PADME project at DAFNE Linac

Venelin Kozhuharov[1,2] & Mauro Raggi[1]

[1]LNF-INFN

[2]University of Sofia

INFN What Next Dark Matter

10 July 2014

Outline

- Motivation
- PADME experiment
- Expected sensitivity
- Dark photon searches at BTF
- Conclusion

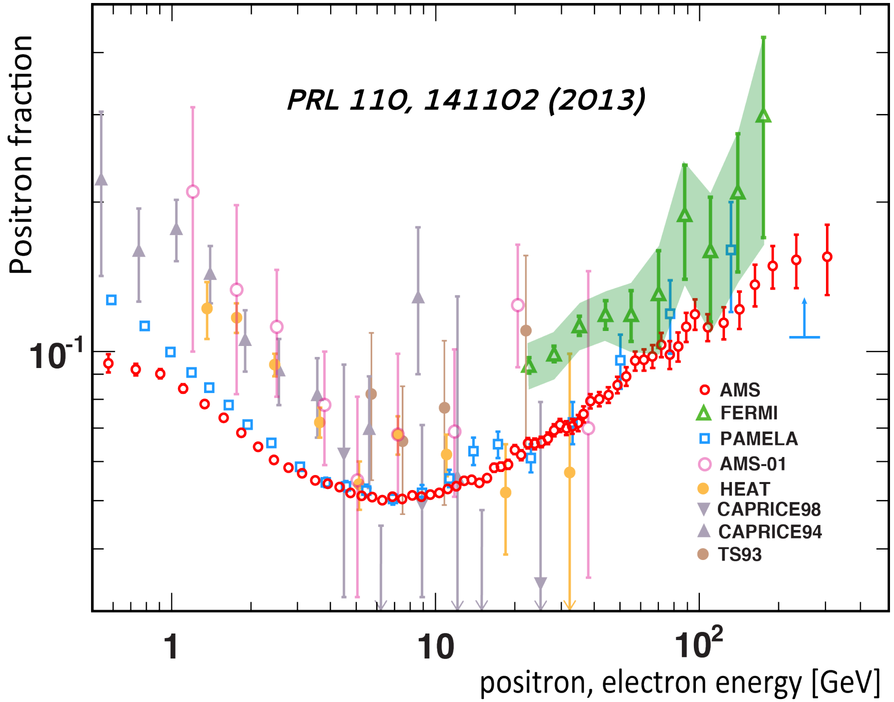
Motivation: New Physics

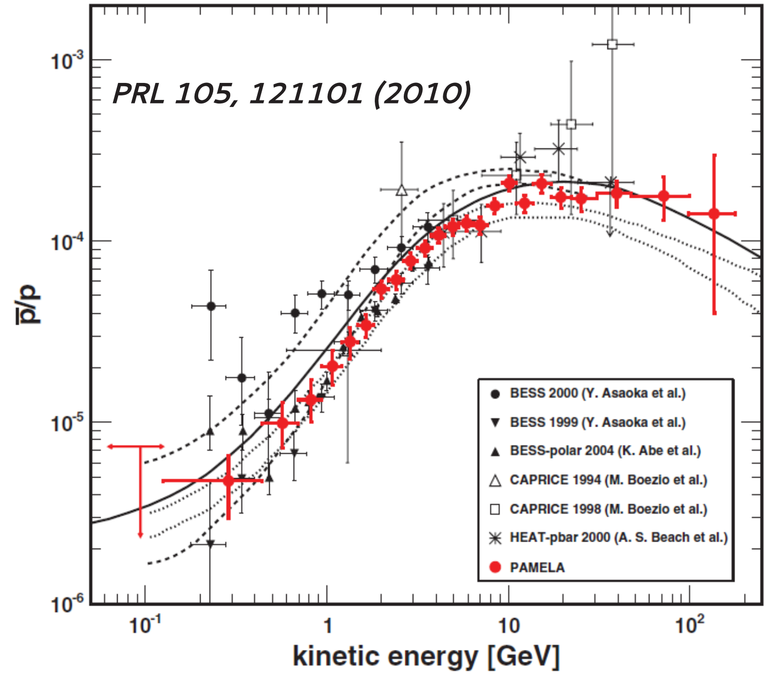
- Standard Model is complete: 2012 LHC - Higgs boson
- Unknowns:
  - Matter-antimatter asymmetry
  - Dark matter
  - Dark Energy
- Still some places of discrepancies between theory and experiment

- The Standard Model is a low energy approximation of a more fundamental theory.

But which theory?

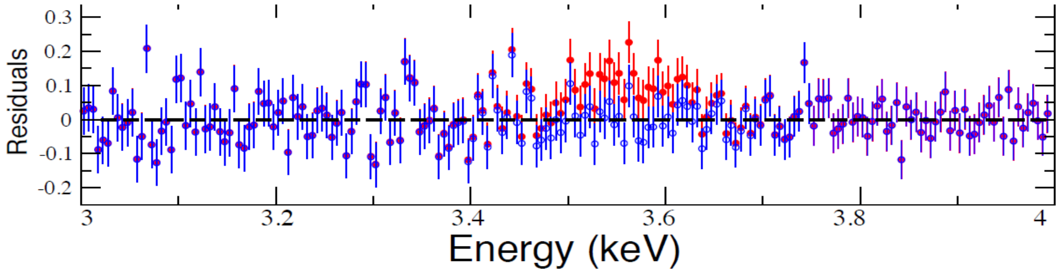
Astrophysics ...





- Positron excess: PAMELA, FERMI, AMS02
- No significant excess in antiprotons: pure secondary production

... and astronomy



Observation of 3.5keV line?

