On Search for Dark Photon and Its Resonant Production in PADME Experiment

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Phys. Rev D. 97, 095004 (2018)

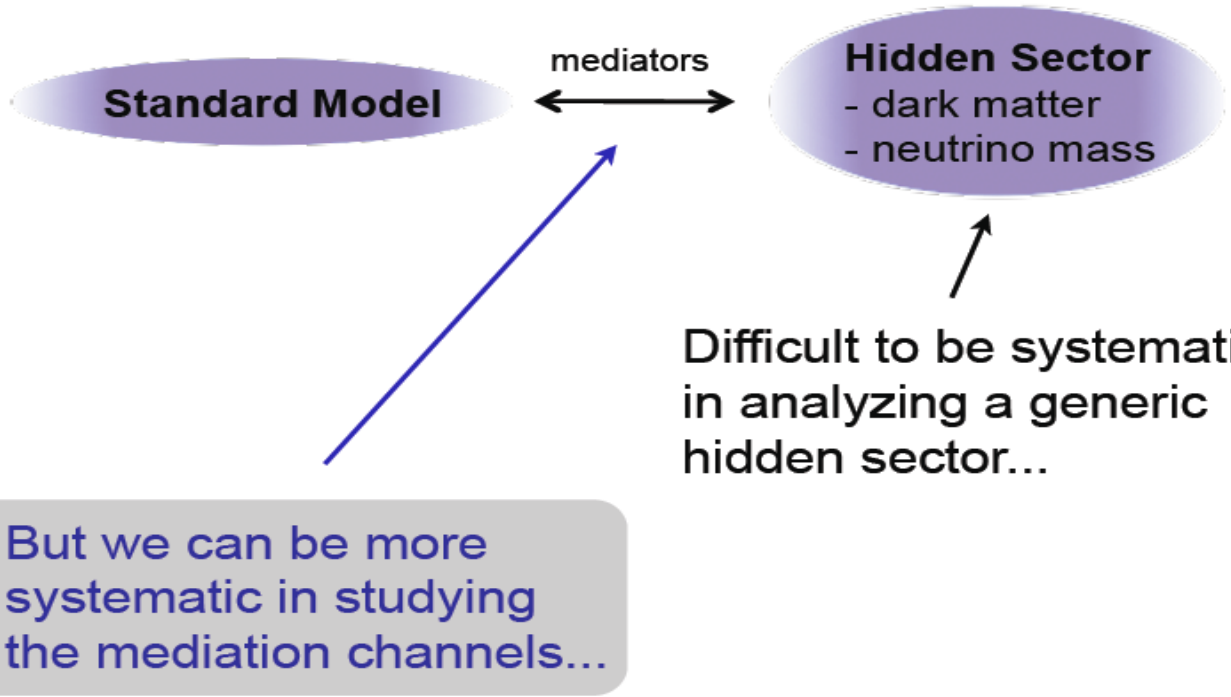
Outline:

- Model and motivations for Dark Photon.
- Current Bounds.
- 8-Be Anomaly in ATOMKI.
- Resonant production of Dark Photons in PADME.

Continued in the next presentation by Cristian.

New physics in a hidden sector

Arguably, most *empirical* evidence for new physics (e.g. neutrino mass, dark matter) doesn't point a priori to a specific mass scale, but rather to a hidden (or dark) sector.

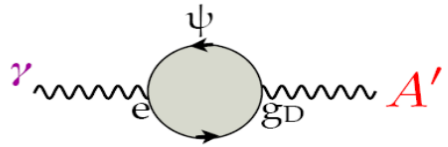


Model

- Model: SM + 1 gauge boson (X) with BSM U(1) symmetry.
- $$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}F'^{2}_{\mu\nu} - \frac{\epsilon}{2}F'_{\mu\nu}B^{\mu\nu} + \frac{m_X^2}{2}X_\mu^2 + \tilde{g}J_X^\mu X_\mu \qquad (1)$$
- This leads to interactions with SM particles through mixing.
- 2 independent parameters: m_X and ϵ.
- New U(1) can be $U_{(B\text{-}L)}(1)$, for leptogenesis. New portal for DM.
- This type of SM $\times$ U(1) are often low energy models for a more general GUT models.
  E.g: $SO(10) \to SU(5) \times U(1) \to SU(3) \times SU(2) \times U(1) \times U(1)$.

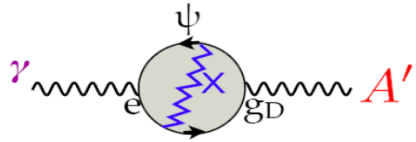
Sources and Sizes of Kinetic Mixing

– Simplest case: one heavy particle ψ with both EM charge & dark charge



generates $\epsilon \sim \frac{e\, g_D}{16\pi^2} \log \frac{m_\psi}{M_*} \sim 10^{-2} - 10^{-4}$

– In Grand Unified Theory, symmetry forbids tree-level & 1-loop mechanisms. GUT-breaking enters at 2 loops



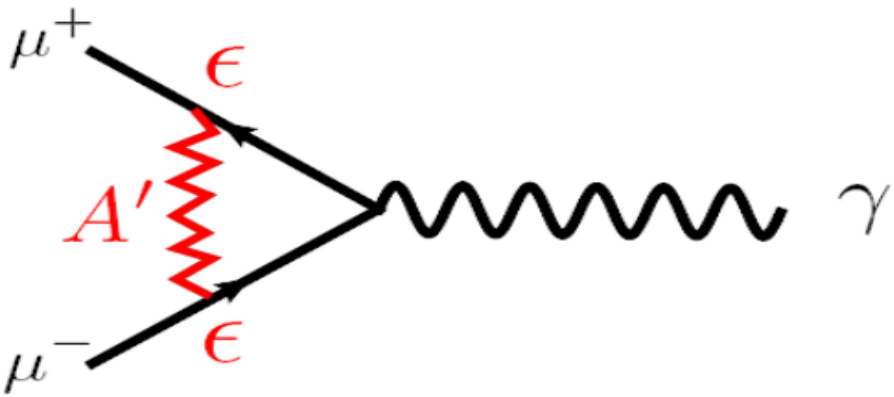
generating $\epsilon \sim 10^{-3} - 10^{-5}$
($\rightarrow 10^{-7}$ if both U(1)'s are in unified groups)

14

$$m^2_{A'} \sim \epsilon m^2_W \tag{2}$$

leading to $m_A \sim MeV - GeV$ when $\epsilon \sim 1 - 10^{-8}$.

