Searching for a dark photon signal with PADME

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on behalf of the PADME collaboration

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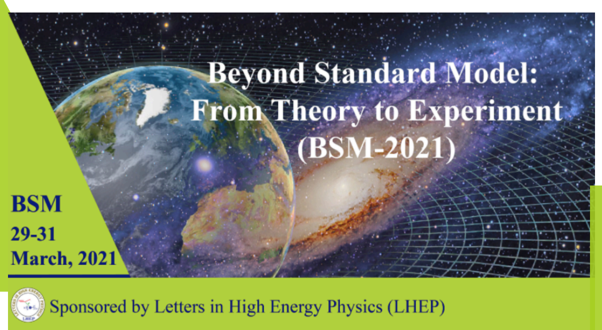


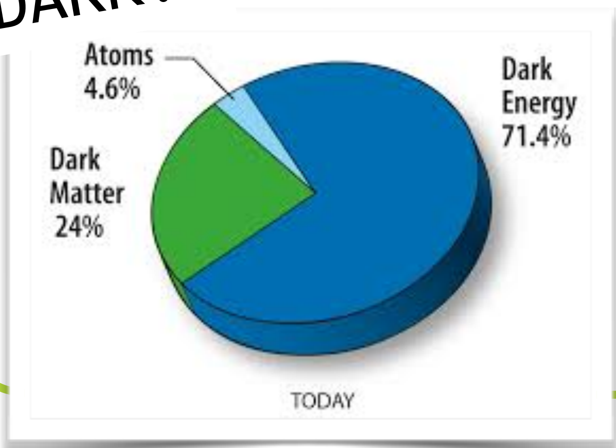
Outline

- *Dark Sector and dark photon*
- *Dark Photon production and decay*
- *Dark photon search in Frascati with PADME*
  - Experimental set-up
  - Signature
  - Background
  - Sensitivity
- *PADME data taking and monitoring*
- Additional dark sector searches at PADME

Dark sector and dark photon

DARK.. ..why does it matter?

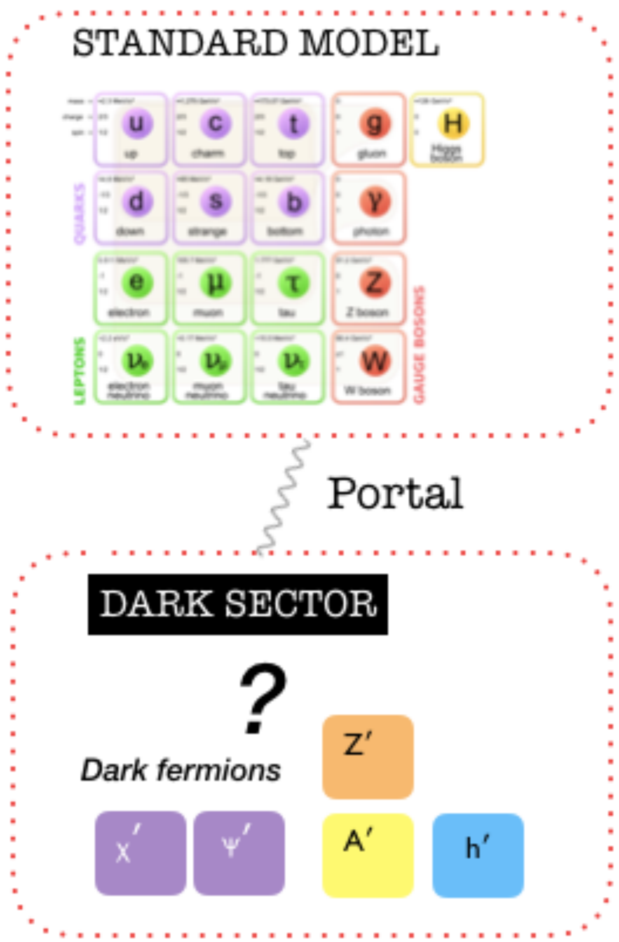
..dancing in the dark



The strong, weak and electromagnetic interactions are described with high precision by the standard model (SM) of particle physics.
Nevertheless, the existence of dark matter, inferred by cosmological and gravitational observations, is a compelling reason to go beyond the SM.

Possible scenario

Dark sector feebly interacting with the world we experience through a neutral portal



MEDIATOR

Pseudo-scalar		Axion
Scalar	?	Higgs
Spin 1/2		Neutrino
Spin 1		Vector

Dark Photon A′

One of the simplest models of the dark sector introduces an additional gauge symmetry U'(1) to describe the interactions among the dark particles.

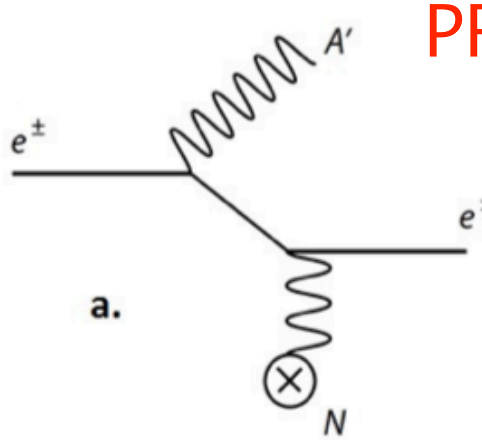
The corresponding gauge boson is the
DARK PHOTON

The simplest mechanism that could determine weak couplings between SM particles and the A′ field is the mixing with the standard model photon described by a kinetic mixing term in the Lagrangian:

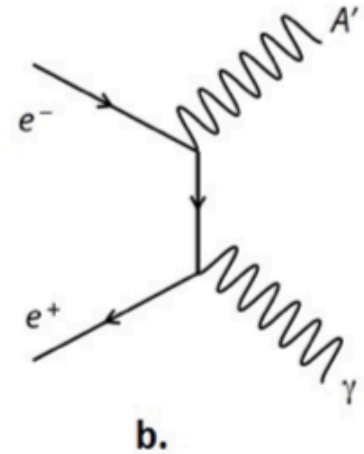
$$\mathcal{L}_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$

Dark Photon production and decay

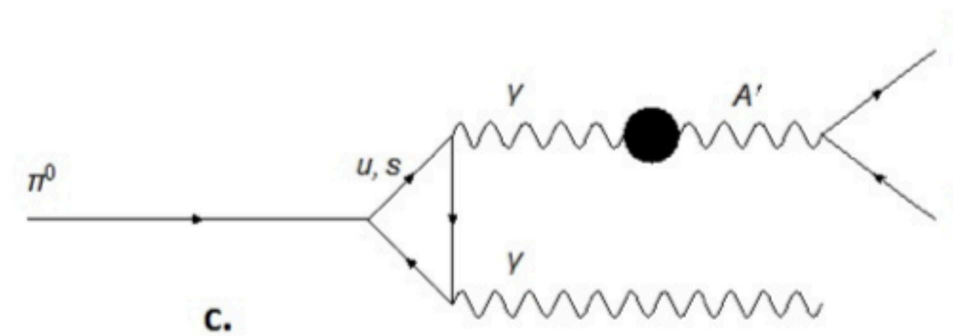
PRODUCTION



A'-strahlung



e+e- annihilations



meson decays

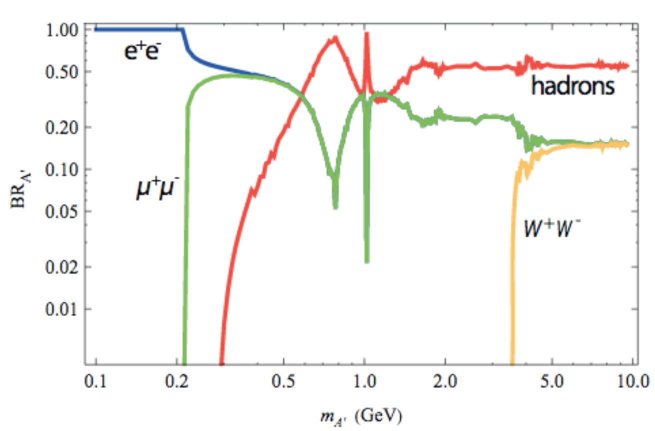
DECAY

Two scenarios, depending on the mass of the DP, with χ hypothetical dark particle

Visible decay

$2m_e < m_{A'} < 2m_\chi$

A' → SM SM



BR 100% e+e- for $m_{A'}$<0.2GeV

Invisible decay

$m_{A'} > 2m_\chi$

A' → χ χ

boo!

