# The PADME Detector

F. PINNA ON BEHALF OF THE PADME COLLABORATION

22ND PARTICLES AND NUCLEI INTERNATIONAL CONFERENCE - PANIC 2021

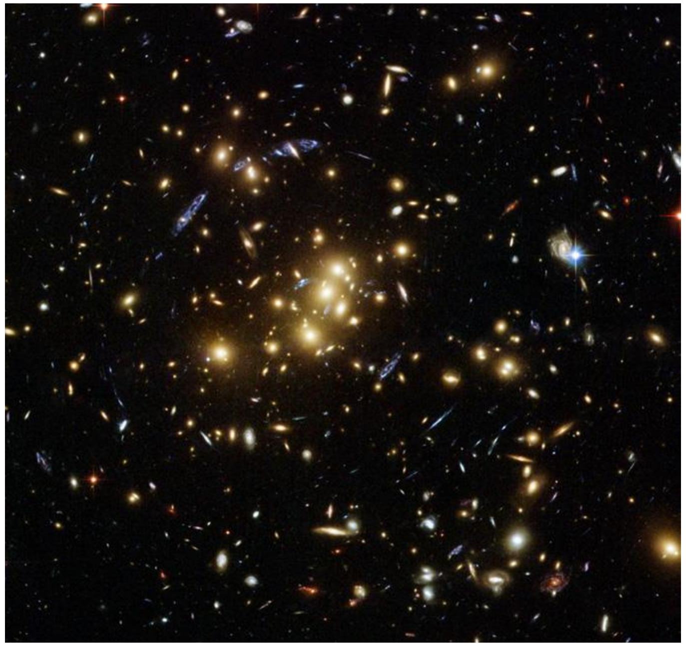
# Dark Matter Puzzle

Richard Massey *et al* 2010 *Rep. Prog. Phys.* **73** 086901

The abundancy of ordinary matter alone is not enough to explain some astrophysical and cosmological phenomena (gravitational lensing, galaxies rotation velocity, …)

**Dark matter** is currently believed to account for **26,8% of the universe mass** (the baryonic matter contribution stops at 4,9%)

It does not interact with e.m. force, making it extremely **hard to investigate**



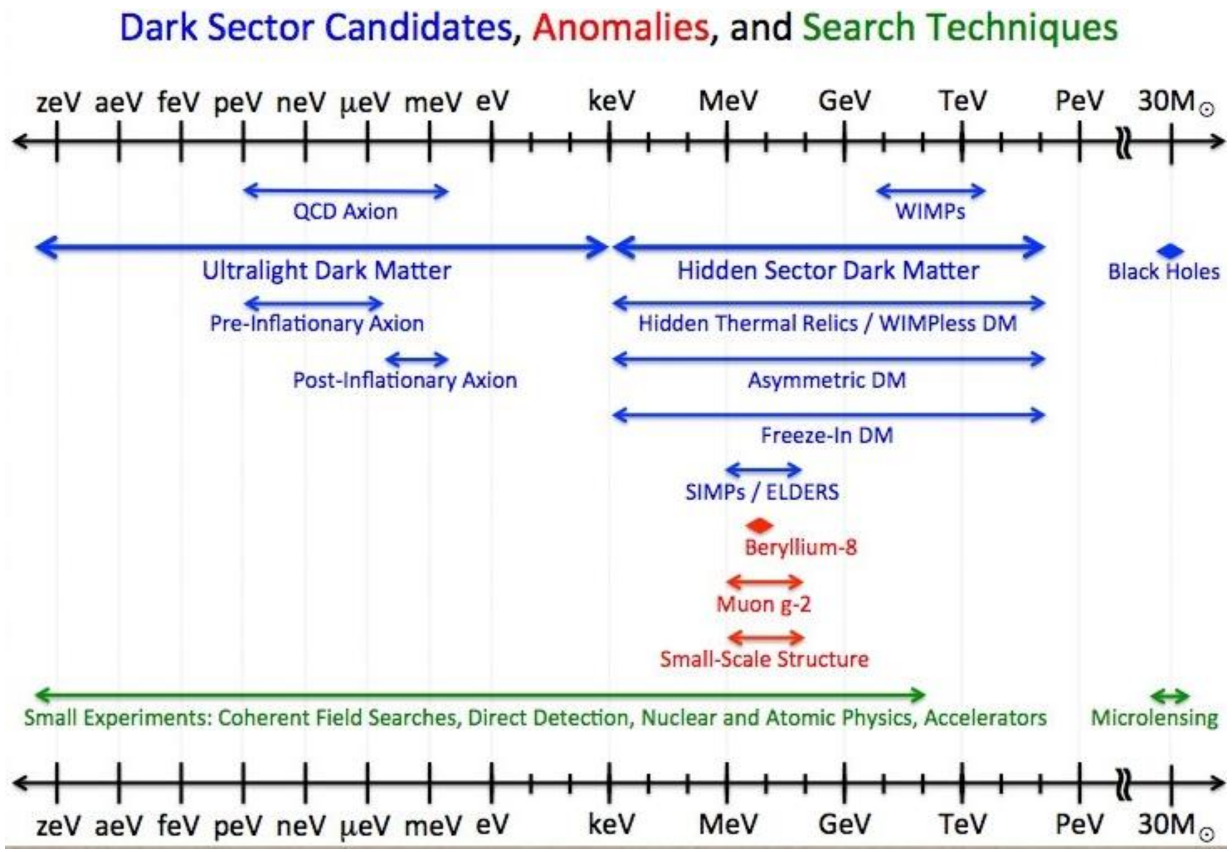
# The PADME Experiment

arXiv:1707.04591v1 [hep-ph]
14 Jul 2017

Dark Matter and mediator particles candidates mass may span over a large range

PADME is testing the existance of a **Dark Photon A'** (DP), able to bridge the SM sector with the Dark Sector (DS)

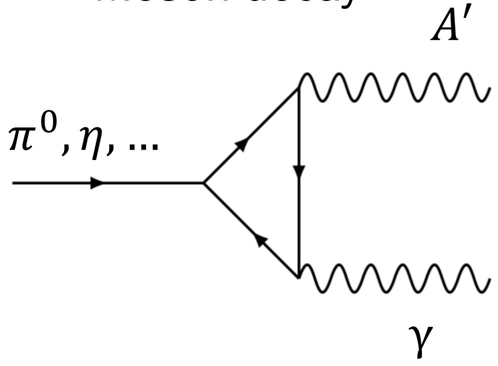
The only assumption is that
**A' couples with leptons**



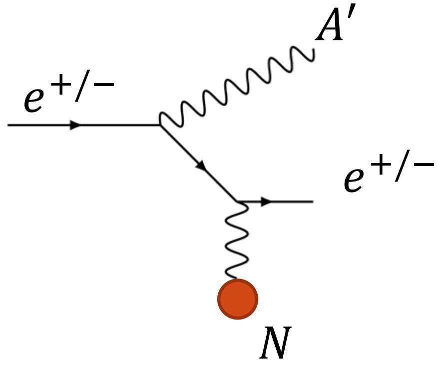
# The PADME Experiment

A’ can be produced mainly through 3 mechanisms

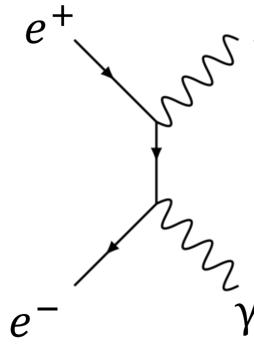
Meson decay




Bremsstrahlung




Annihilation



# The PADME Experiment

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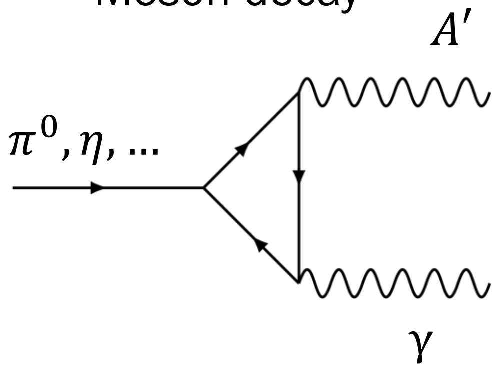
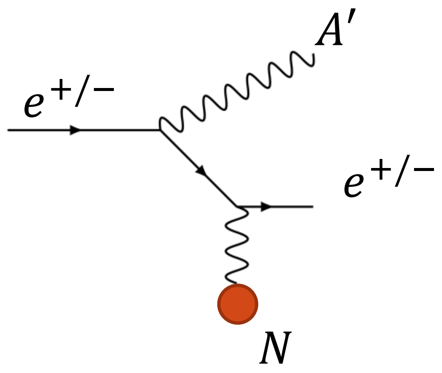
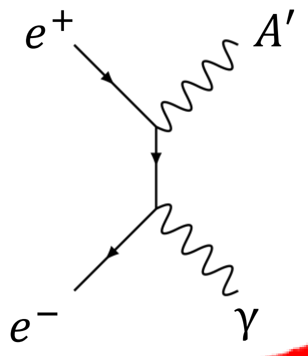



Bremsstrahlung



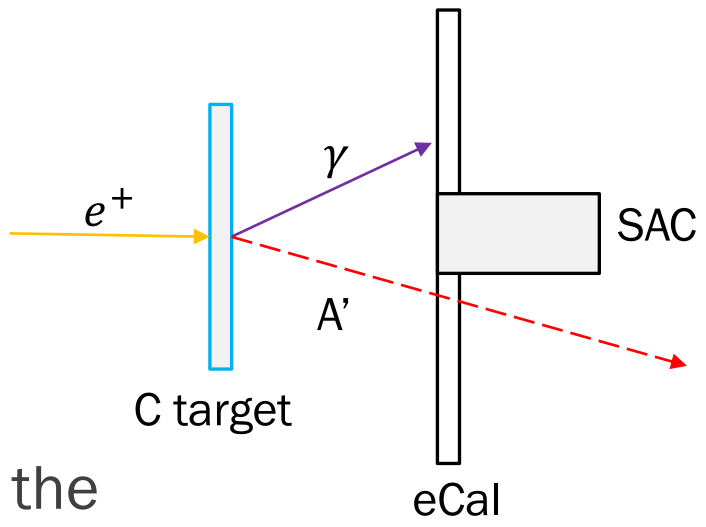

Annihilation



# The PADME Experiment

An $\boldsymbol{e^+}$ **beam** at E<550 MeV is fired **on a 100 $\boldsymbol{\mu}$m thick diamond target** to produce a visible photon $\gamma$ and a dark photon A’

