ICNFP 2020

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEL SALENTO

PADME

The Physics program of the PADME Experiment

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on behalf of the PADME collaboration

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9th International Conference on New Frontiers in Physics (ICNFP 2020)

4-12 September 2020 Creta, Greece

Outline

- Dark Matter cosmological evidences
- Dark Sector
- Dark Photon
- Dark photon search in Frascati with PADME
    - Experimental Technique
    - Signature
    - Background
    - Schedule
- Additional dark sector searches at PADME

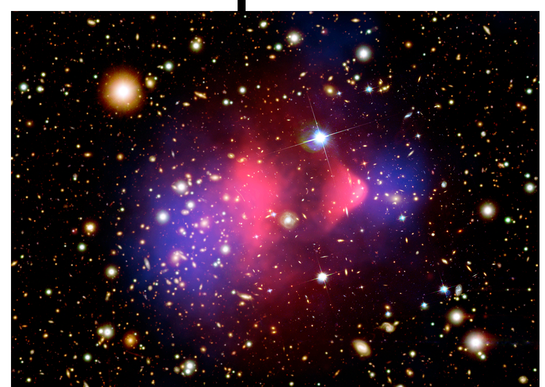
DARK MATTER - Cosmological evidences

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..

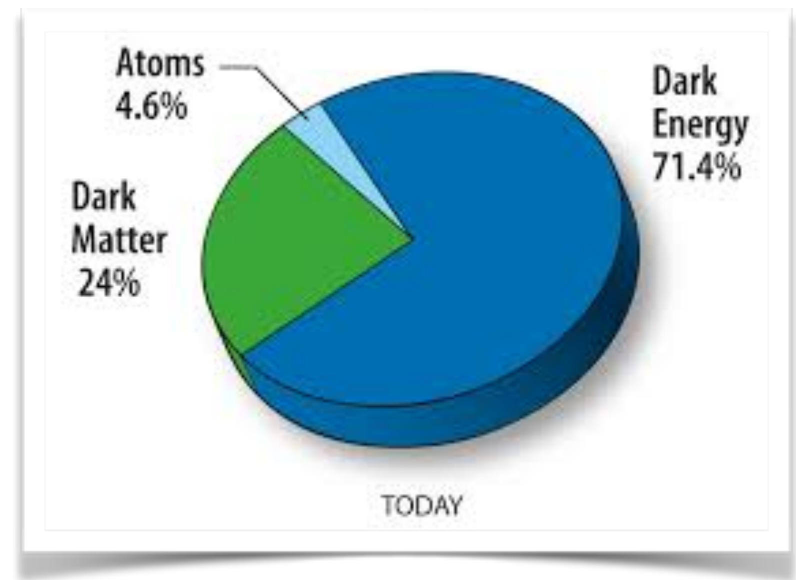
Gravitational lensing, bullet cluster, X-ray emission of hot gas in clusters, fluctuations in the Cosmic Microwave Background Radiation



1930s — 1970s — Today — t

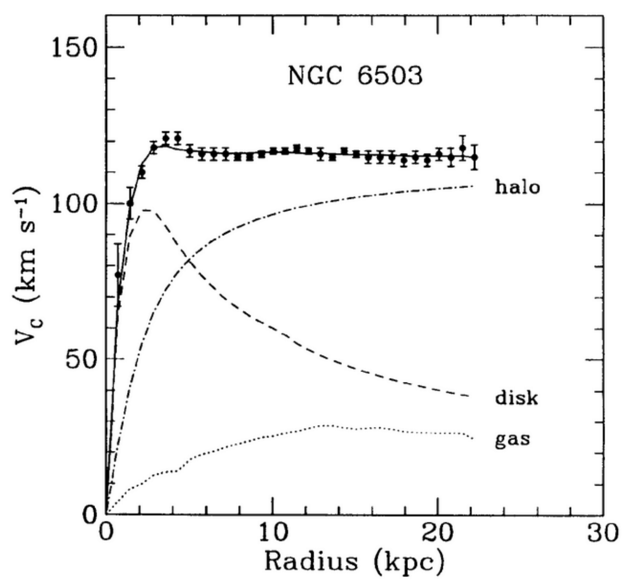
DARK..

Why does it matter?



..dancing in the dark

Study of the galaxy velocity rotation problem



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

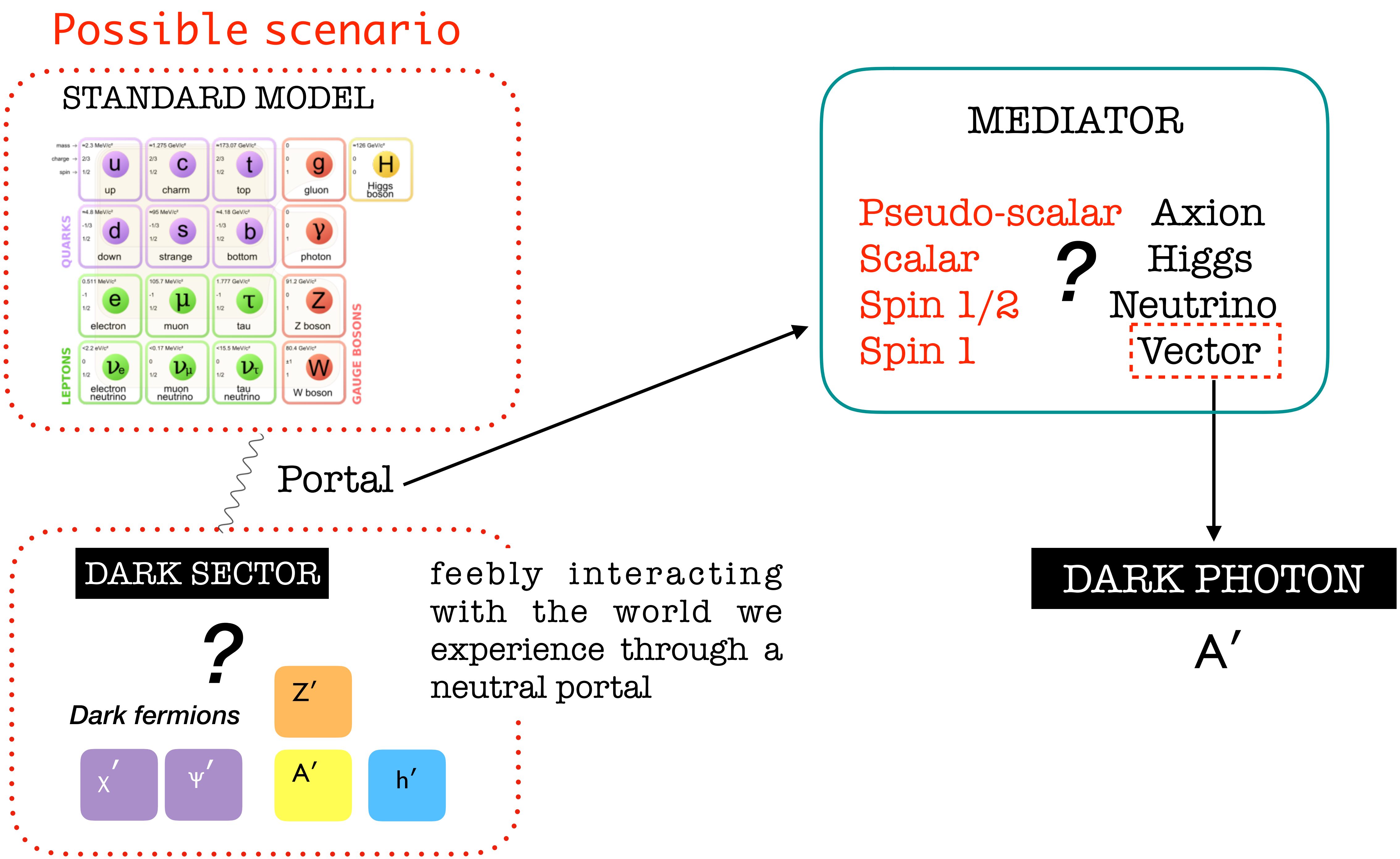
Dark matter was brought to light!

