Dark photon searches with e^+ and e^- beams at LNF

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PADME Kickoff meeting

LNF-INFN

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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.

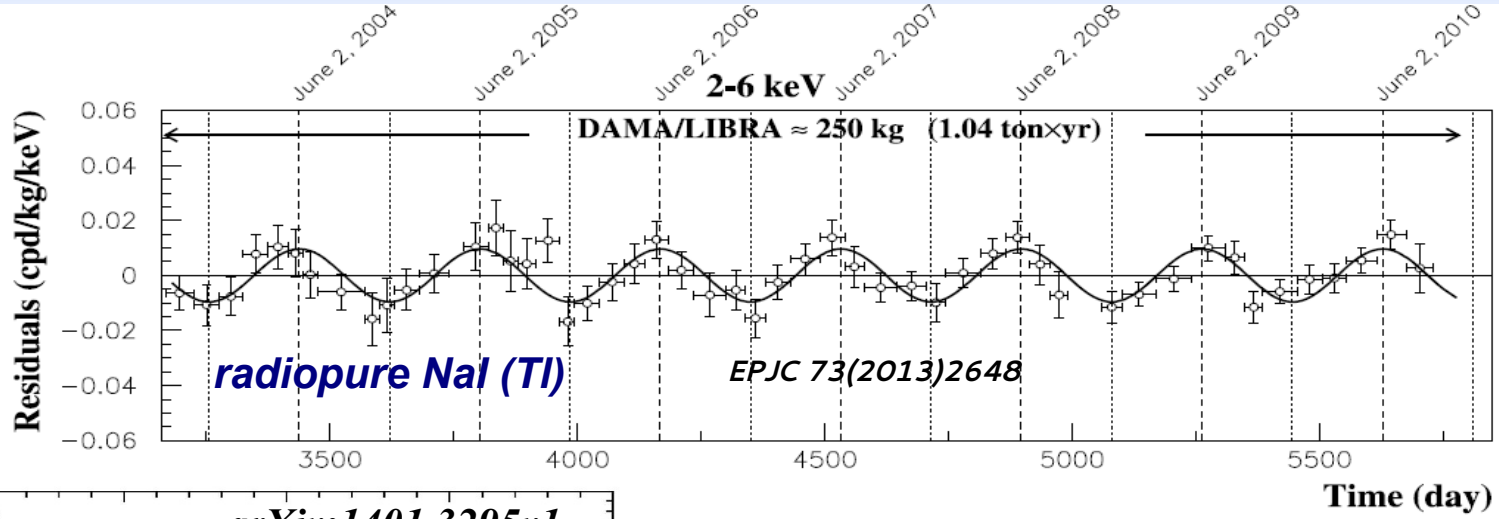
But which theory?

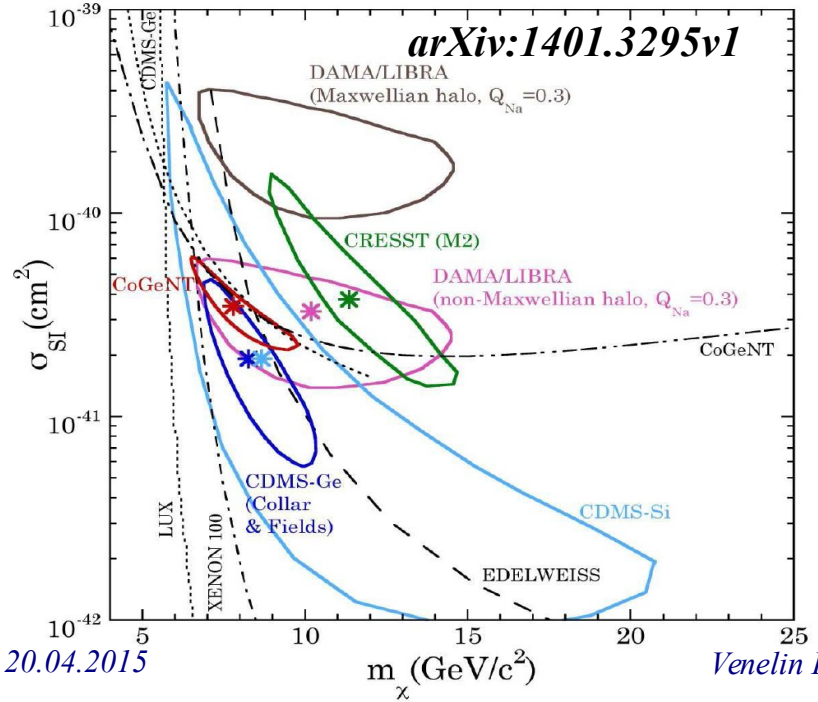
- Despite the highest energy reach LHC did not provide any evidence for new degrees of freedom

Where to look? How to proceed?

Energy frontier vs **Intensity frontier**

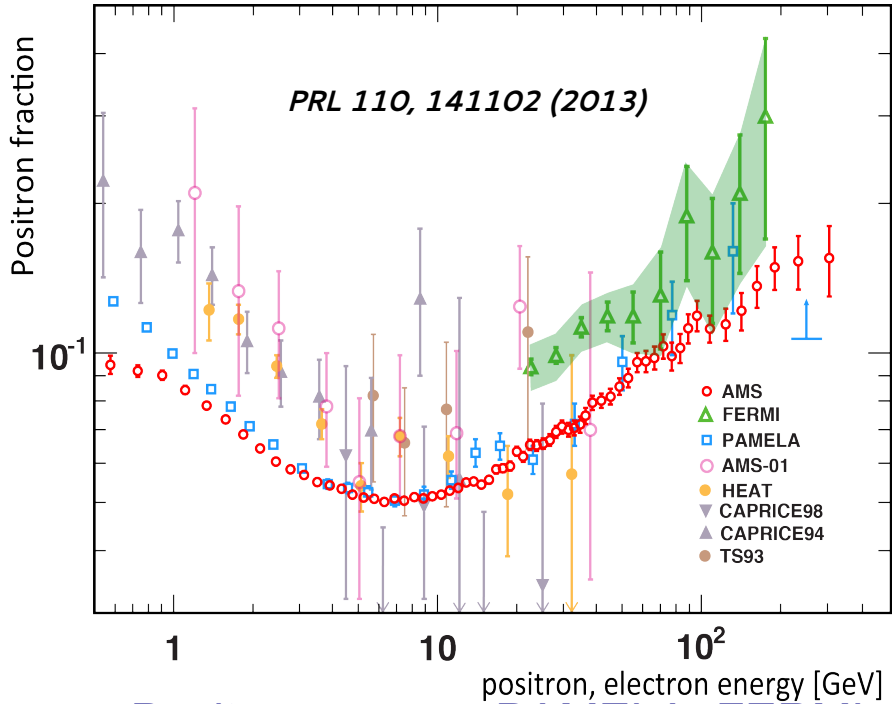
Direct search experiment

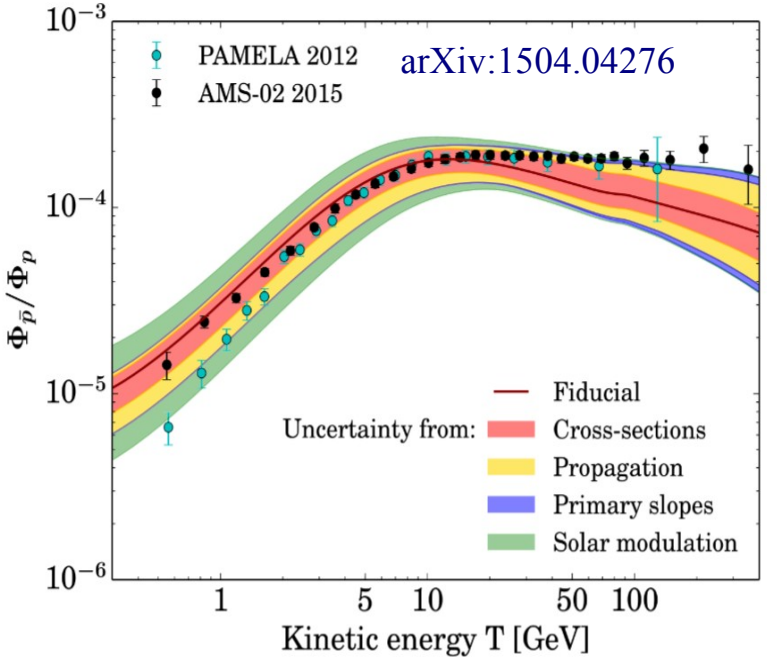




- DAMA/LIBRA results unexplained: 9.2 σ
- Used to be alone, now few other indications emerged
- Seem to be possible to build a consistent picture
- If the explanation is Dark Matter, it should be relative light: ~10 GeV
- Interaction with the nuclei through a mediator. Mass in the MeV range is OK

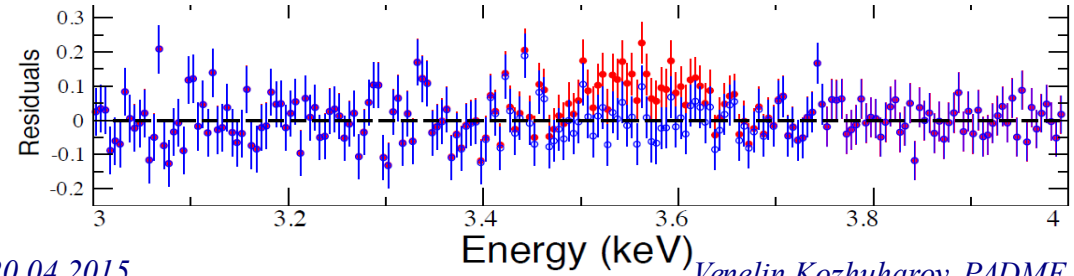
Astrophysics ...