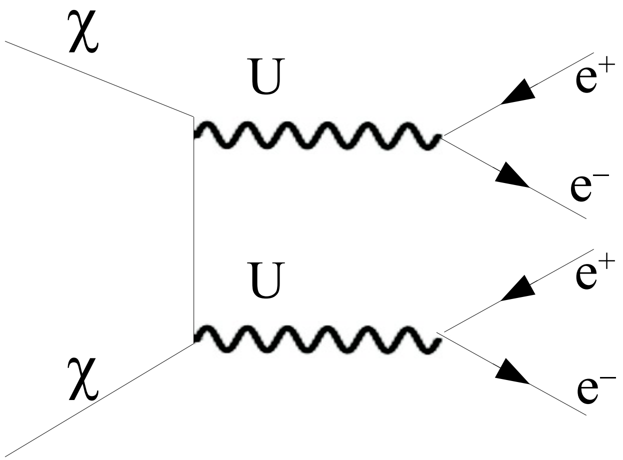
arXiv:1402.2301

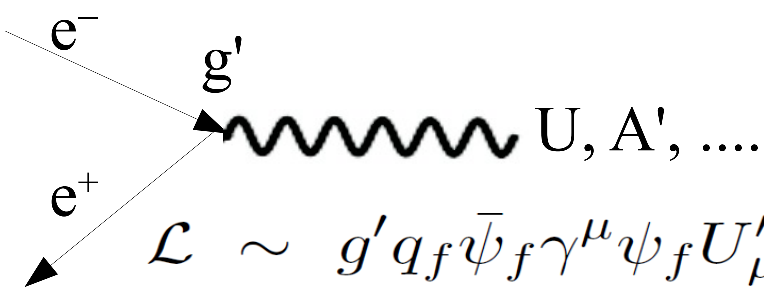
arXiv:1402.4119

Possible interpretation: arXiv:1404.2220

Hint for dark matter?

Dark matter annihilation through

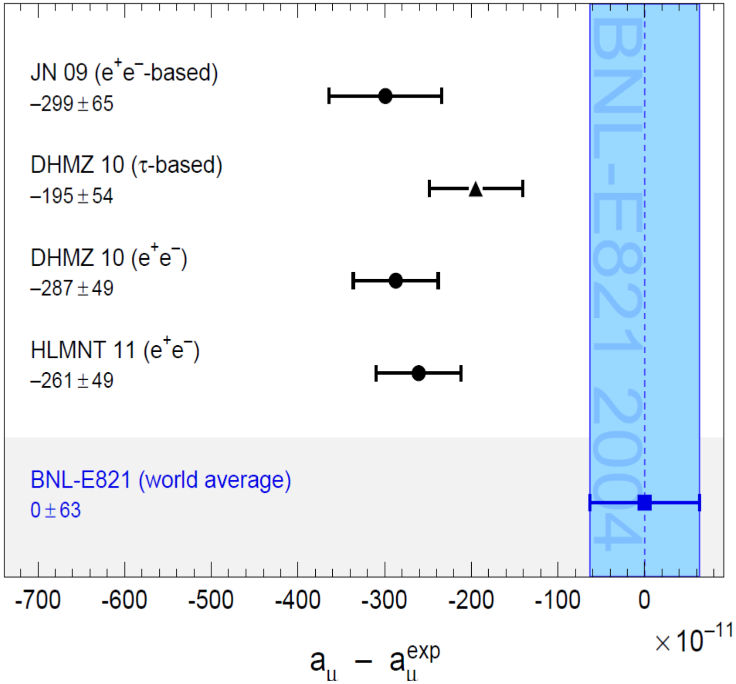


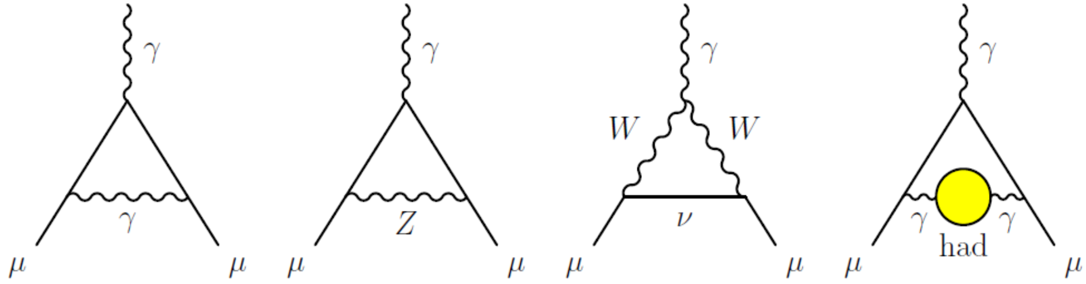


$$\mathcal{L} \sim g' q_f \bar{\psi}_f \gamma^\mu \psi_f U'_\mu$$

- If Dark Matter is the explanation to the positron excess, then the mediator should be light (< $2 \cdot M_{proton}$)
- Coupling constant to DM could be arbitrary (even O(1))
- The Lagrangian term can arise through
  - fermions being charged (mili) under this new gauge symmetry ($q_f \rightarrow 0$ for some flavours)
  - Kinetic mixing between ordinary photon and DM one: $\mathcal{L}_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$
  - **Using simply an effective description:** $g'.q'_e = \varepsilon$, $\alpha' = \alpha * \varepsilon^2$