Muon Anomalous magnetic Moment



Pospelov
Boehm, Fayet

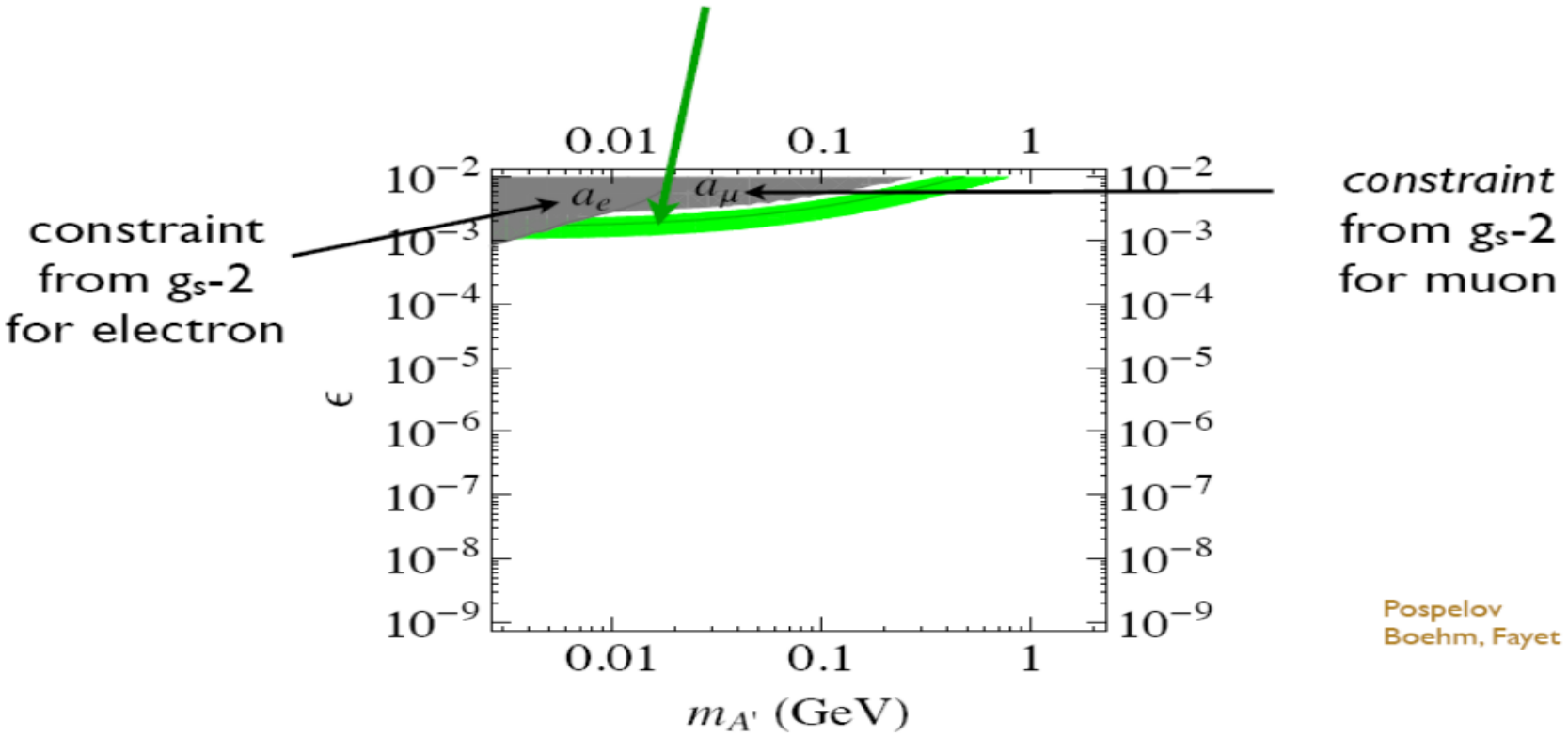
A′ contribution is:

$$(g_s - 2)_\mu^{A'} \simeq \frac{\alpha}{2\pi} \times \epsilon^2 \qquad (m_{A'} \ll m_\mu)$$
$$\simeq 10^{-3} \times \epsilon^2$$

SM/data discrepancy is $\sim 10^{-9}$ so need $\epsilon \sim 10^{-3}$

Muon Anomalous magnetic Moment

A′ may explain observed $(g_s - 2)_\mu$



Pospelov
Boehm, Fayet

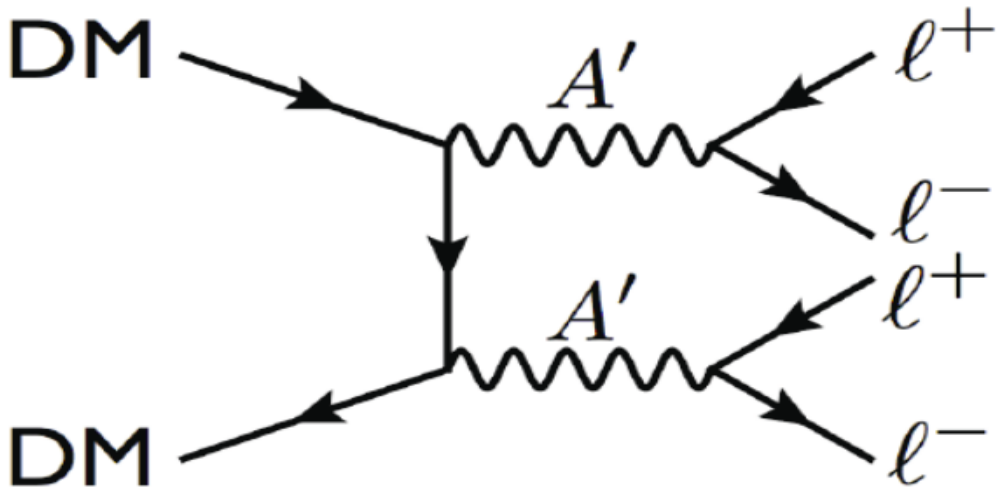
Astrophysical Motivation:

- PAMELA tell us a source of GeV positrons within 1 kpc. But no excess in antiprotons.
- e^+ e^- excess upto 1 TeV observed by FERMI.
- AMS-02 has positron fraction excess.
- These strongly motivate GeV-scale mediator in the dark sector.