Standard Model is not enough!

DARK SECTOR

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 motivation to go beyond the SM.



DARK PHOTON

One of the simplest model of dark sector is the one that 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 the kinetic mixing term in the lagrangian:

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

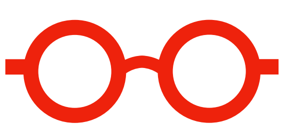
A low value of the mixing parameter $\varepsilon < 10^{-3}$ could justify the lack of experimental evidence for such scenario so far.

The dark photon could be either **massless** or **massive**.

↓

Two possibilities considered

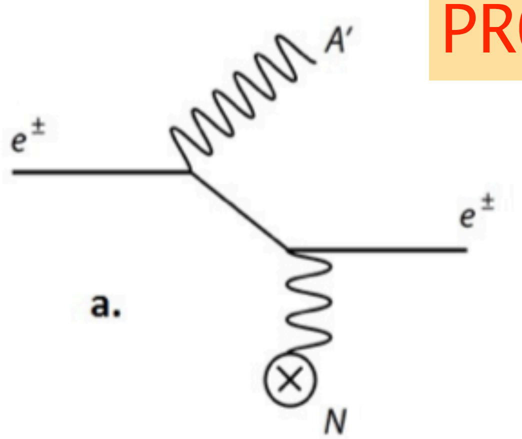
- The Stueckelberg mechanism is a minimal scenario with a massive A′
- A′ can acquire mass through a Higgs mechanism that foreseen the existence of a dark Higgs



Let's FOCUS on the massive case

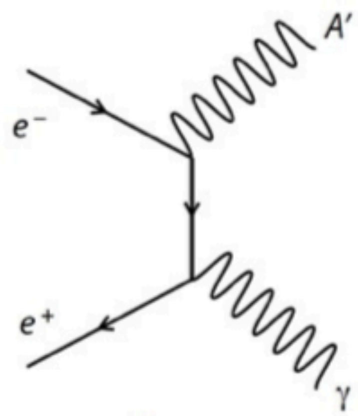
DP PRODUCTION AND DECAY

PRODUCTION



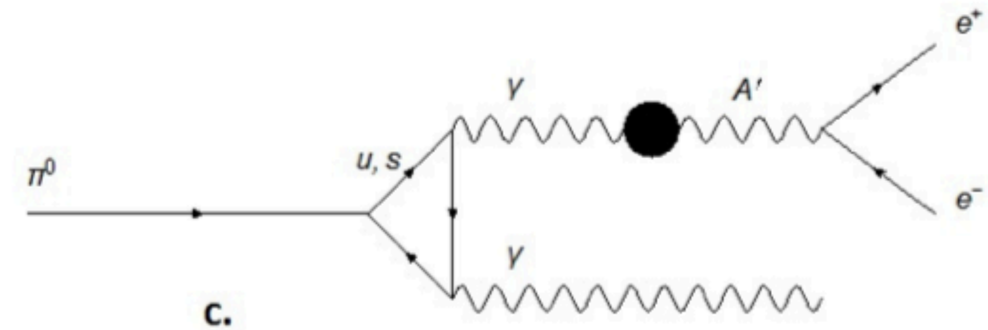
a.

A'-strahlung



b.

e+e- annihilations



c.

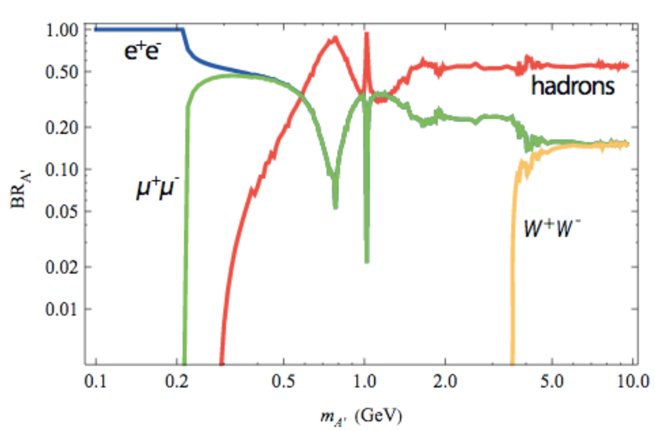
meson decays

DECAY

Visible decay

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

A' → SM
A' → SM



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

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

Invisible decay

boo!