g-2





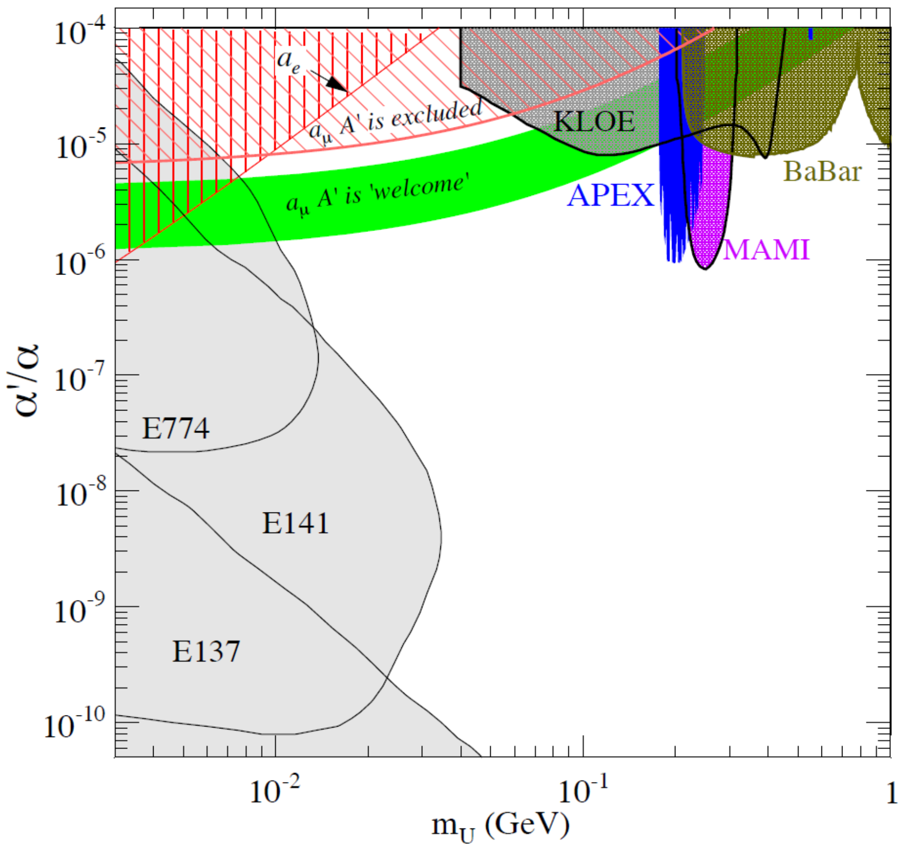
- About 3 σ discrepancy between theory and experiment (3.6 σ, if taking into account only $e^+e^- \rightarrow$ hadrons)

$$a_\mu^{\text{dark photon}} = \frac{\alpha}{2\pi}\varepsilon^2 F(m_V/m_\mu)\,, \qquad (17)$$

where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2 z]\,dz$. For values of $\varepsilon \sim 1$–$2 \cdot 10^{-3}$ and $m_V \sim 10$–$100\,\text{MeV}$, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

Heavy/Dark photon/boson

- The most attractive explanation of the phenomena is the simplest one – with a single object
- If this is the U-boson, it should be sufficiently light – 10-100MeV
- Searches
  - Beam dump experiments
    - A'-strahlung production
    - Every observed event is signal
  - Fixed target
    - peaks in the e^+e^- invariant mass spectrum
  - Meson decays
    - Peaks in M_{e+e-} or $M_{\mu+\mu-}$



How to improve?

- Searching a U-boson in a kinematically constraint event and using full reconstruction
- Basic process: positron on a fixed target

$$e^+ + e^- \rightarrow \gamma + U \begin{cases} \gamma + E_{miss} & \text{(invisible channel, } U \rightarrow \chi\chi) \\ \gamma + e^+e^- & \text{(visible channel, } U \rightarrow e^+e^-) \end{cases}$$