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

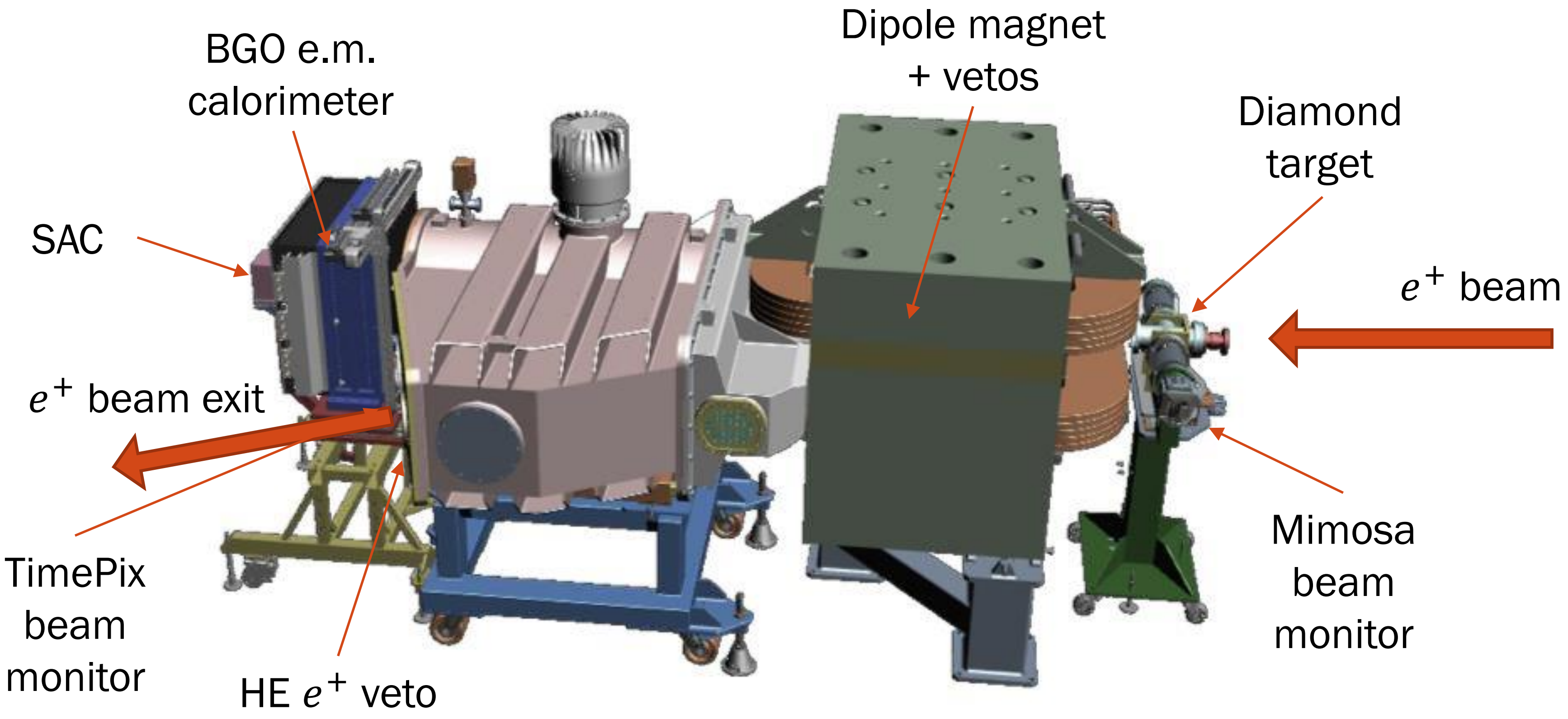



The **mass of A’** will be indirectly evaluated using the **missing mass** method. Knowing the beam energy and the photon’s (measured in eCal), and being the target still, A’ mass can be calculated:

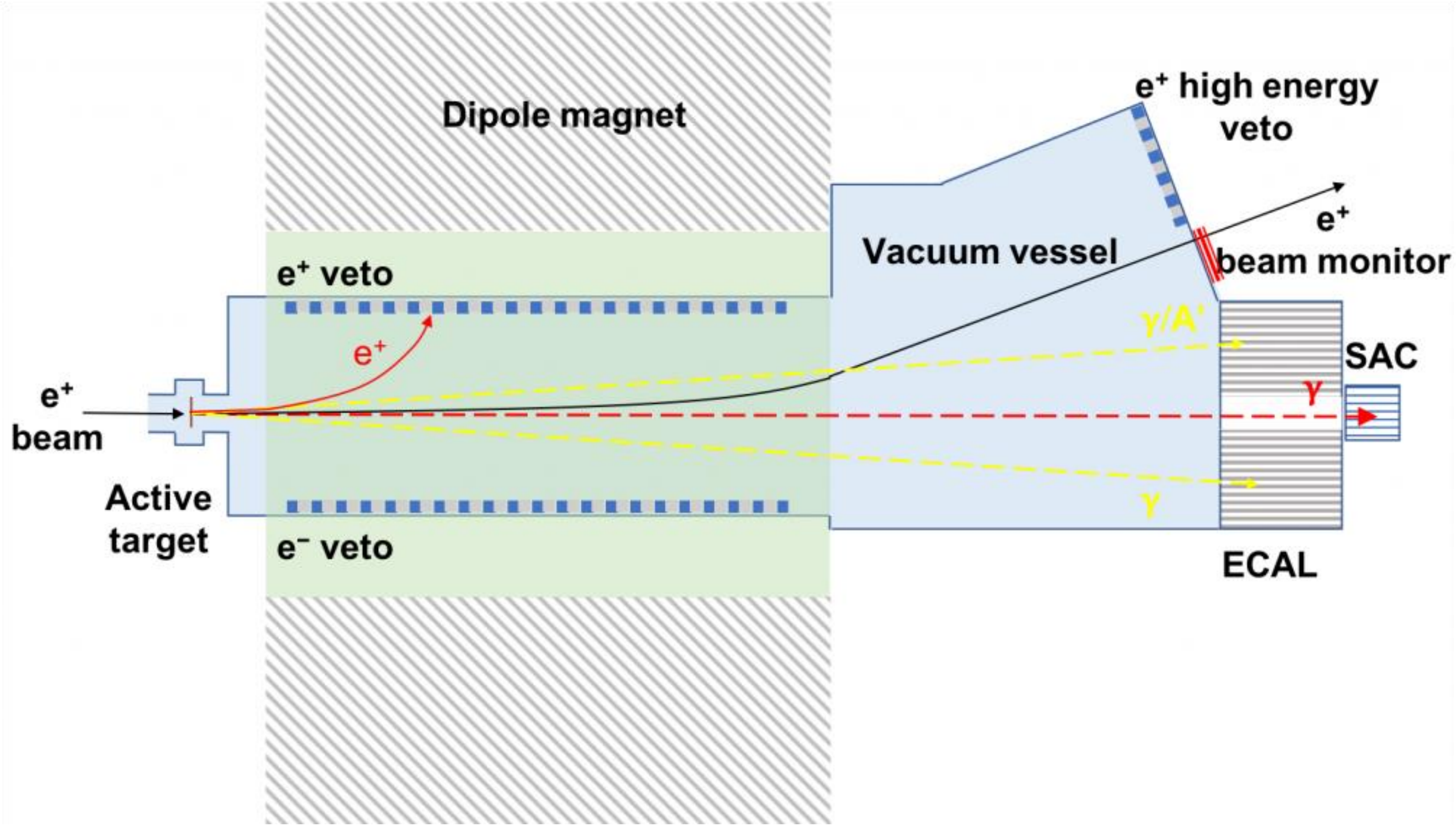
$$M_{A'}^2 = P_{e^+}^2 + P_{e^-}^2 - P_\gamma^2$$

In these conditions, **the mass limit is $\boldsymbol{M_{A'} \leq 23.7}$ MeV**

# The PADME Detector

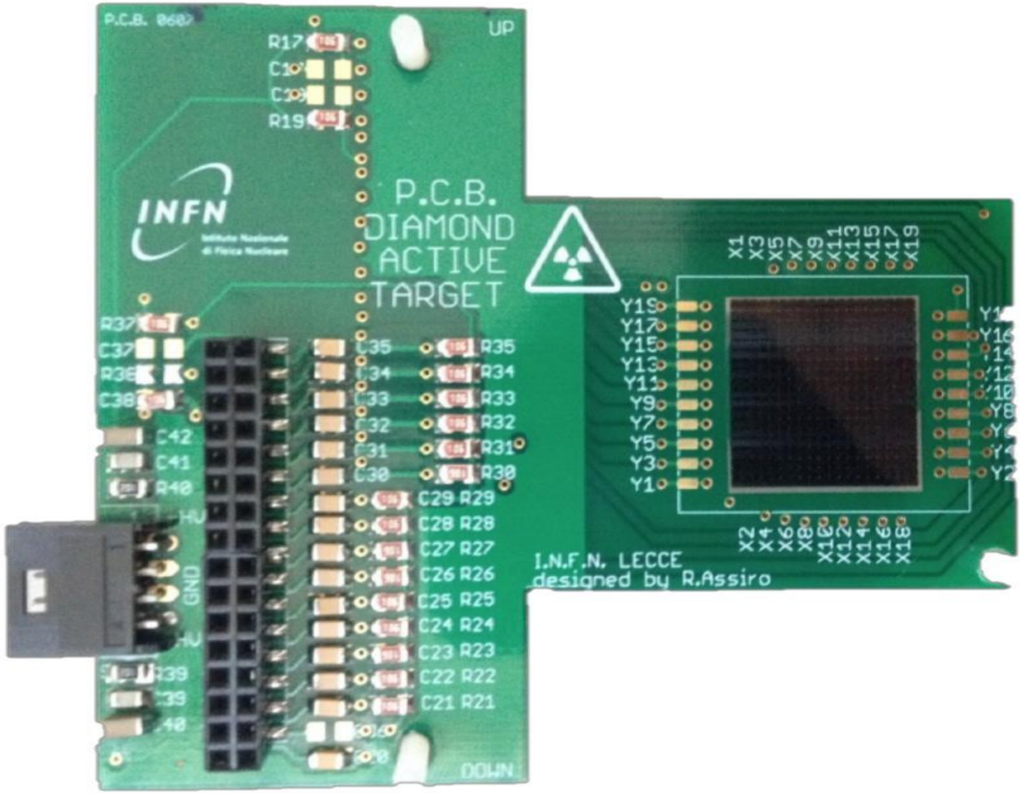


# The PADME Detector



# Diamond target

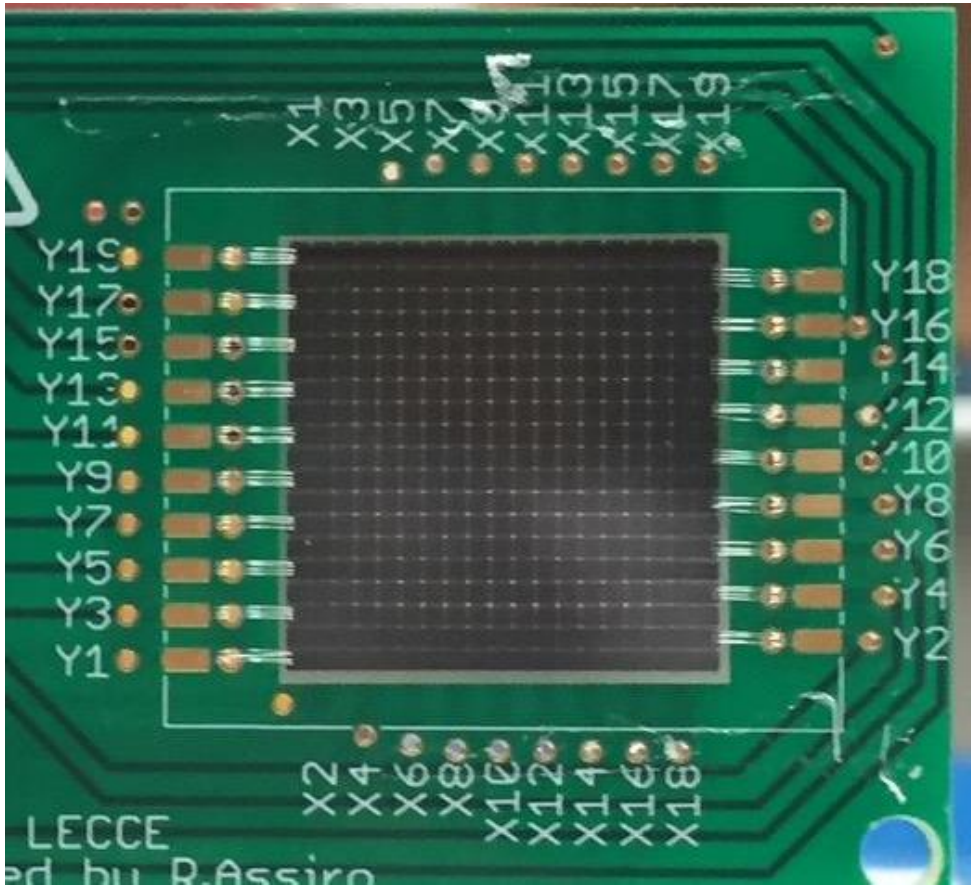
**Electron-positron annihilations** occur in a 100 $\mu$m thick, 2x2 $cm^2$ large, CVD grown **diamond active target**.



