UNIVERSITÀ DEL SALENTO

Istituto Nazionale di Fisica Nucleare
SEZIONE DI LECCE

THE PADME CHARGED PARTICLE SPECTROMETER

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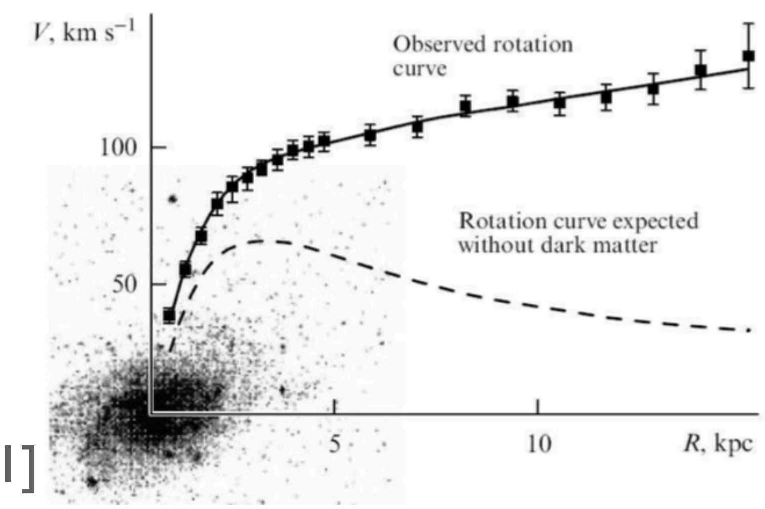
International Conference on Technology and Instrumentation in Particle Physics

TIPP 2021

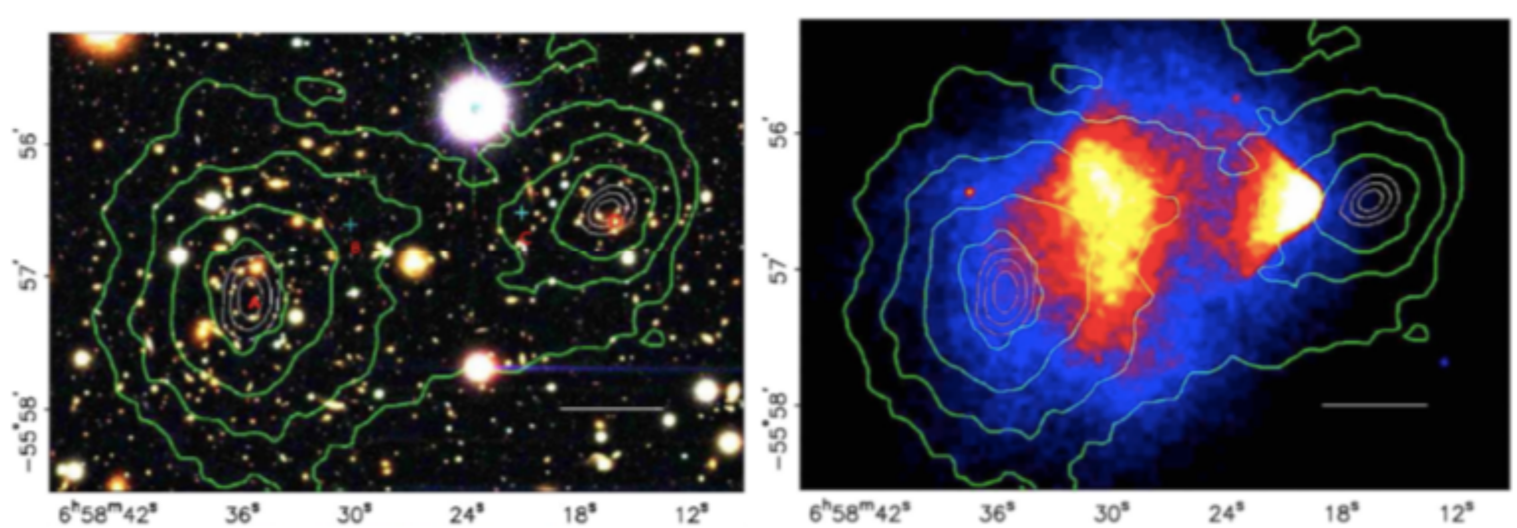
[1]arXiv:1710.10630
[2]DOI: 10.1103/PhysRevD.78.104004

THE MYSTERY OF DARK MATTER

- The visible matter alone is not able to explain some astrophysical and cosmological phenomena
  - Rotation velocity of spiral galaxies
  - Gravitational lensing → Bullet Cluster
  - …



[1]



[2]

A NEW GAUGE BOSON

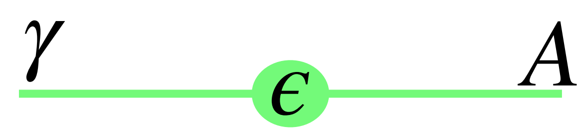
[1]arXiv:1608.0863

- The WIMP paradigm is challenged by LHC. A new idea introduces a hidden sector of particles interacting through a portal with the particles of the visible sector.
- A possible scenario: a New Gauge symmetry $U_D(1)$ in the hidden sector [1]

$$L \sim g' q_f \bar{\psi}_f \gamma^\mu \psi_f A'_\mu$$

- Very weak interaction with the standard model particles via dark photon - photon mixing

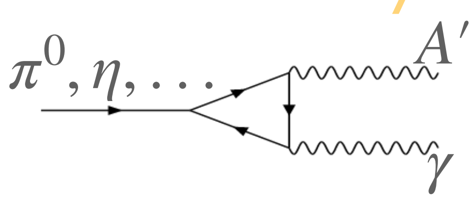
$$L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$