- Normalizing to the concurrent process - **annihilation**

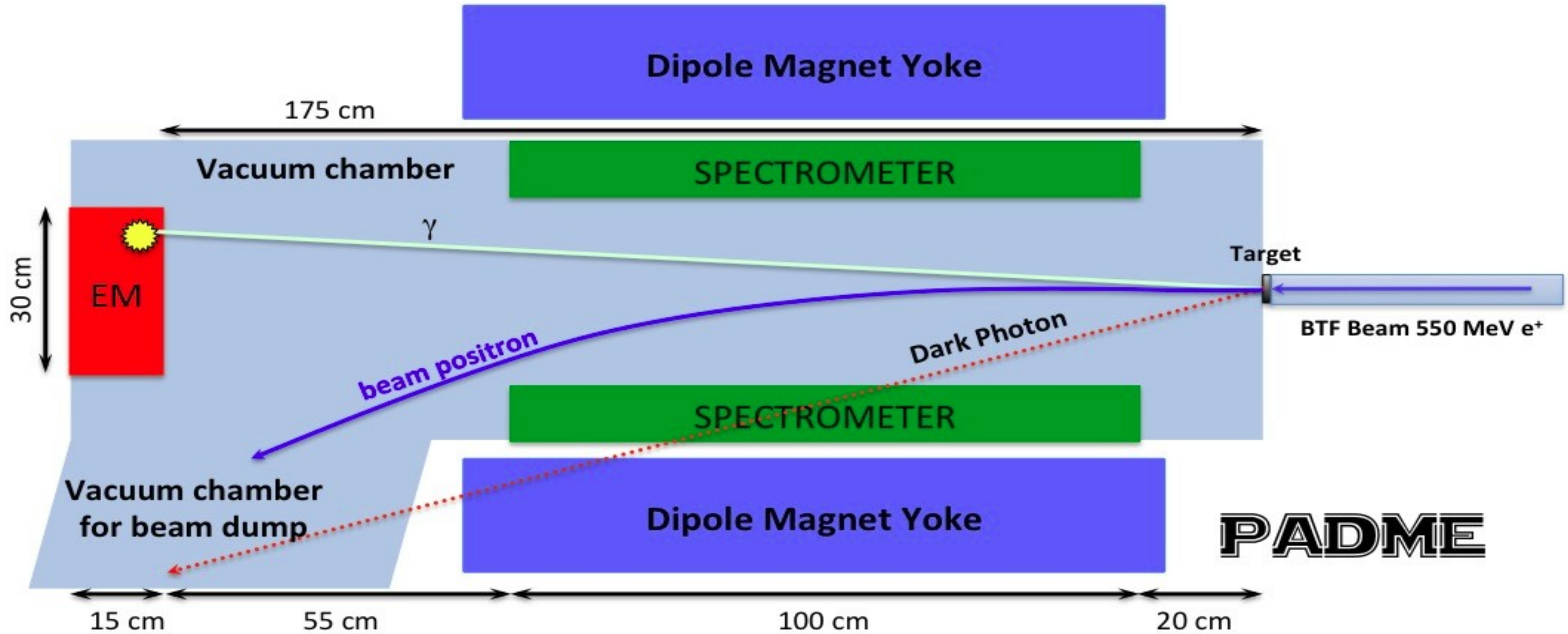
$$\frac{\sigma(e^+e^- \rightarrow \gamma U)}{\sigma(e^+e^- \rightarrow \gamma\gamma)} = \frac{N(\gamma U)}{N(\gamma\gamma)} * \frac{Acc(\gamma\gamma)}{Acc(\gamma U)} = \varepsilon^2 * \delta$$

  - $N(\gamma U)$, $N(\gamma\gamma)$ - number of registered events
  - $Acc(\gamma U)$, $Acc(\gamma\gamma)$ - detection efficiency
  - $\delta = \sigma(e^+e^- \rightarrow \gamma U)/\sigma(e^+e^- \rightarrow \gamma\gamma)$ at $\varepsilon=1$ – cross section enhancement factor

Is it possible such a search to be conducted at BTF?

PADME experiment

Positron Annihilation into Dark Matter Experiment

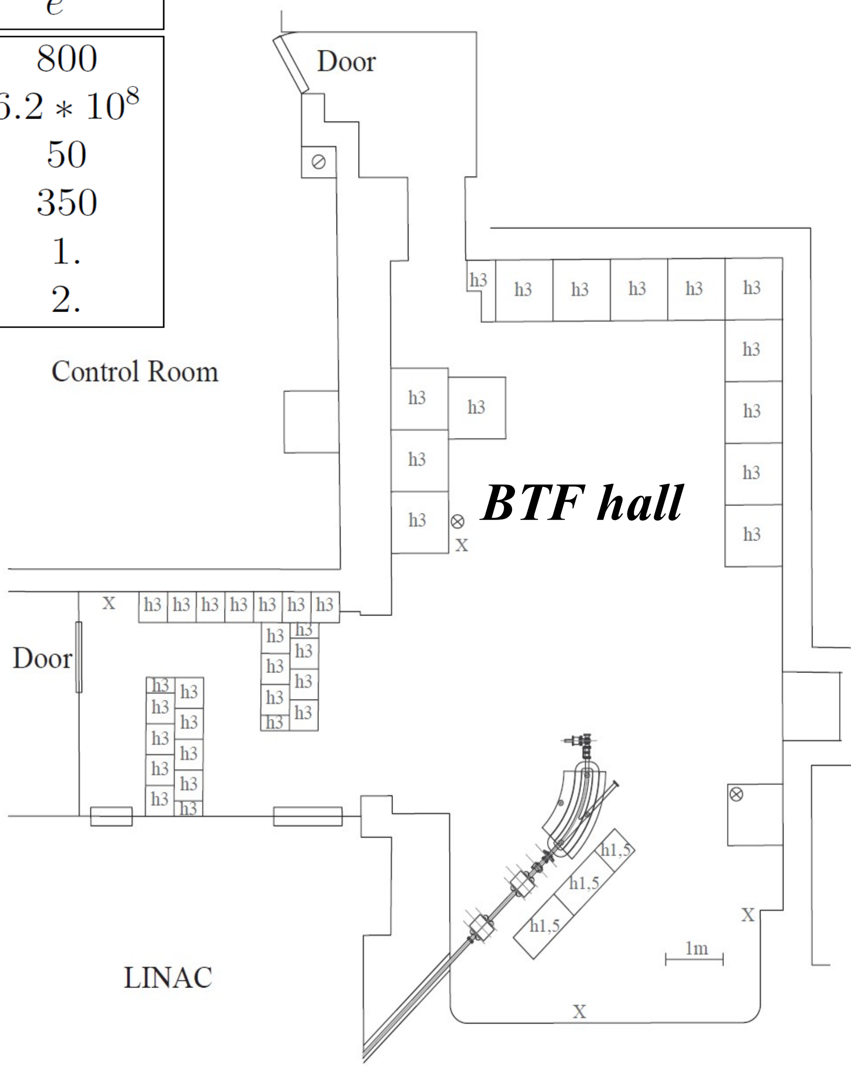


- Small scale fixed target experiment
- Measuring both charged and neutral particles:
  - Spectrometer
  - Calorimeter
  - Beam profile

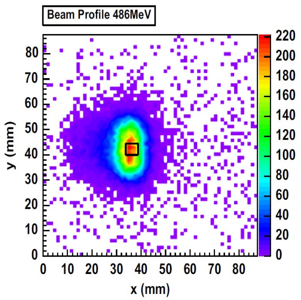
BTF @ LNF

	e^+	e^-
Maximal beam energy [MeV]	550	800
Beam rate [particles/burst]	$6.2 * 10^8$	$6.2 * 10^8$
Number of bursts per second	50	50
Max. averaged current during a burst [mA]	85	350
Typical emittance (mm mrad)	1.5	1.
Beam spot size (σ in mm)	2.	2.