# Diamond target

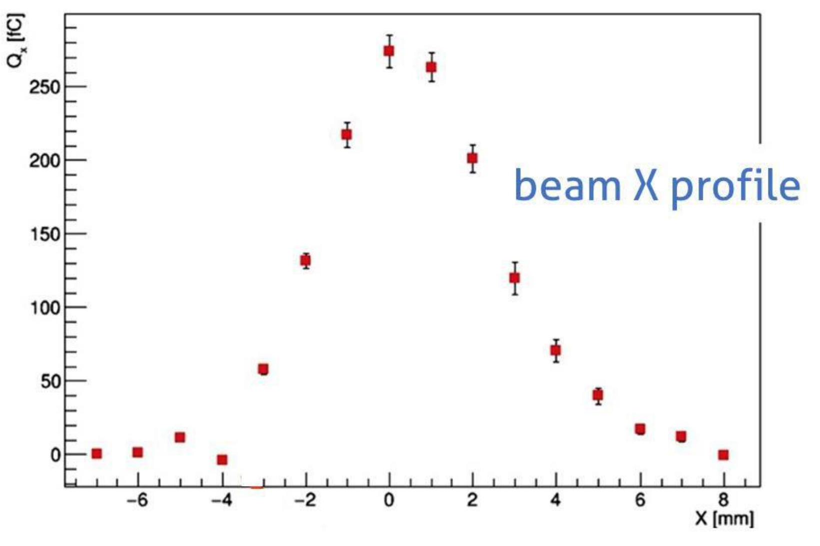
Electron-positron annihilations occur in a 100 $\mu$m thick, 2x2 $cm^2$ large, CVD grown diamond active target.

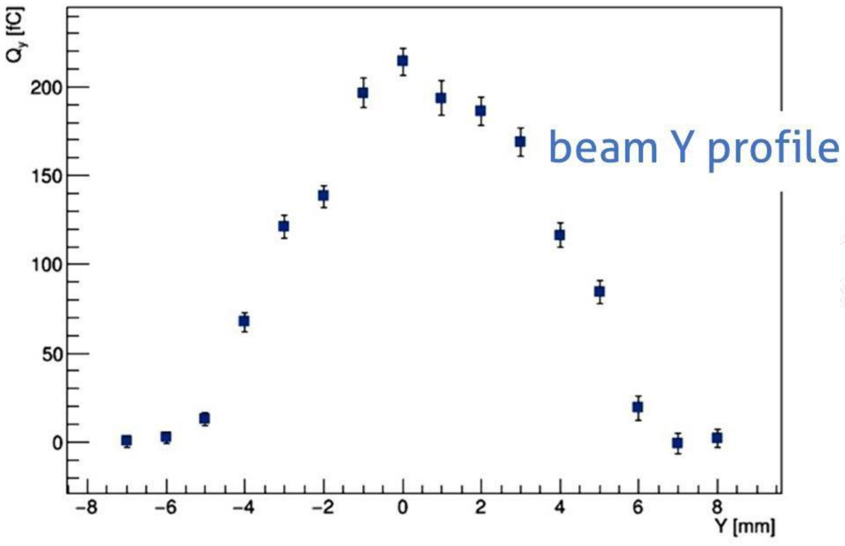
Signals collected by 32 laser made **graphite strips** (16 on the X-axis + 16 on the Y-axis). The strips are 1 mm in pitch and 0,15 mm apart.

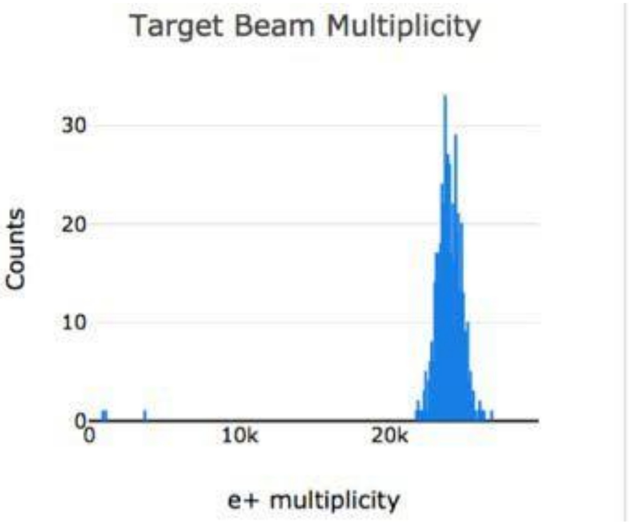


# Diamond target

The beam profile and multiplicity are monitored online

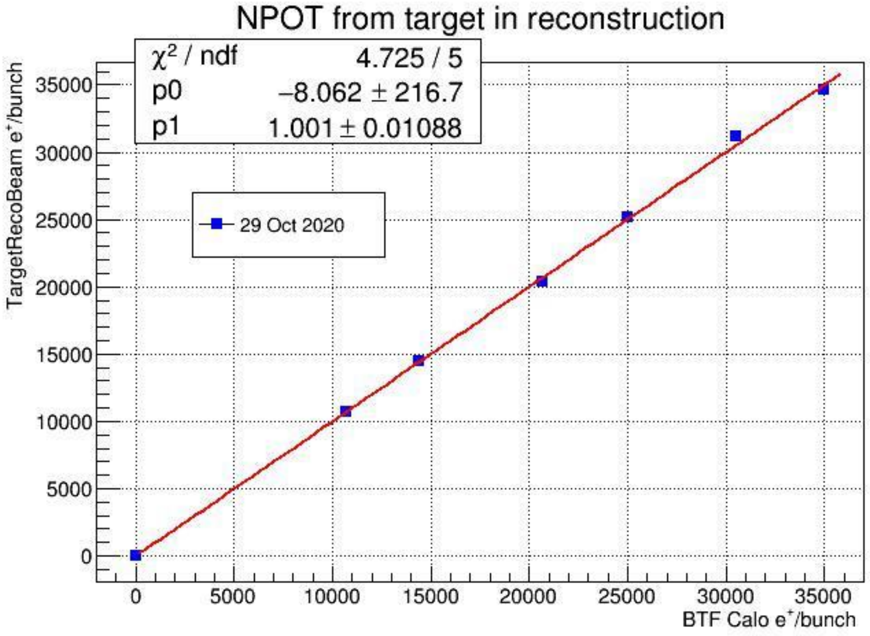


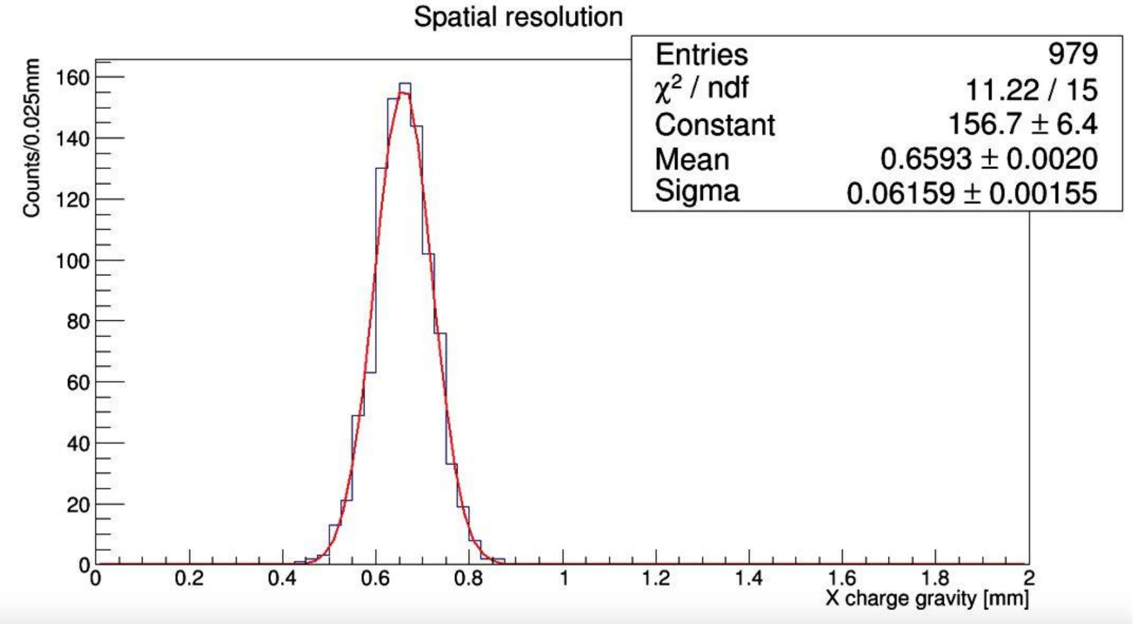



# Diamond target

The target was designed for 5000 $e^+$/bunch, but behaves **linearly even at 35000 $e^+$/bunch** (working region 20k-30k $e^+$/bunch)




The space **resolution is 0,06 mm** (to PADME's end, interaction point must be known with resolution better than 1 mm)

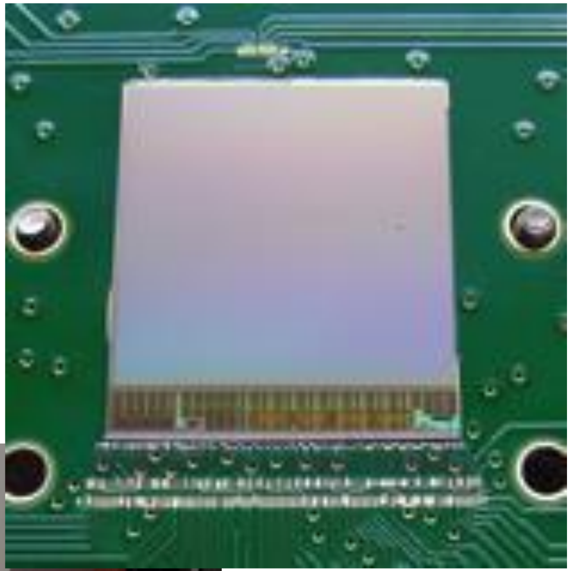


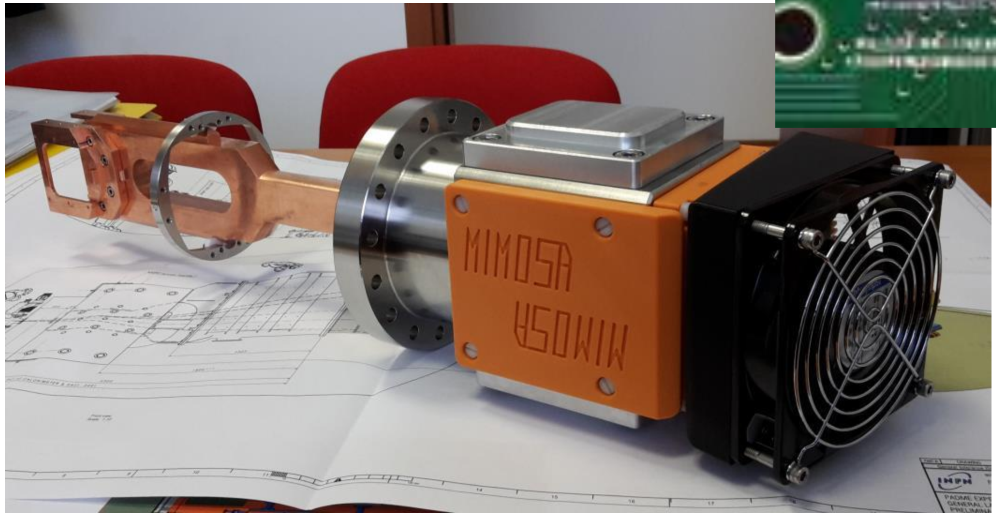
# Mimosa

**MIMOSA-28** is a monolithic 19,9x19,2 mm$^2$ sensor used to **characterize the beam** properties (position, shape, divergence, angle, …)