- Positron excess: PAMELA, FERMI, AMS02
- Now also new results from AMS on the antiproton

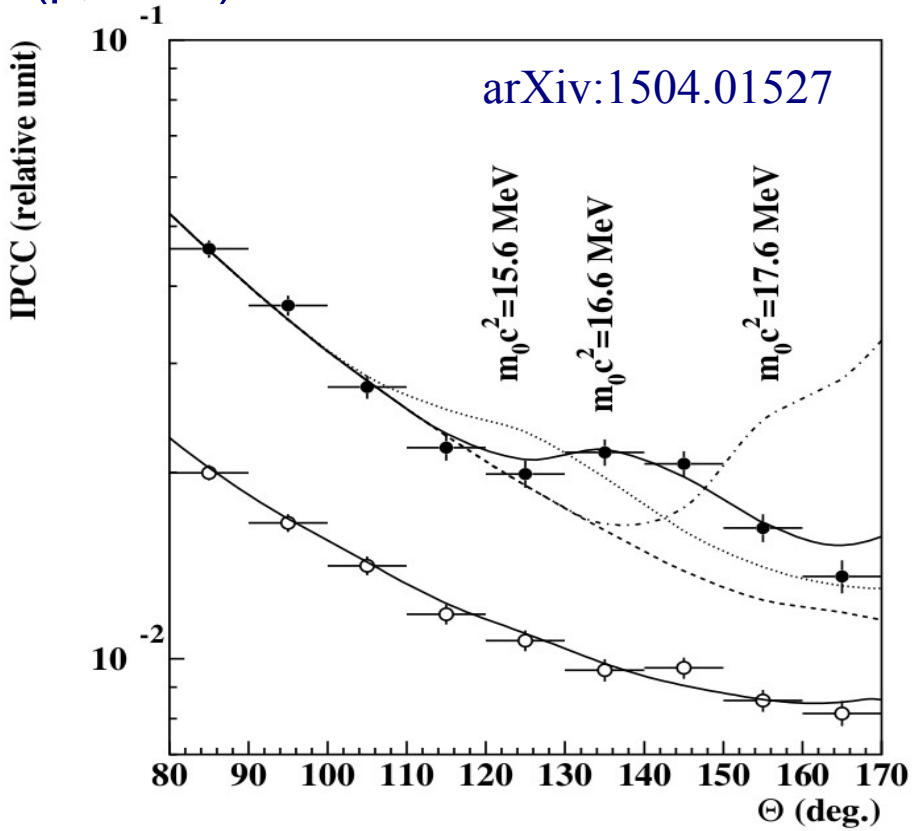
... and astronomy

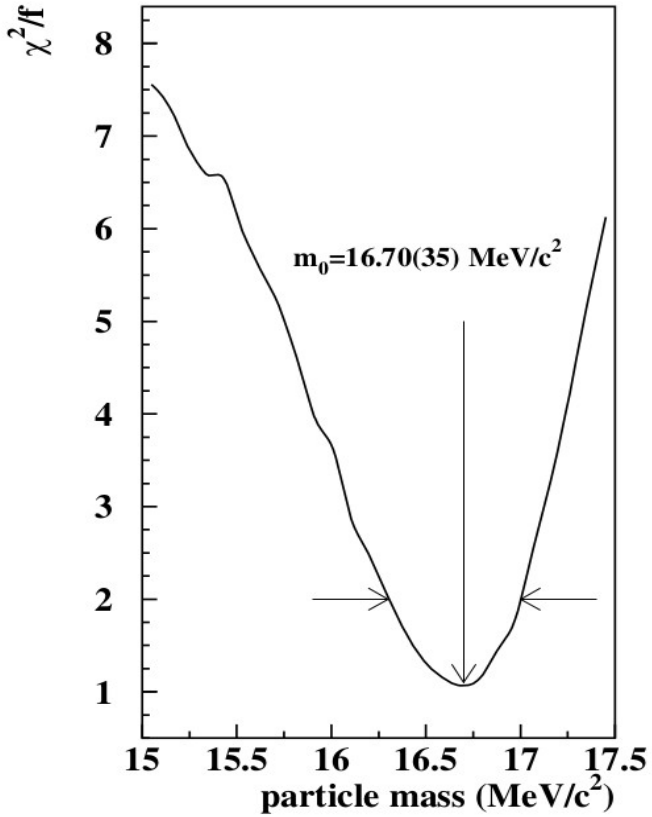


Observation of 3.5keV line?
arXiv:1402.2301
arXiv:1402.4119
Possible interpretation: arXiv:1404.2220

And yet another hint?

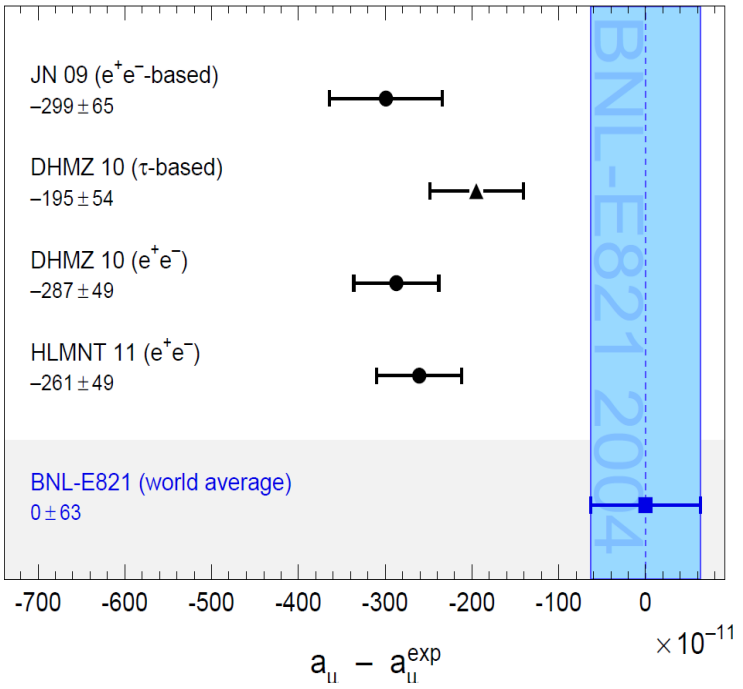
- Recent work on the analysis of Inner Pair Creation in ^{8}Be with the reaction ^{7}Li(p,e+e-)^{8}Be

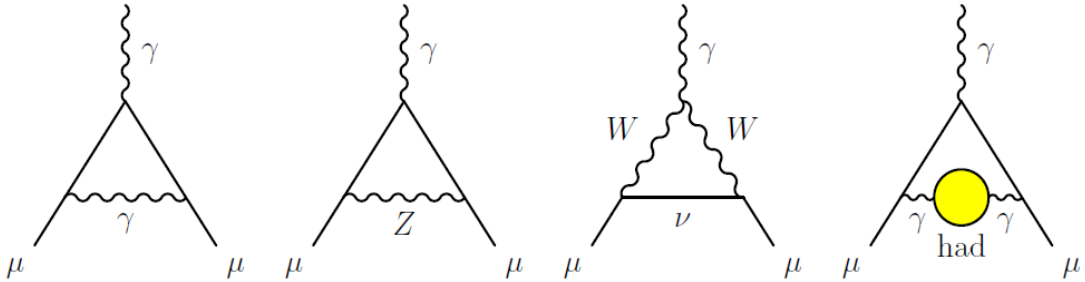




Seems that a new boson in the 16-17 MeV could explain such an anomaly

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 $\varepsilon \sim 1\text{–}2 \cdot 10^{-3}$ and $m_V \sim 10\text{–}100\,\text{MeV}$, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