Astrophysical Motivation

Dark matter can annihilate to A′s

Arkani-Hamed, Finkbeiner, Slatyer, Weiner;
Pospelov & Ritz; Finkbeiner & Weiner;
Cholis, Goodenough, Weiner;



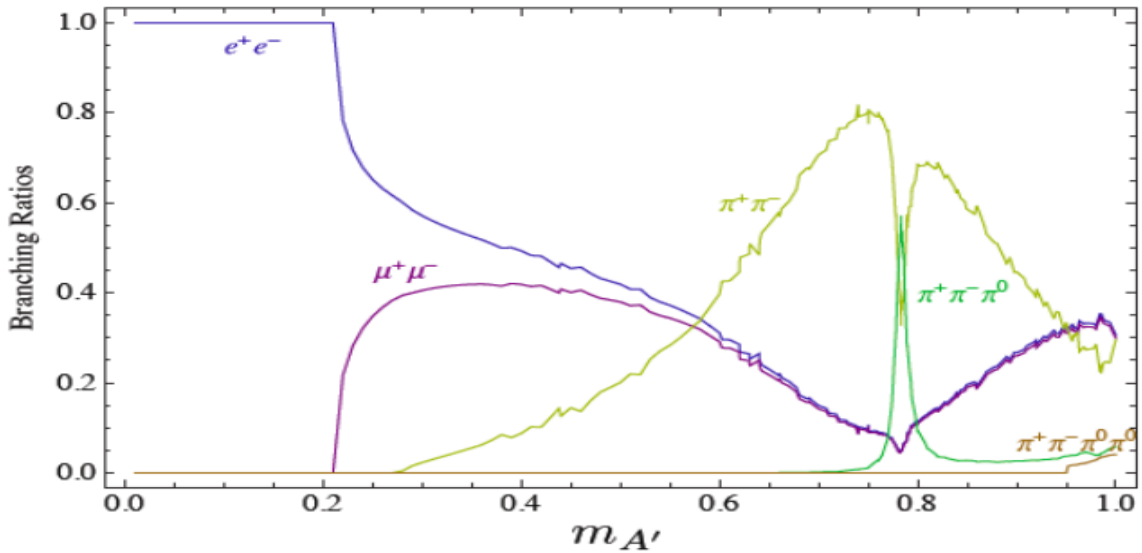
$m_{DM} \sim$ TeV $\quad$ MeV $\lesssim m_{A'} \lesssim$ GeV

no antiprotons!

Branching Ratio of Dark Photon

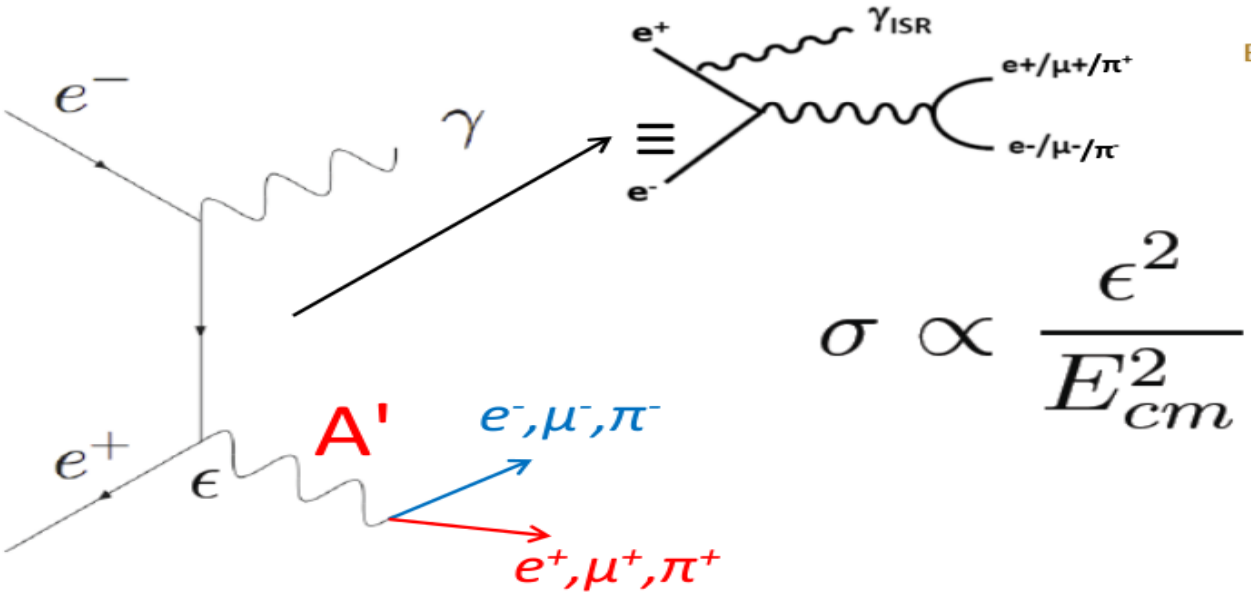
A′ can decay directly to Standard Model

($A' \rightarrow$ hidden sector also possible)



[Meade]

Searches in Particle Physics Experiment



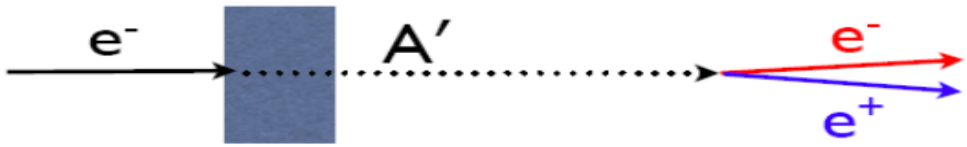
$\Longrightarrow$ want low-energy (1-10 GeV), high intensity colliders (BaBar, BELLE, KLOE, ...)