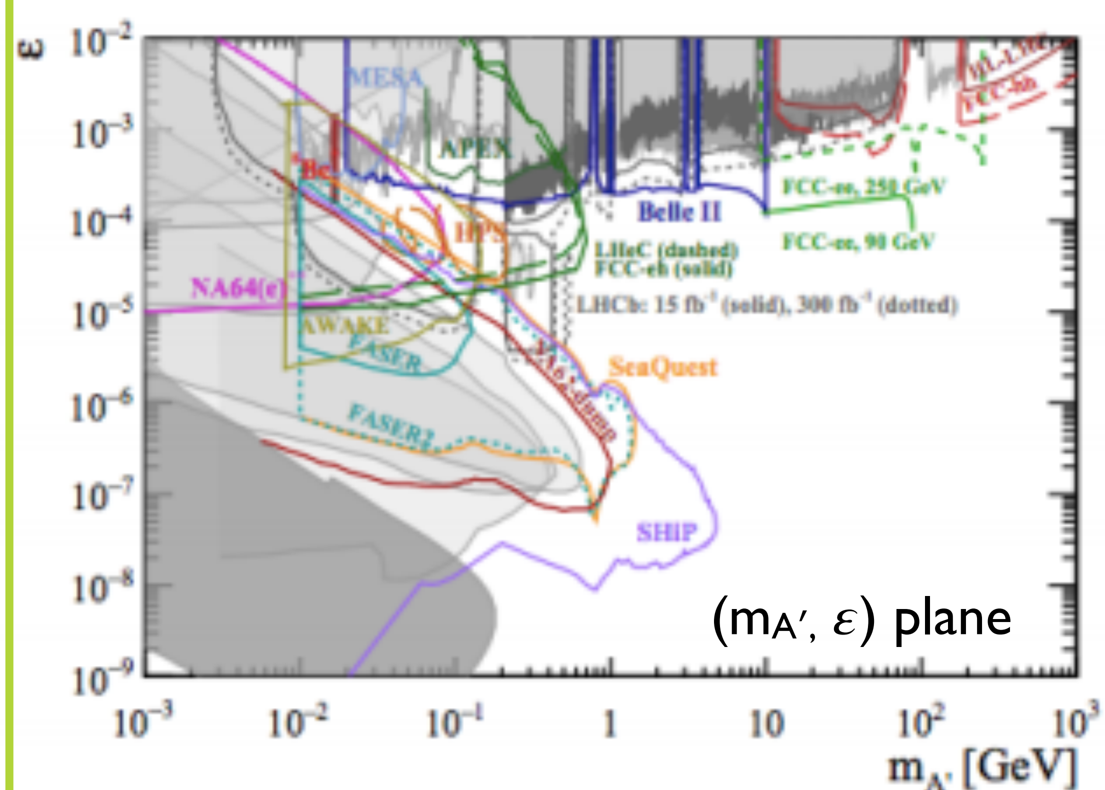
PADME *uses the* ***Missing mass technique*** *which is totally independent from the decay mode*

Looking for the Dark Photon

Experiments around the world

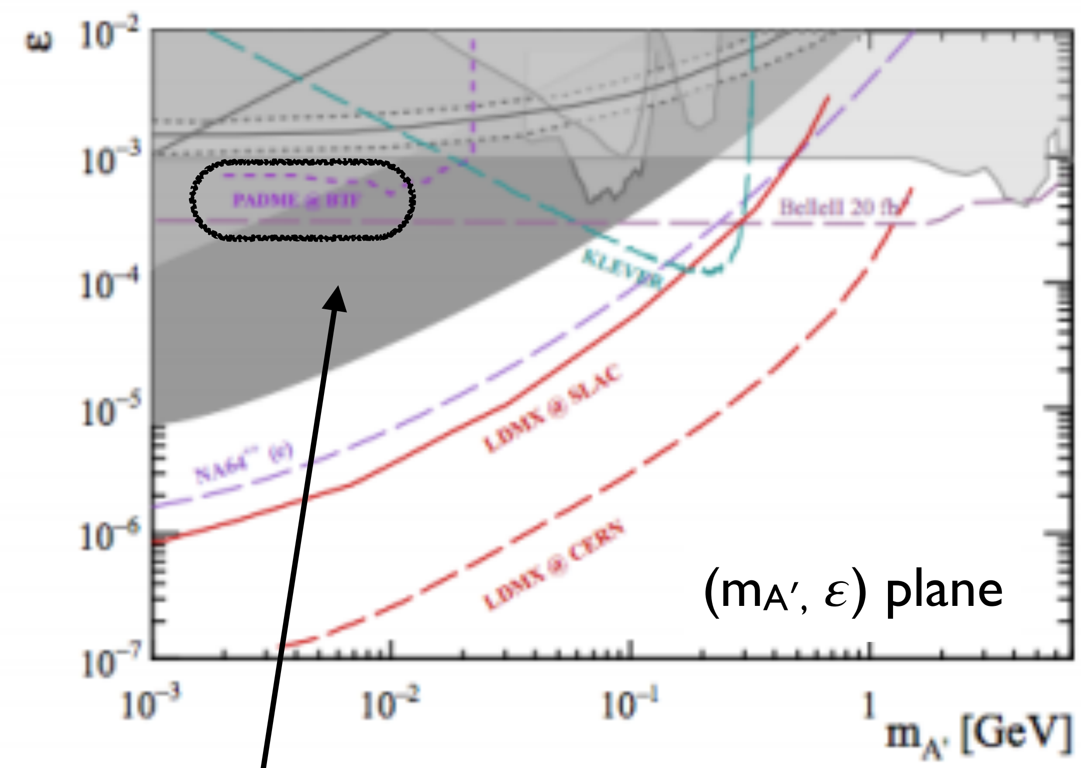
"Well, at least a characteristic of the dark photon was understood.. It is attractive!"

VISIBLE DECAY



Most of the regions excluded

INVISIBLE DECAY

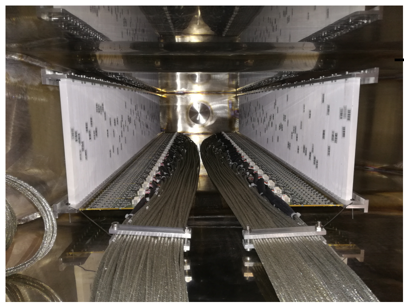


PADME is the first experiment designed and built to search for the DP in a model-independent way.

Dark photon search at PADME

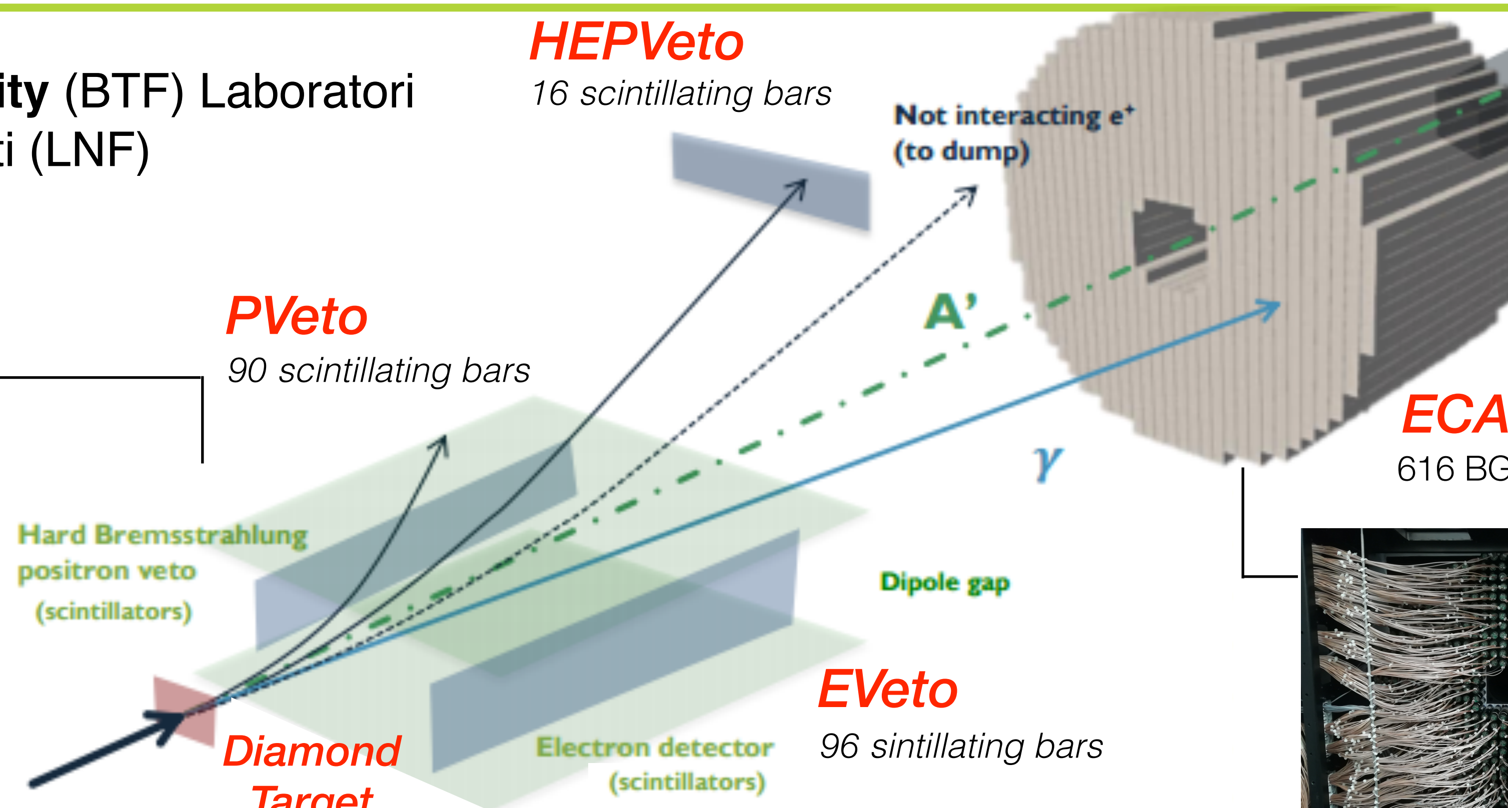
***PADME** searches for a hypothetical dark photon A' produced in the annihilation of a positron of a beam with an electron of a thin diamond target.*