It is a 960x928 pixel array (about **0,9 million pixels**), 20,7 $\mu$m pitch

It is supported by a step motor and a copper cooling frame

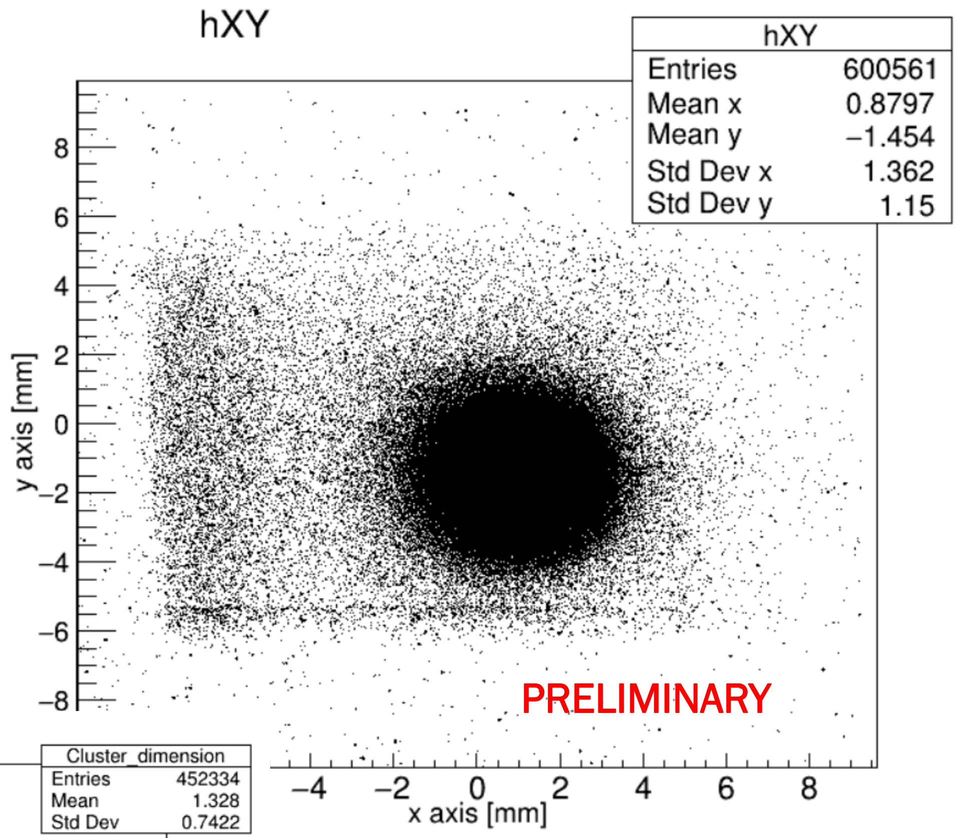


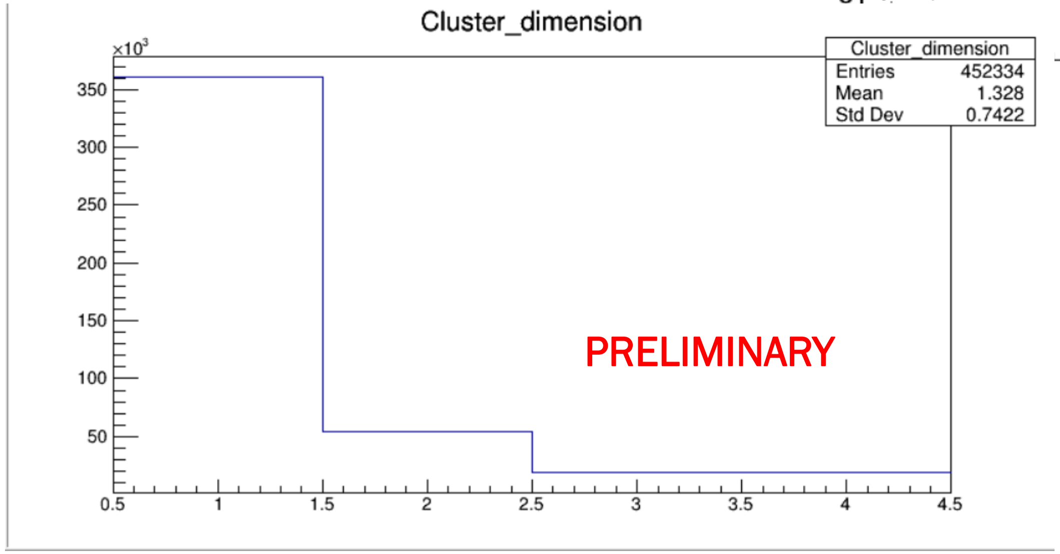


# Mimosa

Single point resolution is 3 $\mu$m, the redout time 200 $\mu$s.

It cannot be used with the diamond target (it would degrade the beam)
Best performances with **multiplicity of 1000 particles** per bunch.



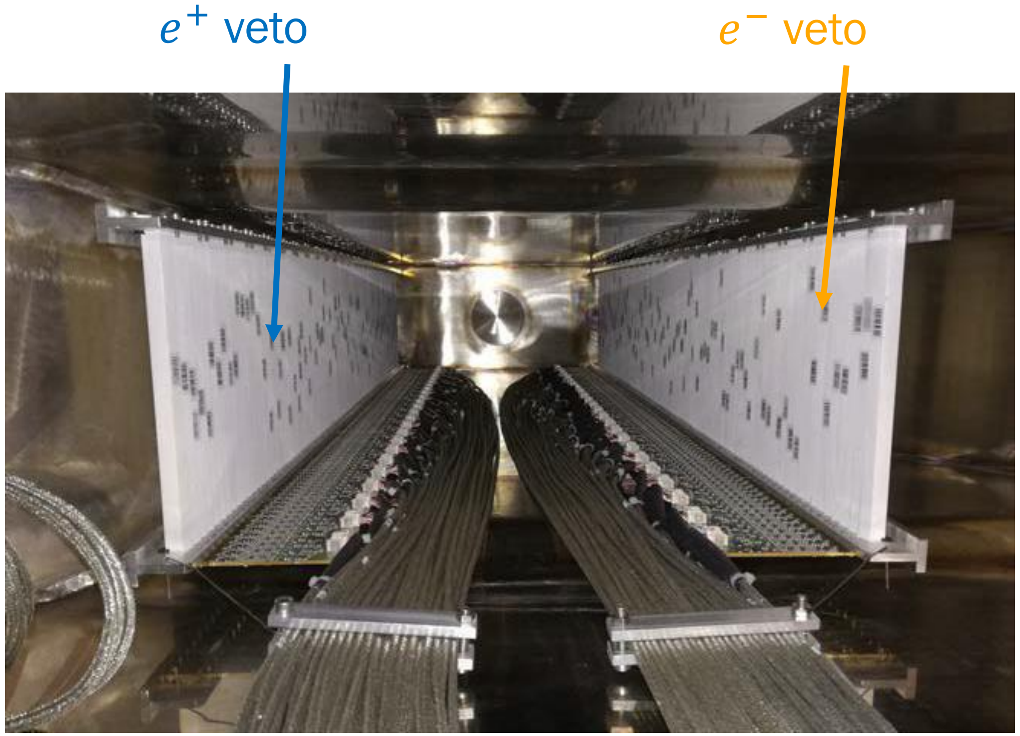

07/2020 data – 300 particles

# Positron/Electron Vetos

Vetos for e+/e- are located right after the target and on the left of the beam exit (HE positron veto); they are needed to **veto bremsstrahlung events**

96 ($e^-$) + 90 ($e^+$) + 16 (HEP) scintillating plastic bars, 1x1x17,8 cm3, coupled with SiPM Hamamatsu S13360

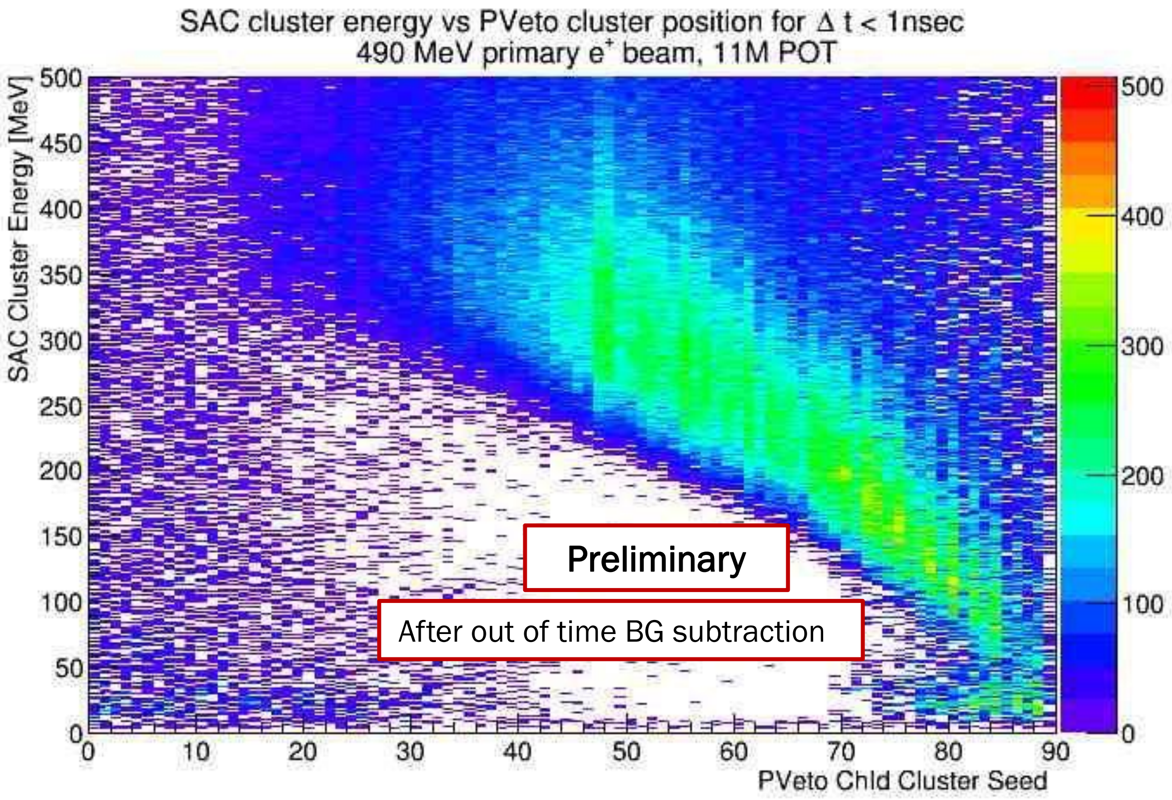
All the vetos are in vacuum ($10^{-5}$ mbar), $e^-$ and $e^+$ are located inside a magnetic field (0,45 T)