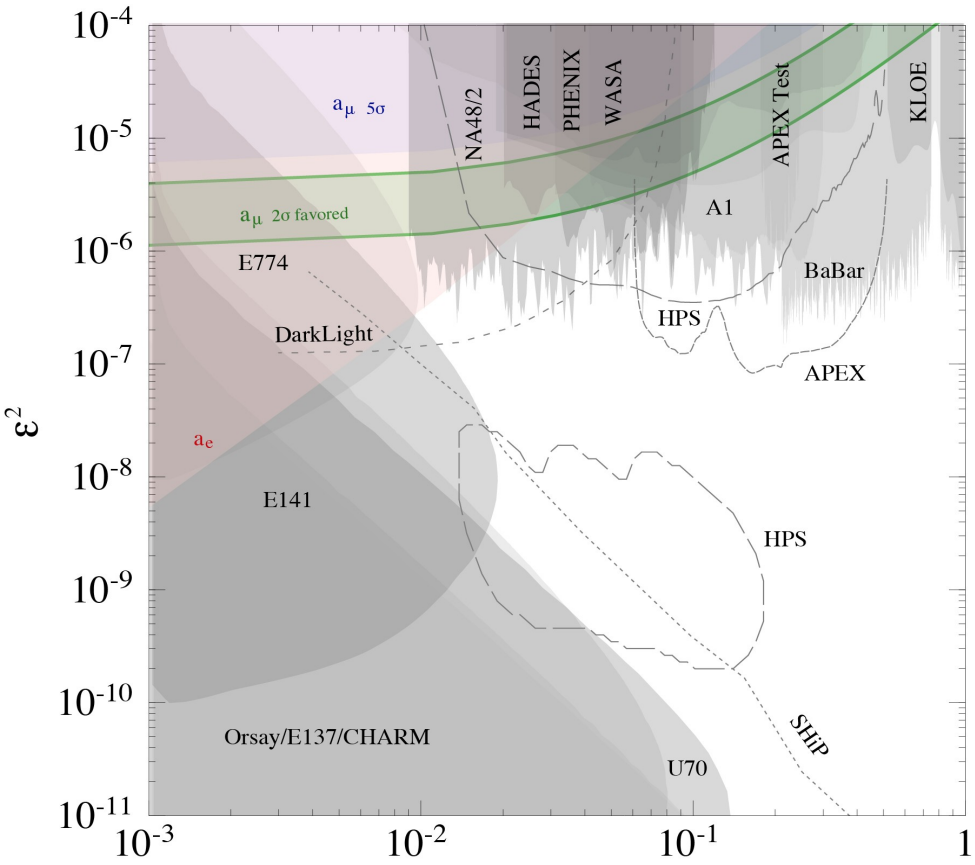
Questions

- Why dark photon
- Why in e+/e- interactions
- Why LNF

Dark photons

- The present studies still do not exclude a large and still interesting part of the DP parameter space
- See the talks of B. Batell & M. Battaglieri

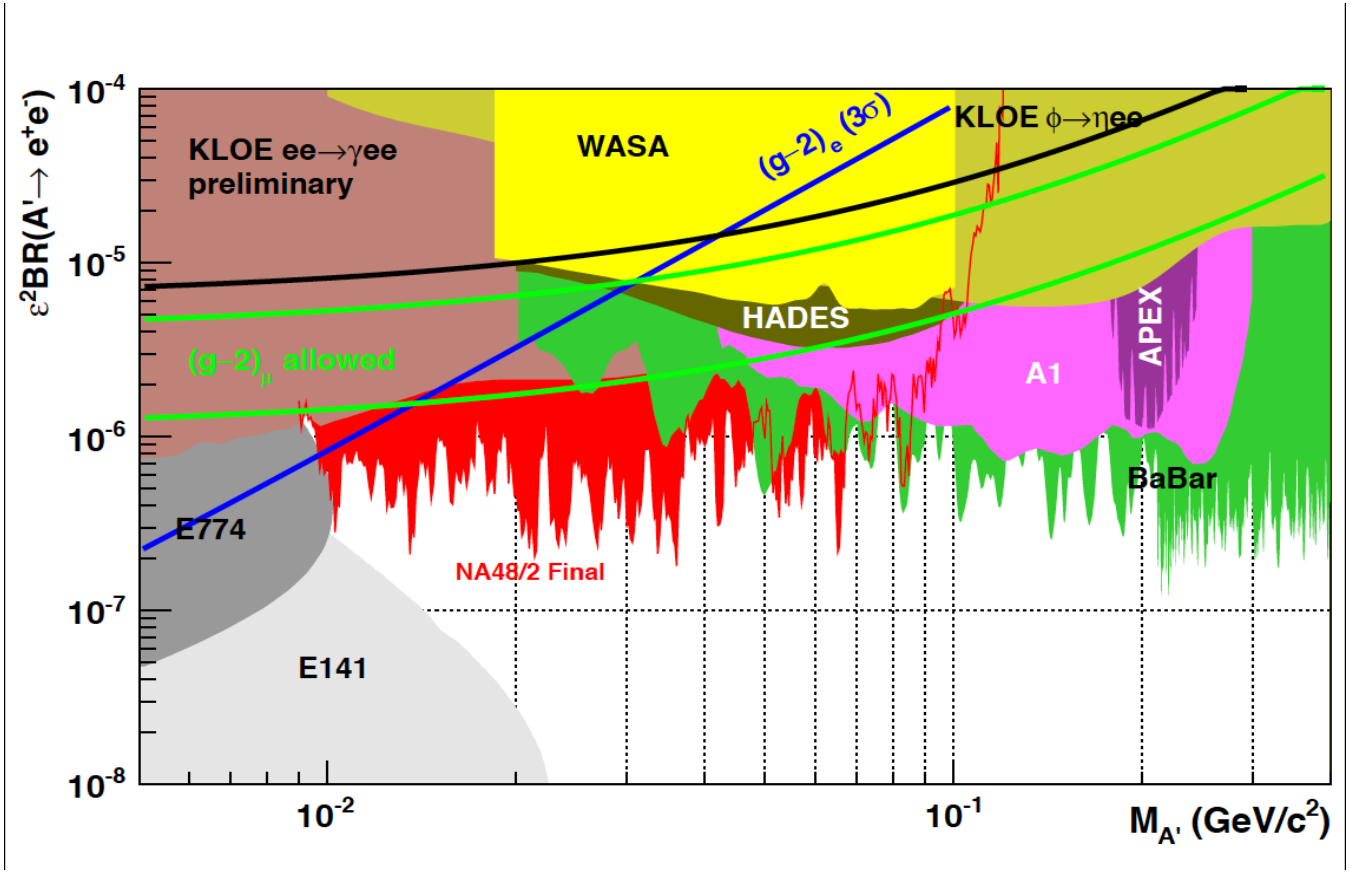
- If one can look for unexplored process, one **SHOULD** do it
  - Many examples in the history, including the dark energy from the study of SN
- Possible explanation of existing puzzles
  - e^+ excess in cosmic rays
  - $(g_\mu - 2)$
  - DM scattering on nuclei