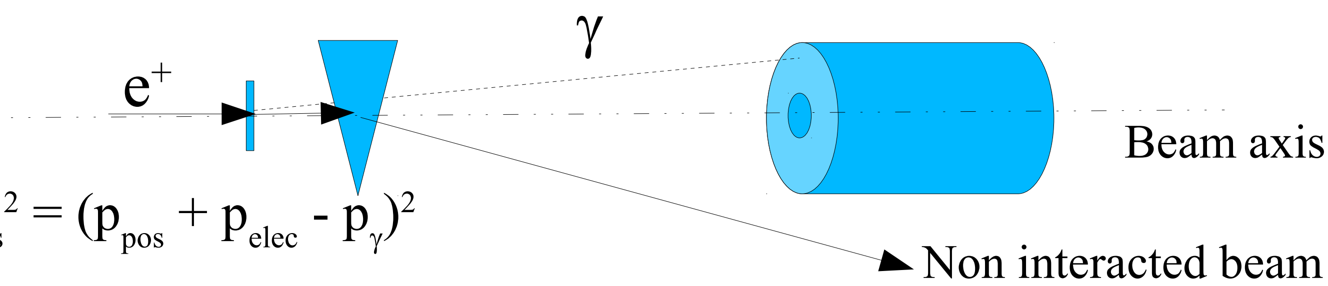
- Variable beam energy
  - from ~250 MeV to E_{MAX}
- Variable beam intensity
- Possibility for single particle beam
  - However we need statistics...
- Both positron and electron beams
- Small beam energy spread
- Available immediately
- The accessible region is limited by the maximal beam energy
  - **Around 23 MeV for 550 MeV e^+ beam**



Basic ideas

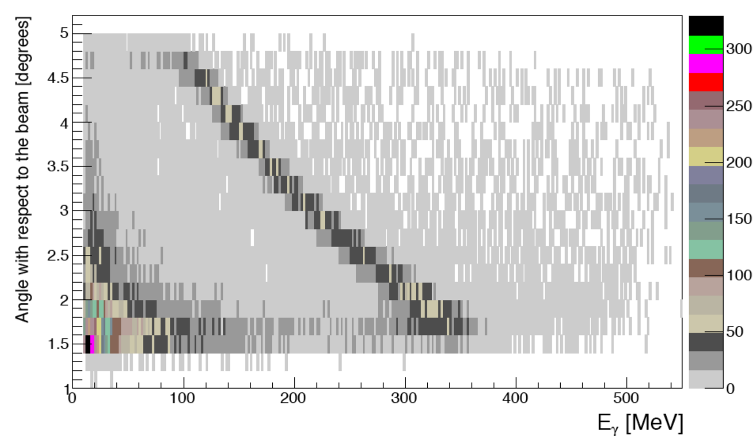


Focusing on the invisible channel

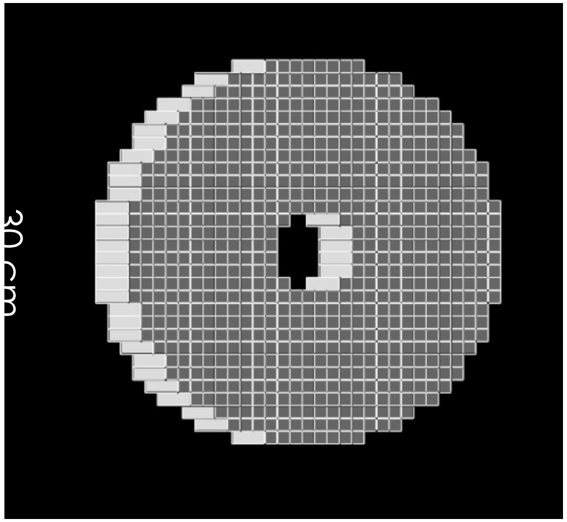


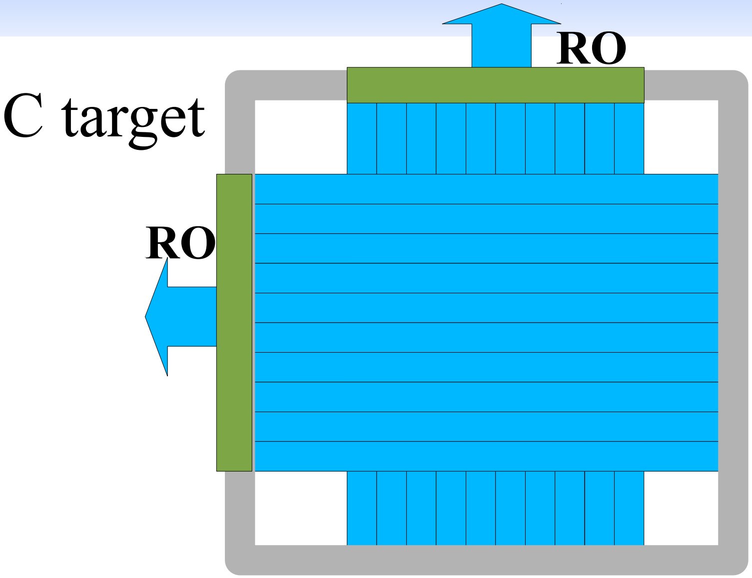
$$M_{miss}^2 = (p_{pos} + p_{elec} - p_\gamma)^2$$