# Positron/Electron Vetos

The impact point of a $e^{+/-}$ on the veto provides an **estimate of its momentum** (2% error)

Calibration in time with SAC allows to detect Bremsstrahlung events



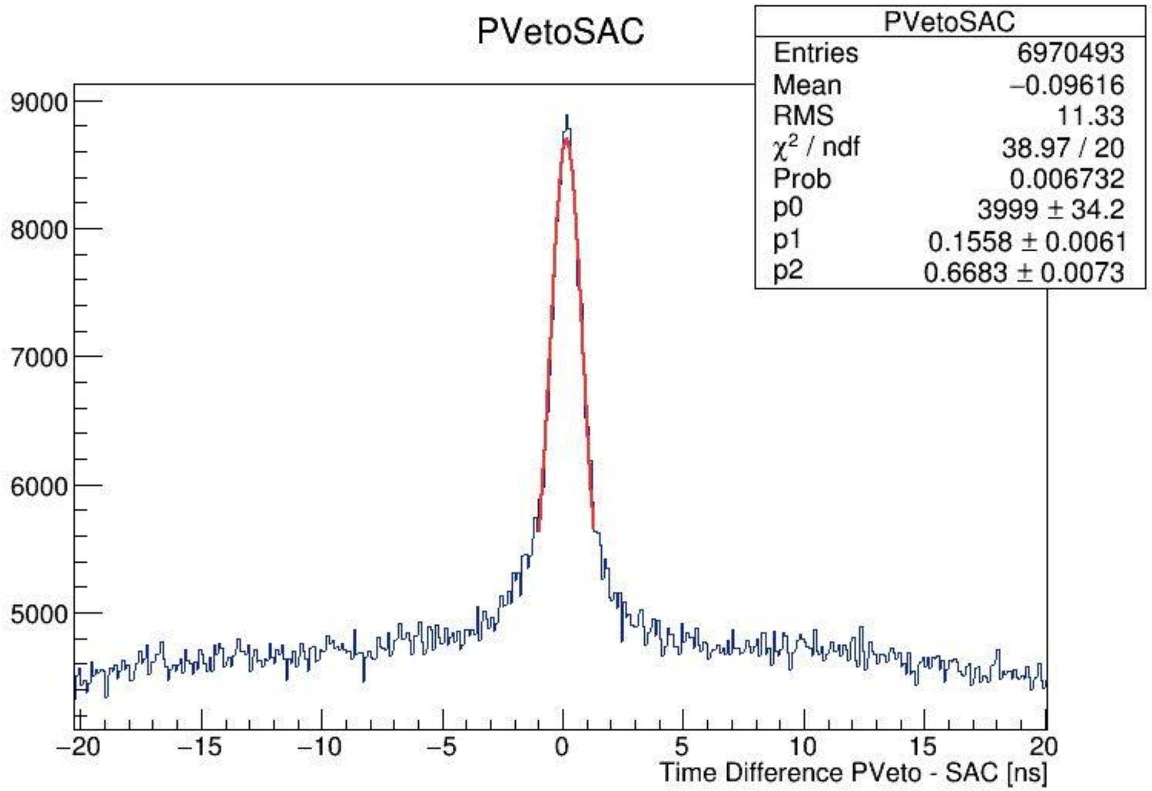

*Increasing $e^+$ momentum*

# Positron/Electron Vetos

The impact point of a $e^{+/-}$ on the veto provides an **estimate of its momentum** (2% error)

Calibration in time with SAC allows to detect Bremsstrahlung events

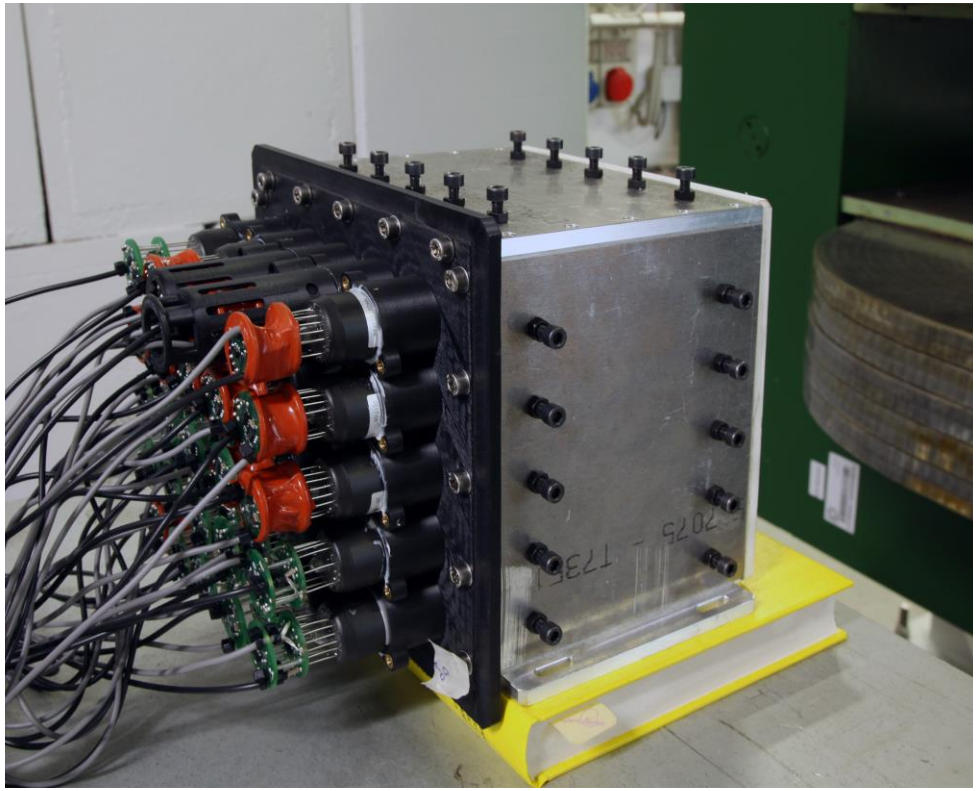
**Time resolution is 0,7 ns**
(at most 1 ns required)



# Small Angle Calorimeter (SAC)

The **Small Angle Calorimeter (SAC)** is devoted to collect photons coming from **bremsstrahlung events** (mainly emitted at small angle)

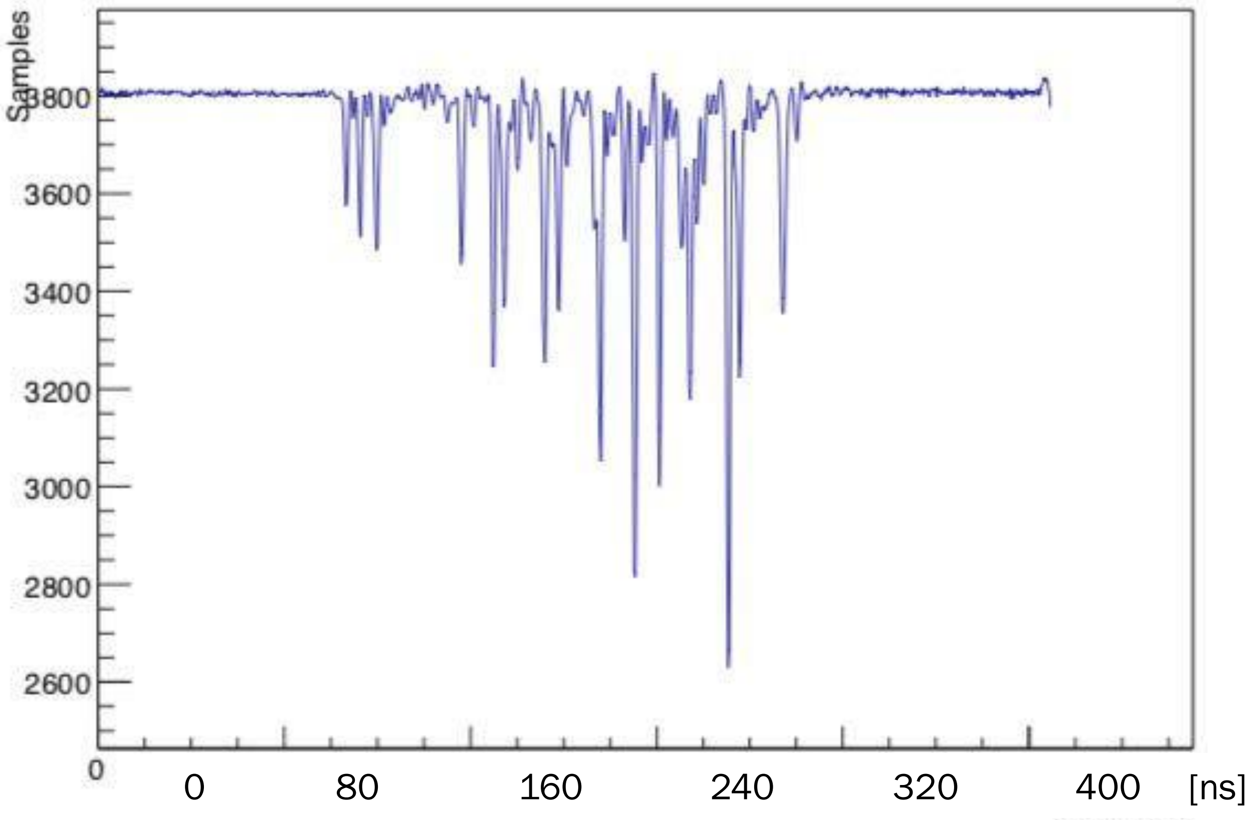
It is a 5x5 assembly of 30x30x140 $mm^3$ Cherenkov Lead Fluoride ($PbF_2$) scintillators, coupled with Hamamatsu R13478UV PMT, covering the angle 0 ÷ 18,9 mrad



# Small Angle Calorimeter (SAC)

The fast signals (~2 ns) allow to follow the rate of Bremsstrahlung radiation (~100 MHz)

Sampling frequency 2,5 GHz, able to detect about 50 $\gamma$/bunch (time resolution = 86 ps)