N.B. multiple notations $A' \equiv U \equiv Z' \equiv Z_d \equiv \ldots$

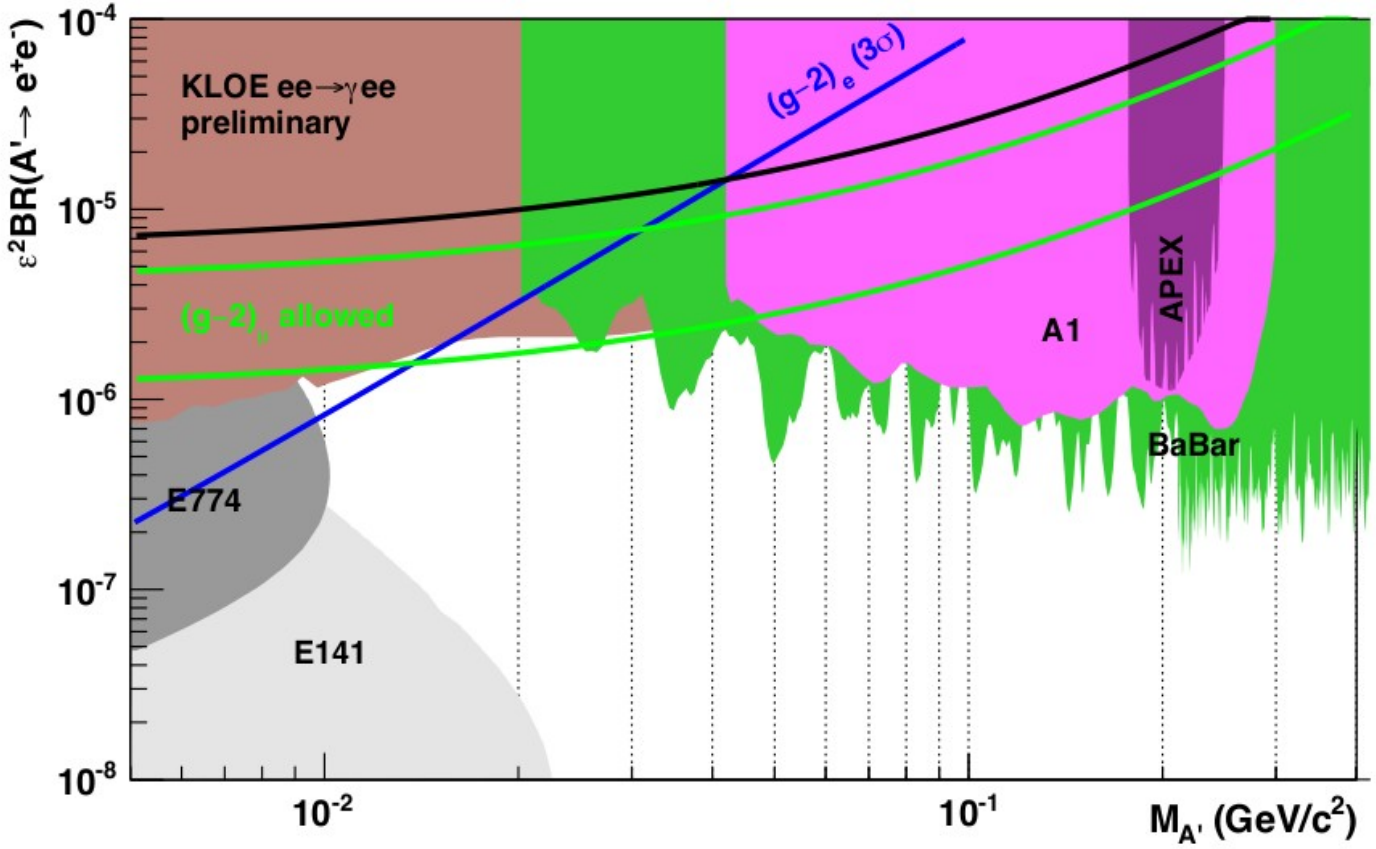
Universal coupling

- E.g. kinetic mixing



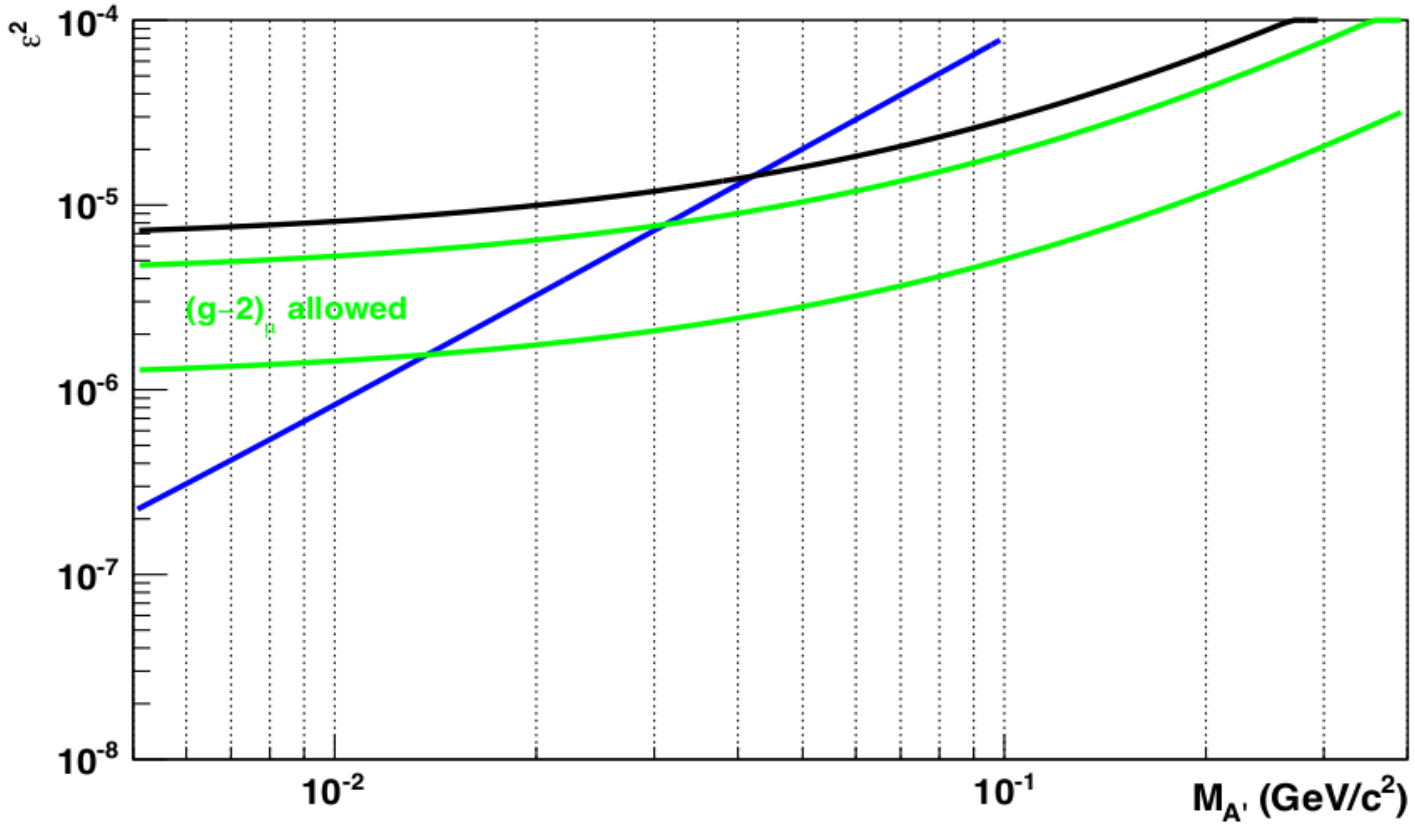
Leptophilic dark photon

- Solution preferred by e+ excess in the cosmic rays
  - Or could be part of the explanation (new AMS results last week)



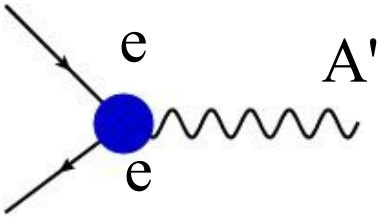
Light dark matter

- A' → χχ if χ is light enough and remains unobserved



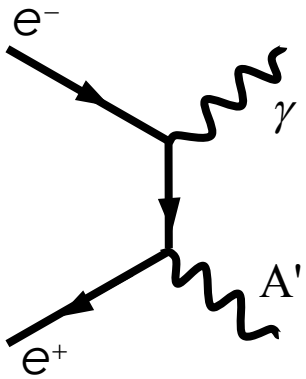
Theoretical scenarios (B. Batell's talk)

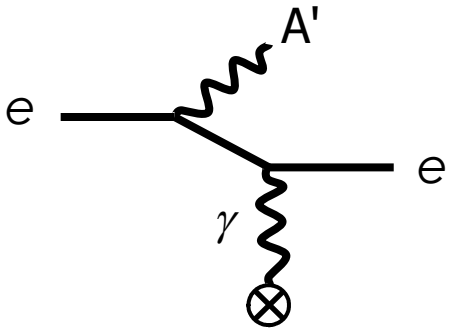
- The effective interaction that can be studied is



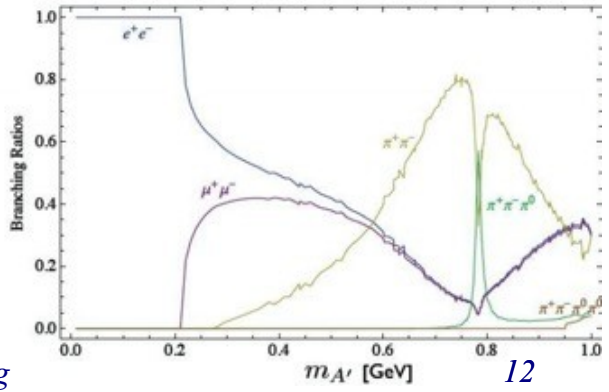
$$\mathcal{L} \sim g\,\overline{\Psi}\,(\gamma_\mu + \alpha_a\,\gamma_\mu\,\gamma^5)\,\Psi\,A'^{\mu},\ \ usually\ \alpha_a = 0$$