@**Beam Test Facility** (BTF) Laboratori Nazionali di Frascati (LNF)

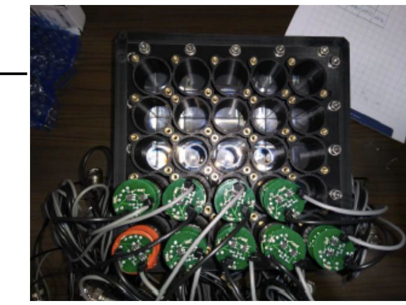


HEPVeto
16 scintillating bars

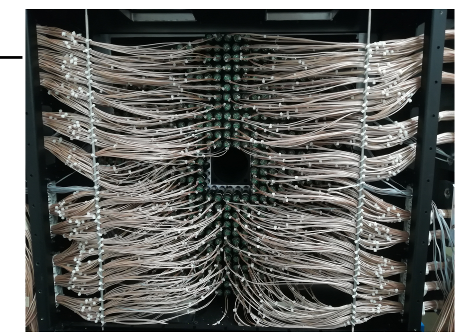
PVeto
90 scintillating bars



SAC
5x5 PbF_2 crystals

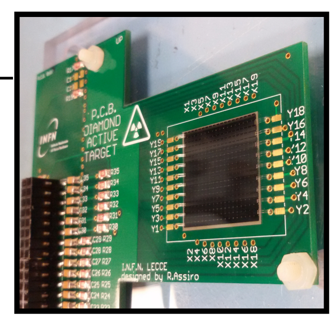


ECAL
616 BGO crystals



EVeto
96 sintillating bars

Diamond Target



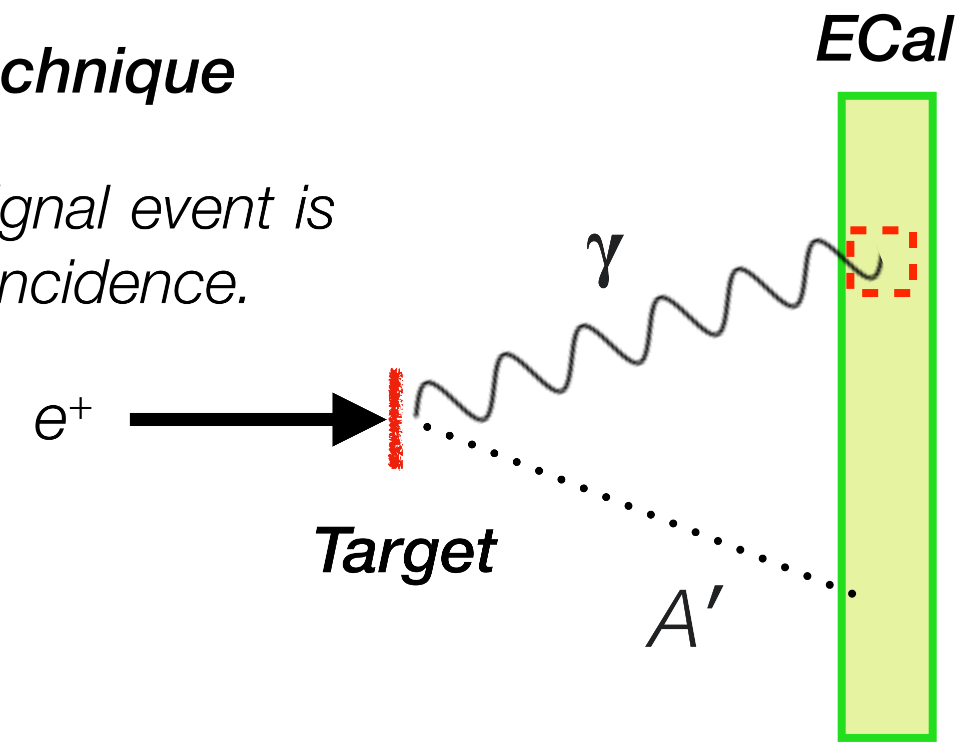
e⁺ beam from LINAC

~25k e⁺/target
Bunch length up to 300 ns
Rate 50 Hz (BTF trigger)
E_{beam} up to 550 MeV

SIGNAL	BACKGROUND
$e^+e^- \to \gamma A'$	$e^+N \to e^+N\gamma$
	$e^+e^- \to \gamma\,\gamma(\gamma)$

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

Missing mass technique



If A' is long lived or it decays in an invisible channels the signal event is represented by an ECAL cluster and nothing else in time coincidence.

Dark Photon mass computed by:

$$m^2_{A'} = (P_{beam} + P_{e-} - P_{\gamma})^2$$

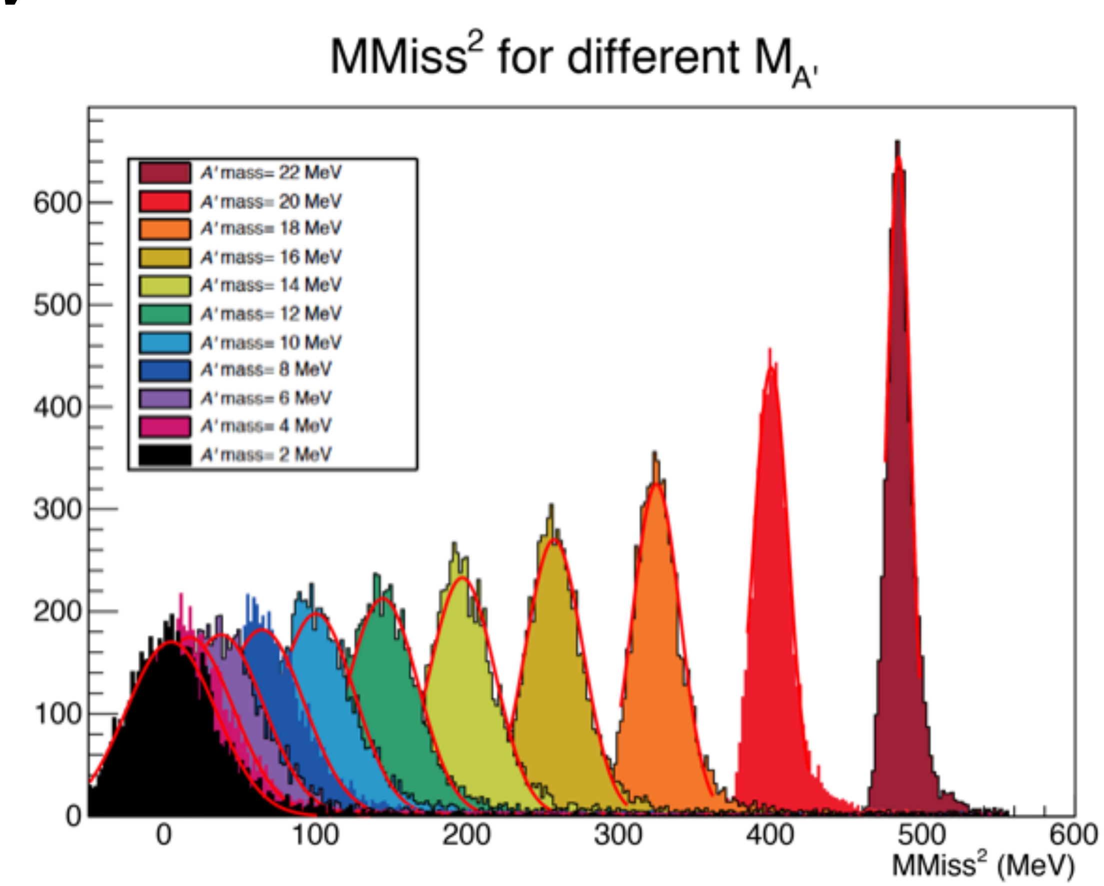
Mass upper limit related to the beam energy