- Electron is at rest
- Positron momentum is determined by the accelerator characteristics – 1% resolution
- Basic contribution to the missing mass resolution – reconstruction of the photon 4-momentum
  - Interaction point inside the target – beam transverse size is small, but the time stability is not sufficient
  - Cluster position in the calorimeter
  - Energy resolution of the calorimeter



Detectors

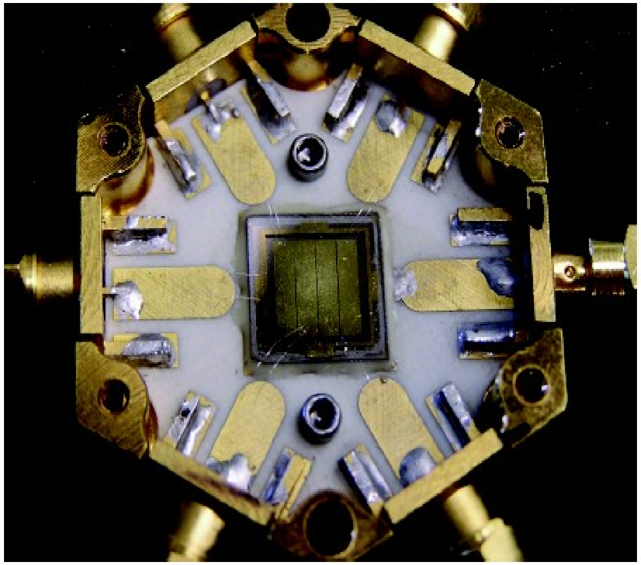




- Cylindrical shape
- 656 LYSO crystals, 1x 1 x 15 cm^3
- Energy resolution:

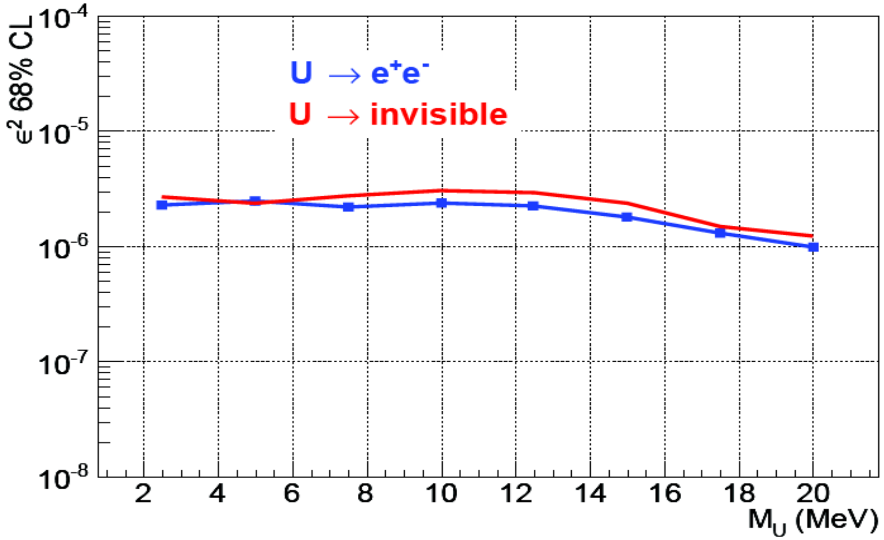
$$\sigma E/E = \frac{1.1\%}{\sqrt{E}} \oplus \frac{0.4\%}{E} \oplus 1.2\%$$

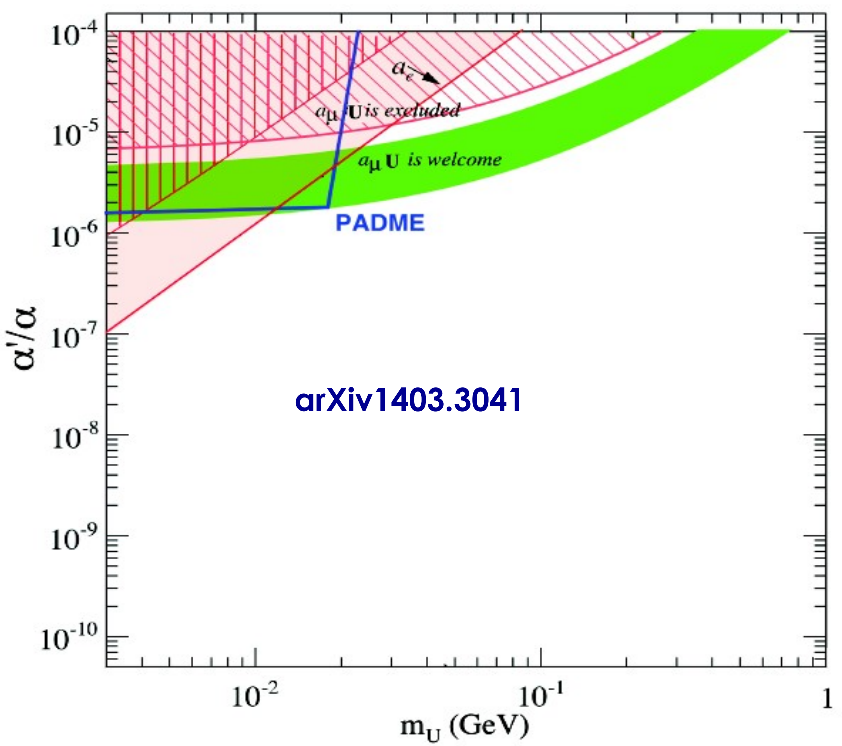
- Possible substitutions: BGO?
  - Available at ROME 1
    - 10x longer decay time