- Production mechanisms





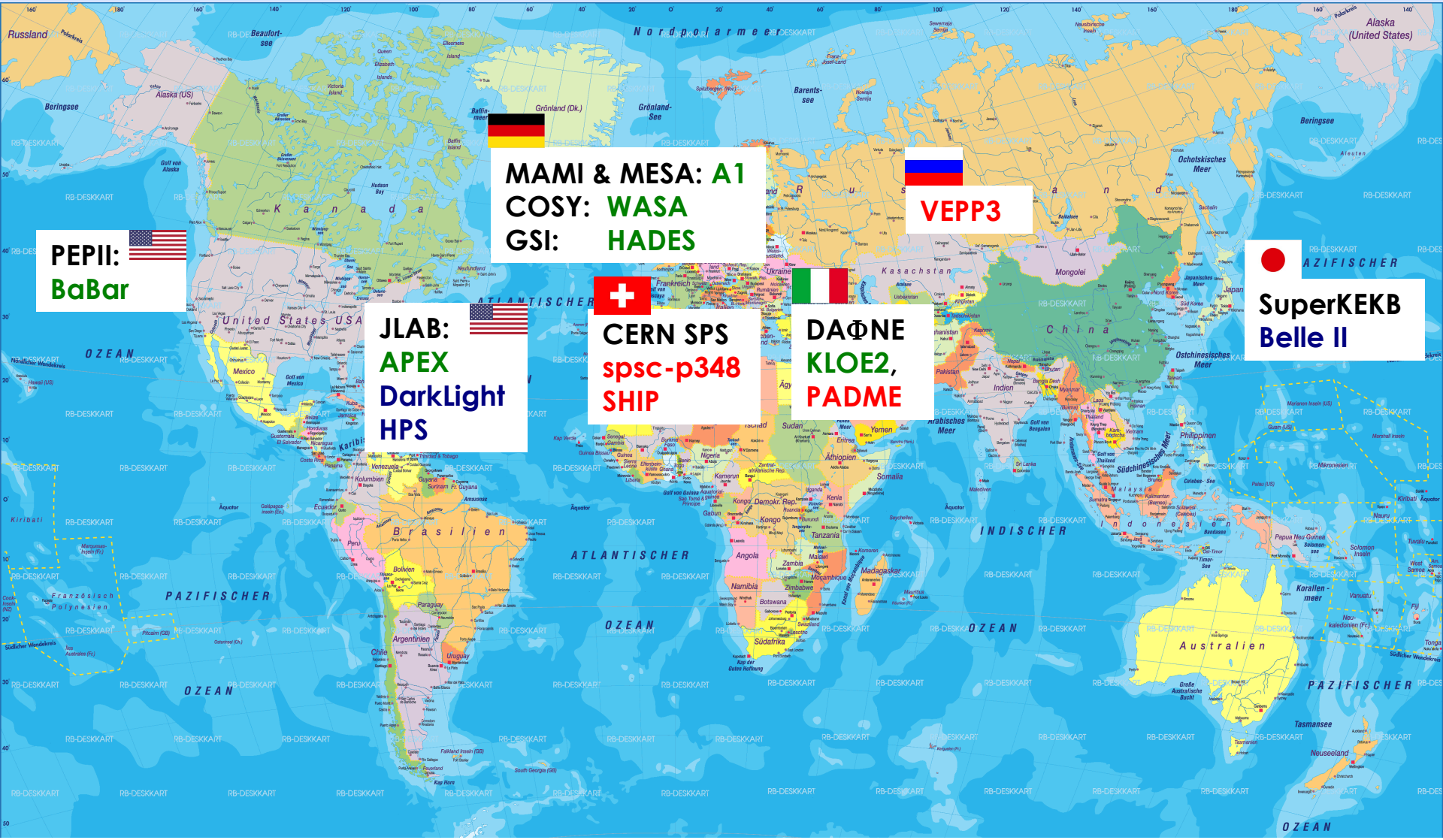
- A search using only electrons can cover many many different dark photon decay models
  - General U'(1) and kinetic mixing with B (A', Z')
    - Universal coupling proportional to the q_{em}
    - Just single additional parameter – ε
  - Leptophilic dark photon (no interactions with quarks
  - Low mass dark matter (i.e. A' → invisible)



Overview

- Available facilities
- Beam dump experiments
- Dark photon searches with positron beam
- Dark matter scattering
- Resonance searches