$$m_{A'} = \sqrt{2 m_e E_{beam}} = 23.7\ \mathrm{MeV/c^2}$$

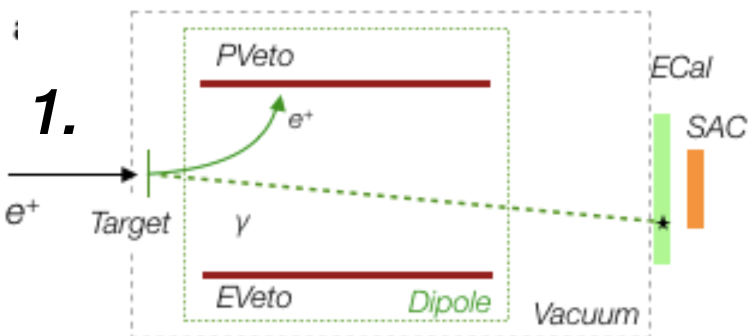
For E_{beam}=550 MeV

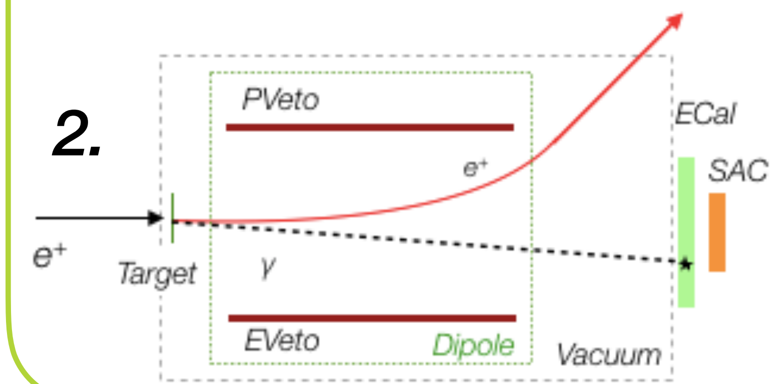
What is needed

- *Production point of the A′ on target*
- *Good measurements of the photon energy and direction*
- *Hermeticity in the azimuth angle in the forward direction*
- *Good background rejection by vetoing very forward photons and charged particles*



Bremsstrahlung





$e^+N \rightarrow e^+N\gamma$ **Bremsstrahlung on the active diamond target**

Target in diamond

Low Z improves Signal/Background (~1/Z)

1. **Background suppression**

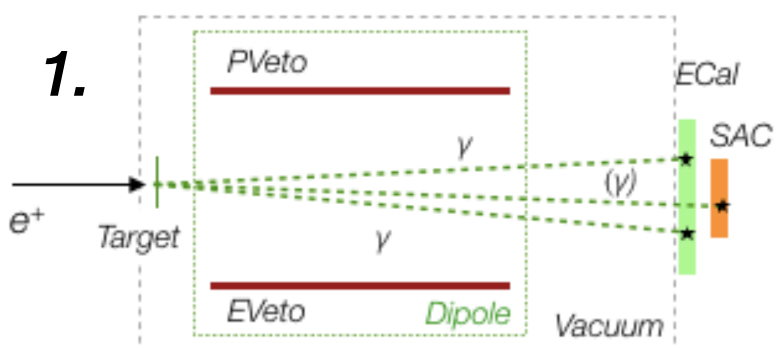
   e^+ in veto +γ in ECal in time with $E_{e+}+E_\gamma = E_{beam}$

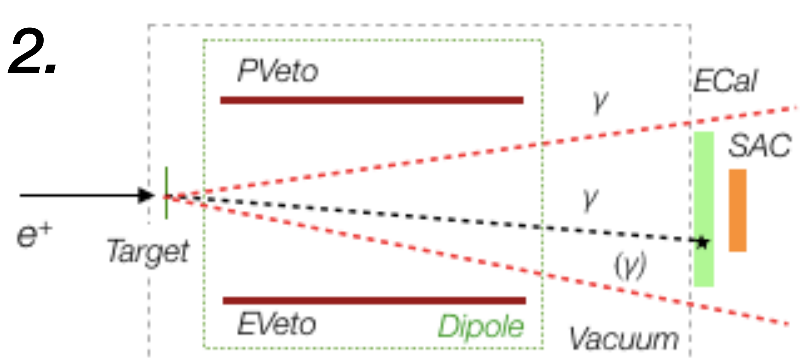
   Bremsstrahlung events are rejected by detecting the slowed down positron in time with the photon

2. **Background of the dark photon signal**

   A single photon in γ in ECal produced by Bremsstrahlung and a positron emitted out of the veto acceptance

Annihilation





$e^+e^- \rightarrow \gamma\,\gamma(\gamma)$ **Annihilation into 2(or 3) SM photons**

1. **Background suppression**

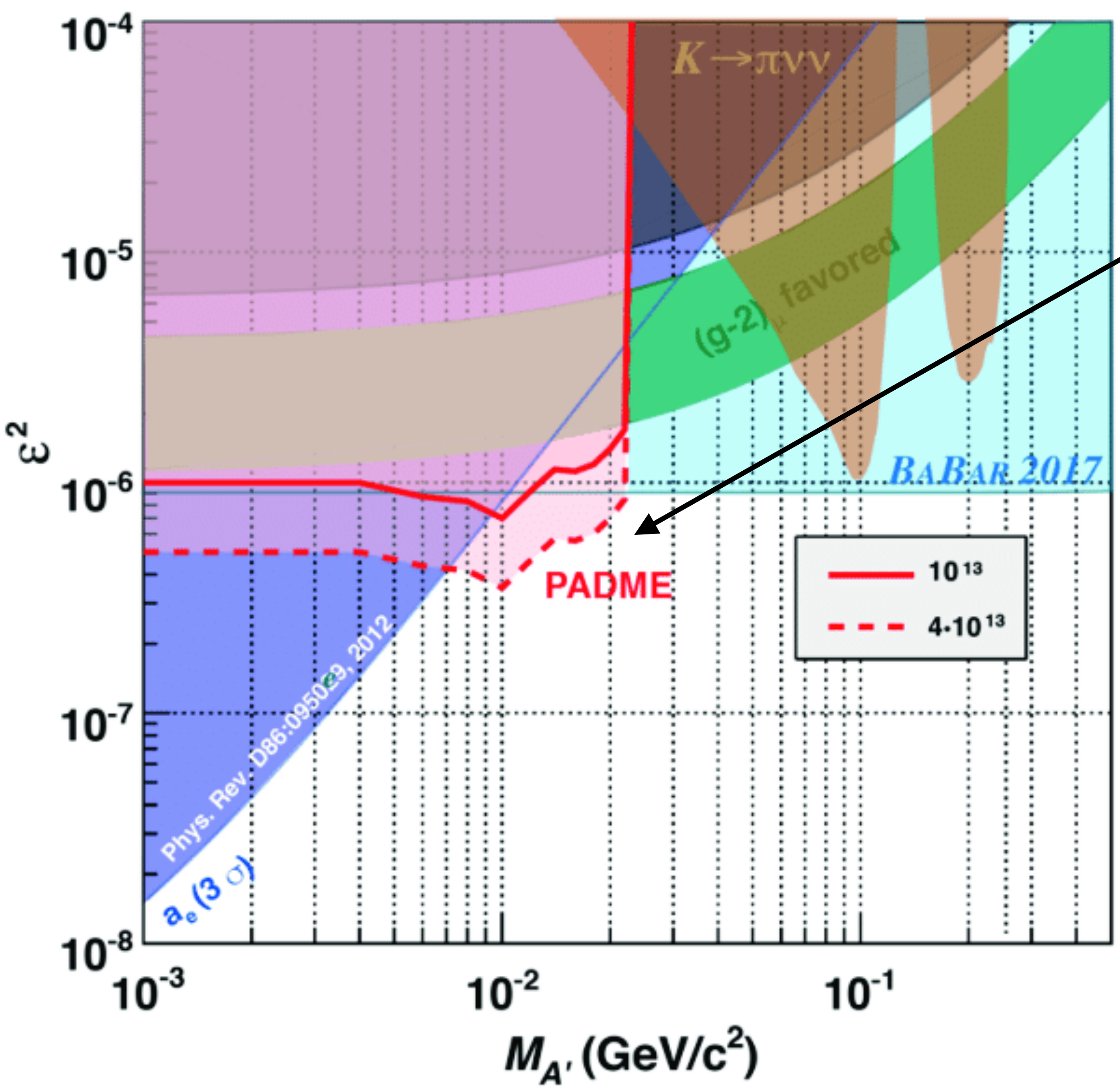
   2γ in Ecal in time with $E_1+E_2 = E_{beam}$
   For 3γ : 2γ in ECal + 1 γ in SAC in time