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

A' → χ
A' → χ

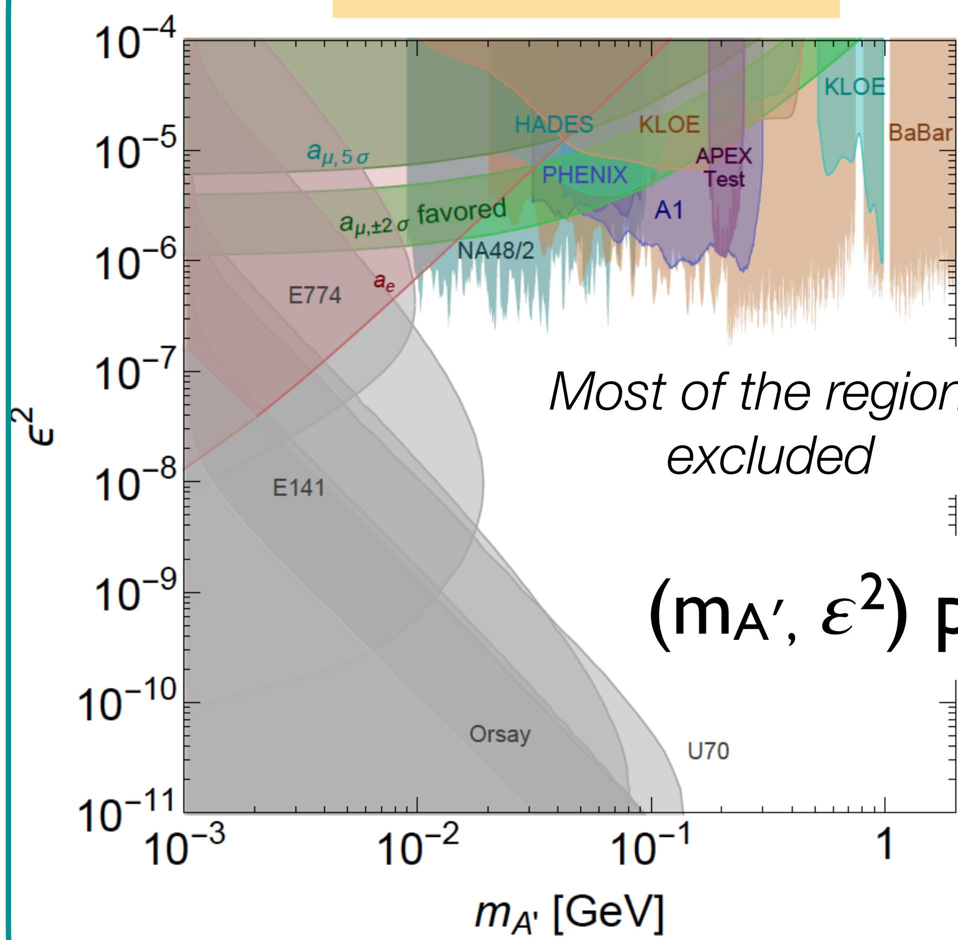
PADME uses the **Missing mass technique** which is totally independent from the decay mode

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

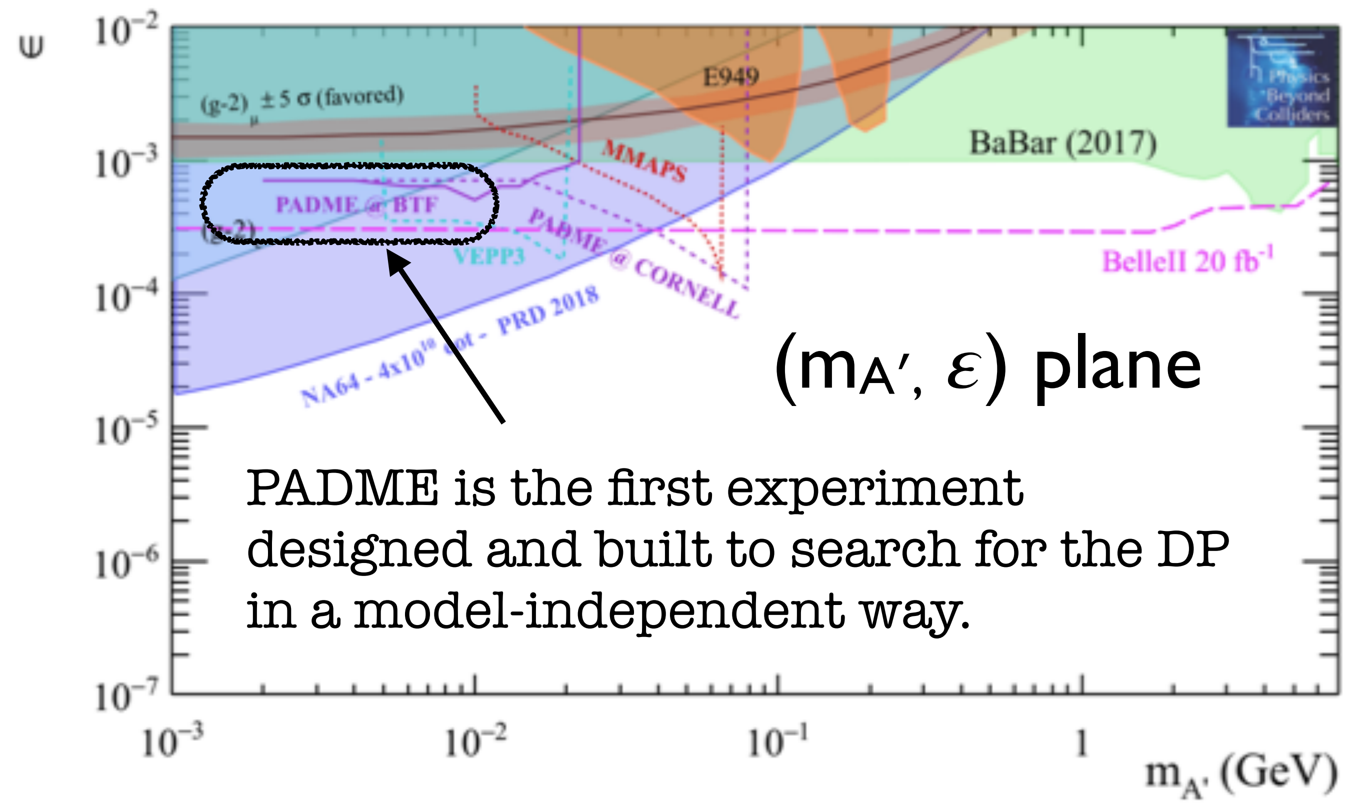


Most of the regions excluded

$(m_{A'}, \varepsilon^2)$ plane

M.Raggi and V..Kozhuharov, "Results and perspectives in dark photon physics", Riv.Nuovo Cim. 38, n.10, pp. 449-505 (2015)