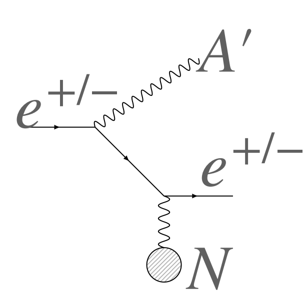
ϵ : kinetic mixing coefficient

Production mechanisms

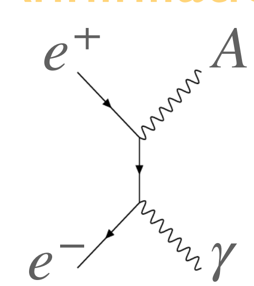
Meson decay



Bremsstrahlung

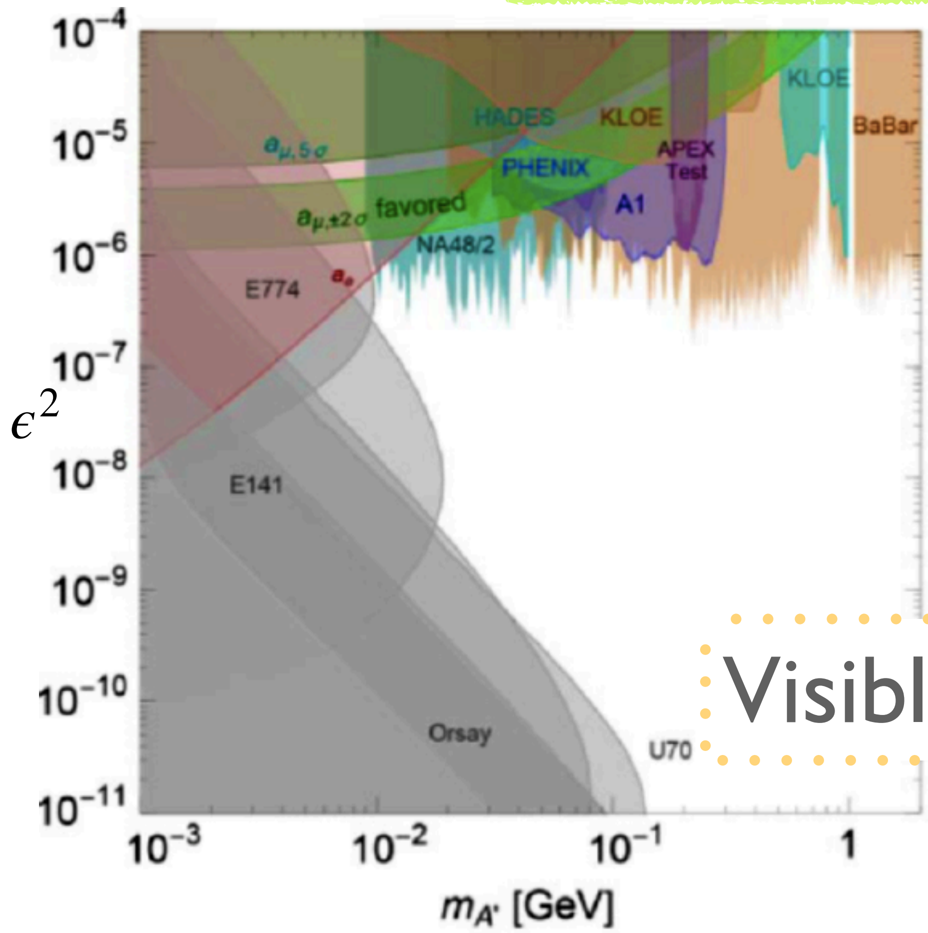


Annihilation

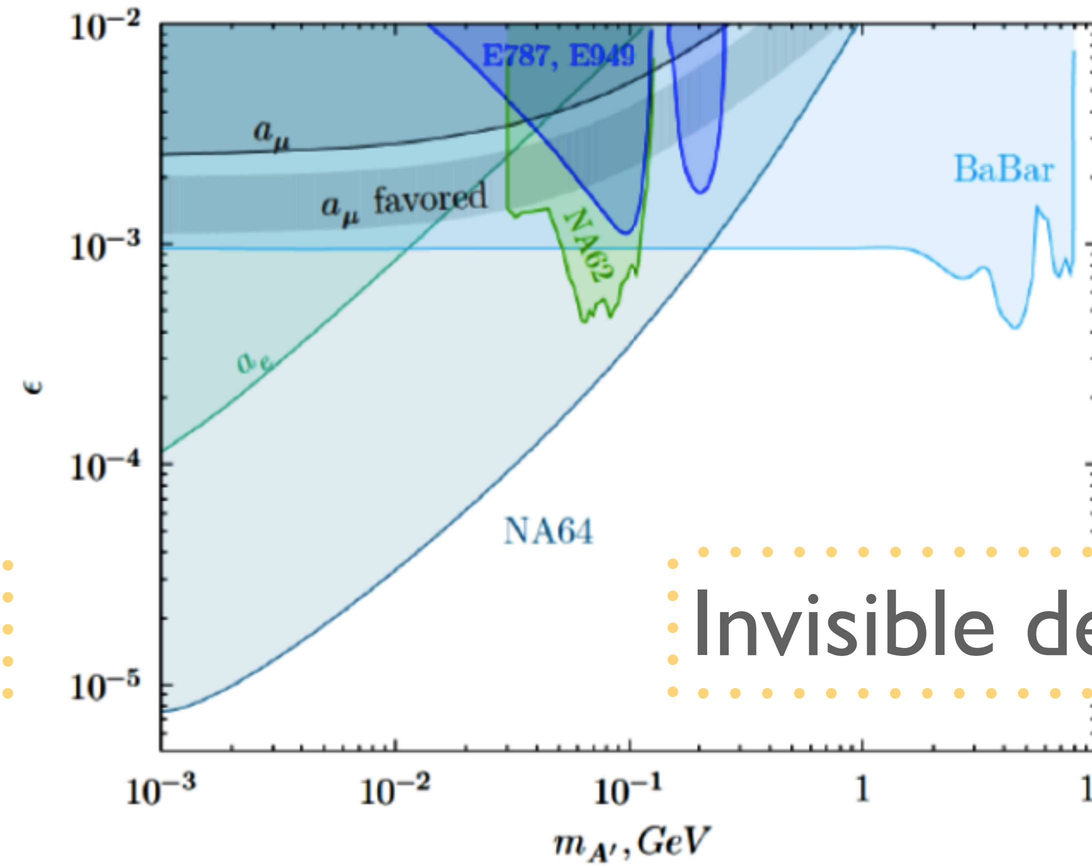


A' PARAMETER SPACE

Decays
– To SM model particles if $M_{DM} > M_{A'} > 2m_e$
– To DM (invisible) particles if $M_{DM} < M_{A'}$



Visible decay



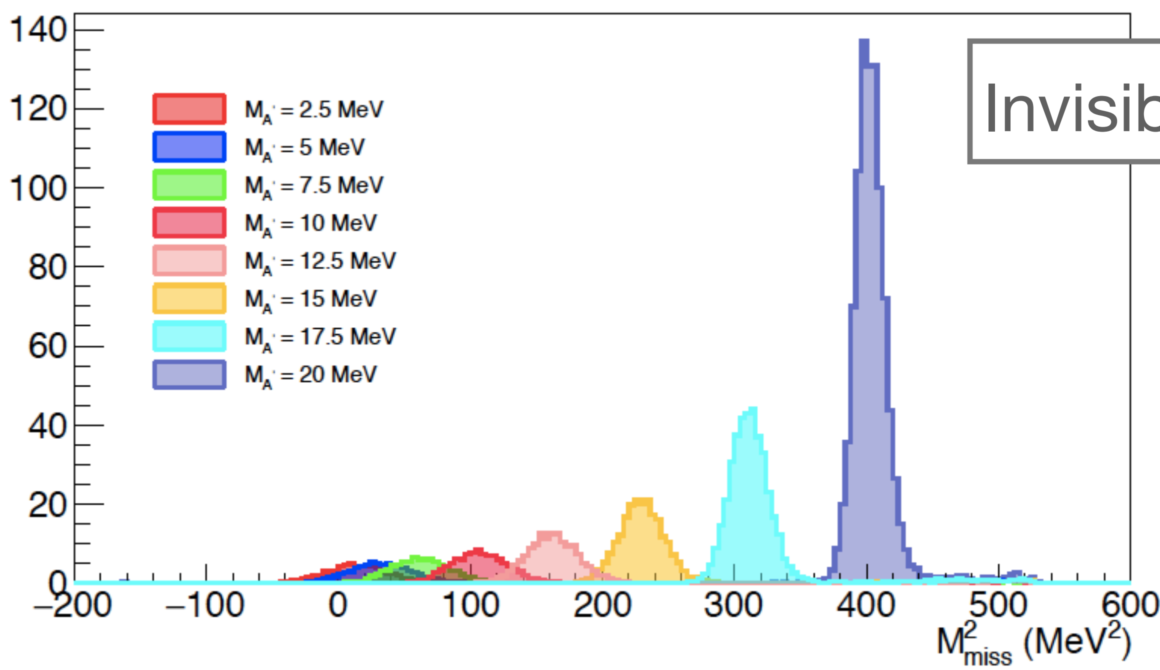
Invisible decay

- searches into visible decay modes
  - e+e- colliders
  - e- or p beam+dump / thick target
  - e- beam + thin target
  - LHC

- searches into invisible particles
  - indirect limits
  - model dependent bounds
  - e+ beam experiments: PADME concept and potential

THE APPROACH OF PADME

[1] $(4 \times 10^{13}$ Positron On Target POT)



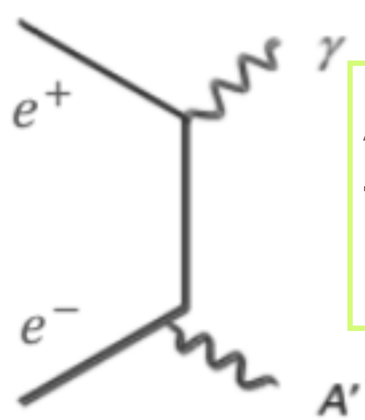
Invisible decay of A' → missing mass method

Possible A' production process

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

Detection though the missing mass method

$$M^2_{miss} = (p_{e^-} + p_{beam} - p_\gamma)^2$$



A positron beam on a fixed target may produce a photon and a dark photon

$\sigma(e^+e^- \rightarrow A'\gamma) \sim$ tens of nb

$$M_{A'} = 10 \text{ MeV}$$

$$\epsilon^2 \simeq 10^{-6}$$

A' mass inferred from energy momentum conservation. A good knowledge of the photon features gives us a good resolution on missing mass

PADME mass reach $M_{A'} \leq 23.7$ MeV for $E_{e^+} = 550$ MeV

PADME EXPERIMENT

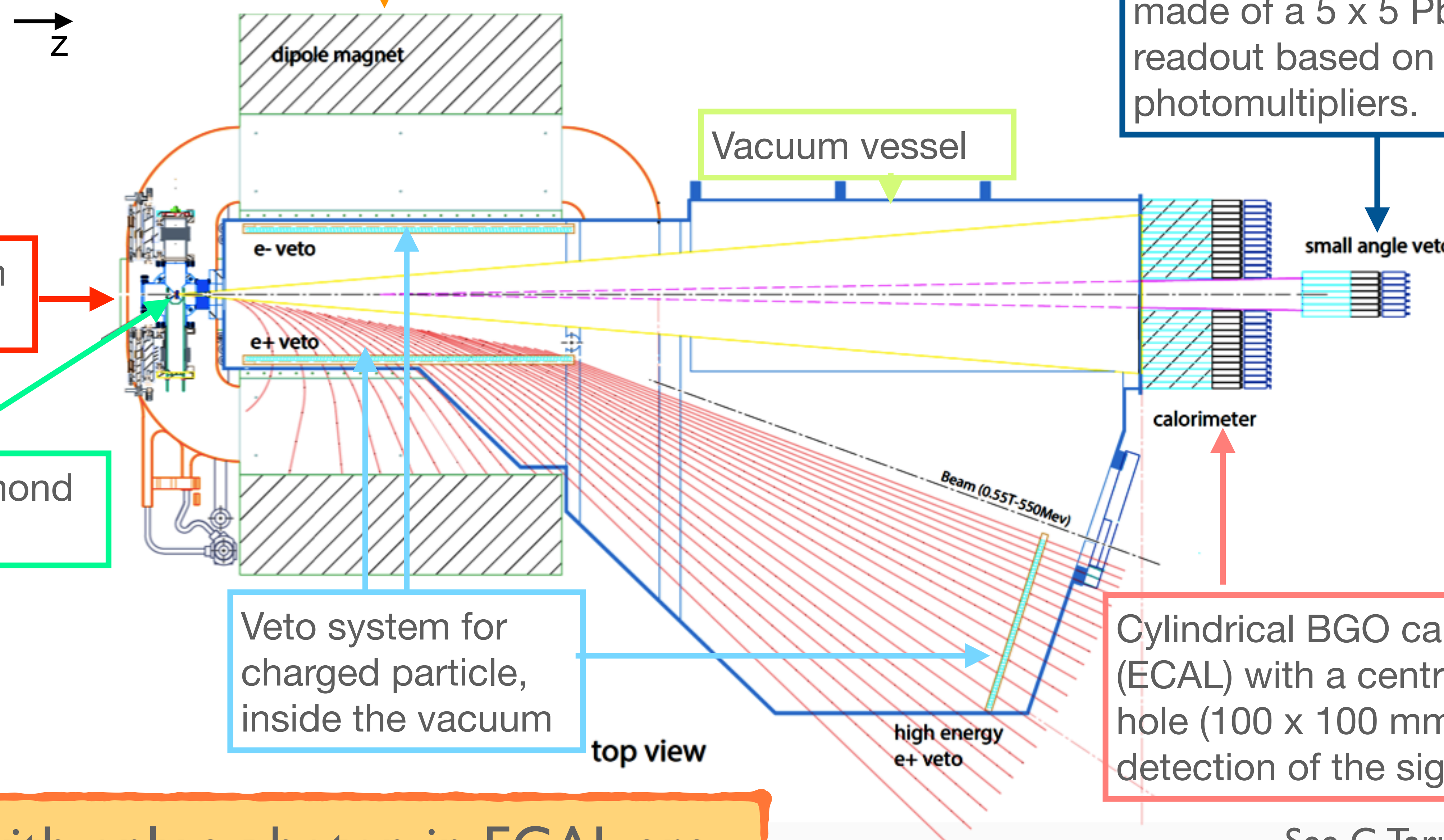
Magnetic field of 0.5 T

Small Angle Calorimeter (SAC), made of a 5 x 5 PbF_2 crystals, readout based on fast photomultipliers.