   Two or three photon events are rejected by
   - *Maximising the detector angular coverage*
   - *Maximising granularity*
   - *Good energy resolution*

2. **Background of the dark photon signal**

   Only a single photon in γ in ECal from annihilation

The PADME sensitivity depends by event in-bunch pile-up and beam background.



M. Raggi, "The PADME experiment", Frascati Physics Series Vol. 66 (2018)

PADME hypothetical excluded region in the parameter space of DP invisible decay for two different luminosity

10^{13} and $4\mathrm{x}10^{13}$ POT

LIMITS ON MASS AND MIXING CONSTANT

$$\frac{\sigma(e^+e^- \to \gamma A')}{\sigma(e^+e^- \to \gamma\gamma)} = \frac{N(A'\gamma)}{N(\gamma\gamma)} \frac{Acc(\gamma\gamma)}{Acc(A'\gamma)} = \epsilon^2 \delta(m_{A'})$$

$m_{A'} \leq 23.7$ MeV/c^2, $\varepsilon > 10^{-3}$

The dark photon mass in the range 10-100 MeV and $\varepsilon < 10^{-3}$ could account for the discrepancy between the measured and the theoretical value of the anomalous magnetic momentum of the muon!

Detector fully installed September 2018

RUN 1

OLD BEAM LINE

Secondary positron beam

(positrons produced in the interactions of the electron beam in a Cu, target placed before the entrance of the BTF hall)

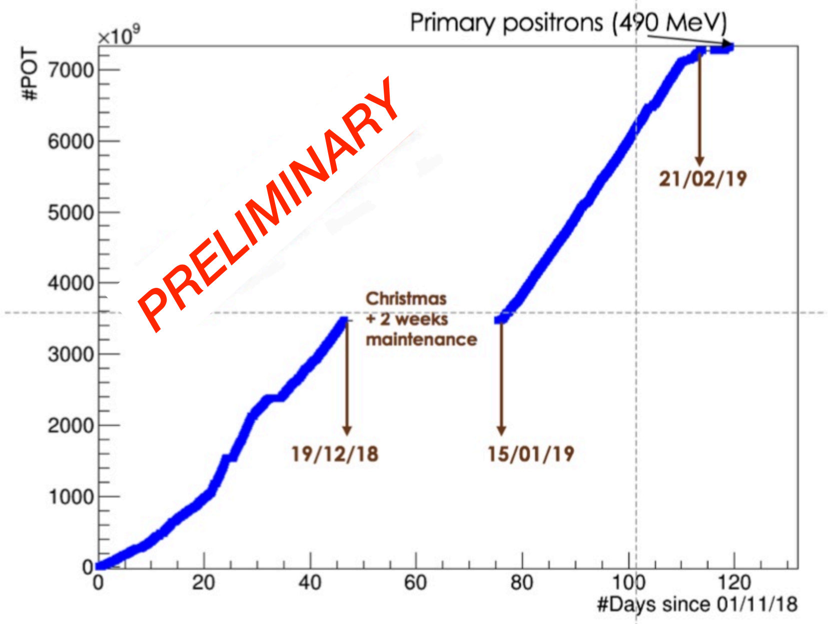
Commissioning Run from 15th Sept 2018
Data taking from October 2018 to 21st Feb 2019

Primary positron beam ***(Lower BG)***

(positrons directly produced in the LINAC thanks to a W-Re positron converter placed just after the production point of the electrons)

Data taking from 21st Feb 2019 to the beginning of March
Data taking July 2019

Number of positrons collected



RUN 2 ***September-December 2020***

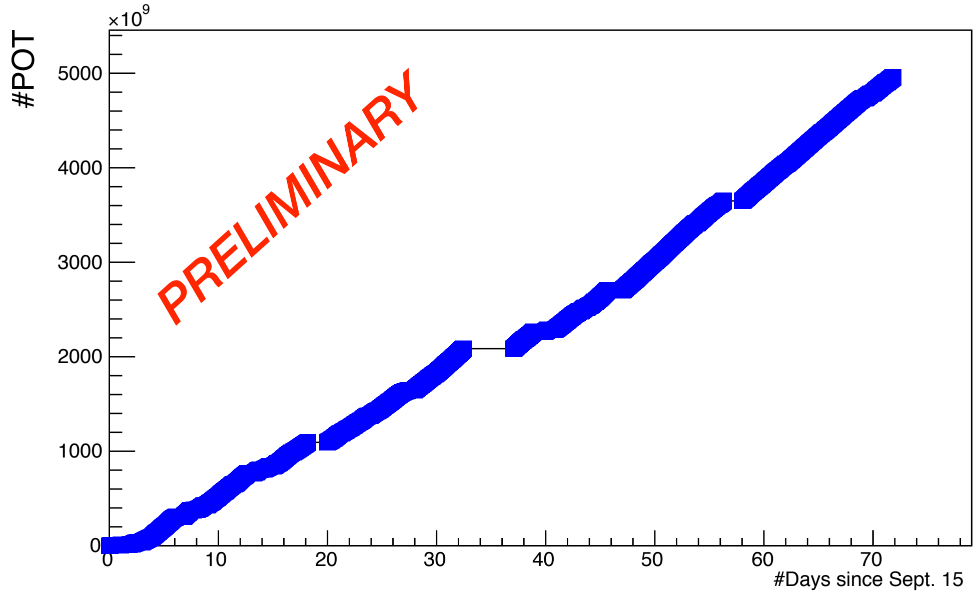
NEW BEAM LINE

Primary positron beam

Commissioning Run July 2020
Hardware intervention in Sep 2020
Data taking from Sept 2020 to 2nd December 2020

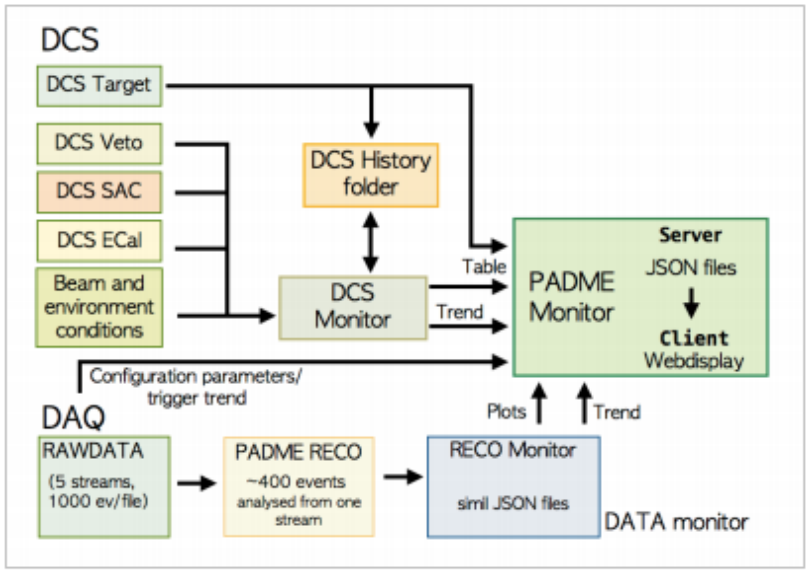
Analysis on going!

