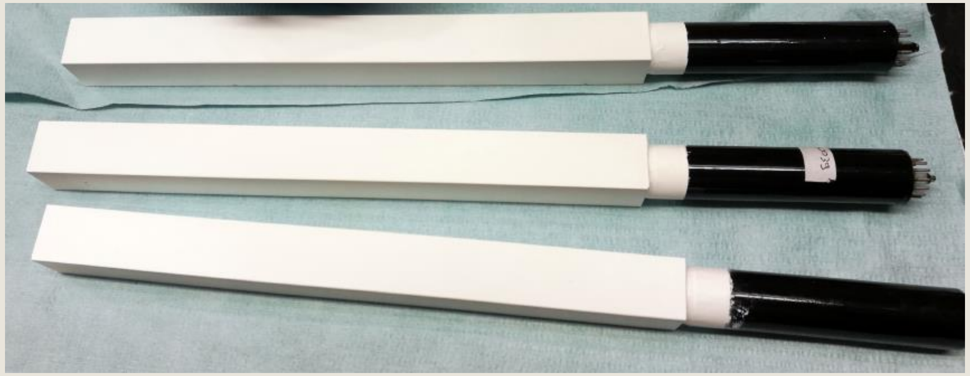
- 96 (e^-) + 90 (e^+) + 16 (HEP, high energy positron) scintillating bars
- 1 × 1 × 17.8 cm^3 plastic scintillators
- 1.2 mm WLS fibers glued to each scintillator
- SiPM Hamamatsu S13360 3 × 3 mm^2 × 25 μm cell
- e^-/e^+ vetoes in vacuum (10^{-5} mbar) and magnetic field (~ 0.45 T)
- They are used to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



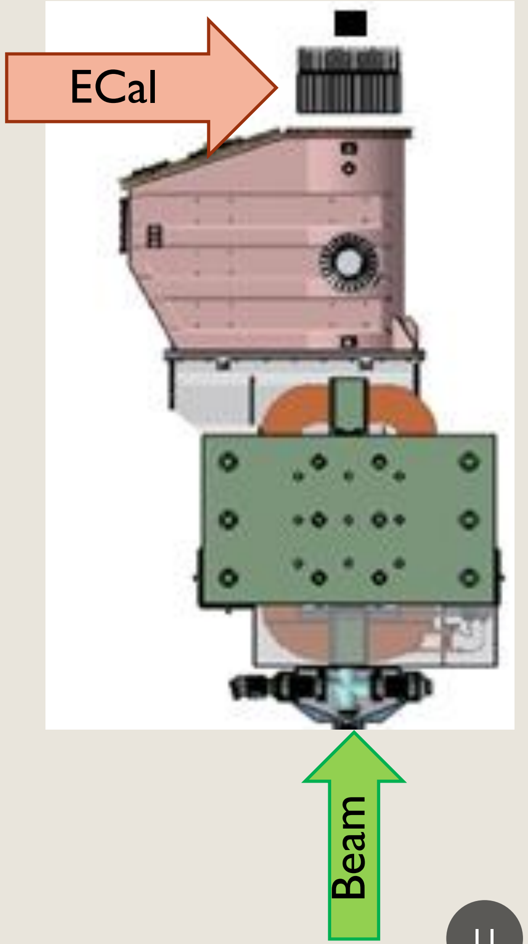
ECAL

- 616 2.1 × 2.1 × 23 cm^3 BGO crystals, scintillation light, ~300 ns decay time, coupled to HZC Photonics XP1911 PMT
- It must detect the γ in the final state, to close the kinematic
- Cylindrical shape of radius ~ 30 cm, central hole of 10.5 × 10.5 cm^2 (Bremsstrahlung rate too high for BGO)
- Angular coverage: [15.7, 82.1] mrad
- Readout sampling: 1 GHz, 1024 samples