INVISIBLE DECAY



$(m_{A'}, \varepsilon)$ plane

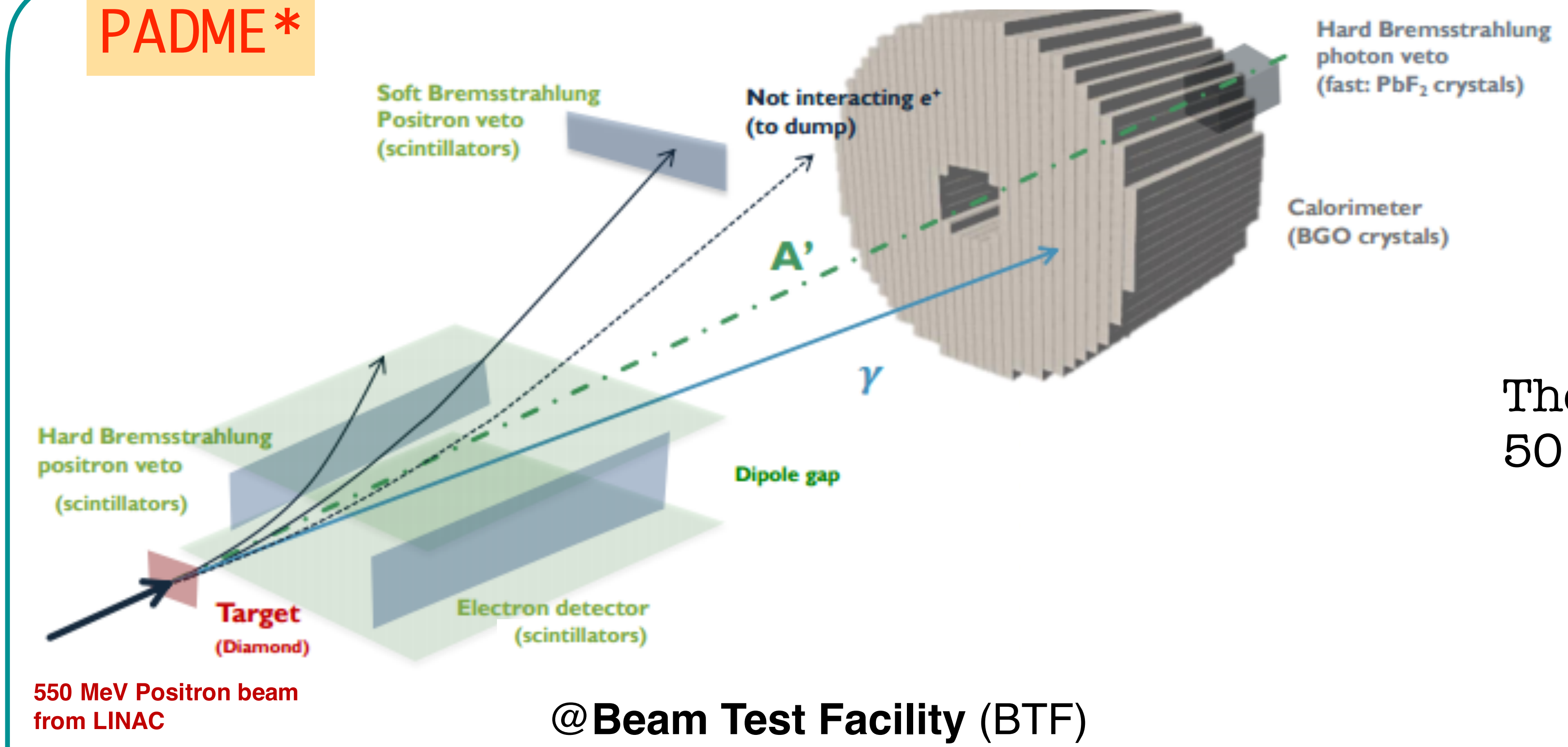
PADME is the first experiment designed and built to search for the DP in a model-independent way.

Beacham, J et al. "Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report." Journal of Physics G: Nuclear and Particle Physics 47.1 (2019)

DP 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.

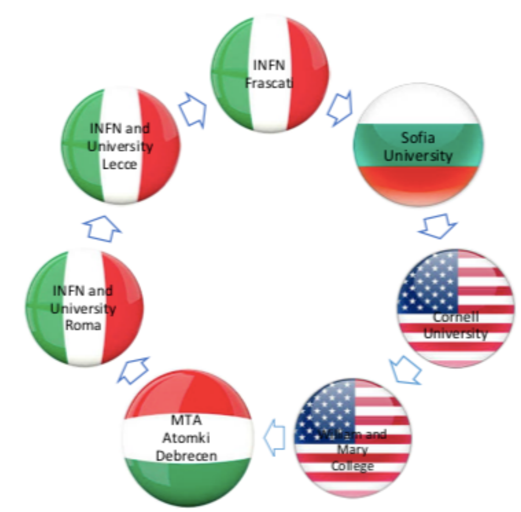
PADME*



- Bunch of 20k e^+
- Bunch length ~250 ns
- Rate 50 Hz (BTF trigger)
- E_{beam} = 490 MeV, up to 550 MeV

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

The collaboration involves 50 physicists from 7 institutions



**For more details on the detector see C.Taruggi's talk*

SIGNAL

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

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

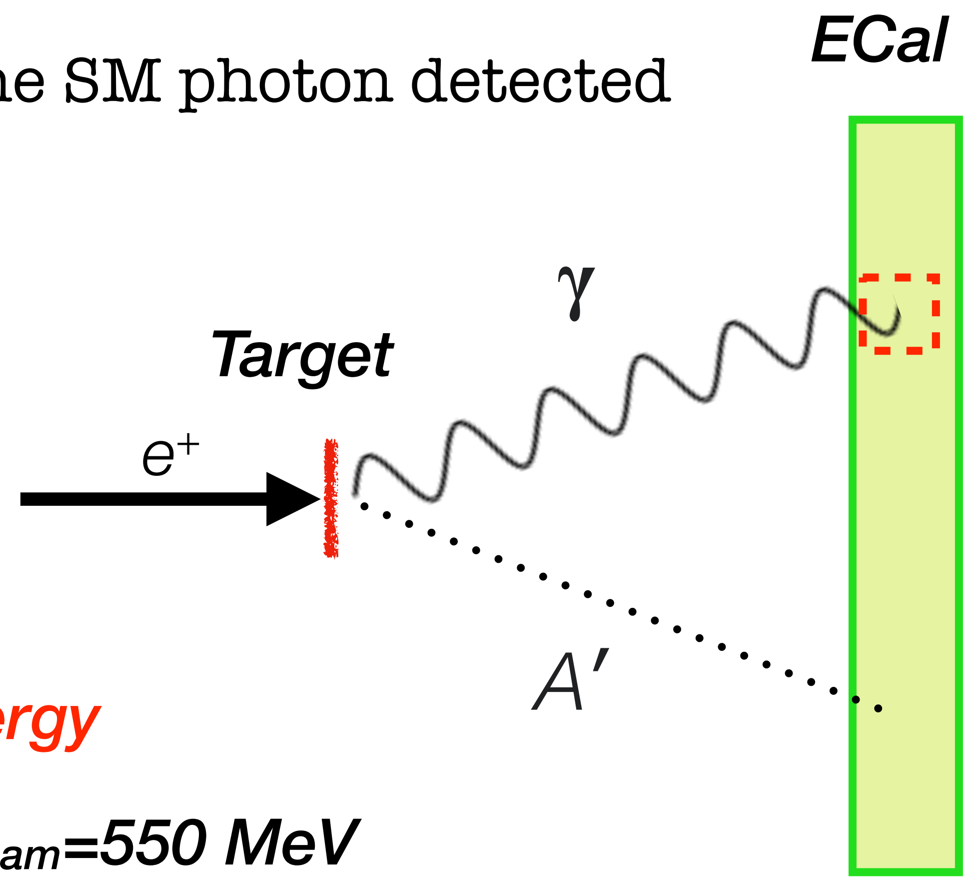
BACKGROUND

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

$e^+N \rightarrow e^+N\gamma$ — Bremsstrahlung on the target

PADME SIGNATURE

SIGNAL $e^+e^- \to \gamma A'$ Only the SM photon detected



Dark Photon mass computed by:

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

Mass upper limit related to the beam energy

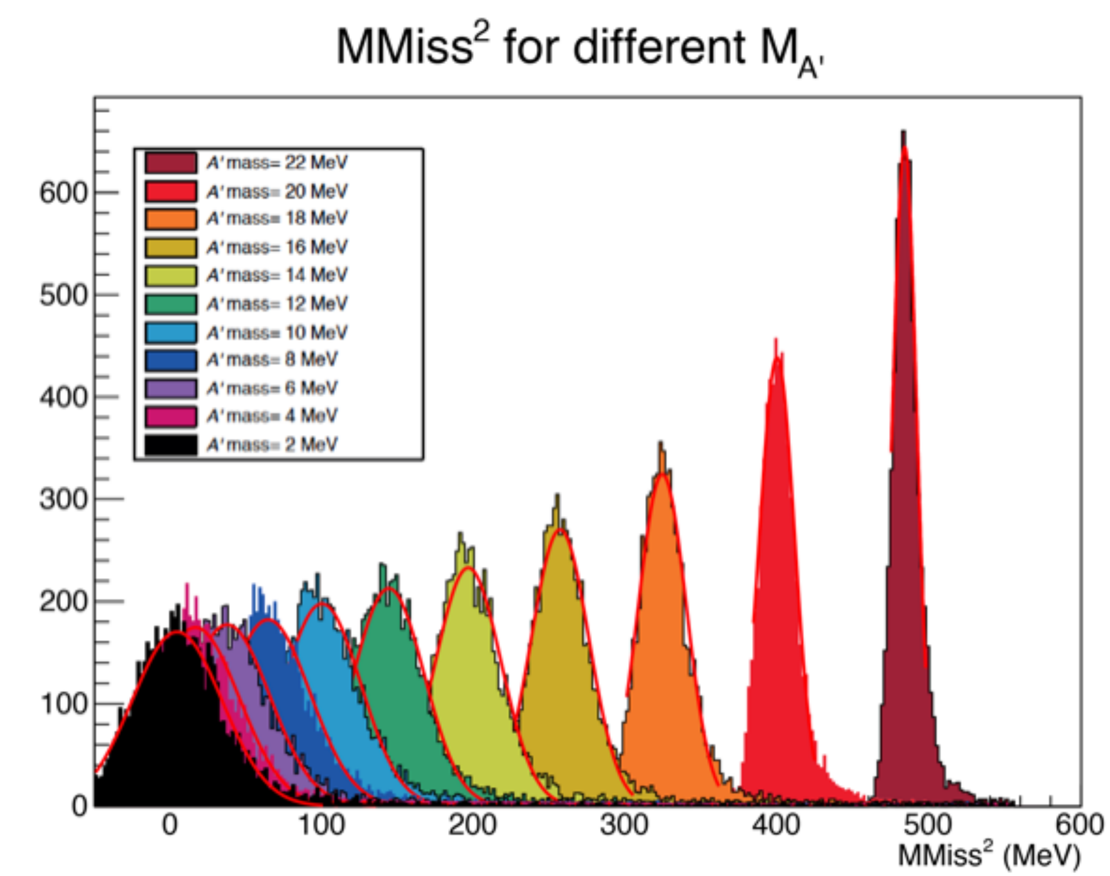
$$m_{A'} = \sqrt{2 m_e E_{beam}} = 23.7\ \mathrm{MeV/c^2}$$

For E_{beam}=550 MeV

"Is getting dark, too dark to see.."

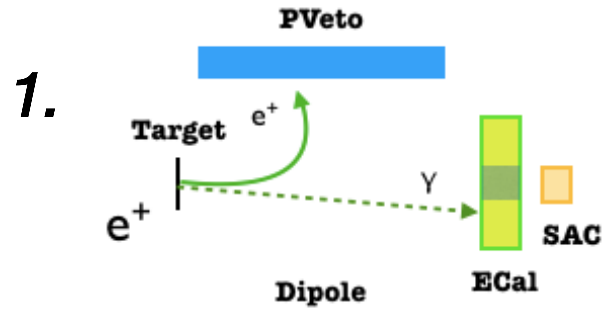
What is needed

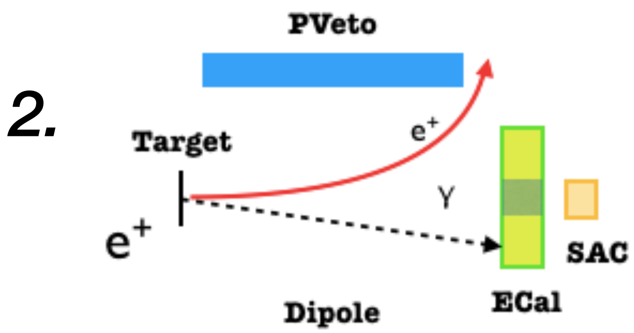
- Production point of the A′ on target
- Good measurements of the photon energy and direction
- Hermeticity in the azimuth angle in the forward direction
- Good background rejection by vetoing very forward photons and charged particles



PADME background

Bremsstrahlung





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

1. **Background suppression**

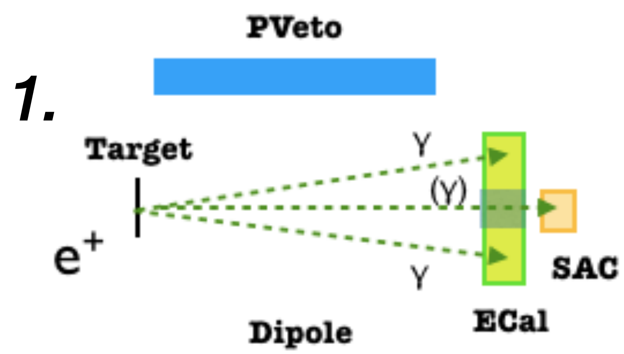
   e^+ in veto $+\gamma$ in ECal in time with $E_{e+}+E_\gamma = E_{beam}$

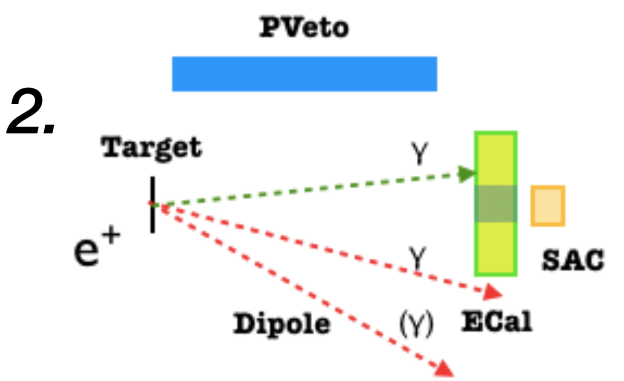
   Bremsstrahlung events are rejected by
   - Detecting the slowed down positron in time with the photon