Number of positrons collected

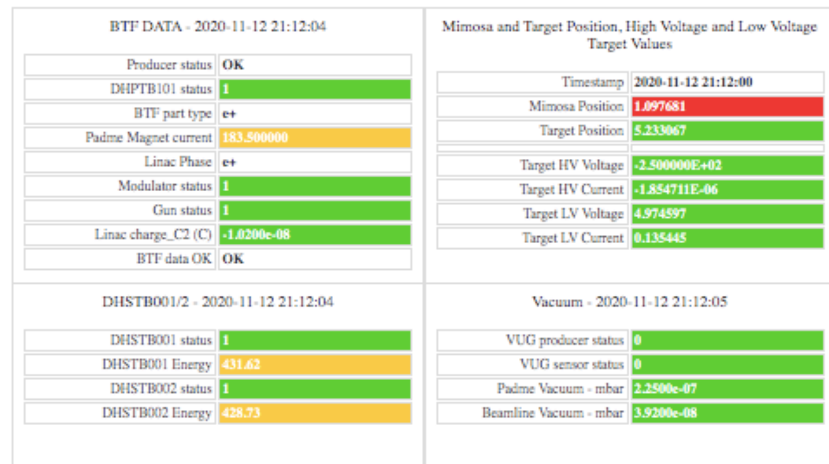


PADME DCS and monitoring

A reliable Detector Control System (DCS), together with a detailed on-line monitoring, were essential tools for the data taking.

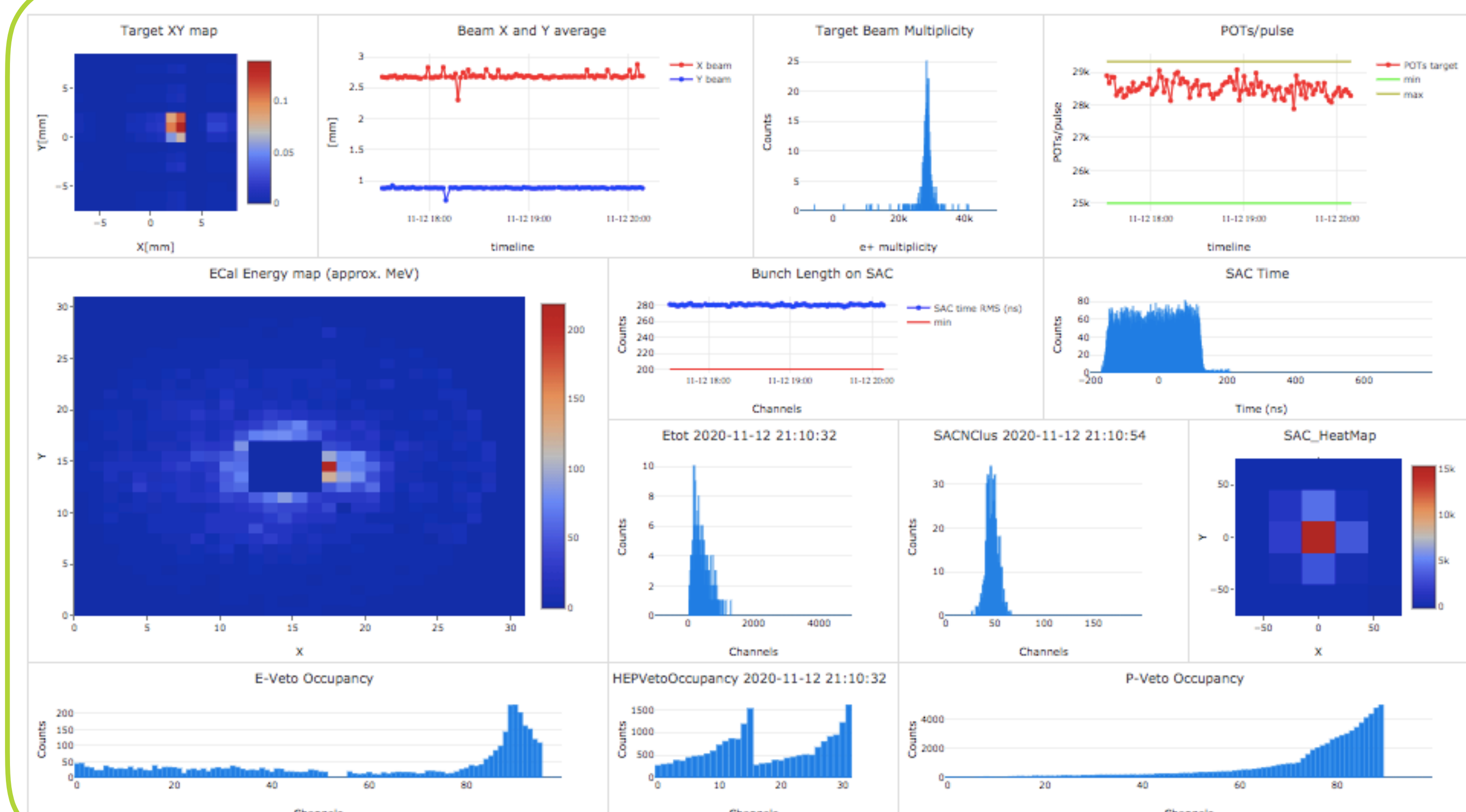


DCS monitor



Beam status, environmental conditions of the experimental hall, the vacuum, the target detectors, the data acquisition and the trigger, are displayed in this page.

Data on-line monitor



Major requirements during the run:

a small spot on target and a high beam intensity (positrons on target>20k)

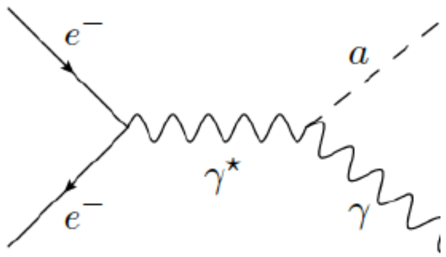
Bunch length >150 ns

Flat structure in time of the beam

Possible future searches

Axion Like Particle

possible pseudo-scalar spin-0 mediator between the Standard Model and the Dark Sector

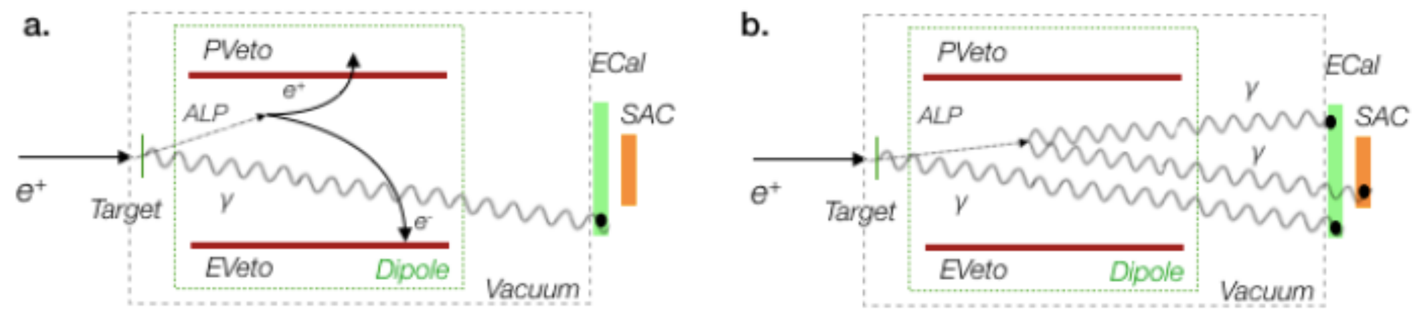


Supposing $g_{a\gamma\gamma} = g_{aee}$ the s channel is dominant for low alp mass values

VISIBLE ALP DECAY

$a \rightarrow e^+e^-$ or $a \rightarrow \gamma\gamma$

PADME accessible final states: $\gamma\, e^+e^-$ or $\gamma\gamma\gamma$



INVISIBLE ALP DECAY

final state: γ + missing mass → *The selection applied for the Dark Photon can work also for ALP search!*

DARK HIGGS

the dark photon can acquire mass through a Higgs-like mechanism, which supposes the existence of a dark Higgs