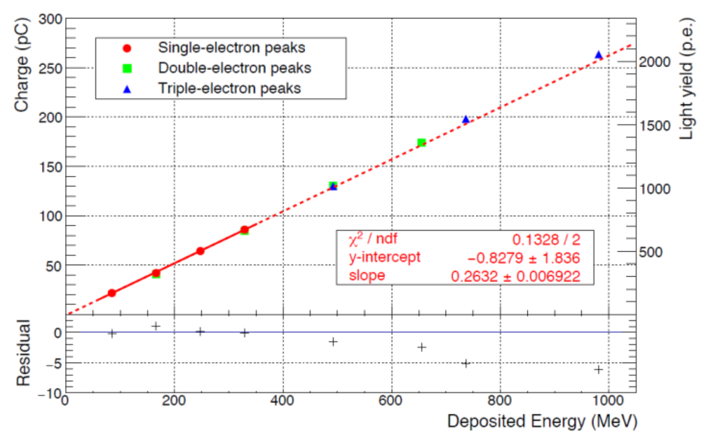


SCINTILLATING UNITS

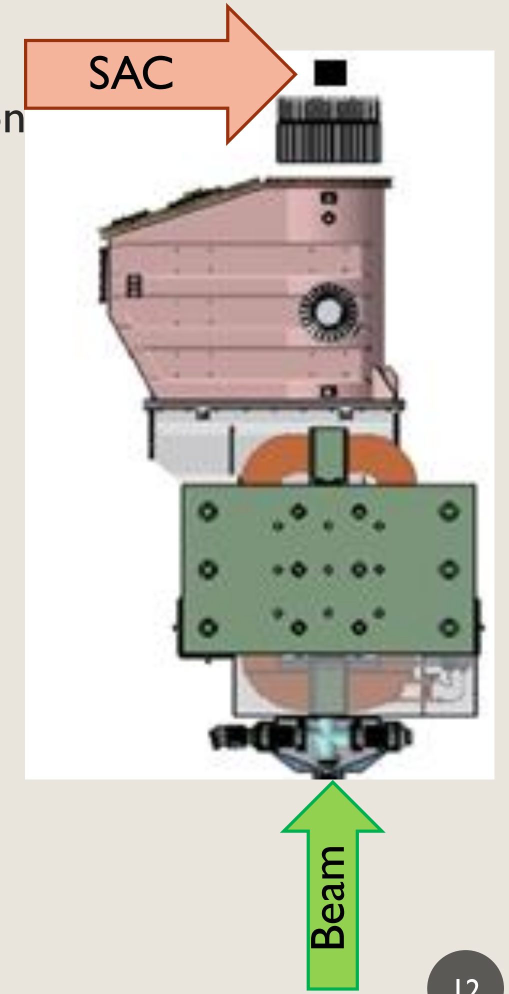


SAC

- 25 3 × 3 × 14 cm^3 PbF_2 crystals (Cherenkov)
- Fast signals (~2 ns), in order to sustain the rate (~100 MHz) of Bremsstrahlung radiation
- Coupled to fast Hamamatsu R13478UV PMT
- Readout sampling: 2.5 GHz, 1024 samples
- Angular coverage: [0, 18.9] mrad
- Two independent calibrations (beam and cosmic rays) were performed