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

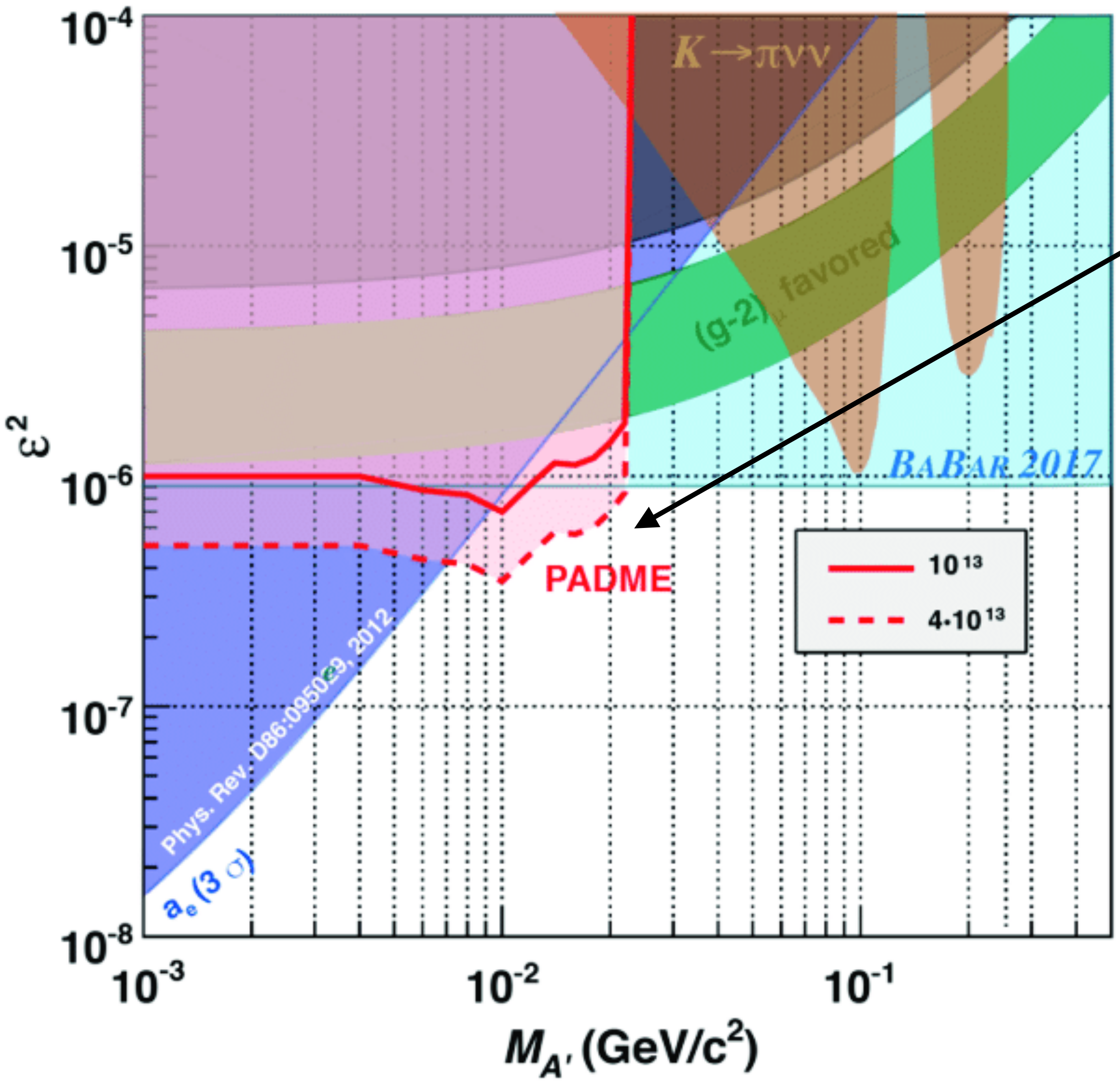
   Two or three photon events are rejected by
   - Maximising the detector angular coverage
   - Maximising granularity
   - Good energy resolution

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

   Only a single photon in γ in ECal from annihilation

PADME SENSITIVITY

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 $4\text{x}10^{13}$ 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!

PADME SCHEDULE

Detector fully installed
September 2018

RUN1 Oct.2018-Feb2019 + July 2019 + July 2020
RUN2 work in progress

Oct. 2018	Feb 2019	July 2019	May 2020	July 2020	Autumn 2020

RUN1

Secondary beam

Beam and background studies

Switch to primary beam

Primary beam

reduced background with primary beam

Beam Commissioning Run (2 weeks)

Primary beam

Beam and background studies

Beam Commissioning Run (2 weeks)

Primary beam

Beam and background studies

Upgraded beamline

Due to CoVid delay

RUN2

Primary beam with the upgraded beamline

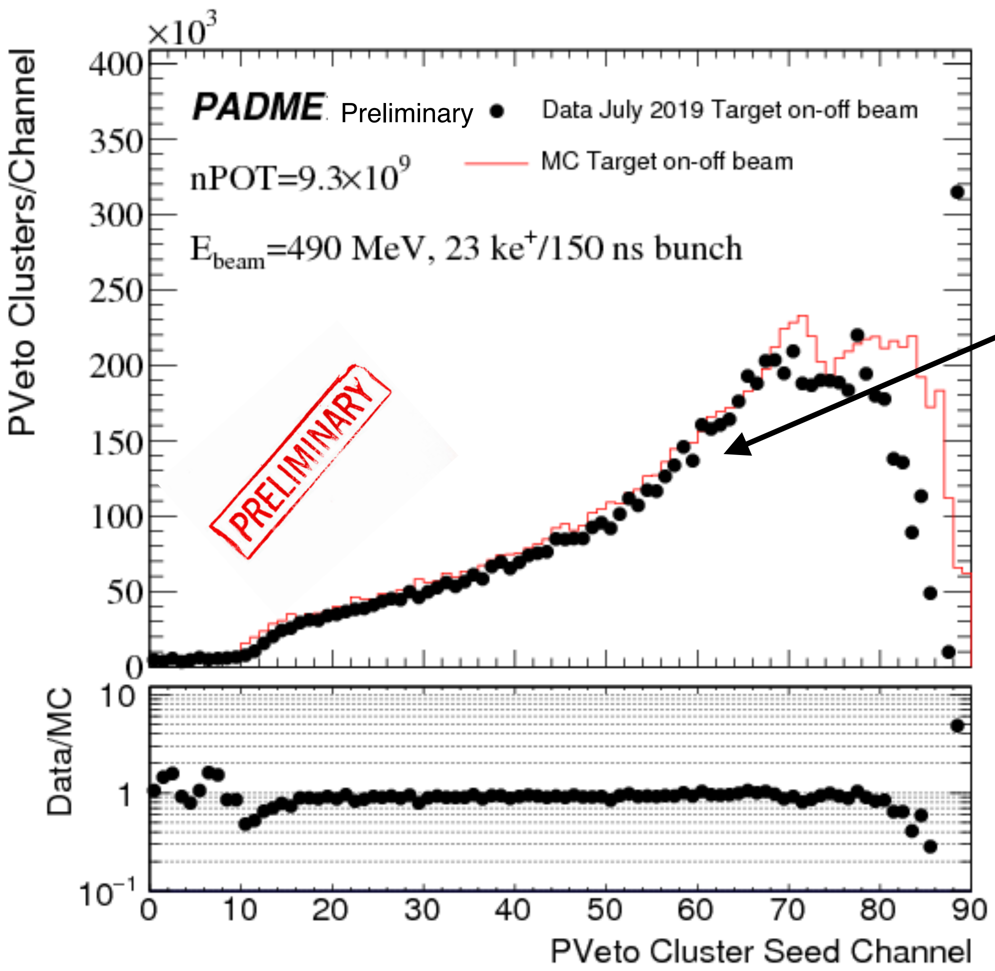
expected

**already explained in the previous slide*

PADME background studies ongoing

Bremsstrahlung and annihilation signal clearly visible with primary beam *MC DATA*