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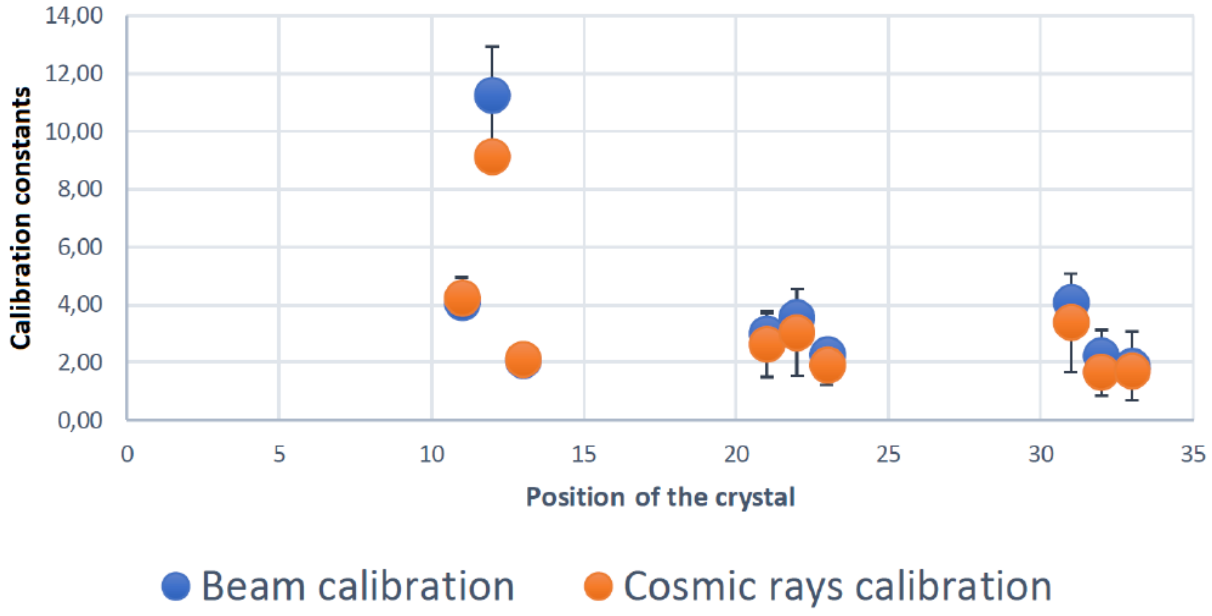
Calibrated both with beam and cosmic rays



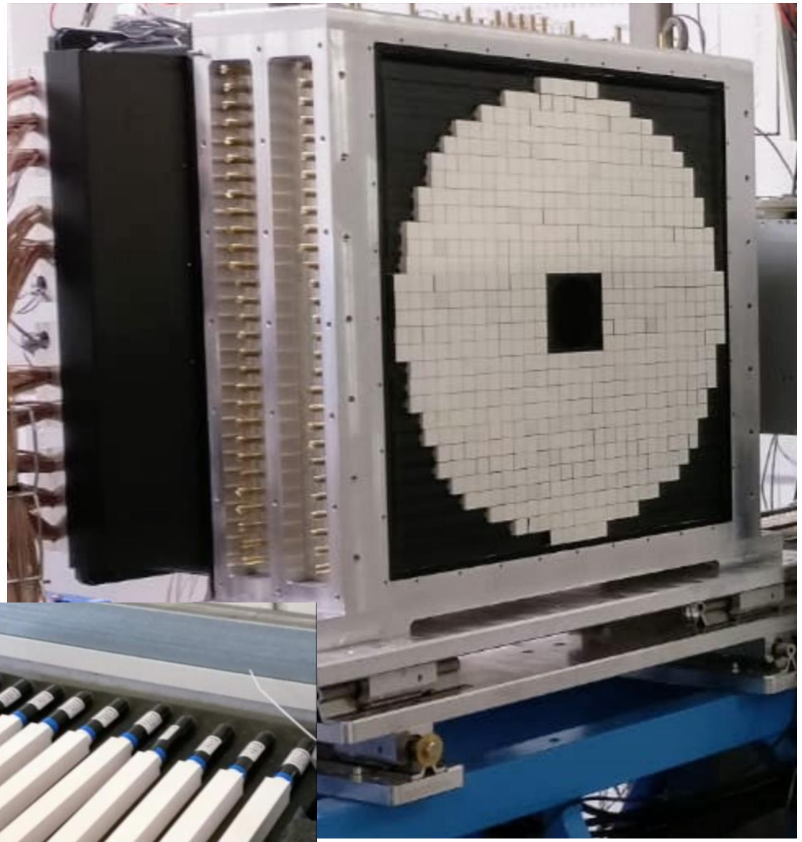
# ECal (BGO e.m. Calorimeter)

616 Bismuth Germanate scintillator crystals, 21x21x230 $mm^3$, about 300 ns of decay time

Readout thorugh PMT [HZC XP1911]

It's 60 cm in diameter and placed 3,45 m downstream the target, covering an angle within 15 ÷ 84 mrad

The central hole (105x105 $mm^2$) hosts the SAC



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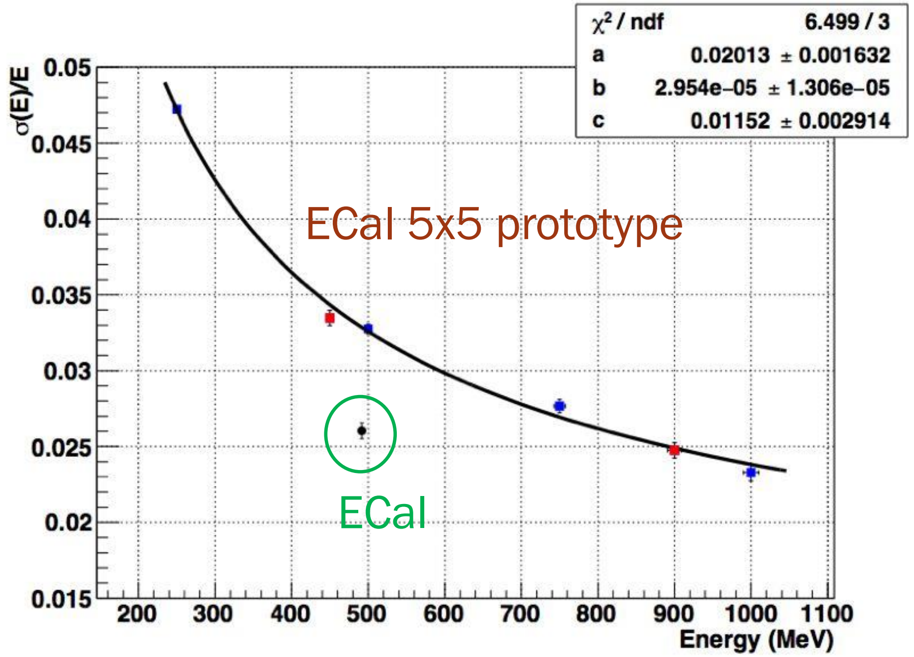
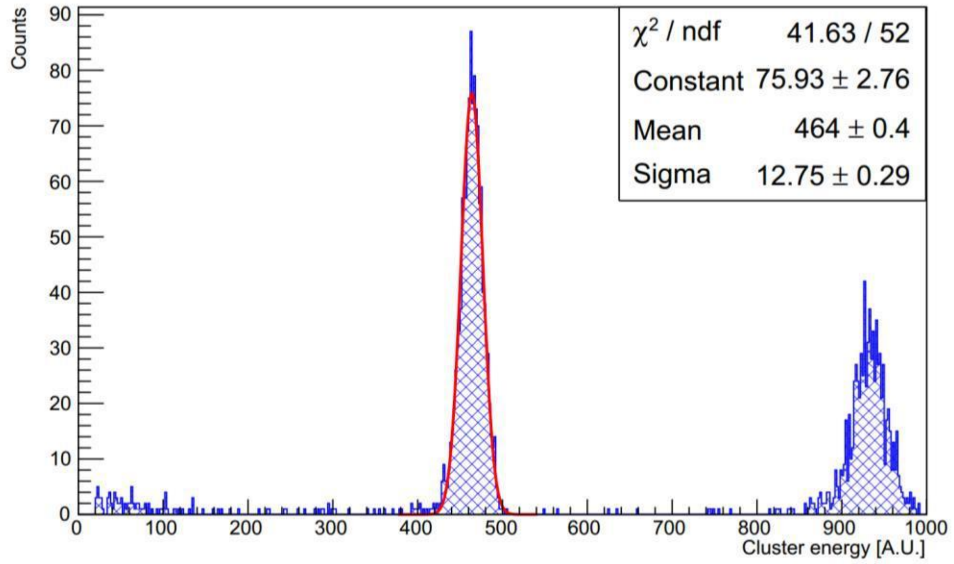



First calibration performed on prototype (5x5 crystals, solid line in plot)

Full calorimeter performs better than the prototype! Energy resolution $\sigma(E)/E \sim 2{,}7\ \%$



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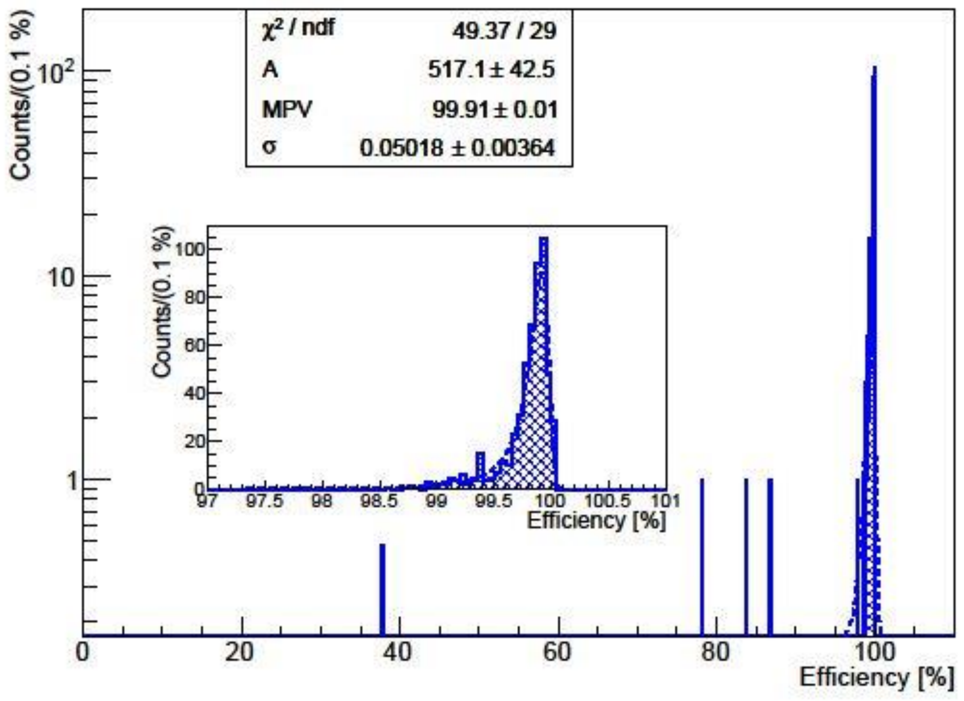
First calibration performed on prototype (5x5 crystals, solid line in plot)

Full calorimeter performs better than the prototype!
Energy resolution $\sigma(E)/E \sim 2{,}7\ \%$