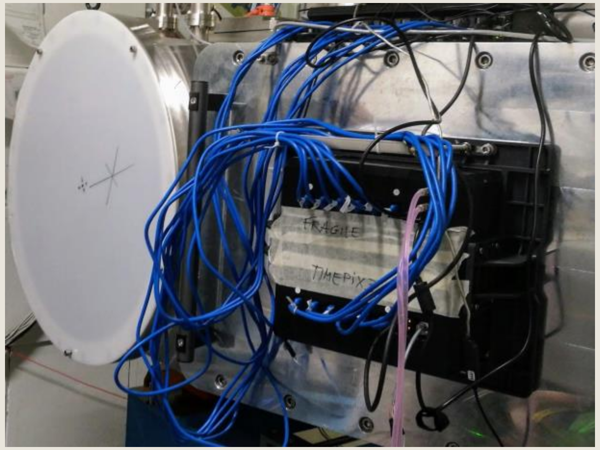


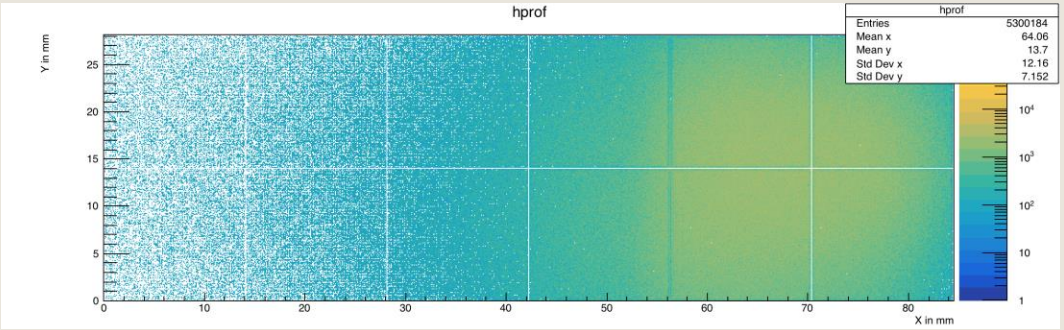
LINEARITY OF A SAC CRYSTAL



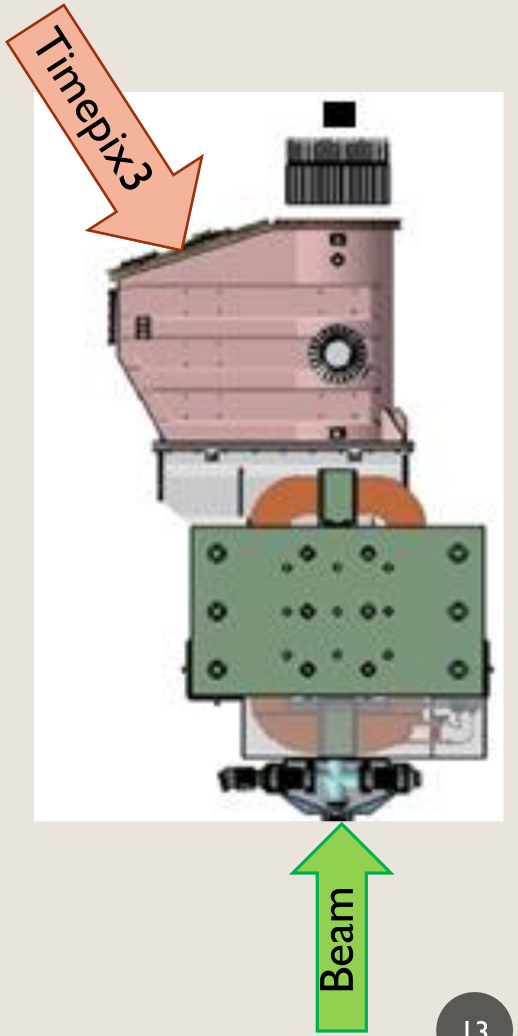
TIMEPIX3

- Single sensor: 256 × 256 matrix, pixel pitch 55 μm
- Whole detector: 12 sensors (786 432 pixels), 8.4 × 2.8 cm^2
- Monitor for the not interacting e^+ beam
- It can measure position, time and energy of each particle
- So far, the biggest TimePix3 array used for particle physics





Beam structure from TimePix3



PADME – TRIGGER AND DAQ (ROMA1/ROMA 3)

Two kinds of board provide trigger in PADME:

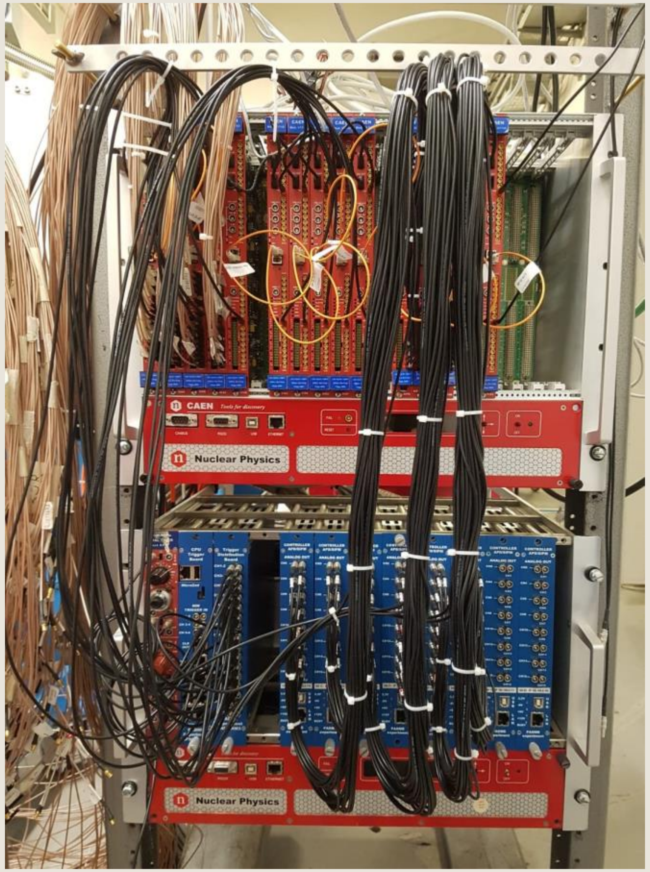
- CPU trigger board (6 inputs)
- Trigger distribution boards (2 × 32 channels)