Signature: bump in l^+l^- invariant mass above the background

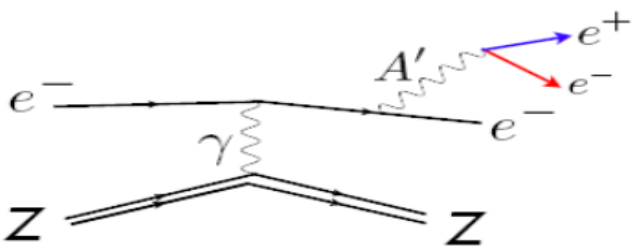
Fixed-Target Experiments

[Bjorken, RE, Schuster, Toro]
[Reece & Wang]
[Freytsis, Ovanesyan, Thaler]

Produce A′ via bremsstrahlung off e⁻ beam on fixed target



Target
(e.g. tungsten)



A′ produced forward,
carries most of E_{beam}

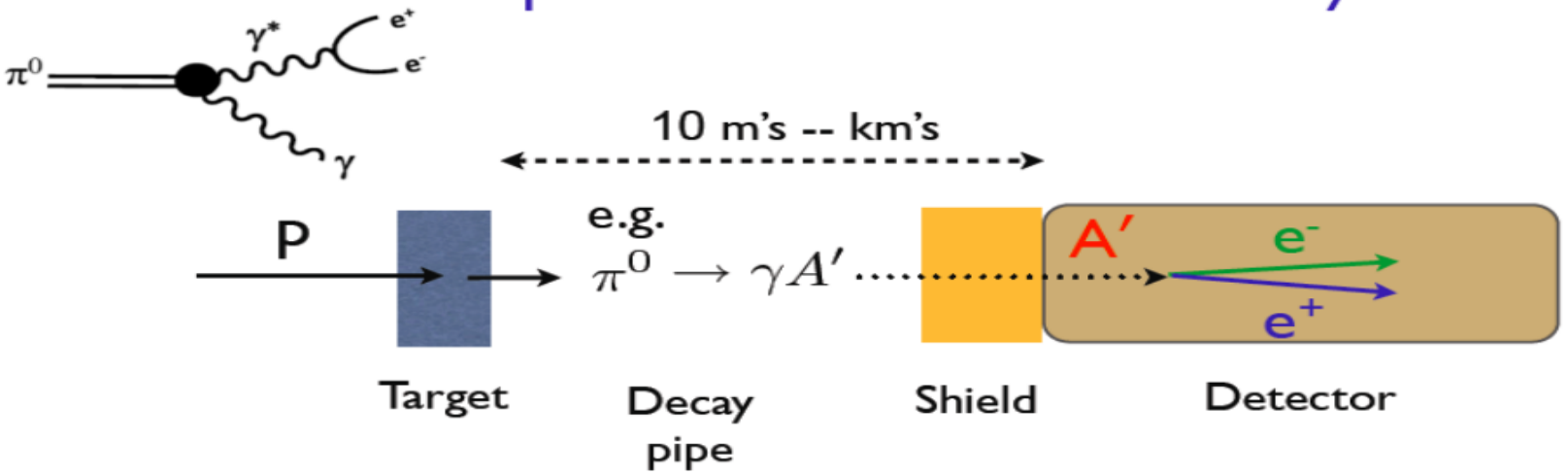
assume A′ decays
to e^+e^- pair

Proton-beam fixed target experiments

[Batell, Pospelov, Ritz]
[RE, Harnik, Kaplan, Toro]

e.g. LSND, MINOS, MiniBooNE, Project X

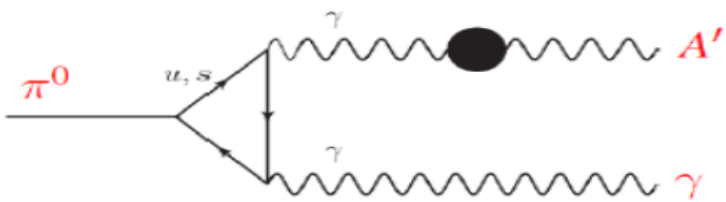
can produce A' from meson decays



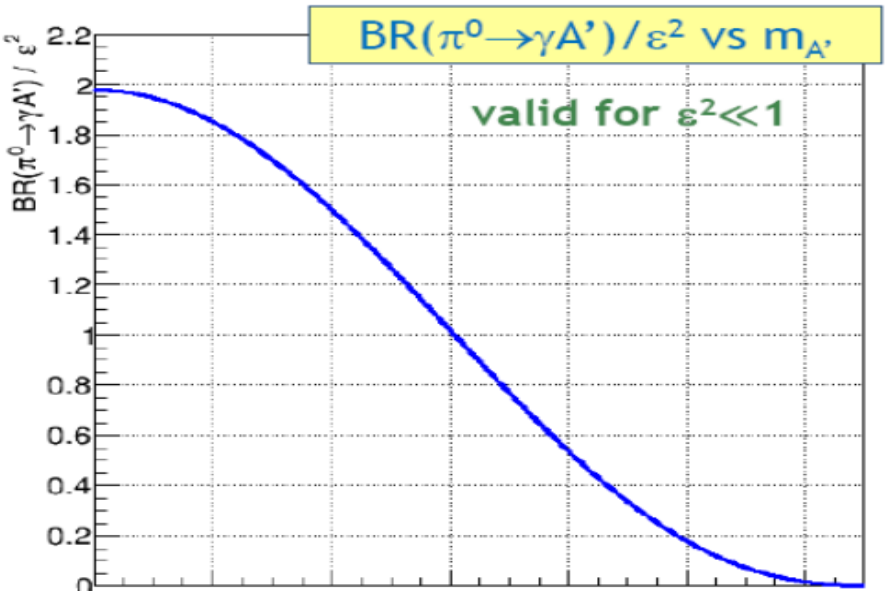
DP production in $\pi^0 \to \gamma A'$ decay