Vacuum vessel

Positron beam from LINAC

Active diamond target



Veto system for charged particle, inside the vacuum

Cylindrical BGO calorimeter (ECAL) with a central squared hole (100 x 100 mm^2), detection of the signal photon

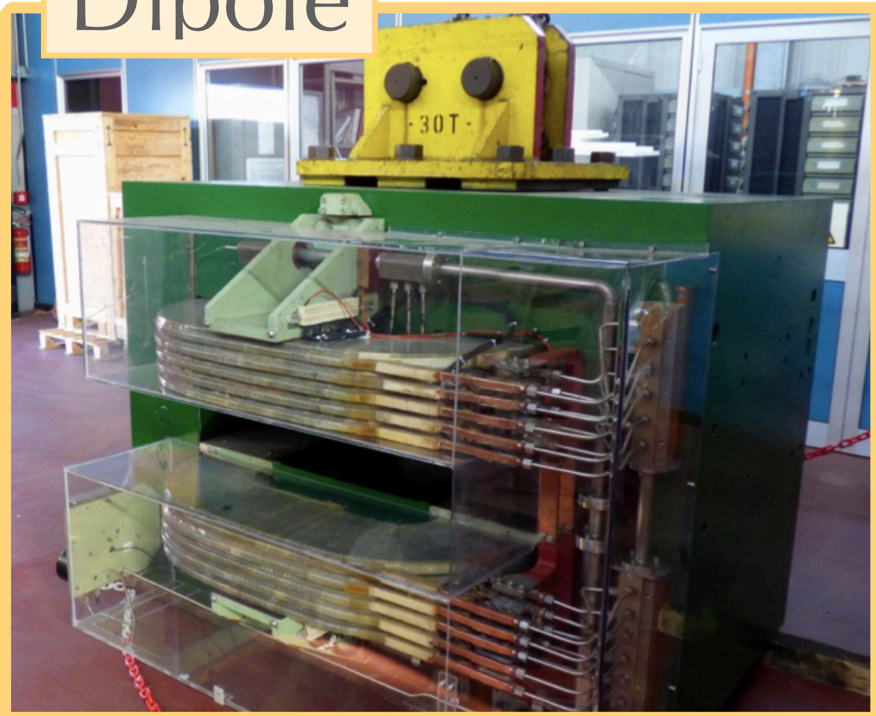
Events with only a photon in ECAL are used to fill the missing mass spectrum

Looking for peaks!

See C.Taruggi's poster on PADME calorimeters!