CPU trigger boards generate signal in 3 configurations:

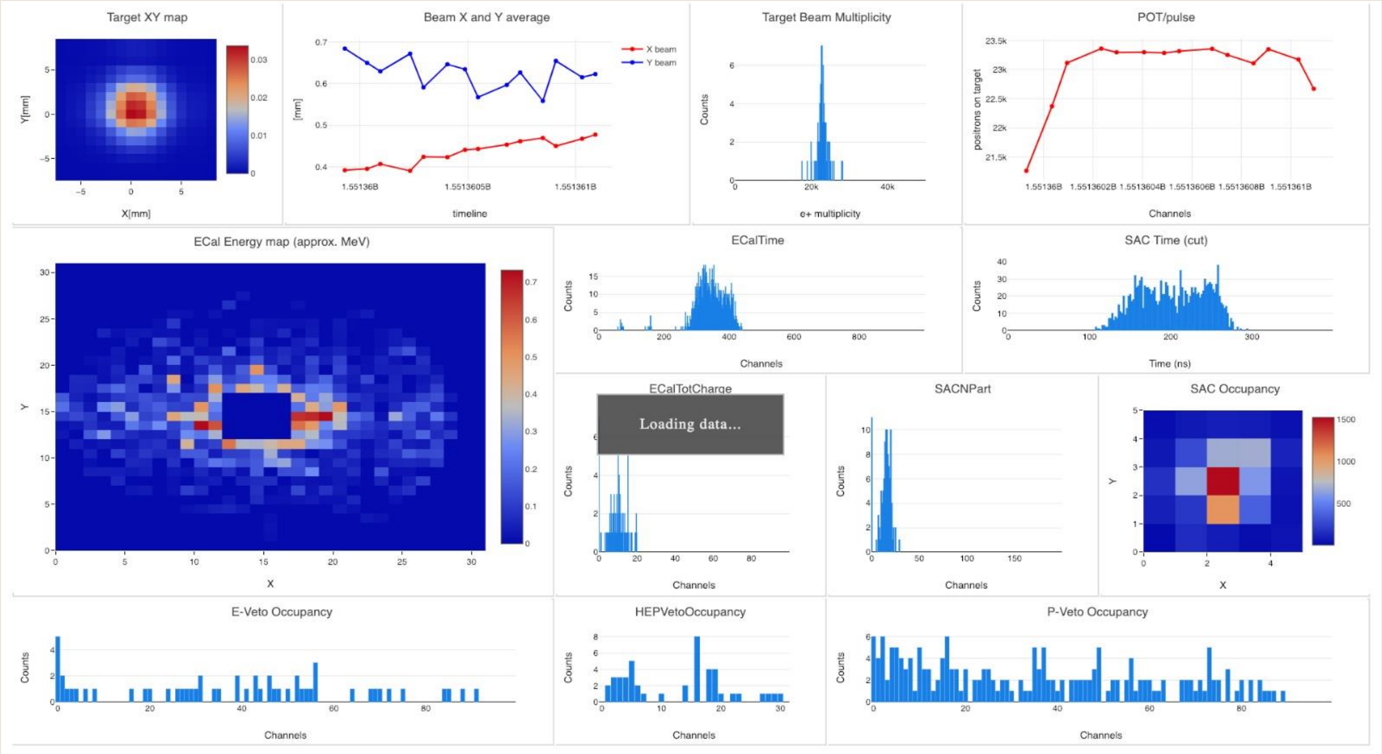
1. BTF bunch, for physics runs
2. Cosmics, for calibration runs
3. Random, for pedestal studies

Data are collected by a two-level readout system:

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



COMMISSIONING DATA TAKING

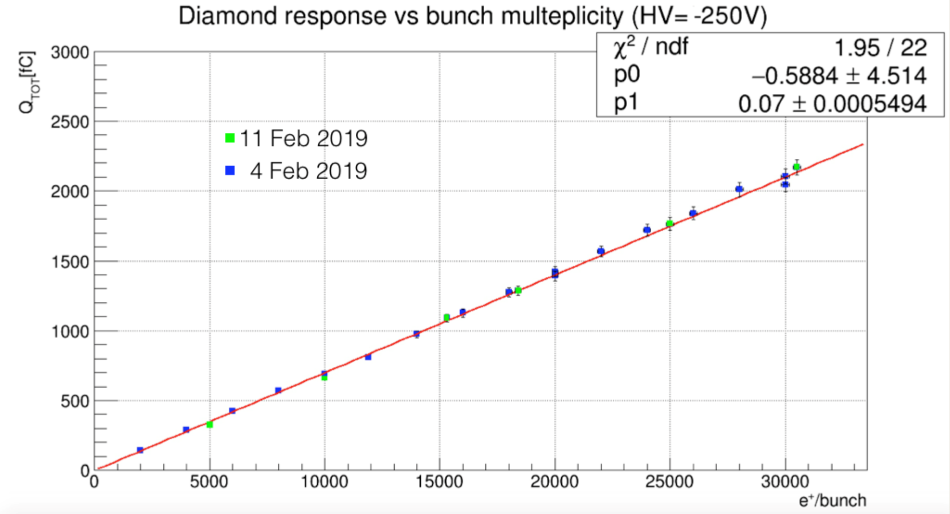


Main technical purposes:

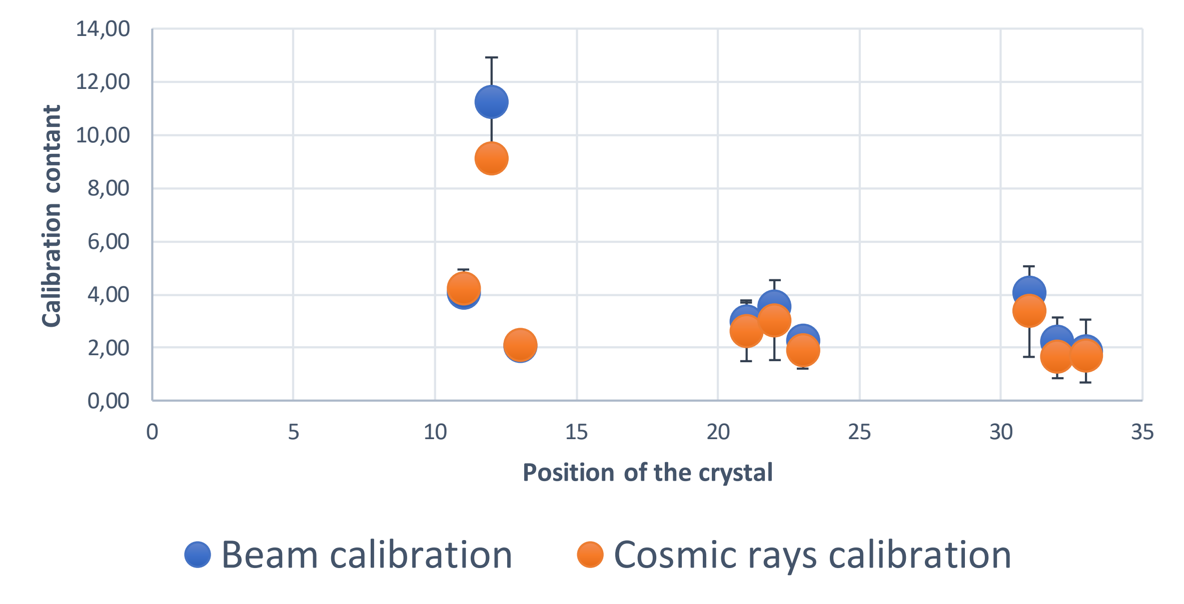
- Online monitor and detector control system for each subdetector
- Calibration for each detector
- Best beam configuration
- Background studies
- Information about POT (positron on target)
- Collect a sample of order of 10^{12} POT

CALIBRATION STUDIES

- **Target**: calibrated at the end of commissioning, very good reproducibility and linearity
- **ECal**: first order calibration on scintillating units before calorimeter assembly. Cosmic ray calibration used to check units calibration
- **SAC**: beam calibration performed on 9/25 crystals. The results from the beam calibration were cross-checked with cosmic rays calibration