Expected sensitivity

GEANT4 based simulation to assess the possible reach





- Rough selection based on **missing mass** cut, **veto** on extra **clusters** and **positrons**
  - 1 year of continuous running
  - 60% efficiency (data taking)
  - 50 bursts/s
  - 10^4 positrons/burst
- Considering the statistical uncertainty of the expected background to set the limits

Present status and future steps

- Interested parties:
  - INFN – LNF: M. Raggi, V. Kozhuharov, B. Bruno, L. Foggetta
  - INFN – ROMA1: P. Valente, E. Leonard, G. Organtini;
  - INFN – Lecce: G. Chiodini, S. Spagnolo
  - Sofia, Bulgaria: V. Kozhuharov
- Planned activities:
  - Test run @BTF: 24.11 – 4.12 . 2014
    - Study the possibility to use BGO
    - Monte Carlo validation
    - Background study at low statistics
    - Diamond beam monitor/target test
    - Positron emittance to be re-measured
  - Bunch structure tests
  - Maximal BTF instantaneous current test

WEB: http://www.lnf.infn.it/acceleratori/padme/

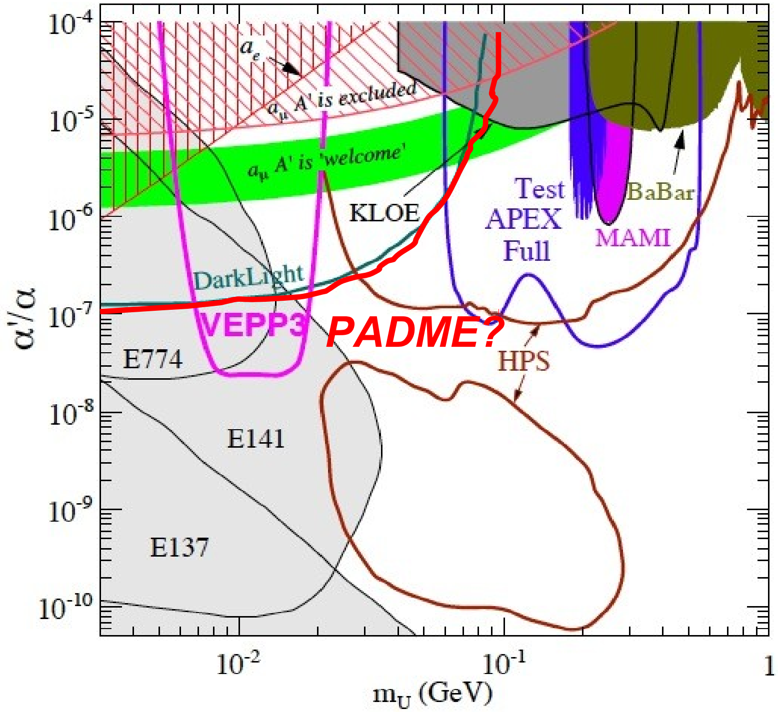
MAIL: https://lists.infn.it/sympa/subscribe/padme-general

PADME future program

conventional electron beam and U-strahlung: $e^- Z \rightarrow e^- Z U$

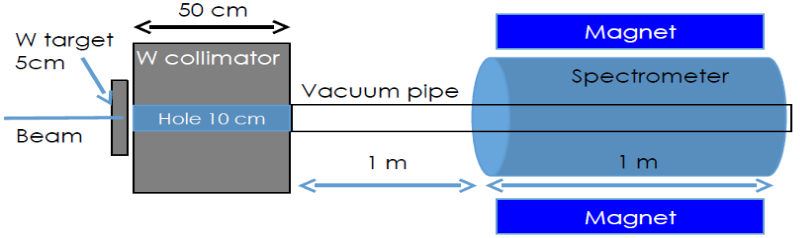
$U \rightarrow e^+e^-$ visible decay search

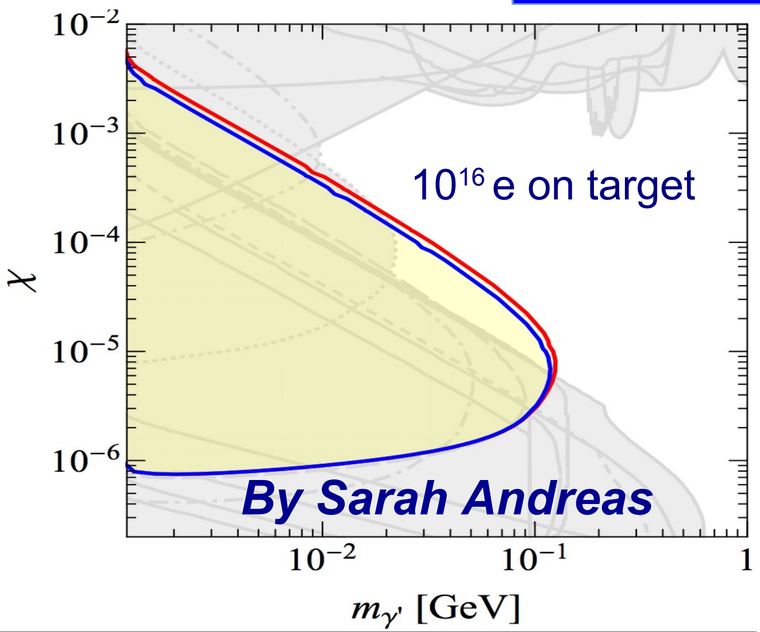
- Measuring e^+e^- momentum with the spectrometer
- Selection based on $M_{e^+e^-}$