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

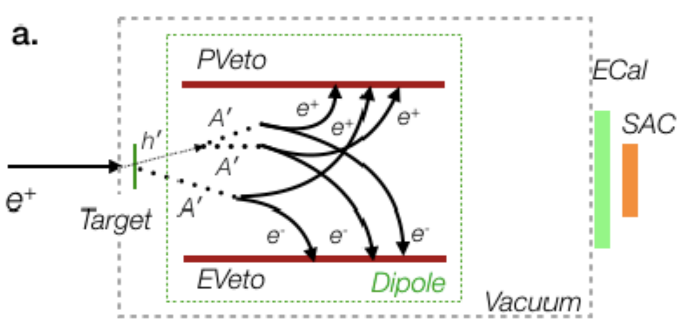
Assuming A′ decays in visible leptons

PADME accessible final states

If $m_{h'} > 2\, m_{A'}$

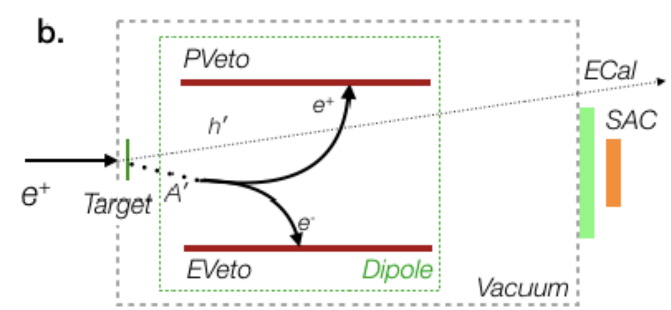
Visible h′ DECAY

$e^+e^- \rightarrow A'h' \rightarrow A'A'A' \rightarrow 3\,(e^+e^-)$



Invisible h′ DECAY

$e^+e^- \rightarrow A'h' \rightarrow e^+e^- +$ *missing mass*



Other scenario

Protophobic X boson

Signal anomaly in excited ^{8}Be and ^{4}He atomic transitions[1,2]

PADME could search for a hadrophobic dark boson with mass of 17 MeV/c^2

beam energy set at 282.7 MeV

Reported also in the article ***https://arxiv.org/pdf/1910.10459.pdf***

New evidence supporting the existence of the hypothetic X17 particle

[..] Nardi and coauthors suggested the resonant production of X17 in positron beam dump experiments. They explored the foreseeable sensitivity of the Frascati PADME experiment in searching with this technique for the X17 boson invoked to explain the 8Be anomaly in nuclear transitions.

The PADME experimental setup could be upgraded to investigate this scenario.

New studies needed to optimise the detector performance, in particular on:

- Resonance width
- Searching a suitable target (higher thickness)
- Increasing multiplicity

Possible future opportunity for PADME

[1] *Krasznahorkay, A. J. et al. "Observation of Anomalous Internal Pair Creation in ^{8}Be. A Possible Indication of a Light, Neutral Boson.", arXiv:1504.01527 (2016);*
[2] *A. J. Krasznahorkay et. al., "New evidence supporting the existence of the hypothetic X17 particle", arXiv:1910.10459 (2019)*

Conclusions

- *PADME was designed and built to search for dark photon with the missing mass technique, independent from the dark photon decay modes*

- *PADME commissioning was successful. The DATA taken helped to understand the background of the experiment.*

- *RUN1 and RUN2 acquired. The upgrade of the beamline in Run2 helped to reduce the beam background. The data analysis is ongoing*

- *Be careful..Dark photon is not the only new particle accessible to PADME!*

ALP, Dark Higgs..

The Dark Photon hunt has just begun

Stay tuned

Let's turn the DARK on!

BACKUP

DARK MATTER - Cosmological evidences

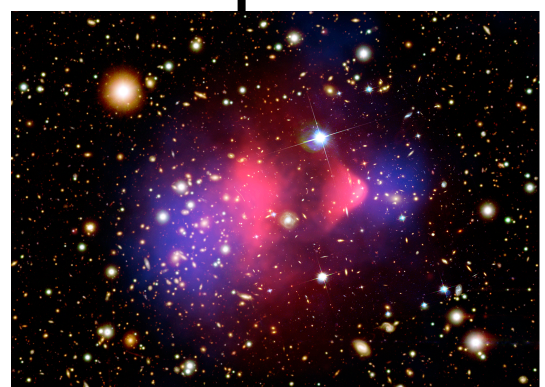
Zwicky

The first who applied the virial theorem to galaxies observations. Disagreement between the theoretical calculation of the dispersion velocity of the famous ***Coma Cluster*** *and its measurement*

Coma cluster anomaly

Other indirect proofs..

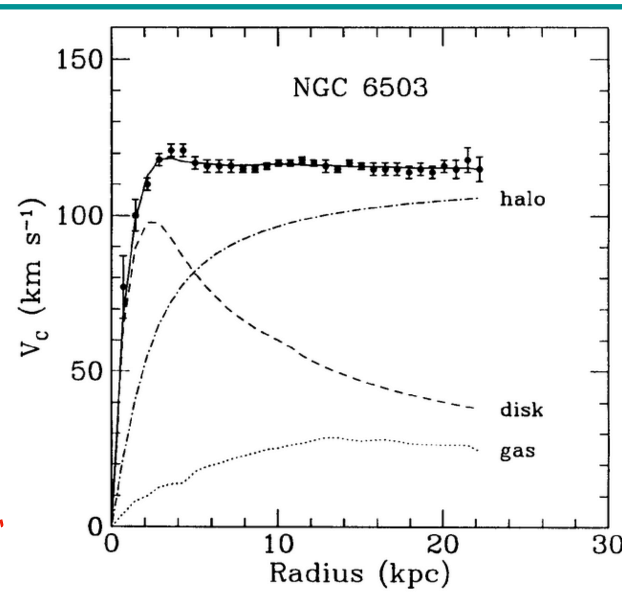
Gravitational lensing, ***bullet cluster****, X-ray emission of hot gas in clusters, fluctuations in the Cosmic Microwave Background Radiation*



1930s — 1970s — Today — t

Study of the galaxy velocity rotation problem

Rubin

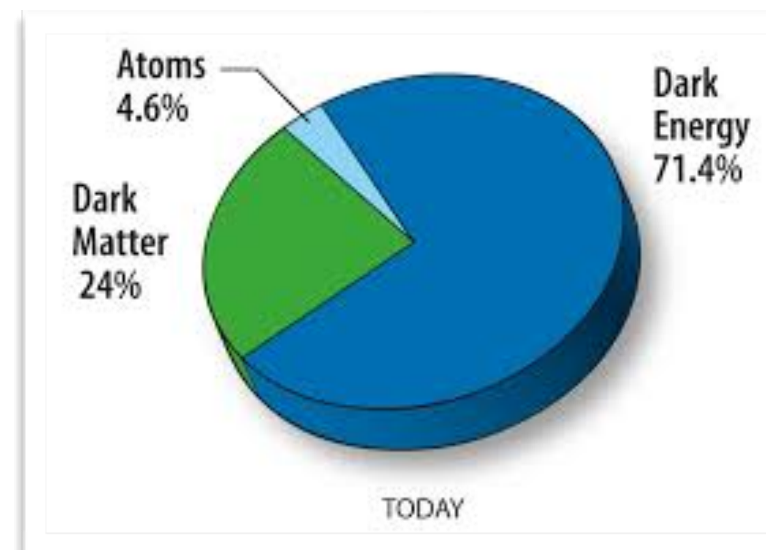


..Only supposing the existence of a halo made of invisible matter, the agreement with data is reached.

Dark matter was brought to light!

DARK..