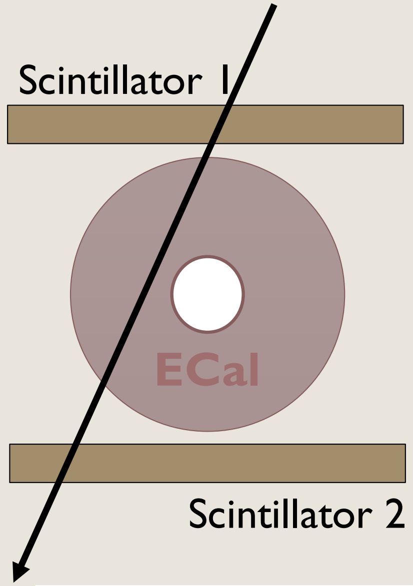
TARGET: COLLECTED CHARGE VS BEAM MULTIPLICITY (EVALUATED BY LEAD GLASS CHERENKOV CALORIMETER)

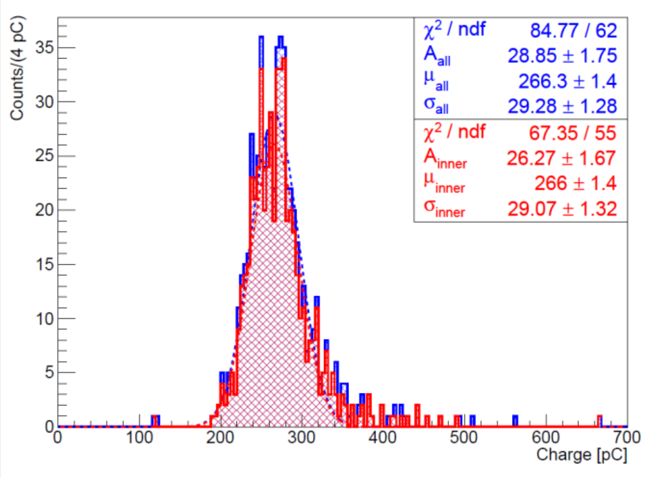


SAC: CALIBRATION CONSTANTS OBTAINED THROUGH BEAM CALIBRATION (BLUE) AND THROUGH COSMIC RAYS CALIBRATION (ORANGE)

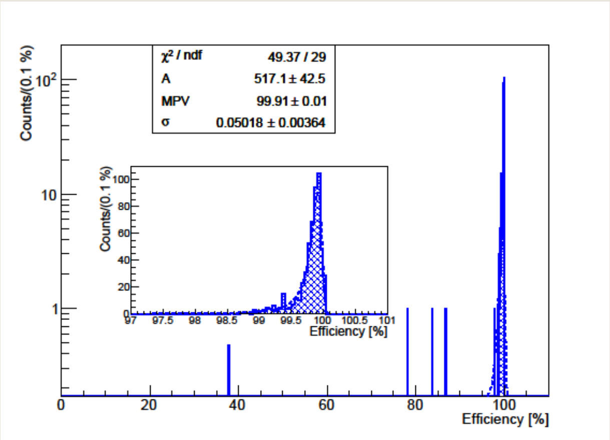
ECAL PERFORMANCE: CR CALIBRATION

- CR used to monitor the detector during data taking, and allowed testing the reliability of the ^{22}Na source calibration
- Two plastic scintillators were placed above and below the calorimeter
- Vertical CR rays were selected, requiring 3 crystals in the same column
- Charge distribution were fitted with a Landau distribution: MPVs were extracted from the fit
- The equalization obtained from of ^{22}Na source measurements for all the scintillating units is better than 11%
- Scintillating units efficiency was also tested by CR: average efficiency is close to 100%





MPV DISTRIBUTION (BLUE: EVERY CRYSTAL; RED: EXTERNAL CRYSTALS EXCLUDED)