Batell, Pospelov and Ritz, PRD80 (2009) 095024

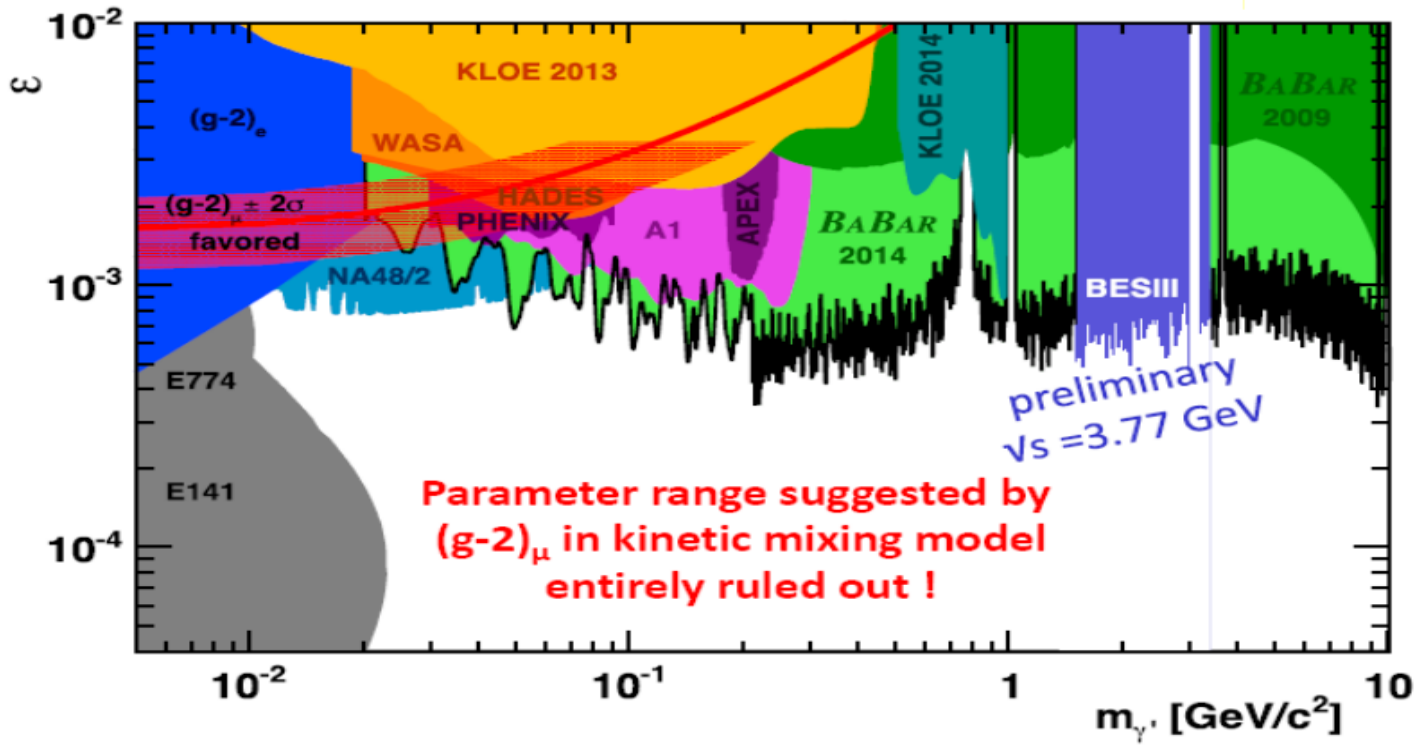
$$\mathcal{B}(\pi^0 \to \gamma A') = 2\varepsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 \mathcal{B}(\pi^0 \to \gamma\gamma)$$



- Two unknown parameters: mass ($m_{A'}$) and mixing (ε^2).
- Sensitivity to DP for $m_{A'} < m_{\pi 0}$.
- Loss of sensitivity to ε^2 as $m_{A'}$ approaches $m_{\pi 0}$, due to kinematical suppression of the $\pi^0 \to \gamma A'$ decay.

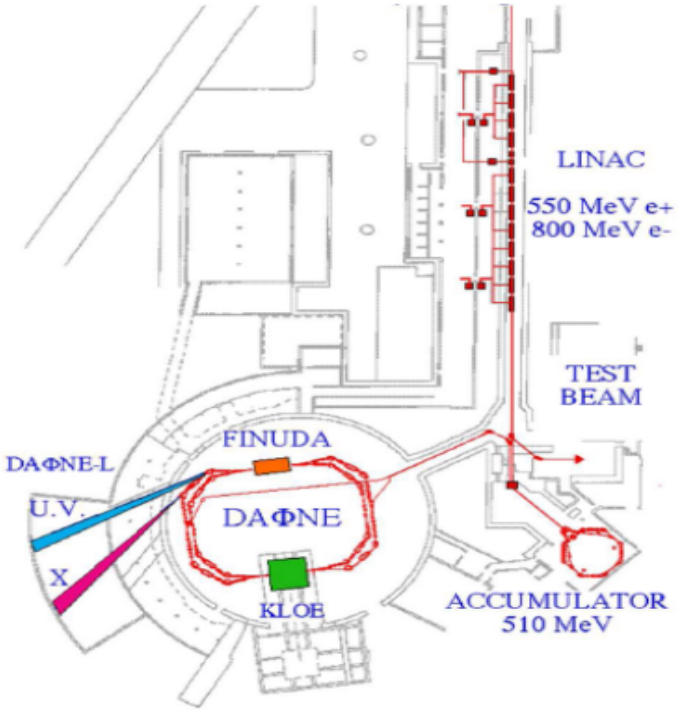


This is where we are today (2017)



Remember: this is valid only for BR(A′→SM particles)=100%

DAϕNE: the Frascati ϕ factory



- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4$ MeV
- 2 interaction regions
- Separate e^+ e^- rings
- 105+105 bunches, 2.7 ns bunch spacing
- $I^-_{peak} \sim 2.4$ A $I^+_{peak} \sim 1.5$ A
- Injection during data taking
- Crossing angle: 2×12.5 mrad