Present status

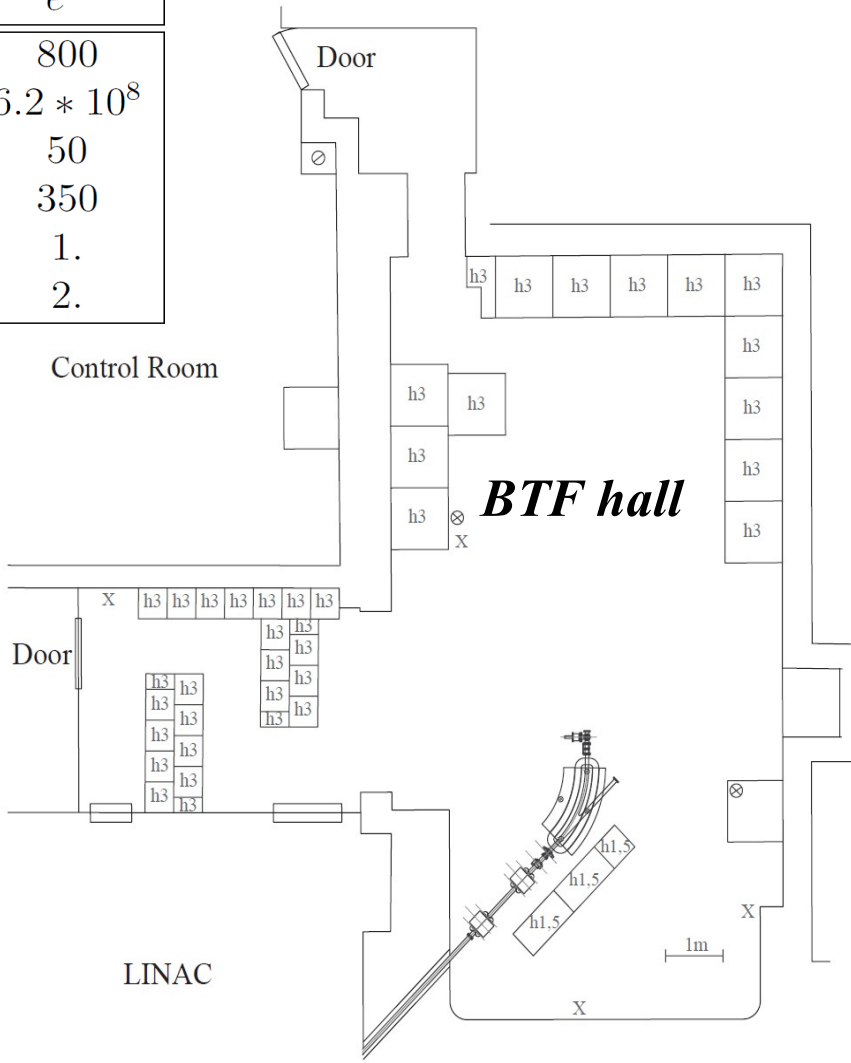


Status: ongoing, planned, proposals

BTF @ LNF

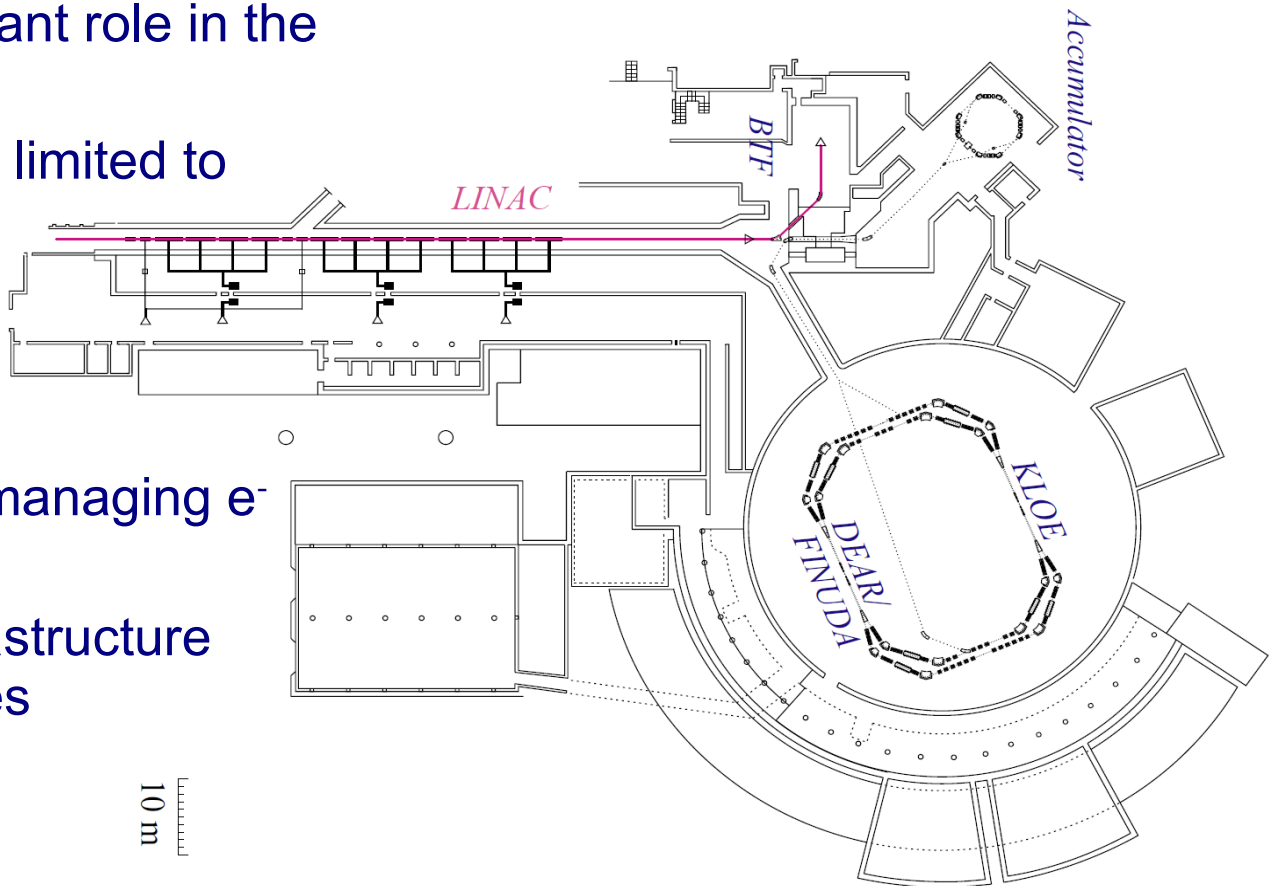
	e^+	e^-
Maximal beam energy [MeV]	550	800
Beam rate [particles/burst]	$6.2 * 10^8$	$6.2 * 10^8$
Number of bursts per second	50	50
Max. averaged current during a burst [mA]	85	350
Typical emittance (mm mrad)	1.5	1.
Beam spot size (σ in mm)	2.	2.

- Variable beam energy
  - from ~250 MeV to E_{MAX}
- Variable beam intensity
- Possibility for single particle beam
- Both **positron** and **electron** beams
- Small beam energy spread
- Available immediately
- This is up to now, many possible upgrades seem to be possible



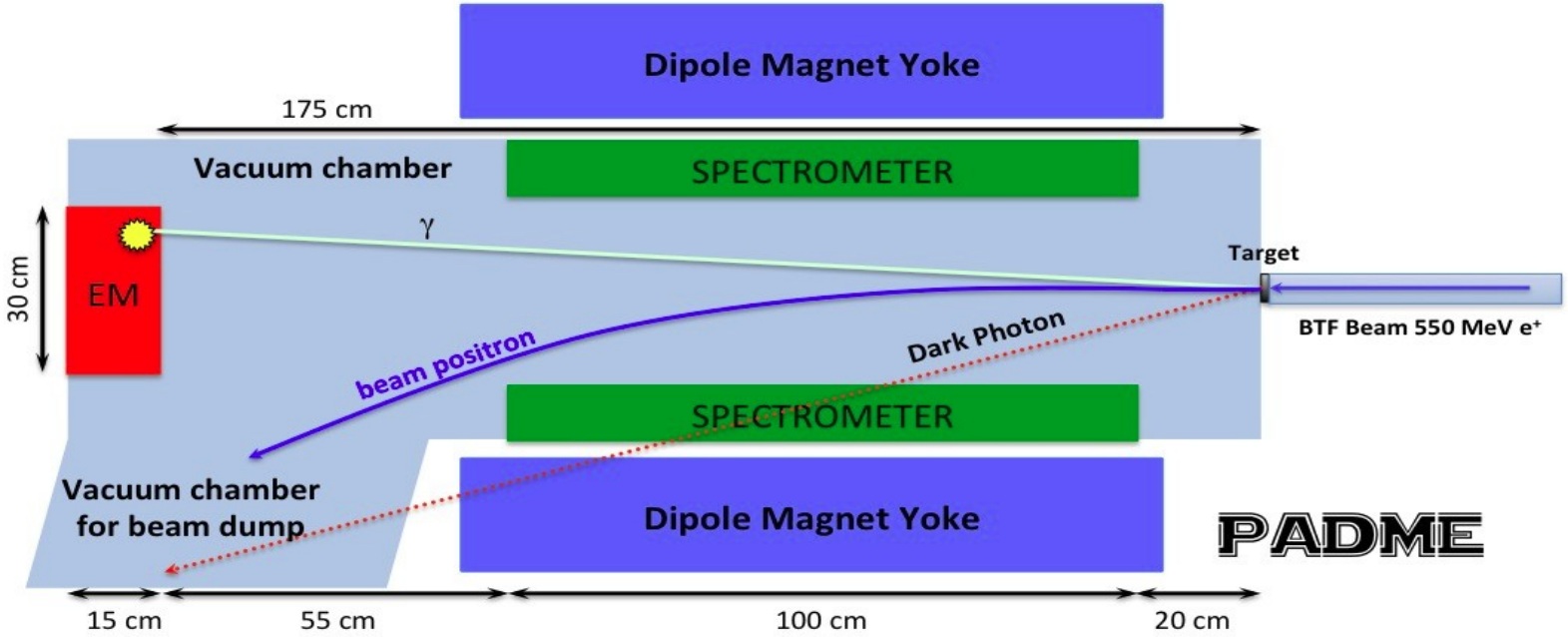
And the complete DAΦNE beauty

- KLOE played an important role in the DP searches
  - Searches up to now limited to visible decays only
  - Other techniques might be possible?
- A huge experience on managing e^- & e^+ beams
- Can profit from the infrastructure and beam transport lines



LNF is one of the few places in the world with high quality medium energy electron and positron beam

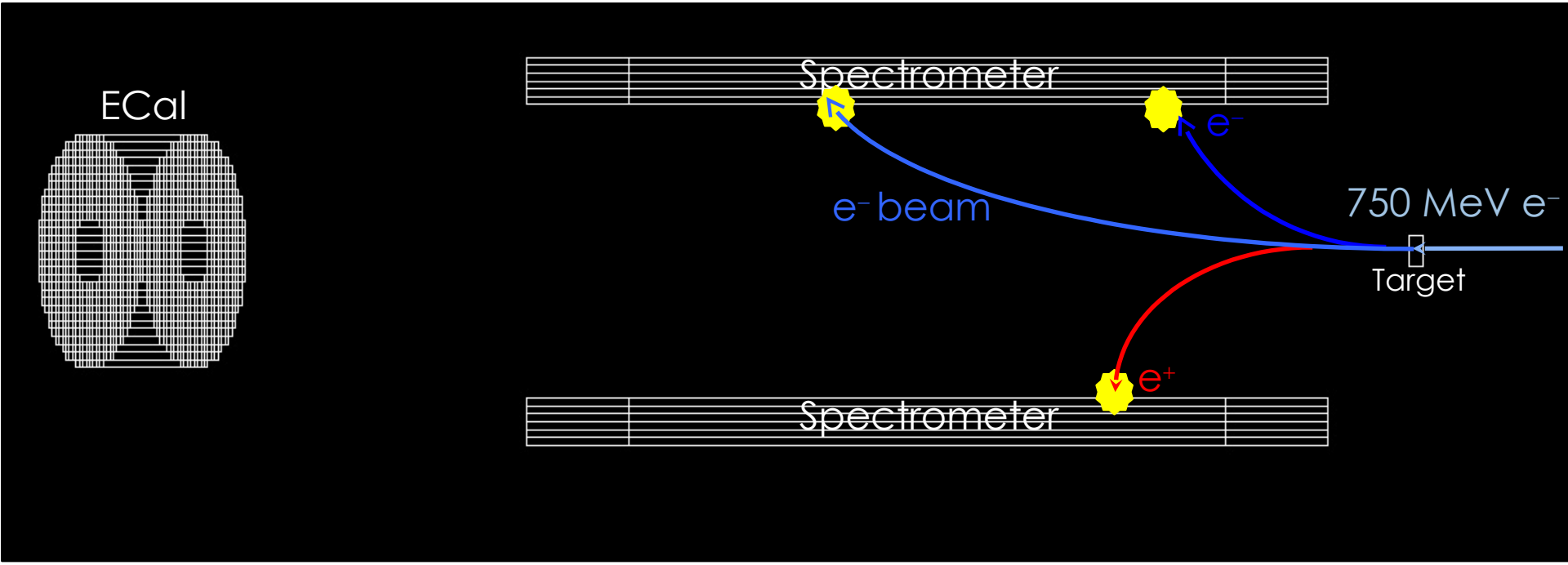
DP annihilation production



- Most probably the best way to search for invisible DP decays due to fixed kinematics of the initial state
- A conceptual layout of the experiment is quite advanced
- Calorimeter, active target, vacuum chamber, magnet and charged particle detector
- Can perform inclusive searches, not dependent on the decay mode