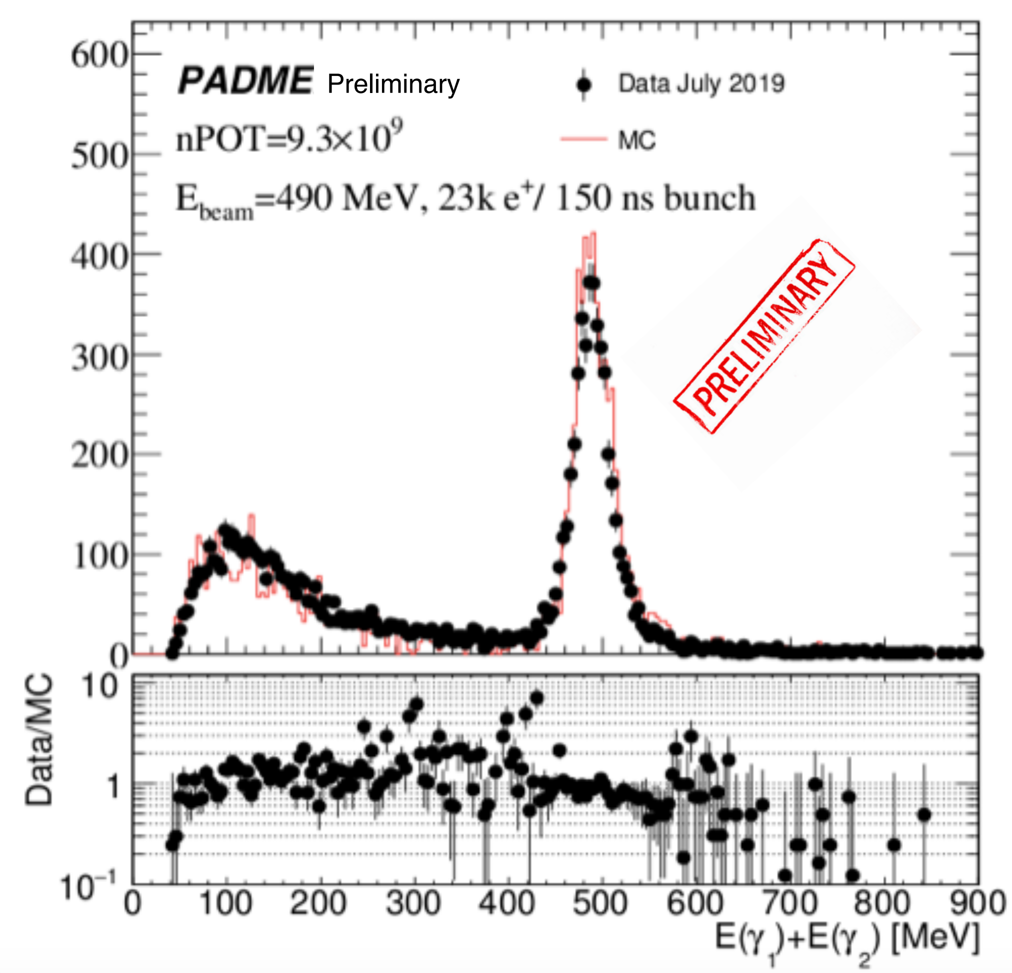
Bremsstrahlung study



DATA comparable with MC

Bremsstrahlung yield on positron veto after subtruction of beam induced yield in a calibration run without target

γγ STUDY



Selection CUTS

$\Delta t <$ **10. ns**

$\Delta\varphi < 20°$

γγ Center Of Gravity **< 1. cm**

Additional dark sector searches at PADME I

NOT ONLY DARK PHOTON! New Physics model accessible with the PADME experiment.

Dark Higgs

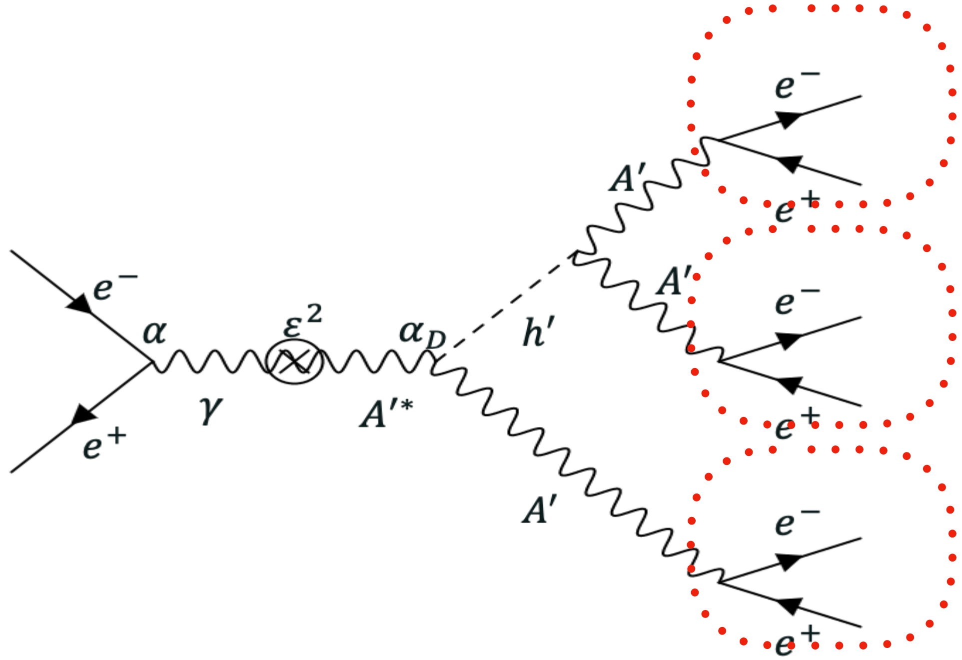
Assuming a minimal model with the dark photon mass generated by a dark Higgs
The dark photon can be produced in the Higgs-strahlung process $e^+e^- \rightarrow A'h'$

If the dark Higss is light as well, can be a new probe to the dark sector with multilepton signatures:

VISIBLE DECAY $m_{h'} > 2\, m_{A'}$

Assuming $h' \rightarrow A'A'$ and A′ decays in visible lepton

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



Measurement of the cross section $e^+e^- \rightarrow$ 6 leptons can be performed

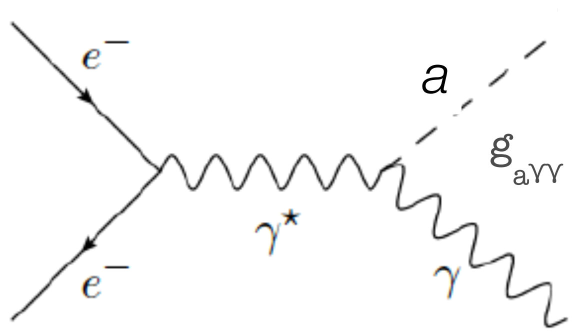
Axions Like Particles (ALP)

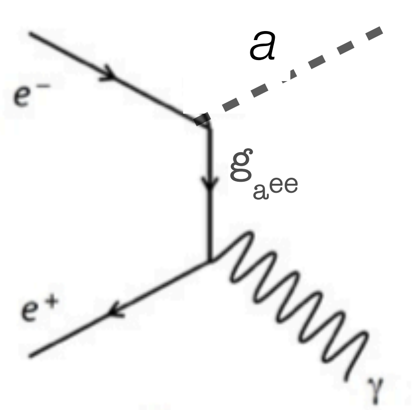
Axion-Like Particles are pseudo-scalars which couple to bosons (like photons with coupling $g_{a\gamma\gamma}$) and fermions (like e- with coupling g_{aee}) with no relation between mass and coupling is assumed (unlike QCD Axions)

The selection applied for the DP could work also for ALP search

ALP Production of interest in PADME

Two possible scenario





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

VISIBLE ALP DECAY $a \rightarrow \gamma\gamma$ or $a \rightarrow e^+e^-$

accessible final state: $\gamma\gamma\gamma$ or $\gamma\ e^+e^-$

INVISIBLE ALP DECAY

final state: γ + missing mass

Visible decay but ALP long lived

In the mass region below 100 MeV the ALP could be long lived, appearing as a missing particle in the PADME setup

final state: γ + missing mass

PADME theorethycal study on going

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)*

CONCLUSION

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

- PADME commissioning was successful. The DATA taken helped to understand the background of the experiment both with secondary and primary beam

- The upgrade of the beamline of July 2020 helped to reduce the beam BG

- Be careful..DP is not the only new particle accessible to PADME! (ALP, Dark Higgs, ...)

- RUN2 will start soon!

The DP hunt has just begun

Stay tuned

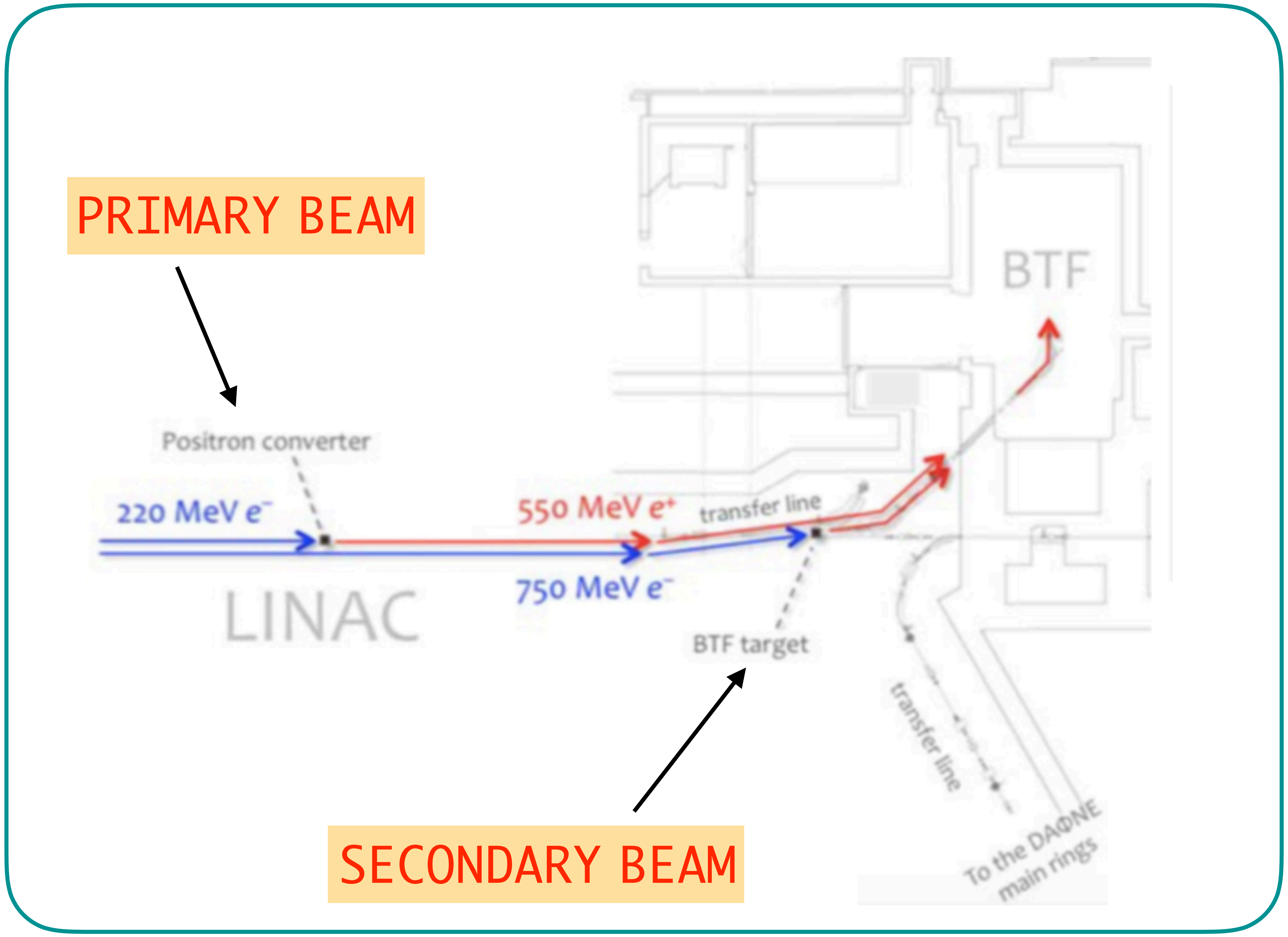
Let's turn the DARK on!

BACKUP

PRIMARY & SECONDARY BEAM

The positrons can be produced in two ways:

- directly from the LINAC thanks to a W-Re positron converter (Primary beam)
- through a Cu target placed just before the BTF experimental hall (Secondary beam)



Important features

Window which divide the vacuum of the LINAC from the one of PADME in Beryllium from September 2018.

Improvements to the beamline of 2020

- Wider beam pipe in some parts
- Window in Mylar placed further from the detector

LESS BEAM BACKGROUND