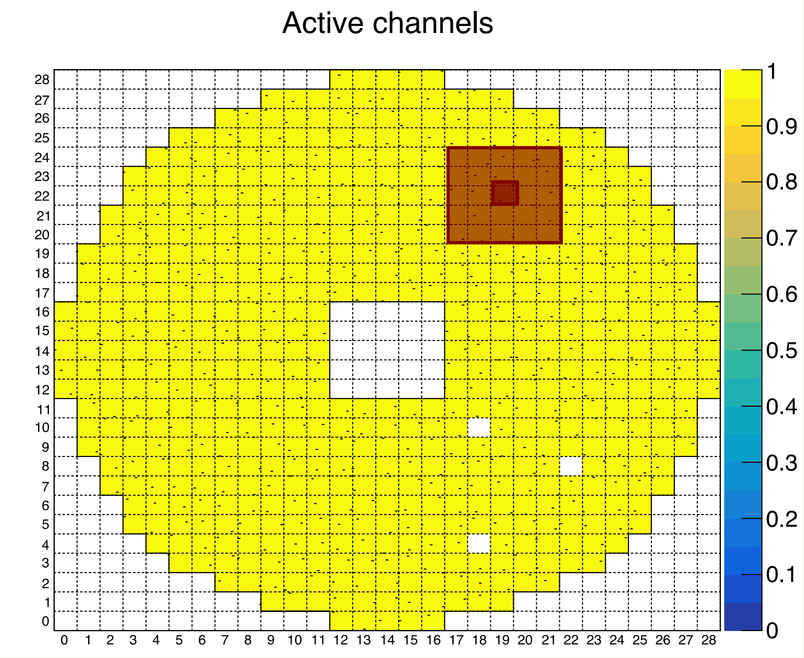


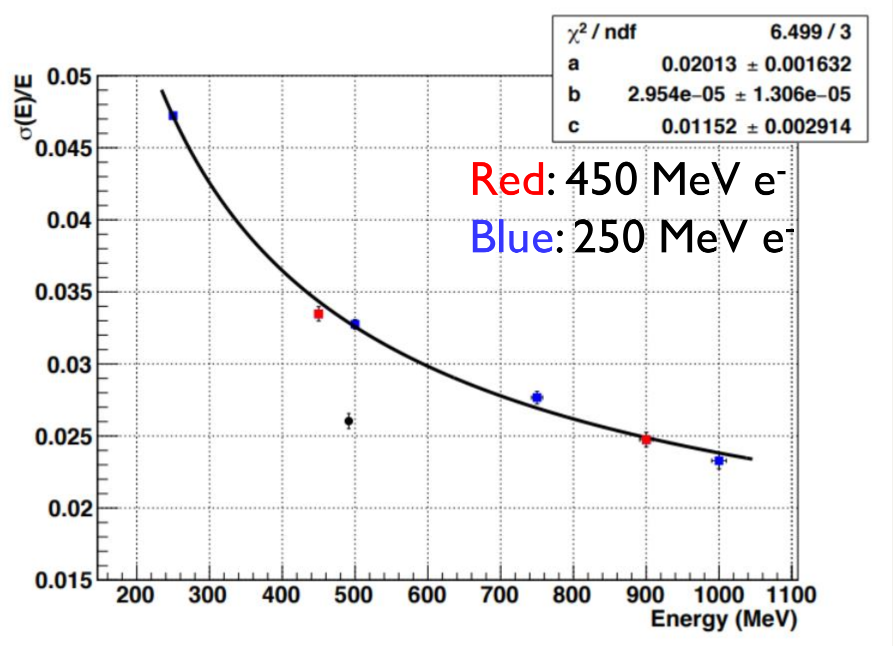
SCINTILLATING UNITS EFFICIENCY DISTRIBUTION

ECAL PERFORMANCE: CLUSTERING

- 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)