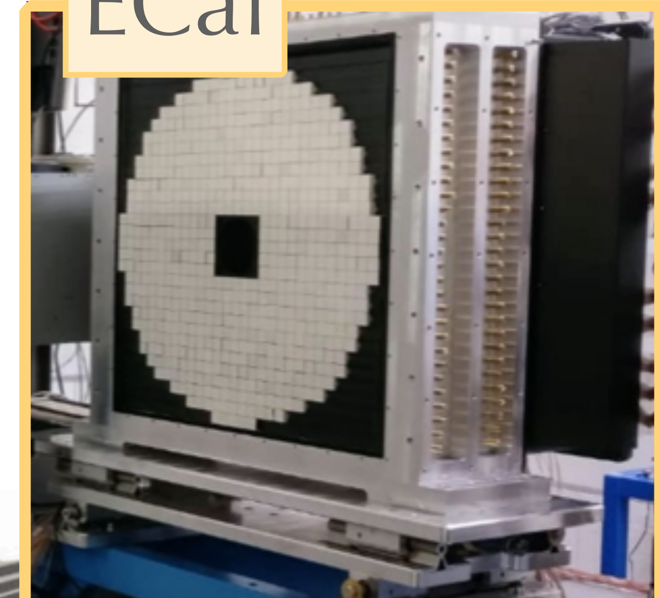
PADME SUBDETECTORS IN A NUTSHELL

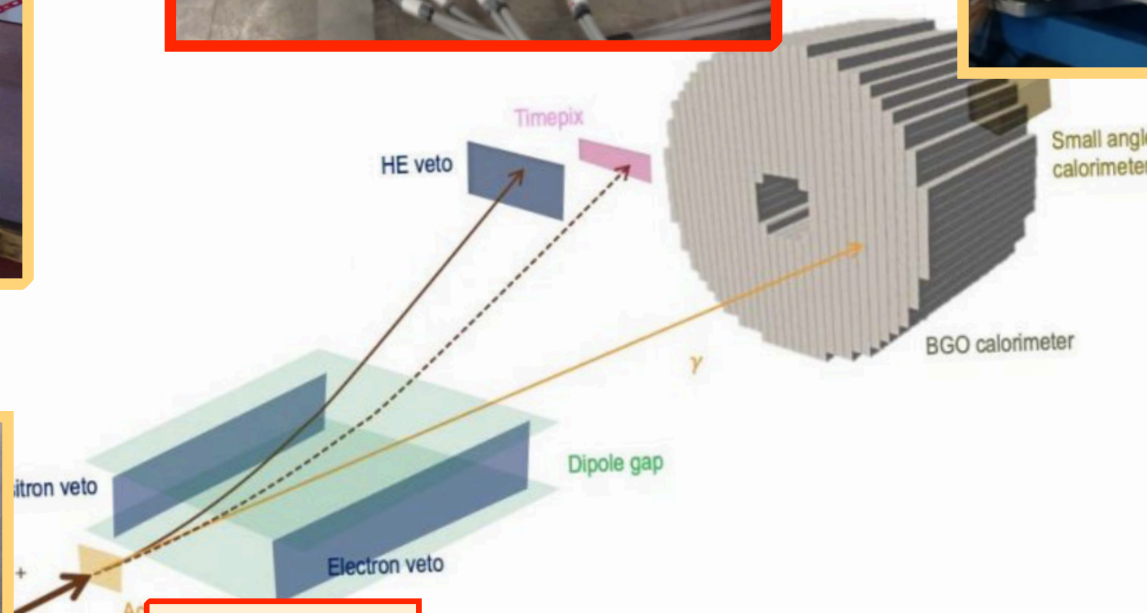
Dipole



HEP-veto

ECal





SAC

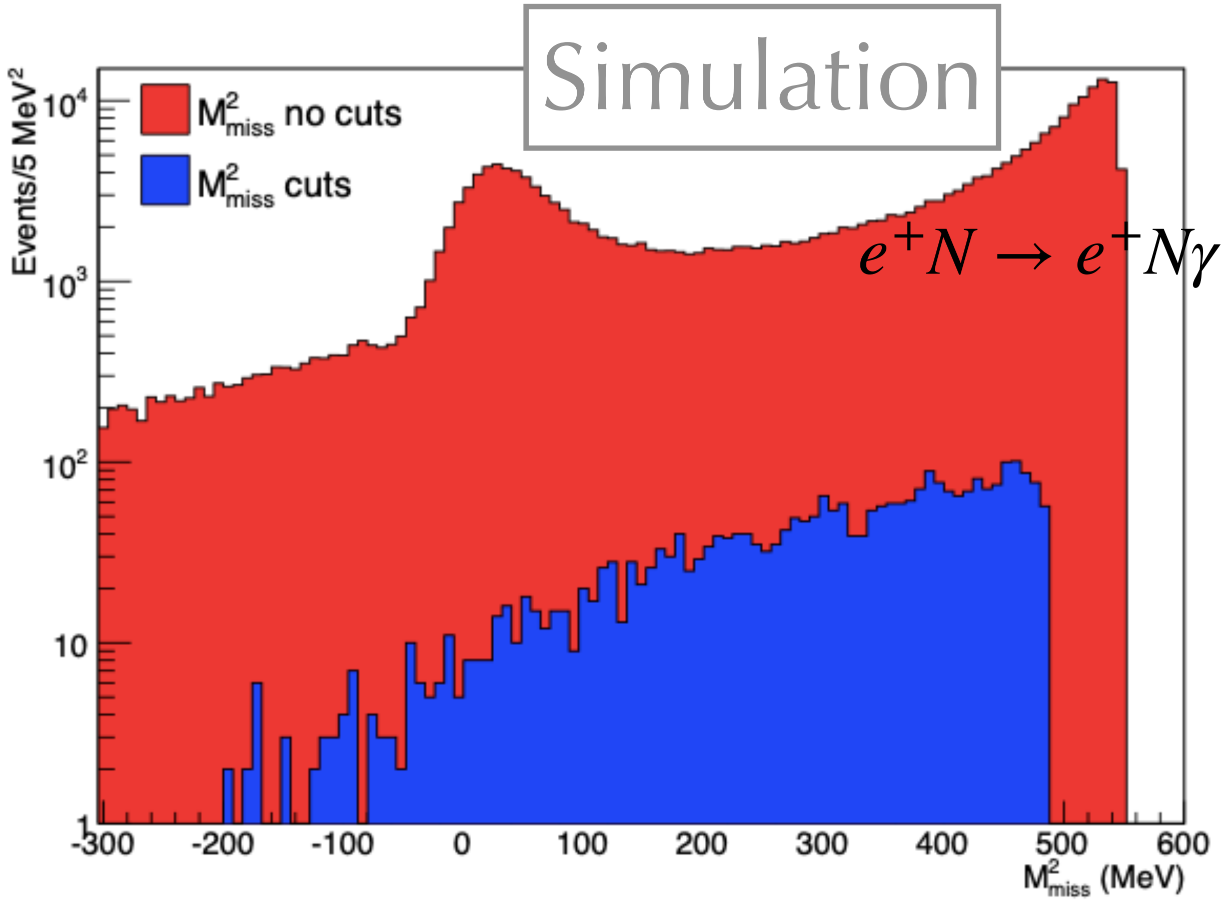
Diamond target

PVeto

EVeto

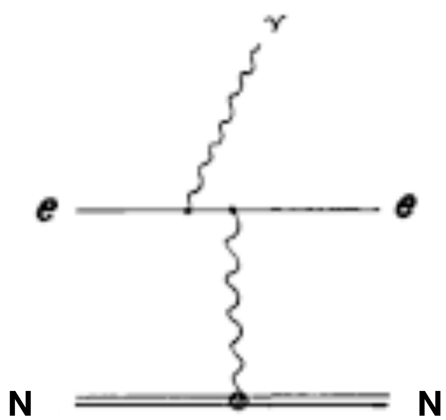
BACKGROUNDS

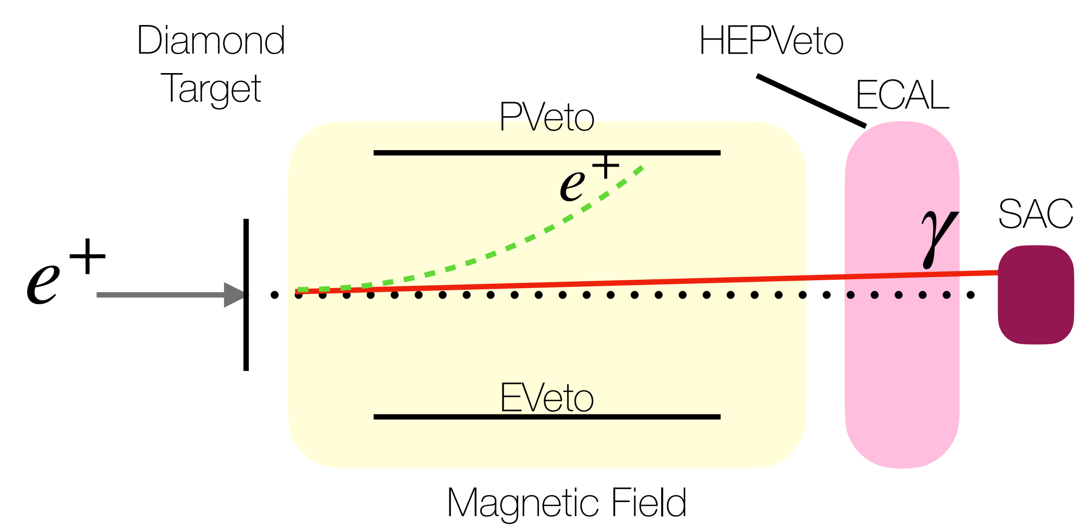
- Bremsstrahlung in the field of the target nuclei $e^+N \rightarrow e^+N\gamma$
  - A photon (preferentially of low energy) in ECAL + a positron in the veto
  - Positron inefficiency gives high M_{miss}



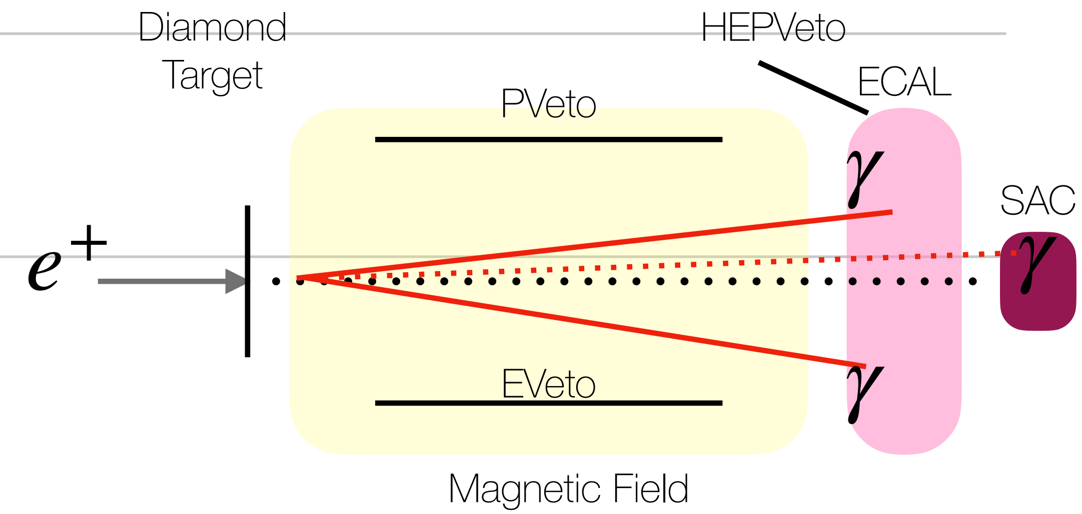
$$E_\gamma > 1 \text{ MeV}$$

$$\sigma(e^+N \rightarrow e^+N\gamma) = 4000 \text{ mb}$$

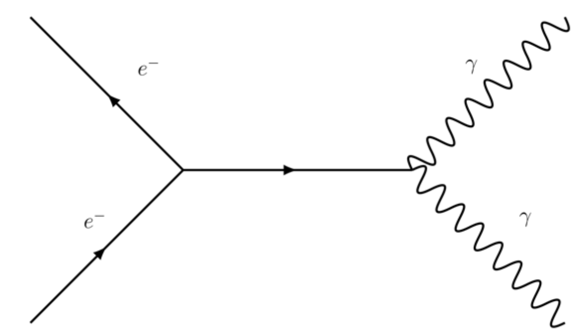




BACKGROUNDS



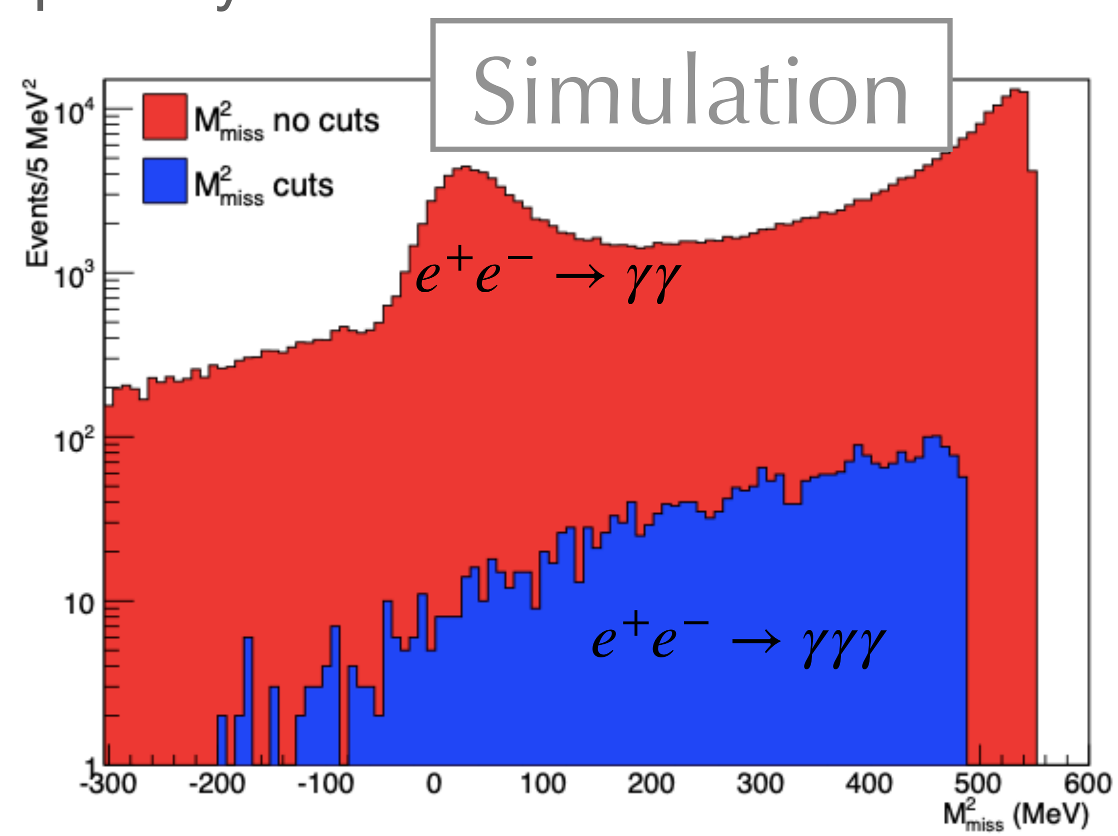
- 2 photon annihilation $e^+e^- \to \gamma\gamma$
  - symmetric in photon azimuth; correlated energy and theta
  - Photon inefficiency gives $M_{miss} = 0$ MeV