DP bremsstrahlung production

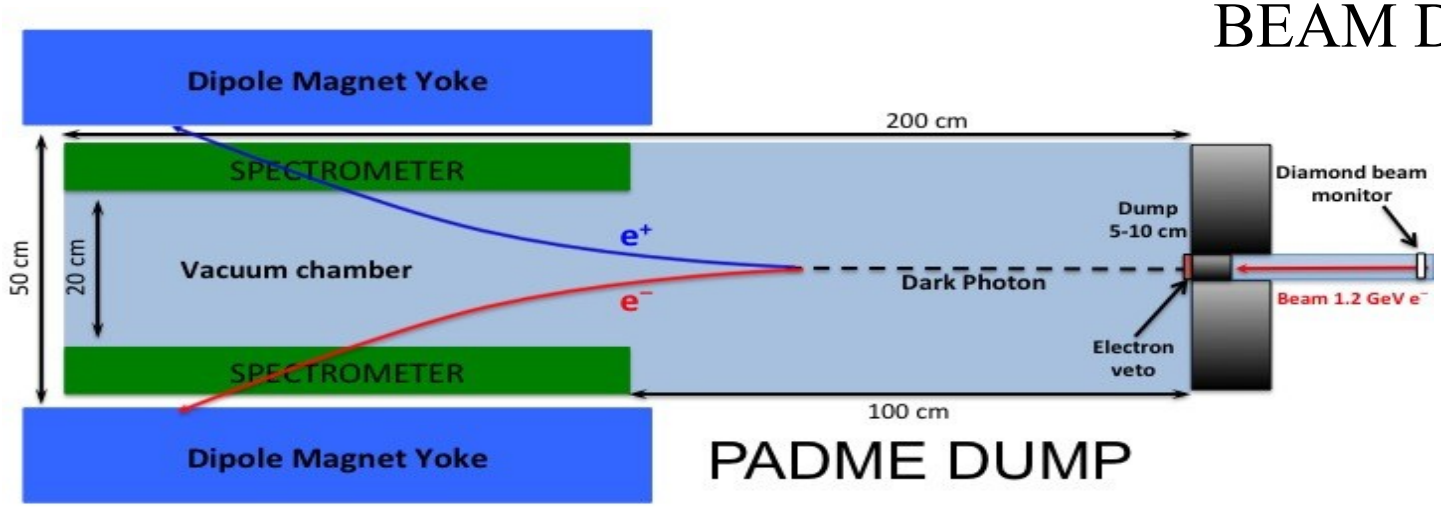
- Thin target



- Searching for peaks in the M_{e+e-} distribution
- Could have sensitivity to unexplored regions for low (<100MeV) DP masses

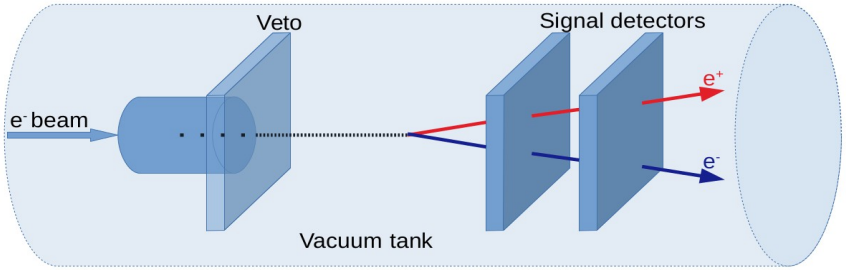
DP bremsstrahlung production

BEAM DUMP



PADME DUMP

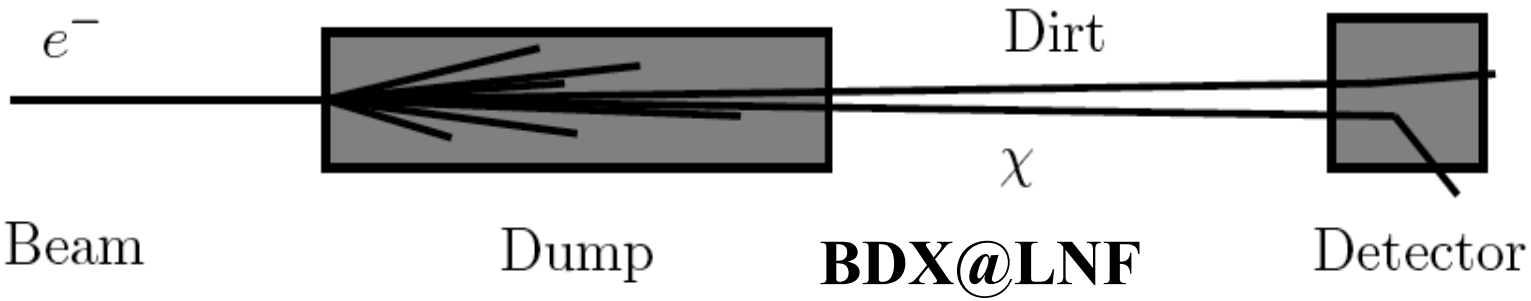
- 5 – 10 cm of tungsten target, not a complete dump (photons leak out)
- Beam veto after the target
- Both thin and thick bremsstrahlung production searches depend on a spectrometer for e+e- momentum reconstruction



OR

Simplified setup → only opening angle study
- tracking devices in vacuum + veto

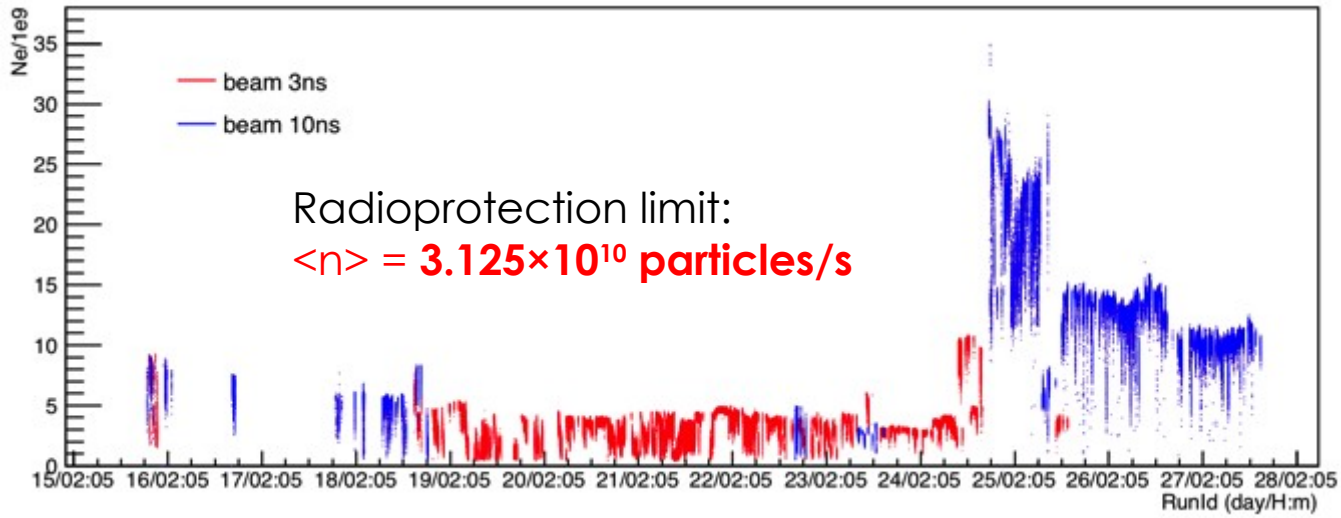
Direct search for dark matter



- When the mediator is the dark photon the experiment is sensitive to the DP parameters – mass and coupling
- Directly explores the invisible decays of the dark photon
  - Sensitive to light dark matter
  - Insensitive to visible decays
- LNF beam structure has advantages with respect to the original BDX proposal that help to reduce the background significantly
  - with the price of lower energy