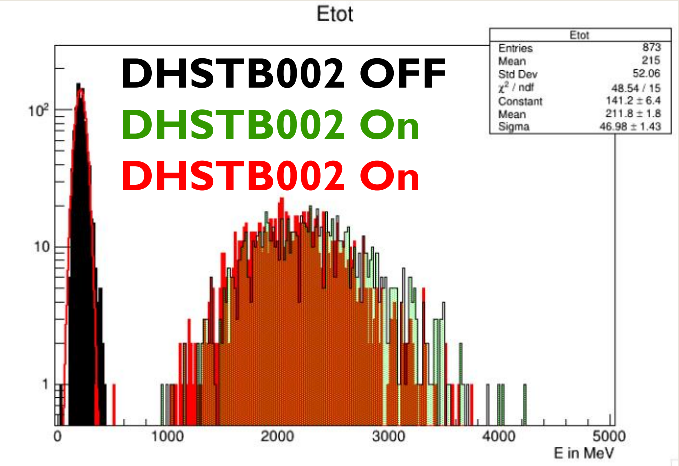




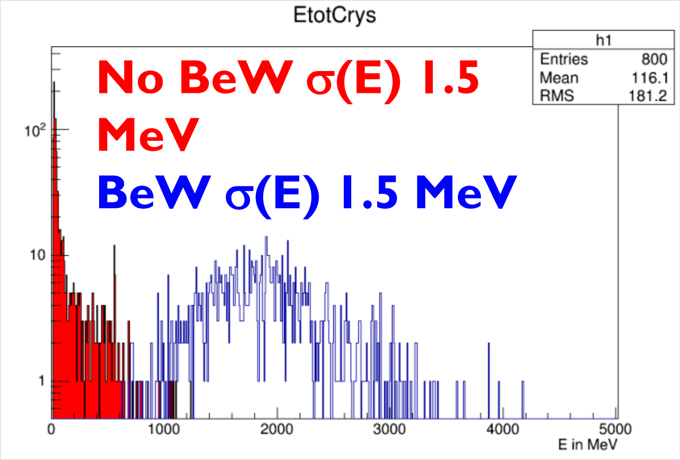
ENERGY RESOLUTION VS BEAM ENERGY IN ECAL PROTOTYPE (FIT) AND DETECTOR (BLACK DOT)

UNDERSTANDING BEAM BACKGROUND

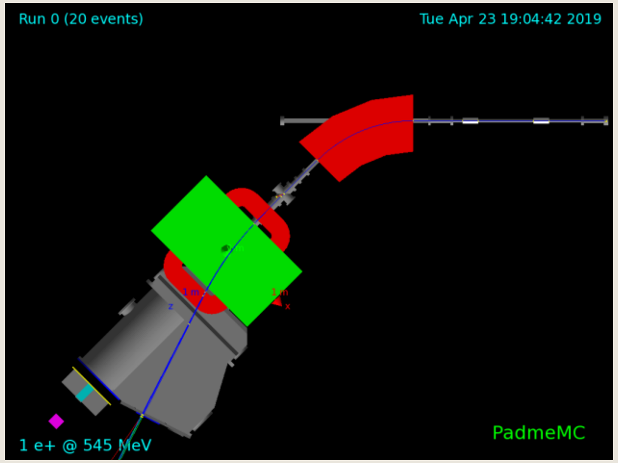
- Observation of an unknown source of beam-induced background during July 2019
- The main cause for beam background seemed to be due to the beam hitting beryllium window separating BTF vacuum from PADME vacuum.
- Beam energy resolutions incompatible with the measured beam spot
- Background energy distribution in data is very similar to MonteCarlo (MC) one when using a beam with an energy resolution of 1.5 MeV
- A new MC simulation also introduced the magnet geometry of the beamline and the target support



DATA



MC



^{8}Be WINDOW REMOVAL AND PRIMARY BEAM

- The beryllium window separating BTF vacuum from PADME vacuum was removed at the end of July 2019
- Unfortunately, the window broke during the removal, forcing a full decontamination of the experimental hall and the dismantling of the beamline
- For this reason, the collaboration resumed all the planned activities with a delay of ~1 year
- A Mylar window has been used in place of the ^{8}Be window: Mylar needs to be substituted more often, but it's not toxic
- During July 2020, the collaboration mainly worked on another beam configuration, in order to obtain less beam induced background
- **Secondary beam**: positrons are obtained by the collision of accelerated electrons on a target and then selected in energy (maximum energy: 550 MeV)
- **Primary beam**: positrons are accelerated to the desired energy after the production (maximum energy: 490 MeV)

CONCLUSIONS

- PADME searches for the dark photon, the possible mediator of a new interaction between Standard Model particles and dark matter particles
- The closed kinematic of the experiment allows the search for dark photon using the missing mass distribution from the annihilation of a 550 MeV positron beam on a diamond target
- On 4/10/18 PADME started the commissioning data taking
- The first data taking showed how reliable the DAQ system is, but also a beam background that must be kept under control
- A failure in the beamline postponed the final calibrations to the summer of 2020
- A test beam during July ’20 provided calibration data and a better beam background control
- A new physics run is expected during fall 2020