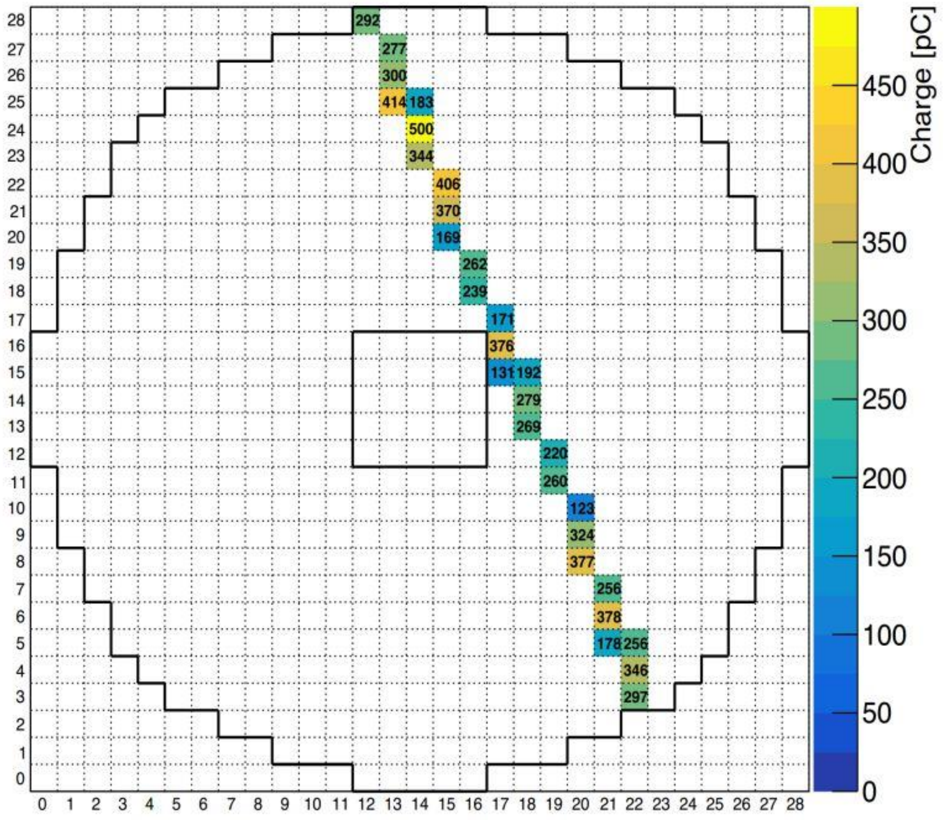
Average efficiency close to 100% (4 dead crystals)



# ECal (BGO e.m. Calorimeter)

Two scintillating plates (coupled to 2 PMTs each) are place above and below the assembly to intercept Cosmic Rays, preventing them to contribute to the background

CR used for online calibration



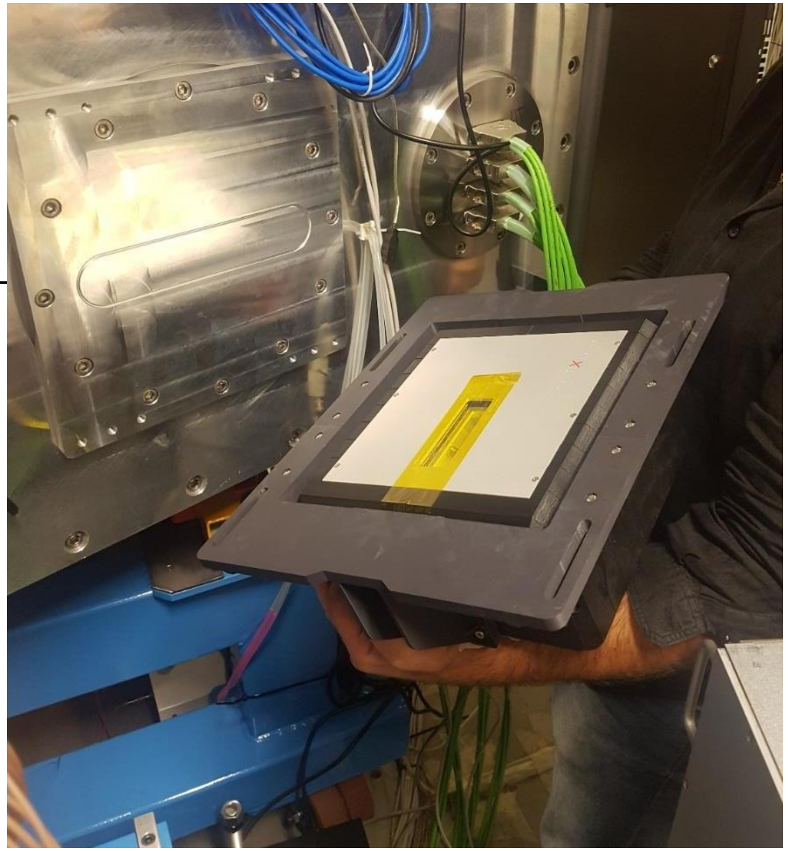

P. Albicocco *et al* 2020 *JINST* **15** T10003

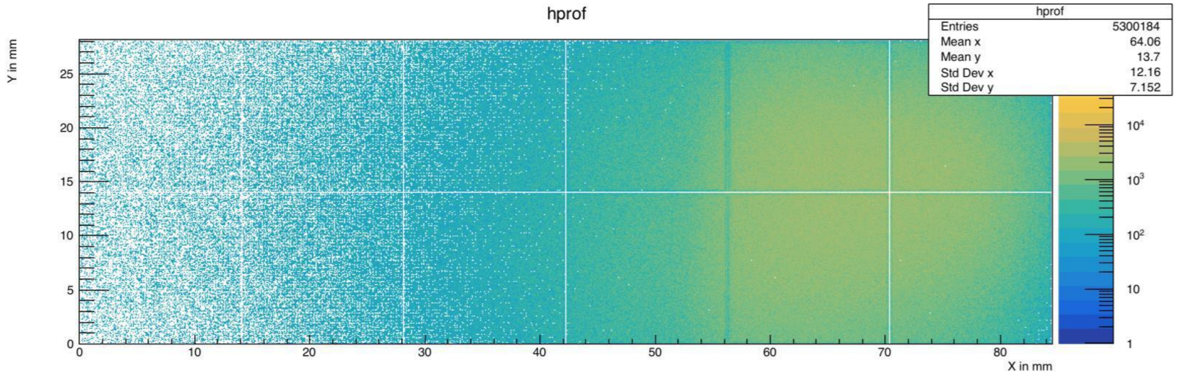
# TimePix3

The detector is made of 2x6 sensors; each sensor is a 256 x 256 pixel matrix ( 55 $\mu$m pitch). The whole detector measures 8,4x2,8 $cm^2$

It collects and monitor the non interacting $e^+$, measuring the energy, position and time of each particle

Allows the measurement of beam energy resolution (X rms spot) and divergence (Y rms spot)





# Conclusions

The PADME experiment is searching for a few MeV massive Dark Photon A’, which could work as a portal between the Dark Sector and the SM Sector by coupling with fermions.

The DP will be produced by annihilation ($e^+e^- \rightarrow \gamma A'$), by bombarding a diamond target with a positron beam. A’ mass is then inferred as a missing mass, by measuring the visible photon energy in the calorimeter ECal.

Detectors’ performances and background are in the desired range

Improvements on simulations and data analysis are currently ongoing


# Thank you!

ON BEHALF OF THE PADME COLLABORATION

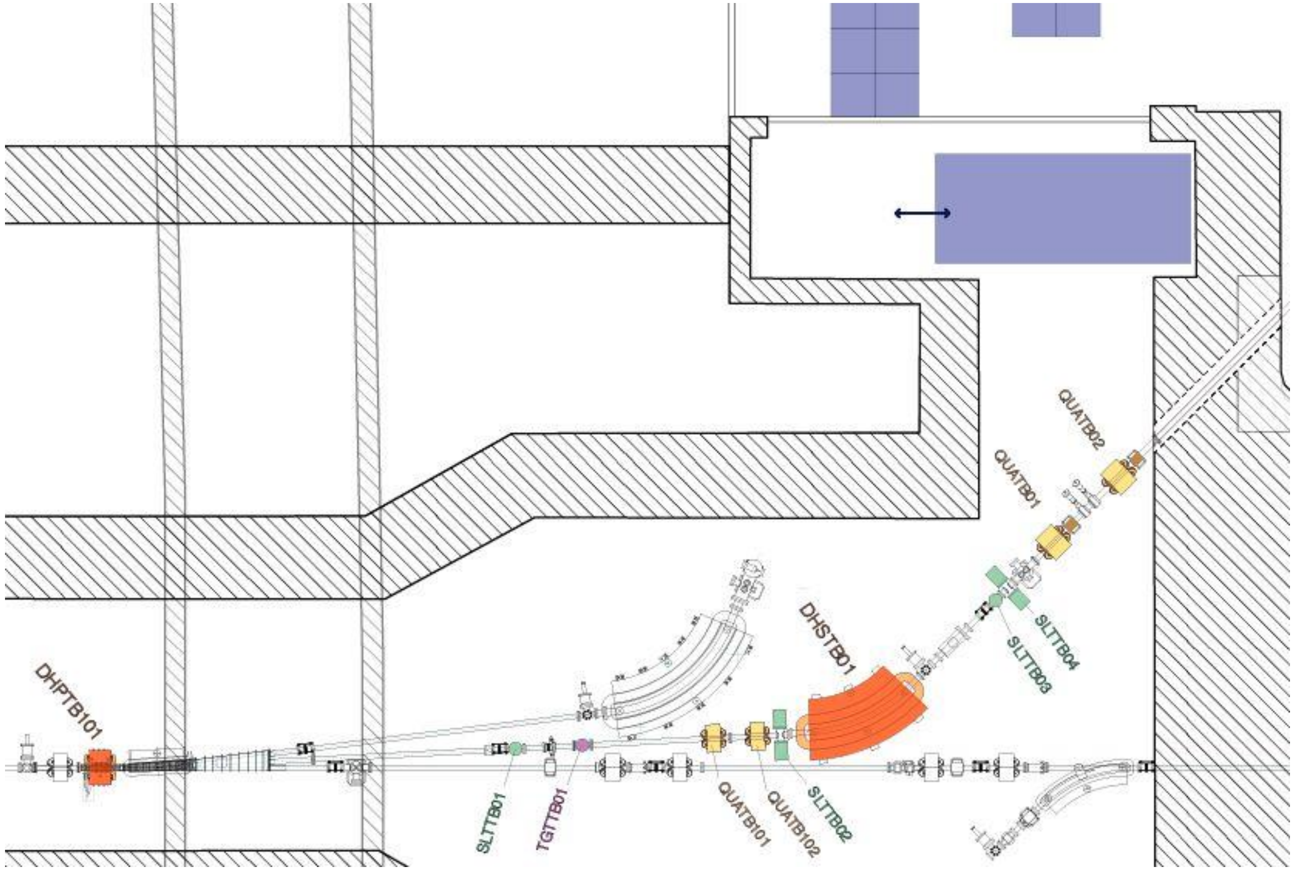
# SPARES

# BTF Beam line

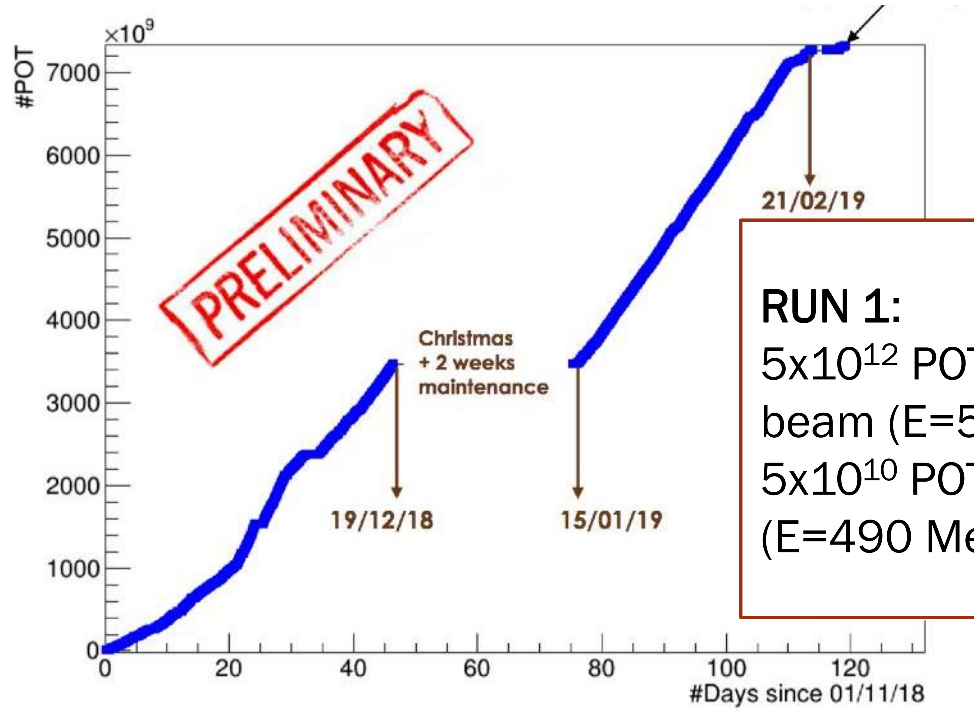
Primary electrons come from a gun and are accelerated up to 800 MeV. Primary positrons come from a converter (W-Re target):

- Hit by electrons at 220 MeV
- Captured positrons accelerated up to 550 MeV

Secondary positron can be produce by a BTF 1.7 X0 Cu target. Energy selection collimation on the BTF transfer-line for defining momentum, spot size, and intensity.