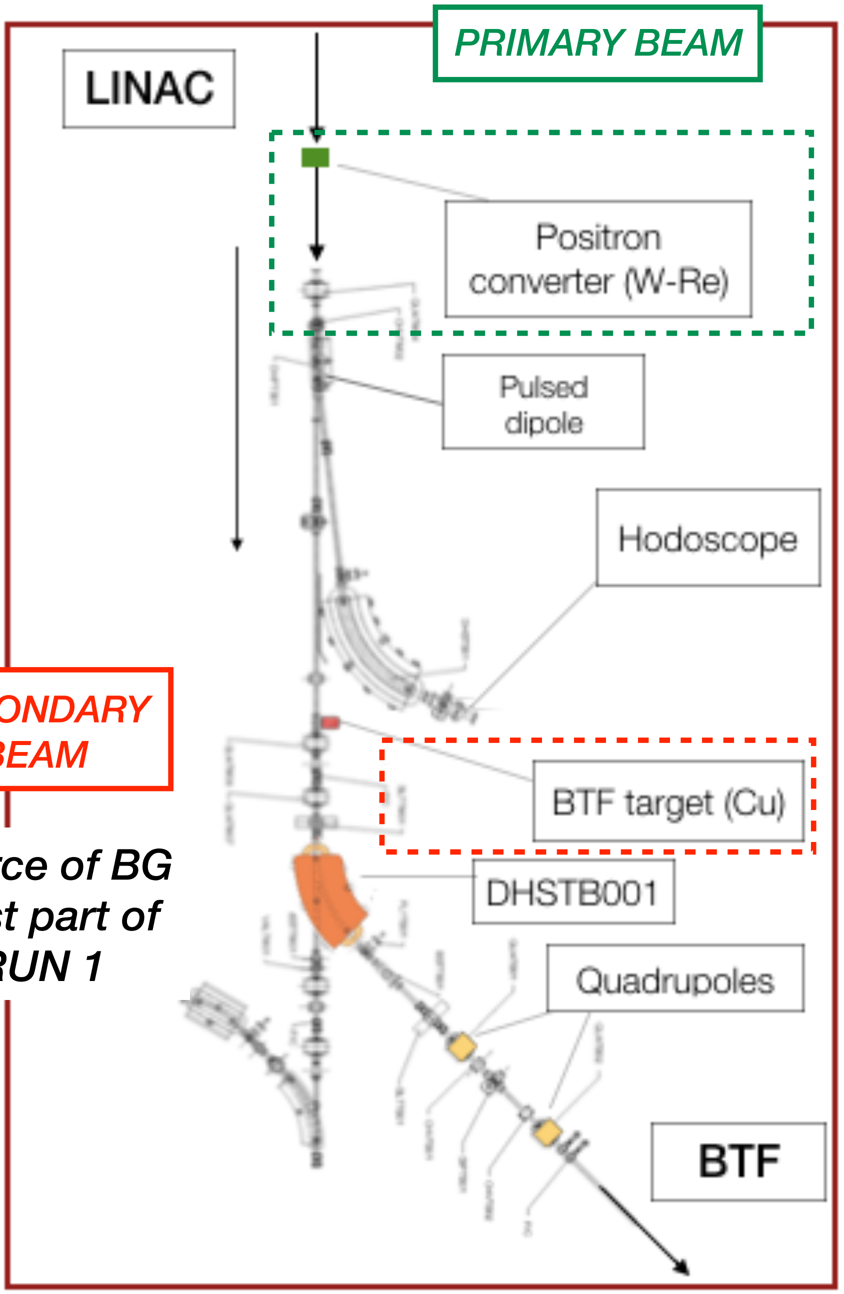
Why does it matter?



..dancing in the dark

Standard Model is not enough!

Primary & Secondary beam



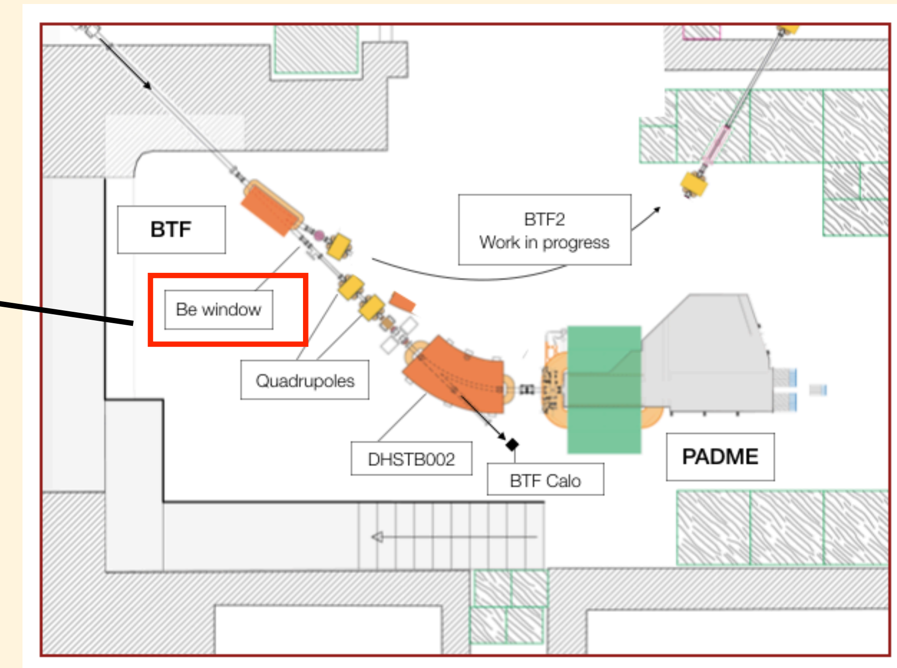
SECONDARY BEAM

Source of BG in1st part of RUN 1

Beam Line RUN 1 (until July 2019)

Vacuum separator LINAC-PADME

Be window 250 μm



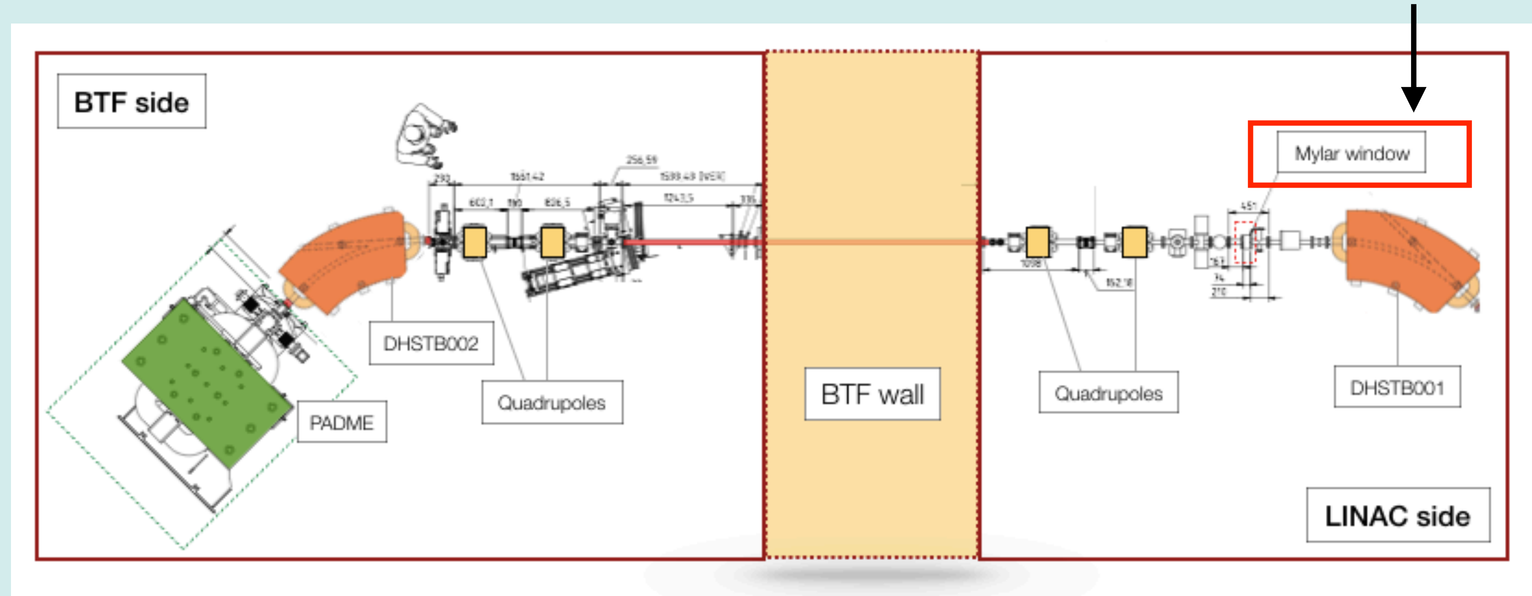
Source of BG in RUN 1

New Beam Line RUN 2

New beam pipe with a larger cross section
New collimators were introduced

Vacuum separator LINAC-PADME

Mylar window 125 μm



Dark matter and dark photon

Let's FOCUS on the Dark Photon massive case

- *The Stueckelberg mechanism is a minimal scenario with a massive A′*
- *A′ can acquire mass through a Higgs mechanism that foreseen the existence of a dark Higgs*