$\sigma(e^+e^- \to \gamma\gamma) = 1.55$ mb

- 3 photon annihilation $e^+e^- \to \gamma\gamma\gamma$
  - $2\ \gamma$ symmetry is lost – reduced veto capability
  - Non peaking M_{miss}

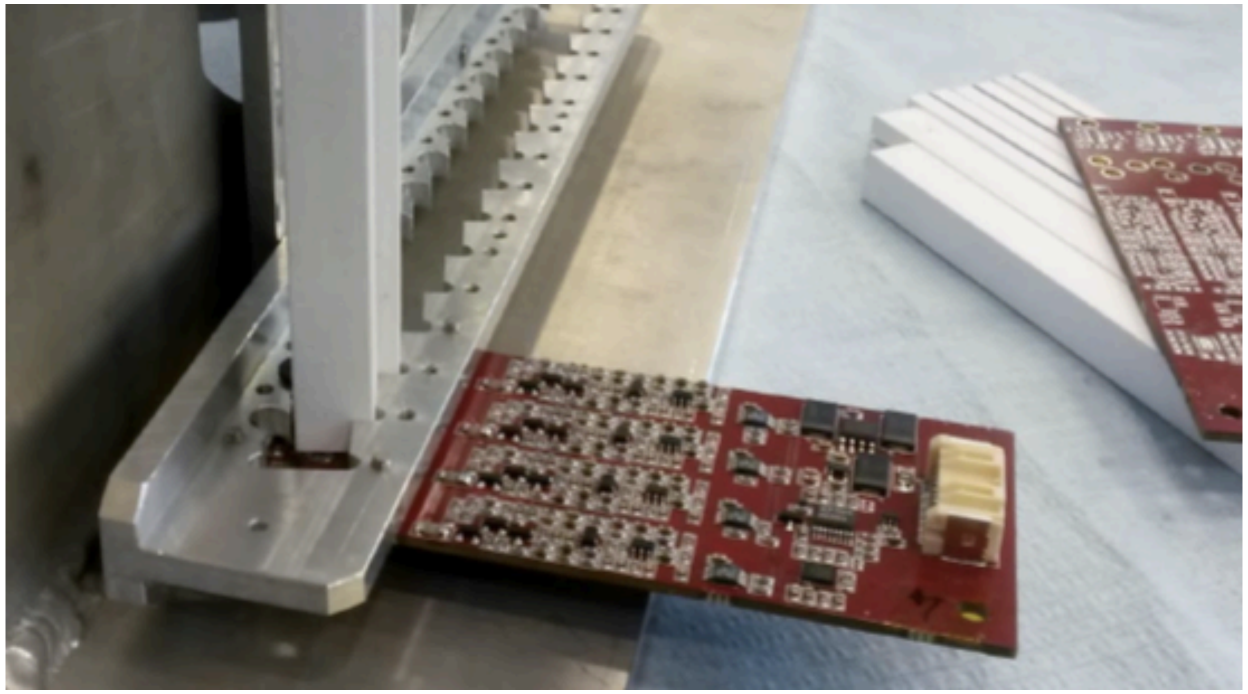
$\sigma(e^+e^- \to \gamma\gamma\gamma) = 7.5 \times 10^{-2}$ mb



VETO SYSTEM

- Plastic scintillator bars $10 \times 10 \times 184 \text{ mm}^3$
  - Polystyrene-based with 15% POPOP, produced by UNIPLAST
- Placed vertically
- SiPM used to detect emitted light
- Three sections
  - PVeto
    - Inside magnetic field
    - 90 scintillating bars
  - HEPVeto
    - Double readout
    - 16 scintillating bars
  - EVeto
    - Inside magnetic field
    - 96 scintillating bars
- To obtain the maximum of the acceptance they are rotated by 0.1 rad

Light Detection and Front-End Electronics



- Detector and electronic
  - inside the vacuum
  - Sustain stationary 0.5 T magnetic field
  - SiMP

- FEE (Front end Electronics) electronic used , each front end
  - Transimpedance amplifier (factor of 4 of gain)
  - Buffer with differential output
  - Dedicate high-voltage regulation module
    - HV and current control

ASSEMBLY

Spacers

- Made on 3D printer
- Fixing the scintillators
- The uniform distribution of tension can be achieved due to the right use of spacers

Longitudinal $1.3 \times 1.3\ \mathrm{mm}^2$ groove houses an optical wavelength shifter (WLS) fiber BCF-92, glued with Eljen EJ500 optical epoxy cement. The BCF-92 fiber has a maximal emission wavelength at 492 nm and maximal absorption wavelength at about 400 nm (matching the POPOP emission spectrum).

Cleaning and gluing

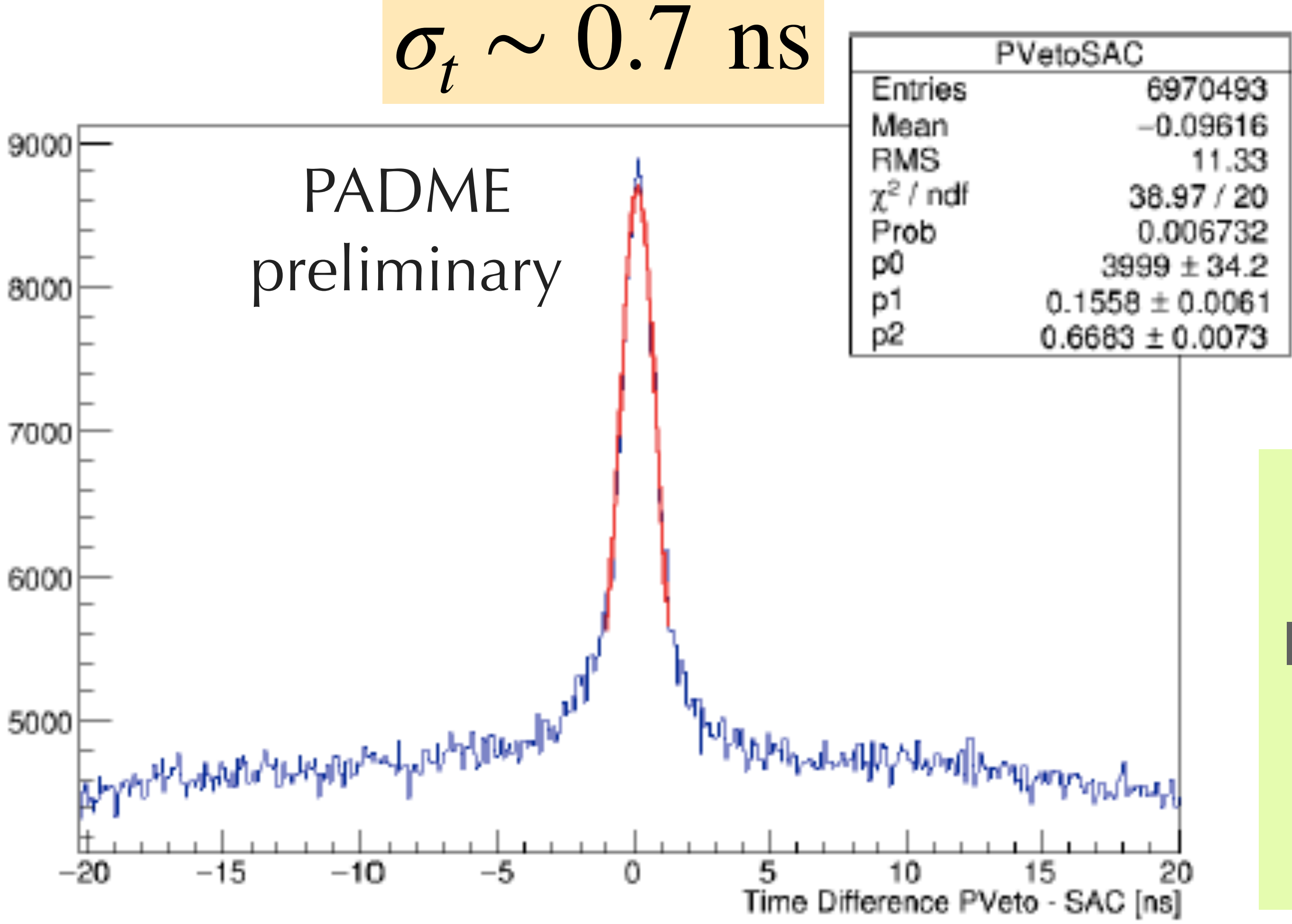
All cards, scintillators and plates were cleaned with isopropile alcohol