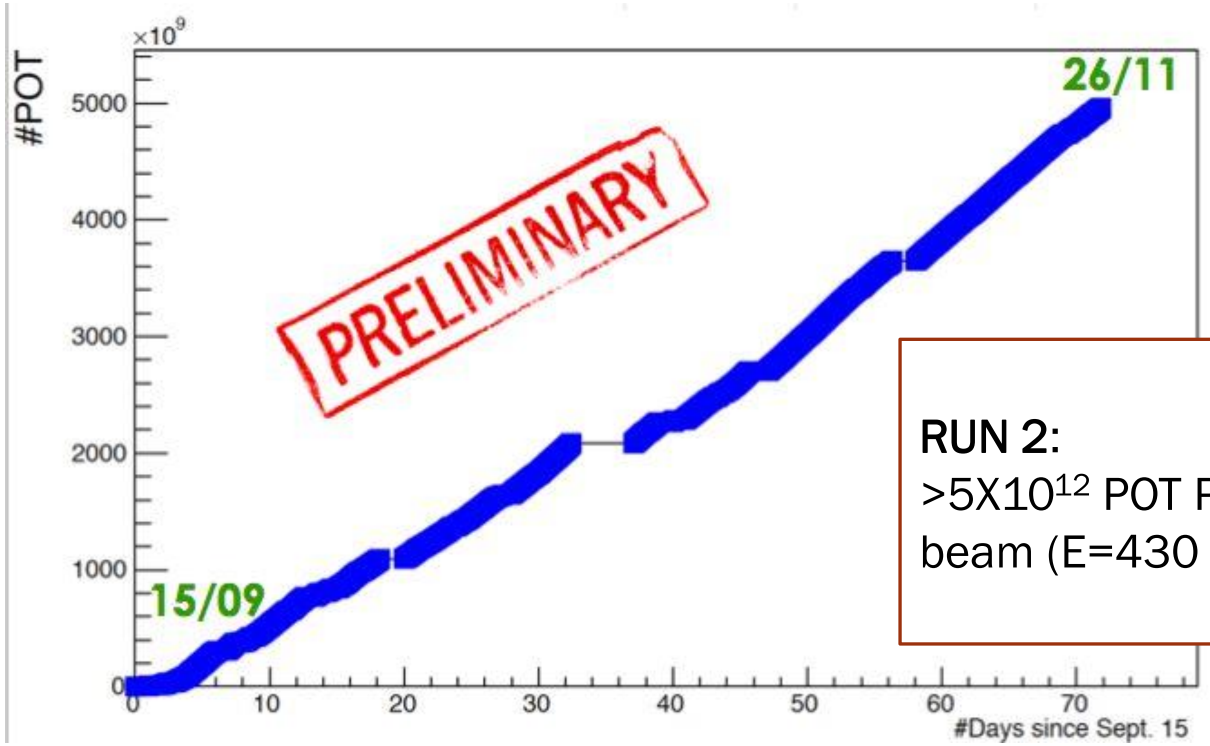
# PADME Run 1




**RUN 1:**
$5 \times 10^{12}$ POT Secondary beam (E=540 MeV) + $5 \times 10^{10}$ POT primary beam (E=490 MeV) for calibration

Run 1 (10/2018 → 02/2019) collected $>5 \times 10^{12}$ POT and was devoted to beam optimization, detector calibration, study of the background, and the removal of beam background from data

# PADME Run 2



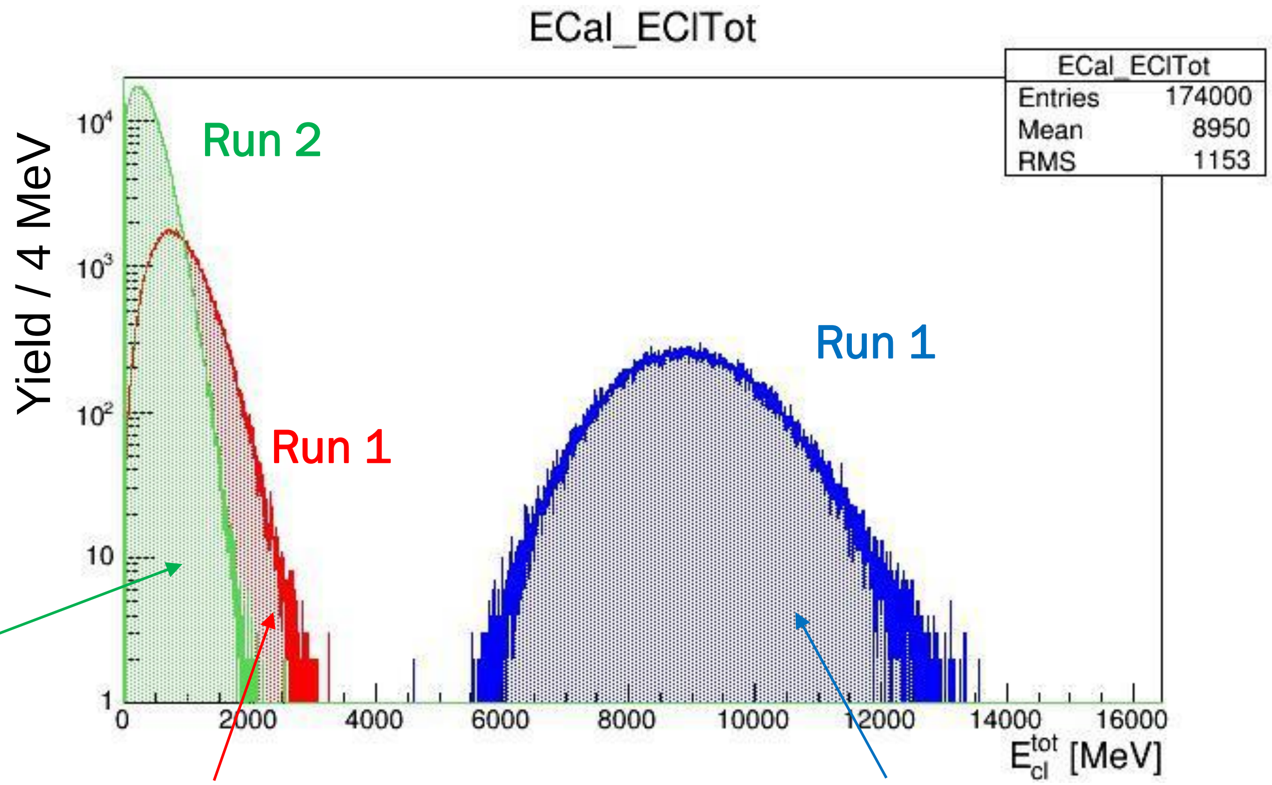

**RUN 2:**
>5X10$^{12}$ POT Primary beam (E=430 MeV)

Run 2 (09/2020 → 11/2020) collected 5,58X10$^{12}$ POT, data analysis still ongoing

# Background reduction

**Beamline improvements:** mylar window between accelerator and experiment instead of a Be one

**Tuning of the beam:** new collimators, optimized beam energy



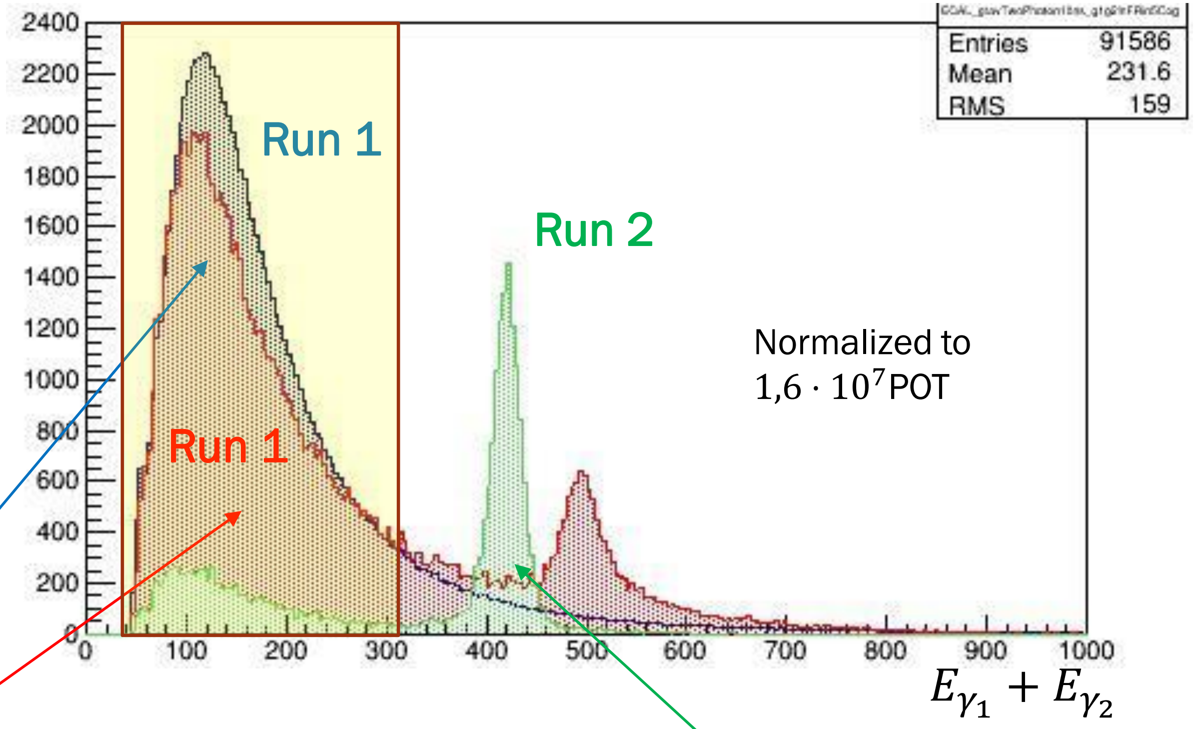

Run II: 430 MeV primary, 28k e+, 280 ns after beam-line upgrades

Run I: 490 MeV primary, 25k e+, 250 ns (Be window)

Run I: 545 MeV secondary, 25k e+, 250 ns (Be window)

# Background reduction in $\gamma\gamma$

Background (low energy peak highlighted in the plot) reduction is evident in $\gamma\gamma$ events




Run I: 545 MeV secondary, 25k e+, 250 ns (Be window)

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Run II: 430 MeV primary, 28k e+, 280 ns after beam-line upgrades

# Background reduction in Bremsstrahlung

Reduction of the low-energy plateau; in Run 2 configuration, the peak from $E_\gamma + E_{e^+}$ is centered around the beam energy value