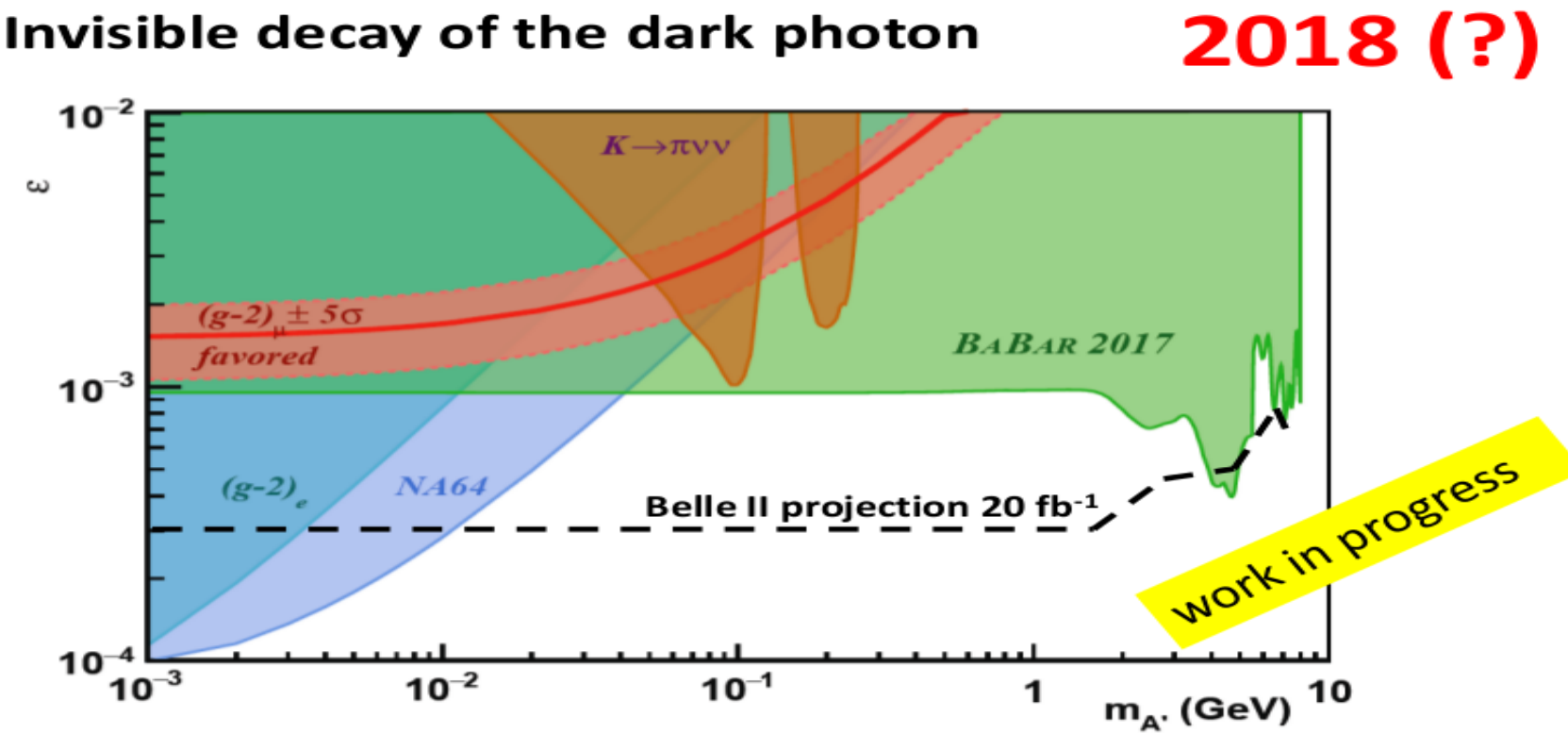
❖ Running period: 1999-2007

❖ Best performances:

➢ $L_{peak} = 1.4 \times 10^{32}\ cm^{-2}s^{-1}$

➢ $\int L dt = 8.5\ pb^{-1}/day$

Searches in Particle Physics Experiment



^{8}Be TRANSITION

EVIDENCE FOR A NEW 17 MEV BOSON

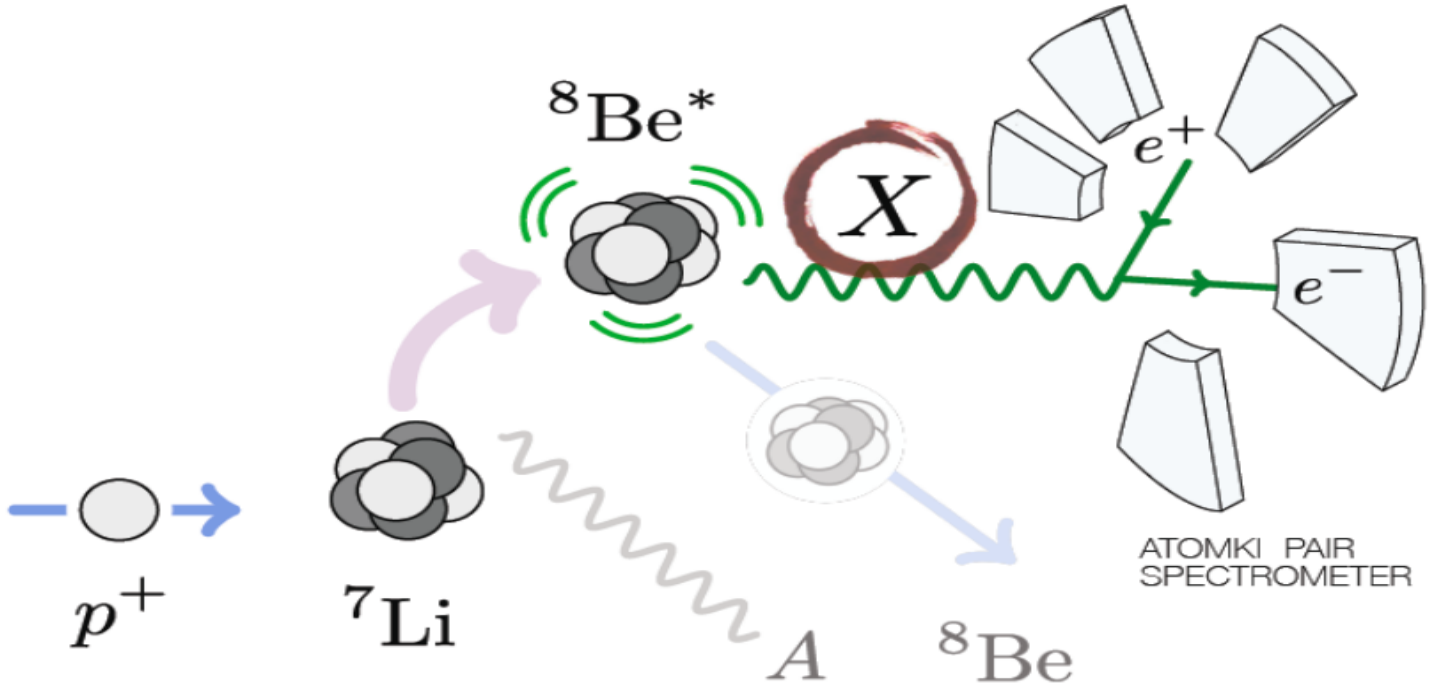
Flip Tanedo
UCI

arXiv:1604.07411 & work in progress
SLAC Dark Sectors 2016 (28 — 30 April)