- A drop of sillicon was put between the SiPM and the optical fiber

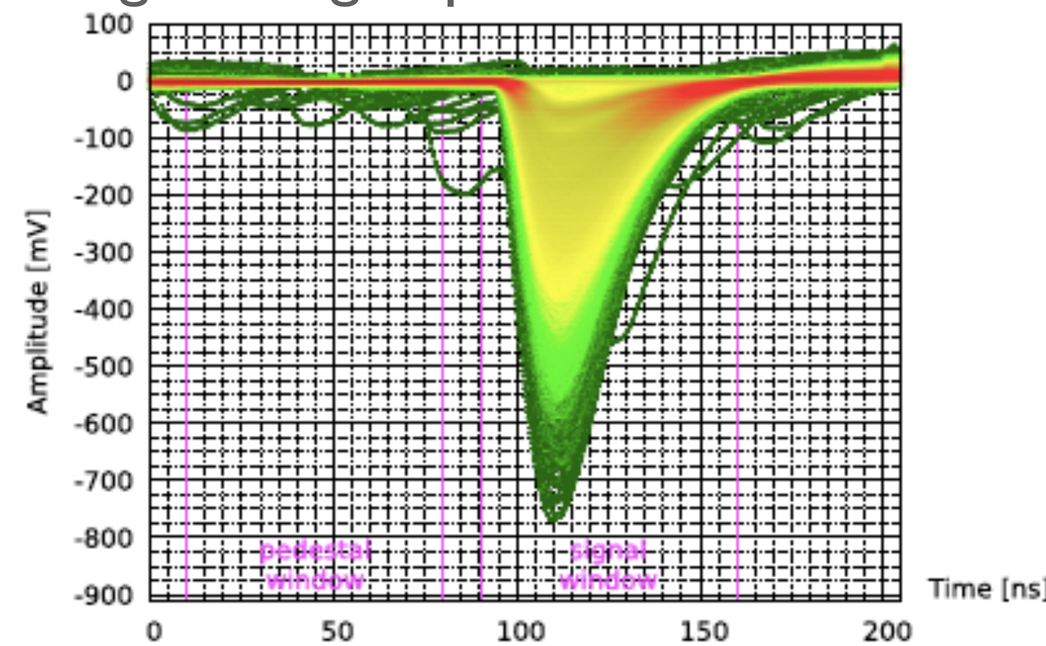
TIME RESOLUTION

- Required by the experiment
  - 1ns

$\sigma_t \sim 0.7 \text{ ns}$



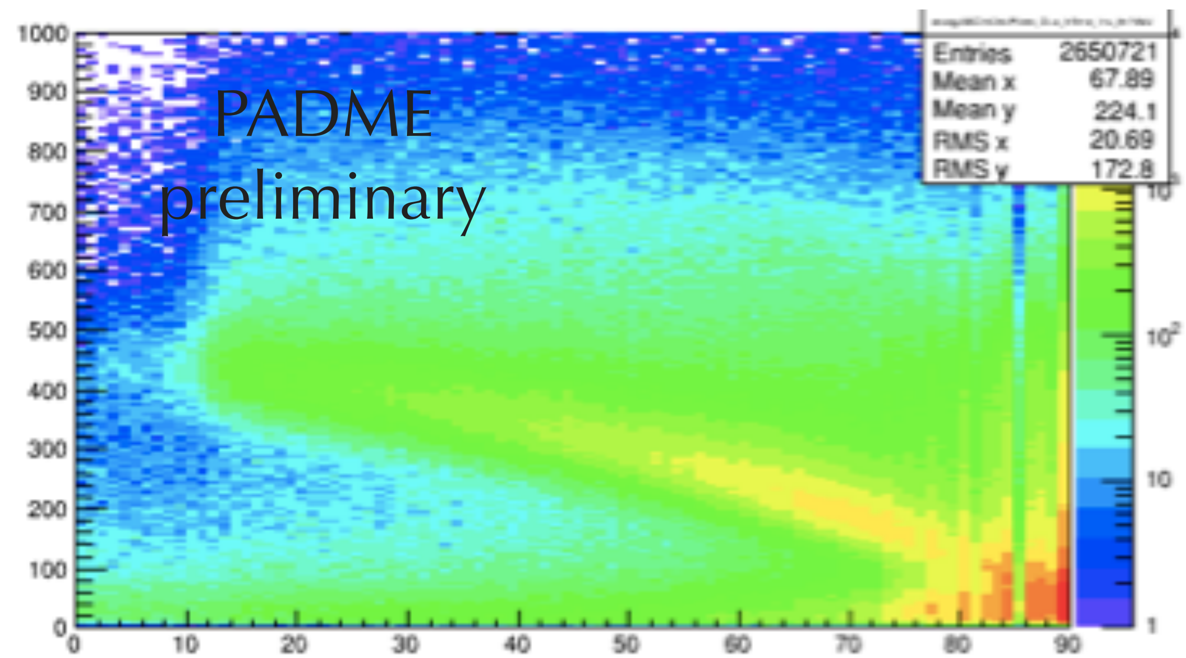
Single charged particle waveform



Resolution of the pVeto extracted from Bremsstrahlung events.
In the plot is shown the difference in time between the photon (detected using fast Cherenkov scintillators) and the positron hitting the veto.

Bremsstrahlung process in PADME

SAC ClEnergy [MeV]

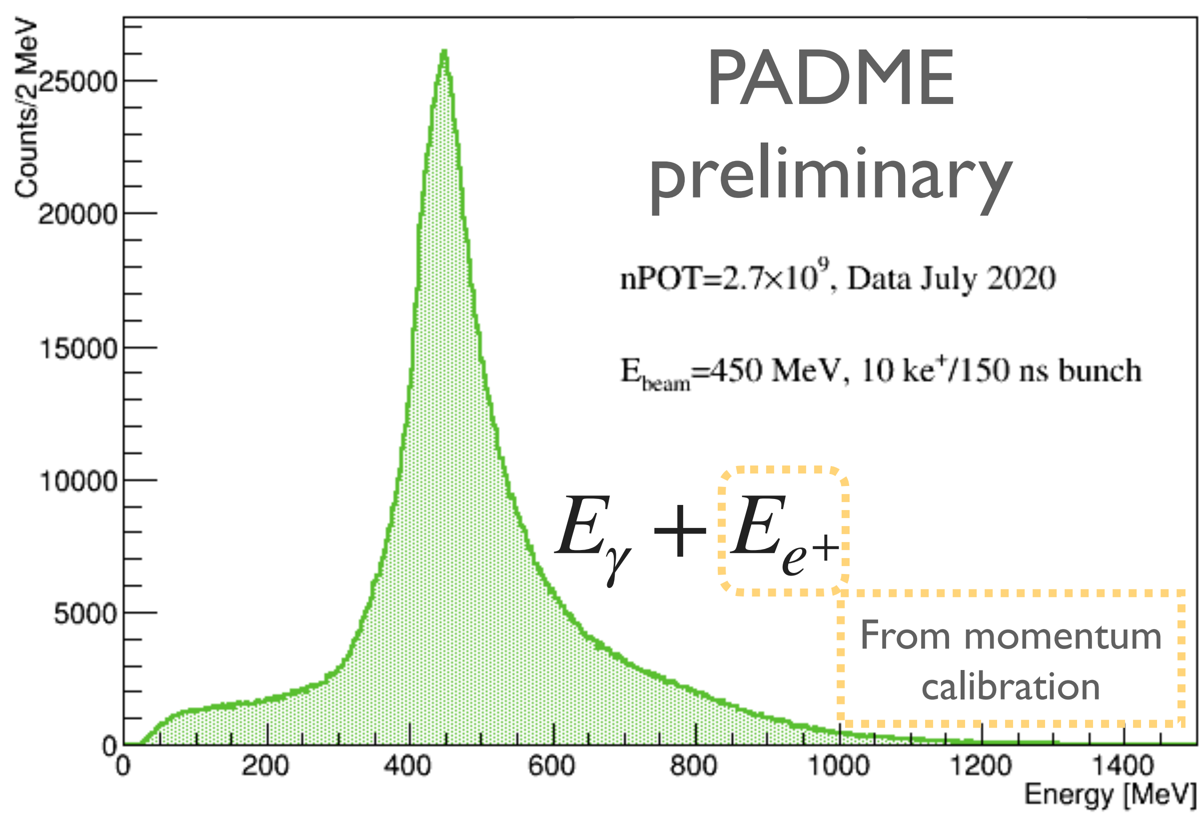


PVeto seed channel

Selection:

$$|t_{\gamma}^{SAC} - t_{e^+}^{PVeto}| < 1.\ \mathrm{ns}$$

$$e^+N \rightarrow e^+N\gamma$$



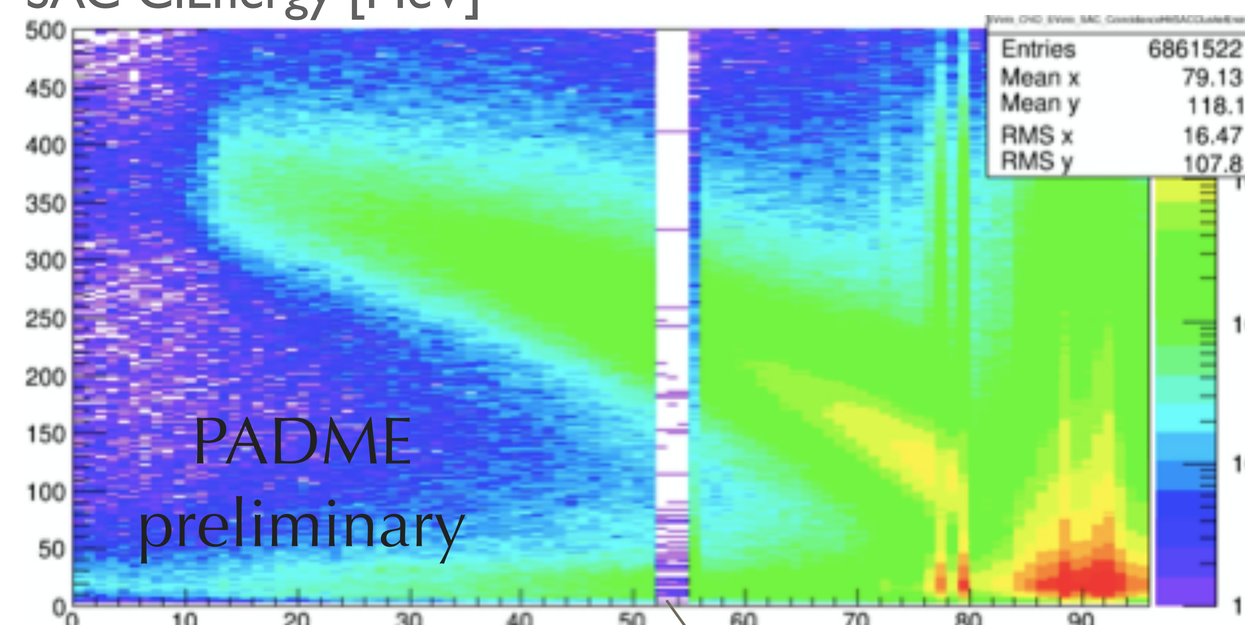
$E_\gamma + E_{e^+}$

From momentum calibration

Also in eVeto!