Planned/ongoing upgrates

- New BTF control room
  - And a new BTF hall
- Increase of the duty cycle
  - Length of the spill increased up to 160 ns and possibly to > 200 ns
- Intensity

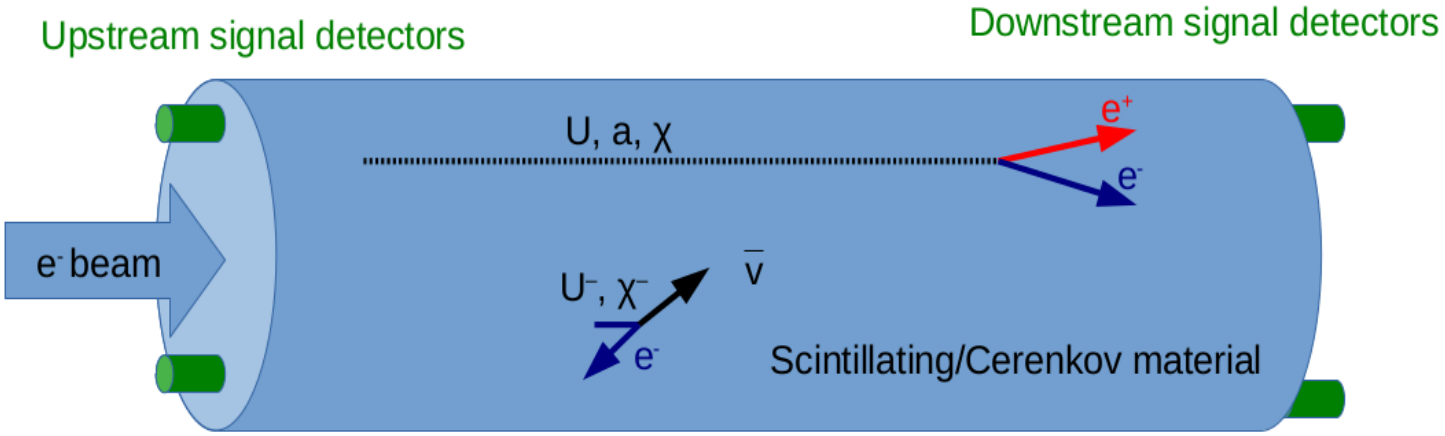


- Energy upgrade → possible electron beam of ~1000 to 1200 MeV

Exotic searches

Search for Particles with Extended Lifetime

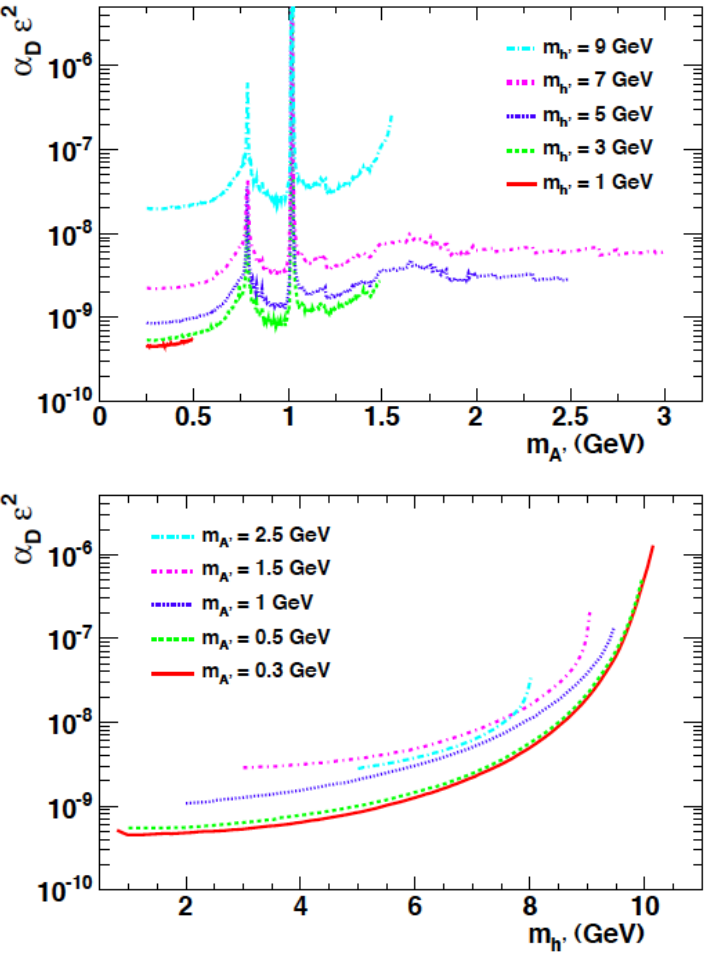
SPEL



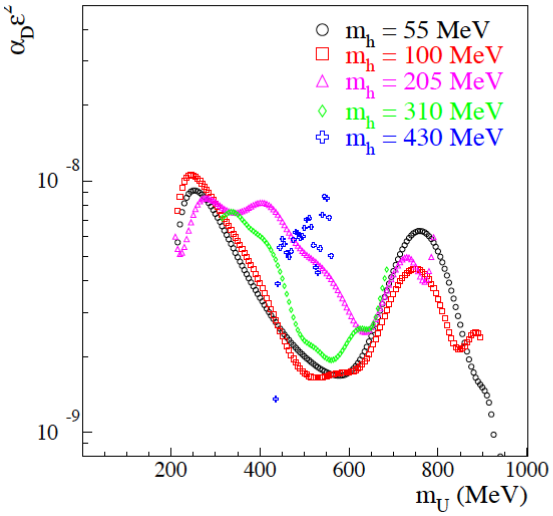
- BTF beam structure allows to use out-of-spill time to conduct searches for long lived particles
  - Such a particle could be either charged (stopped in the detector) or slow neutral particles
- The dump is the active media / detector itself (active dump)
- Radiation hardness requirement limits the possible choices of design/material → quartz
- High beam intensity → background estimation is quite tricky

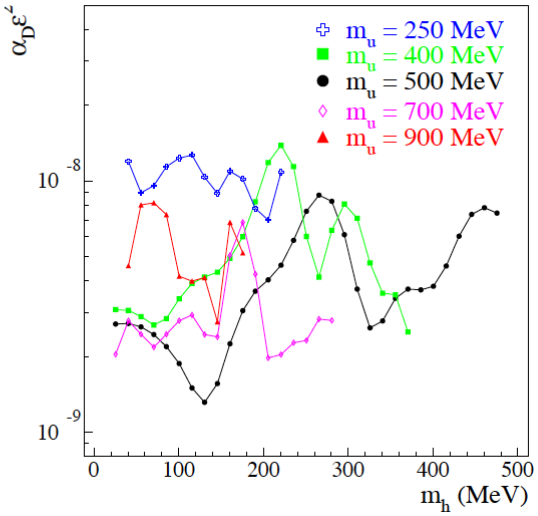
Exotics: DP through dark higgs

BaBar Phys. Rev. Lett. 108, 211801 (2012)



KLOE-2 arXiv:1501.06795





- Also this channel might be interesting to be addressed since no data for M_U below 200 MeV
- However the sensitivity has to verified

And even more exotic

- We were always considering that the dark photon should couple to leptons
  - Positron excess, g_μ-2, etc...
- **What if it does not?**

- We were speculating that it may couple only to leptons (leptophilic DP)
- Can we have DP coupled (weekly) only to quarks for example?
  - Production channel: meson decays
  - Decay channels depending on M_U: $\pi^0\pi^0$, $\pi^+\pi^-$, $\gamma\gamma\gamma$, e^+e^- (loop), $\pi^0\gamma$

- There are no experimental results for pure leptophobic U(1) gauge interaction
- The best way to search for such U-boson could be exactly meson decays into hadrons
- **May be KLOE (and DAΦNE) could be able to shed some light on the existence/exclusions of di-meson resonances**

Conclusions

- Present LNF infrastructure pushes for a thorough study of the possibility to conduct a diverse search for dark matter/mediators
- Preliminary studies indicate that such a programme could address fundamental physics questions and is competitive with the ongoing initiatives in other labs
- The plans for the upgrade of the LINAC and the infrastructure further strengthen such a proposal
- Already groups are being formed within INFN and abroad

Questions

- Why dark photon

  It seems that DP is an important ingredient in the solution to many open puzzles including DM interactions and magnetic

- Why in e+/e- interactions

  Provide access to the most general scenarios of DP interactions

- Why LNF

  …. why not... There are not that many fundamental particle physics cases where a medium size lab could play a significant or leading role

CAN IT BE DONE… ?

Better: how it can be done?