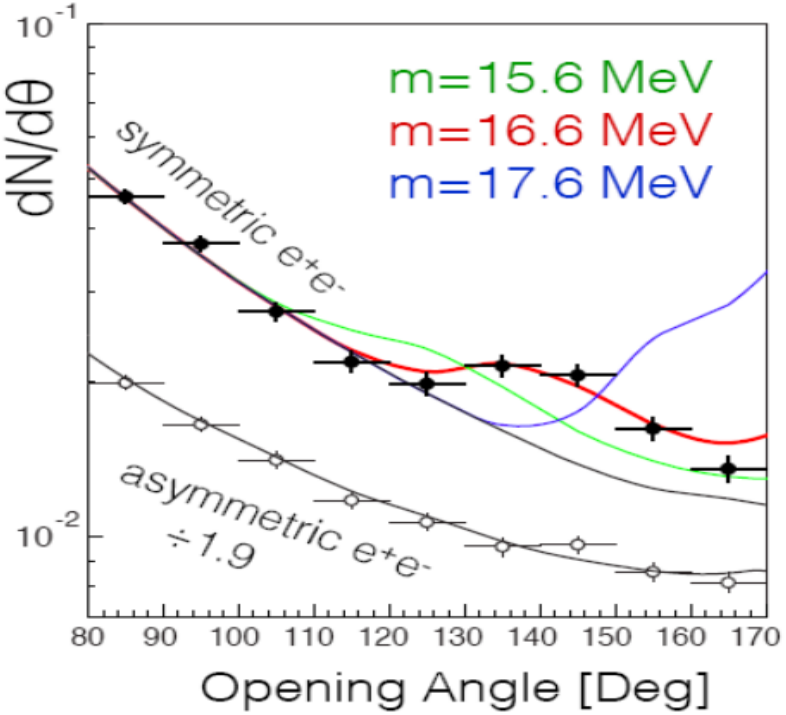
with
Jonathan Feng, Bart Fornal, Susan Gardner, Iftah Galon, Jordan Smolinsky, & Tim Tait

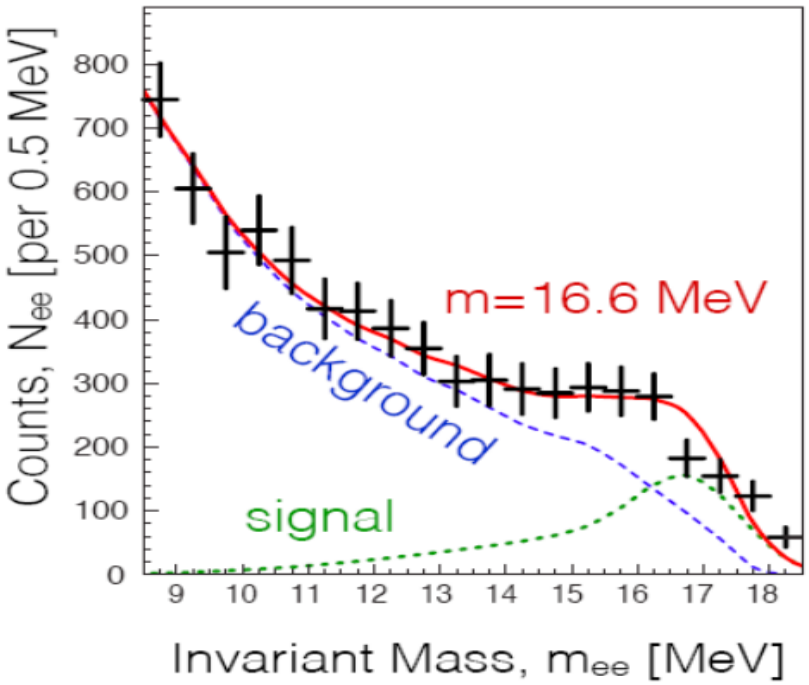


Experiment & interpretation



A 6.8σ anomaly: two measurements

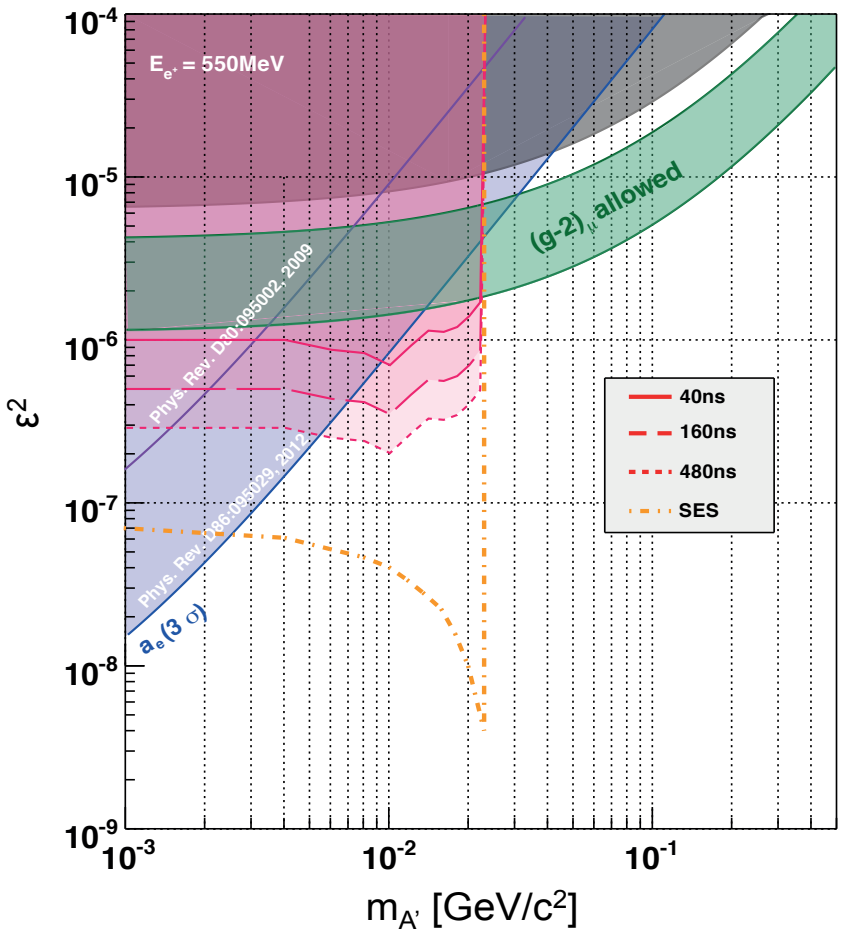




Search in PADME (LNF-Frascati)

- e^+ accelerated from DAΦNE to 550 MeV are hit on fixed target e^-.
- No. of particles $\approx 10^{18}$ per year.
- $\sqrt{s} = \sqrt{2E_{beam}m_e}$. The m_e determines the resolution that can be reached.
- Sensitivity on ϵ upto 10^{-3} and $m_{A'}$ up to 23.7 MeV.