Extend M_U sensitivity, but model dependent

Beam dump experiment: $U \rightarrow e^+e^-$



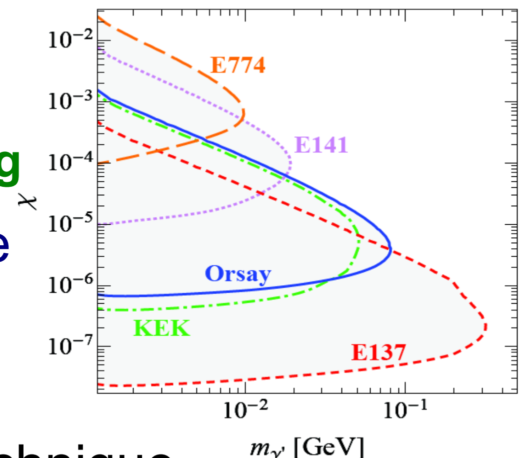


- 10^7 e^-/bunch, 50 bunch/s, 1 year
- E_{e-} = 750 MeV

Beam dump prospects

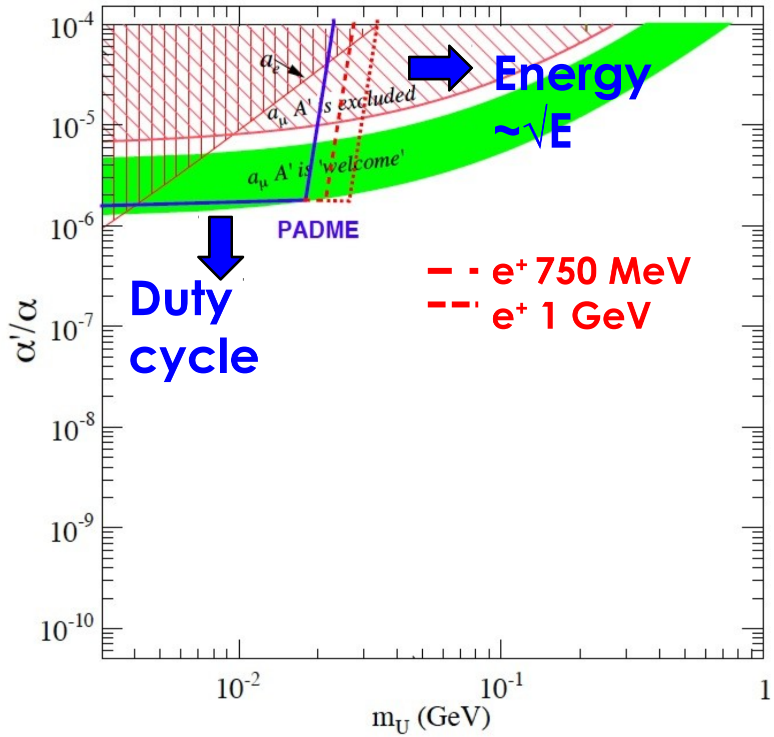
Experiment	target	E_0 [GeV]	N_{el} electrons	N_{el} Coulomb	L_{sh} [m]	L_{dec} [m]	N_{obs}	$N_{95\%up}$
E141 [47]	W	9	2×10^{15}	0.32 mC	0.12	35	1126^{+1312}_{-1126}	3419
E137 [48]	Al	20	1.87×10^{20}	30 C	179	204	0	3
E774 [49]	W	275	5.2×10^{9}	0.83 nC	0.3	2	0^{+9}_{-0}	18
KEK [39]	W	2.5	1.69×10^{17}	27 mC	2.4	2.2	0	3
Orsay [40]	W	1.6	2×10^{16}	3.2 mC	1	2	0	3

- Improvements both in number of electrons and size of the experiment
  - Present BTF limit – 10^{18} e^-/year due to plant authorization
  - **Possible flux up to 10^{21} e^-/year!**
  - **Access to unexplored regions in just 3 days of running**
- Decay length governs the access to high ε – small scale is better if background is under control
- Flux governs the access to higher masses
- A dedicated and optimized search, not a data mining technique



Possible improvements

- Duty cycle upgrade:
  - Present: 50Hz * 10ns = $0.5*10^{-6}$
  - At 10 ns all the particles in the bunch are treated as belonging to the same event
  - At 40ns (100 ns) time resolution of LYSO & Spectrometer improves the veto
  - Improvement on the repetition of equal profit!
- Energy upgrade
  - Extend the access to M_U ~27 MeV
  - Improve the results in the range 20 – 23 MeV



- Bremsstrahlung production and visible/dump detection
  - Extend the mass region
  - Extend the ε^2 region to lower values due to higher U-boson boost
- Beam related background (i.e. accompanying spurious particles)
  - Difficult to access in the simulation, desired to be as minimal as possible

Conclusions

- PADME is a small scale fixed target experiment to search for dark photons in the invisible channel proposed.
- Interesting parameter space could be covered, using $10^3 – 10^5$ e^+/bunch.
- PADME will turn BTF from a test beam facility into a fundamental physics machine
- Test beam and initial studies already ongoing
- The portal for a complete physics program devoted to the dark photon searches is open – **visible, invisible, thin target, thick target, dump, electron or positron**