Special run condition!

SAC ClEnergy [MeV]



EVeto seed channel

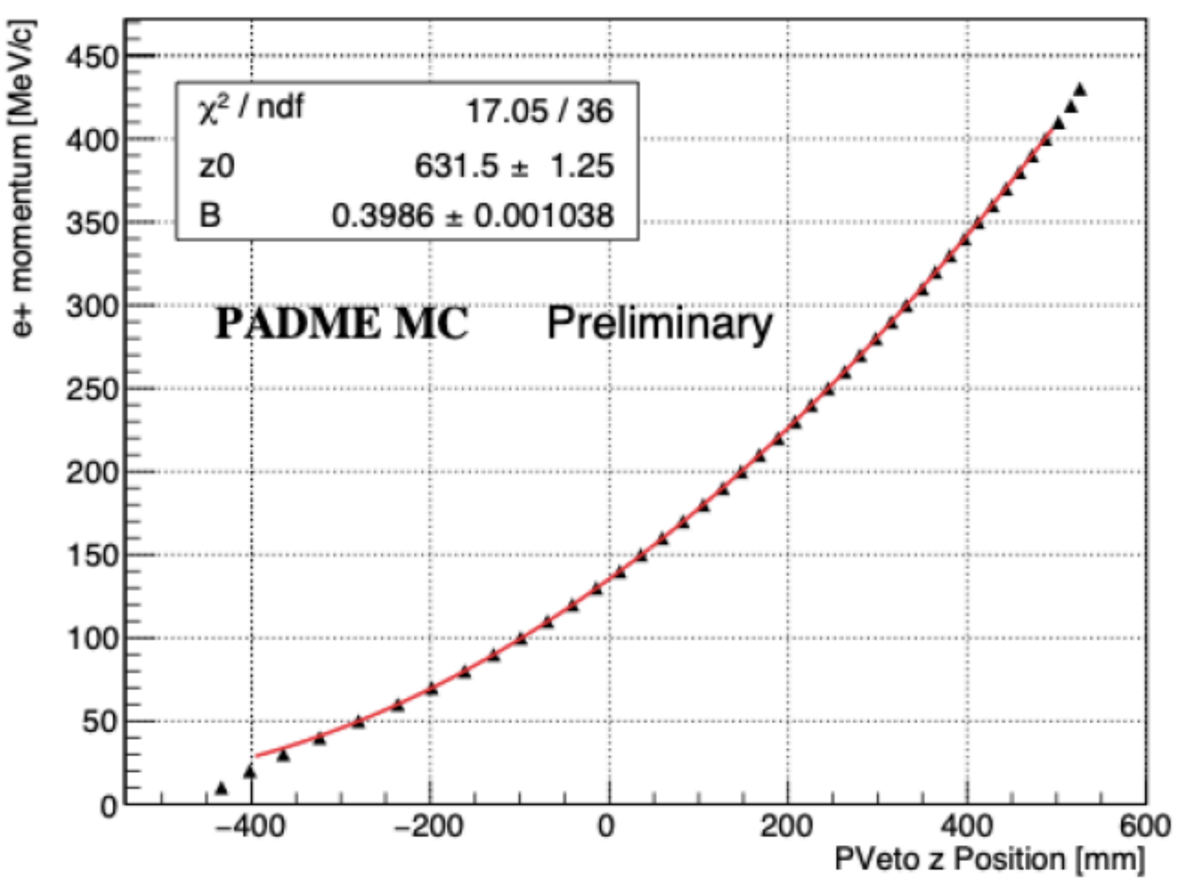
Selection:

$$-3 < t_{cl}^{EVeto} - t_{cl}^{SAC} < 2$$

FEE problem in the acquisition

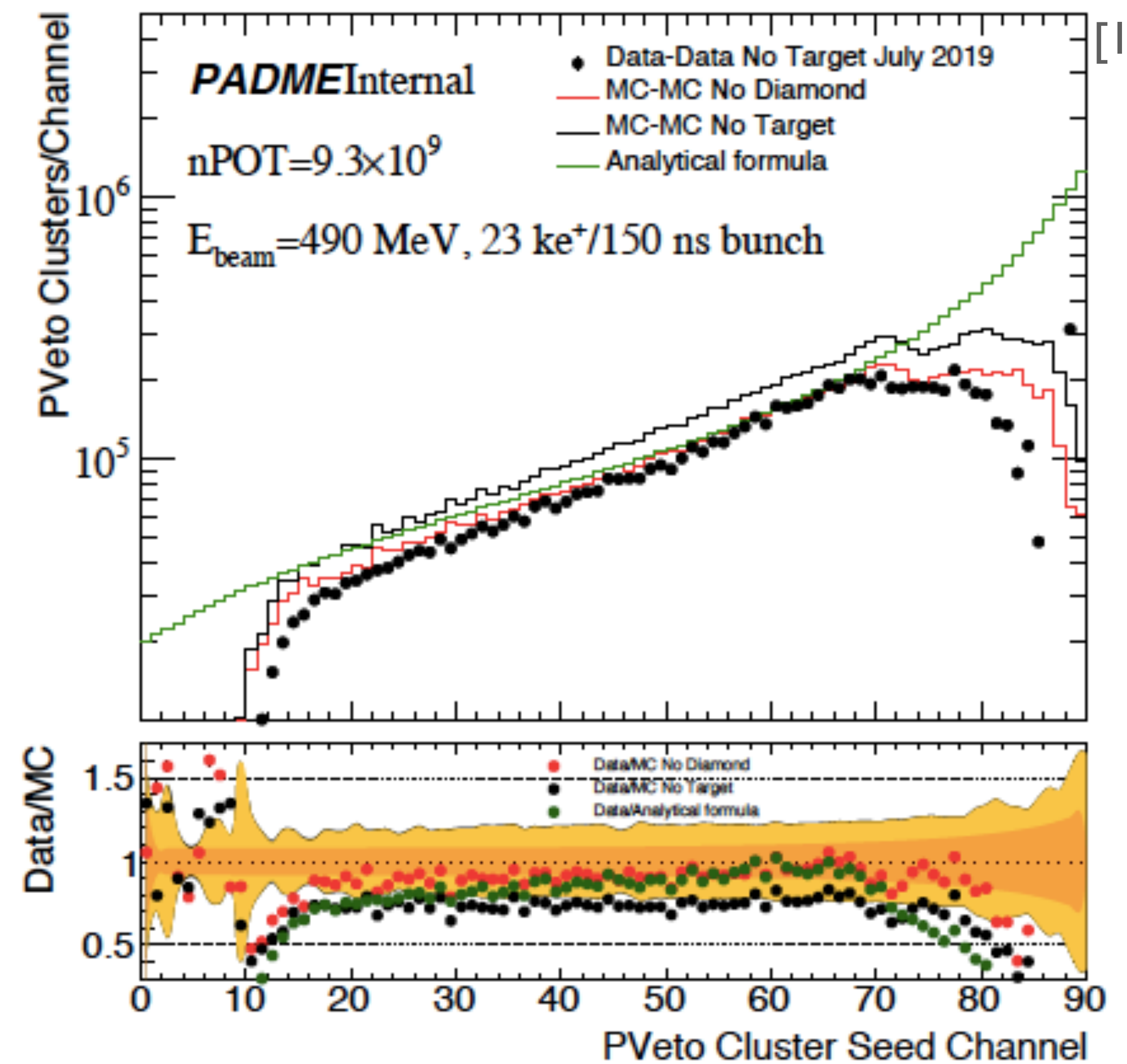
MOMENTUM CALIBRATION

- Momentum calibration using simulation
  - One single positron with different energies in PADME



$$p(z) = \frac{0.3B[(z + z_0)^2] + x^2}{2x}$$

Bremsstrahlung positron profile estimated by subtracting data with target and without target in data and MC compared to analytical formula (PDG)