Padme sensitivity

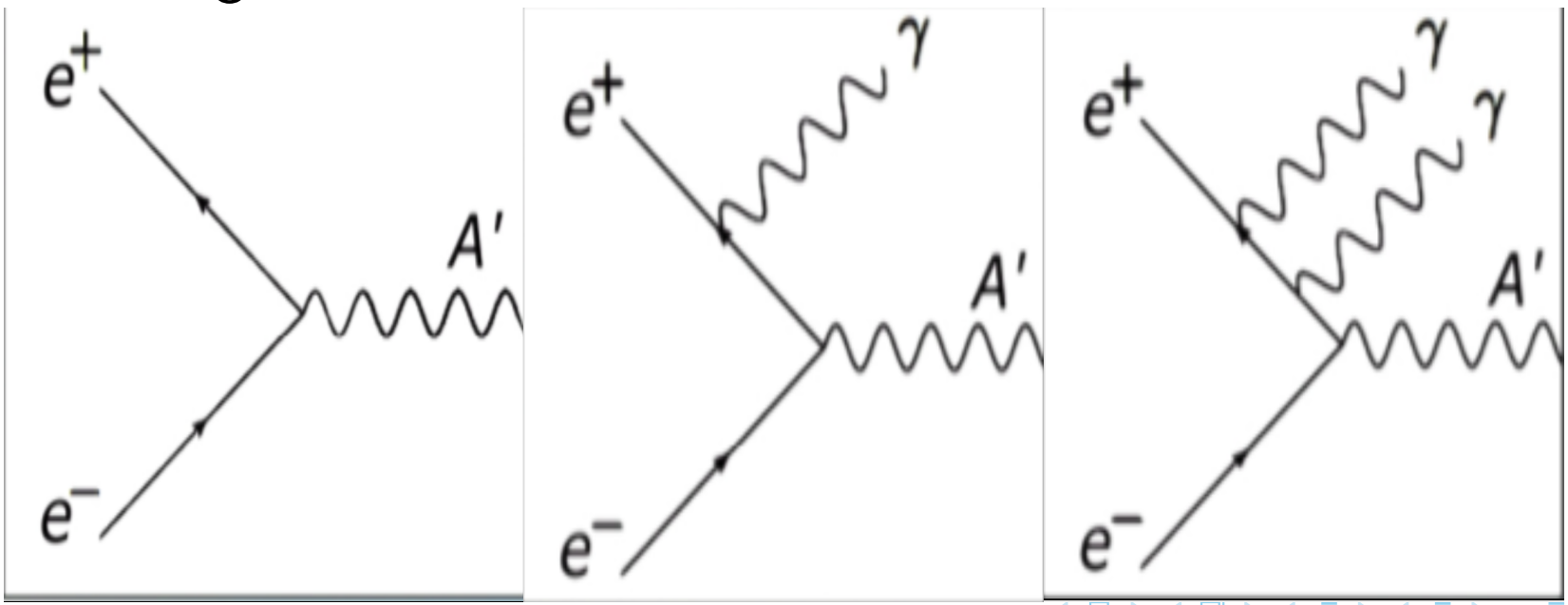


8Be Anomaly

- Anomaly of 17 MeV in ^{8}Be nuclear transition recently observed.
- A DP of 17 MeV is a leading candidate for this anomaly.
- Look for this DP by resonantly producing at PADME as the positron beam can be tuned.
- Remove SM background by setting a detector long enough for SM particles but DP to decay.

New Proposal

- Because of continuous loss of energy while positrons propagating through matter, there is a “scan” downward in energy until hitting the resonance.
- Radiative return also helps enhancing the cross-section by widening the resonance.
- Effect of target electron velocities.
- Effect of positron-electron annihilation adding to SM background.



Summary

- Dark photon: candidate for DM itself and portal for DM from SM as well.
- Although large portion of DP parameter space ruled out by particle physics experiments and cosmology observations. But still significant areas left.
- DP can be a candidate to explain ^{8}Be anomaly.
- New proposal to search for DP in positron beam dump by resonant production and downward scanning.
- PADME in LNF-INFN can observe or rule out the 17 MeV DP as 8Be anomaly candidate.
- Details in the next talk (by Cristian).

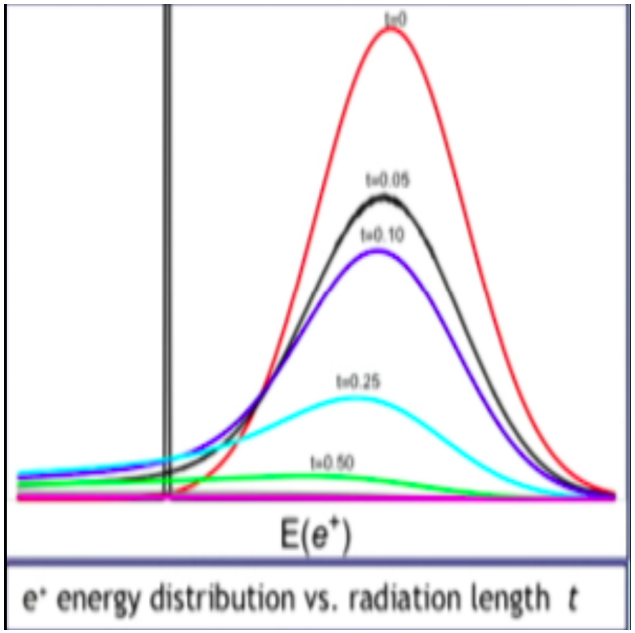
GRATITUDE

Hearty thanks to Professors Davide Meloni and Enrico Nardi (I.N.F.N-LNF) for providing me such a research topic where the phenomenology-experimental interplay is so rich.

References

- PADME collaboration (2015, 2016, 2016).
- arxiv 1507.02614
- arxiv 1701.01221
- arxiv 0804.4157
- arxiv 1309.6599
- arxiv 1311.0029
- arxiv 1405.4123
- Particle data group (2016).
- arxiv 1104.4799
- arxiv 1006.0973
- arxiv 1702.03327
- arxiv 1605.07195
- arxiv 1408.6845
- arxiv 1504.02102
- arxiv 1703.00894
- arxiv 1607.03735
- arxiv 1703.03248
- arxiv 1802.04756
- arxiv 1802.03794
- Talks by Pospelov, Graziani.

Backup



e⁺ energy distribution vs. radiation length t

Sensitivity

In the bigger picture