Conclusion

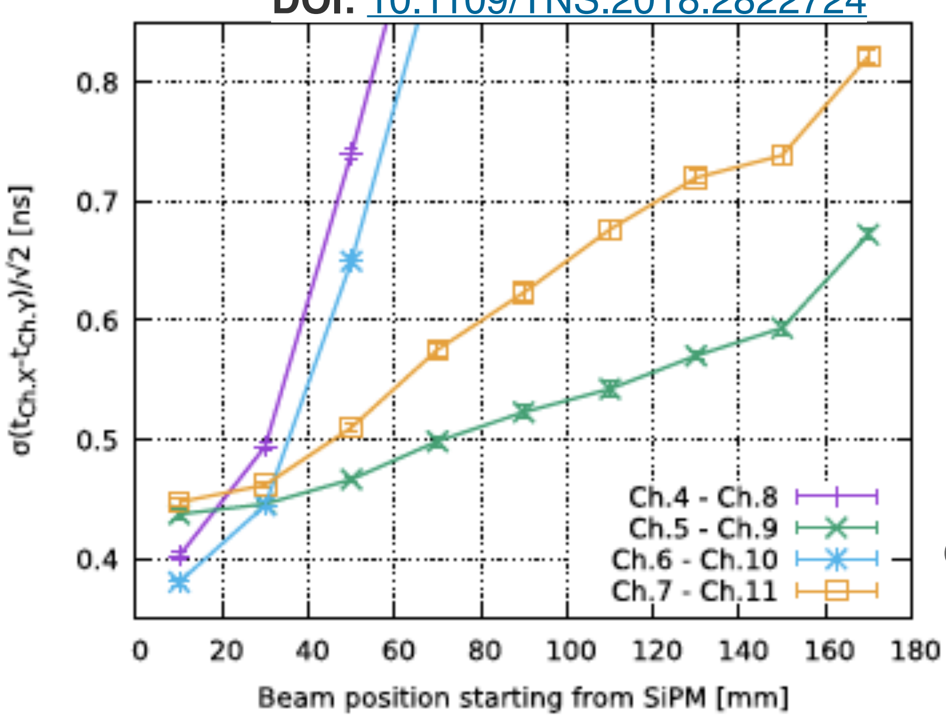
- PADME will investigate on the dark sector hypothesis by exploiting the coupling between the dark-photon and the SM photon and will extract the limits for the kinetic mixing coefficient. It is the first experiment searching for the dark photon in the invisible decay using a positron beam on a fixed target.
- The main background of the experiment is the Bremsstrahlung process, thus the veto system have a crucial role for the PADME experiment
- Several studies ware done on a prototype to understand the best configuration of the system, now several studies are going on to improve the resolution and the efficiency
- The experiment was assembled starting in June 2018, and data taking started in October 2018. The data recorded until February 2019 allowed to study the detector performance and the beam related background. From October to December 2020 a second run was taken with an optimised beam configuration.
- The analysis studies on the QED processes (e.g. Bremsstrahlung) are successfully started and ongoing.

BACKUP

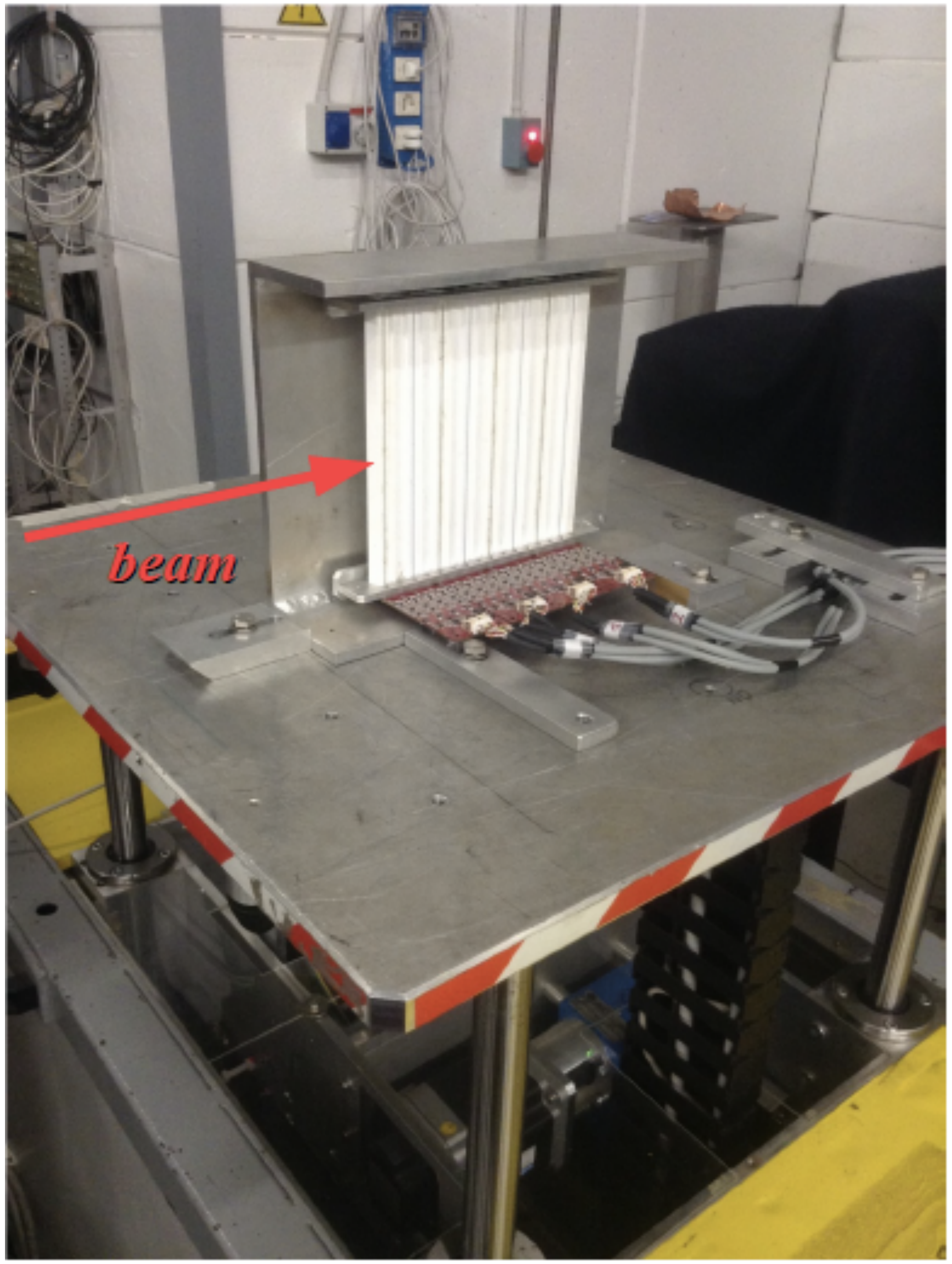
PROTOTYPE CONSTRUCTION

- Aluminium support structure
- 16 scintillating units + FEE board
  - Fiber and scintillator readout
- Beam from BTF dedicate line of DAϕNE
  - $E_{beam} = 500\ \mathrm{MeV}$
  - Pulse duration $10\ \mathrm{ns}$
  - $1e^{+}$/pulse

DOI: 10.1109/TNS.2018.2822724



Tests on light collection results



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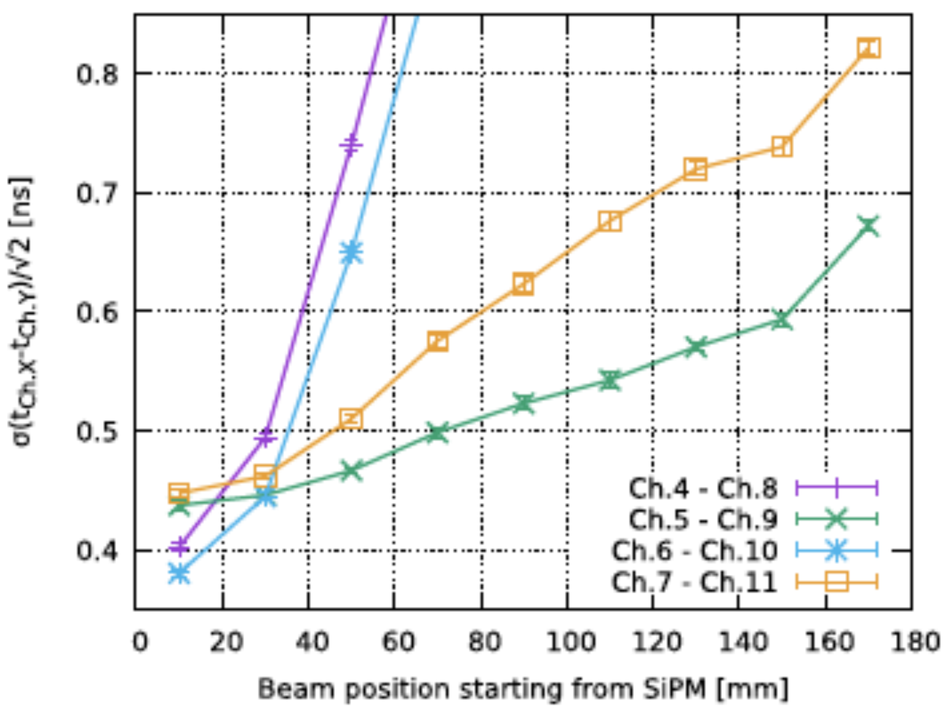
RECONSTRUCTION



RO Channel	Scintillator specs	Light collection
4 and 8	A fiber glued in the groove	Scintillator only
5 and 9	A fiber glued and aluminised	Fiber and scintillator
6 and 10	No fiber used	Scintillator only
7 and 11	A fiber glued in the groove	Fiber and scintillator

Fig. 10. Time resolution comparison for different scintillator light collection types. Max*50% is used as the time reconstruction method.